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MID WEST AQUACULTURE DEVELOPMENT ZONE

Department of Fisheries

MID WEST AQUACULTURE DEVELOPMENT ZONE

PUBLIC ENVIRONMENTAL REVIEW

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Mid West Aquaculture Development Zone – Public Environmental Review

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Invitation to make a submission

The Environmental Protection Authority (EPA) invites people to make a submission on this proposal. The environmental impact assessment process is designed to be transparent and accountable, and includes specific points for public involvement, including opportunities for public review of environmental review documents. In releasing this document for public comment, the EPA advises that no decisions have been made to allow this proposal to be implemented.

The Western Australian Department of Fisheries, on behalf of the Minister for Fisheries, proposes to establish an aquaculture development zone in the Mid West region of Western Australia for the purpose of marine finfish aquaculture. The Mid West Aquaculture Development Zone is being assessed by the EPA as a strategic proposal. In accordance with the Environmental Protection Act 1986, a Public Environmental Review (PER) document has been prepared which describes this strategic proposal and its likely effects on the environment. The PER document is available for a public review period of 4 weeks from 18 July 2016, closing on 15 August 2016.

Comments from government agencies and the public will assist the EPA to prepare an assessment report in which it will make recommendations to government.

Why write a submission?

A submission is a way to provide information, express your opinion and put forward your suggested course of action - including any alternative approach. It is useful if you indicate any suggestions you have to improve the proposal.

All submissions received by the EPA will be acknowledged. Submissions will be treated as public documents unless provided and received in confidence, subject to the requirements of the *Freedom of Information Act 1992* (FOI Act), and may be quoted in full or in part in the EPA's report.

Why not join a group?

If you prefer not to write your own comments, it may be worthwhile joining a group interested in making a submission on similar issues. Joint submissions may help to reduce the workload for an individual or group, as well as increase the pool of ideas and information. If you form a small group (up to 10 people) please indicate all the names of the participants. If your group is larger, please indicate how many people your submission represents.

Developing a submission

You may agree or disagree with, or comment on, the general issues discussed in the PER or the specific proposal. It helps if you give reasons for your conclusions, supported by relevant data. You may make an important contribution by suggesting ways to make the proposal more environmentally acceptable.

When making comments on specific elements of the PER:

- clearly state your point of view;

- indicate the source of your information or argument if this is applicable; and
- suggest recommendations, safeguards or alternatives.

Points to keep in mind

By keeping the following points in mind, you will make it easier for your submission to be analysed:

- attempt to list points so that issues raised are clear. A summary of your submission is helpful;
- refer each point to the appropriate section, chapter or recommendation in the PER;
- if you discuss different sections of the PER, keep them distinct and separate, so there is no confusion as to which section you are considering; and
- attach any factual information you may wish to provide and give details of the source.

Make sure your information is accurate.

Remember to include:

- your name;
- address;
- date; and
- whether and the reason why you want your submission to be confidential.

Information in submissions will be deemed public information unless a request for confidentiality of the submission is made in writing and accepted by the EPA. As a result, a copy of each submission will be provided to the proponent but the identity of private individuals will remain confidential to the EPA.

The closing date for submissions is: **15 August 2016**

The EPA prefers submissions on PER documents to be made electronically on its consultation hub at https://consultation.epa.wa.gov.au**.**

Alternatively, submissions can be:

- posted to;
  - Chairman, Environmental Protection Authority, Locked Bag 10, EAST PERTH WA 6892; or
- delivered to;
  - Environmental Protection Authority, Level 8, The Atrium, 168 St Georges Terrace, Perth.

If you have any questions on how to make a submission, please contact the EPA via telephone at (08) 6145 0800; or via e-mail at info@epa.wa.gov.au.

EXECUTIVE SUMMARY

Overview

The Minister for Fisheries (Minister) proposes to establish an aquaculture development zone (zone) in the Mid West region of Western Australia for the purpose of marine finfish aquaculture.[1]

Rationale

A strategic planning approach to aquaculture development is regarded as best regulatory practice and a key method of providing for industry growth while achieving ecologically sustainable development outcomes.[2] Some Australian states have established significant marine aquaculture industries using a regional zone methodology in their strategic planning.

The Western Australian Government is committed to the development of a sustainable marine aquaculture industry and, to further this commitment, the Minister announced a funding package to enable the establishment of two such zones: one in the Kimberley and one in the Mid West region of the State.[3]

The Department of Fisheries Western Australia (Department) is managing the creation of these two zones on behalf of the Minister.

The proposed Mid West Aquaculture Development Zone (MWADZ Proposal) is located within the southern part of the Abrolhos Islands Fish Habitat Protection Area (FHPA), between the Pelsaert and Easter groups of the Abrolhos archipelago, approximately 65 kilometres west of Geraldton.[4] This will be the second aquaculture development zone to be established in Western Australia, the Kimberley Aquaculture Development Zone being declared by the Minister on 22 August 2014. The MWADZ Proposal is located in a part of the Western Australian coast where there is a confluence of both temperate and tropical sea life, forming one of the State's unique marine areas. This presents a rare opportunity for the development of a range of marine finfish aquaculture species that occur naturally within the West Coast Region of the State.[5]

The establishment of commercial marine finfish aquaculture projects within the zone is not expected to cause a significant environmental impact. This assessment of the likely environmental impacts is due to two factors.

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[1] Section 101A(2A) of the *Fish Resources Management Act 1994* provides for the Minister to declare an area of WA waters (other than inland waters) to be an aquaculture development zone.
[2] *Best practice framework of regulatory arrangements for aquaculture in Australia* [Primary Industries Ministerial Council – 2005].
[3] Refer to the Statement of Commitment – August 2015 at:
http://www.fish.wa.gov.au/Documents/Aquaculture/aquaculture_statement_of_commitment.pdf
[4] Fish Habitat Protection Areas are created by the Minister under the provisions of Part 11, Division 1 of the *Fish Resources Management Act 1994*.
[5] *West Coast Region* is defined in Regulation 3 *Terms used* of the Fish Resources Management Regulations 1995 as:

(a) all land in the State; and
(b) all WA waters,

that are south of 27^{0} 00$^{'}$ south latitude, excluding the South Coast Region;

First, the zone's physical characteristics, in particular the high rates of flushing or water exchange in the Zeewijk Channel that is sufficient to dilute nutrients before they are assimilated by the ecosystem. Second, the adaptive management controls and environmental monitoring framework the Department has developed for the zone, and the individual proposals within it, through the strategic assessment process (see below) consistent with the guidance set out in the relevant Environmental Protection Authority (EPA) policies and guidelines.

Approvals Pathway

The Department referred the MWADZ Proposal to the EPA in April 2013 and the EPA subsequently determined the level of assessment be Public Environmental Review.

The MWADZ Proposal will be assessed through a process that principally involves environmental assessment of the zone as a **strategic proposal** under Part IV of the *Environmental Protection Act 1986* (EP Act).

Once the strategic proposal has been approved by the Minister for Environment, the Minister for Fisheries (with the concurrence of the Minister for Lands) may declare the MWADZ Proposal area to be an aquaculture development zone under section 101A of the *Fish Resources Management Act 1994* (FRMA).

Approval of the strategic proposal will create opportunities for existing and future aquaculture operators to refer project proposals to the EPA as **derived proposals**. The desired outcome is a more efficient and effective zone assessment and regulation process. This will be achieved through the early consideration of the identified potential environmental impacts and additional cumulative impacts associated with the project proposals, and of the relevant management measures designed to control these.

Subject to the Minister for Environment approving these derived proposals, aquaculture licences (granted by the Chief Executive Officer of the Department of Fisheries) and aquaculture leases (granted by the Minister for Fisheries) may be issued to the aquaculture operators.

The Proposal

Subject to the relevant environmental approvals under the EP Act, the MWADZ Proposal aims to:

- declare an area of Western Australian (WA) waters, based on its biological, environmental, economic and social attributes, as suitable for large-scale commercial marine finfish aquaculture; and
- establish an effective management framework, including an efficient approval process, for operators within that area.

The strategic proposal area has been selected by the proponent to maximise suitability for marine finfish aquaculture and minimise potential impacts on existing marine communities and disruption to existing human use.

The MWADZ Proposal, encompasses 3,000 hectares (ha) of marine waters within two separate areas (800 ha and 2,200 ha).

1. The **Southern area** comprises an 800-hectare existing licensed aquaculture site to the north of Sandy Island in the Pelsaert Group. This existing site will likely be the only aquaculture site within the Southern area.

2. The **Northern area** comprises a 2,200-hectare site east of Wooded Island in the Easter Group and north of Gee Bank reef. The final size, location and design of aquaculture sites within the Northern area will be subject to, *inter alia*, the outcomes of the tenure allocation process conducted after the zone has been declared.

The main infrastructure of future derived proposals will consist of floating sea cages, typically arranged in clusters, and secured to the seabed by an anchoring and bridle system. The sea cages are circular in shape and may range in size (18-38 metres diameter) depending on the number and size of the cultured fish. In general, the sides of the proposed cages would have a drop of 18 metres; with the bottom of the cage reaching a depth of around 21 metres. The sea cages must conform to the navigation and marking requirements as specified by the Department of Transport.

Only marine finfish of a species that occurs naturally within the West Coast region of Western Australia are permitted to be cultured within the zone. The use of local species and the outcomes of the technical studies, environmental impact modelling undertaken and the proposed environmental and farm modelling and management regime provide confidence that a standing biomass limit of 24,000 tonnes of marine finfish at any one time for the zone would be appropriate.

Potential Impacts, Risk Assessment and Mitigation

The identification of potential impacts of the MWADZ Proposal, the assessment of the risks they posed and the likely effects of the management and mitigation controls designed to address them has been an iterative process throughout the development of the proposal.

The assessment of these potential impacts was undertaken based on available evidence, current knowledge, and through the application of professional judgement. However, some scientific uncertainty still exists with respect to the actual impacts that may occur; this uncertainty is a result of a number of factors including variation within natural systems, limited understanding of complex systems and interactions between components, and unanticipated or uncontrollable factors that may affect an impact pathway.

Any scientific uncertainty regarding the potential impact of the proposal resulted in the application of a conservative approach to the assessment and to the definition of mitigation and management measures. Where any identified potential impacts are likely to be unknown, unpredictable, or irreversible, this conservative approach was adopted by considering the 'worst-case' situation. This approach, however, did lead to some overly pessimistic initial assessments (refer to the *Approach to Environmental Management* section of this Executive Summary).

A cumulative impact assessment considered potential incremental impacts, in terms of the environmental and social factors outlined in this Public Environmental Review (PER), of the MWADZ Proposal. The cumulative impact assessment evaluated the potential incremental impacts of the MWADZ Proposal when combined with other present and reasonably foreseeable future actions in the vicinity of the proposed MWADZ area.

This cumulative impact assessment was based on a mostly qualitative, high-level analysis of potential impacts using professional judgement of subject matter experts, supported by baseline information (current and historic) and a range of quantitative assessments.

The views of stakeholders were also an important part of the impact assessment process and numerous opportunities were provided throughout the proposal development for their input.

The following Table lists the most significant potential impacts associated with the MWADZ Proposal, along with mitigation and management measures to be implemented to address these.

Table ES: Summary of environmental factors, management and predicted outcomes relevant to the MWADZ Proposal

Environmental Factor	EPA Objective	Existing Environment	Potential Impact	Environmental Management	Predicted Outcome
Benthic Communities and Habitat	To maintain the structure, function, diversity, distribution and viability of benthic communities and habitats at local and regional scales.	The benthic environment consists generally of a shallow (~ 15 centimetre thick) layer of sand overlying rocky substrate. Surveys undertaken in 2014 indicate that the seafloor is a mosaic of habitats consisting of bare sand and mixed biological assemblages where the sand veneer is thin or rocky substrate is exposed. These assemblages comprise of filter feeders (sponges, and bryozoans), macroalgae, rhodoliths and some hard corals (though the latter was observed infrequently). Despite the observed diversity of the biological assemblages, their presence is	1. Direct and indirect disturbance or loss of benthic communities and habitat; 2. Direct and indirect impacts to key sensitive receptors; and 3. Impacts to marine environment and biota quality through release of nutrients, organic material, pharmaceuticals, metals or metalloids and/or petroleum hydrocarbons.	• Avoid direct and indirect impacts on benthic communities and habitat and protect marine environmental quality (EAG 8). This can be achieved by implementing measures that include the following: o Where practical, avoid locating sea cages over areas of benthic communities and habitat. o Adopt best-management practices in relation to infrastructure design, installation, maintenance and animal husbandry. o Locate the sea cages in well-flushed locations with good water circulation, dispersion, with water depth below the sea cages exceeding 10 metres. o Set stocking densities for aquaculture at conservative levels to help minimise enrichment of the surrounding environment. o Use only AQIS-approved, high-quality, species and system-specific feeds in order to minimise feed waste. o Use dry pelletised feed and disease free certified stock to prevent contamination and introduction of pests and pathogens. o Fallow sites to allow seabed recovery. o No prophylactic use of antibiotics; and if required to treat any acute situation, only administer for short periods of time. o Monitor the input of stock feed and fish feeding behaviour to inform and adapt the feeding strategy to maximise feeding efficiency.	• Benthic communities and habitat of the Abrolhos marine environment are well-protected at both local and regional scales from any potential impacts from the proposed aquaculture. • Benthic communities and habitat (EAG 3) are reliant on the maintenance of sediment and water quality to support the environmental value of ecosystem health (EAG 15). • The most significant impacts are restricted to small areas (i.e. less than 300 hectares) when aquaculture production is at full capacity. • The proposal is unlikely to yield significant cumulative losses of benthic communities and habitat. • The cumulative loss would be restricted to less than two per cent of the local assessment units (LAU) that were defined for the MWADZ Proposal (Appendix 1).

Environmental Factor	EPA Objective	Existing Environment	Potential Impact	Environmental Management	Predicted Outcome
		considered itinerant given their propensity to change significantly between surveys, and over time. Habitats in the northern MWADZ area are more diverse and comprise 83% bare sand and 17% mixed assemblages. No seagrasses were observed in the 2014/2015 assessment.		o Monitor concentrations of nutrients and metals in the seabed sediment, and suspended material, light attenuation, chlorophyll a, nutrients and dissolved oxygen in the water column at sites near beneath and surrounding the sea cages.	• Compliance with the EPA's Cumulative Loss Guidelines (EAG 3) that signify a low risk to the ecological integrity of benthic communities and habitat.
Marine Environmental Quality	To maintain the quality of water, sediment and biota so that the environmental values, both ecological and social, are protected.	Waters inside the MWADZ are clean and well mixed. Maximum and minimum water temperatures are achieved in autumn (23.5°C) and winter (20.8°C), respectively. Salinity and dissolved oxygen levels are consistent through the water column with little evidence of stratification. The water is highly	1. Degradation of marine water and sediment quality through the deposition of organic wastes and inorganic nutrients; 2. Direct and indirect impacts to key sensitive receptors; and 3. Impacts to marine environment and biota quality through release of pharmaceuticals, trace metals or	• Avoid direct and indirect impacts on marine environmental quality (EAG 8) by implementing measures that include those outlined above for Benthic Communities and Habitats.	• Environmental values, both ecological and social (EAG 15), are well-protected from any potential impacts from the proposed aquaculture through the maintenance of water, sediment and biota quality. • The Environmental Monitoring and Management Plan (EMMP) (Appendix 2) provides appropriate monitoring and management of these environmental values in the vicinity of the proposed aquaculture.

Environmental Factor	EPA Objective	Existing Environment	Potential Impact	Environmental Management	Predicted Outcome
		oxygenated, achieving surface oxygen saturation levels between 96% and 99% and bottom oxygen saturation levels between 95% and 98%. MWADZ water currents are variable, ranging between 5.8 and 14.4 cm/s. Concentrations of ammonium and chlorophyll-a indicate an overall oligotrophic (nutrient poor) environment. Concentrations of inorganic nutrients and chlorophyll-a are seasonally variable. The benthic environment consists generally of a shallow (~15 cm thick) layer of sand overlying rocky substrate. Higher current speeds in the northern area (northern 13-14.5 cm/s compared	metalloids and/or petroleum hydrocarbons.		• Results of the modelling indicate that the impacts of the proposal can be constrained within small areas of the seafloor within the proposed MWADZ, with no adverse effects to regional environmental quality. • Any fish faecal plumes or phytoplankton blooms within the proposed MWADZ will dissipate rapidly, and water quality will be maintained at levels consistent with a high level of ecological protection. • Phytoplankton concentrations, as indicated by chlorophyll-a concentrations, are not expected to change significantly across the proposed MWADZ. Consequently, any light reduction (or shading) is expected to be insignificant. • Similarly, light and dissolved oxygen levels in the water column of the proposed MWADZ are not expected to be affected.

Environmental Factor	EPA Objective	Existing Environment	Potential Impact	Environmental Management	Predicted Outcome
		to the south 8.7-11 cm/s) are reflected in the tendency toward larger sediment grain sizes in the northern reaches of the MWADZ. Sediment conditions are also variable, with seasonal fluctuations in nitrogen, phosphorus and total organic carbon. Infauna assemblages are diverse and dominated by polychaetes (marine worms).			• No discernible impacts on sub-surface light conditions are expected to be caused by increased phytoplankton blooms or suspended waste in the water column (Appendix 1). • The seafloor sediments beneath the sea cages will be exposed to deposition of organic material. Organic waste inputs will lead to some localised sediment organic enrichment and changes to sediment chemistry. • Appropriate levels of standing biomass and three-year cage cluster site rotation will constrain the extent of the zone of high impact. After more than three years of finfish production at any one location, the zone of high impact is unlikely to breach the cage cluster perimeter (Appendix 1). • It is predicted that the low concentrations of zinc and copper in the fish waste will be insufficient to result in

Environmental Factor	EPA Objective	Existing Environment	Potential Impact	Environmental Management	Predicted Outcome
					sediment concentrations in excess of the Environmental Quality Criteria (EQC), even after five years production at the upper end of the proposed standing biomass limit of 24,000 tonnes of marine finfish for the proposed MWADZ (Appendix 1).

Marine Fauna (including seabirds)	To maintain the diversity, geographic distribution and viability of fauna at the species and population levels.	The MWADZ Proposal is located within the Abrolhos Islands Fish Habitat Protection Area (FHPA). This FHPA surrounds the Abrolhos Islands Reserve, which is the most significant seabird breeding location in the eastern Indian Ocean.
		
		The Abrolhos Islands Reserve and FHPA also provide habitat for an array of marine mammals, comprising mainly whales, dolphins and sea lions. Thirty one cetacean and two pinniped species are
			Note: While there is no terrestrial component to the MWADZ Proposal, the Department nevertheless considered the possibility of any direct or indirect impacts of the proposal on the terrestrial environments of the Abrolhos Islands Reserve. In particular, any possible impacts on seabirds (avifauna) and seabird breeding colonies were investigated (see points 14 and 15 below). As the ESD included seabirds under the environmental factor	• Avoid direct and indirect impacts on marine fauna and protect marine environmental quality (EAG 8) as outlined above.
				• Implement infrastructure design, systems and practices that eliminate, substitute, isolate or otherwise minimise the potential impacts of hazards that may contribute to the attraction of marine fauna. This can be achieved by implementing measures that include the following:
				  o Locate sea cages in areas away from sea lion haul-out sites.
				  o Design railings, floats, net rings, etc. to reduce the opportunity for roosting sites that could be used by increaser seabird species.
				  o Use surface and sub-surface exclusion or "anti-predator" netting.
				  o Minimise opportunities for provisioning (i.e. artificial access to food) of marine fauna by promptly removing any dead or moribund stock and preventing access to pelletised feed.
				  o Contain all post-harvest blood water and effluent.
					• Diversity, geographic distribution and viability of Abrolhos fauna are well-protected at the species and population levels from any potential impacts from the proposed aquaculture.
					
					• The EMMP (Appendix 2), Marine Fauna Interaction Management Plan (Appendix 5) and Waste Management Plan (Appendix 6) provide appropriate monitoring and management of these environmental values in the vicinity of the proposed aquaculture.
					
					• The key pressures associated with aquaculture are inputs of nutrients and organic material derived from fin-fish metabolic processes and

Environmental Factor	EPA Objective	Existing Environment	Potential Impact	Environmental Management	Predicted Outcome
		known to occur within a 50 km radius of the MWADZ. Four species of marine turtle may also occur within this radius. The benthic habitats of the FHPA support rich finfish (including sharks and rays) and invertebrate communities; although the benthos of the MWADZ Proposal area is primarily composed of sand and has correspondingly lower levels of diversity and abundance relative to other locations within the FHPA.	of "marine fauna", that is where it has been addressed in this PER. Direct and indirect impacts on significant marine fauna, include: 1. nutrient enrichment of the water column and increased turbidity; 2. organic deposition and nutrient enrichment of the sediments; 3. release of trace metals, therapeutants and other contaminants into the marine environment; 4. introduction of marine pests and pathogens; 5. additional food from aquaculture activities; 6. physical presence of aquaculture infrastructure; 7. artificial lighting; 8. noise and vibrations;	○ Prevent the recreational fishing and feeding of marine avifauna by aquaculture farm staff on board commercial infrastructure. ○ Use mesh or netting of an appropriate mesh size (e.g. less than 60 millimetres in bar-length), tear-resistant and tangle-resistant. ○ Tension anti-predator netting as tight as is practicable. ○ Manage sea cage infrastructure to minimise entanglement hazards, roosting opportunities and potential collisions with seabirds. ○ Inspect nets, ropes and sea cages daily for any marine fauna that may have become entangled and release them in accordance with protocols outlined in Appendix 5, MWADZ Marine Fauna Interaction Plan. ○ Monitor interactions between seabirds and sea cage infrastructure daily. ○ Monitor seabird activity (by suitably-trained farm crew) and record and report interactions of seabirds with the aquaculture infrastructure. ○ Minimise to levels as low as practicable the intensity and quantity of light emissions from aquaculture infrastructure at night. ○ Use, maintain and inspect noise generating equipment (e.g. vessel engines, drilling equipment) to reduce unnecessary increase in noise levels from the equipment (i.e. all vessels shall operate in accordance with the appropriate industry noise codes).	feeding. • None of the pressures on marine environmental quality and benthic communities and habitat are expected to impact on significant marine fauna (i.e. marine mammal, turtle, seabird, wild fish populations). • The implementation of appropriate management and mitigation measures ensures the potential risks associated with provisioning of food and artificial habitats are low. • Ongoing monitoring of the activity and populations of these species will ensure any impacts to populations of vulnerable species are managed through measures which avoid, minimise, or mitigate any impacts. • Compliance with the EMMP and the adoption of best-practice aquaculture management will minimise any impacts to marine fauna. • In summary, the proponent

Environmental Factor	EPA Objective	Existing Environment	Potential Impact	Environmental Management	Predicted Outcome
			10. competition or genetic mixing implications for wild stocks from escaped farm fish; 11. potential changes in benthic/fish habitat; 12. changes in recruitment patterns and spawning stock of invertebrate and fish species; 13. changes in the abundance and distribution of fish and invertebrate species; 14. attraction to, altered feeding behaviour from, and possible entanglement in or entrapment within, sea cages and associated infrastructure; and 15. indirect impacts on other avifauna (particularly in relation to competition for breeding sites) as a result of any expansion to	○ Comply with the Marine Fauna Interaction Management Plan requirements (including reporting of interactions between ETP and other species). ○ Comply with the Waste Management Plan requirements. ○ Monitor fish feeding behaviour and the generation of waste feed to inform and adapt the feeding strategy to maximise feeding efficiency and minimise waste. ○ Conduct regular cleaning and maintenance of sea cage infrastructure to avoid accumulation of biofouling organisms and reduce the need for anti-foulants. ○ Promote high level of fish welfare and husbandry through regulatory measures and the ACWA Code of Conduct. ○ Use pathogen-free brood stock and exclude known significant pathogens through health testing of stock prior to translocation to sea cages. ○ Limit pressure from biological threats through regular cleaning and exchange of nets. ○ Prevent stock from escaping and report all stock escape events. ○ Train staff in escape-critical operations and techniques. ○ Develop a biosecurity monitoring regime based on a recognised and agreed national biosecurity surveillance system. ○ Report all instances of suspected marine pests to the Department of Fisheries.	considers that the potential risks to marine fauna will be adequately managed such that future derived proposals will achieve the EPA's environmental objective by providing a high level of protection for marine fauna.

Environmental Factor	EPA Objective	Existing Environment	Potential Impact	Environmental Management	Predicted Outcome
			'increaser' seabird species (i.e. silver gull, Pacific gull or pied cormorant) due to aquaculture activities in the proposed MWADZ.		
Amenity	To ensure that impacts to amenity are reduced as low as reasonably practicable.	While the FHPA is a multi-use marine area, it is relatively pristine in condition. Consequently, the environmental quality of its waters is valued by the community. The MWADZ Proposal area is located in a relatively remote part of the FHPA.	1. excessive presence of macroalgae, phytoplankton and encrusting invertebrates on and around the sea cages; 2. reductions in the natural visual clarity of the water; 3. visible film the water from petrochemical origins; 4. floating debris, dust or other objectionable matter; and 5. presence of objectionable odours.	• Protect both the ecological and social values of the marine environment through the establishment and implementation of an effective environmental quality management framework (EQMF) specific to the MWADZ Proposal in accordance with the guidance described in the EPA's EAG 15. • Protect marine environmental quality by implementing measures that include those outlined above for both Marine Fauna and Benthic Communities and Habitats. • Incorporate the management measures to protect the environmental factor of amenity (EAG 8) and maintain aesthetic values (EAG 15) of the area within and surrounding the proposed MWADZ. • Monitor assessments of amenity (based on observations made adjacent to sea cage clusters) against the relevant Environmental Quality Criteria (EQC). • Assess against the Environmental Quality Standards (EQS) based upon credible community observations of the aesthetics within the proposed MWADZ. • Provide community users of the Abrolhos Islands FHPA and other relevant stakeholders with an open invitation to comment on any depreciation of the aesthetic values of the	• Amenity and aesthetic values of the Abrolhos marine environment are well-protected from any potential impacts from the proposed aquaculture. • Protection of both the ecological and social values of the marine environment specific to the MWADZ Proposal (refer to Appendix 2). • The EMMP (Appendix 2) and Waste Management Plan (Appendix 6) provide appropriate monitoring and management of the aesthetic values of the marine environment in the vicinity of the proposed aquaculture. • Any unlikely decrease in the aesthetic values of the marine environment in the vicinity of the proposed aquaculture, as determined

Environmental Factor	EPA Objective	Existing Environment	Potential Impact	Environmental Management	Predicted Outcome
				Zeewijk Channel that may be attributable to the aquaculture within the proposed MWADZ (using the Department's website as a mechanism by which the community and stakeholders can submit comments. • Measure any decreases in aesthetic water quality values of the Zeewijk Channel as an increase in the number of complaints or a distinct change in the perception of the community. • Record instances of complaints and document the correspondence in the Annual Compliance Report. • Include all records associated with the monitoring in the Annual Compliance Report.	using direct measures of the community's perception of aesthetic values (exceedance of EQC), will instigate a prompt and effective management response. • The EPA's environmental factor of amenity (EAG 8) and its associated values are supported through the maintenance of the key environmental value of ecosystem health (EAG 15).
Heritage	To ensure that historical and cultural associations, and natural heritage, are not adversely affected.	In the context of the MWADZ Proposal, heritage encompasses Aboriginal cultural heritage and European (maritime) heritage. A search of the Register of Aboriginal Sites maintained by the Western Australian Department of Indigenous Affairs returned no results. In addition, a search of the available literature on the Abrolhos Islands did	1. The physical presence of marine finfish sea cage aquaculture infrastructure within the MWADZ Proposal area is the only possible potential impact on environmental heritage values. However, there do not appear to be any such values applicable to that particular area.	• Protect marine environmental quality (as outlined above). • Given the absence of any evidence of indigenous heritage and cultural issues relating to the Abrolhos Islands; and considering the remoteness of the wrecks and associated dive trails from the MWADZ Proposal area, it is unlikely that the proposed zone will have any impact on their values. • The MWADZ Proposal does not present any known potential impacts to either of these heritage values. • Nevertheless, if any cultural heritage material is uncovered within the proposed MWADZ at any time in the future, the appropriate authorities (e.g. Department of Aboriginal Affairs and the Western Australian Museum) will be immediately contacted for advice.	• There is unlikely to be any adverse impacts to historical and cultural associations, and natural heritage, as a result of the MWADZ Proposal. • Therefore, there is a high degree of confidence that the EPA objective will be met.

Environmental Factor	EPA Objective	Existing Environment	Potential Impact	Environmental Management	Predicted Outcome
		not indicate there were any indigenous heritage and cultural issues that may be impacted by the MWADZ Proposal. There is currently no native title or native title claim over the Abrolhos Islands and the MWADZ Proposal area. A number of shipwrecks are scattered throughout the Abrolhos Islands; however, none are in the vicinity of the MWADZ Proposal area.			

Further detail of the impact assessment processes undertaken for the MWADZ Proposal is outlined in the Modelling and Technical Studies in Support of the Mid West Aquaculture Development Zone (Appendix 1) and Sections 6 to 13 of this PER.

Approach to Environmental Management

The Environmental Scoping Document (ESD) associated with the Mid West Aquaculture Development Zone (MWADZ) strategic proposal (Assessment No. 1972) was determined by the Environmental Protection Authority (EPA) in July 2013. This document defined the requirements of the PER document that were to be met by the Department of Fisheries (Department) on behalf of the Minister for Fisheries (the proponent for the MWADZ strategic proposal).

The preliminary key environmental factors, scope of works and policy documents relevant to the MWADZ Proposal and required to be addressed in the PER document included the EPA's Environmental Assessment Guidelines (EAG) No.3 Protection of Benthic Communities Habitats in Western Australia's Marine Environment (2009) and the EPA's EAG No.7 Marine Dredging Proposals (2011). Although the MWADZ Proposal didn't involve dredging, the principles and approaches for describing the potential impacts and addressing predictive uncertainty outlined in the latter EAG could be applied when assessing impacts to primary producing and non-primary producing communities and habitat.

These documents played a significant role in shaping the Department's approach towards developing the Environmental Monitoring and Management Plan (EMMP) for the MWADZ Proposal. The EMMP consists of a series of sub-management plans, monitoring programs and protocols that address the potential environmental impacts identified in the PER.

Given there is a level of uncertainty in predicting the long-term consequences of conducting sea cage aquaculture in the Mid West, the Department, with the assistance of its environmental consultant (BMT Oceanica), chose to adopt a conservative approach to developing the EMMP. This conservative approach was taken to ensure that the potential scale and intensity of the potential cumulative impact of the proposed aquaculture operations in the MWADZ on the local marine environment was not understated. In other words, it consistently focused on what could be termed the "most likely worst case" scenario when considering the inputs of aquaculture activity (e.g. fish faeces and uneaten fish feed) and their potential impacts on the receiving environment.

Such an approach was reinforced by the available published literature (albeit mostly relating to marine finfish aquaculture in the Northern Hemisphere) pertaining to the potential environmental impacts that may be associated with large-scale marine finfish sea cage aquaculture, supplemented by the outcomes of the environmental modelling undertaken for the MWADZ Proposal.

While this approach can be effective in reducing the likelihood of any unforeseen negative environmental impacts associated with the MWADZ Proposal, it can also result in an overly negative perception of the magnitude of the likely "actual" environmental impacts of the proposal, and (in this instance) the resultant levels of ecological protection considered appropriate when designing the proposal Environmental Quality Plan (EQP).

The combined effects of these factors led to the Department (through its environmental consultants) exploring the possibility of incorporating the principles described in Environmental Assessment Guidelines No.7 Marine Dredging Proposals (2011) in the design of the MWADZ EQP. This idea was supported in that both the published literature and the environmental modelling undertaken indicated the primary environmental impact of the proposed aquaculture was to the sediments immediately beneath the sea cages; but that such impacts did not extend significantly beyond this deposition area. At the same time, the impact of the aquaculture activity on water quality was likely to be negligible. In this respect, the anticipated behaviour of the organic inputs and the resulting environmental impacts of the MWADZ Proposal more closely reflected those expected of (say) a wastewater outfall rather than that previously thought to represent sea cage aquaculture (such as in some other locations within the State).

As a consequence, based on the available information and outputs of the 'conservative' environmental impact modelling undertaken, an EQP based on a small total area of Low Ecological Protection Area (LEPA), (occupying less than one per cent of the area encompassed within a ten kilometre radius of the zone), surrounded by larger areas of High Ecological Protection Area (HEPA) was contemplated. This was considered to reflect the 'likely worse case' scenario.

However, while the Department was confident that such a level of impact and effect is at the upper end of what might be expected and would not be exceeded by the aquaculture activity, it was of the view that, through good farm management, a better environmental outcome could be achieved. It was also conscious that the resultant 'low' level of ecological protection is not consistent with the recently-published EPA EAG No. 15 Protecting the Quality of Western Australia's Marine Environment (2015) (EAG 15). This document, among other things, sets out the EPA's views on the level of ecological protection it would normally expect to be applied, and the environmental values expected to be protected, in relation to certain types of marine areas, including those areas subject to sea cage aquaculture. For this sea cage aquaculture, EAG 15 suggests the most appropriate level of ecological protection is a Moderate Ecological Protection Area (MEPA).

As set out above, the level of uncertainty and the conservative approach to predicting the potential impacts of the proposed MWADZ in the PER resulted in a level of protection that would likely equate to 'Low'. However, the EAG 7 approach, which is designed for dealing with dredging proposals that typically have similar "levels of uncertainty" involved in predicting impacts to that of large-scale aquaculture, suggests that proponents of derived proposals should not only consider the 'most likely worst case' but should also consider the 'most likely best case'. The latter would indicate the level of impact that would occur if realistic, but less conservative (i.e. more optimistic), assumptions were considered and optimum levels of management were achieved.

Due to the lack of published literature relating to marine finfish sea cage aquaculture in sub-tropical waters where the sea bed predominately comprises calcareous sediments (i.e. like the proposed MWADZ), the design of the EQP for the MWADZ Proposal was based on studies conducted in temperate waters in the Northern Hemisphere and on locations that have sediments markedly different (and arguably more vulnerable to environmental impacts from aquaculture) to those present in the proposed MWADZ. In addition, the relatively 'shallow' depth of sediment in the proposed MWADZ and the likely periodic influence of storms,

which could rework and mobilise sediments, provides a plausible mechanism to reduce organic matter accumulation rates and consequential sediment anoxia.

Combined, the overstating of potential sediment impacts due to the design basis for the EQP (i.e. Northern Hemisphere examples) and the understating of the potential ameliorating effects of shallow sediment depth and periodic storm activity have probably contributed to a far more pessimistic (i.e. worst case) assessment of the likely environmental impacts of the proposed aquaculture activity being incorporated in the modelling than should have been the case.

Considered from this viewpoint, a likely 'best case scenario' would be that organic enrichment and associated levels of oxygen depletion/hydrogen sulphide production would probably **not** occur to the same extent as that generated through the conservative modelling. Under this scenario, it is possible that the resultant environmental quality would more closely resemble that characterised as a 'moderate' level of ecological protection (i.e. MEPA).

The combined effect of the factors set out above creates some uncertainty as to whether the most appropriate EQP approach for the MWADZ Proposal should be based on a LEPA or MEPA. While not dismissing the potential applicability of the LEPA approach to the proposed MWADZ, the Department acknowledges this approach is built upon the worst case scenario and may not be the only viable approach. It recognises the uncertainty surrounding this matter and acknowledges the need to monitor and collect the relevant information necessary to remove this uncertainty.

Consequently, the Department now proposes a different approach in the EMMP for the MWADZ. This approach is iterative, informed by the results of the monitoring and other information gathered over time and aims to ascertain the most appropriate environmental management arrangements for the MWADZ Proposal. The approach includes the following key elements:

- Apply a MEPA approach to the EQP;
- Apply a 24,000 tonne standing biomass limit;
- Implement a specially-designed environmental monitoring program with the aim to acquire the scientific data necessary to clarify what EQP approach is the most appropriate for the MWADZ (noting this monitoring program is not intended to create an additional operational or financial burden to industry);
- Review all information collected over the first ten years[6] of commercial operations in the zone to clarify the continuing:
    - ✓ appropriateness of the current (MEPA) EQP approach;
    - ✓ environmental compatibility of the 24,000 tonne standing biomass limit for the MWADZ; and
- Subject to the outcomes of the review, thereafter, continue the iterative MWADZ management processes of monitoring, evaluation, review, planning and implementation conducted in consultation with industry and other relevant stakeholders.

[6] By the tenth year of commercial operations in the MWADZ operators should have achieved a complete rotation of their sea cage cluster locations throughout their lease and be back at the (year 1) commencement site. They are also likely to be operating close to their maximum allocated standing biomass limits.

It is important to note that, no matter what the outcome, the environmental monitoring program implemented for the MWADZ Proposal and the adaptive management tools available to the aquaculture operators (i.e. derived proponents) and the Department will ensure a rapid and effective response to the information gathered as aquaculture development in the zone progresses. Collectively, these arrangements will ensure both the environmental integrity of the Abrolhos Islands Fish Habitat Protection Area is preserved; and (within this imperative) the sustainable commercial aquaculture opportunities are maximised.

The EMMP (Appendix 2) for the MWADZ Proposal enables the MWADZ to be developed with greater certainty for the Government, the industry and the community.

The EMMP, coupled with the Management and Environmental Monitoring Plan (MEMP), will ensure the commitments in this PER, subsequent assessment reports and any approval or licence conditions are fully implemented.

The key objective of the EMMP is to ensure the MWADZ Proposal is sustainably managed and that its operation does not have a significant impact on the marine environment. The EMMP will provide an appropriate environmental quality management framework (EQMF) to manage the potential impacts of stocking up to 24,000 tonnes of marine finfish across the proposed MWADZ, using pelletised feeds. The aim is to make sure the MWADZ Proposal is managed to achieve the relevant Environmental Values (EVs) and Environmental Quality Objectives (EQOs), as outlined in EAG 15 and the State Water Quality Management Strategy (Government of Western Australia).

While all the EVs and associated EQOs for the marine waters of Western Australia have been addressed in this PER (Section 7.5), the key EQOs most relevant to this EMMP are:

- maintenance of ecosystem integrity; and
- maintenance of aesthetic values.

Maintenance of ecosystem integrity is concerned with maintaining the structure (e.g. the variety and quantity of life forms) and functions (e.g. the food chains and nutrient cycles) of marine ecosystems to an appropriate level. In this context, the EMMP includes strategies and contingency management responses to protect the key ecosystem elements (EPA 2015), taking into account their occurrence and sensitivity to aquaculture pressures. These key ecosystem elements include:

- water quality
- sediment quality
- seabirds
- marine mammals and turtles
- finfish (including sharks and rays)

Maintenance of aesthetic values is concerned with maintaining the visual qualities of the marine environment, including water clarity, odours and incidences of debris (EPA 2015). The monitoring and management frameworks for the ecosystem and aesthetic elements are outlined in the EMMP (Appendix 2).

Consultation

The Department is committed to open and accountable processes that encourage ongoing stakeholder engagement during all stages of the MWADZ Proposal. It began the consultation process for this project with relevant stakeholders in February 2013 and will continue to do so throughout the PER process.

The purpose of engaging stakeholders during the planning and assessment of the MWADZ Proposal is to:

- inform stakeholders about the MWADZ Proposal by providing accurate and accessible information;
- provide adequate opportunities and timeframes for stakeholders to consider the MWADZ Proposal;
- engage stakeholders in meaningful dialogue and provide adequate opportunities to be involved in the decision making processes during the development of the proposal;
- identify and attempt to resolve potential issues;
- consider and address issues raised by stakeholders and provide feedback; and
- consider stakeholder views in planning future engagement.

A range of stakeholders has been engaged as part of the MWADZ Proposal. These included the following broad groups:

- Commonwealth Government
- State Government
- Local Government
- community groups and environment Non-Government Organisations (eNGOs)
- industry groups and representatives
- internal stakeholders

Stakeholder engagement activities for the MWADZ Proposal to date have included:

- consulting with other decision-making authorities identified in the EPA-prepared Environmental Scoping Document (ESD) on the works required to address the requirements of the ESD;
- conducting stakeholder meetings, briefings and presentations;
- posting periodic newsletters on the Department's website outlining the progress of the project; and
- mailing letters to eNGOs and interest groups.

Further details of the consultation processes undertaken for the MWADZ Proposal, including key issues identified, refer to Section 5 of this PER.

Conclusion

The EPA identified three key environmental factors for this proposal. The key environmental objectives for these factors are:

- *To maintain the quality of water, sediment and biota so that the environmental values, both ecological and social, are protected;*
- *To maintain the structure, function, diversity, distribution and viability of benthic communities and habitats at local and regional scales; and*
- *To maintain the diversity, geographic distribution and viability of fauna at the species and population levels.*

Within this PER and associated documents, the Department has addressed these objectives through considering the potential direct, indirect and cumulative environmental impacts of the MWADZ Proposal and comprehensively conducting the scope of work specified within the ESD. It has also addressed (EAG 8) environmental values and objectives (identified through public consultation) that are additional to those specified in the ESD; and conducted a similar assessment of their potential impacts, mitigation and management measures, and predicted outcomes. Although published over two years after the ESD was approved by the EPA, the provisions of the *Environmental Assessment Guideline for Protecting the Quality of Western Australia's Marine Environment* (EAG 15) has also been addressed in this PER. A summary of the EPA's policy and guidance documents, along with an outline of how and where they have been applied in this process, is listed in Table 1-1 of the PER.

Having completed the work outlined above, the Department concludes that all the EPA objectives have been adequately met. Further, that establishment of commercial marine finfish aquaculture projects within the proposed MWADZ is not expected to cause a significant environmental impact and will not result in a net environmental loss to the conservation values of the Abrolhos Islands Fish Habitat Protection Area or the associated Abrolhos Islands Reserve.

This assessment of the likely environmental impacts is due to several key factors, including:

- the zone's physical characteristics, in particular the high rates of flushing or water exchange in the Zeewijk Channel that is sufficient to dilute nutrients before they are assimilated by the ecosystem;
- the adaptive management controls and environmental monitoring framework the Department has developed for the zone, and the individual (derived) proposals within it, through the strategic assessment process for the MWADZ Proposal; and
- confidence in the effectiveness of these management controls and the environmental monitoring framework built upon the experience gained thus far through implementing similar arrangements in the Kimberley Aquaculture Development Zone.

The objectives described in this PER that have been established to determine the predicted environmental outcomes reflect the EP Act principle of conserving biodiversity and ecological integrity. This principle, in addition to the "precautionary" principle that is embodied in both the EP Act and the current FRMA is further reinforced in the *Aquatic*

Resources Management Bill 2015.[7] The Department is the Western Australian Government agency responsible for the administration and implementation of the FRMA and is committed to adopting a conservative approach to managing uncertainties over environmental impacts. This will be achieved through the early consideration of the identified potential environmental impacts and additional cumulative impacts associated with the project proposals, and of the relevant management measures designed to control these.

Collectively, these factors underpin the Department's confidence that the MWADZ Proposal will be environmentally acceptable, subject to the effective implementation of the mitigation and management measures outlined in this PER and its associated documents.

The results from the environmental monitoring program and reviews of the effectiveness of the management plans, protocols and other mitigation measures will also provide valuable information to support evidence-based policy development for future sustainable marine finfish aquaculture production in Western Australia.

[7] The 'precautionary' principle, as specified in s.4A of the FRMA requires that: "*In the performance or exercise of a function or power under this Act, lack of full scientific certainty must not be used as a reason for postponing cost-effective measures to ensure the sustainability of fish stocks or the aquatic environment.*"

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TABLES

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LIST OF ABBREVIATIONS

The following acronyms and abbreviations are commonly used in the Mid West Aquaculture Development Zone Public Environmental Review/Draft Environmental Impact Statement:

ACWA	Aquaculture Council of Western Australia
AIMWTMF	Abrolhos Islands and Mid West Trawl Managed Fishery
ANOVA	Analysis of Variance
ANZECC	Australian and New Zealand Environment and Conservation Council
AQIS	Australian Quarantine and Inspection Service
ARMB	Aquatic Resources Management Bill 2015
ARMCANZ	Agricultural and Resource Management Council of Australia and New Zealand
BCH	Benthic Communities and Habitat
BRA	Biosecurity Risk Assessment
CEO	Chief Executive Officer
Chl-a	Chlorophyll-a
CI	Confidence Interval
CoP	Code of Practice
Cu	Copper
Department	Department of Fisheries Western Australia
DIN	Dissolved Inorganic Nitrogen
DO	Dissolved Oxygen
DoF	Department of Fisheries Western Australia
DPaW	Department of Parks and Wildlife
EAG	Environmental Assessment Guidelines
EF	Environmental Factor
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EMMP	Environmental Monitoring and Management Plan
EO	Environmental Objective
EP Act	*Environmental Protection Act 1986*
EPA	Environmental Protection Authority
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
EQC	Environmental Quality Criteria
EQG	Environmental Quality Guideline
EQMF	Environmental Quality Management Framework
EQMP	Environmental Quality Management Plan
EQO	Environmental Quality Objective
EQP	Environmental Quality Plan
EQS	Environmental Quality Standard
ESD	Ecologically Sustainable Development
ESD	Environmental Scoping Document
ETP	Endangered, Threatened and Protected
EV	Environmental Value
FHPA	Fish Habitat Protection Area
FRMA	*Fish Resources Management Act 1994*
FRMR	*Fish Resources Management Regulations 1995*

GFC	Geraldton Fisherman's Co-operative
GRP	Gross Regional Product
GS	Guidance Statement
GSP	Gross State Product
HEPA	High Ecological Protection Area
IMP	Introduced Marine Pest
LAC	Light Attenuation Coefficient
LAU	Local Assessment Unit
LEP	Level of Ecological Protection
LEPA	Low Ecological Protection Area
LOR	Limits of Reporting
MEMP	Management and Environmental Monitoring Plan
MEPA	Moderate Ecological Protection Area
MFIMP	Marine Fauna Interaction Management Plan
Minister	Minister for Fisheries
MWADZ	Mid West Aquaculture Development Zone
MWADZ Proposal	Mid West Aquaculture Development Zone strategic proposal
NWQMS	National Water Quality Management Strategy
OEPA	Office of the Environmental Protection Authority
PER	Public Environmental Review
ROV	Remotely Operated Vehicle
SCUBA	Self-Contained Underwater Breathing Apparatus
SWQMS	State Water Quality Management Strategy
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
TSS	Total Suspended Solids
WC Act	*Wildlife Conservation Act 1950*
WCDSMF	West Coast Demersal Scalefish Managed Fishery
WCRLMF	West Coast Rock Lobster Managed Fishery
ZMP	Mid West Aquaculture Development Zone Management Policy
Zn	Zinc
zone	Aquaculture Development Zone

GLOSSARY OF TERMS

Anchoring and Bridle System	The series of ropes, chains, weights and anchors used to keep the sea cages and nets in place in the ocean.
Anoxic	Absence of or low concentrations of oxygen.
Anti-predator Net	A net that is suspended around the culture net to prevent predators from entering cages.
Aquaculture	Cultivating fish or marine vegetation for the purposes of harvesting the organisms or their progeny with a view to sell or keep the organisms in a confined area for commercial purposes.
Background (conditions)	Natural environmental conditions that are largely un-impacted by anthropogenic influences.
Baseline (conditions)	Environmental conditions prior to being subject to pressures from a development or operation of concern.
Benthic	Living in or on the seabed.
Benthic Communities and Habitat (BCH)	Are functional ecological communities that inhabit the seabed within which algae (e.g. macroalgae, turf and benthic microalgae), seagrass, mangroves, corals or combinations of these groups are prominent components. BCH also include areas of seabed that can support these communities.
Biofouling	The settlement, attachment and growth of organisms (e.g. microorganisms, plants, algae and animals) on submerged surfaces in aquatic environments.
Brood stock	The group of mature or parent fish used in aquaculture for breeding purposes.
Contaminant	Biological (e.g. bacterial and viral pathogens) and chemical (see Toxicants) introductions capable of producing an adverse response in a biological system, seriously injuring structure or function or causing mortality.
Control site	A site located in an area that is unaffected by a pressure being monitored (generally up-current) and used for determining baseline conditions/quality prior to becoming influenced by the pressure of concern.
Decommissioning	A general term for a formal process to dismantle or remove something from service i.e. removal of sea cage infrastructure.
Detectable change	A measurable change in an indicator (generally beyond the natural variability of that indicator) that is statistically significant.
Environmental Factor	A part of the environment that may be impacted by an aspect of a proposal. There are 15 environmental factors identified as relevant and practical for the EIA process (see EAG 8).
Environmental quality criteria	Environmental quality guidelines and/or standards.

Environmental quality guideline	A threshold numerical value or narrative statement which if met indicates there is a high degree of certainty that the associated environmental quality objective has been achieved.
Environmental quality indicator	A specific parameter that can be measured and used to indicate the quality of that part of the environment by comparing the measurements against the associated EQC for that parameter.
Environmental quality management framework	The framework adopted by the EPA and described in this EAG for managing the quality for the marine environment to meet the EPA's objectives and the community and stakeholder's long-term desires.
Environmental quality objective	A specific management goal for a designated part of the environment that signals the level of environmental quality needed to protect the environmental value.
Environmental quality plan	A plan that identifies the environmental values that apply to an area and spatially maps the zones where the environmental quality objectives (including levels of ecological protection) should be achieved.
Environmental quality standard	A threshold numerical value or narrative statement that indicates a level which if not met indicates there is a significant risk that the associated environmental quality objective has not been achieved and triggers a management response.
Environmental value	Particular value or use of the environment that is important for a healthy ecosystem or for public benefit, welfare, safety or health and that requires protection from the effects of pollution, waste discharges and deposits.
Fallowing	A good husbandry practice that involves moving cages over different seabed areas in order to minimise the build-up of organic wastes in any one area, and to subsequently allow these areas enough time for natural marine processes and the environment to assimilate any wastes.
Feed Conversion Ratio	The amount of food required to produce one unit of growth (e.g. kilogram) in an organism (e.g. fish).
In situ	Situated in the original, natural or existing place or position.
Infauna	Aquatic animals living in the sediment.
Increaser seabirds	Increaser seabird species take advantage of activities associated with humans that result in a food (energy) subsidy particularly during periods when food availability is limiting (Harris and Wanless, 1997, Montevecchi 2002). Additional food resources can result in increased breeding effort and success leading to expanding populations, with potential detrimental impacts on other seabirds and island ecosystems in the area.
Irreversible	Lacking a capacity to return or recover to a state resembling that prior to being impacted within a timeframe of five years or less (also see reversible).
Level of ecological protection	A level of environmental quality desired by the community and stakeholders for the EQO maintenance of ecological integrity.
Matters of National	Matters of national environmental significance are protected under

Environmental Significance	national environment law – the Environment Protection and Biodiversity Conservation Act 1999. These include listed threatened species and communities, listed migratory species, Ramsar wetlands of international importance, Commonwealth marine environment, world heritage properties, national heritage places, the Great Barrier Reef Marine Park and nuclear actions.
Oligotrophic	Nutrient poor.
Pelagic	Organisms that inhabit open water.
Physico-chemical stressor	Refers to physical (e.g. temperature, electrical conductivity, total suspended solids) and chemical characteristics (e.g. dissolved oxygen concentration, nutrient concentrations) of water that can cause changes in biological systems.
Plankton	Organisms (< 0.5 mm) that drift with the ocean currents.
Pollution	Where an emission causes direct or indirect alteration of the environment to the detriment of an environmental value.
Precautionary Principle	A principle of ESD which states that where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.
Reference site	A site located in a similar system, or in a location that experiences similar natural environmental conditions as an area being managed, but largely un-impacted by anthropogenic influences and used as a benchmark for determining the environmental quality to be achieved.
Reversible	A capacity to return or recover to a state resembling that prior to being impacted within a timeframe of five years or less.
Risk	The likelihood of an undesired event (or impact) occurring as a result of some behaviour or action.
Risk Management	The culture, processes and structures that are directed towards the effective management of potential opportunities and adverse effects.
Sedimentation	The settling of particles (e.g. uneaten food and fish faeces) to settle out of the fluid in which they are suspended (e.g. out of the water column of the ocean onto the seabed).
Significant Impact	A significant impact is an impact which is important, notable, or of consequence, having regard to its context or intensity. Whether or not an action is likely to have a significant impact depends upon the sensitivity, value, and quality of the environment which is impacted and upon the intensity, duration, magnitude and geographic extent of the impacts.
Standing Biomass	Is the maximum fish biomass that may be supported in a system on a continuing basis.
State coastal waters	The State coastal waters extend three nautical miles seaward from the territorial sea baseline.

Total Organic Carbon	The amount of carbon bound in an organic compound which is often used as a non-specific indicator of water quality.
Toxicant	A chemical capable of producing serious injury in an organism(s) or death at concentrations that might be encountered in the environment.
Uncertainty	In relation to prediction is doubt or concern about the reliability of achieving predicted outcomes.
WA Marine Waters	State coastal waters and waters within the limits of the state, excluding estuaries and other inland waters.
Waters within the Limits of the State	Waters on the landward side of the territorial sea baseline.
Wave Height	The vertical distance between a wave crest and preceding or succeeding wave trough.
Xenobiotic	A foreign chemical not produced in nature and not normally considered a constituent of a specified biological system. This term is usually applied to manufactured chemicals.

1 INTRODUCTION

The Minister for Fisheries (Minister) proposes to establish an aquaculture development zone (zone) in the Mid West region of Western Australia for the purpose of marine finfish aquaculture.[8]

1.1 Purpose and scope of this document

The purpose of this Public Environmental Review (PER) is to describe the principal components of the Mid West Aquaculture Development Zone proposal (hereafter referred to as the MWADZ Proposal), including an assessment of the environmental impacts reasonably expected to occur, the mitigation and management measures that the Department proposes to implement and the environmental acceptability of the MWADZ Proposal in the context of the objectives and requirements of the Western Australian *Environmental Protection Act 1986* (EP Act).

As the MWADZ Proposal is a strategic proposal and the proponent (i.e. the Minister for Fisheries) will not be the proponent of a future derived proposal under the strategic proposal (i.e. will not be conducting an aquaculture operation within the MWADZ), the MWADZ Proposal does not require assessment under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). However, proponents of future derived proposals may require assessment under the EPBC Act if, for example, they trigger the provisions under that Act relating to endangered, threatened and protected species. This PER contains additional information intended to address such EPBC Act matters should such circumstances ever eventuate.

The PER is primarily intended to inform stakeholders [including the community, other interested parties, the Western Australian Environmental Protection Authority (EPA) and the Commonwealth Department of the Environment (DotE)] about the MWADZ Proposal. Ultimately, the purpose of this document is to provide sufficient information to enable the EPA to assess the MWADZ Proposal and for them to be able to report to the Minister for Environment on the outcome of its environmental assessment of the Strategic Proposal. This then enables the Minister to determine whether or not the MWADZ Proposal can be implemented and, if so, what conditions would apply to future derived proposals identified within the document.

This document presents a PER of the MWADZ Proposal to satisfy the requirements for assessment under the EP Act. Section 4 of this PER describes the approach undertaken to meet the requirements of State (and Commonwealth) legislation.

The scope of the PER covers the establishment, operation and (if ever necessary) decommissioning of the MWADZ. A detailed description of the MWADZ Proposal is provided in Section 2.

The scope of this document considers the likely direct and indirect impacts of the MWADZ Proposal. It also includes an assessment, where relevant, of potential cumulative impacts of the MWADZ Proposal when combined with other past, present, and reasonably foreseeable

[8] Section 101A(2A) of the *Fish Resources Management Act 1994* provides for the Minister to declare an area of WA waters (other than inland waters) to be an aquaculture development zone.

future actions. Section 6 provides further detail on the impact assessment approach adopted and the types of impacts assessed.

1.2 Approach to preparing this Public Environmental Review

1.2.1 Western Australian Environmental Impact Assessment Process

The EPA undertakes the environmental impact assessment (EIA) of some proposals and schemes referred to it under Part IV of the *Environmental Protection Act 1986* (the EP Act).

EIA is a systematic and orderly evaluation of a proposal and its impact on the environment. The assessment includes considering ways in which the proposal, if implemented, could avoid or reduces any impact on the environment.

The EIA of proposals is undertaken in accordance with Part IV Division 1 of the EP Act and the Environmental Impact Assessment Administrative Procedures 2012 (EIAAP).[9]

The Department referred the MWADZ Proposal to the EPA in April 2013, for determination of whether the strategic proposal was valid, whether or not to assess the proposal and (if so) the level of environmental assessment. The referral was accepted by the Environmental Protection Authority (EPA) and the level of assessment determined by the EPA as applying to the MWADZ Proposal set at the Public Environmental Review (PER) level of assessment.

An Environmental Scoping Document (ESD) was prepared by the EPA. This document outlines the works required to demonstrate that the proposal has considered and addressed potential impacts on the environment.

The ESD also identifies the EPA policies and guidance documents that the Office of the Environmental Protection Authority (OEPA) believes are relevant to the MWADZ Proposal and set out how the preliminary key environmental factors are to be considered. These policy and guidance documents, along with an outline of how and where they have been applied in this PER, is listed in Table 1-1.

Table 1-1: Consideration of Relevant EPA Policies and Guidance Documents

Relevant Policy Identified in the ESD	Aspects of the Policy Applied to the Assessment	Section of the PER Document to which the Policy Applies
Environmental Assessment Guidelines No. 1 (EAG 1) *Defining the Key Characteristics of a Proposal*	Project operations of future derived proposals have been considered in defining the Key Characteristics of the MWADZ Proposal. Section 2 of this PER document provides tabular information to define both Key Characteristics of the strategic proposal and future derived proposals. This section contains a written summary that clearly defines the key elements of the derived proposals, including specifications in terms of infrastructure, actions, activities and processes. The geospatial data, maps and illustrative figures within the MWADZ Proposal PER document ensure the proposed	• Figures 2-1 and 2-2: Proposed Area – MWADZ • Section 2.3: Key Characteristics of the Strategic Proposal • Section 2.4 Key Characteristics of Future Derived Proposals

[9] Refer to the following link to the document on the EPA website: http://epa.wa.gov.au/EPADocLib/Environmental%20Impact%20Assessment%20Administrative%20Procedures%202012.pdf

Relevant Policy Identified in the ESD	Aspects of the Policy Applied to the Assessment	Section of the PER Document to which the Policy Applies
	elements are specifically and accurately defined in terms of the extent and intensity of areas of impact and a wider constrained footprint.	
Environmental Assessment Guidelines No. 3 (EAG 3) *Protection of Benthic Primary Producer Habitat in Western Australia's Marine Environment*	The PER document has used and presented a risk-based spatial assessment of the potential cumulative "irreversible loss" and, or, serious damage to benthic community habitats (BCH), including any benthic habitat that may support primary produces, e.g. macro algae and symbiotic filter feeders, such as corals. The PER is consistent in its application of the EAG 3 approach to defining local assessment units (LAU) for the MWDAZ strategic proposal and predicting cumulative loss of BCH within these LAU. Appropriate application of EAG 3 has facilitated a clear and logical indication of the risk the proposal presents to the ecological integrity associated with cumulative loss of BCH.	• Section 6.6.1 Application of EAG 3 • 7.4 Assessment of Potential Impacts • Section 8.3 – 8.6 of the PER document relating to potential and predicted environmental impacts on BCH. • Figure 8-28 The Northern and Southern Local Assessment Units and the indicative benthic substrates in the vicinity of the MWADZ.
Environmental Assessment Guidelines No. 5 (EAG 5) *Protecting Marine Turtles from Light Impacts*	EAG 5 provides specific procedures, methods and minimum requirements expected by the EPA for environmental management to protect marine turtles from the adverse impacts of light. The PER document has been informed by EAG 5 and where applicable, various procedures, methods and minimum requirements have been adopted to avoid interaction between the proposed aquaculture and marine turtles.	• Section 9.4.1.3 Artificial Lighting • Appendix 2. Environmental Monitoring and Management Plan – Section 4.5
Environmental Assessment Guidelines No. 7 (EAG 7) *Marine Dredging Proposals*	The predicted extent, severity and duration of impacts of the proposed aquaculture to benthic habitats are described in the context of EAG7. Although EAG7 was designed for dealing with dredging proposals, it is relevant and directly applicable to managing the most significant environmental impacts of marine sea-cage aquaculture. Deposition of organic waste from aquaculture can be similar in nature to the effects of sedimentation from dredging and disposal of dredge spoil on benthic communities. However, it is important to note and define significant differences between the potential extent, severity and duration of the proposed aquaculture activities in comparison to any dredging proposal. The environmental impact assessment of the strategic proposal is heavily based on the concepts and principles of EAG7. The EAG 7 approach is designed for dealing with dredging proposals, which typically have similar 'levels of uncertainty' involved in predicting impacts to that of large scale aquaculture operations. EAG 7 suggests that proponents of proposals should not only consider the 'most likely worst case' but should also consider the 'most likely best case'. The Environmental Monitoring and Management Plan (EMMP) for the MWADZ Proposal, was also developed in the context of the EAG 7.	• Section 6.6.2 Application of EAG 7 • Section 6.7.6 Biogeochemical processes • 7.4 Assessment of Potential Impacts • Section 8.2.2 • Table 8-3 • 14.2 Proposed Management • Appendix 2. - Environmental Monitoring and Management Plan
Environmental Assessment	EAG 8 was used to develop the basis for the assessing whether the environmental impact was acceptable. This	• Section 6.3.4.1 - Environmental and

Relevant Policy Identified in the ESD	Aspects of the Policy Applied to the Assessment	Section of the PER Document to which the Policy Applies
Guidelines No. 8 (EAG 8) *Environmental Principles, Factors and Objectives*	PER took into account the principles of environmental protection and relevant policies, factors and the associated environmental objectives. EAG 8 was also used as guidance in relation to applying the principles of environmental protection, such as the precautionary principle, the principle of intergenerational equity, the principle of biological diversity and ecological integrity, and the principle of waste minimisation. Additionally the EMMP calls for proponents to exercise best practice and employ management mechanisms aimed at continuous improvement. This PER has identified and addressed five key factors: • Marine Environmental Quality; • Benthic Communities and Habitat; • Marine Fauna; • Heritage; and • Amenity, in addition to the environmental objective associated with each factor. EAG 8 has helped to establish aspirational goals and promoted a holistic approach to the environmental assessment.	Social Objectives • Section 2.3.1.2 - Marine Fauna • 13.3.1.1 - Environmental Monitoring and Management Plan • 14.3 Predicted Outcome • Appendix 2. - Environmental Monitoring and Management Plan
Environmental Assessment Guidelines No. 9 (EAG 9) *Application of a Significance Framework in the Environmental Impact Assessment Process*	EAG 9 was used in conjunction with EAG 8 to ensure the proposal was consistent with the principles of the EP Act. EAG 9 was also used in conjunction with EAG 1 and helped to identify which environmental factors were the most significant, key factors. This was important for gauging the type and quantity of information required to demonstrate that implementation of the proposal would be acceptable.	• Section 6 – Environmental Impact Assessment Framework • (Section 6.3.2 – Identification of Environmental Stressors and Factors • Table 6-3 Environmental Factors and Objectives • Section 6.4 • Table 6-4 • Section 6.5)
Environmental Assessment Guidelines No. 15 (EAG 15) *Protecting the Quality of Western Australia's Marine Environment*	As part of the PER document, an environmental quality management framework (EQMF) has been developed in accordance with EAG 15 (EPA 2015) to protect the environmental values of the marine environment from any organic waste and, or, contaminants associated with the proposed aquaculture. Consistent with EAG 15 the environmental impact assessment (EIA) for the MWADZ Proposal involved modelling the distribution and fate of aquaculture waste. This information informed the development of specific environmental quality criteria for the purpose of monitoring the effects of organic enrichment on the marine environment. For this sea cage aquaculture, EAG 15 suggests the most appropriate level of ecological protection is a Moderate Ecological Protection Area (MEPA). The EQMF developed for the MWADZ Proposal will manage sea	• Sections 6.5 – Technical and Environmental Studies • Section 6.6 – Thresholds for Interrogation of the Ecosystem Model • Section 6.7 Integrated Model components • Section 7.5 – Management Measures • Section 8.5 – Management Measures • Section 14.2 – Proposed Management • Appendix 2 - Environmental

Relevant Policy Identified in the ESD	Aspects of the Policy Applied to the Assessment	Section of the PER Document to which the Policy Applies
	cage aquaculture within 'floating' MEPAs which are proportionate to fifty per cent of any given lease area. The EQMF is devised to maintain the existing environmental quality of remaining fifty per cent of the MWADZ and the surrounding area at a high level of ecological protection (HEPA).	Monitoring and Management Plan
Environmental Assessment Guidelines No. 17 (EAG 17) *Preparation of Management Plans under Part IV of the Environmental Protection Act 1986*	The PER document includes an Environmental Monitoring and Management Plan (EMMP). EAG 17 assisted in the development of the EMMP by providing guidance on high level principles and objectives relating to the function of an EMMP. EAG 17 provided the fundamental context for determining whether the environmental management system described in the EMMP would achieve the EPA's objectives for the key environmental factors that were determined by the environmental impact assessment. It affirmed the key elements of the EMMP, being; best practicable control measures to avoid and minimise potential impacts, and adaptive environmental management, to facilitate continual improvement. The EMMP is an integral part of the PER and demonstrates how the implementation of the proposal will meet the environmental objectives associated with the key environmental factors. The EMMP achieves this by stipulating: • Condition environmental objectives; • Management actions; • Management targets; • Monitoring; and • Reporting.	• Section 1.2 – Western Australian Environmental Impact Assessment Process • Section 2.3 – Key Characteristics of the Strategic and Future Derived Proposals • Section 6.4.5 - Mitigation and Management of Impacts • Section 7.5 - Management Measures • Section 8.5 - Management Measures • Section 9.5 - Management Measures • Section 10.5 - Management Measures • Section 11.4 - Management Measures • Section 12.6 - Management Measures • Section 13.3.1.1 - Environmental Monitoring and Management Plan • Section 14.2 - Proposed Management • Appendix 2 - Environmental Monitoring and Management Plan
EPA Checklist - *for Documents Submitted for Environmental Impact Assessment on Marine and Terrestrial Biodiversity*	The EPA checklist was used during the initial project planning, the environmental scoping process and the final check of the PER document to ensure the proposal is comprehensive and of high quality. The checklist help to ensure that the environmental impact assessment had included all required considerations and issues are addressed in an appropriate context.	• PER Sections 2, 3, 6, 7, 8, 9 and 14 • Appendix 2 - EMMP Section 4. • Appendices 1 – Modelling and Technical Studies in Support of the Mid West Aquaculture Development Zone and the • Appendix 5 – Marine Fauna Interaction Management Plan.
EPA Guidelines for	The EPA's Guidelines for preparing a Public	Entire PER document and

Relevant Policy Identified in the ESD	Aspects of the Policy Applied to the Assessment	Section of the PER Document to which the Policy Applies
Preparing a Public Environmental Review	Environmental Review were utilised in the preparation of the MWADZ PER document. The requirements to describe the proposal and the receiving environment, including potential impacts, management strategies have been fulfilled. The PER demonstrates that the principles of environmental protection had been implemented and it provides justification for the EPA to deem the proposal acceptable. The proponent has liaised with the OEPA and to ensure sound measures were developed to manage relevant environmental factors. The PER has been written to be read by the average, educated community member and contains no significant errors in its science or format.	all appendices
Environmental Protection Bulletin No. 17	The MWADZ Proposal is strategic in its approach, as opposed to a single case proposal. It identifies more than one future development that is likely within that MWADZ, and in combination, multiple derive proposals could have a significant effect on the environment. In accordance with the *Environmental Impact Assessment Administrative Procedures 2012*, the MWADZ Proposal is being assessed at the highest level of assessment, i.e. PER. The environmental impact assessment of the strategic proposal has facilitated early consideration of potential cumulative impacts of multiple derived proposals. The development of the MWADZ Proposal has rigidly followed the Strategic Proposal Assessment process set out in the Environmental Protection Bulletin No. 17. The PER document clearly describes prerequisites required before a future proposal can be deemed a derived proposal under the strategic proposal. Key to its development, the MWADZ PER involve community consultation commencing at the scoping phase and continuing throughout the development of the proposal. The location and final design of the MWADZ has been influenced by public input and stakeholder advice. The PER provides the EPA with a definite and comprehensive account of the MWADZ in terms of: • key characteristics and environmental factors; • the extent of scope of the proposed aquaculture; • the maximum footprint of impact; • cumulative impacts; and • an array of best management practices and strategies that will be implemented to avoid and minimise impacts.	Entire PER document and all appendices

1.2.2 Commonwealth Environmental Impact Assessment Process

The *Environment Protection and Biodiversity Conservation Act 1999* (the EPBC Act) provides a legal framework to protect and manage nationally and internationally-important flora, fauna, ecological communities and heritage places.

Officers of the Department contacted the Commonwealth DotE (formerly SEWPaC) to discuss the referral of the MWADZ Proposal to that agency for assessment under the EPBC Act. The DotE Environmental Assessment and Compliance Division advised the Department that the proposed actions associated with the MWADZ Proposal were not of a magnitude that necessitates a "Strategic Assessment" at the Commonwealth level. DotE further advised that, in view of the fact that the Department (on behalf of the Minister for Fisheries) is not itself proposing to undertake aquaculture operations within the MWADZ (in other words, will not be a derived proponent under the strategic proposal), the Department is not required to refer a proposed action under the EPBC Act.

However, as outlined in sub-section 1.1, proponents of future **derived** proposals (i.e. aquaculture operators within the MWADZ) may require assessment under the EPBC Act if, for example, they trigger the provisions under that Act relating to endangered, threatened and protected species.

1.2.3 Other Environmental Approvals

The Commonwealth, State and local environmental policies, plans and guidelines relating to individual areas of assessment (e.g. biosecurity) are outlined within the relevant sections of this PER. For a detailed description of the environmental management framework and legislation which the Department intends to operate the MWADZ refer to Section 4 and Section 15.3.1.2 of this document.

Typically, the only other (State) environmental approval required of proponents of future derived proposals is the aquaculture licence granted under the *Fish Resources Management Act 1994* (FRMA). As a prescribed requirement the Chief Executive Officer (CEO) of the Department must be satisfied before granting the licence [s. 92(1)(c)], the potential environmental impacts of the proposed aquaculture activities must be considered. The statutory requirement for the applicant to provide an accompanying Management and Environmental Monitoring Plan (MEMP) identifying how the applicant will manage any risks to the environment in relation to the proposed aquaculture activity provides one of several mechanisms available to the CEO to consider and address any potential environmental issues.

1.2.4 Structure of this Document

This PER comprises:

- **Executive Summary** – summarises the content of the PER including the background and need for the MWADZ Proposal, environmental and social factors, key potential impacts, illustrative mitigation and management measures, and the predicted environmental and social outcome of implementing the MWADZ Proposal.

- **Section 1, Introduction and Overview of the Project** (this Section) – introduces the MWADZ Proposal, explains the objective and scope of the PER; and introduces the approach adopted to complete the assessment to meet both State and Commonwealth PER requirements respectively.

- **Section 2, Description of the Proposal** – describes the key characteristics of the MWADZ Proposal, including the associated construction, operation and decommissioning aquaculture activities. It also considers the alternatives to the MWADZ Proposal.

- **Section 3, Overview of Existing Environment** – describes the receiving environment (bio-physical and socio-economic) that the MWADZ Proposal has the potential to impact.

- **Section 4, Legislative Framework** – outlines the principal Commonwealth and State regulations, policies, plans, and guidelines relevant to the MWADZ Proposal.

- **Section 5, Stakeholder Consultation** – describes consultation with stakeholders to date, as well as planned stakeholder engagement.

- **Section 6, Environmental Impact Assessment Framework** – describes the environmental impact assessment framework and the assessment methodology used for the MWADZ Proposal.

- **Section 7, Assessment of Potential Impact on Marine Environmental Quality** – assesses the potential impacts of the MWADZ Proposal on benthic sediments and water quality and describes the mitigation and management measures to be implemented.

- **Section 8, Assessment of Potential Impact on Benthic Communities and Habitat -** assesses the potential impacts of the MWADZ Proposal on benthic communities and their habitat (i.e. seagrass, coral, and algae) and describes the mitigation and management measures to be implemented.

- **Section 9, Assessment of Potential Impact on Marine Fauna -** assesses the potential impacts of the MWADZ Proposal on marine fauna (i.e. fish, marine invertebrates, marine mammals, marine reptiles and marine avifauna) and describes the mitigation and management measures to be implemented.

- **Section 10, Assessment of Potential Impact on Biosecurity** – describes how impacts associated with the potential introduction of non-native species and diseases into the surrounding waters will be mitigated and managed.

- **Section 11, Assessment of Potential Impact on Fisheries** – assesses the potential impacts of the MWADZ Proposal on marine fisheries (both finfish and invertebrates) and describes the mitigation and management measures to be implemented.

- **Section 12, Assessment of Potential Impact on Heritage** – assesses the potential impacts of the MWADZ Proposal on the environmental factor of heritage and describes the mitigation and management measures to be implemented.

- **Section 13, Assessment of Potential Impact on Amenity** – assesses the potential impacts of the MWADZ Proposal on the environmental factor of amenity and describes the mitigation and management measures to be implemented.

- **Section 14, Assessment of Potential Impact on Non-Environmental Matters** – assesses the potential impacts of the MWADZ Proposal on those social and economic matters that are not related to an environmental factor (as listed in EAG 8) but have been raised in the course of the consultation conducted thus far. Where relevant, this section comments on any mitigation and management measures associated with such matters.

- **Section 15, Environmental Management Framework** – describes the environmental management framework to be implemented for the MWADZ Proposal. Additional information, including the technical studies completed to support this PER, is provided in accompanying Appendices, as listed in Section 18.

- **Section 16, Conclusion** – summarises the potential impacts resulting from the MWADZ Proposal, the proposed management of such impacts and the predicted outcomes arising from that management.

2 DESCRIPTION OF PROPOSAL

2.1 Proposal overview

The Department, on behalf of the Minister, proposes to create an Aquaculture Development Zone to provide a management precinct for prospective future aquaculture proposals within State Waters, approximately 65 kilometres west of Geraldton within the Fish Habitat Protection Area of the Abrolhos Islands. The strategic proposal area has been selected by the proponent to maximise suitability for marine finfish aquaculture and minimise potential impacts on existing marine communities and disruption to existing human use.

The strategic proposal, also known as the MWADZ Proposal, encompasses 3,000 hectares of marine waters within two separate areas (800 hectares and 2,200 hectares).

2.1.1 Proposal Title

The formal title of the proposal is the Mid West Aquaculture Development Zone Proposal (MWADZ Proposal).[10]

2.1.2 Proposal Objectives

The MWADZ Proposal aims to:

- declare an area of Western Australian (WA) waters, based on its biological, environmental, economic and social attributes, as suitable for large-scale commercial finfish aquaculture; and

- establish an effective management framework, including an efficient approval process, for operators within that area.

2.1.3 Proposal Background

A strategic planning approach to aquaculture development is regarded as best regulatory practice and a key method of providing for industry growth while achieving ecologically sustainable development outcomes.[11] Some Australian states have established significant marine aquaculture industries using a regional zone methodology in their strategic planning.

The Western Australian Government is committed to the development of a sustainable marine aquaculture industry and, to further this commitment, the Minister announced a funding package to enable the establishment of two such zones: one in the Kimberley and one in the Mid West region of the State.[12] The Kimberley Aquaculture Development Zone (KADZ) is the first aquaculture development zone to be established in Western Australia and was declared by the Minister on 22 August 2014.

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[10] All offshore installation activities, as well as commissioning, operating and decommissioning activities of the infrastructure described in this section and undertaken by the holders of aquaculture licences and leases authorised to conduct aquaculture within the zone, are considered part of the MWADZ Proposal.

[11] *Best practice framework of regulatory arrangements for aquaculture in Australia* [Primary Industries Ministerial Council – 2005].

[12] The Premier's Statement of Commitment to Aquaculture in Western Australia can be accessed at http://www.fish.wa.gov.au/About-Us/News/Pages/Bright-future-for-WA-aquaculture.aspx.

The Department is managing the creation of these two zones on behalf of the Minister.

2.1.4 Project Proponent

The Minister for Fisheries is the proponent of the MWADZ Proposal.[13]

2.1.5 Roles and Responsibilities

On behalf of the Minister for Fisheries, the Department is the zone manager for the MWADZ Proposal. Among other responsibilities within the zone, the Department is responsible for:

- the grant of aquaculture licences and administration of leases within the zone (leases are granted by the Minister for Fisheries);[14]
- adaptive management through aquaculture licence conditions or the Management and Environmental Monitoring Plan (MEMP), as appropriate;
- ensuring lease/licence holders comply with the Environmental Management and Monitoring Plan (EMMP) for the zone;
- ensuring compliance with the zone management policy; and
- ensuring the reporting requirements under the *Environmental Protection Act 1986* (EP Act) specified in the Ministerial Statement and any subsequent Section 45A notices are met.

The Department will work in conjunction with the Office of the Environmental Protection Authority (OEPA) to ensure compliance with authorisations, such as the strategic and derived proposal approvals, provided under the EP Act.

2.1.6 Precedence and Commitments

The MWADZ Proposal will be the second aquaculture development zone to be established in Western Australia. The Kimberley Aquaculture Development Zone was the first, being declared by the Minister on 22 August 2014.

The Department has approached the creation and ongoing management of these zones with the commitments embodied in the zone Mission Statement. This has been adopted as follows:

Mission

"To identify, secure and manage strategically-important areas of Western Australian marine waters for large-scale commercial aquaculture purposes; such that growth in the aquaculture industry is stimulated and expansion is achieved in an environmentally-sustainable manner."

Vision

"Fully utilised, fit-for-purpose Aquaculture Development Zones servicing a range of aquaculture activities that are environmentally, commercially and socially sustainable."

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[13] As defined under s.9 of the FRMA.
[14] The zone Site Allocation Policy will assist in determining the number, size and location of leases that may be established within the zone (refer the Department's website at www.fish.wa.gov.au).

Values

Our core values are:

- ***Integrity*** *- Being honest, reliable and courteous in all matters.*
- ***Transparency and Accountability*** *– Being open, responsible and accountable to stakeholders.*
- ***Responsiveness*** *– Being alert to new information and demonstrating a willingness to innovate.*
- ***Sustainability*** *– Being persistent in seeking environmentally, socially and economically sustainable outcomes.*

2.1.7 Proposal Location

The MWADZ Proposal is located within the southern part of the Abrolhos Islands Fish Habitat Protection Area (Figure 2-1), between the Southern and Easter groups of the Abrolhos archipelago, approximately 65 kilometres west of Geraldton.[15] The zone will be divided into two separate areas of water (Figure 2-2):

1. The **Southern area** comprises an 800-hectare existing licensed aquaculture site to the north of Sandy Island in the Pelsaert Group. This existing site will likely be the only aquaculture site within the Southern area.

   The Southern area has an average water depth of 35 metres.

2. The **Northern area** comprises a 2,200-hectare site east of Wooded Island in the Easter Group and north of Gee Bank reef. The final size, location and design of aquaculture sites within the Northern area will be subject to, *inter alia*, the outcomes of the tenure allocation process conducted after the zone has been declared.

   The Northern area has an average water depth of 40 metres.

[15] Fish Habitat Protection Areas are created by the Minister under the provisions of Part 11, Division 1 of the *Fish Resources Management Act 1994*.

Figure 2-1: Abrolhos Islands Fish Habitat Protection Area

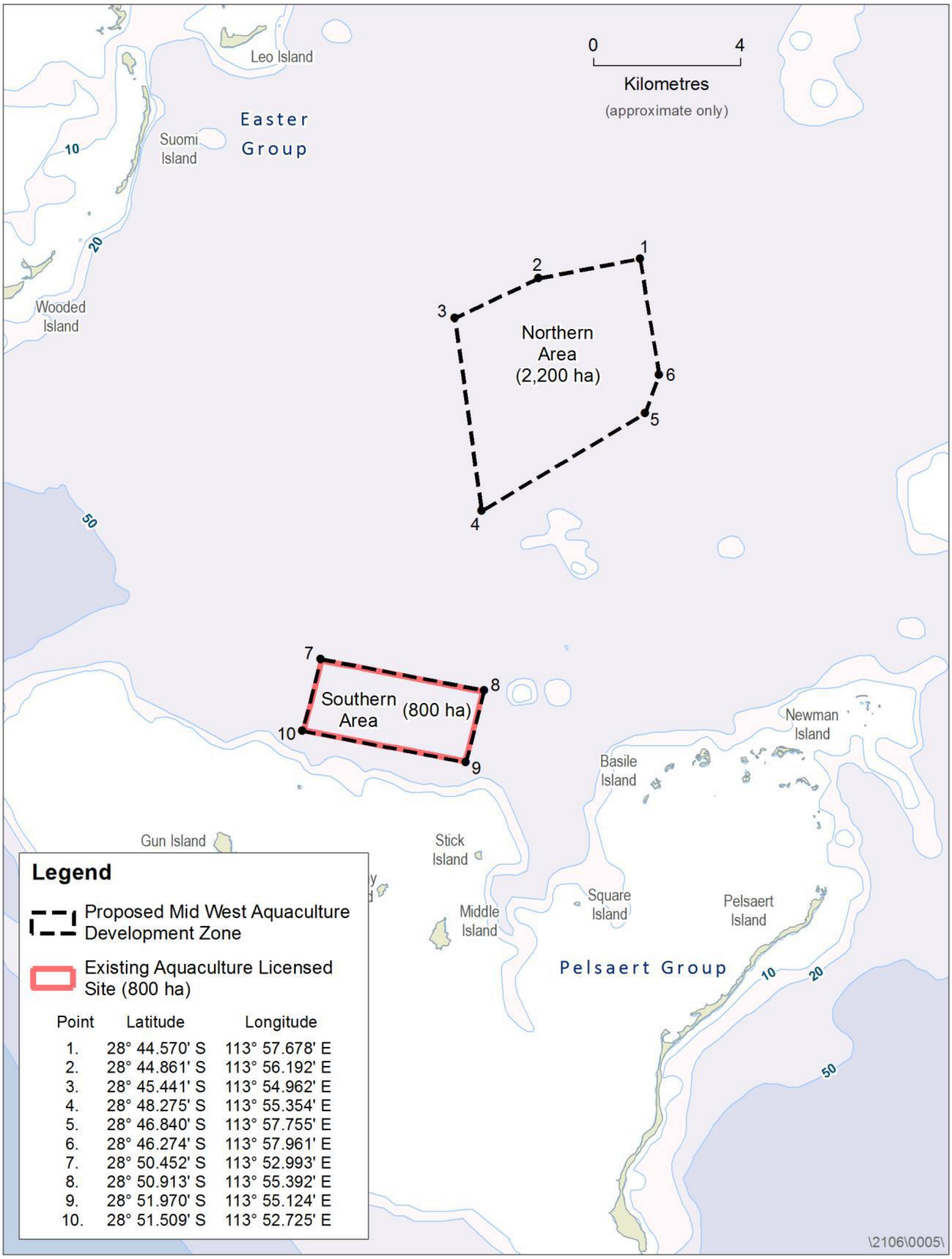

Figure 2-2: Proposed Areas - MWADZ

The MWADZ Proposal is located in a part of the Western Australian coast where there is a confluence of both temperate and tropical sea life, forming one of the State's unique marine

areas. This presents a rare opportunity for the development of any of a range of marine finfish aquaculture species that occur naturally within the West Coast region of the State.[16]

2.1.8 Process to Establish the Proposal Location

The location of the MWADZ Proposal was the outcome of a lengthy process that included:

- identifying those geophysical attributes that would support the development of marine finfish aquaculture (see Table 2-1);
- using Geographic Information Systems (GIS) to analyse this information and indicate those areas within the Mid West region that meet all (or most) of the defined attributes; and
- consulting with stakeholders to establish where the MWADZ Proposal was likely to have the least impact in terms of existing activities and values.

The management objectives and values of the Houtman Abrolhos Islands Management Plan were also taken into consideration during site selection.

A GIS-based Multi-criteria Evaluation technique (MCE) was used to identify potential sites and well-established selection criteria for large marine aquaculture establishments were determined to build the MCE tool. For the purpose of this process, important environmental, social and economic factors, which determine the suitability of an area as an aquaculture development zone for marine finfish, can be divided into:

- primary selection criteria;
- secondary selection criteria; and
- tertiary selection criteria.

Primary criteria were essential broad scale attributes which can be defined within State waters using available data sets. Broad areas which could fulfil the basic requirements for marine finfish aquaculture (primary areas of interest) were identified using primary criteria (e.g. Western Australian waters with a depth of between 20 and 50 metres). The demarcation of primary areas of interest provided an essential starting point for community engagement.

Secondary criteria are important attributes which were used to refine areas of interest to discrete patches of water. Secondary criteria were essential for determining and comparing potential sites in terms of viability as an aquaculture development zone. Some of the information that comprised the secondary criteria was obtained during initial meetings with stakeholders. Some datasets were highly localised, with information existing only for specific areas. Secondary criteria refined the primary areas of interest to smaller areas expected to fulfil the economic, environmental and social requirement of a finfish sea cage aquaculture development zone.

Tertiary criteria were advantageous finer scale attributes which were used to delineate particular sites using localised data or qualitative information. Tertiary criteria will denote the

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[16] *West Coast Region* is defined in Regulation 3 *Terms used* of the Fish Resources Management Regulations 1995 as:
(c) all land in the State; and
(d) all WA waters,
that are south of 27^{0} 00' south latitude, excluding the South Coast Region;

most outstanding areas for finfish sea cage aquaculture. Tertiary criteria relied heavily on information provided by key stakeholders and technical experts.

Once primary, secondary and tertiary criteria were identified, GIS was used to conduct basic Multi-Criteria Evaluation to present three scenarios. The Department considered stakeholder feedback on the scenarios maps and used the input to develop a separate map showing the area where an aquaculture zone, up to 3,000 hectares in size, could be economically viable, yet socially and environmentally acceptable. Community engagement was fundamental to inform the Department on stakeholder values and concerns, and to provide local knowledge, prior to an ultimate location of the site being decided.

The GIS Multi-Criteria Evaluation technique was used to identify areas that were potentially suitable for finfish aquaculture; however, the ultimate decision on the location was substantially influenced by stakeholder advice. This was backed up by underwater video "ground-truthing" of the proposed sites conducted by officers of the Department and the Office of the Environmental Protection Authority (OEPA) to ensure the benthic habitat was predominately sandy bottom. Once the sites were decided, a technical environmental study was undertaken to finalise the boundaries of each site and confirm its suitability as a marine finfish aquaculture development zone.

Table 2-1: GIS Multi-Criteria Evaluation

Factor	Criteria
Jurisdiction/tenure	Avoid Port waters
Shipping	Avoid international shipping routes
Reef Observation Areas	Buffer of one kilometre around Reef Observation Areas
Gas and petroleum industry	No overlap with an area of interest to the gas and petroleum industry
Wave shadow	Areas within 20 kilometres northeast (i.e. in the wave shadow) of any island; or reef /sandbank rising to a depth shallower than the 17 metre depth contour
Proximity to population centre	Less than 85 kilometres (46 nautical miles) of Geraldton
Access to transport	Less than 20 kilometres from an airstrip or a dock
Area	Greater than 1,000 hectares
Effluent	Buffer of at least one kilometre from any effluent outfall
Water depth	Between 20 and 50 metres depth
Environmentally-valuable sites	Buffer of 100 metres around habitats of high conservation value (e.g. coral/seagrass dominated)
Megafauna	Buffer of one kilometre around breeding habitats
Historically-significant sites	Buffer of one kilometre around historically significant sites
Recreational fisheries	No overlap with principal recreational fishing grounds (based upon catch levels)
Commercial fisheries	No overlap with principal commercial fishing grounds (based upon catch levels)

2.2 Development Alternatives

Noting the key outcome sought by the MWADZ Proposal is increased commercial aquaculture production from the Mid West region of Western Australia, development alternatives were also considered. Essentially, these can be summarised in Table 2-2.

Table 2-2: Development Alternatives

<table>
<tr><th></th><th>Alternative considered</th><th>Advantages</th><th>Disadvantages</th></tr>
<tr><td rowspan="3">Increased commercial aquaculture production</td><td>New location within the Mid West region</td><td>• Avoids the Abrolhos Fish Habitat Protection Area</td><td>• Sub-optimal environmental conditions for commercial aquaculture production
• Increased conflict with other existing uses/users</td></tr>
<tr><td>Defer until the environmental outcomes of the operation of the Kimberley Aquaculture Development Zone are known</td><td>• Increased certainty in terms of any possible environmental, social and economic impacts/benefits</td><td>• Economic benefits to the region, State and Commonwealth will be delayed
• Situation in the Kimberley is different to that in the Mid West and many elements are not comparable</td></tr>
<tr><td>No development of commercial aquaculture in the Mid West region</td><td>• Eliminates any potential environmental impacts to the Abrolhos Fish Habitat Protection Area</td><td>• Loss of economic benefits to the nation, State and the Mid West region that would increase general economic growth and sustain regional development
• Loss of job opportunities and business/service income to support the operational activities and the loss of government revenue</td></tr>
</table>

2.3 Key Characteristics of the Proposal

2.3.1 Overview

The MWADZ Proposal has key characteristics that are common to most sea cage marine finfish aquaculture operations.

Essentially, it involves placing hatchery-raised finfish of a species valued for their biological, domestication and marketability attributes into a system of floating artificial structures (i.e. sea cages) anchored in offshore marine waters. The cages are immersed in the sea such that marine waters pass through the cages, but prevent the finfish (i.e. stock) from escaping into the surrounding sea. The stock are then fed a diet of specially-formulated, pelletised feed until such time as they have grown to the desired size. They are then harvested, processed and distributed to local and overseas markets. The cycle is repeated on an ongoing basis.

2.3.2 Key Characteristics of the Strategic Proposal

The key characteristics of the MWADZ strategic proposal are outlined in Table 2-3.

Table 2-3: Key Characteristics of the MWADZ Strategic Proposal

Element	Description
Proposal Title	Mid West Aquaculture Development Zone
Proponent Name	Minister for Fisheries
Project Life	Ongoing
Location	State waters of Abrolhos Islands Fish Habitat Protection Area, Western Australia (~65 km West of Geraldton). The Northern Site is defined by waters bounded by the coordinates: 1. 28° 44.570' S 113° 57.678' E 2. 28° 44.861' S 113° 56.192' E 3. 28° 45.441' S 113° 54.962' E 4. 28° 48.275' S 113° 55.354' E 5. 28° 46.840' S 113° 57.755' E 6. 28° 46.274' S 113° 57.961' E The Southern Site is defined by waters bounded by the coordinates: 7. 28° 50.452' S 113° 52.993' E 8. 28° 50.913' S 113° 55.392' E 9. 28° 51.970' S 113° 55.124' E 10. 28° 51.509' S 113° 52.725' E
Size of Aquaculture Development Zone	3,000 hectares
Species to be Cultured within the Zone	Marine finfish species that naturally occur within the West Coast region of Western Australia
Culture Method	Floating sea cages
Standing Fish Stock Biomass Limit	Maximum of 24,000 tonnes of marine finfish within the Aquaculture Development Zone at any one time

In assessing this strategic proposal, the EPA needs to conclude, with a high level of confidence, that future proposals can be implemented without significant detrimental impacts on the environment. With this in mind, the environmental impact assessment was designed to assess several possible future production scenarios. The Department expects future derived proposals associated with the MWADZ Proposal will have broadly similar operating requirements and environmental impacts to those within the Kimberley Aquaculture Development Zone. Fish farming technologies, management and operational procedures are similar for a range of marine species and so are the environmental impacts of these operations.

If the strategic proposal is granted approval by the Minister for Environment, future aquaculture proponents within the proposed MWADZ would need to refer their aquaculture proposal to the EPA and request that the EPA declares it a derived proposal under section 39B of the EP Act. Future derived proposals will be required to comply with all requirements as outlined in the MWADZ Management Policy (Appendix 3) and comply with the Environmental Monitoring and Management Plan (EMMP) for the MWADZ (Appendix 2).

Compliance with the EMMP will be enforced as a requirement of the Management and Environmental Monitoring Plan (MEMP) associated with the aquaculture licence and may be further strengthened by licence condition. It is also likely to be a requirement of any Notice issued by the Minister for Environment (under section 45A of the EP Act) in relation to the implementation of any declared derived proposal.

2.3.3 Key Characteristics of Future Derived Proposals

The key characteristics for future derived proposals reflect the policy settings developed for management of the MWADZ and are summarised in Table 2-4.

Table 2-4: Key Characteristics of Future Derived Proposals

Element	Description
Aquaculture Lease Location	Within the boundaries of the approved MWADZ
Operations	• Sea cages installed and maintained consistent with industry best practice • Sea cages only stocked with marine finfish species that naturally occur within the West Coast region of Western Australia • Finfish feeding, husbandry and harvesting
Sea Cage Specifications	• Only floating sea cages permitted • Sea cages fitted with anti-predator nets or equivalent to prevent predator access to stocked fish and prevent fish escapes • Minimum of two metres (at lowest astronomical tide) between the sea floor and the bottom of the sea cage • Sea cages to be deployed in clusters such that the Moderate Ecological Protection Area (MEPA) comprises no more than 50 per cent of the proponent's aquaculture lease area • All aquaculture gear must be located within the proponent's aquaculture lease area • Sea cages, including stock, must be located no less than 300 metres of the MWADZ boundary
Standing Fish Stock Biomass Limits	Maximum of eight tonnes per hectare averaged over the area of the lease
Feed Inputs	Only certified commercial pellet feeds that meet Australian Quarantine and Inspection Service requirements permitted
Brood Stock and Juveniles	• Movement of brood stock or juveniles into the MWADZ subject to the Department of Fisheries Translocation Policy (requirement for translocation approval dependent upon circumstances and potential biosecurity risk) • Juvenile seed stock only to be sourced from approved facilities and must be certified disease-free to the satisfaction of the Principal Research Scientist in the Department of Fisheries Fish Health Unit
Approved EMMP	Compliance with the MWADZ Environmental Monitoring and Management Plan (EMMP)

2.4 Construction Activities

2.4.1 Sea Cages

Managers and operators of modern fish farms are improving management practices, including the use of advanced farming systems, methods and equipment that can withstand the elements in unprotected offshore areas. The oligotrophic (low nutrient) waters, strong currents and depths generally characteristic of the open ocean afford better nutrient assimilation and hence increased carrying capacity.[17]

Operators within the proposed MWADZ would be likely to use circular sea cages that are 120 metres in circumference and 38 metres in diameter. In general, the sides of the proposed cages would have a drop of 18 metres; with the bottom of the cage reaching a depth of around 21 metres. The volume of each cage would therefore be at least 20,000 cubic metres.

The sea cages need to be capable of retaining the stock and providing an effective barrier to exclude predators, without posing a significant hazard to either.

Technology has advanced in recent years, to the extent that modern cage systems, such as that illustrated in Figure 2-3, can be tailored to suit the receiving environment. Well-designed sea cages are able to endure the elements over the life of the operation without major failures in their capability to contain and protect stock. The modern materials used for cage construction play an important role in this regard. Tough mesh made of ultra-high-molecular-weight (high-performance) polyethylene fibres and other modern durable plastics are proving to be safe and effective in preventing predator breaches and stock escapes.

For example, high-performance polyethylene netting is reported to be up to 40% stronger than traditional netting of a comparable weight. These nets are highly visible and extremely tear-resistant. Some manufacturers claim their product netting is shark-proof.

In summary, sea cages must be properly designed, installed and maintained to provide a suitable rearing environment that protects both the stock and wildlife. By maintaining the integrity of the cages, the risk of wildlife interactions and environmental impacts are significantly reduced.

[17] Benetti and Welsh, 2010.

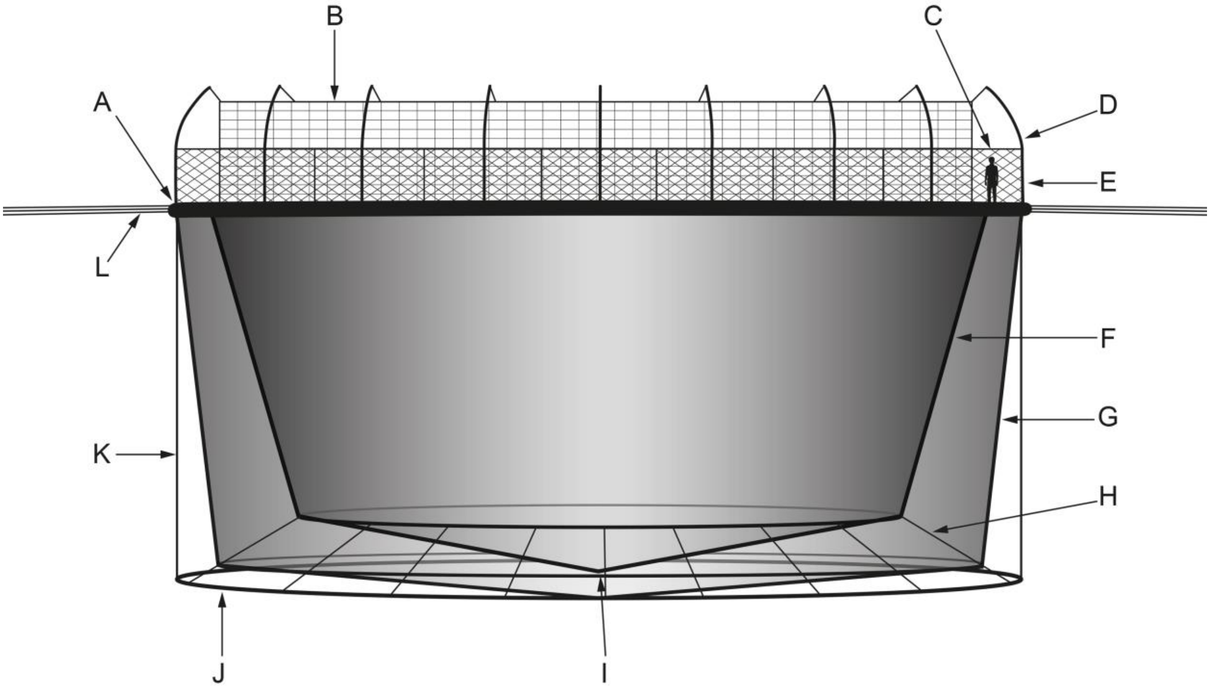

Figure 2-3: Modern Surface Sea Cage Design

Floating Sea Cage (indicative)	
A.	Floating collar to suspends nets
B.	Taut overhead net to keep seabirds away from stock and feed
C.	High sea lion-exclusion barrier to prevent wildlife from accessing the walkway
D.	Long flexible net-poles to support, suspend and maintain tension of the overhead seabird-exclusion nets several metres above the water
E.	Stanchions (posts) to support the sea lion-exclusion barrier
F.	Stock containment net (fully enclosed); a component of the double net system
G.	Marine-predator exclusion net (fully enclosed); a component of the double net system
H.	Net-baseline rope to link nets to the sinker tube
I.	False net-bottom, created by the double net system, to keep stock separated from marine predators
J.	Sinker tube, suspended from the nets, to maintain tension and support the structure of the nets
K.	Weight line to facilitate lifting the sinker tube and bottom of the nets
L.	Mooring lines, connected to the anchoring system, to hold the sea cage in position
Note:	All nets and mesh are durable and high tensile

The Norwegian Standards (Standards) provide a guide to best-management practices. They specify how to set up components of a cage system in accordance with the environmental conditions of a site and describe operational requirements to prevent stock escapes or environmental degradation.[18] The aim is to reduce any risk of stock escape caused by poor installation or failure of the infrastructure.

[18] Norwegian Standards (NS 9415:2009).

The aquaculture operations proposed for the zone will be guided by these Standards and the Environmental Code of Practice applicable to the Western Australian marine finfish aquaculture industry.[19] Cage collars, netting and weighted rings should be designed to function as integrated and balanced systems to handle environmental forces, such as waves and current, of marine environments associated with storm events. Modern nets are tensioned to minimise the impact of predators, optimise water flow, and facilitate in-situ underwater cleaning of the nets.

Modern cage systems are designed to minimise friction between the nets and the supporting structure, thereby reducing any risk of the net tearing. Computers are now used to simulate and analyse the design functionality and verify performance prior to installation of cage systems. Such systems are being used in the offshore waters of South Australia and Tasmania.[20]

Fish farms that provide a form of "reward" or advantage to the local wildlife will likely be exposed to the risk of costly ongoing interactions. Interactions with sea lions, birds and sharks generally account for losses up to 10% of aquaculture production, and further financial losses due to damages to infrastructure.[21,22]

Based upon the Tasmanian experience, sea lions are likely to be the most problematic predator attracted to marine finfish aquaculture. In recent years the Tasmanian industry has largely reduced the damage caused to stock and cages by sea lions by deploying heavy-duty nets (typically, with mesh sizes up to three centimetres in bar length[23]), perimeter fences and higher freeboards.[24] It also uses seal-proof "jump" fences, which consist of raised mesh netting with a breaking strain rating of 300 kilograms encircling the pen and suspended at a minimum of 2.4 metres above the waterline.[25]

A similar approach is expected to be adopted in the proposed MWADZ.

In summary, to avoid aquaculture-wildlife interactions, anti-predator mesh must be of suitable durability, bar-length (i.e. mesh size), and kept taught. The separation of stock from predators is fundamental to the financial viability of the business and will be a requirement of environmental management.[26, 27]

With regard to the place of construction of the sea cages that will be used in the MWADZ, it is likely that these will be fabricated in Geraldton and towed to the intended locations within the relevant lease sites.

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[19] http://www.aquaculturecouncilwa.com/files/9814/0462/7532/ACWA_Marine_Finfish_Environmental_Code_of_Practice_FINAL20V4.pdf
[20] www.aqualine.no/
[21] Price and Morris, 2013.
[22] Nash, Iwamoto and Mahnken, 2000.
[23] "Bar-length" (or "bar-width") refers to the distance between the inside of adjacent knots in square or diamond shaped mesh netting.
[24] Tassal, 2015.
[25] Ibid
[26] Ibid.
[27] Price and Morris, 2013.

2.4.2 Sea Cage Anchoring Systems

The key to maintaining adequate separation between predators and stock is sufficient tensioning on all netted components. Reliable anchoring systems are fundamental to correct net tensioning (Figure 2-4) as they not only allow the potential for wildlife entanglement to be reduced, but also help prevent anchor cable "sweep" effects to the sea floor.

In the proposed MWADZ, the type of anchors used will primarily be determined by the composition of the sea floor to which the sea cage clusters will be attached. This may vary according to location within the zone. Ultimately, the relatively shallow depth of the sediments overlying the limestone platform that characterises much of the seabed in the Zeewijk Channel will most likely be the determining factor in most instances.

In any event, drilling, piling or blasting will not be employed in the anchoring process.

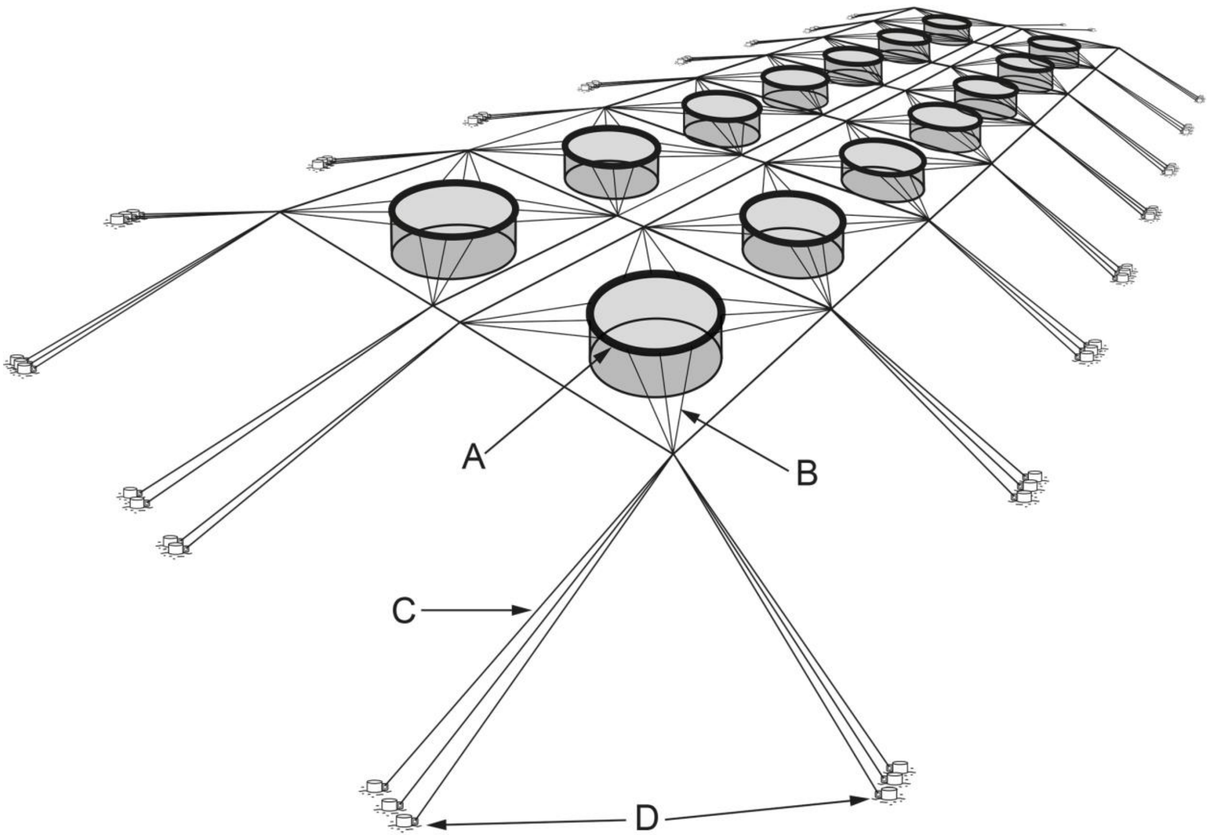

Figure 2-4: Sea Cage Cluster Anchoring Systems

Sea Cage Cluster Anchoring Systems (indicative)	
A.	Sea cage
B.	Mooring lines
C.	Anchor cables
D.	Low-profile mooring anchors
Note:	All lines and cables are durable, high tensile and appropriate for an anchoring system designed to withstand extreme loads.

2.4.3 Positioning of Infrastructure

The sea cages to be used in the zone would typically be grouped together in clusters. For operational reasons, these cage clusters would be set relatively close together on each lease within the zone.

All aquaculture gear (including mooring anchors and anchor cables) must be located within the individual proponent's lease area.[28] In addition, the sea cages themselves (including any fish farm stock held) must be located no less than 300 metres inside of the MWADZ boundary.

The Southern area will likely comprise one 800-hectare lease associated with the existing aquaculture licensed site. It is anticipated that up to two cage clusters would be deployed within this lease area.

Due to its larger area, the Northern area could hold up to four cage clusters in total. As with the Southern area, cage clusters within specific lease areas would generally be situated relatively closely together. The number of cage clusters in each lease would vary according to the lease area.

Figure 2-5 indicates the likely number of sea cages in each cage cluster and also the likely size and initial placement of cage clusters within the proposed zone (at any one time) when the zone is at maximum production.

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[28] As defined in Part 1, section 4 of the FRMA;
"***aquaculture gear*** *means any equipment, implement, device, apparatus or other thing used or designed for use for, or in connection with, aquaculture —*

(a) whether the gear contains fish or not; and

(b) whether the gear is used for aquaculture or for navigational lighting or marking as a part of aquaculture safety,

and includes gear used to delineate the area of an aquaculture licence, temporary aquaculture permit or aquaculture lease".

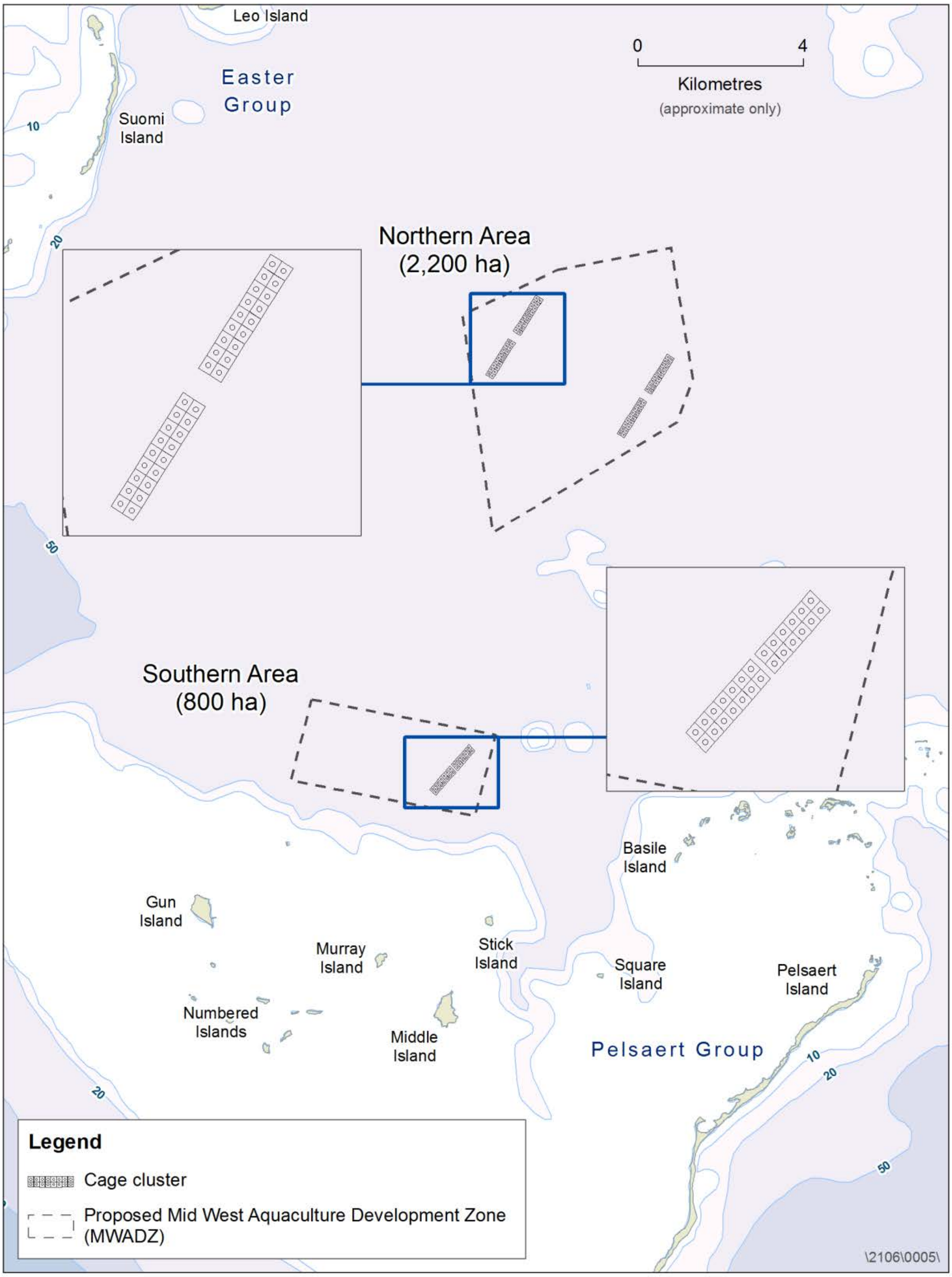

Figure 2-5: Likely Sea Cage Cluster deployment at full-scale production

The maximum standing stock biomass per hectare of lease area would be dependent on the total limit for the zone as imposed by the conditions of the strategic environmental approval. Based upon the results of the technical studies, the proposed total maximum standing stock biomass for the 3,000 hectare zone is 24,000 tonnes.

Over time, operators may relocate sea cage clusters within the leases to enable the ground that was previously near or beneath the cages to be fallowed.[29] This practice ensures the benthic environment within a lease is protected from any potential negative impacts by the aquaculture over the longer term.

2.5 Operational Activities

2.5.1 Stock

The MWADZ is being established specifically for marine finfish aquaculture. Yellowtail kingfish (*Seriola lalandii*) is one species considered likely to provide an economic return in the region (Figure 2-6). Other potentially suitable species include:

- mahi mahi (*Coryphaena hippurus*);
- pink snapper (*Pagrus auratus*);
- mulloway (*Argyrosomus japonicus*);
- cobia (*Rachycentron canadum*);
- coral trout (*Plectropomus spp.*);
- various cod (grouper) species (*Epinephelus* spp.); and
- various tropical snapper (emperor) species (*Lutjanus* spp.).

Figure 2-6: Yellowtail Kingfish

Typically, hatchery-reared fish (certified as free of any clinical disease) are stocked in sea cages as juvenile fish at an average weight of 100 grams or less, then grown to a marketable weight and potentially harvested the same year. Yellowtail kingfish, for example, could be harvested once the fish reach two kilograms. Stock density is an important determinant of financial feasibility and can also influence environmental impact and fish health. High densities can maximise production but excessive densities can result in low dissolved oxygen, increased nutrient concentrations and consequently increased stress and likelihood of disease outbreak. It is common for yellowtail kingfish to be stocked at densities of 10-20 kilograms per cubic metre in modern aquaculture systems.

Technical studies have determined the likely environmental carrying capacity of the proposed MWADZ. This carrying capacity is expected to be up to 24,000 tonnes of standing stock biomass.

[29] In aquaculture, "fallowing" describes a management technique where the production is paused for a period to reduce the impact on the benthic environment and to allow recovery of the site and benthic communities from these impacts. During fallowing, sea cages can be left on-site or moved to another location.

2.5.2 Feed

At the expected stocking densities, each sea cage in the zone would likely receive around four tonnes of feed per day. The only feeds that would currently be permitted in the zone are those that are either AQIS (Australian Quarantine Inspection Service) approved or have been produced by a manufacturer that operates in compliance with the requirements of quality standard AS/NZS ISO 9001:2008 and has in place a quality and risk management system as defined by CAC/RCP 1-1969 (Rev.4-20031). Modern fish feeds (aqua-feeds) are manufactured from ingredients such as fishmeal, vegetable proteins and binding agents such as wheat. Water is added and the resulting paste is extruded through holes in a metal plate, which determines the diameter of the pellets. The pellets are dried and oils are added. Alternative sources of protein have led to a dramatic reduction in fishmeal and fish oil use in making aqua-feeds.[30] The pellets required for aquaculture in the zone are likely to range between 50 milligrams (three millimetre diameter) and 2,000 milligrams (11 millimetre diameter).

Adjusting parameters such as temperature and pressure enables the manufacturers to make extruded feeds that suit different fish farming environments (e.g. pellets that sink more slowly or even at predetermined rates).

Feed accounts for 60 to 90% of the production cost in most fish farming industries today.[31] For this reason, operators within the zone will aim for the best-industry-practice of less than one percent wastage of the feed input (waste). Efficient feed delivery is achieved by monitoring environmental data (water temperature, dissolved oxygen etc.) measured within the cage and controlling feed delivery accordingly. Modern feed delivery systems can provide control over the quantities, timing and rates at which feed is dispensed to the sea cages. During feed delivery, the pellets are not accessible to wildlife. Such systems commonly involve the use of underwater cameras. This allows remote real-time monitoring of feeding response and also stock condition.

To feed stock most efficiently, water temperature and oxygen are considered prior to feeding. Current speed is also taken into account. When these parameters exceed set thresholds, modern systems are designed to temporarily stop feeding and resume it when conditions are optimal; for example, the current sensor system will prevent feed waste caused by currents carrying pellets out of the sea cages.

The pellets would likely be introduced at the surface of the water near the centre of each fish cage for immediate consumption by the stock. Within the sea cages, the pellets would be inaccessible to wildlife. However, before it can be consumed by the stock, up to one percent of the feed will probably sink and drift outside the sea cages.

In summary, stock will consume up to 99% of the feed pellets. Approximately 40 kilograms (i.e. 1%) of residual feed may be lost to the environment from each cage per day. In the marine environment, pellets that are not consumed by stock and exit from the sea cages will break down and be assimilated by the ecosystem. Although wild fish could consume some of the residual feed, it is unlikely that it would be accessible to other wildlife.[32]

[30] Benetti and Welsh, 2010.
[31] Akvagroup.com, 2015.
[32] Price and Morris, 2013.

2.5.3 Harvesting

Harvesting of the farmed stock is conducted on-site from vessels specially equipped for this purpose. The harvested fish are humanely killed on-board and immediately chilled in ice water.

All waste (e.g. blood or offal) from the harvesting is retained on-board the vessel and disposed of back at the mainland (e.g. Geraldton).

2.5.4 Waste Treatment

A stand-alone Waste Management Plan (WMP) has been developed for the MWADZ Proposal (refer to Appendix 6). This WMP:

- identifies, describes and provides guidance on the various waste products that are common to aquaculture facilities including, general rubbish and sewage treatment;
- identifies potential fuel and oil spills and provides guidance for appropriate action and reporting; and
- identifies, describes and provides guidance on the disposal of biological waste common to aquaculture facilities including fish processing waste and mortalities/culls including appropriate biosecurity considerations.

The WMP encourages the use of the Waste Hierarchy detailed in the EPA's *Implementing Best Practice in proposals submitted to the Environmental Impact Assessment Process* No. 55 (2003). Specifically:

1. avoidance of waste production;
2. reuse of wastes;
3. recycling wastes to create useful products;
4. recovery of energy from wastes;
5. treatment of wastes to render them benign;
6. containment of wastes in secure, properly managed structures; and
7. disposal of waste safely in the long term.

Note: any reuse or re-cycling of aquaculture facility products must be done in accordance with biosecurity procedures.

No waste generated by the MWADZ Proposal is permitted to be disposed within the Abrolhos Islands Reserve or the Abrolhos Islands Fish Habitat Protection Area.

2.5.5 Maintenance of Sea Cages

Maintenance of sea cages includes both removal of marine fouling as well as the repair and upkeep of structural and net integrity.

Removal of marine fouling from sea cages may be undertaken in situ using physical or mechanical methods; or achieved by removing the nets and drying/cleaning on the mainland. It is likely the latter approach will be used by most operators (at least initially) in the proposed MWADZ.

Cleaning of infrastructure with heavy biofouling has the potential to result in heavy releases of biological material into the water column during the removal process. For operators cleaning in situ, the Department recommends cleaning on (essentially) a continuous basis to prevent heaving accumulation of biofouling. A regime of regular biofouling removal optimises the flow of water through the sea cages (with resulting benefits to the aquaculture stock) and reduces the potential for any marine pest to become established.

Operators will refer to the National Biofouling Management Guidelines for the Aquaculture Industry (http://www.marinepests.gov.au/marine_pests/publications/Pages/national_biofouling_management_guidelines_aquaculture_industry.aspx) for further information on recommended approaches for control of biofouling to minimise the spread of exotic species that may associated with moving aquaculture stock and equipment.

Technical testing will be conducted on a regular basis to ensure structural integrity of sea cages. Additionally, netting (including anti-predator netting) should be checked and repaired on a continuous basis to ensure the best-practice standards in sea cages (considered in the cage design) are functioning optimally. Both forms of maintenance assist in ensuring potential risks from the MWADZ Proposal (e.g. those relating to marine fauna) are appropriately managed and mitigated.

There will be requirements within individual Management and Environmental Monitoring Plans (MEMPs) to appropriately maintain infrastructure.

2.6 Decommissioning Activities

Should any licence/lease holder within the MWADZ permanently cease their operations (for whatever reason), they are required to remove all structures, equipment and fish from the lease site.

If an aquaculture lease is terminated or expires, the Department of Fisheries (Department) may direct the former lease holder to clean up and rehabilitate the former leased area. If the former lease holder contravenes the direction, the Department may clean up and rehabilitate the area and the reasonable cost of any action taken is recoverable as a debt due to the State from the former lease holder.[33]

Additionally, the former lease holder is required to complete the rehabilitation of the site within three months of the termination/expiry of the aquaculture lease. Failure to do so will result in forfeiture of the remaining structure/equipment/fish to the Crown.[34]

The terms and conditions of the aquaculture lease require that lease holders must provide and maintain security, usually in the form of a bank guarantee, so that the lessor (i.e. the Minister for Fisheries) may recover any loss which the lessor incurs arising from a default by the lessee under the lease.

[33] Section 101 of the *Fish Resources Management Act 1994* refers.
[34] Section 100 of the *Fish Resources Management Act 1994* refers.

3 OVERVIEW OF EXISTING ENVIRONMENT

3.1 Regional Setting

3.1.1 Overview

The Houtman Abrolhos Islands (referred to as "the Abrolhos") is a complex of islands and reefs located at the edge of the continental shelf between 28°15'S and 29°00'S. Situated approximately 65 kilometres offshore from the mid-west coast of Western Australia, the Abrolhos comprises three major island groups:

- North Island-Wallabi Group;
- Easter Group; and
- Pelsaert (or Southern) Group.

The islands support a diverse and unique range of marine and terrestrial flora and fauna. Located at the confluence of temperate and tropical zones, the marine ecosystems may be particularly susceptible to future climate change impacts. Abrolhos waters also harbour some of the most important historical shipwrecks in Australia, with associated historic sites located on the islands themselves.

Not surprisingly, the Abrolhos attracts significant economic and social activity, providing substantial benefits to the Western Australian community. These activities include commercial fisheries for rock lobster, scallops and finfish; aquaculture for pearls; recreational finfish fisheries; diving and associated marine-based activities; and a developing tourism industry. It is also important for scientific research and monitoring.

3.2 Physical Environment

3.2.1 Geology and Geomorphology

The Houtman Abrolhos Islands are very flat, with an elevation above sea level of three to five metres on most islands. Flag Hill, above Turtle Bay on East Wallabi Island, is the highest point in the Abrolhos, at 14 metres above sea level.

The islands of the Abrolhos have an unusual geology, as they are only around 125,000 years old.

The three main island groups are located on separate limestone platforms up to 36 metres thick with deep channels between these. North Island, which is the northernmost island at the Abrolhos, is on the same carbonate platform as the Wallabi Group. Each platform has a fringing reef system, with a windward reef on the southern and western sides and a leeward reef on the eastern side. These reefs are separated by a central shallow lagoon. The majority of the islands in the Abrolhos have formed within the central lagoons or on the eastern (leeward) reefs.

The Abrolhos are formed of solid limestone under a layer of sand, cemented coral rubble and coral shingle. The limestone is the remnants of coral reef which formed at least 125,000 years ago, during a period of high sea level. Coral shingle and sand has been deposited on the

limestone during storms and cyclones. The islands continue to change shape and form today, through the same processes of erosion and deposition during storms and cyclones.

At the peak of the last glacial period (approximately 18,000 years ago), the sea level was about 130 metres lower than it is today, so it was possible to walk, hop or slither across where the Geelvink Channel is today to the Abrolhos Islands, such as East and West Wallabi Islands. At the end of the last glacial period, the ice started to melt and sea levels rose. Around 6,000 years ago, sea levels reached the current level, marooning terrestrial wildlife on the Abrolhos.

The combination of temperate and tropical species, both in the water and on the islands, is unique at the Abrolhos. This unique blend fosters unusual ecological interactions. In addition, the small tidal ponds that occur on many islands are important structures, which are rare on other offshore islands in the south-west of Australia.

3.2.2 Climate

The Abrolhos is subject to strong winds for most of the year, with calm conditions mostly in autumn and early winter. The prevailing winds are from a southerly direction and these are strongest in summer.

There is a weather station on North Island which has been recording temperature and rainfall data since 2000. Based on the data collected at this station to date, the Abrolhos Islands receive an average annual rainfall of 272 millimetres, with the majority of this occurring in April to September. In summer, the mean temperature varies from 21 to 27^{o}C, and in winter between 16 and 22^{o}C.

The Abrolhos is occasionally subject to cyclone activity during the cyclone season from December to May, with more than half the recorded cyclones occurring between March and May. Since 1915, on average, a cyclone passes through coastal waters within 400 kilometres of North Island approximately every 2.5 years.

3.2.2.1 Wind

At the Abrolhos Islands in the summer months winds are characterised by consistently strong south to south easterlies in the morning with generally stronger south to south westerlies in the afternoon (Webster *et al.* 2002). High wind speeds are consistently recorded in the afternoons on the Islands from September through to March, with the months of strongest wind being December, January and February (MBS Environmental 2006). In the autumn and winter months winds tend to be weaker and highly variable in terms of direction (Department of Fisheries 2000).

In the winter months, southern storms to the south of the Geraldton-Abrolhos region can bring winter gales and strong winds up to 35 metres/second (Webster, F *et al.* 2002). Squalls can also occur in the summer months (December to April) and can generate wind speeds between 25 and 30 metres/second in any direction (Webster *et al.* 2002). Occasionally, tropical cyclones may occur within the Abrolhos Islands during the summer months (January to April). Cyclones are generally infrequent occurring on average one every five years.

The Bureau of Meteorology (BoM) records wind data at the Abrolhos wind station situated on the North Island approximately 50 kilometres north of the northern area of the MWADZ Proposal (refer to Figure 3-1).

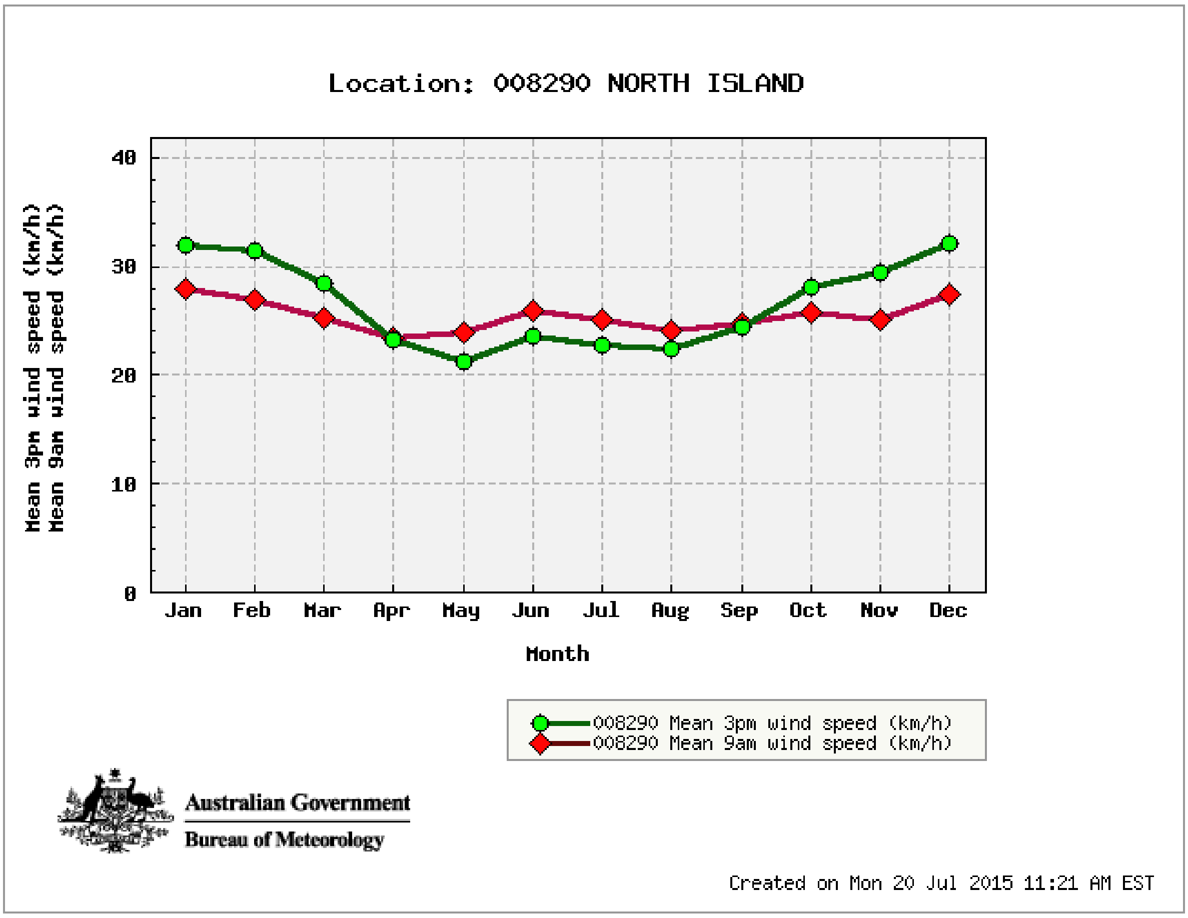

Figure 3-1: Mean Abrolhos Wind Speed – North Island (Source BoM, July 2015)

3.2.2.2 Rainfall

The average rainfall that has been recorded for the North Island of the Abrolhos from 2000 to 2015 is 281.3 millimetres per year. Most of the rainfall occurs during the winter months between May through to August (see Figure 3-2 below). No recent rainfall data has been collected from the Pelsaert Group of islands which are the islands closest to the proposed MWADZ areas. However, historical data collected from this southern group has confirmed the general trends described above with most rainfall occurring during the winter months.

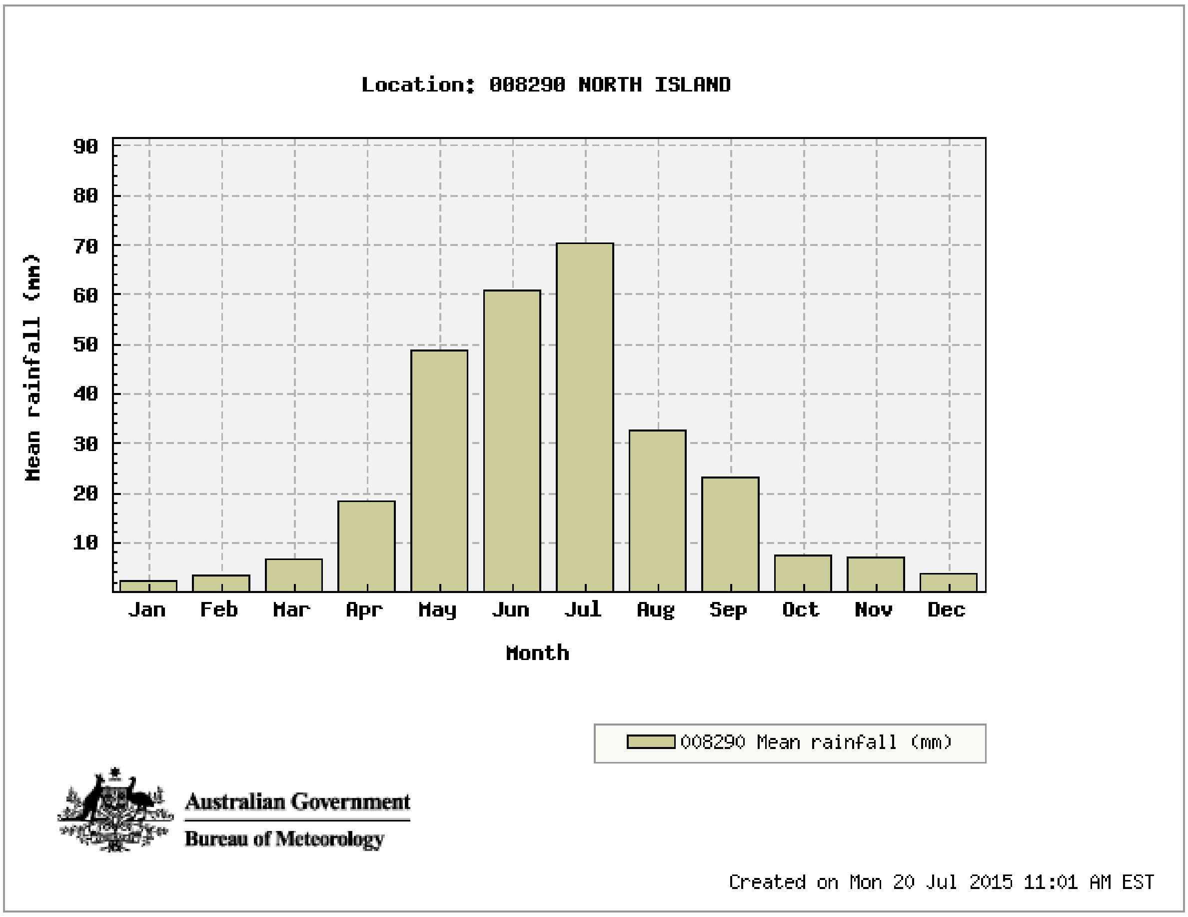

Figure 3-2: Mean Abrolhos Rainfall – North Island (Source BoM, July 2015)

3.2.2.3 Air Temperature

There is a weather station on North Island which has been recording temperature since 2000. In summer, the mean temperature varies from 21°C to 27°C, and in winter between 16°C and 22°C.

3.2.3 Oceanography

3.2.3.1 Tides

Abrolhos tides alternate between diurnal and semi-diurnal (two tide cycles per day), though they are predominantly diurnal (one high tide and one low tide per day). The daily tidal range is low - about 0.7 metres between high and low tides. While wave heights can average about two metres in the open ocean near the Abrolhos, within the island groups they are lower, dampened by the shallow reefs and islands.

The Leeuwin Current runs along the Western Australia coast and brings warm tropical water to higher latitude reefs like those at the Abrolhos. Between the islands, ocean currents are highly variable.

3.2.3.2 *Sea Temperatures and Salinities*

Sea surface temperatures at the islands are very stable, with the monthly mean minimum sea temperatures of 20.0^{o}C occurring in September and the maximum of 23.7^{o}C in March (Pearce, A *et al.* 1999). Water temperatures can drop below 20^{o}C in tidally-exposed areas and shallow pools in winter, when air temperatures drop (Department of Fisheries 2000).

The Leeuwin Current maintains water temperatures at the Abrolhos Islands at warmer levels than inshore. During the winter months the water around the islands can be up to 4^{o}C warmer than at Geraldton (Webster *et al.* 2002).

Salinity levels in the Abrolhos Islands are essentially those of the open ocean, with the monthly mean salinity at the nearby Rat Island varying only from 35.4 parts per thousand to 35.7 parts per thousand (Department of Fisheries 2000).

3.2.3.3 Waves

Wave heights in the open ocean near the south-westerly reef margins of the Abrolhos Islands average about two metres, and can exceed four metres during storm events. However, wave heights are substantially lower on the eastern (leeward) sides of the Abrolhos and in the areas near the MWADZ Proposal area with average wave height reaching approximately 1.2 metres (Webster, F *et al.* 2002). The majority of the swell approaches the islands from the south and west 78% of the time (Department of Fisheries 2000).

3.2.3.4 Currents and Circulation

The dominant oceanic currents affecting the waters of the Abrolhos Islands is a southward flowing current referred to as the Leeuwin Current. At the Abrolhos Islands the Leeuwin Current is strongest in autumn, winter and early spring; raising sea surface temperatures. The flow is greatest and most consistently south along the shelf break, a relatively short distance to the west of the Abrolhos (Webster *et al.* 2002). The currents through and inshore of the islands vary spatially and temporally. During the late spring and summer months, the current through and inshore of the islands tends to set to the north, driven by the prevailing southerly winds with occasional current reversal to the west along the shelf break (Pearce, A *et al.* 1999). During the winter months strong westerlies and north-westerlies can generate southward-setting currents inshore of the Abrolhos Islands (Pearce, A *et al.* 1999).

The waters within the MWADZ Proposal area are well flushed and experience high levels of water circulation and dispersion. Previous oceanographic work focussing on the shallow waters of the Easter Group lagoon indicated currents between 2-5 centimetres/second and fast flushing times between 0.5 and 1.5 days (Sukumaran, A 1997).

The MWADZ Proposal area is located in a more exposed area between the Pelsaert Group and the Easter Group of islands and therefore water circulation and flushing is likely to be higher than that reported in the relatively sheltered Easter Group lagoon.

3.2.3.5 *Water Quality*

Abrolhos waters have a history of higher nutrient levels than coastal waters at Geraldton. There are a number of theories for this, including nutrient upwelling (a phenomenon where dense, cooler and nutrient-rich water is driven from the depths toward the sea surface, replacing warmer, nutrient-poor surface water) and seagrass detritus. During autumn and winter storms, seagrass is torn from the reef substrate. This seagrass detritus accumulates in the relatively calm water in the lagoon areas and releases nutrients as it decays. The higher nutrient levels in Abrolhos waters help to support the diverse marine life.

3.2.3.6 *Sediment Quality*

In general, sediments in the Zeewijk Channel are predominantly composed of calcareous sands of varying proportions of different particle size fraction. Studies suggest some differences in time – fine to coarse sand dominate in the winter season, while fine clays and silts dominate in the summer season. Overall, this reflects the general high level of variability in terms of sediment composition and seasonality across all locations within the Channel.

Sediment depth is thought to be relatively shallow and overlying a flat limestone base.

3.3 Biological Communities

3.3.1 Benthic Habitats

The Abrolhos Islands supports a total of ten species of seagrass which range from small delicate species to large, more robust types that grow in large meadows. These are mainly temperate species, possibly due to the relatively low winter water temperatures. No extensive seagrass meadows are present in the Abrolhos (Webster *et al.* 2002).

Fleshy macro algae form a major component of the benthic communities of the reefs at the Abrolhos Islands. The high- energy outer reef slopes support rich and dense macrophyte communities characterised by large brown algae (e.g. *Dictyota, Glossophora, Sargassum*) including the kelp *Ecklonia radiata*, mixed with fleshy red and green algae (e.g. *Aspargopsis*, *Hypnea, Laurencia, Plocamium and Caulerpa*) (Crossland, C.J *et al.* 1984). The protected reefs are dominated by algae species such as *Turbinaria, Eucheuma and Sargassum* (MBS Environmental 2006).

The Abrolhos Islands also contains some of the southernmost coral reefs in the Indian Ocean. The coral reefs occur in the same area as lush growths of temperate marine algae, or seagrass, which are more characteristic of the south coast of Western Australia.

3.3.1.1 *Marine Flora*

Seagrasses are marine flowering plants that generally grow in shallow coastal areas, protected from ocean swells. In contrast to the marine fauna, which has a strong tropical component, the seagrasses in Abrolhos waters are predominately cooler water species.

In total, ten seagrass species have been recorded at the Abrolhos ranging from small, delicate species to larger, more robust types that grow in large meadows. Small paddle weeds grow in

protected lagoon areas or deep waters between the islands, such as Goss Passage. The larger species may be found growing on reef as well as in sandy areas.

Thalassodendron pachyrhizum, which is encountered growing on the exposed reef crest area, has been recorded at a number of the island groups.

There are also two species of wire weed (*Amphibolis* species), endemic to southern Australia, found at the Abrolhos. The most abundant seagrass is *Amphibolis antarctica*, while *Amphibolis griffithii* appears to be restricted to bays such as Turtle Bay in the Wallabi Group.

The larger ribbon weeds (*Posidonia* species) grow in sheltered bays and lagoons where the sand cover is deeper and more stable (e.g. Turtle Bay, the Gap, East Wallabi Island, the lagoon on the west side of West Wallabi Island and around North Island).

Protection of the diverse seagrass communities in reef areas and sheltered bays at the Abrolhos is necessary for the maintenance and functioning of these productive waters. Seagrasses are not only a key benthic primary producer but also provide habitat for a diverse and abundant community of algae and small invertebrates, like juvenile Western rock lobster. Additionally, seagrasses reduce water movement and stabilise the sea floor.

There are 295 macro algae species documented as occurring in the Abrolhos where they can be found in all habitats. Of these, 13.6% are considered to be endemic (Phillips & Huisman 2009). Kelp (*Ecklonia radiate*) is one of the dominant species, particularly in the lagoonal areas (Hatcher *et al.* 1987). Other fleshy macro algae form a major component of the benthic communities in the Abrolhos, where the high-energy outer reef slopes support rich and dense macrophyte communities (Crossland *et al.* 1984).

3.3.1.2 Marine Fauna

Coral Communities

The Abrolhos are high-latitude coral reefs – some of the southernmost coral reefs in the Indian Ocean. They have a unique assemblage of tropical and temperate fish, corals, algae and other invertebrates.

The coral fauna of the Abrolhos is diverse for a high-latitude reef system, with 211 species of corals discovered so far. All but two of the coral species are tropical.

The greatest diversity and density of corals is found on the reef slopes, shallow reef perimeters and lagoon patch reefs in the more sheltered northern and eastern sides of each of the three limestone platforms that support the island groups. The growth of at least two species of coral abundant at the Abrolhos has been found to be significantly slower than at several locations in the tropics.

Invertebrates

Marine invertebrates present at the Abrolhos include:

- crustaceans
- molluscs
- echinoderms
- sponges
- cnidarians (other than hard corals)

There are 492 mollusc species and 172 echinoderm species which have been identified at the Abrolhos. Some of the species which are important for the fishing industry are Western rock lobster, saucer scallops, octopus and species that produce specimen shells.

Southern saucer scallops (*Amusium balloti*) are short-lived, benthic, filter feeding bivalve molluscs which reside on sandy bottoms. The southern saucer scallop can grow to 13 centimetres in length and live up to three years (DoF 2007). They are subject to great natural fluctuations in reproductive success from year-to-year and grow to maturity within a year. Southern saucer scallops spawn at the Abrolhos between August and March.

In all these groups of marine invertebrates there is a complex assemblage of tropical species living in close association with temperate species and species endemic to Western Australia. There are a higher proportion of tropical species in most groups, but the majority of hydroid (members of the invertebrate order Hydroida) and sponge species are usually found in temperate rather than tropical waters.

Finfish

A total of 389 finfish species have been recorded at the Abrolhos.

The Abrolhos and their surrounding coral and limestone reef systems consist of a combination of abundant temperate macro algae with coral reefs, supporting substantial populations of large species such as baldchin groper and coral trout.

Some of the species occurring in the Abrolhos are dependent on larvae carried southward by the Leeuwin Current from areas further north, such as Shark Bay or Ningaloo Reef. Similarly, populations of some of the species occurring at Rottnest Island are dependent on larvae generated from breeding populations at the Abrolhos.

Temperate fish species such as pink snapper and West Australian dhufish are also found in Abrolhos waters.

Sharks and Rays

More than twenty species of sharks have been identified at the Abrolhos, including Port Jackson sharks, tiger sharks, whaler sharks and wobbegongs. Abrolhos waters are considered to be an important food source for sharks, due to the resident fish populations.

Various species of rays have been recorded at the Abrolhos. These include the giant manta ray and the white spotted eagle ray.

Mammals

Marine mammals frequent Abrolhos waters, with a colony of Australian sea lions living and breeding at the Abrolhos. The Abrolhos represent the northernmost breeding population of Australian sea lions. The current population of approximately 90 is greatly reduced from historical times - when as many as 600 animals may have been resident at the Abrolhos. The population decline is most likely due to hunting, by the hungry crews of wrecked ships and whaling and sealing activities of early fishermen in the 19th century.

Male Australian sea lions are usually dark brown. They can grow to up to 2.5 metres in length and weigh up to 300 kilograms. Female sea lions are smaller and they usually have grey backs with yellow-to-cream underneath. The females can grow to more than 1.5 metres long and weigh up to 100 kilograms.

Australian sea lions breed approximately every 18 months, so there is no annual breeding season. The sea lion pups are dark brown at birth, with a pale-fawn crown until they moult at two months of age. Their juvenile coat is a similar colour to that of an adult female.

The Australian sea lions feed on fish, rock lobster, octopus and occasionally sea birds. They can dive to depths of up to 150 metres in search of their prey. Often they can be seen hauled out at sandy beaches throughout the Abrolhos.

There are 31 species of cetaceans which have the potential to occur within the vicinity (i.e. less than 50 kilometres) of the proposed MWADZ area (DoE 2014 a). Some of these species occasionally transit through the area at low densities (e.g. sperm whales, Antarctic minke whales and oceanic dolphins) although the information currently available is insufficient to confirm a definitive presence within the proposed MWADZ area (BMT Oceanica 2015).

Species that are likely to occur within this radius include the:

- humpback whale;
- Indo-Pacific bottlenose dolphin; and
- common bottlenose dolphin.

Species with a low likelihood of occurring include the:

- blue whale;
- Southern right whale;
- Bryde’s whale;
- killer whale; and
- dugong.

Reptiles

Four marine turtles may occur within a 50 kilometre radius of the MWADZ Proposal area, including the loggerhead turtle, flatback turtle, leatherback turtle and green turtle, with the last two species more likely to be present.

Sea snakes are not resident in the Abrolhos but may be transported to the area during storms from the north.

Seabirds

The Houtman Abrolhos is the most significant seabird breeding location in the eastern Indian Ocean. Eighty percent (80%) of the brown (common) noddy, 40% of the sooty tern and all lesser noddy found in Australia nest at the Houtman Abrolhos (Ross *et al.* 1995). It also contains the largest breeding colonies in Western Australia of wedge-tailed shearwater, little shearwater, white-faced storm petrel, white-bellied sea eagle, osprey, Caspian tern, crested tern, roseate tern and fairy tern (Storr *et al.* 1986, Surman and Nicholson 2009). The Houtman Abrolhos also represents the northernmost breeding islands for both the little shearwater and white-faced storm petrel.

3.3.2 Terrestrial Environment

3.3.2.1 Terrestrial Flora

The terrestrial flora of the Abrolhos archipelago includes a number of vegetation communities on the islands identified as being of conservation significance, including mangroves and *Atriplex cinerea* dwarf shrubland.

Mangroves are coastal plants which live in the upper intertidal zone. A single mangrove species, the grey mangrove (*Avicennia marina*), occurs in the Abrolhos. The grey mangrove provides an important source of nutrients for marine food chains, in addition to habitat for terrestrial and marine animals, including the Australian sea lion and the lesser noddy at the Abrolhos.

Mangroves also protect the Abrolhos shoreline from storm damage and erosion. Extensive stretches of mangroves can be seen on Pelsaert Island, Wooded Island and Morley Island.

The *Atriplex cinerea* dwarf shrubland occurs on sandy soils or shell grit. The deeper soils supporting the shrubland are suitable for burrowing seabirds, such as shearwaters and petrels, to use for building nests.

3.3.2.2 Terrestrial Fauna

There are 26 terrestrial reptile species on the islands, including the carpet python. One previously undiscovered worm lizard, *Aprasia* sp., the Houtman Abrolhos spiny tailed skink and the Abrolhos dwarf bearded dragon are endemic to the Abrolhos. All three species are found on East Wallabi, but the Houtman Abrolhos spiny tailed skink and Abrolhos dwarf bearded dragon occur on a number of other islands as well.

Only two species of indigenous land mammals have been recorded at the Abrolhos - the tammar wallaby and the southern bush rat.

3.4 Socio-Economic Setting

3.4.1 City of Greater Geraldton

The City of Greater Geraldton is the closest Local Government entity to the location of the MWADZ Proposal and is likely to provide the majority of the workforce, accommodation, supporting infrastructure and services associated with the MWADZ Proposal.

A summary of the socio-economic profile of the City of Greater Geraldton is outlined in Table 3-1.

Table 3-1: City of Greater Geraldton – Gross Regional Product (GRP)

GRP Expenditure Method	City of Greater Geraldton
Household consumption	$2,290.374 M
Government consumption	$683.754 M
Private Gross Fixed Capital Expenditure	$877.339 M
Public Gross Fixed Capital Expenditure	$193.999 M
Gross Regional Expenses	**$4,045.465 M**
plus Regional Exports	$1,772.662 M
minus Domestic Imports	-$2,255.405 M
minus Overseas Imports	-$489.550 M
Gross Regional Product	**$3,073.171 M**
Population	37,162
Per Capita GRP	$82,697
Per Worker GRP	$214,592

The City of Greater Geraldton's Gross Regional Product (GRP) is estimated at $3.073 billion. This represents 56.68% of the Mid West Region's GRP of $5.422 billion and 1.16% of Western Australia's Gross State Product of $264.545 billion.

It is estimated that 14,321 people work in Greater Geraldton. Greater Geraldton represents 63.58% of the 22,526 people working in the Mid West region.

The unemployment rate within the City of Greater Geraldton is currently estimated to be approximately 6.9%.

3.4.2 Tenure

The MWADZ Proposal is wholly located within Western Australian State Territorial Waters.

Additionally, the site of the MWADZ Proposal is also entirely within a Fish Habitat Protection Area (FHPA) created under the *Fish Resources Management Act 1994*.[35] Aquaculture is one of the purposes for which the FHPA was created, as specified in the gazettal of the Abrolhos Islands Fish Habitat Protection Area Order 1999.[36]

3.4.3 Sea Use

The waters within the MWADZ Proposal area are currently subject to a range of uses. These include:

- commercial fishing;
- recreational fishing;
- aquaculture;
- marine based tourism (e.g. sailing and diving charters); and
- transit between Geraldton, the Pelsaert Group and the Easter Group of the Abrolhos Islands.

Generally, however, the level of this use is not high due to the remoteness of the area and the benthic habitats within the MWADZ Proposal sites not supporting concentrations of fishing target species. A notable exception is the southern area of the MWADZ Proposal, but only in those years when commercial quantities of Southern saucer scallop (*Amusium balloti*) recruits to the area.

3.5 Key Conservation Values

3.5.1 A Class Reserve

An A Class Reserve since 1929, the Houtman Abrolhos Nature Reserve is vested in the Minister for Fisheries, for the purpose of:

"C*onservation of flora and fauna, tourism, and for purposes associated with the fishing and aquaculture industries*."

The proposed MWADZ is located outside of this Reserve.

3.5.2 Fish and Fish Habitat Protection Area

The State Territorial Waters (i.e. high water mark out to three nautical miles seaward of the Territorial Sea Baseline) of the Abrolhos Islands are a gazetted Fish Habitat Protection Area (FHPA) [37]. This FHPA was gazetted in 1999.

The FHPA is designated for the following purposes:

- *the conservation and protection of fish, fish breeding areas, fish fossils or the aquatic ecosystem;*

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[35] Fish Habitat Protection Areas are created by the Minister under the provisions of Part 11, Division 1 of the *Fish Resources Management Act 1994*.
[36] This Order was printed in Government Gazette No. 23 on 16 February 1999.
[37] Section 115 of the *Fish Resources Management Act 1994* provides that the Minister for Fisheries may, by order published in the Gazette, set aside an area of WA waters as a fish habitat protection area.

- *the culture and propagation of fish and experimental purposes related to that culture and propagation; and*
- *the management of fish and activities relating to the appreciation or observation of fish.*

Under the FRMA, the Department of Fisheries has the power to regulate fishing operations in the FHPA (Department of Fisheries 2001). Regulation of fishing operations may be undertaken for a number of purposes including conservation, fisheries management and for the preservation of areas for observation and eco-tourism pursuits. Regulations may take a number of forms, including:

- area protection
- gear restrictions
- effort restrictions
- temporal/time closures
- catch limits

The proposed MWADZ Proposal is located within this FHPA.

3.5.3 Reef Observation Areas

Within the Abrolhos Islands Fish Habitat Protection Area, special places have been set aside as Reef Observation Areas (ROAs) for the conservation and observation of marine life and habitats (refer to Figure 3-3). The four Reef Observation Areas in the Abrolhos are:

- North Island Reef Observation Area;
- Beacon Island Reef Observation Area (Wallabi Group);
- Leo Island Reef Observation Area (Easter Group); and
- Coral Patches Reef Observation Area (Pelsaert Group).

Catching fish by line, spear or any other method is not permitted in these areas. The ROAs are intended to:

- conserve and protect fish, fish breeding areas, fish fossils and the aquatic ecosystems;
- provide sites for the appreciation and observation of fish in their natural habitat; and
- boost populations of reef fish in areas adjacent to the reef.

The northern area of the MWADZ is located approximately 8.4 kilometres south east of the Leo Island ROA and nine kilometres north-west of the Coral Patches ROA. While the southern area of the MWADZ is located approximately 18 kilometres south of the Wallabi ROA and 7.6 kilometres west of the Coral Patches ROA.

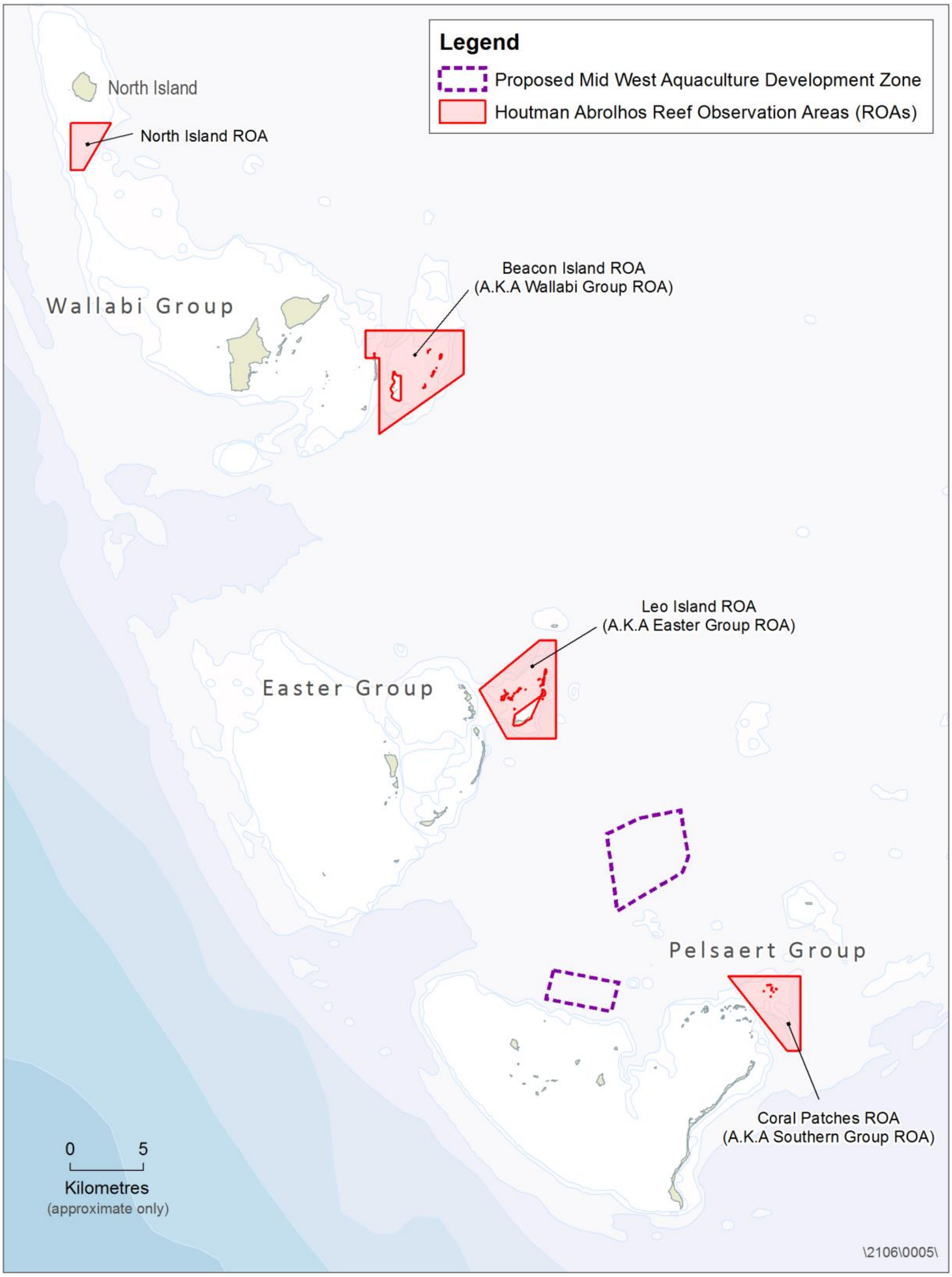

Figure 3-3: Abrolhos Islands Fish Habitat Protection Area – Reef Observation Areas

4 LEGISLATIVE FRAMEWORK

4.1 Principal Commonwealth Legislation

4.1.1 Environment Protection and Biodiversity Conservation Act 1999

The Commonwealth legislation which protects the threatened, endangered and protected species that inhabit the proposed MWADZ is the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The EPBC Act provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places defined in the Act as matters of national environmental significance (Department of the Environment, 2013).

The following Commonwealth Acts are also potentially applicable to the MWADZ Proposal:

Commonwealth Act	Intent
Historic Shipwrecks Act 1976	To protect historic wrecks and relics from the low water mark to the edge of the continental shelf. The Act is mirrored in State legislation with a delegate for each State and Territory taking responsibility in conjunction with their Commonwealth counterpart.
Heritage Act 1990	Encourages and provides protection and conservation of places that have significant cultural heritage value to the State.
Environmental Protection (Sea Dumping) Act 1981	To regulate the loading and dumping of waste at sea. This Act fulfils Australia's obligations under the 'London Protocol' to prevent marine pollution.

As explained in sub-section 1.2.2 of this PER, the Commonwealth (DotE) advised the Department that the proposed actions associated with the MWADZ Proposal were not of a magnitude that necessitates a "Strategic Assessment" under the EPBC Act.

However, referral to the Commonwealth of future derived proposals associated with the MWADZ Proposal could be triggered in certain circumstances.

4.2 Principal Western Australian Legislation

4.2.1 Environmental Protection Act 1986

The principal Western Australian legislation protecting the environment is the *Environmental Protection Act 1986* (EP Act).

The Department, on behalf of the Minister for Fisheries, referred the MWADZ Proposal to the EPA for assessment as a Strategic Proposal under Part IV of the EP Act. Following its assessment of the proposal, the EPA may then recommend to the Minister for the Environment that it is accepted as a strategic proposal.

A **strategic** proposal is a proposal which identifies one or more future proposals that may, individually or in combination, have a significant effect on the environment.

Generally, a strategic proposal does not, of itself, have a direct impact on the environment (although there may be circumstances when it does).

Instead, strategic proposals anticipate that there will be one or more future proposals that may have a significant environmental impact if implemented singly or in combination and which might normally be assessed on a case-by-case basis.

A **derived** proposal is a future proposal which was identified in the strategic proposal, which has been referred to and considered by the EPA, and which is then declared to be a derived proposal.

The assessment of strategic proposals provides a number of benefits. These include:

- the early consideration of environmental issues providing the ability to influence the detailed design of future proposals;
- the ability to consider the cumulative impacts of more than one proposal;
- greater certainty for local communities regarding the maximum extent of cumulative impacts of future developments, and greater confidence for proponents of future developments;
- more flexible timeframes for consideration of environmental issues; and
- potential efficiencies in the approvals process.

Overall approval timeframes can be improved if a strategic proposal is approved, as future proposals can be determined more quickly when they are referred. Certainty for future proponents is also improved if a strategic proposal is approved.

Generally, assessment of strategic proposals aims to establish acceptable environmental parameters within which the derived proposals, individually and in combination, are expected to operate.

4.2.1.1 Process for Assessing Strategic Proposals

Following the EPA's assessment of the strategic proposal, the EPA reports to the Minister for Environment on:

1. the key environmental factors identified during the assessment;
2. whether or not the future proposals, identified in the strategic proposal, may be implemented; and
3. any conditions which should apply to those future proposals, if they are subsequently referred to the EPA and declared to be derived proposals.

As with other proposals, any person may appeal to the Minister for Environment if they disagree with the content of, or any recommendations in, the EPA's report.

After determining any appeal, the Minister for Environment consults with other relevant decision-making authorities for the purposes of deciding whether the future proposals, identified in the strategic proposal, may be implemented. The Minister also consults on any conditions which will apply to the implementation of the future proposals and the strategic proposal.

If the Minister for Environment and relevant decision-making authorities decide that the future proposals may be implemented, with or without conditions, the Minister publishes a "Ministerial Statement". However, it is not until after the EPA has declared a future proposal,

identified in the strategic proposal, to be a derived proposal, that the future proposal can be implemented.

4.2.1.2 Process for Declaring and Implementing Derived Proposals

Once the Ministerial Statement has been issued, the proponent of a future proposal (identified in the Ministerial Statement), may then refer their proposal to the EPA along with a request that it be declared a derived proposal.

Any person may refer a future proposal, identified in a strategic proposal, to the EPA. However, it is not until after the Ministerial Statement has been issued, and the proponent has requested the referred proposal be declared a derived proposal, that the EPA can consider whether to declare it to be a derived proposal.

After receipt of the referral and a request, the referral (and the proponent's request for it to be declared a derived proposal) is advertised for public comment. The EPA can only consider public comment in the context of its decision on whether or not to declare the proposal to be a derived proposal.

After considering public comment and the proposal documentation, the EPA then considers whether or not to declare the referred proposal to be a derived proposal. To do so, the Act requires that the:

- proposal was identified in the strategic proposal; and
- Ministerial Statement provides that the referred proposal may be implemented, subject to any conditions.

The EPA may refuse to declare the referred proposal to be a derived proposal if it considers that:

- the environmental issues raised by the referred proposal were not adequately assessed when the strategic proposal was assessed;
- there is significant new or additional information that justifies the reassessment of the issues raised by the referred proposal; or
- there has been a significant change in the relevant environmental factors since the strategic proposal was assessed.

If the EPA declares the referred proposal to be a derived proposal, it does not assess that proposal. Instead, the Ministerial Statement, together with any accompanying conditions, takes effect and applies to the declared derived proposal. The Minister is required to issue a notice stating this.

If the Ministerial Statement relates to two or more future proposals, the Minister's notice may specify which of the conditions of the Ministerial Statement apply to the derived proposal.

Alternatively, the Minister may request the EPA to inquire into the conditions which apply to the derived proposal or the EPA may decide to inquire into the conditions and, if so, the EPA may recommend changes to conditions and make any other recommendations that it thinks are appropriate.

There are no appeal provisions relating to the EPA's decision to declare a derived proposal, to refuse a declaration, or its determination as to whether or not to inquire into conditions. There is also no appeal in relation to the Minister's notice which specifies the coming into effect of the Ministerial Statement and any conditions which relate to the derived proposal.

If the EPA enquires into the conditions which apply to the derived proposal there is no appeal in respect of the EPA's report to the Minister, however the proponent can appeal any conditions which are set following that enquiry.

4.2.1.3 Summary

To ensure that the benefits of strategic assessments are realised, the EPA takes the following approach to assessing strategic proposals and deciding on derived proposals.

1. The assessment of a strategic proposal should enable the EPA to confidently define the overall environmental outcomes that must be achieved through implementation of any derived proposals identified in the course of the assessment of the strategic proposal.

2. Information submitted with a request that the EPA declare a derived proposals will need to demonstrate how the proposal will meet the environmental outcomes defined through the assessment of the strategic proposal, including any Ministerial conditions.

3. Referrals of future proposals must contain sufficient information to enable the EPA to determine whether the proposals can be declared as derived proposals.

4. Proponents of future proposals should undertake thorough stakeholder consultation.

For further procedural detail, refer to the EPA's Environmental Impact Assessment Administrative Procedures 2012.

4.3 Other Relevant Environmental Management Legislation and Instruments

4.3.1 Fish Resources Management Act 1994

While the State-level environmental impact assessment of the MWADZ Proposal and the principal object of this PER is to address the requirements of the EP Act, it is also important to describe how the provisions of the *Fish Resources Management Act 1994* (FRMA) interact with and support the EP Act in the management of the potential environmental impacts of the proposal. In this context, the following provisions are relevant.

Section 101A (2A) of the *Fish Resources Management Act 1994* (FRMA) provides the power for the Minister to declare an area of Western Australian waters to be an aquaculture development zone.

Section 92 of the FRMA provides the power for the Chief Executive Officer (CEO) of the Department to grant an aquaculture licence, which authorises the licence holder to conduct aquaculture in Western Australia.

There is a requirement that applicants for aquaculture licences demonstrate they have, or will have, appropriate tenure over the area proposed for the aquaculture activity. In most cases, tenure over State waters may be granted through an aquaculture lease, issued under Section 97 of the FRMA. In the zone, an aquaculture lease and an aquaculture licence will both be required for establishing and undertaking aquaculture.

An aquaculture licence authorises the specific aquaculture activity undertaken within a defined site, whereas a lease provides tenure for the specified area of land or water. There is a nexus between the aquaculture licence and the aquaculture lease under the FRMA. For example, under:

- s.99(1), an aquaculture lease does not authorise the use of the leased area without an aquaculture licence;
- s.99(2), if an aquaculture licence authorising the activity being carried out in the leased area is cancelled or not renewed, the lease is terminated; and
- s.99(3), if an aquaculture lease is terminated or expires, an aquaculture licence authorising the activity being carried out in the leased area is cancelled.

The main purpose of this interrelationship is to prevent speculation or investment at a particular site for a purpose other than aquaculture.

The legislative framework also allows for adaptive management to achieve the best management outcomes. Licence and lease conditions may be imposed. For example, the CEO has the power to add a condition to an existing aquaculture licence to set initial carrying capacity or stocking density limits. Conditions may also extend to matters such as applying performance criteria to address any instances of non-use of aquaculture leases.

The FRMA also establishes an environmental management and monitoring framework for all sectors of aquaculture. Under the provisions of Section 92A of the FRMA, unless exempt under Section 92A(4), applications for an aquaculture licence must be accompanied by a Management and Environmental Monitoring Plan (MEMP). The MEMP is the principal instrument by which the Department gives effect to this environmental management and monitoring framework. It relates to and is attached to the aquaculture licence.

Aquaculture activities inside an aquaculture zone require a Category 1 MEMP.[38] As these activities are subject to the provisions of the strategic proposal approval for the zone (see below), a Category 1 MEMP must incorporate (and refer to) the requirements specified in the following documents:

- Ministerial Statement/notice (issued by the Minister for Environment)
- Department of Fisheries EMMP for the zone
- Department of Fisheries Management Policy for the zone

Contravention of a MEMP or condition of an aquaculture licence or lease is an offence under the FRMA and penalties may apply. Further, the FRMA provides the power for the CEO to cancel, suspend or not renew an aquaculture licence.

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[38] The methodology for determining the appropriate category of MEMP is outlined in the Department's MEMP Policy document. This may be accessed at http://www.fish.wa.gov.au/Fishing-and-Aquaculture/Aquaculture/Aquaculture-Management/Pages/default.aspx.

In this fashion, the FRMA, through the MEMP, supports the EP Act by reinforcing the importance of the conditions of the Ministerial Statement/notice (issued by the Minister for Environment) and providing an alternative regulatory mechanism for enforcing compliance with those conditions.

4.3.2 Environmental Code of Practice for the Sustainable Management of Western Australia's Marine Finfish Aquaculture Industry

With input by the Department, the Aquaculture Council of Western Australia (ACWA) produced a number of Environmental Codes of Practice (ECoP), including the *Environmental Code of Practice for the Sustainable Management of Western Australia's Marine Finfish Aquaculture Industry*, which is particularly relevant to the MWADZ Proposal. These ECoPS are intended to create a tool for industry that promotes continued improvement of the environmental integrity of farms. It represents industry "best practice" and is promoted as such by the Department and ACWA.

Although compliance with ECoPs is voluntary, it is expected operators will model their aquaculture businesses and activities to be compliant with them. Compliance with the ECoPs will ultimately lead to benefits for both the operator and the environment.

4.3.3 Other Legislation and Instruments

The Commonwealth, State and local environmental legislation, policies, plans and guidelines relating to individual areas of assessment (e.g. biosecurity) are outlined within the relevant sections of this PER.

5 STAKEHOLDER CONSULTATION

5.1 Introduction

The Department is committed to open and accountable processes that encourage ongoing stakeholder engagement during all stages of the MWADZ Proposal.

Stakeholder engagement in the MWADZ Proposal commenced in 2013 and will continue to do so throughout the PER process. This section outlines stakeholder involvement to date, issues raised during this process and plans for ongoing stakeholder engagement for the MWADZ Proposal.

5.2 Purpose of Stakeholder Engagement

The purpose of engaging stakeholders during the planning and assessment of the MWADZ Proposal is to:

- inform stakeholders about the MWADZ Proposal by providing accurate and accessible information;
- provide adequate opportunities and timeframes for stakeholders to consider the MWADZ Proposal;
- engage stakeholders in meaningful dialogue and provide adequate opportunities to be involved in the decision making processes during the development of the proposal;

- identify and attempt to resolve potential issues;
- consider and address issues raised by stakeholders and provide feedback; and
- consider stakeholder views in planning future engagement.

5.3 Key Stakeholders

A range of stakeholders has been engaged as part of the MWADZ Proposal. Broadly, stakeholders can be categorised into the following groups:

- Commonwealth Government
- State Government
- Local Government
- community groups and environment Non-Government Organisations (eNGOs)
- industry groups and representatives
- internal stakeholders

Aboriginal groups have not been included in the above list on the basis that there are no existing or pending Native Title claims relating to the area applicable to the MWADZ Proposal.[39] However, the PER public comment period will provide an opportunity for any matters relating to this community group to be raised. If any cultural heritage material is uncovered within the proposed MWADZ at any time in the future, the appropriate authorities (e.g. Department of Aboriginal Affairs) will be immediately contacted for advice.

5.4 Methods of Stakeholder Engagement

Stakeholder engagement activities for the MWADZ Proposal to date have included:

- consulting with other decision-making authorities identified in the EPA-prepared Environmental Scoping Document (ESD) on the works required to address the requirements of the ESD;
- conducting stakeholder meetings, briefings and presentations;
- posting periodic newsletters on the Department's website outlining the progress of the project; and
- mailing letters to eNGOs and interest groups.

5.4.1 State Government

In April 2013, the Department referred the MWADZ strategic proposal referral form to the Western Australian EPA for determination of whether the strategic proposal was valid, whether or not to assess the proposal and (if so) the level of environmental assessment. The referral was accepted and set at the public environmental review level of assessment.

An ESD (Appendix 7) for the MWADZ Proposal was subsequently issued by the EPA in July 2013. The ESD was used to guide the preparation of this PER.

State Government agencies (including Decision Making Authorities) were sent project progress status newsletters and provided opportunities for briefings throughout the

[39] National Native Title Tribunal website - http://www.nntt.gov.au/Maps/WA_Geraldton_NTDA_schedule.pdf (as at 25 June 2015).

development of the PER. These relevant agencies will have further input through the final stages of the strategic proposal assessment process.

5.4.2 Commonwealth Government

Officers of the Department contacted the Commonwealth DotE (formerly SEWPaC) to discuss the referral of the MWADZ Proposal to that agency for assessment under the EPBC Act. The DotE Environmental Assessment and Compliance Division advised the Department that the proposed actions associated with the MWADZ Proposal were not of a magnitude that necessitates a "Strategic Assessment" at the Commonwealth level. DotE further advised that, in view of the fact that the Department (on behalf of the Minister for Fisheries) is not itself proposing to undertake aquaculture operations within the MWADZ (in other words, will not be a derived proponent under the strategic proposal), the Department is not required to refer a proposed action under the EPBC Act.

5.4.3 Non-Government Organisations

During the preparation of this PER, a letter was sent to the eNGOs and interest groups. The purpose of this correspondence was to inform the groups of the MWADZ Proposal to enable them to prepare for the public review period of the PER. Some eNGOs also took up the opportunity provided by the Department to attend briefings on the MWADZ Proposal ahead of this public review period.

5.4.4 Local Government

Both the Shire of Northampton (initially) and the City of Greater Geraldton (more recently since the inclusion of the Abrolhos Islands within the City's boundaries) have been consulted through newsletters and briefings in relation to the MWADZ Proposal.

Table 5-1 summarises key stakeholder engagement activities. Future engagement activities for the MWADZ Proposal during the PER period are outlined in Section 5.6.

Table 5-1: Summary of Stakeholder Engagement during the Development of the MWADZ Proposal

Stakeholder Group	Date	Method
Relevant Commonwealth departments [e.g. Department of the Environment (DotE)]	Feb. 2013 Jun. 2013 Feb. 2014 Aug. 2014 Sep. 2015	Periodic newsletters to introduce and provide an update on the progress of the MWADZ Proposal and other relevant issues. Opportunities provided to comment on proposal.
	July 2013	Zones Project manager consulted with DotE with regard to the referral of the MWADZ Proposal under the EPBC Act and provided an opportunity to discuss relevant issues.
Relevant State departments	Feb. 2013 Jun. 2013 Feb. 2014 Aug. 2014 Sep. 2015	Periodic newsletters to introduce and provide an update on the progress of the MWADZ Proposal and other relevant issues. Opportunities provided to comment on proposal.
	Dec. 2012 Sep. 2013 Mar. 2013 Oct. 2015	Opportunity provided to meet with the zone project management team.

Stakeholder Group	Date	Method
	Oct. 2015	Meeting to introduce/discuss the MWADZ Proposal and relevant issues.
Relevant local governments	Feb. 2013 Jun. 2013 Feb. 2014 Aug. 2014 Sep. 2015	Periodic newsletters to introduce and provide an update on the progress of the MWADZ Proposal and other relevant issues. Opportunities provided to comment on proposal.
	Dec. 2013 Mar. 2013 Oct. 2015	Meetings to introduce/discuss the MWADZ Proposal and relevant issues.
Community groups	Feb. 2013 Jun. 2013 Feb. 2014 Aug. 2014 Sep. 2015	Periodic newsletters to update on the progress of the MWADZ Proposal and other relevant issues. Opportunities provided to comment on proposal.
	Feb./Mar. 2013 Oct. 2015	Opportunity provided to meet with the zone project management team.
Environmental non-government organisations	Jan. 2013	Periodic newsletters to introduce and provide an update on the progress of the MWADZ Proposal and other relevant issues. Opportunities provided to comment on proposal.
	Jul. 2013	Meeting to discuss relevant issues.
	Feb./Mar. 2013 Oct. 2015	Opportunity provided to meet with the zone project management team.
Industry groups and representatives	Feb. 2013 Jun. 2013 Feb. 2014 Aug. 2014 Sept. 2015	Periodic newsletters to introduce and provide an update on the progress of the MWADZ Proposal and other relevant issues. Opportunities provided to comment on proposal.
	Dec. 2012 Jan. 2013 Feb. 2015 Sep. 2015	Periodic meetings to discuss the progress of the MWADZ Proposal and other relevant issues.
	2012 - 2015	Other occasional meetings to discuss specific issues.
Others (e.g. interested individuals)	Feb. 2013 Jun. 2013 Feb. 2014 Aug. 2014 Sep. 2015	Periodic newsletters to introduce and provide an update on the progress of the MWADZ Proposal and other relevant issues. Opportunities provided to comment on proposal.
	2012 - 2015	Other occasional meetings to discuss specific issues.

5.5 Stakeholder Issues

A number of key issues were raised by stakeholders during consultation on the MWADZ Proposal and are addressed in Table 5-2. These key issues have been considered in the preparation of this PER.

Table 5-2: Key issues identified through stakeholder consultation

EPA Factor	Issue	Stakeholder	Comment	Response
Benthic Communities and Habitat	Dragging anchors and operations will be detrimental to wild scallops.	Abrolhos Islands and Mid West Trawl Managed Fishery licencees	Machinery and any dragging anchors associated with the MWADZ will be detrimental to the Abrolhos Islands and Mid West Trawl Managed Fishery.	Addressed in Section 2.4 Also refer to Section 4.6.2 of the EMMP (Appendix 2)
	Coral reef and island habitats may be impacted	Western Australian Fishing Industry Council	There needs to be benthic monitoring sites on the southern side of the proposed southern area of the MWADZ to detect any impacts on coral reef and island habitat.	Addressed in Section 2.5 and Sections 8.4 – 8.6 Also refer to Section 4.1 of the EMMP (Appendix 2)
	Environmental impacts associated with the aquaculture of carnivorous finfish will impact marine ecosystem of the Abrolhos Islands	Northern Agricultural Catchments Council	At large operational scales, finfish aquaculture can destroy aquatic habitats. Scientific evidence has demonstrated that sea cage aquaculture of carnivorous finfish have the largest environmental impacts, compared to other types of aquaculture. It is inappropriate to locate finfish sea cages within highly valuable marine ecosystems such as those at the Abrolhos Islands. Finfish aquaculture may be more appropriate at an alternative site, such as Port Gregory. An ecological survey of the proposed location would be required.	Addressed in: Section 2.5.2 Section 7.5 Section 8 Also refer to Section 4.1 of the EMMP (Appendix 2)
Marine Environmental Quality	Environmental impact on fishery-targeted species	Western Australian Fishing Industry Council	The Abrolhos Islands FHPA is vital to the scallop fishery. Small, isolated patches of sand have previously supported large scallop populations. Biological waste, increased predators and poor water quality are potential impacts of finfish aquaculture that could impact on scallop recruitment or the adult stock by stunting the growth or causing mortality.	Addressed in: Section 11 Section 14
	Level of waste produced	Abrolhos Coral and Live Rock aquaculture licencees	There is no control monitoring sites for in the shallow water south of the southern side of the proposed southern area of the MWADZ to detect any impacts on water quality.	Addressed in: Section 6.6.1 Section 6.6.2 Section 8 Also refer to Section 4.1 of the EMMP (Appendix 2)

EPA Factor	Issue	Stakeholder	Comment	Response
	Water quality monitoring	Abrolhos Coral and Live Rock aquaculture licencees	Are water quality monitoring arrangements for the proposed MWADZ adequate to detect any possible changes that may impact on Abrolhos Island coral communities?	Addressed in: Section 6.6.1 Section 6.6.2 Also refer to Section 4.1 of the EMMP (Appendix 2)
	Disclosure	Western Australian Fishing Industry Council	How will the broader community know whether aquaculture operators within the proposed MWADZ are complying with their environmental monitoring and management obligations?	Addressed in: Section 7.1 of the EMMP Appendix 2) and the MWADZ Management Policy (Appendix 3)
	Organic matter and nutrients could impact on wild scallops.	Abrolhos Islands and Mid West Trawl Managed Fishery	Waste from finfish farming, including dissolved nutrients, uneaten fish feed, and fish faecal material, would have a negative effect on wild scallops.	Addressed in: Section 11.4 Also refer to Section 8.2 of the Modelling and Technical Studies (Appendix 1) and Section 4.2 and 4.3 of the EMMP (Appendix 2)
Marine Fauna	Parasites	Conservation Council of Western Australia	Marine finfish aquaculture could harbour fish parasites that may affect natural fish populations within the Abrolhos Islands FHPA.	Addressed in: Section 9.3 Section 9.5 Section 10 Also refer to Section 4.7 of the EMMP (Appendix 2) and the Biosecurity Risk Assessment (Appendix 4)
	Genetics	Western Australian Fishing Industry Council	What are the potential impacts to marine finfish wild populations (e.g. yellowtail kingfish) resulting from farm stock “escapees”?	Addressed in: Section 10 Also refer to Section 4.7 of the EMMP (Appendix 2) and the Biosecurity Risk Assessment (Appendix 4)
	Disease	West Coast Rock Lobster Managed Fishery (Zone A)	Finfish aquaculture could bring fish disease to the Abrolhos.	Addressed in: Section 9.3 Section 9.5

EPA Factor	Issue	Stakeholder	Comment	Response
		licencees		Section 10 Also refer to Section 4.7 of the EMMP (Appendix 2) and the Biosecurity Risk Assessment (Appendix 4)
	Indirect impacts on seabird populations	Conservation Council of Western Australia	Tuna farming in Port Lincoln suggests that that aquaculture could attract and increase the abundance of silver gulls, thereby negatively affecting other fauna. The Abrolhos Islands supports a population of 1.5 million shearwaters that are likely to be affected by the presence of fish farming in the FHPA. A major concern is the potential for populations of cormorants, silver gulls, pacific gulls (and other scavenger types known to benefit from aquaculture activity) to increase with ecological consequences for terrestrial ecosystems.	Addressed in: Section 3.4 Section 9 Also refer to EIA on seabirds (Appendix 1D), Section 4.4 of the EMMP (Appendix 2) and the Marine Fauna Interaction Plan (Appendix 5)
	Finfish aquaculture has not undergone any trial	Conservation Council of Western Australia	Most of the seabird monitoring over the last decade is of diminishing value because it was not consistently collected during periods of environmental and industrial changes at the Abrolhos Islands. There is no data available on the foraging patterns for key receptor species (i.e. cormorants, gulls etc.), which is important baseline data for assessing aquaculture-seabird interactions. A previous yellowfin tuna proposal for the Zeewijk Channel was granted an experimental program (trial) to quantify the extent of wildlife interactions. To date the trial has not commenced and monitoring of interactions has not been undertaken, thus the effects of aquaculture on marine fauna are unknown. The main concerns were: • Potential aquaculture-seabird interactions cannot be pre-empted; and • The proposal is favouring old technology [i.e. surface (rather than sub-surface) sea-cages] that may influence	Addressed in: Section 3.4 Section 9 Also refer to EIA on seabirds (Appendix 1D), Section 4.4 of the EMMP (Appendix 2) and the Marine Fauna Interaction Plan (Appendix 5)

EPA Factor	Issue	Stakeholder	Comment	Response
			seabird behaviour or affect seabird populations.	
	Source of feed	Recfishwest	Where will food for the grow-out cages come from?	Addressed in: Draft Management Policy (Appendix 3) and Section 4.7 of the EMMP (Appendix 2)
	Source of stock	Recfishwest	Where will the source stock come from?	Addressed in: Draft Management Policy (Appendix 3) and Section 4.7 of the EMMP (Appendix 2)
	Attraction of wild fish	Recfishwest	The sea cages and feeding will cause changes in wild fish behaviour (e.g. attract wild fish to the site).	Addressed in: Sections 8.1 and 8.2 of the Modelling and Technical Studies (Appendix 1), Section 4.6 of the EMMP (Appendix 2) and the Marine Fauna Interaction Plan (Appendix 5)
	General comments on the preliminary environmental impact assessment (EIA) of the MWADZ Proposal in relation to marine mammals and turtles	Department of Parks and Wildlife	• The conservation status of the various species of marine fauna, in particular the Australian sea lion, should be considered in relation to State legislation. • The population history, current status and trends, as well as the extent and size of genetic management units to which fauna of the Abrolhos Islands belong, would provide valuable information for determining the importance of individuals at the Abrolhos, particularly for species at greatest risk from the proposed aquaculture. • Loss or degradation of habitat would be of significance to fauna populations of the Abrolhos Islands, particularly of species that are potentially susceptible to influence. • Presentation of the aquaculture zone of influence in relation to wildlife feeding habitats would illustrate the level of significance of any loss of these habitats. • The proponent needs to describe, in sufficient detail, the type and magnitude of potential impacts on species that are identified as being at greatest risk. Infrastructure design and operational requirements should be stated. • The EIA should consider the merits of various mesh sizes	Addressed in: Section 2.4 Section 9.2.4 Section 9.2.5 Also refer to in Section 8.3 of the Modelling and Technical Studies (Appendix 1), Section 4.5 and Section 4.6.2 of the EMMP (Appendix 2) and the Marine Fauna Interaction Plan (Appendix 5)

EPA Factor	Issue	Stakeholder	Comment	Response
			likely to be used in the proposed aquaculture operations.	
	Marine mammals	Department of Parks and Wildlife	Marine mammals are highly vulnerable to adverse impacts of poorly-managed fish farms. In relation to marine mammals and turtles, the Australian sea lions are of primary concern. The PER document needs to identify the key design and operational aspects of the proposal that create the greatest risk to Australian sea lions and which, therefore, need to be a focus for mitigation. These include: • use of predator nets; • net tension; • preventing access between predator nets and fish cages; • optimal mesh sizes; • fit-for-purpose net material; • maintenance regimes (including during periods when cages are fallow); • prompt removal of infrastructure that is not being monitored and maintained; • minimising Australian sea lion attraction through controlled feeding regimes; • prompt removal of dead fish; and • fish harvesting practices that do not discharge offal. Management options to capture and relocate fauna, or the use of harassment techniques such as acoustic deterrents, may not be supported. The PER document should present a comprehensive management framework addressing all potential impacts that were identified by the EIA.	Addressed in: Section 2.4 Section 9.2.4 Section 9.2.5 Also refer to in Section 8.3 of the Modelling and Technical Studies (Appendix 1), Sections 4.5 and 4.6.2 of the EMMP (Appendix 2) and the Marine Fauna Interaction Plan (Appendix 5)
	Australian sea lion	Department of Parks and Wildlife	Every Australian sea lion colony must be protected for biodiversity conservation purposes, as the WA Australian sea lion population is not recovering. The EIA has underestimated the occurrence of Australian sea lion in the proposed MWADZ. All available information on the Australian sea lion (at a local, regional and population scale) should be considered in the EIA. In considering habitat usage patterns, the proponent should also consider the potential changes to abundance as a result of pinniped attraction to fish	Addressed in: Sections 2.4 Section 9.2.4 Section 9.2.5 Also refer to in Section 8.3 of the Modelling and Technical Studies (Appendix 1), Sections 4.5 and 4.6.2 of the EMMP (Appendix 2)

EPA Factor	Issue	Stakeholder	Comment	Response
			farms. The PER document must present a comprehensive management framework of design and operational commitments. These must demonstrate that the minimum standards will be best practice and reduce risks to acceptable levels, ensuring protection of the vulnerable Abrolhos population of Australian sea lion. The Abrolhos Islands Australian sea lion population is important and all risks associated with the proposal need to be eliminated or reduced to very low levels. The management framework should employ a combination of minimum design standards, operational procedures, proposed monitoring and contingency measures and future derived proposals to ensure the proposed aquaculture does not threaten the Abrolhos Islands Australian sea lion population.	and the Marine Fauna Interaction Plan (Appendix 5)
	Whales	Department of Parks and Wildlife	Abrolhos Islands are a well-known resting area used by humpback whales with their calves and escort males.	Addressed in: Section 2.4 Section 9.2.4 Section 9.2.5 Also refer to in Section 8.3 of the Modelling and Technical Studies (Appendix 1), Section 4.5 and Section 4.6.2 of the EMMP (Appendix 2) and the Marine Fauna Interaction Plan (Appendix 5)
	Dolphins	Department of Parks and Wildlife	The EIA has underestimated the occurrence of Indo-Pacific bottlenose dolphin in the proposed MWADZ. In considering habitat usage patterns the proponent should also consider the potential changes to abundance as a result of dolphin attraction to fish farms. Small pods of Indo-Pacific bottlenose dolphins may be displaced by the proposed strategic proposal and dolphin species are known to interact with fish farms, which can lead	Addressed in: Section 2.4 Section 9.2.4 Section 9.2.5 Also refer to in Section 8.3 of the Modelling and Technical Studies (Appendix 1), Section 4.5 and Section 4.6.2 of the EMMP

EPA Factor	Issue	Stakeholder	Comment	Response
			to entanglement and drowning.	(Appendix 2) and the Marine Fauna Interaction Plan (Appendix 5)
	Dugongs	Department of Parks and Wildlife	The EIA should investigate whether the strategic proposal area contains significant feeding habitat for Dugongs.	Addressed in: Sections 2.4 Section 9.2.4 Section 9.2.5 Also refer to in Section 8.3 of the Modelling and Technical Studies (Appendix 1), Section 4.5 and Section 4.6.2 of the EMMP (Appendix 2) and the Marine Fauna Interaction Plan (Appendix 5)
	Turtles	Department of Parks and Wildlife	The EIA should investigate the likely impacts of the proposed aquaculture on any species of turtle that may occur or be attracted into the area. The occurrence of green, loggerhead and hawksbill turtles in the strategic proposal area should be considered in the context of habitat types, noting that turtles may be attracted to fish farms. This would increase their vulnerability to entanglement and falling prey to predators. Lighting is only considered problematic in relation to onshore lighting.	Addressed in: Sections 2.4 Section 9.2.4 Section 9.2.5 Also refer to in Section 8.3 of the Modelling and Technical Studies (Appendix 1), Section 4.5 and Section 4.6.2 of the EMMP (Appendix 2) and the Marine Fauna Interaction Plan (Appendix 5)
Amenity	Attraction of sharks	Specimen Shell Managed Fishery licencees	The strategic proposal area overlaps with area that is suitable for specimen shell licensees to work. There is concern that the proposed aquaculture could attract sharks and would make diving operations more hazardous. Commercial diving operations (Specimen Shell Fishery) may be hampered if sites are more hazardous for divers.	Addressed in: Section 9
	Responsibility for recovery of “lost” (e.g. through storm damage) aquaculture gear	Geraldton Air Charters Pty Ltd	Who is responsible for recovering any aquaculture gear that may have broken loose or otherwise drifted outside of the MWADZ?	Addressed in: Section 13
	Discarded	Recfishwest	In case of a future proposal being shut-down, removal of	Addressed in:

EPA Factor	Issue	Stakeholder	Comment	Response
	infrastructure	Conservation Council of Western Australia	infrastructure should be a condition of approval for derived proposals.	Section 3.5
	Sense of ownership over the land	Recfishwest	Concerned that the approval of future derived proposal may lead to a sense of ownership over the land at the Abrolhos Islands. Land-based facilities associated with the proposed aquaculture may impact upon the amenity of the Abrolhos Islands.	Not applicable to this PER
Terrestrial Environmental Quality	Abrolhos Island Reserve habitats	Western Australian Fishing Industry Council	Reserve habitats may be impacted.	Addressed in: Section 2.5 Also refer to Section 4.4 of the Modelling and Technical Studies and the EIA on seabirds (Appendix 1D)
	Location inconsistent with conservation status of the Abrolhos Islands Reserve	Northern Agricultural Catchments Council Conservation Council of Western Australia	Aquaculture is in conflict with the environmental values of the Abrolhos Islands. The Abrolhos Islands Reserve is an A-Class Reserve and, while the MWADZ Proposal is not within this Reserve, it may impact upon it.	Addressed in: Section 2 Section 6 Section 11 Section 14
Decommissioning and Rehabilitation	Performance criteria	Western Australian Fishing Industry Council	What is to prevent aquaculture operators establishing infrastructure (e.g. sea cages) within the proposed MWADZ but then fail to commence fish culture operations or otherwise cease to use that infrastructure?	Addressed in: Section 4 Section 2 Section 15
Non-environmental factor (i.e. socio-economic matter)	Navigation	West Coast Rock Lobster Managed Fishery (Zone A) licencees	The presence of aquaculture gear in the area identified in the MWADZ Proposal may pose a risk to navigation (e.g. vessels could collide with the sea cages).	Addressed in: Section 11 Section 14 Also refer to Section 7.6 of the Draft Management Policy (Appendix 3)
	Workforce safety	Western Australian Fishing Industry Council	How will the Department and aquaculture operators within the proposed MWADZ provide for the safety of the workforce?	Addressed in: Section 9 Section 11

EPA Factor	Issue	Stakeholder	Comment	Response
				Section 12
	Area exclusion by management	West Coast Rock Lobster Managed Fishery (Zone B) licencees	Will future derived proponents create exclusion zones around sea cages?	Addressed in the Draft Management Policy (Appendix 3)
	Liability for damage caused to aquaculture infrastructure	Geraldton Air Charters Pty Ltd	Who is responsible for any damage to the infrastructure?	Not applicable to this PER. However, other than the FRMA provisions relating to interference with aquaculture gear, the usual criminal, civil and maritime laws of the State would apply.
	Physical obstruction	Abrolhos Islands and Mid West Trawl Managed Fishery licencees	The proposed strategic assessment area overlaps with important fishing grounds for the scallop fishery. Any areas that have a sandy seafloor are considered to be scallop grounds. The scallop fishery is fickle. That is, recruitment and catch of scallops is highly variable and unpredictable. Small patches of sand can suddenly be important scallop grounds. The presence of aquaculture gear in the area identified in the MWADZ Proposal will result in a reduction in the area available to be fished by the Abrolhos Islands and Mid West Trawl Managed Fishery. Anchoring systems associated with sea cages are hazardous to trawling activities. Alternative locations, such as Horrocks and Port Gregory, are of lesser concern to the scallop fishery.	Addressed in: Section 11
	Location inconsistent with conservation status of the Abrolhos Islands Fish Habitat Protection Area (FHPA)	Northern Agricultural Catchments Council Conservation Council of Western Australia	Aquaculture is in conflict with the environmental values of the Abrolhos Islands. Water surrounding the Abrolhos Islands contains some of the most highly valued marine systems in the State. Finfish aquaculture is incompatible with the biologically-significant habitats of the Abrolhos Islands. This will impact on ecotourism and public visitation. Alternative sites should be considered.	Addressed in: Section 2 Section 6 Section 11 Section 14
	Economic impact on wild-catch fisheries	Western Australian Fishing Industry Council	Marine finfish aquaculture will have a major economic impact on finfish wild-catch fisheries in the Mid West region.	Addressed in: Section 11
	Cumulative regional	Recfishwest	Recreational fishers are concerned that the approval of the	Not applicable to this PER

EPA Factor	Issue	Stakeholder	Comment	Response
	effects of multiple Aquaculture Development Zones		MWADZ could set a precedent for approval of other Aquaculture Development Zones (ADZ) in the Mid West, thus reducing access to recreationally important locations. Suggested that the Minister for Fisheries place a caveat over the total number of ADZ permitted in the Mid West region.	
	Alternative sites	Recfishwest Conservation Council of Western Australia Northern Agricultural Catchments Council	The proponent should consider alternative areas, such as Dongara and Port Gregory.	Addressed in: Section 2.2
	The pre-existing licenced aquaculture site	Recfishwest	The proponent should incorporate the existing aquaculture site to the north of the Pelsaert Group of the Abrolhos Islands. This area was already earmarked for aquaculture in the region and is likely to be a viable site.	Addressed in: Section 1.2.5
	Economic competition	West Coast Demersal Scalefish Fishery	Concern that finfish aquaculture would have a major economic impact on the wild-catch demersal scalefish fishery.	Not applicable to this PER

5.6 Ongoing Stakeholder Engagement

The PER presents an opportunity for all stakeholders to provide feedback and comment on the MWADZ Proposal and the Department will respond to these inputs in the Response to Submissions in the final PER.

In addition to direct engagement with stakeholders, other communication methods will be used to inform the broader community of the PER process. These communications will include the MWADZ Project Update newsletter (available on the Department's website at: http://www.fish.wa.gov.au/Fishing-and-Aquaculture/Aquaculture/Pages/default.aspx, and website postings of relevant public documents.

The Department is currently reviewing its consultation processes to provide greater opportunity for stakeholder involvement. This may include public forums, targeted consultation with key interest groups, or a regional approach, depending on the fishery or issues under consideration.

6 ENVIRONMENTAL IMPACT ASSESSMENT FRAMEWORK

6.1 Methods of Assessment

This section describes the method used to identify and assess the potential impacts of the MWADZ Proposal, to determine the mitigation and management measures the Department proposes to implement to address these potential impacts, and to determine the environmental acceptability of the MWADZ Proposal. The results of the assessment are presented and discussed in Sections 7 to 12 of this PER.

6.2 Scope and Approach

The assessment approach has been developed to ensure that it addresses the scope of assessment required under (principally) the Western Australian *Environmental Protection Act 1986* (EP Act) and (to the extent of potential application to future derived proposals) the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

The EP Act provides for the EIA of proposals likely, if implemented, to have a significant effect on the environment. The EPA uses a framework of environmental principles, factors and associated objectives as the basis for assessing whether a proposal's impact on the environment is acceptable. They therefore underpin the EIA process. The framework is shown in Figure 6-1 and is further described below. For further detail refer to the EPA's EAG 8.

Environmental principles

The environmental principles are the principles of the *Environmental Protection Act 1986* and other principles adopted by the EPA which provide overall guidance for its decision-making.

Environmental policies

Environmental policies are international, national and State policies, agreements or treaties which provide a position or establish obligations on environmental protection. They include environmental protection policies and other policies and strategies adopted by Government.

Environmental factors

An environmental factor is a part of the environment that may be impacted by an aspect of the proposal. There are five environmental factors which have been selected to be relevant to the MWADZ Proposal and practical for the EIA process. In addition to these environmental factors, there is one integrating factor.

Environmental objectives

The related environmental objective for each factor is the desired goal that, if met, will indicate that the proposal is not expected to have a significant impact on that part (factor) of the environment.

Environmental guidance

Environmental guidance is the relevant environmental policies, guidelines, or standards that provide advice (to proponents and the public) on the policy position, procedures and minimum requirements that the EPA expects to be met for proposals through the environmental impact assessment process.

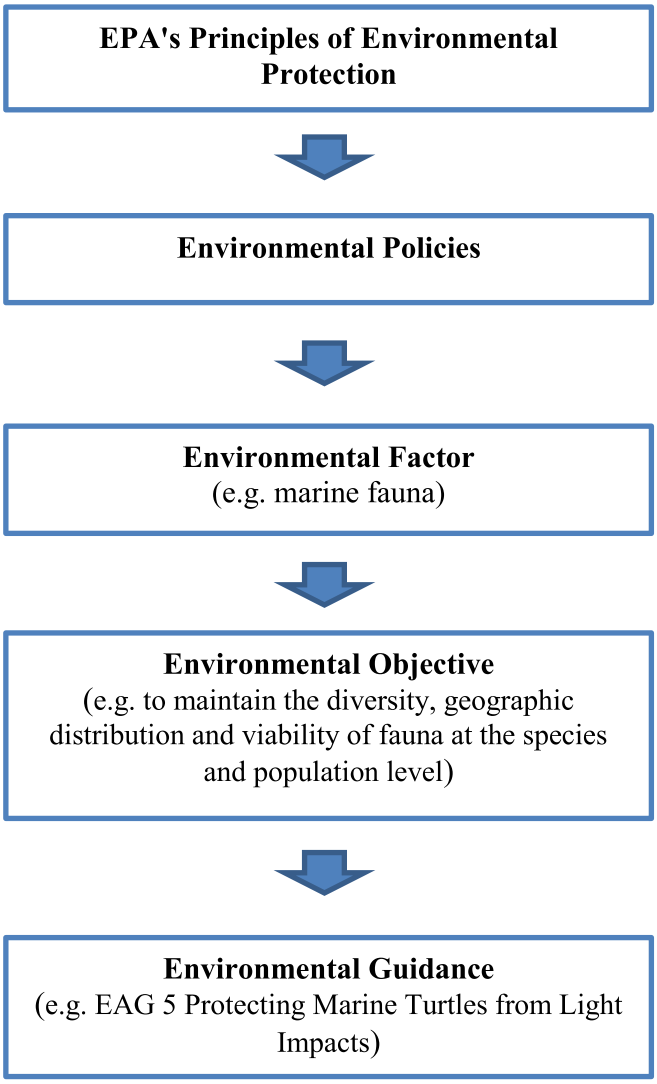


Figure 6-1: The EPA's framework for environmental principles, policies, factors, objectives and guidance

The environmental principles specified in the EP Act and the two additional environmental principles adopted by the EPA are described in Table 6-1.

Table 6-1: Consideration given to the environmental principles of the *Environmental Protection Act 1986 and of the EPA* (EAG 8)

Principle	Relevance	Consideration (if yes)
1. *The precautionary principle* Where there are threats of serious or irreversible damage, lack of scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation. In the application of the precautionary principle, decision should be guided by: (a) careful evaluation to avoid, where practicable, serious or irreversible damage to the environment; and	yes	Comprehensive investigations, including modelling, technical studies, literature searches, risk assessments and field work, have been conducted to provide sufficient information to address potential environmental impacts and inform the EIA. Where uncertainty or information gaps have been encountered, the more

Principle	Relevance	Consideration (if yes)
(b) an assessment of the risk-weighted consequences of various options.		conservative "most likely worst case" scenario has been consistently adopted. This principle is also embedded in the FRMA.
2. The principle of intergenerational equity The present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations.	yes	See item "*3.*" below.
3. The principle of the conservation of biological diversity and ecological integrity Conservation of biological diversity and ecological integrity should be a fundamental consideration.	yes	The EQMF (EAG 15) and related components of the EMMP addresses the conservation of ecosystem integrity and this is supported by the information outlined in item "*1.*" above. The relevant environmental values (EAG 8) are addressed in this PER.
4. Principles relating to improved valuation, pricing and incentive mechanisms (a) Environment factors should be included in the valuation of assets and services. (b) The polluter pays principle – those who generate pollution and waste should bear the cost of containment, avoidance or abatement. (c) The users of goods and services should pay prices based on the full life cycle costs of providing goods and services, including the use of natural resources and assets and the ultimate disposal of any wastes. (d) Environmental goals, having been established, should be pursued in the most cost effective way, by establishing incentive structures, including market mechanisms, which enable those best placed to maximise benefits and/or minimise costs to develop their own solutions and responses to environmental problems.	no	Not applicable.
5. The principle of waste minimisation All reasonable and practicable measures should be taken to minimise the generation of waste and its discharge into the environment.	yes	This principle has been addressed and embedded in the Waste Management Plan and further supported by the arrangements in the Zone Management Policy.
*Best practice** When designing proposals and implementing environmental mitigation and management actions, the contemporary best practice measures available at the time of implementation should be applied.	yes	The principles outlined in EPA's Guidance for the Assessment of Environmental Factors Implementing Best Practice in proposals submitted to the *Environmental Impact Assessment process No. 55 (EPA, 2003)* have been incorporated in the EMMP, Zone Management Policy and ACWA Code of Conduct.
*Continuous improvement**	yes	The EMMP is designed to promote continuous

Principle	Relevance	Consideration (if yes)
The implementation of environmental practices should aim for continuous improvement in environmental performance.		improvement through the environmental monitoring program implemented for the MWADZ Proposal and the adaptive management tools available to the OEPA and the Department. This is also supported by the Aquaculture Development Zone Management Framework. Collectively this will ensure a rapid and effective response to the information gathered as aquaculture development in the zone progresses.

Note: * indicates an adopted environmental principle of the EPA used in conjunction with the five principles specified in the EP Act.

6.2.1 Assessment Scope

The scope of assessment was established following referral of the MWADZ Proposal under the EP Act. The scope is presented in an Environmental Scoping Document (No. 1972) for the MWADZ Proposal (ESD), which was approved by the EPA on 24 July 2013 (refer to Appendix 7).

The scope of the assessment covers the identification, prediction and evaluation of the potential direct and indirect impacts of the MWADZ Proposal. Potential cumulative impacts of the MWADZ Proposal were also identified and assessed.

The ESD requires that the MWADZ Proposal proponent should provide sufficient detail in the PER for the EPA to not only assess the strategic proposal, but also understand the likely characteristics of future (i.e. derived) proposals, and their associated impacts, that will result from the implementation of the MWADZ Proposal. This includes information that should:

- define, as far as possible, the key characteristics of the future proposals, recognising that the assessment may provide opportunities to refine these characteristics;
- define the maximum extent or limits to the scope of any future proposals (e.g. maximum capacity of each individual proposal);
- identify the key environmental factors associated with the future proposals, at a scale commensurate with the nature and extent of those future proposals;
- define the maximum disturbance (impact) footprint of the future proposals (terrestrial and marine) and the envelope within which any future proposals will occur;
- define the potential maximum cumulative environmental impacts and risks from the future proposals, and demonstrate the acceptability of those impacts/risks;

- define potential best practice management principles and strategies to be applied to any future proposal to avoid and minimise impacts to the greatest extent possible; and

- define the proposed governance of future proposals. This should include but not be limited to clearly setting out the legislative process and approval under the *Fish Resources Management Act 1994* that would apply to the establishment of the aquaculture zone and the licencing of the individual aquaculture operations within the zone.

The ESD also identified a number of preliminary key environmental factors, objectives and work required relevant to the MWADZ Proposal (refer to Table 1 of the ESD). The environmental factors and associated objectives identified are among those described in the EPA's Environmental Assessment Guideline for Environmental Principles, Factors and Objectives No. 8 (EAG 8) as outlined in Table 6-2.

Table 6-2: EPA environmental factors and objectives (EAG 8) and relevance to the MWADZ Proposal

Theme	Factor	Objective	Relevance
Sea	Benthic Communities and Habitat	To maintain the structure, function, diversity, distribution and viability of benthic communities and habitats at local and regional scales.	yes
	Coastal Processes	To maintain the morphology of the subtidal, intertidal and supratidal zones and the local geophysical processes that shape them.	no
	Marine Environmental Quality	To maintain the quality of water, sediment and biota so that the environmental values, both ecological and social, are protected.	yes
	Marine Fauna	To maintain the diversity, geographic distribution and viability of fauna at the species and population levels.	yes
Land	Flora and Vegetation	To maintain representation, diversity, viability and ecological function at the species, population and community level.	no
	Landforms	To maintain the variety, integrity, ecological functions and environmental values of landforms and soils.	no
	Subterranean Fauna	To maintain representation, diversity, viability and ecological function at the species, population and assemblage level.	no
	Terrestrial Environmental Quality	To maintain the quality of land and soils so that the environment values, both ecological and social, are protected.	no
	Terrestrial Fauna	To maintain representation, diversity, viability and ecological function at the species, population and assemblage level.	no
Water	Hydrological Processes	To maintain the hydrological regimes of groundwater and surface water so that existing and potential uses, including ecosystem maintenance, are protected.	no
	Inland Waters Environmental Quality	To maintain the quality of groundwater and surface water, sediment and biota so that the environmental values, both ecological and social, are protected.	no
Air	Air Quality	To maintain air quality for the protection of the environment and human health and amenity.	no
People	Amenity	To ensure that impacts to amenity are reduced as low as reasonably practicable.	possible*
	Heritage	To ensure that historical and cultural associations, and natural heritage, are not adversely affected.	yes

Theme	Factor	Objective	Relevance
	Human Health	To ensure that human health is not adversely affected.	no
Integrating Factors	Offsets	To counterbalance any significant residual environmental impacts or uncertainty through the application of offsets.	no
	Rehabilitation and Decommissioning	To ensure that premises are decommissioned and rehabilitated in an ecologically sustainable manner.	possible*

Note: "possible*" indicates a factor that was not specified in the ESD but may be of interest to the public and has therefore been included in this PER.

For the purposes of this PER, the environmental factors identified in the ESD, or emerging from the stakeholder consultation conducted thus far, have been addressed as outlined in Table 6-3.

Table 6-3: Location in the PER of EPA environmental factors relevant to the MWADZ Proposal

EPA Factor	PER Section	Comment
Marine Environmental Quality	Section 7	
Benthic Communities and Habitat	Section 8	
Marine Fauna	Section 9	The biosecurity and fisheries components of this factor have been addressed in Sections 10 and 11 respectively.
Heritage	Section 12	
Amenity	Section 13	
Rehabilitation and Decommissioning	Sections 2 and 15	

6.2.2 Assessment Approach

It is widely recognised in the practice of environmental impact assessment that strategic or "big picture" approaches, rather than case-by-case assessments, can lead to more efficient planning and better environmental outcomes.

One way to take a more strategic view is to utilise the provisions in the EP Act for the assessment of "strategic proposals" by the EPA. Under these provisions, the assessment of a strategic proposal may give rise to more streamlined "derived" proposals that fall within the parameters of the strategic proposal. Such an outcome would be of significant benefit, in terms of efficiency, to the developing marine aquaculture industry in Western Australia. It also takes into account the cumulative effects of such development on the environment, so that any potential future impacts can be assessed and effectively managed.

For these reasons, the Department has adopted the strategic proposal approach for the environmental impact assessment of the MWADZ Proposal as outlined in the EPA's policies and guidelines.

6.2.3 Terms Used

For the avoidance of doubt, the impact assessment terms used in this PER have the meaning described in the adjacent column in Table 6-4.

Table 6-4: Definitions of Impact Assessment Terms Used in this PER

Term	Definition
Consequence	The implication of the potential impact on a factor/s.
Cumulative impact	Potential incremental impacts of the MWADZ Proposal when combined with other present and reasonably foreseeable future actions.
Direct impact	An impact that occurs as a direct result of the MWADZ Proposal (e.g. change in sediment quality due to organic enrichment of sediments directly below the sea cages.
Factor	Includes physical environmental resources (e.g. marine waters) that are valued by society for their intrinsic worth and/or their social, cultural or economic contribution; and receptors (e.g. people, communities, ecological entities – such as naturally-occurring fish populations).
Hazard	A source of potential harm or a situation with a potential to cause loss or adverse effect. Hazard has the same meaning as "threat".
Impact	Interaction of a stressor with an environmental or social factor(s).
Indirect impact	An impact that is not a direct result of the MWADZ Proposal and that may include offsite or downstream impacts, such as impacts on the population dynamics of certain species of seabird as a result of increased populations of other seabirds potentially benefiting from the MWADZ Proposal.
Likelihood	The probability of a stressor impacting on an environmental factor.
Likely impact	An impact that has a real or not remote chance or probability of occurring.
Local/Localised	Impacts restricted to the area directly affected by the MWADZ Proposal and in its immediate vicinity.
Long term	More than five years.
Permanent	Impacts that may arise from irreversible changes in conditions caused by the MWADZ Proposal.
Potential Impact	An impact that can be reasonably expected or is likely to occur in the lifetime of the MWADZ Proposal.
Receptor	A biophysical entity (e.g. species, population, community and habitat) or social/community entity (e.g. people, a community, local businesses).
Residual impact	Impact remaining after the application of proposed mitigation and management measures.
Short-term	Less than five years.
Stressor	A source of potential harm or a situation with a potential to cause loss or adverse effects.
Widespread	Impacts extending beyond the limits of the area directly affected by the MWADZ Proposal and its immediate vicinity.

6.3 Scoping Phase – Establishing the Assessment Context

6.3.1 Identification of Relevant Activities

The first step in the assessment process was to establish the assessment context. This involved:

- determining which MWADZ Proposal activities could potentially result in environmental impacts, but also noting any potential social and economic impacts that may be of public interest;
- identifying MWADZ Proposal stressors, environmental factors and potential impacts that would require examination in the PER;
- identifying potential impacts of the MWADZ Proposal and scoping the investigations and studies required to support their assessment; and
- establishing the MWADZ Proposal assessment framework to determine environmental acceptability.

Note: Potential impacts associated with the activities of third-party facilities were not considered in this assessment. It is assumed that these facilities will operate under their own relevant approvals and/or licences.

6.3.2 Identification of Environmental Stressors that Could Cause Potential Impacts

In addition to the stressors associated with the potential environmental impacts specified in the ESD, other environmental stressors likely to be relevant to the MWADZ Proposal were identified by also comparing the scope of activities associated with the MWADZ Proposal to those examined for the Kimberley Aquaculture Development Zone Proposal (KADZ Proposal) and adopting the same stressors where the activities aligned. Environmental stressors relevant to the MWADZ Proposal were determined based on whether they may:

- pose direct or indirect impacts;
- be of high community/public interest; and
- contribute to cumulative impacts.

Decision-making authorities were also engaged in this identification process to ensure that the selected stressors reflected their expectations. The resulting stressors are listed in Table 6-5.

Table 6-5: Stressors Relevant to the MWADZ Proposal

Stressor	MWADZ Proposal Infrastructure and Activities Associated with Stressor	Considerations
Physical presence of infrastructure	• Preparing, locating, anchoring and operating of aquaculture sea cage clusters. • Feed barge and/or floating staff accommodation. • Marine vessel movements during construction and operation.	• Sea use • Visual amenity • Habitat modification • Navigation • Current alteration
Physical interaction	• Preparing, locating, anchoring and operating of aquaculture sea cage clusters. • Feed barge and/or floating staff accommodation. • Marine vessel movements during construction and operation.	• Entanglement interactions • Marine fauna and vessel collisions
Discharges to sea	• Marine vessel discharges. • Fish stock feed drift outside of sea cages. • Fish stock faeces excretion. • Release of pharmaceuticals. • In-situ removal of bio-fouling from sea cages.	• Residual hydrocarbons • Provisioning • Nutrients • Residual pharmaceuticals • Suspended solids • Shading • Residual trace metals
Noise and vibration	• Marine vessel engine operation. • Feed barge and/or floating staff accommodation. • Operational marine vessel movements. • Automated fish stock feeding systems.	• Anthropogenic noise • Vibration
Seabed disturbance	• Anchoring of aquaculture sea cage clusters. • Movement of aquaculture sea cage clusters. • Anchoring of marine vessels, including feed barges and/or floating staff accommodation.	• Habitat disturbance • Suspended solids • Smothering • Abrasion
Artificial light	• Marine vessel lighting.	• Light spill

Stressor	MWADZ Proposal Infrastructure and Activities Associated with Stressor	Considerations
	• Feed barge and/or floating staff accommodation lighting.	• Glow
Solid and liquid waste	• General waste. • Wastewater. • Biosecurity-risk material. • Blood water from harvesting of stocked fish.	• Potential for spills and leaks associated with storage, transport or disposal
Spills and leaks	• Storing, transporting and handling of chemicals, fuels, wastes and other potentially hazardous materials. • Refuelling. • Marine vessel collision.	• Introduction of toxic, persistent or non-biodegradable substances
Introduction and/or spread of non-indigenous marine species and/or marine pests	• Marine vessel movements. • Moving personnel, equipment and materials. • Translocation and security of farm stock.	• Potential for fish introductions, pests or diseases • Genetics

6.3.3 Preliminary Identification of Potential Impacts

Identification of potential impacts associated with the MWADZ Proposal began during the scoping phase of this PER. Potential impacts were initially identified by considering how each broad activity of the MWADZ Proposal could result in a stressor that could impact upon an identified environmental factor. Identified potential impacts were then analysed by comparing them to those assessed for the KADZ Proposal. The objective was to establish the scope of assessment, data collection, and predictive studies needed to support the assessment.

The preliminary identification of potential impacts relevant to Western Australian (State) jurisdiction was presented in the Environmental Scoping Document (ESD) for the MWADZ Proposal approved by the EPA (July 2013).

Potential impacts relevant to the Commonwealth (i.e. matters of national environmental significance) were also identified through the preliminary identification process.

6.3.4 Establishing the Assessment Framework

The scoping phase also established the framework for determining the acceptability of impacts. This involved:

- establishing the legal and policy context for the assessment of impacts;
- identifying environmental objectives against which impacts would be assessed for their acceptability;
- considering any potential socio-economic matters that may result from the MWADZ Proposal; and
- consulting with relevant stakeholders on this assessment framework.

6.3.4.1 Environmental Objectives

Environmental objectives were identified for each factor. Objectives were derived from the EPA's EAG 8.

The resulting objectives were presented to and approved by the EPA in the ESD issued for the MWADZ Proposal (2013). The established objectives are described under each environmental factor in Sections 7 to 13. These objectives were used to assess the acceptability of potential MWADZ Proposal impacts.

6.4 Assessment Phase

Following finalisation of the ESD a more detailed assessment was undertaken during the preparation of this PER during which the identified stressors, factors and potential impacts were reviewed, confirmed, and/or amended.

The approach adopted to assess the potential impacts of this MWADZ Proposal follows that used by the KADZ Proposal (notwithstanding that these two zones were subject to different levels of assessment) and is based on determining the likelihood and consequence of potential impacts occurring following exposure to one or more stressors. The assessment phase enables the level of potential impact to be determined and quantified (where practicable) and mitigation and management efforts to be prioritised so that an overall acceptable level of potential impact can be achieved.

The assessment method was based on an internal Department of Fisheries process aimed at managing risks associated with development opportunities. The assessment method is consistent with the standards International Organization for Standardisation (ISO) 31000:2009 Risk Management – Principles and Guidelines (ISO 2009), and HB203:2006 Environmental Risk Management – Principles and Process (Standards Australia 2006). The method adopted involved:

- systematically identifying potential incremental and additional impacts of the MWADZ Proposal on environmental and social factors;
- collecting and recording any experience and lessons learnt that could affect the assessment of incremental or additional impacts of the MWADZ Proposal and/or the mitigation measures implemented for the KADZ Proposal; and
- determining the consequence and likelihood of the identified incremental and additional potential impacts occurring and subsequently categorising each residual impact as High, Medium, Low, or Negligible.

6.4.1 Determining the Consequence of Potential Impacts

The following elements were considered in determining the consequence of each identified potential impact:

- the duration, frequency, and reversibility of the potential impact;
- the size, scale, geographic extent, and geographic distribution of the potential impact; and
- the sensitivity of the potentially impacted factor, including its nature, its importance (e.g. whether it is protected under Commonwealth or State legislation) and how adaptable or resilient the factor is to the impact. The legal and policy context that was relevant to protecting environmental and social factors was also considered in determining sensitivity.

The terminology used to describe these elements of consequence is defined in Table 6-4. The approach adopted to address any uncertainties around consequences is described in Section 6.4.4.

Wherever practicable, the magnitude of environmental stressors and of potential impacts was predicted quantitatively. These predictions have drawn on the results of predictive modelling and technical studies (described in Sections 6.5, 6.6 and 6.7) conducted specifically for the MWADZ Proposal and external research reports and papers.

Where relevant, prediction methods have also reflected guidelines (e.g. Guidance Statement No. 8 – The Assessment of Environmental Factors, Environmental Noise [EPA 2007]) and specialist technical studies undertaken by reputable industry specialists using recognised methods and approaches. Potential impacts are based on worst-case scenarios that reflect any uncertainty in design options still being considered.

Where potential impacts could not be quantified, a qualitative approach was applied; for example, Figure 6-1a describes the levels of consequence applied to ETP species.

Objective	Minor (1)	Moderate (2)	Major (3)	Severe (4)
Sustainability of endangered, threatened and protected (ETP) species (including the impacts on social acceptability)	Few individuals directly impacted in most years (i.e. no impact on sustainability) and well below that which will generate public concern.	Catch or impact at the maximum level that will not impact on recovery or cause unacceptable public concern.	Recovery of a vulnerable population may be impeded and/or some clear (but short term) public concern is generated.	Further decline of a vulnerable population and/or significant, widespread and ongoing public concern generated.
Maintenance of Ecosystem Structure and Function	Measurable but minor changes to ecosystem structure, but no measurable change to function.	Maximum acceptable level of change in the ecosystem structure with no material change in function.	Ecosystem function now altered with some function or major components now missing and/or new species are prevalent.	Extreme change to structure and function. Complete species shifts in capture or prevalence in system.
Conservation of Habitat	Measurable impacts very localised. Area directly affected well below maximum accepted.	Maximum acceptable level of impact to habitat with no long-term impacts on region-wide habitat dynamics.	Above acceptable level of loss/impact with region-wide dynamics or related systems may begin to be impacted.	Level of habitat loss clearly generating region-wide effects on dynamics and related systems.

Figure 6-1a: Levels of consequence relating to the environmental management objectives of the MWADZ Proposal (modified from Fletcher, 2015)

6.4.2 Determining the Likelihood of Potential Impacts

The likelihood of a potential consequence occurring took into account the implementation of the mitigation and management measures adopted by the KADZ Proposal. Likelihood is determined based on experience that a consequence has occurred.

The likelihood criteria used are shown in the assessment matrix (Figure 6-1b).

Level	Descriptor
Remote (1)	The consequence not heard of in these circumstances, but still plausible within the time frame (indicative probability 1-2%)
Unlikely (2)	The consequence is not expected to occur in the time frame but some evidence that it could occur under special circumstances (indicative probability of 3-9%)
Possible (3)	Evidence to suggest this consequence level may occur in some circumstances within the time frame (indicative probability of 10 to 39%)
Likely (4)	A particular consequence is expected to occur in the timeframe (indicative probability of 40 to 100%)

Figure 6-1b: Levels of likelihood for each of the main risks analysed in this assessment (modified from Fletcher, 2015)

6.4.3 Determining the Residual Potential Impact

The residual potential impacts of the MWADZ Proposal were determined by evaluating the likelihood and consequence when mitigation and management measures are implemented. The size, extent, and/or duration of the residual impacts were used to determine the degree of potential impact to environmental or social factors. The level of each residual impact was determined by plotting the assigned consequence and likelihood levels onto an assessment matrix (Figure 6-1c).

Where potential impacts on a factor from any particular stressor were not likely to occur or were not likely to have any discernible consequence different to background levels, an impact rating of ‘not significant’ was assigned. Table 6-7 identifies the potential impacts that were assessed as being not significant during the preparation of this PER, including a justification for their exclusion from further assessment in this PER.

		Likelihood Level			
Consequence level		Remote	Unlikely	Possible	Likely
		1	2	3	4
Minor	1	1	2	3	4
Moderate	2	2	4	6	8
Major	3	3	6	9	12
Severe	4	4	8	12	16

Figure 6-1c: Hazard/Risk Analysis Matrix. The numbers in each cell indicate the Hazard/Risk Score; the colour indicates the Hazard/Risk Rankings

Table 6-7: Potential Impacts Screened Out from Further Assessment

Factor	Stressor	Potential Impact	Activity	Justification for Exclusion from Further Assessment
Marine Environmental Quality	Spills and leaks	Reduction in water quality	Accidental spill of fish stock feed	Aquaculture fish stock feed is non-toxic and will be quickly absorbed by the receiving environment.
	Discharges to sea	Change in seabed profile and changes to sediment characteristics	Discharge of deck drainage and cooling water from marine vessels	Discharges to sea are of very low toxicity and short term. They will be released into a highly dissipative marine environment, so are unlikely to migrate to sediments where they could impact sediment quality. Given the very small volumes of discharge involved, the potential for any observable impact on water quality is considered remote.
Benthic Communities and Habitat	Physical interaction	Change in seabed profile and direct physical injury to, or crushing of, benthic flora and fauna causing loss of species abundance and habitat and an increase in turbidity	Anchoring/mooring of aquaculture support vessels and sea cage clusters	Anchoring/mooring could impact benthic fauna living in or on the seabed. However, given the relatively static nature of sea cage aquaculture and the lack of any notable benthic faunal communities in these areas, any potential impact is expected to result in a highly localised loss and rapid recolonisation following the completion of the anchoring/mooring activities.
Marine Fauna	Physical interaction	Injury or mortality to marine fauna resulting from anchoring of vessels or sea cages	Anchoring/mooring of aquaculture support vessels and sea cage clusters	The relatively static nature of sea cage aquaculture operations and the general agility of the marine fauna likely to be present in the MWADZ Proposal area are expected to result in no measurable impacts from anchoring/mooring activities.
	Physical presence	Creation of artificial habitats causing a change in population densities, composition, and distribution	Deployment of aquaculture sea cage clusters and their associated anchoring systems	Sea-cage clusters will be located offshore and any impact will be highly localised. There may be some attraction of marine organisms (e.g. benthic fauna and pelagic fish, sessile encrusting organisms).
Amenity	Physical presence	Change in aesthetics	Introduction of floating sea cages to the seascape	The surface profile of aquaculture sea cages is relatively low and of a design that minimises drag from

Factor	Stressor	Potential Impact	Activity	Justification for Exclusion from Further Assessment
				both wind and waves. The sea cages are aligned and secured within a rectangular grid anchoring system. Even at full production, a maximum of six sea cage clusters will be situated within the MWADZ Proposal area. This equates a total surface structure profile of less than 84 hectares within the 3,000 hectares of the MWADZ Proposal area (i.e. ~3%).
	Physical interaction	Anchor snagging hazard to recreational fishers	Deployment of sea cage cluster anchoring systems	The location of the MWADZ is remote from areas known to be regularly used by recreational fishers. It is acknowledged that there may be an increase in recreational fishing in the MWADZ as a result of the deployment of aquaculture gear in the water column. However, any such fishing activity is likely to target pelagic species and the depths involved would discourage anchoring in any event.

6.4.4 Dealing with Uncertainty

The impact assessment was undertaken based on available evidence, current knowledge, and through the application of professional judgement. However, some scientific uncertainty still exists with respect to the actual impacts that may occur; this uncertainty may be a result of a number of factors including variation in natural systems, limited understanding of complex systems and interactions between components, and unknowable or uncontrollable factors that may affect an impact pathway.

Any scientific uncertainty regarding the potential impact and its seriousness or reversibility resulted in the application of a conservative approach to the assessment and to the definition of mitigation and management measures. Where any identified potential impacts are likely to be unknown, unpredictable, or irreversible, a conservative approach was adopted by considering the 'worst-case' situation. For example, this applies to:

- predicting the consequence of unplanned events in which the realistic worst-case scenario has been predicted and evaluated;
- uncertainties over the exact presence of a factor (e.g. a protected marine fauna) within an area of potential impact; the assessment has assumed those factors they are present and could potentially be affected; and

- multiple consequence scenarios that were identified for a stressor, or uncertainties over a consequence or likelihood categorisation, in which case the higher (i.e. more conservative) category was selected.

6.4.5 Mitigation and Management of Impacts

Many of the mitigation and management measures illustrated in this PER are based on those contained in the current approved version of the KADZ Proposal EMMP and Subsidiary Documents (including the KADZ Proposal Management Policy) as relevant to MWADZ Proposal activities. Mitigation and management measures for the MWADZ Proposal were also identified by considering the experience gained from their implementation by the KADZ Proposal and taking into account any more recent developments in alternative techniques or technologies since the approval of the KADZ Proposal.

The approved KADZ Proposal EMMP is designed within an adaptive management framework, with required changes being identified through either the performance reporting process, the ecological monitoring management trigger process, or the incident response process. The EMMP and Subsidiary Documents (requiring regulatory approval) may also be updated from time to time to reflect any changing circumstances, experience, and lessons.

Any amendments to the EMMP or Subsidiary Documents must be approved and must still meet the objectives and specific requirements in the Ministerial Conditions.

When developing the mitigation and management measures for the KADZ Proposal, a hierarchy of mitigation and management options was considered to identify a preferred approach. This same approach was adopted for the MWADZ Proposal and includes avoidance, minimisation, and restoration/remediation.

The selection of mitigation and management measures for the MWADZ Proposal also reflects the objects and principles of both the EPBC Act and the EP Act, where relevant (refer to Section 6).

Illustrative mitigation and management measures relevant to each stressor, factor, and controlling provisions are described in Sections 7 to 13. Further detail on the environmental management framework the Department intends to implement for the MWADZ Proposal is provided in Section 15.

6.4.6 Predicted Environmental Outcome

The acceptability of potential MWADZ Proposal impacts was evaluated as a ‘predicted environmental outcome’. The predicted environmental outcome of the MWADZ Proposal on each environmental factor was determined by taking into account:

- compliance of the MWADZ Proposal with the environmental objectives established for the assessment of impacts;
- compliance of the MWADZ Proposal with regulatory standards;
- compatibility of the MWADZ Proposal with established government policy, guidelines, and plans; and

- extent to which best practicable means have been applied to manage impacts of the MWADZ Proposal [in accordance with EPA Guidance Statement No. 55 (EPA 2003)].

In addition, the predicted environmental outcome reflects the cumulative impacts of the different stressors on each environmental factor.

6.5 Technical and Environmental Studies

A key component of the EIA was to accurately identify and describe cause-effect-response pathways which lead from the proposed aquaculture to potential environmental impacts. The oceanographic and ecological components of the proposed MWADZ are described in Sections 4 and 5 of the Modelling and Technical Studies; while Sections 6, 7 and 8 of the document provide an overview of the ecological changes which may result from the proposal.

To fully appreciate the risks presented by the MWADZ Proposal, it was first necessary to understand the type and magnitude of the environmental pressures introduced by the proposal, and their likely effect. This understanding, together with a desktop risk evaluation, was subsequently used to identify the key cause-effect-response pathways (Section 4.4 of Modelling and Technical Studies) and to select thresholds that query the model for new information (Section 4.5 of Modelling and Technical Studies).

6.5.1 Identification of Relevant Pressures and Risks

6.5.1.1 Noise

Noise generated by vessel movement and other aquaculture activities has the potential to disturb marine fauna, causing temporary or long-term avoidance of an area. Depending on their magnitude and frequency, underwater sounds may interfere with communication systems, mask important biological cues or cause behavioural disturbances (Richardson et al. 1995, National Research Council 2005, Southall et al. 2007). Underwater noises associated with aquaculture are expected to be limited to engine noises generated by service vessels (i.e. feeding barges) and intermittent low intensity sounds such as those generated by infrastructure maintenance. Engine noises are expected to be of similar frequency and intensity to those of commercial fishing boats (Olesiuk et al. 2012). For marine mammals, the effects of these vessels are transitory and the animals can generally habituate to these sounds with regular exposure. Risks associated with underwater noise are therefore considered low (Appendix 1). Mitigation strategies for managing the effects of underwater noise are included in the Environmental Monitoring and Management Plan (EMMP - Appendix 2).

There will not be a need for drilling, piling or blasting in relation to aquaculture operations associated with the MWADZ Proposal.

6.5.1.2 Physical Presence

Finfish will be grown in large floating sea cages. The design, construction and materials of sea cages will incorporate modern technology and best-practice to minimise environmental impacts. Sea cages will be anchored to the sea floor using equipment and techniques appropriate to marine conditions in the proposed MWADZ.

Where possible, anchoring on the sea cages is undertaken with low profile auger/screw/pin type anchors (e.g. helix anchors, which are embedded in the sea-floor). Low profile anchor points that are flush with the seabed have less impact on the seafloor flora and fauna. Larger weighted anchors (e.g. concrete blocks) might be required as a short-term fix in situations where it is impractical to penetrate the limestone bed-rock beneath the seafloor. Permanent losses of small areas of benthic habitat may occur in instances where weighted anchors are utilised.

The project infrastructure may act as an obstacle to migrating marine life, an artificial substrate that is attractive to seabirds seeking to roost and as an impediment to ambient water currents. The presences of large networks of sea cages may in some circumstances obstruct or disrupt cetacean migration. Placement of sea cage structures should be based on a review of the significance of the region as a migration corridor, as well as the likelihood that the configuration and placement of the infrastructure may act as an obstacle. Ideally, sea cage and/or lease placement should be organised to avoid such interactions. Section 9 provides further discussion on the interactions between wildlife and sea cages.

In addition, floating sea cages may affect local hydrodynamics. Model results show that sea cages restrict water-flow and reduce its speed in the top layer of the ocean. However, the presence of the sea cages increases the flow of water beneath the cages. The effect of the sea cages on the flow of water beneath the cages is dependent on the distance between the bottom of the sea cages and the seafloor. Bottom currents are maximised where the distance to the bottom of the sea cages is roughly half of the depth of the site (BMT-O 2015).

6.5.1.3 Organic Wastes

The cause-effect-response pathways relevant to inputs of fish faeces and uneaten feed (organic waste) are a key consideration in this assessment. Sea cage aquaculture has the potential to impact the sediment due to the settlement of organic wastes beneath or in close proximity to the sea cages (BMT-O 2015). The deposition of organic waste may lead to local organic enrichment or, under worst-case conditions, excessive nutrients enrichment (eutrophication) at a regional scale. Total community respiration increases due to increased organic loads to the sediments, which in turn increases oxygen consumption. Gray (1992) emphasises that the critical effects of eutrophication are experienced when water column oxygen concentrations become depleted. Increased nutrient loadings are generally associated with increased episodes of depleted oxygen (hypoxia) or an absence of oxygen (anoxia), particularly in waters that are not well-mixed. This leads to detrimental effects on the fauna living in the sediment (infauna) or on the seafloor (Baden *et al.* 1990, Schaffner *et al.* 1992). Hypoxia may cause local extinction of seafloor populations of flora and fauna (Gaston & Edds 1994) and changes in biological communities at the seafloor (Pearson & Rosenberg 1978, Josefson & Jensen 1992, Hargrave *et al.* 2008; Hargrave 2010).

Infauna is widely regarded as sensitive indicators of environmental degradation and restoration in marine sediments (Clarke & Green 1988, Austen *et al.* 1989, Warwick *et al.* 1990, Weston 1990, Dimitriadis & Koutsoubas 2011). Impacts to infauna communities commonly occur along gradients of sediment organic enrichment, as shown by numerous studies [following Pearson and Rosenberg 1978 (e.g. Hargrave 2010). Cromey *et al.* (1998) reviewed the fate and effects of sewage solids added to mesocosms. Organic loading rates produce degraded conditions (Cromey *et al.* 1998). Deposition rates above 700 grams of carbon per metre squared per year are widely believed to represent a critical value.

Sediments exposed to this rate of deposition are considered degraded [i.e. diversity of seafloor fauna is significantly reduced (Cromey *et al.* 1998)].

Finfish farming has the potential to impact the sediments beneath and immediately adjacent to sea cages (Carroll *et al.* 2003). Case studies of finfish aquaculture in Tasmania and Europe found that impacts are generally restricted to within 10–100 metres of sea cages. However, the magnitude of impact depends largely on the depth of the water and the rate of water flow through the site (Carroll *et al.* 2003, Crawford 2003, Borja *et al.* 2009). Prevailing water currents through the proposed MWADZ are adequate to promote environmental conditions that usually correspond to ecosystems which are either "moderately" or "not sensitive" to impact. Currents speeds above ten centimetres per second are widely considered "ideal" for sea cage aquaculture and current speeds less than six centimetres per second are generally considered "not ideal" for sea cage aquaculture (Tables 6-8 and 6-9).

Table 6-8: Average Surface and Bottom Water Current Speeds through the MWADZ

Current speeds (cm/s)				
	Northern area		Southern area	
Month	**Surface**	**18 metre water depth**	**Surface**	**18 metre water depth**
Summer	13.2-14.1	10.4-11.0	8.7-9.4	5.8-7.0
Winter	14.0-14.5	9.0-11.5	10.5-11.0	6.1-8.0

Table 6-9: Increasing Suitability of Potential Aquaculture Sites based on Current Speed

Suitability	Current speed (cm/s)	Reference
Not sensitive to impact / desirable	10-25	Carroll *et al.* (2003)
	>15	Borja *et al.* (2009)
	13-77	Benetti *et al.* (2010)
	5-20	Halide *et al.* (2009)
	10-60	Beverage (2004)
Moderately sensitive to impact	5-15	Borja *et al.* (2009)
Sensitive to impact / unsuitable	3-6	Carroll *et al.* (2003)
	<5	Borja *et al.* (2009)

6.5.1.4 Inorganic Nutrients

The cause-effect-response pathways relevant to inputs of inorganic nutrients are another key consideration in this assessment. Finfish aquaculture in open water sea cages may, in some circumstances, cause deterioration in local water quality due to inputs of inorganic nutrients from fish faeces and uneaten food. Aquaculture may contribute inorganic nutrients to the water column, either directly through secretion of ammonia by fish or indirectly through organic matter deposition and remineralisation.

Inorganic nutrients in the form of ammonia, nitrite/nitrate and orthophosphate may lead to adverse environmental effects via a number of environmental cause-effect pathways, whereby aquaculture affects marine plants on the seafloor.

Habitat studies in the proposed MWADZ have revealed a diverse array of benthic habitats, including the presence of vast areas of mixed ecological communities comprising macro-algae, rhodoliths, filter feeders, corals and other primary producers (Section 8.2.1). Macro algae and corals in particular are known to be sensitive to sources of inorganic nutrients. For example, prolonged exposure to nutrients may lead to conditions where living corals are slowly replaced by macro algae (e.g. Littler & Littler 1984, Jackson *et al.* 2001, Bellwood *et al.* 2004, Hughes *et al.* 2010, Rasher *et al.* 2012).

6.5.1.5 Metals and Other Contaminants

If metal concentrations are elevated to threshold levels, marine organisms can be affected by the associated level of toxins (Parsons 2012). Sources of metals include contaminated sites, agricultural and urban runoff, discharges from sewage treatment plants, and copper-based anti-foulants sometime used on sea cages (Parsons 2012).

Metals form a small constituent of commercial aquaculture feeds as trace elements. The trace elements are consumed by finfish and excreted in the faeces. A study of the metal content of trout faeces by Moccia *et al.* (2007) found that zinc and iron were present in the highest concentrations, with relatively low proportions of copper (see Section 7.2.3). Despite the very low concentrations in commercial feeds, monitoring in Tasmanian waters has recorded copper and zinc sediment values at concentrations higher than the ANZECC/ARMCANZ (2000) ISQG-low and ISQG-high guideline values at some sea cage sites (DPIPWE 2011).

Antibiotics are sometimes used to treat bacterial disease occurring in farmed finfish and are generally administered in feed. Antibiotics deposited to the seafloor as faeces may reduce or change the numbers of bacteria in the sediment, thereby affecting broader ecological processes. Oxytetracycline is the most common antibiotic used to treat farmed salmon in Tasmania (Parsons 2012). The use of antibiotics in Tasmania was shown to be highest in the summer months when water temperatures are elevated and pathogens tend to be most virulent.

6.5.2 Ecosystem Nutrient Budget

The nutrient budget of the region is relatively simple in that it currently comprises only discharge of nutrients from the seafloor sediments and the transfer of the nutrients via the flow of the ocean. These environmental processes are both considered minor, in that the existing environment is essentially nutrient-poor. In support of this, monitoring data collected as part of this study showed that water column nutrient concentrations were generally very low (Section 7.3.3).

The addition of large-scale finfish aquaculture creates a considerable disturbance to the existing nutrient cycle, which is a key subject of investigation in this study. The proposed aquaculture presents an immediate nutrient load to the water column (via waste and feed excess) and a delayed load (nutrient discharges via the seafloor sediment).

A diagrammatic representation of existing and impacted conditions, with approximate annual nutrient flows (flux), is included in Figure 6-2 and Table 6-10. These quantities were computed from measurements and model predictions.

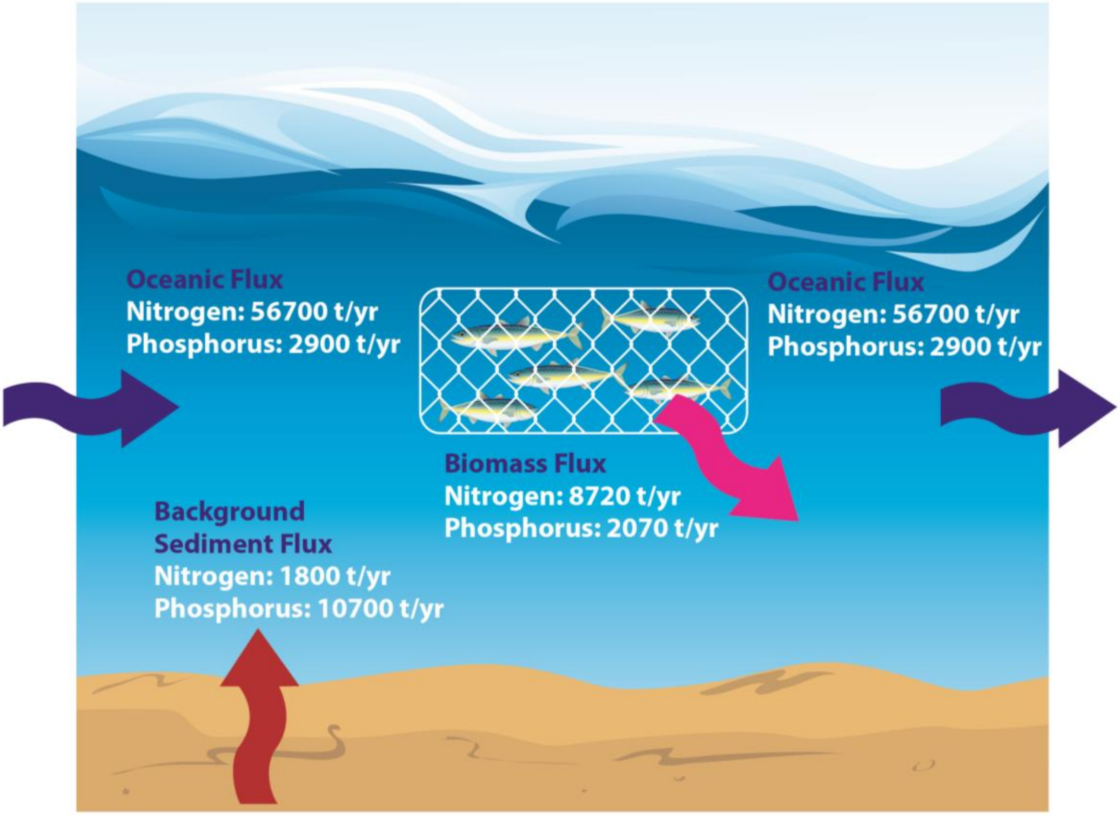


Figure 6-2: Conceptual Diagram of the Baseline and Post-Operation Nutrient Budget under Scenario 1

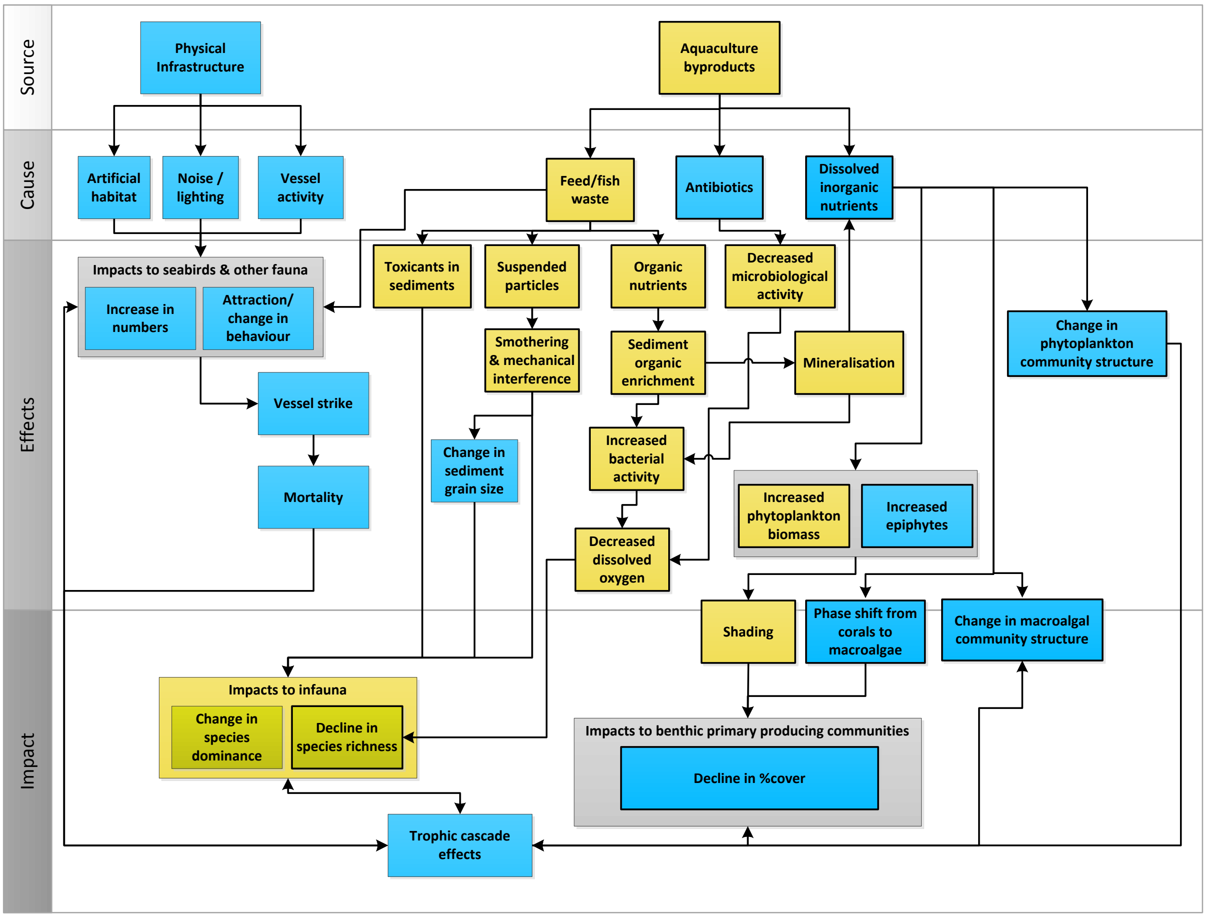
Table 6-10: Baseline and Post-Operation Nutrient Budgets

Scenario	Source (tonnes per year)		
	Aquaculture (biomass)	Oceanic	Background sediment
1-2	Nitrogen 8720 Phosphorus 2070	Nitrogen 56 700 Phosphorus 2900	Nitrogen 1800 Phosphorus 10700
3-4	Nitrogen 13950 Phosphorus 3310		
5-6	Nitrogen 17440 Phosphorus 4130		

6.5.3 Cause-Effect-Response Pathways

The pathways of cause, effect and response between the proposed aquaculture (as a source of stressors) and environmental indicators (the receptors) were identified by following the step-wise approach of Gross (2003). The objective of this approach was to identify the cause-effect-response pathways most likely to be affected by the proposed MWADZ. Receptors exhibiting measurable changes in response to stressor inputs were identified as environmental variables to be monitored (indicators). The understanding gained by this process was used to develop the thresholds described in Section 6.6.

The cause-effect pathways of most concern are presented in the conceptual diagram (Figure 6-3). It shows the relationship between the most important stressors, ecosystem components, effects and biological receptors. The environmental indictors and thresholds were ultimately derived from this conceptual model. It is hierarchical in nature, with the stressors and their sources shown in the upper strata of the model. The receptors are shown in the middle and the effects in the bottom strata of the model.



Notes:

1. Key cause-effect-response pathways. Pathways shown in yellow represent those captured by the modelling and those for which thresholds were developed.

Figure 6-3: Hierarchical Stressor Model showing the Key Cause-Effect-Response Pathways and those chosen for Model Interrogation

6.6 Thresholds for Interrogation of the Ecosystem Model

6.6.1 Application of EAG 3

Environmental Assessment Guidelines No.3 (EAG 3) is concerned with the protection of ecological integrity and biodiversity through a framework for assessing the cumulative loss of, or serious damage to, benthic communities and habitat (BCH) in Western Australia. BCHs are seabed communities within which algae, seagrass, mangroves and corals are prominent components. BCH also include areas of seabed that can support these communities (EPA 2009).

"Irreversible loss" of BCH is commonly associated with excavation or burial. Such activities modify BCH so significantly that the impacted community would not be expected to recover to the pre-impact state and therefore the loss is considered irreversible.

"Serious damage" is also intended to apply to damage to BCH that is effectively irreversible or where recovery would not occur for at least five years (EPA 2009).

EAG 3 (refer to Section 8.2.1) provides guidelines which outline cumulative losses of BCHs that may be acceptable, provided all other options have been exhausted. The waters of the Abrolhos Islands, including the proposed MWADZ, are gazetted as a Fish Habitat Protection Area (FHPA) under Section 115 of the *Fish Resources Management Act 1994*. The FHPA has the following purposes:

- *conservation and protection of fish, fish breeding areas, fish fossils or the aquatic ecosystem;*
- *culture and propagation of fish and experimental purposes related to that culture and*
- *propagation; and*
- *management of fish and activities relating to the appreciation or observation of fish.*

The Management Plan for the FHPA does not identify any areas of high conservation value that would be Category A (Extremely Special Areas) under EAG 3 (Table 7.1). Therefore, the proposed MWADZ should be Category C (Other Designated Areas) under EAG 3. The Cumulative Loss Guidelines (EAG 3) recommend that cumulative loss of BCH within areas deemed to be Category C do not exceed a benchmark of two percent of the BCH within the local assessment unit (LAU) (Section 8.4.1).

6.6.2 Application of EAG 7

The potential for the proposed MWADZ to impart adverse effects on the benthic marine environment (particularly soft sediments) are described (below) in the context of EAG 7 (refer to Section 8.2.1). EAG 7 includes three predefined levels of impact:

- zone of high impact (ZoHI);
- zone of moderate impact (ZoMI); and
- zone of influence (ZoI) (EPA 2015).

EAG 7 was developed to assess the impacts of capital dredging activities to benthic habitats in the State's Northwest, and its application to aquaculture EIA is new (BMT-O 2015).

6.6.2.1 Soft Sediments

The recovery of sediments at the point of fallowing was determined using a sediment biogeochemical model, linked to a hydrodynamic and a particle transport model. The period of recovery was determined across a range of scenarios (Table 6-14). Conditions were simulated in which sediments, beneath and near the sea cages, had received inputs of waste for a period of two, three and five years. At the completion of the two, three and five year periods, the sea cages were fallowed to allow recovery of the sediments.

6.6.2.2 Oxygenation

Recovery was deemed to have occurred when sediment chemical conditions, represented by the concentration and depth of oxygenation and hydrogen sulphide, returned to pre-aquaculture conditions (Table 6-11). Three zones were defined based on threshold criteria for recovery (defined in more detail in Appendix G of the PER). This included consideration of oxygen and sulphide concentrations within the top five centimeters of sediment. The ZoHI was applied when sediment conditions took greater than five years to recover; the ZoMI was applied when sediment conditions took less than five years to recover, and the ZoI was applied when sediments received waste material, but not in proportions great enough to alter the sediment chemistry. Chemical recovery was investigated instead of biological recovery because its path of recovery has readily identifiable beginning and end points and can be quantified and tracked. A path of biological recovery would be too complicated to model and actual recovery would be difficult to define and unlikely to match a quantitative endpoint.

6.6.2.3 Metals

Recovery thresholds for metals were based on the time taken for metal concentrations in the sediment to return to values lower than the EQG trigger values (EPA 2014). The zones of high and moderate impact and zone of influence in for metals in the sediments were applied in accordance with EAG 7 as presented in Table 6-11.

Table 6-11: Thresholds Applied to Soft Sediments

Parameter	Zone of high impact (ZoHI)	Zone of moderate impact (ZoMI)	Zone of influence (ZoI)
Hydrogen sulphide	Concentrations deteriorate and do not recover to baseline levels within a 5 year period	Concentrations deteriorate but recover to baseline levels within a 5 year period	Concentrations not to exceed baseline levels
Oxygenation			Top 5 cm of sediment remain oxygenated
Metals (Zn and Cu)1	Sediment concentrations of Zn and Cu do not recover to values lower than the EPA EQGs with a period of five years	Sediment concentrations of Zn and Cu recover to values lower than the EPA EQGs within a 5 year period	Sediment concentrations of Zn and Cu not to exceed the EPA EQGs

6.6.3 Application of Other Impact Criteria

6.6.3.1 Mixed Assemblages

The thresholds for smothering are based on PIANC (2010). The thresholds for water column oxygenation, suspended particles, algal growth potential, nutrient enrichment and shading are based on EPA (2015). The EPA's criteria were used to compensate for uncertainties relating to lethal and sub-lethal thresholds, and timing of recovery for endemic species, following exposure to nutrient loadings from aquaculture.

6.6.3.2 Smothering

Thresholds for smothering (Table 6-12) are based on the sensitivities of coral published in PIANC (2010) as described in Table 6-13. The thresholds have been used as a best estimate, in place of measurements of coral responses to aquaculture derived nutrient loadings.

Table 6-12: Thresholds based on PIANC (2010)

Effect	Major impact (ZoHI)	Moderate impact (ZoMI)	No impact (ZoI)
Smothering[1]	Sedimentation rate not to exceed 500 $g/m^2/day$	Sedimentation rate not to exceed 100 $g/m^2/day$	Sedimentation rate not to exceed 50 $g/m^2/day$

Table 6-13: Impact Assessment Categories for the Effects of Smothering

Severity of impact	Description
Minor impact	Changes are likely to be detected in the field as localised mortalities, but to a spatial scale that is unlikely to have any secondary consequences.
Moderate impact	Changes are detectable in the field. Moderate impacts are expected to be locally significant.
Major impact	Changes are detectable in the field and are likely to be related to complete habitat loss. Major impacts are likely to have secondary influences on other ecosystems.

6.6.3.3 Suspended Particles

Thresholds for suspended particles were developed to be consistent with the moderate and high levels of marine ecological protection described in EAG 15 (refer to Section 8.2.1). The thresholds are respectively based on the 95th and 80th percentile values obtained during baseline studies. In this context, the 80th percentile is aligned with the criteria used for a high level of ecological protection and the 95th percentile a moderate level of ecological protection. For contextual purposes, Table 6-14 also outlines the limits of acceptable change under a low level of ecological protection. Low ecological protection areas are typically applied to ocean outfalls, where moderate and high levels of ecological protection are not always achievable.

Table 6-14: Levels of ecological protection

Level of ecological protection	Limits of acceptable change
Low	To allow for large changes in the quality of water, sediment and biota (e.g. large changes in contaminant concentrations causing large changes beyond natural variation[1] in the natural diversity of species and biological communities, rates of ecosystem processes and abundance/biomass of marine life, but which do not result in bioaccumulation/biomagnification in near-by high ecological protection areas).
Moderate	To allow moderate changes in the quality of water, sediment and biota (e.g. moderate changes in contaminant concentrations that cause small changes beyond natural variation in ecosystem processes and abundance/biomass of marine life, but no detectable changes from the natural diversity of species and biological communities).
High	To allow small changes in the quality of water, sediment or biota (e.g. small changes in contaminant concentrations with no resultant detectable changes beyond natural variation* in the diversity of species and biological communities, ecosystem processes and abundance/biomass of marine life).

Note:

1. Detectable change beyond natural variation nominally defined by the median of a test site parameter being outside the 20^{th} and 80^{th} percentiles of the measured distribution of that parameter from a suitable reference site

6.6.3.4 Oxygenation

The thresholds for oxygenation [dissolved oxygen levels (DO)] of the water column are based on EPA EAG 15 (2015) (Table 6-15). The thresholds are equivalent to the Environmental Quality Standards (EQS) for achieving moderate and high levels of ecological protection (EPA EAG 15, 2015), which require that DO levels are maintained at 60% and 90% saturation respectively for a period greater than six weeks.

Table 6-15: Thresholds based on EPA (2015)

Factor	Moderate ecological protection	High ecological protection
Oxygenation[1]	DO saturation in the bottom half of water column not to fall below 80% for a period exceeding 6 weeks	DO saturation in the bottom half of water column not to fall below 90% for a period exceeding 6 weeks
Suspended particles[2]	TSS concentration not to exceed 8.4 mg/L more than 50% of the time	TSS concentration not to exceed 2 mg/L more than 50% of the time
Algal growth potential[2]	DIN concentration not to exceed 40 µg/L more than 50% of the time	DIN concentration not to exceed 29 µg/L more than 50% of the time
Nutrient enrichment[2]	Chlorophyll-a not to exceed 0.45 µg/L more than 50% of the time	Chlorophyll-a not to exceed 0.30 µg/L more than 50% of the time
Shading[2,3]	Light intensity at the benthos not to fall below the 5th percentile more than 50% of the time	Light intensity at the benthos not to fall below the 20th percentile more than 50% of the time

Notes:

1. Thresholds for the ZoHI/ZoMI and the ZoI are based respectively on the EPA's EQSs for moderate and high ecological protection (EPA 2005). Threshold assumes continuous exceedance for a period greater than six weeks.
2. Thresholds for the Zone of moderate impact (ZoMI) and Zone of influence (ZoI) are based respectively on the EPA's EQGs for moderate (95th percentile baseline data) and high (80th percentile baseline data) ecological protection (EPA 2015). The threshold for the Zone of high impact (ZoHI) is based on the 99th percentile of baseline data.
3. During daylight hours (8am–6pm).

6.6.3.5 Algal Growth Potential and Shading

Thresholds for inorganic nutrients were developed to address the effects of algal growth potential, nutrient enrichment and shading (Figure 6-4). The thresholds for algal growth potential and nutrient enrichment are based on the 95th and 80th percentile values of the data obtained during the baseline studies (Section 8.2). The thresholds for shading by contrast are based on the 5th and 20th percentile values of the data obtained during baseline studies. In this context, the 20th and 80th percentiles (ZoI) are in alignment with the criteria used for a high level of ecological protection. The 5th and 95th percentiles align to the criteria for a moderate level of protection.

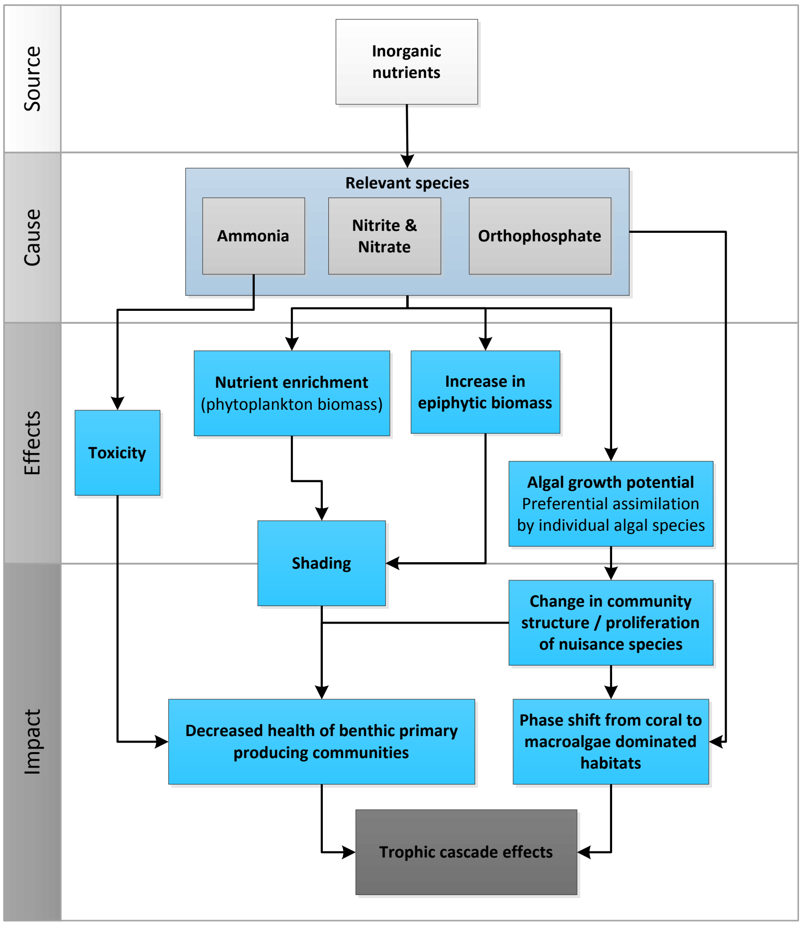


Figure 6-4: Cause-Effect-Response Pathways Relevant to Inorganic Nutrients

6.6.4 Aquaculture Scenarios Chosen for Modelling

Modelling scenarios were agreed in consultation with the Department and the Aquaculture Industry Reference Group at a technical workshop held in October, 2014. Aquaculture production scenarios were developed based on production of yellowtail kingfish (*Seriola*

lalandi) using industry best-practice farming methods, including use of the standard infrastructure as described in Table 6-16.

Table 6-16: Aquaculture Scenarios Chosen for Modelling

Infrastructure component	Details
Cage diameter (metres)	38
Cage circumference (metres)	120
Cage depth (metres)	18
Cage volume (m^3)	20 641
No. cages per cluster	14
Other assumptions	• Two to three clusters in the southern location • Four to six clusters in the northern location • Percentage of uneaten feed = 1%

Six scenarios were modelled in total (Table 6-17). All scenarios assumed the zone was constantly stocked with 15,000; 24,000 or 30,000 tonnes standing biomass and assumed static food consumption and growth rates. No allowances were made for variations in the volume of stock due to growth and/or harvesting of stock. Feed inputs and waste outputs were kept constant.

The effect on the benthic environment of increasing and decreasing stocking densities was examined by manipulating the number of cage-clusters between six and nine. This was undertaken in recognition of the economic-environmental trade-offs between infrastructure requirements and the aquaculture industries desire to maintain higher stocking densities, wherever resources and/or the biology of the target species allows. The numbers of sea cage cluster on a lease will be proportionate to the size of the lease. For the purpose of examining the environmental model, the numbers of sea cage cluster across the two areas making up the proposed MWADZ resembles the likely allocation of infrastructure by potential future proposals based on advice from the Aquaculture Industry Reference Group.

Table 6-17: Modelled Production Scenarios

Scenario No.	S1	S2	S3	S4	S5	S6
Total standing biomass (tonnes)	15,000		24,000		30,000	
Standing biomass north (tonnes)	10,000		16,000		20,000	
Standing biomass south (tonnes)	5,000		8,000		10,000	
No. clusters south	3	2	3	2	3	2
No. clusters north	6	4	6	4	6	4

6.7 Integrated Model Components

The ESD required the development of fully-integrated environmental models to represent biological and chemical ecosystem processes, the influence of the physical surroundings and forces exerted by waves and water currents at the location for the proposed zone, collectively, an Integrated Ecosystem Model (Model). This required the incorporation of several discrete

environmental models, accounting for waves, fish waste, particle transport and hydrodynamics, within a model of the sediment biogeochemistry and water quality of the site. The purpose of the Model was to predict the cumulative environmental effects of the proposed aquaculture, operating across a range of potential production scenarios. The ecosystem Model was capable of simulating regional oceanographic water movements, the deposition and dispersal of wastes from sea cages, the effects of these wastes on the marine environment, and the rate of environmental recovery.

As with all environmental models, the Model developed for the strategic proposal involves many complex driving factors and interactions of those factors. Consequently, there were numerous sources of error that needed to be carefully controlled. The modellers adopted a conservative approach to developing the model to ensure all assumptions were well-educated and based on the literature and professional experience. Although this precautious approach to the modelling avoided under-predicting the impacts, predictions are within the realms of possibility. Outputs from the Model were within the upper range of impacts reported in the aquaculture literature (i.e. Brooks et al. 2004). The Model provided useful predictions of the potential for impacts under "most likely worst case" conditions.

In recognition of the complexity of the Model, the consultants commissioned a staged process of review, in which an independent external reviewer examined the assumptions and individual stages of Model development. The approach to examining the individual modelling components and the assumptions underpinning the modelling are documented in the Modelling and Technical Studies (Appendix 1). The reviewer's comments are included in Appendix 1E of the Modelling and Technical Studies.

6.7.1 Hydrodynamics

Oceanographic data, consisting of conductivity-temperature-depth (CTD), current speeds, current direction, wave height, wave direction, and peak wave period, were collected over a ten month period at a total of four sites and captured for four seasons. The data were collected using Acoustic Doppler Current Profilers (ADCP) equipped with additional data loggers. Four ADCPs were deployed in total: one in each of the northern and southern areas, and one in each of two regional locations north-east and south-east of the proposed zone.

The modelling computer program TUFLOW FV was used as the hydrodynamics modelling engine (http://www.tuflow.com). The primary aim of the hydrodynamics model was to represent the characteristics of the water currents and waves in the proposed zone and to determine the dispersal and distribution of wastes released from aquaculture (e.g. residual feed, stock faeces and associated nutrients). The role of the hydrodynamics model was to inform the models of sediment biogeochemistry and water quality (refer to Modelling and Technical Studies – Appendix 1).

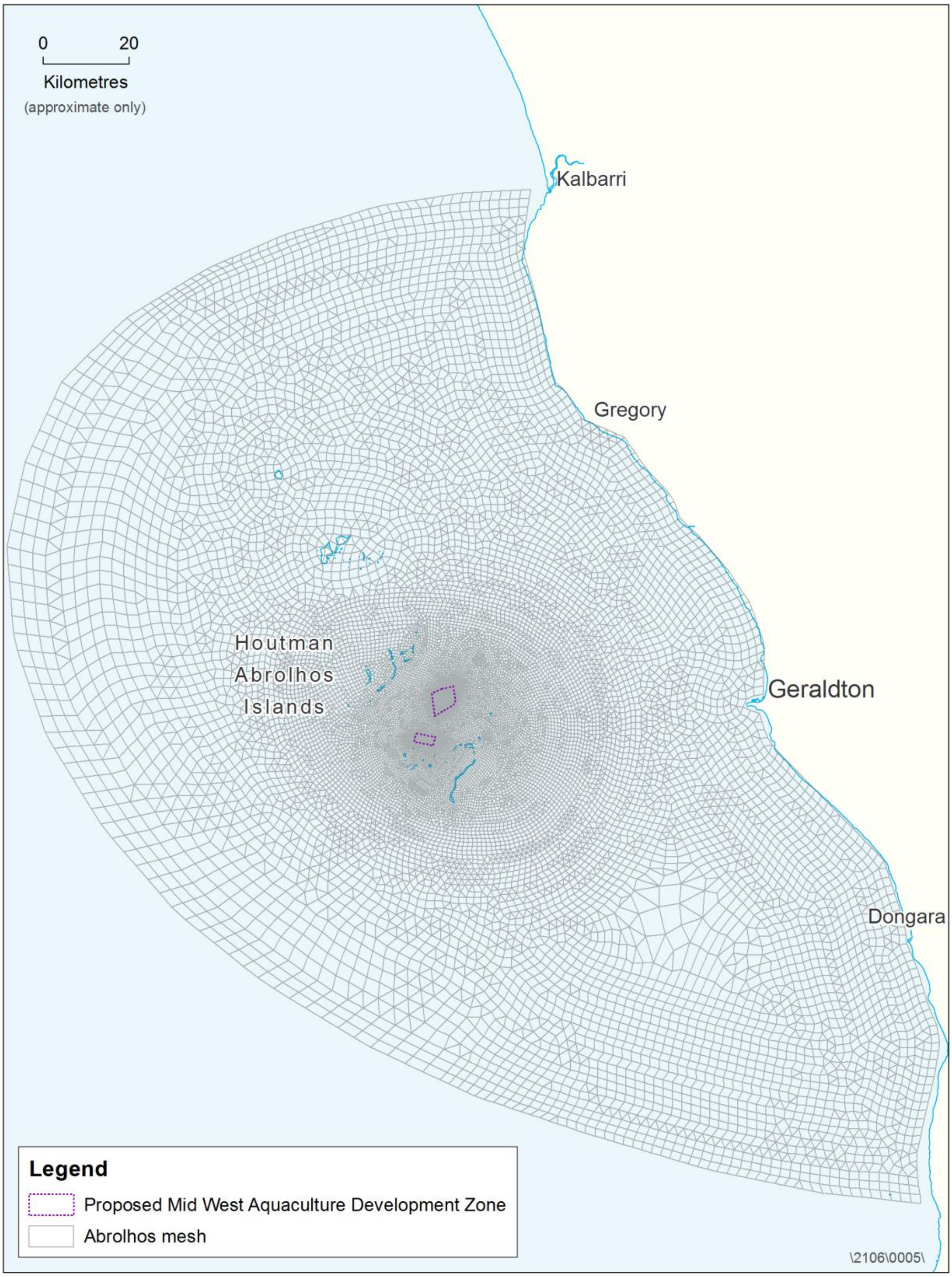


Figure 6-5: The Model Mesh

6.7.2 Wave Model

To account for the influence of wave-driven currents on the suspension and deposition of particles, a wave field was applied to the hydrodynamics model using the model SWAN. In

addition to wind data, SWAN also required regional swell data. This was sourced from WAVEWATCH III, which is a global wave prediction model developed by the National Oceanic and Atmospheric Administration (NOAA). The SWAN model was run on a spatial grid of 500 metres resolution.

6.7.3 Fish Waste Model

A fish waste model was developed to predict the volume of waste for a given volume of fish, including the proportional nitrogen, phosphorus and carbon in the solid and dissolved fractions of waste. Outputs from the fish waste model were utilised by the particle transport model to predict the fate of the organic particles once discharged from the sea cages.

The fish waste model was based on the collective works of Tanner *et al.* (2007), Fernandes and Tanner (2008) and Tanner and Fernades (2010). The model assumes an average fish size of 1.5 kilograms and an average water temperature of 20°C, representing Abrolhos winter temperatures. Respiration, feed conversion ratios (FCR) and specific growth ratio (SGR) values are based on Tanner *et al.* (2007).

6.7.4 Particle Transport Model

The Particle Transport Model (PTM) was used to characterise both the vertical and horizontal transport of aquaculture wastes, while accounting for differing size fractions and settling rates of waste. The science of particle transport through the water column is complex. The model also needed to account for processes of deposition and resuspension from the seabed associated with wave and current energy, and was run over a twelve month simulation period so as to make allowance for a diverse set of environmental conditions.

The PTM calculated the transport of particles away from the sea cages, and quantified the rate of waste deposition near and far from the cages. The PTM was also able to characterise the transfer, dispersion, deposition and resuspension dynamics of particle. Particles were tracked by the model to determine thresholds for settlement of particles on the seabed and resuspension by wave and current energy. No particle breakdown or burial processes were considered in the PTM simulations.

The settling rate of fish waste as it leaves a sea cage will vary according to an extensive array of variables including feed type, fish health, species, fish size, and general farming practices (Chen *et al.* 1999, Felsing *et al.* 2005, Moccia *et al.* 2007, Moran *et al.* 2009). The speed at which fish waste sinks and leaves a sea cage varies depending on many variables, for example, feed type, farming practices and the stock, species, size and health (Chen *et al.* 1999, Felsing *et al.* 2005, Moccia *et al.* 2007, Moran *et al.* 2009). In addition, the difference between the volume of waste leaving a sea cage and the volume reaching the seafloor is complex to determine, and depends on biological and physical factors (e.g. current speeds and the extent of secondary consumption by scavengers beneath the sea cages (Felsing *et al.* 2005). For this study, fish waste was partitioned into waste feed (commercial aquaculture pellets) and fish faeces. Three size fractions of fish faeces was considered, following Chen *et al.* (1999), Cromey *et al.* (2002) and DHI (2013; Table 4.18).

Deposition of waste in this study was based on the understanding that the largest proportion of organic particles falls beneath or close to the sea cages. The smaller the particles, the

further they are carried from the sea cages. Modelling accounted for the prevailing currents, which tended to skew the distribution of the finer particles in one direction over another. This concept is illustrated in Figure 6-6, which shows the rate of particle deposition over one year at equal levels of standing biomass, but at differing stocking densities. Higher volumes are depicted directly under the sea cages (red to orange shading), with decreasing volumes depicted further from the sea cages (yellow to blue shading).

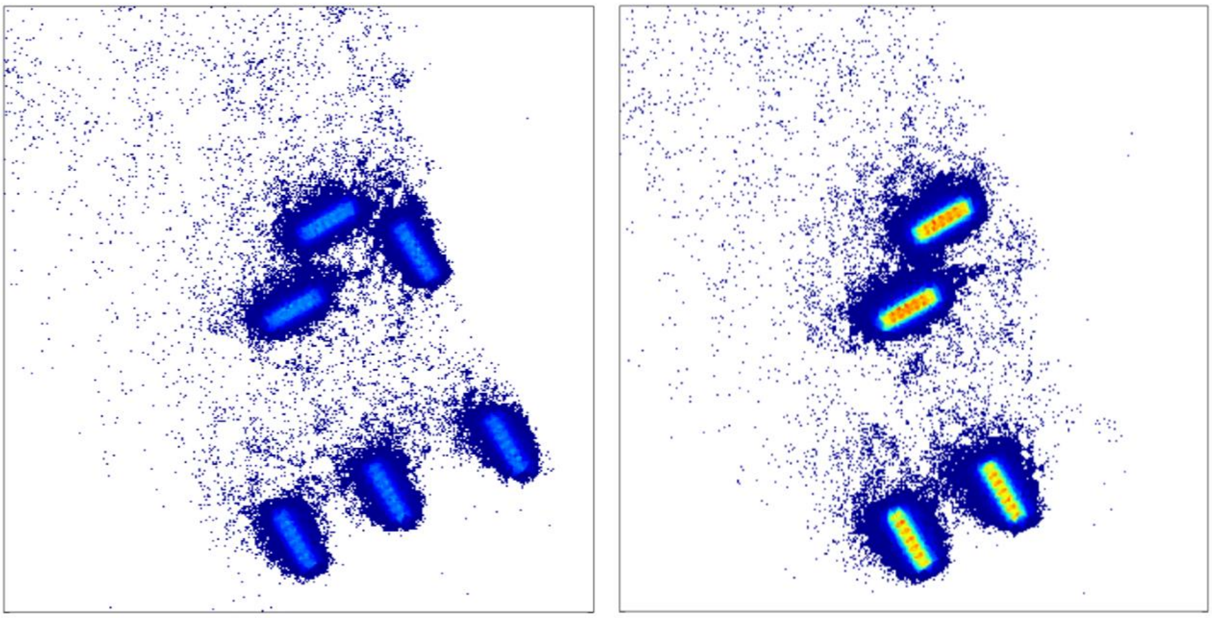


Figure 6-6: Deposition of Waste Material Following Twelve Months of Aquaculture Production under Differing Stocking Densities

6.7.5 Water Quality Model

The water quality model utilised the Aquatic Ecodynamics (AED2) model library developed at the University of Western Australia (http://aed.see.uwa.edu.au/research/models/AED/). In this study it simulated a number of biogeochemical processes relevant to water quality; including sediment organic matter, inorganic nutrients and phytoplankton dynamics. The hydrodynamic and the water quality models were used together to characterise the release, dispersion and dilution of inorganic nutrients from the sea cages, and subsequent intake and growth of phytoplankton. The model was also used to characterise the potential for changes in dissolved oxygen and light attenuation at the bottom of the water column.

6.7.6 Biogeochemical Processes

The biogeochemical processes occurring in the sediments and water at the seafloor were described and considered by developing a model of biological, chemical and geographic characteristics of the seafloor (Diagenesis Model). The Diagenesis Model (CANDI-AED model) was used to estimate the flow of nutrients into and out of the sediments (Appendix 1). The understanding of biogeochemical processes was applied when working with the hydrodynamics and water quality models. This was to ensure the phytoplankton response was based on the cumulative sources of nutrients, both directly from fish respiration and indirectly via chemical processes occurring in the sediments. Importantly, the diagenesis model was also used to determine the recovery of sediments beneath the sea cages. The understanding of sediment recovery beneath the sea cages was a key to mapping the spatial distribution of the

zones of impact and influence (ZoHI, ZoMI and ZoI) associated with the proposed aquaculture.

Based on field observations, the model assumes sediment physical properties to be highly porous and permeable sediment of approximately 15 centimetre depth, with hard rock beneath. In order to simulate the vertical mixing of the sediment, a relatively high bioturbation rate was used, with a constant value from the sediment-water interface to the deepest layer at 15 centimetres.

Chemical concentrations at the sediment-water interface are subject to a mix of competing forces at different spatial and temporal scales. The chemical reactions simulated in the model can be broadly defined as primary and secondary reactions; these are summarised in Section 4.1 of the Modelling and Technical Studies. Primary reactions, driven by bacterial breakdown of organic matter, are the driving force of most of the other chemical reactions that occur in the sediment. Inputs of fish feed and faecal matter serve to quickly unbalance the normal chemical concentrations that occur in marine waters. This is accentuated in marine waters that are naturally nutrient poor (e.g. waters of the Abrolhos Islands).

The diagenesis model was applied to sediment in the proposed MWADZ, firstly under existing environmental conditions, then with two, three and five years of organic deposition from aquaculture, then 7+ years with no deposition (post-fallowing) to simulate a recovery period.

The resulting quantities of organic matter and corresponding chemical concentrations were investigated to characterise the environmental response to a range of stocking densities, near and far from the sea cages. The resulting recovery time of the sediment and absolute concentrations of key sediment variables were calculated to determine the zones of high and moderate impacts, and the zones of influence, as per EAG 7.

6.7.6.1 Metal Accumulation and Recovery

In simulating the biogeochemistry of the sediments, the diagenesis model investigated the chemical processes leading to the accumulation and compound-forming transition of metals (Zn, Cd and Cu). The purpose of the modelling was to determine the potential for metal accumulation in the sediments beneath sea cages and the time required for recovery after fallowing. Chemistry determines that metal concentrations in the sediments are strongly correlated to the presence of sulphides. Accordingly, the diagenesis model simulated the accumulation of metals under conditions where the sediments are low in oxygen and high in sulphide concentrations. The sediments would discharge metals into solution when oxygen and sulphides concentrations returned to normal.

This study assessed the potential for trace metals in commercial feeds to accumulate in the sediment and have environmental consequences. Modelling undertaken for this study focused on the metals in greatest supply (Zinc and Copper) and for which there are EPA triggers (EPA 2014). There are two biochemical processes that could lead to the release of metal as a free solute from the organic matter. This can occur if the organic material undergoes microbial oxidation. Alternatively, metals which precipitate out of solution as metal sulphides can be oxidised due to the sediment being exposed to oxygen and released as a free solute. The criteria for metal contamination are 200 and 65 milligrams/kilogram dry weight for Zn and Cu respectively, or 7.7 and 2.5 millimoles metal/L.

6.7.6.2 Model assumptions

The modelling approach adopted here was to build an integrated environmental model, which comprised simulations of the hydrodynamic, water quality, particle transport and sediment diagenesis of the study area. The integrated model captured the key environmental processes and their interactions. A conservative approach was adopted towards developing the model. This aimed to ensure outputs were equivalent to "most likely worst case" outcomes, as required by the ESD (EPA 2013) (Table 1). As such, the impacts predicted in this document are more extensive than might be expected on average, but are nevertheless within the upper range of impacts reported in the literature (i.e. Brooks *et al.* 2004). The assumptions underpinning the development and execution of the integrated model are summarised below:

- The hydrodynamic and the wave models were calibrated and validated against metocean data collected over a ten month period, encompassing each of the calendar seasons.
- The Feed Conversion Ratio (FCR) and Specific Growth Rate (SGR) values used in the development of the fish waste model (Section 4.6.1) are based on the collective works of Tanner *et al.* (2007), Fernandes and Tanner (2008) and Tanner and Fernandes (2010). The outputs produced by the model are conservative, and aquaculture proponents have a vested interest to achieve the lowest feed conversion ratios achievable.
- Modelled estimates of the total volume of fish waste expected to reach the seafloor are based on the physical and hydrodynamic properties of several different waste fractions: pelletised feed, and size fractions for stock faeces. The two largest fractions were assumed to settle rapidly and the smallest, slowly. Smaller particles tended to settle further from sea cage infrastructure, and larger particles settled closer.
- The faecal matter generated by cultured fish is known to be 'sticky', meaning it has a tendency to clump where it is depositing. Relative to inorganic waste produced by the stock, fish faeces is less likely to be resuspended by strong currents (BMT Oceanica 2015). As the fish faeces was deposited from sea cages most of the carbon was consumed by microscopic flora in the sediment. The assimilation of this organic waste by the environment caused rapid changes to the sediment chemistry.
- In the model context, the smallest fractions of fish faeces remained in suspension indefinitely. Fine particles had a high capacity for dispersion and were expected to dissolve over the twelve months for which the model was run. As a result, the particles were transported over long distances and dispersed widely. However, the volumes were not expected to result in impacts to flora and fauna living in or on the sediment.
- Each cluster of 14 sea cages is anchored within a grid that occupies 14 hectares.

6.7.6.3 Peer review

Doug Treloar of Cardno Water and Environment was engaged throughout the project to provide independent peer reviews of the environmental modelling, during development and on completion. The peer review assessed the approach to modelling, setting of thresholds and the general conclusions of the Modelling and Technical Studies (Appendix 1).

7 ASSESSMENT OF POTENTIAL IMPACT ON MARINE ENVIRONMENTAL QUALITY

7.1 Assessment Framework

7.1.1 Environmental Objective

The environmental objective established in this PER for marine environmental quality is as specified in EAG 8, namely:

"*To maintain the quality of water, sediment and biota so that the environmental values, both ecological and social, are protected.*"

7.1.2 Relevant Legislation, Policies, Plans and Guidelines

Table 7-1: Legislation, Policies, Plans, and Guidelines Relevant to Marine Environmental Quality

Legislation, Polices, Plans and Guidelines	Intent
State	
Environmental Protection Act 1986	This State Act provides for an EPA, for the prevention, control and abatement of pollution and environmental harm, and for the conservation, preservation, protection, enhancement and management of the environment.
Fisheries Resources Management Act 1994	Provides a legal framework to conserve, develop, and share fish resources for the benefit of current and future populations in WA. This legislation also provides the management framework for the Abrolhos Islands reserve and for the establishment and management of the Fish Habitat Protection Areas.
The Management Plan for the Houtman Abrolhos Islands. Fisheries Management Paper 260. (Department of Fisheries 2012)	The Houtman Abrolhos Islands Management Plan outlines both the vision and strategic objectives of management of the Abrolhos for the next ten years. It aims to conserve and promote the unique environmental and cultural heritage values of the Abrolhos Islands. The Plan's management objective for water quality is: "*To minimise the impact on water quality in the waters of the Abrolhos Islands Fish Habitat Protection Area as a result of human activities, such that water quality is maintained within relevant standards, consistent with the purposes for which the waters are used.*"
Environmental Assessment Guidelines (EAG)	
Environmental Assessment Guidelines No.8 (EAG 8) Environmental Assessment Guideline for Environmental Principles, Factors and Objectives (EPA 2015)	The EAG 8 provides guidance for proponents to help them understand the need to consider environmental principles, factors and objectives for the purpose of environmental impact assessment. Environmental principles, factors and objectives are critical to the environmental impact assessment process as they underpin the EPA's decision on the environmental acceptability of a proposal or scheme. In making its decisions, the EPA also takes a holistic approach to assessing environmental acceptability based on a number of broader considerations including whether the proposal aligns with broader international, national and State policies and agreements and takes

	account of the interconnected nature of the environment.
Environmental Assessment Guidelines No.3 (EAG 3) – Protection of Benthic Habitats in Western Australia's Marine Environment December 2009 (EPA 2009	EAG 3 recognises the fundamental importance of the Benthic Primary Producer Habitats (BCH) and the potential consequences of their loss for marine ecological integrity. The EAG 3 expects the following hierarchy of principles to be addressed by proponents when assessing proposals that could damage/ loss of BCH: • Consideration of options to avoid damage or loss of BCH; • Design that minimises damage or loss of BCH; • Best practice in design, construction methods, and environmental management aimed at minimising indirect impacts; • Consideration of environmental offset where substantial cumulative losses of BCH have already occurred; and • Risk to ecosystem integrity within a management unit is not substantial. The EAG 3 also provides a risk-based spatial assessment framework for evaluating cumulative irreversible loss of and/or serious damage of BCHs (EPA 2009). The EPA has termed within which to calculate cumulative losses 'Local Assessment Units'.
Environmental Assessment Guidelines No.7 (EAG 7) Environmental Assessment Guideline for Marine Dredging Proposals (EPA 2011)	The EAG 7 sets out guidance for predicting impacts to benthic communities and habitats due to significant dredging activities. The EPA has developed a spatially-based zonation scheme for proponents to use as a common basis to describe the predicted extent, severity and duration of impacts associated with the dredging proposals. The scheme consists of three zones that represent different levels of impact (EPA 2011) : • Zone of High Impact (ZoHI) - the area where impacts on benthic communities are predicted to be irreversible (defined as lacking capacity to return or recover to a pre-dredging state within a timeframe of five years. • Zone of Moderate Impact (ZoMI) - the area where predicted impacts on benthic communities are expected to be sub lethal and/or the impacts recoverable within a period of five years following completion of the dredging activities. • Zone of Influence (ZoI) - the area where changes in environmental quality associated with dredge plumes are predicted, but these changes are not expected to result in a detectable impact on benthic communities.
Environmental Assessment Guidelines No. 15 (EAG 15) *Protecting the Quality of Western Australia's Marine Environment*	As part of the PER document, an environmental quality management framework (EQMF) has been developed in accordance with EAG 15 (EPA 2015) to protect the environmental values of the marine environment from any organic waste and, or, contaminants associated with the proposed aquaculture. Consistent with EAG 15, the environmental impact assessment (EIA) for the MWADZ Proposal involved modelling the distribution and fate of aquaculture waste. This information informed the development of specific environmental quality criteria for the purpose of monitoring the effects of organic enrichment on the marine environment. For this sea cage aquaculture, EAG 15 suggests the most appropriate level of ecological protection is a Moderate Ecological Protection Area (MEPA). The EQMF developed for the MWADZ Proposal will manage sea cage aquaculture within 'floating' MEPAs which are proportionate to fifty per cent of any given lease area. The EQMF is devised to maintain the

	existing environmental quality of remaining fifty per cent of the MWADZ and the surrounding area at a high level of ecological protection (HEPA).
Commonwealth	
Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC and ARMCANZ 2000)	Provides water quality standards for marine waters and a guide for setting water quality objectives to sustain current or likely future environmental values for natural and semi-natural waters in Australia and New Zealand. Provides trigger values for a range of organic and inorganic compounds that, if exceeded, should be addressed.
National Water Quality Management Strategy - Water Quality Management (ANZECC and ARMCANZ 1994)	Aims to achieve sustainable use of the nation's water resources by protecting and enhancing their quality while maintaining economic and social development.

7.2 Existing Environment

7.2.1 Baseline Sampling

Sampling of marine sediment and water quality was conducted in the marine waters within the MWADZ Proposal study area and the surrounding waters to describe the biogeochemistry of the strategic proposal area and the region for the purpose of establishing a baseline and to inform environmental modelling for the proposal.

The experimental design includes multiple sampling sites at the impact location (north and south), and reference locations to provide multiple sets of data over multiple seasons. The baseline dataset provides a comprehensive context to future monitoring results.

In addition to sediment and water quality parameters, the following phyisco-chemical parameters (below) were logged through the water column:

- temperature (°C)
- pH/oxidation/reduction potential (pH units, mV)
- conductivity/salinity (mS/cm, ppt)
- dissolved oxygen (DO, mg/L)
- turbidity (NTU)
- depth (metres)
- incident irradiance (photosynthetically active radiation [PAR])
- metocean data (hydrodynamics).

7.2.2 Hydrodynamics and Wave Climate

Currents around the Abrolhos Islands are dominated by the Leeuwin Current system, primarily consisting of the Leeuwin Current (an offshore, southward-flowing current, usually stronger in winter and weaker in summer) and the Capes Current (a nearshore, northward-flowing current, strongest in summer) (Pattiaratchi & Woo, 2009).

Current speeds and wave heights were measured in the Northern and Southern Areas of the proposed MWADZ (refer to Appendix 1) with the aid of Acoustic Doppler Current Profilers (ADCPs). These were deployed as described in Table 7-2.

Table 7-2: Timing of the Deployment of ADCPs within the proposed MWADZ

Metocean conditions	Autumn		Winter		Spring		Summer	
	May	**Jun**	**Aug**	**Sep**	**Nov**	**Dec**	**Feb**	**Mar**
ADCPs (Department of Fisheries)	In	Out	In	Out	In	Out	In	Out

Rose plots of depth-averaged current speed measured by the ADCPs are presented in (Figures 7-1 and 7-2). The currents in the Southern Area flowed primarily east and west, influenced by the presence of the adjacent Pelsaert Group of the Abrolhos Islands. Current flow was predominantly westward during the May-June deployment, switching to eastward during the November-December deployment, with no dominant current direction during the August-September or February-March deployments.

Currents in the Northern Area are typically stronger than those in the Southern Area, but with no dominant direction of flow during the May-June (Figure 7-1) and August-September deployments. During the summer deployments, the direction of flow was typically to the northwest, with current speeds of approximately 0.1-0.3 metres per second (Figure 7-2).

The wave climates were similar between the areas in the proposed MWADZ, although with lower significant wave height in the Northern Area. Mean significant wave height was 1.6 metres (northern site) and 2.2 metres (southern site) during the July-November deployment, and 1.5 metres (northern site) and 2.1 metres (southern site) during the November-March deployment.

Mean wave periods were approximately 11-12 seconds during the July-November deployment and 8-10 seconds during the November-March deployment in both areas. Peak wave direction was from the south-southwest.

For further details on the hydrodynamics investigations undertaken, refer to Appendix 1.

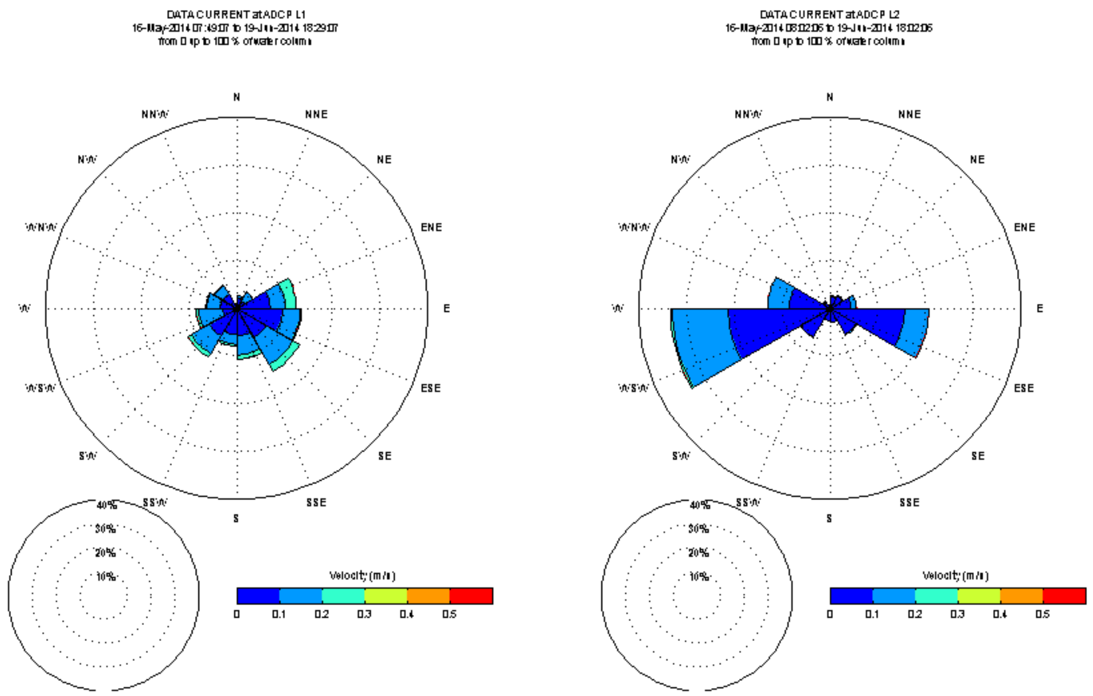


Figure 7-1: Current directions and speeds in the Northern and Southern Areas of the proposed MWADZ between May and June 2014

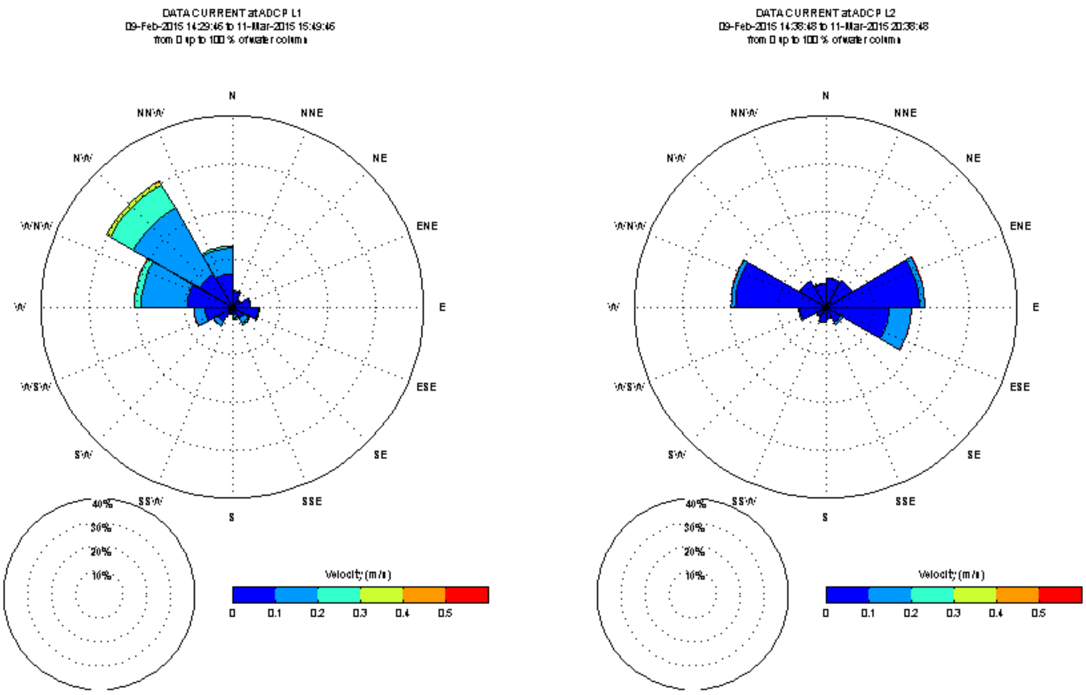


Figure 7-2: Current directions and speeds in the Northern and Southern Areas of the proposed MWADZ between February and March 2014

7.2.3 Marine Sediment Quality

Marine sediment quality measurements and samples were taken in the marine waters at the MWADZ study area and the surrounding waters (Figure 7-3).

7.2.3.1 Baseline Sediment Quality Sampling and Analysis Methods

Sediment samples were obtained at a total of 33 sites comprising of 12 sites in the northern area and 9 sites in the southern area, and an additional 12 reference sites, located at least three kilometres away from the proposed MWADZ. As with the water quality sites, sites were positioned to allow for future Multiple-Before-After-Control-Impact (MBACI) framework of Keogh and Mapstone (1997) and stratified to capture the presence of sediment quality gradients, if present. Refer to Table 7-3 for a list of sediment quality parameters.

For details of the sampling and analysis methodologies, refer to the Modelling and Technical Studies (Appendix 1).

Table 7-3: Timing of Sampling for Baseline Sediment Quality

	Summer	Winter
	August	February
Sediment quality sampling		
Total nitrogen / Total phosphorus	✓	✓
Total organic carbon / Dissolved organic carbon	✓	✓
Trace metals (Ag, As, Cd, Co, Cr, Cu, Ni, Pb, Sb, Se, Zn, Hg, Fe, Li, Mn)	✓	✓
PAH/TPH	✓	✓
pH/oxidation–redox potential	✓	✓
Particle size distribution	✓	✓
Infauna community composition	✓	✓

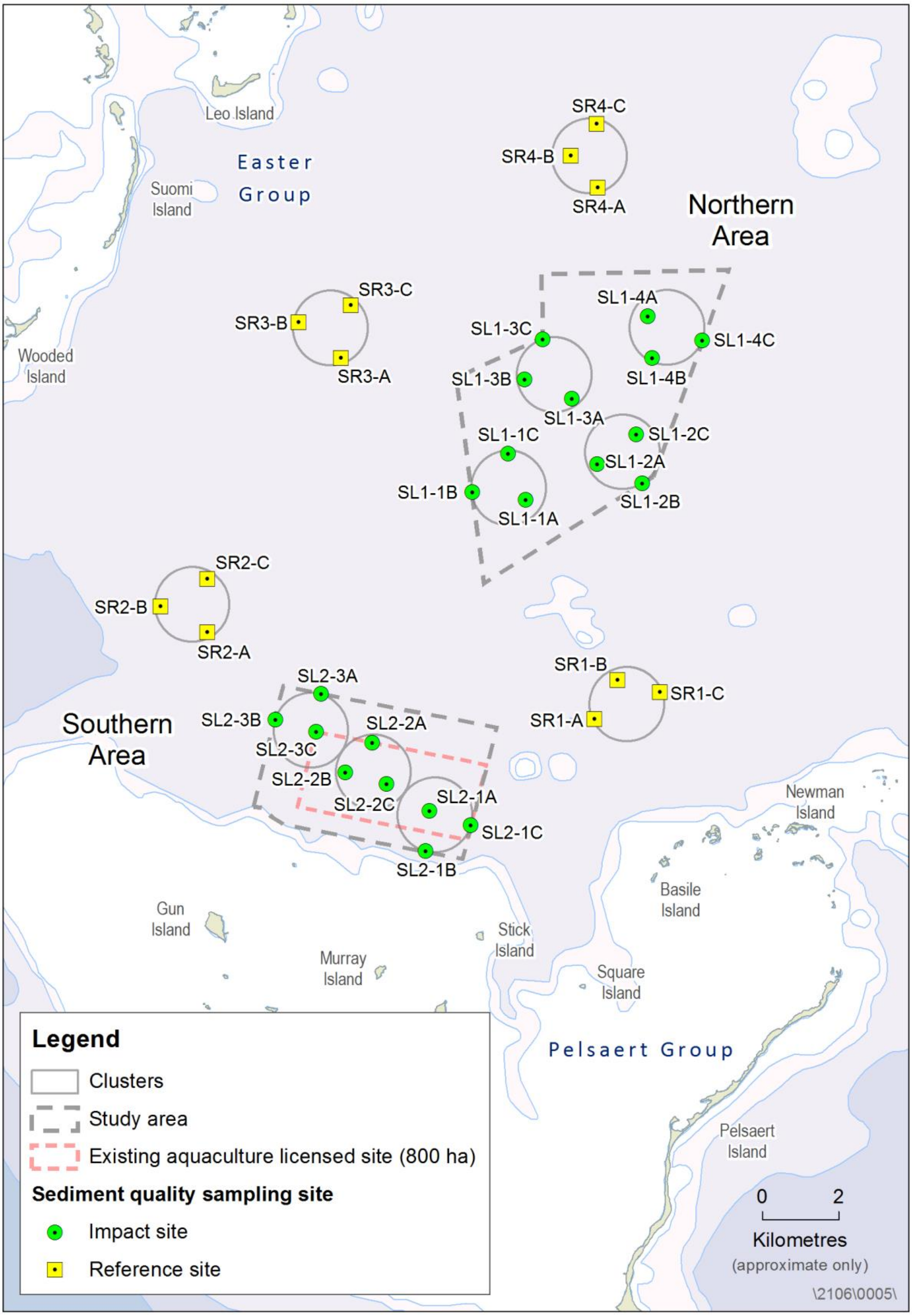


Figure 7-3: Baseline Sediment Quality Sampling Sites

7.2.3.2 Baseline Sediment Quality Sampling and Analysis Results

Particle Size Analysis

In general, there were no major differences in sediment particle sizes between the MWADZ and reference locations (Figure 7-4). However, a high level of variability was observed across locations and seasons. Sediments at all locations were composed of varying proportions of different particle size fractions. Some differences were detected across seasons. Fine to coarse sand particles were dominant fractions in the winter, while fine clays and silts were dominant in summer. Proportions of sediment particle sizes differed across all locations, and across the winter and the summer season.

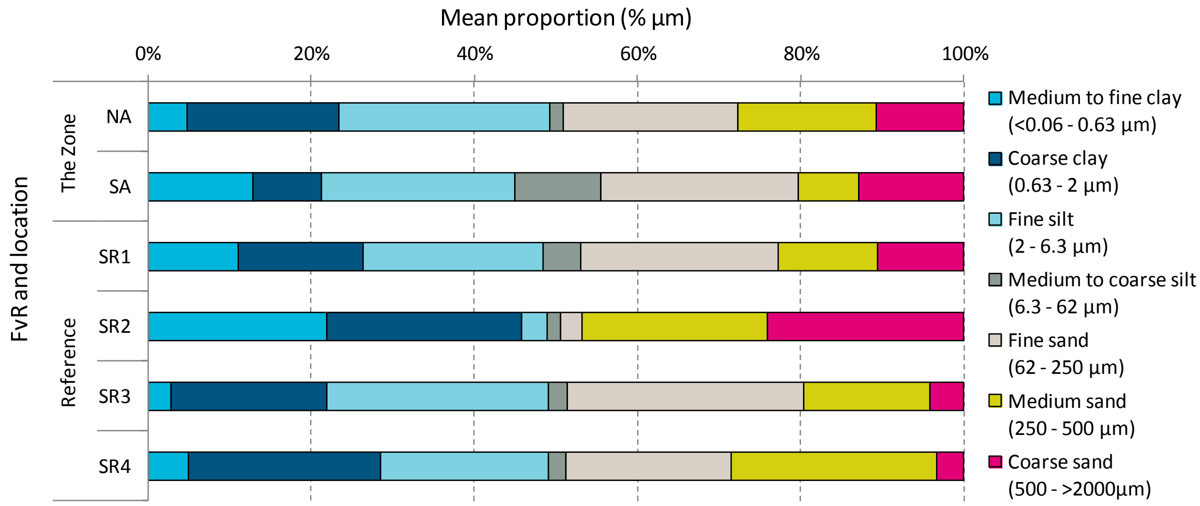


Figure 7-4: Particle Size Results

In relation to sediment composition, the combined northern and southern areas (represented by the proposed MWADZ) differed to the reference locations during the winter. The reference locations were generally dominated by clays (<0.06–0.63 µm) to coarse sands (500>2000 µm). During the summer months both the zone and reference locations were characterised by coarse clay (0.63–2 µm) and medium-sized sand (250–500 µm).

Nutrients

Significant differences were observed between the seasons for ammonium, nitrogen and Total Organic Carbon (TOC) concentrations (Figure 7-5). Phosphorus and TOC concentrations between locations were different. TOC concentrations were higher in the southern area during both summer and winter compared to the northern area.

Ammonium and nitrogen concentrations differed between summer and winter. On average, higher concentrations of ammonium were reported in winter (1.61 mg/kg) relative to summer (1.06 mg/kg). In contrast, a higher percentage of nitrogen was observed in sediments during summer (0.022%) than during winter (0.018%; Figure 7-5). While no seasonal variations were detected for phosphorus concentrations, phosphorus varied across locations.

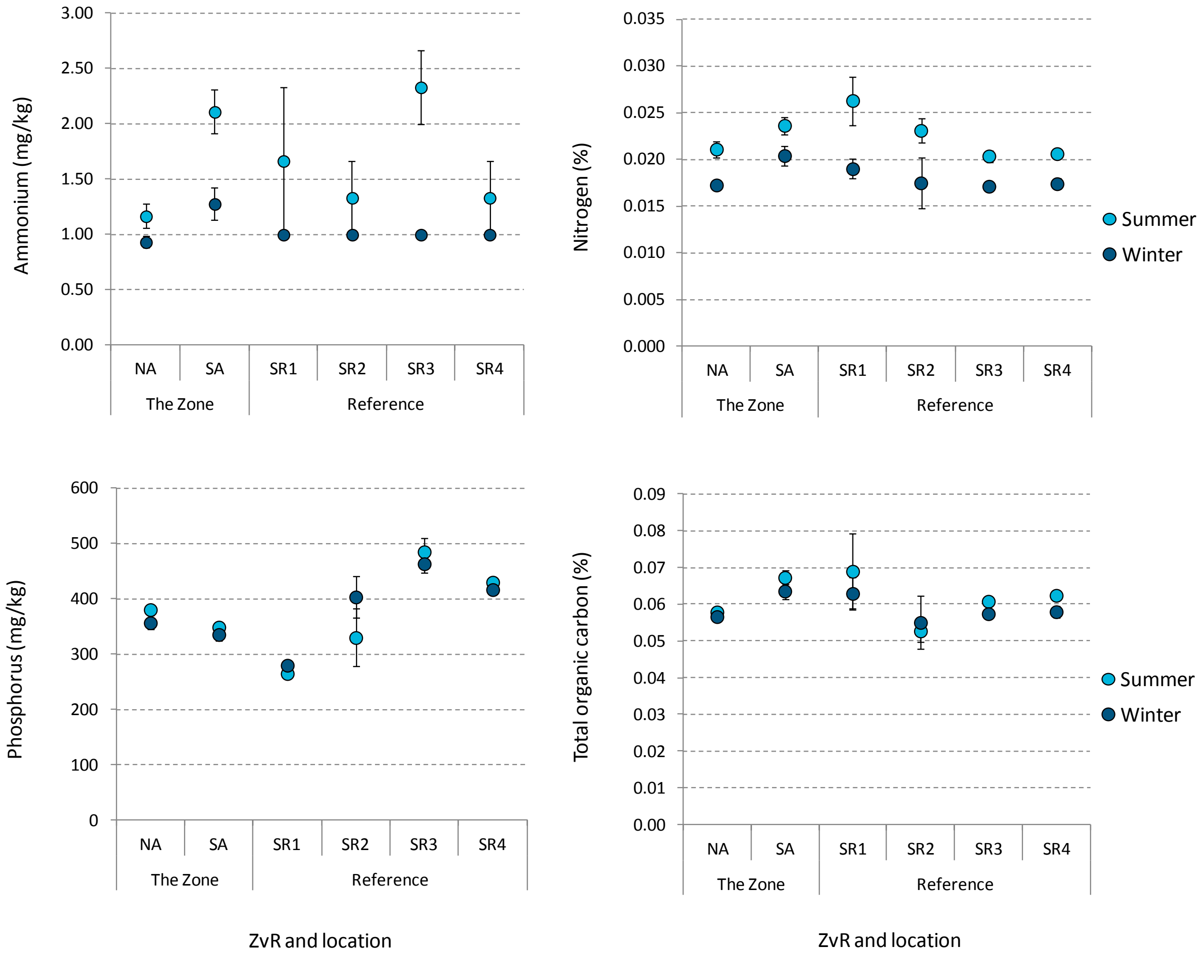


Figure 7-5: Ammonium, Nitrogen, Phosphorus and Total Organic Carbon Concentrations (Mean ± Standard Error) across Seasons and Locations

Metals

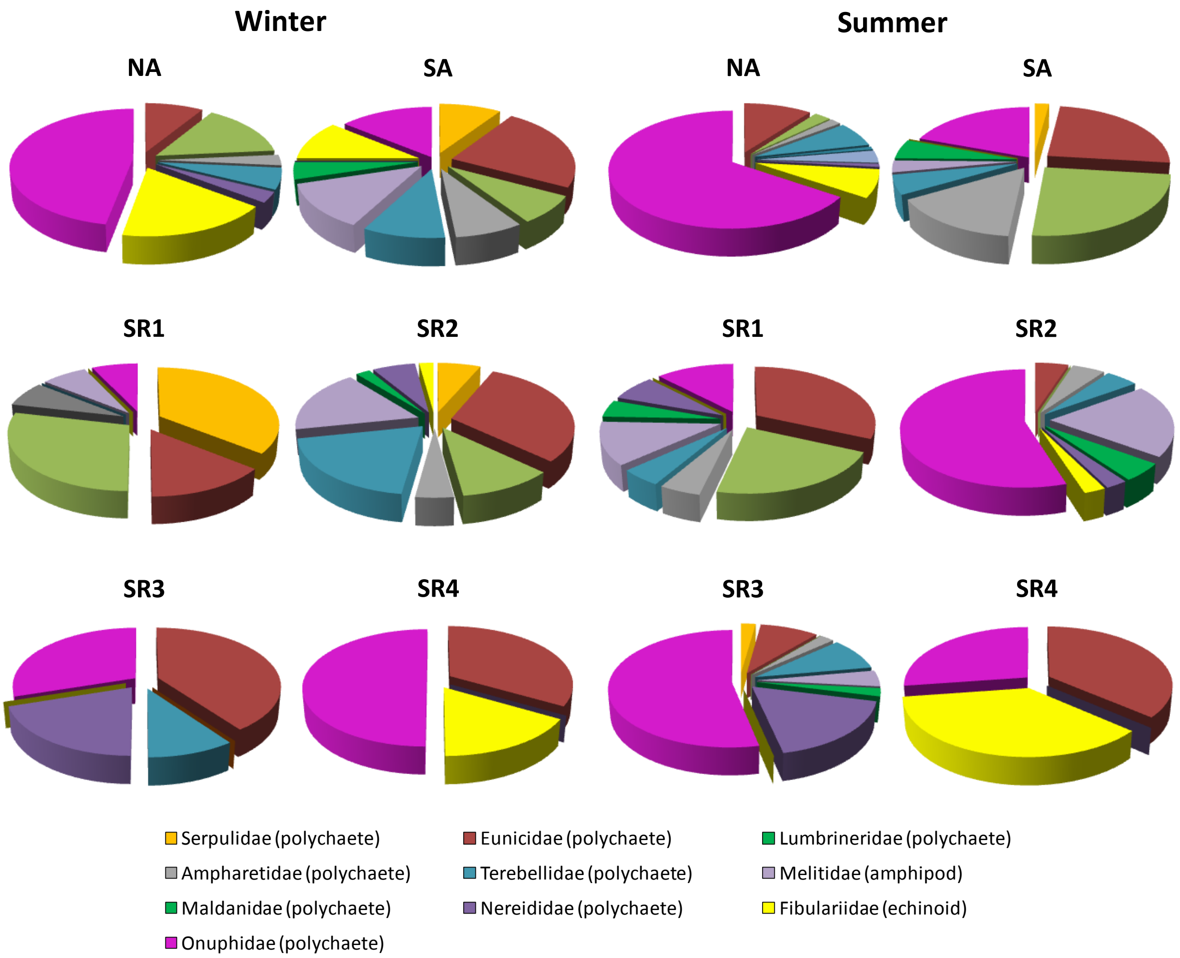
The top five trace metals were aluminium (Al), iron (Fe), chromium (Cr), manganese (Mn) and Cobalt (Co). Trace metals in the MWADZ Proposal area sediments were variable, but low in concentration, across the locations and sampling times. Differences were observed between the zone and the reference locations, but only at certain times. These differences were restricted to the summer sampling period. Differences were detected between the northern and the southern area, and among the reference locations reference locations SR1 and SR4. Reference locations SR2 and SR3 displayed similar characteristics to one another. There was some variability in trace metal concentrations within sampling locations. Reference location SR4 had greater concentrations of Mn, Cr, Fe and Al compared to other locations, while the southern area recorded greater Co concentrations relative to other locations (Appendix 1).

Infauna

Analysis of infauna samples revealed a diverse community, comprising 10 Phyla (Arthopoda, Chordata, Echinodermata, Mollusca, Nematoda, Nemertea, Phoronida, Platyhelminthes, Polychaeta and Sipuncula) and 129 families.

Sampling recorded 36 families of polychaete worms (accounting for 45% of the infauna sampled), 33 families of molluscs (25% of the infauna sampled), 41 families of Arthropods (e.g. crustaceans; 18% of the infauna sampled) and 10 families of echinoderms (e.g. starfish, sea urchins, sand dollars; 7% of the infauna sampled). There was a high level of variability in community structure which was influenced by both season and location.

There were no clear differences in community structure attributable to location only. In general, higher counts of polychaete fauna were reported in summer than winter (Figure 7-6). The southern area contained higher numbers of polychaetes and amphipods in both seasons compared to the northern area; however, the northern area reported higher counts of echinoids, Nereididae and Onuphidae than the southern area.



Note:
2. NA (northern area); SA (southern area); SR (sediment reference locations)

Figure 7-6: Percentage Representation of the Top Ten Most Abundant Infauna Families

Differences in family 'richness' were observed among locations and seasons. In general, higher family richness was observed in summer (17.9 family richness) than in winter (10.1 family richness; Figure 7-7). The southern area reported higher number of families (15.9 family richness) relative to the northern area (11.5 family richness).

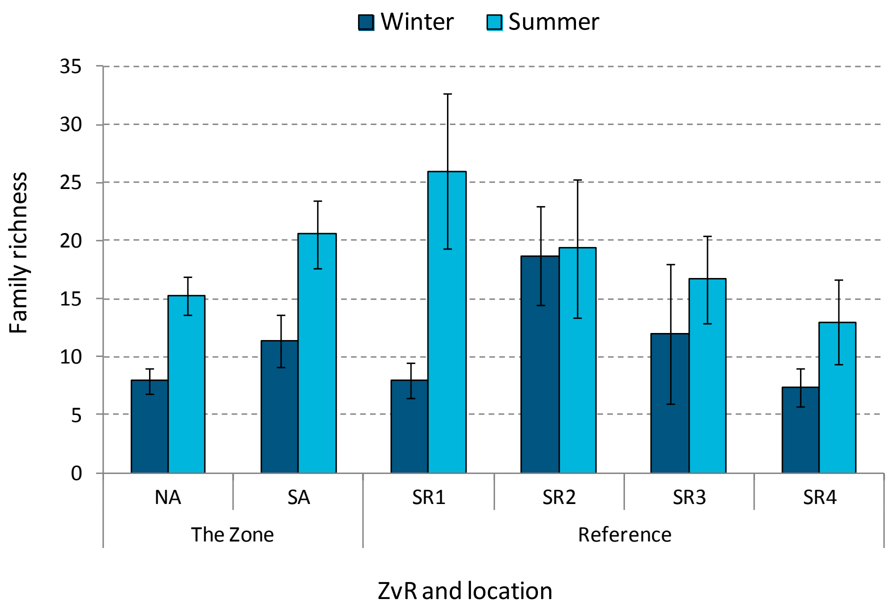


Figure 7-7: Family Richness (Mean ± Standard Error) of Benthic Infauna across Seasons and Locations (Within Zone Vs Richness)

Family abundances were influenced by season, that is, family abundance was greater in summer across all locations (35.39 individual animals) compared to winter (16.09 individual animals; Figure 7-8).

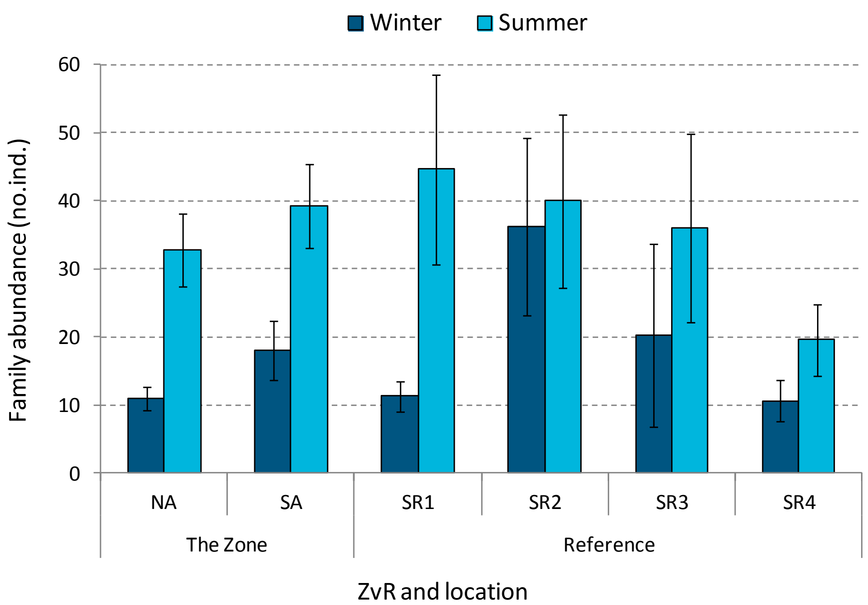


Figure 7-8: Family Abundance (Mean ± Standard Error) of Benthic Infauna across Seasons and Locations

Total Petroleum Hydrocarbons / Polycyclic Aromatic Hydrocarbons

Total petroleum hydrocarbons (TPH) and polycyclic aromatic hydrocarbons (PAH) in marine sediments were generally below the laboratory limit of reporting (LOR). For further results refer to Modelling and Technical Studies (Appendix 1).

7.2.4 Marine Water Quality

Marine water quality measurements and samples were taken in the marine waters at the MWADZ study area and the surrounding waters.

7.2.4.1 Baseline Water Quality Sampling and Analysis Methods

Water samples were obtained at a total of 27 sites comprising of 9 sites in the northern area and 6 sites in the southern area, and an additional 12 reference sites, located at least 3 kilometres away from the perimeter of the proposed MWADZ (Figure 7-9). The water quality sites were positioned to allow for future Multiple-Before-After-Control-Impact (MBACI statistical analysis of the data).

The water samples for chemical analyses were collected at two time points within each season, and from the surface (0–1 metre depth) and bottom (~1 metre from seafloor) of the water column (Table 7.4).

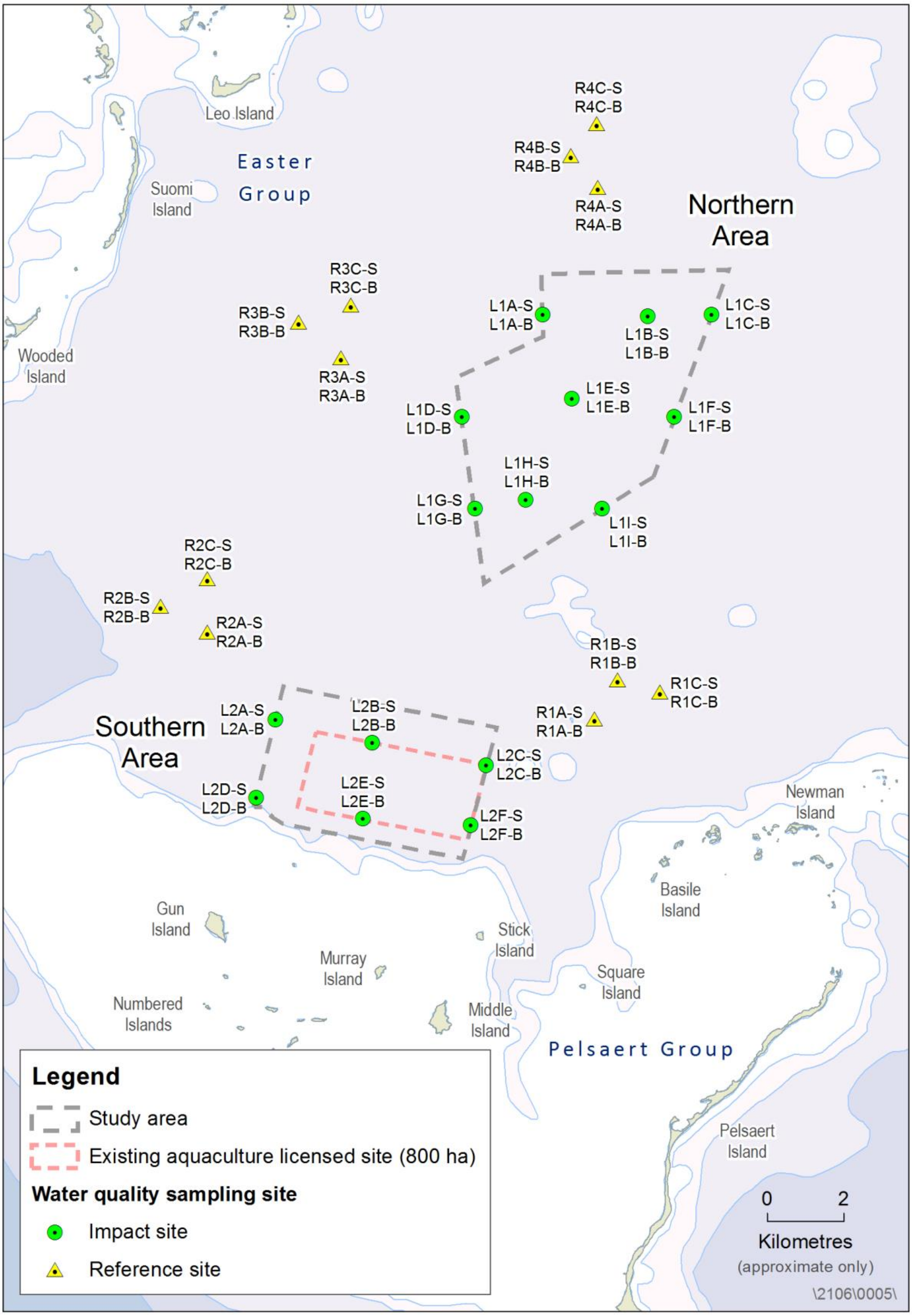


Figure 7-9: Baseline Water Quality Sampling Sites

Table 7-4: Timing of Sampling for Baseline Water Quality (S = surface, B = bottom)

	Autumn				Winter				Spring				Summer			
	May		Jun		Aug		Sep		Nov		Dec		Feb		Mar	
	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B
Light intensity																
In situ PAR data loggers	In		Out		In		Out		In		Out		In		Out	
Water quality sampling																
Physical water quality profiling	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Ammonium / Nitrite + Nitrate / Filterable Reactive Phosphorus	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Total nitrogen / Total phosphorus	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Total organic carbon	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Total suspended solids	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Chlorophyll-a	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Polycyclic Aromatic Hydrocarbon / Total Petroleum Hydrocarbon	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Total sulphides						✓								✓		
Phytoplankton community composition	✓				✓				✓				✓			

7.2.4.2 Baseline Water Quality Sampling and Analysis Results

Salinity

Salinity readings confirmed that the water column was well-mixed at all locations throughout the year. During winter 2014, the northern and southern (SA) MWADZ areas and reference locations had slightly lower salinities throughout the water column [~35.5 g/L (parts per thousand or ‰)] than peak salinities measured in autumn 2014 (~36.2‰) and summer 2015 (~36.0‰; Appendix 1).

Temperature

A temperature gradient was observed at the deeper northern reference location R3 (~43 metres deep) particularly during autumn and summer, when temperatures dropped ~0.36–1.31°C between 15 metres and 25 metres (refer to Appendix 1). The most northern locations displayed similar decreasing trends in water temperatures during autumn and winter. Across all locations, surface temperatures (0–10 metres) were typically lower during spring than summer.

Dissolved Oxygen

Across all locations and sampling periods, mean surface DO saturation was always >96%, while mean bottom DO saturation was always >95%. There was a slight decreasing trend in DO saturation with increasing depth across all locations over all four seasons (Table 7-5).

Table 7-5: Dissolved Oxygen Statistics at All Locations

Season	Autumn			Winter			Spring			Summer		
MWADZ	N	S	R	N	S	R	N	S	R	N	S	R
Mean surface DO (%)	98	98	98	97	96	98	98	99	98	97	98	97
Standard deviation	2	1	2	1	1	2	1	1	1	0	1	1
Mean bottom DO (%)	96	97	95	95	96	96	98	98	97	97	97	97
Standard deviation	3	1	4	1	2	2	1	1	1	0	1	1

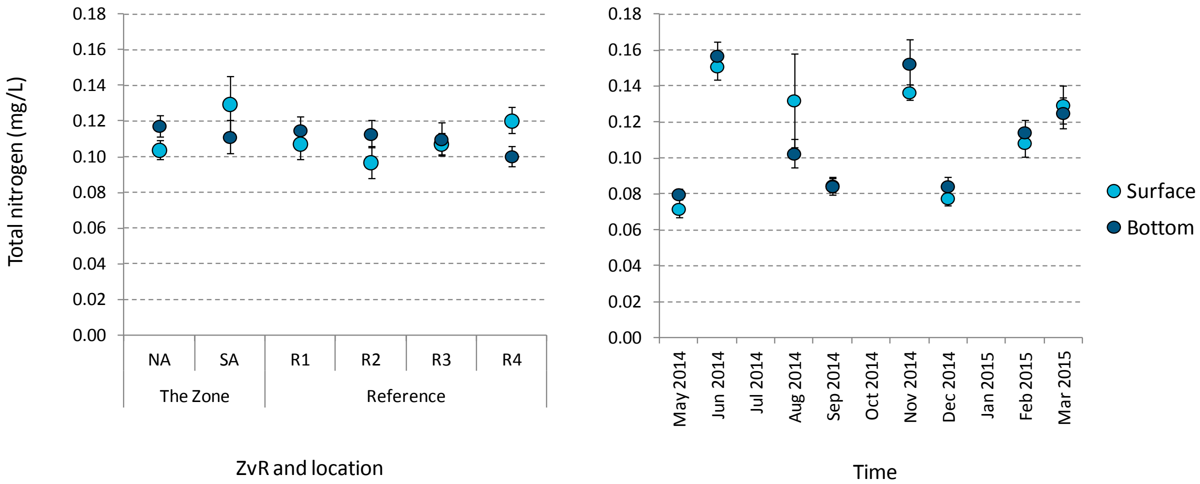
Notes:
1. MWADZ = Mid West Aquaculture Development Zone; N = northern area of MWADZ, S = southern area of MWADZ, R = reference locations
2. DO = dissolved oxygen

Light attenuation and irradiance

During winter (August-September 2014), light attenuation through the water column across the northern and southern areas was similar (0.04–0.19 per metre). During summer (November-December 2014), light attenuation was slightly reduced (0.04–0.15 per metre), from levels seen in winter (above). However, variations in the data across areas were similar.

Total Nitrogen

Total nitrogen (TN) concentrations in both surface and bottom waters fluctuated over time (Figure 7-10). The highest TN concentrations in the water column were reported during winter (June 2014; surface = 0.151 mg/L, bottom = 0.16 mg/L). Generally, the northern and southern study areas (of the proposed MWADZ) recorded slightly higher TN concentrations than the reference locations.



Note:

1. ZvR = Zone locations vs Reference

Figure 7-10: Total Nitrogen (Mean ± Standard Error) Sampled at the Surface and Bottom of the Water Column across Locations (Within ZvR and Time)

Total Phosphorus

Spatial and seasonal fluctuations in total phosphorus (TP) concentrations were apparent (Figure 7-11). In general, both surface and bottom concentrations in TP remained relatively similar across the locations. Generally, surface and bottom waters at all locations recorded higher TP concentrations during summer (February 2014; surface = 0.019 mg/L, bottom = 0.022 mg/L).

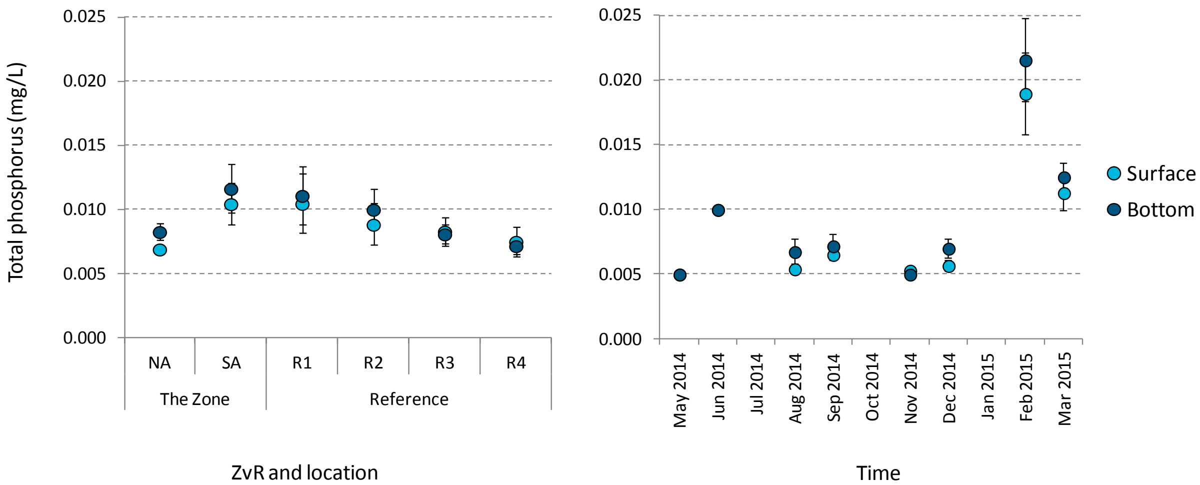


Figure 7-11: Total Phosphorus (Mean ± Standard Error) Sampled at the Surface and Bottom of the Water Column across Locations (Within ZvR and Time)

Total Organic Carbon

Concentrations of total organic carbon (TOC) at all locations varied across sampling times (Figure 7-12). The greatest concentrations of TOC (surface = 1.40 mg/L, bottom = 1.47 mg/L) were recorded during winter (August 2014).

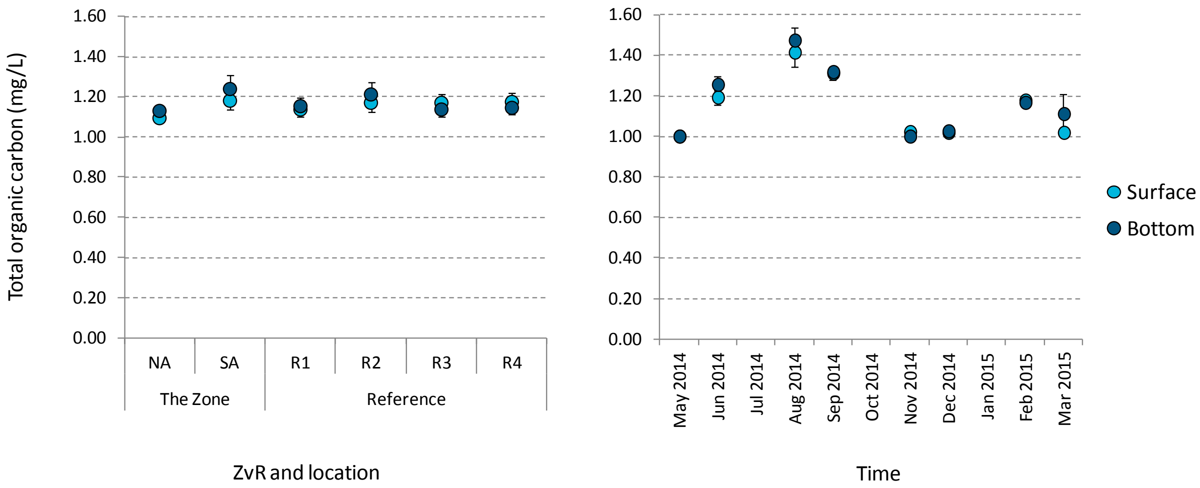


Figure 7-12: Total Organic Carbon (Mean ± Standard Error) Sampled at the Surface and Bottom of the Water Column across Locations (Within ZvR and Time)

Total suspended solids

Concentrations of total suspended solids (TSS) remained relatively constant across all locations, varying between 1.05 mg/L and 2.62 mg/L in surface and bottom waters (Figure 7-13). No differences in TSS concentrations were observed in bottom waters across the sampling locations and times. However, some differences were observed in the surface waters across the sampling times.

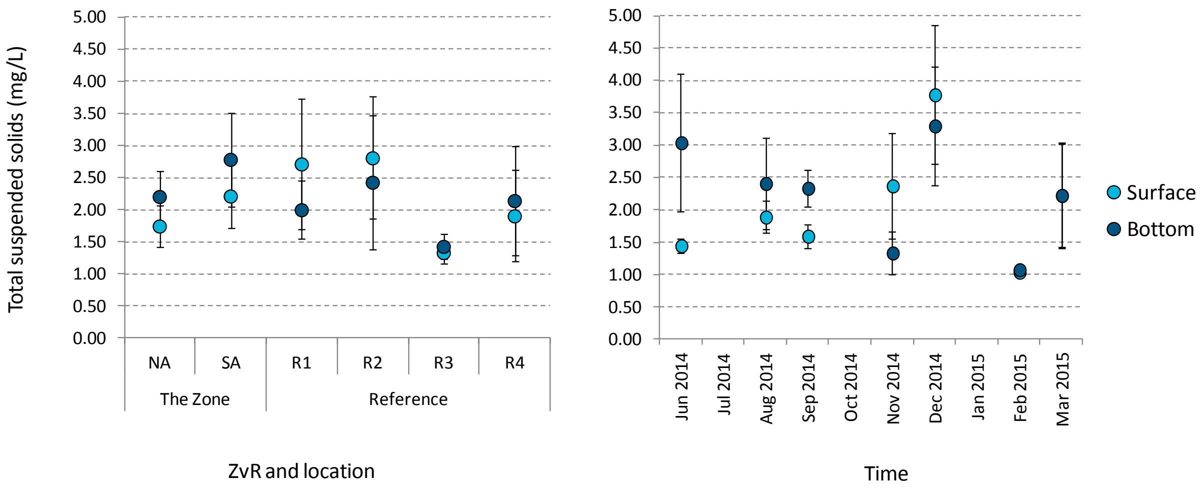


Figure 7-13: Total Suspended Solids (Mean ± Standard Error) Sampled at the Surface and Bottom of the Water Column across Locations (Within ZvR and Time)

Volatile suspended solids

Concentrations of volatile suspended solids (VSS) varied over time and across locations (Figure 7-14). The highest VSS concentrations in surface waters were recorded during summer (December 2014; 1.26 mg/L), and the lowest concentrations in bottom waters were recorded in winter (August 2014; 1.30 mg/L). Notably elevated VSS concentrations were recorded at the reference location R1 (2.33 mg/L) during spring (November 2014).

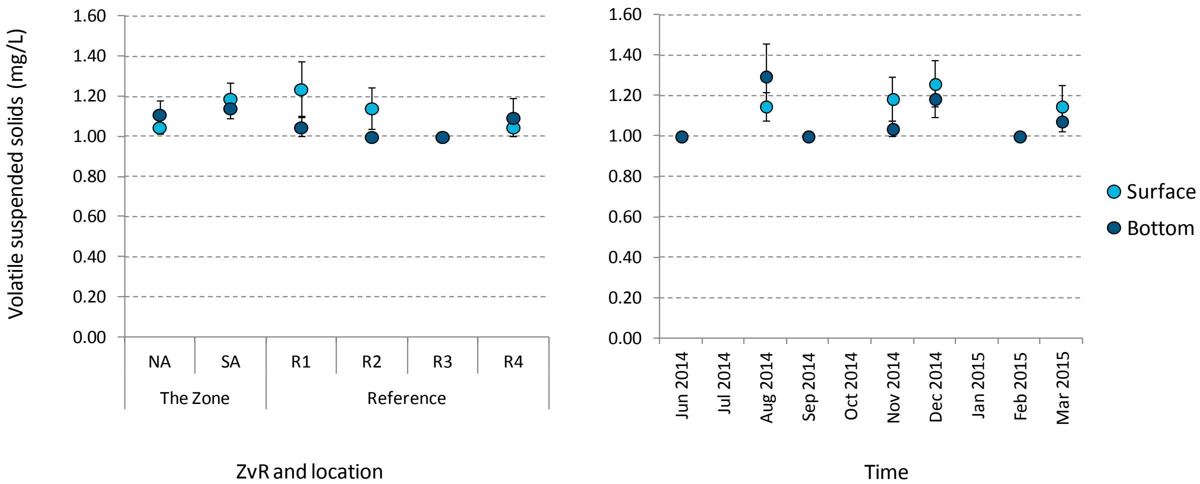


Figure 7-14: Volatile Suspended Solids (Mean ± Standard Error) Sampled at the Surface and Bottom of the Water Column across Locations (Within ZvR and Time)

Ammonia

Ammonia concentrations at the surface of the water column were relatively consistent across locations. However, concentrations were slightly elevated at locations in the northern and southern areas (Figure 7-15). Higher concentrations were also recorded during winter (June 2014; 5.56 µg/L and August 2014; 7.00 µg/L). Similar results were observed for the bottom of the water column. The concentrations were highest in the northern area during winter (June 2014; 9.67 µg/L).

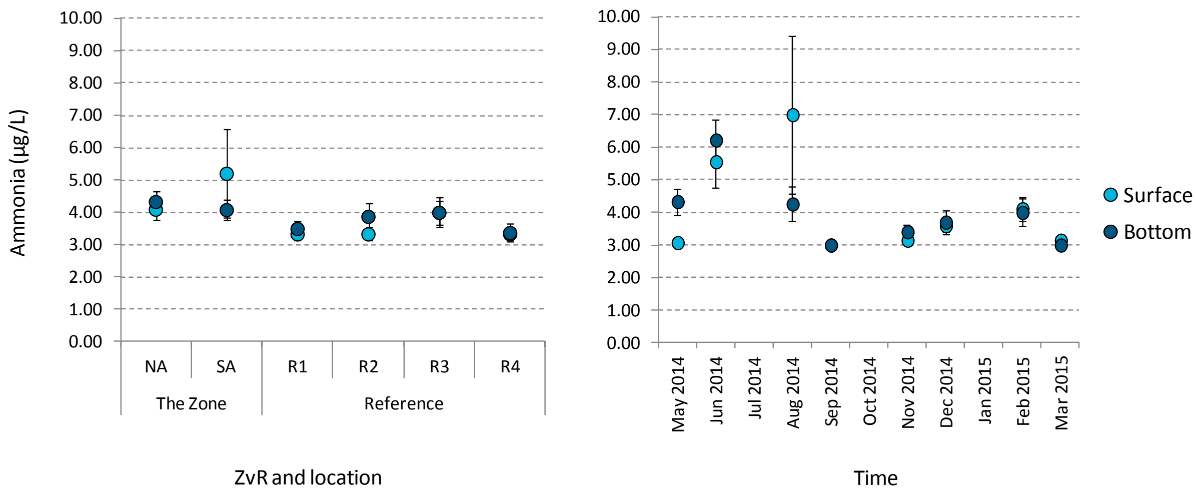


Figure 7-15: Ammonia (Mean ± Standard Error) Sampled at the Surface and Bottom of the Water Column across Locations (Within ZvR and Time)

Orthophosphate

Fluctuations in orthophosphate concentrations were apparent across various locations and sampling times. In general, similar surface concentrations were recorded across the northern and southern areas and the reference locations (Figure 7-16). The highest orthophosphate concentrations (4.52 µg/L) in the surface waters were reported during winter (August 2014) in the southern area and reference location R3.

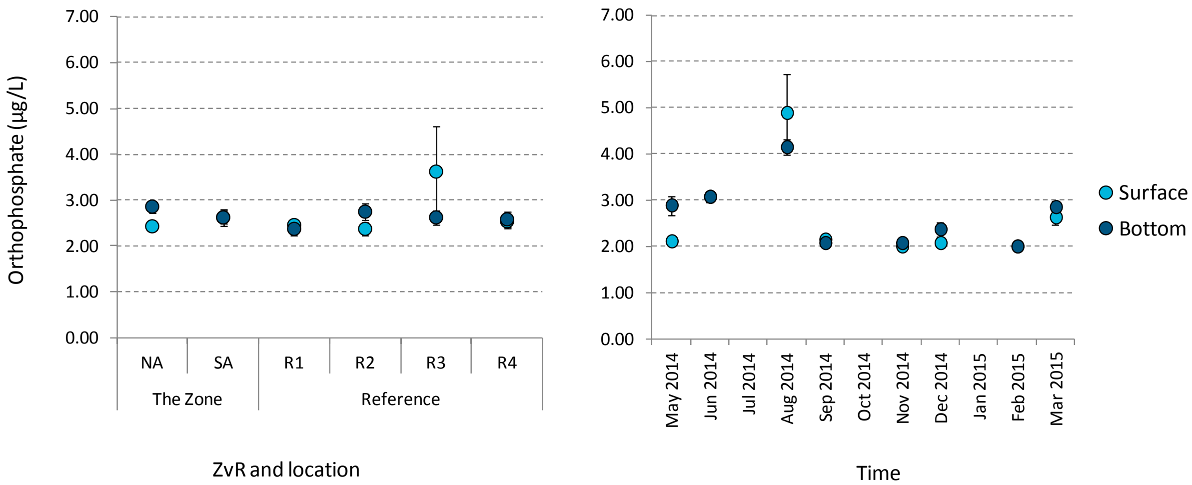


Figure 7-16: Orthophosphate (Mean ± Standard Error) Sampled at the Surface and Bottom of the Water Column across Locations (Within ZvR and Time)

Dissolved inorganic nitrogen

Seasonal variations in concentrations of dissolved inorganic nitrogen (DIN) were observed in the surface and bottom of the water column. DIN concentrations at the surface were highest during winter (August 2014; 39.67 µg/L), but also relatively high in summer (December and February). Bottom waters concentration were highest during winter (August 2014; 30.59 µg/L), and lowest during autumn (March 2015; 7.78 µg/L). The combined northern and southern areas recorded the higher concentrations of DIN (zone locations = 22.58 µg/L) compared to combined reference locations (17.60 µg/L; Figure 7-17).

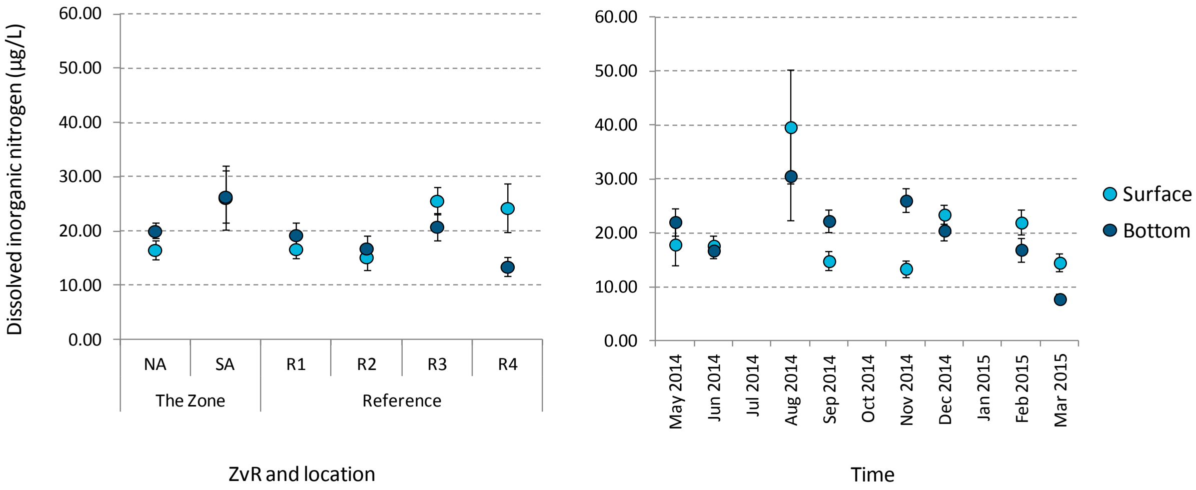


Figure 7-17: Dissolved Inorganic Nitrogen (Mean ± Standard Error) Sampled at the Surface and Bottom of the Water Column across Locations (Within ZvR and Time)

Nitrate and nitrite

Concentrations of nitrate and nitrite (NOx) at the top and bottom of the water column were greatest during winter (August 2014; surface 32.67 µg/L and bottom 26.33 µg/L). There was also some variation in concentrations across the locations. On average, reference locations R3 and R4 recorded the greatest surface waters concentrations (21.63 µg/L and 20.96 µg/L). A decline in bottom water concentrations was recorded over the warmer months, between spring (November 2014) and autumn (March 2015; Figure 7-18).

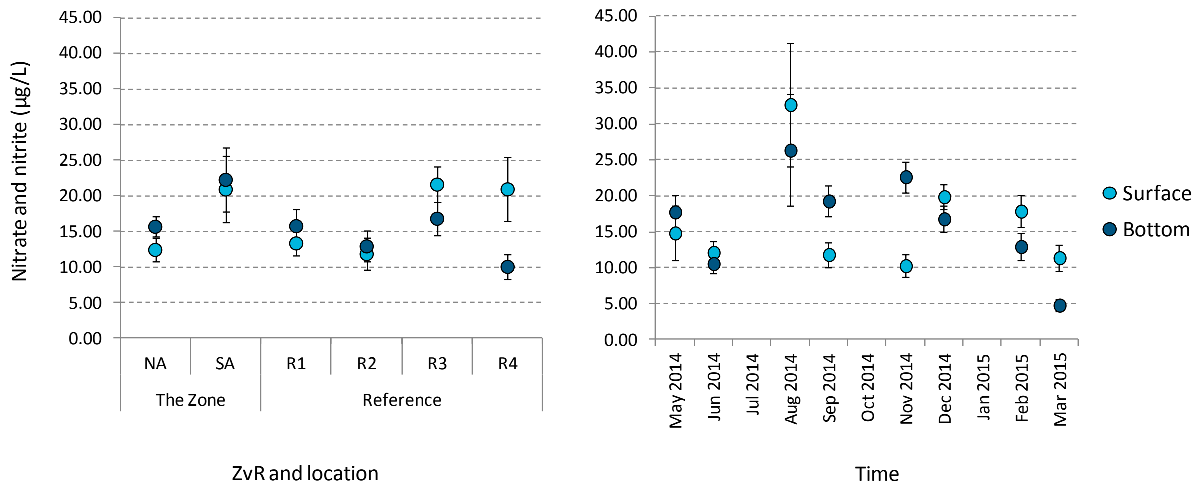


Figure 7-18: Nitrate and Nitrite (Mean ± Standard Error) Sampled at the Surface and Bottom of the Water Column across Locations (Within ZvR and Time)

Hydrogen sulphide

Concentrations of hydrogen sulphide were below the limit of reporting (0.01 mg/L) in all samples.

__Total Petroleum Hydrocarbons / Polycyclic Aromatic Hydrocarbons__

Total petroleum hydrocarbons (TPH) and polycyclic aromatic hydrocarbons (PAH) were generally below the laboratory limit of reporting (LOR). For further results refer to Modelling and Technical Studies (Appendix 1).

__Chlorophyll-a__

Generally, chlorophyll-a concentrations at the surface and bottom of the water column increased during the warmer months, between spring (November 2014) and autumn (March 2015; Figure 7-19). Reference location R1 had greater concentrations of chlorophyll-a at the surface (0.27 µg/L) and bottom (0.25 µg/L) of the water column in comparison to other locations.

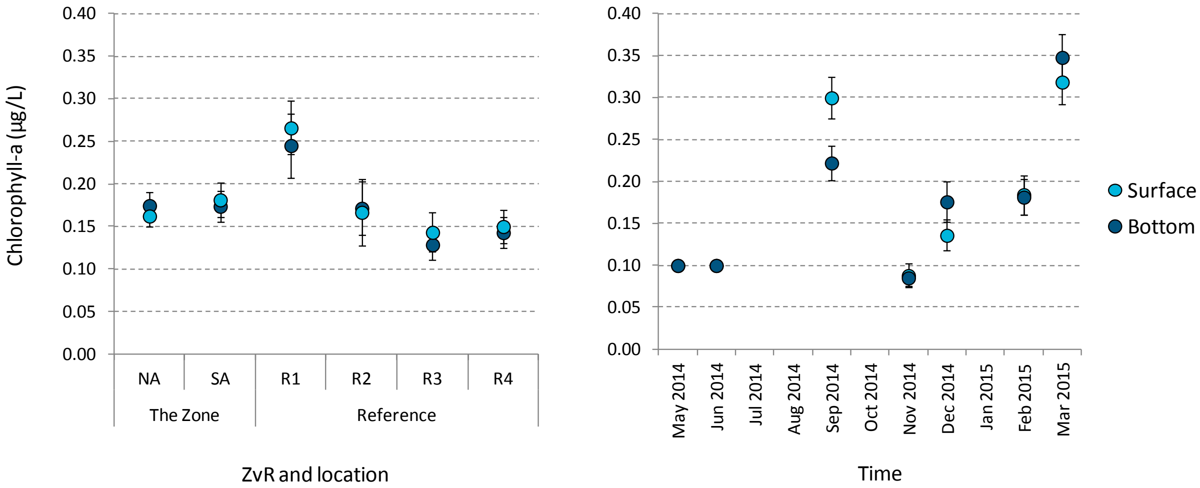


Figure 7-19: Chlorophyll-A (Mean ± Standard Error) Sampled at the Surface and Bottom of the Water Column across Locations (Within ZvR and Time)

__Phytoplankton__

Phytoplankton belonging to six divisions/phyla (Bacillariophyta, Chlorophyta, Chrysophyta, Cryptophyta, Cyanophyta, Dinophyta), plus unidentified others, were sampled across all locations. Counts were notably dominated by the diatoms (Bacillariophyta represented ~90.8% of the total counts), followed by dinoflagellates (~3.5% of the total counts). Of the total counts, 12.4% of taxa were classified as potentially toxic algae and 1.6% as potentially toxic blue green algae.

Large scale fluctuations and differences in community assemblages were evident across locations and sampling times. Phytoplankton counts differed between locations and sampling times. In addition, greater counts of Chlorophyta (green), Cryptophyta (monad), Cyanophyta (blue green) and Dinophyta (dinoflagellates) were reported during autumn (May 2014) and greater counts of Bacillariophyta were recorded during summer (December 2014; 92.93 cells/millilitre; Figure 7-20).

Community assemblages in the northern and southern areas were different to each other; particularly in relation to counts of Dinophyta. Dinophyta was recorded in higher numbers in the southern areas relative to northern area. Reference location R1 recorded phytoplankton counts that were different to counts at reference locations R2, R3 and R4. This difference was primarily driven by relatively high numbers of Bacillariophyta at reference location R1.

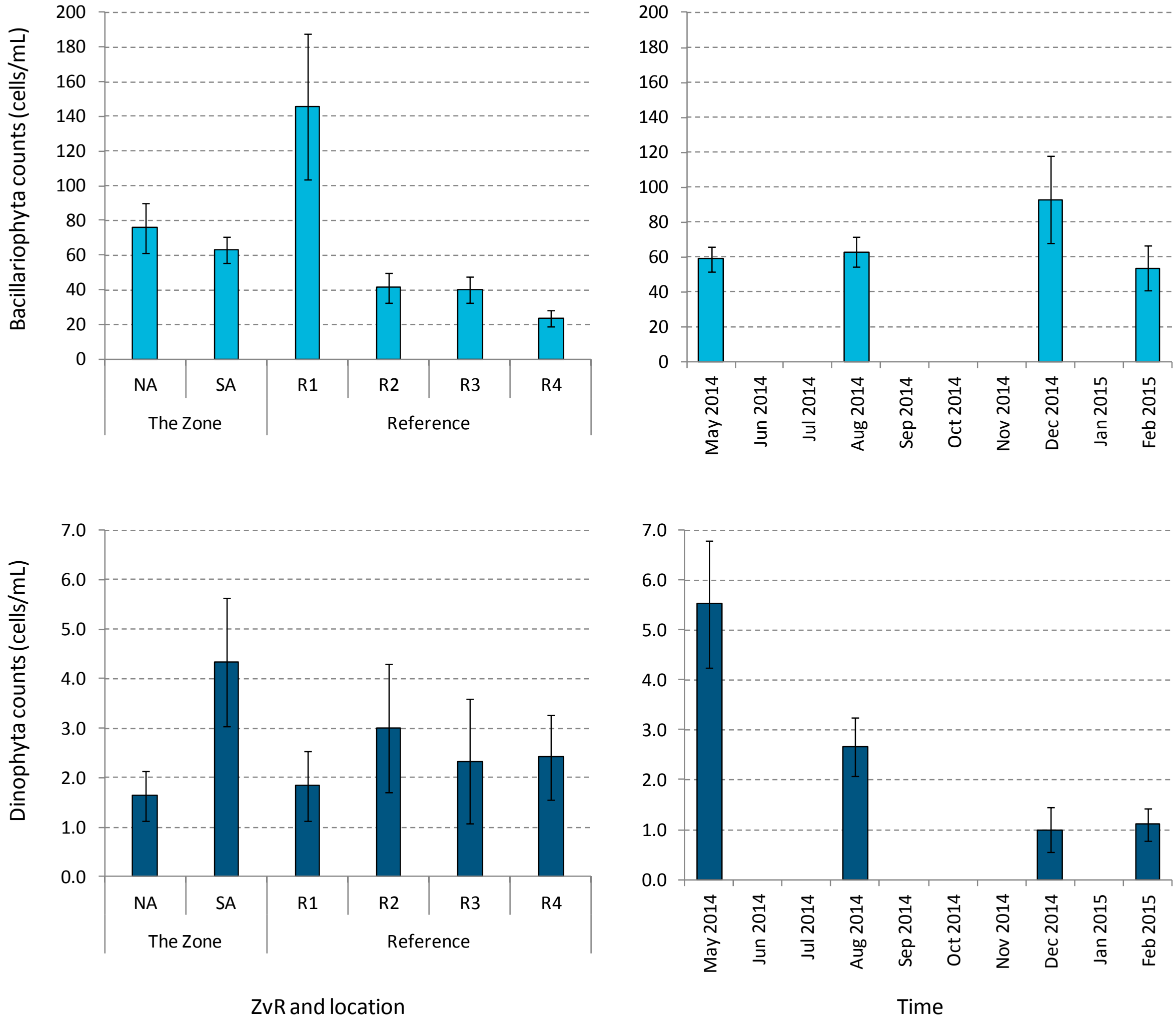


Figure 7-20: Bacillariophyta (Diatoms; Top) and Dinophyta (Dinoflagellates; Bottom) Counts (Mean ± Standard Error) across Locations and Time

Differences in phytoplankton bio-volumes over sampling times and between References locations R1 and R4 were also recorded (Figure 7-21). The reference location R1 recorded notably high bio-volumes of Bacillariophyta and Dinophyta relative to other locations.

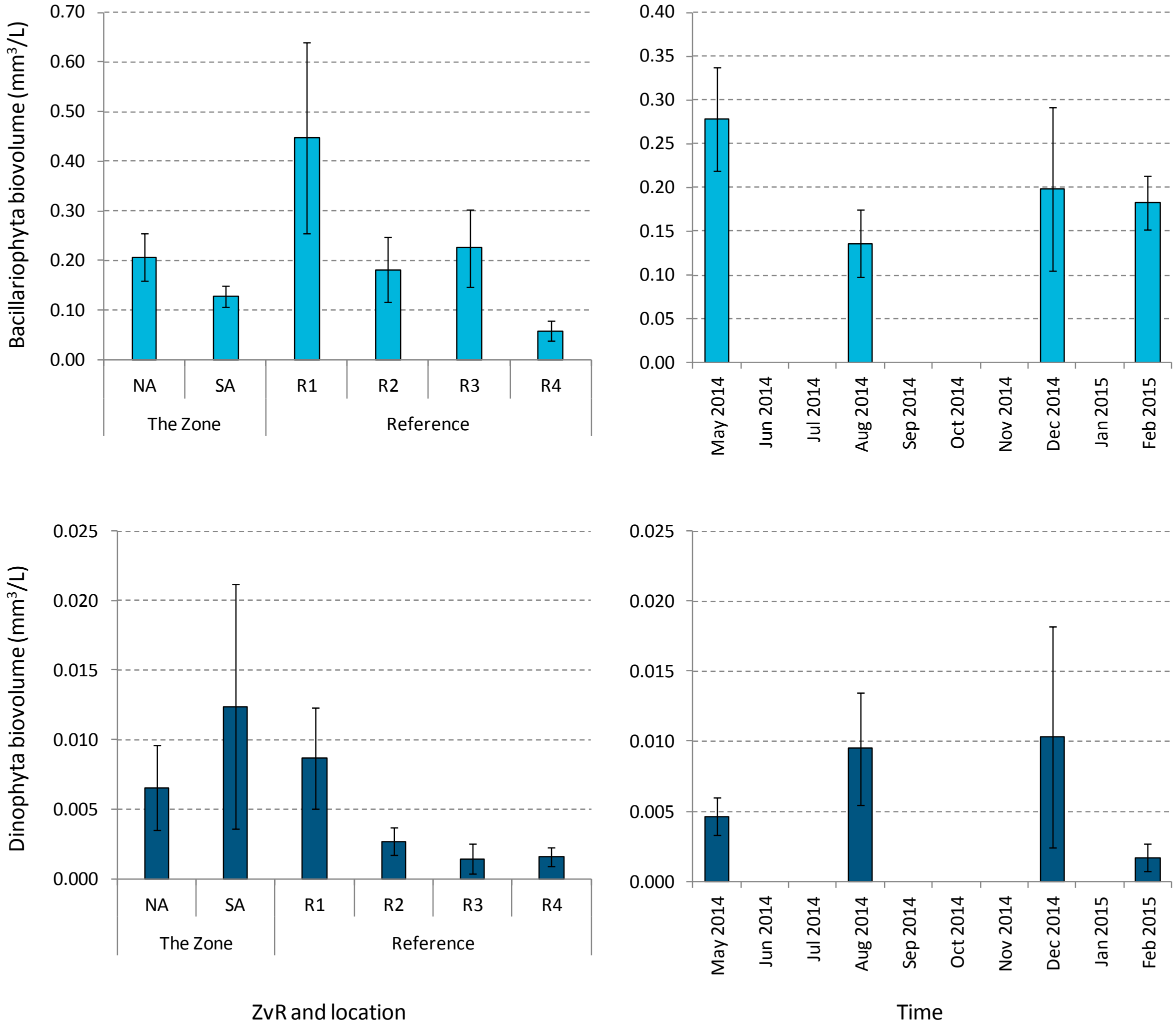


Figure 7-21: Bacillariophyta (Diatoms; Top) and Dinophyta (Dinoflagellates; Bottom) Bio-Volumes (Mean ± Standard Error) across Locations and Time

Total algal and potential toxic algal counts showed differences between locations and sampling times. Differences in algal counts between Reference locations R1 and the other three reference locations (R2, R3 and R4) were recorded. Total algal counts were highest during summer (December 2014; 99.56 cells/millilitre). The greatest counts of potentially toxic algae were recorded during Spring (May 2014; 11.81 cells/millilitre; Figure 7-22).

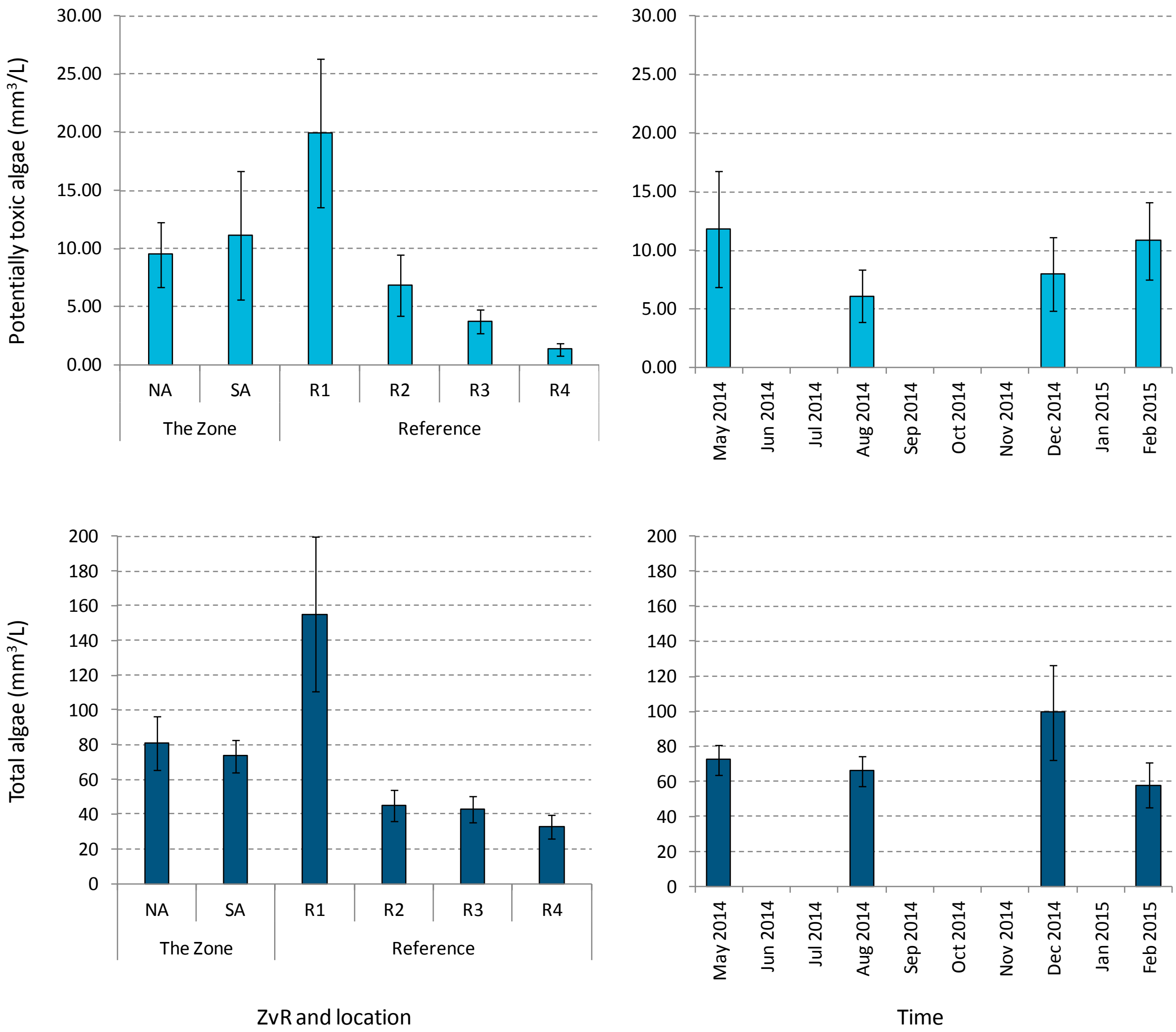


Figure 7-22: Bio-Volumes (Mean ± Standard Error) of Potentially Toxic Algae (Top) and Total Algae (Bottom) across Locations and Time

7.3 Potential Impacts

7.3.1 Organic wastes

Sea cage aquaculture has the potential to impact the sediment when organic wastes settle beneath, or in close proximity to, the sea-cages (Mazzola et al. 2000, Carroll et al. 2003). The deposition of organic material may lead to local organic enrichment or, under worst-case conditions, regional eutrophication. Gray (1992) emphasises that the critical effects of eutrophication are experienced when water column oxygen concentrations become depleted as total community respiration increases due to increased organic loads to the sediments.

Increased nutrient loadings are generally associated with increased episodes of hypoxia (low oxygen) or anoxia (no oxygen). Hypoxia may cause local extinction of benthic populations (Gaston & Edds 1994) and changes in benthic communities (Pearson & Rosenberg 1978, Josefson & Jensen 1992, Hargrave et al. 2008; Hargrave 2010). Changes in communities are typically driven by the sensitivities of infauna, with rare and more sensitive species disappearing first.

More resilient species such polychaetes are known to be resistant to hypoxic or near-hypoxic conditions (Pearson & Rosenberg 1978, Gray 1992, Dauer et al. 1992). Sediment infauna communities generally becomes increasingly degraded (diversity of benthic fauna is significantly reduced) as levels of organic enrichment are increased.

Although finfish farming has the potential to impact sediments beneath, and immediately adjacent to sea cages (Carroll et al 2003), impacts are generally restricted to within 10–100 m of sea cages. The magnitude of impact depended largely on the depth of the water and the rate of water movement through the site (Carroll et al. 2003, Crawford 2003, Borja et al 2009). The current speeds in the MWADZ are conducive to conditions described as either "moderately" or "not sensitive" to impact on the seafloor sediments and associated communities (Appendix 1).

7.3.2 Inorganic nutrients

Finfish aquaculture in open water sea cages may, in some instances, cause deterioration in local water quality due to inputs of inorganic nutrients from fish faeces and uneaten food. Aquaculture may contribute inorganic nutrients to the water column either directly through secretion of ammonia by fish, or indirectly through organic matter deposition and remineralisation. Inorganic nutrients in the form of ammonia, nitrite + nitrate and phosphate may lead to adverse environmental effects via a number of cause-effect pathways, all of which lead to impacts on BCH. Increased levels of nutrients such as ammonia, nitrite + nitrate and phosphate can stimulate plant growth (i.e. phytoplankton levels in the water column could be elevated). However, the water current speeds in the MWADZ are conducive to conditions unlikely to results in impacts to regional water quality (Appendix 1).

7.3.3 Ecosystem nutrient budget

The level of nutrients in the ecosystem is influenced by the release and uptake of substances from seafloor sediments and the flow of oceanic currents through the region. In Abrolhos Islands FHPA, both of these processes are considered to be in balance (in the absence of sea cage aquaculture) relative to other locations [i.e. the existing environment is essentially oligotrophic (naturally low in nutrients)].

The addition of the proposed fish cages causes an imbalance to the natural nutrient budget of the ecosystem, and has been a key subject of investigation in this study. This disturbance takes the form of both an immediate nutrient load to the water column (via waste and feed excess) and a delayed load via impacted sediment nutrients converting back into minerals (Appendix 1). Water current speeds in the MWADZ facilitate the natural assimilative capacity of the ecosystem to maintain acceptable water quality within and surrounding the zone (Appendix 1).

7.3.4 Metals and other contaminants

Toxic effects on marine organisms are likely when metal concentrations exceed certain levels (Parsons 2012); such effects can be intensified via biomagnification. Sources of metals include copper-based anti-foulants, which were historically used on sea-cage infrastructure (Parsons 2012). The use of copper-based anti-foulants will not be permitted within the MWADZ.

Metals form a small constituent of commercial aquaculture feeds as trace elements. The metals are consumed by the stock and excreted in the faeces. The metal content of stock faeces are likely to be highest in zinc and iron, with relatively low proportions of copper; however the concentrations of these elements are not expected to build up in the sediments of the MWADZ (Appendix 1).

Occasionally, when required to manage any incidence of bacterial disease, antibiotics are used to treat the stock. Generally, the antibiotics are administered via the stock feed. Antibiotics may impart pressure on the marine environment by degrading sediment bacterial communities, which in turn could affect their ecological functions. Any concentrations of antibiotics would deplete over several seasons, and are not expected to build up in the sediments of the MWADZ (Appendix 1).

7.4 Assessment of Potential Impacts

7.4.1 Overview

An Integrated Ecosystem Model was used to simulate a total of six scenarios (Scenario 1 – Scenario 6) as per the criteria detailed in Section 6.6.4 and Tables 6-14 and 6-15. Sections 7.4 to 7.6 describe the predicted impacts of each of these scenarios on the marine environment in terms of hydrology, sediments, BCH and regional water quality. Results are described in the context of EAG 3 (EPA 2009) and EAG 7 (EPA 2011), which describe the concepts around acceptable loss of BCH and zones of impact.

7.4.2 Hydrodynamics

Sea cages or any other floating structures at sea invariably impart some resistance to flows acting to slow or deflect waters that surrounds the cages. The effect of MWADZ sea cages on the surrounding hydrodynamic regime was extrapolated using the findings of Wu *et al.* (2014) together with the known characteristics of the MWADZ environment (12–50 metres depth) and the proposed infrastructure (18 metre depth cages).

Generally, current speeds in the lower part of water column (bottom) is expected to increase by approximately 20%, while current speeds within the cages in the upper part of the water column (surface) is expected to reduce by approximately 80%. Modelling indicated that natural current speeds at the bottom were somewhat slower than those at the surface, in both the summer and winter (Table 7-5).

Within the proposed MWADZ, sediment erosion and deposition is affected by shear stress between water currents and the seafloor. The modelling has indicated that this shear stress originates principally from wave action, with current speed a minor influence. While the sea cages potentially increase the speed of the currents near the seabed by 20%, it is not expected that this will substantially affect the erosion of the seafloor sediments beneath the sea cages.

Table 7-6: Current Speeds through the MWADZ before and after the Introduction of Sea Cage Infrastructure

	Summer		Winter	
	Surface	**Bottom**	**Surface**	**Bottom**
Before the introduction of sea cages	8.7–14.1 cm/s	5.8–11.0 cm/s	10.5–14.5 cm/s	6.1–11.5 cm/s
After the introduction of sea cages	1.8–2.8 cm/s	6.9–13.2 cm/s	2.1–3.0 cm/s	7.3–13.8 cm/s

7.4.3 Seafloor Sediments

An integrated ecosystem model (Section 6.7) was used to determine the distribution and impacts of organic wastes leaving the sea cages. Deposition of organic waste at the seafloor was referred to as "organic deposition", expressed in terms of millimoles of carbon per metre squared per year. Organic deposition was used as a surrogate for organic enrichment of the sea floor sediment and as an indicator of potential secondary effects including deoxygenation and accumulation of sulphides in the seabed. EAG 7 was applied with consideration to the potential secondary effects relating to sediment dissolved oxygen and sulphide content of the sediments (Section 7.4.1.4). The results of the modelling of organic deposition are reported here to provide context for the potential secondary effects of organic enrichment.

Accumulation of organic material occurred under each of the scenarios, and commenced rapidly once production has commenced. Organic deposition beneath sea cages was observed to build rapidly, even under biomasses much lower than those modelled here (less than 1,000 tonnes of stock per 14-cage cluster; Appendix 1). Figures 7-21 to 7-24 show the predicted rate of organic deposition at the seafloor, under a range of scenarios (S5, S1, S6 and S2), after twelve months of continuous finfish production. Organic deposition increased with increasing standing biomass (Scenario 5 and Scenario 6 are greater than Scenario 1 and Scenario 2; Figures 7-21 to 7-24) and increasing stocking density (Scenario 6 is greater than Scenario 5, and Scenario 2 is greater than Scenario 1; Figures 7-21 to 7-24). Organic deposition levels greater than background were detectable beneath and near to the sea cages in each of the modelled scenarios. The highest organic depositional values beneath the sea cages corresponded with the highest levels of standing biomass (Scenario 5 is greater than Scenario 1, and Scenario 6 is greater than Scenario 2).

Modelling showed an intense (highly concentrated) deposition of organic waste that is mainly confined to the area of seafloor immediately beneath the sea cages. The highest organic deposition concentrations were immediately beneath the sea cage clusters. The confinement of the majority of organic deposition to the area immediately beneath the sea cages is indicated in the colour change from light blue to red between Scenario 2 (15,000 tonnes) and Scenario 6 (30,000 tonnes), representing a change in organic deposition that is more than seven-fold higher (Figures 7-23 and 7-24). Areas beyond the sea cage clusters maintained similar levels of organic deposition, despite an increase in standing biomass.

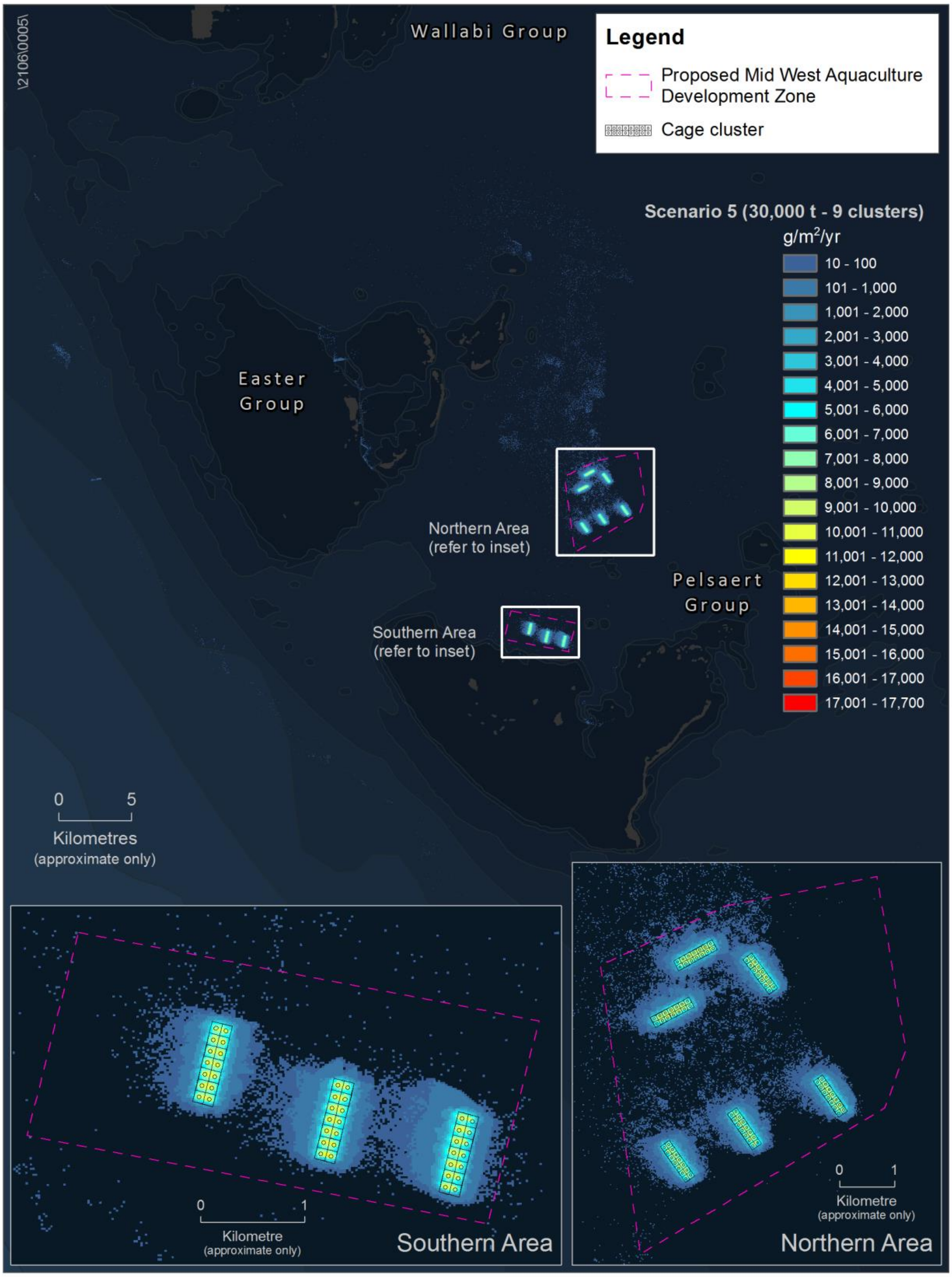


Figure 7-21: Inputs of Organic Carbon under Scenario 5 (30,000 tonnes over 9 clusters)

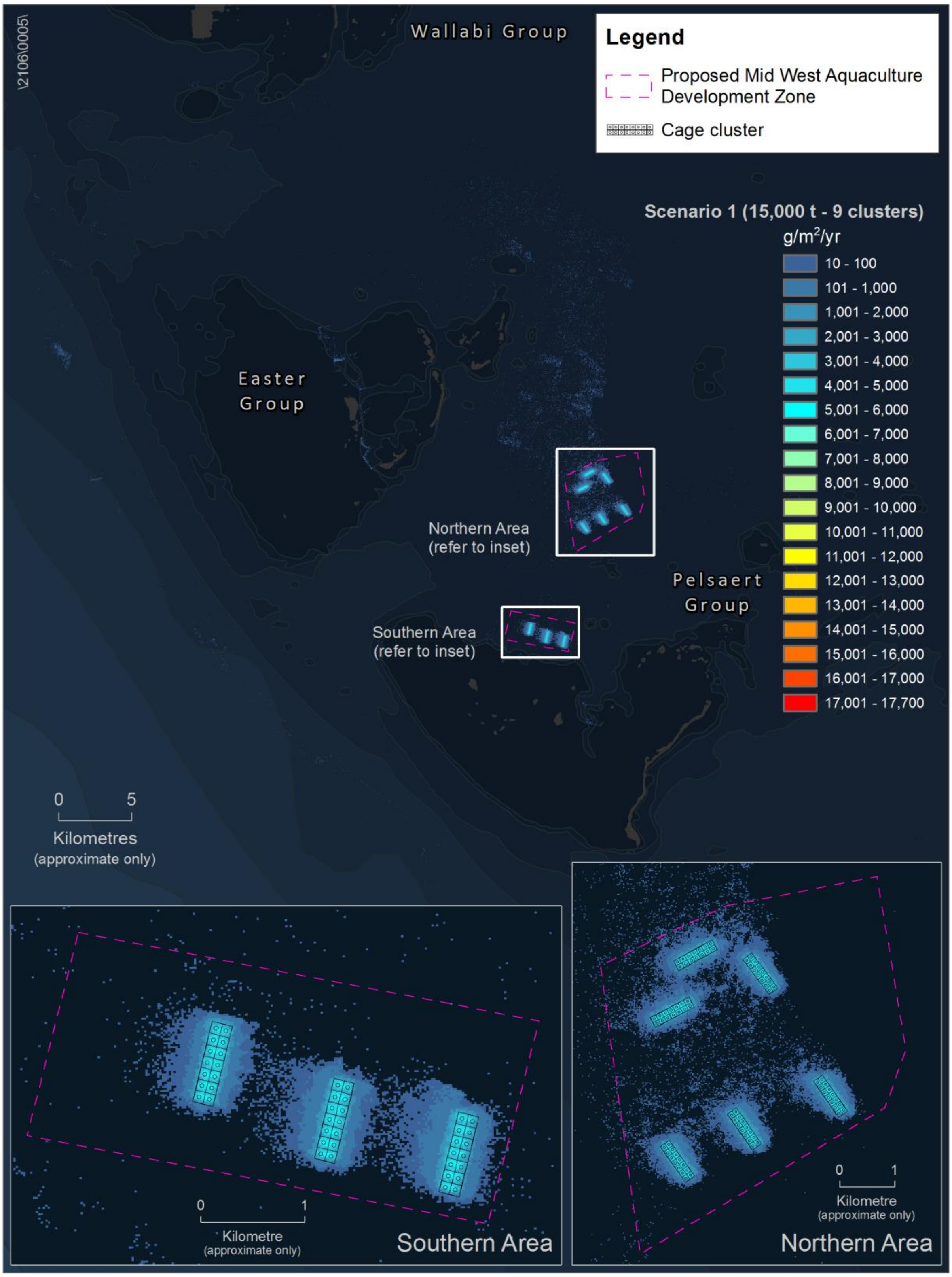


Figure 7-22: Inputs of Organic Carbon under Scenario 1 (15,000 tonnes over 9 clusters)

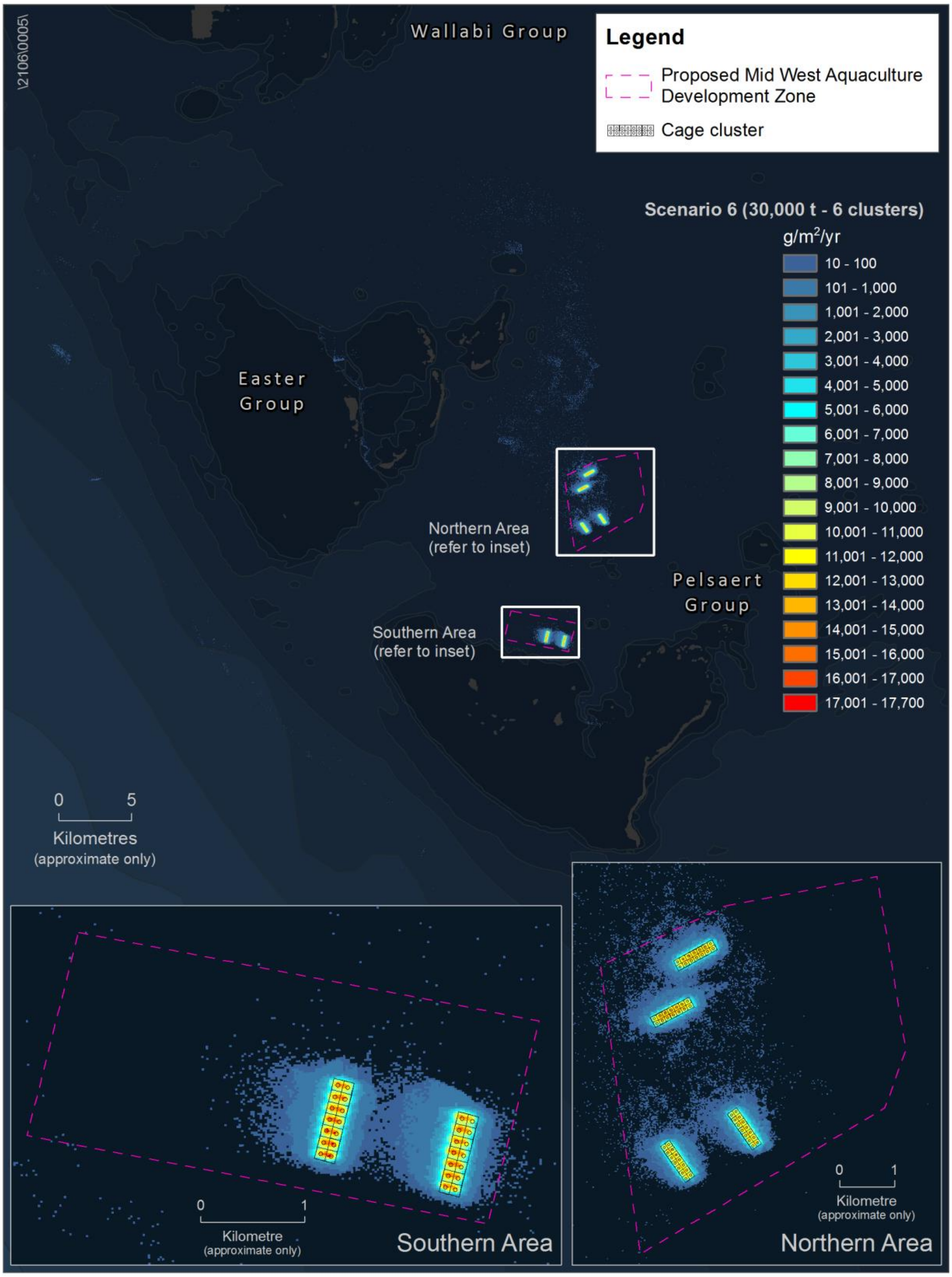


Figure 7-23: Inputs of Organic Carbon under Scenario 6 (30,000 tonnes over 6 clusters)

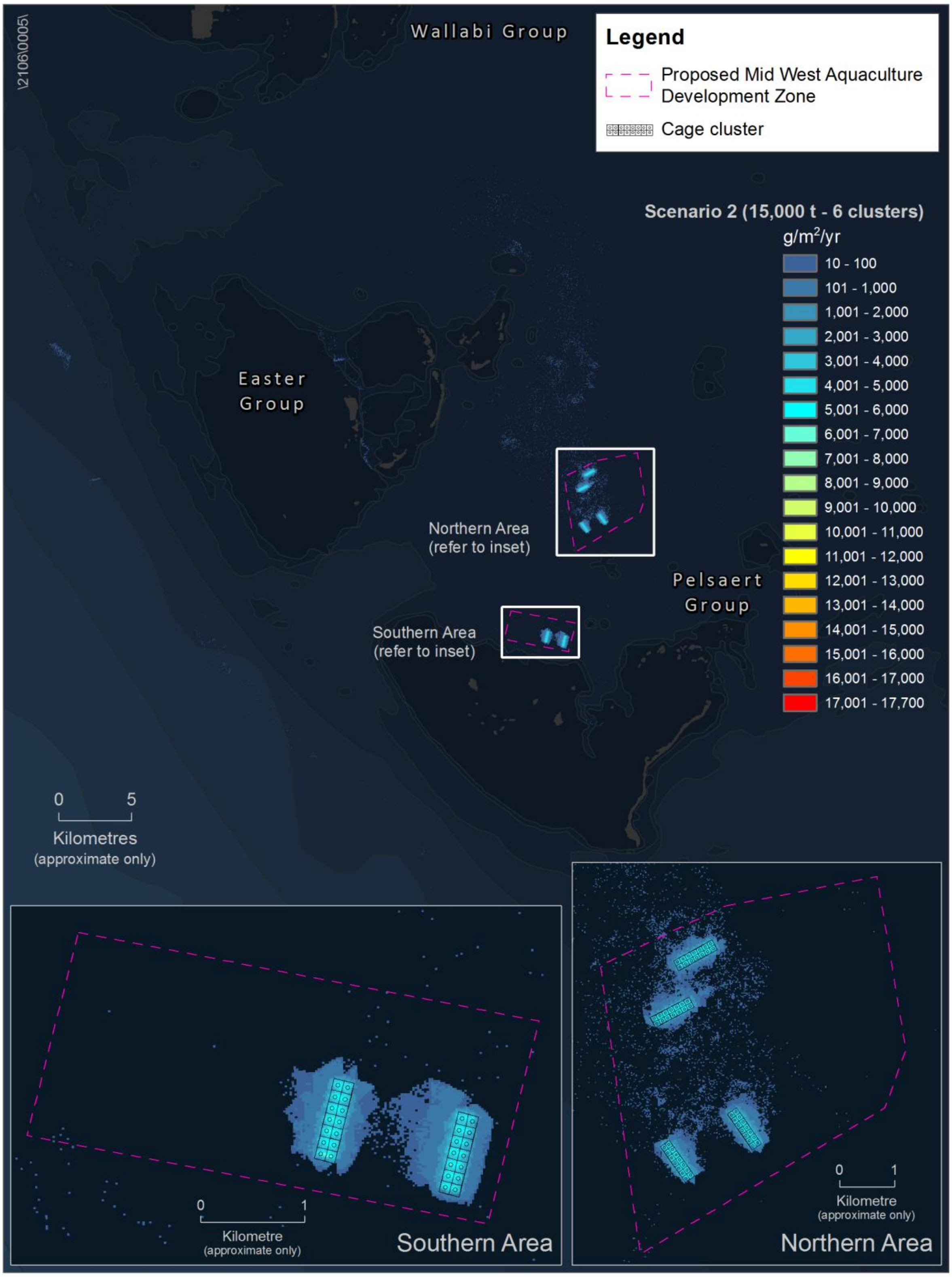


Figure 7-24: Inputs of Organic Carbon under Scenario 2 (15,000 tonnes over 6 clusters)

7.4.3.1 Dissolved Oxygen and Sulphide Content of the Sediment

Applying the criteria in EAG 7 (EPA 2011), spatial extents of three zones of impact were determined (Figure 7-25 to Figure 7-30).

After three and five years of finfish production across the full range of production scenarios (Table 6-15) the modelling identified zones of impact and influence based on the time required for oxygen and sulphide concentrations in the sediment to return to baseline levels. In accordance with EAG 7, habitats requiring greater than five years to recover to baseline levels were designated zones of "high" impact (ZoHI - red colouration), and habitats requiring less than five years were designated zones of "moderate" impact (ZoMI - amber colouration). Areas expected to receive waste, but not in concentrations great enough to alter the sediment chemistry, were designated zones of "influence" (ZoI - green colouration). Areas classified as ZoI are expected to maintain sediment oxygen and sulphide levels that are equivalent to sites located beyond the influence of aquaculture activities, and therefore not impacted.

7.4.3.2 Dispersed Effects – Nine Cage Clusters

The aerial extent of the ZoHI, ZoMI and ZoI in Scenario 1, Scenario 3 and Scenario 5, are illustrated in Figure 7-25 to Figure 7-30 and outlined (in hectares) in Table 7-6. These three scenarios captured the effect of spreading the stock (standing biomass) across a total of nine cage clusters (simulating a "dispersed" effect). The effect of concentrating the stock standing biomass across a reduced number of cage clusters (six) is explored in the subsequent section.

ZoHI were observed in Scenario 1, Scenario 3 and Scenario 5 after three and five year's production. The area occupied by the ZoHI increased in response to increasing standing biomass and the length of finfish production (Table 7-6). After five year's continuous production the ZoHI (as indicated by the red coloured pixels in Figure 7-25, Figure 7-27 and Figure 7-29) extended respectively ~70 metres, ~55 metres and ~40 metres from the cage cluster boundaries in Scenario 5, Scenario 3 and Scenario 1, as measured along the maximum radius down-current from the cage clusters.

The aerial extent of the ZoHI was smaller in the northern area relative to the southern area. This is likely a result of the higher current speeds in the northern MWADZ area, which when simulated in the model, imparted a strong influence on the transportation of depositing particles and resuspension. Both processes, particle transport and resuspension, affected the retention of organic material near the sea cages. Particles tended to disperse under higher current speeds, but tended to sink, deposit and remain close to the sea cages under lower current speeds. This is reflected in Figure 7-25 to Figure 7-30 by the greater spread of particles away from the sea cages in the northern MWADZ area and a tendency of organic deposition to be concentrated, resulting in more intense impacts beneath the cages in the southern MWADZ area.

ZoMI (as indicated by the amber coloured pixels in Figure 7-25 to Figure 7-30) were observed in all scenarios irrespective of the length of the aquaculture production period. With some exceptions, the area occupied by the ZoMI increased with increasing stock standing biomass and increasing length of production; however, the changes were less dramatic than those predicted for the ZoHI. For example, the area occupied by the ZoHI over the range of model settings was between one hectare and 177 hectares, representing an entire order of magnitude increase; whereas the area occupied by the ZoMI over the same modelling treatments was between 239 hectares and 349 hectares, representing a smaller increase (less than an order of magnitude change).

The ZoI (as indicated by the green coloured pixels in Figure 7-25 to Figure 7-30) was the largest (in area) and the most dispersed of the three impact categories. In the northern area of the MWADZ, the higher current speeds acted to increase the dispersion of organic particles, which in turn increased the area occupied by the ZoI. The prevailing north-westerly currents in the northern area of the MWADZ are reflected in the dispersal of particles to the north-west and away from the sea-cages. In the southern area of the MWADZ, the ZoI was generally more constrained and centred on the individual cage clusters. Dominant westerly currents in the southern area of the MWADZ resulted in a tendency for particles to disperse to the west of the cage clusters.

Table 7-6: Areas Occupied by the Zones of High and Moderate Impact and the Zone of Influence under Scenarios S1, S3 and S5 after three and five year's Production

Years of production	Scenario No.	Standing biomass (t)	ZoHI (ha)	ZoMI (ha)	ZoI (ha)
5	S1	15,000	117	239	1,150
	S3	24,000	132	235	1,005
	S5	30,000	177	270	1,226
3	S1	15,000	1	346	1,159
	S3	24,000	11	349	1,012
	S5	30,000	105	334	1,235

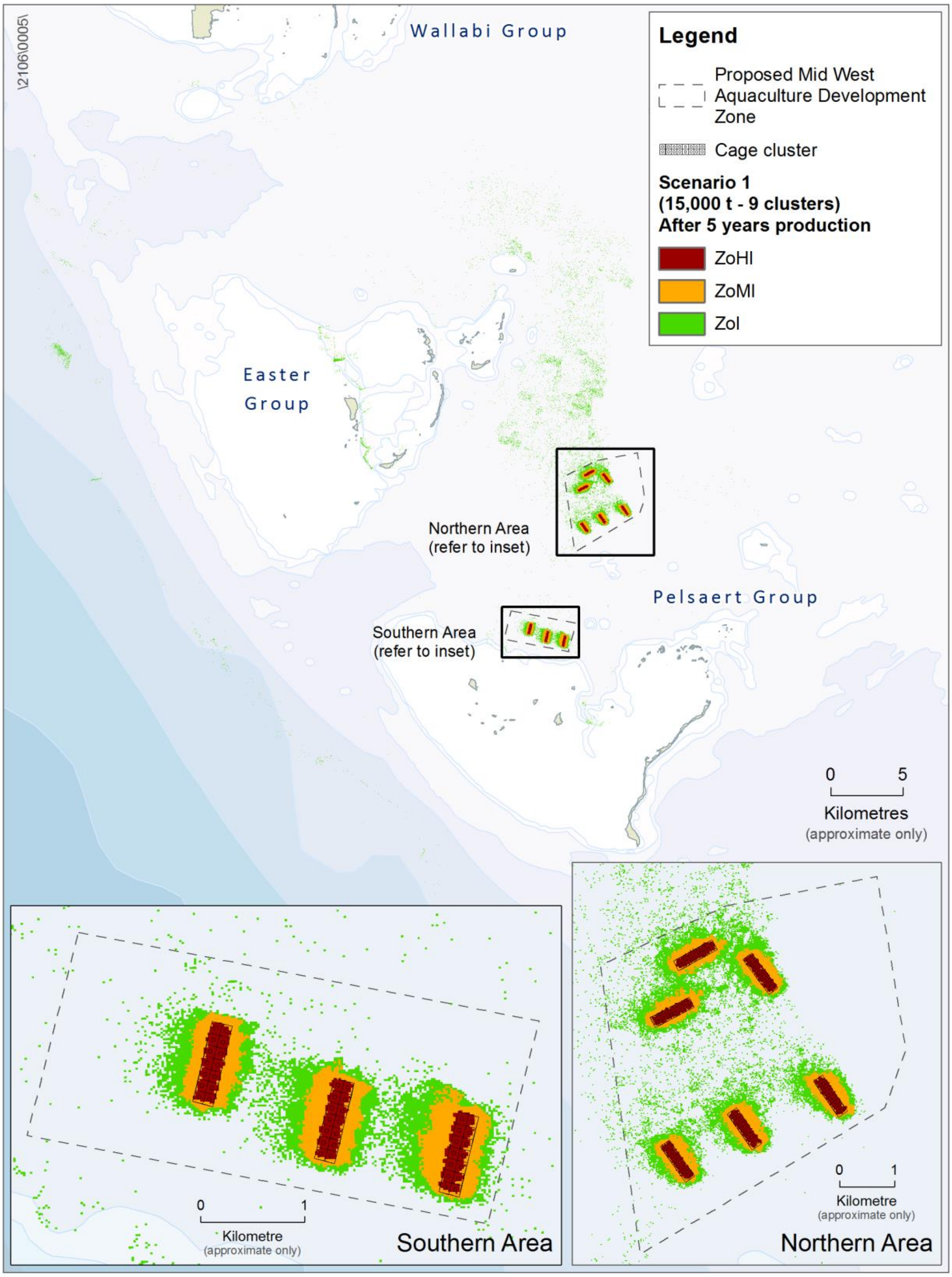


Figure 7-25: Zones of Impact under Scenario 1 (15,000 tonnes) after five years of production

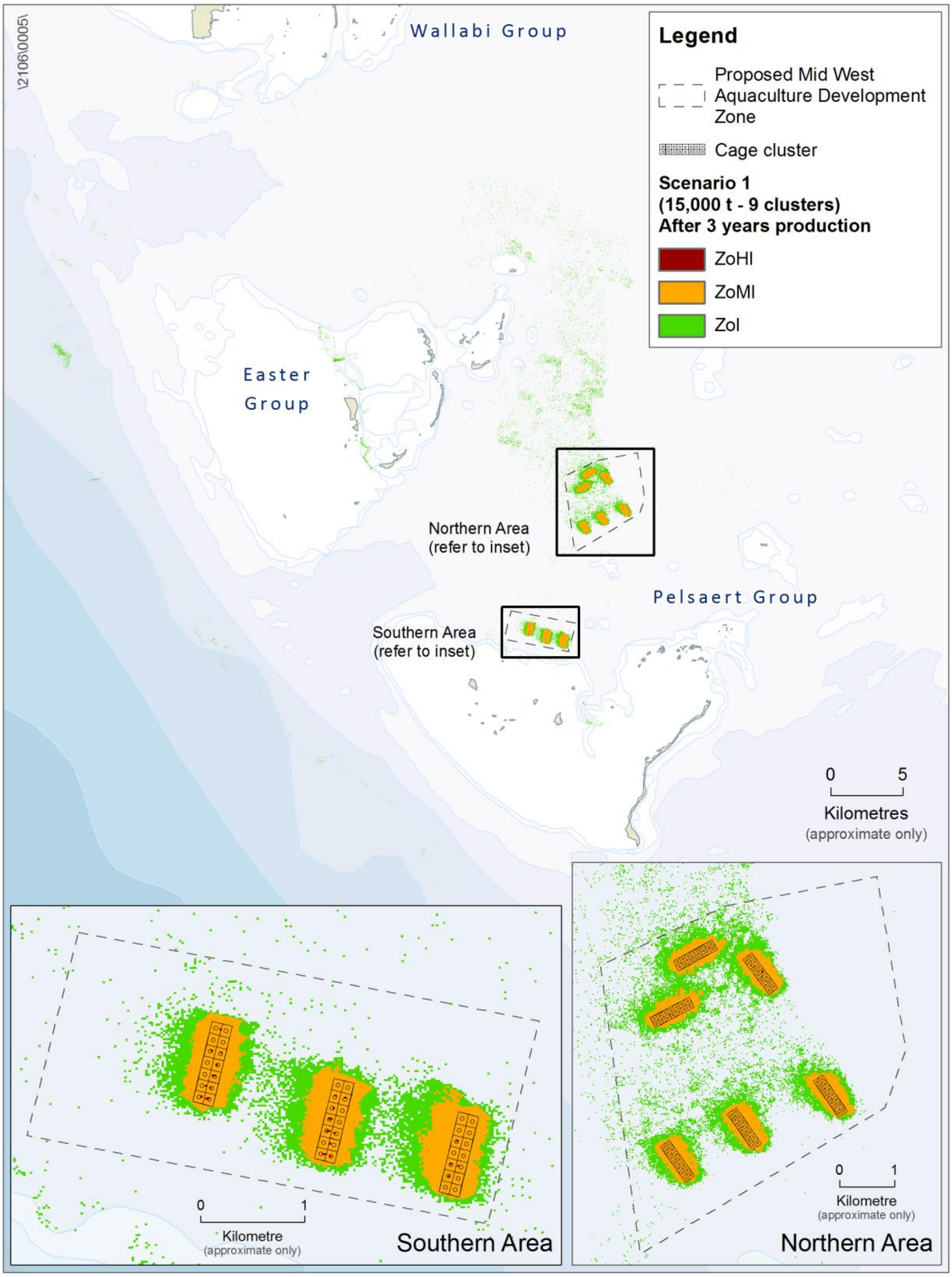


Figure 7-26: Zones of Impact under Scenario 1 (15,000 tonnes after three years of production

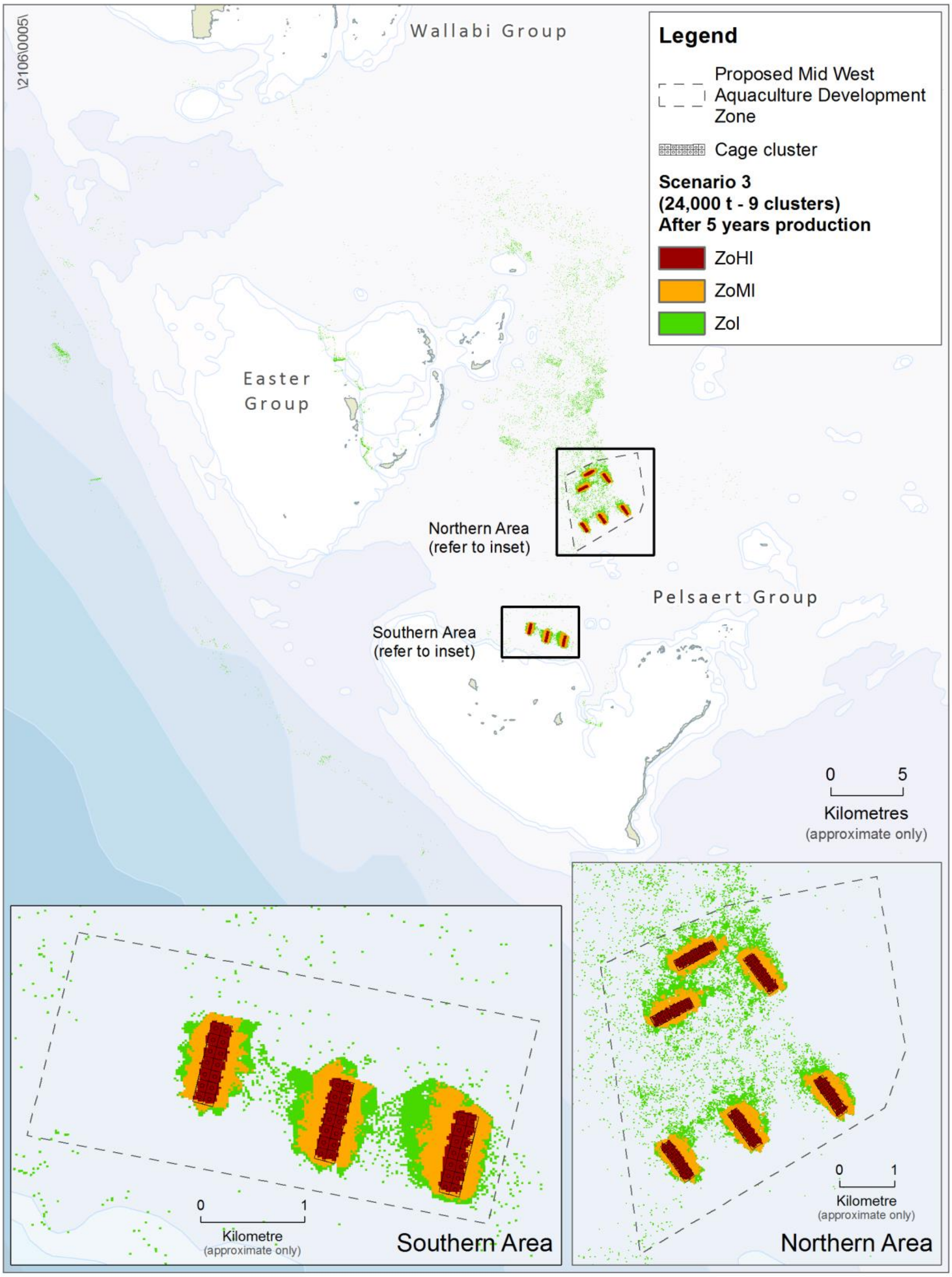


Figure 7-27: Zones of Impact under Scenario 3 (24,000 tonnes after five years of production

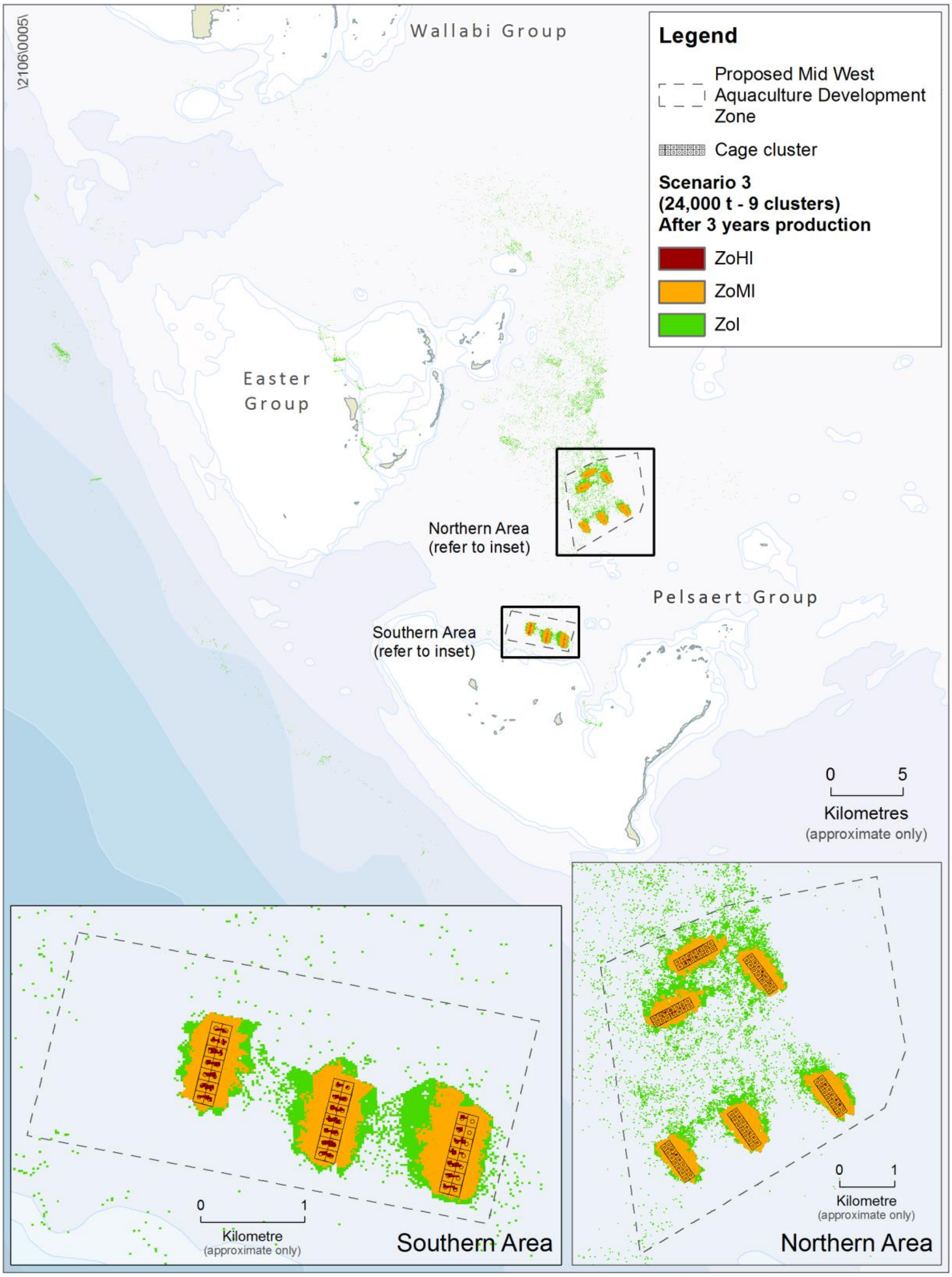


Figure 7-28: Zones of Impact under Scenario 3 (24,000 tonnes) after three years of production

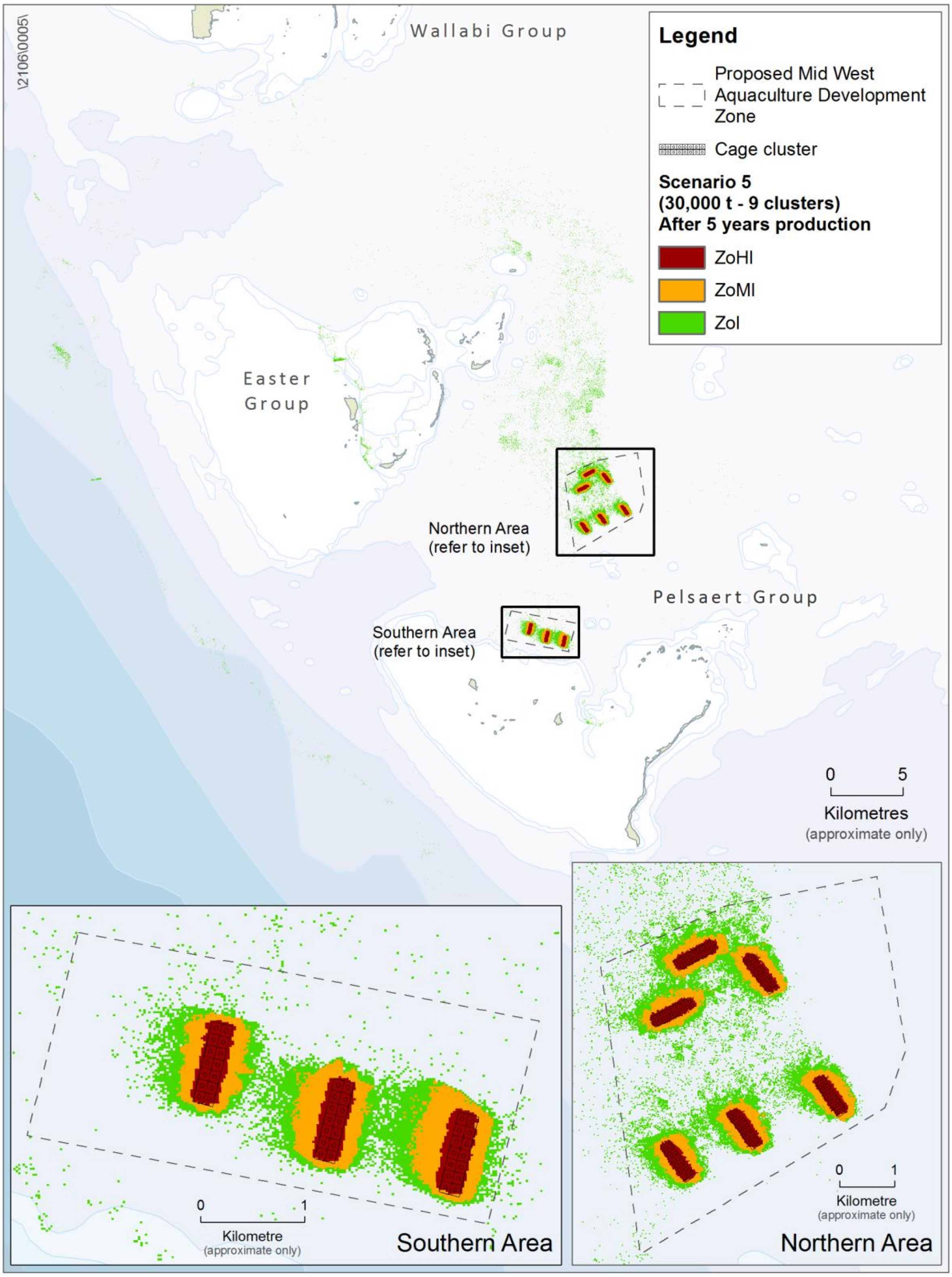


Figure 7-29: Zones of Impact under Scenario 5 (30,000 tonnes) after five years of production

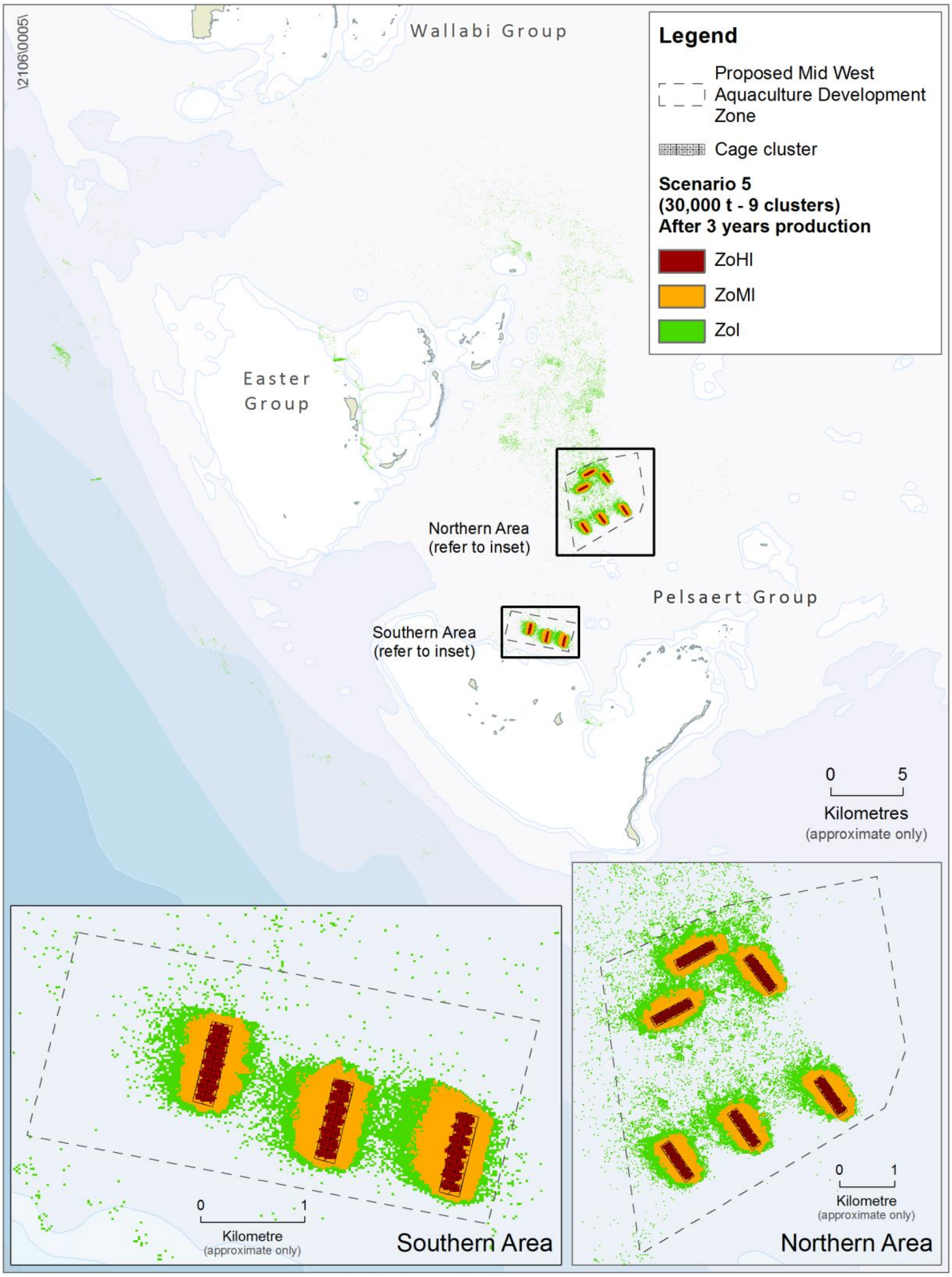


Figure 7-30: Zones of Impact under Scenario 5 (30,000 tonnes) after three years of production

7.4.3.3 Concentrated effects - six cage clusters

The aerial extent of the ZoHI, ZoMI and ZoI, in Scenario 2, Scenario 4 and Scenario 6 is illustrated in Figure 7.31 to Figure 7.36 and outlined (in hectares) in Table 7-7. These scenarios captured the effect of concentrating the standing biomass across a total of six cage clusters, three less than in the "dispersed" effects simulations (described in the chapter above).

As with the results for the "dispersed effects", the ZoHI (as indicated by the red coloured pixels in Figure 7.31 to Figure 7.36) increased with standing biomass and the length of finfish production. Zones of high impact were observed in Scenario 6, Scenario 4 and Scenario 2 after five and three years of production.

Significant reductions in the areas of the ZoHI were achieved by reducing the length of production from five to three. For example, by reducing the length of production from five to three years, close to a 100% reduction was achieved in Scenario 2, a 45% reduction was achieved in Scenario 4 and a 31% reduction was achieved in Scenario 6. Greater reductions were achieved for the dispersed effects scenarios, Scenario 1, Scenario 3 and Scenario 5: corresponding to reductions of 100% for Scenario 1, 92% for Scenario 3 and 41% for Scenario 6 (Table 7-6 and Table 7-7).

Reductions in both the standing biomass and the length of production also reduced the maximum extent of the ZoHI, as measured along the maximum radius down-current from the cage clusters. After five years continuous production, the ZoHI (as indicated by the red coloured pixels in Figure 7.31 to Figure 7.36) extended ~110 metres, ~60 metres and ~50 metres from the cage cluster boundaries in Scenario 6, Scenario 4 and Scenario 2 respectively. However, the maximum distances reduced after three years production: with predictions of 10 metres under Scenario 4, and 55 metres under Scenario 6. Under Scenario 2, the ZoHI did not breach the area beneath the cage cluster.

Increasing the stocking density while maintaining the standing biomass (i.e. stocking density in Scenario 4 was greater than the stocking density in Scenario 3; standing biomass for Scenario 4 was equal to standing biomass Scenario 3) had the effect of reducing the total area occupied by the ZoHI across the zone. This effect was particularly strong after five years production (Table 7-6 and 7-7), but less so after three years production. For example, after five years the total area occupied by the ZoHI was 177 hectares and 139 hectares for Scenario 5 and Scenario 6, respectively; 132 hectares and 113 hectares for Scenario 3 and Scenario 4 respectively; and 117 hectares and 82 hectares for Scenario 1 and Scenario 2, respectively. After three years production, the results were more variable: the total area occupied by the ZoHI was higher in Scenario 2 (two hectares) relative to Scenario 1 (one hectare); higher in Scenario 4 (62 hectares) relative to Scenario 3 (11 hectares) but lower in Scenario 6 (95 hectares) relative to Scenario 5 (105 hectares).

Reducing the number of cage clusters also reduced the total area occupied by the ZoMI and the ZoI. By reducing the number of cage clusters, reductions in the footprints of both zones were achieved irrespective of the standing biomass or the production period modelled (Table 7-6 and Table 7-7). This is a useful finding indicating that reductions in the spatial extent of impacts, as measured under EAG 7 (ZoHI, ZoMI and ZoI), can be achieved by concentrating finfish in individual cage clusters, without a corresponding need to reduce the total standing biomass across the zone. It was noted, however, that while the spatial extent of the impacts

can be reduced based on the criteria in EAG 7, the effect of this is to increase the intensity of impacts immediately under the sea cages. Intensifying the impacts, as Scenario 2, Scenario 4 and Scenario 6, translate to longer recovery periods, as shown in Figure 7.31 to Figure 7.36. The difference in the areas occupied between the dispersed (9 clusters) and concentrated (6 clusters) scenarios is shown in (Table 7-6 and Table 7-7), and illustrated in Figure 7-31 to Figure 8-36.

As observed in Scenario 1, Scenario 3 and Scenario 5, the area occupied by the ZoHI in Scenario 2, Scenario 4 and Scenario 6 also increased in response to increasing standing biomass and the length of finfish production. Zones of high impact were observed in Scenario 6, Scenario 4 and Scenario 2 after five and three years of production. The area occupied by the ZoHI in Scenario 2 after two years production was marginal at less than 1 hectare (Figure 7.31 to Figure 7.36).

The area occupied by the ZoHI after three and five years production increased proportionally with increases in standing biomass, increasing from 82 hectares in Scenario 2 to 139 hectares in Scenario 6 after five years, two hectares in Scenario 2 to 95 hectares in Scenario 6 after three years. Similar increases were apparent with the ZoMI, which increased in size from 160 hectares in Scenario 2 to 203 hectares in Scenario 6, after five years. The area occupied by the ZoI was also observed to increase in response to increasing standing biomass, reaching a maximum coverage in Scenario 6, irrespective of the length of production (Table 7-7).

Significant reductions in the areas of the ZoHI were achieved by reducing the length of production from five to three. For example, by reducing the production period from five to three years close to 100% reductions were achieved in Scenario 2, 45% reductions were achieved in Scenario 4 and 31% reductions were achieved in Scenario 6. Greater reductions were achieved for the dispersed effects; Scenario 1, Scenario 3 and Scenario 5: corresponding to reductions of 100% for Scenario 1, 92% for Scenario 3 and 32% for Scenario 6.

Table 7-7: Areas occupied by the zones of high and moderate impact and the zone of influence under scenarios S2, S4 and S6 after 3 and five years production

Years of production	Scenario No.	Standing biomass (t)	ZoHI (ha)	ZoMI (ha)	ZoI (ha)
5	S2	15,000	82	160	616
	S4	24,000	113	173	697
	S6	30,000	139	203	861
3	S2	15,000	2	234	621
	S4	24,000	62	219	701
	S6	30,000	95	241	868

Note:
ZoHI = zone of high impact, ZoMI = zone of moderate impact, ZoI = zone of influence

The ZoMI (as indicated by the amber coloured pixels in (Figure 8-13 to Figure 8-18) were observed in all scenarios irrespective of the length of the production period. The ZoMI was restricted to the area immediately adjacent to the sea cage clusters, but extended further than the ZoHI. As with the ZoHI, the area occupied by the ZoMI increased with increasing standing biomass and the length of production; however, the changes were less distinct than those observed for the ZoHI. Unlike the ZoHI, which was near absent in Scenario 2 after three years production, moderate impacts were detected irrespective of the model settings.

The ZoI (as indicated by the green coloured pixels in Figure 7.31 to Figure 7.36) was the largest (in area) and the most dispersed of the three impact categories. In the northern area of the proposed MWADZ, the higher current speeds acted to increase the dispersion of organic particles, which in turn increased the area occupied by the ZoI. The prevailing north-westerly currents in the northern area of the MWADZ are reflected in the north-westerly dispersion of the ZoI away from the sea cages. In the southern area of the MWADZ, the ZoI was generally more constrained, and centred on the individual cage clusters. Refer to the Modelling and Technical Studies (Appendix 1) for further details in relation to the modelling.

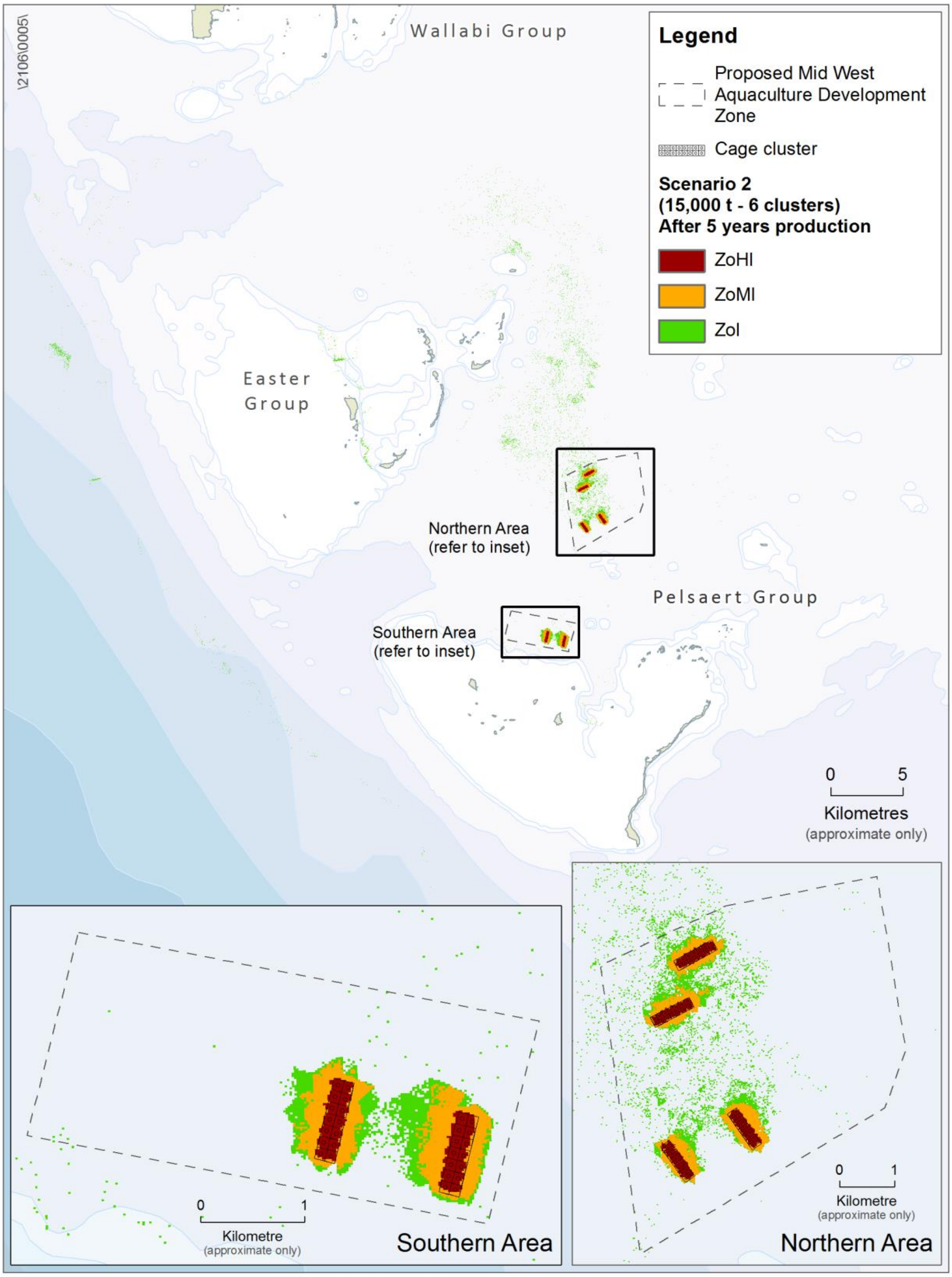


Figure 7-31: Zones of Impact under Scenario 2 (15,000 tonnes) after five years of production

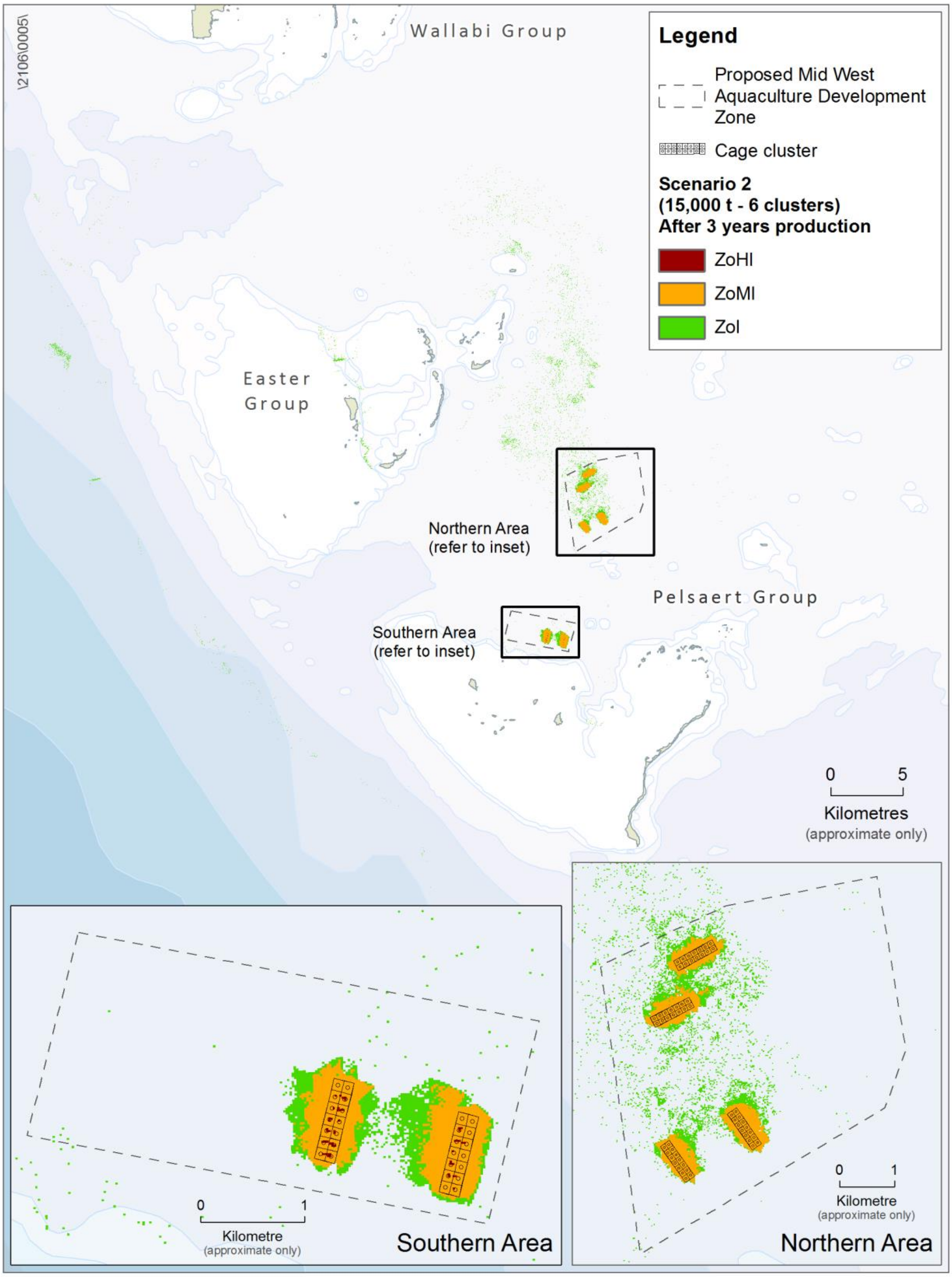


Figure 7-32: Zones of Impact under Scenario 2 (15,000 tonnes) after three years of production

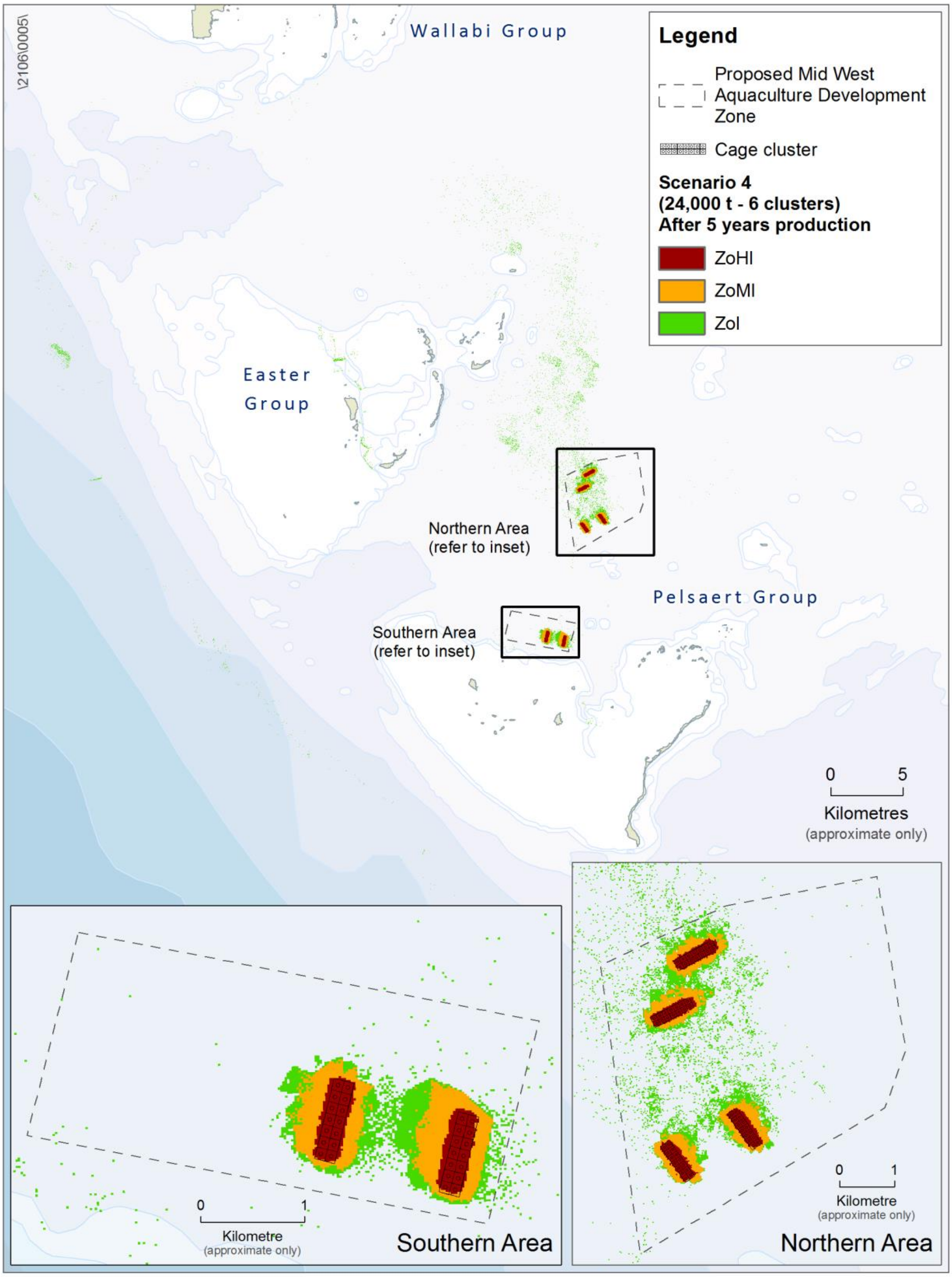


Figure 7-33: Zones of Impact under Scenario 4 (24,000 tonnes) after five years of production

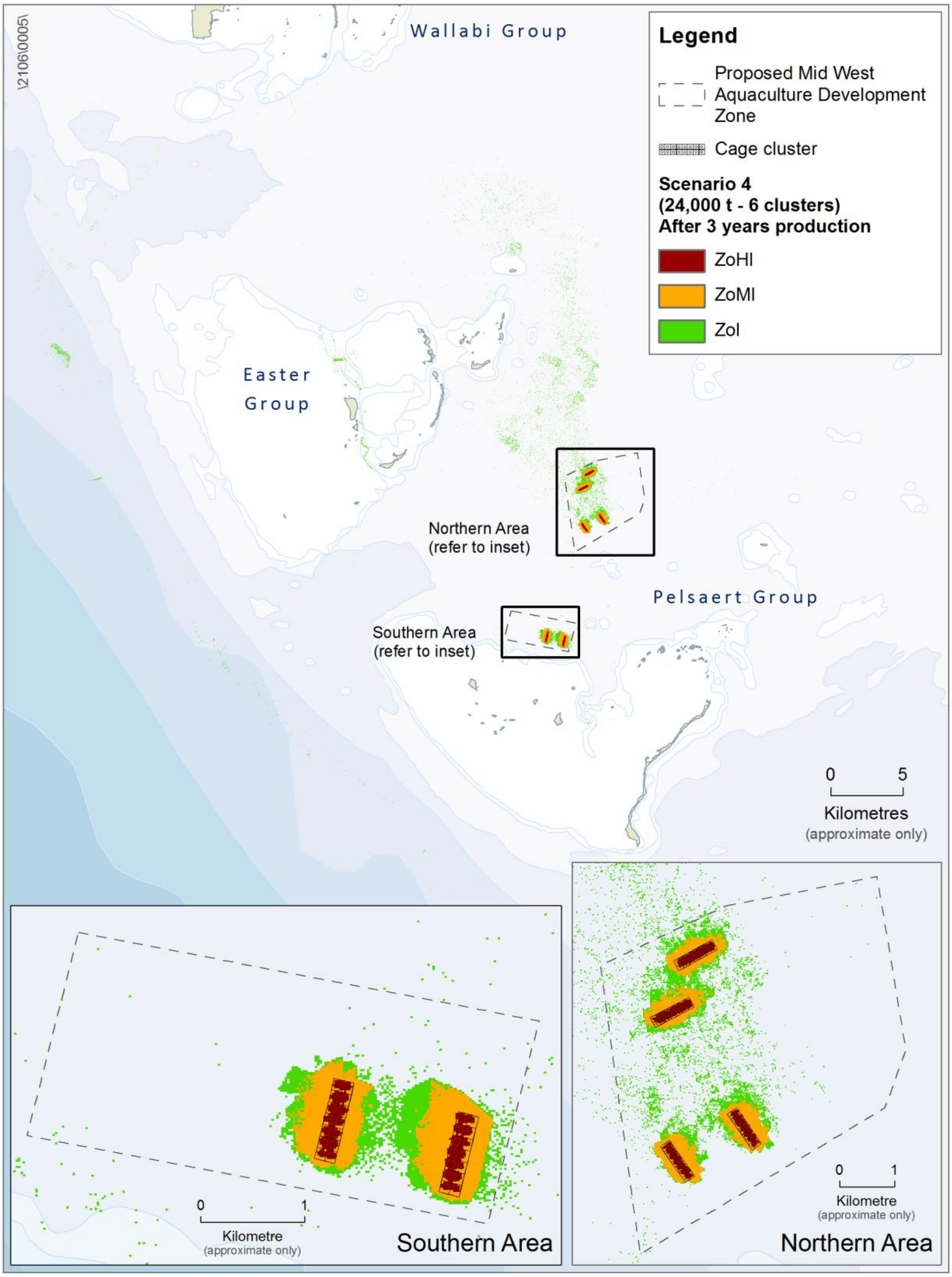


Figure 7-34: Zones of Impact under Scenario 4 (24,000 tonnes) after three years of production

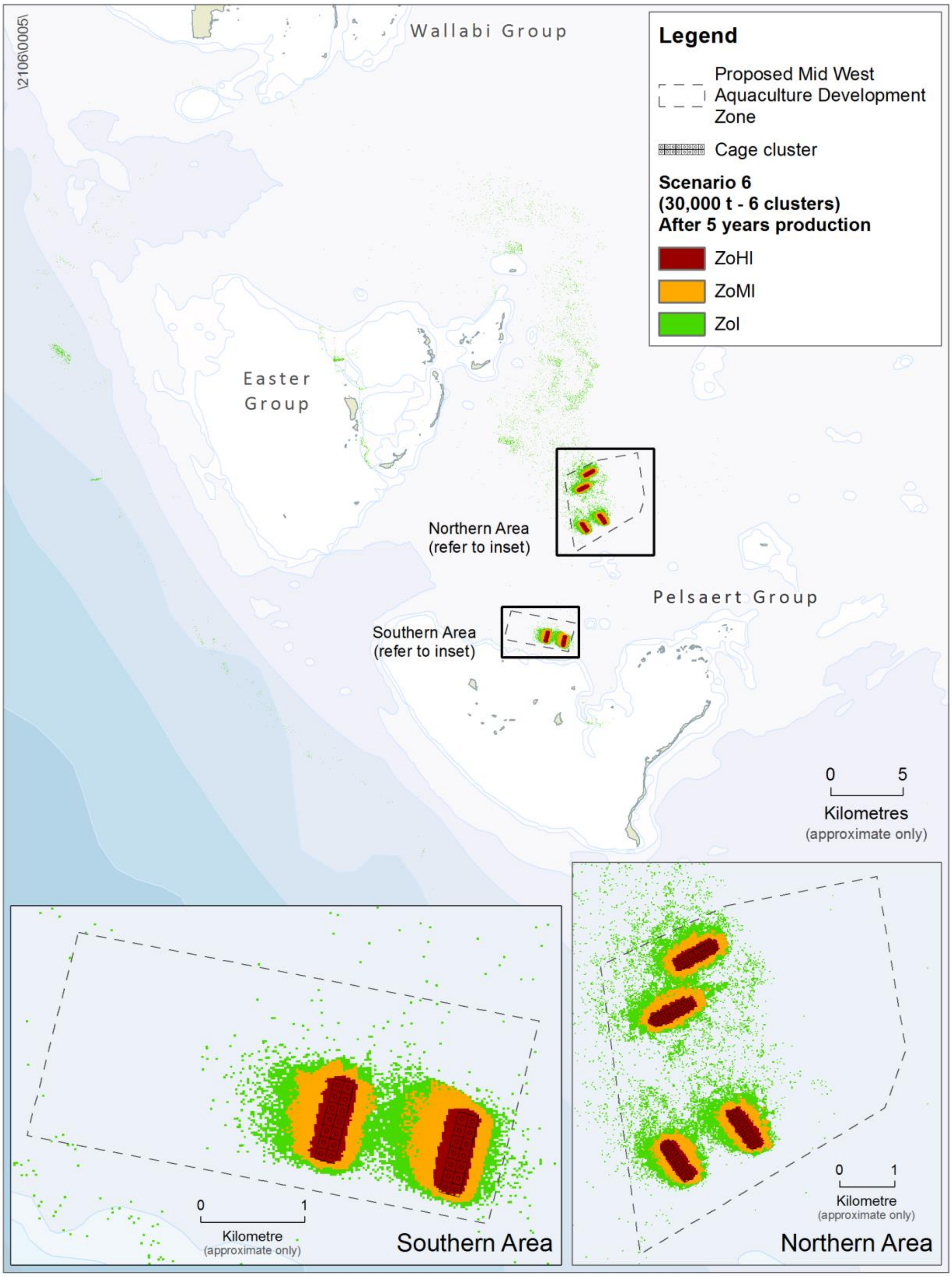


Figure 7-35: Zones of Impact under Scenario 6 (30,000 tonnes) after five years of production

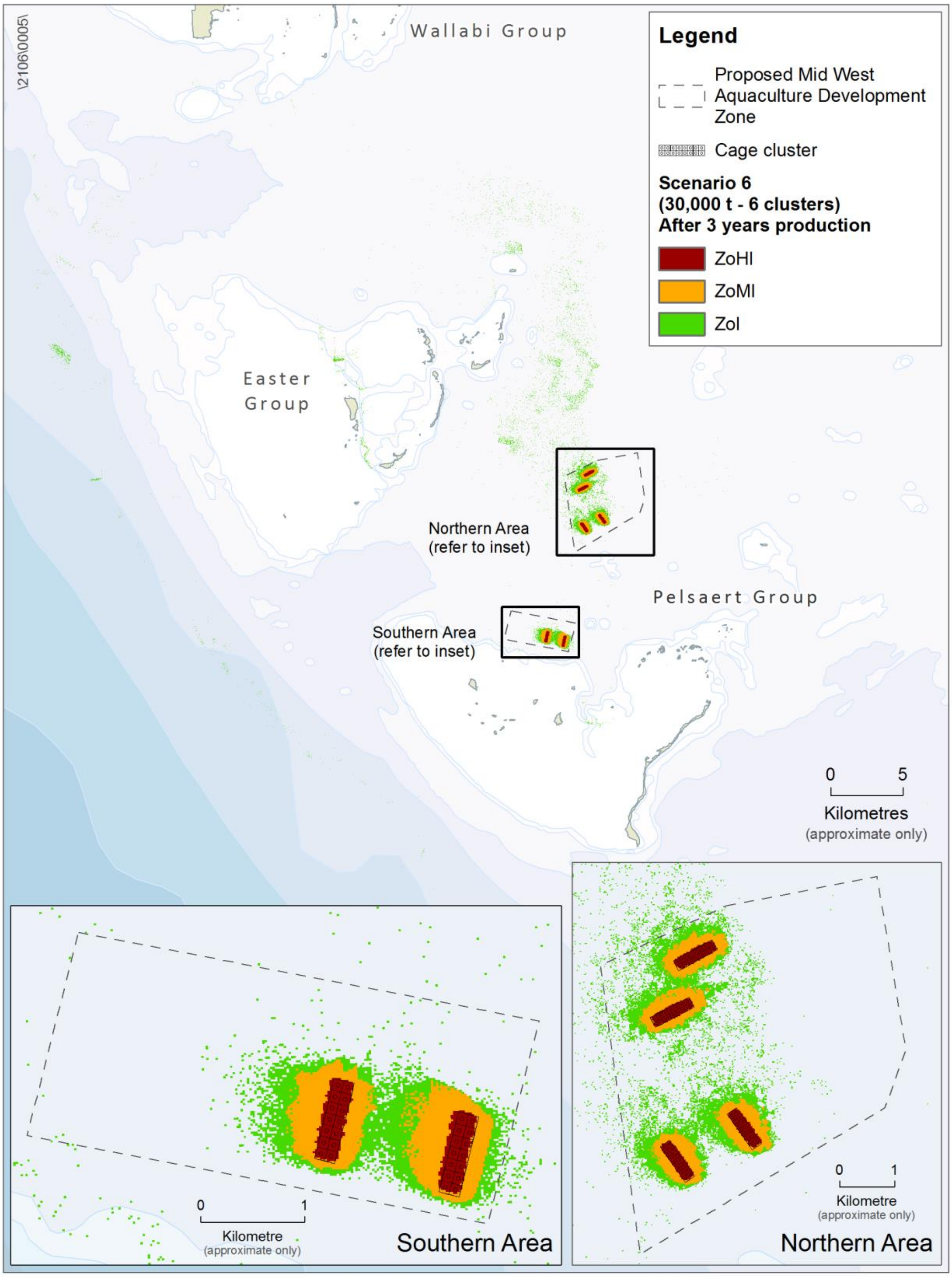


Figure 7-36: Zones of Impact under Scenario 6 (30,000 tonnes) after three years of production

The ZoHI is the area where impacts on benthic habitats are predicted to be irreversible, as per EAG 7. The term "irreversible" is defined as "*lacking a capacity to return or recover to a state resembling that prior to being impacted within a timeframe of five years or less*".

Despite the use of the term irreversible, it is noted that sea cages are not permanent structures and can be moved to facilitate benthic rehabilitation. Recovery times in the ZoHI and ZoMI ranged between one and seven+ years, depending on the scenario and distance from the sea cages. Immediately under the sea cages, sediments required greater than seven years to achieve full recovery. However, this reduced to six after 3 years of production (Figure 7-37 to Figure 7-42).

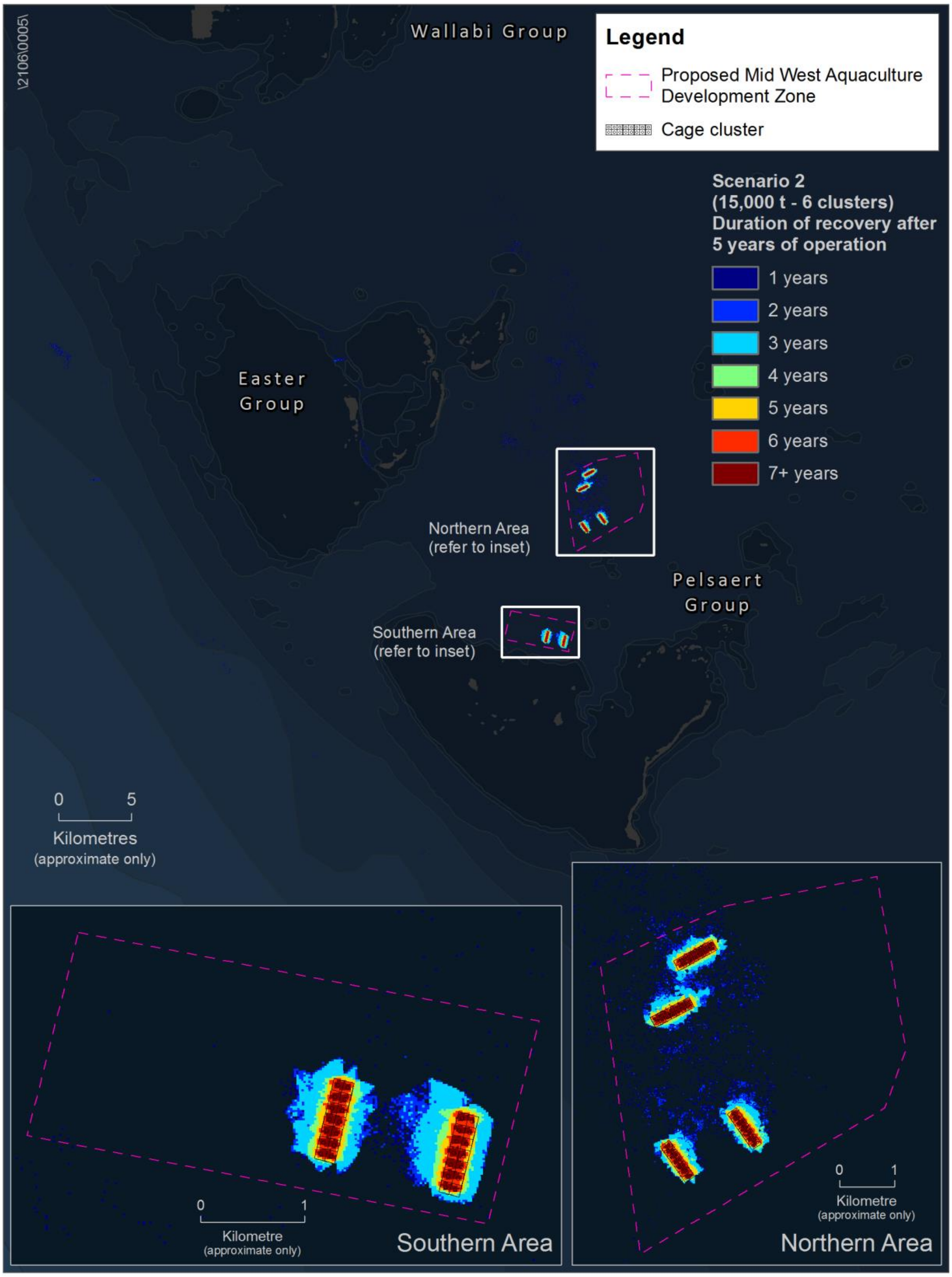


Figure 7-37: Duration of Recovery under Scenario 2 (15,000 tonnes) after five years of operation

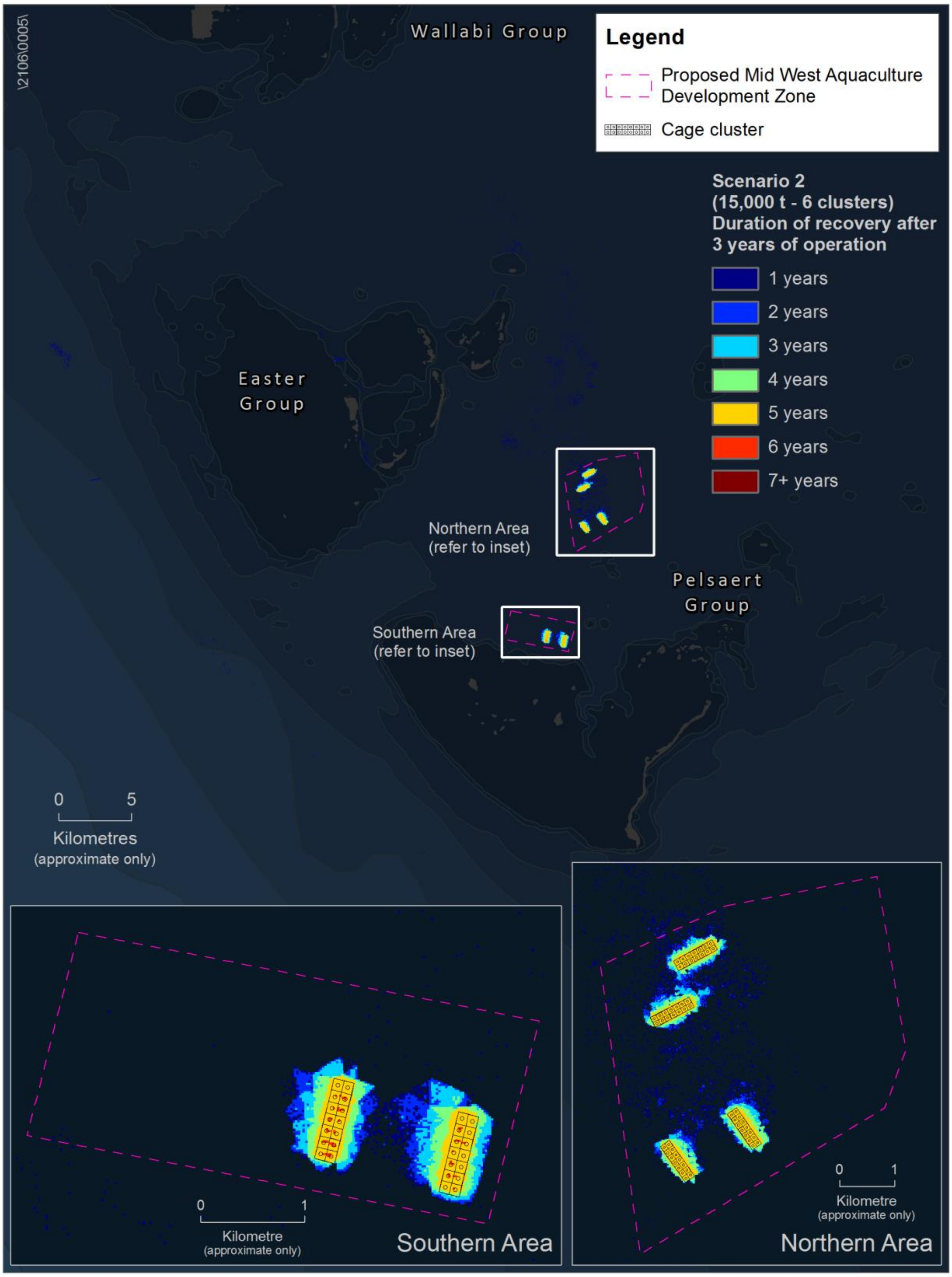


Figure 7-38: Duration of Recovery under Scenario 2 (15,000 tonnes) after three years of operation

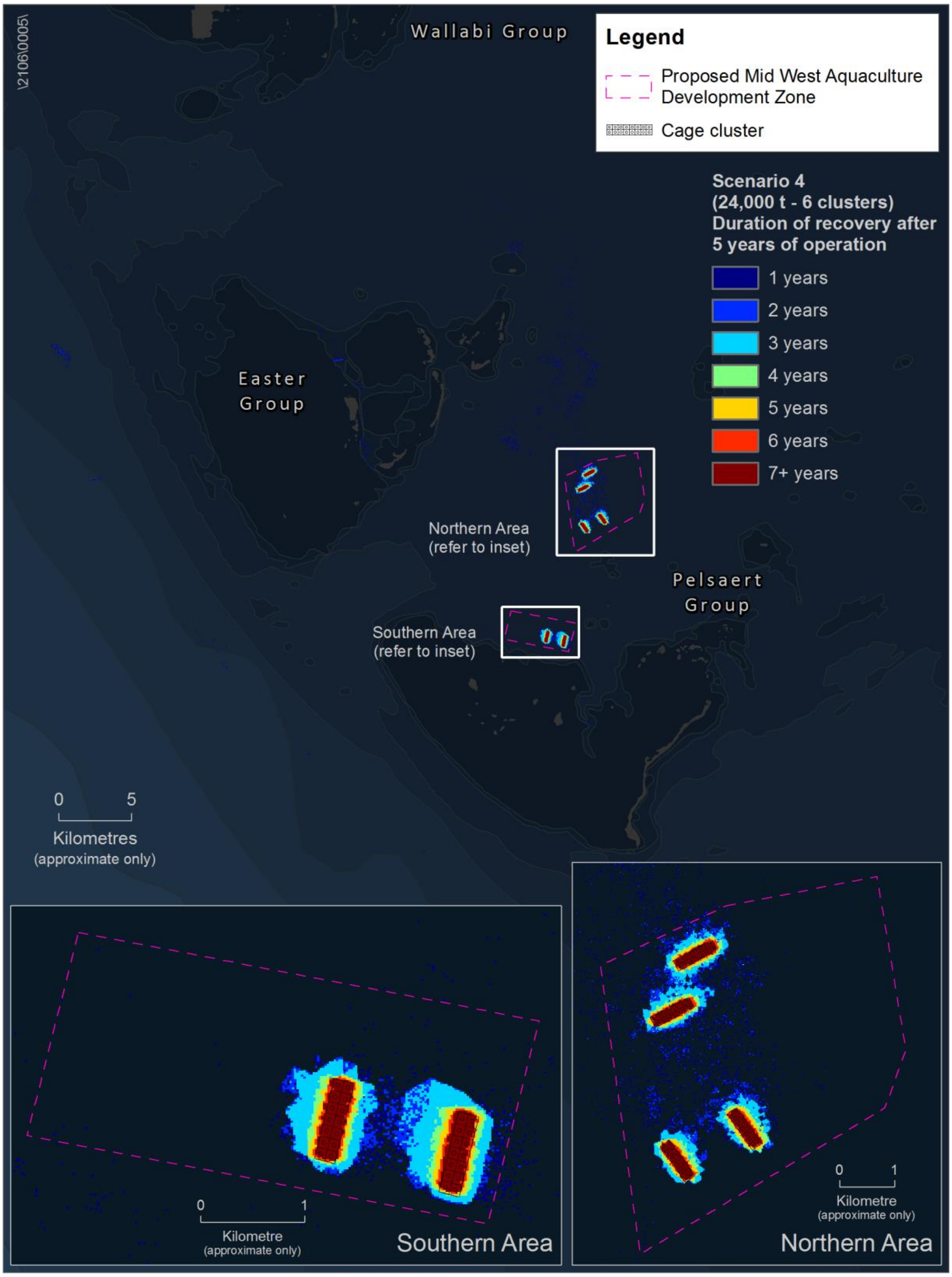


Figure 7-39: Duration of Recovery under Scenario 4 (24,000 tonnes) after five years of operation

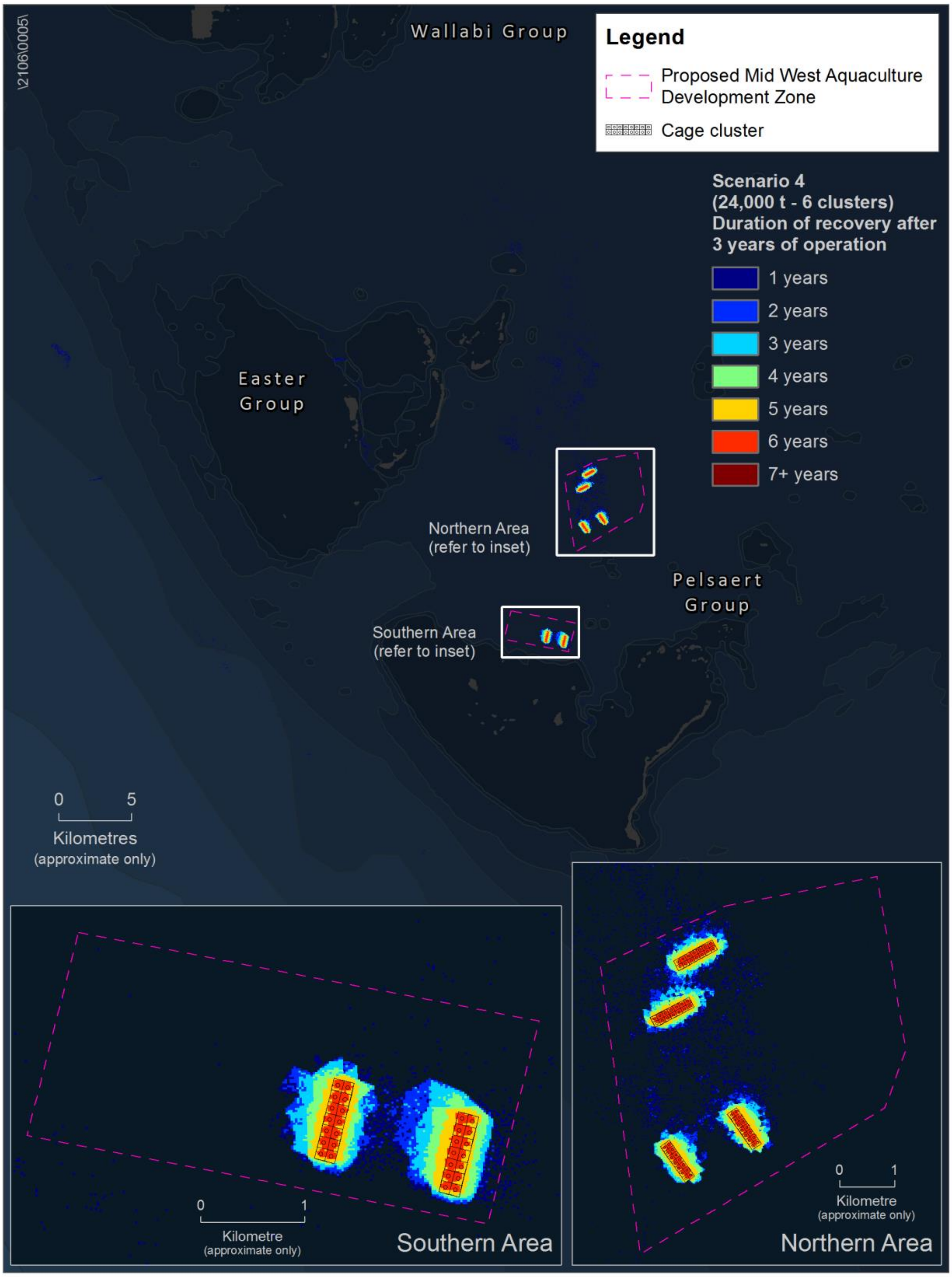


Figure 7-40: Duration of Recovery under Scenario 4 (24,000 tonnes) after three years of operation

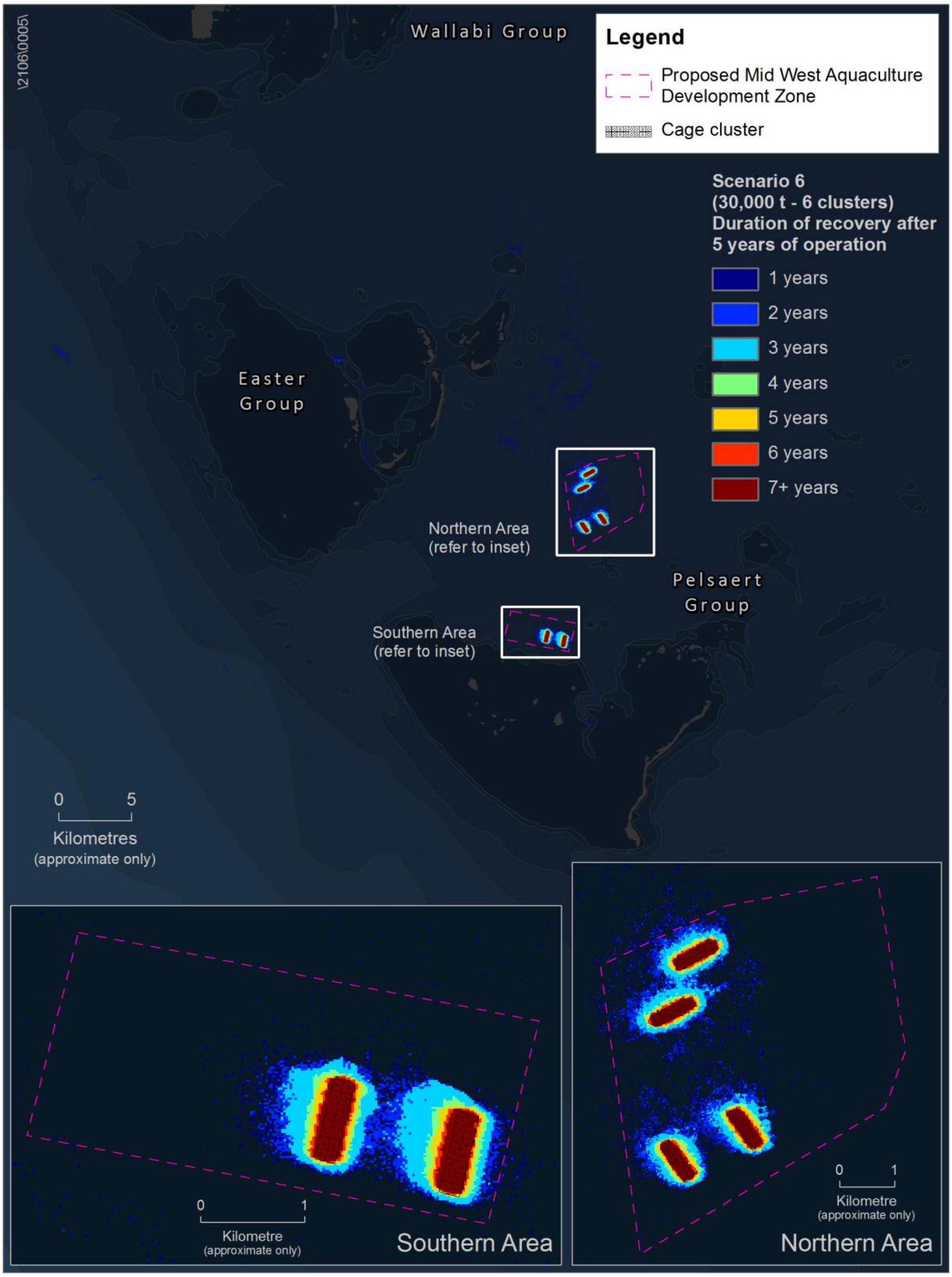


Figure 7-41: Duration of Recovery under Scenario 6 (30,000 tonnes) after five years of operation

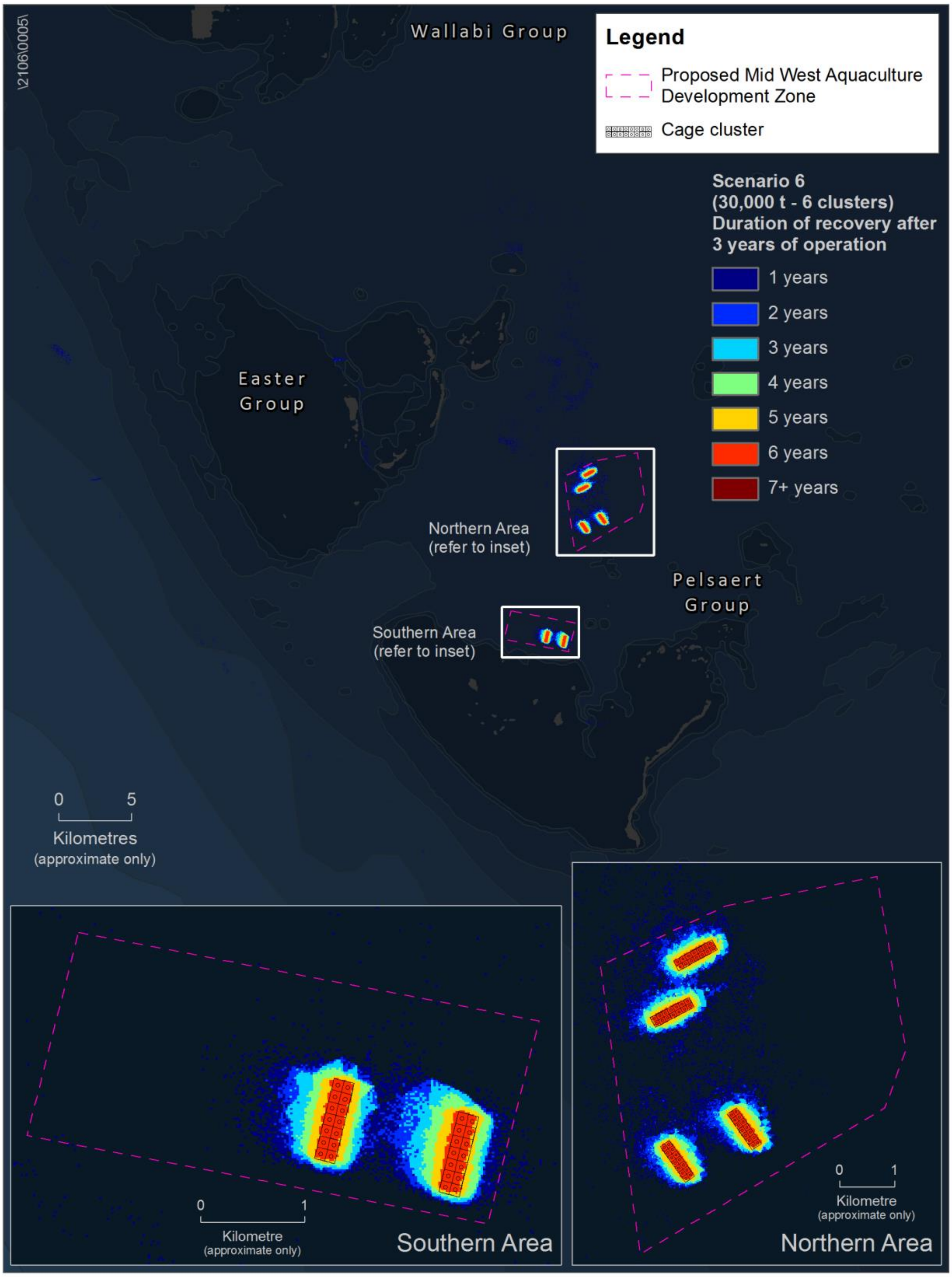


Figure 7-42: Duration of Recovery under Scenario 6 (30,000 tonnes) after three years of operation

7.4.3.4 Comments on the Zone of Influence

The spatial extent of the ZoI, and particularly its outer limits of distribution, was driven largely by the dispersion of the smallest fraction of stock faeces.

The extremities of its distribution in the north, the south-west, and particularly in the deeper lagoon areas of the Abrolhos Islands Easter Group, are product of the design and settlings of the model (i.e. an artefact). Particles may travel this distance from the cages through resuspension, but they are unlikely to accumulate in the densities shown in the Figures because the model understates dispersive processes at very low deposition rates (Appendix 1).

7.4.3.5 Comments on the Modelled Rate at which the Sediment Chemistry Returned to Natural Levels

The rates at which organic matter underwent mineralisation were dependent on the location and other factors, such as the assimilative capacity of the ecosystem (Findlay et al. 1995). A review by Brooks et al. (2003) found that the time required for the fauna in the sediment to recover (biological recovery) varied significantly from a few months to several years (Mahnken 1993, Morrisey et al. 2000, Karakassis et al. 1999). Recovery typically occurred rapidly in the months directly after fallowing, but often slowed over time, presumably due to the different rates and which discrete infauna taxa recolonise recovering sediments (e.g. Mahnken 1993).

Brooks et al. (2004) examined recovery in sediments after more than 2,000 tonnes of salmon were harvested and the cages left to fallow. At peak farming biomass, benthic sediments at the study site were black in colour and characterised by bubbles of hydrogen sulphide and beds of the sulphide-oxidising bacterium *Beggiatoa spp.*, with the effects extending between 18 and 145 metres down-current of the sea cage perimeter. In this worst-case scenario, and following four years of fallowing, biological recovery was nearing completion at distances more than 80 metres from the sea cages but was not complete within this distance. Within 80 metres, it was predicted that the sediment chemistry would require 5.4 years from the start of fallowing to return to background levels (chemical recovery) that are sufficient to support half of the common taxa observed at reference sites. Complete biological recovery would require a longer period.

The observations described in Brooks et al. (2004) validate in part the recovery times reported here, in which it was predicted that between six and seven+ years would be required for sediments directly beneath the sea cages to achieve chemical recovery (Figure 7-37 to Figure 7-42). The longer periods of chemical recovery reported in this assessment are not surprising given the levels of standing biomass examined (between 2,600 and 5,000 tonnes of finfish per 14-cage cluster), and the fact that we adopted a highly conservative approach for estimating the volumes of fish waste (EPA - Appendix 1).

Variability in the timing of recovery is widely reported in the literature: Macleod et al. (2002) reported chemical remediation after two years (with sulphide levels returning to background levels) but incomplete biological recovery (infauna were in a transitionary recovery phase and still significantly different compared to the communities observed at reference sites). Subsequent work by these authors (Macleod et al. 2006) found that sediment returned to its original condition after a three-month period, but did not return to background conditions. Despite similarities in the way the exposure of the impact sites in these studies to aquaculture (i.e. stocking levels and feed inputs) there were differences in the chemical recovery and in the rates of change in the structure of infauna communities. This implies that the link between organic deposition and biological recovery is not straightforward.

Different locations may need different management strategies, particularly with regard to timing of fallowing (Macleod et al. 2006).

As indicated in Section 7.4.1.3 (Figure 7-37 to Figure 7-42), rates of chemical recovery as predicted by the sediment biogeochemical model were assumed to proceed free of major physical disturbances. Although the model incorporated some capacity for biological and physical disturbance and reoxygenation via biologically-driven diffusion and irrigation, neither of these processes could bring about an extreme occurrence which could result in rapid renewal of sediment habitats (e.g. during major scour events such as those which may occur during major storm events or cyclones, the latter of which affects the proposed MWADZ area approximately every 2.5 years). The recovery times presented herein are therefore conservative and longer than those which may occur in reality, especially if the five to seven year recovery period modelled in this assessment was affected by a significant storm event and, or, exceptional levels of biological activity.

7.4.3.6 Metals

The sediment diagenesis model was also used to determine the time taken for sediments to recover following inputs of waste, including trace elements (Zn and Cu). Triggers were set following the EPAs EQG for high ecological protection (EPA 2014). Although present in commercial feeds, and therefore also present in fish faeces, the low molar ratios of Zn and Cu in the fish waste were insufficient to result in sediment concentrations in excess of the EQG, even after five years production at the upper end of the scenarios modelled (Scenario 6).

7.4.4 Water Column

7.4.4.1 Dissolved Oxygen

The potential for deoxygenation of the water column beneath and near the sea cages was investigated using the integrated ecosystem model. Simulations focused on the bottom half of the water column, which for the project area ranged between 12–25 metres and 25–50 metres depth. Modelling also simulated ecosystem processes in the deeper parts (at more than 50 metres depth) of the Abrolhos Islands FHPA to the west of the proposed MWADZ, including the leading edge of continental shelf slope. Median dissolved oxygen concentrations at the edge of the continental shelf were lower than the 80th percentile of background concentrations. Oxygen concentrations in the MWADZ maintained normal levels across all six of the scenarios. There was no evidence of significant levels of oxygen depletion, even at the peak of standing biomass (i.e. Scenario 6). Results of the sediment biogeochemical model, however, point to high levels of biological oxygen demand (BOD) at the sediment water interface. Under these conditions the model predicted that sediment would be anoxic, and waters at the sediment water interface are likely to experience some oxygen consumption by the sediments. However, the extent of water movement through the system is such that the level of oxygen consumption by the sediment is unlikely to have ecological consequence because oxygen levels are quickly resupplied by steady renewal of the overlying seawater.

7.4.4.2 Suspended Particles

Sea cage aquaculture produces volumes of organic wastes which settle to the seafloor. A proportion of these wastes are capable of being resuspended in the water column, where it can interfere with the mechanical processes that sustain filter feeding organisms.

The potential for suspended particles to exceed the thresholds in Table 6-15 was investigated using the hydrodynamic model coupled to the particle transport model (refer to Section 6.7).

Under the range of production scenarios (Scenario 1 – Scenario 6) simulated by the model, none produced Total Suspended Solid concentrations high enough, or over a sufficient durations of time to exceed the thresholds in Table 6-15 (Section 6.6.2). However, subsequent investigations with a threshold using longer time-periods revealed that there was potential for Total Suspended Solid concentrations in the proposed MWADZ to reach levels higher than background on occasion. Nevertheless, the duration and level of exceedance was not sufficient to exceed the published major impact thresholds for filter feeding communities (PIANC 2010).

7.4.4.3 Smothering

Anecdotal observations, and the results of modelling presented here, suggest that the majority of finfish aquaculture waste settles to the sea floor immediately beneath the sea cages. Under conditions of low shear stress, some of this material may accumulate, leading to smothering of resident benthic communities.

The potential for impacts from smothering was investigated using the hydrodynamic model coupled to the particle transport model (refer to Section 6.7) and was assessed using thresholds developed for corals (PIANC 2010; Table 6-10). Corals were chosen because they exhibit poor tolerance to sedimentation relative to other invertebrates (Oceanica 2013), thus providing for a conservative assessment.

Modelling indicated potential for exceedances of both the minor and moderate impact categories, but there were no exceedances of the major impact category (Table 6-11). Moderate impacts were seen only for Scenario 6 and were confined to very small areas immediately under the sea cages (Figure 7-42). Minor impacts were more prevalent and were recorded in Scenario 5 and Scenario 6 (Figure 7-43 and Figure 7-44). The zone of minor impact, although proportionally larger than the zone of moderate impact, was nevertheless predicted to be confined to area of sea floor corresponding to the outer boundary of the sea cage clusters.

Under the PIANC (2010) criteria, areas of the seafloor subjected to exceedances of the minor impact criteria could be expected to result in localised mortalities of coral, but not at a spatial scale expected to flow on to more serious secondary consequences. Under the same criteria, areas subjected to exceedances of the moderate impact criteria could result in locally significant mortalities. Both the zones of minor and moderate impact were predicted to be confined to the area of the sea cage clusters. While no significant corals reefs were observed in the proposed MWADZ (Section 8.5.1) the potential for impact to sensitive filter-feeding communities should be considered during placement of the sea cages.

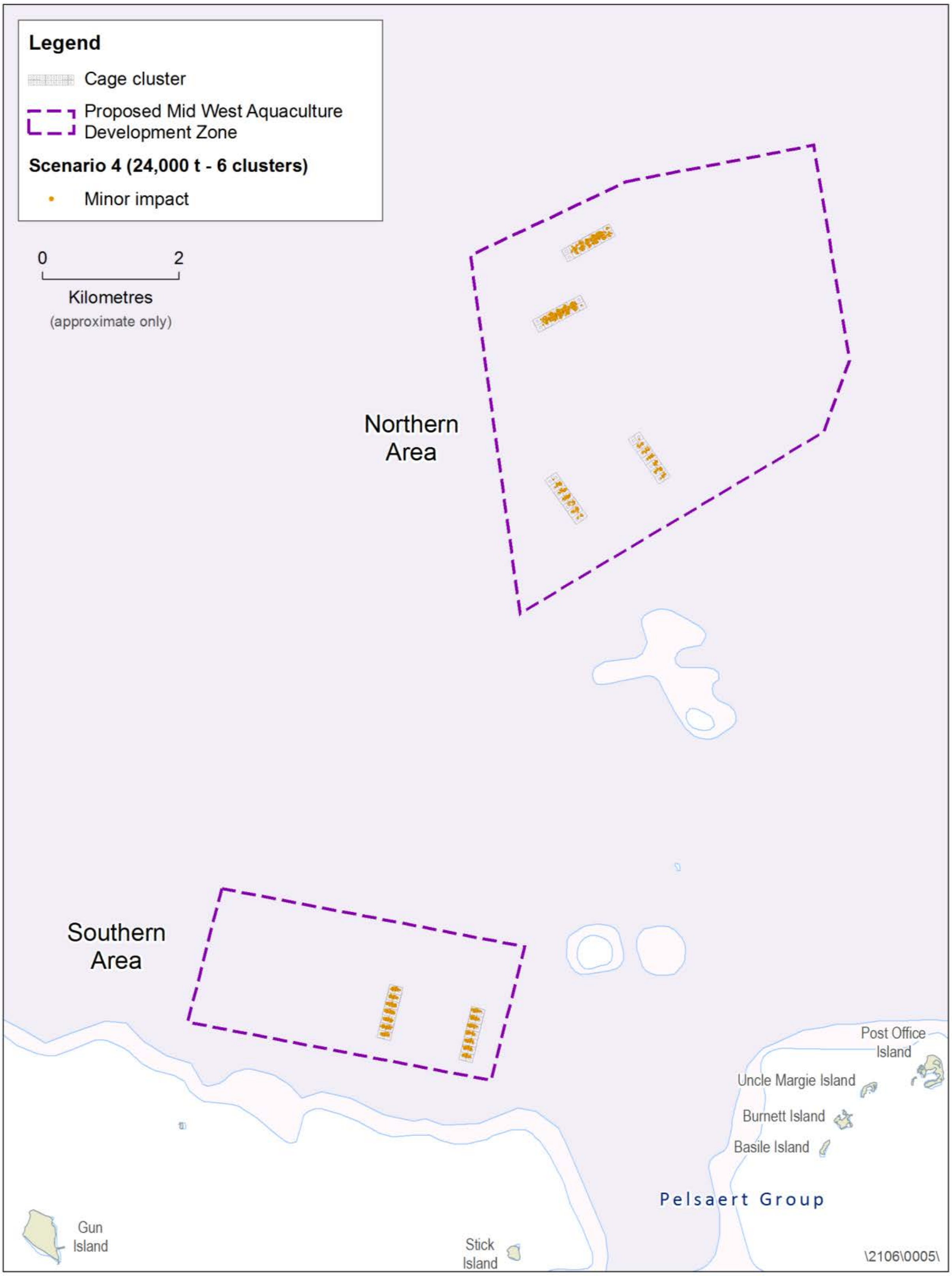


Figure 7-43: Zones of Impact based on the rate of material deposition under Scenario 4 (24,000 tonnes)

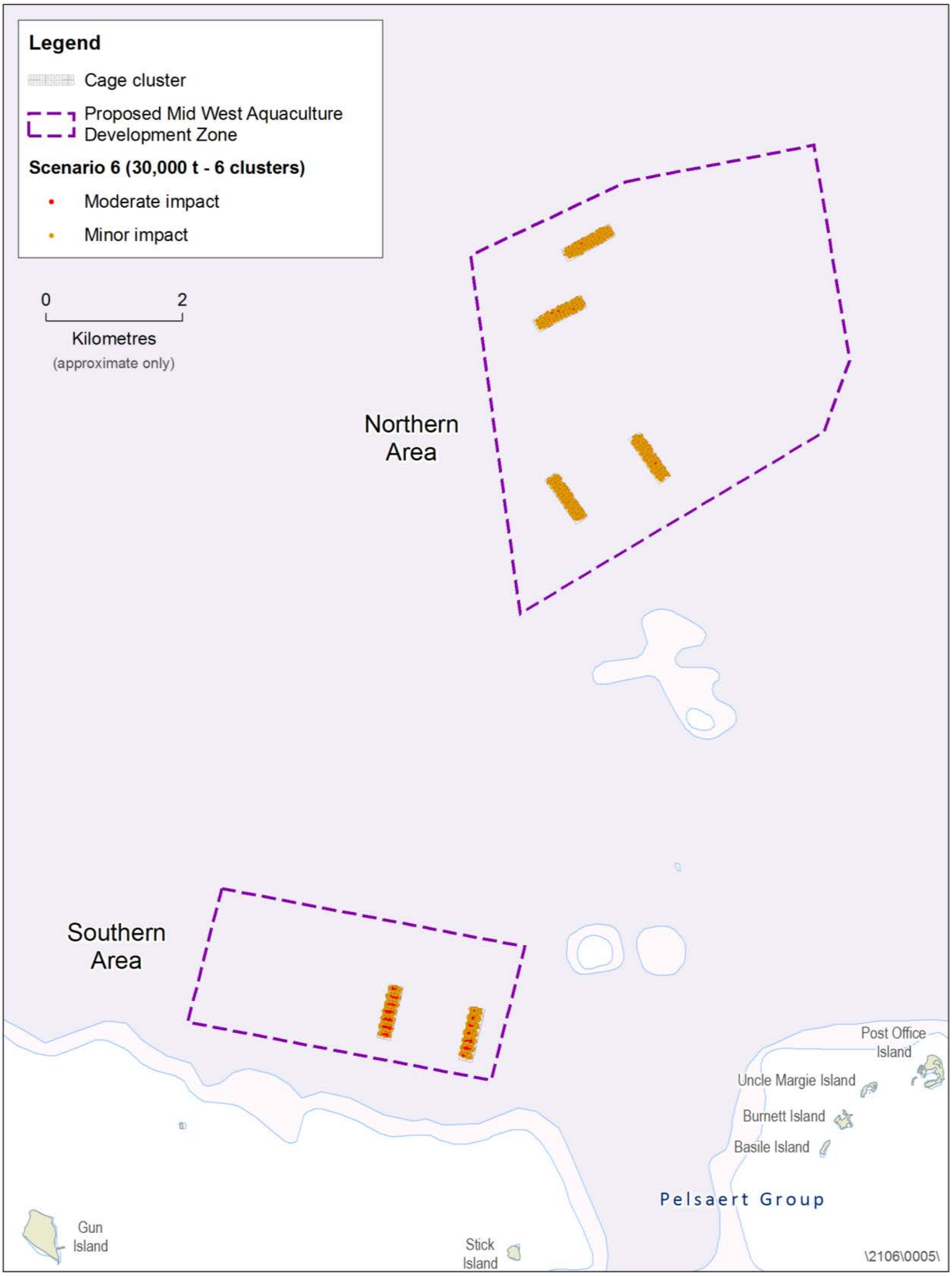


Figure 7-44: Zones of Impact based on the rate of material deposition under Scenario 6 (30,000 tonnes)

7.4.4.4 Light Intensity

Sea cage aquaculture has the potential to lead to increased light attenuation through the water column via a number of cause-effect pathways: typically via increases in suspended particles and, or, increases in phytoplankton biomass. The potential for light intensity to be reduced at the bottom strata of the water column was investigated using the hydrodynamic and water quality model components of the integrated ecosystem model. The potential for environmental impacts was investigated in the context of the thresholds listed in Table 6-13.

Reductions in Photosynthetically Active Radiation (PAR) of ~15% and ~4% were observed, respectively, immediately under the sea cages and to a distance of 100 metres from the sea cage perimeter. However, under the range of production scenarios (Scenario 1 – Scenario 6) simulated by the model, none produced conditions sufficient to reduce PAR to levels exceeding the moderate and high protection thresholds in Table 6-13. The observed reductions in PAR near the sea cages were the combined result of shading of the sea cage infrastructure, and the shading effect of suspended particles (fish wastes). None of the observed declines in PAR resulted from increases in phytoplankton. The response of phytoplankton to the varying inputs of nitrogen, as simulated across the range of scenarios, is discussed further in Section 7.4.2.5.

7.4.4.5 Algal Growth Potential (DIN)

The spatial extent and concentration of DIN released from sea cage infrastructure was investigated under the higher range of production scenarios (Scenario 4 and Scenario 6; Section 6.6.4). Concentrations of DIN near the sea cages increased with increasing biomass and increasing stocking density. Scenario 6 produced the highest concentrations and the largest DIN "footprint", while Scenario 4 produced lower DIN concentrations and a smallest environmental "footprint" (Figure 7-45 and Figure 7-46). The decrease in DIN with distance was driven partly by far-field dilution processes and partly by biological assimilation, both processes simulated in the CANDI-AED-model.

For the purposes of defining zones of impact, acute thresholds were developed following the criteria for high and moderate levels of ecological protection, respectively, under which large and moderate changes would be expected to ecosystem health (Table 6-12). Concentrations of DIN in and immediately adjacent to the sea cage structures exceeded the moderate ecological protection criterion (95^{th} percentile of background) in both scenarios (Scenario 4 and Scenario 6), though the areas occupied by this zone were small and typically restricted to within 150 metres of the sea cage perimeter. The spatial extent of the area exceeding the high protection criterion (80^{th} percentile of background) was more extensive, but varied markedly depending on the scenario and the position of sea cages within the zone. The area exceeding the high protection criterion was greater in the northern MWADZ, where the stronger currents acted to carry the plume farther and more rapidly.

Although the area exceeding the moderate protection criteria was small and restricted to the proposed MWADZ, the area exceeding the high protection criteria encroached (and in some cases breached) the boundaries of the northern MWADZ. This was most pronounced in Scenario 6 (Figure 7-45) but was mitigated in S4 by reducing the stocking density (Figure 7-46).

The area exceeding the combined moderate and high protection criteria represents the area not expected to meet a high level of ecological protection and highlights the potential for algal growth. The extent to which the simulated elevations in DIN translated to algal growth were examined using the water quality model packages (Section 6.7.5).

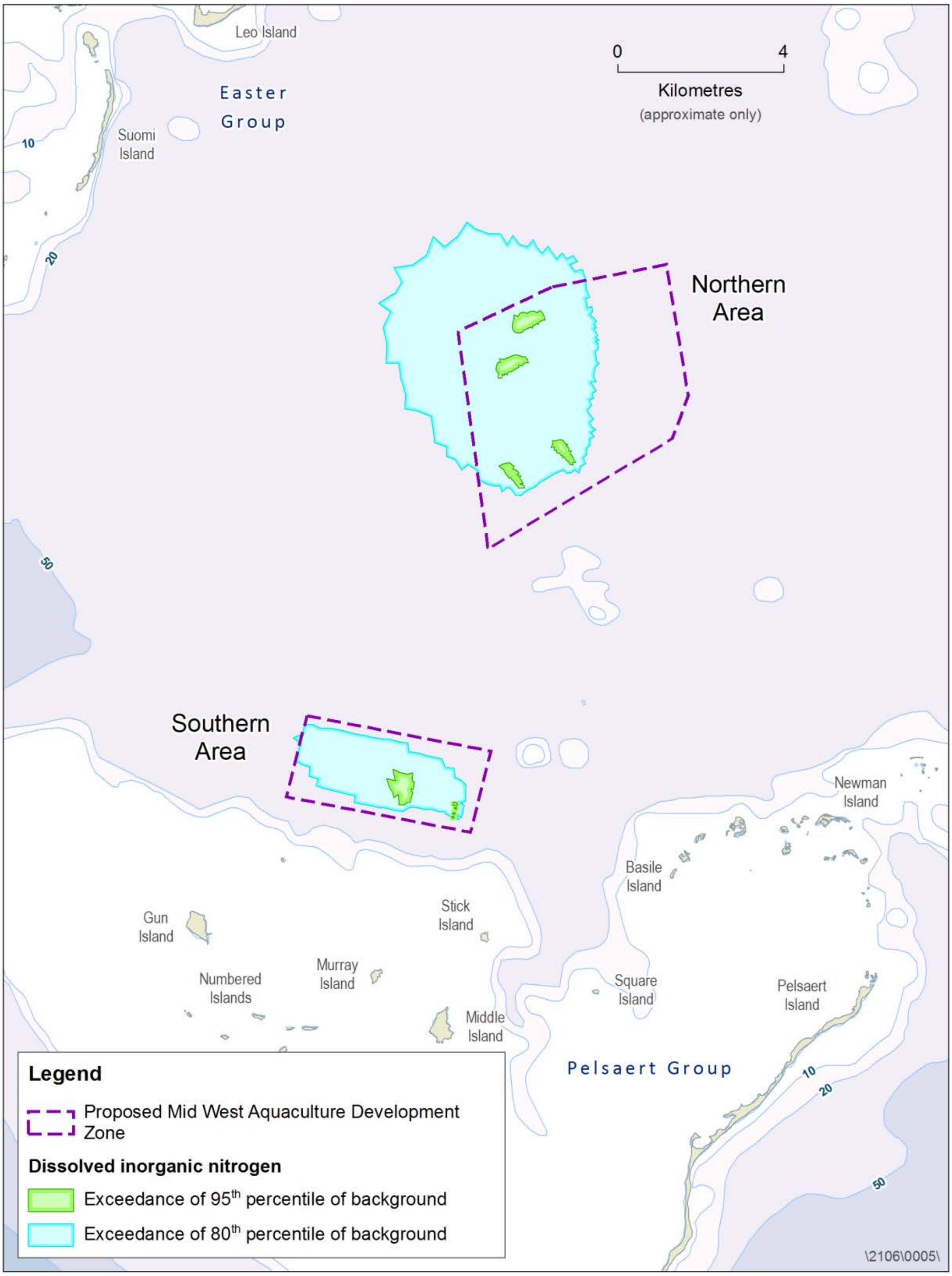


Figure 7-45: Zones of Impact based on Dissolved Inorganic Nitrogen in the water column under Scenario 6

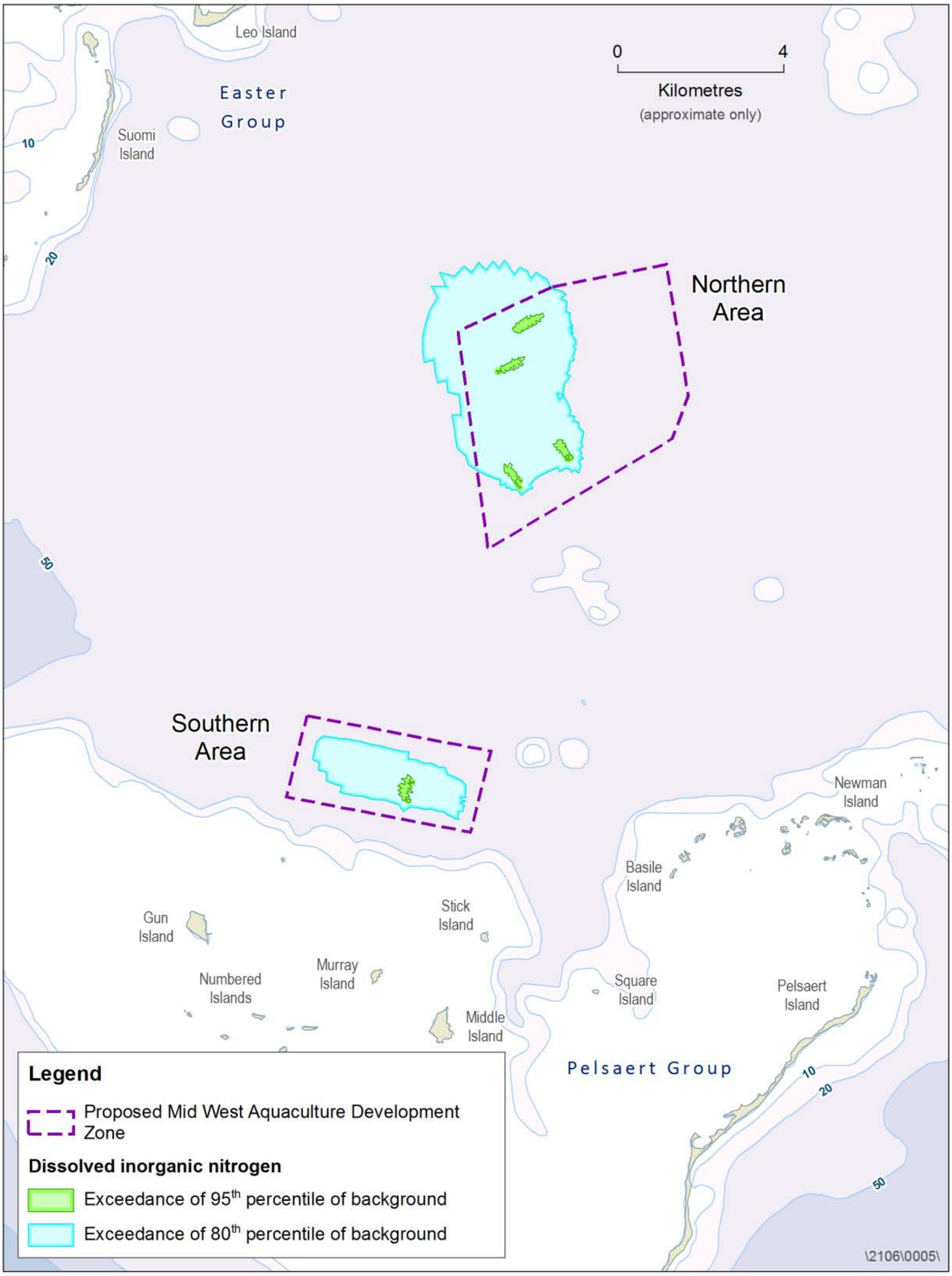


Figure 7-46: Zones of Impact based on Dissolved Inorganic Nitrogen in the water column under Scenario 4

7.4.4.6 Nutrient Enrichment and Chlorophyll-a

Despite significant inputs of Dissolved Inorganic Nitrogen (DIN), there were no discernible increases in chlorophyll-a (the surrogate for phytoplankton biomass) that could be attributed to aquaculture. Furthermore, there were no exceedances of the moderate and/or high ecological protection criteria in the waters surrounding the proposed MWADZ. A natural gradient of chlorophyll-a was detected between deep waters of the MWADZ and shallow waters of the mainland. Chlorophyll-a in coastal waters sustained concentrations higher than the 95th percentile of background oceanic conditions, even when baseline conditions were simulated by the model. This confirmed the observed pattern was not a result of aquaculture activities.

The high concentrations of chlorophyll-a displayed via model simulation are not surprising given the volume and level of water movement through the MWADZ study area and surrounds. Perth's coastal waters, like those of the project area, are oligotrophic and well flushed (but differ in that that they are shallower; 10–20 metres depth). Inputs of DIN for Scenario 1 and Scenario 2 are roughly equivalent to the annual total DIN inputs to Perth's coastal waters via three widely separated ocean outfalls (BMT Oceanica 2015c). Over ten years of intense summer water quality monitoring near these outfalls has not detected long-lasting increases in chlorophyll-a due to these regular DIN inputs. Where chlorophyll-a increases have been detected, they have only persisted for a short time (days) and were typically associated with extended periods of low wind (Oceanica, unpublished data). Although Scenario 4 and Scenario 6 represent inputs of DIN in higher volumes than the combined inputs of Perth’s three ocean outfalls, the scenarios indicate the very high assimilative capacity of the water within the Abrolhos Islands FHPA. The assimilative capacity is likely enhanced by the depth of the water column and associated large receiving volume of the Zeewijk channel and adjoining waters.

7.5 Management Measures

7.5.1 Environmental Quality Management Framework

Marine environmental management in Western Australia is undertaken according to the environmental quality management framework (EQMF) described in EAG 15 (EPA 2015). The Environmental Monitoring and Management Plan (EMMP) (refer to Appendix 2), that has been developed to provide proponents with an appropriate EQMF for managing the potential impacts of stocking up to 24,000 tonnes of marine finfish across the proposed MWADZ, is described in general terms in Section 15.3.1.1.

The EQMF for Western Australian coastal waters defines five environmental values (EVs) as particular values or uses of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety or health, and which require protection from the effects of pollution, waste discharges and deposits (EAG 15). These EVs are:

- ecosystem health;
- fishing and aquaculture;
- recreation and aesthetics;
- industrial water supply; and

- cultural and spiritual.

All five of these EVs are generally expected to apply throughout Western Australian marine waters (including those associated with the MWADZ Proposal).

These values are essentially of two types: ecological and social. The first of these EVs (i.e. ecosystem health) is an ecological value because it relates to the protection of the inherent characteristics of the natural ecosystem. It can also be regarded as a fundamental value because practically all human uses ultimately depend on the condition of the natural system. The other four EVs are regarded as social or utilitarian values because they relate to specific human uses of coastal waters (EPA 2000).

While each of these EVs is separate from each other in that they have different environmental quality objectives (EQOs), there is a degree of connectivity between them in so far as their environmental quality criteria (EQC) often are expressed in similar units of measurement.[40] Where this coincidence of EQC occurs, it is possible to rationally argue (for a particular EQC) that if the EQC for (say) the EQO of "ecosystem integrity" is met and the threshold value for that EQC is **lower** than that of the same EQC for one of the other EQOs, such as "water safe for swimming" (recreation and aesthetics EV), then the EQOs and EQCs of **both** the EVs will be protected. In other words, for similar EQC, to meet the requirements of the lower threshold is to automatically meet the requirements of the higher threshold.

Using this rationale, the Department is of the view that in the case of the MWADZ Proposal, most of the EVs and their associated EQOs can be demonstrated to be met if the EQC for the "primary" EV of ecosystem health is met; noting the EQC for ecosystem health generally have significantly more conservative (i.e. stringent) thresholds than the other EVs. By satisfying the requirements of the EV ecosystem health [even in those areas designated a Moderate Level of Ecological Protection (MEPA)], this also satisfies the requirements of the other EVs. The map at Figure 15-1 illustrates where the EQOs relevant to the MWADZ Proposal will be met. This figure also illustrates where the EQOs for all the other marine environment EVs will be met (i.e. all areas).

7.5.2 Ecosystem Health

The ecologically-based EV "ecosystem health" is concerned with maintaining the structure and functions of marine ecosystems to an appropriate level. It has the EQO of "maintain ecosystem integrity" and four associated levels of ecological protection (LEPs). This structure allows areas identified as important for conservation and biodiversity protection to be maintained in their natural state while recognising that in other parts of the marine environment there are societal uses that may preclude a high level of ecological protection from being achieved (EAG 15).

While aquaculture proponents have an obligation to meet each of the EQOs, only a small number of EQOs are at risk due to aquaculture operations.

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[40] An Environmental Quality Objective (EQO) is a specific management goal for a part of the environment. EQOs can be either *ecologically-based* and describe the desired level of health of the ecosystem (e.g. in terms of limits of acceptable change from natural conditions), or *socially-based* and describe the specific human uses to be protected (e.g. swimming or boating) (EPA 2000).

The cause-effect pathways related to finfish aquaculture are outlined in Section 3.2.2 of the Environmental Monitoring and Management Plan (EMMP - Appendix 2).

The key pressures associated with aquaculture are inputs of nutrients and organic material derived from finfish metabolic processes and feeding. As such, none of the pressures identified in Section 3.2.2 of the EMMP are expected to compromise the EQOs for these EVs.

The EQO, to "maintain ecosystem integrity", is unique in that it encompasses differing levels of ecological protection (LEP): maximum, high, moderate and low (EAG 15). Differing levels are applied in recognition of the competing environmental, societal and industrial uses of the marine environment. Because of competing interests, it is recognised that not all areas can achieve (or retain) high to maximum levels of ecosystem protection, and that some areas must instead be given either moderate or low ecological protection status (EPA 2015), with corresponding limits of acceptable change.

The framework allows for small localised effects, while aiming to maintain overall environmental integrity (EPA 2015). This is important in the context of the MWADZ Proposal EMMP, which includes strategies to manage the expected reduction in environmental quality beneath and immediately adjacent to the MWADZ sea cages, while maintaining broader regional environmental quality (Section 3.2.4 of the EMMP).

The EQO for maintenance of ecosystem integrity requires the spatial definition of four or less LEPs – maximum, high, moderate and low (EAG 15). The rationale for designation of LEPs is based on the expectation that aquaculture operations will reduce environmental quality on a local scale, such that a maximum or high LEP may not be achievable immediately beneath and adjacent to operational infrastructure. The EPA expects the cumulative size of the areas designated as moderate or low ecological protection areas to be proportionally small compared to the areas designated high and maximum.

Guidance provided by the EPA suggests that marine finfish aquaculture (defined as sea cages) in Western Australia should be managed to achieve a "moderate" LEP (Table 3 of EAG 15). In areas assigned a moderate LEP, operational pressures are expected to result in small changes to the abundance and biomass of marine life, and in the rates but not the types of ecosystem processes. Under the same LEP, there should be no detectable and persistent changes in biodiversity due to waste discharges or contamination.

Environmental modelling undertaken for this project predicted that any organic enrichment resulting from aquaculture would be locally constrained, with no resulting regional scale adverse effects (BMT Oceanica 2015). For example, modelling predicted that the most severe impacts from the 24,000 tonne maximum standing biomass of marine finfish (spread over six cage clusters) would be restricted to within a distance of less than 100 metres after three year's production.

While changes to the sediment chemistry and resident biological assemblages are expected to occur at this stocking level, the changes are predicted to be locally constrained, with no resulting detectable impacts beyond 100 metres from the sea cages (under full production). Furthermore, any changes to the sediment chemistry and the resident invertebrate fauna are expected to be fully reversible under a program of routine fallowing (Section 6 of the EMMP).

Based on the above, it is proposed to establish moderate ecological protection areas (MEPA), comprising no more than 50 percent of each MWADZ lease, within a broader high ecological protection area (HEPA). The framework has been designed to be moderately protective of habitats within the MEPA (with a decreasing gradient of effect between the sea-cages and the HEPA boundary) and highly protective of habitats outside of the MEPA, including sensitive coral reef habitats.

Proponents will be expected to demonstrate they are meeting the designated LEPs for the life of the project by complying with the EQC for moderate and high ecological protection as outlined in Sections 4.1 and 4.2 of the EMMP. The proposed MEPA will comprise of both "active" and "recovery" footprints that, when operational, will be assigned a moderate LEP. At the commencement of fallowing, the recovery footprints will be monitored until it can be demonstrated that they have recovered to levels consistent with a high LEP.

The cumulative area occupied by the MEPA (i.e. both active and recovery footprints) is less than 5% of the area within a 10 km radius of the MWADZ, which is within the acceptable limit for MEPA specified in EAG 15 (EPA 2015). The spatial arrangement and extent of the moderate and high LEP to be applied to the MWADZ is illustrated in Figures 15-1 of this PER and 4.1 of the EMMP.

7.5.3 Fishing and Aquaculture

This EV relates to ensuring environmental quality is suitable for the gathering and farming of seafood for human consumption. The intent is to ensure seafood collected or grown in waters where this EV is protected would not have levels of contaminants in the flesh that would exceed the Australian Food Standards (EPA 2000).

The EV "fishing and aquaculture" has two EQOs, "seafood safe for eating" and "marine environment suitable for aquaculture".

Fishing and aquaculture are concerned with the protection of the human population from the potential adverse effects of toxicants and microbiological contaminants (typically present in sewage and storm water) and the protection of nearby aquaculture and industry from the effects of toxicants and other contaminants (EPA 2015a).

As stated in Section 7.5.2 of this PER, the key pressures associated with aquaculture are inputs of nutrients and organic material derived from finfish metabolic processes and feeding. As such, none of the pressures identified in Figure 3.6 of the EMMP (Figure 6-3 of the PER) are expected to compromise the EQOs for this EV.

The monitoring and management arrangements embodied in the MWADZ Proposal EMMP that focus on the key EV of ecosystem health and its associated EQO of maintenance of ecosystem integrity, include strategies and contingency management responses to protect the major elements of the ecosystem; water and sediment quality (as required under the EQMF). These are supplemented with additional (but separate from the EQMF) management arrangements with emphasis on marine mammals and seabirds; as well as human-generated waste (EMMP; ZMP; MFIMP and WMP).

Collectively, the management measures required by the EMMP effectively address all likely potential sources of toxicants and microbiological contaminants that may also impact on the EV fishing and aquaculture and its EQOs. Consequently, this EV is well-protected.

7.5.4 Recreation and Aesthetics

This EV relates to human uses of the environment and includes sporting and leisure activities with frequent direct body contact with the water (e.g. swimming), or less-frequent body contact with the water (e.g. boating) and passive recreation which does not involve contact with the water (pleasant places to be near or look at) (EPA 2000).

The EV of "recreation and aesthetics" has three EQOs, "water safe for swimming", "water safe for secondary contact" and "aesthetic values protected".

In terms of the first two EQOs, the level of protection set is usually expressed in bacteria counts. For instance, the National Health and Medical Research Council (NHMRC) have set a safe limit for swimming of 150 bacteria/100ml of water. If levels of bacteria are lower than this standard, the water is considered "safe" to swim in. If levels of bacteria exceed this standard, the water is considered "unsafe" to swim in. It follows that, if the water was safe to swim in (i.e. primary contact), it would also be safe to undertake on-water activity (i.e. secondary contact) such as boating.

Microorganisms and infectious agents are naturally abundant in all seawater. However, the strains each population experience are different. General coliform bacteria (bacteria) indicate that the water has come in contact with plants or animals. At very high levels, bacteria indicate there is (what amounts to) a lot of organic material (derived from plants or animals) in the water. This could include pathogens. However, most of the bacteria in seawater are harmless to human health.

Human faeces in sea water present the greatest risk to swimmers. Faecal coliforms, particularly *Escherichia coli* (*E. coli*), are an indicator of mammal or bird faeces within the water. The genus *Enterococcus* includes more than 17 species, although only a few cause clinical infections in humans. *Enterococcus* bacteria are persistent in sea waters. They are a more general indicator of faecal contamination from warm-blooded animals and are commonly associated with swimming-related gastrointestinal illness. The risk to human health from exposure to animal faecal matter increases the more closely that animal is related to humans, (i.e. mammals and birds present a greater risk than fish). Essentially, there are no *Enterococci* or thermo-tolerant coliforms in fish faeces.

The MWADZ Proposal provides that human sewage must be either:

- treated, using a sewage disposal system approved by the Department of Health, prior to disposal at sea in accordance with the Department of Transport's Strategy for Management of Sewage Discharge from Vessels into the Marine Environment 2015 (Strategy); or
- stored in tanks on the vessel and disposed of on land at a licensed disposal site in accordance with Local Government Authority by-laws (WMP – Appendix 3 and ZMP – Appendix 6).

By regulating the discharge of human sewage within the boundaries of the proposed MWADZ and implementing management measures designed to reduce the risk of attracting other sources of faecal contamination (e.g. dolphins, sea lions and seabirds) to aquaculture operations within the proposed MWADZ, the risk to human health by bacteria of faecal origin will be effectively addressed.

Bacterial populations in any situation feed on organic material and rely on the availability of oxygen, carbon and nitrogen (Carter, 1989). The EQMF (EAG 15) presented in this PER provide risk-based evidence that organic enrichment associated with aquaculture stock (fish) faeces will not exceed concentrations that could present a risk to swimmers or divers in the waters of the proposed MWADZ.

Total suspended solids (TSS) are a proxy for organic waste generated by the aquaculture stock which (in turn) could be linked to general coliform bacteria. Future proponents (i.e. derived proposal proponents) will measure TSS in the water column six times per year as one of the environmental quality guideline (EQG) requirements for a moderate level of ecosystem protection. The median value for TSS in both the summer sampling period and the winter sampling period must be less than the 95th percentile of the values recorded at the reference sites. Given that the reference sites are isolated water bodies several kilometres away from the nearest human habitation, the EQG for TSS ensures that concentrations of organic waste, linked to concentrations of general coliform bacteria, will be maintained at comparatively low levels.

In the event that the EQG is exceeded, the future proponents must demonstrate through video surveys that no there are no bacterial mats (of the genus *Beggiatoa*) on the seafloor beneath the sea cages. *Beggiatoa* species take advantage of organically-enriched sediments at the water-sediment interface that can be found beneath fish farms that are poorly flushed and/or heavily stocked. It is reasonable to expect that bacterial mats at the water-sediment interface would correlate with general bacteria in the water. The bi-annual benthic quality video assessment provides further confidence that the water quality within the MWADZ is safe for both primary and secondary contact recreation (i.e. in-water activities such as swimming and diving; in addition to on-water activities such as boating).

With respect to the social EQO of "aesthetic values of the marine environment are protected" the measures are more subjective. The term "aesthetics" is very closely related to the EPA environmental factor of "amenity" (Section 13 of this PER and EAG 8). Consequently, by protecting the EV "ecosystem health" (EMMP - Appendix 2) and implementing the management measures outlined for the environmental factor of "amenity", the MWADZ Proposal will protect the "aesthetics" component of the EV "recreation and aesthetics".

7.5.5 Industrial Water Supply

The EV "industrial water supply" is specific to the industry and the industrial process used. In most cases, the industry is able to treat intake water to the quality they require (EAG 15).

As explained in the sections above, the water quality necessary for marine finfish aquaculture is of a standard well in excess of that required for industrial water supply. Therefore, by protecting the EVs of "ecosystem health", "fishing and aquaculture" and "recreation and aesthetics", the EV of "industrial water supply" is similarly protected.

While not a consideration for environmental impact assessment, it is also worth noting the proposed MWADZ is located approximately 65 kilometres offshore of the Mid West city of Geraldton. Consequently, it is improbable that water from the MWADZ Proposal area would be required for industrial use; at least, from the mainland. What is more possible is the potential future requirement for marine water for desalination purposes on the Abrolhos Islands Reserve. However, even should such requirement eventuate, the MWADZ Proposal area is located approximately six kilometres distant from the closest inhabited island and too remote for water extraction purposes; desalination or otherwise.

For the reasons outlined above, the MWADZ Proposal will protect this EV by protecting the EV "ecosystem health" (EMMP - Appendix 2).

7.5.6 Cultural and Spiritual

The EV "cultural and spiritual" applies to Aboriginal cultural and spiritual values. However, it is problematic to define spiritual value in terms of environmental quality requirements. In the absence of any specific environmental quality requirements for protection of this EV, it is assumed that if water quality is managed to protect ecosystem integrity, protect primary contact recreation, protect the quality seafood for eating and maintain aesthetic values, then this may go some way toward maintaining cultural values (EAG 15).

Until more definitive units of measurement of "cultural and spiritual" environmental quality can be determined, the MWADZ Proposal seeks to address this EV by adopting the approach outlined above (EMMP - Appendix 2).

7.5.7 Water Quality

The water quality monitoring program facilitates the assessment of several indicators of ecosystem health that relate to the environmental health of the water column (seawater within and surrounding the proposed MWADZ). Comparisons will be made between data collected at the proposed MWADZ boundary and background data that is measured at reference sites (at least 3,000 metres distant). The comparisons are to determine whether EQG and EQS have been met at the MWADZ boundary, within the High Ecological Protection Area (HEPA). The water quality monitoring program includes measurements for total suspended solids (TSS), chlorophyll-a, light attenuation coefficient (LAC) and dissolved oxygen (DO) (EMMP - Appendix 2).

7.5.8 Sediment Quality

The sediment monitoring program facilitates the assessment of several indicators of ecosystem health relating to the environmental health of the seafloor (benthos). Comparisons are made between data collected at impacts sites (within 300 metres of sea cages) and background data that is measured at reference sites (at least 3,000 metres distant from the sea cages).

The comparisons are to determine whether environmental quality guidelines (EQG) and environmental quality standards (EQS) have been met at the Moderate Ecological Protection Area (MEPA) boundary (i.e. 300 metres from the sea cages) and to build knowledge on the extent and intensity of organic enrichment and/or metal contamination near the sea cages (i.e. inside the MEPA boundary). The sediment monitoring program includes the following analytes: total nitrogen (TN), total phosphorus (TP), total organic carbon (TOC), metals (copper and zinc) and infauna (EMMP - Appendix 2).

7.5.9 Environmental Quality Management Framework for Moderate and High Ecological Protection

Under the MEPA framework, proponents will be required to undertake management (to reduce pressures) upon an exceedance of these criteria, all of which are expected to be exceeded well in advance of the "worst case" levels of impact predicted by the Model (which predicted isolated heavy impacts to sediments beneath the cages, but with no resulting changes in water quality). The EQMF and the criteria contained within the EMMP are a practical solution to management, particularly given the expected slow development of the industry (which will impart only small pressures prior to reaching full production) and the ability for proponents to routinely relocate sea cage infrastructure as needed. Cage clusters will be periodically relocated to allow sediments to return to the equivalent of baseline physical/chemical conditions (i.e. the practice of fallowing). Relocation of entire clusters may be undertaken to allow impacted habitats to recover and shift from conditions representing a moderate level of ecological protection to conditions representing a high level of ecological protection (EMMP - Appendix 2).

At a moderate level of environmental protection, EAG 15 allows for small changes in rates, but not types of ecosystem processes. However, it requires that biodiversity, as measured on both local and regional scales; remain at natural levels (i.e. no detectable change). The EQMF relies on the recovery of marine environmental quality. The Model has demonstrated that sediment chemistry will recover over time. However, recovery of biological components of sediment quality (i.e. restoration of infauna and associated ecosystem functions) is more complex and could not be reliably predicted by the Model. With respect to such limitations, Abelson *et al*. supports the use of existing management frameworks, such as EAG 15, to identify clear restoration targets, but recommends that benchmarks such as the re-establishment of ecosystem functions should be appraised bearing in mind that, in reality, biologically-driven ecosystem functions (having chemical, physical and biological interactions) can take decades (or longer) to return to a state equivalent to the baseline.

Nevertheless, the efforts by proponents to implement the fallowing regime (required in the EMMP - Appendix 2) will bring about recovery of ecosystem services (aspects of the ecosystem valued by people) at the operation-site level and maintain ecosystem functions at a local level. In this context, the EQMF will maintain the quality of water, sediment and biota so that the environmental values, both ecological and social, are protected.

The ability to relocate the infrastructure (either routinely or upon an exceedance of the EMMP criteria) allows the receiving environment to recover prior to recommencement of operations. The ability to fallow areas within aquaculture leases is an important advantage for aquaculture industry over other coastal industries (including harbours and outfalls) that cannot simply be relocated upon discovery of an unacceptable environmental response.

The EQMF and the EMMP are therefore critical to the development of the MWADZ, and provide the security to ensure future derived proposals are sustainable and well managed to achieve levels of environmental quality much higher than that predicted under the modelled "worst case" scenarios (EMMP - Appendix 2).

7.5.10 Response to Exceedances

The periodic relocation of sea cage clusters (i.e. fallowing) allows sediments to return to the equivalent of baseline physical/chemical conditions. Such practices have been shown to be a highly effective method for reducing the point source impacts of aquaculture. Relocation of entire cage clusters may be undertaken to allow impacted habitats to recover, and shift from conditions representing a moderate level of ecological protection, to conditions representing a high level of ecological protection.

Following exceedance of an EQC, the EMMP requires that one or more of the following contingency management measures be applied:

- relocation of cage cluster(s); or
- execution of temporary measures, such as:
  - partial harvest of the stock;
  - reduction in stock density; and/or
  - reduction in feed input.

Fallowing may be undertaken as part of routine operations, or in response to an exceedance of an EQS. In the case of an EQS exceedance, fallowing is recommended to reduce the source of the contaminants and to restore environmental quality to a level commensurate with high level of ecological protection (HEPA). The proponent must report an EQS exceedance to the Department and the OEPA within 24 hours and will commence a contingency management phase to:

- reduce the effect and/or mitigate the source of the contaminants; and
- restore environmental quality within the specified level of ecological protection.

Regardless of the management option, in the event of an EQS exceedance, proponents would be required to capture the transition from operational or impacted conditions to remediated conditions. Recovery monitoring will be undertaken at the former moderate ecological protection area (MEPA) compliance sites, which will be referred to as "recovery" sites. Sampling will be undertaken at a sub-set of the former MEPA compliance sites at distances: centre, 0 metres, 50 metres and 100 metres from the sea cage clusters. Recovery monitoring will be undertaken once during the scheduled summer sampling period and will be supplemented by qualitative video assessment. Recovery will be monitored until the sediment chemistry at the fallowed site achieves conditions commensurate with a high level of ecological protection. To assess recovery, data from the recovery (previously, "monitoring") sites will be compared against data from baseline or reference sites using appropriate statistical methods. The proponent shall report the results of recovery monitoring program to DoF and the OEPA annually (EMMP – Appendix 2).

7.6 Predicted Environmental Outcome

Results presented here indicate that the impacts of the proposal can be constrained within small areas of the seafloor within the proposed MWADZ, with no adverse effects to regional environmental quality.

7.6.1 Water Quality

Sea cage aquaculture may, in some circumstances, lead to elevated concentrations of dissolved inorganic nitrogen (DIN) and suspended particles in the water column. These factors can, in turn, lead to shading and reduced light levels at the seafloor resulting in the loss of BCH (Appendix 1).

Despite large inputs of DIN to the ecosystem, any faecal plumes or phytoplankton blooms within the proposed MWADZ will dissipate rapidly, and water quality will be maintained at levels consistent with a high level of ecological protection. The extent of light reduction (or shading) is largely associated with the extent of particles in the water, a proportion of which is phytoplankton. Phytoplankton concentrations, as indicated by chlorophyll-a concentrations, are not expected to change significantly across the proposed MWADZ. Similarly, light and dissolved oxygen levels in the water column of the proposed MWADZ are not expected to be affected. No discernible impacts on sub-surface light conditions are expected to be caused by increased phytoplankton blooms or suspended waste in the water column (Section 8.2.3.5; Appendix 1).

7.6.2 Sediment quality

The seafloor sediments beneath the sea cages will be exposed to deposition of organic material that will result in changes to concentrations of oxygen and hydrogen sulphide in the sediments (Section 7.4.1.1). Organic waste inputs will lead to some localised sediment organic enrichment and changes to sediment chemistry. Appropriate levels of standing biomass and three-year cage cluster site rotation will constrain the extent of the zone of high impact. After more than three years of finfish production at any one location, the zone of high impact is unlikely to breach the cage cluster perimeter (Appendix 1).

Given the conservative approach adopted for the development of the Model, the predicted impact to the sediment represents a "most likely worst case" outcome, as required by the ESD (EPA 2013). However, it should be noted that the expected environmental outcome sits between the modelled "most likely worst case" outcome and the aspirational "most likely best case" outcome. The precautious approach to the modelling has ensured that outputs relating to marine environmental quality were not under-predicted, but within the upper range of aquaculture related impacts reported in the scientific literature. In balancing the "most likely worst case" outcome (as predicted by the Model) with the "most likely best case" outcome (based on a breadth of relevant aquaculture literature and professional experience) the actual environmental outcome is expected, on average, to be less severe than that predicted by the Model. This provides confidence that the proponents will achieve a moderate level of protection within the operational area (i.e. within 300 metres of sea cages) and a high level of protection in at least 50% of each aquaculture lease within the MWADZ.

A key factor in modelling was that the rates of recovery (refer to Section 7.4), as predicted by the sediment diagenesis model, were assumed to proceed at a steady rate.

Although the modelling of recovery simulated some capacity to account for reoxygenation of the sediment, it did not take into account any extreme oceanic conditions associated with occasional intense low-pressure weather systems. While infrequent, major storm events could result in substantial scouring of the seafloor that could "reset" the sediments and advance their chemical recovery. Under a "most likely best case" scenario, it is expected that "resetting" events (associated with major storms) would result in less accumulation of organic material than described in Section 7 and faster chemical remediation. As such, the impacts predicted in this document are more extensive than might be expected on average. Nevertheless, they are within the upper range of impacts reported in the literature (i.e. Brooks et al. 2004). The greater propensity for flushing and sediment reoxygenation could be expected to reduce the overall impact footprint as predicted by the Model.

Large standing biomasses (up to 8 tonnes per hectare of lease) are achievable, while constraining the benthic impacts to relatively small areas. However, increasing the stocking density by reducing the total sea cage volume used to contain the same standing biomass of stocked fish will increase the intensity of impacts beneath the sea cages. Under the EQMF, proponents are expected to maintain a moderate level of ecological protection to a distance of 300 metres from the cages, beyond which a high level of ecological protection will apply.

The EQMF provides the mechanism for protecting the MWADZ and surrounding region by applying strict environmental performance criteria on proponents. These performance criteria are conservative and therefore useful as "early warning" triggers for management. If stocking densities are sustained around and beyond the upper limits of industry norms, the risk of exceeding the Ecosystem Quality Criteria (EQC) will exponentially increase (for contingency options refer to Section 7.5). Although an exceedance of the EQS will trigger a management action to reduce impacts on sediment quality, the time taken for sediments to achieve chemical remediation is approximately five years (Appendix 1).

Increases in stocking density will extend the time required for sediment (chemical) remediation during fallowing. Therefore, a limit on the stocking density (up to eight tonnes per hectare of lease) is essential for managing the proposed MWADZ. Once a site has been fallowed, impacted seafloor habitats within the operational areas are predicted to recover to a high level of ecological protection within five years. Immediately under the sea cages, the small proportion of sediments that are heavily impacted may require as long as nine years to achieve full biological recovery (Appendix 1).

In addition to contributing organic wastes to the seafloor, any antibiotics administered to stock inside the sea cages will deposit in the sediments beneath. Although its use is rare in the industry today, an incident such as a disease outbreak may require that antibiotics be administered to the stock within the sea cages. The main risk associated with the use of antibiotics in sea cages is the potential degradation of bacterial communities at the seafloor. An impact on bacterial communities could affect biochemical and broader ecological processes. Because antibiotics are administered in feeds, the spatial extent of potential impacts is likely reflected in the settlement patterns of organic wastes. Given the majority of wastes in the proposed MWADZ would be deposited within 60 metres of the sea cages, it would be constrained to relatively small areas. The more commonly used antibiotics in the industry may persist in the sediments beneath sea cages for a number of weeks. However, accumulation over multiple seasons in the MWADZ is considered unlikely and the potential effects are considered negligible (Appendix 1).

Areas outside, and at least half of the area inside, the proposed MWADZ will maintain sediment chemistry (in relation to oxygen and sulphide concentrations) equivalent to background levels, with no resulting changes in infauna diversity. Providing standing biomasses do not exceed eight tonnes per hectare of lease, it is expected that EQC for infauna diversity will not be exceeded (Appendix 1).

Although present in commercial feeds (and therefore also present in fish faeces), it is predicted that the low molar ratios of zinc and copper in the fish waste will be insufficient to result in sediment concentrations in excess of the EQC, even after five years production at the upper end of the proposed standing biomass limit of 24,000 tonnes of marine finfish for the proposed MWADZ (Appendix 1).

8 ASSESSMENT OF POTENTIAL IMPACT ON BENTHIC COMMUNITIES AND HABITATS

8.1 Assessment Framework

8.1.1 Environmental Objective

The EPA environmental objective for Benthic Communities and Habitat (BCH) is as specified in EAG 8, namely:

"*To maintain the structure, function, diversity, distribution and viability of benthic communities and habitats at local and regional scales*".

8.1.2 Relevant Legislation, Policies, Plans and Guidelines

Table 8-1: Legislation, Policies, Plans, and Guidelines Relevant to Benthic Communities and Habitat

Legislation, Polices, Plans and Guidelines	Intent
State	
Environmental Protection Act 1986	This State Act provides for an EPA, for the prevention, control and abatement of pollution and environmental harm, and for the conservation, preservation, protection, enhancement and management of the environment.
Fisheries Resources Management Act 1994	Provides a legal framework to conserve, develop, and share fish resources for the benefit of current and future populations in WA. This legislation also provides the management framework for the Abrolhos Islands reserve and for the establishment and management of the Fish Habitat Protection Areas.
The Management Plan for the Houtman Abrolhos Islands. Fisheries Management Paper 260. (Department of Fisheries 2012)	The Houtman Abrolhos Islands Management Plan outlines both the vision and strategic objectives of management of the Abrolhos for the next ten years. It aims to conserve and promote the unique environmental and cultural heritage values of the Abrolhos Islands. The Plan's management objective for marine biota is: "*To minimise impact from human activities on marine habitats, distribution and populations of marine species in the Abrolhos Fish Habitat Protection Area.*"

Environmental Assessment Guidelines (EAG)	
Environmental Assessment Guidelines No.8 (EAG 8) Environmental Assessment Guideline for Environmental Principles, Factors and Objectives (EPA 2015)	The EAG 8 provides guidance for proponents to help them understand the need to consider environmental principles, factors and objectives for the purpose of environmental impact assessment. Environmental principles, factors and objectives are critical to the environmental impact assessment process as they underpin the EPA's decision on the environmental acceptability of a proposal or scheme. In making its decisions, the EPA also takes a holistic approach to assessing environmental acceptability based on a number of broader considerations including whether the proposal aligns with broader international, national and State policies and agreements and takes account of the interconnected nature of the environment.
Environmental Assessment Guidelines No.3 (EAG 3) – Protection of Benthic Habitats in Western Australia's Marine Environment December 2009 (EPA 2009	EAG 3 recognises the fundamental importance of the Benthic Communities and Habitats (BCH) and the potential consequences of their loss for marine ecological integrity. The EAG 3 expects the following hierarchy of principles to be addressed by proponents when assessing proposals that could damage/ loss of BCH: • Consideration of options to avoid damage or loss of BCH; • Design that minimises damage or loss of BCH; • Best practice in design, construction methods, and environmental management aimed at minimising indirect impacts; • Consideration of environmental offset where substantial cumulative losses of BCH have already occurred; and • Risk to ecosystem integrity within a management unit is not substantial. The EAG 3 also provides a risk-based spatial assessment framework for evaluating cumulative irreversible loss of and/or serious damage of BCHs (EPA 2009). The EPA has termed within which to calculate cumulative losses "Local Assessment Units".
Environmental Assessment Guidelines No.7 (EAG 7) Environmental Assessment Guideline for Marine Dredging Proposals (EPA 2011)	The EAG 7 sets out guidance for predicting impacts to benthic communities and habitats due to significant dredging activities. The EPA has developed a spatially-based zonation scheme for proponents to use as a common basis to describe the predicted extent, severity and duration of impacts associated with the dredging proposals. The scheme consists of three zones that represent different levels of impact (EPA 2011) : • Zone of High Impact (ZoHI) - the area where impacts on benthic communities are predicted to be irreversible (defined as lacking capacity to return or recover to a pre-dredging state within a timeframe of five years. • Zone of Moderate Impact (ZoMI) - the area where predicted impacts on benthic communities are expected to be sub lethal and/or the impacts recoverable within a period of five years following completion of the dredging activities. • Zone of Influence (ZoI) - the area where changes in environmental quality associated with dredge plumes are predicted, but these changes are not expected to result in a detectable impact on benthic communities.

Environmental Assessment Guidelines No.15 (EAG 15) Environmental Assessment Guideline for Protecting the Quality of Western Australia's Marine Environment (EPA 2015)	The EAG 15 provides an environmental quality management framework to protect the environmental values of Western Australia's marine environment from waste discharges and contamination. The EPA has provided this environmental quality management framework in EAG 15 to assist the proponent in predicting and managing the effects of pollution, waste discharges and deposits on the quality of the marine environment (EPA 2015)

8.2 Existing Environment

8.2.1 Benthic Communities and Habitat

8.2.1.1 2014 Baseline Survey

Surveys in 2014 of the study area associated with the MWADZ Proposal indicated that much of the seafloor consisted of a flat layer of limestone reef (at a depth of ~15 centimetres) overlain with sand. The sand had sparsely-distributed biological communities, comprising filter feeders (sponges, and bryozoans), macro algae, rhodoliths and hard corals (although corals were observed infrequently; Figure 8-1). Because the spatial extent of the major habitat categories was interpolated to produce a map of the benthic habitats across an extensive area, some parts of the map could not be described with adequate certainty. These are represented in Figure 8-1 as an absence of coloured pixels.

Northern area

Habitats in the northern part of the study area consisted of mainly bare sand (59%) and mixed assemblages (34%; Figure 8-1). Small patches of reef were present near the north-east boundary but made up only 8% of the identified habitats within the area. Of the total northern study area, the mixed biological community habitats were mainly composed of macro algae (3.7%), rhodolith (3.3%) and sponges (2.3%), with the remainder consisting of bare sand. Examples of the most commonly observed habitats are presented in Figure 8-2.

Southern area

Habitats in the southern part of the study area were predominantly bare sand (95%; Figure 8-1) with sparse mixed biological communities (5%) in the shallower waters to the south. Of the total southern study area, the mixed biological community habitats were mainly composed of rhodoliths (0.3%) and unknown organisms comprised (0.1%), and the remaining habitat dominated by bare sand. There was no evidence of significant hard coral cover.

Reference sites

The habitats of the three reference sites (with the exception of the northern-most reference site) were dominated by bare sand (42.5%) followed by mixed assemblage categories on sand and reef (total 17.7%; Figure 8-1). The northern-most reference site had a more diverse distribution of habitats throughout the area with reef and mixed biological community/reef habitats present (12.4%; Figure 8-1). Of the total reference site area, the mixed biological community habitats were mostly macro algae (2.1%), sponges (1.3%) and hard coral (0.1%).

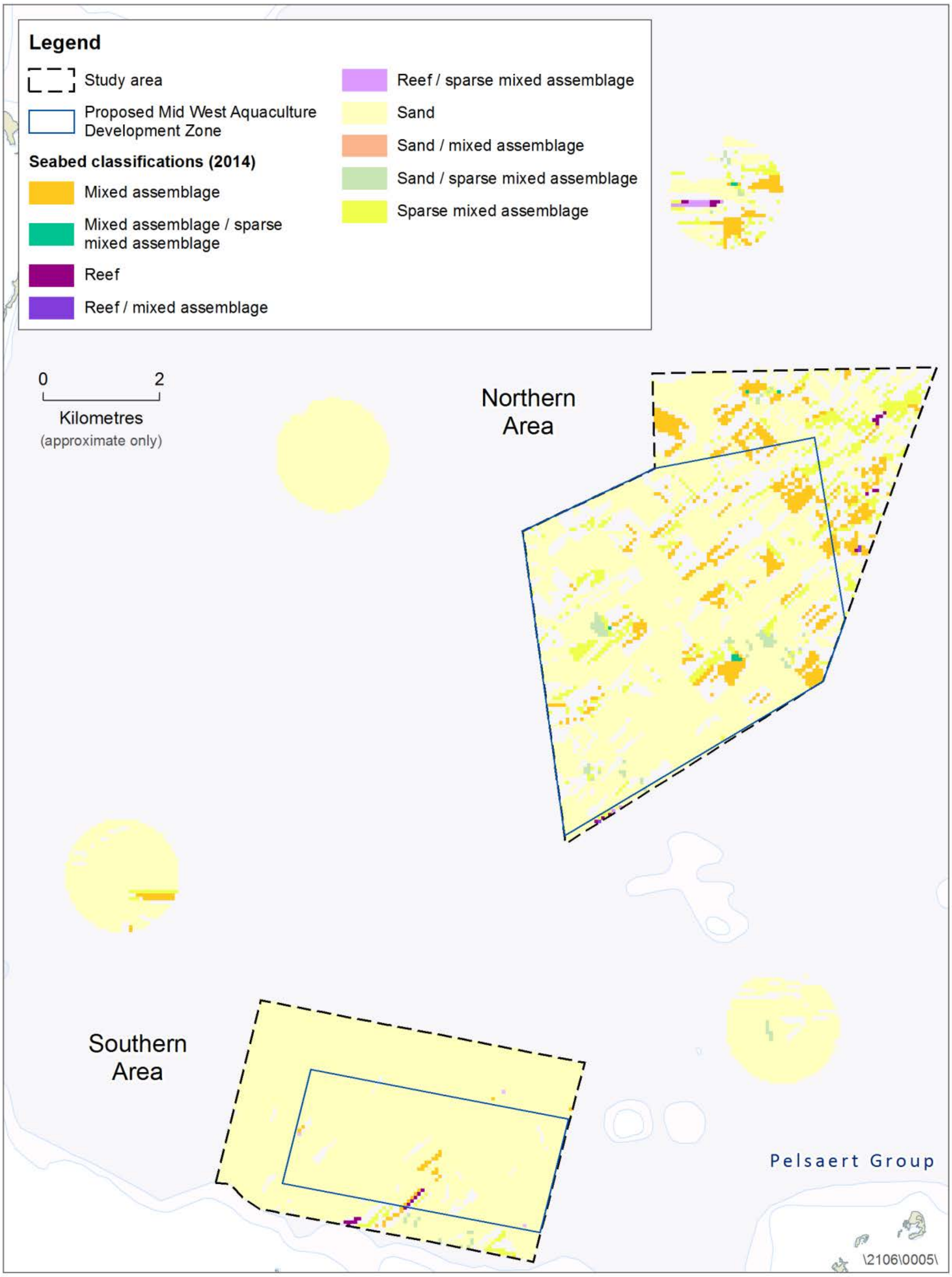
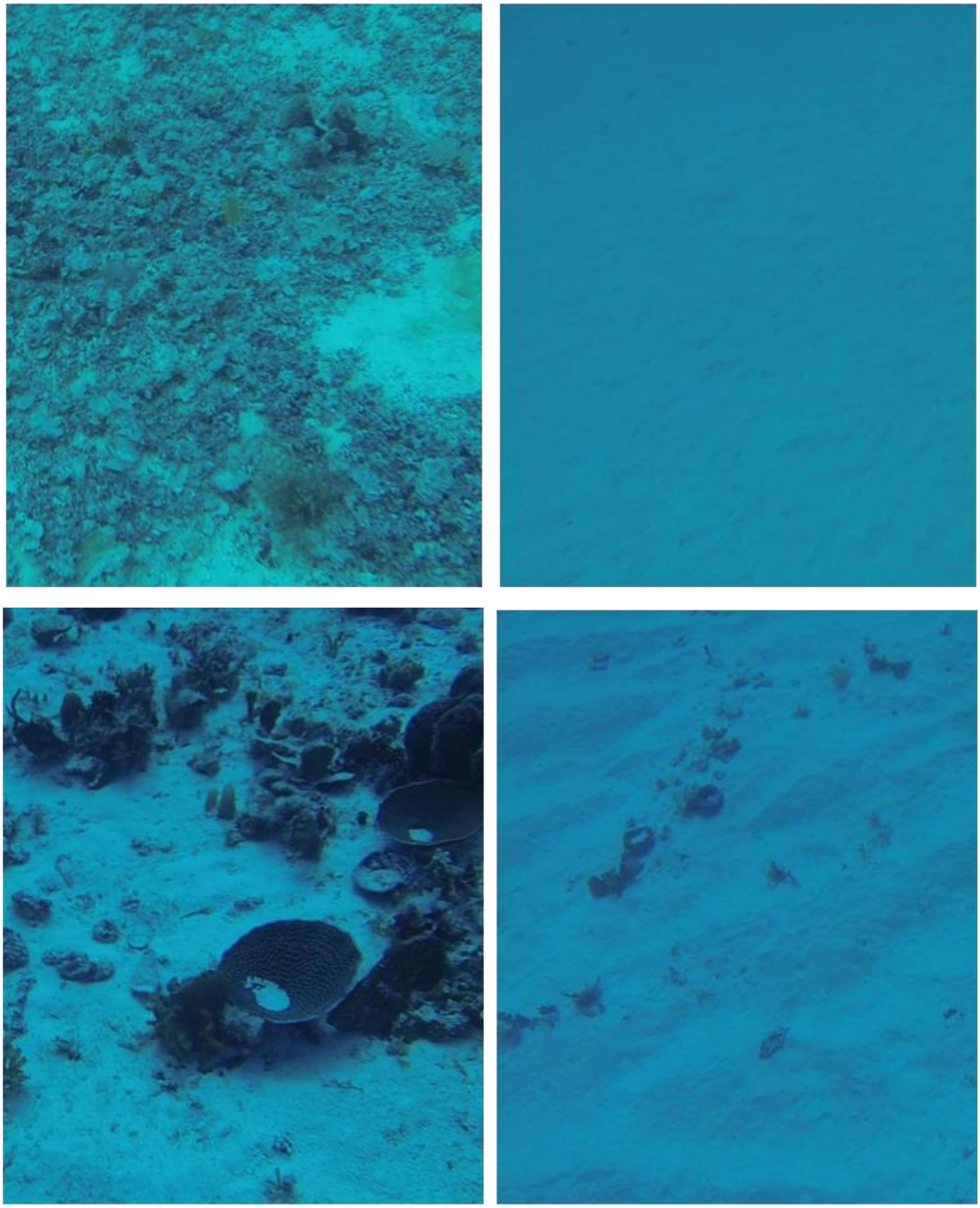


Figure 8-1: Major habitat assemblages observed in the study area in 2014



Notes:

1. Mixed assemblages with hydroids and macro algae (top left); bare sand with rhodoliths (top right); mixed assemblages with sponges and macro algae (lower left) and sparse mixed assemblages (lower right)

Figure 8-2: Examples of the common habitats observed during benthic habitat surveys

8.2.1.2 Previous Surveys

The current benthic habitat survey is provided above. Two previous relevant benthic habitat surveys are described below at a high level for contextual purposes only. Comparisons were made between the current (2014) benthic habitat survey and historical (2003, 2006/2008) benthic habitat surveys:

1. University of Western Australia - Marine Futures Project - hydro-acoustic mapping, towed video and biodiversity sampling in and around the Southern Group of Abrolhos Islands in 2006 and 2008 (hereon referred to as historical 2006 survey); and
2. University of Western Australia and Undersea Community Pty Ltd - Habitat Survey North of the Pelsaert Group of the Abrolhos Islands, by Andy Bickers in 2003. This survey (hereon referred to as historical 2003 survey) used side-scan sonar.

The historical surveys and 2014 survey differed significantly in their approaches, in terms of equipment and the classification schemes used (Appendix 1). Each of the three surveys provided discrete, low-resolution assessments. Comparisons of the surveys indicate considerable temporal variability in benthic habitats within the study area. These changes in the benthic habitat may have occurred between surveys as a result of the dynamic nature of the seabed and is consistent with the effects of sand sheet movement over time.

Although the 2006 survey only captured a portion of the northern part of the MWADZ study area, comparisons identified a recent change to a sand dominated habitat with a noticeable reduction of biological communities (predominately macro algae) observed in 2014 (Appendix 1).

Similarly, comparisons with these previous surveys identified that the southern area has recently shifted to a sand dominated habitat, with a noticeable reduction of biological communities (including rhodoliths) and reef habitats observed in the 2014 survey. Although small areas of seagrass were recorded in the southern part of the MWADZ study area by the historical surveys, no seagrass was observed during the more recent 2014 survey.

8.3 Potential Impacts

The benthic communities living in or on the calcareous sands and reefs within the proposed MWADZ include macro algae (various species of Chlorophyta, Heterokontophyta, and Rhodophyta); and other organisms that rely on symbiotic algae, zooxanthellae (i.e. most species of stoney corals, soft corals, anemones, and gorgonians). The assessment found that the cover of benthic communities and habitat (BCH) within the proposed MWADZ is less than 13 percent and the seafloor within the zone is currently a sand dominated habitat (Section 8.2.1; Appendix 1).

However, the dynamic nature of the sand-sheet movement on the seafloor means that BCH is likely to be transient in its cover and biological composition. No seagrass (e.g. *Halophila* spp.) was observed within the proposed MWADZ during the 2014 survey. *Halophila* spp. was historically present in some habitats of the shallow areas within the southern part of the MWADZ. If in future *Halophila* spp. was to colonise the parts of the MWADZ area, its distribution would be highly restricted to the shallowest patches that have adequate levels of light at the seafloor.

The establishment and physical presence of aquaculture infrastructure is not expected to impact upon BCH. The anchoring points for the sea cage cluster will be low profile, and given its sparse coverage, the installation will not require the destruction of any BCH.

The proposed aquaculture will generate organic particles that will deposit in the immediate vicinity of the sea cages. The organic loads are linked to three potential mechanisms leading to impacts on BCH, namely:

- direct smothering through burial;
- indirect smothering and, or, shading due to increased phytoplankton and epiphyte growth;
- oxygen starvation through anoxia cause by microbial activity; and/or
- toxicity due to the production of sulphides forming in the sediments.

If the settlement of organic material is sufficient to deprive photosynthesising organisms (BCH) of light or oxygen, the interruption to primary production (autotrophic) feeding mechanisms can result in degradation and mortality. The increase in dissolved inorganic nitrogen (DIN) that is associated with the deposition of stock faeces could promote growth of phytoplankton and epiphytes. This cause-effect-response also leads to smothering and/or shading of the BCH. Additionally, changes to sediment chemistry that cause the depletion of oxygen or production of sulphides in the seafloor sediments will result in mortality of BCH. Recovery of BCH after heavy exposure of organic loading will require the seafloor sediment to return to its original condition in term of chemical composition. Chemical and biological recovery may take several years (Appendix 1).

8.4 Assessment of Potential Impacts

8.4.1 Cumulative Loss of Benthic Communities and Habitat

The first consideration as part of this assessment was to determine the extent to which any previous losses of Benthic Community Habitat (BCH) had resulted from historical anthropogenic activities. It is considered that the benthic habitats in the proposed MWADZ are relatively pristine. Historic surveys (refer to Appendix 1) suggest that the composition of the benthic habitats is naturally transient due to the effects of sand sheet movement and corresponding natural variability of the benthic habitat coverage over time. There is no evidence that historical anthropogenic activities have caused lasting impacts that would contribute to cumulative loss.

Environmental Assessment Guidelines No. 3 (EAG 3) requires that the expected cumulative loss of BCH is assessed as a proportion against those in an agreed Local Assessment Unit (LAU). Relevant data was used to define two local assessment units within a one kilometre buffer around the Northern and Southern areas of the proposed zone (Figure 8-28). In relation to benthic habitat, most (71%) of the Northern LAU (44.2 km^2) and nearly all (96%) of the Southern LAU (23.2 km^2) has been surveyed. The benthic layers in Figure 8-28 are primarily based on the 2014 survey (contributing 67% of the data uses to describe the LAU); historical surveys informed some parts of the representation of the one kilometre buffer around the proposed zone.

To gain an understanding of the dynamics of the BCH in and around the strategic proposal areas, and interpolate/extrapolate the coverage of BCH to include a one kilometre strip outside the proposed MWADZ, two historical (2003, 2006/2008) benthic habitat surveys were taken into account. The data was used to estimate the most likely coverage of mixed assemblages, reef and bare sand in the LAUs. For the purposes of this assessment, mixed assemblages and reef have been conservatively assumed to correspond to BCH.

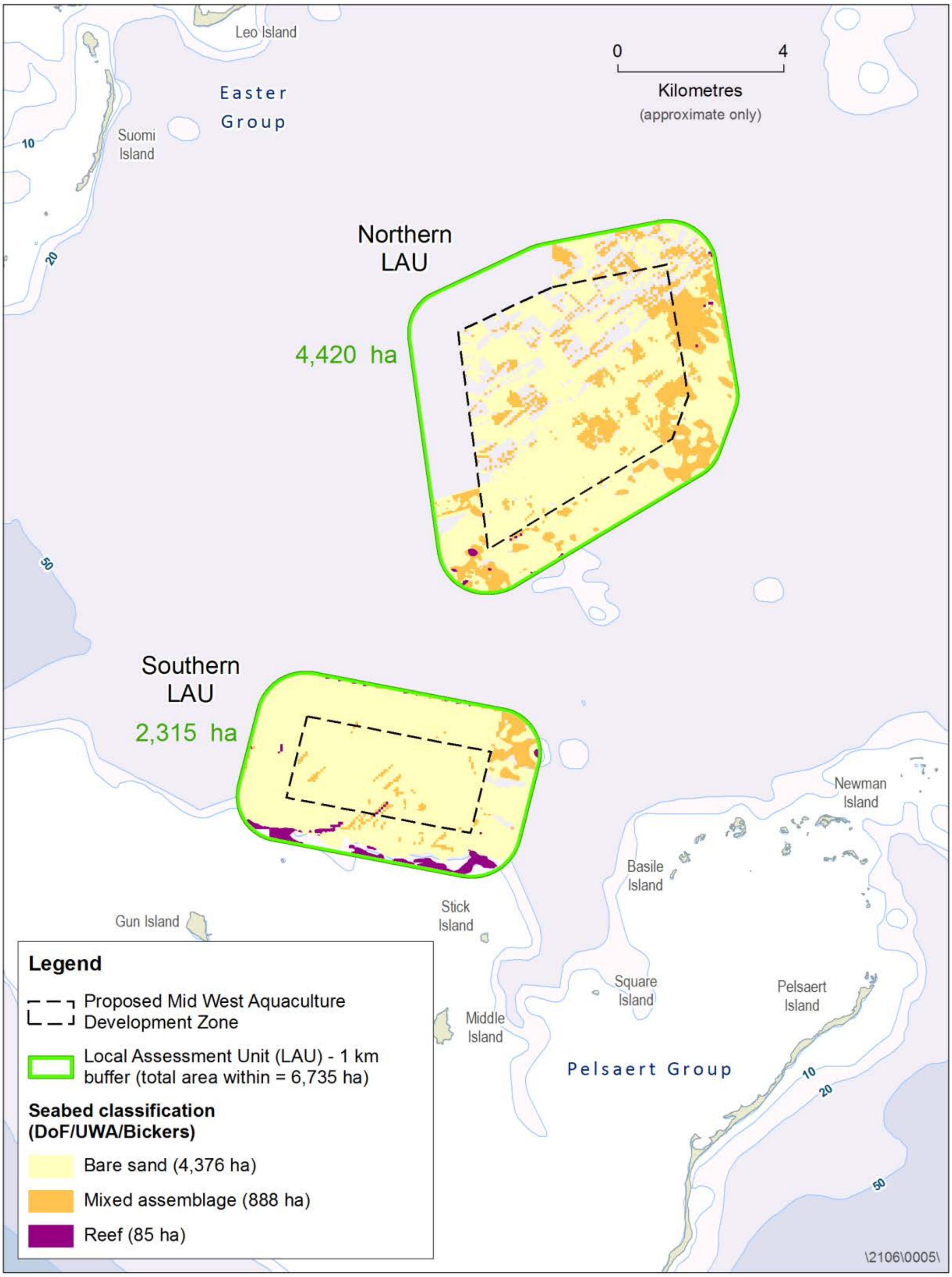


Figure 8-28: The Northern and Southern Local Assessment Units and the indicative benthic substrates in the vicinity of the MWADZ

8.4.2 Estimating the benthic cover of Benthic Communities and Habitat

8.4.2.1 Local Assessment Units

Habitat surveys in both the Northern and Southern Local Assessment Units (LAUs) captured the diversity and natural variability of the benthic environment (i.e. bathymetry and proximity to islands) within one kilometre buffers around the proposed MWADZ. At least 24% of the Northern LAU supports mixed biological communities consisting of algae and sessile invertebrates, while approximately 6% of the Southern LAU supports mixed assemblages consisting of algae, rhodolith and sessile invertebrates.

The benthic substrate classified as reef has some three-dimensional complexity and is the only substrate capable of sustaining coral reef habitat. Reef makes up less than one percent of the Northern LAU and less than four percent of the Southern LAU. The benthic substrate classified as bare sand makes up approximately 75% of the Northern LAU and 91% of the Southern LAU.

Of the 4,420 hectares in the Northern LAU, approximately 25% of this area (1,091 hectare) comprises habitats capable of supporting BCH (i.e. around 0.29% reef and 24% mixed assemblages, while approximately 75% is bare sand). Of the 2,315 hectares in the Southern LAU, approximately 9% (208 hectares) comprises habitats capable of supporting BCH (3.4% Reef and 5.6% mixed assemblages, while approximately 91% is bare sand).

8.4.2.2 Estimated Losses of Benthic Communities and Habitat

Approximately 25% of the Northern LAU (1,091 hectares) and 9% (209.9 hectares) of the Southern LAU comprise habitats capable of supporting BCH. The modelling predicted that the zone of high impact (ZoHI) would occupy 41 hectares and 21 hectares respectively in the Northern LAU and Southern LAU[41] [Section 6.2 of the Modelling and Technical Studies (Appendix 1) refers]. These figures were tripled to account for the one aquaculture impact "footprint" and two "recovering sites" that form over time as cages are relocated and the previous sites are fallowed.

Aquaculture is contained well-within the boundaries of the zone and therefore only the BCH inside the proposed zone can be impacted by aquaculture. The 2014 benthic habitat survey recorded 374 hectares (Northern Area) and 11 hectares (Southern Area) of BCH sparsely distributed throughout the proposed MWADZ.

The technical and environmental studies have predicted that the zone of high impact (ZoHI) beneath and immediately surrounding the sea cages within the proposed MWADZ will cover approximately 123 hectares (Northern Area) and 63 hectares (Southern Area) respectively of the seafloor within the zone areas inside the Northern LAU and Southern LAU. Taking into account the sparse distribution of the BCH within each LAU, we estimated the loss of BCH by calculating the probability that BCH would coincide with areas within the ZoHI. The ZoHI is predicted to coincide with approximately 20.9 hectares and 0.87 hectares of BCH within the Northern LAU and Southern LAU, respectively.

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[41] Note that the figures shown for the area occupied by the ZoHI are based on the modelling outputs for Scenario 4 (i.e. 24,000 tonnes of standing biomass after 3 years of production; Table 8-4).

While the proposed MWADZ is within the Abrolhos Islands Fish Habitat Protection Area (FHPA), the Management Plan for the FHPA does not identify any areas of high conservation value that would be Category A and there have been no historical, irreversible losses of BCH in the LAU. Based on this, the assessment against EAG 3 was undertaken using the Category C cumulative loss guidelines (EAG 3).

The Cumulative Loss Guidelines (EAG 3) recommend for LAUs located in Category C areas, that cumulative losses of BCH should not exceed 2% of the LAU area. The cumulative loss of BCH likely to result from the proposed aquaculture in the Northern LAU and Southern LAU is 1.92% and 0.42% respectively; both of which fall beneath the 2% benchmark.

8.5 Management Measures

The Environmental Monitoring and Management Plan (EMMP - Appendix 2), that has been developed to provide proponents with an appropriate EQMF for managing the potential impacts of stocking up to 24,000 tonnes of marine finfish across the MWADZ, is described in general terms in Section 13.3.1.1.

Maintenance of ecosystem integrity is concerned with maintaining the structure and functions of marine ecosystems to an appropriate level. In this context, the EMMP includes mechanisms to protect the key environmental factor “benthic communities and habitat” (BCH).

Cage clusters will be periodically relocated to allow sediments to return to the equivalent of baseline physical/chemical conditions. Relocation of entire clusters may be undertaken to allow impacted habitats to recover and shift from conditions representing a moderate level of ecological protection to conditions representing a high level of ecological protection (EMMP - Appendix 2).

Although operations within the zone will lead to small localised footprints of impact on water and sediment quality, ecosystem processes, and biodiversity, the EMMP is designed to facilitate a “feed-back-loop” between the monitoring and management processes to maintain acceptable levels of environmental protection of BCH across the proposed MWADZ. Over time, the monitoring program (Section 13.3.1.1) is designed to generate a comprehensive dataset that provides sufficient evidence that impacts on BCH are restricted to local-scale areas and are restored (over time) to a high level of environmental quality (EMMP - Appendix 2).

The monitoring allows operators to demonstrate that EQG and EQS have been met at the MEPA - HEPA boundary. Although conditions in up to 50 percent of the proposed MWADZ may reflect a moderate level of ecological protection, the monitoring and management “feed-back-loop” will ensure that (overall) the BCH within in the proposed MWADZ and the surrounding ecosystem is being maintained at a high level of ecological protection for the maintenance of environmental integrity (EMMP - Appendix 2).

8.6 Predicted Environmental Outcome

Sea cage aquaculture may, in some circumstances, lead to smothering or degradation of seafloor habitats including BCH. The modelling predicted a heavy organic deposition will be spatially-constrained to areas immediately under the sea cages.

The deposition of organic particles in the immediate vicinity of the sea cages will lead to some smothering and interruption to filter feeding processes within the operational area. However, the impact to the sediment chemistry is isolated to the vicinity of the sea cages and the overall cover of BCH within the proposed MWADZ is unlikely to be significantly affected by the aquaculture.

The associated increases in dissolved inorganic nitrogen (DIN) could promote localised algal growth, thereby shading BCH within areas near the sea cages. However, the modelling predicted no changes to water quality would result from the deposition of aquaculture-derived organic particles.

The predicted environmental outcome in relation to BCH is in keeping with the overall results of the EIA, which predicted that the most severe impacts are restricted to small areas (i.e. less than 300 hectares) when aquaculture production is at full capacity. The baseline survey found that the cover of BCH within the proposed MWADZ is less than 13 percent, and the proposal was unlikely to yield significant cumulative losses of BCH. The cumulative loss would be restricted to less than two per cent of the local assessment units that were defined for the MWADZ Proposal (Appendix 1), which complies with the Cumulative Loss Guidelines (EAG 3).

Given the conservative approach adopted for the development of the model, the predicted environmental outcome represents a "most likely worst case" outcome, as required by the ESD (EPA 2013). However, it should be noted that the expected environmental outcome sits between the modelled "most likely worst case" outcome and the aspirational "most likely best case" outcome. A precautious approach to the modelling was adopted to predict the impact on water and sediment quality. Outputs from the model were conservative, but within the upper range of impacts reported in the aquaculture literature (i.e. Brooks et al. 2004). These conservative outputs informed the assessment of potential impacts on BCH. Considering the precautious nature of the modelling, it is reasonable to expect that the actual impact on BCH will be less severe than the conservative estimates of cumulative loss (Section 8.4.2).

9 ASSESSMENT OF POTENTIAL IMPACT ON MARINE FAUNA

9.1 Assessment Framework

9.1.1 Environmental Objective

The environmental objective established in this PER for marine fauna is as specified in EAG 8, namely:

> *"To maintain the diversity, geographic distribution and viability of fauna at the species and populations levels".*

9.1.2 Relevant Legislation, Policies, Plans and Guidelines

Table 9-1: Legislation, Policies, Plans, and Guidelines Relevant to Marine Fauna

Legislation, Polices, Plans and Guidelines	Intent
State	
Environmental Protection Act 1986	This State Act provides for an EPA, for the prevention, control and abatement of pollution and environmental harm, and for the conservation, preservation, protection, enhancement and management of the environment.
Fisheries Resources Management Act 1994	Provides a legal framework to conserve, develop, and share fish resources for the benefit of current and future populations in WA. This legislation also provides the management framework for the Abrolhos Islands reserve and for the establishment and management of the Fish Habitat Protection Areas.
Wildlife Conservation Act 1950	Provide a legal framework for the conservation and protection of flora and fauna in Western Australia.
Conservation and Land Management Act 1984	An Act to make better provision for the use, protection and management of certain public lands and waters and the flora and fauna thereof, to establish authorities to be responsible therefor, and for incidental or connected purposes.
The Management Plan for the Houtman Abrolhos Islands. Fisheries Management Paper 260. (Department of Fisheries 2012)	The Houtman Abrolhos Islands Management Plan outlines both the vision and strategic objectives of management of the Abrolhos for the next ten years. It aims to conserve and promote the unique environmental and cultural heritage values of the Abrolhos Islands. Some of the main management objectives include: • *To protect and maintain marine and terrestrial environments of the Abrolhos; and* • *To facilitate and manage fishing an aquaculture activities consistent the environmental and cultural values of the Abrolhos.*
Environmental Assessment Guidelines (EAG)	
Environmental Assessment Guidelines No.8 (EAG 8) Environmental Assessment Guideline for Environmental Principles, Factors and Objectives (EPA 2015)	The EAG 8 provides guidance for proponents to help them understand the need to consider environmental principles, factors and objectives for the purpose of environmental impact assessment. Environmental principles, factors and objectives are critical to the environmental impact assessment process as they underpin the EPA's decision on the environmental acceptability of a proposal or scheme. In making its decisions, the EPA also takes a holistic approach to assessing environmental acceptability based on a number of broader considerations including whether the proposal aligns with broader international, national and State policies and agreements and takes account of the interconnected nature of the environment.

Environmental Assessment Guidelines No.7 (EAG 7) Environmental Assessment Guideline for Marine Dredging Proposals (EPA 2011)	The EAG 7 sets out guidance for predicting impacts to benthic communities and habitats due to significant dredging activities. The EPA has developed a spatially-based zonation scheme for proponents to use as a common basis to describe the predicted extent, severity and duration of impacts associated with the dredging proposals. The scheme consists of three zones that represent different levels of impact (EPA 2011): • Zone of High Impact (ZoHI) - the area where impacts on benthic communities are predicted to be irreversible (defined as lacking capacity to return or recover to a pre-dredging state within a timeframe of five years. • Zone of Moderate Impact (ZoMI) - the area where predicted impacts on benthic communities are expected to be sub lethal and/or the impacts recoverable within a period of five years following completion of the dredging activities. • Zone of Influence (ZoI) - the area where changes in environmental quality associated with dredge plumes are predicted, but these changes are not expected to result in a detectable impact on benthic communities.
Commonwealth	
Marine Bioregional Plan for the South-west Marine Region (SEWPaC 2012) and associated Conservation Value Report Cards	Sets out broad objectives for the region's biodiversity, identifies regional priorities, and outlines strategies and actions to achieve these. As part of the overall Plan, Conservation Value Report Cards present environmental baseline information and conservation values for the Commonwealth Marine Environment.
Environment Protection and Biodiversity Conservation Act 1999	It provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places — defined in the EPBC Act as matters of national environmental significance.
Marine Fauna and their Habitats	
Australia's Biodiversity Conservation Strategy 2010–2030 (National Biodiversity Strategy Review Task Group 2010)	Sets a national direction for biodiversity conservation over the next decade, including a vision that "Australia's biodiversity is healthy, resilient to climate change and valued for its essential contribution to our existence".
Marine Bioregional Plan for the South-west Marine Region (SEWPaC 2012) and associated Conservation Value Report Cards	Sets out broad objectives for the region's biodiversity, identifies regional priorities and outlines strategies and actions to achieve these. As part of the overall Plan, Conservation Value Report Cards present environmental baseline information and conservation values for the Commonwealth Marine Environment and EPBC Act-listed threatened and migratory species.
Fish and their Habitats	
Memorandum of Understanding (MoU) on the Conservation of Migratory Sharks (Convention on Migratory Species [CMS] 2007)	Australia is a signatory to this MoU, which aims to achieve and maintain a favourable conservation status for seven shark species, including ensuring healthy and viable populations of these species remain in their existing habitats.
National Plan of Action for the Conservation and Management of Sharks 2012 Shark-Plan 2	Shark Plan 2 identifies how Australia will manage and conserve sharks and ensure that Australia meets international conservation and management obligations. It identifies research and management actions across Australia for the long-term sustainability of sharks, including actions to help minimise the impacts of fishing on sharks.

Recovery Plan for the White Shark (*Carcharodon carcharias*)	The overarching objective of this recovery plan is to assist the recovery of the white shark in the wild throughout its range in Australian waters with a view to: • improving the population status, leading to future removal of the white shark from the threatened species list of the EPBC Act; and • ensuring that anthropogenic activities do not hinder recovery or impact on the conservation status of the species in the future.
Conservation Advice *Rhincodon typus* Whale Shark 2015	The Whale Shark Recovery Plan 2005 - 2010 is no longer valid. However, until such time as a new recovery plan is in place (or the need for one is removed) a Conservation Advice (http://www.environment.gov.au/cgi-bin/sprat/public/conservationadvice.pl) is in place.
Recovery Plan for the Grey Nurse Shark (*Carcharias taurus*) 2014	The plan considers the conservation requirements of the species across its range, identifies the actions to be taken to ensure the species' long-term viability in nature and indicates the parties that will undertake those actions.
Sawfish and River Sharks Multispecies Recovery Plan 2015	This recovery plan considers the conservation requirements of these species across their range, identifies the actions to be taken to ensure their long-term viability in nature and the parties that will undertake those actions. The document outlines: the basic biology and ecology of these species; details the known threats; presents the key conservation objectives; and includes performance criteria to measure the achievement of these objectives.
Approved Conservation Advice for Green Sawfish (*Pristis zijsron*) (DEWHA 2008)	Provides advice as to the priority actions for recovery and conservation of this species in the wild. The overall objective is to aid the recovery of the species and abatement of threats (e.g. habitat degradation).
National Plan of Action for the Conservation and Management of Sharks 2012 Shark-Plan 2	Shark Plan 2 identifies how Australia will manage and conserve sharks and ensure that Australia meets international conservation and management obligations. It identifies research and management actions across Australia for the long-term sustainability of sharks, including actions to help minimise the impacts of fishing on sharks.
Marine Mammals and their Habitats	
The Action Plan for Australian Cetaceans (Environment Australia 1996)	The plan aims to provide more information on taxonomy, distribution, habitat preference and diet in Australian waters for cetaceans, as well as identify threatening processes and priority actions.
Conservation Management Plan for the Southern Right Whale - A Recovery Plan under the *Environment Protection and Biodiversity Conservation Act 1999* 2011–2021	The long-term recovery objective is to minimise anthropogenic threats to allow the conservation status of the southern right whale to improve so that it can be removed from the threatened species list under the EPBC Act.
The Blue, Fin and Sei Whale Recovery Plan 2005–2010 (DEH 2005a)	The objectives of this plan are to: • recover populations of blue, fin, and sei whales using Australian waters so that the species can be considered secure in the wild; and • maintain the protection of blue, fin, and sei whales from human threats.
MoU on the Conservation and Management of Dugongs (*Dugong dugon*) and their Habitats throughout their Range (CMS 2007)	Australia is a signatory to this MoU, which aims to facilitate national and transboundary actions that will lead to the conservation of dugong populations and their habitats.
Recovery Plan for the Australian Sea Lion (*Neophoca cinerea*) 2013(DSEWPaC)	Sets out strategies for ensuring the conservation and recovery of the Australian Sea Lion.

Marine Reptiles and their Habitats	
Recovery Plan for Marine Turtles in Australia (Environment Australia 2003)	Aims to reduce detrimental impacts on Australian populations of marine turtles and hence promote their recovery in the wild.

9.2 Existing Environment

9.2.1 Fish

A total of 389 species of fishes have been recorded from the Abrolhos Islands, of which 257 (66%) are tropical species, 74 (19%) warm temperate species and 50 (13%) subtropical species (Hutchins, J.B 1997). Over 70% of the tropical fish species are very low in abundance suggesting that many are not maintaining breeding populations at the Abrolhos (Hutchins, J.B. 1997). It is thought that many of the tropical species occurring in the Abrolhos, do not actually spawn in the islands, but instead are dependent for recruitment of larvae being carried southward by the Leeuwin Current from areas further north, such as Shark Bay or Ningaloo Reef (Hutchins, J.B. 1997). Given that the majority of coral habitat is located on the eastern side of the island groups away from the flow of the Leeuwin Current, it may receive only low numbers of tropical fish recruits (Hutchins, J.B 1997). Another reason for the low abundance of tropical fish species may be due to the dominance of a few types of coral such as *Acropora spp.* (branching coral) at the islands, which may limit the presence of coral specific fish species (Hutchins, J.B. 1997).

The Abrolhos Islands are home to populations of large, non-tropical, coral inhabiting species such as the baldchin groper (*Choerodon rubescens*) and bar-cheek coral trout (*Plectropomus leopardus*). The Abrolhos Islands are the only area of high abundance of coral trout on the west coast of Western Australia. Commercially-important temperate species such as pink snapper (*Chrysophrys auratus)* and Western Australian dhufish (*Glaucosoma herbraicum*) also occur on deep-water limestone reefs and the shallower coral areas in the islands (Department of Fisheries 1997).

No specific studies of marine fish fauna have been conducted at the proposed MWADZ area. However, a number of studies have examined single fish species or assemblages within the Abrolhos Islands FHPA. Biological studies have been conducted on individual target species including baldchin groper (Fairclough, D *et al.* 2011,Nardi, K *et al.* 2006, Fairclough, D *et al.* 2005, Fairclough, D *et al.* 2004) coral trout (How, J 2013, Nardi, K *et al.* 2004) and red-throat emperor (Mclean, D *et al.* 2010). Several research studies have also been conducted on the broader fish assemblages at Abrolhos Islands (Harvey, E.S *et al.* 2012, Shedrawi, G 2008).

The fish community within the strategic MWADZ Proposal area is likely to be comprised of transient species such as cobia (*Rachycentron canadum*), samson fish (*Seriola hippos*), and some demersal scalefish species which inhabit sandy bottom habitat and areas of mixed assemblage substrate. Within the proposal area there are some small areas of mixed assemblage substrate, comprising rubble, low platform reef, algae and/or sponges. These types of habitats at the Abrolhos Islands are often used by juvenile stages of species such as baldchin groper and red-throat emperor. Low platform reef is used by adult target species such as coral trout and pink snapper and may be used during spawning.

While there is some known fish habitat within the MWADZ Proposal area, a large proportion of the habitat within the proposal area does not represent a key habitat for target finfish species. The mixed assemblage fish habitat within the aquaculture zone represents a very small area of the overall habitat of these species within the Abrolhos Islands FHPA. The aquaculture activities in the proposed MWADZ are therefore, unlikely to have significant impact on the broader fish stocks in the area.

9.2.2 Sharks and Rays

In the South West bioregion, in which the Abrolhos Islands are encompassed, there is a rich variety of chondrichthyan fishes (sharks, skates and rays) with 152 species (both demersal and pelagic) believed to occur in these waters occupying a broad ranges of shallow and deep-water habitats (DEWHA 2008). Nine shark and rays species are listed as either threatened or protected/migratory fish species under the EPBC Act and have been identified as potentially occurring within the strategic MWADZ Proposal area (Table 9-2). These species also have regional distributions.

Table 9-2: Conservation Status – Shark and Ray Species Listed as Threatened and/or Migratory that may occur in the Vicinity of the Proposed MWADZ

Common Name	Scientific Name	Conservation Status		Presence in the Vicinity of the Mid West Aquaculture Development Zone
		Commonwealth (EPBC Act) Status	***Western Australian Status***	
Grey Nurse Shark	*Carcharias taurus*	Vulnerable	Specially protected fauna (WC Act)	Possible
Whale Shark	*Rhincodon typus*	Vulnerable, Migratory	Totally protected fish (FRMA) Specially protected fauna (WC Act)	Possible
White Shark	*Carcharodon carcharias*	Vulnerable, Migratory	Totally protected fish (FRMA) Specially protected fauna (WC Act)	Likely
Shortfin Mako Shark	*Isurus oxyrinchus*	Migratory	Not listed	Unlikely
Longfin Mako Shark	*Isurus paucus*	Migratory	Not listed	Unlikely
Scalloped Hammerhead	*Sphyrna lewini*	Potential Migratory listing – under review	Not listed	Possible
Smooth Hammerhead	*Sphyrna zygaena*	Potential Migratory listing – under review	Not listed	Possible

Common Name	Scientific Name	Conservation Status		Presence in the Vicinity of the Mid West Aquaculture Development Zone
		Commonwealth (EPBC Act) Status	*Western Australian Status*	
Green Sawfish	*Prisitis zijsron*	Vulnerable	Totally protected fish (FRMA) Specially protected fauna (WC Act)	Not likely
Giant Manta Ray	*Manta birostris*	Migratory	Not listed	Possible

There are a number of other shark species present at the Abrolhos Islands including the tiger shark (*Galeocerdo cuvier*), bronze whaler shark (*Carcharhinus brachyurus*), dusky whaler shark (*Carcharhinus obscurus*), and sandbar shark (*Caraharhinus plumbeus*).

9.2.2.1 Grey Nurse Shark

The grey nurse shark (*Carcharias taurus*) is listed as two separate populations under the EPBC Act. The east coast population is listed as critically endangered whilst the west coast population is listed as vulnerable (DotE 2014). This species is also protected under the *Wildlife Conservation Act 1950* (Specially Protected Fauna Notice 2006). The grey nurse shark has a broad inshore distribution around Australia (Environment Australia 2002).

Although the distribution of the western population is not well defined, records indicate it extends from the North West Shelf south to coastal waters in the Great Australian Bight (McAuley et al 2002; Cavanagh et al, 2003). Grey nurse sharks are known to occur within the Mid West region, including the Abrolhos Islands (McAuley, R Department of Fisheries, pers. comm.). No aggregation sites or other sites critical to the survival of grey nurse sharks have been identified (Chidlow, J et al 2005).

Grey nurse sharks are often observed near the sea floor in and around deep sandy-bottomed gutters and rocky caves, in the vicinity of inshore rocky reefs and islands (Pollard, 1999). The diet of the adult grey nurse shark mainly consists of a wide range of fish, but the species also consumes other sharks, squids, crabs and lobsters (Compagno, 1984).

The grey nurse shark may be present within the waters of the MWADZ Proposal area.

9.2.2.2 Whale Shark

The whale shark (*Rhincodon typus*) is currently listed as vulnerable and migratory species under the EPBC Act. This species is also protected under the *Wildlife Conservation Act 1950* (Specially Protected Fauna Notice 2006) and the *Fish Resources Management Act 1994*. The whale shark is the world's largest fish (up to 18 metres total length) and, in Western Australia, is commonly recorded at total lengths around 12 metres and weights of approximately 11 tonnes. Individuals are solitary or exist in aggregations of over 100

individuals. They are known to inhabit both deep and shallow coastal waters including lagoons of coral atolls and reefs.

This species has a broad distribution. It is found in both tropical and subtropical seas and is often seen in offshore waters as well as inside lagoons of coral atolls. In Australia, they are usually found in northern waters in latitudes between 30 degrees north and 35 degrees south. In Western Australia, the whale shark is known to aggregate in large numbers at Ningaloo Reef between March and April each year prior to travelling north east along the continental shelf.

Individual whale sharks may pass through the deeper waters outside of the Abrolhos Islands and occasional sightings have been observed inside the Fish Habitat Protection Area.

9.2.2.3 White Shark

The white shark (*Carcharodon carcharias*) is currently listed as a vulnerable and migratory species under the EPBC Act. This species is also protected under the *Wildlife Conservation Act 1950* (*Specially Protected Fauna Notice 2006*) and the *Fish Resources Management Act 1994*. White sharks are widely distributed in temperate and sub-tropical oceans worldwide and have been known to travel large distances. In Australia, its range extends primarily from Moreton Bay in southern Queensland, around the southern coastline to the North West Cape in Western Australia (Environment Australia 2002). They are primarily found in coastal and offshore areas of the continental shelf, but also occur in the open ocean, recorded from the surface down to 1,280 metres (Last & Stevens 2009).

The great white shark is one of the largest of shark species, having a total length up to 600 centimetre total length. Individuals can have wide ranges and undergo migrations in the order of hundreds of kilometres. Generally, the great white shark has a broad prey spectrum; however, an individual’s diet is influenced by its size (Oceanica 2015). Juveniles and small great white sharks consume mainly teleosts (bony fish) and elasmobranchs (sharks), while larger individuals typically prey on marine mammals (DPC 2014). The species is known to follow humpback whales during their southern migration along the Western Australian coastline.

Great white sharks are usually solitary or in pairs; can often be found in feeding aggregations, but do not form schools. Although sightings are rare, they are typically more frequent around pinniped (seals and sea lions) colonies in the southern ocean (Oceanica 2015).

Great white sharks have been recorded within the Fish Habitat Protection Area at the Abrolhos Islands (DEWHA 2008). Given the presence of resident Australian sea lion populations (i.e. Easter and Pelsaert Group Islands) at the islands and the potential increase in the availability of food from the finfish aquaculture activities, this species is likely to be an occasional visitor to the MWADZ Proposal area.

9.2.2.4 Shortfin Mako Shark

The shortfin mako shark (*Isurus oxyrinchus*) is currently listed as a migratory species and is therefore protected under the EPBC Act. This species inhabits both tropical and temperate waters except for those offshore from the Northern Territory. They are rarely found in water

below 16^{o} C and are highly migratory (Last & Stevens 2009). The species is generally found in oceanic waters and unlikely to be present within the MWADZ Proposal area.

9.2.2.5 Longfin Mako Shark

The longfin mako shark (*Isurus paucus*) is currently listed as a migratory species and is protected under the EPBC Act.
This shark species is an oceanic tropical shark found predominantly in northern Australian waters. Its range includes the MWADZ Proposal area and extends from Geraldton across northern Australia to at least Port Stephens in New South Wales on the eastern coast (DoE 2014 a). Given that the Abrolhos Islands is at the southern end of the distribution for this species, it is unlikely this species will be present within the MWADZ Proposal area.

The longfin mako shark is currently listed as a migratory species and is protected under the EPBC Act. This shark species is an oceanic tropical shark found predominantly in northern Australian waters. Its range includes the MWADZ Proposal area and extends from Geraldton across northern Australia to at least Port Stephens in New South Wales on the eastern coast (DoE 2014 a). Given that the Abrolhos Islands is at the southern end of the distribution for this species, it is unlikely this species will be present within the MWADZ Proposal area.

9.2.2.6 Scalloped Hammerhead

The scalloped hammerhead (*Sphyrna lewini*) is likely the most common and well known of the hammerheads. It has a worldwide distribution through tropical and subtropical oceans (Simperdorfer, C 2014). It reaches sizes of over 4 metres in length, grows slowly and produces large litters of young (Harry *et al.* 2011a). The scalloped hammerhead is listed on the CITES Appendix II and internationally is considered threatened. However, in Australian waters the scalloped hammerhead has a non-detriment finding. This species is considered bycatch in the temperate shark fisheries and has a non-detriment finding for international trade if caught within Australian waters, indicating that fishing activities in Australian waters are not considered to be detrimental to the species status (DoF, 2014).

9.2.2.7 Smooth Hammerhead

The smooth hammerhead (*Sphyrna zygaena*) is listed in CITES Appendix II. The main reason for listing the smooth hammerhead is under "look-alike" provisions as its fins are considered very similar to the potentially threatened Scalloped Hammerhead (Simperdorfer, C 2014). The smooth hammerhead shark is a moderate sized hammerhead that occurs in all of the world's subtropical and temperate oceans. In Australian waters, it grows to around 3.5-4.0 metres (Last & Stevens 2009). Age and growth data indicate that, like other similar-sized hammerhead species, the smooth hammerhead shark grows relatively slowly (Coelho *et al.* 2011).

Given that the Abrolhos Islands is at the southern end of the distribution for this species, it is possible that it will be present within the MWADZ Proposal area.

This species is considered bycatch in the temperate shark fisheries and has a non-detriment finding for international trade if caught within Australian waters, indicating that fishing activities in Australian waters are not considered to be detrimental to the species status (DoF, 2014).

9.2.2.8 Green Sawfish

The green sawfish (*Prisitis zijron*) is currently listed as vulnerable and is protected under the EPBC Act. In Australia, this species has been historically recorded in the coastal waters off Broome, Western Australia, around northern Australia and down the east coast as far as Jervis Bay, New South Wales (Stevens *et al.* 2005).
The green sawfish is predominantly a tropical species but is occasionally caught in temperate waters (Last, P.R., Stevens, J .D 2009).

The green sawfish occurs in near-shore coastal environments, including estuaries, river mouths, embayments and along sandy and muddy beaches (Stevens *et al.* 2005). Given the distribution and habitat of the green sawfish, the presence of this species in the MWADZ Proposal area is unlikely.

9.2.2.9 Giant Manta Ray

The giant manta ray (*Mantra bostris*) is currently listed as a migratory species and is protected under the EPBC Act. In Australia, the giant manta ray distribution ranges from as far south as Rottnest Island in Western Australia around the tropical north of Australia and south to the southern coast of New South Wales (Last, P.R., Stevens, J .D 2009). The giant manta ray is commonly sighted along coastlines with regular ocean current upwellings, oceanic island groups and particular offshore pinnacles and seamounts (DEWHA 2008a).

Manta rays may be encountered on shallow reefs while being cleaned by "cleaner" fish or feeding close to the surface inshore and offshore. They are occasionally observed in sandy bottom areas and seagrass beds. No aggregation sites or other sites critical to the survival of giant manta rays have been identified at the Abrolhos Islands. Manta rays may be occasionally present within the MWADZ Proposal area.

9.2.2.10 Tiger Shark

The tiger shark (*Galeocerdo* cuvier) is a relatively common and wide-ranging coastal-pelagic species, found globally in tropical and warm temperate oceans. In Australian waters, tiger sharks have a geographic distribution that extends from the west coast of Western Australian over the northern half of Australia to southern New South Wales. Tiger sharks are known to inhabit inshore waters, and oceanic waters around islands and seamounts; generally to depths of 150 metres. The species is known to make seasonal excursions into temperate waters with their range in Western Australia, possibly becoming more extensive in the last few decades and presumably in response to years of stronger Leeuwin Current (DPC 2014).

Tiger sharks can attain approximately 600 centimetres total length (Last & Stevens 2009).In Western Australia, tiger sharks with an inter-dorsal fin measurement greater than 70 centimetres are "totally protected fish" under the *Fish Resources Management Act 1994* (FRMA). However, the species is not considered to be an Endangered Threatened or Protected (ETP) species in Australia. Nevertheless, the ecological niche the tiger shark occupies as an apex predator and the time taken to mature (i.e. more than 6-7 years) mean it is considered similar to some of the other ETP species of sharks (e.g. the white shark). It is often used, therefore, as a representative species when considering potential impacts to ETP

sharks. It is distributed globally and there are several recorded interactions between tiger sharks and aquaculture.

Tiger sharks are considered a near-threatened species due to excessive finning and fishing by humans according to International Union for Conservation of Nature. Tiger sharks are currently subjected to only minor levels of exploitation by fisheries along the Western Australian coast. Generally most of the captures of these species have occurred in the more northern and more tropical part of their Western Australian range.
However, there have been more frequent captures of this species in temperate waters recently (DPC 2014). This species is likely to be an occasional visitor to the strategic MWADZ Proposal area and could potentially interact with finfish aquaculture in the zone. For the aforementioned reasons, it has been included in this assessment.

9.2.2.11 Other whaler sharks

Bronze whaler sharks (*Carcharhinus brachyurus*) are widely distributed throughout Australia and can be found from Geraldton in Western Australia to Coffs Harbour in New South Wales. The Abrolhos Islands is at the northern end of their range. However, this species may be an occasional visitor to the MWADZ Proposal area and could potentially interact with the finfish aquaculture.

The dusky whaler shark (*Carcharhinus obscurus*) is widely distributed in Australia and is found in both tropical and temperate continental shelf and oceanic waters. Dusky whaler shark is one of the most important and economically-valuable shark species that occurs in the region. The West Australian dusky whaler shark stocks support a significant component of the temperate commercial shark fisheries in the area, most notably the West Coast Demersal Gillnet and Demersal Longline (Interim) Managed Fishery. In the 2012/13 fishing season, dusky whaler shark catches were approximately 204 tonnes, comprising approximately 22% of the overall catch for the fishery (Fletcher, R and Santoro, K 2014).

This species is long lived and late maturing species (i.e. > 30 years to reach sexual maturity) and is particularly vulnerable to overfishing pressures due to these biological characteristics. In Western Australia, dusky whaler sharks have historically been heavily exploited by the temperate commercial shark fisheries. Over the past decade a recovery program has been in place in Western Australia for this species to ensure the stocks are sustainable. Whaler sharks with an inter-dorsal length over 70 centimetres are protected under the FRMA. Dusky whaler sharks may be an occasional visitor to the strategic MWADZ Proposal area and could potentially interact with finfish aquaculture in the zone.

Sandbar sharks (*Carcharhinus plumbeus*) are widely distributed in Australia and are found in both tropical and temperate waters. In Western Australia, they are found as far south as Esperance and extend into Northern Australia (Last & Stevens 2009). This species is susceptible to population depletions due to their longevity and low productivity (Department of the Environment 2015). Sandbar sharks are commercially-important due to its meat and fins and (to a lesser extent) its hide and liver oil (Last & Stevens 2009). They historically provided an important component of the catch in Western Australian commercial shark fisheries. In the 2002/03 fishing season, approximately 87.7 tonnes of sandbar shark were captured in the Western Australian North Coast Shark Fishery (WANCSF). This comprised approximately 17.9% of the overall catch for the fishery that year (McCauley, R *et al.* 2005). The WANCSF is currently non-operational and is likely to remain that way until such time as

a stock assessment on vulnerable species has been conducted on the status of stocks throughout northern Australia. Sandbar sharks may be present within the vicinity of the MWADZ Proposal area.

A number of shark species, including ETP species, are likely to be visitors to the proposed MWADZ area and have the potential to interact with the sea cage aquaculture. The proposal is, however, unlikely to have a significant impact on the sustainability of these species.

9.2.3 Marine Invertebrates

Marine invertebrates include a very broad range of fauna such as molluscs (shellfish), crustaceans, anemones, sponges, sea urchins and worms. There are a total of 492 mollusc species and 172 echinoderm species which have been identified at the Abrolhos Islands (MBS Environmental 2006). There is a complex assemblage of marine invertebrate species with both tropical, temperate and Western Australian endemic species occurring in all three island groups at the Abrolhos (Department of Fisheries 2000). A higher proportion of tropical species are represented in most island groups, but the majority of hydroid (members of the invertebrate order Hydroida) and sponge species are usually found in temperate, rather than tropical, waters (Department of Fisheries 2007). Some of the invertebrate species which are important for both commercial and recreational fisheries include the Western rock lobster, saucer scallops, octopus and species that produce specimen shells.

9.2.3.1 Southern Saucer Scallop

Southern saucer scallops (*Amusium balloti*) are short-lived, benthic, filter-feeding bivalve molluscs that reside on sandy bottoms areas (Department of Fisheries 2007). The species is predominantly sub-tropical and occurs along the continental shelf of Australia. However, it has been known to occur as far south as Jervis Bay on the east coast (Department of the Environment 2013). In Western Australia, the distribution of the species is from just north of Shark Bay to the Western Australian and South Australian border (Kangas, M pers. comm. Department of Fisheries 2015). The species has been reported to occur in depths from 10-75 metres in discrete beds up to 15 kilometres in length and at densities of up to one per square metre (Dredge 1988; Kailola *et al.* 1993, NFS 2015). At the Abrolhos Islands, saucer scallops generally occur in depths of 20-40 metres on the leeward side of the islands; but in some years their distribution can be extensive throughout much of the sandy habitats within and between island groups (Kangas, M pers. comm. Department of Fisheries 2015).

The saucer scallop is known to have two breeding seasons one in winter and the other in spring when the larval phase is believed to be 15-25 days in duration (Caputi, N *et al.* 2015). Saucer scallops develop rapidly, growing to a size of 90 millimetres in just six to twelve months and, characteristic of short lived species with high natural mortality, the species is susceptible to a "boom and bust" stock level (Caputi, N *et al.* 2015). They are subject to great natural fluctuations in reproductive success from year-to-year and grow to maturity within a year. Southern saucer scallops spawn at the Abrolhos between August and March. They are known to inhabit the sandy sea bottom habitats in the strategic MWADZ Proposal area.

9.2.3.2 Western Rock Lobster

The Western rock lobster (*Panulirus cygnus*) is an endemic species which inhabits the continental shelf along the lower west coast of Australia from 25° South to 34°South (Chubb,

C 2003). The species is widespread at the Abrolhos Islands and is known to occur in all three island groups. Unlike the rest of the west coast populations, *Panulirus cygnus* mature at a smaller size at the Abrolhos Islands, before they reach minimum legal length (St John, J 2006). The Abrolhos Islands lobster population contributes a large proportion (i.e. approximately 50%) of the total reproductive output/spawning biomass for the West Coast Rock Lobster Managed Fishery (WCRLMF) (St John, J 2006).

At the Abrolhos Islands, Western rock lobsters predominantly occur over reef habitat with between 45 and 65% of fishing effort occurring in shallow waters (0 - 20 metres) near submerged platforms and exposed reefs (Webster, F *et al.* 2002). These habitats tend to occur generally on the western and central parts of the island groups where there is a high abundance of limestone reef and macro algae habitat (Webster, F *et al.* 2002).

Benthic habitat data collected in the strategic MWADZ Proposal area indicates that the predominant habitat is sand, which does not represent a key habitat area for Western rock lobster [pers. comm. De Lestang, S (DoF)]. Indeed, the majority of the benthic habitat within the MWADZ Proposal area is comprised of soft-bottom, sandy habitats. While sandy benthic habitat can sometimes provide and important transit area for migrating lobster at certain times of the year (i.e. the "whites" run), the MWADZ Proposal area is not known to be important for migrating rock lobster.

9.2.3.3 Coral Reefs

The Abrolhos Islands coral reef system is the most southerly in the Indian Ocean. The presence of coral reefs at such high latitudes is attributed to the Leeuwin Current providing a source of warm water for coral function and survival and coral planulae from equatorial regions (Hatcher, B 1991, Pearce, A 1997, Wilson and Marsh 1979). The Abrolhos reefs have most of the structural habitats of tropical reef systems (Wilson and Marsh 1979). Given the high latitudes, coral diversity is very high for the Abrolhos reefs. There are approximately 184 species of hermatypic corals in 42 genera and a further 10 species of ahermatypes in eight genera are found there (Webster, F *et al.* 2002). All but two coral species are tropical (Hatcher *et al.* 1990, Wilson and Marsh 1979). *Acropora* species dominate both shallow leeward and lagoon reef habitats. While in the deep water, or more sheltered sites, genera including *Montipora, Echinopyllia, Oxypora, Mycedium, Pachyseris* and *Leptoseris* are common (Hatcher *et al.* 1988). Even though being at the extreme southern limit of their latitudinal range, the Abrolhos Islands coral populations are considered to be reproductively active, with 60 per cent of the species spawning in late summer (Babcock *et al.* 1994). It is likely most species spawn during March/April and, given the latitude, do not participate in the second spring spawning characteristic of the warmer northern waters.

Benthic habitat data collected in the MWADZ Proposal area indicates that there are very limited areas of coral habitat (i.e. less than one percent of the proposed 3,000 hectares) within the aquaculture zone. Therefore, it is highly unlikely that the MWADZ Proposal will have a significant impact on coral reef communities within the Abrolhos Islands FHPA.

9.2.3.4 Molluscs

A total of 492 species of marine molluscs have been recorded from the Abrolhos Islands with the majority of the species found in shallow water reef areas. Sixty eight percent of the species were tropical, 20.3% temperate and 11.3% endemic to Western Australia (Webster, F

et al. 2002). Several research studies have been conducted on the molluscs within intertidal and shallow water environments of the Abrolhos Islands (Wells, F and Bryce, C 1997, Jenson, K 1997 and Evertsen, J 2006). However, limited research has been conducted on molluscan fauna in the deeper water areas of the Abrolhos Islands.

A study was conducted by (Glover, E and Taylor, J 1997) around the Wallabi Group at the Abrolhos Islands and results from the study concluded that the molluscan community was dominated by suspension-feeding bivalves (particularly pectinilds), a suspension-feeding gastropod (*Monilea lentiginosa*) and an algal-grazing gastropod (*Calthalotia mundula*) (Glover, E and Taylor, J 1997). No data has been collected on the marine molluscs within the MWADZ Proposal area.

9.2.3.5 Echinoderms

The rich echinoderm fauna of the Abrolhos Islands are dominated by tropical species. Sixty three percent of the 172 species were tropical species, 14% Southern Australian temperate and 21% endemic to Western Australia but no species is confined to the islands (Webster, F *et al.* 2002). The richness of the echinoderms is attributed to the presence of both tropical and temperate species in the West Coast Overlap Zone, due to the warm Leeuwin Current, and the Abrolhos Islands habitat complexity which provides niches for a wide diversity of echinoderms life styles (Marsh 1994). No data is currently available on echinoderms in the proposed MWADZ area. However, there is some anecdotal evidence (from benthic habitat mapping conducted by the Department) to suggest that sea cucumbers may be present within the proposed MWADZ area.

Nevertheless, given any potential impact on benthic invertebrates would be localised (i.e. directly under the sea cages) it unlikely the MWADZ Proposal will have a significant impact on echinoderms in the area.

9.2.4 Marine Mammals

There are ten marine mammal species (Table 9-3) that are known or have the potential to occur within the vicinity of the MWADZ Proposal area. All marine mammals are currently protected under the *Wildlife Conservation Act 1950* (WA) and listed as vulnerable, endangered, marine or migratory under the EPBC Act. Marine mammals are also protected under international wildlife conventions including Appendix II of Convention on Migratory Species (CMS) and Convention on International Trade in Endangered Species (CITES).

Table 9-3: Conservation Status and Likelihood of Marine Mammals Occurring in the Proposed MWADZ

Species	Conservation Status		Likelihood of occurrence within the MWADZ Proposal area	Likely time of occurrence
	Commonwealth (EPBC Act)	***Western Australia (WC Act)***		
Humpback whale (*Megaptera novaeangliae*)	Vulnerable Cetacean Migratory	Vulnerable	Likely	July - November
Blue whale (*Balaenoptera musculus*)	Endangered Cetacean Migratory	Endangered	Unlikely	November - May

Species	Conservation Status		Likelihood of occurrence within the MWADZ Proposal area	Likely time of occurrence
	Commonwealth (EPBC Act)	***Western Australia (WC Act)***		
Pygmy blue whale (*Balaenoptera musculus brevicauda*)	Endangered Cetacean Migratory	Endangered	Occasional	June – August/ October-January
Bryde's whale (*Balaenoptera edeni*)	Cetacean Migratory	Not listed	Possible	Unknown
Southern right whale (*Eubalaena australis*)	Endangered Cetacean Migratory	Vulnerable	Possible	May - November
Killer whale (*Oricinus orca*)	Cetacean Migratory	Not listed	Unlikely	Unknown
Indo-Pacific bottlenose dolphin (*Tursiops aduncus*)	Cetacean	Not listed	Likely	All year
Bottlenose dolphin (*Tursiops truncatus*)	Cetacean	Not listed	Likely	All year
Australian sea lion (*Neophoca cinerea*)	Vulnerable Marine	Specially protected fauna	Likely	All year
Dugong (*Dugong dugon*)	Marine	Other protected	Rare	All year

9.2.4.1 Whale

Humpback Whale

Humpback whales (*Megaptera novaeangliae*) migrate along the Western Australian coastline between their summer feeding grounds (south of 55° South) and winter breeding grounds of Camden Sound in north-west Western Australia (DoE, 2014b, Jenner *et al.* 2001). As the humpback whale migration corridor centres on the 200 metre isobath, the Abrolhos Islands are recognised as a significant habitat during their migration (DoE 2014b). Additionally, the Abrolhos Islands are a well-known resting area used by female humpback whales with their calves and escort males (DoE, 2014b).

In the MWADZ Proposal area, the peak abundance in north-bound migration occurs in July, with breeding and calving taking place between mid-August and early September in Camden Sound (Jenner *et al.* 2001). After the calving period, humpback whales migrate south along the Western Australian coastline with their peak abundance during the south-bound migration near the Abrolhos Islands occurring from mid-October to November each year (Jenner *et al.* 2001). Humpback whales are therefore likely to occur within the vicinity of the MWADZ Proposal area.

Blue Whale

In Australian waters, there are two known sub-species of blue whales which include the Southern (or "true") blue whale (*Balaenoptera musculus intermedia*) and the pygmy blue whale (*B. musculus brevicauda*). As a general distributional trend, Southern blue whales are predominantly found in waters in Australia south of 60 degrees south, while pygmy blue whales are found in waters north of 55 degrees south (DEWHA 2008).

In Western Australia, blue whales are known to inhabit deeper water areas of the Perth coast and near the edge of the continental shelf in 500 to 1,000 metre water depth (McCauley and Jenner 2010, McCauley *et al.* 2001). They are known to regularly forage in upwelling areas in the Perth Canyon and have been frequently sighted on the northern or southern sides of the canyon between December and April each year (Oceanica 2015). Regular sighting of blue whales have also been observed annually in Geographe Bay between October and December each year with over 100 sightings observed in the area in 2003 (Oceanica 2015).
The majority of whales move slowly into the bay from the north and follow the shallow bathymetry around Cape Naturaliste to the west. It appears to be a transitory corridor and/or migratory resting area (Burton, pers. comm.).

Sightings of blue whales in water north of the Perth Canyon have been rare; therefore, this species is unlikely to be present within the MWADZ Proposal area.

Pygmy Blue Whale

In Western Australia, pygmy blue whales (*Balaenoptera musculus brevicauda*) are known to inhabit the waters around the Perth Canyon between January and April each year. They are known to use this area as a foraging ground (Double et al 2012). Passive acoustic monitoring data collected for this species has shown that this species migrates northwards along the Western Australian coastline, passing Exmouth Gulf between April and August and continuing further north into Indonesian waters (McCauley & Jenner 2010). The pygmy blue whale south-bound migration begins from October to late December along the 500 to 1,000 metre depth contour on the edge of the slope (McCauley & Jenner 2010).

The satellite-tagged pygmy blue whales have been recorded in the offshore areas of the Abrolhos Islands, providing evidence that their migratory pathways are in the vicinity of the strategic proposal area. Pygmy blue whales have also been observed in waters near Geraldton and the Abrolhos Islands during aerial surveys as part of the baseline investigations for the Oakajee Deepwater Port Project (Oceanica, 2015). Pygmy blue whales may, therefore, be present near the vicinity of the MWADZ Proposal area during their migratory period.

Southern Right Whale

Southern right whales (*Eubalaena australis*) have a distribution between 20°S and 60°S and have been recorded in coastal waters of all Australian states except the Northern Territory. They migrate from high-latitude feeding grounds in summer, to warm, low-latitude coastal locations in winter (May through to November) between Sydney and Perth, as well as Tasmania (Bannister *et al.*1996). The population is suggested to be growing, and rare sightings are recorded in northern waters, such as Shark Bay and the North West Cape (Bannister *et al.* 1996). Within their broader geographic range, Southern right whales in Australia concentrate in certain areas to breed. Major calving areas are located in Western Australia at Doubtful Island Bay (34°10'S, 119°40'E), east of Israelite Bay (33°15'S, 124°10'E). However, there are no critical habitats recognised in the waters around the Abrolhos Islands. Therefore, sightings of Southern right whales within the MWADZ Proposal area are likely to be rare and infrequent, given that the location of the area is beyond the species usual northern limit of distribution.

Other Cetaceans

The Bryde's whale (*Balaenoptera edeni*) is distributed throughout tropical and warm temperate waters, between 40˚North and 40˚South, in both oceanic and inshore waters (DoE, 2014b). With the exception of the Northern Territory, Bryde's whales have been recorded in all Australian states, although no feeding or breeding areas have been identified in Australia (DoE, 2014b). Observations of Bryde's whales were documented at the Abrolhos Islands and north of Shark Bay.
However, sighting frequency, habitat use and abundance of Bryde's whales at the Abrolhos Islands are not available (Bannister *et al.* 1996). Given that low numbers have been recorded elsewhere in Australia, large numbers of Bryde's whales are not expected to be encountered in the nearshore waters of the MWADZ Proposal area.

Other whale species that have been sighted in the mid-west region include the killer whale (*Orcinus orca*). The killer whale is a migratory species and generally occurs in offshore pelagic areas from the equator to the polar regions (Bannister et al 1996). In Australia, killer whales are widely distributed and have been observed in all states on the continental slope and shelf, near seal colonies and humpback whale resting areas (Oceanica 2015). Recent scientific evidence documented killer whale attacks targeting humpback whales off Ningaloo Reef, WA (Pitman *et al.* 2015), confirming their presence in coastal areas. Killer whales are capable of rapid, long distance movements (approximately 1,000 kilometres) into mid-latitudes, suggesting their capability to intercept and hunt humpback whales during their migration movements (Pitman *et al.* 2015). While the Abrolhos Islands are a known resting area for migrating humpback whales there is only a low likelihood that killer whales may occur within the MWADZ Proposal area.

9.2.4.2 Dolphin

The dolphin (*Tursiops spp.*) most likely to be present throughout the year in the MWADZ Proposal area is the common bottlenose dolphin (*Tursiops truncatus*) and the Indo Pacific bottlenose dolphin (*Tursiops aduncus*) (DSEWPaC 2012). The common bottlenose dolphin distribution is not well documented in Australia, although sightings have been recorded for this species in Queensland, New South Wales, Tasmania, South Australia and south-west Western Australia (DoE 2014 b). Bottlenose dolphins can be found in both offshore waters (more than 30 kilometres offshore) and coastal waters, and inhabit a variety of habitats, such as mud, sand, seagrasses, mangroves and reefs (DoE 2014 b). During the Oakajee Deepwater Port baseline surveys, common bottlenose dolphins formed about 26% of the observations in the mid-west region, the majority of which were located greater than 15 kilometres from shore (Oceanica 2010). Therefore, common bottlenose dolphins are likely to be encountered within the MWADZ Proposal area.

Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) are generally found between the continental shelf and the coastline in reef, sandy and seagrass habitats (DEWSPaC 2012). The distribution and habitat usage for this species varies seasonally, and these patterns are likely to reflect changes in the abundance and distribution of fish in the locations (Oceanic 2015). This species can often be found in estuarine and coastal habitats in the south west region of Australia. Indo-Pacific dolphins are known to occur at the Abrolhos Islands and may be present within the MWADZ Proposal area.

Although other dolphin species, including the common dolphin, Risso's dolphin and the spotted dolphin, are listed in the EPBC Act Protected Matters Report, they have not

previously been observed in the Mid West region (Oceanica 2010). It is therefore unlikely that these species will be present within the MWADZ Proposal area.

9.2.4.3 Dugong

In Australia, dugongs (*Dugong dugon*) are distributed throughout coastal and island waters from Shark Bay in Western Australia (25° South) across the northern coastline to Moreton Bay in Queensland (27° South) (Marsh *et al.* 2002, 2011a). Most of their time is spent in the neritic zone, especially near tidal and subtidal seagrass meadows (DoTE, SPRAT). Areas known to support dugongs in Western Australia include: Shark Bay; Ningaloo Marine Park; Exmouth Gulf; Pilbara coastal and offshore regions (Exmouth Gulf to De Grey River); Eighty Mile Beach and the Kimberley coast (Marsh *et al.* 2002).

Although not commonly sighted south of Shark Bay, dugong are highly migratory and undertake long distance movements (greater than 100 kilometres) over several days, possibly in search of seagrass beds or warmer water (DoE 2014b). During baseline investigations for the Oakajee Deepwater Port Project, aerial surveys of the Mid West region were undertaken. The results included observations of individual dugong at Horrocks, approximately 45 kilometres north of Geraldton (Oceanica 2010).

Benthic habitat data collected as part of this project have shown there are no known areas of *Halophila spp.* seagrass habitat within the MWADZ Proposal area. Given the limited suitable foraging habitat and the rarity of sightings of this species at the Abrolhos, it is unlikely that dugong will be present in the MWADZ Proposal area.

9.2.4.4 Australian Sea Lion

The Australian sea lion (*Neophoca cinerea*) is an endemic species in Australia, with a known distribution extending approximately 3,500 kilometres from the Abrolhos Islands along southern Australia to the Pages in South Australia (Campbell 2005; DSEWPaC 2013a). The Australian sea lion is one of the rarest sea lion species in the world and is currently listed as vulnerable under the EPBC Act. This assessment is based on both primary threats such as fishery bycatch and marine debris entanglement, and secondary threats that include interactions with aquaculture operations (DSEWPAC 2013a). There currently is an Australian National Recovery Plan for the Australian sea lion. The overarching objective of the recovery plan is to halt the decline and assist the recovery of the species throughout its range in Australian waters by increasing the total population size, while maintaining the number and distribution of breeding colonies (DSEWPAC 2013 b).

The Australian sea lion is currently listed as "specially protected fauna" under the *Wildlife Conservation Act 1950* - Wildlife Conservation (Specially Protected) Fauna Notice. The Western Australian Government has implemented several initiatives to support the recovery of the Australian sea lion, including the use of sea lion exclusion devices (SLEDs) in rock lobster pots to mitigate this incidental mortality within the area of known interactions in the West Coast Rock Lobster Managed Fishery (Campbell, *et al.* 2008). The Department of Fisheries is currently in the process of implementing a number of management measures (i.e. exclusion zones around Australian sea lion colonies) within Western Australian demersal gillnetting fisheries to reduce potential adverse interactions (DSEWPAC 2013 b).

In Western Australia, there are currently 28 known breeding sites for Australian sea lions (including the Abrolhos Islands) and 48 sites in South Australia (Shaughnessy *et al.* 2011), most of which are characterised by fewer than 30 pups per breeding season.
The Abrolhos Islands population is small and at the northern limit of the species range. Small, closed populations (such as that at the Abrolhos Islands) are highly vulnerable, especially to increased mortality from anthropogenic causes (Campbell 2008) and the removal of only a few individuals annually may increase the likelihood of decline and potentially lead to the extinction of smaller colonies (DSEWPaC 2013b).

There are only a few Australian sea lion colonies in Western Australia that have accurate, long-term trend data in pup production (AMMC 2014). Of the colonies that have sufficient long term data, it appears that pup production at the Houtman Abrolhos is stable (AMMC 2014). Australian sea lions have extensive historical accounts and sightings from the Abrolhos Islands, which are documented as both breeding and haul-out sites (DSEWPaC 2013a). Historical population abundances at the Abrolhos Islands ranged from 300 to 580 sea lions. In contrast, recent surveys described severely reduced population estimates (76 to 96 sea lions), most likely resulting from historical harvesting (Campbell 2005, DSEWPaC 2013a). In 2004, 17 sea lion pups were counted from breeding areas within the Easter Group islands, and two pups were recorded on the Pelsaert Group islands. The latter are predominantly used as haul-out sites with occasional pupping events (DSEWPaC 2013a).

Recent telemetry data from tagged Australian sea lions recorded foraging ranges with a broad use of coastal shelf waters to the shelf edge (Campbell 2008). Foraging behaviour varied among different Australian sea lion populations and different cohorts within each population. From all Western Australian populations studied, sea lions generally displayed strong foraging site fidelity, and the Abrolhos Islands population had the smallest foraging range observed (Campbell 2008). Females and juveniles had small foraging ranges (less than ten kilometres) and foraging trips comprised travel within the Abrolhos Islands.

As benthic foragers, Australian sea lions may dive up to 90 metres to target prey species, such as cephalopods, crustaceans and fish (Campbell 2005). Among all age groups from Western Australia's populations, similar diving patterns included shallow depths (average depth less than 20 metres) with a maximum of 50 metres. The shallowest range of dive depths was recorded from the Australian sea lions tagged at the Abrolhos Islands, where the mean dive depth was approximately 10 metres for adult females, juveniles and pups, and the maximum dive depth (37 metres) was recorded from a juvenile sea lion (Campbell 2008).

Although the telemetry data were recorded from a low number of sea lions, the documented foraging range, dive depths and significant breeding and haul-out sites confirm that the Australian sea lion population at the Abrolhos Islands are likely to occur within the MWADZ Proposal area (Figure 9-1).

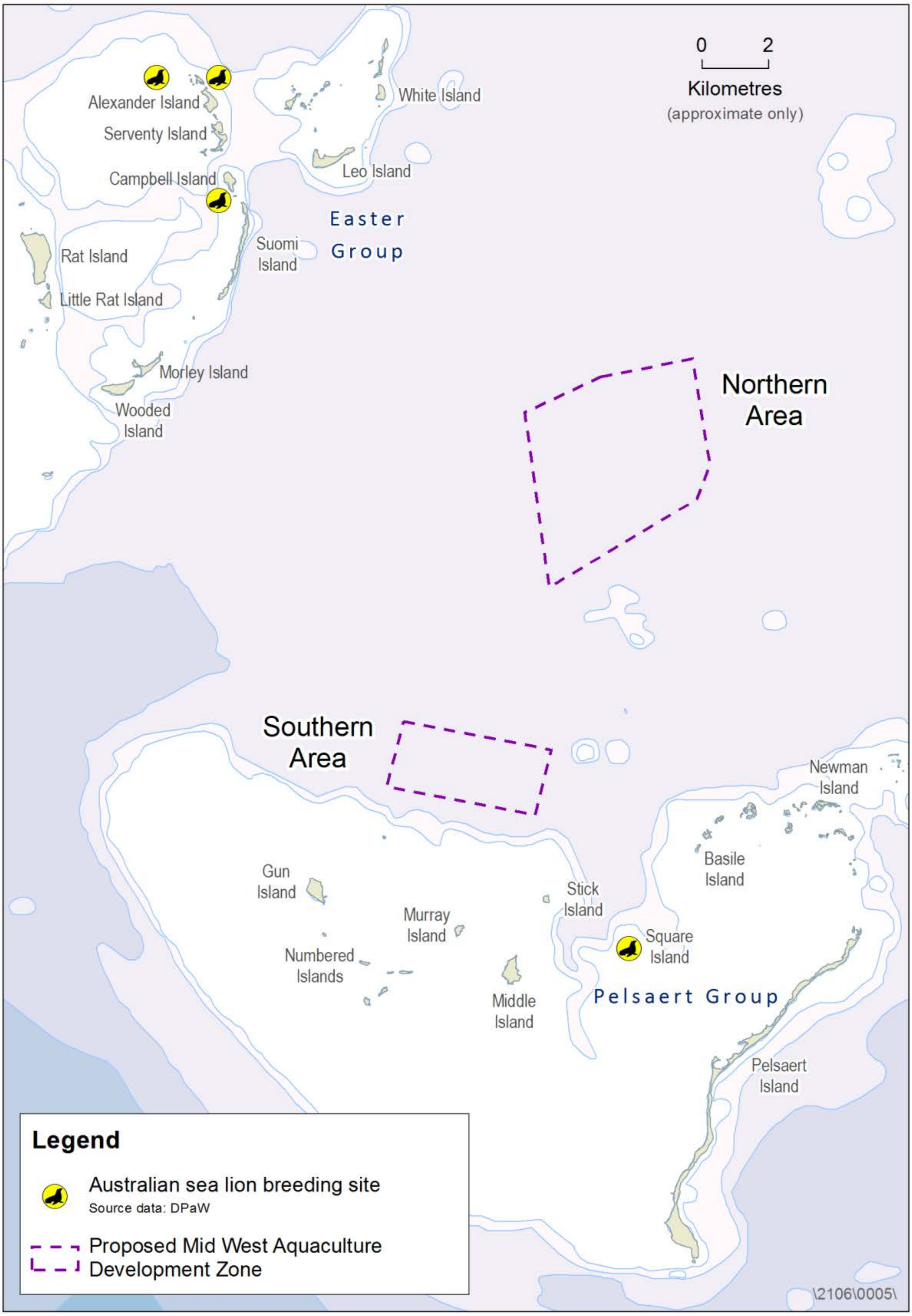

Figure 9-1: Australian Sea Lion Breeding Sites in the Abrolhos Islands

9.2.5 Marine Reptiles

9.2.5.1 Turtle

There are six species of marine turtle that occur in the waters of Western Australia these include green turtle (*Chelonia mydas*), hawksbill turtle (*Eretmochelys imbricatal*), loggerhead turtle (*Caretta caretta*), flatback turtle (*Natator depressus*), leatherback turtle (*Dermochelys coriacea*) and olive Ridley (*Leidochelys olivacea*). All of these species are listed as Threatened and Migratory under the Western Australian *Wildlife Conservation Act 1950* and the EPBC Act. Under the EPBC Act, loggerhead, leatherback and olive Ridely turtle are listed as "endangered"; while the green, flatback and hawksbill turtles are listed as "vulnerable".

The turtle species most likely to be present within the vicinity of the strategic MWADZ Proposal area are the green, leatherback, loggerhead and flatback turtle (refer to Table 9-4).

Green Turtle

Green turtle (*Chelonia mydas*) are found in tropical and subtropical waters globally. Western Australia supports one of the largest green turtle populations in the world, with three genetically distinct stocks comprising approximately 20,000 turtles (DoE 2014b). Important breeding areas for this species include Barrow Island and the Muiron Islands and the nesting period is between November and March (DoE 2014b).

Resident green turtles primarily feed on seagrass and algae in shallow benthic environments. They regularly feed around the Abrolhos Islands, which is recognised as an important foraging area (DEWHA 2008). In Western Australia, telemetry data documented green turtles feeding 200 to 1,000 kilometres away from nesting beaches (DoE 2014b).

Considering all these factors, green turtles are likely to occur within the MWADZ Proposal area.

Loggerhead Turtle

Loggerhead turtle (*Caretta caretta*) are widely distributed throughout tropical, subtropical and temperate waters, preferring the waters of coral and rocky reefs, seagrass beds and muddy bays (DoE 2014b). This species feeds primarily on benthic invertebrates, foraging from the nearshore zone to water depths of approximately 50 to 60 metres (DoE 2014b). In Western Australia, this species is known to forage and nest primarily in the north-west of the state, from Shark Bay to the Pilbara region (DoE 2014b). In south west Western Australia, resident loggerhead turtles are commonly observed foraging in waters from Rottnest Island to Geographe Bay (DEWHA 2008).

The Abrolhos Islands do not represent an important breeding/nesting area for this species, with most loggerhead turtles breeding in areas north of Dirk Hartog Island. Based on their foraging habitats and prey species preferences, adult loggerhead turtles may be present within the Abrolhos Islands/Geraldton region. However, this species is unlikely to occur frequently within the MWADZ Proposal area.

Leatherback Turtle

The leatherback turtle (*Dermochelys coriacea*) is found in tropical, subtropical and temperate waters throughout the world, and has been observed foraging in all Australian waters (DoE 2014b). Primarily in pelagic and coastal waters of all Australian states, leatherback turtles feed on marine invertebrates (such as jellyfish and tunicates). Usually, this occurs in areas of upwelling or convergence where primary productivity is high (DoE 2014b).

Leatherback turtles are most commonly observed foraging in the mid to south-west WA regions (DEWHA 2008). Therefore, it is likely that leatherback turtles may be encountered within the MWADZ Proposal area.

Flatback Turtle

Flatback turtle (*Natator depressus*) are endemic to subtropical and tropical waters of Australia, Papua New Guinea and Irian Jaya, with nesting activity confined to Australia (Limpus 2007, DoE 2014b). They are commonly found in turbid water over soft-bottom habitats in shallow, nearshore waters (DoE 2014b). Without a pelagic phase or global distribution, flatback turtles will mature and remain in shallow coastal waters that are close to their natal beaches (DSEWPaC 2012b). In northwest Western Australia, the mating season for the flatback turtle usually occurs from November to March, with a peak in January (DSEWPaC 2012b). However, flatback turtles are not expected to occur in the mid-west region or south of Exmouth WA (Limpus 2007).

Therefore, this species is unlikely to occur in the MWADZ Proposal area.

Table 9-4: Likelihood of Marine Turtle Species Presence within the Proposed MWADZ

Common name	Scientific name	EPBC Act status	Wildlife Conservation Act status	Presence in the vicinity of the MWADZ
Loggerhead turtle	*Caretta caretta*	Endangered, Marine, Migratory	Endangered	Low likelihood
Leatherback turtle	*Dermochelys coriacea*	Endangered, Marine, Migratory	Vulnerable	Likely
Green turtle	*Chelonia mydas*	Vulnerable, Marine, Migratory	Vulnerable	Likely
Flatback turtle	*Natator depressus*	Vulnerable, Marine, Migratory	Vulnerable	Unlikely

9.2.5.2 Sea Snake

Two sea snake species, namely the spectacled sea snake (*Disteira kingii*) and yellow-bellied sea snake (*Pelamis platura*) are recorded by the EPBC Protected Matters database as species that may occur or whose habitat may occur in the area (DoE 2015). These sea snake species are not resident at the Abrolhos Islands, but during winter storms they may be transported south to the Abrolhos from Shark Bay and further north (Department of Fisheries 1998).

9.2.6 Marine Avifauna

Marine avifauna at the Abrolhos Islands are currently protected under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC) Act, the *Wildlife Conservation Act 1950* (WA) and the Western Australian Wildlife Conservation (Specially Protected Fauna) Notice 2014. Many of the marine avifauna species are also protected under international treaties (e.g. Japan-Australia Migratory Bird Agreement (JAMBA), China-Australia Migratory Bird Agreement (CAMBA) and the Republic of Korea-Australia Migratory Bird Agreement (ROKAMBA) (Surman, C 2015). Seabirds at the Abrolhos Islands that are currently protected under these agreements include the Eastern reef egret, bridled tern, Caspian tern, crested tern, osprey and white-breasted sea eagle (Surman, C 2015).

The Abrolhos Islands represents one of the most significant seabird breeding locations in the eastern Indian Ocean. Eighty percent (80%) of brown (common) noddy (*Anous stolidus*), 40% of sooty tern (*Onychoprion fuscata*) and all the lesser noddy (*Anous tenuirostris melanops*) found in Australia nest at the Houtman Abrolhos (Ross *et al.* 1995). It also contains the largest breeding colonies in Western Australia of wedge-tailed shearwater (*Ardenna pacific)*, little shearwater (*Puffinus assimilis*), white-faced storm petrel (*Pelagodroma marina*), white-bellied sea eagle (*Haliaeetus leucogaster*), osprey (*Pandion haliaetus*), Caspian tern (*Hydroprogne caspia*), crested tern (*Thalasseus bergii*), roseate tern (*Sterna dougalli*) and fairy tern (*Sterna nereis*) (Storr *et al.* 1986, Surman and Nicholson 2009). The Abrolhos Islands also represents the northernmost breeding islands for both the little shearwater and white-faced storm petrel (Surman, C 2015).

Within the Pelsaert and Easter Groups at the Abrolhos, 17 species have been confirmed as breeding regularly. These are the white-bellied sea eagle, osprey, wedge-tailed shearwater, little shearwater and white-faced storm petrel, Pacific gull, silver gull, Caspian tern, crested tern, bridled tern (*Onychoprion anaethetus*), roseate tern, fairy tern, brown noddy, lesser noddy, Eastern reef egret (*Egreta sacra*), pied oystercatcher (*Haematopus longirostris*) and pied cormorant (Surman and Nicholson 2009).

Sooty tern, brown noddy and lesser noddy form a large community of breeding seabirds at the southern end of Pelsaert Island. There are 264,000 brown noddy (100% of total Abrolhos population) and 45,000 lesser noddy (65% of total) breeding over summer at the Pelsaert Group (Surman, C 2015). These seabirds feed in association with predatory fishes (i.e. tunas) as well as over large schools of larval fishes and squids across both shelf and oceanic waters at least 150 kilometres west of the Houtman Abrolhos (Surman pers. obs.).

Other significant marine avifauna likely to be present within the MWADZ Proposal area includes the crested tern (*Thalasseus bergii*), Caspian tern (*Hydroprogne caspia*) and fairy tern (*Sternula nereis)* (Surman, C 2015). Crested tern nest in colonies of up to 1,000 pairs at the Abrolhos Islands. Half of this population nests within the Pelsaert Group (Surman, C 2015).

Crested tern feed predominately on schools of small to medium-sized schooling fishes over shelf waters. At the Abrolhos, this species predominantly preys on scaly mackerel *Sardinella lemura* (Surman and Wooller 2003). Fairy tern also nest in colonies of a few to several hundred pairs. They feed predominately upon small fishes, particularly slender sprat (*Spratelloides gracillis*), juvenile black-spotted goatfish (*Parupeneus signatus*) and

hardyheads (Atherinidae) (Surman, C 2015). The large Caspian tern feeds almost exclusively over shallow reef flats on wrasse, blenny, mullet, whiting and goby (Surman, C 2015).

The wedge-tailed shearwater (*Ardenna pacifica*) is one of the most populous seabird species that currently nests at the Abrolhos Islands (Surman,C 2015). Current population estimates at the islands are approximately 2.2 million, with most occurring on Pelsaert Island (approx. 1,600) and West Wallabi Island (2 million) (Surman, C 2015). This species breeds at the Abrolhos Islands over the summer months before their young fledge in May each year (Surman, C 2015).

Table 9-5 provides a list of the protected marine avifauna that may occur in the vicinity of the MWADZ Proposal area.

Table 9-5: Protected Marine Avifauna that May Occur in the Vicinity of the Proposed MWADZ

Common name	**Scientific name**	***EPBC Act status***	***Wildlife Conservation Act status****	**Presence in the vicinity of the MMADZ**
Common Noddy	*Anous stolidus*	Marine, Migratory	Schedule 3	Likely
Lesser Noddy	*Anous tenuirostris melanops*	Vulnerable, Marine, Migratory	Schedule 1	Likely
Brown noddy	*Anous stolidus*	Marine Migratory	Not listed	Likely
Bridled Tern	*Onychoprion anaethetus*	Marine, Migratory	Schedule 3	Likely
Sooty Tern	*Onychoprion fuscata*	Marine	Not listed	Likely
Roseate Tern	*Sterna dougallii*	Marine, Migratory	Schedule 3	Likely
Fairy Tern	*Sternula nereis*	Vulnerable, Marine, Migratory	Schedule 1	Likely
Crested Tern	*Thalasseus bergii*	Marine	Not listed	Likely
Caspian Tern	*Hydroprogne caspia*	Marine, Migratory	Schedule 3	Likely
Eastern Reef Egret	*Egreta sacra*	Marine Migratory	Schedule 3	Likely
Pacific Gull	*Larus pacificus*	Marine	Not listed	Likely
Red-tailed Tropicbird	*Phaethon rubricauda*	Marine, Migratory	Not listed	Unlikely
Silver Gull	*Chroicocephalus novaehollandiae*	Marine	Not listed	Likely
South Polar Skua	*Stercorarius maccormicki*	Marine, Migratory	Schedule 3	Likely
Southern Giant Petrel	*Macronectes giganteus*	Endangered, Marine, Migratory	Not listed	Likely
Black-browed Albatross	*Thalassarche melanophris*	Marine, Migratory	Schedule 1	Likely
Indian Yellow-nosed Albatross	*Thalassarche carteri*	Marine, Migratory	Schedule 1	Likely
Wedge-tailed Shearwater	*Ardenna pacifica*	Marine, Migratory	Schedule 3	Likely
Fleshy-footed Shearwater	*Ardenna carneipes*	Marine, Migratory	Schedule 3	Likely
Hutton's Shearwater	*Puffinus huttoni*	Marine, Migratory	Schedule 1	Likely
Little Shearwater	*Puffinus assimilis*	Marine	Not listed	Likely

Common name	Scientific name	*EPBC Act status*	*Wildlife Conservation Act status**	Presence in the vicinity of the MMADZ
Wilson's Storm-Petrel	*Oceanites oceanicus*	Marine, Migratory	Schedule 3	Likely
White-faced Storm-Petrel	*Pelagodroma marina*	Marine	Not listed	Likely
White-bellied Sea Eagle	*Haliaeetus leucogaster*	Marine	Schedule 3	Likely
Eastern Osprey	*Pandion cristatus*	Marine, Migratory	Not listed	Likely

In order to determine the potential impacts of the MWADZ Proposal on seabird communities at the Abrolhos Islands an impact assessment was conducted by Surman (2015) (Appendix 1d). During the assessment three increaser seabird species were identified that had the potential to be moderately impacted by the MWADZ Proposal. These include:

- pied cormorant (*Phalacrocorax varius*)
- silver gull (*Chroicocephalus novaehollandiae*)
- Pacific gull *(Larus pacificus)*

9.2.6.1 Pied Cormorants

The pied cormorant is widely distributed throughout mainland Australia. This species is more common on the south coast and along the coast of south-western Australia (Surman, C 2015). The pied cormorant is found in marine habitats (almost exclusively so in Western Australia), including estuaries, harbours and bays. It is also found in mangroves and on large inland wetlands in eastern Australia (Surman, C 2015).

Approximately 1,861 pairs of pied cormorant nest throughout the Abrolhos Islands, most on Wooded Island, however significant numbers (>500) are observed foraging regularly throughout the Pelsaert Group (Surman, C 2015). Pied cormorants have been observed foraging in the region of the Southern (Pelsaert Group) aquaculture site, and may continue to do so in relatively low numbers (Surman, C 2015).

9.2.6.2 Silver Gull

The silver gull is widely distributed throughout Australia and commonly found along coastlines, islands, ports and near any watered habitat. It is rarely seen far from land. The current silver gull summer populations at the Abrolhos Islands are relatively small (~50 pairs), reflecting food availability (nitre bush berries, seabird eggs and chicks, marine invertebrates) during the summer months (Surman, C 2015). A larger breeding population (~ 150+ nests) once nested in the Pelsaert Group during the autumn, taking advantage of bait discards from “A Zone” rock lobster boats and food scraps from fishing camps. The current breeding silver gull population at the Houtman Abrolhos is very small.

Like other gull species, the silver gull has become a successful scavenger, readily pestering humans for handouts of scraps, pilfering from unattended food containers or searching for human refuse at tips. This species has been successfully able to increase in numbers and abundance by exploiting food and rubbish discarded by humans (DEC 2007). Silver gulls have a high fecundity rate and can often produce two broods in one year. The breeding season for this species is usually between August and December each year (DEC 2007).

Due to the foraging behaviour and the ability of this species to exploit food sources associated with marine finfish aquaculture it was identified as a species that could benefit from the MWADZ Proposal through the potential to secure additional sources of food that could (in turn) translate to improved breeding success and an expanded population. However, a potential negative impact of such an effect is the risk that any increase in the silver gull population may be accompanied by increased competition for nesting sites with other species utilising the Abrolhos Islands.

9.2.6.3 Pacific Gull

The Pacific gull *Larus pacificus* is moderately common from Carnarvon in Western Australia through southern Australia and up to Sydney in New South Wales. The Abrolhos Islands represents the largest population of Pacific gulls along the Western Australian coast. Currently, there are 74 active pairs of Pacific gulls across the Easter and Pelsaert Groups at the Abrolhos. Previously research studies have indicated Pacific gull numbers were as high as 127 pairs at these island groups (Surman and Nicholson 2009a). Elsewhere this species is threatened by displacement by the successful scavenging kelp gull *Larus dominicanus*. Almost half of all Pacific gulls found at the Houtman Abrolhos nest within the Pelsaert Group (Fuller *et al.* 1994).

Pacific gulls are predominately predatory, foraging on reef flats at low tide on whelks, trochus shells, turbo shells, baler shells, mantis shrimps, cuttlefish, octopus and crabs. However, during the previous “Zone A” rock lobster fishing season they scavenged for bait scraps from fishing boats and upon fish frames from wet line boats and other areas where fish are cleaned. Due to this foraging behaviour, this species was identified as one of the key species likely to be impacted by the MWADZ Proposal.

9.3 Potential Impacts

Information is based on a literature review of the best available scientific data, documented information on the adverse interactions between marine fauna and aquaculture equipment, impact assessments and “threat identification hazard pathway analysis” and risk identification and assessment methodology (Fletcher, W.J. 2014).

The primary risks identified in the risk assessments that could have a potential impact on invertebrate and fish (including shark and ray) species from the MWADZ Proposal were the following:

- Nutrient enrichment of the water column and increased turbidity
- Organic deposition and nutrient enrichment of the sediments
- Release of trace metals, therapeutants and other contaminants into the marine environment
- Introduction of marine pests and pathogens
- Additional food from aquaculture activities
- Physical presence of aquaculture infrastructure
- Artificial lighting

9.4 Assessment of Potential Impacts

9.4.1 Nutrient Enrichment of the Water Column and Increased Turbidity

Fish feed, fish faeces and metabolic waste including ammonia and urea from aquaculture stock within the MWADZ Proposal area has the potential to increase the level of nutrients (i.e. nitrogen and phosphorous) in the water column (Hargrave, B 2005). Nitrogen and phosphorous are often limiting nutrients for primary production in coastal marine environments (de Jong & Tanner, 2004). The level of nutrient enrichment is however generally highly dependent on the species being cultured, feed sources, farm practices and the density of proximal farm sites (Hargrave, B 2005). An increase in the level of nutrients in the water column can potentially result in elevated levels of primary (i.e. phytoplankton) and macro algal production (Nash *et al.* 2005), which can then lead to eutrophication of the water column. Any potential eutrophication is likely to have a negative impact on both fish and invertebrate species within the localised area.

Research studies on the potential impacts of finfish aquaculture have shown however that any changes to nutrient levels in the water column are generally localised and within close proximity to sea cage infrastructure (Price and Morris 2013). Given the hydrodynamics of the MWADZ Proposal area (i.e. strong current flow, well flushed with high levels of water circulation and dispersion) it is unlikely that an increase in nutrients levels in the area will result in eutrophication events.

Particulates from feed and fish faeces from aquaculture stock would have the potential to cause an increase in the turbidity in the water column in close proximity to the proposed sea cage infrastructure in the MWADZ. These particulates would likely settle beneath the sea cages, resulting in an increase in sedimentation beneath the sea cages. An increase in turbidity can lead to a decrease in light penetration within the water column, which can have negative impacts on photosynthetic organisms (i.e. corals) and cause potential changes to the benthic/fish habitat directly underneath and in close proximity to the sea cages (Price and Morris 2013). Given the hydrodynamics of the MWADZ Proposal area, (i.e. strong current flow, well flushed with high levels of water circulation and dispersion) it is unlikely that an increase in turbidity will have a significant impact on invertebrate and fish species.

9.4.2 Organic Deposition and Nutrient Enrichment of the Sediments

Discharges from uneaten food, faeces and metabolic waste from aquaculture stock in the MWADZ Proposal area, have the potential to cause organic deposition and nutrient enrichment of the sediments beneath the sea cages. An increase in organic deposition through nutrient enrichment of the sediment beneath the sea cages would have the potential to result in potential loss or reduction in diversity of benthic invertebrates through smothering of benthic habitats. Bacterial decomposition of the organic matter can result in an increase in the biological oxygen demand of the sediment, leading to depletion of oxygen at the benthos (Hargrave, B 2005). This could result in anoxic conditions at the sediment-water interface resulting in a sharp decline in populations of invertebrates (i.e. saucer scallops) and other demersal finfish in the area. These anoxic conditions can also result in a significant increase in the small opportunistic benthic invertebrates such as scavengers and deposit feeding species [e.g. capetellid worms (Price and Morris 2013)].

Anoxic conditions could also lead to elevated levels of nitrites and hydrogen sulphide, which are toxic to invertebrate and fish species (Hargrave, B 2005). These conditions could also result in potential changes in biological and chemical processes in the sediment and the ecology of benthic organisms.

Any potential changes to the biochemical properties of the benthic environment within the MWADZ are likely to result in the avoidance of the area by invertebrate species such as saucer scallops. The survival and recruitment of fish species confined to habitats beneath the sea cages and within close proximity are likely to be impacted.

Many studies that have been conducted on the impacts of marine finfish aquaculture on the benthic environment in Australian waters have shown that in most cases impacts have been highly localised and restricted to areas beneath or in the immediate vicinity of the sea cages (McGhie *et al.* 2000; Hoskin & Underwood, 2001; DPIWE, 2004; Woods *et al.* 2004; Felsing *et al.* 2005; McKinnon *et al.* 2008; Edgar *et al.* 2010; Tanner & Fernandes, 2010).
Generally, the level of impact has been found to decrease with increasing distance away from sea cages (Macleod *et al.* 2002).

9.4.3 Release of Trace Metals, Therapeutants and other Contaminants

Worldwide a range of chemicals are used in aquaculture for the purpose of transporting live organisms, in feed formulation, health management, manipulation and enhancement of reproduction and for processing and adding value to the final product (Douet *et al.* 2009). Chemicals and therapeutants include anti-foulants, fertilisers, disinfectants, antibacterial agents, parasticides, feed additives, anaesthetics and breeding hormones (Burridge *et al.* 2010).

Operational activities conducted in the MWADZ are likely to require the use of some chemicals and therapeutants (i.e. veterinary pharmaceuticals) to treat cultured stock with disease, control pests, fish handling and euthanizing fish (i.e. anaesthetics). These chemicals have the potential to be released into the surrounding marine environment; through fish feed, fish faeces and directly into the water column (e.g. leaching from anti-foulants or heavy metals released from feeds). The amount of chemicals released into the environment can vary depending on the specific chemicals used, the characteristics of the aquaculture farm site (e.g. flushing rate and sediment type) and farm management practices (e.g. feeding rates, husbandry techniques etc.).

Chemicals used in the MWADZ Proposal area have the potential to have an impact on both fish and invertebrate species through direct toxicity and bioaccumulation in the food chain (Burridge *et al.* 2010). Heavy metals originating from anti-foulants used in farming practices could also have potential impacts on invertebrate species (i.e. saucer scallops) due to accumulation of contaminants in the sediments below the sea cages (reduces benthic colonisation) and direct toxic effect through bioaccumulation in the food chain (Pittenger et.al 2007).

9.4.4 Introduction of Marine Pests or Pathogens

There are a number of significant pathogens of the marine fish proposed for aquaculture in the MWADZ, including for yellowtail kingfish. Diseases may potentially be introduced into sea cage farms directly from the environment (e.g. as a result of transmission from wild fish), or via infected stocked fish, movement of personnel and infrastructure, the use of untreated aquaculture feeds or other vectors. Once introduced into an aquaculture facility, pathogens may persist, be transmitted between generations and potentially adapt to a state of virulence higher that that seen in the wild (where there may be no evolutionary advantage to kill a host) as a result of the selection pressures associated with intensive aquaculture. Spread of pathogens from aquaculture facilities could then occur via effluent, escapes, and/or predation. The spread of a significant pathogen could ultimately impact a wide range of species and the fisheries and ecosystems which they support.

Marine pests are known to be present in the region and thought to have been introduced into the state mostly as a result of anthropogenic activity involving international shipping. The MWADZ Proposal has the potential to assist with the further spreading of marine pests in the region. Marine pests can be transported in ballast water and as biofouling on vessel hulls. Vessel movements in the region have the potential to spread marine pests that can then establish themselves within the ecosystem. Commercial aquaculture activities also have the potential to be directly responsible for introduction of marine pests e.g. through introduction via feed sources or brood stock or via the use of imported equipment that is not sufficiently cleaned.

9.4.5 Additional Food

The presence of aquaculture stock (including dead or moribund stock), harvesting activities and effluent (i.e. blood, lipids, scales), biological residue (e.g. fish faces) and excess feed has the potential to attract or deter marine fauna from the proposal area. These factors could lead to changes in the behaviour of marine fauna within the MWADZ. These include:

- Increase/decrease in the visitation rates of finfish, shark and ray species
- Increase in the duration of visits for these marine fauna species
- Altered feeding behaviours for fish, sharks and rays and invertebrate species
- Increase/ decrease in the abundance of fish, sharks and rays and invertebrate species within the aquaculture zone.

Aquaculture stock feed which consists of fish meal and fish oil is known to attract fish species (Machias *et al.* 2005). The provision of food and habitat has the potential to lead to changed behaviour in fish species. An increase in food availability within the aquaculture zone has the potential to cause an increase in the abundance of prey species and could influence the behaviour of predatory fish species (e.g. pelagic fish species such as Spanish mackerel and yellow fin tuna) in the MWADZ. An increase in the abundance of prey species could, in turn, influence shark and ray behaviour.

If these fish species are able to regularly gain provision (e.g. food) from the fish farms it is likely to result in an increase in the visitation rates and duration of visits from these species. There are also likely to be a localised increase in the abundance of shark and ray species which could lead to increased rates of predation on aquaculture stock and the risk of interactions and potential entanglement and entrapment in the sea cages.

Aquaculture activities conducted within the MWADZ Proposal area are likely to provide an additional food source from the presence of cultured stock, dead or moribund stock, biological residues and excess feed for increaser marine avifauna species such as pied cormorant, silver gull and Pacific gull. These species are currently reliant upon natural food sources only at the Abrolhos Islands. The current silver gull summer population at the islands is relatively small (approximately 50 pairs) reflecting food availability (nitre bush berries, seabird eggs and chicks, marine invertebrates) during the summer months (Surman, C 2015). Previously large breeding populations (over 150 nests) of silver gull populations once nested in Pelsaert Group of the Abrolhos Islands (Surman, C 2015) during the autumn months, taking advantage of bait discards from rock lobster fisherman from the West Coast Rock Lobster Managed Fishery who operated in that area. Silver gulls have the ability to adjust their behaviour in line with fishery activities and have demonstrated in previous studies to be able to increase populations very quickly when additional food is available in the marine environment (Surman, C 2015). Increased availability of food for silver gulls across the North-west Shelf from gas flares over water has led to massive increases in gull populations with consequential displacement of other nesting seabirds and the predation of their young and eggs and hatchling turtles (Surman, C 2015).

Pied cormorants are known to actively pursue fish prey underwater regularly attaining depths of 20 metres or more (Surman, C 2015). This species is known to chase whole fishes from commercial wetline fishing vessels, and to enter rock lobster pots in pursuit of small fishes attracted to the pots by bait (Surman, C 2015). Pied cormorants are known to actively predate on aquaculture finfish stock in aquaculture farms in Scotland (Beveridge, M.C.M 2001). This species is likely to receive an advantage (provision) if able to feed upon any cultured fish within the MWADZ Proposal area. If these species are able to gain a provision from fish farming it is likely to increase the visitation rates, duration of visits and abundance of this species in the area. An increase in the abundance of pied cormorants may result in an increase in the number of entanglements with sea cage infrastructure. Any potential increase in pied cormorant populations may also result in more habitat loss for the threatened lesser noddy (*Anous tenuirostris melanops*) and hamper the recovery of this species at the Abrolhos Islands (Surman, C 2015).

Pacific gulls are predominantly predatory, foraging reef flats at low tide for whelks, trochus shells, turbo shells, baler shells, mantis shells, mantis shrimps, cuttlefish, octopus and crabs (Surman, C 2015). An increase in the availability of the food through aquaculture activities has the potential to replace the feeding behaviour of this species from predatory to scavenger. Given that current populations of this species are relatively low at the Abrolhos Islands any increase in the abundance of this species may initially be of a positive effect. However, over the longer term a population increase in such a large species may not be sustainable and may have negative impacts during certain times of the year (Surman, C 2015). Any increases in the abundance of this species may also result in an increase in predation rates on other seabird species eggs and chicks; in particular, adult storm petrels (Surman, C 2015).

9.4.6 Physical Presence of Aquaculture Infrastructure

The physical presence of aquaculture infrastructure including sea cages, anchoring and mooring systems and feeding systems could have potential adverse impacts on finfish and invertebrate species within localised areas in the MWADZ Proposal area.

Sea cages could potentially provide an additional three dimensional structure to the marine environment and provide an artificial habitat for fish species. Artificial marine structures are known to provide shelter, habitat complexity and a food source for small fish species (Forrest *et al.* 2007). Mooring lines and anchors used to secure the sea cage infrastructure can also be of advantage to particular fish species or their prey by providing an artificial habitat. These artificial structures commonly become encrusted with ascidians, mussels and encrusting organisms which provide a food source for some fish species.

The presence of infrastructure can modify the behaviour of mobile fish species and can congregate fish species around the area causing Fish Aggregation Device (FAD) effects. The presence of barge accommodation, feeding barges and moored operational vessels are also likely to create FAD effects. The aggregation of fish species to these structures has the potential to increase both recreational and commercial fishing activity within the MWADZ Proposal area. Wild fish species that aggregate around the sea cages may be more vulnerable to any potential diseases or pathogens that aquaculture stock may develop.

The presence of aquaculture farms has the potential to create barriers to movement if it restricts migratory routes or transit routes of marine mammals, reptiles and seabirds between their habitats. The presence of aquaculture infrastructure may also attract larger marine predators including sea lions and dolphins due to FAD effects. Sea-based infrastructures that may have an impact on marine fauna include:

- sea cages;
- mooring and anchoring lines and systems;
- feeding barges; and
- vessels (service and accommodation).

Potential impacts to marine fauna related to the physical presence of aquaculture infrastructure during the installation process and operational activities include:

- changes in natural feeding behaviour of marine fauna as a result of higher fish density from FAD effects;
- serious injury or mortality of marine fauna due to entanglement or entrapment in aquaculture infrastructure;
- habitat changes due to placement of infrastructure and degradation of marine water and sediment quality; and
- changes to marine fauna distribution and migration patterns due to avoidance or attraction cues.

The physical presence of aquaculture infrastructure such as sea cages, accommodation barges and feeding barges has the potential to have adverse impacts on marine avifauna increaser species. These increaser species may become entangled in sea cage netting, bird netting or anti predator netting during foraging or roosting causing drowning. The roosting of these species on the infrastructure has the potential to result in a reduction in water quality from faecal matter, increase the risk of collision with operational vessels and increase the amount of fouling on the infrastructure (Surman, C 2015). Increaser species may also use barges as a potential area for shelter and roosting areas. The increased presence of silver gull and cormorant species on accommodation barges and the sea cage infrastructure is likely to increase the likelihood of human interactions between these species and aquaculture farm staff.

The presence of sea cage infrastructure in the MWADZ Proposal area could also provide an attraction for baitfish, crustaceans and predatory fish due to fish aggregation (FAD) effects. These FAD effects may result in changes to seabird natural foraging behaviour and also result in an increase in populations of increaser species (i.e. gulls and cormorants) which have significant ecological effects. Changes to populations of these increaser species has the potential to lead to changes in ecosystem structure in area and can also lead to increases in kleptoparasitism (i.e. one animal takes prey or other food from another) on other more vulnerable sea bird species (Surman, C 2015). Increases in the pied cormorant colonies could also enhance the mechanical and guano stress on the mangrove habitats on the Abrolhos (Surman, C and Dunlop, N 2015).

9.4.7 Artificial lighting

Artificial light spill and glow generated during the installation and operation of aquaculture farms within the MWADZ area may have potential impacts on marine fauna. Sources of light emissions from activities within the area that may affect marine fauna include:

- routine lighting on aquaculture infrastructure;
- navigation marker lighting; and
- vessel lighting.

Light spill can have the following potential impacts to marine fauna:

- attraction of marine turtle hatchlings and disorientation;
- injury or death of juvenile seabirds attracted to lighting and flying into aquaculture infrastructure; and
- modification of fauna foraging behaviour around infrastructure due to light spill on the water.

Artificial lighting used on sea barge accommodation and on sea cage infrastructure has the potential to have a number of impacts on seabirds in the area. An increase in lighting has the potential to cause disorientation, collision for seabirds with the infrastructure and lead to potential death of seabirds that transit the area at night. Light emissions on aquaculture infrastructure have the potential to attract and extend seabird foraging times within the MWADZ Proposal area. Silver gulls are often attracted to offshore marine lighting as it increases the availability of prey (i.e. insects, fish attracted to light spilling onto the sea surface) (Chevron Australia 2010). The increased availability of prey and the ability of this species to be able to extend their foraging time through the night could potentially result in increased numbers of silver gulls, which may have flow on effects for other seabirds and for marine turtles, through direct competition for breeding habitat and predation of turtle eggs and hatchlings, respectively (Chevron Australia 2010). Light emissions from aquaculture infrastructure may alter the foraging behaviour of other gull species such as the Pacific gull and provide a competitive advantage to this species which may result in population increases in these species (Surman, C 2015).

9.4.8 Vessel Movements

Vessels will operate throughout the MWADZ area during the installation of the aquaculture infrastructure and during operational activities.

A range of vessel types, including service vessels, supply vessels and feeding barges, may be active within the area. The potential impacts to marine fauna related to the physical presence of vessels during the installation process and operational activities include:

- injury or death of marine fauna from vessel strikes;
- disturbance to marine fauna behaviour from vessel movements; and
- habitat degradation (e.g. through anchoring and mooring).

Higher vessel activity is likely during the construction of the aquaculture farms (i.e. installation of sea cages, anchoring and mooring systems) as opposed to during the operational period.

9.4.9 Noise and vibration

Noise and vibrations generated during the installation of aquaculture infrastructure and during operational activities within the MWADZ area may have potential impacts on marine fauna. The primary sources of potential noise and vibration include:

- vessel movements in the area;
- machinery used to install the sea cages, moorings and anchoring systems; and
- machinery used in operations (e.g. hand-held welders, mobile cranes, hand tools, small power tools, blowers and winches).

Anthropogenic marine noise has the potential to impact marine fauna that rely on acoustic cues for feeding, communications, orientation and navigation. The extent of the impacts will vary depending on a number of variables, including the frequency range of the emitting noise and its intensity, the receiving environment (e.g. salinity, water depth, and sea bed type), met-ocean conditions, characteristics and sensitivity of the animal, and its distance from the source. Underwater noise and vibration can have the following impacts on marine fauna:

- behavioural changes;
- temporary or permanent injury and (in extreme cases) mortality;
- stress response;
- complete avoidance of the immediate area (habitat displacement);
- attraction to the noise source; and
- disruption to underwater acoustic cues for navigation, foraging and communication.

However, the assessment provided in the PER concluded that noise and vibration from construction and operational activities within the MWADZ did not pose a significant risk to marine fauna in the area. The majority of noise and vibration is likely to be generated by machinery potentially used to anchor sea cage infrastructure to the seabed and such activity is unlikely to occur on a frequent basis. Noise resulting from vessel movements within the proposed MWADZ is also expected not to exceed that historically generated by the fishing industry in the Abrolhos Islands FHPA.

9.5 Management Measures

Proposed management and mitigation measures that are intended to be implemented to minimise the potential impacts of the risks to marine fish and invertebrate species and marine fauna (including avifauna) are provided in Table 9-6.

Although the degree of risk to the groups (e.g. fish, mammals and avifauna) is different, the management measures applied to address the risk are largely consistent. To avoid repetition, the table below does not address each group separately.

Table 9-6: Proposed Management and Mitigation Measures

Risk	Management Measures
Nutrient enrichment of the water column and increased turbidity	Management measures that can be implemented to reduce the potential impacts of nutrient enrichment of the water column and increased turbidity include: • Adopt good husbandry practices including the monitoring of nutrient levels under farm management practices such as direct measurement of the level of Chlorophyll-a at the farm reference sites. (Chlorophyll-a is a proxy for phytoplankton levels.) • Locate sea cages in well flushed locations with good water circulation and dispersion. • Set densities of aquaculture stock at conservative levels to help minimise the likelihood of water column enrichment. • Use species and system-specific feeds in order to maximise feed conversion ratios (FCR) and minimise waste. • Monitor fish feeding behaviour and particulate matter deposition to inform adapting the feeding strategy to maximise feeding efficiency and minimise particulate matter fallout. • Develop and comply with an EMMP and best-practices in aquaculture, including the requirement to monitor the levels of dissolved nutrients and chlorophyll-a in the water column.
Organic deposition and nutrient enrichment of the sediments	Key management and mitigation strategies that can be used to reduce the potential impacts of organic deposition and nutrient enrichment to sediments include: • Locate the sea cages in well-flushed areas where there is an increased water depth below the sea cages. • Control feed by minimizing feed wastage. This can significantly reduce sediment enrichment effects and help improve sediment conditions underneath the sea cages. • Use high-quality feeding systems which minimise waste. • Use high-quality feed and seek improved feed conversion ratios. • Fallow sites to allow seabed recovery. The rotation of sea cages is likely to allow the recovery of nutrient enrichment in the sediments. • Consider cumulative impacts under the zone management policy. • Monitor sea floor chemistry and infauna. • Encourage integrated multi-trophic aquaculture. • Regulate the density of sea cage operations, in addition to limiting the stocking density per hectare of lease. • Develop and comply with an EMMP and best-practices in aquaculture, including the requirement to monitor the levels of dissolved nutrients and chlorophyll-a.
Release of trace metals, therapeutants and other contaminants into the marine environment	Key management and mitigation measures designed to minimise the impacts of the potential release of chemicals include the following: • Apply good husbandry and farming practices (e.g. removal of sick or dead fish, reducing feed waste, conservative stocking densities etc.) to reduce the need for chemical use associated with marine finfish aquaculture. • Regular monitoring of contaminant levels at the lease sites. • Use high-quality feed. • Regular cleaning and maintenance of sea cage infrastructure to avoid

Risk	Management Measures
	accumulation of biofouling organisms and reduce the need for anti-foulants. • Locate sea cages in well-flushed areas. • Treat any infected aquaculture stock promptly. • Consult the relevant Material Safety Data Sheets (MSDS) before applying chemicals to aquaculture stock, promoting the safety of staff, stock and the environment. • Ensure all chemicals including antibiotics, therapeutants and anti-foulants are secured in storage containers with tightly fitted lids to minimise the risk of spills into the environment. • Ensure all residual or out-of-date chemicals are transferred to land-based facilities and disposed of in an appropriate manner. • Monitor, on an annual basis and as part of the requirements of the EMMP, three of the more common trace metals found in fish feeds. Should levels trigger the guidelines set in the EMMP, differently-formulated feeds may need to be utilised.
Introduction of marine pests or pathogens	The management measures which have been proposed to address the risk of the introduction of marine pests and pathogens have been covered in more detail in the biosecurity assessment in Section 10 of this document.
Additional food and artificial habitat	In order to reduce the potential impacts associated with additional food sources, operators within the MWADZ Proposal area must comply with the relevant requirements in the EMMP. Management arrangements within the EMMP will include requirements to: • Minimise opportunities for provisioning (i.e. by removing dead and moribund stock on a daily basis); • Use appropriate stocking densities [i.e. keep stocking densities at levels below or equal to industry-best-practice bench marks (e.g. 10-25 kg m^2)]; • Minimise feed wastage (e.g. through setting a benchmark of less than two percent wastage). This can be achieved by using efficient delivery systems and real-time monitoring of environmental conditions and stock feeding responses; • Use a high-quality pellet feed, noting: ➢ increasing knowledge on nutritional needs of particular finfish species in aquaculture is leading to improved quality of feed and is responsible for significant improvements in feed conversion ratios; ➢ modern feed for culturing fin-fish contains less fish meal and fish oil that traditional aquaculture feeds; and ➢ modern, high-quality feed can be designed to sink at rates which optimise consumption by stock; • Apply best-practice pelletised feed dispersion approaches to prevent seabirds from gaining access to waste feed and stock mortalities, take care to clean up feed spilled during loading and fully enclosing the feed system under the bird nets. • Prevent access to pellet food stored on site in bulk feed hoppers and store loose bags of feed in the below-deck compartment of the supply boat or on deck covered by heavy-duty PVC tarpaulin. • Use other deterrents (visual and audio) as appropriate. • Cover the above-sea component of sea cages with bird-netting material made of high-visibility, two millimetre polyethylene with a maximum bar-length of 60 millimetres to allow no points of entry for seabirds. • Regulate the quantity of aquaculture feed delivered to farm fish based on fish body weight measurements (to establish biomasses) and

Risk	Management Measures
	observations of fish feeding behaviour to ensure minimal feed remains uneaten by farm fish. • Use contemporary feeding technologies and best-practice farming techniques to reduce feed wastage and optimise food conversion ratios (FCR) as highlighted in the zone Management Policy and the Industry's Code of Practice. • Prevent the feeding of increaser marine avifauna by aquaculture farm staff. • Contain all post-harvest blood water and effluent; and • Monitor (real-time) environmental conditions and stock responses during feeding. • In order to prevent predation of juvenile aquaculture stock by pied cormorants, the following management and mitigation measures will be implemented: • Sub-surface exclusion or "anti-predator" netting with mesh sizes 60 millimetre bar-length or less will be mandatory on sea cages. Operators within the MWADZ will use durable fish nets (heavy-duty single barrier) and (where needed) external anti-predator nets (double barrier) to avoid predation on farmed stock. • Tension on anti-predator netting must be as tight as is practicable to provide a buffer between the grow-out net and the anti-predator net that will prevent any potential access to stocked fish by pied cormorants.
Physical presence of aquaculture infrastructure	Management measures that will be implemented to mitigate and or manage any potential impacts posed by the aquaculture infrastructure include: • Manage sea cage infrastructure to minimise entanglement hazards, roosting opportunities and potential collisions with seabirds. • Design railings, floats, net rings, etc. to reduce the opportunity for roosting sites that could be used by increaser seabird species. • Maintain nets, ropes and sea cages in proper working order, being clean (i.e. free of excessive fouling), taught and without damage (e.g. holes) that may cause entanglement of wildlife. • Inspect nets, ropes and sea cages daily for any marine fauna that may have become entangled. • Prevent sea birds such as pied cormorants, silver gulls and Pacific gulls from entering sea cages to gain provision (i.e. food) in the form of uneaten fish feed and biological residue and implement feeding protocols that reduce the likelihood of increaser marine avifauna species gaining access to feed outside of the sea cages. • Cover the above-sea component of sea cages with bird-netting material made of high-visibility, two millimetre polyethylene with a maximum bar-length of 60 millimetres to allow no points of entry for seabirds. • Monitor interactions between seabirds and sea cage infrastructure daily using semi-quantitative approaches. Record the numbers and types of seabirds and compare with the baseline assessment published in Halfmoon Biosciences (2015). • Engage an independent seabird consultant on site during the initial establishment of the sea cages and at intervals thereafter (for the purposes of establishing baseline data and validating monitoring undertaken by fish farm staff) and incorporate a training program for farm staff to continue ongoing observations, paying particular attention to surface-feeding silver gulls and Pacific gulls, as well as sub-surface feeders such as pied cormorants and wedge-tailed shearwaters (Oceanica 2015). • Monitor seabird activity by farm crew (after training), using identification guides provided by the consultant and require the farm

Risk	Management Measures
	crew to report daily the: ➢ numbers and species of seabird in the vicinity (i.e. within 100 metres) of the sea cages; ➢ types of seabird behaviour (i.e. roosting on floats, feeding on fish food, etc.); ➢ location and cause of any entanglement/entrapment incident and the seabird species involved; and ➢ incidents of any seabirds colliding with any service vessel. • Consolidate and share data in a common database where multiple fish farms are operating within the MWADZ and report results of the individual monitoring programs in the Annual Compliance Report submitted by each operator. • Assess the need to conduct ongoing broad-scale surveys of silver gull populations (based on the success of silver gull exclusion measures) after six and twelve months of operation in consultation with the Office of the Environmental Protection Authority (OEPA).
Artificial lighting	The key management and mitigation measures that will be used to reduce any potential impacts associated with artificial lighting include: • Minimise the light intensity used on vessels to as low as practicable when conducting activities at night and conduct the majority of work on the aquaculture farms during day light hours. • Reduce light spill by shielding lights and pointing lights directly at the work area (directional alignment), thereby reducing the amount of lights shining directly onto water. • Cover windows on accommodation barges with tinting or drapes at night to reduce the light emission. • Avoid (where possible) the use of bright lights (e.g. mercury vapour, metal halide, halogen and fluorescent light) on aquaculture infrastructure and consider the option of using use of low-wattage lights (i.e. Low Pressure Sodium Vapour lighting or orange and red lights). • Keep lighting on moored vessels at night to the minimum consistent with safe operations. • Monitor (periodically) the waters around moored vessels and accommodation barges to determine the level of night-foraging behaviour of silver gulls.
Noise and vibration	The key management and mitigation measures that will be used to reduce any potential impacts associated with noise and vibration include: • maintain and inspect noise generating equipment (e.g. vessel engines, drilling equipment) to reduce unnecessary increase in noise levels from the equipment (i.e. all vessels shall operate in accordance with the appropriate industry noise codes); • avoid the practice of leaving engines, thrusters and auxiliary motors on standby or running mode (where practicable); • the Master of any aquaculture vessel taking note if marine fauna is sighted in the vicinity of the aquaculture infrastructure and reducing speed to minimise noise disturbance (other staff are also responsible for bringing the situation to the attention of the Master of the vessel); and • install sound suppression devices (e.g. mufflers) on noise-emitting equipment (if applicable).

9.6 Predicted Environmental Outcome

The key risks to marine fauna presented by sea cage aquaculture include:

- collision/entrapment associated with the sea cage infrastructure;
- attraction/increased abundance associated with provisioning, due to the availability of stock feed and dead or moribund stock or increased prey availability;
- reward, behavioural changes or population growth due to provision of artificial habitat and supplementary feeding;
- disturbance/collision associated with service vessels;
- habitat exclusion due to the physical presence of sea cage infrastructure;
- disturbance by aquaculture practices with implications to foraging success (e.g. the use of artificial lighting); and
- pressures associated with disease and genetic pollution.

These risks (above) will be eliminated or minimised through best practice management and world-class infrastructure, as required by the EMMP and Draft Management Policy for future derived proposals (i.e. aquaculture operations within the MWADZ). The above risks not eliminated (i.e. residual risks) will be reduced to an acceptable level commensurate with a high level of protection for the maintenance of ecosystem integrity (EMMP - Appendix 2).

Indirect impacts on marine fauna related to organic deposition are not considered significant, as these would be restricted to localised areas in close proximity to the sea cage infrastructure. Aquaculture activities conducted within the MWADZ Proposal area are likely to result in some degree of nutrient enrichment in the water column based on discharge from uneaten feed, faeces and metabolic wastes (such as urea) from aquaculture stock. Organic deposition associated with finfish aquaculture has potential to impact upon benthic communities and habitats which, in turn, can affect some species of marine fauna. Any risks related to the potential use of treatment chemicals or accumulation of trace metals is low due to restricted use, limited spatial distribution, rapid dilution and decomposition in the environment.

Proponents within the MWADZ will be required to work within the EQMF (refer to EMMP - Appendix 2), which requires operators to conduct regular monitoring of the marine environmental quality (EAG 15), through the ecological value of “ecosystem health” and its associated environmental quality objective of “maintain ecosystem integrity”. If proponents fail to achieve the appropriate level of environmental quality required by the EQMF, additional management measures will be applied to reduce the potential impacts. The EQMF and the EMMP are therefore critical to the development of the MWADZ and provide the security to ensure future derived proposals are sustainable and well managed to achieve levels of environmental quality higher than that predicted under the modelled “worst case” scenarios (EMMP - Appendix 2).

The EMMP provides the EQMF to protect marine environmental quality and benthic communities and habitat within the appropriate levels of ecological protection. However, it also includes proactive management strategies to protect the important biological and ecological values of the Abrolhos Islands region, including its significant marine mammal, seabird, wild fin-fish and invertebrate populations (Sections 4.4, 4.5, 4.6 and 4.7 of the EMMP - Appendix 2).

The key pressures associated with aquaculture are inputs of nutrients and organic material derived from fin-fish metabolic processes and feeding. None of the pressures on marine environmental quality and benthic communities and habitat are expected to impact on significant marine fauna (i.e. marine mammal, marine reptile, seabird, wild finfish and invertebrate populations).

The implementation of appropriate management and mitigation measures ensures the potential risks associated with provisioning of food and artificial habitats are low. Ongoing monitoring of the activity and populations of these species will ensure any impacts to populations of vulnerable species are further reduced. Compliance with the EMMP and the adoption of best-management practices will also ensure any impacts to marine mammals are minimised.

To reduce the risk to marine fauna [including endangered, threatened and protected (ETP) species] from the MWADZ Proposal, operators within the MWADZ will be required to develop and implement an individual Management and Environmental Monitoring Plan (MEMP) that corresponds to an overarching zone Environmental Monitoring and Management Plan (EMMP). The Department will support or endorse best-management practices for aquaculture and manage compliance around the MEMPs of individual operators, including mandatory reporting of interactions with ETP species. Failure to comply with the MEMP may result in suspension or cancellation of the aquaculture licence.

Several risk factors were identified in relation to seabirds, including: entanglement, habitat exclusion, disturbance from aquaculture activities, increased prey availability, creation of roosting sites, implications for foraging success; and spread of pathogens (Sagar 2008, 2013, Lloyd 2003, Comeau et al. 2009). Other than the risks associated with artificial light and stock feeds, all other risks to seabirds can be eliminated or significantly reduced through a range of management measures (Halfmoon Biosciences 2015).

The monitoring and management component of the EMMP is aimed at maintaining the integrity of Abrolhos seabird populations, with a focus on limiting potential interactions between increaser species and sea cage aquaculture (EMMP - Appendix 2).

A number of risk factors were identified for marine mammals and turtles relating to sea cage infrastructure, stock feeds, service vessels and the use of artificial lighting. The availability of supplementary feeds was identified as a significant risk factor, with potential to alter the natural feeding regimes of marine mammals and turtles. Other risk factors included physical presence of sea cages, anchor lines and the use of service vessels, all of which create potential for injury (or mortality) via collision and/or entanglement.

The monitoring and management component of the EMMP is aimed at protecting marine mammals and turtles by limiting potential interactions between vulnerable species and sea cage infrastructure (EMMP - Appendix 2). In the context of preventing interactions with marine mammals, particular consideration has been given to managing the risks associated with the physical presence of sea cage infrastructure, vessel movements and artificial light. Mitigation of risks will be undertaken using proactive and reactive management strategies.

The objective of wild finfish management is to minimise environmental and ecological risks to wild finfish populations, including sharks, rays and other finfish. ETP finfish species have been given special consideration. The primary residual risk was the presence of excess feed

pellets and dead or moribund stock attracting wild finfish to sea cage infrastructure to feed. The intent is to manage these attractants by reducing or preventing the:

- strength of signals that may attract wild finfish;
- opportunity for interactions between ETP species wild finfish and aquaculture;
- breaching of sea cage netting by sharks; and
- ecological impacts of such interactions.

The biosecurity management component of the EMMP is aimed at protecting wildlife, particularly wild finfish, from risks associated with pathogens, parasites, genetic pollution, and marine pests.

Compliance with the identified management and mitigation measures through MEMPs and the zone EMMP, that include best-practice management, should result in:

- significant reductions in levels of attractant signals to minimise the likelihood of marine fauna making contact with sea cages;
- significant reductions in opportunities for provisioning from aquaculture by marine fauna to prevent behavioural changes;
- use of anti-predator nets to deny marine fauna access to sea cages (a potential food source);
- use of mesh or netting of an appropriate mesh size (e.g. less than 60 millimetres in bar length), tear-resistant and tangle-resistant to minimise the probability of marine fauna becoming entangled in, or entrapped within, the sea cages; and
- tensioning of aquaculture infrastructure to eliminate the possibility of entanglement of marine fauna.

The potential contribution of aquaculture to mortality rates of marine fauna in the absence of management and mitigation measures could be significant when added to the other various pressures on individual species (particularly ETPs). However, while it is not possible to eliminate signals that could attract marine fauna to the sea cages, the likelihood of entanglement, and potential death, can be substantially reduced.

In summary, the proponent considers that the potential risks to marine fauna will be adequately managed such that proponents of future derived proposals will achieve the EPA's environmental objective by providing a high level of protection for marine fauna (EMMP - Appendix 2).

10 ASSESSMENT OF POTENTIAL IMPACT ON BIOSECURITY

10.1 Assessment Framework

While "biosecurity" is not, of itself, an environmental factor identified in the EPA's EAG 8 for the purpose of organising environmental information for environmental impact assessment, it has the potential to contribute in a significant way to factors other than simply the marine fauna factor specified in Section 2.3 of the ESD.

In relation to the MWADZ Proposal, biosecurity was recognised as the most significant potential risk associated with the proposal (refer to Appendix 4 - *Threat Identification,*

Hazard Pathway Analysis and Assessment of the Key Biosecurity Risks presented by the establishment of the Mid West Aquaculture Development Zone in Western Australia).

Consequently, biosecurity has been included as a separate section in this PER.

10.1.1 Environmental Objective

The environmental objective established in this for biosecurity is essentially that for marine fauna (as specified in EAG 8), namely:

> *"To maintain the diversity, geographic distribution and viability of fauna at the species and populations levels".*

However, noting the potential impacts on biosecurity may extend beyond fauna, the environmental objective for benthic communities and habitats (Section 8 of this PER) may also apply, namely:

> *"To maintain the structure, function, diversity, distribution and viability of benthic communities and habitats at local and regional scales".*

To give effect to these objectives, it is necessary to describe translocation, biosecurity and management arrangements addressing:

- fish disease/pathogen (including parasite) and marine pest management and incident response;
- strategies for preventing disease and pest outbreaks and/or preventative treatment chemicals to escape into the surrounding environment;
- brood stock and translocation issues; and
- prevention and management of escaped fish.

10.1.2 Relevant Legislation, Policies, Plans and Guidelines

10.1.2.1 State Protection

The Department is responsible for managing the State's finfish and invertebrate stocks and to ensure the long-term sustainability of these resources under the FRMA and the *Fish Resources Management Regulations 1995* (FRMR). The Department will transition to a new Act to replace the FRMA subject to its passage through Parliament and proclamation. The *Aquatic Resources Management Bill 2015* (ARMB) builds on key elements of the FRMA, but extends the provisions of the FRMA in a number of areas, including biosecurity. The timing of this transition is currently uncertain.

Part 6 of the proposed ARMB provides powers for the declaration of organisms, the establishment of biosecurity management plans and emergency powers to deal with biological threats. This will require the drafting of regulations to give legislative effect to the Department's existing biosecurity policy.[42] For this reason, some of the documents referred to in the biosecurity assessment section (and associated risk assessment at Appendix 4.) are

[42] Refer to http://www.fish.wa.gov.au/Documents/biosecurity/aquatic_biosecurity_policy.pdf

listed as biosecurity management arrangements. This is because the drafting of regulations to give effect to the ARMB's Part 6 powers are (at the time of writing) not yet finalised.

Table 10-1 outlines the policies, plans and guidelines that currently govern biosecurity management in Western Australia.

Table 10-1: Legislation, Policies, Plans, and Guidelines Relevant to Biosecurity - State

Legislation, Polices, Plans and Guidelines	Intent
State	
Environmental Protection Act 1986	This State Act provides for an EPA, for the prevention, control and abatement of pollution and environmental harm, and for the conservation, preservation, protection, enhancement and management of the environment.
Fisheries Resources Management Act 1994	Provides a legal framework to conserve, develop, and share fish resources for the benefit of current and future populations in WA. This legislation also provides the management framework for the Abrolhos Islands reserve and for the establishment and management of the Fish Habitat Protection Areas.
Department of Fisheries: *Biofouling Biosecurity Policy*	Focus on prevention of introducing marine pests via vessel and equipment biofouling through the key principles of: • prevention • least-restrictive measures • risk-based resource allocation • shared responsibility
Department of Fisheries Guidance Statement: *In-water treatment of vessels in Western Australian waters*	The Western Australia, the in-water cleaning guidelines are a tool to assist in managing vessel hygiene while also meeting the minimum endorsed standard for any prospective in-water treatment systems and specific vessel cleans. (Note: these guidelines dovetail with the Commonwealth *Anti-fouling and In-water Cleaning Guidelines* mentioned below).
ACWA: *Environmental Code of Practice*	Seven species-specific codes designed to assist the continued improvement of industry profitability, environmental performance and community relations through the adoption of environmental management systems and environmental Codes of Practice.
Department of Fisheries Guidance Statement: *Management and Environment Monitoring Plans (MEMP)*	Biosecurity to be addressed as a component of the MEMP.
Conditions associated with the Aquaculture Licence	1. Regulation 69 of the Fish Resources Management Regulations 1995 prescribes *inter alia* certain obligations relating to disease biosecurity that will apply to the holder of the Aquaculture Licence. 2. Section 95 of the FRMA provides for conditions relating to biosecurity to be placed on the Aquaculture Licence.
Department of Fisheries: *Houtman Abrolhos Islands Management Plan*	The Abrolhos Islands Reserve and the associated Fish Habitat Protection Area (FHPA) to be managed in accordance with the Department of Fisheries' vision for these reserves, namely: *To conserve and promote the unique cultural and environmental heritage values of the Abrolhos for the benefit of present and future generations.*
Department of Fisheries: *Western Australian Prevention List for Introduced Marine Pests*	Listing of Introduced Marine Pests (IMP) that either are: • present on national pest lists; or

	• of concern to the protection of Western Australian waters.
Department of Fisheries: *Noxious Fish List*	Lists those species banned from being brought into, or have possession of within, Western Australian under Schedule 5 of the FRMA.
Department of Fisheries: *Policy for managing translocations of live fish into and out of Western Australia*	To protect and conserve fish populations, fish habitats and natural aquatic biodiversity in Western Australia by minimising the risks associated with the translocation of live fish.
Department of Fisheries: *Guidelines for Streamlined Translocation Approval for Commercial Aquaculture*	Guidelines for applying for translocation approval for moving live fish (finfish, crustaceans, algae, shellfish or any other aquatic organism), including a streamlined process for "white list" species.
Environmental Assessment Guidelines (EAG)	
Environmental Assessment Guidelines No.8 (EAG 8) Environmental Assessment Guideline for Environmental Principles, Factors and Objectives (EPA 2015)	The EAG 8 provides guidance for proponents to help them understand the need to consider environmental principles, factors and objectives for the purpose of environmental impact assessment. Environmental principles, factors and objectives are critical to the environmental impact assessment process as they underpin the EPA's decision on the environmental acceptability of a proposal or scheme. In making its decisions, the EPA also takes a holistic approach to assessing environmental acceptability based on a number of broader considerations including whether the proposal aligns with broader international, national and State policies and agreements and takes account of the interconnected nature of the environment.

10.1.2.2 Commonwealth Protection

The Commonwealth legislation that protects the threatened, endangered and protected species is the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The EPBC Act provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places defined in the Act as matters of national environmental significance (Department of the Environment, 2013).

A new Commonwealth *Biosecurity Act 2015*, which will commence in June 2016, replaces the existing *Quarantine Act 1908*. This will become the primary biosecurity legislation for Australia at the national level. (Note that regulation of biofouling is currently only at the State level).

Table 10-2: Legislation, Policies, Plans, and Guidelines Relevant to Biosecurity - Commonwealth

Legislation, Polices, Plans and Guidelines	Intent
Commonwealth	
National Biofouling Management Guidelines for the Aquaculture Industry	Provide recommended approaches for control of biofouling to minimise the spread of exotic species associated with moving aquaculture stock and equipment. These guidelines provide practical management options that can: • reduce the risk of marine pest infestations; • reduce the costs associated with managing an incursion or with quarantine measures if a marine pest is discovered; and • reduce the possible translocation of a marine pest.
National Biofouling Management	These guidelines provide commercial fishing vessel operators with

Guidelines for Commercial Fishing Vessels	tools to minimise the amount of biofouling accumulating on their vessels and thereby to minimise the risk of spreading marine pests around the Australian coastline.
Anti-fouling and In-water Cleaning Guidelines	The guidelines are divided into two parts and address: • the application, maintenance, removal and disposal of anti-fouling coatings at shore-based maintenance facilities; and • in-water cleaning.
AQUAVETPLAN and AQUAVETPLAN Manuals	The Australian Aquatic Veterinary Emergency Plan and associated manuals is a series of working documents that are designed to provide guidance in the event of a disease outbreak for specific pathogens and situations. These are updated as required.[43]

10.2 Existing Environment

A broad overview of the existing environment is described in Section 3 of this PER document.

10.2.1 Introduced Marine Pests

The introduction of marine pests can create significant economic, social, environmental and biological costs to Western Australia (Bridgwood and McDonald, 2014). Invasive species tend to have characteristics that allow them to quickly adapt to their environment and reproduce at a rate that can out-compete native species. The typical management goal is to prevent invasive marine pests from incurring, as once established they are extremely difficult and expensive to eradicate (Bridgwood and McDonald, 2014).

There have been at least four Introduced Marine Pest (IMP) surveys conducted in the Port of Geraldton (Bridgwood and McDonald, 2014). The Geraldton Port is notable because it is the closest commercial port to the Houtman Abrolhos Islands and is at high risk of IMP introduction due to the high number of vessel movements in this area (Bridgwood and McDonald, 2014).

The Commercial Boat Harbour supplies vessels to support trade for the resources industry, with biofouling from slow-moving barges noted as being the major vector for the transfer of IMPs (Commonwealth of Australia, 2010). The Port of Geraldton is also at risk from domestic infection, for example from Fremantle and Kwinana Ports, based on both the number of vessels that transit between these three ports (Bridgwood and McDonald, 2014).

In 2013, the Department of Fisheries conducted IMP monitoring in all three parts of the Port of Geraldton - the Fishing Boat Harbour, the Batavia Coast Boat Harbour and the Commercial Boat Harbour (Hourston, M 2013). This monitoring recorded one IMP species, *Didemnum perlucidum*, which is listed on the National System target list and has a detectable population size in the Batavia Coast Boat Harbour. Repeat monitoring in 2015 again detected *D. perlucidum* but no other IMP species (C. Astbury pers. comm.).

Biofouling and ballast water are the two main vectors for IMPs, both in Australia and internationally (Commonwealth of Australia, 2010). Indeed, in aquaculture and fisheries, it is predominantly biofouling that has resulted in inadvertent transfer of species (Commonwealth

[43] Refer to http://www.agriculture.gov.au/animal/aquatic/aquavetplan.

of Australia, 2010). Aquaculture involves deployment of artificial structures into the water, and movement of those structures and stock between locations.
These novel surfaces can then be rapidly colonised by biofouling species, thus creating opportunities for IMPs to establish in the area. This is how aquaculture and fisheries industries remain a risk of inadvertent transfer of IMPs. However, adopting best-practice to manage biosecurity risks will restrict the likelihood of transfer of IMPs (Commonwealth of Australia, 2010).

In Western Australia, the Aquaculture Council of Western Australia (ACWA) has developed a number of codes of practice including the *Environmental Code of Practice for the Sustainable Management of Western Australia's Marine Finfish Aquaculture Industry 2013*. Although voluntary, the adoption of these codes is strongly encouraged by both ACWA and the Department. Further information on the Environmental Codes of Practice (ECOPs) can be accessed from http://www.aquaculturecouncilwa.com.au.

10.2.2 Aquatic Diseases

Aquaculture production has substantially increased on both an international and national scale. In South Australia, marine finfish aquaculture production has increased from $87 million in 1997/98 to $261 million in 2001/02 (de Jong and Tanner, 2004). With this increase in value and the associated increase in international trade (translating to increased movement of live aquatic animals) has come a heightened risk of introducing pathogens and pests into the environment (Oidtmann et al, 2011).

One of the key concerns associated with sea cage-cultured fish is controlling the spread of native or exotic pathogens from cultured fish to wild populations (Terlezzi et al, 2012). As yet, there have been no documented cases of exotic pathogens in Australia (de Jong and Tanner, 2004). However, on an international scale, there are cases where exotic diseases are thought to have passed from cultured stock to wild fish, with potentially significant repercussions for those wild stocks (Heggberget et al, 1993).

Internationally, documented cases where aquaculture has been implicated in infecting wild populations include *Gyrodactylus salaris* in wild salmon stocks in Norway (Heggberget et al, 1993) and infectious hematopoietic necrosis introduction in Japan via infected sockeye salmon eggs causing significant mortalities in three species of salmon (McDaniel et al, 1994; Waknitz et al, 2003).

In Australia, a number of native nodaviruses have the potential to cause major problems in finfish aquaculture. Nodaviruses have been reported in both wild and cultured finfish indicating that there is the potential to spread any outbreaks between stocks (Barke et al, 2002). Marine white spot is another potential disease. Being an obligatory parasite, it requires a host to survive. The best way to address white spot is to prevent it entering stock in the first place. Therefore, in high-density stocking arrangements, it has the potential to transfer quickly from fish to fish. Maintaining stringent biosecurity and husbandry practices are vital to prevent the spread of such pathogens.

In addition, aquaculture feeds have been implicated in the introduction of disease in turbot (Munro, 1996) and the disease epidemic in wild pilchards off the coast of Western Australia (Jones et al, 1997); although there is no definitive proof in the case of the latter.

10.3 Potential Impacts

Under its Ecosystem-Based Management Framework, the Department applies a qualitative risk assessment methodology to filter the different types of ecological issues (Fletcher, R.J., 2014).[44] The Department's risk assessment methodology is based on a consequence/likelihood matrix that is applied during the risk evaluation step. This step identifies the threats and hazard pathways and identifies management controls that can be implemented to affect the risk rating. Such risk assessments aim to make decisions about which risks need treatment, the degree required and the priority level (Fletcher, R.J., 2014)

The Department prepared a "*Threat Identification, Hazard Pathway Analysis and Assessment of the Key Biosecurity Risks presented by the establishment of the Mid West Aquaculture Development Zone in Western Australia*" (Biosecurity Risk Assessment or BRA) document (refer to Appendix 4). This assessment drew on a number of previously conducted generic aquaculture risk assessments including:

- Marine Finfish Environmental Risk Assessment (de Jong and Tanner, FRDC Project 2003/223)
- National ESD Reporting Framework: The "How to" Guide for Aquaculture. Version 1.1 FRDC, Canberra, Australia (Fletcher et al, 2004)
- Finfish Aquaculture in Western Australia: Final ESD Risk Assessment Report for Sea-Cage and Land-Based Finfish Aquaculture (Vom Berg, 2008; Fisheries Management Paper No 229, Department of Fisheries, Western Australia)
- Finfish Aquaculture in Western Australia: Final ESD management Report for Marine Finfish Aquaculture (Vom Berg 2009; 2008; Fisheries Management Paper No 233, Department of Fisheries, Western Australia).

The BRA used these previous reports as a basis to identify the three primary biosecurity risks that the proposed MWADZ could pose on the surrounding environment. These risks were that:

1. A significant pathogen or disease is spread from an infected aquaculture facility leading to a significant impact on wild target fisheries based around the same or alternate species.

2. Escaped fish lead to a significant impact on the future sustainability of wild stocks through either competitive interaction or genetic mixing.

3. The introduction and/or spread of marine pests in association with aquaculture activity have a significant impact on the sustainability of local ecosystems.

This risk assessment focussed only on the ecological risk and did not consider economic concerns. Each risk was associated with a number of Hazards or Hazard Pathways (see Section 2 of the BRA for a description of the methodology used).

[44] Refer to http://www.fisheries-esd.com/a/pdf/Fletcher%20et%20al%20EBFM%20framework.pdf

10.4 Assessment of Potential Impacts

10.4.1 Risk 1

RISK 1: *Significant pathogen or disease is spread from an infected aquaculture facility leading to a significant impact on wild targeted fisheries based around the same or alternate species*

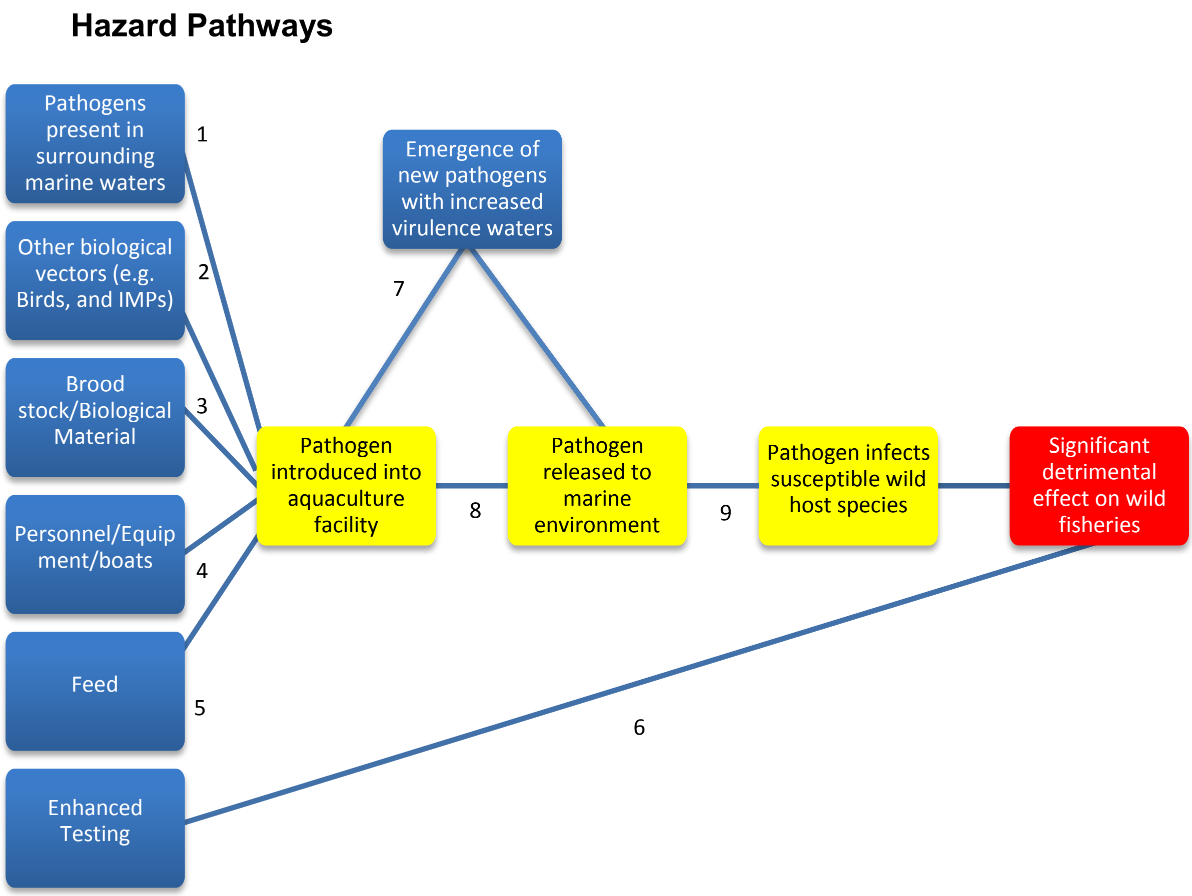

Figure 10-1: Compendium Map of Potential Pathways Leading to a Pathogen Introduction and Potential Disease Outbreak in an MWADZ Aquaculture Facility that may lead to Potential Spread of Disease to Wild Fisheries and Subsequent Significant Impact. Numbers refer to hazard pathways.

10.4.1.1 Pathogens Present in Surrounding Marine Waters

Open sea cage aquaculture (such as that proposed in the MWADZ) exposes cultured species during grow-out to a variety of potential pathogens that are present in the marine environment (reviewed by Lafferty *et al.* 2015). While every effort, using good husbandry techniques and ensuring high health status in hatcheries, can be made to ensure fish are disease free when entering cages, studies have shown that sea water can contain viral particles in the order of 10^7 per mL (Suttle *et al.* 2005). Additionally, wild stock and cultured fish of the same species are likely to share similar profiles of potential susceptibility to pathogens.

Little is known about the transmission of pathogens and disease between cultured and wild stock fish, or between fish and non-fish (de Jong and Tanner, 2004). However, it is recognised that while pathogens and disease naturally occurring in wild stocks may be quite benign, they may cause significant issues for cultured fish (Department of Fisheries, 2015). This is because wild fish have often co-evolved with the pathogen/disease in such a way as to co-exist.

When such a pathogen/disease is introduced into an aquaculture facility, it is presented with a different opportunity (i.e. a different set of selection pressures) that favour rapid evolution combined with lack of wild population constraints on host abundance and can result in strains that cause significant mortality in cultured fish (Einer-Jensen *et al.* 2004). (Refer to the BRA.) Potentially, such new pathogen/disease strains could then be re-introduced into the environment.

Biofouling on aquaculture infrastructure also has the potential to act as a reservoir for pathogens. For example, there is evidence that amoebic gill disease was harboured on sea cages in the Tasmanian Atlantic salmon fisheries (Tan *et al.* 2002 SA risk assessment). However, this particular disease is found free-living within the aquatic environment and there is a need for further research on the transmissions of disease between culture and wild populations (de Jong and Tanner, 2004).

10.4.1.2 Other Biological Vectors

Many pathogens have several vectors, or hosts, with birds in particular having been implicated in the spread of some pathogens (McAllister and Owens, 1992). It is known that bird parasite lifecycle often has an intermediate parasitic phase within fish (Barber, 2003 SA risk assessment). Transfer to the ultimate host is usually via ingestion and possible through the stocking of fingerlings (rather than large adults) in sea cages.

10.4.1.3 Brood Stock/Biological Material

The accidental introduction of disease to Western Australia via translocation of live fish for aquaculture from brood stock facilities is a concern for industry and the environment, particularly given the State's relatively disease free status (Thorne, 2002). Two main risks have been identified for translocation; namely the introduction of:

- exotic disease/pathogens; and
- exotic organisms (i.e. IMPs) (de Jong and Tanner, 2004).

Importation of aquarium fish species has previously been responsible for introducing diseases such as the goldfish ulcer disease (*Aeromonas salmonicidai*) which has the potential to spread to salmonids (including Atlantic salmon) (Carson and Handlinger, 1988; Whittington and Cullis, 1988 and de Jong and Tanner, 2004). Although these aquarium species are not cultured in sea cages, this demonstrates the risks associated with translocation (de Jong and Tanner, 2004). There is also some evidence to suggest that there is a greater risk of translocating native fish within their natural distribution, as any pathogen would be capable of surviving in wild populations that may not have had previous exposure (Langdon, 1989).

Although less well understood, there is evidence that IMPs can be imported with brood stock and/or biological material. For example, the implied origin of invasive *Codium fragile fragile* in Australia is importation with Pacific oysters as, along with *Grateloupia turuturu*, first records are from around Bicheno in eastern Tasmania [pers. comm. Lewis, J (July 2015)]. Organisms such as *Codium* are particularly difficult to eradicate once present as, being essentially a single-celled plant, they are capable of re-growing from a single filament.

10.4.1.4 Personnel/Equipment/Boats

A pathogen may spread through personnel, equipment and boats if it is present:

- in the immediate environment; or
- on the equipment itself (Snow, BRA).

This is considered most likely if equipment or infrastructure is shared between facilities (such as boats moving between farms) or imported/re-used equipment. Through comprehensive epidemiological studies, divers, boats and equipment have all been implicated in the spread of infections such as salmon anaemia virus between marine aquaculture sites (Jarp and Karlsen, 1997).

Biofouling is not only the leading way in which marine species (including IMPs) are transported by humans, but also one of the oldest mechanisms (DAFF, vectors paper). This biofouling can occur on vessels and infrastructure associated with marine operations such as barges, ropes, cages, floats and nets (Fitridge, *et al.* 2012).

Given the presence of *D. perlucidum* in the Batavia Boat Harbour at the Geraldton Port, and at pearling aquaculture leases within the Houtman Abrolhos Islands, movement of vessels between aquaculture facilities and in and out the Geraldton Port have the potential to spread IMPs.

10.4.1.5 Feed

Pellets tend to be the main source of feed for sea cage facilities, consisting predominantly of fishmeal and fish oil from international baitfish wild catch fisheries (de Jong and Tanner, 2004). These imported feeds have been identified as one of the more likely sources for introducing pathogens (Baldock, 1999).

Marine finfish aquaculture is dependent on high-quality brood stock conditioning feeds, especially in the early development stages of new aquaculture species. Beyond the sustainability and general environmental concerns, such feeds have been implicated in the introduction of disease into aquaculture facilities and surrounding wild catch populations (Munro, 1996; Jones *et al.* 1997).

10.4.1.6 Enhanced Testing

The expanding aquaculture industry and focus on good husbandry and management practices, have resulted in enhanced testing regimes that provide increased knowledge about the presence of disease in a geographic range. Largely, such an increase in the testing regimes is a positive outcome of the aquaculture industry, particularly given the greater understanding of how health conditions potentially affect wild fish in the wider ecosystem.

Australia is fortunate to the extent that it has a high biosecurity status and reputation. However, increased testing has the potential to highlight health issues and diseases not previously considered of concern. This may lead to a negative perception in the global trade context both for aquaculture and more broadly for wild catch fisheries.

10.4.2 Risk 2

RISK 2: *Escaped fish lead to a significant impact on the sustainability of wild stocks through either competitive interaction or genetic mixing*

Hazard Pathways

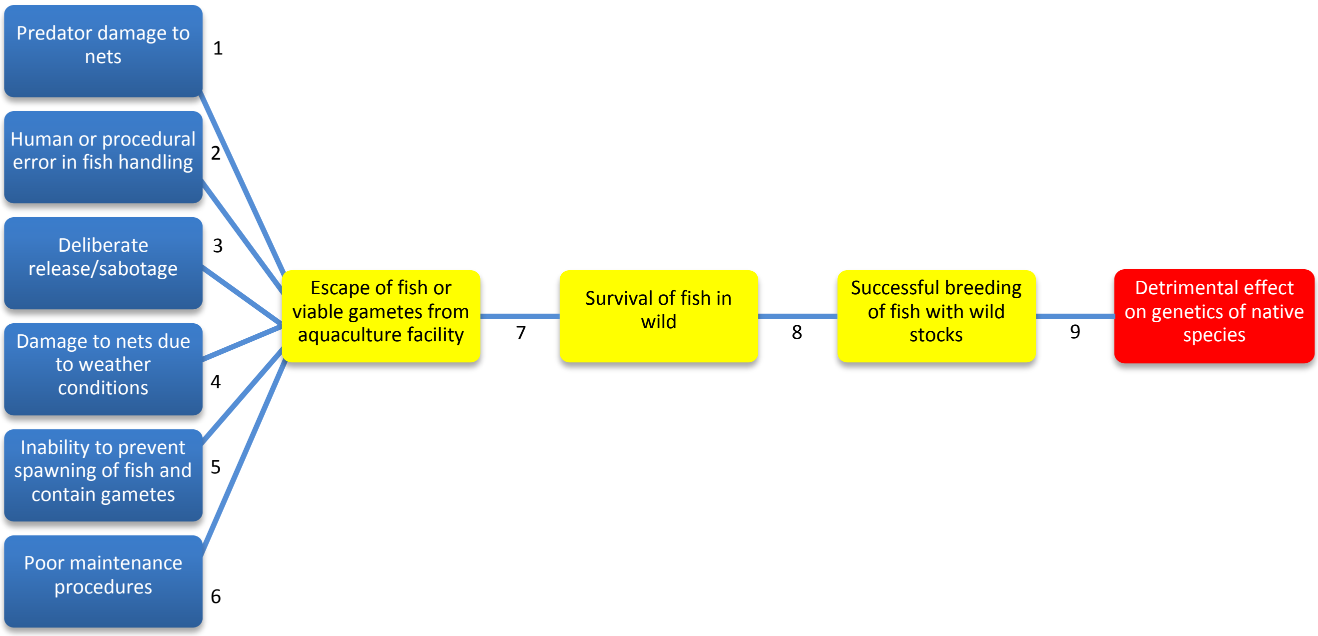

Figure 10-2: Compendium Map of Potential Pathways leading to Potential Negative Genetic Effects on Wild Fisheries arising from a Potential MWADZ Aquaculture Facility that May Lead to Subsequent Significant Impact. Numbers refer to hazard pathways.

10.4.2.1 Stock Escapes

Escape of cultured fish species from marine sea cages is probably unavoidable (Waples *et al.* 2012). However, the consequence (and frequency) of such escapes can be reduced through the implementation of a number management measures (discussed in "Management Measures" below).

There are numerous mechanisms by which escapes from sea cages occur (e.g. net failure caused by predator attack, storms, vandalism and wear). The environmental risks associated with escapees include:

- competition with wild stocks for food and space;
- genetic alteration or degradation of wild stocks;
- spread of pathogens/disease; and

- establishment of feral populations. (PIRSA, 2003d).

The consequence of these escapes is ultimately determined by the volume of escaped fish, coupled with their ability to compete in the wild.

The ecological and genetic impacts of escapees and the mechanisms by which the level of impacts are determined are poorly understood. However, even at the current levels of global aquaculture production such escapes present a problem for the long term sustainability of the aquaculture industry (Naylor *et al.* 2005).

The risk of escape through spawning is increased where a species matures relatively quickly. This risk is further highlighted where the cultured fish are in the known range of native fish of the same species. This would mean that a significant release of viable eggs could put the development of those cultured fish eggs on par with native fish eggs. It also follows that survival of larval fish from aquaculture would be on the same scale as the native individuals.

Successful spawning of escaped fish from both within and external to their native range has been documented in farmed salmon (reviewed by Weir and Grant, 2005). However, spawning success was reduced possibly due to the high level of domestication in farmed salmon. Given that the aquaculture industry in Western Australia is still in its infancy, it is likely that the level of spawning success of species such as the early-maturing yellowtail kingfish could be higher.

10.4.3 Risk 3

RISK 3: *The introduction and/or spread of marine pests associated with aquaculture activity have a significant impact on the sustainability of local and/or regional ecosystems.*

Hazard Pathways

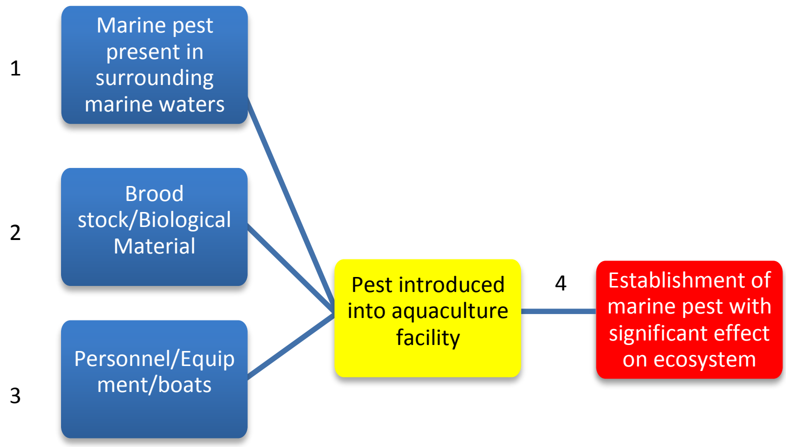

Figure 10-3: Compendium Map of Potential Pathways leading to Marine Pest-Associated Impacts arising from a Potential MWADZ Aquaculture Facility that May Lead to Subsequent Significant Loss. Numbers refer to hazard pathways.

10.4.3.1 Marine Pest Present in Surrounding Waters

The Houtman Abrolhos Islands are already known to have *Didemnum perlucidum* on aquaculture infrastructure associated with pearl farms. The original source of the pest is unknown; however, it is likely that it was introduced via infested vessels visiting the area. *D. perlucidum* is widely distributed around the State and could have been moved to the island via vessels and or equipment from a number of locations (V. Aitken pers. comm.).

The impact of IMPs can be difficult to predict. For example, *D. perlucidum* has largely been restricted to fouling artificial surfaces such as aquaculture or port infrastructure. While mostly restricted in its distribution to disturbed or artificial habitat, it has been recorded in the Swan River, where negative impacts such as overgrowing seagrass has been observed (Simpson, C pers. comm.). *D. perlucidum* has also been observed on coral reefs in the Northern Territory (M Barton, pers. comm.).

10.4.3.2 Brood Stock/Biological Material

This hazard is addressed in sub-section 10.4.1.3.

10.4.3.3 Personnel/Equipment/Boats

This hazard is addressed in sub-section 10.4.1.4.

10.4.3.4 Effect of Introduced Marine Pests on Habitat and Ecosystem

IMPs can have significant impacts on ecosystems and the commercial viability of dependent fisheries. By their nature, IMPs establish readily in appropriate receiving environments, although the risk of establishment and impact is species-dependent. Once established, IMPs are often difficult or impossible to eradicate.

Internationally, examples exist of the detrimental impacts following introductions of seemingly innocuous species. Such an example is the introduction of North American comb jelly into the Black Sea. This resulted in the collapse of pelagic commercial fisheries.

In Australia, the introduction of the Pacific sea star (*Asterias amurensis*) into Tasmania and subsequently into Port Philip Bay poses a very real threat to the viability of mariculture operations as well as wild capture shellfish fisheries in the area. This is due to its rapid population growth and diet of mussels, scallops and clams.

Biofouling species are also known to cause significant problems, particularly when they occupy the same ecological niche. For example, the Asian paddle crab is a very aggressive swimming crab that not only has the potential to outcompete native species but is also known to pose a threat to aquaculture species (New Zealand Government, 2013). Asian paddle crabs are known to travel extensive distances as larvae and are capable swimmers as adults. Human activities, including marine farming, are considered a potential vector for the spread of species. While not currently established in Australia, recent records have found several of these crabs within the Swan River.

10.5 Management Measures

A summary of the proposed management measures associated with the MWADZ Proposal is detailed below.

RISK 1: *Significant pathogen or disease is spread from an infected aquaculture facility leading to a significant impact on wild targeted fisheries based around the same or alternate species*

In order to realise this risk, one or more of the hazard pathways identified in Figure 10-1 must result in the introduction of a potentially significant pathogen into the proposed MWADZ. The pathogen present on the farm must then be exported from the facility at sufficient levels, and come into contact with susceptible wild stocks and successfully infect these susceptible stocks, resulting in disease occurrence. The resulting disease must have a significant impact on wild stocks of fisheries which they support.

There is a number of management measures in place that reduce the likelihood of one or more of the hazard pathways identified leading to the introduction and spread of a significant pathogen or disease from an infected aquaculture facility subsequently impacting on wild fisheries (Table 10-3).

It is in the interest of the State to support development of a sustainable aquaculture industry in the MWADZ through implementation of biosecurity control measures aimed at:

- preventing introduction and emergence of disease onto a farm;
- ensuring effective early detection and containment of significant pathogens; and
- preventing their release into the environment.

Table 10-3: Management Measures to Address Risk 1

Risk	Inherent Risk (no management measures)	Management measures	Residual Risk (based on implementation of identified management measures)
1. Significant pathogen or disease is spread from an infected aquaculture facility leading to a significant impact on wild targeted fisheries based around the same or alternate species.	Moderate (8)	Existing Policy/Plans & Guidelines: • s.92 FRMA/MEMP; • Licence Condition; • EMMP; • Aquatic Biosecurity Policy; • Biofouling Policy; • Translocation Policy; and • ACWA Environmental Codes of Practice. Key Management strategies that could be or (as part of the above) are applied: a. Measures to promote high level of fish welfare and husbandry both through education and regulatory measures ;	Low (4)

Risk	Inherent Risk (no management measures)	Management measures	Residual Risk (based on implementation of identified management measures)
		b. Use of pathogen free brood stock and exclusion of known significant pathogens through a program of sensitive brood stock screening; c. Health testing of stock prior to translocation to sea cages; d. Exclusion devices for predators including birds, appropriate sea cage design; e. Only commercial pelleted food to be used; f. Feed approved by AQIS or complies with ISO 900 1:2008; g. Controlled communication plans and research to extend knowledge around pathogens/disease vectors; h. Limit pressure from pathogens through regular cleaning and exchange of nets i. Implementation (as required in the MEMP) of appropriate and timely disease treatment regime for endemic diseases; and j. Consideration of vaccine treatments to reduce effects of opportunistic or ubiquitous pathogens.	

RISK 2: *Escaped fish lead to a significant impact on the sustainability of wild stocks through either competitive interaction or genetic mixing.*

While escapes associated with sea-case based aquaculture are considered almost inevitable, significant advances have been made in understanding the cause of these escapes and thus developing improved management strategies aimed at limiting their occurrence.

Given weather patterns in Western Australia, the relative exposure of offshore aquaculture operations in the MWADZ and the biology of the species under consideration, the likelihood of escaped fish having an impact to sustainability of wild stocks is linked to the magnitude and frequency of escape events in addition to the size of fish escaping. Evidence does exist to indicate that escaped yellowtail kingfish can survive in the wild (Fowler *et al.* 2003) and where such species are cultured within their natural range, the potential for interaction between wild and cultured fish may also be high as has been demonstrated in Spencer Gulf, South Australia (Fowler *et al.* 2003).

Fish escaping at larger sizes would generally have become adapted to aquaculture conditions and may remain near cages subsequent to escape events, or exhibit modified behaviours which may limit the likelihood of direct interaction with wild stocks. In support of this, Fowler *et al.* (2003) demonstrated that a population of fish in the northern Spencer Gulf region, identified as being of cultured origin, had apparently different opportunistic and reduced foraging behaviours compared to wild fish.

The likelihood of escapes leading to an impact on sustainability of wild stocks is also influenced by the degree of domestication of the aquaculture stock in question.

Higher degrees of domestication and genetic selection in favour of properties considered conducive to aquaculture production (e.g. high growth rates) can lead to a stock which has significantly different genetic and phenotypic characteristics from its parent population. The likelihood of escapee fish impacting sustainability of local wild fish populations can be reduced by limiting the degree of genetic differentiation of the cultured stock from its wild fish siblings. This could be managed by maintaining a strategy of hatchery production of F1 generation stock based on locally sourced brood stock. If marine finfish proposed for culture are all F1 generation, significant genetic selection is unlikely to have occurred and thus the potential for their escape and interaction with wild fish to lead to detrimental effects would be low.

The likelihood that escaped fish lead to a significant impact on the future sustainability of wild stocks through either competitive interaction or genetic mixing may be reduced through the introduction of measures aimed at reducing the frequency and magnitude of escape events.

Table 10-4 below shows the inherent risk level (i.e. with no management measures), summarises the existing policy/plans and guidelines and key management strategies that could be applied to that risk, and finally the residual risk of the threat based on implementation of management measures.

Table 10-4: Management Measures to Address Risk 2

Risk	Inherent Risk (no management measures)	Management measures	Residual Risk (based on implementation of identified management measures)
2. Escaped fish lead to a significant impact on the sustainability of wild stocks through either competitive interaction or genetic mixing.	Moderate (6)	Existing Policy/Plans and Guidelines: • FRMA s.92A/MEMP; • Licence conditions; • Translocation Policy; • Reporting and compliance inspections; and • ACWA Environmental Codes of Practice. Key Management strategies that could be or (as part of the above) are applied: a. Mandatory reporting of all escape events; b. Conduct mandatory technical assessments to determine causes of serious escapes; c. Establishment of a mechanism to analyse and learn from mandatory reporting; d. Technical standards for sea cage aquaculture equipment – with an independent mechanism to enforce the standard; e. Mandatory training of staff in escape-critical operations and techniques; f. Locating sea cages within appropriately sheltered area; g. Maintenance of good husbandry practices; and h. Installation of anti-predator devices and site	Low (4)

		security.	

RISK 3: The introduction and/or spread of marine pests associated with aquaculture activity have a significant impact on the sustainability of local and/or regional ecosystems.

It is more likely that the MWADZ Proposal might play a role in spreading pests already present in the State than be directly responsible for the import of new pest species. In particular, *Didemnum pelucidum* is known to be present on aquaculture infrastructure in existing facilities within the Houtman Abrolhos Islands Fish Habitat Protection Area.

The infrastructure associated with the MWADZ Proposal may represent a new opportunity for the establishment of marine biofouling organisms. Associated vessel movements may also present a vector for subsequent dispersal.
The prevention and control of IMPs in the proposed MWADZ is, therefore, of great importance given that the risk assessment shows that habitat dynamics and ecosystem function have the potential to be fundamentally altered by high levels of IMP abundance.

The likelihood of significant impact from marine pest species is dependent on the degree of biosecurity management associated with facilities within the proposed MWADZ. Table 10-5 below shows the inherent risk level (i.e. with no management measures), summarises the existing policy/plans and guidelines and key management strategies that could be applied to that risk, and finally the residual risk of the threat based on implementation of management measures.

Table 10-5: Management Measures to Address Risk 3

Risk	Inherent Risk (no management measures)	Management measures	Residual Risk (based on implementation of identified management measures)
3. The introduction and/or spread of marine pests associated with aquaculture activity have a significant impact on the sustainability of local and/or regional ecosystems.	High (9)	Existing Policy/Plans and Guidelines: • FRMA s.92A/MEMP; • FRMA Part 9 – Noxious fish • FRMR Reg. 176 • Licence Conditions; • Biosecurity Policy; • EMMP; • Translocation Policy; • Biofouling Policy; • Anti-fouling and In-water Cleaning Guidelines; and • ACWA Environmental Codes of Practice. Key Management strategies that could be or (as part of the above) are applied: a. State-wide monitoring program for the early detection of marine pests at high risk ports in Western Australia (in this case particularly Geraldton);	Moderate (6)

Risk	Inherent Risk (no management measures)	Management measures	Residual Risk (based on implementation of identified management measures)
		b. Development of a monitoring regime based on a recognised and agreed national surveillance system supported by a research program (potentially incorporated into the monitoring section of the MEMP); c. Freezing of non-commercial pellet feed to kill any marine pests; d. Consideration given to an industry based biosecurity specific Code of Practice; e. Development of protocols for farm management practices (e.g. pest monitoring); and f. Compulsory reporting of marine pests.	

10.6 Predicted Environmental Outcome

Overall, the MWADZ Proposal is likely to pose a low to moderate biosecurity risk. The potential impacts posed by MWADZ Proposal can be effectively managed through implementation and compliance with the range of biosecurity legislative, policy and guidelines; either currently in existence or that will be enacted as a result of biosecurity powers conferred by the ARMA.

RISK 1: Significant pathogen or disease is spread from an infected aquaculture facility leading to a significant impact on wild targeted fisheries based around the same or alternate species

There is a threat to wild catch fisheries and aquatic ecosystems from pathogens and/or disease. For this reason the inherent risk associated with the potential spread is likely for any marine aquaculture development to be at least moderate to high. However, perhaps in part due to the seriousness of the threat (and the lack of certainty around the transmission of pathogen/disease between cultured and wild stock fish); a suite of effective management measures is in place.

The level of risk associated with pathogens/disease causing significant impact to wild stocks in the MWADZ can be reduced from moderate to low by applying appropriate management measures. This is largely due to the ability to establish controls over the major known pathways for the introduction of pathogens into farms and the development of protocols to rapidly detect and control emerging disease issues.

In line with the risk assessment, the low risk rating suggests current or planned management/control measures are adequate in reducing levels of identified risk to an acceptable level.

RISK 2: Escaped fish lead to a significant impact on the sustainability of wild stocks through either competitive interaction or genetic mixing

Escapes are almost an inevitable occurrence of sea cage aquaculture associated with equipment failure, extreme weather or predator damage (Jensen *et al.* 2010). The magnitude, frequency and fish size all change the relative consequences of such escapes, particularly in the context of fish that are cultured in their natural range (Snow, BRA).

The level of risk associated with fish escape in the proposed MWADZ causing significant impact to wild stocks can be reduced from moderate to low by applying appropriate management measures that reduce frequency and magnitude of escapes.
Under current proposed aquaculture scenarios, a significant impact on the future sustainability of wild stocks through either competitive interaction or genetic mixing is considered unlikely.

In line with the risk assessment, the low risk rating suggests current or planned management/control measures are adequate in reducing levels of identified risk to an acceptable level.

RISK 3: The introduction and/or spread of marine pests associated with aquaculture activity have a significant impact on the sustainability of local and/or regional ecosystems.

In some cases the presence of a marine pest causes little to no impact. However, given appropriate conditions and a pest with the appropriate biological characteristics, the outcomes can be catastrophic for the environment. This means the consequence remains high even though the risk is low, giving rise to a moderate rather than low risk. Despite this, under current proposed aquaculture scenarios a significant impact to regional habitats and ecosystems as a result of introduction or spread of high-risk marine pests remains unlikely.

The level of risk associated with marine pests causing significant impact to regional habitats and ecosystems can be reduced from high to moderate by applying appropriate management measures. The reason the risk level remains moderate is due to the unpredictable nature of marine pest incursions. In line with the risk assessment the moderate risk rating suggests current or planned management/control measures are adequate in reducing levels of identified risk to an acceptable level.

The Department, as Zone Manager for the proposed MWADZ, understands that a multi-tiered approach to address current and future vulnerabilities for aquaculture biosecurity, as well as the sustainable development of the aquaculture industry, is in the best interest of the State. Biosecurity is of concern not only to regulators and environmental organisations but also to farm operators. The spread of an IMP and/or pathogen/disease through aquaculture operations has the potential to affect not only the environment but also the reputation of individual lease holders and the industry as a whole (Fitridge, *et al.* 2112).

The current aquaculture specific management measures, including MEMPs and licence conditions, have mandatory biosecurity arrangements. However, as part of the Department's overall regulatory changes associated with the ARMB, a number of potential measures for increasing the strength of biosecurity arrangements are being considered. At the time of writing these arrangements have not been finalised, but potentially include:

- a single repository that is publicly available for all biosecurity documents;
- a review of the MEMP/licence arrangements that references key biosecurity documents to assist in consistency and transparency;
- standard protocols and arrangements for biosecurity management, emergency response and disease mitigation in areas where facilities have the potential to interact with one another; and
- biosecurity regulations under Part 6 of the ARMA, including vessel cleaning and bio-fouling practices.

It is also important to acknowledge the contribution of industry in the development of best-practice codes and guidelines and, where possible, strongly encourage the adoption of these. This can be done in conjunction with, or perhaps as a requirement of, more formal legislative arrangements.

Given both the current and proposed biosecurity management measures, the MWADZ Proposal presents a low-moderate risk to the surrounding aquatic environment.

11 ASSESSMENT OF POTENTIAL IMPACT ON FISHERIES

11.1 Assessment Framework

Section 2.3 of the Environmental Scoping Document (ESD) specified that the potential for the MWADZ Proposal to impact upon fisheries be addressed as a component of the scope of works outlined under the marine fauna environmental factor as described in the EPA's EAG 8.

Rather than incorporate this component under the "Assessment of Potential Impact on Marine Fauna" section (Section 9) of this PER, it has (like biosecurity) been included as a separate section.

11.1.1 Environmental Objective

The environmental objective established in this PER for fisheries is essentially that for marine fauna (as specified in EAG 8), namely:

> *"To maintain the diversity, geographic distribution and viability of fauna at the species and populations levels".*

To give effect to this objective, it is necessary to describe the fisheries operating in the region of the MWADZ Proposal and assess the potential direct and indirect environmental impacts on recreationally and commercially important marine species, including impacts to migratory patterns, spawning and nursery areas.

It is important to understand that this environmental objective is different and separate from any potential issues relating to resource (including habitat) sharing between aquaculture and wild-capture fisheries, or indeed other anthropogenic uses of the MWADZ Proposal area. Those issues of a significant resource-sharing nature that have been identified through the consultation process have and will continue to be addressed in parallel, but separate, to this PER process.

11.1.2 Relevant Legislation, Policies, Plans and Guidelines

Table 11-1: Legislation, Policies, Plans, and Guidelines Relevant to Fisheries

Legislation, Polices, Plans and Guidelines	Intent
State	
Environmental Protection Act 1986	This State Act provides for an EPA, for the prevention, control and abatement of pollution and environmental harm, and for the conservation, preservation, protection, enhancement and management of the environment.
Fisheries Resources Management Act 1994	Provides a legal framework to conserve, develop, and share fish resources for the benefit of current and future populations in WA. This legislation also provides the management framework for the Abrolhos Islands reserve and for the establishment and management of the Fish Habitat Protection Areas.
The Management Plan for the Houtman Abrolhos Islands. Fisheries Management Paper 260. (Department of Fisheries 2012)	The Houtman Abrolhos Islands Management Plan outlines both the vision and strategic objectives of management of the Abrolhos for the next ten years. It aims to conserve and promote the unique environmental and cultural heritage values of the Abrolhos Islands. Some of the main management objectives include: • *To protect and maintain marine and terrestrial environments of the Abrolhos; and* • *To facilitate and manage fishing an aquaculture activities consistent the environmental and cultural values of the Abrolhos.*
Environmental Assessment Guidelines (EAG)	
Environmental Assessment Guidelines No.8 (EAG 8) Environmental Assessment Guideline for Environmental Principles, Factors and Objectives (EPA 2015)	The EAG 8 provides guidance for proponents to help them understand the need to consider environmental principles, factors and objectives for the purpose of environmental impact assessment. Environmental principles, factors and objectives are critical to the environmental impact assessment process as they underpin the EPA's decision on the environmental acceptability of a proposal or scheme. In making its decisions, the EPA also takes a holistic approach to assessing environmental acceptability based on a number of broader considerations including whether the proposal aligns with broader international, national and State policies and agreements and takes account of the interconnected nature of the environment.

11.2 Existing Environment

11.2.1 Commercial Fishing

There are a number of commercially managed fisheries that are currently permitted to operate within the broader region of Geraldton and the Abrolhos Islands. These include:

- West Coast Demersal Scalefish (Interim) Managed Fishery
- Temperate Demersal Gillnet and Demersal Longline Fishery
- Abrolhos Islands and Mid-West Trawl Managed Fishery
- Mackerel Managed Fishery

- Marine Aquarium Managed Fishery
- Specimen Shell Managed Fishery
- Octopus Interim Managed Fishery
- West Coast Rock Lobster Managed Fishery
- West Coast Deep Sea Crustacean Managed Fishery
- West Coast Purse Seine Managed Fishery

The fisheries listed above, which are permitted to fish inside the Abrolhos Islands Fish Habitat Protection Area (FHPA) where the strategic MWADZ Proposal area is located, include: West Coast Demersal Scalefish (Interim) Managed Fishery, Abrolhos Islands and Mid West Trawl Managed Fishery, Mackerel Managed Fishery, Marine Aquarium Managed Fishery, Specimen Shell Managed Fishery, Octopus Interim Managed Fishery and the West Coast Rock Lobster Managed Fishery.

11.2.1.1 Invertebrate Fisheries

The two main commercial invertebrate fisheries most likely to be impacted by the MWADZ Proposal are the West Coast Rock Lobster Managed Fishery (Figure 11-1) and the Abrolhos Islands and Mid-West Trawl Managed Fishery (Figure 11-2).

West Coast Rock Lobster Managed Fishery

The West Coast Rock Lobster Managed Fishery (WCRLMF) is one of the most important commercial fisheries at the Abrolhos Islands. The rock lobster fishery targets the western rock lobster (*Panulirus cygnus*) through the use of baited traps (pots) (Fletcher and Santoro 2014). The WCRLMF operates in the waters of the west coast of Western Australia between North West Cape (Exmouth Gulf) and Cape Leeuwin (from 34°24'S to 21°44'S). The fishery is managed in three management zones of which the Abrolhos Islands is classified as Zone A of the fishery.

In 2013, the WCRLMF was transitioned from an input based total allowable effort system to an output based individual transferable quota management model. Under this new system, each individual fisher is now allocated a discrete share of a total allowable commercial catch. The fishery is now managed in accordance with the *West Coast Rock Lobster Managed Fishery Management Plan 2012*, the *Fish Resources Management Act 1994* and other relevant subsidiary legislation. Previously under the input based management system commercial fishers were only permitted to fish at the Abrolhos Islands from 15 March to 30 June each year (St John, J 2006). Under the new management arrangements all commercial fishers authorised to operate in the fishery, including those permitted to operate at the Abrolhos Islands, are permitted to fish all year round (Fletcher and Santoro 2014).

Catch across the whole fishery has historically been close to 11,000 tonnes annually; however, in 2009-10 the total annual catch for the commercial fishery was significantly reduced to less than 6,000 tonnes with the introduction of catch limits and catch targets for each zone.

Commercial rock lobster fishing activity at the Abrolhos Islands predominantly occurs over limestone reef habitat with between 45 and 65% of fishing effort occurring in shallow waters (0 to 20 metres) near submerged platforms and exposed reefs (Webster, F *et al.* 2002). These habitats tend to occur generally on the western and central parts of the islands groups where

there is a high abundance of limestone reef, macro algae and coral habitat (Webster, F *et al.* 2002). Coral reef habitats do also provide an important habitat area for Western rock lobster at the islands (St John, J 2006). Previous research surveys conducted at the Abrolhos have shown that the highest average number of fishing effort for the fishery occurs in the Wallabi/North Island area (273,000) pot lifts compared to the Easter Group (196,000) and the southern Pelsaert Group (98,300) (Webster, F *et al.* 2002).

Benthic habitat data collected in the strategic MWADZ Proposal area indicate that the predominant habitat is sand, which does not represent a key habitat area for Western rock lobster (pers. comm. De Lestang DoF). While sandy benthic habitat can sometimes provide an important area for migrating lobster during the "whites run" at certain times of the year, the MWADZ Proposal is not known to be an important area for migrating rock lobster. Given this information, it is unlikely that the MWADZ project will have a significant impact on the WCRLMF and (as a result) no further assessment was conducted on this fishery.

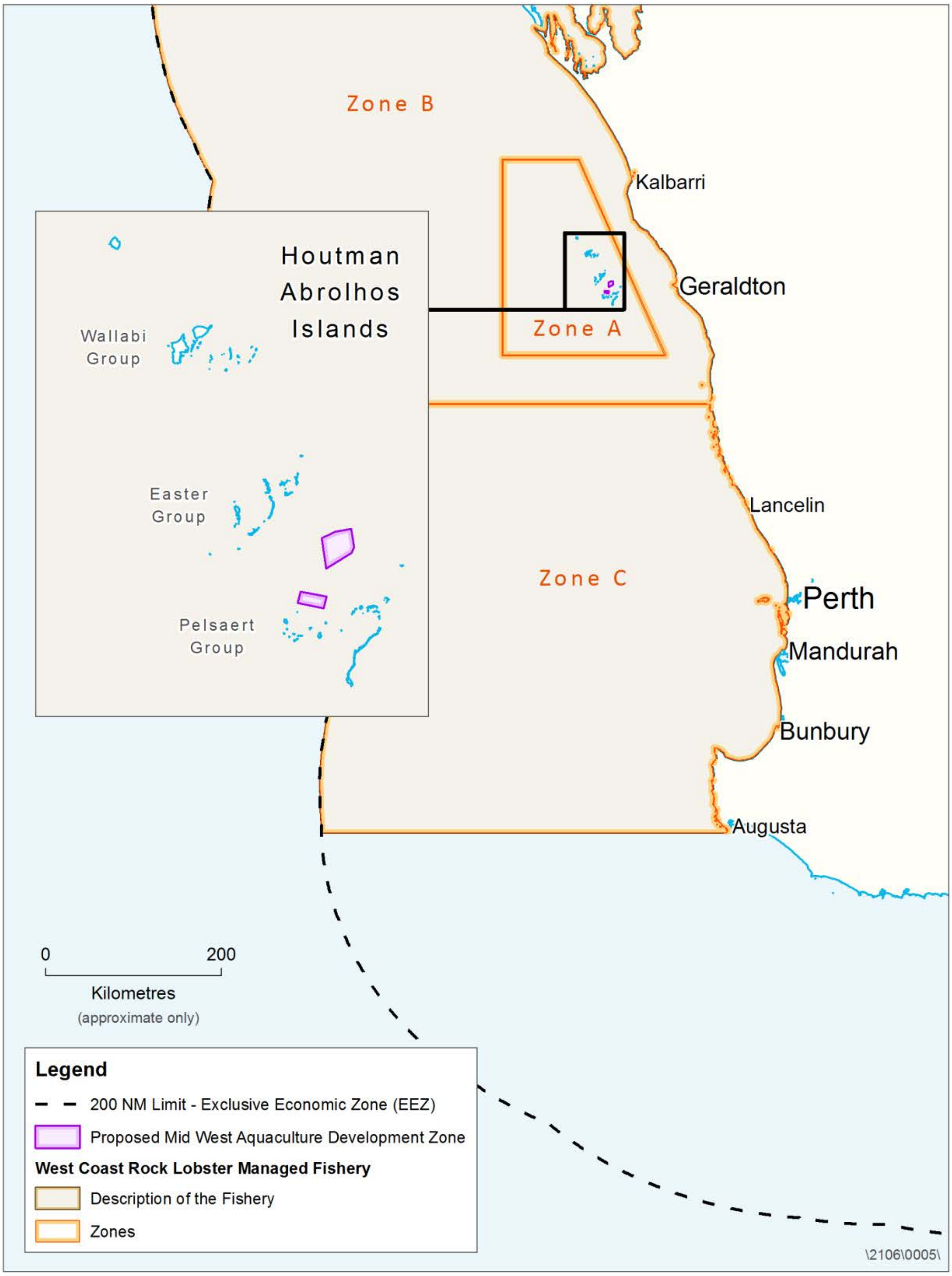

Figure 11-1: The Proposed MWADZ Area within Zone A of the West Coast Rock Lobster Managed Fishery

Abrolhos Islands and Mid-West Trawl Managed Fishery

The Abrolhos Islands and Mid-West Trawl Managed Fishery (AIMWTMF) is the second most important commercial fishery at the Abrolhos Islands in terms of its economic value. This fishery is managed under the *Abrolhos Islands and Mid-West Trawl Limited Entry Fishery Notice 1993*. The fishery mainly targets the saucer scallop (*Amusium balloti*), with a small component targeting the Western king prawn (*Penaeus latisulcatus*) in the Port Gregory area (Fletcher and Santoro 2013). The fishery encompasses the waters of the Indian Ocean between 27^{o} 51' south latitude and 29^{o} 03' south latitude on the landward side of the 200 metre isobath (Fletcher and Santoro 2014). There are currently a total of 16 licences in the fishery (Fletcher and Santoro 2014).

Scallops are a short-lived, benthic, filter feeding bivalve molluscs, which live on sandy bottoms and are subject to great natural fluctuations in reproductive success from year to-year. This variability is apparently related to the strength of the Leeuwin Current, as strong current is correlated with low scallop recruitment (Department of Fisheries 2012 a). The AIMTWMF fishing season normally runs between the months of April to July each year, depending on the results of pre-season recruitment research surveys (Department of Fisheries 2012 a). The major area fished for scallops in the Abrolhos Islands is the sandy sea bottom between the various island groups in waters deeper than 30 metres (Department of Fisheries 2007). Catches can vary greatly from year to year; from 2001 to 2003, for example, the total annual catch totalled 1,182 tonnes, 195 tonnes and 5,840 tonnes (whole weight) respectively (Department of Fisheries 2007).

Since 2012, there has been no scallop fishing at the Abrolhos Islands, due to low scallop abundance which was triggered by unfavourable environmental conditions during that period (Fletcher and Santoro 2014). Some areas of the strategic MWADZ Proposal area (i.e. the southern area) are within historical scallop fishing grounds of the AIMWTMF. The MWADZ Proposal is therefore likely to restrict the extent and availability of fishing ground and have a potential impact on the AIMWTMF.

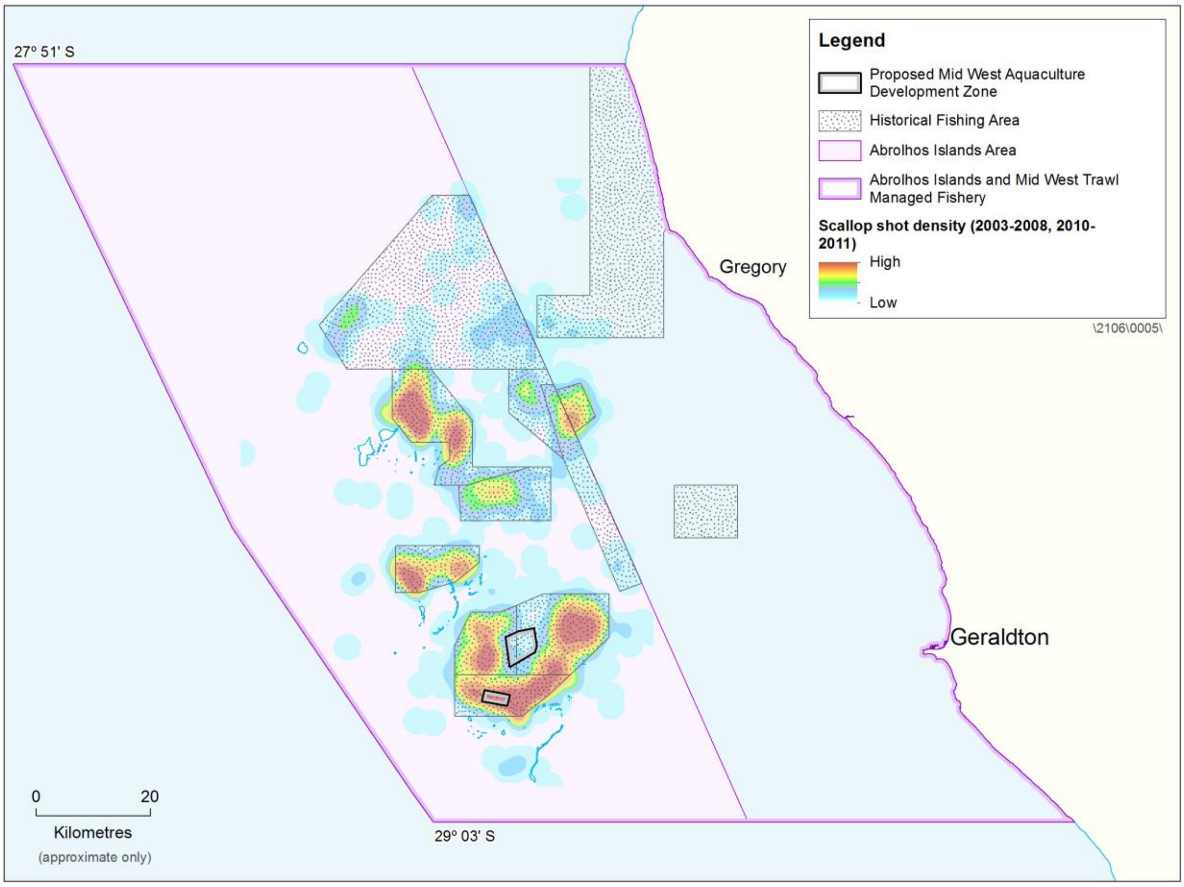

Figure 11-2: Historical Fishing Effort in the AIMWTMF from 2003-2011 and the Location of the Proposed MWADZ in the Fishery

11.2.1.2 Finfish Fisheries

There are two managed commercial finfish fisheries which are permitted to fish in the waters of the Abrolhos Islands FHPA which encompasses the strategic MWADZ Proposal area. These are the West Coast Demersal Scalefish (Interim) Managed Fishery and the Mackerel Managed Fishery.

The West Coast Demersal Scalefish (Interim) Managed Fishery (WCDSIMF) uses hooks and line to target a variety of demersal finfish species such as pink snapper (*Pagrus auratus*), baldchin groper (*Choerodon rubescens*), West Australian dhufish (*Glaucosoma hebraicum*), red throat emperor (*Lethrinus miniatus*) and coral trout (*Plectropomus leopardus*). The fishery currently operates under the *West Coast Demersal Scalefish (Interim) Management Plan 2007*. Under the current management arrangements licence holders in the fishery are only permitted to fish inside the Abrolhos Islands FHPA by means of a dropline by no more than three hooks (Clause 18c *West Coast Demersal Scalefish (Interim) Management Plan 2007*).

The majority of fishing effort from the WCDSIMF within the Abrolhos Islands FHPA is generally concentrated in areas near limestone and coral reef systems on the western and central areas of the islands (Webster, F *et al.* 2002). These areas provide a key habitat area for target species such as baldchin groper and coral trout.

Baseline habitat surveys conducted in the MWADZ Proposal area indicates that majority of the habitat is comprised of sandy bottom, which is not a key habitat for targeted species from the WCDSIMF. In the proposal area there is small areas of mixed assemblage substrate which comprises of rubble, low platform reef, algae and/or sponges. These types of habitat are often used by juvenile stages of species such as baldchin groper and red-throat emperor (Fairclough, D pers. comm. 2015). However, the size of cage clusters within the proposed zone will represent a very small proportion of the overall fish habitat for these species within the Abrolhos Islands FHPA. The proposed finfish aquaculture activities are therefore unlikely to have significant impact on the WCDSIMF.

The Mackerel Managed Fishery uses near-surface trolling gear from vessels in coastal areas, around reefs, shoals and headlands to target Spanish mackerel (*Scomberomorus commerson*) (Fletcher and Santoro 2014). Jig fishing is also used to capture grey mackerel (*Scomberomorus semifasciatus*) with other species from the genera *Scomberomorus*, *Grammatorcynus* and *Acanthocybium* also contributing to commercial catches (Fletcher and Santoro 2014). The fishery extends from the West Coast bioregion to Western Australian/Northern Territory border with most of the effort recorded north of Geraldton. The majority of the catch from the fishery is taken from either Area 1 (Kimberley area) or Area 2 (Pilbara area), which reflects the tropical distribution of the mackerel species. Commercial fishing activity from the fishery is limited at the Abrolhos Islands and is concentrated in areas outside the proposed MWADZ.

11.2.1.3 Other Fisheries

The Specimen Shell Managed Fishery, Octopus Interim Managed Fishery and the Marine Aquarium Managed Fishery are all permitted to fish in waters of the Abrolhos Islands FHPA, but concentrate their fishing activities in areas outside of the proposed MWADZ. These fisheries are therefore unlikely to be impacted by the MWADZ project.

Other commercial fisheries that operate in the Abrolhos region such as the West Coast Deep Sea Crustacean Managed Fishery and Temperate Demersal Gillnet and Demersal Longline Fishery are not permitted to fish within the strategic MWADZ Proposal area. Licence holders are only permitted to fish in waters outside of the Abrolhos Islands FHPA (Fletcher and Santoro 2014). As such no further assessment was conducted on these commercial fisheries.

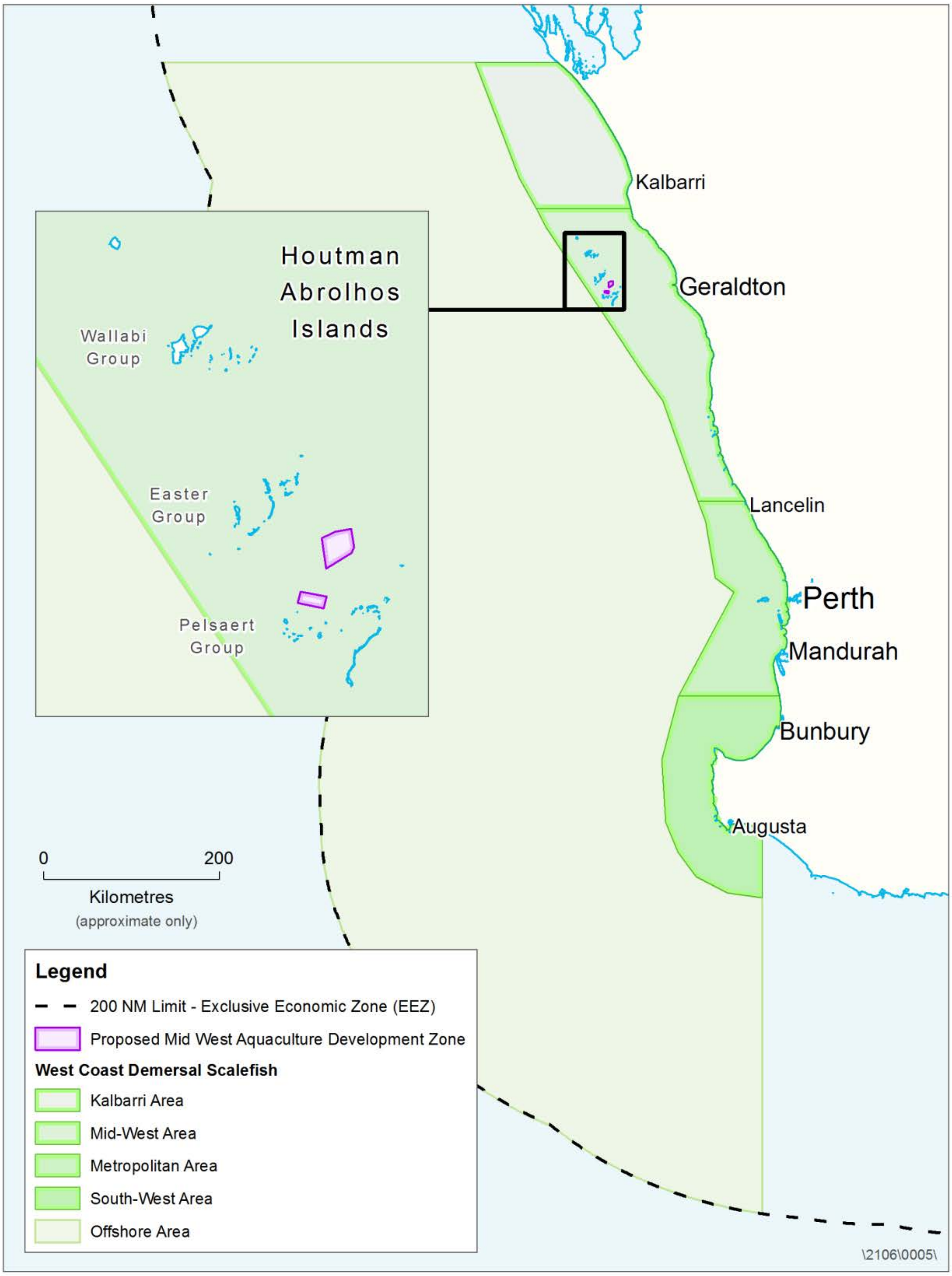

Figure 11-3: The Proposed MWADZ Area within the Mid West Area of the West Coast Demersal Scalefish (Interim) Managed Fishery

11.2.2 Recreational and Charter Fishing

11.2.2.1 Recreational Fisheries

Recreational fishers at the Abrolhos Islands and the surrounding areas target a large number of fish and invertebrate species. The vast majority of recreational fishing is boat based and concentrated within a few kilometres of the islands (Sumner 2006). The most commonly targeted demersal finfish species include, pink snapper (*Pagrus auratus*), baldchin groper (*Choerodon rubescens*), coral trout (*Plectropomus leopardus*), Western Australian dhufish (*Glaucosoma hebraicum*) and emperors (*Lethrinus species*). Recreational fishers also target pelagic species such as narrow-barred Spanish mackerel (*Scomberomorus commerson*) and yellowfin tuna (*Thunnus albacares),* mahi mahi (dolphinfish) (*Coryphaena hippurus*) and yellowtail kingfish (*Seriola lalandi)* (Sumner, N 2006).

Western rock lobster is also caught recreationally around Geraldton and the Abrolhos Islands during the recreational rock lobster season which runs from the 15 October to 30 June each year. Recreational rock lobster fishers have historically only been permitted to take Western rock lobster via pots at the Abrolhos Islands, however recent changes to the fishing regulations now enables fishers to take lobsters via diving methods.

Spear fishing is another popular recreational fishing activity at the Abrolhos Islands with most fishers targeting shallow water finfish species such as baldchin groper (*Choerodon rubescens*) and coral trout (*Plectropomus leopardus*) near shallow water reef habitats (Sumner, N 2006).

Recreational fishers mainly visit the Abrolhos Islands between the months of February to June each year when the weather is favourable for boating. Recreational fishing activity can be placed into four main groups:

- Recreational fishers that stay for one or more nights on private power boats and yachts;
- Commercial rock lobster fishers and their friends and families that stay on the islands in camps;
- Recreational fishers that conduct day trips to the Islands from the mainland; and
- Recreational fishers on vessels owned by tour or charter operators. (Sumner, N 2006).

There is a number of specific fishing regulations which apply to recreational fishers at the Abrolhos Islands. These include:

- The maximum quantity of finfish that a person may be in possession of at the Abrolhos Islands is 10 kilogram of finfish fillets, or one day's bag limit of whole fish or fish trunks.
- Baldchin groper (*Choerodon rubescens*): A fishing closure from 1 November to 31 January each year.
- Western rock lobster (*Panulirus cygnus*) can only be taken during the recreational rock lobster fishing season which is between the 15 October to 30 June each year.
- Samson fish (*Seriola hippos*) and yellowtail kingfish (*Seriola lalandi*) are not permitted to be taken by recreational fishers in the anchorage areas of the inhabited islands at the Abrolhos Islands.

Recreational fishers are required to notify the Department of Fisheries prior to entering the waters of the Abrolhos Islands FHPA. This notification can be made by completing the notification form, available from the Geraldton Regional Office and at: www.fish.wa.gov.au. The form must be lodged with the Geraldton Office either by email, fax and post or in person.

11.2.2.2 Charter Fisheries

There are a number of charter boat operators which operate within the Abrolhos Islands FHPA. Activities that are conducted on these operations include SCUBA diving, recreational fishing, sightseeing as well as other non-extractive activities such as surfing and birdwatching. The majority of charter fishing activity is conducted between the months of March to May when the prevailing winds tend to be lighter (Sumner, N 2006). Data which has been collected from recreational charter fishing surveys has indicated that charter boat operators preferred the Easter Group for extractive fishing activities whilst the Wallabi Group for non-extractive activities (i.e. diving and snorkelling). The majority of charter fishing activity conducted at the islands is outside of the strategic MWADZ Proposal area. Figure 11-4 indicates the level of charter fishing effort over the last five years in the Abrolhos Islands FHPA.

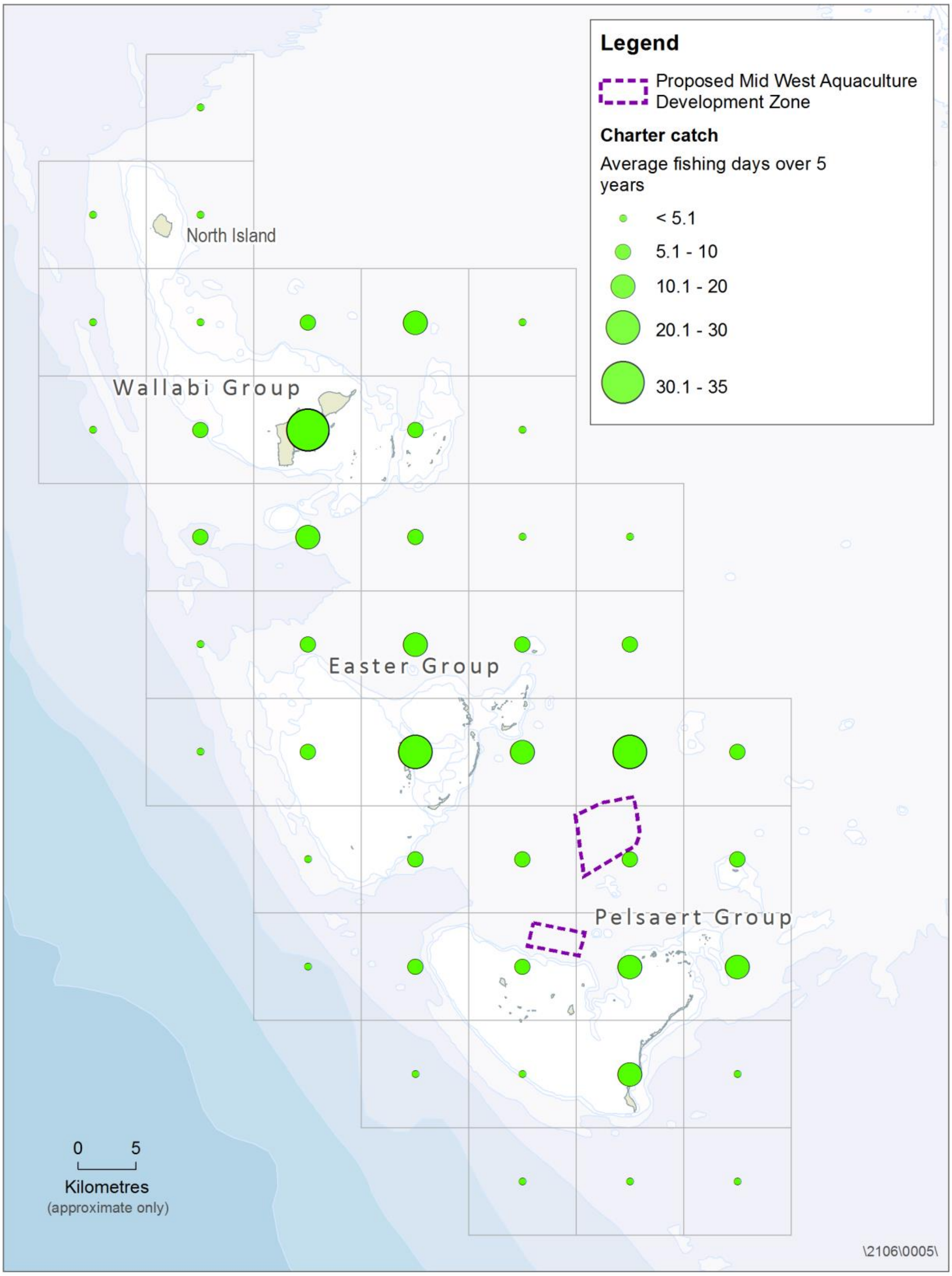

Figure 11-4: Average Number of Charter Fishing Days at the Abrolhos Islands over the Last Five Years

11.2.3 Aquaculture

There is currently a total of 17 aquaculture licences at the Abrolhos Islands covering 21 separate sites (Figure 11-5). Four licences (seven sites) are in the Wallabi Group, three licences (three sites) in the Easter Group and ten licences (11 sites) in the Pelsaert Group of islands. Not all of these are currently in production.

The dominant aquaculture sector at the Abrolhos Islands is based on the production of the black pearl oyster species (*Pinctada margaritifera*), with eight licences currently issued for production of this species. A number of licence holders have recently diversified into the production of sea sponges, other pearl oysters, including akoya pearl oyster (*Pinctada fucata*) and bat wing pearl oyster (*Pteria spp.*), and edible rock oysters, such as Western rock oyster (*Saccostrea glomerata*). In addition, a number of licences have been issued for the culture of live rock, live sand and coral at the Abrolhos Islands, using natural substrates such as limestone.

There is also currently an existing 800 hectare aquaculture licence for the sea cage production of marine finfish species, including those species envisaged for the MWADZ, within the southern area of the MWADZ Proposal.

This licence was originally granted in 2004 and has been in place continuously since that time. The licence holder has indicated a desire for the licensed site to be incorporated in the proposed MWADZ.

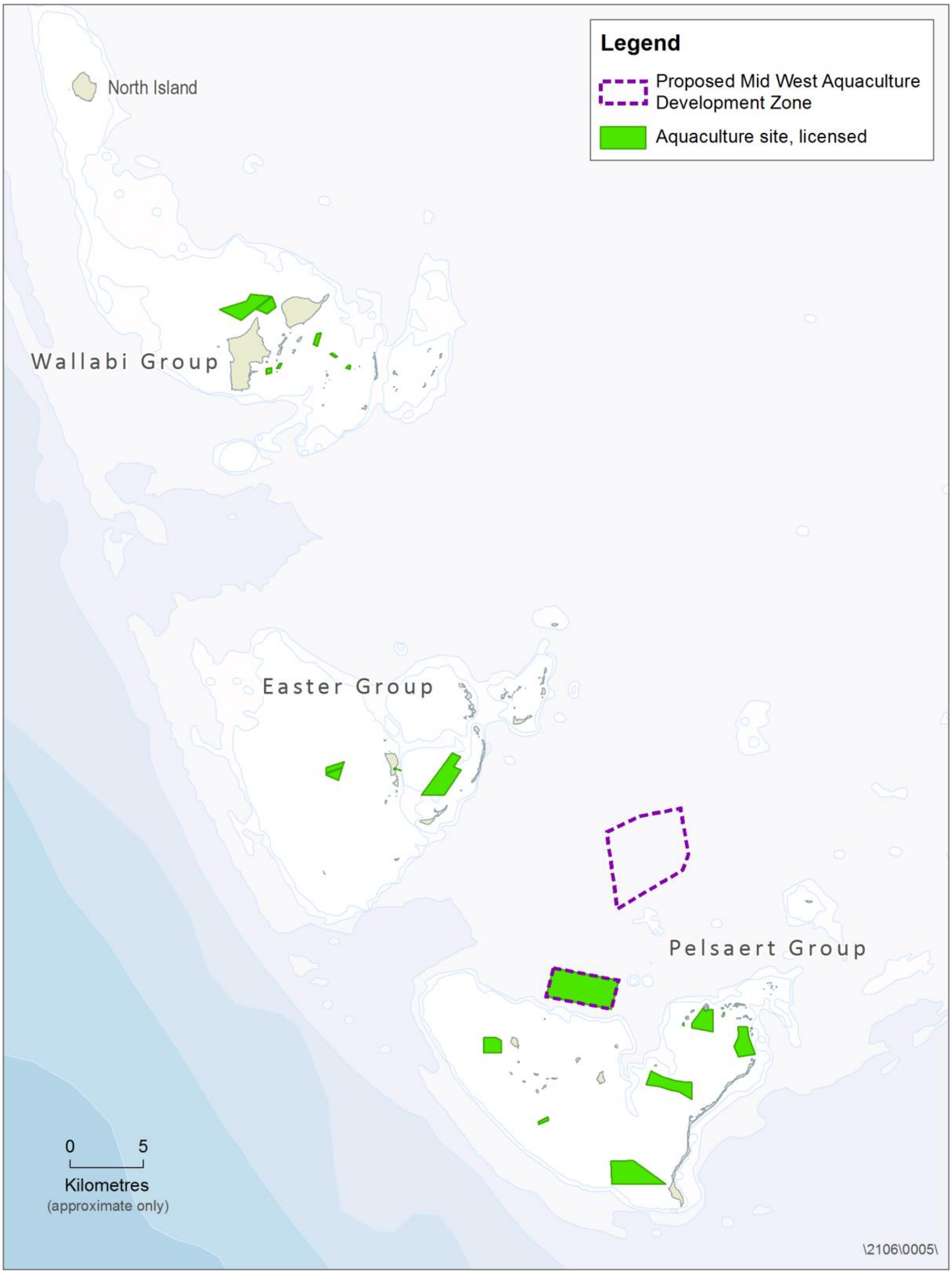

Figure 11-5: Existing Aquaculture Licenced Sites at the Abrolhos Islands

11.3 Potential Impacts

Identification of the potential impacts of the MWADZ Proposal on fisheries is based on a combination of literature review of the best-available scientific data, documented information on the adverse interactions between marine fauna and aquaculture equipment, impact assessments and "threat identification hazard pathway analysis" and risk identification and assessment methodology (Fletcher, W.J. 2014).

Essentially, the primary potential impacts determined through this process were:

- potential changes in the habitat of the fishery target species;
- potential changes in the recruitment patterns and spawning stock of the fishery target species;
- introduction of marine pests or pathogens;
- physical presence of aquaculture infrastructure; and
- potential changes in the abundance and distribution of the fishery target species.

11.4 Assessment of Potential Impacts

11.4.1 Commercial Fisheries

In order to determine and assess the potential impacts of the aquaculture zone on the key commercial fisheries, the Department of Fisheries prepared a "*Threat Identification, Hazard Pathway Analysis and Assessment of the Key Risks to Invertebrate and Finfish Species and Fisheries at the Abrolhos Islands presented by the establishment of the Mid West Aquaculture Development Zone in Western Australia*" (Fish and Invertebrate Risk Assessment) (Appendix 1c). The risk assessment methodology used for this risk assessment is covered in more detail in Section 2 of the risk assessment document.

The assessment was based on the current knowledge/literature of the potential impacts of sea cage finfish aquaculture on commercially-caught fish and invertebrate species and fisheries production. Information that was used as part of the risk assessment included:

- proposed location within the Abrolhos Islands FHPA;
- description of the proposal as provided in this document;
- previous high-level, generic, risk assessment conducted for marine finfish;
- Aquaculture in Australia (FRDC project 2003/223);
- relevant scientific studies and publications and knowledge of fish and invertebrate species within the vicinity of the proposed MWADZ area;
- knowledge of key fisheries within the vicinity of the proposed MWADZ area; and
- commercial catch and effort information for those fisheries.

During the risk assessment process the invertebrate fishery which was identified to be most likely to be impacted by the proposal was the Abrolhos Islands and Mid West Trawl Managed Fishery (AIMWTMF). Some areas of the strategic MWADZ Proposal area (i.e. the Southern area) are within historical scallop fishing grounds of the AIMWTMF, and therefore the proposal is likely to limit the extent of available fishing ground in this fishery. Given these impacts a specific risk assessment was conducted on the AIMWTMF.

The two commercial finfish fisheries were identified to be potentially impacted by the MWADZ Proposal these included the West Coast Demersal Scalefish (Interim) Managed Fishery and the Mackerel Managed Fishery. Catch and effort information which has been reported for these fisheries indicates that the MWADZ Proposal area does not represent a key fishing area for these fisheries at the Abrolhos Islands. The majority of the commercial fishing effort for these fisheries is conducted outside of the MWADZ Proposal area (pers. comm. Fairclough, D DoF). As a result, a more generic risk assessment was conducted for the key finfish fisheries.

11.4.1.1 Abrolhos Islands and Mid West Trawl Managed Fishery

The potential impacts of the MWADZ Proposal on the AIMWTMF that were identified as part of the risk assessment were:

- potential changes in benthic habitat of target invertebrate species;
- potential changes in the recruitment patterns and spawning stock of invertebrate species;
- introduction of marine pests or pathogens;
- physical presence of aquaculture infrastructure; and
- potential changes in the abundance and distribution of target invertebrate species.

Potential changes in benthic habitat

The installation of sea cages and aquaculture infrastructure from the MWADZ Proposal has the potential to result in shading of the marine benthic environment or changes to the benthic habitat underneath the sea cages through modification, isolation, disturbance or fragmentation. Aquaculture activities within the MWADZ are also likely to result in a potential increase in sedimentation, nutrient enrichment of the water column and increased turbidity which can have adverse effects on the benthic habitat. An increase in sedimentation on the seabed can result in a potential loss or reduction in diversity of benthic invertebrates through the smothering of benthic habitats and through oxygen depletion and hydrogen sulphide production during bacterial de-composition of organic matter. This could in turn lead to a dominance of small opportunistic benthic invertebrate species including capetellid worms and other scavengers and deposit feeding species (Hargrave, B 2005).

Particulates from aquaculture feed and fish faeces, is likely to increase the turbidity within close proximity of the sea cages. An increase in turbidity can lead to a decrease in light penetration within the water column, which can have negative impacts on photosynthetic organisms (like corals) directly underneath and in close proximity to the sea cages used in the aquaculture (Price, C and Morris, J 2013).

The installation of the sea cages and associated infrastructure will impact on a relatively small area of soft sediment habitat beneath the sea cages or within close proximity to the aquaculture infrastructure. Anchoring and mooring systems used as part of aquaculture infrastructure is also likely to impact the benthic habitat via smothering and/or exclusion.

Potential changes in the recruitment patterns and spawning stock of invertebrate species

The MWADZ Proposal may have an impact on the survival of settled juveniles and/or adult scallops within the vicinity of the sea cage infrastructure due to localised changes in environmental conditions. The benthic habitat is likely to be modified directly underneath the sea cages and within close proximity to these areas due to increase sedimentation/ smothering of the benthos from fish feed, faeces and other impacts from aquaculture activities. Any alteration to the benthic habitat underneath the sea cages has the potential to cause localised impacts on the settlement /recruitment patterns and spawning stock of invertebrate species. Saucer scallops are filter feeding organisms, which live on sandy bottom habitat any changes to the benthic habitat are likely to directly impact saucer scallops directly underneath the sea cages.

Physical presence of aquaculture infrastructure

The physical presence of aquaculture infrastructure which includes sea cages, anchoring and feeding barges in the proposed MWADZ is likely to limit the extent of available fishing ground within the AIMWTMF. The southern area in the proposed zone area has historically been a key scallop settlement area in the Abrolhos Islands. The physical presence of aquaculture infrastructure will directly exclude commercial scallop fishing vessels from fishing certain areas of the aquaculture zone. Under the proposed management arrangements, commercial fishers will still be permitted to operate within the zone provided they do not interfere with the aquaculture infrastructure.

Introduction of marine pests or pathogens

There is a number of significant pathogens of the marine fish proposed for aquaculture in the MWADZ, including for yellowtail kingfish. Diseases may potentially be introduced into sea cage farms directly from the environment (e.g. as a result of transmission from wild fish), via sub-clinically infected stocked fish, movement of personnel and infrastructure, the use of untreated aquaculture feeds or other vectors. Once introduced into an aquaculture facility, pathogens may persist, be transmitted between generations and potentially adapt to a state of virulence higher that that seen in the wild (where there may be no evolutionary advantage to kill a host) as a result of the selection pressures associated with intensive aquaculture. Spread of pathogens from aquaculture facilities could then occur via effluent, escapes, and/or predation. The spread of a significant pathogen could ultimately impact a wide range of species and the fisheries and ecosystems which they support.

Marine pests are known to be present in the region and the MWADZ Proposal has the potential to assist with the further spreading of these pests. Marine pests can be transported in ballast water and as biofouling on vessel hulls. Commercial aquaculture activities also have the potential to be directly responsible for introduction of marine pests by introduction via feed sources or brood stock or via the use of imported equipment that is not sufficiently cleaned.

Potential changes in the abundance and distribution of saucer scallops

The MWADZ Proposal has the potential to cause changes in the abundance and distribution of saucer scallops which is the targeted species for the AIMWTMF at the Abrolhos Islands.

The southern zone of the MWADZ Proposal has historically been a key scallop settlement area in the AIMWTMF. The distribution of scallops is dependent on larval settlement patterns associated with hydrodynamic processes and spawning stock distribution.

Due to the variable settlement patterns and abundance of scallops in any one year, the quantification of impacts is relatively complex and difficult to assess. It is, however, anticipated that small scale changes in the abundance and distribution of scallops may occur within the vicinity of sea cages if unfavourable environmental conditions (i.e. nutrient enrichment, sedimentation, organic deposition) prevail. Scallops have a limited capacity to move away from settlement areas (i.e. 10 to 100 metres) and therefore, if conditions are unfavourable, there may be some localised changes in the abundance and distribution of saucer scallops in the MWADZ Proposal area.

11.4.1.2 Finfish Fisheries

The primary potential impacts of the MWADZ Proposal on finfish fisheries such as the West Coast Demersal Scalefish (Interim) Managed Fishery (WCDSIMF) within the Abrolhos Islands FHPA were assessed as part of the risk assessment process. The potential impacts that were identified were:

- potential changes in fish habitat;
- potential changes in the settlement/recruitment patterns and spawning stock of fish species;
- introduction of marine pests or pathogens;
- physical presence of aquaculture infrastructure; and
- potential changes in the abundance and distribution of finfish species.

In essence, these are the same as those applicable to invertebrate fisheries.

Potential changes in fish habitat

The habitat of the strategic MWADZ Proposal area is mainly comprised of sandy bottom with some areas of mixed assemblages. Baseline habitat surveys conducted in the MWADZ area indicate that majority of the habitat is comprised of sandy bottom with some areas of mixed assemblages and isolated patches of reef. In the Northern area of the MWADZ 47.1% of the habitat comprised of bare sand, 34.9% of mixed assemblages and 8.5% of reef habitat. While in the Southern area, 91.6% of the habitat comprised bare sand and 5.2% of mixed assemblage (BMT Oceanica 2015).

Mixed assemblage habitat which is comprised of rubble, low platform reef, algae and/or sponges can often be used by juvenile species such as baldchin groper (*Choerodon rubescens*), coral trout (*Plectropomus leopardus*) and red-throat emperor (*Lethrinus miniatus*). These fish species are commonly targeted by commercial fisheries such as the WCDSIMF and recreational fishers. The majority of the habitat within the MWADZ does not represent a key fish habitat area for these target species. While there might be some areas within the aquaculture zone where these species may inhabit (i.e. mixed assemblage habitat) the area where habitat may be potentially affected represents a very small proportion of the overall fish habitat for these species within the Abrolhos Islands FHPA.

The MWADZ Proposal may have an impact on the fish habitat for non-target species which may inhabit sandy areas directly underneath the sea cages and within close proximity to these areas. The proposed development of finfish aquaculture infrastructure including sea cages, anchoring systems as well as potential localised changes in environmental conditions has the potential to result in some localised changes to the fish habitat within the MWADZ area.

Potential changes in the recruitment patterns of spawning stock of finfish species

Finfish aquaculture activities within the MWADZ Proposal has the potential to cause localised changes in environmental conditions near the sea cages due to increased nutrient enrichment and turbidity of the water column, increased sedimentation and smothering of the fish habitat and potential release of trace metals and therapeutants. These impacts have the potential to cause changes in the recruitment patterns of the spawning stock of finfish species within the area.

Introduction of marine pests or pathogens

The potential impacts of the introductions of marine pest or pathogens are discussed in Section 10 of this PER.

Physical presence of aquaculture infrastructure

The physical presence of aquaculture infrastructure including sea cages, anchors and feeding systems from the MWADZ Proposal is likely to directly exclude commercial and recreational fishers from fishing within certain areas of the aquaculture zone. Under the proposed management arrangements both commercial and recreational fishers will be permitted to fish within the strategic MWADZ Proposal area, on the condition they do not interfere with the aquaculture infrastructure.

Sea cage infrastructure used in the proposal is also likely to provide a fish aggregating (FAD) effect and may potentially attract some finfish species to the area. Some species of fish that may be attracted to the infrastructure include baitfish and predatory fish (large and small) such as Spanish mackerel (*Scomberomorus commerson*), yellowfin tuna (*Thunnus albacares*) and mahi mahi (*Coryphaena hippurus*). Potential increases in the visitation rates and the abundance of these species near the infrastructure may potentially lead to an increase in both recreational and commercial fishing activity within the area, and may result in increased fishing pressure on these fish stocks.

Potential changes in the abundance and distribution of finfish species

The MWADZ Proposal has the potential to cause changes in the abundance and distribution of finfish species which are targeted by commercial (and recreational) fishers within the Abrolhos Islands FHPA. Finfish aquaculture in the area has the potential to increase the abundance of some baitfish and predatory fish species through the FAD effect. Aquaculture infrastructure such as sea cages has the potential to provide an additional habitat area for some finfish species and may cause localised changes in their abundance.

Fish farming activities in the proposal area also has the potential to cause localised changes in the abundance and distribution of finfish species.

Harvesting activities and biological residues such as blood, the presence of cultured stock and plumes created from feeding practices are likely to attract more finfish species to the area. The presence of additional food in the MWADZ area could potentially lead to an increase or decrease in the abundance of certain fish species within the zone. Potential changes in the fish habitat due to smothering of the benthic habitat, nutrient enrichment of the water column, increased turbidity and sedimentation also have the potential to cause localised changes in the abundance and distribution of finfish species.

11.4.2 Recreational and Charter Fisheries

As the potential impacts of the MWADZ Proposal on recreational and charter fisheries are essentially the same as those applicable to the commercial fisheries, the assessment of the potential commercial fisheries impacts is also transferable to the recreational and charter fishing context. This is especially so in relation the commercial finfish-related assessments.

11.5 Management Measures

The likelihood that the proposed activities in the MWADZ will have a significant impact on commercial and recreational fisheries may be further reduced through the implementation of management measures. Management measures that can mitigate potential effects from the proposal include those detailed in Table 11-3.

Table 11-3: Proposed Management and Mitigation Measures – Fisheries Issues

Potential Impacts	Management Measures
Potential changes in benthic/fish habitat	Information from preliminary baseline studies and past experiences with marine finfish aquaculture suggest that it is likely that the MWADZ Proposal may have some minor impacts on the benthic/ fish habitat directly underneath the sea cages and within close proximity to these areas. Any impacts on habitat are however likely to be on a relatively small scale and unlikely to have a significant impact on the AIMWTMF and finfish fisheries in the area. The primary sources of impact in terms of changes to benthic and fish habitat are primarily related to aquaculture feed and faeces from aquaculture fish. Possible management measures that could be undertaken to reduce these impacts include the following: • locate the sea cages in well flushed areas where there is an increased water depth below the sea cage; • fallow sea cages, including the rotation and movement of cages to enable fish habitat to recover; • control feed - minimizing feed wastage can significantly reduce sediment enrichment effects which can help improve sediment conditions underneath the sea cages; • reduce stock densities and feed input rates; and • use high quality feed, contemporary feeding techniques and best-practice farming techniques to reduce feed wastage and feed conversion ratios (FCR) are highlighted in the Management Policy and Industry Code of Practice. Each licence holder operating in the MWADZ is required to comply with an Environmental Management and Monitoring Plan (EMMP). Under the EMMP all operators are required to monitor parameters such as Total Organic Carbon (TOC) and Total Phosphorous (TP) in the sediment against Environmental Quality Guidelines (EQG). If any of the EQGs are triggered benthic infauna monitoring is required.

Changes in recruitment patterns and spawning stock of invertebrate and fish species	Any potential changes to the settlement /recruitment patterns and spawning stock of invertebrate and finfish species can be reduced through the implementation of management measures designed to reduce localised changes to environmental conditions. Management measures which can be used to improve environmental conditions include: • feed control – minimising feed wastage can reduce any potential impacts on the benthic habitat and therefore minimise impacts; • locate sea cages in well-flushed areas where there is an increased water depth below the sea cages; and • set the stocking density of fish farms at conservative levels.
Introduction of marine pests and pathogens	The management measures proposed to address the risk of the introduction of marine pests and pathogens have been covered in more detail in the Biosecurity assessment in Section 10 of this PER.
Physical presence of aquaculture infrastructure	The physical presence of aquaculture infrastructure including fish cages anchors and feeding systems is likely to directly exclude commercial trawl fishers from the AIMWTMF from fishing within certain areas of the aquaculture zone. The southern site of the MWADZ has historically been a key fishing area for the AIMWTMF. The proposal has the potential to limit the amount of available fishing ground in this fishery. The MWADZ Proposal area however, represents a very small proportion (0.2%) of the overall available AIMWTMF fishing ground and 1.3% of the historical fishing ground in the fishery. Historical fishing effort for the AIMWTMF from 2003 to 2011 has indicated that the southern site in the MWADZ represents an important area for scallop fishing (refer to PER document AIMWTMF effort map). The northern site of the MWADZ Proposal area however, does not represent a key fishing area for the fishery. Commercial fishing effort in this area has been very limited over the last ten years (Kangas, M pers. comm.). The presence of aquaculture infrastructure in the aquaculture zone is also likely to limit the availability of fishing ground for finfish fisheries including the WCDSIMF. However, the MWADZ Proposal area represents a very small proportion (i.e. less than 1%) of the overall available fishing ground in this fishery and the proposal is therefore unlikely to have a significant impact. Under the proposed management arrangements for the MWADZ Proposal area, commercial and recreational fishers will be permitted to operate within the aquaculture zone provided they do not interfere with the aquaculture infrastructure. Management measures that could be implemented to further reduce the potential impacts of the infrastructure on commercial and recreational fisheries include: • place sea cages in parts of the MWADZ Proposal area that are not significant fishing grounds for commercial and recreational fisheries; and • provide information to commercial and recreational fishers on the lighting and marking locations of aquaculture infrastructure. Under the licencing conditions for the MWADZ Proposal, licence holders will be required to complete a guidance statement for evaluation and determining categories for marking and lighting for aquaculture leases/ licences. This guidance statement will be used by the Department of Transport to determine the marking and navigational lighting requirements for the aquaculture lease/licence. Licence holders will be required to abide by the marking and lighting requirements as part of the conditions on their licence. A copy of a link to this form is available on the Department of Fisheries website http://www.fish.wa.gov.au/Documents/aquaculture_licencing/marking_and_lighting_guidance_statement.pdf

Potential changes in the abundance and distribution of fish and invertebrate species	Possible management measures that could be implemented to minimise any potential changes in the abundance and distribution of fish and invertebrate species include: • develop and comply with a Management and Environmental Monitoring Plan (MEMP) and best-practices in aquaculture, including the requirement for operators to monitor environmental conditions such as water quality and sediment quality; and • adopt best-practice management arrangements, including good husbandry and farming practices. The management measures described above ensure that the likelihood of the proposed aquaculture having a significant impact on the abundance and distribution of fish and invertebrate species is reduced to remote.

11.6 Predicted Environmental Outcome

11.6.1.1 Abrolhos Islands and Mid West Trawl Managed Fishery

The MWADZ Proposal is likely to pose a low risk to the AIMWMTF. Some parts of the aquaculture zone (i.e. the Southern area) of the MWADZ Proposal have historically been a key fishing area for scallop fishing in the AIMWTMF. The physical presence of aquaculture infrastructure is likely to exclude scallop trawl fishing vessels from fishing in the vicinity of the sea cage infrastructure within the aquaculture zone. This has the potential to limit the amount of available fishing ground in the fishery. The proposed MWADZ, however, represents only a very small proportion (less than 0.2%) of the overall available AIMWTMF fishing ground and 1.3% of the historical scallop fishing ground in the fishery.

Historical fishing effort information collected by the Department of the Fisheries for the AIMWTMF from 2003 to 2011 has indicated that the Southern area in the MWADZ represents an important area for scallop fishing (refer to PER document AIMWTMF effort map). The Northern area of the MWADZ Proposal, however, does not represent a key fishing area for the fishery. Commercial fishing effort in this area has been very limited over the last ten years (pers. comm. Kangas, M).

The actual level of impact on the AIMWMTF that the MWADZ Proposal presents into the future cannot be determined with any degree of certainty and the Department will continue to work with the AIMWMTF and the aquaculture industry to explore ways of minimising any such impact.

11.6.1.2 Finfish Fisheries

The MWADZ Proposal is likely to pose a negligible and acceptable risk to finfish fisheries within the Abrolhos Islands Fish Habitat Protection Area (FHPA). Baseline benthic habitat surveys conducted in the MWADZ have indicated that the area does not represent a key habitat area for target finfish species such as coral trout, baldchin groper, red-throat emperor and other demersal fish species which are commonly targeted by finfish fisheries. These species tend to prefer limestone reef, macro algae and coral habitats which are generally located on the western and central parts of the Abrolhos Island groups. While there may be some localised changes to the fish habitat within the aquaculture zone it is unlikely to result in any significant changes in the abundance, distribution, recruitment patterns and spawning stock of these finfish species within the Abrolhos FHPA.

Catch and effort information which has been reported for the finfish fisheries permitted to fish within Abrolhos FHPA indicates that the MWADZ Proposal area does not represent a key fishing area for these fisheries. The majority of the commercial fishing effort for these fisheries is conducted outside of the MWADZ Proposal area. While commercial fishers may be physically excluded from fishing certain areas of the MWADZ due to the presence of aquaculture infrastructure the overall area of the proposed aquaculture zone represents a very small proportion (i.e. less than 1%) of the overall fishing area for these finfish fisheries. It is unlikely that the MWADZ Proposal will have a significant impact on finfish fisheries within the Abrolhos Islands FHPA.

Any potential environmental impacts from the MWADZ Proposal can be managed effectively through the adoption of good husbandry and farming practices including, maximising feeding efficiency and reducing feed waste and the adoption of conservative stocking densities. The potential impacts posed by MWADZ Proposal can also be effectively managed through the implementation of, and compliance with, the zone EMMP (EP Act) and the MEMP (FRMA) for individual operators, both of which include mandatory environmental monitoring.

Consequently, it is expected that the MWADZ Proposal will have negligible environmental (or economic) impacts on commercial finfish fisheries within Abrolhos FHPA.

11.6.1.3 Recreational and Charter Fisheries

Recreational and charter fisheries operating within the MWADZ Proposal area are unlikely to target invertebrate species due to the relative remoteness of the area, the depth of water involved and legislated restrictions on the types of fishing gear permitted to be used.
Instead, the principal focus of these fisheries is a similar suite of marine finfish species to that targeted by the commercial finfish fisheries operating within this area.

The available charter fishing catch and effort data (Figure 11-4) suggests the MWADZ Proposal area is not a key area for recreational charter fishing activity and consultation with recreational fishing stakeholders (including RecFishWest) throughout the PER process to date has reinforced that this is also the case for other forms of recreational fishing (i.e. non-charter recreational fishing).

With regard to the predicted environmental outcome for recreational and charter fisheries, it is expected that this will be the same as for commercial finfish fisheries due to the similarity in potential environmental impacts, management and mitigation measures to be implemented and anticipated environmental responses to such measures.

Consequently, it is expected that the MWADZ Proposal will have negligible environmental impacts on recreational and charter fisheries within Abrolhos FHPA.

12 ASSESSMENT OF POTENTIAL IMPACT ON HERITAGE

12.1 Assessment Framework

As part of the requirements in Section 2.4 of the Environmental Scoping Document (ESD) the proponent is to ensure all other relevant environmental factors and impacts that may be of interest to the public, including heritage, are considered in the environmental review.

12.1.1 Heritage Objectives

The objective established in this PER for heritage values associated with the MWADZ Proposal is as specified in EAG 8, namely:

"To ensure that historical and cultural associations, and natural heritage, are not adversely affected."

12.1.2 Relevant Legislation, Policies, Plans and Guidelines

Table 12-1 lists the policies, plans and guidelines that are relevant to heritage considerations within the MWADZ Proposal area.

Table 12-1: Legislation, Policies, Plans and Guidelines Relevant to Heritage Issues

Legislation, Polices, Plans and Guidelines	Intent
State	
Environmental Protection Act 1986	This State Act provides for an EPA, for the prevention, control and abatement of pollution and environmental harm, and for the conservation, preservation, protection, enhancement and management of the environment.
Heritage of Western Australia Act 1990 (WA)	Provides a legal framework that conserves cultural heritage places of significance and facilities development in harmony with cultural and heritage values.
Maritime Archaeology Act 1973	An Act to make provision for the preservation on behalf of the community of the remains of ships lost before the year 1900, and of relics associated with those wrecks.
Fisheries Resources Management Act 1994	Provides a legal framework to conserve, develop, and share fish resources for the benefit of current and future populations in WA. This legislation also provides the management framework for the Abrolhos Islands reserve and for the establishment and management of the Fish Habitat Protection Areas.
Wildlife Conservation Act 1950	An Act to provide for the conservation and protection of wildlife in Western Australia.
Conservation and Land Management Act 1984	An Act to make better provision for the use, protection and management of certain public lands and waters and the flora and fauna thereof, to establish authorities to be responsible therefor, and for incidental or connected purposes.
The Houtman Abrolhos Islands Management Plan	Provides a management framework to conserve and promote the unique environmental and cultural heritage values of the Abrolhos for the benefit of present and future generations.
Environmental Assessment Guideline (EAG)	

Environmental Assessment Guidelines No.8 (EAG 8) Environmental Assessment Guideline for Environmental Principles, Factors and Objectives (EPA 2015)	The EAG 8 provides guidance for proponents to help them understand the need to consider environmental principles, factors and objectives for the purpose of environmental impact assessment. Environmental principles, factors and objectives are critical to the environmental impact assessment process as they underpin the EPA's decision on the environmental acceptability of a proposal or scheme. In making its decisions, the EPA also takes a holistic approach to assessing environmental acceptability based on a number of broader considerations including whether the proposal aligns with broader international, national and State policies and agreements and takes account of the interconnected nature of the environment.
EPA Guidance Statement No. 33: Environmental Guidance for Planning and Development (EPA 2008)	Specifies that changes to the biophysical environment do not adversely affect historic and cultural associations and that such change complies with heritage legislation.
Commonwealth	
Environment Protection and Biodiversity Conservation Act 1999	It provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places — defined in the EPBC Act as matters of national environmental significance.
Commonwealth Historic Shipwrecks Act 1976	Provides for the protection of historic shipwrecks and all associated artefacts from those wrecks.

12.2 Existing Environment

12.2.1 Cultural Heritage

12.2.1.1 Aboriginal Heritage

A search of the Register of Aboriginal Sites maintained by the Western Australian Department of Indigenous Affairs was undertaken on 17 August 2015. The search returned no results from the register. In addition, a search of the available literature on the Abrolhos Islands did not indicate there were any indigenous heritage and cultural issues that may be impacted by the MWADZ Proposal.

Native Title

The National Native Title Register and Register of Native Title Claims (http://www.nntt.gov.au/applications/imdex.html) was searched in June 2015. There is currently no native title or native title claim over the Abrolhos Islands and the strategic MWADZ Proposal area.

12.2.1.2 European Heritage

Shipwrecks

There are a number of shipwrecks scattered throughout the Abrolhos Islands. One of the most historical shipwreck sites is the *Batavia* which is located near the Wallabi Island Group. The wreck of the Batavia and the associated land sites on Beacon Island, Long Island and West Wallabi Islands together comprise one of the most important maritime archaeological sites in Australia.

In 2006, the Batavia wreck and the Survivors Camp Area were gazetted under the Commonwealths *Environment Protection and Biodiversity Conservation Act 1999*, as an area to be put on the National Heritage List. These sites are of international significance and provide a major attraction for visitors to the Islands.

Shipwrecks and associated land sites are protected under Western Australia's *Maritime Archaeology Act 1973* and the *Commonwealth Historic Shipwrecks Act 1976*. Several shipwrecks in the Abrolhos Islands are gazetted under the Commonwealth *Historic Shipwrecks Act 1976.* These are: *Batavia* (1629), *Zeewijk* (1727), *Hadda* (1877), *Marten* (1878), *Ben Ledi* (1879), *Ocean Queen* (1842) and the *Windsor* (1908). Figure 12-1 illustrates all listed historic shipwrecks and identified dive trails within the vicinity of the MWADZ Proposal.

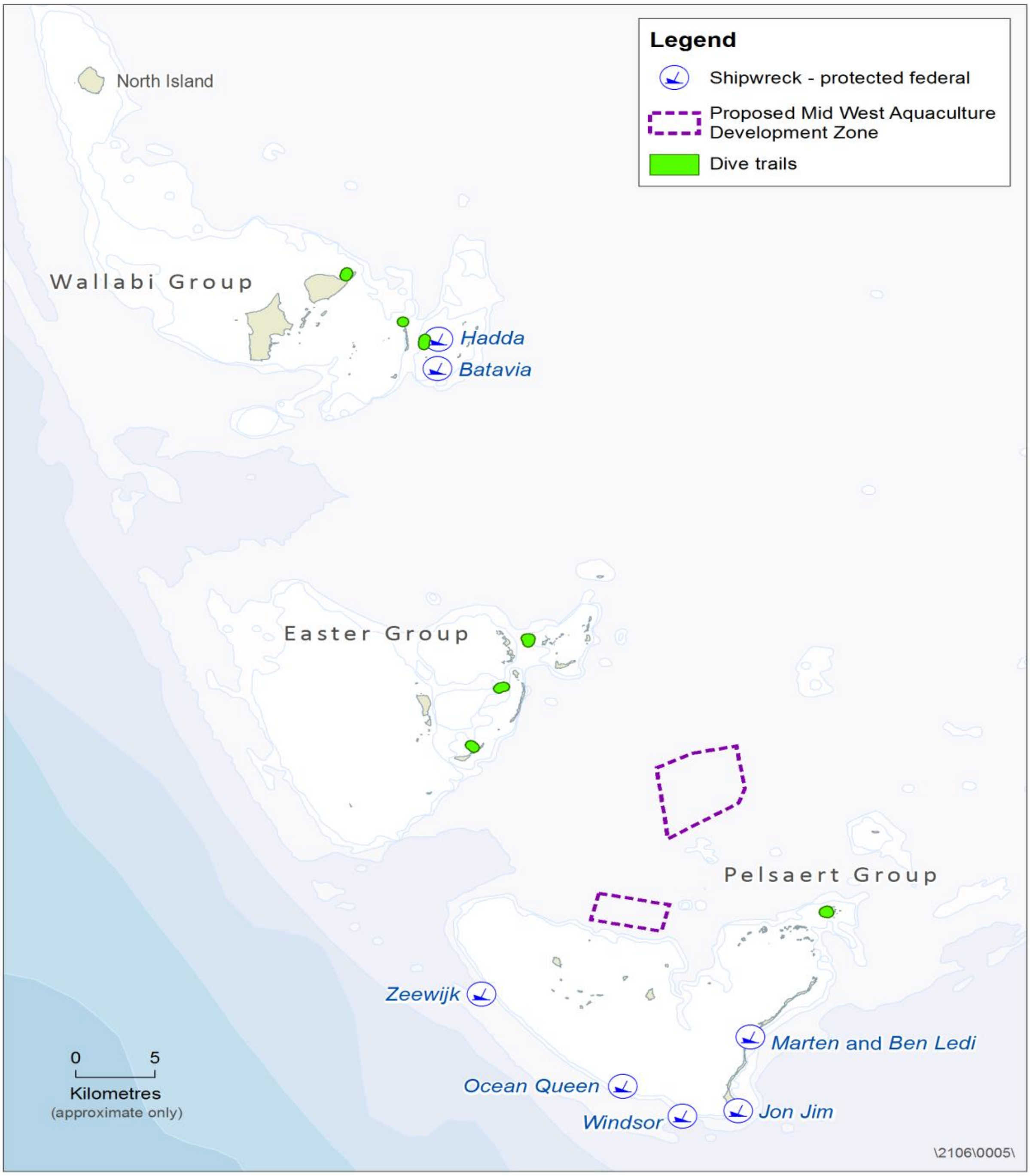

Figure 12-1: Shipwrecks Protected under State and Commonwealth Legislation

As indicated above, there are no National Heritage Places in the vicinity of the MWADZ Proposal.

12.3 Potential Impacts

The physical presence of marine finfish sea cage aquaculture infrastructure within the MWADZ Proposal area is the only possible potential impact on environmental heritage values. However, there do not appear to be any such values applicable to that particular area.

12.4 Assessment of Potential Impacts

In the context of the MWADZ Proposal, heritage encompasses Aboriginal cultural heritage and European (maritime) heritage.

Given the absence of any evidence of indigenous heritage and cultural issues relating to the Abrolhos Islands; and considering the remoteness of the wrecks and associated dive trails from the MWADZ Proposal area, it is unlikely that the proposed zone will have any impact on their values.

12.5 Management Measures

The MWADZ Proposal does not present any known potential impacts to either of these heritage values. Nevertheless, if any cultural heritage material is uncovered within the proposed MWADZ at any time in the future, the appropriate authorities (e.g. Department of Aboriginal Affairs and the Western Australian Museum) will be immediately contacted for advice.

12.6 Predicted Environmental Outcome

There is unlikely to be any adverse impacts to historical and cultural associations, and natural heritage, as a result of the MWADZ Proposal.

13 ASSESSMENT OF POTENTIAL IMPACT ON AMENITY

13.1 Assessment Framework

As part of the requirements in Section 2.4 of the Environmental Scoping Document (ESD) the proponent is to ensure all other relevant environmental factors and impacts that may be of interest to the public are considered in the environmental review.

Consultation thus far with stakeholders has identified the potential for the EPA environmental factor of amenity to also be relevant to the MWADZ Proposal.

13.1.1 Amenity Objectives

The objective established in this PER for amenity values associated with the MWADZ Proposal is as specified in EAG 8, namely:

"To ensure that impacts to amenity are reduced as low as reasonably practicable."

13.1.2 Relevant Legislation, Policies, Plans and Guidelines

The term "amenity" can have a range of meanings and does not appear to be clearly defined in the various statutes applicable to the MWADZ Proposal. For the purposes of this PER, it has been interpreted as relating to *"... a pleasant, attractive or agreeable feature of a geographic location."*

In the context of the MWADZ Proposal and the EPA's EAG 8, this has been taken to mean features associated with the key senses (e.g. sight, hearing and smell), and human perceptions of beauty (i.e. aesthetics). In other words, the assessment of potential environmental impacts relating to amenity is the assessment of impacts that could affect the perceived level of agreeableness in terms of indicators like colour, noise and odour.

This is an important consideration when seeking to differentiate between factors associated with environmental amenity and those associated with non-environmental amenity, such as resource sharing or other socio-economic matters.

Table 13-1 lists the policies, plans and guidelines that are relevant to amenity considerations within the MWADZ Proposal area.

Table 13-1: Legislation, Policies, Plans and Guidelines Relevant to Amenity Issues

Legislation, Polices, Plans and Guidelines	Intent
State	
Environmental Protection Act 1986	This State Act provides for an EPA, for the prevention, control and abatement of pollution and environmental harm, and for the conservation, preservation, protection, enhancement and management of the environment.
Fisheries Resources Management Act 1994	Provides a legal framework to conserve, develop, and share fish resources for the benefit of current and future populations in WA. This legislation also provides the management framework for the Abrolhos Islands reserve and for the establishment and management of the Fish Habitat Protection Areas.
The Houtman Abrolhos Islands Management Plan	Provides a management framework to conserve and promote the unique environmental and cultural heritage values of the Abrolhos for the benefit of present and future generations.
Environmental Assessment Guideline (EAG)	
Environmental Assessment Guidelines No.8 (EAG 8) Environmental Assessment Guideline for Environmental Principles, Factors and Objectives (EPA 2015)	The EAG 8 provides guidance for proponents to help them understand the need to consider environmental principles, factors and objectives for the purpose of environmental impact assessment. Environmental principles, factors and objectives are critical to the environmental impact assessment process as they underpin the EPA's decision on the environmental acceptability of a proposal or scheme. In making its decisions, the EPA also takes a holistic approach to assessing environmental acceptability based on a number of broader considerations including whether the proposal aligns with broader international, national and State policies and agreements and takes account of the interconnected nature of the environment.
Environmental Assessment Guidelines No.15 (EAG 15) Environmental Assessment Guideline for Protecting the Quality of Western Australia's Marine Environment (EPA 2015)	The EAG 15 provides an environmental quality management framework to protect the environmental values of Western Australia's marine environment from waste discharges and contamination. The EPA has provided this environmental quality management framework in EAG 15 to assist the proponent in predicting and managing the effects of pollution, waste discharges and deposits on the quality of the marine environment (EPA 2015)
Commonwealth	
Not applicable	

13.2 Existing Environment

13.2.1 Abrolhos Islands FHPA

13.2.1.1 Context

The State Territorial Waters (i.e. high water mark out to three nautical miles seaward of the Territorial Sea Baseline) of the Abrolhos Islands are a gazetted Fish Habitat Protection Area (FHPA). This FHPA was gazetted in 1999.

The MWADZ Proposal area is located within this FHPA and the Abrolhos Islands FHPA surrounds the Abrolhos Islands Reserve.

The FHPA is designated for the following purposes:

- *the conservation and protection of fish, fish breeding areas, fish fossils or the aquatic ecosystem;*
- *the culture and propagation of fish and experimental purposes related to that culture and propagation; and*
- *the management of fish and activities relating to the appreciation or observation of fish.*

Under the FRMA, the Department of Fisheries has the power to regulate fishing operations in the FHPA (Department of Fisheries 2001). Regulation of fishing and aquaculture operations may be undertaken for a number of purposes including conservation, fisheries management and for the preservation of areas for observation and eco-tourism pursuits.

The scope of other existing uses of the FHPA is covered in Sections 3, 5, 11, 12 and 14 of this PER.

For a more detailed description of the biophysical characteristics of the area, refer to Sections 3 and 9 of this PER.

13.3 Potential Impacts

Potential environmental amenity impacts associated with the MWADZ Proposal were identified in the scoping phase of the PER, when establishing the assessment context (Section 6.3). Essentially, this involved:

- determining which MWADZ Proposal activities could potentially result in environmental impacts (but also noting any potential social and economic impacts that may be of public interest); and
- identifying MWADZ Proposal stressors, environmental factors and potential impacts that would require examination in the PER.

Through this process, the following potential environmental amenity impacts resulted:

- excessive presence of macroalgae, phytoplankton and encrusting invertebrates on and around the sea cages;
- reductions in the natural visual clarity of the water;

- visible film the water from petrochemical origins;
- floating debris, dust or other objectionable matter; and
- presence of objectionable odours.

13.4 Assessment of Potential Impacts

13.4.1 Nuisance Organisms

The presence of macrophytes, phytoplankton scums, filamentous algal mats or blue-green algae may result if nutrient inputs from marine finfish aquaculture activities increase to levels in excess of that able to be assimilated by the surrounding environment. Aquaculture-related activities associated with the MWADZ Proposal include inputs such as fish feed and fish faeces, both of which have the potential to increase nutrient levels.

Should nuisance organisms be present in numbers or frequency above naturally-occurring levels, they may be considered to be impacting negatively on the aesthetic values of the MWADZ Proposal area. They also could contribute towards changes in some of the other environmental quality indicators outlined below.

13.4.2 Water Clarity

Water clarity is often considered an aesthetic indicator of environmental quality, particularly in naturally oligotrophic (i.e. low nutrient) marine environments such as the Abrolhos Islands. It has relevance to a number of recreational activities, including diving.

If aquaculture-related activities associated with the MWADZ Proposal, such as the inputs of fish feed and fish faeces, either directly or indirectly cause the visual clarity of the water to be reduced to levels significantly lower than natural levels, then they may be considered to be having a negative impact on the recreational and aesthetic values of the area.

13.4.3 Surface Films

Visible film on the water from oil or petrochemical origins is not only in conflict with what is considered to be a relatively pristine natural environment, but also likely to have a negative impact on the recreational and aesthetic values of the area. Aquaculture-related activity associated with the MWADZ Proposal that has the potential to result in oil or petrochemical spills or discharges include the operation of surface vessels and other fish farm machinery or equipment.

While the MWADZ Proposal would not be the only potential sources of this type of contaminant, it is important to demonstrate that these aquaculture-related activities do not significantly contribute to the problem.

13.4.4 Surface Debris

Like the oil or petrochemical surface films described above, water surfaces should be free of floating debris, dust or other objectionable matter. Again, these contaminants are inconsistent with an area valued for the relatively pristine status of its natural environment and are likely to be perceived as having a negative impact on these aesthetic values.

Consequently, it is important that aquaculture-related activities associated with the MWADZ Proposal do not contribute negatively to this issue.

13.4.5 Odours

Odours different to that naturally occurring, and particularly those perceived as objectionable, have the potential to have a negative impact on the recreational and aesthetic values of an area.

Therefore, aquaculture-related activities within the MWADZ Proposal area must be managed to avoid generating such odour emissions. The likelihood of this environmental quality indicator being an issue in the proposed MWADZ is the lowest of all the indicators outlined above.

13.5 Management Measures

The management measures to protect the environmental factor of amenity and maintain aesthetic values of the area within and surrounding the proposed MWADZ have been incorporated in the environmental quality management framework (EQMF) for the MWADZ Proposal in accordance with the guidance described in the EPA's EAG 15.

The objective of the aesthetic management program is to assess whether the Environmental Quality Guideline (EQG) and Environmental Quality Standard (EQS) have been met and to provide contextual information about the extent of aesthetic changes in the vicinity of the sea cages. The results of semi-quantitative and qualitative measurements will be compared against the EQG and EQS in Table 13-2, following those recommended in EPA (2015b).

Monitoring will be undertaken twice each year, in summer and winter. Monitoring will coincide with the seasonal water quality and sediment monitoring.

Table 13-2: Environmental quality criteria for the environmental quality objective of maintenance of recreation and aesthetics

Environmental Quality Indicators	Environmental Quality Criteria	
	Environmental Quality Guideline (EQG)	Environmental Quality Standard (EQS)
Nuisance organisms	Macroalgae, phytoplankton and encrusting invertebrates should not be present in excessive amounts on or around the sea cages.	There should be no overall decrease in the aesthetic water quality values of the Zeewijk Channel, Abrolhos Islands that are attributable to aquaculture using direct measures of community perception of aesthetic value.
Water clarity	The natural visual clarity of the water should not be reduced by more than 20%	
Surface films	Petrochemicals, such as engine oil, should not be noticeable as a visible film on the water or detectable by odour.	
Surface debris	Water surfaces should be free of aquaculture-derived floating debris, feed dust and other objectionable matter.	
Odours	There should be no objectionable odours.	

Note:
1. Derived from EPA (2015b)
2. Many of the environmental quality guidelines for aesthetic quality are subjective and relate to the general appreciation and enjoyment of the Abrolhos by the community as a whole. Consequently, when using these criteria, consideration should be given to whether the observed change is in a location, or of intensity, likely to trigger community concern and to whether the changes are transient, persistent or regular events.
3. Further investigation (environmental quality standards) involves direct measures of aesthetic value to determine whether there has been a perceived loss of value. For example, regular community surveys can be used to show trends in community perception of aesthetic value over time.

Assessment against the EQG will be supplemented via a questionnaire supplied to field personnel (Table 13-3). The questionnaire will be completed during the annual water quality monitoring survey and will be based on observations made adjacent to sea-cage clusters.

Assessment against the EQS will be based upon credible community observations of the aesthetics within the proposed MWADZ. Proponents will provide community users of the Abrolhos Islands FHPA and other relevant stakeholders with an open invitation to comment on any depreciation of the aesthetic values of the Zeewijk Channel that may be attributable to the aquaculture within the proposed MWADZ. The Department's website at www.fish.wa.gov.au will provide a mechanism by which the community and stakeholders can submit comments. Any decreases in aesthetic water quality values of the Zeewijk Channel will be measured as an increase in the number of complaints or a distinct change in the perception of the community (refer to EQS in Table 13.2). Instances of complaints will be recorded and documented in the Annual Report. All records associated with the monitoring, need to be included in the Annual Compliance Report.

Table 13-3: Field sheet for demonstrating compliance with environmental quality guidelines for aesthetics

Site: Date:	**Recorder:**	**Comments**
Environmental Quality Guideline		
Algal/plant material visible on surface?	Yes/No	
Water clarity (light attenuation)	Metres	
Petrochemical or other pollutants visible on surface?	Yes/No	
Floating debris visible on the surface?	Yes/No	
Noticeable odour associated with water?	Yes/No	

The decision scheme for assessing EQG and EQS related to aesthetics, including management responses following an exceedance of the EQC is summarised in Table 13-4.

Table 13-4: Management response following an exceedance of the environmental quality criteria for maintenance of aesthetic values

Environmental Quality Indicators	Management following trigger level exceedance	
	Environmental Quality Guideline (EQG)	**Environmental Quality Standard (EQS)**
All instances	Upon an exceedance of the EQG, the proponent will investigate the cause and the source of the exceedance. An exceedance of the EQG will result in further assessment against the EQS. Any instances of an exceedance of the EQG will be reported by the proponent in the Annual Compliance Report (a condition of the Ministerial Statement).	If there is a decrease in the aesthetic values of the Abrolhos Islands marine environment, as determined using direct measures of the community perception of aesthetic values, the proponent will consult with DoF and OEPA to determine an appropriate management response.

13.6 Predicted Environmental Outcome

The Abrolhos Islands are multi-use with an array of stakeholders, all of which have vested interest in preserving the unique features of the Reserve and the surrounding marine environment within the Fish Habitat Protection Area. These features include those relating to the EPA's environmental factor of amenity (EAG 8).

Amenity values are fundamentally reliant on the maintenance of the key environmental value of ecosystem health. Without ecosystem health, amenity values are inevitably diminished. By protecting this key environmental value through the establishment and implementation of an effective EQMF (EAG 15) specific to the MWADZ Proposal (refer to EMMP – Appendix 2), the environmental quality objectives of both ecosystem health and aesthetics will be protected and the impacts to amenity (EAG 8) reduced as low as is reasonably practicable.

14 ASSESSMENT OF POTENTIAL IMPACT ON NON-ENVIRONMENTAL MATTERS

14.1 Assessment Framework

While not within the scope of this PER, there have been several matters identified in the consultation process associated with the MWADZ Proposal that are not of an environmental nature but rather relate to social or economic issues. As some of these may be of interest to the public, they have been mentioned in this section as additional information.

It is important to understand that such matters are not an integral part of the PER and not matters to be considered by the EPA in its assessment of the MWADZ Proposal. However, including them in this document may assist stakeholders and the wider public to distinguish them from the environmental principles, factors and objectives that are the subject of this PER. Such a separation may be helpful when respondents frame their formal submissions during the public comment phase of the MWADZ Proposal PER process.

14.1.1 Socio-Economic Objectives

The MWADZ Proposal objective the Department has established for socio-economic values (i.e. values other than the environmental values addressed elsewhere in this PER) is:

"To take into account other uses of the MWADZ Proposal area while providing the opportunity for the development of ecologically-sustainable, large-scale, commercial aquaculture and associated economic benefits to the community."

14.1.2 Relevant Legislation, Policies, Plans and Guidelines

Table 14-1 lists the legislation, policies, plans and guidelines that are relevant to non-environmental considerations within the MWADZ Proposal area.

Table 14-1: Legislation, Policies, Plans and Guidelines Relevant to Non-Environmental Matters

Legislation, Polices, Plans and Guidelines	Intent
State	
Land Administration Act 1997	An Act to consolidate and reform the law about Crown land and the compulsory acquisition of land generally, to repeal the Land Act 1933 and to provide for related matters.
Fisheries Resources Management Act 1994	Provides a legal framework to conserve, develop, and share fish resources for the benefit of current and future populations in WA. This legislation also provides the management framework for the Abrolhos Islands reserve and for the establishment and management of the Fish Habitat Protection Areas.
The Houtman Abrolhos Islands Management Plan	Provides a management framework to conserve and promote the unique environmental and cultural heritage values of the Abrolhos for the benefit of present and future generations.
Environmental Assessment Guideline (EAG)	
Not applicable	
Commonwealth	
Not applicable	

14.2 Non-environmental Matters

14.2.1 Compatibility with Other Uses

14.2.1.1 Sea Use

While the physical presence of aquaculture infrastructure within the proposed MWADZ has the potential to impact on some components of the commercial sector of the community that have previously had an unrestricted level of access to all parts of this area (e.g. the AIMWMTF) access to the MWADZ will be non-exclusive. The use of State waters for aquaculture does not confer an exclusive access right and persons other than aquaculture licence holders may enter the zone and lease areas, although they are not permitted to interfere in any way with aquaculture gear.

14.2.1.2 Navigation

The lease area must be marked with approved buoys, markers, lights and signage in accordance with the "*Guidance Statement for Evaluating and Determining Categories of Marking and Lighting for Aquaculture and Pearling Leases/Licences (2010)*". This Statement can be accessed at the Department's website (www.fish.wa.gov.au/Documents/aquaculture_licencing/marking_and_lighting_guidance_statement.pdf). These requirements will be a condition on the aquaculture licence.

14.2.1.3 Conservation

The MWADZ Proposal area is located within the Abrolhos Islands FHPA and the strategic and management objectives of the Abrolhos Islands FHPA Strategic Plan and Management Plan have been considered in the development of this proposal. The aquaculture activities associated with the MWADZ Proposal are consistent with the purposes [prescribed in s.115 (2) of the FRMA and reflected in the Abrolhos Islands Fish Habitat Protection Area Order 1999] for which the Abrolhos Islands FHPA was created.

The MWADZ Proposal area is not in the vicinity of any of the FHPA Reef Observation Areas and is most unlikely to have any impacts upon them.

14.2.1.4 Mining and Oil Exploration

The provisions of mining and petroleum-related statutes (Acts) permit petroleum and gas exploration activities in the Abrolhos Islands. Four petroleum exploration wells were drilled in waters surrounding the Abrolhos Island in the late 1960s and 1970s. These wells have been capped and abandoned (Webster, F *et al.* 2002). Currently, there are no active exploration permits in the strategic MWADZ Proposal area. The proposal is therefore likely to have no impact on mining and oil and gas exploration within the area. Figure 14-1 highlights the current oil and gas exploration permits that are within the vicinity of the MWADZ Proposal.

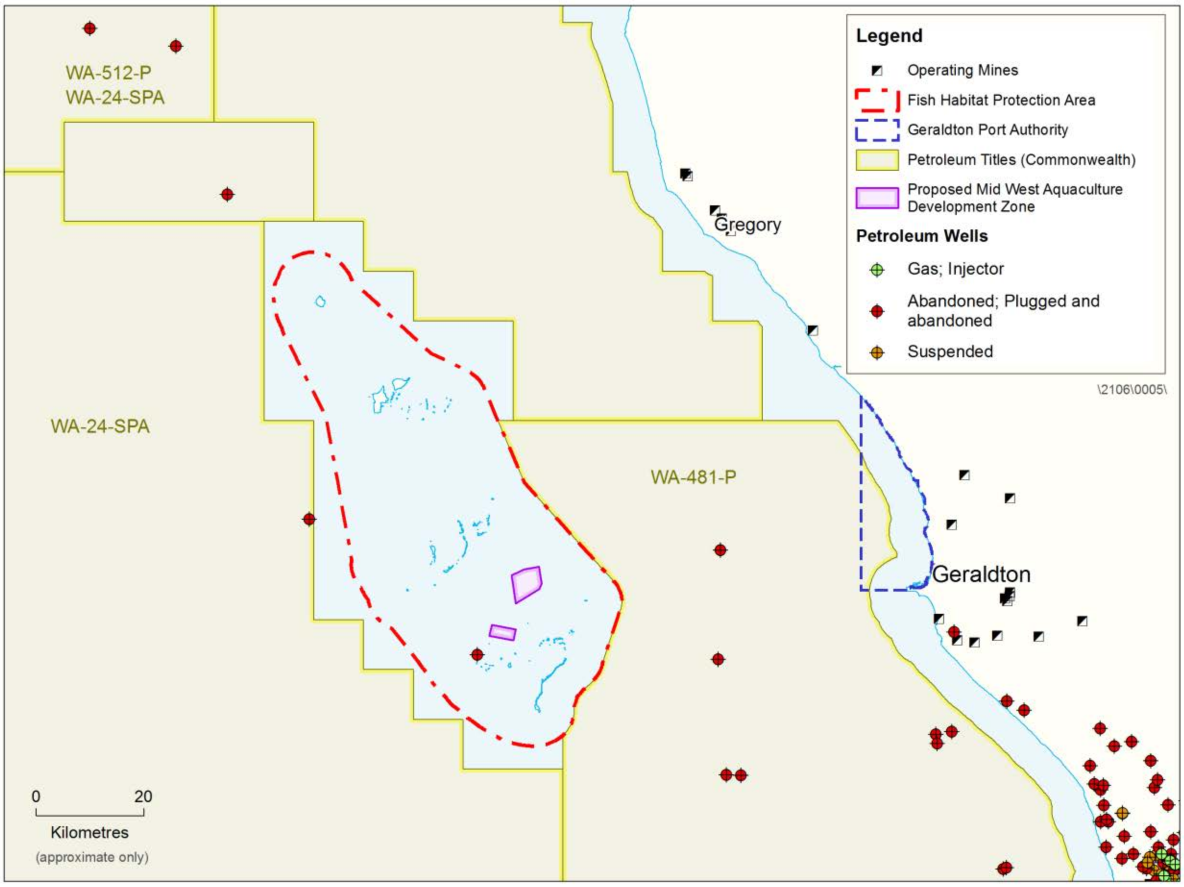

Figure 14-1: Oil and Gas Exploration Permits within the vicinity of the MWADZ

14.2.2 Workforce Health and Safety

The Abrolhos Islands is situated in a remote location which is only accessible by sea-going vessels or appropriate aircraft. The reefs, shoals and currents around the area make it a very difficult area to navigate and considerable caution must be taken when transiting the area.

The MWADZ Proposal area is approximately 65 kilometres offshore of Geraldton and will only be accessible by boat. The closest airstrip to the proposed zone is at Rat Island in the Easter Group of the Abrolhos Islands and is only suitable for light aircraft.

Mobile telephone coverage of the proposed MWADZ area is variable (depending on the prevailing conditions) and cannot be relied upon for matters relating to human safety.

Under Regulation 113AA of the FRMR, the master of a boat must not use the boat to travel to the Abrolhos Islands Fish Habitat Protection Area unless the master gives notice to the Department of the period of stay of the boat in the Abrolhos Islands Fish Habitat Protection Area. This requirement provides the opportunity to obtain information about who is in the FHPA at any one time and how they may be contacted should the need arise (e.g. approaching cyclone). This will facilitate evacuation operations should the need arise. A web-based notification facility will soon be available for these purposes.

14.2.2.1 Cyclone Protection

Tropical cyclones are known to occur periodically at the Abrolhos Islands during the summer months, with one occurring on average every five years (Webster, F *et al.* 2002). During these cyclone events winds can reach up to 165 kilometres per hour, once every 50 years, with 176 kilometre per hour winds possible once every 100 years (Webster, F *et al.* 2002).

14.2.2.2 Emergency Evacuation

All emergency management arrangements at the Abrolhos Islands are currently managed by the Batavia Emergency Management Committee (BEMC) and coordinated by City of Greater Geraldton (pers. comm. Natalie Moore 2015). Under Section 38 of the *Emergency Management Act 2005*, a local government is required to establish one or more Local Emergency Management Committees (LEMCs) for the local government district. The BEMC is the LEMC responsible for the coordination of emergency evacuations at the Abrolhos Islands. The functions of a LEMC, in relation to its district or the area for which it is established, are:

- to advise and assist the local government in ensuring that Local Emergency Management Arrangements (LEMAs) are established for its district;
- to liaise with public authorities and other persons in the development, review and testing of the LEMA; and
- to carry out other emergency management activities as directed by the SEMC or prescribed by the regulations.

Any aquaculture licence holders who operate within the MWADZ will be required to abide by the management arrangements within the LEMA emergency evacuation plan for the Abrolhos Islands. Emergency evacuation will be via helicopter and/or aeroplane, utilising the local airstrips at Rat Island or East Wallabi Island. It is intended that non-critical evacuations be transported via boat to the airstrip, while critical evacuations will be via helicopter direct from the island.

The Department of Fisheries is proposing to develop and implement an Emergency Management and Evacuation Plan in consultation with relevant stakeholders and management agencies. The plan is intended to address all high risk emergency events for the Abrolhos and incorporate requirements for training exercises and regular review (Department of Fisheries 2012c).

14.2.3 Commonwealth, State and Regional Economy

The City of Greater Geraldton local catchment area spans an area of approximately 12,625 square kilometres, of which a large proportion is farming land and rural areas along with areas of residential, industrial, commercial, mining and conservation reserves. In January 2015, the Abrolhos Islands was moved from the Northampton local government catchment area to the City of Greater Geraldton catchment area.

In the City of Greater Geraldton[45] the current population is approximately 41,087 people. The area has experienced considerable growth over the last ten years with a grow rate of approximately 17.2% since 2001. This trend is expected to continue.

The local economy is made up of retail trade, construction, agriculture, mining, fishing, health care, public administration and safety, accommodation and food services and education and training. In 2014, the City of Greater Geraldton's Gross Regional Product (GRP) was estimated at $2.853 billion. Greater Geraldton represents 49.74% of Mid West region's GRP of $5.735 billion, 1.08% of Western Australia's Gross State Product (GSP) of $264.545 billion and 0.18% of Australia's GRP of $1.584 trillion.

The largest industry sectors are mining (15.2%), manufacturing (14.5%), construction (12.1%) and rental, hiring and real estate (9.2%). The three most popular occupations are technicians and trade workers, professionals and administrative workers.

The Abrolhos Islands attracts significant economic and tourist activity, providing substantial benefits to the Western Australian community. The main activities conducted in the area include commercial fishing for rock lobster, scallops and finfish, as well as aquaculture for pearls and coral, recreational fishing, diving and bird watching and tourism. The West Coast Rock Lobster Managed Fishery is the most economically valuable industry at the Abrolhos Islands. Over the past ten years the total value of rock lobster landed in the fishery has ranged between $30 and $50 million a year (Webster, F *et al.* 2002).

The West Coast Rock Lobster Managed Fishery supports a number of local businesses in the Geraldton area, in particular the Geraldton Fisherman's Co-operative (GFC). GFC is one of the largest rock lobster processors in the world, exporting 3,572 tonnes in 2013-14 with a turnover of approximately $237 million. Around 90% of rock lobster captured from the Abrolhos Islands is exported via air to China as "live" animals. Small quantities of frozen product are also exported to countries such as Japan, Taiwan, Hong Kong, Dubai and USA.

Implementation of the MWADZ Proposal should have no significant negative economic impacts on these existing industries but rather provide significant additional rural business opportunities close to the diverse and well-established urban infrastructure of Geraldton. It builds upon the City's traditional strengths in the areas of fishing and maritime servicing vessels, harbour and maintenance facilities and seafood processing establishments. These supporting factors will increase the region's marketability in terms of attracting aquaculture developments. Broader industry growth stimulated by the establishment of an aquaculture zone will generate direct employment as well as substantial flow-on effects for local business and service industries.

These benefits will flow on through State and Commonwealth economies.

14.2.3.1 Employment

The MWADZ Proposal is expected to deliver employment and skill development opportunities that benefit the local and regional population.

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[45] Note that most of the information in this section was obtained from the City of Greater Geraldton Website 2015.

The implementation of the MWADZ Proposal will stimulate the local and regional economy and create new business opportunities (or expand existing ones). It builds on the traditional strengths of the City of Greater Geraldton, particularly in respect to the fishing, maritime and agricultural industries (aquaculture is another form of farming) and will use local goods and services.

It will also provide the tourism industry with an opportunity to diversify experiences available to visitors.

14.3 Conclusion

In summary, the potential non-environmental impacts of the MWADZ Proposal are not predicted to adversely interfere with, or compromise, other social or economic uses of the proposed area. The potential impacts are considered to be able to be managed to acceptable levels by the implementation of the EMMP, the zone Management Policy, the MEMP, and the other plans, protocols and management measures outlined in this PER.

15 ENVIRONMENTAL MANAGEMENT FRAMEWORK

15.1 Overview

The Environmental Management Framework is an overarching strategy that is built not only upon the fundamental environmental requirements of the EP Act, but also draws on the Department's own statutory requirements and associated policies and guidelines to translate the commitments and management measures identified into the development of the MWADZ Proposal. These existing documents, as well as those developed specifically for the MWADZ Proposal, will be used as an integrated mechanism through which the environmental management, mitigation measures, monitoring and reporting requirements associated with the MWADZ Proposal will be implemented (refer to Section 15.3.1).

This section outlines the three tiers of the management framework, from the Department's statutory responsibilities under the *Fish Resources Management Act 1994* (FRMA), the implementation through policy and other documentation of the objects of the FRMA and the reflection of these objectives and requirements in the MWADZ Proposal documentation.

15.2 Tier 1 – Ecologically Sustainable Development Obligations under the *Fish Resources Management Act 1994*

15.2.1 Statutory Requirements

The objects of the *Fish Resources Management Act 1994* (FRMA) provide as follows:

"Objects

(1) The objects of this Act are —
- *(a) to* ***develop and manage*** *fisheries and* ***aquaculture in a sustainable way****; and*
- *(b) to* ***share and conserve*** *the State's* ***fish*** *and other aquatic resources* ***and their habitats*** *for the* ***benefit of present and future generations****.*

(2) Those objects will be achieved by these means in particular —

(a) conserving fish and ***protecting their environment****;*

(b) ensuring that the ***impact of*** *fishing and* ***aquaculture on aquatic fauna and their habitats is ecologically sustainable*** *and that the* ***use*** *of all aquatic resources* ***is carried out in a sustainable manner****;*

(c) enabling the ***management of*** *fishing,* ***aquaculture****, tourism that is reliant on fishing, aquatic eco-tourism and associated non-extractive activities that are reliant on fish and the aquatic environment;*

(d) fostering the ***sustainable development of*** *commercial and recreational fishing and* ***aquaculture****,* ***including the establishment and management of aquaculture facilities for community or commercial purposes****;*

(e) achieving the ***optimum economic, social and other benefits from the use of fish resources****;*

(f) enabling the ***allocation of fish resources between users*** *of those resources, their reallocation between users from time to time and the management of users in relation to their respective allocations;*

(g) providing for the ***control of foreign interests in*** *fishing,* ***aquaculture*** *and associated industries;*

(h) enabling the ***management of fish habitat protection areas and the Abrolhos Islands reserve****."*

Note: Text in bold for emphasis only.

As the State Government agency responsible for the administration of the FRMA, these objects direct the business of the Department of Fisheries WA and guide the development, implementation and on-going maintenance of the MWADZ Proposal.

These objects embody the principles of ecologically sustainable development [i.e. same as the environmental principles (s. 4A) of the EP Act].

15.2.2 Department of Fisheries Western Australia - Policy

The objects of the FRMA are encapsulated in the Department's Ecosystem Based Fisheries Management (EBFM) approach, which views the management of the State's aquatic resources under a holistic EBFM Framework[46]. This comprehensive, risk-based framework takes into account all ecological resources, including assets such as marine mammals that fall outside the remit of the FRMA, as well as social and economic factors in deciding how to manage aquatic resources.

The Western Australian Fisheries Policy Statement 2012 outlines the Western Australian Government's position on, and vision for, the use of the State's fish and aquatic resources by the commercial (including pearling and aquaculture), recreational and Aboriginal customary fishing sectors.

The following broad-scale policies also provide guidance by which the objects of the FRMA will be implemented through the MWADZ Proposal:

- *Aquatic Biosecurity Policy*

[46] Refer to http://www.fisheries-esd.com/a/pdf/Fletcher%20et%20al%20EBFM%20framework.pdf

- Promotes the conservation and protection of fish, fisheries and fish habitat by minimising the negative impacts of aquatic pests and diseases in Western Australia's marine and fresh waters. The focus is on prevention of aquatic pest and disease establishment and continuous improvement of biosecurity practices.

- *Integrated Fisheries Management Policy 2009*

  - Allows for the allocation of fish resources between users.

- *The Houtman Abrolhos Islands Management Plan Fisheries Management Paper No. 260*

  - Provides strategic and management objectives and strategies for the Abrolhos Islands Reserve and the Abrolhos Islands Fish Habitat Protection Area.

15.3 Tier 2 – Environmental Assessment and Monitoring Program

15.3.1 Environmental Impact Assessment Documentation

15.3.1.1 Environmental Monitoring and Management Plan

A condition for environmental approval of the MWADZ Proposal is the implementation of an Environmental Monitoring and Management Plan (EMMP - Appendix 2). The EMMP has been developed to provide proponents with an appropriate environmental quality management framework (EQMF) for managing the potential impacts of stocking up to 24,000 tonnes of marine finfish across the MWADZ (EMMP - Appendix 2).

Maintenance of ecosystem integrity is concerned with maintaining the structure and functions of marine ecosystems to an appropriate level. In this context, the EQMF (refer to the EMMP - Appendix 2) includes mechanisms to protect the key environmental factor, "marine environmental quality" and the associated environmental objective, "*To maintain the quality of water, sediment and biota so that the environmental values, both ecological and social, are protected*". By protecting "marine environmental quality", all associated environmental values of Western Australian coastal waters under the EQMF are protected from impacts related to the degradation of that marine environmental quality (Section 7.5.1). The relevant EQMF environmental values of Western Australian coastal waters that are protected include:

- ecosystem health;
- fishing and aquaculture;
- recreation and aesthetics;
- industrial water supply; and
- cultural and spiritual.

As aquaculture production in the MWADZ increases towards the maximum capacity standing fish stock biomass, the EMMP will ensure future derived proposals are managing all key environmental factors identified in the strategic proposal (in the context of EAG 8). The EMMP includes proactive management strategies and mechanisms by which proponents will protect the environmental factors of:

- marine environmental quality;

- benthic communities and habitat;
- marine fauna;
- amenity; and
- heritage,

in addition to providing evidence of this through multiples lines of evidence across a range of environmental quality indicators.

Implementation of the EMMP by proponents will achieve the environmental objectives by maintaining the:

- structure, function, diversity, distribution and viability of benthic communities and habitats at local and regional scales;
- quality of water, sediment and biota so that the environmental values, both ecological and social, are protected; and
- diversity, geographic distribution and viability of fauna at the species and population levels.

By protecting important biological and ecological values of the Abrolhos region, including its significant marine mammal, turtle, seabird, wild finfish and invertebrate populations, its biosecurity and fisheries (refer to Sections 7, 8, 9, 10 and 11) other environmental factors and values (e.g. heritage and amenity – Sections 12 and 13) are also protected (EMMP - Appendix 2).

The EMMP provides important strategies to manage the anticipated pressures associated with the MWADZ Proposal on the key environmental factors, while maintaining broader regional environmental quality. Small localised effects, at a moderate level of ecological protection, will be managed beneath and immediately adjacent to the MWADZ sea cages, while maintaining overall environmental integrity of the surrounding area of the Zeewijk Channel at the Abrolhos Islands (EPA 2015).

The small localised effects of aquaculture will be confined to “floating” (i.e. moveable but linked to the location of the sea cage clusters) moderate ecological protection areas (MEPAs) within the MWADZ Proposal footprint. The area surrounding the MEPAs will be protected at a high level of ecological protection (HEPA), commensurate with the high ecological protection area status of the waters surrounding the MWADZ Proposal area (Figure 15-1).

Following commencement of aquaculture operations, operators will be required to demonstrate compliance with the environmental quality objectives (EQOs). The extent to which the EQOs have been achieved will be assessed against a suite of environmental quality criteria (EQC). The EQC, comprising guidelines and standards, provide the benchmarks against which environmental quality is measured. Unlike the EQOs, which are qualitative and described as a narrative, the EQC are quantitative and described numerically (EPA 2015; EMMP - Appendix 2).

Specifically, this EMMP will facilitate the maintenance of ecosystem integrity during the operation of the zone by providing the following set of mechanisms:

- indicators to be measured and monitoring protocols;
- areas of ecological protection and their corresponding thresholds (EQC);

- mitigation and management measures to be employed in the event of an EQC being exceeded;
- an adaptive monitoring and management approach (including a feedback loop); and
- a reporting structure.

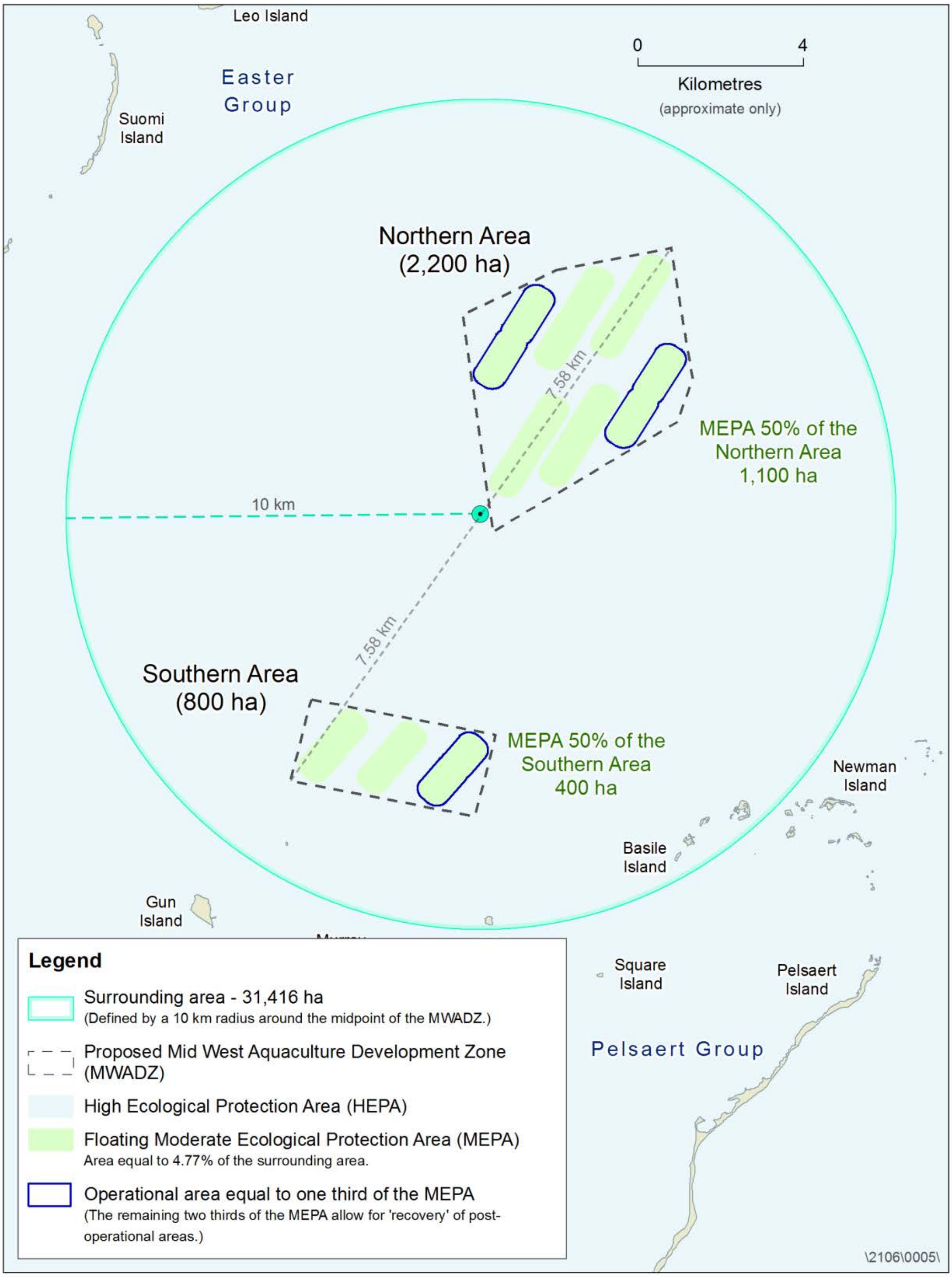

Figure 15-1: Conceptual overview of the EQO "maintenance of ecosystem integrity" for the proposed MWADZ – Location of MEPAs and HEPAs

15.3.1.2 Aquaculture Development Zone Management Framework

The Department will manage the zone within an integrated management framework that incorporates the statutory requirements of both the EP Act and the FRMA. Figure 15-2 provides details of this overarching management framework, its main elements and their inter-relationships.

The management framework comprises the zone Management Policy (Management Policy) and several associated instruments and documents.

In relation to the zone, the purpose of the management framework is to:

- establish an overarching, integrated structure for managing the aquaculture activities;
- provide clear, efficient and effective processes for monitoring, evaluating and reporting;
- continuously improve the approach being used to manage the zone;
- guide the development of marine finfish aquaculture; and
- ensure adaptive management occurs as part of a process of continuous improvement.

15.3.1.3 Aquaculture Development Zone Management Policy

The Management Policy comprises the core of the overarching management framework for the zone. It recognises the statutory requirements of both EP Act and FRMA as they relate to the MWADZ Proposal and position them in a structure such that they integrate with and support each other to ensure environmental values are protected and ecologically sustainable development of aquaculture can occur.

The Management Policy may include or define:

- the zone area, location and co-ordinates;
- spatial separation distances between leases;
- operational requirements including method, gear and feed inputs;
- waste management;
- zone biosecurity, including disease testing and fish health; and
- compliance, including reporting (i.e. triggers reached) and audit mechanisms (such as agreement by all parties on monitoring of reference sites).

15.3.1.4 Ministerial Statement and Conditions

The Department (as the proponent of the strategic assessment approved by the EPA) is required to ensure any conditions defined in the Ministerial Statement (issued under sections 40B and 45 of the EP Act) are reflected in the management framework.

The Ministerial Statement identifies:

- future proposals, which may be implemented if declared to be derived proposals; and
- conditions, which may control the implementation of the derived proposals.

These conditions relates to matters such as:

- compliance planning and reporting;
- public availability of data; and
- implementing the requirements of the EMMP.

15.3.1.5 Section 45A Notice

A Section 45A Notice (under the EP Act) issued to a future proponent provides for:

- implementation of derived proposals; and
- sets the conditions of the Ministerial Statement that apply to the derived proposal.

15.3.1.6 Management and Environmental Monitoring Plan (MEMP)

The Management and Environmental Monitoring Plan (MEMP) describe management and environmental monitoring parameters that are similar to those found in the EMMP. Consequently, in order to avoid duplication in structure and reporting, many elements of each operator's MEMP will likely make reference to the corresponding element of the EMMP.

Under the Department's internal MEMP Policy, the MEMP of each license holder operating within an Aquaculture Development Zone must comprise (and refer to) the relevant Management Policy and EMMP for the zone.

The annual report is a major requirement of MEMPs. This requirement is consistent with enhancing self-management by aquaculture licence holders through targeted audits and regular reporting. It will also help them ensure greater compliance with licence and lease conditions.

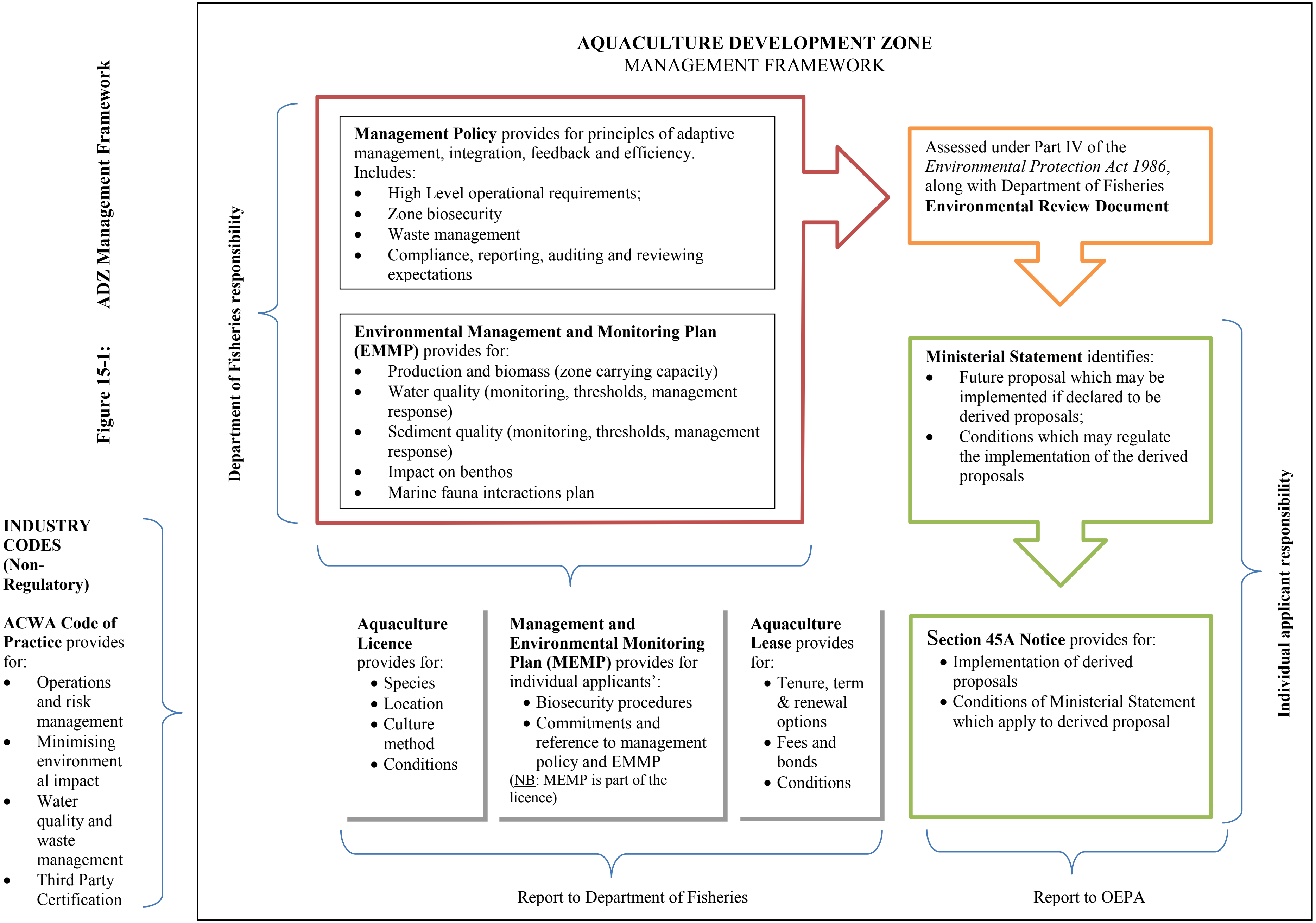

Figure 15-1: ADZ Management Framework

15.4 Tier 3 – Subsidiary Documents

15.4.1 Marine Fauna Interaction

To support the management of potential impacts associated with the EPA's key environmental factor of marine fauna, a separate Marine Fauna Interaction Management Plan (MFIMP) has been developed specifically for the MWADZ Proposal (refer to Appendix 5). This MFIMP focuses primarily on managing potential impacts to marine mammals, marine reptiles and marine avifauna. Specifically, this MFIMP:

- provides an overview of the potential impacts that may occur to marine fauna during the installation process and operational activities;
- outlines management measures and actions adopted to mitigate potential impacts to marine fauna during the sea cage installation process and during operational activities;
- outlines the monitoring requirements/programs required to be serviced by operators within the MWADZ; and
- outlines the marine fauna incident reporting and response strategies required of operators within the MWADZ.

The primary aim of this MFIMP is to ensure that activities conducted within the proposed MWADZ do not cause any significant disturbance to marine fauna within the Abrolhos Islands Fish Habitat Protection Area (FHPA).

The objectives of this plan include minimising:

- human interactions with marine fauna;
- any potential injuries or fatalities to marine fauna that may result from collision with vessels or entanglement;
- noise and vibration disturbance to marine fauna;
- potential impacts to marine fauna from artificial light;
- potential impacts posed to marine fauna by aquaculture infrastructure; and
- adverse effects of fish farming activities within the proposed MWADZ on marine fauna.

This MFIMP considers the EPA Scoping Document's work requirements for the MWADZ by assisting to address the EPA environmental factor "marine fauna" and its associated objective "*To maintain the diversity, geographic distribution and viability of fauna at the species and population levels*". More detailed information is available at Appendix 5.

15.4.2 Waste Management

A stand-alone Waste Management Plan (WMP) has been developed for the MWADZ Proposal (refer to Appendix 6). This WMP:

- identifies, describes and provides guidance on the various waste products that are common to aquaculture facilities including, general rubbish and sewage treatment;
- identifies potential fuel and oil spills and provides guidance for appropriate action and reporting; and

- identifies, describes and provides guidance on the disposal of biological waste common to aquaculture facilities including fish processing waste and mortalities/culls including appropriate biosecurity considerations.

The WMP encourages the use of the Waste Hierarchy detailed in the EPA's Guidance for the Assessment of Environmental Factors No. 55 (2003). Specifically:

1. avoidance of waste production;
2. reuse of wastes;
3. recycling wastes to create useful products;
4. recovery of energy from wastes;
5. treatment of wastes to render them benign;
6. containment of wastes in secure, properly managed structures; and
7. disposal of waste safely in the long term.

Note: any reuse or re-cycling of aquaculture facility products must be done in accordance with biosecurity procedures.

More detailed information is available in the WMP at Appendix 6.

15.4.3 Decommissioning

While not in the form of a separate document, should the MWADZ Proposal ever require decommissioning, the proponent (i.e. the Department of Fisheries on behalf of the Minister for Fisheries) will ensure all operators within the MWADZ clear their lease sites in accordance with the provisions of the *Fish Resources Management Act 1994* and subsidiary legislation as outlined at Section 2.6 of this PER document.

15.4.4 Aquaculture Industry Code of Conduct

Recently revised by ACWA, the *ACWA Environmental Code of Practice for the Sustainable Management of Western Australia's Marine Finfish Aquaculture Industry* (CoP) allows industry members to demonstrate their commitment to operating within the principles of ESD. It focuses on best practice through a documented environmental management system (EMS) and recommends a continuous improvement requirement where the business periodically reviews and evaluates its EMS to identify and implement opportunities for improvement.

The CoP provides recommendations licence holders should follow to remain compliant with the Code, and makes references to the requirements they are obliged to comply with under the legislative framework. Recommendations cover matters associated with:

- facility operations and risk management;
- minimising environmental impacts from production; and
- water quality and waste management.

The CoP emphasises that licence holders must collect and retain specified information on their operations and to formally declare that they have been acting in accordance with licence conditions and the intent of the CoP.

16 CONCLUSION

16.1 Cumulative Impacts

A cumulative impact assessment was considered of the potential incremental impacts, in terms of the environmental and social factors outlined in this PER, of the MWADZ Proposal. The cumulative impact assessment evaluated the potential incremental impacts of the MWADZ Proposal when combined with other present and reasonably foreseeable future actions in the vicinity of the proposed MWADZ area.

The cumulative impact assessment was based on a mostly qualitative, high-level analysis of potential impacts using professional judgement of subject matter experts, supported by baseline information (current and historic) and a range of quantitative assessments, including an Integrated Ecosystem Model (Model). The Model was able to predict the cumulative environmental effects of the proposed aquaculture, operating across a range of potential production scenarios. The ecosystem Model was capable of simulating regional oceanographic water movements, the deposition and dispersal of wastes from sea cages, the effects of these wastes on the marine environment, and the rate of environmental recovery. (EMMP – Appendix 2).

The location of the proposed MWADZ area is relatively remote (i.e. ~65 kilometres offshore of Geraldton) and its marine environment has only been subject to light and occasional anthropogenic use, principally by the Abrolhos Islands and Mid West Trawl Managed Fishery. With a benthos that is composed mostly of sand, it has not been used and is unlikely to be used in the future for other purposes.

At the maximum 24,000 tonne stocked fish standing biomass limit recommended, no unacceptable cumulative impacts to the marine, terrestrial, social and cultural environment are predicted to occur as a result of the MWADZ Proposal. With the mitigation and management controls in place, as outlined in this PER, the potential cumulative impacts are managed to meet the objectives established for the MWADZ Proposal.

16.2 Proposed Management

The Environmental Scoping Document (ESD) associated with the Mid West Aquaculture Development Zone (MWADZ) strategic proposal (Assessment No. 1972) was determined by the Environmental Protection Authority (EPA) in July 2013. This document defined the requirements of the PER document that were to be met by the Department of Fisheries (Department) on behalf of the Minister for Fisheries (the proponent for the MWADZ strategic proposal).

The preliminary key environmental factors, scope of works and policy documents relevant to the MWADZ Proposal and required to be addressed in the PER document included the EPA's Environmental Assessment Guidelines (EAG) No.3 Protection of Benthic Communities Habitats in Western Australia's Marine Environment (2009) and the EPA's EAG No.7 Marine Dredging Proposals (2011). Although the MWADZ Proposal didn't involve dredging, the principles and approaches for describing the potential impacts and addressing predictive uncertainty outlined in the latter EAG could be applied when assessing impacts to primary producing and non-primary producing communities and habitat.

These documents played a significant role in shaping the Department's approach towards developing the Environmental Monitoring and Management Plan (EMMP) for the MWADZ Proposal. The EMMP consists of a series of sub-management plans, monitoring programs and protocols that address the potential environmental impacts identified in the PER.

Given there is a level of uncertainty in predicting the long-term consequences of conducting sea cage aquaculture in the Mid West, the Department, with the assistance of its environmental consultant (BMT Oceanica), chose to adopt a conservative approach to developing the EMMP. This conservative approach was taken to ensure that the potential scale and intensity of the potential cumulative impact of the proposed aquaculture operations in the MWADZ on the local marine environment was not understated. In other words, it consistently focused on what could be termed the "most likely worst case" scenario when considering the inputs of aquaculture activity (e.g. fish faeces and uneaten fish feed) and their potential impacts on the receiving environment.

Such an approach was reinforced by the available published literature (albeit mostly relating to marine finfish aquaculture in the Northern Hemisphere) pertaining to the potential environmental impacts that may be associated with large-scale marine finfish sea cage aquaculture, supplemented by the outcomes of the environmental modelling undertaken for the MWADZ Proposal.

While this approach can be effective in reducing the likelihood of any unforeseen negative environmental impacts associated with the MWADZ Proposal, it can also result in an overly negative perception of the magnitude of the likely "actual" environmental impacts of the proposal, and (in this instance) the resultant levels of ecological protection considered appropriate when designing the proposal Environmental Quality Plan (EQP).

The combined effects of these factors led to the Department (through its environmental consultants) exploring the possibility of incorporating the principles described in Environmental Assessment Guidelines No.7 Marine Dredging Proposals (2011) in the design of the MWADZ EQP. This idea was supported in that both the published literature and the environmental modelling undertaken indicated the primary environmental impact of the proposed aquaculture was to the sediments immediately beneath the sea cages; but that such impacts did not extend significantly beyond this deposition area. At the same time, the impact of the aquaculture activity on water quality was likely to be negligible. In this respect, the anticipated behaviour of the organic inputs and the resulting environmental impacts of the MWADZ Proposal more closely reflected those expected of (say) a wastewater outfall rather than that previously thought to represent sea cage aquaculture (such as in some other locations within the State).

As a consequence, based on the available information and outputs of the 'conservative' environmental impact modelling undertaken, an EQP based on a small total area of Low Ecological Protection Area (LEPA), (occupying less than one per cent of the area encompassed within a ten kilometre radius of the zone), surrounded by larger areas of High Ecological Protection Area (HEPA) was contemplated. This was considered to reflect the 'likely worse case' scenario.

However, while the Department was confident that such a level of impact and effect is at the upper end of what might be expected and would not be exceeded by the aquaculture activity,

it was of the view that, through good farm management, a better environmental outcome could be achieved. It was also conscious that the resultant 'low' level of ecological protection is not consistent with the recently-published EPA EAG No. 15 Protecting the Quality of Western Australia's Marine Environment (2015) (EAG 15). This document, among other things, sets out the EPA's views on the level of ecological protection it would normally expect to be applied, and the environmental values expected to be protected, in relation to certain types of marine areas, including those areas subject to sea cage aquaculture. For this sea cage aquaculture, EAG 15 suggests the most appropriate level of ecological protection is a Moderate Ecological Protection Area (MEPA).

As set out above, the level of uncertainty and the conservative approach to predicting the potential impacts of the proposed MWADZ in the PER resulted in a level of protection that would likely equate to 'Low'. However, the EAG 7 approach, which is designed for dealing with dredging proposals that typically have similar "levels of uncertainty" involved in predicting impacts to that of large-scale aquaculture, suggests that proponents of derived proposals should not only consider the 'most likely worst case' but should also consider the 'most likely best case'. The latter would indicate the level of impact that would occur if realistic, but less conservative (i.e. more optimistic), assumptions were considered and optimum levels of management were achieved.

Due to the lack of published literature relating to marine finfish sea cage aquaculture in sub-tropical waters where the sea bed predominately comprises calcareous sediments (i.e. like the proposed MWADZ), the design of the EQP for the MWADZ Proposal was based on studies conducted in temperate waters in the Northern Hemisphere and on locations that have sediments markedly different (and arguably more vulnerable to environmental impacts from aquaculture) to those present in the proposed MWADZ. In addition, the relatively 'shallow' depth of sediment in the proposed MWADZ and the likely periodic influence of storms, which could rework and mobilise sediments, provides a plausible mechanism to reduce organic matter accumulation rates and consequential sediment anoxia.

Combined, the overstating of potential sediment impacts due to the design basis for the EQP (i.e. Northern Hemisphere examples) and the understating of the potential ameliorating effects of shallow sediment depth and periodic storm activity have probably contributed to a far more pessimistic (i.e. worst case) assessment of the likely environmental impacts of the proposed aquaculture activity being incorporated in the modelling than should have been the case.

Considered from this viewpoint, a likely 'best case scenario' would be that organic enrichment and associated levels of oxygen depletion/hydrogen sulphide production would probably **not** occur to the same extent as that generated through the conservative modelling. Under this scenario, it is possible that the resultant environmental quality would more closely resemble that characterised as a 'moderate' level of ecological protection (i.e. MEPA).

The combined effect of the factors set out above creates some uncertainty as to whether the most appropriate EQP approach for the MWADZ Proposal should be based on a LEPA or MEPA. While not dismissing the potential applicability of the LEPA approach to the proposed MWADZ, the Department acknowledges this approach is built upon the worst case scenario and may not be the only viable approach. It recognises the uncertainty surrounding this matter and acknowledges the need to monitor and collect the relevant information necessary to remove this uncertainty.

Consequently, the Department now proposes a different approach in the EMMP for the MWADZ. This approach is iterative, informed by the results of the monitoring and other information gathered over time and aims to ascertain the most appropriate environmental management arrangements for the MWADZ Proposal. The approach includes the following key elements:

- Apply a MEPA approach to the EQP;
- Apply a 24,000 tonne standing biomass limit;
- Implement a specially-designed environmental monitoring program with the aim to acquire the scientific data necessary to clarify what EQP approach is the most appropriate for the MWADZ (noting this monitoring program is not intended to create an additional operational or financial burden to industry);
- Review all information collected over the first ten years[47] of commercial operations in the zone to clarify the continuing:
    - ✓ appropriateness of the current (MEPA) EQP approach;
    - ✓ environmental compatibility of the 24,000 tonne standing biomass limit for the MWADZ; and
- Subject to the outcomes of the review, thereafter, continue the iterative MWADZ management processes of monitoring, evaluation, review, planning and implementation conducted in consultation with industry and other relevant stakeholders.

It is important to note that, no matter what the outcome, the environmental monitoring program implemented for the MWADZ Proposal and the adaptive management tools available to the aquaculture operators (i.e. derived proponents) and the Department will ensure a rapid and effective response to the information gathered as aquaculture development in the zone progresses. Collectively, these arrangements will ensure both the environmental integrity of the Abrolhos Islands Fish Habitat Protection Area is preserved; and (within this imperative) the sustainable commercial aquaculture opportunities are maximised.

The EMMP (Appendix 2) for the MWADZ Proposal enables the MWADZ to be developed with greater certainty for the Government, the industry and the community.

The EMMP, coupled with the Management and Environmental Monitoring Plan (MEMP), will ensure the commitments in this PER, subsequent assessment reports and any approval or licence conditions are fully implemented.

The key objective of the EMMP is to ensure the MWADZ Proposal is sustainably managed and that its operation does not have a significant impact on the marine environment. The EMMP will provide an appropriate environmental quality management framework (EQMF) to manage the potential impacts of stocking up to 24,000 tonnes of marine finfish across the proposed MWADZ, using pelletised feeds. The aim is to make sure the MWADZ Proposal is managed to achieve the relevant Environmental Values (EVs) and Environmental Quality Objectives (EQOs), as outlined in EAG 15 and the State Water Quality Management Strategy (Government of Western Australia).

[47] By the tenth year of commercial operations in the MWADZ operators should have achieved a complete rotation of their sea cage cluster locations throughout their lease and be back at the (year 1) commencement site. They are also likely to be operating close to their maximum allocated standing biomass limits.

While all the EVs and associated EQOs for the marine waters of Western Australia have been addressed in this PER (Section 7.5), the key EQOs most relevant to this EMMP are:

- maintenance of ecosystem integrity; and
- maintenance of aesthetic values.

Maintenance of ecosystem integrity is concerned with maintaining the structure (e.g. the variety and quantity of life forms) and functions (e.g. the food chains and nutrient cycles) of marine ecosystems to an appropriate level. In this context, the EMMP includes strategies and contingency management responses to protect the key ecosystem elements (EPA 2015), taking into account their occurrence and sensitivity to aquaculture pressures. These key ecosystem elements include:

- water quality
- sediment quality
- seabirds
- marine mammals and turtles
- finfish (including sharks and rays)

Maintenance of aesthetic values is concerned with maintaining the visual qualities of the marine environment, including water clarity, odours and incidences of debris (EPA 2015). The monitoring and management frameworks for the ecosystem and aesthetic elements are outlined in the EMMP (Appendix 2).

16.3 Predicted Outcome

The EPA identified three key environmental factors for this proposal. The key environmental objectives for these factors are:

- *To maintain the quality of water, sediment and biota so that the environmental values, both ecological and social, are protected;*
- *To maintain the structure, function, diversity, distribution and viability of benthic communities and habitats at local and regional scales; and*
- *To maintain the diversity, geographic distribution and viability of fauna at the species and population levels.*

Within this PER and associated documents, the Department has addressed these objectives through considering the potential direct, indirect and cumulative environmental impacts of the MWADZ Proposal and comprehensively conducting the scope of work specified within the ESD. It has also addressed (EAG 8) environmental values and objectives (identified through public consultation) that are additional to those specified in the ESD; and conducted a similar assessment of their potential impacts, mitigation and management measures, and predicted outcomes. Although published over two years after the ESD was approved by the EPA, the provisions of the *Environmental Assessment Guideline for Protecting the Quality of Western Australia's Marine Environment* (EAG 15) has also been addressed in this PER. A summary of the EPA's policy and guidance documents, along with an outline of how and where they have been applied in this process, is listed in Table 1-1 of the PER.

Having completed the work outlined above, the Department concludes that all the EPA objectives have been adequately met. Further, that establishment of commercial marine finfish aquaculture projects within the proposed MWADZ is not expected to cause a significant environmental impact and will not result in a net environmental loss to the conservation values of the Abrolhos Islands Fish Habitat Protection Area or the associated Abrolhos Islands Reserve.

This assessment of the likely environmental impacts is due to several key factors, including:

- the zone's physical characteristics, in particular the high rates of flushing or water exchange in the Zeewijk Channel that is sufficient to dilute nutrients before they are assimilated by the ecosystem;
- the adaptive management controls and environmental monitoring framework the Department has developed for the zone, and the individual (derived) proposals within it, through the strategic assessment process for the MWADZ Proposal; and
- confidence in the effectiveness of these management controls and the environmental monitoring framework built upon the experience gained thus far through implementing similar arrangements in the Kimberley Aquaculture Development Zone.

The objectives described in this PER that have been established to determine the predicted environmental outcomes reflect the EP Act principle of conserving biodiversity and ecological integrity. This principle, in addition to the "precautionary" principle that is embodied in both the EP Act and the current FRMA is further reinforced in the *Aquatic Resources Management Bill 2015*.[48] The Department is the Western Australian Government agency responsible for the administration and implementation of the FRMA and is committed to adopting a conservative approach to managing uncertainties over environmental impacts. This will be achieved through the early consideration of the identified potential environmental impacts and additional cumulative impacts associated with the project proposals, and of the relevant management measures designed to control these.

Collectively, these factors underpin the Department's confidence that the MWADZ Proposal will be environmentally acceptable, subject to the effective implementation of the mitigation and management measures outlined in this PER and its associated documents.

The results from the environmental monitoring program and reviews of the effectiveness of the management plans, protocols and other mitigation measures will also provide valuable information to support evidence-based policy development for future sustainable marine finfish aquaculture production in Western Australia.

While not a consideration for the purposes of this environmental impact assessment, it should also be noted that there are other benefits to be gained by the Mid West region, the State of Western Australia and the nation through the implementation of the MWADZ Proposal.
The proposal will act as a catalyst for economic development as it will provide increased employment opportunities and use local goods and services, as well as provide the tourism industry with an opportunity to diversify experiences available to visitors.

[48] The 'precautionary' principle, as specified in s.4A of the FRMA requires that: "*In the performance or exercise of a function or power under this Act, lack of full scientific certainty must not be used as a reason for postponing cost-effective measures to ensure the sustainability of fish stocks or the aquatic environment.*"

Ultimately, the MWADZ Proposal will become an increasingly valuable contributor to the future food security needs of Western Australia.

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18 APPENDICES

1. Modelling and Technical Studies in Support of the Mid West Aquaculture Development Zone (with the following accompanying appendices :)
   A. Marine Mammals;
   B. Endangered, Threatened and Protected Species;
   C. Fish and Fisheries;
   D. Seabirds;
   E. Peer Review;
   F. Hydro Model Calibration; and
   G. Diagenesis Calibration.

2. Mid West Aquaculture Development Zone Environmental Monitoring and Management Plan (EMMP) (with the following accompanying appendices :)

   A. Map of Sampling Site Co-ordinates; and
   B. Control Charting

3. Mid West Aquaculture Development Zone Management Policy (Draft) (ZMP)

4. Threat Identification, Hazard Pathway Analysis and Assessment of the Key Biosecurity Risks presented by the establishment of the Mid West Aquaculture Development Zone in Western Australia

5. Mid West Aquaculture Development Zone Marine Fauna Interaction Management Plan (MFIMP)

6. Mid West Aquaculture Development Zone Waste Management Plan (WMP)

7. Mid West Aquaculture Development Zone Environmental Scoping Document (ESD)

8. Environmental Protection Authority Checklist (for documents submitted for environmental impact assessment)

Modelling and Technical Studies in Support of the Mid-West Aquaculture Development Zone

1051_009/1_Rev2

April 2016

Modelling and Technical Studies in Support of the Mid-West Aquaculture Development Zone

Prepared for

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Prepared by

BMT Oceanica Pty Ltd, BMT WBM and AED UWA

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Quality Assurance

BMT Oceanica Pty Ltd has prepared this report in accordance with our Health Safety Environment Quality Management System, certified to OHSAS 18001, AS/NZS 4801, ISO 14004 and ISO 9001: 2008.

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Approved for final release:

Authors
Date: 18/4/16

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Executive Summary

Purpose

Risks associated with the Department of Fisheries (DoF) proposal to establish the Mid-west Aquaculture Development Zone (MWADZ) were assessed based on a number of technical studies, including the development and execution of an integrated environmental model. The purpose of this document is to summarise the findings of the technical studies, and to provide advice on the likely cumulative impacts of sea-cage operations on the marine environment under a range of operational scenarios. Results are presented particularly in the context of the key environmental factors identified in the Environmental Scoping Document (ESD). The findings of this Environmental Impact Assessment (EIA) feed into the broader Public Environmental Review (PER) for this project.

Methods and assumptions

Technical studies were supported by empirical and desktop procedures. Baseline water, sediment and metocean data were collected over a nine month period between May 2014 and February 2015, capturing seasonal changes in water and sediment chemistry, wave height and current speeds. Complementing the baseline assessment, single beam echo sounding and towed video methods were used to delineate key benthic habitat types and their relative proportions. The potential for impact on significant marine fauna, including marine mammals, turtles, sea-lions, finfish (sharks and rays), invertebrates and seabirds, was assessed via desktop reviews.

A key component of the assessment was to develop an integrated environmental model capable of resolving the effects of wastes on the marine environment, and the rate of environmental recovery following cessation and/or relocation of the proposed activities (fallowing). Three levels of impact; 'zone of high impact' (ZoHI), 'zone of moderate impact' (ZoMI) and 'zone of influence' (ZoI) were spatially delineated based on exceedances of predetermined environmental thresholds, following the guidance in Environmental Assessment Guideline 7 (EPA 2011). Thresholds were set differently in recognition of the diversity of receiving environments in the MWADZ. For 'sandy' habitats, thresholds were determined based on the biochemistry of the sediments and the rate at which they recovered following cessation of aquaculture activities. For the water column and mixed assemblage habitats, the impact potential was determined using a separate set of thresholds. Thresholds were developed for: nutrient enrichment, algal growth potential and oxygenation, potential for shading, smothering and stressors such as the mechanical interference, such as that produced by elevated levels of suspended particles. The latter thresholds were acute thresholds, and were based on the published literature (PIANC 2010) and the EPA's environmental criteria for high and moderate levels of ecological protection (EPA 2015).

Site description

The MWADZ is proposed to be established within the Fish Habitat Protection Area of the Houtman Abrolhos Islands. It consists of two areas: a northern area (2200 ha), located roughly halfway between the Easter and Pelsaert groups, and a southern area (800 ha), located immediately north of the Pelsaert group, for a total of 3000 ha. The waters of the MWADZ are deep (25-50 m), well flushed and experience high levels of water circulation and dispersion. Previous oceanographic work at the Easter Group islands indicated strong currents (i.e. between 2–5 cm/sec) and fast flushing times (i.e. from 0.5 to 1.5 days) in the shallow waters of the Easter Group lagoon. The MWADZ is located in more exposed waters between the Pelsaert and the Easter Group of islands, where flushing is likely higher than in the sheltered islands.

Baseline conditions

Results indicate that the waters inside the project area are clean and generally well mixed. Maximum and minimum water temperatures were achieved in autumn (23.5°C) and winter (20.8°C), respectively. Salinity and dissolved oxygen levels were fairly consistent through the water column with little evidence of stratification. The water was highly oxygenated at all times, achieving surface oxygen saturation levels between 96% and 99% and bottom oxygen saturation levels between 95% and 98%. Light attenuation in the MWADZ was lower (0.04–0.19 per m) than that obtained (1.2–1.8 per m) in the Kimberley Aquaculture Development Zone (KADZ), which is indicative of very clear water, with good light penetration. Water currents were variable, ranging between 5.8 and 14.4 cm/s. The MWADZ is an oligotrophic, or nutrient poor environment. Concentrations of ammonium (2.7 µg/L) and chlorophyll-a (0.43 µg/L) were similar to those found in Perth's coastal waters and lower than those recorded in the KADZ assessment (5.4 µg/L and 0.9 µg/L, respectively). Nitrite + Nitrate levels (12.9 µg/L) were higher than those recorded in Perth's coastal waters (6.5 µg/L) and in the KADZ (8.7 µg/L). Concentrations of inorganic nutrients and chlorophyll-a were seasonally variable, with higher concentrations in the cooler months.

The benthic environment consisted generally of a shallow layer of sand overlying rocky substrate, with mixed biotic assemblages. Higher current speeds in the northern area (northern 13.2-14.5 cm/s and southern 8.7-11 cm/s) were reflected in the tendency toward larger sediment grain sizes in the northern reaches of the MWADZ. Sediment conditions were variable, with seasonal fluctuations in nitrogen and total organic carbon with generally higher values in warmer months. Infaunal assemblages were diverse (10 phyla; 129 families), with communities dominated by polychaetes. Higher levels of infauna diversity and abundance were observed in the summer months.

Surveys indicated that much of the seafloor consisted of open sandy meadows and mixed biological assemblages, supporting macroalgae, rhodoliths, sessile invertebrates and some corals; however, all of the available data suggest that their presence may be itinerant given the observed differences between surveys. Habitats in the northern study area were more diverse relative to the southern area and comprised 59% bare sand and 34% mixed assemblages. Small patches of reef were present near the north-east boundary of the MWADZ but made up only 8% of the total habitat. The southern area by contrast comprised 96% bare sand and 5% mixed assemblage. Although ephemeral seagrass communities were observed in previous surveys of the MWADZ, no seagrasses were observed in the current assessment.

Impact assessment

Desktop assessments were undertaken to determine the likely impact of the proposal on marine mammals, seabirds and other significant fauna, including sharks, rays, other finfish and invertebrates. Several risks were identified including the potential for the sea-cages to act as a physical impediment to animal migration and water flow, a source of entanglement, an artificial food source, and as a significant artificial attractant and roosting area for seabirds. The risks were considered manageable through the use of best-practice infrastructure and management strategies. Examples of these included use of high-walled sea-cages (to limit access of sea lions), use of nets to exclude seabirds, and implementation of modern fish-feeding methods to both limit wastage and impede opportunistic feeding by sea-birds.

An integrated hydrodynamic, particle transport, water quality and sediment diagenesis model was used to simulate a total of six production scenarios (Table ES.1). Modelling scenarios were agreed in consultation with the DoF and the Aquaculture Industry Reference Group at a technical workshop held in October 2014. Scenarios were developed based on production of yellowtail kingfish (*Seriola lalandi*) using industry best-practice farming methods.

Table ES.1 Modelled production scenarios

Scenario No.	S1	S2	S3	S4	S5	S6
Total standing biomass (t)	15 000		24 000		30 000	
Standing biomass north (t)	10 000		16 000		20 000	
Standing biomass south (t)	5000		8000		10 000	
No. clusters south	3	2	3	2	3	2
No. clusters north	6	4	6	4	6	4

Note:

1. t = tonnes

The potential for impact and loss of benthic primary producing habitats (BPPH) was examined in the context of EAG 3, Category C. The assessment found that the proposal was unlikely to yield significant cumulative losses and the total cumulative loss would be restricted to <1%, which was within the Category C benchmark of 2%.

Integrated modelling examined the likely benthic footprints of the sea-cages under the range of scenarios in Table ES.1. The extent of benthic footprints was determined after two, three and five years production, and the extent of water quality impacts after one year of production. Benthic impacts were examined in the context of sediment organic enrichment and changes to sediment chemistry, with the level of impact determined by the recovery period during fallowing.

Deposition of fish faeces and waste feeds resulted in rapid changes to sediment oxygen and hydrogen sulphide concentrations beneath the sea-cages; however, the spatial extent and intensity of impacts varied significantly depending on the type and the length of the scenario modelled. Results suggested that the ZoHI would occupy 82-117 ha (S2-S1) to 139-177 ha (S6-S5) after 5 years production, but less after 3 (2-1 ha to 95-105 ha) and 2 years (0.2-0 ha to 88-91 ha) production.

Reductions in both the standing biomass and the length of production also reduced the extent of the ZoHI, as measured along the maximum radius down-current from the cage clusters. After 5 years continuous production, the ZoHI, extended to a maximum of 110 m and 70 m under S6 and S5, but less than that under other scenarios, and shorter production periods: in S4 for example, distances reduced to 60 m and 15 m after 3 and 2 years production respectively, and for S3, the distance reduced to 10 m after 3 years production. After 2 years production, the ZoHI in S3 did not breach the cage cluster perimeter.

Increasing the stocking density while maintaining standing biomass (i.e. stocking density S4 > S3; standing biomass S4 = S3) had the effect of reducing the total area occupied by the ZoHI across the zone. This effect was particularly strong after 5 years production, but less so after 3 and 2 years production. For the 24 000 t (S3-S4) and 30 000 t (S5-S6) scenarios, reducing the number of clusters from nine to six reduced the extent of the ZoHI by 15% and 22%, respectively. It was noted that while the spatial extent of the ZoHI was reduced, the effect was to increase the intensity of impacts under the sea-cages, thus extending the recovery time. Results confirmed that large standing biomasses (up to 5 000 t per sea-cage cluster (or 30 000 t spread across 6 clusters)) are achievable, while constraining the benthic impacts to relatively small areas.

Risks associated with dissolved inorganic nitrogen (DIN) and suspended particles were examined after one year of production. Suspended particles were examined in the context of smothering and interruption to filter feeding processes, and DIN in the context of algal growth potential, nutrient enrichment and shading. While modelling predicted no adverse effects to filter feeding processes, modelling predicted minor to moderate impacts (S4-S6) from smothering immediately

under the sea-cages. Concentrations of DIN down-current of the sea-cages were predicted to increase with increasing biomass and increasing stocking density. However, the plumes were predicted to dissipate rapidly, with concentrations generally returning to levels commensurate with a high level of ecological protection inside the MWADZ boundary. Despite significant inputs of DIN to the system, there were no increases in chlorophyll-a or declines in light penetration attributable to fish-farming.

Conclusions

This assessment simulated the effects of finfish standing biomasses between 15 000 and 30 000 t, for periods of one year for water quality and mixed assemblages, and two, three and five years for sandy sediments. Under 30 000 t standing biomass, modelling predicted no adverse changes to water quality and only localised impacts to the sea-floor beneath the sea-cages. The most severe impacts, as represented by the ZoHI, were restricted to 110 m distance after 5 years production, and 55 m and 50 m distance after 3 and 2 years production, respectively. Further improvements were achieved by reducing the standing biomass to 24 000 (S4) under which the ZoHI was restricted to 15 m after 3 years production. Scenario 4 in particular demonstrated a capacity to maintain large volumes of finfish (4000 t per sea-cage cluster), while constraining the impacts (ZoHI) to localised areas.

Results presented here are equivalent to the 'most likely worst case' outcomes as required by the ESD for this project. The scenarios tested were designed to be (a) sufficient to support a viable finfish aquaculture industry and (b) be well within the critical assimilative capacity of the marine environment, based on an understanding of systems with similar flushing regimes and nutrient inputs. Based on this, it is recommended that 24 000 t standing biomass is set as an interim limit, pending further validation of the particle dispersion and sediment diagenesis models, using field data (sediment characteristics and water quality) collected in the first years of operation. It is also recommended that this limit is validated in the context of further metocean assessments, including the effect of significant storms, and the frequency of benthic ‘resetting’ events–both of which were not accounted for in this assessment.

1. Introduction

In late 2011, the Minister for Fisheries announced a funding package to enable establishment of two aquaculture development zones in Western Australia's (WA's) coastal waters. The Department of Fisheries (DoF) is managing the project, and is responsible for undertaking the environmental impact assessments (EIA) for zones in the Kimberley and Mid-West regions of the State.

The first of these zones, the Kimberley Aquaculture Development Zone (KADZ), was approved by the Minister for Environment on 12 May 2014 under Part IV of the *Environmental Protection (EP) Act 1986*, by way of Ministerial Statement 966. The 1993 ha KADZ, located in Cone Bay, has conditional approval to produce up to 20 000 tonnes (t) of marine finfish per year.

The second zone, the Mid-West Aquaculture Development Zone (hereafter the 'MWADZ'), is proposed to be established within the Fish Habitat Protection Area of the Houtman Abrolhos Islands (hereafter the 'Abrolhos'). The MWADZ consists of two areas: a northern area (2200 ha), located roughly halfway between the Easter and Pelsaert groups, and a southern area (800 ha), immediately north of the Pelsaert group (Figure 1-1).

The proposal to develop the MWADZ was referred to the Environmental Protection Authority (EPA) in May 2013 and the level of EIA was set at Public Environmental Review (PER), under Section 38 of the *EP Act 1986*. EIA is an orderly and systematic process for evaluating a proposal (including its alternatives) and its potential effects on the environment.

The scope of the PER is defined in the EPA-prepared environmental scoping document (ESD). A number of technical studies were required (Section 2) to assess the potential impacts of the MWADZ in the context of the key environmental factors outlined in Table 1.1. The technical studies included the development and execution of an integrated environmental model, and multiple desk top assessments.

Table 1.1 Key environmental factors and impacts identified in the Environmental Scoping Document

Key environmental factors	Key environmental impacts
• Hydrodynamics	• Alterations to hydrodynamics
• Marine water and sediment quality (including accumulation of trace contaminants)	• Degradation of marine water and sediment quality
• Marine flora and benthic primary producer habitat • Significant marine fauna • Marine benthic infauna and invertebrates	• Direct and indirect disturbance or loss of benthic communities and habitat • Direct and indirect impacts to key sensitive receptors • Impacts to marine environment and biota quality through release of pharmaceuticals, metals/metalloids and, or petroleum hydrocarbon • Direct and indirect impacts on significant marine fauna

Source: EPA (2013)

The purpose of this document is to summarise the findings of the technical studies, and to identify an upper aquaculture production level (tonnes of finfish) consistent with acceptable environmental impacts. Results are provided in the context of marine (benthic and open water) environments in and around the proposed MWADZ, and in the context of the greater Abrolhos region.

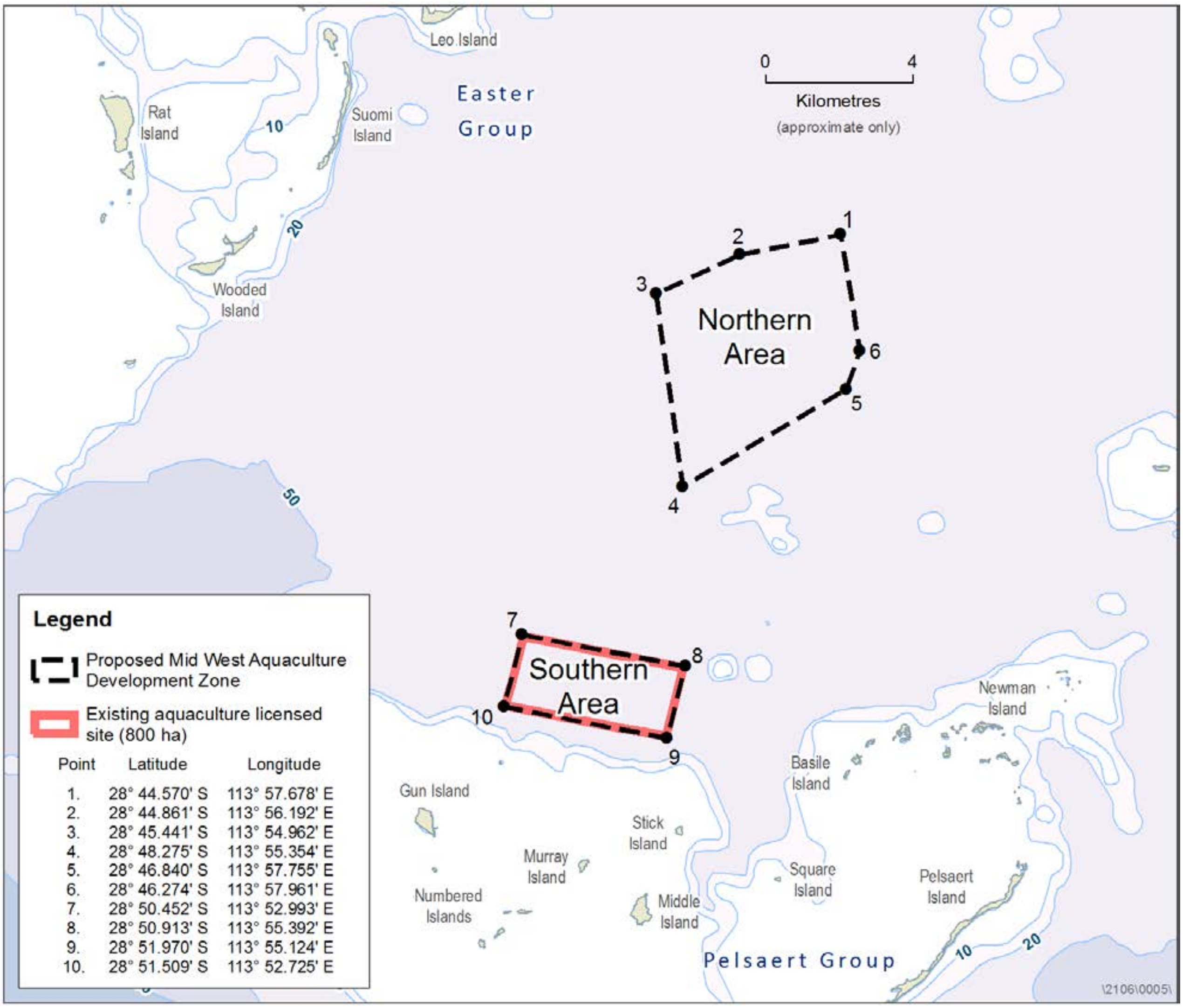


Figure 1-1 Location of the proposed mid-west aquaculture development MWADZ, showing the southern and northern areas

2. Scope of this document

The ESD lists the EPA's objectives, the potential impacts of finfish aquaculture, and the work required (technical studies) to support the EIA (EPA 2013). The scope of the technical studies and the section where it is addressed in this document is provided in Table 2.1.

Table 2.1 Technical studies required to support the EIA and the section of this document where they are addressed

Marine environmental quality		**Section**
EPA objective	To maintain the quality of water, sediment and biota so that the environmental values, both ecological and social, are protected	
Potential impacts	Potential impacts include: • Impacts to water and sediment quality through release of fish feed and faeces leading to nutrient and organic enrichment of the marine environment. • Impacts to water, sediment and biota quality through release of pharmaceuticals or metals/metalloids in fish feed into the marine environment.	
Work required	• Document baseline water and sediment quality (over an approximate 12 month period) in the region of the strategic proposal area in order to effectively capture seasonal and spatial variability to the greatest extent possible, including the following parameters: • **Water** – nutrients, dissolved oxygen (DO), phytoplankton community composition, chlorophyll-a, total suspended solids (organic), hydrogen sulphide (H_2S) and light attenuation coefficient. • **Sediment** – total nitrogen, total phosphorous, total organic carbon (TOC), redox, ammonia (NH_3), DO, H_2S, sediment trace metal and organic concentrations. • **Note** – The Office of the Environmental Protection Authority (OEPA) considers that testing for baseline levels of H_2S in both sediment and water would only be required to be conducted once.	Section 5
	• Accurate and validated modelling of surrounding hydrodynamics, to understand dispersion, deposition and accumulation of nutrients, trace contaminants, organic waste material and pharmaceutical/chemical wastes from the sea cages and any other associated infrastructure. Hydrodynamic and particle transport modelling should take into account factors such as tides, meteorological and seasonal ocean conditions and should be linked to the ecological modelling.	Section 4.6 Appendix F Appendix G
	• A clear and comprehensive description of the predicted cumulative environmental effects of the future proposals within the strategic proposal area operating at maximum capacity based on professional judgement and supported by ecological models that are relevant to the locality and linked to the hydrodynamic modelling. This should include impacts to biodiversity; abundance and biomass; water, sediment and biota quality and ecosystem processes. • Predicted changes in sediment characteristics, both physically (e.g. organic content and TOC) and chemically (e.g. nutrients, H_2S, metals, DO, redox discontinuity) under the most likely or indicative cage locations and configurations to the outer boundary of the zone of reversible impact, for best, worst and most possible case.	Section 7 Section 7.3
	• The proponent must demonstrate a good understanding of the natural rates and types of ecological processes operating in the area and evaluate the possible extent and severity of any changes to the types and/or rates of processes under best case, worst case and most likely case scenarios. • This should include the development of a nutrient budget with and without the potential strategic proposal and future proposals to use as a tool to assess changes in variables such as loading, feeding regimes, assimilation capacity and FCRs etc. The assessment must address the cumulative effects of all elements of the strategic proposal.	Sections 3; 5 Section 4.4.2

	• The documentation should also include a review of the suitability and applicability of the models, and the interpreted outputs of the models, by an independent expert.	Section 4.6.3 Appendix E
	• Develop an environmental quality management framework (EQMF) for the strategic proposal, and to apply to future proposals, based on the recommendations and approaches in Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC & ARMCANZ, 2000) and State Water Quality Management Strategy Report 6 (it is an expectation that the Department of Fisheries would liaise with the OEPA regarding this framework). The framework is underpinned by defining the environmental values to be protected, identifying the environmental concerns or threats and establishing the environmental quality objectives (EQO) and levels of ecological protection to be achieved and where they apply spatially (these should be included in a detailed map). (Note that the effects on environmental quality and biota are linked.) This establishes a framework for the Environmental Impact Assessment (EIA) of the strategic proposal as well as for managing the ongoing operations from future proposals.	Developed separately
	• Develop cause/effect pathway models for nutrient and organic enrichment, sedimentation and other relevant environmental issues of concern.	Section 4.4
Benthic communities and habitat		**Section**
EPA objective	To maintain the structure, function, diversity, distribution and viability of benthic communities and habitats at local and regional scales.	
Potential impacts	Potential impacts include: • direct disturbance or loss through the installation of anchors, wire sweep (deviation to the span of cables), mooring blocks and dragging nets; • direct and indirect impacts or loss through uneaten feed and faeces causing nutrient and organic enrichment of the marine environment leading to shading, smothering, deoxygenation or potential disease of benthic communities and habitats.	
Work required	• Design and conduct a geo-referenced benthic habitat survey with the objective of mapping accurately the spatial extent of benthic habitats (including corals, macro-algae, seagrass, mangroves, filter feeders, microphytobenthos and presence of sediment infauna communities) and defining local assessment units to assess permanent loss of benthic primary producing habitats (BPPH) (in the context of EAG 3). Benthic habitat mapping should at least extend to the outer boundary of the area where both irreversible and reversible effects on biota are predicted to occur and extend into the zone of influence.	Section 4.3 Section 5.5
	• Predict and spatially define zones of high impact (irreversible loss of abundance/biomass or diversity of biota or ecological processes), moderate impact (reversible loss of abundance/biomass or diversity of biota or ecological processes within 5 years) and influence (changes in environmental quality or physiological stress, but no loss of biota or ecological processes) likely to result from the strategic proposal, and therefore the boundary beyond which there will be no effect. These zones need to be derived at maximum capacity and most likely pen configuration and accurately mapped to represent the aquaculture zones footprint. This information will inform the future proponents when selecting the locations and numbers of potential impact sites and un-impacted reference sites.	Section 7
Marine fauna		**Section**
EPA objective	To maintain the diversity, geographic distribution and viability of fauna at the species and population levels	

Potential impacts	• Potential impacts to marine fauna from disturbances such as noise (during construction and operation), lighting, vessel strike and human interaction, entanglement and physical barriers imposed by infrastructure. • Potential impacts on seabirds through changes to population levels, levels of available food and predation. • Potential impacts on wild fish populations, habitats and genetic diversity through introduction of pathogens and parasites, escaped fish and discharge of uneaten feed, faeces and pharmaceuticals. • Potential impacts on fisheries and fisheries production.	
Work required	Marine mammals, seabirds and other significant marine fauna • Identify and assess the values and significance of marine faunal assemblages within the strategic proposal area and immediate adjacent area and describe these values in a local, regional and State context. • Identify critical windows of environmental sensitivity for seabirds, marine mammals, including the Australian Sea Lion (*Neophoca cinerea*), other significant marine fauna and key fisheries in the strategic proposal area and immediate adjacent area. • Describe the presence of marine mammals, including the Australian Sea Lion (*Neophoca cinerea*), seabirds and other significant marine fauna in the proximity of the strategic proposal area and document any known uses of the area by them (e.g. foraging, migrating, calving and nursing etc). • Design, detail and conduct a targeted survey for seabirds. The survey should target the distribution, nesting and roosting habits of all locally relevant seabird species with consideration of survey timing to meet suitable weather conditions, time of day and season for presence of seabirds.	Sections 3; 8 Appendix A Appendix B Appendix C Appendix D Developed separately
	• Identify the construction and operational elements of the proposal that may affect significant fauna and fauna habitat.	Section 4.4.1 Section 8
	• Describe and assess the potential direct and indirect impacts that may result from construction and operation of the proposal to marine mammals, including the Australian Sea Lion (*Neophoca cinerea*), seabirds and other significant marine fauna and their habitat.	Section 8.3 Appendix A Appendix B Appendix C Appendix D
	• Identify measures to mitigate adverse impacts on marine mammals, including the Australian Sea Lion (*Neophoca cinerea*), seabirds and other significant marine fauna and their habitat so that the EPA's objectives can be met. • Describe possible management options to address potential impacts on marine fish populations, marine mammals, including the Australian Sea Lion (*Neophoca cinerea*), seabirds and other significant marine fauna and the surrounding environment. This must include but is not limited to: uneaten feed, marine parasites, biofouling control methods and interaction or entanglement with marine fauna (through development of a marine fauna interaction plan).	Section 8.3 Appendix A Appendix B Appendix C Appendix E Section 8 Appendix A Appendix B Appendix C Appendix D
	Biosecurity • Describe translocation, biosecurity and management arrangements addressing: fish disease/pathogen (including parasites) management and incident response, strategies for preventing outbreaks and/or preventative treatments chemicals to escape into the surrounding environment; brood stock and translocation issues; and prevention and management of escaped fish	Developed separately
	Fisheries • Describe commercial and recreational fishing activity in the Northampton region and Abrolhos Islands that may be affected by the proposal. • Describe and assess the potential direct and indirect environmental impacts on recreationally and commercially important marine species, including impacts to migratory patterns, spawning areas and nursery areas.	Section 8.2 Appendix C

3. Site description

3.1 Climate

The Abrolhos Islands are a group of islands located approximately 60 km west of Geraldton, Western Australia (WA). The islands are clustered into three main groups – Wallabi, Easter and Pelsaert, and are approximately 100 km in length from the northern to the southern tip. In the warmer months (January–April), the Abrolhos Islands experience strong south to south easterly winds in the morning and generally stronger south to south westerly winds in the afternoon (Webster et al 2002). High wind speeds are consistently recorded in the afternoons from September through to March, with the months of strongest wind being December, January and February. During the cooler months, winds tend to be weaker and more variable in direction.

The MWADZ is also characterised by frequent storms and squalls. In the winter months, storms to the south of the region can bring gales and strong winds up to 35 m/sec (Webster et al. 2002). Squalls can also occur in the summer months of December–April, and can generate wind speeds between 25 and 30 m/sec that can occur in any direction (Webster et al. 2002). The majority of rainfall (average 272 mm) occurs between April and September. Mean air temperatures range between 21 to 27°C and 16 and 22°C in the warmer and cooler months, respectively.

The Abrolhos region is occasionally subject to cyclonic activity during the cyclone season from December to May, with more than half the recorded cyclones occurring between March and May. Since 1915, a cyclone has passed through coastal waters within 400 km of the region approximately every 2.5 years on average.

3.2 Oceanography

The waters of the MWADZ are deep (25-50 m), well flushed and experience high levels of water circulation and dispersion (Figure 3-1). The MWADZ is located on the edge of the WA continental shelf between 28°S and 29°S, in the pathway of the warm poleward-flowing Leeuwin Current (Pearce 1997). It is also situated in the Zeewijk Channel, one of three breaks in the Houtman Abrolhos archipelago (Maslin 2005). The region surrounding the Abrolhos is a dynamic system influenced by large-scale regional currents (e.g. Leeuwin Current, Capes Current), wind stresses, upwelling and wave dynamics (Pearce & Pattiaratchi 1999, Feng et al. 2007, Waite et al. 2007, Woo & Pattiaratchi 2008, Rossi et al. 2013). The Leeuwin Current is a well-studied oceanic flow of warm, low salinity tropical water (originating in the Timor Sea) that travels southwards along the Western Australian coast. It is driven by a southwards pressure gradient, and under the influence of Coriolis deflections, hugs the coastline as it travels from near North West Cape to Cape Leeuwin (south of Perth) and then onwards to the Great Australian Bight (Cresswell 1991).

The Leeuwin Current flow is strongest in autumn, winter and early spring, raising sea surface temperatures. The flow is greatest and most consistently south along the shelf break, a relatively short distance to the west of the Abrolhos Islands (Webster et al. 2002). The currents through and inshore of the islands vary spatially and temporally. During the late spring and summer months, the current through and inshore of the islands tends to set to the north, driven by the prevailing southerly winds with occasional current reversal to the west along the shelf break (Pearce et al. 1999). During the winter months strong westerlies and north-westerlies can generate southward setting currents through and inshore of the Abrolhos Islands (Pearce et al. 1999).

The waters of the MWADZ are well flushed and experience high levels of water circulation and dispersion. Their position within the Zeewijk Channel means that the area is exposed to significant westerly currents, which expel large volumes of water out of the zone toward the continental shelf slope (Maslin 2005). Differences in the hydrodynamics between the surface and bottom of the Zeewijk channel have been shown to affect particle transport times (Maslin 2005). Particles in the surface waters are expected to be flushed out of the system rapidly (within 24 hrs), while particles at the bottom of the water column are expected to be retained in the system for longer periods, due to the recirculation of bottom currents (Maslin 2005).

In addition, previous oceanographic work completed by (Sukumaran 1997) at the Easter Group islands indicated fast flushing times (i.e. from 0.5 to 1.5 days) in the shallow waters of the Easter Group lagoon (Sukumaran 1997). The proposed MWADZ is located in a more exposed area north of the Pelsaert Group and east of the Easter Group of islands. Currents speeds through the MWADZ are expected to be higher than that reported in Easter Group lagoon, leading to lower retention times and enhanced flushing capacity.

Wave heights in the open ocean near the south westerly margins of the Abrolhos Islands average ~2 m, and can exceed 4 m during storm events. Wave heights are substantially lower on the eastern leeward sides of the Abrolhos Islands and in the areas near the MWADZ, with average wave height reaching ~1.2 m (Webster et al. 2002). The majority of the swell approaches the islands from the south and west 78% of the time (Department of Fisheries 2000).

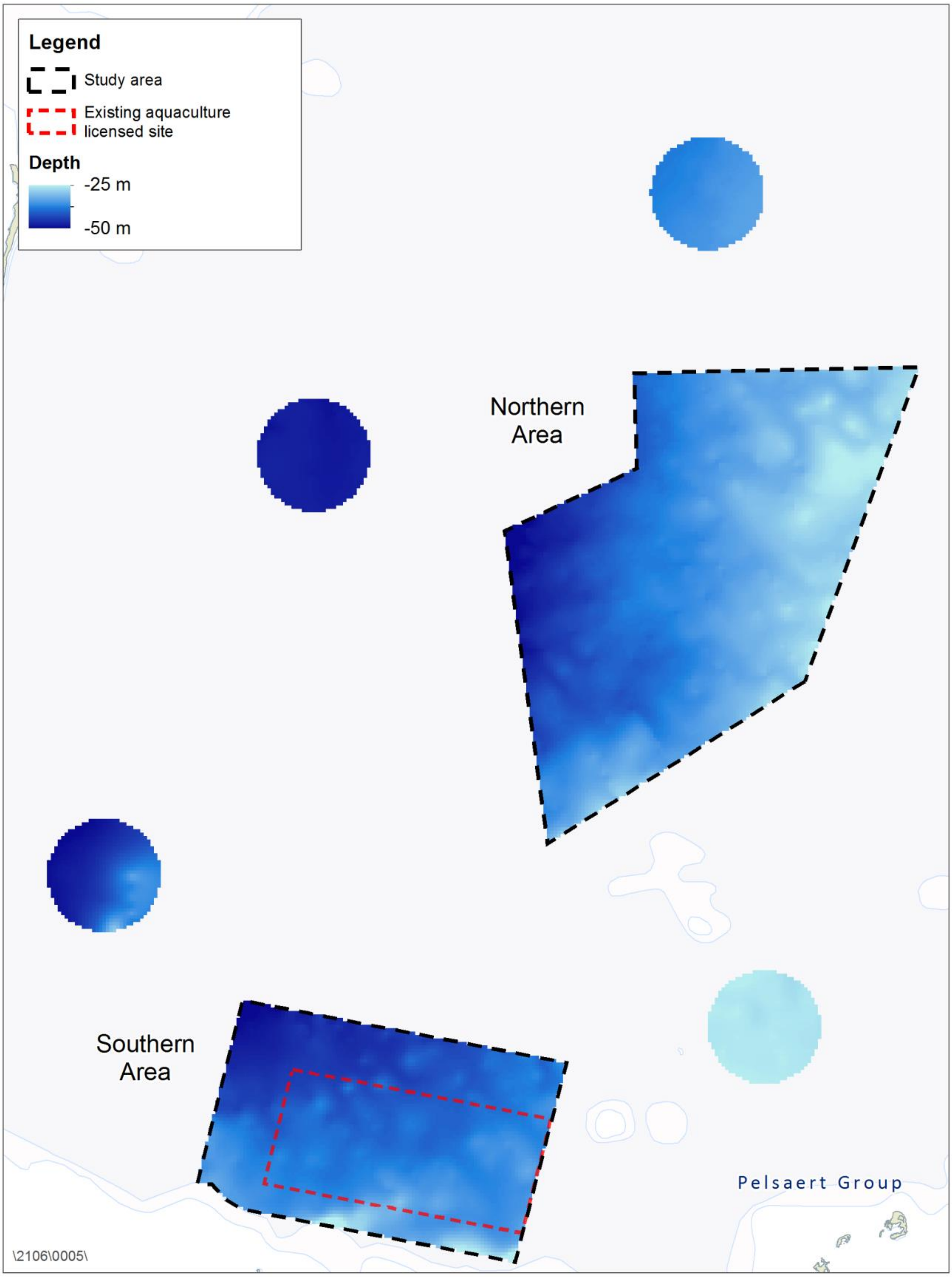


Figure 3-1 Bathymetry of the proposed MWADZ and reference areas

3.3 Sediment biochemical processes

Sediment characteristics of the Abrolhos Islands vary with depth and space (Section 5.4). Sediments in the MWADZ are sandy with grain sizes ranging <0.06 to 2 000 µm. Concentrations of nutrients and organic material are very low and anecdotal observations suggest that much of the MWADZ consists of shallow sediments (15 m thick) overlying rock. Attempts to retrieve consolidated cores for model validation failed owing to the depth of the water (beyond diving depth) and the shallow nature of the sediments which impeded the coring process. Sediment grabs were not appropriate for discerning natural biochemical processes, because of difficulties in retaining consolidated and unmixed samples. Biochemical processes were therefore assumed to be consistent with shallow, well oxygenated sediments. The characteristics of sediments matching these criteria were ground-truthed with the relevant literature (Berner 1980, Boudreau 1997, Fossing et al. 2004).

3.4 Benthic marine fauna and flora

The reefs of the Abrolhos are unusual in that they support both rich coral and macroalgal communities, with corals dominant on the leeward reef sections and macroalgae dominant on the more windward reef sections (Wells 1997).

The corals of the Abrolhos Islands are diverse, with 184 species from 42 genera recorded (Veron & Marsh 1988). While being at the extreme southern limit of their latitudinal range, the Abrolhos Islands coral populations are considered to be reproductively active, with 60% of the 184 species recorded to spawn in late summer (Babcock et al. 1994). As such, the Abrolhos Islands support extensive coral cover despite their southerly location, and the growth rates and calcification rates of *Acropora formosa* and *Porites* spp. from the Abrolhos Islands have been reported to be within the range reported for their tropical counterparts (Smith 1981, Harriott 1998). The family Acroporidae (*Acropora* and *Montipora*) dominates the coral communities at the Abrolhos Islands, and a marine heat wave in 2010/2011 (Pearce & Feng 2013) resulted in coral bleaching and subsequent coral mortality (~12% decline in coral cover) at the Abrolhos (Abdo et al. 2012, Moore et al. 2012). The sea surface temperatures at the Abrolhos Islands were once again above seasonal averages in the 2011/2012 summer period (NOAA 2015), with additional coral bleaching and mortality likely due to the extent of the thermal anomaly.

Besides corals, the Abrolhos has rich and diverse macroalgal communities, with 295 macroalgal species recorded – 13.6% are considered to be endemic to the Abrolhos, and only ~10% have a tropical affinity (Phillips & Huisman 2009). The macroalgal abundance in the lagoonal reefs at the Abrolhos is high in comparison to other tropical coral reefs (Wilson & Marsh 1979) and includes large stands of fucoid algae and kelp, *Ecklonia radiata*, not found on coral reefs (Womersley 1981). It appears that the grazing rates of invertebrates and fish at the Abrolhos are less than on tropical reefs (Hatcher & Rimmer 1985). As such, little of the macroalgal production is consumed by grazers, but rather the macroalgae are removed by storms carried into the lagoons as a nutrient subsidy of particulate carbon (Wells 1997). The lagoons therefore include large aggregations of unattached macroalgae and macroalgal fragments that contribute to a rich detritus-based food web, which includes the Western Rock Lobster fishery – of which ~19% of the WA catch is taken from the Abrolhos region (Abdo et al. 2012).

One of the dominant macroalgae in the Abrolhos is the kelp *Ecklonia radiata*, which can reach densities of 8.2 plants/m^2 at ~12 m depth in lagoonal area (Hatcher et al. 1987). Besides *Ecklonia*, fleshy macroalgae form a major component of the benthic communities of the Abrolhos, where the high-energy outer reef slopes support rich and dense macrophyte communities

characterised by large brown algae (e.g. *Dictyota*, *Glossophora*, *Sargassum*) mixed with fleshy red and green algae (e.g. *Asparagopsis*, *Hypnea*, *Laurencia*, *Plocamium*, *Caulerpa*; Crossland et al. 1984). The protected reef areas within the lagoon vary seasonally, whereby large phaeophytes (e.g. *Caulocystis*, *Cystophyllum*, *Hormophysa*, *Sargassum*, *Turbinaria*) are common in summer, and other fleshy algae (e.g. *Eucheuma*, *Laurencia*) are more common in spring (Crossland et al. 1984).

Besides the dominant coral and macrolgal communities, ten seagrass species have been recorded at the Abrolhos (Brearley 1997). Seven of these species (*Amphilbolis antarctica*, *A. griffithii*, *Thalassodendron pachyrhizum*, *Posidonia angustifolia*, *P. australis*, *P. coriacea*, *P sinuosa*) are predominantly temperate species, and three (*Syringodium isoetifolium*, *Halophila decipiens*, *H. ovalis*) have a tropical affinity (Brearley 1997). However, the seagrass communities at the Abrolhos are sparse and species poor compared to the mainland locations of Shark Bay and Geraldton (Brearley 1997).

Wilson and Marsh (1979) originally considered the non-coral fauna of the Abrolhos to be relatively impoverished and unstable in comparison to the corals. However, diverse molluscs (492 species; Wells & Bryce 1997), echinoderms (172 species; Marsh 1994), oligochaetes (Erseus 1997), polychaetes (Hutchings 1997), and hydroids (Watson 1997) have been recorded, indicating that the known diversity of benthic marine biota in the Abrolhos is substantially higher than that suggested by Wilson and Marsh (1979). In terms of the subtidal molluscs at the Abrolhos, >65% of the bivalves have a tropical affinity, whereas ~45% of the gastropods have a tropical affinity (Glover & Taylor 1997). Moreover, while no literature is available on the diversity of sponges at the Abrolhos, they did comprise a major component of the dredge samples used for the mollusc surveys (Glover & Taylor 1997), and given the high diversity of sponges recorded at Ningaloo (Heyward et al. 2010), the sponges are therefore expected to be relatively diverse at the Abrolhos.

The benthic habitats of the Abrolhos also support rich fish communities, with up to 389 fish species recorded (Hutchins 1997). The majority of these species (~60–65%) are tropical species, ~15% are subtropical, and ~20–25% are temperate species (Hutchins 1997, Watson et al. 2007). Moreover, the structure of the fish assemblages differ between fished and non-fished areas (Watson et al. 2007), and there is a greater relative abundance of many of the targeted fish species in areas protected from fishing (Watson et al. 2009, Nardi et al. 2004).

In addition to the reefal areas, the lagoons and areas east of the Abrolhos Islands are comprised of large open sandy habitats – areas of which are commercially trawled for the scallop *Amusium balloti*. Areas sampled for molluscs over the scallop grounds were generally characterised by fine carbonate sand with shell debris, with patches of coralline algal rubble with attached sponges (Glover & Taylor 1997). The molluscan community was dominated by suspension feeding bivalves (particularly pectiniids), a suspension feeding gastropod (*Monilea lentiginosa*), an algal grazing gastropod (*Calthalotia mundula*), echinoderms (*Prionocidaris bispinosa*, *Luidia australiae*, *Astropecten preissi*), and sponges (Glover & Taylor 1997).

3.5 Marine mammals and turtles

The Abrolhos Islands and surrounding waters provide important habitat for an array of marine mammals, comprising mainly whales, dolphins and sea lions. Thirty one cetacean and two pinniped species are known to occur with a 50 km radius of the MWADZ (DoE 2014a). Some species occasionally transit through the area at low densities, but there is insufficient information to confirm a definitive presence. Species that are likely to occur within a 50 km radius include: blue whale, humpback whale, Australian sea lion, Indo-Pacific bottlenose dolphin and the common bottlenose dolphin. Species with a low likelihood of occurring include: the blue whale, southern right whale, Bryde's whale, killer whale and the dugong. Four marine turtles may occur within a 50 km radius, including the loggerhead turtle, flatback turtle, leatherback turtle and green turtle, with the last two species more likely.

3.6 Finfish, sharks and rays

The benthic habitats of the Abrolhos support rich fish communities, with up to 389 fish species recorded (Hutchins 1997). The majority of these species (~60–65%) are tropical species, ~15% are subtropical, and ~20–25% are temperate species (Hutchins 1997, Watson et al. 2007). The structure of the fish assemblages differs between fished and non-fished areas (Watson et al. 2007) and there is a greater relative abundance of many of the targeted fish species in areas protected from fishing (Watson et al. 2009, Nardi et al. 2004).

These rich communities host a number of threatened, endangered and protected species. These comprise sharks, rays, Queensland grouper and syngnathid (pipefish, seahorses and seadragons). Most syngnathid species inhabit shallow, sheltered coastal waters, well away from the proposed MWADZ. While Queensland grouper possibly exist at the Abrolhos Islands the likelihood of an interaction with the proposed sea-cage operations was consider remote (DoF 2015b). However, interaction between the sharks/rays and the proposed sea-cages is considered more plausible (DoF 2015b). The significant finfish of the Abrolhos are considered in detail in DoF (2015a, 2015b).

3.7 Seabirds

The Houtman Abrolhos is the most significant seabird breeding location in the eastern Indian Ocean. Eighty percent (80%) of the brown (Common) noddies, 40% of sooty terns and all lesser noddies found in Australia nest at the Houtman Abrolhos (Ross et al. 1995). It also contains the largest breeding colonies in Western Australia of wedge-tailed shearwaters, little shearwaters, white-faced storm petrels, white-bellied sea eagles, osprey, caspian terns, crested terns, roseate terns and fairy terns (Storr et al. 1986, Surman and Nicholson 2009). The Houtman Abrolhos also represents the northernmost breeding islands for both the Little Shearwater and White-faced Storm Petrel.

Components of the avifauna at the Abrolhos are protected under three National and State Acts:

- Environment Protection and Biodiversity Conservation (EPBC) Act 1999;
- Conservation and Land Management (CALM) Threatened and Priority Fauna Database and
- Western Australian Wildlife Conservation (Specially Protected Fauna) Notice 2014.

Migratory species are protected under the EPBC Act (1999), and are included in the Japan Australia Migratory Bird Agreement (JAMBA), the China Australia Migratory Bird Agreement (CAMBA) and the Republic of Korea-Australia Migratory Bird Agreement (ROKAMBA). Of these, all migratory waders recorded in Surman and Nicholson (2009), as well as the eastern reef egret and seabirds including the bridled tern, caspian tern, crested tern, osprey and white-breasted sea eagle, are listed under migratory bird agreements with Japan, China or Korea. Birds covered by these agreements are listed in Schedule 3 under the Wildlife Conservation Act 1950 (WA).

Eight bird species found at the Abrolhos are also listed under the CALM Threatened and Priority Fauna Database, although only one of these species, the lesser noddy, is likely to interact with the aquaculture lease area.

Five seabird species occur in the vicinity of the aquaculture leases that are listed under the Western Australian Wildlife Conservation (Specially Protected Fauna) Notice 2014, Schedule 1: Fauna that is rare or likely to become extinct. These are the:

- lesser noddy
- Hutton's shearwater
- fairy tern
- Indian yellow-nosed albatross, and
- black-browed albatross

Both the lesser noddy and fairy tern breed at the Abrolhos, whereas the Hutton's shearwater migrates through the region in late spring, with up to 50 birds occurring in flocks off Eastern Passage (Easter Group) and The Channel (Pelsaert Group) (Surman and Nicholson 2009). Albatrosses in contrast are winter visitors (Surman pers. obs). Hutton's shearwaters forage with wedge-tailed shearwaters on small pelagic fishes and squids, including species that are likely to congregate near sea-cages.

Seventeen species use the Abrolhos as breeding regular breeding grounds. These are the white-bellied sea eagle, osprey, wedge-tailed shearwater, little shearwater and white-faced storm Petrel, pacific gull, silver gull, caspian tern, crested tern, bridled tern, roseate tern, fairy tern, brown noddy, lesser noddy, eastern reef egret, pied oystercatcher, and pied cormorant (Surman and Nicholson 2009).

Three species of seabird are considered most at risk due to interaction with the proposed MWADZ, including the Pacific gull, silver gull and the pied cormorant. Approximately 356 pairs of silver gulls were recorded nesting during an Abrolhos wide survey conducted in 2006 (Surman and Nicholson 2009). The largest colonies were observed on Long Island in the Wallabi Group (142 pairs), Pelsaert Island (43), Leo's Island (34) and Wooded Island (33).

Pied cormorant, silver gull and Pacific gull populations at the Houtman Abrolhos are currently reliant upon natural food sources only. The establishment of finfish farms in either of the proposed areas could potentially lead to in changes in the size of these species populations (or changes in colony location) that could result in increased competition with, or predation of other seabirds or alteration in breeding habitat (Surman 2004). Adult silver gulls are particularly at risk given their propensity for rapid population growth in response to opportunistic food sources. These aspects of breeding biology allow silver gulls to respond rapidly to seasonal changes in food availability.

4. Methods and assumptions

Section 4 of this document summarises the methods and assumptions that underpin the technical studies. The section first provides a technical overview of the methods and experimental design supporting the baseline data collection process. It then goes on to describe the approach to identifying the relevant cause–effect / pressure response–relationships, before describing the approach to model development. All of the work described in this Section is the work of BMT Oceanica, BMT WBM and UWA AED, unless otherwise specified.

4.1 Metocean data collection

4.1.1 Data collected for this project

Metocean data, consisting of conductivity-temperature-depth (CTD), wave height and current speeds, were collected over a 10 month period at a total of four sites, and captured each of the calendar seasons. Metocean data were collected using bottom–mounted data loggers in conjunction with Acoustic Doppler Current Profilers (ADCP). Four ADCPs were deployed in total: one in each of the northern and southern areas), and one in each of two regional locations (north-east and south-east, respectively) (Figure 4-1). A total of 6 deployments were made over a 10 month period (Table 4.1).

Table 4.1 Timing of ADCP deployments

Northern and southern MWADZ	Regional sites
16 May 2014 – 19 June 2014	17 July 2014 – 19 November 2014
17 August 2014 – 18 September 2014	19 November 2014 – 18 March 2015
9 November 2014 – 10 December 2014	-
9 February 2015 – 11 March 2015	-

4.1.2 Historical data

In addition to the above data, some historical data were also utilised including:

- Wave data from the Outer Channel at Geraldton which were provided by the Mid West Port Authority for a ten year period to 1 May 2014
- ADCP data collected in October 2002 and September 2003 from a location within the Pelsaert Group just west of the northern area of the proposed MWADZ
- Tide gauge data from Geraldton port from 1 Jan 2014 to present.

4.2 Baseline water and sediment quality

Coinciding with the metocean data collection period, a baseline water and sediment quality monitoring program was also undertaken between May 2014 and March 2015. The purpose of the monitoring program was to effectively capture the seasonal and spatial variability in a range of water and sediment parameters, as per the requirements of the ESD. Field work associated with the baseline program was undertaken by the DoF research division. Data analysis and interpretation was undertaken by BMT Oceanica, BMT WBM and UWA AED.

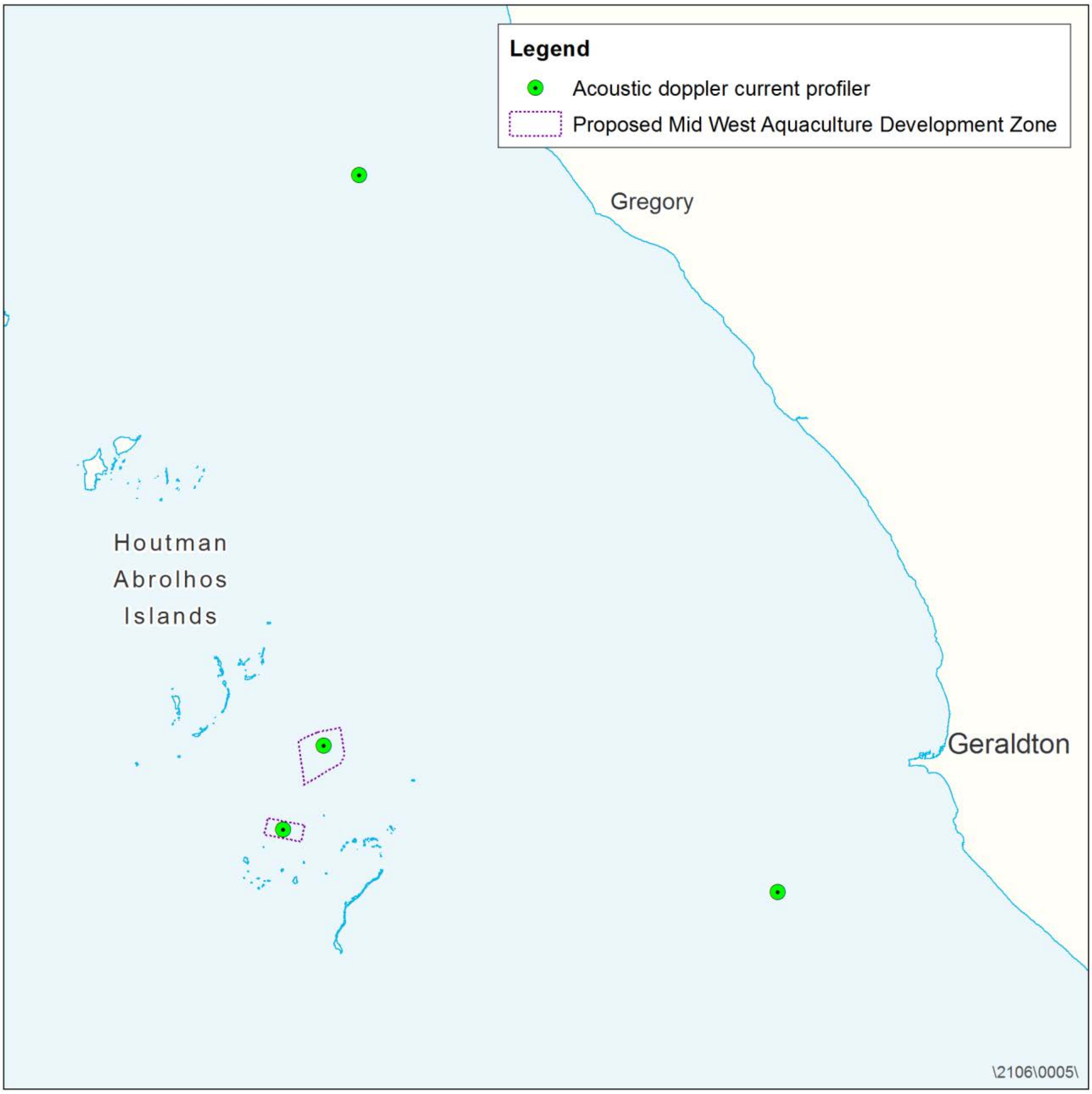


Figure 4-1 Location of acoustic doppler current profilers for metocean data collection

4.2.1 Monitoring program design

Water quality

Water samples were taken at a total of 28 sites comprising of 9 sites in the northern area and 6 sites in the southern area, and 12 reference sites located at the perimeter of the MWADZ (Figure 4-2). Several of the water quality sites were positioned at the boundary of the northern and southern areas of the MWADZ, while others were positioned so as to co-located with sediment sampling sites (Figure 4-3).

Sites were also positioned to allow for future Multiple-Before-After-Control-Impact (MBACI) framework of Keogh and Mapstone (1997). In line with this framework, the design includes multiple impact locations (north and south locations), multiple reference locations and multiple data sets, each collected over multiple seasons.

Phyisco-chemical readings were taken using a Hydrolab Datasonde 5 Multiparameter Probe. The measured parameters (and associated units) were:

- temperature (°C)
- pH/oxidation/reduction potential (pH units, mV)
- conductivity/salinity (mS/cm, ppt)
- dissolved oxygen (DO, mg/L)
- turbidity (NTU)
- depth (m)
- incident irradiance (photosynthetically active radiation [PAR])

Profiles of the above parameters were logged through the water column using a field computer running the Hydras 3 LT data logging software. In addition, incident irradiance at the sea surface was measured using a JFE Advantech ALW-CMP PAR logger installed in an open (unshaded) area on Rat Island at the DoF research station for a period of 12 months. Two identical PAR loggers were deployed ~1 m from the bottom, within each of the northern and southern area of MWDAZ in the same locations as the ADCPs. The PAR loggers were fixed to the deployment frame of the ADCP's, and the data downloaded with the metocean data.

At each water quality monitoring site, water samples were collected and analysed for the following

- ammonium (NH_4)
- nitrate + nitrite (NO_X)
- chlorophyll-a
- total suspended solids (TSS), including loss on ignition
- total phosphorus (TP) + total nitrogen (TN)
- orthophosphate (FRP)
- total organic carbon (TOC) + dissolved organic carbon (DOC)
- hydrogen sulphide (H_2S)–subset of sites and bottom sample only from summer & winter
- polycyclic aromatic hydrocarbons (PAH) (ultra-trace level)
- total petroleum hydrocarbons (TPH)
- phytoplankton community

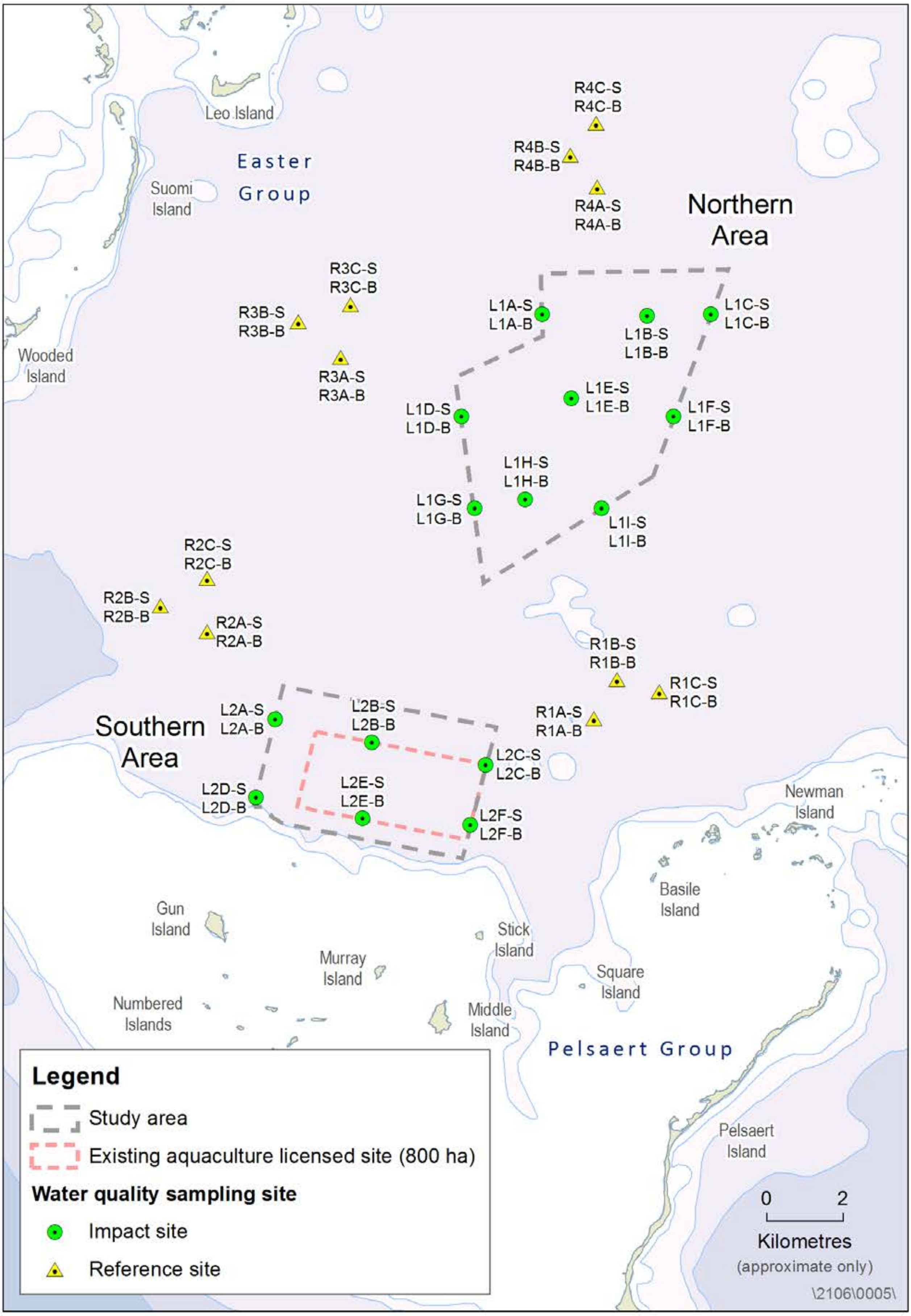


Figure 4-2 Baseline water quality sampling sites

Water samples for chemical analyses were collected using a 4.2 L Van Dorn sampler deployed at each of the 27 water quality sampling sites (Table 4.2), twice within each season, and from the surface (0–1 m) and bottom (~1m from seafloor) of the water column. Once retrieved, the water samples were divided into the aliquots required for each analysis. Once each required sub-sample was obtained, the respective sample bottles were placed into an esky with ice or ice bricks. Once back on land, samples were appropriately stored or post-processed prior to transportation to the laboratory.

For phytoplankton community samples, three discrete water samples were taken using the Van Dorn Sampler (4.2 L each) at the surface, mid and bottom of the water column. The samples were then combined and homogenised in a clean 20 L bucket. This equated to an integrated water column sample of 12.8 L, from which the 250 mL aliquot was obtained.

Table 4.2 Timing of baseline sampling

	Autumn				Winter				Spring				Summer			
	May		Jun		Aug		Sep		Nov		Dec		Feb		Mar	
	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B
Light intensity																
In situ PAR data loggers	In		Out		In		Out		In		Out		In		Out	
Water quality sampling																
Physical water quality profiling	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Ammonium / Nitrite + Nitrate / FRP	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Total nitrogen / Total phosphorus	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Total organic carbon	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Total suspended solids	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Chlorophyll-a	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
PAH/TPH	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Hydrogen sulphide						✓								✓		
Phytoplankton	✓				✓				✓				✓			
Sediment quality sampling																
Total nitrogen / Total phosphorus						✓								✓		
Total organic carbon / Dissolved organic carbon						✓								✓		
Trace metals						✓								✓		
PAH/TPH						✓								✓		
pH / oxidation–redox potential						✓								✓		
Particle size diameter						✓								✓		
Infauna						✓								✓		
Habitat mapping																
Single beam hydro-acoustic mapping		✓														
Metocean																
ADCP (Department of Fisheries)	In		Out		In		Out		In		Out		In		Out	
ADCP (BMT WBM)			In[1]						Out/In						Out	

Notes:

1. First deployed in mid July

Sediment quality

Sediment samples were obtained at a total of 33 sites comprising of 12 sites in the northern area and 9 sites in the southern area, and an additional 12 reference sites, located at the perimeter of the MWADZ. As with the water quality sites, sites were positioned to allow for future MBACI style analyses, and stratified to capture the presence of sediment quality gradients, if present (Figure 4-3).

Sediment samples were collected for the determination of:

- total phosphorus (TP)
- total nitrogen (TN)
- total organic carbon (TOC)
- trace metals: silver (Ag), arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), antinomy (Sb), selenium (Se), zinc (Zn), iron (Fe), manganese (Mn), lithium (Li), and mercury (Hg)
- polycyclic aromatic hydrocarbons (PAH) (ultra-trace level)
- total petroleum hydrocarbons (TPH)
- pH / redox–oxidation potential (ORP)
- particle size distribution , including wet/dry weight ratio
- infauna community composition

Initially sediment sampling was attempted using a modified sediment corer. However, the depth of the water column and the presence of an underlying rocky platform prevented effective sampling. All subsequent sampling was undertaken using a Petite Ponar sediment grab.

Three replicate samples were collected at each sample site. Each of the three replicates were then combined and homogenised, and aliquots were obtained from the homogenised sample. Samples were analysed for the parameters listed in Table 4.3. Samples were stored on ice in the field before being frozen and transported to the laboratory for analysis.

Infauna samples were collected using the Petite Ponar grab. The content of each grab was carefully rinsed through a series of graded sieves (to a minimum of 1 mm). Any material greater than 1 mm was fixed in formalin prior to transportation to the laboratory. Infauna were carefully picked from the samples and retained for identification to species level.

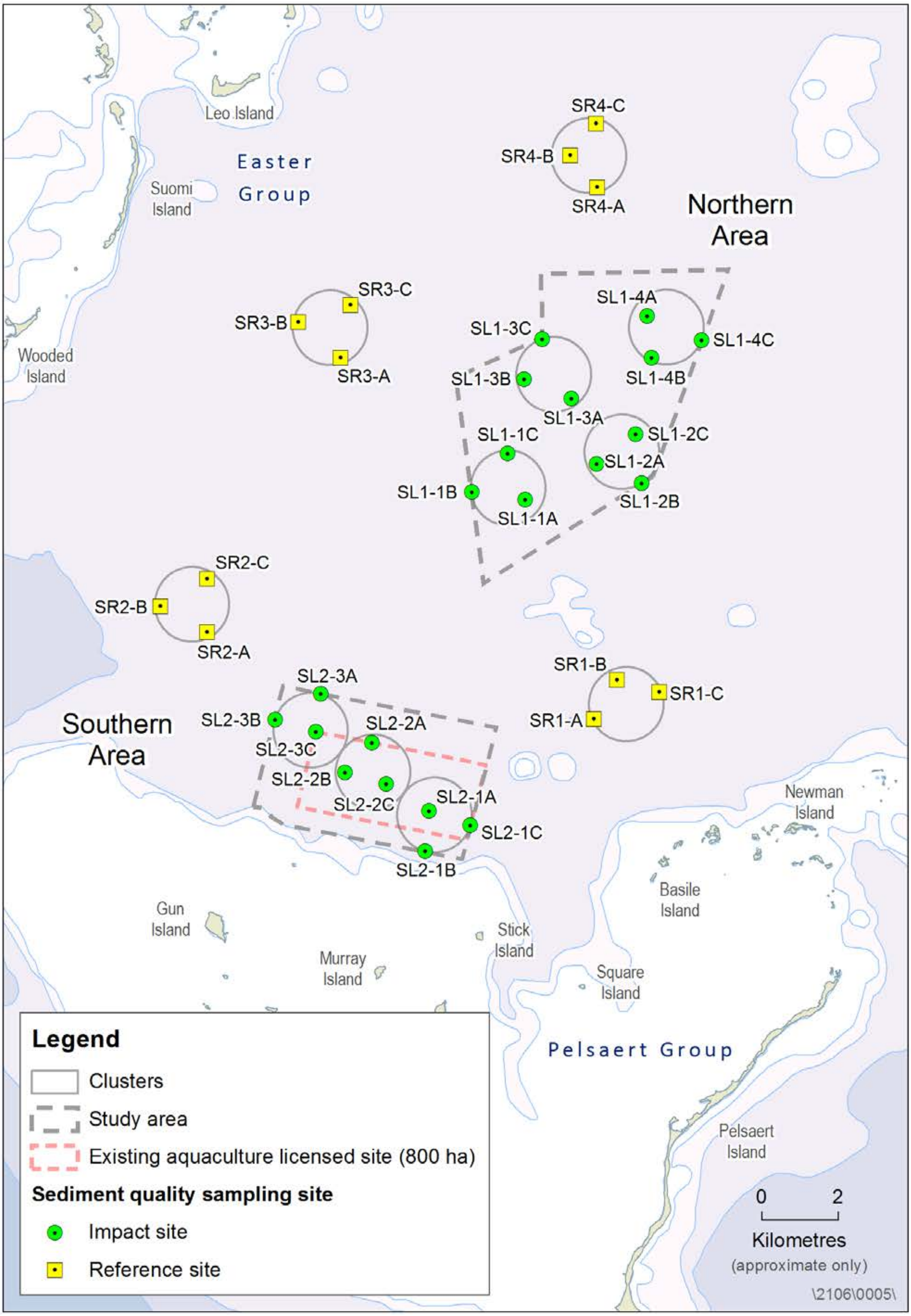


Figure 4-3 Baseline sediment quality sampling sites

Table 4.3 Sediment quality sample vessel and preservations requirements

Analyte	Details	
Total organic carbon (TOC)	Sample volume	125g
	Sample bottle	Polyethylene bottle
	Preservation technique	Fill sample bottle ¾ full.
	Maximum sample holding time and storage conditions	1 month, frozen sample
	Reporting limit	0.05%
Total nitrogen (TN) Total phosphorus (TP)	Sample volume	125g
	Sample bottle	Polyethylene bottle
	Preservation technique	Fill sample bottle ¾ full.
	Maximum sample holding time and storage conditions	1 month, frozen sample
	Reporting limit	10 mg/kg (TP), 0.005% (TN)
Trace metals (Ag, As, Cd, Co, Cr, Cu, Ni, Pb, Sb, Se, Zn, Hg, Fe, Li, Mn)	Sample volume	250g (250g for Hg)
	Sample bottle	Acid washed Polyethylene bottle Hg – plastic jar with Teflon lid
	Preservation technique	
	Maximum sample holding time and storage conditions	1 month, chilled sample 6 months, frozen sample
	Reporting limit	0.001 (Ag, As, Cd, Co, Cu, Pb, Se, Sb); 0.005 (Cr); 0.01 (Ni, Zn); and 0.0001 (Hg) mg/L
Polycyclic aromatic hydrocarbons (PAH) (ultra trace) Total petroleum hydrocarbons (TPH)	Sample volume	100 g
	Sample bottle	Glass jar
	Preservation technique	None
	Maximum sample holding time and storage conditions	14 days, chill sample and keep in dark
	Reporting limit	0.001 mg/kg
Particle size distribution	Sample volume	200 g
	Sample bottle	Ziplock bag (triple bagged)
	Preservation technique	None
	Maximum sample holding time and storage conditions	Chill sample and keep in dark
	Reporting limit	0.02µm and greater (binned by size classes)
Infauna community composition	Sample volume	200mL
	Sample bottle	Plastic Jar
	Preservation technique	Sieved to 1mm
	Maximum sample holding time and storage conditions	Preserved with 10% Formalin
	Reporting limit	Lowest recognisable taxonomic unit and associated abundance

4.2.2 Statistical analysis

The following section describes the statistical procedures used to analyse the baseline dataset. It includes a technical overview of the approaches to the transformation, interrogation and interpretation of the data. The description is necessarily technical to ensure the approaches used are as transparent as possible.

Water quality

All water quality data were analysed statistically using PERMANOVA. Separate univariate analyses tested the relative importance of three main sources of variance, known as factors: (1) Time (fixed factor, orthogonal with ten levels [months]; (2) Zone vs Reference [ZvR] (fixed factor, orthogonal with two levels [zone & reference]; and (3) Location (fixed factor, nested within ZvR, with six levels). The six levels nested in Location included: northern area; southern area, reference 1; reference 2; reference 3 and reference 4. Data obtained at the surface and bottom of the water column were analysed separately.

For all univariate tests, a Euclidean resemblance matrix was applied on untransformed data prior to analysis with PERMANOVA (non-parametric analysis of variance, Version 1.0.1, Primer-E Ltd) (Anderson et al. 2008). Post-hoc pair wise comparisons were then used to test for differences among levels within significant factors. Results from univariate analyses were presented using graphs of means and standard errors for either time or location.

Phytoplankton

For phytoplankton counts, biovolume and total counts analyses, PERMANOVA routines tested the relative importance of three main factors: (1) Time (fixed factor, orthogonal with four levels: May 2014, Aug 2014, Dec 2014, Feb 2015); (2) Zone vs Reference [ZvR] (fixed factor, orthogonal); and (3) Location (fixed factor, nested within ZvR). All statistical analyses, including post-hoc pair-wise comparison tests on significant factors, were undertaken using PERMANOVA.

Multivariate phytoplankton count data were fourth-root transformed prior to analysis. This transformation down-weighted the contribution of dominant phytoplankton taxa and allowed intermediate or rarer groups to play a part in the analyses (Clarke 1993). The Bray-Curtis dissimilarity measure was used prior to analysis with PERMANOVA. If any of the three factors were significant, they were interpreted using post-hoc pair-wise comparisons to test for differences among levels within each factor. Results of multivariate analysis were presented graphically using a non-parametric, multi-dimensional scaling plot (nMDS), which plotted the centroid (average) of each location by averaging over replicates. Vector overlays of the phytoplankton counts were plotted on the MDS to show correlations with the patterns in the multivariate data.

For multivariate phytoplankton biovolume data and total counts, a Bray-Curtis dissimilarity measure was applied to square-root transformed data to create the resemblance matrix for analysis. Data were zero-adjusted prior to creating resemblance matrix by adding a dummy variable of one to all samples (Clarke et al. 2006). This was undertaken to address the high proportion of blank samples and samples with only one species recorded. Without the use of a dummy variable, a Bray-Curtis matrix would have produced undefined similarities where no species were recorded in two compared samples, and highly varied similarities where only one species was recorded in the two samples. The inclusion of a dummy variable moderates these effects (Clarke et al. 2006). If any of the factors were significant following a PERMANOVA, they were interpreted using post-hoc pair-wise comparisons to test for differences among levels within each factor.

Irradiance and light attenuation

Incident irradiance at the sea surface was measured in an open (unshaded) area on Rat Island. Two further identical PAR loggers were deployed ~1 m from the bottom, one in the centre of the southern area and the other in the centre of the northern area of the MWADZ (Figure 4-1). The loggers were deployed for the periods shown in Table 4.4.

Table 4.4 Dates of light logger deployment

Deployment phase	Season	Month/Year of deployment	Dates of deployment duration
1	Autumn	May–June 2014	16/05/2014–20/06/2014
2	Winter	August–September 2014	17/08/2014–19/09/2014
3	Spring	November–December 2014	09/11/2014–11/12/2014
4	Summer	February–March 2015	09/02/2015–11/03/2015

Data were processed as per Chevron (2012). All data collected between 1000 and 1400 each day was retained for analysis. Data collected by the terrestrial light logger unit was multiplied by 0.96 to estimate the intensity just below the water surface (Chevron 2012). Light attenuation coefficient (K_d) was calculated according to the following equation:

$$Kd = \frac{-Ln\left(\frac{Intensity_{depth}}{Intensity_{Surface}}\right)}{Depth\ (m)}$$

Light intensity (as radiance) was calculated for the 1st, 5th, 20th and 50th percentiles for each of the four logger deployments.

Physical-chemistry

Dissolved oxygen measurements were grouped by location (northern area, southern area and reference locations) and by season (summer, autumn, winter and spring. Summary statistics were then produced for the surface (top 50 cm measured) and the bottom (bottom 50 cm measured) of the water column:

- mean surface
- mean bottom
- 20th percentile bottom
- 5th percentile bottom
- 1st percentile bottom

Sediment quality

All sediment quality parameters were analysed to identify potential patterns between four factors: (1) Season (fixed factor, orthogonal with two levels: winter and summer); (2) Future lease vs Reference [ZvR] (fixed factor, orthogonal); (3) Location (fixed factor, nested within ZvR with six levels: SL1, SL2, SR1, SR2, SR3, SR4); and (4) Site (random factor, nested within Location). All statistical analyses, including post-hoc tests on significant factors, were undertaken using PERMANOVA (Anderson et al. 2008). This method enabled analysis of univariate and multivariate datasets, while not explicitly requiring normalised data or homogeneous variances. All analyses were run using permutations of residuals under a reduced model (n = 9 999 permutations).

For percent particle size distribution, data were square-root arcsine transformed following Underwood (1997). A Bray-Curtis dissimilarity matrix was generated and the data were analysed using PERMANOVA. Multivariate statistical outputs were presented graphically using a canonical analysis of principle coordinates (CAP). The CAP routine was used as there were differences among a priori groups in multivariate space that could not be seen in an unconstrained ordination such as a PCO or MDS plot (Anderson et al. 2008). Vector overlays of the particle size groups were plotted on the CAP to show correlations with the patterns in the multivariate data.

Separate univariate analyses were performed on sediment nutrient concentrations. For percent nitrogen and TOC, data were square-root arcsine transformed prior to analysis as this is a standard transformation for proportional datasets that are often binomially distributed (Underwood 1997). No transformations were necessary in the cases of the ammonium and phosphorus data were. Euclidean distance was used as a dissimilarity measure for all univariate analyses. By using the Euclidean measure, PERMANOVA returns an equivalent test statistic to a standard ANOVA (Anderson et al. 2008). If location were significant, they were interpreted using post-hoc pair-wise comparisons to test for differences among levels within locations. Results from univariate analyses were presented using graphs of means and standard errors.

Trace metal data were analysed using both univariate and multivariate techniques. For the multivariate component, data were initially square-root transformed to down-weight the contribution of dominant trace metals and to allowed intermediate or rarer groups to play a part in the analyses (Clarke 1993). A Bray-Curtis dissimilarity matrix was generated and the data were analysed using PERMANOVA. Results of multivariate analysis were presented graphically using nMDS, which plotted the centroid (average) of each location by averaging over replicates. Upon detection of a significant difference among levels within a factor for the multivariate data, vector overlays were plotted on the MDS. This enabled the top five trace metals that had the strongest correlations with the patterns in the multivariate data to be determined.

The trace metals with the highest concentrations (top 5) as identified by the vector overlay were further explored with separate univariate PERMANOVAs. A Euclidean distance measure was applied on untransformed data, allowing PERMANOVA to return an equivalent test statistic to a standard ANOVA (Anderson et al. 2008). Post-hoc pair wise comparisons were used to test for differences among levels within significant factors. Results from univariate analyses were presented using plot of means and standard errors for each location.

For the analysis of infauna, benthic infauna assemblages (multivariate dataset) were first sorted to species level, before being consolidated to the family level. Multivariate assemblage data were square-root transformed to down-weight the contribution of dominant infauna and to allow intermediate or rarer groups to play a part in the analyses (Clarke 1993). A Bray-Curtis dissimilarity matrix was generated and the data were analysed using PERMANOVA.

Results of multivariate analysis were presented graphically using nMDS. This enabled the top ten benthic infauna families that had the strongest correlations with the patterns in the multivariate data to be determined. The top ten benthic families were then presented using pie charts to represent the overall percentage contribution for each season and location. For univariate analyses of infauna abundance and family richness, a Euclidean distance measure was applied on untransformed data, allowing PERMANOVA to return an equivalent test statistic to a standard ANOVA (Anderson et al. 2008). Post-hoc pair wise comparisons were used to test for differences among levels within significant factors. Results from family richness and abundance analyses were presented using bar graphs of means and standard errors for each location.

To examine the relationship between infauna community assemblage and sediment parameters (grain sizes, trace metals, nutrients), a Canonical Analysis of Principal Coordinates (CAP) ordination plot of the community assemblage were graphed with vectors overlayed on the CAP ordination plot of sediment parameters. This enabled the top sediment parameters that had the strongest correlations with the patterns in the multivariate infauna data to be determined.

4.2.3 Program sensitivity

Both the water and the sediment monitoring programs were designed according to the MBACI (Multiple-Before-After-Control-Impact) framework of Keogh and Mapstone (1997). The sensitivity of MBACI designs is generally constrained by the number of locations (both impact and reference) and in some cases, the number of sites nested in locations (Underwood and Chapman 2003). The statistical power of MBACI designs cannot be calculated directly, but can be estimated using Monte Carlo simulations (Underwood and Chapman 2003). While the power of these designs was not tested during the EIA, the use of up to four impact locations and four reference locations compares well with other studies with reasonable levels of sensitivity (capable of detecting changes of between 20-40%) and acceptable levels of statistical power (~0.8; BMT Oceanica, unpublished data).

4.3 Baseline benthic habitat surveys

This assessment utilised two sources of benthic habitat data: historical and publically available data sets captured in 2003, 2006 and 2008 (by the University of Western Australia Marine Futures Project) and more recent data captured by DoF during the baseline assessment between May 2015 and March 2015 (Section 4.3.2). The habitat descriptions and proportional estimates in Section 5.5 are for the MWADZ study area which incorporates an area of 4750 ha (Figure 4-4). These differ from the descriptions in Section 6, which are based on a Local Assessment Area (LAU) of 6735 ha, determined in consultation with the OEPA.

4.3.1 Historical assessments

The 2003 surveys utilised sidescan sonar to map habitat in the southern group of the Abrolhos and the 2006 and 2008 surveys habitats north of the Pelsaert Group. The signal from the sidescan sonar was digitised using SonarWiz equipment and software from Chesapeake Technologies. Processing of the sidescan sonar data consisted of bottom tracking, beam angle correction and slant range correction and mosaiking. The data was analysed to classify benthos into broad categories, which were further defined by a total of 22 subcategories. All data was compiled in ArcView 8.2 GIS.

4.3.2 Surveys undertaken for this project

The current assessment utilised a Biosonic MX digital single beam echosounder and covered both the northern and the southern areas of the MWADZ and the reference locations. The sounder was fixed to the hull of the operational vessel and linked to a differential Global Positioning System (DGPS). The DGPS system provided sub metre accuracy through corrections via the OmniSTAR satellite service.

Depth data were collected 16–19 May 2014 along a xyz configuration of latitude, longitude and depth. East to west transect lines, spaced ~1 km apart were surveyed through both of the MWADZ locations and four reference areas. Sounding data was collected at a rate of 5 sounding records per second, with the boat travelling at approximately 5 knots.

The hydroacoustic surveys were conducted along approximately east-west lines through each area, based on the prevailing conditions, in an effort to minimise the pitch/roll of the vessel during the May 2014 sampling period. The first phase of soundings were spaced ~1 km apart (Figure 4-4) to capture a minimum level of hydroacoustic data for each area. The total linear distance covered was 7 900 meters for the first phase. The second phases of surveys involved infilling the 1 km spaced survey lines (Figure 4-4).

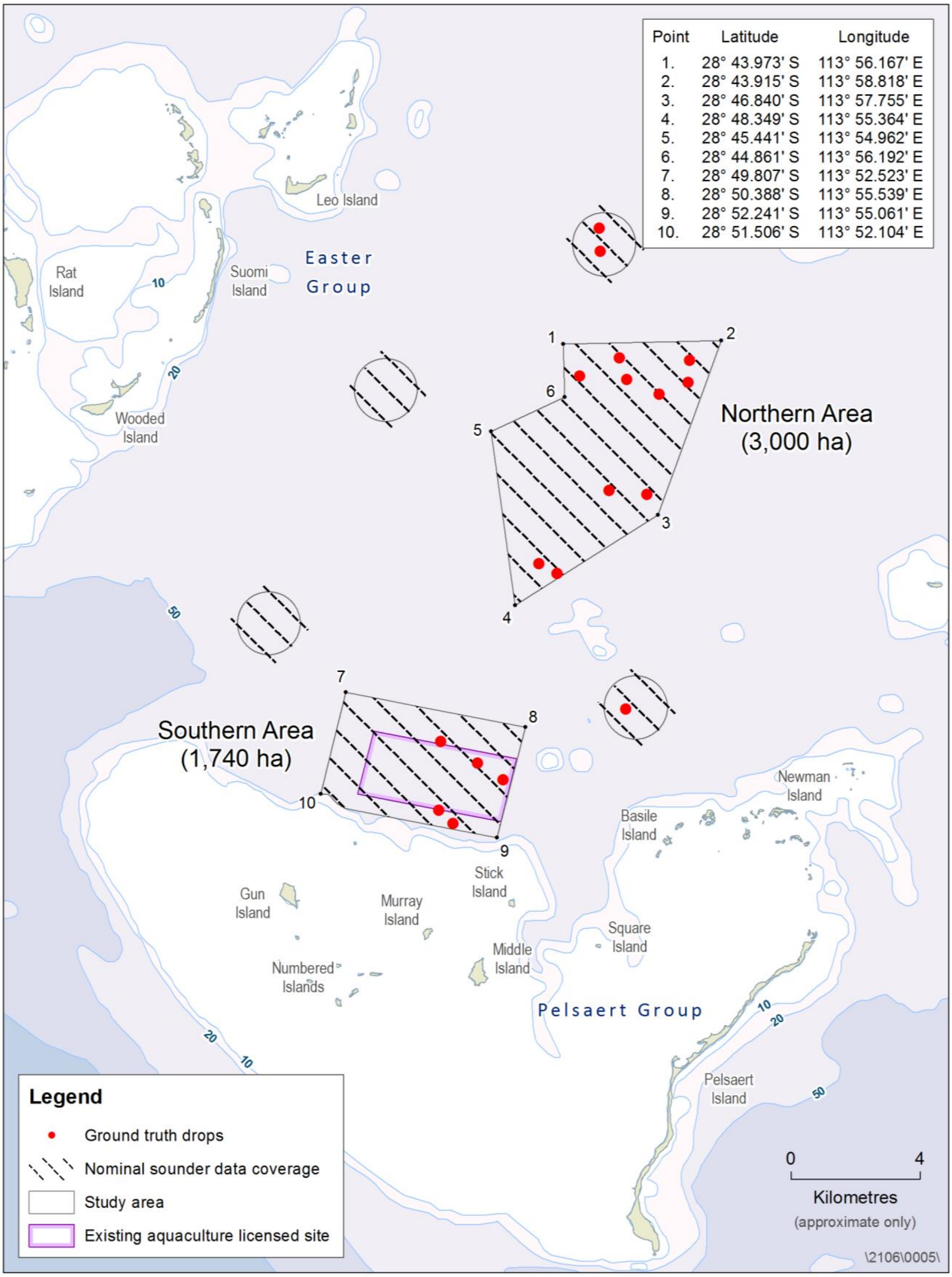


Figure 4-4 Nominal sounder data tracks and location of ground truth sites

The resulting data was used to create an 'unsupervised' classification of the benthos to broad categories of benthos in the surveyed areas.

The unsupervised classification was used to select ground truthing sites for verification via drop video in the field during the June 2014 sampling period (Figure 4-4). The underwater video was a 'live feed' system consisting of a progressive scan camera in an underwater housing attached to weighted frame with legs (the weighted frame keeps the system directly below the vessel, while the legs provide protection and also a scale reference in the image). The system was connected to the vessel by 10 mm rope and a reinforced video umbilical cable. The live feed video, with DGPS overlay, was recorded onto a hard drive recording device or progressive scan HandyCam.

The video data were processed by using the point intercept method to identify the benthic habitats at each sampled site. The benthos was classified into several broad categories, encompassing reef, mixed assemblages (sparse, mixed) and sand. Within these broad categories, the percentage cover of macroalgae, sponges, hard corals and rhodoliths was determined.

Percentage cover of each habitat type, latitude, longitude and depth were recorded for each video drop site. These data were then analysed to determine homogenous habitat types to provide the basis for the supervised classification of the habitat. A classification of 'mixed assemblage' consisted of two or more biotic categories within one location (e.g. filter feeders, macroalgae and rhodoliths).

Data Analysis

All depth data was exported from the 'Biosonic MX digital single beam echo sounder' into Microsoft Excel. All data was collected and analysed in spatial reference datum WGS84. For analysis, depth data was averaged over 50 sounding records (~ every 30 m). Averaged depth data were then corrected to lowest astronomic tide (LAT) using tide information from the Bureau of Meteorology (BoM; see http://www.bom.gov.au/australia/tides) for Geraldton. The Geraldton tide data were used for tide correction as it is measured data, where the Pelsaert and Easter group tide data predicted and may not be accurate. However, variation in tide within a 30 minute period (the longest predicted tide variation at the Abrolhos Islands) at the Geraldton real time tide station fluctuates up to ±0.05 m at Geraldton. Therefore tidal difference between Geraldton and the MWADZ were expected to be minimal.

Digital Elevation Map

The digital elevation model for bathymetry of the MWADZ was developed using the averaged tide corrected depth data in the ArcGIS program ArcMap© using the spatial analyst extension. The 'Topo to Raster' tool was chosen as it is a proven best-practice interpolation method which is specifically designed for the creation of hydrologically correct digital elevation models. An individual model was run for each of the northern and southern areas of the MWADZ and the reference locations, with an output cell size of 50 m. The outputs provided are three interpolated surface rasters of bathymetry for the MWADZ northern, southern and reference areas. Each surface raster has cells with a pixel size of ~50 m, providing a depth data point for each cell within each location.

4.4 Pressure-response relationships

A key component of the EIA was to accurately identify and describe the cause-effect-response pathways relevant to the proposed MWADZ. The oceanographic and ecological components of the MWADZ are described in Section 3. Section 4.4 follows on from Section 3 to provide an overview of the ecological changes which may result from the proposal. To fully appreciate the risks posed by the MWADZ, it was first necessary to understand the types of pressures (and their magnitude) imparted by the proposal, and their likely effect (Section 4.4.1). This understanding, together with a desktop risk evaluation, was subsequently used to identify the key cause-effect-response pathways (Section 4.4.3), and to select thresholds for model interrogation (Section 4.5).

4.4.1 Identification of relevant pressures and risks

Noise

Noise generated by anthropogenic activities has the potential to disturb marine and terrestrial fauna, causing temporary or long-term avoidance of an area that may be important for feeding, reproduction or shelter. Underwater sounds may interfere with communication systems of fish and marine mammals, masking important biological cues or causing behavioural disturbance (Richardson et al. 1995, National Research Council 2005, Southall et al. 2007). Depending on the duration and intensity of underwater noise, an animal may avoid the source of the disturbance completely, thereby altering the overall use and ecology of that marine environment.

Construction and demolition of aquaculture facilities may, in rare circumstance, involve the use of pile-drivers or explosives (Olesiuk et al. 2012). These generate intense sounds, as well as shock waves that may affect critical behaviours and functions, such as feeding, migration, breeding and response to predators (National Research Council 2005; Yelverton et al. 1973; Yelverton 1981; Richardson et al. 1995; Dzwilewski and Fenton 2003; Madsen et al. 2006).

Acoustic Harassment Devices (AHDs) used to deter seal and sea lion attacks at salmon farms have been shown to have far ranging effects on non-target cetaceans, such as harbour porpoise and killer whales, which can be displaced large distances from where AHDs have been deployed. In contrast, pinnipeds (seals and sea lions) appear to habituate to these devices and may experience hearing loss through prolonged exposure or very close approach, such that AHDs are largely ineffective as long-term predator deterrents. AHDs could potentially disrupt the behaviour patterns of some fish that have specialized hearing apparatus, particularly clupeids like herring, but these effects have not been documented (Olesiuk et al. 2012).

Less intense sounds, such as those associated with vessel movements (i.e. movement of feeding barges and/or service vessels) would likely be in similar frequency and intensity ranges as those of commercial fishing and transport operations. For marine mammals at least, the effects of the sounds from these sources are usually transitory, or the animals can habituate to such sounds with regular exposure. However, the range of effects can be large, and the cumulative effects of the frequent exposure to louder vessels is largely unknown (Olesiuk et al. 2012).

Physical presence

Finfish will be grown in circular sea-cages (cages) of 38 m diameter and 18 m height (volume ~20 000 m^3). The design, construction and materials of cages will incorporate modern technology and best-practice to minimise environmental impacts. Cages will be anchored to the sea floor using equipment and techniques appropriate to marine conditions in the MWADZ. Where possible, anchoring on the sea-cages is undertaken with helix 'auger like' anchors which screw into the sea-floor. However, larger anchors, or weighted substrates (i.e. concrete blocks) might be required if the nature of the seafloor prevents penetration by the auger type anchors. Permanent losses of small areas of benthic habitat may occur in this instance.

The project infrastructure may act as a physical barrier to migrating marine life, an artificial substrate for attraction and roosting of seabirds (Section 8.4), and as a barrier to ambient water currents. The presence of large networks of sea-cages may in some circumstances act as a barrier or deterrent to cetacean migration (Section 8.3). Placement of sea-cage structures should proceed based on a review of the significance of the region as a migration corridor, as well as the likelihood that the configuration and placement of the infrastructure may act as a barrier. Ideally cage and/or lease placement should be organised to avoid such interactions.

Networks of floating sea-cages act as fish attractants and artificial substrates for marine invertebrates and sea-birds. For seabirds, direct disturbances may result from adverse interactions while foraging, attraction to, or avoidance of, aquaculture vessels and marine infrastructure, or exposure to contaminants. Direct interactions with finfish farming operations could include:

- supplementary feeding from stock predation, fish food, waste material or food scraps
- collisions with sea cages, other structures or vessels moored at night
- attraction and disorientation due to inappropriate lighting on service vessels, pens or navigation markers at night
- entanglement in cage mesh, predator nets or protective bird netting
- attraction of prey to vessel or sea cages due to “FAD” effects.
- attraction to the fish stock
- use of vessel or sea cages as roosting sites

In addition, floating sea-cages may affect local hydrodynamics. Model results show that the presence of fish cages restricts water flow and reduces the velocity in the surface layer occupied by the cages, but enhances the water velocity in the bottom layer beneath the cages. Increases in current speeds beneath sea-cages are dependent on distance between the bottom of the sea cages, and the seafloor. Bottom currents are maximised where the height of the cages is roughly half of the maximum water depth (Wu et al. 2014).

Organic wastes

The cause-effect-response pathways relevant to inputs of organic waste are a key consideration in this assessment. Sea-cage aquaculture has the potential to impact the sediment when organic wastes settle beneath, or in close proximity to, the sea-cages (Mazzola et al. 2000, Carroll et al. 2003). The deposition of organic material may lead to local organic enrichment or, under worst-case conditions, regional eutrophication. Gray (1992) emphasises that the critical effects of eutrophication are experienced when water column oxygen concentrations become depleted as total community respiration increases due to increased organic loads to the sediments. Increased nutrient loadings are generally associated with increased episodes of hypoxia or anoxia, particularly in stratified waters, with subsequent detrimental effects on the fauna (Baden et al. 1990, Schaffner et al. 1992). Hypoxia may cause local extinction of benthic populations (Gaston & Edds 1994), reduced growth rates of benthic fauna (Forbes & Lopez 1990, Forbes et al. 1994) and changes in benthic communities (Pearson & Rosenberg 1978, Josefson & Jensen 1992, Hargrave et al. 2008; Hargrave 2010). Changes in communities are typically driven by the sensitivities of infauna, with rare and more sensitive species disappearing first. More resilient species such polychaetes are known to be resistant to hypoxic or near-hypoxic conditions (Pearson & Rosenberg 1978, Gray 1992, Dauer et al. 1992).

Infauna are widely regarded as sensitive indicators of environmental degradation and restoration in marine sediments (Clarke & Green 1988, Austen et al. 1989, Warwick et al. 1990, Weston 1990, Dimitriadis & Koutsoubas 2011). Impacts to infauna commonly occur along a gradient of sediment organic enrichment (Pearson and Rosenberg 1978, Hargrave 2010), as evidenced by numerous studies demonstrating a correlation between the level of organic enrichment and the level of infauna community degradation. Cromey et al. (1998) reviewed the fate and effects of sewage solids added to mesocosms. Organic loading rates less than 36 g C/m^2/yr had little effect, rates between 36 and 365 g C/m^2 /yr enriched the sediment community, and a loading over 548 g C/m^2/ yr produced degraded conditions (Kelly & Nixon 1984, Frithsen et al. 1987, Oviatt et al. 1987, Maughan and Oviatt 1993, all cited in Cromey et al. 1998). Eleftheriou et al. (1982) showed that the addition of 767 g C/m^2/yr to unpolluted sediment enriched the fauna, whereas addition of 1 498 g C/m^2/yr caused degraded conditions. Deposition rates

>700 g C/m^2/yr are widely believed to represent a critical value, such that sediments exposed to this rate of deposition are considered degraded, i.e. diversity of benthic fauna is significantly reduced (Cromey et al. 1998). Although useful in terms of predicting the magnitude of effect of infauna, these thresholds give no indication of recovery times (also known as remediation) following removal of the source of the contaminants.

Although finfish farming has the potential to impact sediments beneath, and immediately adjacent to sea-cages (Carroll et al 2003), case studies of finfish aquaculture systems in Tasmania and Europe found that impacts are generally restricted to within 10–100 m of sea-cages and that the magnitude of impact depended largely on the depth of the water and the rate of water movement through the site (Carroll et al. 2003, Crawford 2003, Borja et al 2009). Average current velocities through the proposed MWADZ are 8.7–14.1 cm/s in the summer months, and 10.5–14.5 cm/s in the winter months (Table 4.5). This range of average current speeds is conducive to conditions described as either 'moderately' or 'not sensitive' to impact. Currents speeds >10 cm/s are widely considered 'ideal' for sea-cage aquaculture, and current speeds <6 cm/s are generally considered 'not ideal' for sea-cage aquaculture (Table 4.6).

Table 4.5 Average surface and bottom water current speeds through the MWADZ

	Current speeds (cm/s)			
	Northern area		Southern area	
Month	Surface	18 m water depth	Surface	18 m water depth
Summer	13.2-14.1	10.4-11.0	8.7-9.4	5.8-7.0
Winter	14.0-14.5	9.0-11.5	10.5-11.0	6.1-8.0

Table 4.6 Increasing suitability of potential aquaculture sites based on current speed

Suitability	Current speed (cm/s)	Reference
Not sensitive to impact / desirable	10-25	Carroll et al. (2003)
	>15	Borja et al. (2009)
	13–77	Benetti et al. (2010)
	5–20	Halide et al. (2009)
	10–60	Beverage (2004)
Moderately sensitive to impact	5–15	Borja et al. (2009)
Sensitive to impact / unsuitable	3–6	Carroll et al. (2003)
	<5	Borja et al. (2009)

Inorganic nutrients

Finfish aquaculture in open water sea-cages may, in some instances, cause deterioration in local water quality due to inputs of inorganic nutrients from fish faeces and uneaten food. Aquaculture may contribute inorganic nutrients to the water column either directly through secretion of ammonia by fish, or indirectly through organic matter deposition and remineralisation. Inorganic nutrients in the form of ammonia, nitrite + nitrate and orthophosphate may lead to adverse environmental effects via a number of cause-effect pathways, all of which contain BPPHs as key receptors. As with the cause-effect-response pathways relevant to organic wastes (described above), the cause-effect-response pathways relevant to inorganic nutrients are also considered key in this assessment.

Habitat studies in the MWADZ have revealed a diverse array of benthic habitats, including the presence of vast swathes of mixed assemblages comprising macro-algal, rhodolith, filter feeding, coral and other invertebrate communities (Section 5.4.5). Macroalgae and corals in particular are known to be sensitive to sources of inorganic nutrients, and may in worst-case examples undergo phase shifts. For example, prolonged exposure to nutrients may lead to conditions where living

corals are slowly replaced by macroalgae. Some authors believe that phase shifts are dependent on the degree of herbivory on a reef system (e.g. Littler & Littler 1984, Jackson et al. 2001, Bellwood et al. 2004, Hughes et al. 2010, Rasher et al. 2012). The paradigm is that in the absence of herbivores, algae have been able to proliferate even at low nutrient concentrations (~1 µmol/L).

Metals and other contaminants

Toxic effects on marine organisms are likely when metal concentrations reach threshold levels, or increase via biomagnification (Parsons 2012). Sources of metals include contaminated sites, agricultural and urban runoff, discharges from sewage treatment plants, and copper-based antifoulants sometime used on sea-cage infrastructure (Parsons 2012).

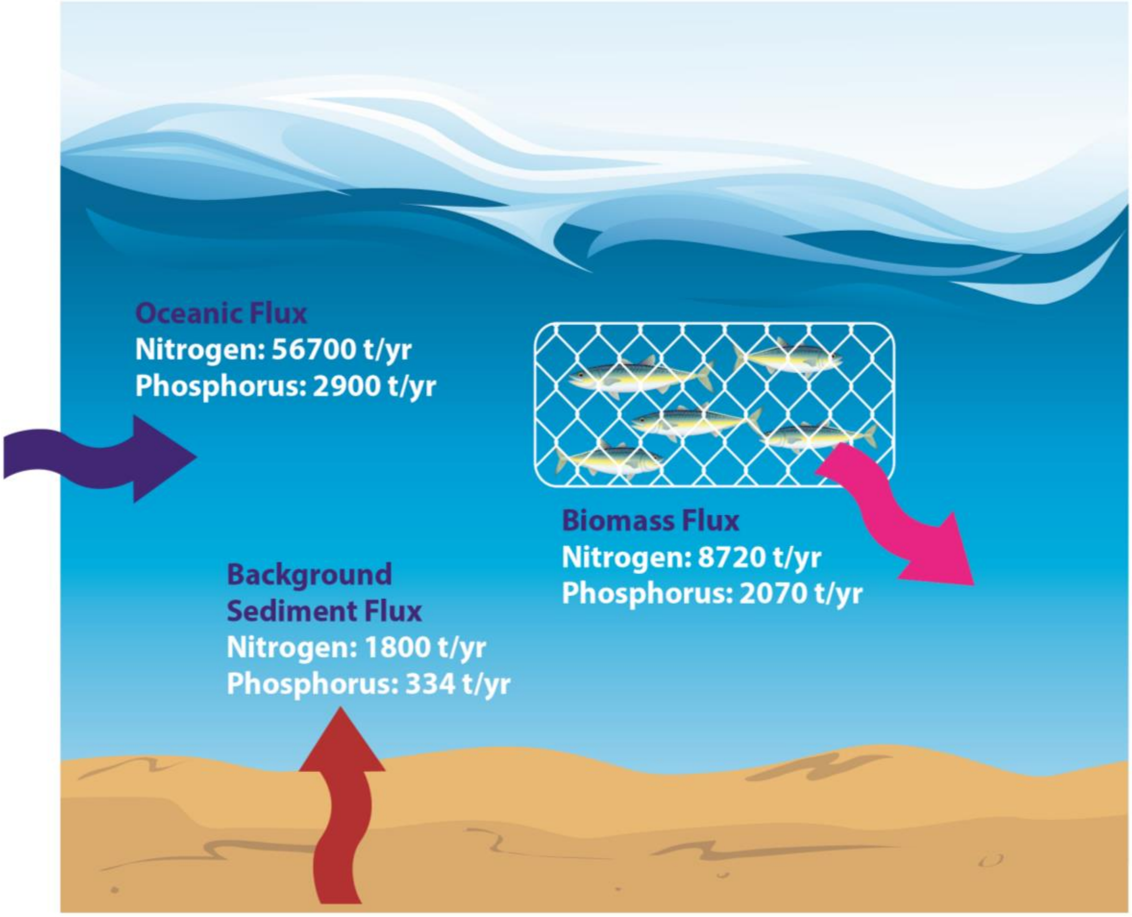
Metals form a small constituent of commercial aquaculture feeds as trace elements. The metals are consumed by finfish and excreted in the faeces. A study of the metal content of trout faeces by Moccia et al. (2007) found that Zn and Fe were present in the highest concentrations, with relatively low proportions of copper (see Section 7.3.3). Despite the very low concentrations in commercial feeds, monitoring in Tasmanian waters has recorded copper and zinc sediment values at concentrations higher than the ANZECC/ARMCANZ (2000) ISQG-low and ISQG-high guideline values at some sea-cage sites (DPIPWE 2011).

Antibiotics are sometimes used to treat bacterial disease occurring in farmed finfish and are generally administered in feed. Antibiotics may impart pressure on the marine environment by reducing or changing numbers of sediment bacteria, which in turn may affect broader ecological processes. In the treatment of farmed salmon in Tasmania, oxytetracycline is the most common antibiotic used, accounting for more than 70% of total antibiotic use during 2006–2008 (Parsons 2012). A strong seasonal component to the use of antibiotics has been noted in Tasmania, with the greatest requirement in the summer months when water temperatures are elevated and pathogens tend to be most virulent.

4.4.2 Ecosystem nutrient budget

The nutrient budget of the region is relatively simple in that it comprises (presently) only advective oceanic fluxes and sediment nutrient fluxes. These are both considered small in that the existing environment is essentially oligotrophic. Supporting this, it is noted that the monitoring data collected as part of this study showed that water column nutrient concentrations were generally very low (Section 5.3.3).

The addition of the proposed fish cages adds a considerable nutrient perturbation to the system, and has been a key subject of investigation in this study. This perturbation takes the form of both an immediate nutrient load to the water column (via waste and feed excess) and a delayed load via impacted sediment nutrient remineralisation. A graphical representation of existing and impacted conditions, with approximate annual nutrient fluxes is included in **Error! Reference source not found.** and Table 4.7. Fluxes have been computed from measurements and model predictions.



Notes:

1. Biomass flux includes both solid and liquid waste nitrogen and phosphorus
2. Sediment flux is the background flux for the southern Abrolhos region (~3,000 km^2); sediment flux is based upon the average sediment nutrient content measured during the baseline sampling program
3. Oceanic flux is the total nutrient flux in and out of the southern Abrolhos region (~3,000 km^2)

Figure 4-5 Conceptual diagram of the baseline and post operation nutrient budget under scenario 1

Table 4.7 Baseline and post operation nutrient budgets

Scenario	Source (t/yr)		
	Aquaculture (biomass)	Oceanic	Background sediment
1-2	Nitrogen 8720 Phosphorus 2070	Nitrogen 56 700 Phosphorus 2900	Nitrogen 1800 Phosphorus 10700
3-4	Nitrogen 13950 Phosphorus 3310		
5-6	Nitrogen 17440 Phosphorus 4130		

4.4.3 Cause-effect-response pathways

Cause-effect-response pathways were developed following the step-wise approach of Gross (2003). The approach included development of two models: a control model and a stressor model. The control model (Figure 4-6) is hierarchical in nature, with the stressors and their sources shown in the upper strata of the model, and the indicators (receptors) and effects shown in the middle to bottom strata of the model. The control model remains relatively simple in that it makes no attempt to account for the magnitude and/or the duration of the stress.

The stressor model is a refined version of the control model focussing on the cause-effect pathways of most concern (Figure 4-7). It articulates the relationship between stressors, ecosystem components, effects and biological receptors and is a succinct account of the major cause effect pathways, from which the indictors and thresholds were ultimately derived.

The objective of this approach was to identify the cause-effect-response pathways most likely to be affected by the MWADZ, and those likely to exhibit measurable changes in response to stressor inputs. The understanding gained by this process was used to develop the thresholds described in Section 4.5.

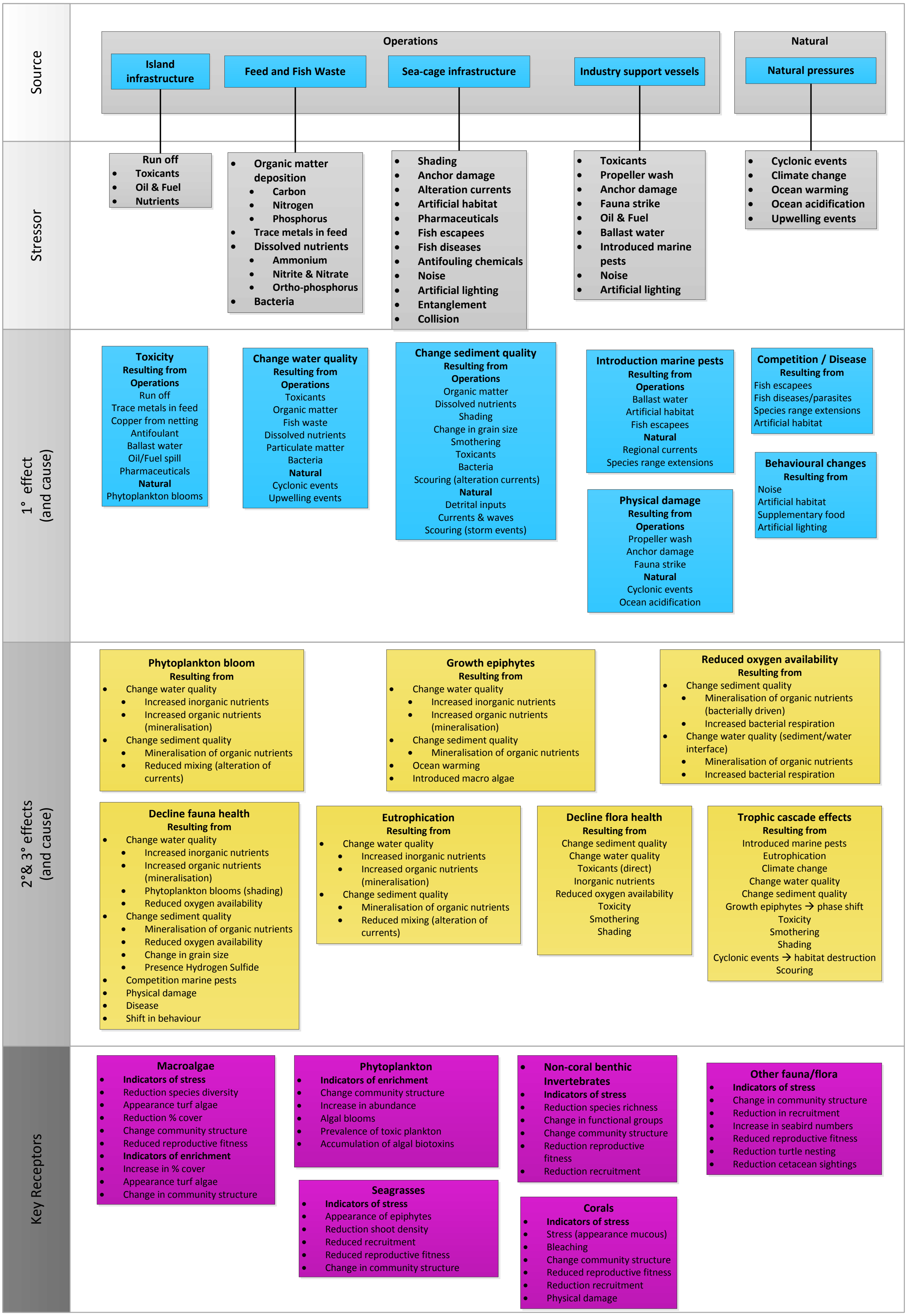
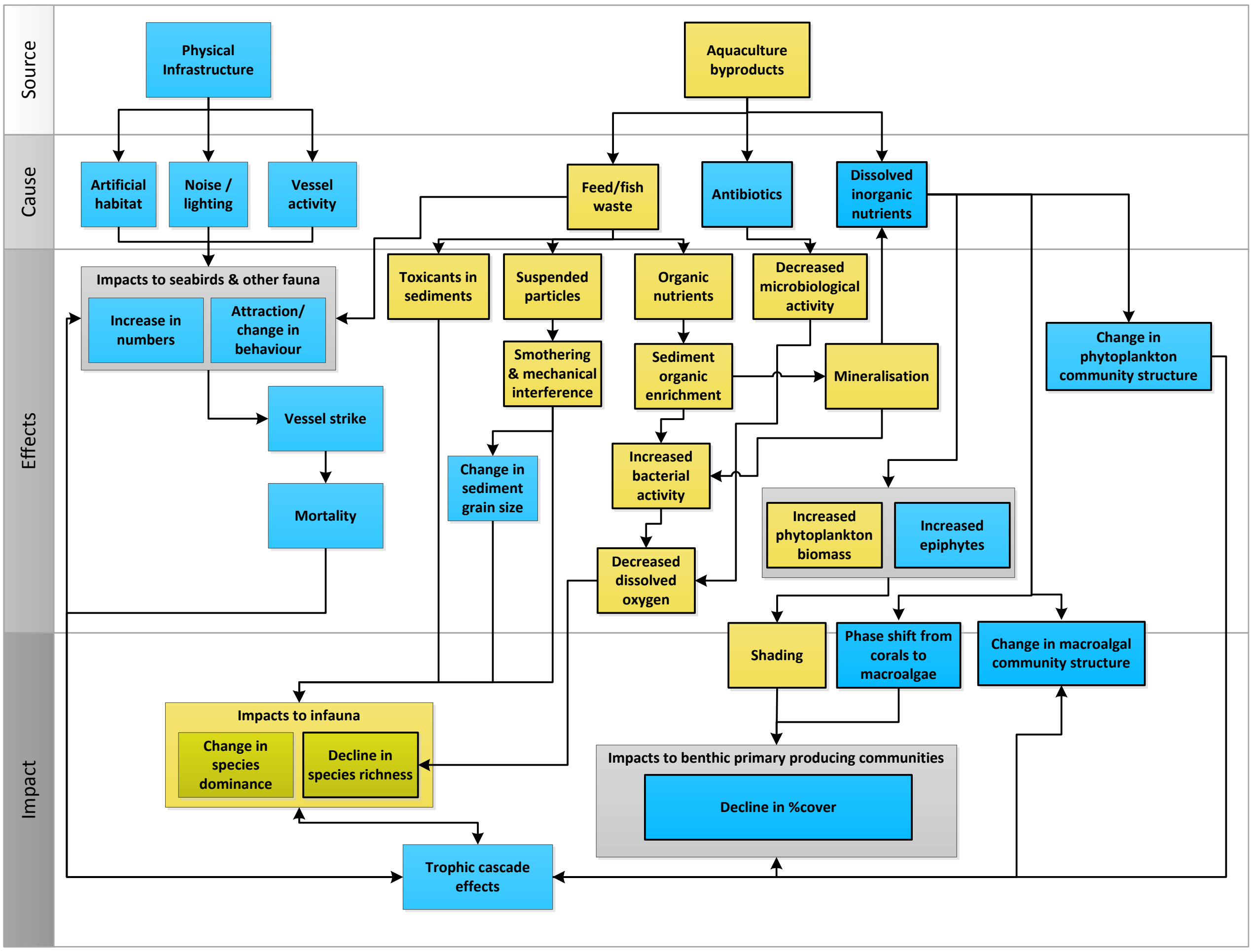


Figure 4-6 Hierarchical control model showing natural and anthropogenic stressors and key cause-effect-response pathways



Notes:

1. Key cause-effect-response pathways. Pathways shown in yellow represent those captured by the modelling and those for which thresholds were developed.

Figure 4-7 Hierarchical stressor model showing the key cause-effect-response pathways and those chosen for model interrogation

4.5 Thresholds for model interrogation

4.5.1 Application of EAG 3

EAG 3 is concerned with the protection of ecological integrity and biodiversity through a framework for assessing the cumulative loss of, and/or serious damage to benthic primary producer habitats (BPPH) in WA. BPPHs are seabed communities within which algae (e.g. macroalgae, turf and benthic microalgae), seagrass, mangroves, corals or mixtures of these groups are prominent components. BPPHs also include areas of seabed that can support these communities (EPA 2009).

'Irreversible loss' of benthic primary producer habitats is commonly associated with excavation or burial. Such activities modify BPPH so significantly that the impacted community would not be expected to recover to the pre-impact state and therefore the loss is considered irreversible. 'Serious damage' is also intended to apply to damage to BPPH that is effectively irreversible or where recovery, would not occur for at least 5 years (EPA 2009).

Applicable category

EAG 3 was applied here given the potential for sea-cage aquaculture to cause both permanent loss and serious damage. Both are hereafter termed cumulative loss.

EAG 3 provides guidelines which outline cumulative losses of BPPHs that may be acceptable, provided all other options have been exhausted. The waters of the Abrolhos Islands, including the MWADZ, are gazetted as a Fish Habitat Protection Area (FHPA) under section 115 of the *Fish Resources Management Act 1994*. The FHPA has the following purposes:

1. conservation and protection of fish, fish breeding areas, fish fossils or the aquatic ecosystem
2. culture and propagation of fish and experimental purposes related to that culture and propagation, or
3. management of fish and activities relating to the appreciation or observation of fish.

The Management Plan for the FHPA does not identify any areas of high conservation value that would be category A; therefore the proposed MWADZ should be category C. The Cumulative Loss Guidelines (EAG 3) recommend that cumulative loss of BPPH within areas deemed to be Category C do not exceed a benchmark of two percent of the BPPH within the LAU (Table 4.8).

Table 4.8 Cumulative loss guidelines for benthic primary producer habitat within defined local assessment units

Category	Description	Cumulative loss guideline[1]
A	Extremely special areas	0%
B	High protection areas other than above	1%
C	Other designated areas	2%
D	Non-designated area	5%
E	Development areas	10%
F	Areas where cumulative loss guidelines have been significantly exceeded	No net damage

Note:
1. Defined as a percentage of the original area of benthic primary producer habitat within a defined local assessment unit

4.5.2 Application of EAG 7

The potential for the MWADZ to impart adverse effects on the benthic marine environment (particularly soft sediments) were described in the context of EAG 7. EAG 7 includes three predefined levels of impact: zone of high impact (ZoHI), zone of moderate impact (ZoMI) and zone of influence (ZoI) (Table 4.9). EAG 7 was developed to assess the impacts of capital dredging activities to benthic habitats in the State's Northwest, and its application to aquaculture EIA is new (see DHI 2013).

Table 4.9 Zone of impact criteria from EAG 7

Zone	Criteria
Zone of high impact (ZoHI)	The area where impacts on benthic organisms are predicted to be irreversible. The term irreversible is defined in accordance with EPA (2009) as 'lacking a capacity to return or recover to a state resembling that prior to being impacted within a timeframe of five years or less'. Areas within and immediately adjacent to proposed dredge and disposal sites are typically within zones of high impact. The irreversible loss of the benthic primary producer habitats within these zones should be considered in the context of Environmental Assessment Guideline No. 3 (EPA, 2009), unless a defensible case for recovery of the impacted benthic primary producing habitat can be presented.
Zone of moderate impact (ZoMI)	The area within which predicted impacts on benthic organisms are sub-lethal, and/or the impacts are recoverable within a period of five years following completion of the dredging activities. This zone abuts, and lies immediately outside of, the zone of high impact. Proponents should clearly explain what would be protected and would be impacted within this zone, and present an appraisal of the potential implications for ecological integrity of the impacts over the timeframe from impact to recovery (e.g. through loss of productivity, food resources, shelter). Where recovery from the impact predicted in this zone is likely to result in an 'alternate state' compared with that present prior to development, then this outcome should be clearly stated in environmental assessment documents, along with justification as to why the predicted impacts should be included within this zone (rather than the zone of High Impact) and an appraisal of the potential consequences for ecological integrity. The outer boundary of this zone is coincident with the inner boundary of the next zone, the zone of Influence.
Zone of influence (ZoI)	The area within which changes in environmental quality associated with dredge plumes are predicted and anticipated during the dredging operations, but where these changes would not result in a detectible impact on benthic biota. These areas can be large, but at any point in time the dredge plumes are likely to be restricted to a relatively small portion of the zone of Influence. The outer boundary of the zone of Influence bounds the composite of all of the predicted maximum extents of dredge plumes and represents the point beyond which dredge-generated plumes should not be discernable from background conditions at any stage during the dredging campaign. Furthermore, this provides transparency for the public regarding where visible plumes may be present, albeit only occasionally, if the proposal receives approval. Reference sites for monitoring natural variability would ideally be located outside of the zone of Influence of the dredging activities.

Soft sediments

The recovery of sediments at the point of fallowing was determined directly using a sediment diagenesis (biogeochemical) model, linked to a hydrodynamic and a particle transport model. The period of recovery was determined across a range of scenarios. Conditions were simulated in which sediments, beneath and near the sea-cages, received inputs of waste for a period of two, three and five years. At the completion of the two, three and five year periods, the cages were fallowed, and the sediments allowed to recover.

Oxygenation

Recovery was deemed to have occurred when sediment chemical conditions, represented by the concentration and depth of oxygenation and hydrogen sulphide, returned to pre-aquaculture conditions (Table 4.10). Three zones were defined based on threshold criteria for recovery (defined in more detail in Appendix G). This included consideration of oxygen and sulphide concentrations within the top 5 cm of sediment. The ZoHI was applied when sediment conditions took greater than 5 years to recover; the ZoMI was applied when sediment conditions took less than 5 years to recover, and the ZoI was applied when sediments received waste material, but not in proportions great enough to alter the sediment chemistry. Chemical recovery was used over biological recovery, as its trajectory is more reliable and it has readily identifiable beginning and end points. Biological recovery, in contrast, may never occur completely as guilds of infauna inhabiting similar ecological niches may replace each another, leading to subtle differences in post remediation community structures – meaning the end point is difficult to quantify.

Metals

Recovery thresholds were based on the time taken for sediment metal concentrations to return to values lower than the EPA's Environmental Quality Guideline (EQG) trigger values (EPA 2014). The ZoHI was applied when sediment conditions took greater than 5 years to recover and the ZoMI was applied when sediment conditions took less than 5 years to recover. The ZoI was applied when sediments received waste containing metals, but not in concentrations great enough to exceed the EQG trigger values.

Table 4.10 Thresholds applied to soft sediments

Parameter	Zone of high impact (ZoHI)	Zone of moderate impact (ZoMI)	Zone of influence (ZoI)
Hydrogen sulphide	Concentrations deteriorate and do not recover to baseline levels within a 5 year period	Concentrations deteriorate but recover to baseline levels within a 5 year period	Concentrations not to exceed baseline levels
Oxygenation			Top 5 cm of sediment remain oxygenated
Metals (Zn and Cu)1	Sediment concentrations of Zn and Cu do not recover to values lower than the EPA EQGs with a period of 5 years	Sediment concentrations of Zn and Cu recover to values lower than the EPA EQGs within a 5 year period	Sediment concentrations of Zn and Cu not to exceed the EPA EQGs

Notes:

1. Zinc (Zn) and Copper (Cu) are the metals present in feeds in the highest proportion and those with EPA (2015) triggers.
2. EQG = Environmental Quality Guideline

4.5.3 Application of other impact criteria

Mixed assemblages and the water column

Unlike soft sediments, for which it was possible to model recovery directly, the development of impact criteria for mixed assemblages and the water column required a different approach. The thresholds for smothering are based on PIANC (2010), and the thresholds for water column oxygenation, suspended particles, algal growth potential, nutrient enrichment and shading are based on EPA (2015). The EPA's criteria were used in lieu of the uncertainty regarding the lethal and sub-lethal thresholds of endemic species, and equal uncertainly regarding their timing of recovery, particularly following exposure to aquaculture stressors (i.e. organic material and inorganic nutrients).

Smothering

Thresholds for smothering are based on lethal and sub-lethal end-point triggers for corals published in PIANC (2010), and are the same as those used in the KADZ assessment (Oceanica 2013) (Table 4.11). The thresholds correspond to the levels of impact described in Table 4.12 which are based on the sensitivities of coral. These thresholds were originally developed for inorganic materials, but in the absence of comparative information, these thresholds were used as a best estimate.

Table 4.11 Thresholds based on PIANC (2010)

Effect	Major impact (ZoHI)	Moderate impact (ZoMI)	No impact (ZoI)
Smothering[1]	Sedimentation rate not to exceed 500 $g/m^2/day$	Sedimentation rate not to exceed 100 $g/m^2/day$	Sedimentation rate not to exceed 50 $g/m^2/day$

Notes:

1. Thresholds based on those developed for sensitive coral species by the PIANC Working Group 108 (2010)

Table 4.12 Impact assessment categories for the effects of smothering

Severity of impact	Description
Minor impact	Changes are likely to be detected in the field as localised mortalities, but to a spatial scale that is unlikely to have any secondary consequences.
Moderate impact	Changes are detectable in the field. Moderate impacts are expected to be locally significant.
Major impact	Changes are detectable in the field and are likely to be related to complete habitat loss. Major impacts are likely to have secondary influences on other ecosystems.

Suspended particles

Thresholds for suspended particles were developed to be consistent with the moderate and high levels of marine ecological protection described in EPA (2015) (Table 4.13). The thresholds are respectively based on the 95th and 80th percentile values obtained during baseline studies. In this context, the 80th percentile is in alignment with the criteria used for a high level of ecological protection and the 95th percentile a moderate level of ecological protection. For contextual purposes, Table 4.13 also outlines the limits of acceptable change under a low level of ecological protection. Low ecological protection areas are typically applied to ocean outfalls, where moderate and high levels of ecological protection are not always achievable.

Table 4.13 Levels of ecological protection

Level of ecological protection	Limits of acceptable change
Low	To allow for large changes in the quality of water, sediment and biota (e.g. large changes in contaminant concentrations causing large changes beyond natural variation[1] in the natural diversity of species and biological communities, rates of ecosystem processes and abundance/biomass of marine life, but which do not result in bioaccumulation/biomagnification in near-by high ecological protection areas).
Moderate	To allow moderate changes in the quality of water, sediment and biota (e.g. moderate changes in contaminant concentrations that cause small changes beyond natural variation in ecosystem processes and abundance/biomass of marine life, but no detectable changes from the natural diversity of species and biological communities).
High	To allow small changes in the quality of water, sediment or biota (e.g. small changes in contaminant concentrations with no resultant detectable changes beyond natural variation* in the diversity of species and biological communities, ecosystem processes and abundance/biomass of marine life).

Note:

1. Detectable change beyond natural variation nominally defined by the median of a test site parameter being outside the 20th and 80th percentiles of the measured distribution of that parameter from a suitable reference site

Water column

Oxygenation

The thresholds for oxygenation (dissolved oxygen; DO) are based on EPA (2015). The thresholds are equivalent to the Environmental Quality Guidelines (EQG) for achieving moderate and high levels of ecological protection (Table 4.13), which require that DO levels are maintained at 80% and 90% saturation respectively for a period greater than six weeks duration.

Table 4.14 Thresholds based on EPA (2015)

	Moderate ecological protection	High ecological protection
Oxygenation[1]	DO saturation in the bottom half of water column not to fall below 80% for a period exceeding 6 weeks	DO saturation in the bottom half of water column not to fall below 90% for a period exceeding 6 weeks
Suspended particles[2]	TSS concentration not to exceed 8.4 mg/L more than 50% of the time	TSS concentration not to exceed 2 mg/L more than 50% of the time
Algal growth potential[2]	DIN concentration not to exceed 40 µg/L more than 50% of the time	DIN concentration not to exceed 29 µg/L more than 50% of the time
Nutrient enrichment[2]	Chlorophyll-a not to exceed 0.45 µg/L more than 50% of the time	Chlorophyll-a not to exceed 0.30 µg/L more than 50% of the time
Shading[2,3]	Light intensity at the benthos not to fall below the 5th percentile more than 50% of the time	Light intensity at the benthos not to fall below the 20th percentile more than 50% of the time

Notes:

1. Thresholds for the ZoHI/ZoMI and the ZoI are based respectively on the EPA's EQGs for moderate and high ecological protection (EPA 2005). Threshold assumes continuous exceedance for a period exceeding six weeks.
2. Thresholds for the Zone of moderate impact (ZoMI) and Zone of influence (ZoI) are based respectively on the EPA's EQGs for moderate (95th percentile baseline data) and high (80th percentile baseline data) ecological protection (EPA 2015). The threshold for the Zone of high impact (ZoHI) is based on the 99th percentile of baseline data.
3. During daylight hours (8am–6pm).

Algal growth potential and shading

Thresholds for inorganic nutrients were developed to address the effects of algal growth potential, nutrient enrichment and shading (Figure 4-8). The thresholds for algal growth potential and nutrient enrichment are based on the 95th and 80th percentile values obtained during baseline studies (Section 5.3). The thresholds for shading by contrast are based on the 5th and 20th percentile values obtained during baseline studies. In this context, the 20th and 80th percentiles (ZoI) are in alignment with the criteria used for a high level of ecological protection; and the 5th and 95th percentiles, a moderate level of protection.

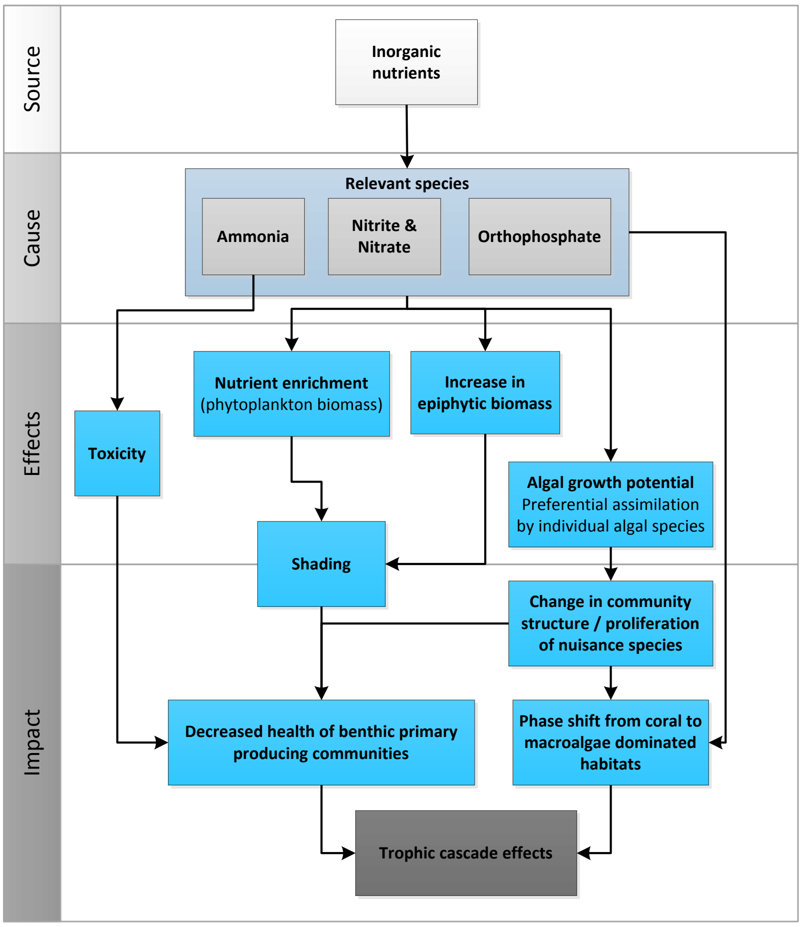


Figure 4-8 Cause-effect-response pathways relevant to inorganic nutrients

4.5.4 Aquaculture scenarios chosen for modelling

Modelling scenarios were agreed in consultation with the DoF and the Aquaculture Industry Reference Group at a technical workshop held in October, 2014. Scenarios were developed based on production of yellowtail kingfish (*Seriola lalandi*) using industry best-practice farming methods, including use of the standard infrastructure as described in Table 4.15.

Table 4.15 Aquaculture infrastructure assumptions

Infrastructure component	Details
Cage diameter (m)	38
Cage circumference (m)	120
Cage depth (m)	18
Cage volume (m^3)	20 641
No. cages per cluster	14
Other assumptions	• Two to three clusters in the southern location • Four to six clusters in the northern location • Percentage of uneaten feed = 1%

Six production scenarios were modelled in total (Table 4.16). All scenarios assumed constant stocking of between 15 000 and 30 000 tonnes standing biomass, and static Food Conversion Ratio (FCR) and Specific Growth Rate (SGR) values of 3.1 and 0.29% respectively (Section 4.6.1). No allowances were made for annual fluctuations in standing biomass due to growth and/or harvesting of stock. Feed inputs and waste outputs were also assumed to be constants in time. The effect on the benthic environment of increasing and decreasing stocking densities was examined by manipulating the number of cage-clusters between six and nine. This was undertaken in recognition of the economic-environmental trade-offs between infrastructure

requirements and the aquaculture industries desire to maintain higher stocking densities, wherever resources and/or the biology of the target species allows. It is noted however, that the choice of cluster numbers was intended to balance the infrastructure proportionally across the two areas making up the proposed MWADZ, and not one intended to constrain the industry to that specific number.

Table 4.16 Modelled production scenarios

Scenario No.	S1	S2	S3	S4	S5	S6
Total standing biomass (t)	15 000		24 000		30 000	
Standing biomass north (t)	10 000		16 000		20 000	
Standing biomass south (t)	5000		8000		10 000	
No. clusters south	3	2	3	2	3	2
No. clusters north	6	4	6	4	6	4

Note:
1. t = tonnes

4.6 Approach to modelling

The ESD required development of an ecological/environmental model to predict the cumulative environmental effects of the proposal, operating across a range of production scenarios. To meet this objective, several models were developed, all of which were integrated to address the requirements of the ESD. The fully integrated model was capable of resolving the regional hydrodynamics, the deposition and dispersal of wastes from sea-cages, the effects of these wastes on the marine environment, and the rate of environmental recovery following cessation and/or relocation of the aquaculture activities. The approach to integrating the individual modelling components is summarised in Section 4.6.1, below, and the assumptions underpinning the modelling are summarised in Section 4.6.2. Full details, including the approach to calibration, are included in Appendix F and Appendix G.

4.6.1 Model integration

Hydrodynamic

The primary aim of the hydrodynamic model was to provide a realistic representation of currents and wave dynamics in the northern and southern areas, for determining the fate of wastes released from aquaculture activities (e.g. waste feed, inorganic nutrients and faecal material), and also to inform the sediment diagenesis and the water quality simulations. The model was calibrated against metocean and water quality data collected during the May 2014 to December 2014 period of the baseline sampling program. Validation was then undertaken by comparing model results against observations made during the December 2014 to March 2015 period of the baseline monitoring program (results of these processes are detailed in Appendix F). TUFLOW FV was used as hydrodynamic modelling engine (http://www.tuflow.com/Tuflow%20FV.aspx). It is capable of solving Non-Linear Shallow Water Equations (NLSWE) on a 'flexible' (unstructured) mesh comprising triangular and quadrilateral cells.

A digital elevation model (DEM) was developed using a regional bathymetry dataset from Geosciences Australia with 250 m resolution, and a higher-resolution dataset of the Abrolhos Islands from the WA Department of Transport. This was interrogated to provide bathymetry values to the model mesh. The model mesh covers an overall area of 2.7 million ha, with a single open boundary of ~413 km stretching from Kalbarri in the north to Leeman in the south. It includes 23 093 horizontal cells, ranging from resolution of ~3.5 km at the open boundary to approximately 40 m resolution within the proposed lease areas Figure 4-9 and Figure 4-10). A variety of cage configurations were included in the mesh to ensure that processes adjacent to cage clusters are highly resolved by the model. Sub-sets of these cage configurations were used developing the modelled scenarios (Section 4.5).

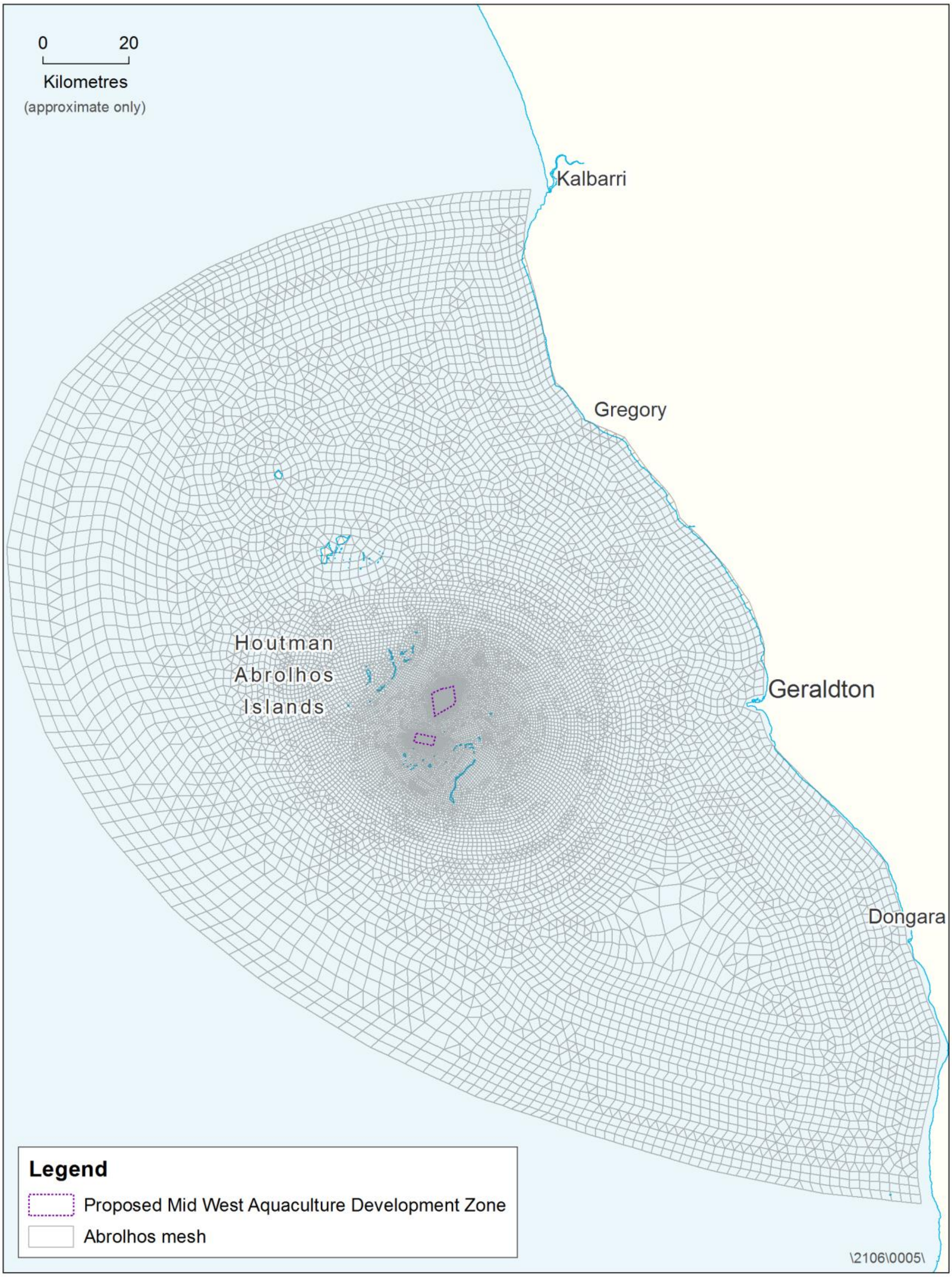


Figure 4-9 Full extent of the model mesh

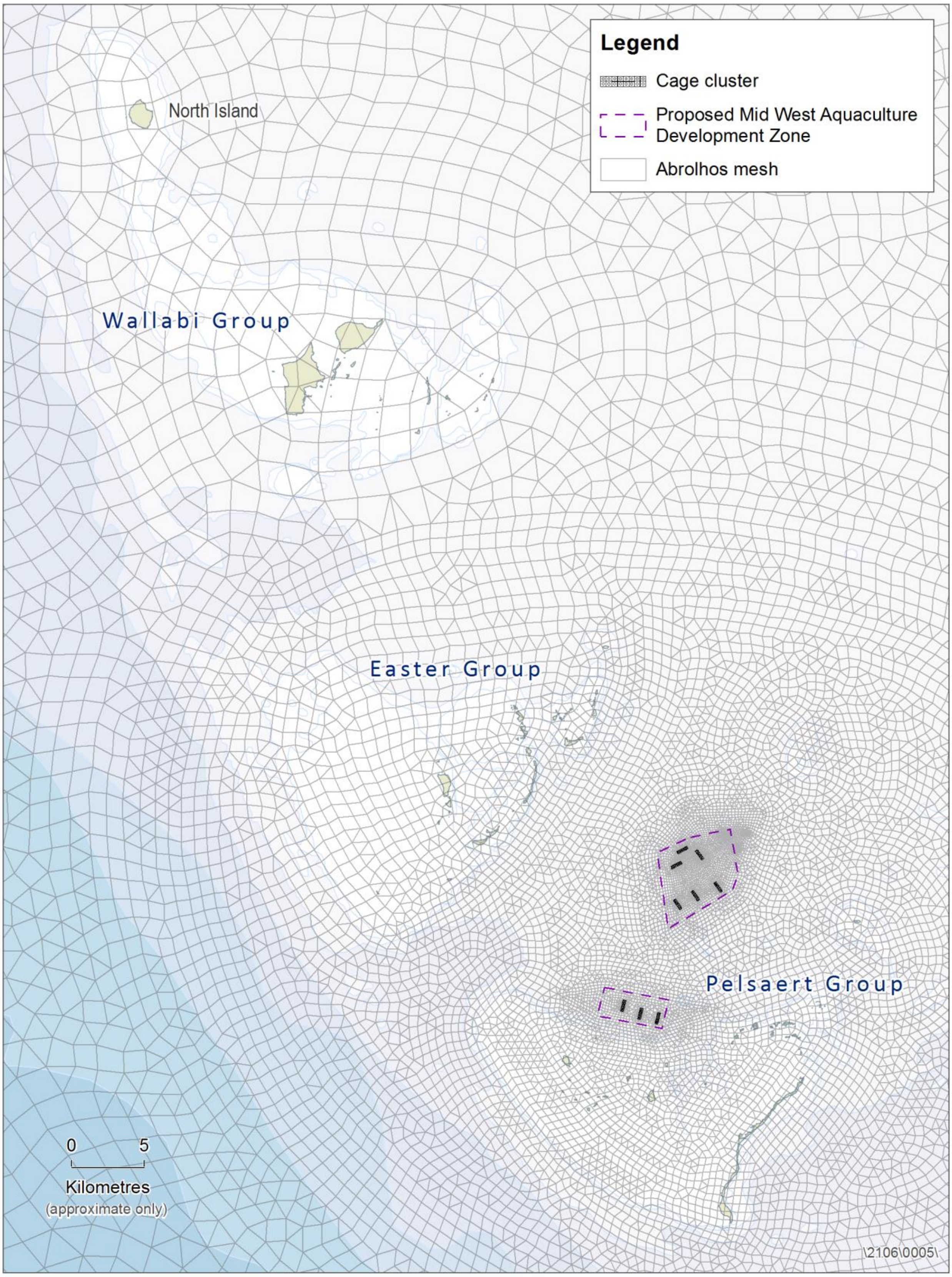


Figure 4-10 Zoomed in view of the model mesh

Wave model

To resolve potential wave-driven currents plus wave-induced drift and to capture suspension/deposition dynamics driven by waves, a wave field was applied to TUFLOW FV using the model SWAN. SWAN is a third-generation wave model, developed at Delft University of Technology, which computes random, short-crested wind-generated waves in coastal regions and inland waters. In addition to wind data (as provided to TUFLOW FV), SWAN also requires swell to be provided on the boundaries. This was sourced from WAVEWATCH III, which is a global wave prediction model developed by the National Oceanic and Atmospheric Administration (NOAA). The SWAN model was run, using default parameters, on a regular grid with 500 m resolution.

Fish waste model

A fish waste model was developed based on the collective works of Tanner et al. (2007), Fernandes and Tanner (2008) and Tanner and Fernades (2010). The model assumes an average fish size of 1.5 kg and an average water temperature of 20°C, representing Abrolhos winter temperatures. Respiration and FCR/SGR values are based on Tanner et al. (2007), respectively. For the purposes of modelling, the SGR and FCR values reported in these papers were averaged to produce values of 0.29% and 3.1, respectively (Table 4.17).

Table 4.17 Specific Growth Rate and Food Conversion Ratio values

Value	SGR	FCR
1	0.25%	3.0
2	0.32%	3.2
Mean	0.29%	3.1

Source: Tanner et al (2007)

The model predicted the volume of waste for a given volume of fish, including the proportional nitrogen, phosphorus and carbon (the solid and dissolved fractions). Outputs from the fish waste model were fed into the particle transport model to predict the fate of the organic particles once discharged from the sea-cages.

Particle transport model

The Particle Transport Model (PTM) was used to resolve both the vertical and horizontal transport of aquaculture wastes, while accounting for differing size fractions and settling velocities of waste particles (i.e. waste feed and faecal material). The PTM was based on a Lagrangian particle tracking scheme driven by three-dimensional currents and wave fields described above. The Lagrangian particle movements included a deterministic component derived from the modelled currents and a stochastic 'random walk' component to represent vertical and horizontal dispersive processes due to unresolved turbulence scales. The processes of deposition and resuspension from the seabed due to wave and current induced shear stresses were also resolved using standard boundary layer and sediment transport calculations. A very large number of Lagrangian particles (~1 million) were released over a 12 month simulation period in order to integrate over a broad ensemble of environmental conditions, including stochastic dispersion processes.

The PTM calculated the transport of particles away from the cages, and quantified the rate of waste deposition near and far from the sea-cages. The Lagrangian PTM approach allowed for high resolution 'meshless' representation of the particle advection, dispersion, deposition and resuspension dynamics. The particle size, settling rates, ratio of nitrogen, phosphorus and carbon in the waste material was held at a constant, based on the outputs from the fish waste model described above. Particles that had settled out of suspension were tracked on the seabed

and remained available for resuspension when wave and current induced shear stresses exceeded prescribed thresholds. No particle breakdown or burial processes were considered in the PTM simulations.

The science of particle transport through the water column is complex, with the bulk of studies focussing on inorganic particles and phytoplankton, with few that address the specifics of fish faeces (but see Chen et al. 1999, Felsing et al. 2005, Moccia et al. 2007, Moran et al. 2009). The settling velocity of fish waste leaving a sea-cage varies depending on an exhausting array of variables: feed type, fish health, species, fish size, and general farming practices (Chen et al. 1999, Felsing et al. 2005, Moccia et al. 2007, Moran et al. 2009). In addition, the difference between the volume of waste leaving a cage and the volume reaching the seafloor is also complex, and depends on biological and physical factors (e.g. current speeds and the extent of secondary consumption by scavengers beneath the cages; Felsing et al. 2005). For this study, fish waste was partitioned into waste feed (commercial aquaculture pellets) and waste faecal material. Faecal material was further partitioned into three size fractions following Chen et al. (1999), Cromey et al. (2002) and DHI (2013; Table 4.18).

Table 4.18 Waste particle fractions and settling velocities

Waste fractions	% of total input	Settling velocity (cm/s)	Source / assumptions
Feed (pellets)	1%	12.1	Tanner et al. (2007)
Faecal fraction 1	43%	1.5	DHI (2013)
Faecal fraction 2	32%	3.5	DHI (2013)
Faecal fraction 3	25%	5.5-6.3	Cromey et al. (2002), Chen et al. 1999.

Deposition of waste in this study was based on the Farmér concept (Tanner et al. 2007), where the largest proportion of particles falls beneath or close to the cages, with increasingly smaller proportions falling further from the cages. Modifications were made to include a total of five release points across the 38 m diameter sea-cages, and to account for the prevailing currents, which tended to skew the distribution of the finer particles in one direction over another. This concept is illustrated in Figure 4-11, which shows the rate of particle deposition over one year of production, but at differing stocking densities. Higher volumes are depicted directly under the cages (red to orange shading), with decreasing volumes depicted further from the cages (yellow to blue shading).

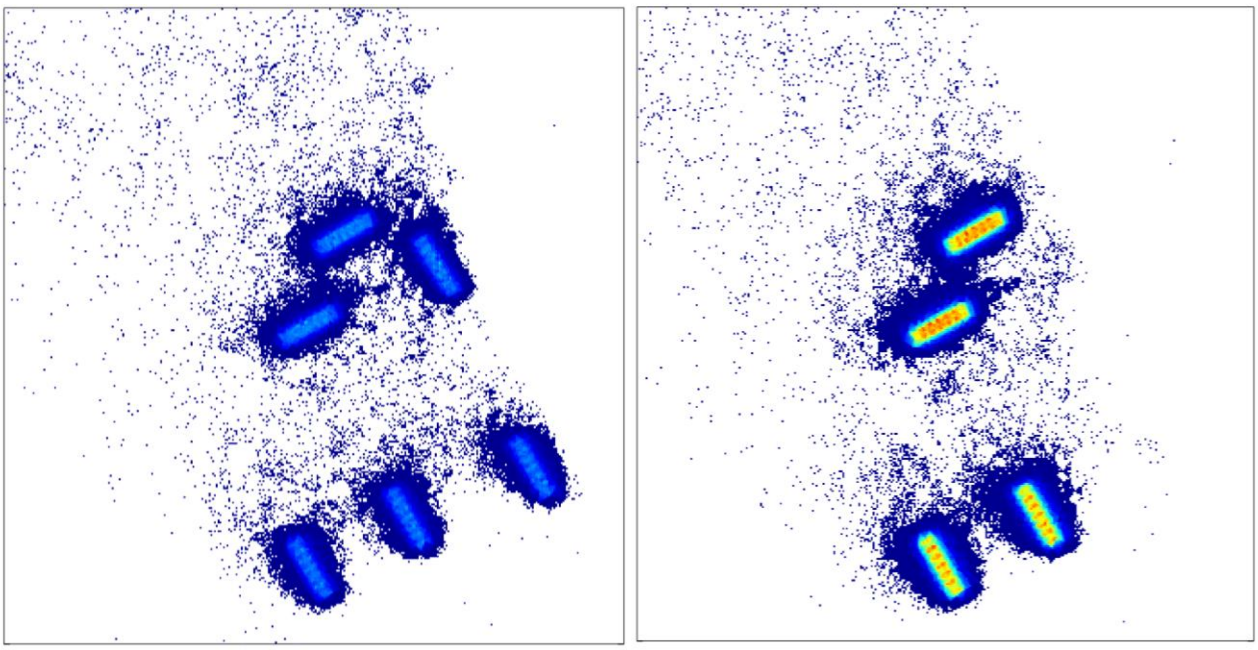


Figure 4-11 Deposition of waste material following twelve months of aquaculture production under differing stocking densities

Water quality model

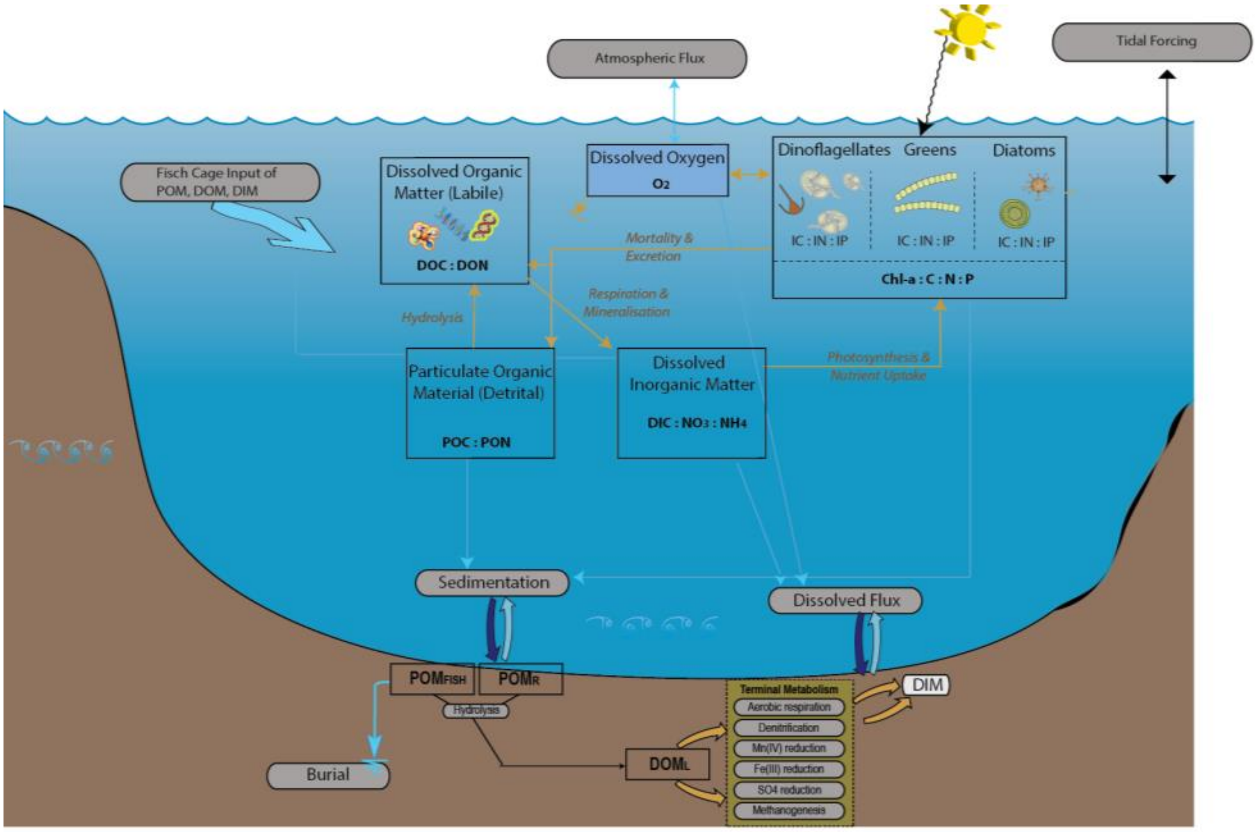
The water quality model utilised the Aquatic Ecodynamics (AED2) model library developed at UWA (http://aed.see.uwa.edu.au/research/models/AED/). It is capable of simulating a number of biogeochemical pathways relevant to water quality, including nutrient, sediment and algal dynamics. In this study it was configured to include organic matter, inorganic nutrients and phytoplankton (Figure 4-12).

The specific suite of parameters AED used in this study were:

- dissolved oxygen
- nutrients (nitrogen, phosphorus and associated species and cycles)
- organic matter (carbon, nitrogen and phosphorus, both particulate and dissolved)
- algae (one generic species in this study).

Boundary conditions for AED were derived from observations collected as part of the sampling program (Section 5.3) and parameters were chosen to represent a typical oligotrophic region.

Working with the hydrodynamic model, the water quality model was used to resolve the release, dispersion and dilution of inorganic nutrients from the sea-cages, and subsequent uptake and growth of phytoplankton. The model was also used to resolve the potential for changes in dissolved oxygen and light attenuation at the bottom of the water column.



Notes:

1. POM (particulate organic matter); DOM (dissolved organic matter); DIM (dissolved inorganic matter); DOC (dissolved organic carbon); DON (dissolved organic nitrogen); IC:IN:IP (inorganic carbon:inorganic nitrogen:inorganic phosphorus); C:N:P (carbon:nitrogen:phosphorus); NO_3:NH_4 (nitrate:ammonia)

Figure 4-12 Carbon and nutrient processes simulated in CANDI-AED

Sediment diagenesis model

Biogeochemistry

The diagenesis[1] model was first used to resolve the biogeochemistry of the seafloor and to estimate the nutrient flux into and out of the sediments under a range of waste deposition scenarios (Appendix G). It was then coupled to the hydrodynamic and water quality models to ensure the phytoplankton response was based on the cumulative sources of nutrients, both directly from fish respiration and indirectly via sediment mineralisation processes. Importantly, the diagenesis model was also used to determine the recovery of sediments beneath the sea-cages, and then from this, to map the spatial distribution of the zones of aquaculture influence (ZoHI, ZoMI and the ZoI).

The diagenesis model adopted in this EIA was the CANDI-AED model, which is an extension of the numerical code written by Boudreau (1996), and widely used across a range of marine and coastal environments (Paraska et al. 2014). The configuration of the model was guided by a previously published sediment biogeochemical model application to finfish aquaculture (Brigolin et al. 2009). Additional sources used for guidance in the development of diagenesis model setup and parameters are given in Table 4.19. For an overview of the theory and applications of sediment diagenesis models refer to the review by Paraska et al. (2014).

Table 4.19 Sources of literature informing the development of the diagenesis model

Reference	Study location
Macleod & Forbes 2004	Salmon farms in Tasmania
Tanner & Fernandes 2007	Yellowtail kingfish farms in Fitzgerald Bay in Spencer Gulf, South Australia
Fernandes &Tanner 2008	
Brigolin et al. 2009	Salmon farms in Loch Creran, Scotland
Volkman et al. 2009	Salmon farms in the Huon Estuary and D'Entrecasteaux Channel, Tasmania

Based on field observations, it was assumed that a generalisation for the sediment physical properties was a highly porous and permeable sediment of approximately 15 cm depth, with hard rock beneath. In previous diagenesis modelling studies, a shallow depth of sediment with hard rock underneath has not been specifically simulated (Paraska et al. 2014). Therefore much of the model was derived from Van Cappellen and Wang (1996), which is a well-established study and based in a marine study site. In order to simulate the vertical mixing of the sediment, a relatively high bioturbation rate of 20 cm^2/y was used, with a constant value from the sediment-water interface to the deepest layer at 15 cm.

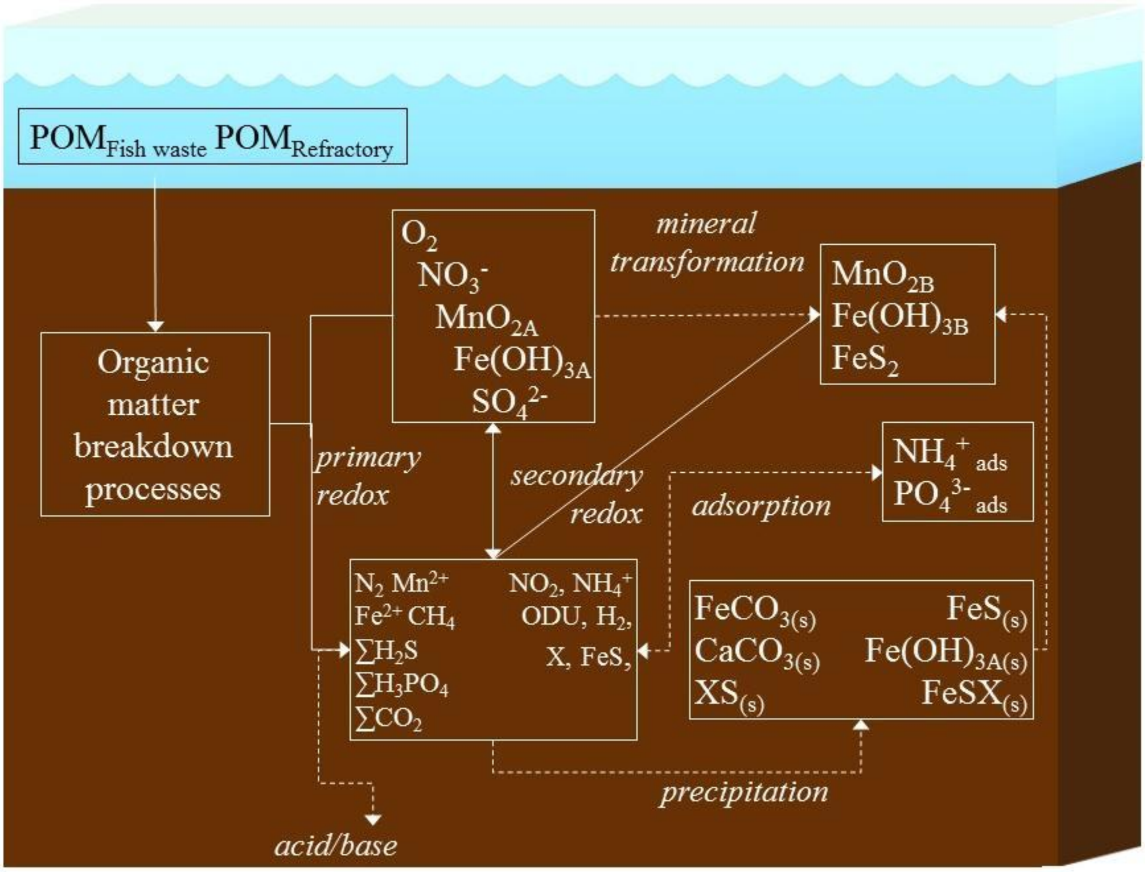
Chemical concentrations at the sediment-water interface are subject to a mix of competing forces at different spatial and temporal scales, for example: solid particles are deposited via gravity and resuspended by currents in the water column; particles are buried following further deposition and ultimately form rock; chemicals diffuse between the water and the sediment, and within the sediment, following concentration gradients; benthic animals and plants cause mixing or binding of the sediment particles, as well as non-local transport of chemicals; bacteria use chemical reactions to fuel their metabolism; benthic animals, plants and bacteria thrive or die depending on the chemicals present in the sediment (Berner 1980, Boudreau 1997, Fossing et al. 2004). The chemical reactions simulated in the model can be broadly defined as primary and secondary reactions; these are summarised in Figure 4-13. Primary reactions are the microbially-driven breakdown reactions of organic matter via a series of oxygen reduction (redox) pathways (Figure 4-14). Primary reactions are the driving force of most of the other chemical reactions that occur in the sediment. Inputs of fish feed and faecal matter serve to quickly shift chemical

[1] *Diagenesis is the term used for all of the changes sediments undergo following inputs of organic material*

concentrations away from the equilibrium that occurs in marine waters, especially those which are naturally nutrient poor (i.e. waters of the Abrolhos Islands).

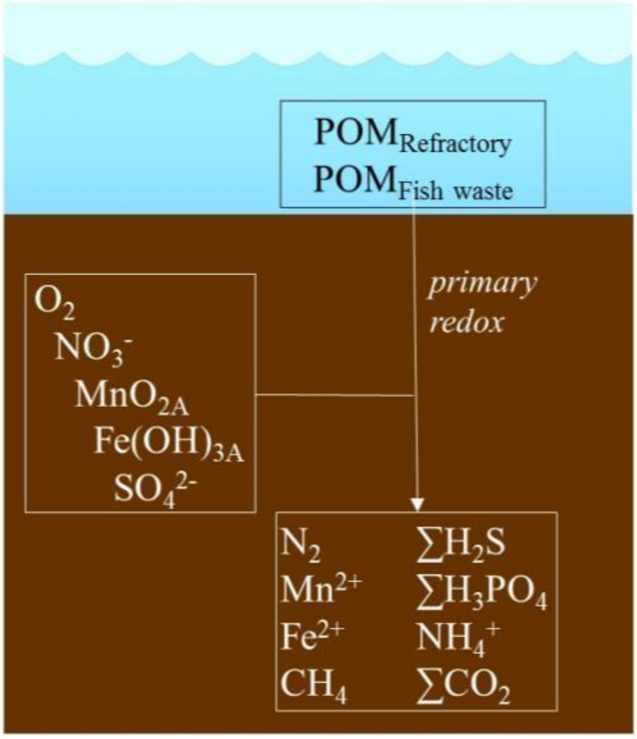
One guiding principle used to understand how the competing pathways of primary organic matter reactions interact is the sediment redox sequence. There is an assumption that there are six major terminal electron accepting pathways for the degradation of organic matter, and that bacteria will use these pathways in order of decreasing free energy yield: aerobic, then denitrifying, manganese reducing, iron reducing, sulfate reducing and finally methanogenic respiration. Since the source of fresh sediment organic matter is always the top of the sediment, each terminal electron accepting pathway corresponds with a depth zone (Van Cappellen et al. 1995).

The diagenesis model was applied to MWADZ sediment, firstly under background conditions, then with 2, 3 and 5 years of organic matter deposition from fish-waste, then 7+ years with no deposition (post fallowing) to simulate a recovery period. The simulation was calibrated against available field data, primarily total organic carbon (TOC), total nitrogen (TN) and total phosphorus (TP) (Section 5.3.3). The resulting chemical concentration profiles were then assessed against a spectrum of organic matter deposition fluxes, from $1×10^2$ to $5×10^6$ mmol/m^2/y to explore how the sediment would respond to a range of stocking densities, near and far from the cages. The resulting recovery time in sediment concentrations, and absolute concentrations of key sediment variables were then assessed, and used to define the zones of high and moderate impacts, and the zones of influence, as per EAG 7.



Note:
1. POM = particulate organic material, ads = adsorbed.

Figure 4-13 Processes simulated in the CANDI-AED sediment diagenesis model



Note:

1. POM = particulate organic material.

Figure 4-14 Organic matter degradation processes simulated in the diagenesis model

Metal accumulation and recovery

In addition to its capacity to simulate the biogeochemistry of the sediments, the diagenesis model simulated the chemical processes leading to the accumulation and compound-forming transition of metals (Zn, Cd and Cu). The purpose of the modelling was to determine the potential for metal accumulation in the sediments beneath sea-cages and the time required for recovery after fallowing. The chemistry is such that the concentrations of metals correlate strongly with the presence of sulphides. A simple approach was simulated in which accumulation occurred under conditions of low oxygen and high sulphide concentrations, and flux (out of sediments) occurred as oxygen and sulphides returned to baseline conditions.

The potential for impacts relating to the metal content of commercial feeds was assessed based on metal concentrations in fish faeces and its potential to accumulate in the sediment. The metal content of the fish faeces was based on the analysis by Moccia et al. (2007; Table 4.20) and then converted to a molar ratio compared with carbon (Table 4.21). Modelling undertaken for this study focussed on the metals in greatest supply (Zn and Cu) and on the metals for which there are EPA triggers (EPA 2014). Concentrations are for total metals in mg/kg. The thresholds used to determine the spatial extent of contamination, and thus the zones of impact are outlined in Table 4.10, Section 4.5.1.

Table 4.20 Elements measured in fish faeces fed on commercial aquaculture feeds

Element	Average (mg/kg)	Standard deviation
As	<1.0	0.0
Cd	<1.0	0.0
Co	<1.5	0.0
Cr	5.01	2.09
Cu	42.22	30.53
Fe	1003.56	296.30
Hg	<0.05	0.0
Mn	695.94	279.79
Mo	<2.5	0.0
Ni	<4.0	0.0
Pb	<5.0	0.0
Se	<1.0	0.0
Zn	620.56	238.47

Source: Moccia et al. 2007

Table 4.21 Fish waste organic matter converted from values in Moccia et al. (2007) to a molar C:metal ratio

	Mass per mass	Molar ratio	Exceedance concentration
Zn	620 mg Zn/kg faeces	2.79×10^{-4} mol Zn/mol C	7.7 mmol Zn/L
Cu	42 mg Cu/kg faeces	1.89×10^{-5} mol Cu/mol C	2.5 mmol Cu/L
C	0.41 kg C/kg faeces	–	–

Source: Moccia et al. 2007

The chemical reactions that metals are subject to are summarised in Table 4.22. Over reactions (1) to (6), organic metals are released from the organic matter upon microbial oxidation and then diffused as a free solute, or precipitated out as a metal sulphide; then metal sulphides can be oxidised by oxygen to release the free metal again. The criteria for metal contamination were 200 and 65 mg/kg dry weight for Zn and Cu respectively, or 7.7 and 2.5 mmol metal/L (Table 4.21).

Table 4.22 Major reaction equations for metal release

$$OM.Zn + oxidant \rightarrow CO_2 + NH_4^+ + PO_4^{3-} + Zn^{2+} \quad (1)$$
$$Zn^{2+} + S^{2-} \rightarrow ZnS \quad (2)$$
$$ZnS + 2O_2 \rightarrow SO_4^{2-} + Zn^{2+} \quad (3)$$
$$OM.Cu + oxidant \rightarrow CO_2 + NH_4^+ + PO_4^{3-} + Cu^{2+} \quad (4)$$
$$Cu^{2+} + S^{2-} \rightarrow CuS \quad (5)$$
$$CuS + 2O_2 \rightarrow SO_4^{2-} + Cu^{2+} \quad (6)$$

4.6.2 Model assumptions

The modelling approach adopted here was to build an integrated hydrodynamic, water quality, particle transport and sediment diagenesis model, which captured the key environmental processes and their interactions. A conservative approach was adopted to ensure the outputs of modelling were equivalent to 'most likely worst case' outcomes, as required by the ESD (EPA 2013) (Table 2.1). As such, the impacts predicted in this document are more extensive than might be expected on average, but are nevertheless within the upper range of impacts reported in the literature (i.e. Brooks et al. 2004). The assumptions underpinning the development and execution of the integrated model are summarised below:

- The hydrodynamic and the wave models were calibrated and validated against metocean data collected over a 10 month period, encompassing each of the calendar seasons. Climatic conditions during the data collection phase were considered normal, and captured the normal seasonal pattern of changing winds, waves and oceanographic currents. Although the metocean data collection period captured the normal pattern of winter storms, no significant storm events were captured. For example, since 1915, a cyclone has passed through coastal waters within 400 km of the region approximately every 2.5 years on average (Bureau of Meteorology).
- The predicted zones of impact shown in Section 7 are based on rates of waste deposition and resuspension averaged over the period of operation (examples for 5 years of operation are given in Section 7.3.2). If viewed as an animation, rather than a static image, the actual area occupied is subject to short-term changes depending on the levels of shear stress operating at the time.
- Rates of recovery (Section 7.3.2) as predicted by the sediment diagenesis model were assumed to proceed free of major disturbances. A constant rate of bioturbation of 20 m^2/y was simulated across all strata of the sediment to a depth of 15 cm, thus simulating some capacity for reoxygenation. However, despite capturing some capacity for biodiffusion and irrigation, neither of these account for the potential 'resetting' of the sediment during major scour events i.e. such as those which may occur during storm events. As such there is a strong conservative factor in the results for longer time frames.
- The Food Conversion Ratio (FCR) and Specific Growth Rate (SGR) values used in the development of the fish waste model (Section 4.6.1) are based on the collective works of Tanner et al. (2007), Fernandes and Tanner (2008) and Tanner and Fernandes (2010). These studies are the only peer reviewed source of information on the respiration, metabolism, energetics and the nutrient and carbon outputs of yellow tail kingfish, and were used here as the basis of the model. The outputs produced by the model are conservative, and likely greater than the outputs that will be achieved once the farms are established. Aquaculture proponents have a vested interest to achieve food conversion ratios better than 3.1, with ratios in the range 1.5–2.0 being standard across the industry.
- Modelled estimates of the total volume of fish waste expected to reach the seafloor are based on the physical and hydrodynamic properties of several different waste fractions: pelletised feed, and three faecal size fractions. The two largest fractions were assumed to settle rapidly (Table 4.23), and the smallest, slowly. Smaller particles tended to settle further from sea-cage infrastructure, and larger particles settled closer. The dispersion of fine particles was enhanced under higher current speeds, and retarded under lower current speeds.
- It was also assumed that fish wastes (faecal material) exhibited cohesive ('sticky') properties, increasing its propensity for 'clumping' and limiting its potential for resuspension relative to inorganic particles (following Nowell et al. 1981; Masalo et al. 2008). The carbon in the material was also assumed to be highly labile, meaning much of it was consumed and oxidised relatively quickly by resident microbiological flora (following deBruyn & Gobas 2004). Hence, much of the material deposited from cages was assimilated quickly resulting in rapid changes to sediment chemistry.
- Notwithstanding the generally assumed cohesive and 'sticky' properties of the waste, the smallest size fraction simulated demonstrated high capacity for dispersion. It was conservatively assumed that these fine particles, which might ordinarily be expected to dissolve over the periods simulated (12 months), remained in suspension indefinitely. This resulted in outputs showing widespread and highly distant dispersion of particles, albeit not in densities/volumes expected to result in impacts to sediment biology.

Table 4.23 Time for modelled particles to reach the seafloor

Distance to sea floor from bottom of cage	Settling time	
	Medium particles	Large particles
5m	2.3 min	1.3 min
30m	14.2 min	7.9 min

4.6.3 Peer review

The approaches to developing the integrated hydrodynamic, particle transport, water quality and sediment digenesis models were subjected to independent peer review. All aspects of the approach, including the collection of baseline metocean data, the development of thresholds and the assumptions underpinning the development of the models were assessed. The peer review process and response is detailed in Appendix E.

5. Baseline Conditions

5.1 Hydrodynamics and wave climate

Currents around the Abrolhos Islands are dominated by the Leeuwin Current system, primarily consisting of the Leeuwin Current (a poleward-flowing, boundary current which is usually stronger in winter and weaker in summer) and the returning Capes Current (a northward-flowing current on the continental shelf, which is strongest in summer; see review by Pattiaratchi & Woo, 2009).

Current speeds and wave heights were measured in the northern and southern areas of the MWADZ and at two regional sites to the east of the MWADZ (Figure 4-1). As illustrated in Figure 5-1, the ADCPs deployed at the regional sites between November 2014 and March 2015 captured the Capes Current, which had typical flows of approximately 0.1-0.2 m/s northwards. The hydrodynamic model captured the Capes Current in summer, with similar velocities (Figure 5-1), and also captured the Leeuwin Current adjacent to the continental slope, with southward velocities ranging between ~ 0.1-0.3 m/s (Figure 5-2).

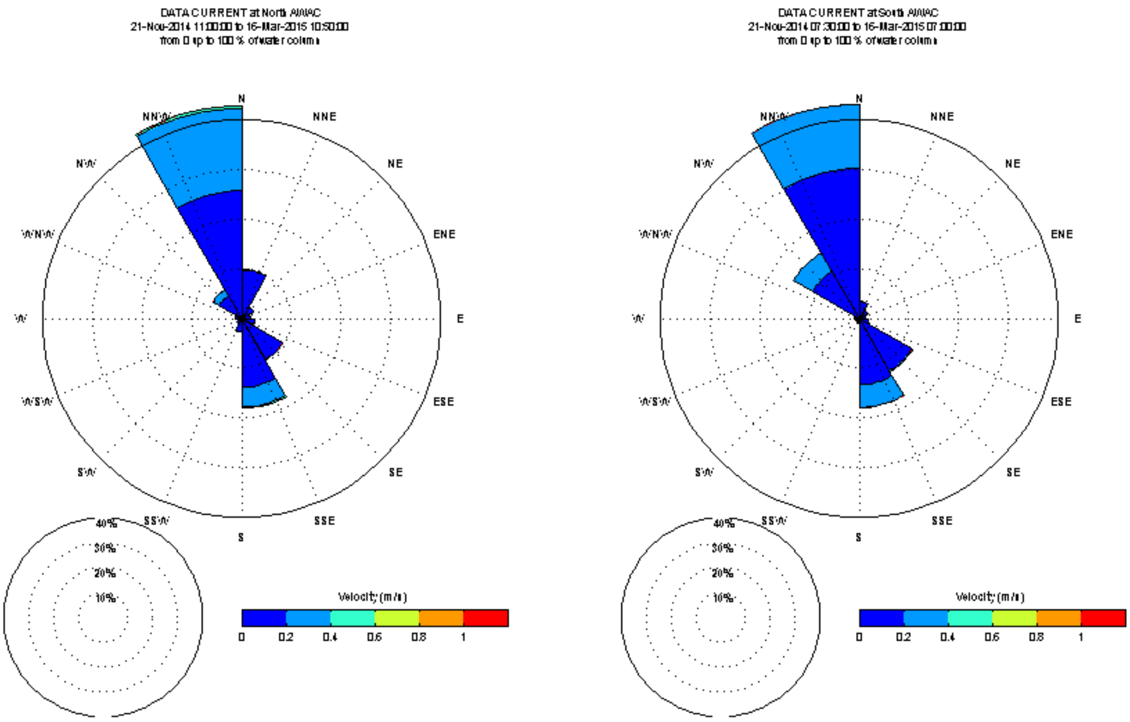


Figure 5-1 **Current directions and speeds at regional sites between November 2014 and March 2015**

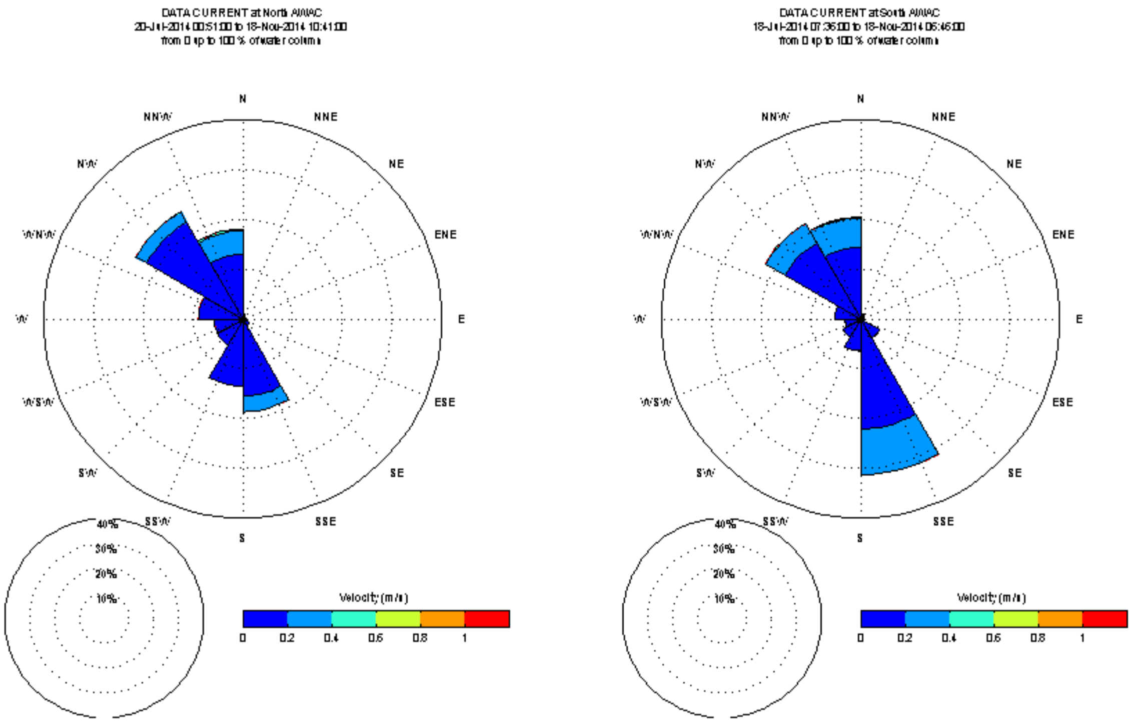


Figure 5-2 Current directions and speeds at regional sites between July 2014 and November 2014

Rose plots of depth-averaged velocity measured by the MWADZ ADCPS are presented in Figure 5-3–Figure 5-4. The currents in the southern area (L2) flowed primarily along the east-west axis, as north-south flow was hindered by the presence of the adjacent islands of the Pelsaert group. Measured flow was predominantly westward during the May-June deployment, switching to eastward during the November-December deployment, with no dominant current direction during the August-September or February-March deployments.

Currents in the northern area (L1) are typically had higher velocities than those in the south, but with no dominant direction of flow during the May-June (Figure 5-3) and August-September deployments. During the summer deployments, the direction of flow was typically to the northwest, with velocities of approximately 0.1-0.3 m/s (Figure 5-4). The hydrodynamic model simulated similar conditions (Appendix F).

The regional sites had somewhat similar wave climates, although with lower significant wave height at the northern site. Mean significant wave height was 1.6 m (northern site) and 2.2 m (southern site) during the July-November deployment, and 1.5 m (northern site) and 2.1m (southern site) during the November-March deployment. Mean wave periods were approximately 11-12 s during the July-November deployment and 8-10 s during the later deployment at both sites, while peak wave direction was from the SSW. At the northern lease site, significant wave heights were lower (means of approximately 1 m during each deployment bar Aug-Sep, which was 1.3 m), periods were similar (approximately 10s) and the peak wave direction was from the WSW.

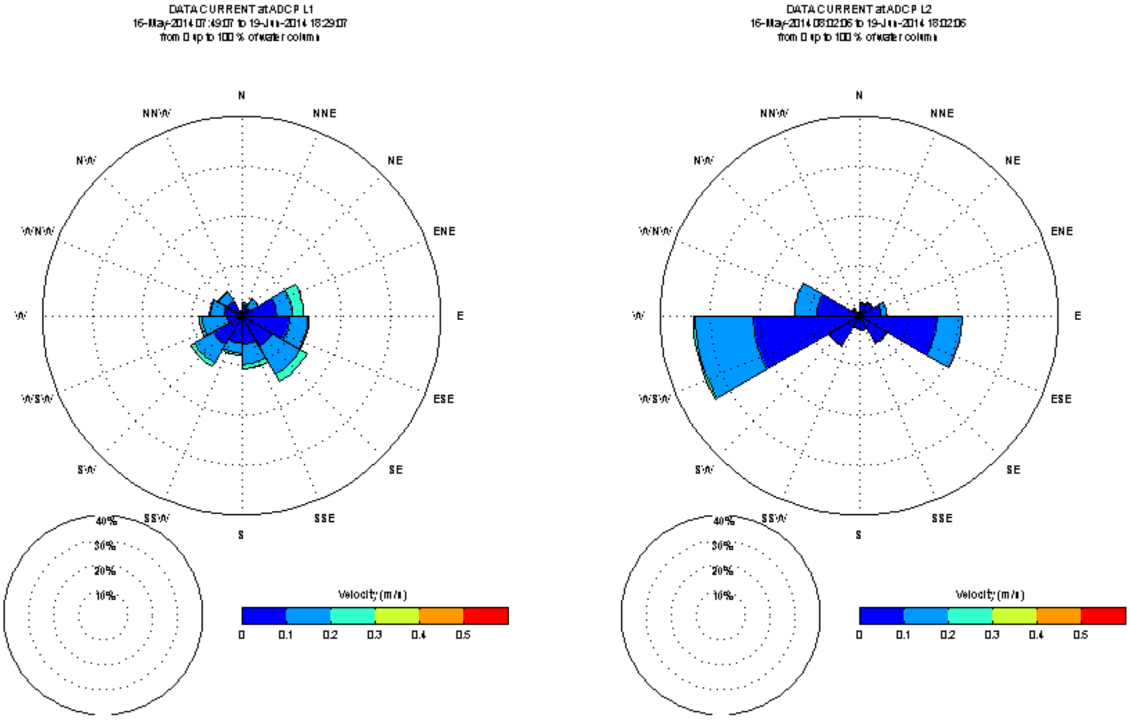


Figure 5-3 Current directions and speeds in the northern (L1) and southern (L2) areas of the MWADZ between May and June 2014

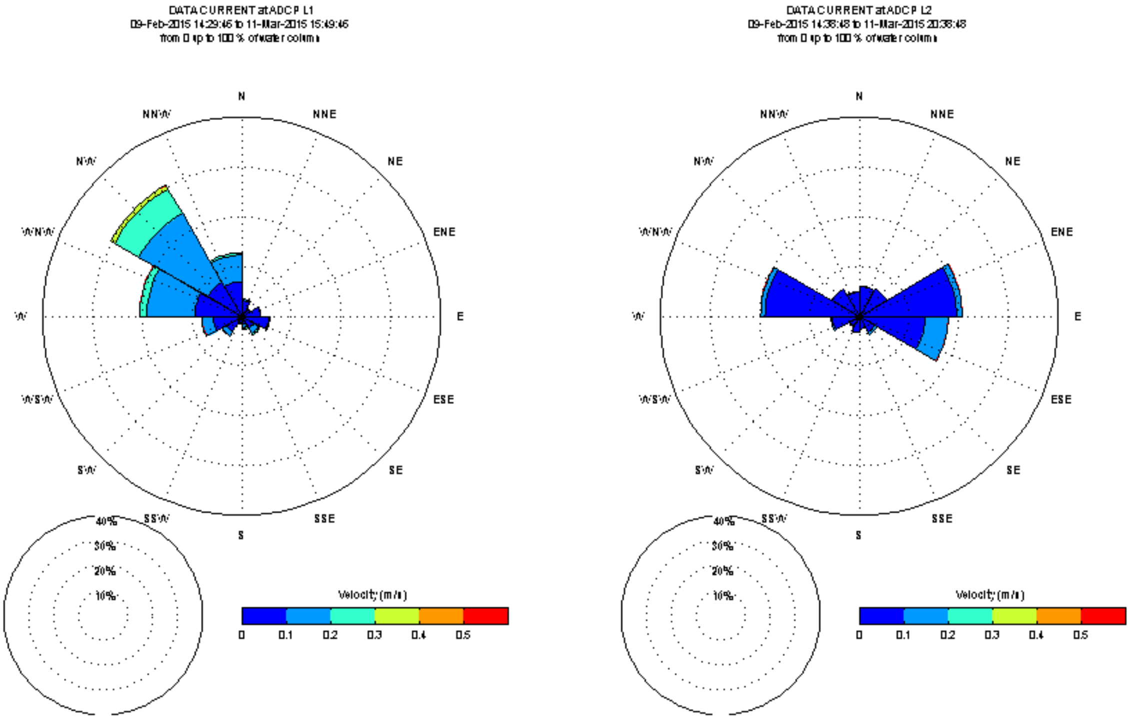


Figure 5-4 Current directions and speeds in the northern (L1) and southern (L2) areas of the MWADZ between February and March 2014

5.2 Biogeochemical processes

Natural biochemical processes were not empirically measured in the MWADZ sediments. Attempts to obtain consolidated sediment cores for this purpose failed due to the deep water (beyond diving depth) and the characteristics of the sediments–consisting of a shallow coarse layer of sand (of ~15 cm depth) overlying a rocky substrate. Given the depth, porosity and coarseness of the sediments, it was assumed that sediments were naturally well oxygenated, and free of sulphides probably throughout the sediment column (i.e. ~15 cm). For further context see Section 3.3.

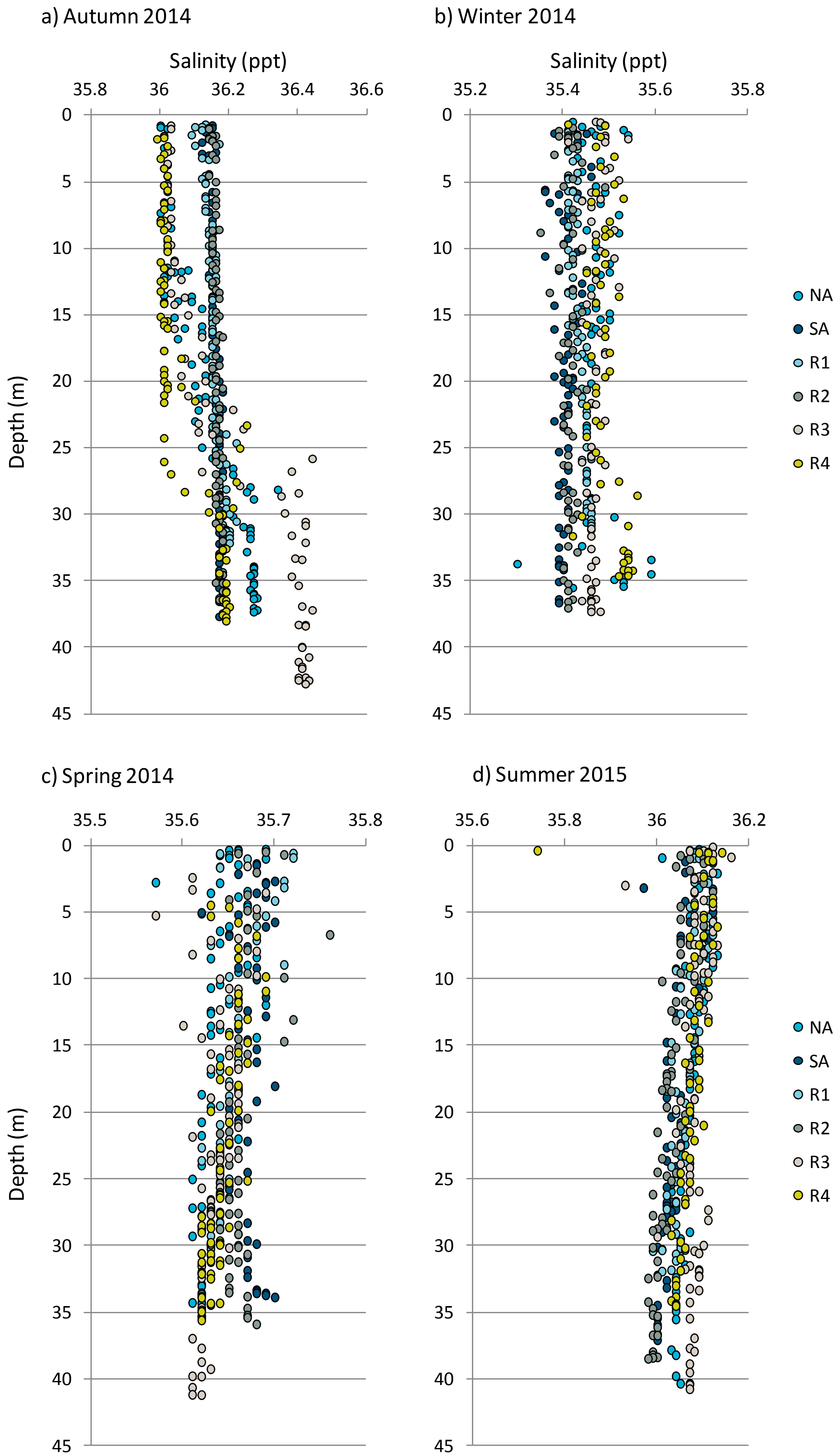
5.3 Water quality

5.3.1 Physical and chemical

Salinity readings confirmed that there was no significant stratification at any location across the seasons, indicating a well-mixed water column. However, salinity readings during autumn 2014 at the northern area (NA) and reference locations R3 and R4 increased from 36 ppt to 36.14–36.43 ppt at 29 m water depth (Figure 5-5). During winter 2014, the northern and southern (SA) MWADZ areas and reference locations had slightly lower salinities throughout the water column (~35.35–35.59 ppt) than autumn 2014 (~35.99–36.44 ppt) and summer 2015 (~35.74–36.16 ppt; Figure 5-5).

A temperature gradient was observed at the deeper reference location R3 (~43 m deep) particularly during autumn and summer, were temperatures dropped ~0.36–1.31°C between 15 m and 25 m (Figure 5-6). The three most northern locations (northern area [NA], R3 and R4) displayed similar decreasing trends in temperatures during autumn and winter (Figure 5-6), possibly a result of cooler water delivered to this area during periods of increased water movement. Across all locations, surface temperatures (0–10 m) were typically lower during spring (21.09–21.71°C) than summer (23.31–23.48°C; Figure 5-6).

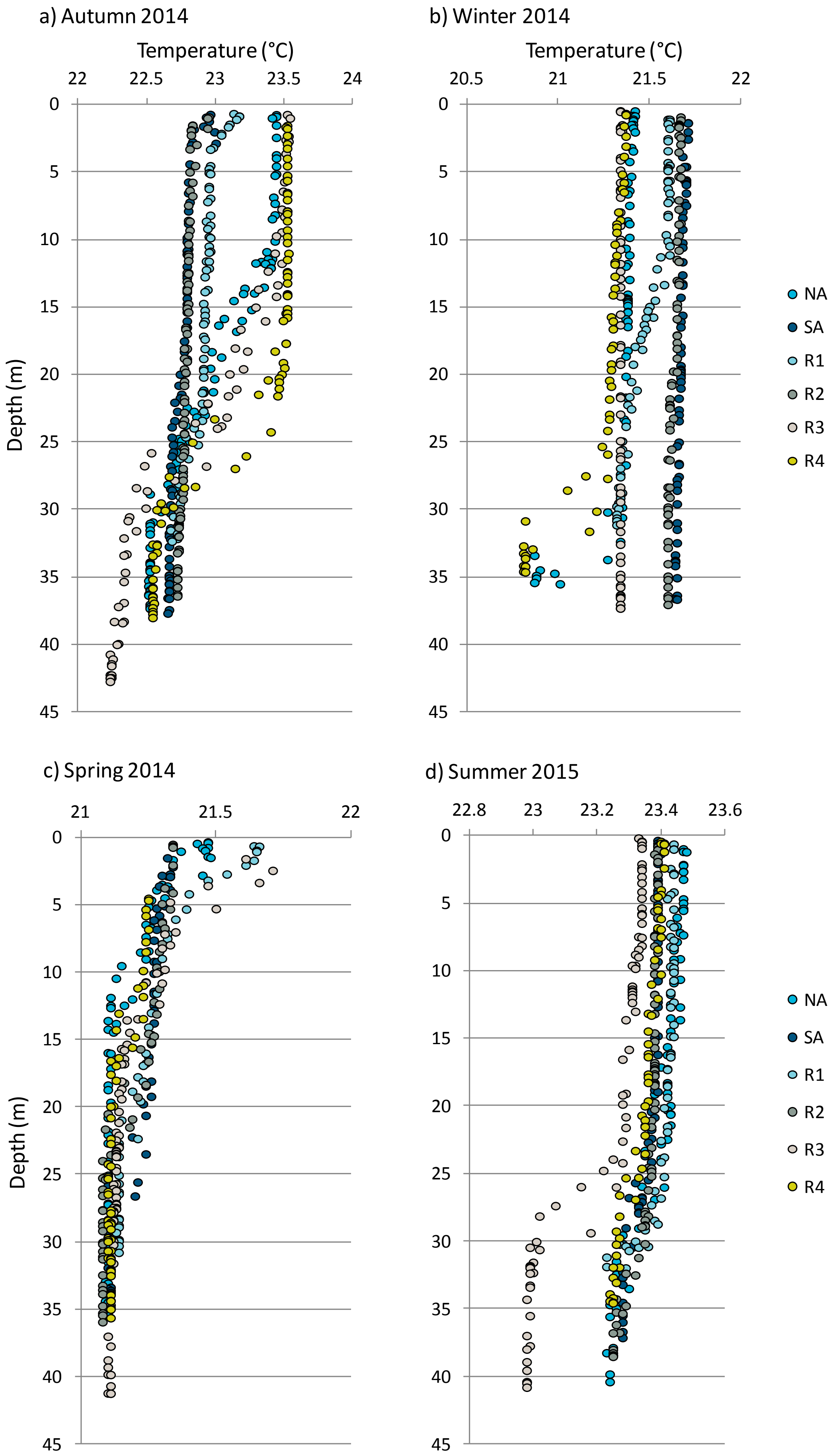
DO concentrations showed no clear trend between the northern, southern and reference locations over the year (Figure 5-7). Across all sites and sampling periods, mean surface DO saturation was always >96%, while mean bottom DO saturation was always >95% (Table 5.1). Mean bottom DO saturation was slightly lower than mean surface DO saturation during the autumn and winter sampling periods. There was a slight decreasing trend in DO saturation with increasing depth across all locations over all four seasons (Figure 5-7). Across all locations and seasons, mean surface (0–10 m) DO saturation values were always >~94.6%, while mean bottom DO saturation values were >95% (Figure 5-7).



Note:

1. NA = northern area, SA = southern area, R1–R4 = reference areas.

Figure 5-5 Salinity measured in autumn, winter and spring 2014, and summer 2015 at all locations



Note:
1. NA = northern area, SA = southern area, R1–R4 = reference areas.

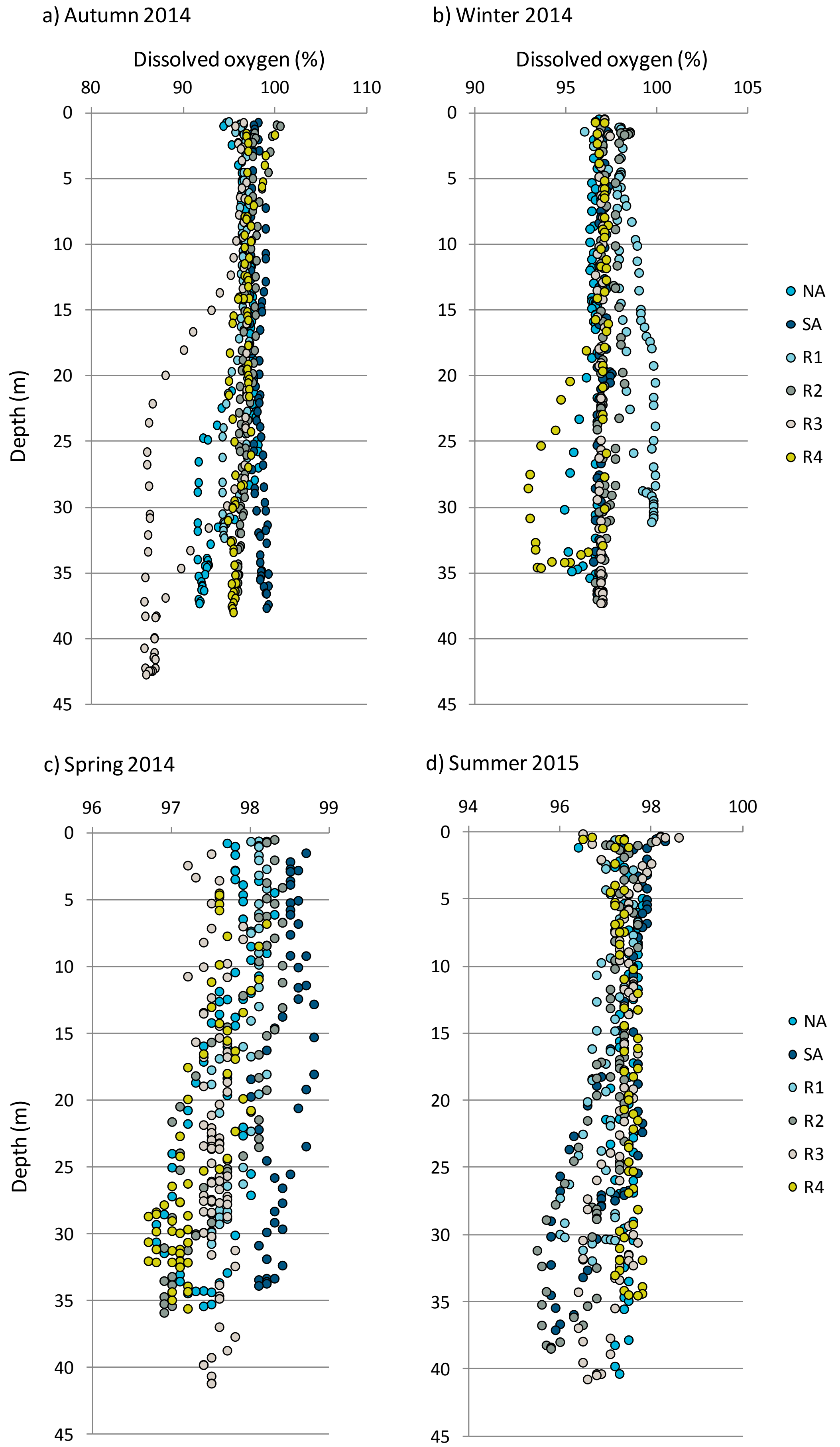
Figure 5-6 Temperature measured in autumn, winter and spring 2014, and summer 2015 at all locations

Table 5.1 Dissolved oxygen statistics at all locations

Season	Autumn			Winter			Spring			Summer		
MWADZ	**N**	**S**	**R**	**N**	**S**	**R**	**N**	**S**	**R**	**N**	**S**	**R**
Mean surface DO (%)	98	98	98	97	96	98	98	99	98	97	98	97
Standard deviation	2	1	2	1	1	2	1	1	1	0	1	1
Mean bottom DO (%)	96	97	95	95	96	96	98	98	97	97	97	97
Standard deviation	3	1	4	1	2	2	1	1	1	0	1	1

Notes:

1. MWADZ = Mid-west aquaculture development zone; N = northern MWADZ, S = southern MWADZ, R = reference
2. DO = dissolved oxygen



Note:

1. NA = northern area, SA = southern area, R1–R4 = reference areas.

Figure 5-7 Dissolved oxygen measured in autumn, winter and spring 2014, and summer 2015 at all locations

5.3.2 Light attenuation and irradiance

During August–September, K_d showed similar variation across the northern and southern areas – in the northern area, K_d ranged 0.04–0.17 per m while in the southern area, K_d ranged 0.06–0.19 per m (Figure 5-8). K_d measured over November-December showed similar variation across areas – in the northern area, K_d ranged 0.04–0.12 per m while in the southern area, K_d ranged 0.04–0.15 per m (Figure 5-9).

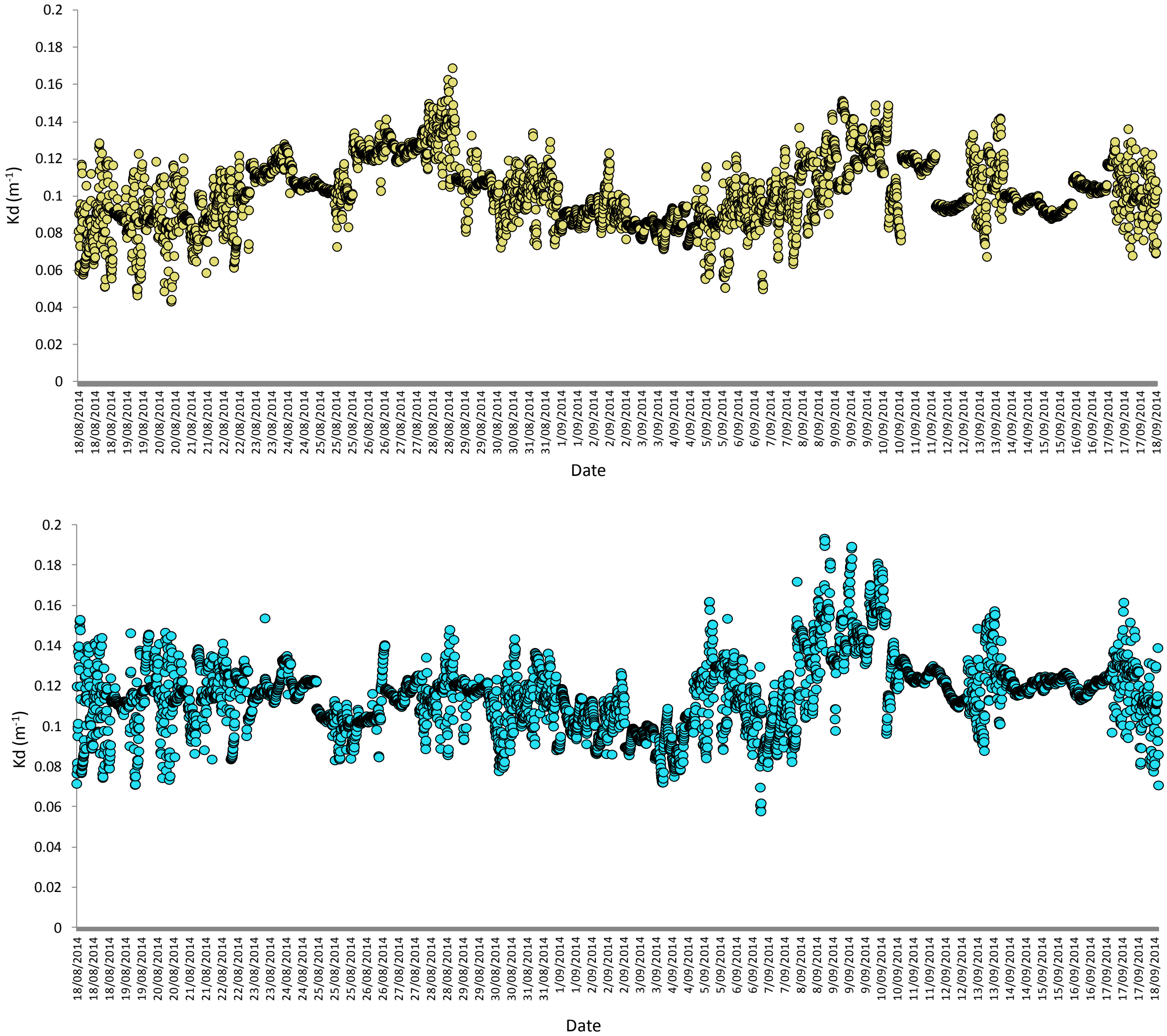
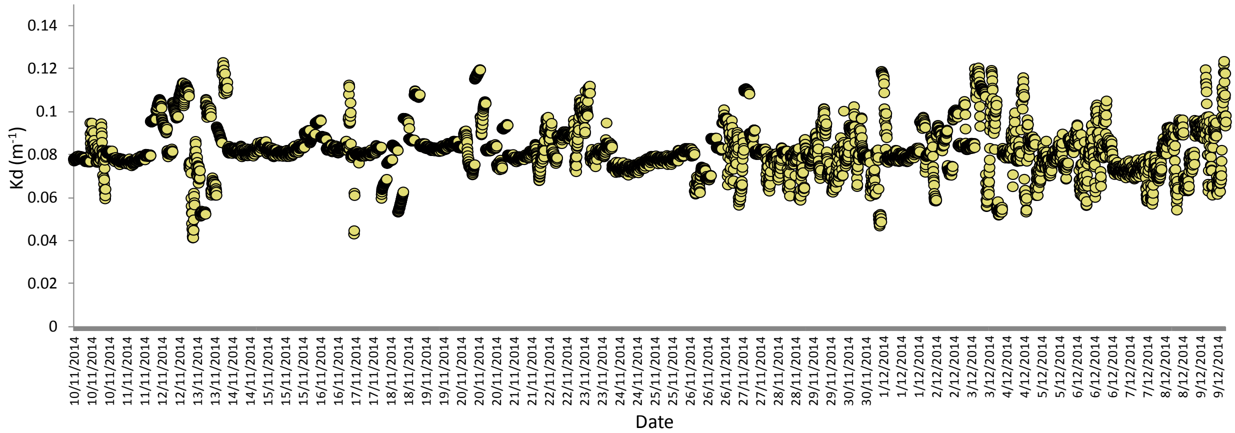


Figure 5-8 Comparative light attenuation data between the northern (upper panel) and southern areas (lower panel) (August–September 2014)



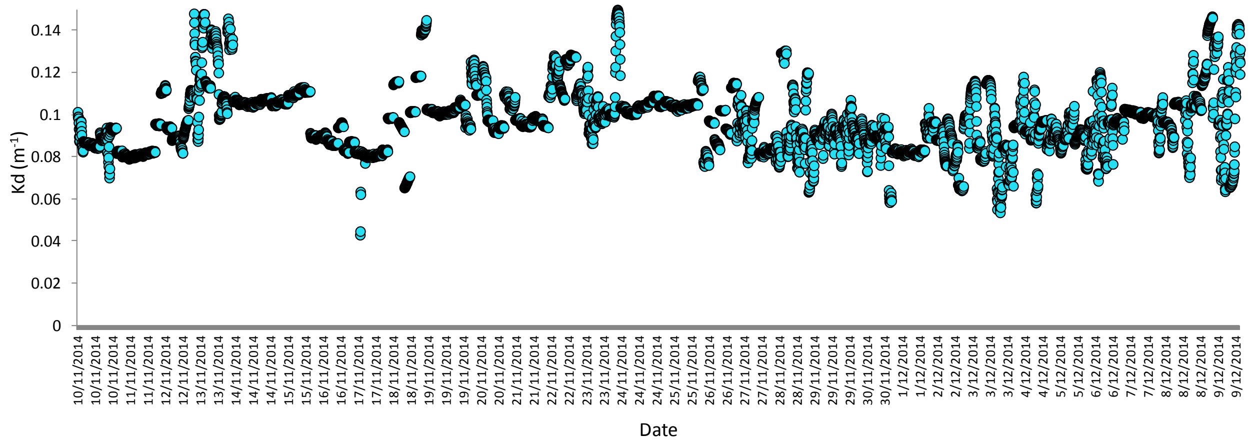


Figure 5-9 Comparative light attenuation data between the northern (upper panel) and southern areas (lower panel) (November–December 2014)

Light intensity for the 1st, 5th, 20th and 50th percentiles was calculated for each of the four sampling periods in the northern area and the southern area of the MWADZ (Table 5.2). Mean light intensity across the percentiles ranged 11.3–52.2 mol.photons/m^2/s in the northern are, while mean light intensity was lower in the southern area ranged 6.2–33.7 photons/m^2/s across percentiles. At both the northern and southern area, spring had the highest light intensity in each percentile, while autumn had the lowest light intensity in each percentile.

Table 5.2 Light intensity statistics from the northern and southern areas

Percentile	Autumn	Winter	Spring	Summer	Mean
Northern area					
1st	0.9	5.1	22.0	17.2	11.3
5th	1.5	8.4	31.3	21.0	15.5
20th	4.3	15.2	59.9	36.5	29.0
50th	9.0	27.6	108.3	64.1	52.2
Southern area					
1st	1.1	3.0	11.9	8.9	6.2
5th	2.6	5.1	17.5	12.0	9.3
20th	4.4	15.0	42.7	23.1	21.3
50th	6.3	22.5	62.7	43.3	33.7

Notes:

1. Northern MWADZ light intensity was measured at Rat Island
2. Autumn = May/June 2014, winter = August/September 2014, spring = November/December 2014 , summer = February/March 2015
3. Units are mol.photons/m^2/s.

5.3.3 Nutrients

Total nitrogen

Total nitrogen (TN) in both surface and bottom waters fluctuated in concentration across time (Table 5.3). June and November 2014 reported higher TN concentrations at the surface (0.151 ± 0.008 mg/L and 0.137 ± 0.004 mg/L, respectively) and bottom (0.16 ± 0.01 mg/L and 0.15 ± 0.01 mg/L, respectively) of the water column (Table 5.3). A significant Time x ZvR interaction in surface waters was detected, as the combined northern and southern areas (Zone) recorded higher TN concentrations than the reference locations, with the exception of May 2014 (Zone = 0.06 ± 0.01 mg/L, Reference = 0.09 ± 0.01 mg/L) and December 2014 (Zone = 0.07 ± 0.01 mg/L, reference = 0.084 ± 0.004 mg/L).

Table 5.3 Results of a three-factor PERMANOVA examining total nitrogen concentrations at the surface and bottom of the water column

Source	df	Surface		Bottom	
		MS	P(perm)	MS	P(perm)
Time	7	2.49E-02	**0.0001*** **	2.14E-02	**0.0001*** **
ZvR	1	3.91E-03	0.2713	1.95E-05	0.9039
Location(ZvR)	4	6.37E-03	0.0913	8.81E-04	0.7361
TimexZvR	7	8.39E-03	**0.0044** **	1.32E-03	0.5612
TimexLocation(ZvR)	28	4.42E-03	0.1800	2.74E-03	0.0602
Res	168	2.99E-03		1.61E-03	
Total	215				

Notes:
1. Significant results shown in bold; **= highly significant (p<0.01), *** = very highly significant (p<0.001).
1. ZvR = Zone vs Reference

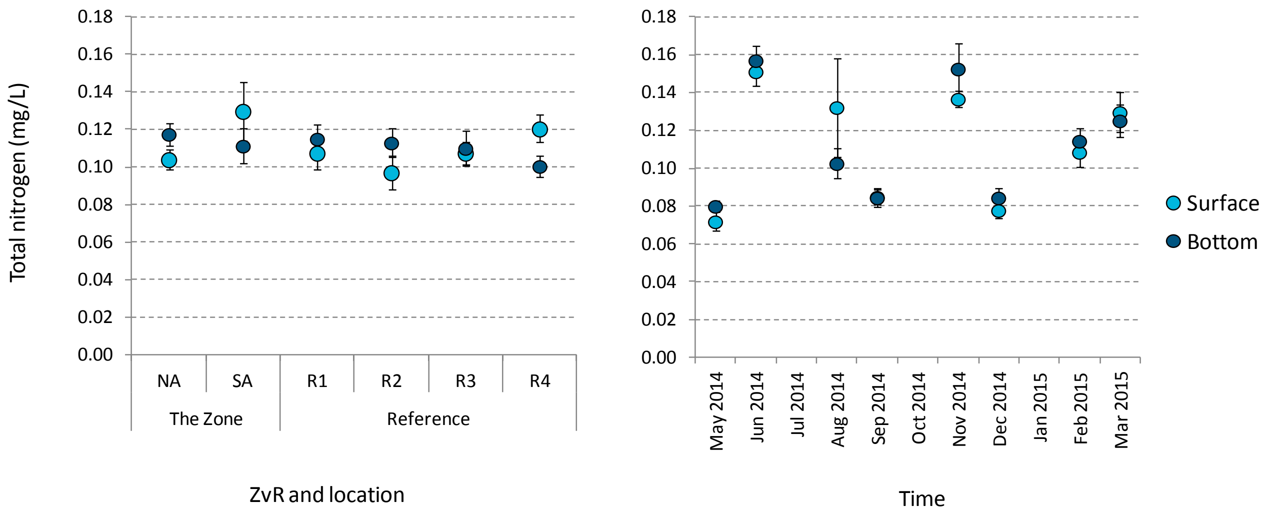


Figure 5-10 Total nitrogen (mean ± S.E.) sampled at the surface and bottom of the water column across locations within ZvR and time

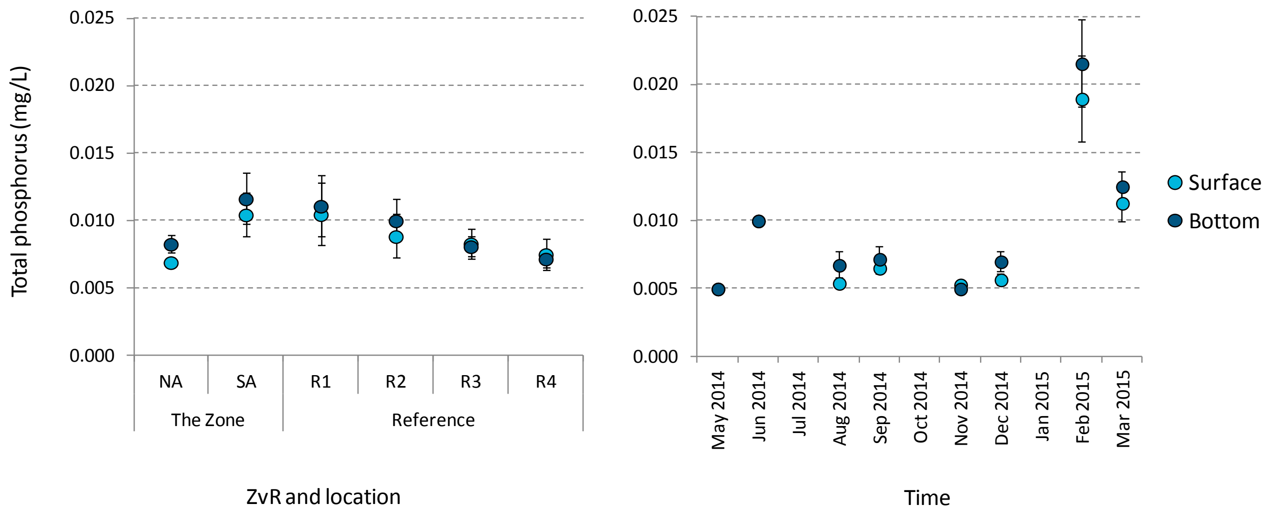
Total phosphorus

Results revealed distinct spatial and seasonal fluctuations in total phosphorus (TP) concentrations (Table 5.4). In general, both surface and bottom concentrations in TP remained relatively similar across Zone and reference locations (Figure 5-11). PERMANOVA results detected a significant Time x Location (ZvR) interaction in both surface and bottom waters (Table 5.4). The significant Time x Location (ZvR) interaction was primarily driven by time and location, with higher TP concentrations reported in February (surface = 0.019 ± 0.003 mg/L, bottom = 0.022 ± 0.003 mg/L) and March 2015 (surface = 0.011 ± 0.001 mg/L, bottom = 0.013 ± 0.001 mg/L) across all Zone and reference locations.

Table 5.4 Results of a three-factor PERMANOVA examining total phosphorus concentrations at the surface and bottom of the water column

Source	df	Surface		Bottom	
		MS	P(perm)	MS	P(perm)
Time	7	9.56E-04	**0.0001*** **	1.04E-03	**0.0001*** **
ZvR	1	2.92E-07	0.9294	1.10E-04	0.0936
Location(ZvR)	4	1.34E-04	**0.0042** **	1.22E-04	**0.0268***
TimexZvR	7	4.36E-06	0.9954	5.83E-05	0.1679
TimexLocation(ZvR)	28	1.30E-04	**0.0002*** **	1.16E-04	**0.0015** **
Res	168	3.23E-05		3.78E-05	
Total	215				

Notes:
1. Significant results shown in bold; **= highly significant (p<0.01), *** = very highly significant (p<0.001).
2. ZvR = Zone vs Reference



Note:
1. ZvR = Zone vs Reference

Figure 5-11 Total phosphorus (mean ± S.E.) sampled at the surface and bottom of the water column across locations within ZvR and time

Total organic carbon

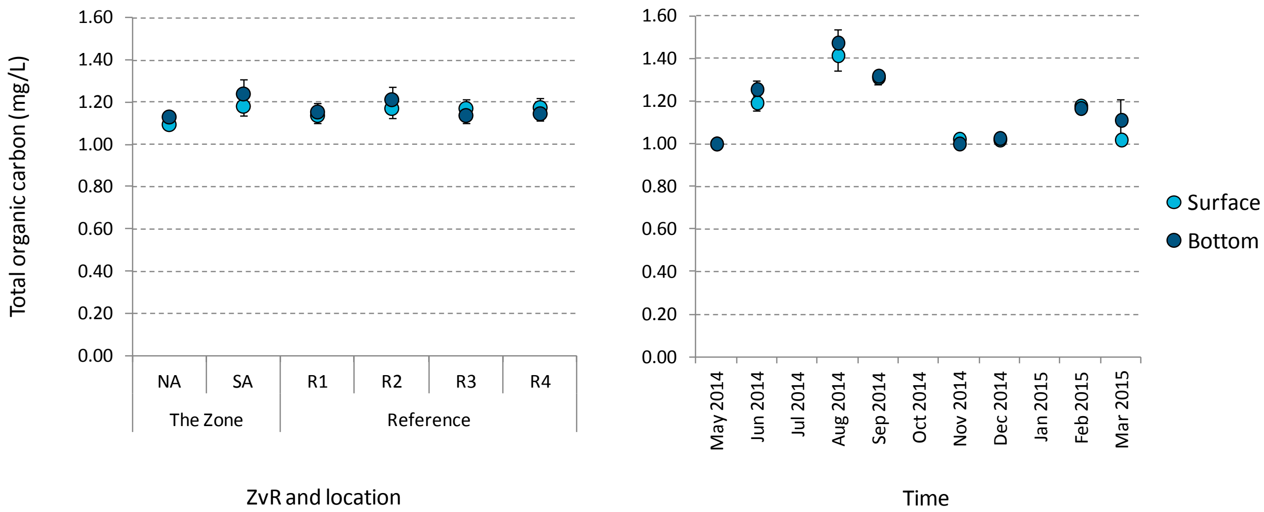
Concentrations of total organic carbon (TOC) varied significantly across time (Table 5.5). Sampling in August (surface = 1.40 ± 0.07 mg/L, bottom = 1.47 ± 0.06 mg/L) and September 2014 (surface = 1.31 ± 0.03 mg/L, bottom= 1.32 ± 0.03 mg/L) reported the greatest concentration of TOC in both surface and bottom waters (Figure 5-12). PERMANOVA also detected a significant Time x Location (ZvR) and Time x ZvR interaction (Table 5.5). Both interactions were driven by time, as TOC concentrations were below the detection limit across all Zone and reference locations during November and December 2014 and March and May 2015.

Table 5.5 Results of a three-factor PERMANOVA examining total organic carbon concentrations at the surface and bottom of the water column

Source	df	Surface		Bottom	
		MS	P(perm)	MS	P(perm)
Time	7	3.7481	**0.0001*** **	3.6251	**0.0001*** **
ZvR	1	7.50E-02	0.2198	1.66E-02	0.6690
Location(ZvR)	4	0.10727	0.0814	8.17E-02	0.4925
TimexZvR	7	0.14088	**0.0097** **	8.95E-02	0.4529
TimexLocation(ZvR)	28	8.62E-02	**0.0185***	0.1023	0.3389
Res	168	5.01E-02		9.31E-02	
Total	215				

Notes:

1. Significant results shown in bold; **= highly significant (p<0.01), *** = very highly significant (p<0.001).



Note:

1. ZvR = Zone vs Reference

Figure 5-12 Total organic carbon (mean ± S.E.) sampled at the surface and bottom of the water column across locations within ZvR and time

Total suspended solids

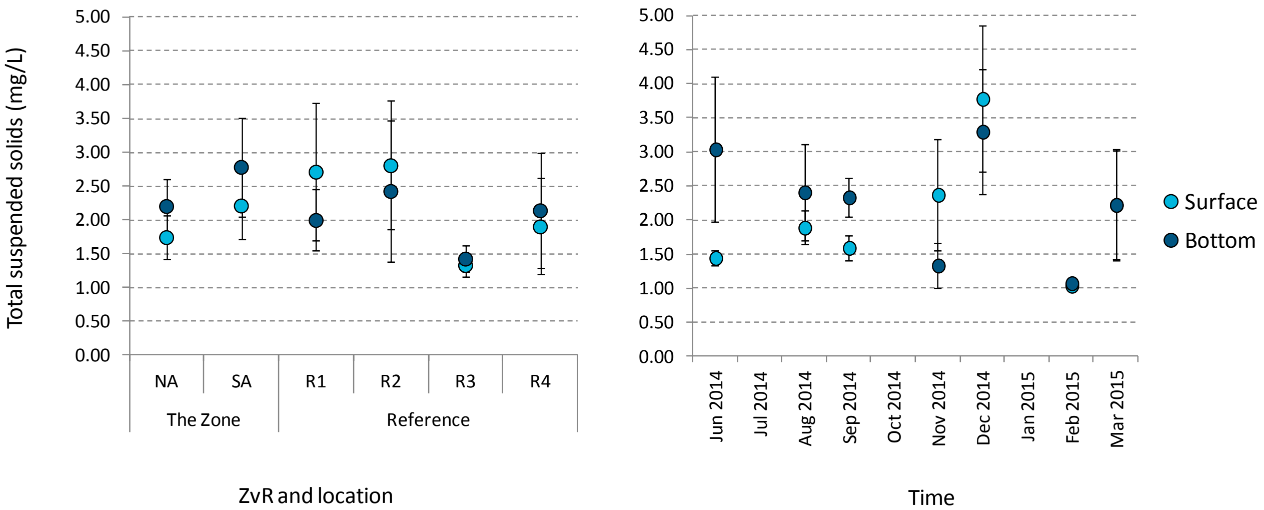
Concentrations of total suspended solids (TSS) remained relatively constant across locations, varying between 1.05 mg/L and 2.62 mg/L in surface and bottom waters (Figure 5-13). While no significant differences in TSS concentrations were detected in bottom waters, TSS concentrations were significantly different across time in surface waters (Table 5.6). Post-hoc tests revealed that TSS concentration measured during February 2015 was significantly different to other times[2].

[2] *No TSS concentrations were measured during May 2014 due to inadequate flushing of salts with deionised water.*

Table 5.6 Results of a three-factor PERMANOVA examining total suspended solids concentrations at the surface and bottom of the water column

Source	df	Surface		Bottom	
		MS	P(perm)	MS	P(perm)
Time	6	21.08	**0.0445***	22.775	0.1222
ZvR	1	2.51E+00	0.6174	0.47421	0.7579
Location(ZvR)	4	1.04E+01	0.3660	5.1543	0.8060
TimexZvR	6	5.76E+00	0.7372	7.4111	0.7869
TimexLocation(ZvR)	24	16.678	0.0510	14.388	0.3889
Res	147	9.59E+00		13.677	
Total	188				

Notes:
1. Significant results shown in bold; **= highly significant (p<0.01), *** = very highly significant (p<0.001).
2. ZvR = Zone vs Reference



Note:
1. ZvR = Zone vs Reference

Figure 5-13 Total suspended solids (mean ± S.E.) sampled at the surface and bottom of the water column across locations within ZvR and time

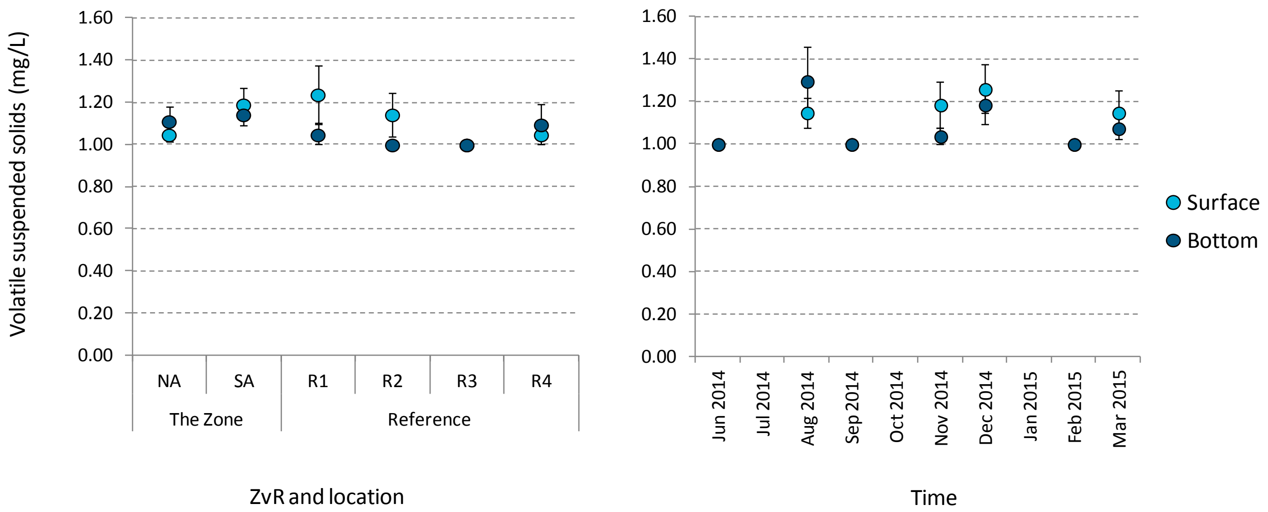
Volatile suspended solids

Concentrations of volatile suspended solids (VSS) varied in time and space (Table 5.7): for example, the highest concentrations in surface waters were detected in December 2014 (1.26 ± 0.11 mg/L), and the lowest concentrations in bottom waters were recorded in August 2014 (1.30 ± 0.16 mg/L). A significant Time x Location (ZvR) interaction was detected at the surface of the water column (Table 5.7). Post-hoc tests revealed that the driver of this interaction was time and location, which resulted from unusually high VSS concentrations at reference site R1 (2.33 ± 0.67 mg/L) during one of the months (November 2014).

Table 5.7 Results of a three-factor PERMANOVA examining volatile suspended solids concentrations at the surface and bottom of the water column

Source	df	Surface		Bottom	
		MS	P(perm)	MS	P(perm)
Time	6	0.99892	**0.0010****	0.88938	**0.0037****
ZvR	1	1.46E-02	0.7981	5.89E-02	0.4324
Location(ZvR)	4	0.55818	**0.0476***	2.14E-02	0.9906
TimexZvR	6	0.2381	0.4003	0.30673	0.3069
TimexLocation(ZvR)	24	0.42068	**0.0295***	0.13743	0.8880
Res	147	0.22676		0.25181	
Total	188				

Notes:
1. Significant results shown in bold
2. *Significant = p<0.05; **Highly significant = p<0.01



Note:
1. ZvR = Zone vs Reference

Figure 5-14 Volatile suspended solids sampled at the surface and bottom of the water column across locations within ZvR and time

Ammonia

Ammonia concentrations at the surface of the water column were relatively consistent in space, though concentrations were marginally elevated at the northern and southern areas (Figure 5-15). Higher concentrations were also detected in June 2014 (5.56 ± 0.79 µg/L) and August 2014 (7.00 ± 2.43 µg/L) relative to other months, resulting in a significant Time x ZvR interaction (Table 5.8). Similar results were observed in the case of bottom waters, with significant Time x ZvR and Time x Location (ZvR) interactions (Table 5.8). These interactions were driven by both time and ZvR, but mainly due to the elevated concentrations at the northern area (SL1) in June 2014 (9.67 ± 1.60 µg/L).

Table 5.8 Results of a three-factor PERMANOVA examining ammonia concentrations at the surface and bottom of the water column

Source	df	Surface		Bottom	
		MS	P(perm)	MS	P(perm)
Time	7	75.107	**0.0040****	28.562	**0.0001*****
ZvR	1	66.477	0.0824	1.0524	0.5984
Location(ZvR)	4	14.786	0.6476	6.0497	0.2120
TimexZvR	7	60.204	**0.0101***	14.604	**0.0040****
TimexLocation(ZvR)	28	37.274	0.1259	10.587	**0.0011****
Res	168	22.312		4.2707	
Total	215				

Notes:
1. Significant results shown in bold
2. *Significant = p<0.05; **Highly significant = p<0.01; ***Very highly significant = p<0.001

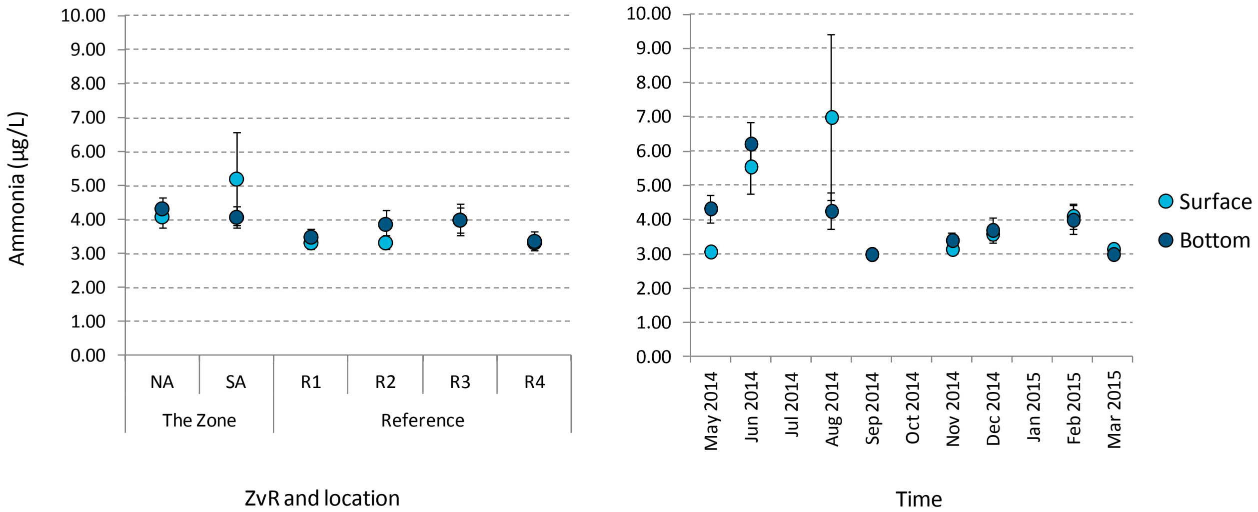


Figure 5-15 Ammonia (mean ± S.E.) (µg/L) sampled at the surface and bottom of the water column across locations within ZvR (left) and time (right)

Orthophosphate

Results revealed distinct spatial and seasonal fluctuations in orthophosphate concentrations. In general, similar surface concentrations were reported across the northern and southern areas and at the reference locations (Figure 5-16). A significant Time x Location(ZvR) interaction in surface waters was detected, primarily driven by time and location as higher orthophosphate concentrations were reported in June (3.04 ± 0.11 µg/L) and August 2014 (4.52 ± 0.50 µg/L) at the southern area (SL2) and reference location R3. For bottom waters, significant Time x Location (ZvR) and Time x ZvR interactions were reported (Table 5.9). These interactions were primarily driven by time, as post-hoc tests found that concentrations in bottom waters were greater at the northern area (SL1) and the reference locations R2, R3 and R4 during May, August and November 2014, and March 2015. Orthophosphate concentrations significantly differed between the northern and southern areas and the reference locations across time, with the exception of June 2014.

Table 5.9 Results of a three-factor PERMANOVA examining orthophosphate concentrations at the surface and bottom of the water column

Source	df	Surface		Bottom	
		MS	P(perm)	MS	P(perm)
Time	7	38.681	**0.0001*** **	22.861	**0.0001*** **
ZvR	1	0.20455	0.6677	1.0681	0.1388
Location(ZvR)	4	3.3833	**0.0104***	1.0384	0.0583
TimexZvR	7	1.46	0.1772	1.8076	**0.0013** **
TimexLocation(ZvR)	28	2.3714	**0.0042** **	1.6314	**0.0001*** **
Res	168	0.98214		0.4988	
Total	215				

Notes:
1. *Significant = p<0.05; **Highly significant = p<0.01; ***Very highly significant = p<0.001
2. Significant results shown in bold

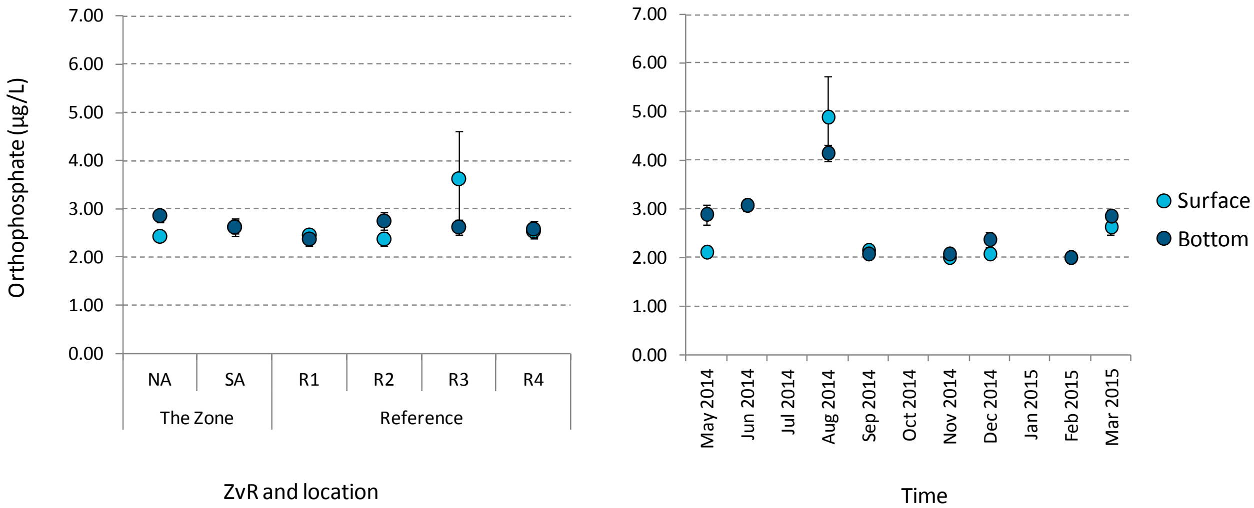


Figure 5-16 Orthophosphate (mean ± S.E.) sampled at the surface and bottom of the water column across locations within ZvR (left) and time (right)

Dissolved inorganic nitrogen

Concentrations of dissolved inorganic nitrogen (DIN) showed seasonal variations in surface and bottom waters (Figure 5-17; Table 5.10). Post-hoc test showed that concentrations at the surface were significantly higher during August 2014 (39.67 ± 10.60 µg/L), December 2014 (23.44 ± 1.83 µg/L) and February 2015 (21.96 ± 2.36 µg/L). For bottom waters, August 2014 reported greater DIN levels (30.59 ± 8.22 µg/L), while March 2015 (7.78 ± 0.86 µg/L) had the lowest concentration of DIN. Furthermore, higher concentrations of DIN were reported in the combined northern and southern areas (Zone = 22.58 ± 2.09 µg/L) compared to reference locations (17.60 ± 1.15 µg/L).

Table 5.10 Results of a two-factor PERMANOVA examining dissolved inorganic nitrogen concentrations at the surface and bottom of the water column

Source	df	Surface		Bottom	
		MS	P(perm)	MS	P(perm)
Time	7	2083.2	**0.0001*** **	1231.7	**0.0004*** **
ZvR	1	41.698	0.8222	1644.6	**0.0144***
Location(ZvR)	4	1160.3	0.0690	475.14	0.2492
TimexZvR	7	561.33	0.3727	388.9	0.3337
TimexLocation(ZvR)	28	442.67	0.5065	213.04	0.6752
Res	168	497.28		330.44	
Total	215				

Notes:

1. *Significant = p<0.05; ***Very highly significant = p<0.001
2. Significant results shown in bold

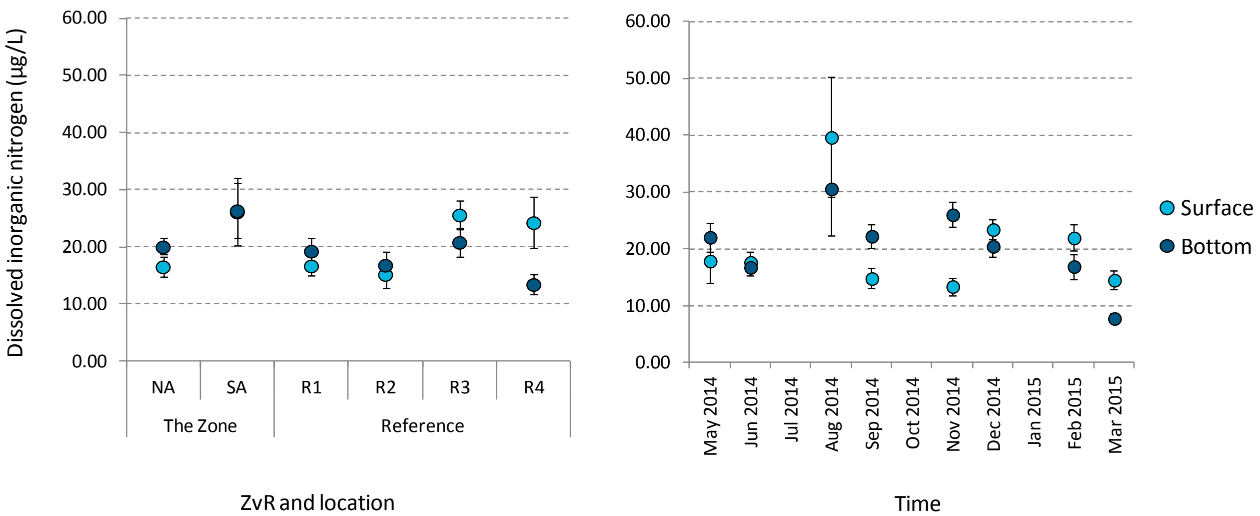


Figure 5-17 Dissolved inorganic nitrogen (mean ± S.E.) sampled at the surface and bottom of the water column across locations within ZvR (left) and time (right)

Nitrate and nitrite

Concentrations of nitrate and nitrite (NOx) were greatest in August 2014 irrespective of depth (surface 32.67 ± 8.62 µg/L and bottom 26.33 ± 7.78 µg/L). There was also a tendency toward spatial variation in concentrations (Figure 5-18). On average, reference locations R3 and R4 reported the greatest concentrations in surface waters (21.63 ± 2.50 µg/L and 20.96 ± 1.72 µg/L, respectively), followed closely by the southern area SL2 (20.94 ± 4.69 µg/L). PERMANOVA detected a significant seasonal decline in bottom water concentrations between November 2014 and March 2015 (Figure 5-18).

Table 5.11 Results of a two-factor PERMANOVA examining nitrate and nitrite concentrations at the surface and bottom of the water column

Source	df	Surface		Bottom	
		MS	P(perm)	MS	P(perm)
Time	7	1121.8	**0.0002*** **	738.59	**0.0020** **
ZvR	1	80.01	0.5147	323.65	0.0763
Location(ZvR)	4	515.8	**0.0239***	126.3	0.3199
TimexZvR	7	213.85	0.3040	145.87	0.2584
TimexLocation(ZvR)	28	269.79	0.0972	101.78	0.5667
Res	168	177.55		115.09	
Total	215				

Notes:

1. *Significant = p<0.05; **Highly significant = p<0.01; ***Very highly significant = p<0.001
2. Significant results shown in bold

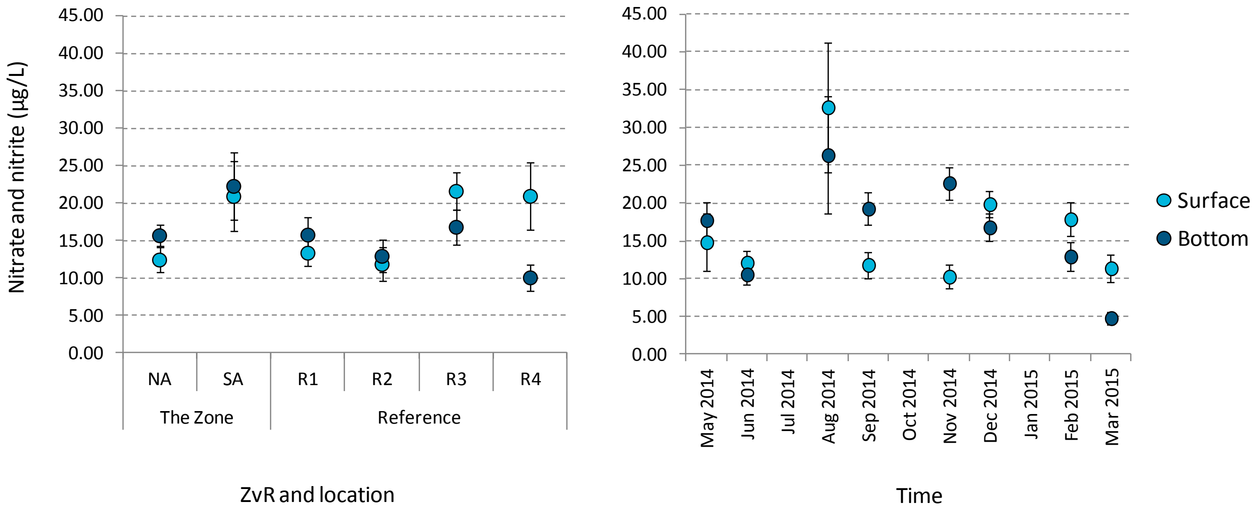


Figure 5-18 Nitrate and nitrite (mean ± S.E.) sampled at the surface and bottom of the water column across locations within ZvR (left) and time (right)

5.3.4 Hydrogen sulphide

Concentrations of hydrogen sulphide were below the limit of reporting (0.01 mg/L) in all samples.

5.3.5 Total Petroleum Hydrocarbons / Polycyclic Aromatic Hydrocarbons

Total petroleum hydrocarbons (TPH) and polycyclic aromatic hydrocarbons (PAH) were generally below the laboratory limit of reporting (LOR). Of the over 400 replicate water samples collected, less than 20 samples exceeded the LOR for PAHs (0.001 µg/L), 1 sample exceeded the LOR for TPH C6-C10, 5 samples exceeded the LOR for TPH C11-C16, 2 samples exceeded the LOR for TPH C17-C34 and 1 sample exceeded the LOR for total TPH (Table 5.24).

Table 5.12 Total Petroleum Hydrocarbons and Polycyclic Aromatic Hydrocarbons concentrations in the surface and bottom of the water column

Chemical	Species	LOR (µg/L)	Site and value (µg/L)
TPH	C6-C10	25	R1 bottom (120)
	C11-C16	25	NA bottom (89) SA surface (32) R1 bottom (41) R3 surface (34) R4 bottom (33 and 46)
	C17-34	100	NA bottom (160) R2 surface (120)
	Total	250	NA bottom (290)
PAH	Benzo(g,h,i)perylene	0.001	NA 3 reps, 1 rep SA (0.002 0.011)
	Phenanthrene		Numerous samples (0.001 – 0.017)
	Benzo(k)fluoranthene		R4 1 rep (0.024)
	Benzo(b)fluoranthene		R4 1 rep (0.038)
	Naphthalene		Numerous samples (0.001 – 0.88)

5.3.6 Chlorophyll-a

Univariate analyses applied to chlorophyll-a concentrations revealed a significant Time x Location interaction term (Table 5.13). This result indicates that there were differences among times, but that these were different for each location. Reference location R1 had greater concentrations of chlorophyll-a at the surface (0.27 ± 0.03 µg/L) and bottom (0.25 ± 0.04 µg/L) of the water column relative to other locations (Figure 5-19). A general increasing trend in chlorophyll-a was also observed at the surface and bottom of the water column from November 2014 to March 2015 (Figure 5-19).

Table 5.13 Results of a two-factor PERMANOVA examining chlorophyll-a concentrations at the surface and bottom of the water column

Source	df	Surface		df	Bottom	
		MS	P(perm)		MS	P(perm)
Time	6	0.24522	**0.0001*****	6	0.17707	**0.0001*****
Location	5	3.25E-02	**0.0005*****	5	3.03E-02	**0.0003*****
TimexLocation	30	2.05E-02	**0.0001*****	30	1.81E-02	**0.0001*****
Res	146	6.72E-03		147	5.48E-03	
Total	187			188		

Notes:
1. ***Very highly significant = p<0.001
2. Significant results shown in bold

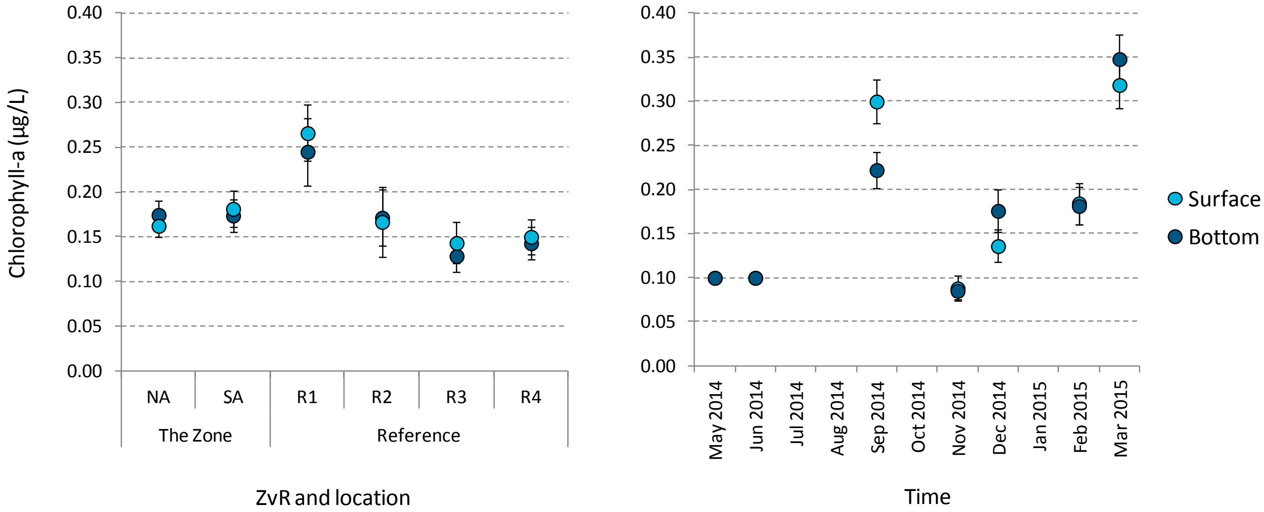


Figure 5-19 Chlorophyll-a (mean ± S.E.) sampled at the surface and bottom of the water column across locations within ZvR (left) and time (right)

5.3.7 Phytoplankton

Phytoplankton belonging to six divisions/phyla (Bacillariophyta, Chlorophyta, Chrysophyta, Cryptophyta, Cyanophyta, Dinophyta), plus unidentified others, were sampled across all locations. Counts were overwhelmingly dominated by the diatoms (Bacillariophyta represented ~90.8% of the total counts), followed by dinoflagellates (~3.5% of the total counts). Of the total counts, 12.4% were classified as potentially toxic algae and 1.6% were classified as potentially toxic blue green algae.

Results were characterised by very large scale fluctuations in community assemblage in time and space. This was reflected in the multivariate PERMANOVA routines which revealed significant differences in phytoplankton counts between months and locations (Table 5.14). Post-hoc pair wise comparisons found significant differences in phytoplankton counts across all times, except those between August 2014 and February 2015, and between December 2014 and February 2015. In addition, greater counts of Chlorophyta (green), Cryptophyta (monad), Cyanophyta (blue green) and Dinophyta (dinoflagellates) were reported during May 2014 (Figure 5-20), and greater counts of Bacillariophyta were recorded in December 2014 (92.93 ± 25.08 cells/ml; Figure 5-20). Post-hoc tests revealed that the northern and southern areas were significantly different to each other. This was particularly evident for Dinophyta, which was recorded in higher numbers at the southern areas relative to northern area (Figure 5-20). Phytoplankton counts at reference location R1 were also significantly different to counts at reference locations R2, R3 and R4. This was driven primarily by Bacillariophyta, which recorded very high numbers at location R1 relative to other locations (Figure 5-20).

Table 5.14 Results of a three-factor PERMANOVA examining phytoplankton counts

Source	df	MS	Pseudo-F	P(perm)
Time	3	2189.1	5.1900	**0.0002*** **
ZvR	1	624.22	1.4799	0.2343
Location(ZvR)	4	1310.7	3.1074	**0.0017*** *
TimexZvR	3	539.33	1.2786	0.2668
TimexLocation(ZvR)	12	566.06	1.3420	0.1328
Res	84	421.8		
Total	107			

Notes:

1. **Highly significant = p<0.01; ***Very highly significant = p<0.001
2. Significant results shown in bold

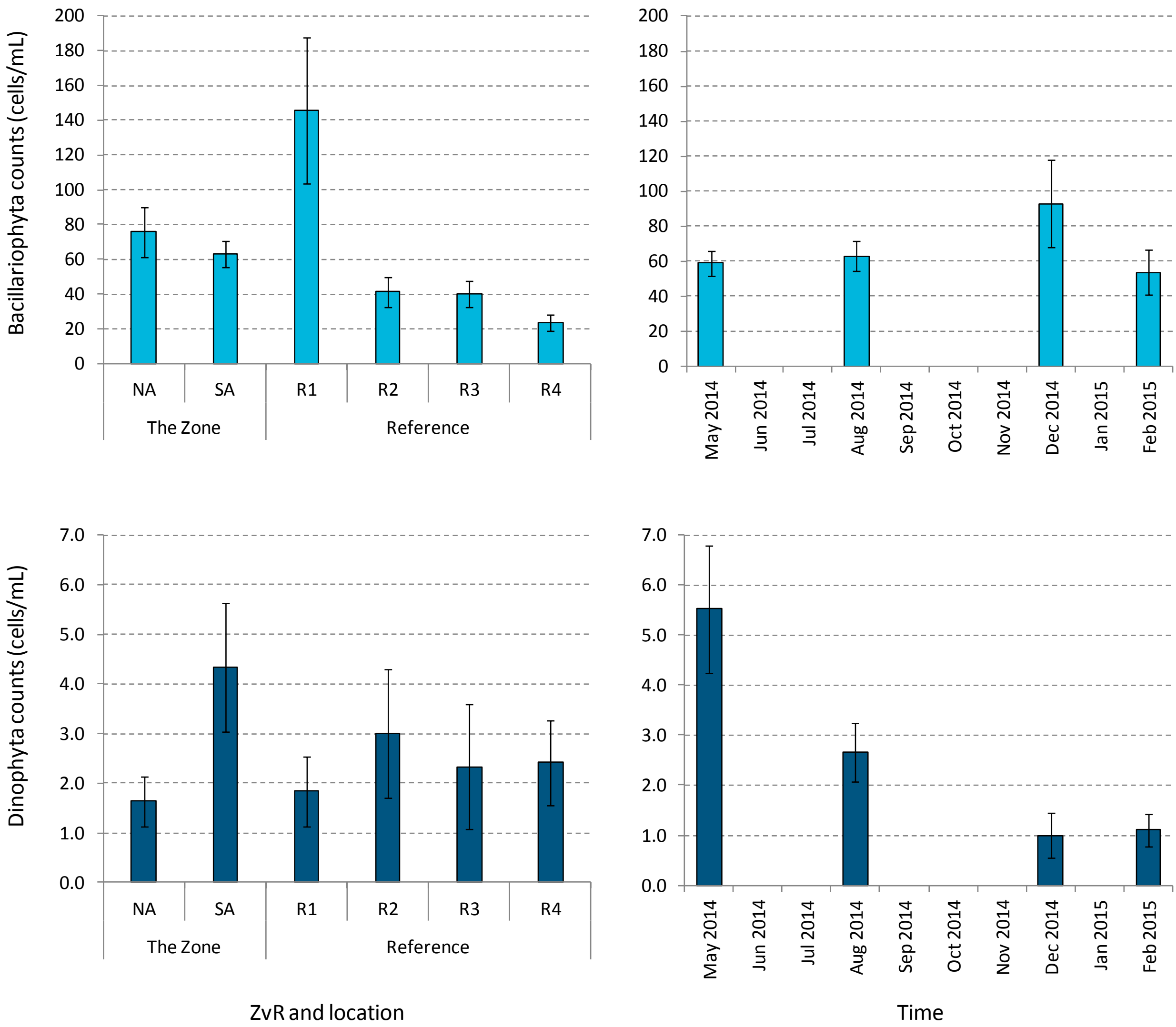


Figure 5-20 Bacillariophyta (diatoms; top left and right) and Dinophyta (dinoflagellates; bottom left and right) counts (mean ± S.E.) across locations and time

The multivariate analysis applied to phytoplankton biovolume revealed similar results as seen in the community data, however a significant Time x Location(ZvR) interaction was detected that was primarily driven by time and location (Table 5.15). Post-hoc test revealed significant differences across times (Figure 5-21) and R1 and R4. Higher biovolumes of Bacillariophyta and Dinophyta were recorded at R1 (Figure 5-21).

Table 5.15 Results of a three-factor PERMANOVA examining biovolume of phytoplankton

Source	df	MS	Pseudo-F	P(perm)
Time	3	303.11	4.1633	**0.0015****
ZvR	1	34.046	0.46762	0.6408
Location(ZvR)	4	248.4	3.4118	**0.0029****
TimexZvR	3	134.91	1.853	0.0983
TimexLocation(ZvR)	12	207.07	2.8441	**0.0002**
Res	84	72.807		
Total	107			

Notes:
1. **Highly significant = p<0.01
2. Significant results shown in bold

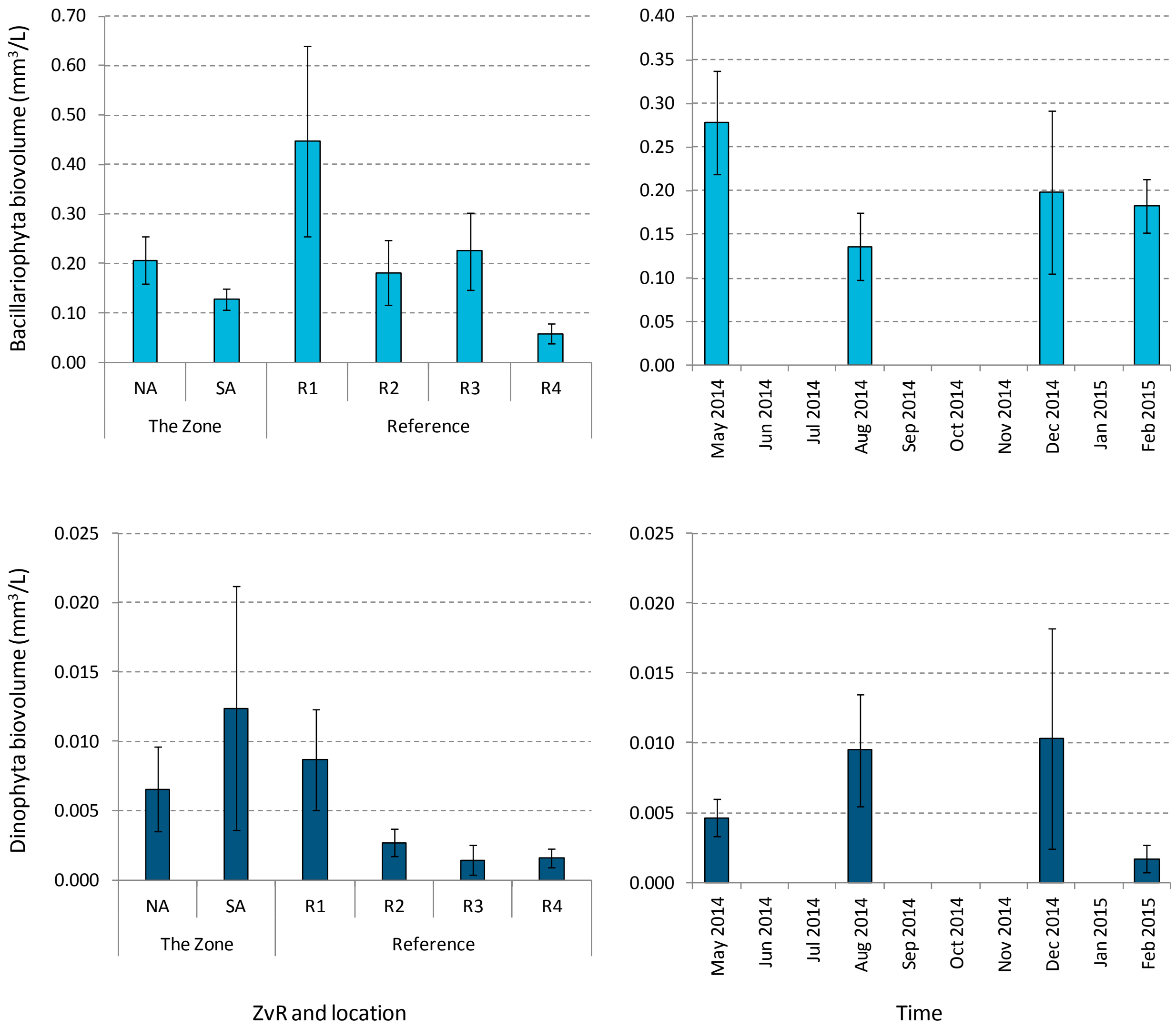


Figure 5-21 Bacillariophyta (diatoms; top left and right) and Dinophyta (dinoflagellates; bottom left and right) biovolumes (mean ± S.E.) across locations

Multivariate analysis of total algal and potential toxic algal counts revealed significant differences between time and locations (Table 5.16). Post-hoc tests for location showed significant differences in algal counts between reference R1 and all other three reference locations (R2, R3 and R4). Post-hoc tests for time only revealed a significant difference in total counts between May 2014 and December 2014. Total algal counts were greatest during December 2014 (99.56 ± 27.08 cells/ml) while May 2014 recorded the greatest counts of potentially toxic algae (11.81 ± 4.92 cells/ml; Figure 5-22).

Table 5.16 Results of a three-factor PERMANOVA examining total algal and potentially toxic algal counts

Source	df	MS	Pseudo-F	P(perm)
Time	3	1248.3	2.5149	**0.0229***
ZvR	1	843.5	1.6993	0.1669
Location(ZvR)	4	2169.8	4.3713	**0.0006*****
TimexZvR	3	999.79	2.0142	0.0686
TimexLocation(ZvR)	12	700.93	1.4121	0.1098
Res	84	496.38		
Total	107			

Notes:
1. *Significant = p<0.05; ***Very highly significant = p<0.001
2. Significant results shown in bold

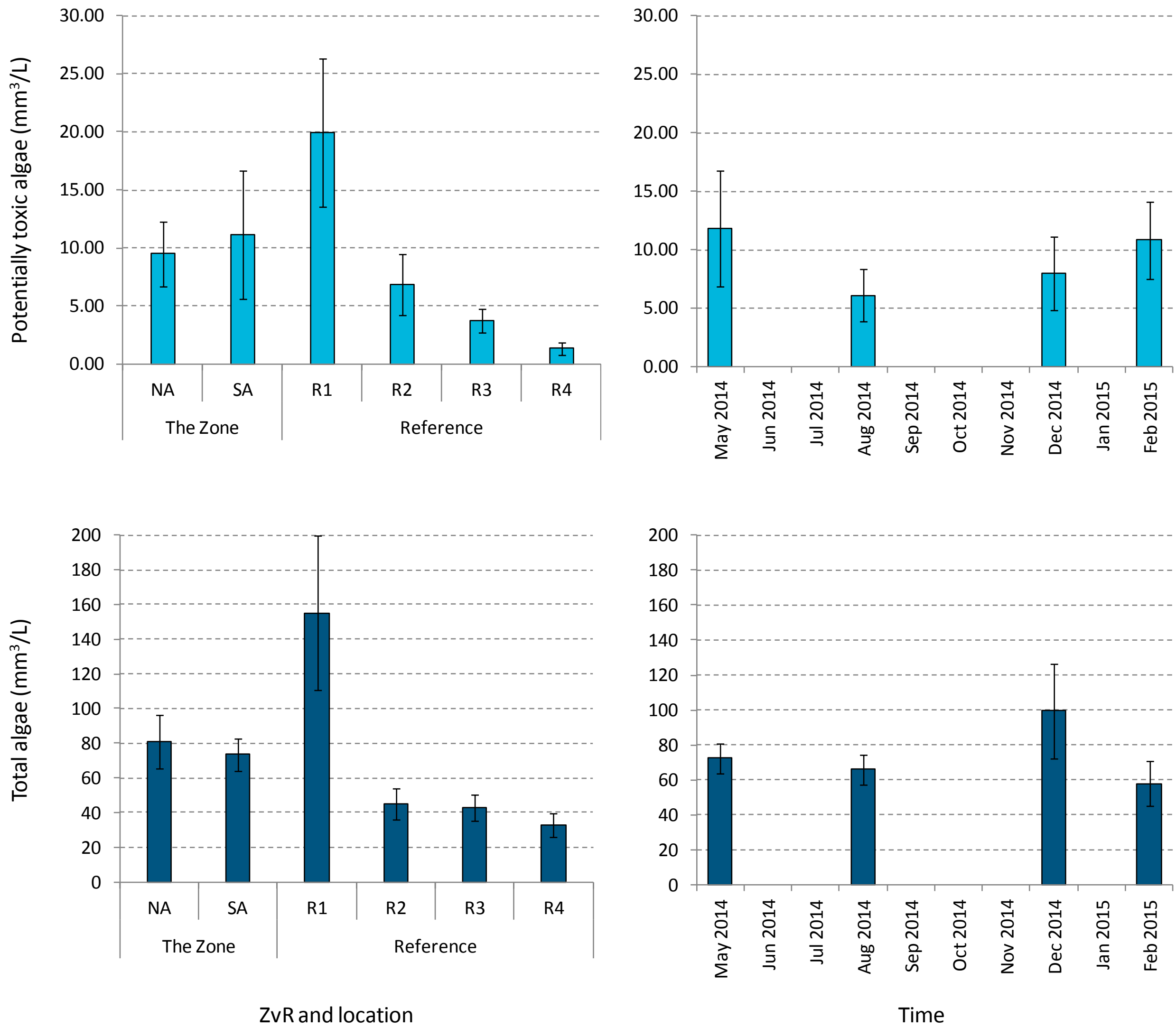


Figure 5-22 Biovolumes (mean ± S.E.) of potentially toxic algae (top left and right) and total algae (bottom left and right) across locations and time

5.4 Sediment quality

5.4.1 Particle size analysis

In general, there were no major differences in sediment particle sizes between the MWADZ and reference locations (Figure 5-23), with sediments in all areas composed of varying proportions of different particle size fractions (Figure 5-23). Some differences in time were detected – fine to coarse sand dominated in the winter season, while fine clays and silts dominated in the summer season. This was reflected in the multivariate analyses applied to sediment particle size data, which revealed significant interaction terms for Season x Location(ZvR) and Season x ZvR (Table 5.17). Post-hoc tests revealed that sediment particle sizes differed across all locations and across the winter and the summer season, again reflecting the general high level of variability.

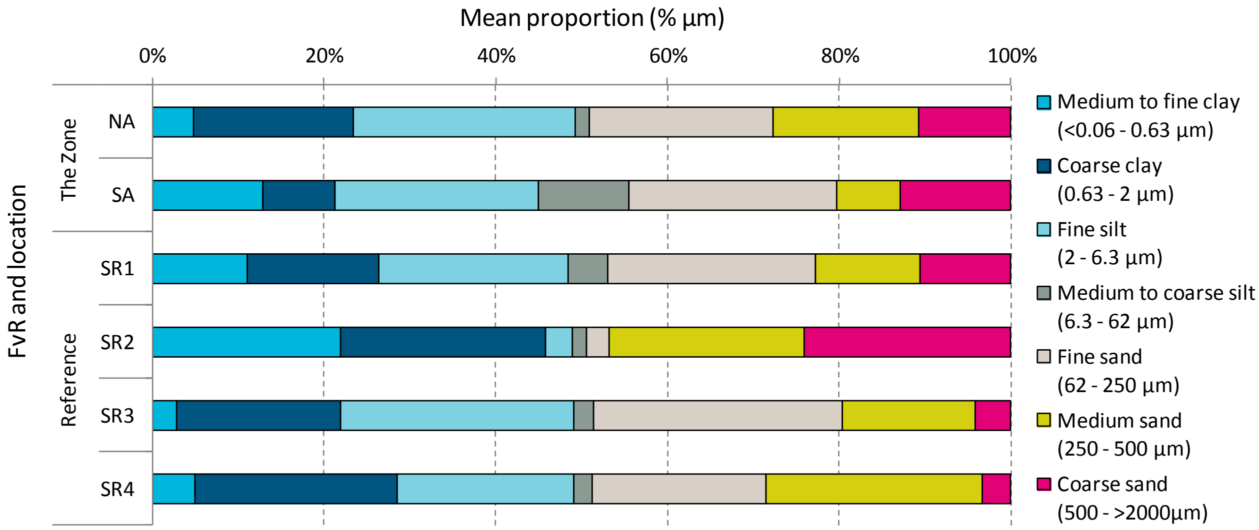


Figure 5-23 Mean proportion (% µm) of seven sediment grain size fractions across locations within ZvR

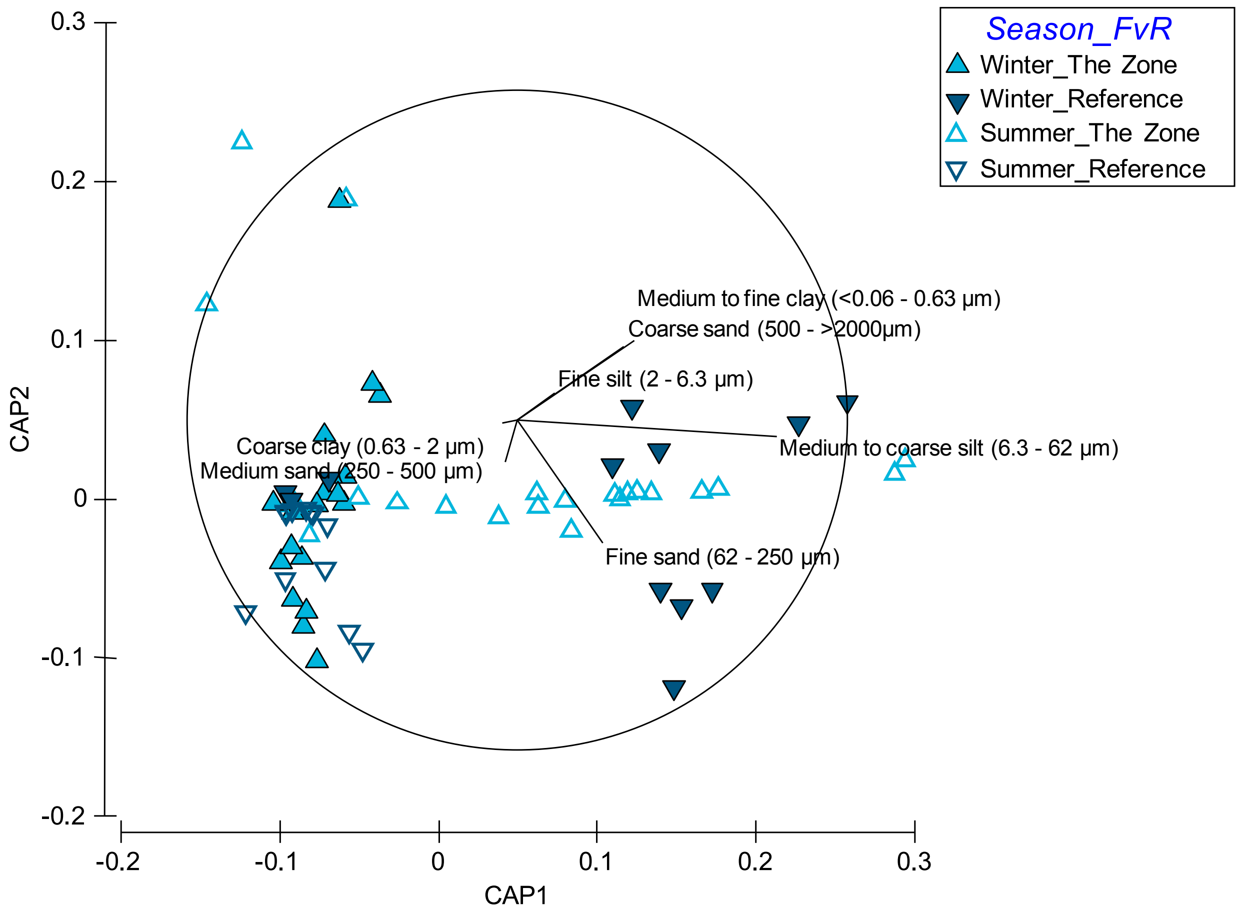
Table 5.17 Results of a four-factor PERMANOVA examining particle size distribution

Source	df	MS	Pseudo-F	P(perm)
Season	1	90802	2098.4	**0.0001*** **
ZvR	1	1357.7	15.575	**0.0042** **
Location(ZvR)	4	1694.3	19.436	**0.0001*** **
SeasonxZvR	1	556.03	12.849	**0.0144***
Site(Location(ZvR))	5	87.172	0.94594	0.5225
SeasonxLocation(ZvR)	4	548.96	12.686	**0.0162***
SeasonxSite(Location(ZvR))	5	43.273	0.46957	0.9274
Res	44	92.154		
Total	65			

Notes:

1. *Significant = p<0.05; **Highly significant = p<0.01; ***Very highly significant =p<0.001
2. Significant results shown in bold

The CAP ordination plot for Season x ZvR showed a separation of the combined northern and southern areas (represented by Zone) and the reference locations in the winter period. Clays (<0.06–0.63 µm) to coarse sands (500>2000 µm) tended to dominate at the reference sites in the winter months whereas coarse clay (0.63–2 µm) and medium-sized sand (250–500 µm) dominated in the summer months (Figure 5-24).

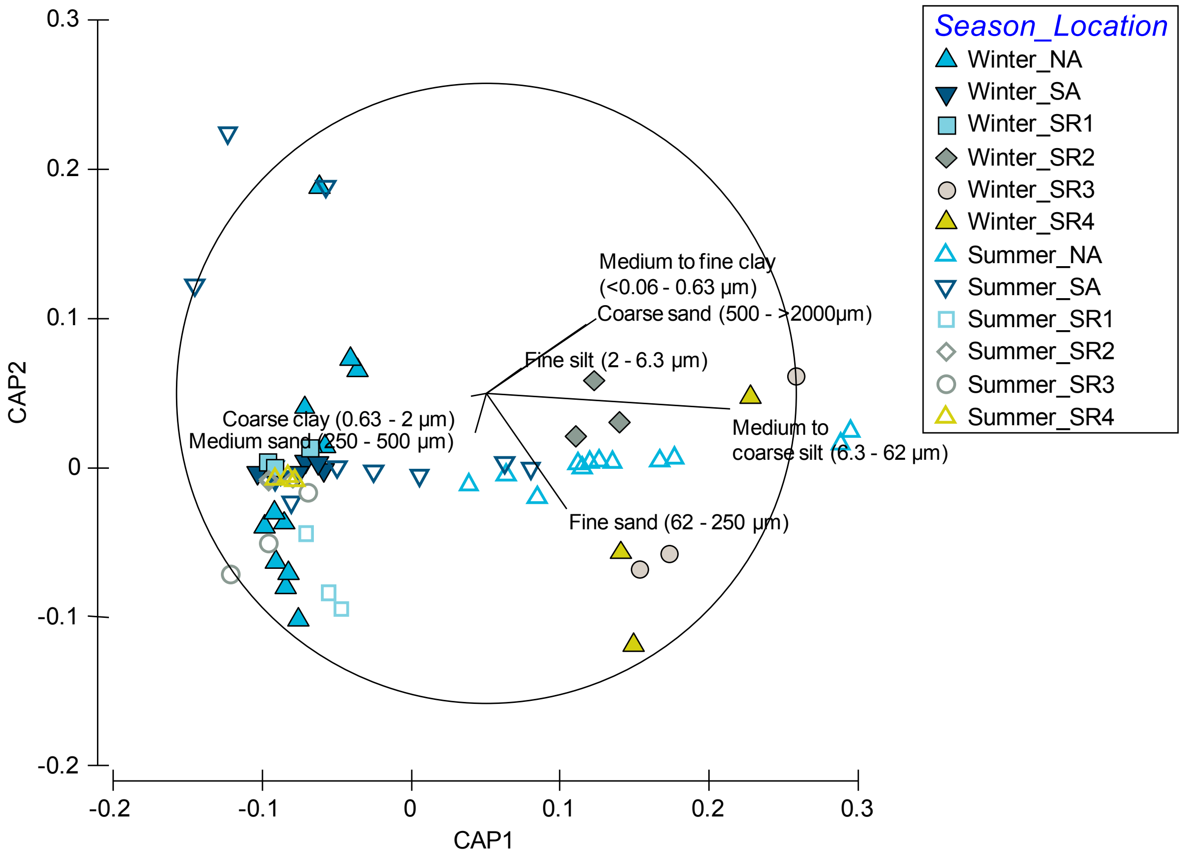


Notes:

1. Zone (combined northern and southern areas); Reference (combined R1-R4 locations)
2. CAP (Canonical analysis of principal coordinates)

Figure 5-24 CAP ordination plot of the particle size distribution among the winter and summer seasons and future lease and reference locations (ZvR) with vector overlays

The CAP ordination plot for Season x Location (ZvR) showed a separation across seasons for locations. Reference locations SR2, SR3 and SR4 were characterised by fine clays (<0.06–0.63 µm) to coarse sand (500–>2000 µm) during the winter months. Both the combined northern and southern areas (represented by the Zone) and the reference locations were characterised by coarse clay (0.63–2 µm) and medium-sized sand (250–500 µm) sampled in the summer months (Figure 5-25).



Notes:

1. NA (northern area); SA (southern area); SR (sediment reference)
2. CAP (Canonical analysis of principal coordinates)

Figure 5-25 CAP ordination plot of the particle size distribution among seasons and locations with vector overlays

5.4.2 Nutrients

Individual PERMANOVA routines revealed highly significant differences between seasons for ammonium, nitrogen and TOC concentrations (Table 5.18, Table 5.19), and a significant difference between locations for both phosphorus and TOC (Table 5.19). Post-hoc pair wise comparisons reported higher TOC concentrations in the southern area in both seasons compared to the northern area.

Table 5.18 Results of a four-factor PERMANOVA examining ammonium and nitrogen concentrations

Source	df	Ammonium		Nitrogen	
		MS	P(perm)	MS	P(perm)
Season	1	5.1822	**0.0011****	2.62E-04	**0.0004*****
ZvR	1	2.30E-02	0.8176	3.59E-06	0.5749
Location(ZvR)	4	1.2483	0.0955	3.19E-05	0.0939
SeasonxZvR	1	6.62E-02	0.4614	4.85E-06	0.3823
Site(Location(ZvR))	5	0.37727	0.1290	1.07E-05	0.1626
SeasonxLocation(ZvR)	4	0.44344	0.0653	4.74E-06	0.5263
SeasonxSite(Location(ZvR))	5	0.10241	0.7768	5.30E-06	0.5447
Res	42	0.20536		6.49E-06	
Total	63				

Notes:

1. **Highly significant = p<0.01***; Very highly significant = p<0.001
2. Significant results shown in bold

Table 5.19 Results of a four-factor PERMANOVA examining phosphorus and total organic carbon concentrations

Source	df	Phosphorus		Total organic carbon	
		MS	P(perm)	MS	P(perm)
Season	1	50.784	0.5766	1.05E-04	**0.0117***
ZvR	1	12583	0.1452	3.59E-05	0.3504
Location(ZvR)	4	32605	**0.0397***	2.77E-04	**0.0073****
SeasonxZvR	1	3341.1	**0.0047****	5.30E-07	0.8008
Site(Location(ZvR))	5	4948.2	**0.0012****	3.37E-05	0.5256
SeasonxLocation(ZvR)	4	2015.6	**0.0067****	1.86E-05	0.1774
SeasonxSite(Location(ZvR))	5	121.75	0.9884	7.27E-06	0.9639
Res	42	1021.4		4.02E-05	
Total	63				

Notes:

1. *Significant = $p<0.05$; **Highly significant = $p<0.01$
2. Significant results shown in bold

A seasonal effect was evident for ammonium and nitrogen concentrations (Figure 5-26). On average, higher concentrations of ammonium were reported in winter (1.61 ± 0.12 mg/kg) relative to summer (1.06 ± 0.05 mg/kg). In contrast, a higher percentage of nitrogen was observed in sediments during summer (0.022 ± 0.001 %) than winter (0.018 ± 0.001 %; Figure 5-26). While no seasonal variations were detected for phosphorus concentrations, phosphorus varied among locations – lower concentrations were reported at reference location SR1 (272.50 ± 4.43 mg/kg) and higher concentrations were reported at reference location SR3 (472.00 ± 13.19 mg/kg).

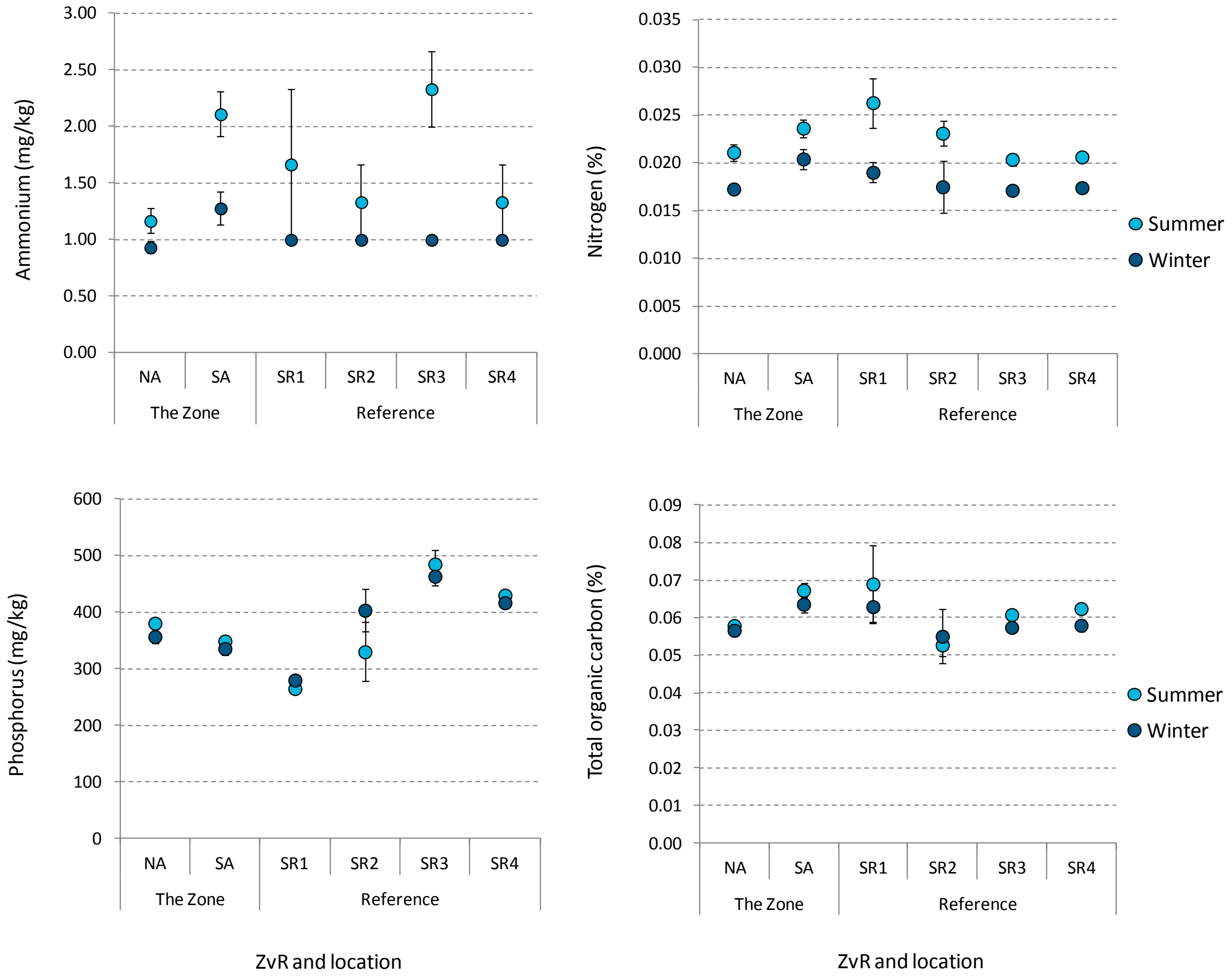


Figure 5-26 Ammonium (mg/kg; top left), nitrogen (%; top right), phosphorus (mg/kg; bottom left) and total organic carbon (%; bottom right) concentrations (mean ± S.E.) across seasons and locations

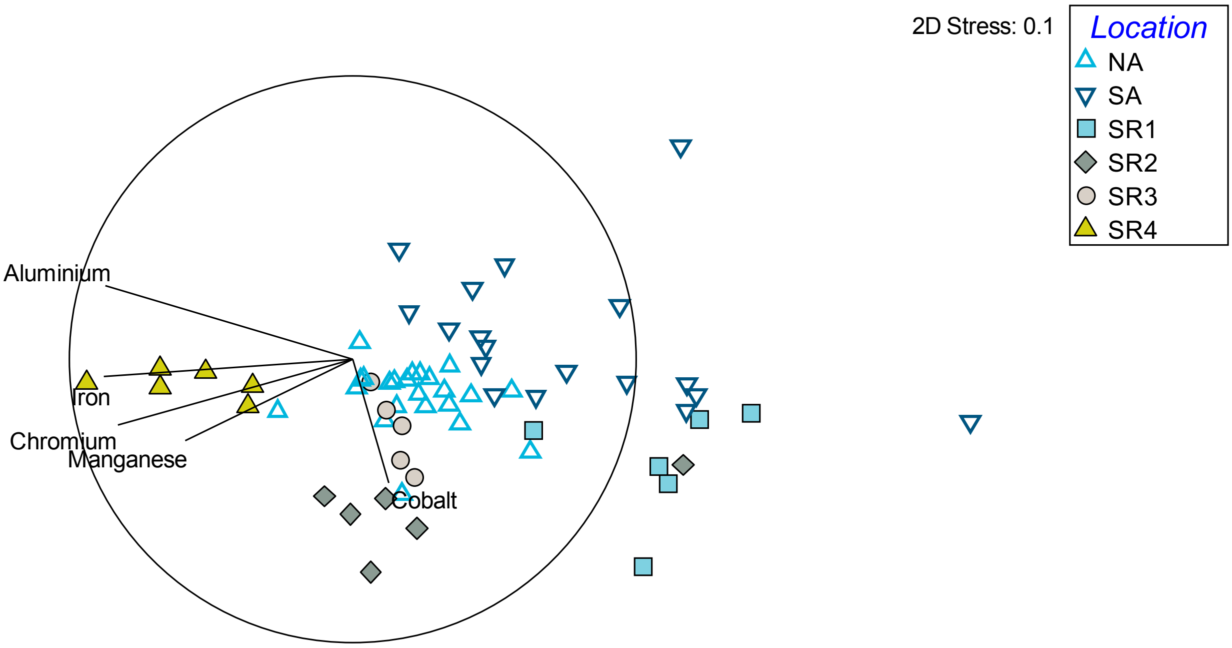
5.4.3 Metals

Trace metals in the MWADZ sediments were variable in space in time, but were otherwise low in concentration. Multivariate analysis revealed a significant Season x ZvR interaction term (Table 5.19), indicating there were differences between the zone and the reference locations, but only at certain times. Post-hoc tests on the interaction term revealed that the differences were restricted to the summer sampling period only. On a finer scale, differences were also detected between the northern and the southern area, and among the reference locations SR1 and SR4. SR2 and SR3 displayed similar characteristics to one another. The tendency toward inter-locational variability was reflected in the MDS plot which showed separations in trace metal concentrations across locations (Figure 5-27). The top five trace metals were aluminium (Al), iron (Fe), chromium (Cr), manganese (Mn) and Cobalt (Co). The vector overlay on the MDS plot show that the reference location SR4 had greater concentrations of Mn, Cr, Fe and Al compared to other locations, while the southern area recorded greater Co concentrations relative to other locations (Figure 5-27).

Table 5.20 Results of a four-factor multivariate PERMANOVA examining concentrations of trace metals

Source	df	SS	MS	P(perm)
Season	1	103.51	103.51	**0.0199***
ZvR	1	246.01	246.01	0.1446
Location(ZvR)	4	1821.7	455.42	**0.0222***
SeasonxZvR	1	60.896	60.896	**0.0366***
Site(Location(ZvR))	5	463.01	92.603	**0.0001*****
SeasonxLocation(ZvR)	4	71.753	17.938	0.5201
SeasonxSite(Location(ZvR))	5	95.451	19.09	0.4653
Res	42	810.8	19.305	
Total	63	3645.7		

Notes:
1. *Significant = p<0.05; ***Very highly significant = p<0.001
2. Significant results shown in bold



Note:
1. NA (northern area); SA (southern area); SR (sediment reference)
2. MDS (multi-dimensional scaling ordination)

Figure 5-27 MDS ordination of trace metal concentrations among locations with vector overlays

5.4.4 Infauna

Community assemblage

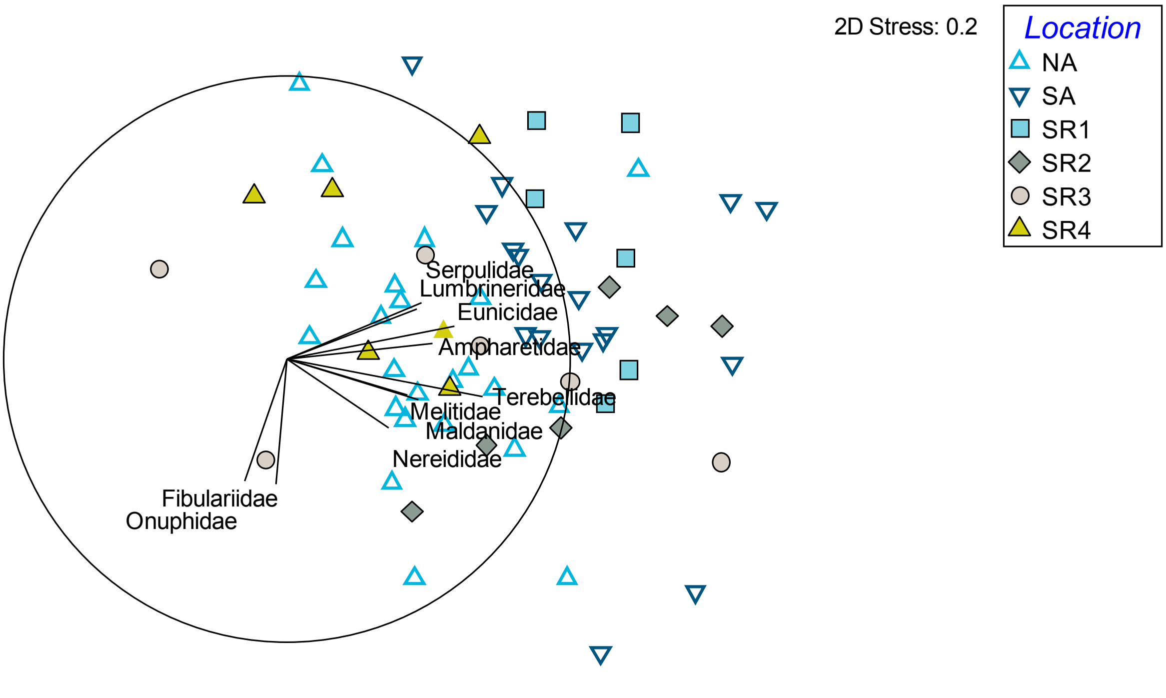
Analysis of infauna samples revealed a diverse community, comprising 10 phyla (Arthopoda, Chordata, Echinodermata, Mollusca, Nematoda, Nemertea, Phoronida, Platyhelminthes, Polychaeta and Sipuncula) and 129 families. Sampling recorded 36 families of polychaetes (accounting for 45% of the infauna sampled), 33 families of molluscs (25% of the infauna sampled), 41 families of Arthropods (18% of the infauna sampled) and 10 families of echinoderms (7% of the infauna sampled). The PERMANOVA analysis revealed high levels of variability. This was reflected in significant results for the factors Season and Location (IvR), indicating that both were important in driving the observed community structure (Table 5.21).

The general variability in the community is also mirrored in the MDS ordination (Figure 5-28). The MDS shows differences at the site level, but no clear separation at the location level. In general, higher counts of polychaete fauna were reported in summer than winter (Figure 5-29). The southern area contained higher numbers of polychaetes and amphipods in both seasons compared to the northern area; however, the northern area reported higher counts of echinoids, Nereididae and Onuphidae than the southern area (Figure 5-29). Reference location SR2 had the greatest counts of polychaete fauna and amphipods, followed by reference locations SR1 and SR3, however neither reference location contained echinoids (Figure 5-28).

Table 5.21 Results of a four-factor PERMANOVA on community assemblage

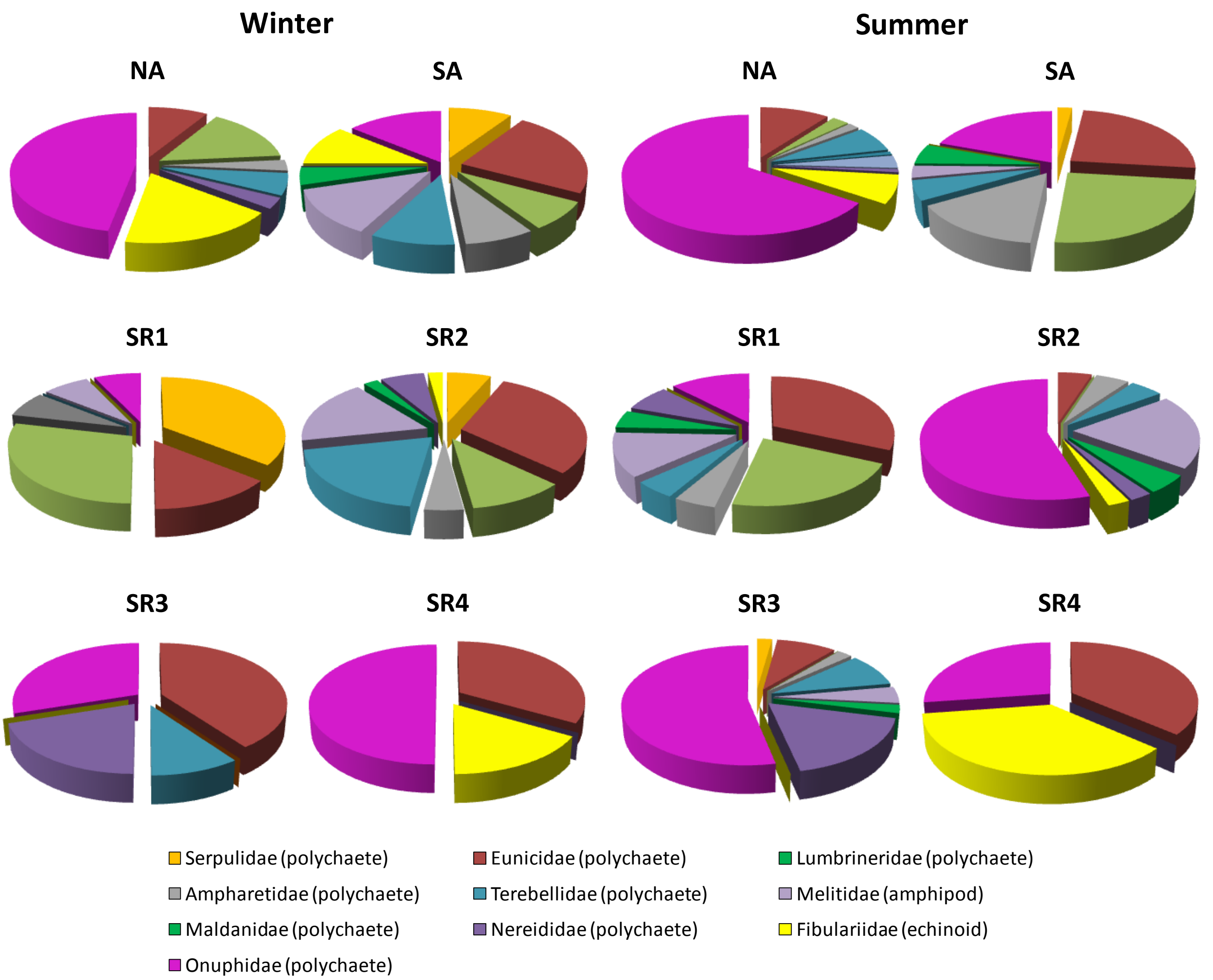
Source	df	SS	MS	Pseudo-F	P(perm)
Season	1	13580	13580	4.8147	**0.0089****
IvR	1	4396.1	4396.1	1.2607	0.2721
Location(IvR)	4	24859	6214.6	1.7822	**0.0197***
SeasonxIvR	1	2954.9	2954.9	1.0477	0.4076
Site(Location(IvR))	5	17436	3487.1	1.3505	**0.0148***
SeasonxLocation(IvR)	4	17935	4483.8	1.5897	0.0557
SeasonxSite(Location(IvR))	5	14103	2820.5	1.0923	0.2672
Res	44	1.14E+05	2582.1		
Total	65	2.09E+05			

Notes:
1. *Significant = p<0.05; **Highly significant - p<0.01
2. Significant results shown in bold



Note:
1. NA (northern area); SA (southern area); SR (sediment reference)
2. MDS (multi-dimensional scaling ordination)

Figure 5-28 MDS ordination of community assemblage among locations with vector overlays



Note:
1. NA (northern area); SA (southern area); SR (sediment reference)

Figure 5-29 Percentage representation of the top ten most abundant infauna families

Family richness

Univariate tests revealed significant differences in family richness among Locations(ZvR) and seasons (Table 5.22). In general, higher family richness was observed in summer (17.9 ± 1.3 richness) than in winter (10.1 ± 1.0 richness; Figure 5-30). The southern area reported higher family richness (15.9 ± 2.1 richness) relative to the northern area (11.5 ± 1.2 richness).

Table 5.22 Results of a four-factor PERMANOVA on family richness

Source	df	SS	MS	Pseudo-F	P(perm)
Season	1	913.69	913.69	16.8920	**0.0081****
IvR	1	28.082	28.082	1.8570	0.2116
Location(IvR)	4	458.09	114.52	7.5730	**0.0160***
SeasonxIvR	1	4.0029	4.0029	7.40E-02	0.7919
Site(Location(IvR))	5	75.611	15.122	0.31209	0.9072
SeasonxLocation(IvR)	4	261.3	65.325	1.2077	0.4033
SeasonxSite(Location(IvR))	5	270.44	54.089	1.1163	0.3594
Res	44	2132	48.455		
Total	65	4251.8			

Notes:
1. *Significant = p<0.05; **Highly significant = p<0.01
2. Significant results shown in bold

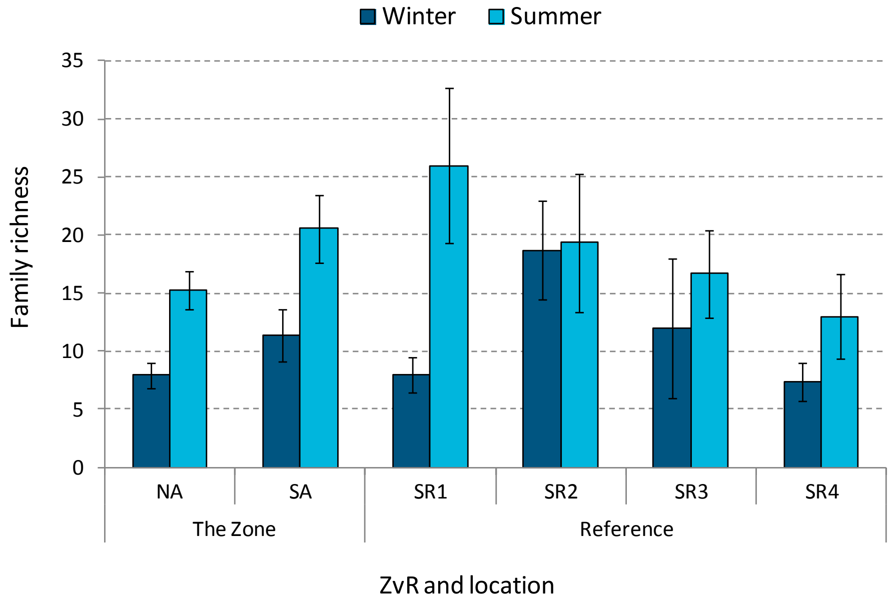


Figure 5-30 Family richness (mean ± SE) of benthic infauna across seasons and locations within ZvR

Family abundance

The four-factor design revealed a significant seasonal effect for family abundance (Table 5.23). Family abundance was greater in summer across all locations (35.39 ± 3.27 individual animals) compared to winter (16.09 ± 2.33 individual animals; Figure 5-31).

Table 5.23 Results of a four-factor PERMANOVA on family abundance

Source	df	SS	MS	Pseudo-F	P(perm)
Season	1	5156.7	5156.7	24.833	**0.0046****
IvR	1	65.789	65.789	0.3290	0.5794
Location(IvR)	4	2067.8	516.94	2.5851	0.1451
SeasonxIvR	1	138.96	138.96	0.6692	0.4514
Site(Location(IvR))	5	999.83	199.97	0.73962	0.5970
SeasonxLocation(IvR)	4	751.8	187.95	0.9051	0.5217
SeasonxSite(Location(IvR))	5	1038.3	207.66	0.7681	0.5735
Res	44	11896	270.36		
Total	65	23145			

Notes:
1. **Highly significant = p<0.01
2. Significant results shown in bold

Relationship between benthic assemblage and sediment parameters

Vector overlays of the sediment parameters onto the infauna CAP ordination plot showed that the infauna assemblage at the northern lease area (SL1) and reference location SR4, which include higher counts of polychaetes, amphipods, echinoids, Nereididae and Onuphidae (see text on 'Community assemblage', above), reside in fine to coarse sediments (62–>2000 μm) (Figure 5-28). Polychaetes and amphipods, which were found in greater abundance at the southern lease area (SL2) and reference location SR1 (see text on 'Community assemblage', above), inhabited sediments containing higher TOC content, phosphorus, aluminium and chromium levels (Figure 5-32).

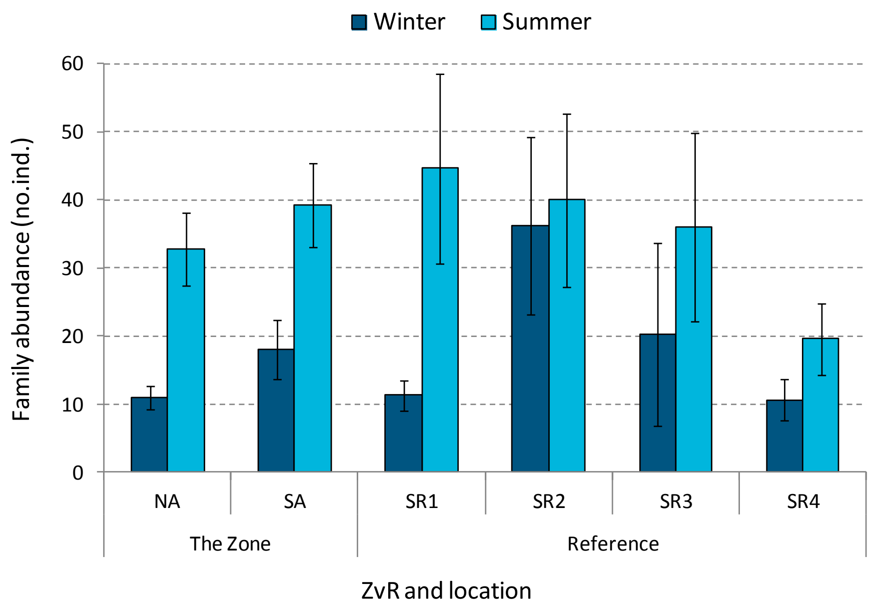
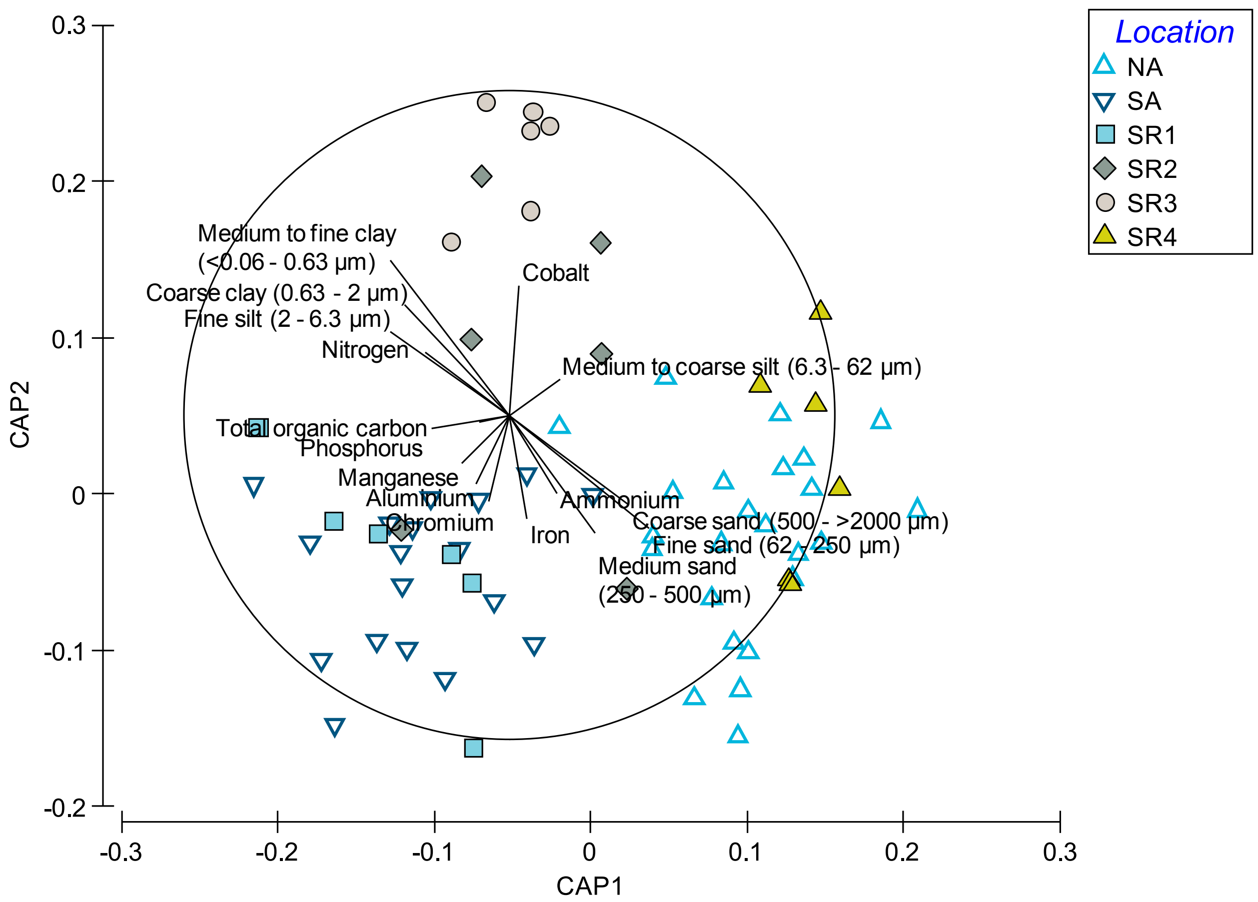


Figure 5-31 Family abundance (mean ± SE) of benthic infauna across seasons and locations



Note:

1. NA (northern area); SA (southern area); SR (sediment reference)

Figure 5-32 CAP ordination plot of the benthic assemblage among locations with vector overlays of sediment parameters

5.4.5 Total Petroleum Hydrocarbons / Polycyclic Aromatic Hydrocarbons

Total petroleum hydrocarbons (TPH) and polycyclic aromatic hydrocarbons (PAH) in marine sediments were generally below the laboratory limit of reporting (LOR). Of the 188 replicate sediment samples collected, 16 samples exceeded the LOR for PAHs (0.001 µg/L), 1 sample exceeded the LOR (100 mg/kg) for TPH C16-C34 and 1 sample exceeded the LOR (200 mg/kg) for total TPH (Table 5.24).

Table 5.24 Total Petroleum Hydrocarbons and Polycyclic Aromatic Hydrocarbons concentrations in sediments

Chemical	Species	LOR (mg/kg)	Site and value (mg/kg)
TPH	C16-34	100	SA winter (110)
	Total	200	SA winter (200)
PAH	Anthracene	0.001	SR4 summer (0.002)
	Fluoranthene		SA summer (0.002) SR4 summer (0.044)
	Fluorene		SR4 summer (0.006)
	Naphthalene		NA summer (0.002) SA summer 2 reps (0.001) SR1 summer (0.001) SR2 summer 2 reps (0.001 and 0.002) SR3 summer 2 reps (0.002) SR4 summer 3 reps (0.001 and 0.006)
	Phenanthrene		SA summer (0.007) SA winter (0.001) SR4 summer (0.078)
	Pyrene		SA winter 3 reps (0.001 – 0.002) Sa summer (0.002) SR4 summer (0.033)

5.5 Benthic habitats

5.5.1 Northern area

Surveys of the MWADZ study area indicated that much of the seafloor consisted of rocky pavement overlain with sand, with sparsely distributed biological assemblages. This contributed to a mosaic of habitats consisting of sandy meadows and areas of mixed assemblages, comprising filter feeders (sponges, and bryozoans), macroalgae, rhodoliths and hard corals (though the latter was observed infrequently). Because interpolation was used to spatially determine the major habitat categories, some parts of the study area could not be mapped with adequate certainly. These are shown in Figure 5-33 as white coloured pixels.

Habitats in the northern area consisted mainly of bare sand (59%) and mixed assemblages (34%; Figure 5-33). Small patches of reef were present near the north-east boundary but made up only 8% of the identified habitats within the area. The mixed assemblage habitats were mainly composed of macroalgae, rhodolith and sponges with a distribution of 3.7%, 3.3% and 2.3% of the total northern lease area respectively, with the remainder consisting of sand. Examples of the most commonly observed habitats are presented in Figure 5-34.

5.5.2 Southern area

Habitats in the southern area were predominantly bare sand (96%; Figure 5-33) with sparse mixed assemblages (5%) close to the Island. Of the mixed assemblages, rhodoliths and unknown organisms comprised 0.3% and 0.1% of the total southern lease area, respectively, with the remainder consisting of sand. Reef areas in the southern lease were dominated by rohodolith communities, with no evidence of significant hard coral cover.

5.5.3 Reference sites

The habitats of the three reference sites (with the exception of the northern-most reference site) were dominated by bare sand (42.5%) followed by mixed assemblage categories on sand and reef (total 17.7%; Figure 6.24). The northern reference site had a more diverse distribution of habitats throughout the area with reef and mixed assemblages/reef habitats present (12.4%; Figure 5-33). The main biotic constituents of the mixed assemblage habitats were macroalgae, sponges and hard coral with a distribution of 2.1%, 1.3% and 0.1% of the total reference site area, respectively.

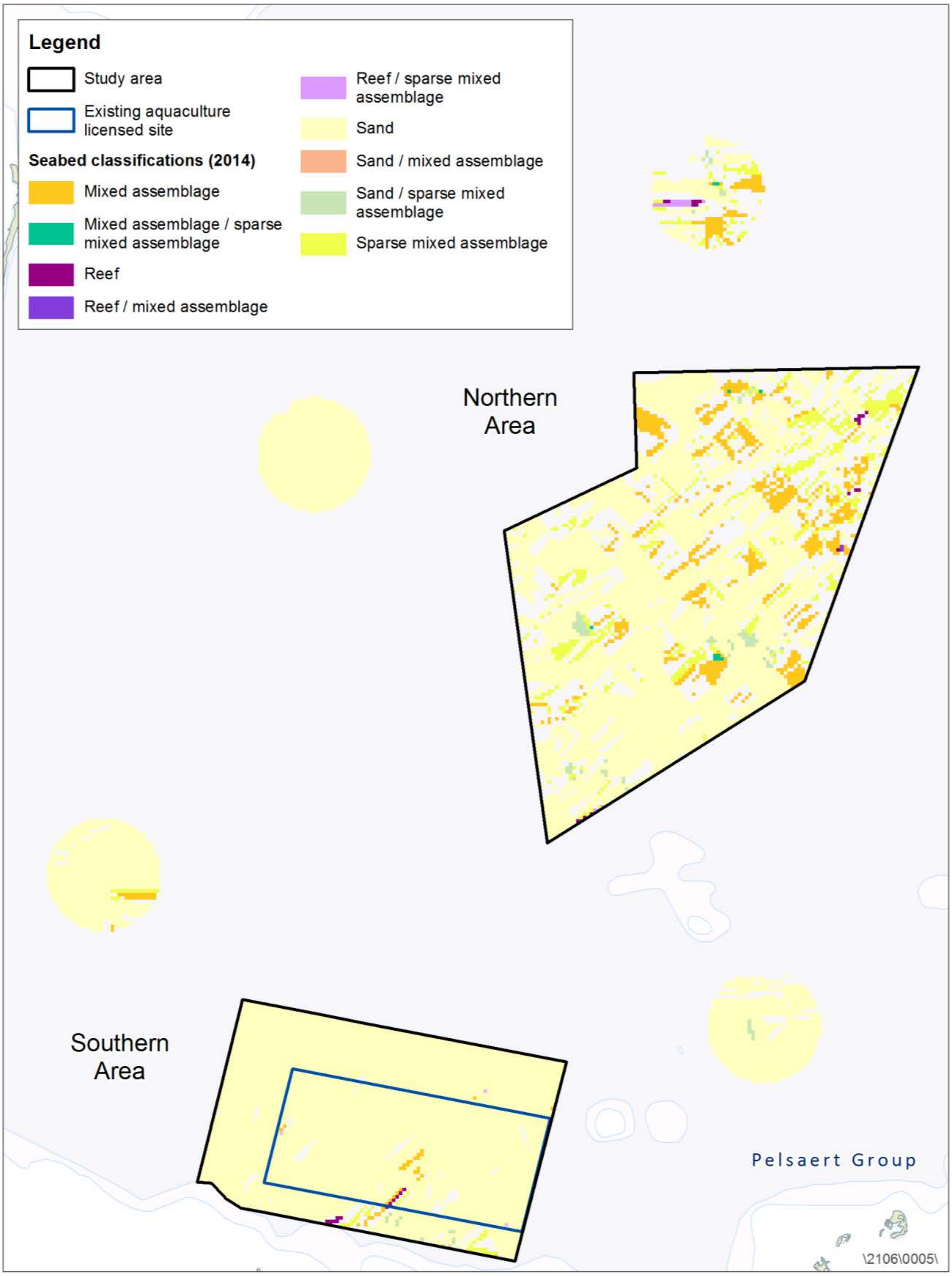
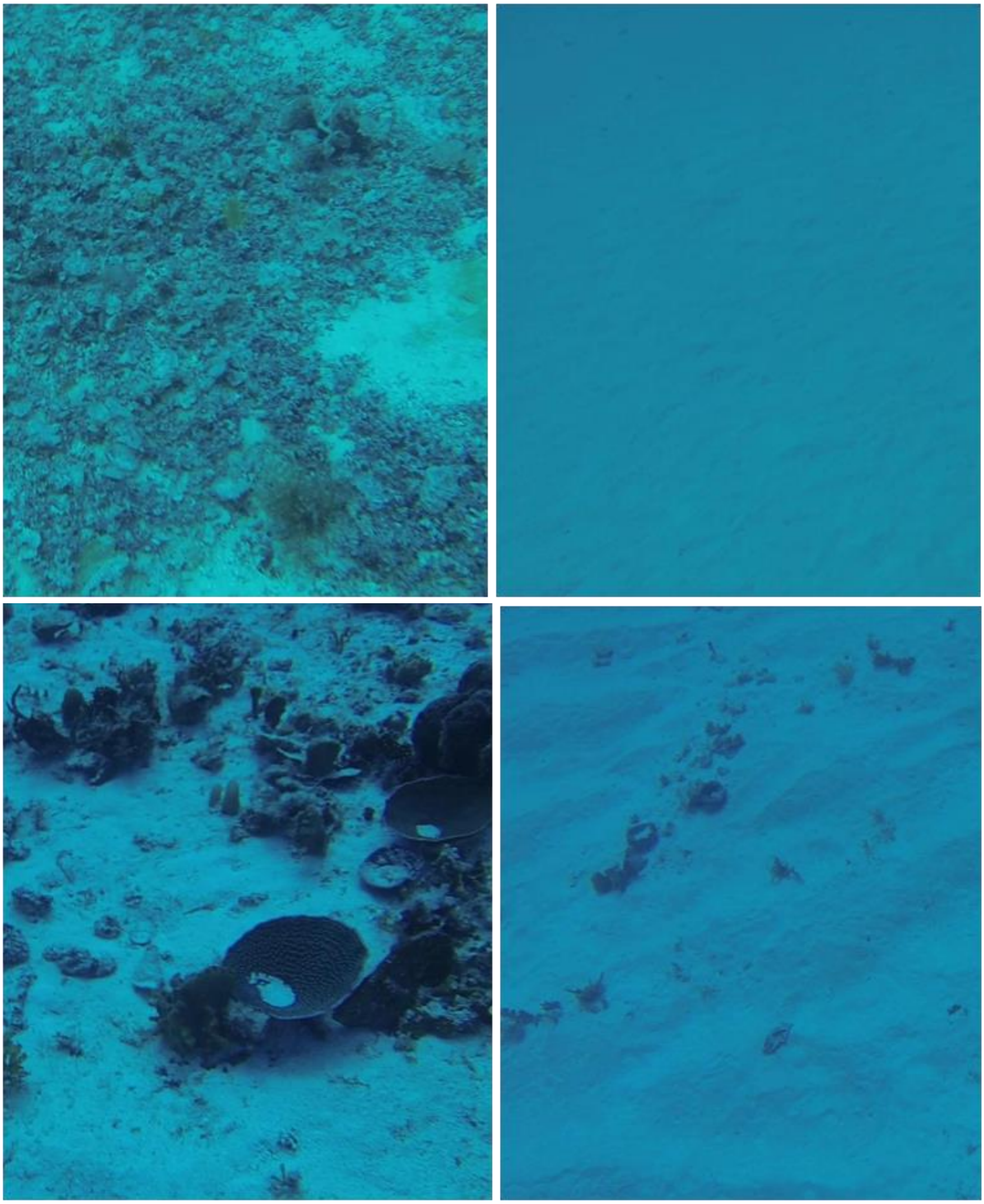


Figure 5-33 Major habitat assemblages observed in the study area in 2014



Notes:
1. Mixed assemblages with hydroids and macroalgae (top left); Mixed assemblages with rhodoliths (top right); mixed assemblages with sponges and macroalgae (lower left) and sparse mixed assemblages (lower right)

Figure 5-34 Examples of the common habitats observed during benthic habitat surveys

5.5.4 Agreement with previous surveys

Comparisons between the surveys are made at a high level, and results are provided here for contextual purposes only. The historical 2003, 2006/2008 and 2014 surveys differed significantly in their approaches, in terms of equipment and the classification schemes used. Changes may have occurred between surveys as a result of the dynamic nature of the seabed within the project area and is indicative the effects of sand sheet movement and variability over time.

Historical surveys (Section 4.3.1) identified a range of habitats present in the northern and southern lease areas (Figure 5-35, Figure 5-36) that were not consistently identified in 2014. For example, although the 2006 survey only captured a fraction of the proposed northern MWADZ, it identified larger proportions of mixed assemblage than the 2014 survey. The 2014 survey indicated a change to a sand dominated habitat with a noticeable reduction of mixed assemblages and reef habitats.

Similarly, previous surveys of the southern MWADZ identified significant areas of rhodolith, reef and sand with areas of *Halophila* spp., algae and mixed assemblages. A shift to a sand dominated habitat with a reduction of biotic organisms (<1%; Figure 5-36) was observed in 2014. No seagrass was observed within the southern lease area in 2014.

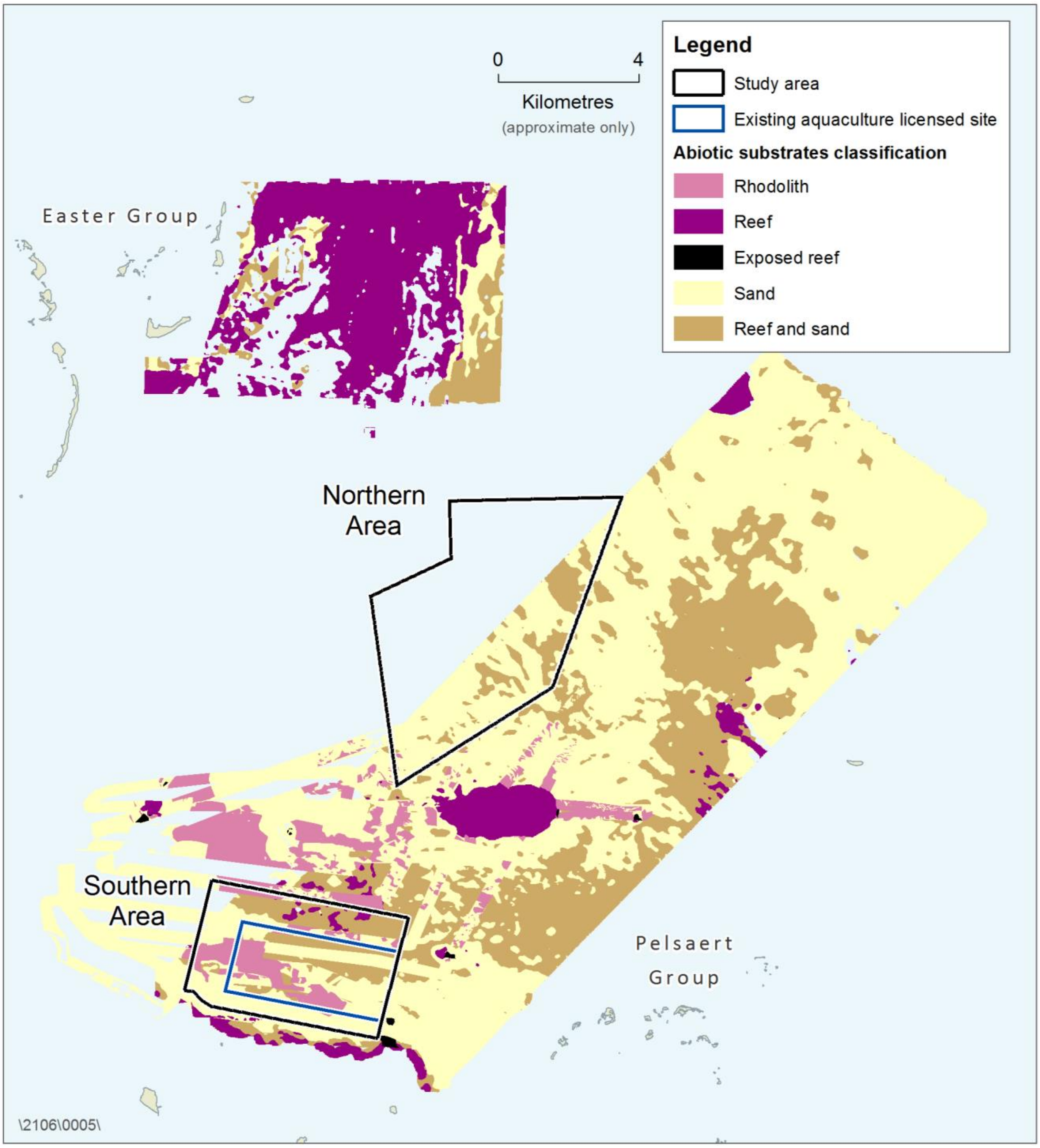


Figure 5-35 Major abiotic habitat assemblages observed in 2003, 2006 and 2008

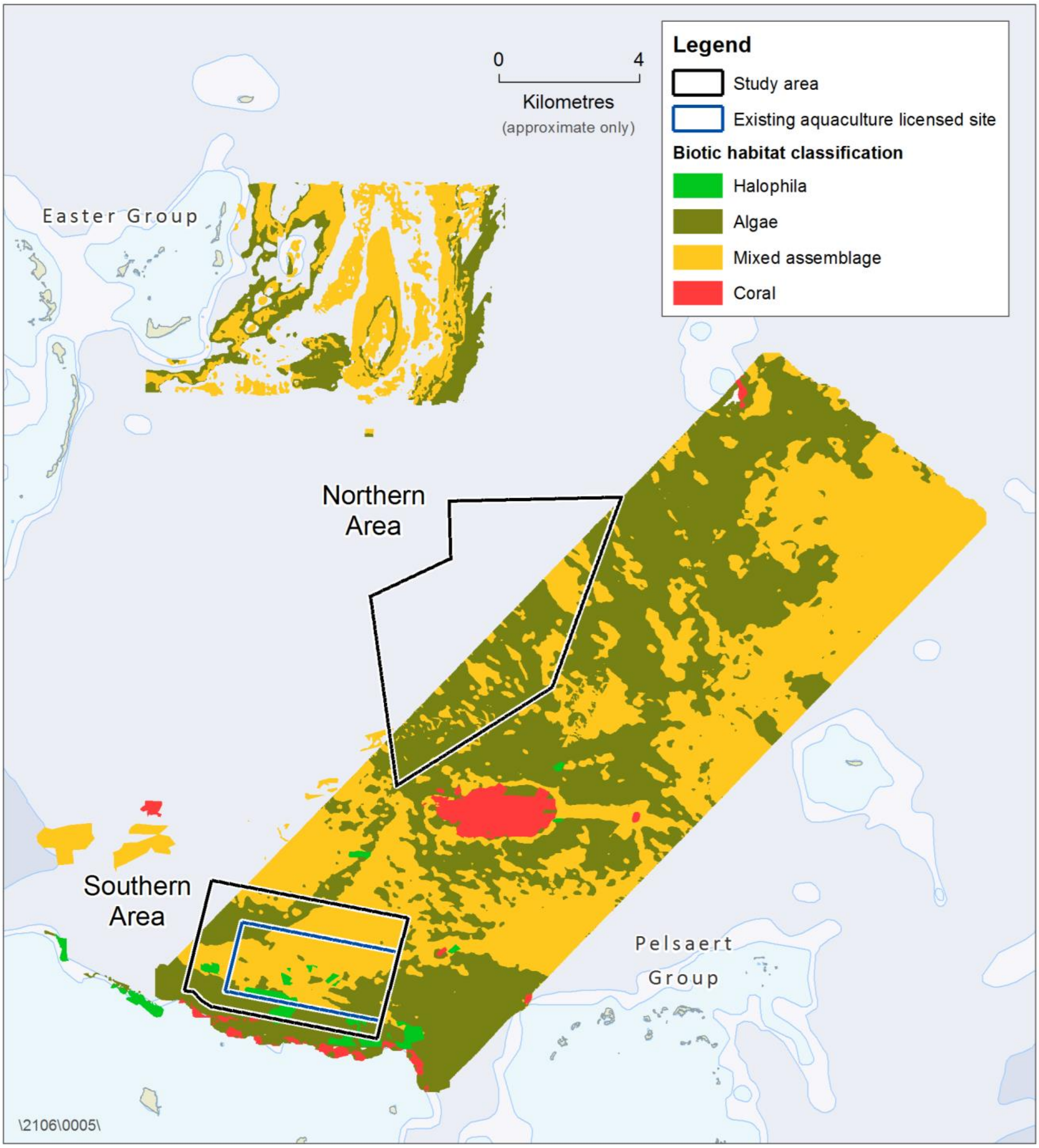


Figure 5-36 Major biotic habitat assemblages observed in 2003, 2006 and 2008

6. Impact Assessment - Cumulative loss of BPPH

6.1 Development of the local assessment unit

The LAU for this assessment was developed by DoF in consultation with the OEPA. The first point was to consider the extent of previous losses of BPPH, such as those which may have been lost due to historical anthropogenic activities. It was considered that benthic habitats in the MWADZ are relatively pristine, and that any effects of historical anthropogenic activities were transient, and now fully recovered.

EAG 3 requires that the expected cumulative losses of BPPHs are assessed as a proportion against those in an agreed Local Assessment Unit (LAU). In consultation with the EPA, DoF used relevant data to define two local assessment units (LAU) within a one kilometre buffer around the Northern and Southern Areas of the proposed zone (Figure 6-1). In relation to benthic habitat, most (71%) of the Northern LAU (44.2 km^2) and nearly all (96%) of the Southern LAU (23.2 kilometre squared) has been surveyed. The benthic layers in the attached map are primarily based on a hydro-acoustic survey of the study site for the MWADZ proposal undertaken by the Department of Fisheries Marine Ecosystem Monitoring Section. This survey was conducted in 2014, using a single beam echo sounder and a drop video for ground-truthing (here on referred to as the DoF 2014 survey).

To gain an understanding of the dynamics of the BPPH in and around the strategic proposal areas, and interpolate/extrapolate the coverage of BPPH to include a 1 km strip outside the proposed MWADZ, two other habitat surveys were taken into account:

1. The University of Western Australia Marine Futures Project - hydro-acoustic mapping, towed video and biodiversity sampling in and around the Southern Group of Abrolhos Islands, 2006 and 2008 (here on referred to as Marine Futures 2006 survey).
2. The University of Western Australia and Undersea Community Pty Ltd Habitat Survey North of the Pelsaert Group of the Abrolhos Islands, by Andy Bickers in 2003. This survey (here on referred to as Bickers 2003 survey) used side-scan sonar.

Each of the three surveys provided discrete, low-resolution assessments and used different technical approaches. The surveys served to provide an indicative description of the benthic substrates in the vicinity of the MWADZ at the times they were conducted. Interpolation of the one kilometre strips surrounding the proposed MWADZ is primarily based on the Marine Futures 2006 survey. The Bickers 2003 survey data was used to describe the small portions of the LAUs that were not covered by the other surveys. The data used to describe both the Northern and Southern LAUs consists of 67% DoF 2014 survey data, 31% Marine Futures 2006 survey data, and two percent Bickers 2003 survey data.

Collectively, all of the available data from the three surveys suggest that the benthic environment within the Northern and Southern LAUs are continually changing due to sand sheet movement and corresponding natural variability of the benthic habitat coverage. The data was used to estimate the most likely coverage of Mixed Assemblages, Reef and Bare Sand in the LAUs. For the purposes of this assessment, Mixed Assemblages and Reef have been conservatively assumed to correspond to habitats capable of supporting BPPH.

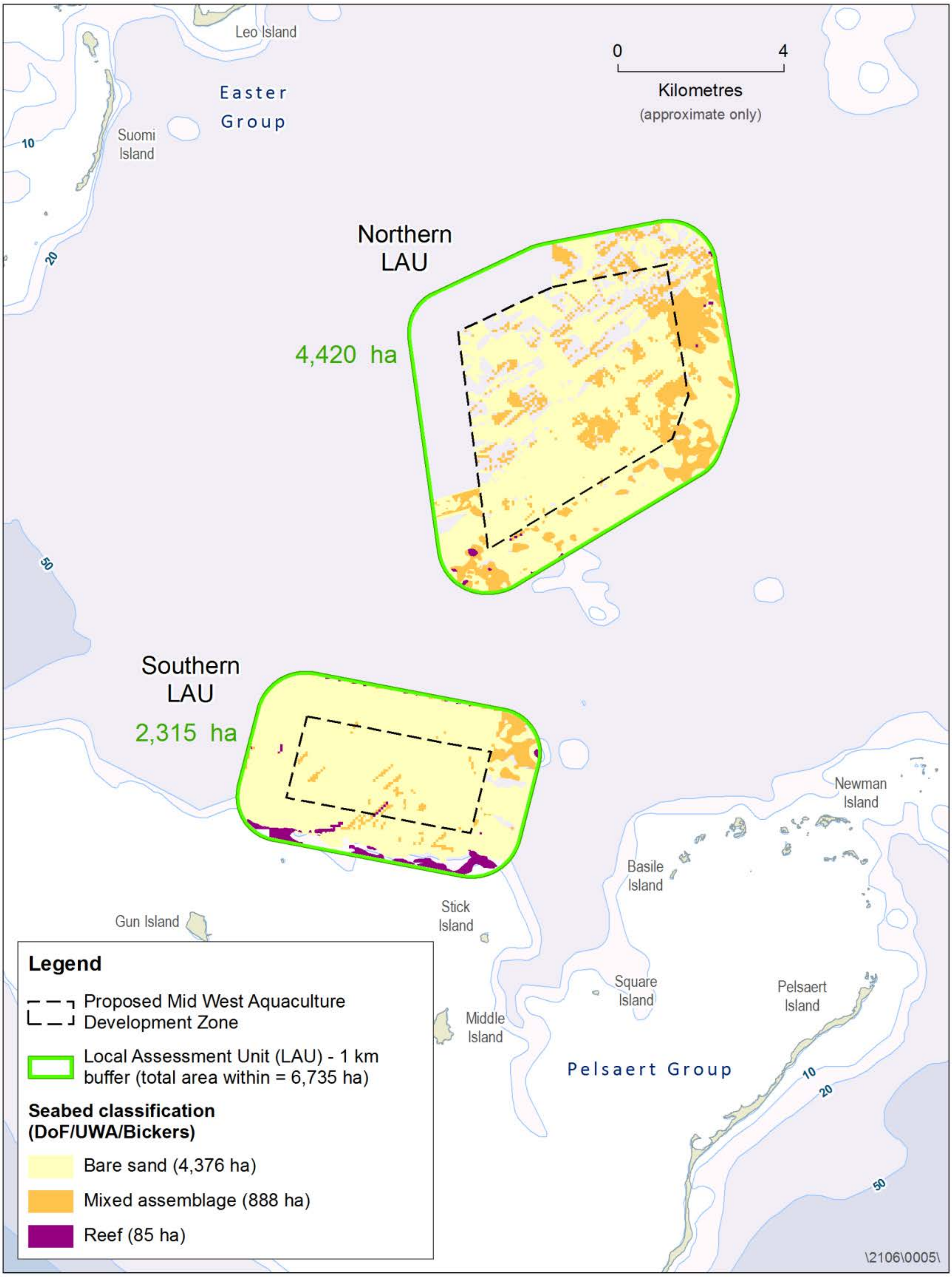


Figure 6-1 The Northern and Southern Local Assessment Units and the indicative benthic substrates in the vicinity of the MWADZ

6.2 Estimating the benthic cover of BPPHs

6.2.1 Northern LAU

Habitat surveys in Northern LAU adequately captured the diversity and natural variability of the environment (i.e. bathymetry and proximity to islands) within a one kilometre buffer around the Northern Area of the MWADZ. Although approximately 29% of the Northern LAU has not been surveyed in relation to benthic habitat, this portion was extrapolated for the purposes of this assessment.

The existing data suggests at least 24% of the Northern LAU supports mixed assemblages consisting of algae and sessile invertebrates (Table 6.1). The benthic substrate classified as reef (medium relief) is the only substrate capable of sustaining coral reef habitat and makes up less than one percent of the Northern LAU. The benthic substrate classified as bare sand makes up approximately 75% of the Northern LAU. The DoF ground-truthing studies indicate that this substrate is predominantly bare sand overlying platform limestone reef (to a depth ~15 cm).

Of the 4420 hectares in the Northern LAU, approximately 25% of this area (1091 hectare) comprises habitats capable of supporting BPPH (i.e. around 0.29% reef and 24% mixed assemblages, while approximately 75% is bare sand) (Table 6.1).

Table 6.1 Calculation used to estimate and extrapolate BPPH cover within the Northern LAU

Habitat Type	Relative contributions (ha)			Calculations to estimate coverage based on: Total area surveyed in Northern LAU (3133 ha) Area of Northern LAU (4420 ha)
	DoF survey 2014	Marine Futures 2006	Bickers survey 2003	
Reef	3	6	0	Sum (9 ha) div. by 3133 x 100 = 0.29% 0.29% div. by 100 x area of Northern LAU = 12.7 ha
Mixed Assemblage	427	312	25	Sum (764 ha) div. by 3133 x 100 = 24.4% 24.4% div.by 100 x area of Northern LAU = 1078 ha
Bare Sand	1476	837	47	Sum (2360 ha) div. by 3133 x 100 = 75.3% 75.3% div. by 100 x area of Northern LAU = 3329 ha

6.2.2 Southern LAU

Data compiled from both recent and historical habitat surveys were used to determine the diversity and variability of the benthic environment in the Southern Area of the MWADZ. Surveys covered habitats out to a distance of 1 km from the zone boundaries. Although 4% of the Southern LAU has not been mapped, the remaining habitats were extrapolated for the purposes of this assessment.

The existing data suggests approximately 6% of the Southern LAU supports mixed assemblages consisting of algae, rhodolith and sessile invertebrates. The benthic substrate classified as reef (medium relief) is the only substrate capable of sustaining coral reef habitat and makes up less than four percent of the Southern LAU. The benthic substrate classified as bare sand makes up approximately 91% of the Southern LAU. The DoF ground truthing studies indicate that this substrate is predominantly bare sand overlying limestone platform reef (to ~15 cm depth).

Of the 2315 hectares in the Southern LAU, approximately 9% (208 hectares) of the Southern LAU comprises habitats capable of supporting BPPH (3.4% Reef and 5.6% mixed assemblages, while approximately 91% is bare sand).

Table 6.2 Calculation used to estimate and extrapolate BPPH cover within the Southern LAU

Habitat Type	Relative contributions (ha)			Calculations to estimate coverage based on: Total area surveyed in the Southern LAU (2217 ha) Area of Southern LAU (2315 ha)
	DoF survey 2014	Marine Futures 2006	Bickers survey 2003	
Reef	4	62	10	Sum (76 ha) div. by 2217 x 100 = 3.4% 3.4 div. by 100 x area of Southern LAU = 79.4 ha
Mixed Assemblage	29	95	1	Sum (125 ha) div. by 2217 x 100 = 5.6% 5.6 div. by 100 x area of Southern LAU = 130.5 ha
Bare Sand	1621	354	41	Sum (2016 ha) div. by 2217 x 100 = 90.9% 90.9 div. by 100 x area of Southern LAU = 2105.1 ha

6.3 Estimated losses of BPPH

6.3.1 Northern LAU

Approximately 25% of the Northern LAU (1091 hectares) comprises habitats capable of supporting BPPH. Under S4 (24 000 t), modelling predicted that the ZoHI in the Northern LAU would occupy 41 ha after three years production[3] (Section 7.3.2). This figure was doubled to allow for recovery sites generated by fallowing the aquaculture sites.

Table 6.3 Calculation used to estimate the loss of BPPH within the Northern LAU

Average area of BPPH (ha) within the Northern LAU under ZoHI	Estimated % loss of BPPH within the Northern LAU
Area of BPPH inside the Northern Area of the Zone 269 ha *Percentage of BPPH within the Zone* 269 ha divided by the Northern Area of the Zone (2200 ha) x 100 = 12.3% *ZoHI within the Zone* ZoHI (41 ha) x 2 (recovery sites) = 82 ha *Area of BPPH effected by the ZoHI* (12.3 % divided by 100) x 82 ha = 10.1 ha	Estimated % loss of BPPH 10.1 ha divided by area of BPPH in the Northern LAU (1091 ha) x 100 = 0.93%

6.3.2 Southern LAU

Approximately nine percent (209.9 hectares) of the Southern LAU comprises habitats capable of supporting BPPH. Under S4 (24 000 t), modelling predicted that the ZoHI in the Southern LAU would occupy 21 ha after three years production. This figure was doubled to allow for recovery sites generated by fallowing the aquaculture sites.

[3] *Note that the figures shown for the area occupied by the ZoHI in Section 7.3.2 are for the combined northern and southern areas.*

Table 6.4 Calculation used to estimate the loss of BPPH within the Southern LAU

Average area of BPPH (ha) within the Southern LAU under ZoHI	Estimated % loss of BPPH within the Southern LAU
Area of BPPH inside the Southern Area of the Zone 279.1 ha *Percentage of BPPH within the Zone* 10.6 ha divided by the Southern Area of the Zone (800 ha) x 100 = 1.33% *ZoHI within the Zone* ZoHI (21 ha) x 2 (recovery sites) = 42 ha *Area of BPPH effected by the ZoHI* (1.33% divided by 100) x 42 ha = 0.56 ha	*Estimated % loss of BPPH* 0.56 ha divided by area of BPPH in the Southern LAU (209.1 ha) x 100 = 0.27%

6.4 Conclusion

The proposed MWADZ is within the FHPA. The Management Plan for the FHPA does not identify any areas of high conservation value that would be category A, and there have been no historical irreversible losses of BPPH in the LAU. Based on this, the assessment against EAG 3 was undertaken using the Category C cumulative loss guidelines (Table 4.8).

The Cumulative Loss Guidelines (EAG 3) recommend that cumulative losses of BPPH within Category C areas should not exceed 2% of the BPPH within the LAU. The cumulative loss of BPPH likely to result from the proposed aquaculture in the Northern LAU and Southern LAU was estimated at <1%, which is below the 2% benchmark.

7. Impact Assessment – Modelled

7.1 Overview

An integrated hydrodynamic, particle transport, water quality and sediment diagenesis model was used to simulate a total of six scenarios (S1–S6) as per the criteria detailed in Section 4.5.4 and Table 4.16. Sections 7.2 to 7.4 describe the predicted impacts of each of these scenarios on the marine environment, in terms of hydrology, sediments, benthic primary producing habitats and regional water quality. Results are described in the context of EAG 3 (EPA 2009) and EAG 7 (EPA 2011), which respectively describe the area of acceptable loss of BPPHs and the zones of impact, based on the criteria outlined in Table 4.9, Section 4.5.

7.2 Hydrodynamics

Sea-cages, or any other floating structures at sea, invariably impart some resistance to flows acting to slow or deflect waters in the vicinity of the cages. The potential for changes to the hydrodynamic regime in and around the proposed MWADZ sea-cages was investigated using the findings of Wu et al. (2014) and Cornejo et al. (2014).

Both Wu et al. (2014) and Cornejo et al. (2014) used numerical models and appropriate assumptions to determine the impact of cage clusters on the local current field. Cornejo et al. (2014) used a numerical model of an idealized environment to describe the changes to current dynamics and the formation of a wake arising from the introduction of sea-cages. They examined the impacts for various choices of mesh type for each cage, from high-drag materials (Cd=1.7) to low-drag materials (Cd=0.7).

Wu et al. (2014) derived a relationship between cage height, depth and an assumed friction parameter (Hasegawa et al. 2011) which can be used described impacts on the current field: $H=0.5H_0$, where H is the cage height and H_0 is depth. The assumed friction parameter used to derive this relationship was $\lambda=0.6$ per/m. The effect of MWADZ sea-cages on the surrounding hydrodynamic regime was extrapolated using the findings of Wu et al. (2014) together with the known characteristics of the MWADZ environment (12–50 m depth) and the proposed infrastructure (18 m depth cages).

Under high-drag scenarios and the ambient velocities observed in the proposed MWADZ (~0.1 m/s), bottom velocity is expected to increase by approximately 20% and surface velocity within the cages is expected to reduce by approximately 80%. Natural surface current velocities through the proposed MWADZs 8.7–14.1 cm/s in the summer months, and 10.5–14.5 cm/s in the winter months. Current velocities recorded at depth were somewhat lower than this at 5.8–11 cm/s and 6.1–11.5 cm/s in the summer and winter months, respectively (Table 4.5). Based on the findings of Wu et al. (2014) surface current speeds inside the sea-cages are expected to reduce to between 1.8–3.0 cm/s and currents speeds under the cages, to increase to between 6.9–13.8 cm/s.

While this analysis indicates a potential increase in velocity near the seabed of 20%, it is not expected that this will substantially affect the erosion of sediments under the aquaculture cages. Sediment erosion and deposition is driven by bottom shear stress, and the hydrodynamic model indicates that bottom shear stress is dominated by wave action rather than current velocities within the proposed lease areas.

Table 7.1 Current speeds through the MWADZ before and after the introduction of sea-cage infrastructure

	Summer		Winter	
	Surface	**Bottom**	**Surface**	**Bottom**
Before the introduction of sea-cages	8.7–14.1 cm/s	5.8–11.0 cm/s	10.5–14.5 cm/s	6.1–11.5 cm/s
After the introduction of sea-cages	1.8–2.8 cm/s	6.9–13.2 cm/s	2.1–3.0 cm/s	7.3–13.8 cm/s

7.3 Soft sediments

7.3.1 Inputs of organic waste (carbon)

An integrated hydrodynamic, particle transport, water quality and sediment diagenesis model was used to determine the trajectory, settlement and impacts of organic wastes leaving the sea-cages. For modelling purposes, inputs of organic waste to the seafloor were termed 'flux of organic matter', or rate of FOM mmol.C/m^2/yr. FOM was used as a proxy for organic enrichment, and as an indicator of potential secondary effects, including deoxygenation and accumulation of sulphides. FOM data are reported here for contextual purposes only. EAG 7 was applied with consideration to the potential secondary effects described in Section 7.3.2.

Figure 7-1–Figure 7-4 show the predicted rate of FOM to the seafloor under a range of scenarios (S1,S2, S5 and S6), and after twelve months of continuous finfish production. FOM increased with increasing standing biomass (FOM S5-S6 > FOM S1-S2) (Figure 7-1, Figure 7-2) and increasing stocking density (FOM S6>S5 and S2>S1) (Figure 7-3, Figure 7-4). FOM levels greater than background were detectable beneath and near to the sea-cages in each of the modelled scenarios–the highest FOM values beneath the sea-cages corresponded with the highest levels of standing biomass (FOM S5>S1 and FOM S6>S2). Accumulation of organic material occurred under each of the scenarios, and commenced rapidly following beginning of production; FOM beneath sea-cages was observed to build rapidly, even under biomasses much lower than those modelled here (<1000 t finfish per cluster) (Appendix G).

The highest FOM was concentrated immediately below the sea-cage clusters. The confinement of the majority of FOM to the area immediately beneath the sea-cages is indicated in the colour change from light blue to red between scenarios S2 (15 000 t) and S6 (30 000 t), representing a change in FOM from ~2 x 10^5 to 15 x 10^5 mmol.C/m^2/yr (Figure 7-4, Figure 7-3). Areas beyond the sea-cage clusters, by contrast, maintained similar levels of FOM, despite the modelled increases in standing biomass. These data are indicative of a highly concentrated effect, whereby the deposition of organic waste is centred on the area of seafloor immediately under the sea-cages.

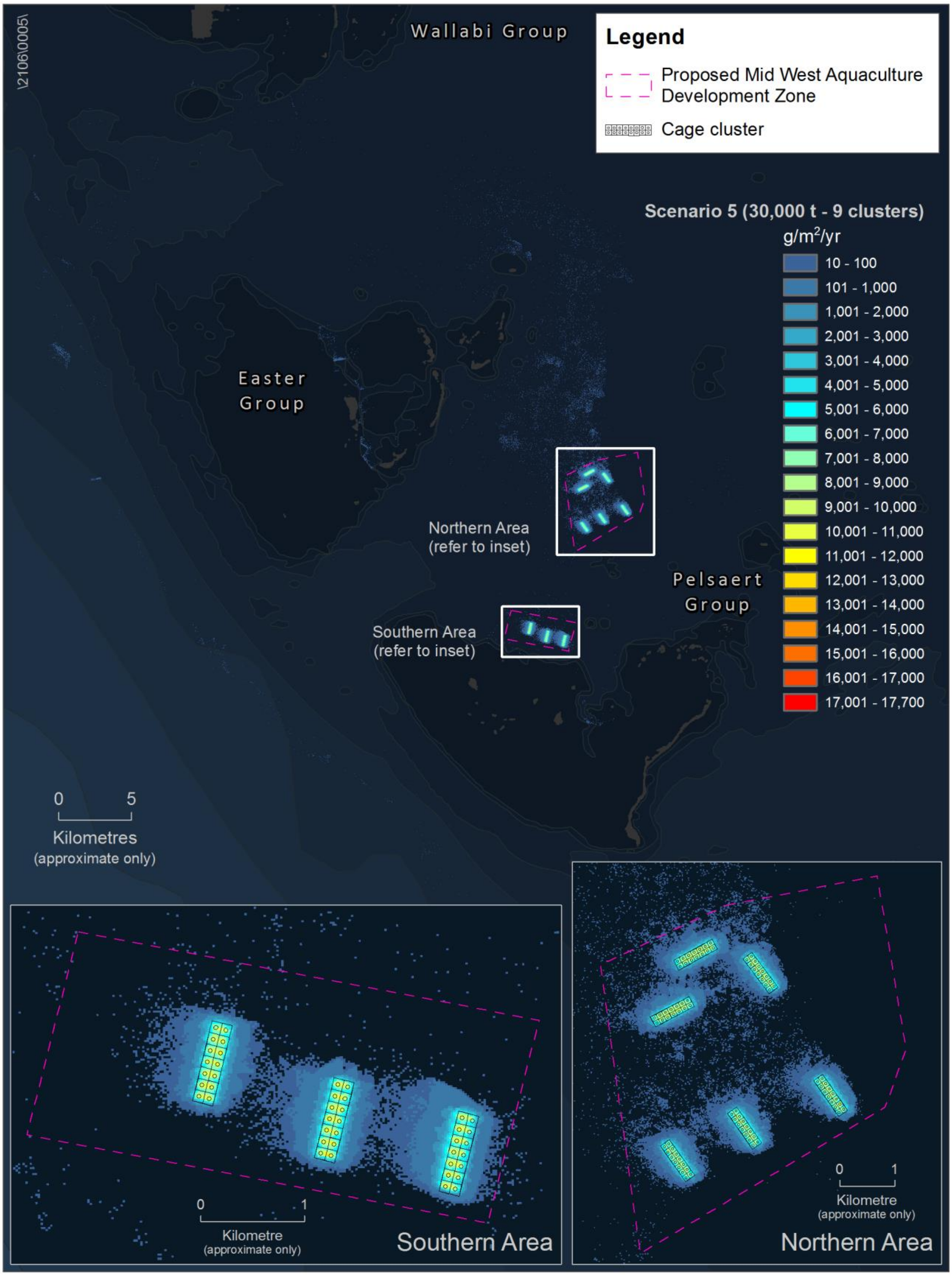


Figure 7-1 Inputs of organic carbon (FOM) under scenario 5 (30 000 t; 9 clusters)

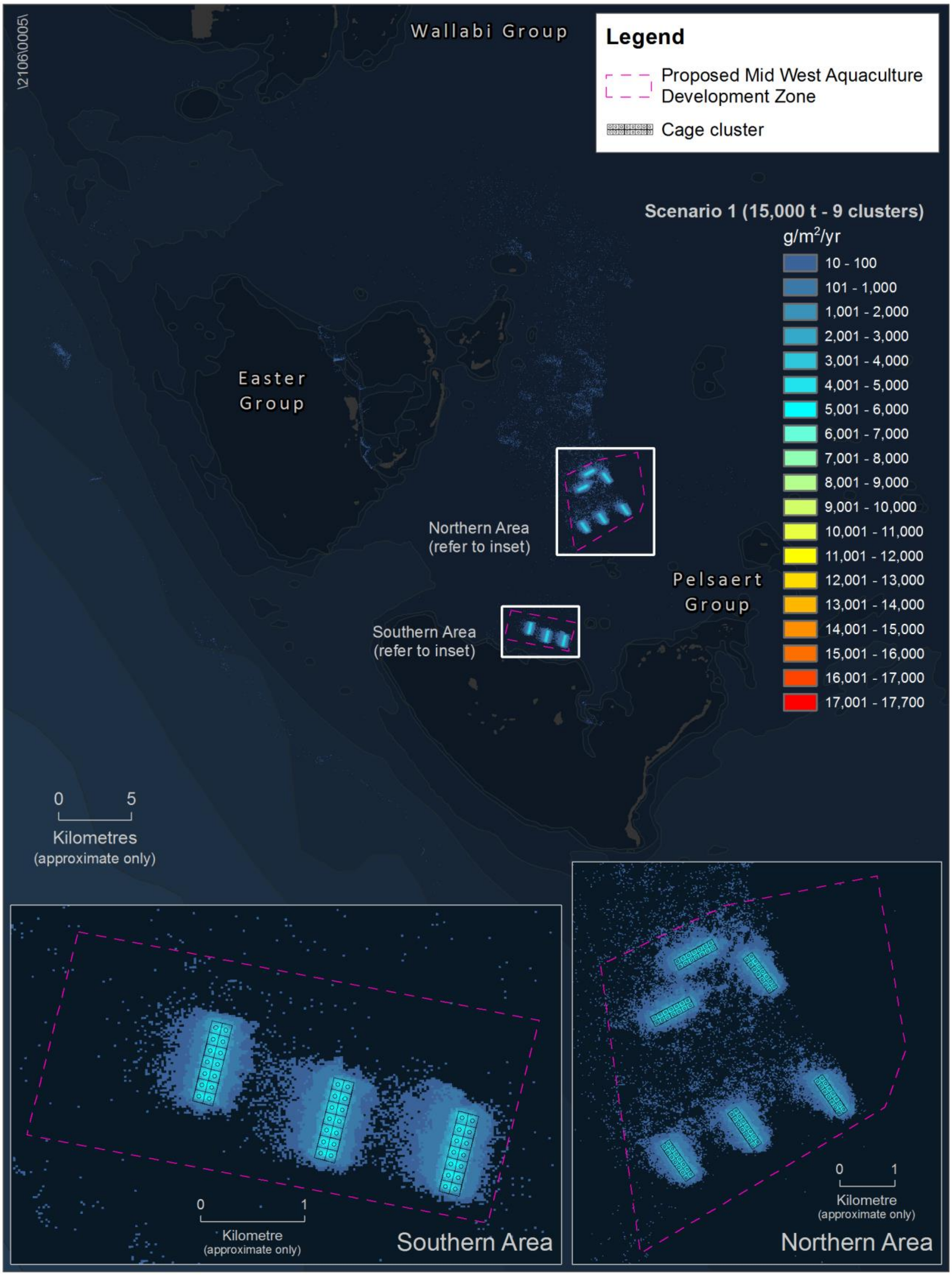


Figure 7-2 Inputs of organic carbon (FOM) under scenario 1 (15 000 t; 9 clusters)

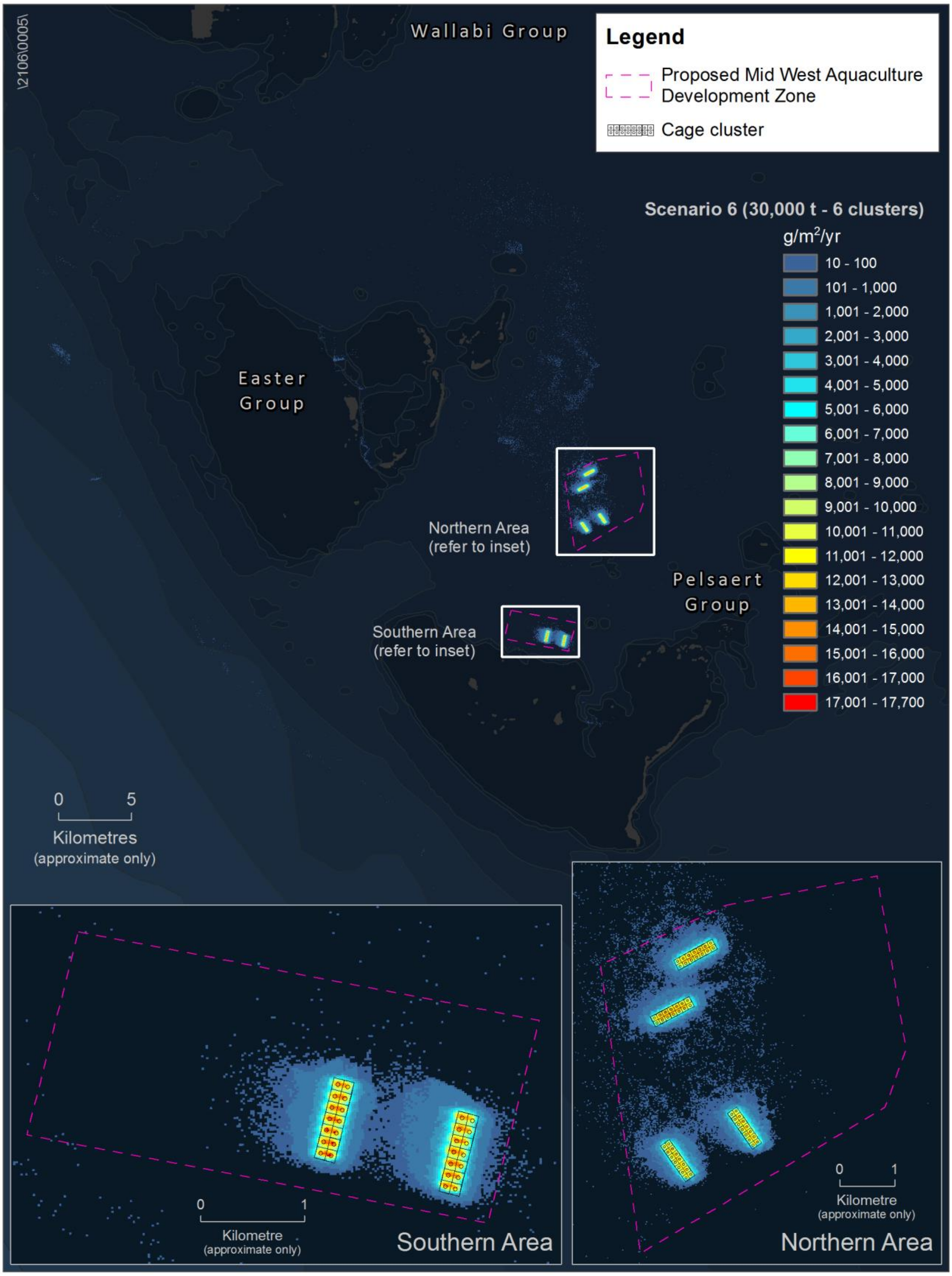


Figure 7-3 Inputs of organic carbon (FOM) under scenario 6 (30 000 t; 6 clusters)

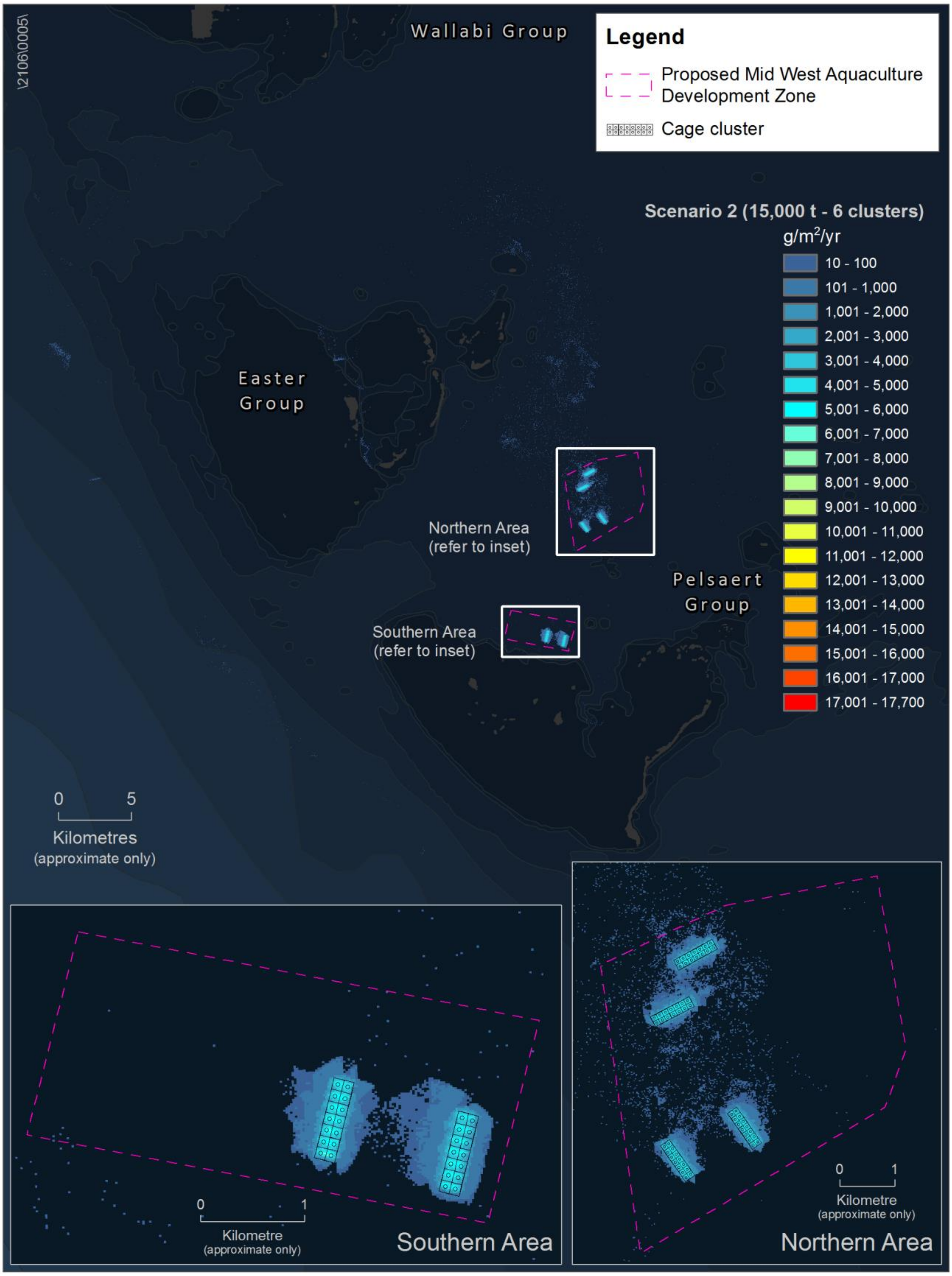


Figure 7-4 Inputs of organic carbon (FOM) under scenario 2 (15 000 t; 6 clusters)

7.3.2 Sediment dissolved oxygen & sulphide content

Figure 7-5–Figure 7-22 show the spatial extents of three zones of impact, following application of the criteria in EAG 7 (EPA 2011). The zones were defined based on the time required for sediment oxygen and sulphide concentrations to return to baseline levels, following two, three and five years of finfish production, and across the full range of production scenarios, 1 to 6 (S1-S6; Table 4.16). As per EAG 7, habitats requiring greater than five years to recover to baseline levels were designated zones of 'high' impact (ZoHI - red colouration), and habitats requiring less than five years were designated zones of 'moderate' impact (ZoMI - amber colouration). Areas expected to receive waste, but not in concentrations great enough to alter the sediment chemistry, were designated zones of influence (ZoI - green colouration). Areas classified as ZoI are expected to maintain sediment oxygen and sulphide levels equivalent to unimpacted sites located beyond the influence of aquaculture activities.

Dispersed effects – nine cage clusters

The aerial extent of the ZoHI, ZoMI and ZoI, in S1, S3 and S5 is illustrated in Figure 7-5–Figure 7-13 and outlined (in hectares) in Table 7.2. These three scenarios captured the effect of spreading the finfish standing biomass across a total of nine cage clusters (simulating a 'dispersed' effect). The effect of concentrating the finfish standing biomass across a reduced number of cage clusters (six) is explored in the subsequent chapter.

Zones of high impact were observed in S3 and S5 after 2, 3 and 5 years production and in S1 after 3 and 5 years production. Under S1, no high impacts were observed after 2 years of production (Figure 7-6 and Figure 7-7). The area occupied by the ZoHI increased in response to increasing standing biomass and the length of finfish production (Table 7.2). After 5 years continuous production, the ZoHI, as indicated by the red coloured pixels in Figure 7-5–Figure 7-13, extended respectively ~70 m, ~55 m and ~40 m from the cage cluster boundaries in S5, S3 and S1, as measured along the maximum radius down-current from the cage clusters.

Further reductions were achieved by reducing the duration of production from 5 to 3 or from 5 to 2 years (Table 7.2). For example, in S3 the ZoHI after 5 years was 132 ha in area, and extended ~55 m from the cage-cluster boundary. By reducing the production period to 3 years the ZoHI contracted to 11 ha, was constrained to small ‘patches’ within the cage cluster boundaries, and did not breach the cage cluster boundary. A further reduction to 3 ha was achieved by reducing the production period from 3 to 2 years production (Figure 7-8 and Figure 7-9). Reducing the production duration also reduced the intensity of the impact. For example, in S1, reducing the production period from 5 to 2 years resulted in a reduction in the impact status from highly (ZoHI) to moderately (ZoMI) impacted (Figure 7-5 and Figure 7-6).

The aerial extent of the ZoHI was smaller areas in the northern area, relative to the southern area. This is likely a result of the higher current speeds in the northern MWADZ, which when simulated in the model, imparted a strong influence on particle transport and resuspension–both processes which affected the retention of organic material near the sea-cages. Particles tended to disperse under higher current speeds, but tended to sink, deposit and remain close to the sea-cages under lower current speeds. This is reflected in Figure 7-5–Figure 7-13, by the greater spread of particles away from the sea-cages in the northern MWADZ, and the greater tendency toward deposition and concentration of particles in the southern MWADZ.

Zones of moderate impact, as indicated by the amber coloured pixels in Figure 7-5–Figure 7-13, were observed in all scenarios irrespective of the length of the production period. With some exceptions, the area occupied by the ZoMI increased with increasing standing biomass and increasing length of production; however, the changes were less dramatic than those predicted

for the ZoHI. For example, the area occupied by the ZoHI over the range of modelling treatments was between 0 ha and 177 ha, representing an order of magnitude change; whereas the area occupied by the ZoMI over the same modelling treatments was between 239 ha and 348 ha, representing a smaller, and within order of magnitude change.

The Zone of Influence, as indicated by the green coloured pixels in Figure 7-5–Figure 7-13, was the largest (in area) and the most dispersed of the three impact categories. In the northern area of the MWADZ, the higher current speeds acted to increase the dispersion of organic particles, which in turn increased the area occupied by the ZoI. The prevailing south-easterly currents in the northern area of the MWADZ are reflected in the north-westerly trajectory of particles to the north-west and away from the sea-cages. In the southern area of the MWADZ, the ZoI was generally more constrained, and centred around the individual cage-clusters. Dominant westerly currents in the southern area of the MWADZ resulted in a tendency for particles to disperse to the west of the cage clusters.

Table 7.2 Areas occupied by the zones of high and moderate impact and the zone of influence under scenarios S1, S3 and S5 after 2, 3 and 5 years production

Years of production	Scenario No.	Standing biomass (t)	ZoHI (ha)	ZoMI (ha)	ZoI (ha)
5	S1	15 000	117	239	1150
	S3	24 000	132	235	1005
	S5	30 000	177	270	1226
3	S1	15 000	1	346	1159
	S3	24 000	11	349	1012
	S5	30 000	105	334	1235
2	S1	15 000	0	336	1170
	S3	24 000	3	348	1021
	S5	30 000	91	333	1250

Note:
1. ZoHI = zone of high impact, ZoMI = zone of moderate impact, ZoI = zone of influence

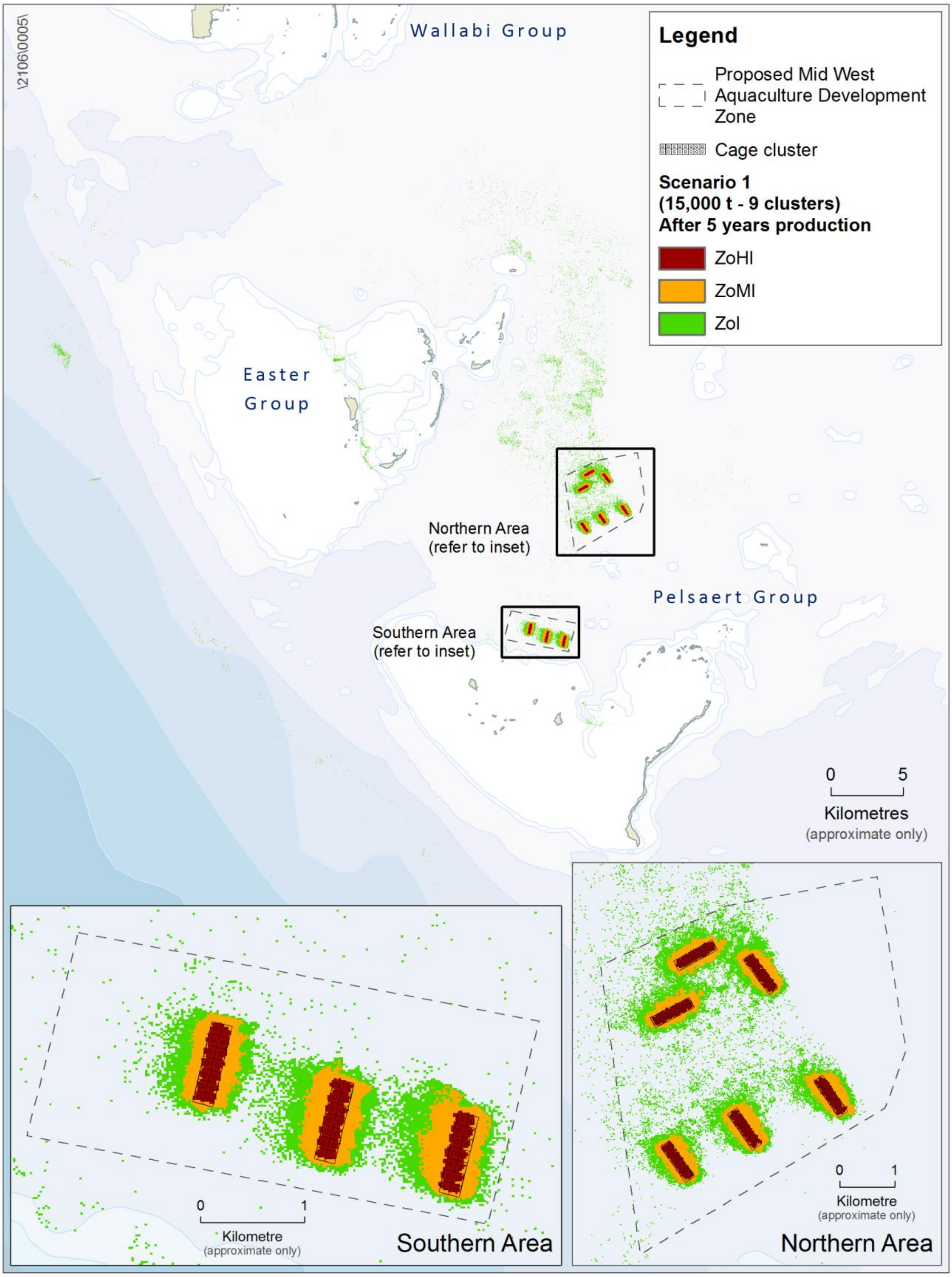


Figure 7-5 Zones of impact under scenario 1 (15 000 t) after 5 years production

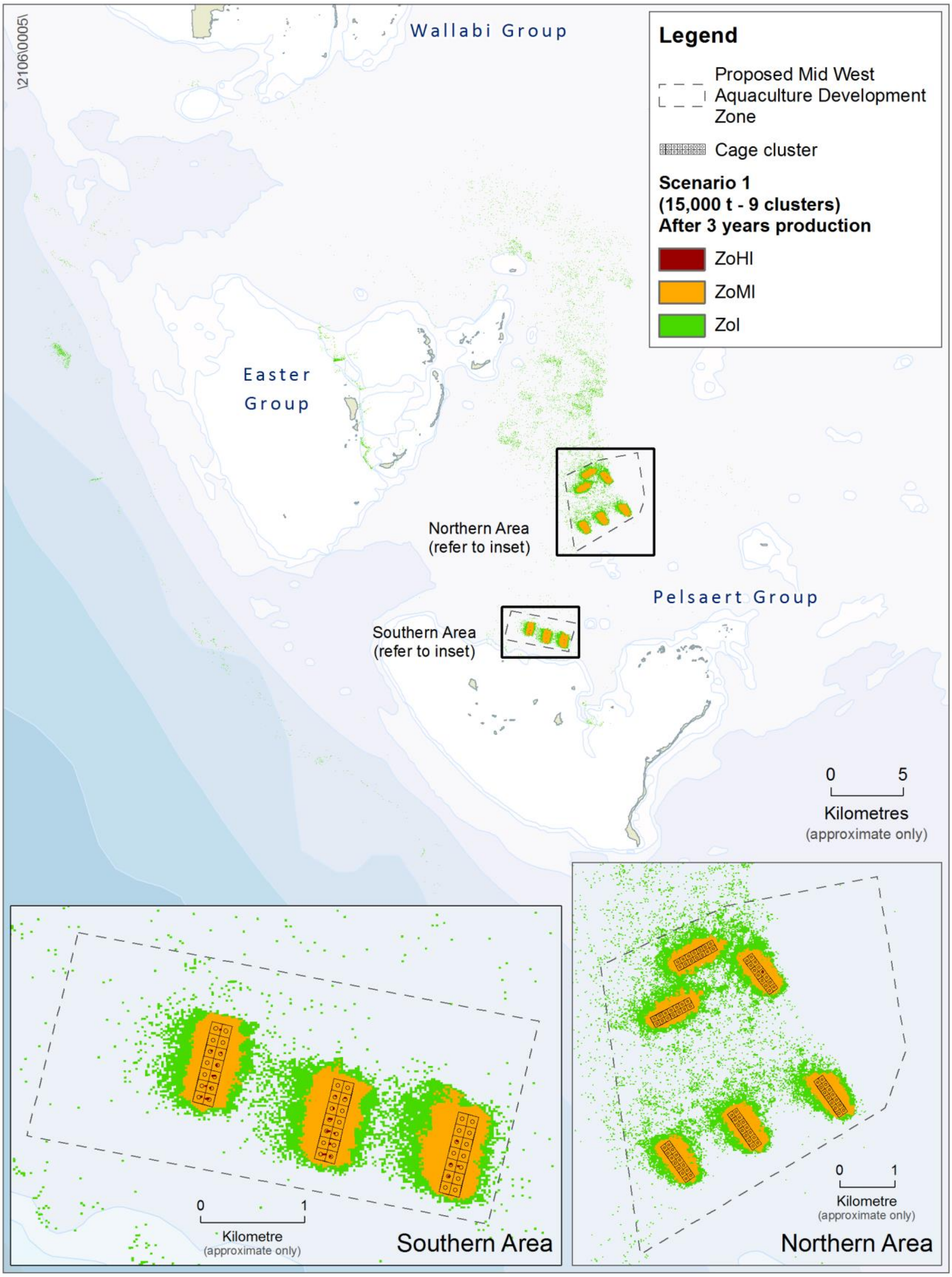


Figure 7-6 Zones of impact under scenario 1 (15 000 t) after 3 years production

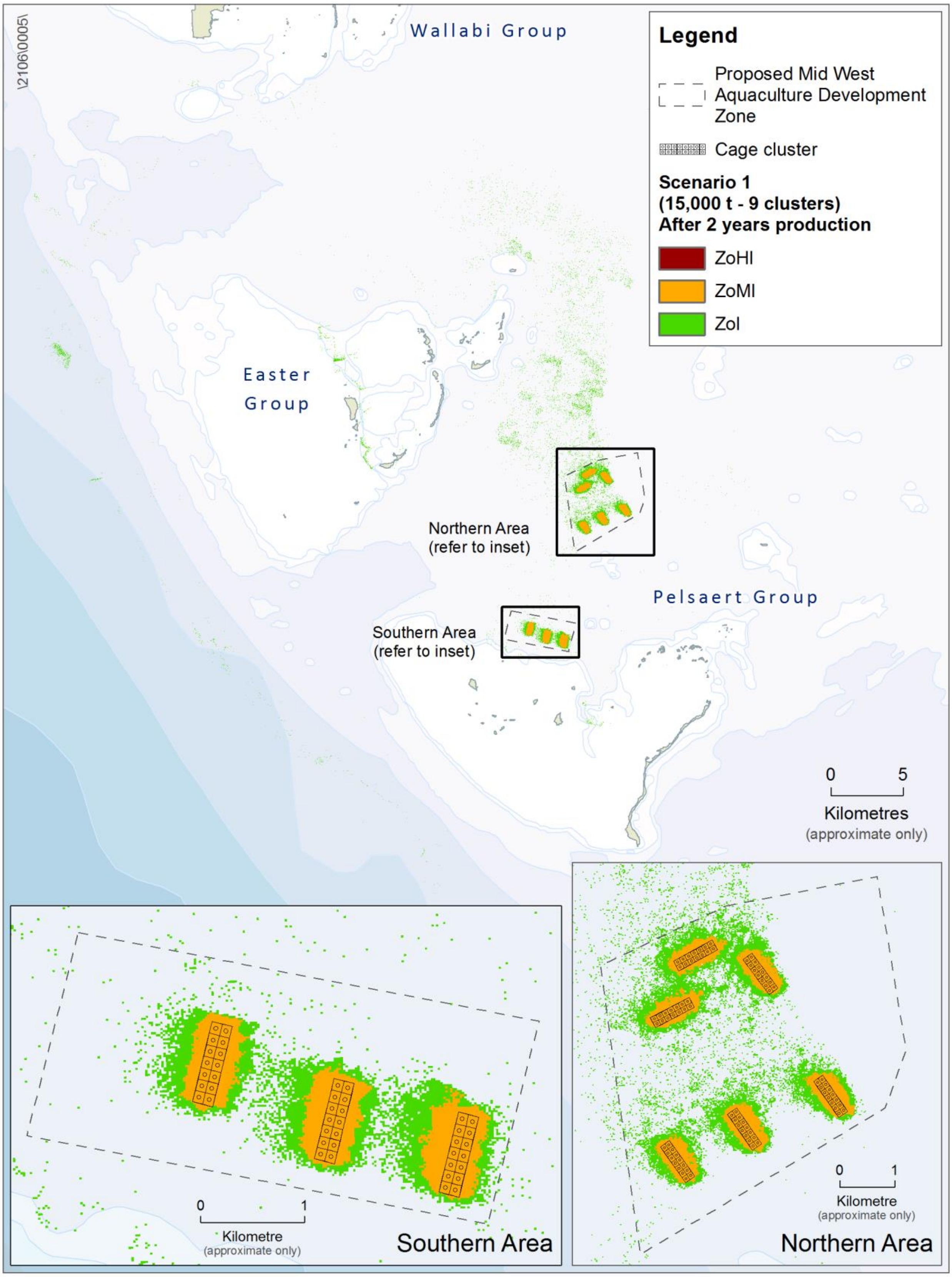


Figure 7-7 Zones of impact under scenario 1 (15 000 t) after 2 years production

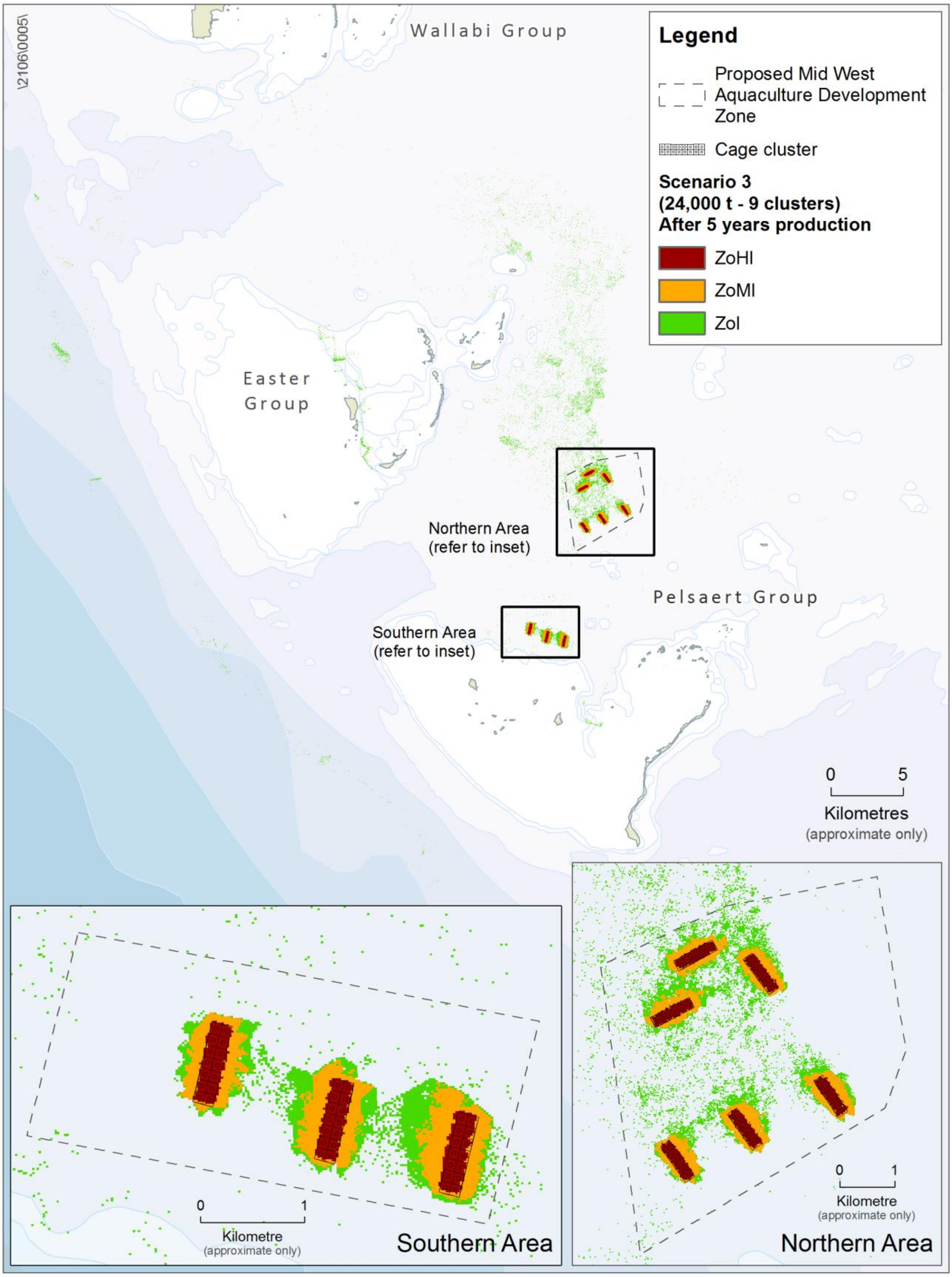


Figure 7-8 Zones of impact under scenario 3 (24 000 t) after 5 years production

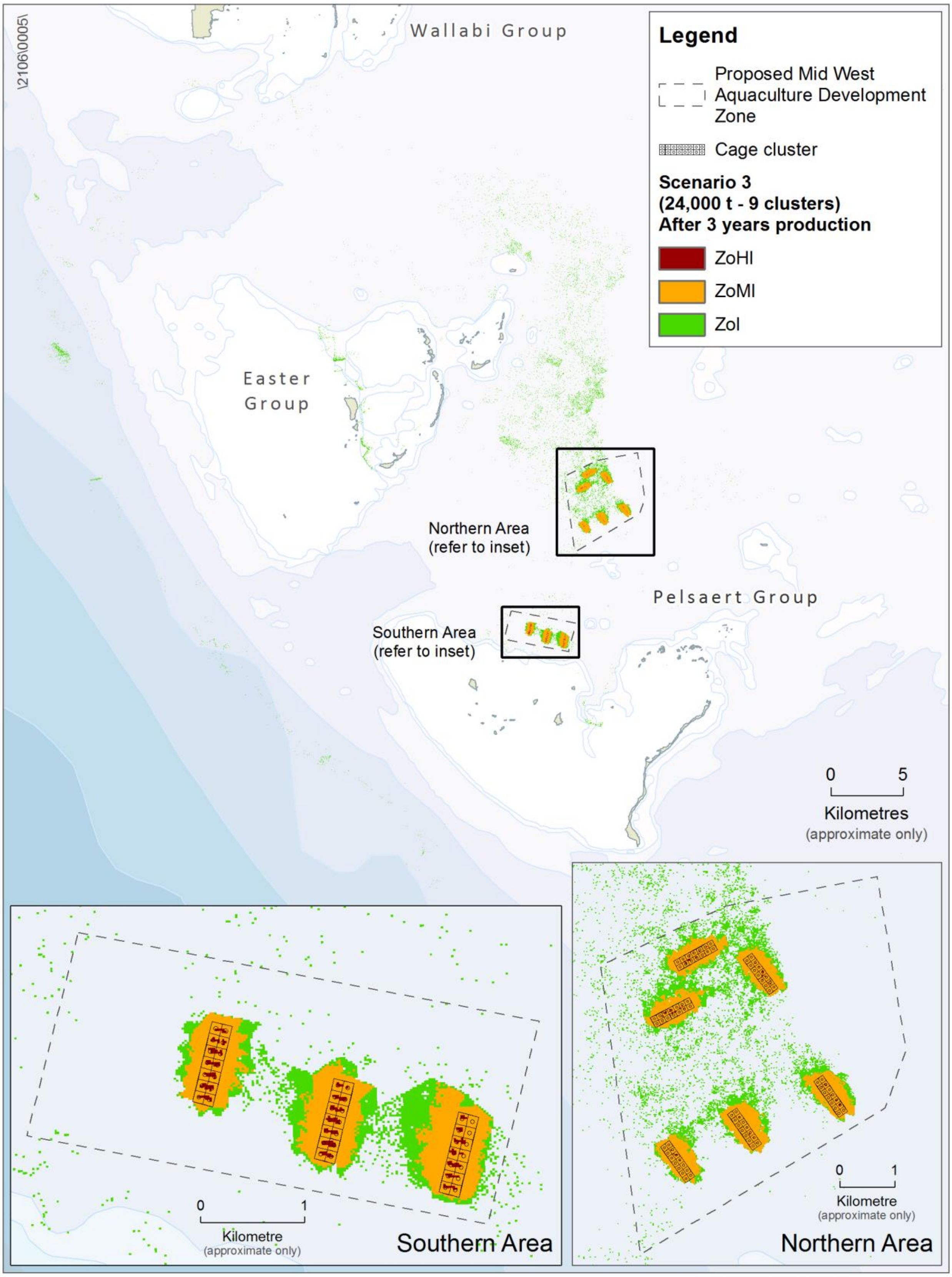


Figure 7-9 Zones of impact under scenario 3 (24 000 t) after 3 years production

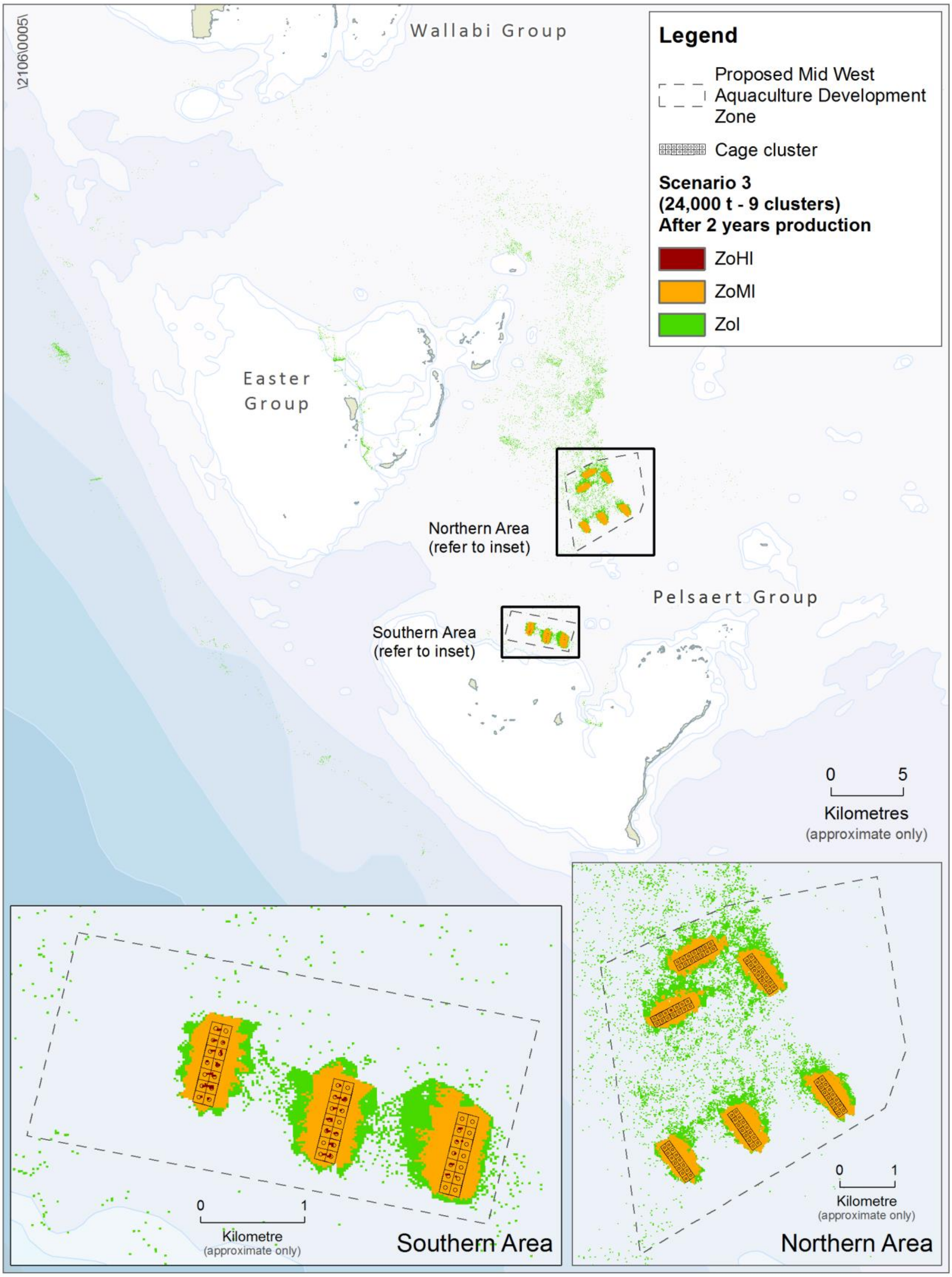


Figure 7-10 Zones of impact under scenario 3 (24 000 t) after 2 years production

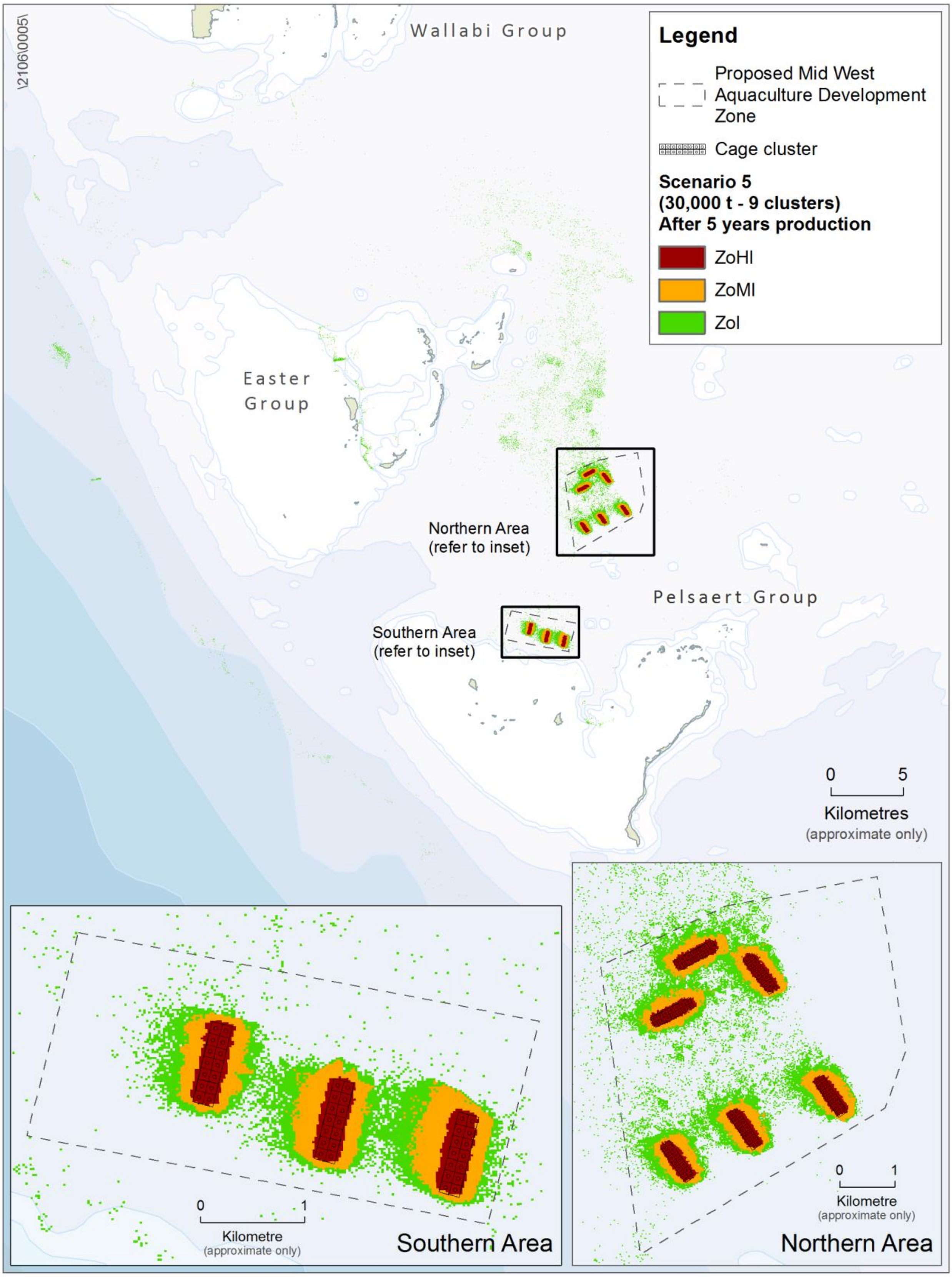


Figure 7-11 Zones of impact under scenario 5 (30 000 t) after 5 years production

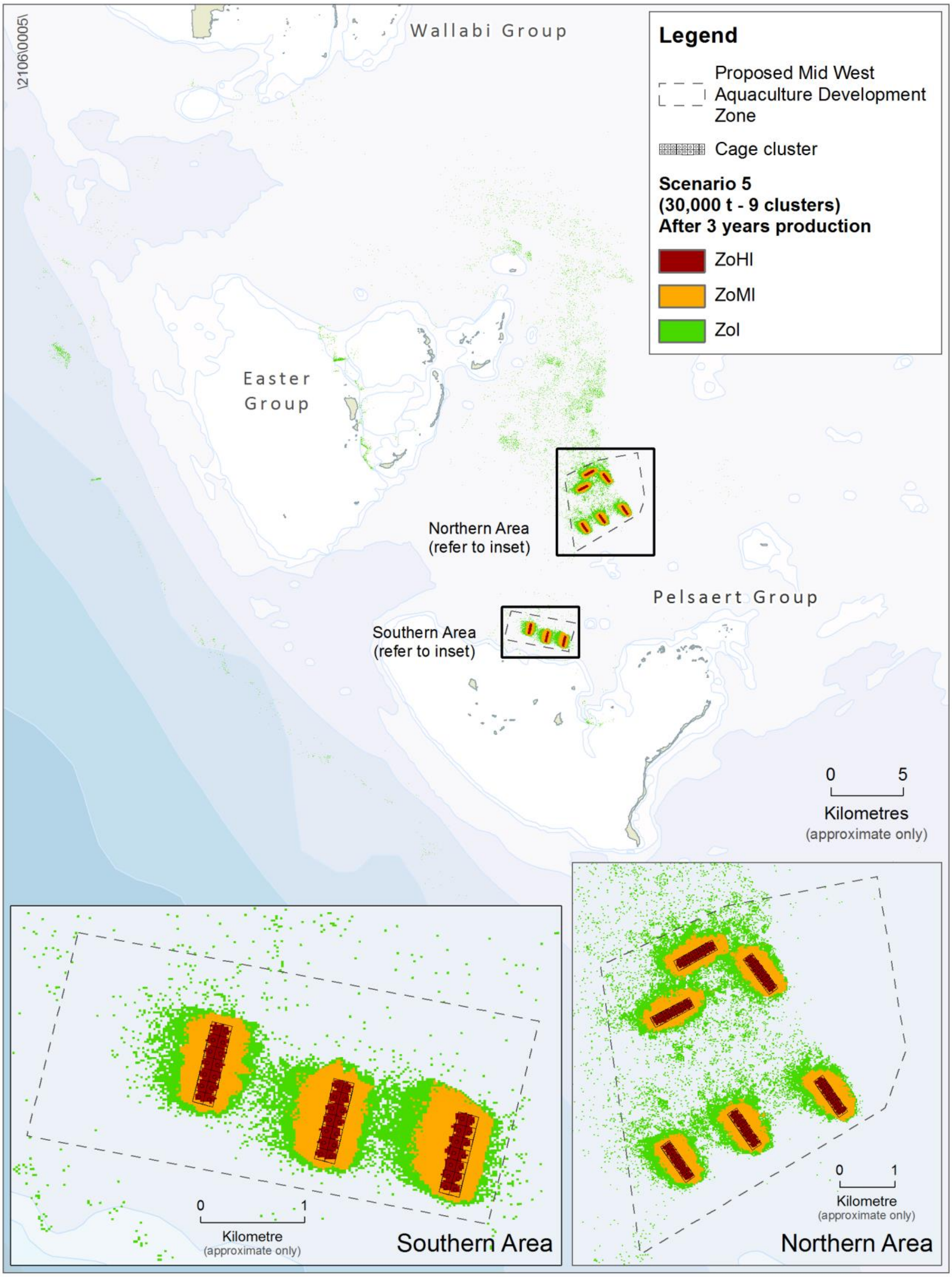


Figure 7-12 Zones of impact under scenario 5 (30 000 t) after 3 years production

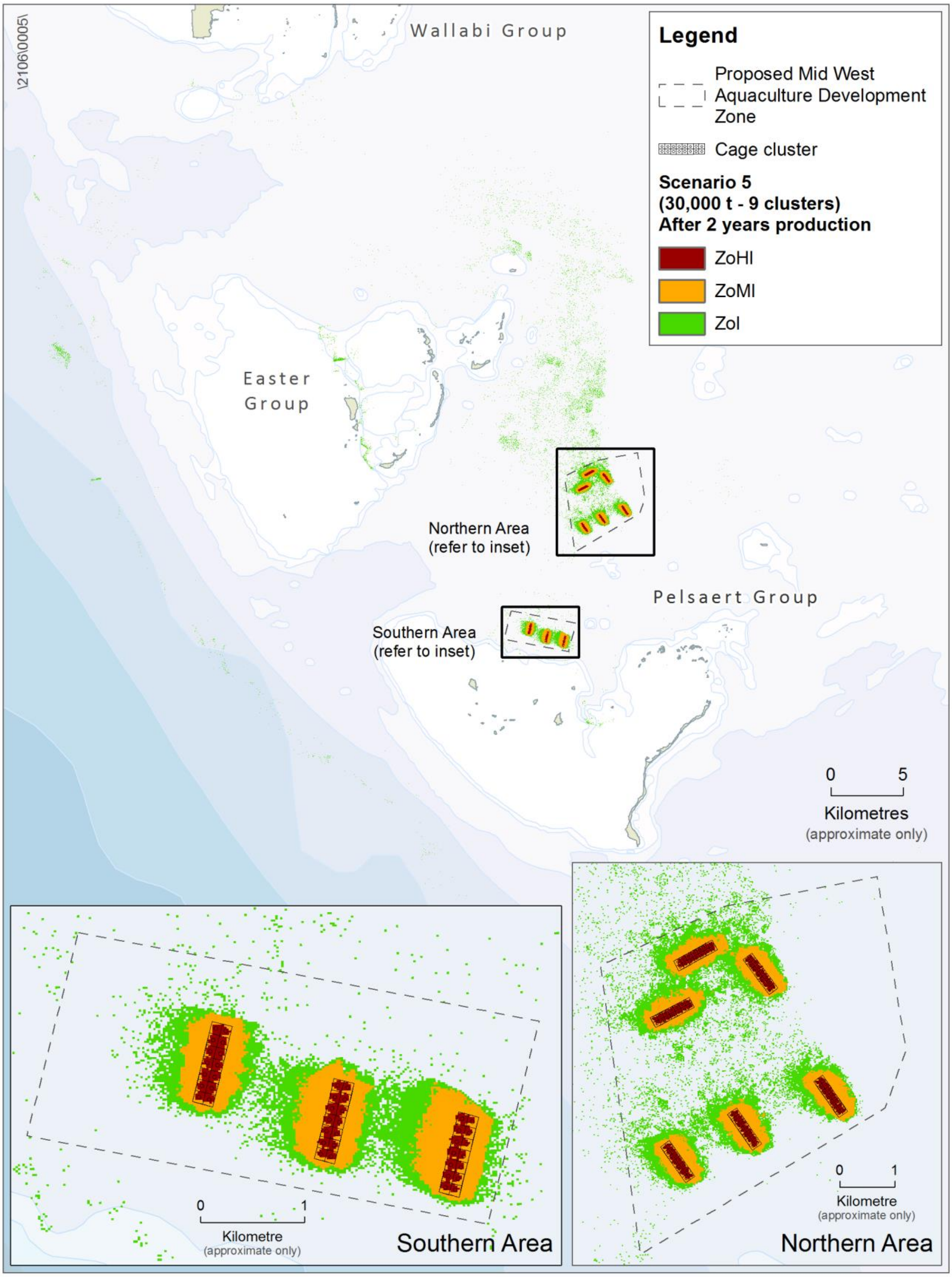


Figure 7-13 Zones of impact under scenario 5 (30 000 t) after 2 years production

Concentrated effects - six cage clusters

The aerial extent of the ZoHI, ZoMI and ZoI, in S2, S4 and S6 is illustrated in Figure 7-14–Figure 7-22 and outlined (in hectares) in Table 7.3. These scenarios captured the effect of concentrating the standing biomass across a total of 6 cage clusters, 3 less than in the 'dispersed' effects simulations (described in the chapter above).

As with the results for the 'dispersed' effects', the ZoHI, as indicated by the red coloured pixels in Figure 7-14–Figure 7-22, increased with standing biomass and the length of finfish production. Zones of high impact were observed in S6, S4 and S2 after 5 and 3 years production and in S6 and S4 after 2 years production. The area occupied by the ZoHI in S2 after 2 years production was marginal at less than 1 ha (Figure 7-14–Figure 7-22).

Significant reductions in the areas of the ZoHI were achieved by reducing the length of production from 5 to 3, and from 3 to 2 years. For example, by reducing the length of production from 5 to 3 years, close to a 100% reduction was achieved in S2, a 45% reduction was achieved in S4 and a 31% reduction was achieved in S6. Greater reductions were achieved for the dispersed effects scenarios, S1, S3 and S5: corresponding to reductions of 100% for S1, 92% for S3 and 41% for S6 (Table 7.2 and Table 7.3).

Reductions in both the standing biomass and the length of production also reduced the maximum extent of the ZoHI, as measured along the maximum radius down-current from the cage clusters. After 5 years continuous production, the ZoHI, as indicated by the red coloured pixels in Figure 7-14–Figure 7-22, extended ~110 m, ~60 m and ~50 m from the cage cluster boundaries in S6, S4 and S2, respectively. However, the maximum distances reduced after 3 and 2 years production: with predictions of 10 m and 15 m respectively under S4, and 55 m and 50 m respectively under S6. Under S2, the ZoHI did not breach the cage cluster perimeter.

Increasing the stocking density, while maintaining the standing biomass (i.e. stocking density S4 > stocking density S3; standing biomass S4 = standing biomass S3), had the effect of reducing the total area occupied by the ZoHI across the zone. This effect was particularly strong after 5 years production (Table 7.2 and Table 7.3), but less so after 3 and 2 years production. For example, after 5 years, the total area occupied by the ZoHI was 177 ha and 139 ha for S5 and S6, respectively; 132 ha and 113 ha for S3 and S4 respectively; and 117 ha and 82 ha for S1 and S2, respectively. After 3 years production, the results were more variable: the total area occupied by the ZoHI was higher in S2 (2 ha) relative to S1 (1 ha); higher in S4 (62 ha) relative to S3 (11 ha) but lower in S6 (95 ha) relative to S5 (105 ha). Similar variable results were achieved after 2 years production (Table 7.2 and Table 7.3).

Reducing the number of cage clusters also reduced the total area occupied by the ZoMI and the ZoI. By reducing the number of cage clusters, reductions in the footprints of both zones were achieved irrespective of the standing biomass or the production period modelled (Table 7.2 and Table 7.3). This is a useful finding indicating that reductions in the spatial extent of impacts, as measured under EAG 7 (ZoHI, ZoMI and ZoI), can be achieved by concentrating finfish in individual cage clusters, without a corresponding need to reduce the total standing biomass across the zone. It was noted, however, that while the spatial extent of the impacts can be reduced based on the criteria in EAG 7, the effect of this is to increase the intensity of impacts immediately under the sea-cages. Intensifying the impacts, as S2, S4 and S6, translate to longer recovery periods, as shown in Figure 7-23–Figure 7-31. The difference in the areas occupied between the dispersed (9 clusters) and concentrated (6 clusters) scenarios is shown in Table 7.2 and Table 7.3, and illustrated in Figure 7-14–Figure 7-22.

As observed in S1, S3 and S5, the area occupied by the ZoHI in S2, S4 and S6 also increased in response to increasing standing biomass and the length of finfish production. Zones of high impact were observed in S6, S4 and S2 after 5 and 3 years production and in S6 and S4 after 2 years production. The area occupied by the ZoHI in S2 after 2 years production was marginal at less than 1 ha (Figure 7-14–Figure 7-22).

The area occupied by the ZoHI after 2, 3 and 5 years production increased proportionally with increases in standing biomass, increasing from 82 ha in S2 to 139 ha in S6 after 5 years, 2 ha in S2 to 95 ha in S6 after 3 years and 0.2 ha in S2 to 88 ha in S6 after 2 years. Similar increases were apparent with the ZoMI, which increased in size from 160 ha in S2 to 203 ha in S6, after 5 years. The area occupied by the ZoI was also observed to increase in response to increasing standing biomass, reaching a maximum coverage in S6, irrespective of the length of production (Table 7.3).

Significant reductions in the areas of the ZoHI were achieved by reducing the length of production from 5 to 3, and from 3 to 2 years. For example, by reducing the production period from 5 to 3 years close to 100% reductions were achieved in S2, 45% reductions were achieved in S4 and 31% reductions were achieved in S6. Greater reductions were achieved for the dispersed effects scenarios, S1, S3 and S5: corresponding to reductions of 100% for S1, 92% for S3 and 41% for S6.

Table 7.3 Areas occupied by the zones of high and moderate impact and the zone of influence under scenarios S2, S4 and S6 after 2, 3 and 5 years production

Years of production	Scenario No.	Standing biomass (t)	ZoHI (ha)	ZoMI (ha)	ZoI (ha)
5	S2	15 000	82	160	616
	S4	24 000	113	173	697
	S6	30 000	139	203	861
3	S2	15 000	2	234	621
	S4	24 000	62	219	701
	S6	30 000	95	241	868
2	S2	15 000	0.2	229	628
	S4	24 000	51	222	710
	S6	30 000	88	237	879

Note:

1. ZoHI = zone of high impact, ZoMI = zone of moderate impact, ZoI = zone of influence

Zones of moderate impact, as indicated by the amber coloured pixels in Figure 7-14–Figure 7-22, were observed in all scenarios irrespective of the length of the production period. The ZoMI was restricted to the area immediately adjacent to the sea-cage clusters, but extended further than the ZoHI. As with the ZoHI, the area occupied by the ZoMI increased with increasing standing biomass and the length of production; however, the changes were less distinct than those observed for the ZoHI. Unlike the ZoHI, which was near absent in S2 after 2 years production, moderate impacts were detected irrespective of the modelled treatment.

The Zone of Influence, as indicated by the green coloured pixels in Figure 7-14–Figure 7-22, was the largest (in area) and the most dispersed of the three impact categories. In the northern area of the MWADZ, the higher current speeds acted to increase the dispersion of organic particles, which in turn increased the area occupied by the ZoI. The prevailing south-easterly currents in the northern area of the MWADZ are reflected in the north-westerly trajectory of the ZoI, which was predicted to advect away from the sea-cages. In the southern area of the MWADZ, the ZoI was generally more constrained, and centred on the individual cage-clusters.

The ZoHI is the area where impacts on benthic habitats are predicted to be irreversible, as per EAG 7. The term irreversible is defined as 'lacking a capacity to return or recover to a state resembling that prior to being impacted within a timeframe of five years or less'. Despite the use of the term irreversible, it is noted that sea-cages are not permanent structures and can be moved to facilitate benthic rehabilitation. Recovery times in the ZoHI and ZoMI ranged between 1 and 7+ years, depending on the scenario and distance from the sea-cages. Immediately under the sea-cages, sediments required greater than 7 years to achieve full recovery. However, this reduced to 6 and 5-6 after 3 and 2 years production respectively (Figure 7-23–Figure 7-31).

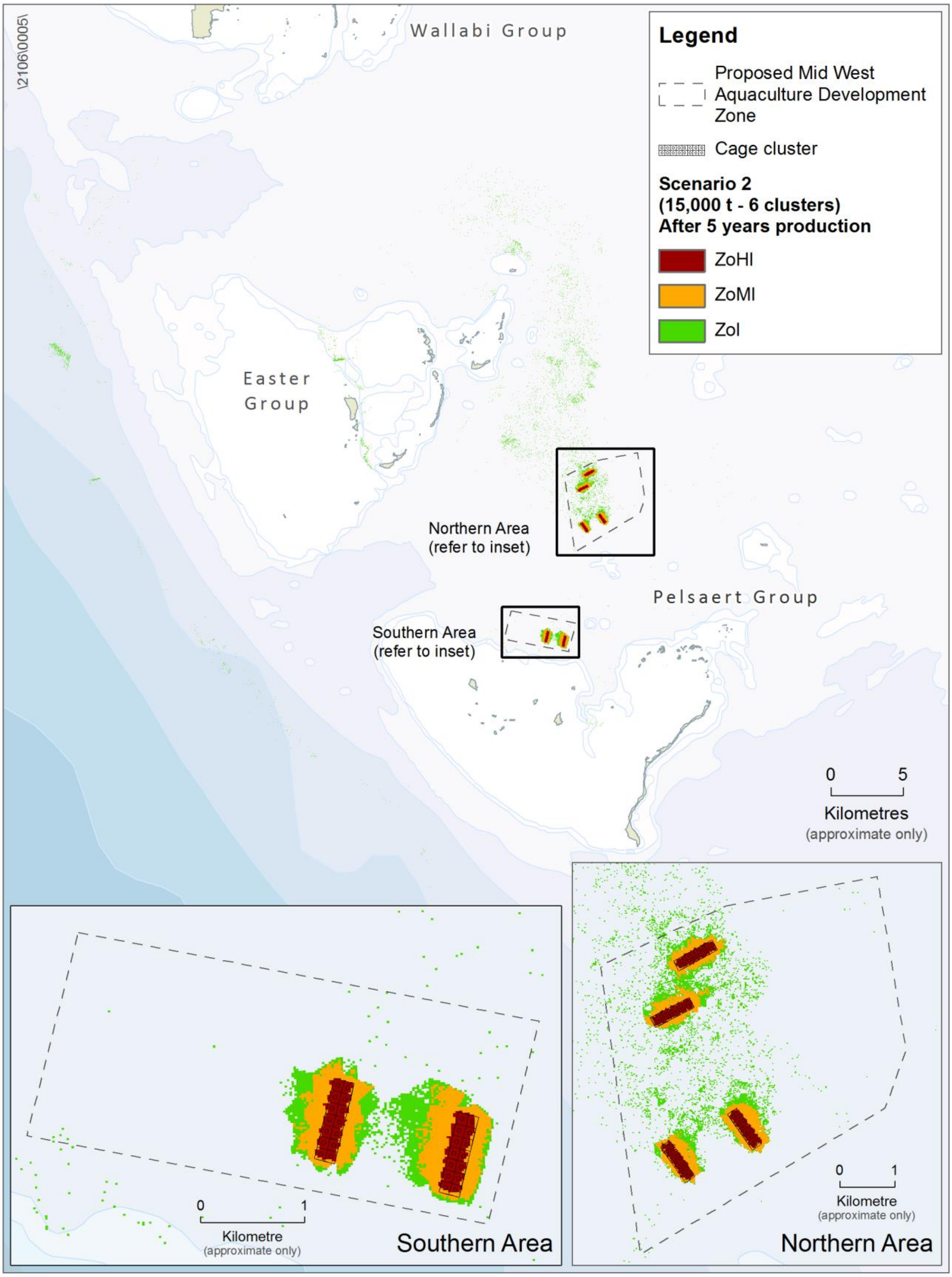


Figure 7-14 Zones of impact under scenario 2 (15 000 t) after 5 years production

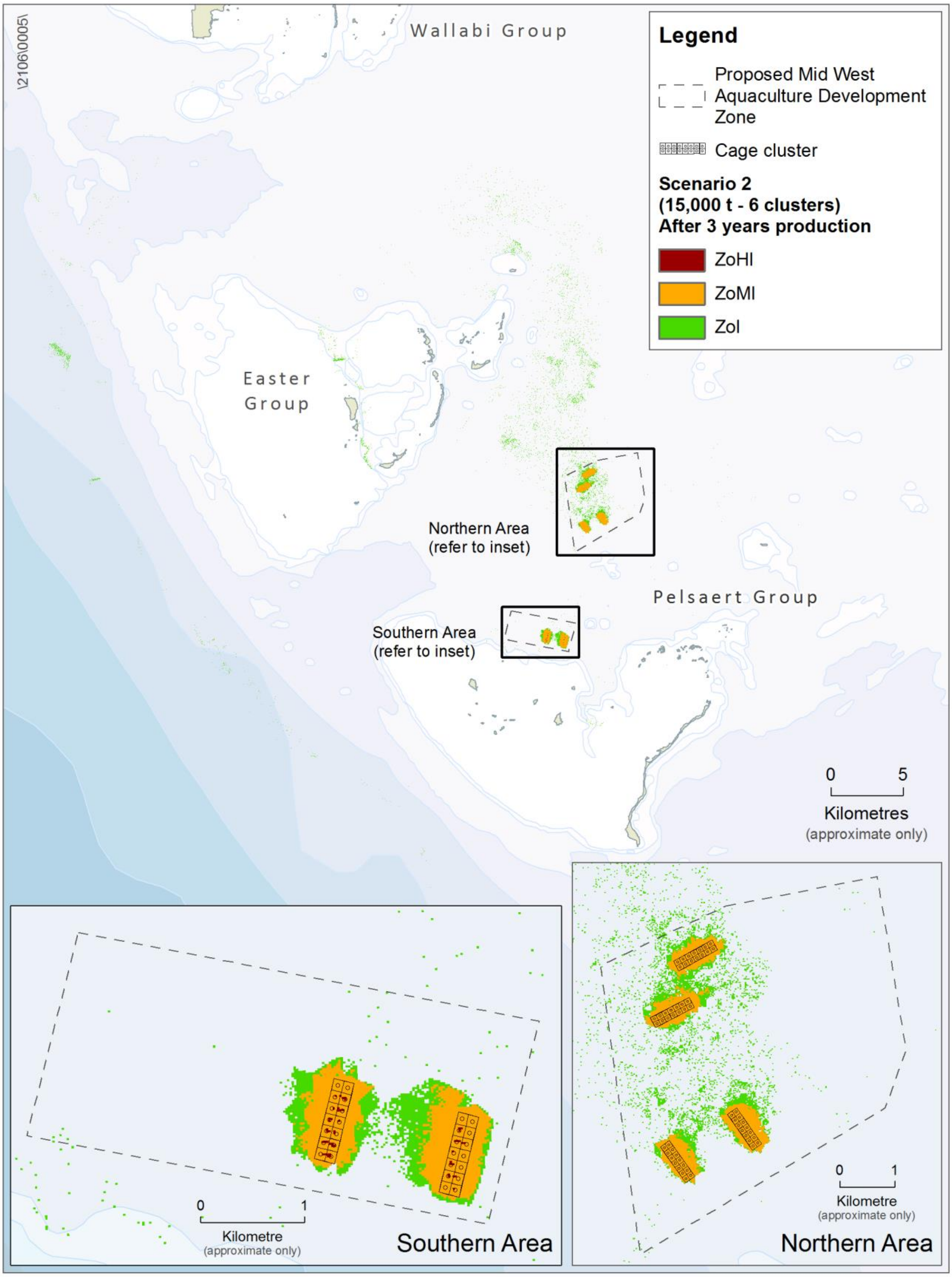


Figure 7-15 Zones of impact under scenario 2 (15 000 t) after 3 years production

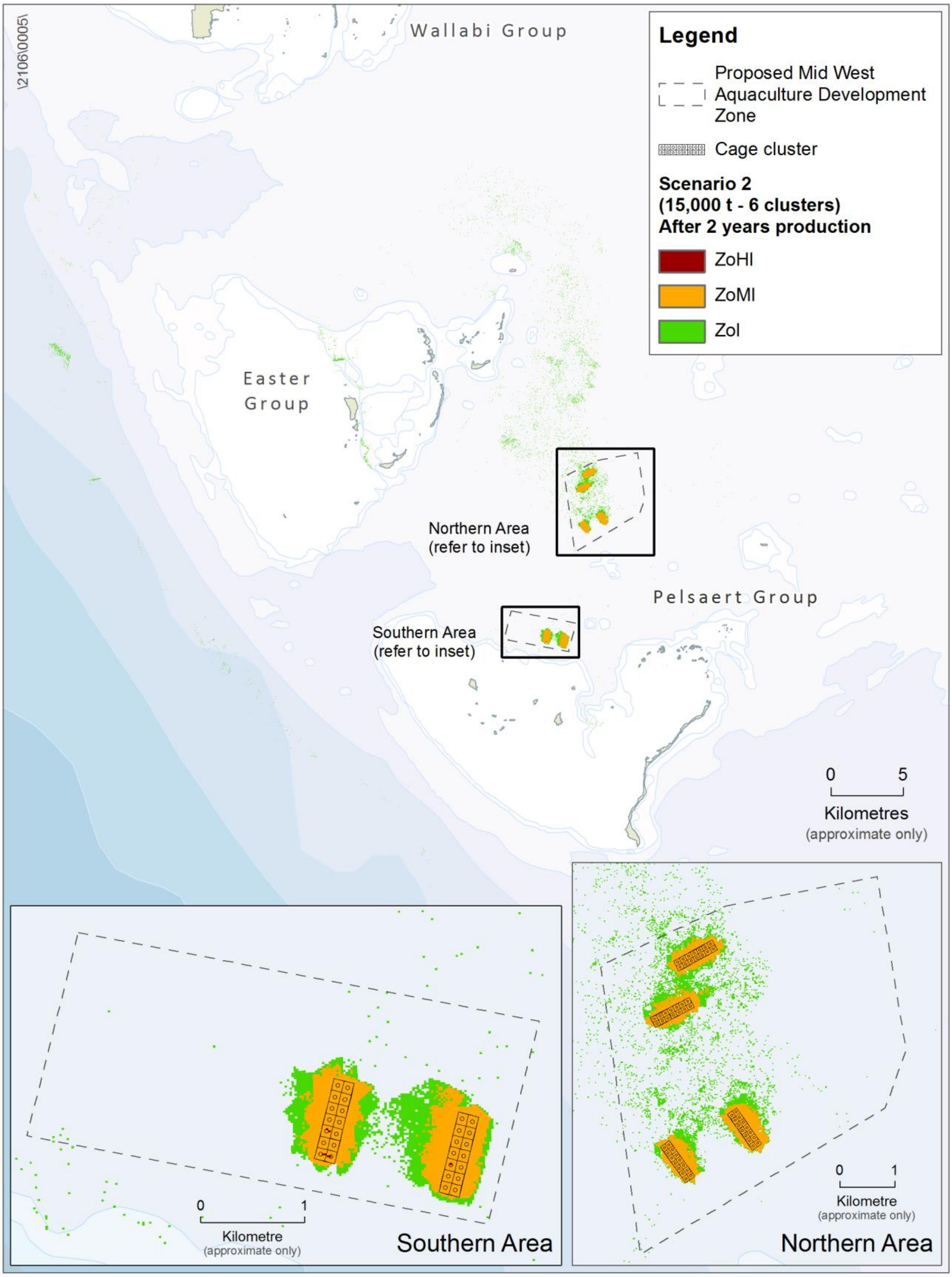


Figure 7-16 Zones of impact under scenario 2 (15 000 t) after 2 years production

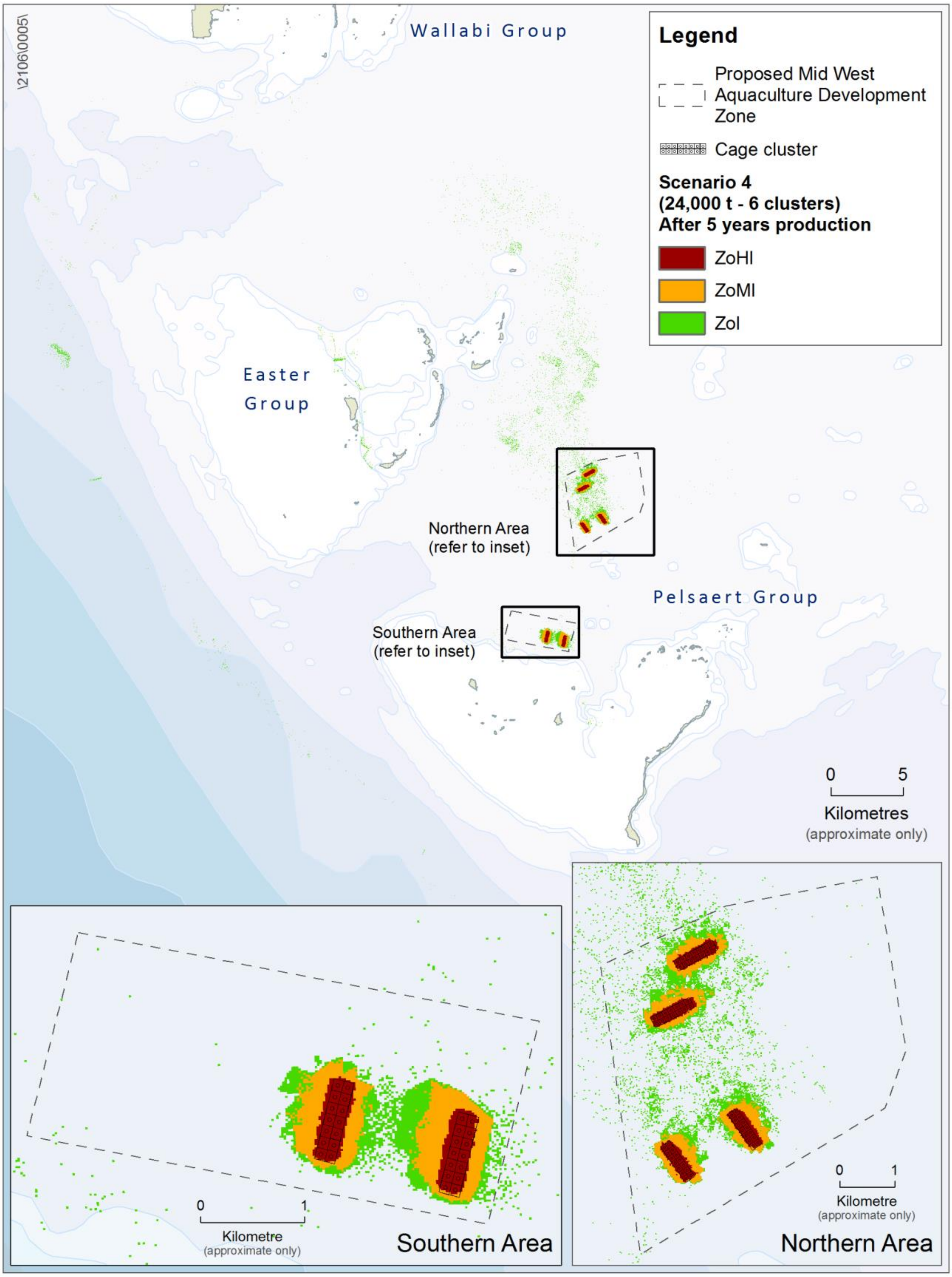


Figure 7-17 Zones of impact under scenario 4 (24 000 t) after 5 years production

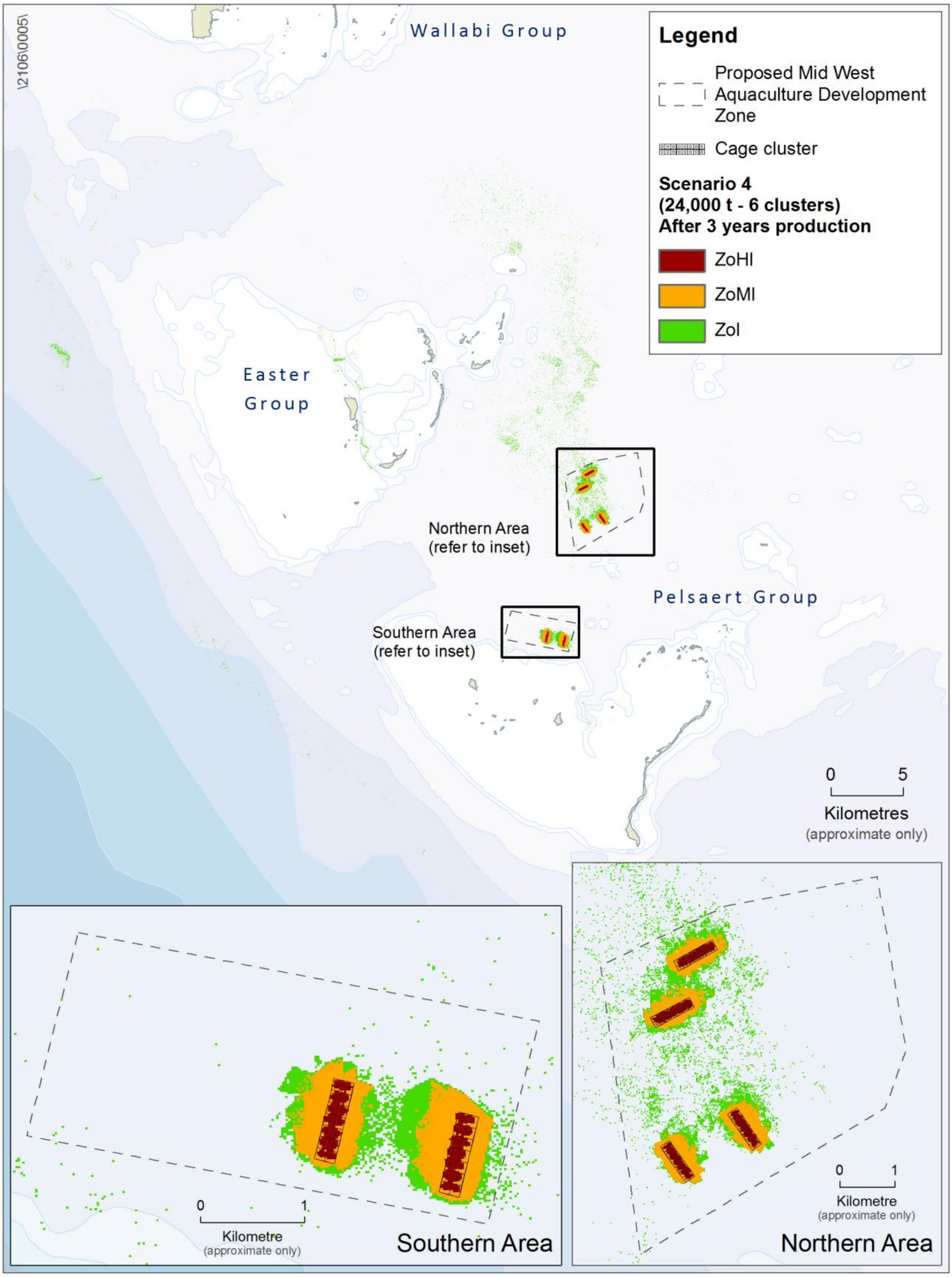


Figure 7-18 Zones of impact under scenario 4 (24 000 t) after 3 years production

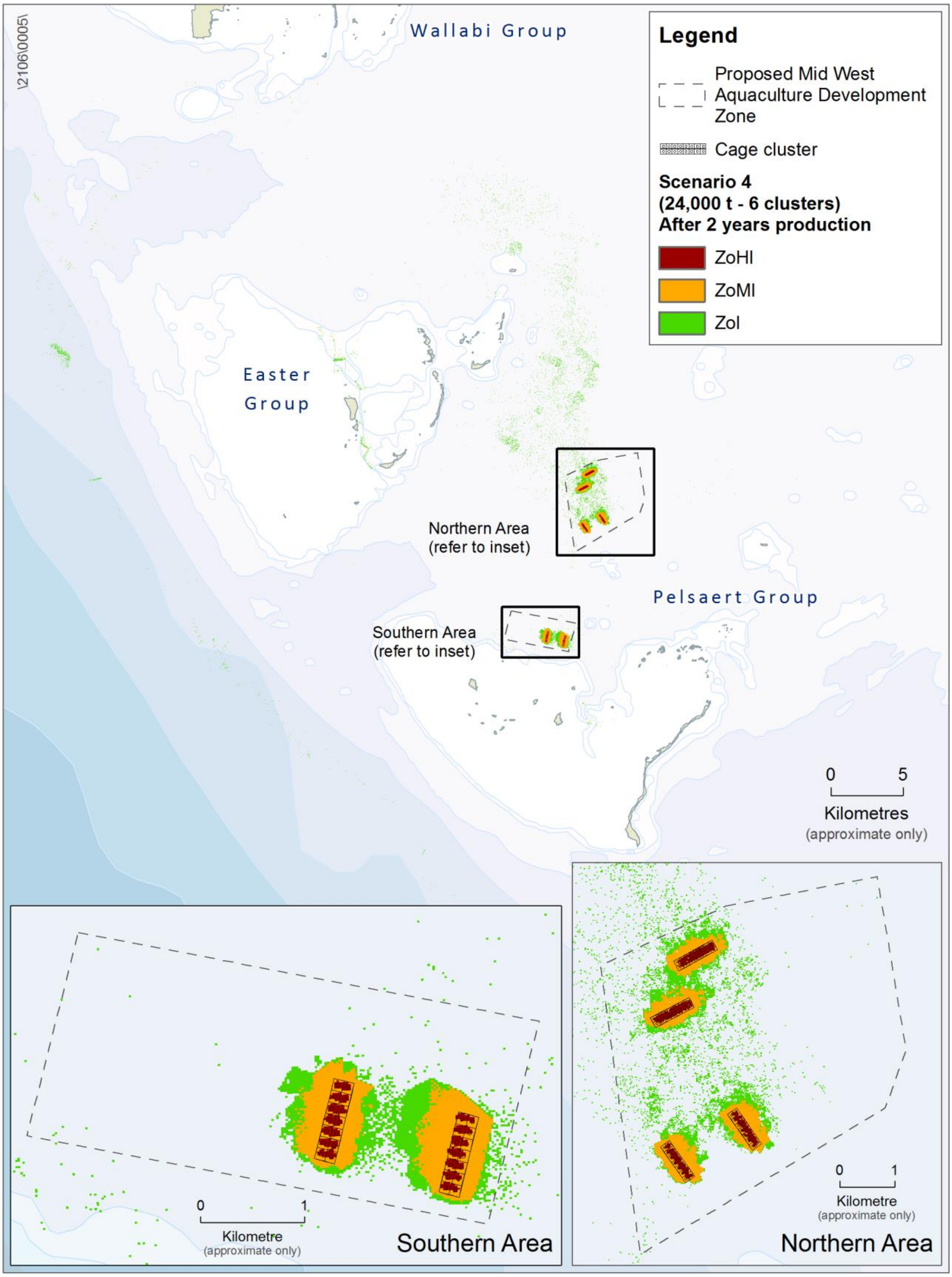


Figure 7-19 Zones of impact under scenario 4 (24 000 t) after 2 years production

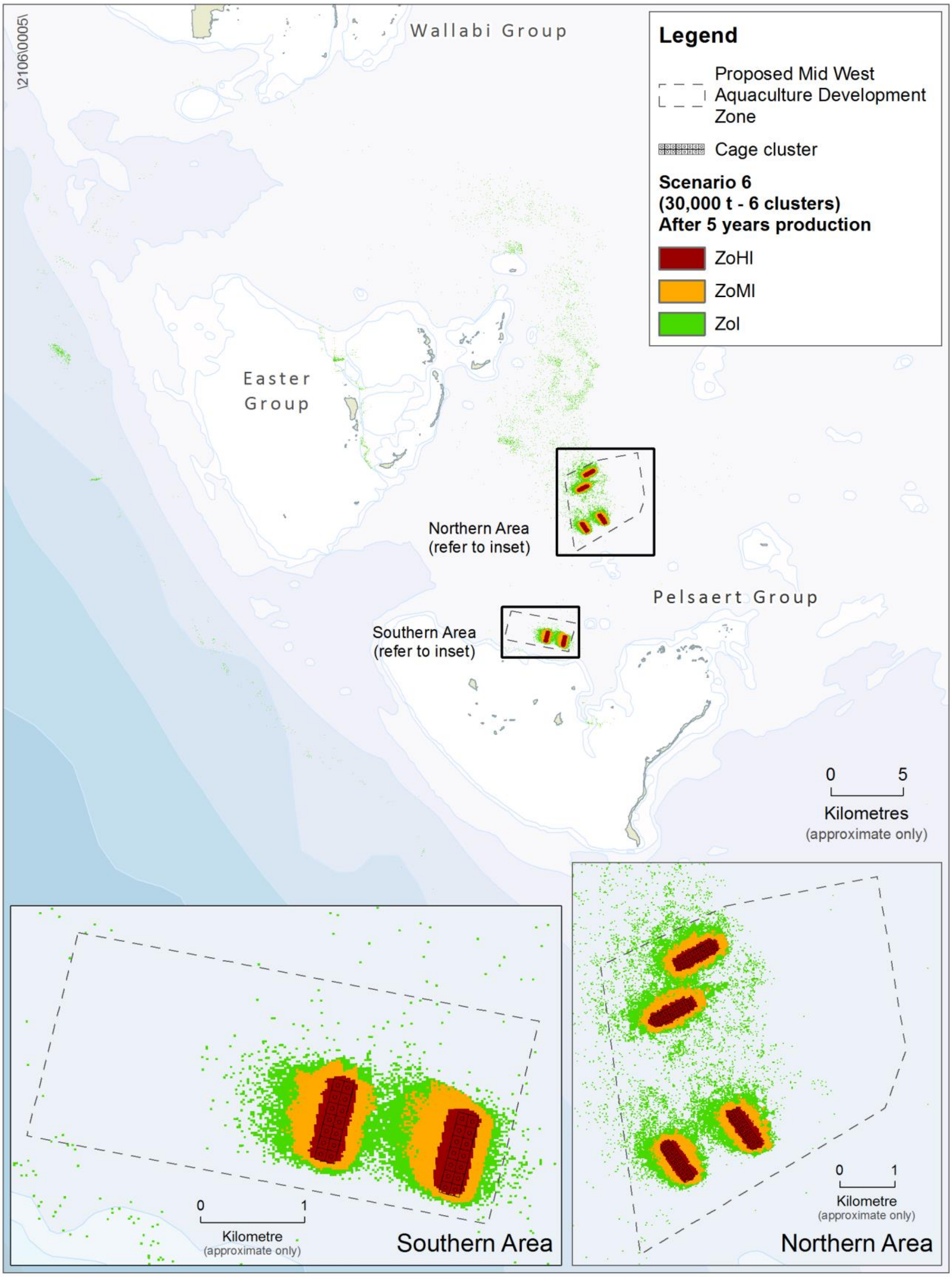


Figure 7-20 Zones of impact under scenario 6 (30 000 t) after 5 years production

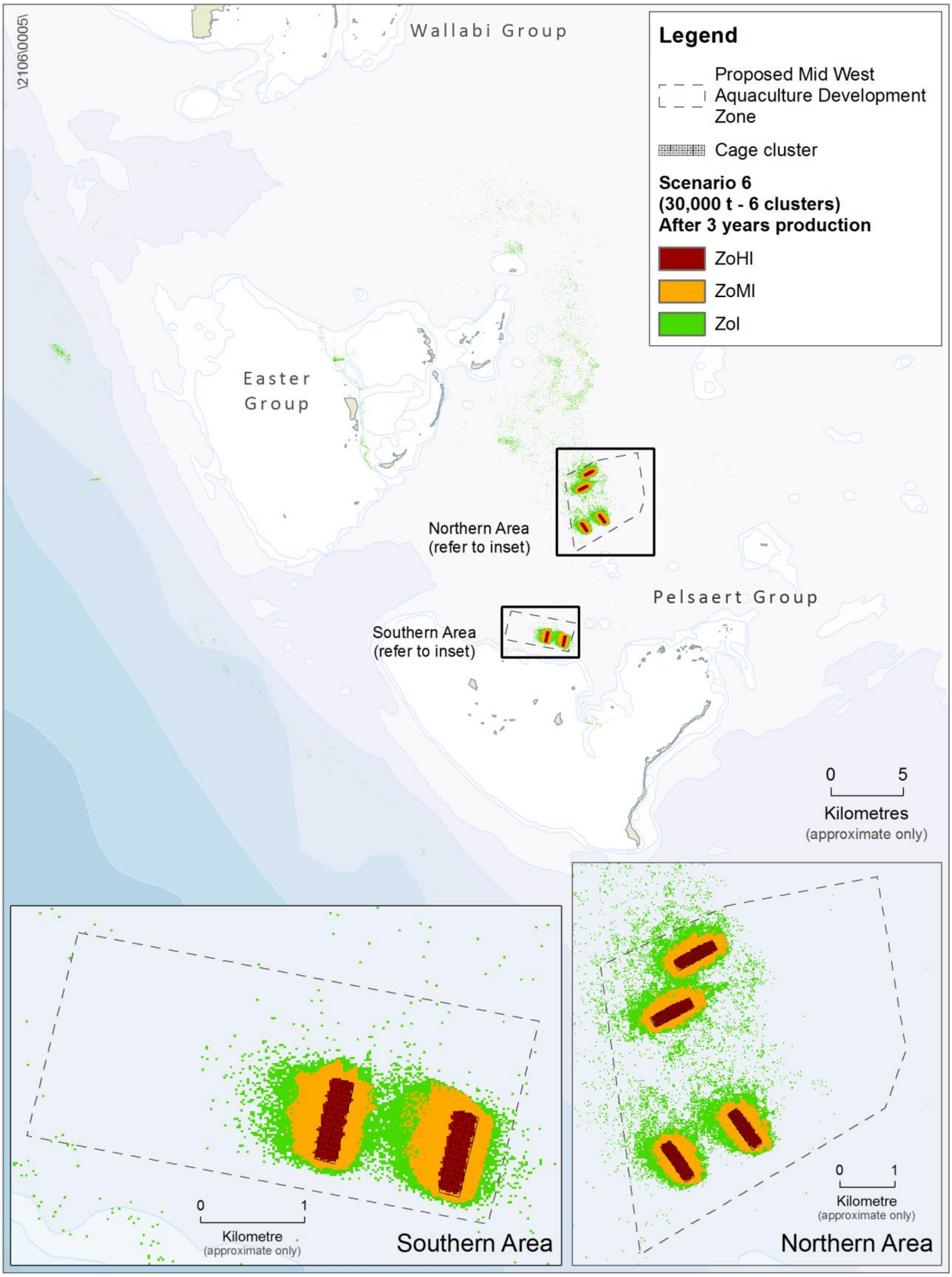


Figure 7-21 Zones of impact under scenario 6 (30 000 t) after 3 years production

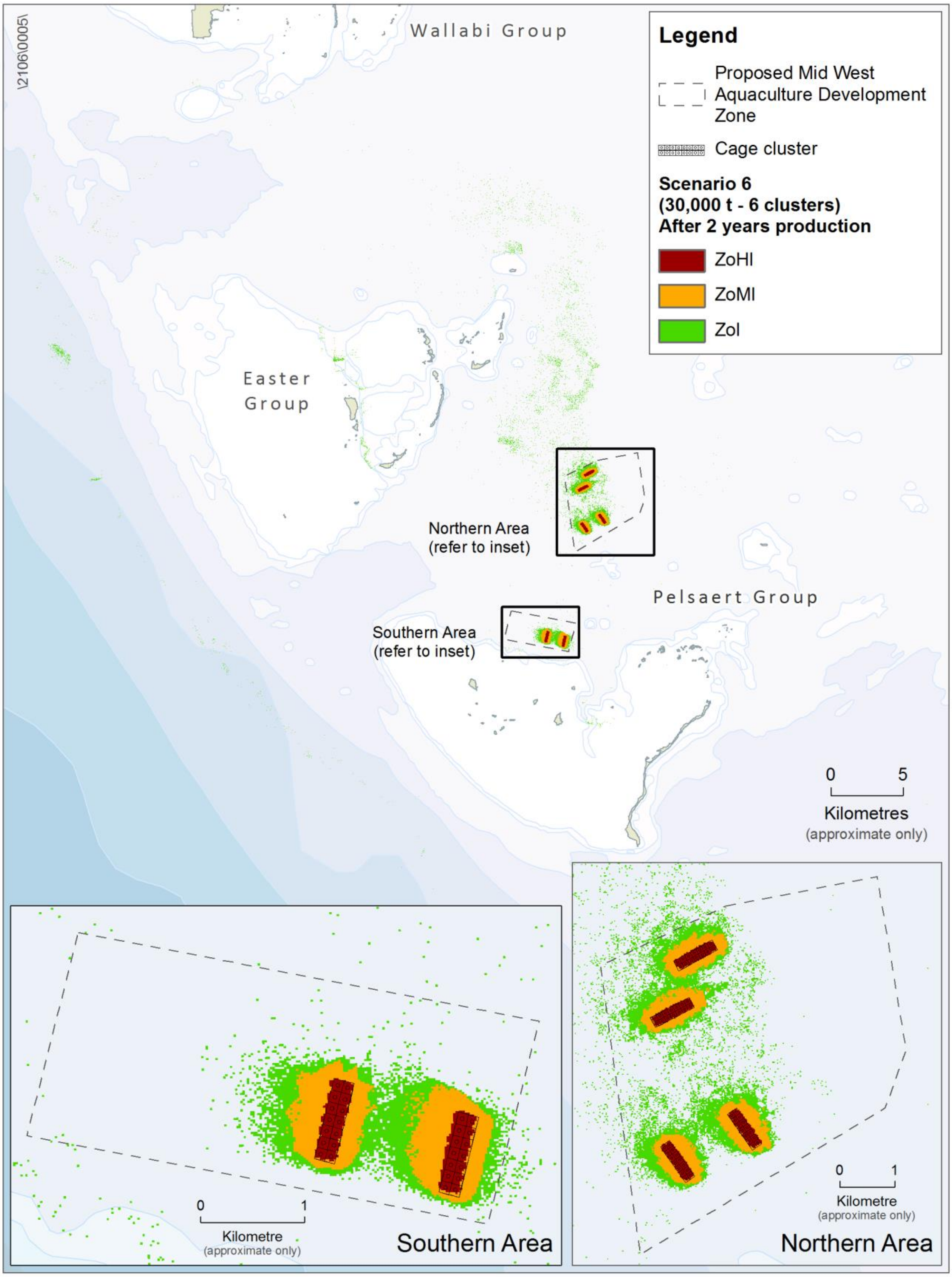


Figure 7-22 Zones of impact under scenario 6 (30 000 t) after 2 years production

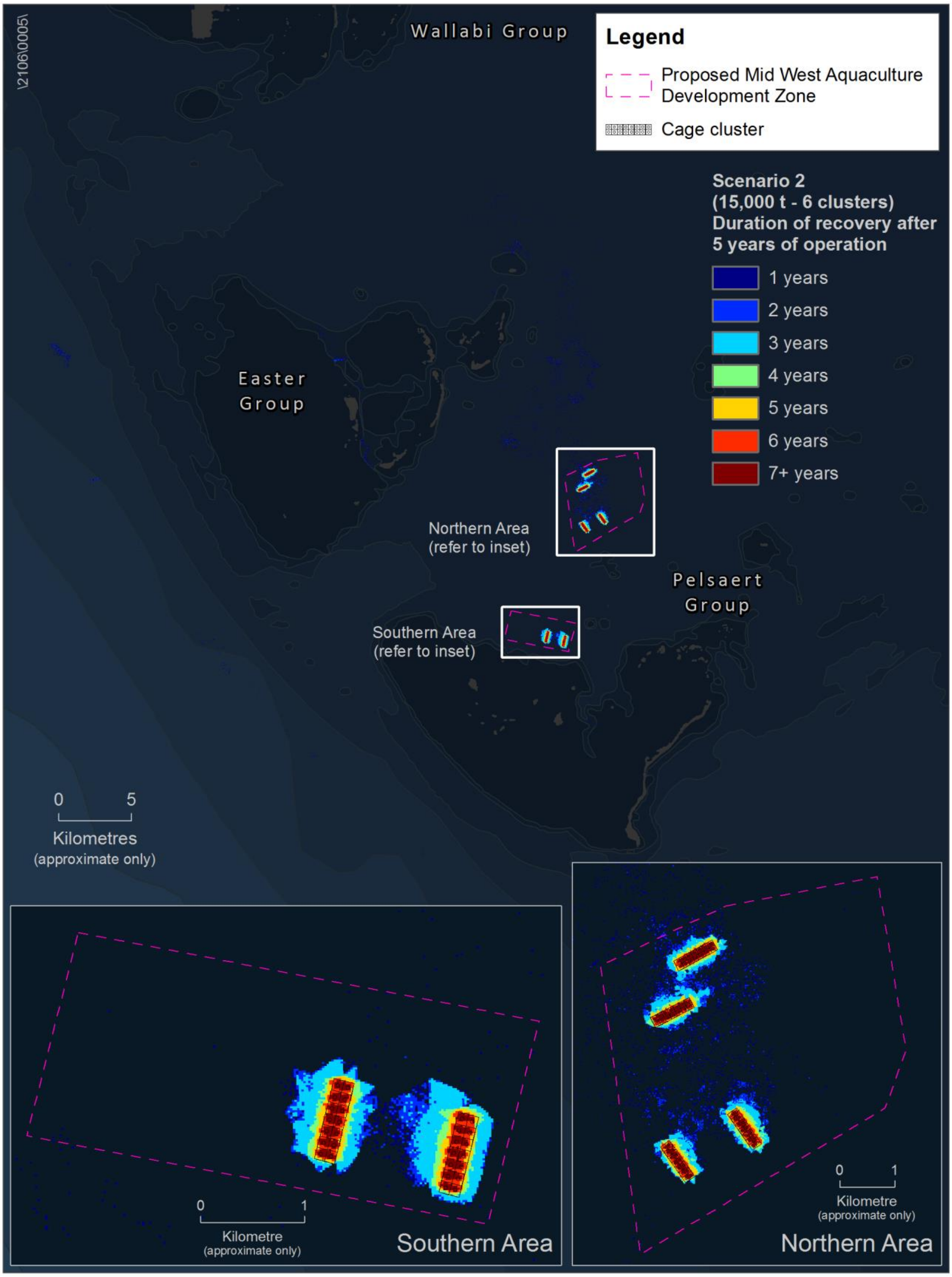


Figure 7-23 Duration of recovery under scenario 2 (15 000 t) after 5 years of operation

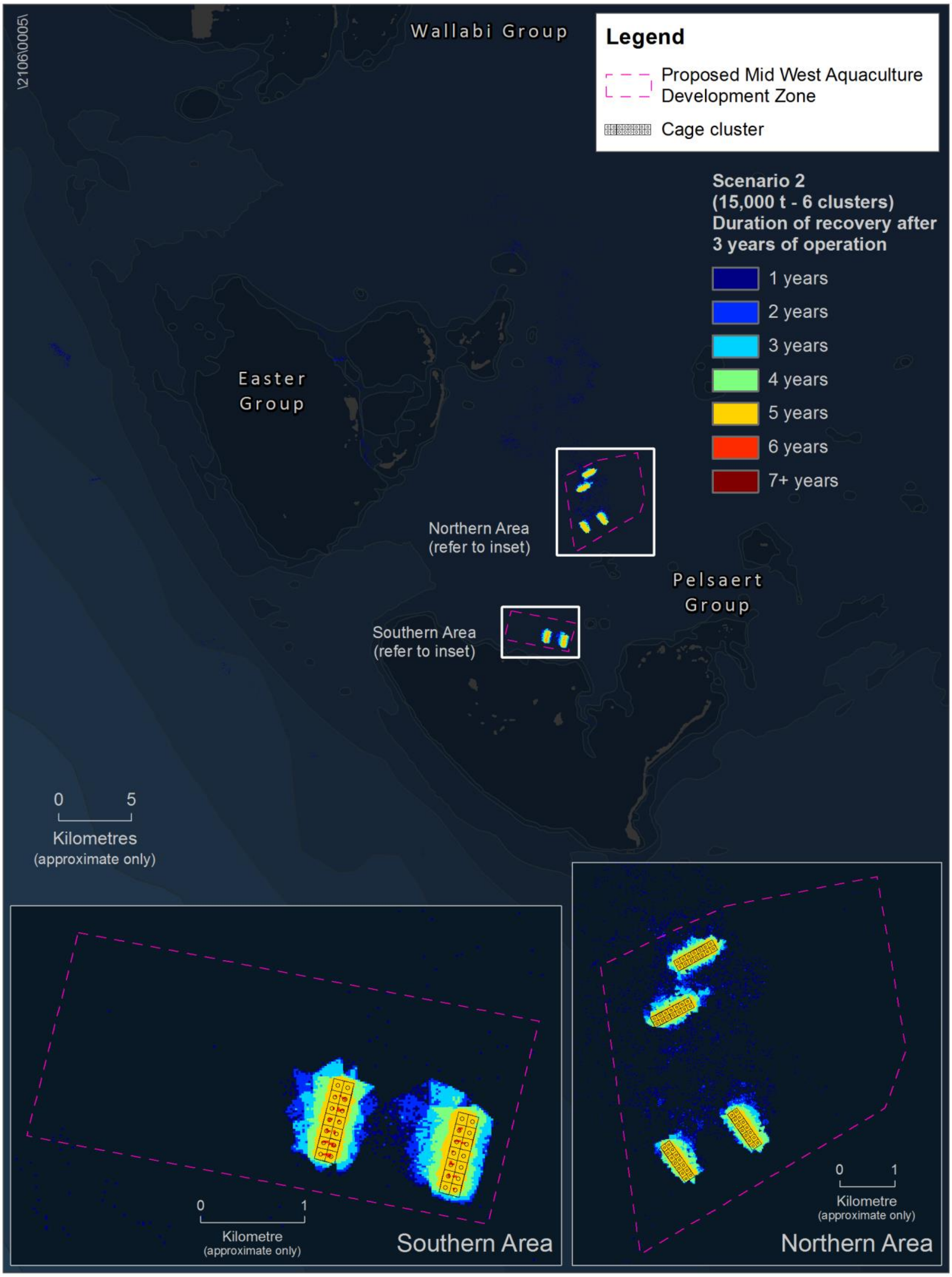


Figure 7-24 Duration of recovery under scenario 2 (15 000 t) after 3 years of operation

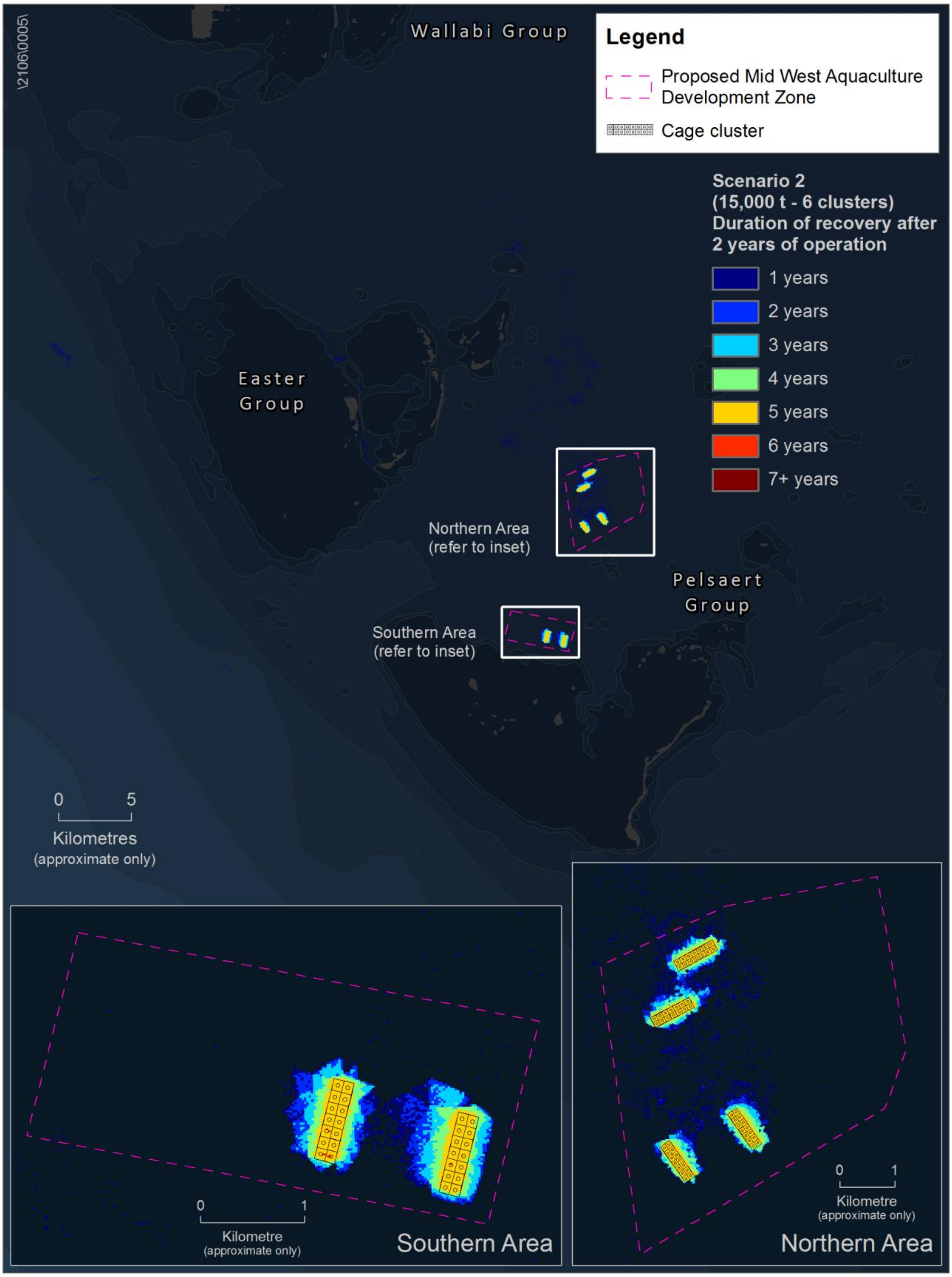


Figure 7-25 Duration of recovery under scenario 2 (15 000 t) after 2 years of operation

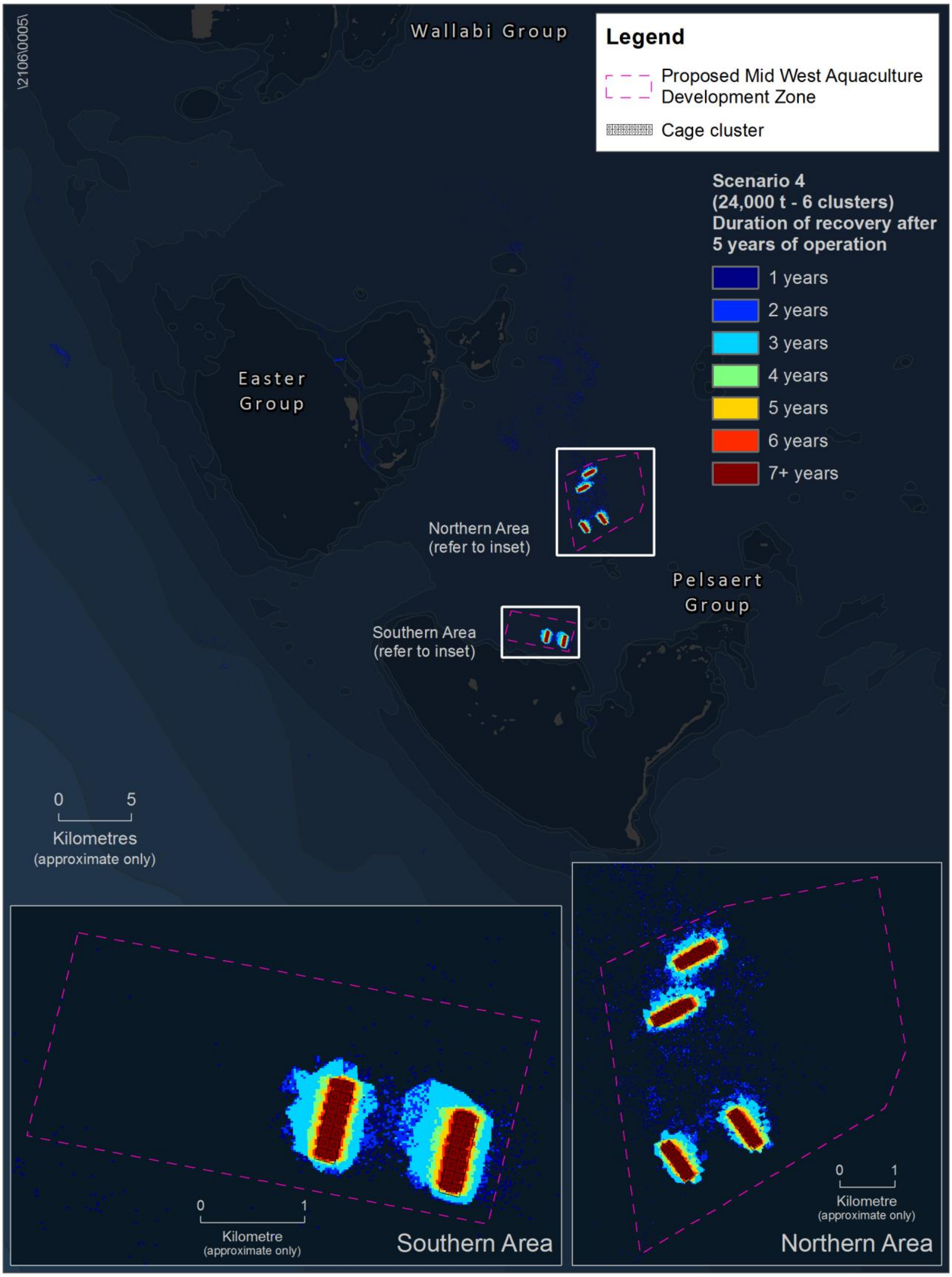


Figure 7-26 Duration of recovery under scenario 4 (24 000 t) after 5 years of operation

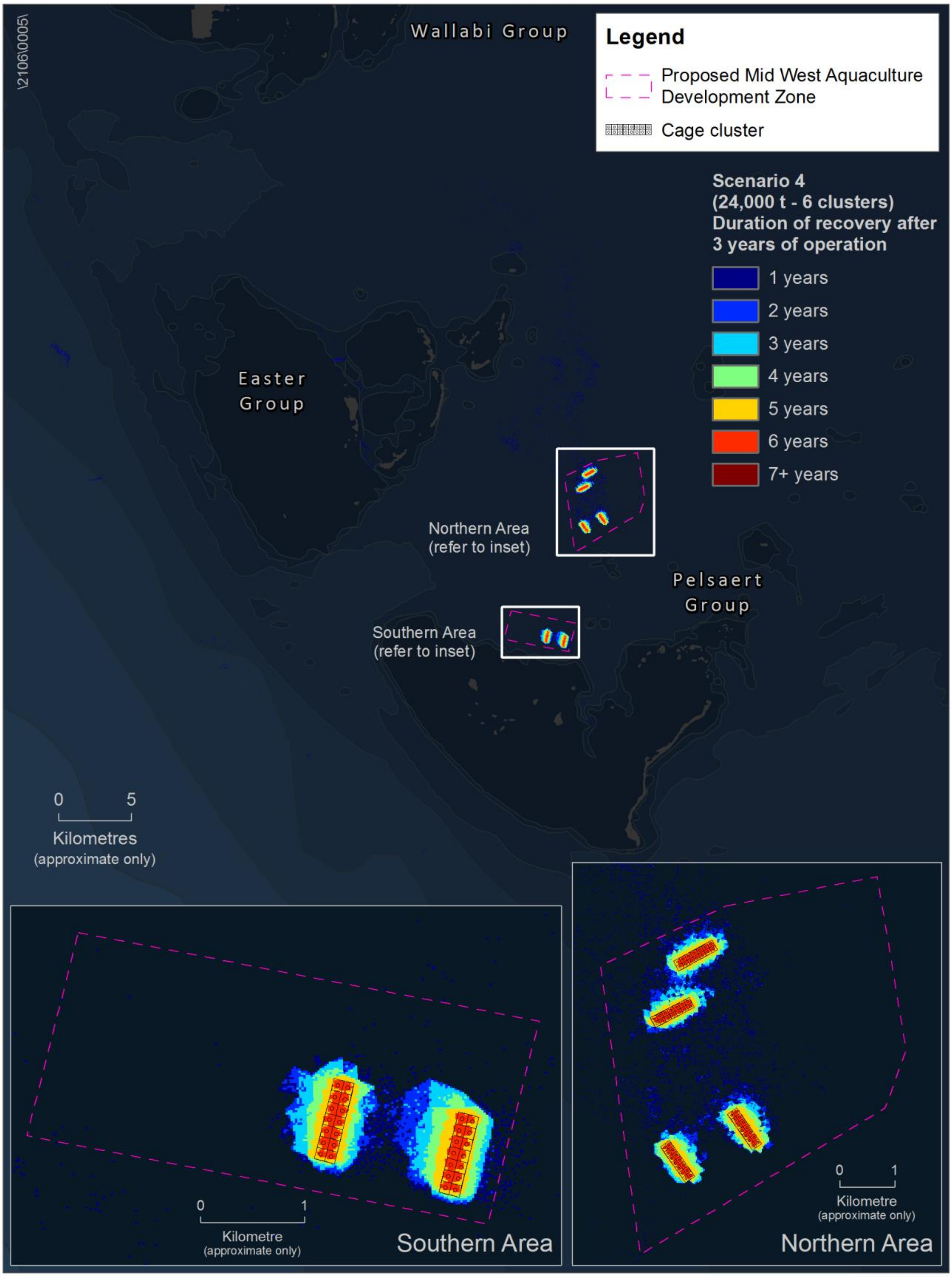


Figure 7-27 Duration of recovery under scenario 4 (24 000 t) after 3 years of operation

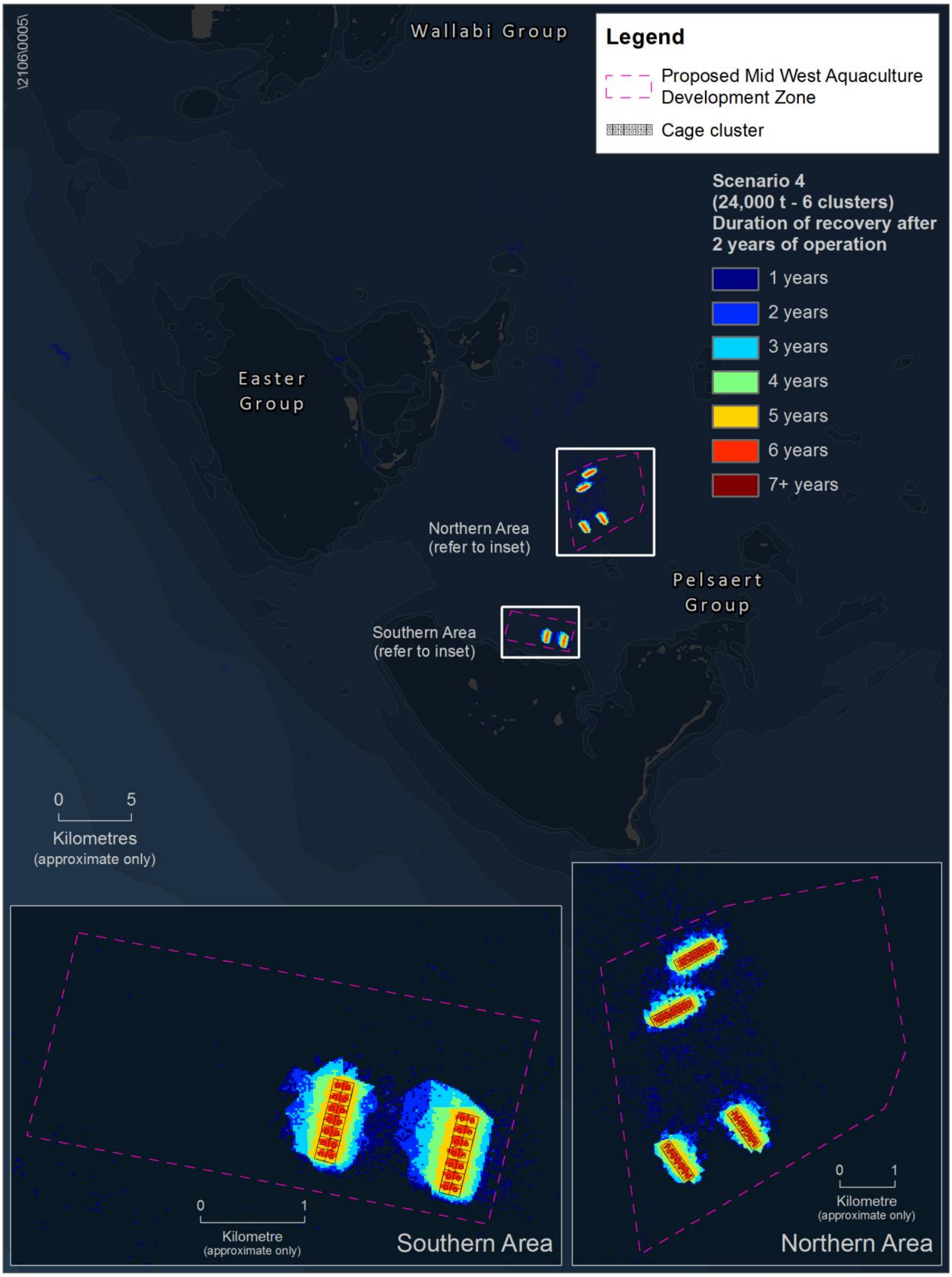


Figure 7-28 Duration of recovery under scenario 4 (24 000 t) after 2 years of operation

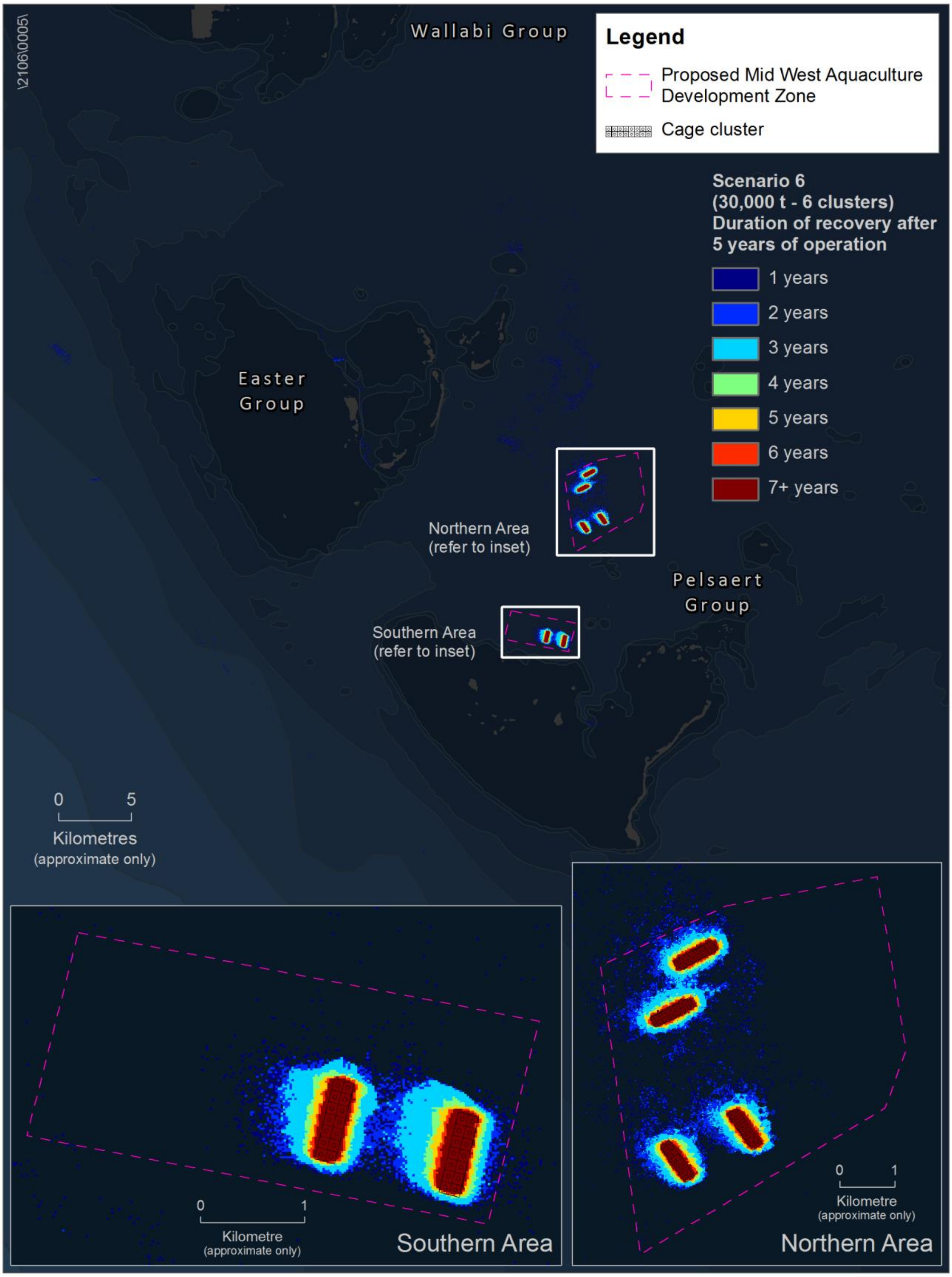


Figure 7-29 Duration of recovery under scenario 6 (30 000 t) after 5 years of operation

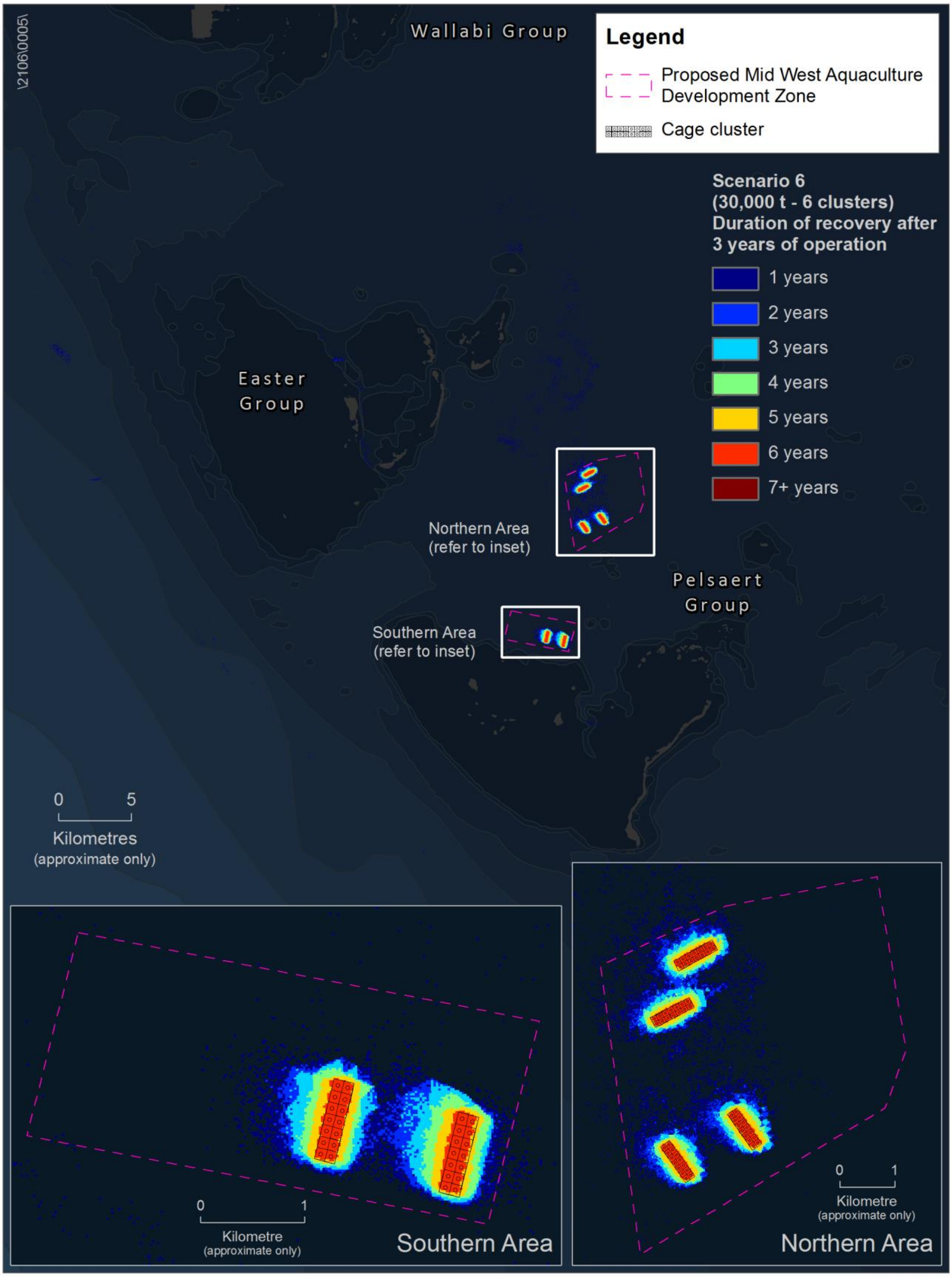


Figure 7-30 Duration of recovery under scenario 6 (30 000 t) after 3 years of operation

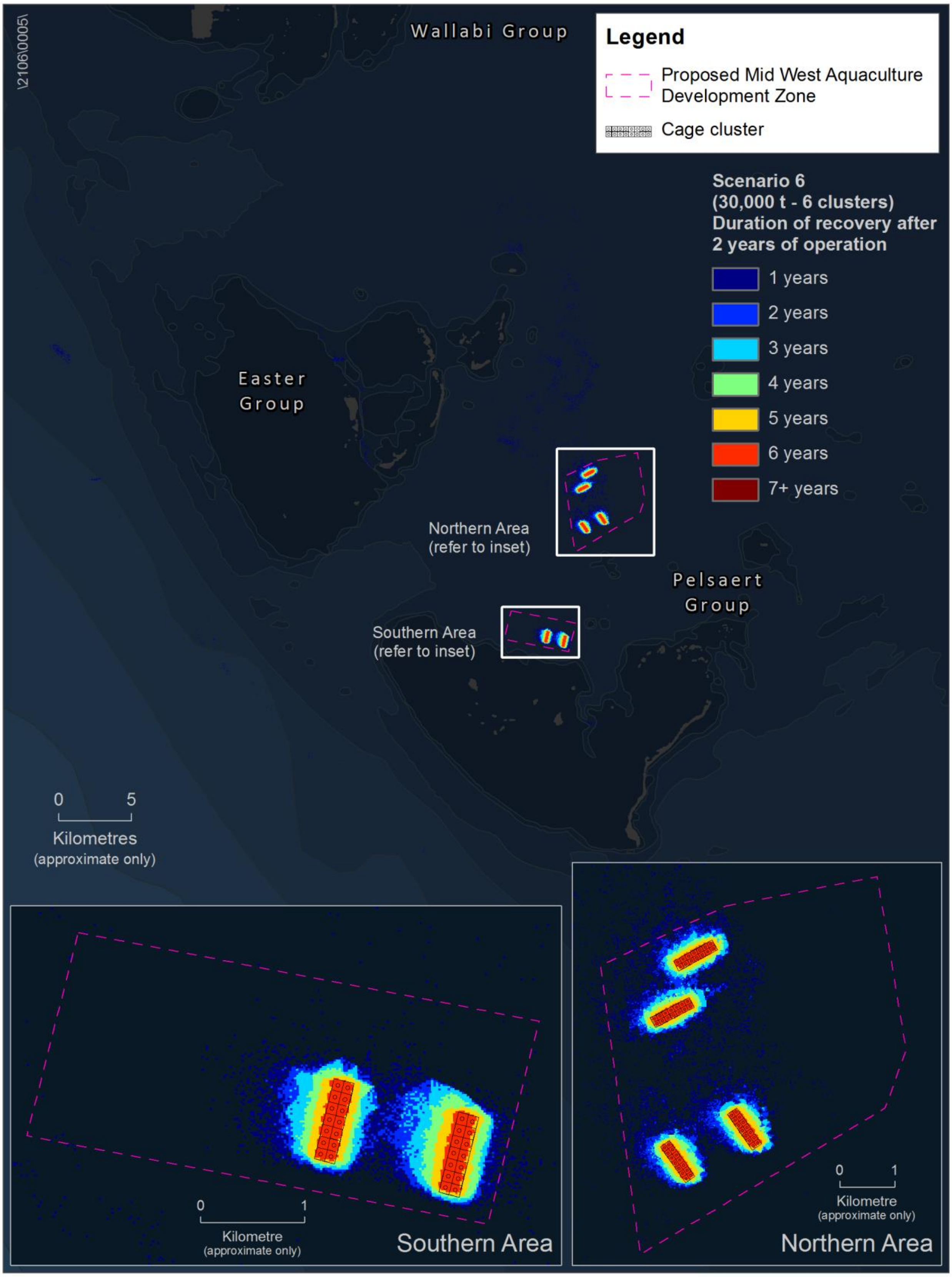


Figure 7-31 Duration of recovery under scenario 6 (30 000 t) after 2 years of operation

Comments on the zone of influence

The spatial extent of the ZoI, and particularly its outer limits of distribution, was driven largely by the dispersion of the smallest faecal fraction (see Section 4.6.1). The extremities of its distribution in the north, the south-west, and particularly in the deeper lagoonal areas of the Easter Group, are an artefact of the modelling. Particles may travel this distance from the cages through resuspension, but they are unlikely to accumulate in the densities shown in the Figures because the model understates dispersive processes at very low deposition rates.

The model does not simulate every single particle released during operations, as to do so would exceed hardware limits such as memory and disk space. Instead, multiple particles are packaged together in a single discrete unit of 10kg, which means that the lowest deposition rate that can be resolved is 10 kg/year. This 'package' will have all the physical characteristics of the particles it is representing (e.g. settling velocities, resuspension dynamics, density) but using it greatly reduces computational overhead. At high deposition rates (e.g. in the vicinity of cages), packaging particles in this manner will not change overall model results, but in areas with low deposition rates (e.g. the lagoonal area of the Easter Group) deposition will be overstated if only a few packages are deposited at the same location.

The accumulations of FOM in the lagoon of the Easter Group (Figures 6.1–6.4) were due in part to the deeper water in this area (leading to reduced wave-driven bed shear stress and, hence, resuspension), but also due to the packaging of particles for modelling purposes as noted above (see also Section 4.6.1). This was only an issue where smaller numbers of particles were involved and the model predicted the spatial extent of the ZoI nearer to the cage clusters much more precisely. The higher precision in this case was driven by the higher number of particles near to the cages compared to the extremities of the zone. The Monte Carlo approach used to predict particle transport is more precise when dealing with large numbers of particles.

Comments on the modelled rate of chemical remediation

Rates of organic matter mineralisation are site-specific and depend, among other things, on the assimilative capacity of the system (Findlay et al. 1995). A review by Brooks et al. (2003) found that biological remediation times varied significantly from a few months to several years (Mahnken 1993, Morrisey et al. 2000, Karakassis et al. 1999). Recovery typically proceeded rapidly in the months directly after fallowing but often slowed as time progressed, presumably because the recolonisation rates of infauna differ (e.g. Mahnken 1993).

Brooks et al. (2004) examined recovery in sediments after >2000 t of salmon were harvested and the cages left to fallow. At peak farming biomass, benthic sediments at the study site were black in colour and characterised by bubbles of hydrogen sulphide and beds of the sulphide-oxidising bacterium *Beggiatoa* spp, with the effects extending between 18 and 145 m down-current of the sea-cage perimeter. In this worst-case scenario, and following four years of fallowing, biological remediation was nearing completion at distances >80 m from the sea-cages but was not complete within this distance. Within 80 m, it was predicted that that chemical remediation sufficient to support half of the common taxa observed at reference sites would be complete 5.4 years post-fallowing, with complete biological remediation requiring a longer period.

The observations described in Brooks et al. (2004) validate in part the recovery times reported here, in which it was predicted that between 6 and 7+ years would be required for sediments directly beneath the sea-cages to achieve chemical remediation (see above). The longer periods of recovery reported in this assessment are perhaps not surprising given the levels of standing biomass examined (between 2600 and 5000 t of finfish per cage-cluster), and the fact that we adopted a highly conservative approach for estimating the volumes of fish waste (see Section 4.6.1).

Variability in the timing of recovery is widely reported in the literature: Macleod et al. (2002) reported chemical remediation after two years (with sulphide levels returning to reference levels), but incomplete biological remediation (infauna were in a transitionary recovery phase, and still significantly different from reference sites). Subsequent work by these authors (Macleod et al. 2006) found that sediment returned to pre-stocking conditions after a three-month period, but did not return to reference conditions. Despite similarities in the way the impact sites were treated in these studies (i.e. stocking levels and feed inputs), there were differences in the recovery response and in the rate of change in infauna community structure. This implies that the link between sediment organic load and recovery is not straightforward and that different locations may need different management strategies, particularly with regard to timing of fallowing (Macleod et al. 2006).

As indicated in Section 4.6.2, rates of chemical remediation as predicted by the sediment diagenesis model were assumed to proceed free of major physical disturbances. Although the model incorporated some capacity for bio-physical disturbance and biological reoxygenation via biodiffusion and irrigation (based on a constant of 20 m^2/y to a depth of 15 cm), neither of these processes accounted for the potential 'resetting' of the sediment during major scour events i.e. such as those which may occur during major storm events or cyclones, the latter of which affects the MWADZ approximately every 2.5 years. The recovery times presented herein are therefore conservative and longer than those which may occur in reality, especially if the 5-7 year recovery period modelled in this assessment was affected by a significant storm event.

7.3.3 Metals

The sediment diagenesis model was also used to determine the time taken for sediments to recover following inputs of waste, including trace elements (Zn and Cu). Triggers were set following the EPAs EQG for high ecological protection (EPA 2014). Although present in commercial feeds and therefore also present in fish faeces, the low molar ratios of Zn and Cu in the fish waste were insufficient to result in sediment concentrations in excess of the EQG, even after five years production at the upper end of the scenarios modelled (S6).

7.4 Mixed assemblages / Water column

7.4.1 Dissolved oxygen

The potential for deoxygenation of the water column beneath and near the sea-cages was investigated using the integrated hydrodynamic, water and sediment diagenesis model. Simulations focused on the bottom half of the water column, which for the project area ranged between 12–25 m and 25–50 m depth. Simulations also included deeper areas (>50 m depth) to the west of the MWADZ, including the leading edge of continental shelf slope. Median dissolved oxygen concentrations at the edge of the continental shelf were lower than the 80th percentile of background concentrations. Oxygen concentrations in the MWADZ maintained normal levels across the scenarios, with no evidence of significant oxygen drawdown even at peak standing biomass (i.e. S6). Results of the sediment diagenesis model, however, point to high levels of biological oxygen demand (BOD) at the sediment water interface (Appendix G). Under the anoxic sediment conditions predicted by the model, waters at the sediment water interface (and in some cases, the layers above the sediment water interface) are likely to experience some oxygen drawdown. However, the extent of water movement through the system is such that the level of drawdown is unlikely to be of any ecological consequence, as oxygen levels are quickly resupplied by new seawater inputs.

7.4.2 Suspended particles

Sea-cage aquaculture produces volumes of organic wastes which when expelled from the sea-cages, settle to the sea-floor. A proportion of these wastes retain potential for resuspension, creating potential for mechanical interference to filter feeding processes. The potential for suspended particles to exceed the thresholds in Table 4.14 was investigated using the hydrodynamic model coupled to the particle transport model (refer to Section 4.6.1).

Under the range of production scenarios (S1–S6) simulated by the model, none produced TSS is concentrations high enough, or over sufficient durations of time (i.e. 50% given the criteria are based on the median value in time) to exceed the thresholds in Table 4.14. Under these thresholds, the EPAs criteria for moderate and high levels of ecological protection were met. However subsequent contextual investigations using a higher time threshold (i.e. 95%) revealed potential for short-term exceedances (5% of the time) of both the high and moderate protection criteria, but only in the northern area. Hence, although there was potential for TSS concentrations in the MWADZ to reach levels higher than background on occasion, the duration and level of exceedance was not sufficient to exceed the published major impact thresholds for filter feeding communities (PIANC 2010).

7.4.3 Smothering

Anecdotal observations, and the results of modelling presented here, suggest that the majority of aquaculture waste settles to the sea-floor immediately beneath the sea-cages (Section 7.3.1). Under conditions of low shear stress, some of this material may accumulate, leading to smothering of resident benthic communities.

The potential for impacts from smothering was investigated using the hydrodynamic model coupled to the particle transport model (refer to Section 4.6.1) and was assessed using thresholds developed for corals (PIANC 2010) (Table 4.11). Corals were chosen because they exhibit poor tolerance to sedimentation relative to other invertebrates (Oceanica 2013), thus providing for a conservative assessment. Rates of sediment deposition were calculated on a square meter basis over a 12 month period, and averaged over a 365 day period. Because modelling assumed constant rates and volumes of deposition, changes related only to variation in current speed (as captured by the hydrodynamic model).

Modelling indicated potential for exceedances of both the minor and moderate impact categories, but there were no exceedances of the major impact category (Table 4.12). Moderate impacts were restricted to S6, and were confined to very small areas immediately under the sea-cages (Figure 7-33). Minor impacts were more prevalent, and were recorded in S5 and S6 (Figure 7-32 and Figure 7-33). The zone of minor impact although proportionally larger than the zone of moderate impact, was nevertheless predicted to be confined to area of seafloor corresponding to the outer boundary of the sea-cage structures.

Under the PIANC (2010) criteria, areas of the seafloor subjected to exceedances of the minor impact criteria could be expected to result in localised mortalities of coral, but not at a spatial scale expected to flow on to more serious secondary consequences. Under the same criteria, areas subjected to exceedances of the moderate impact criteria, could result in locally significant mortalities. From the results, both the zones of minor and moderate impact were predicted to be restricted to area occupied by the sea-cages. While no significant corals reefs were observed in the MWADZ (Section 5.4.5), the potential for impact to sensitive filter feeding communities under the sea-cages should be considered during placement.

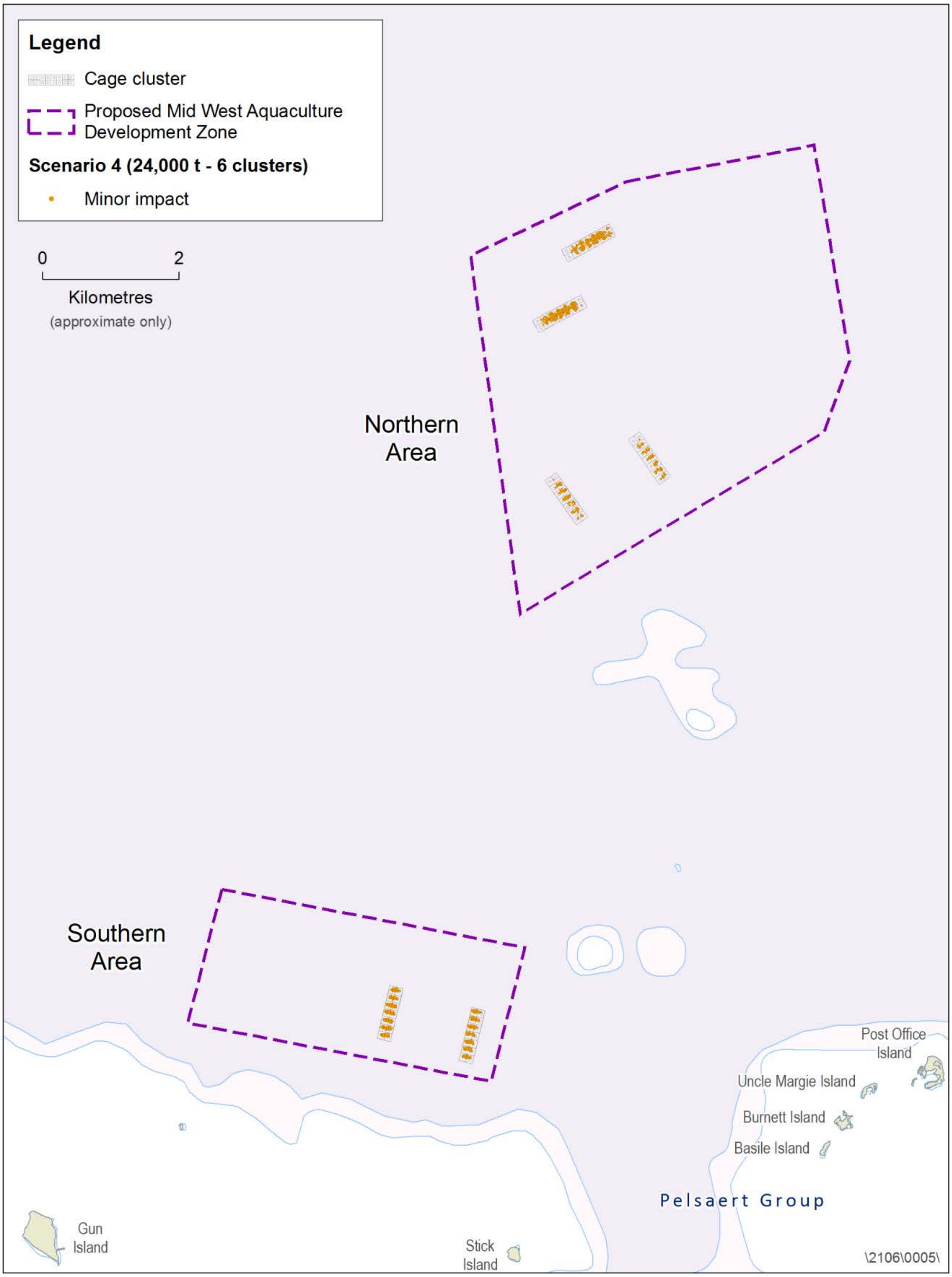


Figure 7-32 Zones of impact based on the rate of material deposition under scenario 4 (24 000 t)

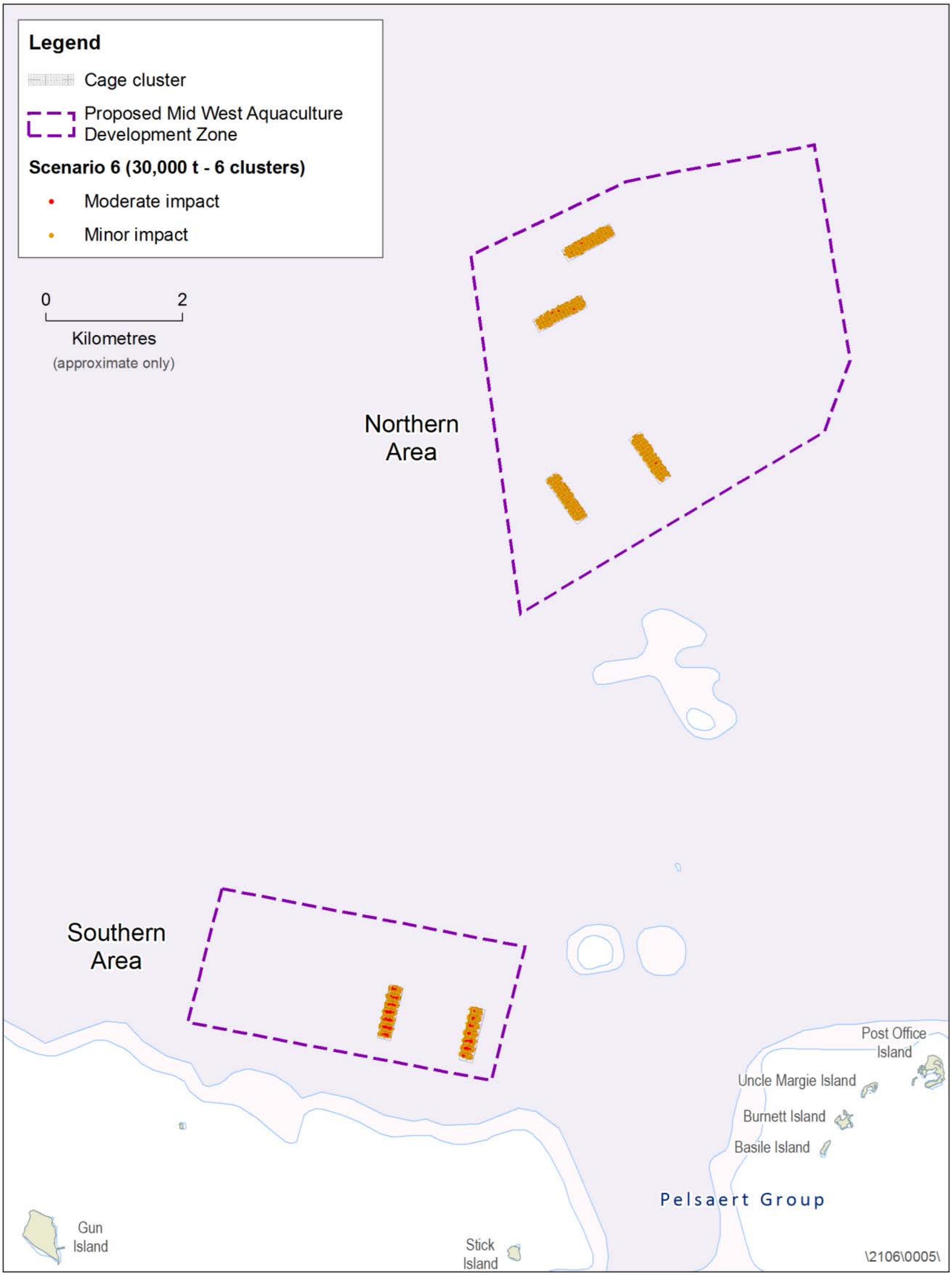


Figure 7-33 Zones of impact based on the rate of material deposition under scenario 6 (30 000 t)

7.4.4 Light intensity

Sea-cage aquaculture has the potential to lead to increased light attenuation (at the benthic level) via a number of cause effect pathways: typically via increases in suspended particles and/or increases in phytoplankton biomass. The potential for light intensity reduction in the bottom strata of the water column was investigated using the coupled TUFLOW FV - AED hydrodynamic and water quality model. The potential for impacts was investigated in the context of the thresholds listed in Table 4.14.

Reductions in PAR of ~15% and ~4% were respectively observed immediately under the sea-cages and to a distance of 100 m from the sea-cage perimeter. However, under the range of production scenarios (S1–S6) simulated by the model, none produced conditions sufficient to reduce PAR to levels exceeding the moderate and high protection thresholds in Table 4.14. The observed reductions in PAR near the sea-cages were the combined result of shading of the sea-cage infrastructure, and the shading effect of suspended particles (fish wastes). None of the observed declined in PAR resulted from increases in phytoplankton. The response of phytoplankton to the varying inputs of nitrogen, as simulated across the range of scenarios, is discussed further in Section 7.4.6.

7.4.5 Algal growth potential (DIN)

The spatial extent and concentration of DIN released from sea-cage infrastructure was investigated under the higher range of production scenarios (S6-S4); Section 4.5.4). Concentrations of DIN near the sea-cages increased with increasing biomass, and increasing stocking density. Scenario S6 produced the highest concentrations and the largest DIN 'footprint', while scenario S4 produced lower DIN concentrations and a smallest environmental 'footprint' (Figure 7-34 and Figure 7-35). The decrease in DIN with distance was driven partly by far-field dilution processes and partly by biological assimilation, both processes simulated in the CANDI-AED-model.

For the purposes of defining zones of impact, acute thresholds were developed following the criteria for high and moderate levels of ecological protection, under which large and moderate changes to ecosystem health, respectively, could be expected (Section 4.5.2). Concentrations of DIN in and immediately adjacent to the sea-cage structures exceeded the moderate ecological protection criterion (95th percentile of background) in both scenarios (S4 and S6), though the areas occupied by this zone were small, and typically restricted to within 150 m of the sea-cage perimeter. The spatial extent of the area exceeding the high protection criterion (80th percentile of background) was more extensive, but varied markedly depending on the scenario, and the position of sea-cages within the zone. The area exceeding the high protection criterion was greater in the northern MWADZ, where the stronger currents acted to carry the plume farther and more rapidly.

Although the area exceeding the moderate protection criteria was small and restricted to the MWADZ, the area exceeding the high protection criteria encroached (and in some cases breached) the boundaries of the northern MWADZ. This was most pronounced in S6 (Figure 7-34), but was mitigated in S4 by reducing the stocking density (Figure 7-35). The area exceeding the combined moderate and high protection criteria represents the area not expected to meet a high level of ecological protection, and highlights the potential for algal growth. The extent to which the simulated elevations in DIN translated to algal growth were examined using the water quality model packages (Section 7.4.6).

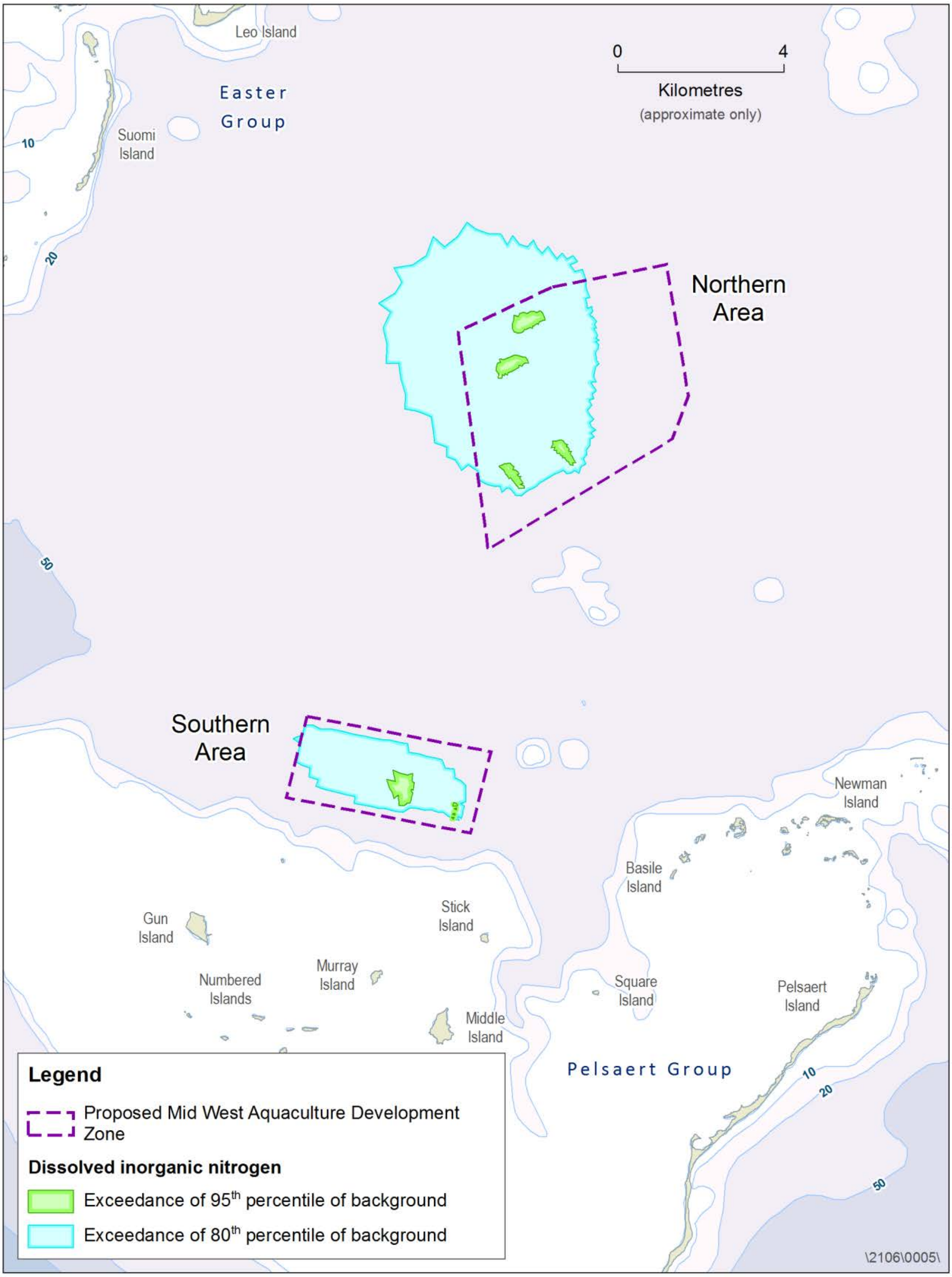


Figure 7-34 Zones of impact based on dissolved inorganic nitrogen in the water column under scenario 6

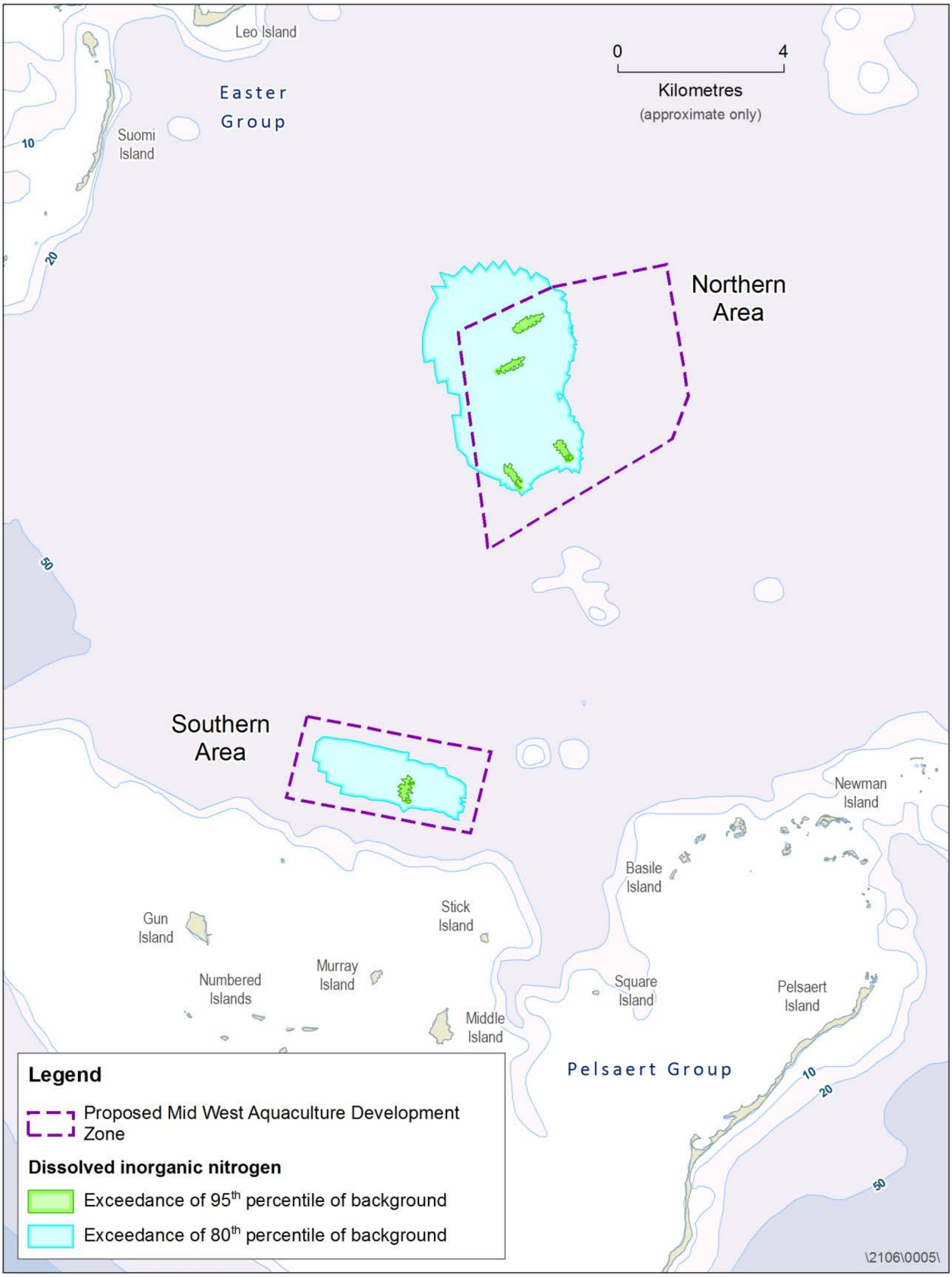


Figure 7-35 Zones of impact based on dissolved inorganic nitrogen in the water column under scenario 4

7.4.6 Nutrient enrichment (chlorophyll-a)

Despite significant inputs of DIN, there were no discernible increases in chlorophyll-a (the proxy for phytoplankton biomass) that could be attributed to sea-cage production, and no exceedances of the moderate and/or high ecological protection criteria in the waters surrounding the MWADZ. A natural gradient of chlorophyll-a was detected between deep waters of the MWADZ and shallow waters of the mainland. Chlorophyll-a in coastal waters sustained concentrations higher than the 95th percentile of background oceanic conditions, even when simulated under baseline conditions, confirming the observed pattern was not a result of aquaculture activities.

The results achieved via simulation are perhaps not surprising given the volume and level of water movement through the project area. Inputs of DIN for scenarios S1-S2 are roughly equivalent to the annual total DIN inputs to Perth's coastal waters via three widely separated ocean outfalls (BMT Oceanica 2015c). Perth's coastal waters, like those of the project area, are oligotrophic and well flushed (but differ in that that they are shallower; 10–20 m depth). Over ten years of intense summer water quality monitoring near these outfalls has failed to detect long-lasting increases in chlorophyll-a due to these regular DIN inputs. Where chlorophyll-a increases have been detected, they have only persisted for a short time (days) and were typically associated with extended periods of low wind (Oceanica, unpublished data). Scenarios S3–S6, although contributing DIN in higher volumes than those contributed to Perth's coastal waters by the ocean outfalls, are indicative of the very high assimilative capacity of the water within the project area, an attribute which is likely enhanced by the depth of the water column (and associated large receiving volume).

8. Impact Assessment – Supported by Literature

8.1 Threatened, endangered and protected finfish

8.1.1 Approach

The potential for adverse interactions between finfish populations and the proposed MWADZ was investigated via two desktop assessments: one focussing on potential impacts to the sustainability of threatened, endangered and protected fish species (sharks and rays) (this section) and the other focussing on potential impacts to invertebrate and finfish species and fisheries (Section 8.2). Section 8.1 provides a summary of the key risks presented by the proposal to the sustainability of threatened, endangered and protected fish populations, focussing particularly on sharks. Text included in this section is excerpted from DoF (2015a). Full details are provided in Appendix B.

8.1.2 Potential adverse interactions

Threatened, endangered and protected fin- fish with potential to be adversely affected by the proposal are outlined in Table 8.1. Although all of these species may be affected by the proposal, locally relevant data for the majority of the species listed in Table 8.1 is scarce. The review was therefore centred on species for which there was available information. The review hence focused on the white shark, grey nurse shark, tiger shark and whale shark.

Table 8.1 Threatened, endangered and protected species of fish potentially affected by the MWADZ proposal

Common name	Family	Species
White shark	Lamnidae	*Carcharodon carcharias*
Shortfin mako		*Isurus oxyinchus*
Longfin mako		*Isurus paucus*
Grey nurse shark	Odontaspididae	*Carcharias Taurus*
Tiger shark[1]	Sphyrnidae	*Galeocerdo cuvier*
Smooth hammerhead		*Sphyrna zygaena*
Scalloped hammerhead		*Sphyrna lewini*
Great hammerhead		*Sphyrna mokarran*
Green sawfish	Pristiophoridae	*Pritis zijsron*
Whale shark	Rhincodontidae	*Rhincodon typus*
Manta ray	Mobulidae	*Manta birostris*

Note:

1. Tiger sharks are not considered threatened, endangered or protected; however, as an iconic species it was included in this assessment.
2. Blue highlighted sections pertain to taxa considered representative of the broader threatened, endangered and protected shark and ray species, and the taxa included in the assessment

Sea-cage farming may adversely affect threatened, endangered and protected species through interactions with the aquaculture related activities (mainly feeding) and infrastructure (sea-cages, vessels). Organic wastes, including fish faeces and feeds, are predicted to exit the cages and accumulate immediately under and adjacent to sea-cages (Section 7.3). Aquaculture waste products in particular are likely to attract smaller fish, which in turn may attract larger predatory species, including sharks.

The key cause cause-effect-response pathways identified in the risk assessment (Appendix B) are summarised in Figure 8-1. Risks are considered particularly in the context of the potential for sea-cage aquaculture to act as an attractant, leading to secondary changes in the behaviour and abundance of threatened, endangered and protected species.

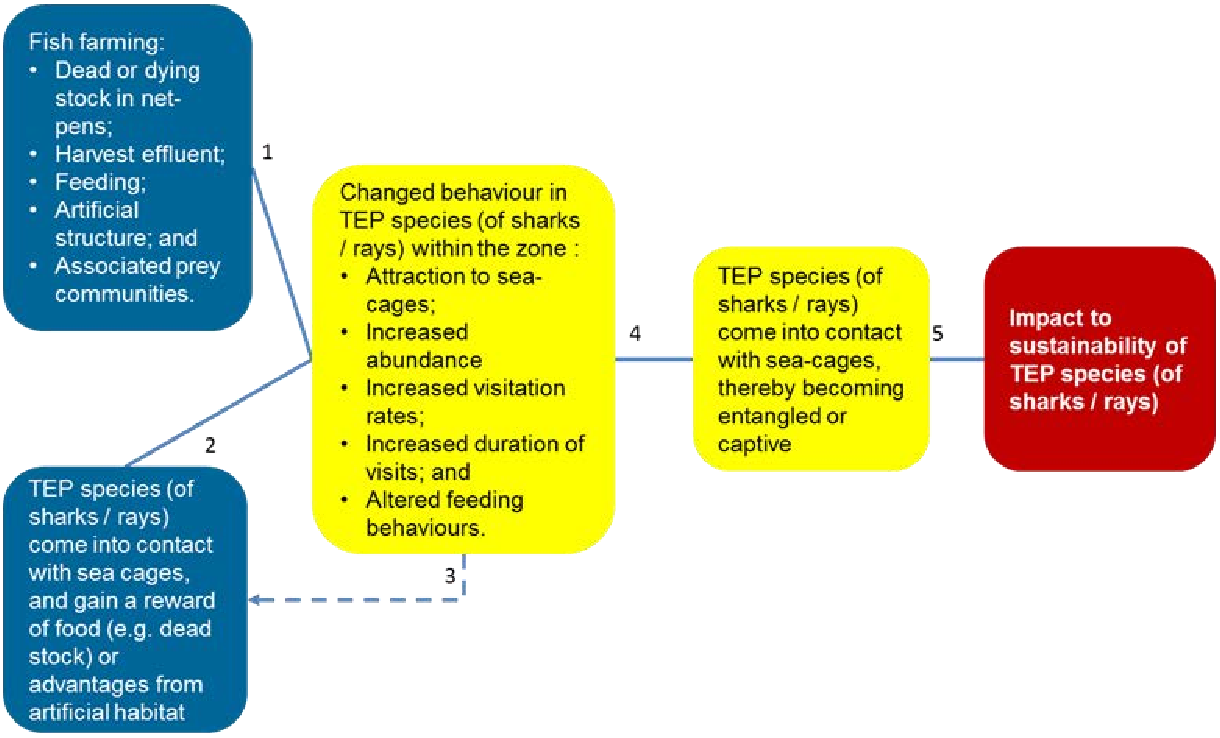


Figure 8-1 Conceptual model of hazards associated with aquaculture and the potential cause-effect pathways which could affect the sustainability of threatened, endangered or protected species of finfish

8.1.3 Possible behavioural responses

Significant populations of sharks currently reside in and in close proximity to the MWADZ (Appendix B). Sea-cages are likely to attract threatened, endangered and protected fish species, leading to localised changes in population structure. Key attractants include: live and dead (or dying) finfish stock, availability of artificial feeds (both pellets and fish waste), harvest activities (blood in the water), and the artificial sea-cage structures themselves, which may serve as shelter, and artificial habitat.

Behavioural responses are likely to include attraction and higher rates of visitation. The increased presence of sharks and rays in the MWADZ is also likely to increase the probability of fauna interactions. Success in gaining provision (via feeding reward) is likely to exacerbate the issue, leading to repeat visitation and increased probability of adverse interactions. At a local scale, the increased presence of sharks in the MWADZ is likely to increase the potential for entanglement or capture.

8.1.4 Major findings and recommendations

Modern fish farms alone are unlikely to cause levels of mortality that will impact the sustainability of threatened, endangered and protected species of sharks or rays. However, fish farms could contribute, by way of a small number of deaths, to the total number of anthropogenic shark mortalities within the region. The review found that the probability of adverse impacts could be reduced (to 'minor') by eliminating, or reducing the probability of interactions, through best-practice mitigation and management strategies, as follows:

- Use of appropriate anti-predator netting materials
- Use of well-designed and durable sea-cages suited to the local environment
- Containment of all post-harvest blood water
- Prevention of food provision through regular removal of dead and moribund stock
- Regular inspections using submerged cameras to detect tears in the mesh
- Controlled feeding regimes and
- Compliance with the industry benchmark of less than 1% feed wastage.

The review indicated that the risk posed to threatened endangered and protected species is low and that the residual risks are manageable, provided the mitigation strategies listed in the bullet points above are implemented and followed for the life of the project. For the full assessment refer to Appendix B.

8.2 Invertebrate and finfish species and fisheries

8.2.1 Approach

Section 8.2 summarises the risks to invertebrate and finfish species and fisheries at the Abrolhos Islands, posed by the introduction of aquaculture sea-cages and associated activities. Text included in this section is excerpted from DoF (2015b). For the full assessment refer to Appendix C.

8.2.2 Potential adverse interactions

The potential for impacts to invertebrate and finfish species and fisheries was assessed via a comprehensive risk assessment. Following the identification of key threats and detailed analysis of hazard pathways leading to potential realisation of these threats, four overarching risks of most relevance to the activities proposed in association with the MWADZ were identified. These were:

- Aquaculture activity in the zone has a significant impact on the populations of invertebrate species (i.e. saucer scallop) in the Abrolhos Islands FHPA
- Aquaculture activity in the zone has a significant impact on the populations of finfish species in the Abrolhos Islands FHPA
- Aquaculture activity in the zone has a significant impact on the invertebrate fishery (i.e. Abrolhos Islands and Mid West Trawl Managed Fishery) and
- That aquaculture activity in the zone has a significant impact on finfish fisheries in the Abrolhos Islands FHPA

The first two risks are risks associated with potential ecological impacts on the species populations. By comparison, the last two risks are risks that essentially comprise the effects of the first two risks (i.e. the ecological impacts) in addition to the potential resource access impacts resulting from the physical presence of aquaculture infrastructure within the MWADZ.

All the above risks were assessed with a consideration of potential cumulative impact using the precautionary approach described in the methodology. This process investigated pathways or cause-effect linkages between hazards and key factors that contribute to a broad risk category.

Results from the risk assessment concluded that the proposal poses a negligible and acceptable risk to three of the four key risks identified. The MWADZ proposal is anticipated to generate negligible impacts on saucer scallop and finfish populations within the Abrolhos Islands FHPA. With respect to the Abrolhos Islands and Mid West Trawl Managed Fishery, the risk assessment identified that the MWADZ proposal poses a low risk, due to the potential to limit the amount of available fishing ground in the fishery.

The key cause-effect-response pathways considered in the review are summarised in Figure 8-2–Figure 8-6.

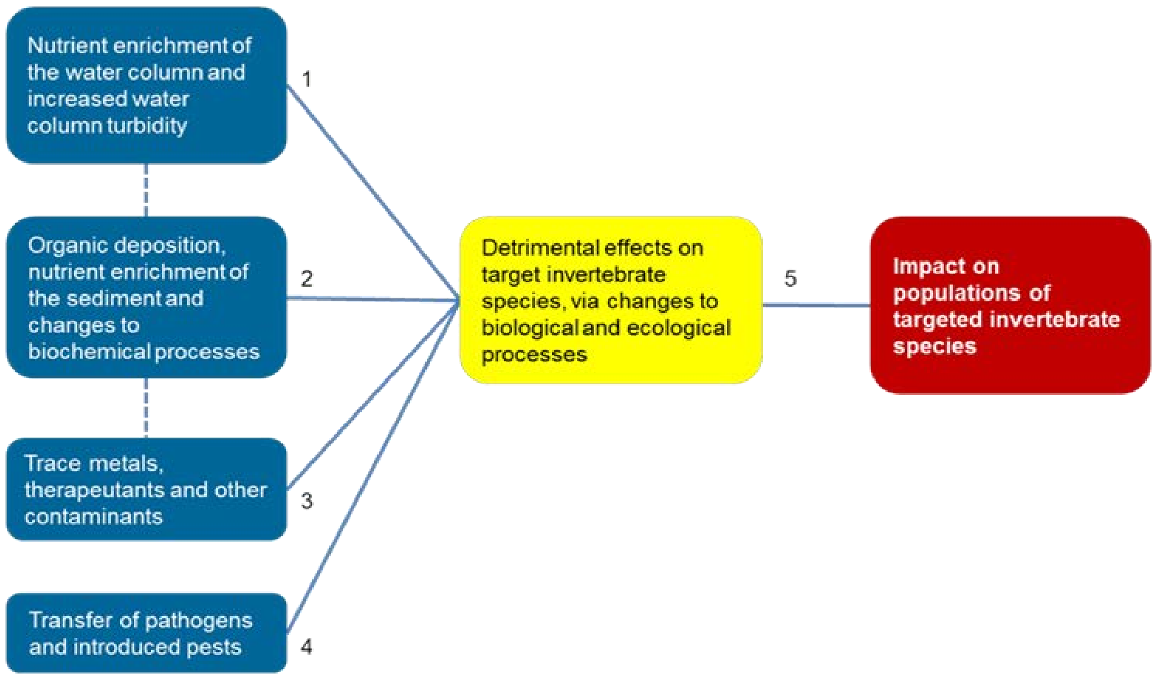


Figure 8-2 Conceptual model illustrating potential cause-effect pathways of possible impacts from finfish aquaculture on invertebrate species populations

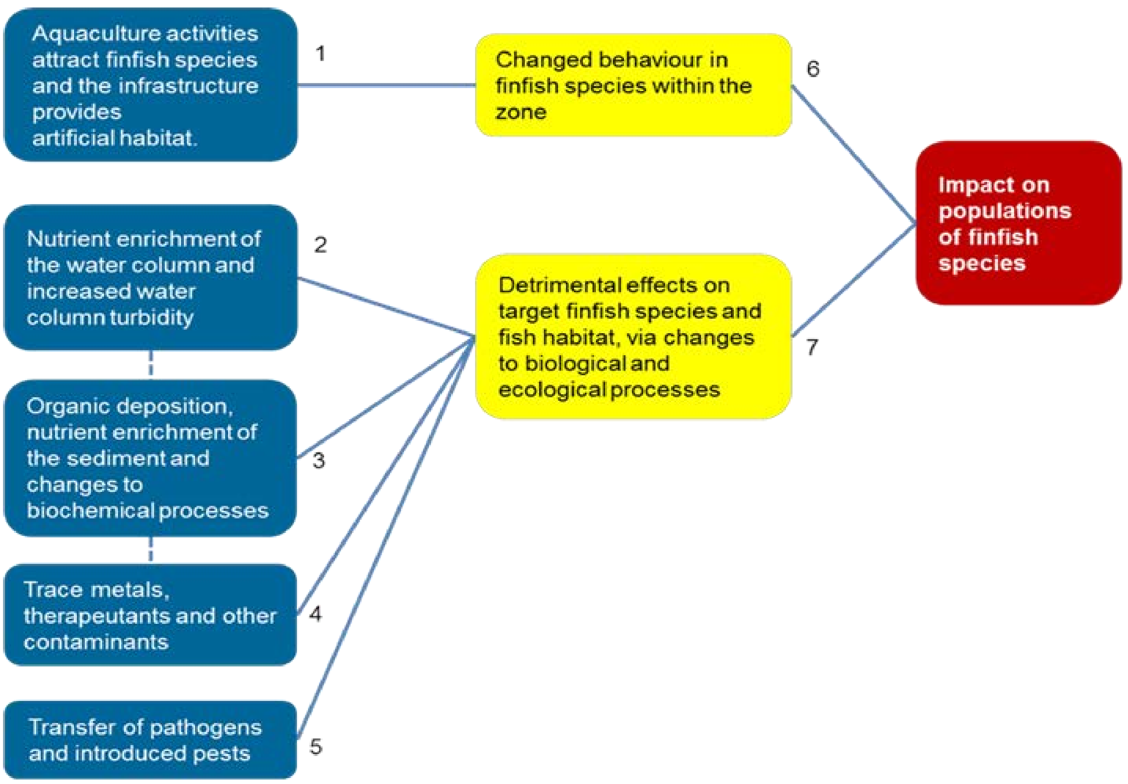


Figure 8-3 Conceptual model illustrating potential cause-effect pathways of possible impacts from finfish aquaculture on wild finfish species populations

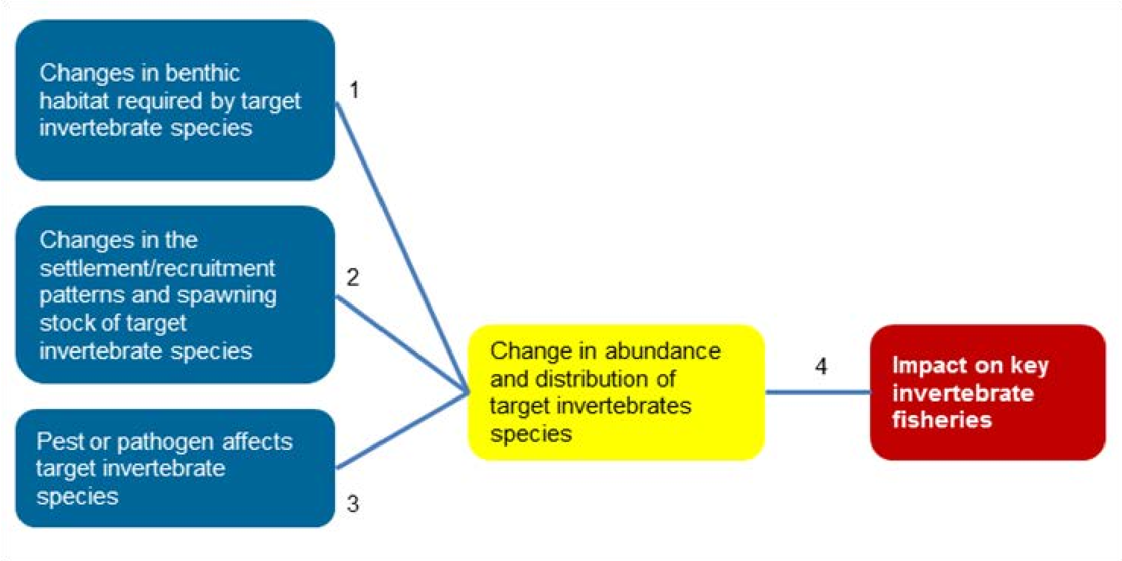


Figure 8-4 **Conceptual model illustrating potential cause-effect pathways of possible impacts from finfish aquaculture on invertebrate fisheries**

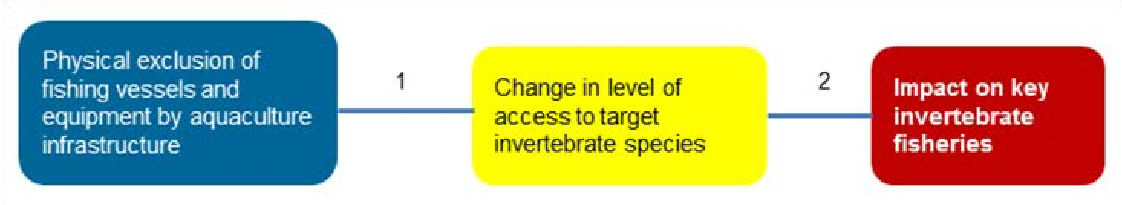


Figure 8-5 **Conceptual model illustrating potential cause-effect pathways of possible resource access impacts from finfish aquaculture on invertebrate fisheries**

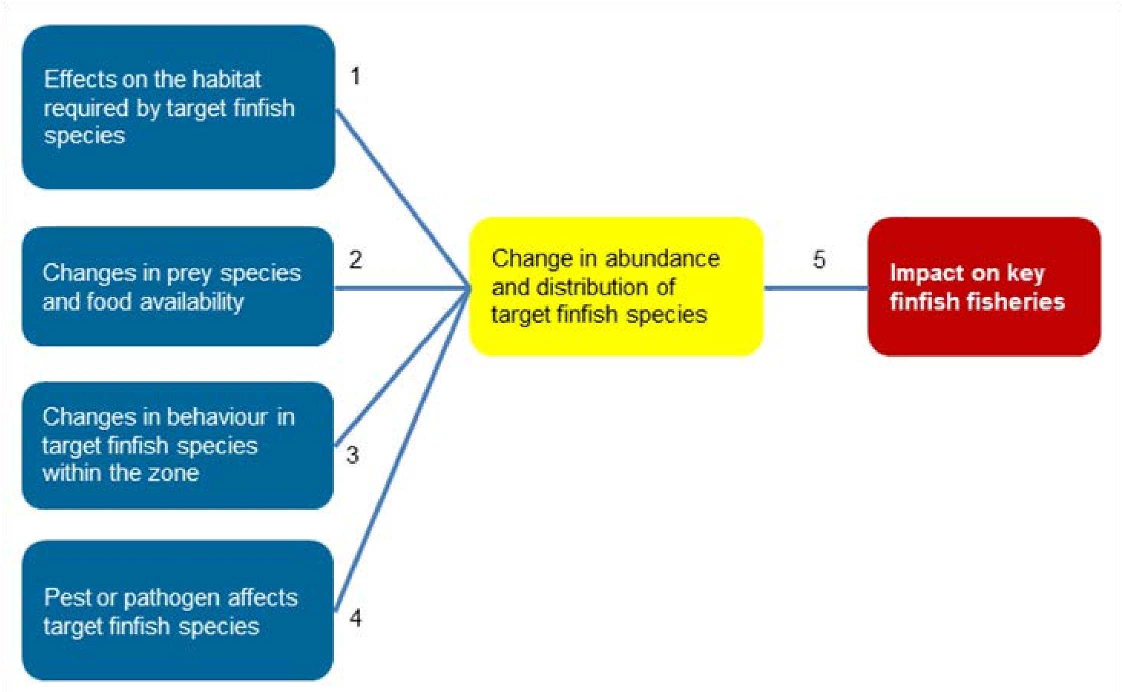


Figure 8-6 **Conceptual model illustrating potential cause-effect pathways of possible ecological impacts from finfish aquaculture on finfish fisheries**

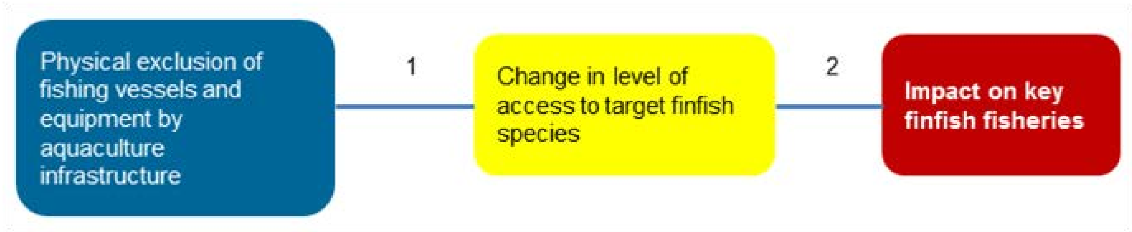


Figure 8-7 Conceptual model illustrating potential cause-effect pathways of possible resource access impacts from finfish aquaculture on finfish fisheries

8.2.3 Possible behavioural responses

Invertebrate populations

Impacts to benthic invertebrates are likely to be limited to very small areas beneath the sea-cages, where rates of organic matter deposition are predicted to be high, irrespective of the production scenario (Section 7.3). Modelled rates of organic matter deposition were considered in the context of the smothering thresholds listed in Table 4.11; Section 4.5.3. Results indicated that the minor and moderate level impacts would be confined to within the cage cluster boundaries (Section 7.4.3).

Under the sea-cages, invertebrates may be adversely affected by organic matter deposition, smothering, interruption to filter feeding processes and changes to sediment biochemical processes. In some circumstances, this may lead to avoidance behaviour in some target species, mortality of sensitive species and/or a change in species composition.

Invertebrate fisheries

Changes in sediment characteristics beneath the sea-cages may adversely affect the survivorship of settled invertebrate juveniles, including scallops. However, as predicted by the modelling (Section 7.4.3), impacts are expected to be limited to the area immediately under the sea-cages.

It is also expected that the presence of aquaculture infrastructure including, anchors, sea-cages and feeding systems may in some circumstances prevent access to potential scallop fishing grounds.

Finfish populations

Some finfish species are naturally attracted to artificial structures, and many are especially attracted to artificial food sources. Aquaculture feeds consist of fish meal and fish oil both of which are known finfish attractants (e.g. Machias et al 2005). It was considered that the combination of food sources and artificial shelters/habitats may attract finfish and alter the behaviour of certain finfish species, across a range of trophic levels. The following behavioural responses were considered likely:

- attraction to or avoidance of the farming area
- increased/decreased visitation rates
- increased duration of visits
- increased/decreased abundance and
- altered feeding behaviours

Finfish fisheries

The proposal may impact fish habitats for non-target species inhabiting sandy areas beneath and adjacent to the proposed sea-cages. However, any impacts are likely to be highly localised and typically restricted to within 110 m of the sea-cages (Section 7.3.2).

The proposal is also unlikely to significantly impact the habitats of target finfish species landed within the MWADZ, i.e. baldchin groper, snapper, West Australian dhufish, spangled emperor, coral trout and other demersal scalefish species. The area proposed for the MWADZ and the potential zone affected by inorganic and organic nutrient dispersal (Section 7.3), represents a very small component of the distribution of these species. As such, the proposed aquaculture activities are unlikely to have significant impact on finfish recruitment patterns and/or the spawning stock of finfish species.

Sea-cages are likely to aggregate some species of finfish and may potentially attract predatory fish including sharks and large pelagic species to the area. This may result in increased numbers of predatory fishes in the vicinity of cages that may be attractive to recreational and commercial fishers (e.g. mackerel, tuna etc.). However, it was considered unlikely that the proposal will lead to significant changes in the abundance and distribution of finfish species within the broader proposal area.

8.2.4 Major findings and recommendations

Invertebrate populations

The area expected to be affected by a decline in abundance of the target invertebrates is negligible relative to the natural range of the species considered (much less than 1 %).

Invertebrate fisheries

The MWADZ proposal is unlikely to cause significant adverse impact to habitats occupied by commercially targeted scallop species from the AIMWTMF. Any changes, if they occur at all, are expected to be localised and constrained within the footprint of the sea-cages.

The presence of physical aquaculture infrastructure requires a relatively small portion of the current fishing ground within the AIMWTMF. The physical presence of aquaculture infrastructure including fish cages, anchors and feeding systems will prevent fishing in the area where the cage clusters are located. Moreover, commercial fishers are likely to avoid areas within the MWADZ, given risks of entanglement.

Finfish populations

The review highlighted the need to reduce, wherever possible, the sources finfish attractants. The following mitigation and management measures were identified:

- removal of dead and moribund stock on a daily basis
- moderate stocking levels
- containment of all post-harvest blood water
- use of a high quality pellet feed
- controlled feeding regimes and
- compliance with the industry benchmark of less than 1% feed wastage

Finfish fisheries

The physical presence of aquaculture infrastructure including fish cages, anchors and feeding systems will prevent fishing in the area where the cage clusters are located. However, under the proposed management policy, the MWADZ will be non-exclusive, meaning commercial and recreational fishers will be permitted to fish the zone under the extent to which they are currently permitted, noting that the current extent of commercial line fishing in the proposal area is relatively minor.

8.3 Marine mammals and turtles

8.3.1 Approach

The potential for adverse interactions between the proposed MWADZ and regionally significant marine mammal and turtle populations was investigated via a comprehensive desktop assessment. Section 8.3 provides a summary of the assessment focussing on the species considered most at risk, the potential adverse effects of sea-cage aquaculture and the potential mitigation strategies that maybe used to reduce the risks to manageable levels. Text included in this section is excerpted from BMT Oceanica (2015b). For the full assessment, refer to Appendix A.

8.3.2 Potential adverse interactions

Thirty-one cetacean and two pinniped species may occur in or near the MWADZ. The species that are likely to be encountered include: the pygmy blue whale; humpback whale, Australian sea lion; Indo-Pacific bottlenose dolphin; and the common bottlenose dolphin. Species with a low likelihood of occurring include: the blue whale; southern right whale; Bryde's whale; killer whale; and the dugong.

Several aspects of the proposal have the potential to impart adverse effects to marine mammals and turtles, including: physical presence of the aquaculture sea-cages, vessel movements and artificial light. The physical presence of sea-cages may change natural feeding behaviours, cause serious injury or change the distribution and migration patterns. Vessel collisions may result in injury, harm or behavioural disturbance to marine fauna, and increased artificial light levels may disrupt or disorient marine turtles (BMT Oceanica 2015b).

The potential for impacts to marine mammals and turtles will be monitored and managed under the EMMP for this proposal, which is published separately (BMT Oceanica 2015a).

8.3.3 Possible behavioural responses

Presence of sea-cages

The physical presence of sea-cages invariably attracts large marine predators, which visit the cages in search of food. Food sources include either the accumulations of wild finfish beneath and around the sea-cages (which provide refuge for certain fish-species), or the aquaculture stock inside the sea-cages. Pinnipeds (fur seals and sea lions) in particular are capable of developing complex predation behaviour, ranging from damaging nets and cages to entering enclosed structures and feeding on the fish inside (Kemper et al. 2003). Once the behaviour is established in individuals, attempts to predate on fish within aquaculture sea-cages may occur all year round with seasonal or daily patterns, potentially resulting in serious injury or mortality to (Vilata et al. 2010). Seals and sea lions have been entangled in the cage nets, anchor lines and anti-predator nets that are designed as a protective barrier around the sea-cages. Entanglements generally result where sea-cages employ larger mesh sizes (>15 cm), have unrepaired holes, open bottom nets and/or loose or baggy nets (Kemper et al. 2003).

It has been determined that pinniped visitation is up to 10 times higher at fish farms that are located within 30 km of significant 'haul-out' sites (where sea lions congregate on land). At Port Lincoln, South Australia, for example, tuna sea-cages were located within 25 km to the second-largest, Australian sea lion breeding colony at Dangerous Reef, directly influencing the high level of pinniped predation observed (Kemper et al. 2003). Since the MWADZ is less than 10 km from the Australian sea lion haul-out site on the Easter Group of Islands, individuals from this population may be attracted to the proposed sea-cages. Recent population viability analyses revealed that all WA Australian sea lion populations are extremely vulnerable to additional

mortality pressure, the impacts of which may lead to population declines, reduced survivorship and increased extinction risk for the species (Campbell 2005). Habitat degradation and interactions with aquaculture operations were identified as significant factors contributing to the lack of recovery for the species (DSEWPaC 2013a, b). Therefore, any threat of incidental mortality, including potentially negative impacts from aquaculture operations, may significantly affect Australian sea lions populations at the Abrolhos Islands.

Cetaceans also have a history of adverse interactions with sea-farms. In the Mediterranean Sea, coastal marine fish farms experienced a year-round presence of common bottlenose dolphins that were likely foraging opportunistically at or around the fish cages (Lopez & Shirai 2007). Entanglements have occurred, especially when the anti-predator nets are loose, and employ large mesh sizes (>15 cm). Furthermore, a recent Mediterranean study concluded that productive waters around aquaculture sea-cages attracted bottlenose dolphins and altered their foraging strategies, while they fed on discarded fish from the cages (Piroddi et al. 2011). In Australia, non-fatal and fatal entanglements in anti-predator nets with large mesh sizes (>15 cm) have been documented across several dolphin species, including common, bottlenose and dusky dolphins (Kemper et al. 2003). From these documented cases, the proposed MWADZ may have impacts on bottlenose dolphins, including indirect changes to their natural foraging behaviours and directly, via serious injury or mortality due to entanglement in anti-predator nets.

Adverse interactions between whales and aquaculture sea-cages have also been recorded. A humpback whale became entrapped within a sea-cage in Port Lincoln, and an unidentified whale is documented to have collided with a salmon cage in Tasmania (Pemberton et al. 1991, Kemper et al. 2003). Between 1982 and 2010, five humpback whales have become entangled in WA aquaculture gear for abalone, pearl and mussel (Groom & Coughran 2012). Humpback whales are common in the Abrolhos region (DSEWPaC 2013a), and there is therefore an elevated risk of adverse interactions with the MWADZ.

Additionally, the presence of sea-cages has the potential to adversely impact the marine environment through nutrient enrichment, which is a management concern for marine fauna, particularly marine turtles and dugongs (DSEWPaC 2012b). Inputs of inorganic nutrients, primarily dissolved inorganic nitrogen, are rapidly assimilated by phytoplankton. Under ideal conditions, inputs of nutrients may lead to excessive phytoplankton growth, resulting in extensive algal blooms (see Section 4.4.1); though, for this proposal, the risk of algal blooms is considered low (Section 7.4.6). Algal blooms are associated with reduced growth, development and reproduction in turtles (DSEWPaC 2012b).

Vessel movements

The proposed MWADZ will employ a range of vessels for operations, including maintenance, feeding and harvesting. Vessel presence and movements may directly (i.e. injuries and mortalities from collisions) and indirectly (i.e. behavioural disturbance from noise) impact marine mammals and turtles. The likelihood of a serious injury or mortality for a large whale from a vessel strike decreases when vessels travel at speeds less than 15 knots (Vanderlaan & Taggart 2007). Although dolphins are known to avoid moving vessels, large whales and turtles may not respond to approaching vessels depending on their activity at the time of collision. Behavioural disturbance may be indicated by various reactions, including (but not limited to) avoidance, swimming speed changes, quick dives, breathing changes and aggression (DEH 2006). Vessel collisions may incidentally injure or kill dugongs while feeding in shallow inshore waters, and dugongs are known to habituate to vessel traffic and disturbance, thereby increasing the likelihood for collisions and injuries (DSEWPaC 2012b). Management measures to reduce the likelihood of adverse impacts from vessel movements may include restrictions for approach distance and speed limits, as per the Australian National Guidelines for Whale and Dolphin Watching 2005 (DEH 2006).

Artificial lights

For safety, navigation and operational reasons, the proposed sea-cages may require lighting at night. Artificial lighting may cause adverse environmental impacts to marine fauna that are sensitive to light (such as marine turtles) by disrupting their natural behaviour through disorientation, attraction or avoidance (EPA 2010). Adult female turtles are known to avoid nesting at beaches illuminated with artificial light, and hatchlings depend on natural light to navigate to the open sea and maybe misguided by artificial light.

8.3.4 Major findings and recommendations

Sea-cage aquaculture has the potential to adversely impact marine mammal and turtle populations via a number of cause-effect-response pathways. Experiences elsewhere have shown that risks are exacerbated by farm practices and the choice of infrastructure. For example, incidents of visitation were heightened where excessive wastes (fish carcasses) were present in the water, and incidents of entanglement occurred in predator nets with mesh sizes greater than 15 cm. Other operational aspects that may increase the potential for adverse interactions included use of high intensity artificial light, excessive noise and vessel speeds greater than 15 knots.

Efforts to reduce interactions with Australian sea lions and bottlenose dolphins may include controlled feeding regimes, prompt removal of dead fish, tensioning nets and employing anti-predator nets with mesh sizes less than 15 cm in diameter (Schotte & Pemberton (2002) recommend mesh sizes of ~6 cm diameter). The most successful mitigation strategy requires physically excluding the fish stocks in the cages and during any movements or transfers (Robinson et al. 2008). Examples of the types of management measures to be implemented are provided in Table 8.2. All management options would most effectively be employed during routine operations, and/or incorporated to the aquaculture infrastructure. Compliance with the recommended approaches is likely to be assessed via an audit of operation records, including records of interactions with marine mammals and turtles.

Table 8.2 Summary of project aspects, potential environmental impacts and possible management measures for interactions with marine mammals and turtles

Project Aspect	Potential Environmental Impact	Possible Management Measures
Aquaculture cage	Feeding behaviour change Serious injury or mortality Habitat change	Anti-predator nets (mesh size <15 cm) Constant maintenance and monitoring Controlled feeding regimes to minimise waste and prompt removal of dead stock Use of semi-rigid or well tensioned net material Adequate distance from known fauna habitats High walled sea-cages to prevent pinniped access
Aquaculture activities	The availability of supplementary food (stock feed) may change feeding behaviour Noise associated with the installation of cages may cause behavioural disturbances	Controlled feeding regimes – to minimise feed waste Prompt removal of dead stock Noise levels at all times will be within Environment Protection (Noise) Regulations thresholds and it is preferential to install the cages outside of humpback whale southern migratory months (given humpback whales are the only "likely" migratory cetacean)
Vessel movements	Serious injury or mortality Behavioural disturbance	Do not approach within 100 m of a whale and 50 m of a dolphin Do not approach calves or pods with calves Move at slow speed (<15 knots) Avoid sudden/repeated changes in direction Avoid sudden/excessive noise Allow fauna to move in against the shore

Project Aspect	Potential Environmental Impact	Possible Management Measures
Lighting disturbance	Behavioural disturbance through: • disorientation • attraction • avoidance of important habitats	Reduce intensity of artificial light Use long-wavelength lights
Environmental quality	Toxicity Regional eutrophication	Water quality monitoring Sediment quality monitoring

8.4 Seabirds

8.4.1 Approach

The Abrolhos are one of the most significant seabird breeding locations in the eastern Indian Ocean (Section 3.7). Section 8.4 provides a summary of a desktop impact assessment applied to Abrolhos seabird populations. Text included in this section is excerpted from Halfmoon biosciences (2015), the full content of which is included in Appendix D.

The suggested approach to managing seabird interactions is outlined further in the EMMP for this proposal, which is published separately (BMT Oceanica, 2015).

8.4.2 Potential adverse interactions

Interactions which can have a detrimental impact upon seabirds can occur at the island breeding colony or whilst foraging at sea. Direct disturbance to colonies from human visitation can include trampling or exposure of nests, disorientation of nestlings, enhanced predation or kleptoparasitism and interruption to breeding or feeding behaviours. Adverse interactions while foraging may arise from attraction to, or avoidance of, vessels and marine infrastructure or disturbance to prey aggregations or associated predators and exposure to contaminants. Direct interactions with finfish farming operations could include:

- supplementary feeding from stock predation, fish food, waste material or food scraps
- collisions with sea cages, other structures or vessels moored at night
- attraction and disorientation due to lighting on service vessels, pens or navigation markers
- entanglement in cage mesh, predator nets or protective bird netting
- attraction of prey to vessel or sea cages due to “FAD” effects.
- attraction to the fish stock
- use of vessel or sea cages as roosting sites

The location of the Pelsaert Group aquaculture zone is 2 km from Stick Island. There is a mixed colony of little shearwaters and white-faced storm petrels on Stick Island (Surman and Nicholson 2009), and many wedge-tailed shearwaters use Middle Channel as a flight path back to their colonies on Pelsaert, Middle and Gun Islands from their foraging grounds. All these petrel species return to their colonies at night. The presence of a semi-permanently moored vessel could potentially impact upon individuals of these species through:

- collision
- light attraction
- disorientation

Collision rates will be greatly increased by unmasked, bright lights. These impacts may result in either injury or death. Also, birds found on the vessel decks invariably regurgitate meals meant to be delivered to young at the nest, thereby depriving those nestlings of a single feed.

At certain times of year, fledgling shearwaters and storm petrels depart nesting grounds and head to sea in the darkness of pre-dawn. These young inexperienced birds orientate to light on the horizon and are particularly vulnerable to being attracted to lighting, becoming disorientated. The food for the juvenile stock raised in the cages will be pelletised, which will have negligible attractiveness to pursuit-diving seabirds such as pied cormorants and wedge-tailed shearwaters. However, pied cormorants may be attracted to the cages to feed upon the juvenile stock and in doing so may attempt to reach fish through the mesh. This may present an entanglement issues for this species.

8.4.3 Possible behavioural responses

The Figures below outline cause-effect-response pathways for six key groups of seabirds that have been identified as being potentially impacted from fin fish aquaculture at the Abrolhos. These are:

- pied cormorants
- silver gulls
- pacific gulls
- wedge-tailed shearwaters
- neritic terns
- pelagic foraging terns and noddies

Of these, pied cormorants, silver gulls and Pacific gulls were considered particularly at risk due to their propensity to increase with proximity to new anthropogenic food sources (Halfmoon biosciences (2015)).

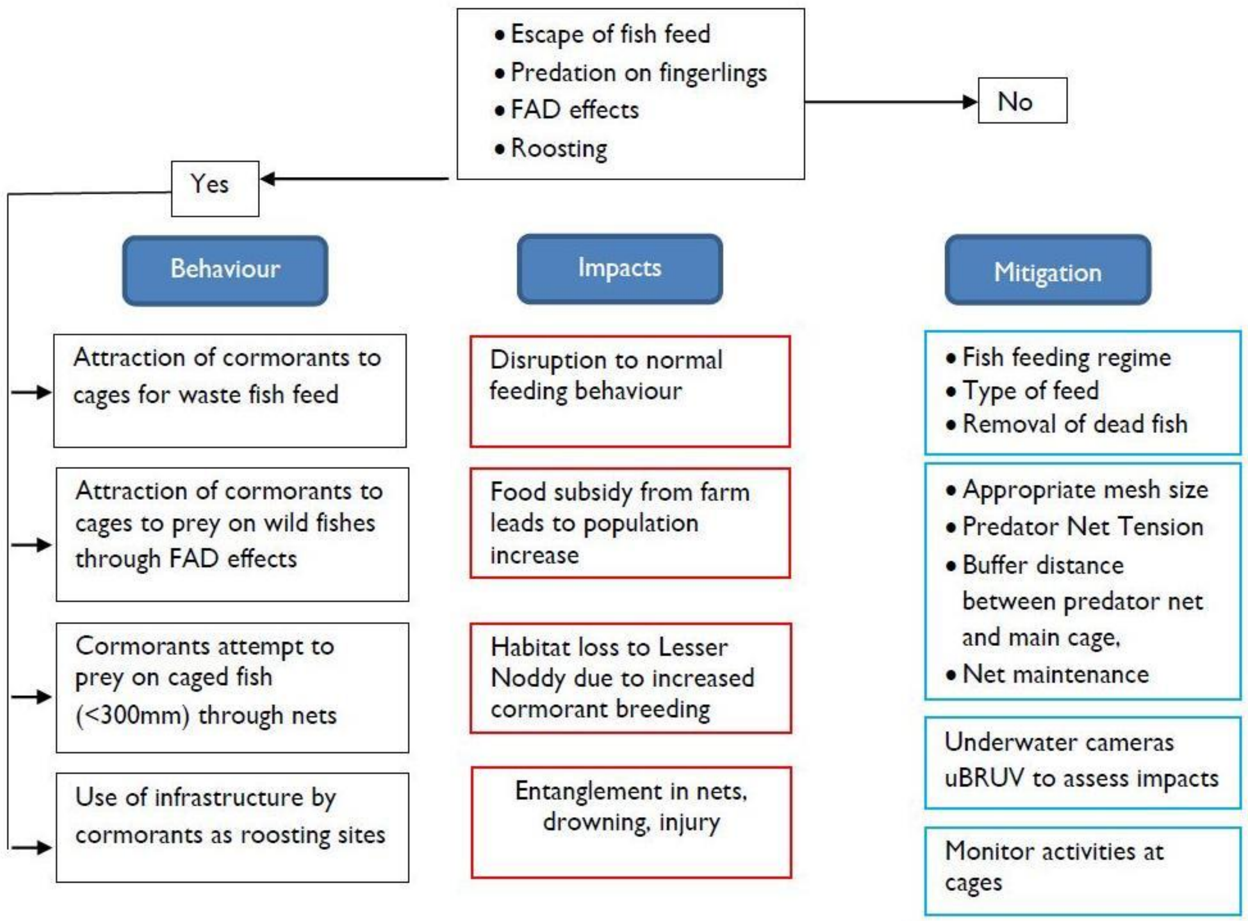


Figure 8-8 Potential impacts to cormorants and possible mitigation measures

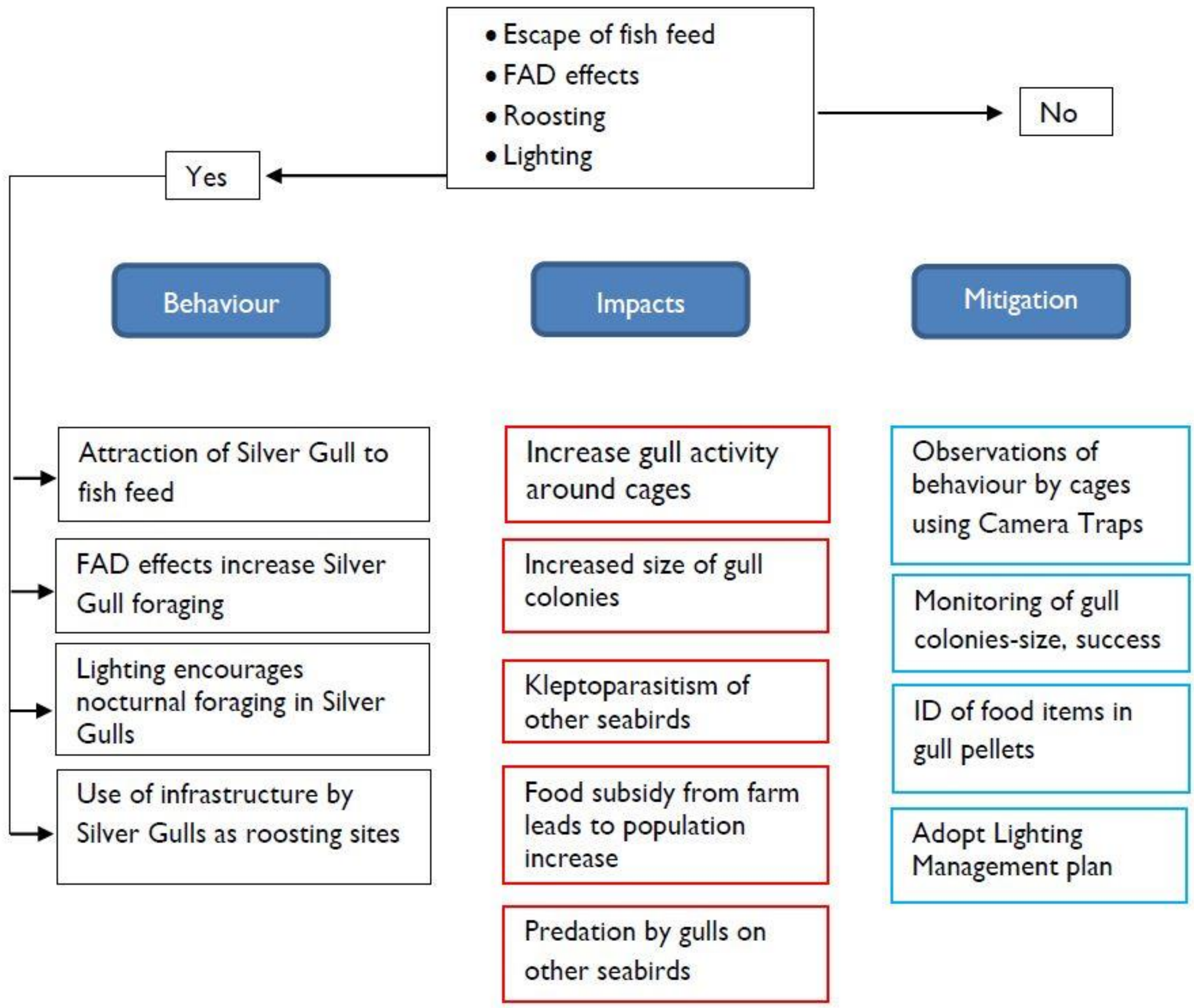


Figure 8-9 Potential impacts to silver gulls and possible mitigation measures

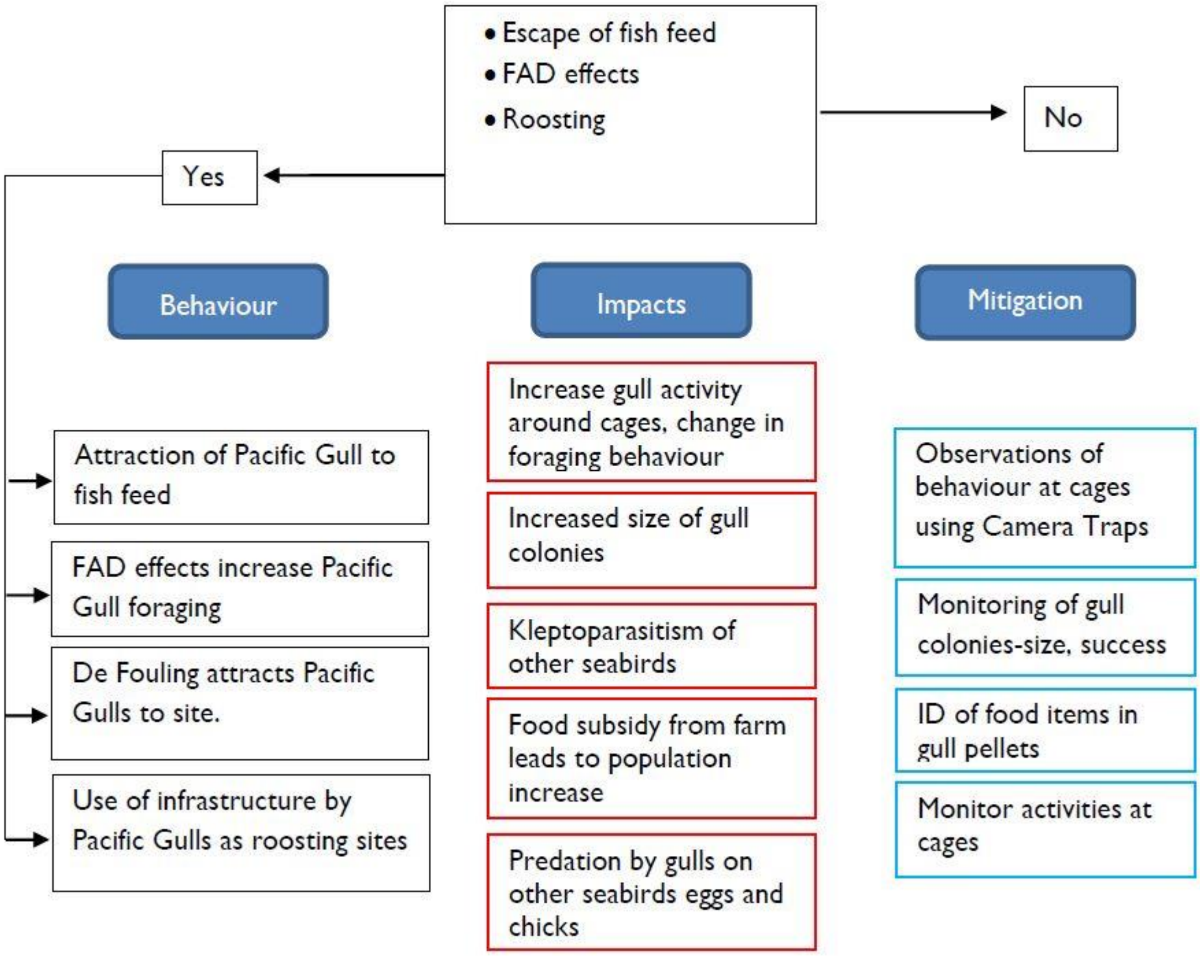


Figure 8-10 Potential impacts to Pacific gulls and possible mitigation measures

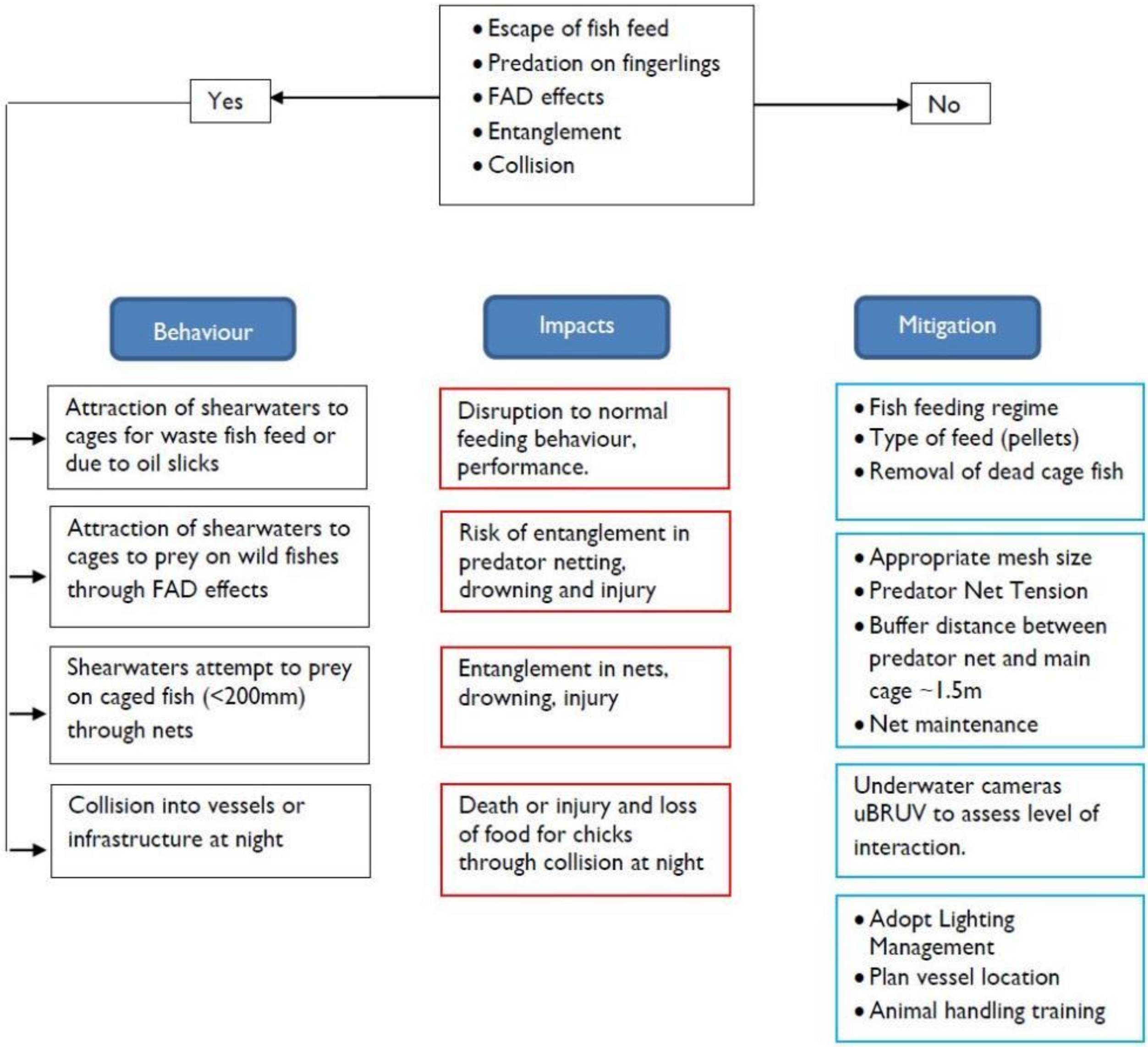


Figure 8-11 Potential impacts to wedge-tailed shearwaters and possible mitigation measures

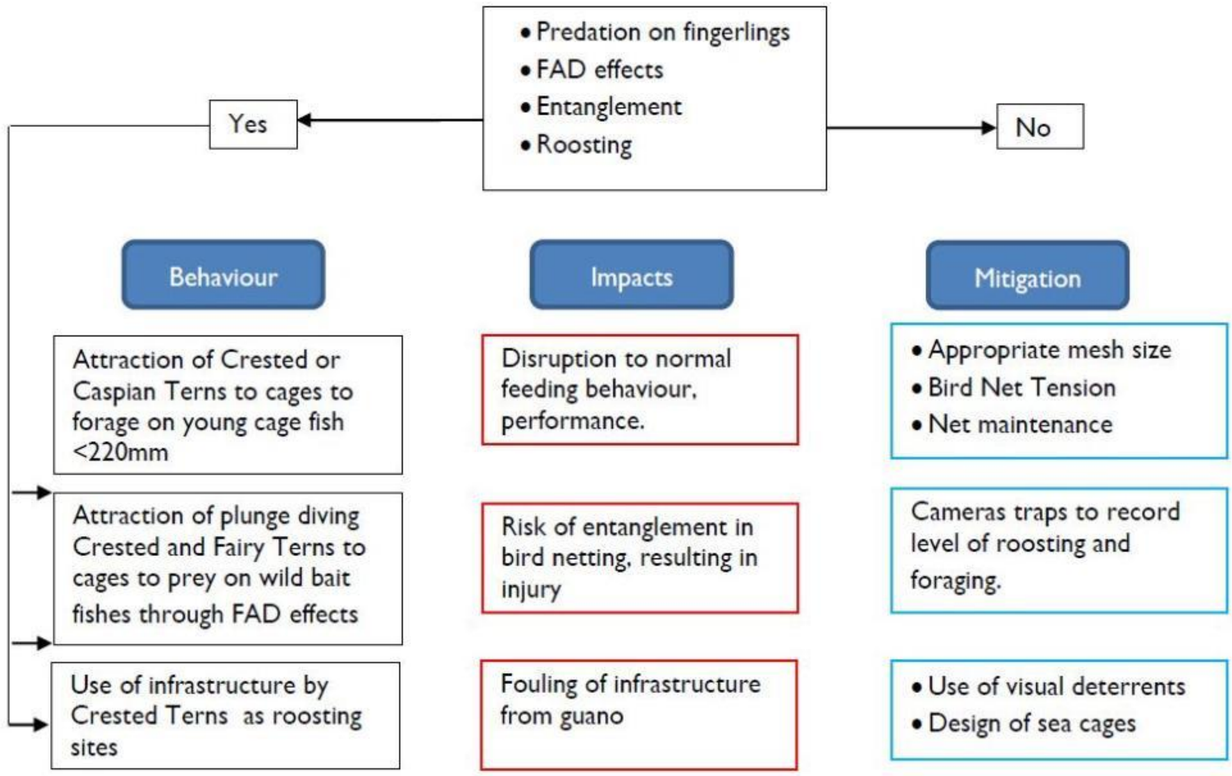


Figure 8-12 Potential impacts to neritic terns and possible mitigation measures

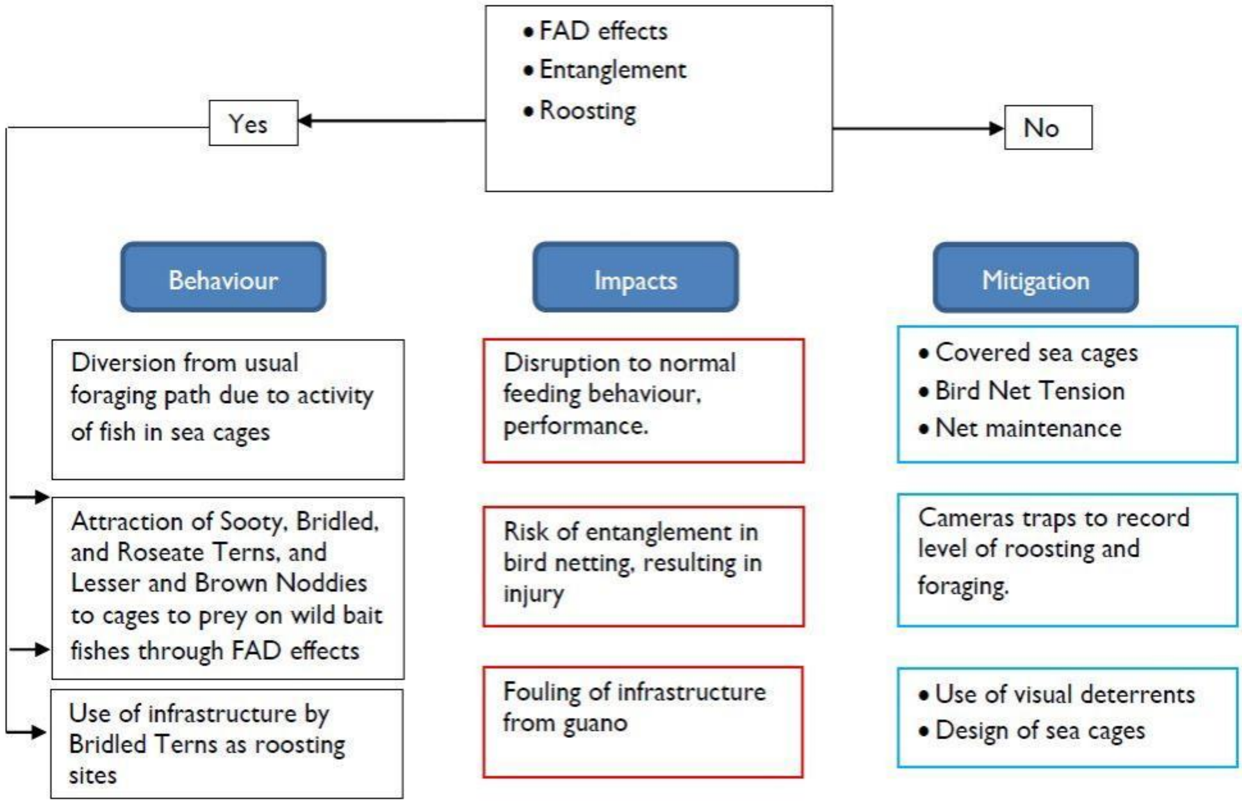


Figure 8-13 Potential impacts to pelagic foraging terns and noddies and possible mitigation measures

8.4.4 Risk and mitigation assessment

The potential adverse interactions (risks) between seabirds and sea-cage fish-farming at the Abrolhos are identified together with the available 'best practice' mitigation measures in Table 8.3.

Table 8.3 Seabird interaction risk mitigation

Factor	Interaction	Potential Consequence	Available Mitigation Methods
1. Pen Location	Attraction: • Seabirds attracted to pens from colonies on the Houtman Abrolhos Islands. • Seabirds distracted from normal flight path by fish activity adjacent sea cages or within sea cages.	• Changes in seabird behaviour or energetics, changing reproductive performance or increasing mortality • Changes in seabird population sizes leading to increased interspecific competition, kleptoparisitism, predation of eggs and young and habitat alteration on the Houtman Abrolhos Islands. • Shifts in terrestrial ecosystems driven by changes in breeding seabird numbers.	• All locations are within foraging range of all seabird breeding species. Choice between proposed fish-farming zones on this scale is unlikely to reduce potential for interactions.
2. Fish - feed	Fish feed is available to foraging seabirds providing an energy / nutrient subsidy, this is less likely if pelletised feed is used. Species likely to exploit fish food are gulls and cormorants.	• Increasing populations of potential increaser species (Silver Gulls, Pacific Gulls and Pied Cormorants) leading to ecological changes (see 1 above). • Increase Pied Cormorant populations will reduce nesting habitat for Lesser Noddies on Wooded Island. • Increased gull populations may impact other nesting seabirds through predation and competition.	• Pellets preferred over whole fish. • Sub-surface, slow release feeders. • Current speeds not sufficient to allow lateral export of feed through meshes. • Complete pen coverage with bird mesh. • Submersible sea-cages
3.Cultured fish size	• Seabirds attracted to forage on farmed stock within their preferred prey size ranges. • Seabirds distracted by large schooling species associated with mixed species foraging aggregations.	• Increasing populations of both gulls and cormorants leading to ecological changes (see 2 above). • Loss of cultured stock. • Reduced foraging efficiency reducing reproductive performance. • Risk of entanglement in anti-predator netting.	• Complete pen coverage with bird mesh. • Submersible sea-cages. • Anti-predator nets with appropriate mesh size for seabirds (6cm) • Space between anti predator net and sea cage ~1.5m.
4. Sea-pen diameter	Interactions with aerial-snatch predators (e.g. Sea-Eagles & Ospreys) will increase with pen diameter.	• Loss of farmed stock, and redistribution or increased abundance of marine raptors.	• Complete pen coverage with bird mesh. • Limit diameter of sea-cages. • Submersible sea-cages
5. Raft characteristics	Some seabirds (e.g. Bridled Terns, gulls) preferentially perch on flotsam or floating objects and may utilise sea-cages as roosts.	• Faeces from birds may reduce water quality, transfer pathogens / parasites to stock. • Collisions with structures or entanglement with nets. • Fouling of gear. • Negative interactions from staff towards native fauna	• Complete pen coverage with bird mesh. • Design of railings, floats, net-rings to reduce perching. • Alternative artificial rafts. • Submersible sea-cages • Bird Deterrents (Visual, audio, physical)
6. FAD effects	Attraction of larval fish and crustaceans, bait fishes and predatory fishes due to FAD effects of superstructures.	• Seabirds may concentrate around fish farms increasing potentially adverse interactions (see 1 above). • Increased foraging opportunities for some species (increaser species). • Increased risk of entanglement from foraging seabirds	• FAD effects are likely to increase with distance from reefs. • Alternative artificial rafts or reefs. • Mesh sizes.
7. Fish oil slicks	Oily residues from stock and feed will form slicks which draw-in forage fishes (enhancing FAD effect) and seabirds (particularly olfactory foragers such as shearwaters and storm-petrels).	• Seabirds may concentrate around fish farms increasing potentially adverse interactions (see 1 above). • Increased foraging opportunities for some species (increaser species). • Increased risk of entanglement from foraging seabirds, particularly diving species.	• Reduce oil content /production of feeds. • Remove dead fish from cage
8. Superstructure and predator nets	Structures including netting above and below the water surface may entrap or entangle foraging or roosting seabirds.	• Increased mortality particularly among pursuit diving species, e.g. cormorants and shearwaters. • Potential entanglement from Osprey and White-breasted Sea Eagles.	• Appropriate mesh sizes, visibility and net tension. • Regular net checks and maintenance • Camera trap monitoring • Remote Underwater Video (BRUV) monitoring
9. Lighting	• Many seabirds fly at night and are disorientated by bright navigation or vessel flood-lights. • Lights may also attract zooplankton further increasing the FAD effect of sea-cages allowing gulls to feed at night	• Increased seabird mortality from collisions with super structure of cages and moored vessels. • Enhanced prey aggregation around fish-farms may increase adverse interactions with seabirds. • Enhanced food supply for increaser species, Silver Gulls are known to forage under lights at night.	• Development of lighting management plan • Design of light horizon and wavelength. • Reduction in use of lighting. • Seasonal lighting reduction policies.
10.Moored Vessels	• Accommodation and farm vessels on site increase collision and disorientation risks to seabirds. • Moored vessels provide roosts for seabirds • Vessel wastes may attract increaser species. • Increased boating traffic may deter natural foraging behaviour.	• Increased seabird mortality from collisions (see 9 above). • Loss of food for seabird young from adults regurgitating after collision or disorientation on vessel. • Enhanced food supply for increaser species, Silver Gulls are known to forage under lights at night or on waste from vessels (food scraps, bait, and offal).	• Development of lighting management plan • Design of light horizon and wavelength. • Management plan for reducing impacts from collision • Training for bird handling and reporting • Reduction in use of lines or rigging across vessel • Mooring location outside of flight paths.
11.Marine Debris	Loss of lines, netting, plastics, floats or refuse from operations.	• Entanglement of marine fauna in portions of nets or lines lost from farm or over side of vessels (scuppers). • Ingestion of plastics from farm wastes, reduction in foraging efficiency and delivery of food to young.	• Waste management plan • Return of all waste to mainland • Maintenance of farm gear • Mesh over scuppers to prevent loss to sea.
12. Food Supplementation from de-fouling operations	Gulls that rely naturally on marine invertebrates may be attracted to operations removing encrustations	Food supplementation or entrapment	• Collection of biological material for disposal away from aquaculture operations or burial.

8.4.5 Major findings and recommendations

Studies of the potential adverse interactions between seabirds and aquaculture installations identified similar risk factors to those discussed in Halfmoon biosciences (2015). These include entanglement, habitat exclusion, disturbance from farm activities, increased prey availability, creation of roosting sites, implications to foraging success and spread of pathogens (Sagar 2008, Lloyd 2003, Comeau et al. 2009). However, additional findings are presented in Halfmoon biosciences (2015) including the potential for disruption to foraging patterns, decline in nesting habitat to vulnerable species and importantly changes in foraging behaviour and consequent predicted population changes in increaser gull species.

Key findings of the assessment outlined particularly the potential adverse effects of lighting and waste aquaculture feeds (Halfmoon biosciences 2015). Lights shining on the water-surface have the effect of attracting and concentrating plankton and other marine life suitable as feed for seabirds. This effect has resulted in increases in silver gull numbers in the offshore oil and gas industry, attracting the night-time visitation of seabirds to feed on the resulting prey aggregations. Bright lights directed towards the horizon may also attract and disorientate seabirds at night including shearwaters, storm-petrels and pelagic terns. Fledging shearwater chicks orientate to lights on the horizon and are common casualties at coastal towns, on ships and fishing boats. However, these effects were found to be easily mitigated through best-practice approaches to lighting management (Halfmoon biosciences 2015).

Under best-practice feed management, approximately 1% of uneaten feed is expected to enter the marine environment through the sides and bottom of the sea-cages. It is expected that waste feed will result in aggregations wild fish in the size ranges attractive to foraging pied cormorants (Halfmoon biosciences 2015). Investigations of the foraging ecology of 'high risk' increaser species, including pied cormorants, silver gulls and pacific gulls, indicate that all are reliant on naturally available prey types. Littoral zone invertebrates dominate the gull diets and benthic fishes dominate pied cormorant diets. While there is potential for pied cormorants, silver gulls and pacific gulls to increase through exploitation of food sources associated with the MWADZ, it is understood that best practices approaches to management (sea cage design, selection of netting and waste feed minimisation) are likely to reduce the potential for exploitation by these seabirds. For further context refer to Halfmoon biosciences (2015) in Appendix D.

9. Conclusions

Risks associated with the DoF proposal to establish a finfish aquaculture zone at the Abrolhos Islands were assessed based on a number of technical studies, including the development and execution of an integrated environmental model and multiple technical desktop assessments. The purpose of this document was to summarise the findings of the technical studies, and to provide advice on the likely cumulative impacts of sea-cage operations on the marine environment under a range of operational scenarios. Results have been evaluated in the context of the key environmental factors identified in the ESD (Table 1.1), and the findings of this document will feed into the broader PER for the MWADZ.

9.1 Baseline status of the proposed aquaculture zone

Results of the baseline studies indicate that the waters inside the project area are clean and well mixed. Maximum and minimum water temperatures were achieved in autumn (23.5°C) and winter (20.8°C), respectively. Salinity and dissolved oxygen levels were consistent through the water column with little evidence of stratification (Section 5.3.1). The water was highly oxygenated, achieving surface oxygen saturation levels between 98 and 99% and bottom oxygen saturation levels between 95 and 98% (Section 5.3.1). Light attenuation in the MWADZ was lower (0.04–0.19 per m) than that obtained in the KADZ (1.2–1.8 per m), results indicative of very clear water, with excellent light penetration.

Water currents are variable, ranging between 5.8 and 14.4 cm/s (Section 7.2). Concentrations of ammonium (2.7 µg/L) and chlorophyll-a (0.43 µg/L) were lower than those recorded in the Kimberley Aquaculture Development Zone (KADZ) (5.4 µg/L and 0.9 µg/L, respectively and compared well with those recorded in Perth's coastal waters, pointing to an overall oligotrophic (nutrient poor) environment. Nitrite + Nitrate levels (12.9 µg/L) were higher than those recorded in Perth's coastal waters (6.5 µg/L) and in the KADZ (8.7 µg/L). Concentrations of both inorganic nutrients and chlorophyll-a were seasonally variable, but higher in the cooler months.

The benthic environment consisted generally of a shallow (~15 cm thick) layer of sand overlying rocky substrate. Higher current speeds in the northern area (northern 13-14.5 cm/s compared to the south 8.7-11 cm/s) were reflected in the tendency toward larger sediment grain sizes in the northern reaches of the MWADZ (Section 5.4.1). Sediment conditions were variable, with seasonal fluctuations in ammonium, nitrogen and total organic carbon and generally higher values in warmer months. Infaunal assemblages were diverse (10 phyla; 129 families), with communities dominated by polychaetes (Section 5.4.4). Higher levels of infauna diversity and abundance were observed in the summer months.

Surveys indicated that the seafloor is a mosaic of habitats consisting of open sandy meadows and mixed biological assemblages. This mixture of substrates supports macroalgae, rhodoliths, sessile invertebrates and some corals; however, all of the available data suggest that their presence may be itinerant given the observed differences between surveys (Section 5.5). Northern MWADZ habitats were more diverse, with the northern area comprising 59% bare sand and 34% mixed assemblages. Small patches of reef were present near the north-east boundary of the MWADZ but only made up 8% of the total habitat. By contrast, the southern MWADZ comprised 96% bare sand and 5% mixed assemblage. Although ephemeral seagrass communities were have been observed historically in the MWADZ (Section 5.4.5), none were observed during the current assessment.

9.2 Suitability of the proposed aquaculture zone

Desktop assessments were undertaken to determine the likely impact of the proposal to marine mammals, seabirds and other significant fauna, including sharks and rays and other finfish. Several risks were identified, including the potential for the sea-cages to act as a physical impediment to animal movement and water flow, a source of entanglement/capture, an artificial source of food and as a significant artificial attractant and roosting area for seabirds.

These risks are not unique to the proposed MWADZ. Experience gained in Australia and in other parts of the world has resulted in significant advances in knowledge of aquaculture environmental management, including in the development of methods for both minimising risks and managing residual risks (Section 8). It was considered that where residual risks remained, these could be managed via the use of industry best-practice infrastructure and management strategies. Examples of these included use of high-walled sea-cages (to limit access of pinnipeds), use of nets to exclude seabirds, and implementation of modern fish-feeding methods to both limit wastage and impede opportunistic feeding by sea-birds. The suggested approach to management is outlined further in the EMMP for this proposal, which is published separately (BMT Oceanica 2015a).

Sea-cage aquaculture may under some circumstances lead to smothering or serious damage to benthic habitats including benthic primary producing habitats (BPPHs). The potential for impacts to BPPHs was assessed in the context of EAG 3 (see approach in Section 4.5.1). The assessment was undertaken against Category C in the Cumulative Loss Guidelines (EAG 3) which stipulates allowable losses of no more than 2% within an agreed local assessment unit (LAU). The assessment found that the proposal was unlikely to yield significant cumulative losses and the total cumulative loss would be restricted to less than 1%, which is below the 2% Category C benchmark. The findings of the assessment are in keeping with the overall results of the EIA, which predicted that the most severe impacts are restricted to small areas (Section 7.3).

The effect of sea-cages was also examined in the context of the local and regional hydrodynamics. Sea-cages invariably impart some resistance to flows, acting to slow or deflect waters in the vicinity of the cages. Sea-cages have the effect of increasing current speeds around and immediately beneath the cages. Where the cages are 'tall', and placed in shallow water, this can have the effect of scouring the underlying marine sediments. Hydrodynamic modelling undertaken in this study showed that the proposed cages were placed in sufficient water depths to avoid scouring of the benthos. Modelling indicated that water currents were slowed inside the cages, and slightly elevated (relative to background) beneath the cages. However, none of these effects were predicted to result in ecological consequences.

The results of the integrated modelling provided insights into the likely benthic footprints of the sea-cages under a range of scenarios (Table 4.16). Modelling was based on the assumption that wastes from sea-cages would exhibit different settling velocities. It was also assumed that the particles exhibited 'adhesive' properties (partly due to its mucus content), which reduced their resuspension potential relative to inorganic particles (Nowell et al. 1981; Masalo et al. 2008).

Risks associated with key water column contaminants, dissolved inorganic nitrogen (DIN) and suspended particles were examined after one year of production. Suspended particles were examined in the context of smothering and interruption to filter feeding processes, and DIN in the context of algal growth potential, nutrient enrichment and shading. Risks associated with organic waste inputs were examined in the context of sediment organic enrichment and changes to sediment chemistry. The time taken for sediments to achieve chemical remediation was determined following two, three and five years of finfish production.

Concentrations of DIN down-current of the sea-cages increased with increasing biomass and increasing stocking density. However, the plumes dissipated rapidly, with concentrations returning to levels consistent with a high level of ecological protection inside the southern MWADZ boundary, and within 2.3 km of the northern MWADZ boundary. Despite large inputs of DIN to the system, none of the scenarios resulted in significant changes to the chlorophyll-a concentrations in the broader project area. Similar results were obtained with respect to light and water column dissolved oxygen levels. The extent of light reduction (or shading) is largely associated with the extent of particles in the water, a proportion of which is phytoplankton. Although the proposal presents conditions under which phytoplankton may be stimulated, thus also increasing light attenuation, none of the modelled scenarios resulted in discernible chlorophyll-a concentrations and sub-surface light conditions were not affected (Section 7.4.4).

Deposition of organic material resulted in rapid changes to concentrations of oxygen and hydrogen sulphide in sediments beneath the sea-cages (Section 7.3.2). Results suggested that the ZoHI would occupy 82-177 ha (S2-S1) to 139-177 ha (S6-S5) after 5 years production (Section 7.3), but less after 3 (2-1 ha to 95-105 ha) and 2 years (0-0.2 ha to 88-91 ha) production. By reducing the length of the production period from 5 to 3 years, the area occupied by the ZoHI reduced by close to a 100% in S2, 45% in S4 and 31% in S6.

Reductions in both the standing biomass and the length of production also reduced the extent of the ZoHI, as measured along the maximum radius down-current from the cage clusters. After 5 years continuous production, the ZoHI, extended to a maximum of 110 m and 70 m under S6 and S5, but less than that under other scenarios, and shorter production periods: in S4 for example, distances reduced to 60 m and 15 m after 3 and 2 years production respectively, and for S3, the distance reduced to 10 m after 3 years production. After 2 years production, the ZoHI in S3 did not breach the cage cluster perimeter.

Increasing the stocking density, while maintaining the standing biomass (i.e. stocking density S4 > stocking density S3; standing biomass S4 = standing biomass S3), had the effect of reducing the total area occupied by the ZoHI across the zone. This effect was particularly strong after 5 years production, but less so after 3 and 2 years production. While the spatial extent of the ZoHI was reduced under these scenarios, the effect was to increase the intensity of impacts beneath the sea-cages, thus extending the time required for sediment (chemical) remediation during fallowing. Notwithstanding this prediction, the model indicated that large standing biomasses (up to 5000 t per sea-cage cluster) are achievable, while constraining the benthic impacts to relatively small areas. This is also reflected in the literature, with most detectable impacts to the sea-floor being restricted to within 10 and 100 m of the sea-cage perimeter (Carroll et al. 2003; Crawford 2003, Borja et al 2009).

The ZoHI is the area where impacts on benthic habitats are predicted to be irreversible, as per EAG 7. The term irreversible is defined as 'lacking a capacity to return or recover to a state resembling that prior to being impacted within a timeframe of five years or less'. Despite the use of the term irreversible, it is noted that sea-cages are not permanent structures and can be moved to facilitate benthic rehabilitation. Recovery times in the ZoHI and ZoMI ranged between 1 and 7+ years, depending on the scenario, duration of production and the distance from the sea-cages. Immediately under the sea-cages, sediments required greater than 7 years to achieve full recovery, irrespective of the standing biomass modelled. However, this reduced to 6 and 5-6 after 3 and 2 years production respectively.

In addition to contributing organic wastes to the seafloor, aquaculture may contribute pharmaceuticals to the marine environment. Antibiotics are used as needed to treat bacterial disease occurring in farmed fish and are generally administered in feed. Calculations have

shown that 70% to 80% of drugs used administered in fish farms end up in the environment, and drug concentrations with antibacterial properties have been detected in sediments beneath sea-cages (Samuelsen et al. 1992). Antibiotics may impart pressure on the environment by reducing or changing numbers of sediment bacteria, which in turn may affect biochemical and/or broader ecological processes. The persistent use of antibiotics has also been shown to lead to bacterial resistance (Anderson and Levin 1999). In the treatment of farmed salmon in Tasmania, oxytetracycline is the most common antibiotic used, accounting for more than 70% of total antibiotic use during 2006–2008 (Parsons 2012). A strong seasonal component to the use of antibiotics has been noted in Tasmania, with the greatest requirement in the summer months when water temperatures are elevated and pathogens most virulent. Oxytetracycline has been found to persist in marine sediments beneath sea cages for up to twelve weeks, with a half-life of ten weeks (Jacobsen and Berglind 1988). However, traces of the drug may be present for up to two years after treatment (Lalumera et al. 2004). It is also relatively persistent to anoxic conditions which are common under sea-cages (Jacobsen and Berglind 1988). Because antibiotics are administered in feeds, the spatial extent of potential impacts is likely reflected in the settlement patterns of organic wastes. Modelling predicted that the majority of wastes[4] in the MWADZ would be deposited to the seafloor within 60 m of the sea-cages. If antibiotics are required, it would be administered for short periods of time. The strongest effects of antibiotics could last for up to 10 weeks but are likely to be constrained to relatively small areas.

Suspended particles were examined in the context of smothering and interruption to filter feeding processes, and DIN in the context of algal growth potential, nutrient enrichment and shading. While none of the triggers for filter feeding processes were exceeded, some effects of smothering were detected (S4-S6), but where they occurred, were spatially constrained to areas immediately under the sea-cages. The very low density of (at least a significant portion) of fish faecal waste was reflected in the tendency for the smallest particles to disperse great distances beyond the sea-cages (several km over a 12 month period). These particles which contributed to the ZoI, were not predicted to reach the sediments in high enough volumes to exceed the environmental criteria. Areas classified as the ZoI could be expected to maintain normal chemical (oxygen and sulphide) signature, with no resulting changes in infaunal diversity.

In summary, results presented here indicate that the impacts of the proposal can be constrained within small areas of the MWADZ, with no adverse effects to regional environmental quality. Risks associated with significant marine fauna were considered manageable via the implementation of industry best-practice methods and use of appropriate infrastructure. Findings demonstrated the general suitability of the project area given its:

- water depth, which in turn contributes to a very large volume
- average current speeds, which are at the lower limit of ideal
- lack of extensive or permanent BPPHs
- location on historic trawling grounds and
- size, allowing ample scope for fallowing and associated recovery of benthic habitats

All of the modelling scenarios tested were based on full scale production, with between 15 000 and 30 000 t of standing biomass in the water at any one time (for up to five years). A conservative approach was adopted to ensure the outputs of modelling were equivalent to 'most likely worst case' outcomes, as required by the ESD (Table 2.1). As such, the impacts predicted in this document are more extensive than might be expected on average, but are within the upper range of impacts reported in the literature (i.e. Brooks et al. 2004).

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[4] *Based on the Zone of High Impact after three years production*

9.3 Interim production limits

This assessment simulated the effects of standing biomasses in the range 15 000 t to 30 000 t of finfish, for periods of between one year (water quality) and five years (sediments). Despite using a conservative approach, none of the simulations were predicted to result in detrimental changes in water quality, and only scenarios S4–S6 were predicted to impart severe impacts (ZoHI) to sediments greater than 70 m beyond the immediate vicinity of the sea-cages.

The constraining factor, therefore, is whether the scale of impacts to sediment is environmentally acceptable, and whether they can be controlled via targeted management strategies (such as fallowing) and through the use of appropriately classified areas of ecological protection (EPA 2015). It is also considered that even when calibrated appropriately, environmental models are subject to many sources of compounding error. Although no adverse effects to the regional environment were predicted at the upper range of the scenarios tested (i.e. 30 000 t), it is recommended that 24 000 t standing biomass is set as an interim limit, pending further validation of the particle dispersion and sediment diagenesis models.

Baseline field data on sediment characteristics and water quality collected during operations will provide suitable information with which to validate the models, and thus fine-tune their precision. This in turn may be used to adjust the allowable future production limits, according to the results of the modelling outputs.

9.4 Recommendations

Results presented within this report are equivalent to the 'most-likely worst-case' outcomes as per the requirements of the ESD. The tested scenarios were designed to be (a) sufficient to support a viable finfish aquaculture industry and (b) within the critical assimilative capacity of the marine environment, based on an understanding of systems with similar flushing regimes and similar nutrient inputs (see Section 7.4.6). As such, it is recommended that the mid-range limit 24 000 t standing biomass is set as an interim limit, pending further validation post-commencement of operational monitoring. It is further recommended that this limit is validated in the future in the context of additional metocean assessments, including the effect of severe storms, and the frequency of benthic 'resetting' events.

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Appendix A

Potential for Impact to Marine Mammals and Turtles

Appendix B

Potential for Impact to Endangered and Protected Finfish

Appendix C

Potential for Impact to Invertebrates and Finfish Species & Fisheries

Appendix D

Potential for Impact to Seabirds

Appendix E

Peer Review of Modelling Processes and Interpretation

Appendix F

Development and Calibration of the Hydrodynamic and Wave Models

Appendix G

Development of the Sediment Diagenesis Model

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MEMORANDUM

ATTN:	John Eyres	**CC:**	Laurie Caporn
ORGANISATION:	Department of Fisheries	**FROM:**	Michelle Bejder and Gabrielle Cummins
PROJECT NO:	1051_009	**DATE:**	7/10/2015
SUBJECT:	Potential adverse interactions between the Mid-west Aquaculture Development Zone and marine mammals and turtles		

A. This document

Risks associated with the Department of Fisheries (DoF) proposal to establish the Mid-west Aquaculture Development Zone (MWADZ) were assessed based on the outcomes of environmental modelling and desk-top assessments. Desktop assessments have examined the potential for adverse interactions between the proposal and key marine fauna, including sea-birds, sharks and rays, and fin-fish and invertebrates (see BMT Oceanica 2015a). This desk-top assessment summarises the potential for adverse interactions between the MWADZ and marine mammals and turtles. It is designed to feed into the broader PER, and addresses the following specific objectives:

1. Identify and assess the values and significance of marine mammals (including the Australian sea lion) and turtles within the strategic proposal area and immediate adjacent area and describe these values in a local, regional and State context
2. Identify critical windows of environmental sensitivity for marine mammals and turtles in the strategic proposal area and immediate adjacent area
3. Describe the presence of marine mammals and turtles in the proximity of the strategic proposal area, documenting any known uses of the area (e.g. foraging, migrating, calving and nursing)
4. Identify the construction and operational elements of the proposal that may affect marine mammals and turtles
5. Briefly describe and assess the potential direct and indirect impacts that may result from the construction and operation of the proposal to marine mammals and turtles
6. Briefly summarize (high level) potential mitigation and management measures for adverse impacts on marine mammals and turtles.

The document focuses particularly on objectives 1 to 5. Objective six is addressed briefly in Section 5. For a more detailed overview, the reader is directed to the Environmental Monitoring and Management Plan (EMMP) for the MWADZ proposal, which is published separately (see BMT Oceanica 2015b).

B. Site description

B.1 Relevant legislation

The MWADZ lies in Western Australian (WA) State waters within three nautical miles of the mainland, and is therefore regulated under the Wildlife Conservation Act 1950. It is also bound by Australian Commonwealth Matters of National Environmental Significance (MNES) listed under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act).

B.1.1 Commonwealth

The EPBC Act requires approval from the Commonwealth Minister for the Environment for any action that has, will have or is likely to have a significant impact on any of the following MNES:

- World Heritage properties
- National Heritage places
- Ramsar wetlands of international importance
- Nationally threatened species (animal and plant) and ecological communities
- Migratory species protected under international agreements
- The Commonwealth marine environment
- The Great Barrier Reef Marine Park
- Nuclear actions
- Water resources, in relation to coal seam gas and large coal mining developments.

B.1.2 State

The WA State legislation for marine fauna protection is the Wildlife Conservation Act 1950, which lists threatened native plants and animal species in need of special protection based on the threat of extinction or rare occurrence.

This assessment considered the potential for impacts in the context of both State and Commonwealth regulatory frameworks.

C. Key species and their likelihood of occurrence

C.1 Marine mammals

The EPBC Act Protected Matters Search Tool (DoE 2014a) identified 31 cetacean and two pinniped species with the potential to occur within <50 km of the MWADZ (DoE 2014a; Appendix A). The following sections describe species that are most likely to be encountered, as well as three species listed as Endangered or Vulnerable under the EPBC Act and the Wildlife Conservation Act (Table C.1).

Table C.1 EPBC Act threatened marine mammal species potentially occurring within 50 km of the MWADZ, including Wildlife Conservation Act status

Scientific Name	Common Name	EPBC Act Status	Wildlife Conservation Act Status
Balaenoptera musculus	Blue whale and pygmy blue whale	Endangered Cetacean Migratory	Endangered
Eubalaena australis	Southern right whale	Endangered Cetacean Migratory	Vulnerable
Megaptera novaeangliae	Humpback whale	Vulnerable Cetacean Migratory	Vulnerable
Neophoca cinerea	Australian sea lion	Vulnerable Marine	Other protected fauna
Balaenoptera edeni	Bryde's whale	Cetacean Migratory	Not listed
Orcinus orca	Killer whale	Cetacean Migratory	Not listed
Tursiops aduncus	Indo-Pacific bottlenose dolphin	Cetacean	Not listed
Tursiops truncatus s. str.	Bottlenose dolphin	Cetacean	Not listed
Dugong dugon	Dugong	Marine Migratory	Other protected fauna

Source: EPBC Act Protected Matters Search Tool (DoE 2014a) and Wildlife Conservation (Specially Protected Fauna) notice 2014

C.1.1 Blue and pygmy blue whales

Two sub-species of blue whales are known to occur in Australian waters: the southern (or 'true') blue whale (*Balaenoptera musculus intermedia*) and the pygmy blue whale (*B. musculus brevicauda*). These two subspecies differ based on distribution, morphology, acoustics and genetics (Attard et al. 2012). Both migrate seasonally between their feeding grounds at high latitudes in the Austral summer and their breeding grounds at low latitudes in the Austral winter. As a general distributional trend, southern blue whales are found south of 60°S and pygmy blue whales are generally found north of 55°S (DEWHA 2008). Since 1994, relatively high numbers of blue whales have been observed between October–December in Geographe Bay, a shallow embayment in south-west WA, which may be a transitory corridor and/or migratory resting area (Salgado Kent et al. 2011, DSEWPaC 2012a). Surveys in 2003 recorded more than 100 sightings in Geographe Bay (Burton 2003).

Blue whales are documented in deeper waters off the Perth coast and near the edge of the continental shelf in 500–1000 m water depth (McCauley & Jenner 2010, McCauley et al. 2001). The only known areas of significance to blue whales are feeding areas around the southern continental shelf, notably the Perth Canyon, WA, and the Bonney Upwelling and adjacent upwelling areas of South Australia and Victoria (Jenner & Jenner 2004). In the Perth Canyon, up to 40 blue whales have been sighted in a single aerial survey. During vessel surveys, 211 unique individuals have been photo-identified over six years (2000–2005). Of these, one whale was sighted over four separate seasons, one whale over three seasons and 11 whales over two seasons (Jenner & Jenner 2004). Limited satellite tagging data revealed that blue whales have probable foraging patterns not only over the Canyon, but also over the upper shelf slope to its north and south as well. While their Australian distribution is widespread, blue whales are commonly found in deep, oceanic waters, and they are unlikely to be sighted in significant numbers in the MWADZ proposal area (Table C.3) (but see some examples below).

Pygmy blue whales have been recorded in similar areas to the blue whales about 40–100 km offshore (Double et al. 2012). Perth Canyon is the only recognised feeding area for the species in WA (DoE 2014b; McCauley & Jenner 2010) and is more than 350 km south of the MWADZ proposal area. Passive acoustic data documented the north-bound migration of pygmy blue whales as they left the Perth Canyon and travelled up the WA coastline, passing Exmouth Gulf between April and August and continuing into Indonesian waters (McCauley & Jenner 2010). The pygmy blue whale south-bound migration begins from October to late December along the 500–1000 m depth contour on the edge of the slope (McCauley & Jenner 2010). During baseline investigations for the Oakajee Deepwater Port Project, blue whales were observed during aerial surveys near Geraldton and the Abrolhos Islands on four out of thirty three aerial surveys in the period November 2008 to January 2010 (Oceanica 2010).

Satellite-tracking data recorded a similar pygmy blue whale migratory pattern, with a north-bound migration off Exmouth and the Montebello Islands between June and August, and south-bound migration passing through the same areas from October to January, with a peak in late November to early December (Double et al. 2012). The satellite-tagged pygmy blue whales were recorded in the offshore areas of the Abrolhos Islands, providing evidence of migration near the MWADZ proposal area (Table C.3).

C.1.2 Southern right whales

Distributed between 30°S and 60°S, southern right whales (*Eubalaena australis*) have been recorded in coastal waters of all Australian states. They migrate from high-latitude feeding grounds in summer to warm, low-latitude coastal locations in winter (May through to November) between Sydney and Perth, as well as Tasmania (Bannister et al. 1996). The population is

suggested to be growing, and rare sightings were recorded in northern waters, such as Shark Bay and the North West Cape (Bannister et al. 1996). In Australia, important calving areas in WA are at Doubtful Island Bay and east of Israelite Bay (on the south coast of WA). However, there are no critical habitats recognised in the waters around the Abrolhos Islands. Therefore, any sightings of southern right whales from the MWADZ proposal area will be rare and infrequent (Table C.3).

C.1.3 Humpback whales

Humpback whales (*Megaptera novaeangliae*) migrate along the WA coastline between their summer feeding grounds (south of 55°S) and winter breeding grounds of Camden Sound in north-west WA (DoE 2014b, Jenner et al. 2001), located approximately 1,700 km north-east of the MWADZ. The Abrolhos Islands are recognised as a significant habitat during humpback whale migration (DoE 2014c). Humpback whales have been documented to use the sheltered waters adjacent to the Abrolhos Islands to opportunistically rest during their southern migration to the Antarctic feeding grounds (DoE 2014c, DEWHA 2007).

Fishermen have reported sightings of northbound humpback whales around the Abrolhos Islands between May and June, however the peak northbound migration is early to mid July (Jenner et al. 2001). Humpback whales migrate south along the WA coastline after the breeding and calving period. The peak southern migration period which incorporates a corridor through the proposal area is in late September (Jenner et al. 2001) (Table C.3).

C.1.4 Australian sea lions

The Australian sea lion (*Neophoca cinerea*) is endemic to Australia, with a distribution extending from the Abrolhos Islands, Western Australia to the Pages in South Australia (Campbell 2005; DSEWPaC 2013a). Their main breeding rookies comprise offshore islands (Campbell 2005), with beaches and rocky shores used as year-round haul-out areas (Orsini et al. 2006). The Abrolhos population is small and at the northern limit of the species range.

The Australian sea lion is listed as Vulnerable under the EPBC Act based on primary threats such as fatal capture as fishery bycatch and entanglement with marine debris (Hesp et al. 2012). Secondary threats include interactions with aquaculture operations (DSEWPAC 2013a). The Recovery Plan for the Australian sea lion describes the conservation requirements for the species across its range and identified actions to ensure its long-term viability in nature as well as the parties that will undertake those actions (DSEWPaC 2013b).

There are 28 large known breeding sites for Australian sea lions in WA including two at the Abrolhos Islands (here, the Easter Group is referred to as one breeding site and the Pelsaert Group is referred to as one breeding site however there are separate islands within these sites) and 48 sites in South Australia (Goldsworthy et al. 2009, Shaughnessy et al. 2011, DSEWPaC 2013b). The overall estimated abundance of Australian sea lions in WA is much lower (~2000 individuals) than in South Australia (~12 700 individuals) (Goldsworthy et al. 2009).

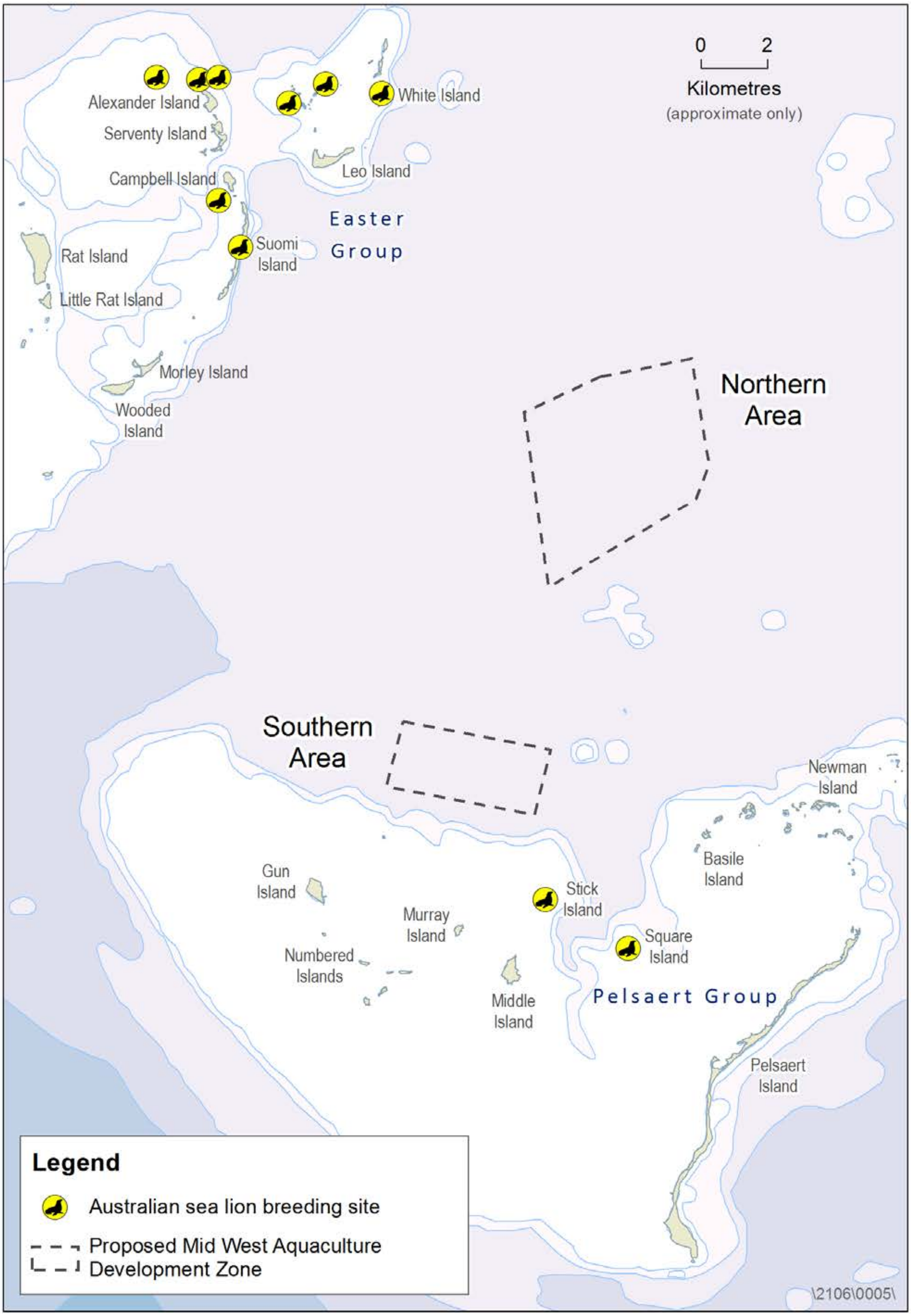
The Abrolhos Islands population, which is a small and closed population, is highly vulnerable, especially to increased mortality from anthropogenic causes (Campbell 2008). Scientific data suggest that there are approximately 14,780 Australian sea lions, and the most recent pup counts from Kangaroo Island, South Australia, indicated a general decline of 0.54–0.67% per year between 1985 and 2010 (Goldsworthy et al. 2011). Population estimates are based on pup numbers to infer the overall population size.

Australian sea lions have a characteristically slow rate of maturation and low fecundity, with females having asynchronous breeding seasons between colonies and producing only one pup every 18 months. Female Australian sea lions have a high rate of natal site fidelity (or natal philopatry), thus supporting their restricted home range as well as limited gene flow with other regions (Campbell 2005). As a result, some breeding colonies or clusters of breeding colonies are unique populations, and recolonisation of extinct breeding colonies is unlikely. In contrast, male Australian sea lions have foraging ranges that extend up to 60 km from their birth colonies, with some males ranging more than 180 km (Hamer et al. 2011).

Historical population abundances at the Abrolhos Islands ranged from 300–580 sea lions, while recent surveys described severely reduced population estimates (76–96 sea lions), most likely resulting from historical harvesting (Campbell 2005, DSEWPaC 2013a). Unlike other harvested pinniped species, Australian sea lion populations have not recovered, and there is evidence that some small populations are still in decline.

In the Easter Group of the Abrolhos Islands, young pups and breeding activity has been recorded on Alexander Island, Serventy Island, Campbell Island, Gilbert Island, Helm Island, Stokes Island White Island and Suomi Island (Figure C.1) (Gales et al. 1994, Campbell 2005). In the Pelsaert Group, adults and pups have been observed made at Stick Island and Square Island (Figure C.1), however, when observed, numbers have been restricted to ~3-7 individuals (Campbell 2005). In 2004, 17 sea lion pups were recorded at breeding areas within the Easter Group, and two pups were recorded on the Pelsaert Group. There was some speculation that islands in the Pelsaert Group are predominantly used as haul-out sites with only occasional pupping events (DSEWPaC 2013a).

Recent telemetry data from tagged Australian sea lions recorded foraging ranges with a broad use of coastal shelf waters, including coastal areas to the shelf's edge (Campbell 2008). Foraging behaviour varied among different Australian sea lion populations and different cohorts within each population. From all WA populations studied, sea lions generally displayed strong foraging site fidelity, and the Abrolhos Islands population had the smallest foraging range observed (Campbell 2008). Females and juveniles had small foraging ranges (<10 km), and foraging trips comprised travel within the Abrolhos Islands. As benthic foragers, Australian sea lions may dive up to 90 m to target prey species, such as cephalopods, crustaceans and fish (Campbell 2005). Interactions between Australian sea lions and the MWADZ are considered likely (Table C.3).



Source: Combined observation from DPaW 2015 and Campbell 2005

Figure C.1 Australian sea lion breeding sites in the Easter and Pelsaert Groups, Abrolhos Islands

C.1.5 Bryde's whale

The Bryde's Whale (*B. edeni*) is distributed throughout tropical and warm temperate waters, between 40˚N and 40˚S, in both oceanic and inshore waters (DoE 2014b). With the exception of the Northern Territory, Bryde's whales were recorded in all Australian states, although no feeding or breeding areas have been identified (DoE 2014b). Observations of Bryde's whales have been documented at the Abrolhos Islands indicating this area may be important for this rarely sighted species (DEWHA 2008). However, sighting frequency, habitat use and abundance of Bryde's whales at the Abrolhos Islands are not known (Bannister et al. 1996, DEWHA 2008). Large numbers of Bryde's whales are not expected to be encountered in the nearshore waters of the MWADZ proposal area. Although, it remains possible that Bryde's whale may visit the MWADZ proposal area (Table C.3).

C.1.6 Killer whale

Killer whales are a cosmopolitan species that generally occurs in offshore, pelagic areas from the equator to polar regions (Bannister et al. 1996). In Australia, killer whales have been sighted from all states on the continental slope and shelf, and near seal colonies and humpback whale resting areas. Sightings were frequently recorded from Tasmania, South Australia and Victoria, with a possible key locality at Macquarie Island (Bannister et al. 1996). Recent scientific evidence documented killer whale attacks targeting humpback whales off Ningaloo Reef, WA (Pitman et al. 2015), confirming their presence in coastal areas.

In other areas, mammal-eating killer whales are capable of rapid, long distance movements (approximately 1,000 km) into mid-latitudes, suggesting their capability to intercept and hunt humpback whales during their migration movements (Pitman et al. 2015). However, it is considered unlikely that killer whales will visit the MWADZ proposal area (Table C.3).

C.1.7 Bottlenose dolphins

Two subspecies of bottlenose dolphins are likely to occur within the MWADZ proposal area: the Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) and the common bottlenose dolphin (*T. truncatus*; DSEWPaC 2012a). Indo-Pacific bottlenose dolphins are observed between the continental shelf and the coastline (<200 m water depth) in reef, sandy and seagrass habitats (DSEWPaC 2012a). In both estuarine and coastal habitats in the southwest region of Australia, resident Indo-Pacific bottlenose populations have been surveyed for over 20 years and on a year-round basis. Scientific evidence confirmed both long-term residency and short-term associations with coastal, non-resident dolphins (Finn 2005; Chabanne et al. 2012). Therefore, as Indo-Pacific bottlenose dolphins are known to occur throughout the Abrolhos Islands, it is likely that they will be encountered in the MWADZ proposal area (Table C.3).

Common bottlenose dolphin distribution is not well documented in Australia, although records exist from Queensland, New South Wales, Tasmania, South Australia and south-western WA (DoE 2014b). Sightings are documented from both offshore (waters deeper than 30 m) and coastal waters, and in a variety of habitats: mud, sand, seagrasses, mangroves and reefs (Hale et al. 2000, DoE 2014b). Common bottlenose dolphins are often sighted in association with other cetacean species, including pilot whales, white-sided dolphins, spotted dolphins, rough-toothed dolphins, humpback whales and Southern right whales. During the Oakajee Deepwater Port baseline surveys, common bottlenose dolphins formed ~26% of the observations, the majority of which were located <15 km from shore (Oceanica 2010). Based on this assessment, common bottlenose dolphins are likely to be encountered within the MWADZ proposal area (Table C.3).

C.1.8 Dugongs

A significant proportion of the world's dugongs are found in north Australian waters from Shark Bay, WA, to Moreton Bay, Queensland (Marsh et al. 1994; Marsh et al. 2002). Specific areas supporting dugongs in WA include: Shark Bay; Ningaloo Marine Park; Exmouth Gulf; Pilbara Coastal and offshore regions (Exmouth Gulf to De Grey River); Eighty Mile Beach; and Kimberley Coast Region (Marsh et al. 2002). Dugongs are herbivores and use fresh water to varying degrees, although they also frequent coastal waters, estuarine creeks and streams, and travel upstream for several kilometres (Lawler et al. 2002). Feeding aggregations occur in wide, shallow protected bays, wide, shallow mangrove channels and in the lee of large inshore islands (Heinsohn et al. 1979). They are generally distributed around areas of deep-water seagrasses.

Although not commonly sighted south of Shark Bay, dugongs are highly migratory and undertake long distance movements (>100 km) over several days, possibly in search of seagrass beds or warmer water (DoE 2014b). During baseline investigations for the Oakajee Deepwater Port Project, aerial surveys of the mid-west region were undertaken near the Abrolhos Islands. The results included observations of individual dugongs at Horrocks, ~45 km north of Geraldton (Oceanica 2010). Therefore, there is a rare likelihood of encountering dugongs within the MWADZ proposal area (Table C.3).

C.2 Likelihood of marine mammals within the zone

The likelihood of marine mammals occurring within the MWADZ proposal area is outlined in Table C.3, with likelihood definitions prescribed from Fletcher 2014 (Table C.2).

Table C.2 Likelihood definitions

Level	Descriptor
Remote	Never heard of, but not impossible
Rare	May occur in exceptional circumstances
Unlikely	Uncommon, but has been known to occur elsewhere
Possible	Some evidence to suggest this is possible here
Occasional	May occur
Likely	It is expected to occur

Source: Fletcher 2014

Table C.3 Likelihood of marine mammal occurrences within the proposal area

Common name	Likelihood in MWADZ proposal area	Occurrence period
Blue whale	Unlikely	November–May
Pygmy blue whale	Occasional	June–August; October–January
Southern right whale	Possible	May–November
Humpback whale	Likely	July–November
Australian sea lion	Likely	All year
Bryde's whale	Possible	Unknown
Killer whale	Unlikely	Unknown
Indo-Pacific bottlenose dolphin	Likely	All year
Common bottlenose dolphin	Likely	All year
Dugong	Rare	All year

C.3 Marine turtles

The EPBC Act Protected Matters Search Tool (DoE 2014a) identified four marine turtle species (Table C.4) that are likely to occur within 50 km of the MWADZ proposal area (DoE 2014a). All

four species are listed as Threatened and Migratory under the EPBC Act and the WA Wildlife Conservation Act 1950. As nesting is not known to occur in the Abrolhos Islands, the following sections describe the likelihood that adult marine turtles will occur within the MWADZ.

Table C.4 Protected marine turtles relevant to the proposal

Scientific name	Common name	EPBC Act status	Wildlife Conservation Act status
Caretta caretta	Loggerhead turtle	Endangered, Marine, Migratory	Endangered
Dermochelys coriacea	Leatherback turtle	Endangered, Marine, Migratory	Vulnerable
Chelonia mydas	Green turtle	Vulnerable, Marine, Migratory	Vulnerable
Natator depressus	Flatback turtle	Vulnerable, Marine, Migratory	Vulnerable

C.3.1 Loggerhead turtles

Loggerhead turtles are widely distributed throughout tropical, subtropical and temperate waters, preferring the waters of coral and rocky reefs, seagrass beds and muddy bays (DoE 2014b). This species feeds primarily on benthic invertebrates, foraging from the nearshore zone to water depths of approximately 50–60 m (DoE 2014b). The WA stock is known to forage and nest primarily in north-west WA, from Shark Bay to the Pilbara Region (DoE 2014b). In the south-west of WA, resident loggerhead turtles are commonly observed foraging in waters from Rottnest Island to Geographe Bay (DEWHA 2008). Based on their foraging habitats and prey species preferences, adult loggerhead turtles may prefer the coastal waters of the MWADZ proposal area. Loggerhead turtles are not reported to be resident in the Abrolhos Islands, however reproductive adults may be encountered migrating through the region (DSEWPaC 2012b). Therefore, it is possible that the loggerhead turtle may visit the MWADZ proposal area (Table C.5).

C.3.2 Leatherback turtles

The leatherback turtle is found in tropical, subtropical and temperate waters throughout the world, and has been observed foraging in all Australian waters (DoE 2014b). Primarily in pelagic and coastal waters of all Australian states, leatherback turtles feed on marine invertebrates (such as jellyfish and tunicates), most commonly in areas of upwelling or convergence where primary productivity is high (DoE 2014b). Leatherback turtles are most commonly observed foraging in the mid- to south-west WA regions (DEWHA 2008). There are records of leatherback turtles being entangled in crayfish pot ropes at the Abrolhos Islands; therefore, it is likely this species may visit the MWADZ proposal area (Table C.5).

C.3.3 Green turtles

Green turtles are found in tropical and subtropical waters globally. WA supports one of the largest green turtle populations in the world, with ~20,000 turtles comprising three genetically distinct stocks from the north-west WA (DoE 2014b). Resident green turtles primarily feed on seagrass and algae in shallow benthic environments and regularly feed around the Abrolhos Islands reefs, which is recognised as an important foraging area (DEWHA 2008). In WA, telemetry data documented green turtles feeding up to 200–1000 km away from nesting beaches (DoE 2014b). Green turtles have been observed at the reefs of the Abrolhos Islands (DEWHA 2008). Moreover, the Abrolhos Islands and surrounding waters have been documented by the Commonwealth Government as a regionally important foraging area for the green turtle (DEWHA 2008). Therefore, green turtles are likely to occur within the MWADZ proposal area (Table C.5).

C.3.4 Flatback turtles

Flatback turtles are endemic to subtropical and tropical waters of Australia, Papua New Guinea and Irian Jaya, with nesting activity confined to Australia (Limpus 2007, DoE 2014b). They are

commonly found in turbid water over soft-bottom habitats in shallow, nearshore waters (DoE 2014b). Without a pelagic phase or global distribution, flatback turtles will mature and remain in shallow coastal waters that are close to their natal beaches (DSEWPaC 2012b). However, flatback turtles are not expected to occur in the mid-west region or south of Exmouth, WA (Limpus 2007). Therefore, their likelihood of occurrence in the MWADZ proposal area is remote (Table C.5).

C.4 Likelihood of marine turtles within MWADZ proposal area

The likelihood of marine turtles occurring within the MWADZ proposal area is outlined in Table C.5, with likelihood definitions prescribed from Fletcher 2014 (Table C.2).

Table C.5 Likelihood of marine turtle occurrences within the proposal area

Common name	Occurrence in proposal area
Loggerhead turtle	Possible
Leatherback turtle	Likely
Green turtle	Likely
Flatback turtle	Remote

Source: Fletcher 2014

D. Potential for adverse interactions

D.1 Marine mammals and turtles

The following section briefly describes the potential environmental impacts that may occur to marine mammals and turtles within the MWADZ proposal area. This information is based on a literature review of the best available scientific data. Potential environmental impacts on marine mammals and turtles may result from the following aspects of the proposed aquaculture cages:

- physical presence of the aquaculture cages;
- vessel movements; and
- artificial light.

The potential environmental impacts that may result from these aspects are described in the following sections.

D.1.1 Physical presence of aquaculture cages

The physical presence of aquaculture farms could attract larger marine predators by concentrating fish within the sheltered water, and thereby alter the natural marine environment of MWADZ proposal area. Potentially adverse impacts on local, marine mammal populations may include:

- changes in natural feeding behaviour as a result of higher fish density;
- serious injury or mortality due to aquaculture structures and/or poor mitigation methods
- inadvertent secondary effects on target species or other species due to aquaculture structures and/or mitigation methods
- habitat changes; and
- changes to marine fauna distribution and migration patterns.

In Australia, the history of marine mammal predation on fish farms spans more than 25 years, with pinniped species being the most vulnerable to potential impacts (Pemberton et al. 1991, Kemper et al. 2003). Pinniped predation most commonly involves fur seals and sea lions, but with rare interactions of leopard and elephant seals (Kemper et al. 2003). Fish stock in marine

aquaculture is likely to act as an attractant to pinnipeds, which may develop complex predation techniques, depending on predator and prey species and ranging from damaging nets and cages to entering enclosed structures and feeding on fish inside (Kemper et al. 2003). By altering their natural foraging behaviours, attempts to predate on fish within marine aquaculture cages may occur all year round with seasonal or daily patterns and result in serious injury and mortality to pinnipeds (Vilata et al. 2010).

Cetaceans may be attracted to fish farms to feed on fish inside the cages and other fish attracted to the marine farms (Diaz Lopez et al. 2005, Wursig & Gailey 2002). Noise may be an issue particularly during installation of the anchoring system for aquaculture sea-cages (DoF 2009). However, anchoring and relocation is expected to be infrequent and could be timed not to coincide with migratory pathways for sensitive species. Any impacts from noise are expected to be short-term and infrequent (DoF 2009) and therefore negligible.

Seals and sea lions have been entangled in cage nets, anchor lines and anti-predator nets. Entanglements generally result from large mesh sizes (>15 cm), unrepaired holes, open bottom nets and loose or baggy nets (Kemper et al. 2003).

Pinniped interactions are estimated to increase up to 10 times when fish farms are located within 30 km from significant haul-out sites. At Port Lincoln, South Australia, tuna feedlots were located within 25 km to the second-largest, Australian sea lion breeding colony at Dangerous Reef, resulting in a high level of pinniped interaction and predation (Kemper et al. 2003).

Recent analyses revealed that WA sea lion populations are extremely vulnerable to any additional level of mortality, the impacts of which may include reduced survival rates and population decline, which could lead to an increased extinction risk for the species (Campbell 2008). Habitat degradation and interactions with aquaculture operations were identified as significant factors contributing to the lack of recovery for the species (DSEWPaC 2013a, b). Therefore, any threat of incidental mortality, may significantly affect the population of Australian sea lions in the proposal area.

Dolphins and whales have a history of adverse interactions with marine fish farms. In the Mediterranean Sea, common bottlenose dolphins forage opportunistically around fish cages (Lopez & Shirai 2007). There has also been a high rate of incidental dolphin captures within loose, anti-predator nets with large mesh sizes (>15 cm), leading to entanglement and fatality (Kemper et al. 2003). To potentially mitigate entanglements a net mesh size of 6 cm is recommended (Schotte & Pemberton 2002). Furthermore, a an ecosystem-based model evaluating bottlenose dolphin interactions in the Mediterranean Sea, concluded that highly productive waters around open sea-cages altered the foraging strategies of bottlenose dolphins (Piroddi et al. 2011). In Australia, non-fatal and fatal entanglements in anti-predator nets with mesh sizes >15 cm have been documented (Kemper et al. 2003).

Aquaculture farms have occasionally recorded adverse impacts to large baleen whales, with a humpback whale trapped within an aquaculture cage in Port Lincoln, and an unidentified whale collision with a salmon cage and possible entanglement with its anchoring lines (Pemberton et al. 1991, Kemper et al. 2003). Between 1982 and 2010, five humpback whales were entangled in WA aquaculture gear for abalone, pearl and mussel (Groom & Coughran 2012).

The presence of the MWADZ is expected to lead to localised nutrient enrichment of the waters near the sea-cages, and organic enrichment of sediments beneath the sea-cages. Nutrient enrichment has been identified as a management concern for marine turtles and dugongs (DSEWPaC 2012b), and inputs of organic materials may alter light levels and lead to algal

blooms (Bouwan et al. 2013). Risks associated with key water column contaminants, dissolved inorganic nitrogen (DIN) and suspended particles were examined as part of the broader EIA for this proposal (NMT Oceanica 2015a). DIN was examined the context of algal growth potential, nutrient enrichment and shading.

Based on the results of modelling, concentrations of DIN down-current of the sea-cages were predicted to increase with biomass and increasing stocking density. However, the plumes dissipated rapidly, with concentrations returning to levels consistent with a high level of ecological protection inside the southern MWADZ boundary, and within 2.3 km of the northern MWADZ boundary. Despite large inputs of DIN to the system, none of the scenarios resulted in significant changes to the chlorophyll-a concentrations in the broader project area. Similar results were obtained with respect to light and water column dissolved oxygen levels. The extent of light reduction (or shading) is largely associated with the extent of particles in the water, a proportion of which is phytoplankton. Although the proposal presents conditions under which phytoplankton may flourish, thus also increasing light attenuation, none of the modelled scenarios predicted changes in chlorophyll-a concentrations and calculated light and dissolved oxygen conditions were not affected.

A small proportion on the MWADZ will be occupied by sea-cages and associated infrastructure, including support vessels, anchor lines and anchors on/in the seabed. Marine mammals and turtles may temporarily be disturbed by infrastructure or their movements may be disrupted as they attempt to avoid contact with the infrastructure.

D.1.2 Vessel movements

The proposal will be serviced by a number of small vessels. The vessels will be used for routine operations, such as maintenance, feeding and harvesting. The use of service vessels may lead to injuries and mortalities through collisions and/or changes in behaviour disturbance from noise) impact marine mammals and turtles, particularly when operating at speeds. The risk of collision increases when vessels travel at speeds greater than 15 knots (Vanderlaan & Taggart 2007). Generally, dolphin species avoid moving vessels, although large whales and turtles may not respond to approaching vessels depending on their activity at the time.

Behavioural disturbance may include avoidance, swimming speed changes, evasive dives, breathing changes and aggression (DEH 2006). Within the species range, vessel collisions have incidentally injured or killed dugongs while feeding in shallow inshore waters. Dugongs are known to habituate to vessel traffic and disturbance, thereby increasing the likelihood for collisions and injuries (DSEWPaC 2012c). While dugongs are unlikely to be encountered within the MWADZ proposal area, management measures to reduce the likelihood of adverse impacts may include restrictions on approach distance and speed limits, as per the Australian National Guidelines for Whale and Dolphin Watching 2005 (DEH 2006).

D.1.3 Artificial light

For safety and operational reasons, the aquaculture cages may require lighting at night. Artificial lighting may cause adverse environmental impacts to marine fauna by disrupting their natural behaviour through disorientation, attraction or avoidance (EPA 2010). While nesting is not known to occur at the Abrolhos Islands, adult female turtles are known to avoid nesting at beaches with artificial light, and any hatchlings depend on natural light to navigate to the open sea and risk dehydration and predation if misguided by artificial light.

E. Potential mitigation and management measures

Potential mitigation and management measures are summarised below based on a comprehensive review of literature undertaken during the EIA process. Further, more detailed recommendations are provided in the MWADZ EMMP (BMT Oceanica 2015).

Experience gained in Australia and in other parts of the world has resulted in significant advances in knowledge of aquaculture environmental management, including in the development of methods for both minimising risks and managing residual risks. Examples of the mitigation and management measures are provided in Table E.1. The management strategies listed here are proactive management strategies to be employed during routine operations, and/or incorporated into the aquaculture infrastructure.

Table E.1 Summary of project aspects, potential environmental impacts and possible management measures

Project Aspect	Potential Environmental Impact	Possible Management Measures
Aquaculture cage	Feeding behaviour change Serious injury or mortality Habitat change	Anti-predator nets (mesh size <15 cm) Constant maintenance and monitoring Controlled feeding regimes to minimise waste and prompt removal of dead stock Use of semi-rigid or well tensioned net material Adequate distance from known fauna habitats High walled sea-cages to prevent pinniped access
Aquaculture activities	The availability of supplementary food (stock feed) may change feeding behaviour Noise associated with the installation of cages may cause behavioural disturbances	Controlled feeding regimes – to minimise feed waste Prompt removal of dead stock Noise levels at all times will be within Environment Protection (Noise) Regulations thresholds and it is preferential to install the cages outside of humpback whale southern migratory months (given humpback whales are the only "likely" migratory cetacean)
Vessel movements	Serious injury or mortality Behavioural disturbance	Do not approach within 100 m of a whale and 50 m of a dolphin Do not approach calves or pods with calves Move at slow speed (<15 knots) Avoid sudden/repeated changes in direction Avoid sudden/excessive noise Allow fauna to move in against the shore
Lighting disturbance	Behavioural disturbance through: • disorientation • attraction • avoidance of important habitats	Reduce intensity of artificial light Use long-wavelength lights
Environmental quality	Toxicity Regional eutrophication	Water quality monitoring Sediment quality monitoring

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EPBC Act Protected Matters Report

This report provides general guidance on matters of national environmental significance and other matters protected by the EPBC Act in the area you have selected.

Information on the coverage of this report and qualifications on data supporting this report are contained in the caveat at the end of the report.

Information is available about Environment Assessments and the EPBC Act including significance guidelines, forms and application process details.

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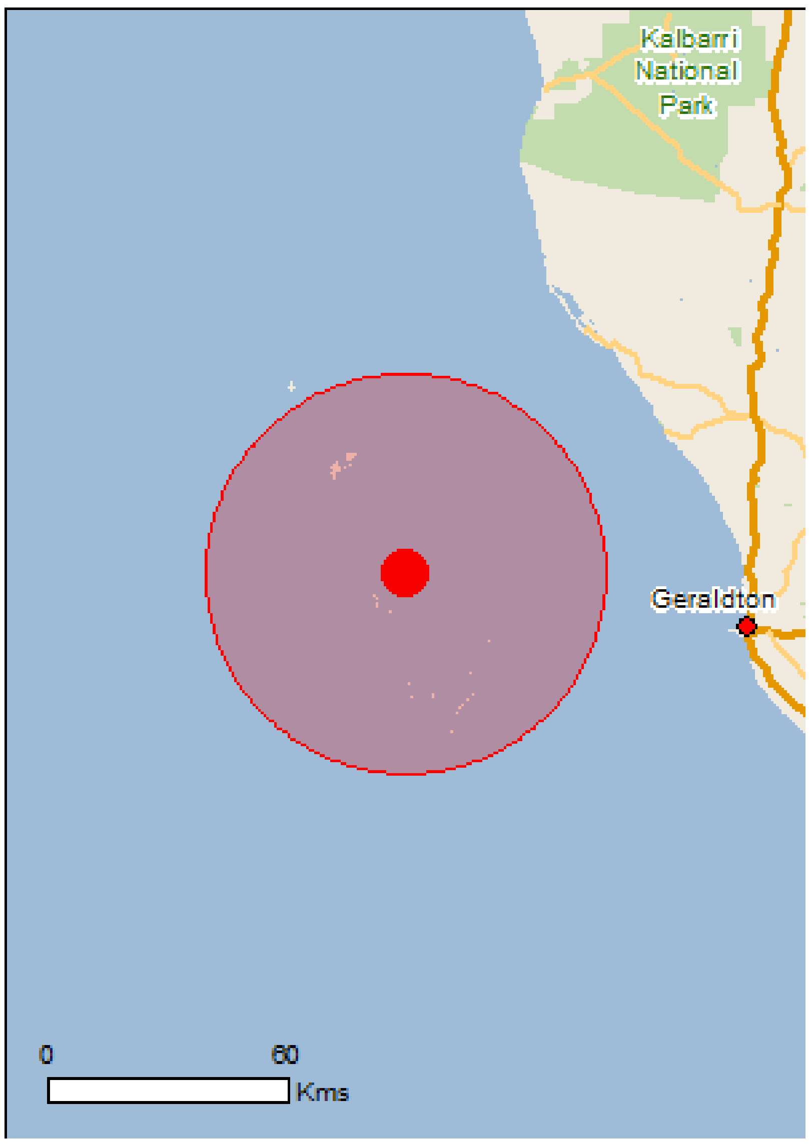

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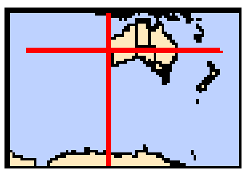

Summary

Matters of National Environmental Significance

This part of the report summarises the matters of national environmental significance that may occur in, or may relate to, the area you nominated. Further information is available in the detail part of the report, which can be accessed by scrolling or following the links below. If you are proposing to undertake an activity that may have a significant impact on one or more matters of national environmental significance then you should consider the Administrative Guidelines on Significance.

World Heritage Properties:	None
National Heritage Places:	1
Wetlands of International Importance:	None
Great Barrier Reef Marine Park:	None
Commonwealth Marine Areas:	1
Listed Threatened Ecological Communities:	None
Listed Threatened Species:	27
Listed Migratory Species:	37

Other Matters Protected by the EPBC Act

This part of the report summarises other matters protected under the Act that may relate to the area you nominated. Approval may be required for a proposed activity that significantly affects the environment on Commonwealth land, when the action is outside the Commonwealth land, or the environment anywhere when the action is taken on Commonwealth land. Approval may also be required for the Commonwealth or Commonwealth agencies proposing to take an action that is likely to have a significant impact on the environment anywhere.

The EPBC Act protects the environment on Commonwealth land, the environment from the actions taken on Commonwealth land, and the environment from actions taken by Commonwealth agencies. As heritage values of a place are part of the 'environment', these aspects of the EPBC Act protect the Commonwealth Heritage values of a Commonwealth Heritage place and the heritage values of a place on the Register of the National Estate.

This part of the report summarises other matters protected under the Act that may relate to the area you nominated. Approval may be required for a proposed activity that significantly affects the environment on Commonwealth land, when the action is outside the Commonwealth land, or the environment anywhere when the action is taken on Commonwealth land. Approval may also be required for the Commonwealth or Commonwealth agencies proposing to take an action that is likely to have a significant impact on the environment anywhere.

A permit may be required for activities in or on a Commonwealth area that may affect a member of a listed threatened species or ecological community, a member of a listed migratory species, whales and other cetaceans, or a member of a listed marine species.

Commonwealth Land:	1
Commonwealth Heritage Places:	None
Listed Marine Species:	63
Whales and Other Cetaceans:	31
Critical Habitats:	None
Commonwealth Reserves Terrestrial:	None
Commonwealth Reserves Marine	2

Extra Information

This part of the report provides information that may also be relevant to the area you have nominated.

Place on the RNE:	10
State and Territory Reserves:	None
Regional Forest Agreements:	None
Invasive Species:	3
Nationally Important Wetlands:	None
Key Ecological Features (Marine)	4

Details

Matters of National Environmental Significance

National Heritage Properties [Resource Information]

Name	State	Status
Historic		
Batavia Shipwreck Site and Survivor Camps Area 1629 - Houtman Abrolhos	WA	Listed place

Commonwealth Marine Areas [Resource Information]

Approval may be required for a proposed activity that is likely to have a significant impact on the environment in a Commonwealth Marine Area, when the action is outside the Commonwealth Marine Area, or the environment anywhere when the action is taken within the Commonwealth Marine Area. Generally the Commonwealth Marine Area stretches from three nautical miles to two hundred nautical miles from the coast.

Name
EEZ and Territorial Sea

Marine Regions [Resource Information]

If you are planning to undertake action in an area in or close to a Commonwealth Marine Area, and a marine bioregional plan has been prepared for the Commonwealth Marine Area in that area, the marine bioregional plan may inform your decision as to whether to refer your proposed action under the EPBC Act.

Name
South-west

Listed Threatened Species [Resource Information]

Name	Status	Type of Presence
Birds		
Anous tenuirostris melanops Australian Lesser Noddy [26000]	Vulnerable	Breeding known to occur within area
Diomedea epomophora epomophora Southern Royal Albatross [25996]	Vulnerable	Species or species habitat may occur within area
Diomedea epomophora sanfordi Northern Royal Albatross [82331]	Endangered	Species or species habitat may occur within area
Diomedea exulans amsterdamensis Amsterdam Albatross [82330]	Endangered	Species or species habitat may occur within area
Diomedea exulans exulans Tristan Albatross [82337]	Endangered	Species or species habitat may occur within

Name	Status	Type of Presence
		area
Diomedea exulans (sensu lato) Wandering Albatross [1073]	Vulnerable	Species or species habitat may occur within area
Macronectes giganteus Southern Giant-Petrel [1060]	Endangered	Species or species habitat may occur within area
Macronectes halli Northern Giant-Petrel [1061]	Vulnerable	Species or species habitat may occur within area
Pterodroma mollis Soft-plumaged Petrel [1036]	Vulnerable	Foraging, feeding or related behaviour likely to occur within area
Sternula nereis nereis Australian Fairy Tern [82950]	Vulnerable	Species or species habitat known to occur within area
Thalassarche carteri Indian Yellow-nosed Albatross [64464]	Vulnerable	Foraging, feeding or related behaviour may occur within area
Thalassarche cauta cauta Shy Albatross, Tasmanian Shy Albatross [82345]	Vulnerable	Species or species habitat may occur within area
Thalassarche cauta steadi White-capped Albatross [82344]	Vulnerable	Foraging, feeding or related behaviour likely to occur within area
Thalassarche melanophris Black-browed Albatross [66472]	Vulnerable	Species or species habitat may occur within area
Thalassarche melanophris impavida Campbell Albatross [82449]	Vulnerable	Species or species habitat may occur within area
Turnix varius scintillans Painted Button-quail (Houtman Abrolhos) [82451]	Vulnerable	Species or species habitat likely to occur within area
Mammals		
Balaenoptera musculus Blue Whale [36]	Endangered	Migration route known to occur within area
Eubalaena australis Southern Right Whale [40]	Endangered	Species or species habitat likely to occur within area
Megaptera novaeangliae Humpback Whale [38]	Vulnerable	Species or species habitat known to occur within area
Neophoca cinerea Australian Sea-lion [22]	Vulnerable	Breeding known to occur within area
Reptiles		
Caretta caretta Loggerhead Turtle [1763]	Endangered	Species or species habitat known to occur within area
Chelonia mydas Green Turtle [1765]	Vulnerable	Foraging, feeding or related behaviour known to occur within area
Dermochelys coriacea Leatherback Turtle, Leathery Turtle, Luth [1768]	Endangered	Species or species habitat known to occur within area

Name	Status	Type of Presence
Natator depressus		
Flatback Turtle [59257]	Vulnerable	Species or species habitat known to occur within area
Sharks		
Carcharias taurus (west coast population)		
Grey Nurse Shark (west coast population) [68752]	Vulnerable	Species or species habitat known to occur within area
Carcharodon carcharias		
Great White Shark [64470]	Vulnerable	Foraging, feeding or related behaviour known to occur within area
Rhincodon typus		
Whale Shark [66680]	Vulnerable	Species or species habitat may occur within area

Listed Migratory Species

[Resource Information]

* Species is listed under a different scientific name on the EPBC Act - Threatened Species list.

Name	Threatened	Type of Presence
Migratory Marine Birds		
Anous stolidus		
Common Noddy [825]		Breeding known to occur within area
Diomedea amsterdamensis		
Amsterdam Albatross [64405]	Endangered*	Species or species habitat may occur within area
Diomedea dabbenena		
Tristan Albatross [66471]	Endangered*	Species or species habitat may occur within area
Diomedea epomophora (sensu stricto)		
Southern Royal Albatross [1072]	Vulnerable*	Species or species habitat may occur within area
Diomedea exulans (sensu lato)		
Wandering Albatross [1073]	Vulnerable	Species or species habitat may occur within area
Diomedea sanfordi		
Northern Royal Albatross [64456]	Endangered*	Species or species habitat may occur within area
Macronectes giganteus		
Southern Giant-Petrel [1060]	Endangered	Species or species habitat may occur within area
Macronectes halli		
Northern Giant-Petrel [1061]	Vulnerable	Species or species habitat may occur within area
Puffinus carneipes		
Flesh-footed Shearwater, Fleshy-footed Shearwater [1043]		Species or species habitat likely to occur within area
Puffinus pacificus		
Wedge-tailed Shearwater [1027]		Breeding known to occur within area
Sterna anaethetus		
Bridled Tern [814]		Breeding known to occur within area
Sterna caspia		
Caspian Tern [59467]		Breeding known to occur within area
Sterna dougallii		
Roseate Tern [817]		Breeding known to occur within area
Thalassarche carteri		
Indian Yellow-nosed Albatross [64464]	Vulnerable	Foraging, feeding or related behaviour may

Name	Threatened	Type of Presence
		occur within area
Thalassarche cauta (sensu stricto) Shy Albatross, Tasmanian Shy Albatross [64697]	Vulnerable*	Species or species habitat may occur within area
Thalassarche impavida Campbell Albatross [64459]	Vulnerable*	Species or species habitat may occur within area
Thalassarche melanophris Black-browed Albatross [66472]	Vulnerable	Species or species habitat may occur within area
Thalassarche steadi White-capped Albatross [64462]	Vulnerable*	Foraging, feeding or related behaviour likely to occur within area
Migratory Marine Species		
Balaenoptera bonaerensis Antarctic Minke Whale, Dark-shoulder Minke Whale [67812]		Species or species habitat may occur within area
Balaenoptera edeni Bryde's Whale [35]		Species or species habitat may occur within area
Balaenoptera musculus Blue Whale [36]	Endangered	Migration route known to occur within area
Carcharodon carcharias Great White Shark [64470]	Vulnerable	Foraging, feeding or related behaviour known to occur within area
Caretta caretta Loggerhead Turtle [1763]	Endangered	Species or species habitat known to occur within area
Chelonia mydas Green Turtle [1765]	Vulnerable	Foraging, feeding or related behaviour known to occur within area
Dermochelys coriacea Leatherback Turtle, Leathery Turtle, Luth [1768]	Endangered	Species or species habitat known to occur within area
Eubalaena australis Southern Right Whale [40]	Endangered	Species or species habitat likely to occur within area
Isurus oxyrinchus Shortfin Mako, Mako Shark [79073]		Species or species habitat likely to occur within area
Isurus paucus Longfin Mako [82947]		Species or species habitat likely to occur within area
Lagenorhynchus obscurus Dusky Dolphin [43]		Species or species habitat may occur within area
Lamna nasus Porbeagle, Mackerel Shark [83288]		Species or species habitat may occur within area
Manta birostris Giant Manta Ray, Chevron Manta Ray, Pacific Manta Ray, Pelagic Manta Ray, Oceanic Manta Ray [84995]		Species or species habitat likely to occur within area
Megaptera novaeangliae Humpback Whale [38]	Vulnerable	Species or species habitat known to occur within area

Name	Threatened	Type of Presence
Natator depressus Flatback Turtle [59257]	Vulnerable	Species or species habitat known to occur within area
Orcinus orca Killer Whale, Orca [46]		Species or species habitat may occur within area
Physeter macrocephalus Sperm Whale [59]		Species or species habitat may occur within area
Rhincodon typus Whale Shark [66680]	Vulnerable	Species or species habitat may occur within area
Migratory Terrestrial Species		
Haliaeetus leucogaster White-bellied Sea-Eagle [943]		Species or species habitat known to occur within area

Other Matters Protected by the EPBC Act

Commonwealth Land [Resource Information]

The Commonwealth area listed below may indicate the presence of Commonwealth land in this vicinity. Due to the unreliability of the data source, all proposals should be checked as to whether it impacts on a Commonwealth area, before making a definitive decision. Contact the State or Territory government land department for further information.

Name
Commonwealth Land -

Listed Marine Species [Resource Information]

* Species is listed under a different scientific name on the EPBC Act - Threatened Species list.

Name	Threatened	Type of Presence
Birds		
Anous stolidus Common Noddy [825]		Breeding known to occur within area
Anous tenuirostris melanops Australian Lesser Noddy [26000]	Vulnerable	Breeding known to occur within area
Catharacta skua Great Skua [59472]		Species or species habitat may occur within area
Diomedea amsterdamensis Amsterdam Albatross [64405]	Endangered*	Species or species habitat may occur within area
Diomedea dabbenena Tristan Albatross [66471]	Endangered*	Species or species habitat may occur within area
Diomedea epomophora (sensu stricto) Southern Royal Albatross [1072]	Vulnerable*	Species or species habitat may occur within area
Diomedea exulans (sensu lato) Wandering Albatross [1073]	Vulnerable	Species or species habitat may occur within area
Diomedea sanfordi Northern Royal Albatross [64456]	Endangered*	Species or species habitat may occur within area
Haliaeetus leucogaster White-bellied Sea-Eagle [943]		Species or species habitat known to occur

Name	Threatened	Type of Presence
		within area
Larus novaehollandiae Silver Gull [810]		Breeding known to occur within area
Larus pacificus Pacific Gull [811]		Breeding known to occur within area
Macronectes giganteus Southern Giant-Petrel [1060]	Endangered	Species or species habitat may occur within area
Macronectes halli Northern Giant-Petrel [1061]	Vulnerable	Species or species habitat may occur within area
Pandion haliaetus Osprey [952]		Breeding known to occur within area
Pelagodroma marina White-faced Storm-Petrel [1016]		Breeding known to occur within area
Phaethon rubricauda Red-tailed Tropicbird [994]		Breeding known to occur within area
Phalacrocorax fuscescens Black-faced Cormorant [59660]		Breeding likely to occur within area
Pterodroma macroptera Great-winged Petrel [1035]		Foraging, feeding or related behaviour known to occur within area
Pterodroma mollis Soft-plumaged Petrel [1036]	Vulnerable	Foraging, feeding or related behaviour likely to occur within area
Puffinus assimilis Little Shearwater [59363]		Breeding known to occur within area
Puffinus carneipes Flesh-footed Shearwater, Fleshy-footed Shearwater [1043]		Species or species habitat likely to occur within area
Puffinus huttoni Hutton's Shearwater [1025]		Foraging, feeding or related behaviour known to occur within area
Puffinus pacificus Wedge-tailed Shearwater [1027]		Breeding known to occur within area
Sterna anaethetus Bridled Tern [814]		Breeding known to occur within area
Sterna bergii Crested Tern [816]		Breeding known to occur within area
Sterna caspia Caspian Tern [59467]		Breeding known to occur within area
Sterna dougallii Roseate Tern [817]		Breeding known to occur within area
Sterna fuscata Sooty Tern [794]		Breeding known to occur within area
Sterna nereis Fairy Tern [796]		Breeding known to occur within area
Thalassarche carteri Indian Yellow-nosed Albatross [64464]	Vulnerable	Foraging, feeding or related behaviour may occur within area

Name	Threatened	Type of Presence
Thalassarche cauta (sensu stricto) Shy Albatross, Tasmanian Shy Albatross [64697]	Vulnerable*	Species or species habitat may occur within area
Thalassarche impavida Campbell Albatross [64459]	Vulnerable*	Species or species habitat may occur within area
Thalassarche melanophris Black-browed Albatross [66472]	Vulnerable	Species or species habitat may occur within area
Thalassarche steadi White-capped Albatross [64462]	Vulnerable*	Foraging, feeding or related behaviour likely to occur within area
Fish		
Acentronura australe Southern Pygmy Pipehorse [66185]		Species or species habitat may occur within area
Campichthys galei Gale's Pipefish [66191]		Species or species habitat may occur within area
Choeroichthys suillus Pig-snouted Pipefish [66198]		Species or species habitat may occur within area
Halicampus brocki Brock's Pipefish [66219]		Species or species habitat may occur within area
Hippocampus angustus Western Spiny Seahorse, Narrow-bellied Seahorse [66234]		Species or species habitat may occur within area
Hippocampus breviceps Short-head Seahorse, Short-snouted Seahorse [66235]		Species or species habitat may occur within area
Hippocampus subelongatus West Australian Seahorse [66722]		Species or species habitat may occur within area
Lissocampus fatiloquus Prophet's Pipefish [66250]		Species or species habitat may occur within area
Maroubra perserrata Sawtooth Pipefish [66252]		Species or species habitat may occur within area
Mitotichthys meraculus Western Crested Pipefish [66259]		Species or species habitat may occur within area
Nannocampus subosseus Bonyhead Pipefish, Bony-headed Pipefish [66264]		Species or species habitat may occur within area
Phycodurus eques Leafy Seadragon [66267]		Species or species habitat may occur within area
Phyllopteryx taeniolatus Common Seadragon, Weedy Seadragon [66268]		Species or species habitat may occur within area
Pugnaso curtirostris Pugnose Pipefish, Pug-nosed Pipefish [66269]		Species or species habitat may occur within area

Name	Threatened	Type of Presence
Solegnathus lettiensis Gunther's Pipehorse, Indonesian Pipefish [66273]		Species or species habitat may occur within area
Stigmatopora argus Spotted Pipefish, Gulf Pipefish [66276]		Species or species habitat may occur within area
Stigmatopora nigra Widebody Pipefish, Wide-bodied Pipefish, Black Pipefish [66277]		Species or species habitat may occur within area
Syngnathoides biaculeatus Double-end Pipehorse, Double-ended Pipehorse, Alligator Pipefish [66279]		Species or species habitat may occur within area
Urocampus carinirostris Hairy Pipefish [66282]		Species or species habitat may occur within area
Vanacampus margaritifer Mother-of-pearl Pipefish [66283]		Species or species habitat may occur within area
Mammals		
Arctocephalus forsteri New Zealand Fur-seal [20]		Species or species habitat may occur within area
Neophoca cinerea Australian Sea-lion [22]	Vulnerable	Breeding known to occur within area
Reptiles		
Aipysurus pooleorum Shark Bay Seasnake [66061]		Species or species habitat may occur within area
Caretta caretta Loggerhead Turtle [1763]	Endangered	Species or species habitat known to occur within area
Chelonia mydas Green Turtle [1765]	Vulnerable	Foraging, feeding or related behaviour known to occur within area
Dermochelys coriacea Leatherback Turtle, Leathery Turtle, Luth [1768]	Endangered	Species or species habitat known to occur within area
Disteira kingii Spectacled Seasnake [1123]		Species or species habitat may occur within area
Natator depressus Flatback Turtle [59257]	Vulnerable	Species or species habitat known to occur within area
Pelamis platurus Yellow-bellied Seasnake [1091]		Species or species habitat may occur within area

Whales and other Cetaceans [Resource Information]

Name	Status	Type of Presence
Mammals		
Balaenoptera acutorostrata Minke Whale [33]		Species or species habitat may occur within area
Balaenoptera bonaerensis Antarctic Minke Whale, Dark-shoulder Minke Whale [67812]		Species or species habitat may occur within area

Name	Status	Type of Presence
Balaenoptera edeni Bryde's Whale [35]		Species or species habitat may occur within area
Balaenoptera musculus Blue Whale [36]	Endangered	Migration route known to occur within area
Delphinus delphis Common Dophin, Short-beaked Common Dolphin [60]		Species or species habitat may occur within area
Eubalaena australis Southern Right Whale [40]	Endangered	Species or species habitat likely to occur within area
Feresa attenuata Pygmy Killer Whale [61]		Species or species habitat may occur within area
Globicephala macrorhynchus Short-finned Pilot Whale [62]		Species or species habitat may occur within area
Globicephala melas Long-finned Pilot Whale [59282]		Species or species habitat may occur within area
Grampus griseus Risso's Dolphin, Grampus [64]		Species or species habitat may occur within area
Kogia breviceps Pygmy Sperm Whale [57]		Species or species habitat may occur within area
Kogia simus Dwarf Sperm Whale [58]		Species or species habitat may occur within area
Lagenodelphis hosei Fraser's Dolphin, Sarawak Dolphin [41]		Species or species habitat may occur within area
Lagenorhynchus obscurus Dusky Dolphin [43]		Species or species habitat may occur within area
Megaptera novaeangliae Humpback Whale [38]	Vulnerable	Species or species habitat known to occur within area
Mesoplodon bowdoini Andrew's Beaked Whale [73]		Species or species habitat may occur within area
Mesoplodon densirostris Blainville's Beaked Whale, Dense-beaked Whale [74]		Species or species habitat may occur within area
Mesoplodon grayi Gray's Beaked Whale, Scamperdown Whale [75]		Species or species habitat may occur within area
Mesoplodon layardii Strap-toothed Beaked Whale, Strap-toothed Whale, Layard's Beaked Whale [25556]		Species or species habitat may occur within area
Mesoplodon mirus True's Beaked Whale [54]		Species or species habitat may occur within area
Orcinus orca Killer Whale, Orca [46]		Species or species

Name	Status	Type of Presence
		habitat may occur within area
Peponocephala electra Melon-headed Whale [47]		Species or species habitat may occur within area
Physeter macrocephalus Sperm Whale [59]		Species or species habitat may occur within area
Pseudorca crassidens False Killer Whale [48]		Species or species habitat may occur within area
Stenella attenuata Spotted Dolphin, Pantropical Spotted Dolphin [51]		Species or species habitat may occur within area
Stenella coeruleoalba Striped Dolphin, Euphrosyne Dolphin [52]		Species or species habitat may occur within area
Stenella longirostris Long-snouted Spinner Dolphin [29]		Species or species habitat may occur within area
Steno bredanensis Rough-toothed Dolphin [30]		Species or species habitat may occur within area
Tursiops aduncus Indian Ocean Bottlenose Dolphin, Spotted Bottlenose Dolphin [68418]		Species or species habitat likely to occur within area
Tursiops truncatus s. str. Bottlenose Dolphin [68417]		Species or species habitat may occur within area
Ziphius cavirostris Cuvier's Beaked Whale, Goose-beaked Whale [56]		Species or species habitat may occur within area

Commonwealth Reserves Marine [Resource Information]

Name	Label
Abrolhos	Multiple Use Zone (IUCN VI)
Abrolhos	Special Purpose Zone (IUCN VI)

Extra Information

Places on the RNE [Resource Information]

Note that not all Indigenous sites may be listed.

Name	State	Status
Natural		
Houtman Abrolhos Islands Reserve	WA	Registered
Houtman Abrolhos Marine Area	WA	Registered
Historic		
Batavia Shipwreck	WA	Registered
Ben Ledi Shipwreck	WA	Registered
Hadda Shipwreck	WA	Registered
Marten Shipwreck	WA	Registered
Ocean Queeen Shipwreck	WA	Registered
Ruins of Huts on West Wallabi Island	WA	Registered
Windsor Shipwreck	WA	Registered
Zeewijk Shipwreck	WA	Registered

Invasive Species [Resource Information]

Weeds reported here are the 20 species of national significance (WoNS), along with other introduced plants that are considered by the States and Territories to pose a particularly significant threat to biodiversity. The following feral animals are reported: Goat, Red Fox, Cat, Rabbit, Pig, Water Buffalo and Cane Toad. Maps from Landscape Health Project, National Land and Water Resouces Audit, 2001.

Name	Status	Type of Presence
Mammals		
Mus musculus		
House Mouse [120]		Species or species habitat likely to occur within area
Plants		
Lycium ferocissimum		
African Boxthorn, Boxthorn [19235]		Species or species habitat likely to occur within area
Opuntia spp.		
Prickly Pears [82753]		Species or species habitat likely to occur within area

Key Ecological Features (Marine) [Resource Information]

Key Ecological Features are the parts of the marine ecosystem that are considered to be important for the biodiversity or ecosystem functioning and integrity of the Commonwealth Marine Area.

Name	Region
Ancient coastline at 90-120m depth	South-west
Commonwealth marine environment surrounding	South-west
Western demersal slope and associated fish	South-west
Western rock lobster	South-west

Coordinates

-28.66667 113.85

Caveat

The information presented in this report has been provided by a range of data sources as acknowledged at the end of the report.

This report is designed to assist in identifying the locations of places which may be relevant in determining obligations under the Environment Protection and Biodiversity Conservation Act 1999. It holds mapped locations of World Heritage and Register of National Estate properties, Wetlands of International Importance, Commonwealth and State/Territory reserves, listed threatened, migratory and marine species and listed threatened ecological communities. Mapping of Commonwealth land is not complete at this stage. Maps have been collated from a range of sources at various resolutions.

Not all species listed under the EPBC Act have been mapped (see below) and therefore a report is a general guide only. Where available data supports mapping, the type of presence that can be determined from the data is indicated in general terms. People using this information in making a referral may need to consider the qualifications below and may need to seek and consider other information sources.

For threatened ecological communities where the distribution is well known, maps are derived from recovery plans, State vegetation maps, remote sensing imagery and other sources. Where threatened ecological community distributions are less well known, existing vegetation maps and point location data are used to produce indicative distribution maps.

For species where the distributions are well known, maps are digitised from sources such as recovery plans and detailed habitat studies. Where appropriate, core breeding, foraging and roosting areas are indicated under 'type of presence'. For species whose distributions are less well known, point locations are collated from government wildlife authorities, museums, and non-government organisations; bioclimatic distribution models are generated and these validated by experts. In some cases, the distribution maps are based solely on expert knowledge.

Only selected species covered by the following provisions of the EPBC Act have been mapped:

- migratory and
- marine

The following species and ecological communities have not been mapped and do not appear in reports produced from this database:

- threatened species listed as extinct or considered as vagrants
- some species and ecological communities that have only recently been listed
- some terrestrial species that overfly the Commonwealth marine area
- migratory species that are very widespread, vagrant, or only occur in small numbers

The following groups have been mapped, but may not cover the complete distribution of the species:

- non-threatened seabirds which have only been mapped for recorded breeding sites
- seals which have only been mapped for breeding sites near the Australian continent

Such breeding sites may be important for the protection of the Commonwealth Marine environment.

Acknowledgements

This database has been compiled from a range of data sources. The department acknowledges the following custodians who have contributed valuable data and advice:

-Department of Environment, Climate Change and Water, New South Wales
-Department of Sustainability and Environment, Victoria
-Department of Primary Industries, Parks, Water and Environment, Tasmania
-Department of Environment and Natural Resources, South Australia
-Parks and Wildlife Service NT, NT Dept of Natural Resources, Environment and the Arts
-Environmental and Resource Management, Queensland
-Department of Environment and Conservation, Western Australia
-Department of the Environment, Climate Change, Energy and Water
-Birds Australia
-Australian Bird and Bat Banding Scheme
-Australian National Wildlife Collection
-Natural history museums of Australia
-Museum Victoria
-Australian Museum
-SA Museum
-Queensland Museum
-Online Zoological Collections of Australian Museums
-Queensland Herbarium
-National Herbarium of NSW
-Royal Botanic Gardens and National Herbarium of Victoria
-Tasmanian Herbarium
-State Herbarium of South Australia
-Northern Territory Herbarium
-Western Australian Herbarium
-Australian National Herbarium, Atherton and Canberra
-University of New England
-Ocean Biogeographic Information System
-Australian Government, Department of Defence
-State Forests of NSW
-Geoscience Australia
-CSIRO
-Other groups and individuals

The Department is extremely grateful to the many organisations and individuals who provided expert advice and information on numerous draft distributions.

Please feel free to provide feedback via the Contact Us page.

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Threat Identification, Hazard Pathway Analysis and Assessment of the Key Risks to the Sustainability of Endangered, Threatened and Protected Fish Populations at the Abrolhos Islands, presented by the establishment of the Mid West Aquaculture Development Zone, Western Australia

Prepared by

Department of Fisheries, Western Australia

August 2015

Summary of the risk level

Risk	**Inherent Risk** (no management measures)	**Residual Risk** (based on implementation of identified management measures)
Aquaculture activity in the zone will potentially have a significant impact on endangered, threatened or protected (shark and ray) species within the Abrolhos Islands Fish Habitat Protection Area, either from a sustainability or social acceptability perspective.	**Moderate**	**Low**

Table of Contents

1. Context and Scope

The ecological risk assessment presented in this report has been undertaken to assist in identifying and assessing the potential impacts of finfish aquaculture associated with a Department of Fisheries proposal to establish an aquaculture development zone in the Mid West of Western Australia (referred to hereafter as the Mid West Aquaculture Development Zone or MWADZ), on the sustainability of endangered, threatened and protected fish species.

An environmental management objective of the MWADZ proposal is to ensure the establishment and operation of the MWADZ without significantly impacting on marine ecosystem functions, habitats and endangered, threatened and protected species which depend on these. This assessment does not seek to replicate previously conducted generic aquaculture risk assessments that are relevant to the MWADZ proposal, including the following:

- Marine Finfish Environmental Risk Assessment (de Jong &Tanner, FRDC Project 2003/223)
- National ESD Reporting Framework: The “How to” Guide for Aquaculture. Version 1.1 FRDC, Canberra, Australia (Fletcher et al., 2004)
- Finfish Aquaculture in Western Australia: Final ESD Risk Assessment Report for Sea-Cage and Land-Based Finfish Aquaculture (Vom Berg, 2008; Fisheries Management Paper No 229, Department of Fisheries, Western Australia)
- Finfish Aquaculture in Western Australia: Final ESD Risk Assessment Report for Marine Finfish Aquaculture (Vom Berg, 2009; Fisheries Management Paper No 233, Department of Fisheries, Western Australia)

Instead, the current assessment has used these previous reports as a basis to identify the main broad areas of threat that are most relevant to the MWADZ proposal. These threats were further broken down through the consideration of the detailed hazard pathways that may lead to the realisation of these threats. Consideration of the threats facilitated the identification of key overarching risks to the identified objective of the assessment.

This document describes the assessment of one key risk presented by the establishment of the MWADZ to the sustainability of endangered, threatened and protected fish populations. Both the inherent risk (risk before application of management controls) coupled to the residual risk (following application of proposed management controls) were assessed in order to determine the nature and level of management controls required to bring the cumulative risks around sea-cage culture of finfish in the MWADZ to an acceptable level.

Using this methodology, the current assessment sought to clearly identify the current risk management measures in place and assess their adequacy in bringing identified risks to ecosystem sustainability associated with the MWADZ proposal to an acceptable level.

An aquaculture development zone is a designated area of water selected for its suitability for a specific aquaculture sector (in this case marine finfish). Designating areas as aquaculture development zones is a result of Departmental policy aimed at stimulating aquaculture investment through providing an 'investment ready' platform for organisations that wish to set up commercial aquaculture operations.

More streamlined approvals processes are in place for organisations that want to establish aquaculture operations within these zones. Extensive studies and modelling underpins the approval of a zone to ensure its potential effects are identified, well understood and managed. Establishing new aquaculture operations, or expanding existing ones, will provide significant economic benefits to the local community through the creation of job opportunities and regional economic diversification

A Kimberley Aquaculture Development Zone (KADZ) in WA's northern waters has already been declared by the Minister for Fisheries. Covering a total area of almost 2,000 hectares, the zone is located within Cone Bay approximately 215 kilometres northeast of Broome. Extensive environmental studies completed for the zone indicate its capacity to support 20,000 tonnes of finfish without any significant environmental impact. An existing barramundi farm operates within the boundaries of the KADZ. The establishment of the zone has enabled the operator, Marine Produce Australia Pty Ltd, to secure environmental approval to increase its production capability from 2,000 to nearly 7,000 tonnes per annum.

This assessment relates to a second planned aquaculture development in the Mid West region of Western Australia (WA). The MWADZ will be located within the State waters of the Abrolhos Islands Fish Habitat Protection Area (FHPA), north of the Pelsaert Group, about 60 kilometres west of Geraldton. The exact site will be determined after evaluating the results of environmental and technical studies.

The zone is being established through a process that primarily involves environmental assessment of the zone as a strategic proposal under Part IV of the *Environmental Protection Act 1986*. Approval of this strategic proposal will create opportunities for existing and future aquaculture operators to refer their proposals to the Environmental Protection Authority (EPA) as 'derived proposals'. The aim of the zone concept is a more efficient assessment and regulation process due to early consideration of potential environmental impacts and cumulative impacts identified during the assessment process for the zone.

The Department surveyed and sampled a study area of 4,740 hectares in two locations within the FHPA. This process identified 2,200 hectares in the Northern Area and 800 hectares in the Southern Area (see Figure 1) as the most suitable areas for finfish aquaculture. Technical environmental studies of these locations helped determine the delineation of the zone. The proposed zone is situated away from areas of highest conservation value and is subject to considerable water flushing driven by prevailing winds, waves and currents. Good water flow through the sea-cages in which the fish are grown is essential for high productivity and to minimise environmental impact.

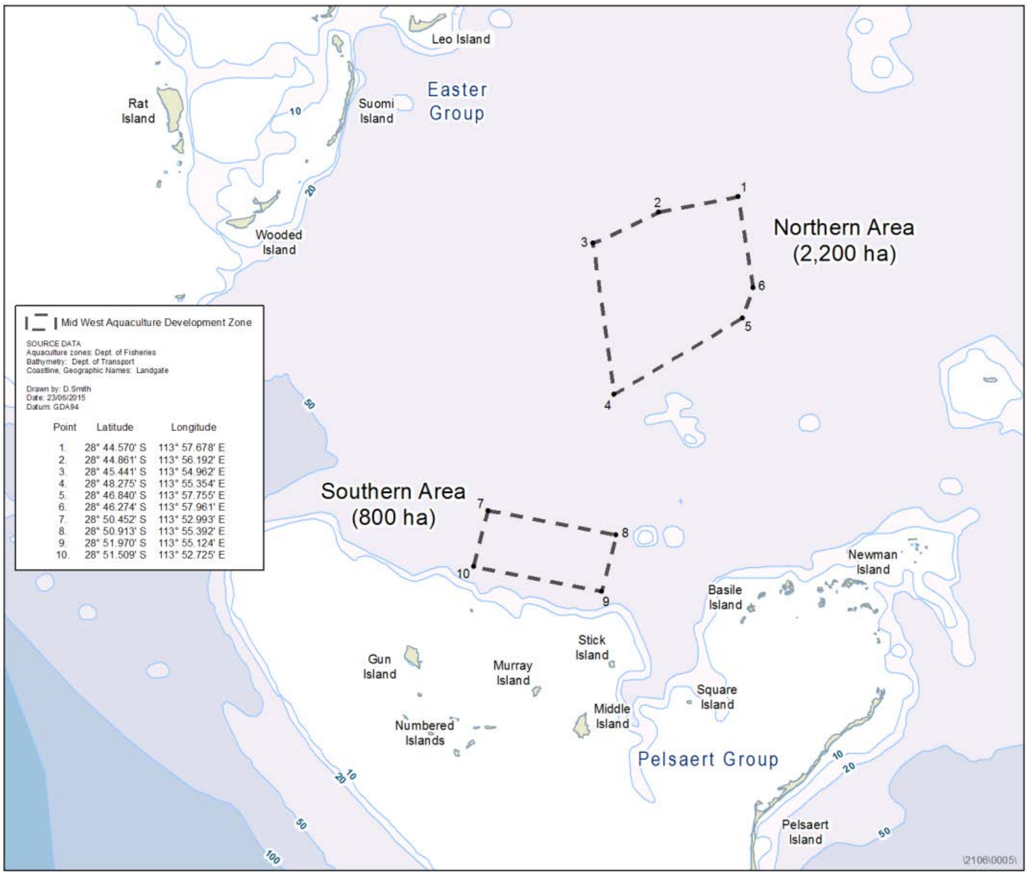

Figure 1: Proposed Mid West Aquaculture Development Zone

The Department will manage aquaculture operations in the MWADZ within an integrated management framework. This framework will be similar to that developed for the Kimberley Aquaculture Development Zone. Its purpose is to:

- establish an overarching, integrated structure for managing the aquaculture activities within the zone;
- provide clear, efficient and effective processes for monitoring, evaluating and reporting;
- guide the development of marine finfish aquaculture;
- implement the monitoring and reporting processes; and

- ensure adaptive management occurs as part of a process of continuous improvement.

The zone management framework will incorporate:

- a zone Management Policy;
- an Environmental Monitoring and Management Plan (EMMP);
- a Ministerial Statement/Notice;
- Aquaculture Licences;
- Management and Environmental Monitoring Plans (MEMPs); and
- Aquaculture Leases.

The selection of suitable species for aquaculture in WA is managed through the requirement for commercial aquaculture operators to obtain an aquaculture licence which is assessed with regard to the Department's Translocation Policy. Likely suitable fish species to be cultured in the zone, based on existing commercial aquaculture interest, the positive outcome of previous research trials, their suitability for aquaculture in WA and/or ability to meet Departmental licensing and biosecurity requirements (e.g. being native species and suited to feeding with a formulated, pathogen-free diet) include the following:

- Yellowtail kingfish (*Seriola lalandi*)
- Mulloway (*Argyrosomus japonicus*)
- Dolphin fish (*Coryphaena hippurus*)

Based on this context, the current threat identification, hazard pathway analysis and risk assessment was conducted to identify and assess the potential impacts of finfish aquaculture on endangered, threatened and protected species of fish (ETP species) within the MWADZ.

ETP species of fish comprise sharks, rays, Queensland grouper, and syngnathids (pipefish, seahorses and seadragons). Most syngnathid species inhabit shallow, sheltered coastal waters. This assessment has not included sygnathids because there are no factors linked to the proposed aquaculture that are likely to influence sygnathids or habitats they are reliant on.

This assessment has also not included Queensland grouper. Queensland grouper is occasionally recorded in temperate waters; however, it is usually found in tropical waters throughout the Indo-Pacific. While Queensland grouper possibly exist at the Abrolhos Islands and may potentially be influenced by finfish aquaculture, the likelihood of an interaction is considered extremely remote.

From this point in the assessment onwards, "ETP species" refers to ETP species of sharks and rays (listed in Table 1).

This ecological risk assessment is generic in nature, but is knowledge-based on the limited records relating to interactions between sharks/rays and culture of marine finfish. The assessment has also considered all available relevant information relating to the:

- proposed location within the Abrolhos Islands Fish habitat Protection Area (FHPA);
- ETP species known to inhabit the FHPA in the vicinity of the MWADZ and (in particular) the behavioural biology of white shark (*Carcharodon carcharias*) as a representative species;
- likely characteristics of yellowtail kingfish aquaculture (proposed aquaculture); and
- proposed management framework and options for minimising interactions between ETP species and the proposed aquaculture.

Information on interactions between sharks/rays and aquaculture is limited. Almost all of the available data are focused on white shark and shark species other than ETP species (i.e. tiger shark).

Given the lack of information on ETP species-aquaculture interactions, the information known on the interactions of white shark/tiger shark/similar species with finfish aquaculture was used for the purposes of this assessment. It is acknowledged that while there could be different types of interactions between other ETP species (e.g. sawfish and whale shark) and finfish aquaculture, the behavioural characteristics of the iconic white shark/tiger shark/similar species could be reasonably considered indicative of the wider ETP species group. Therefore, this iconic suite of species was used to assess the overall potential impacts of the proposal on ETP species. A list of the endangered, threatened and protected species (ETPs) that could potentially be affected by the MWADZ proposal has been provided in Table 1.

Table 1: Endangered, threatened and protected species of fish (ETP species) potentially affected by the proposal

Common name	Family	Species
White shark	Lamnidae	*Carcharodon carcharias*
Shortfin mako		*Isurus oxyrinchus*
Longfin mako		*Isurus paucus*
Grey Nurse shark	Odontaspididae	*Carcharias taurus*
Tiger shark[1]	Sphyrnidae	*Galeocerdo cuvier*
Smooth hammerhead		*Sphyrna zygaena*
Scalloped hammerhead		*Sphyrna lewini*
Great hammerhead		*Sphyrna mokarran*
Green sawfish	Pristiophoridae	*Pritis zijsron*
Whale shark	Rhincodontidae	*Rhincodon typus*
Manta ray	Mobulidae	*Manta birostris*

[1] Tiger shark is not considered to be an ETP species, however, as an iconic marine species is considered to be representative of many of the ETP species of fish listed above.

2. Assessment Methodology

The identification of threats, analysis of hazard pathways and assessment of risks that may be generated by the proposal to develop an aquaculture zone in the Mid West region of WA was completed using methods that are consistent with the international standards for risk management and assessment (ISO 31000, 2009; IEC/ISO; 2009; SA-HB89; 2012). The process for assessment included three components – threat identification, hazard pathway analysis, identification of overarching risks, assessment of the contribution of hazards and factors, and the overarching risk assessment (see Figure 2).

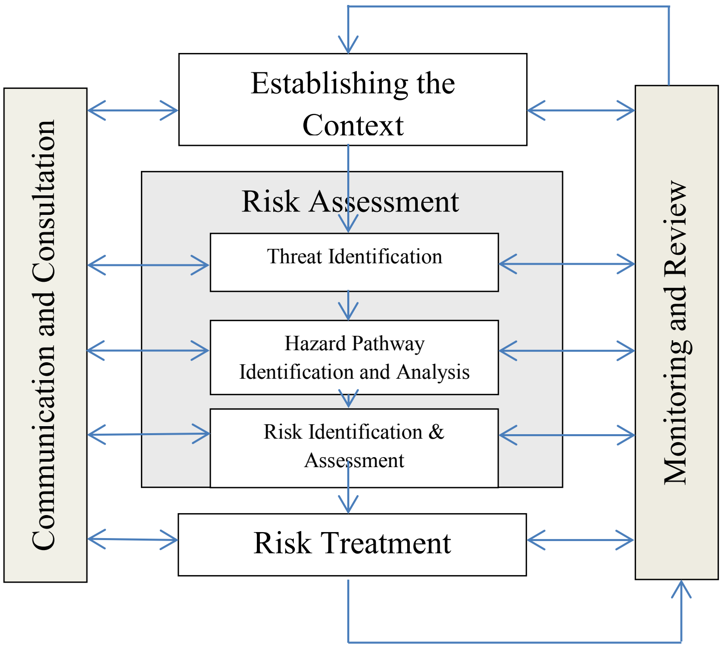

Figure 2: Description of risk assessment within the risk management process (modified from SA, 2012)

The specific protocols to complete each of these steps have been specifically tailored and extensively applied across a number of different aquatic management situations in Australia (Fletcher 2005, Fletcher et al. 2002, Jones and Fletcher 2012). Moreover this methodology has now been widely applied in many other locations in the world (Cochrane et al. 2008, FAO 2012, Fletcher 2008, Fletcher and Bianchi 2014) and is considered one of the 'must be read' methods supporting the implementation of the ecosystem approach (Cochrane 2013).

2.1. Threat Identification

Threat identification was based on a review of the following previously conducted assessments and consideration of specific information associated with the MWADZ proposal:

- Marine Finfish Environmental Risk Assessment (de Jong & Tanner, FRDC Project 2003/223)
- National ESD Reporting Framework: The “How to” Guide for Aquaculture. Version 1.1 FRDC, Canberra, Australia (Fletcher et al., 2004)
- Finfish Aquaculture in Western Australia: Final ESD Risk Assessment Report for Sea-Cage and Land-Based Finfish Aquaculture (Vom Berg, 2008; Fisheries Management Paper No 229, Department of Fisheries, Western Australia)
- Finfish Aquaculture in Western Australia: Final ESD Risk Assessment Report for Marine Finfish Aquaculture (Vom Berg, 2009; Fisheries Management Paper No 233, Department of Fisheries, Western Australia)

2.2. Hazard Pathway Identification

The identification of hazard pathways associated with the broad threat identified within the scope of the current assessment was accomplished using ‘Failure Mode Analysis’. Failure Mode Analysis is an engineering technique used to identify critical steps or hazard pathways that can lead to systems failure or the realisation of threats (in this case, the effects of interactions between ETP species and aquaculture operations in the MWADZ). This process was conducted in order to assist with the orderly identification of issues relevant to assessment. The generated hazard pathways were used to assist with the identification of critical steps that may result in threats that need to be considered as a result of undertaking aquaculture activity in the MWADZ (Figure 3).

2.3. Hazard Pathway Analysis

Individual hazards in each pathway were individually assessed according to their risk (Table 6); with respect to both inherent risk (i.e. baseline risk if no management measures aimed at mitigating the risk were in place) and residual risk (i.e. remaining risk once one or more of proposed management controls have been effected). This process was undertaken to both understand the individual inherent hazards as well as to provide clarity as to the specific hazard or risk that a particular management activity is targeted at mitigating. This, in turn, assists in assessing whether management controls are adequate to manage risk of the entire pathway to an acceptable level and to identify any additional management actions required to address specific unacceptable risks.

The Consequence–Likelihood method was used to assess the level of the identified hazard pathway components associated with the key identified threats. The broad approach applied is a widely used method (SA, 2012) that is applied by many WA Government Agencies through WA RiskCover.

Undertaking hazard or risk analysis using the Consequence-Likelihood (CxL) methodology involves selecting the most appropriate combination of consequence (levels of impact; Table 2) and the likelihood (levels of probability; Table 3) of this consequence actually occurring. The combination of these scores is then used to determine the risk rating (Table 4; IEC/ISO, 2009, SA, 2012). In considering the hazard pathways associated with an impact on the sustainability of ETP species, consequence (as described in Table 2) was determined against achievement of the corresponding objective.

The International standards definition of risk is "*the effect of uncertainty on objectives*" (ISO, 2009). This definition of risk makes it clear that examining risk will inherently include the level of uncertainty generated from having incomplete information (SA, 2012).

In the context of assessing the threats and risk associated with this proposal, the objective is to ensure ETP species are not significantly impacted by aquaculture operations and infrastructure in the MWADZ. Accordingly, a "significant impact" that would result in a high risk would be one for which there was a reasonable likelihood that the number of individuals of a ETP species affected by aquaculture operations and infrastructure would materially alter the longer-term sustainability of that species at the population level, thereby resulting in a significant community concern.

Table 2: Levels of consequence relating to the environmental management objectives of the MWADZ proposal (modified from Fletcher, 2015)

Objective	Minor (1)	Moderate (2)	Major (3)	Severe (4)
Sustainability of endangered, threatened and protected (ETP) species (including the impacts on social acceptability)	Few individuals directly impacted in most years (i.e. no impact on sustainability) and well below that which will generate public concern.	Catch or impact at the maximum level that will not impact on recovery or cause unacceptable public concern.	Recovery of a vulnerable population may be impeded and/or some clear (but short term) public concern is generated.	Further decline of a vulnerable population and/or significant, widespread and ongoing public concern generated.
Maintenance of Ecosystem Structure and Function	Measurable but minor changes to ecosystem structure, but no measurable change to function.	Maximum acceptable level of change in the ecosystem structure with no material change in function.	Ecosystem function now altered with some function or major components now missing and/or new species are prevalent.	Extreme change to structure and function. Complete species shifts in capture or prevalence in system.

Conservation of Habitat	Measurable impacts very localised. Area directly affected well below maximum accepted.	Maximum acceptable level of impact to habitat with no long-term impacts on region-wide habitat dynamics.	Above acceptable level of loss/impact with region-wide dynamics or related systems may begin to be impacted.	Level of habitat loss clearly generating region-wide effects on dynamics and related systems.

Table 3: Levels of likelihood for each of the main risks analysed in this assessment (modified from Fletcher, 2015)

Level	Descriptor
Remote (1)	The consequence not heard of in these circumstances, but still plausible within the time frame (indicative probability 1-2%)
Unlikely (2)	The consequence is not expected to occur in the time frame but some evidence that it could occur under special circumstances (indicative probability of 3-9%)
Possible (3)	Evidence to suggest this consequence level may occur in some circumstances within the time frame (indicative probability of 10 to 39%)
Likely (4)	A particular consequence is expected to occur in the timeframe (indicative probability of 40 to 100%)

Table 4: Hazard/Risk Analysis Matrix. The numbers in each cell indicate the Hazard/Risk Score, the colour indicates the Hazard/Risk Rankings (see Table 6)

		Likelihood Level			
Consequence level		Remote	Unlikely	Possible	Likely
		1	2	3	4
Minor	1	1	2	3	4
Moderate	2	2	4	6	8
Major	3	3	6	9	12
Severe	4	4	8	12	16

The residual consequences, likelihoods and resultant levels of hazard or risk are all dependent upon the effectiveness of the risk mitigation controls that are in place (SA, 2012). Determining the most appropriate combinations of consequence and likelihood scores therefore involves the collation and analysis of all information available on an issue.

The best-practice technique for applying this method now makes use of all available lines of evidence for an issue and is effectively a risk-based variation of the 'weight of evidence' approach that has been adopted for many assessments (Linkov et al. 2009, Wise et al. 2007, Fletcher in press).

The hazard evaluation step uses the outcomes of the risk analysis to help make decisions about which hazards need treatment, the level of treatment, and the priority for action. The different levels of management action can be determined by having the hazard or risk scores separated into different categories of hazard (Table 6).

Table 5: Risk Evaluation, Rankings and Outcomes [modified from Fletcher et al. (2002, 2005, 2015)]

Risk Level	Hazard/Risk Score (C x L)	Description	Likely Management Response
Negligible	0-2	Acceptable with no management actions or regular monitoring.	Brief justification
Low	3-4	Acceptable with no direct management actions and monitoring at specific intervals.	Full justification and periodic reports
Moderate	6-8	Acceptable with specific, direct management and regular monitoring.	Full regular performance report
High	9-16	Unacceptable unless additional management actions are undertaken. This may involve a recovery strategy with increased monitoring or even complete cessation of the activity.	Frequent and detailed performance reporting

<u>Information Utilised</u>

The key information used to generate the hazard and risk scores included:

- Broad knowledge of the aquaculture proposal as provided in its application;
- A previous high-level generic risk assessment conducted for marine finfish aquaculture in Australia (FRDC project 2003/223); and
- Relevant scientific studies and publications on finfish aquaculture, ETP species of fish, and interactions between aquaculture and wildlife, for example, sharks (see references).

2.4. Risk Identification and Assessment

Based on consideration of the identified broad areas of threat and constituent hazard pathways, an overarching risk was identified associated with the MWADZ proposal. Assessment of this overarching risk was conducted as described for the hazard pathway assessment described above. Once again, the inherent hazard or risk was assessed in the absence of any management control measures. The residual risk following application of the identified management controls was then assessed.

While this assessment is focused upon ecological risk, social acceptability is also a primary risk consideration in relation to aquaculture-ETP species interaction risks.

The assessment of economic impact on the aquaculture industry resulting from such risk was not considered within the scope of this assessment.

3. Threat Identification, Hazard Pathway Identification and Hazard Pathway Analysis

3.1. Threat Identification

The identification of risks utilised a component-tree approach (Fletcher et al., 2004). This approach assists with the orderly identification of issues (components) for an assessment by providing a standardised starting point and framework to structure components in a consistent and hierarchical manner. Threats to ETP species were identified that were considered both most relevant to the MWADZ proposal and within the scope of the current assessment. The key threat that was identified was:

> *The proposed aquaculture activity could have a significant impact on ETP (shark and ray) species in the vicinity of the Abrolhos Islands FHPA, from an ecological sustainability and social acceptability perspective.*

3.2. Hazard Pathway Identification

Key threats were identified by linking various hazards, via probable pathways of cause-effect, to contributing factors leading to a potential detrimental effect on the sustainability of one or more ETP species (Figure 3). This process facilitated the identification of management measures that could mitigate risks by reducing or eliminating the consequences and by minimising probability of occurrences.

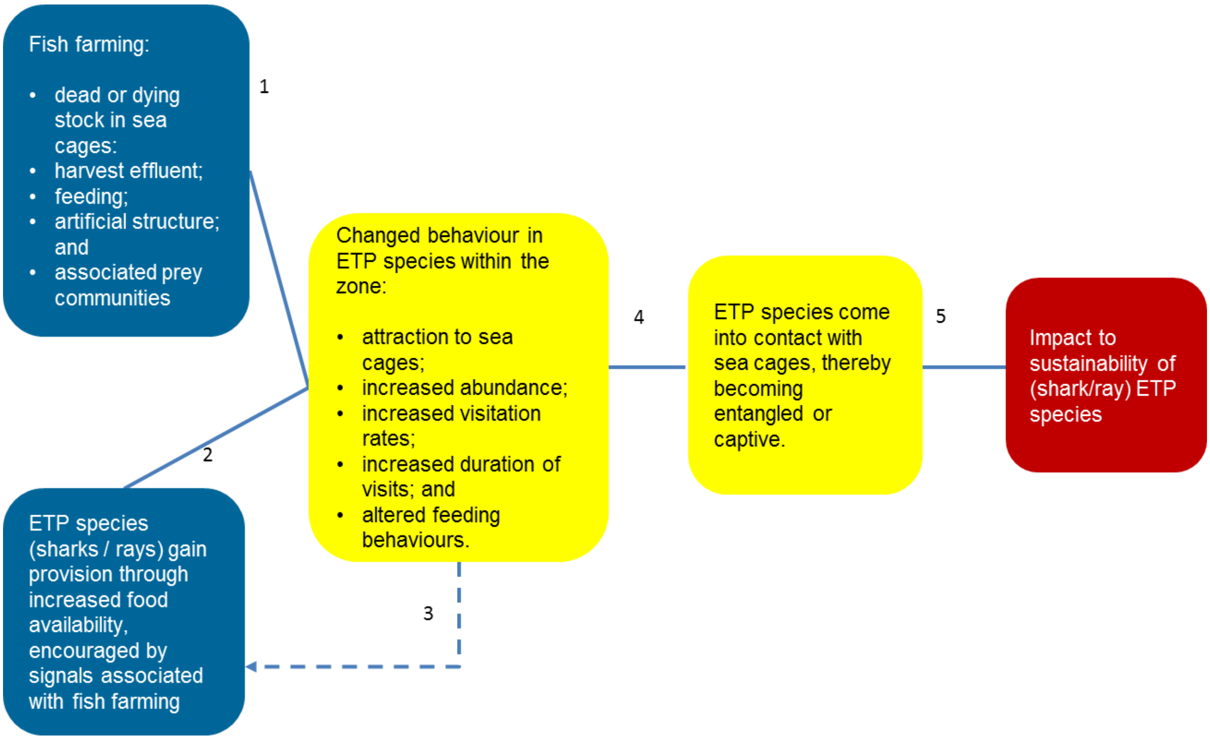

Figure 3: Conceptual model of hazards associated with aquaculture and the potential cause-effect pathways leading from hazards to factors which could impact on the ecological sustainability of threatened, endangered or protected species of fish (sharks and rays). Numbers refer to hazard pathways reviewed in Table 6.

3.3. Hazard Pathway Analysis

For the purpose of hazard pathway analysis, hazards were considered based on the direct and indirect consequences to ETP species as detailed in Table 6. Whilst significant ecological consequences are generally a prerequisite that may lead to subsequent social consequences (e.g. economic and reputational costs via loss of market access resulting from a non-sustainable status that has resulted in trade issues and social amenity impact) these aspects are not comprehensively evaluated in the current assessment.

3.4. Potential negative effects of aquaculture on the sustainability of endangered, threatened and protected species of sharks and rays

3.4.1. Overview of potential impacts of aquaculture on the sustainability of an endangered, threatened or protected species of shark/ray

Marine sea-cage farming has the potential to have negative effects on ETP shark and rays species, primarily through interactions of these species with aquaculture gear. The opportunity for interaction may be increased due to a positive attraction of such species to sea-cages for reasons relating to food and habitat provision as a result of aquaculture activity within the MWADZ.

The risks to ETP species were assessed based on potential socio-political and/or sustainability concerns. The key risks that were identified in the assessment process were:

- fish farming activities leads to the attraction of ETP species to the MWADZ;
- ETP species (sharks and rays) gain provision through increased food availability, encouraged by signals associated with fish farming;
- changes in the behaviour of ETP species (i.e. shark and rays) within the MWADZ;
- entanglement or mortality of ETP species in aquaculture infrastructure; and
- impact to sustainability of ETP species (shark/ray species) caused by mortalities resulting from entanglements or captures in sea-cages.

Information is limited on the interactions between ETP shark and ray species and marine finfish aquaculture. All available relevant information is predominantly focused on aquaculture interactions with white sharks and non-ETP shark species such as tiger sharks. Consequently, information from the relevant research studies on these species was used to assess the potential negative effects of the proposal on shark and ray ETP species.

3.4.2. Hazard Analysis: Potential negative effects of aquaculture on endangered, threatened and protected species

Table 6: Assessment of hazards identified in Figure 3 *Hazards were individually analysed with respect to both the inherent hazard (i.e. baseline hazard if no management measures aimed at mitigating the hazard were in place) and their residual hazard (i.e. remaining hazard once one or more of the proposed management controls have been implemented)*

Hazard	Inherent Hazard Assuming No Management Controls	Justification	Residual Hazard Following Implementation of Management Controls	Justification and Identified Management Controls
1. Fish farming activities leads to the attraction of ETP species to the MWADZ	**Consequence: Moderate (2)** **Likelihood: Likely (4)** **Hazard score: (8)** **Risk level: Moderate**	**Consequence** While attraction cues are important for bringing sharks into contact with aquaculture cages, significant populations of sharks currently reside in the vicinity of the proposed zone. A discrete consequence of attracting sharks closer to the sea-cages may be significant, but is not well understood and (at present) unquantified. An increased presence of sharks and rays in the proposed zone is likely to increase the probability that an individual shark or ray will come into contact with aquaculture. The consequence of an increased presence of sharks and rays is linked to other hazards, which are discussed in sections 2-5 of this table. Consequence is assessed as **Moderate (2)**. **Likelihood** There are four primary signals that are **Likely (4)** to attract sharks to the zone:	**Consequence: Minor (1)** **Likelihood: Possible (3)** **Hazard score: (3)** **Risk level: Low**	**Consequence** Consequence of any attraction could be reduced to **Minor (1)** by reducing the consequence on threatened species through elimination of the opportunity to interact negatively with aquaculture gear. Appropriate management measures include: • use of appropriate anti-predator netting materials; and • prevention of food provision, through regular removal of dead and moribund stock and aiming for less than 1% wastage of feed. **Likelihood** Likelihood of positive attraction can be reduced to **Possible (3)** based on a removal of as many of the potential sources of attractants as practical through actively

		• cultured stock (fish at high densities); • dead or moribund stock; • harvest activities (stress responses of the stock, and biological residues, such as blood etc.); and • plumes of minute traces of fish oils (contained in the pelletised feed) created when feeding the stock [2]. Only sharks and rays that are already in the near vicinity of the cultured fish the signals could detect signals likely to attract them to the source.[3] Similarly, only on small spatial and temporal scales is 'berleying' known to influence specific sites occupied by sharks[4]. <u>Cultured stock:</u> The long-term presence of high densities of cultured stock in the upper water column is likely to be a continuous, low-level source of biological residue (oil, scales, faeces, blood etc.) which could attract sharks to the proposed zone. <u>Dead or moribund stock:</u> Stock mortality is an inevitable factor in aquaculture and occasionally dead stock could be present in sea-cages for a number of hours or even days. Anecdotally, this potentially available source of food is reported to be the most		managing their levels of accumulation. Specific management mechanisms include the following: Development and compliance with a Management and Environmental Monitoring Plan (MEMP) and best-practices in aquaculture that include the following requirements: 1. Removal of dead and moribund stock on a daily basis; 3. Moderate stocking levels; 4. Humane harvesting methods; 5. Containment of all post-harvest blood water; and 6. Use of a high quality pellet feed. Modern feed for culturing fin-fish contains less fish meal and fish oil that traditional aquaculture feeds and can be designed to sink at rates which optimise consumption by stock; 7. Real-time monitoring of environmental conditions and stock responses during feeding.

[2]Bruce, 1998.
[3] Ibid.
[4]Price and Morris, 2013.

		significant signal for attracting white sharks to fish farms[5]. <u>Harvest activities:</u> It is not common practice in the industry to purposely discard harvest by-products on site. However, it is reasonable to expect that there is a variety of other cues associated with harvesting cultured fish that could attract sharks. Harvest activities could introduce fish blood to the environment and bring about stress behaviours in cultured stock. During a workshop on shark-aquaculture interactions, it was documented that dead and dying stock in a sea-cage is the most important attractant of sharks to fish farms. For example, the tuna farming industry in South Australia reported that a single, freshly-dead or dying fish was enough to bring about a shark interaction[6]. <u>Feed:</u> Aquaculture stock feed consists of fish meal and fish oil - known attractants to sharks and rays. It is plausible that the daily release of substantial quantities of feed to the water column within the proposed zone will have an influence on particular species of sharks. The tuna farming industry in South Australia reported that farm infrastructure alone does not appear to attract white sharks. However, while there is no evidence that the presence of		

[5] MurrayJones, 2004.
[6] Ibid.

		aquaculture structure alone will directly attract sharks and rays, the habitat structure provided by aquaculture infrastructure could attract natural prey species of finfish that (in turn) attract sharks. The scenario where the input of stock feed could influence shark behaviour relies on at least one of two major factors: 1. A substantial quantity of uneaten stock feed would need to build up in the local environment to a level which could influence shark behaviour; or 2. A concentration of uneaten feed would need to drive growth in populations of prey species within the proposed zone[7]. Additional food could build up in the local environment, thereby facilitating the growth of populations of prey species. An increase in the abundance of prey species could subsequently influence shark behaviour in the proposed zone. Sharks can be conditioned to stay around a source of food for periods longer than they otherwise would[8,3]. Sea-cage clusters provide additional three-dimensional structures to the marine environment. Given artificial reefs are known to attract fish communities[9], it is reasonable to expect that prey species will utilise this artificial habitat and wild predators will be among the various species that will spend time around these structures.		

[7]Price and Morris, 2013.
[8]Godvin, 2005.
[9]Machias, Karakassis and Giannoulaki, 2005.

2. ETP species (sharks and rays) gain provision through increased food availability, encouraged by signals associated with fish farming	**Consequence: Moderate (2)** **Likelihood: Likely (4)** **Hazard score: (8)** **Risk level: Moderate**	**Consequence** Success in gaining provision (food) from the fish farm will increase the rate at which individual sharks attempt to gain reward from the sea-cages. It is well-established in the literature that (generally) wildlife that are exposed to unnatural provisioning tend to change their feeding behaviours to maximise potential advantages. It is therefore reasonable to expect that any provisioning by a fish farm would be linked to increases in visitation rates, duration of visits, or abundance of sharks and rays at the sea-cages. In turn this could result in increased rates of attempted predation on the stock. Consequence is assessed as **Moderate (2)**. There are flow-on consequences associated with this hazard. These are discussed in sections 3-5 of this table. **Likelihood** Section 1 above has established that sharks are likely to be attracted to sea-cage aquaculture. Stock mortality is an inevitable factor in aquaculture and there are numerous examples from around the world of sharks biting through sea-cage netting to access dead stock. Although it is common practice in the industry to remove dead and moribund stock from cages on a daily basis (weather permitting) occasionally dead stock could be present in sea-cages for a number of hours or even days.	**Consequence: Minor (1)** **Likelihood: Possible (3)** **Hazard score: (3)** **Risk level: Low**	**Consequence** Consequence of any attraction could be reduced to **Minor (1)** by reducing the consequence on threatened species by preventing their opportunity to interact negatively with aquaculture gear. Appropriate management measures include: • use of appropriate anti-predator netting materials; and • prevention of food provision through regular removal of dead and moribund stock and aiming for less than 1% wastage of feed. **Likelihood** Likelihood can be reduced to **Possible (3)** by the measures outlined above. Reducing the likelihood of negative interactions with farming equipment can be achieved through use of appropriate predator exclusion controls. Development and compliance with a Management and Environmental Monitoring Plan (MEMP) and best-practices in aquaculture, including the requirement to remove dead and moribund stock on a daily basis should also occur.

		Given that sharks are likely to be present in the proposed zone regardless of the presence of aquaculture, it is reasonable to expect that (by chance alone) sharks will occasionally come into contact with the aquaculture infrastructure and attempt to access the stock behind the barriers. This hazard is dependent on a range of factors not limited to the species of shark and stock species, density and condition. Most of the shark species listed in Table 1 could be susceptible to provisioning and fish farming could facilitate this. Provisioning can be a powerful stimulus in changing feeding behaviour in wildlife. Given that some species of shark have been recorded staying longer than they otherwise would in fish farm areas, the effects of increased provisioning of sharks/rays could increase the rate at which sharks/rays attempt to gain food from behind sea-cage barriers. Likelihood is assessed as **Likely (4)**.		
3. Changes in the behaviours of ETP species (sharks and rays) in the zone: • **Attraction to the zone;**	**Consequence: Moderate (2)** **Likelihood: Likely (4)** **Hazard score: (8)** **Risk level:**	**Consequence** Provisioning is known to affect the behaviour of sharks and other species at local scales[10]. However, Laroche et. al. 2009 indicated that moderate levels of provisioning are unlikely to affect the behaviour of White sharks at the ecosystem level.	**Consequence: Minor (1)** **Likelihood: Unlikely (2)** **Hazard score: (2)** **Risk level:**	**Consequence** Consequence of any attraction, increased visitation rates, duration of visits, abundance or altered feeding behaviours could be reduced to **Minor (1)** by preventing the opportunity for ETP species to interact negatively with aquaculture gear.

[10] Ibid.

• **Increased visitation rates;** • **Increased duration of visits;** • **Increased abundance; or** • **Altered feeding behaviours**	**Moderate**	At a local scale, increased presence of sharks in the proposed zone increases the potential for entanglement or capture (as discussed in section 5 of this table). Consequence is assessed as **Moderate (2)**. **Likelihood** There are numerous records from Australia and other parts of the world of sharks accessing stock from fish farms. This may be driven by signals from aquaculture that attracts sharks and rays. However, it is important to note that provisioning itself can be a powerful stimulus in changing feeding behaviour. Consequently, there is a two-way link between changed behaviour in shark and ray and provisioning. For example, the residence times of white sharks at a site is influenced by whether or not an individual gains a 'reward' at that site (i.e. a feed).[11] 'Provisioning' of wildlife has been linked to changes in animal behaviour that can manifest over different time scales and with impacts on other species within the surrounding area[12]. Conversely, the ability of a shark to gain a reward from a fish farm will depend on the duration of its visit to the farm. The frequency of entanglement or capture will be influenced by the behaviour of sharks. Given that some species of shark have been recorded staying longer than they otherwise would in fish farm areas,[13] the effects of increased provisioning of sharks/rays could increase the rate at which	**Negligible**	Appropriate management measures include: • use of robust sea-cages with appropriate anti-predator netting materials; • industry benchmark of less than 1% wastage of feed; and • prevention of food provision through regular removal of dead and moribund stock. **Likelihood** Long term changes in behaviours can be minimised to **Unlikely (2)** through reducing the level of attraction for threatened species and which is also potentially related to minimising opportunity for rewarding that changed behavior. Management mechanisms to achieve this include: • review the management arrangement in relation to the removal of dead and moribund stock, and make required modifications to the requirements; • regulation of the density of sea-cage operations,[15] in addition to limiting the stocking density per hectare of lease;

[11]McAuley pers. com.
[12]Orams, 2002.
[13]Ibid.
[15]Papastamatiouet. al. 2010.

		sharks/rays attempt to gain food from behind sea-cage barriers. If sharks and rays spend extra time around the sea-cages, there is a greater probability that these individuals will make contact with the cages when presented with opportunities to feed on stock. Therefore, the risk of entanglement is escalated. In principle, aquaculture could elevate levels of dissolved nutrients in the water column surrounding the cages, thereby stimulating plankton growth. Research on the environmental factors important to whale sharks is lacking. However, given that whale sharks and manta rays are active pelagic filter-feeders targeting concentrations of plankton or fish, it is plausible that in certain situations aquaculture could indirectly attract these planktivorous fish. Whale sharks and manta rays are known to be attracted to areas that offer large concentrations of zooplankton and have been reported to visit seasonal shrimp blooms. They have also been known to aggregate in nutrient-rich feeding areas. In much of their range, there are a limited number of sites containing nutrient-rich waters associated with elevated abundance of zooplankton[14]. The scenario whereby sharks and rays are influenced by the presence of aquaculture through a provisioning mechanism can include a wide variety of species. Any increase in visitation rates, duration of visits or abundance of sharks or rays could increase the probability of entanglement or capture (as discussed in section 4 of this table). The likelihood of this scenario manifesting is dependent on the species. Given that the likelihood of entanglement is dependent on		• (in relation to planktivorous species) development and compliance with a Management and Environmental Monitoring Plan and best-practices in aquaculture, including the requirement to manage the levels of dissolved nutrients and chlorophyll-a. Chlorophyll-a is a proxy for phytoplankton levels. Median dissolved inorganic nitrogen levels must remain less than 500 µg/L. Median Chlorophyll-a levels must remain less than two-fold that at the Reference sites. Whale sharks and manta rays are rarely observed as far south as the Abrolhos Islands FHPA. However, future visitation to the Abrolhos Islands is possible. Providing phytoplankton levels remain at background levels, it is unlikely that the fish farms could affect the behaviour of whale sharks and manta rays.

[14]Froese and Pauly, 2015.

		species, an elevated level of uncertainty has necessitated a likelihood rating of **Likely (4)**.		
4. Entanglement and mortality of ETP species in aquaculture infrastructure	**Consequence: Major (3)** **Likelihood: Likely (4)** **Hazard score: High (12)** **Risk level: High**	**Consequence** Consequence is assessed as **Major (3)** given the social risks associated with the entanglement of protected species. Sustainability risks may also be a valid argument, dependent on the species and the level of knowledge regarding its population status in the wild. The global experience is that attempts by sharks to prey upon stock behind a netted barrier have resulted in sharks becoming entangled in the netting or caught within the cage [4]. Provisioning could negatively affect a target species through incidental mishap resulting in injury[16]. Changes in behaviour (including increased predation effort) have been known to result in the entanglement or capture of sharks in aquaculture netting, with fatal consequences [3,4,11]. It is hypothesised that white sharks are impacted by the Port Lincoln tuna industry through capture in sea-cages and, or, subsequent destruction by operators. This hazard is linked to potential impacts on the sustainability of shark / ray species, depending on the rate of shark and ray mortalities. Refer to section 5 below. **Likelihood** The literature suggests that there are several factors that could influence the visitation rates and	**Consequence: Major (3)** **Likelihood: Unlikely (2)** **Hazard score: (6)** **Risk level: Moderate**	**Consequence** Consequence remains **Major (3)** due to the social consequences of capturing and/or entangling any threatened species. **Likelihood** Likelihood may be reduced to **Unlikely (2)** based on the following management controls: Compliance around Management and Environmental Monitoring Plan (MEMP) and best practices in aquaculture, including requirements to: 1. minimise all attractant signals, e.g. keep stocking densities at low to moderate levels; 2. minimise opportunities for provisioning, e.g. the immediate or early removal of any dead and moribund stock; 3. use fit-for-purpose, well-designed sea-cages suited to the environmental conditions; 4. maintain the integrity of infrastructure; 5. use anti-predator nets to deny sharks access to the grow net (typically, ultra-high-molecular weight polyethylene fibre

[16] Orams, 2002.

		duration of visits by sharks to an area: • distance from shore; • depth of water; • mobility of the species; and • 'reward' provided in the area[17]. Any of the species listed in Table 1 could already be present in the proposed zone. Alternatively, these species could move into it as a response to an attraction signal or previous provisioning. The literature suggests that there are several factors that could influence the probability of a shark being captured or entangled in a sea-cage: • species of shark; • size of the individual; • design of the sea-cage; • maintenance of the sea-cage; • stocking density; and • presence of dead stock. Considering: • all of the species listed in Table 1, may already exist in the proposed area;		nets); 6. use mesh or netting less than 6 cm bar width; and 7. conduct regular, thorough inspections (e.g. using submerged cameras) to detect any damage to the mesh. While it is not possible to eliminate signals that could attract sharks and rays to the sea-cages, the management measures (above) make it unlikely that sharks and rays would become entangled or captured.

[17] Ibid.

		• stocking densities could be relatively high; • design and maintenance of sea-cages is the responsibility of the industry; and • dead and moribund stock could be present in the sea-cages, it is **Likely (4)** sharks will attempt to access stock behind sea-cage barriers. Due to their morphology, it is considered unlikely that rays would become entangled in sea-cage mesh or captured within the cages.		
5. Impact to sustainability of ETP species (shark / ray species) caused by mortalities resulting from entanglements or captures in sea-cages	**Consequence: Severe (4)** **Likelihood: Unlikely (2)** **Hazard score: (8)** **Risk level: Moderate**	**Consequence** Deaths of ETP species must be recorded, and could have consequences for the industry. For example, white sharks are protected under the FRMA, *Wildlife Conservation Act 1950* and the EPBC Act. If the rate of entanglement or capture increases beyond that of natural mortality rates, the sustainability of a ETP species of shark or ray could be threatened. The contribution aquaculture could make to anthropogenic mortality rates represents a potentially significant contribution in relation to anthropogenic pressure on particular ETP species. Consequences relating to a decline in the ecological sustainability of ETP species are confounded by secondary consequences associated with a high degree of public concern around ETP species. Such consequences are	**Consequence: Severe (4)** **Likelihood: Remote (1)** **Hazard score: (4)** **Risk level: Low**	**Consequence** The consequence assessment of **Severe (4)** would remain unchanged if sustainability issues were to occur. **Likelihood** Likelihood of sustainability impacts can be further reduced to **Remote (1)** based on implementation of management measures aimed at reducing interactions of endangered species with aquaculture operations (refer to sections 1-4 of this table). Operators within the MWADZ will be required to develop and implement an individual Management and Environmental Monitoring Plan (MEMP) that corresponds to an overarching zone *Environmental Monitoring*

		considered **Severe (4)**. **Likelihood** It is considered **Unlikely (2)** that in the absence of controls the interaction of threatened species with aquaculture operations could cause sustainability concerns, where population sizes of a certain species are very low and/or specific local populations exist. The Commonwealth's Marine Bioregional Plans assessed the risk of collision or entanglement of white sharks with aquaculture infrastructure (e.g. ropes and nets) as being of 'potential concern' in the *South-west Marine Region* of Australia. Such interactions could result in entanglement and drowning.[18] The probability of an impact on the sustainability of ETP species is dependent on the mortality rates for each species. For example, a risk assessment undertaken as part of the Western Australian Shark Hazard Mitigation Drum Line Program 2014-17 in relation to the tiger shark stocks off the west coast of WA states that the number of sharks that would need to be removed before even a measurable change in their population would occur is likely to be in the order of hundreds. However, it should be noted that other species of sharks and rays may mature later and therefore be more vulnerable to anthropogenic population depletion (i.e. low levels of mortality could contribute to impact on the sustainability of particular ETP species).[19]		*and Management Plan* (EMMP). The EMMP needs to be approved by the Western Australian Minister for Environment. The document, *inter alia*, describes strategies for minimising and avoiding interactions with significant marine vertebrates and also requires reporting of any interactions that occur. The Department of Fisheries will support or endorse best management practices for aquaculture and manage compliance around *Management and Environmental Monitoring Plans* (MEMPs) of individual operators, including mandatory reporting of interactions with ETP species. Failure to comply with the MEMP may result in suspension or cancellation of an offending licence. The industry could collect data on the rate of visitation of tagged sharks prior to starting-up aquaculture operations. Baseline data may be useful to quantify any changes in visitation rates of tagged sharks at aquaculture sites, after the introduction of stock and feed. This would be useful to provide an early warning to aquaculture managers if the rates of shark visitation or duration of visits increase in the vicinity of the fish farms. Collectively, the management framework (comprising the aforementioned mitigating and ameliorating mechanisms) significantly reduces the likelihood of ETP species mortalities caused by aquaculture

[18] Australian Government, 2013.
[19] DotPaC (2014)

		As stated in section 4 of this table, the morphology of ray species are such that it is considered unlikely rays would become entangled in sea-cage mesh or captured within the cages. Anecdotal records of sharks becoming entangled in aquaculture nets and subsequently being killed by the operators of the farms have been reported worldwide. For example, the aquaculture industry out of Port Lincoln was estimated to be responsible for up to 20 white shark deaths per year prior to a review by Malcolm et al. (2001). Modern fish farms alone are unlikely to be a major cause of mortality rates that could impact the sustainability of ETP species of sharks or rays. However, fish farms could contribute, by way of a small number of deaths, to the total number of anthropogenic shark mortalities within the region. Although fish farms are associated with a number of factors that could negatively affect shark and ray ETP species, it is considered Unlikely (Likelihood Score 2) that the proposed aquaculture could affect the sustainability of shark or ray ETP species in the MWADZ proposal area.		infrastructure or activity to be remote.

4. Risk Identification, Analysis and Assessment

4.1. Risk Identification

The key risk to local populations of ETP species was identified from detailed analysis of hazard pathways linked to the proposed activities associated with the MWADZ. This key risk was considered to be:

The proposed aquaculture activity could have a significant impact on ETP (shark and ray) species in the vicinity of the Abrolhos Islands FHPA, from an ecological sustainability and social acceptability perspective.

This risk was assessed with a consideration of potential cumulative impact using the precautionary approach described in the methodology. This process investigated pathways or cause-effect linkages between environmental hazards and key factors that contribute to a broad risk category.

4.2. Risk Analysis

Nature of Risk

The assessment considers the biological characteristics of species such as white sharks and tiger sharks to represent broad categories of protected fish taxa found in the area that have the potential to interact with aquaculture cages. Mortalities associated with marine finfish aquaculture worldwide typically result from entanglement or capture of individual animals (e.g. sharks) in the sea-cage mesh or within the cage itself which can lead to those individuals drowning or being destroyed by farm operators.

4.2.1. Inherent Risk Analysis

Likelihood

ETP species of concern (Table 1) are known to be present or migrate within the MWADZ general area and may be attracted to the zone based on a number of cues associated with aquaculture. These include:

- stock at high densities;
- dead or moribund stock;
- harvest activities (e.g. stress responses of the cultured fish and biological residues, such as blood, generated during harvest etc.);
- plumes of minute traces of fish oils (contained in the pelletised feed) created when feeding the stock; [20] and
- increased wild fish availability through their local attraction to sea cages.

[20]Bruce, 1998.

The degree to which these sources of attraction are managed will influence the likely visitation rates of shark and ray species and thus the likelihood of interacting with aquaculture gear.

In addition, the degree to which shark and ray species are rewarded though these encounters will also influence the likelihood of increased visitation and interactions with aquaculture gear. This so-called provisioning effect (access to an unnatural reward of food) is thought to be a powerful stimulus in changing the feeding behaviour of sharks and rays, including the white shark[21], black ray and eagle ray.[22]

Provisioning could:

- attract sharks and rays to the zone;
- increase visitation rates;
- increase duration of visits;
- increase localised abundance; and
- alter feeding behaviours.

Previous success in gaining provision from a fish farm will increase the likelihood that individuals (ETP species of sharks/rays) will continually attempt to gain reward from the sea-cages. Changes in feeding behaviour and effort have been known to result in the entanglement or capture of sharks and rays in aquaculture netting, with fatal consequences[23],[24].

Modern fish farms alone are unlikely to result in mortality rates that would threaten the sustainability of shark or ray ETP species. However, fish farming could potentially be one of several anthropogenic mechanisms which are contributing to a population decline in ETP species. In isolation, the proposed MWADZ is not considered a significant threat to ETP species sustainability. However, there may be social risks, relating to concerns for ETP species sustainability or with any potential capture of a ETP species.

Globally, there are clear records of sharks becoming entangled in aquaculture nets and subsequently being killed by the operators of aquaculture farms. In Port Lincoln, South Australia, the aquaculture industry was estimated to be responsible for up to 20 white shark deaths per year, prior to a review by Malcolm et al. (2001).

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[21]Bruce and Bradford, 2011.
[22]Newsome, Lewis and Moncrieff, 2004.
[23]Australian Government (SEWPaC) 2013.
[24]Price and Morris, 2013.

However, the rate of interaction of shark species with aquaculture cages in Australia has been reduced in recent years, coinciding with increased public scrutiny, tighter regulations, and better reporting associated with third party accreditation of particular companies. The inherent likelihood of the MWADZ having a significant effect on the sustainability of these species is considered **Unlikely (2)**

Consequence

The ecological consequence of aquaculture activity in the MWADZ having a significant impact on ETP species was assessed from both, sustainability and social acceptability, perspectives. Any threat to the ecological sustainability of ETP species is confounded by consequences associated with a high degree of public concern around ETP species, and as such was assessed as **Severe (4)**. This consequence is deemed primarily to be social in nature. However, impacts on certain species could contribute to consequences in relation to ecological sustainability. The white shark, grey nurse, hammerhead, mako, sawfish and whale shark are protected under the FRMA, *Wildlife Conservation Act 1950* and EPBC Act. Deaths of EPBC listed species must be recorded, and the industry operating within the MWADZ is likely to seek to minimise rates of mortality in ETP species to avoid negative consequences, such as non-compliance related penalties under the FRMA and other legal implications relating to non-compliance with the *Wildlife Conservation Act 1950* and, or, EPBC Act.

4.2.2. Overall Inherent Risk

Using Table 4, the Hazard/Risk Score (C x L) for the overall inherent risk is 8 and the **inherent risk level is Moderate**.

4.2.3. Residual Risk Analysis

Likelihood

When a combination of management measures are put in place to reduce the likelihood in the hazard pathways identified in Figure 3, the likelihood of MWADZ activities having a significant impact on ETP species, either from a sustainability or social acceptability perspective, is reduced. These management measures include those highlighted below:

Control category	Management Control	DoF Control Mechanism
1. Reducing the strength of signals that may attract sharks/rays	• Removal of dead and moribund stock on a daily basis • Containment of all stock • Containment of all post-harvest by-products • Humane harvest methods • Appropriate stocking densities [i.e. stocking densities kept at levels below or equal to industry-best-practice bench marks (e.g. 10-25 kg/m^2)] • Minimisation of feed wastage (e.g. through setting a benchmark of less than 2% wastage, achieved by using efficient delivery systems and real-time monitoring of environmental conditions and stock feeding responses) • Use of a high-quality pellet feed, noting: ➢ increasing knowledge on nutritional needs of particular finfish species in aquaculture is leading to improved quality of feed and is responsible for significant improvements in feed conversion ratios ➢ modern feed for culturing fin-fish contains less fish meal and fish oil that traditional aquaculture feeds ➢ modern high-quality feed can be designed to sink at rates which optimise consumption by stock	Monitoring and enforcement of compliance with: ➢ Management and Environmental Monitoring Plans (MEMPs); and ➢ Licence conditions, to achieve best management practices, in accordance with the zone Environmental Monitoring and Management Plan (EMMP) and the zone Management Policy. Encouraging industry adoption of the Aquaculture Council of Western Australia Environmental Code of Practice.
2. Reducing opportunity for interactions between ETP species of sharks/rays and aquaculture	• Immediate or early removal of any dead and moribund stock (i.e. remove the most significant shark attractant signal) • Use of effective predator barriers, including: ➢ fit-for-purpose sea-cages suited to the environmental conditions ➢ durable, high tensile strength sea-cage mesh (e.g. made from ultra-high molecular weight, polyethylene fibre) ➢ highly-visible mesh (to reduce the likelihood of ETPs accidentally colliding with the sea-cages)	Monitoring and enforcement of compliance with: ➢ Management and Environmental Monitoring Plans (MEMPs); and ➢ Licence conditions, to achieve best management practices, in accordance with the zone Environmental Monitoring and Management Plan (EMMP) and the zone Management Policy.

Control category	Management Control	DoF Control Mechanism
	• regular, thorough inspections of sea-cages to detect any tears in the mesh (e.g. using submerged cameras)	Encouraging industry adoption of the Aquaculture Council of Western Australia Environmental Code of Practice.
3. Prevention of predators breaching the sea-cage netting	Use of best management practices in aquaculture (i.e. guided by the Norwegian Standards and the Aquaculture Council of Western Australia Environmental Code of Practice for marine finfish aquaculture) including: • sea-cage design and installation • sea-cage mesh that is durable, of suitable bar width (size) and having high-tensile-strength (e.g. ultra-high molecular weight, polyethylene fibre) • anti-predator nets (e.g. 'armour' nets external to the sea-cage net) • removal of dead and moribund stock on a daily basis • appropriate stocking densities [i.e. stocking densities kept at levels below or equal to industry-best-practice bench marks (e.g. 10-25 kg m^3)] • humane harvest methods • containment of all post-harvest blood water • real-time monitoring of environmental conditions and stock responses during feeding • regular, thorough inspections of sea-cages to detect any tears in the mesh (e.g. using submerged cameras)	Monitoring and enforcement of compliance with: ➢ MEMPs; and ➢ Licence conditions, to achieve best management practices, in accordance with the zone Environmental Monitoring and Management Plan (EMMP) and the zone Management Policy. Encouraging industry adoption of the Aquaculture Council of Western Australia Environmental Code of Practice.

Control category	Management Control	DoF Control Mechanism
4. Reducing impacts of potential interactions	• Industry adoption of the Aquaculture Council of Western Australia Environmental Code of Practice • Implementation of the Marine Fauna Interaction Plan • Mandatory training for workers responsible for maintaining the aquaculture infrastructure • Sea-cage design to facilitate release of captured ETP species • Adequate anchoring systems to correctly tension sea-cage clusters • Sea-cage nets correctly tensioned to minimise the impacts of predators and reduce the risk of the net wearing or tearing • Regular, thorough inspections (e.g. using submerged cameras) of sea-cages and associated aquaculture infrastructure to detect any entanglements, damage or weaknesses	Monitoring and enforcement of compliance with: ➢ MEMPs (incorporating Marine Fauna Interaction Plans); and ➢ Licence conditions, to achieve best management practices, in accordance with the zone Environmental Monitoring and Management Plan (EMMP) and the zone Management Policy. Encouraging industry adoption of the Aquaculture Council of Western Australia Environmental Code of Practice.
5. Reduced uncertainties in relation to how sharks/rays interact with offshore finfish aquaculture	• Mandatory recording and reporting of interactions with ETP species • Monitoring and scientific research in relation to shark behaviours within the proposed MWADZ • Adaptation of management arrangements to take advantage of new data/information as it becomes available	As above, plus annual review of ETP species interactions records and reports. In-kind support for industry to commission monitoring and research on ETP species-aquaculture interactions.

An overarching Environmental Management and Monitoring Plan (EMMP) has been developed which provides strategies to minimise the rate of interactions between aquaculture and ETP species.

Operators within the zone are also required to comply with individual MEMPs that require (*inter alia*) operators within the proposed zone to comply with the overarching EMMP. Additionally, a MEMP requires the adoption of best-practices in aquaculture. There are several factors which are important in reducing signals that may attract sharks and rays to the proposed zone. These include:

- removal of dead and moribund stock on a daily basis;
- moderate stocking levels;
- humane harvest methods;
- containment of all post-harvest blood-water; and
- use of a high-quality pellet feed.

The industry has the ability to collect data on the rate of visitation by tagged sharks prior to starting-up aquaculture operations. Baseline data may be useful to check that visitation rates and the duration of visits by tagged sharks at aquaculture sites are not increased after the introduction of stock and feed. This would be useful to provide an early warning to aquaculture managers, in case the presence of sharks and, or rays, significantly increase near sea-cages in the proposed zone.

A MEMP will also require operators to monitor the levels of dissolved nutrients and chlorophyll-a, which is a proxy for phytoplankton levels. Median concentrations of dissolved inorganic nitrogen must remain less than 500 µg/L. Median concentrations of Chlorophyll-a must remain less than two-fold that at the Reference sites. These requirements will ensure that phytoplankton levels remain at background levels. Therefore, it is unlikely that outputs of the proposed aquaculture could affect the behaviours of Whale sharks and Manta rays.

Overall, industry's compliance around MEMPs and the zone EMMP, which include best-management practices, should result in:

- significant reductions in levels of attractant signals to minimise the likelihood of ETP species making contact with sea-cages;
- significant reductions in opportunities for provisioning of ETP species by aquaculture to prevent behavioural changes;
- use of anti-predator nets to deny ETP species access to cages (a potential food source);
- use of mesh or netting of an appropriate mesh size (e.g. less than 4cm in bar width), tear-resistant and tangle-resistant to minimise the probability of ETP species becoming entangled in, or entrapped within, the sea-cages; and

- tensioning of aquaculture infrastructure to eliminate the possibility of entanglement of ETP species.

Collectively, these factors significantly reduce the likelihood of ETP species mortalities caused by aquaculture infrastructure or activity to **Remote (1)**.

Consequence

An impact to sustainability of ETP species caused by the proposed aquaculture is considered from both an ecological and social perspective, and did not change from being a **Severe (4)** consequence**.**

4.2.4. Overall Residual Risk

The overall residual risk of an impact to sustainability of ETP species caused by the proposed aquaculture zone is considered low and acceptable.

Using Table 4, the Hazard/Risk Score (C x L) for the overall residual risk is 4 and the **residual risk level is Low**.

5. Summary

The broad risk to ETP species presented by the proposal to develop marine finfish aquaculture associated with the MWADZ was identified as:

> *The proposed aquaculture activity could have a significant impact on ETP (shark and ray) species in the vicinity of the Abrolhos Islands FHPA, from an ecological sustainability and social acceptability perspective.*

Critical pathways that could collectively lead to the realisation of this risk were identified (hazards) and reviewed systematically. The residual risk has taken into account the management measures associated with development of the MWADZ to address the hazards. Low risks suggest that current risk control measures are adequate in reducing the levels of identified risks to acceptable levels.

A primary hazard is the attraction of sharks to sea-cage aquaculture within the zone, through four primary signals:

- cultured stock;
- dead or moribund stock;
- harvest activities; and
- feed.

Sharks and rays that are already in the vicinity of the cultured fish could detect signals (associated with food and habitat) that are likely to attract them to the source. It is well established that sharks and rays are attracted to aquaculture by the presence of cultured stock at high densities and the act of feeding the stock.

Fish cage clusters are artificial three-dimensional structures that function as additional habitats within the existing marine environment. Given artificial reefs are known to attract fish communities[25], it is reasonable to expect that prey species will utilise this artificial habitat and wild predators will be among the various species that will spend time around these structures. An increased presence of sharks and rays in the proposed zone is likely to increase the probability that an individual shark or ray will come into contact with aquaculture.

The probability of positive attraction can be reduced by limiting the potential sources of attractants as much as possible. The overarching EMMP and individual operator MEMPs require all potential sources of attractants associated with aquaculture activity are reduced to the greatest extent practicable.

The consequences of changed behaviour in ETP species due to the proposed aquaculture can be significantly reduced by eliminating opportunities for ETP species to interact negatively with aquaculture gear through a number of practical management measures (set out in the zone EMMP and MEMPs). However, given that sharks are likely to be present in the proposed zone, regardless of the presence of aquaculture, it is reasonable to expect that sharks will occasionally come into contact with the aquaculture structures and attempt to access the stock behind the barriers.

Provisioning can be a powerful stimulus in changing feeding behaviours in wildlife. The provision of reward or advantage to wild animals has been shown to perpetuate the behaviours that contribute to the reward. If aquaculture facilitates provisioning of food or habitat to ETP species, it could increase the rates at which ETP species make contact with the sea-cages.

Aquaculture could elevate levels of dissolved nutrients in the water column surrounding the cages, thereby stimulating plankton growth in the water column. This, theoretically, could provision planktivorous species. Although this pathway of cause-effect is considered unlikely, the theory highlights the level of uncertainty associated with the potential for a wide variety of species to be influenced by aquaculture through factors such as provisioning.

Providing phytoplankton levels remain in the vicinity of background levels, it is unlikely that the fish farms could affect the behaviours of whale sharks and manta rays.

[25]Machias, Karakassis and Giannoulaki, 2005.

The consequence of altered feeding behaviours can be reduced by preventing the provisioning of ETP species. This can be achieved through appropriate management measures such as:

- use of robust sea-cages with appropriate anti-predator netting materials;
- adopting an industry benchmark of less than 1% wastage of feed; and
- regular removal of dead and moribund stock from sea-cages.

Due to their morphology, it is considered unlikely that rays would become entangled in sea-cage mesh or captured within the cages. However, attempts by sharks to access stock are likely in the absence of such control measures. It is also possible that large individuals of particular species will breach the barriers containing the cultured stock. The Commonwealth's Marine Bioregional Plans assessed the risk of collision or entanglement of white sharks with infrastructure as being of 'potential concern' in the South-west Marine Region of Australia in relation to interactions with aquaculture ropes and nets, which could result in entanglement and drowning.

The available literature suggests that there are several factors that could influence the probability of a shark being captured or entangled in a sea-cage. These include:

- the species of shark/ray ETP species;
- size of the individual shark/ray;
- design of the sea-cage;
- maintenance of the sea-cage;
- density of the stock in culture; and
- presence of dead/moribund stock.

The last four factors (of the six above) can be controlled to substantially reduce the risk of ETP species mortalities due to aquaculture.

While it is not possible to eliminate signals that could attract sharks and rays to the sea-cages, the likelihood that sharks and rays would become entangled or captured is considered remote. Operators must comply with mitigating management measures set-out in the zone EMMP and MEMPs and failure to comply could result in the suspension or cancellation of the offending aquaculture licence.

Throughout the world, there is anecdotal evidence that fish farms could contribute, by way of a small number of deaths, to the total number of anthropogenic shark mortalities. The contribution aquaculture could make to mortality rates could be significant in relation to the various pressures on particular ETP species. However, modern aquaculture operations (with high-tech infrastructure and industry best-practices) are unlikely to cause mortality rates in shark and ray ETP species that would threaten ecological sustainability of a species.

Residual risk analysis (from an ecological sustainability or social perspective) considered the potential consequences of the proposed aquaculture impacting on biological sustainability of ETP species to be Severe; however the likelihood of occurrence was Remote. Therefore, the overall risk of an impact to sustainability of ETP species of shark or rays caused by the proposed MWADZ is considered low and acceptable. The Department of Fisheries will promote best-management practices for aquaculture and regulate compliance around the implementation of MEMPs for individual operators, including mandatory reporting of interactions with all ETP species.

In addition to their responsibilities under the *Environment Protection and Biodiversity Conservation Act 1999*, *Fish Resources Management Act 1994*, *Wildlife Conservation Act 1950*, and *Environmental Protection Act 1986*, the industry is likely to adhere to the marine finfish aquaculture Environmental Code of Practice developed by the Aquaculture Council of WA.

The risk of impact to biological sustainability of ETP species could be further reduced by the aquaculture industry participating in the collection of data on visitation rates of tagged ETP species. For example, operators within the zone could deploy acoustic receivers at their fish farms to record data on the behaviour of tagged sharks before and after the introduction of stock and feed to sea-cages. This would reduce some of the uncertainties surrounding shark-aquaculture interactions. It would also benefit the industry to provide an early warning to aquaculture managers if the rates of shark visitation or duration of visits to fish farms increases over time.

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Threat Identification, Hazard Pathway Analysis and Assessment of the Key Risks to invertebrate and finfish species and fisheries at the Abrolhos Islands, presented by the establishment of the Mid West Aquaculture Development Zone in Western Australia

Prepared by

Department of Fisheries Western Australia

August 2015

Summary of the assessed risk level:

Risk	**Inherent Risk** (no management measures)	**Residual Risk** (based on implementation of identified management measures)
1. Aquaculture activity in the zone has a significant impact on the populations of invertebrate species (i.e. saucer scallop) in the Abrolhos Islands FHPA	**Negligible**	**Negligible**
2. Aquaculture activity in the zone has a significant impact on populations of finfish species in the Abrolhos Islands FHPA.	**Negligible**	**Negligible**
3. Aquaculture activity in the zone has a significant impact on the invertebrate fishery (i.e. Abrolhos Islands and Mid West Trawl Managed Fishery).	**Low**	**Low**
4. Aquaculture activity in the zone has a significant impact on finfish fisheries in the Abrolhos Islands FHPA.	**Negligible**	**Negligible**

Table of Contents

1 Context and Scope

The ecological risk assessment presented in this report has been undertaken to assist in identifying and assessing the potential impacts of finfish aquaculture associated with a Department of Fisheries proposal to establish an aquaculture development zone in the Mid West region of Western Australia (referred to hereafter as the Mid West Aquaculture Development Zone or MWADZ) on the sustainability of ecosystems and their dependent extractive finfish fisheries. This assessment does not seek to replicate previously conducted generic aquaculture risk assessments which remain relevant to the MWADZ proposal and which include the following:

- Marine Finfish Environmental Risk Assessment (de Jong & Tanner, FRDC Project 2003/223)
- National ESD Reporting Framework: The “How to” Guide for Aquaculture. Version 1.1 FRDC, Canberra, Australia (Fletcher et al., 2004)
- Finfish Aquaculture in Western Australia: Final ESD Risk Assessment Report for Sea-Cage and Land-Based Finfish Aquaculture (Vom Berg, 2008; Fisheries Management Paper No 229, Department of Fisheries, Western Australia)

Instead, the current assessment has used these previous reports as a basis to identify the main areas of threat that are most relevant to the MWADZ proposal. These threats were further broken down through the consideration of the detailed hazard pathways that may lead to the realisation of these threats. Consideration of the threats facilitated the identification of key overarching risks to the identified objective of the assessment, which was to ensure the establishment and operation of the MWADZ without significantly impacting the sustainability of ecosystems and their dependent fisheries. These risks were then assessed.

Using this methodology, the current assessment sought to clearly identify the current risk management measures in place and assess their adequacy in bringing identified risks to ecosystem and economic sustainability associated with the MWADZ proposal to an acceptable level.

An aquaculture development zone is a designated area of water selected for its suitability for a specific aquaculture sector (in this case, marine finfish). Designating areas as aquaculture development zones is a result of Department of Fisheries (Department) policy aimed at stimulating aquaculture investment through providing an ‘investment ready’ platform for organisations that wish to set up commercial aquaculture operations. More streamlined approvals processes are in place for organisations wanting to establish aquaculture operations within these zones.

Extensive studies and modelling underpin the approval of a zone to ensure its potential effects are identified, well understood and managed. Establishing new aquaculture operations, or expanding existing ones, will provide significant economic benefits to the local community through the creation of job opportunities and regional economic diversification.

A Kimberley Aquaculture Development Zone (KADZ) had already been officially declared by the Minister for Fisheries in WA's northern waters. Covering a total area of almost 2,000 hectares, the zone is located within Cone Bay approximately 215 kilometres northeast of Broome. Extensive environmental studies completed for the zone indicate its capacity to support the production of 20,000 tonnes of finfish without any significant environmental impact. An existing barramundi farm operates within the boundaries of the KADZ. The establishment of the zone has enabled the operator, Marine Produce Australia Pty Ltd, to secure environmental approval to increase its production capability from 2,000 to nearly 7,000 tonnes per annum.

This assessment relates to a second planned aquaculture development zone in the Mid West region of Western Australia. The Mid West Aquaculture Development Zone (MWADZ) will be located within the State waters of the Abrolhos Islands Fish Habitat Protection Area (FHPA), north of the Pelsaert Group, about 60 kilometres west of Geraldton.

The zone is being established through a process that primarily involves environmental assessment of the zone as a strategic proposal under Part IV of the *Environmental Protection Act 198*6. Approval of this strategic proposal will create opportunities for existing and future aquaculture operators to refer their proposals to the Environmental Protection Authority as 'derived proposals'. The objective is a more streamlined assessment and regulation process due to early consideration of potential environmental impacts and cumulative impacts identified during the assessment process for the zone.

The Department surveyed and sampled a study area of 4,740 hectares in two locations within the FHPA. This identified 2,200 hectares in the Northern Area and 800 hectares in the Southern Area (see Figure 1) as the most suitable areas for finfish aquaculture. Technical environmental studies of these locations helped determine the exact delineation of the zone. The proposed zone is situated away from areas of highest conservation value and is subject to considerable water flushing driven by prevailing winds, waves and currents. Good water flow through the sea-cages in which the fish are grown is essential for high productivity and to minimise environmental impact.

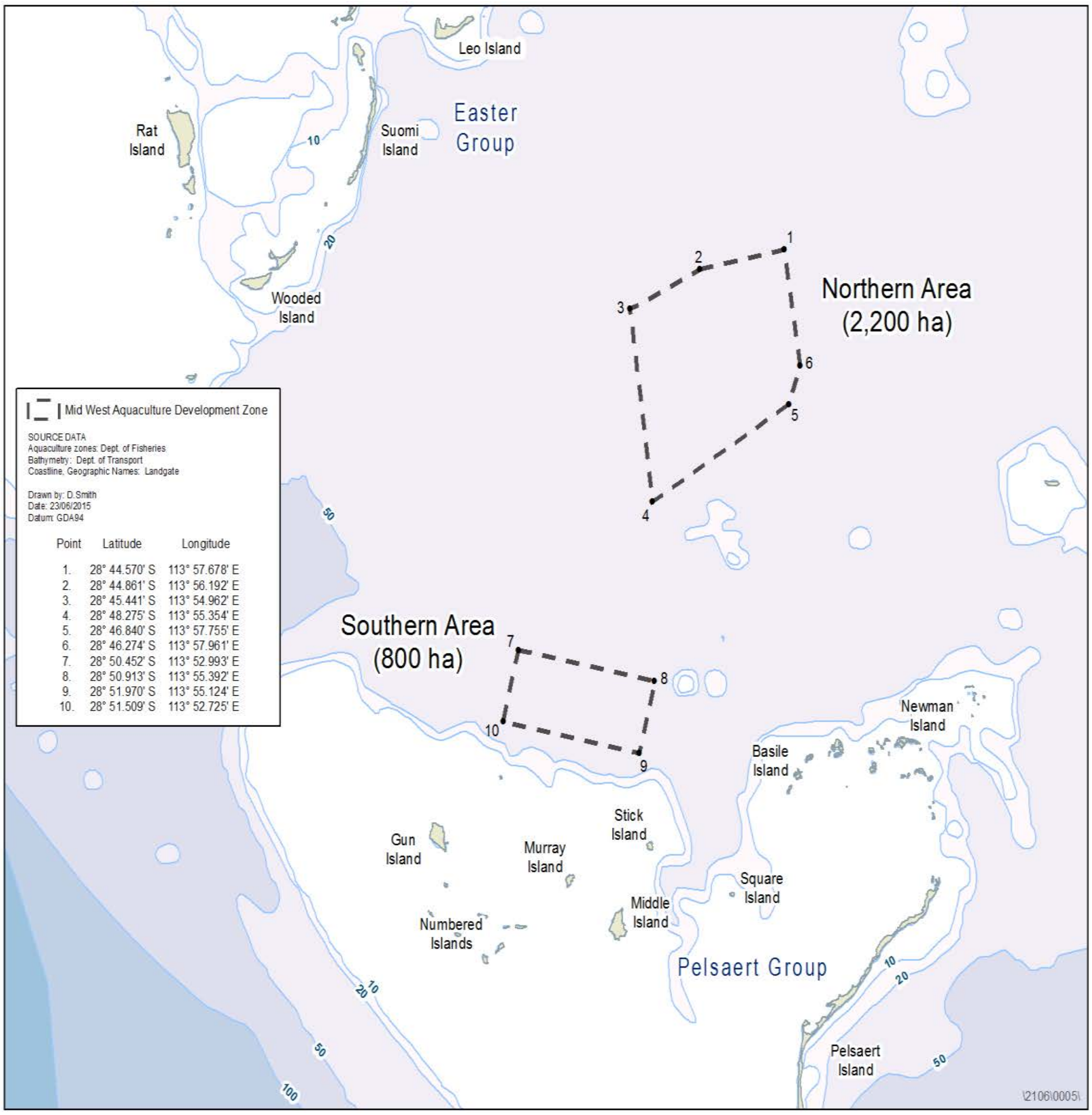

Figure 1: Proposed Mid West Aquaculture Development Zone

The Department will manage the proposed MWADZ within an integrated management framework that governs the workings of the zone. This will be similar to the framework developed for the Kimberley Aquaculture Development Zone. Its purpose is to:

- establish an overarching, integrated structure for managing the aquaculture activities within the zone;
- provide clear, efficient and effective processes for monitoring, evaluating and reporting;
- guide the development of marine finfish aquaculture;
- implement the monitoring and reporting processes; and
- ensure adaptive management occurs as part of a process of continuous improvement.

The zone management framework will incorporate:

- a Zone Management Policy;
- an Environmental Monitoring and Management Plan (EMMP);
- a Ministerial Statement/Notice;
- Aquaculture Licences;
- Management and Environmental Monitoring Plans (MEMPs); and
- Aquaculture Leases.

Likely suitable fish species to be cultured in the zone, based on existing commercial aquaculture interest, their suitability for aquaculture in Western Australia and/or ability to meet Departmental licensing and biosecurity requirements (e.g. being native species and suited to feeding with a formulated, pathogen-free diet) include the following species:

- yellowtail kingfish (*Seriola lalandi*)
- mulloway (*Argyrosomus japonicus*)
- dolphin fish (*Coryphaena hippurus*)
- pink snapper (*Chrysophrys auratus*)

Based on this context, the current threat identification, hazard pathway analysis and risk assessment was conducted to identify and assess the potential impacts of finfish aquaculture of these species associated with establishment and operation of the MWADZ on the sustainability of ecosystems, and their dependent fisheries. Both the inherent risk (risk before application of management controls) coupled to the residual risk (following application of proposed management controls) was assessed in order to determine the nature and level of management controls required to bring the cumulative risks around sea-cage culture of finfish in the MWADZ to an acceptable level.

The assessment is based on the current knowledge/literature of the potential impacts of sea cage finfish aquaculture on fish and invertebrate species and fisheries production. The assessment also considers all available relevant information relating to:

- the proposed location within the Abrolhos Islands Fish Habitat Protection Area (FHPA);
- fish and invertebrate species known to inhabit the FHPA in the vicinity of the MWADZ;
- key invertebrate and commercial fisheries which are permitted to currently operate within the strategic MWADZ area; and
- yellowtail kingfish as the proposed culture species for the MWADZ project.

2 Threat Identification, Hazard Pathway Analysis and Risk Identification and Assessment Methodology

The identification of threats, analysis of hazard pathways and assessment of risks that may be generated by the proposal to develop an aquaculture zone in the Mid West of Western Australia was completed using methods that are consistent with the international standards for risk management and assessment (ISO 31000, 2009; IEC/ISO; 2009; SA-HB89; 2012). The process for assessment included three components – threat identification, hazard pathway analysis, identification of overarching risks and their assessment (see Figure 2).

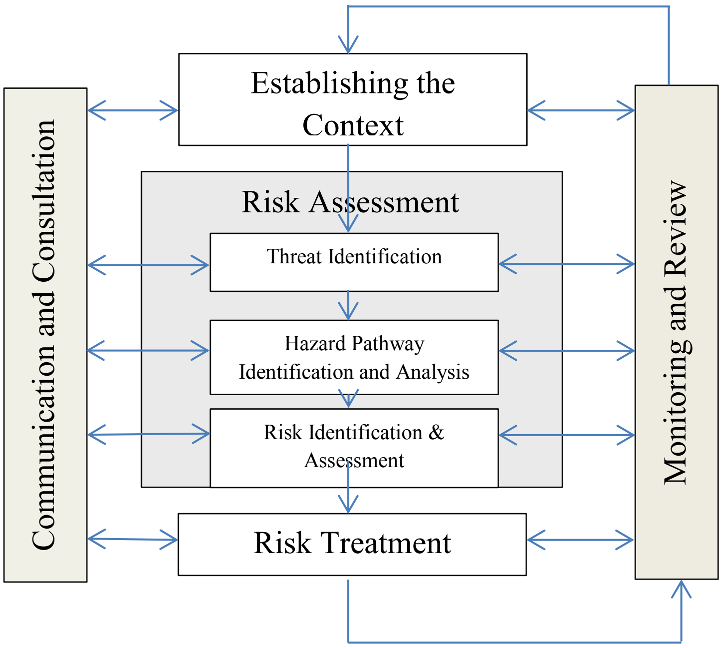

Figure 2: Description of risk assessment within the risk management process (modified from SA, 2012)

The specific protocols to complete each of these steps has been specifically tailored and extensively applied across a number of different aquatic management situations in Australia (Fletcher 2005, Fletcher et al. 2002, Jones and Fletcher 2012). Moreover, this methodology has now been widely applied in many other locations in the world (Cochrane et al. 2008, FAO 2012, Fletcher 2008, Fletcher and Bianchi 2014) and is considered one of the 'must be read' methods supporting the implementation of the ecosystem approach (Cochrane 2013).

2.1 Threat Identification

Threat identification was based on review of the following previously conducted assessments and consideration of specific information associated with the MWADZ proposal:

- Marine Finfish Environmental Risk Assessment (de Jong & Tanner, FRDC Project 2003/223)
- National ESD Reporting Framework: The “How to” Guide for Aquaculture. Version 1.1 FRDC, Canberra, Australia (Fletcher et al., 2004)
- Finfish Aquaculture in Western Australia: Final ESD Risk Assessment Report for Sea-Cage and Land-Based Finfish Aquaculture (Vom Berg, 2008; Fisheries Management Paper No 229, Department of Fisheries, Western Australia)

2.2 Hazard Pathway Identification

The identification of hazard pathways associated with the four main threats identified within the scope of the current assessment was accomplished using ‘Failure Mode Analysis’. Failure Mode Analysis is an engineering technique used to identify critical steps or hazard pathways that can lead to systems failure or the realisation of threats (in this case, impacts on invertebrate and fish species and key commercial and recreational fisheries arising from an aquaculture facility in the MWADZ). This process was conducted in order to assist with the orderly identification of issues relevant to assessment. The generated hazard pathways were used to assist with the identification of critical steps that may result in threats that need to be considered as a result of undertaking aquaculture activity in the MWADZ (Figures 3-6a).

2.3 Hazard Pathway Analysis

Individual hazards in each pathway were individually assessed (Tables 2-5a) with respect to both inherent risk (i.e. baseline risk if no management measures aimed at mitigating the risk were in place) and residual risk (i.e. remaining risk once one or more of the proposed management controls have been implemented). This process was undertaken to both understand the individual inherent hazards as well as to provide clarity as to the specific hazard or risk that a particular management activity is targeted at mitigating. This, in turn, assists in assessing whether management controls are adequate to manage risk of the entire pathway to an acceptable level and to identify any additional management actions required to address specific unacceptable risks.

The Consequence – Likelihood method was used to assess the level of the identified hazard pathway components associated with the key identified threats. The broad approach applied is a widely used method (SA, 2012) that is applied by many Western Australian Government Agencies through WA RiskCover.

Undertaking hazard or risk analysis using the Consequence-Likelihood (C x L) methodology involves selecting the most appropriate combination of consequence (levels of impact; Table 1a) and likelihood (levels of probability; Table 1b) of this consequence actually occurring. The combination of these scores is then used to determine the risk rating (Table 1c; IEC/ISO, 2009, SA, 2012).

The International standards definition of risk is "*the effect of uncertainty on objectives*" (ISO, 2009). This definition of risk makes it clear that examining risk will inherently include the level of uncertainty generated from having incomplete information (SA, 2012). In the context of assessing the threats and risks associated with this proposal, the objective to be achieved is to ensure the maintenance of sustainable ecosystems, including fish and invertebrate species, (and any dependent fisheries) and that they are not significantly impacted by the establishment of aquaculture operations in the MWADZ. Consequently, a "significant impact" that would result in a high risk would be one for which there was a reasonable likelihood that either the sustainability of the species was at risk or it was likely to have a significant impact on a commercial or recreational fishery.

Table 1a: Qualitative levels of consequence for each of the main objectives relevant to the assessment (modified from Fletcher, 2015)

Objective	Minor (1)	Moderate (2)	Major (3)	Severe (4)
Sustainability of fish and invertebrate species	Measurable but minimal "impacts" of the potential aquaculture development on fish stocks that are highly acceptable and easily meet sustainability objectives.	Maximum acceptable level of "impact" of the potential aquaculture development on fish stocks that would still meet the sustainability objectives.	Above acceptable level of "impact" of the potential aquaculture development on fish stocks. Broad and/or long-term negative effects on sustainability objectives which may no longer be met. Restoration can be achieved within a short to moderate time frame.	Well above acceptable level of impact of the potential aquaculture development on fish stocks. Very serious effects on sustainability objectives that are clearly not being met and may require a long restoration time or may not be possible.
Ecosystem structure	Measurable but minor changes to ecosystem structure, but no measurable change to function.	Maximum acceptable level of change in the ecosystem structure with no material change in function.	Ecosystem function now altered with some function or major components now missing and/or new species prevalent.	Extreme change to structure and function. Complete species shifts in capture or prevalence in system.
Habitat	Measurable impacts very localised. Area directly affected well below maximum accepted.	Maximum acceptable level of impact to habitat with no long-term impacts on region-wide habitat dynamics.	Above acceptable level of loss/impact with region-wide dynamics or related systems may begin to be impacted.	Level of habitat loss clearly generating region-wide effects on dynamics and related systems.

Economic	Detectable but no real impact on the economic pathways for the industry or the community.	Some level of reduction for a major fishery or a large reduction in a small fishery that community is not dependent upon.	Major sector decline and economic generation with clear flow on effects to the community.	Permanent and widespread collapse of economic activity for industry and the community including possible debts.

Table 1b: Generic levels of likelihood for each of the four main risks) analysed in this assessment (modified from Fletcher, 2015)

Level	Descriptor
Remote (1)	The consequence not heard of in these circumstances, but still plausible within the time frame (indicative probability 1–2%)
Unlikely (2)	The consequence is not expected to occur in the time frame, but some evidence that it could occur under special circumstances (indicative probability of 3–9%)
Possible (3)	Evidence to suggest this consequence level may occur in some circumstances within the time frame (indicative probability of 10–39%)
Likely (4)	A particular consequence level is expected to occur in the time frame (indicative probability of 40–100%)

Table 1c: Hazard/Risk Analysis Matrix. The numbers in each cell indicate the Hazard/Risk Score; the colour indicates the Hazard/Risk Rankings (see Table 2)

		Likelihood Level			
Consequence level		Remote	Unlikely	Possible	Likely
		1	2	3	4
Minor	1	1	2	3	4
Moderate	2	2	4	6	8
Major	3	3	6	9	12
Severe	4	4	8	12	16

The residual consequences, likelihoods and resultant levels of hazard or risk are all dependent upon the effectiveness of the risk mitigation controls that are in place (SA, 2012). Determining the most appropriate combinations of consequence and likelihood scores therefore involves the collation and analysis of all information available on an issue. The best-practice technique for applying this method now makes use of all available lines of evidence for an issue and is effectively a risk-

based variation of the 'weight of evidence' approach that has been adopted for many assessments (Linkov *et al*. 2009, Wise *et al*. 2007, Fletcher in press).

The hazard evaluation step uses the outcomes of the risk analysis to help make decisions about which hazards need treatment, the level of treatment and the priority for action. The different levels of management action can be determined by having the hazard or risk scores separated into different categories of hazard (Table 2).

Table 1d: Risk Evaluation, Rankings and Outcomes (modified from Fletcher *et al.* (2002, 2005, 2014)

Risk Level	Hazard/Risk Score C x L	Probable management response	Expected reporting requirements
Negligible	0-2	Acceptable with no management actions or regular monitoring	Brief justification
Low	3-5	Acceptable with no direct management actions and monitoring at specified intervals	Full justification and periodic reports
Moderate	6-8	Acceptable with specific, direct management and regular monitoring	Full regular performance report
High	9-16	Unacceptable unless additional management actions are undertaken. This may involve a recovery strategy with increased monitoring or even complete cessation of the activity.	Frequent and detailed performance reporting

Information Utilised

The key information used to generate the hazard and risk scores included:

- Broad knowledge of the proposal as provided in its application.
- A previous high-level generic risk assessment conducted for marine finfish aquaculture in Australia (FRDC project 2003/223).
- An identified list of species likely to be under consideration for aquaculture in the MWADZ.
- Relevant scientific studies and publications (see references) and knowledge of the fish and invertebrate species within the vicinity of the proposed MWADZ area.
- Knowledge of the key fisheries within the vicinity of the proposed MWADZ area.
- Research survey information for the West Coast bioregion.

- Commercial catch and effort information for relevant WA fisheries within the vicinity of the MWADZ area.
- Relevant biological and behavioural information on finfish and invertebrates species.
- Other relevant scientific studies and publications (see references).

2.4 Risk Identification

Based on consideration of the identified broad areas of threat and their constituent hazard pathways, overarching risks were identified associated with the MWADZ proposal. Assessment of these overarching risks was conducted as described for the hazard pathway assessment described above. Once again, the inherent hazard or risk was assessed in the absence of any management control measures. The residual risk following application of the identified management controls was then assessed.

During the risk assessment process, the invertebrate fishery which was identified likely to be most significantly impacted by the MWADZ proposal was the Abrolhos Islands and Mid West Trawl Managed Fishery (AIMWTMF). Some areas of the strategic MWADZ proposal area (i.e. the southern area) are within historical scallop fishing grounds of the AIMWTMF. Therefore, the proposal is likely to limit the extent of available fishing ground in this fishery. Given these impacts, a specific risk assessment was conducted on the AIMWTMF. A separate risk assessment was also conducted on the saucer scallop (*Amusium balloti*) which is the key target species for the AIMWTMF.

The other invertebrate commercial fishery that was identified to potentially be impacted by the MWADZ proposal was the West Coast Rock Lobster Managed Fishery (WCRLMF). The waters around the Abrolhos Islands FHPA provide an important area for the fishery, with approximately 15% of the fishery's total average catch coming from this area (Department of Fisheries 2012). Commercial rock lobster fishing activity at the Abrolhos Islands predominantly occurs over reef habitat, with between 45 to 65 percent of fishing effort occurring in shallow waters (0 to 20 metres) near submerged platforms and exposed reefs (Webster, F *et al* 2002). These habitats tended to occur generally on the western and central parts of the islands groups where there is a high abundance of limestone reef and macroalgae habitat (Webster, F *et al* 2002). Previous research surveys conducted in the area have shown that the highest average number of fishing effort for the fishery occurs in the Wallabi/North Island area (273,000) pot lifts compared to the Easter Group (196,000) and the Southern Pelseart Group (98,300) (Webster, F *et al* 2002). Benthic habitat data collected in the strategic MWADZ proposal area indicates that the predominant habitat is sand, which does not represent a key habitat area for western rock lobster [pers comm De Lestang, S (DoF)].

While sandy benthic habitat can sometimes provide and important area for migrating lobster “whites run” at certain times of the year, the MWADZ proposal is not known to be an important area for migrating rock lobster.

Catch and effort information which has also been recorded from the WCRLMF indicates that the majority of historical effort at the Abrolhos Islands is conducted outside of the strategic proposal area. In addition, the MWADZ proposal area represents a very small proportion (i.e. 3,000 hectares) less than 0.1% of the overall area of the fishery.

As a result, it is unlikely that the MWADZ project will have a significant impact on the WCRLMF. Consequently, no further assessment was conducted in relation to this species or fishery.

During the risk identification process two commercial finfish fisheries were identified to be potentially impacted by the MWADZ proposal. These included the West Coast Demersal Scalefish (Interim) Managed Fishery and the Mackerel Managed Fishery. Catch and effort information reported for these fisheries indicates that the MWADZ proposal area does not represent a key fishing area for these fisheries at the Abrolhos Islands. The majority of the commercial fishing effort for these fisheries is conducted outside of the MWADZ proposal area [pers comm Fairclough, D (DoF)]. As a result, a more generic risk assessment was conducted for the key finfish fisheries.

Given that the proposed finfish aquaculture in the MWADZ has the potential to impact target and non-target finfish species, a generic risk assessment was also conducted for finfish species.

3 Threat Identification, Hazard Pathway Analysis and Risk Identification

3.1 Threat Identification

Using a component-tree based approach (Fletcher *et al.*, 2014) four broad areas of threats were identified that were considered both most relevant to the MWADZ proposal and within the scope of the current assessment. The key threats were as follows:

- Potential impacts on the populations of invertebrate species (i.e. saucer scallop) within the Abrolhos Islands FHPA.
- Potential impacts on the populations of finfish species within the Abrolhos Islands FHPA.
- Potential impacts on the invertebrate fisheries (i.e. Abrolhos Islands and Mid West Trawl Managed Fishery) that operates in the Abrolhos Islands FHPA.

- Potential impacts on the finfish fisheries that operate in the Abrolhos Islands FHPA.

The qualitative component-tree structure (refer to Table 1 a) was used to assist with the identification of the environmental, ecological and biological components that needed to be assessed as part of the proposed MWADZ project.

3.2 Hazard Pathway Identification

Four hazard identification pathways associated with the key identified threats (Figures 3, 4, 5, 5a, 6 and 6a) were generated. These were pathways leading to potential impacts on:

- populations of invertebrate species (i.e. saucer scallops);
- populations of finfish species;
- invertebrate fisheries (Abrolhos Islands and Mid West Trawl Managed Fishery); and
- finfish fisheries.

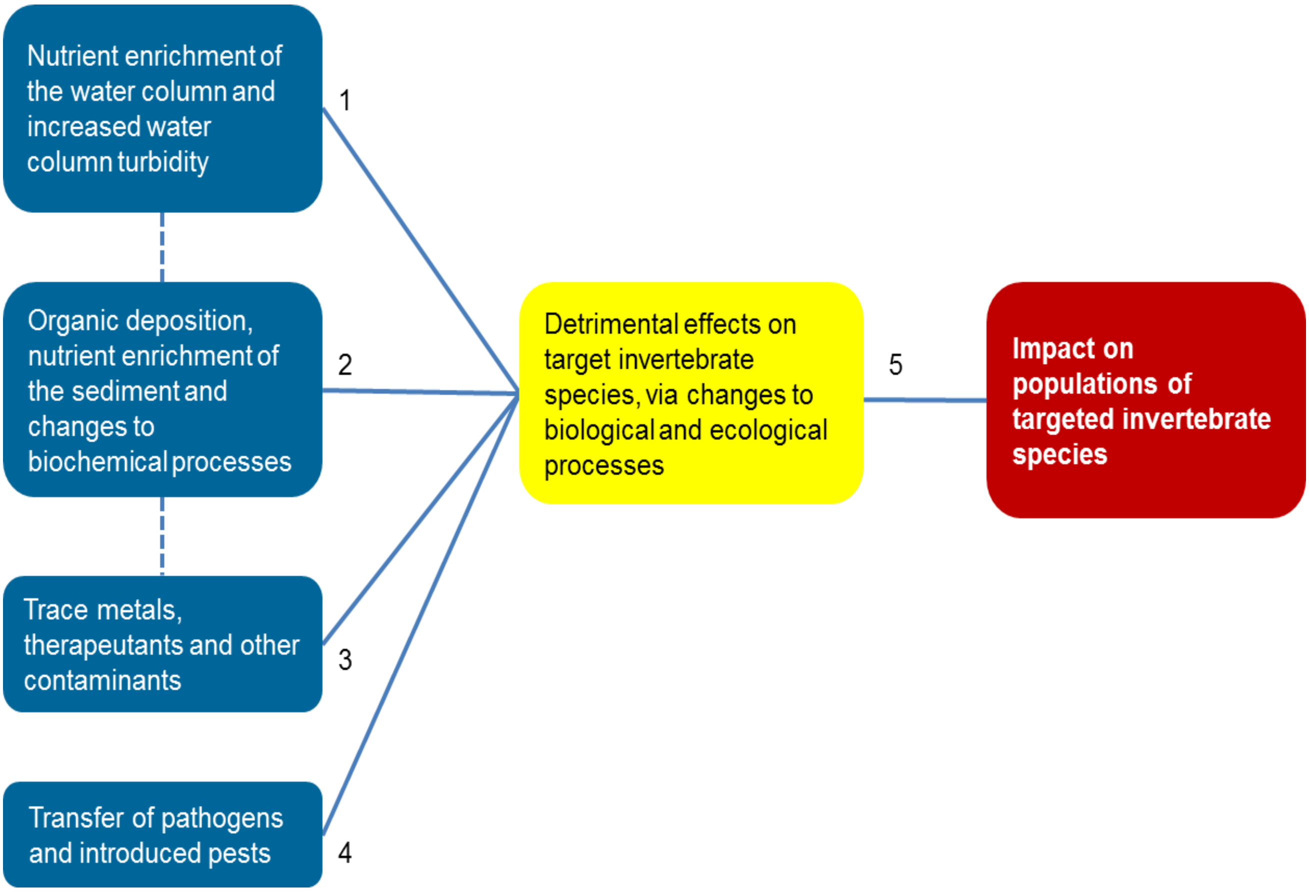

Figure 3: Conceptual model of ecological hazards associated with finfish aquaculture and the potential cause-effect pathways leading from the hazards to factors which could impact on the populations of invertebrate species (Saucer scallop). *Numbers refer to hazard pathways reviewed in Table 2.*

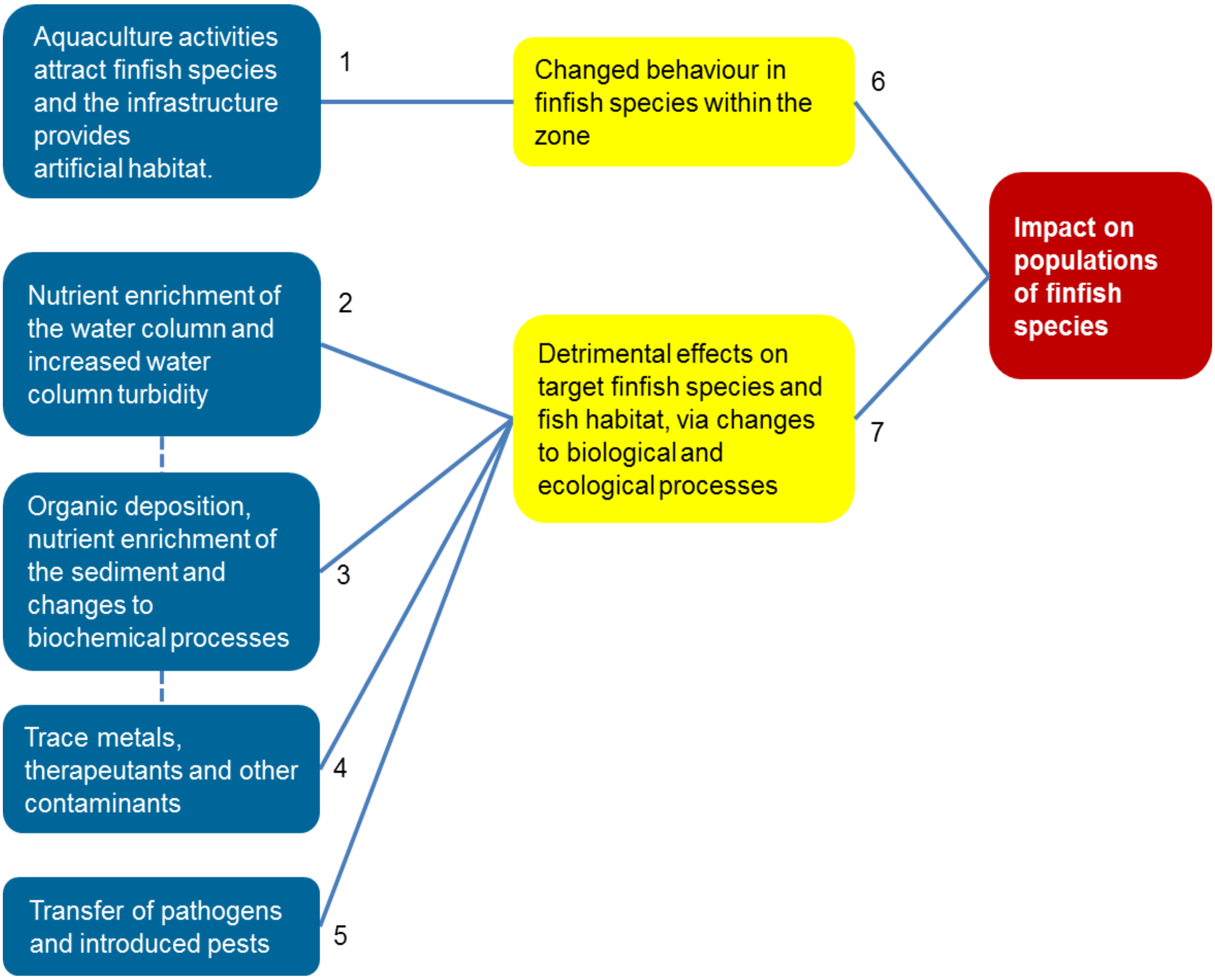

Figure 4: Conceptual model of ecological hazards associated with finfish aquaculture and the potential cause-effect pathways leading from the hazards to factors that could impact on populations of finfish species. *Numbers refer to hazard pathways reviewed in Table 3*

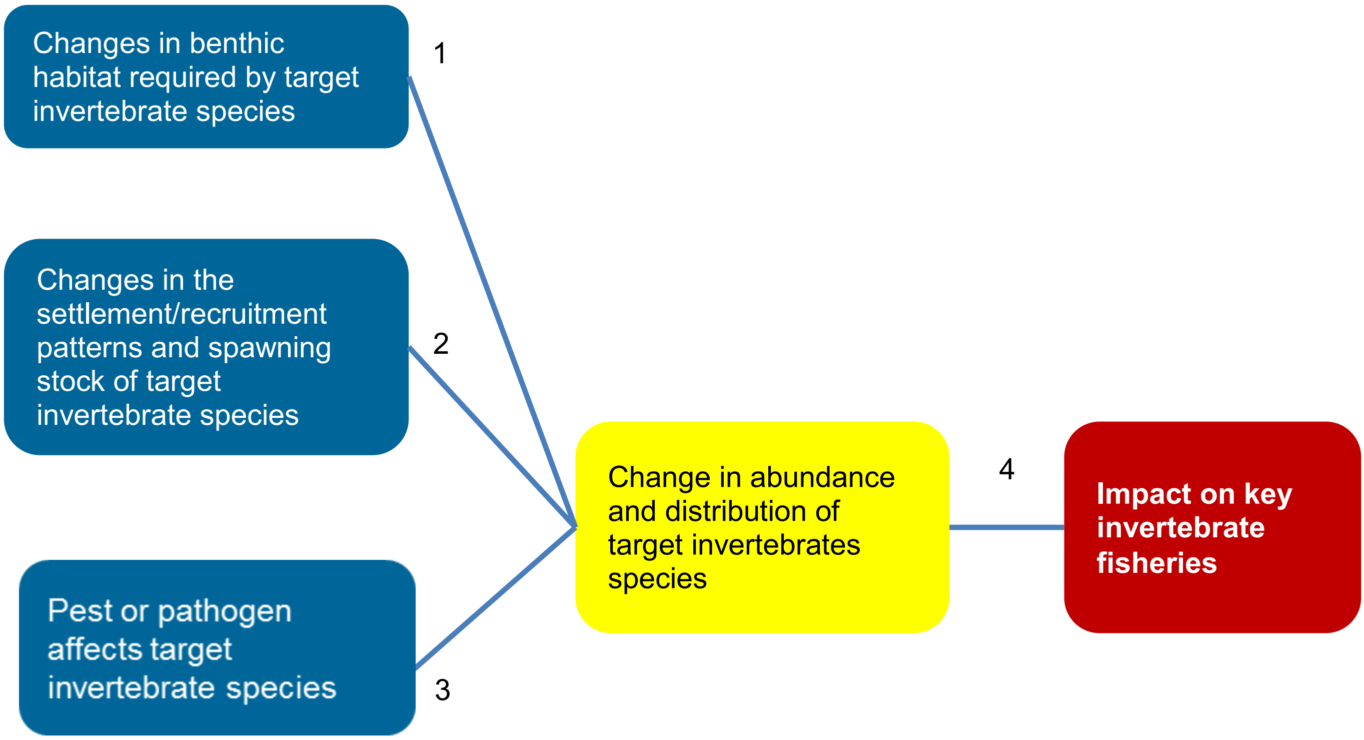

Figure 5: Conceptual model of ecological hazards associated with finfish aquaculture and the potential cause-effect pathways leading from the hazards to factors that could impact on the invertebrate fishery (i.e. Abrolhos Islands and Mid West Trawl Managed Fishery). *Numbers refer to hazard pathways reviewed in Table 4*

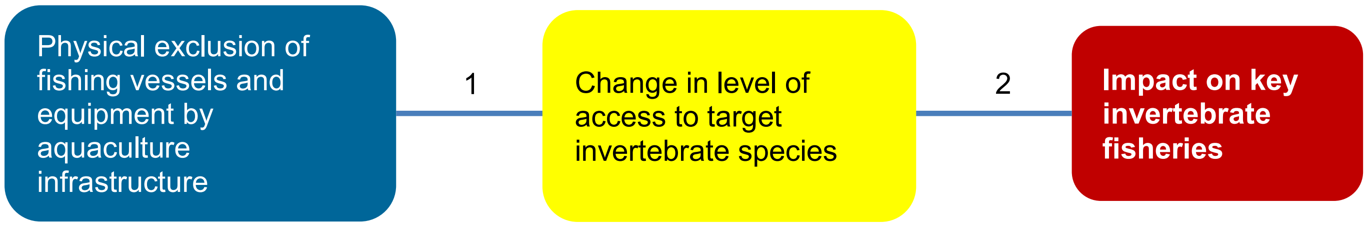

Figure 5a: Conceptual model of a resource access hazard associated with finfish aquaculture and the potential cause-effect pathways leading from the hazards to factors that could impact on the invertebrate fishery (i.e. Abrolhos Islands and Mid West Trawl Managed Fishery). *Numbers refer to hazard pathways reviewed in Table 4a*

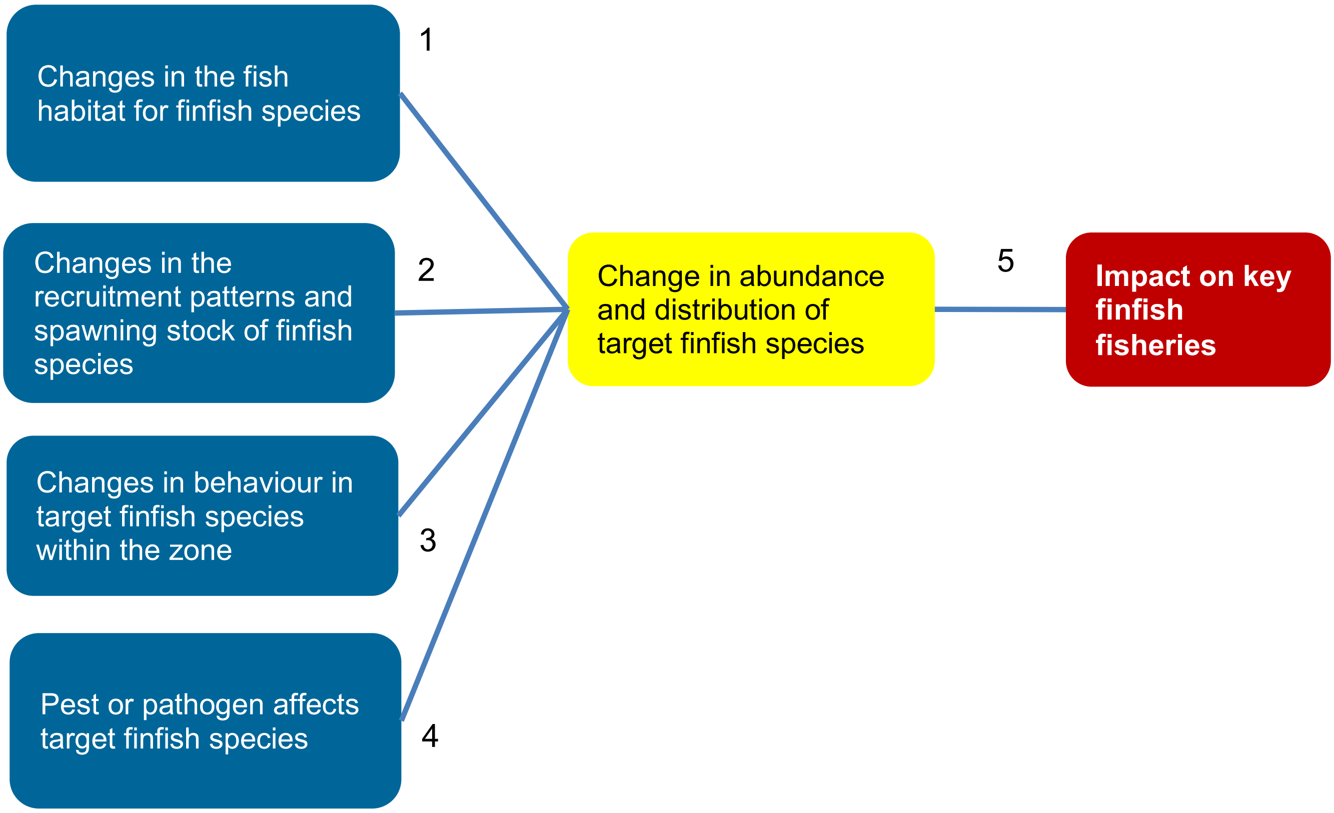

Figure 6: Conceptual model of ecological hazards associated with finfish aquaculture and the potential cause-effect pathways leading from the hazards to factors that could impact on finfish fisheries. *Numbers refer to hazard pathways reviewed in Table 5*

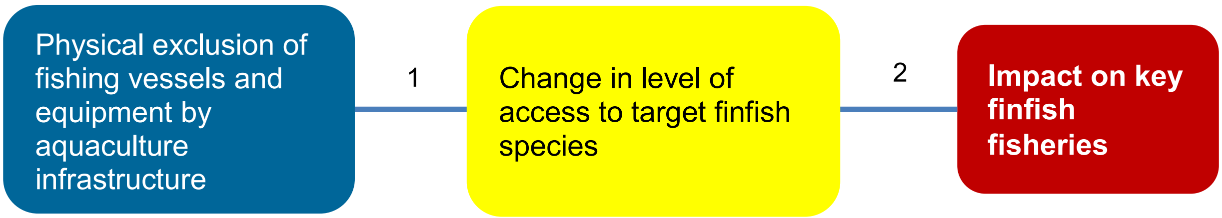

Figure 6a: Conceptual model of resource access hazard associated with finfish aquaculture and the potential cause-effect pathways leading from the hazards to factors that could impact on finfish fisheries. *Numbers refer to hazard pathways reviewed in Table 5a*

3.3 Hazard Pathway Analysis

The hazard pathway components identified in the conceptual diagrams of cause-effect pathways, detailed in Figures 3-6a, were individually analysed with respect to both the inherent hazard (i.e. baseline hazard if no management measures aimed at mitigating the hazard were in place) and their residual hazard (i.e. remaining hazard once one or more of the proposed management controls have been effected) as indicated in Tables 2-5a.

Prior to conducting this exercise a review of relevant literature documenting the impacts of aquaculture on wild fish and fisheries was conducted, with a focus on yellowtail kingfish (YTK) as the cultured species in this case study. Consequence to invertebrate and finfish species and fisheries was specifically considered in developing this assessment based on a worst-case scenario model. This used relevant examples applicable to the culture of the proposed species, with a focus on YTK.

3.2.1 Hazard Pathway 1: Impact on populations of invertebrate species within the Abrolhos Islands FHPA

The primary potential impacts of the MWADZ proposal on invertebrate species that were identified during the risk assessment process were the following:

- Nutrient enrichment of the water column and increased turbidity;
- Organic deposition, nutrient enrichment of the sediment and changes to biochemical processes;
- Trace metals, therapeutants and other contaminants;
- Transfer of pathogens and introduced pests; and
- Impact on populations of invertebrate species, due to detrimental effects on biological and ecological processes from aquaculture.

During the risk assessment process, it was identified that saucer scallop (*Amusium balloti*) were one of key invertebrate species likely to be impacted by the sea cage finfish aquaculture. Previous research studies conducted within the proposed MWADZ area by the Department of Fisheries has shown that saucer scallops have been historically abundant within certain areas of the proposed aquaculture development zone. This species is also one of the key target species of the AIMWTMF. Given the availability of biological and ecological information on this species and its commercial importance in terms of the AIMWTMF, a specific assessment was conducted on this species.

Table 2: Assessment of hazards identified on the impact on targeted invertebrate species (i.e. saucer scallop). *Hazards were individually analysed with respect to both the inherent hazard (i.e. baseline hazard if no management measures aimed at mitigating the hazard were in place) and the residual hazard (i.e. remaining hazard once one or a number of the proposed management controls have been implemented)*

Hazard	Inherent Hazard Assuming No Management Controls	Justification	Residual Hazard Following Implementation of Management Controls	Justification and Identified Management Controls
1. Nutrient enrichment of the water column and increased water turbidity **(Refer to Figure 3)**	**Likelihood: Possible (3)** **Consequence: Minor (1)** **Hazard score: (3)** **Risk: Low**	**Likelihood** *Nutrient enrichment* Marine cage aquaculture is a recognized source of nitrogenous and phosphorous discharge from uneaten food, faeces and metabolic wastes including ammonia and urea (Nash et al 2005). The level of nitrogen and phosphorous discharge is highly dependent on the types of feeds, feed conversion ratios and feeding efficiencies (of the cultured species), and other farm practices (e.g. stocking densities). Sea cage aquaculture could elevate levels of dissolved nutrients in the water column surrounding the cages, thereby stimulating phytoplankton productivity in the water column. *Increased Turbidity* Particulates from feed and fish faeces are likely to increase the turbidity within close proximity of the sea cages. These particulate will settle beneath the sea-cages, resulting in an increase in sedimentation beneath the sea cages or pens (Hargrave, B 2005).	**Likelihood: Possible (3)** **Consequence: Minor (1)** **Hazard score: (3)** **Risk: Low**	**Likelihood** *Nutrient enrichment* There is likely to be some level of nutrient enrichment in the water column in localised areas within the MWADZ. The **Possible (3)** ranking is unlikely to change in that some level of enrichment is almost inevitable. *Increased Turbidity* Likelihood ranking is unlikely to change as some degree of turbidity/ increased sedimentation is likely to occur underneath and within close proximity to the sea-cages. Most of the effects of organic deposition and smothering of the benthos are likely to be localised and within close proximity to the footprint

		Particular species of phytoplankton are known to cause shellfish poisoning; however the strong water currents in area and mixing of the water column reduce the likelihood of toxic algae blooms affecting any target benthic invertebrates. It is therefore **Possible (3)** that the MWADZ proposal could increase nutrient enrichment and turbidity within close proximity to the sea cages and potentially has an impact on target benthic invertebrates. **Consequence** *Nutrient enrichment* Elevated dissolved nitrogen in the water column is typically a localised effect (within hundreds of meters) of the sea cages. Increases in dissolved phosphorous, however, is generally not considered to be a primary concern (Nash et al 2005), and most marine waters are nitrogen limited. Nutrient enrichment can result in elevated levels of primary (i.e. phytoplankton) and macro algal production (Nash et al 2005), and thus eutrophication of the water column (and oxygen depletion of the water column). Any potential eutrophication as a consequence of nutrient enrichment in the water column in the localised area is likely to have negative impact on scallop populations. *Increased Turbidity* An increase in turbidity can lead to a decrease in light penetration within the water column, which can have negative impacts on photosynthetic organisms (like corals) directly underneath and in close proximity to the sea cages (Price and Morris, 2013).		of the sea cages (Hargrave, B 2005). **Consequence** The consequence remains unchanged as **Minor (1)**. *Nutrient enrichment* Consequences can be reduced through the adoption of good farming practices that maximize the feeding efficiency and reduce feed waste. Monitoring of nutrient levels under farm management practices, including direct measurement of the level of Chl-*a* at the farm and reference sites (e.g. Pittenger et al. 2007) will further reduce the level and thus consequence of water column nutrient enrichment. Chlorophyll-a is a proxy for phytoplankton levels. Median dissolved inorganic nitrogen levels must remain below 500µg/L. Median Chlorophyll-a levels must remain less than two-fold that at the Reference sites. Additionally, situating farms in well-flushed locations, and setting stocking densities of farms at conservative levels will help to minimise the likelihood of water column enrichment.

		An increase in sedimentation on the seabed can result in a potential loss or reduction in diversity of benthic invertebrates through smothering of benthic habitats and through oxygen depletion and hydrogen sulphide production during bacterial de-composition of organic matter. This could in turn lead to a dominance of small opportunistic benthic invertebrate species including capetellid worms and other scavengers and deposit feeding species (Hargrave, B 2005) Increased turbidity and sedimentation is likely to have a negative impact on scallop populations directly underneath the sea cages and in close proximity to the cage footprint. The risk of nutrient enrichment and increased turbidity causing detrimental effects on target invertebrate species in the overall Abrolhos Islands FHPA is, however, considered M**inor (1)**.		*Increased Turbidity* The consequence of increased turbidity and sedimentation can be reduced through the adoption of best practice arrangement. These include: • maximizing feeding efficiency and reducing feed waste; • situating sea cages within well-flushed locations; and • setting the stocking density of farms at conservative levels.
2. Organic deposition nutrient enrichment of the sediment and changes to biochemical processes **(Refer to Figure 3)**	**Likelihood: Possible (3)** **Consequence: Minor(1)** **Hazard score: (3)** **Risk level: Low**	**Likelihood** Globally sea cage aquaculture in known to have an impact on marine sediments (Price and Morris 2013).Research studies conducted by Price and Morris 2013 have shown that globally an average of 20-463kg of nitrogen and 5-80 kg of phosphorus are released into sediments (from fish farms) per metric ton of fish produced. Reviews conducted by Wu,R.S 1995, have shown that approximately 23% of the carbon from feed accumulates in sediments beneath cages; similarly, Pearson and Black (2001) report 4.1-78g carbon/m^2/day is input in to sediments. Nutrient enrichment, sedimentation and changes in sediment biogeochemistry are generally restricted to within 500 metres of culture cages (Price and Morris 2013).	**Likelihood: Unlikely (2)** **Consequence: Minor (1)** **Hazard score: (2)** **Risk level: Negligible**	**Likelihood** Likelihood of the impacts can be further reduced to **Unlikely (2)** based on implementation of management measures outlined below: • Locating the sea cages in well flushed areas where there is an increased water depth below the sea cages • Feed Control- minimizing feed wastage can significantly reduce sediment enrichment effects which can help improve sediment conditions underneath the sea cages

		The level of nutrient enrichment (N,P,C) is highly dependent on the species being cultured, feed source and farm practices, and density of proximal farm sites. Additionally, the type of sediment found under the farm is a major contributing factor to the extent and severity impacts (Price and Morris 2013). Increased sedimentation beneath the sea cages or pens can result in a potential loss or reduction in diversity of benthic invertebrates through smothering of benthic habitats. Bacterial de-composition of the organic matter results in an increase in the biological oxygen demand of the sediment, leading to depletion of oxygen at the benthos. This could result in anoxic conditions at the sediment-water interface resulting in a sharp decline in populations of target invertebrates, and a dominance of small opportunistic benthic invertebrate, i.e. scavengers and deposit feeding species, e.g. capetellid worms. Anoxic conditions could also lead to elevated levels of nitrites and hydrogen sulphide, which are toxic to invertebrates (Hargrave, B 2005). Increased organic deposition nutrient enrichment of the sediment and changes to biochemical processes is likely to have an effect on target invertebrate species, via changes to biochemical properties of the benthic environment. This is likely to result in avoidance of the area by target invertebrates. Survival and recruitment of sessile target species beneath the sea-cages (and within 100 meters) is likely to be impacted. The likelihood as been rated as **Possible (3)**. **Consequence** The most significant impact of nutrient enrichment of sediments is changes to the biogeochemical parameters of the sediment. Alterations of sediment sulfide, redox		• The use of good quality feeding systems which minimize waste • The use of high quality feed and improvements in feed conversion ratios • Fallowing of sites to allow seabed recovery. The rotation of sea cages is likely to allow the recovery of nutrient enrichment in the sediments. • Consider cumulative impacts under management plans • Pre-stocking monitoring, and use of multiple biotic and abiotic indices to monitor any impacts • Encourage integrated multi-trophic aquaculture (Price and Morris 2013) • Regulation of the density of sea-cage operations, in addition to limiting the stocking density per hectare of lease • Development of and compliance with a Management and Environmental Monitoring Plan (MEMP) and best-practices in aquaculture, including the requirement to monitor the levels of dissolved nutrients and chlorophyll-a. **Consequence** Consequence would remain unchanged [i.e. **Minor (1)**].

		potential, sediment oxygen consumption and nitrogen mineralization are consistently reported to be sensitive to nutrient input. These biogeochemical changes can induce changes in micro and macrofauna that live on or in the sediments, due to the shift from aerobic to anoxic conditions (Hargrave, B 2005). Nitrate toxicosis of invertebrate species can also occur through metabolism of nitrate due to nitrite being an intermediate. This process generally leads to lack of oxygen in organ tissues of animals. Although metabolism of nitrite can convert it to ammonia, if there is more nitrite than can be converted, animals will be unable to respire. Nitrate is much less toxic than ammonia. However, levels over 30 ppm of nitrate can inhibit growth, impair the immune system and cause stress in some aquatic species[1]. Vezzulli et al 2004 found bacterial levels below a sea bream farm were up to three times higher than the reference site, with the bacterial community shifting toward gram-negative species and an occurrence of pathogenic *Vibrio* species. Decreased species diversity and richness and changes in biomass of macrofauna have been widely reported for sediments beneath cages compared to reference sites (Vezzulli et al 2002). Hydrodynamics of the farm site will tend to disperse organic wastes over larger areas, but also provide a mechanism for aerobic assimilation of waste nutrients within the marine environment (Price and Morris 2013). While impacts are generally reported to be localized (i.e. up to 500m from cages) far-field impacts have been recorded in terms of changes to benthic community structure (Wildish et al 2005).		

		Previous aquaculture research studies have demonstrated that the effects of sediment enrichment display a strong gradient of rapidly decreasing impact with increasing distance from the sea cages (Forrest, B et al 2007). Canadian studies indicate that impacts may take more than five years to manifest and may disrupt food webs at larger scales, impacting commercial fisheries (Price and Morris 2013, Wildish et al 2005). It is expected any decline in abundance of the target invertebrates would be restricted to the depositional area in close proximity (i.e. within 100 metres) and directly underneath the sea-cage infrastructure. Consequence **Minor (1)**.		
3. Trace metals, therapeutants, and other contaminants **(Refer to Figure 3)**	**Likelihood: Unlikely (2)** **Consequence: Moderate (2)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** Chemicals (antibiotics, therapeutants, antifoulants and heavy metals) used within marine cage farming practices may be released into the surrounding environment; through feed, faeces and directly in the water column (e.g. leaching from antifoulants or heavy metal release from feeds). The likelihood of a chemical impact is highly dependent on specific chemicals, the characteristics of the farm site (e.g. flushing rate, sediment type) and farm management practices (e.g. feeding rates, husbandry techniques etc.). Considering the uncertainty, the likelihood is rated as **Unlikely (2)**. **Consequence** Therapeutants can have toxic effects on invertebrates including commercially important species such as scallops	**Likelihood: Remote (1)** **Consequence: Minor (1)** **Hazard score: (1)** **Risk level: Negligible**	**Likelihood** Most therapeutants have limited environmental significance as they are usually highly water soluble and breakdown readily in the environment (Forrest B *et al* 2007). Given the high level of flushing and dispersion of organic deposition in the MWADZ area it is unlikely, that unacceptable levels of heavy metals will be present in the aquaculture zone. Any potential impacts on the scallop populations are likely to be localised and within close proximity to the sea cages. The likelihood can be reduced to **Remote (1)** by having strict controls

		and rock lobster (e.g. Haya et al. 2001). Heavy metals originating from feeds or from antifoulants used in aquaculture farming practices can accumulate in sediments below sea cages (reducing benthic colonization), and can have direct toxic effects of benthic invertebrates and can lead to bioaccumulation within the food chain (Forrest, B et al 2007). Therefore consequence is rated as **Moderate (2)**.		on the use of chemicals associated with aquaculture, and appropriate approval, licensing and compliance regime. **Consequence** Consequence can be reduced through the following practices: • Good husbandry and farming practices • Reducing the use of copper-based anti-foulant paints to structures which are essential and manual defouling used on other structures • Reducing the level of therapeutants in feed (e.g. zinc) Consequence of any attraction could be reduced to **Minor (1)** by reducing the extent and intensity of organic enrichment of the benthos.
4. Transfer of pathogens and introduced pests **(Refer to Figure 3)**	***See biosecurity risk assessment**	***See biosecurity risk assessment**	***See biosecurity risk assessment**	***See biosecurity risk assessment**
5. Impact on populations of a target invertebrate	**Likelihood: Unlikely (2)** **Consequence: Minor (1)**	**Likelihood** Increased organic deposition nutrient enrichment of the sediment and changes to biochemical processes is likely to have a detrimental effect on target invertebrate species,	**Likelihood: Remote (1)** **Consequence: Minor (1)**	**Likelihood** Likelihood of sustainability impacts can be further reduced based on implementation of management

species, due to detrimental effects on biological and ecological processes, resulting from aquaculture **(Refer to Figure 3)**	**Hazard score: (2)** **Risk level: Negligible**	via changes to biological and ecological processes. This is likely to result in avoidance of the area by target invertebrates. Survival and recruitment of sessile target species beneath the sea-cages (and within 100 metres) is likely to be impacted. However, such a decline in abundance of the target invertebrates would be restricted to the depositional area in close proximity (i.e. within 100 metres) and directly underneath a sea-cage. Given the area affected by a decline in abundance of the target invertebrates is a negligible proportion (much less than 1 percent) of its natural range, the contribution aquaculture could make to anthropogenic-caused mortality is not considered significant. Therefore, the likelihood that the proposed aquaculture will have an impact of the overall target invertebrate species populations in the Abrolhos FHPA is rated **Unlikely (2).** **Consequence** The consequences of the proposed aquaculture having an impact on the population of saucer scallops are rated as **Minor (1)**.	**Hazard score: (1)** **Risk level: Negligible**	measures aimed at reducing wastage of stock feed associated with the aquaculture. Operations will be required to comply with a Management and Environmental Monitoring Plan (MEMP), which requires operators to conduct water quality and sediment quality monitoring. Department of Fisheries will support or endorse best-practices in aquaculture. It will manage compliance around MEMP requirements including mandatory reporting on water and sediment quality. Failure to comply with the MEMP may result in suspension or cancellation of the offending licence. The industry will collect and report on water and sediment quality. This provides an early warning to aquaculture managers if the rates of organic enrichment increase beyond acceptable limits within the proposed zone. The management measures described above will ensure that the likelihood of the proposed aquaculture significantly impacting the target invertebrate species population is reduced to **Remote (1)**.

				Consequence Consequence would remain unchanged at **Minor (1)**.

3.2.2 Hazard Pathway 2: Impact on populations of finfish species within the Abrolhos Islands FHPA

The primary potential impacts of the MWADZ proposal that were identified during the risk assessment process on finfish species were the following:

- Aquaculture activities attract finfish species and provide additional food and artificial habitat;
- Nutrient enrichment of the water column and increased water column turbidity;
- Organic deposition nutrient enrichment of the sediment and changes to biochemical processes;
- Trace metals, therapeutants and other contaminants;
- Transfer of pathogens and introduced pests;
- Changes in behavior of finfish species within the aquaculture zone; and
- Impact on populations of finfish species, due to detrimental effects on biological and ecological processes, resulting from aquaculture.

Given the lack of available information on finfish species within the proposed MWADZ area, and the potential impacts finfish aquaculture could have on both target and non-target finfish species, a generic assessment on finfish species was conducted.

Table 3: Assessment of hazards identified on the potential impacts of the proposal on finfish species. *Hazards were individually analysed with respect to both the inherent hazard (i.e. baseline hazard if no management measures aimed at mitigating the hazard were in place) and the residual hazard (i.e. remaining hazard once one or a number of the proposed management controls have been implemented).*

Hazard	Inherent Hazard Assuming No Management Controls	Justification	Residual Hazard Following Implementation of Management Controls	Justification and Identified Management Controls
1. Aquaculture activities attract finfish species to the sea-cages and provide additional food and artificial habitat **(Refer to Figure 4)**	**Likelihood: Likely (4)** **Consequence: Moderate (2)** **Hazard score: (8)** **Risk level: Moderate**	**Likelihood** Fish farming is associated with: • residue from cultured stock; • harvest activities and effluent; • artificial feed; • increased food availability; • artificial structure; and • attracted prey species. This could lead to changes in the behaviour of target species within the zone, including: • attraction to or avoidance of the fish farming area; • increased/decreased visitation rates;	**Likelihood: Possible (3)** **Consequence: Minor (1)** **Hazard score: (3)** **Risk level: Low**	**Likelihood** Likelihood of positive attraction can be reduced to **Possible (3)** based on a removal of as many of the potential sources of attractants as possible through actively managing their levels of accumulation. Specific management mechanisms include the following: Development and compliance with a Management and Environmental Monitoring Plan (MEMP) and best-practices in aquaculture, including the following requirements: • removal of dead and moribund stock on a daily basis; • moderate stocking levels; • containment of all post-harvest blood

		• increased duration of visits; • increased/decreased abundance; and • altered feeding behaviours. It is documented that marine cage culture can increase the abundances of fish at local scales (e.g. Machias et al 2005). This is primarily a result of the excess food and waste released from farming activities acting as a food source for wild fishes (Machias et al 2005). Aquaculture stock feed consists of fish meal and fish oil, which are known attractants to fish. The likelihood of attraction of finfish to sea-cage aquaculture is dependent on the species. Generally, the provision of food and habitat can lead to changed behaviour in wildlife including fish. Given that some species of finfish are attracted to fish farms, e.g. Pink snapper (*Chrysophrys auratus)*, it is **Likely (4)** that the effects of increased provisioning (food and habitat) could extend the residence time of some scalefish populations near the sea-cages. Other attraction signals include: *Stock* The long-term presence of high densities of aquaculture stocks in the upper water column is likely to produce a continuous, low-level source of biological residue (oil, scales, faeces, blood etc.) which may attract some species of finfish to the proposed zone. Some level of stock mortality is inevitable in aquaculture and occasional dead and		water; and • use of a high-quality pellet feed. **Consequence** Consequence of any attraction could be reduced to **Minor (1)** by eliminating some of the signals that attract target species to the sea-cages. Appropriate management measures include those that reduce or eliminate feed and biological residue being released to the ocean.

		decomposing stock in sea-cages could influence the presence of particular fish species. Additional food could facilitate the growth of populations of prey species. An increase in the abundance of prey species could, in turn, influence behaviour of predatory fish species (e.g. sharks and pelagic species such as Spanish mackerel and tuna) in the proposed zone. *Biological residue* It is not common practice in the industry to purposely discard harvest by-products on site. However, it is reasonable to expect that there is a variety of other cues associated with harvesting cultured fish that could attract particular species of wild fish, e.g. faeces, blood, lipids, pheromones and scales from stock. *Artificial structure* Fish cage clusters can provide additional three dimensional structures to the marine environment. Mooring lines and anchors used to secure the sea cage infrastructure could be of advantage to particular finfish species or their prey by providing an artificial habitat. Given artificial reefs are known to attract fish species, it is reasonable to expect that these structures will increase complex benthic habitat in the area. The attraction of fish is likely to be restricted to those already known to occur in the vicinity of the aquaculture. The pathway of cause-effect assumes that the aquaculture facility acts as an attractant to small fish species on a spatial and temporal scale.		

		Consequence The discrete consequence of attracting finfish to aquaculture cages is the increased probability that finfish populations will reside in the area, utilising additional habitat and feeding opportunities provided (Price and Morris 2013). Generally, aquaculture is considered to positively influence the presence of finfish species in the vicinity of the sea-cages. However, the provision of food and habitat by aquaculture may extend the residence time of some finfish species around the sea-cages, making them more available and therefore vulnerable to fishing. The consequence of changed behaviour in finfish species is considered **Moderate (2)**, in relation to potentially higher levels of fishing. It should be noted that an increased presence of finfish in the zone could increase the probability that finfish species will also be exposed to other hazards, which are discussed in section 6 of this table.		
2. Nutrient enrichment of the water column and increased water column turbidity **(Refer to Figure 4)**	**Likelihood: Possible(3)** **Consequence: Minor (1)** **Hazard score: (3)** **Risk level: Low**	**Likelihood** *Nutrient enrichment* Marine sea-cage aquaculture is a recognised source of nitrogenous and phosphorous discharge from uneaten food, faeces and metabolic wastes, including ammonia and urea (Nash et al 2005). The level of nitrogen and phosphorous discharge is highly dependent on the types of feeds, feed conversion ratios and feeding efficiencies (of the cultured species) in addition to other farm practices (e.g. stocking densities). Sea-cage	**Likelihood: Possible (3)** **Consequence: Minor (1)** **Hazard score: (3)** **Risk level: Low**	**Likelihood** *Nutrient enrichment* There is likely to be some level of nutrient enrichment in the water column in localised areas within the MWADZ. The likelihood is unlikely to change in that some level of enrichment is almost inevitable. Likelihood **Possible (3)**. *Increased Turbidity*

		aquaculture could elevate levels of dissolved nutrients in the water column surrounding the cages, thereby stimulating phytoplankton production in the water column (Hargrave, B 2005). *Increased Turbidity* Fish waste, particulates from feed and increased phytoplankton levels are likely to increase the turbidity within close proximity of the sea-cages (Hargrave, B 2005). Particular species of phytoplankton are known to cause mortalities in finfish. However, the strong water currents in the area and mixing of the water column are likely to reduce, the probability of toxic algae blooms affecting fish. It is **Possible (3)** that aquaculture activities will result in nutrient enrichment of the water column and an increase in turbidity within close proximity to the sea-cages. **Consequence** *Nutrient enrichment* Elevated dissolved nitrogen in the water column is typically a localised effect (within hundreds of metres) of the sea-cages. Increases in dissolved phosphorous, however, are generally not considered to be a primary concern (Nash et al 2005, Costa-Pierce et al 2007). Most marine waters are nitrogen limited. Nutrient enrichment can result in elevated levels of primary (i.e. phytoplankton) and macro-algal production (Nash et al 2005) and thus eutrophication (and oxygen depletion) of the water column.		Likelihood is unlikely to change as some degree of turbidity/increased sedimentation is likely to occur underneath and within close proximity to the sea-cages. Most of the effects of organic deposition and smothering of the benthos are likely to be localised and within close proximity to the footprint of the sea-cages (Hargrave, B 2005). **Consequence** Remains unchanged at **Minor (1)**. *Nutrient enrichment* Consequences can be reduced through the adoption of good farming practices that maximise the feeding efficiency and reduce feed waste. Monitoring of nutrient levels under farm management practices, including direct measurement of the level of Chl-*a* at the farm and reference sites (e.g. Pittenger et al. 2007) will further reduce the level and thus consequence of water column nutrient enrichment. Additionally, situating farms in well-flushed locations, and setting of density of farms at conservative levels will help to minimise the consequence of water column enrichment.

		Any potential eutrophication as a consequence of nutrient enrichment in the water column may have a negative impact on finfish populations in the localised area. *Increased Turbidity* An increase in turbidity can lead to a decrease in light penetration within the water column. This can have negative impacts on photosynthetic organisms (like corals) directly underneath and in close proximity to the sea-cages (Price and Morris, 2013). Increases in turbidity will have a greater influence in nearshore sites compared to open ocean sites, especially in sites located close to critical habitats such as corals and seagrass beds. Given the proposed MWADZ is a deeper water environment (i.e. average depth 30 to 40 metres), nutrient enrichment and increases in turbidity are likely to be localised and have been rated as a **Minor (1)** consequence.		*Increased Turbidity* The consequence of increased turbidity and sedimentation can be reduced through the adoption of best practice arrangements. These include: • maximising feeding efficiency and reducing feed waste; • situating sea cages within well-flushed location; and • setting the stocking densities at conservative levels.
3. Organic deposition nutrient enrichment of the sediment and changes to biochemical processes **(Refer to Figure 4)**	**Likelihood: Possible (3)** **Consequence: Minor (1)** **Hazard score: (3)** **Risk level: Low**	**Likelihood** Increased sedimentation beneath the sea-cages or pens can result in a potential loss or reduction in diversity of finfish through smothering of benthic habitats. Bacterial de-composition of the organic matter results in an increase in the biological oxygen demand of the sediment, leading to depletion of oxygen at the benthos. This could result in anoxic conditions at the sediment-water interface resulting in a decline in populations of	**Likelihood: Unlikely (2)** **Consequence: Minor (1)** **Hazard score: (2)** **Risk level: Negligible**	**Likelihood** The likelihood can be reduced to **Unlikely (2)** by regulating the density of sea-cage operations, in addition to limiting the stocking density per hectare of lease. Development and compliance with a MEMP and best-practices in aquaculture, including the requirement to monitor the

		finfish and a dominance of small opportunistic benthic invertebrates (i.e. scavengers and deposit-feeding species such as capetellid worms). Anoxic conditions could also lead to elevated levels of nitrites and hydrogen sulphide, which are toxic to biota (Hargrave, B 2005). Increased organic deposition nutrient enrichment of the sediment and changes to biochemical processes is likely to have a detrimental effect on finfish species, via changes to biochemical properties of the benthic environment. This is likely to result in avoidance of the area by finfish species. Survival and recruitment of fish species confined to habitats beneath the sea-cages and within close proximity are likely to be impacted. Likelihood is assessed as **Possible (3)**. **Consequence** The most significant impact of nutrient enrichment of sediments is changes to the biogeochemical parameters of the sediment. Alterations of sediment sulfide, redox potential, sediment oxygen consumption and nitrogen mineralization are consistently reported to be sensitive to nutrient input. These biogeochemical changes can induce changes in micro and macrofauna that live on or in the sediments, due to the shift from aerobic to anoxic conditions (Hargrave, B et al 2008). Decreased species diversity and richness and changes in biomass of macrofauna have been widely reported for sediments beneath cages compared to reference sites (Hargrave, B et al 2008). Hydrodynamics of the farm site will tend to disperse organic wastes over larger areas,		levels of dissolved nutrients and chlorophyll-a, would also assist. The likelihood could also be reduced by reducing feed waste improving feeding efficiency and adopting good husbandry and farming practices. **Consequence** Consequence remains at **Minor (1)**.

		however also provide a mechanism for aerobic assimilation of waste nutrients within the marine environment (Price and Morris 2013). Consequence **Minor (1)**. Any potential decline in abundance of finfish species is likely to be restricted to areas directly underneath the sea-cage and within the depositional area.		
4. Trace metals, therapeutants, and other contaminants **(Refer to Figure 4)**	**Likelihood: Unlikely (2)** **Consequence: Moderate (2)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** Chemicals (antibiotics, therapeutants, antifoulants and heavy metals) used within marine sea-cage farming practices may be released into the surrounding environment; through feed, faeces and directly to the water column (e.g. leaching from anti-foulants or heavy metal release from feeds). Improved regulation has seen a decline in the use of chemicals in marine fish aquaculture. The likelihood of a chemical impacts is highly dependent on the specific chemicals used, the characteristics of the farm site (e.g. flushing rate and sediment type) and farm management practices (e.g. feeding rates, husbandry techniques etc.). Likelihood rated as **Possible (2)**. **Consequence** Chemicals pose several environmental risks including the evolution of resistant strains of pathogenic organisms, non-lethal toxicity, direct mortality and bioaccumulation in the food chain (Price and Morris 2013). Laboratory and field studies have found the persistence of chemicals	**Likelihood: Remote (1)** **Consequence: Moderate (2)** **Hazard score: (2)** **Risk level: Negligible**	**Likelihood** Likelihood can be reduced to **Remote (1)** by having strict controls on the use of chemicals associated with aquaculture and an appropriate approval, licensing and compliance regime. **Consequence** Consequence remains unchanged as **Moderate (2)**. Good husbandry and farm practices (e.g. removing sick or dead fish, reducing feed waste, conservative stocking densities etc.) can reduce the need for chemical use associated with marine sea-cage aquaculture within the MWADZ. Additionally, the location of the farm site and stringent environmental management protocols (e.g. monitoring of sediments for presence of chemicals used in aquaculture farms within the MWADZ) will further reduce the likelihood of

		(administered/used during marine sea-cage culture) from a few days to years depending on the chemical/metal in question and geophysical properties of the water or sediments at the farm site (Price and Morris 2013). Exposure to chemicals like antibiotics and therapeutants allows bacteria and other pathogenic organisms to adapt and become resistant (Price and Morris 2013). Direct toxicity is also a known consequence from chemicals originating from marine sea-cage aquaculture. Therapeutants can have toxic effects on finfish (e.g. Haya et al. 2001). Heavy metals originating from feeds or from antifoulants can also accumulate in sediments below farms (reducing benthic colonisation) with direct toxic effects and accumulation within the food chain (Pittenger et al 2007). Consequence rated as **Moderate (2)**.		chemical input consequences being realised.
5. Transfer of pathogens or introduced pests	***See biosecurity risk assessment**	***See biosecurity risk assessment**	***See biosecurity risk assessment**	***See biosecurity risk assessment**
6. Changes in behaviour of finfish species within the aquaculture development zone **(Refer to Figure 4)**	**Likelihood: Possible (3)** **Consequence: Minor (1)** **Hazard score: (3)**	**Likelihood** It is **Possible (3)** that sea cage finfish aquaculture will result in potential changes in behaviour of finfish species within the vicinity of the proposed MWADZ area. Some finfish species have the potential to change their behaviour (i.e. higher visitation rates etc.) in the aquaculture zone given	**Likelihood: Possible: (3)** **Consequence: Minor (1)** **Hazard score: (3)**	**Likelihood** The likelihood is unlikely to change in that finfish species will have changed behaviour if there is an increase in food availability within the aquaculture development zone. The likelihood therefore remains **Possible (3)**.

	Risk level: Low	any increase in the availability of food from aquaculture feed. **Consequence** It has also been suggested that marine sea-cage culture has potential concentrating effects on finfish species. This may make some species more vulnerable to fishing pressure, with some authors recommending the prohibition of fishing in close proximity to sea-cages (e.g. Dempster et al 2006). Research studies conducted have also suggested that marine sea-cage culture may also have negative influences, such as the use of lights at night impacting on juvenile migratory fishes (Nash et al 2005). Other documented influences include entanglement of wild fishes (Huntington et al 2006), disease transfer and/or the consumption of medicated feeds by wild fishes (Braaten 2007). The overall consequences of changes in behavior of finfish species within the MWADZ has been rated as **Minor (1)**.	**Risk level: Low**	**Consequence** Consequence remains unchanged at **Minor (1)**. Consequence to fish communities, however, can be further reduced through implementation of the following management controls: • Good husbandry and farm practices (e.g. removing sick or dead fish, reducing feed waste, conservative stocking densities etc.) are likely to reduce negative influences of marine sea-cage aquaculture within the MWADZ; • Reducing the density of farms within the MWADZ would reduce the level of fish attraction to the area. These management practices would help reduce the secondary likelihood of impacts on Threatened Endangered Protected (TEP) species by helping reduce the attraction of potential wild food sources.
7. Impact on populations of finfish species due to detrimental effects on biological and ecological	**Likelihood: Unlikely(2)** **Consequence: Minor (1)** **Hazard score: (2)**	**Likelihood** Increased organic deposition nutrient enrichment of the sediment and changes to biochemical processes is likely to have a detrimental effect on finfish species, via changes to biological and ecological processes. This may result in	**Likelihood: Unlikely (2)** **Consequence: Minor(1)** **Hazard score: (2)**	**Likelihood** The management measures described in the above sections ensures that the likelihood the aquaculture proposal will have an impact on the populations of finfish species remains rated as **Unlikely**

processes resulting from aquaculture **(Refer to Figure 4)**	**Risk level: Negligible**	avoidance of the area by finfish. Survival and recruitment of finfish species beneath the sea-cages is likely to be negatively impacted. Any decline in abundance of the finfish would be restricted to the depositional area in close proximity and directly underneath a sea-cage. Given the area potentially affected by a decline in abundance of the target finfish is a negligible proportion (much less than 1 percent) of their natural range, the contribution aquaculture could make to anthropogenic-caused mortality is not considered significant. Therefore, the likelihood that the proposed aquaculture could have a significant impact on populations of finfish species is considered **Unlikely (2)**. **Consequence** The consequences of the proposed aquaculture having an impact on populations of finfish species is rated **Minor (1)**.	**Risk level: Negligible**	**(2)**. **Consequence** Consequence would remain unchanged at **Minor (1)**.

3.2.3 Hazard Pathway 3: Impacts on invertebrate fisheries (i.e. Abrolhos Islands Mid West Trawl Managed Fishery)

The primary potential ecological impacts of the MWADZ proposal on the AIMWTMF that were assessed in the hazard analysis were the following:

- Changes in benthic habitat of targeted invertebrate species;
- Changes in the sediment/recruitment patterns and spawning stock of target invertebrate species;
- Pest or pathogen affects wild populations; and
- Changes in the abundance and distribution of target invertebrate species, leads to a significant impact on the invertebrate fisheries.

In addition to these potential ecological hazards, a potential resource access impact was also identified and assessed in the hazard analysis. This was:

- Physical exclusion from fishing ground due to presence of equipment and sea cage infrastructure.

The consequence- likelihood method was used to assess the level of risk for each of the identified hazards for the AIMWTMF that could potentially be impacted by the finfish aquaculture proposal.

Table 4: Assessment of ecological hazards identified on the potential impacts on key of invertebrate fisheries (i.e. Abrolhos Islands and Mid West Trawl Managed Fishery). *Hazards were individually analysed with respect to both the inherent hazard (i.e. baseline hazard if no management measures aimed at mitigating the hazard were in place) and the residual hazard (i.e. remaining hazard once one or a number of the proposed management controls have been implemented). Note that no reference has been made to recreational invertebrate fisheries. Scallops are unlikely to be targeted by recreational fishers.*

Hazard	Inherent Hazard Assuming No Management Controls	Justification	Residual Hazard Following Implementation of Management Controls	Justification and Identified Management Controls
1. Changes in benthic habitat of target invertebrate species **(Refer to Figure 5)**	**Likelihood: Unlikely(2)** **Consequence: Minor (1)** **Hazard score: (2)** **Risk level: Negligible**	**Likelihood** It is considered **Unlikely (2)** that the MWADZ proposal will have a significant effect on the benthic habitat of commercially-targeted scallop species in the Abrolhos Islands and Mid West Trawl Managed Fishery (AIMWTMF). The MWADZ proposal may have impact on the survival of settled juveniles and/or adult scallops within the vicinity of the sea-cages as scallops prefer sandy habitats, not mud or very fine sediments. The benthic habitat is likely to be modified directly underneath the sea-cages and within close proximity to these areas due to any increase in sedimentation/smothering and other impacts from aquaculture (Refer to Table 3). **Consequence** The consequence of the MWADZ proposal on the overall habitat for scallops in the AIMWTMF has	**Likelihood: Unlikely(2)** **Consequence: Minor (1)** **Hazard score: (2)** **Risk level: Negligible**	**Likelihood** Likelihood remains unchanged at **Unlikely (2)** in that the MWADZ proposal is unlikely to have a significant impact on the overall benthic habitat for saucer scallops that are targeted by the AIMWTMF. Any impacts to benthic habitat are likely to be directly underneath the sea-cages and within close proximity to these areas. **Consequence** The consequences of the MWADZ proposal having a significant effect on benthic habitat for scallops in the AIMWTMF remain unchanged at **Minor (1)**.

		been deemed as **Minor (1)**. Any impacts on benthic habitat are likely to be small scale and directly within high-impact zone areas under the sea-cages. Scallops do have some capacity to move short distances (up to 10-100 metres) if disturbed or possibly if habitat becomes unsuitable.		
2. Changes in the settlement/ recruitment patterns and spawning stock of target invertebrate species **(Refer to Figure 5)**	**Likelihood: Unlikely (2)** **Consequence: Minor (1)** **Hazard score: (2)** **Risk level: Negligible**	**Likelihood** It was considered **Unlikely (2)** that there will be any significant changes in settlement/recruitment patterns and spawning stock of target invertebrate species within the AIMWTMF in the absence of any control interactions. There may be some potential changes in the settlement patterns or survival of settling larvae and/or juveniles in a small localised area within the MWADZ. Scallops are known to have highly variable settlement/recruitment patterns on a very small-scale. However, the southern area of the proposed MWADZ is located within a broader area that has historically been a high-density scallop settlement area in the Abrolhos Islands. **Consequence** The consequences of any potential changes in the settlement/recruitment patterns and spawning stock of scallops have been deemed **Minor (1)**. Impacts are likely to be localised and within the footprint of the sea-cages within the MWADZ.	**Likelihood: Unlikely (2)** **Consequence: Minor (1)** **Hazard score: (2)** **Risk level: Negligible**	**Likelihood** The likelihood remains unchanged as **Unlikely (2)** due to the inability to mitigate any potential localised impacts of the proposal on settlement/recruitment and spawning stock. **Consequence** Consequence remains unchanged at **Minor (1)**. Due to variable settlement patterns and abundance in any one year, the quantification of impacts is relatively complex. In some years the specific areas under sea-cages may be important for the saucer scallops, while in other years they could be less so.

3. Pest or pathogen effects on invertebrate fisheries **(Refer to Figure 5)**	***See biosecurity risk assessment**	***See biosecurity risk assessment**	***See biosecurity risk assessment**	***See biosecurity risk assessment**
4. Changes in the abundance and distribution of target invertebrate species, leads to a significant impact on the invertebrate fisheries **(Refer to Figure 5)**	**Likelihood:** **Likely(4)** **Consequence: Minor (1)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** It has been considered **Likely (4)** that there will be some minor changes in the abundance and distribution of saucer scallops within the AIMWTMF in the absence of any control interactions. The distribution of scallops will primarily be dependent of larval settlement patterns associated with hydrodynamic processes and spawning stock distribution and abundance. The southern area of the proposed MWADZ is located within a broader area that has historically been a high-density scallop settlement area in the Abrolhos Islands. Small-scale changes in the distribution of scallops could potentially occur in close vicinity of sea-cages if unfavorable conditions prevail directly below them. Scallops do have a limited capacity to move (swim) away (i.e. 10 to 100 metres) from these impacted areas. **Consequence** The overall consequences of any potential changes in the distribution and abundance patterns of scallops within the Abrolhos Islands FHPA have been deemed as **Minor (1)**. Any impacts are likely to be localised and within the footprint of the sea-cages within the MWADZ area.	**Likelihood: Likely(4)** **Consequence: Minor (1)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** The likelihood remains unchanged at **Likely (4)** due to the inability to mitigate any potential localised impacts of the proposal on scallop distribution and abundance patterns. **Consequence** Consequence remains unchanged at **Minor (1)**. Due to variable settlement patterns and abundance in any one year and subsequent abundance and distribution of adult (harvestable) scallops, the quantification of impacts is relatively complex. In some years the specific areas under sea-cages may be quite important for the saucer scallops, while in other years they could be less so.

		The MWADZ proposal area represents less than 0.2 % (i.e. 3,000 hectares) of the overall available AIMWTMF fishing ground (1,309,740 hectares) and 1.3% of the historically fished scallop grounds. Any impacts to the scallop abundance and distribution are not likely to have a significant impact on the fishery. Historically, commercial fishing effort information collected from the AIMWTMF indicates that the southern area of the MWADZ is located within a broader area that has been a key scallop fishing area in the past. However, the same fishing effort information demonstrates that northern area in the MWADZ area does not represent a key fishing area for the AIMWTMF.		

Table 4a: Assessment of resource access hazard identified on the potential impacts on key invertebrate fisheries. *Hazard was analysed with respect to both the inherent hazard (i.e. baseline hazard if no management measures aimed at mitigating the hazard were in place) and the residual hazard (i.e. remaining hazard once one or a number of the proposed management controls have been implemented.*

Hazard	Inherent Hazard Assuming No Management Controls	Justification	Residual Hazard Following Implementation of Management Controls	Justification and Identified Management Controls
1. Physical exclusion of the fishing vessels and associated equipment by aquaculture infrastructure **(Refer to Figure 5a)**	**Likelihood: Likely (4)** **Consequence: Minor (1)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** The physical presence of aquaculture infrastructure including sea-cages, anchoring and feeding systems is **Likely (4)** to directly exclude AIMWTMF commercial scallop fishing vessels from fishing where the sea-cage clusters are located. The presence of this infrastructure is therefore likely to effectively create an 'exclusion zone' to fishing wherever the aquaculture infrastructure is located within the MWADZ. In some years, these locations will be within areas that have historically been shown to produce significant quantities of scallops. **Consequence** The physical presence of aquaculture infrastructure is likely to limit the extent of the available fishing ground within the AIMWTMF. However, access arrangements to the MWADZ proposal area will be non-exclusive; meaning commercial fishers (and others) will still be permitted to travel through and fish within the aquaculture development area. Commercial fishers	**Likelihood: Likely (4)** **Consequence: Minor (1)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** As the physical presence of aquaculture infrastructure in the MWADZ remains the same, the likelihood of it directly excluding AIMWTMF commercial scallop fishing vessels from fishing where the sea-cage clusters are located remains **Likely (4).** **Consequence** If timely information is provided to the commercial fishing industry (particularly the AIMWTMF) of the locations of mooring/anchoring systems and sea-cage infrastructure within the MWADZ, commercial fishers will then be able to fish areas within the MWADZ while avoiding those areas where trawl gear could potentially get hooked up on aquaculture infrastructure. Such notifications could be incorporated in the management arrangements for the MWADZ.

		(and others) who fish within the MWADZ will not be permitted to interfere with the aquaculture infrastructure. The consequence of this hazard is difficult to determine due to the highly variable nature of the recruitment and settlement of scallops within the AIMWTMF from year to year. In recent (4-5) years, there has been no consequence whatsoever as there has not been any commercial scallop fishing in the area of the proposed MWADZ. It is acknowledged there is no certainty this trend will continue into the future. On balance, the consequence has been rated as **Minor (1)**.		The consequence of an impact on the AIMWTMF could therefore be reduced by this arrangement. Nevertheless, it is not possible to guarantee a zero consequence and so the consequence rating must remain **Minor (1)**.

3.2.4 Hazard Pathway 4: Impact on sustainability on finfish fisheries

The primary potential ecological impacts of the MWADZ proposal on the finfish fisheries that were assessed in the hazard analysis were the following:

- Changes in the fish habitat for finfish species;
- Changes in the recruitment patterns and spawning stock of finfish species;
- Pest or pathogen affects finfish fisheries; and
- Changes in the abundance and distribution of finish species, leads to a significant impact on key finfish fisheries.

In addition to these potential ecological hazards, a potential resource access impact was also identified and assessed in the hazard analysis. This was:

- Physical exclusion from fishing ground due to presence of equipment and sea cage infrastructure.

The consequence-likelihood method was used to assess the level of risk for each of the identified hazards for the finfish fisheries that could be potentially impacted by the finfish aquaculture proposal.

Table 5. Assessment of hazards identified on the potential impacts on key finfish fisheries. *Hazards were individually analysed with respect to both the inherent hazard (i.e. baseline hazard if no management measures aimed at mitigating the hazard were in place) and the residual hazard (i.e. remaining hazard once one or a number of the proposed management controls have been implemented.*

Hazard	Inherent Hazard Assuming No Management Controls	Justification	Residual Hazard Following Implementation of Management Controls	Justification and Identified Management Controls
1. Changes in the fish habitat for finfish species **(Refer to Figure 6)**	**Likelihood: Unlikely (2)** **Consequence: Minor (1)** **Hazard score: (2)** **Risk level: Negligible**	**Likelihood** It is **Unlikely (2)** that the MWADZ proposal will have a significant effect on fish habitat required by targeted commercial finfish species such as baldchin groper, snapper, West Australian dhufish, spangled emperor, coral trout and other demersal scalefish species. The MWADZ proposal may have impact on the fish habitat for non-target species which may inhabit sandy areas directly underneath the sea-cages and within the close proximity to these areas. Impacts are, however, likely to be localised. Baseline habitat surveys conducted in the MWADZ area indicate that the majority of the habitat is comprised of sandy bottom with some areas of mixed assemblages and isolated patches of reef. In the northern area of the MWADZ 47.1 % of the habitat comprised of bare sand, 34.9% of mixed assemblages and 8.5% of reef habitat. While in the southern area 91.6% of the habitat comprised of bare sand and 5.2% of mixed assemblage (BMT Oceanica 2015). Mixed assemblage substrate, comprising rubble, low platform reef, algae and/or sponges, are often	**Likelihood: Remote (1)** **Consequence: Minor (1)** **Hazard score: (1)** **Risk level: Negligible**	**Likelihood** Likelihood may be reduced to **Remote (1)** based on management controls including: • situating sea cages in areas of sand and away from any potential fish habitat; and • fallowing of sea cages (i.e. rotation and movement of sea-cages to enable any fish habitat impacted to recover. **Consequence** The consequence of the MWADZ proposal having a significant effect on fish habitat remains unchanged with a ranking of **Minor (1)**.

		used by juvenile stages of species such as Baldchin groper and Redthroat emperor. Low platform reef is used by adults of the target species and may be used during spawning periods. However, the 'footprint' of the sea-cage clusters within the proposed MWADZ and the potential area affected by nutrient dispersal represents a very small part of the distribution area of these species. Consequently, the proposed aquaculture activities are unlikely to have a significant impact on the broader finfish stocks. It is unknown if the MWADZ is likely to have an impact on known spawning areas and nursery areas for key target demersal scalefish species (e.g. coral trout, Baldchin groper, etc.). However, given the small spatial extent of the proposal and the large range of most species, the likelihood of significantly impacting habitats is low. The fish habitat is likely to be modified directly underneath the sea-cages and within close proximity to these areas due to increased sedimentation/smothering and other impacts of aquaculture (Refer to Table 3). **Consequence** The consequence of the MWADZ proposal has been deemed **Minor (1).** Any potential impacts on fish habitats are likely to be relatively small-scale impacts directly within high impact zone areas. If fish habitat is affected, the potential consequences on the broader stocks of target species are likely to be low.		

2. Changes in the recruitment patterns and spawning stock of finfish species **(Refer to Figure 6)**	**Likelihood: Remote (1)** **Consequence: Minor (1)** **Hazard score: (1)** **Risk level: Negligible**	**Likelihood** The area proposed for the MWADZ, the cage clusters and the potential zone affected by nutrient dispersal, represents a very small component of the distribution of these species and the proposed aquaculture activities are unlikely to have significant impact on their broader stocks. The likelihood of the MWADZ proposal having an impact on the recruitment patterns and spawning stock of finfish species is rated as **Remote (1)**. **Consequence** The habitat of the proposed area comprises sandy substrate with some areas of mixed assemblages. Mixed assemblage substrate (comprising rubble, low platform reef, algae and/or sponges), for example, are often used by juvenile stages (recruits) of species such as Baldchin groper and Redthroat emperor. Low platform reef is used by adults of the target species and may be used during spawning periods. Given that the MWADZ proposal area does not represent a key recruitment area for finfish species, the consequence has be rated as **Minor (1)**.	**Likelihood: Remote (1)** **Consequence: Minor (1)** **Hazard score: (1)** **Risk level: Negligible**	**Likelihood** The likelihood remains unchanged at **Remote (1)** due to the inability to mitigate any potential localised impacts of the proposal on settlement/recruitment and spawning stock. **Consequence** Remains unchanged as **Minor (1)**.
3. Pest or pathogen affects finfish fisheries **(Refer to Figure 6)**	***See biosecurity risk assessment**	***See biosecurity risk assessment**	***See biosecurity risk assessment**	***See biosecurity risk assessment**

4. Changes in the abundance and distribution of finfish species leads to a significant impact on key finfish fisheries **(Refer to Figure 6)**	**Likelihood: Unlikely (2)** **Consequence: Minor (1)** **Hazard score: (2)** **Risk level: Negligible**	**Likelihood** It was considered **Unlikely (2)** that there will be any significant changes in the abundance and distribution of finfish species within the Abrolhos Islands FHPA. Although there may be some localised changes in abundance, resulting from either increases associated with increased production or decreases associated with affected habitat/nutrient enrichment around the proposed MWADZ, it is unlikely these will result in large-scale changes in the abundance or distribution of the targeted species at a whole of stock level. Thus, there is **Unlikely (2)** to be any significant impact on the line fisheries for these finfish species. **Consequence** The consequences of any potential changes in the distribution and abundance finfish species have been deemed as **Minor (1)**. Impacts are likely to be localised and within the footprint of the sea-cages within the MWADZ.	**Likelihood: Remote (1)** **Consequence: Minor (1)** **Hazard score: (1)** **Risk level: Negligible**	**Likelihood** Likelihood of changes in the abundance and distribution of finfish species could be further reduced to **Remote (1)** based on implementation of management measures aimed at reducing the (low) level of stock feed wastage associated with the aquaculture. **Consequence** The consequence will remain unchanged at **Minor (1)**.

Table 5a: Assessment of resource access hazard identified on the potential impacts on key finfish fisheries. *Hazard was analysed with respect to both the inherent hazard (i.e. baseline hazard if no management measures aimed at mitigating the hazard were in place) and the residual hazard (i.e. remaining hazard once one or a number of the proposed management controls have been implemented.*

Hazard	Inherent Hazard Assuming No Management Controls	Justification	Residual Hazard Following Implementation of Management Controls	Justification and Identified Management Controls
1. Physical exclusion of the fishing vessels and associated equipment by aquaculture infrastructure **(Refer to Figure 6a)**	**Likelihood: Likely (4)** **Consequence: Minor (1)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** The physical presence of aquaculture infrastructure including sea-cages, anchoring and feeding systems is **Likely (4)** to directly exclude commercial and recreational fishers from fishing within the immediate area where the sea-cage clusters are located. Under the proposed management arrangements, both commercial and recreational fishers will be permitted to fish within the MWADZ provided they do not interfere with the aquaculture infrastructure. Sea-cages and their associated infrastructure are likely to aggregate some species of finfish and may potentially attract to the area predatory fish (large and small) including pelagic species. This may result in increased numbers of predatory fishes remaining in the vicinity of cages that may be attractive to recreational and commercial fishes (e.g. mackerel, tuna etc.). Consequently, such aggregations could potentially increase both recreational and commercial fishing activity within the area.	**Likelihood: Likely (4)** **Consequence: Minor (1)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** The likelihood remains unchanged at **Likely (4)** due to the inability to mitigate any direct loss of available fishing ground. The number of sea-cage clusters permitted to be deployed within the MWADZ will have a bearing on the degree to which this likelihood will be realised. Ultimately, this aspect will largely be determined by the environmental carrying capacity of the MWADZ. **Consequence** Consequence will remain unchanged at **Minor (1)**.

		Consequence The physical presence of aquaculture infrastructure is likely to limit access to the fishing grounds currently available to both commercial and recreational fisheries. However, this limitation is largely restricted to those areas under the sea-cage clusters. The proposed access arrangements to the proposed MWADZ area will be non-exclusive, meaning both commercial and recreational fishers will otherwise still be permitted to fish within the MWADZ to the extent they are currently permitted. It should be noted that the current extent of commercial (and recreational) line fishing in the MWADZ area is relatively **Minor (1)**.		

4 Risk Assessment

Following the identification of key threats and detailed analysis of hazard pathways leading to potential realisation of these threats, four overarching risks of most relevance to the activities proposed in association with the MWADZ were identified as follows:

1. Aquaculture activity in the zone has a significant impact on the populations of invertebrate species (i.e. saucer scallop) in the Abrolhos Islands FHPA.
2. Aquaculture activity in the zone has a significant impact on the populations of finfish species in the Abrolhos Islands FHPA.
3. Aquaculture activity in the zone has a significant impact on the invertebrate fishery (i.e. Abrolhos Islands and Mid West Trawl Managed Fishery).
4. That aquaculture activity in the zone has a significant impact on finfish fisheries in the Abrolhos Islands FHPA.

Overarching risks 1 and 2 are risks associated with potential ecological impacts on the species populations. By comparison, overarching risks 3 and 4 are risks that essentially comprise the effects of overarching risks 1 and 2 (i.e. the **ecological impacts**) in addition to the potential **resource access impacts** resulting from the physical presence of aquaculture infrastructure within the MWADZ.

All the above risks were assessed with a consideration of potential cumulative impact using the precautionary approach described in the methodology. This process investigated pathways or cause-effect linkages between hazards and key factors that contribute to a broad risk category.

5 Risk Analysis Results

5.1 Risk 1 - Impact on the populations of invertebrate species (i.e. saucer scallop) within the Abrolhos Islands FHPA

5.1.1 Inherent Risk Analysis

5.1.1.1 Likelihood

Aquaculture activity will almost inevitably result in some degree of nutrient enrichment of the water column based on discharge from uneaten feed, faeces and metabolic wastes. Finfish aquaculture is also likely to result in increased organic deposition, nutrient enrichment of the sediment and changes to biochemical processes. This is likely to result in some changes in the behaviour, abundance and distribution of the saucer scallop within the area. Survival and recruitment of this species beneath the sea-cages is also likely to be impacted. Given the area likely to be affected by a MWADZ, is a negligible proportion (much less than 1 percent) of the saucer scallop natural range, the likelihood that the proposed aquaculture could

impact the populations of the target invertebrate species within the Abrolhos Islands FHPA was rated as **Unlikely (2).**

5.1.1.2 Consequence

The consequence of aquaculture activity in the MWADZ proposal area having a significant impact on the populations of the target invertebrate species i.e. saucer scallop was assessed based on the known biological information on the species and the literature collected on the known impacts of aquaculture on invertebrate species. Whilst the aquaculture activity may have an impact on the abundance and distribution of the saucer scallop within the MWADZ area, the consequence has been rated as **Minor (1)** in terms of its impact on the overall populations of this species at the Abrolhos Islands FHPA.

5.1.1.3 Overall Inherent Risk

Inherent Risk level is Negligible

5.1.2 Residual Risk Analysis

5.1.2.1 Likelihood

The likelihood that the MWADZ proposal will have an impact on the invertebrate species saucer scallop can further be reduced through the implementation of management measures. Management controls that can mitigate potential effects from the proposal include those detailed in table below:

Control Category	Management Control	DoF Control Mechanism
1. Restricting the amount of biomass held in the aquaculture zone	• Limiting maximum biomass to be held on the farm.	Licensing conditions. Mechanism to ensure compliance with biomass conditions and accurate reporting of stock levels.
2. Reducing feed wastage and improvements in feeding efficiency	• Measures to govern feed type and usage. • Good husbandry practices to ensure high food conversion ratios and appropriate feeding regime.	Development and compliance with a Management and Environmental Monitoring Plan and best management practices in aquaculture.
3. Reducing the release of therapeutants and other contaminants into the environment	• Regulation of chemicals used for aquaculture and reduced requirements through good husbandry practices. • Reducing the level of therapeutants in feed.	Development and compliance with a Management and Environmental Monitoring Plan and best management practices in aquaculture.

4. Reducing the level of nutrient enrichment in the water column and turbidity	• Regular monitoring of nutrient levels within the vicinity of sea cages. • Situating sea cages in well flushed areas. • Maximising feeding efficiency and reducing fish waste. • Setting the stock densities at conservative levels.	Development and compliance with a Management and Environmental Monitoring Plan and best management practices in aquaculture.
5. Reducing impacts on sediment and changes in biochemical processes	• As per above	As per above

Based on implementation of these measures, the residual likelihood of aquaculture operations having an impact on populations of saucer scallops in the Abrolhos Islands FHPA is considered to be **Remote (1)**.

5.1.2.2 Consequence

Residual Consequence remains unchanged at **Minor (1).**

5.1.2.3 Overall Residual Risk

Residual Risk level is Negligible

5.2 Risk 2 - Impact on populations of finfish species within the Abrolhos Islands FHPA

5.2.1 Inherent Risk Analysis

5.2.1.1 Likelihood

It has been identified through aquaculture literature reviews, baseline water and sediment quality data that sea cage aquaculture is likely have some potential impacts on finfish species. The majority of the risks identified during the assessment relate to the potential changes in localised environmental conditions within the MWADZ area. These changes are likely to occur due to the nutrient enrichment of the water column, increased turbidity, organic deposition and nutrient enrichment of sediments and potential release of trace metals, therapeutants and other contaminants. Information obtained from previous environmental assessments of sea cage aquaculture indicates that any changes to environmental conditions are

likely to be localised and either directly underneath or within close proximity to the sea cages.

Feed from aquaculture activities, residue from cultured stock and harvesting activities and effluent from the operations is also likely to have a potential impact on finfish species. An increase in the availability of food sources from fish feed, residue from cultured stock, or effluent from harvest activities has the potential to increase or decrease the visitation and or potential abundance of some finfish species within the MWADZ area. The physical presence of sea cage infrastructure is also likely to have Fish Aggregation Device (FAD) effects which may also increase or decrease the abundance of abundance of predatory and opportunistic finfish species within the aquaculture development zone.

An increase in the abundance of these species has the potential to influence the behaviour of other finfish species within the vicinity of the MWADZ proposal area. However, whilst there are likely to be some localised environmental impacts, potential changes in fish abundance and fish behaviour near the sea cages, the inherent likelihood the MWADZ proposal would have a significant impact on the overall populations of finfish species within the Abrolhos Islands FHPA was rated as **Unlikely (2).**

5.2.1.2 Consequence

The consequence of the proposed aquaculture having an impact on populations of finfish species within the Abrolhos Islands FHPA was rated as **Minor (1).**

5.2.1.3 Overall Inherent Risk

Inherent Risk level is Negligible

5.2.2 Residual Risk Analysis

5.2.2.1 Likelihood

The likelihood that the MWADZ proposal will have a significant impact on the finfish species can be further reduced through the implementation of management measures. Management controls that can mitigate potential effects from the proposal include those detailed in table below:

Control Category	Management Control	DoF Control Mechanism
1. Reducing the positive attraction of finfish species to the sea cages due to availability of additional food	• Limiting maximum biomass to be held on farm. • Maximising feeding efficiency and reducing fish waste. • Removal of dead and moribund stock on a daily basis. • Use of high-quality pellet feed.	Development of and compliance with a Management and Environmental Monitoring Plan (MEMP) and best-management practices in aquaculture.
2. Reducing the level of nutrient enrichment in the water column and turbidity	• Regular monitoring of nutrient levels within the vicinity of sea cages. • Situating sea cages in well flushed areas. • Maximising feeding efficiency and reducing fish waste. • Setting the stock densities at conservative levels. • Regular monitoring of levels of dissolved nutrients and	Development of and compliance with a Management and Environmental Monitoring Plan (MEMP) and best-management practices in aquaculture.
3. Reducing the release of therapeutants and other contaminants into the environment	• Regulation of chemicals used for aquaculture and reduced requirements through good husbandry practices • Reducing the level of therapeutants in feed	As per above

Based on implementation of these measures, the residual likelihood of aquaculture operations having an impact on the populations of finfish species at the Abrolhos Islands FHPA is considered to be **Remote (1)**.

5.2.2.2 Consequence

Residual Consequence remains unchanged at **Minor (1).**

5.2.2.3 Overall Residual Risk

Residual Risk level is Negligible

5.3 Risk 3 - Impact on invertebrate fisheries (i.e. Abrolhos Islands and Mid West Trawl Managed Fishery)

5.3.1 Inherent Risk Analysis

5.3.1.1 Likelihood

It has been identified through the assessment process that the MWADZ proposal is likely to have some impacts on the Abrolhos Islands and Mid West Trawl Managed Fishery (AIMWTMF). The physical presence of aquaculture infrastructure including sea cages, anchors and feeding systems will directly exclude scallop trawl fishing vessels from fishing in the immediate vicinity of the sea cage infrastructure within the aquaculture development zone.

The aquaculture activities are also likely to have localised impacts on the benthic habitat of the target species (i.e. saucer scallop). This may result in some small changes in settlement/recruitment patterns and potential changes in the abundance and distribution of this species within the MWADZ area.

The inherent likelihood that the MWADZ proposal will have an impact on the AIMWTMF was rated as **Likely (4)**.

5.3.1.2 Consequence

The overall consequence of any potential changes in the distribution and abundance patterns of scallops within the Abrolhos Islands FHPA (i.e. the ecological impacts) has been deemed as Minor (1).

While there may potentially be some localised changes in the distribution and abundance patterns of scallops directly underneath the sea cages and within close proximity to the infrastructure, the consequences to the overall scallop stocks in the Abrolhos region is likely to be minimal.

As mentioned previously, the physical presence of aquaculture infrastructure is likely to restrict the availability of historical fishing ground with the AIMWTMF. However, the MWADZ area represents a very small proportion (i.e. less than 0.2 % or 3,000 hectares) of the overall available AIMWTMF fishing ground (1,309,740 hectares) and 1.3% of the historically-fished scallop fishing ground in the fishery (pers comm DoF 2015).

Historical fishing effort information collected by the Department of the Fisheries for the AIMWTMF from 2003 to 2011 has indicated that the southern area in the MWADZ has represented an important area for scallop fishing (refer to PER document AIMWTMF effort map). However, due to the highly variable nature of the recruitment and settlement of scallops within the AIMWTMF from year to year, there has been no commercial scallop fishing in this area in recent years.

The northern site of the MWADZ proposal area does not represent a key fishing area for the fishery. Commercial fishing effort in this area has been very limited over the last 10 years [pers comm Kangas, M (DoF)].

Under the proposed management arrangements for the MWADZ, commercial fishers will still be permitted to operate within the aquaculture development zone provided they do not interfere with the aquaculture infrastructure.

Given this information, the Inherent consequence of the proposed aquaculture activities in the MWADZ having a significant impact on the AIMWTMF was rated as **Minor (1).**

5.3.1.3 Overall Inherent Risk

Inherent Risk level is Low

5.3.2 Residual Risk Analysis

5.3.2.1 Likelihood

The overall residual likelihood remained unchanged as **Likely (4)** due to the inability to mitigate any potential localised impacts on the potential changes to benthic habitat, settlement/recruitment patterns, and distribution and abundance of the saucer scallop species.

5.3.2.2 Consequence

The consequence could potentially be reduced if information is provided to industry of the actual locations of mooring/anchoring systems and sea cage infrastructure within the MWADZ at any one time. Armed with this information, the AIMWTMF could maximise the area available to be fished within the zone. Nevertheless, the Residual Consequence remains unchanged at **Minor (1).**

5.3.2.3 Overall Residual Risk

Residual Risk level is Low

5.4 Risk 4 - Impact on finfish fisheries

5.4.1 Inherent Risk Analysis

5.4.1.1 Likelihood

In this risk analysis a number hazard pathways were analysed as part of the assessment of the potential impacts of the MWADZ proposal on the finfish fisheries. These included changes to fish habitat, changes in recruitment patterns and

spawning stock of finfish species, pest or pathogen transfer, physical exclusion of fishing vessels and changes in the abundance and distribution of finfish species.

Baseline benthic habitat surveys conducted in the MWADZ have indicated the MWADZ area does not represent a key habitat area for target finfish species such as coral trout, baldchin groper, redthroat emperor and other demersal fish species that are commonly targeted by finfish fisheries. These species tend to prefer limestone reef, macroalgae and coral habitats; which are generally located on the western and central parts of the Abrolhos Island groups.

While there may be some localised changes to the habitat within the aquaculture development zone, it is unlikely to result in any significant changes in the abundance, distribution, recruitment patterns and spawning stock of these finfish species within the Abrolhos FHPA.

Catch and effort information reported for the finfish fisheries permitted to fish within Abrolhos FHPA indicates that the MWADZ proposal area does not represent a key fishing area for these fisheries. The majority of the commercial fishing effort for these fisheries is conducted outside of the MWADZ proposal area. While commercial finfish fishers may be physically excluded from fishing certain parts of the MWADZ due to the presence of aquaculture infrastructure, the overall area of the proposed aquaculture development zone represents a very small proportion (i.e. less than 1%) of the overall fishing area for these finfish fisheries. Therefore, the inherent likelihood that the MWADZ proposal would have a significant impact on finfish fisheries within the Abrolhos Islands FHPA was rated as **Unlikely (2).**

5.4.1.2 Consequence

The consequence of the proposed aquaculture activities in the MWADZ having a significant impact on finfish fisheries in the Abrolhos Islands FHPA was rated as **Minor (1).**

5.4.1.3 Overall Inherent Risk

Inherent Risk level is Negligible

5.4.2 Residual Risk Analysis

5.4.2.1 Likelihood

The likelihood that the proposed aquaculture activities will have a significant impact on the sustainability of finfish fisheries may be further reduced through the implementation of management measures. Management controls that can mitigate potential effects from the proposal include those detailed in table below:

Control Category	Management Control	DoF Control Mechanism
1. Reducing the potential impacts of aquaculture activities on fish habitat	• Situating sea cages in well flushed areas over sand habitat and away from potential fish habitat. • Fallowing of sea cages – rotation and movement of cages to enable fish habitat to recover.	Compliance with individual operator's MEMPs to achieve best management practices, in accordance with the EMMP for the Zone, the Aquaculture Council of Western Australia's (ACWA) Code of Practice, and the Zone Management Policy.
2. Reducing the positive attraction of finfish species to the sea cages due to availability of additional food	• Limiting maximum biomass to be held on farm. • Maximising feeding efficiency and reducing fish waste. • Removal of dead and moribund stock on a daily basis. • Use of high-quality pellet feed.	Development of and compliance with a Management and Environmental Monitoring Plan (MEMP) and best-management practices in aquaculture.

Based on implementation of these measures, the residual likelihood of aquaculture operations in the MWADZ proposal area having a significant impact on the sustainability on finfish fisheries is considered to be **Remote (1).**

5.4.2.2 Consequence

Residual Consequence remains unchanged at **Minor (1).**

5.4.2.3 Overall Residual Risk

Residual Risk level is Negligible

6 Summary

The potential risks arising from aquaculture activities in the proposed MWADZ on invertebrate and finfish species and key fisheries were assessed using the risk assessment methods that conform to international standards (ISO 31000, 2009; IEC/ISO; 2009; SA-HB89; 2012). Information that was used as part of the assessment included relevant biological and ecological information on invertebrate and finfish species, previous marine finfish aquaculture risk assessments, commercial fisheries catch rate and catch information, and relevant scientific studies and publications on aquaculture.

During the risk assessment, four key risks were identified as having the potential to be realised as a result of the proposed finfish aquaculture activities within the MWADZ. These are summarised as follows:

1. *An impact on populations of invertebrate species (i.e. saucer scallop) within the Abrolhos Islands FHPA;*
2. *An impact on populations of finfish species within the Abrolhos Islands FHPA;*
3. *Potential impacts on the invertebrate fisheries (i.e. Abrolhos Islands and Mid West Trawl Managed Fishery); and*
4. *Potential impacts on the finfish fisheries.*

Results from the risk assessment concluded that the proposal poses a negligible and acceptable risk to three of the four key risks identified. The MWADZ proposal is anticipated to generate negligible impacts on saucer scallop and finfish populations within the Abrolhos Islands FHPA. While it was recognised during the assessment process that there may be some localised impacts on these species, the overall impacts on the abundance, distribution, recruitment patterns and spawning stock of these species within the Abrolhos Islands FHPA is likely to negligible. The area of the MWADZ (i.e. approximately 3,000 hectares) represents a very small proportion of the overall natural range of these species within the Abrolhos region and Western Australia. Any changes to the abundance of these species within the aquaculture development zone, is likely to have minimal impact on the overall populations of these species.

The risk assessment identified that MWADZ proposal poses a low risk to the AIMWTMF. Some areas of the aquaculture zone (i.e. southern site) have historically been a key area for scallop fishing in the AIMWTMF. The physical presence of aquaculture infrastructure in the zone is likely to directly exclude scallop trawl fishing vessels from fishing in the immediate vicinity of the sea cage infrastructure within the aquaculture development zone. This has the potential to limit the amount of available fishing ground in the fishery.

The MWADZ area, however, represents only a very small proportion (i.e. less than 0.2 %) of the overall available AIMWTMF fishing ground and 1.3% of the historically-fished scallop fishing ground in the fishery. There has been no commercial scallop fishing in the proposed MWADZ in recent years. Under the proposed management arrangements for the MWADZ proposal, commercial and recreational fishing vessels will still be permitted to operate within the aquaculture development zone provided they do not interfere with the sea cage infrastructure.

Additional hazard pathways identified as having potential impacts (such as changes to behavioural characteristics of species and biosecurity risks) on the invertebrate and finfish species and their associated fisheries are likely to pose a low or negligible risk.

The level of risk posed by these hazards and other risks assessed as part of this assessment can be managed to acceptable levels through the adoption of best-practice management arrangements and regular compliance monitoring and enforcement around the implementation of Management and Environmental

Monitoring Plans (MEMPs). Under the requirements of the MEMP's, individual aquaculture operators will be required to conduct mandatory environmental monitoring within the MWADZ.

In addition to their responsibilities under the MEMP's, industry is also encouraged to adhere to Marine Finfish Environmental Code of Practice developed by the Aquaculture Council of Western Australia.

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Impact Assessment of aquaculture on seabird communities of the Abrolhos Islands, to support the Mid-West Aquaculture Development Zone proposal.
DoF21/2013

Final Report
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Contents

1. Introduction

1.1 Background

In June 2014 The Department of Fisheries (DoF) engaged Halfmoon Biosciences to undertake an environmental impact assessment (EIA) of potential interactions between proposed marine finfish aquaculture and seabird communities including their marine ecosystems and island habitats. The investigation focussed on breeding colonies found in the vicinity of the Pelsaert Group and Easter Group of the Houtman Abrolhos Islands adjacent to areas being assessed as designated finfish aquaculture zones. The EIA is required to inform a Public Environmental Review (PER) for the Department's Mid-West Aquaculture Development Zone (MWADZ) proposal to be assessed by the WA Environmental Protection Authority.

1.2 Impact assessment of aquaculture on seabird communities

The offshore production of marine finfish is one of the aquaculture sectors considered most likely to provide large scale industry development in Western Australia. The Department of Fisheries has identified several advantages associated with creating aquaculture management zones to reduce conflict with other users of the marine environment and to streamline the environmental approvals process for entrants into the sea cage finfish aquaculture industry.

Two potential Mid-West aquaculture areas at the Abrolhos Islands were identified as options for evaluation during the data gathering stage, one north of the Pelsaert Group and the other east of the Easter Group.

In May 2013, the Department referred the Mid-West Aquaculture Development Zone (the Zone) proposal to the Office of the Environmental Protection Authority (OEPA) for assessment as a strategic proposal, and the level of assessment was set at Public Environmental Review (PER). The proposed area (Zone) will be established within the Fish Habitat Protection Area of the Houtman Abrolhos Islands (Refer to Attachment 1 – Zone study area). Some environmental approval process steps were previously completed for an existing finfish aquaculture site within one potential Zone, north of the Pelsaert Group of the Abrolhos Islands (EPA, 2003).

The Commonwealth has decided not to conduct a joint assessment of the aquaculture Zone but may assess fish-farming proposals within them should they eventuate. There are numerous potential wildlife related triggers for EPBC Act at the Abrolhos. The matters of national significance include threatened species, migratory species, petrels and cetaceans.

One of the Department's objectives is to protect the seabird populations and island ecosystems within the Abrolhos Islands Ministerial Reserve (Abrolhos Islands Management Plan). To meet this objective, the cause / effect relationships that could lead to changes to population levels and ecological relationships must be understood. This includes flow-on risk from changes to the function of terrestrial ecosystems on the seabird breeding islands. The Department has requested an investigation into the current status of seabirds on the

Abrolhos Islands and potential interactions between seabirds and finfish aquaculture. This work will contribute to the environmental and technical field studies that will inform a Management Framework, including a Management Policy for aquaculture operations within the Zone.

The aims of this study were:

- The assessment of potential interactions between proposed marine finfish aquaculture and seabird communities and their habitats found in the vicinity of the Pelsaert Group and Easter Group of the Houtman Abrolhos Islands.

- Provide a summary of the current knowledge of seabirds, key seabird species and stressor-response relationships between seabirds and potential aquaculture projects, including identification of, and baseline monitoring of previously identified high risk increaser-species (e.g. Silver Gulls *Chroicocephalus novaehollandiae*, Pacific Gulls *Larus pacificus* and Pied Cormorants *Phalacrocorax varius*).

- Identify significant potential interactions between seabirds and aquaculture and provide an assessment of the ecological risk arising from them.

- Develop a basic conceptual model of ecological cause-effect pathways involving high risk species (e.g. Silver Gulls, Pacific Gulls and Pied Cormorants), that may lead to ecological change.

- Develop a practical monitoring program to inform management to minimise any potential impacts of the interactions between fish-farming operations and seabirds,

- Provide advice on additional mitigation measures and appropriate operational management strategies to mitigate adverse interactions with seabirds from any residual risks (not treated by practices required by the Department).

1.3 Review of breeding seabirds on potentially impacted islands of the Houtman Abrolhos

1.3.1 Birds of the Houtman Abrolhos.

The Houtman Abrolhos is the most significant seabird breeding location in the eastern Indian Ocean. Eighty percent (80%) of Brown (Common) Noddies *Anous stolidus*, 40% of Sooty Terns *Onychoprion fuscata* and all the Lesser Noddies *Anous tenuirostris melanops* found in Australia nest at the Houtman Abrolhos (Ross *et al.* 1995). It also contains the largest breeding colonies in Western Australia of Wedge-tailed Shearwaters *Ardenna pacifica*, Little Shearwaters *Puffinus assimilis*, White-faced Storm Petrels *Pelagodroma marina*, White-bellied Sea Eagles *Haliaeetus leucogaster*, Osprey *Pandion haliaetus*, Caspian Terns *Hydroprogne caspia*, Crested Terns *Thalasseus bergii*, Roseate Terns *Sterna dougalli* and Fairy Terns *Sterna nereis* (Storr *et al.* 1986, Surman and Nicholson 2009a). The Houtman Abrolhos also represents the northernmost breeding islands for both the Little Shearwater and White-faced Storm Petrel.

Within the Pelsaert and Easter Groups, seventeen (17) species have been confirmed as breeding regularly. These are the White-bellied Sea Eagle, Osprey, Wedge-tailed Shearwater, Little Shearwater and White-faced Storm Petrel, Pacific Gull, Silver Gull, Caspian Tern, Crested Tern, Bridled Tern *Onychoprion anaethetus*, Roseate Tern, Fairy Tern, Brown Noddy, Lesser Noddy, Eastern Reef Egret *Egreta sacra*, Pied Oystercatcher *Haematopus longirostris*, and Pied Cormorant (Surman and Nicholson 2009a).

1.3.2 Potential Increaser Seabird Species

Previous experience indicates that several species of seabird populations may have adverse interactions with the development of sea cage, finfish aquaculture at the Houtman Abrolhos. However, both the experience from fish-farming elsewhere in Australia and the local foraging information indicate three species have at least moderate risk. These are the two gull species (Pacific Gull and Silver Gull) and the Pied Cormorant. These three species would be able to take advantage of activities associated with humans that result in a food (energy) subsidy particularly during periods when food availability is limiting (Harris and Wanless, 1997, Montevecchi 2002). Additional food resources can result in increased breeding effort and success leading to expanding populations, with potential detrimental impacts on other seabirds and island ecosystems in the area.

Approximately 356 pairs of Silver Gulls were recorded nesting at the Houtman Abrolhos on 25 islands during an island wide survey conducted in December 2006 (Surman and Nicholson 2009a). The largest colonies were observed on Long Island in the Wallabi Group (142 pairs), Pelsaert Island (43), Leo's Island (34) and Wooded Island (33). During previous studies in relation to finfish aquaculture (Surman and Nicholson 2008, 2009b) there were found to be significant differences in the size of Silver Gull colonies in spring/summer and autumn. For example, there were approximately 41 pairs nesting on Post Office Island in the autumn, compared with only 2 pairs during the summer period. In May 2007, on Long Island in the Wallabi Group, there were at least 142 pairs of Silver Gulls attending nests, whereas in December 2006 only three nests were active (Surman, *pers. obs*). The larger colony sizes in May were attributed to increased food availability to this species during the

presence of Rock-lobster fishers during the March 15-June 30 rock lobster fishing season. The A Zone rock lobster fishing season was recently removed.

Adult Silver Gulls are only incapable of reproduction for about 10 weeks a year during the moult period when the gonads regress to a resting state. This non-reproductive / moult period is triggered by increasing day length in late spring or early summer. After this period the gonads reactivate and breeding can resume at any time if there are sufficient resources available for the females to produce their eggs (Dunlop 1987). The timing of the onset of breeding varies from location to location. At some colonies breeding can occur continuously for 9-10 months with females capable of producing multiple clutches and some pairs raising two broods per season (Wooller & Dunlop 1979, Wooller & Dunlop 1981a). These aspects of breeding biology allow Silver Gulls to respond rapidly to seasonal changes in food availability. The massive increases in Silver Gull numbers at Port Lincoln was driven by increased food availability from finfish aquaculture, particularly the sardines fed to ranched Southern Blue-fin Tuna *Thunnus maccoyii* (Harrison 2010).

Pied Cormorant, Silver Gull and Pacific Gull populations at the Houtman Abrolhos are currently reliant upon natural food sources only. The establishment of a finfish farms in either of the proposed areas could potentially lead to in changes in the size of these species populations (or changes in colony location) that could result in increased competition with, or predation of other seabirds or alteration in breeding habitat (Surman 2004). Increases in the Pied Cormorant colonies and could enhance the mechanical and guano stress on the mangrove habitats. Comparable changes in island vegetation have been observed with increasing Pied Cormorant numbers off the Perth metropolitan region (Wooller & Dunlop 1981b). The increase in cormorants in this region is attributed to the eutrophication of the southern metropolitan coastal waters and Peel/Harvey Estuary.

1.3.3 Potential Adverse Interactions with Seabirds

Interactions which can have a detrimental impact upon seabirds can occur at the island breeding colony or whilst foraging at sea. Direct disturbance to colonies from human visitation can include trampling or exposure of nests, disorientation of nestlings, enhanced predation or kleptoparasitism and interruption to breeding or feeding behaviours. Adverse interactions while foraging may arise from attraction to, or avoidance of, vessels and marine infrastructure or disturbance to prey aggregations or associated predators and exposure to contaminants.

Direct interactions with finfish farming operations could include:

- Supplementary feeding from stock predation, fish food, waste material or food scraps
- Collisions with sea cages, other structures or vessels moored at night
- Attraction and disorientation due to inappropriate lighting on service vessels, pens or navigation markers at night
- Entanglement in cage mesh, predator nets or protective bird netting
- Attraction of prey to vessels or sea cages due to "FAD" effects.
- Attraction to the fish stock
- Use of vessel or sea cages as roosting sites

The location of the Pelsaert Group aquaculture zone is just 2km from Stick Island. There is a mixed colony of Little Shearwaters and White-faced Storm Petrels on Stick Island (Surman and Nicholson 2009a), and many Wedge-tailed Shearwaters use Middle Channel as a flight path back to their colonies on Pelsaert, Middle and Gun Islands from their foraging grounds (ibid). All these petrel species return to their colonies at night. The presence of a semi-permanently moored vessel could potentially impact upon individuals of these species through:

- Collision
- Light attraction
- Disorientation

Collision rates will be greatly increased by unmasked, bright lights.

These impacts may result in either injury or death. Also, birds found on the decks invariably regurgitate meals meant to be delivered to young at the nest, thereby depriving those nestlings of a single feed.

At certain times of year, fledgling shearwaters and storm petrels depart nesting grounds and head to sea in the darkness of pre-dawn. These young inexperienced birds orientate to light on the horizon and are particularly vulnerable to being attracted to lighting, becoming disorientated.

It is assumed that the food for the fingerlings raised in the cages will be pelletised, which will have negligible attractiveness to pursuit-diving seabirds such as Pied Cormorants and Wedge-tailed shearwaters. However, Pied Cormorants may be attracted to the cages to feed upon fingerlings themselves, and in doing so may attempt to reach fish through the mesh. This may present an entanglement issues for this species.

The management plan for the proposed fish farm would need to address these concerns with mitigation methods to address the potential for entanglement if Pied Cormorants are attracted to the cages to feed on fingerlings.

1.4 Assumptions about production systems utilized in fish-farming precincts

The scientific literature on marine wildlife interactions with sea-cage operations in Australia is limited. Most of the observations are either anecdotal or presumably in compliance monitoring reporting that is not available in the public domain. This lack of transparency would appear to be an issue in itself. A review of the environmental effects of fish-farming, including wildlife interactions, was done in New Zealand (Forrest *et al.* 2007) but the coverage on seabirds was speculative with no reference to structured observations.

During the early stages of the Atlantic Salmon *Salmo salar* sea-cage aquaculture in Tasmania problematic interactions were reported with New Zealand Fur Seals *Arctocephalus forsteri*, Silver Gulls, Water Rats *Hydromys chrysogaster*, Great Cormorants, *Phalacrocorax carbo* Black-faced Cormorants *Phalacrocorax fuscescens* and Sea-eagles (Pemberton *et al.* 1991). Of

these only Silver Gulls, cormorants (mainly Pied Cormorants) and Sea-eagles (also Ospreys) are present at the Abrolhos Islands. The Australian Sealions *Neophoca cinerea* at the Abrolhos Islands may be attracted to the sea-cages if they are rewarded with feeding opportunities. In the Tasmanian operations the gulls targeted stock and feed from above the pens, sea-eagles attacked stock from above, whilst cormorants pursued stock from underwater through the mesh of the pen. Sea-eagles only attempted foraging over the large diameter pens. Since the 1990s predator and bird-nets, fur-seal barriers and other measures have been introduced into the Tasmanian salmon industry. However the outcomes of this have apparently not been scientifically assessed and reported in the public domain. It is assumed that best practice wildlife exclusion methods now used in Tasmania would be adopted at the Abrolhos from the outset.

At Southern Bluefin Tuna ranching pens at Port Lincoln the stock are still fed whole pilchards from defrosting frozen blocks, with some shovelling of fish to the pen surface to excite a feeding response. Silver Gulls scavenged an estimated 2.3% of feed from one operator. An estimated 790 tonnes of pilchards was taken by seabirds from all the tuna pens annually. This energy subsidy allowed the Silver Gull to expand its breeding season (now parallels the ranching season), increase their reproductive output (per pair) and exponentially increasing its local breeding population from 3 300 pairs in 1999 to 27 800 pairs in 2005 (Harrison 2010). The downstream ecological consequences on other species has not been assessed. Again it is assumed that best practice will be applied at the Abrolhos and feed will not be directly accessible to gulls or other seabirds.

The largest known impact of sea-cage aquaculture on Australian marine ecosystems resulted from two massive fish kill epidemics in pilchards caused by the introduction of a novel herpes virus via imported whole fish (sardine) feed at Port Lincoln in the 1990s (Whittington *et al.* 2008). This epidemic caused a major reduction in the pilchard stock and was known to impact several seabird species dependent on these forage fish including Little Penguins *Eudyptula minor* (Dann *et al*. 2000), Australasian Gannet *Morus serrator* (Bunce & Norman 2000) and Crested Terns (J.N. Dunlop *pers.obs*.). This event highlighted the importance of pathogen biosecurity for minimizing the ecological risks posed by open system sea-cage aquaculture. It is assumed that farmed stock will not be fed whole frozen fish and that the fishmeal in food pellets will be screened for microbes or sterilized. Under the management arrangements proposed for the mid-west aquaculture development zone, the use of pilchards and other wet (fresh or frozen) fish as stock feed will not be permitted. Only manufactured pellets will be used as stock feed.

The Department of Fisheries has provided a 'Representation of Aquaculture Operations' for the proposed mid-west aquaculture development zone. Whilst this appears to cover best-practice in marine finfish sea-cage operations it does not specifically mandate the mitigation measures required to minimise seabird (and other wildlife) interactions. The interaction between risks, mitigation measures and monitoring strategy will be dealt with in Section 4.

The Department's brief indicates that most previously developed mitigation methods to separate wildlife from stock, feed and hazards will be employed. The currently 'untreated' risks in the Departments brief appear to be the FAD affect, lights and feed drift through the cage mess. The latter potentially attracting seabirds, particularly cormorants, to aggregations of small wild fishes.

1.5 Threat Status

Components of the avifauna at the Houtman Abrolhos are protected under three National and State Acts; the Environment Protection and Biodiversity Conservation (EPBC) Act 1999, the Conservation and Land Management (CALM) Threatened and Priority Fauna Database and the Western Australian Wildlife Conservation (Specially Protected Fauna) Notice 2014.

Migratory species are protected under the EPBC Act (1999), and are included in the Japan Australia Migratory Bird Agreement (JAMBA), the China Australia Migratory Bird Agreement (CAMBA) and the Republic of Korea-Australia Migratory Bird Agreement (ROKAMBA). Of these, all migratory waders recorded in Surman and Nicholson (2009a), as well as the Eastern Reef Egret and seabirds including the Bridled Tern, Caspian Tern, Crested Tern, Osprey and White-breasted Sea Eagle, are listed under migratory bird agreements with either Japan, China or Korea. Birds covered by these agreements are listed in Schedule 3 under the Wildlife Conservation Act 1950 (WA).

Eight bird species found at the Houtman Abrolhos are also listed under the CALM Threatened and Priority Fauna Database, although only one of these species, the Lesser Noddy, is likely to interact with the aquaculture lease area.

Five seabird species occur in the vicinity of the aquaculture leases that are listed under the Western Australian Wildlife Conservation (Specially Protected Fauna) Notice 2014, Schedule 1: Fauna that is rare or likely to become extinct. These are the:

- Lesser Noddy *Anous tenuirostris melanops*
- Hutton's Shearwater *Puffinus huttoni*
- Fairy Tern *Sternula nereis nereis*
- Indian Yellow-nosed Albatross *Thalassarche carteri,* and
- Black-browed Albatross *Thalassarche melanophris*

Both the Lesser Noddy and Fairy Tern breed at the Houtman Abrolhos, whereas the Hutton's Shearwater migrates through the region in late spring, with up to 50 birds occurring in flocks off Eastern Passage (Easter Group) and The Channel (Pelsaert Group). (Surman and Nicholson 2009a), and the two albatrosses are winter visitors (Surman *pers. obs*). Hutton's Shearwaters forage with Wedge-tailed Shearwaters on small pelagic fishes and squids, including some species likely to accumulate adjacent to sea cages.

2 Methods

2.1 Field surveys

Field surveys at the Easter and Pelsaert Groups were conducted between 18-27 June 2014 and 14-23 October 2014.

Thirty one (31) islands at the Easter Group and 35 islands across the Pelsaert Group were surveyed during each field survey. Access to potential breeding colonies on each island was possible with the use of *Persephone* - 4.5m center consul/ 50 hp aluminium research vessel.

Each island was either surveyed on foot or circumnavigated by vessel with intensive searches for nests conducted when either Silver Gull, Pacific Gull or Pied Cormorant colonies were located. Nest sites, once located were assessed for condition and/or breeding status as either;

- Old/disused – unused in recent time
- Autumn – nest considered to have been used during the previous autumn nesting season (applicable to the October survey only).
- Relined/empty – nest cup reconstructed with fresh seaweeds in preparation for breeding.
- Egg – The number of eggs (1-3) in each nest.
- Chicks – The numbers and age of chicks still in the nest, or hidden in vegetation nearby.

Estimates of breeding numbers of Silver Gulls and Pacific Gulls were undertaken using;

- Complete counts of all nests of both gull species
- Assessment of the status of each nest (i.e. active/inactive)
- Measurement of Silver Gull eggs/chicks to determine the date of commencement of breeding.

Each nest site of Silver and Pacific Gulls was plotted using a Garmin handheld GPS unit. The perimeters of colonial-nesting Pied Cormorants were plotted and then traced onto aerial photographs of each island group using GPS Visualizer and Adobe Illustrator. Nest sites were then mapped using recent aerial imagery (DoF 2012) as a base layer in ArcGIS using the Index Map Numbers shown in Figure 1.0.

2.2 Timing of nesting

Laying chronology was estimated by backdating the age of eggs, using egg water loss techniques (Wooller and Dunlop 1980, Surman and Wooller 1995). Eggs were measured and weighed at the nest, and their age in days determined with the formula below.

$$V = L.B^2$$
$$D = M/V$$

$$\text{Fresh Egg Mass} = 1.06\,(V) + 0.34$$

Where M = Egg Mass, V = Volume, D = Density, L = Maximal egg length and B = maximal egg breadth.

2.3 Collection and analysis of dietary data

The hard regurgitated pellets of Silver Gulls, Pacific Gulls and Pied Cormorants were collected from areas adjacent to nest sites and known roosting areas. In the case of Pied Cormorants it was only possible to collect pellets after breeding had finished due to the high density and vulnerability to disturbance of this species.

Pellets were stored dry and sorted in the laboratory. Prey items were identified from hard parts – either exoskeletons, cephalopod beaks, seeds, shell fragments, opercula or the premaxillae or pharangeal bones of some fishes (see Bellwood 1994, Allen and Steene 1994, Edgar 1997, Lu and Ickeringill 2002, Wilson 1994).

In addition, observations of prey item remains from Pacific Gull anvil sites were also made. Pacific Gulls drop hard-shelled prey items (i.e. Gastropods and Urchins) onto rocky platforms, or on some islands exposed concrete pathways or concrete pads.

The total number of individuals of each prey type in each sample was recorded and the frequency of occurrence of each prey taxon in all samples for each seabird species.

2.4 Stable isotope analysis

2.4.1 Background

The carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotope ratios in protein based tissues can be used to provide on foraging ecology (Bond & Jones 2009), defining what is sometimes referred to as an isotopic niche.

Stable isotopes of carbon (^{13}C) and nitrogen (^{15}N) occur naturally in the environment. The ratio of the heavier isotopes to the common forms are changed by the physical sorting of biological processes such as photosynthesis in plants, or food digestion or metabolism in microbes and animals. These changes in the isotopic ratio are referred to as fractionation. The values given to the stable isotope ratios ($\delta^{13}C$ or $\delta^{15}N$) are measured in parts per thousand ($^{o}/_{oo}$) and may be positive or negative because they represent deviations from the values of standard materials (Bond & Jones 2009).

Both $\delta^{13}C$ and $\delta^{15}N$ values in consumer tissues can be used to infer the sources of carbon (energy) in food-chains if the producer signatures (the isotopic baselines) are known. Nitrogen 15 ($\delta^{15}N$) values show a stepwise increase with trophic level due to the tendency of animals to differentially excrete ^{14}N during digestion and assimilate ^{15}N during protein synthesis. The trophic position of consumer organisms can be inferred above a known producer $\delta^{15}N$ baseline (Bond & Jones 2009). The synthesis of different consumer tissues (e.g. blood, muscle and feathers) may involve different turnover rates (time periods) and variable fractionation patterns, which need to be considered when making inferences from stable-isotope data (Bond & Jones 2009).

The $\delta^{15}N$ values in marine producers such as phytoplankton will be dependent on the fractionation of the nitrogen source. This in turn reflects the various nitrifying and de-nitrifying transformations occurring through the nitrogen cycle and on nitrogen availability. Inorganic (nitrate) nitrogen is relatively enriched in ^{15}N producing a high $\delta^{15}N$ signature. Recycled (ammonia) nitrogen is less enriched and recently fixed (N_2) nitrogen is depleted in ^{15}N. The $\delta^{15}N$ signature is a combined indicator of nitrate source, availability and uptake (Graham *et al.* 2010).

Stable isotope ratios in protein-based biological materials can also be used to track anthropogenic sources of energy and nutrient in aquatic environments, e.g. measuring the scale of nitrate subsidization from treated sewage outfalls (Connolly *et al.* 2013). Artificial fish feeds supplied to sea-cage stock will have distinctive $\delta^{13}C$ or $\delta^{15}N$ values reflecting the mixture of terrestrial plant and fish-meal ingredients. The 'signature' of the feed will be translated into the tissues of consumer organisms including the farmed stock, wild fish and marine invertebrates, seabirds and marine mammals at various levels in the aquatic food-chain. Since any measurable energy and nutrient subsidy to the hosting marine environment could potentially force ecological change the method can be used to provide warning of incipient changes in consumer populations, competition or predator-prey relationships.

2.4.2 Sample collection & processing

The feathers from the three high risk ' increaser' seabird species were collected from nests or nesting areas in breeding colonies, roosts, corpses and from 'runners' (mobile gull chicks). Feathers were packaged for dry storage in labelled zip lock plastic bags. Later the selected feather samples were physically cleaned of foreign matter and washed in de-ionized water and dried.

Fresh regurgitate material was preserved in a dry state, frozen or stored in 70% ethanol for later examination and sample compilation. All samples were dried, chopped into fine pieces and ground to a flour-like consistency using a ball-mill in preparation for the laboratory analysis.

2.4.3 Stable isotope analysis

The $\delta^{13}C$ or $\delta^{15}N$ values from all the samples compiled were determined by a registered stable isotope laboratory at Monash University in Melbourne. Adequate feather samples were available from each of the three potential 'increaser' species. Seabird prey items were extracted from regurgitated pellets. The taxa for SI analysis were selected to provide a spread in trophic levels and provide for sufficient sample sizes.

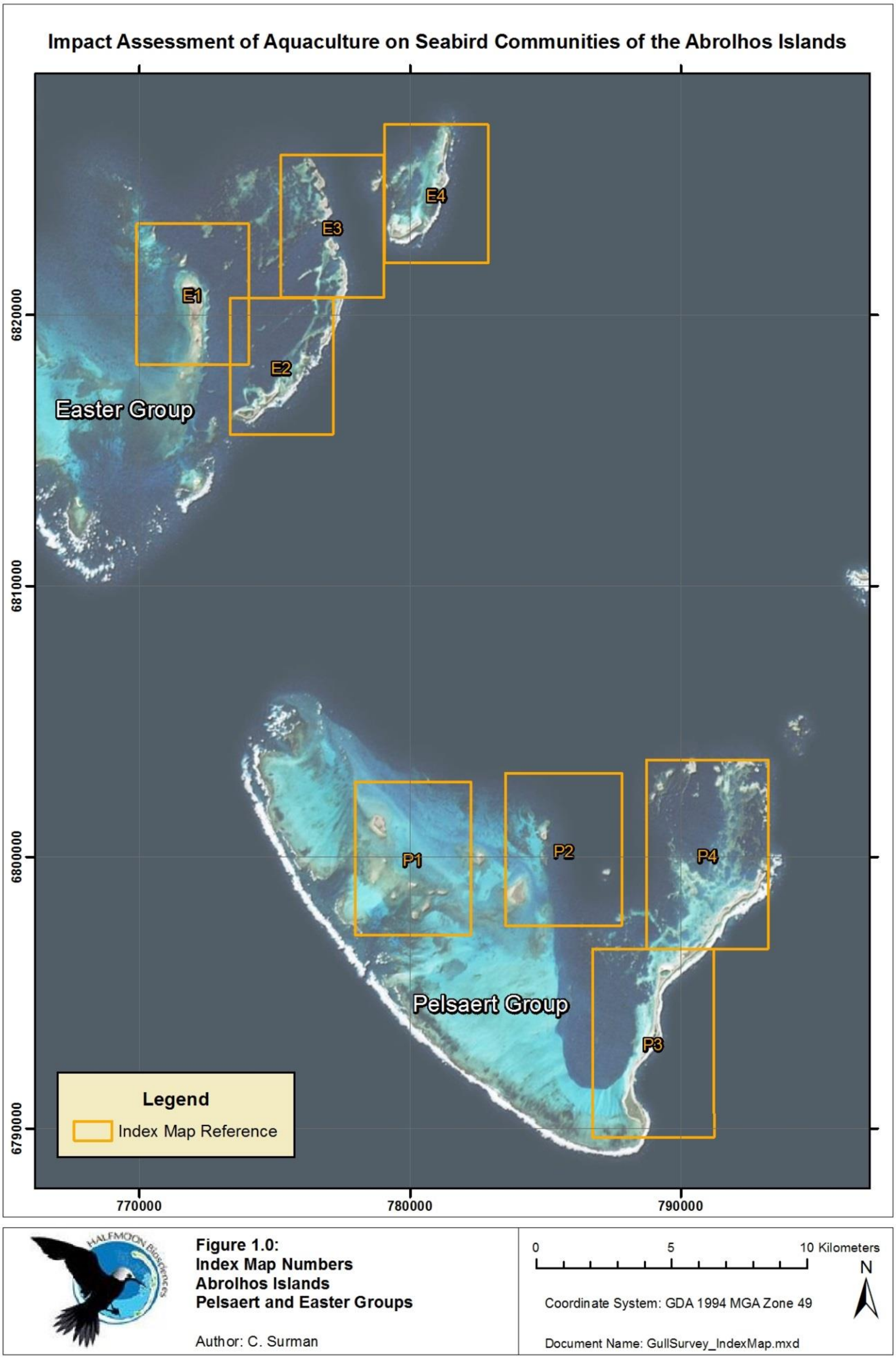


Figure 1.0:
Index Map Numbers
Abrolhos Islands
Pelsaert and Easter Groups

Author: C. Surman

3 Results

3.1 Distribution and abundance of seabirds

Figures 2.1-2.8 shows the distribution of active and inactive nest sites of Silver Gulls, Pacific Gulls and Pied Cormorants nesting in the Easter and Pelsaert Groups adjacent to the two aquaculture zones during June 2014. Figure 3.1-3.8 shows the distribution of active and inactive nest sites of Silver Gulls, Pacific Gulls and Pied Cormorants nesting in the Easter and Pelsaert Groups adjacent to the two aquaculture zones during October 2014.

3.1.1 June 2014

A total of 85 Silver Gull nests and 22 Pacific Gull nests were located across the two groups during the June 2014 survey (Table 3.1 and 3.2). Most Silver Gull nests were located in the Pelsaert Group during June, with most on Newman Island (24) and Post Office Island (18). However, of the 85 Silver Gull nests located, only one contained eggs, and four contain chicks at a time when autumn-nesting would usually be in full swing. As Pacific Gulls area summer breeding species, it was not surprising to locate only old or nests recently used from the previous summer.

Table 3.1: Nest contents of Silver Gull nests located during surveys of the Easter and Pelsaert Groups, June 2014.

Island	Nest Contents							
Pelsaert Group	**Old Nest**	**Empty**	**1 Egg**	**2 Egg**	**3 Egg**	**Chick**	**Runner**	**Total**
Coronation	2	0	0	0	0	2	0	4
Eight	0	1	0	0	0	0	0	1
Gun	1	0	0	0	0	0	0	1
Newman	7	15	0	1	0	1	0	24
One	4	0	0	0	0	0	0	4
Post Office	8	9	0	0	0	1	0	18
Stick	1	0	0	0	0	0	0	1
Sweet	1	3	0	0	0	0	0	4
Pelsaert Group Total	**24**	**28**	**0**	**1**	**0**	**4**	**0**	**57**
Easter Group								
Rat	7	6	0	0	0	0	0	13
Wooded	6	9	0	0	0	0	0	15
Easter Group Total	**13**	**15**	**0**	**0**	**0**	**0**	**0**	**28**
TOTAL	**37**	**43**	**0**	**1**	**0**	**4**	**0**	**85**

Table 3.2: Nest contents of Pacific Gull nests located during surveys of the Easter and Pelsaert Groups, June 2014.

Island	Nest Contents							
Pelsaert Group	Old Nest	Empty	1 Egg	2 Egg	3 Egg	Chick	Runner	Total
Eight	0	2	0	0	0	0	0	2
Pelsaert	2	7	0	0	0	0	0	9
Stick	0	1	0	0	0	0	0	1
Three	3	1	0	0	0	0	0	4
Pelsaert Group Total	**5**	**11**	**0**	**0**	**0**	**0**	**0**	**16**
Easter Group								
Leos	0	3	0	0	0	0	0	3
Morley	1	1	0	0	0	0	0	2
Sandy	1	0	0	0	0	0	0	1
Easter Group Total	**2**	**4**	**0**	**0**	**0**	**0**	**0**	**6**
TOTAL	**7**	**15**	**0**	**0**	**0**	**0**	**0**	**22**

3.1.2 October 2014

A total of 237 Silver Gull nests and 87 Pacific Gull nests were located across the two groups during the October 2014 survey (Table 3.3 and 3.4). Of these 144 Silver Gull nests were located in the Pelsaert Group and 93 in the Easter Group. The largest Silver Gull colonies in the Pelsaert Group were on Pelsaert Island (60 nests), Post Office Island (38 nests) and Newman Island (28 nests). In the Easter Group nearly half of all nests were located on Wooded Island (45 nests). Of the 237 nests, only 50 (21.9%) were occupied (26 contained eggs and 24 chicks). In contrast 77 (32.6%) were old nests, and 110 (46.4%) remained empty.

Pacific Gulls tend to nest solitarily, although a single colony of eight pairs of Pacific Gulls nests on Pelsaert Island. Of the 51 Pacific Gull nests located in the Pelsaert Group, 18 (35.3%) were on Pelsaert Island, and seven (13.7%) on Three Island. Within the Easter Group, eight nests (22.2%) were located on Leo's Island, with five nests on each of Rat Island, Suomi Island and Wooded Island. Across the two groups, 14 Pacific Gull nests contained eggs and 26 contained chicks. This agrees with nesting commencing in late August for this species (Surman 1998).

A census of Pied Cormorant nests located breeding colonies on three islands in each group, although only the Wooded Island colony appeared to have been active during the 2014 breeding season (Table 3.5). A census of occupied nests at the Wooded Island colony taken from an aerial photograph obtained in October 2014 showed that 676 of the 1222 nests (55.3%) were active.

Table 3.3: Nest contents of Silver Gull nests located during surveys of the Easter and Pelsaert Groups, October 2014.

Island	**Nest Contents**							
Pelsaert Group	**Old Nest**	**Empty**	**1 Egg**	**2 Egg**	**3 Egg**	**Chick**	**Runner**	**Total**
Burnett Islet	0	0	0	0	0	1	0	1
Burton	0	1	0	0	0	0	0	1
Coronation	1	2	0	0	0	2	0	5
Lagoon	0	3	0	0	0	0	0	3
Newman	13	11	1	0	0	3	0	28
One	1	1	0	0	0	0	0	2
Pelsaert	21	23	3	8	0	5	0	60
Post Office	15	17	3	0	0	3	0	38
Robinson	0	1	0	0	0	0	0	1
Rotundella	0	1	0	0	0	0	0	1
Stick	0	2	0	0	0	0	0	2
Sweet	0	1	0	0	0	1	0	2
Pelsaert Group Total	**51**	**63**	**7**	**8**	**0**	**15**	**0**	**144**
Easter Group								
Bynoe	4	4	0	2	0	0	0	10
Keru	3	2	0	0	0	1	0	6
Leos	3	12	1	0	0	0	0	16
Rat	6	5	0	0	0	3	0	14
Stokes	1	0	0	0	0	0	0	1
Suomi	0	1	0	0	0	0	0	1
Wooded	9	23	6	2	0	5	0	45
Easter Group Total	**26**	**47**	**7**	**4**	**0**	**9**	**0**	**93**
TOTAL	**77**	**110**	**14**	**12**	**0**	**24**	**0**	**237**

Table 3.4: Nest contents of Pacific Gull nests located during surveys of the Easter and Pelsaert Groups, October 2014.

Island	**Nest Contents**							
Pelsaert Group	**Old Nest**	**Empty**	**1 Egg**	**2 Egg**	**3 Egg**	**Chick**	**Runner**	**Total**
Arthur	0	1	0	0	0	0	0	1
Basile	0	0	0	0	0	1	0	1
Burnett Islet	0	0	0	0	0	1	0	1
Burton	0	0	1	0	0	0	0	1
Eight	1	1	0	1	0	0	0	3
Gun	2	1	1	0	0	1	0	5
Jackson's	0	0	0	0	0	1	0	1
Jon Jim	0	0	0	0	0	1	0	1
Lagoon	0	1	0	0	0	0	0	1
Little Jackson	0	0	0	0	0	1	0	1
One	0	1	0	0	0	1	0	2
Pelsaert	4	7	1	3	0	3	0	18
Post Office	0	0	0	0	0	1	0	1
Robinson	1	0	0	0	0	0	0	1
Square	1	0	1	0	0	0	0	2
Stick	0	0	0	1	0	0	0	1
Sweet	0	1	1	0	0	0	0	2
Three	1	5	0	0	0	1	0	7
Travia mid	0	0	0	0	0	1	0	1
Pelsaert Group Total	**10**	**18**	**5**	**5**	**0**	**13**	**0**	**51**
Easter Group								
Alexander	0	0	0	0	0	2	0	2
Bynoe	0	0	1	0	0	0	0	1
Campbell	0	4	0	0	0	0	0	4
Gibson	0	1	0	0	0	0	0	1
Joe Smith	0	0	0	0	0	1	0	1
Keru	0	0	0	0	0	1	0	1
Leos	0	4	2	0	0	2	0	8
Morley	0	1	0	0	0	0	0	1
Morley Islet	0	0	0	1	0	0	0	1
Rat	1	1	0	0	0	3	0	5
Shearwater Islet	0	0	0	0	0	1	0	1
Suomi	0	3	0	0	0	2	0	5
Wooded	2	2	0	0	0	1	0	5
Easter Group Total	**3**	**16**	**3**	**1**	**0**	**13**	**0**	**36**
TOTAL	**13**	**34**	**8**	**6**	**0**	**26**	**0**	**87**

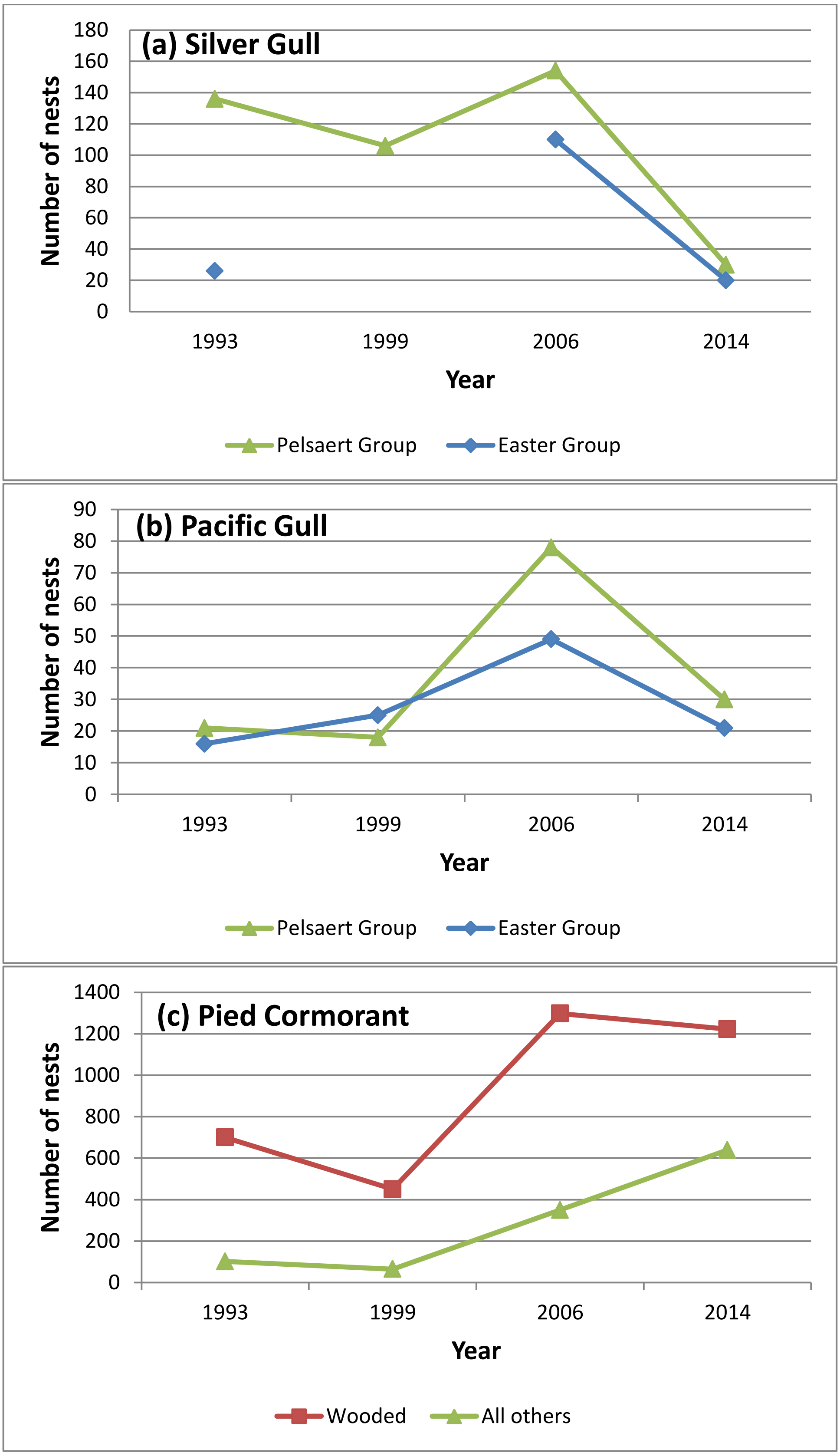
Table 3.5: Nest contents of Pied Cormorant nests located during surveys of the Easter and Pelsaert Groups, October 2014.

Island	**Nest Contents**				
Pelsaert Group	**Old Nest**	**Empty**	**I Egg**	**Chick**	**Total**
Eight	0	89	0		89
Gun	90	0	0		
Three	0	176	0		
Pelsaert Group Total	**90**	**265**	**0**	**0**	**89**
Easter Group					
Roma Islet N		198			
Roma Islet S		86			
Wooded		546	607	69	1222
Easter Group Total	**0**	**830**	**607**	**69**	**1222**
TOTAL	**90**	**1095**	**607**	**69**	**1311**

3.2 Historical seabird numbers

There has been a decline in the numbers of active Silver Gull and Pacific Gull nests at the Houtman Abrolhos since 2006 (Figure 3.2). Presumably, since the change in the timing of the fishing season of the rock-lobster fishery, there has been a reduced availability in food for gulls. Unlike the gulls however, Pied Cormorants continue to remain at relatively stable numbers, most likely due to little change in their usual food supply, and as they are not known to exploit discarded rock-lobster fishing bait.

Figure 3.2: The absolute numbers of active Silver Gull, Pied Cormorant and Pacific Gull nests recorded during annual survey counts between 1993 and 2014 (Fuller *et al.* 1994, Burbidge and Fuller 2004, Surman and Nicholson 2009a).



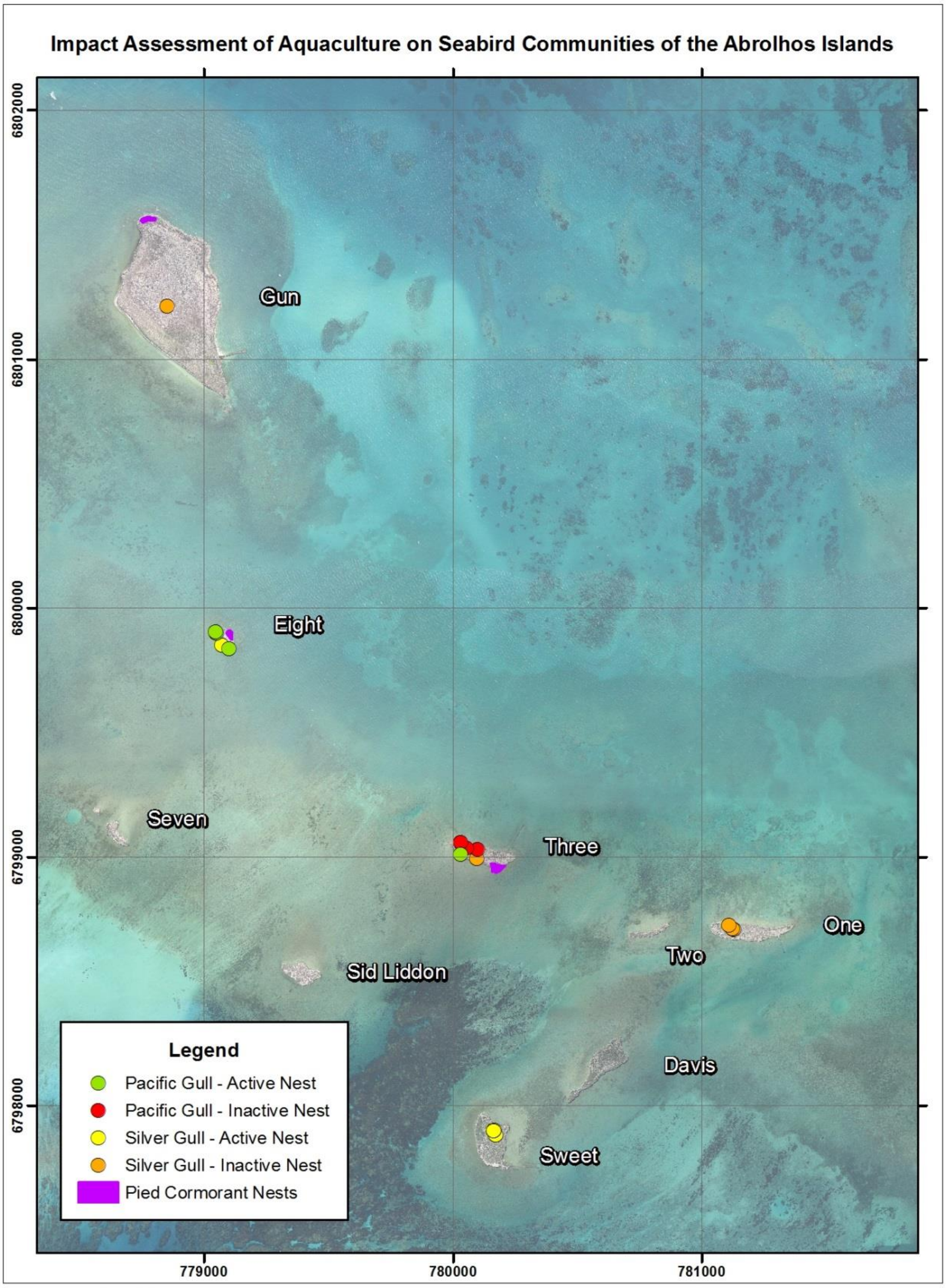


Figure 2.1:
Gull Distribution
Pelsaert Group
Index Map Reference Number P1
June 2014.
Author: C. Surman

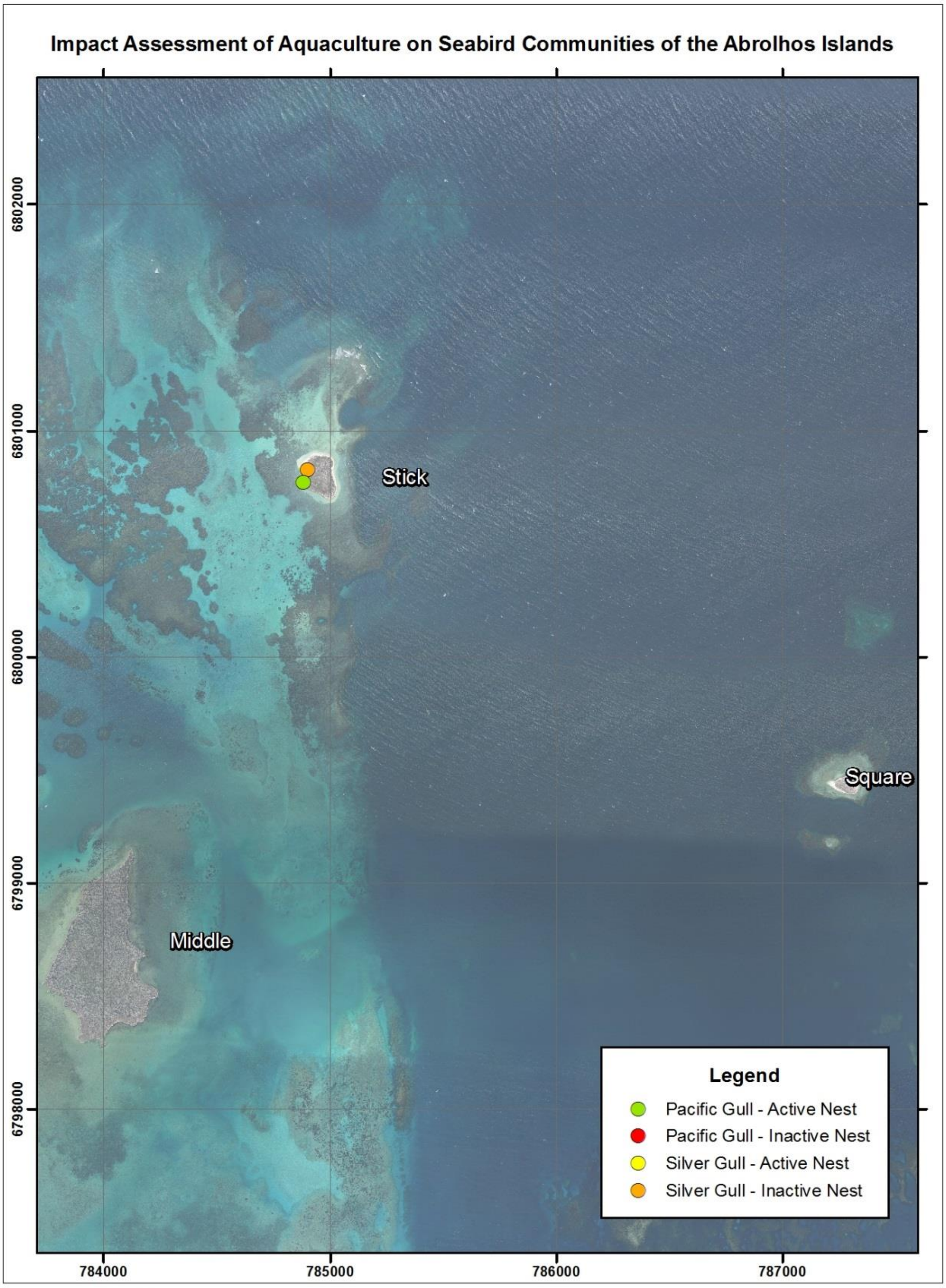


Figure 2.2:
Gull Distribution
Pelsaert Group
Index Map Reference Number P2
June 2014.
Author: C. Surman

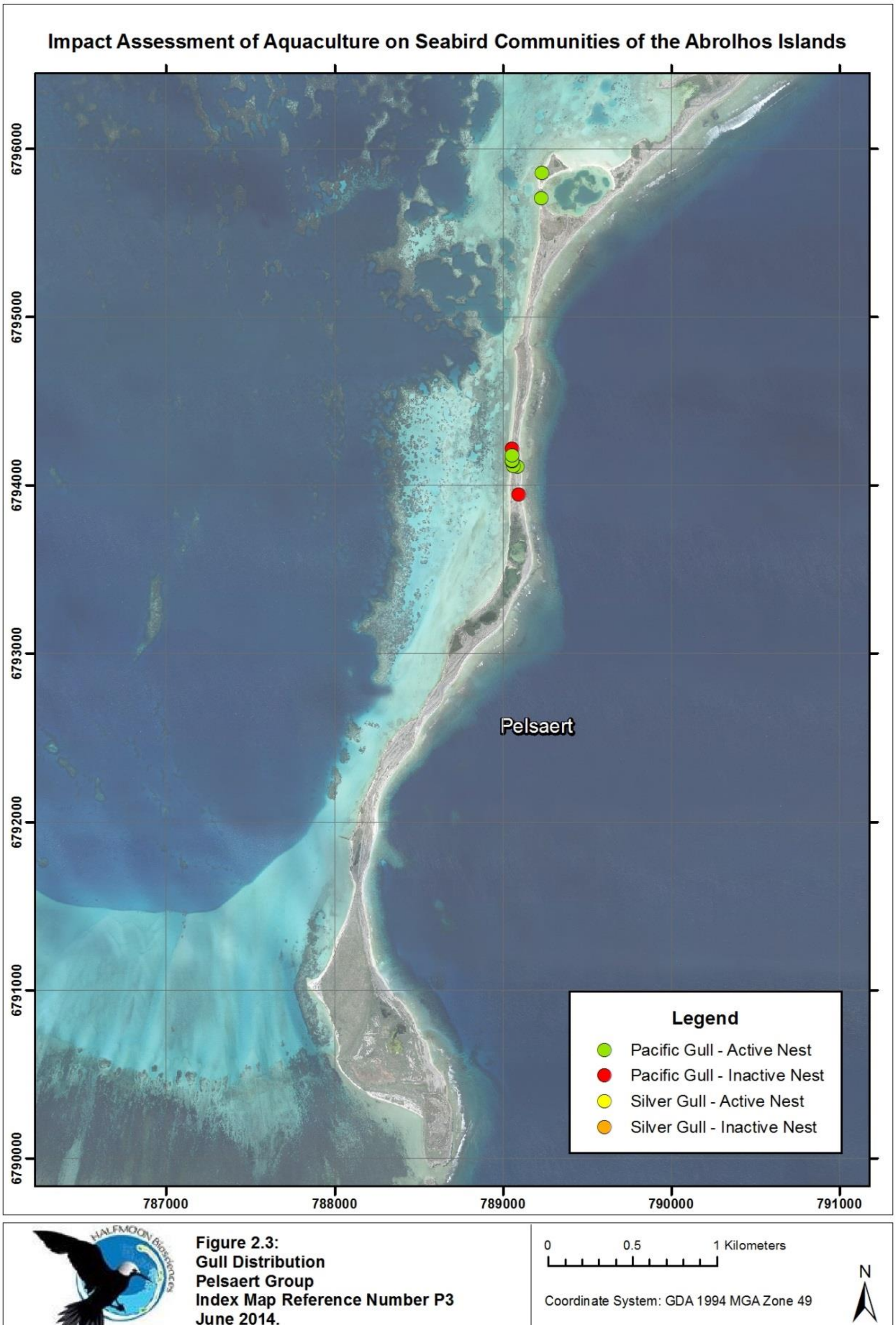


Figure 2.3:
Gull Distribution
Pelsaert Group
Index Map Reference Number P3
June 2014.
Author: C. Surman

Coordinate System: GDA 1994 MGA Zone 49

Document Name: GullSurvey_June2014_Fig23.mxd

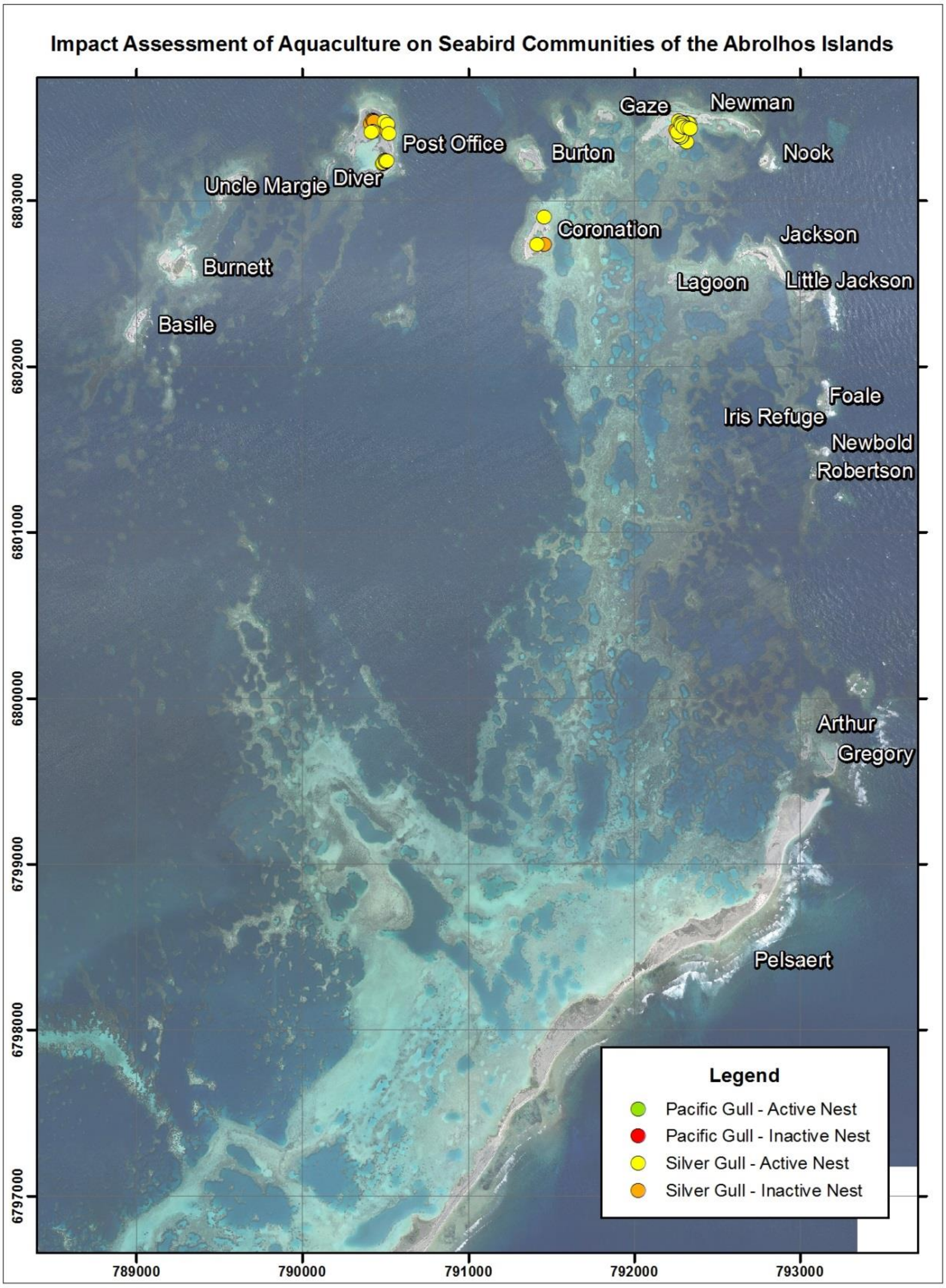


Figure 2.4:
Gull Distribution
Pelsaert Group
Index Map Reference Number P4
June 2014.
Author: C. Surman

Coordinate System: GDA 1994 MGA Zone 49

Document Name: GullSurvey_June2014_Fig24.mxd

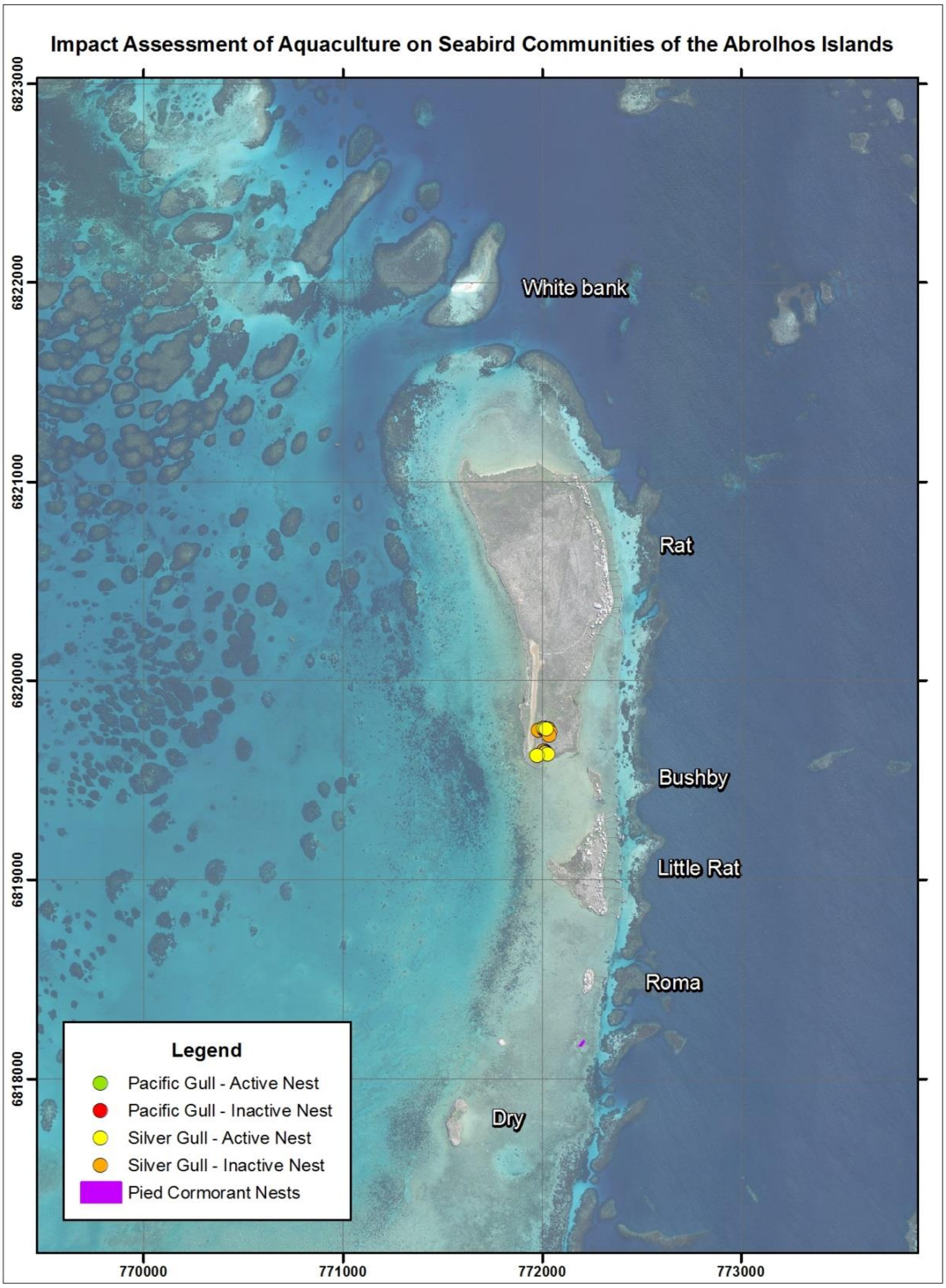


Figure 2.5:
Gull Distribution
Easter Group
Index Map Reference Number E1
June 2014.
Author: C. Surman

0 0.5 1 Kilometers
Coordinate System: GDA 1994 MGA Zone 49
Document Name: GullSurvey_June2014_Fig25.mxd
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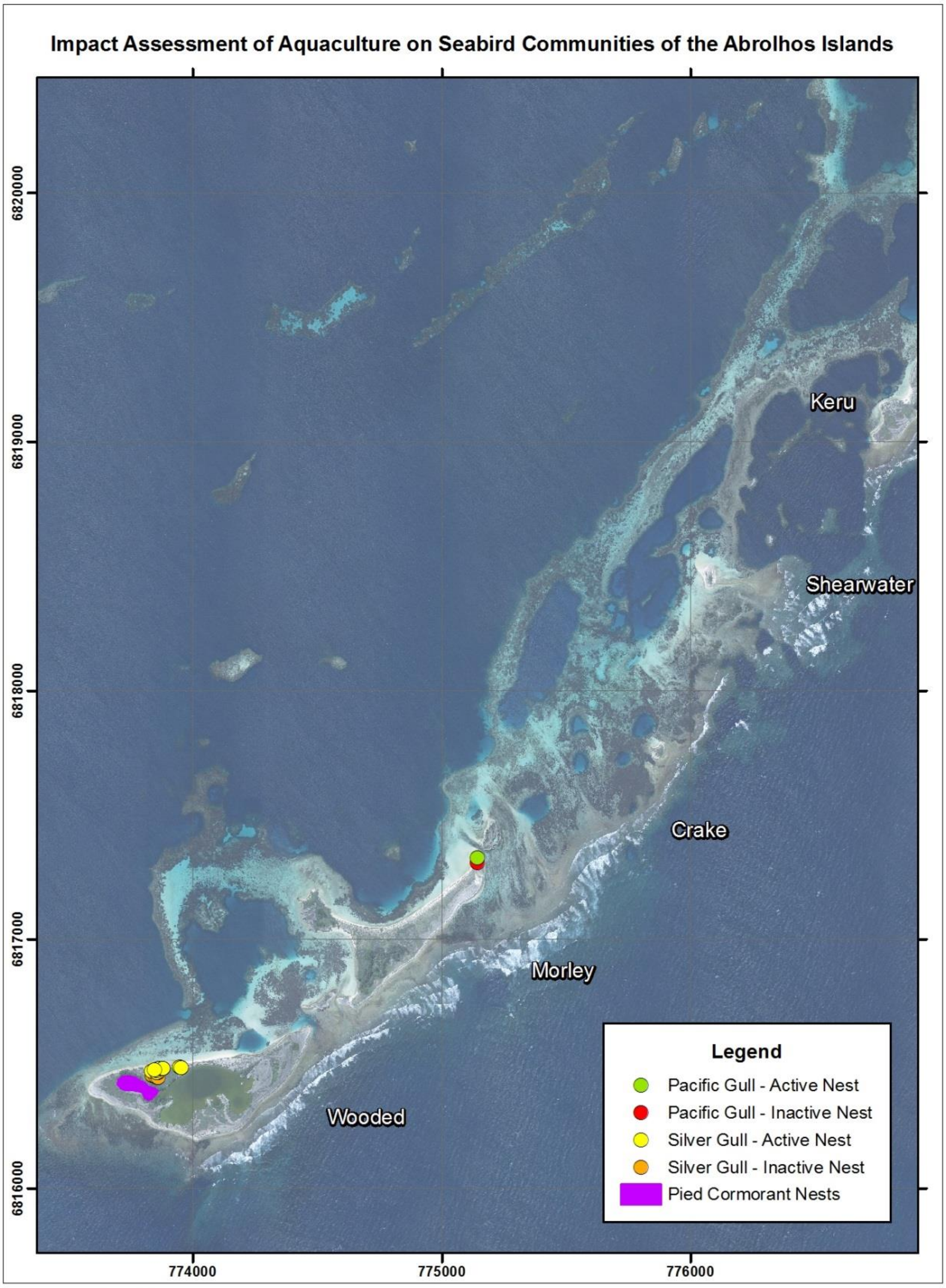


Figure 2.6:
Gull Distribution
Easter Group
Index Map Reference Number E2
June 2014.
Author: C. Surman

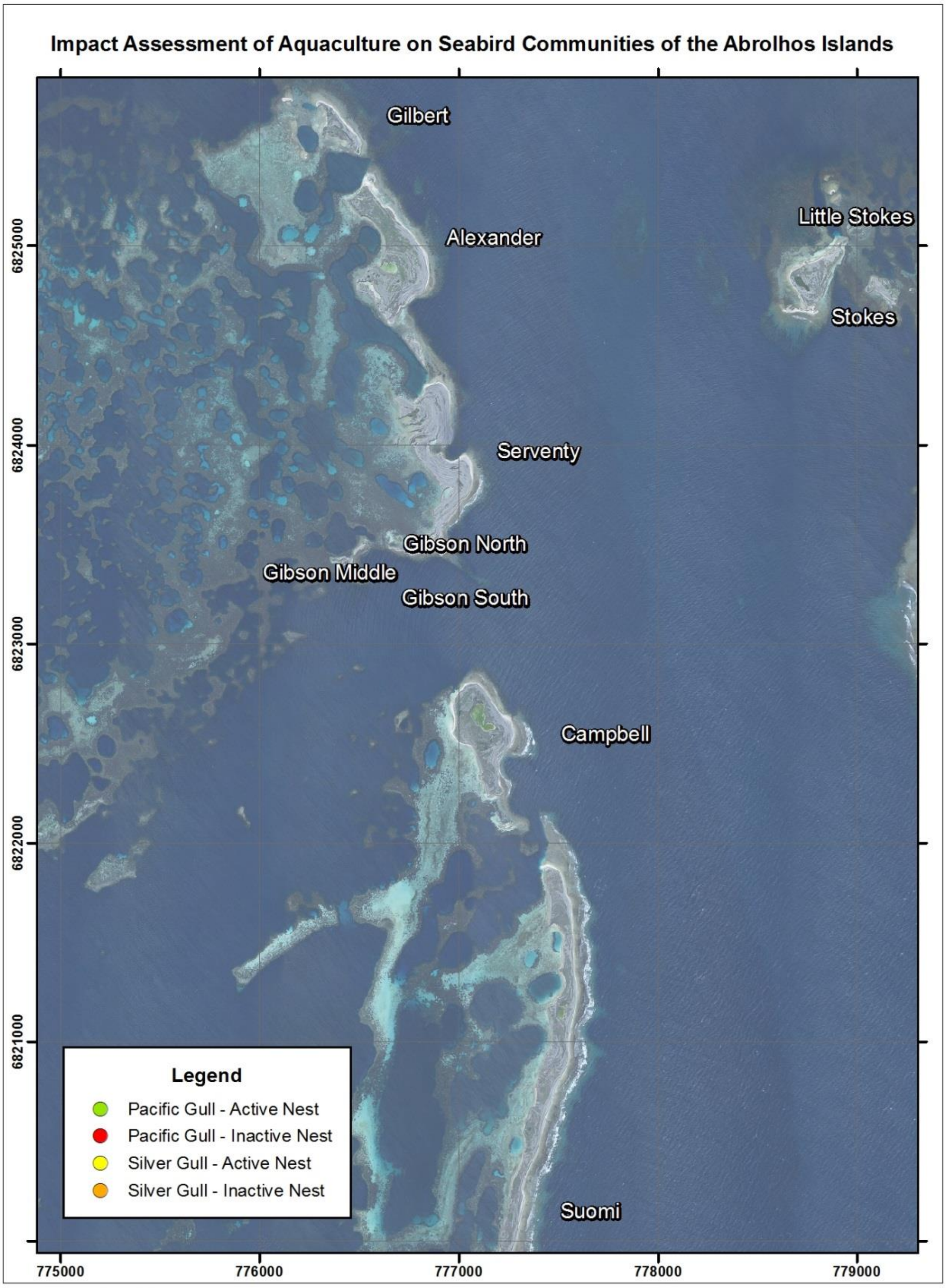


Figure 2.7:
Gull Distribution
Pelsaert Group
Index Map Reference Number E3
June 2014.
Author: C. Surman

0 0.5 1 Kilometers

Coordinate System: GDA 1994 MGA Zone 49

N

Document Name: GullSurvey_June2014_Fig27.mxd

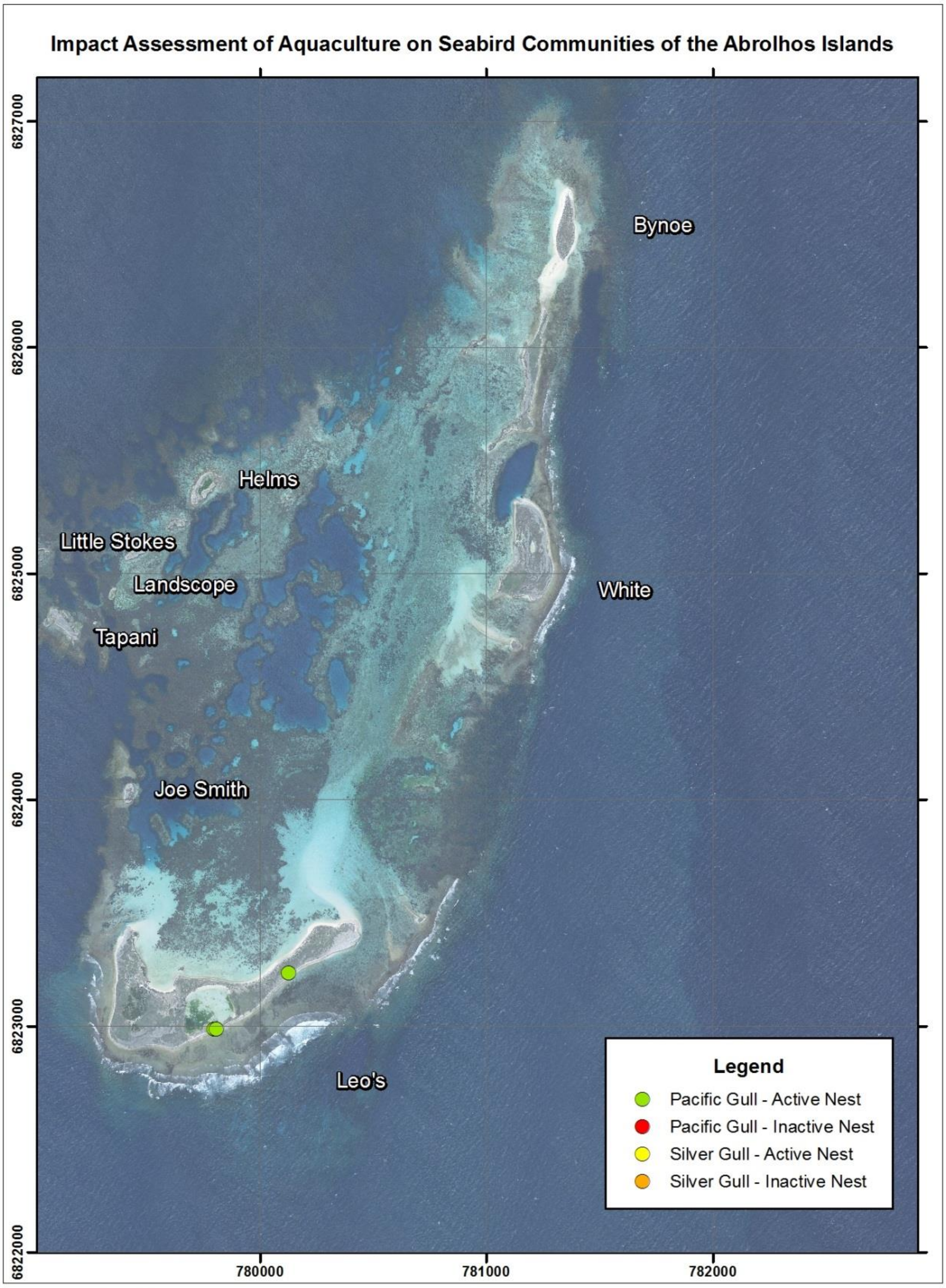


Figure 2.8:
Gull Distribution
Easter Group
Index Map Reference Number E4
June 2014.
Author: C. Surman

0 0.5 1 Kilometers

Coordinate System: GDA 1994 MGA Zone 49

N

Document Name: GullSurvey_June2014_Fig28.mxd

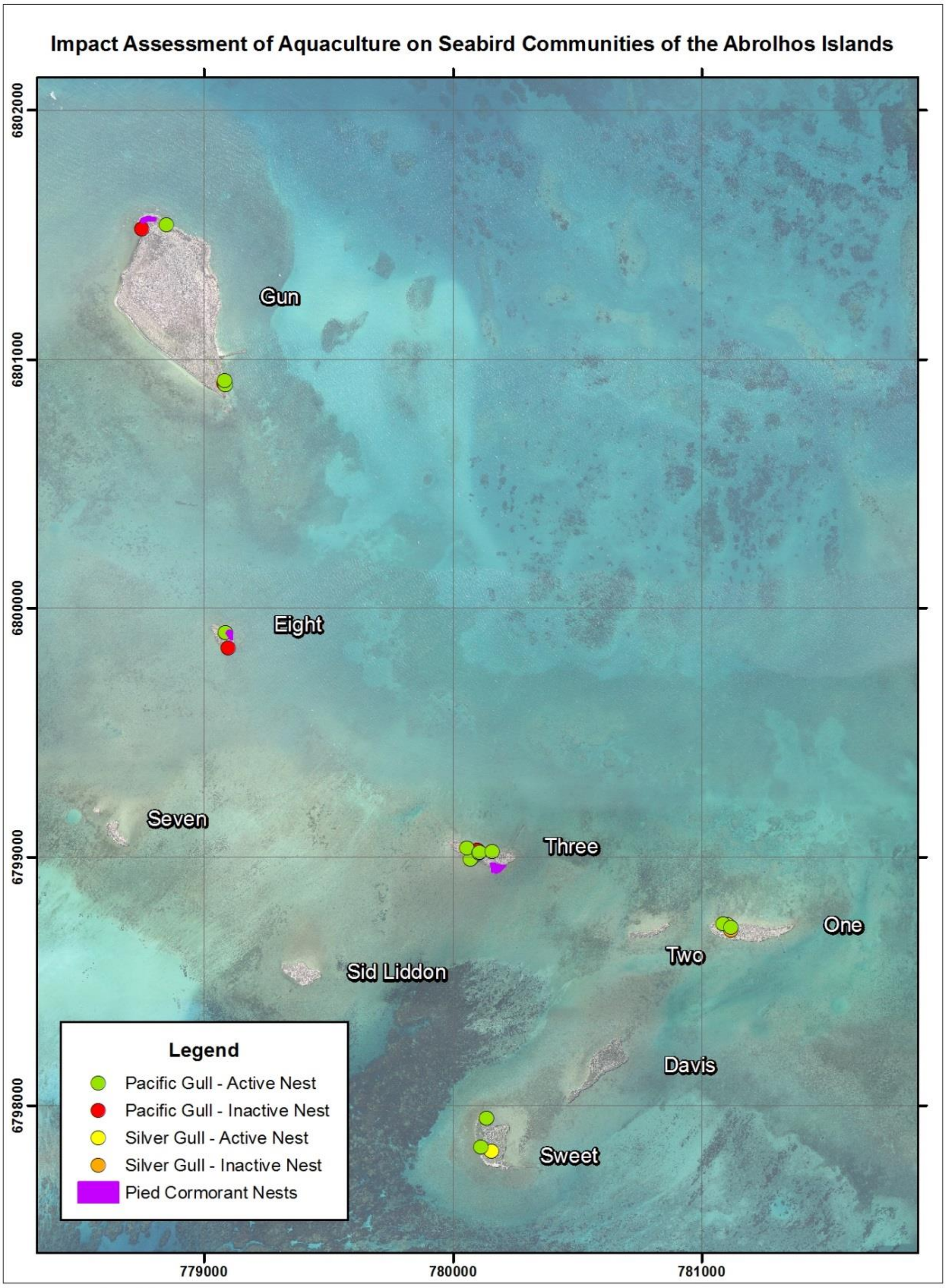


Figure 3.1:
Gull Distribution
Pelsaert Group
Index Map Reference Number P1
October 2014.
Author: C. Surman

0 0.5 1 Kilometers

Coordinate System: GDA 1994 MGA Zone 49

Document Name: GullSurvey_October2014_Fig31.mxd

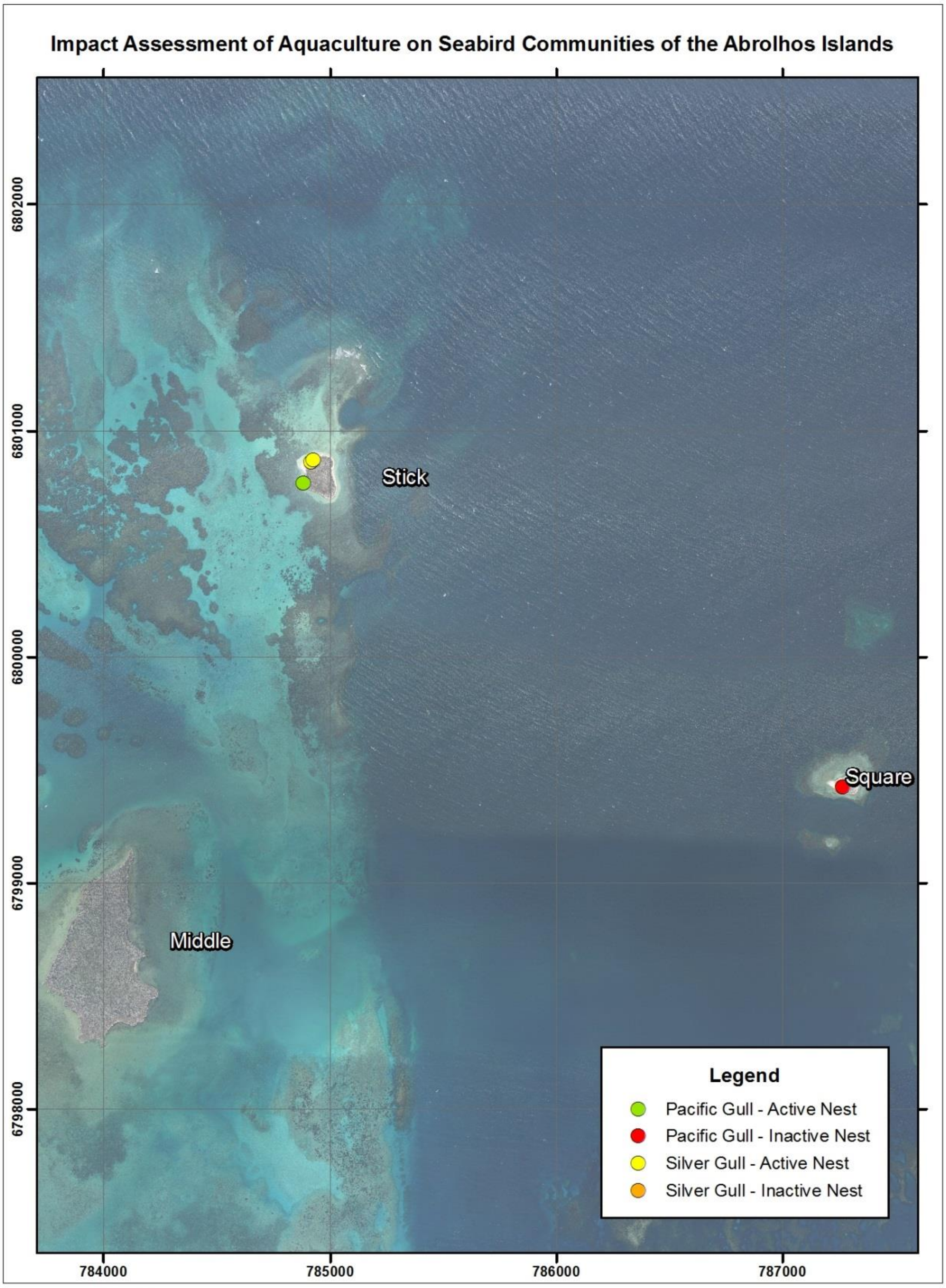


Figure 3.2:
Gull Distribution
Pelsaert Group
Index Map Reference Number P2
October 2014.
Author: C. Surman

0 0.5 1 Kilometers

Coordinate System: GDA 1994 MGA Zone 49

N

Document Name: GullSurvey_October2014_Fig32.mxd

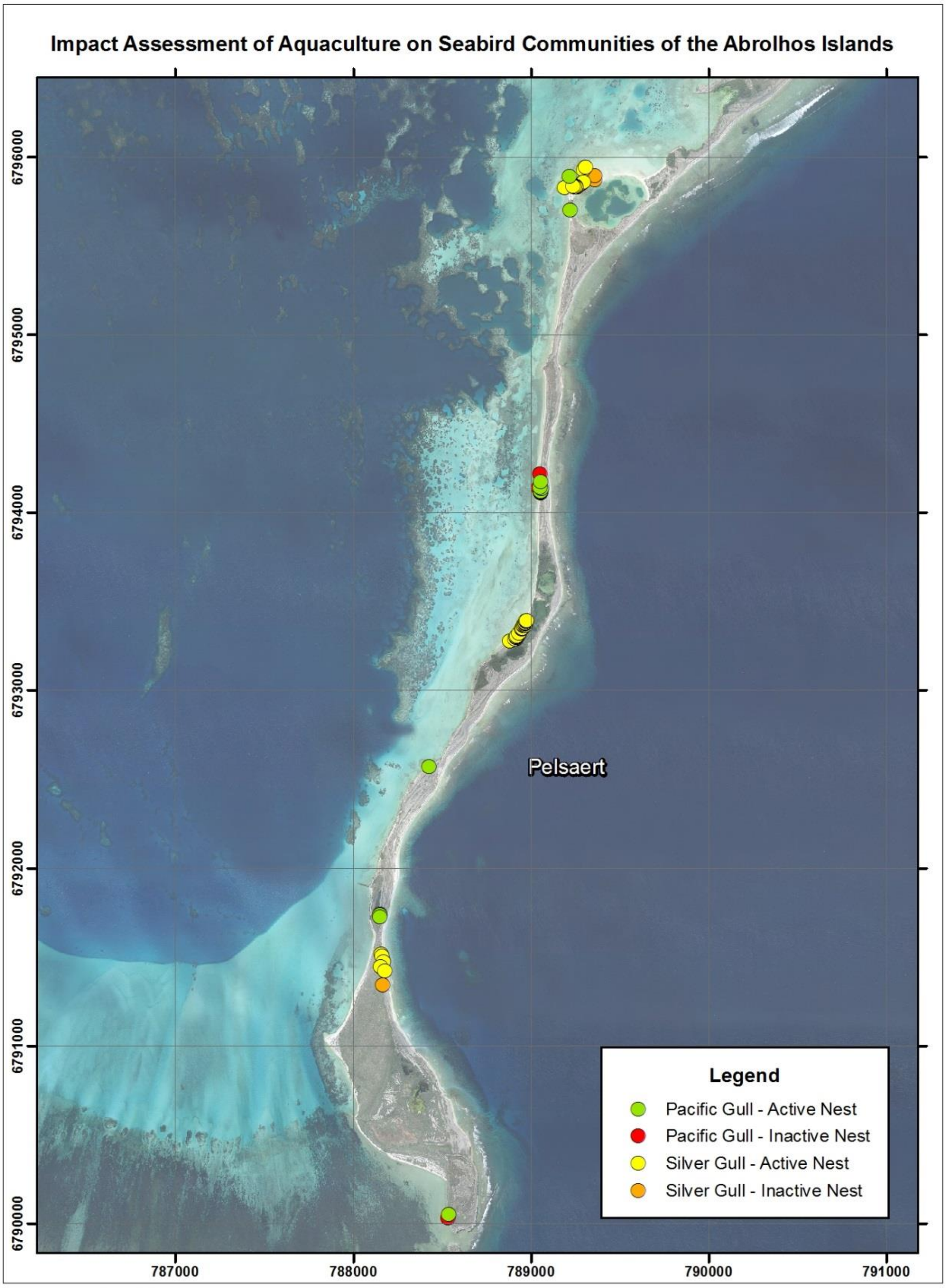


Figure 3.3:
Gull Distribution
Pelsaert Group
Index Map Reference Number P3
October 2014.
Author: C. Surman

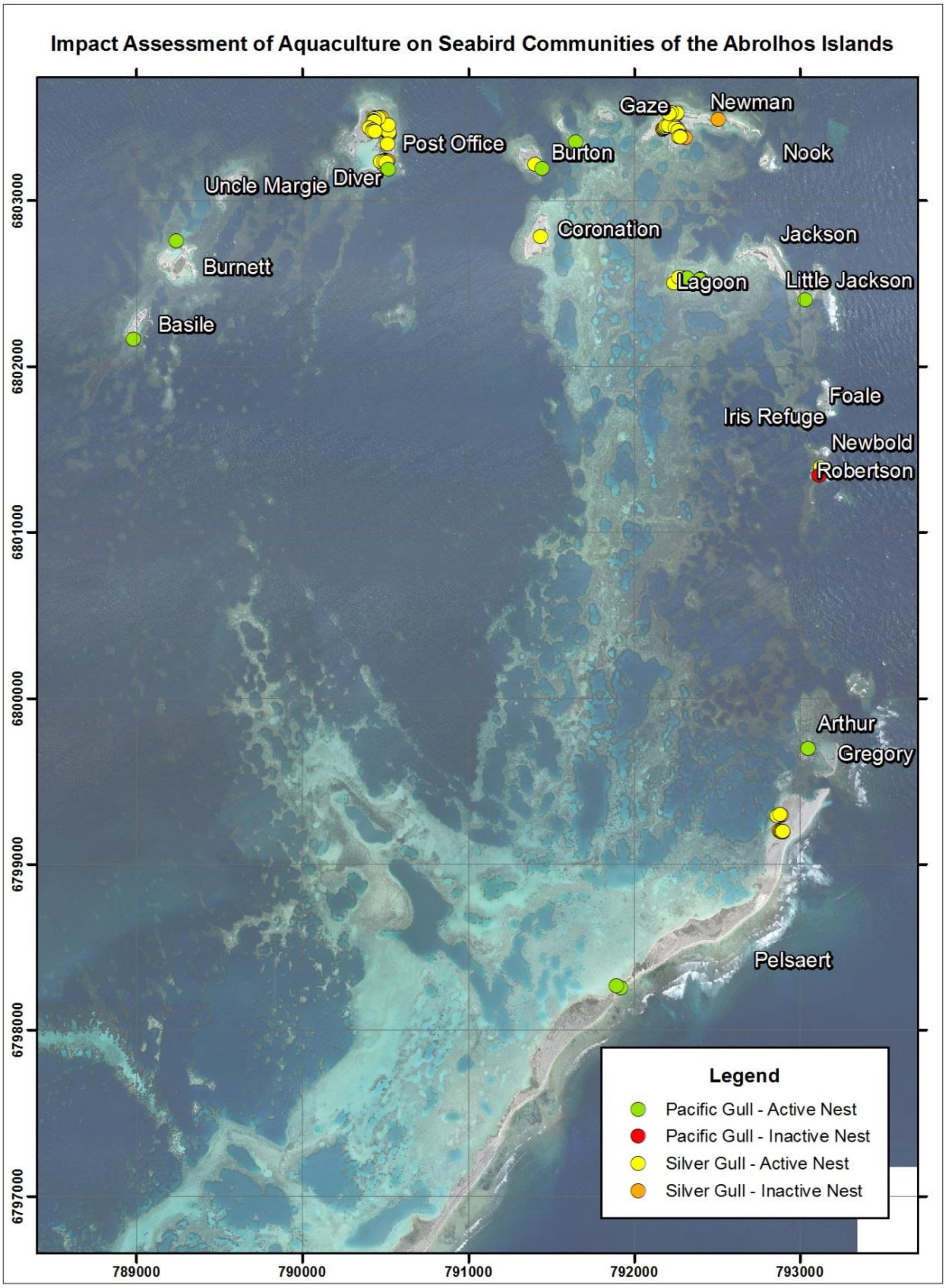


Figure 3.4:
Gull Distribution
Pelsaert Group
Index Map Reference Number P4
October 2014.
Author: C. Surman

Coordinate System: GDA 1994 MGA Zone 49

Document Name: GullSurvey_October2014_Fig34.mxd

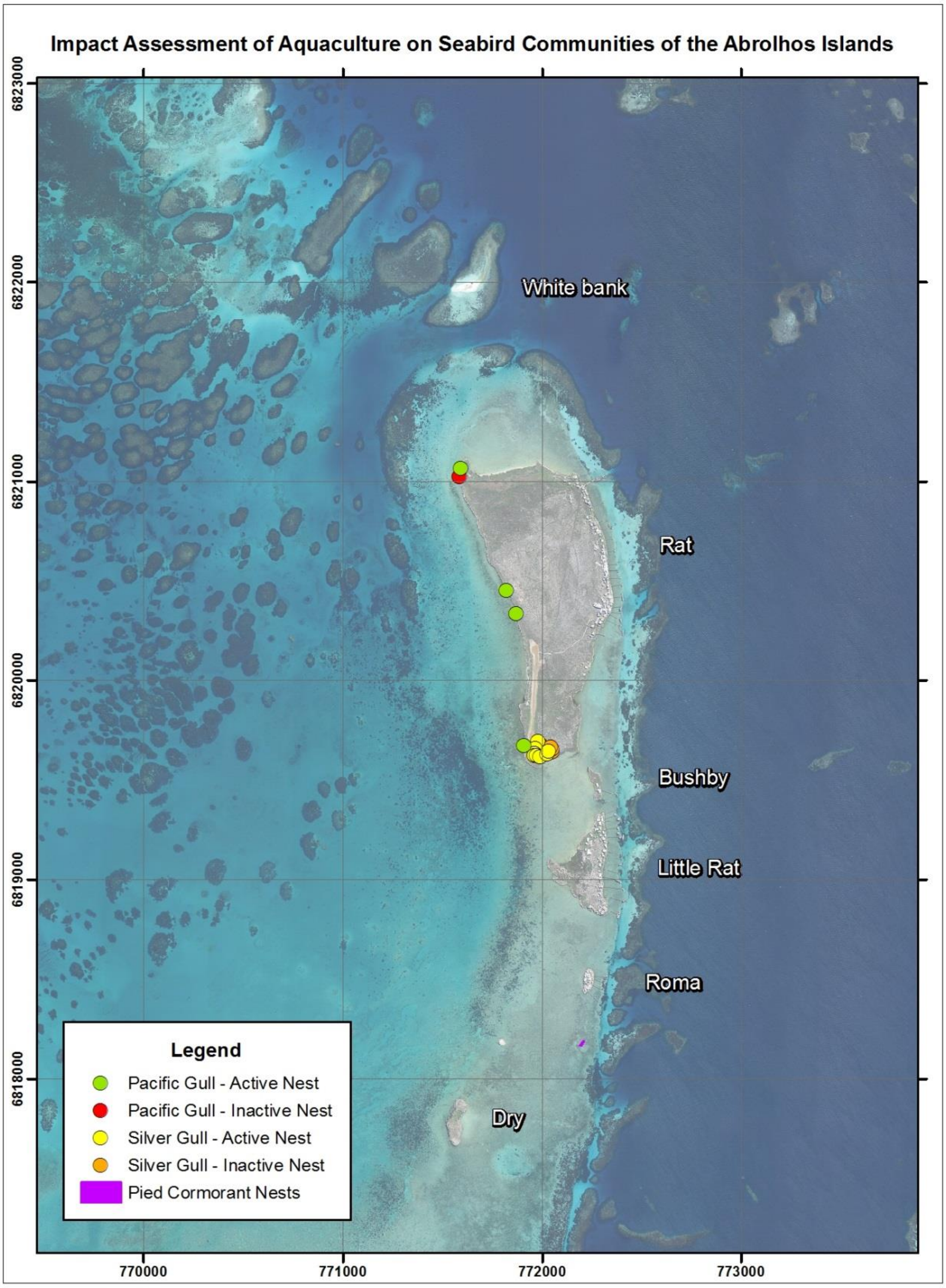


Figure 3.5:
Gull Distribution
Easter Group
Index Map Reference Number E1
October 2014.
Author: C. Surman

0 0.5 1 Kilometers

Coordinate System: GDA 1994 MGA Zone 49

N

Document Name: GullSurvey_October2014_Fig35.mxd

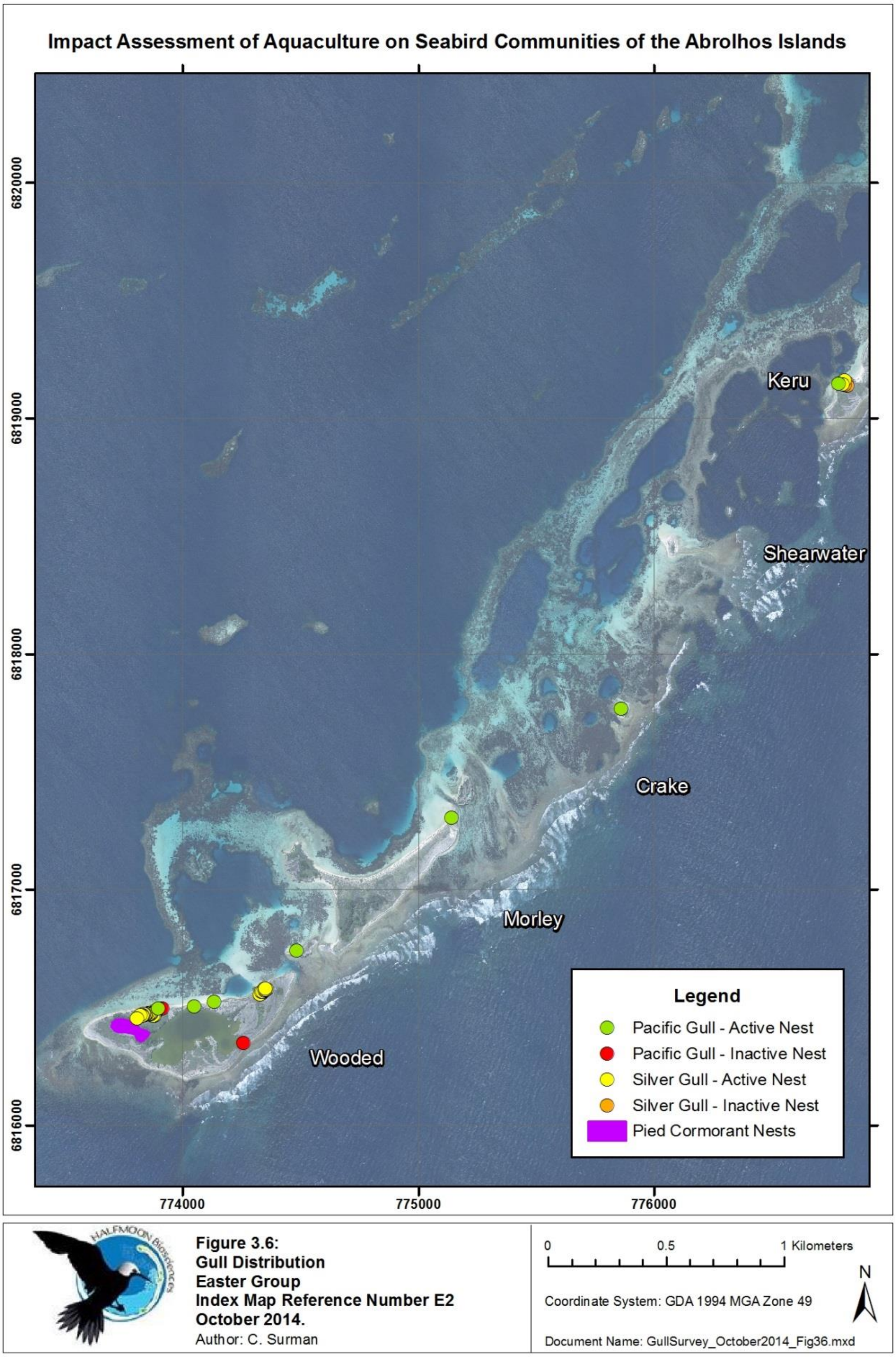


Figure 3.6:
Gull Distribution
Easter Group
Index Map Reference Number E2
October 2014.
Author: C. Surman

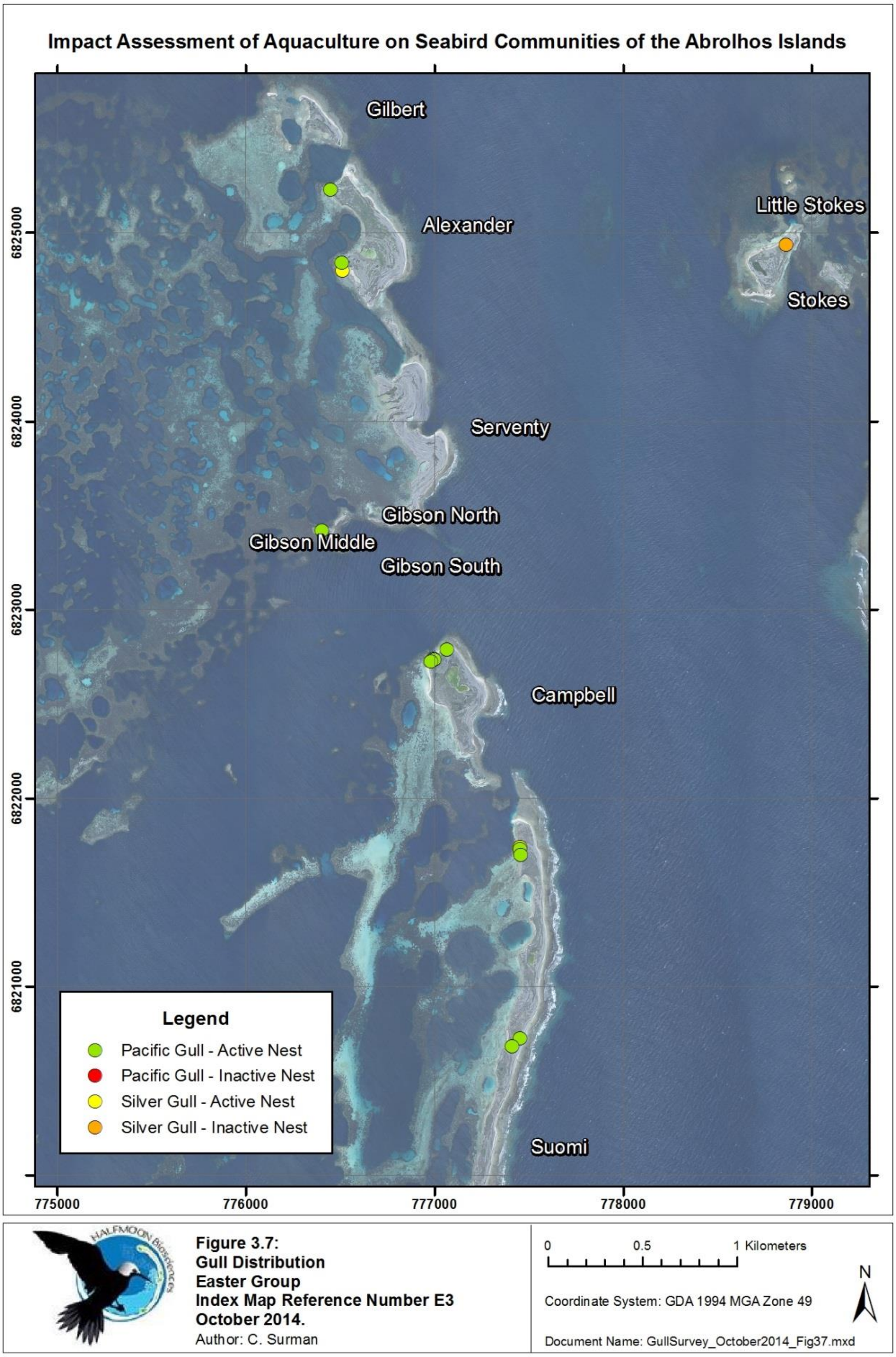


Figure 3.7:
Gull Distribution
Easter Group
Index Map Reference Number E3
October 2014.

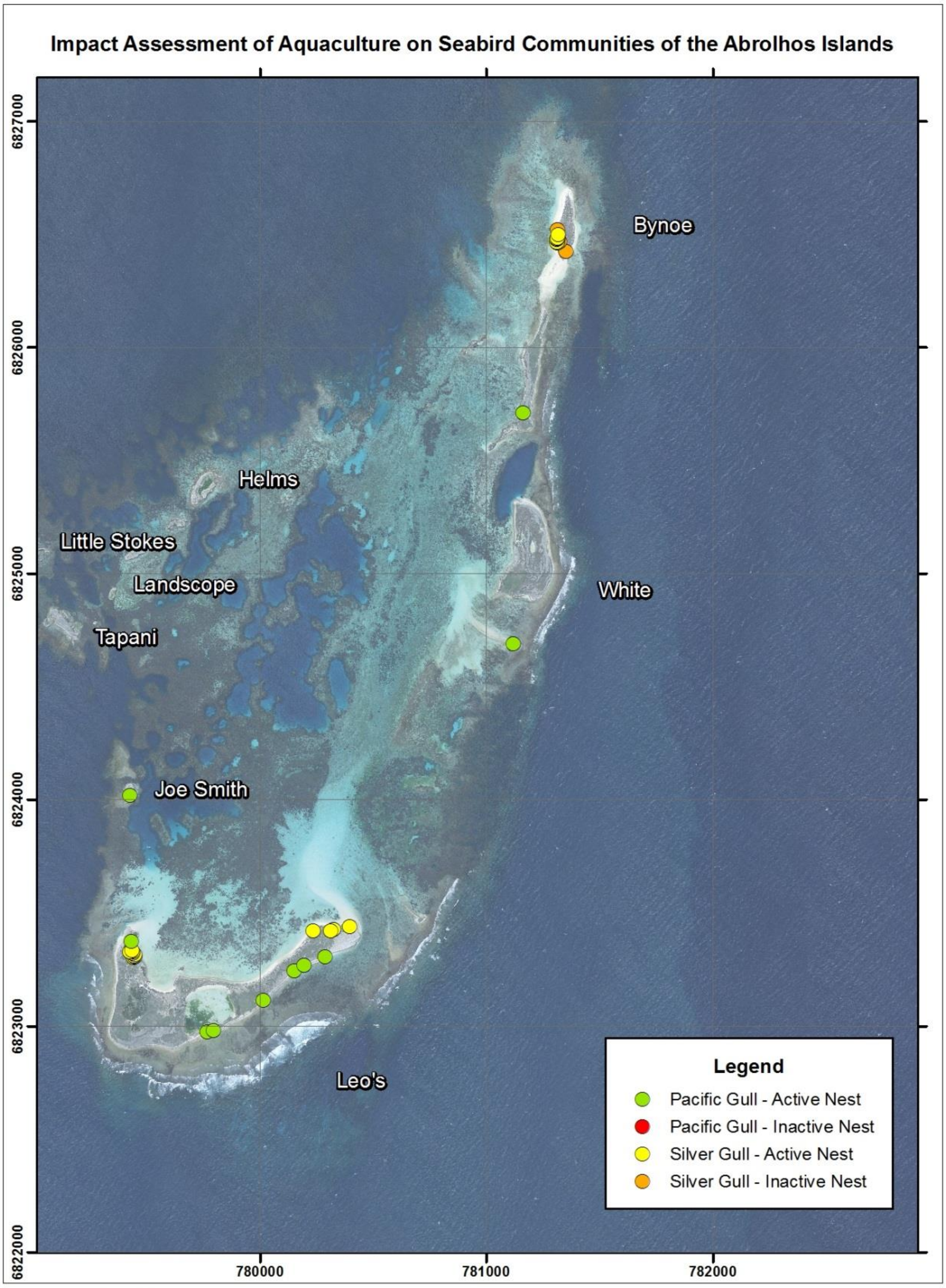


Figure 3.8:
Gull Distribution
Easter Group
Index Map Reference Number E4
October 2014.
Author: C. Surman

3.3 Diet

Table 3.6 and Figure 3.3 summarises the dietary data from regurgitated pellets from Silver Gulls, Pacific Gulls and Pied Cormorants collected during the 2014 field season. A total of 40 Pied Cormorant, 78 Silver Gull and 93 Pacific Gulls regurgitates were collected and sorted. Overall, 45 species of prey ranging from bird remains to insects were identified from regurgitated pellets.

The regurgitated pellets of Pied Cormorants were dominated by the remains of fishes, specifically Parrotfishes (Scaridae) and Wrasses (Labridae), which occurred in 50% and 10% of samples. Due to the degraded nature of pellets, there was a relatively high proportion of unidentified bony fish material, much of which contained fragmented portions of pharyngeal bones that could not be assigned to either the Scaridae or Labridae.

The two gull species had a wide-ranging diet. Overall the Silver Gull took 25 species of prey comprising two bird species, 8 crustaceans, 4 fishes, three plant species, two insects and two molluscs. Their diet was characterised specifically by intertidal crustaceans, occurring in 31.2% of all regurgitates, as well as plant material (30.1% of samples) and fishes. Silver Gulls were the only species with remains of fishing waste, with the remnants of Baldchin Groper occurring in one regurgitate.

The diet of Pacific Gulls consisted of 33 species; three species of birds, 16 species of crustaceans, six molluscs, two fish, one sea urchin and two plant species. Their diet was characterised predominately by intertidal crustaceans (59.1% of samples including shore, reef and hermit crabs as well as mantis shrimp), plant material (24.7% of samples) and cephalopods (22.6%). Their diet reflects a foraging habit along shorelines and reef flats during low tide. Table 3.7 is a summary of other dietary items recorded from Pacific Gull anvil sites. Interestingly, gastropod molluscs are more dominant at these sites, reflecting the lack of hard parts regurgitated from these prey types in the pellets of Pacific Gulls. Of the 167 prey items recovered from anvil sites, 82 (49.1%) were Turban Shells (*Turbo pulcher*), 23 (13.8%) were Shame-faced Crabs (*Calappa sp.*) and 22 (13.2%) were Baler Shells (*Melo amphora*).

Table 3.6: The contents of regurgitated pellets from Silver Gulls, Pacific Gulls and Pied Cormorants collected from the Houtman Abrolhos in 2014. N = total number of items of each prey type identified, F = Frequency of occurrence of each prey type (%).

	Pacific Gull		Silver Gull		Pied Cormorant	
Species	**N**	**F**	**N**	**F**	**N**	**F**
Aves						
Anous stolidus			7	8.9		
Anous tenuirostris			1	1.3		
Ardenna pacifica	1	1.1				
Pelagodroma marina	1	1.1				
Puffinus assimilis	1	1.1				
Unid	2	2.2	1	1.3		
Crustacea						
Odontodactylus sp.	4	4.3	13	9.7		
Dardanus sp.	1	1.1				
Calappa sp.	8	4.3				
Leptograpsus variegatus	18	11.8	6	6.4		
Thalamita sima	13	5.4	10	10.3		
Trizopagurus strigmanus	5	5.4				
Crab sp 3	3	2.2				
Portunas sp.	7	2.2				
Crab sp 5	3	3.2				
Nectocarcinus tuberculosus	4	4.3				
Crab sp 7			1	1.3		
Crab sp 8	3	2.2				
Ozius truncatus	18	4.3				
Crab sp 10	2	2.2				
Crab sp 11			1	1.3		
Crab sp 12			5	2.6		
Crab sp 13			3	1.3		
Crab sp 14	4	3.2				
Crab sp 15	3	2.2	1	1.3		
Crab sp 16	1	1.1				
Unid			6	3.9		
Osteichthyes						
Choerodon rubescens			1	1.3		
Scaridae sp1	2	2.2	10	7.7	12	20.0
Scaridae sp2			1	1.3	6	7.5
Scaridae sp3					6	10.0
Scaridae sp4					2	2.5
Labridae sp1					3	5.0
Labridae sp2					2	5.0
Labridae unid	2	2.2	3	2.6		

	Pacific Gull		Silver Gull		Pied Cormorant	
Species	**N**	**F**	**N**	**F**	**N**	**F**
Unid sp1					2	2.5
Unid sp2					1	2.5
Unid	11	11	10	10.3	16	32.5
Mollusca						
Gastropoda						
Ornithochiton quercinus	2	2.2				
Tectus Pyramus	32	8.6				
Turbo pulcher	12	5.4				
Unid					1	2.5
Cephalopoda						
Octopus sp.	2	2.2				
Sepiateuthis australis	9	4.3	1	1.3		
Sepia apama	1	1.1				
Unid	14	15.0	1	1.3	3	5.0
Echinoidea						
Tripneustes gratilla	1	1.1				
Insecta						
Coleoptera			5	4		
Dermaptera			4	2		
Plantae						
Myoporum insulare	211	4.3	181	7.7		
Nitraria billardierei	461	20.4	289	28.2		
Atropa belladonna			1925	25.6		
Plastics			1	1.3		

Figure 3.3: Diet composition by class of (a) Silver Gull, (b) Pacific Gull and (c) Pied Cormorant at the Houtman Abrolhos during 2014.

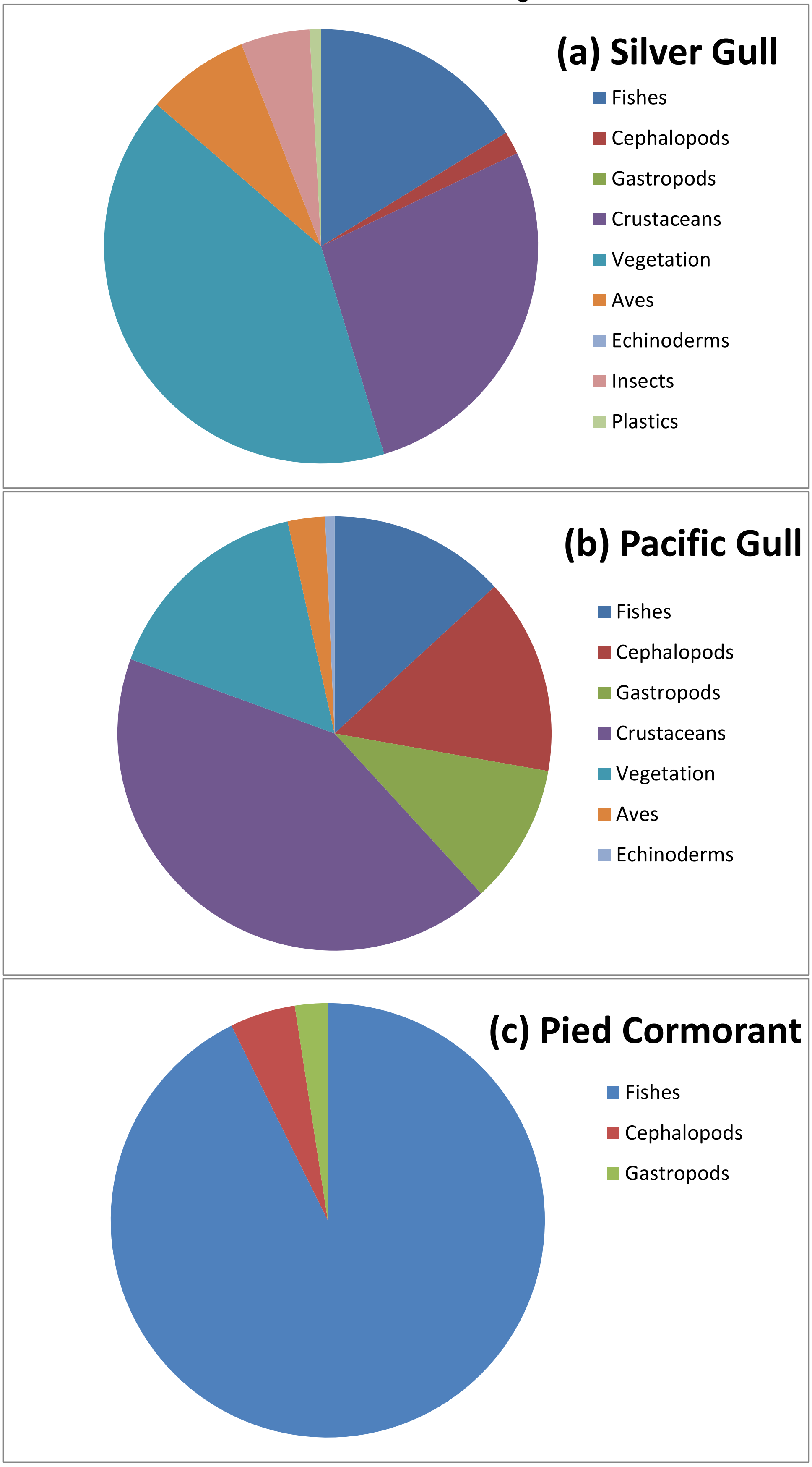


Table 3.7: Diet composition of the Pacific Gull collected from anvil sites at the Houtman Abrolhos during 2014.

Island	Animalia													Plantae
	Mollusca					Crustacea			Echinodermata		Chordata			
	Gastropoda				Cephalopoda	Decapoda			Echinoidea		Osteichthyes			
Easter Group	*Tectus Pyramus*	*Turbo pulcher*	*Cymatium mundum*	*Melo amphora*	*Unid.*	*Calappa sp.*	*Leptograpsus sp.*	*Dardanus sp.*	*Tripneustes gratilla*	*Echinometra mathaei*	*Scomber sp.*	*Choerodon rubescens*	*Unid*	*Nitraria*
Alexander	8	9	0	0	0	0	0	0	0	0	0	0	0	0
Bynoe	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Dry	2	2	0	0	0	0	0	0	0	0	0	0	0	0
Eight	2	2	0	2	0	0	0	0	0	0	0	0	0	0
Gibson	2	0	1	0	2	0	0	0	0	0	0	1	0	0
Helms	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Leo	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Little Rat	3	3	0	0	0	0	0	0	0	0	0	0	0	0
Little Stokes	1	0	0	0	0	1	0	0	0	0	0	0	0	1
Rat	8	0	0	0	0	0	0	0	1	0	0	0	0	0
Shearwater Islet	3	15	0	0	0	0	0	0	0	0	0	0	0	0
Pelsaert Group														
Basile 1	3	12	0	0	0	0	0	0	0	0	1	0	0	0
Basile 2	0	11	0	0	0	0	0	0	0	0	0	0	0	0
Davis	0	1	0	3	0	20	0	0	0	0	0	0	0	0
Gun	2	6	0	0	1	0	0	0	0	0	0	0	0	0
Lagoon	5	0	0	0	0	0	0	0	0	0	0	0	0	0
One	5	2	0	8	0	0	0	0	0	0	0	0	0	0
Pelsaert 1	0	0	0	0	1	0	1	1	4	2	0	0	1	0
Pelsaert 2	0	0	0	0	0	0	1	0	1	0	0	0	0	0
Sid Liddon	0	2	0	2	0	0	0	0	0	0	0	0	0	0
Sweet	2	5	0	7	0	1	0	0	0	0	0	0	0	0
Travia middle	0	10	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	**46**	**82**	**1**	**22**	**4**	**23**	**2**	**1**	**6**	**2**	**1**	**1**	**1**	**4**

3.4 Assessment of foraging behaviour - Stable Isotope Analysis

The current isotopic niches of the three potential increaser seabirds Mantis Shrimp, Top Shell *Tectus* and Squid are plotted on Figure 3.4. Also plotted are $\delta^{13}C$ or $\delta^{15}N$ values from Sooty Terns and Flying Fish (Sooty Tern prey items) from the regional oceanic food-chain (J.N. Dunlop unpublished data) to put the Abrolhos littoral ecosystem into its wider marine context. The $\delta^{13}C$ or $\delta^{15}N$ values for the dominant terrestrial ant on the Abrolhos Islands (*Polyrachis ammonoeides*, Dunlop *et al.* 2013) are also included to provide the isotopic niche of a terrestrial omnivore.

The $\delta^{13}C$ or $\delta^{15}N$ values for the gull mollusc, crustacean and cephalopod prey items from the gull pellets are consistent with these prey being taken from oligotrophic waters with much of the carbon (energy) coming from seagrasses (Smit *et al.* 2005, Hyndes & Lavery 2005) and probably from corals. The $\delta^{13}C$ or $\delta^{15}N$ values in flying-fish and Sooty Terns show the depleted $C^{13}$and slightly more enriched N^{15} (more productive) values for the adjacent oceanic waters.

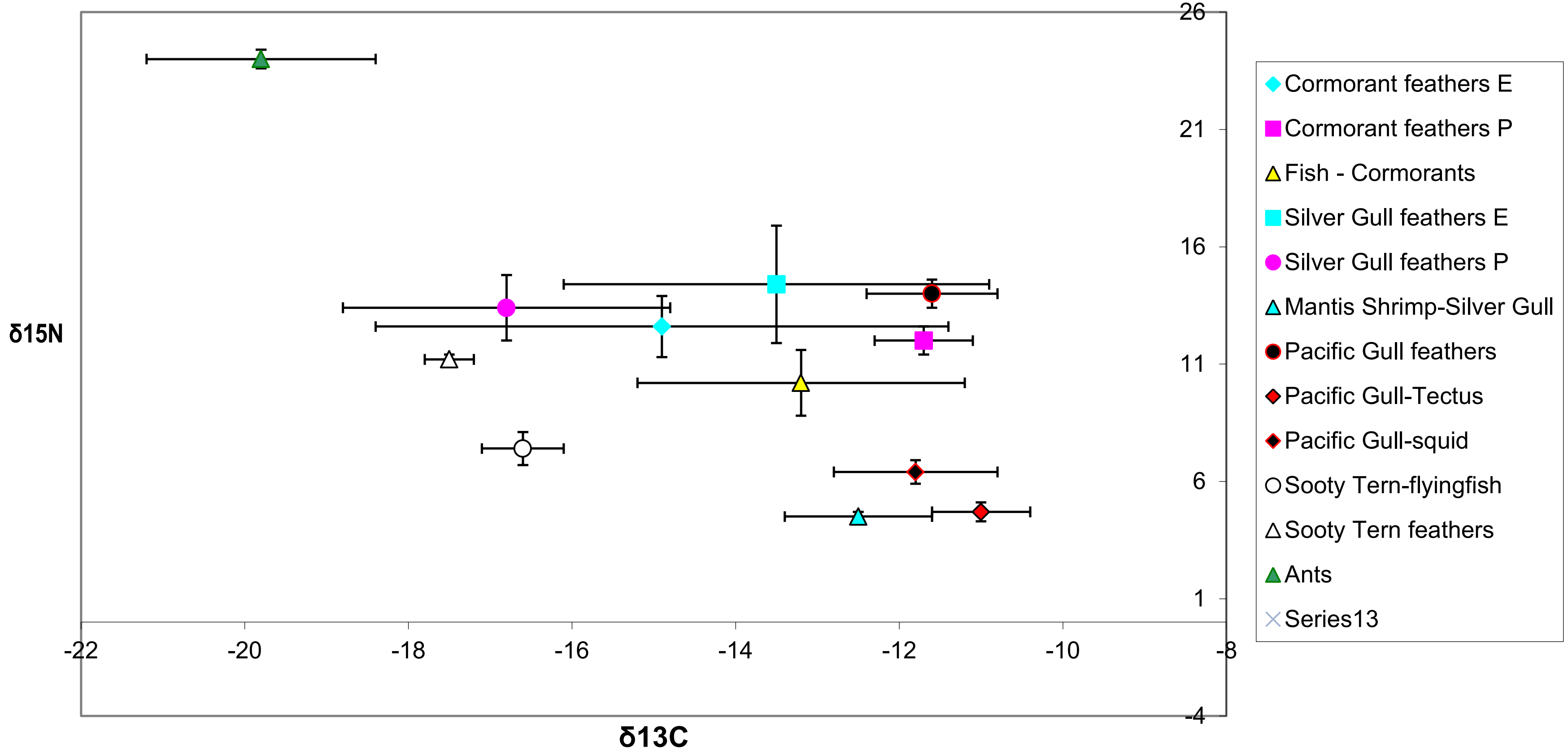
The fish samples taken from cormorants indicate a similar foraging environment (perhaps with some carbon coming from benthic algae) but the fish prey were feeding at a higher trophic level. Pied Cormorants in the Easter Group are evidently foraging over a wider range habitats than those from the Pelsaert Group, including more areas where the carbon is coming from macro-algae and /or phytoplankton.

The pellet analysis shows that the diet of Pied Cormorants is almost entirely fish and the nitrogen stable isotope ratios in the Cormorant feathers were effectively one trophic level above the prey sampled. The Gulls however were observed to have diverse diets and the feather samples were around two trophic levels higher than the prey (Mantis Shell, Top Shell and Cephalapods) sampled from the pellets. These prey with hard body parts are probably over-represented in pellets and fish of greater importance. Silver Gulls have slightly lower trophic levels than Pacific Gulls probably indicating the larger gull's raptorial behaviour (e.g. as a predator of other seabirds, and scavenger of dead predators). This would also raise the $\delta^{15}N$ values relative to the prey sampled from their pellets.

The high $\delta^{15}N$ values and lower $\delta^{13}C$ in Silver Gull feathers relative to the pellet material sampled for SI analysis probably reflects the degree to which these opportunists supplement their marine diet with terrestrial material. The consumption of various berries and insects was observed in the dietary analysis and in the field. The terrestrial ecosystems of seabird islands have very high $\delta^{15}N$ baseline values due to the volatilization of ammonia from guano (note location of the ant signature on Figure 3.4).

This analysis of current foraging patterns indicates that all species may respond to any increased availability of fish in the fish-farming areas. The gulls, and particularly the Silver Gulls, are most likely to utilise any direct subsidy from fish feed.

Figure 3.4: The current isotopic niches (as represented by $\delta^{13}C$ or $\delta^{15}N$ values) of the three potential increaser seabirds the Pied Cormorant, Silver Gull and Pacific Gull taken from feather, mantis shrimp, trochus shell (*Tectus pyramis*) and squid samples at both the Easter (E) and Pelsaert (P) Groups. Isotope values from Sooty Terns and Ants from Rat Island are included as a comparison.



4 Prediction of behavioural and population responses

4.1 Foraging behaviour and potential interactions with Houtman Abrolhos seabirds: Cause effect flow diagrams for key threats.

The sections below outline cause effect pathways for six key groups of seabirds that have been identified as being potentially impacted from fin fish aquaculture at the Houtman Abrolhos, these are:

- Pied Cormorants
- Silver Gulls
- Pacific Gulls
- Wedge-tailed Shearwaters
- Neritic Terns
- Pelagic Foraging terns and noddies

4.1.1 Pied Cormorants

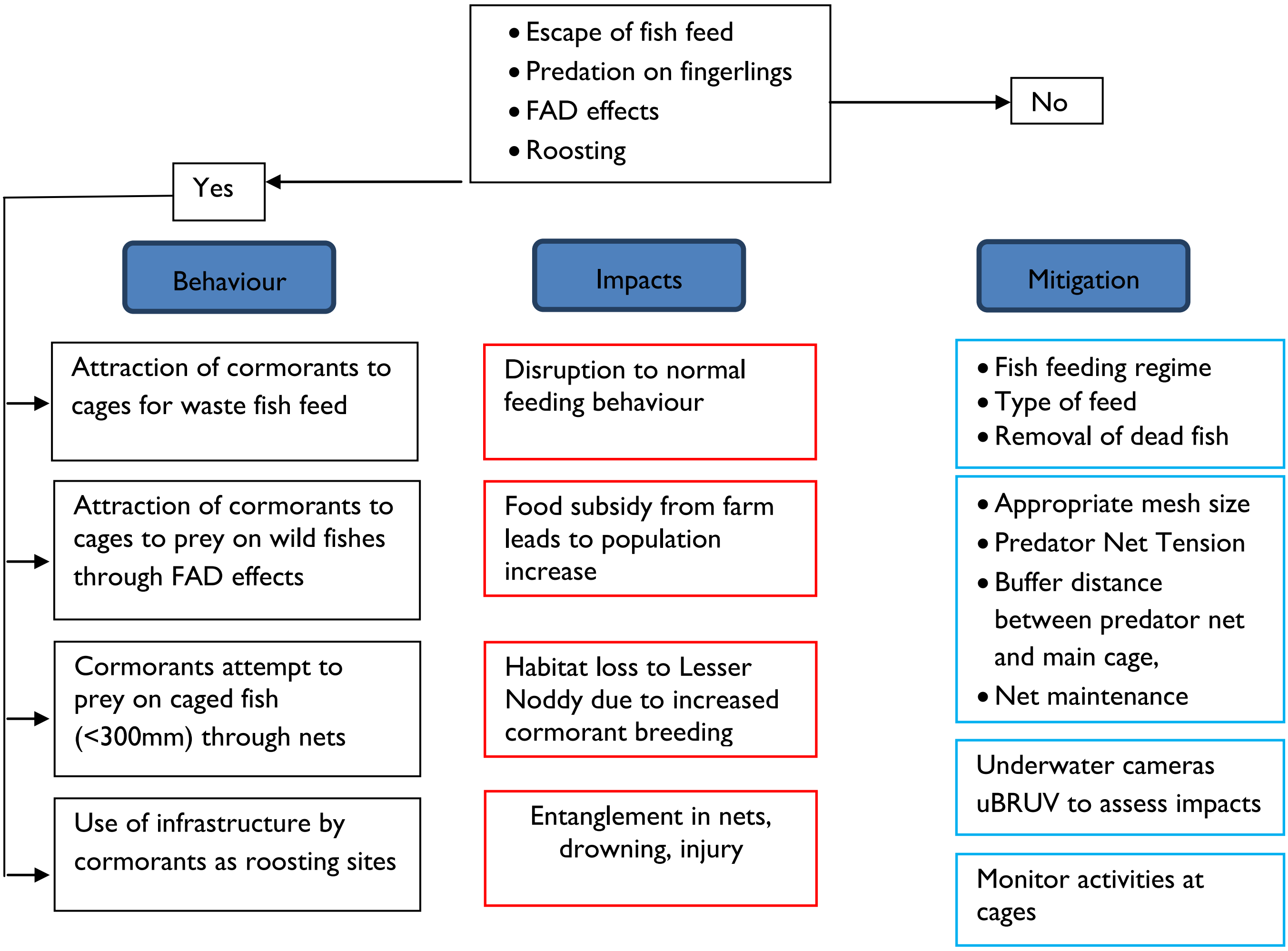
Conservation Status: Increasing in numbers in southern metropolitan coastal waters and possibly in Shark Bay Population: 1, 861 pairs, 1,222 Easter Group, 639 Pelsaert Group.

Approximately 1,861 pairs of Pied Cormorant nest throughout the Houtman Abrolhos, most on Wooded Island, however significant numbers (>500) are observed foraging regularly throughout the Pelsaert Group. Pied Cormorants have been observed foraging in the region of the Southern (Pelsaert Group) aquaculture site, and may continue to do so in relatively low numbers.

Pied Cormorants actively pursue fish prey underwater regularly attaining depths of 20 m or more. Moreover, Pied Cormorants are known to chase whole fishes from wetline vessels, and to enter rock-lobster pots in pursuit of small fishes attracted to the pots by bait. Beveridge (2001) identified cormorants as presenting the most likely seabird predator around sea cages in fish farms in Scotland. This species is likely to feed upon any cultured fish available that are less that 300mm long, as well as on fish prey attracted to sea cages through FAD effects and feed drift.

A risk associated with this activity is entanglement in the mesh of the walls of the cages, resulting in drowning. Mitigation would involve strict controls of excess fish food being allowed to escape the cages, regular maintenance of nets to repair holes and maintain tautness (Kemper *et al.* 2003, Pemberton 1996), and an appropriate mesh size (approximately 6cm, see Kemper *et al.* 2003).

Best management practices regarding maintenance of predator nets will reduce the risk of entanglement, as well as reduce predation of fish prey. However FAD effects of sea cages may result in an increase in food supply and feeding opportunities to Pied Cormorants, resulting in an increase in this species population size. Any increase in Pied Cormorant population size may result in more habitat loss for the threatened Lesser Noddy through nest site competition at mangroves in the Easter Group.


• Escape of fish feed
• Predation on fingerlings
• FAD effects
• Roosting
No
Yes
Behaviour
Impacts
Mitigation
Attraction of cormorants to cages for waste fish feed
Attraction of cormorants to cages to prey on wild fishes through FAD effects
Cormorants attempt to prey on caged fish (<300mm) through nets
Use of infrastructure by cormorants as roosting sites
Disruption to normal feeding behaviour
Food subsidy from farm leads to population increase
Habitat loss to Lesser Noddy due to increased cormorant breeding
Entanglement in nets, drowning, injury
• Fish feeding regime
• Type of feed
• Removal of dead fish
• Appropriate mesh size
• Predator Net Tension
• Buffer distance between predator net and main cage,
• Net maintenance
Underwater cameras uBRUV to assess impacts
Monitor activities at cages

4.1.2 Silver Gulls

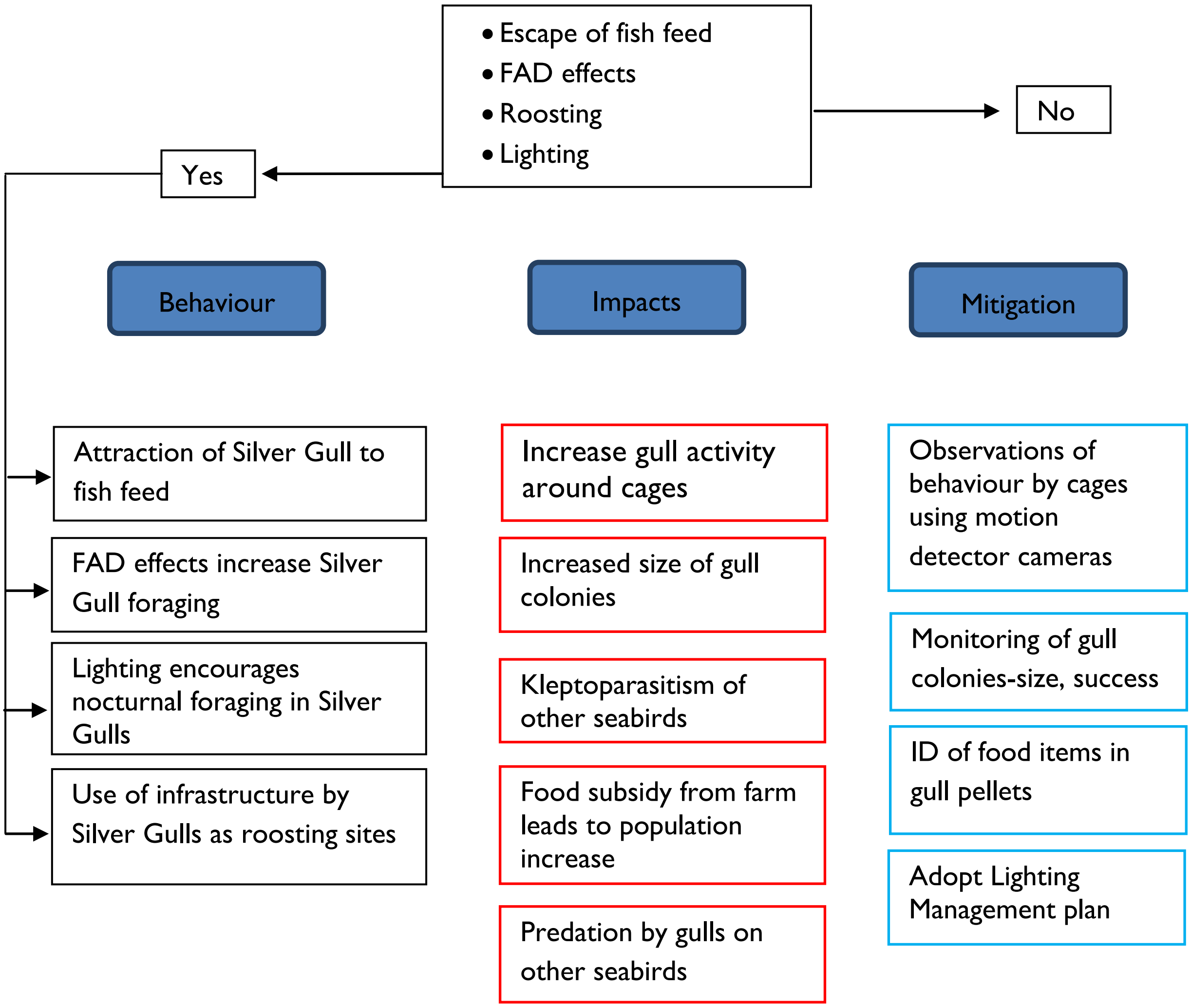
Conservation Status: Increased near major urban centres such as Perth and Albany and on islands near oil platforms

Population: Highly variable, 50-264 pairs. The current Silver Gull summer population is relatively small (~50 pairs), reflecting food availability (Nitre bush berries, seabird eggs and chicks, marine invertebrates) during the summer months. A larger breeding population (~ 150+ nests) once nested in the Pelsaert Group during the autumn, taking advantage of bait discards from A Zone rock-lobster boats and food scraps from fishing camps. There is a latent breeding population indicated by the large proportion of nest sites built without breeding attempts (110 of the 237 nests located across the two groups – see Table 3.3). Throughout Western Australia, higher numbers of Silver Gulls are often in association with refuse sites. The current breeding Silver Gull population at the Houtman Abrolhos is naturally very small.

Gulls elsewhere predate heavily on the eggs and young of other seabird species (Becker 1995) and will also kleptoparasitize other seabirds-and cormorants for their food (Stienen *et al.* 2001). The greatest risk for the proposed fish-farming development is an increase in the availability of food to the autumn breeding population of gulls and the flow on impacts to other seabirds nesting in the area.

Both gulls and fulmars adjusted their behaviour in line with fishery activities (Hamer *et al.* 1997, Oro *et al.* 1997). Discards from trawl fisheries increased the frequency of feeds provided to chicks and resulted in more successful breeding. In a largely fish eating gull species, discards from trawl fisheries accounted for 73% of the diet, having a dramatic effect of adult time budgets and chick provisioning rates. Increased availability of food for gulls across the North-west Shelf from gas flares over water has led to massive increases in gull populations with consequential displacement of other nesting seabirds and the predation of their young and eggs (L. Nicholson *pers comm*.) and hatchling turtles. The situation with the Silver Gull population explosion in response to the tuna pens at Port Lincoln was summarized in section 1.4, however access to fish food (pilchards) allowed the Silver Gull to expand its breeding season (now parallels the tuna ranching season), increase their reproductive output (per pair) and exponentially increasing its local breeding population from 3,300 pairs in 1999 to 27,800 pairs in 2005 (Harrison 2010).

Unlike Pied Cormorants, Silver Gulls cannot dive for prey, therefore access to young fish, or pelletised food is likely to be at the surface. However, the FAD effects of sea cages may present a foraging opportunity, particularly if lights are used at night aggregating zooplankton.


Escape of fish feed
FAD effects
Roosting
Lighting
No
Yes
Behaviour
Impacts
Mitigation
Attraction of Silver Gull to fish feed
FAD effects increase Silver Gull foraging
Lighting encourages nocturnal foraging in Silver Gulls
Use of infrastructure by Silver Gulls as roosting sites
Increase gull activity around cages
Increased size of gull colonies
Kleptoparasitism of other seabirds
Food subsidy from farm leads to population increase
Predation by gulls on other seabirds
Observations of behaviour by cages using motion detector cameras
Monitoring of gull colonies-size, success
ID of food items in gull pellets
Adopt Lighting Management plan

4.1.3 Pacific Gulls

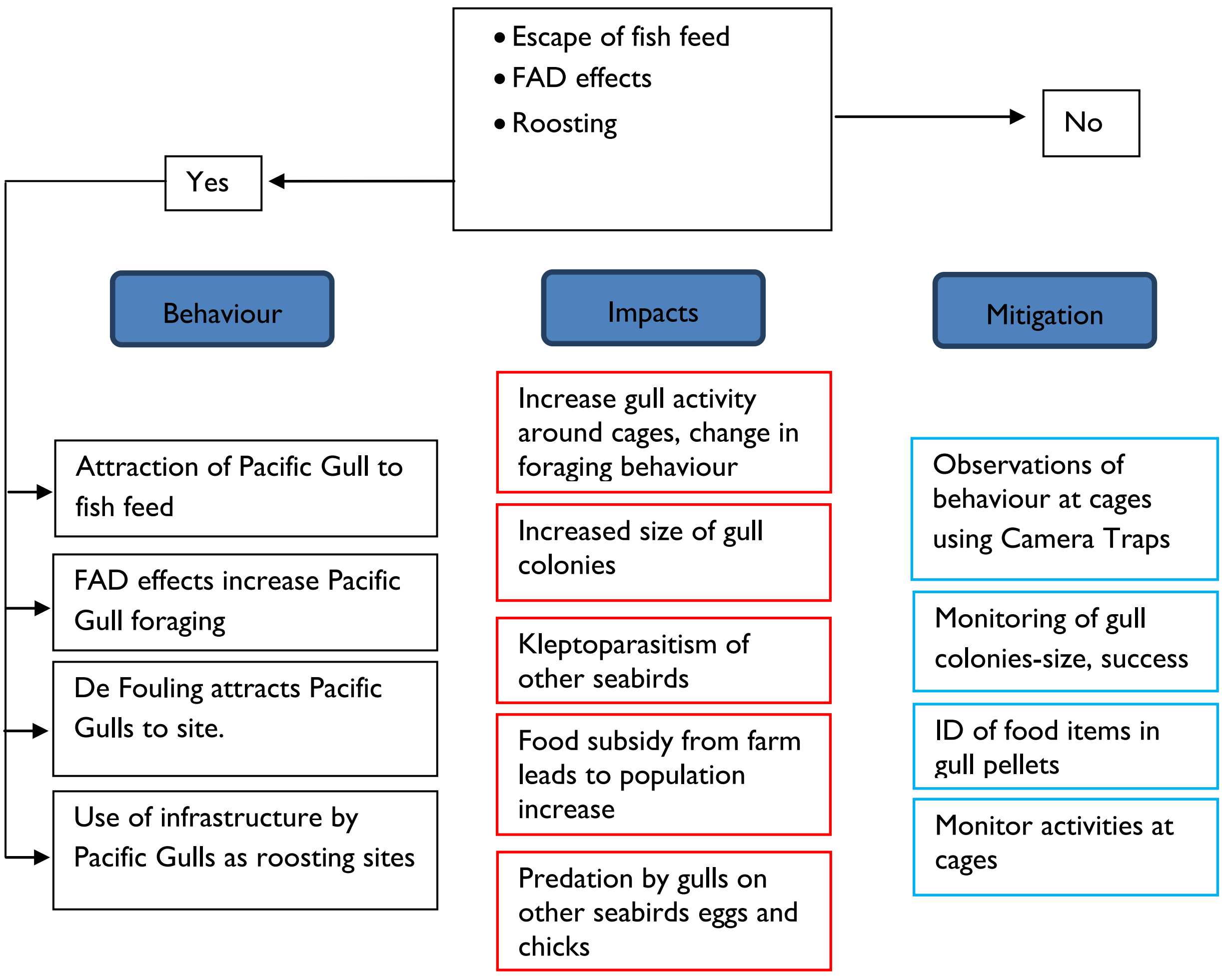
Conservation Status: Considered near threatened with a small and possibly genetically distinct west coast population.

Population: Highly variable, 50-264 pairs.

The Houtman Abrolhos represents the largest population of Pacific Gulls *Larus pacificus* along the Western Australian coast. Currently there are 74 active pairs of Pacific Gulls across the Easter and Pelsaert Groups at the Houtman Abrolhos (Table 3.4). Previously we recorded 127 Pacific Gulls (Surman and Nicholson 2009a). Elsewhere this species is threatened by displacement by the successful scavenging gull the Kelp Gull *Larus dominicanus*. Almost half of all Pacific Gulls found at the Houtman Abrolhos nest within the Pelsaert Group (Fuller *et al.* 1994).

Pacific Gulls are predominately predatory, foraging on reef flats at low tide on whelks, trochus shells, turbo shells, baler shells, mantis shrimps, cuttlefish, octopuses and crabs. However, during the previous seasonal Zone A rock lobster fishing season they scavenged for bait scraps from fishing boats and upon fish frames from wet line boats and other areas where fish are cleaned.

Impacts from an increase in food availability include the replacement of predatory behaviour for scavenging behaviour in this species. These impacts however, may provide a net positive increase for the Pacific Gull population given that it is so small. However, over the longer term, population increases in such a large species may not be sustainable and increases based on available food during the summer may have negative population impacts during other times of the year. Predation rates on other seabird species eggs and chicks and in particularly adult Storm-petrels may increase.



4.1.4 Wedge-tailed Shearwaters.

Conservation Status: EPBC Marine and Migratory.
Population: 1.1 million pairs.

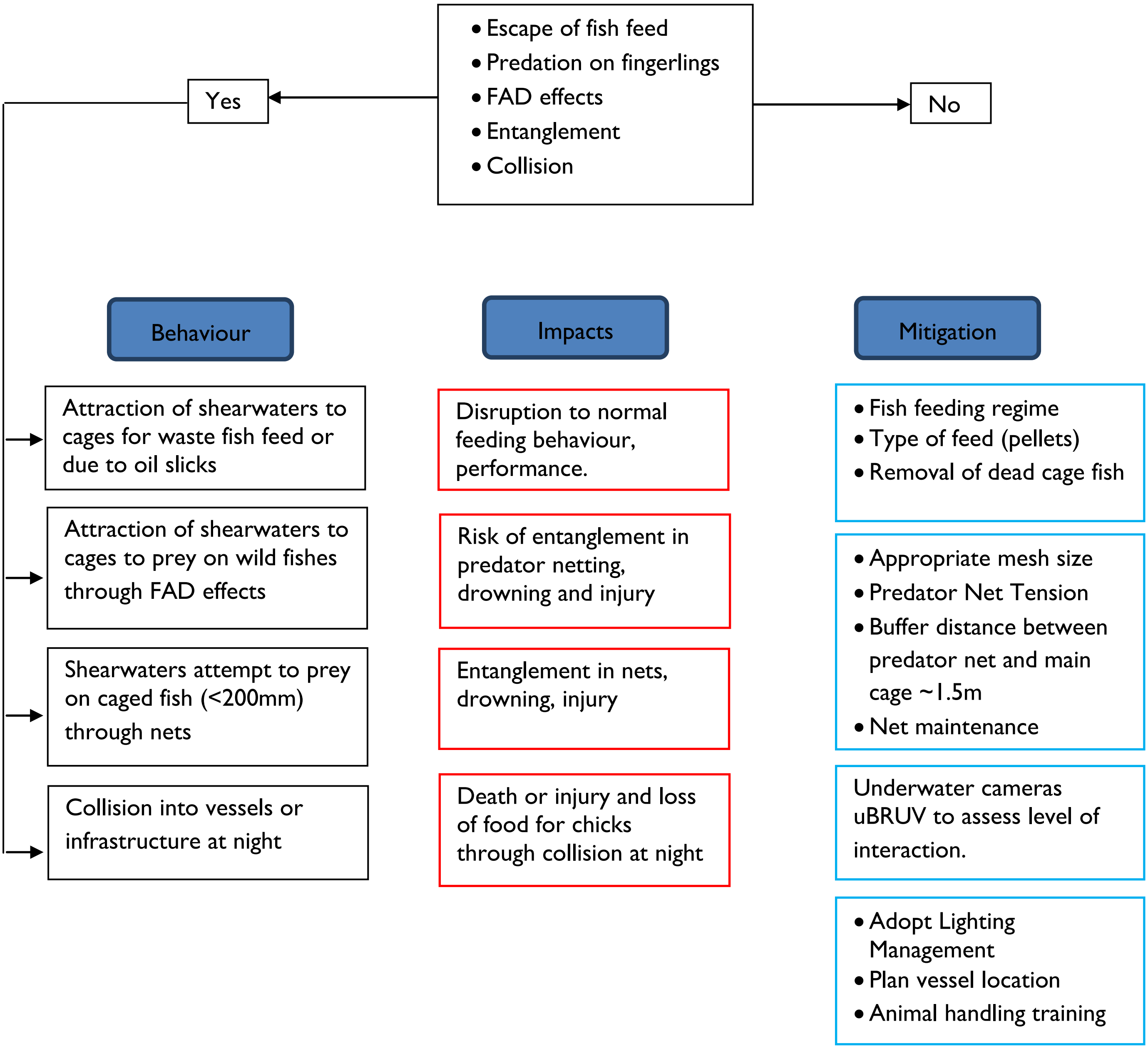
Wedge-tailed Shearwaters *Ardenna pacifica* is the most populous seabird nesting at the Houtman Abrolhos. Current estimates indicate a population of 2.2 million birds scattered over 11 islands, most on Pelsaert (160 000) and West Wallabi (2 million). As with the majority of seabirds, they return to the Houtman Abrolhos in August and breed over the summer months before their young fledge in May. The Abrolhos populations are significant at a national level.

Wedge-tailed Shearwaters pursue their prey actively underwater, and are capable of reaching depths of between 3-66m (Burger 2001). This allows them access to any fish feed on the surface, below the cages or seeping from cage walls. These shearwaters accompany operating lobster boats scavenging bait discards and capturing animals exiting through the escape gaps of pots during pulling. They would be capable of foraging in and out of the nets, as well as below the cages for any fish scraps. In doing so they may potentially be entangled in the mesh of the cages and drown. Wedge-tailed Shearwaters are also vulnerable to collision as they forage at night and commute to and from the colony under the cover of darkness. Shearwaters are often disorientated by lighting, resulting in collisions and injury or death. Mooring of any vessels overnight on site will require stringent light management protocols for part of the year.

Heffernan (1999) found that diving seabirds in the northern hemisphere, like puffins and guillemots, visit fish farms to feed upon increased wild fishes attracted to sea cages (i.e. the FAD effect). Wedge-tailed Shearwaters have been observed foraging regularly in the Middle Channel and Geelvink Channel in the vicinity of the proposed aquaculture leases, although these are not regarded as the major foraging sites. However this species forages on prey (i.e. Scaly Mackerel, Slender Sprat – see Gaughan *et al.* 2002) that are likely to aggregate around sea cages, and if attracted May potentially become entangled. They are also known to be attracted by oil slicks from sea cages, and dead fish.

Wedge-tailed Shearwaters are also known to undergo high variability in their reproductive success due to natural variability in marine productivity (Dunlop *et al.* 2002) that may be measured through growth rates in chicks (Petit *et al.* 1984). They consume large amounts (1000's of tonnes pa) of Scaly Mackerel *Sardinella lemura* and squids (Gaughan *et al.* 2002).

Best management practices regarding maintenance of anti-predator nets as outlined by Sagar (2013 and Kemper et al. 2003) will reduce the risk of entanglement of diving shearwaters, as well as reduce predation upon smaller cultured fish prey. These are listed in Table 4.1, and in Table 4.5.


• Escape of fish feed
• Predation on fingerlings
• FAD effects
• Entanglement
• Collision
Yes
No
Behaviour
Impacts
Mitigation
Attraction of shearwaters to cages for waste fish feed or due to oil slicks
Disruption to normal feeding behaviour, performance.
• Fish feeding regime
• Type of feed (pellets)
• Removal of dead cage fish
Attraction of shearwaters to cages to prey on wild fishes through FAD effects
Risk of entanglement in predator netting, drowning and injury
• Appropriate mesh size
• Predator Net Tension
• Buffer distance between predator net and main cage ~1.5m
• Net maintenance
Shearwaters attempt to prey on caged fish (<200mm) through nets
Entanglement in nets, drowning, injury
Underwater cameras uBRUV to assess level of interaction.
Collision into vessels or infrastructure at night
Death or injury and loss of food for chicks through collision at night
• Adopt Lighting Management
• Plan vessel location
• Animal handling training

4.1.5 Neritic Terns

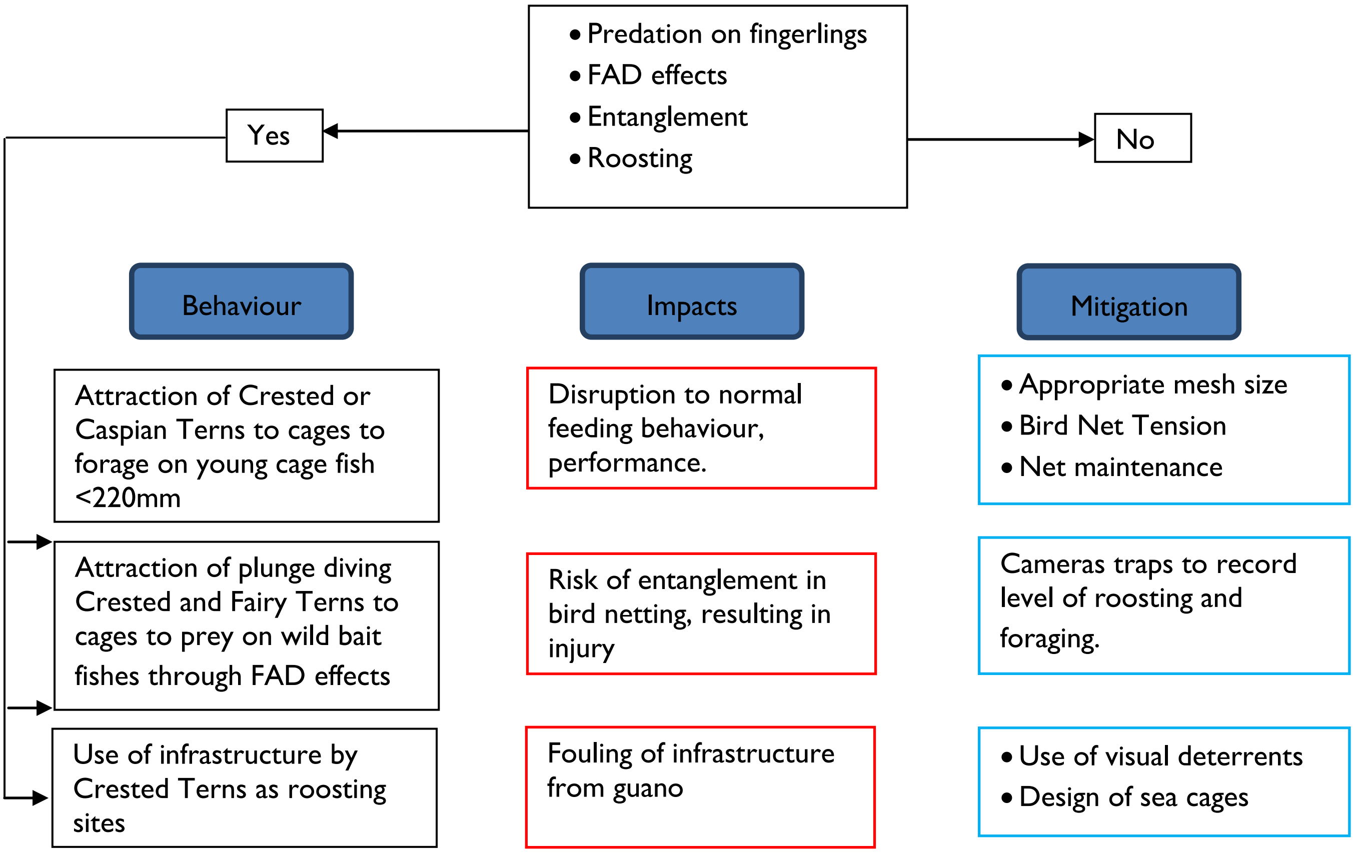
Conservation Status: EPBC Marine and Migratory (Fairy Tern Threatened).
Populations: Crested Tern ~3000 pairs.
Caspian Tern ~70 pairs
Fairy Tern ~550 pairs.

Neritic terns are those tern species that in part forage over shallow waters adjacent to coasts or islands. At the Houtman Abrolhos these comprise Crested, Fairy, and Caspian Terns. These birds are plunge-divers, which can reach depths of 1 m or so in pursuit of schooling bait fishes.

Crested Terns nest in colonies of up to 1000 pairs throughout the Houtman Abrolhos (Fuller *et al*. 1994, Surman and Nicholson 2009a) with half the population nesting within the Pelsaert Group. Crested Terns feed predominately upon schools of small-medium sized schooling fishes over shelf waters. At the Houtman Abrolhos their preferred prey are Scaly Mackerel *Sardinella lemura* (Surman and Wooller 2003). Of the 4300 Crested Terns nesting at the Houtman Abrolhos, 52 % are on the Pelsaert Group. Fairy Terns also nest in colonies from a few pairs to several hundred pairs. They feed predominately upon small fishes, particularly slender sprat (*Spratelloides gracillis*), juvenile black-spotted goatfish (*Parupeneus signatus*) and hardyheads (Atherinidae). The large Caspian Tern feeds almost exclusively over shallow reef flats on wrasses, blennys, mullet, whiting and gobies.

Crested Terns are likely to be influenced by the presence of fishes in cages, and may also feed in cages if sea cages are not covered. Fairy Terns are more likely to feed upon small surface fishes attracted to sea cages through FAD effects.

Fairy Terns nest in large colonies in the Easter and Pelsaert Groups and plunge dive for smaller, schooling fishes including post larval Mullids and hardyheads (Atherinids). They may be attracted to fish schools aggregated around the pens from time to time.

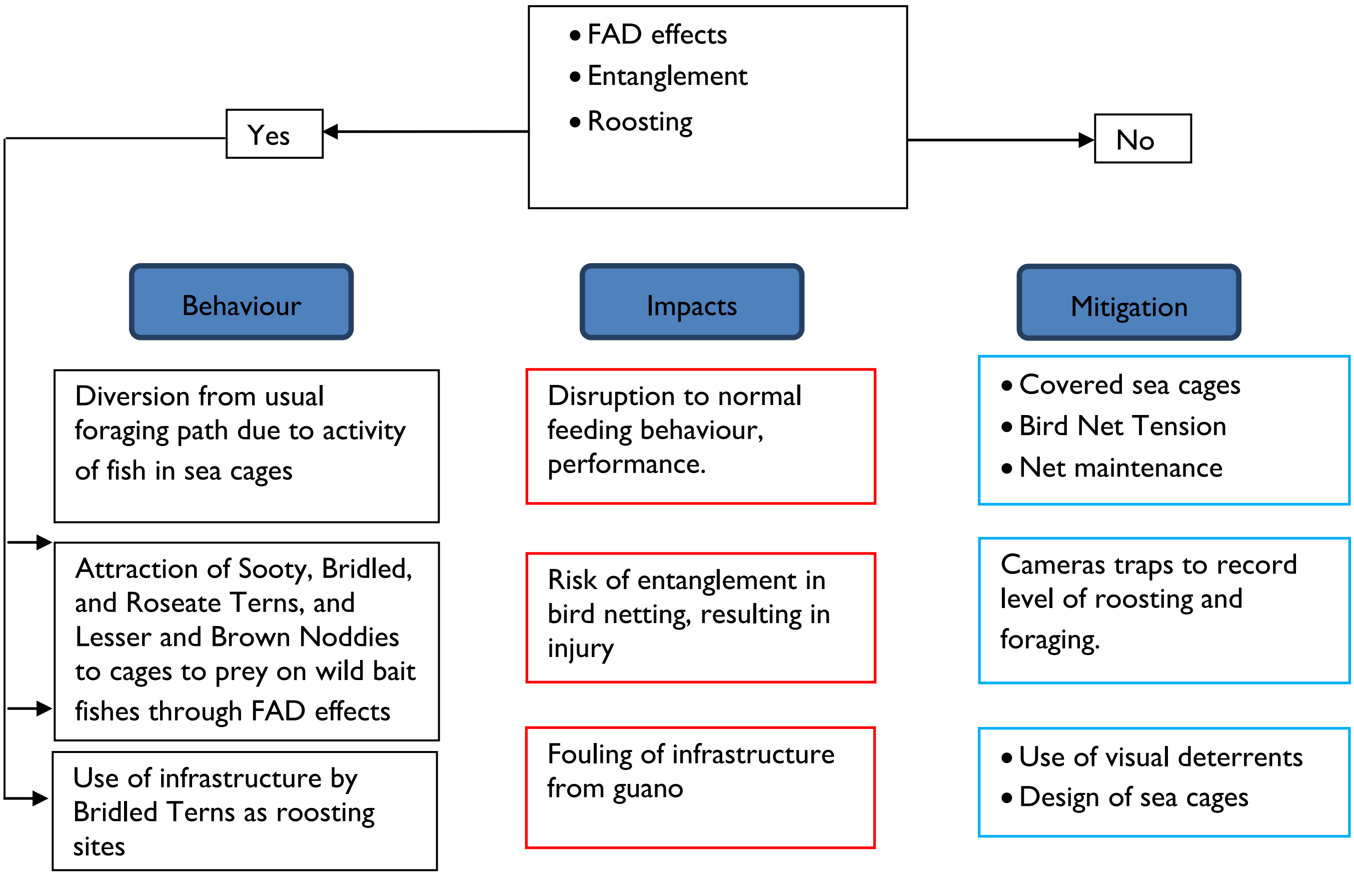

• Predation on fingerlings
• FAD effects
• Entanglement
• Roosting
Yes
No
Behaviour
Impacts
Mitigation
Attraction of Crested or Caspian Terns to cages to forage on young cage fish <220mm
Attraction of plunge diving Crested and Fairy Terns to cages to prey on wild bait fishes through FAD effects
Use of infrastructure by Crested Terns as roosting sites
Disruption to normal feeding behaviour, performance.
Risk of entanglement in bird netting, resulting in injury
Fouling of infrastructure from guano
• Appropriate mesh size
• Bird Net Tension
• Net maintenance
Cameras traps to record level of roosting and foraging.
• Use of visual deterrents
• Design of sea cages

4.1.6 Pelagic foraging terns and noddies

Conservation Status: EPBC Marine and Migratory (Lesser Noddy Threatened).
Populations: Lesser Noddy 34500 pairs.
Brown Noddy 132000 pairs
Sooty Tern ~200000 pairs.
Roseate Tern 4210 pairs
Bridled Tern ~7000 pairs

Sooty Terns *Onychoprion fuscata*, Brown Noddies *Anous stolidus* and Lesser Noddies *A. tenuirostris* form a large community of breeding seabirds at the southern end of Pelsaert Island. There are 260 000 Sooty Terns (65 % of total Abrolhos population), 264 000 Brown Noddies (100 % of total) and 45 000 Lesser Noddies (65 % of total) breeding over summer at the Pelsaert Group. These seabirds feed in association with predatory fishes (i.e. tunas) as well as over large schools of larval fishes and squids across both shelf and oceanic waters at least 150km west of the Houtman Abrolhos (Surman *pers. obs*.).

Large numbers of Sooty Terns and Brown Noddies may pass over the proposed fish farm, and may be influenced by activity of the fishes in the cages and diverted from their normal flight paths and foraging trips. Bridled Terns *Onychoprion anaethetus* occur in the area in lower densities but will use any floating objects to rest upon, and may also forage upon aggregations of baitfishes associated with the sea cages. Mixed flocks of seabirds (Roseate Terns, Bridled Terns, Crested Terns and Wedge-tailed Shearwaters) have been recorded foraging in the area in association with skipjack tuna and bronze whaler sharks.



4.2 Risk & Mitigation Assessment

In Table (4.1) all the potential adverse interactions (risks) between seabirds and sea cage fish-farming at the Abrolhos Islands are identified together with the available 'best practice' mitigation measures. It is assumed that all the relevant wildlife mitigation measures outlined in the Department's ' Representation of Aquaculture Operations' will be adopted by any proponent from the outset.

Table 4.1: Seabird Interaction Risk Mitigation at Floating Pen Fish Farms at the Houtman Abrolhos Islands.

Factor	Interaction	Potential Consequence	Available Mitigation Methods
1. Pen Location	Attraction: • Seabirds attracted to pens from colonies on the Houtman Abrolhos Islands. • Seabirds distracted from normal flight path by fish activity adjacent sea cages or within sea cages.	• Changes in seabird behaviour or energetics, changing reproductive performance or increasing mortality • Changes in seabird population sizes leading to increased interspecific competition, kleptoparisitism, predation of eggs and young and habitat alteration on the Houtman Abrolhos Islands. • Shifts in terrestrial ecosystems driven by changes in breeding seabird numbers.	• All locations are within foraging range of all seabird breeding species. Choice between proposed fish-farming zones on this scale is unlikely to reduce potential for interactions.
2. Fish - feed	Fish feed is available to foraging seabirds providing an energy / nutrient subsidy, this is less likely if pelletised feed is used. Species likely to exploit fish food are gulls and cormorants.	• Increasing populations of potential increaser species (Silver Gulls, Pacific Gulls and Pied Cormorants) leading to ecological changes (see 1 above). • Increase Pied Cormorant populations will reduce nesting habitat for Lesser Noddies on Wooded Island. • Increased gull populations may impact other nesting seabirds through predation and competition.	• Pellets preferred over whole fish. • Sub-surface, slow release feeders. • Current speeds not sufficient to allow lateral export of feed through meshes. • Complete pen coverage with bird mesh. • Submersible sea-cages
3.Cultured fish size	• Seabirds attracted to forage on farmed stock within their preferred prey size ranges. • Seabirds distracted by large schooling species associated with mixed species foraging aggregations.	• Increasing populations of both gulls and cormorants leading to ecological changes (see 2 above). • Loss of cultured stock. • Reduced foraging efficiency reducing reproductive performance. • Risk of entanglement in anti-predator netting.	• Complete pen coverage with bird mesh. • Submersible sea-cages. • Anti-predator nets with appropriate mesh size for seabirds (6cm) • Space between anti predator net and sea cage ~1.5m.
4. Sea-pen diameter	Interactions with aerial-snatch predators (e.g. Sea-Eagles & Ospreys) will increase with pen diameter.	• Loss of farmed stock, and redistribution or increased abundance of marine raptors.	• Complete pen coverage with bird mesh. • Limit diameter of sea-cages. • Submersible sea-cages
5. Raft characteristics	Some seabirds (e.g. Bridled Terns, gulls) preferentially perch on flotsam	• Faeces from birds may reduce water quality, transfer pathogens / parasites to stock.	• Complete pen coverage with bird mesh. • Design of railings, floats, net-rings to reduce

Factor	Interaction	Potential Consequence	Available Mitigation Methods
	or floating objects and may utilise sea-cages as roosts.	• Collisions with structures or entanglement with nets. • Fouling of gear. • Negative interactions from staff towards native fauna	perching. • Alternative artificial rafts. • Submersible sea-cages • Bird Deterrents (Visual, audio, physical)
6. FAD effects	Attraction of larval fish and crustaceans, bait fishes and predatory fishes due to FAD effects of superstructures.	• Seabirds may concentrate around fish farms increasing potentially adverse interactions (see 1 above). • Increased foraging opportunities for some species (increaser species). • Increased risk of entanglement from foraging seabirds	• FAD effects are likely to increase with distance from reefs. • Alternative artificial rafts or reefs. • Mesh sizes.
7. Fish oil slicks	Oily residues from stock and feed will form slicks which draw-in forage fishes (enhancing FAD effect) and seabirds (particularly olfactory foragers such as shearwaters and storm-petrels).	• Seabirds may concentrate around fish farms increasing potentially adverse interactions (see 1 above). • Increased foraging opportunities for some species (increaser species). • Increased risk of entanglement from foraging seabirds, particularly diving species.	• Reduce oil content /production of feeds. • Remove dead fish from cage
8. Superstructure and predator nets	Structures including netting above and below the water surface may entrap or entangle foraging or roosting seabirds.	• Increased mortality particularly among pursuit diving species, e.g. cormorants and shearwaters. • Potential entanglement from Osprey and White-breasted Sea Eagles.	• Appropriate mesh sizes, visibility and net tension. • Regular net checks and maintenance • Camera trap monitoring • uBRUV monitoring
9. Lighting	• Many seabirds fly at night and are disorientated by bright navigation or vessel flood-lights. • Lights may also attract zooplankton further increasing the FAD effect of sea-cages allowing gulls to feed at night	• Increased seabird mortality from collisions with super structure of cages and moored vessels. • Enhanced prey aggregation around fish-farms may increase adverse interactions with seabirds. • Enhanced food supply for increaser species, Silver Gulls are known to forage under lights at night.	• Development of lighting management plan • Design of light horizon and wavelength. • Reduction in use of lighting. • Seasonal lighting reduction policies.
10.Moored Vessels	• Accommodation and farm vessels	• Increased seabird mortality from collisions (see 9 above).	• Development of lighting management plan

Factor	Interaction	Potential Consequence	Available Mitigation Methods
	on site increase collision and disorientation risks to seabirds. • Moored vessels provide roosts for seabirds • Vessel wastes may attract increaser species. • Increased boating traffic may deter natural foraging behaviour.	• Loss of food for seabird young from adults regurgitating after collision or disorientation on vessel. • Enhanced food supply for increaser species, Silver Gulls are known to forage under lights at night or on waste from vessels (food scraps, bait, and offal).	• Design of light horizon and wavelength. • Management plan for reducing impacts from collision • Training for bird handling and reporting • Reduction in use of lines or rigging across vessel • Mooring location outside of flight paths.
11.Marine Debris	Loss of lines, netting, plastics, floats or refuse from operations.	• Entanglement of marine fauna in portions of nets or lines lost from farm or over side of vessels (scuppers). • Ingestion of plastics from farm wastes, reduction in foraging efficiency and delivery of food to young.	• Waste management plan • Return of all waste to mainland • Maintenance of farm gear • Mesh over scuppers to prevent loss to sea.
12. Food Supplementation from de-fouling operations	Gulls that rely naturally on marine invertebrates may be attracted to operations removing encrustations	Food supplementation or entrapment	Collection of biological material for disposal away from aquaculture operations or burial.

References: Sagar (2013)

4.3 Risk assessment of direct and indirect impacts of the MWADZ proposal on seabirds

4.3.1 Context and scope

The current threat identification, hazard pathway analysis and risk assessment in relation to seabirds at the Houtman Abrolhos was conducted to identify and assess the potential impacts of finfish aquaculture on seabirds within of the MWADZ. Both the inherent risk (risk before application of management controls) coupled to the residual risk (following application of proposed management controls) were assessed in order to determine the nature and level of management controls required to bring the cumulative risks around sea-cage culture of finfish in the MWADZ to an acceptable level.

The assessment is based on applied knowledge and from the limited records relating to interaction between seabirds and culture of marine finfish (see Sagar 2008, 2013, Lloyd 2003, Pemberton 1996, Kemper *et al.* 2003 and Price and Morris 2013). The assessment has also considered all available relevant information relating to:

- the proposed location within the Abrolhos Islands' Fish habitat Protection Area (FHPA);
- Seabirds known to inhabit the FHPA in the vicinity of the MWADZ, and in particular the behavioural biology of each seabird species;
- the likely characteristics of yellow tail kingfish aquaculture (proposed aquaculture);
- Proposed management framework and options for minimising interactions between seabirds and the proposed aquaculture.

Information on interactions between seabirds and aquaculture is limited. However, this risk assessment was undertaken using the combined knowledge of 80 years of working with seabirds in the marine environment (Dr JN Dunlop, Dr LW Nicholson and Dr CA Surman), and for one of us (CAS) a total of 25 years of research conducted at the Houtman Abrolhos.

4.3.2 Hazard Pathway Analysis

Individual hazards as listed in Table 4.1 above were assessed with respect to their risk with respect to both inherent risk (i.e. baseline risk if no management measures aimed at mitigating the risk were in place) and residual risk (i.e. remaining risk once one or a number of proposed management controls have been effected). This process was undertaken to both understand the individual inherent hazards as well as to provide clarity as to the specific hazard or risk that a particular management activity is targeted at mitigating. This in turn assists in assessing whether management controls are adequate to manage risk of the entire pathway to an acceptable level and to identify any additional management actions required to address specific unacceptable risks.

In order to determine a quantifiable Risk Level (see Table 4.3 for definitions of Risk Levels), a consequence versus likelihood risk matrix for each potential threat was undertaken (Table 4.2, Fletcher 2014). We have chosen a 4x4 matrix for this analysis.

The consequence rating (1-4) is a measure of the outcome of an event that may impact the objectives, that is it is an arbitrary measure of the level of impact resulting from a threat. The Likelihood rating (1-4) is the probability of such an event occurring. The combined score of the consequence and likelihood rating is then used to determine the overall Risk Rating (Table 4.4) considered from the threat or impact. Definitions of both likelihood and consequence are presented in Table 4.3.

To facilitate the thought process of assessing potential threats to seabirds from aquaculture we have produced flow diagrams and descriptions of threat pathways for each of the main seabird species considered to be potentially impacted from fin fish aquaculture (see Section 4.1 above).

Table 4.2: Consequence versus likelihood risk matrix (after Fletcher 2014) for risk assessment for seabirds resulting from the MWADZ.

		Likelihood			
		Remote	Unlikely	Possible	Likely
Consequence		1	2	3	4
Minor	1	1	2	3	4
Major	2	2	4	6	8
Extreme	3	3	6	9	12
Minor	4	4	8	12	16

Table 4.3: Descriptions of likelihood and consequence indicators in relation to impacts to seabirds from the MWADZ (after Fletcher 2014).

Likelihood Level	**Likelihood descriptor**
Remote	A particular consequence level is unknown in such projects, but may still be plausible, probability 1-2%.
Unlikely	The consequence is not expected to occur within the lifetime of the project, probability of 3-9%.
Possible	A particular consequence level may occur within the lifetime of the project with a probability of 10-39%.
Likely	A particular consequence level is expected to occur within the time frame with a probability of 40-100%
Consequence Level	**Consequence descriptor**
Minor	Measureable but minimal impacts that are acceptable and meet objectives
Moderate	Maximum acceptable level of impacts that will still meet objectives.
Major	Above acceptable levels of impact with broad and/or long term negative effects on objective. Restoration may be achieved within a short to moderate time frame.
Extreme	Unacceptable level of impact. Serious effects upon objective with long or unobtainable restoration period.

Table 4.4: Levels of risk (and colour coding) and likely management responses and reporting requirements in relation to impacts to seabirds form the MWADZ (after Fletcher 2014).

Risk Level	Risk Score (Consequence vs. Likelihood)	Management Response	Expected Management/Mitigation Requirements
Negligible (0)	0-2	Acceptable; no specific control measures needed	None specific
Low (1)	3-4	Acceptable; with current risk control measures in place (no new management required)	Specific management and/or monitoring required
Moderate (2)	6-8	Not desirable; continue strong management actions OR new and/or further risk control measures to be introduced in near future	Increases to management activities needed
High (3)	9-16	Unacceptable; major changes required to management in immediate future	Increases to management activities needed urgently

4.3.3 Hazard Analysis: Potential negative effects of aquaculture on Seabirds

Table 4.5. Assessment of hazards to seabirds. Hazards were individually analysed with respect to both the inherent hazard (i.e. baseline hazard if no management measures aimed at mitigating the hazard were in place) and their residual hazard (i.e. remaining hazard once one or a number of the proposed management controls have been implemented). Please refer to Table 4.1 for details on interactions, consequences and mitigation methods for each identified Hazard.

Hazard (see Table 4.1 for details)	**Inherent Hazard Assuming No Management Controls**	**Justification**	**Residual Hazard Following Implementation Of Management Controls**	**Justification And Identified Management Controls** (See Section 4.1 for details).
1 Entanglement. Seabirds becoming entangled in sea cage netting, bird netting or anti predator netting during foraging or roosting, causing drowning.	Likelihood Likely (4) Consequence Moderate (3) Hazard Score (12) Risk Level (3) **High**	***Consequence: Moderate.*** *More than a few individuals impacted particularly EPBC protected diving species (Shearwaters) as well as Pied Cormorants* ***Likelihood: Likely***. *Certain that without management measures seabirds will become entangled.*	Likelihood Possible (3) Consequence Minor (1) Hazard Score (3) Risk Level (1) **Low**	***Consequence: Minor***. *A few individuals may be impacted in each year* ***Likelihood: Possible.*** *Occasional entanglement may occur even with best practices.* ***Management Controls***: • *Appropriate net maintenance including net tension* • *Spacing between predator net and sea cage (1.5m)* • *Appropriate mesh size (6cm).* • *Digital Camera monitoring of interactions i.e. uBRUV and*

				Camera Trap monitoring
2. Food Subsidy from fish feed. Gulls or cormorants receiving food subsidy from sea cages and increasing population size. Increase in gull or cormorant numbers impacting upon eggs and young of other seabird species including EPBC listed species.	Likelihood Likely (4) Consequence Major (3) Hazard Score (12) Risk Level (3) **High**	***Consequence: Major*** *Recovery of a vulnerable population impeded (Lesser Noddies), ecosystem altered through increase in gull or cormorant numbers.* ***Likelihood: Likely*** *Certain that without management measures gulls and cormorants will exploit fish fee and respond with increase in breeding populations.*	Likelihood Unlikely (2) Consequence Minor (1) Hazard Score (2) Risk Level (0) **Negligible**	***Consequence: Minor*** *Minor changes to ecosystem structure, few individuals impacted in most years.* ***Likelihood: Unlikely*** *Not expected to occur, but may occur under special circumstances.* ***Management Controls**:* • *Fish fed pelletized food* • *Feed rate controlled to prevent escape of feed for sea cages* • *Appropriate bird netting and maintenance including net tension* • *Appropriate anti-predator netting mesh size and spacing.* • *Appropriate mesh size (6cm).* • *Digital Camera monitoring of interactions i.e. uBRUV and Camera Trap monitoring.*
3. Attraction due to Pen Location. Seabirds attracted to sea cages from colonies at Houtman Abrolhos, resulting in changes to foraging behaviour,	Likelihood Likely (4) Consequence Moderate (2) Hazard Score	***Consequence: Moderate*** *Change to population impacted or potential change in ecosystem structure through increase in the size of breeding populations of increaser species (gulls or cormorants) resulting in kleptoparasitism*	Likelihood Possible (3) Consequence Moderate (2) Hazard Score	***Consequence: Moderate*** *Locations of sites are within range of all seabird populations. Choice of sites is unlikely to reduce this interaction.*

reproductive performance or mortality (see also 2 above)	(8) Risk Level (2) **Moderate**	*or predation.* ***Likelihood: Likely*** *Certain that without management measures gulls and cormorants will exploit fish fee and respond with increase in breeding populations.*	(6) Risk Level (2) **Moderate**	***Likelihood: Possible*** *Occasional interactions may occur even with best practices.* ***Management Controls**:* • *Appropriate bird netting and maintenance including net tension may reduce attractiveness of site to some species.* • *Digital Camera monitoring of interactions i.e. uBRUV and Camera Trap monitoring to see if non-increaser species are attracted to sea cages.*
4. FAD effects. Attraction of baitfish, crustaceans and predatory fishes due to FAD effects of superstructures. May result in changes to seabird's natural foraging behaviour.	Likelihood Likely (4) Consequence Moderate (2) Hazard Score (8) Risk Level (2) **Moderate**	***Consequence: Moderate*** *Change to population impacted or potential change in ecosystem structure through increase in the size of breeding populations of terns or cormorants or other seabird species.* ***Likelihood: Likely*** *Certain that without management measures baitfish will aggregate around sea cages and seabirds will exploit this resource.*	Likelihood Possible (3) Consequence Moderate (2) Hazard Score (6) Risk Level (2) **Moderate**	***Consequence: Moderate*** *Maximum level of change acceptable, will impact some seabird populations positively, i.e. some tern species and pied cormorants.* ***Likelihood: Possible*** *Will occur even with best practices.* ***Management Controls**:* • *Digital Camera monitoring of interactions i.e. uBRUV and Camera Trap monitoring to see if non-increaser species are attracted to sea cages and feed on baitfish schools.* • *Monitoring of gull and cormorant colonies annually to*

				assess populations if feeding observed at sites.
5. Habitat exclusion. Loss of foraging habitat to seabirds due to surface area of sea cages.	Likelihood Likely (3) Consequence Moderate (1) Hazard Score (3) Risk Level (1) **Low**	***Consequence: Minor*** *Measureable loss of habitat to foraging seabirds minimal.* ***Likelihood: Possible*** *Loss of habitat is likely to occur at a low level.*	Likelihood Likely (3) Consequence Moderate (1) Hazard Score (3) Risk Level (1) **Low**	***Consequence: Minor*** *Measureable loss of habitat to foraging seabirds minimal.* ***Likelihood: Possible*** *Loss of habitat is likely to occur at a low level.*
6. Lighting management. Disorientation, collision and death of seabirds transiting through site at night due to inappropriate navigation or vessel lighting levels. Lighting may increase zooplankton and provide nocturnal feeding opportunities for diurnal foragers.	Likelihood Likely (4) Consequence Moderate (2) Hazard Score (8) Risk Level (2) **Moderate**	***Consequence: Moderate*** *Impact to population of shearwaters or storm petrels may be at upper limit, EPBC species likely to be injured or die.* ***Likelihood: Likely*** *Certain that without management measures nocturnal seabirds will collide with structures or vessels. Silver Gulls will forage at night.*	Likelihood Possible (3) Consequence Minor (1) Hazard Score (3) Risk Level (1) **Low**	***Consequence: Minor*** *Minor changes to ecosystem structure, few individuals impacted in most years.* ***Likelihood: Possible*** *May occur under special circumstances.* ***Management Controls***: • *Prepare Lighting management plan* • *Design of orientation, wavelength and use of lighting* • *Minimise requirements to operate at night* • *Remove need for vessels in area*

				at night. • *Adopt seasonal lighting plan to reduce impacts.*
7. Marine Debris. Ingestion or entanglement of foreign objects such as plastics, netting and other waste from farm activities, causing death.	Likelihood Likely (4) Consequence Minor (1) Hazard Score (4) Risk Level (1) **Low**	***Consequence: Minor*** *Few individuals directly impacted in each year, however shearwaters or other seabird species may be injured or die.* ***Likelihood: Likely*** *Certain that without management measures seabirds will either ingest waste or become entangled in netting.*	Likelihood Possible (3) Consequence Minor (1) Hazard Score (3) Risk Level (1) **Low**	***Consequence: Minor*** *Minor changes to ecosystem structure, few individuals impacted in most years.* ***Likelihood: Possible*** *May occur under special circumstances.* ***Management Controls:*** • *Prepare Waste management plan, including nil overside policy.* • *Maintain regular maintenance of farm infrastructure.* • *Screen vessel scuppers to prevent loss of material overside.* • *Return all wastes including food scraps to mainland for disposal.*
9. Roosting. Seabirds using farm infrastructure as roosting sites, resulting in fouling of infrastructure, reduction in water quality from faecal matter, risk of collision or entanglement and	Likelihood Likely (4) Consequence Moderate (2) Hazard Score (8)	***Consequence: Moderate*** *Potential positive impact to increaser species (gulls and cormorants) as well as Bridled Terns.* ***Likelihood: Likely*** *Certain that without management measures seabirds will utilize sea cages or vessels as roosting sites.*	Likelihood Possible (3) Consequence Minor (1) Hazard Score (3)	***Consequence: Minor*** *Minor changes to ecosystem structure, few individuals impacted in most years.* ***Likelihood: Possible*** *May occur under special circumstances.*

negative staff interactions with fauna.	Risk Level (2) **Moderate**		Risk Level (1) **Low**	***Management Controls***: • *Appropriate bird netting covering entire sea cage, and maintenance including net tension.* • *Design of railings, floats, net rings to reduce roosting sites.* • *Digital Camera monitoring of interactions i.e. uBRUV and Camera Trap monitoring to see if increaser species are roosting on sea cages.* • *Use of visual bird deterrents (model hawks/owls).*
10. Seabird Predators. Attraction of aerial snatch predators (Osprey/ White Bellied Sea Eagle) to uncovered sea cages.	Likelihood Possible (3) Consequence Moderate (2) Hazard Score (6) Risk Level (1) **Low**	***Consequence: Moderate*** *Maximum level of impact acceptable due to potential loss of Osprey or sea eagles through entanglement.* ***Likelihood: Possible*** *This may occur with uncovered cages.*	Likelihood Unlikely (2) Consequence Minor (1) Hazard Score (2) Risk Level (0) **Negligible**	***Consequence: Minor*** *Few if any individuals impacted in most years.* ***Likelihood: Unlikely*** *Not expected to occur, especially with bird mesh.* ***Management Controls***: • *Appropriate bird netting and maintenance including net tension* • *Appropriate mesh size (6cm).* • *Digital Camera monitoring of interactions above surface around cages i.e. Camera Trap monitoring.*

12. Oil Slicks Created by stock feed and dead fish may increase attract ion of site to olfactory seabirds such as shearwaters and storm petrels increasing risk of entanglement in netting.	Likelihood Likely (4) Consequence Moderate (2) Hazard Score (8) Risk Level (2) **Moderate**	***Consequence: Moderate.*** *More than a few individuals impacted particularly EPBC protected diving species (Shearwaters) as well as Pied Cormorants* ***Likelihood: Likely***. *Certain that without management measures EPBC protected seabirds will be attracted to sea cages and may become entangled.*	Likelihood Possible (3) Consequence Minor (1) Hazard Score (3) Risk Level (1) **Low**	***Consequence: Minor*** *Minor changes to ecosystem structure, few individuals impacted in most years.* ***Likelihood: Possible*** *May occur in some circumstances within the time frame.* ***Management Controls***: • *Fish fed pelletized food* • *Feed rate controlled to reduce feed waste* • *Dead fish removed from nets* • *Appropriate bird netting (6cm) and maintenance including correct net tension* • *Appropriate anti-predator netting mesh size and spacing.* • *Appropriate mesh size (6cm).* • *Digital Camera monitoring of interactions i.e. uBRUV and Camera Trap monitoring.*
13. Moored Vessels. Location of accommodation vessel at sites Increase in collision hazard to seabirds, provide roosts, vessel traffic may deter foraging.	Likelihood Likely (4) Consequence Moderate (2) Hazard Score (8)	***Consequence: Moderate*** *Impact to population of shearwaters or storm petrels may be at upper limit, EPBC species likely to be injured or die from collision.* ***Likelihood: Likely*** *Certain that without management*	Likelihood Possible (3) Consequence Minor (1) Hazard Score (3)	***Consequence: Minor*** *Minor changes to ecosystem structure, few individuals impacted in most years.* ***Likelihood: Possible*** *May occur under special*

	Risk Level (2) **Moderate**	*measures nocturnal seabirds and some tern or Noddy species will collide with structures or vessel when commuting to from colonies.*	Risk Level (1) **Low**	*circumstances.* ***Management Controls****:* • *Moor vessel near inhabited islands away from site (flight path) and colonies.* • *Prepare Lighting management plan (see above)* • *Minimise requirements to operate vessels at night* • *Reduce lines and rigging on vessels* • *Train staff in appropriate bird handling and reporting.*
14. De fouling operations. Gulls may exploit marine invertebrates from cleaning operations, resulting in food subsidization.	Likelihood Likely (4) Consequence Moderate (2) Hazard Score (8) Risk Level (2) **Moderate**	***Consequence: Moderate*** *Potential positive impact to increaser species (gulls) through food supplementation (see 2 above).* ***Likelihood: Likely*** *Certain that without management measures gulls will feed on waste from de fouling operations.*	Likelihood Possible (3) Consequence Minor (1) Hazard Score (3) Risk Level (1) **Low**	***Consequence: Minor*** *Minor changes to ecosystem structure, few individuals impacted in most years.* ***Likelihood: Possible*** *May occur under special circumstances.* ***Management Controls****:* • *Adopt de-fouling protocols to reduce waste providing food.* • *Dispose of waste away from farm site* • *Digital Camera monitoring of interactions above surface during de fouling operations i.e. Camera*

				Trap monitoring.
6. Disturbance Disturbance to seabirds or colonies from farm site activities, increased activity at Houtman Abrolhos, including vessel operations.	Likelihood Likely (4) Consequence Minor (1) Hazard Score (4) Risk Level (2) **Low**	***Consequence: Minor*** ***Potential impact to some seabirds through increased operational and potential recreational activities by staff.*** ***Likelihood: Likely*** *Certain that without management guidelines increased human activity, particularly recreational may impact seabird colonies.*	Likelihood Unlikely (2) Consequence Minor (1) Hazard Score (2) Risk Level (0) **Negligible**	***Consequence: Minor*** *Few if any individuals impacted in most years.* ***Likelihood: Unlikely*** *Not expected to occur, especially with management of activities.* ***Management Controls***: • *Adopt management plan to reduce impacts from farm activities, including access to areas adjacent active seabird colonies.* • *Restrict or limit recreational activities, including use of vessels, to those away from seabird colonies.* .

5 Proposed Mitigation Measures

5.1 Risk and Mitigation recommendations

5.1.2 Residual or Untreated Risks

The Department's ' Representation of Aquaculture Operations' outlines the regulators expectations with respect to sea cage design and operation within the Mid-West Aquaculture Zone. This document outlines the best practice tools now used to reduce adverse wildlife interactions including pen construction materials, predator nets, bird nets, barriers, and appropriate feeds and food delivery systems. The use of hormones and antibiotics in fish feed should be limited and regulated by the DoF to reduce the risk of seabirds ingesting treated fish feed.

The residual risks, assuming the effective implementation of those measures, would appear to be FAD effects, lighting and some lateral drift of fish feed outside the seacages.

Mitigation measures are not available for the FAD effects. Should monitoring indicate that prey resources have materially increased for any seabird population then Level 2 monitoring should be implemented (see Section 6). Shifting the pen locations within the Zone may provide temporary relief.

Lights shining on the water-surface enhance the FAD effect by attracting and concentrating plankton and other marine life. This has been a major cause of increasing Silver Gull numbers in the offshore oil and gas industry as the birds feed at night on the resulting prey aggregations. Some wavelengths (e.g. yellow or red light) may reduce the attraction to phototrophic organisms.

Bright lights directed towards the horizon will draw in and disorientate seabirds that make landfall at their colonies at night including shearwaters, storm-petrels and pelagic terns. Fledging Shearwater chicks orientate to lights on the horizon and are common casualties at coastal towns, on ships, fishing boats and even on freeways. The use of bright spotlights or deck lights should be avoided or only operated when they are needed to conduct an operation.

The 'Representation of Aquaculture Operations' indicates that perhaps 1% of feed will be transported outside the pens through the mesh in the lower part of the water column. This feed may aggregate wild fish in the size ranges attractive to foraging Pied Cormorants (i.e. 15-25cm, Sullivan et al. 2006). Cormorants are known to be opportunistic foragers and may take advantage of aggregated prey (Bostrom 2012). If the suggested unbaited underwater video monitoring (see Section 6) indicates the Pied Cormorants are being subsidized in this way then Level 2 monitoring should be implemented. Should feed drift be attracting cormorants to prey aggregations further steps will need to be taken to ensure pellet material (including oils) do not escape from the pens.

6 Monitoring seabird interactions with sea-cage aquaculture

6.1 Monitoring framework

The objective of aquaculture businesses is to sustainably produce marketable fish products by means that are economically profitable.

The objective of the Abrolhos Islands natural resource managers is to ensure that no activities within the Abrolhos Islands Ministerial Reserve cause ecological or social changes that have a negative impact on its other values.

A risk-mitigation framework was presented in Table 4.1 in Section 4 that matched the risk of adverse seabird interactions with sea-cage aquaculture with a variety of previously employed mitigation methods. If implemented these may increase logistical difficulties in fish production and result in additional operating costs. If these measures are not implemented, or are poorly implemented, this may increase the ecological risk. The intensity and scale of monitoring should depend on how each risk is treated or left untreated.

It is proposed that three levels of seabird monitoring be identified and implemented when necessary.

6.1.1 Level 1 - Seabird interactions at the sea-cages

This involves structured observation by the operators to determine if seabirds are being attracted to the pens, whether they are gaining access to supplementary food resources and whether any structures, lights may be causing seabird mortality.

Operators should be required to:

1. Report all seabird mortalities within or immediately adjacent to the aquaculture area (supported by digital photos of the situation) to the Department of Fisheries. DoF should also inform the Department of Parks & Wildlife of significant incidents or issues involving threatened species (Lesser Noddy, Fairy Tern, Australian Sea-lion, and White-pointer Shark etc.).

2. Unbaited Remote (Digital) Underwater Video cameras (uBRUV) should be operated from the seabed and orientated towards the cage mesh during fish-feeding. Interactions with wild fish and protected species should be recorded on the underwater video cameras should be reported for one hour before, during and one-hour after fish feeding. uBRUVs should be rotated around all installed sea cages with each sea cage sampled once a month.

3. Digital Motion Detector Cameras (e.g. Spypoint BF10) with time-lapse capabilities should be deployed on poles with coverage of the surface areas of the sea cages. Periodic time-lapse imagery (daylight= colour, night = IR) should be programmed to monitor for seabird activity on sea cage infrastructure. The cameras will record interaction with seabirds such as roosting (diurnal/nocturnal), foraging (day/night) or hovering over cages.

6.1.2 Level 2 monitoring

The next level of monitoring would be required if repeated interactions are recorded at the sea-cages. If these relate to food subsidization (that isn't to be immediately mitigated) then annual monitoring of seabird tissues (e.g. stable isotope analysis) or seabird diets (pellets / regurgitations) should be required to determine if the energy flow to the seabird population is material and likely to force changes in colony distribution or population size.

If the interactions involve entrapment / entanglement or collisions the seabird mortality should be documented, reported (as for Level 1) and the seabird behaviour will need to be investigated to determine the causal factors.

6.1.3 Level 3 monitoring

If either seabird incidental mortality or food subsidization is significant, and continues to be incompletely mitigated, then it will be necessary to monitor changes in breeding population-size of the interacting (and potentially associated) seabird species. The methodology for components of colony monitoring is outlined in Section 2.

6.2 Monitoring framework methodology

Depending upon the levels of interactions between seabirds and sea cages, monitoring may vary from operator based to intensive independently monitored seabird populations.

We have recommended a performance driven 3 tiered approach to monitoring the likely potential impacts to seabirds. In the first instance, the majority of monitoring may be undertaken using remote digital technology, installed by scientists and operated and maintained by the operators after training. As outlined above, this will involve unbaited Remote Underwater Videos (uBRUV), motion-detector cameras and seabird interaction reporting sheets. The data collected will be heavily reliant upon operators maintaining protocols and reporting honestly and regularly. Although footage from both the uBRUVs and cameras should be retained for examination by DoF inspectors.

We believe the current report, as well as previous data collected by Halfmoon Biosciences, will suffice as a baseline for Stable Isotope levels and existing size and activity patterns of the three key increaser species (i.e. Silver Gull, Pacific Gull and Pied Cormorant). However, depending upon the timing of operations, monitoring of key nesting sites on an adhoc basis will be necessary to ensure that current population levels are consistent. The current low breeding numbers of both gull species is a response to the removal of rock-lobster fishing bait from the system – if for example Silver Gull numbers increase significantly in the interim period prior to sea cages being deployed, and adhoc counts of nests and nest status are not undertaken, then operators will invariably be held responsible for the gull increase.

Currently Halfmoon monitors several seabird populations across the Houtman Abrolhos. It would be feasible to undertake a one-day survey of key SG/PG sites in the Pelsaert Group (these being Post Office Island. Newman Island and Pelsaert Island) to plot and assess breeding status during Halfmoon larger surveys, thereby reducing operator costs.

6.3 Summary of recommended monitoring proposed

The below is a prioritised list of monitoring techniques that meet the DoF guidelines of best practice as well as being practicable, cost effective and time efficient for operators.

Level 1: Surveillance of seabird interactions with sea-cages

1a - Mandatory reporting of all interactions causing seabird entanglement, injury of mortality as described in section 6.1.1.

1b - Sub-surface monitoring of underwater interactions using uBRUVs as described in section 6.1.1.

1c - Above pen surface monitoring of seabird interaction using motion detector cameras as described in 6.1.1.

Level 2: Monitoring for onset of material food/energy subsidisation

2a - Repeat dietary sampling for three increaser species or add species if there is an unpredicted foraging interaction.

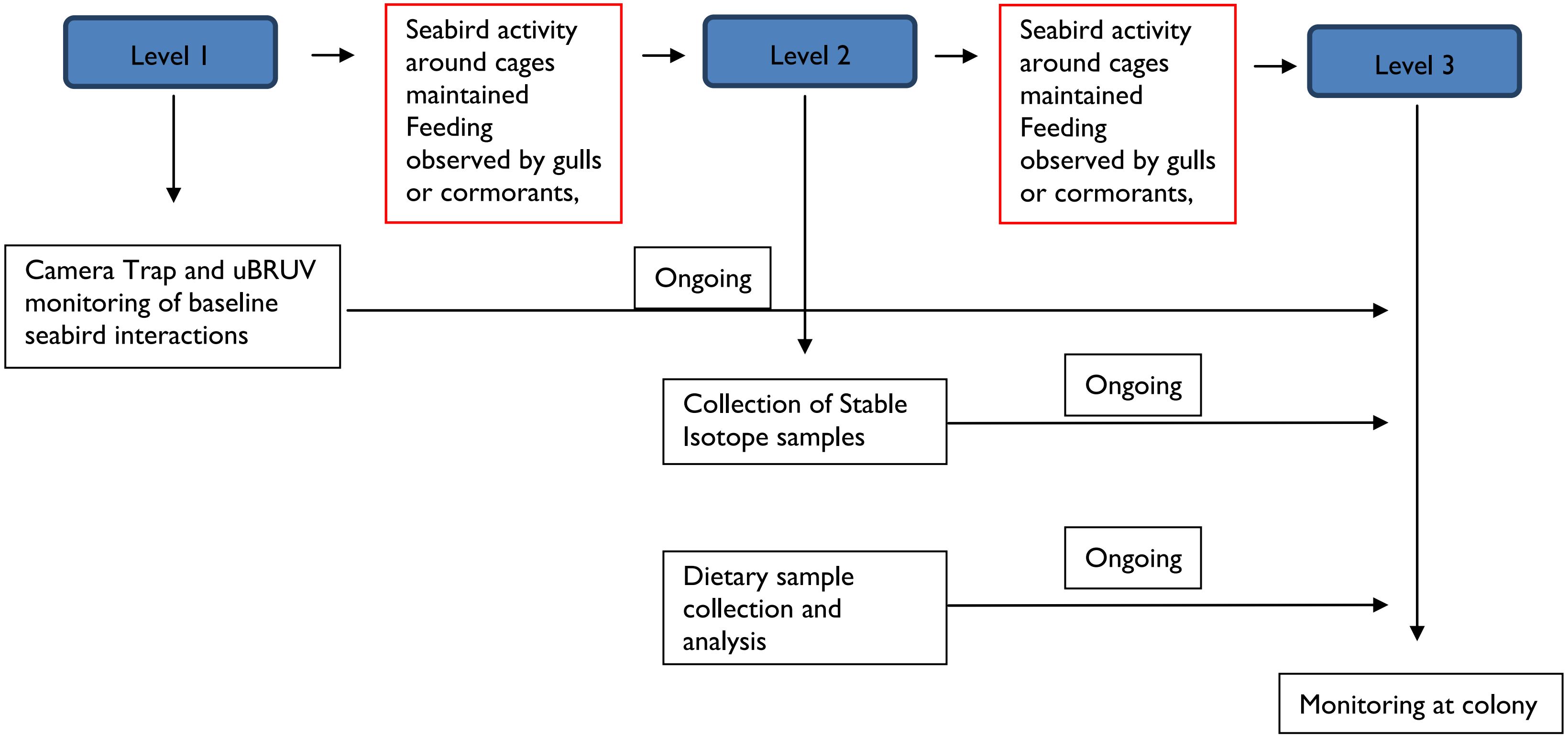
2b - Repeat stable isotope analysis for three increaser species.

Level 3: Monitoring for changes in seabird population size should a significant energy flow from the aquaculture zone be detected by Level 2 monitoring.

3.1 Census and mapping of colonies of the affected species on islands in the Easter and Pelsaert Groups.

3.2 Institute island habitat monitoring (e.g. guano addition, mangroves, colony vegetation) in the event of measured increases in subsidized seabird species from 3.1.

Figure 6.1: Flow diagram illustrating the three tiered approach to monitoring seabird interactions.



7 Conclusion

Several other studies on the potential impacts upon seabirds from aquaculture have identified similar risk factors to those discussed in this document. These include entanglement, habitat exclusion, disturbance from farm activities, increased prey availability through FAD affects, creation of roost sites, changes to foraging success and spread of pathogens (see Sagar 2008, 2013, Lloyd 2003, Comeau *et al*. 2009).

This study shows that additional potential risks associated with aquaculture are the disruption to usual foraging patterns, decline in nesting habitat to vulnerable species through the increase in Pied Cormorant numbers and importantly changes in foraging behaviour and consequent predicted population changes in increaser gull species.

While the potential for populations of the three increaser species (Pied Cormorants, Silver Gulls and Pacific Gulls) to increase through exploitation of food sources associated with sea cage aquaculture are real, we believe that best practices in the structure of sea cages, size and management of netting and protocols of reducing feed waste are likely to reduce the potential for exploitation by these increaser species.

The baseline survey of the distribution of Silver Gulls shows a decline in numbers and the collapse of the autumn breeding period that was almost certainly subsidized by fishery discards and food-waste from the former March - June Zone A rock-lobster fishing season. This rapid response to a change in food availability illustrates the way food subsidization from sea cage aquaculture operations could enhance gull populations with a range of ecological consequences.

The Pacific Gull population has also declined since the last census and this may also be attributable to the reduction of fishing activity at the Abrolhos. No trend is evident in Pied Cormorant numbers.

The baseline investigations on the foraging ecology of the three potentially 'high risk' increaser species indicate that all are currently reliant on naturally available prey types, with littoral zone invertebrates dominating the gull diets and benthic fishes that of Pied Cormorants.

The stable isotope analysis supported the dietary analysis indicating the importance of littoral (benthic and detrital producer) habitats for all three species. The two gulls both showed relationships with the terrestrial food-chains on the islands with Silver Gulls making use of natural berry crops during the food-limited autumn period and Pacific Gulls also functioning as terrestrial predators (probably on other smaller seabirds). This illustrated the potential for changes in gull numbers to alter island ecosystems.

The analysis of seabird movements and foraging behaviour identified a range of potential interactions with fish-farming operations. It was considered that most of these could be mitigated if the management expectations outlined by the Department of Fisheries were effectively implemented from the outset. Three residual risks related to FAD effects, lighting and the lateral drift of feed are identified and possible mitigation measures suggested.

A monitoring framework based on three, performance-based, risk levels has been proposed.

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Appendix 1: δ15N and δ13C Stable Isotope Values (in parts per thousand °/$_{oo}$) for predator and prey tissues collected from the Easter and Pelsaert Groups of the Houtman Abrolhos in 2014.

Field No.	Sample	Predator	δ13C	δ15N
CE1	Feather, Pied Cormorant, Easter Group		-10.8	10.8
CE2	Feather, Pied Cormorant, Easter Group		-9.9	10.6
CE3	Feather, Pied Cormorant, Easter Group		-13.0	13.4
CE4	Feather, Pied Cormorant, Easter Group		-17.9	14.0
CE5	Feather, Pied Cormorant, Easter Group		-18.8	13.8
CE6	Feather, Pied Cormorant, Easter Group		-19.7	12.9
CE7	Feather, Pied Cormorant, Easter Group		-12.2	10.8
CE8	Feather, Pied Cormorant, Easter Group		-16.1	13.2
CE9	Feather, Pied Cormorant, Easter Group		-17.0	12.9
CE10	Feather, Pied Cormorant, Easter Group		-13.4	13.5
PP1	Topshell - *Tectus sp*	Pacific Gull	-11.6	4.8
PP2	Topshell - *Tectus sp*	Pacific Gull	-11.6	5.4
PP3	Topshell - *Tectus sp*	Pacific Gull	-10.2	4.2
PP4	Topshell - *Tectus sp*	Pacific Gull	-10.9	4.3
PP5	Topshell - *Tectus sp*	Pacific Gull	-11.2	4.8
PP6	Topshell - *Tectus sp*	Pacific Gull	-10.3	4.4
PP7	Squid, beaks and mantle	Pacific Gull	-13.0	6.4
PP8	Squid, beaks and mantle	Pacific Gull	-12.0	6.6
PP9	Squid, beaks and mantle	Pacific Gull	-9.8	5.9
PP10	Squid, beaks and mantle	Pacific Gull	-11.2	6.0
PP11	Squid, beaks and mantle	Pacific Gull	-12.0	5.7
PP12	Squid, beaks and mantle	Pacific Gull	-11.8	7.0
PP13	Squid, beaks and mantle	Pacific Gull	-12.4	7.0
PP14	Squid, beaks and mantle	Pacific Gull	-12.3	6.6
SE1	Feather, Silver Gull, Easter Group		-16.7	13.0

SE2	Feather, Silver Gull, Easter Group		-14.0	12.7
SE3	Feather, Silver Gull, Easter Group		-18.2	13.2
SE4	Feather, Silver Gull, Easter Group		-11.7	17.3
SE5	Feather, Silver Gull, Easter Group		-10.6	17.4
SE6	Feather, Silver Gull, Easter Group		-10.1	15.0
SE7a	Feather, Silver Gull, Easter Group		-13.7	13.6
SE7b	Feather, Silver Gull, Easter Group		-14.7	13.5
SE8	Feather, Silver Gull, Easter Group		-12.3	15.1
SE9	Feather, Silver Gull, Easter Group		-12.8	13.0
CE11	Fish scales, Easter Group	Pied Cormorant	-16.0	11.2
CE12	Fish scales, Easter Group	Pied Cormorant	-15.3	11.7
CE13	Fish scales, Easter Group	Pied Cormorant	-12.1	8.4
CE14	Fish scales, Easter Group	Pied Cormorant	-12.0	9.5
CE15	Fish scales, Easter Group	Pied Cormorant	-12.7	8.8
CE16	Fish scales, Easter Group	Pied Cormorant	-10.9	11.3
PP15	Chick feathers, Pacific Gull, Pelsaert Group		-12.6	14.7
PP16	Chick feathers, Pacific Gull, Pelsaert Group		-10.2	13.0
PP17	Chick feathers, Pacific Gull, Pelsaert Group		-12.2	13.8
PP18	Chick feathers, Pacific Gull, Pelsaert Group		-11.3	14.2
PP19	Chick feathers, Pacific Gull, Pelsaert Group		-12.0	14.8
PP20	Chick feathers, Pacific Gull, Pelsaert Group		-10.7	13.8
PP21	Chick feathers, Pacific Gull, Pelsaert Group		-11.2	14.1
PP22	Chick feathers, Pacific Gull, Pelsaert Group		-12.0	13.3

PP23	Chick feathers, Pacific Gull, Pelsaert Group		-12.4	13.9
PP24	Chick feathers, Pacific Gull, Pelsaert Group		-11.6	14.6
CP1	Feathers, Pied Cormorant, Pelsaert Group		-10.3	12.3
CP2	Feathers, Pied Cormorant, Pelsaert Group		-10.4	11.5
CP3	Feathers, Pied Cormorant, Pelsaert Group		-11.3	11.3
CP4	Feathers, Pied Cormorant, Pelsaert Group		-10.4	12.4
CP5	Feathers, Pied Cormorant, Pelsaert Group		-16.1	12.5
CP6	Feathers, Pied Cormorant, Pelsaert Group		-15.8	12.8
CP7	Feathers, Pied Cormorant, Pelsaert Group		-12.1	12.3
CP8	Feathers, Pied Cormorant, Pelsaert Group		-10.7	11.8
CP9	Feathers, Pied Cormorant, Pelsaert Group		-10.1	12.1
CP10	Feathers, Pied Cormorant, Pelsaert Group		-9.6	10.7
SP1	Mantis shrimp carapace	Silver Gull-Pelsaert	-11.8	4.6
SP2	Mantis shrimp carapace	Silver Gull-Pelsaert	-11.8	4.9
SP4	Mantis shrimp carapace	Silver Gull-Pelsaert	-13.6	4.4
SP5	Mantis shrimp carapace	Silver Gull-Pelsaert	-11.9	4.3
SP6	Mantis shrimp carapace	Silver Gull-Pelsaert	-13.5	4.4
SP7	Crab, *Leptograpsus* carapace	Silver Gull-Pelsaert	-12.7	8.4
CP11	Fish scales	Pied Cormorant-Pelsaert	-9.2	7.7
CP12	Fish scales	Pied Cormorant-Pelsaert	-10.6	10.6

CP13	Fish scales	Pied Cormorant-Pelsaert	-9.3	7.8
CP14	Fish scales	Pied Cormorant-Pelsaert	-9.4	7.6
CP15	Fish scales	Pied Cormorant-Pelsaert	-11.4	8.7
SE10	Feathers, Silver Gull, Easter Group		-14.8	13.9
SE11	Feathers, Silver Gull, Easter Group		-15.8	13.2
SE12	Feathers, Silver Gull, Easter Group		-17.1	13.7
SE13	Feathers, Silver Gull, Easter Group		-14.2	16.7
SE14	Feathers, Silver Gull, Easter Group		-14.3	14.6
SP8	Feathers, Silver Gull, Pelsaert Group		-17.9	13.2
SP9	Feathers, Silver Gull, Pelsaert Group		-19.9	11.5
SP10	Feathers, Silver Gull, Pelsaert Group		-17.0	14.1
SP11	Feathers, Silver Gull, Pelsaert Group		-18.1	13.0
SP12a	Feathers, Silver Gull, Pelsaert Group		-18.6	12.3
SP12b	Feathers, Silver Gull, Pelsaert Group		-17.1	13.6
SP13	Feathers, Silver Gull, Pelsaert Group		-17.0	13.4
SP14	Feathers, Silver Gull, Pelsaert Group		-20.6	12.2
SP15	Feathers, Silver Gull, Pelsaert Group		-19.5	12.4
SP16	Feathers, Silver Gull, Pelsaert Group		-10.8	16.0
RBP1	Ant *Polyrachis amoneoides* chitin	live sample	-21.2	23.8
RBP2	Ant *Polyrachis amoneoides* chitin	live sample	-21.2	23.3
RBP3	Ant *Polyrachis amoneoides* chitin	live sample	-20.8	23.6
RBP4	Ant *Polyrachis amoneoides* chitin	live sample	-21.1	23.8
RBP5	Ant *Polyrachis amoneoides* chitin	live sample	-21.2	23.6
NBP1	Ant *Polyrachis amoneoides* chitin	live sample	-17.9	24.4

NBP2	Ant *Polyrachis amoneoides* chitin	live sample	-18.7	24.4
NBP3	Ant *Polyrachis amoneoides* chitin	live sample	-18.4	24.4
NBP4	Ant *Polyrachis amoneoides* chitin	live sample	-19.0	24.4
NBP5	Ant *Polyrachis amoneoides* chitin	live sample	-18.7	24.2

Our Ref 59915062/L003

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23 October 2015

BMT WBM Pty Ltd
Level 8, 200 Creek Street
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Attention: Dr Michael Barry - Manager, Catchments & Receiving Environments

Dear Sir,

MIDWEST ZONE AQUACULTURE MODELLING PEER REVIEW
REVIEW OF PROJECT REPORTS
FINAL REPORTS

As part of this EIS project, BMT WBM have requested that Cardno Water & Environment review BMT WBM and University of Western Australia reports:-

'Midwest Zone Aquaculture Modelling Calibration Report' (BMT WBM October 2015), and

'Midwest Zone Aquaculture Modelling, Sediment quality impact assessment' (UWA October 2015).

This work follows-on from previous BMT WBM and UWA reports on this matter. It is noted that the modelling adopts the TUFLOW FV and AED (BMT WBM hydrodynamic and water quality) and Diagenesis (vertical sediment water quality UWA) model systems.

The authors have considered Cardno's previous review comments and provided updated reports to us in October 2015.

Following our review of the October 2015 versions of the BMT WBM and UWA reports we advise that they have satisfied Cardno's comments/information requests in great detail.

I am satisfied that the model-based investigations have been undertaken with attention to detail and to a level that generally equals or exceeds standard industry practice.

Yours faithfully,

P.D. Treloar

P.D. Treloar
Senior Principal
for **Cardno (NSW/ACT) Pty Ltd**

BMT WBM

Midwest Zone Aquaculture Modelling Calibration Report

Reference: R.B20639.001.02.Calibration.docx
Date: October 2015
Confidential

Midwest Zone Aquaculture Modelling Calibration Report

Prepared for:	Cardno Level 9 The Forum 203 Pacific Highway St Leonards NSW 2077
Prepared by:	BMT WBM Pty Ltd (Member of the BMT group of companies)

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Document:	R.B20639.001.02.Calibration.docx
Title:	Midwest Zone Aquaculture Modelling Calibration Report
Project Manager:	Michael Barry
Author:	Rob Holmes
Client:	Cardno Level 9 The Forum 203 Pacific Highway St Leonards NSW 2077
Client Contact:	Dr. Doug Treloar
Client Reference:	

Synopsis: **A report detailing the calibration of a hydrodynamic, water quality and sediment quality model of the Abrolhos Islands, as part of the Midwest Zone Aquaculture Study.**

REVISION/CHECKING HISTORY

Revision Number	Date	Checked by		Issued by	
0	23rd June 2015	RH		MEB	
1	15th September 2015	RH		MEB	
2	20th October 2015	RH		MEB	

DISTRIBUTION

Destination	Revision										
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Cardno	PDF	PDF	PDF								
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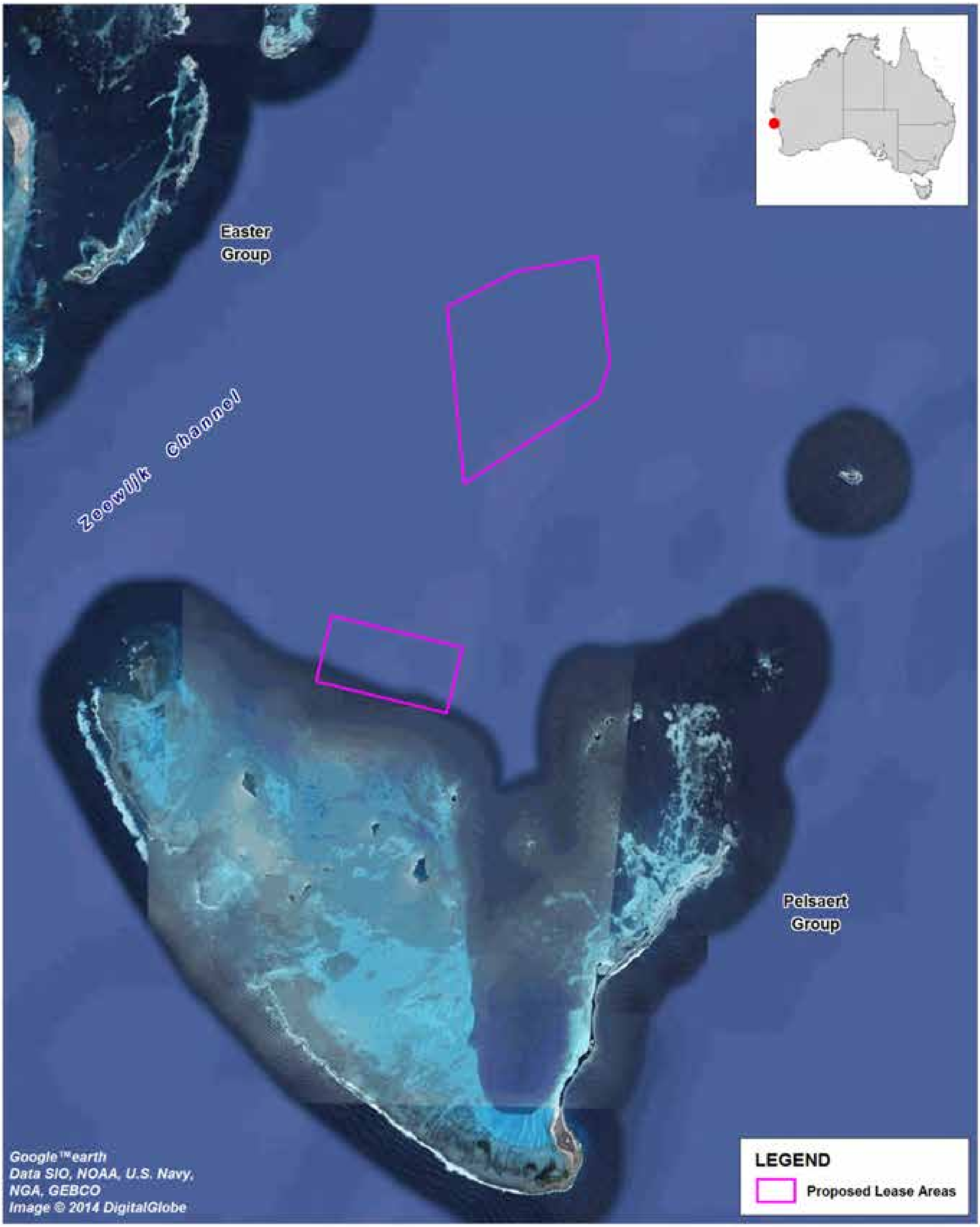
1 Introduction

The Department of Fisheries, Western Australia (DoF), on behalf of the Minister for Fisheries, proposes to create an 'Aquaculture Development Zone' to provide a management precinct for prospective aquaculture proposals within the State Waters off the Houtman Abrolhos Islands (HAI) Fish Habitat Protection Area (FHPA), which is approximately 75 kilometres west of Geraldton. DoF has engaged BMT Oceanica, alongside BMT WBM and the University of Western Australia, to undertake the technical studies for the environmental impact assessment (EIA) associated with operations within this proposed Midwest Aquaculture Development Zone (MWADZ).

A map of the area of interest, including the proposed aquaculture lease areas, is presented in Figure 1-1. The region surrounding the Abrolhos Islands is a dynamic system influenced by large-scale regional currents (e.g. Leeuwin Current, Capes Current), wind stresses, upwelling and wave dynamics (Pearce & Pattiaratchi, 1999; Feng *et al.,* 2007; Waite *et al.*, 2007; Woo & Pattiaratchi, 2008; Rossi *et al.*, 2013). Simulating such an environment is challenging, as a model must resolve the dynamic processes affecting the area on a regional scale (e.g. regional currents), the meso-scale (e.g. eddy formation) and the local scale (e.g. the influence of local bathymetric features on current velocities). Nevertheless, the impact assessment requires the development of hydrodynamic and water quality models of the area to quantify the potential impacts of aquaculture activities on water quality parameters (e.g. turbidity, nutrient concentrations, chlorophyll concentrations, etc.). The proposed methodology for the modelling component of this study was outlined in a letter dated 27th March 2015 (included in Appendix A) and this report details the development and calibration of the hydrodynamic and water quality model described in that letter.



Title:

Proposed Lease Areas

Figure: 1-1

Rev: B

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Filepath : I:\B20639_I_JLB Abrolhos Islands Aquaculture Modelling MEB\DRG\CAR_002_150601_Proposed Lease Areas_RevB.WOR

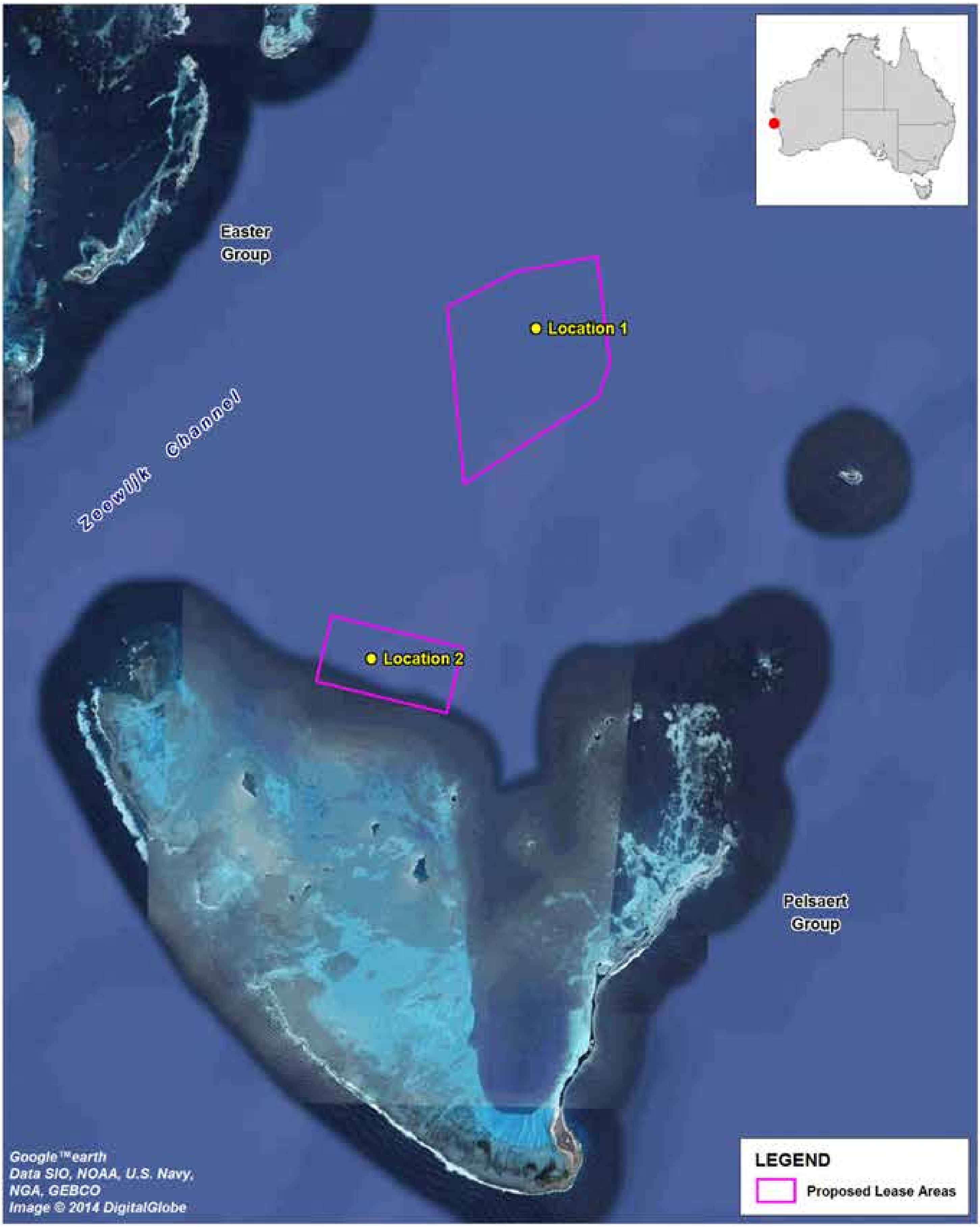
2 Sampling Program

A suite of hydrodynamic and water quality data were collected during a series of equipment deployments between May 2014 and March 2015. This section contains a summary of the data collected that is relevant to the hydrodynamic and water quality model calibrations. Full details of the sampling program are included in the letter dated 27th March 2015, which is included in Appendix A.

2.1 Hydrodynamic data

Four bottom-mounted Acoustic Doppler Current Profilers (ADCPs) were deployed in total: one in each of the MWADZ areas (hereafter referred to as the 'lease-area sites'; Figure 2-1), one to the north-east of the study area and one to the south-east (hereafter referred to as the 'regional sites'; Figure 2-2). Depth data were collected at all sites, bar the southern lease-area site during the first 3 deployments. Wave and temperature data were collected by sensors co-located with the ADCPs, although not at all times and locations. No wave data were collected during the first lease-area deployment between May and June 2014 due to a faulty sensor. The fault was repaired for subsequent deployments. A conductivity sensor was co-located with the ADCP at the northern regional site during the first deployment, although these data were not suitable for use as sand clogged the sensor during the first week. Conductivity sensors were co-located with the ADCPs at the regional sites during the second deployment, which provided approximately 3 months of data before bio-fouling introduced a clear bias. The dates of all equipment deployments were as follows:

- Lease-area sites:
  - 16th May 2014 – 19th June 2014
  - 17th August 2014 – 18th September 2014
  - 9th November 2014 – 10th December 2014
  - 9th February 2015 – 11th March 2015.
- Regional sites:
  - 17th July 2014 – 19th November 2014
  - 19th November 2014 – 18th March 2015.



Title:

ADCP Locations - Proposed Lease Areas

Figure: 2-1

Rev: B

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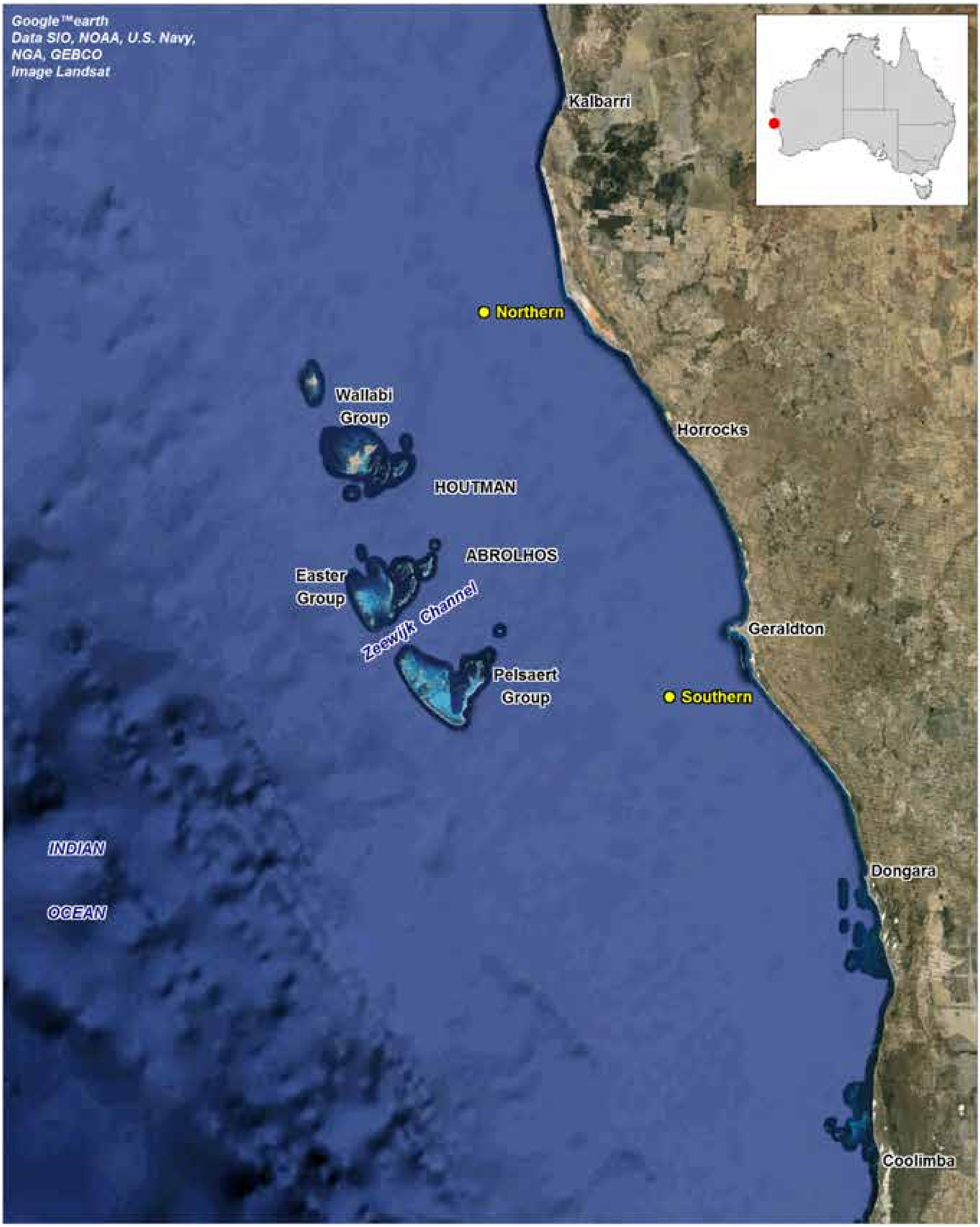

Title:

ADCP Locations

Figure: 2-2

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Approx. Scale

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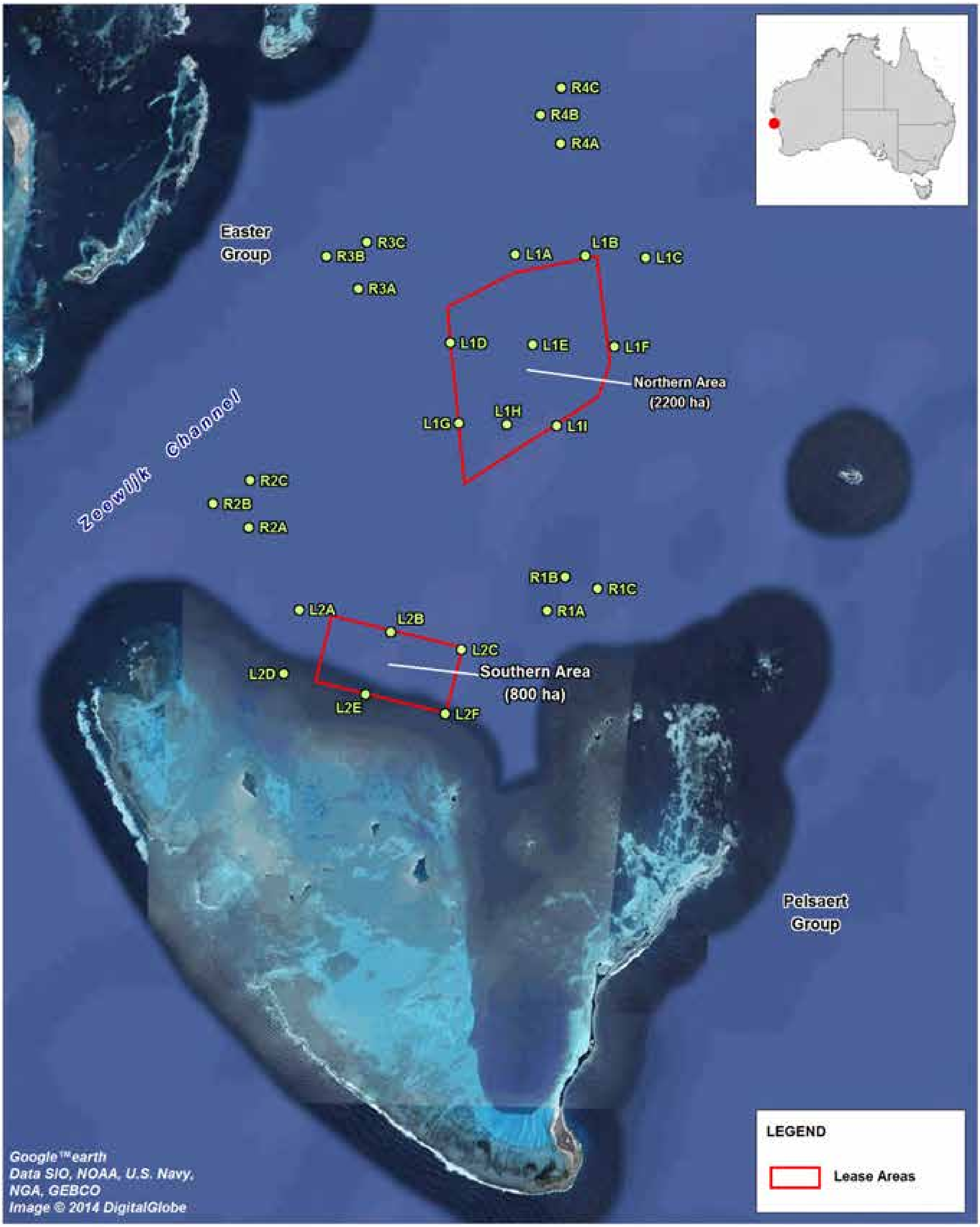
2.2 Water quality data

A suite of water quality variables were sampled at a total of 27 sites within the MWADZ areas (Figure 2-3). The suite included the following variables relevant to the modelling component of this study:

- Total nitrogen (TN)
- Total phosphorus (TP)
- Oxidised inorganic nitrogen (nitrate + nitrite)
- Ammonia
- Filterable reactive phosphorus (FRP)
- Chlorophyll-a
- Total organic carbon (TOC)
- Dissolved oxygen (DO)
- Turbidity
- TSS
- Photosynthetically active radiation (PAR).

The sampling program took place over the following dates:

- 20th-21st May 2014
- 20th June 2014
- 18th August 2014
- 18th September 2014
- 10th November 2014
- 11th December 2014
- 18th February 2015.



Title:

Water Quality Sampling Locations and Proposed Lease Areas

Figure: 2-3

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BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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3 Model Framework

BMT WBM's letter dated 27th March 2015 outlined the proposed model framework, including the development and calibration of a hydrodynamic and water quality model of the study area (Appendix A). This section provides details on the adopted model setup, which includes some modifications (e.g. mesh changes) of the setup proposed previously.

The primary aim of the hydrodynamic model is to provide a realistic representation of currents and wave dynamics at the lease-area sites, for the purposes of determining the fate of particles released from aquaculture activities (e.g. food & faeces), and also to provide a realistic hydrodynamic regime to the biogeochemical model for water quality simulations. To this end, the model was calibrated against data collected during the sampling program detailed above, the results of which are included in Section 4.

3.1 Hydrodynamic Model

The platform used was our in-house-developed hydrodynamic modelling engine TUFLOW FV (http://www.tuflow.com/Tuflow%20FV.aspx). TUFLOW FV is a powerful hydrodynamic model engine that solves the Non-Linear Shallow Water Equations (NLSWE) on a 'flexible' (unstructured) mesh comprising triangular and quadrilateral cells. The mesh is not limited to square or rectangular grid arrangements, a feature which we believe will be critical to the successful execution of this study. This unstructured mesh approach has significant benefits when applied to study areas involving complex bathymetric features, flow paths, and hydrodynamic processes, and varying areas of interest, such as this study area. The finite volume (as opposed to finite difference (fixed grid) and finite element) numerical scheme is also capable of simulating the advection and dispersion of multiple scalar constituents within the model domain. TUFLOW FV is configured to solve the NLSWE in 2D (vertically averaged) and 3D with the ability to employ both first-order and second-order numerical solution schemes. The model can be run in both 2D vertically-averaged mode and fully 3D mode by specifying a vertical layer structure. Importantly, the TUFLOW FV engine leverages the parallel processing capabilities of modern computer workstations, using the OpenMP implementation of shared memory parallelism, such that computation capability can be used to its maximum potential.

3.1.1 Bathymetry

A digital elevation model (DEM) was developed using a regional bathymetry dataset from Geosciences Australia with 250m resolution, and a higher-resolution dataset of the Abrolhos Islands from the Western Australian Department of Transport (Figure 3-1 and Figure 3-2). This was interrogated to provide bathymetry values to the model mesh.

3.1.2 Model mesh

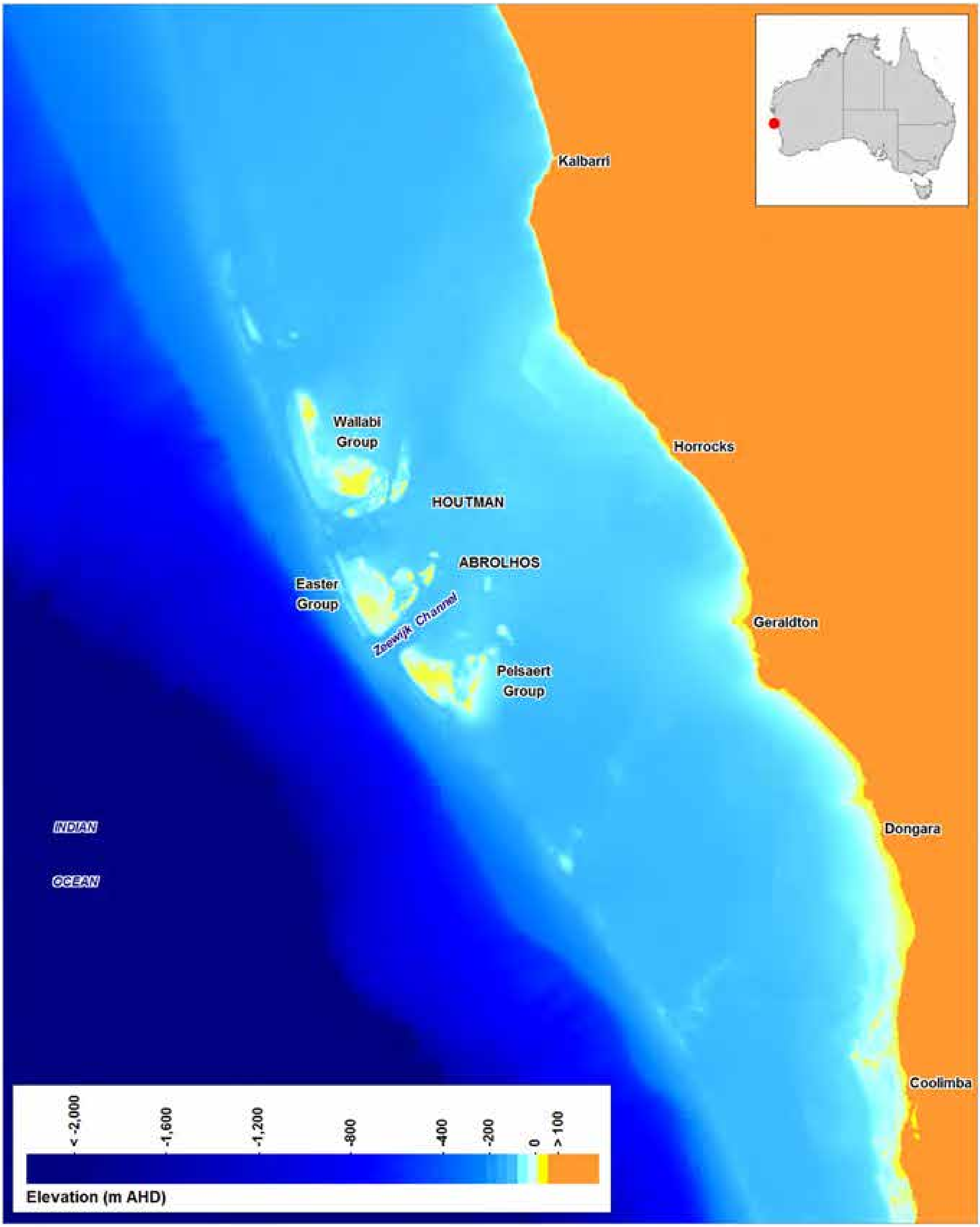
The model mesh covers an overall area of 2.7 million hectares, with a single open boundary of approximately 413 km stretching from Kalbarri in the north to Coolimba in the south. It includes 23,093 horizontal cells, ranging from resolution of approximately 3.5 km at the open boundary to approximately 40 m resolution within the proposed lease areas (Figure 3-3 and Figure 3-4). Vertical resolution comprises of up to 26 fixed-level z layers (Table 3-1) and 2 surface, variable-

level sigma layers, for a total of up to 28 vertical levels with resolution increasing near the surface to approximately 1m. The seabed sits at approximately -40m AHD in the vicinity of the lease areas, meaning the model has 10 z layers plus 2 sigma layers in this region. In total there are 264,412 computational cells and the mesh resolution both horizontally and vertically compares favourably with similar models developed for aquaculture assessments in Western Australia (e.g. DHI, 2013). Time-steps in the model are scaled to an assigned Courant value (0.7) and can vary over time. Typical time-steps were approximately 0.3s.

Table 3-1 Depths of fixed-level z layers

Layer number	Depth (m AHD)
1	-2
2	-4
3	-6
4	-8
5	-10
6	-15
7	-20
8	-25
9	-30
10	-40
11	-50
12	-70
13	-100
14	-150
15	-250
16	-500
17	-750
18	-1000
19	-1250
20	-1500
21	-1750
22	-2000
23	-2250
24	-2500
25	-2750
26	-3000

As can be seen in Figure 3-4, a variety of cage configurations have been included in the mesh to ensure that processes adjacent to cage clusters are highly resolved by the model. A selection of some or all of these cage configurations will be used when developing scenarios.



Title:

Digital Elevation Model

Figure: **3-1**

Rev: **A**

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Approx. Scale

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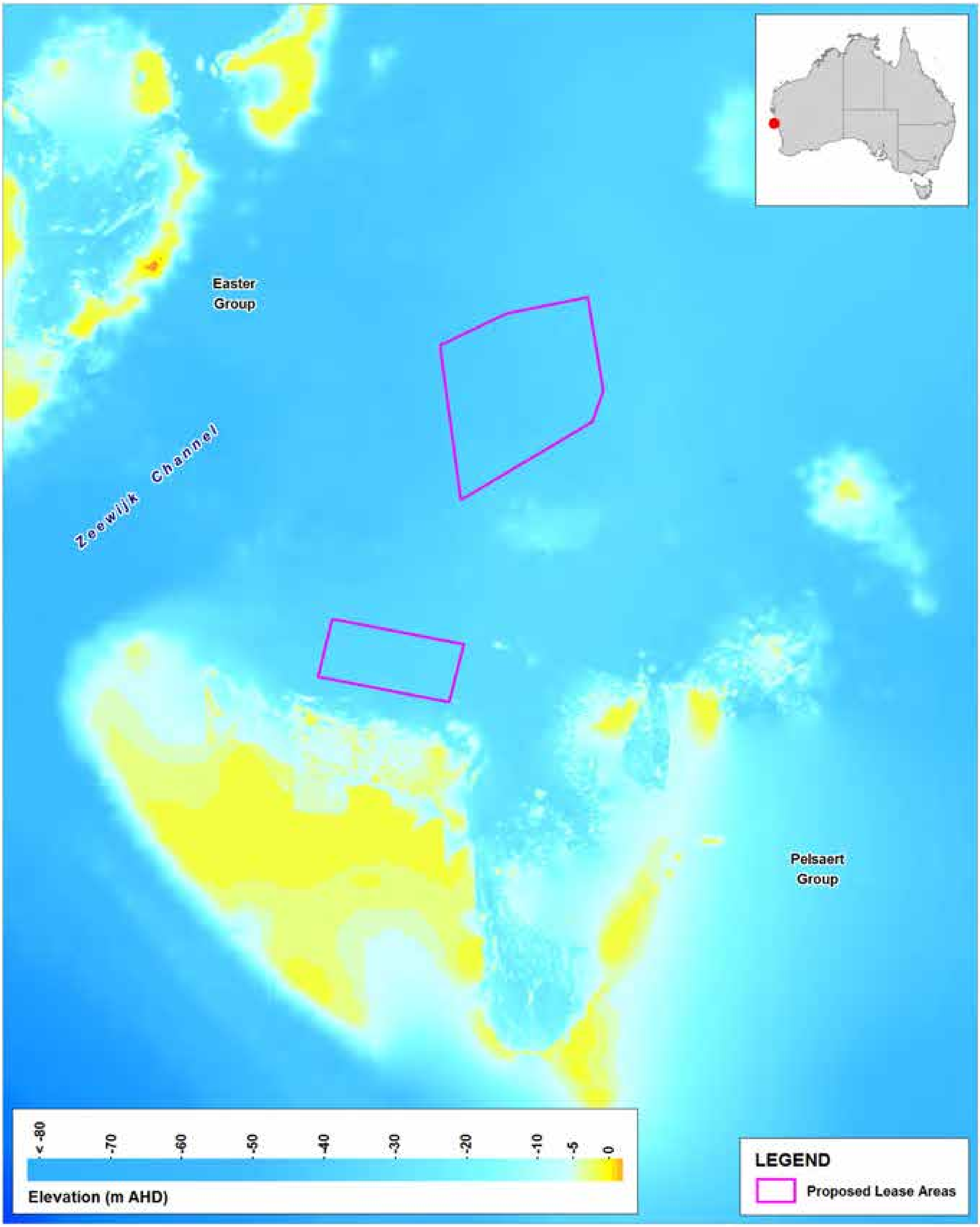

Title:

Digital Elevation Model – Proposed Lease Areas

Figure: **3-2**

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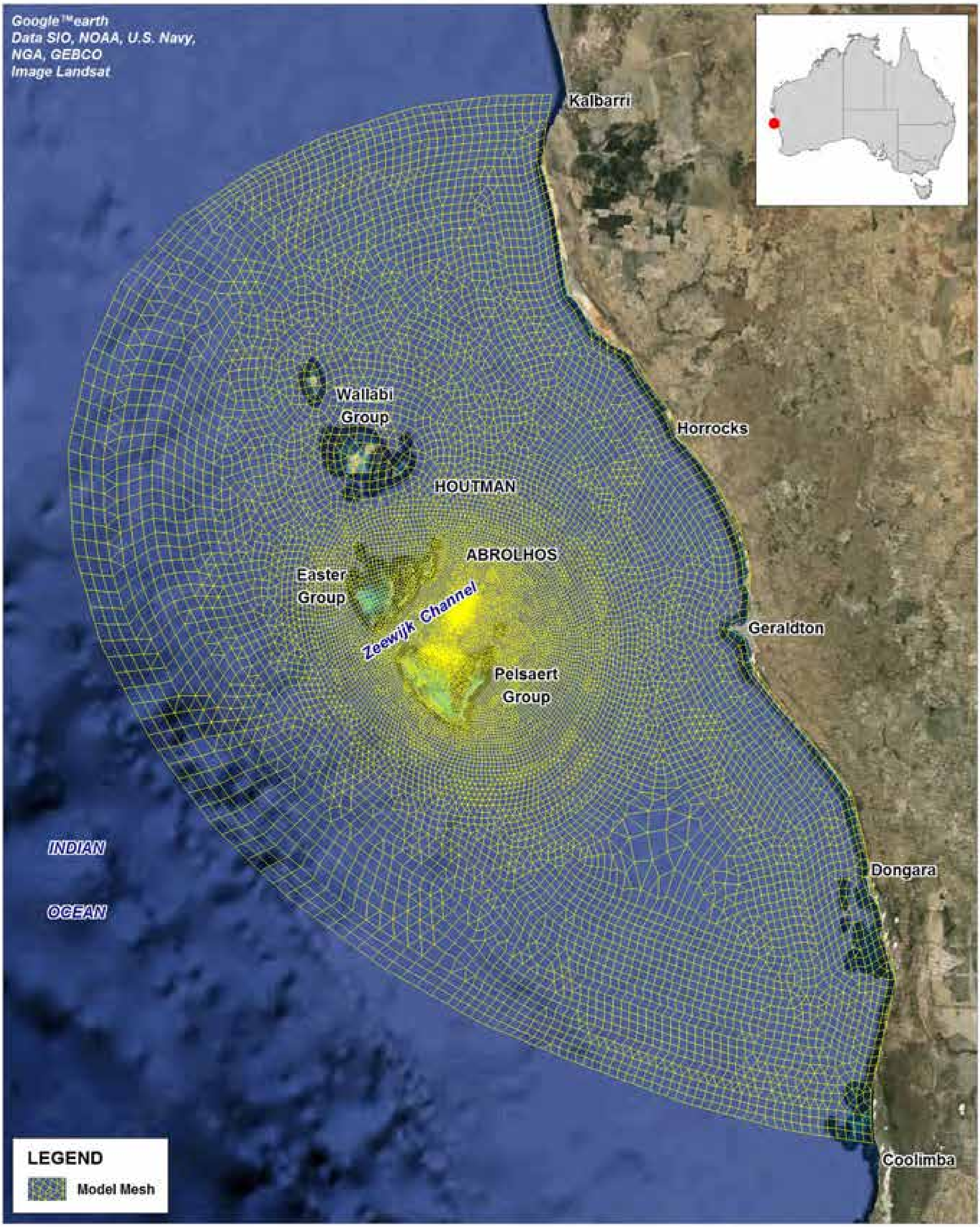

Title:
Model Mesh

Figure: 3-3

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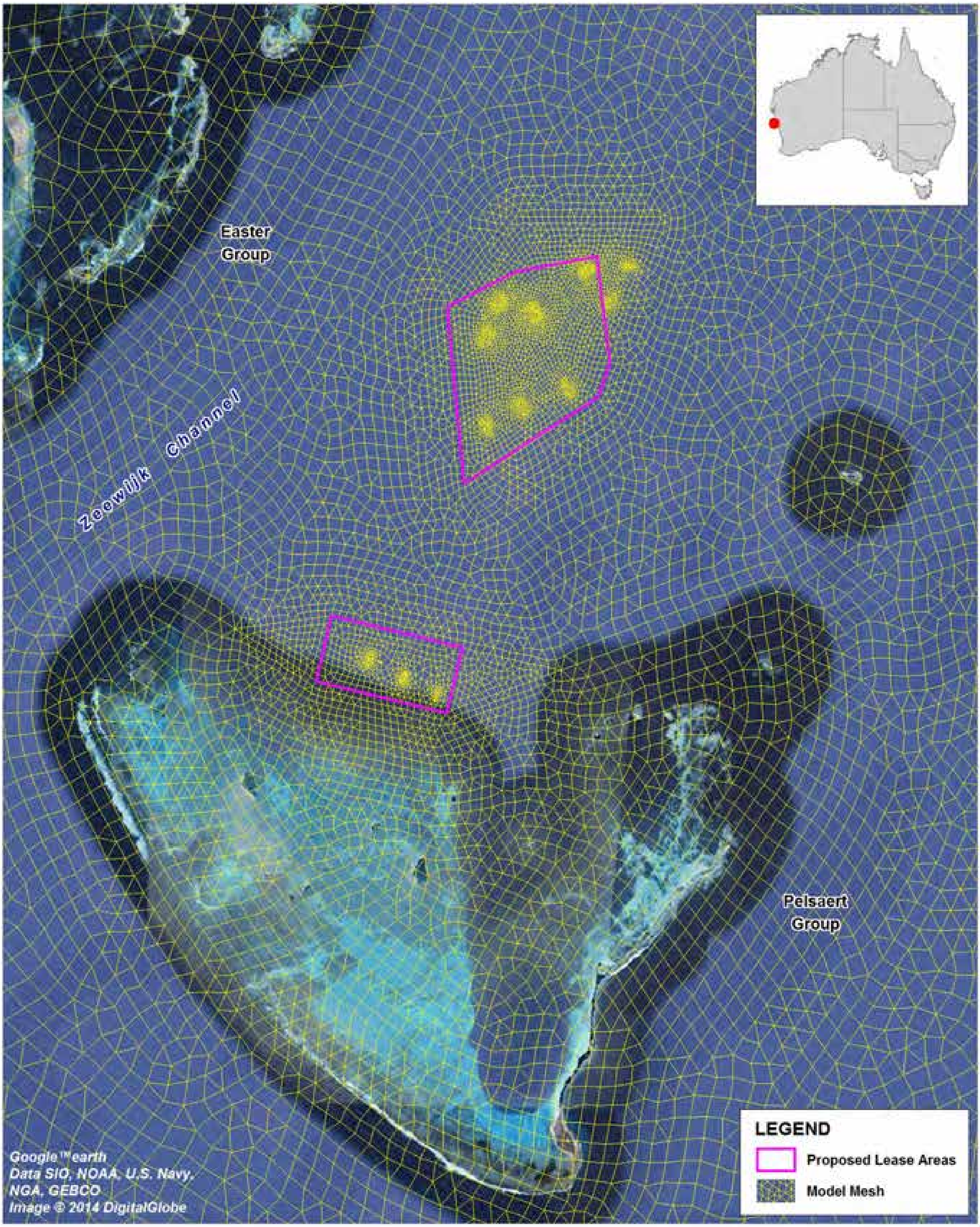

Title:

Model Mesh – Proposed Lease Areas

Figure: 3-4

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Approx. Scale

BMT WBM

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3.1.3 Boundary conditions

A number of boundary conditions were required by the model, including water levels, currents, temperature, salinity and meteorological forcing. The datasets used to provide these conditions were as follows:

- Tidal boundary conditions were provided by the TPXO71 global tide model (https://www.esr.org/polar_tide_models/Model_TPXO71.html).
- Regional currents (e.g. Leeuwin Current), residual water levels, temperature and salinity boundary conditions were provided by the global climate model HYCOM (https://hycom.org/). Salinity values provided by HYCOM were found to consistently exceed those measured during the sampling program. As such a constant offset of 0.3 PSU was applied to the salinity forcing. Details of this analysis are provided in Section 4.
- Meteorological data was taken from the US National Centers for Environmental Protection (NCEP) Climate Forecast System Reanalysis (CFSR) model. This is a global data-assimilation model which provides the full suite of meteorological data required by TUFLOW FV, namely: air temperature, rainfall, relative humidity, downward short-wave and long-wave radiation, windspeed and wind direction.
- To resolve potential wave-driven currents plus wave-induced drift and to capture suspension/deposition dynamics driven by waves, a wave field was applied to TUFLOW FV using the model SWAN. SWAN is a third-generation wave model, developed at Delft University of Technology, which computes random, short-crested wind-generated waves in coastal regions and inland waters. In addition to wind data provided by the meteorological datasets above, SWAN also requires swell to be provided on the boundaries. This was sourced from WAVEWATCH III, which is a global wave prediction model developed by the National Oceanic and Atmospheric Administration (NOAA). The SWAN model was run, using default parameters, on a regular grid with 500 m resolution.

Temperature, salinity and regional currents were taken from the HYCOM model, and water-levels were a combination of TPX (for tidal dynamics) and HYCOM (for the non-tidal components). These hydrodynamic boundaries were specified using an active Flather condition (as derived from Flather et al., 1976) which relaxes the barotropic (depth-averaged) component to ensure that the model remains internally consistent and mass conservative.

3.2 Water Quality

The water quality model utilised was the Aquatic Ecodynamics (AED) model library developed at UWA by the research group led by A/Prof. Matt Hipsey (http://aed.see.uwa.edu.au/research/models/AED/). It can simulate a number of biogeochemical pathways relevant to water quality, including nutrient, sediment and algal dynamics (Figure 3-5).

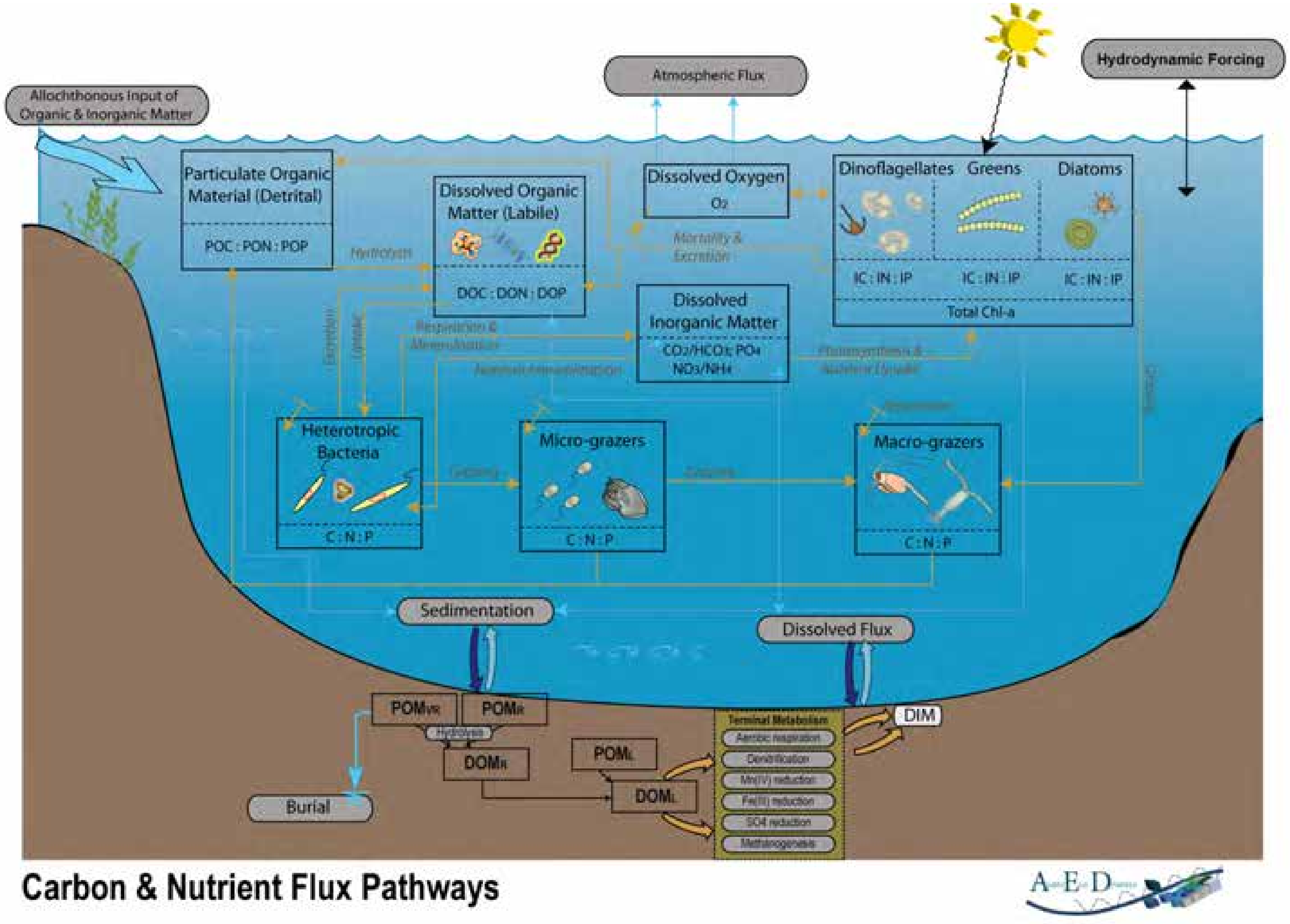

Figure 3-5 Carbon and nutrient processes simulated in AED

Boundary and initial conditions are required for each of the variables simulated by AED. These were derived from the water quality samples conducted as part of this study and are presented in Table 3-2. Rather than seasonally variable values, constant values were applied because an analysis of water quality samples indicated minimal seasonality in the water quality constituents of interest. Figure 3-6 contains time-series of TN and TP concentrations from samples taken at site L1A, from the CSIRO Atlas of Regional Seas (CARS) climatology (http://www.marine.csiro.au/~dunn/cars2009/), and averaged over all samples taken during this study. There is some variability in the samples but this is within the bounds of variability between replicates, as indicated by the two samples of TN taken on 20th June 2014 and 11th March 2014 at site L1A. Generally, however, the figures demonstrate that the CARS data are relatively poor representations of actual conditions (particularly with respect to the key biological nutrient phosphorus) and as such were not used in this study.

Table 3-2 AED variables oceanic boundary and initial conditions

Variable	Value at oceanic boundary (mg/L)
Dissolved Oxygen	6.8
Silicate	0.0281
Ammonia	0.0042
Nitrate	0.014
Filterable Reactive Phosphorus	0.0031
Dissolved Organic Nitrogen	0.09
Particulate Organic Nitrogen	0.012
Dissolved Organic Phosphorus	0.001
Particulate Organic Phosphorus	0.001
Dissolved Organic Carbon	0.204
Particulate Organic Carbon	0.204
Phytoplankton (in mg C / L)	0.006

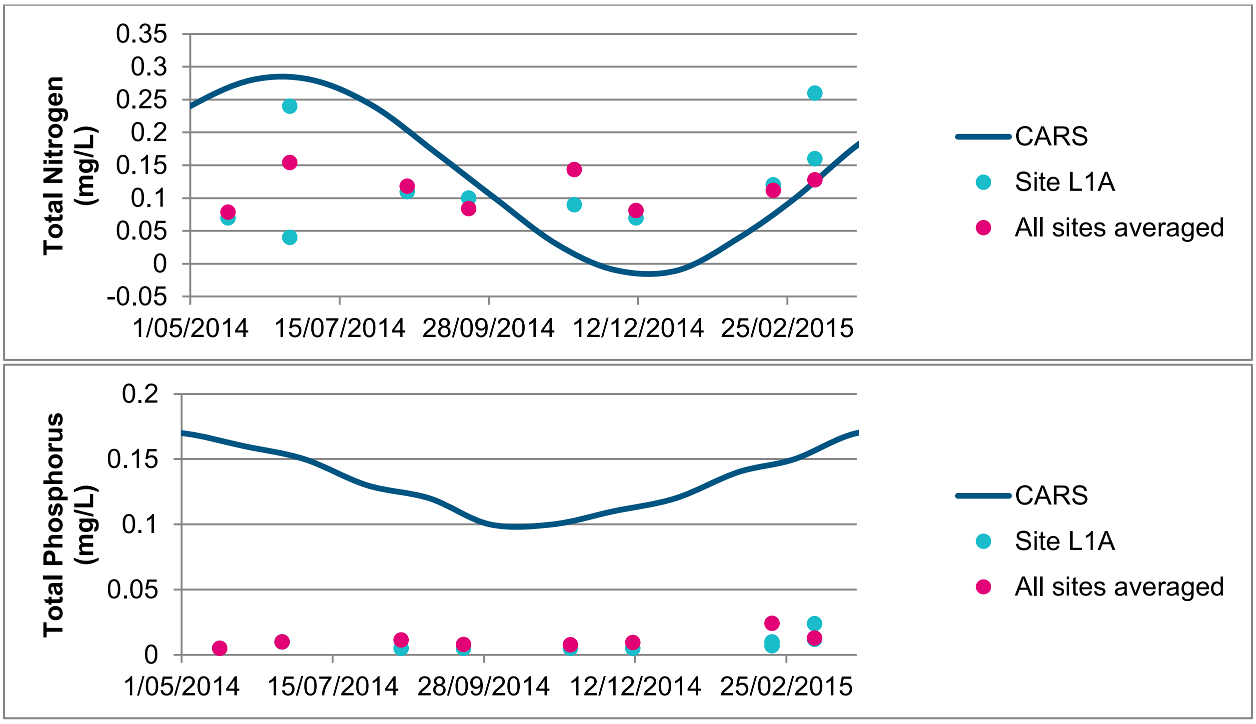

Figure 3-6 TN and TP comparisons between the CARS database and samples taken in the course of this study

4 Calibration Results

Once constructed, the hydrodynamic and water quality model was run for a period of one year from 1st March 2014 to 1st March 2015 to encompass the majority of the sampling program. The model could not be run further into the March period (to capture samples taken on 11th March 2015) as not all boundary conditions were available at the time.

Model results were compared against observations for a number of key hydrodynamic and water quality variables, as described in the sub-sections below. In addition to time-series plots, a suite of univariate statistics was used to compare model data with observations, where appropriate, using the approach outlined in Stow et al. (2009). The statistics examined were:

- The r statistic
- Average error (AE)
- Root mean squared error (RMSE)
- Absolute average error (AAE)
- Modelling efficiency (MEF).

Univariate statistics are sensitive to phase errors and should be considered in concert with the time-series plots for this reason. The suite of metrics should also be considered in their entirety, as some statistics may provide a misleading impression of the skill of the model. For example, a score of 1 for the r statistic indicates that the model varies perfectly in step with the observations, but it says nothing about any bias that may be present. Also, high scores for RMSE, AE and AAE may indicate a bias within the model, or may just be the result of one or two outlier observations that affect the overall score. The following provides some notes on interpreting each metric:

- r
  - Varies between -1 and 1, with a score of 1 indicating the model varies perfectly with the observations and a negative score indicating the model varies inversely with the observations. Model and observations do not need to match to provide a high score, as a consistent bias may be present.
- AE
  - Measures the mean magnitude and direction of the difference between model data and observations, and hence can be used to measure bias. Values near zero are desirable but negative and positive errors cancel each other out so low scores can be misleading.
- RMSE
  - Measures the mean magnitude, but not direction, of the difference between model data and observations. This accounts for the cancelling of positive and negative errors, but is weighted towards large errors and is therefore sensitive to outliers. Values near zero indicate good model skill.
- AAE

- Also measures the mean magnitude, but not direction, of the difference between model data and observations. AAE is always equal to or lower than the RMSE and the difference between the two is a measure of the variability of the errors. If the difference between AAE and RMSE is low, this indicates a consistent bias and low error variability; if the difference is large, this indicates a small number of outliers and high error variability. Values near zero indicate good model skill.

- MEF
  - Is a measure of how well a model predicts observations relative to the mean of the observations. A value near 1 suggests the model is skilful. A value near 0 suggests the model is no better at predictions than the average of the data. A value below 0 indicates that the mean of the observations would be a better predictor than the model.

The following sub-sections contain the time-series plots, statistics and additional commentary on each of the variables compared. Each sub-section contains a brief summary of results initially, followed by more detailed analysis subsequently.

4.1 Hydrodynamic calibration

4.1.1 Water levels

4.1.1.1 Summary

The model captures the variability of water levels very well, over timescales ranging from a single tidal cycle (i.e. the timing of high/low tide) to fortnightly spring/neap dynamics and monthly variability of residual water levels. Tidal range is slightly under-predicted at both lease-area and regional sites, by approximately 4-7 cm on average. Thirteen constituents were utilised from the TPX tide model, which should be sufficient to resolve the diurnal signal in this region. The under-prediction is therefore likely due to errors in the magnitude of constituents within the TPX model.

To investigate the under-prediction of tidal range, a sensitivity test was conducted with the range increased by 30% at the open boundary. This improved the water-level calibration slightly, but tidal range was still under-predicted at the regional sites and the change proved detrimental to the velocity calibration at the lease-area sites. In the context of this study, current velocities are of greater importance than water-levels in simulating the fate of particles released from aquaculture activities. Although the tidal range was slightly under-predicted, it was decided to proceed with the original TPX tidal forcing to obtain the best possible representation of the velocity field.

4.1.1.2 Additional detail

Depth measurements were taken at the four ADCP locations outlined in Section 2.1. For comparison against the model, which is referenced to Australian Height Datum (AHD), measurements for each sensor and each deployment were referenced to the mean of the measurements. In most cases, this resulted in a clear bias (e.g. Figure 4-1) and so a constant offset was applied to the data to allow for a like-for-like comparison. The offset applied to each set of data is provided in Table 4-1.

The ADCP in the southern lease area did not collect depth data for all except the final deployment (Feb 2015 to Mar 2015). To produce comparisons for these periods, therefore, the depth data from the nearby northern lease area was used, with a further offset of 2.5m applied to account for bed elevation differences between the sites.

Note that the time-series plots below contain codes to reference each location, as follows:

- ADCP_L1 – northern lease-area site
- ADCP_L2 –southern lease-area site
- North AWAC – northern regional site
- South AWAC – southern regional site.

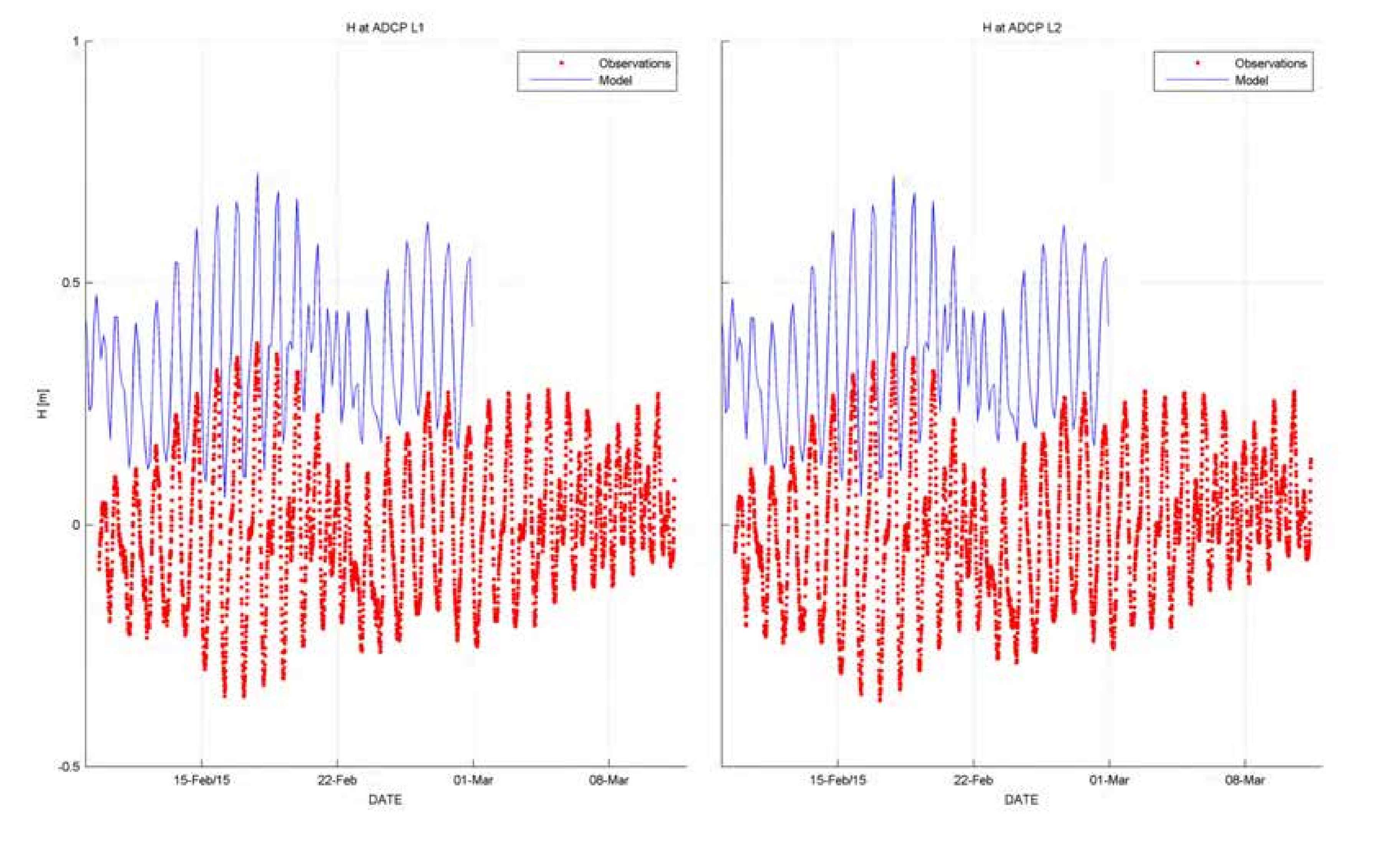

Figure 4-1 Example of bias when comparing simulated water levels (H) against depth measurements referenced to their mean

Table 4-1 Table of offsets applied to allow a comparison between model results (referenced to AHD) and depth measurements

Location (code)	Deployment	Offset (cm)
Northern lease area (ADCP_L1)	May 2014 to Jun 2014	50
	Aug 2014 to Sep 2014	35
	Nov 2014 to Dec 2014	25
	Feb 2015 to Mar 2015	25
Southern lease area (ADCP_L2)	May 2014 to Jun 2014	50
	Aug 2014 to Sep 2014	35
	Nov 2014 to Dec 2014	25
	Feb 2015 to Mar 2015	40
Northern regional (North AWAC)	Jul 2014 to Nov 2014	37
	Nov 2014 to Mar 2015	32
Southern regional (South AWAC)	Jul 2014 to Nov 2014	30
	Nov 2014 to Mar 2015	32

Water-level comparisons at the regional sampling sites outside of the lease areas (North AWAC & South AWAC) are presented in Figure 4-2 (first deployment) and Figure 4-3 (second deployment). For clarity, additional plots of the same comparison broken down into individual calendar months are presented in Appendix B.1. The plots indicate that the model does a good job of capturing variability across multiple timescales, with r values of 0.954 to 0.974. The model slightly under-predicts the tidal range in these regions, with RMSE of approximately 5-6 cm, which is small in the context of a 1 m tidal range.

Water-level comparisons within the lease areas are presented in Figure 4-4 to Figure 4-7. The model again captures variability well in this region, with r values of 0.945 to 0.972, although tidal range is also slightly underestimated, with RMSE of 4-7 cm.

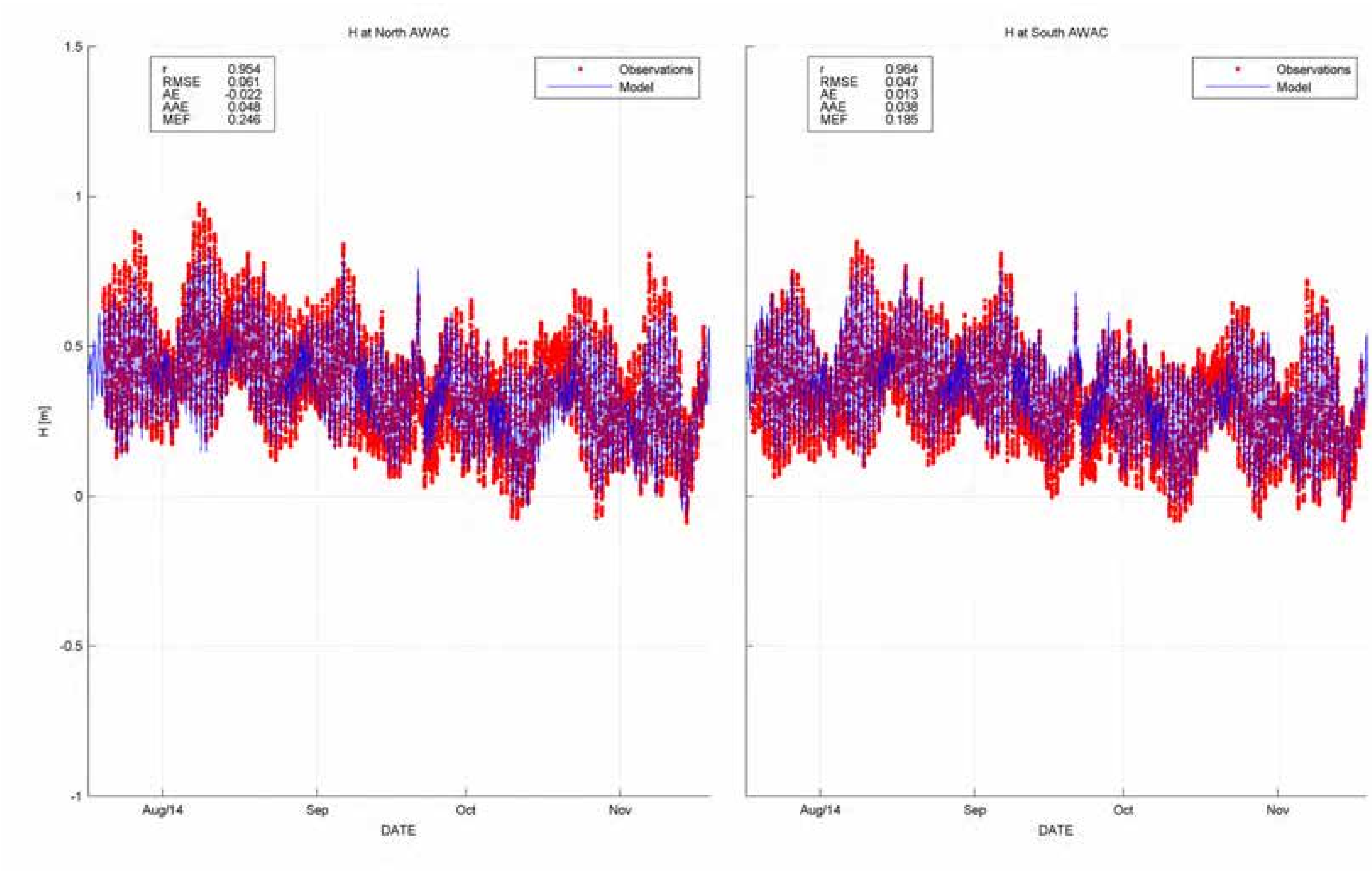

Figure 4-2 Water-level comparisons at regional sites – July 2014 to Nov 2014 deployment

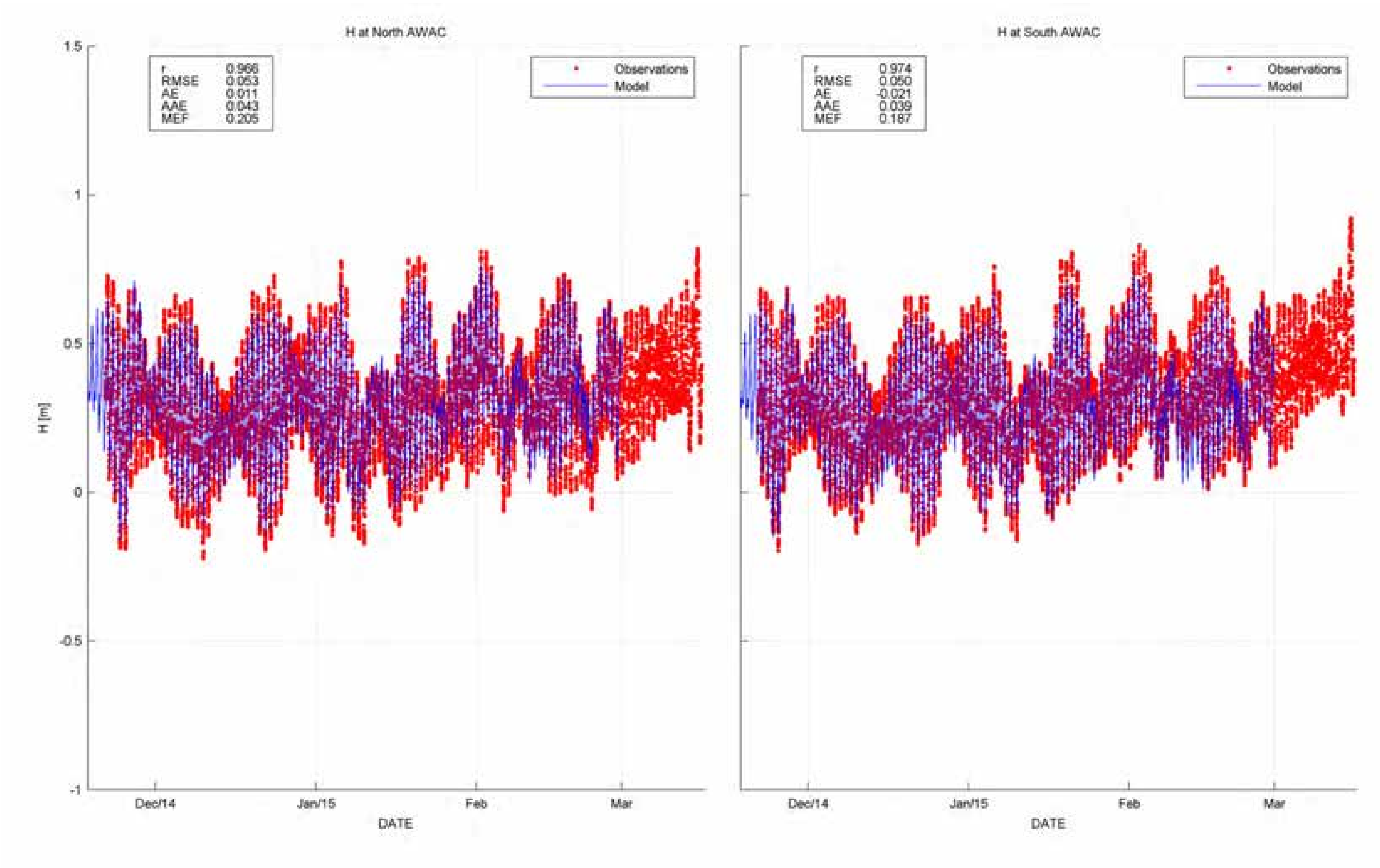

Figure 4-3 Water-level comparisons at regional sites – Nov 2014 to Mar 2015 deployment

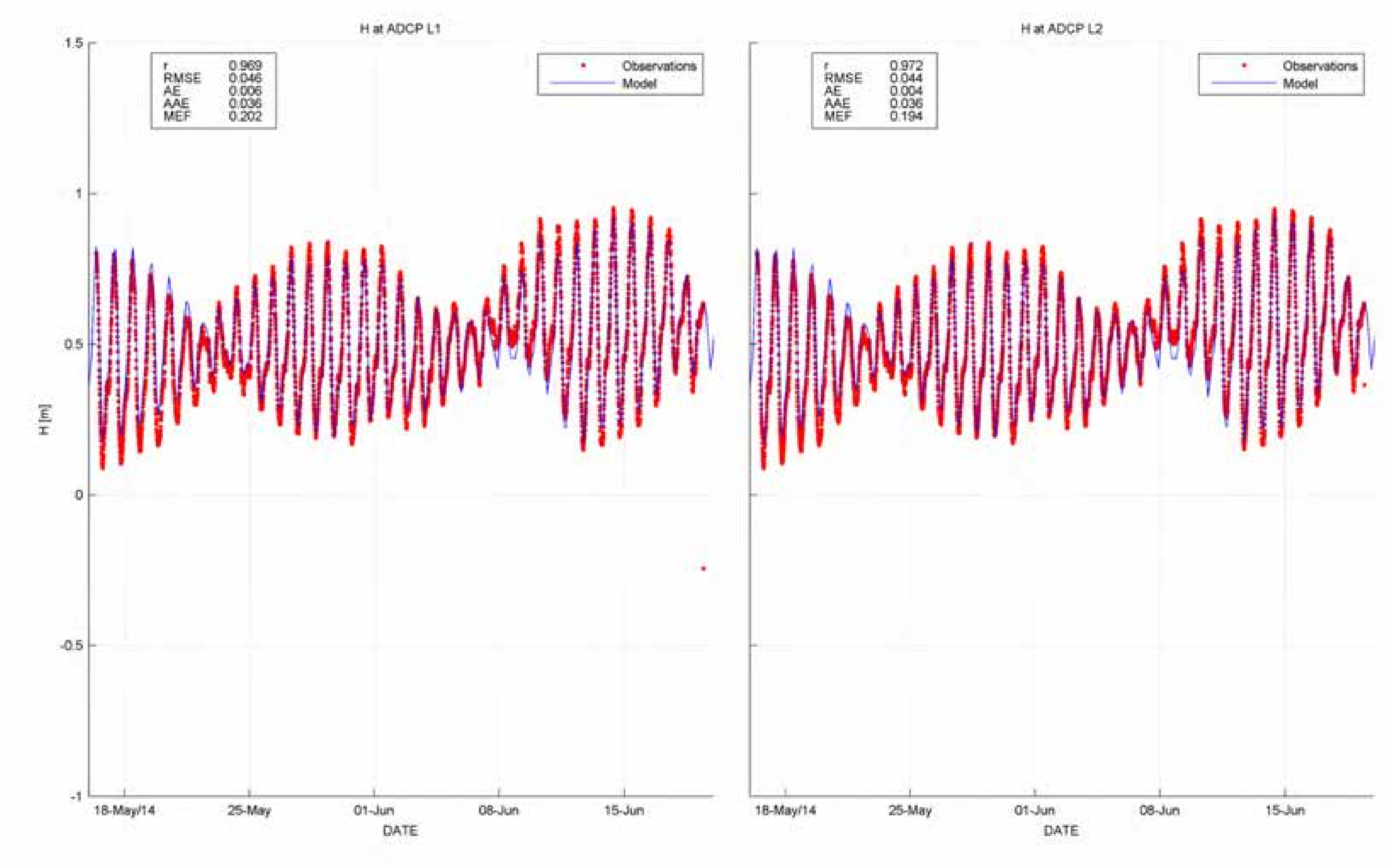

Figure 4-4 Water level comparisons at sampling sites within the proposed lease areas – May 2014 to Jun 2014 deployment

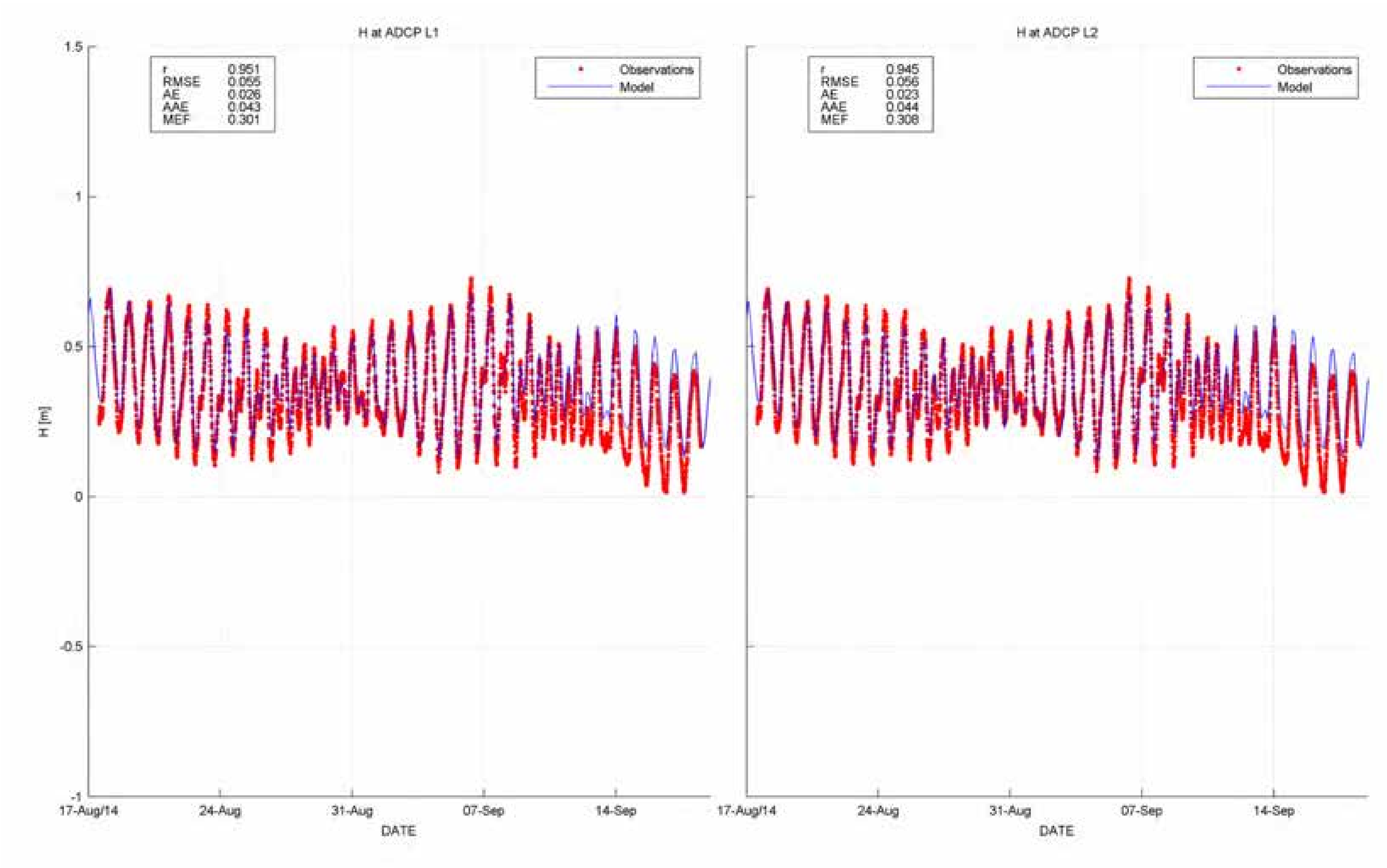

Figure 4-5 Water level comparisons at sampling sites within the proposed lease areas – Aug 2014 to Sep 2014 deployment

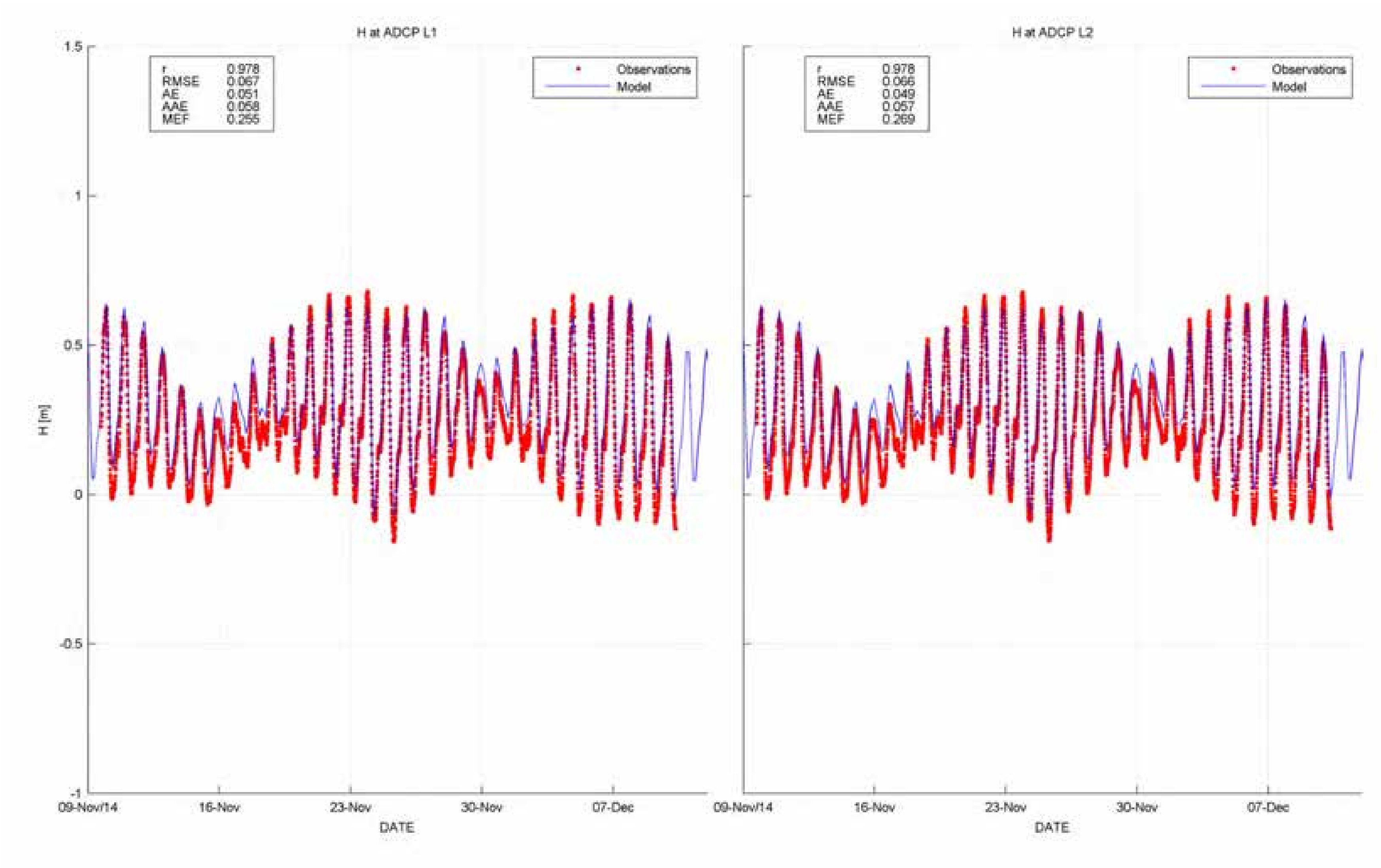

Figure 4-6 Water level comparisons at sampling sites within the proposed lease areas – Nov 2014 to Dec 2014 deployment

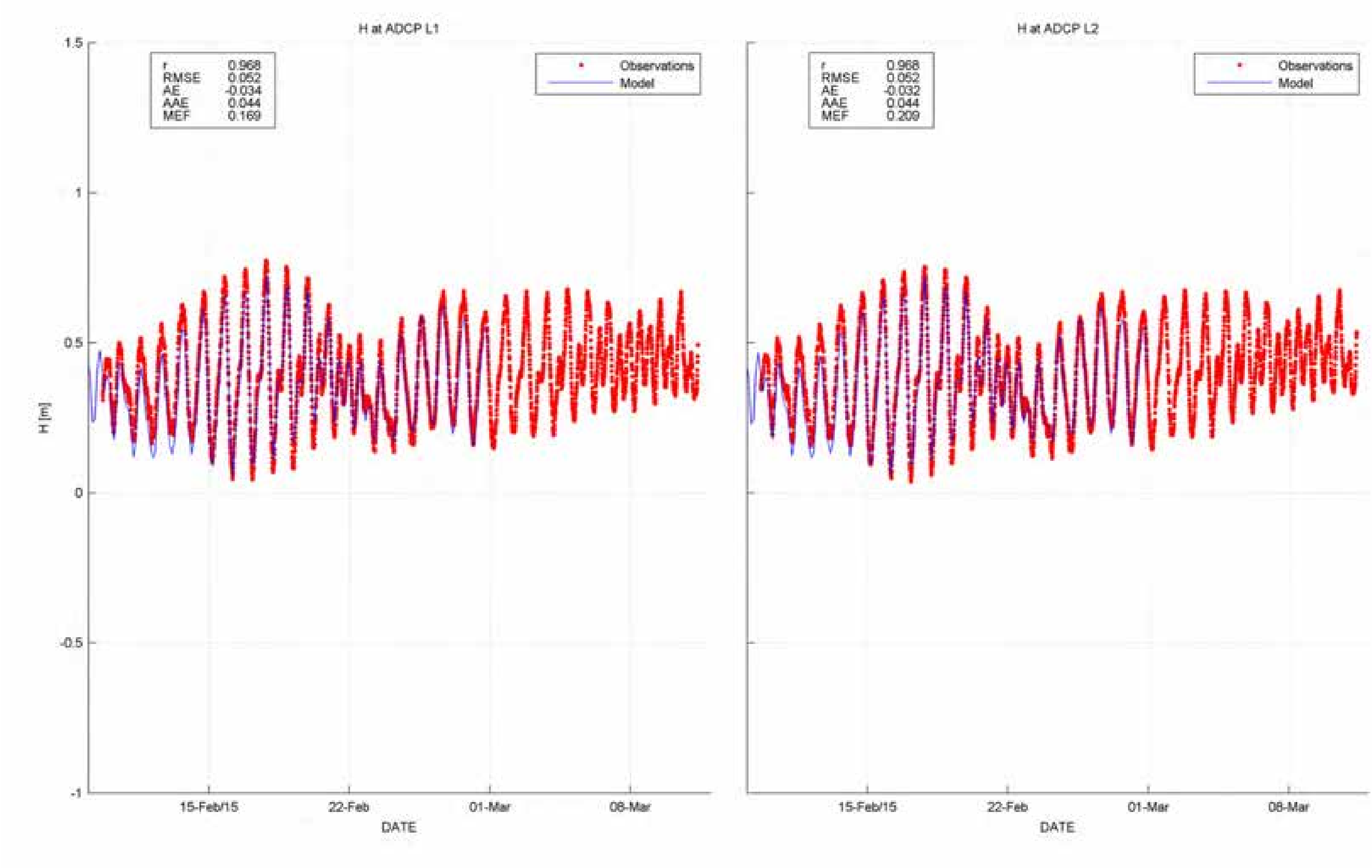

Figure 4-7 Water level comparisons at sampling sites within the proposed lease areas – Feb 2014 to Mar 2014 deployment

As noted in the summary above, to address the under-prediction of tidal range, a test run was conducted which increased the magnitude of the tide at the oceanic boundary by 30%. This improved the comparison outside of the lease areas, although the model still under-predicted the tidal range (Figure 4-8). Within the lease areas, the tidal range was then over-predicted, with a RMSE of 6-7 cm, similar to the magnitude of error in the run without modifying the tidal forcing (Figure 4-9). Furthermore, modifying the tidal forcing adversely affected the velocity calibration within the proposed lease areas. In the context of the distribution of particles arising from aquaculture activities, velocity was considered to be more important than water level. It was decided, therefore, to continue with the original tides as these provided a better velocity calibration in the area of interest. Additional plots pertaining to this analysis are presented in Appendix B.1.2.

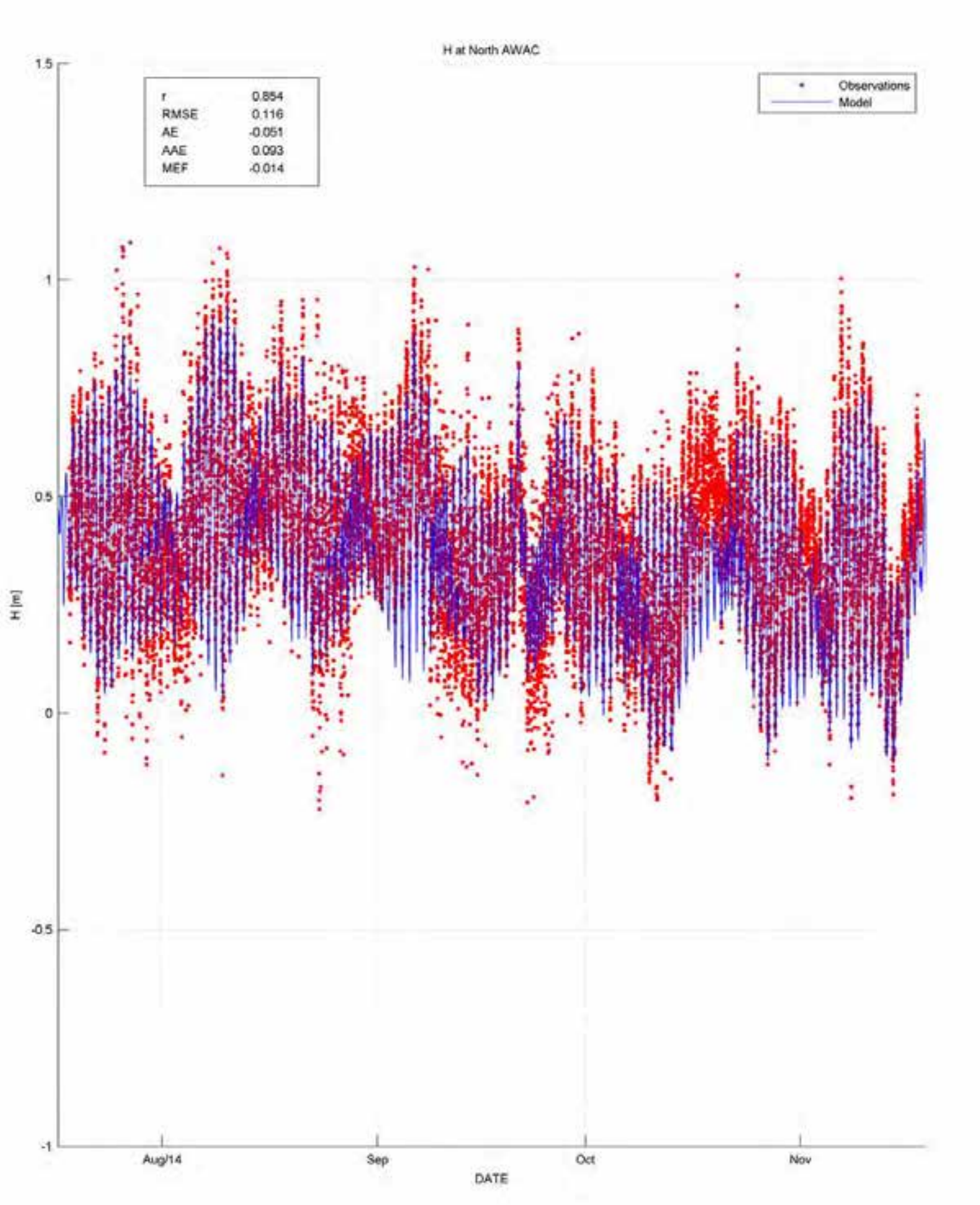

Figure 4-8 Example of under-prediction of tidal range at regional sites following modification of boundary condition

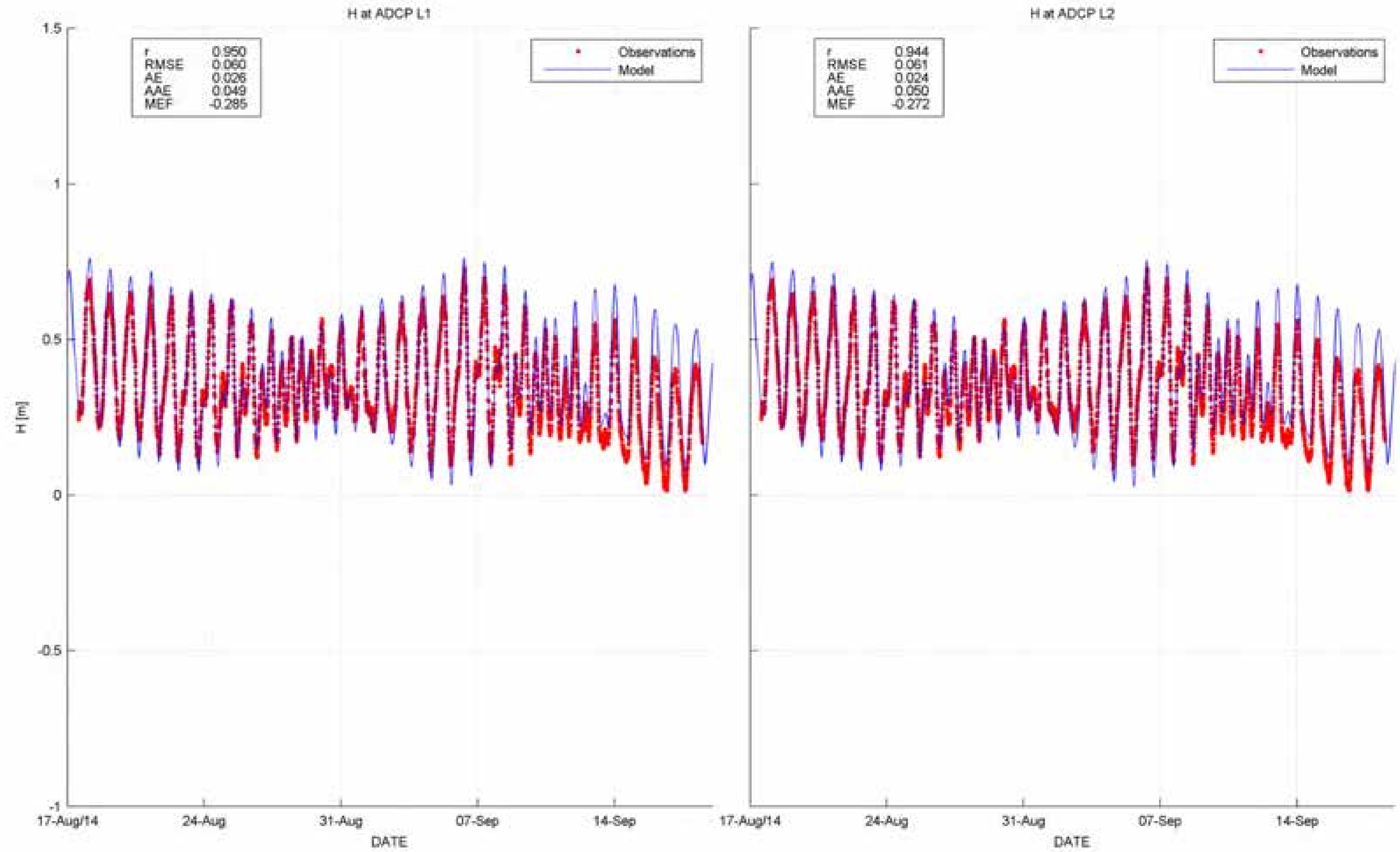

Figure 4-9 Example of over-prediction of tidal range at lease-area sites following modification of boundary condition

4.1.2 Velocities

4.1.2.1 Summary

Simulated current velocities compared very well with observations at both regional and lease-area sites. The model successfully captures both the variability and magnitude of velocities at all sites, with good scores for the skill metrics outlined at the beginning of Section 4. As noted in Section 3.1, a primary aim of the hydrodynamic model is to provide a satisfactory representation of the velocity and wave field, for the purposes of simulating the fate of particles released from aquaculture activities.

It is BMT WBM's opinion that the model does an excellent job of predicting the velocity field within this region. The choice of active Flather condition for the combination of TPX and HYCOM data at the open boundary results in a very favourable comparison with observations at the open-ocean sites. Furthermore, the local features within the Pelsaert and Easter island groups are sufficiently well-resolved to capture the important processes affecting the velocity field within this region, which is particularly challenging to simulate due to the dynamic interaction between regional currents and local bathymetric features.

4.1.2.2 Additional detail

Velocity measurements from each deployment were decomposed into X (east-west) and Y (north-south) components prior to comparison against model results, to allow for line-plot comparisons of both easterly and northerly components of velocities. Such comparisons provide greater transparency and allow for easier interpretation of model skill, when compared against, for example, rose-plot snapshots or vector plots. Each dataset was also analysed to remove values that were considered to be affected by surface noise (e.g. breaking waves), which would adversely skew depth-averaged velocity. A comparison of a velocity field pre- and post-removal of surface noise is included in Figure 4-10.

Comparisons of velocities for the regional sites are presented in Figure 4-11 and Figure 4-12. The time-series plots demonstrate that the model does an excellent job of recreating observed velocities, and that it is capturing regional currents well. This is also borne out by the univariate metrics, with r values of 0.745 to 0.915 and relatively low AAE values of 0.033 m/s to 0.077 m/s (mean observed velocities are 0.119 m/s to 0.147 m/s).

During July and August 2014, the X component of velocity in the model is positive while observations tend to zero. This may be due to a water-level gradient towards the coast that is not recreated by the model (which is ultimately driven by the third-party HYCOM data), or by slight errors in the direction of regional currents in HYCOM during this period. Some efforts were made to overcome this through modifying the X component of velocity in the boundary conditions, but this was detrimental to the overall calibration in other areas. Rose plots summarising the surface velocity fields at these locations are presented in Figure 4-13 and Figure 4-14, and additional surface and bottom velocity time-series plots are included in Appendix B.2. Other departures from observations (e.g. late August at the southern regional site) may be caused by slight errors in the HYCOM or CFSR forcing data. These errors are not consistent and, hence, are unlikely to be caused by a fixed component such as model bathymetry or parameterisation.

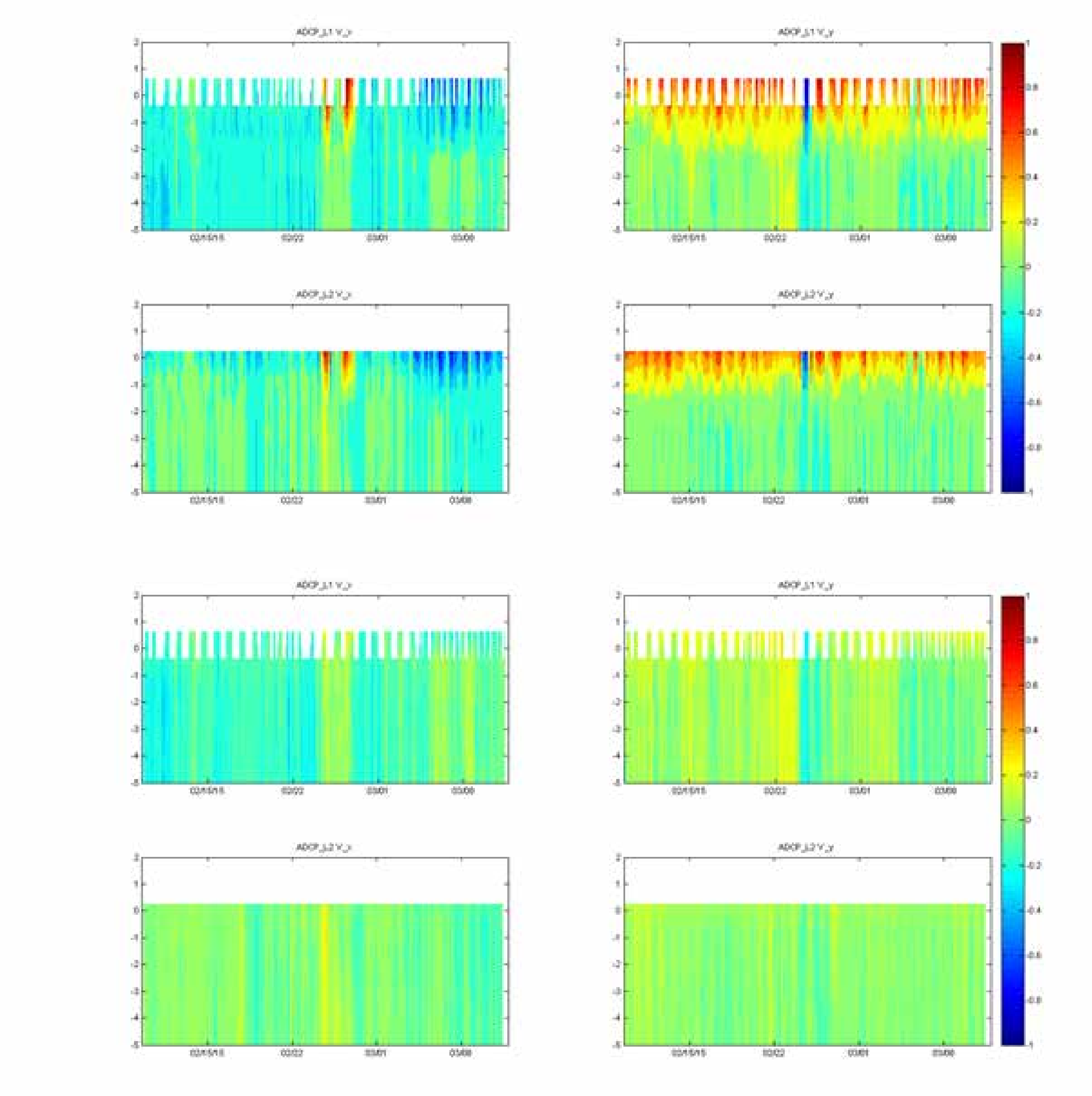

Figure 4-10 Comparisons of velocity fields (in m/s) prior to removal of surface noise (top 4 panels) and after removal of surface noise (bottom 4 panels)

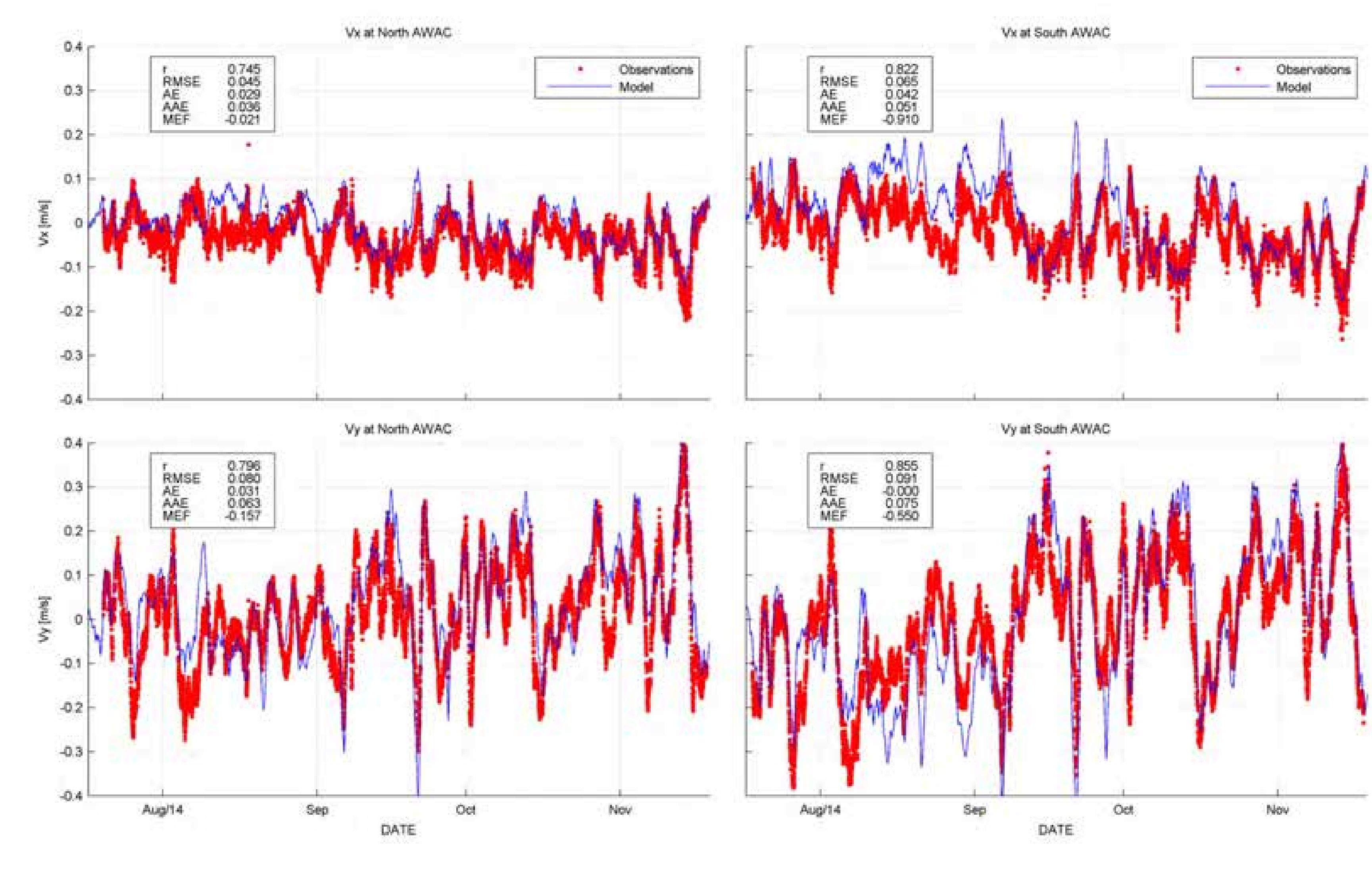

Figure 4-11 Depth-averaged velocity at sites outside of the proposed lease areas – Jul 2014 to Nov 2014 deployment

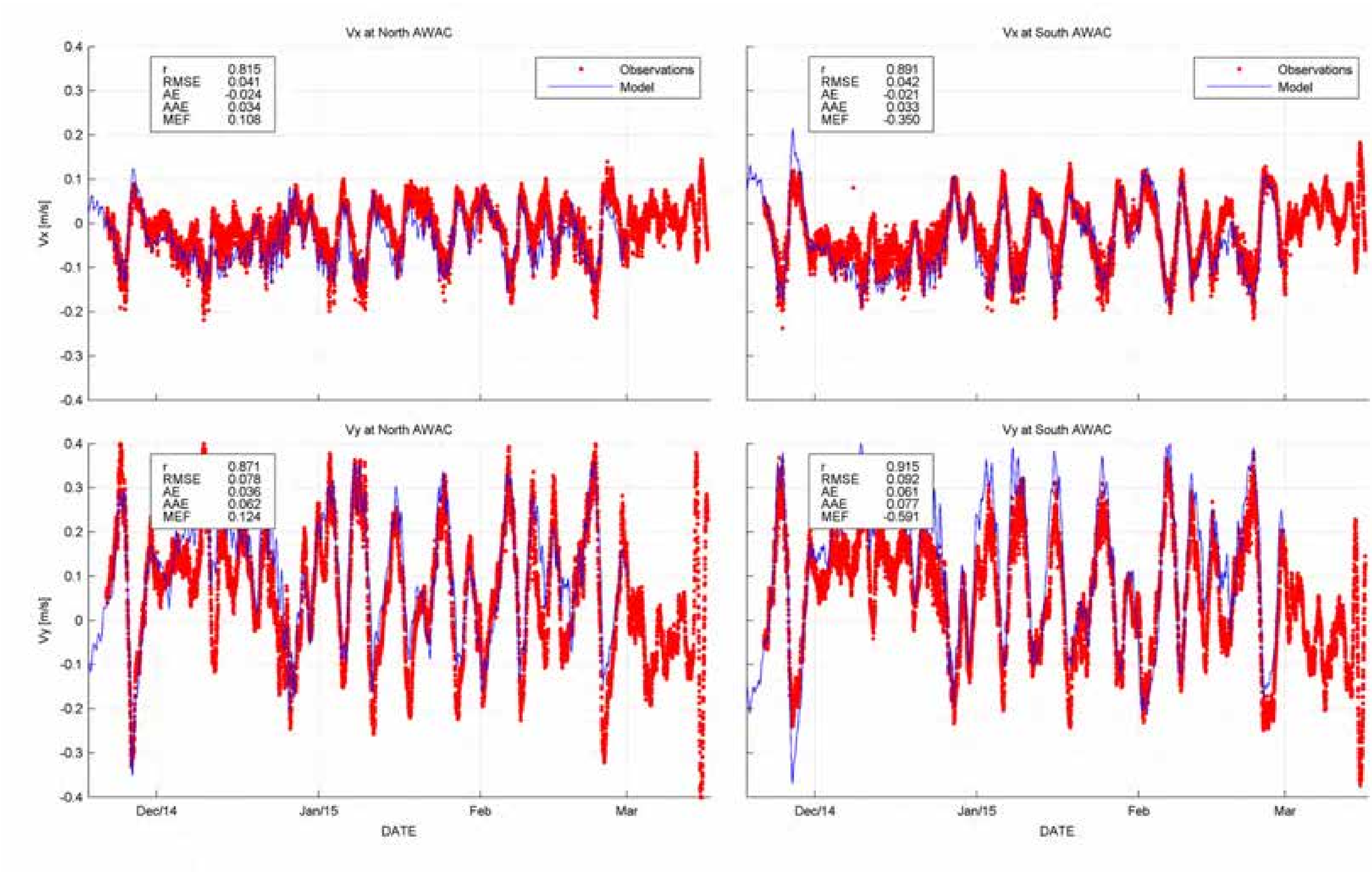

Figure 4-12 Depth-averaged velocity at sites outside of the proposed lease areas –Nov 2014 to Mar 2015 deployment

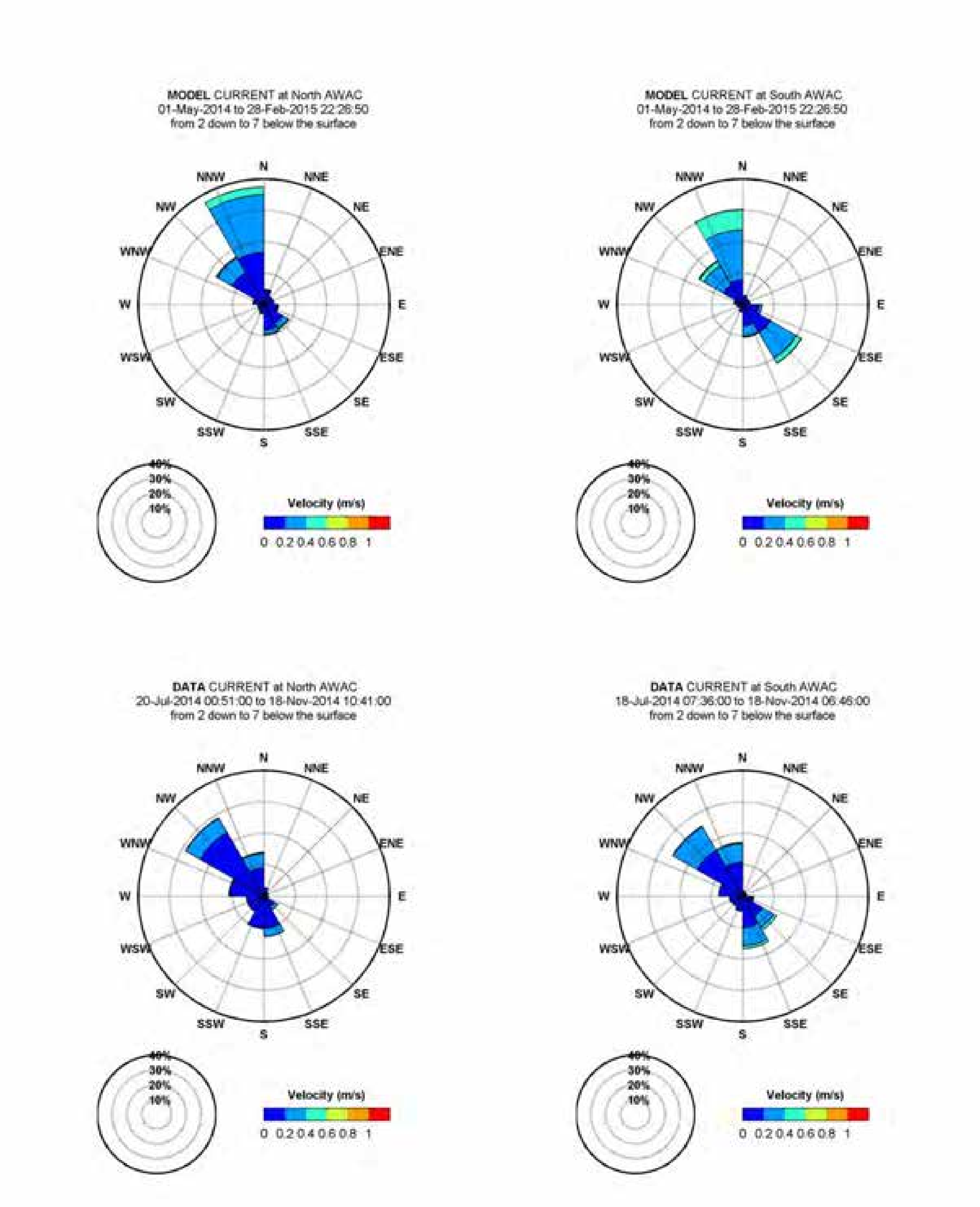

Figure 4-13 Rose plot of surface (2m to 7m depth) velocity – Jul 2014 to Nov 2014 deployment

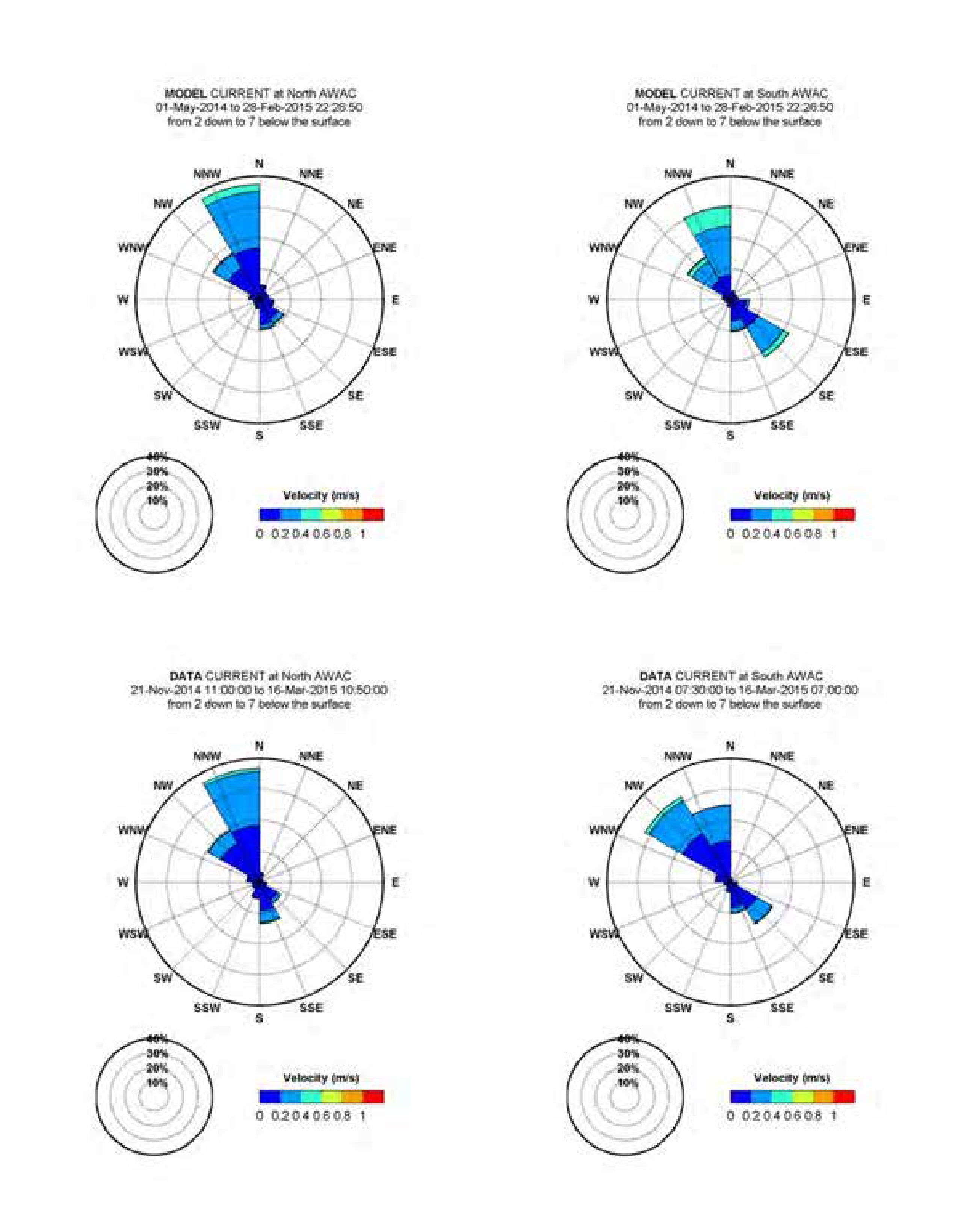

Figure 4-14 Rose plot of surface (2m to 7m depth) velocity – Nov 2014 to Mar 2015 deployment

Depth-averaged velocity comparisons for sites within the lease areas are presented in Figure 4-16 to Figure 4-19. In comparison to the open-ocean sites, this region poses a greater challenge to the model in that regional currents interact with islands and other bathymetric features to create a dynamic environment. Depending on the corresponding regional eddy field, the prevailing currents can rapidly switch from an east-to-west flow through the Zeewijk Channel, to flow in the opposite direction (e.g. during late November at site ADCP L1, Figure 4-18). Despite the difficulties of modelling such an environment, the model does an excellent job of recreating the observed velocities, albeit with slightly lower statistical scores than at the open-ocean sites. During some periods (e.g. May 2014) the model does not always match the variability of the measured velocity fields, which, as noted above, is likely due to errors in the boundary forcing data as it is not a consistent feature throughout. There are other periods (e.g. November 2014) in which the model follows observations very closely. This variability results in a range of r values from -0.072 (Y component at ADCP L2 during May/June 2014) to 0.815 (X component at ADCP L1 during February/March 2015). The Y component of velocity at site ADCP L2 typically has the lowest r values, which is likely due to the island chain south of this point curtailing north-south flows, making local effects rather than regional currents the dominant factor.

Currents at both the regional and lease-area sites are primarily driven by the residual currents provided by HYCOM (mesoscale eddies and regional currents such as the Leeuwin Current). A fast Fourier transform (FFT; Figure 4-15) of velocities identifies peaks at 12.5 and 24 hours, suggesting there are tidal influences, but velocity time-series suggest these are minor in comparison to those of regional currents. Furthermore, a test was carried out to examine the impact of wave action on velocities within the lease areas, which found that waves had a negligible impact on velocities, but were an important contributor to bed shear stress (Section 4.1.3).

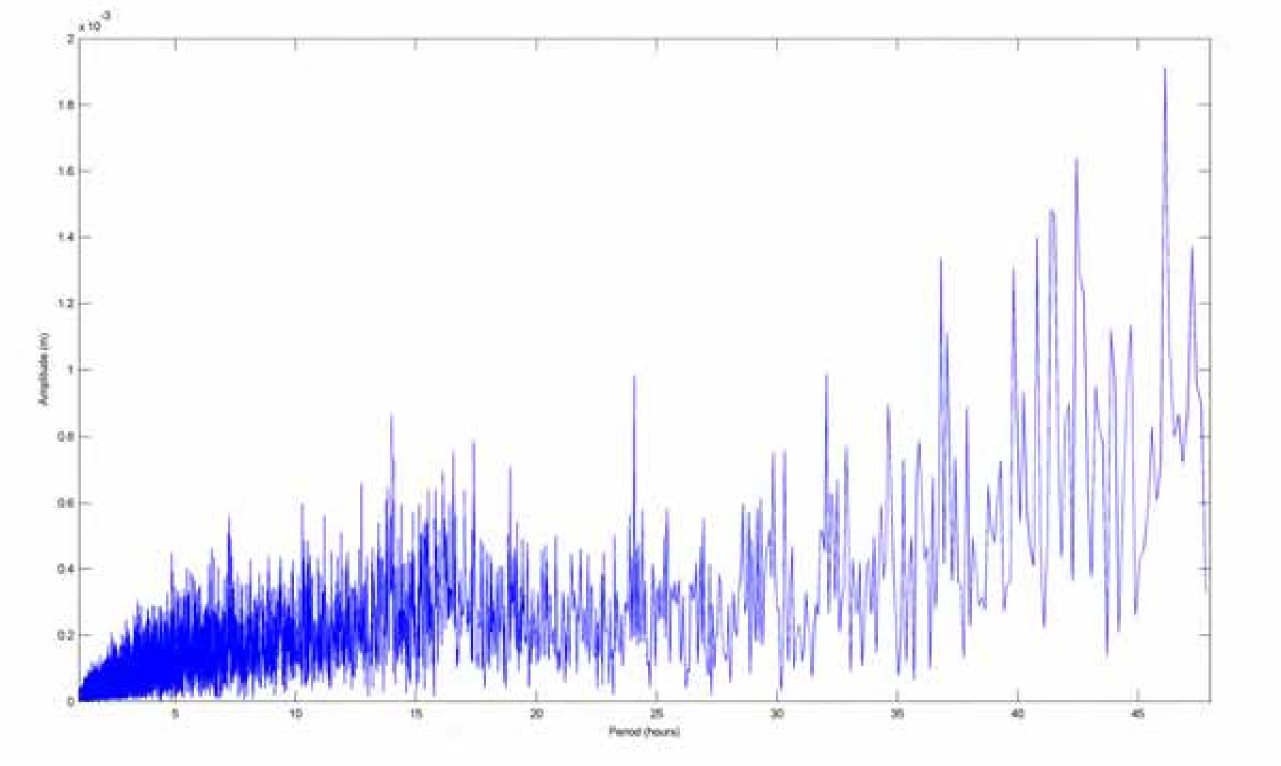

Figure 4-15 Periods from fast Fourier transform of velocity at the northern regional site during the July to November 2014 deployment.

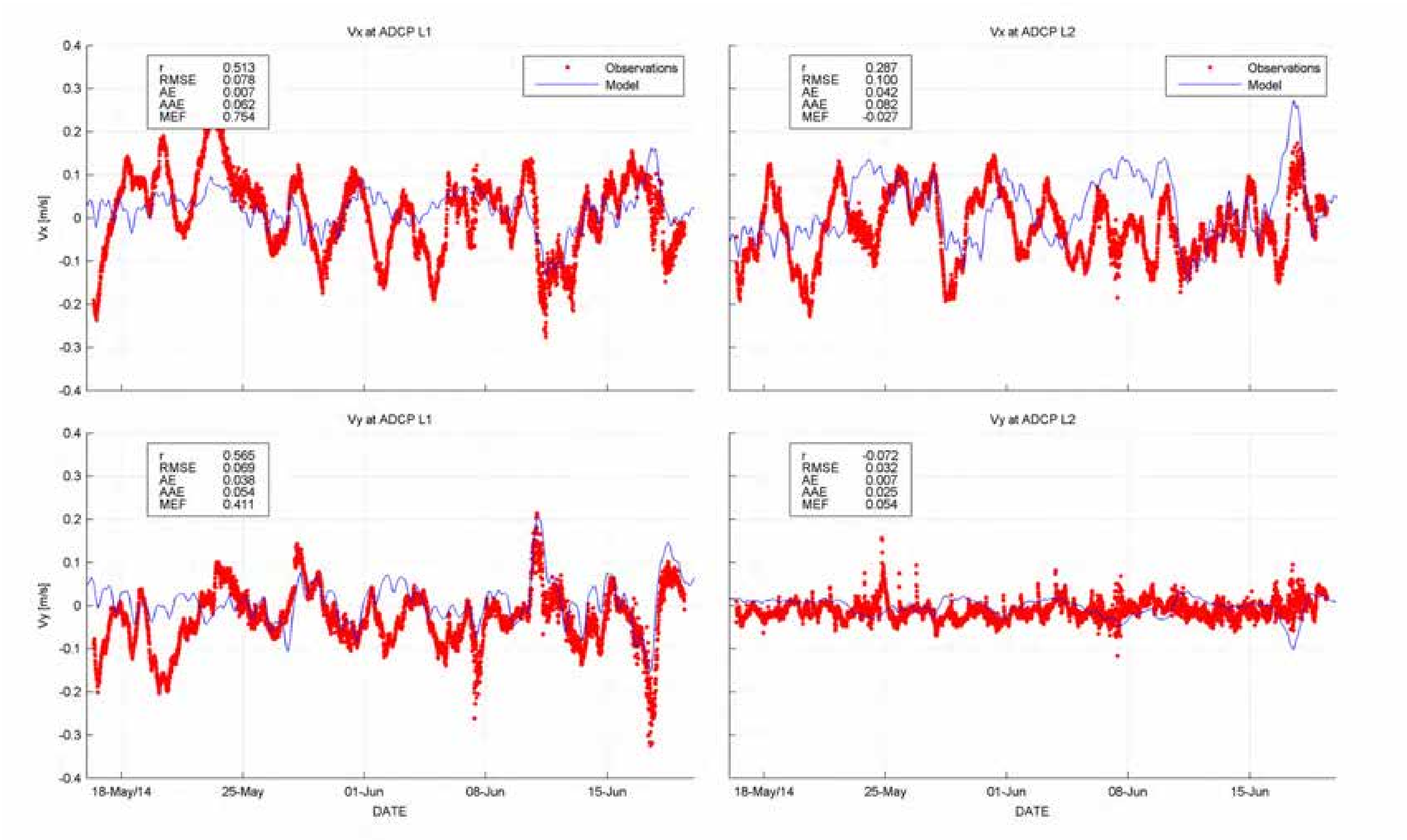

Figure 4-16 Depth-averaged velocity at sites within the proposed lease areas – May 2014 to Jun 2014 deployment

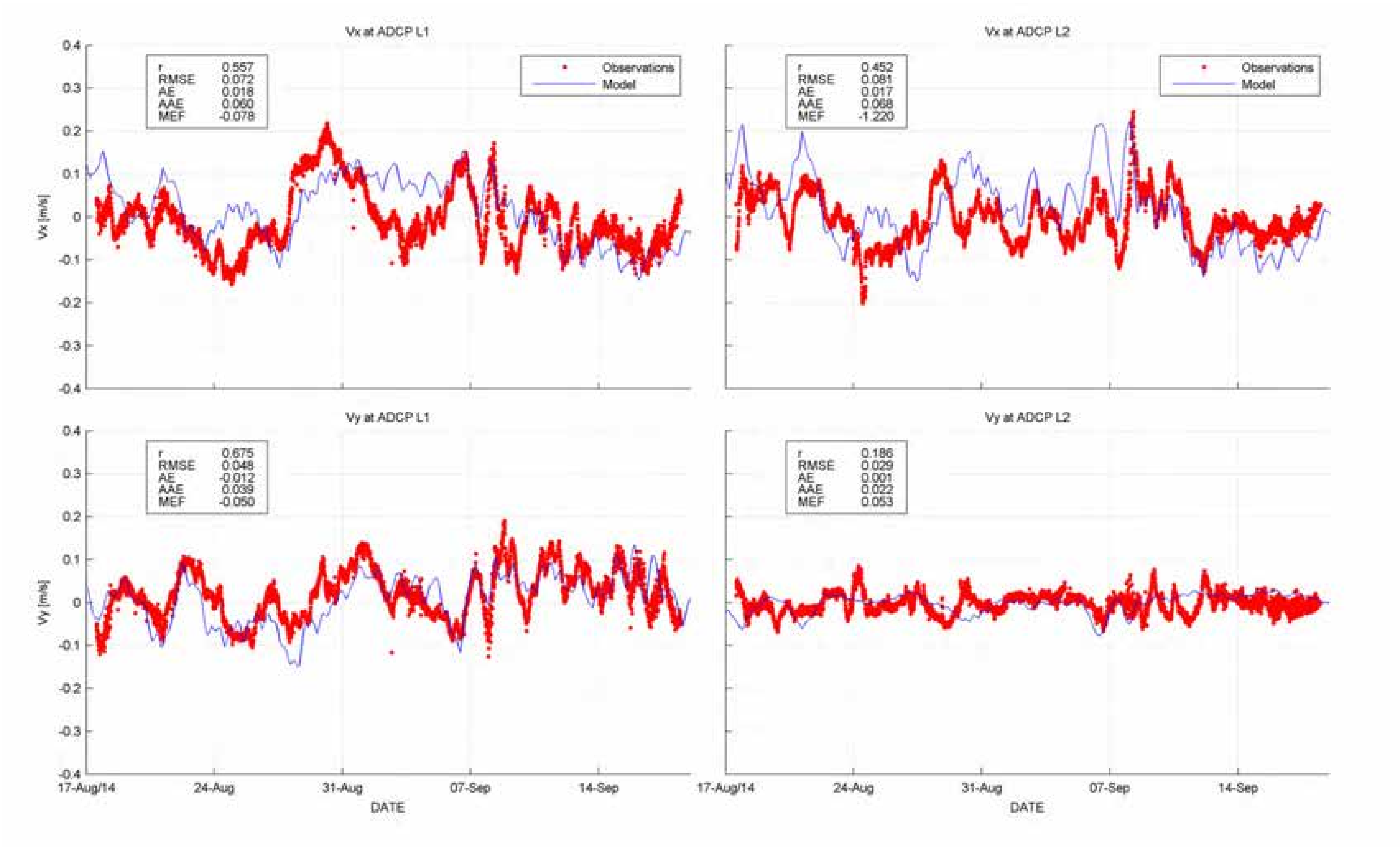

Figure 4-17 Depth-averaged velocity at sites within the proposed lease areas – Aug 2014 to Sep 2014 deployment

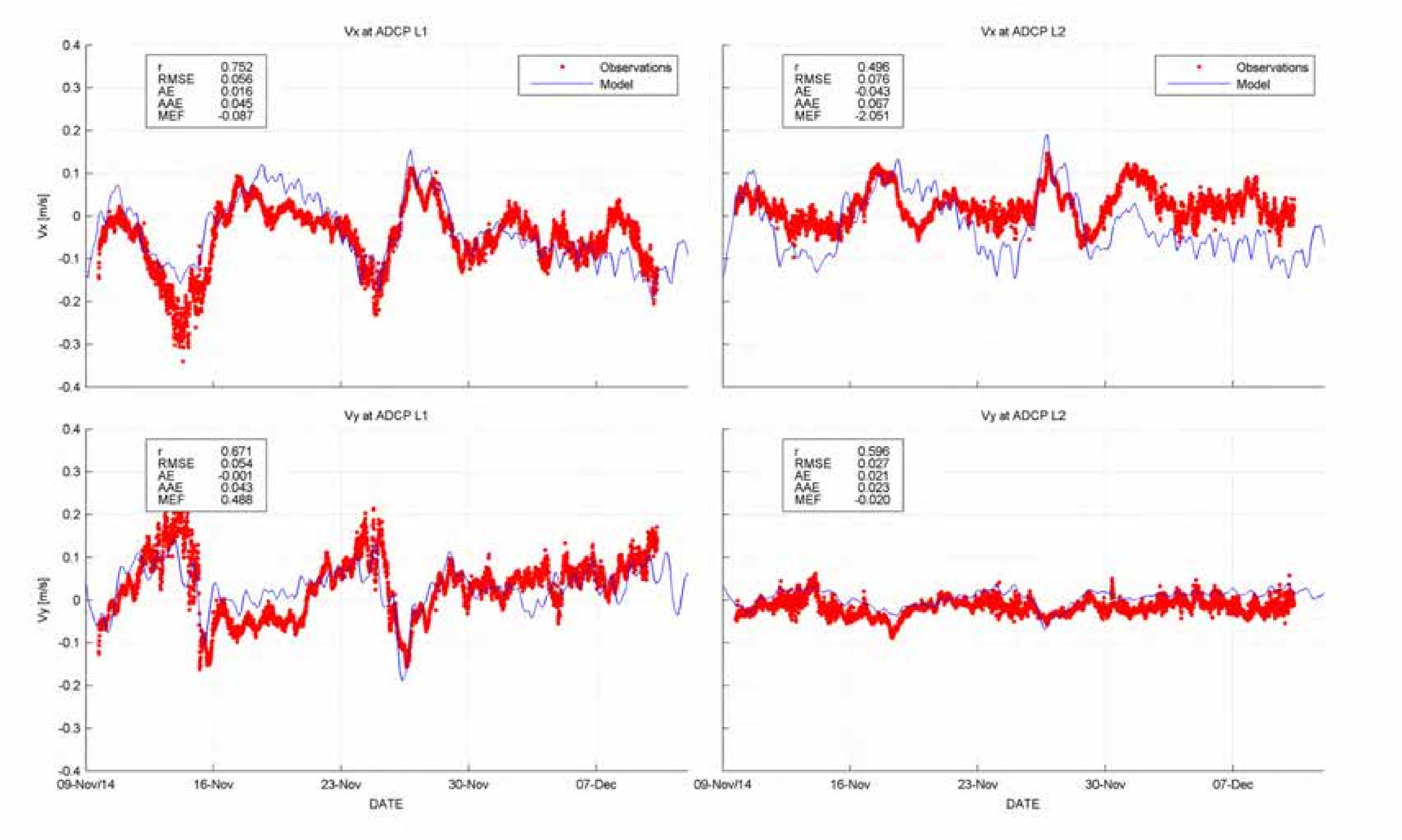

Figure 4-18 Depth-averaged velocity at sites within the proposed lease areas –Nov 2014 to Dec 2014 deployment

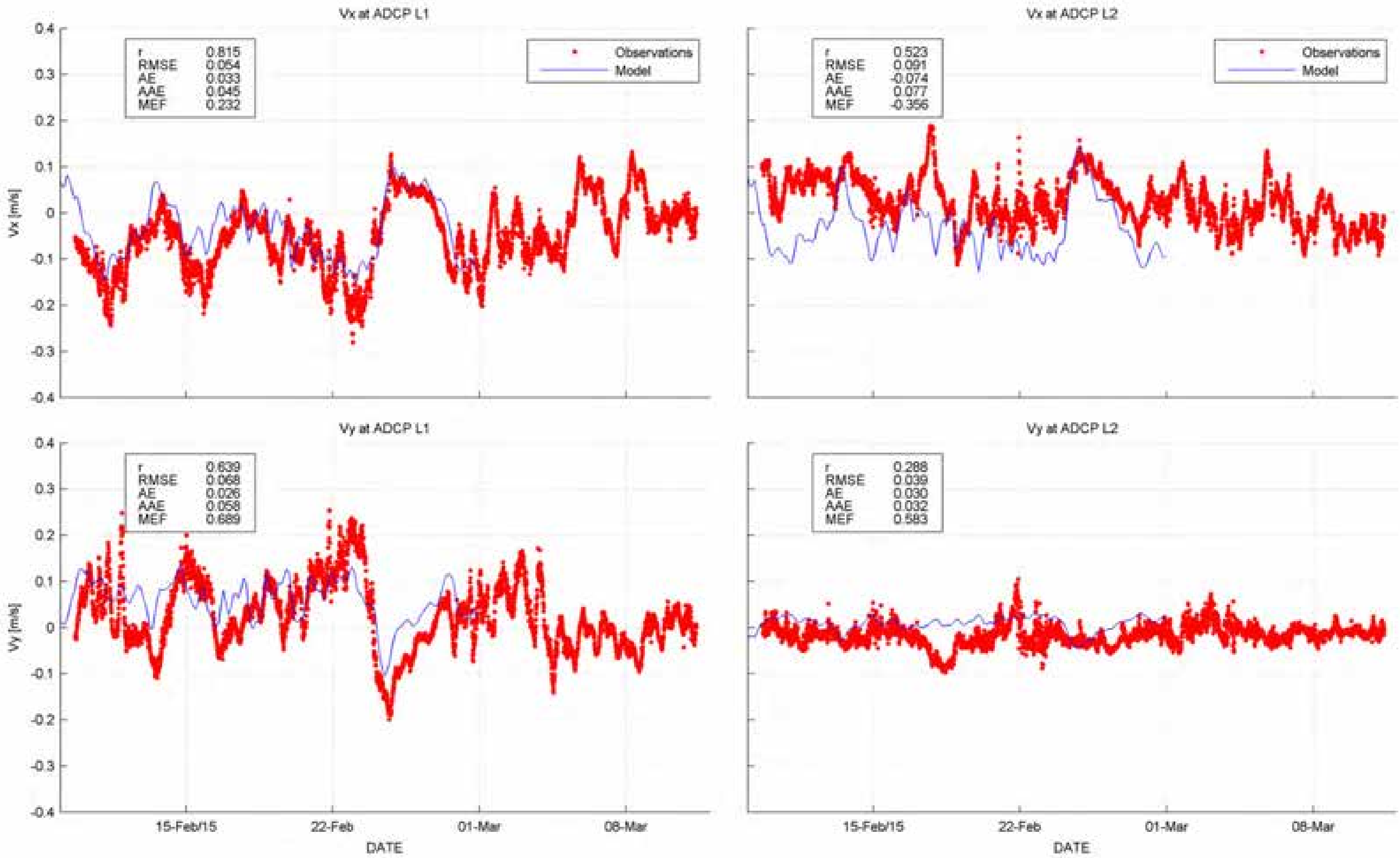

Figure 4-19 Depth-averaged velocity at the lease-area sites – Feb 2015 to Mar 2015 deployment

4.1.3 Waves

4.1.3.1 Summary

Along with current velocities, wave dynamics are of key importance to this study, due to their influence on resuspension and deposition of food and faecal particles arising from aquaculture activities. As illustrated below, the model does an excellent job of capturing both the magnitude and variability of peak wave period at both the regional and lease-area sites, which is a key parameter affecting the resuspension of particles on the seabed. Peak wave direction is also successfully reproduced, while significant wave height is typically over-estimated at both regional and lease-area sites, although the model captures the variability of wave height extremely well ($r > 0.84$ for all sites). The over-prediction in the SWAN model is likely due to over-predictions of swell from the Wavewatch III model, which is used as a forcing boundary condition.

To investigate the impact of significant wave height on particle distribution, a sensitivity test was run with significant wave height reduced by 20% when applied to the TUFLOWFV model. The sensitivity test indicated that the reduced wave height did not have a notable impact on the distribution of particles released from fish cages. Nevertheless the original forcing will be used for scenario runs as this represents the conservative approach.

4.1.3.2 Additional detail

Comparisons of SWAN wave model output against observations at the regional and lease-area sites are presented in Figure 4-20 to Figure 4-25 below for significant wave height, peak wave period and peak wave direction. Additional plots for the period of the second, regional-site deployment are also included in Appendix B.4, although these only cover the period to 1st January 2015 as boundary conditions from the global Wavewatch III swell model were not available for later dates at the time the model was run.

As can be seen in the time-series plots of Figure 4-22 to Figure 4-25, the model does an excellent job of capturing both peak wave period and peak wave direction at both lease-area and regional sites. Within the lease areas, peak wave direction is constrained by topography, which typically results in waves coming from the west through the Zeewijk Channel, or from the southeast, having refracted around the Pelsaert group and leading to the binary behaviour illustrated in Figure 4-25.

As noted in Section 4.1.3.1 above, however, significant wave height is over-predicted by the model. As the model is approximately 40m deep at both regional and lease-area sites, it is thought that bed friction is not an important component of the wave model and, therefore, that the likely cause of the over-prediction is excessive wave heights at the model boundary. To overcome this issue, a sensitivity test was run with significant wave height reduced by 20% when applied to the TUFLOWFV model (Figure 4-26). The test included the TUFLOWFV particle tracking module, which was run with particle parameters similar to the finest particles arising from aquaculture activities, as follows:

- Critical erosion shear stress of 0.15 N/m^2
- Erosion rate of 0.02 $g/m^2/s$.

The criteria for the environmental impact assessment relate to the area surrounding fish cages, which is affected by the deposition of organic material. The area over which particles are deposited to the seabed for both model runs is included in Figure 4-27. As can be seen, the over-predicted wave height has a limited impact on the area upon which particles are deposited, with similarly-sized footprints for both model runs. Nevertheless, the original, over-predicted wave forcing will be included in scenarios for this assessment, as this represents the conservative approach in determining the upper limit of stocking densities which can be sustained.

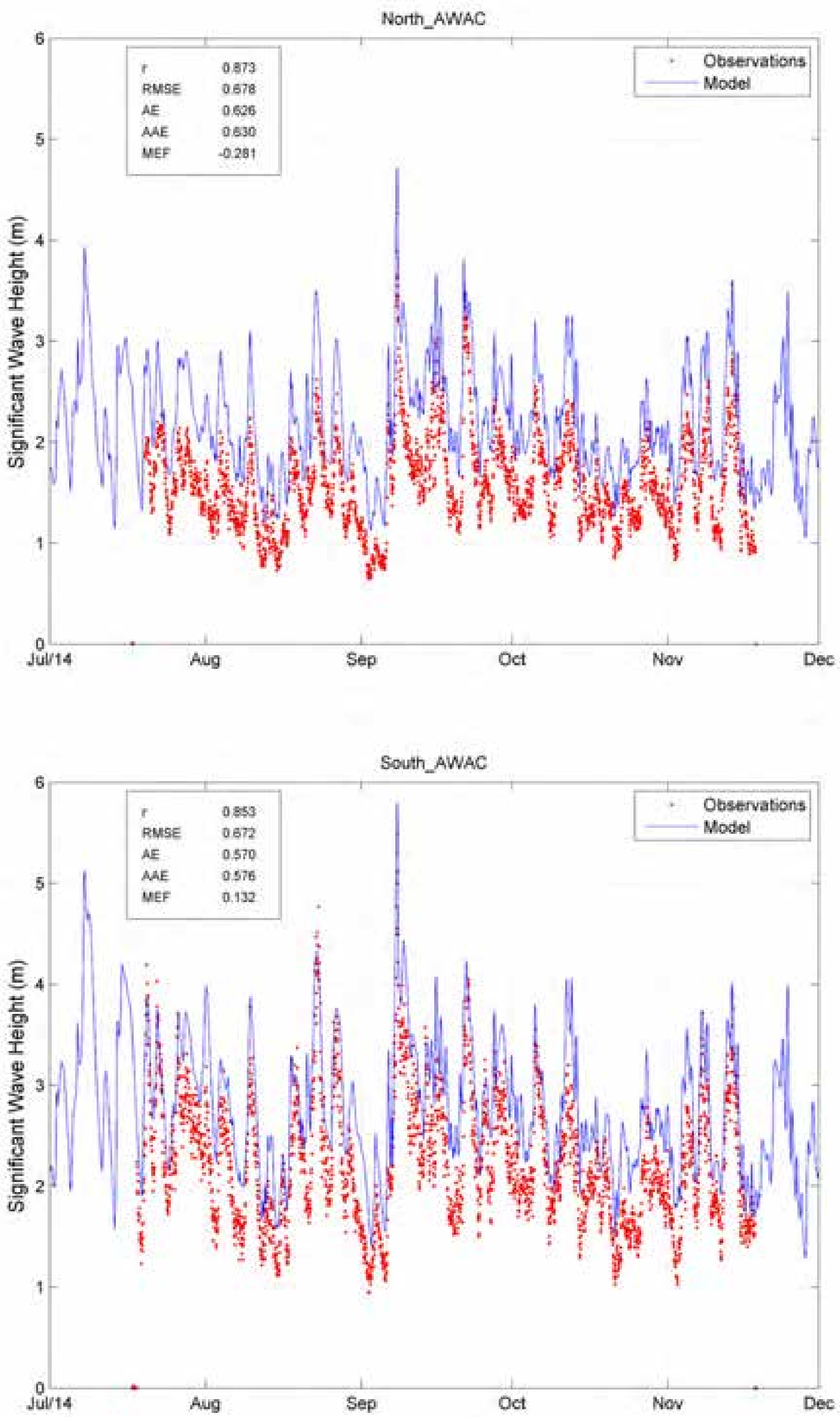

Figure 4-20 Significant wave height at regional sites

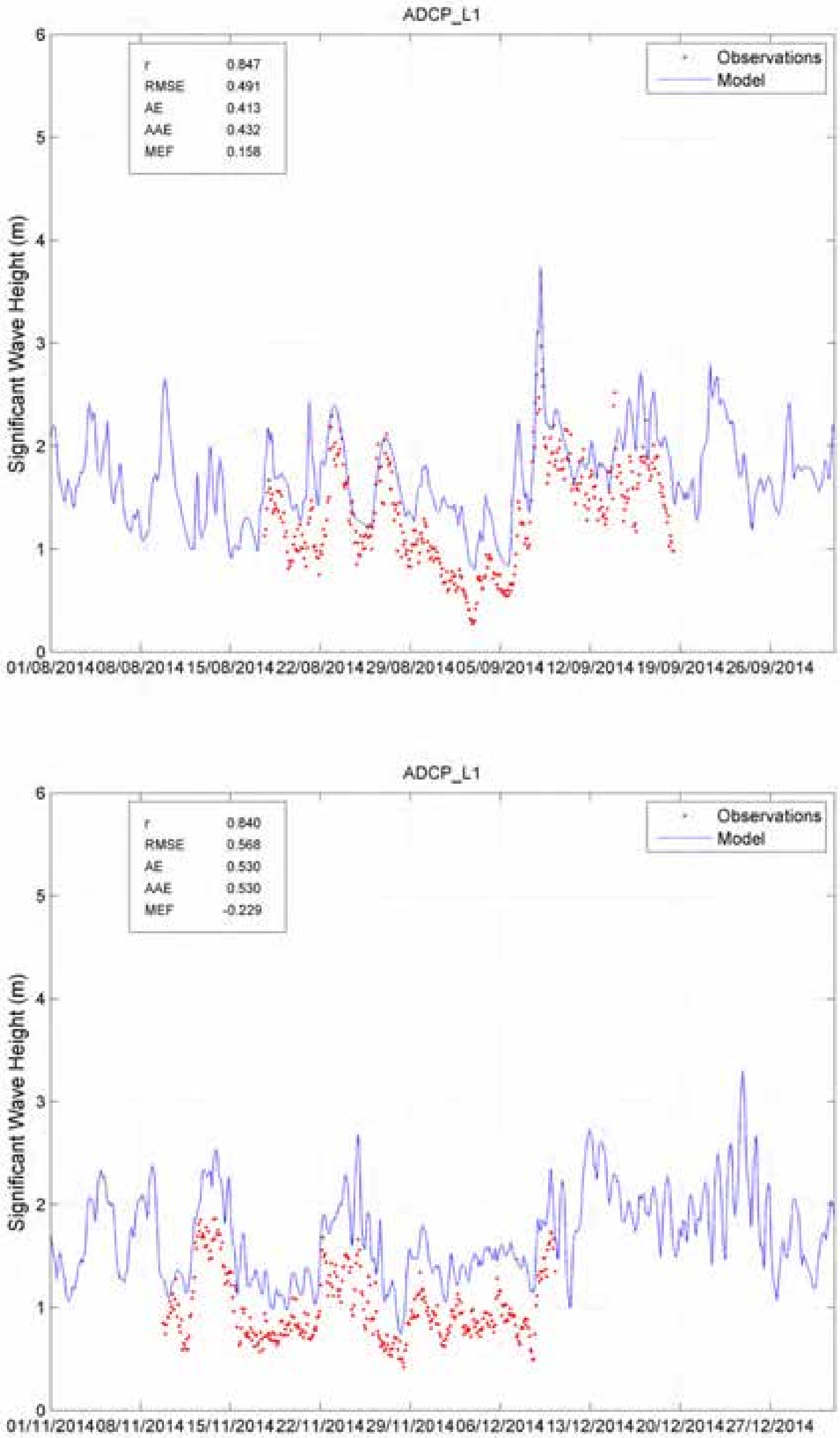

Figure 4-21 Significant wave height at northern lease-area site

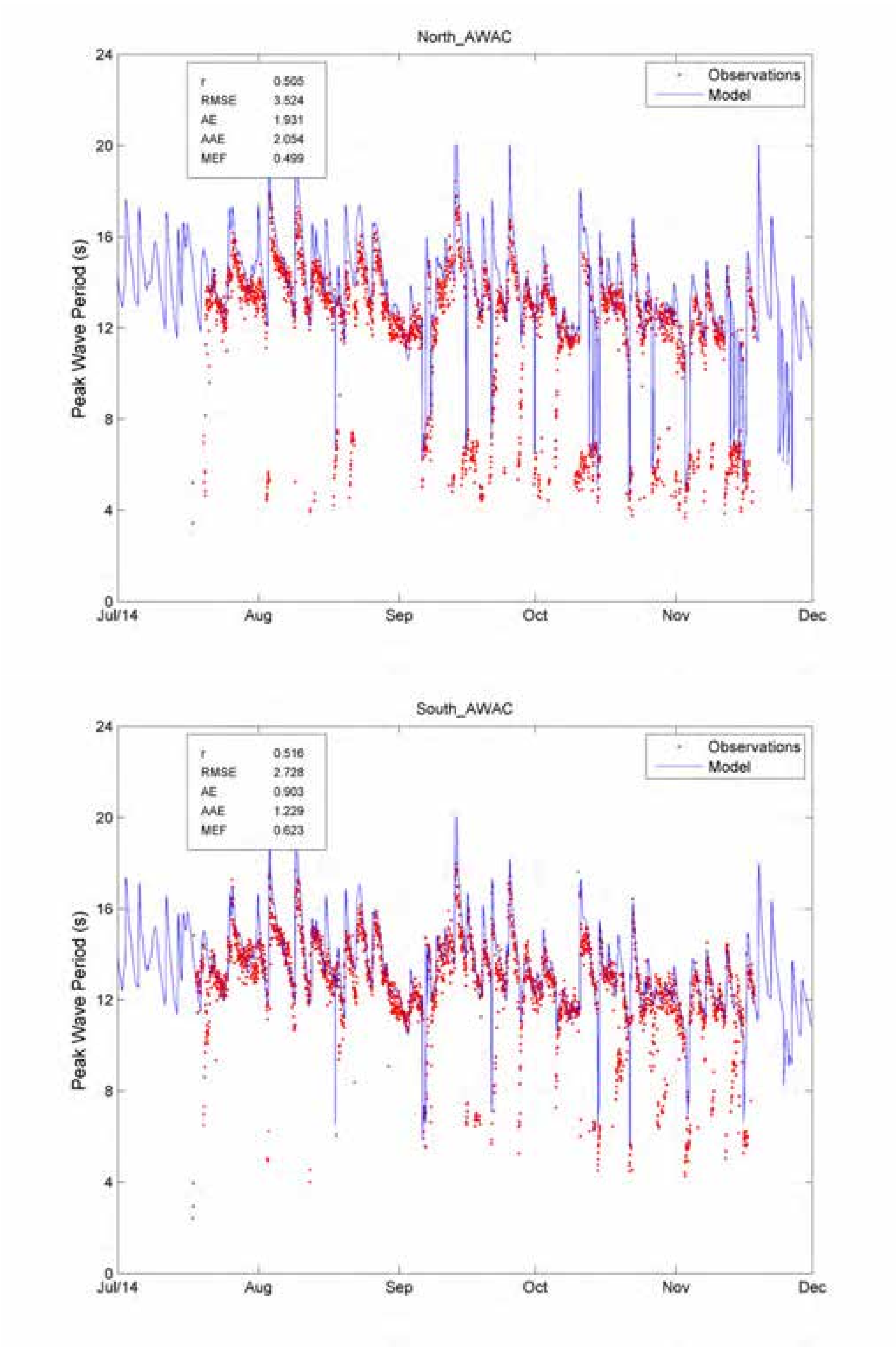

Figure 4-22 Peak wave period at regional sites

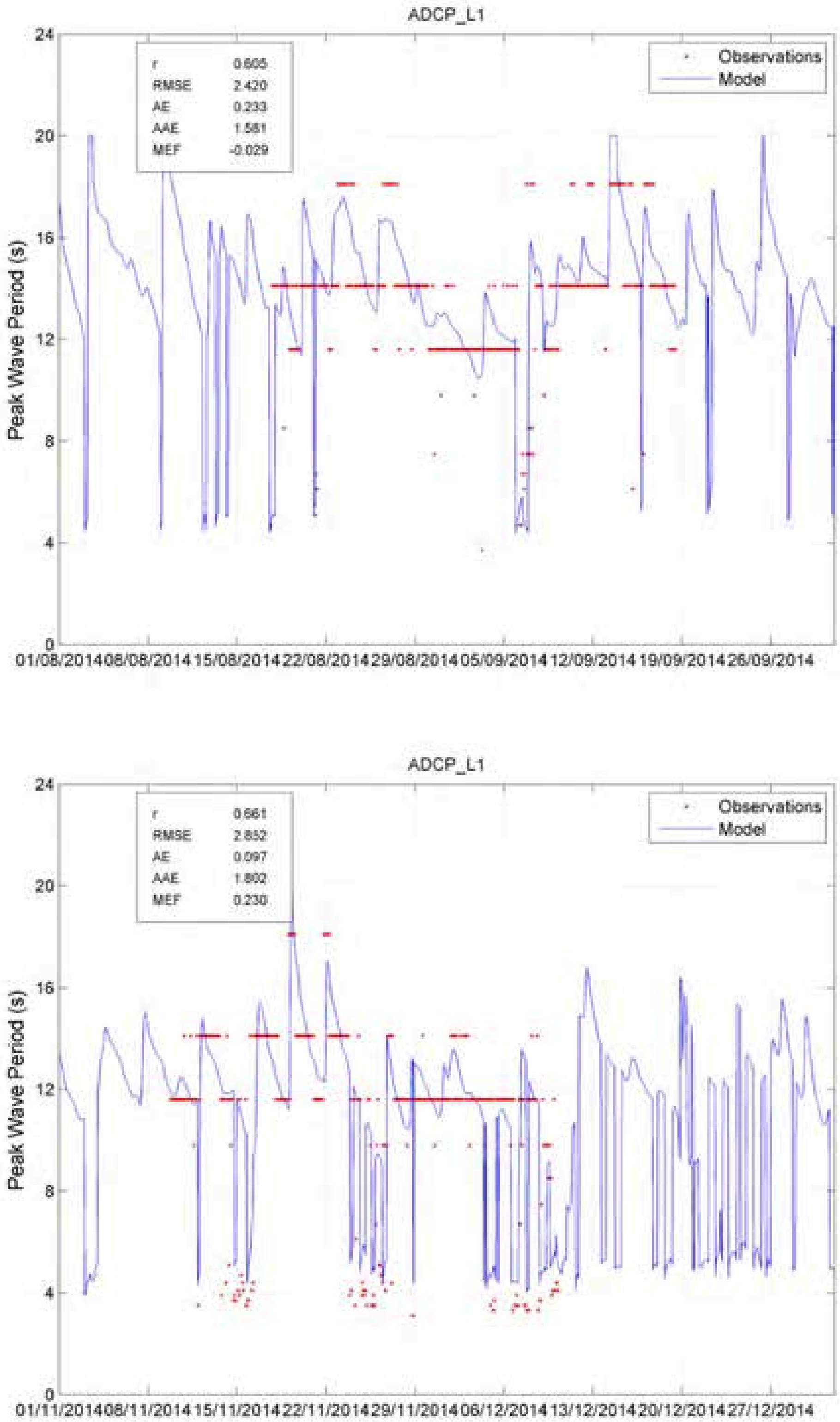

Figure 4-23 Peak wave period at northern lease-area site. Observation data is presented as it was provided by DoF, which appears to bin data into particular bands.

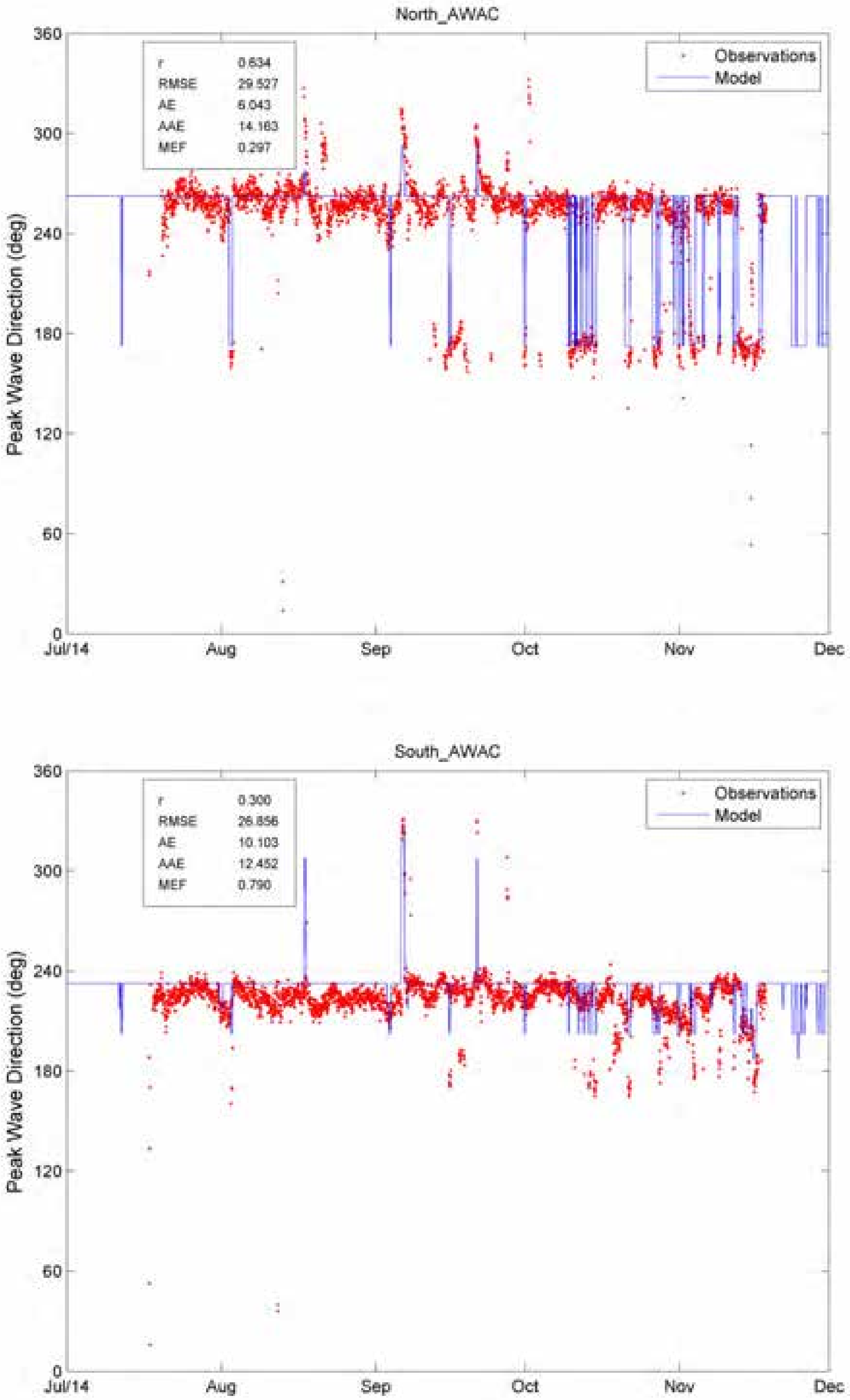

Figure 4-24 Wave direction at regional sites

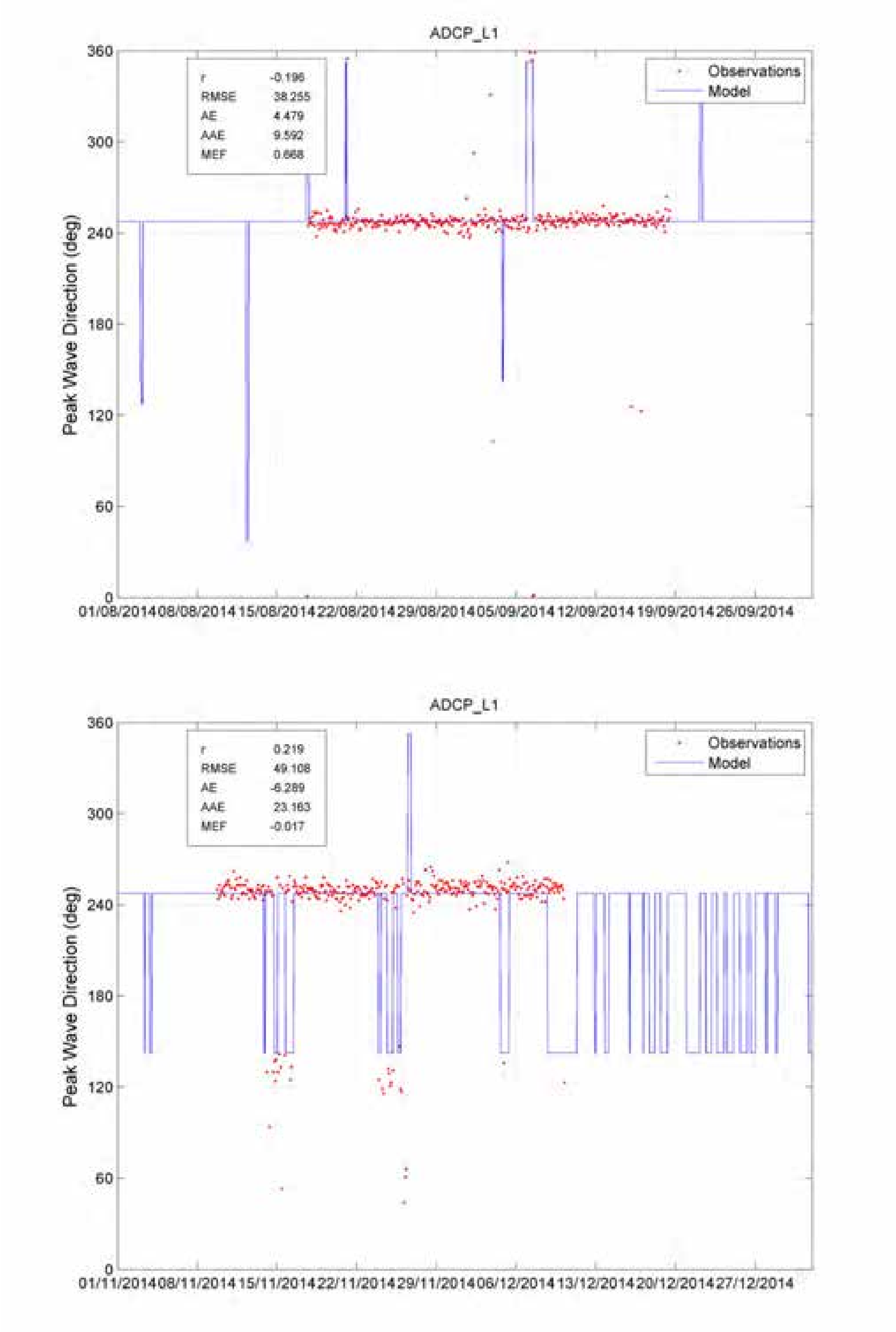

Figure 4-25 Wave direction at northern lease-area site.

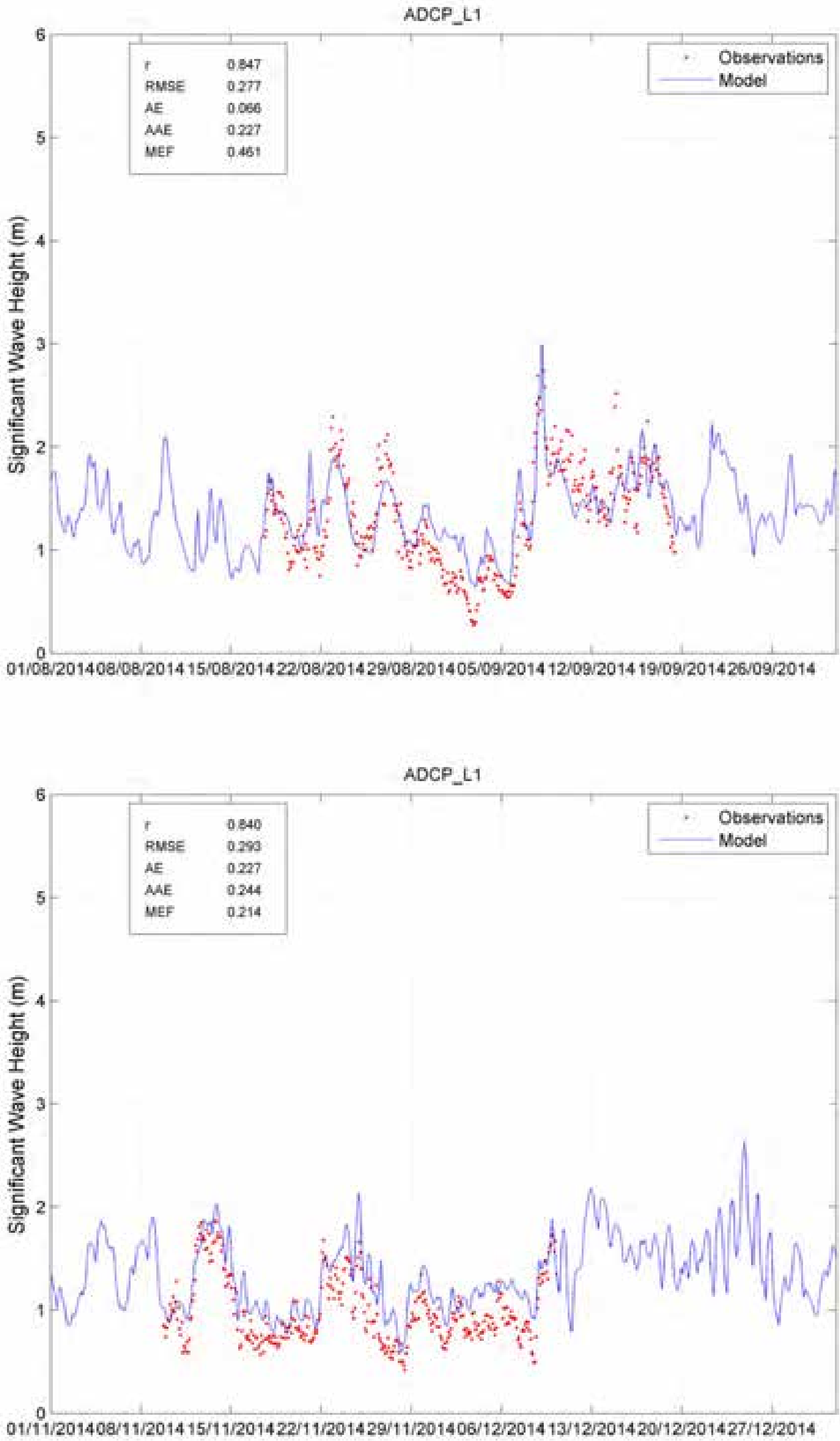

Figure 4-26 Comparison against observations if significant wave height were reduced by 20%

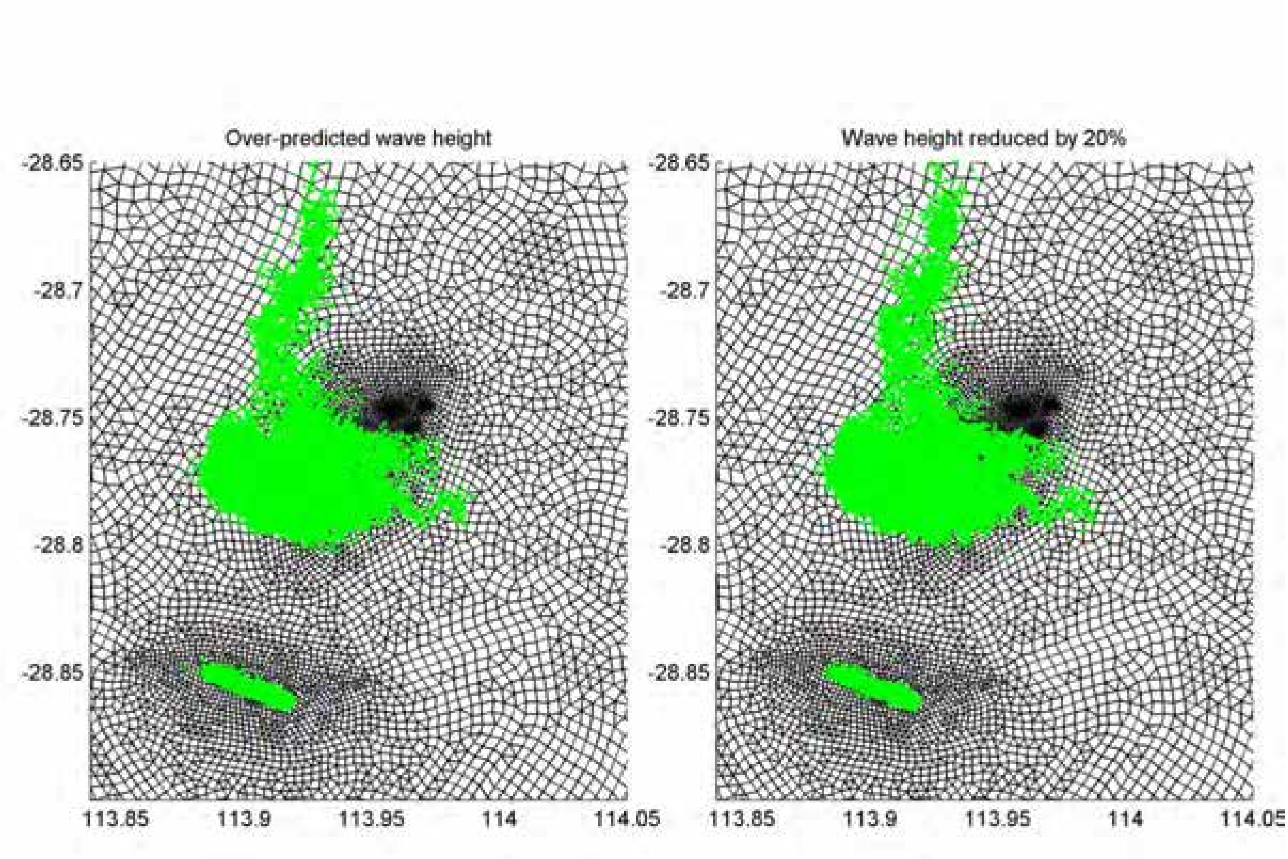

Figure 4-27 Comparison of depositional area under the original wave forcing (left plot) and the wave forcing with reduced significant wave height (right plot)

4.1.4 Temperature

4.1.4.1 Summary

A good temperature calibration is of primary importance to the water quality model, as temperature has a controlling effect on the rate of key biogeochemical processes. It is particularly important to recreate the variability of temperature with depth to ensure that stratification processes are captured.

The model does a good job of recreating observed temperature at both the regional and lease-area sites. Seasonal dynamics are well captured, with particularly good r values for the second four-month deployment. Short-term dynamics are also recreated, with the model capturing the passage of regional eddies through the system (e.g. during late December at the southern regional site), albeit occasionally simulating a warm-core eddy rather than a cold-core eddy (e.g. during August 2014 at the northern regional site). The model does miss some short-term events but overall the comparison of temperature time-series is very good. An example of such an event is the temperature drop around 15th November 2014 at the southern lease-area site, which the model does not capture. A temperature over-prediction of approximately 1 °C, such as that observed here, would cause some water quality processes to progress more quickly than they otherwise

would through an Arrhenius factor. However, there is no consistent departure from observations of this magnitude and average errors tend to be much smaller over time (AE < 0.5 °C typically).

Depth profiles taken at multiple sites around the lease areas illustrate that there is no significant stratification in the region most of the time, although there are occasional, isolated stratification events (e.g. at the L2D and L2E sites during June, Figure 4-37). Importantly, the model recreates these isolated stratification events, and subsequent dismantling, indicating that the processes driving the events are well captured. Site R2C (Figure 4-38) provides a good example of a stratification event (or events) beginning in May 2014, strengthening in June 2014 and entirely dismantled during subsequent sampling periods.

4.1.4.2 Additional Details

Comparisons of temperature at the regional sites are presented in Figure 4-28 and Figure 4-29, with figures of the same time-series broken down into calendar months included in Appendix B.3. Comparisons of temperature at the lease-area sites are presented in Figure 4-31 to Figure 4-34. Additionally, depth profiles of temperature at each location are presented in Figure 4-35 to Figure 4-39, which illustrate a short-lived stratification event simulated in February 2015. This event was driven by both HYCOM boundary conditions and meteorological data, but wasn't sampled by depth profiles taken at this time. It is possible that the event may have been mis-timed by the model, or that those features that dismantle stratification (wind, swell, etc.) were under-predicted at this time.

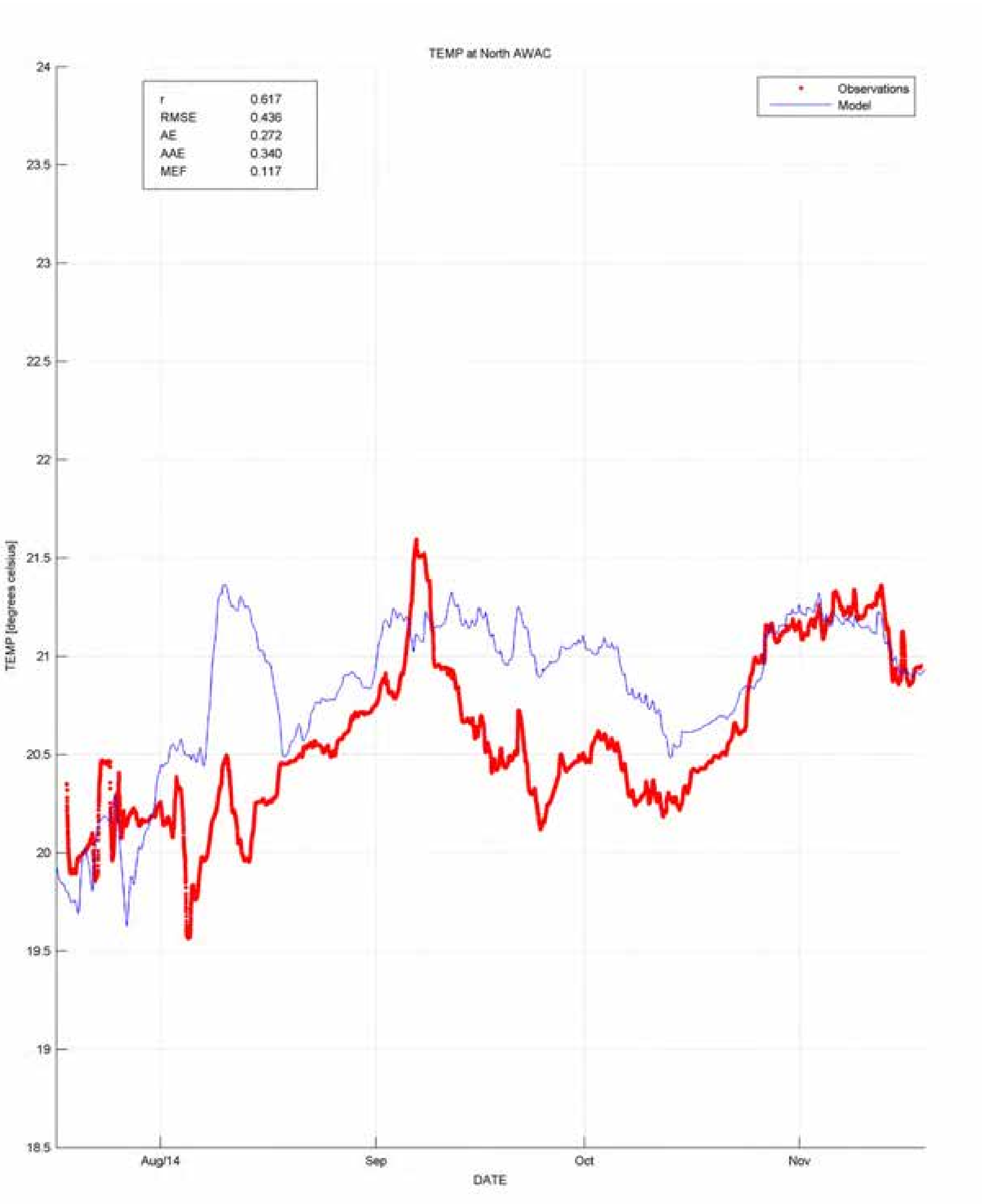

Figure 4-28 Seabed temperature at the northern regional site – Jul 2014 to Nov 2014 deployment

Figure 4-29 Seabed temperature at the regional sites –Nov 2014 to Mar 2015 deployment

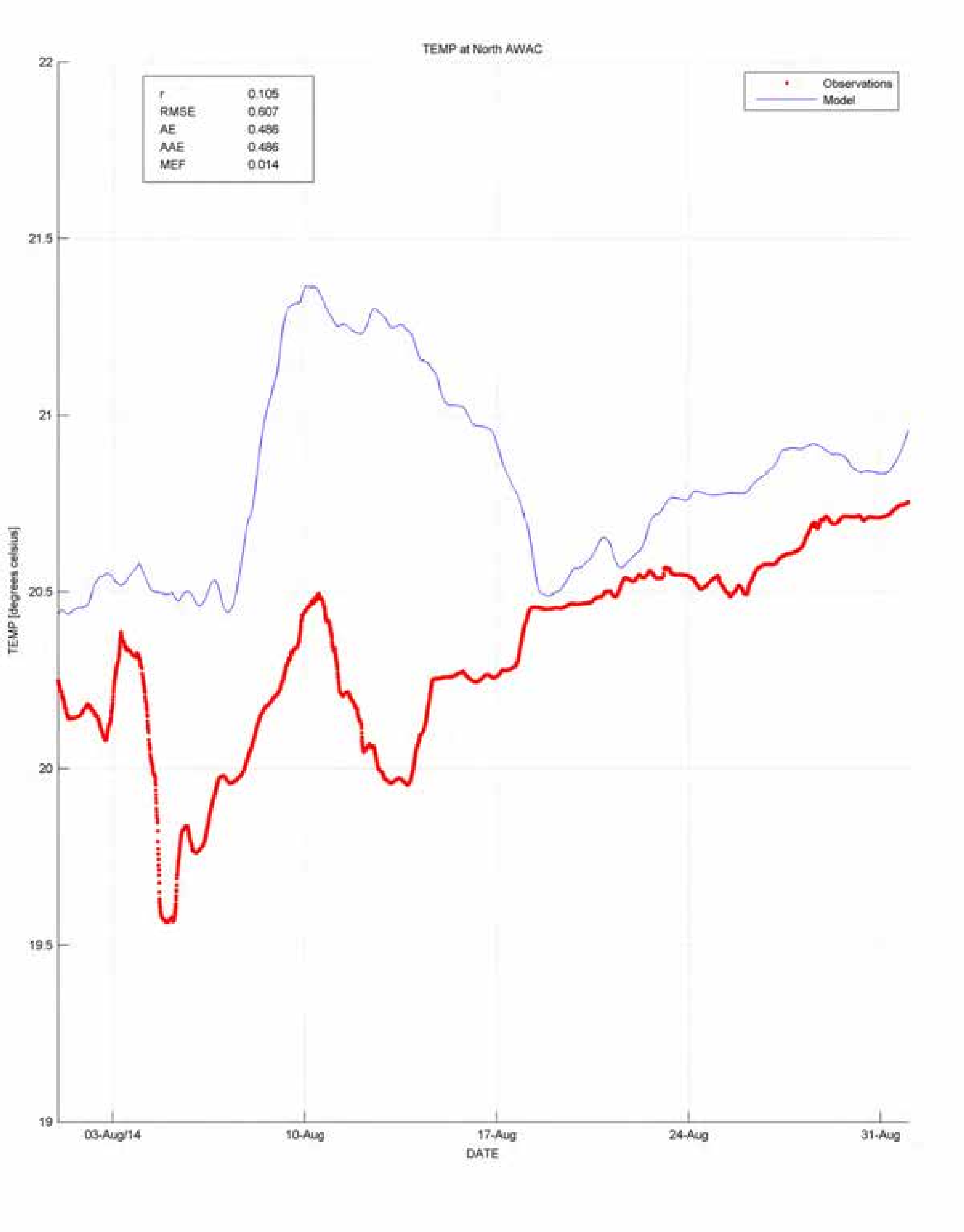

Figure 4-30 Seabed temperature at northern regional site during Aug 2014

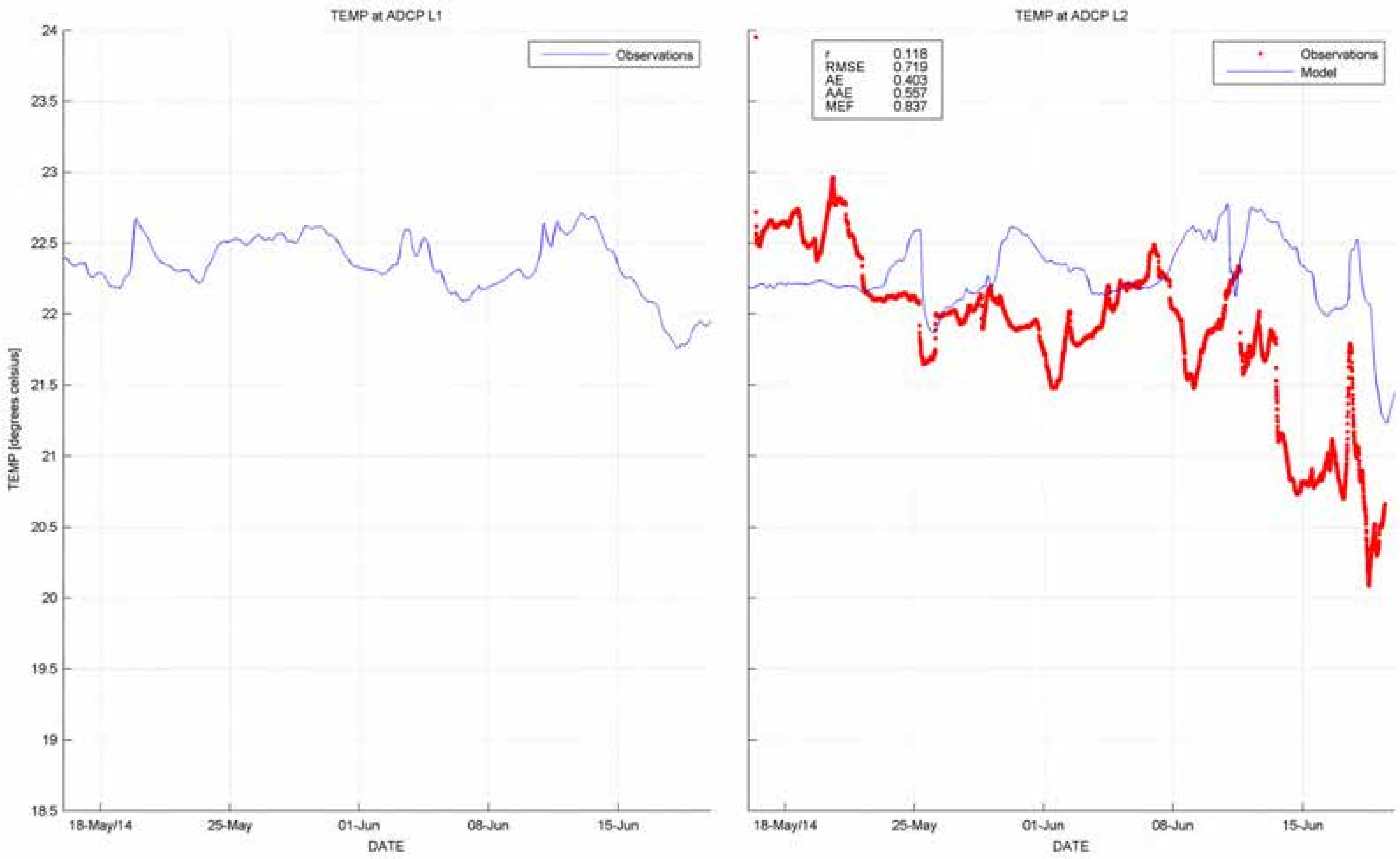

Figure 4-31 Seabed temperature at lease-area sites – May 2014 to Jun 2014 deployment

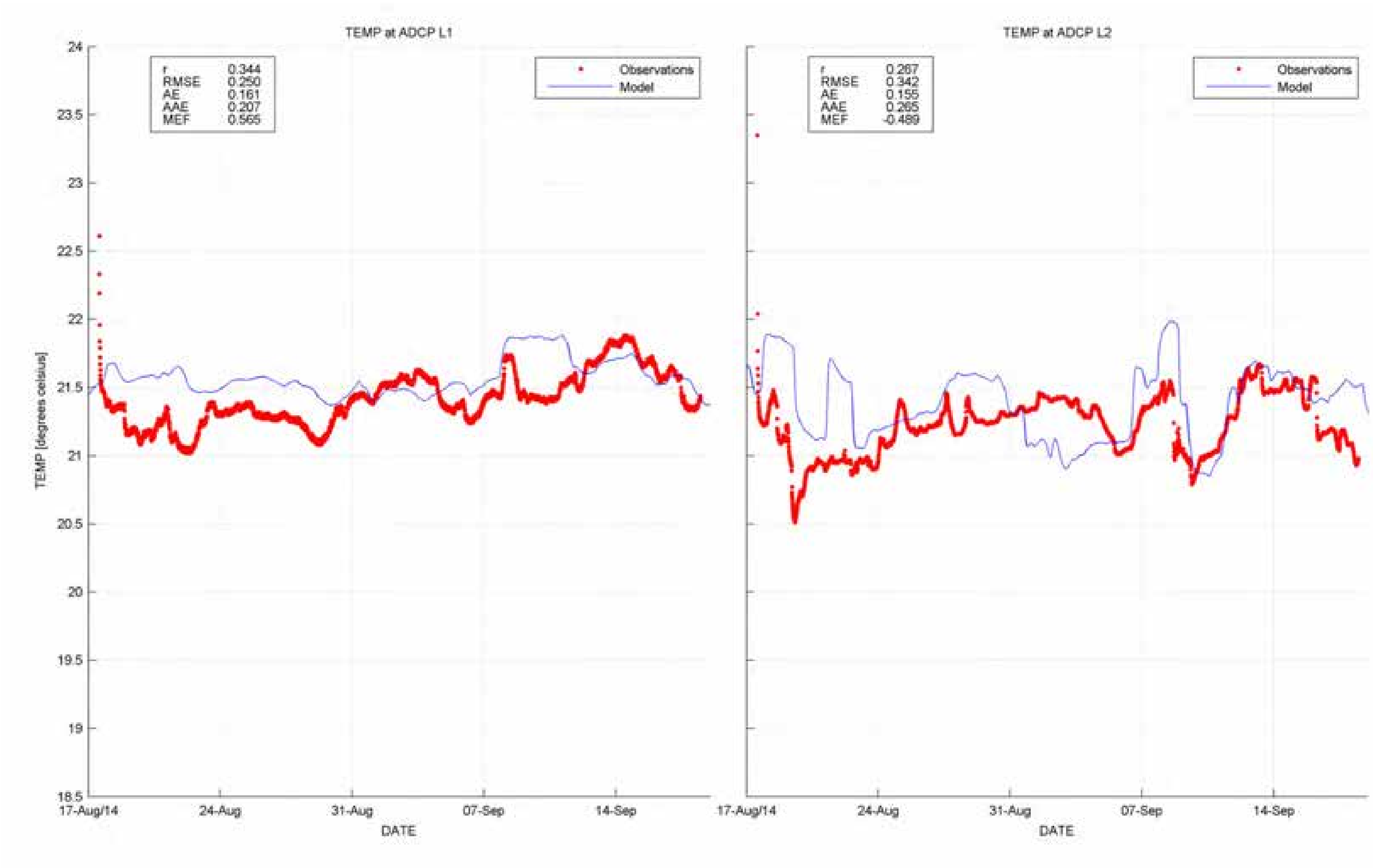

Figure 4-32 Seabed temperature at lease-area sites – Aug 2014 to Sep 2014 deployment

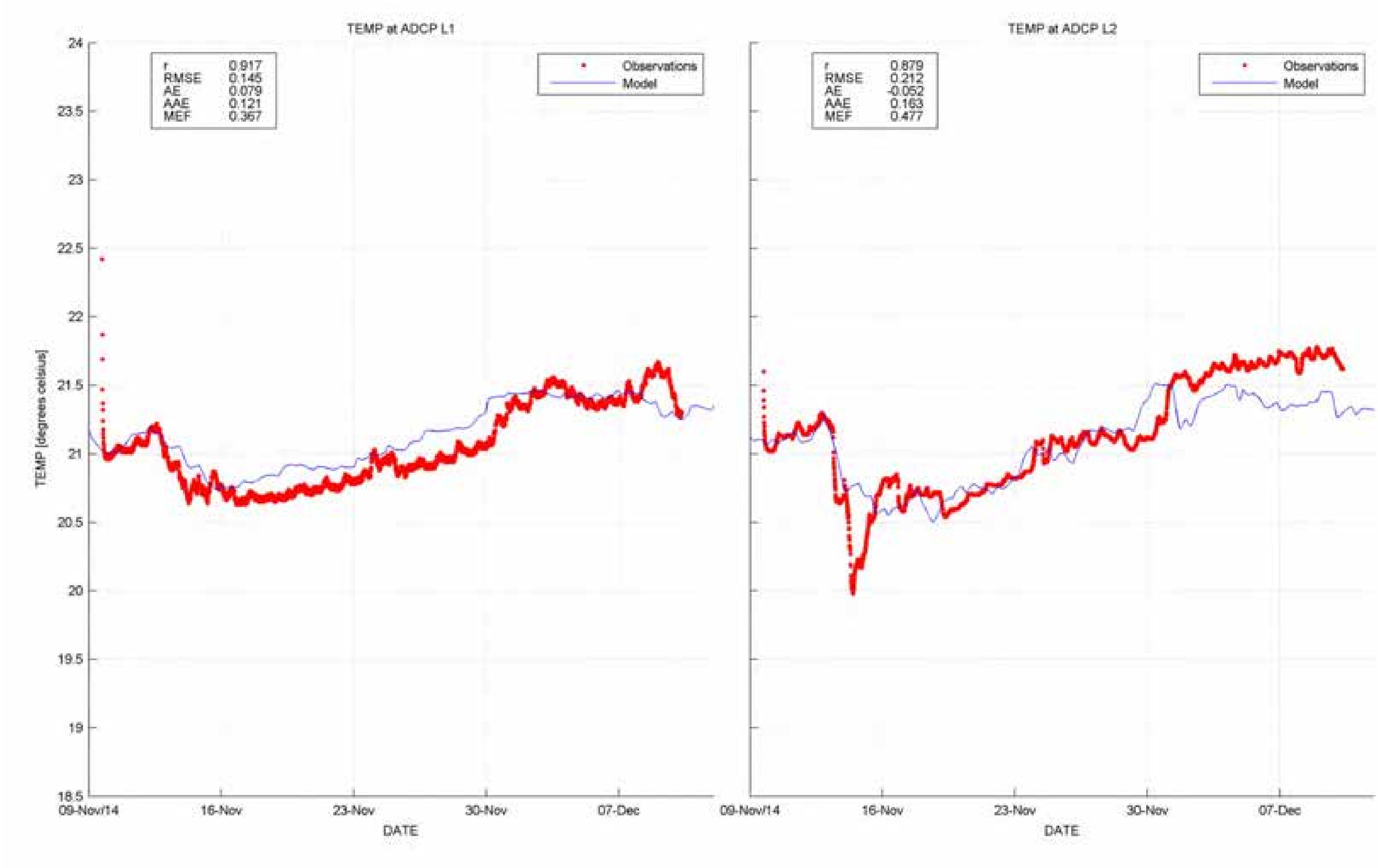

Figure 4-33 Seabed temperature at lease-area sites – Nov 2014 to Dec 2014 deployment

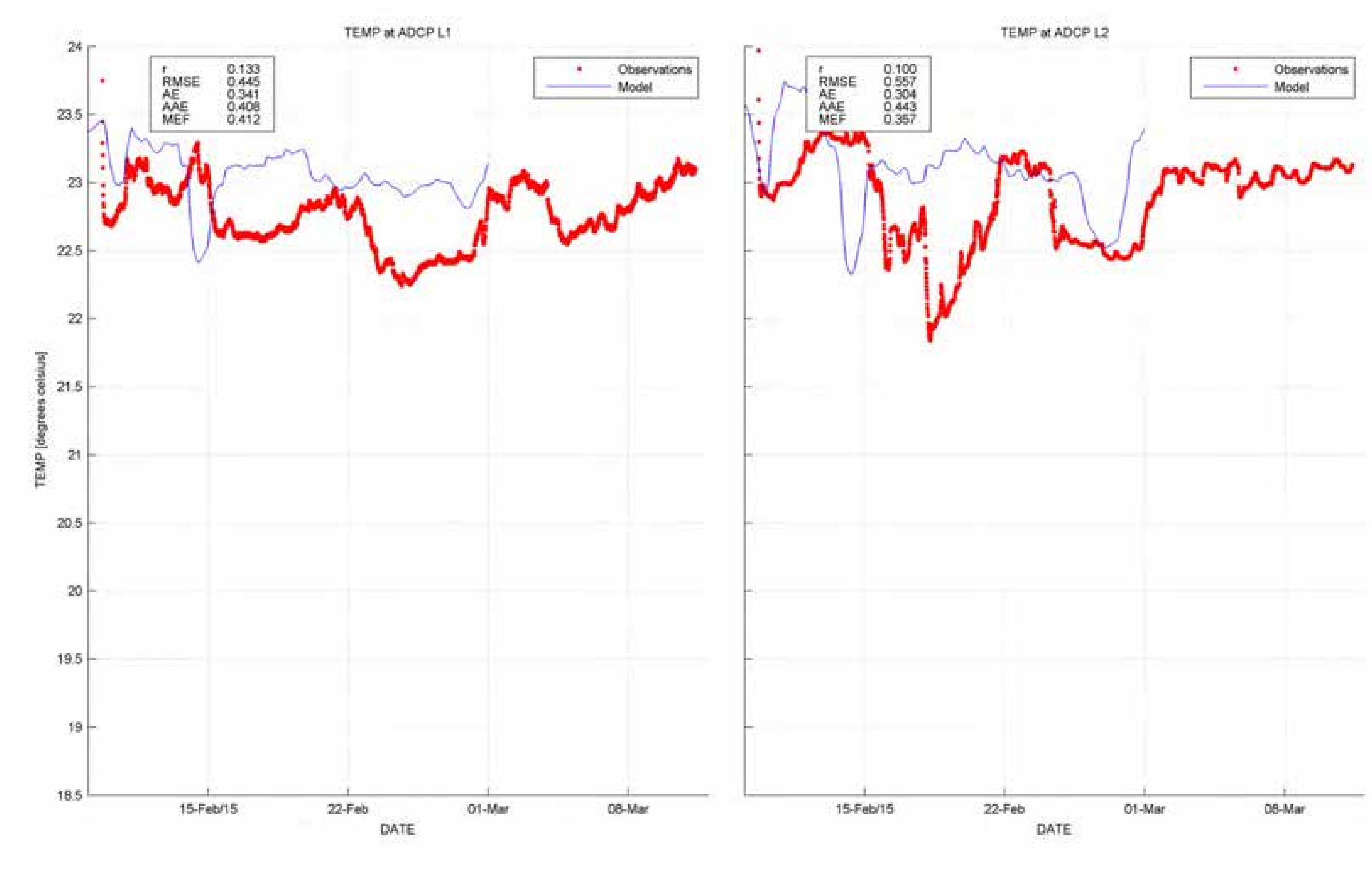

Figure 4-34 Seabed temperature at lease-area sites – Feb 2014 to Mar 2014 deployment

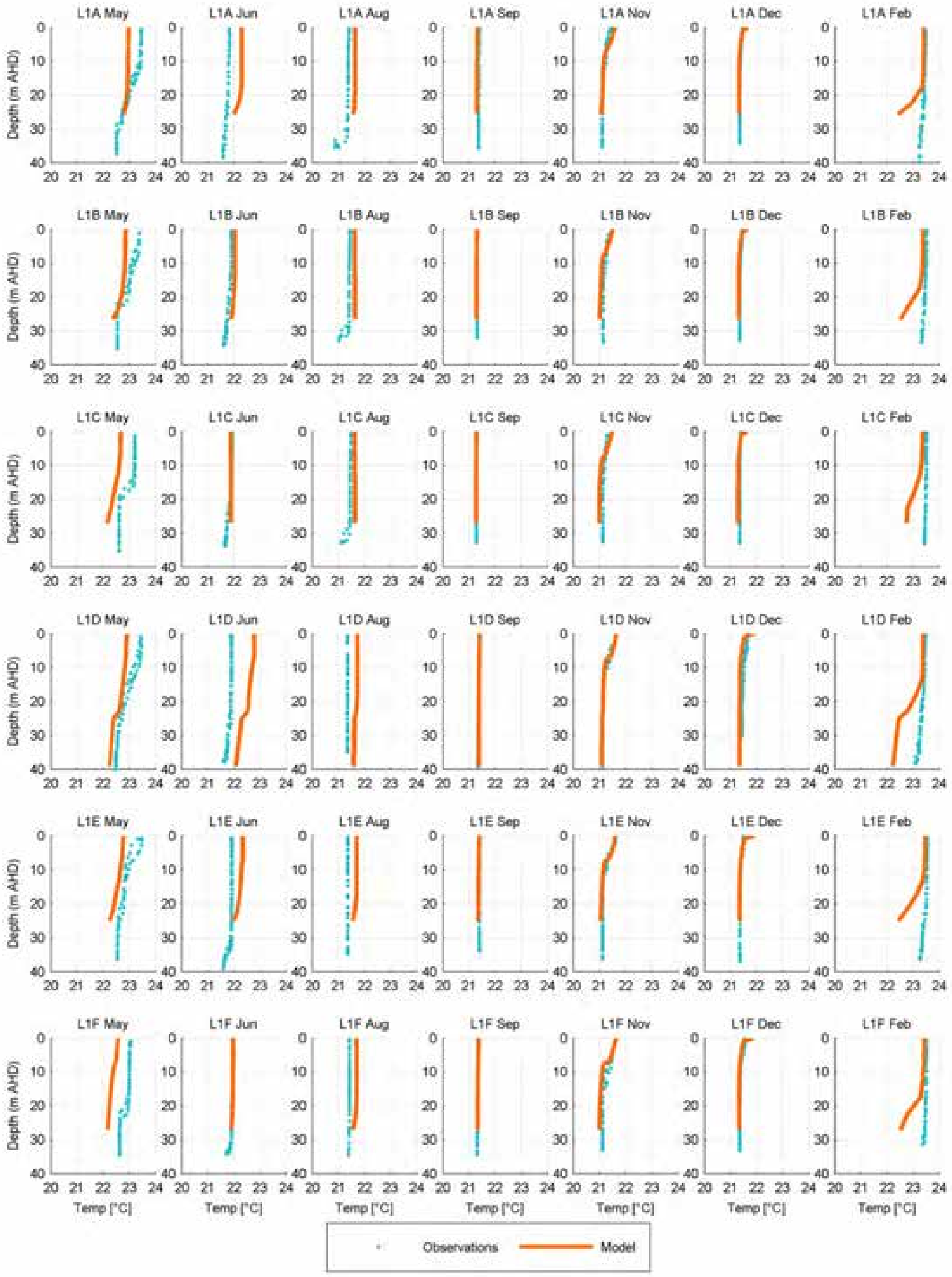

Figure 4-35 Depth profiles of temperature at lease-area sites – 1 of 5

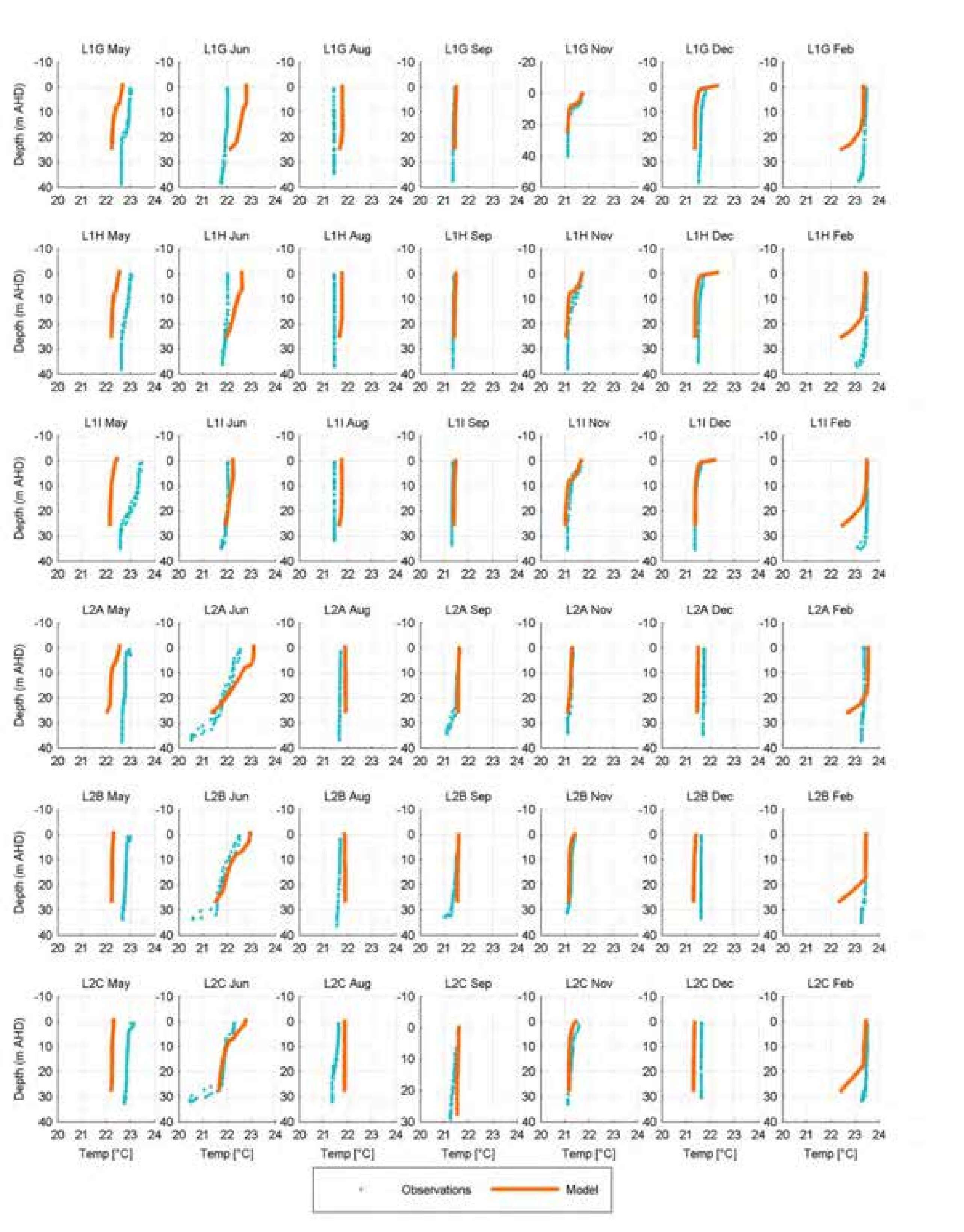

Figure 4-36 Depth profiles of temperature at lease-area sites – 2 of 5

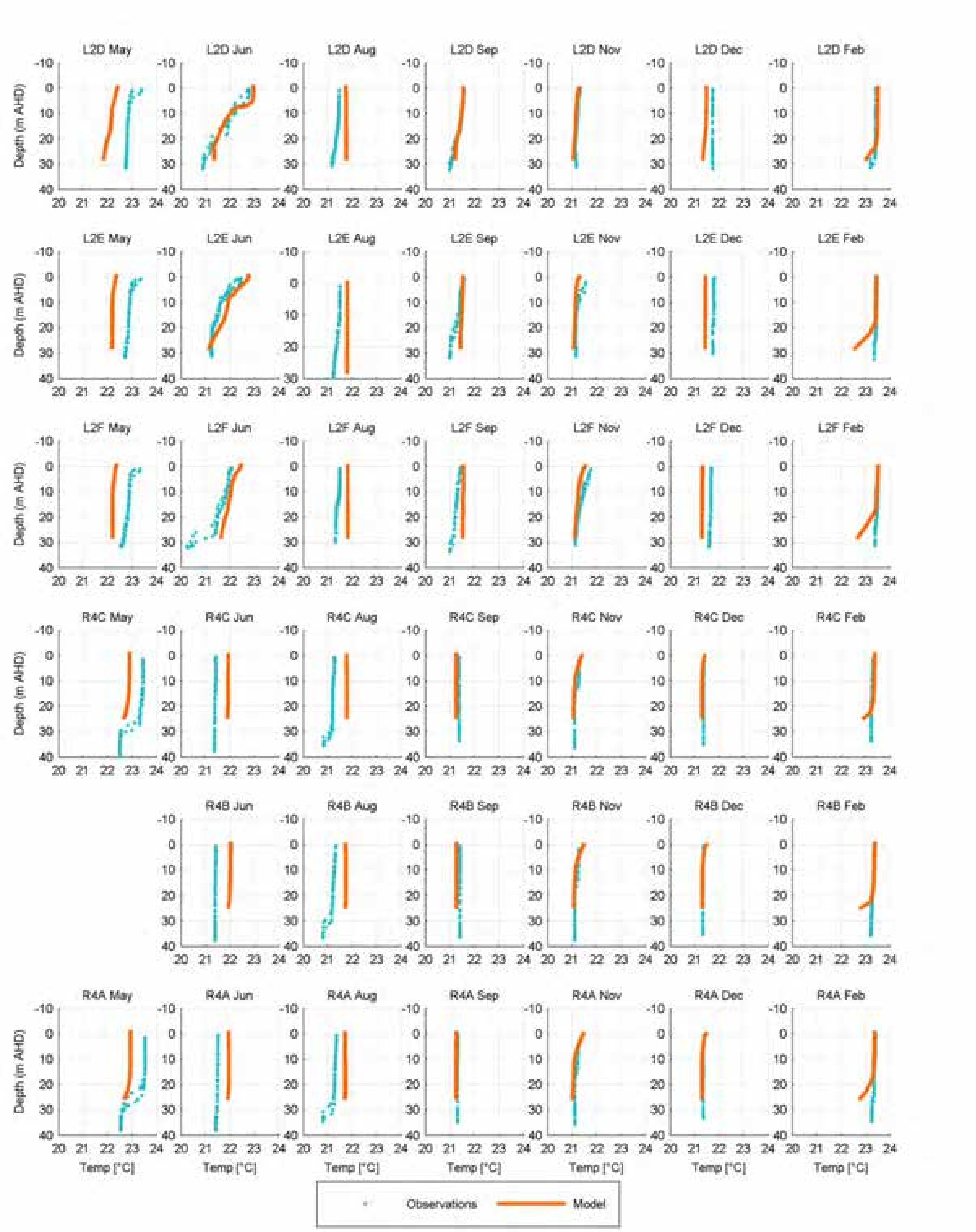

Figure 4-37 Depth profiles of temperature at lease-area sites – 3 of 5

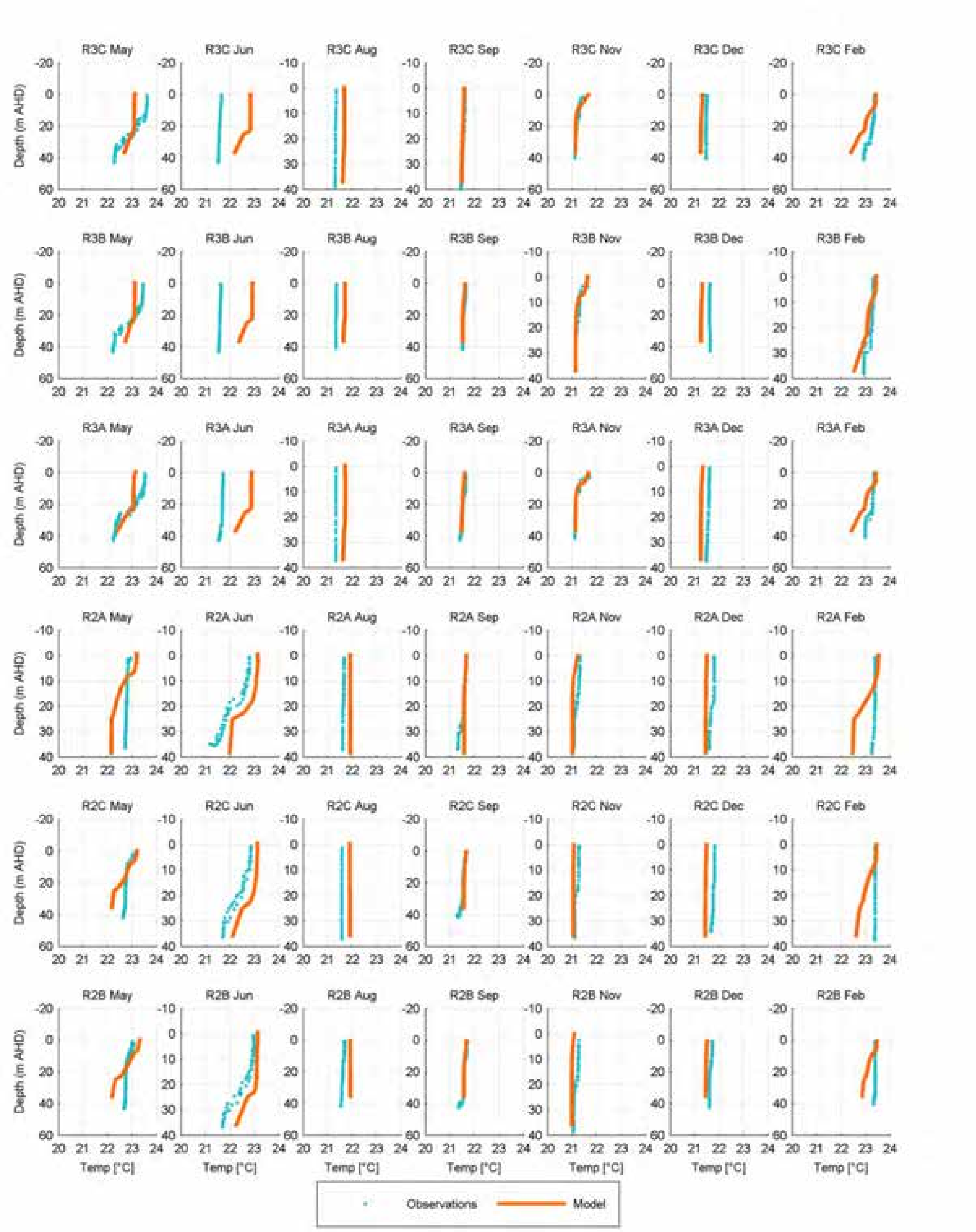

Figure 4-38 Depth profiles of temperature at lease-area sites – 4 of 5

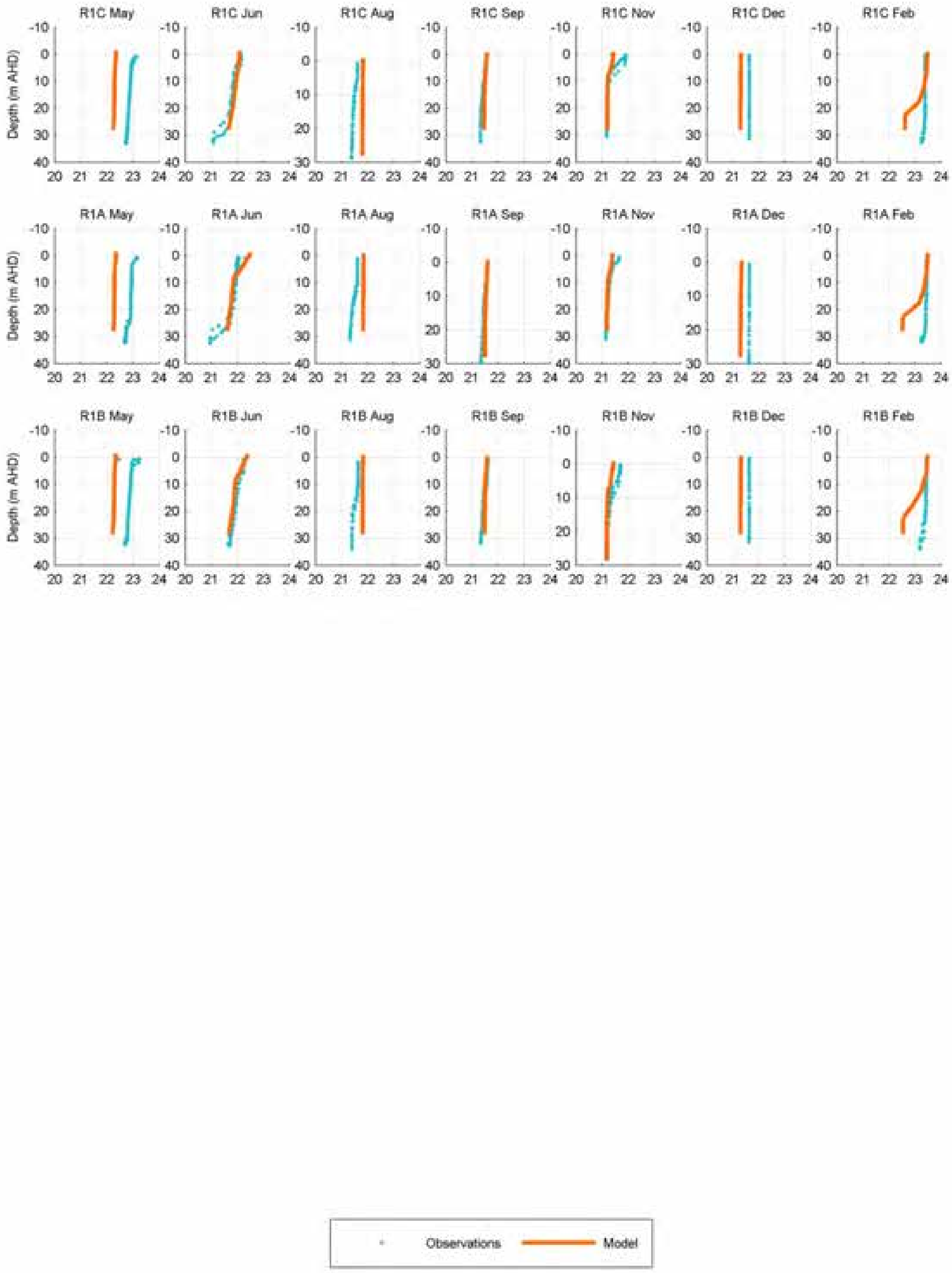

Figure 4-39 Depth profiles of temperature at lease-area sites – 5 of 5

4.1.5 Salinity

Comparisons of salinity at the regional sites are presented in Figure 4-40. Note that a decrease in salinity is apparent in the observations beginning in February 2015, which is likely the result of bio-fouling (apparent measured salinity decreases are often a signature of bio-fouling). This is particularly clear at the northern site ('North AWAC'). Initial calibration runs indicated a consistent bias of approximately 0.3 PSU at regional sites (Figure 4-41) so an offset of 0.3 PSU was applied to the HYCOM boundary forcing to mitigate the bias, which improved the results.

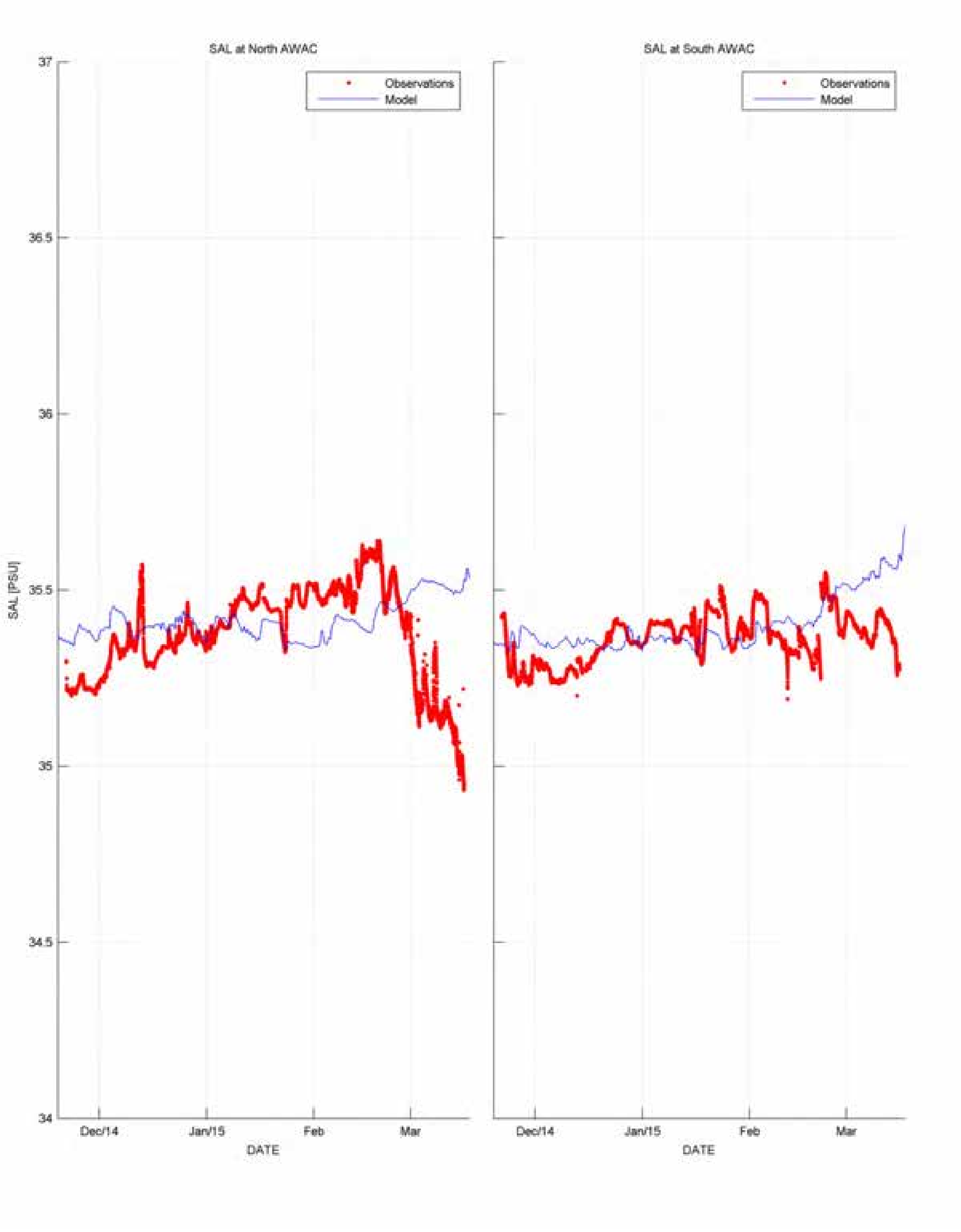

Figure 4-40 Seabed salinity at regional sites – Nov 2014 to Mar 2015 deployment

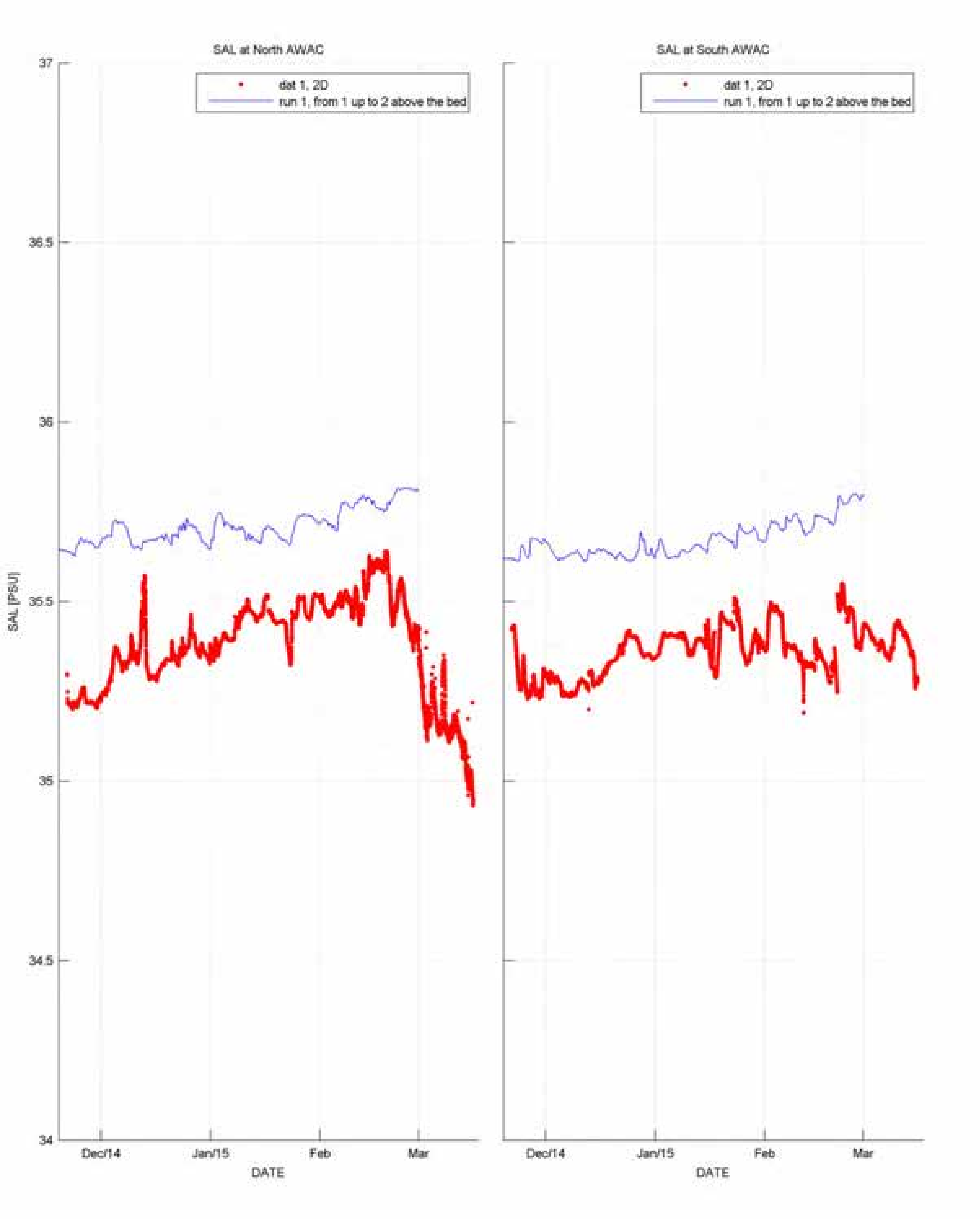

Figure 4-41 Initial salinity comparison indicating bias of 0.3 PSU

4.2 Water quality calibration

The water quality samples taken during the monitoring program indicate that the MWADZ study area is oligotrophic, with low nutrient and chlorophyll concentrations that are often below the limits of detection. As noted in Section 3.2, there is also little in the way of temporal variability and, therefore, no clear system dynamics to calibrate the model to. As such, the calibration process was reduced to one of 'verification', which simply compared simulated water quality concentrations to observations, without the need for changes to water quality parameter sets. This section provides those comparisons for the following key variables:

- Dissolved oxygen saturation
- Total nitrogen
- Ammonium
- Oxidised inorganic nitrogen (nitrate plus nitrite)
- Total phosphorus
- Phosphate
- Chlorophyll a.

Note that suspended sediment was not included in the calibration process, as observations indicated that turbidity is routinely very low, with low ambient suspended sediment concentrations. Two-thirds of all TSS measurements were at or below the detection limit of 1 mg/L, while the median of the remaining one-third was 2 mg/L. Introduction of aquaculture activities is expected to affect turbidity, so the suspended sediment module will be included when assessing the impact of those activities on water quality.

4.2.1 Dissolved oxygen

Time series of simulated DO are presented in Figure 4-42, with depth profiles of simulated and observed DO at the same sites presented in Figure 4-43 to Figure 4-47. There are no major sinks of DO in the model, resulting in values of close to 100% saturation at all times. Nevertheless there are occasionally very slight variations of DO with depth, which the model manages to successfully recreate (e.g. site L2A, L2B and L2C in June 2014; Figure 4-44).

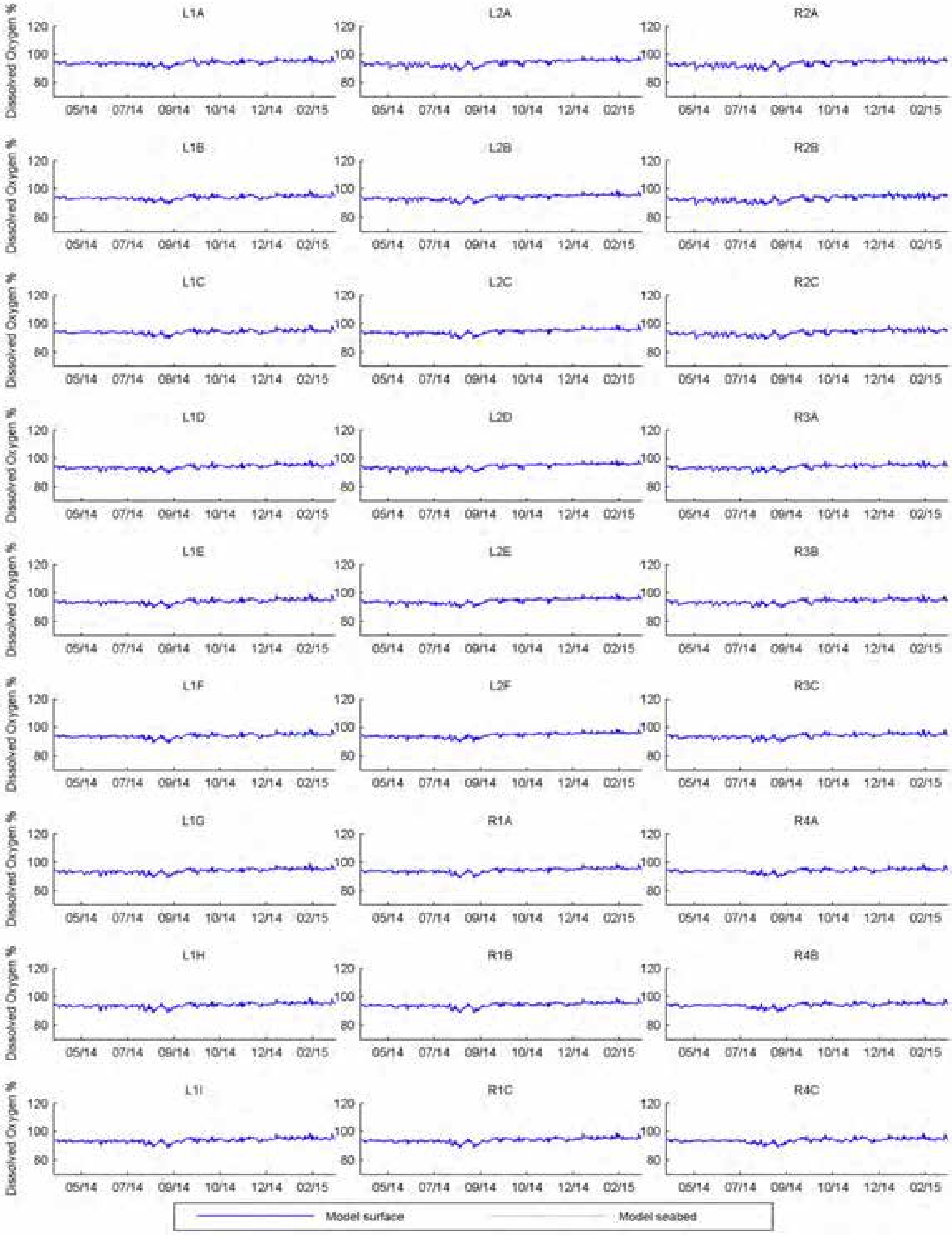

Figure 4-42 Time series of simulated percent DO saturation at lease-area sites

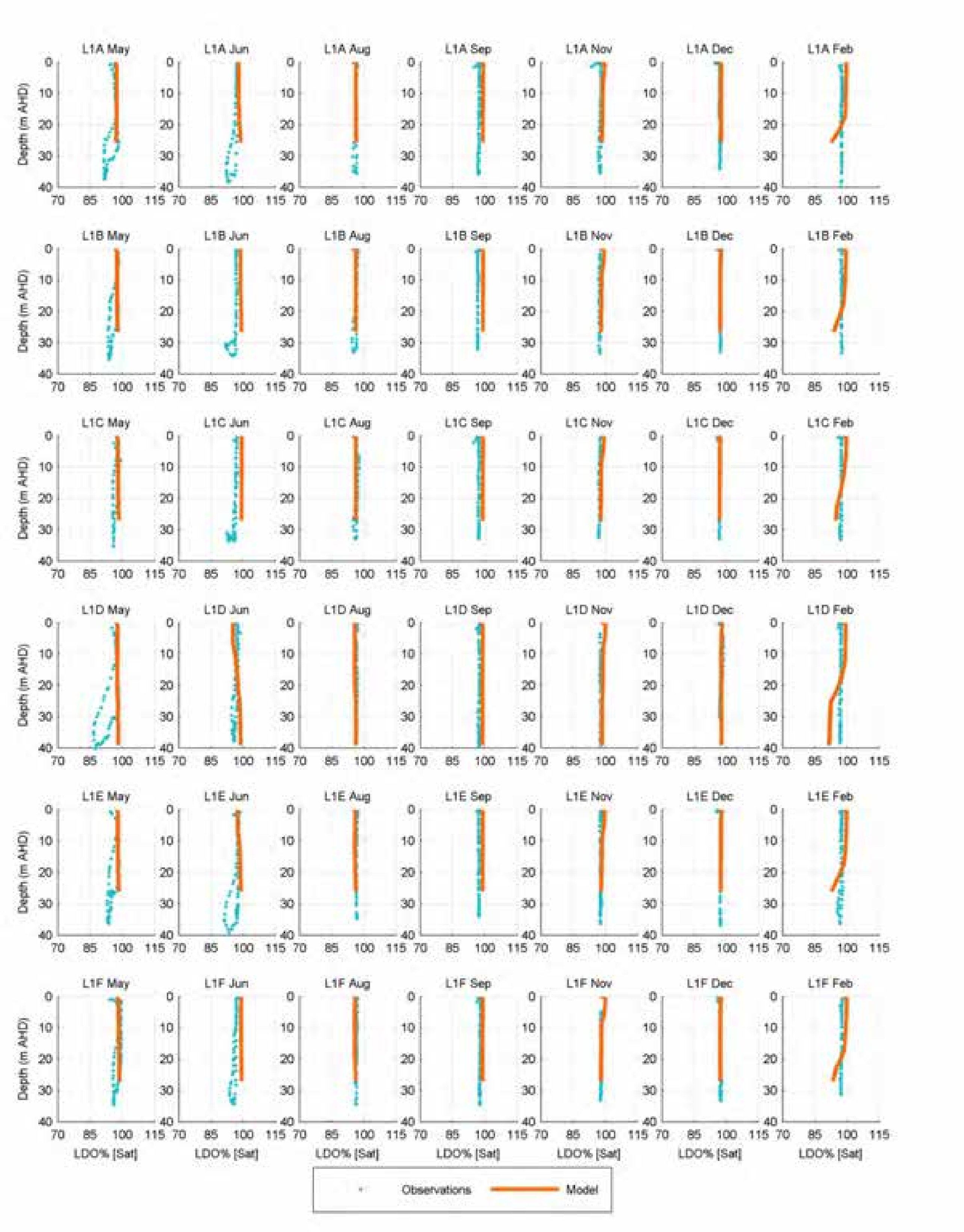

Figure 4-43 Depth profiles of percent DO saturation at lease-area sites – 1 of 5

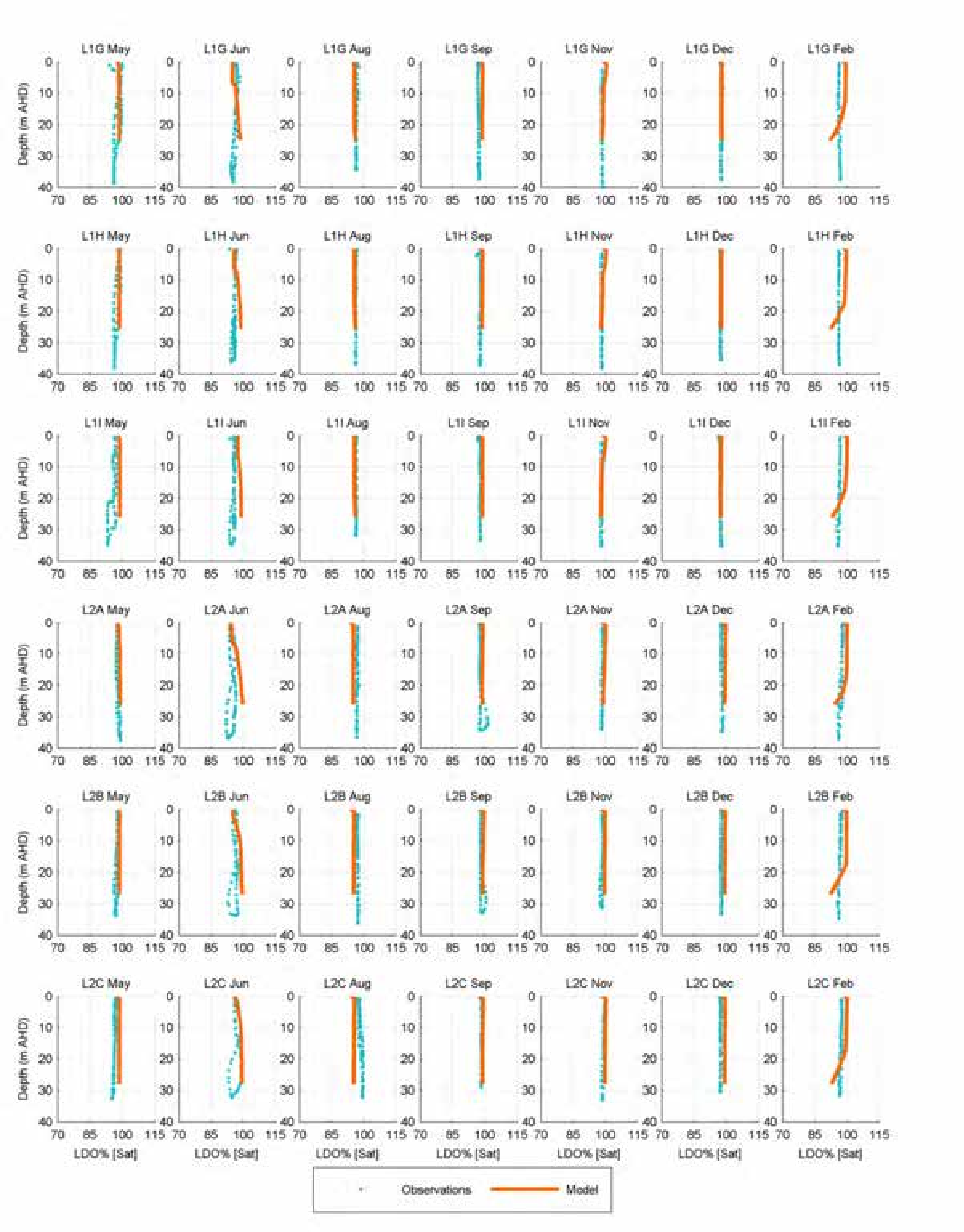

Figure 4-44 Depth profiles of percent DO saturation at lease-area sites – 2 of 5

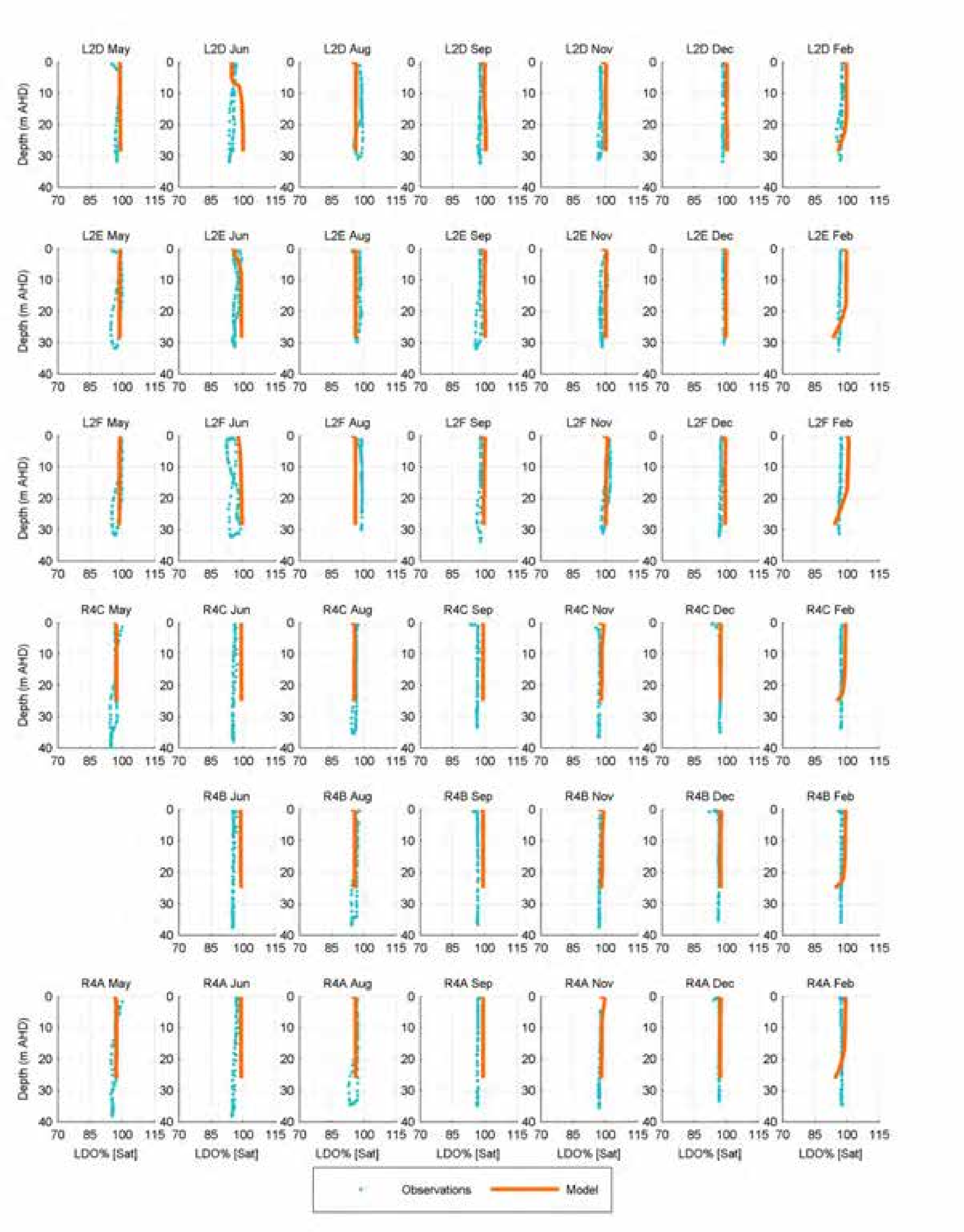

Figure 4-45 Depth profiles of percent DO saturation at lease-area sites – 3 of 5

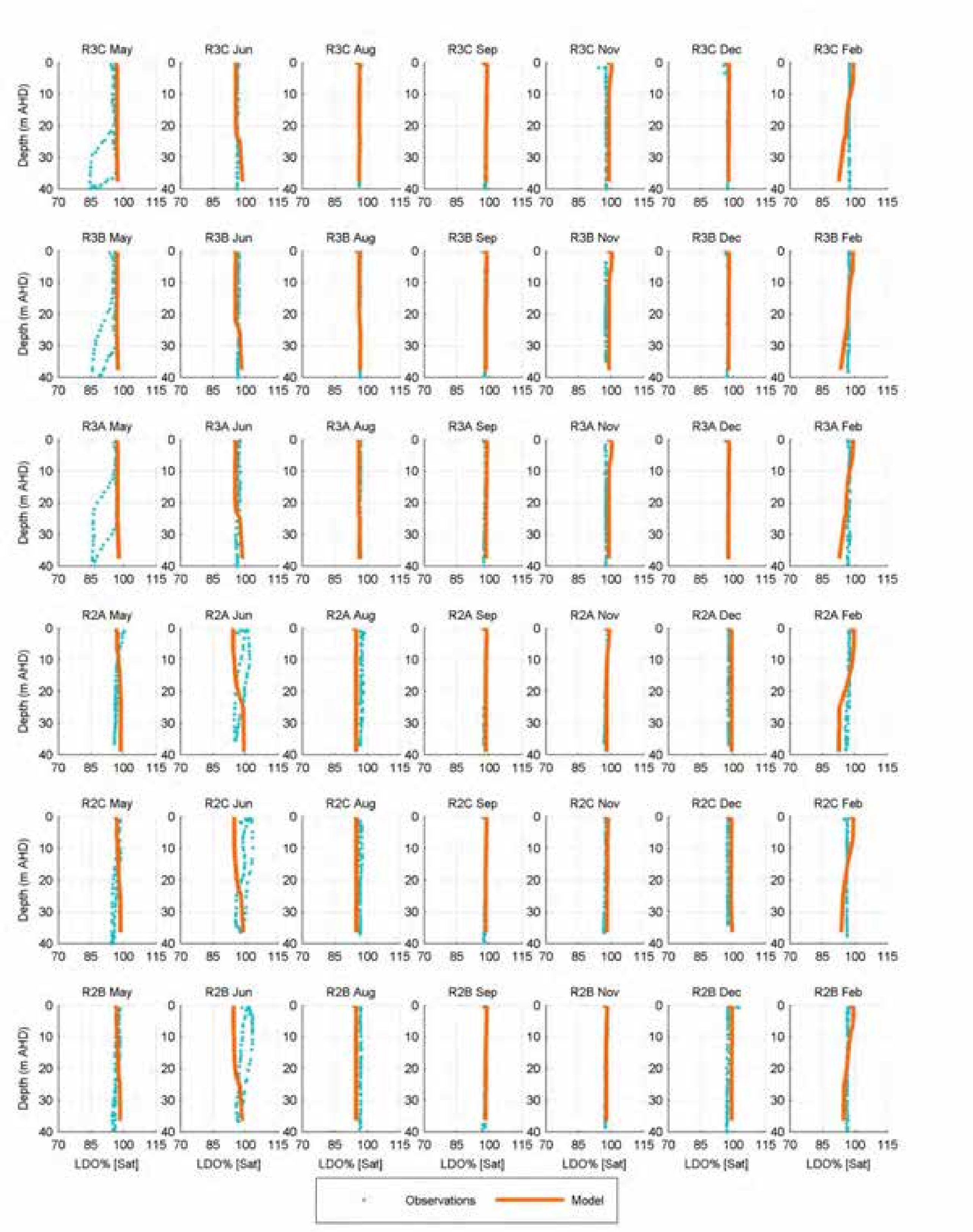

Figure 4-46 Depth profiles of percent DO saturation at lease-area sites – 4 of 5

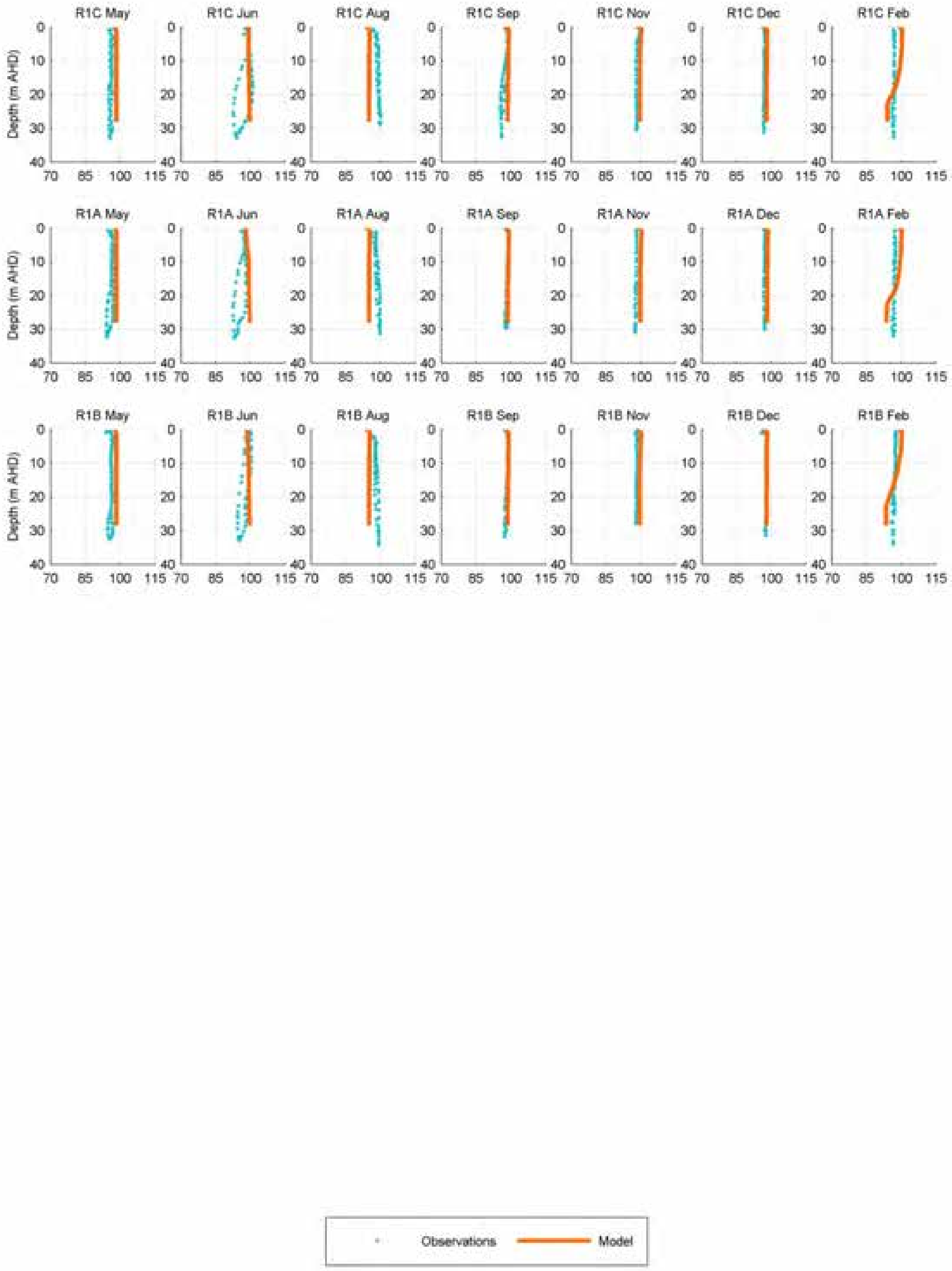

Figure 4-47 Depth profiles of percent DO saturation at lease-area sites – 5 of 5

4.2.2 Nitrogen

Time-series comparisons of simulated and observed TN, oxidised inorganic nitrogen and ammonium are presented in Figure 4-48, Figure 4-49 and Figure 4-50, respectively. Concentrations of TN are typically 0.2 mg/L or less, with similarly low values of speciated nitrogen, although there are some outliers (e.g. at L2A in August 2014). The model does not vary significantly during the calibration period, but agrees well with observations.

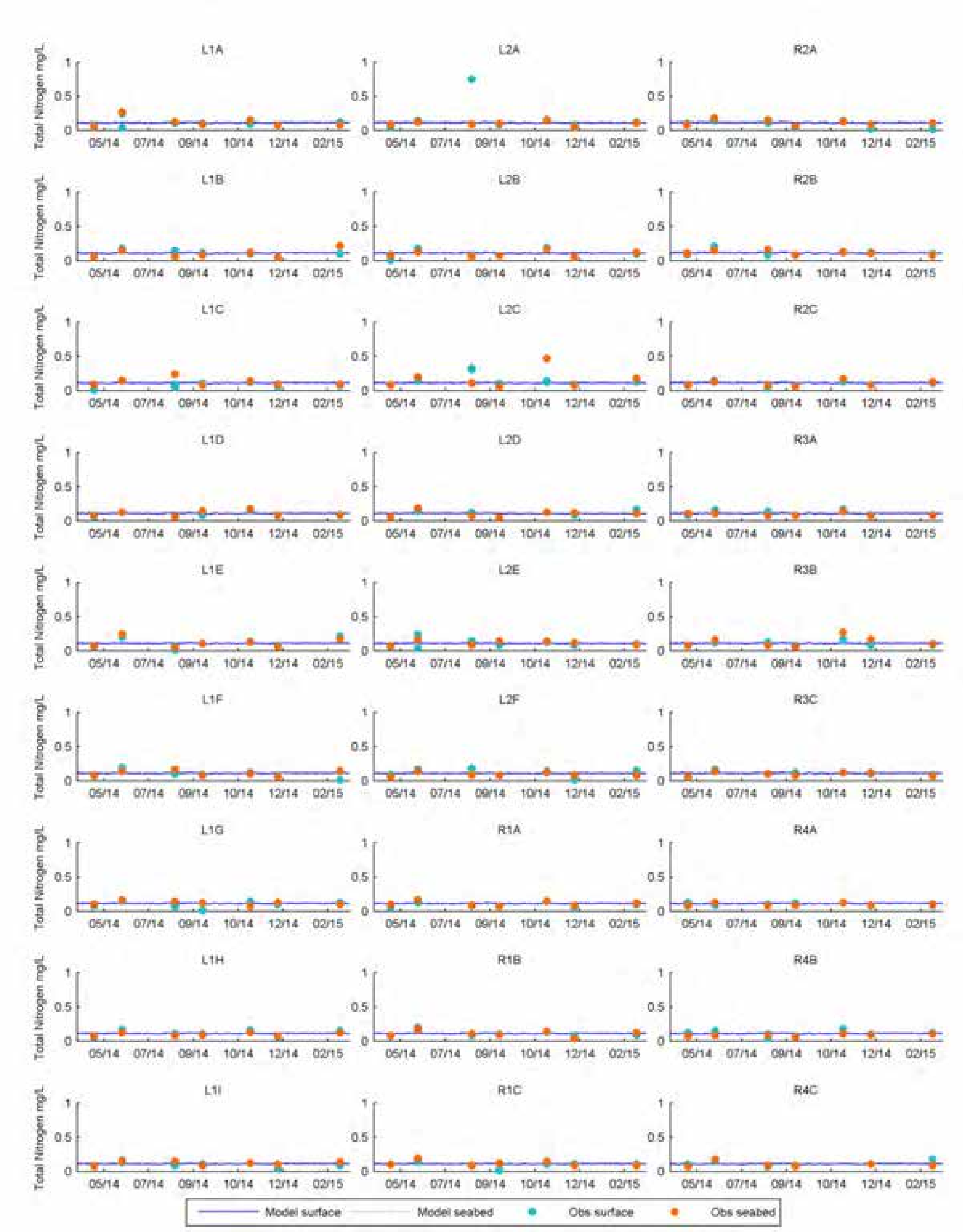

Figure 4-48 Time-series of total nitrogen at lease-area sites

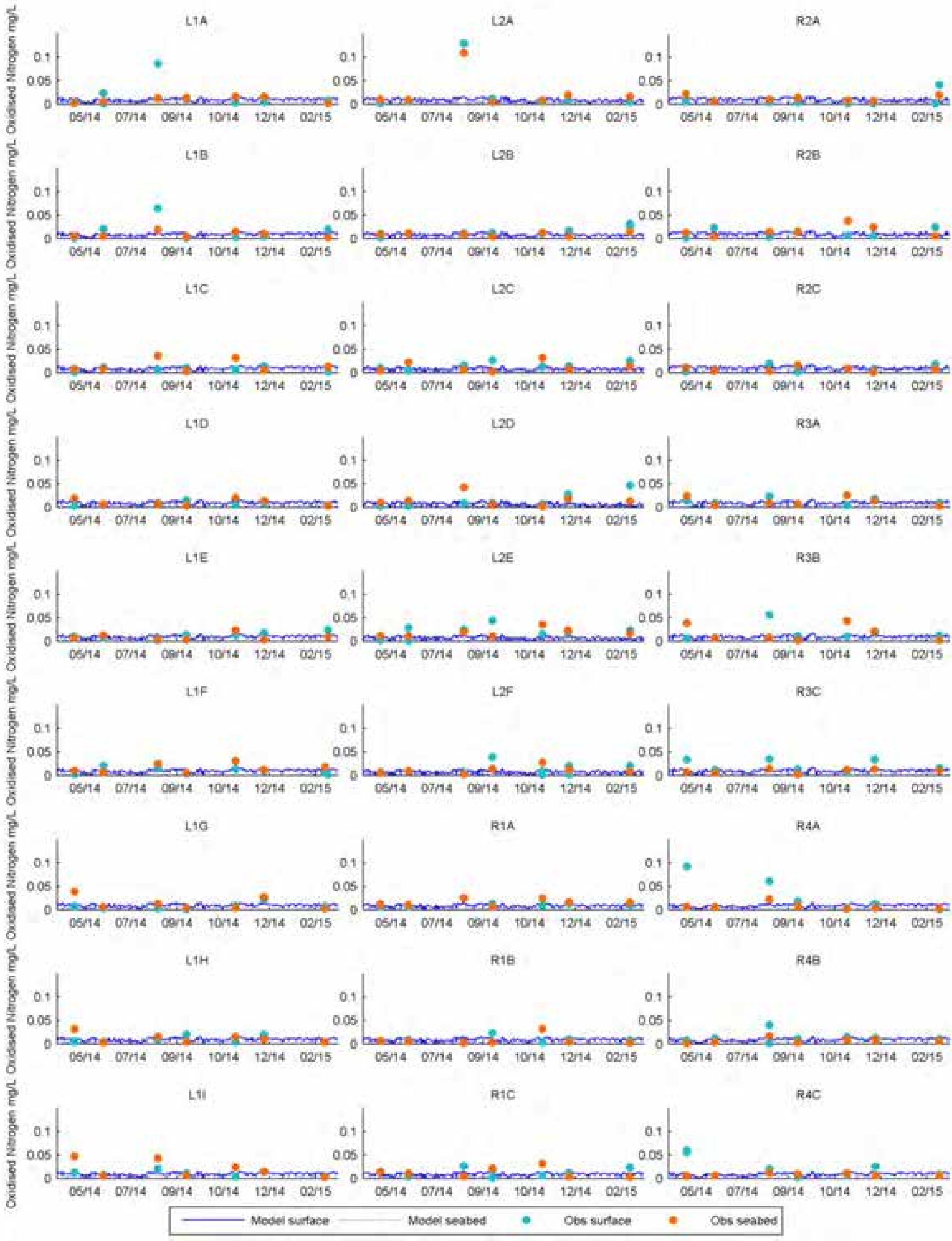

Figure 4-49 Time-series of oxidised inorganic nitrogen at lease-area sites

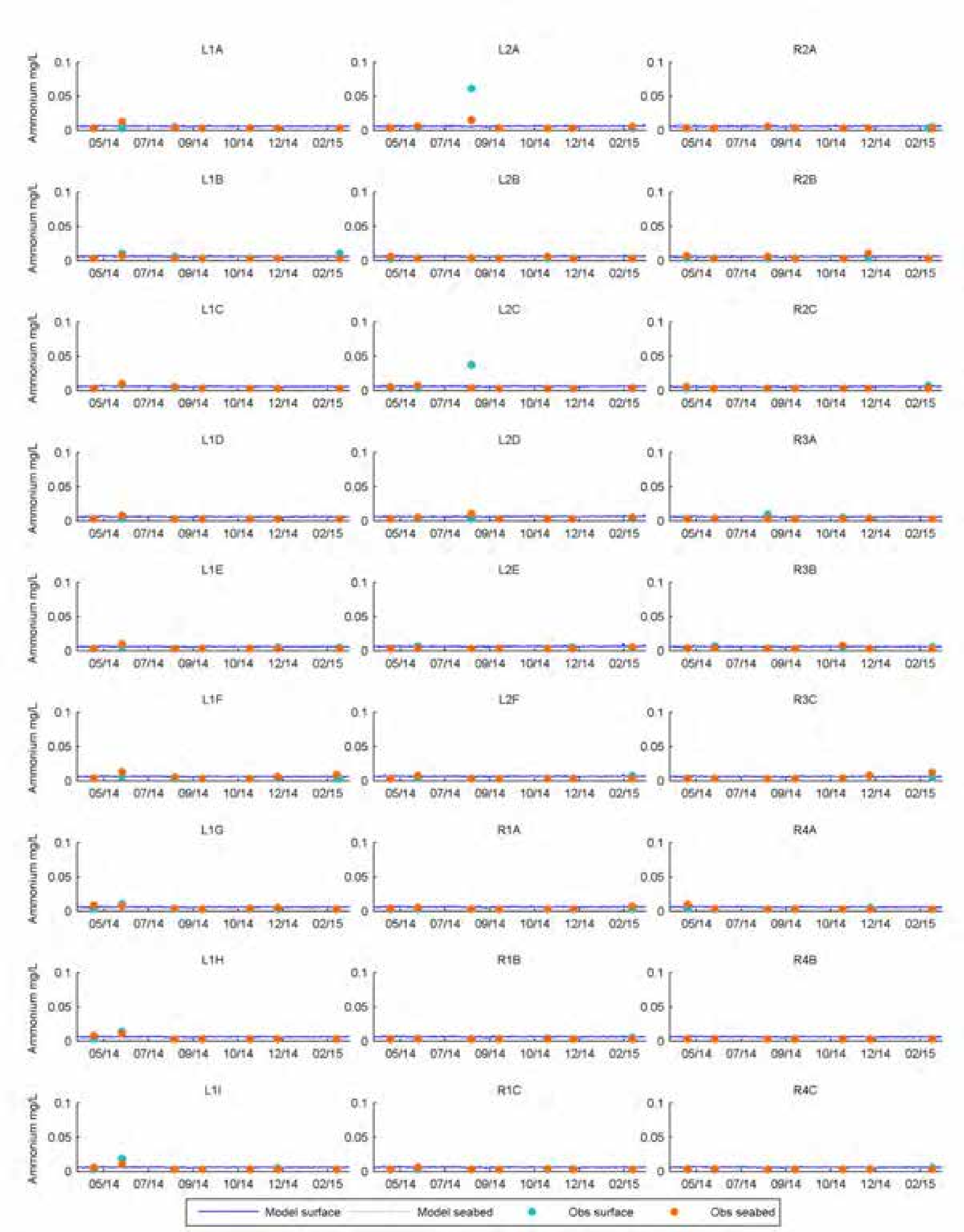

Figure 4-50 Time-series of ammonium at lease-area sites

4.2.3 Phosphorus

Comparisons of simulated and observed TP and FRP are presented in Figure 4-51 and Figure 4-52, respectively. Similarly to nitrogen, concentrations of TP and FRP are low, with occasional outliers. Neither model nor measured concentrations vary substantially during the calibration period.

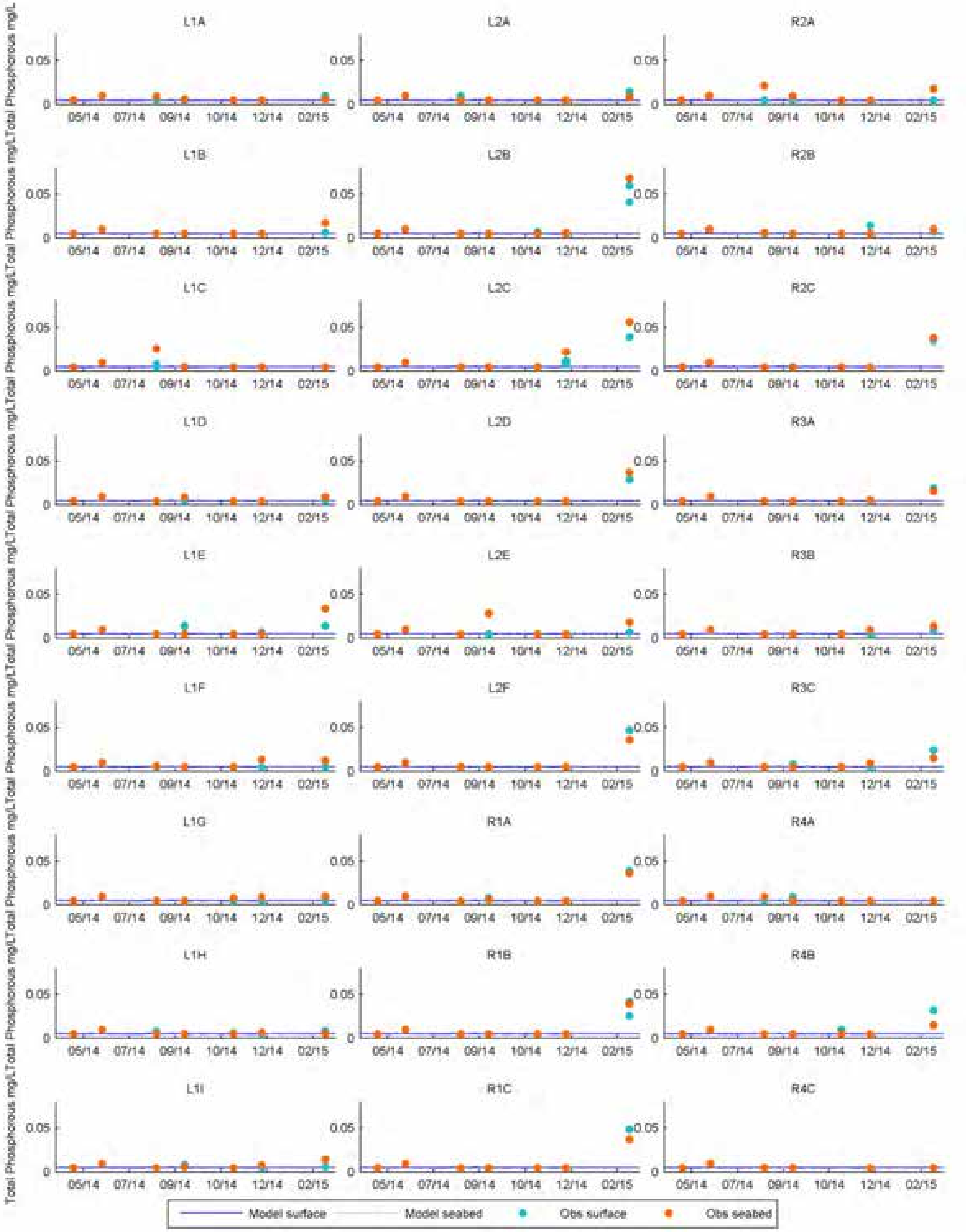

Figure 4-51 Time-series of total phosphorus at lease-area sites

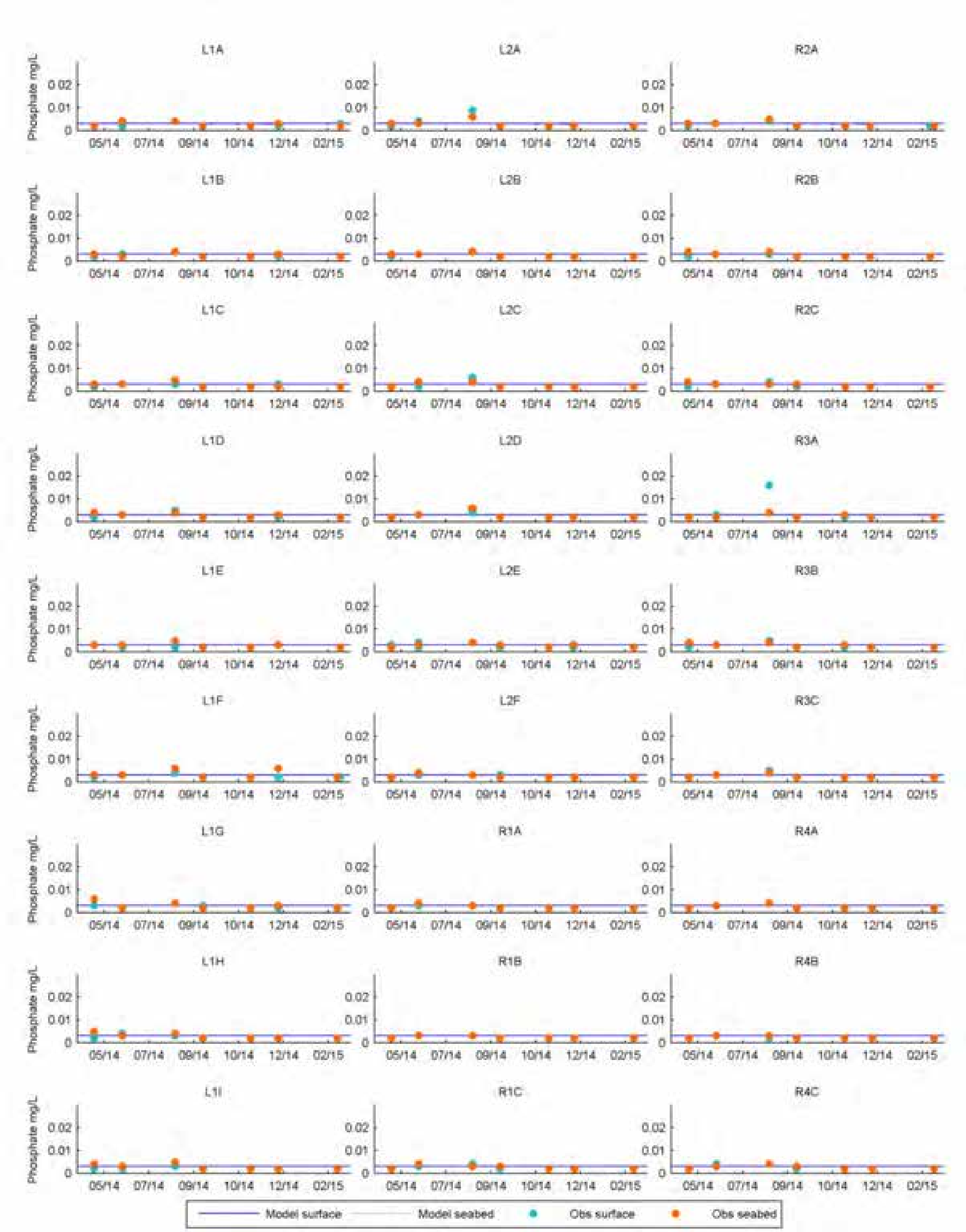

Figure 4-52 Time-series of FRP at lease-area sites

4.2.4 Chlorophyll a

Comparisons of simulated and observed chlorophyll *a* concentrations are presented in Figure 4-53. Similarly to nutrients, chlorophyll *a* concentrations are low and do not vary substantially. Observed concentrations are often at or below the detection limit of 2 µg/L and the model also simulates chlorophyll *a* concentrations around this level.

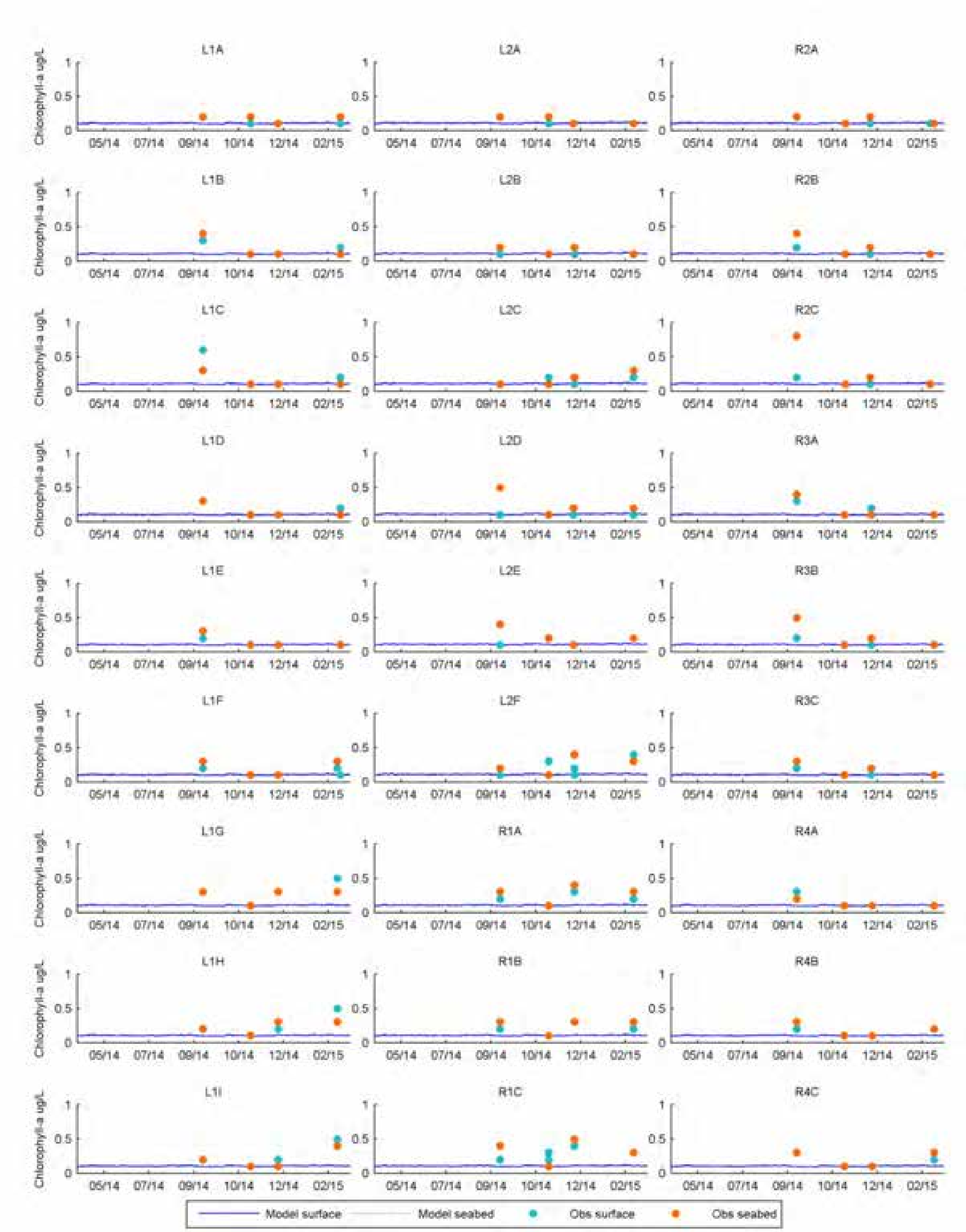

Figure 4-53 Time-series of chlorophyll *a* at lease-area sites

5 Discussion

As noted in the introduction, the region surrounding the Abrolhos Islands is challenging from a modelling perspective, as it requires the successful resolution of processes on a range of spatial scales from regional (e.g. Leeuwin Current) to local (e.g. local bathymetric features). The model described in this report achieves this by including the following:

- Global, assimilative models as boundary forcing to capture regional effects (HYCOM, TPX, CFSR)
- Kilometre-scale resolution outside of the area of interest to capture eddy dynamics
- Horizontal spatial scales down to approximately 40m to resolve local effects in the vicinity of the proposed cage locations
- Vertical spatial scales of 1 m or less to simulate stratification and other density-driven processes
- Hourly meteorological data to provide fine-scale resolution of key weather-driven processes (e.g. wave dynamics, radiative processes).

By including the above features, the model does an excellent job of replicating the hydrodynamic environment in the area of interest and is fit for the purposes of simulating the fate of particles released from aquaculture activities and providing a realistic hydrodynamic regime to the water quality module. Additionally, the water quality model recreated the oligotrophic conditions at the site, and therefore is 'fit-for-purpose' in assessing the effects of aquaculture activities on water quality concentrations within the area of interest.

Current velocities and wave dynamics are particularly well represented, with the model capturing both short-term and long-term variability. This is key to a successful study as these processes are vital in accurately simulating particle distribution, which, in turn, is crucial in determining the impact of food and faecal particles on the environment surrounding fish cages. Tidal range is slightly under-predicted but a sensitivity test indicated that changing the model to address this was detrimental to the velocity calibration, which is more important. Significant wave height also has a slight bias but this was shown to have a limited effect on the 'footprint' of particles released from fish cages. While wave height magnitude was slightly over-predicted, the simulated *variability* of wave height matched observations very well, with r values greater than 0.84 at all sites. The other wave parameters of peak wave direction and peak wave period compared very favourably in both magnitude and variability.

The model captured seasonal and short-term temperature dynamics very well, including a number of localised and short-term thermal stratification events, as demonstrated by comparisons against 188 depth profiles taken during the study. The ability to recreate these events indicates that the model's representation of bathymetric features around the Abrolhos Islands is good, and it captures the interaction between these and the important large-scale currents in the region. Arguably, it is more important to capture the seasonal dynamics as the impact of aquaculture activities will be assessed over the long-term. The model illustrated its capability in this regard by successfully recreating the onset of summer temperatures, with r values of 0.916 and 0.957 during the

November 2014 to Mar 2015 deployment. Furthermore, the model matched salinity observations well once a constant offset of 0.3 PSU was applied to the HYCOM boundary forcing.

The water quality model compared well with observations, but no significant water quality dynamics were observed during the sampling period. Most samples were at or below the detection limit and, as such, the calibration was more of a 'verification' that the model would also recreate the oligotrophic conditions apparent in the region.

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Appendix A Methodology Letter – March 2015

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Our Ref: L.B20639.005.Methodology.docx

15 September 2015

Cardno
Level 9 The Forum
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NSW 2077

Attention: Dr. Doug Treloar

Dear Doug,

RE: MIDWEST ZONE AQUACULTURE MODELLING PROPOSED METHODOLOGY

Thank you for your comments reviewing our proposed methodology for this study, provided during the meeting at BMT WBM's office on 5th March 2015 and based on the latest revision of our methodology document (L.B20639.004.Methodology.pdf; minutes of meeting outlined in M.20639.001.MethodsReviewMeetingMinutes.pdf).

A finalised methodology document, addressing each of the comments, is included below for your records.

Yours Faithfully
BMT WBM

Michael Barry

1 Introduction and Background

The Department of Fisheries, Western Australia (DoF), on behalf of the Minister for Fisheries proposes to create an 'Aquaculture Development Zone' to provide a management precinct for prospective aquaculture proposals within the State Waters, off the Houtman Abrolhos Islands (HAI) Fish Habitat Protection Area (FHPA), which is approximately 75 kilometres west of Geraldton. The Mid-West Aquaculture Development Zone (MWADZ) has been selected by DoF to maximise suitability for marine finfish aquaculture, and minimise potential impacts on existing marine communities and human use.

The MWADZ is proposed to encompass an area of 8041.83 hectares (ha) across two development areas (Figure 1). The study sites are located within the two MWADZ areas:

- A 3000 ha area located in Zeewijk Channel, between the Pelsaert and Easter Groups; and
- A 1740 ha study area located north of Murray Island in the Pelsaert Group

Under the Environmental Scoping Document (ESD) associated with the proposed MWADZ, DoF is required to prepare a Public Environmental Review (PER) document in accordance with the Western Australian Environmental Protection Act 1986 (EP Act). The objectives of this assessment are to identify an environmentally acceptable location for the MWADZ and to identify the operational limits and objectives to apply to future proposals in the MWADZ to manage the cumulative impacts of multiple sea cage operations. To fulfil the requirements of the ESD and the preparation of the PER, DoF has engaged BMT Oceanica to undertake the technical studies for the environmental impact assessment (EIA) associated with operations within the proposed MWADZ. This involves investigating the influence of various factors such as nutrient and contaminant input, establishment of infrastructure, management practices, and the hydrodynamics of the surrounding marine environment.

BMT Oceanica, alongside its sub-consultants BMT WBM and the University of Western Australia (UWA) (hereafter, 'We'), will develop environmental models to assess the potential impact of finfish aquaculture on marine flora and fauna in the area, including significant marine fauna of the region. This document contains a description of the modelling sampling program that will be undertaken, the modelling methodology that will be employed, and the pressure-response analysis strategy that will be used to address the regulatory requirements. It is intended that this document be reviewed on technical grounds by the team's peer reviewer, with a view to refining/modifying the proposed methods to the satisfaction of the reviewer.

2 Pressure-Response Analysis Strategy

2.1 Pressure-response relationships and trigger parameters

Pressure-response relationships and the environmental trigger parameters (thresholds) relating to aquaculture in tropical and subtropical environments are well known to BMT Oceanica. BMT Oceanica has 20+ years of experience of pressure-response relationships associated with sewage outfalls (which impart similar pressures to aquaculture), and recently played a key role in the development of an EIA for the Kimberley Aquaculture Development Zone (KADZ). A review of literature undertaken for the KADZ project (encompassing over 100 peer reviewed articles and reports), for example, identified critical threshold values for a number of key receptors (e.g. corals, sessile filter feeders and infauna) that could reasonably be applied across tropical and sub-tropical marine environments generally. The receptors and the critical thresholds for the Mid-West assessment are expected to be near identical to those identified in the KADZ project and for this reason will be used as the starting point in this project. Groundtruthing of thresholds will be undertaken using Mid-West specific data collected during the baseline assessment between May 2014 and February 2015. Ultimately, all thresholds will be set conservatively in line with approach of the EPA (2000), where 'safety factors' are applied to mitigate against uncertainty. The term ‘safety factor’ is used by the EPA to ensure modelling scenarios are conservative. Safety factors will be applied by (1) overestimating the stocking densities/standing biomass of fish stocks, (2) by using upper-end estimates for faecal-pellet sinking rate and the carbon content of faecal matter, and (3) by using appropriately conservative values for model parameters (e.g. sediment mineralisation rates). Outputs from the models will incorporate this uncertainty and use a conservative approach to ensure the cumulative impacts of proposed aquaculture operations are overestimated.

2.2 Developing and applying the trigger parameters

The EPA scoping guideline for this proposal requires the application of the impact categories outlined in EAG 7 (EPA 2011), which was originally designed to assess the impact of dredging activities and, hence, contains dredging terminology throughout. EAG 7 contains three predefined levels of impact: zone of high impact (ZoHI); zone of moderate impact (ZoMI) and the zone of influence (ZoI). The application of these categories is determined by ‘recovery time’: specifically, how long the impacted habitat will take to recover once the stressor(s) has/have been completely removed. Habitats requiring greater than five years to recover are designated zones of 'high' impact, and habitats requiring less than five years to recover are designated zones of 'moderate' impact. EAG 7 defines the ZoI as the area within which changes in environmental quality associated with dredge plumes are predicted and anticipated during the dredging operations (aquaculture operations in the case of this study), but where these changes would not result in detectable impacts on benthic biota.

While the EAG 7 approach is robust in theory, it is limited by local taxonomic information and a poor understanding of the response of organisms following different magnitudes of impact. This is exacerbated by the fact that, as EAG 7 was originally written to inform EIA processes associated with capital dredging works in the State’s north-west, much of the relevant literature focuses on inorganic suspended materials and its effect on corals. Hence, the effect of organic wastes and inorganic nutrients to other flora and fauna, and their recovery following removal of the ‘pressure’, has received relatively little attention.

2.3 Application of models to inform the EIA process

The EIA will proceed by investigating a number of cause-effect pathways and determining the likely impact of each pathway through the use of numerical models, where appropriate. A list of cause-effect pathways, and their receptors are included in Figure 1. Two distinct modelling approaches will be utilised:

- An integrated hydrodynamic, water quality and sediment-diagenesis model to investigate the potential environmental impacts of changes in water quality; and
- An integrated hydrodynamic, sediment particle transport and sediment-diagenesis model to investigate the potential environmental impacts of changes in sediment quality from aquaculture activities. This will include estimates of the time taken for sediments to recover to baseline conditions following removal of fish cages.

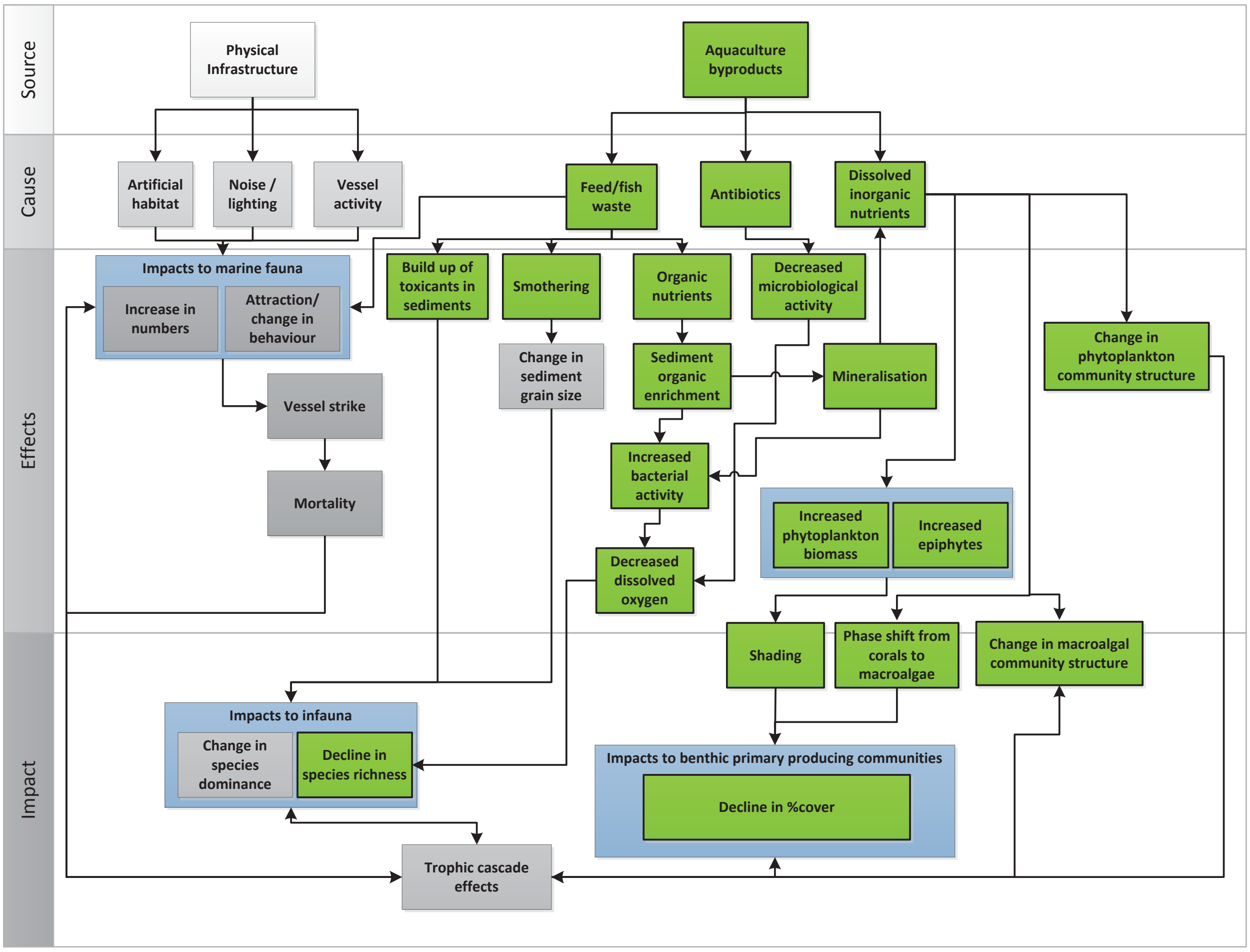


Figure 1 Cause-effect pathways to be investigated by modelling

As per EAG 7, the objective of the modelling is to determine the extent to which aquaculture will (1) impart 'high' and/or 'moderate' impacts to benthic habitats, and (2) impart an 'influence' on surrounding environmental quality without impacting benthic habitats. We propose to apply different approaches depending on two distinct receiving environments:

- Soft, sandy substrates, which are assumed to contain no significant flora or sessile benthic fauna.
- Hard substrates, with resident macroalgae, filter feeder or coral communities.

A habitat survey is planned to confirm the assumptions mentioned above (see Section 3.2.1) and, if possible, the cages will be preferentially placed such that hard-substrate habitats are avoided.

For soft substrates, the zones of impact will be modelled directly using the integrated hydrodynamic, particle transport and sediment-diagenesis models. Recovery times will be determined based on the time taken to achieve ‘chemical’ remediation. In this context, chemical remediation refers to the time taken for sediment conditions (e.g. nutrient, oxygen and chlorophyll concentrations) to return to their baseline condition. This is as opposed to ‘biological’ remediation, which refers to the time taken for sediment biological communities to return to their baseline state. Chemical remediation is a more reliable process with readily identifiable beginning and end points, while biological remediation, in contrast, may never occur completely, as guilds of infauna inhabiting similar ecological niches may replace each another, leading to subtle differences in post-remediation community structures–meaning the end point is difficult to quantify. In addition, chemical remediation may be modelled directly, whereas simulating biological remediation would require a model capable of resolving multiple species and successional processes at a number of trophic levels–which is unadvisable given its complexity, and presently impossible given the constraints of the model. For soft substrates, therefore, we believe the chemical-remediation approach is the most robust (a description of the relevant models is included in Section 4).

For hard substrates, the chemical remediation approach above will be followed but an additional step will be included to assess the impact on other receptors (corals, seagrasses and macroalgae). This additional assessment will proceed in two stages: (1) for each of the receptors, the critical thresholds at which high and moderate impacts are likely to occur will be determined and (2) these will then be cross-reference with the contaminant concentration gradients produced by the models, to spatially represent the zones of impact in two-dimensional space (aerial perspective). This is a complicated impact assessment because it has more assumptions than the soft sediment impact assessment. To mitigate the confounding effects of this complexity, the first step in the EIA process, where possible, will be to set up the model such that the sea-cage clusters (each consisting of 14 cages of approximately 38 m diameter) are positioned over soft sediment habitats and at least 100 m from the nearest hard substrate.

If the proposed MWADZ is positioned over hard substrate, it will be necessary to develop thresholds for a range of receptors. Hard substrates of the Abrolhos are sometimes inhabited by a combination of corals, macroalgae, seagrass and filter feeders. Because each has differing tolerances, it will not be possible to model recovery using a single time line, as some will recover faster than others. To overcome this, thresholds will be developed based on the most sensitive of receptors, or the most dominant of the receptors (whichever is more appropriate). Experience in the KADZ assessment suggests the thresholds will be based on corals (specifically *Acropora* spp).

For impacts associated with more diffuse (less direct) cause-effect pathways e.g. shading resulted from regional algal blooms, thresholds will be developed from known minimum light tolerances for benthic primary producing habitats, or the inorganic nutrient thresholds known to result in ecological phase shifts i.e. corals to macroalgal dominated reefs. Previous work undertaken as part of the KADZ assessment indentified thresholds based on both inorganic and organic stressors for a range of receptor organisms. Because some organisms were more sensitive than others, the complexity of the EIA was reduced by applying conservative thresholds based on the most sensitive species. Examples of the application of this process are provided below.

2.3.1 Suspended particles and sedimentation stressors

Thresholds for suspended particles were based on magnitude and duration of exposure (concentration [mg/L) by time [days]), and the thresholds for sedimentation were based on the depth of burial (mm). In terms of suspended particles, corals were found to be more sensitive (5-25 mg/L over a given percentage of time) than other types of filter feeders (10-1000 mg/L over 'X' number of days). Similar results were found in terms of sedimentation, with corals being more sensitive (with the lowest tolerance) (1.7-17.5 mm) than mobile invertebrates (20-30 mm) and bivalves (10-40 mm). It was also acknowledged through this process that the above thresholds were based on the effect of inorganic particles, and that the effect of organic particles, such as food or faecal particles, may differ. However, in the absence of comparative information relevant to organic particles, these thresholds were used as an estimate. It is also recognised that as much of the work associated with the KADZ assessment concentrated on the effects to resident corals and other filter feeders, further work will be required under the MWADZ assessment to determine the relative sensitivities of seagrasses and macroalgae to the effects of shading and sedimentation. Using the conservative approach advocated by the EPA (2000), and once armed with all relevant information, we will define the zones of impact using the known tolerances of the most sensitive microhabitats, and then derive recovery times based on the known biology of the constituent organisms, including times required for recolonisation and growth.

2.3.2 Inorganic-nutrient stressors

Aquaculture may contribute inorganic nutrients to the water column either directly through secretion of ammonia by fish, or indirectly through organic matter deposition and remineralisation. Inorganic nutrients in the form of ammonia, nitrite + nitrate and orthophosphate may lead to adverse environmental effects via a number of cause-effect pathways, all of which contain benthic, primary-producing organisms (BPPO) as key receptors (Figure 2).

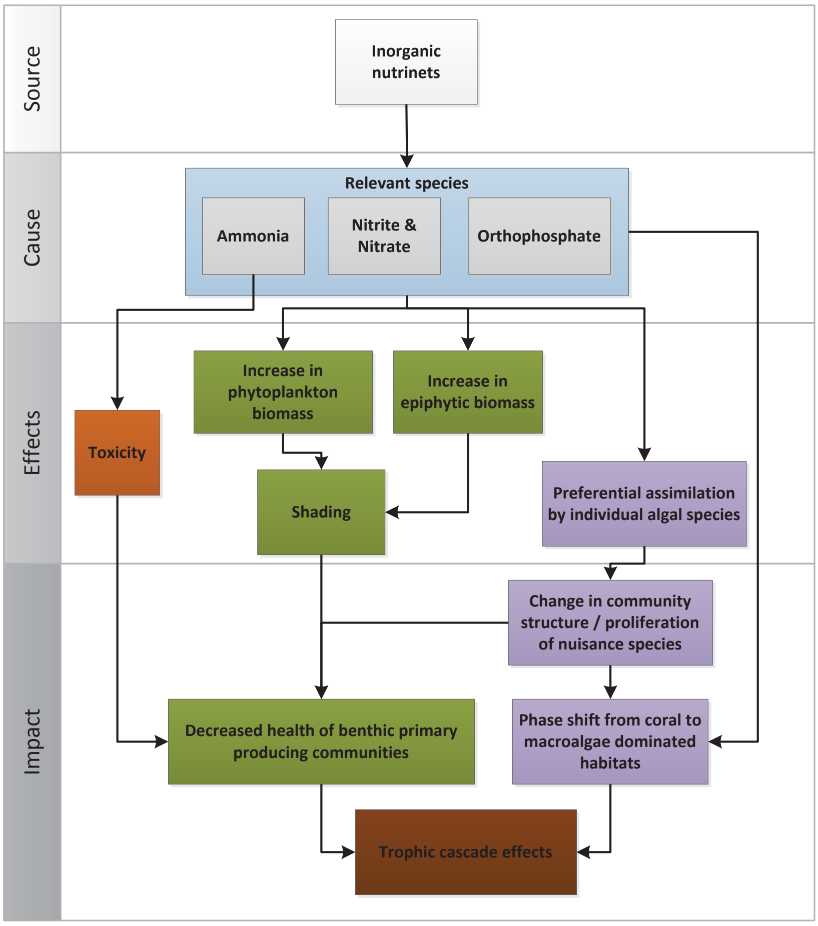


Figure 2 Relevant cause effect pathways relevant to inputs of dissolved inorganic nutrients

Adverse effects to corals have received particular attention in the literature. Prolonged exposure to nutrients may, under worst-case scenarios, lead to a phase shift, whereby healthy living corals are slowly replaced by macroalgae. The paradigm is that in the absence of herbivores, algae will proliferate at low dissolved inorganic nitrogen (DIN) concentrations of ~1 µmol/L. For the KADZ assessment, the threshold for inorganic nutrients was conservatively set based on this concentration, and specifically, whether or not local corals were exposed to this concentration for period greater than six months at a time. As the MWADZ assessment is likely to include other BPPO including seagrasses, the extent to which this threshold of ~1 µmol/L can be applied will be assessed. If necessary, a new threshold which takes into account the relative sensitivities of seagrasses will be built into the model. As with the assessment of the effects of organic stressors, the zones of impact will be determined based on the biology of the organisms and the timeframes required for recolonisation following complete removal of the pressure.

The thresholds for DIN are based on the paradigm established for corals in the 80's and 90's. The threshold of 1 uM/L is widely regarded to be highly conservative. Other studies report higher thresholds of between 1 and ~4 uM/L. The threshold is exclusively a concentration threshold, and no specific information is given in terms of duration (gain this varies from study to study). The 6 month duration used in the KADZ assessment was largely arbitrary and designed to cover (roughly) the duration of the wet different seasons (wet and dry). Given that our models will run over much longer periods (5-6 years), we will investigate whether it is defensible to extend the duration beyond 6 months.

2.3.3 Shading stressors

Light reduction at the benthic level may lead to sub-lethal or lethal effects on BPPO, including corals, seagrass and macroalgae. Light thresholds for the MWADZ assessment will be developed conservatively so that they are protective of the most sensitive of the BPPO, whether that be corals or other. By way of example, the light thresholds chosen for model interrogation in the KADZ were based on the triggers developed for the BHPB Outer Harbour Project. EAG 7 requires that thresholds are developed around the most sensitive organisms. The use of a sub-lethal threshold of a <60% reduction in SI is considered appropriate as the threshold for the ZoMI, because these levels of SI are known to cause sub-lethal stress in *Acropora* species. *Acropora* spp. are also likely to be common in the Houtman Abrolhos.

3 Sampling Program

The study area comprises two locations within the HAI FHPA in the Mid-West region of Western Australia. Location 1 is 3000 hectares located in Zeewijk Channel north of the Pelsaert Group, and Location 2 is 1740 hectares located immediately north of Sandy Island in the Pelsaert Group (Figure 3). Under the Environmental Scoping Document (ESD), EPA requires that the PER is supported by a comprehensive EIA including a comprehensive water, sediment and habitats survey to characterise baseline conditions. BMT Oceanica received a preliminary baseline survey design from DoF at the commencement of the project. Advice provided by BMT Oceanica resulted in changes to the program including the redistribution and expansion of sampling sites, and the recommendation that the study be supported by additional ADCP data.

DoF will collect the majority of the baseline datasets to support the EIA studies being undertaken and provide the raw data required for the modelling studies to the BMT Oceanica team. The baseline studies will be undertaken by DoF's Research Division through the Marine Ecology and Monitoring Section (MEMS).

BMT Oceanica's team is also collecting some additional (and complementary) hydrodynamic data in the region, in addition to DoF's data collection program. These data include 2 bed mounted Acoustic Doppler Current profiler (ADCP) instruments with supporting and co-located conductivity temperature depth (CTD) sensors. For simplicity, the DoF and BMT Oceanica's team deployments are presented and described together in this document.

For water quality, a total of 28 sites will be sampled comprising of 9 sites within Location 1 and 6 sites within Location 2, plus an additional 12 reference sites. All sites will be located within a similar depth contour (approximately 30-40m) (Figure 3). Sites have been positioned to allow for future Before-After-Control-Impact (BACI) style analyses and stratified to capture the presence of water quality gradients (if present at all). It should be noted that some sites are located within traditional trawl grounds for the Mid-West Trawl Fishery.

For sediment quality, a total of 33 sites will be sampled comprising of 12 sites within Location 1 and 9 sites within Location 2, plus an additional 12 reference sites. All sites will be located within a similar depth contour (approximately 30-40m). As with the water quality sites, sites have been positioned to allow for future BACI style analyses, and stratified to capture the presence of sediment quality gradients, if present (Figure 4).

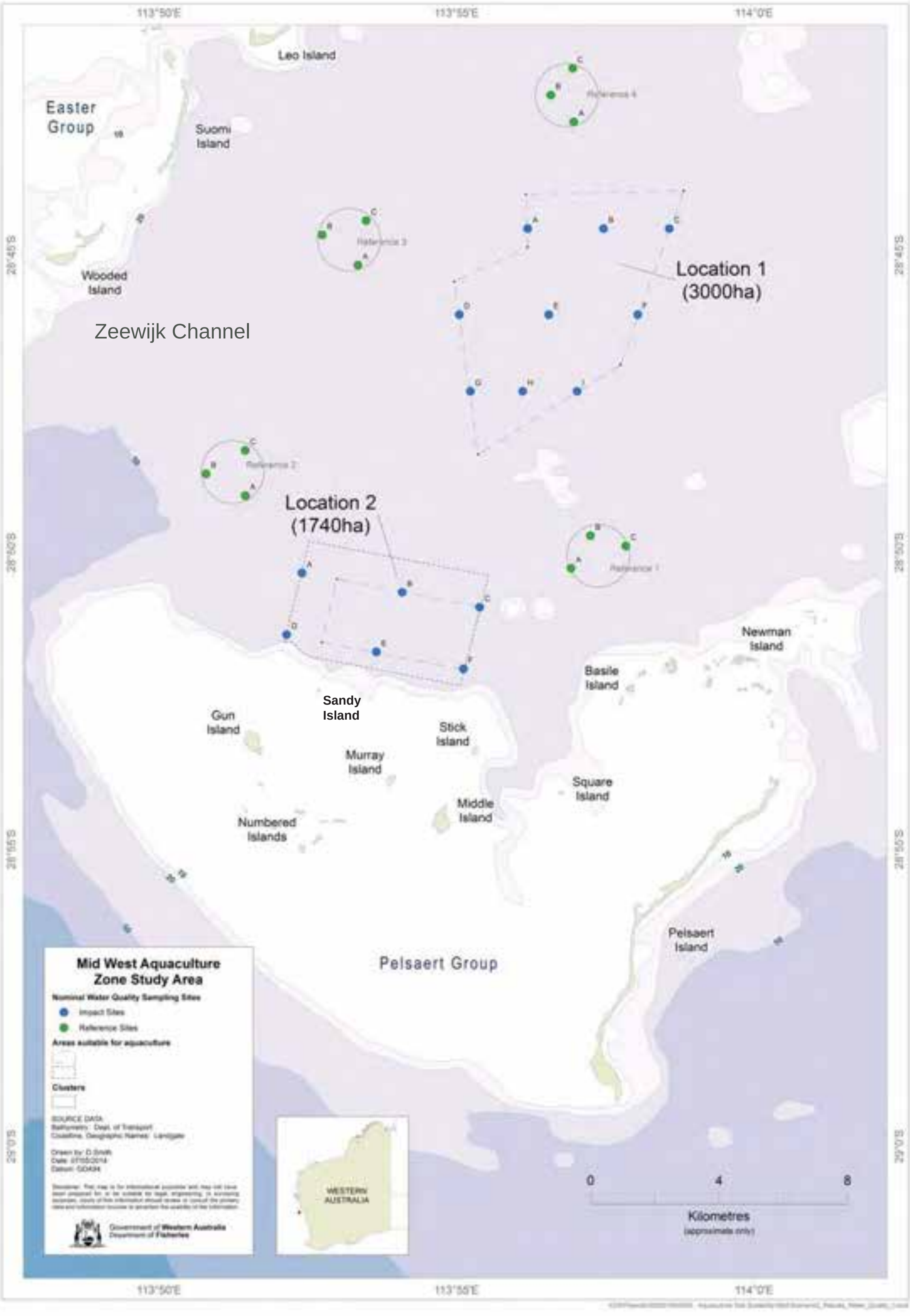


Figure 3 Baseline water quality sampling sites

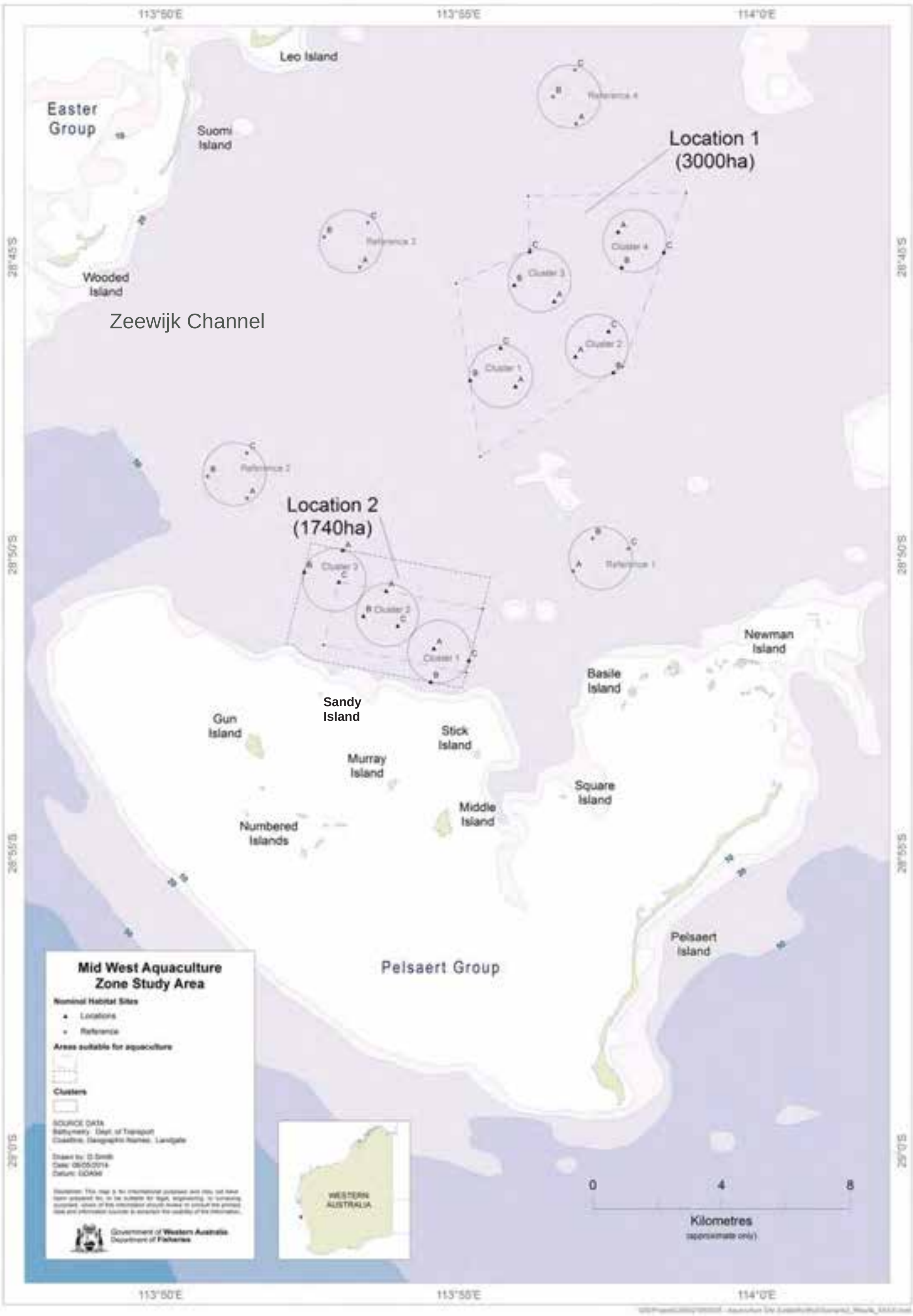


Figure 4 Baseline sediment quality sites

The sampling program will provide insight into the hydrodynamic, water quality and benthic regime in the study area, and will be used to inform the key processes that must be successfully simulated by the modelling framework. The program includes hydrodynamic, water quality, sediment quality and benthic habitat surveying components, which are described in detail below. The frequency of sampling for each component is detailed in Figure 5.

	Autumn				Winter				Spring				Summer			
	May		Jun		Aug		Sep		Nov		Dec		Feb		Mar	
	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B
In situ measurements	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
In situ PAR dataloggers		In		Out		In		Out		In		Out		In		Out
Water quality sampling	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Phytoplankton sampling	✓				✓				✓				✓			
Sediment quality sampling						✓								✓		
Single-beam hydroacoustic mapping		✓														
Drop video habitat sampling				✓				✓*				✓*				✓*
Acoustic Doppler Current Profiling		In		Out		In		Out		In		Out		In		Out

Figure 5 MWADZ temporal sampling design. Note S = surface and B = bottom of the water column. Asterix indicates only a sub-sample of the initial drop video sites will be temporally sampled to capture any changes in benthic habitats.

3.1 Hydrodynamic Sampling

Four bottom-mounted Acoustic Doppler Current Profilers (ADCPs) have been deployed in total: one in each of the MWADZ areas (Figure 3) one to the north-east of the study area and one to the south-east (Figure 6). The ADCP located in Location 1, and both the ADCPs located outside of the study area, also collect wave and depth data. Furthermore, a CTD (conductivity, temperature and depth) sensor has been deployed alongside the ADCP north-east of the study area, and both the ADCPs in the study areas are fitted with temperature sensors.

Figure 6 Location of AWAC ADCPs outside of the MWADZ areas

The ADCPs within each MWADZ will be deployed for approximately one month during each season, with the final deployment in approximately March 2015. The first deployment was completed over May and June 2014, although no wave data was collected at this time due to a faulty sensor. The fault was repaired for the subsequent August to September 2015 deployment.

The ADCPs outside of the MWADZs were deployed in July 2014 and will remain *in situ* and log continuously until they are retrieved in approximately March 2015. Each will be serviced in mid-November 2014. It is expected that the long servicing interval for these ADCPs will result in some bio-fouling of the instruments, which will likely affect the conductivity sensor, in particular. The cost constraints of this project preclude more frequent servicing, but the data produced by these instruments will be carefully assessed for any bias that may be introduced over time.

During the deployment and retrieval of the ADCPs, and during maintenance voyages, opportunistic data collection will be conducted which will include conductivity and temperature profiles. *Ad hoc* bathymetry measurements and ADCP transects have also been requested, but collection of these has not been possible to date and it is unlikely they will be on future voyages. In addition to these datasets, some historical data has been made available to the project, including:

- Wave data from the Outer Channel at Geraldton which have been provided by the Mid West Port Authority for a ten year period to 1st May 2014.

- ADCP data collected in October 2002 and September 2003 from a location within the Pelsaert Group just west of MWADZ area 1.
- Wave data from the region have been collected by Mitsubishi Development as part of the Oakajee Port and Rail project and may be provided to this project, although this has yet to be confirmed.
- Tide gauge data from Geraldton port to cover 1st Jan 2014 to present.

3.2 Benthic Sampling

3.2.1 Benthic Habitat Mapping

A benthic habitat mapping exercise will be conducted as part of the sampling program. Surveys will cover the Reference (1-4) and the proposed aquaculture Locations (1&2). Using a Biosonic MX digital single beam echosounder (and associated processing software), surveys of both proposed MWADZ areas will be made. The sounder will be fixed to the operational vessel and linked to a differential Global Positioning System (DGPS). The DGPS system will produce submetre accuracy through corrections via the OmniSTAR correction system.

The hydroacoustic surveys will be conducted along east-west lines through each area, based on the expected prevailing conditions, to try minimising the pitch of the vessel during the May 2014 sampling period. The first phase of soundings will be spaced 1km apart (Figure 7), this is to capture a minimum level of hydroacoustic data for each area accounting for weather redundancies and maximum vessel speed. The total linear distance covered equals 7900 meters for the first phase. The second phases of surveys will infill the 1km spaced survey lines (Figure 7). This will be undertaken if time permits following the first phase of hydroacoustic surveys. This would add an additional linear coverage of 7500 meters.

The Biosonic MX echosounder will capture data on bathymetry (which will need to be corrected for tidal fluctuations using data from the National Tidal Centre to provide lowest astronomical tide (LAT) depths), seafloor hardness and vegetation height (if present). The resulting data will be used to create an ‘unsupervised’ classification of the benthos to broad categories of benthos in the surveyed areas (see MEMS Benthic Mapping SOP).

The unsupervised classification will be used to select ground truthing sites to be verified via drop video in the field during the June 2014 sampling period. The underwater video is a ‘live feed’ system consisting of a progressive scan camera in an underwater housing attached to weighted frame with legs (the weight frame keeps the system directly below the vessel, while the legs provide protection and also a scale reference in the image). The system is connected to the vessel by 10mm rope and a reinforced video umbilical cable. The live feed video, with DGPS overlay, is recorded onto a hard drive recording device or progressive scan HandyCam (see MEMS Benthic Mapping SOP for more details).

The video data will be processed by using the point intercept method to identify the benthic habitats at each sampled site (see MEMS Benthic Mapping SOP for more details). The benthos will be classified into seven broad categories; coral, algae, seagrass, abiotic, filter feeder, other and unknown. Each category also had a number of subcategories;

- Coral - growth form or morphology (i.e. branching, plating, massive etc.)
- Algae – Sargassum sp, Ecklonia sp, other Macroalgae
- Seagrass – Posidonia sp, Amphibiolous sp, Halophila sp or other

- Abiotic – sand, rubble, silt or dead hard coral
- Filter feeder – Sponge, Gorgonian, Other filter feeder
- Other – wrack, rhodoliths
- Unknown – video was not clear enough to analyse.

Percentage cover of each habitat type, latitude, longitude and depth were recorded for each video drop site. This data is then analyses to determine homogenous habitat types to provide the basis for the supervised classification of the habitat (see MEMS Benthic Mapping SOP).

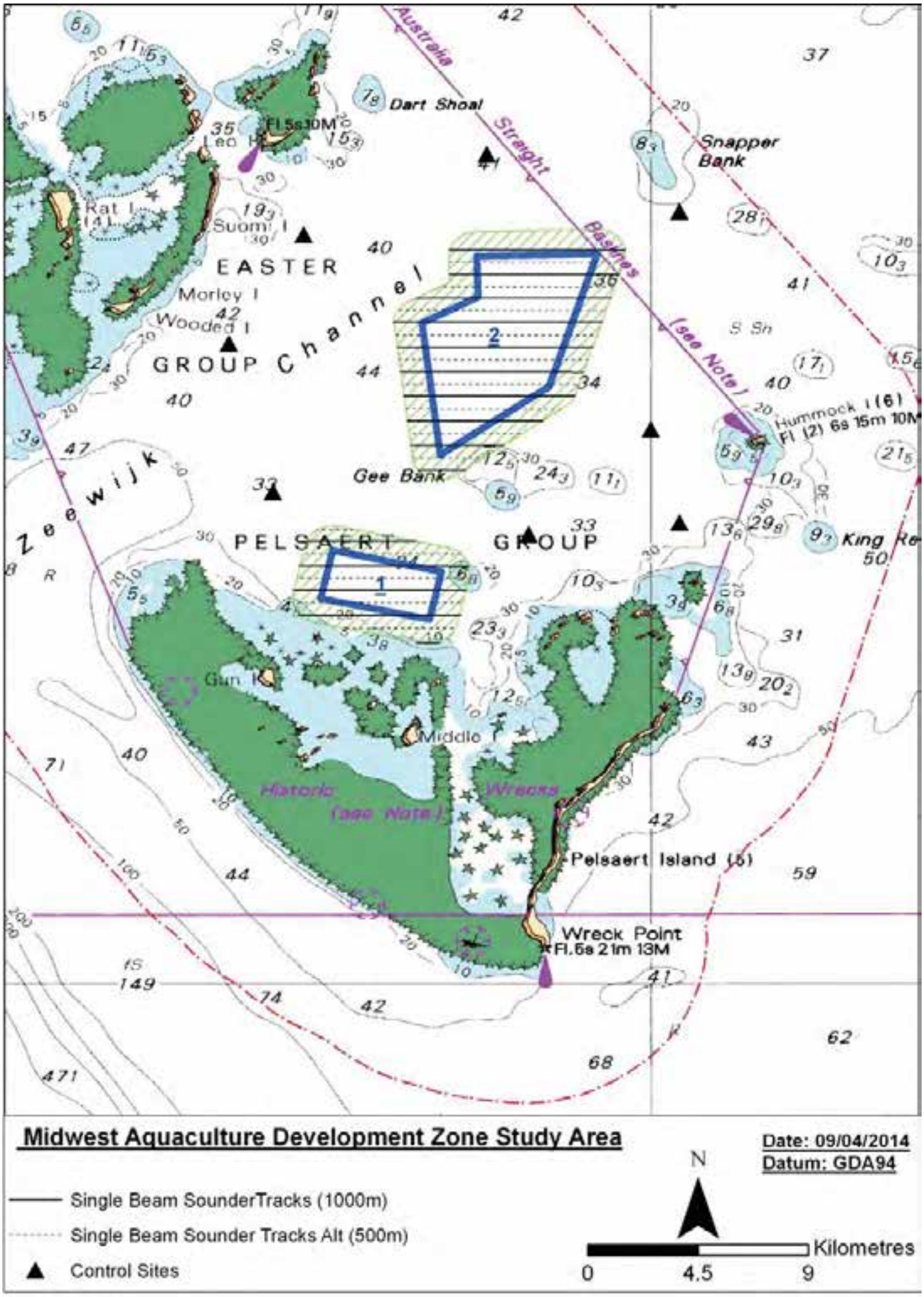


Figure 7 Location of hydroacoustic surveys. Solid lines are the first phase of data collection, and the dashed lines are the second phase. Additional hydroacoustic data will be collected in a 500 m diameter circle around each reference site (indicated by the solid triangles).

3.2.2 Sediment Quality Sampling

Sediment samples will be collected for the determination of:

- Total Phosphorus (TP)
- Total Nitrogen (TN)
- Total Organic Carbon (TOC)
- Trace Metals: Silver (Ag), Arsenic (As), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Copper (Cu), Nickel (Ni), Lead (Pb), Antinomy (Sb), Selenium (Se), Zinc (Zn), and Mercury (Hg)
- Polycyclic Aromatic Hydrocarbons (PAH) (Ultra Trace Level)
- Total Petroleum Hydrocarbons
- pH/ORP
- Particle Size Distribution
- Infauna.

Initially sediment sampling will be attempted using a modified 7kg K-B sediment corer (as per Office of the Environmental Protection Authorities methodologies). If the K-B corer does not capture suitable sediment samples (given the depth of the water column, and potential underlying reef pavement), a Petite Ponar sediment grab will be used. The 33 sites are split into clusters of 3 at 11 locations, comprised of 7 locations within the proposed lease areas and 4 reference locations outside of these zones. A map detailing the sampling layout is included in Figure 4, and Figure 5 details the frequency at which sediment sampling will be conducted. Detailed sampling requirements are outlined in Table 1.

Table 1 Sample requirements for sediment quality analyses during baseline studies of the MWADZ

Parameter	Sample required	Sample container	Preservation technique	Storage conditions	Holding time
TOC, TN, TP	1 x 70 ml	Pre-cleaned polyethylene jar	Refrigeration (freezer for extended storage)	-4°C	14 days
Metals (ICP)	1 x 70 ml	Pre-cleaned polyethylene jar	Refrigeration (freezer for extended storage)	-4°C	30 days
Particle size analysis	Minimum of half a zip-lock bag	Zip-lock bag	Refrigeration (freezer for extended storage)	-4°C	Indefinite
PAHs/TPHs	1 x 250 ml	Pre-cleaned glass jar, with teflon lid	Refrigeration (freezer for extended storage)	-4°C	14 days
Infauna	To be determined	Screw top jar	10% formalin/90% seawater	Cool and in the dark Do not freeze	Indefinite

3.3 Water Quality Sampling

In situ simultaneous measurements of the following water quality parameters will be collected using a Hydrolab Datasonde 5 multiparameter probe:

- Temperature (°C)
- pH/ORP (pH units, mV)
- Conductivity/Salinity (mS/cm, ppt)
- Dissolved Oxygen (DO) (mg/L) – measured with Luminescent DO sensor
- Turbidity (NTU)
- Depth
- Photosynthetically Active Radiation (PAR) – measured with dual PAR sensor.

With the exception of PAR, all parameters will be measured in profile, between the surface and bottom of the water column. Data for each parameter will be recorded on field datasheets as outlined in the MEMS Water Quality Sampling Standard Operational Procedure (WQ SOP).

Water samples will be collected for the determination of:

- Ammonium (NH4)
- Nitrate (NO3)
- Nitrite (NO2)
- Orthophosphorus (Ortho-P)
- Chlorophyll-a
- Total Suspend Solids (TSS), including Loss on Ignition
- Total Phosphorus (TP)
- Total Nitrogen (TN)
- Total Organic Carbon (TOC)
- Hydrogen Sulphide (H2S)
- Silica (SiO2)
- Trace Metals (Ag, As, Cd, Co, Cr, Cu, Ni, Pb, Sb, Se, Zn, Hg)
- Polycyclic Aromatic Hydrocarbons (PAH) (Ultra Trace Level)
- Total Petroleum Hydrocarbons.

Water samples will be collected using a 4.2L Van Dorn sampler deployed at a total of 27 sites within the study area. Twelve of the sites are split into clusters of 3 at 4 reference locations, while the remaining 15 sites are split between Location 1 (9 sites) and Location 2 (6 sites). A map detailing the sampling layout is included in Figure 3. Samples will be taken at two time points within each season (Figure 5), and will be collected from both the surface (0-1m) and bottom (approx. 1m from seafloor) of the water column (see MEMS WQ SOP). Each sampling effort will take approximately 1.5 to 2 days in total.

Additionally, samples will be collected for the determination of the Phytoplankton community within the two proposed MWADZ areas. Discrete samples will be taken at three depths within the water column (surface, mid and bottom). Each sample will then be preserved as detailed in Table 2, to await transportation to SydneyWater with its associated CC form for identification of the phytoplankton community to the lowest recognizable taxonomic unit and enumeration of abundance of the phytoplankton community.

Incident irradiance at the sea surface will be measured using a JFE Advantech ALW-CMP PAR logger installed in an open (no shading) area on Rat Island at the DoF research station for a period of 12 months. Data collected by the terrestrial light logger on Rat Island will be multiplied by 0.96 to estimate the intensity just below the water surface. Two identical PAR loggers will be deployed ~1 m from the bottom, within each MWDAZ development area when the ADCPs are deployed. The PAR loggers will be fixed to the deployment frame of the ADCP's, and left in situ for 1 month in each season (Figure 5).

Table 2 Sample requirements for water quality analyses during baseline studies of the MWADZ

TSS	Sample volume	1L
	Sample bottle	Polyethylene bottle
	Preservation technique	Using a pre-weighed GFC filter paper, filter the 1L sample using a Nalgene Vacuum Filter Flask. Rinse filter with at least 250mL of deionized water after filtering sample.
	Maximum sample holding time and storage conditions	1 month, frozen sample
	Reporting limit	1 mg/L
Hydrogen Sulphide (H_2S)	Sample volume	125mL
	Sample bottle	Polyethylene bottle
	Preservation technique	Completely fill sample bottle to exclude air. Preserve with Zinc acetate.
	Maximum sample holding time and storage conditions	1 week, chilled sample
	Reporting limit	1 mg/L
Dissolved Organic Carbon (DOC) **Total Organic Carbon (TOC)**	Sample volume	125mL
	Sample bottle	Polyethylene bottle
	Preservation technique	Fill sample bottle ¾ full.
	Maximum sample holding time and storage conditions	1 month, frozen sample
	Reporting limit	1 mg/L
Ammonia (NH_4) **Nitrate (NO_3)** **Nitrite (NO_2)**	Sample volume	125mL
	Sample bottle	Polyethylene bottle
	Preservation technique	Filter sample through 0.45µm filter. Fill sample bottle ¾ full.

	Maximum sample holding time and storage conditions	1 month, frozen sample
	Reporting limit	0.01 mg/L (NH_4, NO_3), 0.02 mg/L (NO_2)
Total Nitrogen (TN) **Total Phosphorus (TP)**	Sample volume	125mL
	Sample bottle	Polyethylene bottle
	Preservation technique	Fill sample bottle ¾ full.
	Maximum sample holding time and storage conditions	1 month, frozen sample
	Reporting limit	0.005 mg/L (TP), 0.01 mg/L (TN)
Chlorophyll-a	Sample volume	1L
	Sample bottle	Polyethylene bottle
	Preservation technique	Using a pre-weighed GFC filter paper, filter the 1L sample using a Nalgene Vacuum Filter Flask.
	Maximum sample holding time and storage conditions	1 month, frozen sample
	Reporting limit	0.001 mg/L
Trace Metals (Ag, As, Cd, Co, Cr, Cu, Ni, Pb, Sb, Se, Zn, Hg)	Sample volume	250mL (250mL for Hg)
	Sample bottle	Acid washed Polyethylene bottle Hg – Glass jar with Teflon lid
	Preservation technique	Filter sample through 0.45µm filter. Fill sample bottle ¾ full.
	Maximum sample holding time and storage conditions	1 month, chilled sample 6 months, frozen sample
	Reporting limit	0.001 (Ag, As, Cd, Co, Cu, Pb, Se, Sb); 0.005 (Cr); 0.01 (Ni, Zn); and 0.0001 (Hg) mg/L
Polycyclic Aromatic Hydrocarbons (PAH) (Ultra Trace)	Sample volume	1L
	Sample bottle	Polyethylene bottle
	Preservation technique	None
	Maximum sample holding time and storage conditions	14 days, chill sample and keep in dark
	Reporting limit	0.001 µg/L
Total Petroleum Hydrocarbons	Sample volume	1L
	Sample bottle	Polyethylene bottle
	Preservation technique	None
	Maximum sample holding time and storage conditions	14 days, chill sample and keep in dark
	Reporting limit	0.001 µg/L
Phytoplankton Community	Sample volume	250mL

Composition	Sample bottle	Polyethylene bottle
	Preservation technique	Add Lugols solution to final concentration of 1% (2.5mL of Logols stock solution)
	Maximum sample holding time and storage conditions	1 month, chilled sample and kept in dark

4 Modelling Methodology

4.1 Overview

The proposed modelling framework is comprised of three primary components: hydrodynamics, sediments and water quality. Each component will be dynamically linked to ensure a consistent and flexible approach. The broad methodology is as follows:

(1) Develop and calibrate a hydrodynamic model of the region, with mesh resolution focussed on the proposed lease areas.

(2) Using the hydrodynamic model, a wave model and a suitable sediment transport model, simulate the transport of particles arising from aquaculture activities (e.g. food pellets, faecal pellets) to produce a map of deposition rates within the region.

(3) Develop and calibrate a sediment diagenesis model, to simulate the biogeochemical fate of organic matter (e.g. food and faecal matter) once it is deposited on the seabed.

(4) Based on the sediment deposition maps produced in (2) above, simulate a range of deposition scenarios using the standalone sediment diagenesis model developed in (3). Timescales of sediment recovery based on deposition rates would then be calculated to satisfy regulatory requirements.

(5) Develop and calibrate a water quality model of the region, linked with the sediment diagenesis model, to quantify the feedback of sediment processes to water column biogeochemistry.

(6) Run the dynamically linked hydrodynamic, water quality and sediment diagenesis model under a range of scenarios. The exact suite of scenarios to be run is yet to be decided.

Details of each of the proposed modelling components are included below.

4.2 Hydrodynamic Modelling

We propose to use our in-house-developed hydrodynamic modelling engine TUFLOW FV (http://www.tuflow.com/Tuflow%20FV.aspx). TUFLOW FV is a powerful hydrodynamic model engine that solves the Non-Linear Shallow Water Equations (NLSWE) on a 'flexible' (unstructured) mesh comprising triangular and quadrilateral cells. The mesh is not limited to square or rectangular grid arrangements, a feature which we believe will be critical to the successful execution of this study. This unstructured mesh approach has significant benefits when applied to study areas involving complex bathymetric features, flow paths, and hydrodynamic processes, and varying areas of interest, such as this study. A preliminary mesh for the hydrodynamic model has been included in Figure 8 below. The finite volume (as opposed to finite difference (fixed grid) and finite element) numerical scheme is also capable of simulating the advection and dispersion of multiple scalar constituents within the model domain. TUFLOW FV is configured to solve the NLSWE in 2D (vertically averaged) and 3D with the ability to employ both first-order and second-order numerical solution schemes. The model can be run in both 2D vertically-averaged mode and fully 3D by specifying a vertical layer structure. Importantly, the TUFLOW FV engine leverages the parallel processing capabilities of modern computer workstations, using the OpenMP implementation of shared memory parallelism, such that computation capability can be used to its maximum potential.

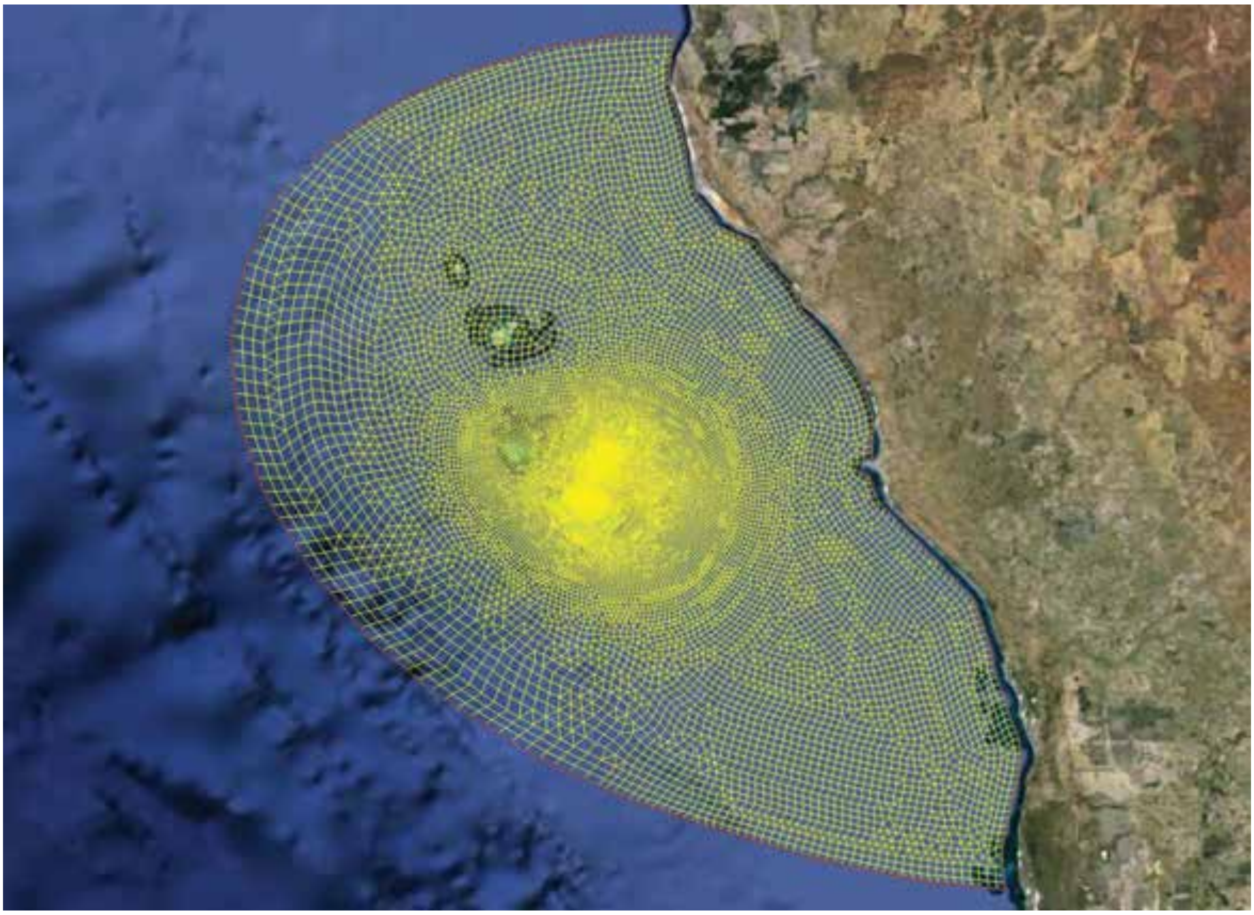


Figure 8 Preliminary TUFLOW FV hydrodynamic model mesh

When run in 3D mode (as will be the case for the Abrolhos Islands study), TUFLOW FV has the ability to simulate temperature, salinity and density stratification in order to fully resolve baroclinic (density) driven processes. Intimately linked with this ability is TUFLOW FV's capability to accept and respond to spatially variable high temporal resolution atmospheric forcing data from global circulation models (including air temperature, relative humidity, long- and short-wave radiation and wind speed and direction) to fully simulate atmospheric heat-exchange processes as required. To do this, a number of forcing datasets are required by TUFLOW FV as initial and boundary conditions, and a bathymetry dataset is required to inform model geometry. The datasets we propose to use are as follows:

- For bathymetry, a digital elevation model will be developed using a variety of sources including the 250m Geosciences Australia bathymetry dataset for regional bathymetry and a dataset of the Abrolhos Islands themselves provided by the Western Australian Department of Transport. Measurements taken by ships of opportunity, including those deploying and retrieving equipment as part of this study, will also be used.
- Tidal boundary conditions will be provided by the TPXO71 global tide model (https://www.esr.org/polar_tide_models/Model_TPXO71.html).
- Regional currents (e.g. Leeuwin Current), residual water levels, temperature and salinity boundary conditions will be provide by the global climate model HYCOM (https://hycom.org/). HYCOM is a data-assimilation model which we have used in several coastal studies of this type.

- Meteorological data will be provided by NCEP (National Centers for Environmental Protection) meteorological models; specifically the NCEP Reanalysis II model and the NCEP Climate Forecast System Reanalysis (CFSR) model. Both are global data-assimilation models which provide the full suite of meteorological data required by TUFLOW FV, namely: air temperature, rainfall, relative humidity, downward short-wave and long-wave radiation, windspeed and wind direction.
- To resolve potential wave-driven currents plus wave-induced drift and to capture suspension/deposition dynamics driven by waves, a wave field will be applied to TUFLOW FV using the model SWAN. SWAN is a third-generation wave model, developed at Delft University of Technology, which computes random, short-crested wind-generated waves in coastal regions and inland waters. In addition to wind data provided by the meteorological datasets above, SWAN also requires swell to be provided on the boundaries. This will be sourced from WAVEWATCH III, which is a global wave prediction model developed by the National Oceanic and Atmospheric Administration (NOAA).

It is possible that some datasets may not be available for the timeframe required. For example, the NOAA and NCEP datasets can have a lag time of several months. If this is the case, then appropriate alternatives will be sourced (e.g. ECMWF [European Centre for Medium-range Weather Forecasting] products) or, failing this, a climatology will be produced based on previous years' data.

Specification of the oceanic boundary, in particular, is expected to be a critical component of a skilful hydrodynamic model of the study area. As noted above, BMT WBM proposes to specify temperature, salinity and regional currents using the HYCOM model, and water-levels using a mix of TOPEX (for tidal dynamics) and HYCOM (for the non-tidal components). These hydrodynamic boundaries will be specified using an active Flather condition (as derived from Flather *et al.,* 1976) which relaxes the barotropic (depth-averaged) component to ensure that the model remains internally consistent.

The horizontal spatial resolution of the unstructured TUFLOW FV model mesh will range from approximately 3.5 km at the offshore boundary down to approximately 200m within the area of interest. Vertical resolution will comprise of approximately 37 fixed-level z layers and 2 surface, variable-level sigma layers, for a total of up to 39 vertical levels with resolution increasing near the surface to approximately 1m. This model resolution will allow the model to capture all important hydrodynamic processes within the area of interest, while still remaining computationally efficient. It is noted that sediment deposition and water quality impacts arising from the aquaculture cages will need to be resolved to smaller spatial scales than 200m. Aquaculture cages will be approximately 38m in diameter and so sediment deposition in particular will need to resolve scales of approximately 5-10m. This will be achieved through Lagrangian particle tracking which is effectively grid-less and will allow for the creation of deposition maps to the required resolution (see Section 4.3 for details). The water quality model is not run in a Lagrangian framework, so to investigate the feedback of biogeochemical fluxes from the sediment into the water column BMT WBM propose to use the 200 m hydrodynamic model for water quality calibration purposes and switch to a higher-resolution model (approximately 50m) for running scenarios with the aquaculture cages in place. If the computational cost is not excessive, the higher-resolution model may also incorporate increased vertical resolution near the sea-bed to more accurately capture the impact of benthic processes on the overlying water column. Full details of the water quality model are included in Section 4.4.

4.3 Sediment Modelling

It is expected that aquaculture activities will result in the deposition of particulate organic matter on the seabed, particularly in the form of faecal pellets and food wastage. To track the transport and deposition/resuspension of these organic particles, particle tracking algorithms will be added to the TUFLOW FV software. The particle tracking capability will simulate a range of particle sizes and material types, and will incorporate processes such as the break-down of organic particles as they pass through the water column. It will also be based on the Lagrangian framework so that the results are not confined to the spatial grid within the hydrodynamic model. In this manner, the fine-grained spatial resolution required by the sediment model can be achieved. Stochastic behaviour and resuspension will also be applied, using the techniques described in Cromey *et al*. 2002, to provide a range of results for a given hydrodynamic and particle-generation scenario. Once completed, the particle tracking results will be used to draw up a series of maps of various deposition scenarios, which in turn will be used as inputs to the sediment diagenesis model. Parameters for relevant processes (e.g. the physical properties of particles) will be sourced from the scientific literature.

The sediment diagenesis model code was developed at UWA by A/Prof Hipsey's research group, which is an extended version of the widely used original version created by Boudreau (1996). The UWA version extends the original version by including improvements for organic matter dynamics (e.g. dissolved organic matter fractions – of interest to the current study), metals and geochemical conditions. It has been validated within Cockburn Sound (Read 2008) and within the Swan Estuary (Paraska et al. 2011, Norlem et al. 2013).

The model simulates different components of organic matter and how they breakdown under varying concentrations of oxidants and other species. Reactions include the hydrolysis of the complex (e.g. high molecular weight) OM pools (POMV R, POMR, DOMR, POML) and transformation of Low Molecular Weight (LMW) dissolved OM by oxidants (O2, MnO2, Fe (III) and SO42- – the so-called 'terminal metabolism'), and the release of resulting nutrients (NO3−, NH4+, PO43-) and reduced by-products (Mn2+, Fe2+, N2, H2S, CH4) and CO2. Oxidants, nutrients, metals and by-products are all capable of interacting, for example through complexation or re-oxidation of reduced species. The model predicts the long-term burial of carbon and other particulates through loss terms, and the benthic flux of all dissolved constituents.

Initial conditions of the sediment diagenesis model will be derived from samples taken as part of habitat mapping exercises and literature values, as appropriate. Boundary conditions will be derived from literature values and the deposition rates determined by the hydrodynamic/sediment transport model.

Our approach will be to calibrate the standalone sediment diagenesis model to the samples taken as part of the benthic habitat mapping exercise, and thereby develop a 'baseline' model.

Once calibrated, the sediment diagenesis model would then be run in standalone mode under a suite of deposition rates as determined by the hydrodynamic/sediment transport model described above. Running the sediment diagenesis model in this way is much less computationally expensive than dynamically linking it to the full hydrodynamic/sediment transport model, so it allows for a full spectrum of deposition scenarios to be examined, and for run periods to extend to 10-15 years and longer if required. By taking this approach, both the impact period (when aquaculture activities are taking place) and the recovery period following cessation of activities (a parameter used to determine the level of impact) can be simulated for multiple years.

Results from the standalone model will then be used to map zones of impact, which will then be applied to the full hydrodynamic/water quality model (described below) to analyse potential impacts of aquaculture activities on both benthic habitats and the overlying water column. The sediment diagenesis model will also be dynamically linked with the hydrodynamic/water quality model at this point to ensure an ongoing interaction between chemical processes in the sediment and in the overlying water column. However, computational constraints will mean only one instance of the sediment diagenesis model will be included per mapped zone, rather than one per model grid cell. Combining the models in this manner will allow for a dynamically-calculated benthic flux to be applied to the full hydrodynamic/water quality model, while maintaining computational efficiency and the ability to run multi-year simulations.

4.4 Water Quality Modelling

We will use the Aquatic Ecodynamics (AED) model library, linked with TUFLOW FV, to simulate nutrient, sediment and algal dynamics within the water column (http://aed.see.uwa.edu.au/research/models/GLM/). AED was also developed at UWA by the research group led by A/Prof. Matt Hipsey and has been linked with TUFLOW FV and used to simulate water quality and plankton dynamics in a number of projects to date. It can simulate a number of biogeochemical pathways relevant to water quality, as illustrated by the schematic presented in Figure 9.

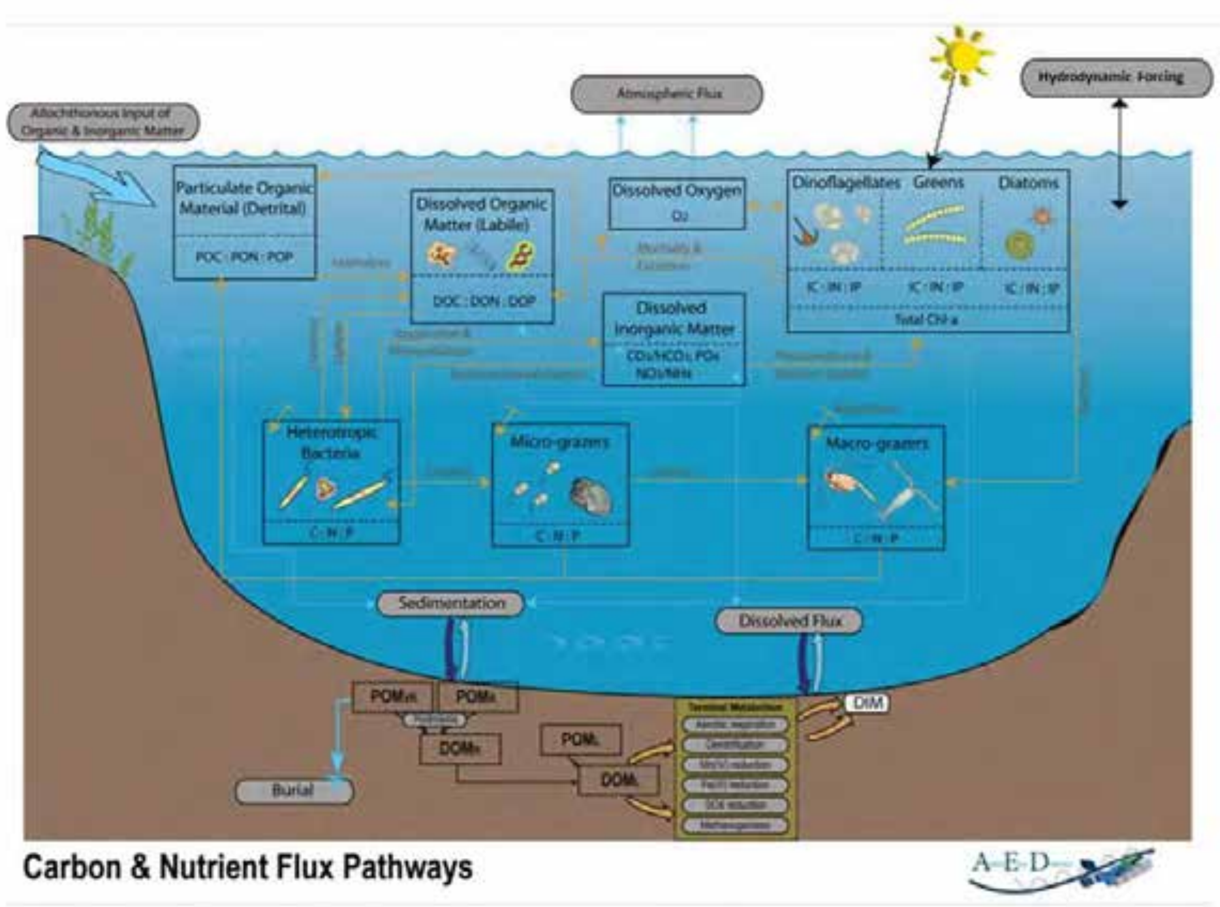


Figure 9 Carbon and nutrient processes simulated in AED

Boundary and initial conditions are required for each of the variables simulated by AED. These will be derived from a combination of:

- Water quality samples conducted as part of this study.
- The CSIRO Atlas of Regional Seas (CARS) climatology (http://www.marine.csiro.au/~dunn/cars2009/).
- Literature values, as appropriate.

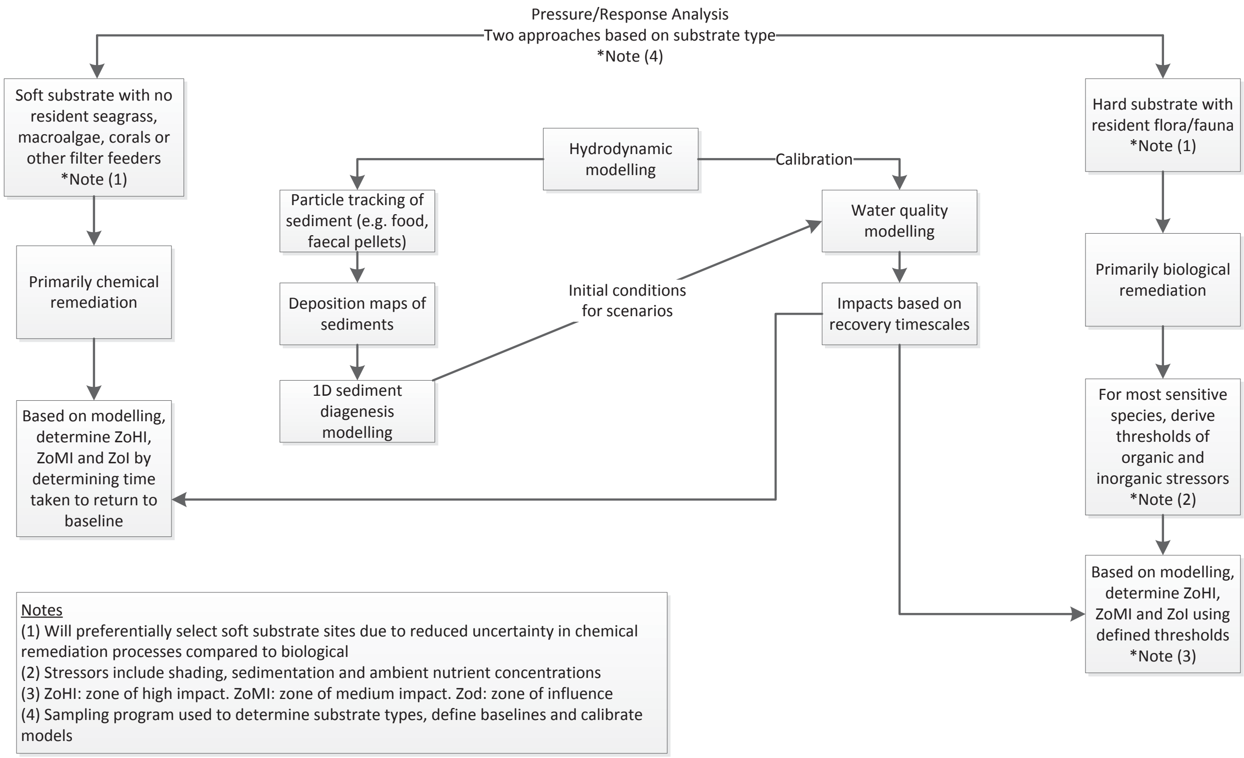
Similarly to the sediment diagenesis model, our approach will be to parameterise the water quality model using the samples taken as part of the monitoring program described above, and thereby develop a 'baseline' model. For the parameterisation exercise, the water quality model will be linked to the hydrodynamic model with 200 m spatial resolution in the vicinity of the lease areas. This will be sufficient resolution for the purposes of creating a baseline model, and it will greatly improve model runtimes and the efficiency of the calibration process. For the scenario runs, however, resolution will be increased to 50 m to capture the aquaculture-related flux of nutrients and dissolved organic matter from the benthos into the water column that will be predicted using the sediment diagenesis model described above.

Once parameterised, a suite of metrics comparing model results to water quality samples will be used to verify that the model has skill in simulating water quality dynamics. As part of this verification process, a relationship between TSS and turbidity will be derived from the sample data so that model TSS concentrations can be compared to the turbidity profiles taken during the monitoring program.

Following the verification process, the full hydrodynamic/water quality model will be run to examine the recovery period following cessation of aquaculture activities under a variety of scenarios (yet to be decided). It is expected that each scenario run will incorporate an initial period of one year where aquaculture activities are ongoing, followed by up to five years following cessation. The benthic initial conditions applied to each scenario will be derived from the standalone sediment diagenesis model described in Section 4.3, and may incorporate periods much longer than one year. By linking the standalone sediment diagenesis model and full hydrodynamic/water quality model in this way, scenario simulations can be made of multiple years of impact, followed by multiple years of recovery, which would otherwise not be possible due to the computational overhead of the full hydrodynamic/water quality model.

5 Summary

The following is a summary of the proposed overall monitoring and modelling strategy, including how model link together and deliver a series of results regarding benthic impacts to DoF (specifically ZoHI, ZoMI & ZoI) in terms of recovery timescales following removal of stressors. The schematic presents this visually, and this is supported by subsequent dot point commentary.



- The habitat remediation processes based to a large extent of the type of substrate in place:
  - Soft substrate with no benthic flora/fauna requires primarily chemical remediation processes
  - Hard substrate with corals/macroalgae/seagrass requires primarily biological remediation processes.
- Two approaches based on type of substrate:
  - Soft substrate: recovery timescales based on direct modelling of chemical processes and return to baseline conditions
  - Hard substrate: determine stressor thresholds of most sensitive species with desktop analysis then use modelling of stressor processes to determine zones of impact.
- Sampling program designed to determine baseline conditions including substrate type, sediment composition, hydrodynamic regime, etc. Also designed to provide calibration and validation data to the hydrodynamic, sediment diagenesis and water quality models.
- Hydrodynamic model developed to provide background conditions to analysis and to determine fate of organic particles (e.g. faeces, food pellets) through Lagrangian particle tracking.
- Particle deposition maps derived from hydrodynamic modelling to be used as sedimentation inputs to 1D sediment diagenesis model, and to inform sedimentation stressors for sensitive organisms as part of pressure-response analysis.
- 1D sediment diagenesis model developed and results used to define zones of impact for benthic chemistry, and to inform possible benthic stressor thresholds for sensitive organisms (biological remediation processes).

- Water quality model developed using above benthic modelling as a boundary condition and results used to define zones of impact for water-column chemistry, and to inform possible pelagic stressor thresholds for sensitive organisms (biological remediation processes).

6 References

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Flather RA. 1976. A tidal model of the northwest European continental shelf. Mem. Soc. R. Sci. Liege 10(6): 141–164.

Appendix B Additional Calibration Plots

B.1 Water levels

This section contains additional plots comparing simulated water-levels against observations. The time-series presented in Section 4.1.1 above are decomposed into calendar months and included in Section B.1.1 below, while results of the sensitivity testing of tidal boundary conditions are presented in Section B.1.2.

B.1.1 Monthly plots of long term deployments

The following plots present the same data as Figure 4-2 and Figure 4-3 but decomposed into calendar months for clarity. Statistics presented in each figure refer only to the time-series plotted and not to the entire time-series of each deployment.

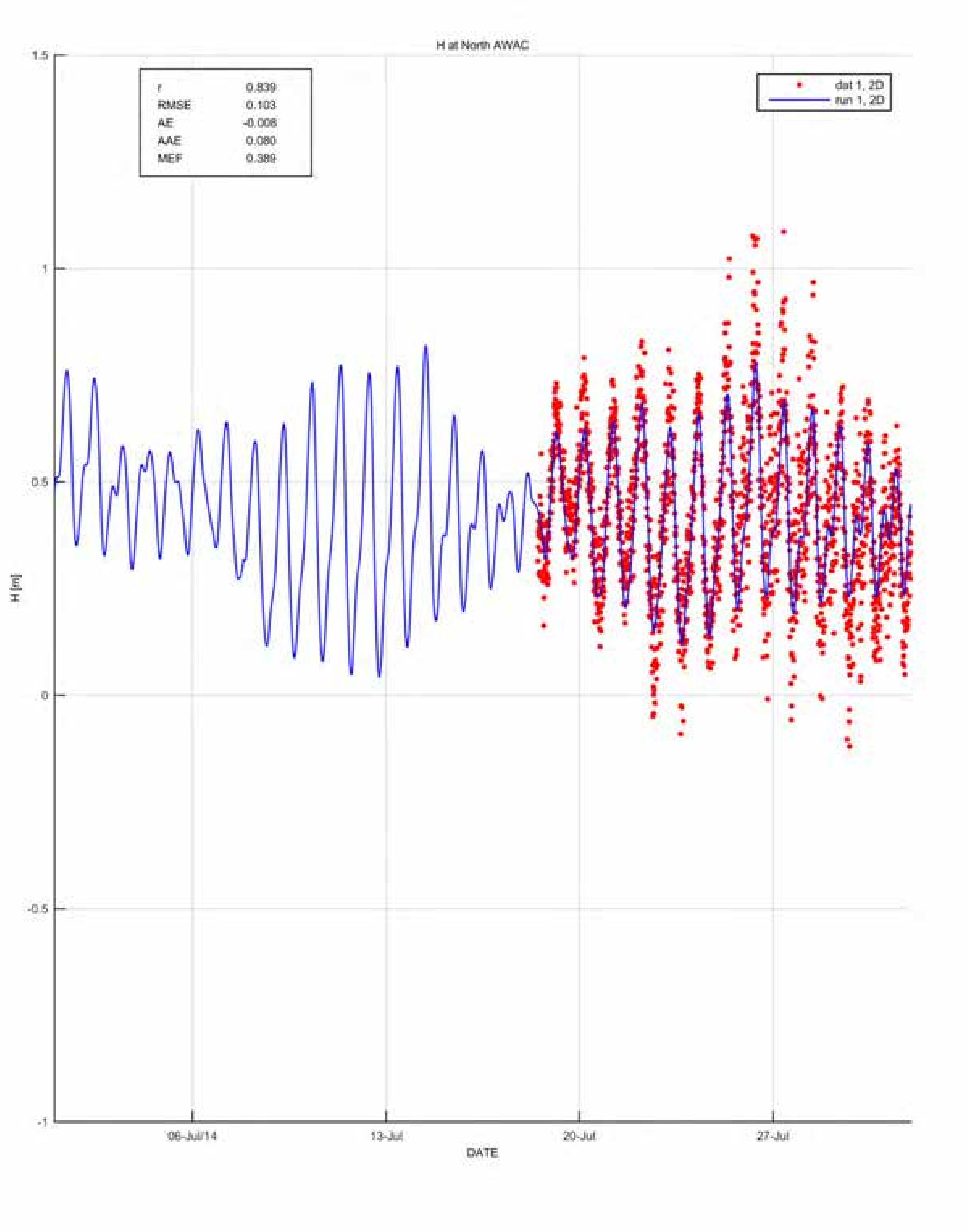

Figure B-1 Water levels at northern regional site – July 2014

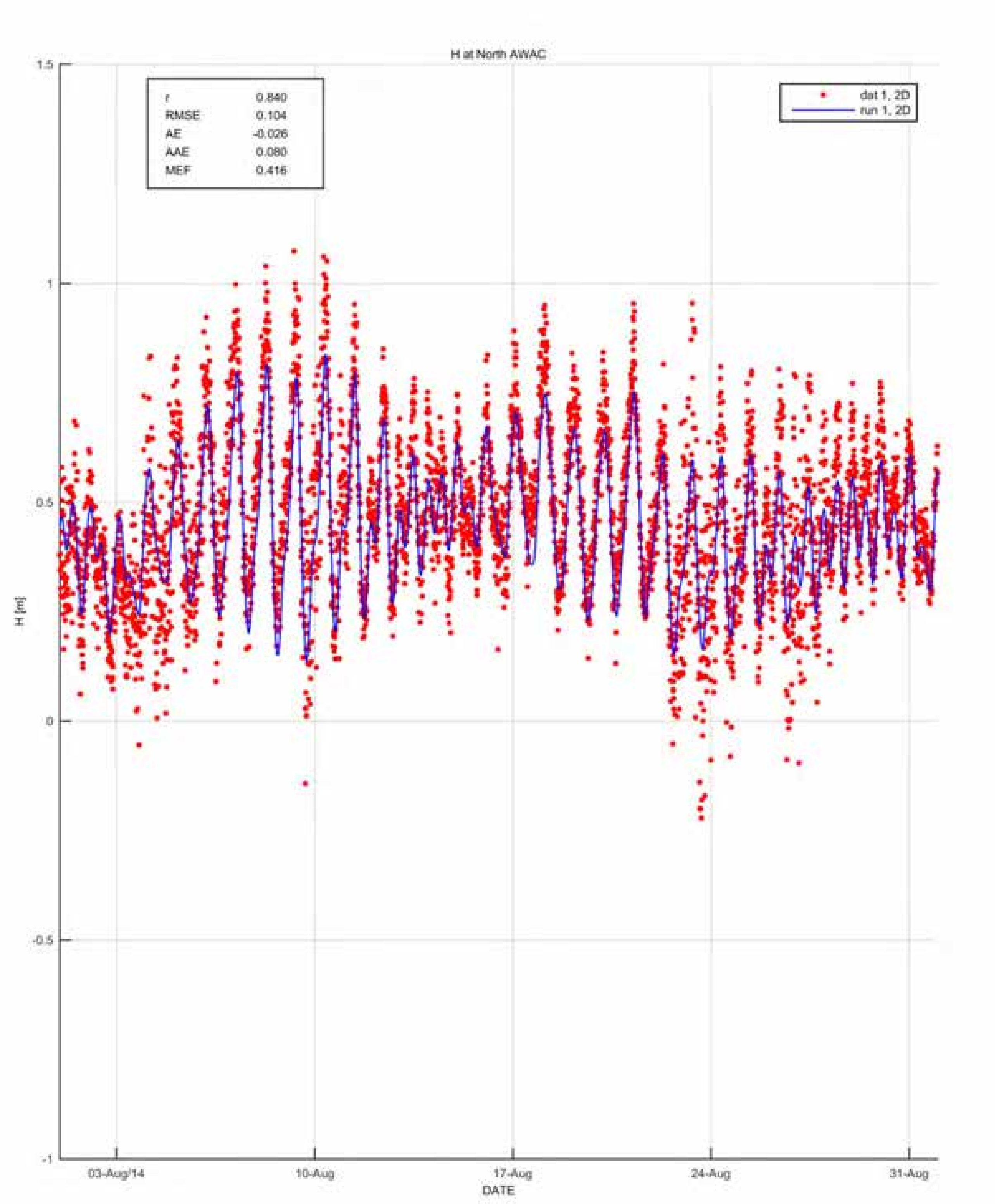

Figure B-2 Water levels at northern regional site – August 2014

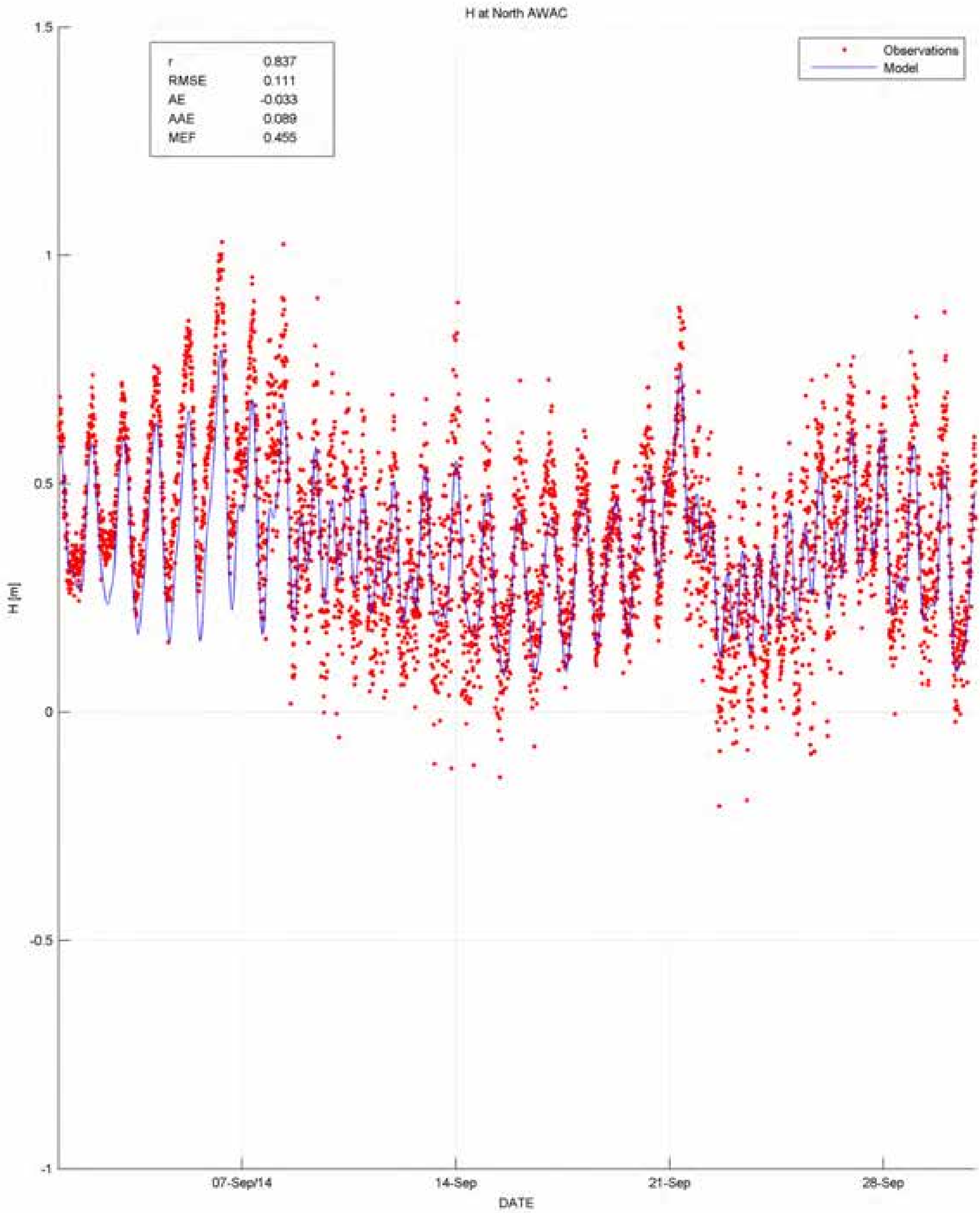

Figure B-3 Water levels at northern regional site – September 2014

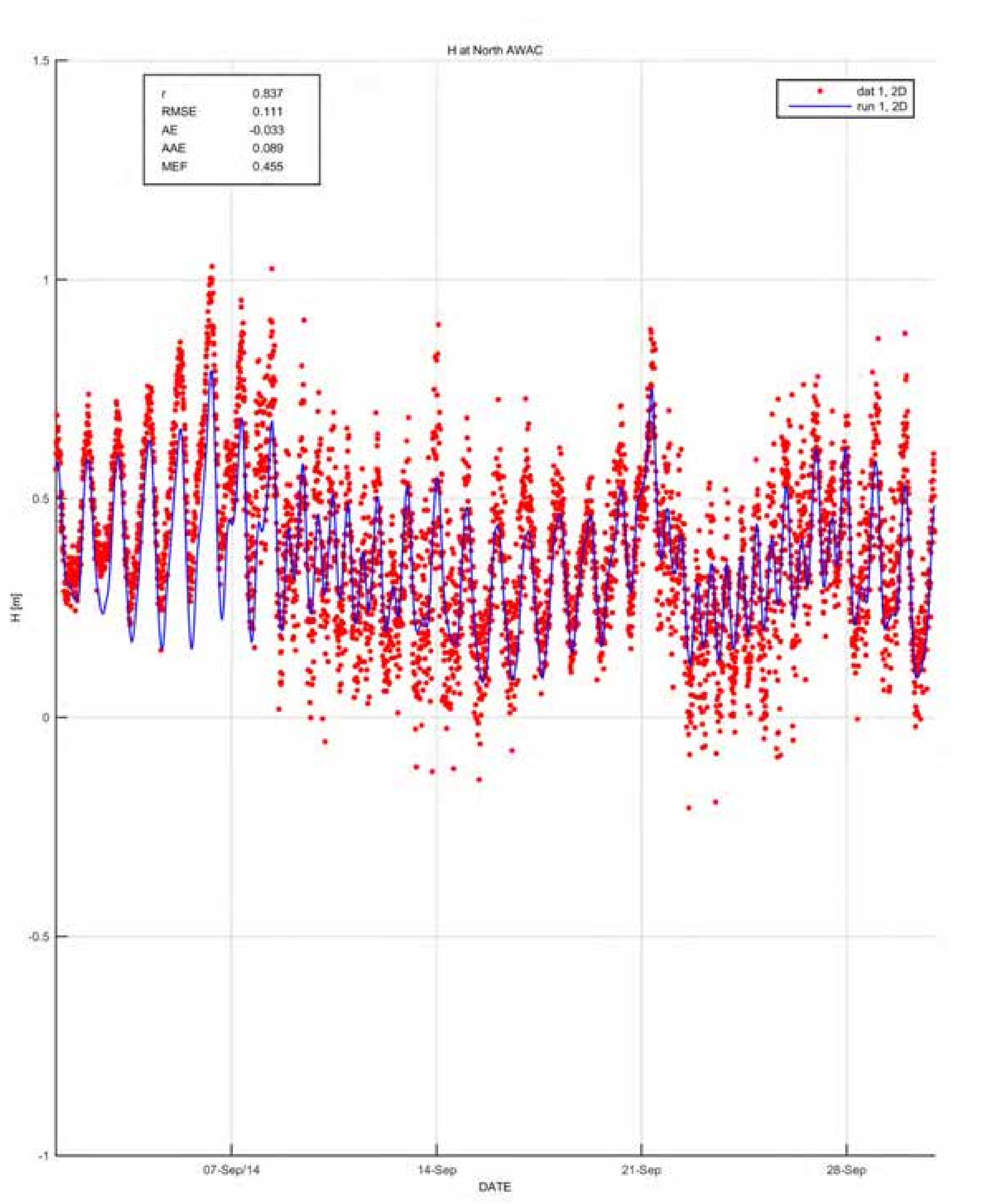

Figure B-4 Water levels at northern regional site – October 2014

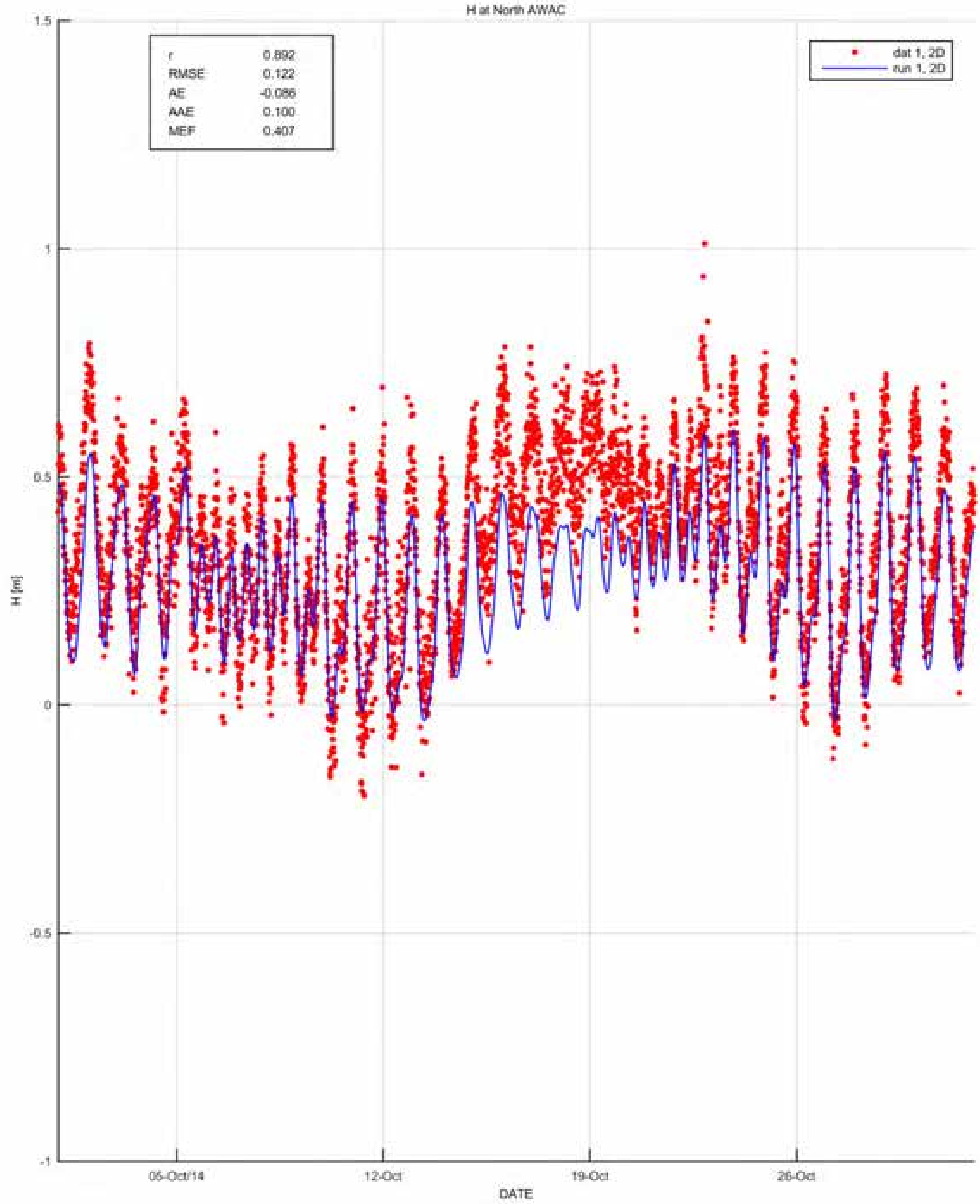

Figure B-5 Water levels at northern regional site – November 2014

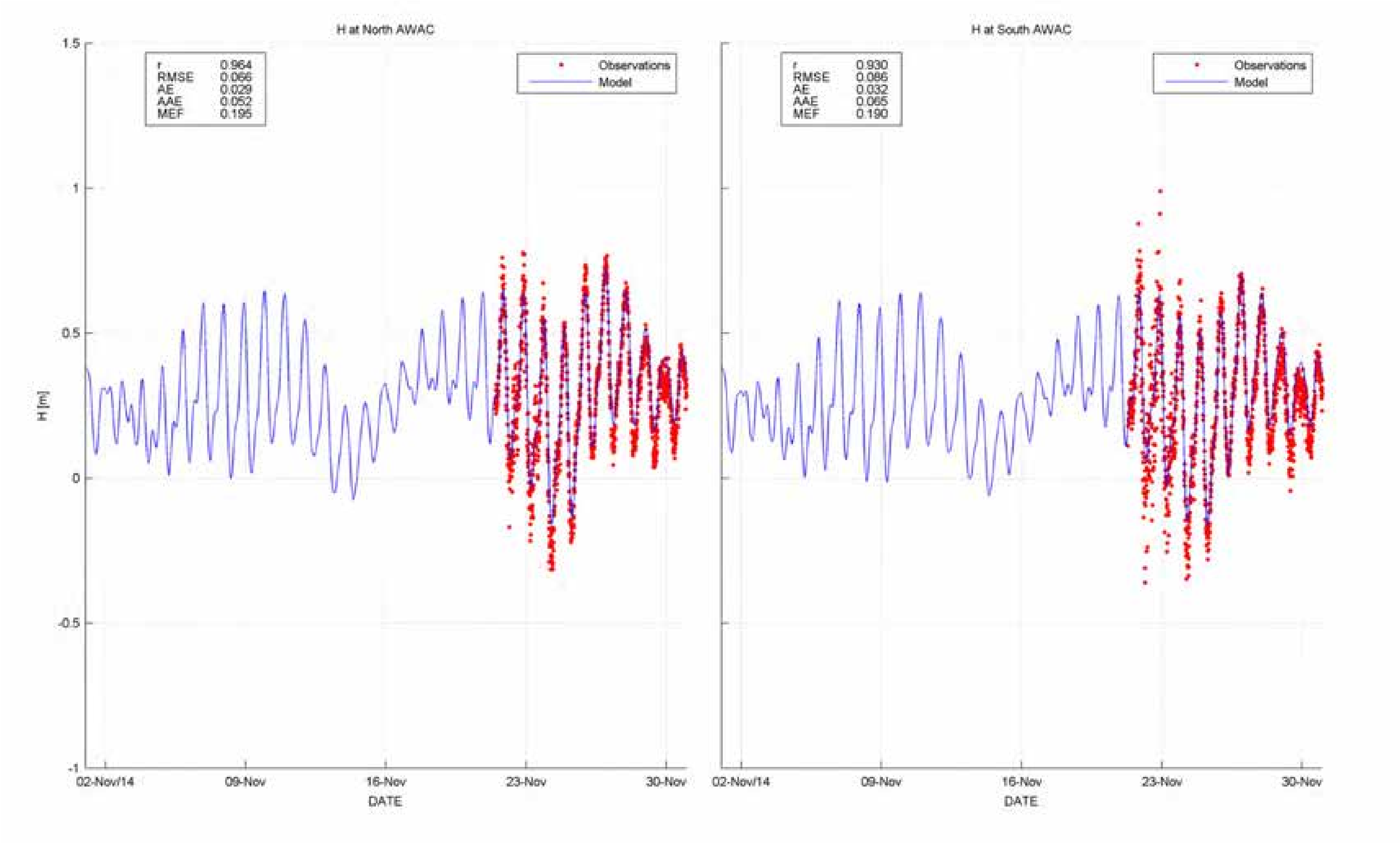

Figure B-6 Water levels at regional sites – November 2014 (second deployment)

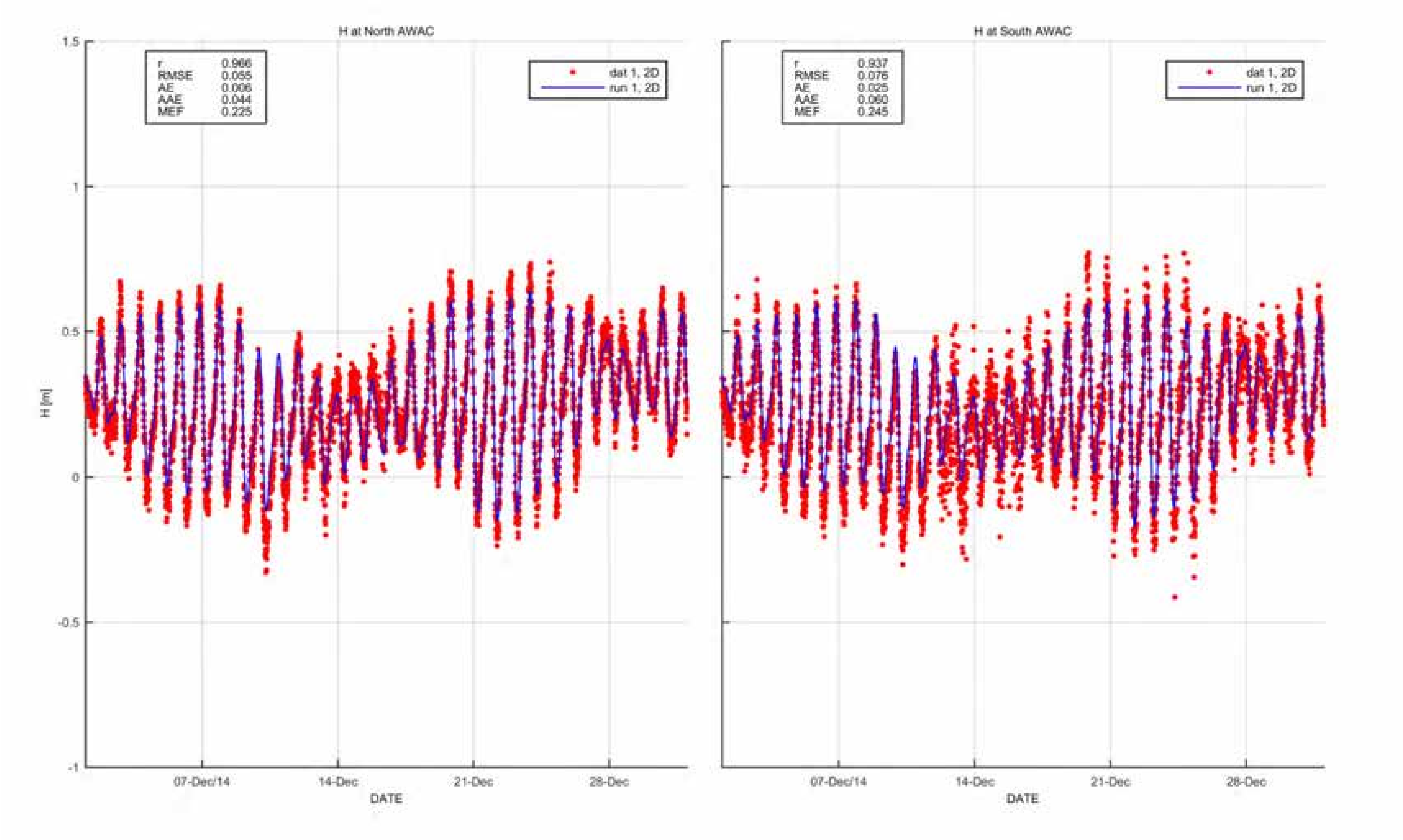

Figure B-7 Water levels at regional sites – December 2014

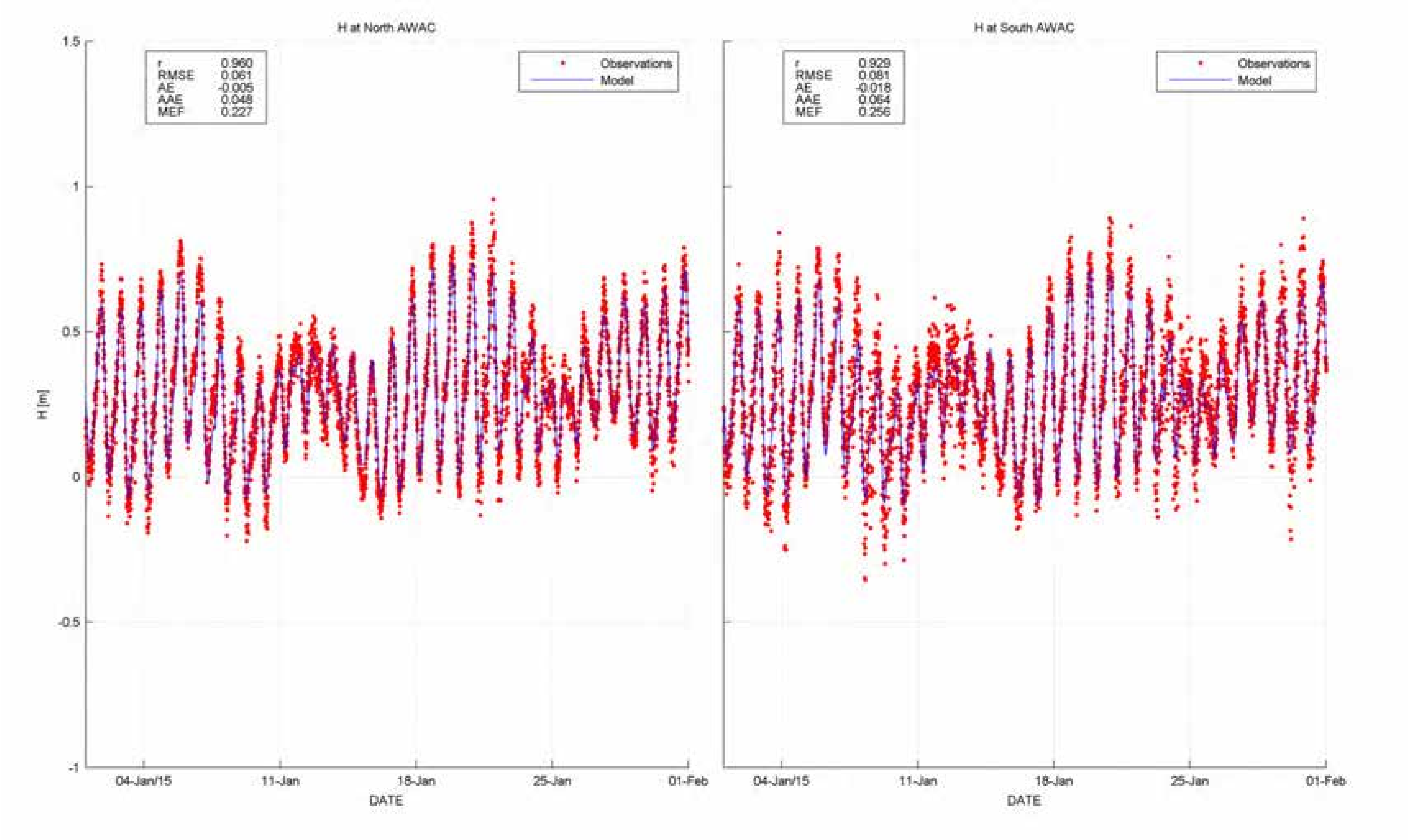

Figure B-8 Water levels at regional sites – January 2015

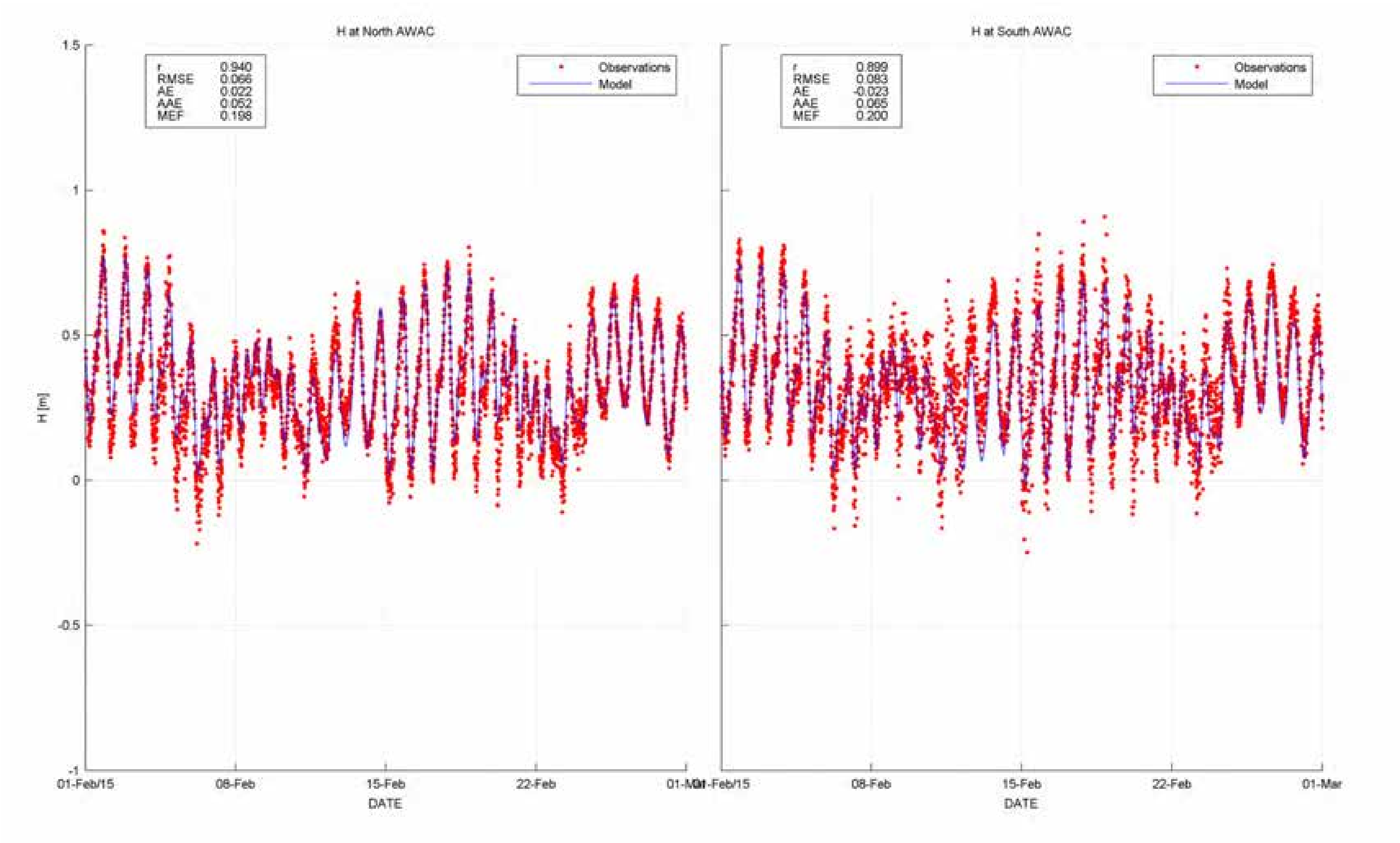

Figure B-9 Water levels at regional sites – February 2015

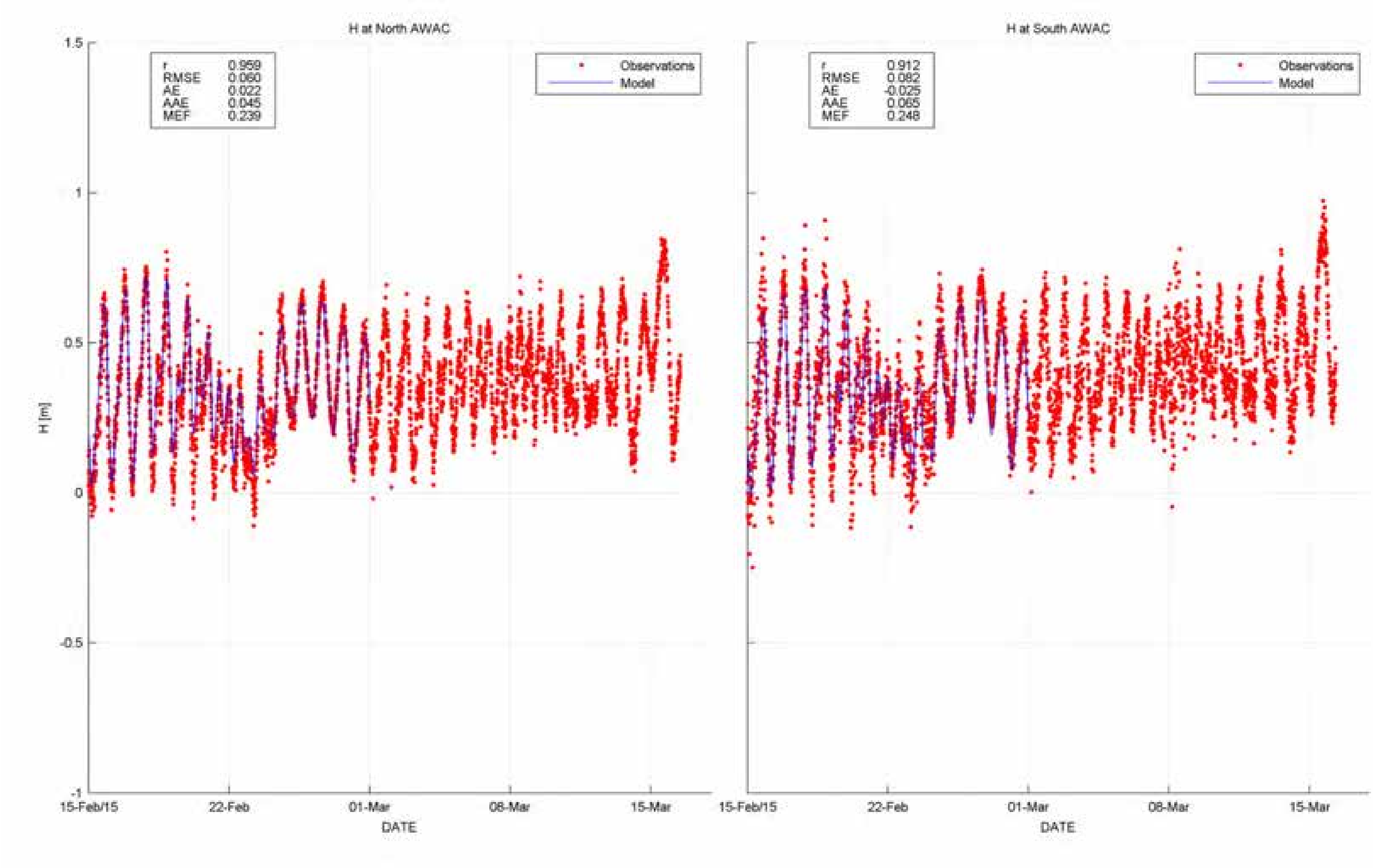

Figure B-10 Water levels at regional sites – March 2015

B.1.2 Tide forcing sensitivity testing

To attempt to overcome the under-prediction of water levels by the model, as illustrated in Figure 4-2, the tidal range at the model boundary was increased by 30%. As noted in section 4.1.1., this improved the water-level calibration at regional sites, but was detrimental to the water-level calibration at lease-area sites. Additionally, the velocity calibration at the lease-area sites was worse when the increased tidal range was applied. The figures below present model results from both the final calibration run and the sensitivity test with increased tidal range.

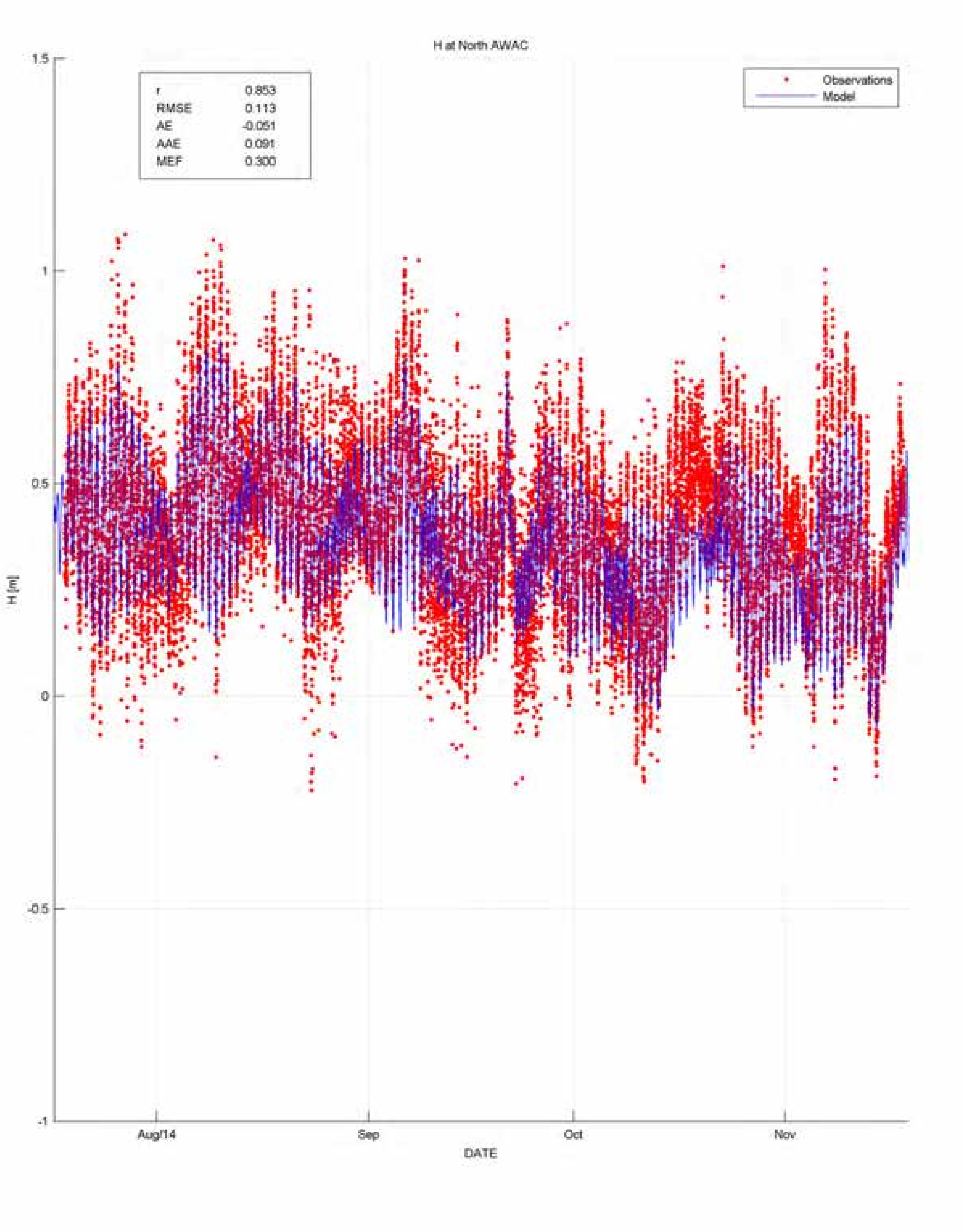

Figure B-11 Water-level comparisons at northern regional site – original tidal forcing

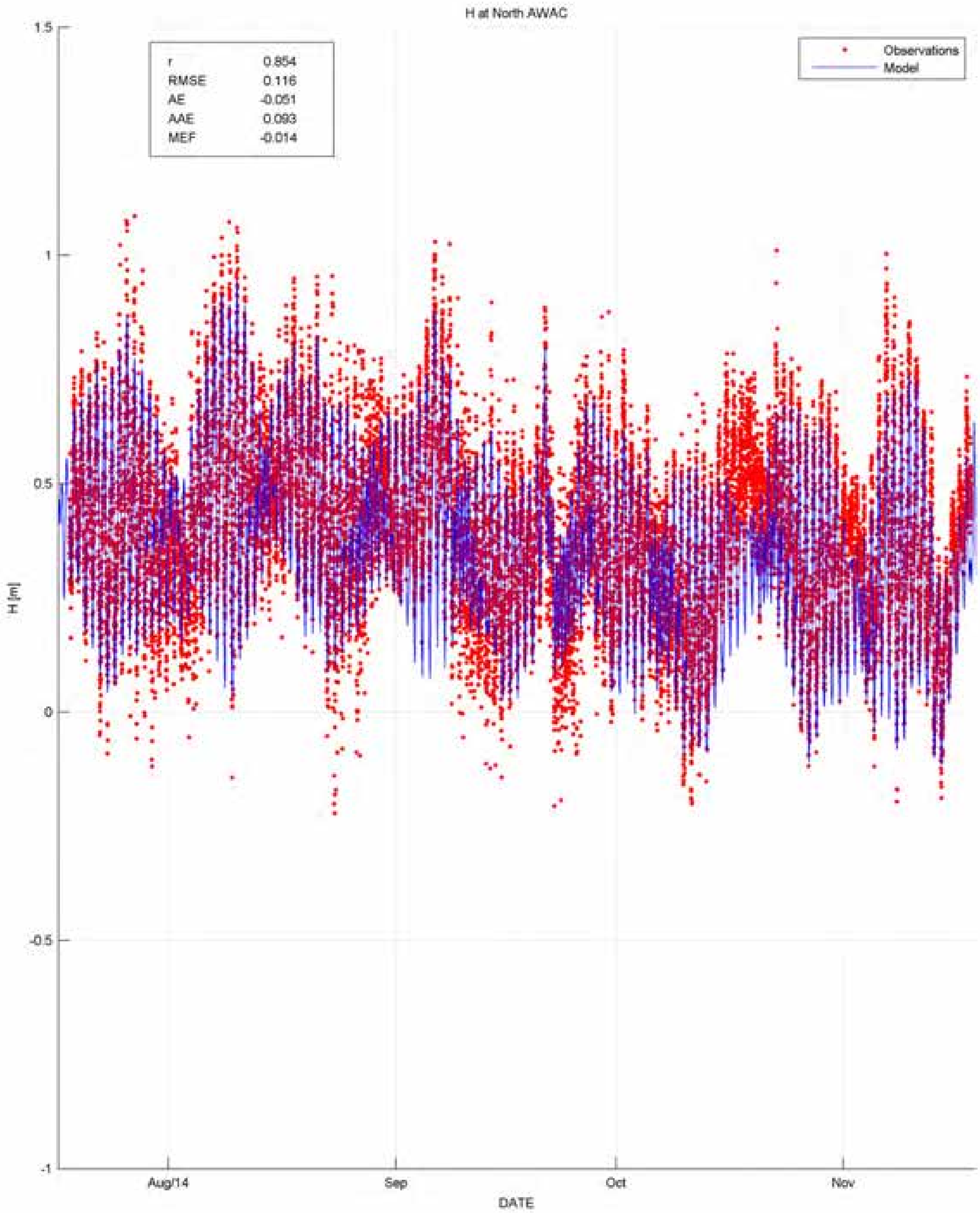

Figure B-12 Water-level comparisons at northern regional site – increased tidal range

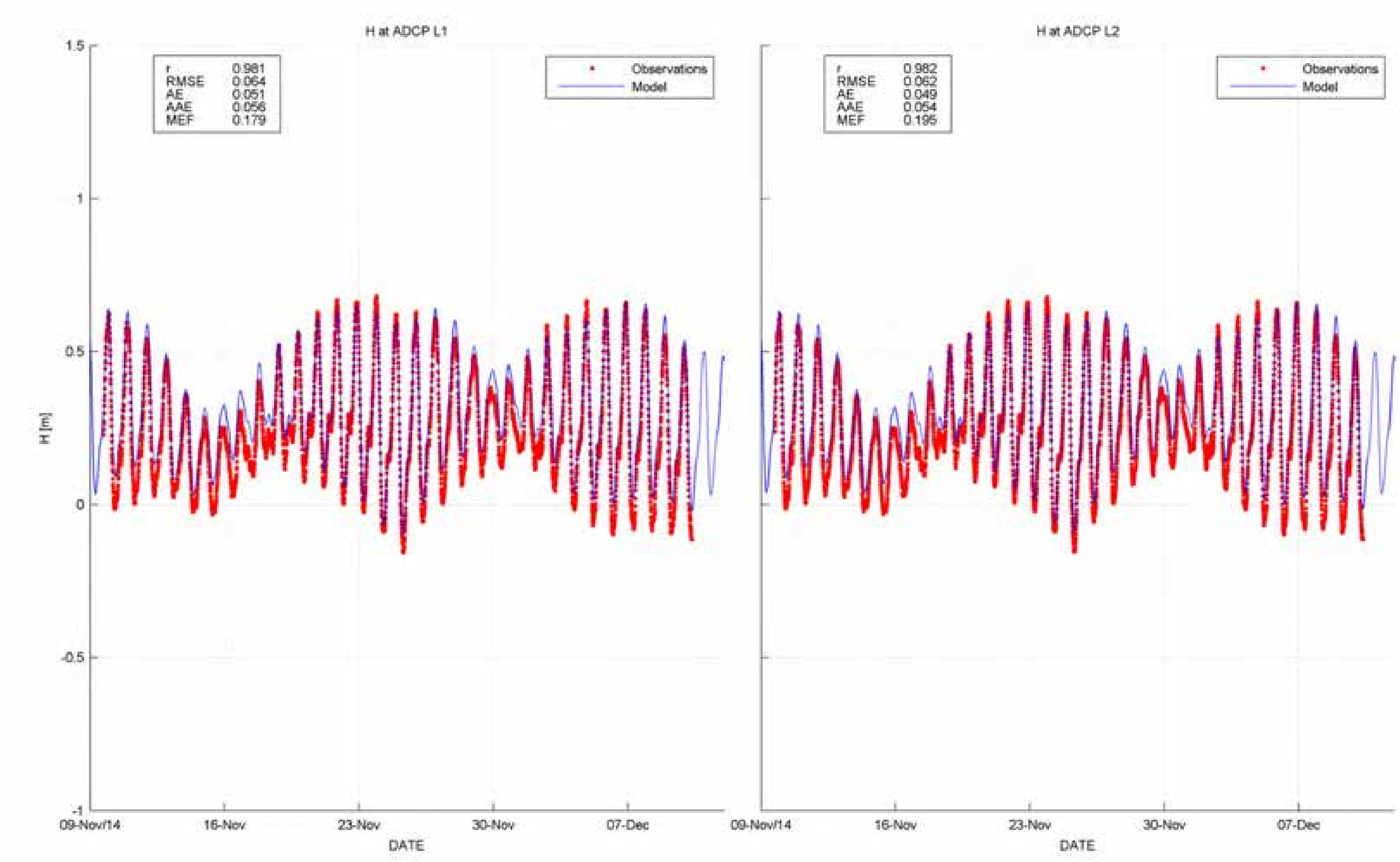

Figure B-13 Water-level comparisons at lease-area sites – original tidal forcing

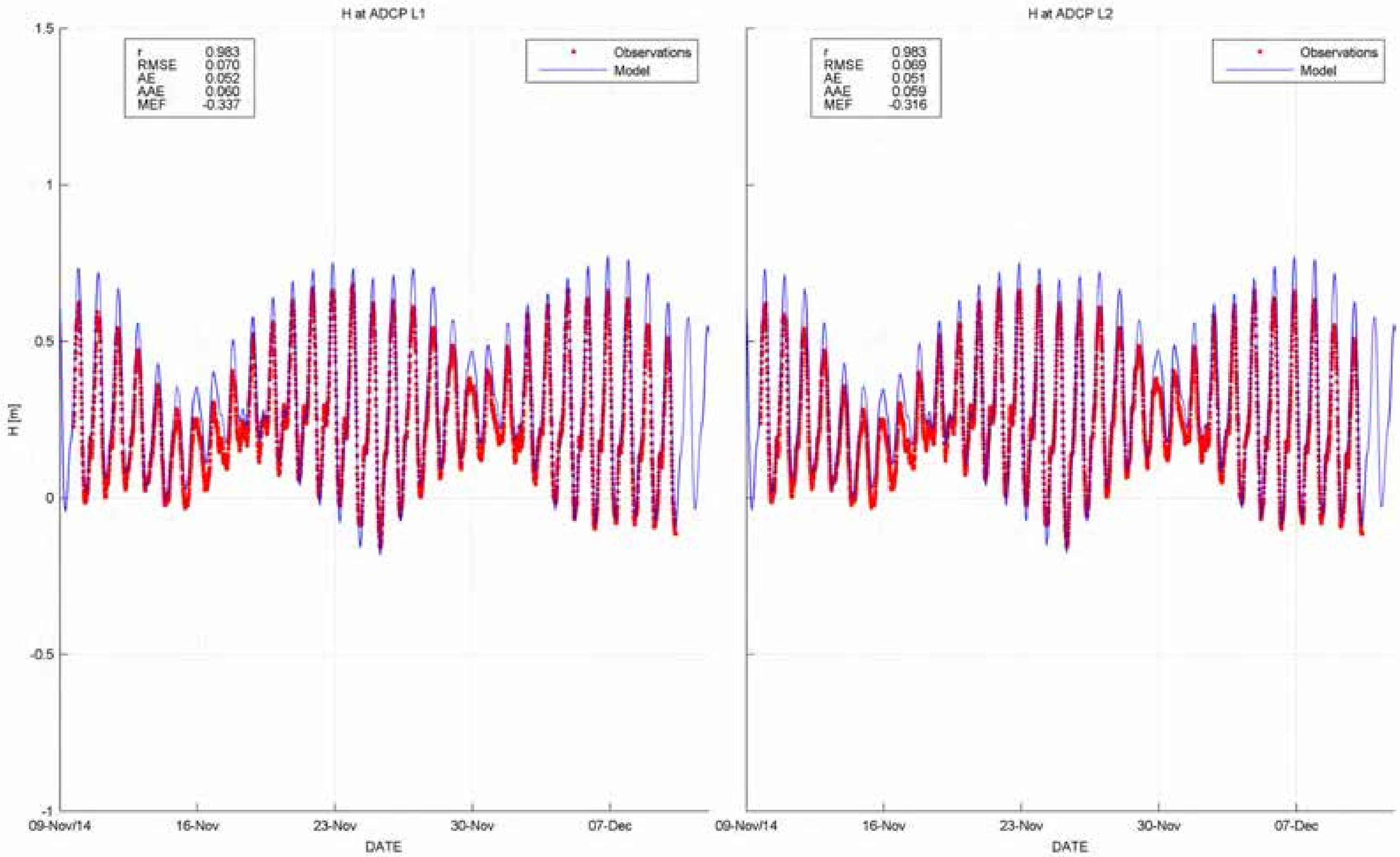

Figure B-14 Water-level comparisons at lease-area sites – increased tidal range

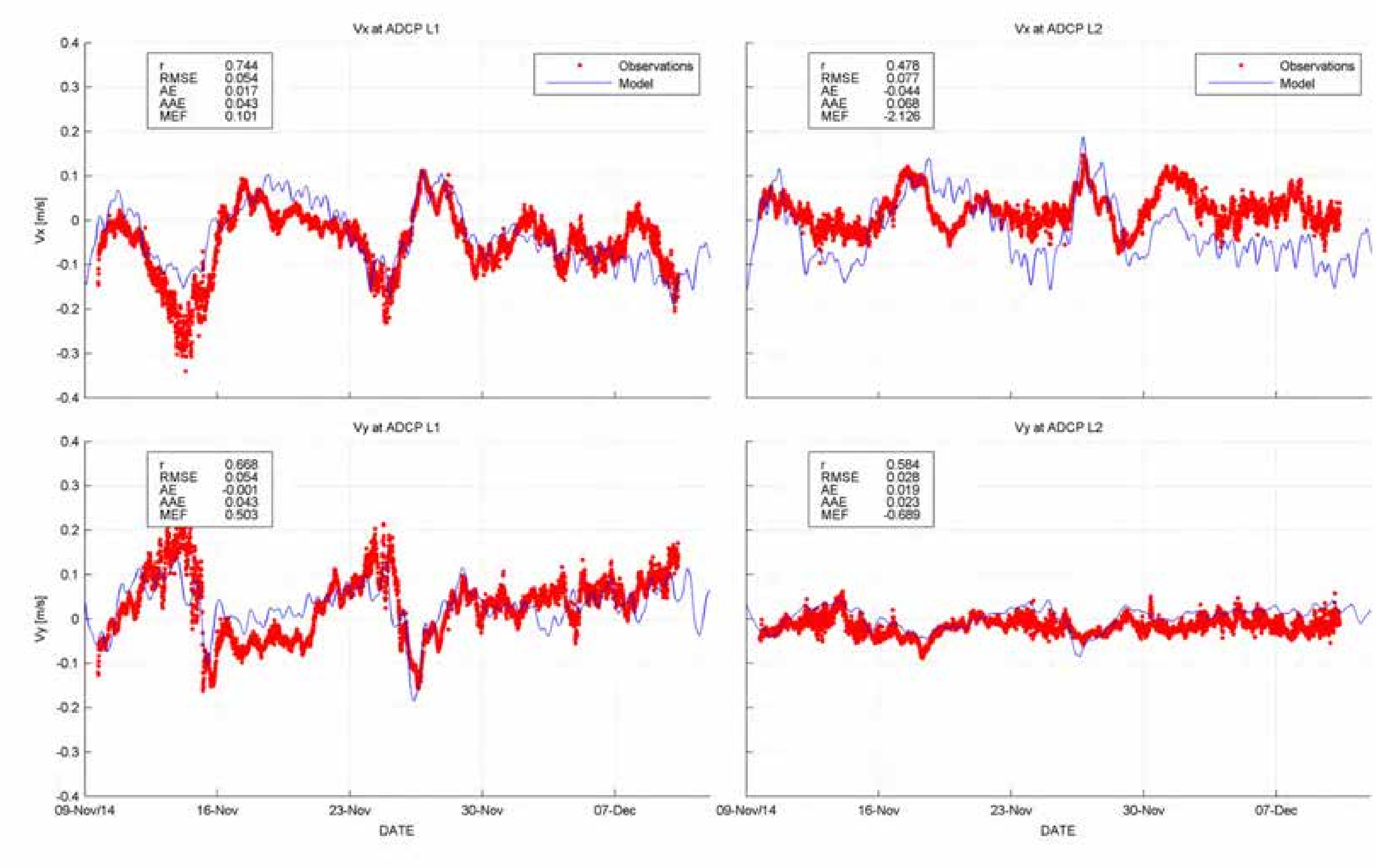

Figure B-15 Velocity comparisons at lease-area sites – original tidal forcing

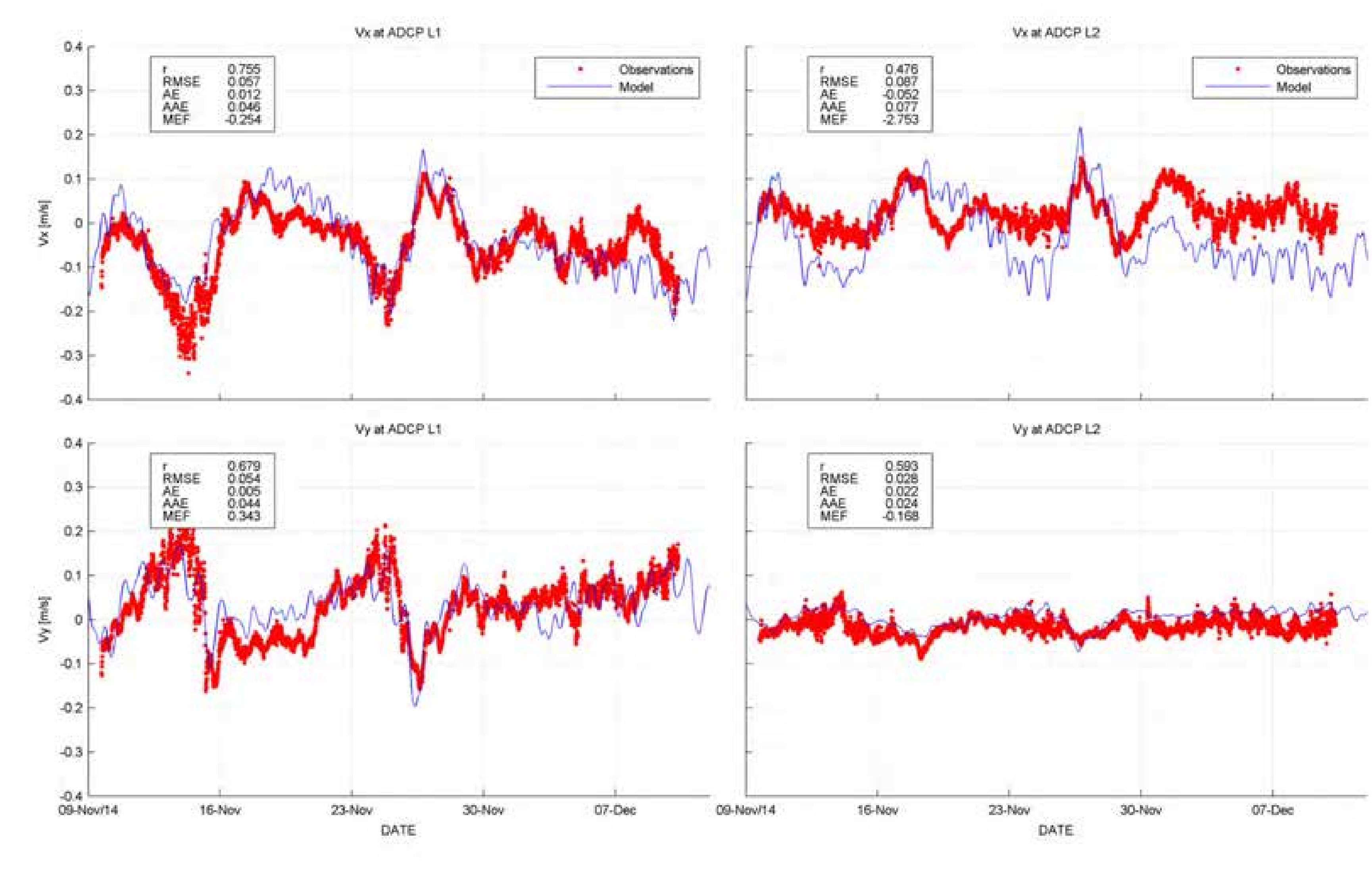

Figure B-16 Velocity comparisons at lease-area sites – increased tidal range

B.2 Velocities

Additional plots, complementing Section 4.1.2, are provided in this section. Section 4.1.2 contains a number of figures comparing simulated, depth-averaged velocities against depth-averaged observations. This section contains comparisons of surface velocities (Figure B-17 to Figure B-22) and bottom velocities (Figure B-23 to Figure B-28) at the same times and locations. The model appears to be similarly skilful for surface, bottom and depth-averaged velocities, although some of the surface variability is not reproduced, resulting in lower r values.

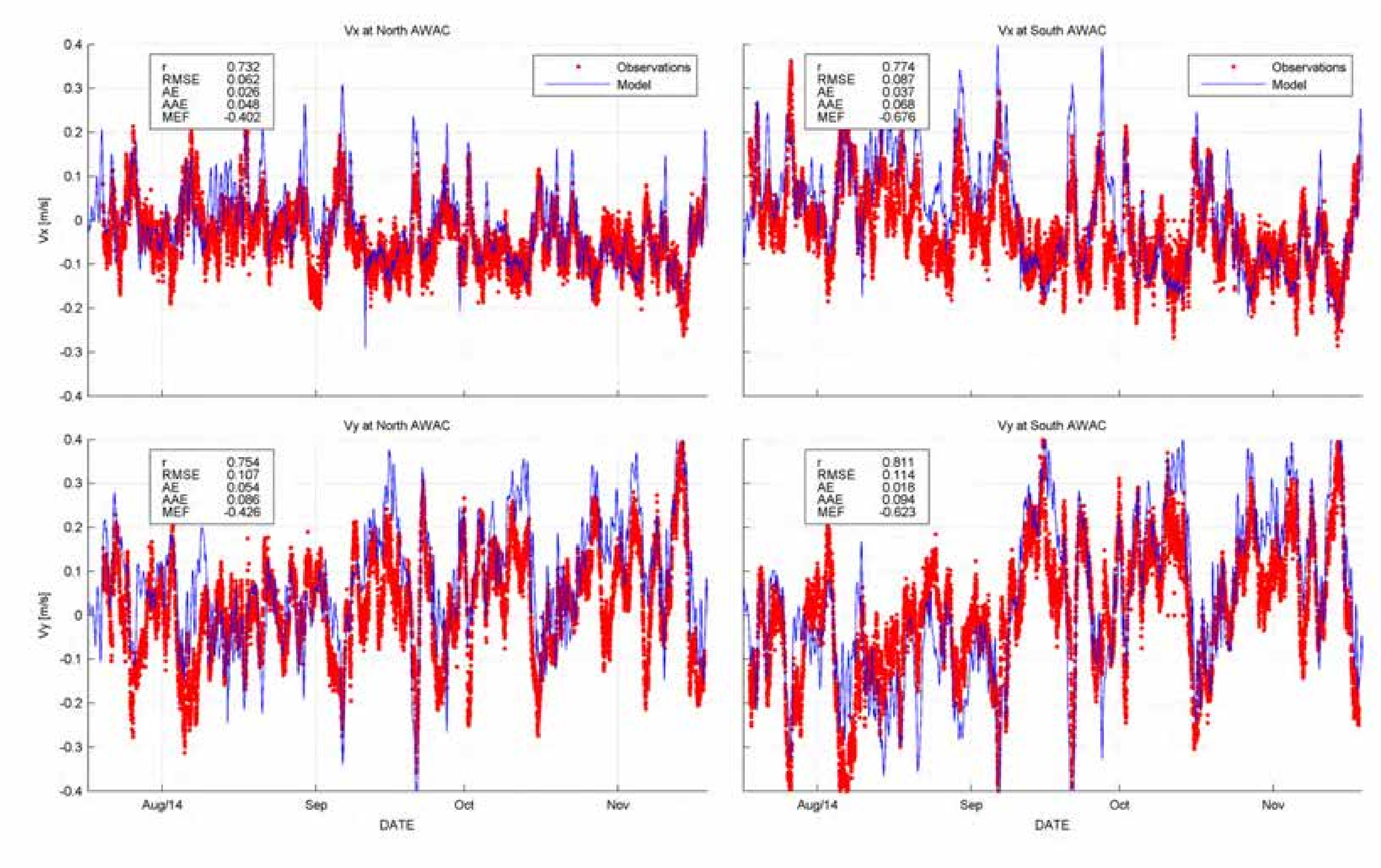

Figure B-17 Time-series of surface velocity (0-5 m depth) at regional sites – Jul 2014 to Nov 2014 deployment

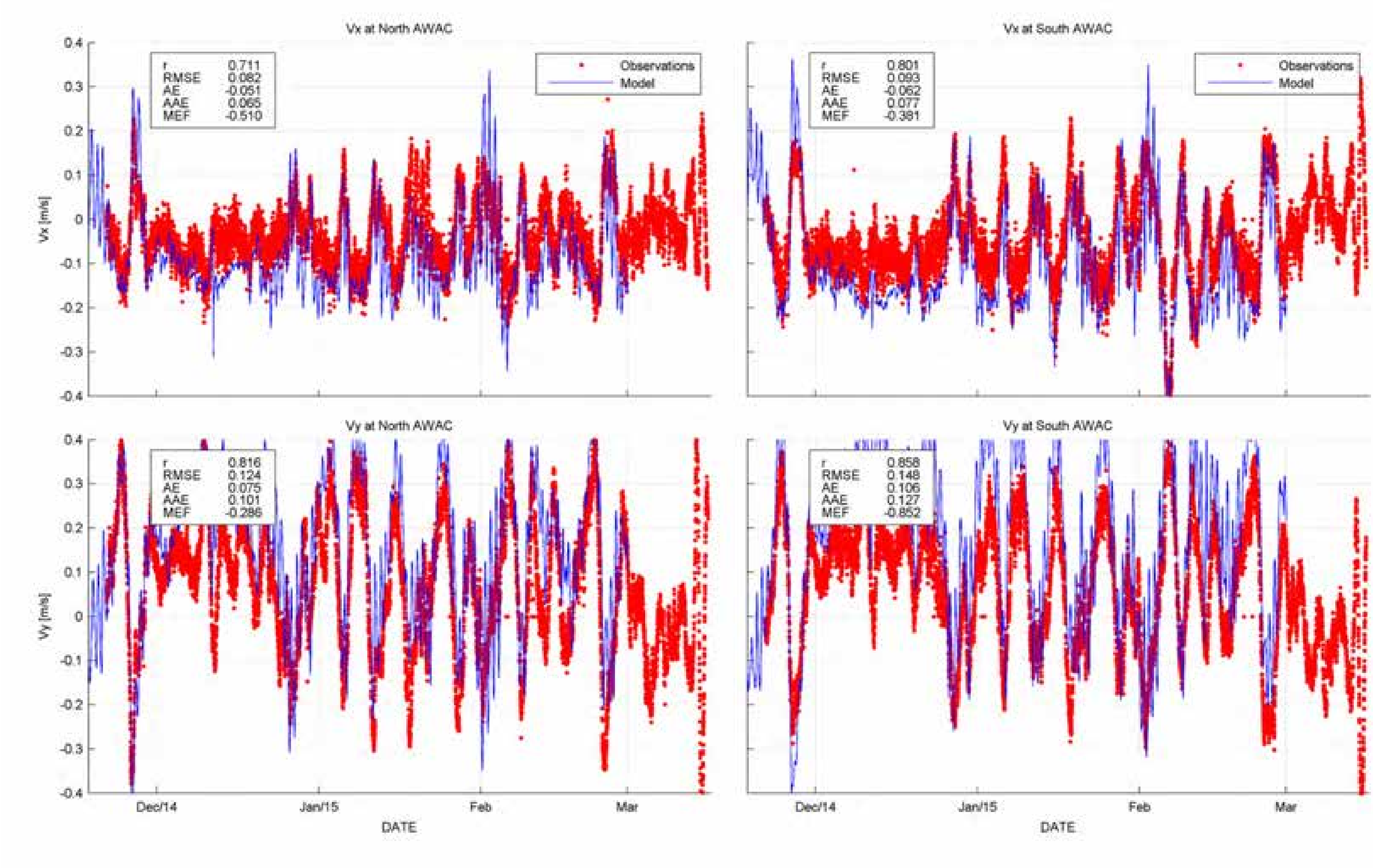

Figure B-18 Time-series of surface velocity (0-5 m depth) at regional sites – Nov 2014 to Mar 2015 deployment

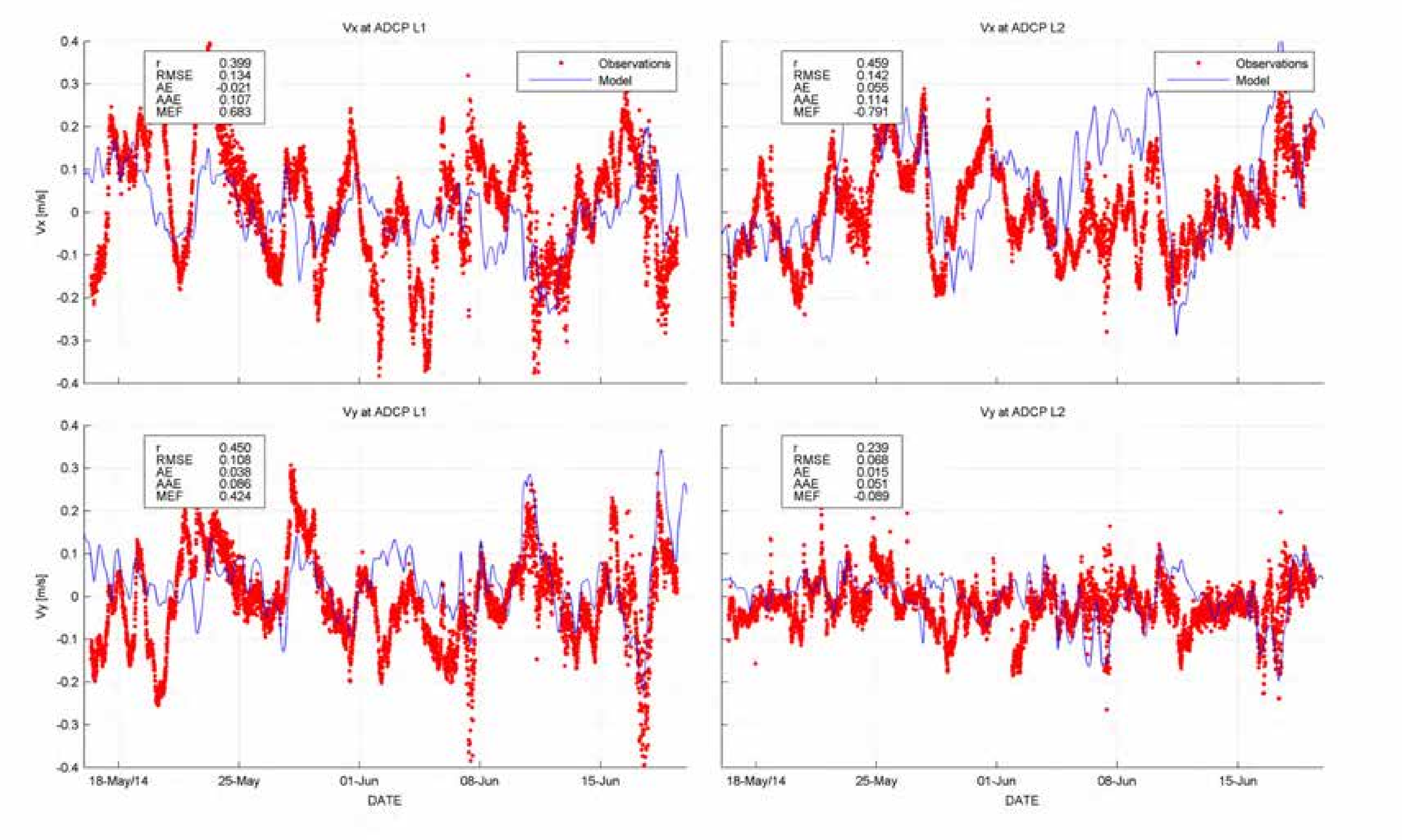

Figure B-19 Time-series of surface velocity (0-5 m depth) at lease-area sites – May 2014 to Jun 2014 deployment

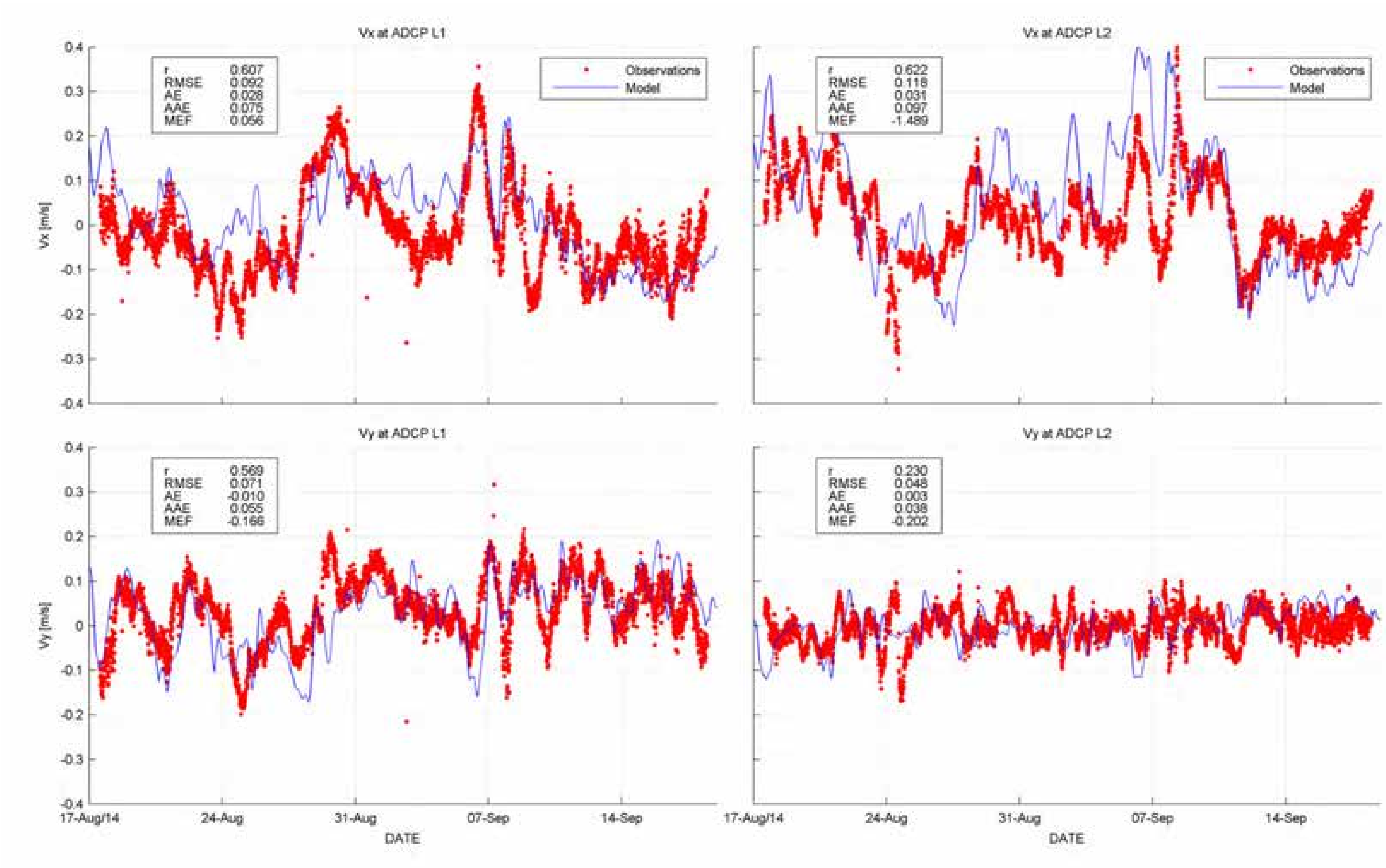

Figure B-20 Time-series of surface velocity (0-5 m depth) at lease-area sites – Aug 2014 to Sep 2014 deployment

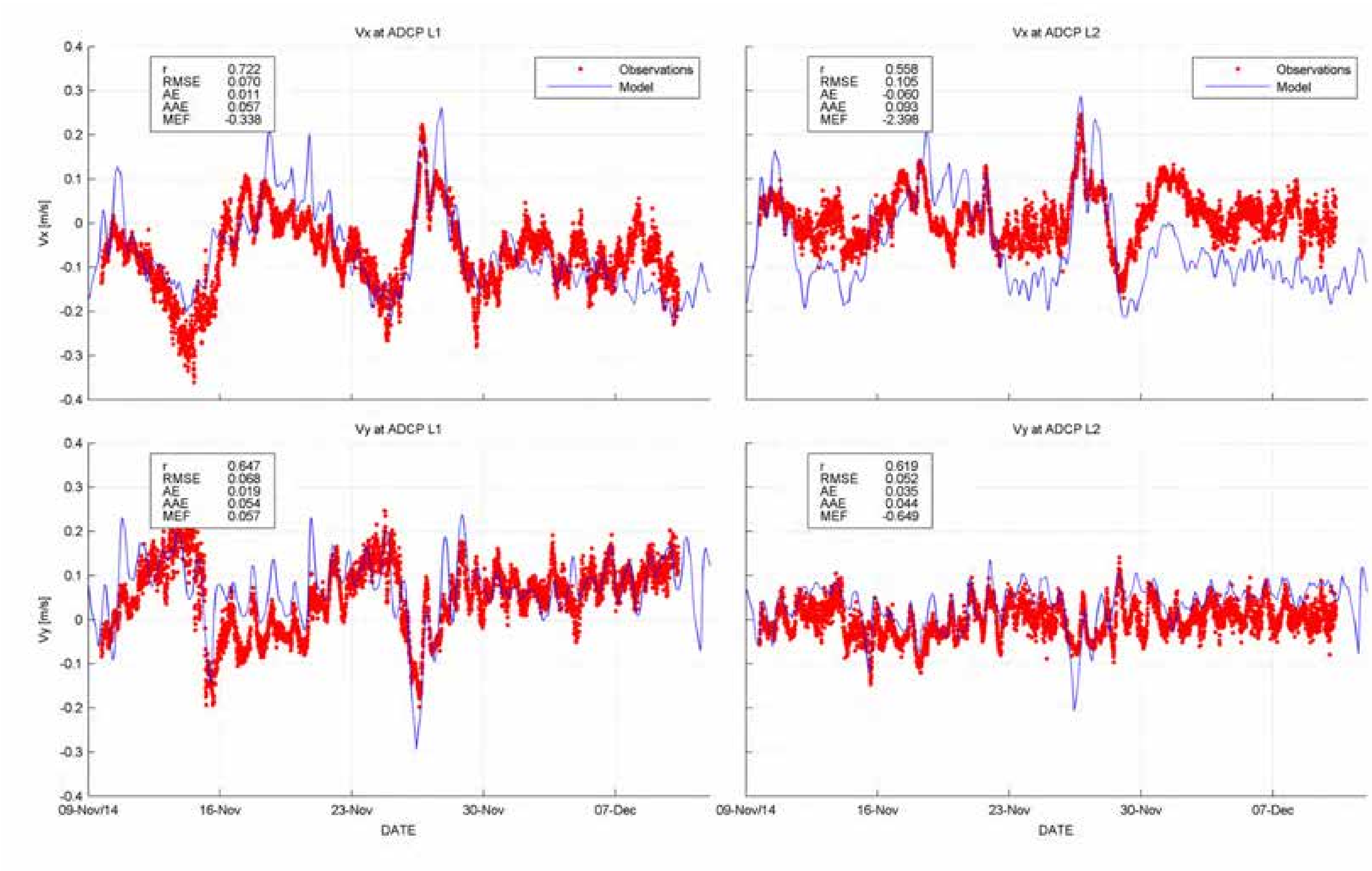

Figure B-21 Time-series of surface velocity (0-5 m depth) at lease-area sites – Nov 2014 to Dec 2014 deployment

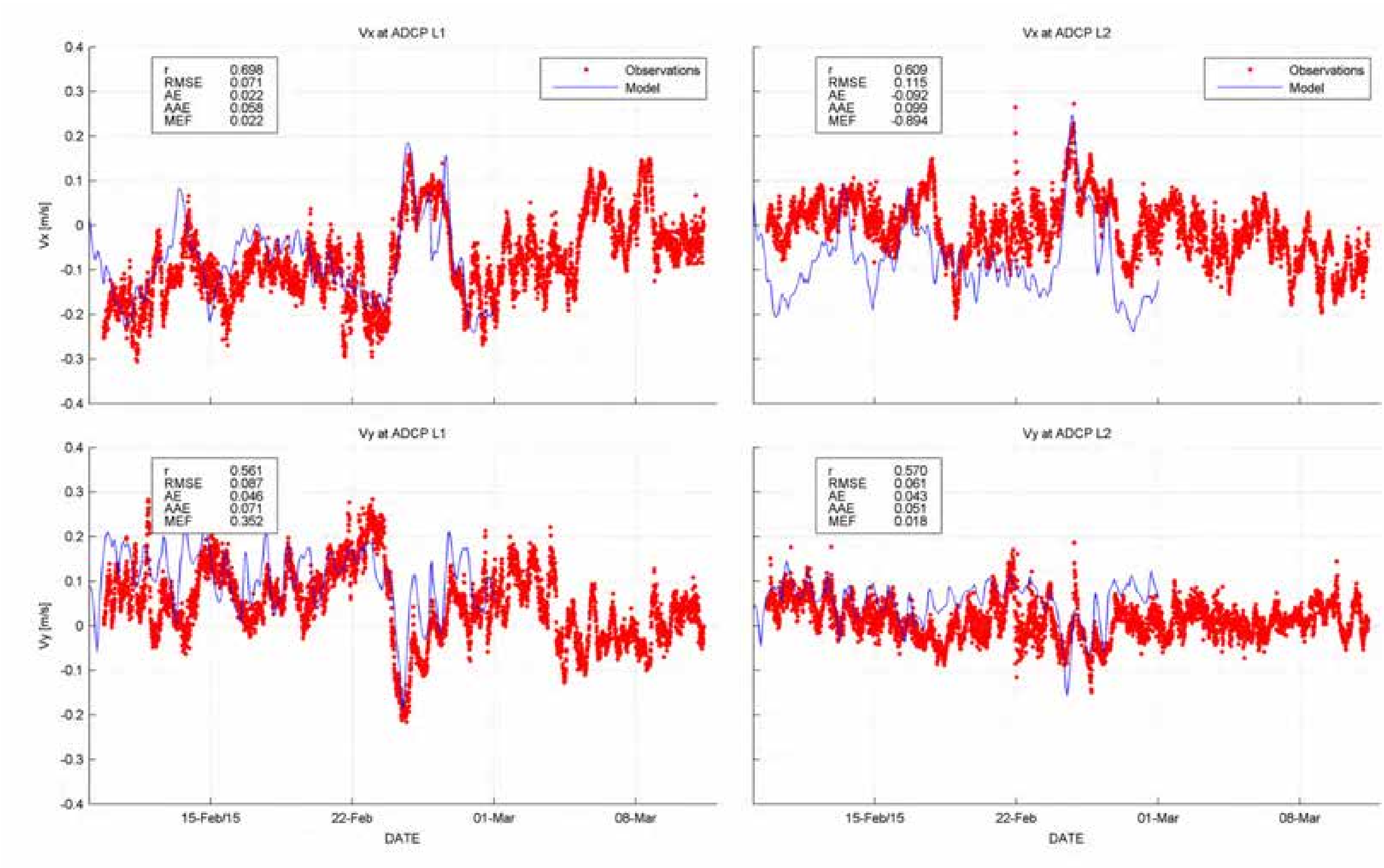

Figure B-22 Time-series of surface velocity (0-5 m depth) at lease-area sites – Feb 2015 to Mar 2014 deployment

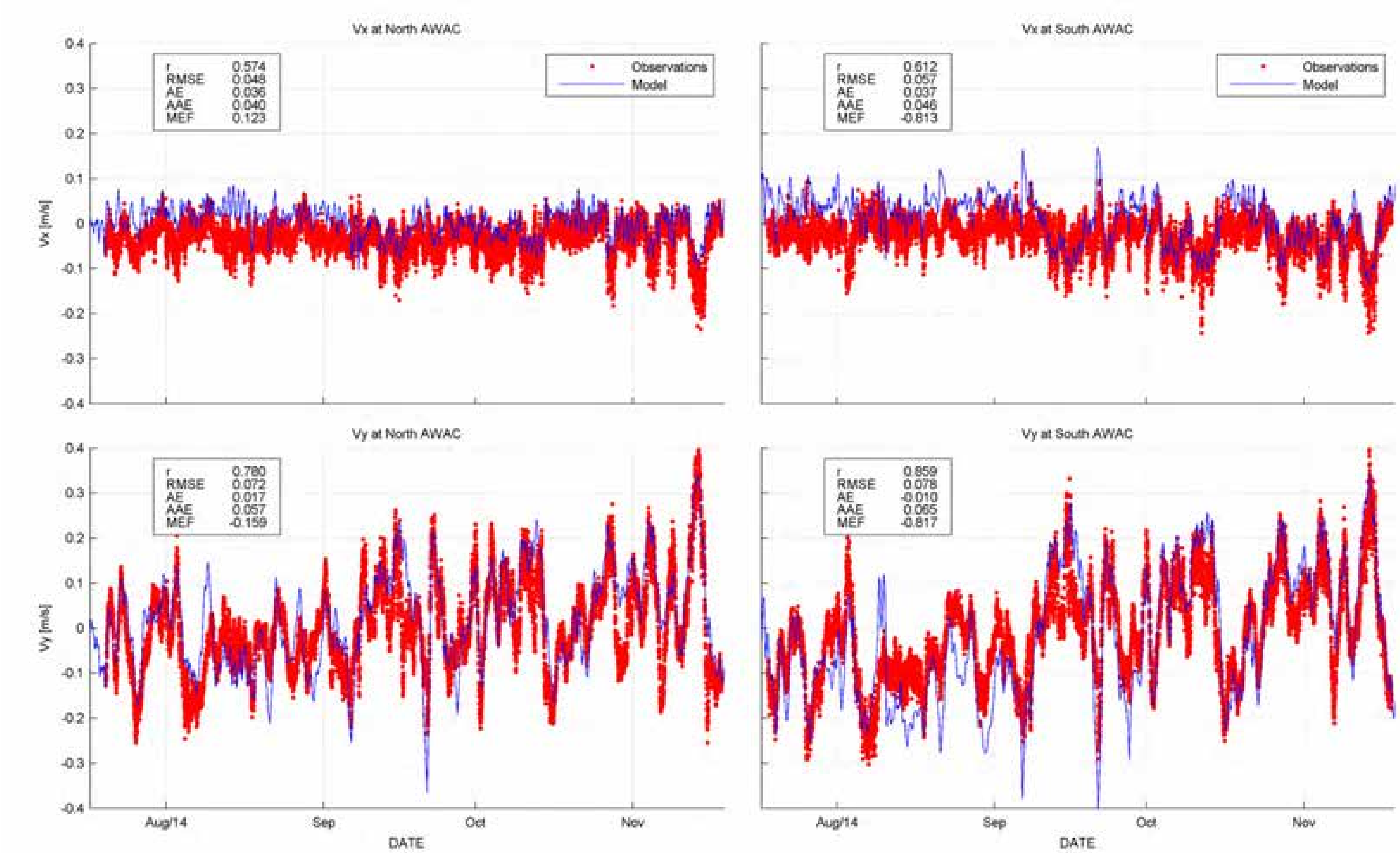

Figure B-23 Time-series of bottom velocity (0-5 m above seabed) at regional sites – Jul 2014 to Nov 2014 deployment

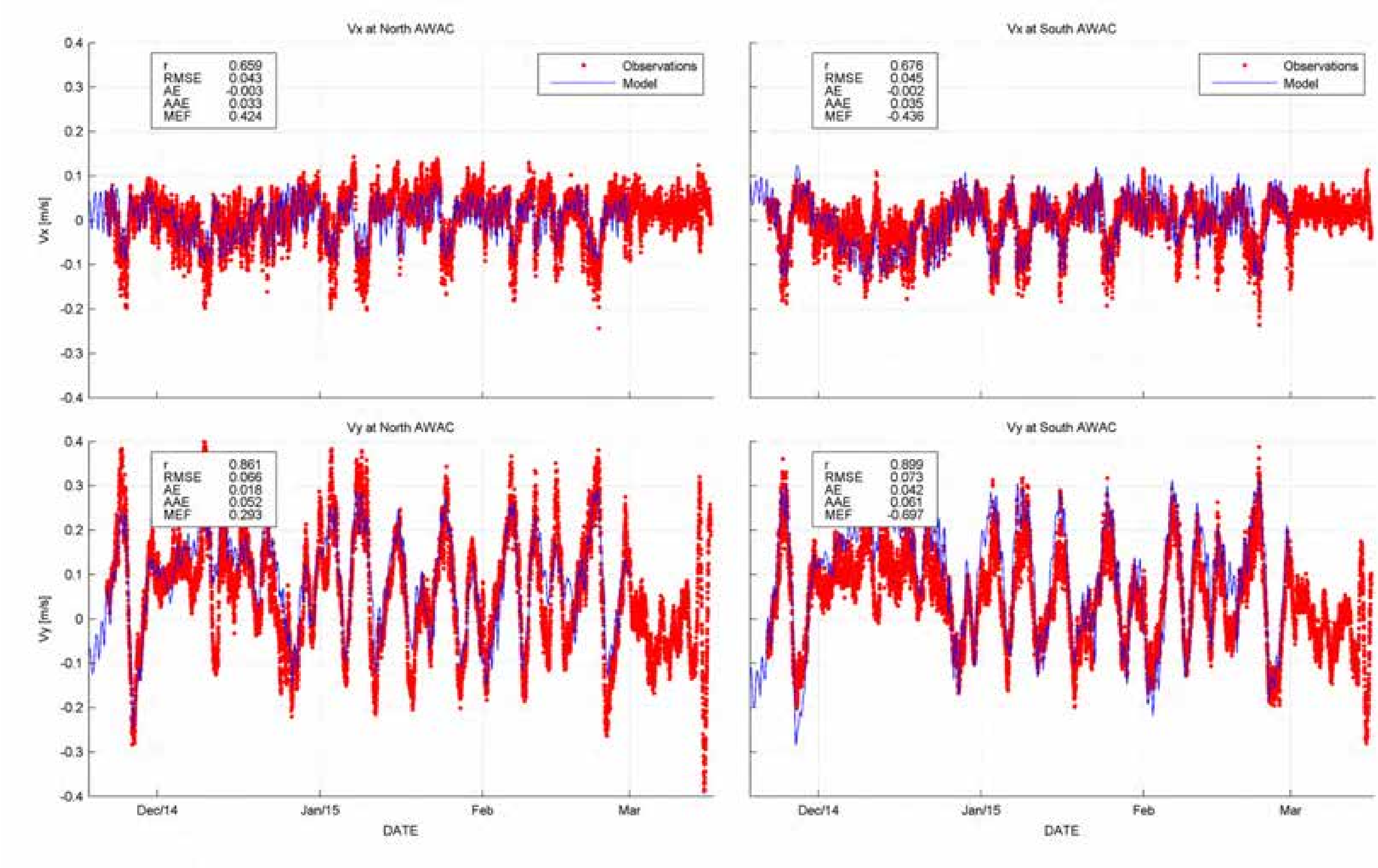

Figure B-24 Time-series of bottom velocity (0-5 m above seabed) at regional sites – Nov 2014 to Mar 2015 deployment

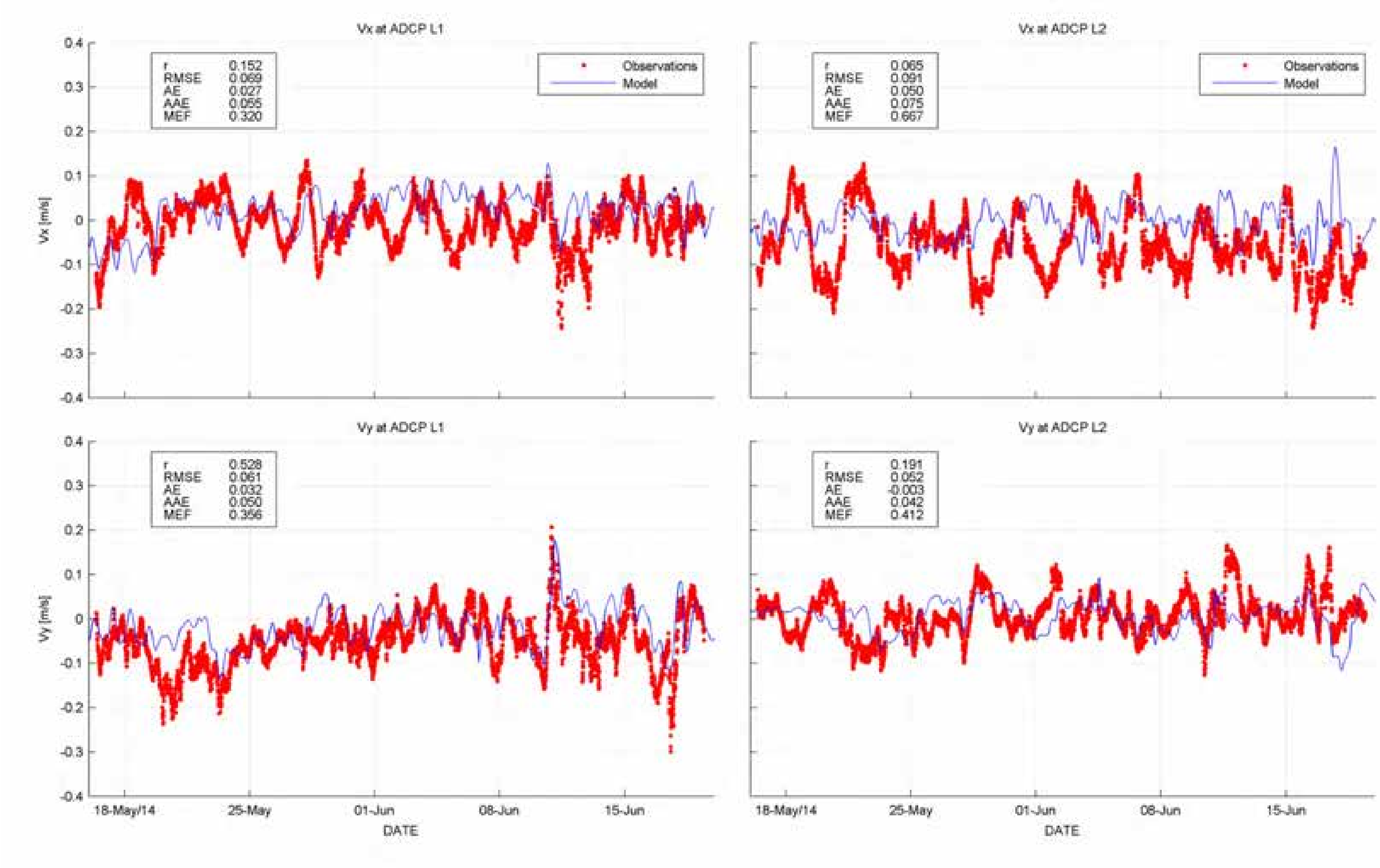

Figure B-25 Time-series of bottom velocity (0-5 m above seabed) at lease-area sites – May 2014 to Jun 2014 deployment

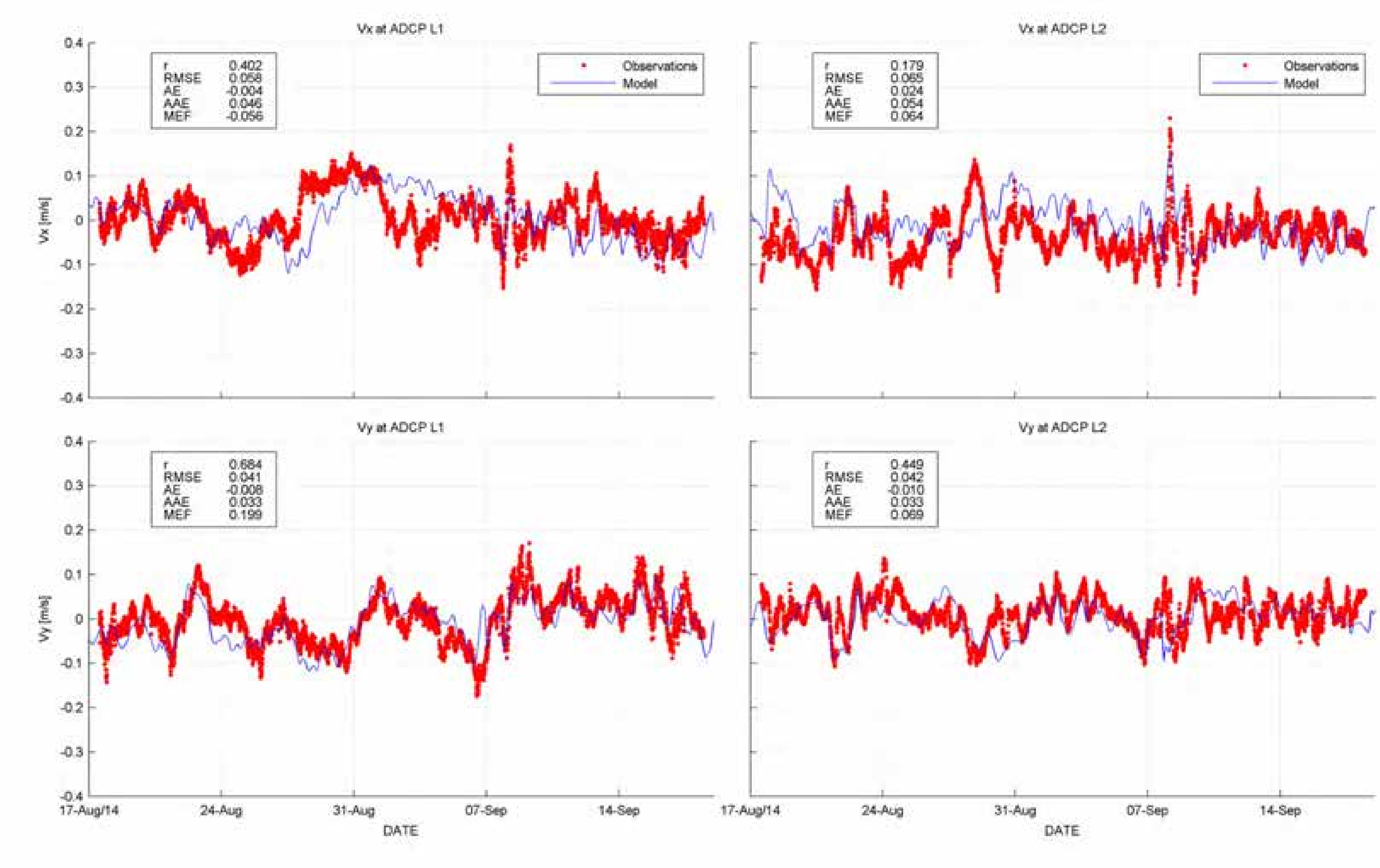

Figure B-26 Time-series of bottom velocity (0-5 m above seabed) at lease-area sites – Aug 2014 to Sep 2014 deployment

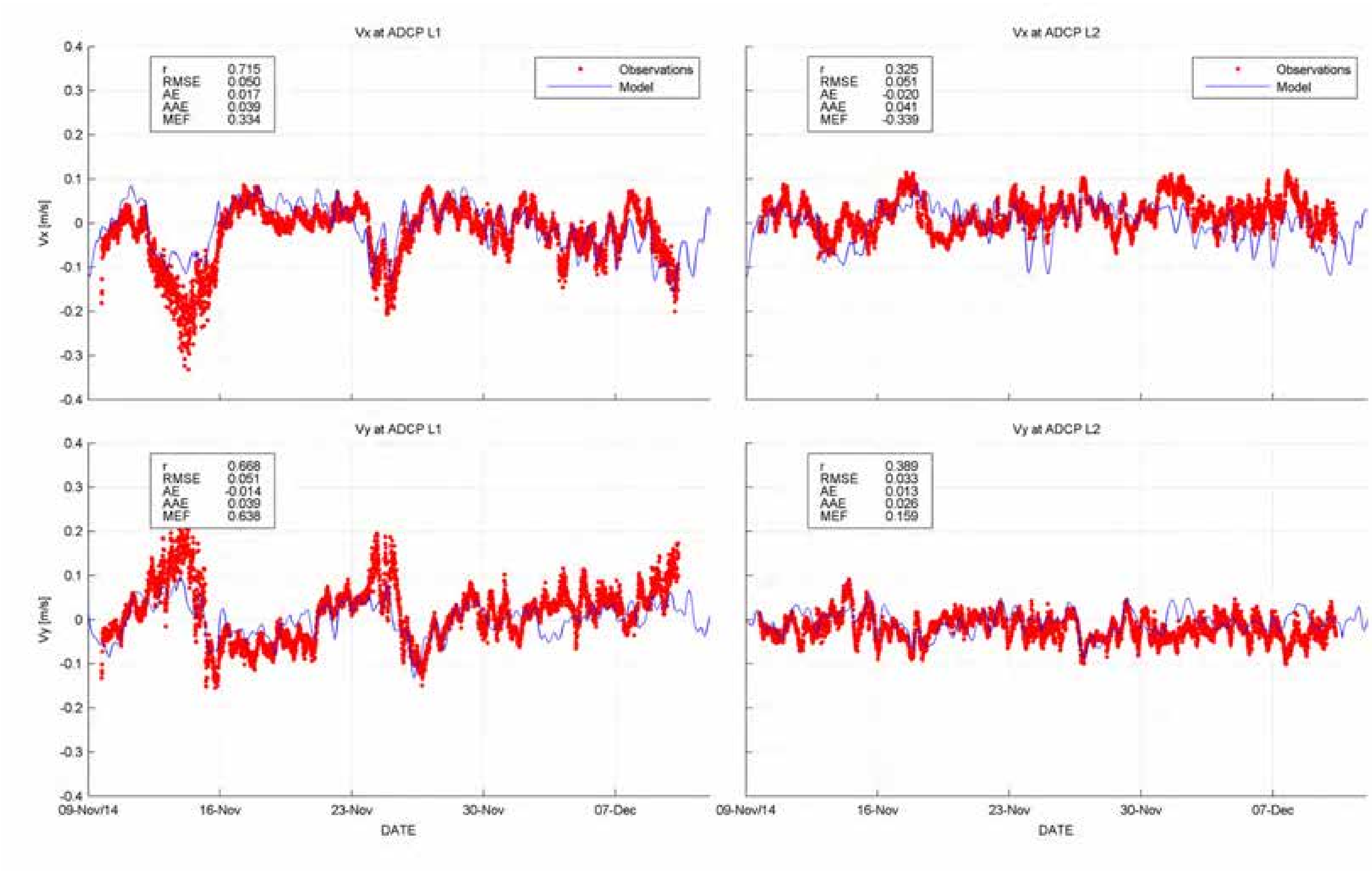

Figure B-27 Time-series of bottom velocity (0-5 m above seabed) at lease-area sites – Nov 2014 to Dec 2014 deployment

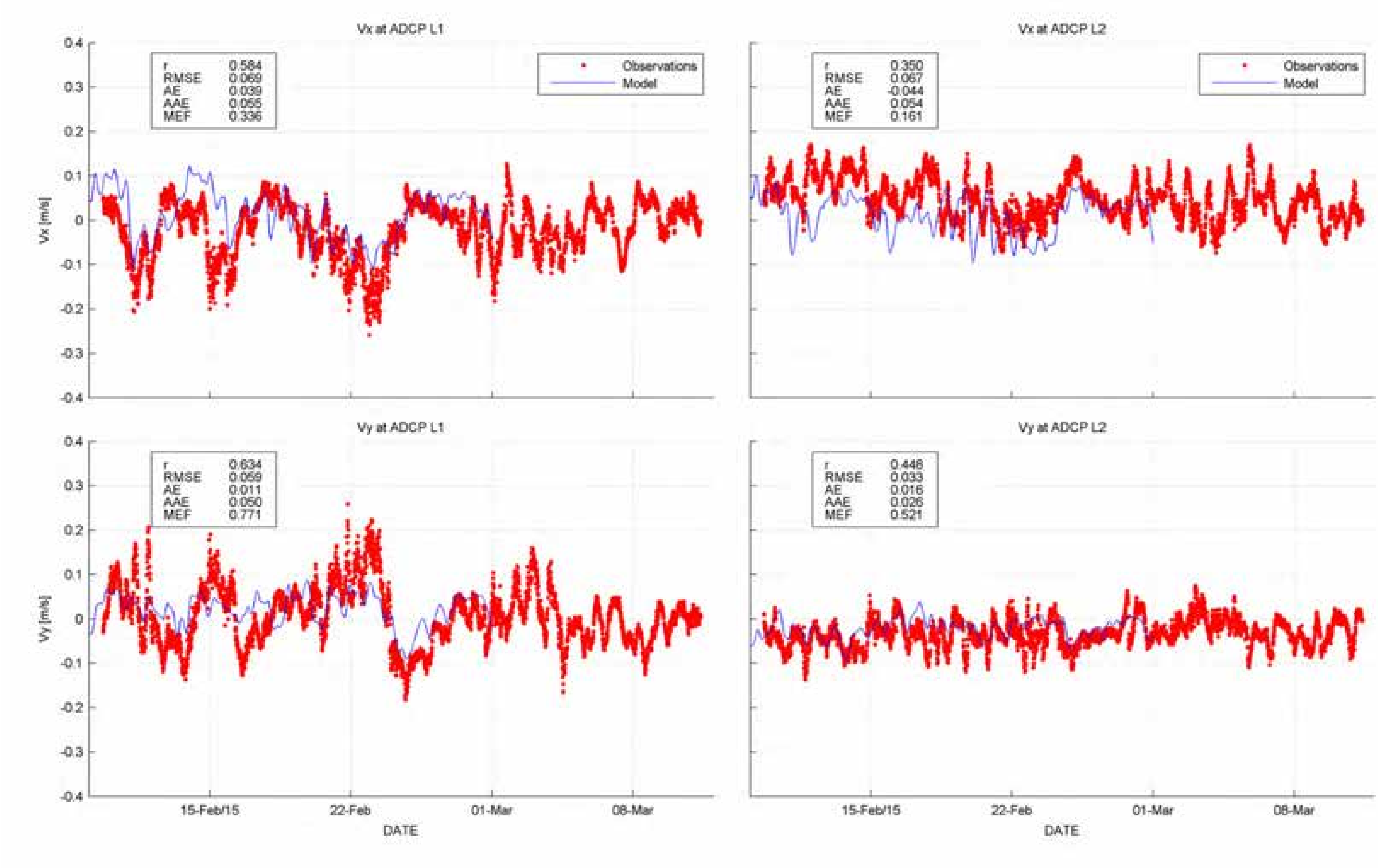

Figure B-28 Time-series of bottom velocity (0-5 m above seabed) at lease-area sites – Feb 2015 to Mar 2014 deployment

B.3 Temperature

This section includes time-series of seabed temperature collected at the regional sites, decomposed into calendar months for clarity. The first deployment is detailed in Figure B-29 to Figure B-33, and the second in Figure B-34 to Figure B-38.

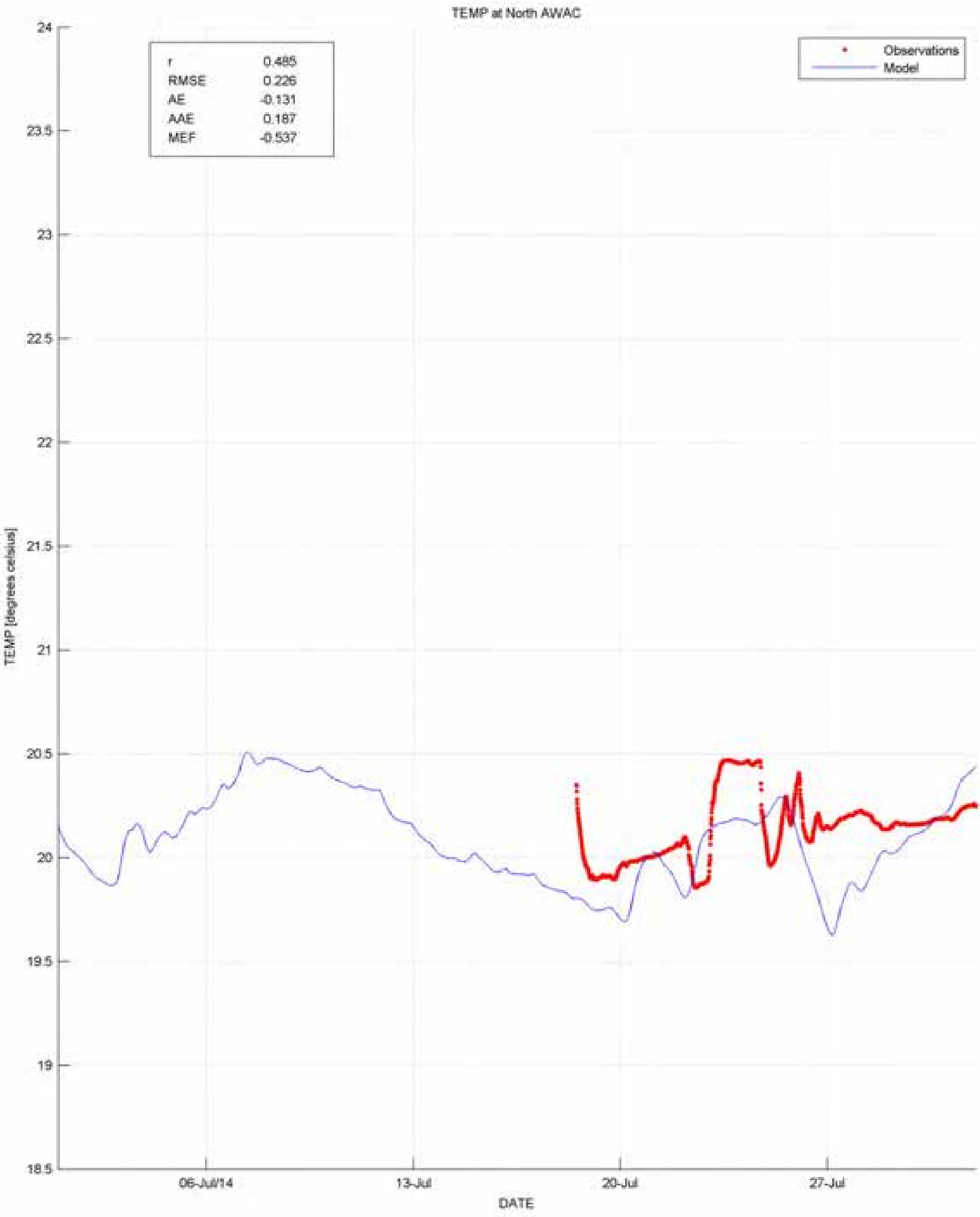

Figure B-29 Time-series of seabed temperature at northern regional site – July 2014

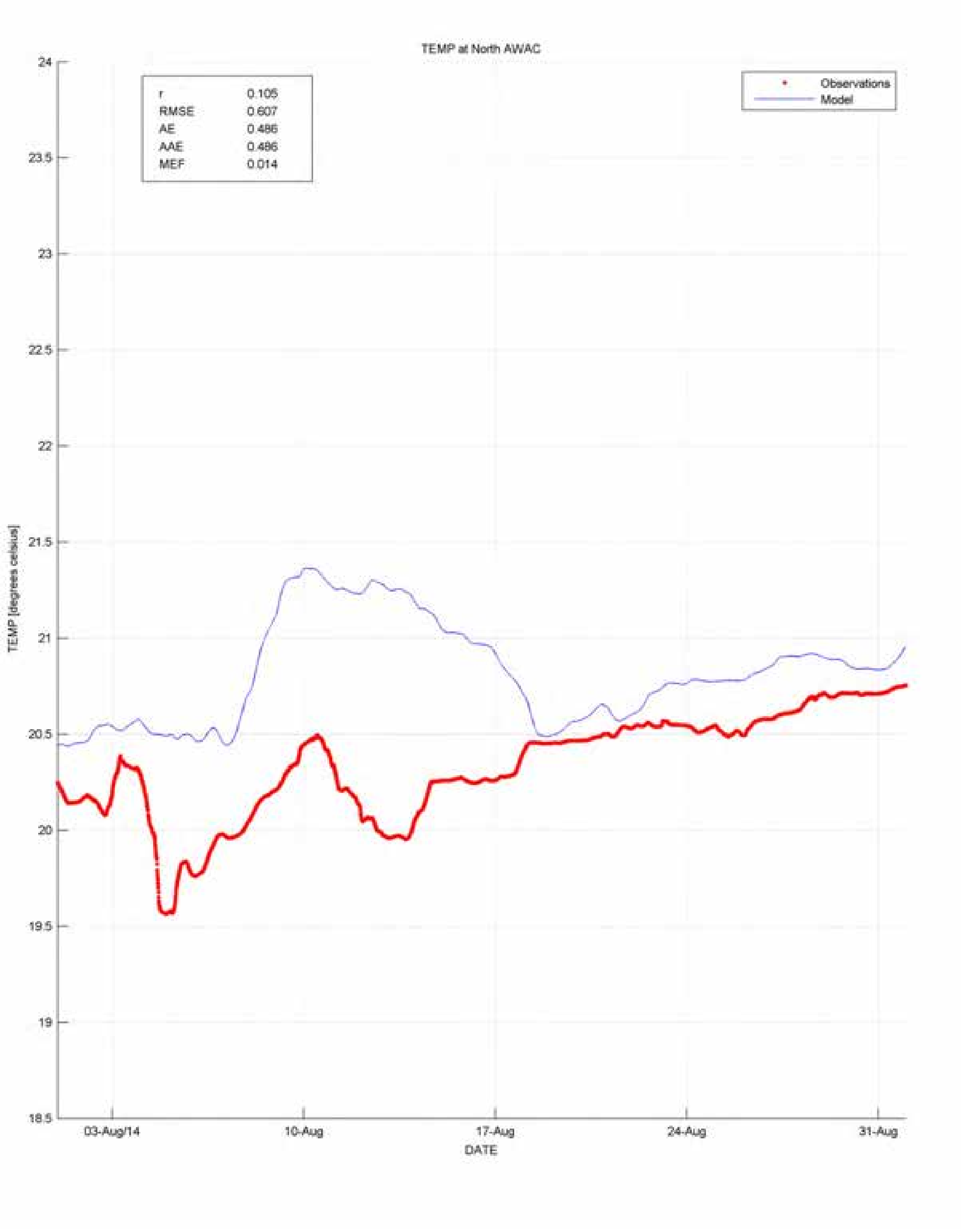

Figure B-30 Time-series of seabed temperature at northern regional site – August 2014

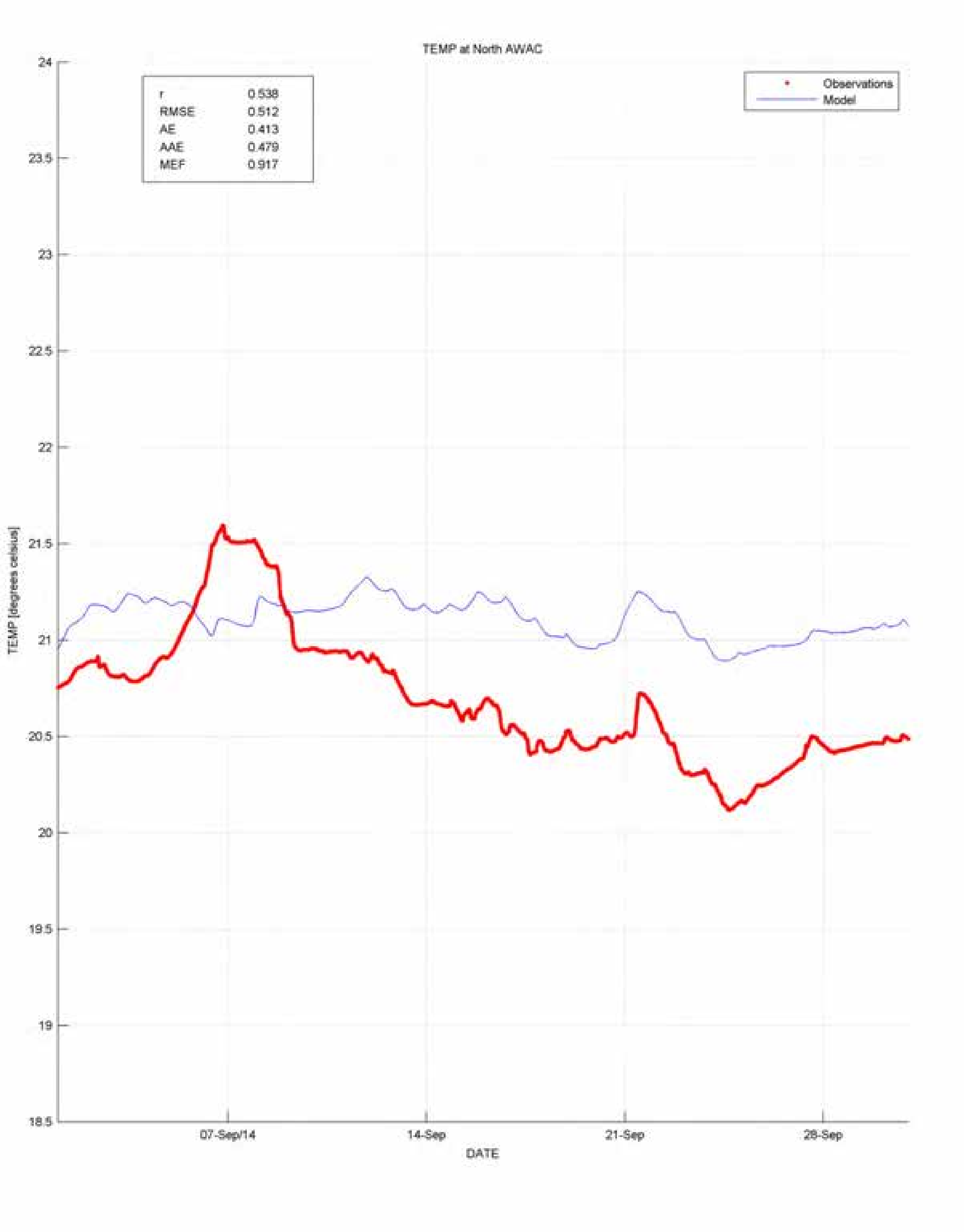

Figure B-31 Time-series of seabed temperature at northern regional site – September 2014

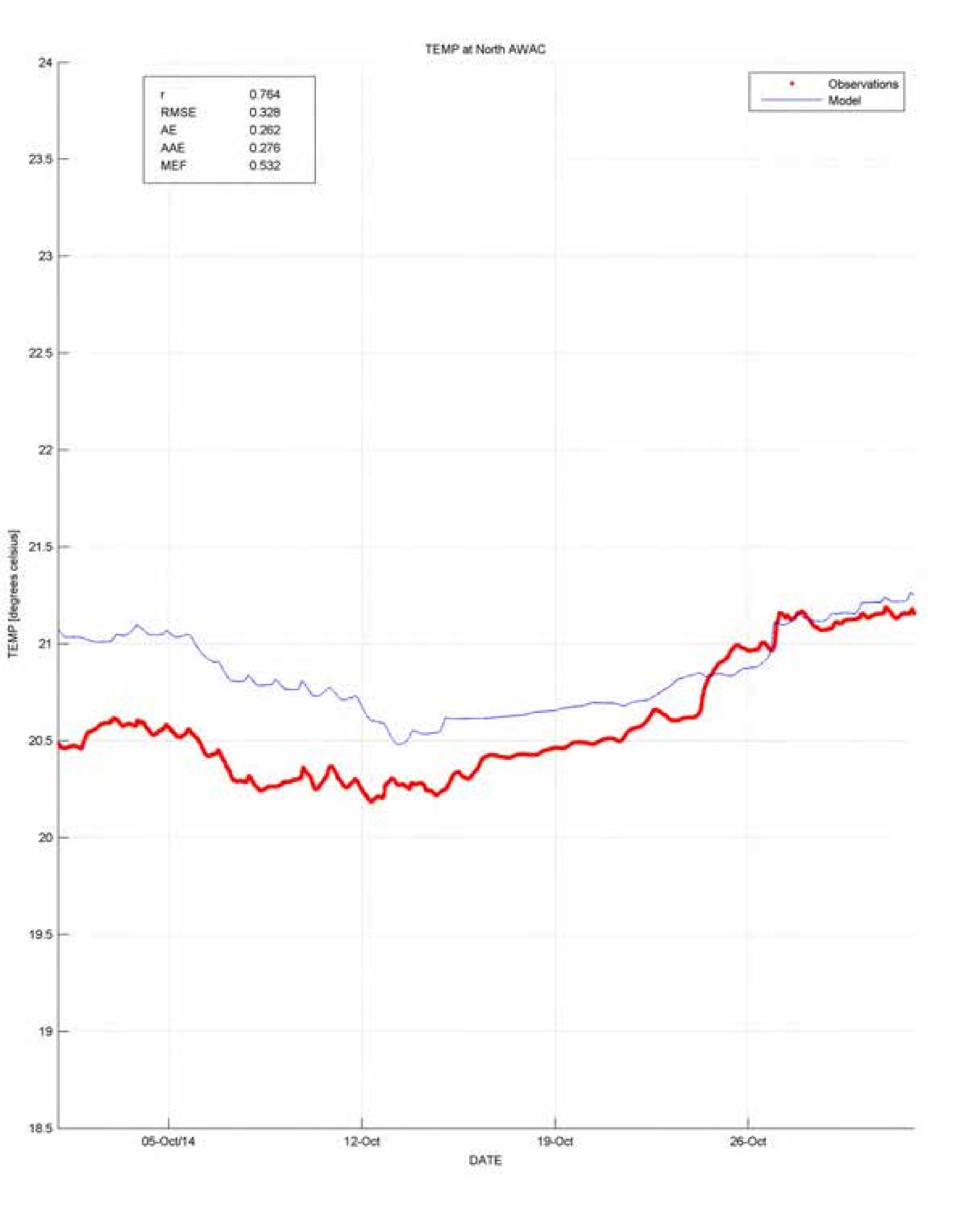

Figure B-32 Time-series of seabed temperature at northern regional site – October 2014

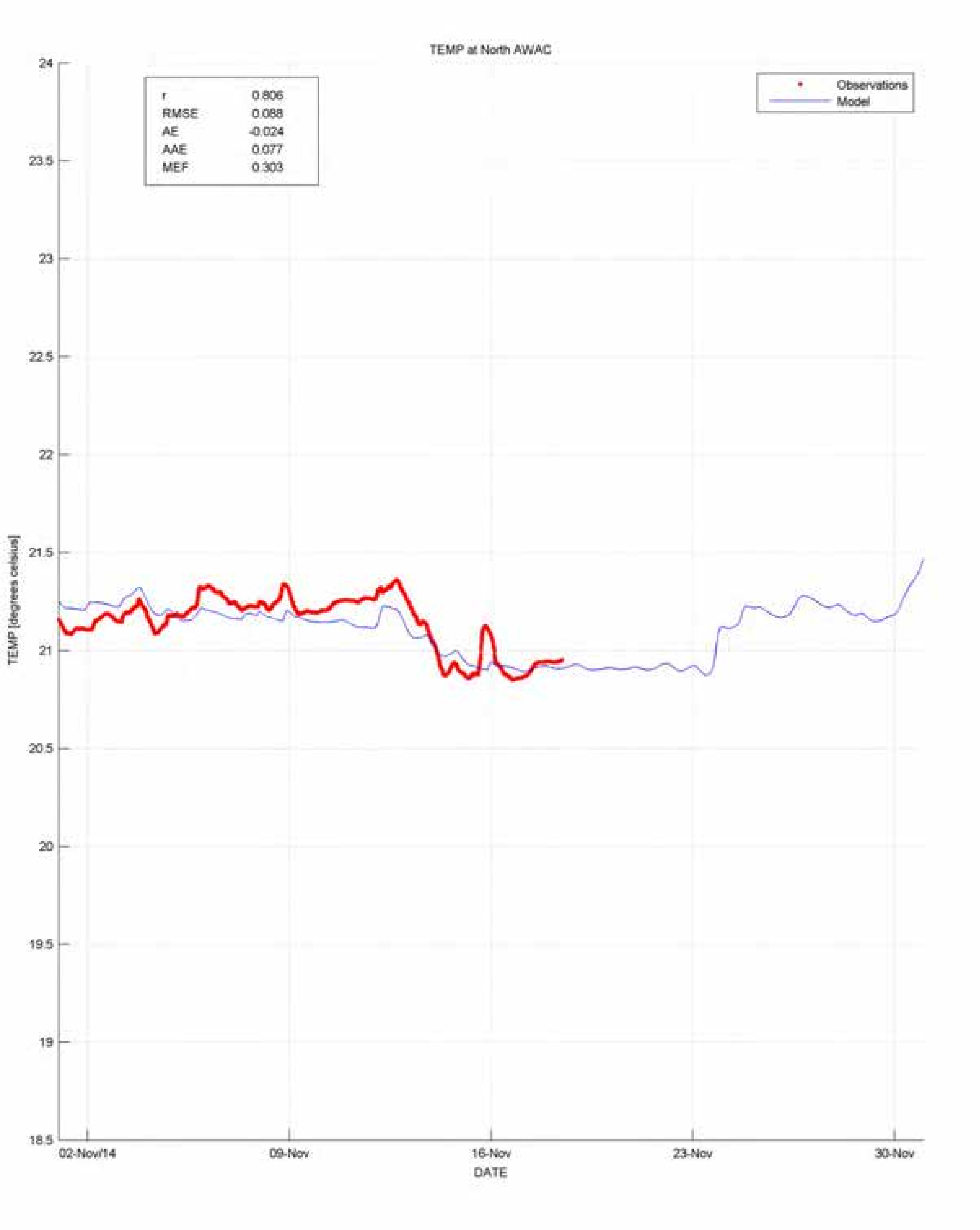

Figure B-33 Time-series of seabed temperature at northern regional site – November 2014

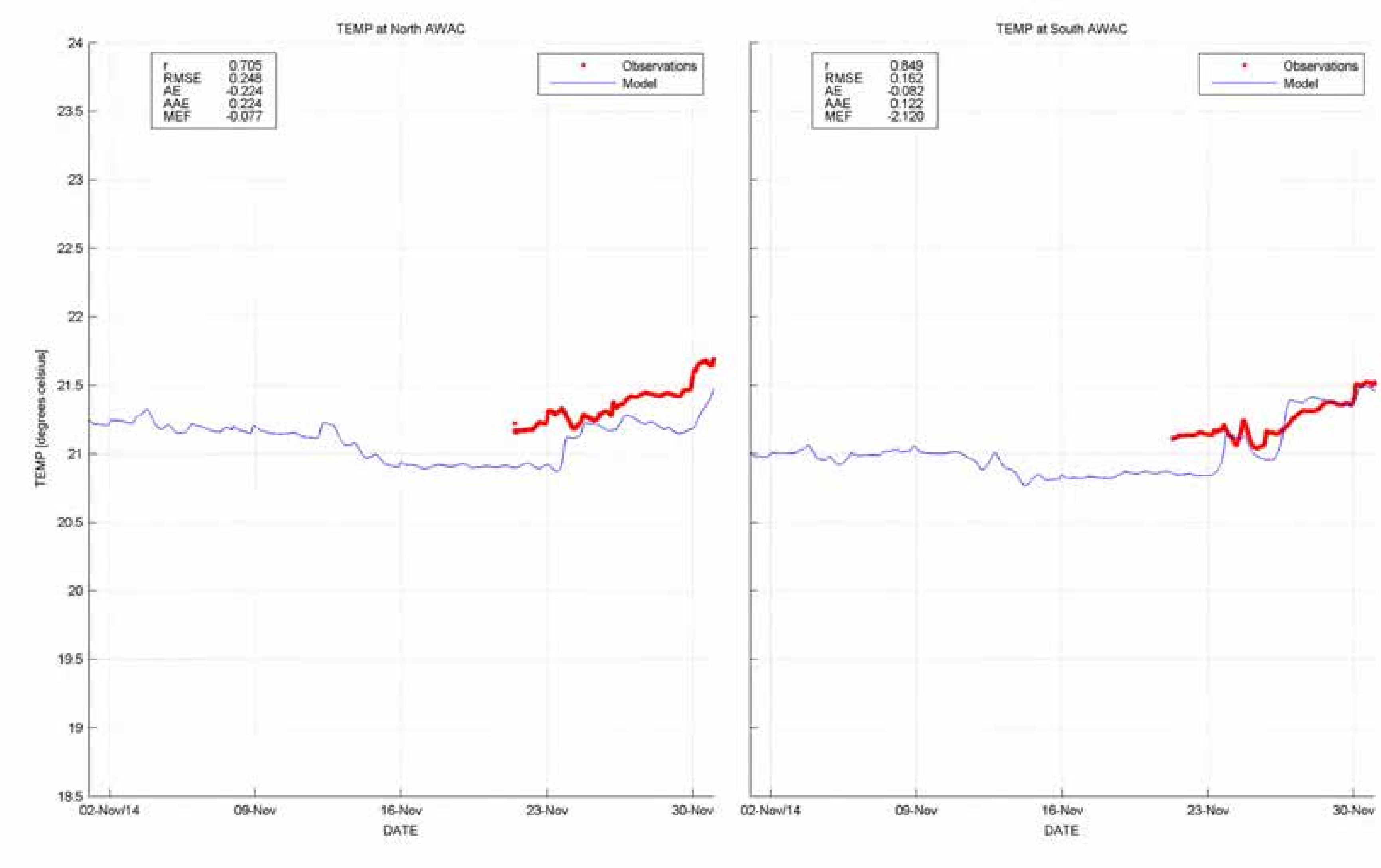

Figure B-34 Time-series of seabed temperature at northern regional site – November 2014 (second deployment)

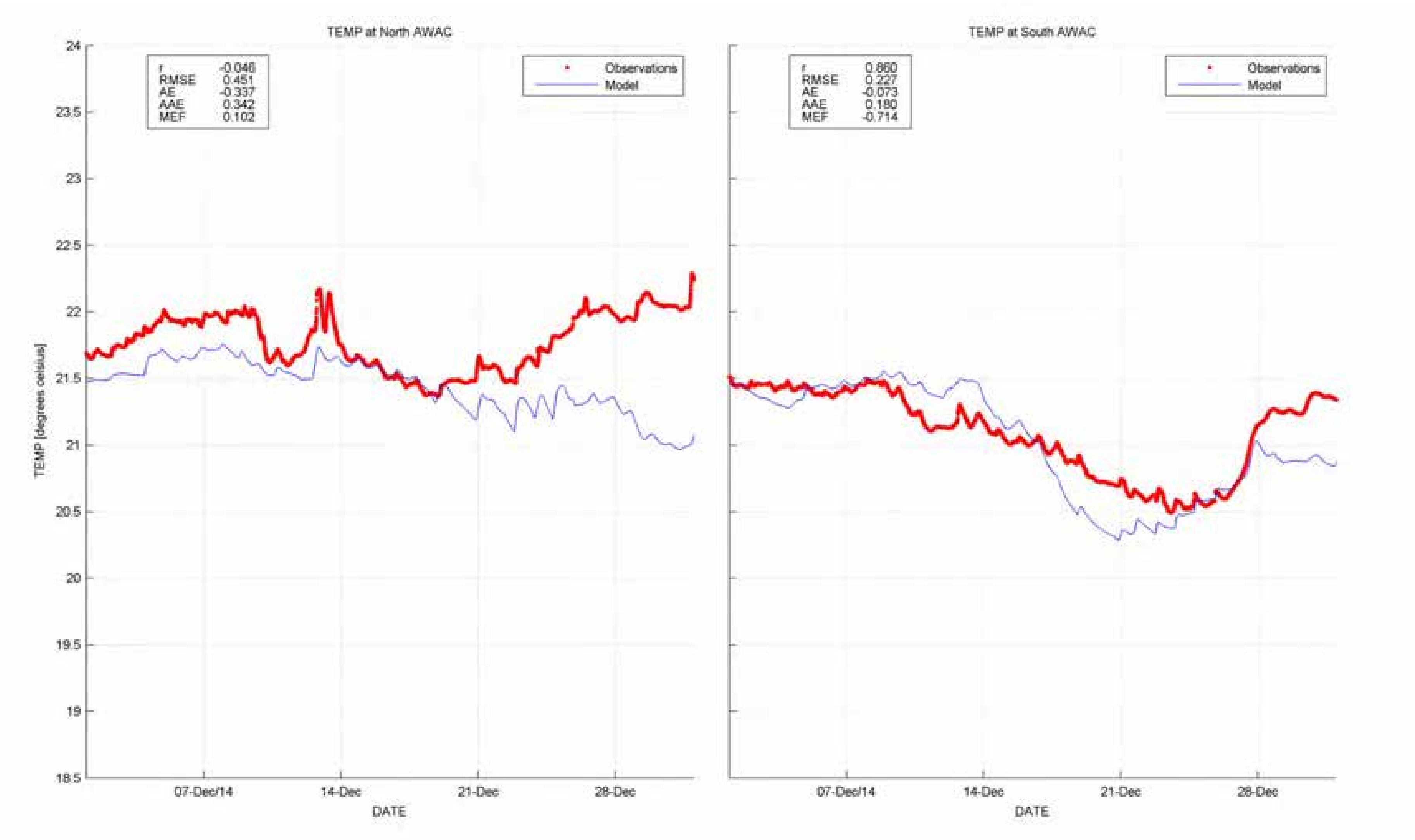

Figure B-35 Time-series of seabed temperature at northern regional site – December 2014

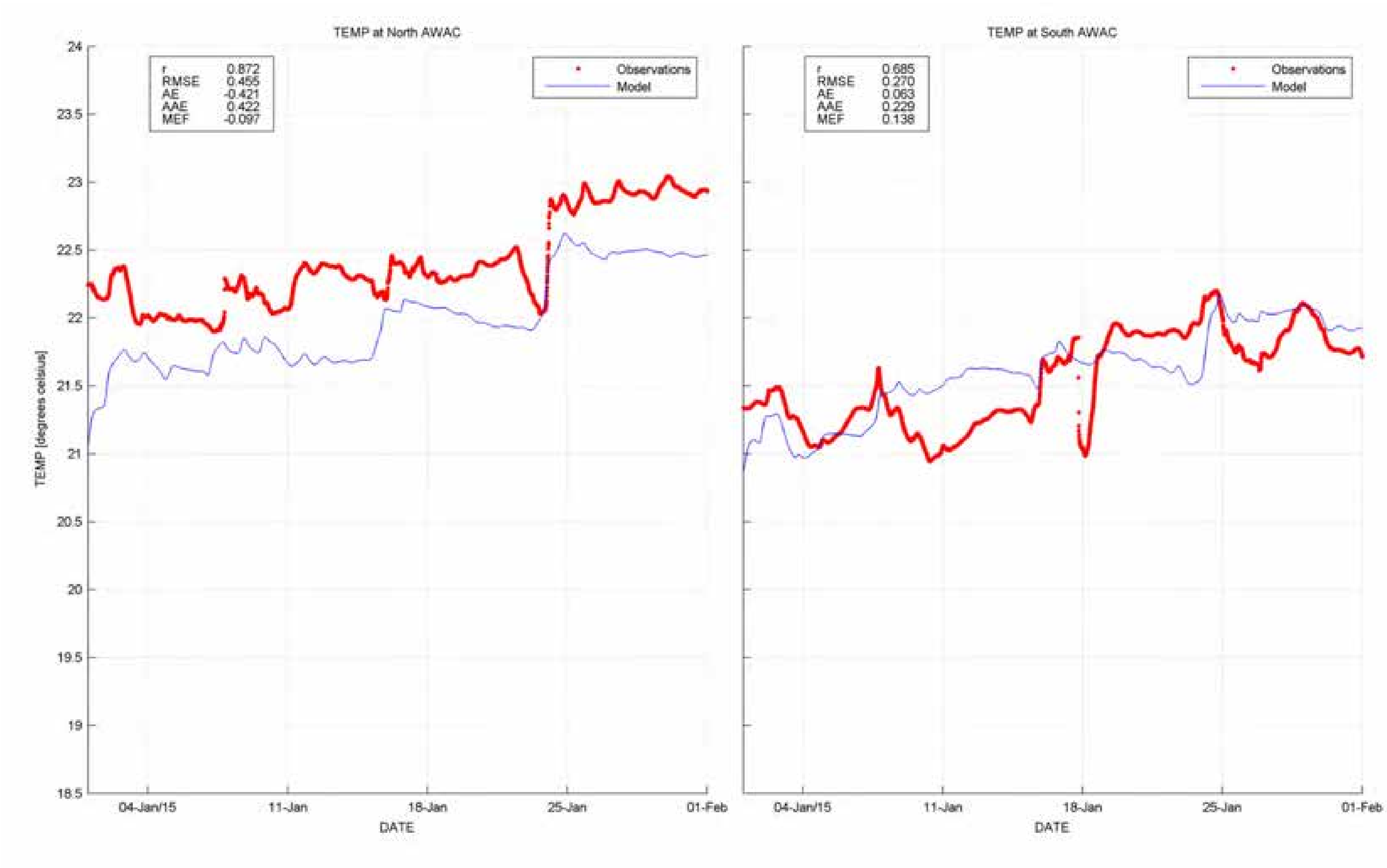

Figure B-36 Time-series of seabed temperature at northern regional site – January 2015

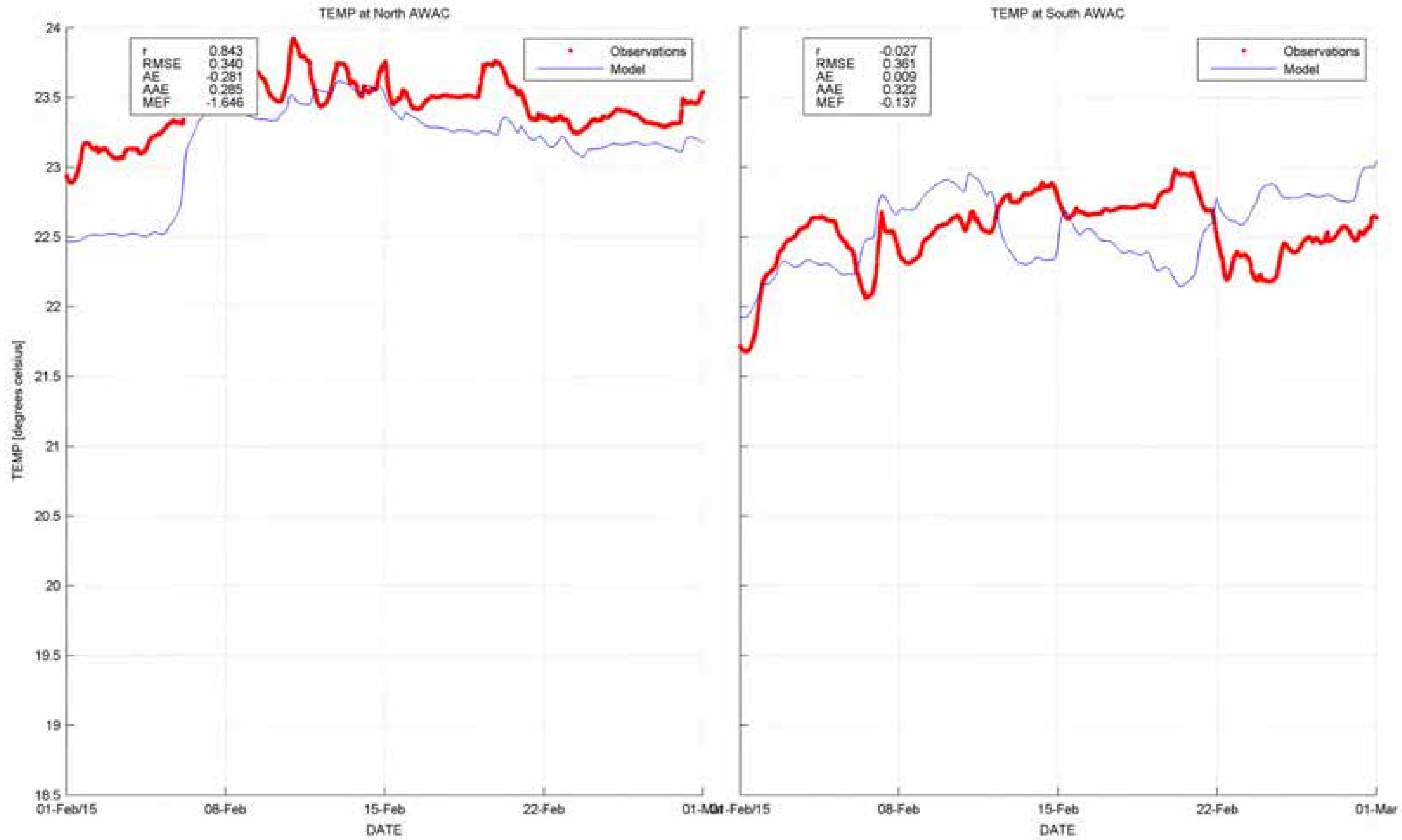

Figure B-37 Time-series of seabed temperature at northern regional site – February 2015

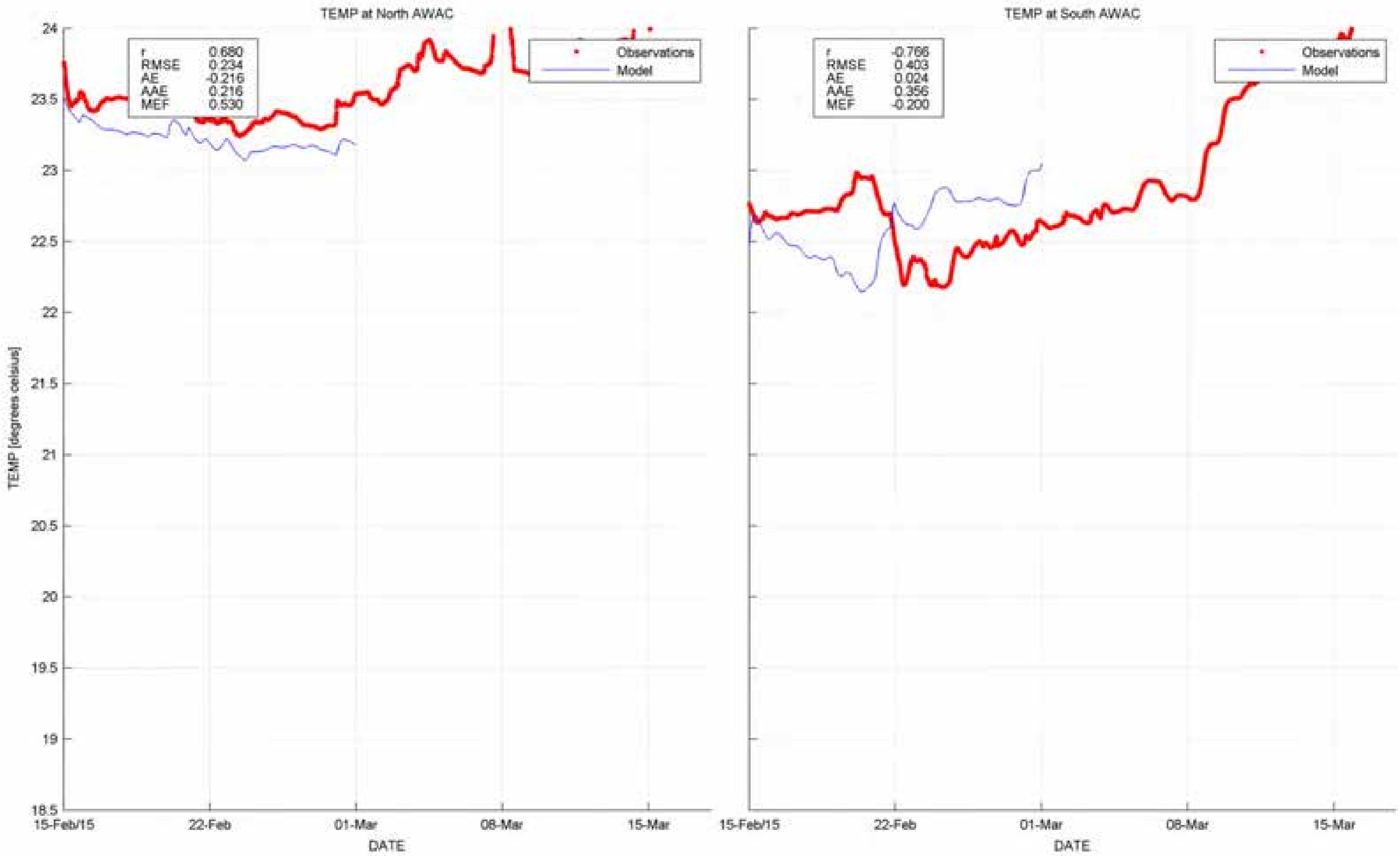

Figure B-38 Time-series of seabed temperature at northern regional site – March 2015

B.4 Waves

Additional calibration plots for the SWAN wave model are included in this section for the period 19th November 2014 to 1st January 2015. Comparisons of significant wave height, peak wave period and wave direction at the regional sites are presented in Figure B-39, Figure B-40 and Figure B-41, respectively.

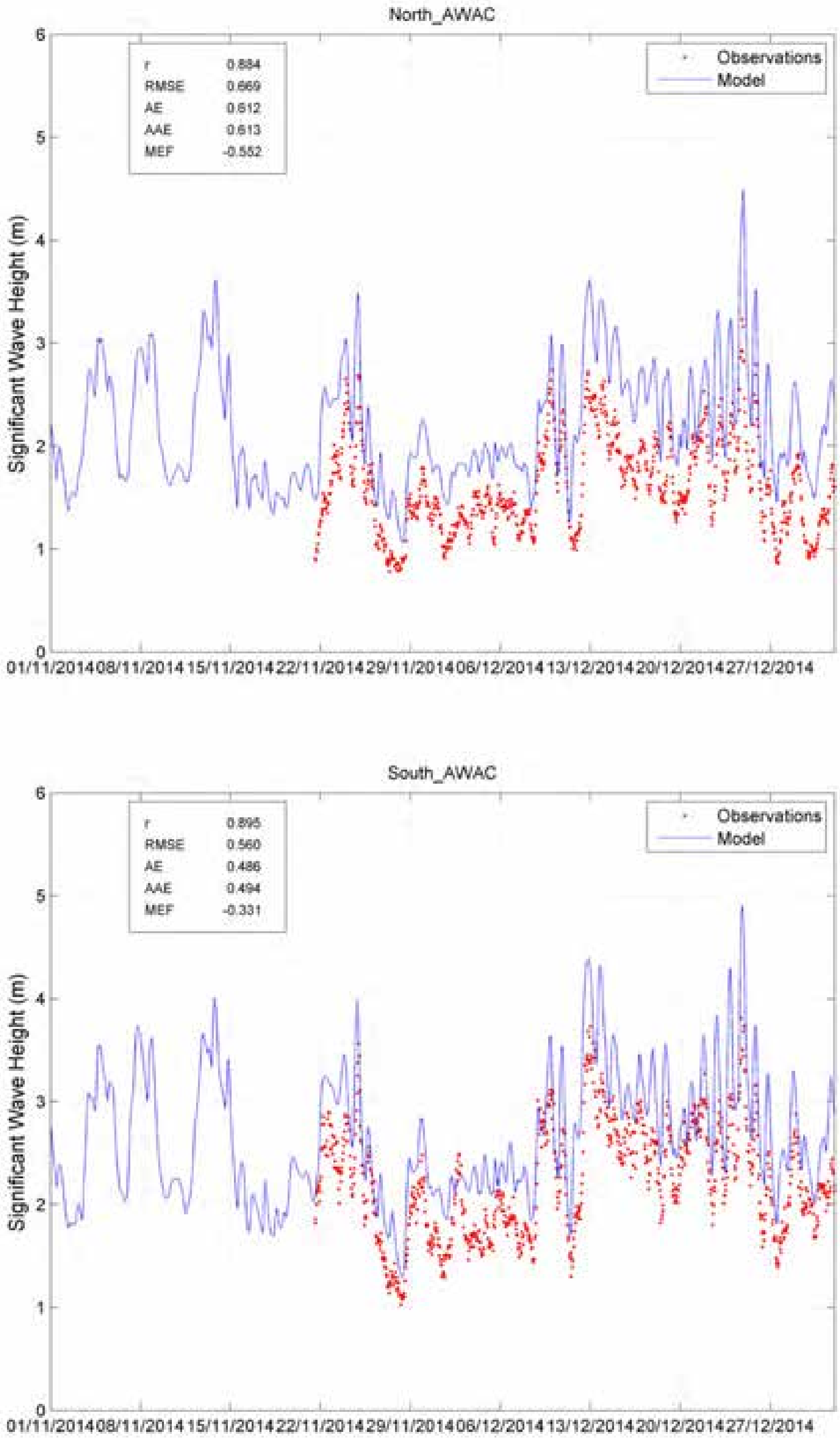

Figure B-39 Significant wave height at regional sites – Nov 2014 to Mar 2015 deployment

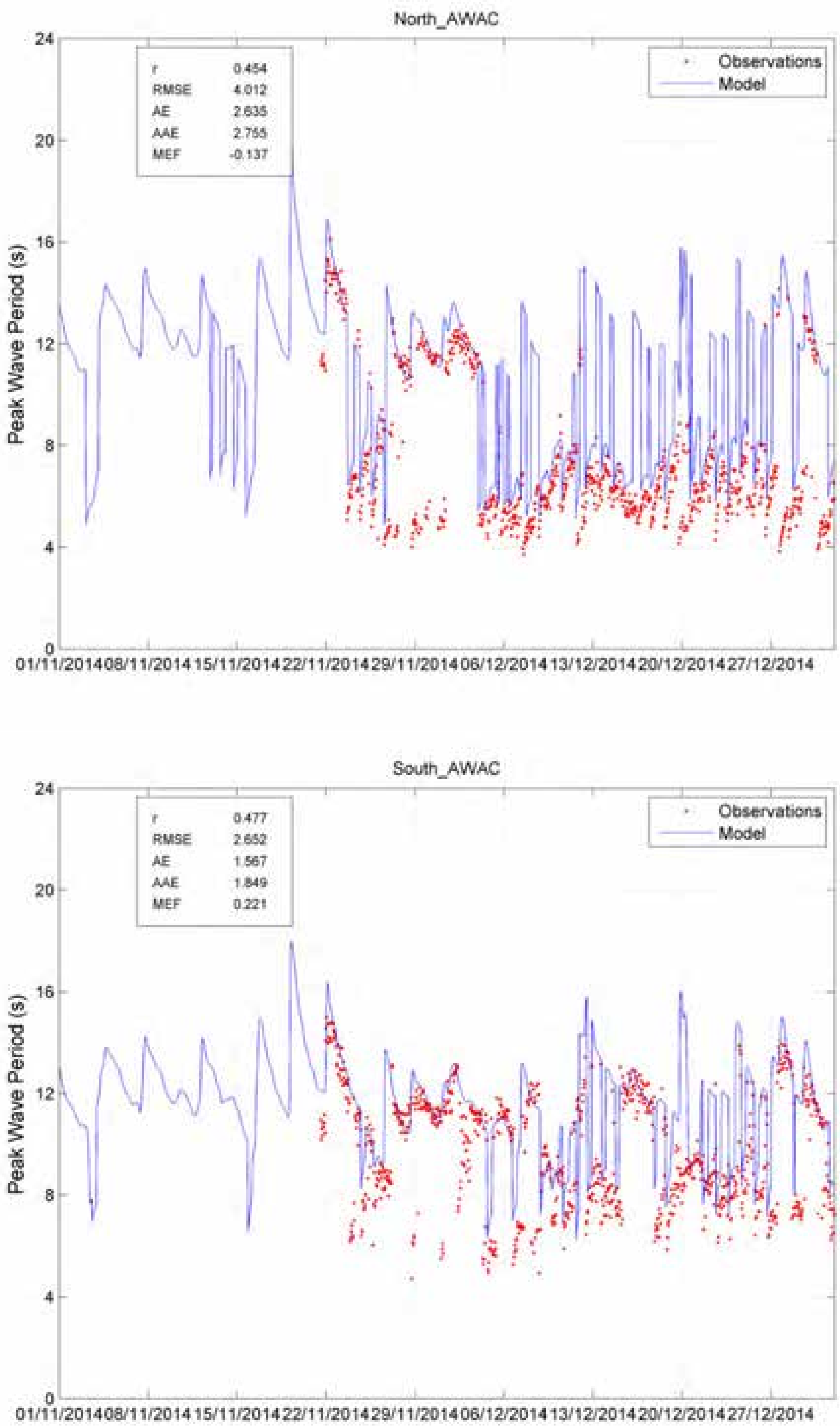

Figure B-40 Peak wave period at regional sites – Nov 2014 to Mar 2015 deployment

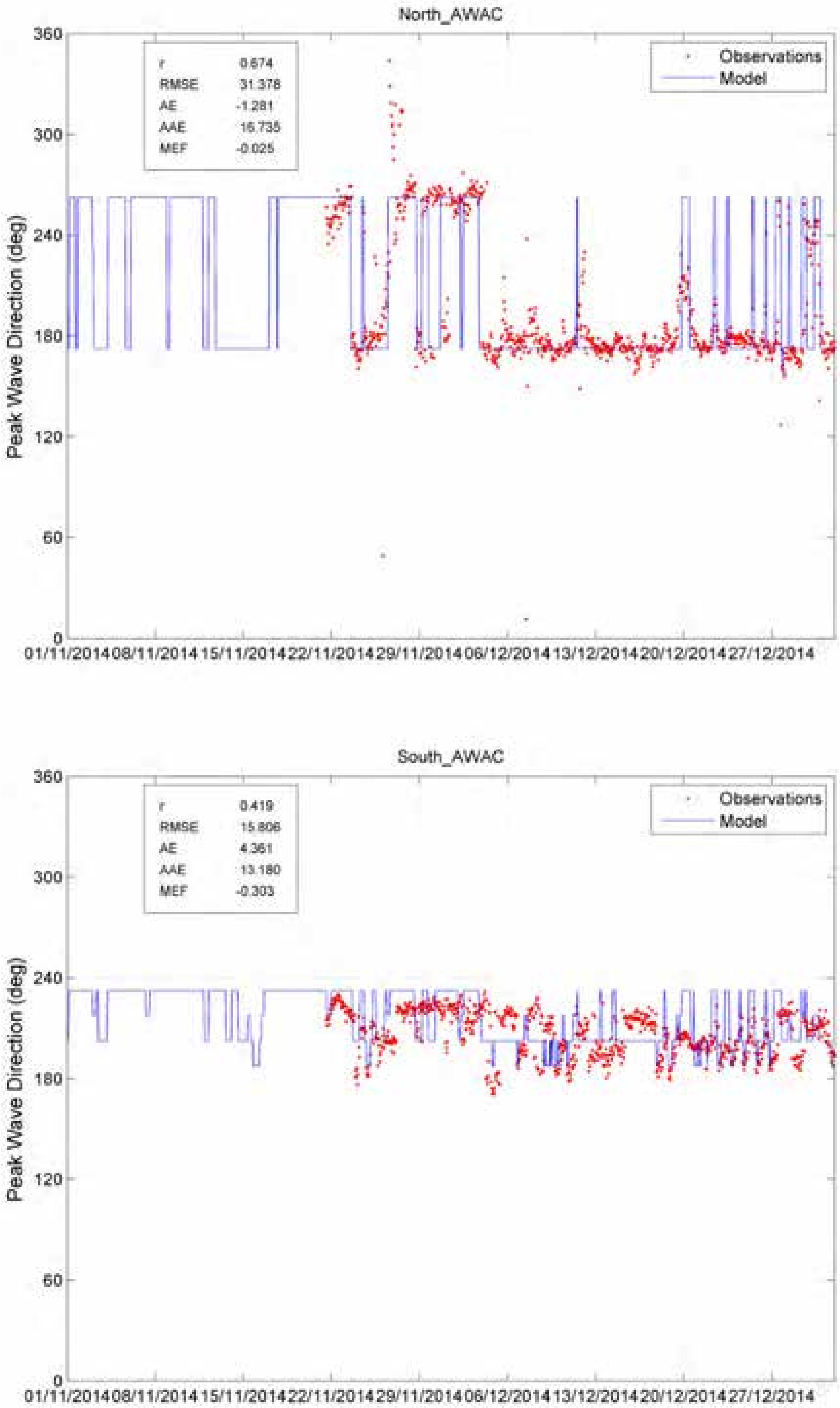

Figure B-41 Wave direction at regional sites – Nov 2014 to Mar 2015 deployment

BMT WBM Bangalow	6/20 Byron Street, Bangalow 2479 Tel +61 2 6687 0466 Fax +61 2 66870422 Email bmtwbm@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Brisbane	Level 8, 200 Creek Street, Brisbane 4000 PO Box 203, Spring Hill QLD 4004 Tel +61 7 3831 6744 Fax +61 7 3832 3627 Email bmtwbm@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Denver	8200 S. Akron Street, #B120 Centennial, Denver Colorado 80112 USA Tel +1 303 792 9814 Fax +1 303 792 9742 Email denver@bmtwbm.com Web www.bmtwbm.com
BMT WBM London	International House, 1st Floor St Katharine's Way, London E1W 1AY Email london@bmtwbm.co.uk Web www.bmtwbm.com
BMT WBM Mackay	PO Box 4447, Mackay QLD 4740 Tel +61 7 4953 5144 Fax +61 7 4953 5132 Email mackay@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Melbourne	Level 5, 99 King Street, Melbourne 3000 PO Box 604, Collins Street West VIC 8007 Tel +61 3 8620 6100 Fax +61 3 8620 6105 Email melbourne@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Newcastle	126 Belford Street, Broadmeadow 2292 PO Box 266, Broadmeadow NSW 2292 Tel +61 2 4940 8882 Fax +61 2 4940 8887 Email newcastle@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Perth	Level 3, 20 Parkland Road, Osborne, WA 6017 PO Box 1027, Innaloo WA 6918 Tel +61 8 9328 2029 Fax +61 8 9486 7588 Email perth@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Sydney	Level 1, 256-258 Norton Street, Leichhardt 2040 PO Box 194, Leichhardt NSW 2040 Tel +61 2 8987 2900 Fax +61 2 8987 2999 Email sydney@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Vancouver	Suite 401, 611 Alexander Street Vancouver British Columbia V6A 1E1 Canada Tel +1 604 683 5777 Fax +1 604 608 3232 Email vancouver@bmtwbm.com Web www.bmtwbm.com

Oct 15

Midwest Zone Aquaculture Modelling

Sediment quality impact assessment

FINAL

Dan Paraska, Louise Bruce and Matthew Hipsey

Report prepared for: BMT Oceanica

The University of Western Australia

School of Earth and Environment
University of Western Australia

AED

DOCUMENT AND PROJECT DETAILS:

Document title:	*Sediment quality impact assessment*
Document author(s):	Dan Paraska, Louise Bruce, Matthew Hipsey
Project title:	Midwest Zone Aquaculture Modelling
Project investigators:	Glenn Shiell, Michael Barry, Matthew Hipsey
Client organisation:	BMT Oceanica ex WA Department of Fisheries
Client contacts:	Glenn Shiell (Glenn.Shiell@bmtocenica.com.au)
Synopsis:	This report outlines technical details associated with modeling the sediment response to proposed rates of fish-waste deposition. Threshold deposition fluxes for recovery times are defined.

REVISION AND DISTRIBUTION HISTORY:

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*) E: electronic, H: hardcopy

RELEASE STATUS:

Confidential: YES

Table of Contents

A. Introduction & Objectives

This report assesses the potential effect of fish farm waste deposition on the biogeochemistry of marine sediment. The analysis is a component of a larger modelling investigation being undertaken to assess any potential environmental impacts associated with aquaculture operations, proposed to be placed among the Abrolhos Islands, off the Western Australian coast.

A.1. Background

Finfish aquaculture is an increasingly important contributor to the global food supply (Tacon and Metlan 2013). However, the challenge for regulatory agencies is that the intensive nature of aquaculture cages leads to local environmental impacts, including degradation of water and sediment quality. The high concentration of fish in the cages is known to create a high rate of organic matter deposition to the sea floor beneath the cage, primarily from the deposition of faeces and uneaten food. The organic matter drives the metabolism of sediment bacteria and triggers a series of chemical reactions that cause deterioration of the health of the sediment environment. In particular, accumulation of high concentrations of labile organic matter drive dissolved oxygen consumption and excessive hydrogen sulfide production, ultimately leaving the sediment environment uninhabitable for benthic infauna (Hargraves et al. 2008).

For successful planning and management of cage installations it is therefore essential to identify the critical amounts of organic matter deposition, and therefore stocking densities, that lead to sulfidic conditions and the unacceptable loss of benthic infauna. However, there is no simple relationship between organic matter influx and the resulting sediment chemical concentrations that can be applied to all environments. Hargrave et al (2008) provide a synthesis of a diversity of empirical studies, however, measurements of the sediment are difficult to obtain because of the fine spatial and temporal scale that needs to be measured below the seabed surface. Other studies summarising sediment quality impacts from finfish aquaculture have been reported by Macleod and Forbes (2004), Tanner and Fernandes (2007), Fernandes and Tanner (2008) and Volkman et al. (2009).

There are limited publications describing the use of modelling tools for assessment of aquaculture impacts to sediment. In this report, a sediment biogeochemical model was used to simulate the concentrations of sediment chemical processes in coastal sediment typical of the Abrolhos region, using an approach based on previously-published models and other empirical research. Model simulations were undertaken to explore the sensitivity of sediment chemical profiles to a wide range of rates of organic matter loading from fish-cage waste. The simulations were setup to allow us to test the impact of cages that could be in place for between one - five years before being moved, both during and after cage operation.

A.2. Scope of work

This report summarises a work-package which is part of the Modelling and Technical Studies associated with the Environmental Impact Assessment (EIA) for the Mid-West Aquaculture Development Zone (BMT Oceanica, 2015). The aim of the analysis was to provide relationships allowing us to:

- quantify the extent of changes in sediment chemical concentrations and dissolved fluxes at the sediment water interface during aquaculture operations,
- predict the time needed for the sediment chemical concentrations to return to pre-fish farming conditions, and
- identify indicative thresholds of organic matter loading, above which the loss of benthic integrity is likely to occur.

The approach taken to develop the relationships between organic matter deposition rate and duration and sediment response was to first develop a comprehensive sediment diagenesis model able to predict the physical, chemical and biological processes within the seabed sediment. The model used is called CANDI-AED, and in order to demonstrate the suitability of the model, it was benchmarked against a commonly used data and parameter set of Van Cappellen and Wang (1996).

The model was then tailored to coastal sediment typical of the Abrolhos region, and calibrated to match available field data, primarily total organic carbon (TOC), total nitrogen (TN) and total phosphorus (TP) concentrations. Simulations were then run with 5 years of no aquaculture (spin-up), then under 1-5 years of fish-waste deposition (operation period), and then seven (+) years with no cage deposition when the sediment was able to recover to pre-farming condition.

Relationships between organic matter deposition flux and i) surficial chemical concentrations, ii) sediment-water nutrient fluxes and iii) recovery times were then established. Deposition rates over a wide range from 1×10^2 to 5×10^6 mmol C m^{-2} y^{-1} were assessed to explore how the sediment would respond to a wide range of conditions to capture the variation in stocking densities and distance from the cages. Thresholds relevant to management for low, moderate and high impacts were then defined.

A.3. Relationship with hydrodynamic-biogeochemical modelling

The simulation results within this analysis are not directly assessing scenarios as undertaken in the main EIA document, but rather establish the relationship between the deposited material at the sediment-water interface and the likely response. The relationships presented herein can therefore be used in conjunction with the main hydrodynamic-biogeochemical models of the water column used within the EIA (Figure 1).

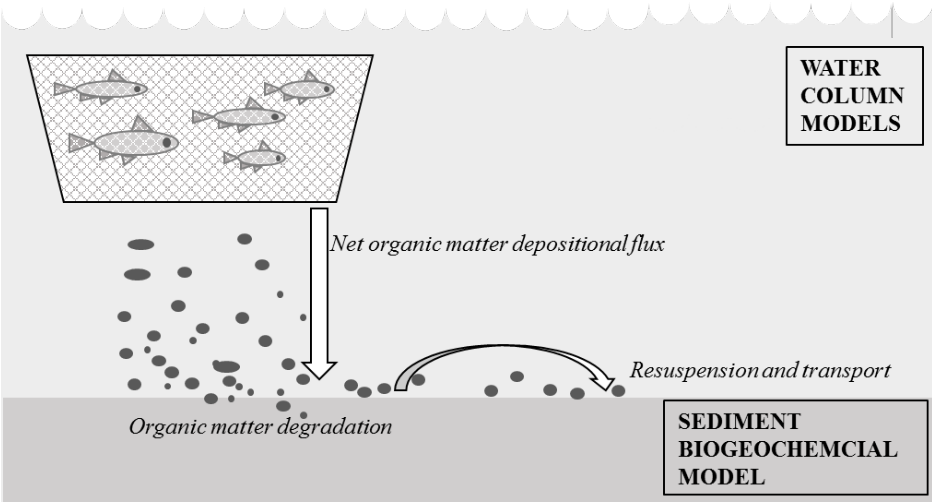

Figure 1. Schematic diagram of cage impacts on underlying sediment. Fish waste may be simulated as particles released from cages within a 3D hydrodynamic model (e.g. TUFLOW-FV). The deposited particle mass at any location is accumulated and forms the basis of the depositional flux that drives the sediment biogeochemical model. The focus on this analysis is to understand how the organic matter accumulation and degradation impacts sediment quality for a range of depositional rates.

The relationships and thresholds defined in this report are designed to be used with the hydrodynamic-particle tracking model (BMTWBM, 2015). Specifically, the model TUFLOW-FV was used to predict:

- the relationship between fish stocking density and resulting organic matter deposition rate to the sediment-water interface for any given cage operation and oceanographic scenarios;
- the spatial extent of deposition due to transport through the water column and resuspension of material across the sediment surface.

In order to provide an overview of how waste deposition may vary for any given stocking scenario and set of oceanographic conditions, an example plot of waste deposition flux is shown in Figure 2. For detail on the approach and assumptions used to predict the waste export from the cage clusters and the associated process of transport and sedimentation to the seabed, then readers should refer to BMT Oceanica (2015).

For any location in the above domain the deposition flux rate must be converted to a prediction of sediment response, which is the focus of this report. The sediment model may feedback to water column biogeochemistry as the particles decay and consume oxygen and release inorganic nutrients. The results of the present analysis (Section H1) quantify the relationship between deposition and dissolved flux in order for a spatially variable flux to be assigned.

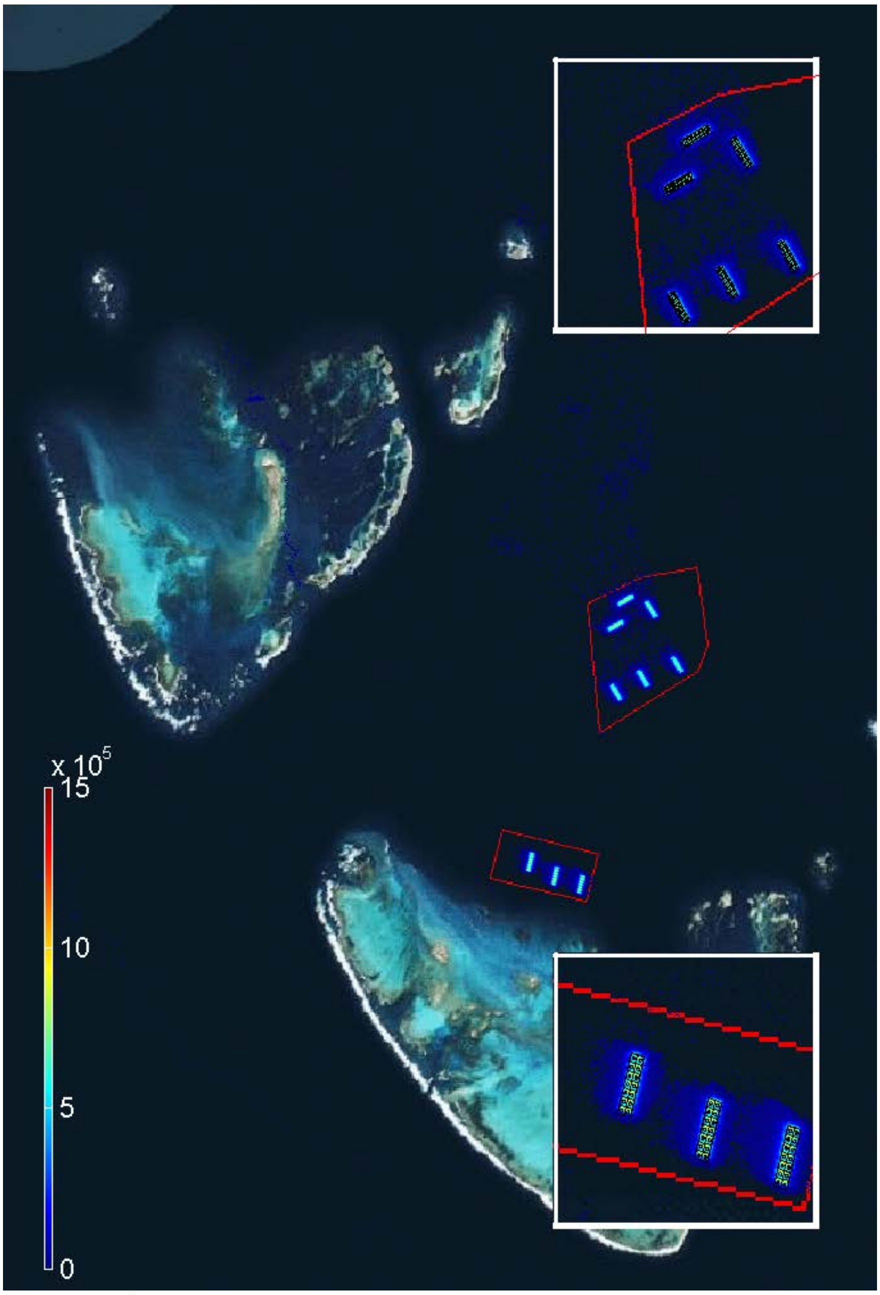

Figure 2. An example map of waste deposition (mmol C m^{-2} y^{-1}) that is output from the TUFLOW-FV particle transport model. After release from the cage clusters, particles are subject to advection, sedimentation and resuspension prior to their resting in their final deposition location. The map is an indicative scenario only of 1 year of cage operations.

B. Review

The most notable published assessment of aquaculture impact on sediment quality is by Brigolin et al. (2009), who used a sediment diagenesis model. In this study they applied a deposition flux of fish waste of between 2×10^{2} and 3×10^{5} mmol C $m^{-2}y^{-1}$. Additional sources used for guidance in this project are given in Table 1.

Table 1. Reports and journal articles that review the effects of aquaculture on coastal and estuarine environments.

Reference	Study site
Macleod & Forbes 2004	Finfish in Tasmania
Tanner and Fernandes 2007	Fitzgerald Bay in Spencer Gulf, South Australia
Fernandes and Tanner 2008	Fitzgerald Bay in Spencer Gulf, South Australia
Brigolin et al. 2009	Salmon in Loch Creran, Scotland
Volkman et al. 2009	Huon Estuary and D'Entrecasteaux Channel, Tasmania

C. Study Site and Data Available

The site is located approximately 80 km off the Geraldton coast of Western Australia. Available background sampling sites for sediment and water quality parameters are shown in Figure . Refer to the associated report by BMT Oceanica (2015) for detail on the sediment and water column dataset.

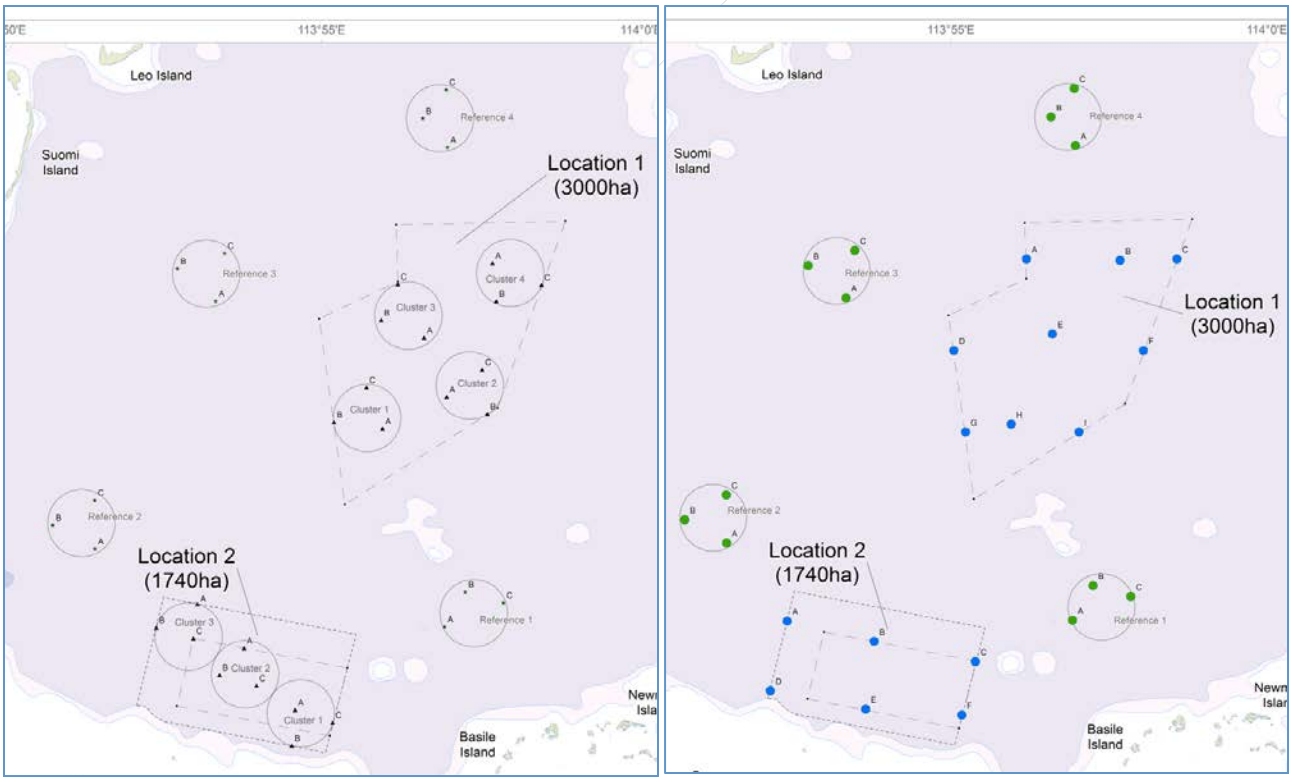

Figure 3. Benthic sampling sites from BMT Oceanica (2015). The potential aquaculture sites are labelled as Locations 1 and 2, within which are clusters 1 to 4, within which are points A, B and C. The four reference sites have only the subcategories of points A, B and C. Thus the sediment field data labels follow the format sediment-location/reference-cluster-point, for example SL1-1-A (sediment location 1, cluster 1, point A), or SR1-A (sediment reference 1, point A). The data available for these sites is sediment quality data.

D. Model Description and Capability

D.1 Sediment biogeochemical model

After the particulate matter is deposited, the sediment biogeochemical model undertakes the vertical transport and reaction calculations to simulate sediment conditions and also to produce a sediment flux for associated water column models. The diagenesis model used for this report was an extension of the Carbon and Nutrient Diagenesis model (CANDI) by Boudreau (1996) that was an implementation of original work by Berner (1980). Similar models by Van Cappellen and Wang (1996) and Soetaert et al. (1996) were also introduced and the three models are now widely used for sediment assessment across a range of marine and coastal environments. For an overview of the theory and applications of sediment diagenesis models that have been developed refer to the review by Paraska et al. (2014).

The diagenesis model solves the 1D advection-dispersion-reaction equation for numerous particulate and dissolved chemicals numerically over spatial and temporal steps. It is common to assume that vertical gradients in chemical concentration dominate over horizontal gradients, and therefore the model is resolved with layers of depth, the thickness of which increase exponentially (from mm to cm). The transport reactions include vertical diffusion and advection, where advection is the progress of each layer downwards relative to the sediment-water interface, caused by deposition. Diffusion is a result of chemical diffusion due to chemical concentration gradients for solutes, and bioturbation and bioirrigation in the upper layers of sediment where benthic infauna mix both solutes and solids.

The chemical reactions that occur following organic matter accumulation can be broadly defined as primary and secondary reactions, summarised in Figure 4. Primary reactions are microbially-driven breakdown reactions of organic matter via the series of six redox pathways (Figure, Appendix B), and are the driving force of most of the other chemical reactions that take place in the sediment. In this context, a large deposition of fish food and faecal matter serve to shift chemical concentrations away from the natural equilibrium that occurs in oligotrophic marine waters. Secondary reactions are the redox reactions of the by-products of primary reactions (Appendix B), such as reduced iron and H_2S, as well as acid-base reactions, precipitation-dissolution reactions and adsorption-desorption reactions (Appendix B).

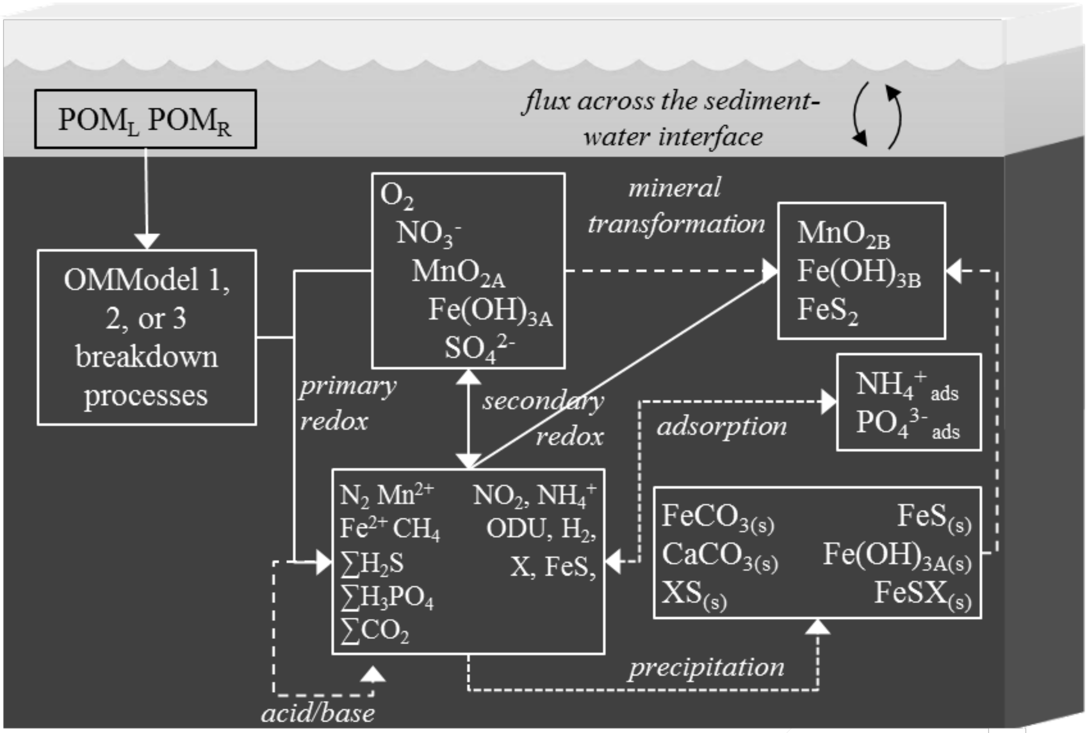

Figure 4. CANDI-AED includes chemical processes of organic matter transformation and oxidation, and reduction/oxidation, crystallisation, adsorption and precipitation reactions of inorganic by-products. Most of the processes are triggered by the input of Particulate Organic Matter (POM) at the sediment-water interface. X is any metal cation that can precipitate with S^{2-} or FeS.

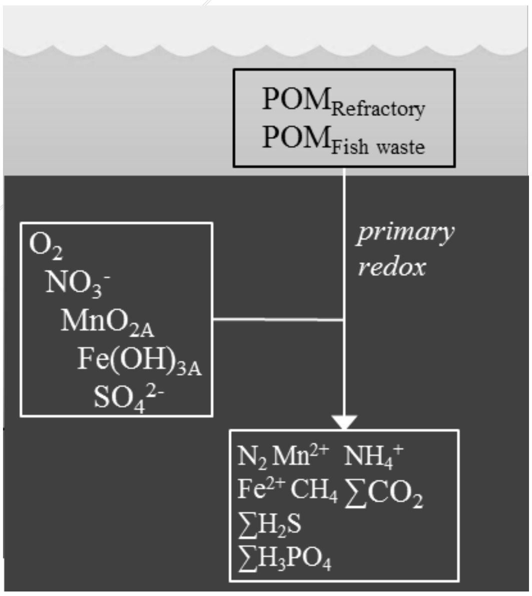

Figure 5. Organic matter degradation conceptual model used in this project. Background “refractory” organic matter and fish farm waste are degraded by sediment bacteria, which use different oxidation pathways to oxidise organic matter to CO_2 and the shown by-products.

E. Model Setup & Application

E.1 General model setup and parameter selection

Since there was limited local depth-resolved pore-water and sediment constituent data for the site, simulations were first undertaken to benchmark the simulation against a commonly used ocean sediment biogeochemical model. The details of this simulation can be found in Appendix B.

The model domain was then configured to be representative of the Abrolhos sediment, using a vertical grid of >50 layers. The basic setup was that the model was run for 17 years, including a 5 year period of no aquaculture, 5 years of aquaculture and then seven years for recovery (Figure 6). For the first five years of 'spin up', with no fish waste deposition, the concentrations of refractory (background) organic matter, total phosphorus and total nitrogen were calibrated to be equal to the field data values collected for the region (see Section C). The spin up was followed by either one, two, three or five years of farming, and for each ten different simulations were run, each with an incremental increase in the flux of organic carbon derived from fish farm waste (Table 2). The remaining parameter setup is given in Tables 3-5.

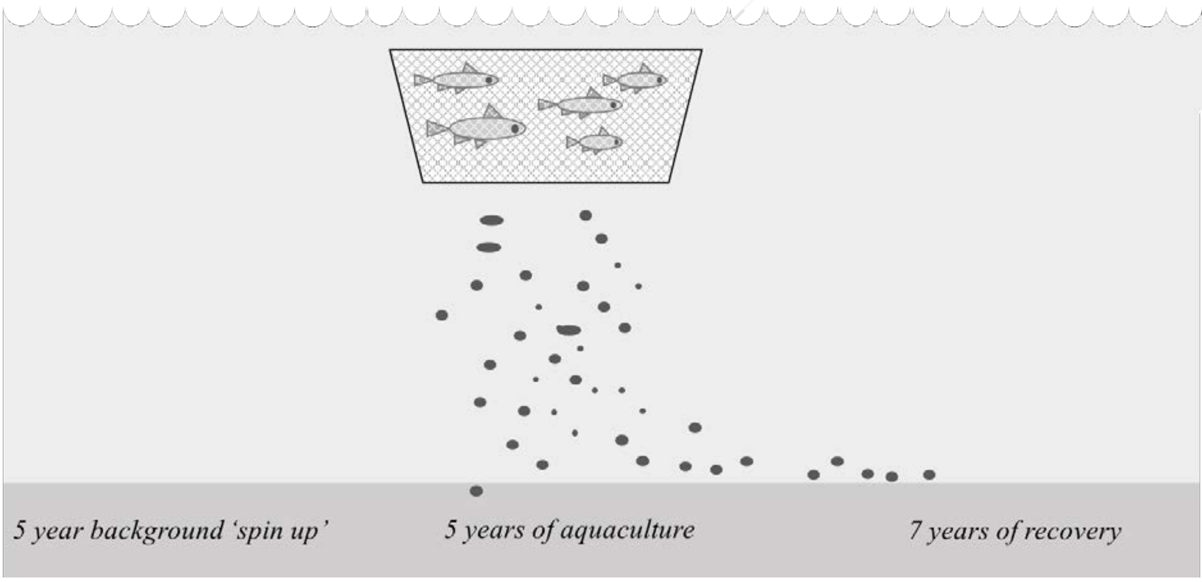

Figure 6 Basic setup for the simulations. A 17 year simulation was run firstly for 5 years with only background organic matter inputs, then aquaculture waste for 5 years, then 7 years of simulation with no aquaculture waste, during which the sediment could recover to pre-aquaculture conditions.

Table 2 Ten sets of simulations were run, each with an increased organic matter flux from aquaculture waste.

Simulation number	Organic matter flux (mmol m^{-2} y^{-1})	Simulation number	Organic matter flux (mmol m^{-2} y^{-1})
1	1×10^2	6	5×10^4
2	5×10^2	7	1×10^5
3	1×10^3	8	5×10^5
4	5×10^3	9	1×10^6
5	1×10^4	10	5×10^6

Table 3 Kinetic redox constants for refractory organic matter oxidation and secondary redox reactions.

Symbol	Value (y^{-1})	Description
k_{POMR}	0.005	Kinetic constant for oxidation of refractory organic matter by bacteria
k_{MnOx}	0.0	Kinetic constant for oxidation of Mn^{2+} by O_2
k_{FeOx}	1.45×10^{5}	Kinetic constant for oxidation of Fe^{2+} by O_2
k_{CH4Ox}	1×10^{7}	Kinetic constant for oxidation of CH_4 by O_2
k_{FeSOx}	3.2×10^{2}	Kinetic constant for oxidation of FeS by O_2
k_{FeS_2Ox}	0.0	Kinetic constant for oxidation of FeS_2 by O_2
k_{MnNO3}	0.0	Kinetic constant for oxidation of Mn^{2+} by NO_3^-
k_{FeNO3}	0.0	Kinetic constant for oxidation of Fe^{2+} by NO_3^-
k_{HSNO_3}	0.0	Kinetic constant for oxidation of HS^- by NO_3^-
k_{FeMn}	3×10^{3}	Kinetic constant for oxidation of Fe^{2+} by MnO_2
k_{HSMn}	2×10^{1}	Kinetic constant for oxidation of FeS_2 by MnO_2
k_{FeSMn}	0.0	Kinetic constant for oxidation of FeS by MnO_2
k_{HSFe}	8.0	Kinetic constant for oxidation of HS^- by $Fe(OH)_3$
k_{FeSFe}	0.0	Kinetic constant for oxidation of FeS by $Fe(OH)_3$
k_{CH4SO4}	10.0	Kinetic constant for oxidation of CH_4 by SO_4^{2-}
$k_{FeOH(s)}$	0.0	Kinetic constant for precipitation of $Fe(OH)_{3A}$
$k_{FeS(s)}$	1.5×10^{-1}	Kinetic constant for precipitation of FeS
$k_{FeCO(s)}$	2.5×10^{-1}	Kinetic constant for precipitation of $FeCO_3$
$k_{CaCO(s)}$	0.0	Kinetic constant for precipitation of $CaCO_3$

Table 4 Monod half saturation constants for limitation and inhibition between organic matter redox pathways (mmol L^{-1}).

F_{TEA}		
K_{O_2}	2×10^{-2}	Monod constant for O_2 limitation
$K_{NO_3^-}$	5×10^{-3}	Monod constant for NO_3^- limitation
K_{MnO_2}	16	Monod constant for MnO_2 limitation
$K_{Fe(OH)_3}$	100	Monod constant for $Fe(OH)_3$ limitation
$K_{SO_4^{2-}}$	1.6	Monod constant for SO_4^{2-} limitation

Table 5 Initial and boundary conditions

Variable	Initial concentration (mmol L^{-1})	Bottom water concentration (μ mol L^{-1})	Solid flux (mmol m^{-2} y^{-1})
O_2	231	231	-
SO_4^{2-}	28 000	28 000	-
PO_4^{3-}	0.0	500	-
NH_4^+	0.0	0.25	-
CH_4	0.0	0.0	-
HCO_3^-	2.5×10^{3}	2.5×10^{3}	-
H_2S	0.0	0.0	-
POC_R	450 000	-	500
Mn^{2+}	0.0	2	-
NO_3^-	0.0	0.0	-
MnO_{2A}	0.0	400	-
MnO_{2A}	0.0	0.0	-
$MnCO_3$	1000	0.0	-
Fe^{2+}	0.0	0.0	-
$Fe(OH)_{3A}$	0.0	-	750
$Fe(OH)_{3B}$	0.0	-	0.0
FeS	0.0	-	0.0
FeS_2	0.0	-	0.0
$FeCO_3$	1000	-	0.0
Ca^{2+}	0.0	0.0	-

E.2 Defining fish cage outputs and deposition flux

The deposition of particulate organic matter derived from waste fish food and fish faeces varies depending: a) on the stocking density of the cages and b) on the level of hydrodynamic advection and dispersion that occurs from the release point at the base of the cage to the seabed. These two aspects must be simulated by a hydrodynamic model to estimate the deposition flux at the sediment-water interface.

In order to build a general relationship, here we run the model over a wide range of deposition fluxes to create a continuous relationship between flux and response. The range is intended to cover variation both due to high and low stocking densities, and neat and far proximity to the cage base. For all simulations, the C:N:P ratio of deposited material was fixed at 9.09 : 0.76 : 1, which was a P-rich mixture based on fish food input values supplied by BMT Oceanica (2015).

E.3 Stochastic approach for assessing predictive uncertainty

From a water quality management perspective it is necessary to have a quantitative understanding of how the range of parameter uncertainties in the deterministic model predictions is relevant to the decision-making process. Therefore, simulations were run with a basic setup as described above, but forty repeated simulations were run with randomly-generated parameter values for the key uncertain parameters listed below (Table 6). The forty results were then compiled and the median value was calculated, along with the 5, 10, 25, 75, 90 and 95th percentile results. These have been assessed for specified depths below the seabed at all times.

Parameters assessed include the biodiffusion and bioirrigation coefficient since these impact significantly the ability of oxygenated bottom water to penetrate into the sediment. While these are designed to account for surficial blending of the surface sediment due to infauna, the latter also is able to account for potential flushing of the surficial layers due to wave-induced pore-water pumping.

Table 6 Parameter values from which a random value was selected for the uncertainty calculations.

Parameter name	Range	Unit	Parameter description
Db0	0 to 40	$cm^2\ y^{-1}$	Surface biodiffusion rate
xs	0 to 5	cm	Half depth for Gaussian distribution of bioturbation
w00	0.05 to 5	$cm\ y^{-1}$	Sediment particle burial velocity
p0	0.7 to 0.99	water/space	Porosity at the sediment-water interface
p00	0.0 to 0.1	water/space	Porosity at depth
pomspecial2dic	1 to 50	y^{-1}	Kinetic oxidation constant of fish-derived organic matter
knh4ox	900 to 2000	y^{-1}	Kinetic oxidation constant for NH_4^+ by O_2
ktsox	1 to 1000	y^{-1}	Kinetic oxidation constant for H_2S by O_2
xirrig	0 to 5	cm	Maximum irrigation depth by benthic infauna

F. Baseline Conditions Simulation

Using the assigned initial conditions and kinetic parameters representative of the Abrolhos coast, the model predicts the baseline conditions after a 5-year 'spin up' period, before the onset of fish farming. The resulting profiles of sediment concentrations are common to all simulations and form the reference condition by which the aquaculture impacts were then assessed (Figure). They have the characteristic high oxygen penetration depth (~10cm), dominance of iron oxides (with limited reduced Fe), and absence of metal sulfides. Whilst limited data is available the models captures typical concentrations of TOC, TN and TP observed in the field.

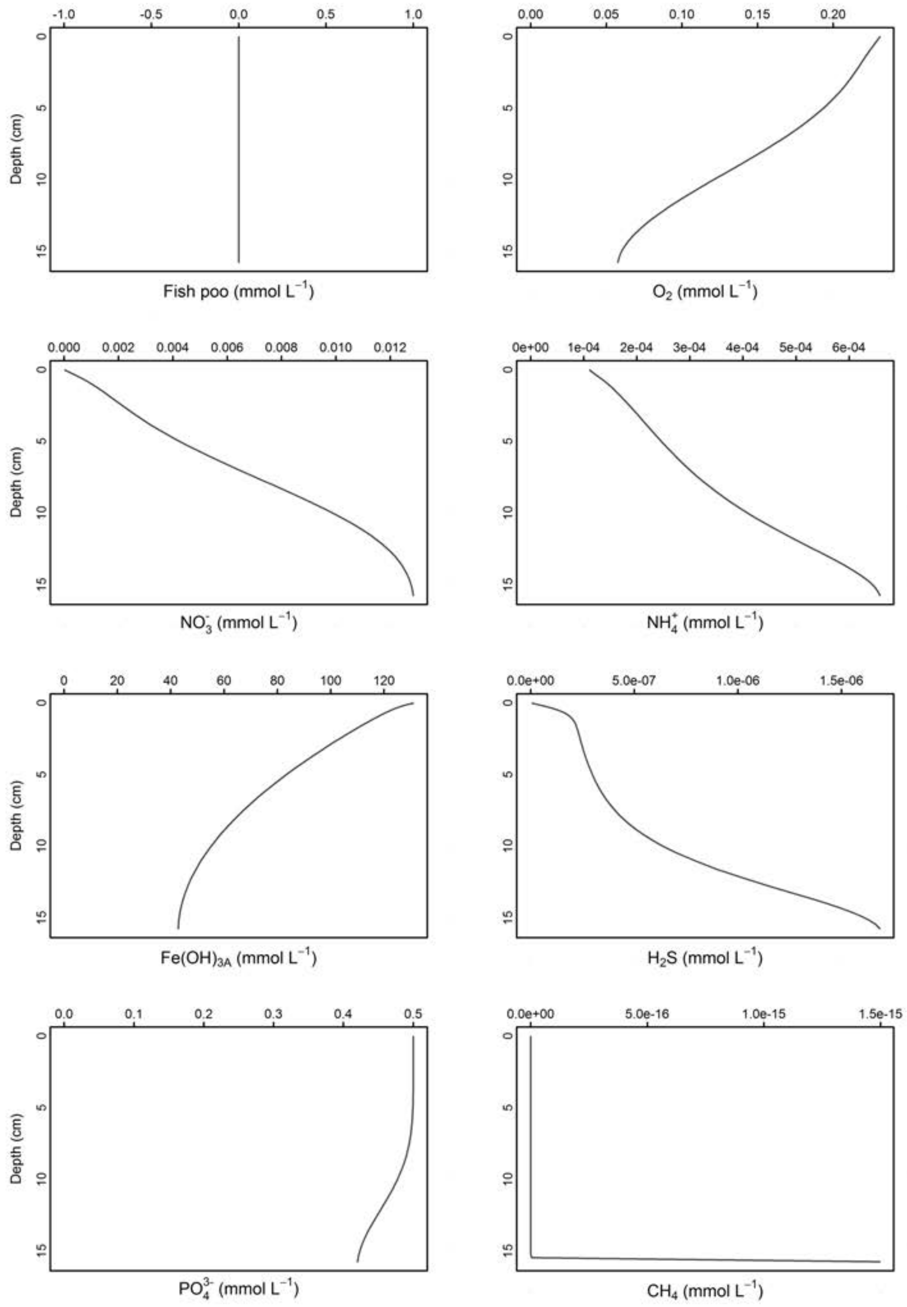

Figure 7. Depth profiles of the main sediment constituents based on the Abrolhos representative configuration.

G. Changes to Sediment Condition During Fish Farming

This section outlines how the sediment concentration profiles vary under low and high rates of additional organic matter deposition from the fish waste. Two rates are explored in detail here, 5×10^3 and 1×10^5 mmol C m^{-2} yr^{-1}; these are approximately equivalent to (0.0012 to 60 kg waste m^{-2} yr^{-1}) of total waste material, respectively. These are intended to demonstrate the range of impacts that can occur directly under densely stocked cages or in distinct areas that receive only minor deposition.

G1 - Low waste deposition rate: 5×10^3 mmol C m^{-2} y^{-1}

With a low fish waste deposition flux, the effects on sediment concentration during aquaculture are low but nevertheless visible relative to base conditions (Figure 8). The oxygen penetration depth reduces to <1cm, denitrification increases and reduces nitrate, and ammonium builds up. The change in sediment fluxes is also shown (Figure 9). Figure 10 shows the depth – concentration changes during and after 5 years of aquaculture.

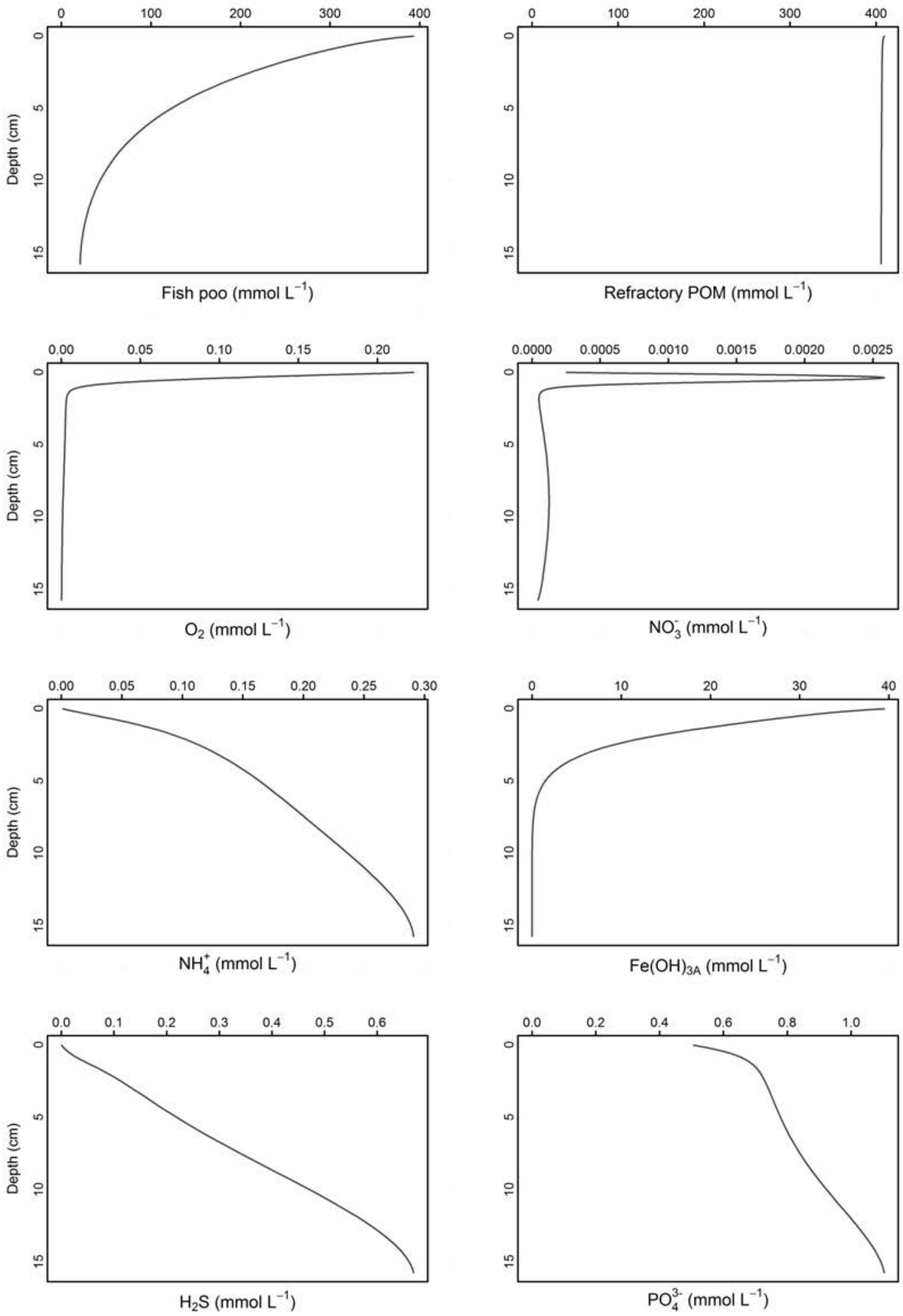

Figure 8. Sediment concentration depth profiles for other chemical variables at 10 years from the simulation start (5 years of aquaculture). Note scale differences relative to Figure 7.

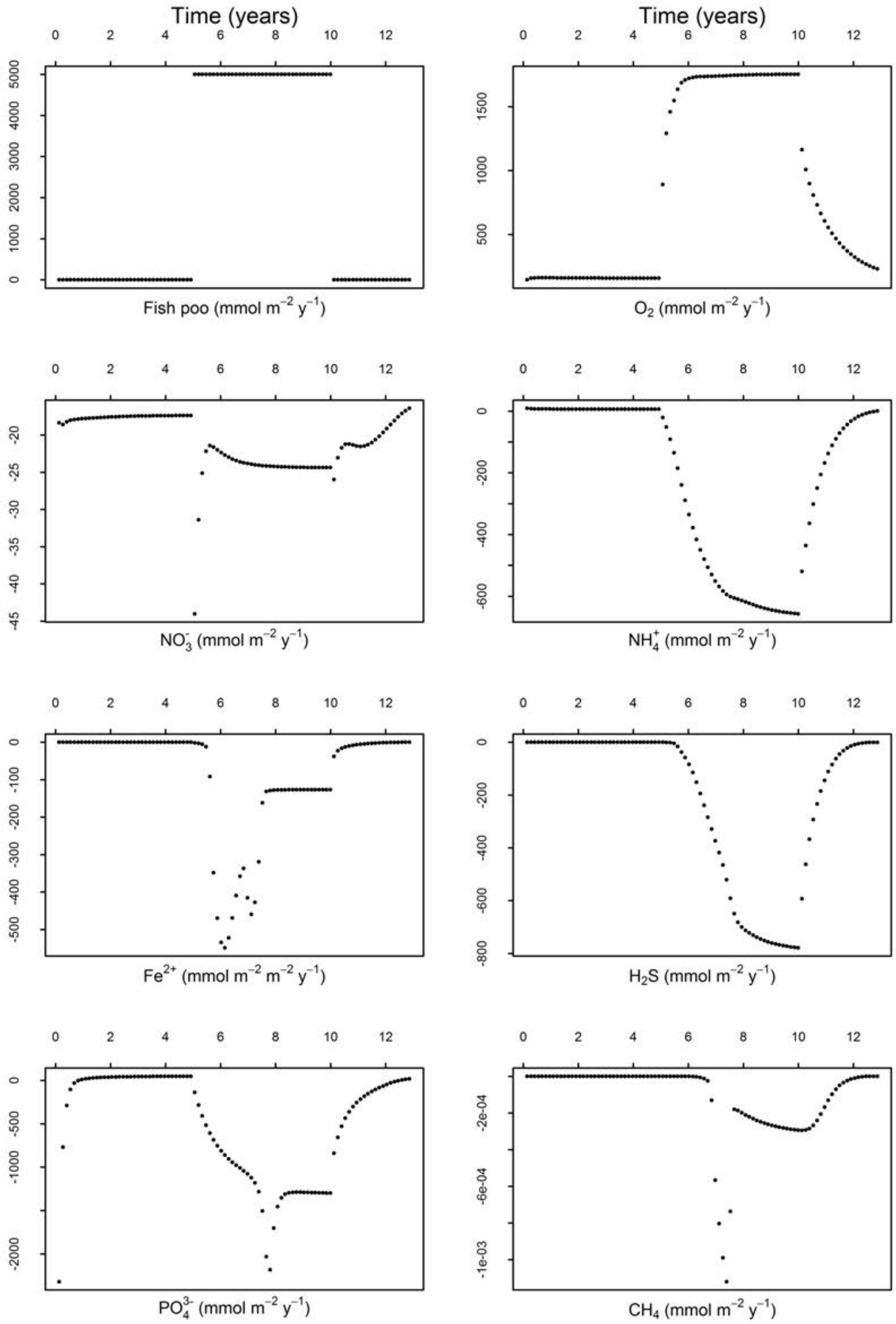

Figure 9. Fluxes at the sediment-water interface for key variables (mmol m^{-2} y^{-1}). The x axis is time, with 5 years of spin up, then aquaculture, then recovery. The y axis is flux in mmol m^{-2} sediment y^{-1}, where a positive value indicates a drawdown into the sediment and negative value indicates production in the sediment and diffusion to the water column. The simulation assumes a deposition rate of 5×10^3 mmol m^{-2} y^{-1}, for 5 year operation period.

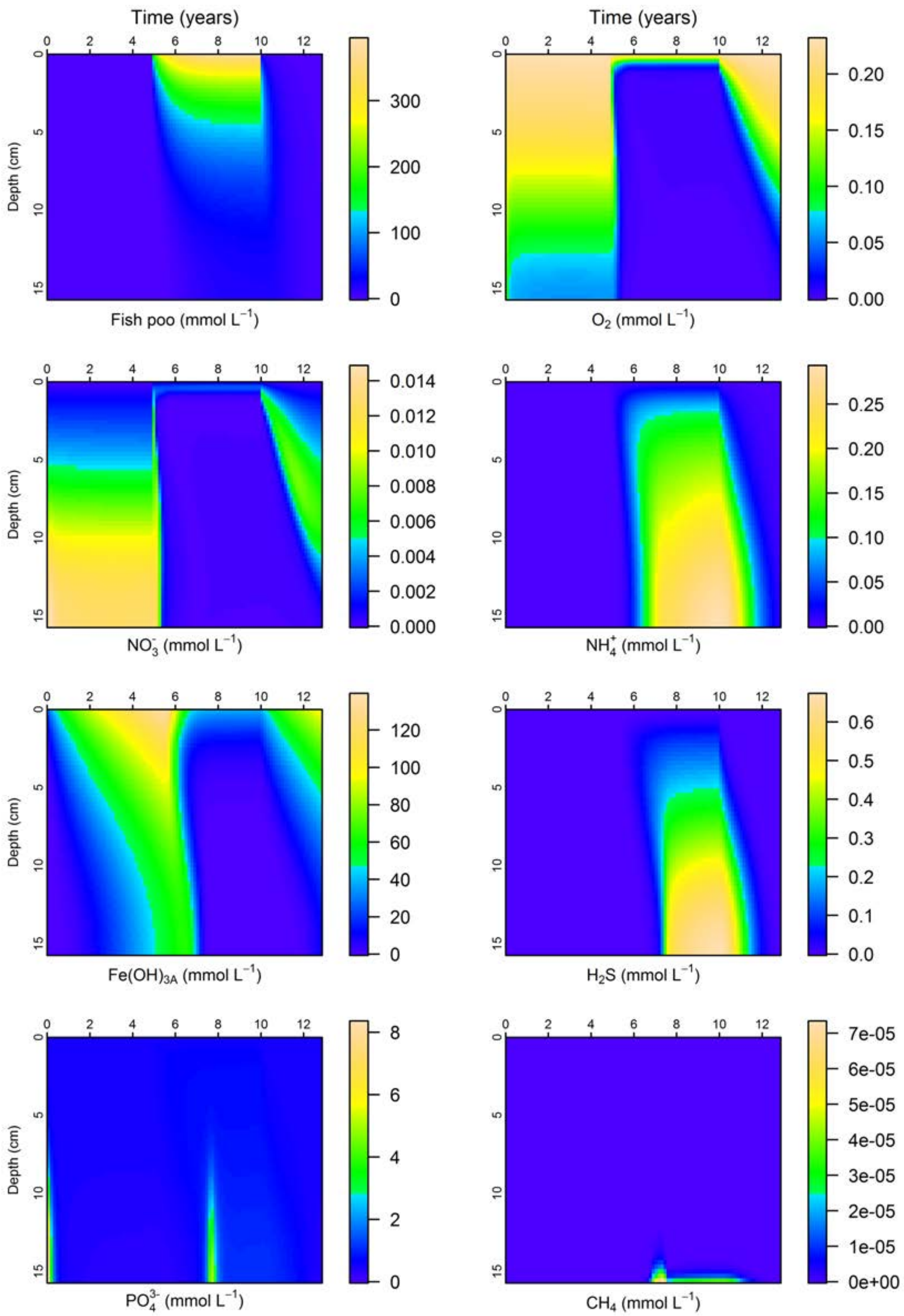

Figure 10. Contour plots of sediment concentrations, with the x-axis indicating time (y), the y-axis indicating depth into the sediment (cm). The colour bar is concentration of the relavant consituent (mmol L^{-1}), with the variation highlighting the changes that occur across the profile from 5-10 years, and the subsequent recovery.

G2 - High rate of waste deposition: 1×10^5 mmol C m^{-2} y^{-1}

Under conditions of high waste export, the organic matter content within the sediment becomes dominated by fish waste (Figure 11). The sediment becomes highly anaerobic with profiles of O_2, NO_3^- and $Fe(OH)_3$ concentrations all tending to zero, and strong accumulation of NH_4^+ and PO_4^{3-} as well as reduced by-products

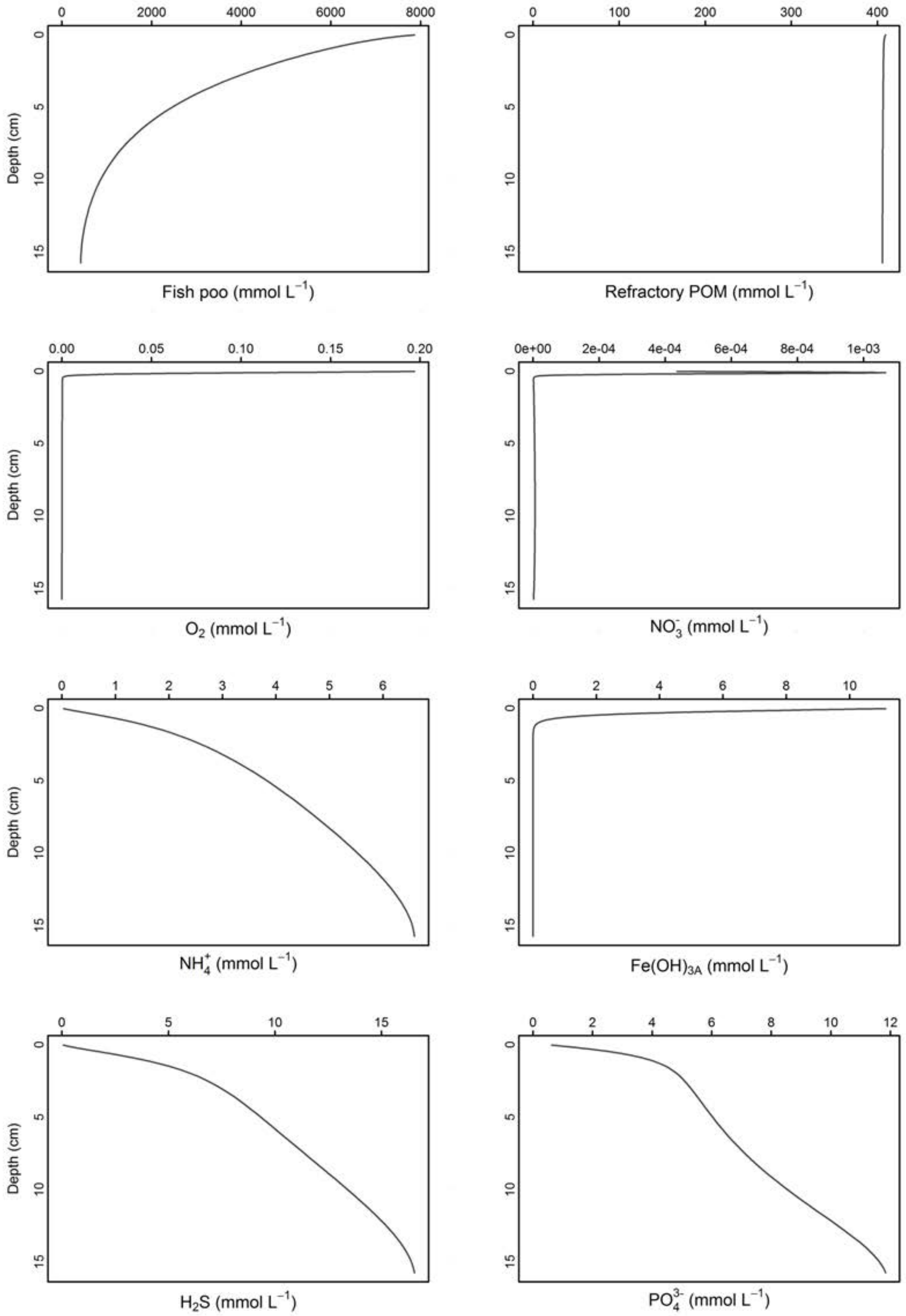

Figure 11. Sediment concentration depth profiles for other chemical variables after 5 years of aquaculture.

Under these conditions the sediment responds with a much higher outflux of NH_4^+ and PO_4^{3-} (Figure 12). There was also an outflux of Fe^{2+}, H_2S and CH_4, because the lower energy (anaerobic) redox pathways become engaged at these high organic matter loadings.

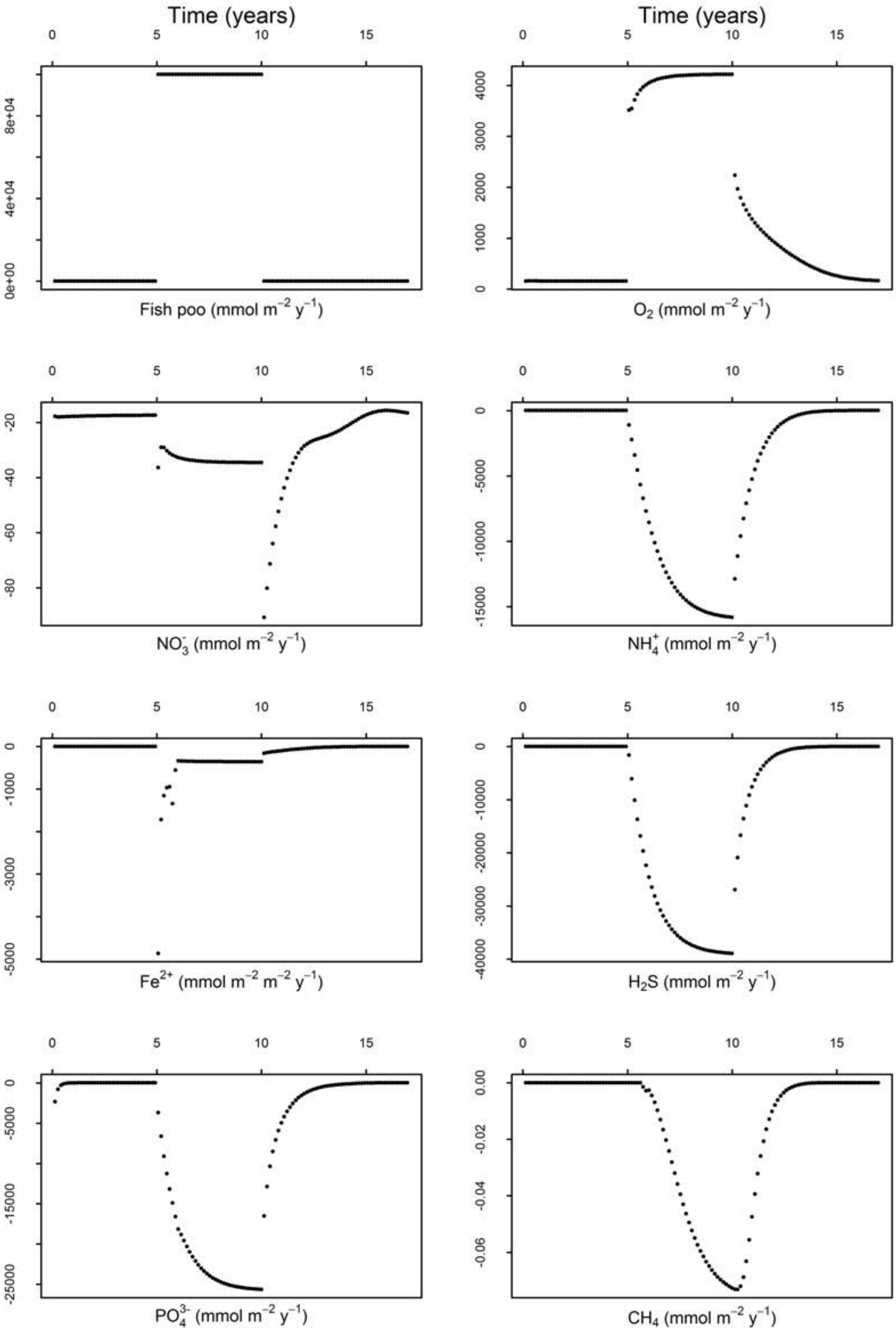

Figure 12. Fluxes at the sediment-water interface for key variables (mmol m^{-2} y^{-1}). The x-axis is the time (y). The simulation assumes a deposition rate of $1x10^5$ mmol m^{-2} y^{-1}, for 5 year operation period.

When considering the concentrations across all depths and all time, the effect of this fish waste flux is very clear (Figure 13). Most solutes appear to recover to their pre-farming condition within 2-3 years, apart from O_2. Solid $Fe(OH)_3$ also takes a relatively long time to recover. The images in Figure 13 illustrate the effect on the sediment, but the recovery time is not quantified precisely (refer to Section H).

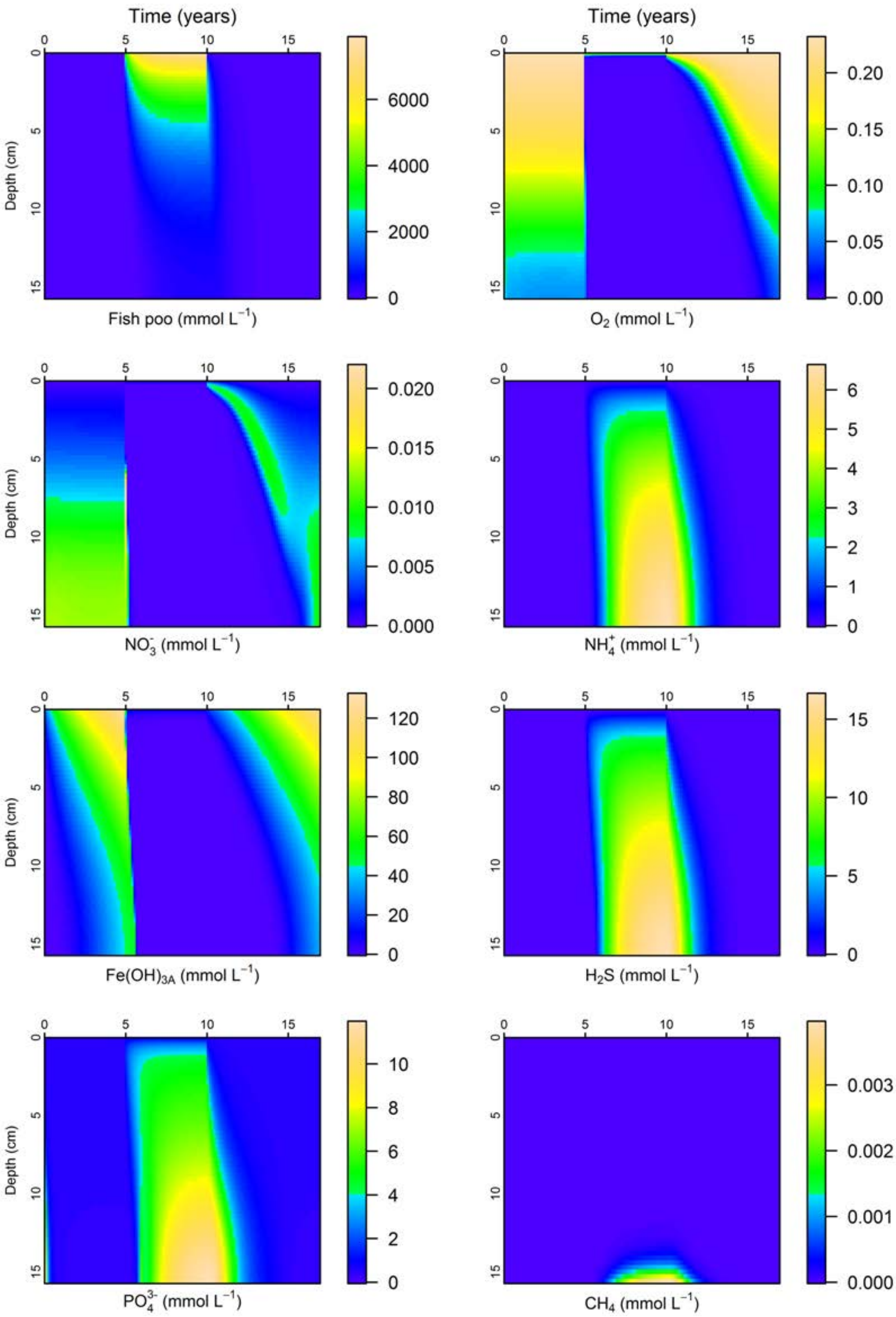

Figure 13. Contour plots of sediment concentrations, with the x-axis indicating time (y), the y-axis indicating depth into the sediment (cm). The colour bar is concentration of the relevant consituent (mmol L^{-1}), with the variation highlighting the changes that occur across the profile from 5-10 years, and the subsequent recovery.

H. Relationships between deposition and sediment response

The previous section demonstrated changes to sediment conditions near the upper and lower limits of fish waste deposition rates. Here we compare across all ten simulations where the deposition flux was varied from 1×10^2 to 5×10^6 mmol C m^{-2} y^{-1} in order to build relationships between:

a) the fish-waste deposition flux and the associated response in sediment chemical fluxes within the water column,
b) the fish waste deposition flux to expected surficial sediment concentrations of key sediment condition attributes relevant to management triggers, and
c) the fish-waste deposition flux and the recovery time of sediment after aquaculture ceases.

These flux values can be used by the other water column models in the greater project as a benthic boundary of sediment source and sink fluxes.

H.1 – Changes to the sediment-water interface chemical fluxes

The average fluxes of four key variables (O_2, NO_3, NH_4, PO_4) across the sediment-water interface are shown for all ten waste deposition flux simulations, and these are shown before, during and after 5 years of continuous cage operation (Figure 14). The analysis allows us to assign oxygen and nutrient fluxes (computed are per m^2 of seabed) to a sediment area once the corresponding deposition flux for that area is predicted by the waste particle transport model.

O_2 returned to its pre-farming flux within 5 years for fish waste depositions between 1×10^2 and 1×10^5 mmol C m^{-2} y^{-1}. NH_4^+ and PO_4^{3-} returned to their near-zero fluxes within 5 years despite very large increases at high deposition rates. NO_3^- displayed a more complex pattern; with fish waste deposition between 10^2 and 10^6 mmol C m^{-2} y^{-1} during aquaculture, there was a net production of NO_3^-, from the nitrification of organic N; for fish wastes above 10^6 mmol C m^{-2} y^{-1}, O_2 was consumed and there was a net consumption of NO_3^- due to denitrification. Although the net flux of NO_3^- is greater than the background flux with a fish waste deposition of 1×10^6 mmol C m^{-2} y^{-1}, the organic matter flux at which denitrification starts to dominate over NO_3^- outflux is at 1×10^5 mmol C m^{-2} y^{-1}. The release of NO_3^- at fluxes above 1×10^6 mmol C m^{-2} y^{-1} after fish farming ceases is a result of the legacy organic N and NH_4^+. Based on these flux analyses, the sediment recovers to its pre-farming condition in five years for deposition flux rates of 1×10^5 mmol C m^{-2} y^{-1} or less.

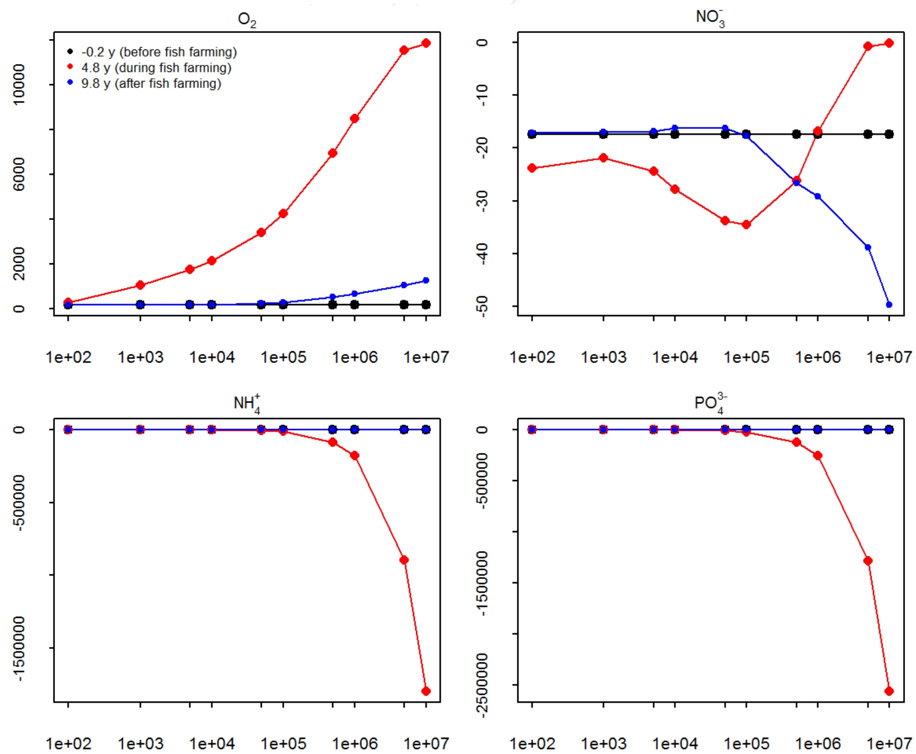

Figure 14. Fluxes of solutes across the sediment-water interface (mmol m^{-2} y^{-1}) as a function of the waste deposition flux. Positive numbers on the y axes indicate a flux from the water column into the sediment, or a demand by the sediment. Negative numbers indicate a flux from the sediment to the water column, thus, production in the sediment.

H.2 – Response of surficial sediment concentrations to fish waste accumulation

A means of assessing sediment impact is to assess the extent to which the concentrations of total organic carbon (TOC), total nitrogen (TN) and total phosphorus (TP), sulfide and nutrients exceed normal background concentrations during cage operation. We therefore averaged the concentrations in the layers corresponding to the top 5cm of sediment for each of the ten waste deposition scenarios using the mean of the parameter set (Figure 15).

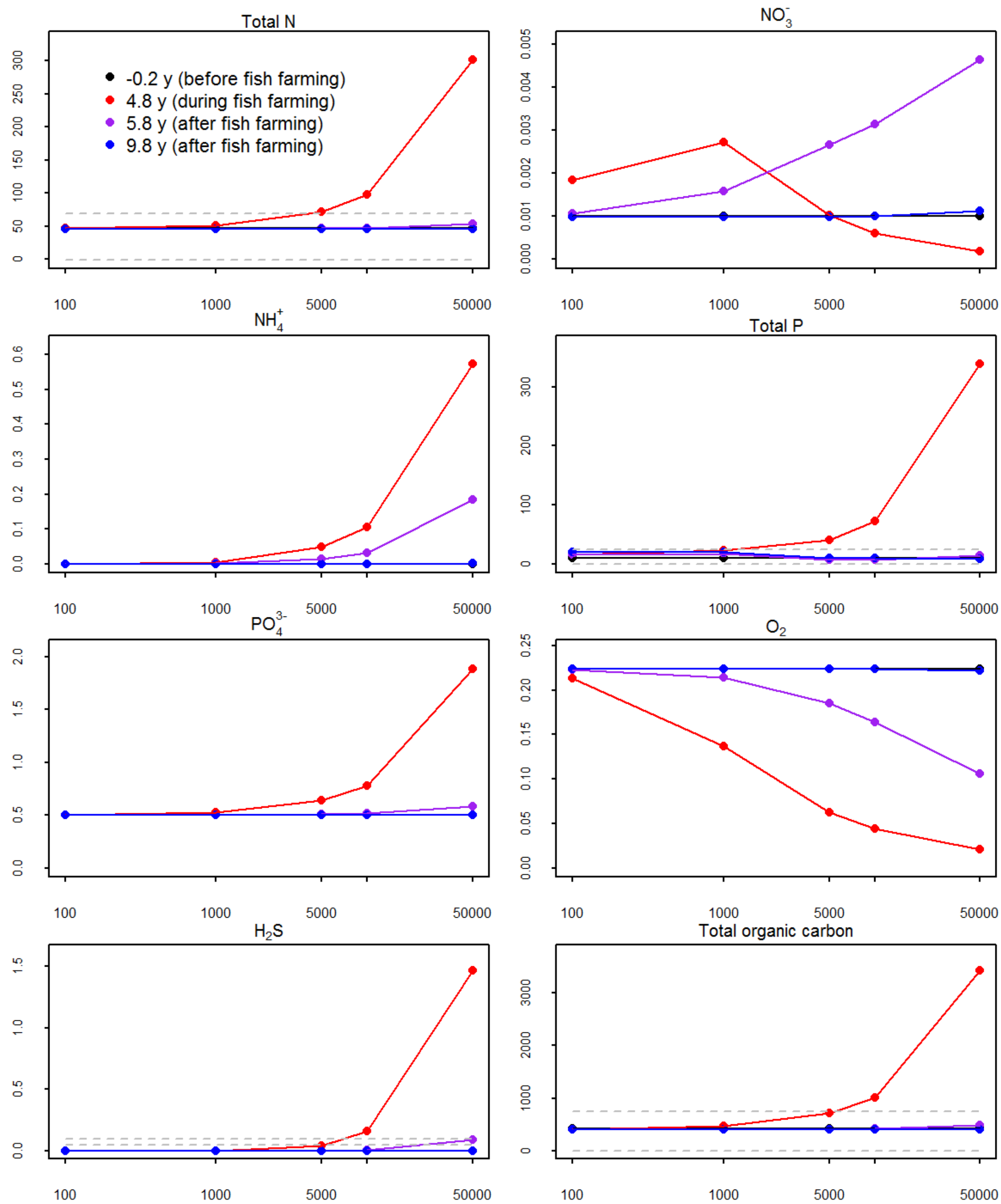

Figure 15. Average concentrations over the top 5 cm of sediment relative to the fish-waste deposition rate (x-axis, mmol C m^{-2} y^{-1}). Black indicates the pre-aquaculture concentrations; red indicates the concentrations after 5 years of aquaculture; purple indicates concentration after 1 year after cage operaton, and blue indicates ocncentrations 5 years after cage operation was ceased. The 95th percentile concentrations for TN, TP and TOC are seen in the field data and indicated as the dashed grey line. In the case of H_2S, the dashed grey lines indicate the threshold concentrations discussed in Section I.

H.3 – Computing sediment recovery time

For a first approximation, concentrations of key variables (O_2, H_2S and TOC) were further assessed to ascertain the time required to recover to pre-farming conditions and this was assessed for 1, 2, 3 and 5 years of cage operation. This was undertaken by considering concentrations at each depth level, and also the average concentration over the top 5cm of sediment (as in Section H2).

Oxygen was observed to be the slowest variable to recover and relevant to benthic infauna health. Therefore the sediment recovery time was computed as being the time at which O_2 returned to a concentration greater than 85% of its pre-farming concentration (Figure 16). The uncertainty is highest in the deeper sediment.

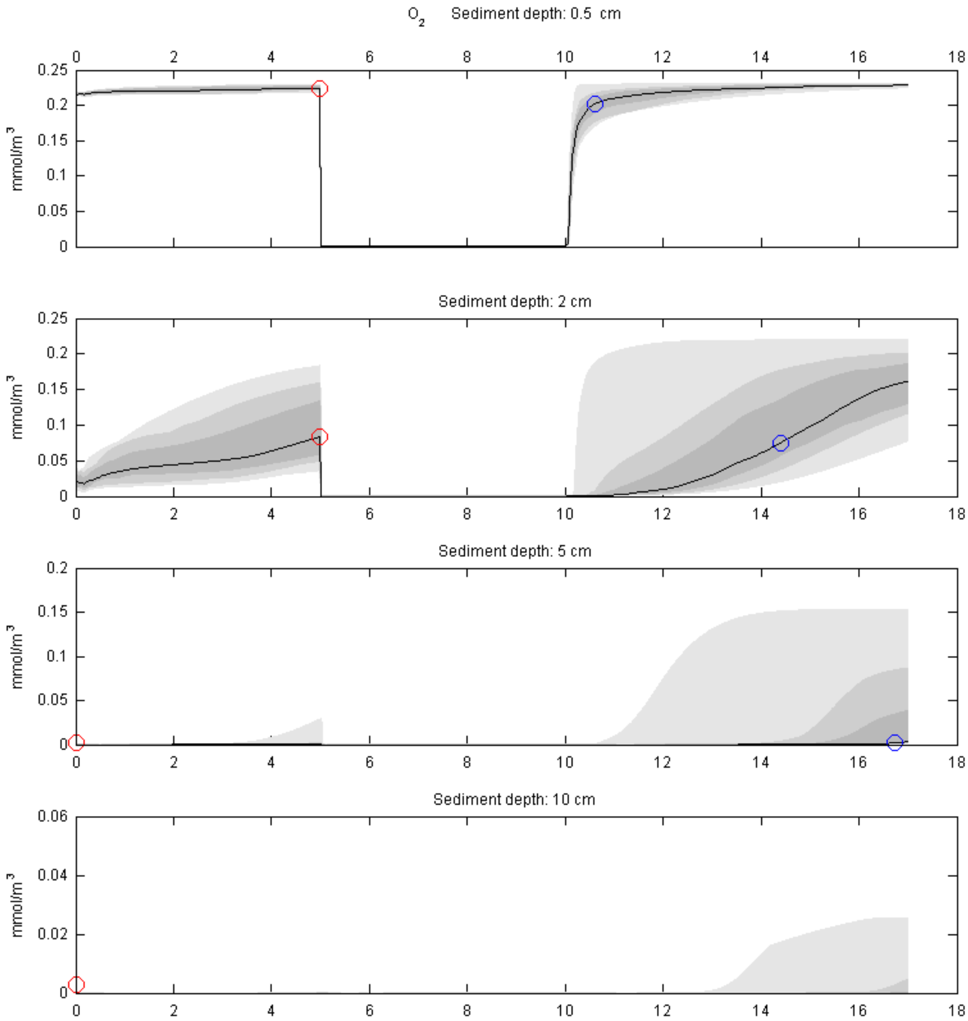

Figure 16. The recovery concentration of O_2 was assessed at four depths for a fish waste deposition of 1×10^5 mmol C m^{-2} y^{-1}. The maximum concentration before fish farming began was found: for the median value, this is the red circle. The time at which the concentration reached 90% of the pre-farming concentration was found: for the median value, this is the blue circle. The results of the uncertainty calculations are shown with the grey bands: the darkest is the range between 25 and 75%, the next paler between 10 and 90%, the palest between 5 and 95%.

To generate a relationship between the deposition flux and the sediment recovery time, concentrations at a depth of 2 cm were focused on, since this is the depth at which field measurements of sediment quality are typically taken, and it is also the threshold depth for the assessment of aerobic conditions for benthic infauna used by McLeod and Forbes (2004). The time varies depending on the parameter combination chosen, as indicated by the uncertainty bands on Figure 17. As each simulation was for only run for 17 years, including 5 years of background conditions and 5 years of aquaculture, the maximum time assessed for recovery was 7 years, beyond which recovery time is considered to be >7. A summary of the deposition rates and associated recovery times for 1, 2, 3 and 5 years of cage operation are shown in Table 7, and a demonstration of how this can be used in conjunction with the particle transport model is shown in Figure 18.

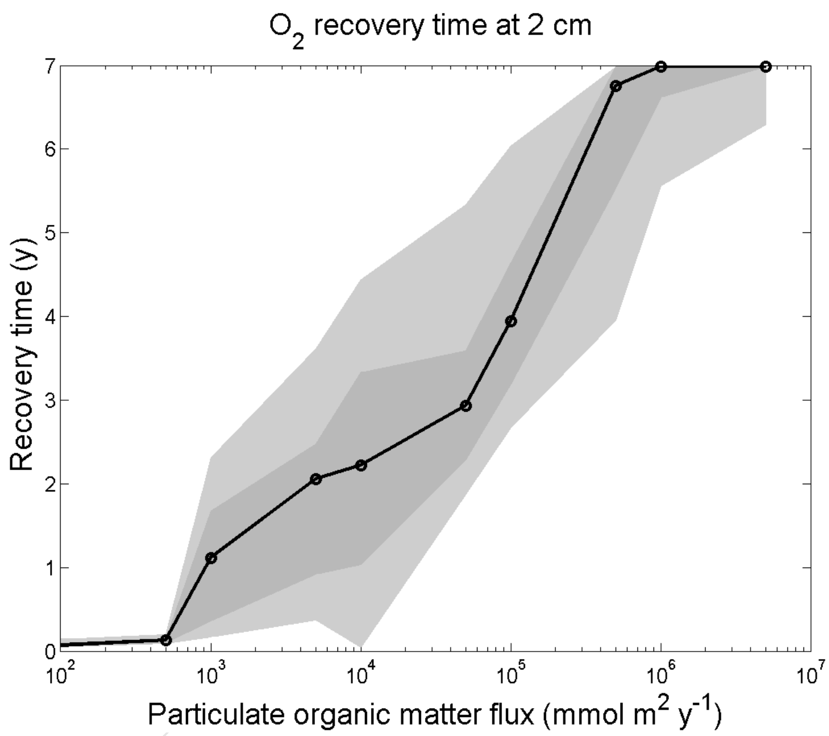

Figure 17 Recovery times for O_2 at 2 cm deep. The x axis is the fish waste deposition flux for each of the simulations (mmol C m^{-2} y^{-1}). The y axis is the time at which the concentration reaches 85% of the maximum O_2 concentration reached before the start of aquaculture (years).

Table 7. Threshold deposition values (mmol C m^{-2} y^{-1}) used to categorise sediment recovery times based on constant a cage operation period of 1, 2, 3 or 5 years.

Category	Threshold deposition: 1 yr of cage operation	Threshold deposition: 2 yr of cage operation	Threshold deposition: 3 yr of cage operation	Threshold deposition: 5 yr of cage operation
1 yr	$> 3.31\times10^3$	$> 2.88\times10^3$	$> 2.11\times10^3$	$> 1.00\times10^3$
2 yr	$>3.31\times10^3$ & $<1.31\times10^4$	$>2.88\times10^3$ & $<1.04\times10^4$	$>2.11\times10^3$ & $<7.87\times10^3$	$>1.00\times10^3$ & $<4.50\times10^3$
3 yr	$>1.31\times10^4$ & $<5.18\times10^4$	$>1.04\times10^4$ & $<3.73\times10^4$	$>7.87\times10^3$ & $<2.94\times10^4$	$>4.50\times10^3$ & $<5.00\times10^4$
4 yr	$>5.18\times10^4$ & $<2.05\times10^5$	$>3.73\times10^4$ & $<1.34\times10^5$	$>2.94\times10^4$ & $<1.10\times10^5$	$>5.00\times10^4$ & $<1.00\times10^5$
5 yr	$>2.05\times10^5$ & $<5.15\times10^5$	$>1.34\times10^5$ & $<5.05\times10^5$	$>1.10\times10^5$ & $<4.50\times10^5$	$>1.00\times10^5$ & $<2.00\times10^5$
6 yr	$>5.15\times10^5$ & $<3.21\times10^6$	$>5.05\times10^5$ & $<1.74\times10^6$	$>4.50\times10^5$ & $<1.53\times10^6$	$>2.00\times10^5$ & $<3.00\times10^5$
7+ yr	$>3.21\times10^6$ & $<1.27\times10^7$	$>1.74\times10^6$ & $<6.26\times10^6$	$>1.53\times10^6$ & $<5.70\times10^6$	$>3.00\times10^5$ & $<1.00\times10^6$

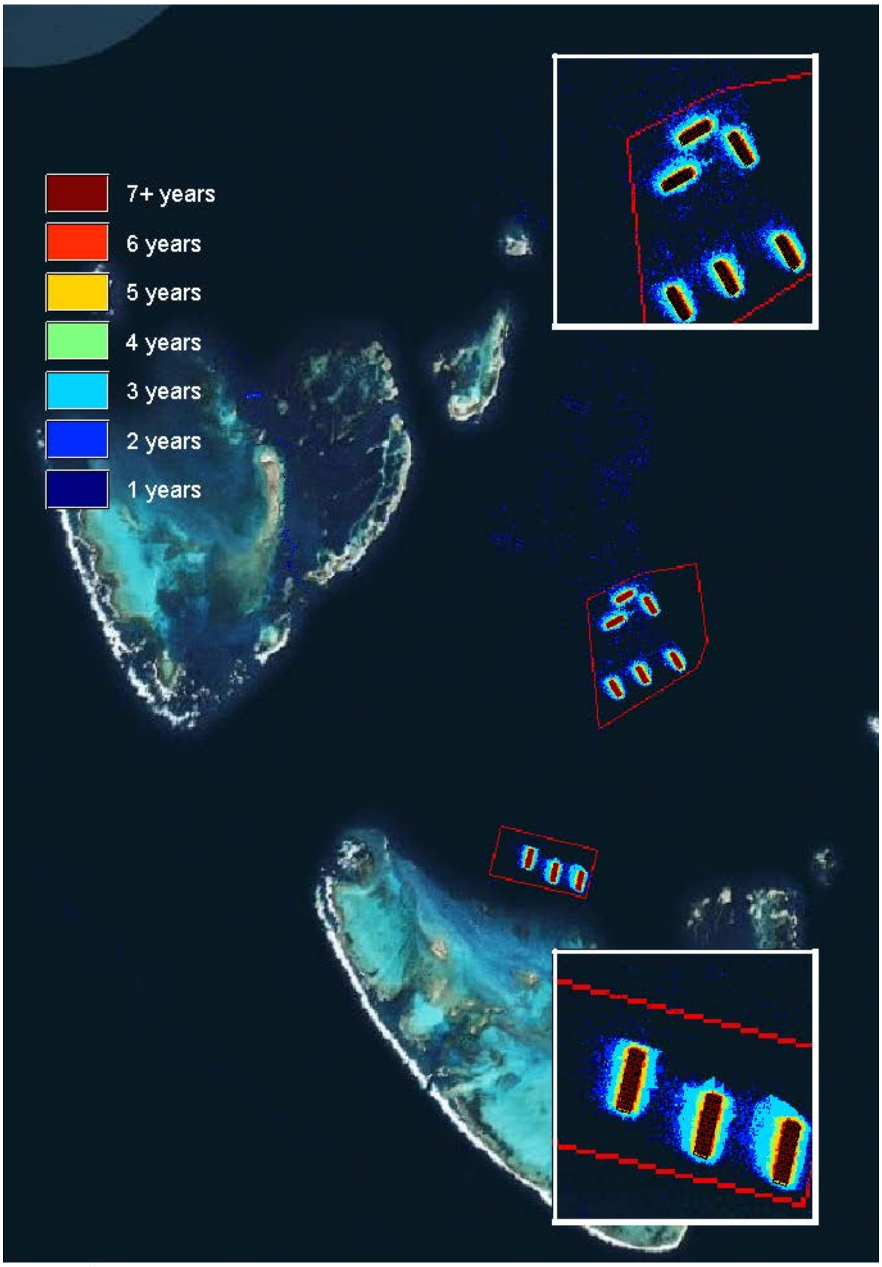

Figure 18. By combining the recovery time estimates for different deposition intensities (Figure 23) and the depositing flux map (Figure 2), this plot shows how sediment recovery time varies spatially. Note this is an indicative prediction and results will vary from this depending on the associated assumptions of particle transport model.

I. Identification of Deposition Thresholds for Impact Classification

The nature of sediment quality changes has been subject to several analyses that have attempted to classify the degree of degradation and impact. Three methods for classifying the degree of impact are described below:

- Exceedance of TOC in surficial sediment above the 95th percentile of measurements.
- Threshold definition based on the degree of impact to benthic macrofauna
- Assessment of the likelihood for sediment to recover within an acceptable period once fallowed

H.1 – Flux thresholds where TOC exceeds the background conditions

In this case, the normal background concentration is defined as the average concentration over the top 2 cm of sediment, and the exceedance criterion as anything greater than the 95th percentile of variation in the values from field data (collected from the sites in Figure 3). The critical fish waste flux is approximately 5×10^3 mmol C m^{-2} y^{-1} (Figure 19).

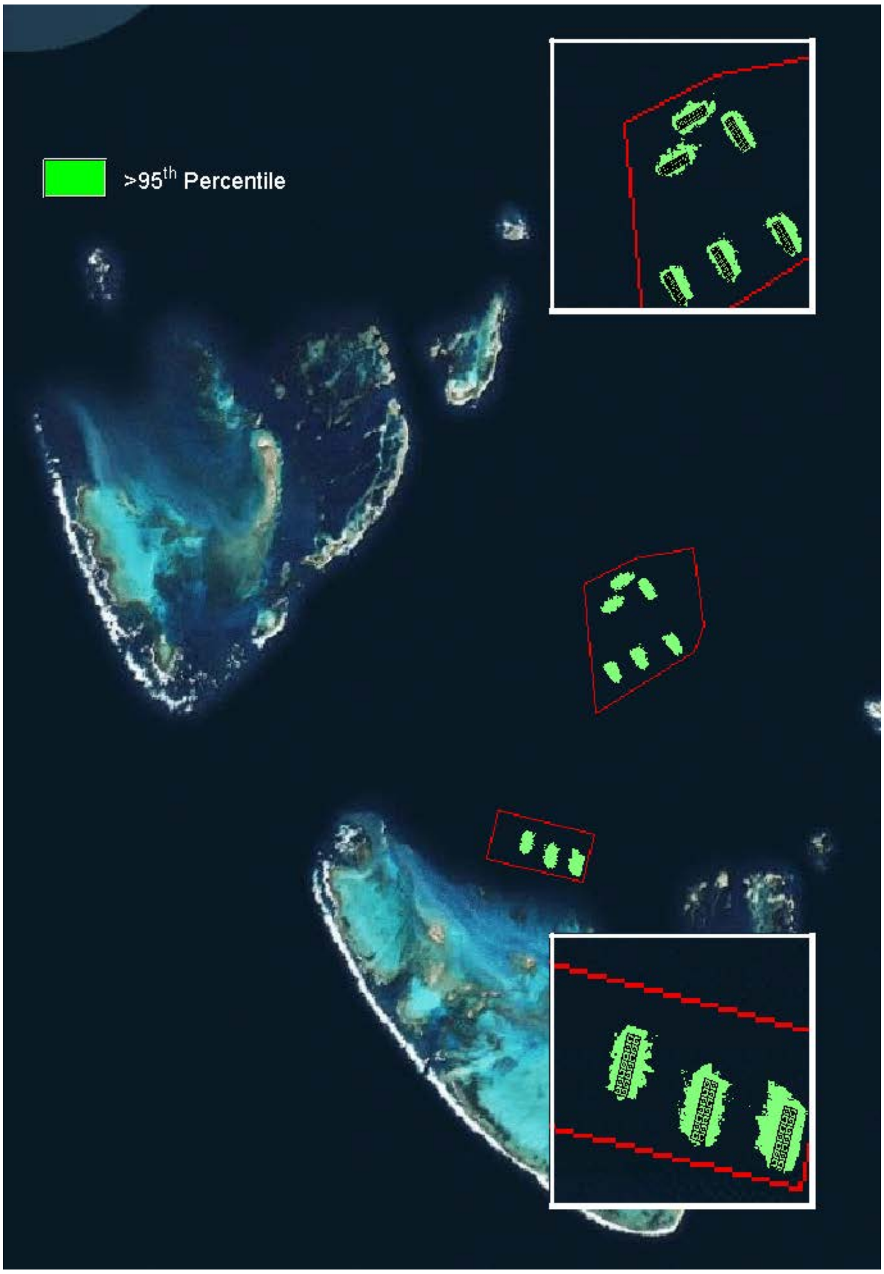

Figure 19. By combining the deposition flux rate where the TOC 95th percentile is exceeded (Figure 21) and the deposition flux map (Figure 2), this plot shows areas where TOC concentration would exceed background conditions. Note this is an indicative prediction and results will vary from this depending on the associated assumptions of particle transport model.

H.2 – Flux thresholds where conditions become damaging to benthic fauna

Damage to the sediment from fish farming may be assessed based on the depth of oxygen penetration, and by the concentration of H_2S (Hargrave et al., 2008). In Australia, criteria based oxygen and sulfide were listed by McLeod and Forbes (2004) as:

- Polluted – $H_2S > 100$ µmol L^{-1} at 3 cm; Anaerobic 0 to 1 cm
- Transitory – $H_2S > 50$ µmol L^{-1} at 3 cm; Anaerobic 1 to 2 cm
- Normal – $H_2S < 50$ µmol L^{-1} at 3 cm; Aerobic to 2 cm

In our initial assessment of the modelled profiles of oxygen, it was found that with a fish waste input of 5×10^3 mmol C m^{-2} y^{-1} the sediment is very close to zero mmol O_2 L^{-1} at 2 cm (Figure 20). The transitory condition above is satisfied with a deposition of 3×10^3 mmol C m^{-2} y^{-1}. In every case, however, oxygen returned to pre-farming concentrations at 2 cm deep after aquaculture finished. Using the specific depth of 3 cm as in McLeod and Forbes (2004), H_2S concentration was between 50 and 100 µmol L^{-1} at 3 cm with a fish waste flux of 4×10^3 mmol m^{-2} y^{-1}, and is greater than 100 µmol L^{-1} with a fish waste flux of 5×10^3 mmol C m^{-2} y^{-1} (Figure 27). Thus, the assessment for the effect on benthic infauna during aquaculture suggests that the critical fish waste depositions were around 3×10^3 mmol C m^{-2} y^{-1} for the threshold between normal and transitory, and 5×10^3 mmol C m^{-2} y^{-1} for the threshold between transitory and polluted.

The more recent detailed synthesis of studies from the around the globe by Hargrave et al. (2008) led to the development of a more detailed nomogram linking the degree of anaerobic conditions, sulfide concentration and loss of benthic macrofauna. For the purposes of this analysis we define four categories based on this:

- **High Ecological Protection**: When the local rate of deposition material is sufficiently low not to contribute to anoxia or H_2S accumulation in the upper 2 cm, then the benthic macrofauna abundance and diversity is considered to not be affected. Based on Hargrave et al. (2008), this category requires the H_2S to remain below 100 µmol L^{-1}.
- **Medium Ecological Protection**: The medium category relates to a deposition rate whereby mild hypoxic stress may occur, reducing benthic macrofauna abundance by no more than 50%. This occurs when the upper 2 cm H_2S concentration remains within the 100 – 300 µmol L^{-1} range.
- **Low Ecological Protection (>50%)**: The zone of low ecological protection indicates that the deposition rate is significantly reducing sediment quality through hypoxic stress and loss of more than 50% of benthic macrofauna. This is assigned to occur when the upper 2 cm of sediment ranges between 300 and 6000 µmol L^{-1}.

- **Low Ecological Protection** (>85%): The final category is for conditions of persistent anoxia, whereby benthic macrofauna abundance is expected to have a mean reduction of taxa by >85%. Based on the analysis by Hargrave et al. (2008) this occurs when the upper 2 cm H_2S concentration exceeds 6000 μM.

We highlight that these categories have different threshold concentrations from McLeod and Forbes (2004), however, those used here from Hargrave et al. (2008) are directly connected to the health of benthic macrofauna, and summarise a wider range of aquaculture studies. We therefore computed the average concentrations of O_2 and H_2S in the top 2cm and identified the deposition flux where the thresholds in Table 8 were exceeded after 1, 2, 3 or 5 years of continuous aquaculture operations. See Figure 22 for an example model output.

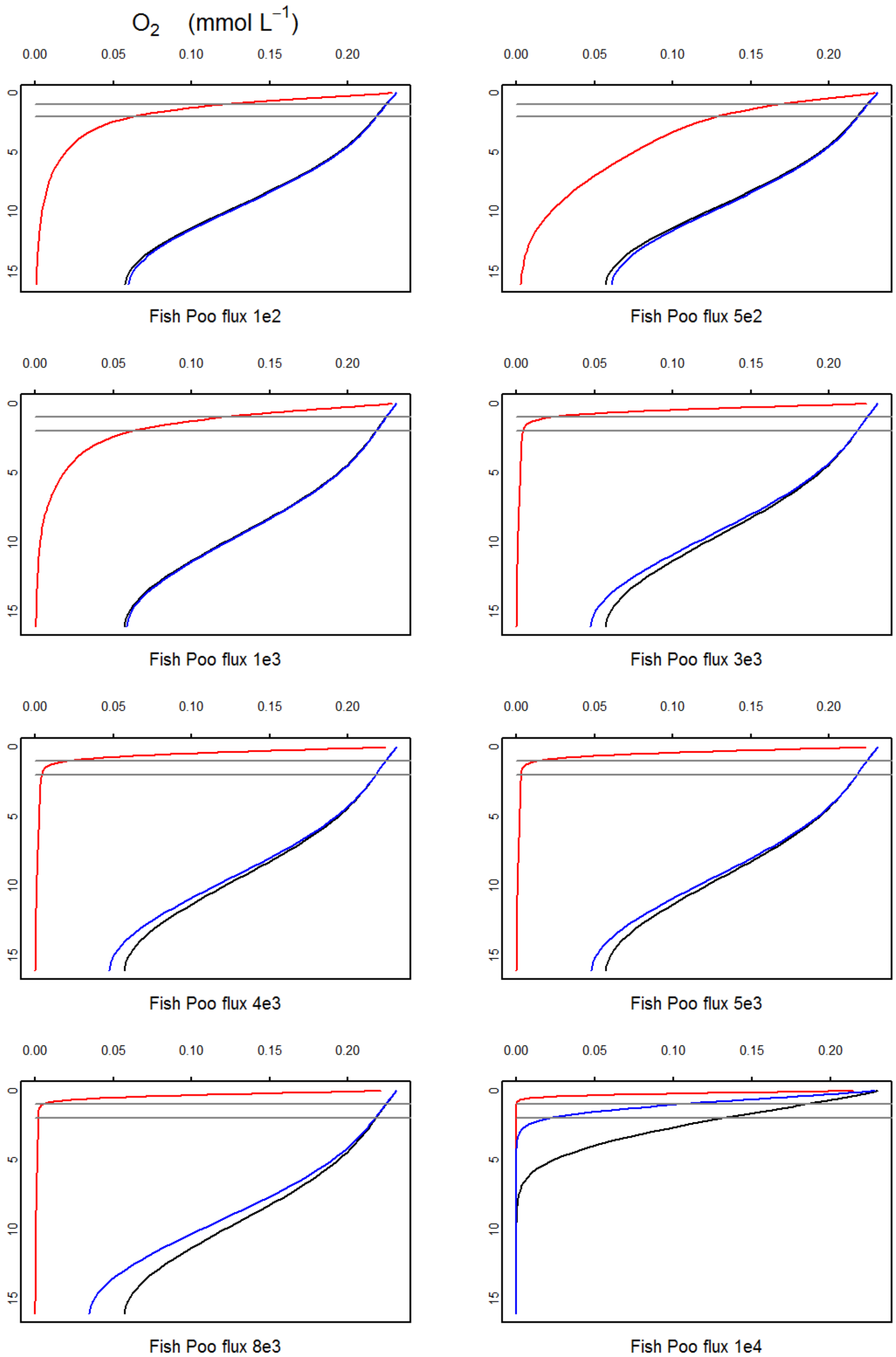

Figure 20. Sediment concentration profiles for simulations with fish waste fluxes between 100 (1e2) and 10 000 (1e4) mmol C m^{-2} y^{-1}. The x axes are O_2 concentration (mmol O_2 L^{-1}) and the y axes depth into the sediment (cm). The grey horizontal lines are at the critical assessment depths of 1 and 2 cm. Black is pre aquaculture, red is after 5 years of operation and blue is after 5 years of recovery.

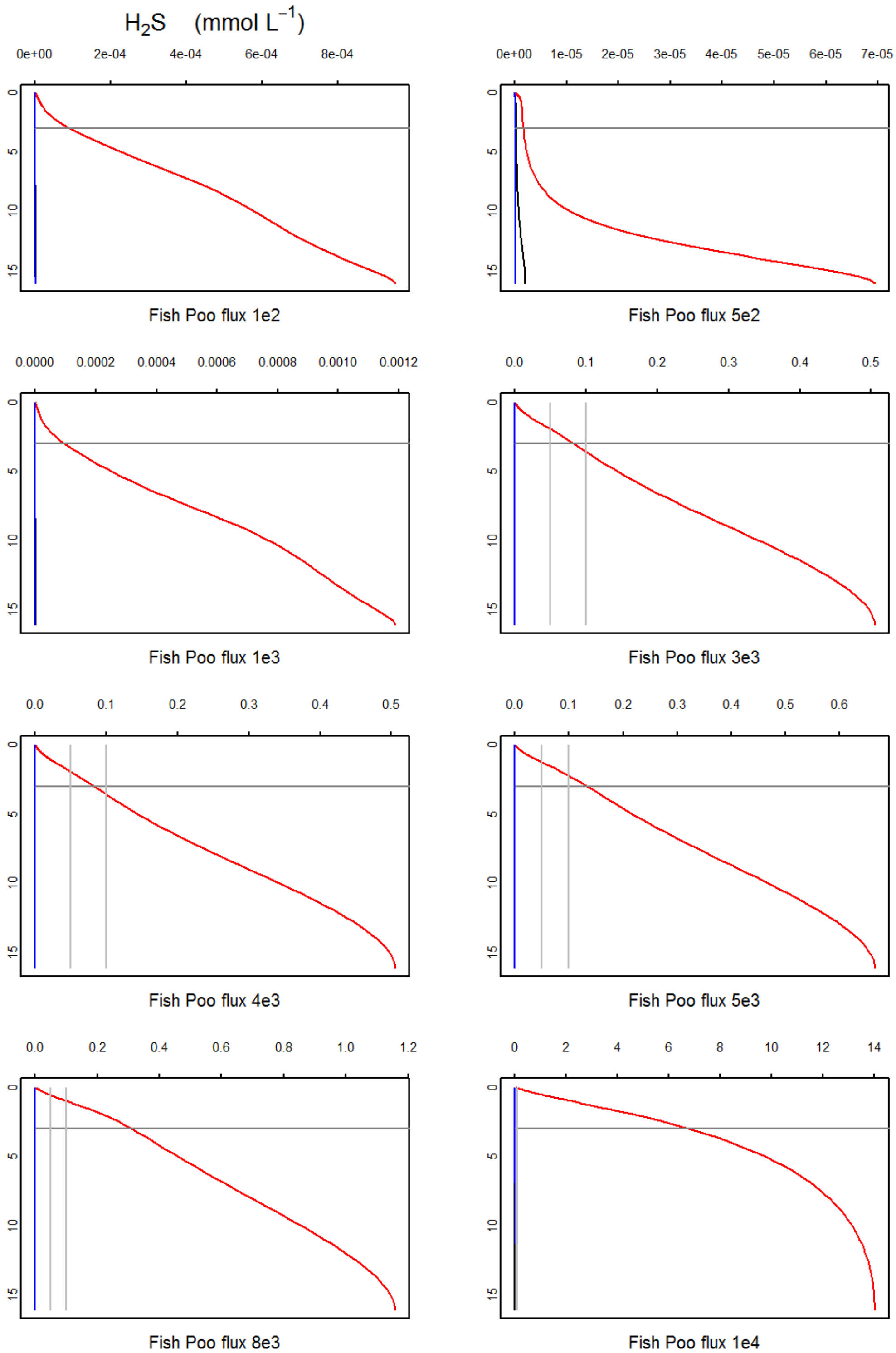

Figure 21. Sediment concentration profiles for simulations with fish waste fluxes between 100 (1e2) and 10 000 (1e4) mmol C m^{-2} y^{-1}. The x axes are H_2S concentration (mmol L^{-1}) and the y axes depth into the sediment (cm). The grey vertical lines represent the critical assessment concentrations of 50 and 100 µmol H_2S L^{-1} (0.05 and 0.1 mmol L^{-1}). The grey horizontal line is at 3 cm deep, which was the measurement depth used by McLeod and Forbes (2004). The concentration of H_2S at 3 cm passes the threshold concentrations with fish waste depositions between 3×10^3 and 5×10^3 mmol C m^{-2} y^{-1}. Black is pre aquaculture, red is after 5 years of operation and blue is after 5 years of recovery.

Table 8. Threshold deposition values (mmol C m^{-2} y^{-1}) used to categorise sediment impacts due to organic matter enrichment. Values based on a constant cage operation period of 1, 2, 3 or 5 years.

Category	Description	Threshold deposition: 1 yr of cage operation	Threshold deposition: 2 yr of cage operation	Threshold deposition: 3 yr of cage operation	Threshold deposition: 5 yr of cage operation
Organic Enrichment Zonation category					
HEP	High Ecological Protection	< 0.85×10^4	< 0.78×10^4	< 0.70×10^4	< 0.70×10^4
MEP	Medium Ecological Protection	>0.85×10^4 & <3.0×10^4	>0.78×10^4 & <2.8×10^4	>0.70×10^4 & <2.6×10^4	>0.70×10^4 & <1.28×10^4
LEP (>50)	Low Ecological Protection (>50% loss of benthic macrofauna)	>3.0×10^4 & <2.5×10^6	>2.8×10^4 & <2.0×10^6	>2.6×10^4 & <1.7×10^6	>1.28×10^4 & <1.5×10^6
LEP (>85)	Low Ecological Protection (>85% loss of benthic macrofauna)	> 2.5×10^5	> 2.0×10^5	> 1.7×10^5	> 1.5×10^5

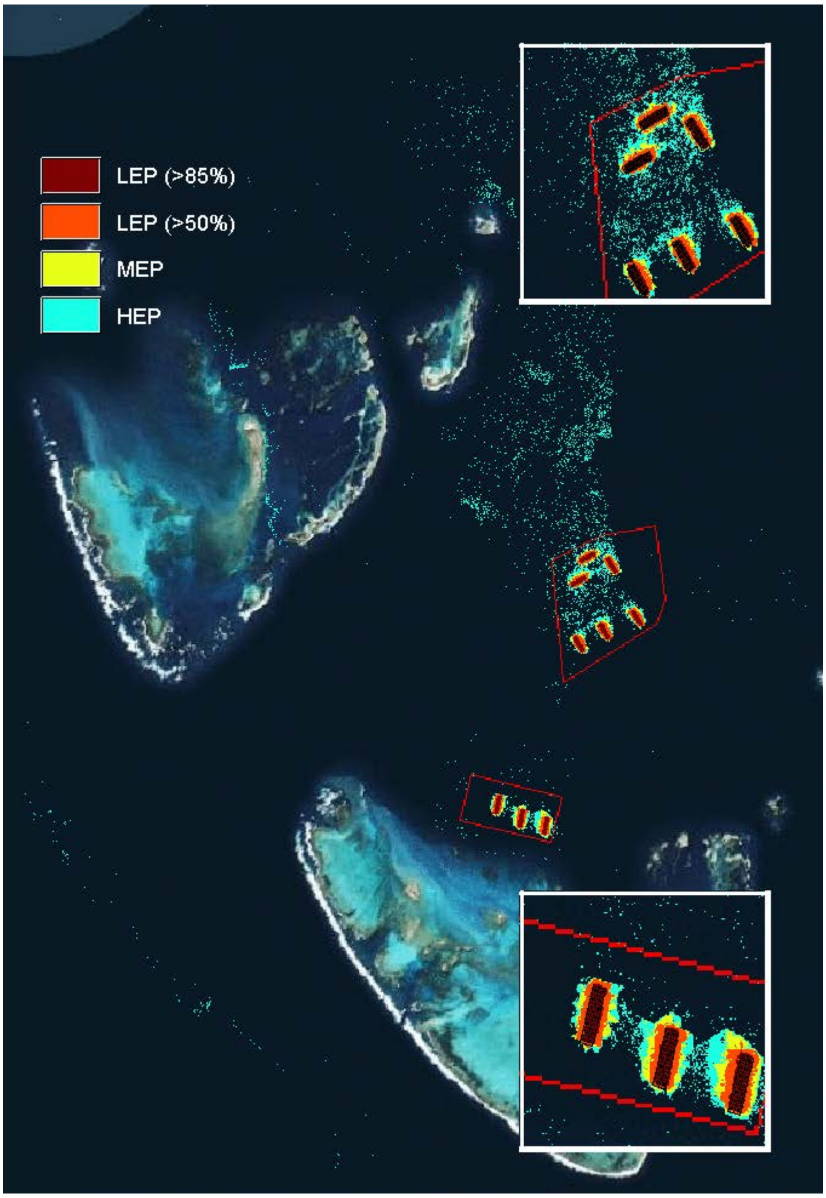

Figure 22. Application of the organic enrichment zonation categories to the deposition flux rate (Figure 2), reveals the predicted extent of low, moderate and high zones of ecological protection. Note this is an indicative prediction and results will vary from this depending on the associated assumptions of particle transport model.

H.3 – Definition of recovery time thresholds

The time for recovery of sediment after being "fallowed" is an important consideration in determining management options and regulatory approvals. The categories defined in this section represent areas based on the extent to which they can recover, with the assumption that sediments that remain anaerobic and sulfidic for long periods of time are unlikely to see rapid re-establishment of benthic macrofauna.

In previous assessments, impacts to marine benthic communities from dredging have been classified into zones of high impact, moderate impact and influence (Masini 2012). In order to identify critical deposition rates we adopt a similar classification, with the definitions defined as:

- **Zone of High Impact** (ZoHI): Sediment is considered to be highly impacted when the sediment conditions do not return to their original condition within 5 years. In this case the effects on benthic organisms are predicted to be irreversible over this period.
- **Zone of Moderate Impact** (ZoMI): Sediment is considered to be moderately impacted when the sediment condition is impacted during aquaculture operation, but can recover within 1 to 5 years.
- **Zone of Influence** (ZoIn): In this category the sediment concentrations are affected but the surficial sediment concentrations would return to a pre-aquaculture state in less than 1 year after aquaculture ceases.

As highlighted in Section H.3, oxygen was found to be the best proxy for recovery time and we therefore use this variable as the basis for the threshold definition (Table 9). Consistent with the sediment-water interface fluxes described above, O_2 at 2 cm deep recovered to its pre-aquaculture concentration within 1 year when the deposition flux of fish waste was around 1×10^4 mmol C m^{-2} y^{-1}. O_2 at 2 cm deep has recovered within 5 years when the deposition flux of fish waste is less than 2×10^5 mmol C m^{-2} y^{-1}. NO_3^- did not recover within 5 years for fish waste depositions greater than 1×10^5 mmol C m^{-2} y^{-1} (not shown), however, since this is lower than for oxygen this confirms the use of O_2 as the most conservative indicator. Deposition thresholds for shorter cage operation periods were slightly higher than for a 5 year operation window, which highlights that the higher rate of deposition is required to exceed the thresholds for shorter operation period.

As a demonstration of the application of these thresholds with output form the hydrodynamic-particle model, the thresholds were used to map the zones of high impact, moderate impact and influence around the proposed fish farm cage sites, for an example scenario with high stocking densities for a 5 year operation period (Figure 23).

Table 9. Threshold deposition values (mmol C m^{-2} y^{-1}) used to categorise sediment recovery times based on constant a cage operation period of 1, 2, 3 or 5 years.

Category	Description	Threshold deposition: 1 yr of cage operation	Threshold deposition: 2 yr of cage operation	Threshold deposition: 3 yr of cage operation	Threshold deposition: 5 yr of cage operation
Recovery Time Thresholds					
ZoHI	Impacted relative to base conditions with sediment unlikely to occur within 5 yrs post-cage operation	$> 5.15\times10^5$	$> 5.05\times10^5$	$> 4.5\times10^5$	$> 2\times10^5$
ZoMI	Impacted relative to base conditions with recovery taking 1 – 5 yrs	$>1.2\times10^4$ & $<5.15\times10^6$	$>1.2\times10^4$ & $<5.05\times10^6$	$>1.05\times10^4$ & $<4.5\times10^6$	$>1\times10^4$ & $<5\times10^6$
ZoIn	Influenced relative to base conditions, but recovers in <1 yr	$< 1.2\times10^4$	$< 1.2\times10^4$	$< 1.05\times10^4$	$< 1\times10^4$

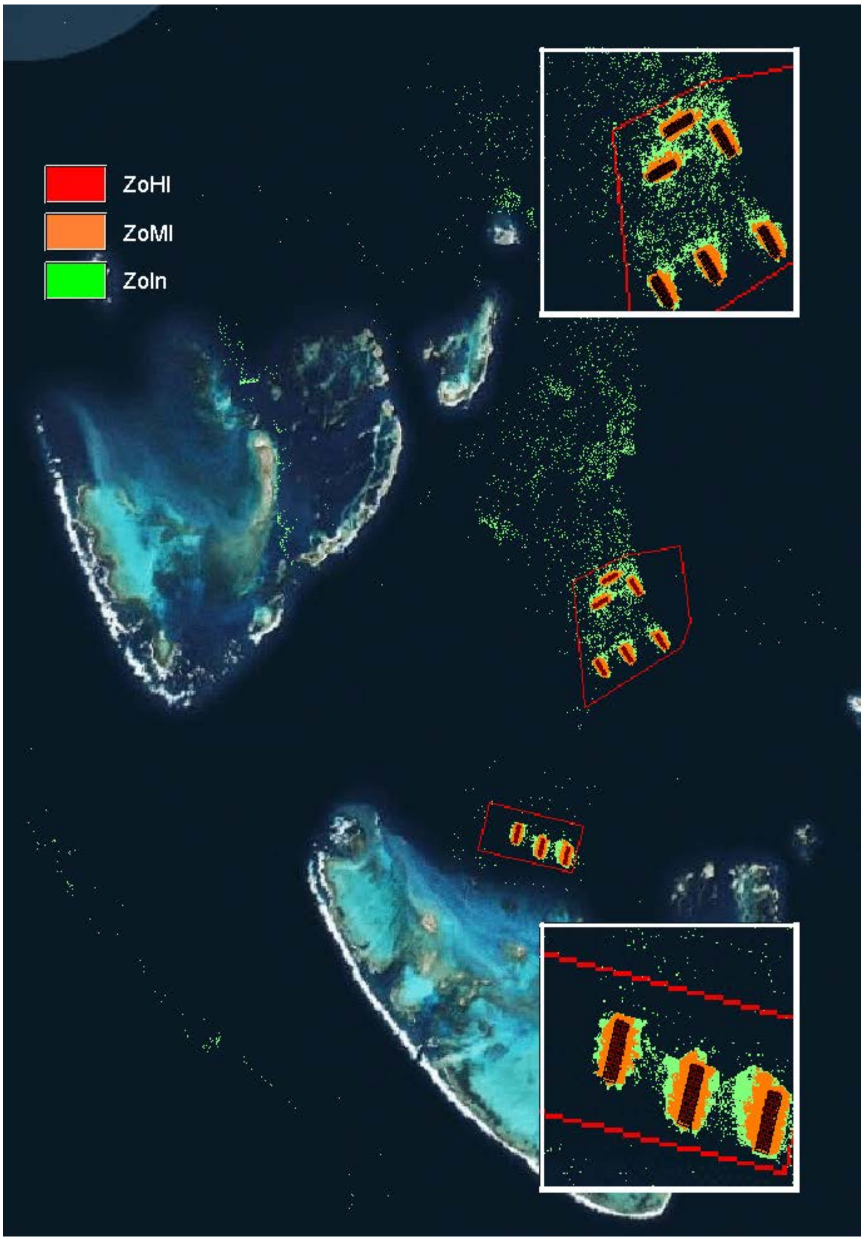

Figure 23. Map of the zones of high impact, moderate impact and influence around the proposed aquaculture sites near the Abrolhos Islands.

J. Summary

The analysis has applied a vertically resolved sediment diagenesis model to predict the change in sediment geochemical conditions over a range of fish-waste loading scenarios. To demonstrate the model is appropriate for this type of prediction, simulations were run to benchmark it against a widely used ocean sediment biogeochemical model. A baseline configuration of the Abrolhos was then configured, based on available sediment grab data and general knowledge of sandy sediments characteristic of the region. The parameters chosen were therefore representative of sediment typical of the region, however some variability in the nature of the sediment exists, including the degree of permeability and level of bioturbation in the surface layers. Model simulations were therefore run within a Monte Carlo framework where uncertain parameters were adjusted to provide an indication of the uncertainty in the predictions.

Sediment within the region will experience a rate of organic matter deposition depending on the amount of fish-waste released from the cages, and the distance of the sediment from the cages. To cater for this range, scenarios assessing deposition fluxes of 1×10^2 to 5×10^6 mmol C m^{-2} yr^{-1} (0.0012 to 60 kg waste m^{-2} yr^{-1}) were undertaken and interpreted to characterise the response in overall sediment condition. In particular the simulations were used to identify:

a) the typical sediment oxygen and nutrient fluxes that occur during and after aquaculture operations,
b) response of surficial sediment concentrations (TOC, TN and TP) relevant for management,
c) the response of O_2 and H_2S profiles, interpreted in the context of benthic infauna tolerances,
d) the recovery time of sediment experiencing certain deposition flux rates

Thresholds depositional fluxes were also identified based on classification of sediment into areas of impact to benthic macrofauna, and recovery times. The thresholds were defined for cage-operation periods of 1, 2, 3 and 5 years.

When used in conjunction with a particle transport model, the predictions from this model assessment can be combined with deposition flux maps to assess the spatial distribution of sediment condition and recovery times. This has been demonstrated using a idealised cage operation scenario in this report, and for further detail on application of the model to assess alternate cage operation scenarios, the reader is referred to BMT Oceanic (2015).

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Appendix A: Model Description

The chemical reactions solved by the model are shown overpage (Table A1-A3).

Appendix B: Model Benchmark Assessment

The model CANDI AED has been calibrated against the published modelling results of Van Cappellen and Wang (1996) in order to confirm that the numerical setup of the model functions adequately. All boundary fluxes, bottom water concentrations, rate constants, irrigation and bioturbation coefficients were set to the same values as those in Van Cappellen and Wang (1996). An evenly spaced grid was used, with 400 layers to a depth of 20 cm.

For the calibration, the organic matter oxidation model was parameterized with no organic matter influx and with an oxidation rate that changes with depth. For the fish farm simulations of this report, organic matter oxidation was instead a function of organic matter concentration, driven by deposition from the water column. CANDI AED has a flexible setup, which allows the organic matter oxidation model to be changed with little other alteration of the model parameters.

In the calibration setup, the surface oxidation rate and depth attenuation were the same as Van Cappellen and Wang (1996). The mineral precipitation reactions were implemented only for $MnCO_3$, $FeCO_3$ and FeS, as per the equations in Van Cappellen and Wang (1996), rather than the larger set of precipitation reactions possible with AED CANDI. Additionally, the ageing reactions of iron and manganese minerals were disabled. Ammonium adsorption was the same as in Van Cappellen and Wang (1996), however, iron and manganese adsorption was not included.

The rates of aerobic respiration and denitrification using CANDI AED were close to the simulated rate of Van Cappellen and Wang, though in the deepest part of the sediment, the simulated rate was greater using this model (Figure B1). As a result of the classic inhibition sequence, the deeper aerobic respiration inhibits denitrification to a deeper depth layer, and this carries through to cause all oxidation rates to occur deeper than in the Van Cappellen and Wang simulation. Manganese reduction was smaller than in the Van Cappellen and Wang simulation, however, both were very low rates relative to the other terminal electron accepting pathways (Figure B2). Iron reduction was close, though lower, and could not be calibrated any closer without decreasing the closeness of the iron concentration profiles. The sulfate reduction profiles were very close and as with Van Cappellen and Wang, methanogenesis was completely inhibited.

Table A1 Primary terminal redox reactions. x, y and z are stoichiometric coefficients.

Description	Reaction	
Aerobic respiration	$OM + xO_2 + (-y + 2z)HCO_3^- \rightarrow (x - y + 2z)CO_2 + yNH_4^+ + zHPO_4^{2-} + (x + 2y + 2z)H_2O$	(1)
Denitrification	$OM + 0.8xNO_3^- \rightarrow (0.2x - y + 2z)CO_2 + 0.4xN_2 + (0.8x + y +- 2z)HCO_3^- + yNH_4^+ + zHPO_4^{2-} + (0.6x - y + 2z)H_2O + H_3PO4 + 177.2H_2O$	(2)
Mn oxide reduction	$OM + 2xMnO_2 + (3x + y - 2z)CO_2 + (x + y - 2z)H_2O \rightarrow 2xMn^{2+} + (4x + y - 2z)HCO_3^- + yNH_4^+ + zHPO_4^2$	(3)
Fe oxide reduction	$OM + 4xFe(OH)_3 + (7x + y - 2z)CO_2 + (x - 2z)H_2O \rightarrow 4xFe^{2+} + (8x + y - 2z)HCO_3^- + yNH_4^+ + zHPO_4^{2-} + (3x + y - 2z)H_2O$	(4)
Sulfate reduction	$OM + 0.5xSO_4^{2-} + (y - 2z)CO_2 + (y - 2z)H_2O \rightarrow 0.5xH_2S + (x + y - 2z)HCO_3^- + yNH_4^+ + zHPO_4^{2-}$	(5)
Methanogenesis	$OM + (y - 2z)H_2O \rightarrow 0.5xCH_4 + (0.5x - y + 2z)CO_2 + (y - 2z)HCO_3^- + yNH_4^+ + zHPO_4^{2-}$	(6)

Table A2 Secondary redox reactions.

Description	Reaction	Rate equation	
NH_4^+ oxidation by O_2	$NH_4^+ + 2O_2 + 2HCO_3^- \rightarrow NO_3^- + 2CO_2 + 3H_2O$	$R_{NH_4Ox} = k_{NH_4Ox}(NH_4^+)(O_2)$	(7)
Mn^{2+} oxidation by O_2	$Mn^{2+} + kX + 0.5O_2 + 2HCO_3^- \rightarrow MnO_{2A}\text{-}X_k + 2CO_2 + H_2O$	$R_{MnOx} = k_{MnOx}(Mn^{2+})(O_2)$	(8)
Fe^{2+} oxidation by O_2	$4Fe^{2+} + O_2 + 4CO_2 + 2H_2O \rightarrow 4Fe^{3+} + 4HCO_3^-$	$R_{FeOx} = k_{FeOx}(Fe^{2+})(O_2)$	(9)
H_2S oxidation by O_2	$H_2S + 2O_2 + 2HCO_3^- \rightarrow SO_4^{2-} + 2CO_2 + 2H_2O$	$R_{TSOx} = k_{TSOx}(H_2S)(O_2)$	(10)
CH_4 oxidation by O_2	$CH_4 + O_2 \rightarrow CO_2 + H_2O$	$R_{CH_4Ox} = k_{CH_4Ox}(CH_4)(O_2)$	(11)
FeS oxidation by O_2	$FeS\text{-}X_m + 2O_2 \rightarrow SO_4^{2-} + Fe^{2+} + mX$	$R_{FeSOx} = k_{FeSOx}(FeS)(O_2)$	(12)
FeS_2 oxidation by O_2	$FeS_2\text{-}X_m + 3.5O_2 + 2HCO_3^- \rightarrow Fe^{2+} + mX + 2SO_4^{2-} + 2CO_2 + H_2O$	$R_{FeS_2Ox} = k_{FeS_2Ox}(FeS_2)(O_2)$	(13)
NH_4^+ oxidation by NO_2^-	$NH_4^+ + NO_2^- \rightarrow N_2 + 2H_2O$	$R_{NH_4NO_2} = k_{NH_4NO_2}(NH_4^+)(NO_2^-)$	(14)
Mn^{2+} oxidation by NO_3^-	$5Mn^{2+} + 2NO_3^- + 8HCO_3^- + kX \rightarrow 5MnO_{2A}\text{-}X_k + 8CO_2 + 4H_2O + N_2$	$R_{MnNO_3} = k_{MnNO_3}(Mn^{2+})(NO_3^-)$	(15)
Fe^{2+} oxidation by NO_3^-	$5Fe^{2+} + NO_3^- + 6CO_2 + 3H_2O \rightarrow 0.5N_2 + 5Fe^{3+} + 6HCO_3^-$	$R_{FeNO_3} = k_{FeNO_3}(Fe^{2+})(NO_3^-)$	(16)
$\sum H_2S$ oxidation by NO_3^-	$2.5H_2S + 4NO_3^- + HCO_3^- \rightarrow 2.5SO_4^{-2} + 2N_2 + CO_2 + 3H_2O$	$R_{TSNO_3} = k_{TSNO_3}(H_2S)(NO_3^-)$	(17)
Fe^{2+} oxidation by $MnO_{2A,\,B}$	$2Fe^{2+} + 2lX + (MnO_{2A}\text{-}X_k + MnO_{2B}\text{-}X_k) + 2HCO_3^- + 2H_2O \rightarrow 2Fe(OH)_{3A}\text{-}X_l + Mn^{2+} + kX + 2CO_2$	$R_{FeMn_{A,B}} = k_{FeMn}(Fe^{2+})(MnO_{2A,B})$	(18)
$\sum H_2S$ oxidation by $MnO_{2A,\,B}$	$H_2S + 4(MnO_{2A}\text{-}X_k + MnO_{2B}\text{-}X_k) + 6CO_2 + 2H_2O \rightarrow SO_4^{-2} + 4Mn^{2+} + 4kX + 6HCO_3$	$R_{TSMnO_2} = k_{SMn}(H_2S)(MnO_{2A,B})$	(19)
FeS oxidation by $MnO_{2\,A,\,B}$	$FeS\text{-}X_m + 4(MnO_{2A}\text{-}X_k + MnO_{2B}\text{-}X_k) + 8CO_2 + 4H_2O \rightarrow SO_4^{-2} + 4Mn^{+2} + Fe^{2+} + (m + 4k)X + 8HCO_3$	$R_{FeSMn} = k_{FeSMn}(FeS)(MnO_{2A,B})$	(20)
$\sum H_2S$ oxidation by $Fe(OH)_{3A,\,B}$	$H_2S + 8(Fe(OH)_{3A}\text{-}X_l + Fe(OH)_{3B}\text{-}X_l) + 14CO_2 \rightarrow SO_4^{-2} + 8Fe^{2+} + 8lX + 14HCO_3^- + 6H_2O$	$R_{TSFe_{A,B}} = k_{TSFe}(H_2S)(Fe(OH)_{3A,B})$	(21)
FeS oxidation by $Fe(OH)_{3A,\,B}$	$FeS\text{-}X_m + 8(Fe(OH)_{3A}\text{-}X_l + Fe(OH)_{3B}\text{-}X_l) + 16CO_2 \rightarrow SO_4^{-2} + 9Fe^{2+} + (m + 8l)X + 16HCO_3^- + 4H_2O$	$R_{FeSFe_{A,B}} = k_{FeSFe}(FeS)(Fe(OH)_{3A,B})$	(22)
CH_4 oxidation by SO_4^{2-}	$CH_4 + SO_4^{2-} + CO_2 \rightarrow H_2S + 2HCO_3^-$	$R_{CH_4SO_4} = k_{CH_4SO_4}(CH_4)(SO_4^{2-})$	(23)

Table A3. Geochemistry $X_{1\text{-}6}$ = metal or metalloid where 1=As, 2=Cu, 3=Cd, 4=Pb, 5=Ni, 6=Zn and dissolved X includes free ion and all solution complexes. If reaction mode = 1, the rate of precipitation is zero.

Description, Reaction	Rate equation	
MnO_{2A} ageing $MnO_{2A}\text{-}X_k \rightarrow MnO_{2B}\text{-}X_k$	$R_{MnAge} = k_{MnAge}(MnO_{2A})$	(24)
$Fe(OH)_{3A}$ precipitation	If reaction mode = 2 $R_{FeSppt} = k_{FeOHppt}[Fe^{2+}]$	
$Fe^{3+} + lX + 3H_2O \rightarrow Fe(OH)_{3A}\text{-} + 3H^+$	If reaction mode = 3 $R_{FeOHppt} = k_{FeOHppt}\left(1 - \left(\frac{K_{sp}}{IAP}\right)_{FeOH}\right)$ $R_{FeOHdiss} = -k_{FeOHppt}\left(1 - \left(\frac{IAP}{K_{sp}}\right)_{FeOH}\right)$	(25) (26)
$Fe(OH)_{3A}$ ageing $Fe(OH)_{3A}\text{-}X_k \rightarrow Fe(OH)_{3B}$	$R_{FeAge} = k_{FeAge}(Fe(OH)_{3A})$	(27)
FeS precipitation $Fe^{2+} + H_2S \rightarrow FeS + 2H^+$	If reaction mode = 2 $R_{FeSppt} = k_{FeSppt}[Fe^{2+}][HS^-]$	(28)
	If reaction mode = 3 $R_{FeSppt} = k_{FeSppt}\left(1 - \left(\frac{K_{sp}}{IAP}\right)_{FeS}\right)$ $R_{FeSdiss} = -k_{FeSppt}\left(1 - \left(\frac{IAP}{K_{sp}}\right)_{FeS}\right)$	(29) (30)
	If reaction mode = 4 $R_{FeSppt} = k_{FeSppt}\delta_{FeS}(\Omega_{FeS} - 1)$ $R_{FeSdiss} = k_{FeSdiss}\delta_{-FeS}(1 - \Omega_{FeS})$ $\Omega_{FeS} = \left(\frac{[Fe^{2+}][HS^-]}{[H^+]K'_{FeS}}\right)$ $\Omega_{FeS} > 1: \delta_{FeS} = 1, \delta_{-FeS} = 0$ $\Omega_{FeS} \leq 1: \delta_{FeS} = 0, \delta_{-FeS} = 1$	(31) (32) (33) (34)
FeS transformation to FeS_2 $FeS + H_2S \rightarrow FeS_2 + H_2$	$R_{Pyrite} = k_{pyrite}(FeS)(H_2S)$	(35)
XS precipitation $X^{2+} + H_2S \rightarrow XS + 2H^+$	$R_{XSppt} = k_{XSppt}\left(1 - \left(\frac{K_{sp}}{IAP}\right)_{XS}\right)$ $R_{XSdiss} = -k_{XSppt}\left(1 - \left(\frac{IAP}{K_{sp}}\right)_{XS}\right)$	(36) (37)
$FeCO_3$ precipitation $Fe^{2+} + CO_3^{2-} \rightarrow FeCO_3$	If reaction mode = 3 $R_{Sidppt} = k_{Sidppt}\left(1 - \left(\frac{K_{sp}}{IAP}\right)_{Sid}\right)$ $R_{Siddiss} = -k_{Sidppt}\left(1 - \left(\frac{IAP}{K_{sp}}\right)_{Sid}\right)$	(38) (39)
	If reaction mode = 4 $R_{Sidppt} = k_{Sidppt}\delta_{Sid}(\Omega_{Sid} - 1)$ $R_{Siddiss} = k_{Siddiss}\delta_{-Sid}(1 - \Omega_{Sid})$ $\Omega_{Sid} = \left(\frac{[Fe^{2+}][CO_3^{2-}]}{K'_{Sid}}\right)$ $\Omega_{Sid} > 1: \delta_{Sid} = 1, \delta_{-Sid} = 0$ $\Omega_{Sid} \leq 1: \delta_{Sid} = 0, \delta_{-Sid} = 1$	(40) (41) (42) (43)
$CaCO_3$ precipitation $Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3$	$R_{Calppt} = k_{Calppt}\left(1 - \left(\frac{K_{sp}}{IAP}\right)_{Cal}\right)$ $R_{Caldiss} = -k_{Calppt}\left(1 - \left(\frac{IAP}{K_{sp}}\right)_{Cal}\right)$	(44) (45)
$MnCO_3$ precipitation $Mn^{2+} + CO_3^{2-} \rightarrow MnCO_3$	If reaction mode = 3 $R_{Rodppt} = k_{Rodppt}\left(1 - \left(\frac{K_{sp}}{IAP}\right)_{Rod}\right)$ $R_{Roddiss} = -k_{Rodppt}\left(1 - \left(\frac{IAP}{K_{sp}}\right)_{Rod}\right)$	(46) (47)
	If reaction mode = 4 $R_{Rodppt} = k_{Rodppt}\delta_{Rod}(\Omega_{Rod} - 1)$ $R_{Roddiss} = k_{Roddiss}\delta_{-Rod}(1 - \Omega_{Rod})$ $\Omega_{Rod} = \left(\frac{[Mn^{2+}][CO_3^{2-}]}{K'_{Rod}}\right)$	(48) (49)

	$\Omega_{Rod} > 1: \delta_{Rod} = 1, \delta_{-Rod} = 0$ $\Omega_{Rod} \leq 1: \delta_{Rod} = 0, \delta_{-Rod} = 1$	(50)
Sulfide equilibria	$HS^{-} + H^{+} \leftrightarrow H_2S$	(51)
	$S^{2-} + 2H^{+} \leftrightarrow H_2S$	(52)
Phosphate equilibria	$HPO_4^{2-} \leftrightarrow PO_4^{2-} + H^{+}$	(53)
	$H_2PO_4^{-} \leftrightarrow PO_4^{3-} + 2H^{+}$	(54)

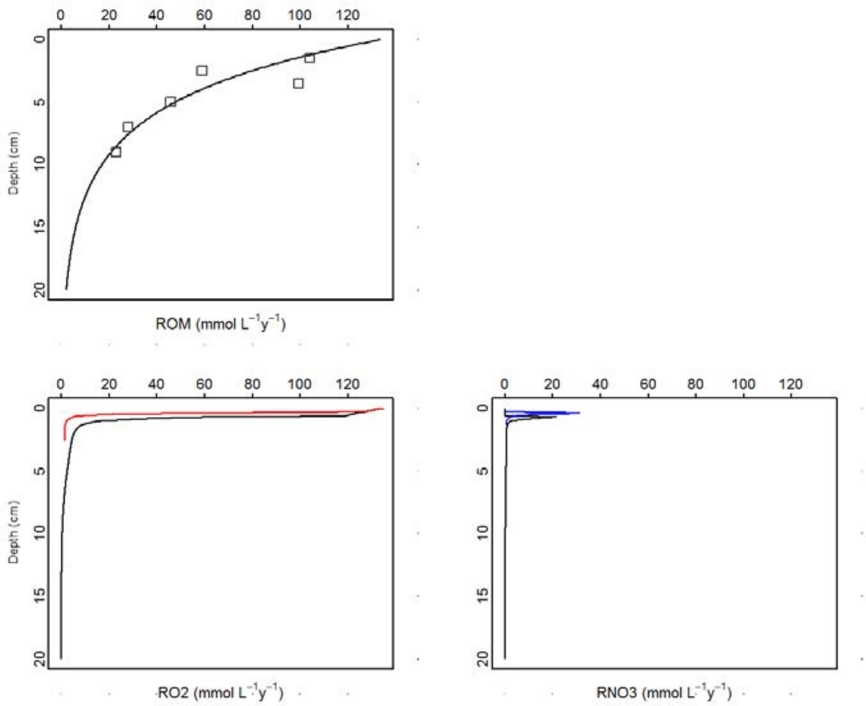

Figure B1. Simulated rates from CANDI AED. Top left: the overall carbon oxidation rate is set by depth, in order to fit the squares measured by Canfield et al. (1993). Bottom left: aerobic respiration using CANDI AED (black line) was close to the simulated rate of Van Cappellen and Wang (red). In the deepest part of the sediment, the simulated rate was greater using this model. Bottom right: denitrification with this model (black line) was slightly less and occurred slightly deeper than for Van Cappellen and Wang.

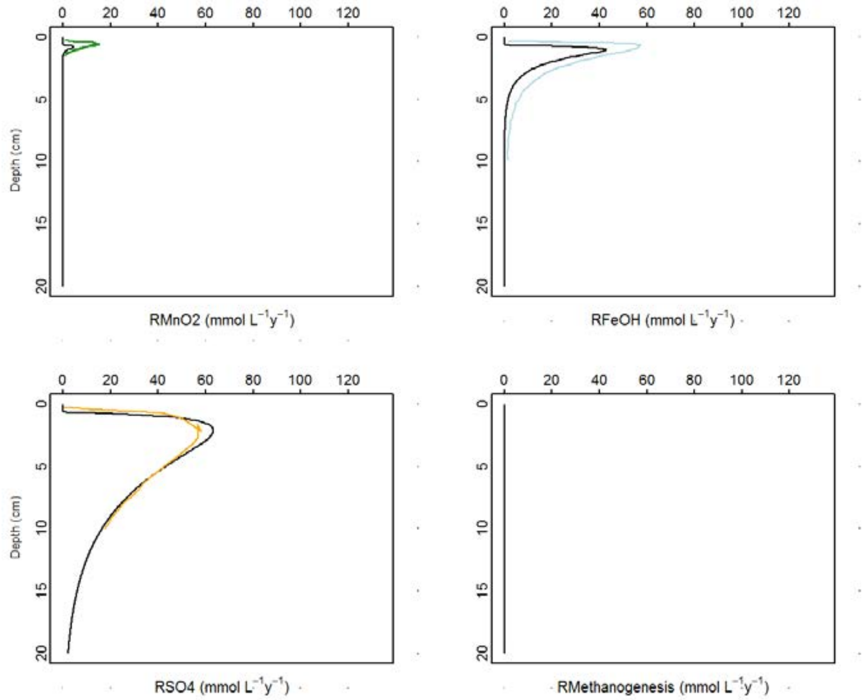

Figure B2. As with Figure B3, rates simulated here are in black and rates taken from Van Cappellen and Wang are coloured lines. Top left: the manganese reduction rate in this simulation was lower than the (green) rate calculated by Van Cappellen and Wang, but both were small in proportion to the overall oxidation rate. Top right: the iron reduction rate was lower than that simulated by Van Cappellen and Wang, peaking at around 40 rather than 60 mmol L^{-1} y^{-1}, yet peaking at the same depth. Bottom left: the sulfate reduction rate in this simulation (black) was very close to the rate in Van Cappellen and Wang (1996) (orange). Bottom right: as with Van Cappellen and Wang, methanogenesis was inhibited.

The O_2 concentration profile matched the Van Cappellen and Wang simulation very closely, however, the concentration of NO_3^- was higher than in the Van Cappellen and Wang simulation because the denitrification rate was inhibited (Figure B3). The slightly higher concentration of oxygen at the deepest point may have carried through to inhibit denitrification. The ammonium concentration did not match the data points as well as in the Van Cappellen and Wang simulation, however, it was nonetheless close to the data points. The pH profile was between 7 and 8.

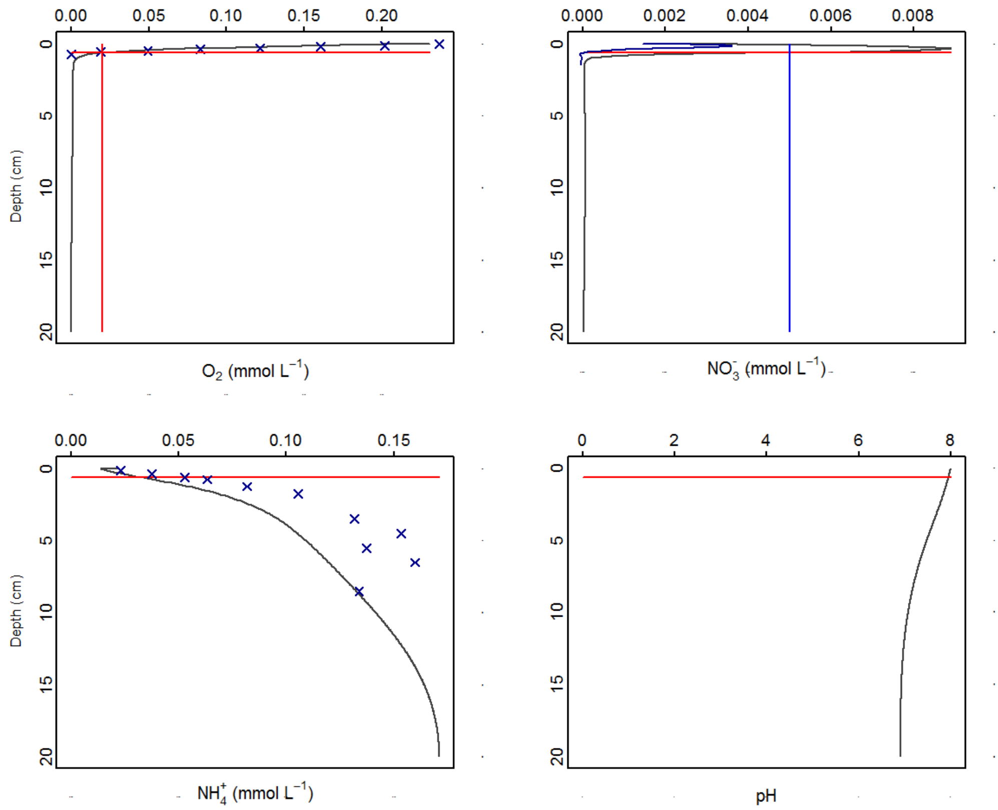

Figure B3. Concentration profiles for this simulation (black lines). The depth at which oxygen was below its half-saturation constant is shown with a horizontal red line. Top left: the O_2 concentration profile matched each of the data points except for the deepest point, where the simulation was higher. The O_2 half-saturation concentration is shown by the vertical red line. Top right: the NO_3^- concentration from this simulation (black line) was higher than that simulated by Van Cappellen and Wang (blue line). The NO_3^- half saturation concentration is shown with the blue vertical line. Bottom left: the NH_4^+ concentration is lower than the field data and not as good a fit as that achieved by Van Cappellen and Wang, yet it is close nonetheless. Bottom right: the pH ranged from 7 to 8.

BMT Oceanica

Mid West Aquaculture Development Zone Environmental Monitoring and Management Plan

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Mid West Aquaculture Development Zone

Environmental Monitoring and Management Plan

Prepared for

Department of Fisheries

Prepared by

BMT Oceanica Pty Ltd

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Date: 28 April 2016

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1. Background

1.1 Environmental approvals

In late 2011, the Minister for Fisheries announced a funding package to establish two aquaculture development zones in Western Australia's (WA) coastal waters. The WA Department of Fisheries (DoF) is managing the project, and is responsible for undertaking the environmental impact assessments (EIA) for zones in the Kimberley and Mid-west regions of the State.

This document relates to the Mid West Aquaculture Development Zone (MWADZ) which is proposed to be established within the Fish Habitat Protection Area of the Houtman Abrolhos Islands (hereafter the 'Abrolhos'). The MWADZ consists of two areas: a northern area (2200 ha), located roughly halfway between the Easter and Pelsaert groups and a southern area (800 ha), immediately north of the Pelsaert group (Figure 1.1).

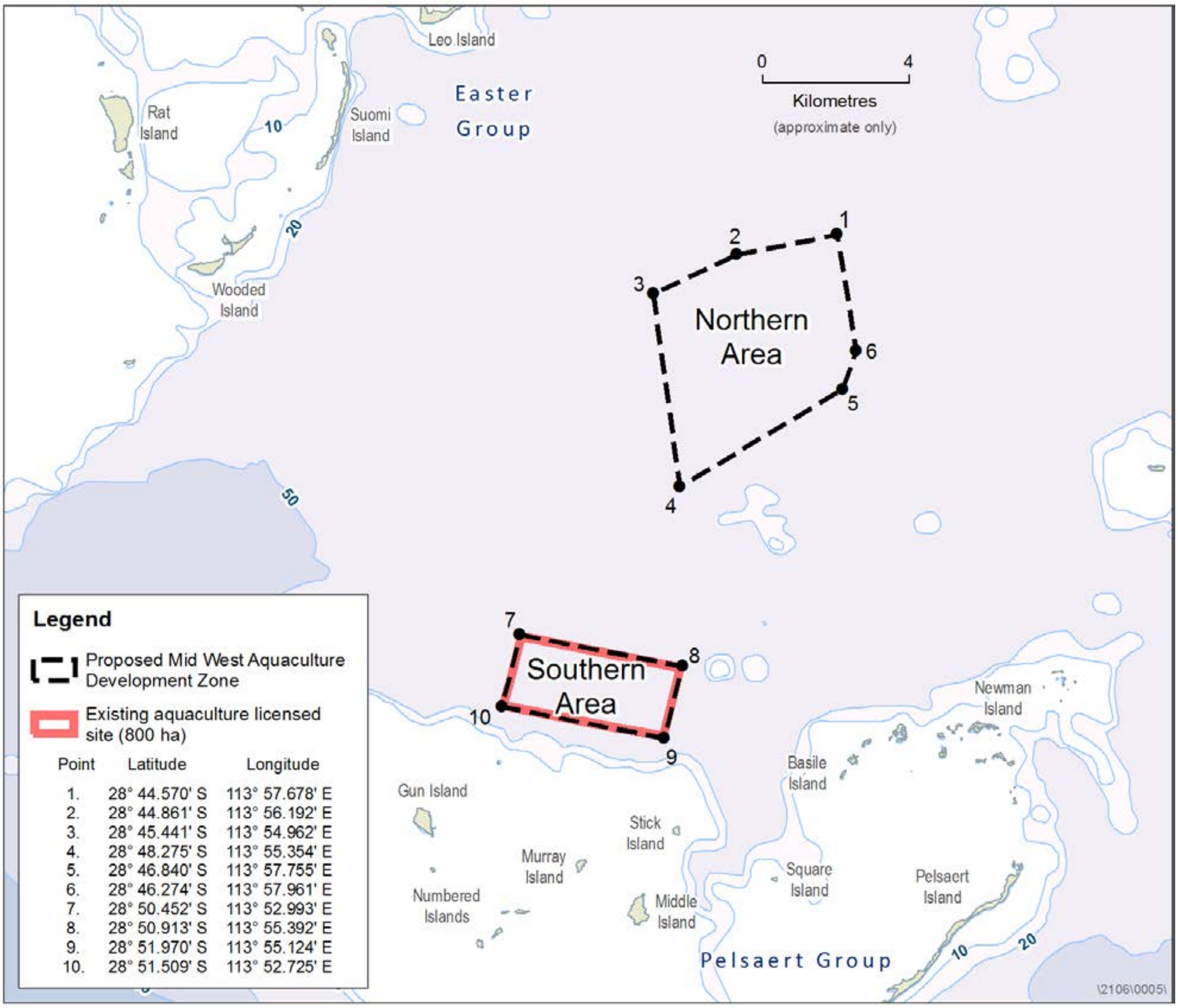


Figure 1.1 Location of the proposed Mid West Aquaculture Development Zone

The strategic proposal to develop the MWADZ was referred to the Environmental Protection Authority (EPA) in May 2013 and the level of assessment was set at Public Environmental Review (PER), under Section 38 of the Environmental Protection Act 1986. The Minister for Fisheries is the proponent for the strategic proposal under Part IV of the *Environmental Protection Act 1986* (EP Act). The Department of Fisheries (DoF) is acting as the proponent for the strategic proposal on behalf of the Minister for Fisheries. Existing and future aquaculture

operators who refer project proposals to the Environmental Protection Authority (EPA) as derived proposals under the approval of the strategic proposal are herein referred to as 'Proponents'.

The requirements of the EIA are defined in the EPA prepared environmental scoping document (ESD; EPA 2013) and included a number of technical studies including environmental modelling and multiple desktop assessments. The outcomes of these studies are detailed in BMT Oceanica (2015a, 2015b), Halfmoon Biosciences (2015) and DoF (2015a, 2015b and 2015c).

In addition to the technical studies required of the EIA, a further requirement of the ESD was to develop an environmental quality management framework (EQMF) for future aquaculture operations. The framework defines the environmental values (EVs) to be protected, the environmental quality objectives (EQO) and levels of ecological protection to be achieved and where they apply spatially.

1.2 Purpose of this Plan

This document, the Environmental Monitoring and Management Plan (EMMP) (hereafter 'the Plan'), provides the EQMF to protect sediment and water quality within the broader aquaculture zone, to a level commensurate with the agreed levels of ecological protection. While the EQMF is designed to manage water and sediment quality within the MWADZ (Sections 4.1 and 4.2), this Plan also includes proactive management strategies to protect the important biological and ecological values of the Abrolhos region, including its significant marine mammal, turtle, seabird, wild fin-fish and invertebrate populations (Sections 4.4, 4.5, 4.6 and 4.7).

2. Existing Marine Environment

The Abrolhos Islands are a group of islands located approximately 60 km west of Geraldton, Western Australia (WA). The islands are clustered into three main groups – Wallabi, Easter and Pelsaert, and are approximately 100 km in length from the northern to the southern tip. Both the MWADZ and the broader Abrolhos region have high conservation status owing to their near-pristine marine environmental qualities and the high socio/economic importance of the area.

This Plan details the monitoring and management strategies that will be used to protect the MWADZ and the broader Abrolhos marine environment for the life of the project. The key environmental elements are described in Sections 2.1 to 2.6, with an emphasis on the key environmental factors identified in the ESD (Table 2.1). The potential impacts of the proposal on key environmental factors are considered in Section 3.2.1.

Table 2.1 Key environmental factors and impacts identified in the Environmental Scoping Document

Key environmental factors	Key environmental impacts
• Hydrodynamics	• Alterations to hydrodynamics
• Marine water and sediment quality (including accumulation of trace contaminants)	• Degradation of marine water and sediment quality
• Marine flora and benthic primary producer habitat • Significant marine fauna • Marine benthic infauna and invertebrates	• Direct and indirect disturbance or loss of benthic communities and habitat • Direct and indirect impacts to key sensitive receptors • Impacts to marine environment and biota quality through release of pharmaceuticals, metals/metalloids and, or petroleum hydrocarbon • Direct and indirect impacts on significant marine fauna

2.1 Hydrodynamics

The MWADZ is located on the edge of the WA continental shelf between 28°S and 29°S, in the pathway of the warm poleward-flowing Leeuwin Current (Pearce 1997). It is also situated in the Zeewijk Channel, one of three breaks in the Houtman Abrolhos archipelago (Maslin 2005). The region surrounding the Abrolhos is a dynamic system influenced by large-scale regional currents (e.g. Leeuwin Current, Capes Current), wind stresses, upwelling and wave dynamics (Pearce & Pattiaratchi 1999, Feng et al. 2007, Waite et al. 2007, Woo & Pattiaratchi 2008, Rossi et al. 2013). The Leeuwin Current is a well-studied oceanic flow of warm, low salinity tropical water (originating in the Timor Sea) that travels southwards along the Western Australian coast. It is driven by a southwards pressure gradient, and under the influence of Coriolis deflections, hugs the coastline as it travels from near North West Cape to Cape Leeuwin (south of Perth) and then onwards to the Great Australian Bight (Cresswell 1991).

The Leeuwin Current flow is strongest in autumn, winter and early spring. The flow is greatest and most consistently south along the shelf break, a relatively short distance to the west of the Abrolhos Islands (Webster et al. 2002). The currents through and inshore of the islands vary spatially and temporally. During the late spring and summer months, the current through and inshore of the islands tends to set to the north, driven by the prevailing southerly winds with occasional current reversal to the west along the shelf break (Pearce et al. 1999). During the winter months strong westerlies and north-westerlies can generate southward setting currents through and inshore of the Abrolhos Islands (Pearce et al. 1999).

The waters of the MWADZ are well flushed and experience high levels of water circulation and dispersion. Their position within the Zeewijk Channel means that the area is exposed to significant westerly currents, which expel large volumes of water out of the zone toward the continental shelf slope (Maslin 2005). Differences in the hydrodynamics between the surface and bottom of the Zeewijk channel have been shown to affect particle transport times (Maslin 2005). Particles in the surface waters are expected to be flushed out of the system rapidly (within 24 hrs), while particles at the bottom of the water column are expected to be retained in the system for longer periods, due to the recirculation of bottom currents (Maslin 2005).

2.2 Water and sediment

Waters inside the MWADZ are clean and well mixed (BMT Oceanica 2015). Maximum and minimum water temperatures are achieved in autumn (23.5°C) and winter (20.8°C), respectively. Salinity and dissolved oxygen levels are consistent through the water column with little evidence of stratification. The water is highly oxygenated, achieving surface oxygen saturation levels between 96% and 99% and bottom oxygen saturation levels between 95% and 98% (BMT Oceanica 2015).

MWADZ water currents are variable, ranging between 5.8 and 14.4 cm/s. Concentrations of ammonium (2.7 µg/L) and chlorophyll-a (0.43 µg/L) are comparable to those recorded in Perth's coastal waters, pointing to an overall oligotrophic (nutrient poor) environment. Nitrite + Nitrate levels (12.9 µg/L) were higher than those recorded in Perth's coastal waters (6.5 µg/L) and in the Kimberley Aquaculture Development Zone (8.7 µg/L). Concentrations of inorganic nutrients and chlorophyll-a are seasonally variable, but are higher in the cooler months (BMT Oceanica 2015).

The benthic environment consists generally of a shallow (~15 cm thick) layer of sand overlying rocky substrate. Higher current speeds in the northern area (northern 13-14.5 cm/s compared to the south 8.7-11 cm/s) are reflected in the tendency toward larger sediment grain sizes in the northern reaches of the MWADZ. Sediment conditions are also variable, with seasonal fluctuations in nitrogen, phosphorus and total organic carbon, with generally higher values for these analytes in the warmer months. Infaunal assemblages are diverse (10 phyla; 129 families) and dominated by polychaetes. Higher levels of infauna diversity and abundance are observed in the summer months (BMT Oceanica 2015).

2.3 Marine flora and benthic primary producing habitats

Surveys undertaken in 2014 indicate that the seafloor is a mosaic of habitats consisting of open sandy meadows and mixed biological assemblages (BMT Oceanica 2015), comprising filter feeders (sponges, and bryozoans), macroalgae, rhodoliths and some hard corals (though the latter was observed infrequently). Despite the observed diversity of the biological assemblages, their presence is considered itinerant given their propensity to change significantly between surveys, and over time (BMT Oceanica 2015).

Habitats in the northern MWADZ are more diverse and comprise 83% bare sand and 17% mixed assemblages. Small patches of reef were observed outside the north-east boundary of the MWADZ but make up only 8.5% of the total habitat within the study area. By contrast, the habitats in the southern area comprise 99% bare sand and 1% mixed assemblages. Although ephemeral seagrass communities have historically been observed in the MWADZ, no seagrasses were observed in the 2014/2015 assessment (BMT Oceanica 2015).

2.4 Seabirds

The Houtman Abrolhos is the most significant seabird breeding location in the eastern Indian Ocean. Eighty percent (80%) of the brown (Common) noddies, 40% of sooty terns and all lesser noddies found in Australia nest at the Houtman Abrolhos (Ross et al. 1995). It also contains the largest breeding colonies in Western Australia of wedge-tailed shearwaters, little shearwaters, white-faced storm petrels, white-bellied sea eagles, osprey, caspian terns, crested terns, roseate terns and fairy terns (Storr et al. 1986, Surman and Nicholson 2009). The Houtman Abrolhos also represents the northernmost breeding islands for both the Little Shearwater and White-faced Storm Petrel.

Within the Pelsaert and Easter Groups, 17 species have been confirmed as breeding regularly. These are the white-bellied sea eagle, osprey, wedge-tailed shearwater, little shearwater and white-faced storm Petrel, Pacific gull, silver gull, caspian tern, crested tern, bridled tern, roseate tern, fairy tern, brown noddy, lesser noddy, eastern reef egret, pied oystercatcher and pied cormorant (Surman and Nicholson 2009).

Seabirds are of great ecological significance in the Abrolhos region and have been considered carefully in this Plan. Management strategies for protecting seabirds and limiting their interaction with the proposed sea-cage operations are outlined in Section 4.4 of this Plan.

2.5 Marine mammals and turtles

The Abrolhos Islands and surrounding waters provide important habitat for an array of marine mammals, comprising mainly whales, dolphins and sea lions. Thirty one cetacean and two pinniped species are known to occur within a 50 km radius of the MWADZ (DoE 2014). Some species occasionally transit through the area at low densities, but there is insufficient information to confirm a definitive presence. Species that are likely to occur within a 50 km radius include: humpback whale, Australian sea lion, Indo-Pacific bottlenose dolphin and the common bottlenose dolphin. Species with a low likelihood of occurrence include: the blue whale, southern right whale, Bryde's whale, killer whale and the dugong. Four marine turtles may occur within a 50 km radius, including the loggerhead turtle, flatback turtle, leatherback turtle and green turtle, with the last two species more likely.

Adverse interactions between marine mammals and sea-cage aquaculture are well documented in the literature (BMT Oceanica 2015). The potential for adverse effects, particularly between sea lions and the sea-cage infrastructure has been considered in this plan and will require careful management. Management strategies aimed at reducing the potential for adverse interactions are outlined in Section 4.5 of this Plan.

2.6 Finfish (including sharks and rays)

The significant finfish of the Abrolhos are considered in detail in DoF (2015a, 2015b). The benthic habitats of the Abrolhos support rich fish communities, with up to 389 fish species recorded (Hutchins 1997). The majority of these species (~60–65%) are tropical species, ~15% are subtropical, and ~20–25% are temperate species (Hutchins 1997, Watson et al. 2007). The structure of the fish assemblages differs between fished and non-fished areas (Watson et al. 2007) and there is a greater relative abundance of many of the targeted fish species in areas protected from fishing (Watson et al. 2009, Nardi et al. 2004).

Within these rich communities exists a number of Endangered, Threatened and Protected (ETP) species of finfish. These comprise a variety of sharks, rays, Queensland grouper and syngnathid (pipefish, seahorses and sea-dragons). Most syngnathid species inhabit shallow, sheltered coastal waters, away from the proposed MWADZ. While Queensland grouper possibly exist at

the Abrolhos Islands the likelihood of an interaction with the proposed sea-cage operations was considered remote (DoF 2015b). However, interactions between the sharks/rays and the proposed sea-cages are considered more plausible (DoF 2015b).

Management strategies for limiting the potential for adverse interactions between the sea-cage infrastructure and finfish, including sharks and rays, are provided in Sections 4.6 and 4.7 of this Plan.

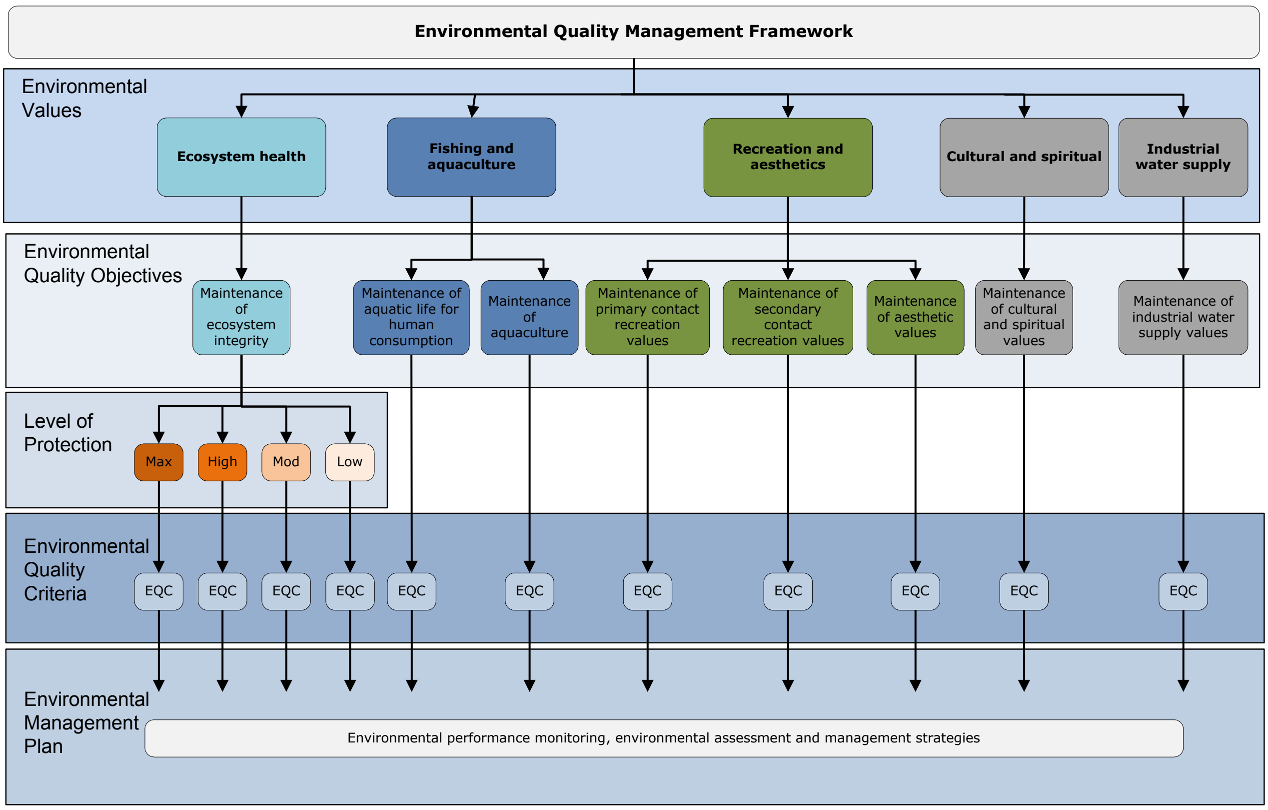
3. Environmental Management Framework

3.1 Approach to marine environmental management

Marine environmental management in WA is undertaken according to the environmental quality management framework (EQMF) described in EAG 15 (EPA 2015). The purpose of this section is to describe the elements of the EQMF, which together provide the foundation for this Plan.

3.1.1 Environmental values and environmental quality objectives

The intent of the EQMF is that, for each significant water body in WA, a series of EVs with associated EQOs will be selected and applied in consultation with the community and stakeholders. EVs refer a particular value or use of the marine environment that are important for a healthy ecosystem or, for public benefit, welfare, safety or health, and which requires protection from the effects of pollution, environmental harm, waste discharges and deposits. The EQOs are high-level management objectives required to protect the EVs (EPA 2015) (Figure 3.1). The objective is to ensure the marine environment (in this case the MWADZ and surrounding region) is managed to achieve the relevant Environmental Values (EVs) and Environmental Quality Objectives (EQOs), as outlined in Environmental Assessment Guideline (EAG) No. 15 (EPA 2015) and the State Water Quality Management Strategy (Government of Western Australia 2004) (Table 3.1).



Notes:

1. Modified from Figure 1 (page 7) of EPA (2015a)
2. EQC are environmental quality criteria (see Section 3.1.4)

Figure 3.1 Conceptual overview of the environmental quality management framework applied to Western Australia's marine environment

Table 3.1 Environmental values and environmental quality objectives that apply in the MWADZ and surrounds

Environmental Values	Environmental Quality Objectives
Ecosystem health	1. Maintain ecosystem integrity at a high level of ecological protection 2. Maintain ecosystem integrity at a moderate level of ecological protection This means maintaining the structure (e.g. the variety and quantity of life forms) and functions (e.g. the food chains and nutrient cycles) of marine ecosystems to an appropriate level
Recreation and aesthetics	Water quality is safe for primary contact recreation (e.g. swimming and diving). Water quality is safe for secondary contact recreation (e.g. fishing and boating). Aesthetic values of the marine environment are protected.
Cultural and spiritual	Cultural and spiritual values of the marine environment are protected.
Fishing and aquaculture	Seafood (caught or grown) is of a quality safe for eating. Water quality is suitable for aquaculture purposes.
Industrial water supply	Water quality is suitable for industrial use.

Notes:

1. Modified from Table 1 of EPA (2015a).
2. Refer to Figure 3.7 of this EMMP.

3.1.2 Environmental values and objectives at risk from operations

While aquaculture Proponents have an obligation to meet each of the EQOs, only a small number EQO are at risk due to aquaculture operations. The cause effect pathways related to fin-fish aquaculture are outlined in Section 3.2.2 of this Plan. The EVs for Recreation, Fishing and aquaculture and Industrial water supply are concerned with the protection of the human population from the potential adverse effects of toxicants and microbiological contaminants (typically present in sewage and storm water) and the protection of nearby aquaculture and industry from the effects of toxicants and other contaminants (EPA 2015a). The key pressures associated with aquaculture are inputs of nutrients and organic material derived from fin-fish metabolic processes and feeding. As such, none of the pressures identified in Section 3.2.2 of this Plan are expected to compromise the EQOs for these EVs.

The cultural and spiritual values of the Abrolhos region will be protected by maintaining key ecosystem functions, and the general aesthetic qualities of the nearby water. These are protected in this Plan by a commitment to meet the EQOs for maintenance of ecosystem integrity and aesthetic values, which in turn will to be assessed against a series of Environmental Quality Criteria (EQC), also been developed as part of this Plan.

3.1.3 Levels of ecological protection

The EQO, to 'maintain ecosystem integrity', is unique in that it encompasses differing levels of ecological protection (LEP): maximum, high, moderate and low (Table 3.2). Differing levels are applied in recognition of the competing environmental, societal and industrial uses of the marine environment. Because of competing interests, it is recognised that not all areas can achieve (or retain) high to maximum levels of ecosystem protection, and that some areas must instead be given either moderate or low ecological protection status (EPA 2015), with corresponding limits of acceptable change. The framework allows for small localised effects, while aiming to maintain overall environmental integrity (EPA 2015). This is important in the context of this Plan, which includes strategies to manage the expected reduction in environmental quality beneath and immediately adjacent to the MWADZ sea-cages, while maintaining broader regional environmental quality (see Section 3.2.4).

Table 3.2 Levels of ecological protection linked to the environmental quality objective for maintenance of ecosystem integrity

Level of ecological protection	Environmental quality conditions (limit of acceptable change)	
	Contaminant concentration indicators	**Biological indicators**
Maximum	No contamination – pristine	No detectable change from natural variation
High	Very low levels of contaminants	No detectable change from natural variation
Moderate	Elevated levels of contaminants	Moderate changes from natural variation
Low	High levels of contaminants	Large changes from natural variation

3.1.4 Environmental quality criteria

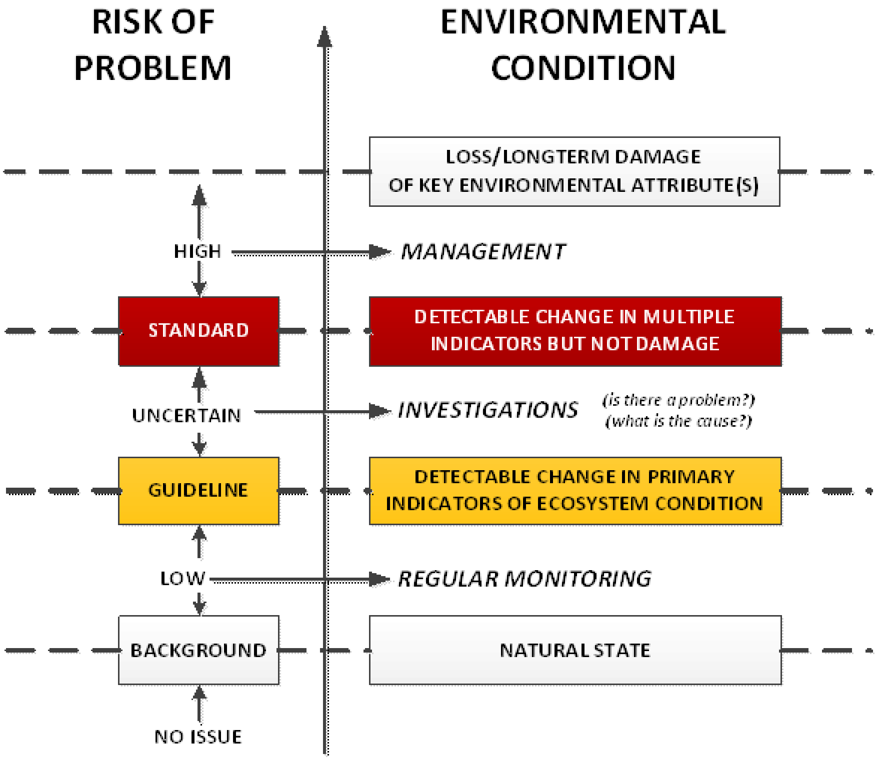
Following commencement of aquaculture operations, Proponents will be required to demonstrate they are achieving the EQOs. The extent to which the EQOs have been achieved will be assessed against a suite of environmental quality criteria (EQC). The EQC, comprising guidelines and standards, provide the benchmarks against which environmental quality is measured. Unlike the EQOs, which are qualitative and described as a narrative, the EQC are quantitative and described numerically (EPA 2015).

The EQC are based on cause-effect-response relationships relating to the potential impacts (pressures) of the proposed activity, and to the specific environmental systems (response) where the activity will occur (EPA 2015).

An important aspect of the EQMF is that the EQC define the limits of acceptable change to environmental quality. Under the EQMF, Proponents are required to maintain environmental quality within the bounds described by the EQC. If the EQC are met, then it is assumed that the EQOs have been achieved. There are two levels of EQC:

- Environmental Quality Guidelines (EQGs) are quantitative, investigative triggers which, if met, indicate there is a high degree of certainty that the associated EQO has been achieved. Indicators used as EQGs should be closer to the pressure end of a pressure-response relationship (i.e. provide early warning of a potential problem). If the guideline is not met, there is uncertainty as to whether the associated EQO has been achieved; and
- Environmental Quality Standards (EQSs) are threshold numerical values or narrative statements that indicate a level beyond which there is a significant risk that the associated EQO has not been achieved. EQSs should be closer to the response end of a pressure-response relationship (i.e. measure the affected organisms/habitats). Continued exceedance of an EQS will trigger a management response. The response would normally focus on identifying the cause of the exceedance and reducing the contaminant loads. In situ remedial work may also be required. EQSs are generally equivalent to the water quality objectives described in ANZECC & ARMCANZ (2000a).

The conceptual framework for applying the EQC is illustrated in Figure 3.2.



Notes:

1. Adapted from Figure 3 (page 14) of EPA (2015a)

Figure 3.2 Conceptual framework for applying the environmental quality guidelines and standards

3.2 Applying the management framework

3.2.1 Environmental pressures of aquaculture

This section of the plan considers the potential for adverse interactions between the MWADZ and the marine environment. The potential for adverse effects is considered in the context of the key environmental factors and impacts outlined in the ESD (Table 2.1). Strategies for managing the potential impacts of the MWADZ proposal are outlined in Section 4.

Aquaculture service vessels

Noise generated by vessel movement and other aquaculture activities has the potential to disturb marine fauna, causing temporary or long-term avoidance of an area. Depending on their magnitude and frequency, underwater sounds may interfere with communication systems, mask important biological cues or cause behavioural disturbances (Richardson et al. 1995, National Research Council 2005, Southall et al. 2007). Underwater noises associated with aquaculture are expected to be limited to engine noises generated by service vessels (i.e. feeding barges) and intermittent low intensity sounds such as those generated by infrastructure maintenance. Engine noises are expected to be of similar frequency and intensity to those of commercial fishing boats (Olesiuk et al. 2012). For marine mammals, the effects of these vessels are transitory and the animals can generally habituate to these sounds with regular exposure. Risks associated with underwater noise are therefore considered low. Mitigation strategies for managing the effects of underwater noise are included in Section 4.5.

Sea-cage infrastructure and feeding

The MWADZ will employ floating sea cages, arranged within clusters anchored to the seafloor (Figure 3.3) and will employ state of the art sea-cage infrastructure encompassing durable high-tensile materials and anchoring systems appropriate to the local environment. A conceptual overview showing indicative sea-cage configuration is shown in Figure 3.4.

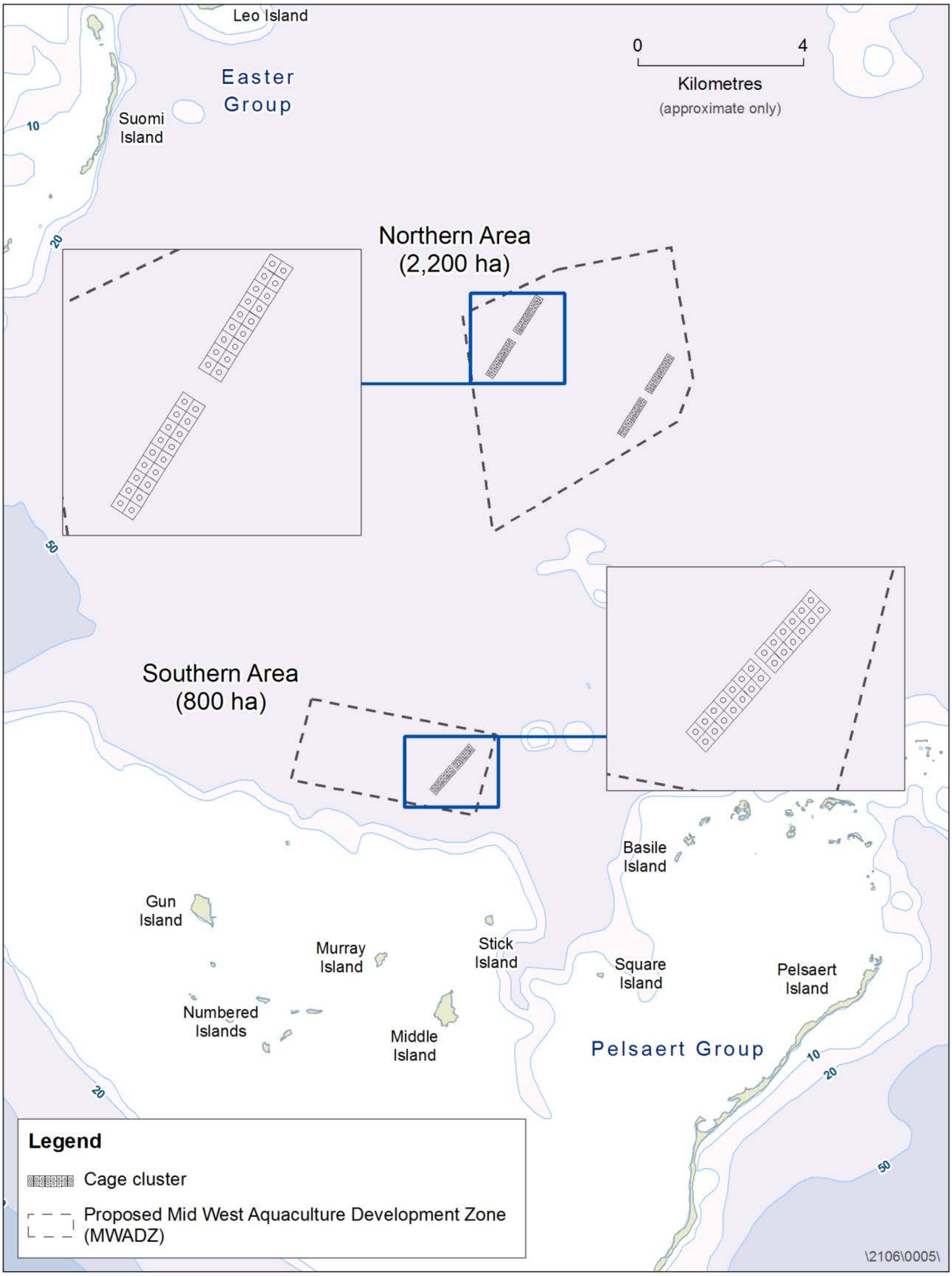


Figure 3.3 Conceptual overview of possible sea-cage cluster configurations

Of the potential pressures imparted by the infrastructure, most (i.e. physical presence, changes to hydrodynamics, risk of entanglement/entrapment and an attractant/distraction) are considered manageable (BMT Oceanica 2015), and few present residual risks with ongoing needs for environmental monitoring. These findings notwithstanding, the pressures resulting from feeding (and to a lesser extent, care of stock) are potentially significant, and form a key consideration in this Plan. There are two significant cause-effect pathways beginning with inputs of artificial feeds: (1) those resulting in changes to seabird, turtle, marine mammal and finfish behaviour, and (2) those resulting in environmental nutrient enrichment and the secondary effects which follow (Section 3.2.2).

The Proponent will include in the Annual Compliance Report, aquaculture associated data recorded quarterly for each operational cage[1]:

1. Standing stock densities;
2. Stock biomass;
3. Stock growth rates;
4. Feed/waste ratio;
5. Location, i.e. GPS coordinates;
6. Depth of water;
7. Quantity of feed administered to stock;
8. Feed type, make and specifications; and
9. Type and quantity of treatment pharmaceuticals administered to stock in situ.

Seabirds, marine mammals and finfish

The EIA for this proposal (BMT Oceanica 2015) identified certain seabirds (Pacific and silver gulls) and the Australian sea-lion as being particularly at risk due to the introduction of sea-cages. Through their attraction to artificial food sources (and to a lesser extent artificial habitats), both may exhibit changes in behaviour and feeding habitats, with potential for secondary effects to populations structure (through either increases or decreases in population size). However, experience gained in Australia and internationally has resulted in advances in knowledge of aquaculture environmental management, including methods for minimising the risks to seabirds and marine mammals.

The EIA for this proposal found that the use of best practice approaches to the design of sea cages, management of netting, exclusion devices and protocols for reducing feed wastage are expected to reduce the potential for exploitation by these animals (Sections 4.4, 4.5 and 4.6). Mitigation strategies for managing the potential adverse effect of artificial feed sources (both pelletised feeds and the aquaculture stock) on sea-birds, marine mammals and finfish are outlined in Sections 4.4, 4.5 and 4.6, respectively.

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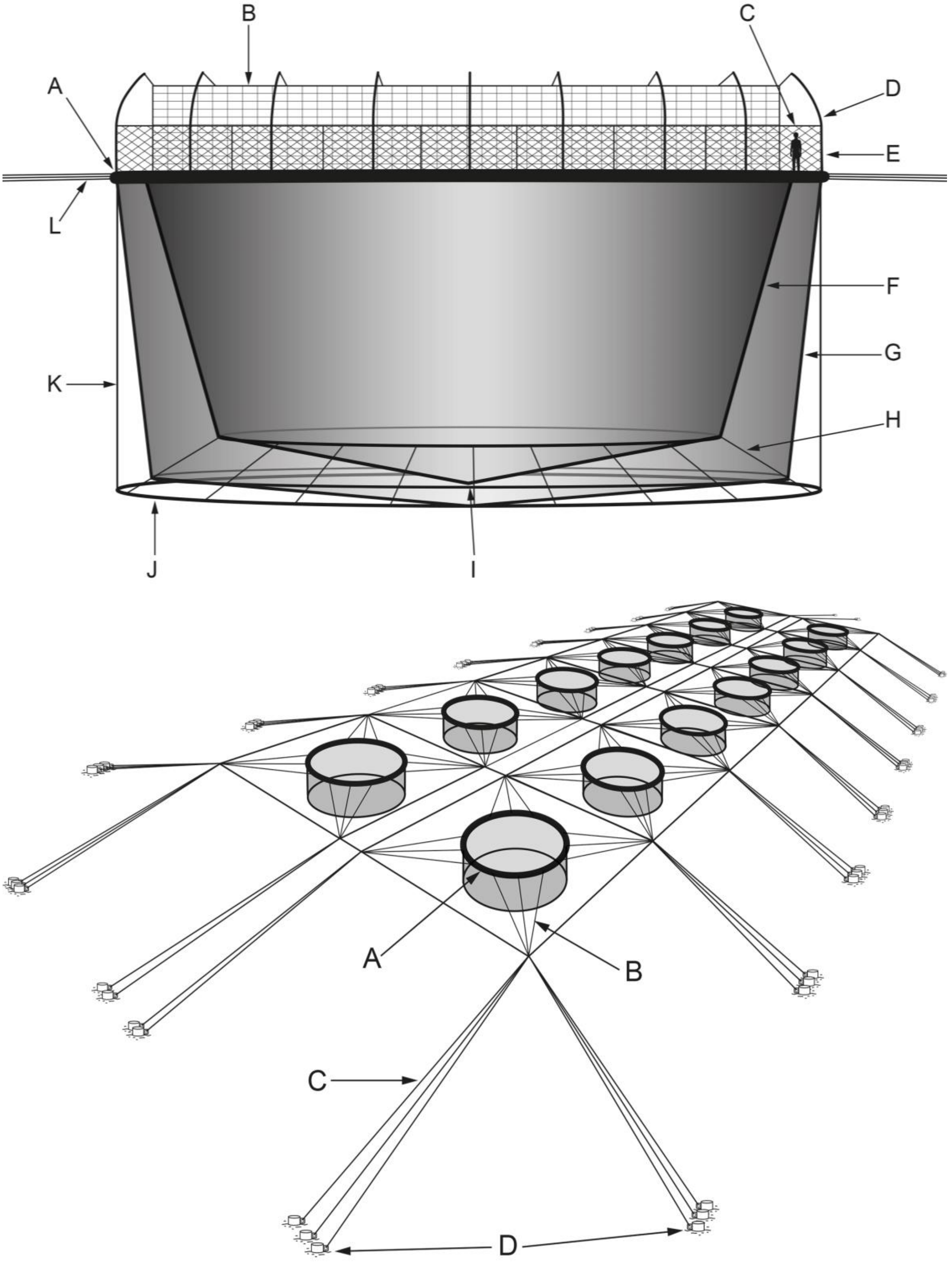
[1] *Parameters 1 - 9 can be estimated using all available information (i.e. are not required to be precise, direct measurements).*



Notes:

1. Upper Panel: All nets and mesh are durable and high tensile: A - Floating collar to suspends nets; B - Taut overhead net to prevent seabird access to stock and feed; C - High sea lion-exclusion barrier to prevent wildlife from accessing the walkway; D - Long flexible net-poles to support, suspend and maintain tension of the overhead seabird-exclusion nets several metres above the water; E - Stanchions (posts) to support the sea lion-exclusion barrier; F - Stock containment net (fully enclosed); a component of the double net system; G - Marine-predator exclusion net (fully enclosed); a component of the double net system; H - Net-baseline rope to link nets to the sinker tube; I - False net-bottom, created by the double net system, to keep stock separated from marine predators; J - Sinker tube, suspended from the nets, to maintain tension and support the structure of the nets; K - Weight line to facilitate lifting the sinker tube and bottom of the nets; L -Mooring lines, connected to the anchoring system, to hold the sea cage in position.
2. Lower Panel: All lines and cables are durable, high tensile and appropriate for an anchoring system designed to withstand extreme loads: A - Sea Cage; B - Mooring lines; C - Anchor cables; D - Low profile mooring-anchors.

Figure 3.4 Indicative sea-cage engineering (upper), configuration and anchoring (lower)

Sediments

Finfish aquaculture has the potential to impact the sediment when organic wastes settle beneath or in close proximity to the sea-cages (Mazzola et al. 2000, Carroll et al. 2003), resulting in increased nutrient loads. Significant nutrient loadings are generally associated with increased episodes of anoxia, particularly in stratified waters, with subsequent detrimental effects to infauna (Baden et al. 1990, Hargraves et al. 2008, Schaffner et al. 1992). Heavy metals form a small constituent of aquaculture feeds which are consumed and excreted in the faeces. A review of the metal content of trout faeces by Moccia et al. (2007) found that copper, iron and zinc were present in the highest proportions, although overall concentrations were low. Despite the low concentrations in commercial feeds, monitoring in Tasmanian waters has recorded copper and zinc values at concentrations higher than the ANZECC & ARMCANZ (2000) ISQG-low and ISQG-high guideline values at some sea-cage sites (DPIPWE 2011). The EIA for this proposal found that metal in feeds posed a very low risk to the marine environment. The approach to monitoring and managing the potential impacts of organic wastes is outlined in Section 4.2.

In addition to contributing organic wastes to the seafloor, aquaculture may contribute pharmaceuticals to the marine environment. Antibiotics are used as needed to treat bacterial disease occurring in farmed fish and are generally administered in feed. Calculations have shown that 70% to 80% of drugs administered in fish farms end up in the environment, and drug concentrations with antibacterial properties have been detected in sediments beneath sea-cages (Samuelsen et al. 1992). Antibiotics may impart pressure on the environment by reducing or changing numbers of sediment bacteria, which in turn may affect biochemical and/or broader ecological processes. The persistent use of antibiotics has also been shown to lead to bacterial resistance (Anderson and Levin 1999). In the treatment of farmed salmon in Tasmania, oxytetracycline is the most common antibiotic used, accounting for more than 70% of total antibiotic use during 2006–2008 (Parsons 2012). A strong seasonal component to the use of antibiotics has been noted in Tasmania, with the greatest requirement in the summer months when water temperatures are elevated and pathogens most virulent. Oxytetracycline has been found to persist in marine sediments beneath sea cages for up to twelve weeks, with a half-life of ten weeks (Jacobsen and Berglind 1988). However, traces of the drug may be present for up to two years after treatment (Lalumera et al. 2004). It is also relatively persistent to anoxic conditions which are common under sea-cages (Jacobsen and Berglind 1988). Because antibiotics are administered in feeds, the spatial extent of potential impacts is likely reflected in the settlement patterns of organic wastes. Modelling predicted that the majority of wastes[2] in the MWADZ would be deposited to the seafloor within 60 m of the sea-cages[3]. If antibiotics are required, it would be administered for short periods of time. The strongest effects of antibiotics could last for up to 10 weeks but are likely to be constrained to relatively small areas.

Water Column

Sea-cage aquaculture contributes inorganic nutrients to the water column either directly through secretion of ammonia by fish, or indirectly through organic matter deposition and remineralisation and the sea-floor level. Inorganic nutrients (ammonia, nitrite + nitrate and orthophosphate) may lead to adverse environmental effects via a number of cause-effect-response pathways (Figure 3.5). Nutrients may be assimilated directly by phytoplankton and/or macroalgae, leading to shading effects, phytoplankton blooms or the proliferation of 'nuisance' epiphytes.

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2 *As represented by the Zone of High Impact*

3 *After 3 years production*

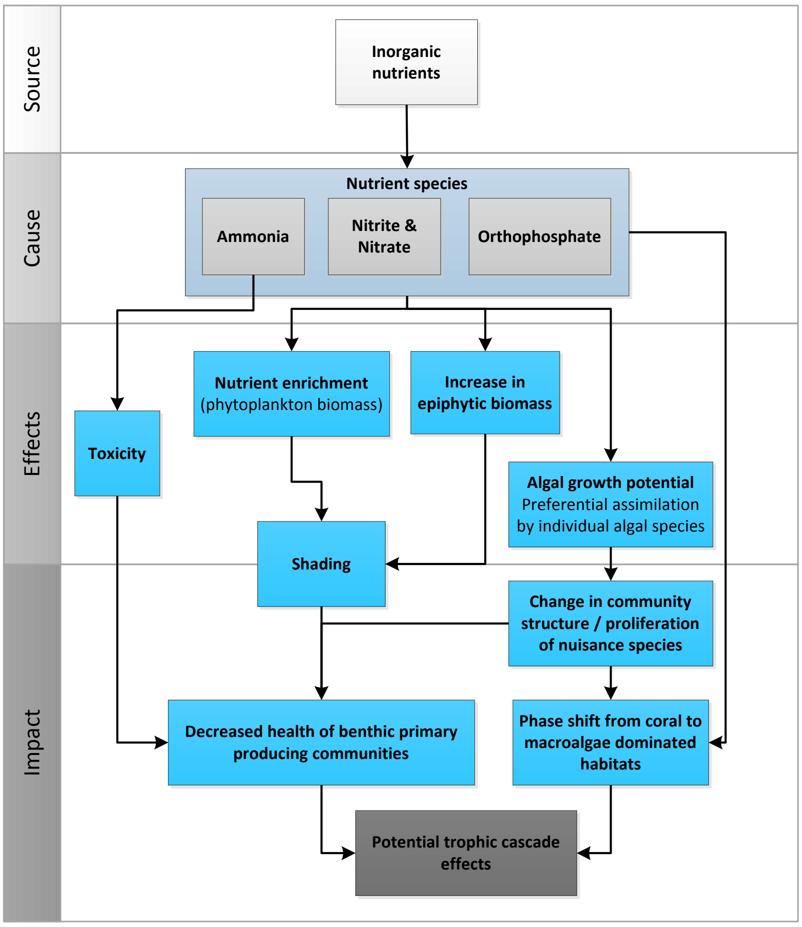


Figure 3.5 Cause-effect-response pathways relevant to inorganic nutrients

Sea-cage aquaculture may also lead to an increase in the concentration of suspended particles (total suspended solids) in the water column (Figure 3.6). Smothering may be an issue when the organic wastes expelled from the sea-cages settle to the sea-floor. Smothering occurs when the volume of material reaching the seafloor exceeds the shedding capacity of marine organisms, or their limit of inundation tolerance (PIANC 2010). Smothering is a concern under conditions of low shear stress, when dispersion potential is reduced (BMT Oceanica et al. 2015). A proportion of these wastes may be resuspended, creating additional scope for mechanical interference to filter feeding processes, or reduction of photosynthetic pathways particularly at depth (Erftemeijer et al. 2012). The deposition of organic material may also lead to dissolved oxygen drawdown in the water column as biological respiration increases in response to increased sediment nutrient loads (Gray 1992). Episodes of hypoxia or anoxia can subsequently cause loss of benthic populations, changes in benthic communities, or reduced growth rates (Forbes & Lopez 1990, De Zwann et al. 1992, Josefson & Jensen 1992, Stachowitsch 1992, Gaston & Edds 1994, Forbes et al. 1994).

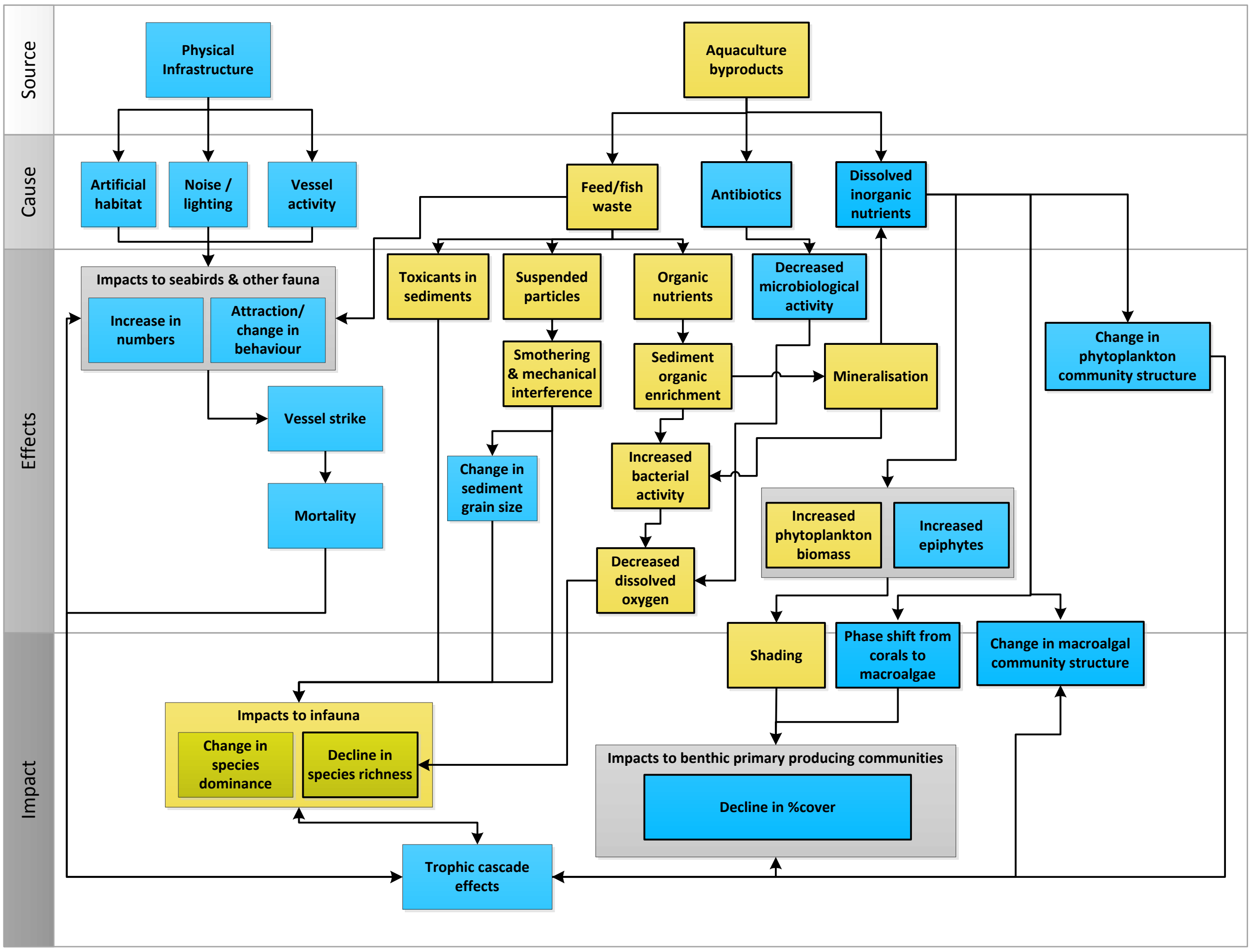
The potential for the MWADZ to adversely affect the local and regional marine environment was evaluated using an integrated environmental model (BMT Oceanica et al. 2015). Deposition of organic material was predicted to lead to changes in sediment oxygen and sulphide concentrations beneath the sea-cages. Results indicated that the size of the impact was related to stocking density and the duration of operations (BMT Oceanica 2015).

Concentrations of dissolved inorganic nitrogen (DIN) down-current of the sea-cages increased with increasing finfish biomass. However, the plumes dissipated rapidly, and concentrations generally returned to levels commensurate with a high level of ecological protection inside the MWADZ boundary (BMT Oceanica 2015). Any corresponding increase in chlorophyll-a resulting from aquaculture activities would therefore be expected to occur away from the sea cages. Although the proposal presents conditions under which phytoplankton may flourish, thus also

increasing light attenuation, none of the modelled scenarios predicted increases in chlorophyll-a concentrations and sub-surface light conditions were not affected.

3.2.2 Cause-effect-response relationships

The cause-effect-response pathways are summarised below (Figure 3.6). The objective was to identify the key stressors and their effects, based on the risks identified in Section 3.2.1. The understanding gained by this process was used to identify the indicators and receptors that form the EQC in this Plan.



Notes:

1. Key cause-effect-response pathways. Pathways shown in yellow represent those for which EQC were developed.

Figure 3.6 Hierarchical stressor model showing the cause-effect pathways of most concern and the receptors potentially impacted by aquaculture

3.2.3 Environmental quality criteria for aquaculture

EQC were derived based on the key environmental pressures identified in Section 3.2.1 and the cause-effect pathways shown in Figure 3.6. EQG and EQS were developed for measurable indicators, or for indicators for which there were precedents as guided by EPA (2014) (Table 3.3). EQC were thus developed for water quality, sediment quality and aesthetics. The EQC for these elements are included in Sections 4.1, 4.2 and 4.8.

The potential for adverse effects to other receptors, marine mammals, turtles, sea-birds and finfish were considered manageable via engineering and/or proactive management solutions, and no EQC were developed in these cases. Management strategies relevant to these elements are included in Sections 4.4, 4.5, 4.6, and 4.7.

Table 3.3 Measurable indicators used to derive the environmental quality criteria

Source / Cause	Monitoring	EQG	EQS
• Aquaculture feeds • Finfish wastes • Inorganic nutrients	Water quality	Light attenuation coefficient	Total suspended solids Infauna community diversity
		Total suspended solids	
		Chlorophyll-a	Light attenuation coefficient
		Dissolved oxygen	Surface-bottom dissolved oxygen
	Sediment	Total nitrogen	Sediment infauna Bottom water dissolved oxygen
		Total phosphorus	
		Total organic carbon	
		Copper	Infauna community diversity
		Zinc	
• Physical infrastructure • General operations • Finfish and other wastes • Litter and spills	Aesthetics	Nuisance organisms	
		Water clarity (qualitative)	
		Petrochemical surface films	
		Surface debris	
		Odours	

3.2.4 Levels of ecological protection for aquaculture

The EQO for maintenance of ecosystem integrity requires the spatial definition of four or less LEPs – maximum, high, moderate and low (Section 3.1.3). The rationale for designation of LEPs is based on the expectation that aquaculture operations will reduce environmental quality on a local scale, such that a maximum or high LEP may not be achievable immediately beneath and adjacent to operational infrastructure. The EPA expects the cumulative size of the areas designated as moderate or low ecological protection areas to be proportionally small compared to the areas designated high and maximum.

Guidance provided by the EPA suggests that finfish aquaculture (defined as sea-cages) in Western Australia should be managed to achieve a 'moderate' LEP (LEP) (Table 3, EAG 15). In areas assigned a moderate LEP, operational pressures are expected to result in small changes to the abundance and biomass of marine life, and in the rates but not the types of ecosystem processes. Under the same LEP, there should be no detectable and persistent changes in biodiversity due to waste discharges or contamination.

Environmental modelling undertaken for this project (BMT Oceanica 2015) predicted that any organic enrichment resulting from aquaculture would be locally constrained, with no resulting regional scale adverse effects (BMT Oceanica 2015). For example, modelling predicted that the most severe impacts would be restricted to a distance of 110 m after 5 years production, and 55 m and 50 m after 3 and 2 years production, respectively. While changes to the sediment chemistry and resident biological assemblages are expected to occur under these scenarios, the changes are predicted to be locally constrained, with no resulting detectable impacts beyond 100 m from the sea-cages (under full production). Furthermore, any changes to the sediment chemistry and the resident invertebrate fauna are expected to be fully reversible under a program of routine fallowing (see Section 6).

Based on the above, it is proposed to establish three moderate ecological protection areas (MEPAs), each of 300 m radii, within a broader high ecological protection area (HEPA): two in the northern area and one in the southern area. The framework has been designed to be moderately protective of habitats within the MEPA (with a decreasing gradient of effect between the sea-cages and the HEPA boundary) and highly protective of habitats outside of the MEPA, including sensitive coral reef habitats. Proponents will be expected to demonstrate they are meeting the

designated LEPs for the life of the project, by complying with the EQC for moderate and high ecological protection as outlined in Sections 4.1 and 4.2 of this Plan.

The proposed MEPAs will be complemented by an additional six recovery zones, which when operational, will also be assigned a moderate LEP. At the commencement of fallowing, the recovery zones will be monitored until it can be demonstrated that they have recovered to levels consistent with a high LEP. The cumulative area occupied by the MEPAs and the recovery zones is less than 5% of the area within a 10 km radius of the MWADZ, which is within the acceptable limit for MEPAs specified in EAG 15 (EPA 2015). The spatial arrangement and extent of the moderate and high LEPs to be applied to the MWADZ is illustrated in Figure 3.7.

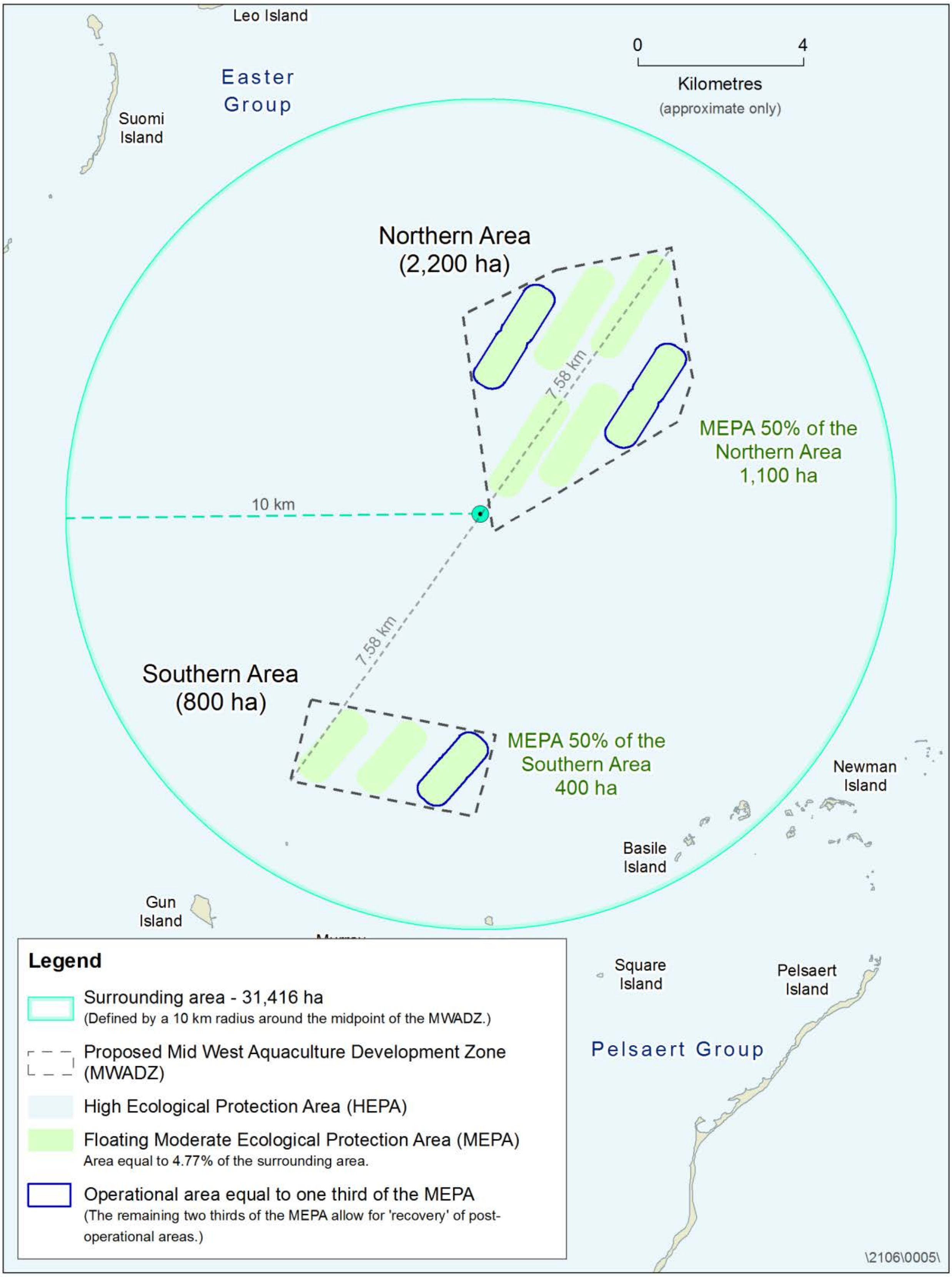


Figure 3.7 Environmental Quality Plan (EQP) for the MWADZ and surrounds. The locations of the MEPAs are conceptual, but will be contained within the Northern and Southern areas of the MWADZ and not exceed 50% of the area in each.

Note: The MEPAs and HEPA shown in the EQP relate to the EV of 'Ecosystem Health'. All social use EVs ('Fishing and Aquaculture', 'Recreation and Aesthetics', 'Cultural and Spiritual' and 'Industrial Water Supply') apply throughout the MWADZ and surrounds.

4. Monitoring and Management

Each of the key environmental factors identified in the ESD is encompassed within the EV for ecosystem health and the EQO for maintenance of ecosystem integrity. In this context, the Plan includes strategies and contingency management responses to protect the major elements of the ecosystem: water and sediment quality, as required under the EQMF, with additional emphasis on seabirds, marine mammals, turtles, and finfish (Sections 4.1, 4.2, 4.4, 4.5 and 4.6). The importance of biosecurity is also considered (Section 4.7). The EQOs for aesthetic, cultural and spiritual values are also considered relevant, but only the EQO for aesthetic values is considered further in this Plan (Section 4.8).

4.1 Water quality

4.1.1 Objectives

The water quality monitoring program aims to determine whether the EQC have been met in the MEPA generally, and at the HEPA boundary located 300 m down-current of the sea-cages. It complements the sediment monitoring program by providing complementary information about the volume of suspended materials (TSS) and dissolved oxygen (DO) near to and at increasing distances from the sea-cages. It also provides data necessary to determine the extent of nutrient enrichment (if any) at the Zone boundary (Chl-a) and the potential for secondary shading effects (LAC). The water quality monitoring program includes measurements for total suspended solids (TSS), chlorophyll-a, light attenuation coefficient (LAC) and dissolved oxygen (DO). All records associated with the water quality monitoring program, including the results of statistical analyses, shall be included in the Annual Compliance Report (see Section 7.1).

4.1.2 Timing

Water quality sampling will be conducted at monthly intervals between December and February (three times in total), capturing the summer season, and at monthly intervals between June and August (three times in total), capturing the winter season.

4.1.3 Program design

Dissolved oxygen and TSS

DO and TSS measurements will be taken along a transect bridging the high and moderate ecological protection areas, with three sites in the HEPA and seven in the MEPA. Each transect will be positioned along the vector corresponding to the prevailing current direction (Figure 4.1). To enable comparisons with background levels, sampling for DO and TSS will also be undertaken at the nearest four reference sites (Figure 4.1). Reference site coordinates are provided in Appendix A.

Chlorophyll-a and light attenuation coefficient sampling design

The program for chlorophyll-a and LAC was developed based on the assumption that any signature attributable to aquaculture will not be immediately detectable (given levels of flushing and the time-lag between nutrient assimilation and phytoplankton growth). Sampling will be undertaken at six compliance sites around the northern zone boundary and four compliance sites around the southern zone boundary[4] (Figure 4.1), all of which will be required to achieve a high LEP. To enable comparison with background levels, sampling for chlorophyll-a and LAC will also be undertaken at the four reference sites nearest to the area occupied (Figure 4.1). Zone and Reference site coordinates are provided in Appendix A.

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[4] *If only one zone is occupied, then sampling will be restricted to the boundary of that zone. Once both zones (northern and southern areas) are operational, then monitoring will be undertaken at the boundaries of both zones. Proponents will be responsible for monitoring the boundaries of the zones in which they hold leases.*

Chlorophyll-a samples should be collected in duplicate. While both chlorophyll-a samples will be frozen prior to analysis, only one of the samples will be analysed immediately. The other should be stored as a back-up sample.

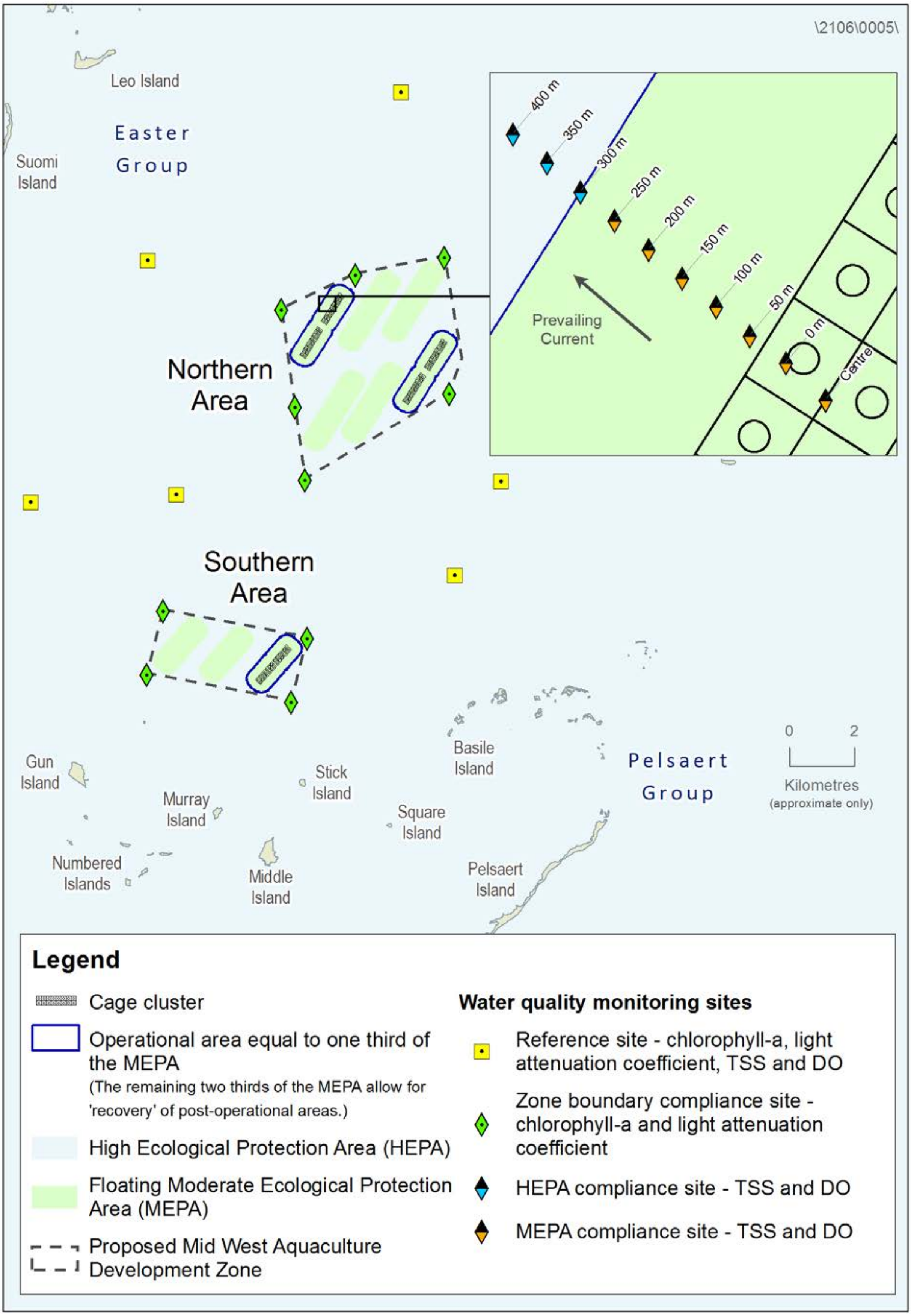


Figure 4.1 Water quality monitoring sites

4.1.4 Approach to sampling

The suite of parameters to be sampled on each occasion is detailed in Table 4.1.

Table 4.1 Water quality parameters to be sampled on each occasion

Protection zone	Parameters			
	TSS	DO	LAC	Chlorophyll-a
MEPA	✓	✓	-	-
HEPA	✓	✓	-	-
Area (HEPA) boundary	-	-	✓	✓
Reference	✓	✓	✓	✓

Notes:

1. TSS = total suspended solids; LAC = light attenuation coefficient; DO = dissolved oxygen

Dissolved oxygen and light attenuation coefficient sampling methods

DO measurements will be taken approximately 50 cm from the bottom using a calibrated water quality sensor. LAC measurements will be conducted using one light sensor positioned ~1 m below the surface and the second approximately 7 m below the surface (this may vary depending on the depth of the water at each site). The light attenuation coefficient (LAC) should be calculated as the difference between the logarithim_{10} of irradiance values at each depth according to the equation:

$$\textit{Light Attenuation Coefficient} \text{ (LAC)} = (\log_{10} I_1 - \log_{10} I_7) \div \text{water depth}$$

Total suspended solids and chlorophyll-a sampling methods

Measurements of TSS and chlorophyll-a will be undertaken using depth-integrated sampling. Additional measurements of TSS will be taken ~50 cm from the bottom of the water column using a Niskin bottle, being careful not to disturb the seabed during sampling. Standard laboratory analytical procedures will be employed throughout and all sampling and analyses undertaken according to NATA-accredited methods.

4.1.5 Environmental Quality Criteria

The EQG and EQS for water quality and their triggers are provided in Table 4.2 and Table 4.3, respectively. The EQG provide early warning of environmental change, and focus on primary (TSS and LAC) and secondary effects (DO and chlorophyll-a) along the cause-effect-response pathways. As the ammonia fraction of DIN is rapidly assimilated by phytoplankton[5], the potential for adverse effects resulting from inorganic nutrients will be assessed against the EQG for nutrient enrichment, following EPA (2015b). In some instances, the EQS have multiple criteria. The EQS will be exceeded if one of more of the criteria is exceeded. Details on how to apply the EQG and the EQS, including the application of the control charting approach, are provided in Section 5.

[5] *Microscopic algae in the water column*

Table 4.2 Environmental quality guidelines for water quality

Effect[2]	EQG[1]	High Protection	Moderate Protection
Shading & smothering	TSS	Median TSS over a three month period, at any HEPA compliance site, must be less than the 80%ile of reference site data	Median TSS over a three month period, at any MEPA compliance site must be less than the 95%ile of reference site data
	LAC	Median LAC over a three month period, at any Area (HEPA) compliance site, must be less than the 80th %ile of reference site data	N/A[3]
Nutrient enrichment	Chl-a	Median chlorophyll-a over a three month period at any Area (HEPA) compliance sites must be less than the 80th percentile of reference site data	N/A[3]
Physical & chemical stressors	DO	Median bottom water DO over a three month period at any HEPA compliance site must be greater than 90% saturation	Median bottom water DO over a three month period at any MEPA compliance site must be greater than 80% saturation

Notes:

1. EGQ = environmental quality guideline; TSS = total suspended solids; LAC = light attenuation coefficient; DO = dissolved oxygen
2. Effect refers to the cause-effect pathways described in Figure 3.6
3. Assessed in the HEPA only

Table 4.3 Environmental quality standards for water quality

Effect[1]	EQS[2]	High Protection	Moderate Protection
Shading & smothering	TSS	The upper 95% CI of TSS from pooled HEPA compliance sites, not to be lower than the lower 95% CI of the reference sites, as determined via control charting	(i) The number of infauna families recorded (across pooled MEPA sites) is not to be less than the number of families recorded during baseline surveys, or relative to the reference sites in two consecutive sampling events or (ii) Video surveys undertaken under or at any distance from the sea-cages shall not record the combined presence of bacterial mats (*Beggiatoa* spp.) or spontaneous outgassing of hydrogen sulphide, relative to earlier baseline assessments
	LAC	The upper 95% CI of LAC from pooled Zone compliance sites, not to be lower than the lower 95% CI of the reference sites, as determined via control charting	N/A[4]
Nutrient enrichment	Chl-a	The upper 95% CI of Chl-a from pooled Zone compliance sites, not to be lower than the lower 95% CI of the reference sites, as determined via control charting	N/A[4]
Physical & chemical stressors	DO	(i) Median bottom water DO over a three month period at any HEPA compliance site must be greater than 60% saturation, and not the result of a regional event as indicated by similar reductions in DO at the reference sites or (ii) The number of infauna families recorded (across pooled MEPA sites) is not to be less than the number of families recorded during baseline surveys, or	(i) Median bottom water DO over a three month period at any MEPA compliance site must be greater than 60% saturation and not the result of a regional event as indicated by similar reductions in DO at the reference sites or (ii) The number of infauna families recorded (across pooled MEPA sites) is not to be less than the number of families recorded during baseline surveys, or

Effect[1]	EQS[2]	High Protection	Moderate Protection
		relative to the reference sites in two consecutive sampling events or (iii) Video surveys undertaken under or at any distance from the sea-cages shall not record the combined presence of bacterial mats (*Beggiatoa* spp.) or spontaneous outgassing of hydrogen sulphide, relative to earlier baseline assessments	relative to the reference sites in two consecutive sampling events or (iii) Video surveys undertaken under or at any distance from the sea-cages shall not record the combined presence of bacterial mats (*Beggiatoa* spp.) or spontaneous outgassing of hydrogen sulphide, relative to earlier baseline assessments

Notes:

1. Effect refers to the cause-effect pathways described in Figure 3.6
2. CI = Confidence Interval
3. EQS = environmental quality standard; TSS = total suspended solids; LAC = light attenuation coefficient; DO = dissolved oxygen
4. Assessed in the HEPA only

4.2 Sediment quality

4.2.1 Objectives

The sediment quality monitoring program aims to determine whether the EQC have been met in the MEPA generally, and at the HEPA boundary located 300 m down-current of the sea-cages. It complements the water monitoring program by providing information about the extent of contamination (metals) and/or organic enrichment in the sediments, and the potential for secondary biological effects (infauna) near to and at increasing distances from the sea-cages. The sediment monitoring program includes the following analytes: total nitrogen (TN), total phosphorus (TP), total organic carbon (TOC), metals (copper and zinc) and infauna. All records associated with the sediment quality monitoring program, including the results of statistical analyses, shall be included in the Annual Compliance Report (see Section 7.1).

4.2.2 Timing

Consistent with the water quality sampling, sampling for nutrients and metals will be undertaken at monthly intervals (three times) in the summer season (December to February) and again at monthly intervals in the winter season (June to August). Sampling for infauna will be undertaken once at the beginning of the summer season and again at the end of the summer season.

4.2.3 Program design

Sediment sampling will be undertaken along a transect bridging the high and moderate ecological protection areas, with three sites in the HEPA and seven in the MEPA. Each transect will be positioned along the vector corresponding to the prevailing current direction (Figure 4.2). To enable comparisons with background levels, sampling will also be undertaken at the nearest four reference sites (Figure 4.2). Reference site coordinates are provided in Appendix A.

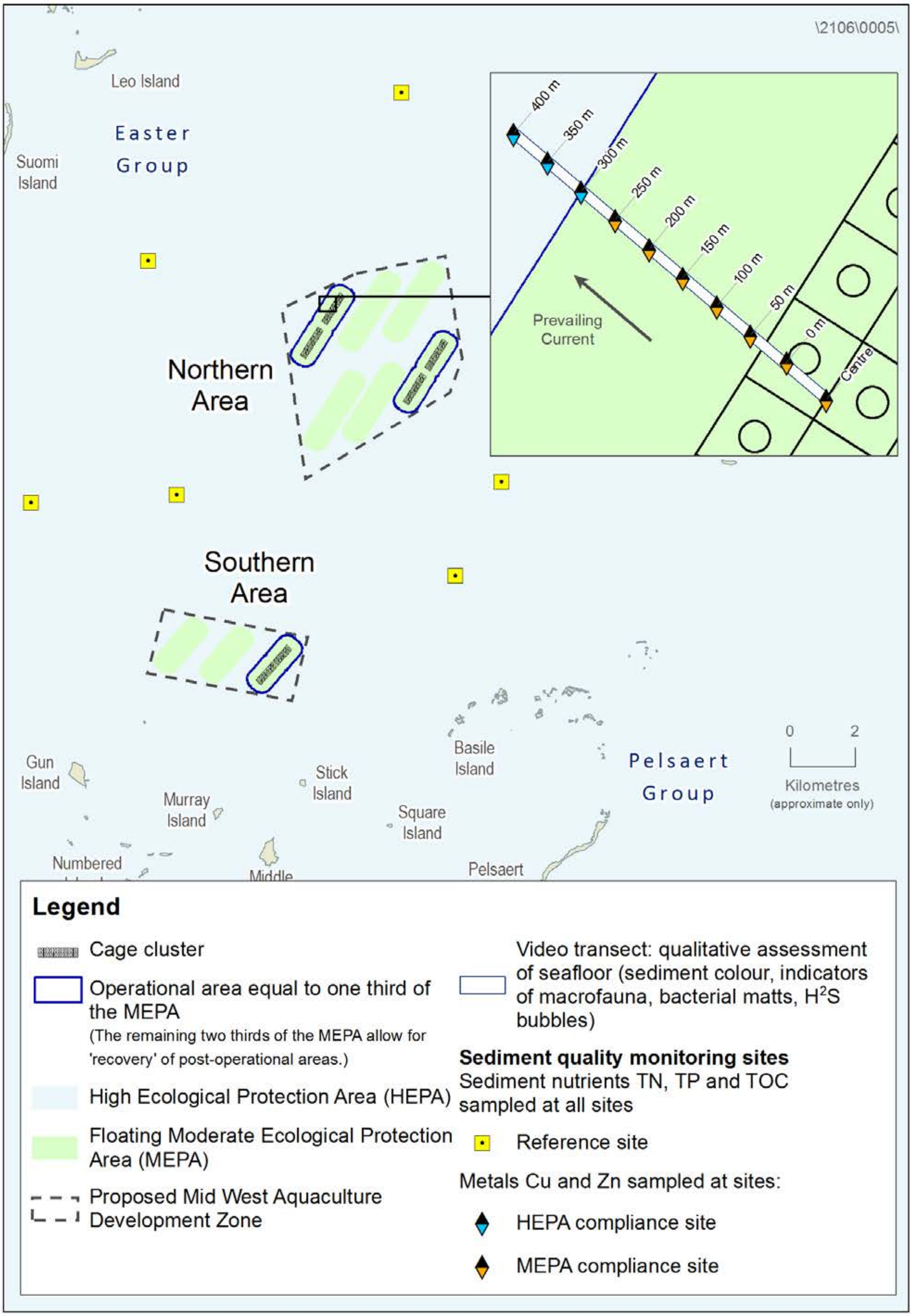


Figure 4.2 Sediment quality monitoring sites

4.2.4 Approach to sampling

The suite of parameters to be measured on each sampling occasion is detailed in Table 4.4.

Table 4.4 Sediment quality parameters to be measured on each sampling occasion

Protection zone	Parameters					
	TN	TP	TOC	Copper	Zinc	Infauna[2]
MEPA	✓	✓	✓	✓	✓	✓
HEPA	✓	✓	✓	-	-	✓
Reference	✓	✓	✓	-	-	✓

Notes:
1. TN = total nitrogen; TP = total phosphorus; TOC = total organic carbon; Copper and Zinc to be sampled four times in the winter and four times in the summer season
2. Infauna to be sampled once at beginning of summer and once at the end of summer

Sediment samples will be collected using protocols modified from EPA (2005). Sample analysis will be undertaken by NATA-accredited laboratories and will achieve limits of reporting (LOR) equal to or less than the ANZECC/ARMCANZ (2000) sediment quality guidelines. Where concentrations are less than the LOR, the LOR will be used in the calculations.

Nutrients and metals

Sediment samples for nutrients and metals will be collected using a Van Veen or equivalent grab sampler. Nutrients will be sampled at MEPA and HEPA compliance and at the reference sites. Metals will be sampled at MEPA compliance sites only (Table 4.4). A minimum[6] of three grabs incorporating the upper 2 cm of sediment will be taken at each site. Each of the grabs shall be homogenised to form one sample as shown in Figure 4.3. The sample will be divided into identical aliquots for nutrient analysis and metals analysis. All aliquots will be frozen for transport to the laboratory, but only half of the subsamples will be analysed immediately. The other half are to be retained as a back-up samples (see Section 5.1.2).

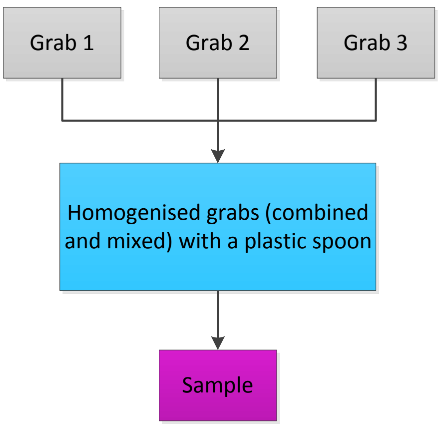


Figure 4.3 Sampling protocol for sediment

Infauna sampling methods

Sampling for infauna will be undertaken once at the beginning of the summer season and again at the end of the summer season. Infauna samples will be collected at the MEPA and HEPA compliance sites and the nearest four reference sites (Figure 4.4; Appendix A). Sediment samples for infauna will be collected using a Van Veen or equivalent grab sampler. Four grabs incorporating the upper 2-5 cm of sediment will be taken at each site. Following collection, the contents of two of the grabs will be consolidated to form one sample, and the content of the other two, to form another. The content of one of the samples will be gently washed through a series of

[6] *It may be necessary to use more than two grabs if two grabs fails to yield enough sample for analysis.*

graded sieves (1-4 mm). Any material retained on the sieves will be fixed in 10% formalin in seawater. This process should then be repeated for the other sample. One of the samples will be sent to the laboratory, and the other stored for later analysis as necessary (see Section 5.1.2). Infauna samples will be processed by laboratories specialising in invertebrate taxonomy. Individual organisms will be identified to family level and counts of each taxonomic group will be recorded.

Although best-practice is to enumerate the number of infauna families present using standard microscopy, it is also recognised that the process is costly and laborious. In the last five years there has been significant progress in 'eDNA bar coding' techniques. These methods offer potentially accurate, cost effective and rapid assessments of infauna taxonomy, particularly if only presence/absence resolution is required. It is recommended that future Proponents investigate the viability of the method and possibly look to use it as an alternative to the approach described above.

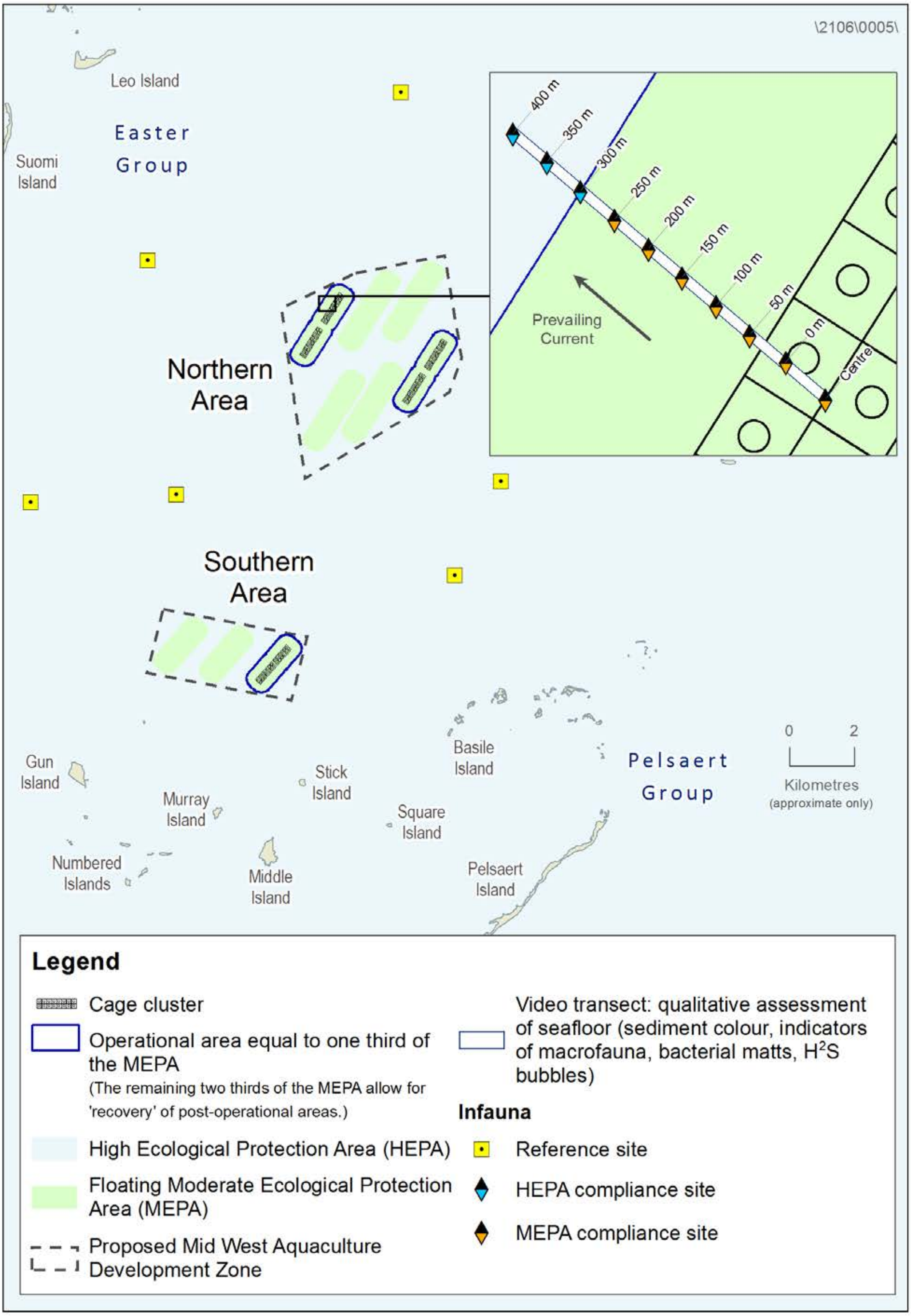


Figure 4.4 Infauna monitoring sites

4.2.5 Environmental Quality Criteria

The EQG and EQS for sediments are outlined in Table 4.5 and Table 4.6, respectively. In some instances, the EQS have multiple criteria. The EQS will be exceeded if one or more of the criteria are exceeded. For details on how to apply the EQG and the EQS, refer to Section 5.

Table 4.5 Environmental quality guidelines for sediments

Effect	EQG	High protection	Moderate protection
Nutrient enrichment	TN TP	Median nutrient concentration over a three month period at any HEPA compliance site must be less than the 80th %ile of reference site data	Median nutrient concentration over a three month period at any MEPA compliance site must be less than the 95th %ile of reference site data
	TOC	Median concentration of TOC over a three month period at any HEPA compliance site must be less than the 80th %ile of reference site data	Median concentration of TOC over a three month period at any MEPA compliance site must be less than the 95th %ile of reference site data
Toxicity	Copper Zinc	Median metal concentration over a three month period at any HEPA compliance site must be less than the Interim Sediment Quality Guidelines - Low (ANZECC/ARMCANZ 2000) (65 mg/kg for copper; 200 mg/kg for zinc)	Median metal concentration over a three month period at any MEPA compliance site must be less than the Interim Sediment Quality Guidelines - Low (ANZECC/ARMCANZ 2000) (65 mg/kg for copper; 200 mg/kg for zinc)

Notes:

1. TN = total nitrogen; TP = total phosphorus; TOC = total organic carbon

Table 4.6 Environmental quality standards for sediments

Effect	EQS	High protection	Moderate protection
Nutrient enrichment	TN TP TOC	(i) The number of infauna families recorded (across pooled HEPA sites) is not to be less than the number of families recorded during baseline surveys, or relative to the reference sites in two consecutive sampling events or (ii) Median bottom water DO at any HEPA compliance site over a three month period must be greater than 60% saturation or (iii) Video surveys undertaken under or at any distance from the sea-cages shall not record the combined presence of bacterial mats (*Beggiatoa* spp.) or spontaneous outgassing of hydrogen sulphide, relative to earlier baseline assessments	(i) The number of infauna families recorded (across pooled MEPA sites) is not to be less than the number of families recorded during baseline surveys, or relative to the reference sites in two consecutive sampling events, or (ii) Median bottom water DO calculated from pooled MEPA compliance sites over a three month period must be greater than 60% saturation and not the result of a regional event as indicated by similar reductions in DO at the reference sites, or (iii) Video surveys undertaken under or at any distance from the sea-cages shall not record the combined presence of bacterial mats (*Beggiatoa* spp.) or spontaneous outgassing of hydrogen sulphide, relative to earlier baseline assessments
Toxicity	Copper Zinc	The number of infauna families recorded (across pooled HEPA sites) is not to be less than the number of families recorded during baseline surveys, or relative to the reference sites in two consecutive sampling events	The number of infauna families recorded (across pooled MEPA sites) is not to be less than the number of families recorded during baseline surveys, or relative to the reference sites in two consecutive sampling events

Notes:

1. TN = total nitrogen; TP = total phosphorus; TOC = total organic carbon
2. CI = Confidence Interval
3. The environmental quality standard for copper and zinc is commensurate with EQS E in Table 3 of EPA (2014). EQS E requires that there be no significant changes in a biological or ecological indicator that can be demonstrably linked to the contaminant.

4.3 Benthic quality (video)

4.3.1 Objectives

In addition to the quantitative measurements described above, further qualitative assessments will be undertaken using underwater video. The objective of the video assessment is to provide complementary observational data based on known indicators of sediment organic enrichment, including presence/absence of 'blackened' sediment, indicators of bioturbation (burrows & tracks), bacterial mats (*Beggiatoa* spp.) and the presence of gaseous bubbles (typically hydrogen sulphide). The use of such criteria is well established in other parts of Australia, and its use here forms complementary but essential data for comparison with the EQS.

4.3.2 Timing

Video assessment will be undertaken prior to commencement of stocking and then at six monthly intervals during operations (timed to coincide with the summer and winter monitoring programs). Monitoring will be undertaken at the operational and recovery sites.

4.3.3 Monitoring program design

Video assessments will be undertaken along a single transect commencing at the sea-cages (centre) and finishing 400 m down-current (Figure 4.2). The transect will be positioned along the vector corresponding to the prevailing current direction and will encompass MEPA and HEPA compliance sites.

4.3.4 Approach to sampling

To capture video footage an appropriate sled or remotely operated vehicle (ROV) carrying an underwater video camera will be flown along the transect. Two passes will be made along each transect. Video footage will be analysed and a database of observations will be generated.

The presence and number of sighted benthic fauna and flora (including the presence of *Beggiatoa* spp.) will be recorded along with observations of other benthic characteristics, including evidence of spontaneous outgassing, sediment colour and bioturbation. An example template for semi-quantitative and qualitative observations is provided in Table 4.7, with red cells indicating observations of concern, some of which form part of the EQS outlined in Table 4.6.

Table 4.7 Example template showing potential qualitative criteria for video surveys

LEP	Distance	Colour					
		Baseline	June 2016	Jan 2017	June 2017	Jan 2018	June 2018
MEPA	Centre	White	Off white	Brown	Brown	Near black	Black
	0 m	White	Off white	Off white	Off white	Off white	Brown
	50 m	White	White	Off white	Off white	Off white	Off white
	100 m	White	White	White	Off white	Off white	Off white
	150 m	White	White	White	White	White	White
	200 m	White	White	White	White	White	White
	250 m	White	White	White	White	White	White
HEPA	300 m	White	White	White	White	White	White
	350 m	White	White	White	White	White	White
	400 m	White	White	White	White	White	White
LEP	**Distance**	**No. burrows (per m^2)**					
		Baseline	**June 2016**	**Jan 2017**	**June 2017**	**Jan 2018**	**June 2018**
MEPA	Centre	15	16	10	5	2	0
	0 m	21	24	24	12	6	1
	50 m	15	16	18	8	7	5
	100 m	21	17	21	19	15	10
	150 m	14	13	14	12	14	21
	200 m	12	10	12	24	12	14
	250 m	24	52	24	17	24	12
HEPA	300 m	17	19	17	21	15	24
	350 m	20	21	17	23	16	15
	400 m	18	17	22	15	14	17
LEP	**Distance**	**Presence of *Beggiatoa* spp.**					
		Baseline	**June 2016**	**Jan 2017**	**June 2017**	**Jan 2018**	**June 2018**
MEPA	Centre	Nil	Nil	Nil	Nil	Present	Present
	0 m	Nil	Nil	Nil	Nil	Nil	Present
	50 m	Nil	Nil	Nil	Nil	Nil	Nil
	100 m	Nil	Nil	Nil	Nil	Nil	Nil
	150 m	Nil	Nil	Nil	Nil	Nil	Nil
	200 m	Nil	Nil	Nil	Nil	Nil	Nil
	250 m	Nil	Nil	Nil	Nil	Nil	Nil
HEPA	300 m	Nil	Nil	Nil	Nil	Nil	Nil
	350 m	Nil	Nil	Nil	Nil	Nil	Nil
	400 m	Nil	Nil	Nil	Nil	Nil	Nil

Notes:

1. Table dates are hypothetical. Categories are indicative only. Qualitative categories (i.e. colour, No. burrows and presence of Beggiatoa spp) are not exhaustive. Proponents may add categories as they see fit.

4.4 Seabirds

4.4.1 Objectives

The potential for adverse interactions between seabirds and sea-cage aquaculture infrastructure was investigated as part of the EIA for the MWADZ (see BMT Oceanica et al. 2015; Halfmoon biosciences 2015). Several risk factors were identified including: entanglement, habitat exclusion, disturbance from aquaculture activities, increased prey availability, creation of roosting sites, and implications to foraging success and spread of pathogens (Sagar 2008, 2013, Lloyd 2003, Comeau et al. 2009). Of the risks identified, only lighting and waste feeds were listed as residual risks (Halfmoon Biosciences 2015).

The objective of the seabird monitoring and management program is to maintain the integrity of Abrolhos seabird populations, and particularly to limit the interaction of potential increaser species with sea-cage infrastructure and waste feeds.

4.4.2 Protocols

The integrity of seabird populations will be maintained using a combination of best-practice and proactive infrastructure management. The success of these programs will be monitored by the Proponent with assistance from suitably qualified experts. Reactive management strategies will be employed to manage incidents as they arise. The proposed approaches to seabird monitoring and management follow those recommended in Halfmoon Biosciences (2015) and Surman (2008).

Infrastructure management

Infrastructure will be managed as follows:

- Sea-cage infrastructure will be managed to minimise entanglement hazards, roosting opportunities and potential collisions due to the disorientating effects of lighting; key to this will be the selection and use of appropriate bird netting; wherever practicable, the above-water portion of the sea-cages should be completely enclosed in bird netting of an appropriate mesh size;
- All pelletised feeds used in open sea-cages must be Australian Quarantine and Inspection Service (AQIS) approved or produced by a manufacturer that complies with AS/NZS ISO 9001:2008 standards or equivalent. Contemporary feeding technologies and practices will be used in order to minimise the release of feed to the surrounding environment; sinking pelletised feeds are to be used in preference to floating pelletised feeds; wet feeds, such as pilchards, will not be permitted in the MWADZ (see also Section 4.7); pelletised food should be stored in secure bulk feed hoppers, and any 'loose' bags stored in the below deck compartment of the supply boat or on deck covered by a heavy tarpaulin.
- Cameras or sensors should be deployed to determine optimum feed input rates and feeding systems should incorporate stop-feeding signals to reduce feed wastage.
- Seabirds will be prevented from gaining access to waste feeds/ dead stock through best practice approaches to feeding and use of bird netting, and dissuaded from roosting opportunities via the implementation of industry best-practice sea-cage design; sea-cages will be completely enclosed by the bird netting. The recommended mesh for excluding seabirds is high-visibility 2 mm polyethylene with a maximum bar size of 60 mm; Proponents may consider other seabird deterrents (visual and audio) in accordance with the Zone Management Policy, providing the deterrent does not cause any harm to seabirds or other fauna;
- The need for lighting will be carefully managed. Although spotlights may be used from time to time they are not expected to form a part of everyday operations. The majority of work will

be conducted during daylight hours. If bright lights are required, care will be taken to minimise usage and to utilise low wattage and long wavelength lights wherever possible;

- The following strategies will be employed to minimise risk of injury to migrating seabirds through disorientation resulting from marine farm lights (following Surman 2008). Wherever practicable, Proponents will:
  - utilise low wattage lights;
  - utilise sensory and, or, timed lighting systems;
  - install wildlife-friendly Low Pressure Sodium Vapour lighting on vessels;
  - orientate lights by either directing, shielding, or focusing;
  - tint vessel windows or where vessel lighting is required at night, use drapes;
  - extinguish non-essential lighting.

Monitoring

Monitoring will be undertaken as follows:

- Interactions between seabirds and sea-cage infrastructure will be monitored daily using semi-quantitative approaches. Seabirds will be identified and enumerated, and the data compared with the baseline assessment published in Halfmoon Biosciences (2015);
- Proponents will arrange for an independent Consultant to attend the site in the early stages of operation to validate the Proponent's field observations against the Consultant's observations. The Consultant will develop and facilitate a training program for farm staff to enable 'in-house' monitoring capabilities. Training will focus particularly on species identified as high risk species. e.g. surface feeding silver gulls and Pacific gulls, as well as sub-surface feeders the pied cormorant and wedge-tailed shearwater;
- The responsibility for monitoring of seabird activity will be handed over to the farm crew at the completion of training, and the Consultant will provide identification guides and data sheets. The crew will be required to record daily the:
  - number and species of seabird in the vicinity (100 m) of the cages and the type of behaviour, i.e. roosting on floats, feeding on fish food etc., and
  - incidence, location/cause of any entanglement/entrapment and the bird species (Table 4.8); and
  - any incidence of seabirds colliding with sea-cages, service vessels, or other aquaculture infrastructure.
- Where multiple Proponents are operating, data will be consolidated and shared in a common database. Results of the individual and combined monitoring programs will be recorded.
- Based on the success of silver gull exclusion measures, the need to conduct broad scale survey of silver gull populations will be assessed after six and twelve months of each operation (derived proposal) introducing stock to sea cages. The Department of Fisheries will determine the need to continue or cease the monitoring of seabirds interactions in consultation with the OEPA (see reactive management protocols below).
- All records associated with the monitoring, shall be included in the Annual Compliance Report (Section 7.1).

Table 4.8 Details of interactions to be recorded for seabirds

Data recorded	Details required
Date	Location, i.e. GPS coordinates
Type of seabird	Species
Number of seabirds	Approximate number
Type of behaviour	Examples: • Roosting on floats, feeding on fish food • Sighted flying in the vicinity of the sea-cage infrastructure • Direct interaction with sea-cage infrastructure • Attempting to enter sea-cages via the side walls
Incidence (record which infrastructure component was involved and the cause of any entanglement / entrapment)	Examples: • Collision with infrastructure / entanglement in the bird netting • Trapped between the predator net and the containment net

Reactive management

Reactive management will be implemented as follows:

- Upon discovery of distressed and/or entangled seabirds in fish farming infrastructure, efforts will be made to untangle the individual bird. Entanglements of seabirds in fish farming equipment will be reported to DPaW Wildcare Hotline on (08) 9474 9055 and the local DPaW office within 24 hrs of the incident. In event of collision between a seabird and aquaculture infrastructure, the following procedure will be followed:
  - Pick up bird with a towel, keeping it lightly wrapped and the wings contained (folded in natural position against side of birds body). Be aware of the sharp beak. Wear gloves and eye protection.
  - Place the bird in a well-ventilated cardboard box, and place in a covered, quiet location.
  - Record and report the species, number, location found (infrastructure component involved), likely cause of collision and any injuries.
  - Do not forcefully administer food or water via the bird's mouth.
  - If the bird has no obvious signs of injury then the bird may be released. The recommended approach is to take the bird to a quiet part of the vessel at dawn, and release the bird in an area free from obstructions (masts, railings, wires etc.) so that it may take off directly into the wind.
- If monitoring finds that pied cormorant, pacific gull and/or silver gull numbers are increasing, and the increase is attributable to aquaculture, then further monitoring will be conducted by a suitable expert. If significant increases in gull populations are detected and the cause is confirmed attributable to the MWADZ then population control measures will be taken, with guidance of a qualified seabird expert.

4.4.3 Timing

Proactive approaches to infrastructure management will be undertaken for the life of the project. Routine inspections of predator exclusion nets, fences, and stock containment nets will be undertaken on a daily basis, if weather and sea conditions permit. An independent assessment of the efficacy of the exclusion approaches will be undertaken (Table 4.9). Monitoring of sea bird numbers near the sea-cages will be undertaken by the Proponent during feeding of stock. Broad-scale assessments of the efficacy of approaches to infrastructure management (including the efficacy of seabird exclusion practices) will be assessed by the Department of Fisheries in consultation with a relevant seabird expert after six and twelve months of each operation (derived proposal) introducing stock to sea cages. The Department of Fisheries will consult with the OEPA and DPaW in relation to any adaptive management measure that may be required.

The design, frequency and scope of the monitoring and management program will be reviewed after the first ten years of implementation in consultation with the OEPA.

Table 4.9 Frequency of seabird monitoring

Performance Indicator	Frequency	Responsibility
Baseline assessment of silver gull population	Prior to stocking	Complete (Halfmoon Biosciences 2015)
Entanglement or injury of seabirds due to fish farm infrastructure and activities	Within 24 hours of incident	Proponent
Interactions with sea birds	Daily	Proponent
Independent assessment of efficacy of seabird exclusion practices	Six months and twelve months post commencement of operations	Relevant independent expert (to be appointed)[1]

Notes:

1. Consultant with relevant expertise in seabird management who is not employed directly by the Proponent

4.5 Marine mammals and turtles

4.5.1 Objectives

The potential for adverse interactions between marine mammals and turtles and proposed aquaculture operations was reviewed as part of the EIA process (BMT Oceanica (2015). A number of risk factors were identified including: the physical presence of sea-cages, availability of supplementary feeds, service vessels and the use of artificial lighting.

The availability of supplementary feeds was identified as a significant risk factor, with potential to alter the natural feeding regimes of mammals and turtles. Other risk factors included physical presence of sea-cages, anchor lines and the use of service vessels, all of which create potential for injury (or mortality) via collision and/or entanglement. Furthermore, mitigation measures aimed at reducing interactions with the sea-cage infrastructure may inadvertently result in changes to marine fauna distribution and/or migration patterns.

The marine mammal and turtle management program aims to maintain the integrity of local populations, and particularly limit interactions between vulnerable species and the sea-cage infrastructure. In the context of preventing interactions with marine mammals, particular consideration has been given to managing the risks associated with the physical presence of sea-cage infrastructure, vessel movements and artificial light. Mitigation of risks will be undertaken using proactive and reactive management strategies.

4.5.2 Protocols

The integrity of marine mammal and turtle populations will be maintained using a combination of best-practice and proactive infrastructure management and ongoing monitoring by the Proponent. Reactive management strategies will also be employed to manage incidents as they arise. The proposed approaches to management follow those approved by the EPA for the KADZ EMMP (DoF 2014).

Infrastructure management

Infrastructure will be managed as follows:

- Staff and contractors will be trained and inducted in MWADZ policies to ensure they are fully aware of the correct manner in which to interact with marine mammals and turtles; staff representatives shall receive training in marine mammal and turtle identification, to allow for identification and enumeration of fauna (see Table 4.10).
- The operation will utilise external predator-exclusion nets (double barrier) or, as required, rigid predator-exclusion mesh (single barrier) to avoid predation on farmed stock by sea lions, sharks and dolphins; mesh sizes greater than 15 cm in diameter have been shown to reduce incidence of entanglements, and should be used wherever practicable; sea-cages should be inspected on a daily basis; nets will be checked for integrity and any faults that may increase the probability of marine mammal interaction.
- Sea lions must be prevented from hauling out onto sea-cage collars or breaching the any barriers above or below the water; wherever practicable, high walled sea-cages will be used to restrict access by sea lions; all practicable measures must be taken to prevent marine mammals and turtles from gaining access to or gaining reward from the sea-cage aquaculture operation. Feeding protocols must be observed to minimise the amount of uneaten feed entering the surrounding water; wet feeds, such as pilchards, are not permitted in the MWADZ. To discourage scavenging or predation by marine fauna, dead stock will be removed from sea-cages on a daily basis and disposed to landfill (or recycled) on the mainland in accordance with waste management authority (City of Greater Geraldton) regulations.
- Aquaculture staff and visitors will be prevented from feeding, touching, interacting or swimming with marine fauna. Interaction in this context includes recreational fishing; if sighted, under no circumstances will vessels be a permitted to approach whales. Vessels will attempt to maintain a distance of 100 m from whales at all times; though it is recognised that fauna may approach vessels from time to time.
- Wherever practical and especially following a sighting of a whale, vessels are to maintain speeds less than 15 knots as the incidence of serious injury or mortality to whales from vessel strikes has been shown to decrease at this speed; if any marine mammals are sighted, vessels should avoid sudden and/or repeated changes in direction; navigate with caution.
- The need for lighting will be carefully managed: although spotlights may be used from time to time they are not expected to form a part of everyday operations. The majority of work will be conducted during daylight hours. If bright lights are required, care will be taken to minimise usage and to utilise low wattage lights wherever possible.
- The following strategies will be employed to minimise risk of injury to migrating marine mammals through disorientation resulting from marine farm lights. The licensee will:
    - utilise low wattage and long wave-length lights wherever practicable
    - utilise sensory and, or, timed lighting systems
    - wherever practicable, install wildlife-friendly Low Pressure Sodium Vapour lighting
    - orientate lights by either directing, shielding, or focusing
    - where vessel lighting is required, use drapes on vessel windows
    - extinguish non-essential lighting whenever practicable

Monitoring

Interactions between marine mammals and turtles and sea-cage infrastructure will be monitored using semi-quantitative approaches. Numbers and types of marine mammals and turtles coming within a 50 m radius of the sea-cage infrastructure will be recorded, and a description of their activity noted (Table 4.10). All records associated with the monitoring, shall be included in the Annual Compliance Report.

Table 4.10 Details of interactions to be recorded for marine mammals and turtles

Data recorded	Details required
Date	Location, i.e. GPS coordinates
Type of fauna	Species
Number of fauna	Single or multiple (approximate number)
Population	Adults, juveniles or a combination
Level of interaction (i.e. physical contact / feeding)	Example: • Vessel strike • Collision / entanglement • Attempting to enter sea-cages • Feeding on pelletised feeds or biofouling
Activity	Example: • Sighted at distance swimming away from sea-cage infrastructure • Direct interaction with sea-cage infrastructure

Reactive management

Reactive management actions will include:

- Collision or entanglement incidents will be reported to the DPaW Wildcare Hotline on (08) 9474 9055 and the local DPaW office within 24 hrs of the incident occurring, and the details of the incident including the actions taken, will be documented
- Any incident involving a marine mammal or turtles in distress, including that resulting from entanglement, collision or stranding will be reported immediately to DPaW Wildcare Hotline on (08) 9474 9055 and the local DPaW office within 24 hrs of the incident occurring
- Ongoing incidents of entanglement and/or breaching of sea-cage netting / barriers will be reported to DPaW and an appropriate management response will be determined by DoF in consultation with OEPA.

4.5.3 Timing

Proactive approaches to infrastructure management will be undertaken for the life of the project. Monitoring of interactions will be undertaken by the Proponent. The efficacy of these programs will be monitored by the Proponent, and reviewed in consultation with the OEPA twelve and 24 months post commencement of operations.

4.6 Finfish

4.6.1 Objectives

The objective of wild finfish management is to minimise environmental and ecological risks to wild finfish populations, including sharks, rays and other finfish. Endangered threatened, and protected (ETP) finfish species have been given special consideration. The potential for adverse interaction between ETP, other finfish species and the proposed aquaculture operations was investigated as part of the EIA (BMT Oceanica et al. 2015). Identified risk factors included:

- wild finfish attracted to sea-cage infrastructure to feed on stock or pelletised feeds

- behavioural changes in ETP species of fish
- transfer of disease/parasites to wild finfish populations
- escape of aquaculture stock leading to competition with wild finfish and
- genetic contamination from escaped stock fish breeding with wild finfish

The primary residual risk, apart from transfer of disease and genetic contamination (covered separately in Section 4.7), was the presence of excess feed pellets or dead/moribund stock attracting wild finfish to sea cage infrastructure to feed. The intent is to manage these attractants to reduce or prevent:

- the strength of signals that may attract sharks and rays
- opportunity for interactions between ETP species of sharks/rays and aquaculture
- predators breaching the sea-cage netting
- the biological/ecological impacts of interactions

4.6.2 Protocols

The integrity of ETP and other wild finfish populations will be maintained using a combination of proactive and reactive management strategies.

Infrastructure management

Infrastructure will be managed as follows:

- All practicable measures must be taken to prevent ETP species of finfish and other finfish from gaining access to or gaining reward from the sea-cage aquaculture operation; feeding protocols must be observed to minimise the amount of uneaten feed entering the surrounding water; to discourage scavenging or predation by marine fauna, dead stock will be removed from sea-cages on a daily basis and disposed to landfill (or recycled) on the mainland in accordance with waste management authority (City of Greater Geraldton) regulations.
- Sea-cages should be designed taking into account best practice management strategies as guided by the Norwegian Standards and the Aquaculture Council of Western Australia Environmental Code of Practice for marine finfish aquaculture.
- Proponents shall wherever practicable: use durable, high tensile sea-cage (e.g. ultra-high molecular weight, polyethylene fibre) mesh of suitable bar width (size); use anti-predator nets (e.g. external 'armour' nets); maintain appropriate stocking densities (i.e. stocking densities kept at levels below or equal to industry-best-practice bench marks (e.g. 10-25 kg m^3)); use humane harvesting methods; contain all post-harvest blood water, and implement regular inspections of sea-cages.
- Proponents shall wherever practicable: aim to minimise feed wastage to less than 2%, use high quality and sinking pelletised feeds and immediately remove dead or moribund stock;
- Proponents shall develop an ETP species interaction plan and staff shall be aware of procedures for dealing with ETP species; in the event of entanglement, and/or breach of the sea-cage walls by an ETP animal, the Proponent shall implement the plan and wherever possible avoid harming the animal. Considerations should be given to sea-cages designs that allow for easy release of an ETP or any other large marine animal.
- All pelletised feeds used in open sea-cages must be Australian Quarantine and Inspection Service (AQIS) approved or produced by a manufacturer that complies with AS/NZS ISO 9001:2008 standards or equivalent; contemporary feeding technologies and practices will be used in order to minimise feed wastage to the surrounding environment. Wet feeds, such as pilchards, are not permitted in the MWADZ.
- Pellet food will primarily be stored on site in bulk feed hoppers. Loose bags of feed will be stored in the below deck compartment of the supply vessel or on deck covered by heavy duty PVC tarpaulin.

- Cameras or sensors should be deployed to determine optimum feed input rates and feeding systems should incorporate stop-feeding signals to reduce feed wastage.

Monitoring

Interactions between ETP species of fish and sea-cage infrastructure will be monitored using semi-quantitative approaches, as documented in the ETP species interaction plan. Numbers and species of ETP species coming into contact with the sea-cage infrastructure will be recorded, and a description of any interactions recorded (Table 4.11). All records associated with the monitoring, shall be included in the Annual Compliance Report (Section 7.1).

Table 4.11 Details of interactions to be recorded for Endangered, Threatened and Protected species of fish

Data recorded	Details required
Date	Location, i.e. GPS coordinates
Type of fish	Species
Number of individuals	Single or multiple (approximate number)
Type of behaviour	Example: Direct interaction with sea-cage infrastructure e.g. attempting to feed on stock via the side walls of the sea cage.
Incidence (location/cause of any entanglement/entrapment)	Example: Entanglement/entrapment in the sea-cage, such as shark trapped between the predator net and the containment net.

Reactive management

Management and reporting of escaped fish stock shall be undertaken in consultation with DoF, and in alignment with MWADZ biosecurity protocols described below (Section 4.7). Incidents of fish stock escapes must be reported in the Annual Compliance Report (Section 7.1).

4.6.3 Timing

Proactive and reactive management will be undertaken for the life of the project.

4.7 Biosecurity

4.7.1 Objectives

The objective of the biosecurity section of this Plan is to minimise risks associated with disease, parasites, marine pests and the potential for adverse genetic effects. Potential risk factors relevant to biosecurity were investigated as part of the EIA for the MWADZ project (DoF 2015c). The assessment identified and assessed individual hazard pathways associated with each of three primary biosecurity risks, including:

1. Spread of pathogen disease from an infected aquaculture facility
2. Impacts on the (genetic) sustainability of wild fish following escape of aquaculture stock and
3. The introduction and/or spread of marine pests associated

The biosecurity management protocols described below outlined the approach to reducing these risks through a number of mitigation protocols and management strategies.

4.7.2 Protocols

A high level of biosecurity will be maintained using a combination of best-practice and proactive infrastructure management. Reactive management strategies will be employed to manage incidents as they arise. The proposed approaches to risk mitigation and incident management follow a comprehensive analysis of risks and a review of best practice mitigation strategies undertaken by DoF (2015c), and the proposed management protocols outlined below are excerpted directly from this document (DoF 2015c).

Infrastructure management

Infrastructure will be managed as follows:

- Prior to commencement of operation, the Proponent will seek input on biosecurity measures from the Western Australian Department of Fisheries (Principal Research Scientist in the Fish Health Unit). Prior to stocking, the Proponents will develop and implement biosecurity management arrangements, as part of a Management and Environmental Monitoring Plan, in accordance with the Zone Management Policy and in consultation with DoF; These arrangements will cover all aspects of biosecurity management including a disease testing regime and relevant response protocols, translocation, biosecurity and quarantine including management of vessels, equipment and infrastructure. Responses to biosecurity hazards and incidents shall be informed by the development and implementation of the biosecurity management arrangements; all staff will receive appropriate training to enable them to implement the biosecurity management arrangements to effectively deal with biosecurity hazards and/or incidents as they arise.
- Sea-cage systems shall be designed and maintained so as to eliminate or reduce the likelihood of fish escapes, and/or the breach of sea-cage netting by external predators, including ETP species; in addition, Proponents will be required to conduct regular inspections of the sea-cage systems to ensure integrity, by looking for and resolving any issues that may increase the probability of escape.
- The Proponent will continually review and update their approach to biosecurity and associated protocols as agreed with DoF.
- In addition to the above, the Proponents will implement the following mitigation measures to reduce the risk of disease due to the proximity of another farm: monitor the health of brood-stock and immediately quarantine any individuals suspected of carrying disease; use only Australian sourced brood-stock; and maintain controls over stock and feed input to the MWADZ to prevent introduction of pathogens to the marine environment.
- All pelletised feeds used in open sea-cages must be Australian Quarantine and Inspection Service (AQIS) approved or produced by a manufacturer that complies with AS/NZS ISO 9001:2008 standards or equivalent. Wet feeds, such as pilchards, are not permitted in the MWADZ.
- Proponents will use best management practices to prevent escapes from sea-cages, including observing the Aquaculture Council of Western Australia (ACWA) marine based finfish Environmental Code of Practice, which has been designed to encourage environmentally responsible behaviour in the aquaculture industry. Proponents are required to operate in accordance with the Zone Management Policy and the conditions of an aquaculture licence, which require the prevention of stock escapes. The Zone Management Policy also documents the importance of the suitable site location (i.e. frequency of storm events, degree of exposure), minimizing risks during stock transfers, using strong and durable materials for culture unit construction and regularly inspecting and adjusting the infrastructure to ensure no tears or openings.
- Proponents must develop site-specific contingency plans (escape emergency plans) that describe actions to be taken in the event of any major stock escapes. Guidance on what to do in the event of an escape is provided in the Fish Resources Management Regulations 1995. The use of any recapture nets requires authorisation of the CEO of DoF.
- To prevent the introduction and spread of introduced marine pests, Proponents will undertake regular inspection and cleaning of sea-cage nets; prior to bringing aquaculture gear into the MWADZ, thoroughly inspect and clean any used equipment / infrastructure sourced (including vessels) from areas outside of the MWADZ. In addition to the biosecurity management arrangements mentioned above, Proponents will observe the National Biofouling Management Guidelines for the Aquaculture Industry.

Reactive management

Reactive management actions will include:

- Proponents must (with DoF) develop incident response plans detailing the procedures to be followed in the event of (i) disease outbreaks, (2) escapes of significant volumes of stock or (3) detection of introduced marine pests; the intent of these plans is to ensure adequate reporting of the events, managed the escaped fish and any predators including ETP species, prevent wherever practicable, the establishment and proliferation of that pest or disease, aiming to control and potentially eradicating that pest or disease, and to minimise the risk of that pest or disease being transferred to other locations within Western Australia.
- All unusually high levels of mortalities, or suspicions or signs of diseases or conditions, must be recorded and details (quantity of stock/circumstances) reported in writing to the Principal Research Scientist in DoF's Fish Health Unit[7], within 24 hours of becoming aware, or suspecting, any fish at the property are affected. The Proponent will work with DoF to resolve the issue using an agreed response plan or as otherwise determined with DoF.
- ALL species listed as pests or noxious fish and any other species that appear to have clear impacts or invasive characteristics must be reported to DoF via FISHWATCH (ph. 1800-815-507) or by email at biosecurity@fish.wa.gov.au,within 24 hours following (a) initial detection and (b) subsequent analysis and confirmation of identity. If the species is positively identified as a marine pest, the Proponent will work with DoF to resolve the issue using an agreed response plan or as otherwise determined with DoF.
- Any use of treatment chemicals and/or pharmaceuticals, under advisement of the Principal Research Scientist in the Fish Health Unit at DoF, will be recorded and reported to DoF and the OEPA in accordance with approved protocols.
- All instances of suspected significant (i.e. greater than 100 fish) stock-escapes must be recorded and details (quantity of stock/circumstances) reported to the CEO of DoF within 24 hrs of the event. Interactions with ETPs, which result in escapes, should be reported to the relevant authority. The Proponent must investigate and determine how an escape occurred and what is required to prevent future similar stock-escapes; the findings of the investigation shall be reported to DoF within 5 working days of the event. The Proponent will work with DoF to resolve the issue using an agreed response plan or as otherwise determined by DoF.
- All biosecurity incidents (including stock-escapes) and use of treatment chemicals, e.g. pharmaceuticals, must be recorded in the Annual Compliance Report. Best management practices to facilitate biosecurity will be maintained for the life of the MWADZ. The Proponent will review and adapt management practices to remain in step with best-practice approaches.

4.8 Aesthetics

4.8.1 Objective

The EQO to maintain aesthetic values aims to ensure that WA's coastal waters are aesthetically pleasing and that the aesthetic value is protected. The Abrolhos Islands are multi-use with an array of stakeholders, all of which have vested interest in preserving the unique features of the Islands and the surrounding marine environment.

The objective of the aesthetic management program is to assess whether the EQG and EQS have been met at the HEPA/MEPA boundary, and to provide contextual information about the extent of aesthetic changes in the vicinity of the sea-cages. The results of semi-quantitative

[7] *A reference to the Principal Research Scientist in the Fish Health Unit includes reference to an accredited pathologist or epidemiologist.*

measurements will be compared against the EQG and EQS in Table 4.12, following those recommended in EPA (2015b).

4.8.2 Timing

Monitoring will be undertaken twice each year, in summer and winter. Monitoring will coincide with the seasonal water quality and sediment monitoring (Sections 4.1 and 4.2).

4.8.3 Environmental quality criteria

Aesthetic quality will be assessed against the EQG and EQS in Table 4.12 using a combination of semi-quantitative and qualitative assessments. The required management response following an exceedance of the EQC is set out in Section 5.2.

Table 4.12 Environmental quality criteria for the environmental quality objective of maintenance of recreation and aesthetics

Environmental Quality Indicators	Environmental Quality Criteria	
	Environmental Quality Guideline (EQG)	Environmental Quality Standard (EQS)
Nuisance organisms	Macroalgae, phytoplankton and encrusting invertebrates, should not be present in excessive amounts on and around the sea-cages.	There should be no overall decrease in the aesthetic water quality values of the Zeewijk Channel, Abrolhos Islands that are attributable to aquaculture using direct measures of the community's perception of aesthetic value.
Water clarity	The natural visual clarity of the water should not be reduced by more than 20%.	
Surface films	Petrochemicals, such as engine oil, should not be noticeable as a visible film on the water or detectable by odour.	
Surface debris	Water surfaces should be free of aquaculture-derived floating debris, feed dust and other objectionable matter.	
Odours	There should be no objectionable odours.	

Note:

1. Derived from EPA (2015b)
2. Many of the environmental quality guidelines for aesthetic quality are subjective and relate to the general appreciation and enjoyment of the Abrolhos by the community as a whole. Consequently, when using these criteria, consideration should be given to whether the observed change is in a location, or of intensity, likely to trigger community concern and to whether the changes are transient, persistent or regular events.
3. Further investigation (environmental quality standards) involves direct measures of aesthetic value to determine whether there has been a perceived loss of value. For example, regular community surveys can be used to show trends in community perception of aesthetic value over time.

4.8.4 Visual indicators

In addition to monitoring against the EQG and EQS in Table 4.12, the visual appearance of the marine environment will be taken into account. Assessment against the EQG will be supplemented via a questionnaire supplied to field personnel (Table 4.13). The questionnaire will be completed during the annual water quality monitoring survey and will be based on observations made adjacent to sea-cage clusters.

Proponents will provide community users of the Abrolhos Islands FHPA and other relevant stakeholders with an open invitation to comment on any depreciation of the aesthetic values of the Zeewijk Channel that may be attributable to the aquaculture within the MWADZ. The DoF website at www.fish.wa.gov.au will provide a mechanism by which the community and stakeholders can submit comments. Any decreases in aesthetic water quality values of the Zeewijk Channel will be measured as an increase in the number of complaints or a distinct

change in the perception of the community (Refer to EQS in Table 4.12). Instances of complaints will be recorded and documented in the Annual Report. All records associated with the monitoring, need to be included in the Annual Compliance Report.

Table 4.13 Field sheet for demonstrating compliance with environmental quality guidelines for aesthetics

Site: Date:	Recorder:	Comments
EQG Indicator		
Algal material / invertebrate encrustation visible on and around the sea-cages?	Yes/No	
Water clarity (light attenuation)	Metres	
Petrochemicals or other pollutants visible on the surface of the water?	Yes/No	
Floating debris visible on the surface of the water?	Yes/No	
Noticeable odour associated with the water?	Yes/No	

5. Statistical approach

5.1 Water quality and sediment monitoring

The objective of the water and sediment monitoring programs is to assess whether the EQG and EQS have been met within the MEPA generally and at the HEPA boundary (Figure 4.1). Comparison with the guidelines and standards requires calculation of test statistics (medians [50^{th} percentiles] and 80th and 95th percentiles), and the application of control charting procedures is recommended. The approach for calculating test statistics and running the control charting procedures is outlined in Appendix B. Procedures are described in the context of a single sea-cage cluster positioned within a single MEPA. Transects will be replicated as production increases. For example, there should be one transect, incorporating sites at centre, 0 m, 50 m, 100 m, 150 m, 200 m, 250 m (MEPA), 300 m, 350 m and 400 m (HEPA) for every 12 cages in a cluster. Hence a cage-cluster with 13 or more cages will incorporate 2 transects, and a cage-cluster with 25 or more cages will incorporate 3 transects, as per the example in Figure 5.2. Transects should be regularly spaced with approximately the same number of cages each side of the transect, e.g. 4-6 cages on each side (as per the example in Figure 5.2).

5.1.1 Environmental quality guidelines

Sections 4.1 and 4.2 describe the EQG criteria for application within the MEPA and HEPA. The frequency of assessment is the same irrespective of the LEP. In the case of the MEPA, HEPA and Area (HEPA), comparison with the EQG will be undertaken at the completion of the three month winter sampling period and again at the end of the three month summer sampling period.

On completion of the seasonal sampling periods, the relevant EQG test statistics (median, 80th and 95th percentiles) will be calculated from the pooled:

1. individual HEPA compliance sites (n=3)
2. individual Zone compliance sites (n=3)
3. MEPA compliance sites (n=3) and
4. Reference site data (n=12)

For sediment metals and dissolved oxygen, the median values should be respectively compared against the ISQG trigger values and the percentage saturation criteria in Table 4.5. For all other analytes, median values should be compared against the 80th or 95th percentile values calculated from pooled reference site data obtained over the entire three month period (n=12).

In the event that an EQG is exceeded, assessment against the relevant EQS should be undertaken as soon as reasonably practicable. The decision scheme for assessing the EQG is summarised in Figure 5.1.

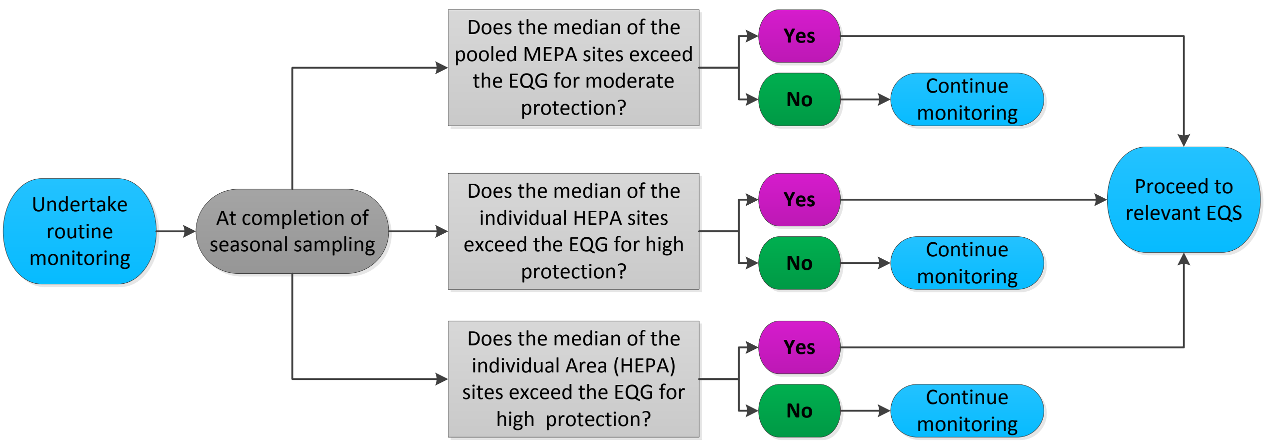


Figure 5.1 Decision scheme for assessing the environmental quality guidelines

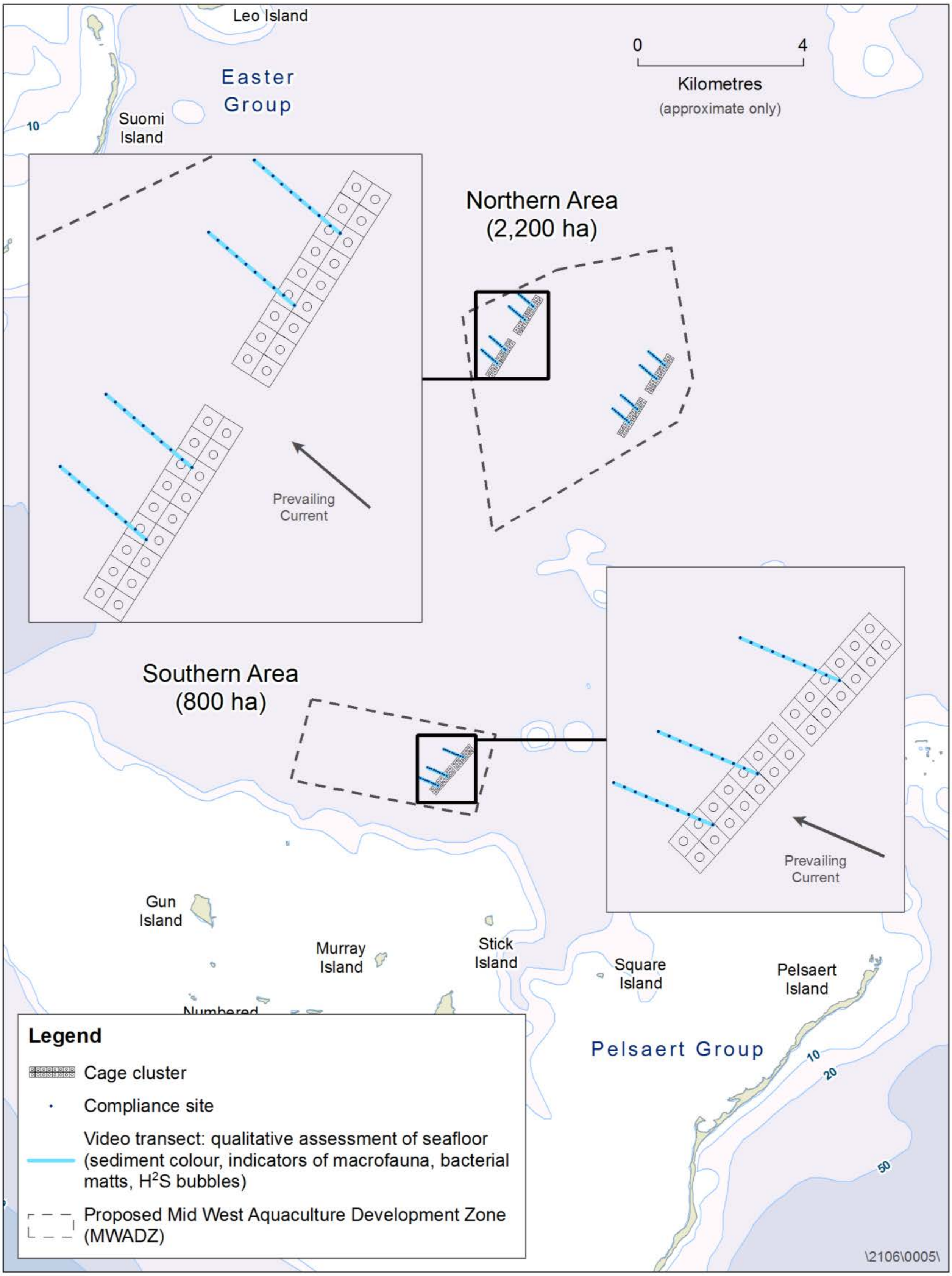


Figure 5.2 Conceptual number and arrangement of transects under different cage configurations

5.1.2 Environmental quality standards

Upon an exceedance of an EQG, the Proponent will undertake monitoring against the relevant EQS as soon as reasonably practicable. Calculations should be based on the data from the cage cluster(s) where the exceedance was detected and the relevant Reference site data. Test statistics shall be compared with the EQS triggers in Table 4.3 and Table 4.6.

DO

Assessment of the EQS for dissolved oxygen is straightforward and only requires calculation of the median DO percent saturation value. The median value should be compared against the EQS criteria listed in Table 4.3. The EQS will be exceeded where the median value is less than 60% saturation, provided it has occurred in the absence of a similar exceedance at the reference sites, which may indicate a natural regional effect.

TSS, LAC and chlorophyll-a

Assessment against the EQS for TSS, LAC and chlorophyll-a requires the application of control charting procedures. Control charting procedures are an effective way for visually comparing the trajectories of two or more times series data, and are thus a simple but useful tool for managers. When upper and lower confidence limits (around the means) are incorporated into time series data, control charts may also be used to run simple statistical tests, which in practice are equivalent to Analysis of Variance (ANOVA) and t-test procedures. A control charting example is provided in Appendix B.

Infauna

Assessment against the EQS for infauna requires the analysis and enumeration of infauna families present in the MEPA and HEPA compliance site samples. While infauna samples are required to be taken at all MEPA and HEPA sites, only the MEPA samples should be analysed immediately upon sampling and irrespective of the result of the moderate protection EQG assessment. HEPA samples shall be analysed only upon an exceedance of the high protection EQG for dissolved oxygen, TSS or sediment nutrients. This is in recognition of the point source nature of the operation, in which sites positioned closer to the sea-cages are more likely to undergo changes (and more rapidly) than sites positioned further from the sea-cages.

The EQS for infauna is consistent with the guidance set out in the relevant EPA policies and Guidelines (e.g. EAG 15) and has been developed following advice from the OEPA. The intent is to demonstrate that the number of infauna families across the MEPA (pooled sites) does not differ from the number observed during the baseline assessment, and does not differ from those observed at the reference sites in the ongoing assessments. OEPA recognises that the high family richness together with its highly variable abundance may lead to false positives where an EQS is exceeded because a family is excluded simply be chance (i.e. the family is actually present at the site, but was missed in the sampling due to its rareness). To counter this, the EQS is based upon only those families with a greater than 20% probability of occurring in a single sample over the summer period and within a specific area (either north or south). Therefore there is a reasonable chance of detecting each of these families provided five or more samples are collected and provided the family is present. Table 5.1 provides the list of families for each of the aquaculture areas, and their probability of detection based on their abundance during the baseline surveys.

Table 5.1 Families included in the EQS for infauna with their probability of detection

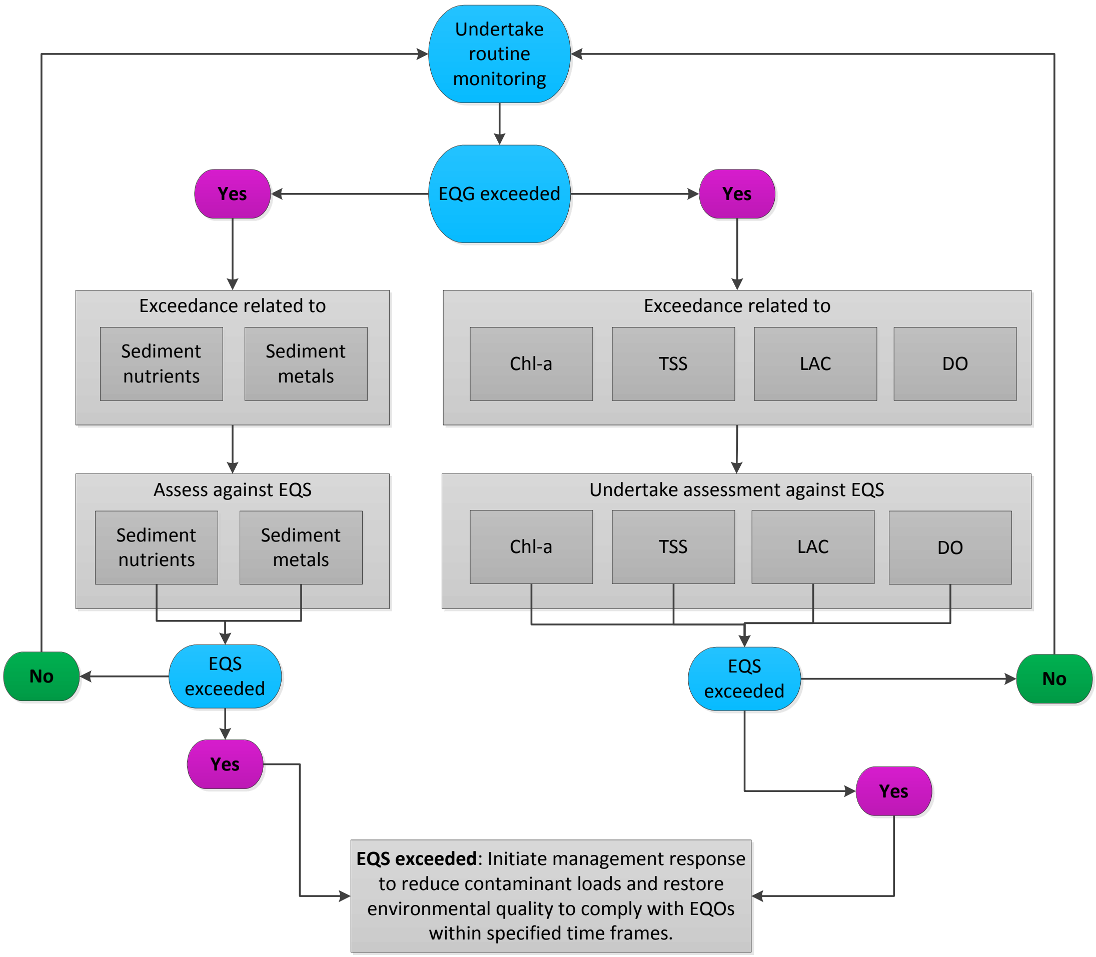
Southern Area			Northern Area		
Family	**Taxa**	**Probability of detection**	**Family**	**Taxa**	**Probability of detection**
Ampeliscidae	Worm	30%	Glycymerididae	Worm	21%
Phoxocephalidae	Worm	21%	Psammobiidae	Worm	45%
Caprellidae	Worm	21%	Veneridae	Bivalve	33%
Ostracoda (Class)	Crustacean	24%	Ampharetidae	Worm	24%
Glycymerididae	Bivalve	21%	Eunicidae	Worm	36%
Psammobiidae	Worm	52%	Lumbrineridae	Worm	24%
Retusidae	Worm	21%	Onuphidae	Worm	36%
Eunicidae	Worm	30%	Orbiniidae	Worm	27%
Onuphidae	Worm	45%	Phyllodocidae	Worm	21%
Orbiniidae	Worm	24%	-	-	-
Phyllodocidae	Worm	21%	-	-	-

The intent of this approach is to (a) maintain a moderate level of ecological protection across the zone by demonstrating no change in the infauna families across the MEPA generally and (b) to build a comprehensive understanding of the type and number of infauna present, and of the effect of aquaculture pressures on these assemblages, as the pressures grow over time. This understanding is likely to be used in the future to develop a new EQS based on some other environmental indicator. The utility of the approach will be reviewed in consultation with the OEPA once an appropriate data-set has been established.

Recommended additional sampling and / or analyses

The decision scheme for assessing EQS is depicted in Figure 5.3. Assessments against the EQS should be undertaken carefully and with consideration of the potential for making a Type I or II statistical inference error. For EQS assessments, Proponents are advised to increase the level of replication at the appropriate sites, or relevant boundaries, wherever practicable. Proponents are also advised to consider collecting more data, or undertaking further analyses that may serve as additional lines of evidence. Additional analyses such as multivariate statistical procedures for example may be used to provide either early warning and/or context to the observed changes in infauna communities, which may be driven by a combination of species richness and abundance measures. Suggested approaches include the use of visual tools such as control charting (Appendix B), non-metric Multidimensional Scaling (nMDS), and hypothesis-based statistical methods such as PERMANOVA (following Anderson et al. 2008) or generalised linear modelling.

In the event that an EQS is exceeded, Proponents are advised to undertake contingency management action as outlined in Section 6.



Notes:

1. EQS = environmental quality standard; Chl-a = chlorophyll-a; LAC = light attenuation coefficient; TSS = total suspended solids; DO = dissolved oxygen; TN = total nitrogen; TP = total phosphorus; TOC = total organic carbon; ANOVA = analysis of variance; EQO = environmental quality objectives

Figure 5.3 Decision scheme for assessing environmental quality standards

5.2 Aesthetics monitoring

Aesthetic appearance will be compared against the criteria in Table 4.12. Assessment against the EQG will be facilitated by a questionnaire supplied to field personnel (Table 4.13). The questionnaire will be completed during the annual water quality monitoring survey and will be based on observations made around the perimeter of the sea-cage clusters. Assessment against the EQS will be based upon credible community observations of the aesthetics within the MWADZ.

The decision scheme for assessing EQG and EQS related to aesthetics, including management responses summarised in Table 5.2.

Table 5.2 Management response following an exceedance of the environmental quality criteria for maintenance of aesthetic values

Environmental Quality Indicators	Management following trigger level exceedance	
	Environmental Quality Guideline (EQG)	**Environmental Quality Standard (EQS)**
All instances	Upon an exceedance of the EQG, the Proponent will investigate the cause and the source of the exceedance. An exceedance of the EQG will result in further assessment against the EQS. Any instances of an exceedance of the EQG will be reported by the Proponent in the Annual Compliance Report (Section 7.1).	If there is a decrease in the aesthetic values of the Abrolhos marine environment as determined using direct measures of the community's perception of aesthetic values, the Proponent will consult with DoF and OEPA to determine an appropriate management response.

6. Contingency Management

6.1 Cage cluster relocation as a management option

The periodic relocation of cage-clusters (fallowing) allows sediments to return to the equivalent of baseline physical/chemical conditions. Such practices have been shown to be a highly effective method for reducing the point source impacts of aquaculture. Relocation of entire cage clusters may be undertaken to allow impacted habitats to recover, and shift from conditions representing a moderate level of ecological protection, to conditions representing a high level of ecological protection (see Section 3.1.3).

Fallowing may be undertaken as part of routine operations, or in response to an exceedance of an EQS. In the case of an EQS exceedance, the intent is to reduce the source of the contaminants and to restore environmental quality to a level commensurate with high level of ecological protection.

6.2 Other management options

Apart from relocating sea-cages, Proponents have the following options for managing site specific contamination:

- Movement or partial harvest of the stock may be considered as a temporary measure to reduce pressures on water or sediment quality, and to allow time for sediment and water quality indicators to comply with the specified levels of ecological protection
- Reduction of stocking density through splitting cages and selective harvest may be implemented as a temporary measure to reduce pressures on water or sediment quality, and to allow time for sediment and water quality indicators to comply with the specified levels of ecological protection, and
- Reduction of feed input rates may be implemented as a temporary measure to reduce pressures on water or sediment quality, and to allow time for sediment and water quality indicators to comply with the specified levels of ecological protection.

6.3 Reporting of exceedances

In the event an EQS is exceeded, the Proponent will report the matter to DoF and the OEPA within 24 hours of detecting the exceedance and will commence management to (i) reduce the effect and/or mitigate the source of the contaminants, and (ii) to restore environmental quality within the specified level of ecological protection.

6.4 Recovery monitoring

6.4.1 Following relocation

As described in Section 6.1, relocation of sea-cages may be undertaken in response to an exceedance, or as part of a routine fallowing program. In any case, Proponents will be required to capture the transition from operational (or impacted) conditions to remediated conditions via a supplementary monitoring program, using a sub-set of sites and analytes.

Recovery monitoring will be undertaken at the former MEPA compliance sites (Section 4.2), which will be referred to as recovery sites (Figure 3.7, Figure 4.1 and Figure 4.2). Sampling will be undertaken at a sub-set of the former MEPA compliance sites at distances: centre, 0 m, 50 m and 100 m. Recovery monitoring will be undertaken once during the scheduled summer sampling period and will be supplemented by qualitative video assessment. Recovery will be monitored until the sediment chemistry at the fallowed site achieves conditions commensurate with a high LEP. To assess recovery, data from the recovery (previously monitoring) sites will be

compared against data from baseline or reference sites using appropriate statistical methods. The Proponent shall report the results of recovery monitoring program to DoF and the OEPA annually (Section 7.1).

6.4.2 Following exceedance of an environmental quality standard

All of the EQSs in this Plan are designed to be assessed within the MEPA, or at either the HEPA boundary or the Area (HEPA) boundaries. For an exceedance within the MEPA or at the HEPA boundary, the most appropriate course of action may be to move the cage-cluster, or if this is not feasible, implement one of the approaches outlined in Section 6.2. If relocation is selected, then the timing and extent of monitoring shall proceed as in Section 6.4.1. If the Proponent chooses to implement other forms of management, the Proponent will be required to consult with DoF for endorsement of intended actions and needs to monitor the impacted site(s) on a monthly basis, until an appropriate level of environmental quality has been restored (to a 'moderate' level or higher in this case).

For an exceedance at the northern or southern MWADZ Area boundaries, management will be determined in consultation with DoF and OEPA. Management options such as those listed in Section 6.2 will be considered. During the consultation meetings, monitoring of the impacted site(s) will proceed on a monthly basis, until the approach to management has been decided.

During the contingency management phase, the Proponent will be required to report the results of the monitoring to DoF and the OEPA on a quarterly basis (four times per annum) until it can be demonstrated that a high level of environmental quality has been restored, and is being maintained.

7. Implementation

7.1 Reporting and auditing

Each Proponent will produce an Annual Compliance Report summarising the results of the monitoring and submitted it to the OEPA and DoF by 1 June annually in accordance with the conditions of their Derived Proposal approval. Refer to Section 4, Monitoring and Management, for details on requirements relating to records and reports.

7.2 Review and revision

The DoF will undertake regular audits to ensure each of the components of this Plan have been implemented and the results reported annually.

The design, frequency and scope of the monitoring and management program will be reviewed after the first three years of implementation in consultation with the OEPA. Subsequent reviews will be undertaken every three years after that.

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Appendix A

Sample Site Coordinates

Appendix B

Control Charting Example

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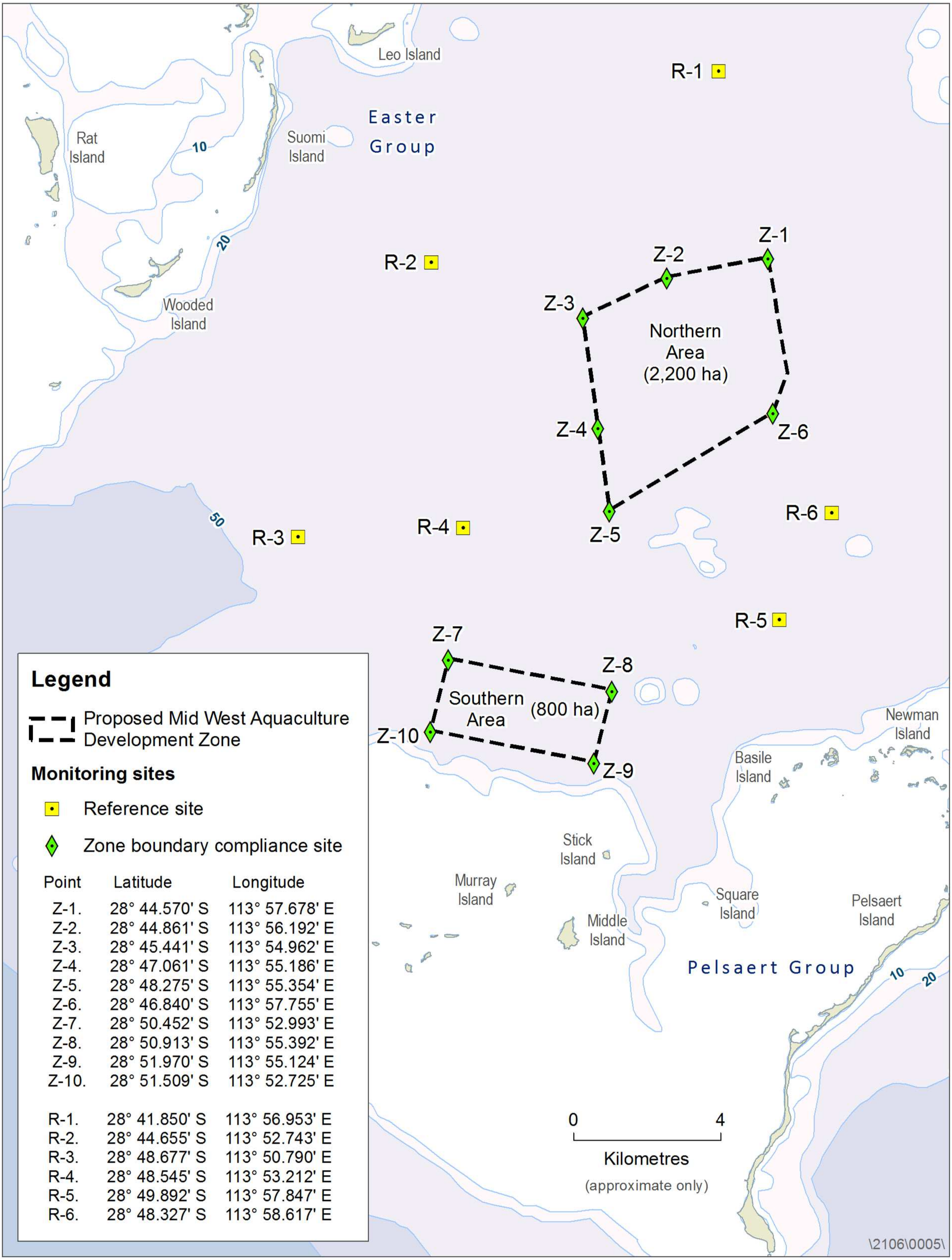

Leo Island
R-1
Easter
Group
Rat
Island
10
Suomi
Island
20
R-2
Z-1
Z-2
Z-3
Wooded
Island
Northern
Area
(2,200 ha)
Z-4
Z-6
50
R-3
R-4
Z-5
R-6
R-5
Z-7
Z-8
Southern
Area
(800 ha)
Z-10
Z-9
Newman
Island
Basile
Island
Stick
Island
Murray
Island
Middle
Island
Square
Island
Pelsaert
Island
Pelsaert Group
10
20
Legend
Proposed Mid West Aquaculture Development Zone
Monitoring sites
Reference site
Zone boundary compliance site
Point Latitude Longitude
Z-1. 28° 44.570' S 113° 57.678' E
Z-2. 28° 44.861' S 113° 56.192' E
Z-3. 28° 45.441' S 113° 54.962' E
Z-4. 28° 47.061' S 113° 55.186' E
Z-5. 28° 48.275' S 113° 55.354' E
Z-6. 28° 46.840' S 113° 57.755' E
Z-7. 28° 50.452' S 113° 52.993' E
Z-8. 28° 50.913' S 113° 55.392' E
Z-9. 28° 51.970' S 113° 55.124' E
Z-10. 28° 51.509' S 113° 52.725' E
R-1. 28° 41.850' S 113° 56.953' E
R-2. 28° 44.655' S 113° 52.743' E
R-3. 28° 48.677' S 113° 50.790' E
R-4. 28° 48.545' S 113° 53.212' E
R-5. 28° 49.892' S 113° 57.847' E
R-6. 28° 48.327' S 113° 58.617' E
0
4
Kilometres
(approximate only)
\2106\0005\

B. Control Charting Example

B.1 Background

Control charting, also known as Statistical Process Control (SPC), dates back to the 1930s where it was first used in industrial applications to control drift and variation in manufacturing standards (ANZECC & ARMCANZ (2000). However, control charting techniques used for the last 70 years in industry have an important role to play in an environmental context. ANZECC & ARMCANZ (2000) and EPA (2005) highlight the usefulness of control charting for comparing sample data with environmental guidelines or standards: "*Regulatory agencies are moving away from the 'command and control' mode of water quality monitoring, and recognising that, in monitoring, the data generated from environmental sampling are inherently 'noisy'. The data's occasional excursion beyond a notional guideline value may be a chance occurrence or may indicate a potential problem. This is precisely the situation that control charts target. They not only provide a visual display of an evolving process, but also offer 'early warning' of a shift in the process level (mean) or dispersion (variability).*" When upper and lower confidence limits (around the means) are incorporated to time series data, control charts may also be used to run simple statistical tests, which in practice are equivalent to Analysis of Variance (ANOVA) and t-test procedures. For further information, refer to ANZECC & ARMCANZ (2000).

B.2 Application

Control charts are particularly useful for comparing sample data with a guideline (EQG) or standard (EQS), particularly when sample data are recorded as time series data. The advantages of control charts are that:

- minimal processing of data is required;
- they are graphical – trends, periodicities and other features are easily detected; and
- they have early warning capability – the need for remedial action can be seen at an early stage.

An example of the application of control charting to the MWADZ project is shown in Figure B.1. In this example, time series data are shown for infauna family richness. The variability in the data was generated using Monte Carlo simulation, and draws on the actual baseline data collected by DoF in 2014 and 2015. Figure B.1A shows the expected variability in the mean (or average) richness over time, up until the commencement of operation where the data were manipulated (whilst still maintaining variability) to simulate a putative impact (represented by a gradual decline in family richness). In this example, the proposed MEPA site data (red line) repeatedly overlap the reference site data until the commencement of operation, at which point the lines begin to diverge – thus simulating the beginning of a gradual decline in richness due to the predicted increase in sediment organic loading (BMT Oceanica 2015). This example demonstrates the early warning utility of the control charting procedure – where the early stages of change are observable well in advance of exceeding the environmental trigger, which is this case is represented by the EQS (see Figure B.1B).

Figure B.1B uses the same data and simulation process but shows the variability based on the upper and lower 95% confidence intervals (CI) (as opposed to the means in Figure B.1A). Comparison of upper and lower 95% CI is critical to the assessment of the EQS for infauna, LAC, TSS and Chlorophyll-a (see Sections 4.1 and 4.2). In this example, which is based on infauna, note how the MEPA lower 95% CI and the Reference upper 95% CI remain separated throughout the baseline period up until commencement of operation, when they begin to converge (and eventually overlap). What is key here, is that relative to the mean values in Figure B.1A, the upper and lower 95% confidence intervals do not overlap until later in the operational period.

This is indicative of the value in the approach, whereby divergence between means serves as early warning of an approaching exceedance, and the convergence (and eventual overlap) of the 95% CIs is representative of the exceedance (of the EQS) – which in this application is equivalent to a statistical difference between the means.

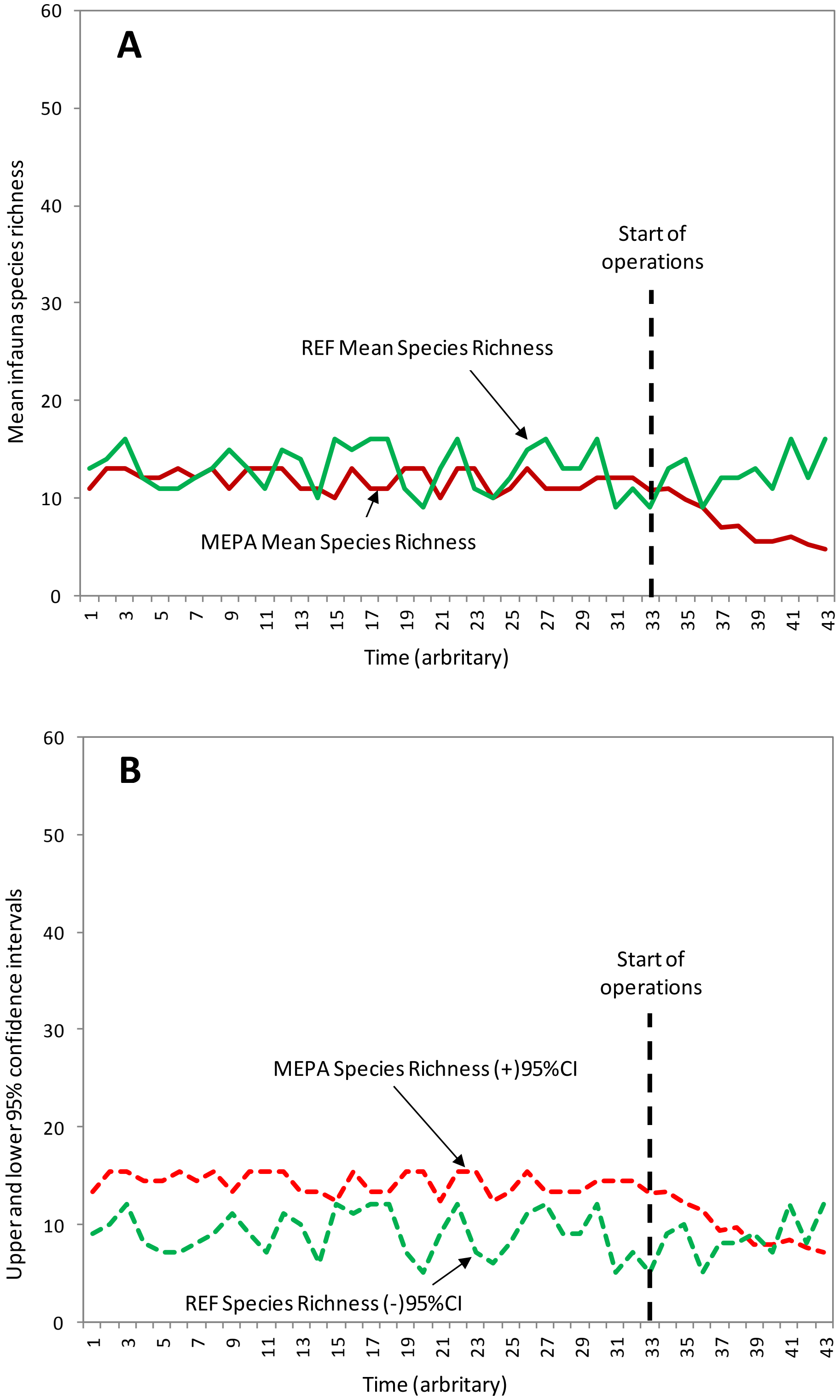

Figure B.1 Control charting example using infauna species richness

B.3 Worked example

As described above, control charts are an effective way for visually comparing the trajectories of two or more times series data, and are thus a simple but useful tool for environmental managers. Control charts can readily be developed using simple and readily available software such as MS

Excel. A worked example is provided below (the spreadsheet template used to develop this example is available from the Department of Fisheries).

The example below is based on hypothetical infauna species richness data obtained from the moderate ecological protection area (MEPA).

At the completion of each sampling period, enter the data under the appropriate MEPA distance (0 m-200 m) (Figure B.2). Means and Standard Deviations (SD) should update automatically, using the built in formulas =average() and =stdev(). The 95% confidence interval can be obtained using the formula =CONFIDENCE(0.05,SD,n). Upper (+) and lower (-) 95% CI around the mean can then be calculated. These values (means and 95%CIs) are in turn captured in the Chart Template Table (see Figure B.3).

Data entered in the Chart Template Table are linked to the Control Chart plots, for mean species richness and 95%CI species richness. Once the data are entered, the plots will update automatically (Figure B.4).

=CONFIDENCE(0.05,J4,K4)

CONFIDENCE(**alpha**, standard_dev, size)

MEPA

Data	Distance					Statistics					
	0m	50m	100m	150m	200m	Mean	SD	n	95% CI	(+)95%CI	(-)95%CI
Baseline	13	12	10	11	12	11.600	1.140	5.0	:NCE(0.05	12.599	10.601
Baseline	10	11	13	12	10	11.200	1.304	5.0	1.143	12.343	10.057
Operation	13	11	11	13	11	11.800	1.095	5.0	0.960	12.760	10.840
Operation	10	11	11	13	11	11.200	1.095	5.0	0.960	12.160	10.240

Reference

Data	Site 1									
	Site 1	Site 2	Site 3	Site 4	Mean	SD	n	95% CI	(+)95%CI	(-)95%CI
Baseline	10	13	13	12	12.000	1.414	4.0	1.386	13.386	10.614
Baseline	12	11	10	11	11.000	0.816	4.0	0.800	11.800	10.200
Operation	11	13	11	12	11.750	0.957	4.0	0.938	12.688	10.812
Operation	13	12	10	10	11.250	1.500	4.0	1.470	12.720	9.780

Figure B.2 Formula for calculating 95% confidence intervals

=I4

	D	E	F	G	H	I	J	K	L	M	N
MEPA											
Data	**Distance**					Statistics					
	0m	**50m**	**100m**	**150m**	**200m**	**Mean**	**SD**	**n**	**95% CI**	**(+)95%CI**	**(-)95%CI**
Baseline	13	12	10	11	12	11.600	1.140	5.0	0.999	12.599	10.601
Baseline	10	11	13	12	10	11.200	1.304	5.0	1.143	12.343	10.057
Operation	13	11	11	13	11	11.800	1.095	5.0	0.960	12.760	10.840
Operation	10	11	11	13	11	11.200	1.095	5.0	0.960	12.160	10.240

Reference

Data	**Site 1**									
	Site 1	**Site 2**	**Site 3**	**Site 4**	**Mean**	**SD**	**n**	**95% CI**	**(+)95%CI**	**(-)95%CI**
Baseline	10	13	13	12	12.000	1.414	4.0	1.386	13.386	10.614
Baseline	12	11	10	11	11.000	0.816	4.0	0.800	11.800	10.200
Operation	11	13	11	12	11.750	0.957	4.0	0.938	12.688	10.812
Operation	13	12	10	10	11.250	1.500	4.0	1.470	12.720	9.780

Chart template

Monitoring occasion		Mean		(+) 95% CI		(-) 95% CI	
		MEPA	Ref	MEPA	Ref	MEPA	Ref
Baseline	1	=I4	12.000	12.599	13.386	10.601	10.614
Baseline	2	11.200	11.000	12.343	11.800	10.057	10.200
Operation	3	11.800	11.750	12.760	12.688	10.840	10.812
Operation	4	11.200	11.250	12.160	12.720	10.240	9.780
	5						
	6						

Figure B.3 Approach for linking the raw data to the Chart Template Table

Chart template

Monitoring occasion		Mean		(+) 95% CI		(-) 95% CI	
		MEPA	Ref	MEPA	Ref	MEPA	Ref
Baseline	1	11.600	12.000	12.599	13.386	10.601	10.614
Baseline	2	11.200	11.000	12.343	11.800	10.057	10.200
Operation	3	11.800	11.750	12.760	12.688	10.840	10.812
Operation	4	11.200	11.250	12.160	12.720	10.240	9.780
	5						
	6						

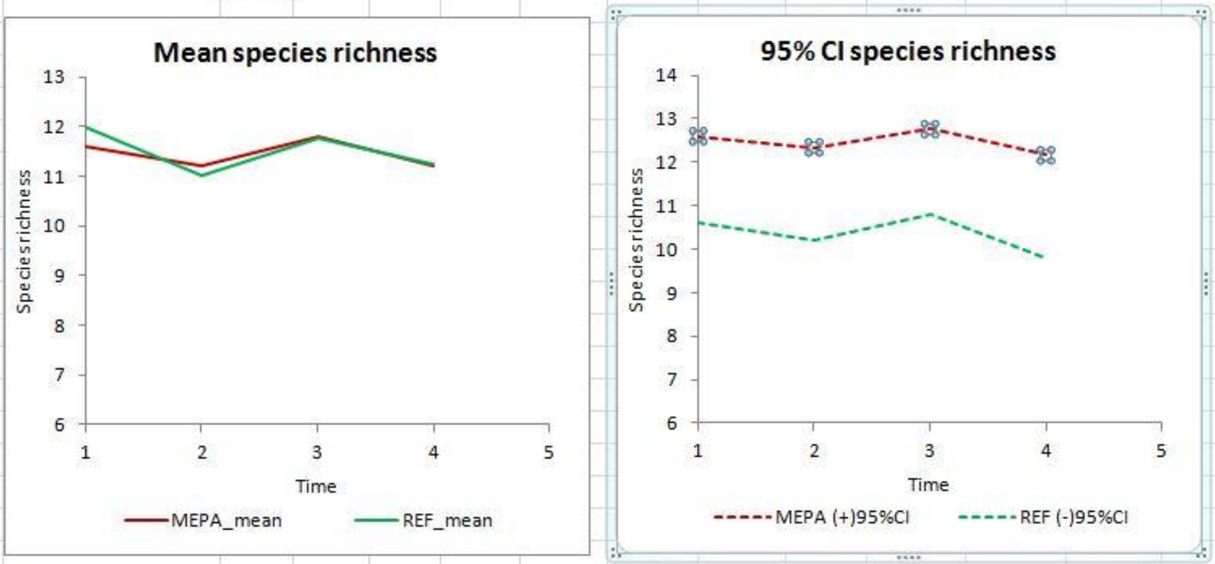

Figure B.4 Link between the Chart Template Table and the Control Charts

B.4 References

ANZECC & ARMCANZ (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality, National Water Quality Management Strategy No. 4. Australian and New Zealand Environment and Conservation Council/Agriculture and Resource Management Council of Australia and New Zealand, Canberra, Australian Capital Territory

BMT Oceanica (2015) Modelling and Technical Studies in Support of the Mid-West Aquaculture Development Zone. Prepared for Western Australian Department of Fisheries by BMT Oceanica Pty Ltd, BMT WBM, and AED UWA, Report No. 1051_009/1_Rev0, Perth, Western Australia, September 2015

EPA (2005) Manual of Standard Operating Procedures for Environmental Monitoring against the Cockburn Sound Environmental Quality Criteria (2003-2004) – A supporting document to the State Environmental (Cockburn Sound) Policy 2005. Environmental Protection Authority Report 21, January 2005

Government of Western Australia
Department of Fisheries

MID WEST AQUACULTURE DEVELOPMENT ZONE

MANAGEMENT POLICY

Draft as at 3 May 2016

CONTENTS

1 FOREWORD

1.1 Introduction

A strategic planning approach to aquaculture development is regarded as best regulatory practice and a key method of providing for industry growth while achieving ecologically sustainable development outcomes.[1] Some Australian states have established significant marine aquaculture industries using a regional zone methodology in their strategic planning.

The Western Australian Government is committed to the development of a sustainable marine aquaculture industry and, to further this commitment, the Minister for Fisheries (Minister) announced a funding package to enable the establishment of two such zones: one in the Kimberley and one in the Mid West region of the State.

The Department of Fisheries (Department) is managing the creation of these two zones on behalf of the Minister.

The Mid West Aquaculture Development Zone (zone) is located within the southern part of the Abrolhos Islands Fish Habitat Protection Area (FHPA), between the Pelsaert and Easter groups of the Abrolhos archipelago, approximately 65 km west of Geraldton.[2] This is the second aquaculture zone to be established in Western Australia, the Kimberley Aquaculture Development Zone being declared by the Minister on 22 August 2014. The Mid West zone is located in a part of the Western Australian coast where there is a confluence of both temperate and tropical sea life, forming one of the State's unique marine areas. This presents a rare opportunity for the development of any of a range of marine finfish aquaculture species that occur naturally within the West Coast Region of the State.[3]

The zone has been created through a process that principally involves environmental assessment of the zone as a **strategic proposal** under Part IV of the *Environmental Protection Act 1986* (EP Act).

Approval of this strategic proposal will create opportunities for existing and future aquaculture operators to refer project proposals to the Environmental Protection Authority (EPA) as **derived proposals**. The desired outcome is a more streamlined zone assessment and regulation process. This will be achieved through the early consideration of the identified potential environmental impacts and additional cumulative impacts associated with the project proposals, and of the relevant management measures designed to control these.

The establishment of commercial marine finfish aquaculture projects within the zone is not expected to cause a significant environmental impact. This assessment of the likely environmental impacts is due not only to the zone's physical characteristics, in particular the high rates of flushing or water exchange in the Zeewijk Channel that is sufficient to dilute

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[1] *Best practice framework of regulatory arrangements for aquaculture in Australia* [Primary Industries Ministerial Council – 2005].

[2] Fish Habitat Protection Areas are created by the Minister under the provisions of Part 11, Division 1 of the *Fish Resources Management Act 1994*.

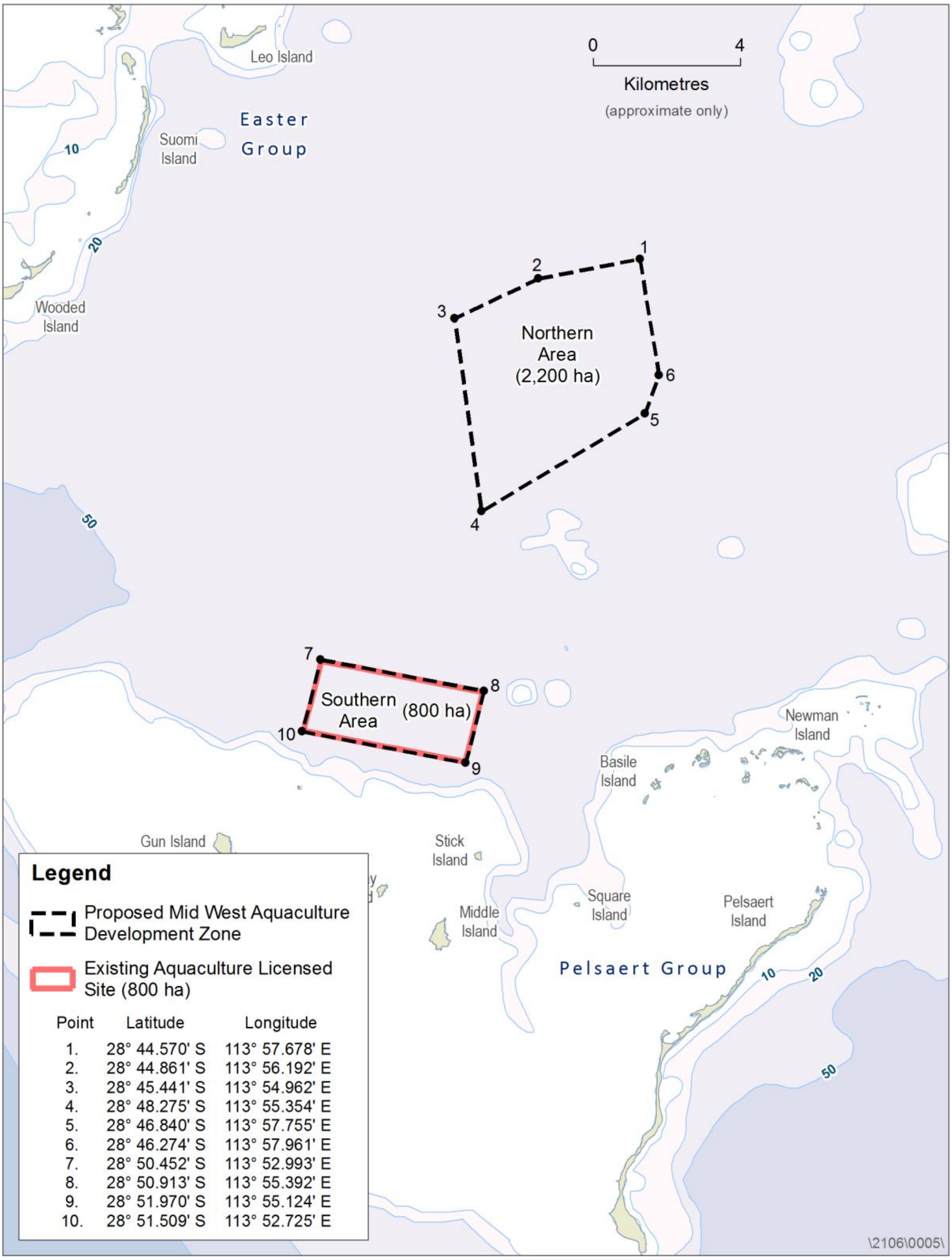
[3] *West Coast Region* is defined in Regulation 3 *Terms used* of the Fish Resources Management Regulations 1995 as:

(a) all land in the State; and

(b) all WA waters,

that are south of 27^{0} 00$'$ south latitude, excluding the South Coast Region;

nutrients before they are assimilated by the ecosystem, but also to the adaptive management controls and environmental monitoring framework the Department (in conjunction with the EPA) has developed for the zone, and the individual proposals within it, through the strategic assessment process.



Point	Latitude	Longitude
1.	28° 44.570' S	113° 57.678' E
2.	28° 44.861' S	113° 56.192' E
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6.	28° 46.274' S	113° 57.961' E
7.	28° 50.452' S	113° 52.993' E
8.	28° 50.913' S	113° 55.392' E
9.	28° 51.970' S	113° 55.124' E
10.	28° 51.509' S	113° 52.725' E

Figure 1: Location of the Mid West Aquaculture Development Zone.

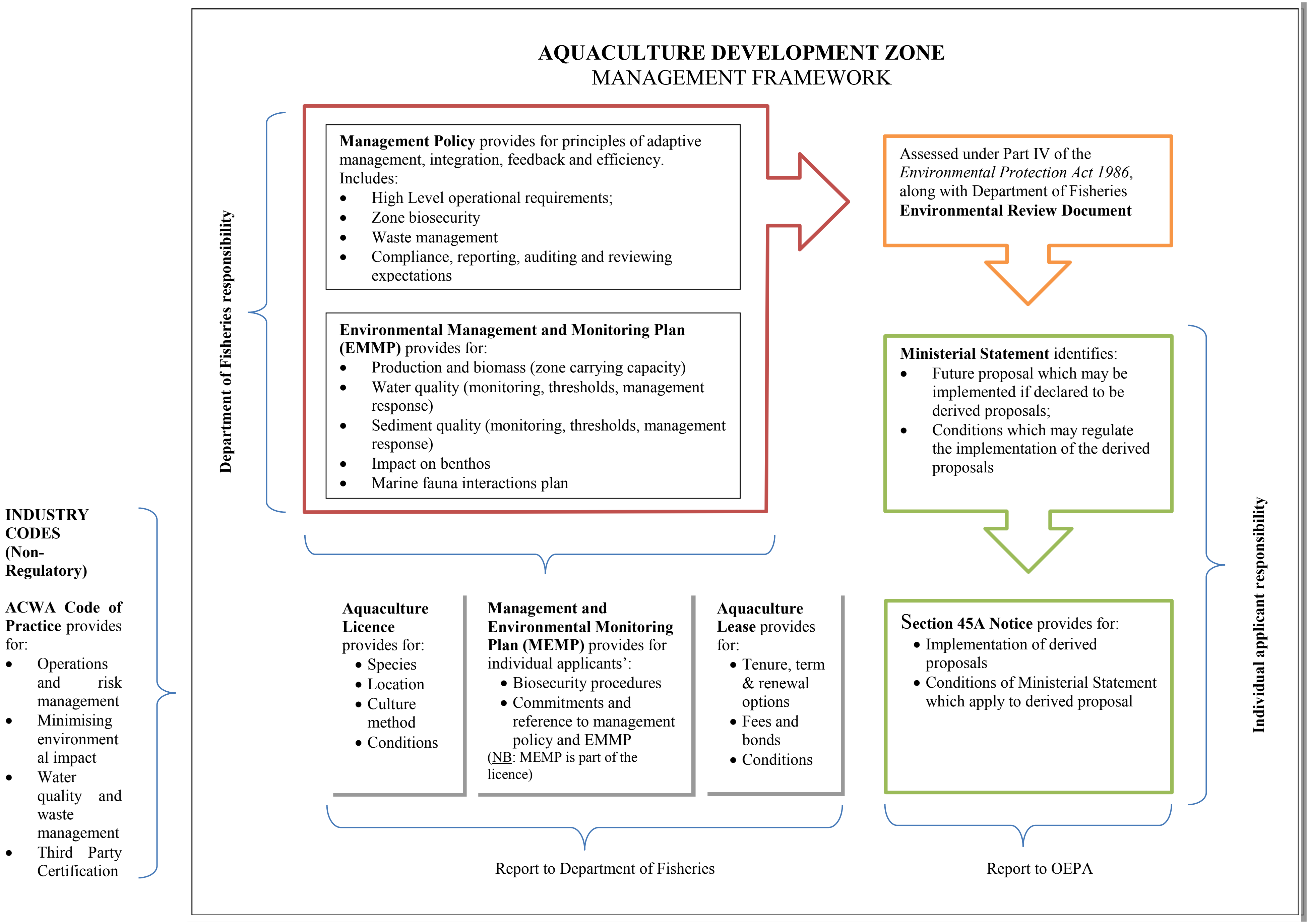
AQUACULTURE DEVELOPMENT ZONE
MANAGEMENT FRAMEWORK
Department of Fisheries responsibility
Management Policy provides for principles of adaptive management, integration, feedback and efficiency.
Includes:
• High Level operational requirements;
• Zone biosecurity
• Waste management
• Compliance, reporting, auditing and reviewing expectations
Environmental Management and Monitoring Plan (EMMP) provides for:
• Production and biomass (zone carrying capacity)
• Water quality (monitoring, thresholds, management response)
• Sediment quality (monitoring, thresholds, management response)
• Impact on benthos
• Marine fauna interactions plan
Assessed under Part IV of the Environmental Protection Act 1986, along with Department of Fisheries Environmental Review Document
Ministerial Statement identifies:
• Future proposal which may be implemented if declared to be derived proposals;
• Conditions which may regulate the implementation of the derived proposals
Section 45A Notice provides for:
• Implementation of derived proposals
• Conditions of Ministerial Statement which apply to derived proposal
Individual applicant responsibility
INDUSTRY CODES (Non-Regulatory)
ACWA Code of Practice provides for:
• Operations and risk management
• Minimising environmental impact
• Water quality and waste management
• Third Party Certification
Aquaculture Licence provides for:
• Species
• Location
• Culture method
• Conditions
Management and Environmental Monitoring Plan (MEMP) provides for individual applicants':
• Biosecurity procedures
• Commitments and reference to management policy and EMMP
(NB: MEMP is part of the licence)
Aquaculture Lease provides for:
• Tenure, term & renewal options
• Fees and bonds
• Conditions
Report to Department of Fisheries
Report to OEPA

Figure 2

2 POLICY STATEMENT AND PURPOSE

2.1 The Management Framework

The Department will manage the zone within an integrated management framework. **Figure 2** provides details of this overarching management framework, its main elements and their inter-relationships.

The management framework comprises the zone management policy (management policy) and several associated instruments and documents.

In relation to the zone, the purpose of the management framework is to:

- establish an overarching, integrated structure for managing the aquaculture activities;
- provide clear, efficient and effective processes for monitoring, evaluating and reporting;
- continuously improve the approach being used to manage the zone;
- guide the development of marine finfish aquaculture; and
- ensure adaptive management occurs as part of a process of continuous improvement.

2.2 The Management Policy

The management policy fits within, and comprises the core of, the overarching management framework for the zone.

Essentially, the purpose of the management policy is to guide the ecologically-sustainable development of marine finfish aquaculture within the zone. It does this through streamlined assessment and planning processes and a feedback mechanism that continuously improves the efficiency of monitoring and management activities.

The management policy deals with strategic issues likely to remain unchanged in the medium term. Other instruments and documents associated with the management policy are more suitable for providing for adaptive management in the shorter term. This adaptive management approach provides a structured, iterative process for decision making where uncertainties may exist. It also provides the opportunity to take advantage of emerging or new knowledge as it becomes available. The aim is to reduce the level of uncertainty over time through a continuous cycle of system monitoring, reporting, evaluating and implementing any necessary enhancements. In this way, decision making simultaneously meets both current resource management objectives and actively accrues information needed to improve future management.

The management policy is designed to be generic, non-prescriptive and provide broad principles for management of the zone. It is integrated with, and supported by, a separate set of companion documents and instruments, which provide greater detail on the legislative, regulatory, monitoring and reporting requirements. These associated documents and instruments are the:

- **Ministerial Statement** issued under Part IV of the EP Act approving the establishment of the zone as a strategic proposal under that Act;[4]
- **environmental monitoring and management plan** (EMMP) ensuring environmental quality and ecological integrity are maintained within acceptable limits;[5]
- **aquaculture licence** authorising the aquaculture activity;
- **aquaculture lease** providing suitable tenure;
- **management and environmental monitoring plan** (MEMP) giving effect (under the FRMA) to the requirements of the management policy and the EMMP;[6]
- **notice(s)** (issued under section 45A of the EP Act approving the implementation of derived proposals); and
- *Environmental* ***Code of Practice*** *for the Sustainable Management of Western Australia's Marine Finfish Aquaculture Industry* [Aquaculture Council of Western Australia (ACWA)] describing aquaculture "best practice".

Collectively, these documents and instruments:

- regulate the aquaculture proposals within the zone; and
- guide specific approaches to management, monitoring and evaluation that are within the broader bounds of the management policy.

Of necessity, there is some overlap between these various documents. However, they are designed to be consistent with each other and to provide capacity for adaptive management.

The principles contained within the management policy, together with a comprehensive environmental management and monitoring program, have been developed to ensure the industry is ecologically sustainable and that its potential cumulative environmental impacts are understood and well managed.[7]

2.3 Code of Practice

The Aquaculture Council of Western Australia has developed an updated *Environmental Code of Practice for the Sustainable Management of Western Australia's Marine Finfish Aquaculture Industry* (ACWA CoP).

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[4] Refer to the EPA website at http://epa.wa.gov.au/peia/approvalstatements/Pages/default.aspx?cat=Ministerial%20Approval%20Statements&url=peia/approvalstatements

[5] Refer to the zone Environmental Monitoring and Management Plan (EMMP) at http://www.fish.wa.gov.au/Fishing-and-Aquaculture/Aquaculture/Aquaculture%20Zones/Pages/Mid-West-Aquaculture-Zone.aspx

[6] Unless the applicant is exempt under subsection 92A(4) of the FRMA, an application for an aquaculture licence must be accompanied by a MEMP identifying how the applicant will manage any risks to the environment and public safety in relation to the proposed activity for which the licence is sought.

[7] One of the principles adopted in the management policy is adaptive management. This approach recognises that adaption occurs through the management processes and is given effect through the feedback loop of monitoring and reporting. The key elements of the adaptive management process used in the zone are:

- production scale and assimilative capacity of the environment;
- collection and use of information generated;
- information and risk management;
- monitoring and evaluation; and
- community engagement.

An industry initiative, the ACWA CoP builds on the June 2009 Fisheries Management Paper No. 233: *Finfish Aquaculture in Western Australia: Final ESD Management Report for Marine Finfish Aquaculture*, published by the Department.[8]

The ACWA CoP focuses on best practice through a documented environmental management system. It recommends a continual improvement requirement by the business through periodic reviews and evaluations to identify and implement opportunities for improvement.

Among its other objectives, the ACWA CoP provides a mechanism for environmental self-regulation of the marine finfish aquaculture sector as a valuable alternative to detailed regulation of every aspect of the industry's activity. It could also lead to the development of a system of environmental accreditation.

While the ACWA CoP is associated with the management policy, it is not a requirement under legislation. Compliance with it is voluntary, not mandatory. Therefore, it is considered to be outside (but supportive of) the legislative management framework.

3 LEGISLATIVE FRAMEWORK

Section 101A (2A) of the *Fish Resources Management Act 1994* (FRMA) provides the power for the Minister to declare an area of Western Australian waters to be an aquaculture development zone.

Prior to the Minister making the declaration for the Mid West zone, the Department, on the Minister's behalf, referred the proposal to the EPA as a strategic proposal under Part IV of the EP Act. The EPA assessed the proposal and recommended the Minister for the Environment accept it as a strategic proposal. Further detail in relation to the environmental assessment and authorisations under the EP Act is provided below under item 4 "*Environmental Assessment and Authorisations*".

Section 92 of the FRMA provides the power for the Chief Executive Officer (CEO) of the Department to grant an aquaculture licence, which authorises the licence holder to conduct aquaculture in Western Australia.

As a result of amendments to the FRMA, there is a requirement that applicants for aquaculture licences demonstrate they have, or will have, appropriate tenure over the area proposed for the aquaculture activity. In most cases, tenure over State waters may be granted through an aquaculture lease, issued under section 97 of the FRMA. In the zone, both an aquaculture lease and an aquaculture licence will be required for establishing and undertaking aquaculture.

An aquaculture licence authorises the specific aquaculture **activity** undertaken within a defined site, whereas a lease provides **tenure** for the specified area of land or water. There is a nexus between the aquaculture licence and the aquaculture lease under the FRMA. For example, under:

[8] The Department supports the development of Codes of Practice for industry sectors and, where possible, will support these codes through licensing conditions or regulations.

- s.99(1), an aquaculture lease does not authorise the use of the leased area without an aquaculture licence;
- s.99(2), if an aquaculture licence authorising the activity being carried out in the leased area is cancelled or not renewed, the lease is terminated; and
- s.99(3), if an aquaculture lease is terminated or expires, an aquaculture licence authorising the activity being carried out in the leased area is cancelled.

The main purpose of this interrelationship is to prevent speculation or investment at a particular site for a purpose other than aquaculture.

The legislative framework also allows for adaptive management to achieve the best management outcomes. Licence and lease conditions may be imposed. For example, the CEO has the power to add a condition to an existing aquaculture licence to set initial carrying capacity or stocking density limits. Conditions may also extend to matters such as applying performance criteria to address any instances of unjustified non-use of aquaculture leases.

The FRMA also establishes an environmental management and monitoring framework for all sectors of aquaculture. Under the provisions of section 92A of the FRMA, unless exempt under section 92A(4), applications for an aquaculture licence must be accompanied by a MEMP. The MEMP is the principal instrument by which the Department gives effect to this environmental management and monitoring framework. It relates to and is attached to the aquaculture licence.

Aquaculture activities inside an aquaculture zone require a Category 1 MEMP.[9] As these activities are subject to the provisions of the strategic proposal approval for the zone (see below), a Category 1 MEMP must incorporate (and refer to) the requirements specified in the following documents:

- Ministerial Statement/notice (issued by the Minister for Environment)
- Department of Fisheries EMMP for the zone
- Department of Fisheries management policy for the zone

Contravention of a MEMP or condition of an aquaculture licence or lease is an offence under the FRMA and penalties may apply. Further, the FRMA provides the power for the CEO to cancel, suspend or not renew an aquaculture licence.

4 ENVIRONMENTAL ASSESSMENT AND AUTHORISATIONS

The EPA assessed the zone as a **strategic proposal** under Part IV of the EP Act. Three documents are considered for the purposes of finalising this assessment, the zone:

- **Public Environmental Review (PER) document**;
- **EMMP**; and
- **Management Policy** (i.e. this policy).

The EPA forwards its assessment of the proposal in a report to the Minister for Environment.

[9] The methodology for determining the appropriate category of MEMP is outlined in the Department's MEMP Policy document. This may be accessed at http://www.fish.wa.gov.au/Fishing-and-Aquaculture/Aquaculture/Aquaculture-Management/Pages/default.aspx.

In turn, that Minister confers with other relevant decision-making authorities before issuing a statement (Ministerial Statement) in relation to the implementation of future proposals (i.e. aquaculture proposals) identified in the zone.
This statement includes conditions which apply to the implementation of those future proposals if referred to, and declared by, the EPA to be a **derived proposal**.

The Ministerial Statement identifies the proposals which may be implemented in the zone; and the conditions that will apply to those proposals.

In addition to the licence and lease required under the FRMA, applicants wanting to implement aquaculture proposals in the zone will need to refer that proposal to the EPA; along with a request that the proposal be declared a derived proposal and an explanation as to why such a declaration should be made. Their request to the EPA must include a statement (and, if necessary, supporting documentation) demonstrating that the referred proposal includes the implementation of the EMMP.

Upon receipt of this referral and request, the EPA considers whether to declare the referred proposal a derived proposal having regard to the provisions in section 39B of the EP Act. Applicants should use EPA's *Environmental Protection Bulletin No. 17 "Strategic and derived proposals"* for guidance when referring an aquaculture proposal and request to the EPA.

If the EPA recommends to the Minister for Environment that a referred proposal be a derived proposal that Minister issues a **notice** (under section 45A of the EP Act) declaring the proposal is a derived proposal. The Minister may also specify which of the conditions of the strategic proposal (i.e. the Mid West Aquaculture Development Zone) will apply to implementing the declared derived proposal. It is an offence under the EP Act to fail to implement a proposal other than in accordance with the implementation conditions.

While unlikely, there may also be a requirement for assessment under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999.* This could occur should aquaculture activities within the zone set off any of the environmental 'triggers' (e.g. unacceptable interactions with rare and endangered species) applicable to that legislation.

5 ENVIRONMENTAL MONITORING AND MANAGEMENT

Environmental impacts within the zone are principally managed through implementing the requirements of the EMMP for the zone; and supported by the requirements outlined in the zone management policy.

In addition to compliance with the conditions of any notice issued under the EP Act (see above), licence holders must comply with the environmental monitoring requirements specified in the EMMP.

It is the responsibility of each licence holder to manage their lease area within the environmental quality guidelines and standards outlined in the EMMP. For the avoidance of any doubt, the EMMP requirements are also reflected in the approved MEMP. Licence holders must ensure competency in environmental sampling, timely reporting of results and appropriate training of staff.

Should multiple licence holders be operating within the zone, it may be in their interest to co-operate and share in environmental monitoring and reporting activities to avoid duplication of effort and the associated cost. This could be achieved by monitoring the reference sites closest to the individual lease areas.

Licence holders should be familiar with the ACWA CoP, and operate in accordance with its recommendations.

6 ZONE SPECIFICATIONS

The Mid West zone comprises of two locations (northern and southern areas) that cover waters with a total area of approximately 3,000 hectares. Within this figure, the northern area covers approximately 2,200 hectares and the southern area covers approximately 800 hectares. The zone boundaries are defined in **Figure 1**.

Average water depth is approximately 40 metres, over mostly sandy bottom.

6.1 Zone Manager

On behalf of the Minister for Fisheries, the Department is the zone manager for the Mid West Aquaculture Development Zone. Among other responsibilities within the zone, the Department is responsible for:

- the grant of aquaculture licences and administration of leases within the zone (leases are granted by the Minister for Fisheries);[10]
- adaptive management through licence conditions or the MEMP, as appropriate;
- ensuring lease/licence holders comply with the EMMP for the zone;
- ensuring compliance with this management policy; and
- ensuring the reporting requirements specified in Ministerial Statement and any subsequent s. 45A notices (under the EP Act) are met.

The Department works in conjunction with the Office of the Environmental Protection Authority to ensure compliance with authorisations, such as the strategic and derived proposal approvals, provided under the EP Act.

6.2 Site Separation

Within the zone, the minimum spatial separation distance between leases owned by different companies or other legal entities is one kilometre. This requirement is principally aimed at reducing any potential biosecurity risks for operators.

While necessary, this minimum spatial separation distance can impact on the area within the zone that is available for lease. The more proponents for aquaculture sites inside the zone, the greater the percentage area of the zone that could potentially be taken up by lease separation "buffers" and therefore unavailable for lease and subsequent aquaculture production.

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[10] The zone Site Allocation Policy will assist in determining the number, size and location of leases that may be established within the zone (refer the Department's website at www.fish.wa.gov.au).

As the zone area is a finite resource (i.e. 3,000 hectares maximum), this factor will need to be considered when determining the total number of proponents offered an aquaculture lease within the zone.

Licence holders granted leases are able to locate aquaculture gear, including sea cages, anywhere within their lease. This facilitates aquaculture best-practice techniques, including fallowing.[11]

7 OPERATIONAL REQUIREMENTS

7.1 Species

In accordance with the likely conditions of the Ministerial Statement, only marine finfish of a species that occurs naturally within the West Coast region of Western Australia are permitted to be cultured within the zone.[12]

Genetically modified fish (excluding triploids) must not be farmed.[13]

7.2 Sea Cages

The only culture method in the zone permitted under the strategic environmental approval will be floating sea cages. The size of the sea cages may be determined by the licence holder. All sea cages must be:

- constructed of net or mesh of a size, type and quality that will reliably provide a complete barrier that will retain the fish stocked in the cage;
- constructed so fish cannot escape by jumping out of the sea cages (i.e. "jump" nets are incorporated in the construction of the cage);
- fitted with effective "predator" barriers or their equivalent to prevent predator damage to sea cages that could result in fish escapes;
- positioned to have at least a two metre clearance between the bottom of the cage and the sea floor at the lowest astronomical tide at all times; and
- be securely fastened to anchorage and mooring infrastructure that is used in such a way as not to physically damage any reef or coral habitat.

All 'aquaculture gear' must be located within the lease boundary.[14]

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[11] Fallowing is the interval between operational periods when sea cages are empty. Fallowing can be used to allow recovery of the site from benthic impacts and reduce the likelihood of their occurrence. During fallowing, sea cages can be left on-site or moved to another location.

[12] As defined in Regulation 3 of the *Fish Resources Management Regulations 1995*.

[13] Genetically modified organisms (GMOs) can be defined as organisms in which the genetic material (DNA) has been altered in a way that does not occur naturally.

[14] As defined in Part 1, section 4 of the FRMA;

"***aquaculture gear*** *means any equipment, implement, device, apparatus or other thing used or designed for use for, or in connection with, aquaculture —*

> *(a) whether the gear contains fish or not; and*
>
> *(b) whether the gear is used for aquaculture or for navigational lighting or marking as a part of aquaculture safety,*

and includes gear used to delineate the area of an aquaculture licence, temporary aquaculture permit or aquaculture lease".

Fallowing or movement of sea cages to minimise impact directly under the sea cages is permitted within lease areas. Movement outside lease areas, but within the zone, is subject to a lease variation application.

All aquaculture gear such as grids and nets must be:

- kept taut (and without excess ropes or mesh) in order to minimise the risk of entanglement with marine fauna;
- free from holes/gaps so as to prevent the escape of fish; and
- kept clean of sediment/biofouling such as to not impede or reduce water flow through the grids/nets to the extent that the risks to fish health and gear breakage/loss are unnecessarily increased.

Regular inspections and maintenance should be carried out to ensure the functions of aquaculture gear are not inhibited and the risk of marine fauna interactions is minimised.

The use of copper-based or tributyltin (TBT) containing anti-foulants on aquaculture gear is prohibited.

7.3 Standing Fish Stock Biomass Limits and Production Capacity

This management policy manages the standing stock biomass limit of 24,000 tonnes of marine finfish at any one time for the zone, as set by the strategic environmental approval. For each licence holder, this zone biomass limit translates to an individual biomass limit proportional to the licence holder's total lease area within the zone. In other words, on the basis of a 24,000 tonne zone biomass limit, the maximum permissible biomass limit of marine finfish (based on number and live weight of fish) for each individual operator is a total of eight tonnes per hectare, averaged over that licence holder's total lease area within the zone. For example, a 6,000 tonne standing biomass operation requires a minimum lease area of 750 hectares.

However, consistent with the principles of adaptive management and as additional fish health and environmental monitoring data are generated, it is possible that the standing biomass limits allowed within individual lease sites may be modified (up or down) through a new or varied licence condition. The purpose of any such adjustment made is to maintain the total zone production potential, while avoiding environmental triggers and complying with environmental standards.

Stocking densities must be consistent with industry best practice for the species being farmed.

In terms of the total fish production capacity of the zone, there are no specified limits. Rather, the production capacity of both the zone and the individual lease sites within it is determined by the efficiency with which individual operators convert their respective standing stock biomass limits into harvested fish production. This approach promotes innovation and efficiency in fish farming operations, while providing management flexibility and a framework that is protective of the supporting marine environment.

The following operational data must also be collected by each licence holder quarterly and submitted annually to the Department in an agreed format. This may extend to inclusion in the annual compliance assessment report required for derived proposals under the EP Act.

Parameter	Data required
Location	GPS coordinates
Depth of water	metres
Total standing biomass	kilograms for each species per sea cage
Standing stock densities	kilograms per metre^3
Total feed inputs	kilograms for each species per sea cage
Feed type	make and specification
Feed/waste ratio	ratio
Stock growth rates	grams per day
Treatment pharmaceuticals (if any) administered to stock	type and quantity

7.4 Feed Inputs

Only certified (AS/NZS ISO 9001:2008) commercial pellet feeds that meet the strict regulations of the Australian Quarantine and Inspection Service are permitted.[15] The use of alternative feeds will be assessed on a case-by-case basis and in accordance with best practice farming techniques for the species of interest.

Contemporary feeding technologies and practices should be used, where practicable, in order to minimise feed wastage and environmental impact.

7.5 Brood Stock and Juveniles

Movements of fish (brood stock and juveniles) into commercial aquaculture systems are likely to be subject to translocation approval (see 8.3 below) however this is dependent upon the individual circumstances and the potential biosecurity risks involved.

Juvenile seed stocks must be sourced from licensed hatcheries or other approved source and must be certified disease-free to the satisfaction of the Principal Research Scientist in the Department's Fish Health Unit.[16]

7.6 Marking and Lighting

The lease area must be marked with approved buoys, markers, lights and signage in accordance with the "*Guidance Statement for Evaluating and Determining Categories of Marking and Lighting for Aquaculture and Pearling Leases/Licences (2010)*".

[15] ISO 9001:2008 specifies requirements for a quality management system where an organization needs to demonstrate its ability to consistently provide product that meets customer and applicable statutory and regulatory requirements, and aims to enhance customer satisfaction through the effective application of the system, including processes for continual improvement of the system and the assurance of conformity to customer and applicable statutory and regulatory requirements. All requirements of ISO 9001:2008 are generic and are intended to be applicable to all organizations, regardless of type, size and product provided.

[16] A reference to the Principal Research Scientist includes reference to an accredited pathologist or epidemiologist.

This Statement can be accessed at the Department's website (www.fish.wa.gov.au/Documents/aquaculture_licencing/marking_and_lighting_guidance_statement.pdf). These requirements will be a condition on the aquaculture licence.

7.7 Non-Exclusive Access

The use of State waters for aquaculture does not confer an exclusive access right. Persons other than aquaculture licence holders may enter the zone and lease areas, although they are not permitted to interfere in any way with aquaculture gear. A person who interferes with aquaculture gear or removes fish from such gear commits an offence under the FRMA.[17]

7.8 Performance Criteria

Performance criteria are associated with aquaculture licences to ensure appropriate use of waters within the zone. Where licence holders do not comply with conditions such as performance criteria, the licence may not be renewed, the lease terminated and that site within the zone reallocated.[18]

8 ZONE BIOSECURITY

The zone is treated as one biosecurity unit due to the relative close proximity of aquaculture operations and the physical environment within the Zeewijk Channel.

Fisheries legislation requires all aquaculture licence holders [unless exempt under section 92A(4)] to have a MEMP, which includes biosecurity procedures. All licence holders operating within the zone will be required to have an approved MEMP for their operation that has been developed in accordance with the "*Aquaculture Management and Environmental Monitoring Plan (MEMP) Guidance Statement*" (www.fish.wa.gov.au/Documents/Aquaculture/memp_guidance_statement.pdf) that is available on the Department's website at www.fish.wa.gov.au.

In addition to the biosecurity principles outlined in this management policy, the biosecurity procedures must include, but are not limited to:

- record keeping (such as translocation approvals, health certificates, disease management records, fish escape reports, unusual mortality reports, internal and external stock transfers, facility and stock inspections, facility access records for staff and visitors);
- aquaculture gear and vessels used (such as maintenance, disinfection and inspections);
- biosecurity emergency procedures;
- disposal of waste (such as dead fish, diseased, contaminated or infected fish stocks);

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[17] Section 172 of the FRMA provides:
"*A person must not —*
(a) remove fish from any fishing or aquaculture gear; or
(b) interfere with any fishing or aquaculture gear,
unless the person is the owner of the gear or is acting with the authority of the owner or has some other lawful excuse.
Penalty: In the case of an individual, $25,000 and imprisonment for 12 months. In the case of a body corporate, $50,000."

[18] Under the provisions of the FRMA, if an aquaculture licence is not renewed the associated aquaculture lease for that area is terminated.

- disease testing protocols and quarantine; and
- management of fish escapes.

8.1 Disease Management

Disease prevention, rather than treatment, is vital in any aquaculture operation; but even more so in an aquaculture zone where aquaculture operations may be located in close proximity to one another.

The following management strategies will be implemented to minimise the risk of a fish disease outbreak. In addition to the procedures and protocols outlined in individual MEMPs, licence holders must comply with the following minimum requirements:

- stock (fish) must be marine finfish of a species that occurs naturally within the Mid West region (a condition of the Ministerial Statement);
- all stock, other than brood stock sourced under permit from the wild and taken in the Mid West region, must be certified disease-free and accompanied by a health certificate issued by the Department before being moved into the zone;
- a stock health surveillance program and quarantine procedures must be implemented; and
- a biosecurity manager for each operation must be appointed and responsible for ensuring biosecurity measures are implemented.

In the event of a disease outbreak:

- the licence holder must report the outbreak according to section 8.2 below;
- any pharmaceuticals such as antibiotics that are used must be prescribed by a veterinarian or approved by the Australian Pesticides and Veterinary Medicines Authority and administered in accordance with the recommended dosages;
- stock must not be moved without the written approval of the Principal Research Scientist in the Department's Fish Health Unit;
- vessel movements between individual sites will also be restricted in accordance with the advice of the Principal Research Scientist in the Department's Fish Health Unit;
- disinfection of equipment, vessels and barges down to and including the waterline should be done prior to movement and in accordance with the ACWA CoP; and
- any other aquaculture operators within the zone must be informed immediately.

8.2 Disease Incident Reporting

Disease reporting requirements are stipulated in Regulation 69(d), (e), (f), (g) and (h) of the *Fish Resources Management Regulations 1995* (FRMR). All employees of operators within the zone must be aware of these regulations, which are intended to provide for adequate monitoring and adaptive management of any emerging disease risks.

Under Regulation 69, aquaculture licence holders must notify the CEO of the Department in writing within 24 hours of becoming aware or suspecting that fish may be affected by any disease. Any material, significant or unusually high fish mortalities must be reported, as they may be caused by disease. To minimise the interval between the CEO first being notified of suspected disease outbreaks and the CEO giving directions appropriate to each incident in response, aquaculture licence holders must provide details of the disease outbreak, or

suspected disease, as soon as possible (but within the prescribed timeframes) by e-mail to each of the following:

- fishhealth1@fish.wa.gov.au; **and**
- aquaculture@fish.wa.gov.au; **and**
- biosecurity@fish.wa.gov.au

The e-mails should have the subject heading: "NOTIFICATION TO CEO UNDER REG 69."

E-mail notifications to each of these three addresses within the prescribed timeframes meets the requirements of both this management policy and those of Regulation 69.

8.3 Translocation

Movement of fish (brood stock and juvenile seed stock) for commercial aquaculture purposes are subject to translocation approval dependent upon the circumstances in each instance and the potential biosecurity risks involved. For example, juvenile seed stock produced in a Geraldton hatchery from adult brood stock originating from Mid West region wild stock would not require translocation approval (only disease-free certification); whereas juvenile seed stock produced in (say) a hatchery located in the eastern states from adult brood stock originating from other than the Mid West region would require translocation approval (in addition to the disease-free certification).

Licence holders should refer to the "*Policy for Managing Translocation of Live Fish into and within Western Australia*" (www.fish.wa.gov.au/Documents/biosecurity/dof_translocation_policy.pdf) and contact the Translocation Officer at the Department of Fisheries (by e-mail to translocation@fish.wa.gov.au) prior to translocating fish.

This document, and additional information, is available on the Department of Fisheries website at www.fish.wa.gov.au.

8.4 Fish Escapes

Any suspected escape of a significant number (i.e. greater than 100) of fish from aquaculture gear subject to an aquaculture licence within the zone, or circumstances which gives rise to a significant risk of escape, must be reported to the CEO of the Department by e-mail to aquaculture@fish.wa.gov.au and biosecurity@fish.wa.gov.au within 24 hours.

9 MARINE FAUNA INTERACTIONS

To address potential interaction between operators and infrastructure in the Mid West Aquaculture Development Zone, a stand-alone Marine Fauna Interaction Management Plan (MFIMP) has been developed. This MFIMP focuses primarily on managing potential impacts to marine mammals, marine reptiles and marine avifauna. Specifically, this MFIMP:

- provides an overview of the potential impacts that may occur to marine fauna during the installation process and operational activities;

- outlines management measures and actions adopted to mitigate potential impacts to marine fauna during the sea cage installation process and during operational activities;
- outlines the monitoring requirements/programs required to be serviced by operators within the MWADZ; and
- outlines the marine fauna incident reporting and response strategies required of operators within the MWADZ.

The primary aim of this MFIMP is to ensure that activities conducted within the MWADZ do not cause any significant disturbance to marine fauna within the Abrolhos Islands Fish Habitat Protection Area (FHPA).

The objectives of this plan include minimising:

- human interactions with marine fauna;
- any potential injuries or fatalities to marine fauna that may result from collision with vessels or entanglement;
- noise and vibration disturbance to marine fauna;
- potential impacts to marine fauna from artificial light;
- potential impacts posed to marine fauna by aquaculture infrastructure; and
- adverse effects of fish farming activities within the proposed MWADZ on marine fauna.

For further details of the marine fauna interaction management requirements for operators within the zone, refer to the *Mid West Aquaculture Development Zone Marine Fauna Interaction Management Plan.* This document is available on the Department of Fisheries website at www.fish.wa.gov.au.

10 WASTE MANAGEMENT

Waste material (such as empty feed bags, staff domestic waste, old ropes, net mesh and other discarded equipment) must be placed in sealed waste containers and, or, securely stowed on board the vessel and disposed of at a port on the mainland.

Marine debris can be harmful to the environment and farm staff must ensure it is disposed of correctly. Similarly, if marine debris is sighted within or around the aquaculture operation, its collection and disposal is an environmental responsibility to be met by all operators.

Removal of marine fouling from sea cages may be undertaken *in situ* using physical or mechanical methods; or achieved by removing the nets and drying/cleaning on the mainland.

Dead fish must be placed in silage bins or other sealed containers, transported back to a port on the mainland and reused or disposed of in accordance with Local Government Authority by-laws.

No fish processing is permitted at sea except for harvesting, slaughtering, bleeding, washing and chilling of fish. Harvest bins must be watertight and sealed to ensure blood water is contained.

Sewage must be either:

- treated, using a sewage disposal system approved by the Department of Health, prior to disposal at sea in accordance with the Department of Transport's *Strategy for Management of Sewage Discharge from Vessels into the Marine Environment*; or
- stored in tanks on the vessel and disposed of on land at a licensed disposal site in accordance with Local Government Authority by-laws.

To reduce the potential for oil and oily wastes (including fuel) generated through vessel operations to enter the environment, any used oil or oil-soaked absorbents must be securely stored and then properly disposed of at an appropriate oil recycling facility (available at most ports).

If oil or oily waste is discharged into the marine environment, licence holders must immediately report the marine oil spill to the Department of Transport (DoT) on (08) 9480 9924 (24-hour reporting number) or e-mail (marine.pollution@transport.wa.gov.au.). Do not pour anything onto the oil. If a marine oil spill kit is on hand it may be possible to mop up the spill with absorbent pads and contain it.

Refer to the DoT website (http://www.transport.wa.gov.au/imarine/report-marine-pollution-and-oil-spills.asp) for further information regarding requirements for oil spill or pollution situations.[19]

For further details of the waste management requirements for operators within the zone, refer to the *Mid West Aquaculture Development Zone Waste Management Plan*. This document is available on the Department of Fisheries website at www.fish.wa.gov.au.

11 COMPLIANCE AND REPORTING

Licence holders must comply with the arrangements outlined in this management policy, licence conditions, MEMPs and any other management controls imposed by any relevant statutory or government authority from time to time in relation to the licence holder's activities in the zone. This includes the relevant requirements specified in those instruments and documents provided for under the EP Act (e.g. Ministerial Statement and Section 45A Notice/s). In the event of any breaches of lease conditions or management controls in relation to the leases in the zone, the lease holder (whether also the licence holder or not) is responsible.[20]

Importantly, it is the licence/lease holder and not the Department that is liable for any of the abovementioned breaches. The Department's role is one of a manager, regulator and (if necessary) enforcer of the zone.

In summary, the e-mail contacts for the relevant reporting procedures are:

Disease, suspected disease and unusual mortalities:

fishhealth1@fish.wa.gov.au and

[19] Noting the zone is located within State Waters, Western Australian legislation will apply in the first instance.
[20] Refer to *Part 8 – Aquaculture* of the FRMA.

aquaculture@fish.wa.gov.au and
biosecurity@fish.wa.gov.au

Fish escapes, suspected escapes or circumstances that may give rise to an escape:

aquaculture@fish.wa.gov.au and
biosecurity@fish.wa.gov.au

MEMP report and exceedance of an environmental monitoring trigger value:

aquaculture@fish.wa.gov.au

12 AUDITS AND REVIEWS

Licence holders should have their internal audit mechanisms documented and conduct regular internal audits to ensure compliance with the requirements of this policy. Independent audits are more robust and are the recommended approach.

Periodic inspections of aquaculture licenced sites are undertaken by Fisheries Officers to ensure adherence to licence and lease conditions. The number and type of inspections undertaken is usually dependent on the outcomes of compliance risk assessments that take into account a range of issues, including the likelihood and consequence of events such as:

- stock disease outbreaks;
- stock escapes;
- interactions with commercial, recreational and customary fishers;
- failures to comply with site marking and lighting provisions; and
- non-compliance with environmental monitoring requirements.

The Department will periodically review this management policy to ensure it is up-to-date and meets Government requirements and community expectations.

13 GLOSSARY

ACWA – Aquaculture Council of Western Australia
CoP – Code of Practice
Department – Department of Fisheries
EMMP – Environmental Monitoring and Management Plan
EPA – Environmental Protection Authority
EP Act - *Environmental Protection Act 1986*
ESD – Ecologically Sustainable Development
FRMA – *Fish Resources Management Act 1994*
FRMR - *Fish Resources Management Regulations 1995*
management policy – Mid West Aquaculture Development Zone Management Policy
MEMP – Management and Environmental Monitoring Plan
zone – Mid West Aquaculture Development Zone

14 REFERENCES

Aquaculture Management and Environmental Monitoring Plan (MEMP) Guidance Statement [Department of Fisheries]

AS/NZS ISO 9001:2008 Quality Management Systems [Standards Australia]

Best practice framework of regulatory arrangements for aquaculture in Australia [Primary Industries Ministerial Council – 2005].

Draft *Aquaculture Management and Environmental Monitoring Plan (MEMP) Policy*

Environment Protection and Biodiversity Conservation Act 1999

Environmental Code of Practice for the Sustainable Management of Western Australia's Marine Finfish Aquaculture Industry [Aquaculture Council of Western Australia - 2013]

Environmental Protection Act 1986

Environmental Protection Bulletin No. 17 "Strategic and derived proposals" [Environmental Protection Authority]

Finfish Aquaculture in Western Australia: Final ESD Management Report for Marine Finfish Aquaculture [Fisheries Management Paper No. 233 - June 2009]

Fish Resources Management Act 1994

Fish Resources Management Regulations 1995

Guidance Statement for Evaluating and Determining Categories of Marking and Lighting for Aquaculture and Pearling Leases/Licences [Department of Fisheries – 2010]

Mid West Aquaculture Development Zone Environmental Monitoring and Management Plan (Draft)

Mid West Aquaculture Development Zone Marine Fauna Interaction Plan [Department of Fisheries]

Mid West Aquaculture Development Zone Waste Management Plan [Department of Fisheries]

Policy for Managing Translocation of Live Fish into and within Western Australia [Department of Fisheries]

Strategy for Management of Sewage Discharge from Vessels into the Marine Environment [Department of Transport]

Threat Identification, Hazard Pathway Analysis and Assessment of the Key Biosecurity Risks presented by the establishment of the Mid West Aquaculture Development Zone in Western Australia

Prepared by

Department of Fisheries Western Australia

August 2015

Executive Summary

A threat identification, hazard pathway analysis and assessment of the key biosecurity risks posed by the development of the Mid West Aquaculture Development Zone in Western Australia was undertaken to assist in determining whether current proposed management controls are adequate to bring associated risks to the wider ecosystem to an acceptable level.

The assessment identified and assessed individual hazard pathways associated with each of three primary biosecurity risks that were identified associated with the proposal. Individual hazard pathways which might cumulatively lead to each of these risks were identified and evaluated with respect to their inherent risk (assuming no management controls) and their residual risk (following implementation of identified management controls). Analysis of these hazard pathways facilitated assessment of overall risk for each of the major overarching three risks identified below in a similar manner. In this way the adequacy of current management measures in place was assessed with respect to their ability to bring identified biosecurity risks to ecosystem sustainability associated with the aquaculture zone proposal to an acceptable level.

Risk	**Inherent Risk** (no management measures)	**Residual Risk** (based on implementation of identified management measures)
1. Significant pathogen or disease is spread from an infected aquaculture facility leading to a significant impact on wild targeted fisheries based around the same or alternate species.	Moderate	Low
2. Escaped fish lead to a significant impact on the sustainability of wild stocks through either competitive interaction or genetic mixing.	Moderate	Low
3. The introduction and/or spread of marine pests associated with aquaculture activity has a significant impact on the sustainability of local and/or regional ecosystems	High	Moderate

Residual risks were assessed as **Low** in the cases of disease and escaped fish (Risks 1 & 2). Such low residual risk levels are deemed acceptable given the implementation of the current management controls identified. Residual risk was assessed as **Moderate** in the case of marine pest risk (Risk 3). While residual likelihood was assessed as unlikely in this case, the moderate risk rating reflects the potentially significant consequence of marine pests to ecosystem structure as a whole. Moderate risk is not desirable and indicates a need for continuation of strong management actions and/or consideration of further risk control measures to be introduced in the near future.

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1. Context and Scope

The threat identification, hazard pathway analysis and risk assessment presented in this report has been undertaken to assist in identifying and assessing the potential biosecurity-related risks of finfish aquaculture associated with a Department of Fisheries (Department) proposal to establish an aquaculture development zone in the Mid West of Western Australia (referred to hereafter as the MWADZ (Mid West Aquaculture Development Zone) to the sustainability of ecosystems and their dependent extractive fisheries. The Environmental Protection Authority (EPA) received the proposal for the MWADZ development on the 16 April 2013; accepted that it was a strategic proposal; set the level of assessment at a Public Environmental Review (PER); and approved an Environmental Scoping Document (ESD) on 24 July 2013. To fulfill the ESD the PER is required to provide a detailed assessment of the preliminary key environmental factors identified for the strategic proposal, and achieve environmental quality objectives (EQO) of the ANZECC 2000 guidelines[1]. Ecosystem Health is an important EQO, which required the Department to achieve the EPA's objective to maintain the structure, function, diversity, distribution and viability of the benthic communities and habitats at a local and regional scale. The current assessment forms part of an overall ESD submission and specifically addresses biosecurity related risks.

This assessment does not seek to replicate previously conducted generic aquaculture risk assessments which are broader in scope, remain relevant to the MWADZ proposal and which include the following:

- Marine Finfish Environmental Risk Assessment (de Jong & Tanner, FRDC Project 2003/223)
- National ESD Reporting Framework: The "How to" Guide for Aquaculture. Version 1.1 FRDC, Canberra, Australia (Fletcher et al., 2004)
- Finfish Aquaculture in Western Australia: Final ESD Risk Assessment Report for Sea-Cage and Land-Based Finfish Aquaculture (Vom Berg, 2008; Fisheries Management Paper No 229, Department of Fisheries, Western Australia)
- Finfish Aquaculture in Western Australia: Final ESD Management Report for Marine Finfish Aquaculture (Vom Berg 2009; 2008; Fisheries Management Paper No 233, Department of Fisheries, Western Australia)

Instead, the current assessment has used these previous reports as a basis to identify the main broad areas of biosecurity threat that are most relevant to the MWADZ proposal. These threats were further broken down through the consideration of detailed hazard pathways that may lead to the realisation of these threats.

[1] ANZECC & ARMCANZ. 2000. Australian and New Zealand guidelines for fresh and marine water quality. National Water Quality Management Strategy No 4, Australia and New Zealand Environment and Conservation Council and Agricultural and Resource Management Council of Australia and New Zealand, Canberra, ACT.

Consideration of the threats facilitated the identification of key overarching risks to the identified objective of the assessment which was to ensure the establishment and operation of the MWADZ without biosecurity-related threats having significant impact on the sustainability of ecosystems and their dependent fisheries. These risks were then assessed.

Using this methodology, the current assessment sought to clearly identify the current risk management measures in place and assess their adequacy in bringing identified biosecurity risks to ecosystem sustainability associated with the MWADZ proposal to an acceptable level.

An aquaculture development zone (ADZ) is a designated area of water selected for its suitability for a specific aquaculture sector (in this case marine finfish). Designating areas as ADZs is a result of Departmental policy aimed at stimulating aquaculture investment through providing an 'investment ready' platform for organisations that wish to set up commercial aquaculture operations. More streamlined approvals processes are in place for organisations wanting to establish aquaculture operations within these zones. Extensive studies and modeling underpins the approval of a zone to ensure its potential effects are identified, well understood and managed. Establishing new aquaculture operations, or expanding existing ones, will provide significant economic benefits to the local community through the creation of job opportunities and regional economic diversification.

A Kimberley Aquaculture Development Zone (KADZ) has previously been officially declared by the Minister for Fisheries in Western Australia's northern waters. Covering a total area of almost 2,000 hectares, the zone is located within Cone Bay approximately 215 kilometres northeast of Broome. Extensive environmental studies completed for the zone indicate its capacity to support 20,000 tonnes of finfish without any significant environmental impact. An existing barramundi farm operates within the boundaries of the KADZ. The establishment of the zone has enabled the operator, MPA Fish Farms Pty Ltd, to secure environmental approval to increase its production capability from 2,000 to nearly 7,000 tonnes per annum.

This assessment relates to a second planned aquaculture development in the Mid West of Western Australia. The Mid West Aquaculture Development Zone (MWADZ) will be located within the State waters of the Abrolhos Islands Fish Habitat Protection Area (FHPA), north of the Pelsaert Group, about 60 kilometres west of Geraldton. The exact site will be determined after evaluating the results of environmental and technical studies.

The zone is being established through a process that primarily involves environmental assessment of the zone as a strategic proposal under Part IV of the *Environmental Protection Act 1986*. Approval of this strategic proposal will create opportunities for existing and future aquaculture operators to refer their proposals to the Environmental Protection Authority (EPA) as 'derived proposals'. The objective is a more streamlined assessment and regulation process due to early consideration of potential environmental impacts and cumulative impacts identified during the assessment process for the zone.

The Department surveyed and sampled a study area of 4,740 hectares in two locations within the FHPA. This identified 2,200 hectares in the Northern Area and 800 hectares in the Southern Area (see Figure 1) as the most suitable areas for finfish aquaculture. Technical environmental studies of these locations helped determine the exact delineation of the zone. The proposed zone is situated away from areas of highest conservation value and is subject to considerable water flushing driven by prevailing winds, waves and currents. Good water flow through the sea-cages in which the fish are grown is essential for high productivity and to minimise environmental impact.

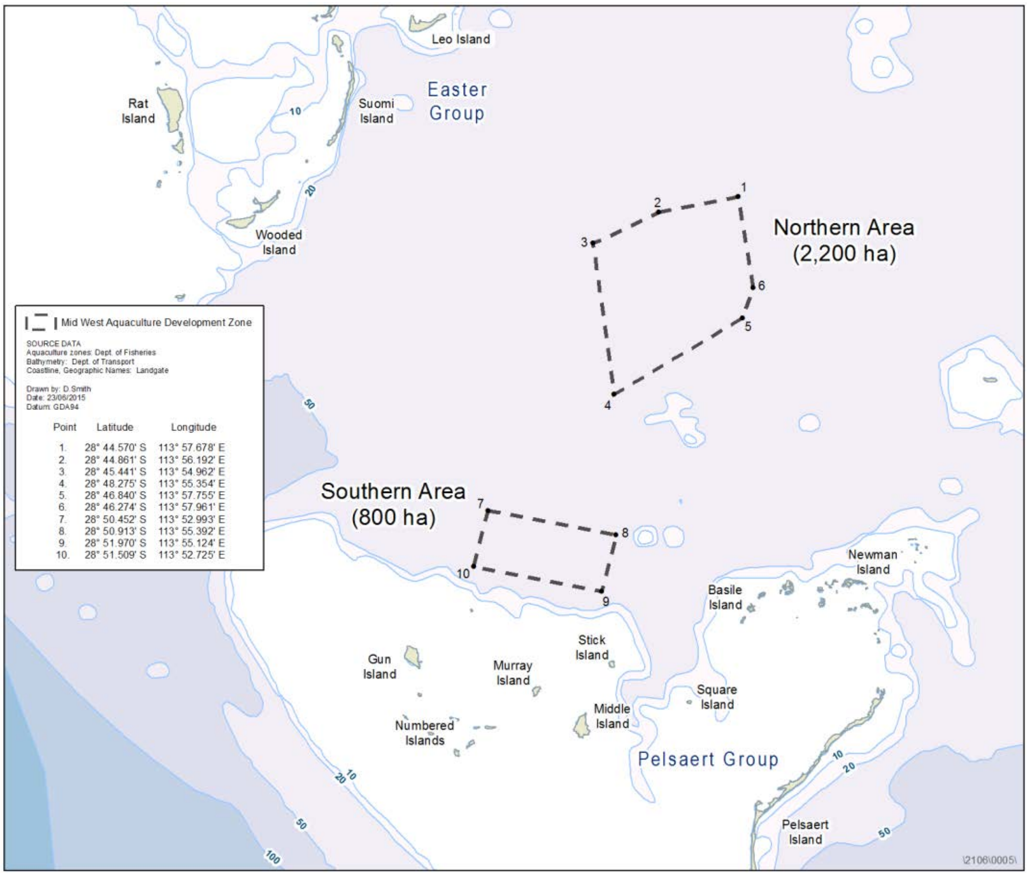

Figure 1: Proposed Mid West Aquaculture Development Zone

The Department will manage the proposed MWADZ within an integrated management framework that governs the workings of the zone. This will be similar to the framework developed for the Kimberley Aquaculture Development Zone. Its purpose is to:

- establish an overarching, integrated structure for managing the aquaculture activities within the zone;
- provide clear, efficient and effective processes for monitoring, evaluating and reporting;
- guide the development of marine finfish aquaculture;
- implement the monitoring and reporting processes; and
- ensure adaptive management occurs as part of a process of continuous improvement.

The zone management framework will incorporate:

- a zone Management Policy;
- an Environmental Monitoring and Management Plan (EMMP);
- a Ministerial Statement/Notice;
- Aquaculture Licences;
- Management and Environmental Monitoring Plans (MEMPs); and
- Aquaculture Leases.

The selection of suitable species for aquaculture in Western Australia is managed through the requirement for commercial aquaculture operators to obtain an aquaculture licence which is assessed with regard to the Department's Translocation Policy. The translocation of live fish into or within Western Australia, including those associated with aquaculture, can result in introduction and establishment of significant pest fish and pathogens. The introduction of these pest fish or pathogens into an area with a different disease status, or containing distinct native fish populations, can create significant economic, social, environmental and biological costs to Western Australia. The primary potential biosecurity risks associated with translocating fish into the state for marine aquaculture purposes include; disease transfer (to wild populations or cultured stocks), escapes and potential impacts on genetic diversity of native species, and the introduction of marine pests.

Likely suitable fish species to be cultured in the zone, based on existing commercial aquaculture interest, their suitability for aquaculture in Western Australia and/or ability to meet Departmental licensing and biosecurity requirements (e.g. being native species and suited to feeding with a formulated pathogen-free diet). They include the following species:

- Yellow tail kingfish (*Serioloa lalandi*)
- Mulloway (*Argyrosomus japonicus*)
- Dolphin fish (*Coryphaena hippurus*)
- Pink Snapper (*Pagrus auratus*)
- Cobia (*Rachycentron canadus*)

Based on this context, the current threat identification, hazard pathway analysis and risk assessment was conducted to identify and assess the potential biosecurity impacts of finfish aquaculture of these species associated with establishment and operation of the MWADZ on the sustainability of ecosystems, and their dependent fisheries. Both the inherent risk (risk before application of management controls) coupled to the residual risk (following application of proposed management controls) was assessed in order to determine the nature and level of management controls required to bring the cumulative risks around sea-cage culture of finfish in the MWADZ to an acceptable level.

The assessment is generic in nature but has focused on yellow tail kingfish as a case study for aquaculture based on the following rationale:

- Yellow tail kingfish (YTK) is a likely candidate for consideration for culture in the Mid West of Western Australia, given the development of previous and current R&D projects based on this species.
- Disease risks of YTK are relatively well understood, given the development of a significant YTK industry and technical capacity elsewhere in Australia.
- Previous research projects have focused on disease risks associated with YTK [FRDC 2003/216 Detection and management of health issues in yellowtail kingfish (YTK, *Seriola lalandi*) - the foundation for a health program for Australian finfish aquaculture].
- An assessment of biosecurity risk based around this species is likely to be directly applicable to other species proposed for culture in the MWADZ.
- The current assessment is high level and generic in nature given the level of uncertainty around any future proposed aquaculture project and its extent.

2. Threat Identification, Hazard Pathway Analysis and Risk Identification and Assessment Methodology

The identification of threats, analysis of hazard pathways and assessment of risks that may be generated by the proposal to develop an aquaculture zone in the Mid-West of Western Australia was completed using methods that are consistent with the international standards for risk management and assessment (ISO 31000, 2009; IEC/ISO; 2009; SA-HB89; 2012). The process for assessment included three components – threat identification, hazard pathway analysis, identification of overarching risks and their assessment, and overarching risk assessment (see Figure 2).

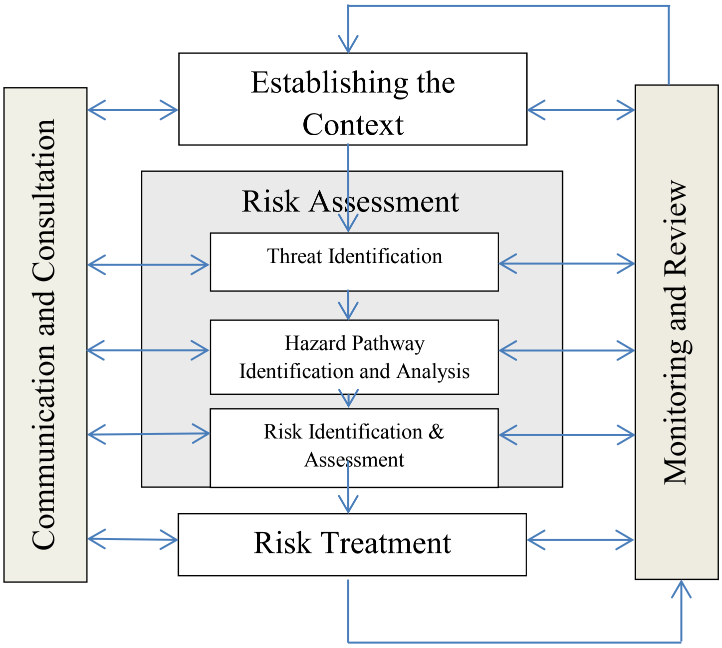

Figure 2: Description of risk assessment within the risk management process (modified from SA, 2012)

The specific protocols to complete each of these steps have been specifically tailored and extensively applied across a number of different aquatic management situations in Australia (Fletcher 2005, Fletcher et al. 2002, Jones and Fletcher 2012). Moreover this methodology has now been widely applied in many other locations in the world (Cochrane et al. 2008, FAO 2012, Fletcher 2008, Fletcher and Bianchi 2014) and is considered one of the 'must be read' methods supporting the implementation of the ecosystem approach (Cochrane 2013).

1.1 Threat Identification

Threat identification was based on review of the following previously conducted assessments and consideration of specific information associated with the MWADZ proposal:

- Marine Finfish Environmental Risk Assessment (de Jong & Tanner, FRDC Project 2003/223)
- National ESD Reporting Framework: The "How to" Guide for Aquaculture. Version 1.1 FRDC, Canberra, Australia (Fletcher et al., 2004)
- Finfish Aquaculture in Western Australia: Final ESD Risk Assessment Report for Sea-Cage and Land-Based Finfish Aquaculture (Vom Berg, 2008; Fisheries Management Paper No 229, Department of Fisheries, Western Australia)
- Finfish Aquaculture in Western Australia: Final ESD Management Report for Marine Finfish Aquaculture (Vom Berg 2009; 2008; Fisheries Management Paper No 233, Department of Fisheries, Western Australia)

1.2 Hazard Pathway Identification

The identification of hazard pathways associated with the key threats identified within the scope of the current assessment was accomplished using 'Failure Mode Analysis'. Failure Mode Analysis is an engineering technique used to identify critical steps or hazard pathways that can lead to systems failure or the realisation of threats. This process was conducted in order to assist with the orderly identification of issues relevant to assessment. The generated hazard pathways were used to assist with the identification of critical and often consecutive steps that may result in these threats that need to be considered as a result of undertaking aquaculture activity in the MWADZ.

1.3 Hazard Pathway Analysis

Individual hazards in each pathway were individually assessed with respect to their risk with respect to both inherent risk (i.e. baseline risk if no management measures aimed at mitigating the risk were in place) and residual risk (i.e. remaining risk once one or a number of proposed management controls have been effected). This process was undertaken to both understand the individual inherent hazards as well as to provide clarity as to the specific hazard or risk that a particular management activity is targeted at mitigating. This, in turn, assists in assessing whether management controls are adequate to manage risk of the entire pathway to an acceptable level and to identify any additional management actions required to address specific unacceptable risks.

The Consequence–Likelihood method was used to assess the level of the identified hazard pathway components associated with the key identified threats. The broad approach applied is a widely used method (SA, 2012) that is applied by many Western Australian Government agencies through WA RiskCover.

Undertaking hazard or risk analysis using the Consequence-Likelihood (C x L) methodology involves selecting the most appropriate combination of consequence (levels of impact; Table 1a) and the likelihood (levels of probability; Table 1b) of this consequence actually occurring (See Figure 3). The combination of these scores is then used to determine the risk rating (Table 1c; IEC/ISO, 2009, SA, 2012).

The International standards definition of risk is "*the effect of uncertainty on objectives*" (ISO, 2009). This definition of risk makes it clear that examining risk will inherently include the level of uncertainty generated from having incomplete information (SA, 2012). In the context of assessing the threats and risk associated with this proposal, the objectives to be achieved are the maintenance of sustainable ecosystems and their dependent fisheries, such that they are not significantly impacted by biosecurity impacts that may result from establishment of aquaculture operations in the MWADZ. Consequently, a "significant impact" that would result in a high risk would be one for which there was a reasonable likelihood that the number of individuals of an affected species would materially alter the longer-term sustainability of the ecosystem or its dependent commercial fisheries.

Table 1a: Levels of consequence for each of the objectives relevant to the assessment (modified from Fletcher, 2014)

Objective	Minor (1)	Moderate (2)	Major (3)	Severe (4)
Target Species	Measureable but minor levels of depletion but no impact on dynamics. Abundance range 100–70% unfished levels (B_0).	Target species Stock has been reduced to levels approaching that associated with B_{msy}. Abundance range <70% B_0 to >B_{msy}.	Stock has been reduced to levels below B_{msy} and close to where future recruitment may be affected. Abundance range B_{msy} to B_{rec}.	Significant stock size or range contraction has occurred with average recruitment levels clearly reduced (i.e. recruitment limited). Abundance range B_{rec}.
Ecosystem structure	Measurable minor changes to ecosystem structure, but no measurable change to function.	Maximum acceptable level of change in the ecosystem structure with no material change in function.	Ecosystem function now altered with some function or major components now missing and/or new species are prevalent.	Extreme change to structure and function. Complete species shifts in capture or prevalence in system.
Habitat	Measurable impacts very localised. Area directly affected well below maximum accepted.	Maximum acceptable level of impact to habitat with no long-term impacts on region-wide habitat dynamics.	Above acceptable level of loss/ impact with region-wide dynamics or related systems may begin to be impacted.	Level of habitat loss clearly generating region-wide effects on dynamics and related systems.

Table 1b: Levels of likelihood for each of the main risks analysed in this assessment (modified from Fletcher, 2015)

Level	Descriptor
Remote (1)	The consequence not heard of in these circumstances, but still plausible within the time frame (indicative probability 1-2%)
Unlikely (2)	The consequence is not expected to occur in the time frame but some evidence that it could occur under special circumstances (indicative probability of 3-9%)
Possible (3)	Evidence to suggest this consequence level may occur in some circumstances within the time frame (indicative probability of 10 to 39%)
Likely (4)	A particular consequence is expected to occur in the timeframe (indicative probability of 40 to 100%)

Table 1c: Hazard/Risk Analysis Matrix. The numbers in each cell indicate the Hazard/Risk Score, the colour indicates the Hazard/Risk Rankings (see Table 2)

		Likelihood Level			
Consequence level		Remote	Unlikely	Possible	Likely
		1	2	3	4
Minor	1	1	2	3	4
Moderate	2	2	4	6	8
Major	3	3	6	9	12
Severe	4	4	8	12	16

The residual consequences, likelihoods and resultant levels of hazard or risk are all dependent upon the effectiveness of the risk mitigation controls that are in place (SA, 2012). Determining the most appropriate combinations of consequence and likelihood scores therefore involves the collation and analysis of all information available on an issue. The best-practice technique for applying this method now makes use of all available lines of evidence for an issue and is effectively a risk-based variation of the 'weight of evidence' approach that has been adopted for many assessments (Linkov et al. 2009, Wise et al. 2007, Fletcher, 2014).

The hazard evaluation step uses the outcomes of the risk analysis to help make decisions about which hazards need treatment, the level of treatment and the priority for action. The different levels of management action can be determined by having the hazard or risk scores separated into different categories of hazard (Table 2).

Table 2: Risk Evaluation, Rankings and Outcomes [modified from Fletcher et al. (2002, 2005, 2015)]

Risk Level	**Hazard/Risk Score (C x L)**	**Description**	**Likely Management Response**
Negligible	0-2	Acceptable with no management actions or regular monitoring.	Brief justification
Low	3-4	Acceptable with no direct management actions and monitoring at specific intervals.	Full justification and periodic reports
Moderate	6-8	Acceptable with specific, direct management and regular monitoring.	Full regular performance report
High	9-16	Unacceptable unless additional management actions are undertaken. This may involve a recovery strategy with increased monitoring or even complete cessation of the activity.	Frequent and detailed performance reporting

Information Utilised

The key information used to generate the hazard and risk scores included:

- Broad knowledge of the proposal as provided in its application;
- A previous high level generic risk assessment conducted for marine finfish aquaculture in Australia (FRDC project 2003/223);
- An identified list of species likely to be under consideration for aquaculture in the MWADZ;
- A literature review of significant disease, genetic and marine pest issues associated with worldwide aquaculture with a focus on relevance to proposed culture species (with a focus on yellow tail kingfish); and
- Other relevant scientific studies and publications (see references).

1.4 Risk Identification and Assessment

Based on consideration of the identified broad areas of biosecurity threat and their constituent hazard pathways, overarching risks were identified associated with the MWADZ proposal. Assessment of these overarching risks was conducted as described for the hazard pathway assessment described above. Once again the inherent hazard or risk was first assessed in the absence of any management control measures, followed by assessment of residual risk following application of the identified management controls.

The assessment of economic impact on the aquaculture industry itself resulting from such risks was not considered within the scope of this assessment.

This set of assessments is focused upon biosecurity risks and as such does not specifically examine any wider ecological, social, economic or political risks surrounding the development of the MWADZ.

3. Threat Identification, Hazard Pathway Identification and Hazard Pathway Analysis

3.1 Threat Identification

Using a component-tree based approach (Fletcher et al., 2004) three broad areas of biosecurity-related threat were identified that were considered both most relevant to the MWADZ proposal and within the scope of the current assessment. These key threats were as follows:

- Potential impacts of disease on wild targeted fish species.
- Potential impact of escaped fish on wild targeted fish stocks (genetic and competitive).

- Potential impact of introduced marine pests associated with aquaculture on ecosystem sustainability.

3.2 Hazard Pathway Identification

Three separate hazard identification pathways were generated associated with the key threats identified (Figures 3a, b & c) to reflect identification of the pathways leading to:

- introduction of a significant pathogen or disease into an aquaculture facility that would first be required to result in subsequent impact to target fisheries sustainability (e.g. through spread of disease);
- aquaculture escapes and resultant potential significant detrimental genetic or competitive effects on wild fish populations, impacting targeted species sustainability; and
- potential introduction/spread and establishment of marine pest species, impacting ecosystem sustainability.

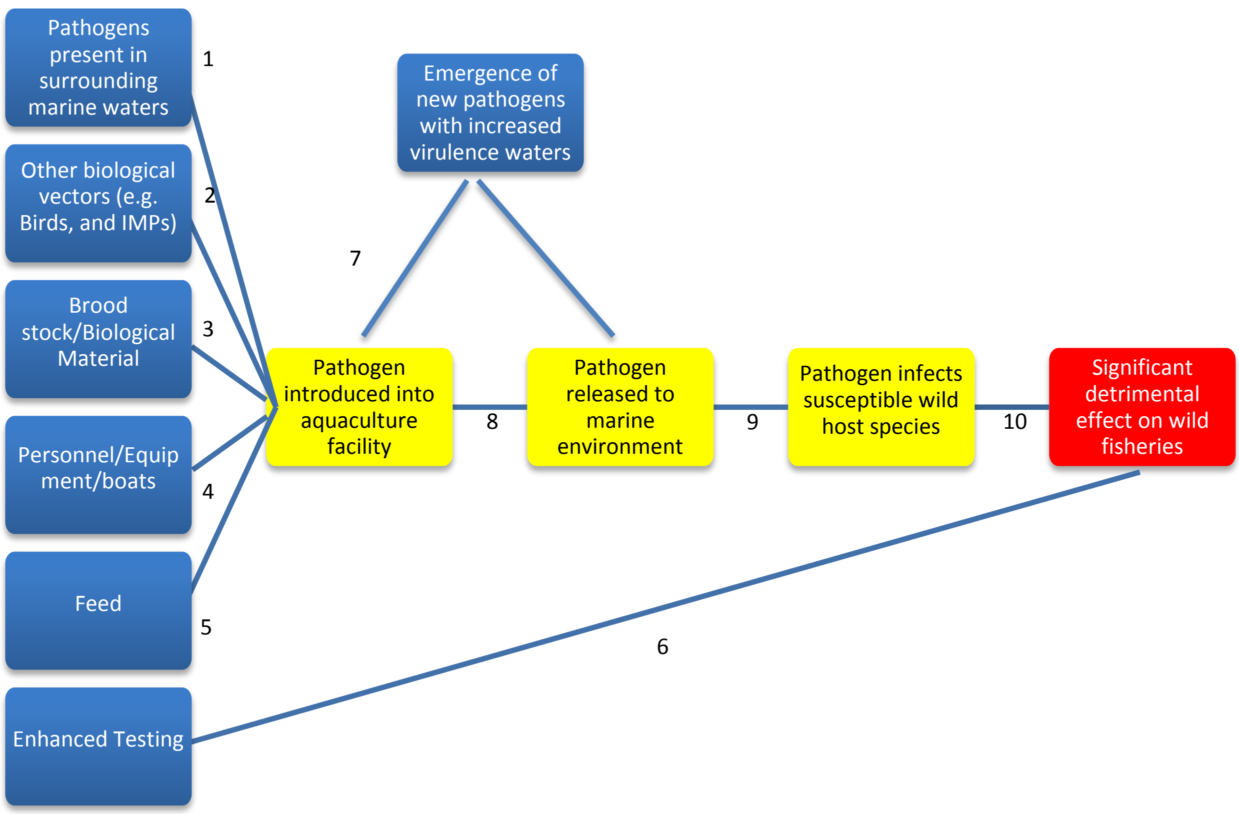

Figure 3a: Compendium map of potential pathways leading to a pathogen introduction and potential disease outbreak in an MWADZ aquaculture facility that may lead to potential spread of disease to wild fisheries and subsequent significant impact. *Numbers refer to hazard pathways reviewed in Table 3.*

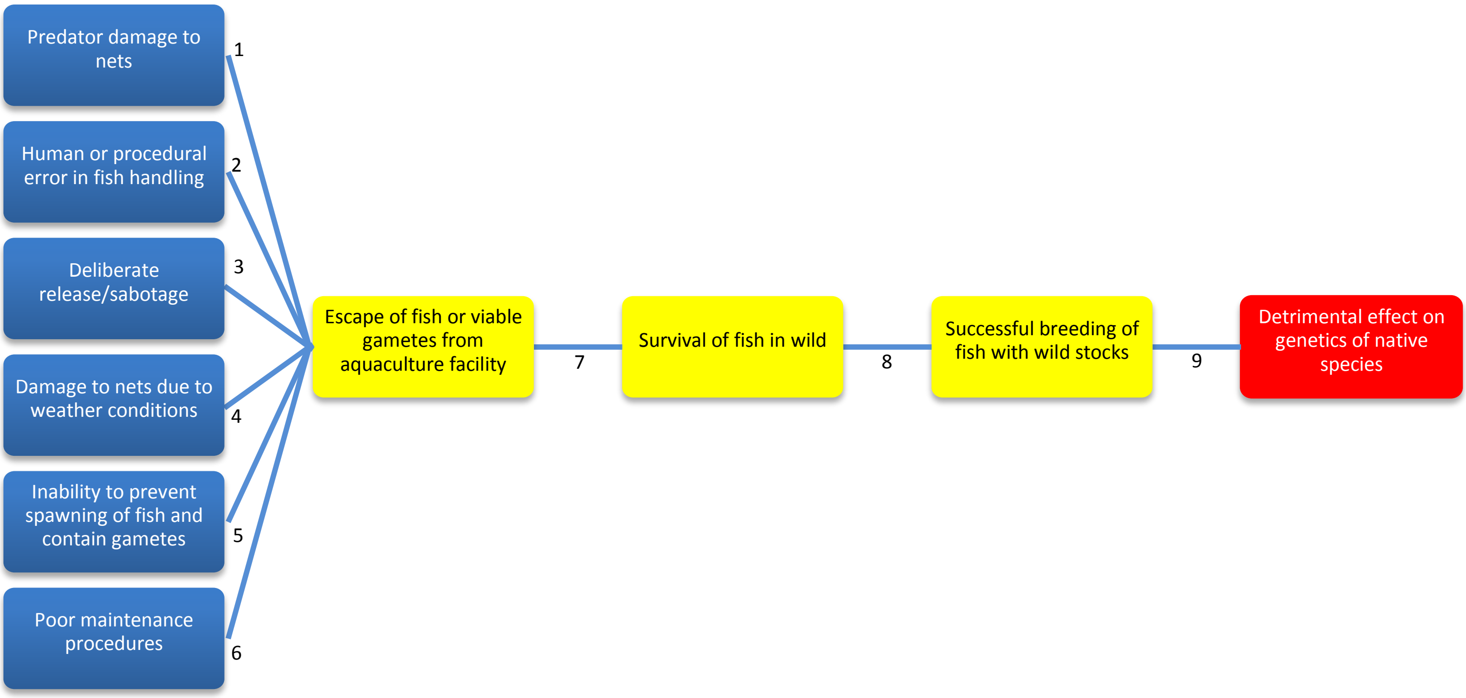

Figure 3b: Compendium map of potential pathways leading to potential negative genetic effects on wild fisheries arising from a potential MWADZ aquaculture facility that may lead to subsequent significant impact. *Numbers refer to hazard pathways reviewed in Table 3*

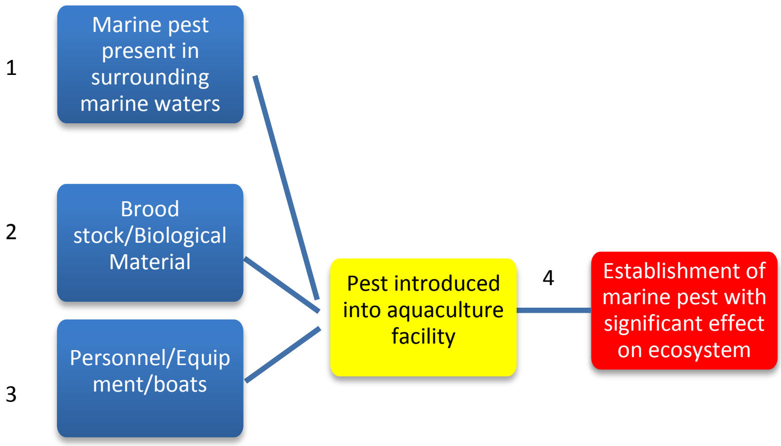

Figure 3c: Compendium map of potential pathways leading to marine-pest associated impacts arising from a potential MWADZ aquaculture facility that may lead to subsequent significant loss. *Numbers refer to hazard pathways reviewed in Table 3*

3.3 Hazard Pathway Analysis

For the purpose of hazard pathway analysis, hazards were considered based on biological consequence to target species, ecosystem and/or habitat as detailed in Table 1a. While significant biological consequence is generally a prerequisite that may lead to subsequent economic and social consequence (e.g. economic and reputational loss via loss of market access resulting from detection of pathogen which leads to trade issues and social amenity impact) these aspects are not evaluated in the current assessment.

2.3.1 Hazard Pathway 1: Pathogen introduction and disease development

2.3.1.1 Overview of potential impacts of disease originating from aquaculture on wild fish

The potential effect of disease on marine fisheries worldwide was recently assessed by Lafferty et al (2015), who identified 67 examples of disease that can impact commercial species of which 49% affect marine finfish. Many documented examples exist where marine sea-cage cultured fish, that may be produced under controlled hatchery conditions, are affected by disease likely introduced from the surrounding marine environment (e.g. Nylund et al, 2003, Snow et al, 2004, Snow et al, 2010). This is perhaps not surprising, given the nature of open sea-cage based aquaculture and the level of potential pathogens demonstrated to be naturally present in coastal sea water (Suttle, 2005). The majority of potential pathogens of fish may be relatively benign in wild fish where co-evolution and a naturally low abundance of potential hosts has favoured development of a life cycle that does not cause death of a host that might otherwise ultimately result in extinction of that pathogen.

Aquaculture, however, presents a different opportunity and set of selective pressures that favour more rapid evolution of pathogens and development of a life cycle that is not constrained by host abundance (Einer-Jensen et al, 2004). Indeed, many examples exist of the emergence of new pathogenic strains of viruses that are naturally present in wild fish but have been responsible for significant mortality in aquaculture (e.g. Nylund et al, 2003, Snow et al, 2004, Snow et al, 2010). The potential re-export of large quantities of potentially modified pathogens into the environment remains a key concern associated with marine cage-based aquaculture, though the impact of disease export on wild fisheries remains controversial since there are few quantitative data demonstrating that wild species near farms suffer more from infectious diseases than those in other areas (Lafferty et al, 2015).

This problem is exacerbated in part due to the difficulties in identifying and studying disease epizootics in wild fish where sick fish may be hard to identify and a decreased fitness likely renders them at increased risk of predation.

In addition to the risk of new emerging pathogens associated with aquaculture practices, significant disease risks are also associated with translocation of fish for aquaculture which may expose previously naive fish to an exotic range of new pathogens against which they may have limited natural immunity. The introduction of VHSV in the Great Lakes region of North America appears to be an example of the apparent translocation of a previously exotic virus to a new environment. This appears to have resulted in widespread and non-specific fish kill events in wild fish, though the exact source of origin of the virus remains unclear (Kim & Faisal, 2011).

2.3.1.2 Hazard analysis: Pathogen introduction and disease development

The hazard pathway components identified in the compendium map detailed in Figure 3a were individually analysed with respect to both the inherent hazard (baseline hazard if no management measures aimed at mitigating the hazard were in place) and their residual hazard (remaining hazard once one or more of the proposed management controls have been effected) as indicated in Table 3a. Prior to conducting this exercise, a review of relevant literature documenting pathogens that are known to affect the range of species identified for the potential development of aquaculture in the MWADZ was conducted, with a focus on yellow tail kingfish (YTK) as a case study. Consequence to target species was specifically considered as the primary likely consequence in developing this assessment based on a worst-case scenario model using relevant examples applicable to the culture of the proposed species (i.e. YTK).

Table 3a: Assessment of hazards identified in Figure 3a *Hazards were individually analysed with respect to both the inherent hazard (baseline hazard if no management measures aimed at mitigating the hazard were in place) and their residual hazard (remaining hazard once one or a number of the proposed management controls have been implemented).*

Hazard	Inherent Hazard Assuming No Management Controls	Justification	Residual Hazard Following Implementation of Management Controls	Justification and Identified Management Controls
1. Pathogens present in surrounding marine waters	**Likelihood: Likely (4)** **Consequence: Moderate (2)** **Hazard score: (8)** **Risk Level: Moderate**	**Likelihood** While every effort can be made to develop juvenile fish of a high health status in hatcheries, open sea-cage aquaculture (as proposed for the MWADZ) exposes cultured species during their grow-out phase to a range of potential pathogens that are present in the marine environment and are horizontally transmitted via water (reviewed by Lafferty et al 2015). Interestingly, studies have shown that in the order of 10^7 viral particles may be present in every millilitre of coastal seawater (Suttle et al, 2005). An additional risk factor is the interaction of cultured fish species with wild fish. This interaction may include both their wild conspecific counterparts, which would be expected to share a similar profile of potential susceptibility to pathogens and other local species. Numerous studies, worldwide, have documented examples of the likely introduction of significant disease-causing pathogens into marine aquaculture sea-cages from surrounding waters based on presumed horizontal transmission (e.g.	**Likelihood: Likely (4)** **Consequence: Minor (1)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** Likelihood remains unchanged at **Likely (4)** due to inability to control the presence of and introduction of pathogens into sea-based aquaculture facilities. **Consequence** Consequence may be reduced to **Minor (1)** with respect to wild fish stocks based on the implementation of management controls including the following: • Management and industry measures to promote high levels of fish welfare and husbandry conditions in aquaculture; Management policy only permitting locally-sourced and present species for aquaculture in the zone. This ensures suitability for culture under proposed conditions (local adaptation and welfare) in addition to reducing consequence of introduction of exotic diseases;

		infectious salmon anaemia virus, viral haemorrhagic septicemia virus, salmonid alpha virus; Nylund et al, 2003, Snow et al, 2004, Snow et al, 2010). Such introductions have resulted from pathogens shown to be naturally present in local waters that, prior to their emergence in marine aquaculture, were considered to be exotic. In the case of seriolids, which are a species under consideration for culture in the MWADZ, wild fish are believed to be the primary reservoir of parasitic infection for fish cultured in sea-cages (Diggles & Hutson 2005). Significant knowledge of the range of pathogens affecting kingfish aquaculture in Australia has developed alongside an emerging industry (for review see Diggles & Hutson 2005). A total of 41 plausible disease hazards to YTK health were compiled by Shepherd et al (2003) who further evaluated the risk of these hazards associated with YTK aquaculture. The likelihood of introduction of these pathogens into sea-based aquaculture facilities is assessed as **Likely (4)** based on the documented presence and association of many of them with YTK aquaculture to date in Australia and the general difficulty in preventing introduction of pathogens known to be abundant in the environment into open sea-cage aquaculture systems. **Consequence** Overall, Red Sea bream-like iridovirus (RSIV) has been previously identified as one of the highest risk hazards to YTK aquaculture (Shepherd 2003). This pathogen is also considered of particular potential consequence to wild fisheries based on its non-specific host range and pathogenicity.		• Siting of proposed aquaculture farms away from the habitat of susceptible hosts; • Establishment of zones based on effective disease control principles; and • Development of emergency response plans and capability (government and industry) to contain disease outbreaks and limit spread of pathogens to wild fish.

		At the facility level, the consequence of introduction of pathogen such as RSIV would be dependent on a range of husbandry factors and may not necessarily result in a disease outbreak and significant transmission to wild fisheries. The interactions between the susceptible host, the virulent pathogen, and the favorable environmental conditions required for a disease to develop are complex and difficult to predict for both cultured and wild fish. However, numerous examples of significant losses to the aquaculture industry are known, with potentially stressful conditions associated with aquaculture known to be a contributing factor. While consequence to the aquaculture sector may be severe [the focus of the previous risk assessments e.g. Shepherd (2003)], consequence to the overarching objective of this assessment (that disease would impact the longer-term sustainability of wild fisheries target species) is considered to be **Moderate (2)**. This is based on the fact that, while there have been no documented cases of the direct transfer of native or exotic diseases from sea-cage cultured fish to wild stock in Australia (de Jong & Tanner 2004), examples do exist worldwide as recently reviewed by Lafferty et al (2015). Lafferty considered that of 57 evaluated infectious agents found in aquaculture, 45 might be exported to wild species. Whether pathogens potentially amplified in aquaculture impact wild fisheries depends on the quantity, location, and nature of the exported infectious agent combined with host susceptibility, resistance and tolerance (Lafferty et al, 2005). Fortunately, wild stocks are often adapted to their infectious agents as a result of co-evolution and		

		the population-level consequences of increased exposure should be mild (Jackson et al 2013). Consequence is considered moderate based on a precautionary principle and takes into account potential of exotic disease introduction where such inherent disease resilience in wild stocks is less likely.		
2. Other biological vectors (e.g. birds)	**Likelihood: Possible (3)** **Consequence: Moderate (2)** **Hazard score: (6)** **Risk level: Moderate**	**Likelihood** Interaction with native fish is considered above due to the fact that horizontal transfer from fish generally occurs via the water column. Birds have been implicated in the spread of some pathogens (e.g. infectious pancreatic necrosis virus of Atlantic salmon; McAllister and Owens, 1992) and their involvement in introduction of pathogens into a sea-cage facility is thus assessed as **Possible (3)** in the absence of appropriate management controls. **Consequence** Consequence (as per section 1 of this table) is assessed as **Moderate (2)**.	**Likelihood: Unlikely (2)** **Consequence: Minor (1)** **Hazard score: (2)** **Risk level: Negligible**	**Likelihood** Likelihood can be reduced to **Unlikely (2)** based on implementation of a range of management measures specifically designed to exclude predators including birds. **Consequence** Consequence may be reduced to **Minor (1)** based on the rationale described above.

3. Brood stock/ biological material	**Likelihood: Likely (4)** **Consequence: Moderate (2)** **Hazard score: (8)** **Risk level: Moderate**	**Likelihood** Brood stock or hatchery-reared juveniles are a source of potential introduction of pathogen into a sea-cage aquaculture facility. Pathogen transfer can occur via vertical transmission from parental brood stock (which may be wild-sourced) or via horizontal transmission from within a hatchery. In the absence of management controls and basic biosecurity measures, the transfer of potentially significant pathogen is considered **Likely (4)** in association with the translocation of biological material. **Consequence** Consequence (as per sections 1 & 2 of this table) is assessed as **Moderate (2)**.	**Likelihood: Unlikely (2)** **Consequence: Minor (1)** **Hazard score: (2)** **Risk level: Negligible**	**Likelihood** Likelihood may be reduced to **Unlikely (2)** based on consideration of the following management measures: • The use of specific pathogen-free brood stock and exclusion of known significant pathogens through a program of sensitive brood stock screening conducted by an appropriate laboratory; • A brood stock development program aimed at "closing" the genetic pool as soon as practical to reduce the threat of introduction of new pathogens; • Development of and compliance with approved biosecurity management arrangements and best-husbandry practice; and • Health testing of stock prior to translocation to a sea-cage environment. **Consequence** Potential consequence may be reduced to **Minor (1)** based on the management controls described in section 1 of this table.

4.Personnel/ equipment/boats	**Likelihood: Possible (3)** **Consequence: Moderate (2)** **Hazard score: (6)** **Risk level: Moderate**	**Likelihood** For this scenario, the pathogen must first be present in the local environment or on imported equipment. This is considered **Possible (3)** if equipment or infrastructure is shared between facilities and/or imported for re-use. Comprehensive epidemiological studies based on other significant pathogens of aquaculture (e.g. infectious salmon anaemia virus; Jarp & Karlsen, 1997) have documented the role of personnel and equipment in spreading infection between marine aquaculture sites (e.g. divers, boats, equipment, etc.). Likelihood in the absence of management control or industry best-practice guidelines is assessed as **Possible (3)**. **Consequence** Consequence (as per sections 1, 2 & 3 of this table) is assessed as **Moderate (2)**.	**Likelihood: Unlikely (2)** **Consequence: Minor (1)** **Hazard score: (2)** **Risk level: Negligible**	**Likelihood** Likelihood may be reduced to **Unlikely (2)** based on the implementation of management controls including: • Development of and compliance with approved biosecurity management arrangements and best-husbandry practice. • Adequate site and individual operator separation. Dedicated infrastructure not shared with other high-risk users (e.g. processing plants, other aquaculture enterprises, wild-capture fisheries enterprises). • Adequate exclusion zones around aquaculture facilities • Development of an industry code-of-practice focused on biosecurity. • Consolidation of industry and avoidance of existence of multiple independent operators in close proximity to one another. **Consequence** Consequence may be reduced to **Minor (1)** based on the rationale described above.

5. Feed	**Likelihood: Likely (4)** **Consequence: Moderate (2)** **Hazard score: (8)** **Risk level: Moderate**	**Likelihood** Imported feed has been identified as one of the more likely sources for potential introduction of exotic viruses (Baldock 1999). Marine finfish aquaculture may be dependent on high-quality, brood stock-conditioning feeds, especially in the development stages of new species aquaculture. In the absence of any control on feed sourcing, likelihood of disease introduction is considered **Likely (4)**. Feed has been previously implicated in the introduction of disease to aquaculture (VHS in turbot; Munro, 1996) and also in the introduction of a virus that caused a disease epidemic in wild pilchards in Australia (Jones et al 1997). **Consequence** Consequence (as per sections 1, 2, 3 & 4 of this table) is assessed as **Moderate (2)**.	**Likelihood: Unlikely (2)** **Consequence: Minor (1)** **Hazard score: (2)** **Risk level: Negligible**	**Likelihood** Likelihood may be reduced to **Unlikely (2)** based on the implementation of management controls including the following: • Feed must be AQIS-approved or produce by a manufacturer that complies with ISO 9001:2008. • Commercial pelleted-feed only allowed at sea-cage facilities. • Feed other than commercial pellets must be frozen to kill macro-parasites. • Fish-based feed must only be used within bio-secure hatchery facilities. • Fish for grow-out required to be monitored for mortality and health screened prior to translocation to sea-based grow-out sites. • Development of and compliance with approved biosecurity management arrangements and best-husbandry practice. **Consequence** Consequence may be reduced to **Minor (1)** based on the rationale described above.

6. Enhanced testing	**Likelihood: Likely (4)** **Consequence: Minor (1)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** It is **Likely (4)** that an expanding aquaculture industry associated with an enhanced testing regime results in an increased knowledge with respect to the range of potential diseases affecting a species or present in a geographic range. This has proven the case for seriolids in Australia, where there has been a considerable increase in knowledge with respect to their potential health issues (Diggles and Hutson 2005). **Consequence** Increased testing leads to an improved understanding of health conditions potentially affecting wild fish and wider ecosystems. This may be of benefit in understanding impacts on wild stocks in relation to changing environmental pressures. Increased testing is also likely to reduce potential consequence to wild fisheries by reducing risks of significant disease occurrence and subsequent spread to wild fish. If significant pathogen was detected through extensive brood stock screening, animals would be destroyed while in quarantine and not enter the production cycle. Thus, potentially limiting consequence. Australia enjoys a high biosecurity status and reputation, being free from a range of significant pathogens affecting finfish worldwide. Consequence is assessed as **Minor (1)**.	**Likelihood: Likely (4)** **Consequence: Minor (1)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** Likelihood remains unchanged at **Likely (4)** based on the possibility that previously unrecognised health issues may be identified based on increased levels of health surveillance. **Consequence** Consequence of enhanced testing having a detrimental effect can be further reduced [though remains **Minor (1)**] through implementation of management controls aimed at rapid communication and containment of disease outbreaks based on results of increased diagnostic surveillance. Examples of management controls include: • Development of a controlled communication plan to limit negative effect. • Research to back up understanding consequence of the finding (e.g. is it likely that the pathogen was already present in Western Australian waters?). • Development of and compliance with approved biosecurity management arrangements and best-husbandry practice. • Regular compliance visits and

		However, while out of scope of the current hazard evaluation focused on sustainability impacts to target species, the highlighting of a detrimental health issue (or disease previously considered to be exotic) associated with a species could have significant negative consequence to trade and to the wild fisheries sector.		record auditing. • Potential to routinely test selected animals from the farm (targeted surveillance). • Potential to improve passive surveillance via introduction of a compulsory real-time mechanism for reporting of mortalities to the regulating body.
7. Emergence of significant new pathogens with increased virulence with an aquaculture facility	**Likelihood: Possible (3)** **Consequence: Moderate (2)** **Hazard score: (6)** **Risk level: Moderate**	**Likelihood** Introduction and maintenance of pathogens in intensive aquaculture could lead to the **Possible (3)** emergence of previously unknown or emerging disease. Examples of where this is thought to have occurred include Viral Haemorrhagic Septicaemia Virus (VHSV) (Einer-Jensen et al., 2004) and Infectious Salmon Anaemia Virus (ISAV) (Godoy et al., 2013). The potential stressors associated with commercial aquaculture that exert selection pressures on pathogens that drives their evolution (especially in the case of rapidly evolving organisms such as RNA viruses) are also well understood and include factors such as high stocking densities, stress, temperature and availability of susceptible hosts. **Consequence** Consequence (as per sections 1, 2, 3, 4 & 5 of this table) is assessed as **Moderate (2)**.	**Likelihood: Unlikely (2)** **Consequence: Minor (1)** **Hazard score: (2)** **Risk level: Negligible**	**Likelihood** Likelihood can be reduced to **Unlikely (2)** based on the following management controls: • Development and compliance with approved biosecurity management arrangements and best-husbandry practice. • Potential to implement measures to ensure fallowing as part of the production cycle to ensure pathogens are not maintained continuously within a facility or within an area. • Potential to insist on management controls to limit the pressure from pathogens (e.g. regular cleaning and exchange of nets as required in the South Australian YTK industry).

		The adaptation of pathogens within aquaculture and their subsequent release poses a relatively unknown consequence to wild fish stocks which may be less adapted to be able to overcome new variants of pathogen.		• Establishment of zones based on effective pathogen control principles. **Consequence** Consequence may be reduced to **Minor (1)** based on the rationale described above.
8-9. Pathogen is released to the marine environment and infects susceptible species	**Likelihood: Likely (4)** **Consequence: Moderate (2)** **Hazard score: (8)** **Risk level: Moderate**	**Likelihood** Pathogens will **Likely (4)** be released to the wider environment if they are present in a sea-cage aquaculture site due to the lack of ability to contain it. Some documented examples exist that suggest evidence of infection of wild fish with pathogens thought to have originated from aquaculture operations (Krkosek et al., 2006). Often these are associated with wild fish that enter and live in sea-cages alongside the cultured target species. **Consequence** Consequence (as per sections 1, 2, 3, 4, 5 & 7 of this table) is assessed as **Moderate (2)**. Consequence of infection alone is considered moderate in the potential case of a disease previously considered exotic to Australia or in the case of a modified variant of pathogen that might evolve in association with aquaculture for reasons outlined in section 1. This is especially the case where significant infection levels or emerging disease issues are	**Likelihood: Likely (4)** **Consequence: Minor (1)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** Likelihood remains unchanged at **Likely (4)** due to lack of ability to completely contain potential spread of infection. The level of spread can, however, be reduced - leading to potentially lower consequence. **Consequence** Consequence (level of transfer of pathogen) can be reduced to **Minor (1)** through implementation of management measures aimed at early detection and subsequent fallowing of farms. Examples of management measures include: • Development of and compliance with approved biosecurity management arrangements and best-husbandry practice. • All measures taken to ensure early detection of significant pathogen (e.g. passive and targeted surveillance).

		left unchecked without treatment or containment measures.		• Regulator to ensure clear process for timely implementation of containment measures in the event of detection of significant pathogen. • Implementation of appropriate and timely disease treatments regime for endemic diseases. • Consideration of vaccination as a strategy to reduce effects of opportunistic or ubiquitous pathogens.
10. Pathogen results in significant impact to wild fish/ecosystems	**Likelihood: Possible (3)** **Consequence: Severe (4)** **Hazard score: (12)** **Risk level: High**	**Likelihood** In the absence of management controls, likelihood is assessed as **Possible (3)**. Susceptibility of a species (e.g. YTK) to a disease in aquaculture that results in disease suggests it likely that wild stocks of the same species in the region might also be susceptible to the pathogen in question. Likelihood will depend on a range of factors including the pathogen shedding rate and survival outside the host, requirement for intermediate hosts, water currents and dilution effects, and proximity to and density of susceptible species. There have been few examples worldwide of pathogens leading to measurable losses in wild stocks despite their abundance in significant finfish aquaculture industries.	**Likelihood: Unlikely (2)** **Consequence Severe (4)** **Hazard score: (8)** **Risk level: Moderate**	**Likelihood** Likelihood may be reduced to **Unlikely (2)** based on the introduction of management measures aimed at reducing risk of disease emergence and ensuring rapid containment of emerging disease as described above. **Consequence** Consequence remains unchanged at **Severe (4)**.

		However, it should be noted that impacts of disease on wild stocks may be difficult to detect since compromised animals are often predated upon and obvious large fish kills due to disease are rare events. An exception is a mass mortality event that occurred in pilchards in South and Western Australia. The exact origins of this virus were never fully determined, but were considered likely to have been associated with practices connected to the tuna aquaculture industry (Jones et al., 1997). **Consequence** Consequence of this hazard is assessed as **Severe (4)** based on a scenario where significant impacts to the sustainability of targeted wild species occur.		

2.3.2 Hazard Pathway 2: Potential negative effects of aquaculture escapees on wild fisheries

2.3.2.1 Overview of potential impacts of aquaculture escapees on wild fish

Escapes are an almost inevitable occurrence in association with marine sea-cage aquaculture and occur largely as a result of technical and operational failures of fish farming equipment (Jensen et al 2010). They may be ongoing at a low level or episodic and significant based on, for example, extreme weather events. The size and extent of escapes can be difficult to measure and can not only occur as a result of juvenile or adult fish escaping nets but can also result from the release of viable larvae following spawning of aquacultured fish. Common causes of escapes in Norwegian aquaculture (reviewed by Jensen et al., 2010) include progressive mooring failure, breakdown and sinking of steel cages and abrasion and tearing of nets with the latter category accounting for two thirds of reported escape incidents. In terms of volumes, large-scale escape events constituted only 19% of incidents but accounted for 91% of escaped fish, indicating that a management focus on this category of escapes might have the greatest effect in diminishing consequence of escapes (Jensen et al., 2010). The impact of escapes can include negative genetic effects on wild populations through interbreeding and a potentially high relative contribution of aquaculture fish to the wild breeding stock in local areas following significant levels of escapes. Other impacts can include competition between aquaculture fish with wild fish for resources (e.g. food/habitat). Worldwide, this issue has been the subject of significant study for Atlantic salmon, based on the significant worldwide culture of this species, coupled to conservation concerns surrounding declining populations in the wild. In addition, Atlantic salmon are at a relative advanced level of domestication (often associated with reduced or altered genetic diversity) and wild stocks are composed of distinct populations that are often genetically identifiable at the local catchment level.

2.3.2.2 Hazard Analysis: Potential negative effects of aquaculture escapees on wild fisheries

The hazard pathway components identified in the compendium map detailed in Figure 3b were individually analysed with respect to both the inherent hazard (baseline hazard if no management measures aimed at mitigating the hazard were in place) and their residual hazard (remaining hazard once one or more of the proposed management controls have been effected) as indicated in Table 3b. Prior to conducting this exercise a review of potential negative genetic and competitive effects of aquaculture escapees on wild fisheries from the potential development of aquaculture in the MWADZ was conducted, with a focus on yellowtail kingfish (YTK) as a case study. Consequence to target species was specifically considered in developing this assessment based on a worst-case scenario model using relevant examples applicable to the culture of the proposed species, with a focus on YTK.

Table 3b: Assessment of hazards identified in Figure 3b *Hazards were individually analysed with respect to both the inherent hazard (baseline hazard if no management measures aimed at mitigating the hazard were in place) and their residual hazard (remaining hazard once one or a number of the proposed management controls have been implemented).*

Hazard	Inherent Hazard Assuming No Management Controls	Justification	Residual Hazard Following Implementation of Management Controls	Justification and Identified Management Controls
1. Escape of fish associated with sea cage operations	**Likelihood: Likely (4)** **Consequence: Moderate (2)** **Hazard score: (8)** **Risk level: Moderate**	**Likelihood** The issue of escapes has undoubtedly been most widely studied in the North Atlantic where in Norway alone, 3.93 million Atlantic salmon, 0.98 million rainbow trout and 1.05 million cod escaped between 2001 and 2009 (Jensen et al 2010). A review of the Department of Primary Industry Finfish escape register (http://www.pir.sa.gov.au/aquaculture/monitoring_and_assessment/register_-_finfish_escape) illustrates the fact that escapes are an ongoing and anticipated hazard also associated with YTK finfish aquaculture in Australia. On this basis escapes from sea-cages within the MWADZ are considered **Likely (4)**. Escapes are largely caused by technical and operational failures of fish farming equipment and may result from low level “leakage” and through significant episodic events such as storms (Naylor et al 2005). In general, causes of escapes can include predator damage (e.g. caused by birds or sharks), human error, deliberate sabotage, poor selection of or maintenance of equipment, and damage caused by weather.	**Likelihood: Likely (4)** **Consequence: Minor (1)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** Remains unchanged at **Likely (4)** due to the fact that a certain level of escapes associated with marine aquaculture probably cannot be avoided (Waples et al., 2012). **Consequence** May be reduced to **Minor (1)** based on the implementation of policy controls aimed at limiting the frequency and extent of escape events as advocated in a review by Jensen et al. (2010) which include the following: • Mandatory reporting of all escape events. • Establishment of a mechanism to analyse and learn from mandatory reporting. • Conduct mandatory, rapid technical assessments to determine causes of serious

		Consequence Consequence of escapes is ultimately dependent on the volume of escaped fish coupled to the ability of those fish to survive in the wild, compete for resources, spread disease and/or contribute their genes to future generations. This hazard considers consequence from a perspective of volume of fish released, since other aspects are dealt with separately elsewhere. In the absence of adequate management controls the consequence of escapes will undoubtedly be increased through the enhanced opportunity of increased volumes of fish to be released to the wider environment. The present level of escapees worldwide is regarded as a problem for the future sustainability of sea-cage aquaculture (Naylor et al., 2005). The ecological and genetic impacts of escapees are dependent on a wide range of poorly understood and species-specific factors but may be exacerbated by the numerical imbalances between caged compared to wild populations (e.g. in Norway 0.5-1 million fish return to rivers each year versus 325 million fish held in sea-cages at any one time (Jensen et al 2010). The only practical way to limit the potential impact of escaped aquaculture fish is to implement measures to reduce the likelihood of escape events occurring. In the absence of such measures, the likelihood of escapes is high and the consequence (in terms of volume of escapes) is deemed **Moderate (2)**.		escapes. • Introduce a technical standard for sea-cage aquaculture equipment coupled to an independent mechanism to enforce the standard. • Ensure mandatory training of fish farm staff in escape-critical operations and techniques. Correlative evidence has indicated that after implementation of a technical standard for sea-cage farms in Norway (NS9415) took effect in 2004, the total number of escaped salmon declined from >600,000 fish per year (2001-2006) to <200,000 fish per year (2007-2009) despite the total number of fish held in sea-cages increasing by 44% during this period (Jensen et al 2010). Such an approach did not lead to reduced escapes of cod however, suggesting that other measures such as improved netting materials may be warranted. Other methods to reduce frequency of escape events include siting of sea-cages in areas with appropriate shelter from inclement weather, the maintenance of good husbandry procedures, adequate staff training, installation of anti-predator devices and ensuring security of sites.

2. Escape through spawning	**Likelihood: Likely (4)** **Consequence: Moderate (2)** **Hazard score: (8)** **Risk level: Moderate**	**Likelihood** Escape through spawning has been documented to occur for pelagic spawning species such as Atlantic cod (Jorstad et al 2008). Species such as YTK have been shown to mature and spawn at 13 months of age under favourable conditions (Kolkovski et al., 2004). Since a single female may produce 0.5-2 million eggs per spawning event, the capacity for escape of fertilised eggs from open sea-cages is high. This hazard is thus deemed **Likely (4)** in the absence of measures to limit potential release of viable gametes and larvae. **Consequence** Consequence is again influenced by a wide variety of factors that influence the subsequent development and fate of fertilised eggs and larvae. Consequence is rated as **Moderate (2)** based on the expectation that rearing of fish over a general 2-year production cycle is likely to lead to some maturation of fish (though this issue requires species-specific consideration) and thus potentially significant release of viable eggs. The fact that this occurs within the known range of native fish of the same species suggests that opportunity for future development of those eggs may be on a par with those of native fish. This may be especially so given the expected lack of domestication of stock that may be associated with emerging industries marine finfish industries in the MWADZ.	**Likelihood: Likely (4)** **Consequence: Moderate (2)** **Hazard score: (8)** **Risk level: Moderate**	**Likelihood** Likelihood remains unchanged at **Likely (4)**. Although mechanisms to inhibit escape by this method are being explored for some sectors, a practical and cost-effective method has yet to be developed and remains a research priority (Jensen 2010). **Consequence** Consequence remains unchanged at **Moderate (2)** given the level of uncertainty surrounding levels of spawning, survival and subsequent recruitment linked to cultured fish. In the proximity of an experimental cod farming sea-cage, 20-25% of cod larvae in plankton samples were determined by genetic analyses to have originated from 1000 farmed cod (Jorstad et al 2008). Previous recommendations have suggested that in the case of Atlantic salmon, intrusion rates should be kept below 5% to avoid substantial and definite genetic changes to wild populations (Hindar & Diserud., 2007).

3. Survival of fish in wild and competition for resources.	**Likelihood: Likely (4)** **Consequence: Minor (1)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** In the example cited above, 4-6% of juvenile cod caught in the area in the following year were offspring of experimentally-farmed cod (Jorstad et al 2008) suggesting the contribution of escaped larvae to wild stocks could be substantial (Jorstad et al 2008). This is obviously highly species and locational specific. Within a fish's native range, survival of larval fish from aquaculture (especially based on F1 generation) may be expected to be on a par with those of wild fish, given a suitable receiving environment. Escaping older fish may, however, fare less well due to conditioning associated with aquaculture. This hazard is thus deemed **Likely (4)**. **Consequence** The degree of competition for resources is likely to depend on numbers of escaped fish relative to numbers of fish of the same species and of other wild fish species. Again, in the case of Atlantic salmon, escapees have been shown to consume much the same diet as wild salmon in coastal oceanic waters (Hislop and Webb 1992, Jacobsen and Hansen 2001). In the case of YTK, tagging work has suggested the possibility of interaction between farmed and wild fish in the Spencer Gulf, South Australia. YTK are carnivorous (Henry and Gillanders 1999) and therefore escaped fish have potential to compete for food resources with other carnivorous species.	**Likelihood: Likely (4)** **Consequence: Minor (1)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** Remains unchanged at **Likely (4)** due to the inability to influence survival of fish in the wild. **Consequence** Remains unchanged at **Minor (1)** due to the relative inability to influence survival once escaped from aquaculture. That said, experience suggests that escaped YTK often reside near cages for days, which can facilitate their recapture (Zaluski 2003). While this is not a recommended strategy upon which to rely, appropriate emergency response protocols could reduce the consequence in the case of adult fish.

		However, there is no evidence that levels of non-fishing mortality in species such as YTK are currently density dependent; suggesting the consequence to stocks resulting from the competition for resources may be **Minor (1)**.		
4.Breeding of cultured fish with wild stocks	**Likelihood: Likely (4)** **Consequence: Moderate (2)** **Hazard score: (8)** **Risk level: Moderate**	**Likelihood** Successful spawning of escaped farmed salmon in rivers both within and outside their native range has been demonstrated (reviewed by Weir and Grant 2005). Given domestication, however, spawning success may be just 20-40% of that of wild salmon and even lower for males (1-24%; Fleming et al., 1996, 2000). Given the lack of domestication associated with other new aquaculture species considered for culture in Western Australia and the nature of their reproductive biology it seems likely that this potential spawning contribution to wild fish populations could be higher. Likelihood is thus assessed as **Likely (4)**. **Consequence** Again, consequence is largely dependent on the volume of escapes and thus potential of escapees to interfere with the breeding of wild stocks either directly or indirectly. It is assessed as **Moderate (2)** based on the potential for pelagic batch spawning to spawn in cages and escape as either juveniles or adults in areas known to be within the native range of the cultured species.	**Likelihood: Likely (4)** **Consequence: Minor (1)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** Likelihood remains unchanged at **Likely (4)** due to the very likely possibility of some aquaculture escapees interbreeding with wild fish. **Consequence** Maybe reduced to **Minor (1)** based on implementation of a range of measures described above aimed at reducing numbers of escapes, preventing their interaction with wild fish and/or promoting their recapture.

5.Detrimental genetic effects on wild populations	**Likelihood: Likely (4)** **Consequence: Moderate (2)** **Hazard score: (8)** **Risk level: Moderate**	**Likelihood** In 2007, a large EU-funded project sought to assess the genetic impact of aquaculture activities on native populations on a species by species basis (Svasand et al 2007). In the case of Atlantic salmon, the study concluded that escapes can have significant direct impacts on wild populations by reducing mean fitness. Modeling suggested the impact will depend on the magnitude and frequency of escapes. In the case of Atlantic cod, a pelagic batch-spawner (similar to species under consideration for culture in the MWADZ), less is known though studies are ongoing on possible gene interactions between wild and farmed cod. In the case of YTK, recent studies aimed at assessing the genetic population structure of this species across temperate Australia and New Zealand indicated that Western Australian *Seriola lalandi* was genetically distinct from those sampled from other localities (Miller et al., 2011). Based on a precautionary approach, the likelihood of escapes having a detrimental effect (especially those of a different origin to those naturally found in Western Australia) on wild stocks of the same species is deemed **Likely (4)**, especially in the case with pelagic spawners where maturation and spawning may be very difficult to control. **Consequence** In the case of Atlantic salmon, modelling suggesting the impact will depend on the magnitude and frequency of escapes (Svasand et	**Likelihood: Likely (4)** **Consequence: Minor (1)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** Likelihood remains unchanged at **Likely (4)** based on some degree of likely future interaction of cultured and wild fish stocks. **Consequence** The consequence of a detrimental effect can be reduced to **Minor (1)** through measures aimed at reducing the volume of escapees and/or their ability to contribute to future generations. Such measures applicable to the MWADZ include the general management and technical measures detailed above to prevent escapes. In the case of cod aquaculture, research efforts are focusing on the possibility of using sterile fish for aquaculture and to develop a line of fish that reaches harvest size prior to maturation (Jorstad et al., 2008). In the case of the MWADZ, likelihood of a negative genetic impact may be reduced through local sourcing of brood stock and through strategies aimed at ensuring harvest of fish prior to large scale spawning. Given that *Seriola lalandi* have been reported to generally spawn at 5-7 years this may reduce likelihood with respect to this species.

		al., 2007). It seems reasonable to assume that the same applies to other species, coupled to the local abundance of wild fish and genetic population structuring of the same species. In the case of YTK, the existence of a discrete genetic and potentially locally-adapted stock of Western Australian *Seriola lalandi* may enhance the potential consequence of interbreeding between escapees of a different origin. Given a lack of management controls aimed at controlling translocation of fish into the MWADZ (e.g. sourcing of fish from South Australia) enhanced consequence may result from a lack of control over aquaculture-associated translocation. Based on the general lack of knowledge surrounding the genetic implications of marine finfish escapees, the consequence of escaped fish and larva on the genetics of wild populations is assessed as **Moderate (2)** in the absence of management controls.		

2.3.3 Hazard Pathway 3: Potential negative effects of marine pests introduced or spread as a result of aquaculture activity

2.3.3.1 *Overview of potential impacts of marine pests introduced or spread as a result of aquaculture activity (habitat and ecosystem)*

Invasive marine pests are plants or animals that may be introduced into marine ecosystems outside their natural range and that have significant economic, socio-cultural/human health and/or ecological impacts. Damages and costs associated with controlling invasive marine species in the USA are estimated to amount to US$14.2 billion annually (Pimentel *et al*., 2005).

Marine pests can have significant impacts on ecosystems and the commercial viability of their dependent fisheries and are often difficult or impossible to eradicate once established. For example, the North American comb jelly (*Mnemiopsis leidyi*) was introduced into the Black Sea in the early 1980s, with its population subsequently exploding to reach a billion tonnes in the region. The jellyfish was responsible for the collapse of pelagic commercial fisheries, resulting in severe economic hardship in the region. The introduction of the Pacific Sea Star (*Asterias amurensis*) into Tasmania and subsequently Port Philip Bay resulted in populations growing to approximately 30 million. This pest feeds on mussels, scallops and clams and hence poses a huge threat to shellfish fisheries as well as to the commercial viability of mariculture operations. Pests can also carry new diseases that can have significant impact on wild capture fisheries and aquaculture species (e.g. White Spot Syndrome Virus which poses a risk to the most valuable wild-capture crustacean fisheries in the State).

Aquaculture businesses could assist in the further spreading of marine pests already present in the State, through movements associated with commercial operations of through provision of infrastructure suited to their proliferation. Alternatively, the aquaculture industry itself could be directly responsible for introduction of marine pests, for example, through introduction via feed sources or brood stock or via the use of imported equipment that is not sufficiently cleaned.

This assessment focuses on the potential ecological impacts of marine pests to ecosystems and their dependent fisheries. However, it is clear that marine pests can also significantly impact the commercial viability of aquaculture operations themselves (Edwards & Leung, 2008; Fitridge et al., 2012).

2.3.3.2 *Hazard Analysis: Potential negative effects of aquaculture on the environment*

The hazard pathway components identified in the compendium map detailed in Figure 3c were individually analysed with respect to both the inherent hazard (baseline

hazard if no management measures aimed at mitigating the hazard were in place) and their residual hazard (remaining hazard once one or more of the proposed management controls have been effected) as indicated in Table 3c. Prior to conducting this exercise, a literature review of potential negative effects resulting from the introduction of marine pests from the potential development of aquaculture in the MWADZ was conducted. Consequence was assessed based on impact to habitats and ecosystem which are most likely to be primarily affected by marine pests.

Table 3c: Assessment of hazards identified in Figure 3c *Hazards were individually analysed with respect to both the inherent hazard (i.e. baseline hazard if no management measures aimed at mitigating the hazard were in place) and their residual hazard (i.e. remaining hazard once one or more of the proposed management controls have been implemented).*

Hazard	Inherent Hazard Assuming No Management Controls	Justification	Residual Hazard Following Implementation of Management Controls	Justification and Identified Management Controls
1.Marine pest present in surrounding waters	**Likelihood: Likely (4)** **Consequence: Minor (1)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** Examples exist of marine biofouling pest species thought to be introduced to the State that have been introduced into aquaculture facilities (i.e. *Didemnum perlucidum* at pearl farms in the Abrolhos Islands). The source of introduction remains unknown but is likely to have resulted from infested vessels visiting the area and/or via water-borne transmission from the surrounding environment. This indicates that marine pests are likely to be present in the surrounding waters of the MWADZ. A key vector for introduction of marine pests into Western Australia is international shipping, with major ports representing key sources of initial introduction. The main access port for the MWADZ is likely to be the port of Geraldton. Geraldton port is the largest and the primary vector node in the area that hosts international vessels; predominantly bulk carriers to support trade for the region's resources industry.	**Likelihood: Possible (3)** **Consequence: Minor (1)** **Hazard score: (3)** **Risk level: Low**	**Likelihood** Likelihood can be reduced to **Possible (3)** based on management actions targeted around reducing risk of introduction of marine pests into the State. Current measures in place include: 1. Management strategy aimed at preventing marine pests being introduced into Western Australia. The Department uses a risk-based approach to preventing introduction of marine pests into Western Australia. This approach includes a risk-based assessment of international vessels entering State waters based on maintenance and voyage history. High-risk vessels undergo specialist pest inspections prior to being granted entry into Western Australia. This program is supported by a compliance regime.

		A detailed assessment of its marine pest risk profile was recently conducted (Bridgwood and McDonald 2014) which identified its primary sources of international and domestic risk as China and Kwinana/Fremantle respectively. Other potential marine pests have been reported at the Port of Geraldton in previous Introduced Marine Pest (IMP) surveys. Based on the known presence of marine pests in the area and the regular visitation of international and domestic shipping from areas known to harbour potential marine pests, the likelihood of marine pests being present in local waters is assessed as **Likely (4)** in the absence of management controls. **Consequence** Consequence is **Minor (1)** from the perspective of the MWADZ unless the marine pest in question is introduced into the facility, becomes established and/or is spread to the wider ecosystem.		Resource projects often operate under a suite of specific ministerial conditions which dictate specific additional biosecurity requirements. Management of other vessels is voluntary through the new Department of Fisheries Vessel Check (international/interstate movements). Current control is by regulation 176 of the *Fish Resources Management Regulations 1995*, movement of non-endemic fish (as all high-risk Invasive Marine Species (IMS) are listed as noxious except pacific oysters). 2. Statewide monitoring program for the early detection of marine pests at high risk ports in Western Australia. The Department maintains a state-wide monitoring regime to detect pest incursions at an early stage, which is necessary to support their potential control. This is based on a recognised and agreed national surveillance system and is supported by a research program aimed at continuous improvement to the monitoring network. 3. Development of pest control and management strategies. The Department maintains emergency response capacity to determine the spread of marine pests and to attempt their control using a risk-based

				assessment process. **Consequence** Consequence would remain unchanged at **Minor (1)**.
2.Brood stock /biological material	**Likelihood: Unlikely (2)** **Consequence: Minor (1)** **Hazard score: (2)** **Risk level: Negligible**	**Likelihood** The MWADZ proposal is focused around finfish aquaculture of species native to Western Australia. It seems unlikely that brood stock likely to be locally sourced would be a significant source of introduction of marine pests (excluding disease agents and/or parasites which are considered under disease risks). Other biological material introduced could be associated with feed sources which, depending on their composition, could represent some risk if unmanaged. Overall likelihood is considered **Unlikely (2)**. **Consequence** Consequence is **Minor (1)** from the perspective of the MWADZ, unless the marine pests in question is introduced into the facility, becomes established and/or is spread to the wider ecosystem.	**Likelihood: Remote (1)** **Consequence: Minor (1)** **Hazard score: (1)** **Risk level: Negligible**	**Likelihood** Likelihood may be further reduced to **Remote (1)** based on licensing requirements to restrict species to native locally-sourced species and to restrict sources of feed as outlined among the measures below: • Feed must be AQIS-approved or produced by a manufacturer that complies with ISO 9001:2008. • Only commercial pelleted feed permitted at sea-cage facilities. • Feed other than commercial pellet must be frozen to kill any marine pests. • Development of and compliance with approved biosecurity management arrangements and best-husbandry practice. **Consequence** Consequence would remain unchanged at **Minor (1)**.

3.Personnel/ Equipment/Boats	**Likelihood: Possible (3)** **Consequence: Minor (1)** **Hazard score: (3)** **Risk level: Low**	**Likelihood** Equipment and vessels can be a source of introduction of marine pests in the absence of effective management controls. Around the world aquaculture has been identified as a major vector for the introduction of marine pests (Grosholz et al., 2015). This has occurred through the intentional introduction of non-indigenous culture species (from foreign waters), as well as accidentally translocated species (Grosholz et al., 2015). Accidental introduction is likely, primarily through 'hitch hiking' on vessels associated with aquaculture activities. Limited data exists on introduced pests associated with aquaculture, but a recent study of introduced pests in Californian waters found 126 non-native species originating from aquaculture activities, of which 112 of these introductions are believed to be accidental introductions. 106 of these species have become established in at least one location (Grosholz et al., 2015). Likelihood is thus assessed as **Possible (3)**. **Consequence** Consequence is **Minor (1)** from the perspective of the MWADZ, unless the marine pest in question is introduced into the facility, becomes established and/or is spread to the wider ecosystem.	**Likelihood: Unlikely (2)** **Consequence: Minor (1)** **Hazard score: (2)** **Risk level: Negligible**	**Likelihood** Likelihood can be reduced to **Unlikely (2)** based on application of biosecurity management controls appropriate to the aquaculture operation. These would include the following: • Development of and compliance with approved biosecurity management arrangements and best-husbandry practice. • Development of an industry Code of Practice focused on biosecurity. • Development of protocols for farm management practices (e.g. regular vessel hull cleaning, regular monitoring for high-risk introduced species, etc.) **Consequence** Consequence would remain unchanged at **Minor (1)**.

4. Establishment of introduced marine pests and significant detrimental effect on habitat and ecosystem	**Likelihood: Likely (4)** **Consequence: Major (3)** **Hazard score: (12)** **Risk level: High**	**Likelihood** Marine pests are, by their nature, species shown to establish readily in appropriate receiving environments and have significant ecological and/or other impacts. If they are introduced, they are **Likely (4)** to become established and have an impact. The likelihood is species-dependent and (in part) based on the environmental requirements of the pest species (often broad in the case of marine pests) with that of the receiving environment. A comprehensive likelihood analysis was conducted by Bridgwood and McDonald (2014). This considers such requirements of specific pest species to identify those of most risk to the Mid West region where the proposed MWADZ is to be developed. **Consequence** Generally, the impact of invasive marine species (from aquaculture activities) is negative (Grosholz et al., 2015). The establishment of marine pests can (by definition) alter habitat dynamics and ecosystem function with the appearance of new species that may compete for resources with existing species. The impact of marine pests can be difficult to predict. In the case of *Didendum perlucidum*, impact has largely been restricted to artificial structures such as those associated with aquaculture and or port infrastructure. While mostly restricted in its distribution to disturbed or artificial habitat, it has been recorded in the Swan River, where negative impacts such as fouling	**Likelihood: Unlikely (2)** **Consequence Major (3)** **Hazard score: (6)** **Risk level: Moderate**	**Likelihood** Likelihood of establishment and spread may be reduced to **Unlikely (2)** by implementation of the controls outlined above. In addition, installation of a biosecurity monitoring program in association with the MWADZ would support early detection of marine pests and reduce chance of establishment. Enforcing compulsory reporting of marine pest incidents to regulators would also enhance the prospect of early detection and reduce likelihood of establishment through providing opportunity to implement controls. Likelihood can be reduced through eradication at the earliest possible stage in the invasion process. The Department maintains an incident response capacity and is developing tools and capacity to support effective eradication of marine pests associated with man-made infrastructure. **Consequence** Consequence would remain unchanged at **Major (3)** should pests establish to the point where the implementation of controls are unlikely to be effective.

		seagrass has been observed (Simpson pers comm.). Potential consequence clearly remains highly dependent on the marine pest in question and its biological characteristics. Consequence is conservatively assessed as **Major (3)**.		

4. Risk Identification and Assessment

4.1 Risk Identification

Following identification of key threats and detailed analysis of hazard pathways leading to potential realization of these threats, three overarching risks of most relevance to the activities proposed in association with the MWADZ were identified. These were as follows:

1. *That a significant pathogen or disease spread from an infected aquaculture facility could lead to a significant impact on wild targeted fisheries based around the same or alternate species.*

2. *That escaped fish could lead to a significant impact on the sustainability of wild stocks through either competitive interaction or genetic mixing.*

3. *That the introduction of marine pests could lead to a significant impact on habitat dynamics and alteration of ecosystem function at a regional scale.*

These risks were assessed with a consideration to their cumulative impact using the precautionary approach described in the methodology.

4.2 Risk Analysis Risk 1

4.2.1 Nature of Risk

That a significant pathogen or disease spread from an infected aquaculture facility could lead to a significant impact on wild targeted fisheries.

In order to realise this risk, one or more of the hazard pathways identified in section 3 must result in the introduction of a potentially significant pathogen into the MWADZ. The pathogen present on the farm must then be exported from the facility at sufficient levels, and come into contact with susceptible wild stocks and successfully infect these susceptible stocks, resulting in disease occurrence. The resulting disease must have a significant impact on wild stocks of fisheries which they support. This risk assesses the material risk to stocks and does not cover potential consequent reputational loss.

4.2.2 Inherent Risk Analysis

4.2.2.1 Likelihood

There are a number of significant pathogens of the marine fish proposed for aquaculture in the MWADZ, including for YTK.

Diseases may potentially be introduced into sea-cage farms directly from the environment (e.g. as a result of transmission from wild fish), via sub-clinically infected stocked fish, via movement of personnel and infrastructure, via the use of untreated aquaculture feeds or via other vectors. Once introduced into an aquaculture facility, pathogens may persist, be transmitted between generations and potentially adapt to a state of virulence higher that that seen in the wild (where there may be no evolutionary advantage to kill a host) as a result of the selection pressures associated with intensive aquaculture. Spread of pathogens from aquaculture facilities could then occur via effluent, escapes, and/or predation. In the absence of biosecurity management controls, the inherent likelihood of a significant disease occurring at a marine aquaculture farm, being spread to wild stocks and having a significant impact on those stocks and associated fisheries is assessed as **Likely (4).**

4.2.2.2 Consequence

The consequence of this risk is assessed as **Moderate (2).** The severity of consequence is, in part, linked to the specific nature of the species and pathogen or disease under consideration. It is also linked to the relative abundance of farmed versus wild fish and opportunities for their interaction. This assessment reflects the fact that, while some major pathogens associated with marine finfish aquaculture may have a broad host range and be responsible for high levels of mortality in aquaculture, there is little evidence to suggest that they have had a significant impact on wild fish stocks. This is even the case for aquaculture in the northern hemisphere where, despite intensive studies on Atlantic salmon, the extent to which aquaculture exerts a negative influence on wild stocks remains contentious. While declines in wild fish stocks may be measurable, difficulties exist in determining the factors contributing to these declines which may be multifactorial. Marine finfish fisheries represent significant Western Australian fisheries in economic terms. They also have a high social value, supporting regional employment and communities as well as a strong recreational sector. Spread of a significant pathogen could ultimately impact a wide range of species and the fisheries and ecosystems which they support.

4.2.2.3 Overall Inherent Risk

Using Table 1c, the Hazard/Risk Score (C x L) for the overall inherent risk is 8 and therefore the **inherent risk level is Moderate**.

4.2.3 Residual Risk Analysis

4.2.3.1 Likelihood

There are a number of management measures in place that reduce the likelihood of one or more of the hazard pathways identified in section 3 leading to the introduction and spread of a significant pathogen or disease from an infected aquaculture facility and (in turn) leading to a demonstrated impact on wild fisheries.

It is in the interest of the State to support development of a sustainable aquaculture industry in the MWADZ through implementation of biosecurity control measures aimed at:

- preventing introduction and emergence of disease onto a farm;
- ensuring effective early detection and containment of significant pathogens; and
- preventing their release into the environment.

A summary of the proposed management measures associated with the MWADZ is detailed below:

Control Category	Management Control	DoF Control Mechanism
1. Preventing pathogen introduction and disease emergence	Sourcing of brood stock from within Australia.	• Translocation policy and translocation approvals.
	Effective quarantine and surveillance of brood stock for detection of known pathogen hazards.	• Protocols and Department-approved testing regimes. • Management and Environmental Monitoring Plan (MEMP) requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines).
	Regulation of permitted unpasteurised feeds for brood stock conditioning.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines).
	Controls over water intake to prevent introduction of pathogens into hatchery facilities.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA).
	Adherence to good-husbandry practices to maintain high on-farm health and biosecurity standards.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines).
2. Early detection of disease issues	Timely recording and reporting of abnormal mortalities to the Department of Fisheries.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines). • Regulation 69 of the FRMR.
	Regular passive surveillance of stocks and investigation of cause of mortalities.	• MEMP requirements (under s.92A of the FRMA).

3. Preventing release of pathogen into the environment	Development of and adherence to technical standards governing sea-cage construction and operation (i.e. to reduce the likelihood of release of stock via escapes).	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA).
	Facility and Departmental contingency plans to optimise containment in event of an incident.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Aquatic Biosecurity section Incident Management Protocol – at a broad generic level • Emergency powers to deal with biological threats (Part 16A of the FRMA)
	Development of emergency response and containment protocols.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Aquatic Biosecurity section Incident Management Protocol – at a broad generic level • Emergency powers to deal with biological threats (Part 16A of the FRMA)
	Adherence to good-husbandry practices to maintain high on-farm health and biosecurity standards.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines).

Assuming both implementation of and compliance with these management measures, the residual likelihood associated with the proposal is assessed as **Unlikely (2)**. This is due to the establishment of controls over the major known pathways for introduction of pathogens onto farms and development of protocols to rapidly detect and control emerging disease issues.

4.2.3.2 Consequence

Residual Consequence remains unchanged at **Moderate (2)**.

4.2.3.3 Overall Residual Risk

The overall residual risk of a significant pathogen or disease spread from an infected aquaculture facility within proposed aquaculture zone leading to a significant impact on wild targeted fisheries is considered low and acceptable.

Using Table 1c, the Hazard/Risk Score (C x L) for the overall residual risk is 4 and therefore the **residual risk level is Low**.

4.3 Risk Analysis Risk 2

4.3.1 Nature of Risk

> *That escaped fish could lead to a significant impact on the future sustainability of wild stocks through either competitive interaction or genetic mixing.*

In order to realise this risk, fish escaping either as larvae, juveniles or adults must survive in the wild and interact with wild fish of the same species causing significant impacts to wild fish populations either through competition for resources or by interbreeding.

4.3.2 Inherent Risk Analysis

4.3.2.1 Likelihood

While escapes associated with sea-cage based aquaculture are considered almost inevitable, significant advances have been made in understanding the cause of these escapes and thus developing improved management strategies aimed at limiting these occurrences. Given weather patterns in Western Australia, the relative exposure of offshore aquaculture operations in the MWADZ, and the biology of the species under consideration, the likelihood of escaped fish having an impact to sustainability of wild stocks is linked to the magnitude and frequency of escape events in addition to the size of fish escaping. Evidence exists to indicate that escaped yellowtail kingfish can survive in the wild (Fowler et al., 2003). Where such species are cultured within their natural range, the potential for interaction between

wild and cultured fish may also be high as has been demonstrated in the Spencer Gulf of South Australia (Fowler et al., 2003). Fish escaping at larger sizes may have become adapted to aquaculture conditions and may hang around cages subsequent to release events or exhibit modified behaviours which may limit the likelihood of direct interaction with wild stocks. In support of this, Fowler et al. (2003) demonstrated that a population of fish in the northern Spencer Gulf region, identified as being of cultured origin, had apparently different opportunistic and reduced foraging behaviours compared to wild fish. While little direct evidence exists to suggest that escapes from the proposed MWADZ would have a significant genetic or competitive impact on sustainability of wild fish, likelihood is conservatively assessed as **Possible (3)**.

4.3.2.2 Consequence

Consequence is conservatively assessed as **Moderate (2)** with potential reductions to stocks that could approach levels estimated as approaching that associated with levels lower than 70% of unfished levels.

4.3.2.3 Overall Inherent Risk

Using Table 1c, the Hazard/Risk Score (C x L) for the overall inherent risk is 6 and therefore the **inherent risk level is Moderate**.

4.3.3 Residual Risk Analysis

4.3.3.1 Likelihood

Likelihood that escaped fish lead to a significant impact on the future sustainability of wild stocks through either competitive interaction or genetic mixing may be further reduced through introduction of measures aimed at reducing the frequency and magnitude of escape events.

The range of primary management measures aimed at further reducing this likelihood are detailed below:

Control Category	Management Control	DoF Control Mechanism
1. Preventing escapes	Development of and adherence to technical standards governing sea-cage construction and operation (i.e. to reduce the likelihood of release of stock via escapes).	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA).
	Mandatory reporting of escapes.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines).
	Mandatory technical investigations to determine cause of significant escapes.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines).
	Mandatory training for staff in escape-critical operations.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA).
	Adherence to good-husbandry practice (e.g. removal of mortalities, predator controls).	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines).
	Reducing capacity for spawning of aquaculture stock.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA).
2. Promoting recapture	Development of and adherence to recapture protocols and emergency response procedures.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines).

	Mandatory reporting of escapes.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines).
3. Reducing opportunity for interaction of stock escapees with wild fish	Siting of zone and farms in areas outside those of key habitats for cultured species.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA).
	Good-husbandry practice (e.g. limiting excess feed) to minimise attraction of wild fish to cages.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA).
4. Reducing impact of potential interaction	Use of F1 generation brood stock sourced from a sufficient breeding nucleus of local stock.	• Translocation policy and translocation approvals. • Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA).

Likelihood of escapes leading to an impact on sustainability of wild stocks is also influenced by the degree of domestication of the aquaculture stock in question. Higher degrees of domestication and genetic selection in favour of properties considered conducive to aquaculture production (e.g. high growth rates) can lead to a stock which has significantly different genetic and phenotypic characteristics from its parent population. The likelihood of escapee fish impacting sustainability of local wild fish populations can be reduced by limiting the degree of genetic differentiation of the cultured stock from its wild fish siblings. This could be managed by maintaining a strategy of hatchery production of F1 generation stock based on locally-sourced brood stock. If marine finfish proposed for culture are all F1 generation, significant genetic selection is unlikely to have occurred and thus the potential for their escape and interaction with wild fish to lead to detrimental effects would be low.

Based on implementation of these measures, the residual likelihood of escaped fish leading to a significant impact on the future sustainability of wild stocks through either competitive interaction or genetic mixing is considered to be **Unlikely (2)** under current proposed aquaculture scenarios.

4.3.3.2 Consequence

Consequence would remain unchanged as **Moderate (2)**.

4.3.3.3 Overall Residual Risk

Using Table 1c, the Hazard/Risk Score (C x L) for the overall residual risk is 4 and therefore the **residual risk level is Low**.

4.4 Risk Analysis Risk 3

4.4.1 Nature of Risk

> *That the introduction of or spread of existing marine pests as a result of aquaculture activity associated with the MWADZ could lead to a significant impact on habitat dynamics and alteration of ecosystem function at a regional scale.*

In order to realise this risk, marine pests must either be present in the MWADZ region or be imported into the area as a direct result of aquaculture or other activities in the area. They must then become established on aquaculture infrastructure and/or in the wider environment which (in turn) leads to a significant and detrimental ecological impact.

4.4.2 Inherent Risk Analysis

4.4.2.1 Likelihood

Potential marine pests are known to be present in the region and thought to have been introduced into the State mostly as a result of anthropogenic activity involving international shipping. It is more likely that the MWADZ proposal might play a role in spreading pests already present in the State than be directly responsible for the import of new pest species.

In the absence of management controls governing biosecurity in the MWADZ, the likelihood of activities associated with the MWADZ contributing to the introduction or spread of marine pests that may lead to a significant impact to local ecosystems is assessed as **Possible (3)**. The infrastructure associated with marine farming will represent a new opportunity for the establishment of marine biofouling organisms. Associated vessel movements may present a vector for subsequent dispersal.

4.4.2.2 Consequence

The consequence of significant impact is assessed as **Major (3)** at the ecosystem level since habitat dynamics and ecosystem function are likely to be fundamentally altered by the presence of new species at potentially high levels of abundance.

4.4.2.3 Overall Inherent Risk

Using Table 1c, the Hazard/Risk Score (C x L) for the overall inherent risk is 9 and therefore the **inherent risk level is High**.

4.4.3 Residual Risk Analysis

4.4.3.1 Likelihood

The likelihood of significant impact from marine pest species is dependent on the degree of biosecurity management associated with facilities within the MWADZ. Management controls that can mitigate potential effects include those detailed in table below:

Control Category	Management Control	DoF Control Mechanism
1. Measures to prevent introduction of marine pests from surrounding waters	Adherence to good-husbandry practices to maintain high on-farm health and biosecurity standards. Regular cleaning of infrastructure (e.g. nets). Implementation of a supporting vessel-management regime.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines).
2. Measures to prevent introduction of marine pests in association with brood stock/ biological material	Sourcing of brood stock from within Western Australia. Regulation of permitted unpasteurized feeds for brood stock conditioning.	• Translocation policy and translocation approval. • Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines).
3. Measures to prevent introduction of marine pests with personnel/ equipment/ vessels	Adherence to good-husbandry practices to maintain high on-farm health and biosecurity standards. Development of specific industry cleaning protocols for any materials introduced from outside the region.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines).
4. Measures to prevent establishment of marine pests resulting from aquaculture activity and consequential ecological impact	Development of and compliance with a regular biosecurity monitoring regime for the MWADZ. Compulsory reporting of suspect pests by MWADZ operators. Industry/Departmental biosecurity incident response processes and capacity. Translocation control of species cultured within the MWADZ.	• Translocation policy and translocation approval. • Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines). • Monitoring for invasive marine species (e.g. Early-Warning System checks) • Zone-specific incident response plans • Emergency powers to deal with biological threats (Part 16A of the FRMA) • Protocols and Department-approved testing regimes.

Based on implementation of these control measures, the residual likelihood of aquaculture operations introducing and/or spreading marine pests resulting in a significant impact to regional habitats and ecosystems is considered **Unlikely (2)** under current aquaculture scenarios.

4.4.3.2 Consequence

Residual consequence remains unchanged at **Major (3)**.

4.4.3.3 Overall Residual Risk

Using Table 1c, the Hazard/Risk Score (C x L) for the overall residual risk is 6 and therefore the **residual risk level is Moderate**.

5. Summary

Key overall risks identified in association with the proposal to develop marine finfish aquaculture in the MWADZ were identified as follows:

1. *That a significant pathogen or disease is spread from an infected aquaculture facility leading to a significant impact on wild target fisheries based around the same or alternate species.*

2. *That escaped fish lead to a significant impact on the future sustainability of wild stocks through either competitive interaction or genetic mixing.*

3. *That the introduction and/or spread of marine pests in association with aquaculture activity have a significant impact on the sustainability of local ecosystems.*

Critical pathways that could collectively lead to realisation of these risks were identified (hazards) and reviewed systematically. Considering the biosecurity measures associated with development of the MWADZ to address these hazards, the residual risk of identified overarching risks for risks 1-3 was assessed as **Low**, **Low** and **Moderate**, respectively. Low-moderate risks suggest that current or planned risk control measures are adequate in reducing levels of identified risk to acceptable levels.

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Mid West Aquaculture Development Zone

Marine Fauna Interaction Management Plan

Prepared by

Department of Fisheries, Western Australia

Version 3.0 – April 2016

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1. Introduction

1.1 Purpose

This Marine Fauna Interaction Management Plan (MFIMP) focuses primarily on managing potential impacts to marine mammals, marine reptiles and marine avifauna associated with the Mid West Aquaculture Development Zone (MWADZ) at the Abrolhos Islands. Specifically, this MFIMP:

- provides an overview of the potential impacts that may occur to marine fauna during the installation process and operational activities;
- outlines management measures and actions adopted to mitigate potential impacts to marine fauna during the sea cage installation process and during operational activities;
- outlines the monitoring requirements/programs required to be serviced by operators within the MWADZ; and
- outlines the marine fauna incident reporting and response strategies required of operators within the MWADZ.

Specific information relating to the management of interactions with other marine fauna, including finfish, are covered in more detail in the MWADZ Environmental Monitoring and Management Plan (EMMP) and the Public Environmental Review (PER/EIS) document. This MFIMP is an appendix to the PER document used for strategic assessment of the MWADZ proposal.

1.2 Objectives

The primary aim of this MFIMP is to ensure that activities conducted within the proposed MWADZ do not cause any significant disturbance to marine fauna within the Abrolhos Islands Fish Habitat Protection Area (FHPA).

The objectives of this plan include minimising:

- human interactions with marine fauna;
- any potential injuries or fatalities to marine fauna that may result from collision with vessels or entanglement;
- noise and vibration disturbance to marine fauna;
- potential impacts to marine fauna from artificial light;
- potential impacts posed to marine fauna by aquaculture infrastructure; and
- adverse effects of fish farming activities within the proposed MWADZ on marine fauna.

1.3 Structure

The MFIMP provides the following information:

- an overview of fauna species likely to occur within the MWADZ;
- identification of potential impacts of the MWADZ on marine fauna species;
- identification of management measures to minimise the impacts associated with the installation of aquaculture infrastructure and during operational activities;
- an overview of environmental project management strategies; and
- information on the environmental monitoring, recording and reporting requirements for proponents operating within the MWADZ.

1.4 Project Overview

The Department of Fisheries, on behalf of the Minister for Fisheries, proposed to create an 'Aquaculture Development Zone' to provide a management precinct for prospective aquaculture proposals within State Waters, approximately 65 kilometres west of Geraldton within the FHPA of the Abrolhos Islands. The strategic proposal area was selected to maximise suitability for marine finfish aquaculture and minimise potential impacts on existing marine communities and disruption to existing human uses.

The strategic proposal, also known as the MWADZ, encompasses 3,000 hectares (ha) of marine waters within two separate areas: the northern area (approx. 2,220 ha) and the southern area (approx. 800 ha) (Refer to Figure 1).

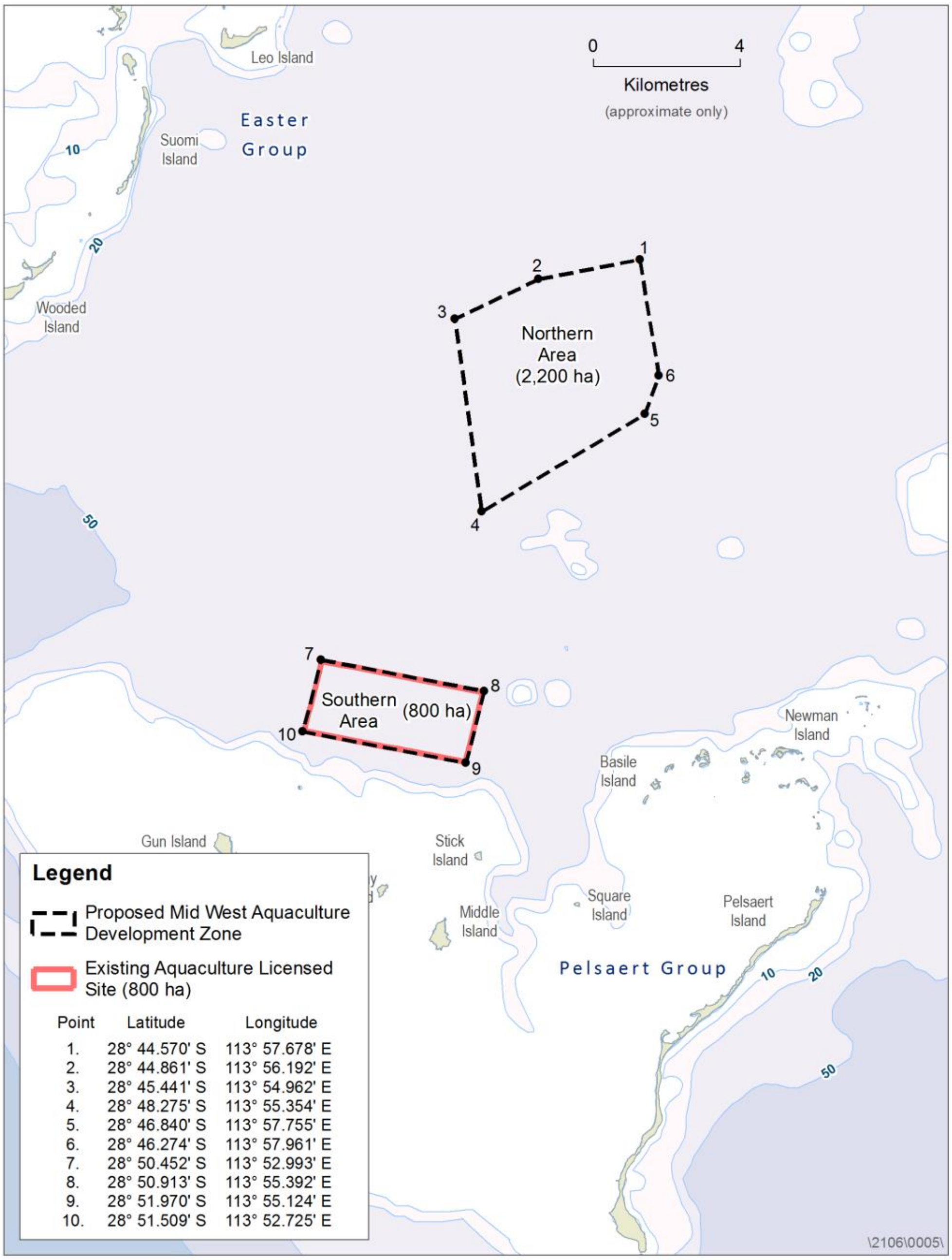
The MWADZ is established through a process that primarily involves environmental assessment of the zone as a strategic proposal under Part IV of the *Environmental Protection Act 1986*. Approval of this strategic proposal will create opportunities for existing and future aquaculture operators to refer their proposals to the Environmental Protection Authority as 'derived proposals'. The objective is a more streamlined assessment and regulation process due to early consideration of potential environmental impacts and cumulative impacts identified during the assessment process for the zone.

Operators within the MWADZ are likely to use circular surface sea cages for the purposes of finfish aquaculture. Multiple sea cages (typically up to 14 in number) are setup within a grid (referred to as a cage cluster) that is securely anchored to the sea bed. A cage cluster of 14 sea cages, anchoring system included, occupies approximately 130 hectares and must be entirely contained within an aquaculture lease.

The key components of the marine finfish aquaculture infrastructure likely to be used in the MWADZ include the following:

- sea cages
- feeding barges
- anchoring/mooring systems
- operational, supply and accommodation vessels

Figure 1: Location of the Mid West Aquaculture Development Zone



2. Existing Environment

2.1 Marine Mammals Overview

There are 31 species of cetaceans and two pinniped species which have the potential to occur within the vicinity (i.e. less than 50 km) of the MWADZ area (DoE 2014 a). Some of these species occasionally transit through the area at low densities (e.g. sperm whales, Antarctic minke whales, oceanic dolphins) although the information currently available is insufficient to confirm a definitive presence within the MWADZ area (BMT Oceanica 2015). Other dolphin species (including common dolphin, Risso's dolphin and spotted dolphin) have not previously been observed in the mid-west region of WA (Oceanica 2010). Given that these species are unlikely to venture into the MWADZ area they are not considered further in this MFIMP.

Nevertheless, the management actions proposed in this plan will be effective for all marine mammal species.

The marine mammal species considered in this MFIMP are:

- Humpback whale (*Megaptera novaeangliae*)
- Blue whale (*Balaenoptera musculus*)
- Pygmy blue whale (*Balaenoptera musculus brevicauda*)
- Southern right whale (*Eubalaena australis*)
- Bryde's whale (*Baelenoptera edeni*)
- Killer whale (*Orcinus orca*)
- Indo-Pacific bottlenose dolphin (*Tursiops aduncus*)
- Bottlenose dolphin (*Tursiops truncatus*)
- Spinner dolphin (*Stenella longirostris*)
- Australian sea lion (*Neophoca cinerea*)
- Dugong (*Dugong dugon*)

In Western Australia, marine mammals are protected under the *Wildlife Conservation Act 1950* (WC Act). Marine mammals are also protected by Commonwealth legislation under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and international conventions (CMS, CITES, IUCN) (BHP 2011). The conservation status of the eleven marine mammal species listed above is provided in Table 1.

Table 1: Conservation status of marine mammals known or likely to occur in the MWADZ proposal area

Species	Conservation Status		Likelihood of occurrence within the MWADZ proposal area
	EPBC Act	WC Act	
Humpback whale (*Megaptera novaeangliae*)	Vulnerable, Cetacean Migratory	Schedule 1[1]	Likely
Blue whale (*Balaenoptera musculus*)	Endangered, Migratory Cetacean	Schedule 1	Unlikely
Pygmy blue whale (*Balaenoptera musculus brevicauda*)	Endangered, Migratory Cetacean	Schedule 1	Likely
Bryde's whale (*Balaenoptera edeni*)	Migratory Cetacean	Not listed	Unlikely
Southern right whale (*Eubalaena australis*)	Endangered, Migratory Cetacean	Schedule 1	Unlikely
Killer whale (*Oricinus orca*)	Migratory Cetacean	Not listed	Unlikely
Indo-Pacific bottlenose dolphin (*Tursiops aduncus*)	Cetacean	Not listed	Likely
Bottlenose dolphin (*Tursiops truncatus*)	Cetacean	Not listed	Likely
Australian sea lion (*Neophoca cinerea*)	Vulnerable, Marine	Schedule 4	Likely
Dugong (*Dugong dugong*)	Marine, Migratory	Schedule 4	Unlikely
Spinner dolphin (Stenella longirostris)	Marine, Migratory	Not listed	Unlikely

2.2 Marine Reptile Overview

There are four marine turtle species (Table 2) that are known or likely to occur within the MWADZ area. All marine turtles are currently protected under the *Wildlife Conservation Act 1950* (WA) and listed as vulnerable or endangered and/or, migratory under the EPBC Act.

Two sea snake species, namely the spectacled sea snake (*Disteira kingii*) and yellow-bellied sea snake (*Pelamis platura*) are recorded by the EPBC Protected Matters database as species that may occur or whose habitat may occur in the area (DoE 2015). These sea snake species are not resident at the Abrolhos Islands, but during winter storms they may be transported south to the Abrolhos from Shark Bay and further north (Department of Fisheries 1998).

[1] Designates fauna under the *Wildlife Protection Act 1950* that is rare or likely to become extinct and is in need of special protection.

Table 2: Conservation status of marine turtle species known or likely to occur in the MWADZ proposal area

Species	Conservation Status		Likelihood of occurrence within the MWADZ proposal area
	EPBC Act	WC Act	
Green turtle (*Chelonia mydas*)	Vulnerable, Marine, Migratory	Schedule 1[2]	Likely
Flatback turtle (*Natator depressus*)	Vulnerable, Marine, Migratory	Schedule 1	Unlikely
Loggerhead turtle (*Caretta caretta*)	Endangered, Marine, Migratory	Schedule 1	Unlikely
Leatherback turtle (*Dermochelys coriacea*)	Endangered, Marine, Migratory	Schedule 1	Unlikely

2.3 Marine Avifauna Overview

There are 26 marine avifauna species (Table 3) that are known or likely to occur within the MWADZ area. Within the Pelsaert and Easter Groups at the Abrolhos Islands, 17 of these 26 species have been confirmed to breed regularly. These are the white-bellied sea eagle, osprey, wedge-tailed shearwater, little shearwater and white-faced storm petrel, Pacific gull, silver gull, Caspian tern, crested tern, bridled tern, roseate tern, fairy tern, brown noddy, lesser noddy, Eastern reef egret, pied oystercatcher, and pied cormorant (Halfmoon Biosciences 2015).

Of the seabird species known to occur in the vicinity of the MWADZ area, five species are currently listed under the *Western Australian Wildlife Conservation (Specially Protected Fauna) Notice 2014* as Schedule 1 species: (i.e. fauna that is rare or likely to become extinct) and nine species are listed as Schedule 3 species: (i.e. migratory birds protected under an international agreement such as the Japan-Australia Migratory Bird Agreement (JAMBA), China-Australia Migratory Bird Agreement (CAMBA) and the Republic of Korea-Australia Migratory Bird Agreement (ROKAMBA) (See Table 3).

[2] Ibid

Table 3: The conservation status of marine avifauna species known or likely to occur in the MWADZ proposal area

Common name	Scientific name	EPBC Act status	Wildlife Conservation Act status	Presence in the vicinity of the MMADZ
Common noddy	*Anous stolidus*	Marine, Migratory	Schedule 3	Likely
Lesser noddy	*Anous tenuirostris melanops*	Vulnerable, Marine, Migratory	Schedule 1	Likely*
Brown noddy	*Anous stolidus*	Marine, Migratory	not listed	Likely*
Bridled tern	*Onychoprion anaethetus*	Marine, Migratory	Schedule 3	Likely*
Sooty tern	*Onychoprion fuscata*	Marine	not listed	Likely
Roseate tern	*Sterna dougallii*	Marine, Migratory	Schedule 3	Likely*
Fairy tern	*Sterna nereis nereis*	Vulnerable, Marine, Migratory	Schedule 1	Likely*
Crested tern	*Thalasseus bergii*	Marine	not listed	Likely*
Caspian tern	*Hydroprogne caspia*	Marine, Migratory	Schedule 3	Likely*
Eastern reef egret	*Egreta sacra*	Marine, Migratory	Schedule 3	Likely*
Pied cormorant	*Phalacrocorax varius*	Not listed	not listed	Likely*
Pied oystercatcher	*Haematopus longirostris*	Not listed	not listed	Likely*
Pacific gull	*Larus pacificus*	Marine	not listed	Likely*
Silver gull	*Chroicocephalus novaehollandiae*	Marine	not listed	Likely*
South Polar skua	*Stercorarius maccormicki*	Marine, Migratory	Schedule 3	Likely
Southern giant petrel	*Macronectes giganteus*	Endangered, Marine, Migratory	not listed	Likely
Black-browed albatross	*Thalassarche melanophris*	Marine, Migratory	Schedule 1	Likely
Indian yellow-nosed albatross	*Thalassarche carteri*	Marine, Migratory	Schedule 1	Likely
Wedge-tailed shearwater	*Ardenna pacifica*	Marine, Migratory	Schedule 3	Likely*
Fleshy-footed shearwater	*Ardenna carneipes*	Marine, Migratory	Schedule 3	Likely
Hutton's shearwater	*Puffinus huttoni*	Marine, Migratory	Schedule 1	Likely
Little shearwater	*Puffinus assimilis*	Marine	not listed	Likely*
Wilson's storm petrel	*Oceanites oceanicus*	Marine, Migratory	Schedule 3	Likely
White-faced storm petrel	*Pelagodroma marina*	Marine	not listed	Likely*
White-bellied sea eagle	*Haliaeetus leucogaster*	Marine, Migratory	Schedule 3	Likely*
Eastern osprey	*Pandion cristatus*	Marine, Migratory	not listed	Likely*

Note: * indicates species breeds regularly within the Pelsaert and Easter Groups at the Abrolhos Islands.

2.4 Shark and Ray Overview

There are several species of shark and ray that have the potential to occur within the vicinity (i.e. less than 50 kilometres) of the MWADZ area. Some of these have conservation status under Commonwealth (EPBC Act) and/or Western Australian (FRMA/WC Act) legislation (refer to Table 4).

Those species, however, that are most likely to be present in the vicinity of the MWADZ, have the potential to be attracted to marine finfish aquaculture and be of a physical size capable of interacting with the sea cages are the:

- white shark (*Carcharodon carcharias*); and
- tiger shark (*Galeocerdo cuvier*).

While the focus has been on the risks associated with these two iconic (and in the case of the white shark, protected) species, the management actions proposed in this plan will be effective for all shark species.

Due to their morphology, it is considered unlikely that rays would become entangled in sea cage mesh or captured within the cages.

Table 4: The conservation status of shark and ray species possibly occurring in the MWADZ proposal area

Common Name	Scientific Name	Conservation Status		Presence in the Vicinity of the Mid West Aquaculture Development Zone
		Commonwealth (EPBC Act) Status	Western Australian Status	
Grey Nurse Shark	*Carcharias taurus*	Vulnerable	Specially protected fauna (WC Act)	Possible
Whale Shark	*Rhincodon typus*	Vulnerable, Migratory	Totally protected fish (FRMA) Specially protected fauna (WC Act)	Possible
White Shark	*Carcharodon carcharias*	Vulnerable, Migratory	Totally protected fish (FRMA) Specially protected fauna (WC Act)	Likely
Shortfin Mako Shark	*Isurus oxyrinchus*	Migratory	Not listed	Unlikely
Longfin Mako Shark	*Isurus paucus*	Migratory	Not listed	Unlikely
Scalloped Hammerhead	*Sphyrna lewini*	Migratory	Not listed	Possible
Smooth Hammerhead	*Sphyrna zygaena*	Migratory	Not listed	Possible
Green Sawfish	*Prisitis zijsron*	Vulnerable	Totally protected fish (FRMA) Specially protected fauna (WC Act)	Not likely
Giant Manta Ray	*Manta birostris*	Migratory	Not listed	Possible
Tiger shark[3]	*Galeocerdo cuvier*	Not listed	Not listed	Likely

[3] Tiger shark is not considered to be an ETP species, however, as an iconic marine species is considered to be representative of many of the ETP species of fish listed above.

3. Potential Impacts

The following section provides an overview of the potential environmental stressors that may have an impact on marine fauna within the MWADZ area. The information is based on a literature review of the best available scientific data, as well as documented information on the adverse interactions of marine fauna with marine aquaculture. The potential environmental stressors that were identified to potentially have an impact on marine fauna are:

- physical presence of aquaculture infrastructure;
- vessel movements;
- artificial light;
- noise and vibration; and
- fish farming activities (e.g. feeding).

A detailed assessment of the potential impacts to marine fauna is provided in sections 9 and 10 of the PER/EIS.

3.1 Physical Presence of Aquaculture Infrastructure

The physical presence of aquaculture farms has the potential to create barriers to fauna movement if it restricts migratory routes or transit routes of marine mammals, marine reptiles and seabirds between their habitats. The presence of aquaculture infrastructure could also attract larger marine predators including sharks, sea lions and dolphins due to the infrastructure providing Fish Aggregation Device (FAD) effects. Sea-based infrastructures that may have an impact on marine fauna include:

- sea cages;
- mooring and anchoring lines and systems;
- feeding barges; and
- vessels (service and accommodation).

Potential impacts to marine fauna related to the physical presence of aquaculture infrastructure during the installation process and operational activities include:

- changes in natural feeding behaviour of marine fauna as a result of higher fish density from FAD effects;
- serious injury or mortality of marine fauna due to entanglement or entrapment in aquaculture infrastructure;
- habitat changes due to placement of infrastructure and degradation of marine water and sediment quality; and
- changes to marine fauna distribution and migration patterns due to avoidance or attraction cues.

3.2 Vessel Movements

Vessels will operate throughout the MWADZ area during the installation of the aquaculture infrastructure and during operational activities. A range of vessel types, including service vessels, supply vessels and feeding barges, may be active within the area. The potential impacts to marine fauna related to the physical presence of vessels during the installation process and operational activities include:

- injury or death of mobile marine fauna from vessel strikes;
- disturbance to marine fauna behaviour from vessel movements; and
- habitat degradation (e.g. through anchoring, mooring, etc.).

Higher vessel activity will likely occur during the construction of the aquaculture farms (i.e. installation of sea cages, anchoring and mooring systems) and there will probably be reduced vessel movement during the operational period.

3.3 Artificial Light

Artificial light spill and glow generated during the installation and operation of aquaculture farms within the MWADZ area may have potential impacts on marine fauna. Sources of light emissions from activities within the area that may affect marine fauna include:

- routine lighting on aquaculture infrastructure;
- navigation marker lighting; and
- vessel lighting.

Light spill can have the following potential impacts to marine fauna:

- attraction of marine turtle hatchlings and disorientation;
- injury or death of juvenile seabirds attracted to lighting and flying into aquaculture infrastructure; and
- modification of fauna foraging behaviour around infrastructure due to light spill on the water.

3.4 Noise and Vibration

Noise and vibrations generated during the installation of aquaculture infrastructure and during operational activities within the MWADZ area may have potential impacts on marine fauna. The primary sources of potential noise and vibration generating from the activities include:

- vessel movements in the area;
- machinery used to install the sea cages, moorings and anchoring systems; and

- machinery used in operations (e.g. hand-held welders, mobile cranes, hand tools, small power tools, blowers and winches) (NSW Department of Primary Industries 2012).

Anthropogenic marine noise has the potential to impact marine fauna that rely on acoustic cues for feeding, communications, orientation and navigation. The extent of the impacts will vary depending on a number of variables, including the frequency range of the emitting noise and its intensity, the receiving environment (e.g. salinity, water depth, and sea bed type), met-ocean conditions, characteristics and sensitivity of the animal, and its distance from the source. Marine fauna which are considered sensitive to underwater noise include cetaceans, marine turtles, seabirds and fish.

Underwater noise and vibration can have the following impacts on marine fauna:

- behavioural changes;
- temporary or permanent injury and (in extreme cases) mortality;
- stress response;
- complete avoidance of the immediate area (habitat displacement);
- attraction to the noise source; and
- disruption to underwater acoustic cues for navigation, foraging and communication.

The assessment provided in the PER/EIS concluded that noise and vibration from construction and operational activities within the MWADZ did not pose a significant risk to marine fauna in the area. The majority of noise and vibration is likely to be generated by machinery potentially used to anchor sea cage infrastructure to the seabed. This does not include piling or blasting, as these construction methods are not required for aquaculture operations within the MWADZ.

Noise and vibrations are also likely to be generated by the sea-state conditions and vessel movements undertaken within the aquaculture zone (NSW DPI 2012). Therefore, the MFIMP provides management and mitigation measures designed to reduce noise generated by vessels and other machinery.

3.5 Fish Farming Activities

Fish farming activities within the MWADZ has the potential to have adverse impacts on marine fauna in the area. The presence of cultured stock, dead or moribund stock, harvesting activities and the provision of feed into the sea cages, has the potential to attract or deter marine fauna to or from the area. An increase in food availability within the area has the potential to cause an:

- increase in visitation rates of marine fauna species (e.g. Australian sea lions);
- increase in the duration of visits of marine fauna species (e.g. sharks);
- alteration in the natural feeding behaviour/regimes of marine fauna species; and

- increase in the abundance of opportunistic marine fauna (increaser species, e.g. silver gulls).

4. Mitigation and Management Measures

The potential for impacts to marine fauna associated with anthropogenic interaction are assessed and mitigated under the marine fauna section of the MWADZ Environmental Monitoring and Management Plan (EMMP) and individual operator Management and Environmental Monitoring Plans (MEMPs).

The integrity of significant marine fauna populations are maintained using a combination of best-practice and proactive infrastructure management; and ongoing environmental monitoring by the operators in the MWADZ. Reactive management strategies are also employed to manage incidents as they arise. The approaches to management follow those approved by the Environmental Protection Authority (EPA) for the Kimberley Aquaculture Development Zone Environmental Monitoring and Management Plan.

4.1 Physical Presence of Aquaculture Infrastructure

Management measures implemented to mitigate and/or manage impacts posed by the presence of aquaculture sea cage infrastructure on marine fauna include:

- Staff and contractors fully trained and inducted in the zone Management Policy to ensure they are fully aware of the protocol for managing interactions with marine fauna.
- All field staff trained in marine fauna identification, to allow for identification and enumeration of marine mammals, turtles and other reptiles sighted within 50 metres (radius) of the sea cage infrastructure and seabirds sighted within 100 metres (radius) of such structures.
- Predator exclusion systems mandatory on sea cages. Operators are required to use durable fish nets (heavy-duty, single barrier) and external anti-predator nets (double barrier) to avoid predation on farmed stock by sea lions, sharks and dolphins.
- Sea cage netting to be inspected daily to ensure its integrity is intact, free from debris and maintained to a standard that will minimise entanglement.
- Rigorous maintenance programs for all aquaculture infrastructure, particularly nets, ropes and cages, to be implemented to ensure there is limited capacity for entanglements of marine fauna.
- Nets, ropes and cages maintained in proper working order; being taught, without fouling, and without holes that may cause entanglement of wildlife.
- All practicable measures taken to prevent marine mammals, turtles and seabirds from gaining access to or reward from the sea cage aquaculture operation. Feeding protocols to be observed to minimise the amount of

uneaten feed entering the surrounding water. To discourage scavenging or predation by marine fauna, dead finfish are to be removed from sea cages on a daily basis and disposed of at appropriate landfill sites on the mainland.

4.2 Vessel Movements

To minimise potential interactions or vessel strikes with marine fauna, all staff operating on-board vessels in the MWADZ are required to:

- abide by the Australian National Guidelines for Whale and Dolphin Watching (i.e. not permitted to approach within 100 metres of a whale and within 50 metres for dolphins and turtles - refer to Figure 2);
- implement observer protocols [i.e. routinely keep a watch for marine fauna (notably marine mammals and turtles) when travelling between sea cage infrastructure and the accommodation barge]; and
- restrict construction and operational activities to daylight hours.

To minimise potential interactions or vessel strikes with marine fauna, the Master of a vessel operating in the MWADZ is required to:

- avoid making sudden or repeated changes in direction, or generating excessive noise, near marine fauna in the area;
- operate vessels within the proposed MWADZ at reduced speed limits (i.e. less than 15 knots); and
- avoid the use of vessels at night wherever possible.

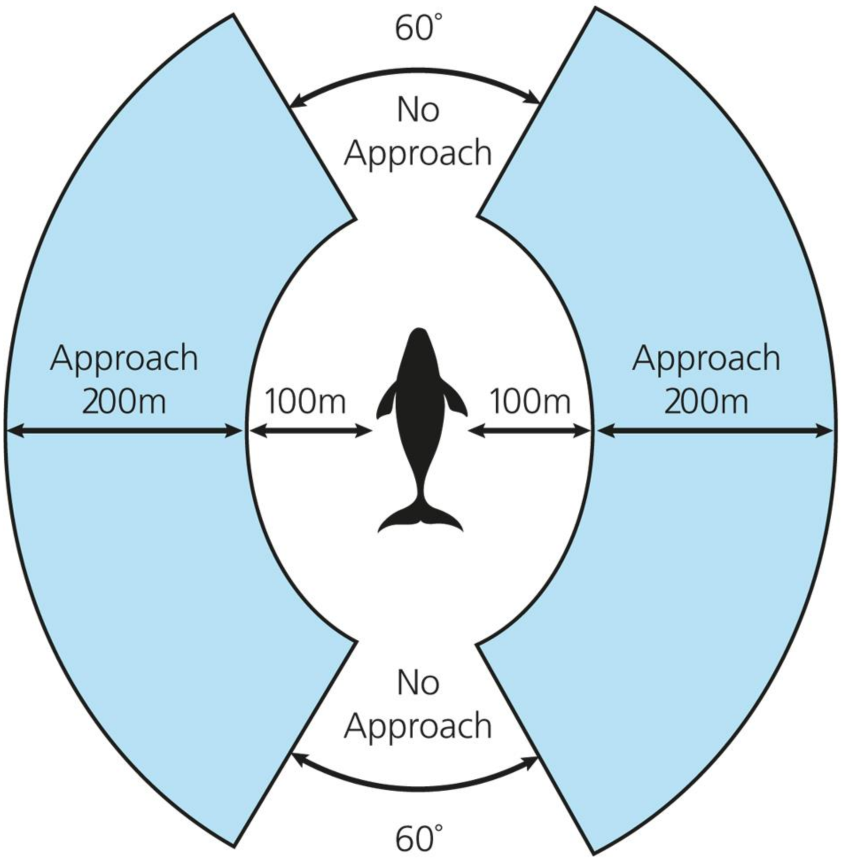


Figure 2: Approach Distances for Marine Fauna (whales = 100 metres, dolphins and turtles = 50 metres)

4.3 Artificial Light

The key management measures and guidelines observed by all staff operating in the MWADZ in order to minimise potential adverse impacts of artificial light on marine fauna include:

- minimise light intensity on vessels to as low as reasonably practicable when conducting activities at night;
- avoid the use of bright white lights (e.g. mercury vapour, metal halide, halogen and fluorescent light) on aquaculture infrastructure (orange lights, red lights and low-pressure sodium lights are to be used where practicable);
- reduce light spill by shielding lights, pointing lights directly at the work area (directional alignment), reducing the amount of light shining directly onto water and covering windows with tinting or drapes to reduce light emissions from service vessels;
- reduce horizon glow through the use of downward-facing luminaries, attention to reflecting surfaces (adjusting lights so they don't shine onto reflective surfaces) and reducing the intensity of indoor lighting used in accommodation and feed barges;

- restrict lighting on moored vessels at night to the minimum required for safe operations; and
- periodic monitoring of the waters around moored service vessels for presence of juvenile sea birds and other marine fauna that may have been affected by light emissions.

4.4 Noise and Vibration

Noise and vibration emissions generated from the aquaculture activities within the MWADZ will be managed by the implementation of mitigation and management measures including:

- routinely maintaining and inspecting noise generating equipment (e.g. vessel engines, drilling equipment) to reduce unnecessary increase in noise levels from the equipment (all vessels shall operate in accordance with the appropriate industry noise codes);
- avoiding the practice of leaving engines, thrusters and auxiliary motors on standby or running mode (where practicable);
- the Master of any aquaculture vessel operating in the area taking note if marine fauna is sighted in the vicinity of the aquaculture infrastructure and reducing speed to minimise noise disturbance (other staff are also responsible for bringing the situation to the attention of the Master of the vessel); and
- fitting sound suppression devices (e.g. mufflers) on noise-emitting equipment (if applicable).

4.5 Fish Farming Activities

The potential impacts associated with fish farming activities on marine fauna will be monitored and managed under the MWADZ EMMP and individual licensee MEMPs. Management and mitigation measures implemented to reduce these potential impacts are outlined below.

4.5.1 Feeding Practices

Feeding activities within the MWADZ area shall be managed in accordance with the following to minimise feed wastage and reduce the potential attraction to and/or reward from sea cages by marine fauna:

- use high-quality pellet feed containing less fish meal and fish oil than traditional aquaculture feeds and designed to sink at rates which optimise consumption by stock;
- primarily storing pellet feed on site in bulk feed hoppers and storing any loose bags of feed in either the below-deck compartment of the supply boat or on-deck covered by heavy duty PVC tarpaulin or similar;

- ensuring staff are adequately trained in the use of the portable blower system used to deliver feed into the sea cages to ensure minimal or no spillage and no distribution of feed outside the sea cages; and
- not permitting the feeding of marine fauna within the MWADZ proposal area.

4.5.2 Farm Fish Mortalities

In order to minimise the attraction of marine fauna such as sea lions, dolphins and other predators, including sharks, to the proposed MWADZ area, the following management measures will be implemented:

- dead and moribund stock will be removed daily from the sea cages; and
- all dead fish so removed will be stored in enclosed containers until disposed of at appropriate land-based disposal facilities on the mainland.

4.5.3 Exclusion Devices

Management and mitigation measures that will be implemented to minimise the potential interactions of marine fauna with the sea cage infrastructure include:

- sea cages will be covered with bird netting (of a mesh size 60 millimetre bar-width or less) to prevent seabirds from gaining access to fish feed and stock mortalities inside the sea cages;
- other seabird deterrents (visual and audio) may be used in accordance with the Zone Management Policy, provided the deterrent does not cause any harm to fauna;
- sub-surface exclusion or “anti-predator” netting (with mesh sizes 60 millimetres bar-width or less) will be mandatory on sea cages within the proposed MWADZ;
- durable fish nets (heavy-duty single barrier) and (as required) external anti-predator nets (double barrier) will be used to avoid predation on farmed stock by sea lions, sharks and dolphins;
- sea cage netting must be inspected daily to ensure its integrity is intact, free from debris and maintained to a standard that will minimise marine fauna entanglement;
- sea lion-proof “jump fences”, consisting of mesh netting with a breaking strain rating of at least 300 kilograms and suspended at a minimum of 2.4 metres above the waterline, are to encircle the sea cages to prevent sea lions from hauling out on the cage collar and breaching the barriers to access the sea cages;
- incorporating features such as “false bottom” anti-predator netting or predator-proof metal plate into the sea cage design to prevent sea lions and dolphins from accessing any dead stock at the bottom of the sea cages; and
- tensioning “anti-predator” netting as tight as practical to provide a buffer between the grow-out net and the anti-predator net to avoid any potential access from marine fauna.

5.0 Environmental Project Management

5.1 Induction and Training

Training and induction programmes provide personnel with an understanding of their environmental responsibilities and increase their awareness of the management measures required to reduce potential impacts on the environment. Personnel engaged in the construction and operation of the aquaculture farms are required to attend environmental inductions as part of their site inductions. These inductions will ensure that staff are aware of the importance of marine fauna conservation and emphasis the precautions that need to be observed by personnel to minimise interactions with marine fauna (e.g. sea lions and seabirds).

5.2 Code of Practice

The Aquaculture Council of Western Australia (ACWA) has developed a marine-based finfish Environmental Code of Practice, which has been designed to encourage environmentally-responsible behaviour in the aquaculture industry. This Environmental Code of Practice provides a mechanism to promote ecologically-suitable objectives in the industry and specifies the legal requirements; including the licence conditions imposed under the *Fish Resources Management Act 1994* (FRMA) and the MEMP annual reporting requirements. This document is regularly reviewed with respect to changes in government requirements or community values.

Aquaculture licence operators within the MWADZ area are obligated to operate within the guidelines provided in this Environmental Code of Practice document.

6.0 Monitoring, recording and reporting

6.1 Marine Fauna Monitoring - General

A daily record of all interactions with wildlife will be kept, as detailed below. The template provided in **Appendix 1** is to be used for recording all wildlife sightings, observations and interactions (two worked examples are also provided in this template). A copy of this template will be kept with the vessel log book on-board work vessels at all times. The following observations/interactions with wildlife must be recorded:

- the number of marine mammals, turtles, seabirds, large finfish (such as sharks) and other animals sighted in the area of the sea cages and their observed behaviours;
- all sightings of cetaceans, sea lions, turtles and any other species of conservation significance within 50 metres of the sea cages; and

- any specific interactions with wildlife, such as aggression by wildlife to aquaculture personnel, access of wildlife to sea cages, collision, entrapment, or entanglement of wildlife in aquaculture infrastructure will be recorded by personnel and reported to the site manager.

To enable identification of species of conservation significance, staff will have access to and be familiar with identification guides such as the Australian Fisheries Management Authority's (AFMA) Protected Species Guide (available at http://www.afma.gov.au/wp-content/uploads/2014/12/protected-species-id-guide.pdf and the Department of Parks and Wildlife (DPAW) marine wildlife guide of Southern WA http://www.dpaw.wa.gov.au/images/documents/conservation-management/marine/Marine_Life_of_Southern_WA.pdf. A copy of one of these guides will be kept on board work vessels along with binoculars to aid in the identification of any species of conservation significance sighted.

If turtles and marine mammals are frequently sighted within 500 metres of the sea cages or work vessel routes, a reduced speed will be adopted by work vessels.

If any wildlife is found entangled or entrapped in aquaculture equipment, the cause of interaction will be reviewed and maintenance and operational practices will be adjusted accordingly.

6.2 Marine Avifauna Monitoring - Specific

In addition to the requirements specified in section 6.1, the monitoring that will be undertaken for marine avifauna is as outlined below:

- Interactions between seabirds and sea cage infrastructure will be monitored daily using semi-quantitative approaches.
- An independent seabird expert will be present on site during the initial establishment of the sea cages and at intervals thereafter for the purposes of establishing baseline data and validating monitoring undertaken by fish farm staff.
- An independent expert will develop and facilitate a training program for fish farm staff to continue ongoing seabird monitoring. Particular attention will be paid to surface-feeding silver gulls and Pacific gulls, as well as to sub-surface feeders such as the pied cormorant and wedge-tailed shearwater.
- Responsibility for monitoring of seabird activity will be handed over to the fish farm crew after training. The independent consultant will provide an identification guide for this purpose.
- Fish farm staff will be required to record daily:
  - numbers and species of seabird in the vicinity (i.e. within 100 metres) of the sea cages;
  - types of seabird behaviour (e.g. roosting on floats, feeding on fish food, etc.);

- location and cause of any entanglement/entrapment incident and the seabird species involved; and
- incidents of seabirds colliding with any service vessel.

- Where multiple fish farms are operating within the MWADZ, data will be consolidated and shared in a common database. Results of the individual monitoring programs will be reported annually in the Annual Compliance Report submitted by each operator in the MWADZ.
- Based on the success of silver gull exclusion measures, the need to conduct ongoing broad-scale surveys of silver gull populations will be assessed after six and twelve months of operation in consultation with the Office of the Environmental Protection Authority (OEPA).

6.3 Incident Reporting and Response Strategy

6.3.1 Marine Mammals, Turtles and Other Marine Reptiles

The incident reporting and response strategies for incidents within the MWADZ relating to marine mammals, turtles and other marine reptiles include the following:

- All collision or entanglement incidents that may occur with marine fauna will be reported to the DPAW Wildcare Hotline on telephone number: (08) 9474 9055 and the Geraldton DPAW office within 24 hours of the incident occurring and the details of the incident, including the actions taken, will be documented.
- Any incident involving a marine mammal or turtle in distress, including those involving entanglement, collision or stranding, will be reported immediately to DPAW Wildcare Hotline on telephone number: (08) 9474 9055 and the Geraldton DPAW office within 24 hours of the incident occurring.
- Ongoing incidents of entanglement and/or breaching of sea cage netting/barriers will be reported to DPAW and an appropriate management response will be determined in consultation with Office of Environmental Protection Authority (OEPA) and the Department of Fisheries (DoF).
- If marine fauna is discovered distressed due to entanglement/entrapment in aquaculture infrastructure, then all reasonable efforts will be made by fish farm staff to untangle the individual animal. Staff will be encouraged to contact DPAW staff for advice prior to attempting to assist distressed animals. Staff will act only if safe to do so and will not, under any circumstances, put their own safety at risk to assist wildlife in distress.
- A list of emergency contact numbers will be displayed on-board service vessels and work platforms used to service the aquaculture farms.

6.3.2 Marine Avifauna

- Upon discovery of a distressed seabird (entangled or entrapped) in fish farming infrastructure, efforts will be made by staff to release the individual

bird if safe to do so. Entanglements/entrapments of seabirds in fish farming equipment will be reported DPAW Wildcare Hotline on telephone number: (08) 9474 9055 and the Geraldton DPAW office within 24 hours of the incident occurring.

- In the event of a collision between a seabird and aquaculture infrastructure, the following procedures will be followed:
  - Pick up the bird with a towel, keeping it lightly wrapped and the wings contained (folded in natural position against side of bird's body). Be aware of the sharp bill. Wear gloves and eye protection.
  - Place the bird in a well-ventilated cardboard box and place the box in a covered, quiet location.
  - Record and report the species, number, location found, likely cause of collision and any injuries.
  - Do not forcefully administer food or water via the bird's mouth.
  - If the bird has no obvious signs of injury, the bird may be released. The recommended approach is to take the bird to a quiet part of the vessel at dawn and release the bird in an area free from obstructions (masts, railings, wires, etc.) so that it may take off directly into the wind.

6.3.3 Sharks and Rays

The incident reporting and response strategies for incidents within the MWADZ relating to shark and ray species include the following:

- Operators should notify the Department in the event of an entanglement/entrapment by contacting the closest regional office. The report should detail the following information:
  - Species;
  - Size;
  - Location within infrastructure;
  - Behaviour (e.g. agitated).

  The Department will advise on a case by case basis how to best respond and, where necessary, assist in providing all relevant paperwork to allow the appropriate actions to be undertaken.
- If a shark or ray is discovered entangled/entrapped in aquaculture infrastructure, then all reasonable efforts will be made by fish farm staff to untangle the individual animal. However, aquaculture operators should only act if safe to do so and not, under any circumstances, put their own safety at risk.
- For ETP species, while there is no statutory requirement, all collision or entanglement incidents that may occur within Western Australian waters that involve sharks (or rays) listed under the Commonwealth EPBC Act should be reported to the DPAW Wildcare Hotline on telephone number: (08) 9474 9055 and the Geraldton DPAW office within 24 hours of the incident occurring.

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8.0 Appendix 1

Wildlife interaction and sightings template

General information							Species Details							Weather/sea conditions	
Sightings No.	**Date**	**Time** (24 hour)	**Animal seen from** (land/vessel/ sea cage)	**Latitude** (degrees and decimal minutes)	**Longitude** (degrees and decimal minutes)	**Your activity** (feeding/ net maintenance / transport)	**Species –** using identification guides	**How sure?** (very sure/ sure/ not sure)	**Total no of animals**	**Description of sighting and animals behaviour**	**Other animals present** (including fish, birds, etc.)	**Other notes**	**Photo /video taken ?** (Y/N)	**Sea State** (see Beaufort table below)	**Overall visibility**
1	30/1/15	08:45	Vessel	17 43 0 E	121 57 0 S	transport	Humpback whale	Sure	4	Breaching	Lots of small tuna	None	Yes	2	
2	2/4/15	12:30	Sea cage	14 52 0 E	121 60 0 S	feeding	Silver gulls	Very sure	50	Flying/circling over sea cages	none	Some birds attempting to access feed	No	3	
3															
4															

Sea state (Beaufort Number) descriptions

Beaufort Number	Wind Speed (knots)	Wind Description	Specification for use on land
0	Less than 1	mirror calm	Sea like a mirror
1	1 to 3	light air	Ripple with the appearance of scales are formed, but without foam crests
2	4 to 6	light breeze	Small wavelets still short, but more pronounced. Crests have a glassy appearance and do not break.
3	7 to 10	Small wavelets	Large wavelets. Crests begin to break Foam of glassy appearance. Perhaps scattered white horses.
4	11 to 16	gentle breeze	Small waves, becoming larger; fairly frequent white horses
5	17 to 21	Fresh breeze	Moderate waves, taking a more pronounced long form; many white horses are formed. Chance of some spray
6	22 to 27	Strong breeze	Large waves begin to form; the white foam crests are more extensive everywhere. Probably some spray
7	29 to 33	Near gale	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind
8	34 to 40	Gale	Moderately high waves of greater length; edges of crests begin to break into spindrift. The foam is blown in well-marked streaks along the direction of the wind.
9	41 to 47	Severe gale	High waves. Dense streaks of foam along the direction of the wind. Crests of waves begin to topple, tumble and roll over. Spray may affect visibility.
10	48 to 55	Storm	Very high waves with long overhanging crests. The resulting foam, in great patches, is blown in dense white streaks along the direction of the wind. On the whole the surface of the sea takes on a white appearance
11	56 to 63	Violent storm	Exceptionally high waves (small and medium-size ships might be for a time lost to view behind the waves). The sea is completely covered with long white patches of foam lying along the direction of the wind.
12	More than 63	Cyclone/hurricane	The air is filled with foam and spray. Sea completely white with driving spray; visibility very seriously affected

(Sourced from Worley Parsons 2008)

Mid West Aquaculture Development Zone

Waste Management Plan

Prepared by

Department of Fisheries, Western Australia

Version 2.0 – December 2015

TABLE OF CONTENTS

1. Introduction

1.1 Background

In late 2011, the Minister for Fisheries announced a funding package to enable the establishment of two regional aquaculture development zones to further aquaculture investment in Western Australia. The first of these, the Kimberley Aquaculture Development Zone in WA's northern waters, was officially declared in August 2014. The Mid West Aquaculture Development Zone (MWADZ), located in the southern part of the Abrolhos Islands Fish Habitat Protection Area, is the second proposed regional zone.

The proposal for the MWADZ was referred to the Environmental Protection Authority (EPA) in May 2013 which set the level of Environmental Impact Assessment (EIA) at Public Environmental Review (PER). The requirements of the EIA are defined in the Environmental Scoping Document (ESD, 2013) prepared by the EPA. The Minister for Fisheries is the proponent for the MWADZ and the Department of Fisheries (Department) is managing the proposal on his behalf. This document addresses the following ESD requirement:

'*A waste management plan to address all waste generated on site in addition to potential fuel and oil spills. This plan must include fish processing waste, dead fish and sewage treatment'*.

1.2 Purpose and Scope

Aquaculture activities produce a variety of waste products, both biological and non-biological. The Waste Management Plan (WMP) for the MWADZ intends to provide high level guidance to waste management within the MWADZ only[1].

The purpose of this WMP is to identify, describe and provide guidance on the:

- various waste products that are common to aquaculture facilities, including general rubbish and sewage treatment;
- potential fuel and oil spills, including appropriate action and reporting; and
- disposal of biological waste common to aquaculture facilities (e.g. processing waste and mortalities/culls) including appropriate biosecurity considerations.

The WMP is designed to forecast the overall waste management requirements within the zone. Individual operators will be required to address specific waste management requirements where they fall outside this generic WMP for the zone.

[1] This WMP does not include any waste associated with the Abrolhos Islands reserve. Waste disposal on the reserve must be in accordance with the *Fish Resources Management Regulations 1995*.

1.3 Objectives

The following waste management objectives will be applied to the zone:

- Comply with applicable environment protection legislation.
- Comply with applicable fisheries legislation and best practices guidelines and codes.
- Minimise adverse effects to the marine environment.
- Minimise potential biosecurity risks from the zone.
- Minimise potential risks to human health.
- Adhere to the waste hierarchy framework (e.g. avoid, reduce, re-use and recycle waste where appropriate).

1.4 Project Overview

The MWADZ is located in the Abrolhos Islands Fish Habitat Protection Area (FHPA) between the Pelsaert and Easter groups of the Abrolhos archipelago, approximately 65km west of Geraldton. The zone comprises two areas, together totalling approximately 3,000 hectares. The Northern Area is located between the Easter and Pelsaert Island Groups and is approximately 2,200 hectares. The Southern Area is approximately 800 hectares (an existing aquaculture lease) and is located north of the Pelsaert Group (Figure 1).

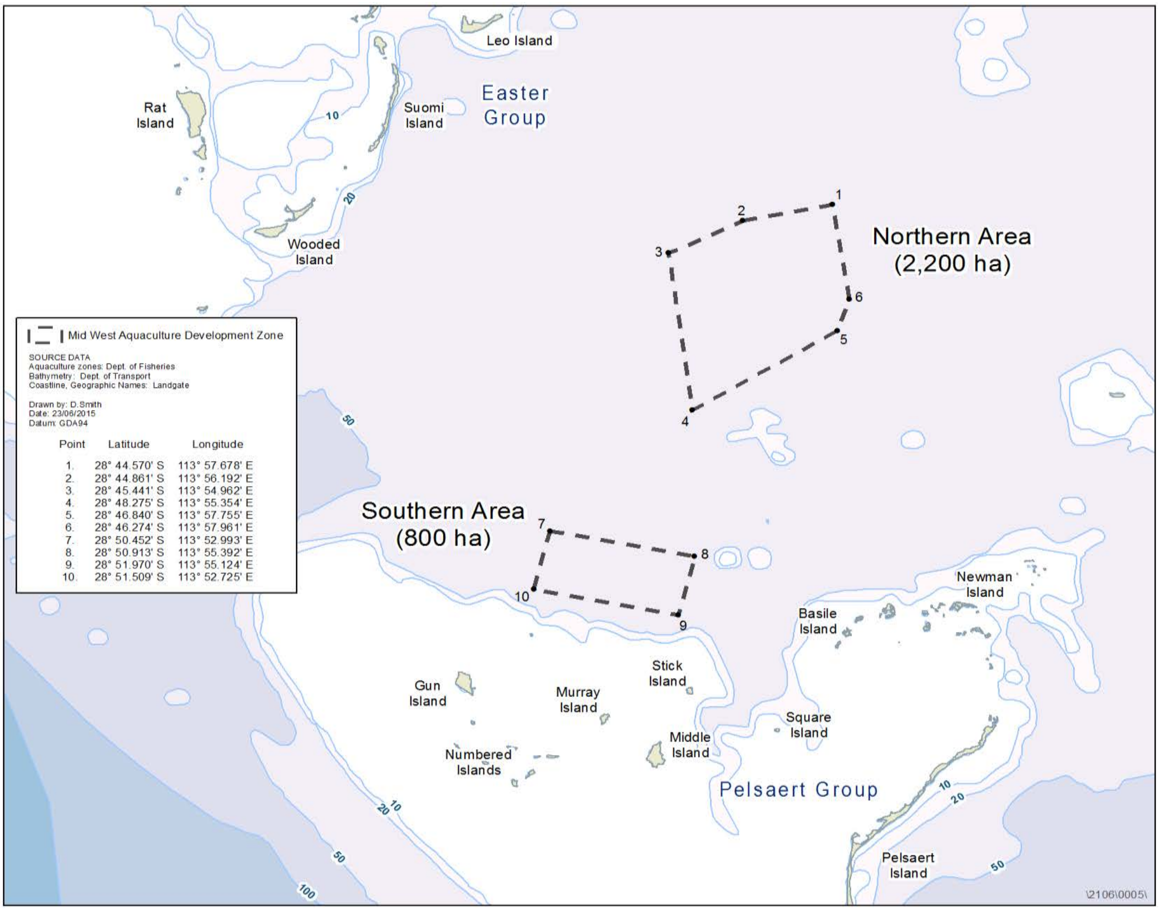

Figure 1: Location of the proposed Mid West Aquaculture Development Zone

There is no land-based component to the MWADZ.

2. Legislation and Policy Framework

Regulatory requirements in Western Australia for waste management in the marine environment are administered through a number of Acts, Regulations, Policies, Guidelines and Codes of Practice, including the:

- *Fish Resources Management Act 1994*
- Fish Resources Management Regulations 1995
- *Environmental Protection Act 1986*
- Environmental Protection Regulations 1987
- Environmental Protection (Unauthorised Discharges) Regulations 2004
- *Pollution of Waters by Oil and Noxious Substances Act 1997*
- *Health Act 1911*
- Marine Order 96 (Marine Pollution Prevention – Sewage) 2009
- *Protection of the Sea (Prevention of Pollution from Ships) Act 1983*

2.1 Specific Aquaculture Legislation and Policy Frameworks

Waste management procedures are required to be clearly documented in the statutory Management and Environmental Monitoring Plan (MEMP). The MEMP requirements have been developed with input from the EPA and the former Department of Environment and Conservation (DEC), including the Marine Parks and Reserves Authority (MPRA). Under s.92A of the *Fish Resources Management Act 1994* (FRMA) all applications for an aquaculture licence must be accompanied by a MEMP [unless exempt under s.92A(4)].

For operations within an Aquaculture Development Zone the following is required:

- EIA assessment by the EPA
- MEMP
- Ministerial Statement (Minister for Environment)
- EMMP (including this document)
- Aquaculture Development Zone Management Policy

In terms of waste management, MEMPs specifically require operators to *inter alia* address:

- Waste and waste water management (including biosecurity procedures)
- Disposal of waste
- Quarantine and disease-testing management (including recovery of sea cage mortalities) (DoF, 2013 MEMP Guidance Statement)

Separate from the legislative management framework outlined above, the Aquaculture Council of Western Australia (ACWA) has developed an updated Environmental Code of Practice for the Sustainable Management of Western Australia's Marine Finfish Aquaculture Industry (CoP).

An industry initiative, the CoP focuses on best practice through a documented environmental management system. It recommends a continual improvement requirement by the business through periodic reviews and evaluations to identify and implement opportunities for improvement.

Among its other objectives, the CoP provides a mechanism for environmental self-regulation of the marine finfish aquaculture sector as a valuable alternative to detailed regulation of every aspect of the industry's activity. It could also lead to the development of a system of environmental accreditation.

While the CoP is associated with the zone management policy, it is not a requirement under legislation. Compliance with it is voluntary, not mandatory. Therefore, it is considered to be outside (but supportive of) the legislative management framework.

3. Best Practice Management

3.1 General

All operators, staff and contractors are required to comply with this WMP, facility-specific requirements through the MEMP process and other applicable environmental protection legislation. Adherence to best practice guidelines, including the ACWA Environmental Code of Practice, is actively encouraged.

In line with the EPA's Guidance for the Assessment of Environmental Factors Implementing Best Practice in proposals submitted to the Environmental Impact Assessment process No. 55 (EPA, 2003) the Department strongly encourages the use of the Waste Hierarchy:

1. Avoidance of waste production;
2. Reuse of wastes;
3. Recycling wastes to create useful products;
4. Recovery of energy from wastes;
5. Treatment of wastes to render them benign;
6. Containment of wastes in secure, properly managed structures; and
7. Disposal of waste safely in the long term.

However, any reuse or recycling of aquaculture facility products must be done in accordance with biosecurity procedures.

3.2 Instruction and Training

All staff and contractors at individual operations will be provided with a copy of the WMP and MEMP and receive an onsite induction on waste management, including appropriate biosecurity handling procedures.

4. Minimising Waste

The minimisation of all waste within the zone will be encouraged. More specifically, beyond the avoidance of waste production, materials fall into three main categories for waste management purposes:

1. Reuse

Off cuts, spare netting, ropes, etc. that can potentially be used in future operations or for repair should be appropriately decontaminated and labelled and stored for future use.

2. Recycle

Materials that cannot be used in their present form but could potentially be used for other purposes should be appropriately decontaminated, labelled, recorded and stored for future reference.

3. Landfill on the mainland

If materials cannot be reused or recycled they must be returned to the mainland and disposed of in landfill under the appropriate council permits. See individual sections of this WMP for the disposal of biological wastes.

5. Waste Management within the MWADZ

This WMP outlines the overarching waste management procedures that govern all aquaculture operations that occur within the MWADZ. Derived proposals (i.e. individual operations within the MWADZ) will also be required to comply with the waste management requirements within their individual MEMPs.

An annual systematic review of individual facilities should be undertaken to further develop and improve WMPs.

5.1 Fish Feed and Fish Faeces

Fish feed and fish faeces waste from marine based aquaculture can potentially have a significant impact on the environment. This is particularly true where there are low currents, tides and wave amplitude that, in turn, drive minimal water exchange.

The zone location has been chosen to take advantage of the relatively deep, clean, well-flushed waters and open sandy sea floor between the Pelsaert and Easter groups of the Abrolhos Islands. However, the risk of waste accumulation for any aquaculture operation needs to be managed.

To address this issue, fish feed and faeces waste should be managed according to best-practice techniques, including:

- Rotation of stock
- Fallowing or resting of sites
- Stocking densities appropriate to site water flow, depth and sediment type characteristics
- Appropriate feeding methods to minimise over feeding

Operators will be required to address the management of feed and faeces waste in relation to their specific activities and level of operation. Detailed management arrangements and mitigation measures must be addressed in the MEMP and approved by the Department prior to the commencement of operations.

5.2 Stock Mortalities and Culls

All aquaculture operations experience stock mortality and/or harvest of unsaleable stock. Disposal of dead fish also requires consideration of appropriate biosecurity handling procedures (see section 6).

To discourage scavenging or predation by marine fauna, dead stock will be removed from sea cages on a daily basis and disposed to landfill on the mainland in accordance with waste management authority (City of Geraldton) regulations. Under no circumstances is biological waste to be disposed of at sea.

To minimise mortality, the following control techniques should be implemented:

- Minimise stock stress during inspections and dead stock collection.
- Implement a Veterinary Health Plan and promptly address any health or welfare problems (in consultation with fish health experts where appropriate).
- Maintain complete records of each inspection, including number of mortalities removed and likely cause of death (determined by appropriately-competent person). Mortalities can then be subtracted from total population to maintain population estimates.

- Daily removal (weather permitting) and disposal of dead or moribund (wounded or sick) stock to ensure predatory species are not attracted to the farm as well as limit any risk of disease spread.

5.3 Harvesting and Processing Wastes

The only processing permitted to be undertaken at sea is harvesting, slaughtering, bleeding, washing and chilling of fish. Any additional processing must take place at an approved facility on land. All organic waste, including blood, is prohibited from disposal at sea under Regulation 62 of the Fish Resources Management Regulations 1995.

Organic waste, including blood water, must be sealed in watertight containers, taken to the mainland and disposed of in landfill under the relevant waste authority regulations.

5.4 Sewage

Sewage must be either:

- treated, using a sewage disposal system approved by the Department of Health, prior to disposal at sea in accordance with the Department of Transport's Strategy for Management of Sewage Discharge from Vessels into the Marine Environment 2015 (Strategy); or
- stored in tanks on the vessel and disposed of on land at a licensed disposal site in accordance with Local Government Authority by-laws.

Under the Strategy, no discharge of sewage from vessels (either treated or untreated) is permitted within Zone 1 (as defined in the Strategy) fish habitat protection areas where the dilution/dissipation factor is deemed unsatisfactory.

The MWADZ location has specifically been chosen for its high level of water exchange and, as such, is likely to fall under Zone 2 of the Strategy. This means discharge is only permitted from vessels with approved treatment systems.

As part of the broader Abrolhos Islands Management Plan, a WMP is being developed to cover the combined Abrolhos Islands Reserve and the surrounding FHPA. If necessary, the MWADZ WMP and the content of MEMPs associated with operators within the zone will be amended to reflect any additional requirements specified in the Abrolhos-wide WMP.

5.5 Rubbish and Pest/Scavenger Control

Waste material (e.g. empty feed bags, old ropes, floats, net mesh and any other discarded equipment, as well as staff domestic waste such as food scraps, papers, plastic packaging, etc.) must be placed in sealed waste containers and/or securely stowed on board the vessel and disposed of in landfill on the mainland in accordance with the relevant waste management regulations (City of Geraldton as the waste management authority). Such waste should be removed daily to prevent local build-up of material that can attract pests (e.g. insects) and scavengers (e.g. silver gulls).

Marine debris can be harmful to the environment and farm staff must ensure it is disposed of correctly. Similarly, if marine debris is sighted within or around the aquaculture operation, its collection and disposal is an environmental responsibility to be met by all operators.

5.6 Oil and Oily Waste

To reduce the potential for oil and oily wastes (including fuel) generated through vessel operations to enter the environment, any used oil or oil-soaked absorbents must be securely stored in tanks on the vessel and disposed at an appropriately-licensed oil recycling facility (available at most mainland ports). Containers used to transport such wastes must be sealed and secured for the duration of their relocation.

If oil or oily waste is discharged into the marine environment, licence holders must immediately report the marine oil spill to the Department of Transport (DoT) on (08) 9480 9924 (24-hour reporting number) or e-mail (marine.pollution@transport.wa.gov.au.).

Should an oil spill occur, do not pour anything onto the oil. If a marine oil spill kit is on hand it may be possible to mop up the spill with absorbent pads and contain it.

Refer to the DoT website (http://www.transport.wa.gov.au/imarine/report-marine-pollution-and-oil-spills.asp) for further information regarding requirements for oil spill or pollution situations.

5.7 Biofouling

Removal of marine fouling from sea cages may be undertaken *in situ* using physical or mechanical methods; or achieved by removing the nets and drying/cleaning on the mainland.

If operators choose to clean sea cages on site within the MWADZ, it is recommended this be done on a very regular (almost continuous) basis so as to prevent any heavy accumulation of biofouling that could translate to a correspondingly heavy release of biological material into the water column when removed from the aquaculture gear.

A regime of regular biofouling removal optimises the flow of water through the sea cages (with resulting benefits to the aquaculture stock) and reduces the potential for any marine pest to become established.

The *National Biofouling Management Guidelines for the Aquaculture Industry* (http://www.marinepests.gov.au/marine_pests/publications/Pages/national_biofouling_management_guidelines_aquaculture_industry.aspx) should be referred to for further information on recommended approaches for control of biofouling to minimise the spread of exotic species that may associated with moving aquaculture stock and equipment.

6. Biosecurity

Biosecurity is a specific concern for the disposal of biological wastes, particularly in the case of unexplained stock mortality.

Fisheries legislation requires all aquaculture licence holders [unless exempt under section 92A(4)] to have a MEMP, which includes biosecurity procedures. All licence holders operating within the zone will be required to have an approved MEMP for their operation that has been developed in accordance with the "*Aquaculture Management and Environmental Monitoring Plan (MEMP) Guidance Statement*" (www.fish.wa.gov.au/Documents/Aquaculture/memp_guidance_statement.pdf) that is available on the Department's website at www.fish.wa.gov.au.

Biosecurity procedures must include, but are not limited to:

- record keeping (such as translocation approvals, health certificates, disease management records, fish escape reports, unusual mortality reports, internal and external stock transfers, facility and stock inspections, facility access records for staff and visitors);
- aquaculture gear and vessels used (such as maintenance, disinfection and inspections);
- biosecurity emergency procedures;
- disposal of waste (such as dead fish, diseased, contaminated or infected fish stocks);
- disease testing protocols and quarantine; and
- management of fish escapes.

The Department has a Fish Health Unit that provides a range of services to investigate the health problems of wild and farmed fish stocks, including 'fish kills' or sudden mortalities. In the event of large unexplained mortalities, licensees must contact the Fish Health Unit (see section 7.2) and assist them to determine the cause of death and degree of risk posed by such deaths. This includes collecting key data and samples to allow a thorough investigation into the cause of the fish kill.

To minimise the risk of potential transfer of disease through either carcasses or equipment, the following basic protocols should be adhered to:

- Biological material should be separated from other waste and kept away from water bodies and other contaminates pathways to minimise the risk of spreading pathogenic agents.
- Personnel should maintain appropriate hygiene procedures including the use of safety gear (e.g. gloves).
- In the event of a fish kill, key data and samples should be stored to allow a thorough investigation.
- No disposal of stock mortalities or culls at sea (it is an offence under the *Environmental Protection Act 1986* to do otherwise). All stock mortalities must be placed in sealed containers for transport, returned to the mainland and disposed of in landfill according to local waste authority regulations.

The zone will be treated as one biosecurity unit due to the relative close proximity of aquaculture operations and the physical environment within the Zeewijk Channel.

6.1 Disease Management

Disease prevention, rather than treatment, is vital in any aquaculture operation; but even more so in an aquaculture zone where aquaculture operations may be located in close proximity to one another.

The following management strategies will be implemented to minimise the risk of a fish disease outbreak. In addition to the procedures and protocols outlined in individual MEMPs, licence holders must comply with the following minimum requirements:

- stock (fish) must be marine finfish of a species that occurs naturally within the Mid West region (a condition of the Ministerial Statement);
- all stock, other than brood stock sourced under permit from the wild and taken in the Mid West region, must be certified disease-free and accompanied by a health certificate issued by the Department before being moved into the zone;
- a stock health surveillance program and quarantine procedures must be implemented; and
- a biosecurity manager for each operation must be appointed and responsible for ensuring biosecurity measures are implemented.

In the event of a disease outbreak:

- the licence holder must report the outbreak (according to section 7.2 below);
- any pharmaceuticals such as antibiotics that are used must be prescribed by a veterinarian or approved by the Australian Pesticides and Veterinary Medicines Authority and administered in accordance with the recommended dosages;
- stock must not be moved without the written approval of the Principal Research Scientist in the Department's Fish Health Unit;
- vessel movements between individual sites is to be restricted;
- disinfection of equipment, vessels and barges down to and including the waterline should be done prior to movement and in accordance with the CoP; and
- any other aquaculture operators within the zone must be informed immediately.

7. Reporting

7.1 General Reporting Requirements

In accordance with MEMP requirements, licence holders are required to submit a MEMP Report to the Department annually. These reports include:

- monitoring results undertaken as components of the MEMP compliance requirements;
- summary of any significant exceedance of environmental monitoring values (as defined in the EMMP);
- reactive management actions;
- biosecurity measures implemented/issues;
- chemical usage; and
- marine fauna interactions.

Individual licence holders will report any injury or entanglement of rare or protected fauna immediately to DPaW[2].

7.2 Biosecurity/Incident Reporting Requirements

Licence holders within the MWADZ will report incidents to the Department by calling (08) 9482 7333 or by email to aquaculture@fish.wa.gov.au or biosecurity@fish.wa.gov.au within 24 hours of:

- any suspected escape from a fish farm, or circumstances which gives rise to a significant risk of escape;
- all unusual mortalities (noting the Regulation 69 requirements outlined below); and
- any exceedance of an environmental monitoring threshold value.

[2] Refer to the MWADZ Marine Fauna Interaction Plan.

Disease reporting requirements are stipulated in Regulation 69(d), (e), (f), (g) and (h) of the Fish Resources Management Regulations 1995 (FRMR). All employees of operators within the zone must be aware of these regulations, which are intended to provide for adequate monitoring and adaptive management of any emerging disease risks.

Under Regulation 69, aquaculture licence holders must notify the CEO of the Department in writing within 24 hours of becoming aware or suspecting that fish may be affected by any disease. Any material, significant or unusually high fish mortalities must be reported, as they may be caused by disease. To minimise the interval between the CEO first being notified of suspected disease outbreaks and the CEO giving directions appropriate to each incident in response, aquaculture licence holders must provide details of the disease outbreak, or suspected disease, as soon as possible (but within the prescribed timeframes) by e-mail to each of the following:

- fishhealth1@fish.wa.gov.au; and
- aquaculture@fish.wa.gov.au; and
- biosecurity@fish.wa.gov.au

The e-mails should have the subject heading: “NOTIFICATION TO CEO UNDER REG 69.”

E-mail notifications to each of these three addresses within the prescribed timeframes meets the requirements of both this management policy and those of Regulation 69.

8. References

Environmental Scoping Document Mid West Aquaculture Development Zone Assessment No. 1972, Environmental Protection Authority, 24 July 2013

Environmental Code of Practice for the Sustainable Management of Western Australia's Marine Finfish Aquaculture Industry; ACWA/DoF, 2013

Aquaculture Management and Environmental Monitoring Plan Guidance Statement, Department of Fisheries, August 2013.

Fish Kill Incident Response Manual Department of Fisheries/Department of Water

Environmental Protection Authority Guidance for the Assessment of Environmental Factors Implementing Best Practice in proposals submitted to the Environmental Impact Assessment process No. 55 December 2003

Aquatic Animal Health Code

Tucker, C.S & Hargreaves, J.A. Eds *Environmental Best Management Practices for Aquaculture – Facilities Operation and Maintenance pages 316 – 320* Blackwell Publishing, 2008.

GOVERNMENT OF
WESTERN AUSTRALIA

Environmental Protection Authority

Mr Stuart Smith
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Department of Fisheries
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Cloisters Square
PERTH WA 6850

Our Ref: EA07-2013-0003
Enquiries: *Mike Pengelly 6145 0815*
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Stuart

Dear ~~Mr Smith~~

PROJECT NAME: MID WEST AQUACULTURE DEVELOPMENT ZONE
ASSESSMENT NO: 1972
LEVEL OF ASSESSMENT: PUBLIC ENVIRONMENTAL REVIEW – STRATEGIC PROPOSAL

The Environmental Scoping Document (ESD) (Final July 2013) specifying the scope and content of the Public Environmental Review (PER) document for the above proposal was considered by the Environmental Protection Authority (EPA) at meeting number 1054 on 18 July 2013. The ESD has been approved as providing an acceptable basis for the preparation of the PER document.

Guidelines for preparing a PER document are available on the EPA website (www.epa.wa.gov.au).

During the preparation of the PER you are encouraged to consult with Mike Pengelly, the Office of the Environmental Protection Authority assessment officer for the project, who can be contacted on telephone number 6145 0815.

Yours sincerely

P Vogel

Dr Paul Vogel
CHAIRMAN

24 July 2013

ENVIRONMENTAL SCOPING DOCUMENT

PROPOSAL:	**Mid West Aquaculture Development Zone (Assessment No.1972)**
LOCALITY:	**Mid West - Offshore WA Waters, Within the Region of the Abrolhos Islands**
PROPONENT:	**Department of Fisheries**
LEVEL OF ASSESSMENT:	**Public Environmental Review with a 4 week public review period**

This Environmental Scoping Document (ESD) is provided to define the requirements of the Public Environmental Review (PER) document to be prepared in accordance with the Western Australian *Environmental Protection Act 1986* (EP Act).

The preliminary key environmental factors to be addressed in the PER document are identified in Section 2. The generic guidelines for the format of an environmental review document are available at the Environmental Protection Authority's (EPA's) website www.epa.wa.gov.au.

The Public Environmental Review document must adequately address all elements of this scoping document prior to approval being given to commence the public review.

1. Introduction

The *Environmental Protection Act 1986* (EP Act) sets out that where a proposal is considered to have a significant environmental impact it will be subject to an assessment by the EPA under section 38 of the EP Act. The EP Act also provides for the assessment of a strategic proposal, which is a future proposal (or a number of future proposals implemented together) that may in combination have a significant effect on the environment. A strategic proposal is normally assessed by the EPA at the level of Public Environmental Review (PER).

The desired objective of assessing a strategic proposal is to identify all potential significant environmental impacts and management as early as possible, and provide for greater certainty to local communities and proponents over future development, improved capacity to address cumulative impacts at the landscape level and flexible timeframes for consideration of environmental issues.

If it is agreed that a strategic proposal may be implemented, a Ministerial Statement for the strategic proposal is published.

Future Proposals will be managed in accordance with Section 11 of the *Environmental Impact assessment (Part IV Divisions 1 and 2) Administrative Procedures 2012.*

Where a proposal is subject to PER, the proponent is required to produce a PER document in accordance with an approved Environmental Scoping Document (ESD). The purpose of the ESD is to:

- develop proposal-specific guidelines to direct the proponent on the key environmental issues for the strategic proposal that should be addressed in preparing the PER document; and
- identify the necessary impact predictions for the strategic proposal, and the information on the environmental setting required to carry out the assessment.

The EPA has determined that it will prepare and issue the ESD outlining the scope and content of the PER in relation to this proposal.

The EPA, in its formulation of the ESD, undertakes consultation with the proponent regarding the details of the proposal, its environmental setting and the environmental surveys and investigations required and expected outcomes. In addition the EPA will consult with the relevant government agencies, including Decision Making Authorities. The Office of the EPA (OEPA) provides services and facilities for the EPA. In many cases the OEPA will act for the EPA.

The proponent will then be required to prepare a PER document in accordance with the ESD. When the EPA is satisfied that the PER document has adequately addressed all of the environmental factors and studies identified in the ESD, the proponent will be required to release the document for a public review period of 4 weeks.

ESDs prepared by the EPA are not subject to a public review period. The ESD will be available on the EPA website (www.epa.wa.gov.au) upon finalisation and must be included as an appendix in the PER document.

The EPA considers that adequate consultation can be demonstrated when the stakeholders:

- are included in the consultation process and are able to make their concerns known;
- are kept informed about the potential and actual environmental impacts; and
- receive responses to the concerns raised, including identifying how the proposal has been modified and/or identifying management measures that will be implemented to address the concerns raised.

To facilitate adequate public input, the PER document should be made available as widely as possible and at a reasonable cost.

2. Specific Guidelines for the Preparation of the Environmental Review

The objectives of this assessment are to identify an environmentally acceptable location for the Mid West Aquaculture Development Zone(s) and to identify the operational limits and objectives to apply to future proposals in the Zone(s) to manage the cumulative impacts of multiple sea cage operations.

2.1 The strategic proposal

The Department of Fisheries, on behalf of the Minister for Fisheries proposes to create an 'Aquaculture Development Zone' to provide a management precinct for prospective future aquaculture proposals within State Waters, approximately 75 kilometres west of Geraldton within the Fish Habitat Protection Area of the Abrolhos Islands. The strategic proposal area has been selected by the proponent to maximise suitability for marine finfish aquaculture, and minimise potential impacts on existing marine communities and disruption to existing human use.

The strategic proposal, also known as the Mid West Aquaculture Development Zone (MWADZ), is proposed to encompass an area of 3000 hectares (ha) within the identified 5,200 ha study site (Attachment 1). The study site comprises two areas:

- a 4400 ha area located in Middle Channel, between the Easter Group and Wallabi Group; and
- a 800 ha study area located in Zeewijk Channel, between Pelsaert Group and Easter Group of the Abrolhos Islands.

2.2 Future Proposals

In assessing a strategic proposal, the EPA should be able to reasonably conclude at an appropriately high level that the future proposal(s) could be implemented without significant deleterious impacts on the environment.

At this time it is understood that the MWADZ will provide the management framework for future proposals, which would likely include the development of infrastructure such as sea cage systems, including grids to support multiple cages in the water column and aquaculture of marine fin fish species which naturally occur within the Mid West bioregion of WA. No processing other than preliminary post-harvest activities, such as icing, is proposed. There are no land based components to this strategic proposal.

With regard to the finfish species that would be likely to be considered for use, the Department of Fisheries has advised that for a range of species of marine finfish the farming technologies and management methods are much the same.

It is expected the proponent will identify the strategic proposal including the identification of future proposals within the PER document, in accordance with *Environmental Protection Bulletin No. 17 "Strategic and derived proposals".*

Sufficient detail should be made available in the PER document to allow the EPA to clearly understand the likely characteristics of future proposals, and their associated impacts, that will result from the implementation of the MWDAZ. The following dot

points should be addressed to enable the EPA to confidently define the overall environmental outcomes that must be achieved:

- define, as far as possible, the key characteristics of the future proposals, recognising that the assessment may provide opportunities to refine these characteristics;
- define the maximum extent or limits to the scope of any future proposals (e.g. maximum capacity of each individual proposal);
- identify the key environmental factors associated with the future proposals, at a scale commensurate with the nature and extent of those future proposals;
- define the maximum disturbance (impact) footprint of the future proposals (terrestrial and marine) and the envelope within which any future proposals will occur;
- define the potential maximum cumulative environmental impacts and risks from the future proposals, and demonstrate the acceptability of those impacts/risks;
- define potential best practice management principles and strategies to be applied to any future proposal to avoid and minimise impacts to the greatest extent possible; and
- define the proposed governance of future proposals. This should include but not be limited to clearly setting out the legislative process and approval under the *Fish Resources Management Act 1994* that would apply to the establishment of the aquaculture zone and the licencing of the individual aquaculture operations within the zone.

2.3 Preliminary key environmental factors, scope of works and policy documents relevant to this proposal

The PER should give a detailed assessment of each of the preliminary key environmental factors identified for this proposal. At this stage, the Office of the Environmental Protection Authority (OEPA) believes the preliminary key environmental factors, objectives and work required is detailed in Table 1.

Table 1 also identifies a list of relevant policy documents for this proposal, which set out how the preliminary key environmental factors are to be considered. The EPA expects that the treatment of environmental factors will be consistent with the approaches set out in these policy documents.

Table 1: Environmental factors and scope of works relevant to the proposal

Marine Environmental Quality	
EPA objective	To maintain the quality of water, sediment and biota so that the environmental values, both ecological and social, are protected.
Potential Impacts	Potential impacts include: - Impacts to water and sediment quality through release of fish feed and faeces leading to nutrient and organic enrichment of the marine environment. - Impacts to water, sediment and biota quality through release of pharmaceuticals or metals/metalloids in fish feed into the marine environment.

Work required	- Document baseline water and sediment quality (over an approximate 12 month period) in the region of the strategic proposal area in order to effectively capture seasonal and spatial variability to the greatest extent possible, including the following parameters: - **Water** - nutrients, dissolved oxygen, phytoplankton community composition, chlorophyll *a*, total suspended solids (organic), H_2S and light attenuation coefficient. - **Sediment** - total nitrogen, total phosphorous, total organic carbon (TOC), redox, NH_3, DO, H_2S, sediment trace metal and organic concentrations. - **Note** – The OEPA consisiders that testing for baseline levels of H_2S in both sediment and water would only be required to be conducted once. - Accurate and validated modelling of surrounding hydrodynamics, to understand dispersion, deposition and accumulation of nutrients, trace contaminants, organic waste material and pharmaceutical/chemical wastes from the sea cages and any other associated infrastructure. Hydrodynamic and particle transport modelling should take into account factors such as tides, meteorological and seasonal ocean conditions and should be linked to the ecological modelling. - A clear and comprehensive description of the predicted cumulative environmental effects of the future proposals within the strategic proposal area operating at maximum capacity based on professional judgement and supported by ecological models that are relevant to the locality and linked to the hydrodynamic modelling. This should include impacts to biodiversity; abundance and biomass; water, sediment and biota quality and ecosystem processes. The proponent must demonstrate a good understanding of the natural rates and types of ecological processes operating in the area and evaluate the possible extent and severity of any changes to the types and/or rates of processes under best case, worst case and most likely case scenarios. This should include the development of a nutrient budget with and without the potential strategic proposal and future proposals to use as a tool to assess changes in variables such as loading, feeding regimes, assimilation capacity and FCRs etc. The assessment must address the cumulative effects of all elements of the strategic proposal. The documentation should also include a review of the suitability and applicability of the models, and the interpreted outputs of the models, by an independent expert. - Predicted changes in sediment characteristics, both physically (e.g. organic content and TOC) and chemically (e.g. nutrients, H_2S, metals, DO, redox discontinuity) under the most likely or indicative cage locations and configurations to the outer boundary of the zone of reversible impact, for best, worst and most possible case. - Develop an environmental quality management framework (EQMF) for the strategic proposal, and to apply to future proposals, based on the recommendations and approaches in Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC & ARMCANZ, 2000) and State Water Quality Management Strategy Report 6 (It is an expectation that the Department of Fisheries would liaise with the OEPA regarding this framework). The framework is underpinned by defining the environmental values to be protected, identifying the environmental concerns or threats and establishing the environmental quality objectives (EQO) and levels of ecological protection to be achieved and where they apply spatially (these should be included in a detailed map). (Note that the effects on environmental quality and biota are linked.) This establishes a framework for the EIA of the strategic proposal as well as for managing the ongoing operations from future proposals. - Develop cause/effect pathway models for nutrient and organic enrichment, sedimentation and other relevant environmental issues of concern. - A draft Environmental Monitoring and Management Plan (EMMP) for the

	proposal which includes the practical implementation of the EQMF. The parameters (environmental indicators) selected for monitoring will be based on the environmental quality objectives to be achieved, the identified environmental concerns/threats, cause/effect pathways and local constraints. EQG and EQS should be defined for each environmental issue of concern based on the level of ecological protection to be achieved and the recommended approaches from ANZECC and ARMCANZ (2000). - The draft EMMP needs to ensure environmental quality and ecological integrity are being maintained within acceptable limits when production reaches maximum capacity. The draft EMMP therefore needs to include a description of the monitoring protocols for each parameter, the proposed methodologies for interpreting the monitoring data and comparing against the EQG and EQS, the possible management actions that will be triggered if monitoring indicates that the EQOs are not being achieved and reporting procedures. The EMMP must also incorporate monitoring for any other environmental issues of concern identified through an environmental risks analysis of the strategic proposal. - A waste management plan to address all waste generated on site in addition to potential fuel and oil spills. This plan must include fish processing waste, dead fish and sewage treatment.
Relevant policy/guidance documents	- *National Water Quality Management Strategy* Report 4. - EPA (2002*) Implementation Framework for Western Australia for the Australian and New Zealand Guidelines for Fresh and Marine Water Quality and Water Quality Monitoring and Reporting* (Guidelines Nos 4 & 7: National Water Quality Management Strategy). - EPA (2004) *A framework to guide the development of environmental monitoring programs for marine aquaculture in seagrass dominated coastal environments in South Australia.* - EPA (2009) Environmental Assessment Guideline No. 3 – *Protection of Benthic Primary Producer Habitats in Western Australia's Marine Environment.*

Benthic Communities and Habitat	
EPA objective	To maintain the structure, function, diversity, distribution and viability of benthic communities and habitats at local and regional scales.
Potential Impacts	Potential impacts include: - direct disturbance or loss through the installation of anchors, wire sweep (deviation to the span of cables), mooring blocks and dragging nets; - direct and indirect impacts or loss through uneaten feed and faeces causing nutrient and organic enrichment of the marine environment leading to shading, smothering, deoxygenation or potential disease of benthic communities and habitats.
Work required	- Design and conduct a geo-referenced benthic habitat survey with the objective of mapping accurately the spatial extent of benthic habitats (including corals, macro-algae, seagrass, mangroves, filter feeders, microphytobenthos and presence of sediment infauna communities) and defining local assessment units to assess permanent loss of BPPH (in the context of EAG 3). Benthic habitat mapping should at least extend to the outer boundary of the area where both irreversible and reversible effects on biota are predicted to occur and extend into the zone of influence. - Predict and spatially define zones of high impact (irreversible loss of abundance/biomass or diversity of biota or ecological processes), moderate impact (reversible loss of abundance/biomass or diversity of biota or ecological processes within 5 years) and influence (changes in environmental quality or physiological stress, but no loss of biota or ecological processes) likely to result from the strategic proposal, and therefore the boundary beyond which there will be no effect. These zones need to be derived at maximum capacity and most

	likely pen configuration and accurately mapped to represent the aquaculture zone's footprint. This information will inform the future proponents when selecting the locations and numbers of potential impact sites and un-impacted reference sites.
Relevant policy/guidance documents	- EPA (2009) Environmental Assessment Guideline No. 3 – *Protection of Benthic Primary Producer Habitats In Western Australia's Marine Environment.* - EPA (2011) Environmental Assessment Guideline No. 7 – *Marine Dredging Proposals.* (Although the proposal doesn't involve dredging the principles of this EAG can be applied when assessing impacts to primary producing and non-primary producing communities and habitat.)

Marine Fauna	
EPA objective	To maintain the diversity, geographic distribution and viability of fauna at the species and population levels.
Potential Impacts	- Potential impacts to marine fauna from disturbances such as noise (during construction and operation), lighting, vessel strike and human interaction, entanglement and physical barriers imposed by infrastructure. - Potential impacts on seabirds through changes to population levels, levels of available food and predation. - Potential impacts on wild fish populations, habitats and genetic diversity through introduction of pathogens and parasites, escaped fish and discharge of uneaten feed, faeces and pharmaceuticals. - Potential impacts on fisheries and fisheries production.
Work required	*Marine mammals, seabirds and other significant marine fauna* - Identify and assess the values and significance of marine faunal assemblages within the strategic proposal area and immediate adjacent area and describe these values in a local, regional and State context. - Identify critical windows of environmental sensitivity for seabirds, marine mammals, including the Australian Sea Lion (*Neophoca cinerea*), other significant marine fauna and key fisheries in the strategic proposal area and immediate adjacent area. - Describe the presence of marine mammals, including the Australian Sea Lion (*Neophoca cinerea*), seabirds and other significant marine fauna in the proximity of the strategic proposal area and document any known uses of the area by them (e.g. foraging, migrating, calving and nursing etc). - Design, detail and conduct a targeted survey for seabirds. The survey should target the distribution, nesting and roosting habits of all locally relevant seabird species with consideration of survey timing to meet suitable weather conditions, time of day and season for presence of seabirds. - Identify the construction and operational elements of the proposal that may affect significant fauna and fauna habitat. - Describe and assess the potential direct and indirect impacts that may result from construction and operation of the proposal to marine mammals, including the Australian Sea Lion (*Neophoca cinerea*), seabirds and other significant marine fauna and their habitat. - Identify measures to mitigate adverse impacts on marine mammals, including the Australian Sea Lion (*Neophoca cinerea*), seabirds and other significant marine fauna and their habitat so that the EPA's objectives can be met. - Describe possible management options to address potential impacts on marine fish populations, marine mammals, including the Australian Sea Lion (*Neophoca cinerea*), seabirds and other significant marine fauna and the surrounding environment. This must include but is not limited to: uneaten feed, marine parasites, biofouling control methods and interaction or entanglement with marine fauna (through development of a marine fauna interaction plan).

	Biosecurity - Describe translocation, biosecurity and management arrangements addressing: fish disease/pathogen (including parasites) management and incident response, strategies for preventing outbreaks and/or preventative treatments chemicals to escape into the surrounding environment; brood stock and translocation issues; and prevention and management of escaped fish. *Fisheries* - Describe commercial and recreational fishing activity in the Northampton region and Abrolhos Islands that may be affected by the proposal. - Describe and assess the potential direct and indirect environmental impacts on recreationally and commercially important marine species, including impacts to migratory patterns, spawning areas and nursery areas.
Relevant policy/guidance documents	*National Biofouling Management Guidance for Non-trading Vessels* (Commonwealth of Australia, 2009). *Wildlife Conservation Act 1950.*

These preliminary key factors must be addressed within the environmental review document for the public to consider the impacts of the proposal and proposed management, and make comment to the EPA. All technical reports, modelling and referenced documents (not currently in the public domain) used in the preparation of the PER document should be included as appendices to the document. Documents used in the preparation of the PER must not contain disclaimers that preclude their public availability.

2.4 Other Environmental Issues

The EPA expects the proponent to take due care in ensuring all other relevant environmental factors and impacts which may be of interest to the public are addressed and that management is covered in the environmental review. For example, Heritage is another environmental factor that should be discussed in the PER.

If during the course of the preparation of the PER document other potential environmental matters or environmental factors are identified, the OEPA should be consulted to determine whether they are to be addressed in the PER document.

2.5 Agreed Assessment Milestones

EPA Environmental Assessment Guideline No. 6 "Timelines for EIA of Proposals" addresses the responsibilities of proponents and EPA for achieving timely and effective assessment of proposals.

This timeline (Table 2) is agreed between the EPA and proponent. Proponents are expected to meet the agreed proposal assessment timeline, and in doing so, provide adequate, quality information to inform the assessment. Proponents will need to allocate sufficient time to undertake the necessary studies to the appropriate standard and incorporate the outcomes of the studies into the PER.

Where an agreed timeline is not being met by the proponent, or if adequate information is not submitted by the proponent, the timeline for subsequent steps will be re-established. Where the OEPA is unable to meet a date in the agreed timelines the proponent will be advised and the timeline adjusted.

The EPA will report to the Minister for Environment on whether the agreed proposal assessment timeline has been met. Where the timeline has not been met, the reasons for this will be identified.

Table 2: Agreed Milestones for the proposal

Key Stage of Proposal	**Agreed Milestone**
EPA approval of ESD Document	July 2013
Proponent submits first adequate draft of PER Document	December 2014
OEPA provides comment on first draft PER Document	6 weeks*
Proponent submits adequate revised draft PER Document	February 2015
EPA authorises release of PER Document	2 weeks
Proponent releases approved PER Document	March 2015
Public Review of PER Document	4 weeks
Response to Public Submissions	May 2015
OEPA assesses proposal for consideration by EPA	7 weeks
Preparation and finalisation of EPA Report (including 2 weeks consultation on draft conditions with proponent and key Government agencies)	5 weeks from receipt of final information

*Note - if the document is received over the Christmas period the timeline may be required to be adjusted to reflect availability of Government Agency's to provide advice during this period.

2.3 Decision Making Authorities

At this preliminary stage, the EPA had identified the following Decision Making Authorities (DMAs) (see Table 3). Throughout the assessment process further DMAs may be identified.

Table 3: Nominated Decision Making Authorities

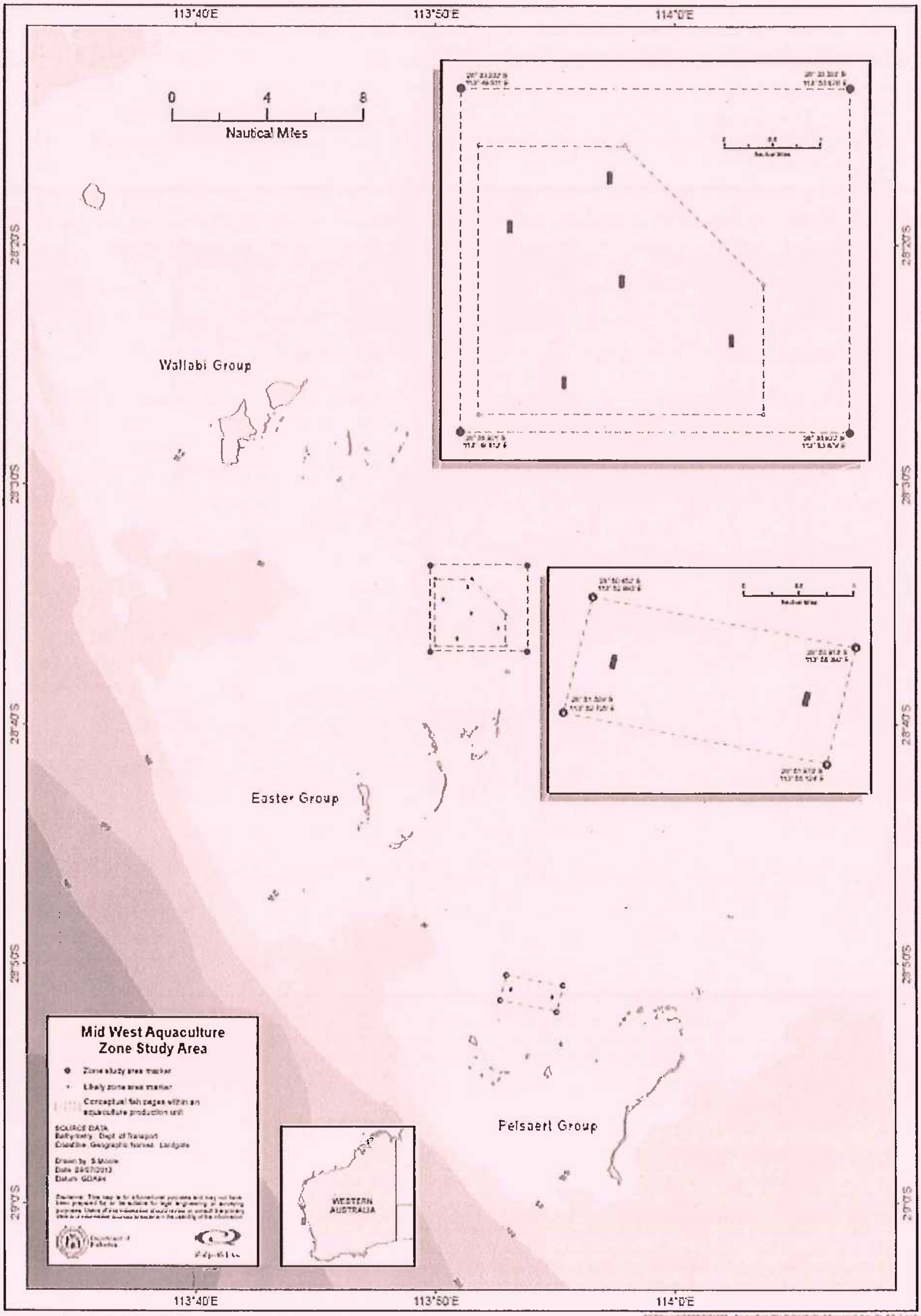
Decision Making Authority	Relevant Legislation
Minister for Lands	*Land Administration Act 1997* – (vested with Fisheries – Houtman Abrolhos Nature Reserve No. A20253).
Minister for Fisheries	*Fish Resources Management Act 1994* – Vested Fish Habitat Protection Area.
WA Museum (If consent is required to damage any archaeological site as defined under the Act).	*Maritime Archaeology Act 1973*

2.4 Preparation of the Environmental Review Document

The recommended format is described in the generic guidelines for the format of an environmental review document, available at the Environmental Protection Authority's (EPA's) website www.epa.wa.gov.au. When the EPA is satisfied with the standard of the environmental review document (see EAG 6 Section 4.3) it will provide a written sign-off, giving approval to advertise the document for public review. The review document may not be advertised for release before written approval is received.

The proponent is responsible for advertising the release and availability of the PER in accordance with the guidelines which will be issued to the proponent by the OEPA. The EPA must be consulted on the timing and details for advertising the document.

Attachment 1



Environmental Protection Authority

GOVERNMENT OF
WESTERN AUSTRALIA

Checklist for documents submitted for EIA on marine and terrestrial biodiversity

PURPOSE

It is hoped that this checklist will be useful to environmental consultants and proponents both during the proponent's initial project planning and environmental scoping process, and specifically in the final checking of documents they intend to submit to the Environmental Protection Authority (EPA) for environmental impact assessment (EIA). This checklist may be refined and reviewed periodically to refer to additional EPA guidance documents.

The purpose of this checklist is to provide the basis for consultants and proponents to conduct initial in-house screening of the quality of their EIA documents. The intent is to more clearly define a minimum standard for the fundamental elements of EIA documentation that is expected to be met before documents are submitted to the EPA. Meeting this minimum standard should, in turn, facilitate timely consideration of documents by the EPA.

The checklist has been set out in four parts. Part 1 addresses general elements of document quality. Parts 2 and 3 deal with key EIA requirements specific to marine and terrestrial biodiversity/marine water quality impacts respectively. Part 4 sets out the requirements for proponent certification of the checklist.

To confirm that each element has been addressed, proponents are asked to place a tick in the boxes provided. Where an element of the checklist is not relevant to the proposal, checking the box with "N/A" will be adequate.

A copy of this checklist certified by an appropriate proponent representative as complete and accurate must be lodged with EIA documentation submitted to the EPA. Completed checklists will be reviewed by the EPA when documents are lodged. **Incomplete or inaccurate checklists will be returned for proponents to address outstanding matters before the EPA will commence its review of EIA documents.**

It should be noted that the EPA's acceptance of a complete and accurate checklist simply indicates that basic requirements in terms of document quality and general comprehensiveness have been met. **The EPA's acceptance of the checklist does not imply adequacy of technical work or appropriateness of 'policy' application / interpretation.** These matters are reviewed in more detail later in the EIA process.

THE CHECKLIST

PART 1 – GENERAL QUALITY OF DOCUMENTS

Ensure that the following standard elements are present in all documentation (including appendices):

- A clear and concise title that outlines basic information about the proposal and purpose of the document. ☑
- Date and document revision number. ☑
- Information identifying the document's author and publishing entity. ☑
- All issues identified in a scoping guideline or scoping document have been addressed and covered in the report. ☑
- Complete and correct tables of contents, maps, tables and figures. ☑
- Suitably-sized scale maps placing the proposal into both a regional and local context. ☑
- Figures, plates, maps, technical drawings or similar including scale bar, legend, informative caption, labels identifying important or relevant locations/features referred to in the document text. ☑
- All survey site locations and derived data products (e.g. benthic habitat maps, vegetation maps) have been provided in map and appropriate GIS-based electronic database forms. ☑
- All survey data from terrestrial biological surveys have been provided in electronic database form (Access/Excel). ☐ N.A.
- Proposed infrastructure is shown on scale maps and associated spatial data and are provided in an appropriate GIS-based electronic database form. ☑
- A list of references that have been cross-checked to ensure that all references in the Reference list are cited in the text (and vice versa). ☑
- All information based on 'expert' opinion/judgement are explicitly attributed, by name and qualification, to a person/s or organisation. ☑
- Where relevant, appendices are attached to the main EIA document that describe the details of technical work undertaken to underpin the content of the main document, and explicitly attributed by name to the author/s and (if applicable) their organisation. ☑
- Description(s) of the proposal are internally consistent throughout all documentation and are couched to allow potential environmental impacts to be placed in local and regional contexts, including cumulative impacts of existing and approved developments. ☑

  Please identify relevant sections of the report in the box below.

  PER Sections 3, 7.3 - 8.6, 14.1 and 14.2

- Descriptions of the local and regional environmental features most likely to be directly or indirectly affected by the proposal. ☑

  Please identify relevant sections of the report in the box below.

  PER Sections 2.1, 6.3 (table 6.2 + 6.3), 6.4 and 6.5

PART 2 – MARINE ENVIRONMENTAL ISSUES

For proposals likely to impact on arid zone tropical mangroves in the Pilbara, the EIA document describes how potential impacts have been addressed in the context of Guidance Statement No.1 (April 2001). ☐ N.A

If applicable, please identify relevant sections of the report in the box below.

N. A.

For proposals likely to impact on benthic primary producer habitat, the EIA document describes how potential impacts have been addressed in the context of Environmental Assessment Guideline No.3 (December 2009), including: ☑

- details of the measures taken to address the Overarching Environmental Protection Principles; ☑
- scale benthic habitat maps showing the current extent and distribution of benthic habitats and the areas of habitat predicted to be lost if the proposal proceeds; ☑
- descriptions of technical work (e.g. benthic habitat surveys) carried out to underpin the benthic habitat map (e.g. a technical appendix); and ☑
- clearly set out calculations of cumulative loss. ☑

If applicable, please identify relevant sections of the report in the box below.

PER Sections 8.3 and 8.4

For proposals that involve any type of waste discharge or disposal in State coastal waters between Mandurah and Yanchep, or off the Pilbara coast, potential impacts are couched in the context of the *State Environmental (Cockburn Sound) Policy 2005*, *Perth's Coastal Waters: Environmental Values and Objectives* (EPA, 2000), or *Pilbara Coastal Water Quality Project Consultation Outcomes* document (DoE, 2006) and relevant guidance provided in the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC/ARMCANZ, 2000). ☑

If applicable, please identify relevant sections of the report in the box below.

PER Sections 6.6.3.4 and 6.7.4

EMMP Section 4.2.4

For proposals that involve any type of waste discharge or disposal in State coastal waters outside of the areas described above, potential impacts are couched in the context of the guidance provided in the *State Water Quality Management Strategy Document No.6* (Government of WA, 2004) and the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC/ARMCANZ, 2000). ☑

If applicable, please identify relevant sections of the report in the box below.

PER Sections 6.6.2, 6.5.1.5,

7.1, 7.4. EMMP Sections 3.13, 3.2, 4.2.4 and 4.2.5

For proposals with potential to impact on an existing or proposed marine conservation reserve, potential impacts are couched in the context of the guidance provided in the relevant indicative or final Management Plan for the reserve on the advice of DEC or another designated management agency. ☐ N.A

If applicable, please identify relevant sections of the report in the box below.

N. A.

If numerical modelling has been carried out to inform the prediction of environmental impacts, the report(s) associated with this modelling, including the key assumptions, is (are) provided as a technical appendix. ☐

If applicable, please identify the relevant appendix in the box below.

Sections 6.5, 6.6 and 6.7

Appendices 1E, 1F and 1G.

PART 3 – TERRESTRIAL BIODIVERSITY ISSUES N.A.

For proposals likely to impact on native flora and vegetation, the EIA document describes how potential direct and indirect impacts have been addressed in the context of EPA Guidance Statement No. 51 - *Terrestrial Flora and Vegetation Surveys for Environmental Impact Assessment in Western Australia* (June 2004) and Technical Guide – *Flora and Vegetation Surveys for Environmental Impact Assessment* EPA and DPaW (2015) including:

- determining the level of flora and vegetation survey, including a survey area encompassing direct and indirect impacts, utilising suitable survey methodology and listing survey limitations; ☐ N.A.
- maps illustrating the survey area in both a local and regional context, location of quadrats, vegetation unit mapping, location of significant species or vegetation, vegetation condition and predicted extent of impact on the vegetation; ☐ N.A.
- a comprehensive list of flora species (using the nomenclature of the WA Herbarium) which are known or reasonably expected to occur in the area and a quantitative assessment of direct and indirect impacts to threatened, priority or other significant flora and/or threatened, priority or other significant vegetation (as defined in Technical Guide); ☐ N.A.
- an evaluation of the impact of the proposal on flora and vegetation, including analysis of the local, regional and cumulative impacts of the project; and ☐ N.A.
- quadrat data provided as excel spreadsheet in raw form, in addition to hardcopy reports. ☐ N.A.

If applicable, please identify relevant sections of the report in the box below.

N.A.

For proposals likely to impact on vertebrate fauna or fauna habitat, the EIA document describes how potential impacts have been addressed in the context of EPA Guidance Statement No. 56, *Terrestrial Fauna Surveys for Environmental Impact Assessment* (June 2004) and Technical Guide – *Terrestrial Vertebrate Fauna Surveys for Environmental Impact Assessment* EPA and DEC (2010), including: N.A.

- determining the level of fauna survey consistent with that expected; ☑
- describing the survey methodologies, including timing, duration and survey effort used to sample each of the fauna groups sampled, any survey limitations and the nomenclature used (WA Museum/Birdlife Australia); ☑
- maps illustrating the survey area in both a regional and local context; fauna habitats within and outside the development envelope; description of predicted extent of impact on the habitat; location of survey sites and conservation significant fauna in relation to the proposal; and ☑
- a comprehensive list and assessment of vertebrate fauna known or reasonably expected to occur in the area, including Specially Protected, Priority and other significant fauna (as defined in Guidance Statement No. 56), and an evaluation of the impact of the proposal on the species and key habitat/s. ☑

If applicable, please identify relevant sections of the report in the box below.

PER Section 9.2, EMMP Sections 4.4 - 4.6
Appendices 1D and 5.

For proposals with the potential to impact on short range endemic (SRE) invertebrate fauna or SRE habitat, the EIA document describes how potential impacts have been addressed in the context of EPA Guidance Statement No. 20, *Sampling of Short Range Invertebrate Fauna for Environmental Impact Assessment in Western Australia* (May 2009), including: } N.A

- assessment for restricted habitat types that have potential to support SRE fauna, including advice from the WA Museum, DPaW and OEPA; ☐ N.A.
- maps illustrating the survey area in both a regional and local context, and identifying potential SRE habitats within and outside the development envelope and extent of predicted impact on the habitat; ☐ N.A.
- a description of the survey methodologies, including timing and survey effort used to sample each of the fauna groups and any survey limitations; ☑
- the results and interpretation of any molecular analysis used; and ☐ N.A.
- a survey report with assessment of SRE fauna found or reasonably expected to occur in the area, their conservation status, their known occurrence/habitats locally and their wider status if known, and an evaluation of the risk of the proposal to long-term survival of the species and community. ☐ N.A

If applicable, please identify relevant sections of the report in the box below.

Appendix 1 - Section 4.2.1

For proposals with the potential to impact on subterranean (stygofauna and troglofauna) fauna, the EIA document describes how potential impacts have been addressed in the context of EPA Environmental Assessment Guideline 12 *Consideration of subterranean fauna in EIA in WA* and Guidance Statement No. 54a, *Sampling Methods and Survey Considerations for Subterranean Fauna in Western Australia* (Draft, August 2007), including: N.A.

- an assessment of the likely presence of habitat that could support subterranean fauna, including advice from the WA Museum and OEPA; ☐ N.A.
- maps identifying survey sites and illustrating the known or predicted extent of habitats in relation to the proposal; a description of the geology/habitat supporting subterranean fauna within and outside the development envelope; extent of predicted impacts on the subterranean fauna and habitat; ☐ N.A.
- a description of the survey methodologies (see Guidance Statement No. 54a), including reference to site selection, sampling techniques, survey effort, specimen collection and molecular analysis used undertaken as part of the survey, and any survey limitations; and ☐ N.A.
- a list of subterranean fauna recorded and their distribution or reasonably expected to occur in the area, including their conservation status, their known occurrence/habitats locally and their wider status if known, and an evaluation of the risk of the proposal to long-term survival of the species and community. ☐ N.A.

If applicable, please identify relevant sections of the report in the box below.

N.A.

PART 4 – PROPONENT'S CERTIFICATION OF COMPLETENESS AND ACCURACY OF RESPONSES

Name

Laurie Caporn

Position

Principal Management Officer

Signature

Date

4 / 5 / 2016