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Western Australian sea cucumber resource assessment report

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Executive Summary

- The sea cucumber resource comprises eight species that inhabit the tropical shallow continental shelf waters of the North Coast Bioregion and are taken in the Western Australian Sea Cucumber Fishery (WASCF). However, >99% of the harvest in the WASCF is two main species, *Holothuria scabra* (sandfish) and *Actinopyga echinites* (redfish), which this assessment report is primarily focused on.

- Sandfish and redfish are both widely distributed tropical Indo-Pacific species. Redfish is sometimes known as the deepwater redfish to distinguish it from a closely related species, the surf redfish (*Actinopyga mauritania*), however, the distinction has not been necessary thus far for Western Australia as only *A. echinites* is harvested. Historically, the resource has been harvested from the Kimberley and Pilbara bioregions, and a new Shark Bay fishery has developed since 2018. Sandfish is harvested from the Kimberley and Pilbara bioregions, with most of the catch coming from the Kimberley (70%). Redfish is harvested from the Pilbara and Shark Bay regions, with 95+% of the harvest from the Pilbara.

- The resource is harvested by hand collection while diving or wading. Small quantities of sea cucumber species not targeted by the WASCF are collected by the Marine Aquarium Fish Managed Fishery for aquarium display purposes and some are discarded in trawl fisheries. Recreational and customary take is negligible, however Aboriginal communities have been given access to harvest sea cucumber for commercial purposes in waters adjoining traditional grounds.

- There is a dichotomy of opinion of the inherent vulnerability of sea cucumbers to fishing. Some studies suggest populations are unable to be sustained under exploitation rates of greater than 5% of unfished biomass. Other analyses suggest they are inherently robust due to early age-at-maturity, high fecundity, and high natural mortality. Unmanaged and unregulated fishing has been a major contributor to the poor track record for sea cucumber fisheries worldwide, and even inherently robust species cannot be sustained without good management. Overall, a conservative approach is required.

- Data on the life history of individual species that comprise the resource is sparse for Western Australia. Substantial information on age, growth, mortality, genetics and distribution of these species does exist, however, owing to their commercial and artisanal importance throughout communities within the Indo-Pacific region. This information in combination with accurate catch and effort logbooks, and biological surveys where necessary has been used to guide management of this resource.

- The sandfish and redfish stocks are assessed each year using annual indices of biomass derived from a population model that uses fine-scale catch, effort and fishery-independent survey (FIS) abundance data. These are compared with specified reference points, namely biomass targets, thresholds, and limits developed using the population models. If the threshold or limit reference points are breached the prescribed management action (involving fishery closures) is implemented according to the harvest strategy.

Accompanying any management action is a review involving exploration of additional data including fine-scale fishing patterns and catch rates and trends in annual mean weights and size-frequency information.

- A weight-of-evidence assessment of the stocks in 2022 used the following lines of evidence: catch, catch distribution, abundance indices (catch rates), fishery independent surveys, mean size of catch, PSA (Productivity Susceptibility Analysis), and model-based biomass estimates of depletions relative to unfished biomass (B_0). Current risk levels to Kimberley sandfish, Pilbara redfish, and Shark bay redfish stocks were low. The risk level to the Pilbara sandfish stocks was medium. These findings indicate the status of sea cucumber stocks in WA is adequate and that current management settings are maintaining risk at acceptable levels. Further work is needed on maintaining the independent survey program in the 4 main harvest areas to support the stock assessment and harvest strategies.

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List of Abbreviations

CAES	Catch and Effort Statistics
Department	Department of Primary Industries and Regional Development (formerly Department of Fisheries)
EBFM	Ecosystem-Based Fisheries Management
ENSO	El Niño Southern Oscillation
ESD	Ecologically Sustainable Development
EPBC	Environment Protection and Biodiversity Conservation (Act)
FRMA	Fish Resources Management Act
GLM	Generalised Linear Model
MAFMF	Marine Aquarium Fish Managed Fishery
MSC	Marine Stewardship Council
NCB	North Coast Bioregion
SCPUE	Standardised Catch per Unit Effort (catch rate)
WA	Western Australia
WASCF	Western Australian Sea Cucumber Fishery

1 Scope

This document provides a cumulative description and assessment of the Sea Cucumber Resource and all of the fishing activities (i.e. fisheries / fishing sectors) affecting this resource in Western Australia (WA). The overall resource comprises two main species (sandfish *Holothuria scabra* and redfish *Actinopyga echinites*), and few minor species that inhabit the tropical shallow continental shelf waters of the North Coast and Gascoyne Bioregions (Figure 3.1). Based on the stock units considered for management, the resource is separated into three main regional areas; the Kimberley, Pilbara and Gascoyne (Shark Bay) regions.

The report is focused on the two main species that comprise this resource. Commercial harvest is permitted by license holders in the Western Australian Sea Cucumber Fishery (WASCF). Permitted harvest collection method is hand collection by diving and wading primarily in shallow waters of northern WA, from Shark Bay to the Northern Territory border. Small quantities of sea cucumber species not targeted by the WASCF are collected by the marine aquarium managed fishery for aquarium display purposes and some are discarded in trawl fisheries.

The report contains information relevant to assist the assessment of the Sea Cucumber Resource against the Environment Protection and Biodiversity Conservation (EPBC) Act export approval requirements and the Marine Stewardship Council (MSC) Principles and Criteria for Sustainable Fishing.

2 How the Department Operates

Fisheries management in WA has evolved over the last 40-50 years from a focus on managing catch of target species by commercial fishers to a fully integrated Ecosystem-Based Fisheries Management (EBFM) approach, which ensures that fishing impacts on the overall ecosystems are appropriately assessed and managed (Fletcher et al. 2010). In line with the principles of Ecologically Sustainable Development (ESD; Fletcher 2002), the EBFM approach also recognises that the economic and social benefits of fishing to all users must be considered.

Implementation of EBFM involves a risk-based approach to monitoring and assessing the cumulative impacts on WA's aquatic resources from all fishing activities (commercial, recreational, customary), operating at a bioregional or ecosystem level. The level of risk to each resource is used as a key input to the Department of Primary Industries and Regional Development (DPIRD, the Department) Risk Register for fisheries and aquatic resources, which is an integral component of the annual planning cycle for assigning activity priorities (research, management, compliance, education etc.) across each bioregion. A summary of the Department's risk-based annual planning cycle that is delivering EBFM in the long-term is provided in Figure 2.1.

To ensure that management is effective in achieving the relevant ecological, economic and social objectives, formal harvest strategies are being developed for each resource. These harvest strategies outline the performance indicators used to measure how well objectives are being met, and set out control rules that specify the management actions to be taken in situations when objectives are not being met. The WA harvest strategy policy (Department of Fisheries 2015) has been designed to ensure that the harvest strategies cover the broader scope of EBFM and thus consider not only fishing impacts of target species, but also other retained species, bycatch, endangered, threatened and protected (ETP) species, habitats and other ecological components (Fletcher et al. 2016).

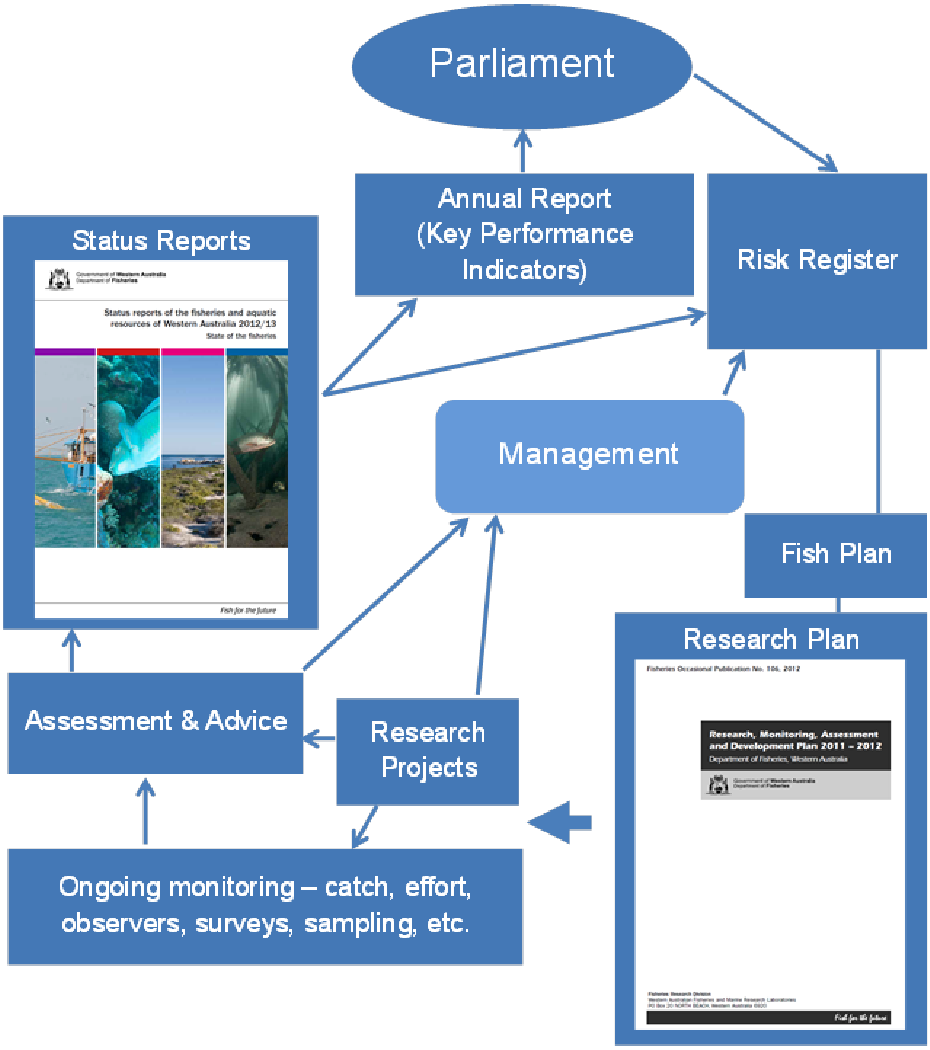


Figure 2.1. An outline of the risk-based planning cycle used for determining Departmental priorities and activities.

3 Aquatic Environment

The North Coast Bioregion (NCB) of WA (see Figure 3.1) has a unique combination of features that distinguish it from other marine regions around Australia; including the wide continental shelf, very high tidal regimes, high cyclone frequency, unique current systems, warm oligotrophic surface waters and unique geomorphological features (Brewer et al. 2007). The oceanography of the NCB includes waters of Pacific origin that enter through the Indonesian archipelago bringing warm, low-salinity water pole-wards via the Indonesian Through-flow and seasonal Holloway Current. Ocean temperatures range between 22°C and 33°C, with localised higher temperatures in coastal waters, particularly along the Pilbara coast. Fish stocks in the NCB are tropical, with most having an Indo-Pacific distribution

Coastal waters are generally low-energy in terms of wave action, but are seasonally influenced by infrequent, but intense, tropical cyclones, storm surges and associated rainfall run-off. These cyclone events generate the bulk of the annual rainfall, although the Kimberley coast does receive limited monsoonal thunderstorm rainfall over summer. Significant river run-off and related coastal productivity can be associated with cyclone events, with run-off ceasing during winter. The north coastal region is subject to very high evaporation rates (three metres per year), although the Pilbara coast is more arid than the Kimberley coast, due to lower annual rainfall. Another influence on coastal waters is the extreme tidal regime. Spring tides range from 11 metres along the Kimberley coast down to around two metres in the west Pilbara.

The Kimberley coast has a well-developed and highly indented shoreline, with bays and estuaries backed by a hinterland of high relief, a suite of local nearshore islands and a distinct suite of coastal sediments. Broad tidal mudflats and soft sediments with fringing mangroves are typical of this area. The eastern Pilbara coast is more exposed than the Kimberley, with few islands and extensive intertidal sand flats. Softer sediments and mangroves occur around river entrances in this region. The western Pilbara is characterised by a series of significant, but low-relief islands, including the Dampier Archipelago, Barrow Island and the Montebello Islands. Near-shore coastal waters include rocky and coral reef systems, creating significant areas of protected waters. West Pilbara shorelines also include areas of soft sediments, salt-marshes and mangrove communities.

The marine environment of the Gascoyne Coast Bioregion (Figure 3.1) represents a transition between the tropical waters of the North West Shelf of the North Coast Bioregion and the temperate waters of the West Coast Bioregion. Offshore ocean temperatures range from about 22°C to 28°C, while the inner areas of Shark Bay regularly fall to 15°C in winter. The major fish stocks are generally tropical in nature, with the exceptions of the temperate species, pink snapper, whiting and tailor, which are at the northern end of their distributions in Shark Bay. The waters off the Gascoyne Coast are also strongly influenced by the southward-flowing Leeuwin Current, generated by flow from the Pacific through the Indonesian archipelago. This tropical current becomes evident in the North West Cape area and flows along the edge of the narrow continental shelf where, coupled with low rainfall and run-off plus the north flowing

Ningaloo Current, it supports the diverse Ningaloo Reef marine ecosystem and the World Heritage-listed Shark Bay. The inner waters of the embayment are hyper-saline, due to the high evaporation and low rainfall of the adjacent terrestrial desert areas, however the waters close to Dirk Hartog island are more oceanic in nature and support localised communities of tropical sea cucumbers including *Actinopyga echinities* (Redfish) and *Holuthuria whitmaei* (black teatfish).

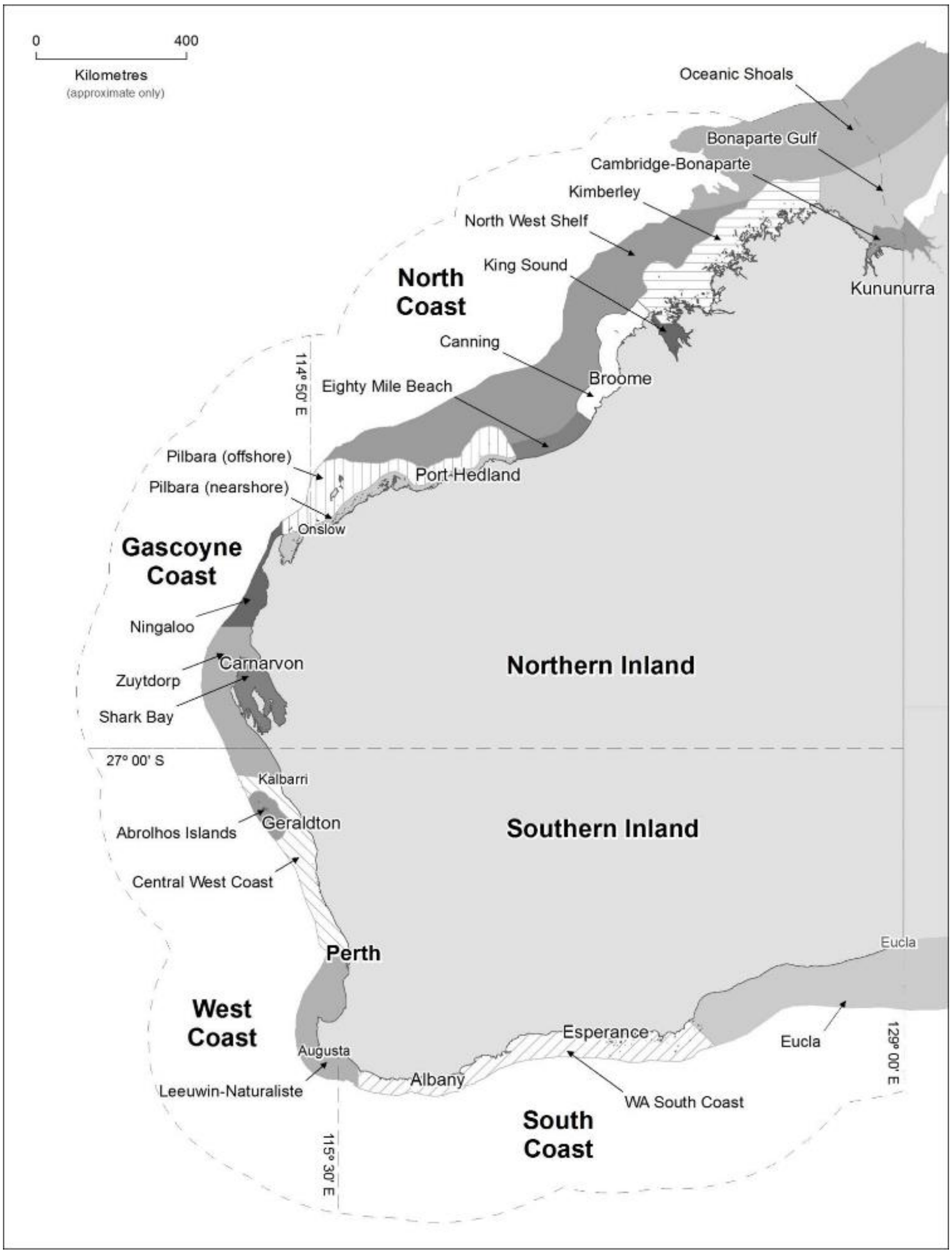


Figure 3.1. Locality of aquatic resource bioregions in WA. Sea cucumber is fished in North and Gascoyne Coast). Boundaries of IMCRA ecosystems are also identified.

4 Resource Description

4.1 Sea Cucumber Resource

Sea cucumbers or 'trepang', are in the Phylum Echinodermata, Class Holothuroidea. They are soft-bodied, elongated animals that usually live with their ventral surface in contact with the benthic substrate or buried in the substrate. The resource targeted by the fishery comprises two tropical Indo-Pacific species, sandfish (*Holothuria scabra*) and deepwater redfish (*Actinopyga echinites*). Redfish is sometimes known as the deepwater redfish to distinguish it from a closely-related species, the surf redfish (*A. mauritania*). In tropical Western Australia, sandfish and redfish occur primarily within low energy environments behind fringing reefs or within protected bays.

There are six other commercial species that fishers in the WASCF may retain: Black teatfish (*Holothuria whitmaei*), white teatfish (*H. fuscogilva*), prickly redfish (*Thelenota ananas*), lollyfish (*H. atra*), brown curry fish (*Stichopus wastus*) and curry fish (*S. hermanni*). However, since 2001, only black teatfish have been retained in significant numbers, i.e. >1 tonne, in addition to the two main target species.

As data on local sea cucumber populations remain sparse, information on the life history, biological information required for management purposes in WA is predominantly sourced from other jurisdictions within the Indo-Pacific region where sea cucumber fisheries have high commercial and artisanal importance.

The stock structures of the sandfish and redfish in WA have not yet been established, however, genetic studies of sandfish populations in Northern Territory and Queensland state waters have indicated genetically distinct stocks occur within these regions (Uthicke and Benzie 2001; Gardner and Fitch 2012). This suggests there may be genetic differences in stocks along the WA coast, and particularly between the fished stocks of the Kimberley, the Pilbara, and the Shark bay (Gascoyne) bioregions (Figure 3.1).

Sandfish can produce up to 18 million viable eggs and spawning can occur year round, although the main spawning season occurs during September to November. The planktotrophic larvae feed on microalgae in the water column during the dispersive larval phase, metamorphose and settle to the sea floor (Mercier et al. 2000). In populations outside of WA, sexual maturity occurs at approximately 150 mm in length or two years of age. This species exhibits sexually dimorphic growth, with males maturing earlier than females. Redfish can produce up to 25 million viable eggs and the size at maturity is approximately 120 mm.

There is a dichotomy of opinion of the inherent vulnerability of sea cucumbers to fishing. Some studies suggest they are particularly vulnerable, unable to be sustained under exploitation rates of greater than 5% of unfished biomass (Purcell et al. 2013). Other analyses suggest they are inherently robust due to early age-at-maturity, high fecundity, and high natural mortality. Unmanaged and unregulated fishing has been a major contributor to the poor track record for

sea cucumber fisheries worldwide, and even inherently robust species cannot be sustained without management. Overall, a conservative approach is required.

5 Species Description

5.1 Sandfish (*Holothuria scabra*)

Figure 5.1. *Holothuria scabra* in its (a) natural sandy habitat, and (b) burrowed mud habitat).

5.1.1 Taxonomy and Distribution

Sandfish, *Holothuria scabra*, vary in shades of greyish-black on the upper side with dark-coloured wrinkles (Figure 5.1) but paler on the underside. In Australia it grows up to 40 cm long, is broader than it is high and has a tough pliable skin. It is generally recognised that a sub-species of *H. scabra*, known as *H. scabra versicolour* does exist (Hamel et al. 2001). The distinction however, has not been made for WA stocks, and all animals harvested are assumed to be *H. scabra*.

5.1.2 Stock Structure

Holothuria scabra is widely dispersed in shallow water on soft sediments throughout the Indo-Pacific region, bounded by the East Coast Africa, the tropics of Cancer and Capricorn and west of mid Pacific Ocean (Bell et al. 2008) (Figure 5.2).

In WA, the boundaries of commercially fished populations are Barrow Island in the south-west of its range, and Wyndham in the north, a distance of about 1800 km. Within these populations, areas fished are discrete and generally separated by large distances. Most fishing activity targets the densest populations of sandfish, occurring within the remote bays and estuaries of the Pilbara and Kimberley coasts.

Uthicke and Benzie (2001) investigated gene flow in *H. scabra* populations with a view to increasing knowledge on this commercially important species and assisting management along the north-east coast of Australia. Allozyme analyses identified and concluded that *H. scabra* populations along the north-east coast of Australia can be grouped into at least 3 genetically distinct stocks: (1) southern populations from the Hervey Bay area, (2) one population from

the central coast, and (3) populations from Torres Strait. The latter region is closely related to samples from the Solomon Islands. A similar result was reported by Gardner and Fitch (2012) in relation to *H. scabra* populations within Northern Territory waters, suggesting the existence of genetically distinct stocks in the Gulf of Carpentaria (or eastern population) and the Arafura Sea (or western population).

In view of these studies, and noting the existence of morphological differences between Pilbara and Kimberley sandfish, these are considered to represent two separate stocks for management purposes.

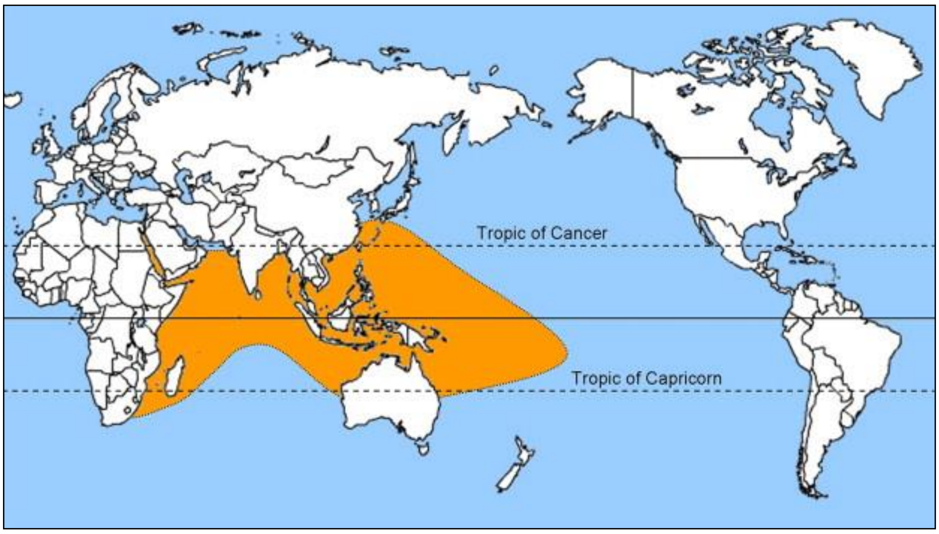


Figure 5.2. Global distribution of sandfish, *Holothuria scabra.*

5.1.3 Life History

Holothuria scabra are sexually dimorphic, although this is not apparent by their visual appearance and their sexual maturity will vary slightly depending on geographic location. Animals will generally mature at 150 mm in length after approximately two years, although the size can vary substantially between sexes and locations (Table 5.1). Animals can spawn year round but spawning can also be triggered by temperature, salinity and lunar changes. Spawning aggregations will occur in deeper water where broadcast fertilisation will follow (Figure 5.4). A fertilised egg will form into an auricularia larvae after 1 – 2 days, this is a feeding phase. The doliolaria stage (non-feeding) will follow after which 1 mm pentactula will settle in shallow water substrate, seagrass and mangroves. Juveniles will inhabit this zone up to 10 mm long.

5.1.3.1 Morphological Relationships

Adults generally measure between 150 and 400 mm in length (Figure 5.3). The body wall accounts for about 56 % of the total weight (Conand 1989). The reported body weight varies considerably, between 300 and 3000 g, over its geographical range. However, it has been noted that the weight depends on the amount of coelomic water and sediment in the alimentary canal (Conand 1989) and length-weight measurements can be highly variable. An illustration of the

length-weight relationships in *H. scabra* is found in Figure 5.5, Figure 5.6, and Table 5.1. The relationship for WA is of a similar form to a Queensland population from the Torres Strait.

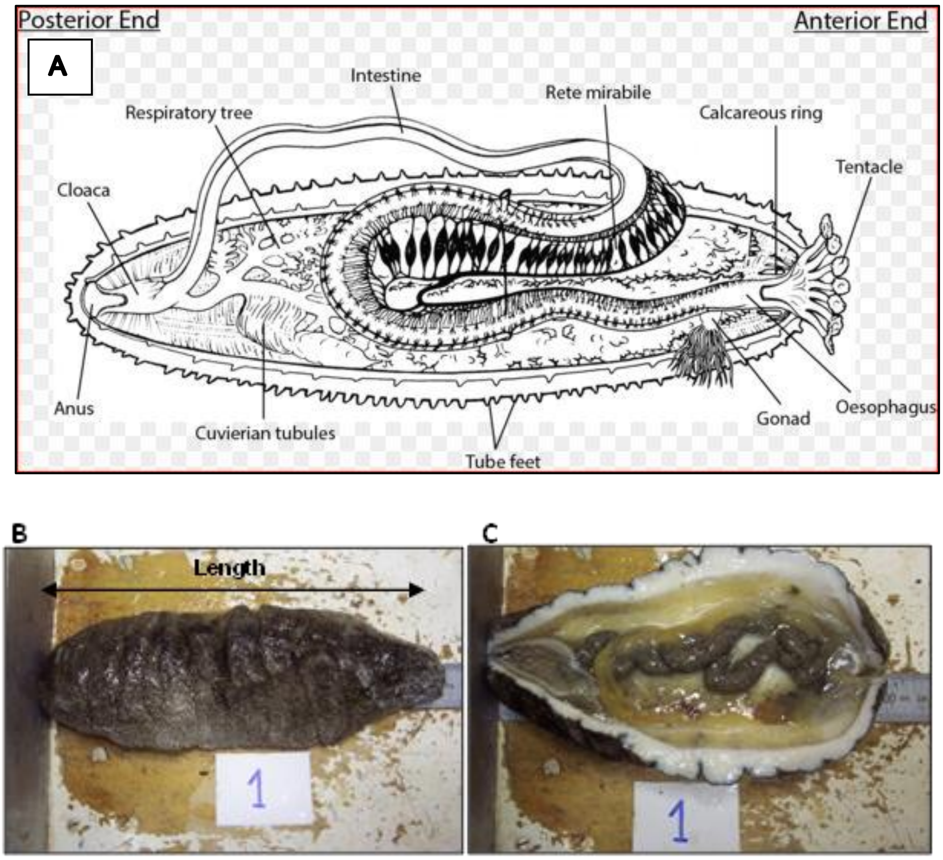
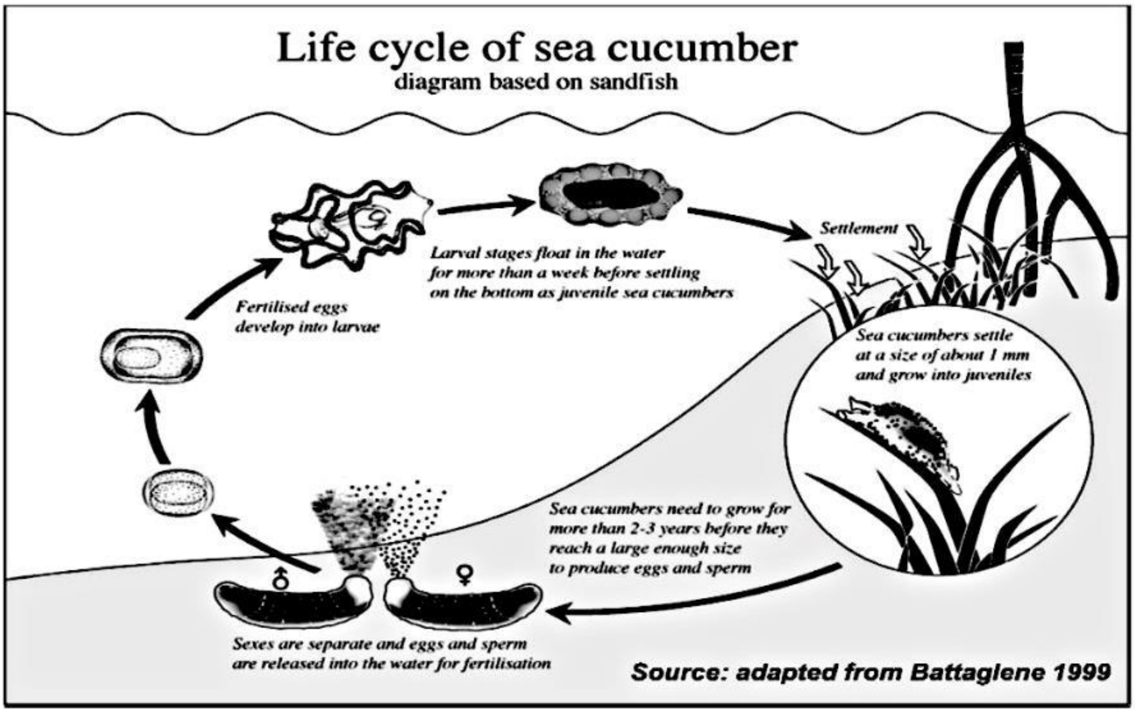


Figure 5.3. Anatomy and morphometric measurement commonly used to measure the morphology of *Holothuria scabra.*



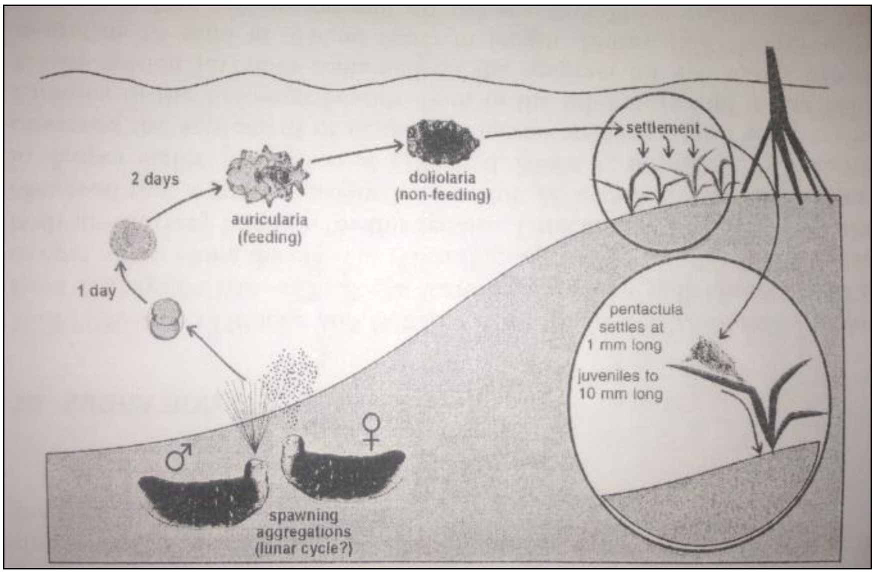


Figure 5.4. Life cycle of sandfish, *Holothuria scabra* (from Hamel et al. 2001).

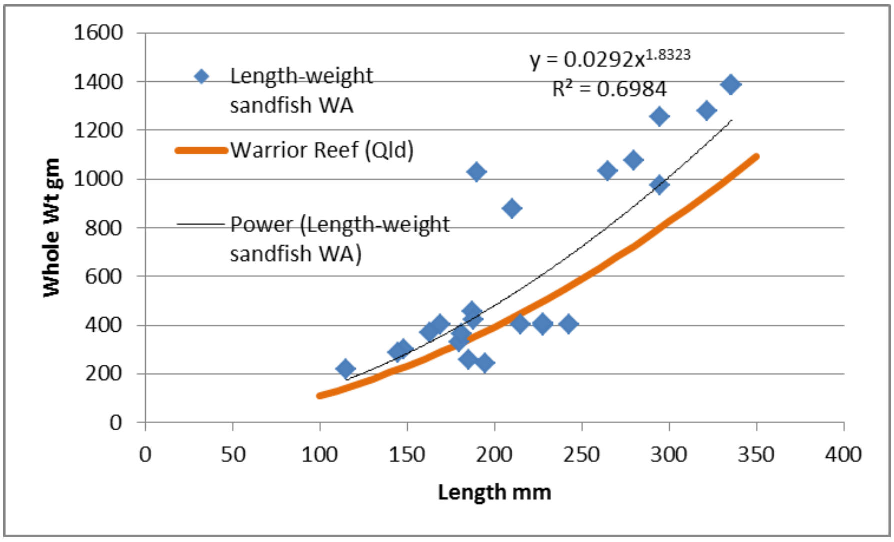


Figure 5.5. Length-weight relationship between WA sandfish (Kimberley region) and Queensland sandfish (Warrior reef - curve from Skewes et al. 2000).

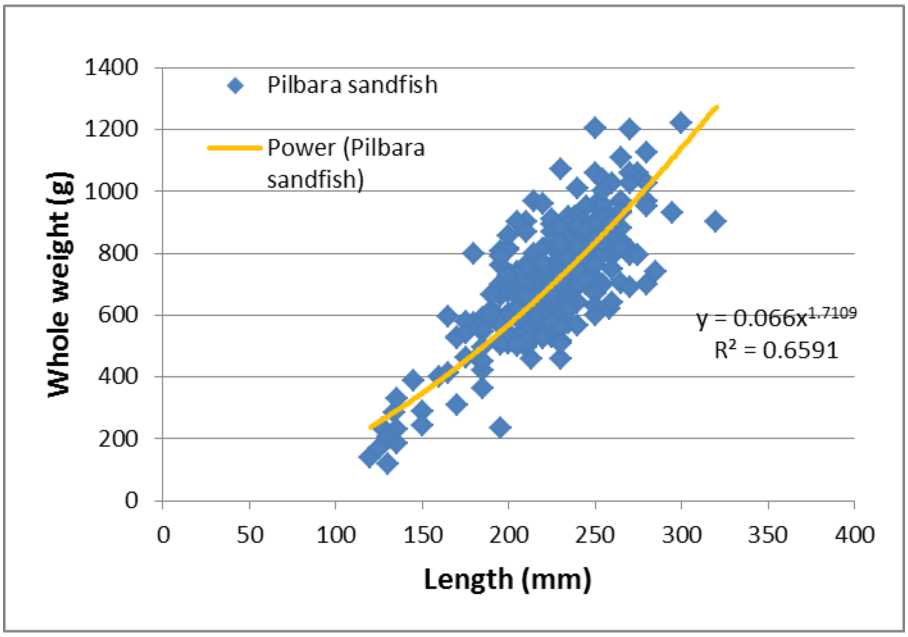


Figure 5.6. Length-weight relationship for sandfish in the Dampier Archipelago (Pilbara region – Karratha Bay).

Table 5.1. Summary of biological parameters for sandfish (*Holothuria scabra*)

Parameter	Value(s)	Comments / Source(s)
Growth parameters		
L_∞ (mm)	350	Dissanayake & Wijeyaratne (2007)
K (year^{-1})	0.8	Dissanayake & Wijeyaratne (2007)
Maximum age (years)	6 – 10 years	Skewes et al. (2014)
Maximum size (mm)	400	Skewes et al. (2014)
Natural mortality, M (year^{-1})	0.4, 1.16, 1.49	Skewes et al. (2014), Dissanayake & Wijeyaratne (2007)
Length-weight parameters		
a (Kimberley)	0.0292	$W = a\,TL^b$; *W in g, TL in mm*
b (Kimberley)	1.83	$W = a\,TL^b$; *W in g, TL in mm*
a (Pilbara)	0.066	$W = a\,TL^b$; *W in g, TL in mm*
b (Pilbara)	1.71	$W = a\,TL^b$; *W in g, TL in mm*
Reproduction		
Maturity parameters		
A_{50} (years)	2	
L_{50} (mm)	Females 200, Males 140-170	Hamel et al. (2001), Kithakeni and Ndara (2002)
Fecundity	9 – 17 x 10^6 oocytes per female	Hamel et al. (2001)
Size-fecundity parameters	Not Available	
Spawning frequency	Spawning occurs year round in some areas, but is likely seasonal in spring months in Australia	Hamel et al. (2001)

5.1.3.2 Habitats

Holothuria scabra are distributed within low energy environments behind fringing reefs or within protected bays. Original distributions are mostly the shallow sub-tidal areas but can occur in depths up to 40 m. Strong tidal currents appear to be the common habitat/environmental feature of both historical and presently important areas of wild stocks.

5.1.3.3 Age and Growth

Average growth of *H. scabra* under controlled conditions range from 7 to 15 mm per month and a corresponding weight gain, estimated between 6 to 27 grams per month (Battaglene et al. 1999). When *H. scabra* were stocked at a biomass > 225 g m^{-2}, growth ceased and some individuals even lost weight (Battaglene et al. 1999; Conand 1983).

In contrast, studies in the wild, although scarce indicate a growth rate of 10 to 15 mm per month (Mercier et al. 2000). Hatchery reared *H. scabra* juveniles of 15 mm cm have been known to attain 10 cm after six months spent in a closed lagoon.

Age and growth estimation is difficult in Holothurians due to their variable morphology, however sandfish have been estimated to live beyond six years of age and reach the age at maturity in two years (Conand 1989, 1998; Kinch et al. 2008).

5.1.3.4 Natural Mortality (*M*) and intrinsic rate of increase (*r*)

Limited information is available on natural mortality (*M*) in these species due to the difficulty in measuring age and size, or conducting mark-recapture experiments. A recent review of harvest strategies for populations of sea cucumbers on East Coast Sea Cucumber fishery of Queensland assumed an *M* of 0.4 year^{-1} was appropriate for most species, with 0.3 year^{-1} being used in species considered especially vulnerable (Skewes et al. 2014). These estimates of *M* are considerably lower than several estimates reported in the literature for *H. scabra* (e.g. Dissanayake & Wijeyaratne 2007), and highlights the uncertainty surrounding knowledge of this important parameter. Given this uncertainty, and the fundamental importance of *M* in fisheries assessment, for the purposes of estimating stock levels using population modelling, an *M* of 0.35 (with appropriate uncertainty) was assumed for *Holothuria scabra* in WA. See Table 9.8 and section 9.3.8 for more information.

Natural mortality is closely linked with another key population parameter, the intrinsic rate of increase (*r*). Based on a meta-analysis, a formula derived for producing an estimate of r from M for invertebrates is $r = 2.0M$ (Zhou et al. 2016). Using the results of that meta-analysis, an *M* of 0.35 y^{-1} may be expected to equate to an *r* of 0.7. These parameters give an indication of the general productivity dynamics of a species, and in data poor situations, can be used to assist in assessment and management.

5.1.3.5 Reproduction

In Australia, the main spawning season of *H. scabra* occurs in the spring months of September to November. Geographically, there is variability from month to month and season to season. Triggers for spawning include temperature, salinity and lunar changes, including chemical cues from males which initiate spawning. Numerous studies have concluded spawning continues year round (Hamel et al. 2001).

Size at-maturity (L_{50}) for male *H. scabra* various geographically, and has been reported in the range of 140 to 170 mm. Females were identified from 199 mm onwards and the sex ratio reached 45:55 female to male at maturity, other studies in different geographical locations indicate sex ratios are more even at 1:1 (Hamel et al. 2001; Table 5.1). No studies are available for size at maturity studies of WA populations of sandfish and voluntary size limits are based on Northern Territory data. Preliminary examination of 20 animals in the size-range of 115 to 330 mm from WA populations found only three animals with undefined gonads (Hart and Murphy, unpublished data).

Conand (1989, 1993) evaluated potential fecundity by dissecting mature whole gonads of *H. scabra* and proposed values of >2 – 18 million oocytes per female, with higher values for the larger females. Conand (1989, 1993) found that the absolute fecundity of *H. scabra versicolour* varied between nine and 17 x 10^6 oocytes per female and was correlated with body size (Hamel et al. 2001).

5.1.3.6 Factors Affecting Year Class Strength and Other Biological Parameters

Field studies in the Solomon Islands (Mercier et al. 2000) indicate the larvae of *H. scabra* actively select certain seagrasses, possibly through chemical selection. Mercier et al. (2000) hypothesised that larvae settling on suitable seagrass have an increased chance of growth and survival because they are provided with a suitable sub-stratum to grow, and a bridge to sandy sub-stratum.

James et al. (1994) indicated that the main predators of the larval forms of *H. scabra* were copepods and ciliates that attacked the larvae, causing injury and death. These organisms also indirectly harmed juveniles, especially those recently settled, by competing for food (Battaglene et al. 1999).

In relation to *H. scabra*, water temperature, salinity and tidal movements are likely to be the most important factors affecting settling recruits for this species as they generally inhabit protected bays and estuaries of the Kimberley.

5.1.3.7 Diet, Trophic Level and Ecosystem Function

Holothuria scabra are classified as deposit and detritus feeders, and diet descriptions are relatively uniform the literature. On soft bottoms they ingest large amounts of sediment using their retractile tentacles from which they extract food (Conand 1998). Gut contents are generally composed of bacteria, copepods, diatoms and other algae, molluscs, foraminiferans, sand and mud.

Sea cucumbers tend to be preyed upon by a relatively small group of predators, which can be attributed to the success of chemical defence mechanisms in preventing predation by generalists (Bakus 1968, 1973, see Francour 1997 for a review). However, a number of sea cucumber species are consistently targeted by specialist predatory species, indicating that some predators depend on sea cucumbers for part of their dietary intake (Francour 1997). It has also been suggested that juvenile sea cucumbers are an important prey item in food webs (Purcell et al. 2013). For example, Wiedemeyer (1994) showed that the main predators of the larval forms of *A. echinites* were gastropods, causing injury and death. These predators also adversely affected juveniles by competing for food. Fish species preying upon juvenile *A. echinites* include; scorpion fish, lion fish, groupers, lizard fish, trigger fish and puffer fishes.

Sea cucumbers play an important ecological role in the ecosystems in which they occur (Birkeland 1988; Uthicke 2001; Wolkenhauer et al. 2010). Burrowing species assist in oxygenating sediments through bioturbation (e.g. Bakus 1973; Birkeland 1988; Uthicke 1999). By consuming large quantities of sediments, organic detritus is converted into animal tissue

and nitrogenous wastes, which can be taken up by algae and seagrasses and increase their productivity (e.g. Uthicke and Klump 1998; Wolkenhauer et al. 2010). In coral reef systems this nutrient-recycling function is likely to be significant (Birkeland 1988). It has also been suggested that the presence of sea cucumbers improves sediment quality and phytoplankton abundance through bioturbation and (incidental) ‘grazing’ of cyanobacteria (Purcell et al. 2013). For example, Uthicke (1999) showed that in aquaria without sea cucumbers sediments were eventually covered in a mat of cyanobacteria, while diatoms dominated the aquariums with sea cucumbers, while Moriarty (1982) – conducting cage experiments on the Great Barrier Reef – observed that mats of cyanobacteria established where holothurians were excluded. Purcell et al. (2013) therefore suggested that the removal of sea cucumbers may reduce primary production in some systems and affect sediment infauna by reducing the aerobic layer of sediments.

5.1.3.8 Parasites and Diseases

Juvenile *H. scabra* reared in the Aqua-Lab hatchery of Toliara, Madagascar, suffered a disease that caused death within three days. The first sign of the infection is a white spot that appears on the integument of individuals, close to the cloacal aperture. The spot extends quickly onto the whole integument leading to the death of individuals. The lesions consist in a zone where the epidermis is totally destroyed and where collagen fibres and ossicles are exposed to the external medium. This zone is surrounded by a border line where degrading epidermis is mixed with connective tissue. Lesions include three bacterial morphotypes: rod-shaped bacteria, rough ovoid bacteria, and smooth ovoid bacteria. Three species of bacteria have also been put in evidence in the white spot lesions thanks to biomolecular analyses (DGGE and sequencing): Vibrio sp., Bacteroides sp., and a Proteobacterium (Lovatelli et al. 2004).

5.1.4 Inherent Vulnerability

Plaganyi et al. (2013) examined climatic effects on managing sea cucumber fisheries and concluded that higher sea temperatures will have a positive effect i.e. higher production and yields given the expected faster growth rates leading to larger sizes and increased fecundity. This positive view on their vulnerability is supported by a productivity susceptibility analysis (PSA) which indicates that sea cucumbers are inherently robust to exploitation as a result of their life history parameters which suggest they are high productivity populations (Section 9.3.6).

However, sea cucumbers are also considered to have a high level of inherent vulnerability to fishing. Most species with tropical distributions inhabit shallow waters within the range of breath-hold or hookah-assisted divers (Kinch et al. 2008). They tend to have sluggish displacement rates (e.g. Purcell and Kirby 2006 with respect to *H. scabra*), indicating they are slow to move away from high density patches identified and targeted by fishers (Purcell et al. 2013).

As gonochoric broadcast spawners, sea cucumbers need to be in close proximity of mates to ensure fertilisation success (Purcell et al 2013). Fertilisation rates decline with decreasing

density, due to reduced gamete densities and associated reduced probabilities of egg-sperm encounters (Levitan 1991; Babcock et al. 1994; Wahle and Peckham 1999). Such changes in fertilization success and resulting reduced gamete production are disproportional to changes in adult densities, a form of Allee effect (Uthicke 2004).

Allee effects and population density extremes have been suggested to be more pronounced in broadcast-spawning echinoderms with planktotrophic larval stages (such as sandfish) as opposed to species with lecithotrophic development. This is because larvae of the latter species are independent from the requirement to feed in the plankton and tend to settle quicker (presumably resulting in lower mortality rates in the plankton and enhanced local recruitment) (Uthicke et al. 2009).

For species vulnerable to Allee effects, the severity of a population decline and ultimate time for recovery depends on the geographic extent of the decline, and the connectivity of subpopulations (Uthicke et al. 2009). In the case of the *H. scabra*, population reduction in the Torres Strait off northern Australia (which resulted in a population biomass of <10% of the original biomass determined from fishery surveys in 2002 and 2004, 4 and 6 years after the fishery was closed in 1998, showed that recovery was very slow (Skewes et al. 2000).

5.2 Redfish (*Actinopyga echinites*)

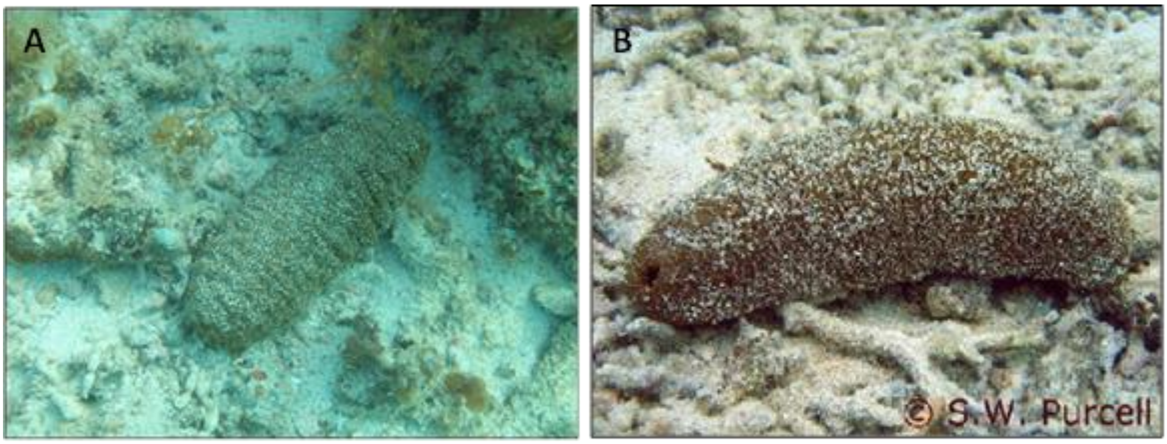


Figure 5.7. *Actinopyga echinites* in its (a) sandy, coral habitat, and (b) coralline habitat.

5.2.1 Taxonomy and Distribution

Deepwater redfish or redfish, *Actinopyga echinites*, is a sea cucumber which varies in colour from light brown to orange and has a rough outer skin covered in numerous papillae, the upper surface is often covered with sand (Figure 5.7). Distribution occurs throughout the Indo-Pacific region, bounded by the East Coast Africa, the tropics of Cancer and Capricorn and west of mid Pacific Ocean (Figure 5.8).

5.2.2 Stock Structure

Actinopyga echinites is a broadcast spawner that produces up to 25 million viable eggs. The egg and larval stages spend up to two weeks in the plankton. The animal is widely dispersed in

northern WA, however, commercially fished populations are located on the southern Pilbara coast, and in Shark Bay (Gascoyne coast). Most fishing activity targets the densest populations of deepwater redfish, which occur within the north-eastern shallow water lagoons between Barrow and Montebello Islands. For management purposes, redfish in the Pilbara is considered to represent a single stock, as is the newly discovered Shark Bay stock of *Actinopyga echnities*. The Shark bay stock of *A. echinities* was identified in 2020 and 2021 as part of an experimental fishery, which was established under an exemption for 5 years, to test the viability of commercial fishing in that area.

5.2.3 Life History

Actinopyga echinites are sexually dimorphic, although this is not apparent by their visual appearance and their sexual maturity will vary slightly depending on geographic location. Animals will generally mature at 120 mm in length after approximately two years (Table 5.2). Studies at Reunion Island in the Western Indian Ocean indicate animals have a major spawn in December and January and another minor spawn in May (Kohler et al. 2009). The southern Pilbara coast has similar latitude to Reunion Island.

Spawning aggregations will occur in deeper water where broadcast fertilisation will follow. A fertilised egg will form into an auricularia after 1 – 2 days, this is a feeding phase. The doliolaria stage (non-feeding) will follow after which 1 mm pentactula will settle in shallow water substrate, and have a stronger preference for limestone and dead coralline material. Juveniles will inhabit this zone up to 10 mm long and then start to forage.

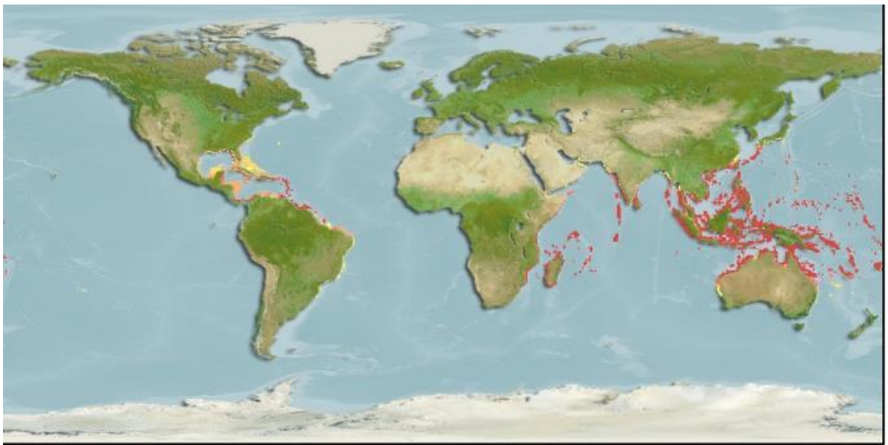


Figure 5.8. Worldwide distribution of redfish, *Actinopyga echinites* (computer generated native distribution map, source: www.aquamaps.org, version of Aug. 2013.

5.2.3.1 Movements

The movements of sea cucumber larvae prior to settlement on the benthos are dictated by physical oceanographic processes such as tidal movements, wave action, prevailing winds and currents. Once attached the animals have further ability to colonise new habitats or move to a more favourable position. *A. echinites* move with their tube feet densely distributed on their ventral surface of the body wall and also through muscular action of the body wall.

Table 5.2. Summary of biological parameters for redfish (*Actinopyga echinites*)

Parameter	Value(s)	Comments / Source(s)
Growth parameters		
L_∞ (mm)	320	Dissanayake & Wijeyaratne (2007)
K (year^{-1})	1.9	Dissanayake & Wijeyaratne (2007)
Maximum age (years)	12+ years	
Maximum size (mm)	320 - 350	Skewes et al. (2014), unpublished WA data
Natural mortality, M (year^{-1})	0.3 - 2.69	Dissanayake & Wijeyaratne (2007)
Length-weight parameters		
a	5.86 x 10^{-5}	$W = a\ TL^b$
b	3.02	$W = a\ TL^b$
Reproduction		
Maturity parameters		
A_{50} (years)	2	
L_{50} (mm)	120 mm	Kohler et al. (2009)
Fecundity	4 – 25 x 10^6 oocytes per female	Conand (1983, 1989, 1998)
Size-fecundity parameters	Not Available	
Spawning frequency	Major and minor spawning events in Spring and Autumn	Kohler et al. (2009)

5.2.3.2 Age and Growth

Actinopyga echinites generally grows to sizes of 300 – 350 mm. Growth of holothurians is the least established biological parameter of the taxon. Kohler et al. (2009) measured a maximum size of 650 g total weight for *A. echinites* in the Western Indian Ocean, but the age is unknown. In Okinawa, Japan, Wiedemeyer (1994) results show an exponential increase in weight of juvenile *A. echinites* from 0.87 to 12.82 g during a single year growth experiment, but this exponential growth trajectory is unlikely to be sustained over the entire life cycle, as it would mean that maximum size (200 g drained body weight- 600 g total weight) is attained around two years of age.

Preliminary morphometric relationships have been derived for *Actinopyga echnites* from the WASCF (Figure 5.9). However there is considerable variability in weight at length, highlighting the difficulty in establishing growth information for sea cucumbers. Experiments designed to standardise length measurements through the use of anaesthetic techniques did not reduce the weight-length variability in this species (unpublished data).

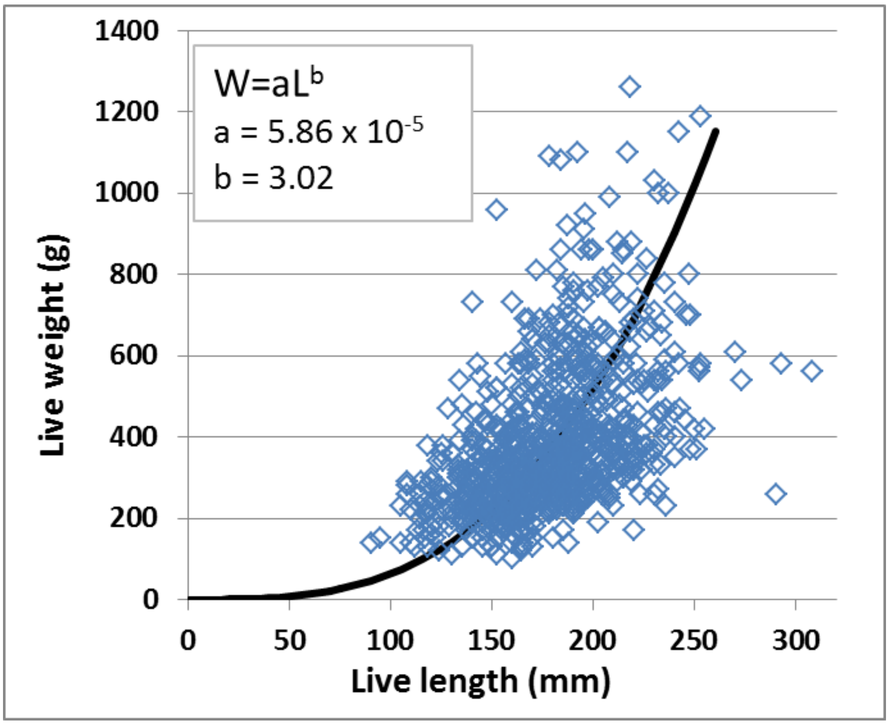


Figure 5.9. Length (mm) – weight (g) relationship for *Actinopyga echinites* from the Montebello Islands. Weight is live whole weight (no processing).

5.2.3.3 Natural Mortality

Limited information is available on natural mortality in these species due to the difficulty in measuring age and size, or conducting mark-recapture experiments. A review of harvest strategies for populations of sea cucumbers on East Coast Sea Cucumber Fishery of Queensland, assumed an M of 0.4 was appropriate for most species (Skewes et al. 2014). However a study using standard length-based methods in Sri Lanka estimated M to be 2.6 for this species (Dissanayake & Wijeyaratne 2007). Given this uncertainty, and the fundamental importance of M in fisheries assessment, for the purposes of estimating stock levels using population modelling, an M of 0.35 (with appropriate uncertainty) was assumed for *Actinopyga echinites* in Western Australia. See Table 9.9 and section 9.3.8 for more information.

Natural mortality is closely linked with another key population parameter, the intrinsic rate of increase (r). Based on a meta-analysis, a formula derived for producing an estimate of r from M for invertebrates is $r = 2.0M$ (Zhou et al. 2016). Using the results of that meta-analysis, an M of 0.35 y^{-1} may be expected to equate to an r of 0.7. These parameters give an indication of the general productivity dynamics of a species, and in data poor situations, can be used to assist in assessment and management.

5.2.3.4 Reproduction

Studies of *A. echinites* on Reunion Island indicate a major spawning event, deduced by a strong increase of gonad index (GI) from October to a maximum in December followed by a decline until February indicating that gametes were released during this two-month period (Kohler et al. 2009). GI was slightly peaking again in April, followed by a second decrease until June revealing a minor second spawning event within this month. Mean monthly GI increased and coincided with increasing temperature from October to December during gamete development, but there after no correlation remained. However, there was a stronger correlation between light illumination and GI. In the lead up to the major spawning event illumination was increasing, and GI decreased from January to May when illumination was falling. There was no correlation between rainfall and GI (Kohler et al. 2009)

Size at-maturity for *A. echinites* is approximately 120 mm. From 160 samples of *A. echinites* at Reunion Island, 94 were female, 47 male and 18 of undetermined sex, giving a sex ratio significantly different from 1:1 and closer to 1:2 ratio. Undetermined sex specimens, i.e. resting and immature stages, were encountered from June to October (Kohler et al. 2009).

The weight at first sexual maturity in which 50 % of *A. echinites* were in stages 3, 4 and 5 was found to have a mode of 46 – 55g of eviscerated weight, equal to a total weight of 65 g (Kohler et al. 2009).

Fecundity of *A. echinites* is rather high, cited in the literature for New Caledonia (Conand 1983, 1989, 1998) with values of absolute fecundity from four to 25 million oocytes compared to the weight of ripe ovaries from the different sites. Concerning the influence of environmental factors on the reproductive cycle of *A. echinites* in La Réunion, the onset of gametogenesis seems to be triggered by the increase of solar illumination in July. However, for *A. echinites* both temperature and rainfall factors did not seem to control the reproduction.

5.2.3.5 Factors Affecting Year Class Strength and Other Biological Parameters

Field studies in Japan (Wiedemeyer 1994) indicate the larvae of *A. echinites* displayed a strong preference for plate substrate consisting of limestone and dead coralline material and coarse sand. Wiedemeyer (1994) hypothesised that larvae settling on suitable hard substrate have an increased chance of growth and survival because they are provided with a suitable sub stratum to forage and grow.

5.2.3.6 Diet, trophic level, and ecosystem function

Sea cucumbers tend to be preyed upon by a relatively small group of predators, which can be attributed to the success of chemical defence mechanisms in preventing predation by generalists (Bakus 1968, 1973, see Francour 1997 for a review). Further discussion of their trophic level and ecosystem function is found in section 5.1.3.7.

5.2.3.7 Parasites and Diseases

Amongst echinoderms, the Holothuroidea represents the class that is the most infested by parasites. Parasites of holothuroids are Bacteria, Protozoa and Metazoa. There are about 150 species of metazoans which parasite holothuroids. Most of them are turbellarians, gastropods, copepods, crabs or fishes. The main body compartments suffering of the infestations are the digestive system and the coelom. The diseases induced by metazoan parasites are mostly structural: they create galls at the surface of the epidermis, pierce the respiratory tree or dig into the body wall down to the coelom. Most metazoans that live in the digestive system do not induce obvious diseases and their relationship with their hosts is probably close to commensalism. Most Protozoa that parasite holothuroids are sporozoans. They occur mainly in the coelom and/or the haemal system, one species having been reported infesting the gonads. Even in heavily infested hosts, the signs of disease induced by sporozoans are low: at most, host haemal lacuna is occluded by trophozoites or cysts are formed into the coelomic epithelium. The most pathogen agents reported from cultured sea cucumbers are Bacteria. Cultivated holothuroids may suffer from a bacterial disease, called skin ulceration disease that affects their body wall.

5.2.4 Inherent Vulnerability

Plaganyi et al. (2013) examined climatic effects on managing sea cucumber fisheries and concluded that higher sea temperatures will have a positive effect i.e. higher production and yields given the expected faster growth rates leading to larger sizes and increased fecundity. This positive view is supported by a productivity susceptibility analysis (PSA) which indicates that sea cucumbers are inherent robust to exploitation as a result of their life history parameters which suggest they are high productivity populations (Section 9.3.6).

However, sea cucumbers are also considered to have a high level of inherent vulnerability to fishing. Further discussion of this is found in section 5.1.4.

It may also be that unmanaged and unregulated fishing has been a major contributor to the poor track record for sea cucumber fisheries, and thus their vulnerability is not an indication of "management" *per se*, but more likely no management at all. In any case the dichotomy of opinion on their inherent vulnerability suggests considerable uncertainty and a conservative approach is required.

6 Fishery Information

6.1 Fisheries / Sectors Capturing Resource

A commercial fishery for the Western Australian Sea Cucumber Resource first developed in 1995, originally known as the Bêche-de-Mer Fishery. It is a small, low value fishery with a GVP in 2020 of less than $300,000 (Hart et al. 2021). Management has been primarily through input controls including limited entry, maximum number of divers, species-specific minimum target sizes (until 2017), and gear restrictions. Originally six licences were issued, however consolidation of these licenses occurred with their purchase by one company (Tasmanian

Seafoods Pty Ltd) in 2000. This was followed by a substantial reduction in effort due to the use of smaller boats (resulting in a holding capacity reduction from 30 t to 10 t), fewer crew (reduction from 7-10 to 3-4 crew) and shorter fishing trips.

A small experimental fishery for sea cucumber was developed in 2018, for a period of five years (2018-2023), in the Gascoyne bioregion, primarily Shark Bay. The fishery was established to provide opportunity for persons representing the Mulgana, Bayungu, and Thalanyji Aboriginal people to take sea cucumbers for a commercial purpose in waters adjacent to their traditional lands. A preliminary assessment of the long-term sustainability of this fishery is undertaken in this Resource Assessment Report (see sections 9.3.7.4 and 9.3.8.7).

Other commercial sectors that harvest sea cucumbers include: the Marine Aquarium Fish Managed Fishery (MAFMF), which is permitted to collect sea cucumber species not targeted by the WASCF for marine aquarium display purposes only, and inshore trawl fisheries, which capture sea cucumbers in very low numbers as bycatch but discard them.

Recreational harvest of sea cucumbers is allowed under a daily bag limit, however the actual recreational catch is negligible. Similarly, customary take is allowed, but also negligible.

The section(s) below provide more detailed information about the main fisheries / sectors that target the sea cucumber resource

6.2 Western Australian Sea Cucumber Fishery

6.2.1 History of Development

Commercial fishing for sea cucumbers began in 1995, and until 2007 it was primarily a single species fishery with 99% of the catch being sandfish (*Holothuria scabra*). Redfish (*Actinopyga echinites*) has been targeted since 2007 (Figure 6.1). Apart from sandfish and redfish, only black teatfish is caught with some consistency, although still in very low numbers.

Initially high catches of sandfish were taken (a total of 1360 t in the first 6 years), however, total catch of sea cucumbers has averaged 90 tonnes per year in the subsequent 16 years (Figure 6.1). Total catch has varied between 0 t (2013) and 380 t (1997). Between 2007 and 2018, redfish was typically the dominant species caught, however, sandfish remains the primary species in the fishery due to its wider distribution and longer catch history.

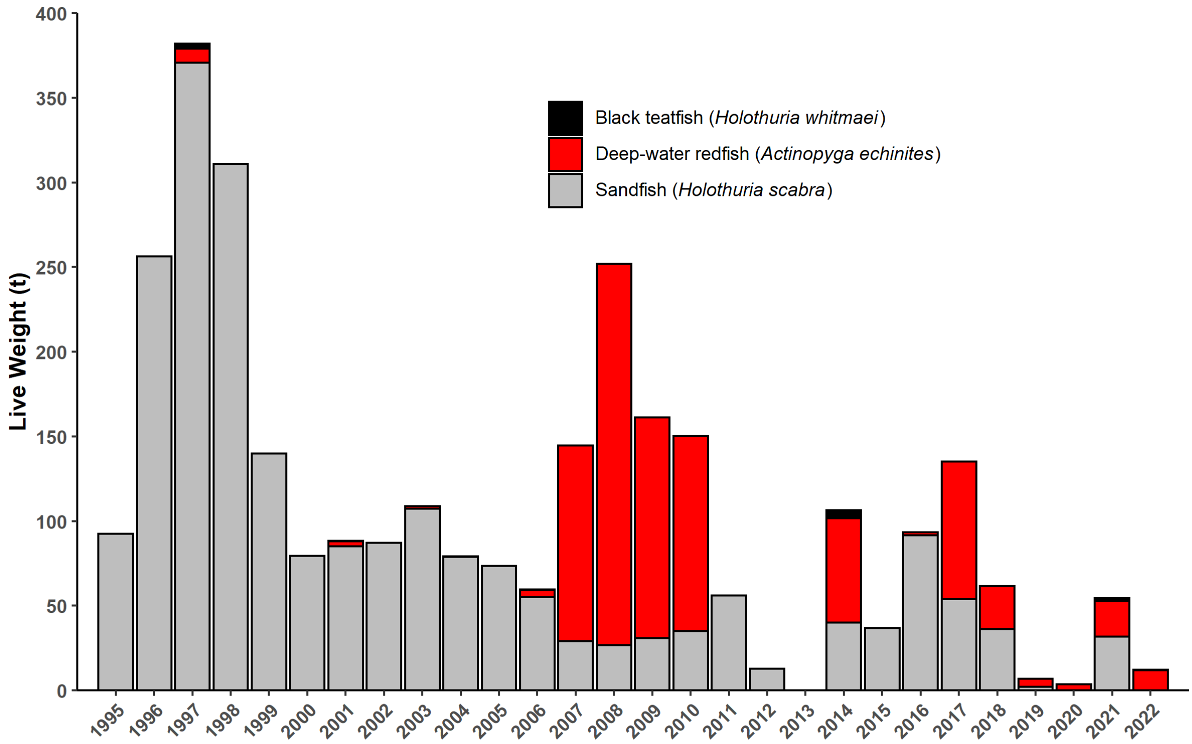


Figure 6.1. Annual total retained catches (tonnes) in the WASCF between 1995 and 2022. Catches in 2022 are only for a part year.

6.2.2 Current Fishing Activities

A summary of key attributes of the WASCF and the fishing fleet is provided in Table 6.1.

The WASCF is currently managed under Fisheries Notice No. 366 (Prohibition for Commercial Fishers Unless Otherwise Endorsed- Shellfish, Coral, Fish of class Echinoidea and Bêche-de-Mer). Fishers in the WASCF operate under an exemption to this Notice under Section (7)(3)(c) of the *Fish Resources Management Act* (FRMA). Currently there are two exemptions issued to permit commercial exploitation of sea cucumbers in the WASCF. One exemption permits commercial fishing in all areas of WA, and the other exemption permits commercial fishing by appropriate persons in waters adjacent to the traditional lands of the Mulgana, Bayungu, and Thalanyji Aboriginal people, which are in the Shark Bay and Exmouth Gulf regions.

The WASCF is permitted to operate throughout WA waters with the exception of marine parks, reserves and sanctuaries and a number of specific closures around Cape Keraudren, Cape Preston and Cape Lambert, the Rowley Shoals and the Abrolhos Islands (Figure 6.2). To date however fishing has only occurred on tropical species in the northern half of the state.

Table 6.1. Summary of key attributes of the commercial sea cucumber fishery (WASCF)

Attribute	
Fishing methods	Hand collection (95% diving, 5% wading)
Fishing capacity	Maximum of 7 vessels
Number of permits	2
Number of vessels	1-2 operating in any given year
Size of vessels	10-12 m
Number of people employed	<10
Value of fishery	$<1 million (Level 1)

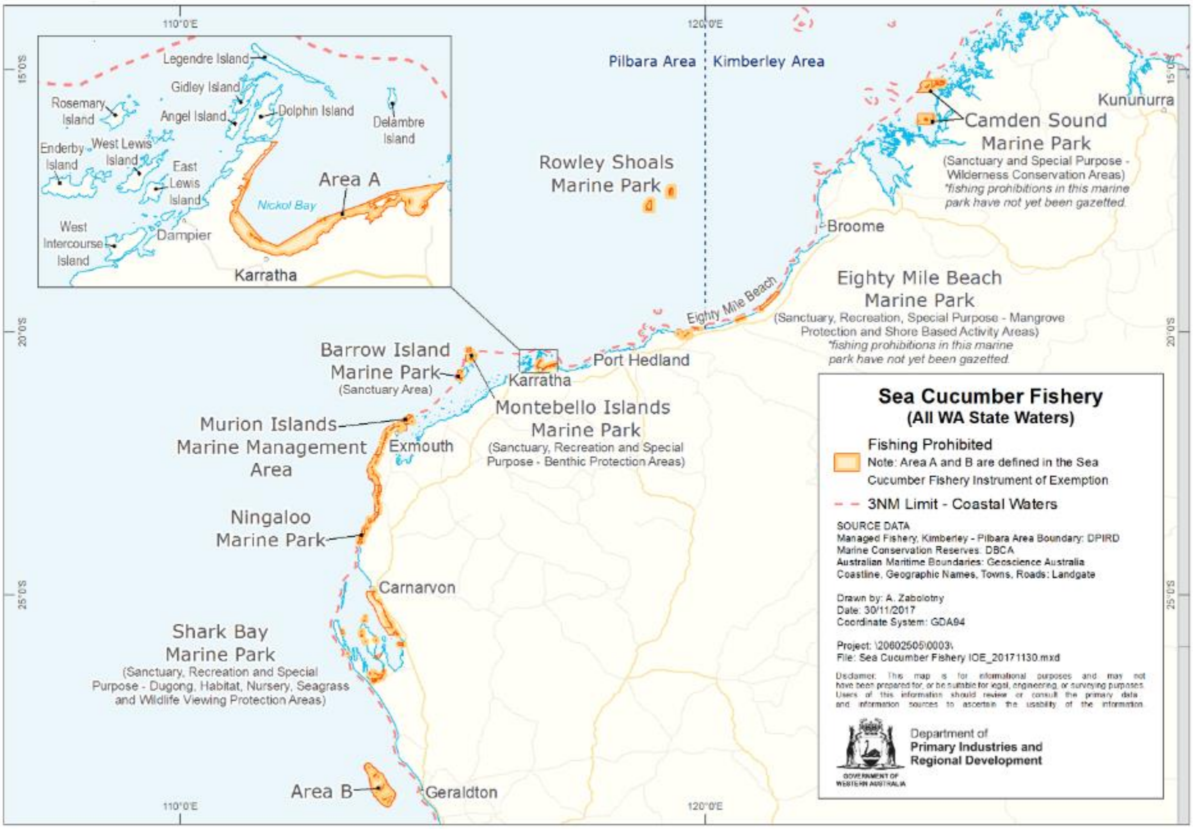


Figure 6.2. Fishing area (out to 3 nm) with closures (shaded areas) for the WASCF.

The WASCF targets remote and largely inaccessible stocks in a very large region with challenging conditions (e.g. extreme tidal movements, strong currents, poor visibility and the presence of saltwater crocodiles). Both the Kimberley region for sandfish (*H. scabra*) and the Barrow Island/ Montebello Islands and Shark Bay regions for redfish (*A. echinites*) are isolated, making these populations difficult and expensive to access and requiring immediate processing of the catch (gutting, boiling, freezing) to maintain the quality of the product for market.

The environmental conditions under which fishing in these regions takes place result in limited 'windows of opportunity'. To maintain high catch rates, current practice for sandfish is a 'pulse' fishing operation that targets sandfish aggregations throughout a number of specific locations in the Kimberley on average for two to three trips of 14-20 days each per year. Sandfish in the Pilbara region have been targeted less frequently. Redfish has historically been targeted sporadically, and the newly developed Shark Bay fishery has only received one year of significant catch. These conditions have resulted in natural refuges for sea cucumbers and significant periods during which aggregations that are targeted by the fishery are left undisturbed.

6.2.3 Fishing Methods and Gear

The method of fishing involves drift diving using hookah, scuba, or free diving, in small vessels <3 m long known as dorys. Fishers operate using the one up one down method, one diver is in the water collecting sea cucumbers and the other remaining in the vessel steering its course. Diving is typically in water <5 m deep. The divers and dorys return to the main vessel at the end of a day where the sea cucumbers undergo initial processing. This involves gutting, boiling and a short drying period before being frozen in blocks. Secondary processing occurs in Melbourne where sea cucumbers are dried and packaged before being exported as 'beche-de-mer' to Asian markets.

6.2.4 Susceptibility

The species are both widely distributed in the shallow near-shore habitat; however fishing mostly occurs in shallow-water mangrove lagoons and estuaries during neap tides, as the strong currents and poor visibility in the Pilbara and Kimberley regions due to the extreme tidal ranges renders fishing impractical at other times. Collection is limited to specific sites characterised by easily accessible, open water areas where impediments to fishing operations from crocodiles are less likely to occur and visibility is sufficient to allow collection by hand. These limitations, coupled with the burrowing nature of sea cucumbers (for example, Skewes et al. (2000) found that the population abundance of the sandfish can be underestimated by up to 60 % due to its burrowing habit in seagrass beds at high tide), means that individuals less than the size at maturity are rarely caught, as evidenced also by observed trends in size structure (Section 0).

6.3 Recreational and Customary Fishery

Recreational harvest of sea cucumbers is allowed under a capped daily bag limit of 10 individuals of other "non-listed" molluscs and invertebrate species. However the actual recreational catch is negligible. Similarly, customary take is allowed, but also negligible to date. Currently management arrangements for Aboriginal and customary fishing are being reviewed and one permit for commercial fishing in waters adjacent to Aboriginal tribal lands has been issued (see section 6.2.2).

7 Fishery Management

7.1 Management System

The harvest strategy for the sea cucumber resource of WA is a *constant exploitation approach* where the catch varies in proportion to variation in stock abundance.

The sandfish fishery in the Kimberley is based on a large number of smaller populations that have been harvested over a longer time period, whereas the sandfish and redfish fisheries in the Pilbara and Shark Bay primarily target a small number of populations in the Montebello Islands, Dampier Archipelago, and western Shark Bay regions. Consequently, it is possible to conduct cost-effective fishery-independent biomass surveys of sandfish and redfish stocks across these regions, due the finite number of viable populations.

In line with the harvest strategy, the WASCF is managed primarily using input controls, including limited entry, species restrictions and minimum legal sizes, gear/method restrictions, and spatial closures.

Recreational harvest of sea cucumbers is allowed under a capped daily bag limit of 10 individuals of other [non-listed] molluscs and invertebrate species. However, the actual recreational catch is negligible. Similarly, customary take is allowed, but also negligible.

7.2 Harvest Strategy

A harvest strategy for the sea cucumber resource outlines the long- and short-term objectives for management (DPIRD 2018). It also provides a description of the performance indicators used to measure performance against these objectives, reference levels for each performance indicator, and associated control rules that articulate pre-defined, specific management actions designed to maintain the resource at target levels. The main objectives, performance indicators, reference levels and control rules are defined in Table 7.1 for each of the key stocks currently fished. A graphical representation of the performance of the stocks against each biological reference point is shown in Figure 7.1. The spawning biomass indices for the Kimberley sandfish and Shark Bay Redfish were developed after the publication of the overall harvest strategy (DPIRD, 2018), and are thus presented for the first time in this Resource Assessment Report.

All performance indices are biomass estimates from a population model which uses three main data sources: 1) catch data from the beginning of each fishery; 2) catch rate data from monthly logbooks initially, and from the inception of the daily logbook programme in 2007, and 3) fishery independent surveys (see section 9.3.8 for more detail). Associated reference points have been set using the estimate of unfished biomass (B_0) at the beginning of the fishery. Reference levels defined as: Target (50% B_0), threshold (40% B_0) and limit (30% B_0). These reference levels have been updated since the original harvest strategy (DPIRD, 2018), in response to a surveillance report of the fishery made under the MSC (Marine Stewardship Council) assessment criteria (MSC 2021). A comparison of the old and new reference levels

for sandfish (*Holothuria scabra*) and Redfish (*Actinopyga echinites*) in the Pilbara region is provided in Appendix 1, Figure A.1.1.

It must be noted that although the definitions of the reference levels do not change (e.g. Target is 50% B_0) the estimates of B_0 and other parameters may vary from year to years as new data is included in the model. This is often the case when the model is updated with FIS data every three to five years.

Given the developing nature of this fishery, if catch data show that new (previously unfished) sea cucumber populations have been discovered, a review of the harvest strategy and stock-based reference points and will be undertaken. It will also consider what level of future monitoring of that area is required. For example, the rediscovery of a lightly exploited area of sandfish in the Pilbara region in 2016, with an initial catch of 70 t (Figure 9.2) at high catch rates (Figure 9.12), led to the completion of a fishery-independent survey to determine biomass-based reference points and performance indicators for this stock in 2017. However, there are still productive areas of sandfish habitat in the Pilbara outside of the current survey boundaries and these have been historically fished.

In the period 2017 to 2021, significant new information became available to improve the harvest strategy and assessment for the main species under exploitation. This new information includes additional Fishery Independent Surveys (FIS) of three different stocks 1) *Holothuria scabra* in the Kimberley, 2) *Actinopyga echinites* at a new location (Rosemary Island) in the Pilbara, and 3) *Actinopyga echinites* at Shark Bay. The 2022 assessment also includes catch and catch rate data from the newly established Shark Bay sea cucumber fishery, and an initial estimate of population parameters such as B_0 and B_{MSY}.

Table 7.1. Key performance indicator, reference levels and control rules for the two species and four stocks of the Sea Cucumber Resource. All reference levels and performance indicators have been updated since the 2018 harvest strategy was published.

Management Objective	Resource/ Asset	Performance Indicator(s)	Reference Levels	Control Rules
To maintain spawning stock biomass of each retained species above B_{MSY} to sustain high productivity and ensure the main factor affecting recruitment is the environment.	Sandfish (Kimberley stock)	Annual biomass estimate (t whole weight)	**Target:** 483	1. If the PI is ≥ Target, no specific management action required. 2. If the PI is < Target and ≥ Threshold, review all available information to decide if further management action is required.
			Threshold: **386**	3. If there is <80% probability that the PI is > Threshold, implement a 2-year spatial closure for the stock.
			Limit: **289**	4. If there is <80% probability that the PI is > Limit, implement a 3-year spatial closure for the stock.
	Sandfish (Pilbara stock	Annual biomass estimate (t whole weight)	**Target:** 101	1. If the PI is ≥ Target, no specific management action required 2. If the PI is < Target and ≥ Threshold, review all available information to decide if further management action is required.
			Threshold: 81	3. If there is <80% probability that the PI is > Threshold, implement a 2 year spatial closure for the stock.
			Limit: 60	4. If there is <80% probability that the PI is > Limit, implement a 3 year spatial closure for the stock.
	Redfish (Pilbara stock)	Annual biomass estimate (t whole weight)	**Target:** 884	1. If the PI is ≤ the Target, no specific management action required 2. If the PI is < Target and ≥ Threshold, review all available information to decide if further management action is required.
			Threshold: 707	3. If there is <80% probability that the PI is > Threshold, implement a 2 year spatial closure for the stock.
			Limit: 530	4. If there is <80% probability that the PI is > Limit, implement a 3 year spatial closure for the stock.
	Redfish (Shark Bay stock)	Annual biomass estimate (t whole weight)	**Target:** 44	1. If the PI is ≤ the Target, no specific management action required 2. If the PI is < Target and ≥ Threshold, review all available information to decide if further management action is required.
			Threshold: **35**	3. If there is <80% probability that the PI is > Threshold, implement a 2 year spatial closure for the stock.
			Limit: **26**	4. If there is <80% probability that the PI is > Limit, implement a 3 year spatial closure for the stock.

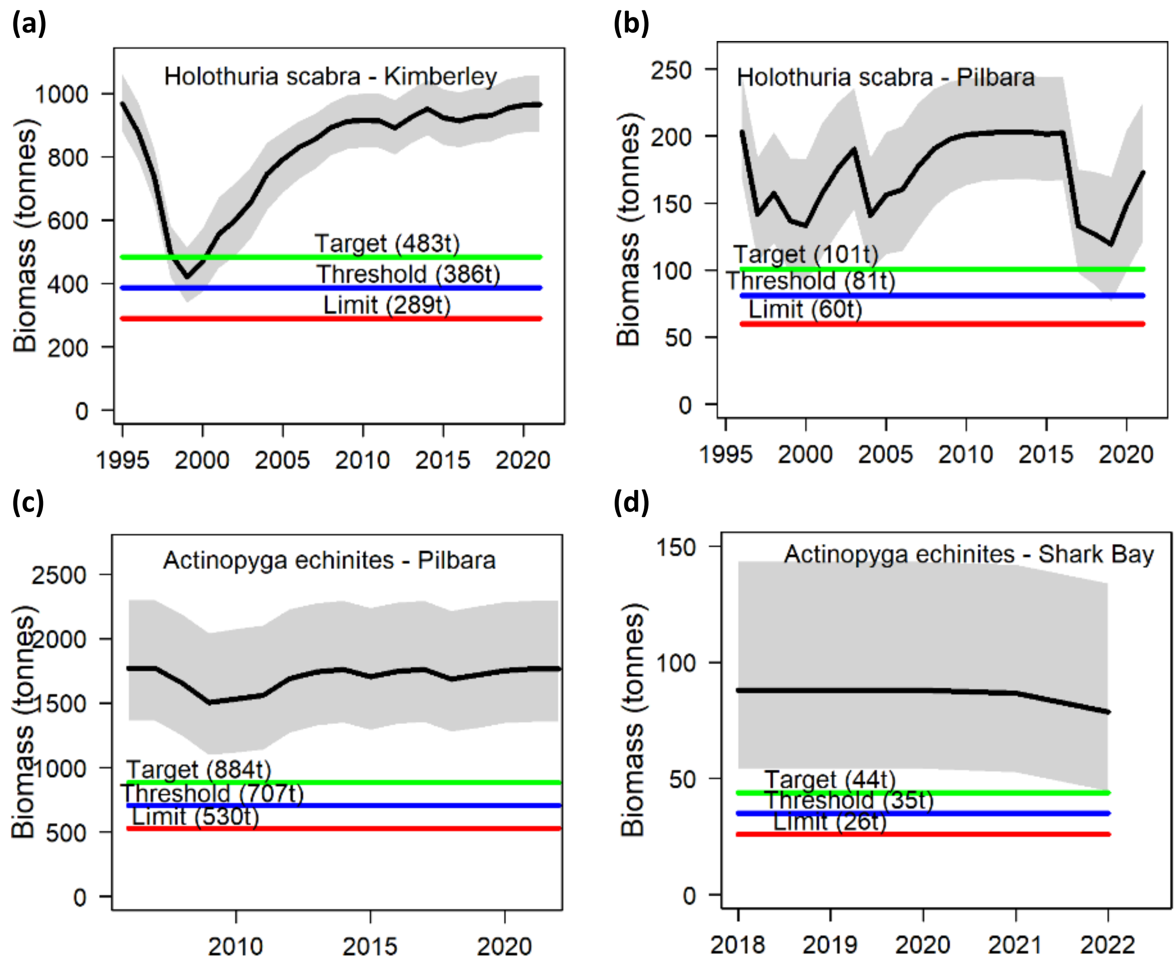


Figure 7.1. Summary of the key performance indicator (Biomass) and reference levels for the WA Sea Cucumber Resource. Shaded areas are 95% CLs for the performance indicator (black line). (a) Kimberley sandfish, (b) Pilbara sandfish, (c) Pilbara redfish, and (d) Shark Bay redfish.

7.3 External Influences

External influences include other activities and factors that occur within the aquatic environment that may or may not impact on the productivity and sustainability of fisheries resources and their ecosystems. The main external influences are environmental factors.

7.3.1 Environmental Factors

The species harvested in the sea cucumber resource are distributed through shallow water lagoons in remote regions throughout the Kimberley, Pilbara, and Shark Bay ecosystems. Consequently, they are impacted from time to time by tropical deluges and adverse swell conditions associated with cyclones. These have the potential to create localised stock depletion or even extinctions. Anthropogenic influences, such as run-off from polluted waterways are largely considered negligible due the low human population densities within the fished regions.

Other studies (see Holbrook and Johnson 2014 for a review) on the observed and/or anticipated impacts of global climate change on fisheries count: (i) distributional shifts, (ii) expansion of 'locally invasive' species, (iii) range contraction of thermally sensitive species, (iv) earlier age at maturity/mortality and (v) habitat loss/degradation, among the potential outcomes of climate change.

There is little data from which the environmental impacts on sea cucumbers and preferred shallow water habitats in WA can be estimated, but there is some evidence to support the idea that sea cucumbers are not among the most susceptible of organisms to ocean acidification (e.g. Dupont et al. 2010) and increased water temperatures. With respect to the latter, Plaganyi et al. (2013) assessed the potential impacts of projected climate changes to physical variables and critical habitats for a range of life history variables and for each of three sea cucumber life history stages. The results suggested that higher sea temperatures may have a positive effect on growth rates and fecundity although these benefits may be (partially) offset by increased larval and juvenile mortality and potential declines in seagrass habitats, which are nurseries for sandfish juveniles.

7.3.1.1 Climate Change

A risk assessment of WA's key commercial and recreational finfish and invertebrate species has demonstrated that climate change is having a major impact on some exploited stocks (Caputi et al. 2015). This is primarily occurring through changes in the frequency and intensity of El Niño Southern Oscillation (ENSO) events, decadal variability in the Leeuwin Current, increase in water temperature and salinity, and change in frequency and intensity of storms and tropical cyclones affecting the state (Caputi et al. 2015). In 2010/11, a very strong Leeuwin Current resulted in unusually warm ocean temperatures in coastal waters of south-western WA (Pearce et al. 2011). This "marine heatwave" altered the distribution and behaviour (e.g. spawning activity and migration) of some species and caused widespread mortalities of others.

8 Information and Monitoring

8.1 Range of Information

A summary of the research and monitoring activities for the WA Sea Cucumber Resource is provided in Table 8.1. Data types range from fishery dependent catch and effort records, VMS spatial tracking, exploratory fishing trials, and fishery-independent survey information.

Table 8.1. Summary of information available for assessing the WA Sea Cucumber Resource

Data type	Fishery-dependent or independent	Purpose / Use	Area of collection	Frequency of collection	History of collection
Monthly commercial catch and effort statistics	Dependent	Monitoring of commercial catch and effort trends and calculation of catch rates	Whole fishery	By month and statistical block (60 x 60 miles)	1995 to 2006
Daily catch and effort statistics	Dependent	Fine spatial scale analyses Performance indicators	Whole fishery	By individual fishing event (diving or wading)	2007 to present
VMS data	Dependent	Verification of boat locations for logbook analysis	Whole fishery	Opportunistic	Sporadic, VMS exists on vessels, but no requirement to use it exists
2004 Fishing trials	Dependent	Exploration of indices for developing performance indicators; benchmark data for different fishing grounds and exploratory fishing	Previously fished and unfished areas throughout the fishery	One-off trial in 2004	2004
Biomass and population surveys	Independent	Calculate biomass for redfish and sandfish	Whole fishery	Every 3-5 years per stock	2015-2021
Biological information	Independent	Morphometry, determining conversion factors	Whole fishery	Opportunistic	2004, 2015

8.2 Monitoring

8.2.1 Commercial Catch and Effort (1995 to 2006)

Historically, sea cucumber fishers provided monthly returns under the statutory catch and effort statistics (CAES) system. These returns contain data on catch (processed weight and/or live weight), days and hours fished by month and year, and number of crew on each vessel. Catch

and effort are spatially allocated to 60 x 60 nm statistical blocks. Fishers also note method fished and condition of catch (whole or "gilled and gutted"). Most catch is recorded as gutted and boiled therefore whole weight (live weight) is calculated using a conversion factor of 3.0 for sandfish (*Holothuria scabra*) and 4.0 for redfish (*Actinopyga echinites*). For redfish harvest in Shark Bay, a different conversion factor is employed as the processing method is a "gut only" method. The conversion is "Landed weight / 0.575". These conversion factors have been established by experiments.

A map of the 60 x 60 mile (111 x 111 km) statistical blocks used to map the catch and effort between 1995 and 2006 is shown for the Kimberley and Pilbara regions (Figure 8.1 and Figure 8.2). Although there are many large blocks, historically the majority of catch has come from two blocks. In the Kimberley, over 60% of the harvest is from Blocks 1425 and 1426 (Figure 8.1). In the Pilbara, over 70% of the harvest is from block 2015 and 2016 (Figure 8.2). Due to the discrete spatial nature of the populations, the Fishery Independent surveys (FIS) were focused on the main areas of the fishery, i.e Grid 1426 for the Kimberly (Figure 8.1), and Grid 2015 (redfish) and Grid 2016 (sandfish) for the Pilbara regions (Figure 8.2).

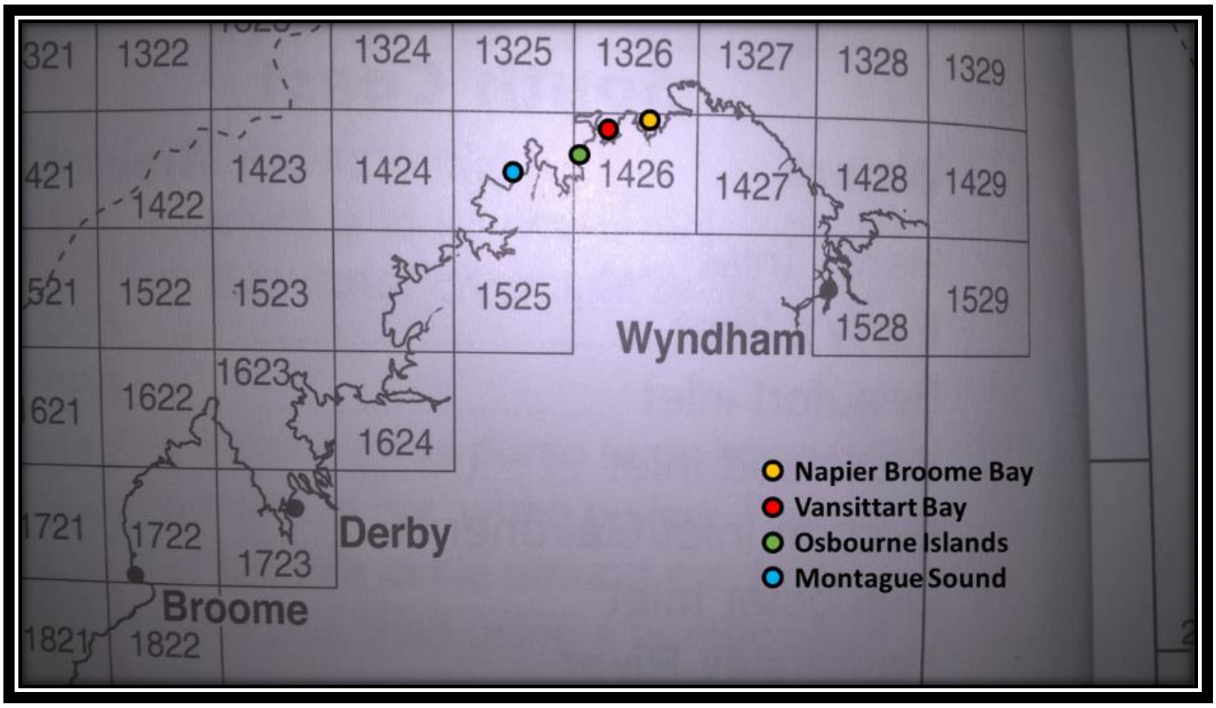


Figure 8.1. Kimberley catch and effort grids used to collate sea cucumber catch and effort information for (*Holothuria scabra*) between 1995 and 2006, prior to the introduction of more accurate logbooks in 2007. The four coloured dots in Grids 1425 and 1426 are the location of the main fishing areas. The three main fishing areas in Grid 1426 was surveyed by FIS in August 2019, see Figure 8.6 and Figure 8.7. Scale of grids are 60 x 60 nautical miles (111 x 111 km).

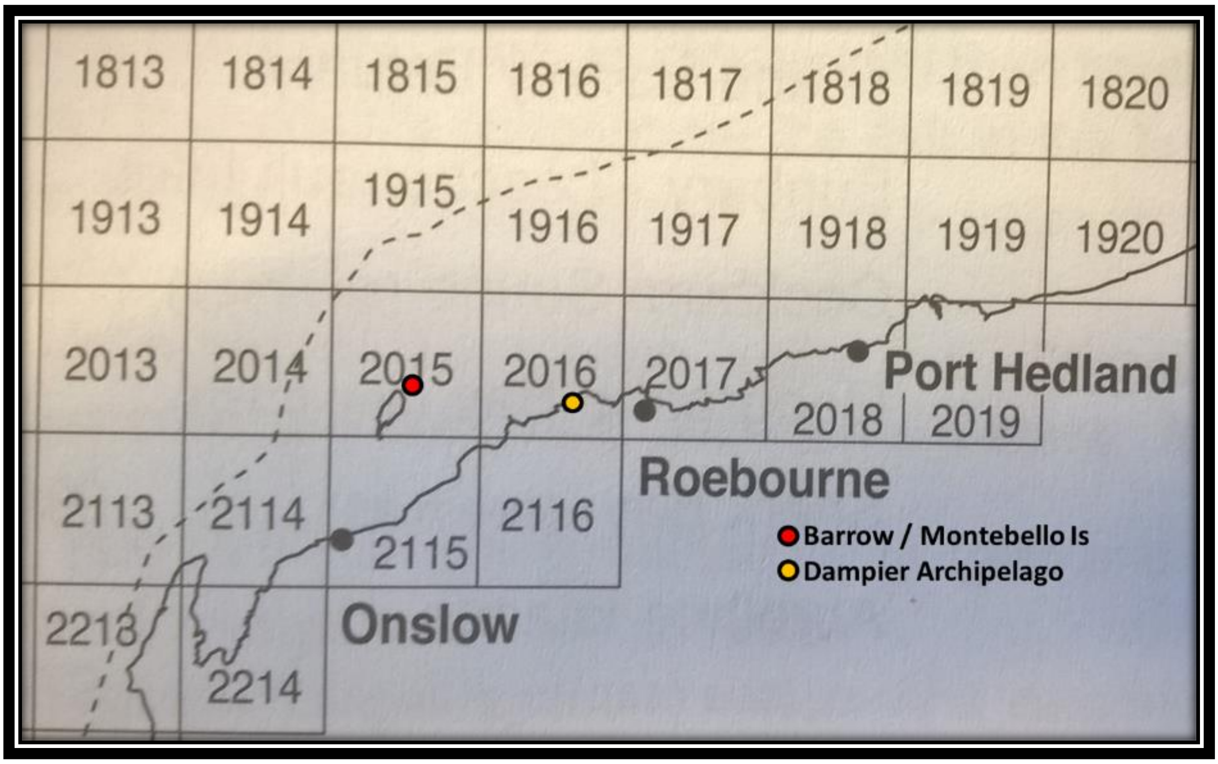


Figure 8.2. Pilbara catch and effort grids used to collate sea cucumber catch and effort information between 1995 and 2006. More accurate logbooks were introduced in 2007. The coloured dots in grid 2015 and grid 2016 are the location of the main fishing areas. Grid 2015 (Redfish – *Actinopyga echinites*) was surveyed by FIS in 2015 and 2020, Grid 2016 (Sandfish – *Holothuria scabra*) was surveyed by FIS in 2017 and 2020. Scale of grids are 60 x 60 nautical miles (111 x 111 km).

8.2.2 Commercial Catch and Effort (2007 - 2021)

Since 2007 fishers have recorded a daily catch and effort logbook. The effort component includes number of dives (air supply or snorkel) and wades, catch by method in both biomass (kg) and numbers, GPS starting positions, duration of effort and depth fished, and distances covered. This is used to develop detailed spatial maps of the catch distribution trends (section 9.3.3). See Appendix 4 for an example of the daily logbook.

8.2.3 Customary Catch

Cultural take is uncapped and included under allowances (as opposed to allocations) factored in when setting commercial and recreational allocations. The cultural take of sea cucumbers in WA is negligible. The total annual harvest for non-fish – other (which includes sea cucumbers) in WA was estimated at 49 animals (Henry and Lyle 2003). While there is a provision under Section 251 of the FRMA for the Department of Fisheries WA to grant Aboriginal communities non-transferable licences authorising the commercial take of culturally significant species, there has been negligible catch to date with respect to sea cucumbers. Recently however, an exemption permit allowing the take sea cucumber for a commercial purpose has issued to

appropriate persons to fish in waters adjacent to the traditional lands of the Mulgana, Bayungu, and Thalanyji Aboriginal people. These are in the Shark Bay and Exmouth Gulf regions.

8.2.4 Illegal, Unreported or Unregulated Catch

Considered as negligible, with both overt and covert surveillance undertaken by Commonwealth and State agencies, primarily for border protection. Surveillance is also undertaken to prevent illegal fishing. Also, the remoteness and patchy nature of the stocks affords extra protection due to the cost involved in access.

8.2.5 Fishery-Dependent Monitoring

In addition to catch and effort data, daily logbook returns provide information on numbers of animals caught as well as weight (Appendix 4). Consequently, an average weight index for each species is also obtained and used in assessments.

8.2.6 Fishery-Independent Surveys (FIS)

Fishery-independent surveys (FIS) are undertaken in the WASCF. The objective of these surveys is to estimate biomass to inform the population dynamics model and harvest strategy for each of the species and stocks. Areas surveyed were the Barrow and Montebello Islands in the Pilbara region, and Shark Bay, for the redfish stock in 2015, 2020 and 2021. Also, the Dampier Archipelago of the Pilbara region for the sandfish stock in 2017 and 2020, and the Kimberley region for sandfish stocks in 2019 (Table 8.2). These surveys shall be repeated every five years to update the harvest strategy. Where appropriate, and resources permit, surveys of other areas/species are undertaken as the need arises. For example, a survey of Shark Bay sea cucumber populations was undertaken in 2021 in response to a developing fishery in that region (see Figure 8.5 and Figure 9.9 for more details).

8.2.6.1 Redfish (*Actinopyga echinites*)

Commercially fished sea cucumber habitat in the Pilbara and in Shark Bay regions were mapped, and fishery-independent surveys targeted on strata within the known fishing grounds (Table 8.2). Overall, surveys targeted 300 km^2 of populations with 844 survey sites (Table 8.2). In the first survey in 2015 in the Pilbara region, nine strata divided across two main areas, north and south of Parakeelya Island were investigated (Figure 8.3). For the second survey in 2020, size and location of strata in the Pilbara region were modified to target the known areas of high density (Figure 8.4) and also included 8.6 km^2 of a newly discovered population at Rosemary island in the Dampier archipelago. Shark Bay was surveyed in 2021, targeting an initial area of 11 km^2 consisting of 10 km^2 of low-density areas and 1 km^2 of high density "hotspots (Figure 8.5). Population density data (numbers) were collected by hookah dive survey from a total of 390 survey sites, each consisting of a transect of 100 m^2 (Figure 8.3). Size-structure information (length and weight) was collected from 772 individuals in the 2015 Pilbara surveys, and 413 individuals in the 2020 surveys. Data collected were used to estimate current biomass (Section 0), and virgin biomass as part of the input information to a biomass dynamics model (Section 9.3.8).

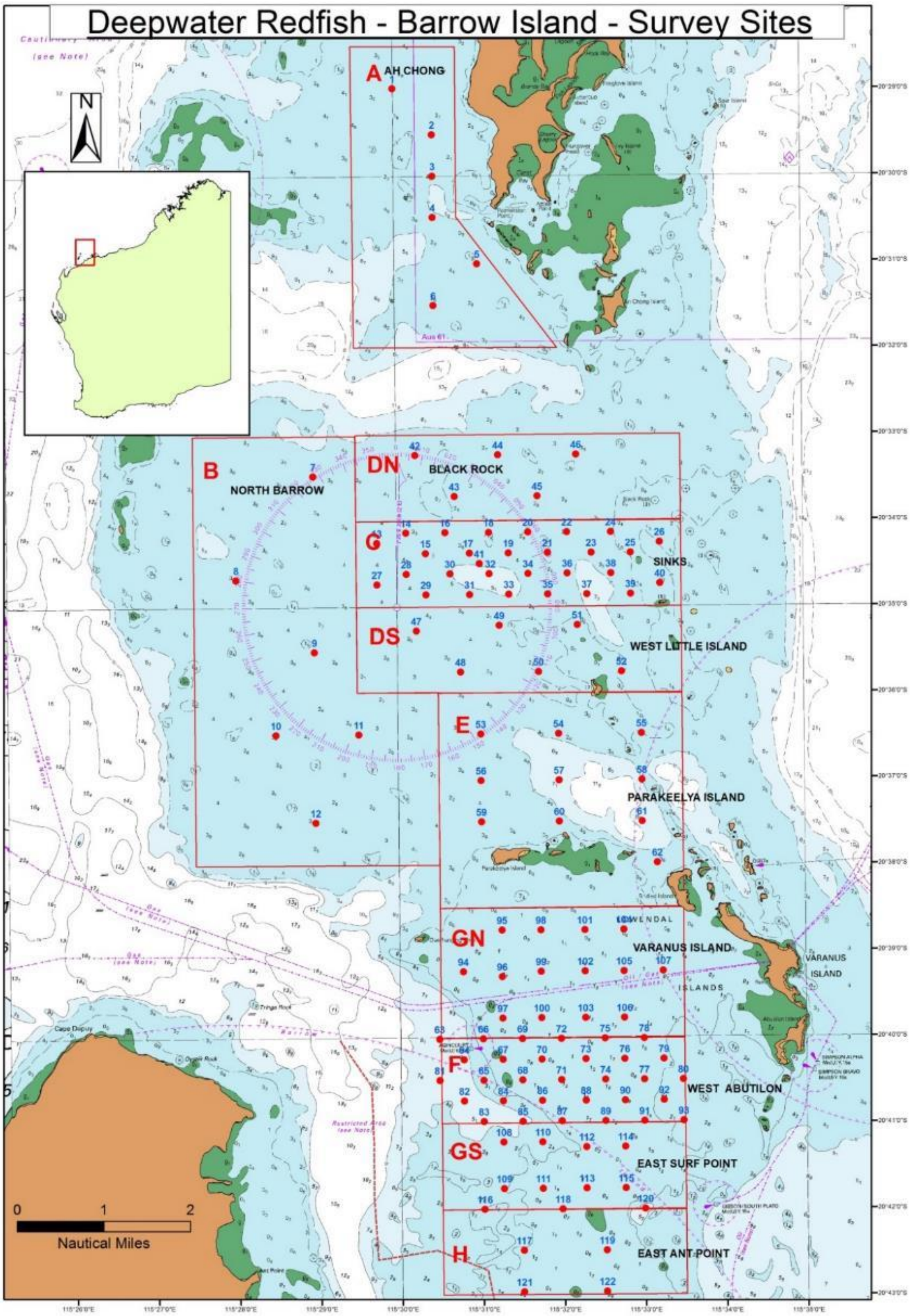


Figure 8.3. Survey design for redfish (*Actinopyga echinites*) in 2015 at Barrow and Montebello Islands. Strata divided into North (A, B, DN, G, DS, E) and South (GN, F, GS, H) of Parakeelya Island. Red dots indicate each survey site (100 x 1 m^2 transect), and blue numbers above red dots are the site numbers. Strata A, B and H were excluded from estimation procedures and future surveys, as no *A. echinites* were found in these areas.

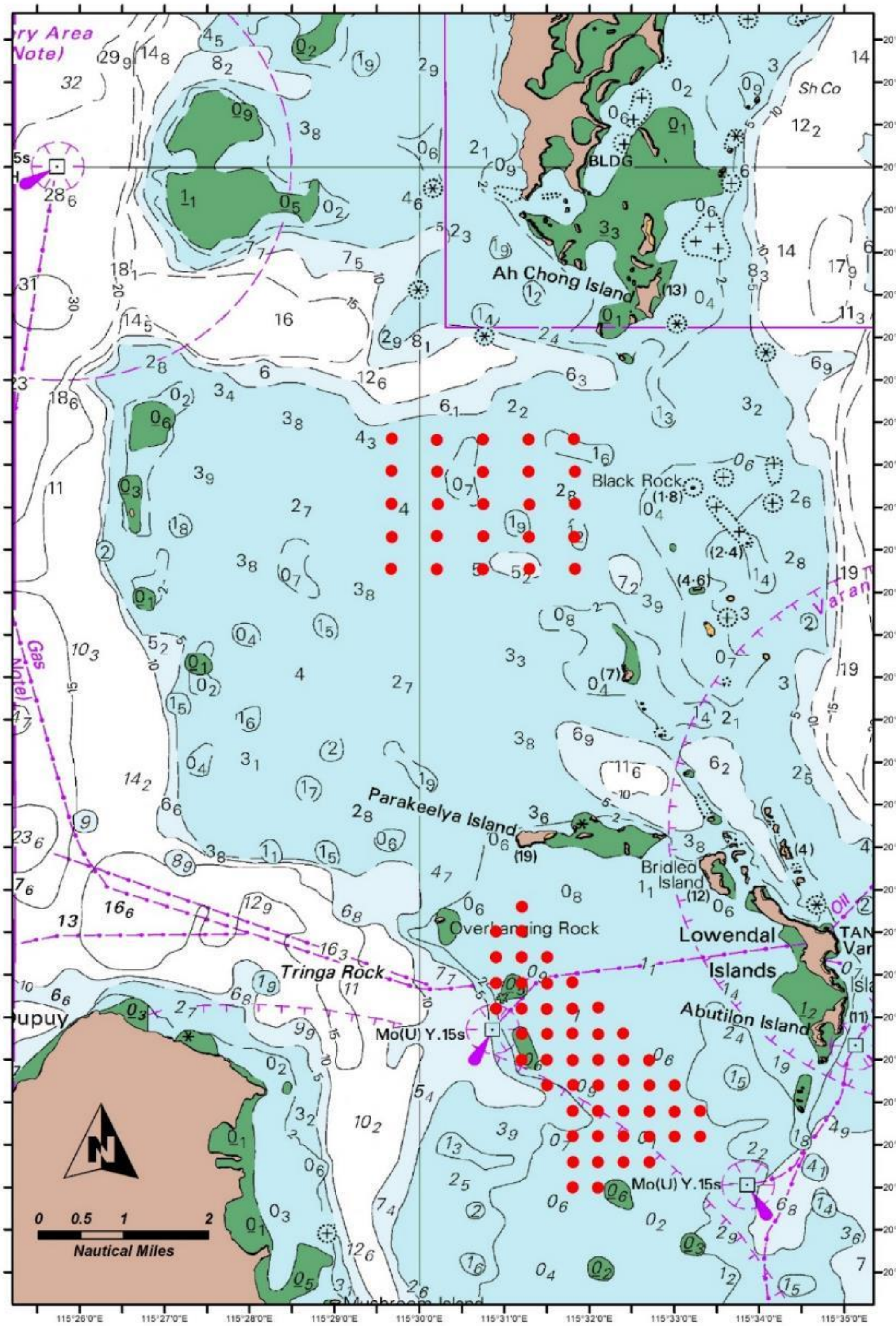


Figure 8.4. Survey design for redfish (*Actinopyga echinites*) in 2020 at Barrow and Montebello Islands in 2020. Survey strata were refined from the 2015 survey (Figure 8.3), and divided into two strata, North and South, for a total of 24km² surveyed. Red dots indicate each survey site (100 x 1 m² transect).

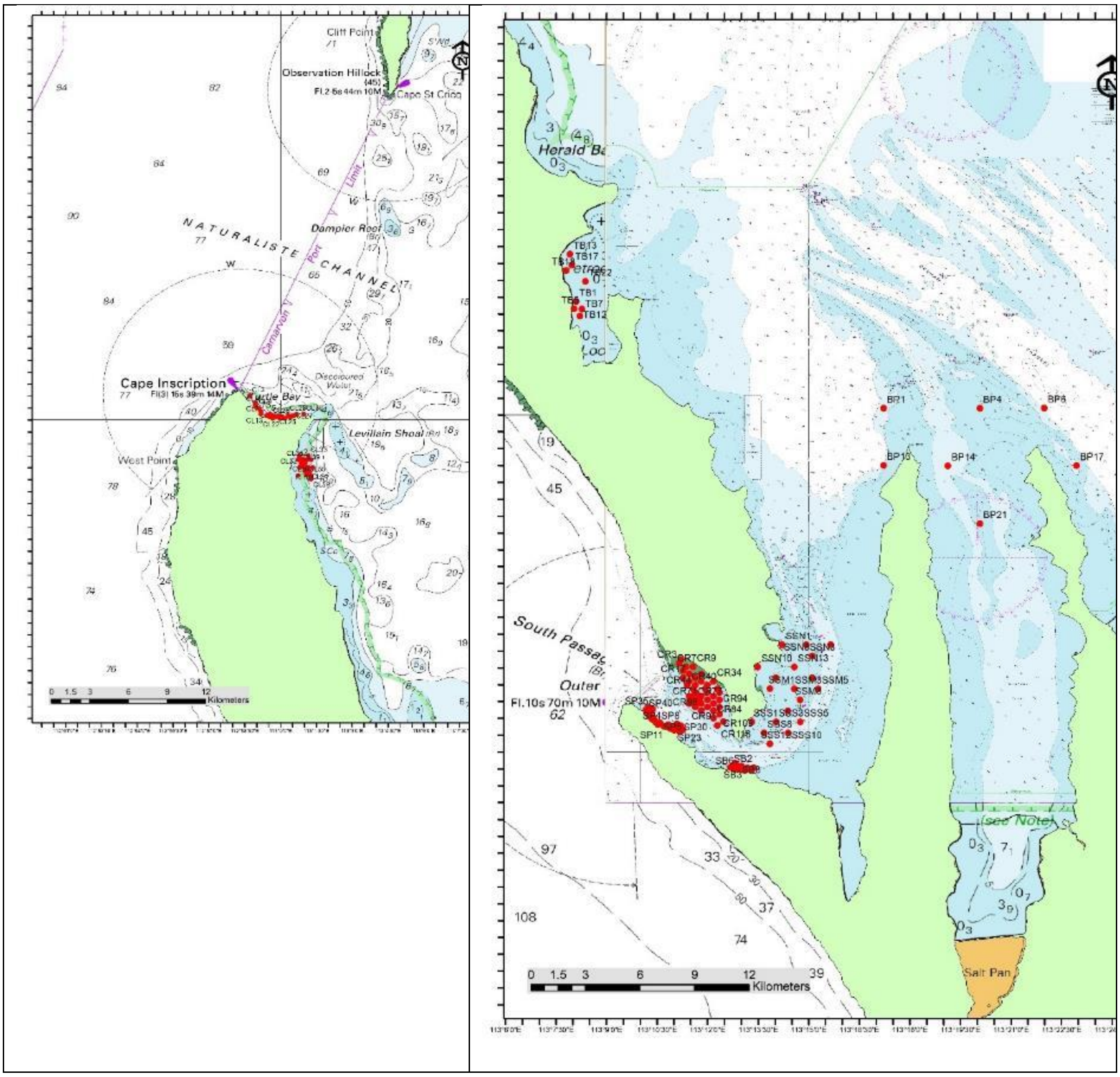


Figure 8.5. Survey design for redfish (*Actinopyga echinites*) in 2021 at Shark Bay. Survey strata were defined into North (left panel) and South (right panel) of Dirk Harthog Island on the Western boundary of Shark Bay. A total of 11 km^2 was surveyed, consisting of 10 km^2 of low-density areas and 1 km^2 of high density "hotspots". Red dots indicate each survey site (100 x 1 m^2 transect).

Table 8.2. Survey method and design for fishery independent surveys (FIS) of *Actinopyga echinites* and *Holothuria scabra* in the Kimberley, Pilbara, and Shark Bay regions of Western Australia. Strata are geographically defined units, and sites within strata were chosen with systematic sampling. A site was a transect of 100m² for all *A. echinites* strata, and for *H. scabra* in the Kimberley. For *H. scabra* populations in the Pilbara, a site was a 50m² transect. ROV-Remotely Operated Vehicle.

***Species* and Region**	**Survey Method**	**Year**	**Total area of strata (km^2)**	**Mean area of strata (km^2)**	**Total No. of Strata**	**No. of strata surveyed**	**No. of sites**
Actinopyga echinites							
Pilbara	Divers	2015	162	13.2	10	10	122
Pilbara	Divers	2020	45.5	15.1	3	3	96
Shark Bay	Divers	2021	11.1	1.58	9	9	172
Sub-Total			**219**		**22**	**22**	**390**
Holothuria scabra							
Kimberley	ROV	2019	53.6	0.7	81	13	161
Pilbara	Divers	2017	18.6	1.2	16	15	183
Pilbara	Divers	2020	8.9	2.0	19	4	110
Sub-Total			**81**		**116**	**32**	**454**
TOTAL			***300***		***138***	***54***	***844***

8.2.6.2 Sandfish (*Holothuria scabra*)

Habitat in the Kimberley and Pilbara and regions were mapped using GPS information from daily logbook returns, and spatial information sourced from industry skippers. Surveys targeted 81 km^2 of populations from 116 strata (Table 8.2). In the Kimberley region, surveys were undertaken in 2019 at the Osbourn Islands (Figure 8.6b), Vansittart Bay (Figure 8.7c), and Napier Broome Bay (Figure 8.7d). These were located in Grid 1426 (Figure 8.1; Figure 8.6a) and were surveyed by an ROV (Remotely Operated Vehicle – see section 8.2.7). Mean area of individual strata in the Kimberley region was 70 hectares or 0.7 km^2 (± 0.1 SE). In the Pilbara region, sandfish were surveyed in 2017 and 2020, targeting 15 strata in the Dampier archipelago and the Burrup peninsula (Figure 8.8) and data was collected by hookah dive survey from a total of 293 sites (Table 8.2). Additionally, size-structure information (length, and weight) were obtained by sampling 300 animals from 10 sites (30 per site) within Karratha Bay, which was the area of the main population. Data collected were used to estimate current biomass (Section 0), and virgin biomass as part of the input information to a biomass dynamics model (Section 9.3.8).

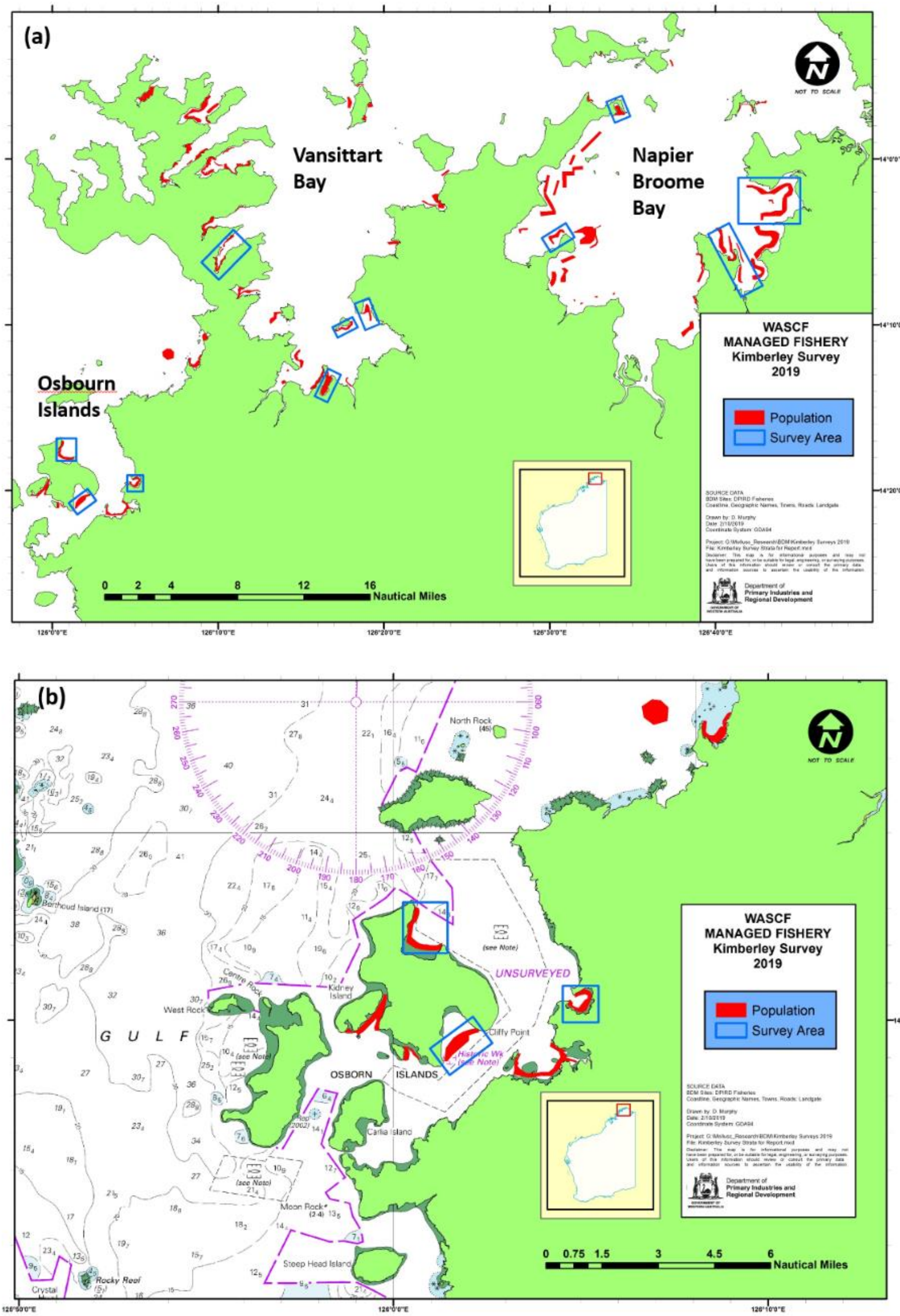


Figure 8.6. Biomass survey design for sandfish (*Holothuria scabra*) within the Kimberley region, populations in red shading, survey areas in blue box. (a) All areas combined, (b) Osborn Islands.

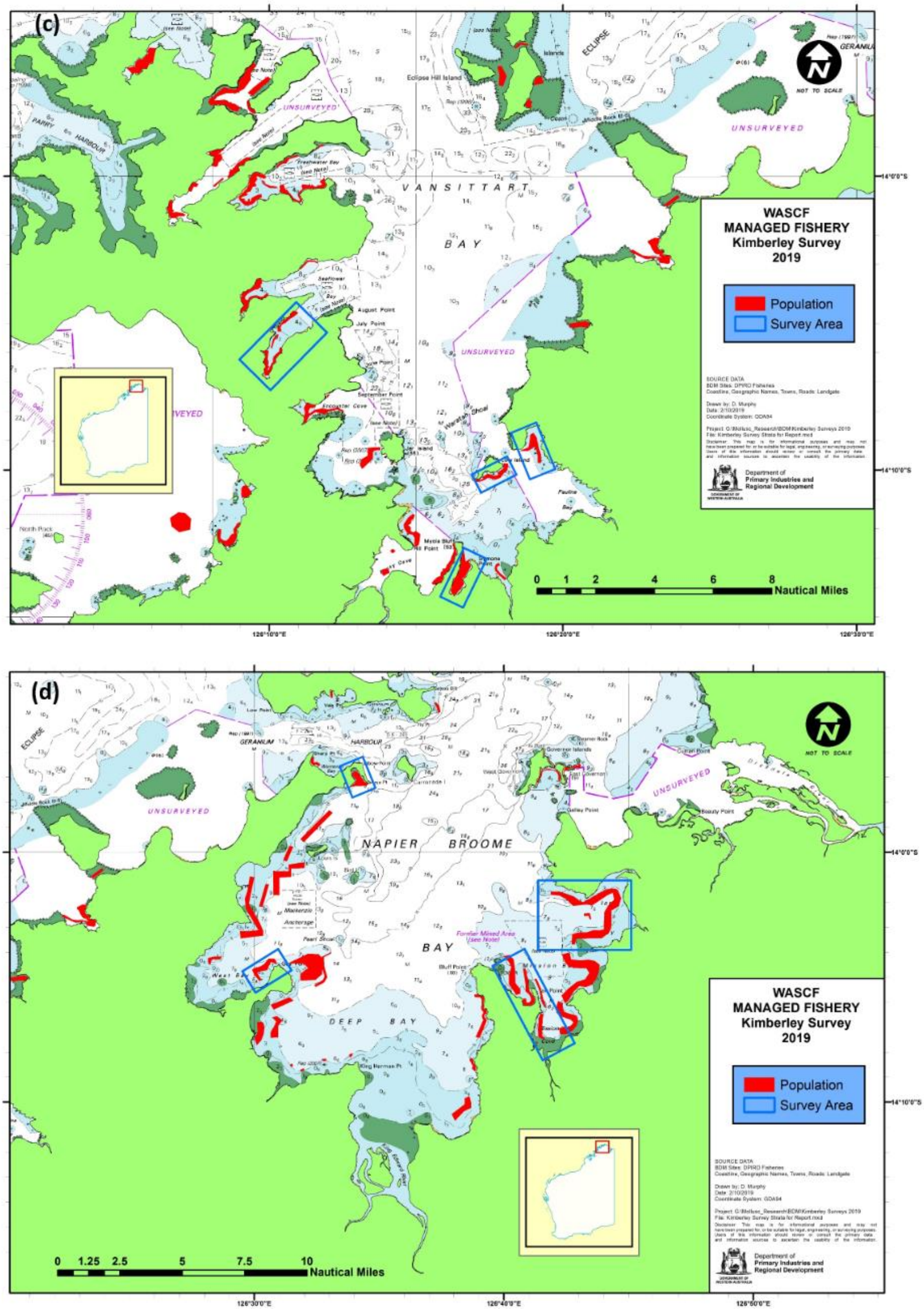


Figure 8.7. Biomass survey design for sandfish (*Holothuria scabra*) within the Kimberley region (c) – Vansittart Bay, and (d) Napier Broome Bay.

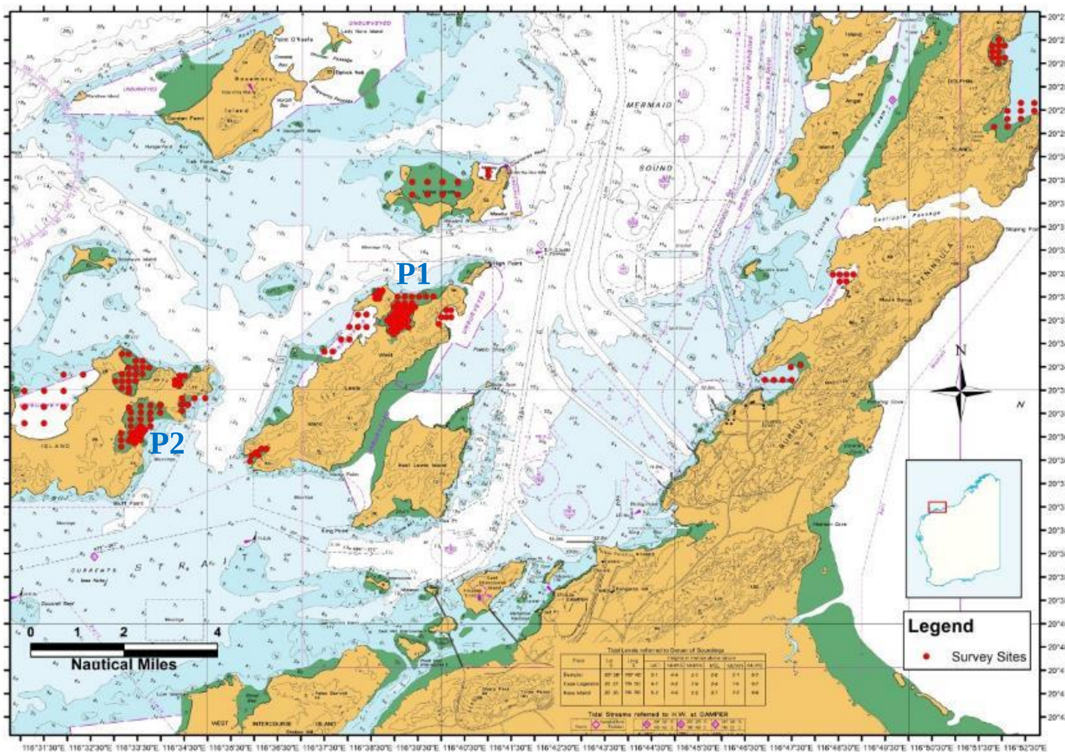


Figure 8.8. Survey design for sandfish (*Holothuria scabra*) in 2017 at the Dampier Archipelago of the Pilbara region. Survey strata divided into 15 bays and inlets across the Archipelago. Red dots indicate each survey site (50 x 1 m^2 transect). A total of 183 sites were surveyed across the 15 strata. P1 (Karratha Bay) and P2 (Enderby South) indicate the strata that contained significant populations of sandfish (see Section 9.3.7.1). Surveys in 2020 focused on these high density populations.

8.2.6.3 Spatial constraints in fishery independent monitoring

Sea cucumber population distribution is governed by habitat heterogeneity and prevailing oceanography. For example, in the Kimberley area in 2019, 81 strata were identified as holding populations of sandfish for a total of 56.6 km^2 (Table 8.2). However, the average area was small, being 70 hectares or 0.7 km^2. In comparison, in the Pilbara, only 3 strata were identified for populations of redfish, totalling 45.5 km^2, with a much larger average strata size of 15.1 km^2 (Table 8.2). Sandfish and redfish have wide Indo-Pacific distribution and are key components of tropical marine ecosystems. However, none of the three regions (Kimberley, Pilbara, Shark Bay) have been comprehensively surveyed and there is likely to be populations that have remained undiscovered.

To account for this spatial constraint, a parameter that scales the area of FIS survey (e.g. 45.5 km^2 for redfish in the Pilbara in 2021; Table 8.2) to the total area of available habit for each bioregion, has been included in the population modelling (see Table 9.8 and Table 9.9). This estimate has been based on historical fishing data and some exploratory surveys, however very

small areas can hold substantial biomass, for example, 123 tonnes was found in 1.3 km^2 in Karratha Bay in 2017 (Table 9.4). Unsurveyed populations will be included in future surveys where resources permit, and it is anticipated that the known area of populations shall increase over time.

8.2.7 Remotely Operated Vehicle (ROV)

The marine waters of the Kimberley region are heavily infested with crocodiles. Consequently, the use of in-water divers was considered too hazardous. As a substitute a remotely operated vehicle was employed to conduct the fishery independent surveys. The ROV model was "BlueROV2" (Figure 8.9a), manufactured by Blue Robotics (https://bluerobotics.com/about/). The BlueROV2 is connected to a laptop via a tether (cable) and its flight and data collection was controlled by a 3-person team. A pilot using an X-Box handheld consol drove the ROV, a survey assistant accompanied the pilot to record the sea cucumber data from the live footage stream, and a tender handled the ROV and its umbilical cord. To ensure the pilot and survey assistant could control the BlueROV2 in a suitability reduced glare and noise environment, a command booth consisting of a matt black interior with shade cloth curtain was constructed (Figure 8.9c).

(a) (b) (c)

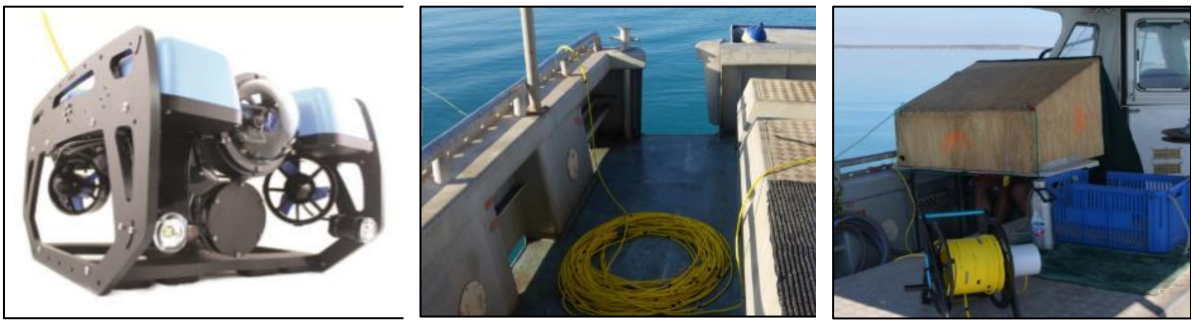


Figure 8.9. Blue Robotics BlueROV2 (a), tether cable (b) and command booth (c).

8.2.7.1 Calibrating for hover distance

Quantitative survey data are most reliable when the ROV is hovering at a known distance above the substratum so a standardised transect width of 1m can be maintained. To achieve this, the BlueROV2 employs a sensor to indicate its current depth and the pilot can engage a depth hold option to maintain the BlueROV2 at a set distance from the surface (and therefore from the substrate).

To account for changes in visibility and depth, an operational matrix was developed to include four hover distances above the bottom, i.e. 200 mm, 300 mm, 400 mm and 500 mm. At low visibility the ROV was operated closer to the bottom (i.e. 200 mm), at high visibility, a higher hover distance was used. The camera was locked at the same position to ensure consistency.

Having set the hover distances for the ROV, it was necessary to calibrate the 1m swath on the laptop screen for each of the hover distances. Calibration was achieved using a 1m length of PVC that was deployed on the substrate. The ROV was piloted to the PVC length, and then raised to the designated hover distance. For each distance, the positions of the ends of the 1 m length of PVC were recorded onto the laptop screen using different coloured adhesive indicators (Figure 8.10). The green dot is a 1m width at a 300mm hover, the red dot is a 1m width at 400mm, the blue dot is a 1m width at 500mm above the substrate (Figure 8.10).

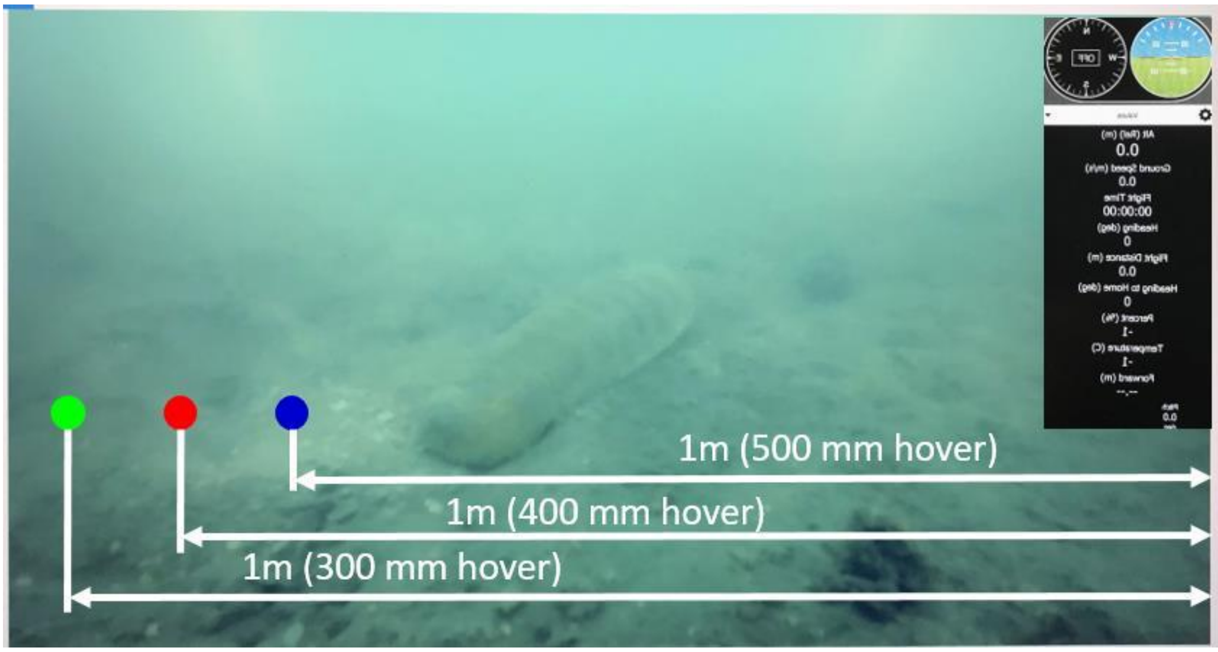


Figure 8.10. Hover distance calibration indicators (coloured dots) for 1m wide transect visual swath using the BlueROV2. *Holothuria scabra* at centre of screen. Screen shot taken from a sea cucumber transect at the Osbourn Islands.

8.2.7.2 BlueROV2 Survey Methodology

A research crew of 3 staff would arrive by vessel at one of the pre-determined survey sites and deploy the vessel anchor. Two staff (pilot and data recorder) would take position in the command booth (Figure 8.9c) and the third staff member (tender) would take a compass bearing in the sector off the stern of the vessel (Figure 8.11a). The compass bearing gave the direction along which the pilot would navigate the BlueROV2 the prescribed 100 m^2 transect length, with the length of the survey transect marked on the tether cable in 1 m increments (Figure 8.9b). The tender would deploy the BlueROV2 under the direction of the pilot and then instruct the pilot to submerge the BlueROV2 to the bottom, once it was clear of the stern of the vessel.

Once the BlueROV2 arrived on the bottom, the pilot and recorder would decide on the hover distance based on visibility, set the camera tilt, pivot to the prescribed compass bearing (visually indicated on the laptop screen) and then commence the 100m transect by moving

forwards. Periodically during the transect or if the visibility changed, the pilot would settle the BlueROV2 on the bottom to check the depth and adjust the hover distance as required. Any sea cucumbers that were observed passing through the visual field between the indicators on the laptop screen during the transect were be recorded by the survey assistant (Figure 8.10). Additional details recorded included BlueROV2 battery voltage, flight time, depth and depth hold selection, substrate type and tide and wind.

The tender would periodically inform the pilot and survey assistant of distance of the BlueROV2 from the point of initial submergence. At the 100m mark (+ depth as noted from the vessels depth sounder), the tender would instruct the pilot to terminate the survey and bring the BlueROV2 to the surface. The BlueROV2 would then be manually pulled back to the vessel via the tether cable (Figure 8.11c).

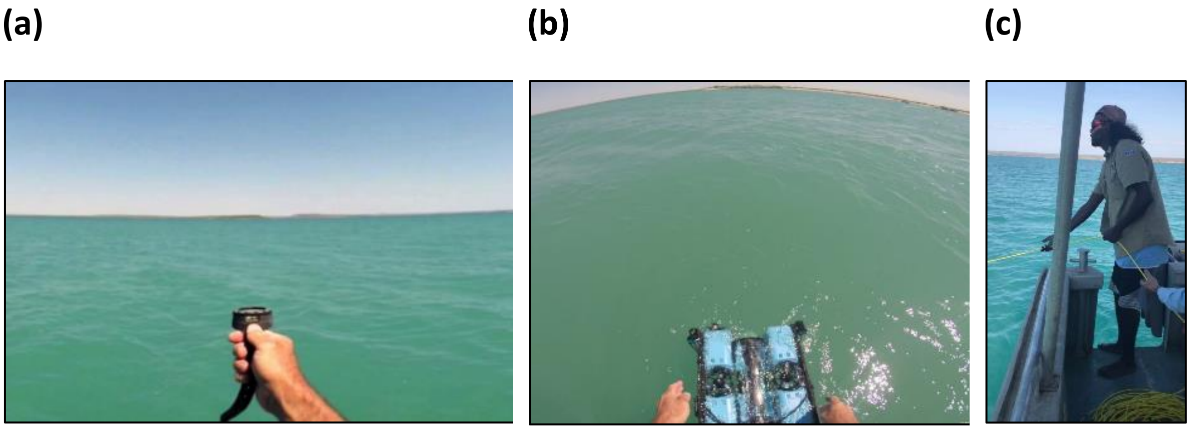


Figure 8.11. Pre- flight bearing (a), BlueROV2 deployment (b) and manual retrieval (c).

8.2.8 Environmental Monitoring

Databases with environmental variables (e.g. water temperature, wind and sea level) are continuously updated and extended as new data becomes available from collections by the Department, internet sources and from other agencies (see Caputi et al. 2015). The environmental variables from these databases have been used in analyses of correlations with biological parameters of species and allow for the examination of long-term trends.

9 Stock Assessment

9.1 Assessment Principles

The different methods used by the Department to assess the status of aquatic resources in WA have been categorised into five broad levels, ranging from relatively simple analysis of annual catches and catch rates, through to the application of more sophisticated analyses and models that involve estimation of fishing mortality and biomass (Fletcher and Santoro 2015). The level of assessment varies among resources and is determined based on the level of ecological risk, the biology and population dynamics of the relevant species, the characteristics of the fisheries exploiting the species, data availability and historical level of monitoring.

Irrespective of the types of assessment methodologies used, all stock assessments undertaken by the Department take a risk-based, weight-of-evidence approach (Fletcher 2015). This requires specifically the consideration of each available line of evidence, both individually and collectively, to generate the most appropriate overall assessment conclusion. The lines of evidence include the outputs that are generated from each available quantitative method, plus any qualitative lines of evidence such as biological and fishery information that describe the inherent vulnerability of the species to fishing. For each species, all of the lines of evidence are then combined within the Department's ISO 31000 based risk assessment framework (see Fletcher 2015; Appendix 2) to determine the most appropriate combinations of consequence and likelihood to determine the overall current risk status.

9.2 Assessment Overview

The stock status of the sea cucumber resource in WA is assessed using a weight-of-evidence approach that considers all the available (fishery-dependent and fishery-independent) information for this resource. This annual assessment is primarily based on monitoring of catch, effort, catch distribution, trends in size-structure, fishery-dependent standardised catch rates (catch per unit effort, SCPUE), and fishery independent biomass surveys. Appropriate statistical approaches such as the use of generalised linear models (GLM) to estimate abundance indices from catch rates or stratified random sampling techniques for deriving estimates of population size or biomass are applied where necessary. Fishery catch and catch rate data are combined with the fishery independent survey data in population models to estimate unfished biomass, MSY, and other important parameters of stocks. These estimates were then used to derive target, threshold and limit reference points to support the harvest strategy for sea cucumber stocks. Further details are found in Section 0 and 9.3.8.

9.2.1 Peer Review of Assessment

Stock assessments of key target species are internally reviewed as part of the Department's process for providing scientific advice to management and the Minister on the status of fish stocks. Assessment summaries (see weight-of-evidence risk assessment presented in Section 9.3.8) are signed off by the relevant Supervising Scientists and the Director of Research before being provided to the fishery managers to inform decision-making. Assessments and annual

catch information are also presented by the Department and discussed with commercial licence holders at Annual Management Meetings (AMMs).

In recent years, the Department has had a schedule for peer review of assessments for all fisheries; this "rolling" schedule aimed to generate major reviews of 5 – 8 fisheries per year, employing a mix of internal and external (e.g. universities, CSIRO, inter-state fisheries departments) fisheries experts. The sea cucumber fishery has also been assessed by the Federal government as part of an export approval process to ensure the fishery is sustainable under the provisions of the EPBC Act 1999. This fishery is currently accredited for export until 2025.

The sea cucumber fishery is currently certified as sustainable against the Marine Stewardship Council (MSC) standard for sustainable fishing (V2.0). The MSC is a 3rd party independent review process.

9.3 Analyses and Assessments

9.3.1 Data Used in Assessment

CAES / Logbook / Processor returns / VMS data Fishery-dependent data Fishery-independent survey data

9.3.2 Catch and Effort Trends

9.3.2.1 Commercial Catches

Catches between 1995 and 2006 were predominantly sandfish, post-2006 the majority of catches were redfish (Figure 9.1). Based on the last ten years of fishing, catches of sea cucumber in the WASCF are approximately 38% sandfish, 61% redfish, and <1% black teatfish, with other species making up a very minor contribution (Table 9.1).

Table 9.1. Total catches of sea cucumbers (tonnes, whole weight) retained by the WASCF targeting the resource, estimated as a total, and an annual average, for 2007-2021.

Common name	Species name	Retained catch (2007 to 2021)		% of catch
		Total	15 year average	
Sandfish	*Holothuria scabra*	479	31.9	38.2
Redfish	*Actinopyga echinites*	770	51.3	61.4
Black teatfish	*Holothuria whitmaei*	5.6	0.38	0.4
Other species		0.4	0.03	<0.1
Total		**1255**		

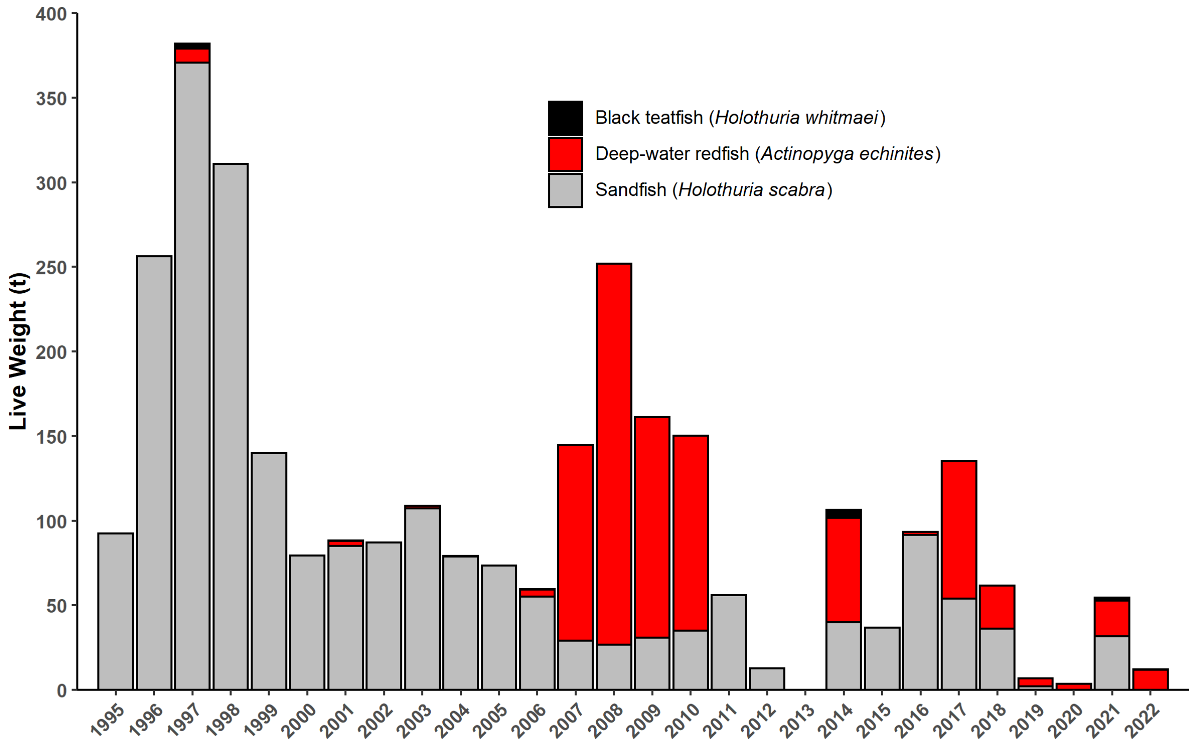


Figure 9.1. Annual total retained catches (tonnes) of three species of sea cucumber in the WASCF from 1995 to 2022. 2022 data is limited to Jan-Mar.

9.3.2.1.1 Sandfish

Catches of sandfish peaked at 370 t in 1997 in the third year of the fishery (Figure 9.2). By 2000 it had declined to less than 100 t and has remained below this figure since. A contributing reason for the reduced catch has been a consolidation of industry effort and the implementation of more precautionary and economical fishing practices, such as use of smaller boats requiring less crew, shorter fishing trips and a voluntary rotational fishing strategy.

The majority of the catch has come from the Kimberley region, but in recent years the Pilbara has been more important (Figure 9.2). Catch increased significantly in 2016 to 90 t, which was primarily due to the rediscovery of a population within the Pilbara region that had not been fished since 2004. In 2021 the Kimberley region was targeted for the first time since 2017.

9.3.2.1.2 Redfish

Catches of redfish were only minor in the first 10 years of the WASCF (Figure 9.1) but increased sharply to 116 t in 2007 (Figure 9.3). The catch peaked the in 2008 at 225 t before declining to around 120 t in 2009 and 2010 (Figure 9.3). Since 2010, redfish has only been targeted in two years (61 t in 2014; 25 t in 2017), and a minor catch of < 2 t landed in 2016. This is the result of a rotational fishing strategy, enforced by contractual arrangements between the license owners and the lease fishers. A new redfish fishery began in Shark Bay in 2020 and 2021 (Figure 9.3). Redfish has been the most significant component of the WASCF over the most recent decade, comprising 61% of the total catch (Table 9.1).

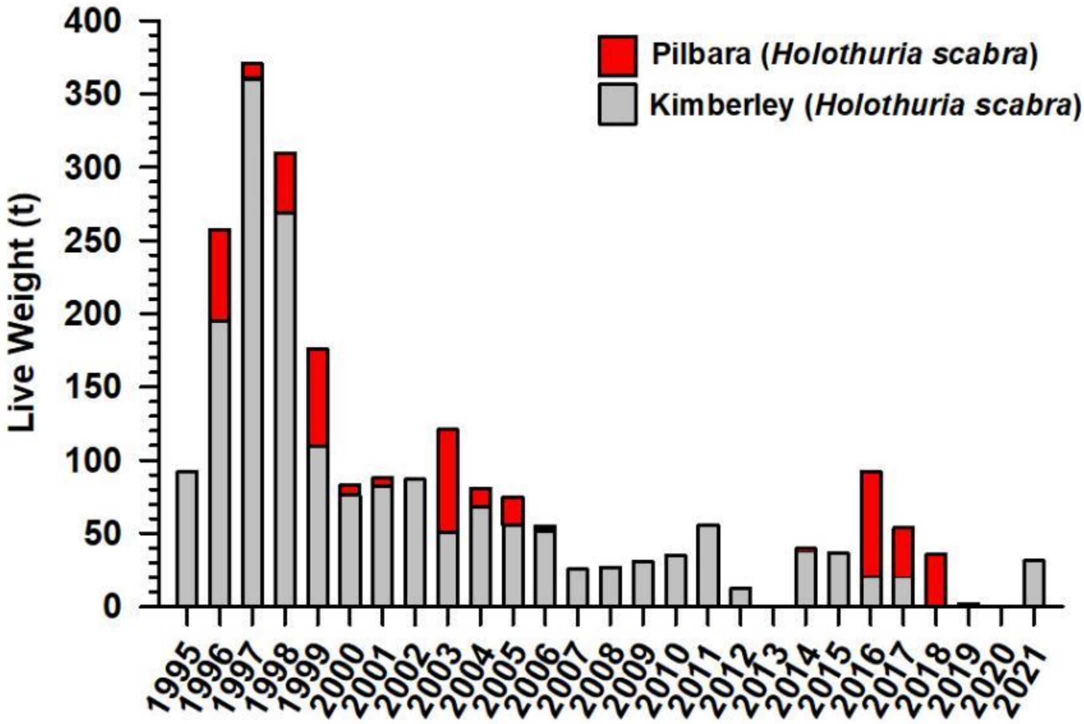


Figure 9.2. Annual total retained catches (tonnes) of sandfish (*Holothuria scabra*) in the Kimberley (grey bars) and Pilbara (red bars) from 1995 to 2021.

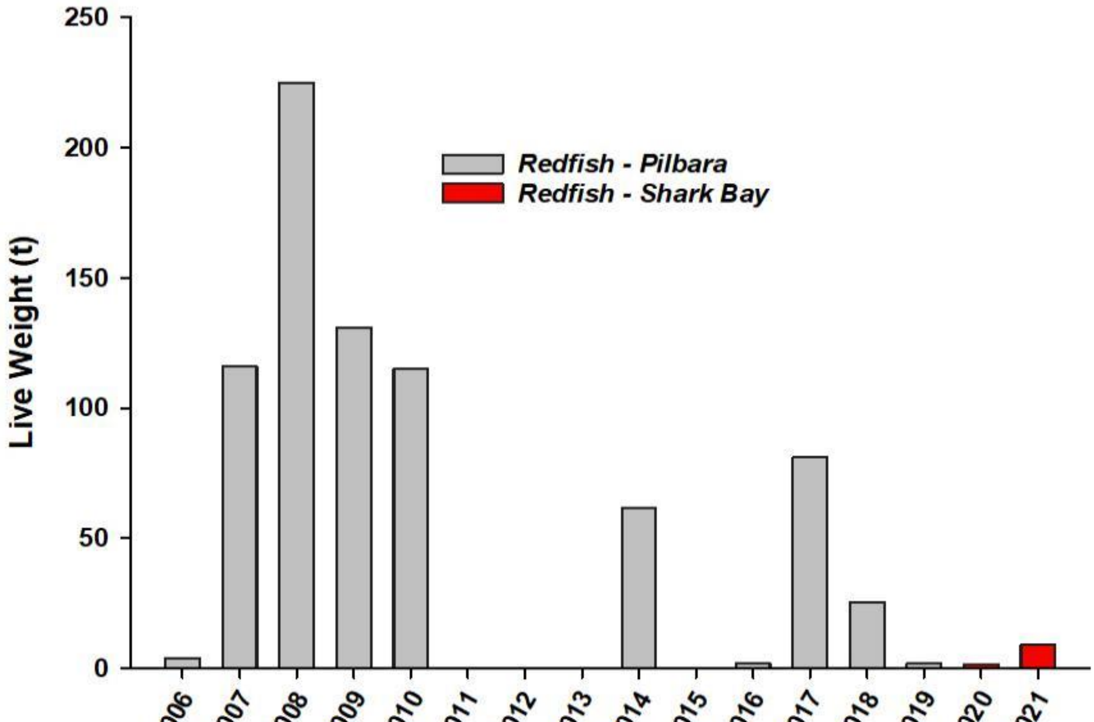


Figure 9.3. Annual total retained catches (tonnes) of redfish (*Actinopyga echinites*) in the Pilbara (grey bars) and Shark Bay (red bars) between 2006 and 2021.

9.3.2.2 Commercial Effort

Fishers initially provided monthly and daily returns under the statutory catch and effort system, either by statistical block or by fishing event (Table 8.1). These contained data on catch, days fished, hours fished, and spatial location as well as crew numbers. Effort is calculated in the metric of "crew days", with the following equation.

Crew days = Days fished x number of crew.

The other metric for effort is hours fished. This information has been available since 2007, from the daily logbook data, which requires fishers to accurately record the time spent fishing at a finer spatial scale.

Effort rose dramatically from 700 to 4000 crew days in the first four years of the fishery, then declined markedly over the next two years to 1200 days and has slowly decreased since then to an average of around 300 days in the last decade (Figure 9.4). In the first ten years, the majority of effort was expended in the Kimberley region, with occasional forays into the Pilbara stocks (Figure 9.4). The highest levels of effort in the Pilbara occurred during the early exploration phase of the fishery in 1998 and 1999. In the second decade of the fishery (2007 to 2016), approximately equal effort was allocated between the Kimberley and Pilbara stocks.

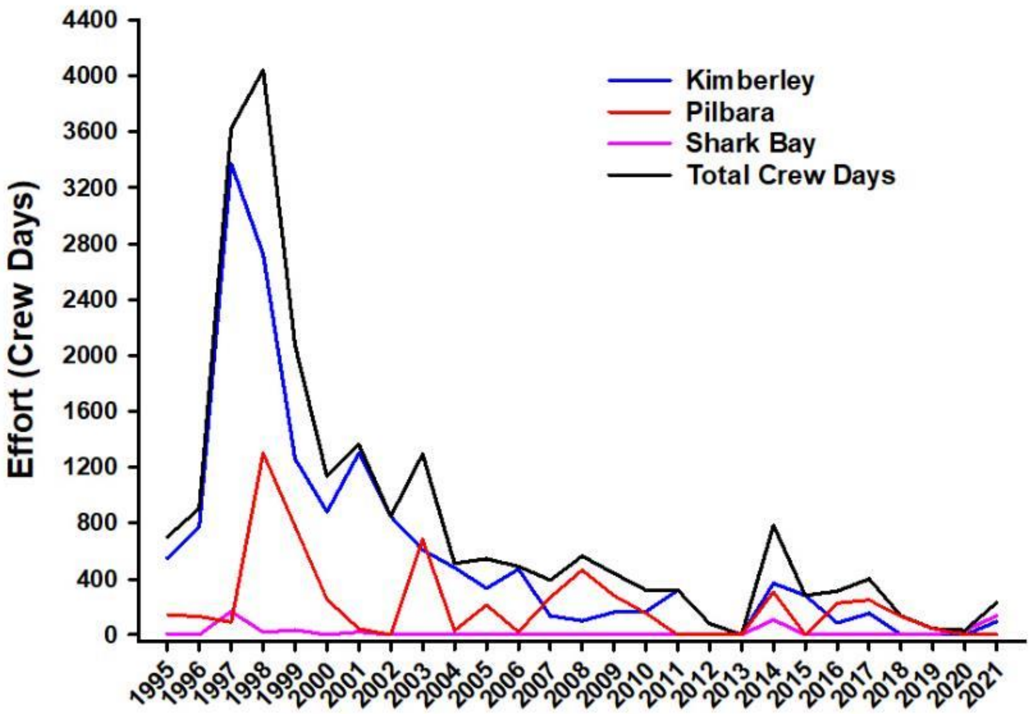


Figure 9.4. Effort in crew days by area and total for the WASCF between 1995 and 2021.

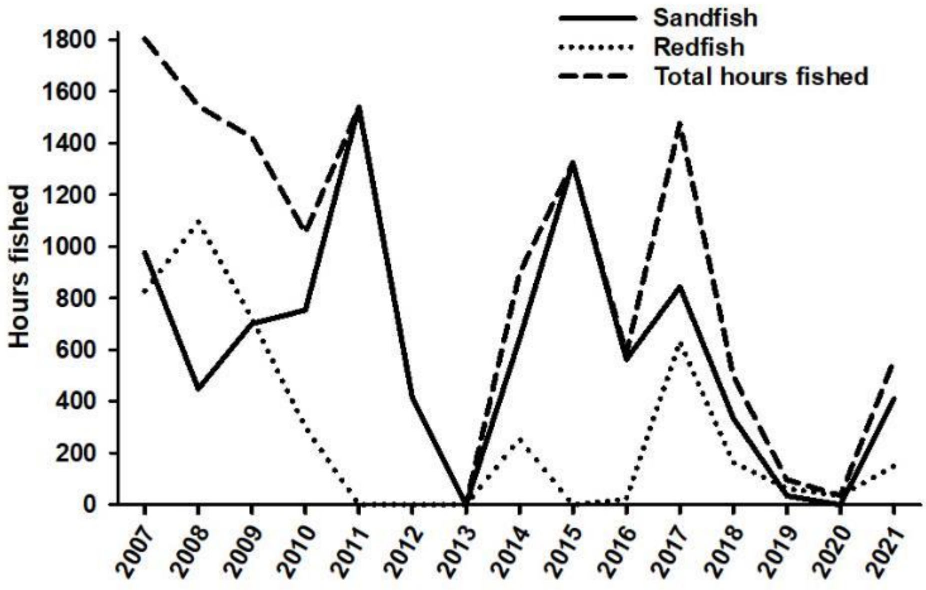


Figure 9.5. Effort in hours fished by species and total for the WASCF between 2007 and 2021.

Total hours fished has declined since 2007, from around 1800 hours to 1000 hours in 2017 (Figure 9.5). The majority of effort has been focused on sandfish, with the exception of 2008 and 2009, which were the peak years for the redfish fishery (Figure 9.5). A key reason for the reduced effort has been a consolidation of industry ownership, which led to changes in fishing practices, such as use of smaller boats (i.e. reduction in holding capacity), smaller crews, shorter trips and a voluntary rotational fishing strategy.

9.3.2.3 Recreational / Charter Catches

The recreational catch of sea cucumber in WA is negligible – the most recent estimate of the recreational annual harvest of 'other taxa' in WA (including sea cucumbers, sea urchins, cunjuvoi and 'other non-fish') was <1,000 individuals (Henry and Lyle 2003).

9.3.2.4 Recreational / Charter Effort

There are no estimates of recreational effort for sea cucumbers, however, it is assumed to be negligible.

9.3.2.5 Conclusion

Sandfish (Kimberley)	Catch and effort in this fishery has followed a typical fishery developmental path, with initial large catch and effort and reductions thereafter, instigated largely by conditions from assessments (e.g. under the EPBC Act), which required the development of fine-scale catch and effort records, and changes in industry practices, such as use of smaller boats (i.e. a reduction in holding capacity), smaller crews, shorter trips and rotational fishing strategies. There is no indication within the catch data of unacceptable stock depletion.
Sandfish (Pilbara)	Catch and effort in this fishery has followed a similar pattern to the Kimberley stock, although effort has been more intermittent, with minimal effort on sandfish over the past ten years. In 2016 a sandfish stock was discovered and fished between 2016 and 2018, with declining catches There is some indication within the catch data of unacceptable stock depletion between 2016 and 2018.
Redfish (Pilbara)	Catches from this stock were initially large (587 t in first 4 years), however, minimal catch in the past 8 years. Stock is exploited on a rotational basis by commercial contractual agreements within Industry. There is no indication within the catch data of unacceptable stock depletion.
Redfish (Shark Bay)	Catches from this stock in 2020 - 2022 constituted the first 3 years of the fishery. There is not sufficient data to detect if there is unacceptable stock depletion.

9.3.3 Catch Distribution Trends

9.3.3.1 Sandfish (*Holothuria scabra*)

In WA, the extent of commercially fished populations of sandfish ranges from Barrow Island in the south-west of its range, and Wyndham in the north, a distance of about 1800 km. Within these populations, areas fished are discrete and separated by large distances. Most fishing activity targets the densest populations, which occur in nearshore waters, mainly within bays and estuaries, of the Kimberley and Pilbara coasts (Figure 9.6; Figure 9.7).

In terms of the catch distribution between the Kimberley and Pilbara stocks over the history of the fishery, the overall proportions are 84% Kimberley and 16% Pilbara (Figure 9.10). However that has varied significantly from year to year. In 2004, 2016 and 2017, the majority of catch has been taken in the Pilbara region (Figure 9.10).

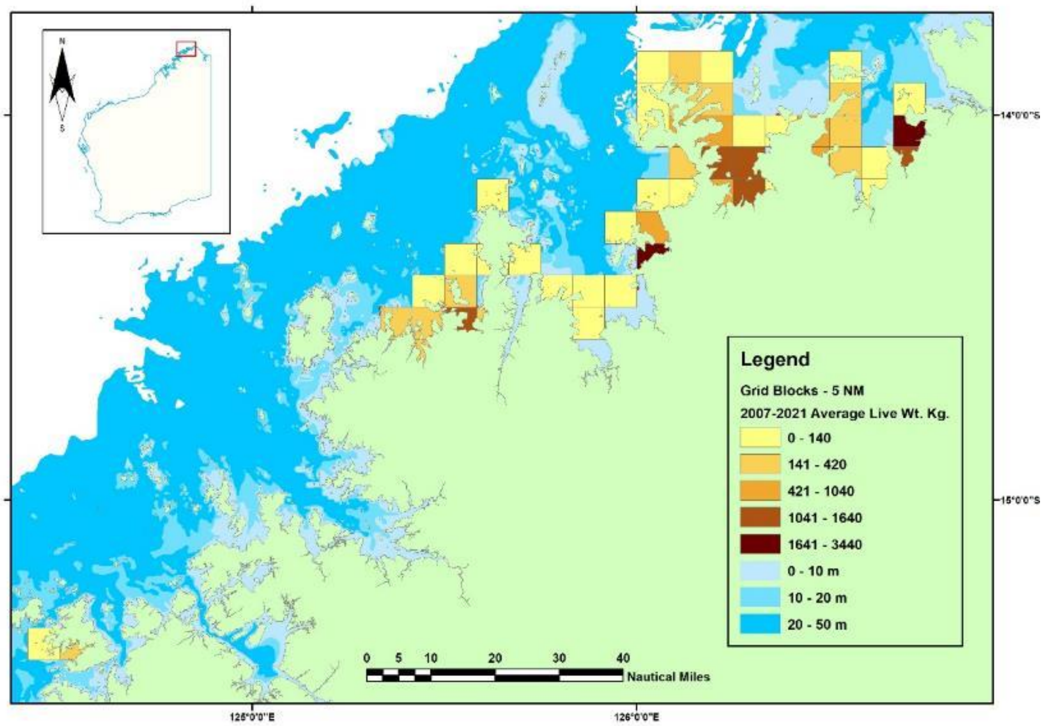


Figure 9.6. Catch distribution map (5 x 5 nm blocks) for the Kimberley stock of sandfish (*Holothuria scabra*). Data is mean annual catch for the period (2007-2021) when fine-scale fishing data has been available

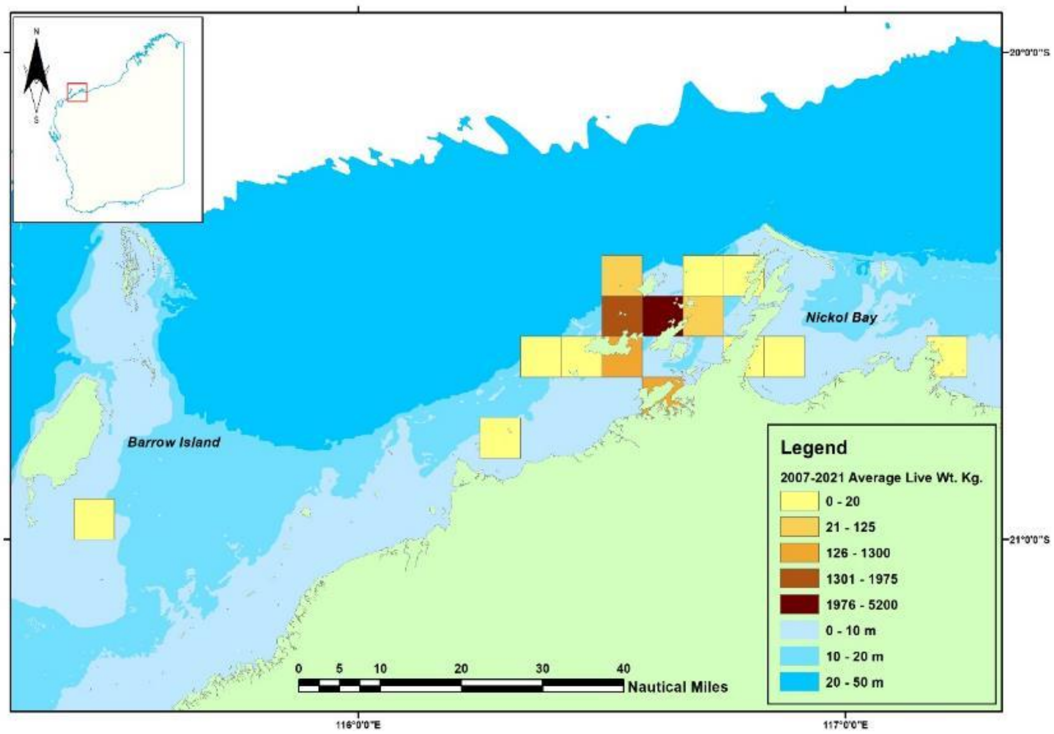


Figure 9.7. Catch distribution map (5 x 5 nm blocks) for the Pilbara stock of sandfish (*Holothuria scabra*). Data is mean annual catch for the period (2007-2021) when fine-scale fishing data has been available.

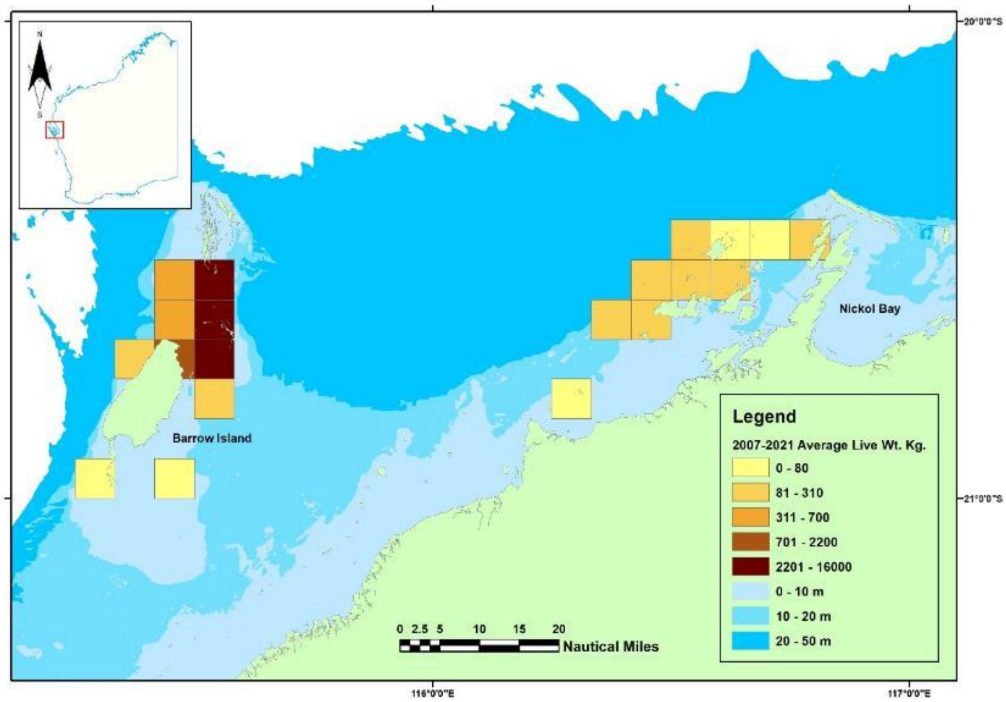


Figure 9.8. Catch distribution map (5 x 5 nm blocks) for the Pilbara stock of redfish (*Actinopyga echinites*). Data is mean annual catch for the period (2007-2021) when fine-scale fishing data has been available.

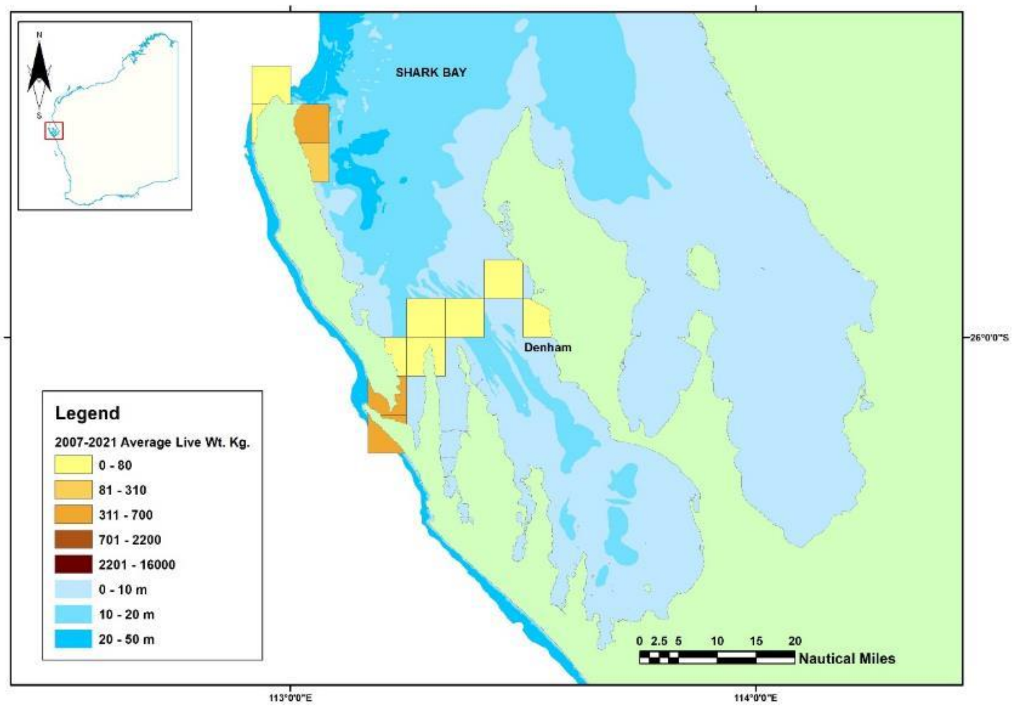


Figure 9.9. Catch distribution map (5 x 5 nm blocks) for the Gascoyne (Shark Bay) stock of redfish (*Actinopyga echinites*). Data is mean annual catch for the period (2007-2021) when fine-scale fishing data has been available, noting that only 2020 and 2021 has been fished.

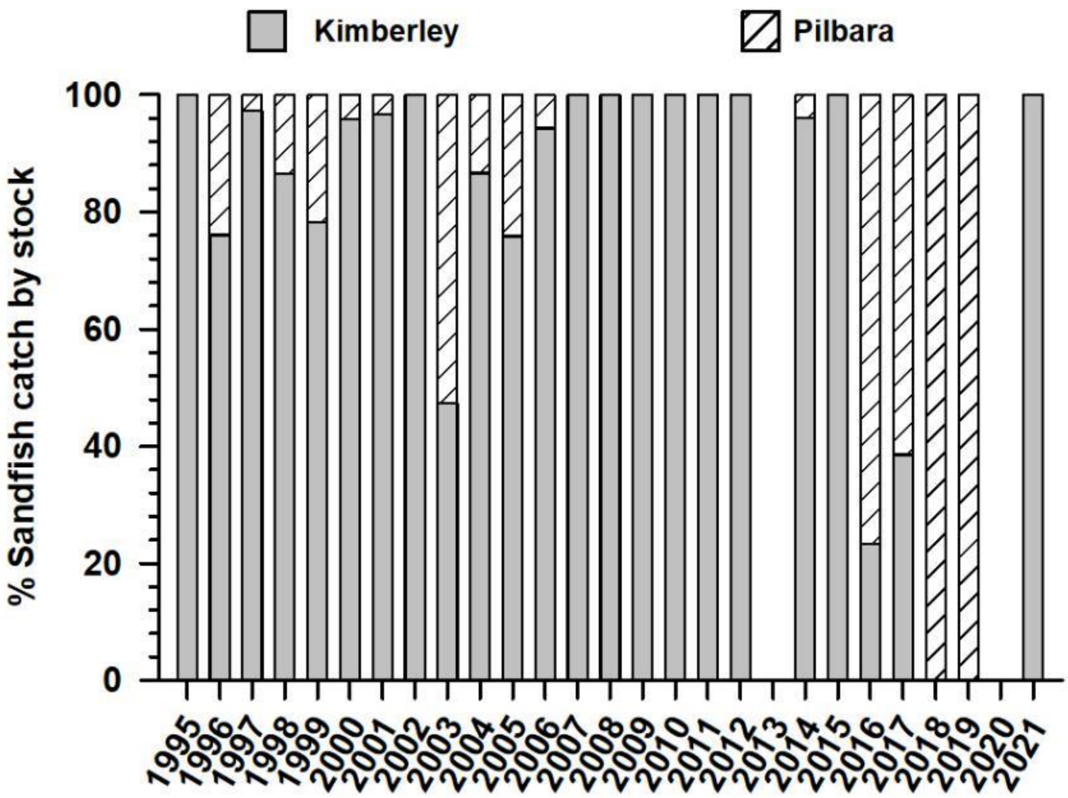


Figure 9.10. Percent distribution of sandfish catch between the two main stocks over the history of the fishery

9.3.3.2 Redfish (*Actinopyga echinites*)

Redfish is widely distributed, but only very small catches were taken prior to 2007. The Montebello Islands redfish fishery (Pilbara region) began in 2007, which was the first year of the daily catch and effort logbook. Consequently it was possible to obtain a detailed analysis of the spatial scale of the fishery from its inception. Spatial distribution of catch in the redfish fishery is summarised in Figure 9.8 and Figure 9.9. The Shark Bay fishery began in 2020, and the catch came from two discrete stocks at the north and south of Dirk Hartog Island. Overall, the majority of redfish in WA comes from a shallow water lagoonal area between Barrow Islands and the Montebello Islands (Figure 9.8).

9.3.3.3 Conclusion

Sandfish (Kimberley)	The spatial distribution of catch has remained largely consistent over the history of the fishery. The fishery is widespread, with catch coming from a few high productivity areas, and a variable number of lower productivity areas. Catch distribution is also managed by rotational harvest strategies. There is no indication that catch levels have been maintained by a progressive shifting of the areas fished that would be indicative of unacceptable serial stock depletion.
Sandfish (Pilbara)	Effort in the Pilbara has historically been focused on redfish and has involved fishing in places where sandfish are not abundant. The rediscovery of lightly exploited high-density populations of sandfish (such as those fished in the Dampier Archipelago in 2016 and 2017) may influence effort distribution in the Pilbara in the future. There is no indication that catch levels have been maintained by a progressive shifting of the areas fished that would be indicative of unacceptable serial stock depletion.
Redfish (Pilbara)	The fishery is primarily based on the discovery of an unexploited stock in 2007 at Montebello Islands. Effort has been re-focused on the same spatial areas, although there is considerable fine-scale variation in the harvested areas. Stocks have been targeted 5 times in from 2014 to 2018, but not since then. There is no indication that catch levels have been maintained by a progressive shifting of the areas fished that would be indicative of unacceptable serial stock depletion.
Redfish (Shark Bay)	Catch distribution data from this stock in 2020-2022 constituted the first 3 years of the fishery. There is not sufficient data to detect changes in catch distribution that would indicate stock depletion.

9.3.4 Fishery-Dependent Catch Rate Analyses

Standardisation of catch rates is an integral part of the stock assessment and is used to inform the annual review and harvest strategy. The current standardised catch rate (SCPUE) models applied to data for each species and stock are summarised below.

Since the introduction of the daily logbook in 2007, it has been possible to accurately measure effort in hours fished, which takes into account the actual time fishing and the number of fishers in the water. Prior to 2007, data was only returned on monthly logsheets with a coarse level of spatial resolution (60 x 60 nautical mile blocks) and could not account for the finer-scale spatial distribution of the fishery. This earlier dataset (1996 to 2006) is excluded from the standardised CPUE analysis.

The SCPUE model applied to catch rates is numbers per hour, for each stock, is defined as follows:

$$\ln(CPUE+1) = \mu + \beta_1(Year) + \beta_2(Sub-area) + \varepsilon$$

Where ln is the base$_e$ logarithm, CPUE is the catch rate data (numbers/hour) from each fishing event recorded per day (1 – 6 events per day); β_2 (Sub-area) is the effect of spatial differences

in abundance between targeted stocks. The “Sub-areas” are geographical regions within the fishery, for example, Admiralty Gulf, Augustus Island, Napier Broome Bay and Vansitart Bay for the Kimberley sandfish stock. The least squares mean of the Year factor is used to produce an annual index of the relative abundance (SCPUE) of sea cucumbers.

Given the patchy and often exploratory nature of fishing (drift diving) for sea cucumbers, a data selection rule is applied to stabilise the SCPUE abundance index. This rule states only the first *n* drifts that result in 95% of total harvest of a stock/bioregion are included in the analysis. For example, in the 2017 Pilbara sandfish fishery, 40 drifts were recorded for the total harvest, however 95% of the harvest was taken in 25 or 60% of drifts.

The Shark Bay fishery for redfish began in 2021 with one vessel fishing. Sufficient data is not available to analyse a yearly trend, however an overall analysis for 2021 is provided, accounting for two sub-areas (North and South Dirk Hartog Island).

9.3.4.1 Sandfish

Overall trends in Kimberley sandfish abundance, as indexed by SCPUE, have varied between 10 and 50 animals per hour (Figure 9.11). There is, however, a long-term-trend upwards, indicating that abundance has increased since the mid-2000s. However, the rotational strategy of the commercial fishers means that, in recent years, different vessels are fishing and there is likely to be an element of this vessel uncertainty contributing to the variable SCPUE.

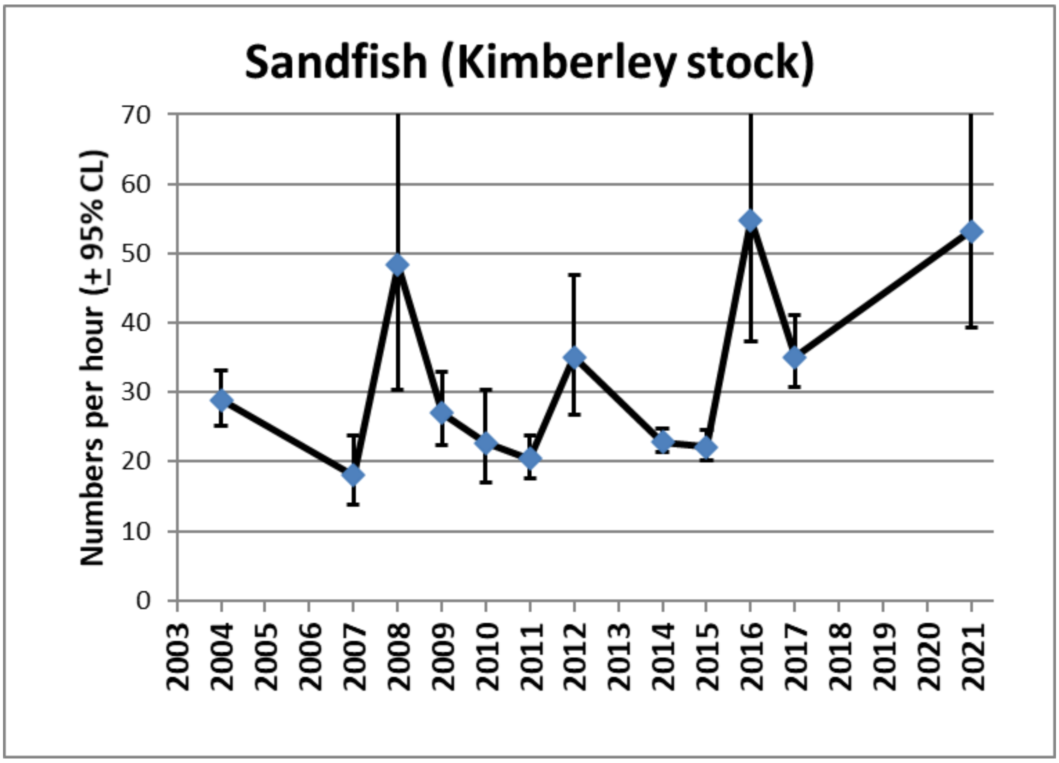


Figure 9.11. Standardised catch rate index (SCPUE; ±95% CL) for the Kimberley sandfish stock (*Holothuria scabra*). Data from the daily catch and effort logbook.

The Pilbara stock of sandfish is a minor contributor to catch in the WASCF, about 16% over the history of the fishery, although in 2016 and 2017 it produced 65% of the total harvest (Figure 9.10) after being unfished for over ten years. There are only four years of data with accurate catch rates in the Pilbara; 2004, 2016 to 2018. Catch rates were around 100 animals per hour in 2004 and 2016, and declined to around 50 animals per hour in 2018 after 3 consecutive years of fishing (Figure 9.12).

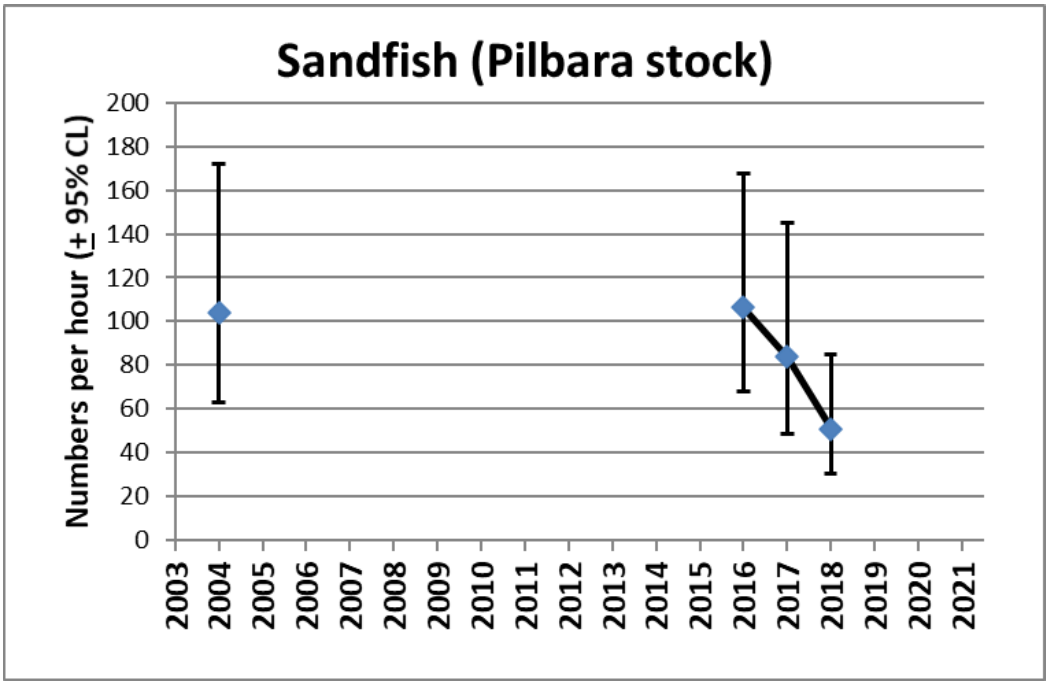


Figure 9.12. **Standardised catch rate index (SCPUE; ±95% CL) for the Pilbara sandfish stock (*Holothuria scabra*). Data from the daily catch and effort logbook**

9.3.4.2 Redfish

Redfish standardised CPUE was stable for the first three years of the Pilbara fishery, and then increased in the fourth year (Figure 9.13). Over 500 tonnes was harvested in this period. Catch rates declined in 2014, then increased again in 2016 and 2017. Only 2 tonnes was harvested in 2016, compared to 64 tonnes and 25 tonnes in 2014 and 2017 (Figure 9.3). Overall the abundance signals arising from the SCPUE need more years to be confident in their interpretation, however, no declines are evident from them. They are also relatively high (mean = 190 animals per hour), compared to sandfish catch rates (mean = 50 animals per hour). In Shark Bay, only 3 years of redfish data from 2020 to 2022 are available, and here is an increasing trend, but with considerable uncertainty.

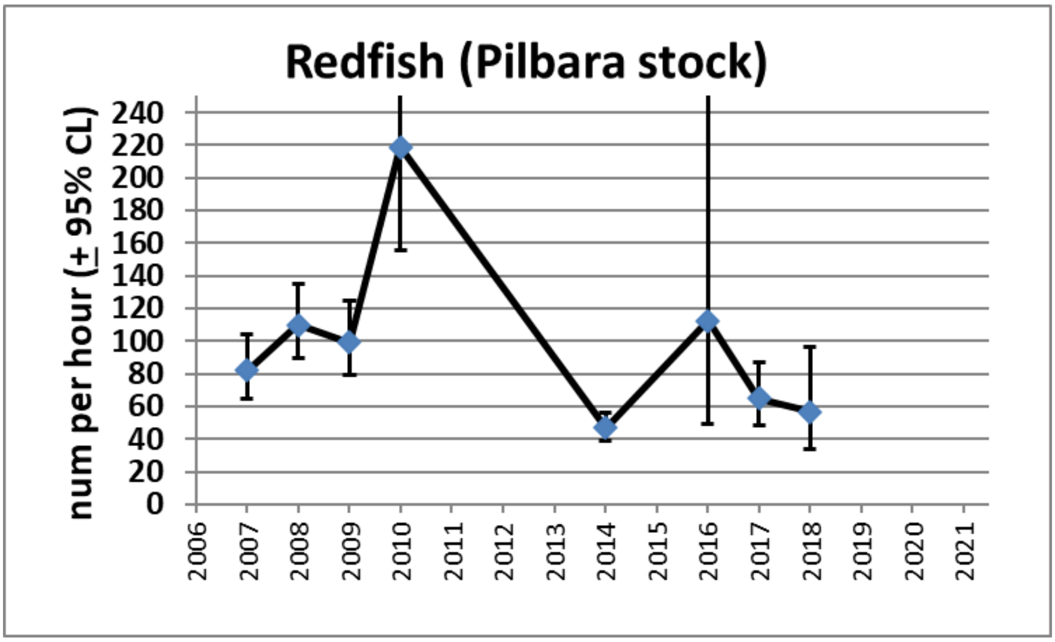


Figure 9.13. Abundance trends in the Pilbara redfish stock (*Actinopyga echinites*), as measured by a standardised catch rate index (SCPUE). The units of the index are number per hour (±95% CL).

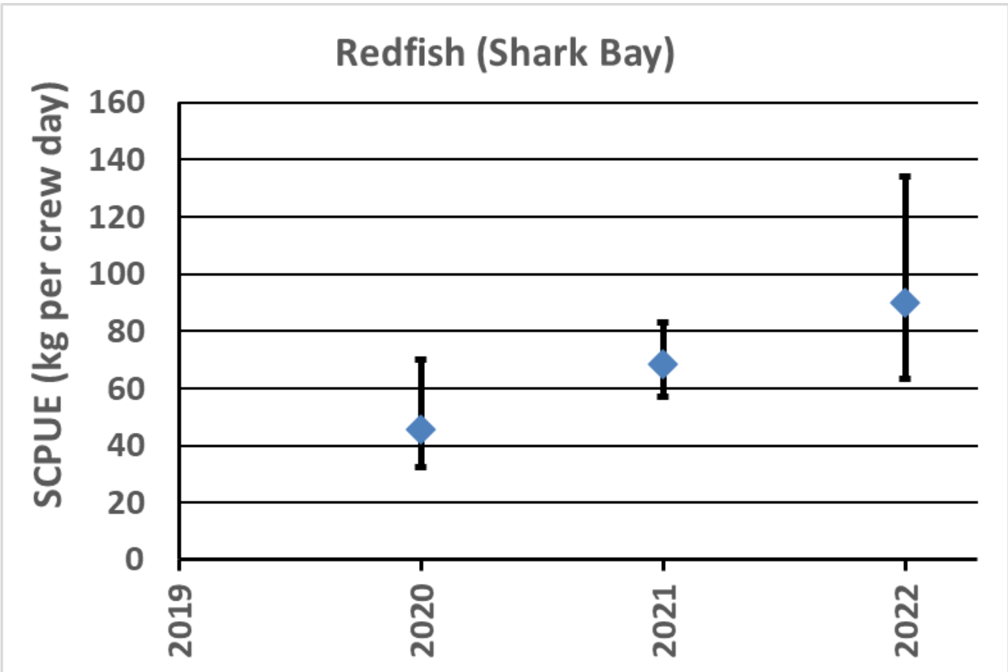


Figure 9.14. Abundance trends in the Shark Bay redfish stock (*Actinopyga echinites*), as measured by a standardised catch rate index (SCPUE). The units of the index are kg per crew day (±95% CL).

9.3.4.3 Conclusion

Sandfish (Kimberley)	The SCPUE in the Kimberley sandfish fishery has oscillate widely, but with a clear upward trend. In 2021, the SCPUE was at its 2nd highest level on record There are no indications from catch rates of unacceptable stock depletion since 2007.
Sandfish (Pilbara)	The SCPUE in the Pilbara sandfish fishery declined during the years 2016 to 2018, but there has been no fishing since 2019. There is an indication from catch rates of potentially unacceptable stock depletion during 2015 to 2019. No fishing in 2020 and 2021 may have promoted a recovery, but evidence is not yet available.
Redfish (Pilbara)	Catch rates in the Pilbara redfish fishery have oscillated over time, with no clear overall trend upwards or downwards, but there has been no fishing since 2018. There are no indications from catch rates of unacceptable stock depletion during the history of the fishery.
Redfish (SharkBay)	Catch rates in the Shark Bay redfish fishery increased between 2020 and 2022. There are no indications from catch rates of unacceptable stock depletion during the history of the fishery.

9.3.5 Trends in Size Structure

Since the introduction of the daily logbook in 2007, it has been possible to measure average size harvested, as information on both numbers caught and weight of catch is provided. The average size at harvest, particular in relation to size-at-maturity, provides another line of evidence to assess stock status. The analysis model of average size harvested takes into account differences in size between regions in determining the overall size of sea cucumbers caught. The GLM is as follows

$$W = \mu + \beta_1(Year) + \beta_2(Sub - area) + \varepsilon$$

where *W* is the average weight of sea cucumbers (numbers / weight) from each fishing event recorded per day (1 – 6 events per day); β_2 (Sub-area) is the effect of spatial differences in abundance between targeted stocks. The “Sub-areas” are geographical regions within the fishery; there are currently 9 defined geographical regions; five from the Kimberley area and three from the Pilbara area, and Shark Bay.

9.3.5.1 Sandfish

Average annual weight of sandfish harvested in WA is compared against the mean size and weight-at-maturity to establish what protection is being afforded by the size-at-maturity (Figure 9.15).

Size at-maturity for sandfish has been estimated to be 150 mm for Queensland populations of this species (Table 3 of Skewes et al. 2014), with other populations exhibiting variability between 140 and 200 mm, depending on location and sex (Table 5.1). No studies are available for size at maturity estimates of WA populations of sandfish, and voluntary size limits are based on Queensland and Northern Territory data. A 150 mm sandfish in WA is approximately 0.3 kg, based on length-weight relationships provided in Figure 5.5 and Figure 5.6.

Average weight of sandfish harvested in Kimberley region varied between 0.7 kg and 1.9 kg in the period 2004 to 2021 (Figure 9.15). This was much greater than the estimated size-at-maturity (0.3 kg; Figure 5.5), which implies a substantial component of the spawning stock is not vulnerable to being fished. Average weight of sandfish harvested in the Pilbara region was smaller than the Kimberley and varied between 0.7 and 1.3 kg (Figure 9.15). This was greater than the estimated size-at-maturity (0.3 kg; Figure 5.5), which provides protection of the spawning stock.

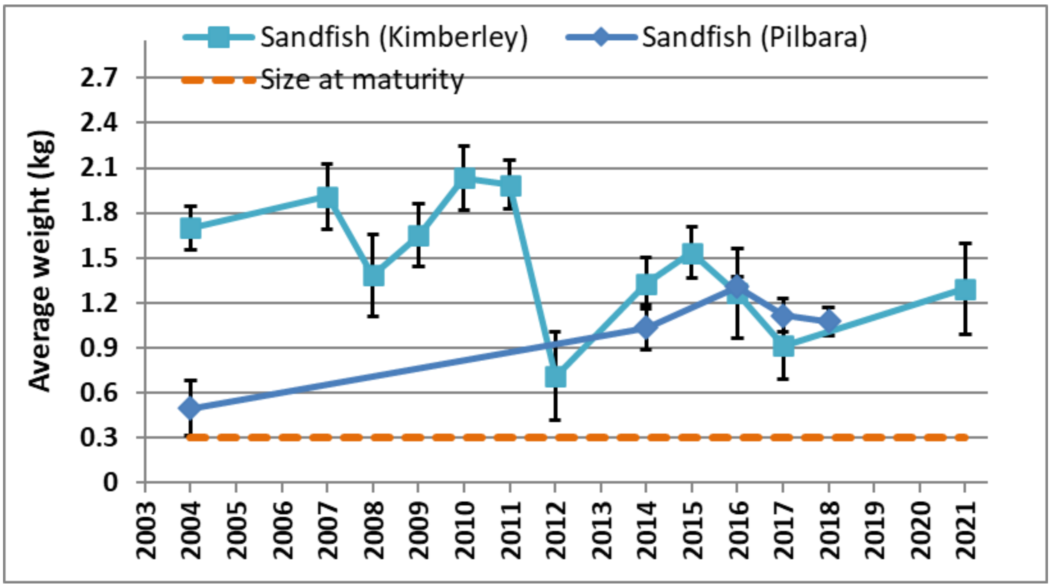


Figure 9.15. Standardised average weight of sandfish (*Holothuria scabra*) caught in the Kimberley and Pilbara regions of the WASCF between 2004 and 2021. Orange dotted line is estimated weight of animals with a 150 mm size-at-maturity (see Figure 5.5 for weight-length relationship).

9.3.5.2 Redfish

Average weight of redfish harvested in the fishery is compared against the size-at-maturity to establish if current size limits are protecting the spawning stock (Figure 9.16).

Size at-maturity for redfish has been estimated to be 120 mm for Queensland populations of this species (Table 3 of Skewes et al. 2014). A similar size-at-maturity was detected by Kohler et al. (2009) for Western Indian Ocean populations of redfish. No studies are available for size at maturity estimates of WA populations of sandfish, and voluntary size limits are based on

Queensland and Northern Territory data. A 120 mm redfish in WA is approximately 0.13 kg, based on length-weight relationships provided in Figure 5.9.

Average weight of redfish harvested in the WASCF was consistent at around 0.8 to 1.0 kg in the period 2007 to 2017 (Figure 9.16). This is significantly greater than the estimated size-at-maturity (0.13 kg; Figure 5.9), which provides protection of the spawning stock. The significant increase in weight in 2018 was not due to any changes in skipper, vessel, or processing time

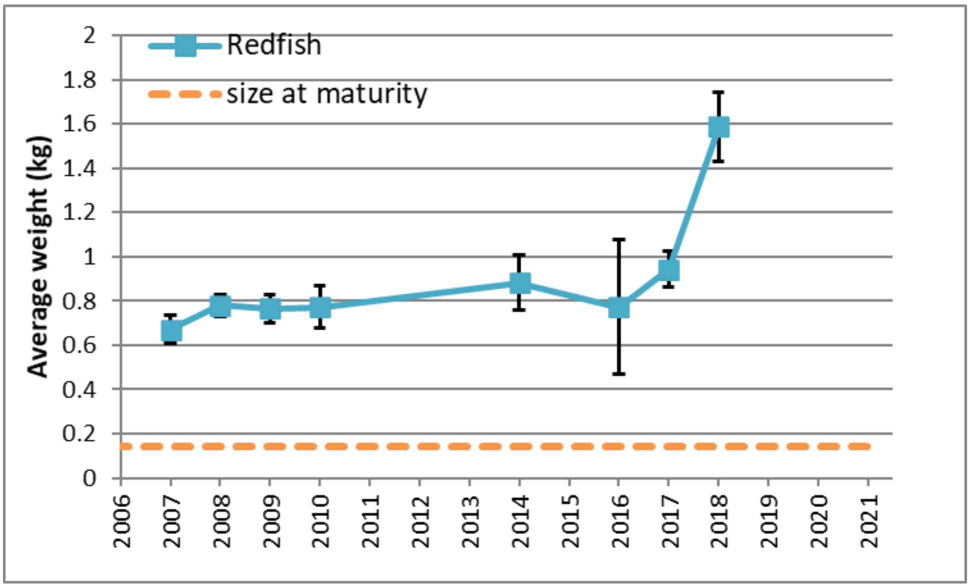


Figure 9.16. Standardised average weight of redfish (*Actinopyga echinites*) caught in the WASCF between 2004 and 2021. Orange dotted line is estimated weight of animals with a 120 mm size-at-maturity. Data are the Montebello fishery only. The anomaly in 2016 needs further investigation.

9.3.5.3 Conclusion

Sandfish (Kimberley)	Average weight of sandfish harvested in the Kimberley in the period 2004 to 2021 was > 3 times than the estimated size-at-maturity and stable over time. There are no indications from average size fished of unacceptable stock depletion during the history of the fishery
Sandfish (Pilbara)	Average weight of sandfish harvested in the Pilbara has been increasing since 2004 and is > 3 times than the estimated size-at-maturity. There are no indications from average size fished of unacceptable stock depletion during the history of the fishery.
Redfish (Pilbara)	Average weight of redfish harvested in the WASCF in the period 2007 to 2021 was > 3 times greater than the estimated size-at-maturity. This provides protection of the spawning stock, and fishing mortality is likely to be low. There are no indications from average size fished of unacceptable stock depletion during the history of the fishery.

9.3.6 Productivity Susceptibility Analysis

Productivity Susceptibility Analysis (PSA) is a semi-quantitative risk analysis originally developed for use in Marine Stewardship Council (MSC) assessments to score data-deficient stocks, i.e. where it is not possible to determine status relative to reference points from available information (Hobday et al. 2011; MSC 2014). The PSA approach is based on the assumption that the risk to a stock depends on two characteristics: (1) the productivity of the species, which will determine the capacity of the stock to recover if the population is depleted, and (2) the extent of the impact on the stock due to fishing, which will be determined by the susceptibility of the species to fishing activities (see Appendix 3).

Although a valuable tool for determining the overall inherent vulnerability of a stock to fishing, the PSA is limited in its usefulness for providing stock status advice. This is because of the simplicity and prescriptiveness of the approach, which means that risk scores are very sensitive to input data and there is no ability to consider management measures implemented in fisheries to reduce the risk to a stock (Bellchambers et al. 2016). Consequently, the PSA is used by the Department to produce a measure of the vulnerability of a stock to fishing, which is then considered within the overall weight of evidence assessment of stock status.

The sections below outline the PSA scores for each indicator species of the WA Sea Cucumber Resource.

9.3.6.1 Productivity

An assessment of the biological characteristics of the two WASCF target species in accordance with MSC scoring guidance (as set out under section PF4.3 in the MSC Fisheries Certification Requirements Version 2.0) results in low risk productivity scores of 1.33 for sandfish and 1.5 for redfish (Table 9.2). They are relatively fast-growing broadcast spawners with high estimates of natural mortality and thus score 1 in most attributes. The only productivity attribute

in which they scored 3 was for density dependence (Table 9.2), due to their vulnerability to Allee effects. Allee effects and population density extremes have been suggested to be more pronounced in broadcast-spawning echinoderms with planktotrophic larval stages (such as sandfish and redfish) as opposed to species with lecithotrophic development. This is because larvae of the latter species are independent from the requirement to feed in the plankton and tend to settle quicker (presumably resulting in lower mortality rates in the plankton and enhanced local recruitment) (Uthicke et al. 2009).

Table 9.2. PSA productivity scores for sandfish and redfish

Productivity attribute	Sandfish	Redfish
Average maximum age	1	2
Average age at maturity	1	1
Reproductive strategy	1	1
Fecundity	1	1
Trophic level	1	1
Density Dependence	3	3
Total productivity (average)	1.33	1.50

9.3.6.2 Susceptibility

An examination of the susceptibility to fishing characteristics of sandfish and redfish results in similar scores. Both are widely distributed throughout WA within low energy environments behind fringing reefs or within protected bays, but populations of commercial density are less numerous. Also, given the current fishing operations (i.e. a single vessel spending 2 to 3 trips of 14-20 days each in the region), the areal overlap is likely to be <10%, but is conservatively estimated here as being in the range of 10-30%.

In the criteria of vertical overlap or encounterability, the method of fishing (by hand collection in shallow waters) means that sea cucumbers are susceptible to being encountered in the areas where fishing occurs. Although poor visibility prevents fishing to be as viable in neighbouring deeper waters, a conservative maximum score of 3 is applied.

In terms of selectivity, the analysis of average size caught indicates that animals harvested are well above size-at-maturity (Figure 9.15; Figure 9.16), indicating that fishing mortality is likely to be low. In the case of redfish, further evidence for a high size at selectivity is provided by the fishery-independent survey (Figure 9.21). Average size of animals in the stock was 0.4 kg (Figure 9.21), compared to average size of animals in the fishery (0.8 kg; Figure 9.16). However, given the difficulties of extracting reliable morphometric measurements from sea

cucumbers, and the likelihood of considerable variability in size-at-maturity between different regions, a conservative score of 2 was applied (Table 9.3).

Finally, in the criteria of post-capture mortality, all catch is retained, therefore the maximum score of 3 is applied (Table 9.3).

Table 9.3. PSA susceptibility scores for sandfish and redfish

Susceptibility attribute	Sandfish	Redfish
Areal overlap	2	2
Vertical overlap	3	3
Selectivity	2	2
Post-capture mortality	3	3
Total susceptibility (multiplicative)	1.88	1.88

9.3.6.3 Conclusion

Based on the productivity and susceptibility scores, the overall weighted PSA scores were 2.3 for the sandfish resource and 2.4 for the redfish resource. These scores translate to associated MSC scores of 89 and 87 (out of 100), respectively, which indicates low inherent risks to the stocks.

Sandfish (Kimberley and Pilbara)	Sandfish are assumed to have a relatively short life span (maximum age around 10-14 years), and mature at 2 years of age. With a productivity score of 1.33 and susceptibility score of 1.88, the overall derived PSA score is 2.3 (MSC score > 80). This level of vulnerability indicates there is a relatively low chance of overfishing occurring at current levels of effort. However the significant risk of sea cucumber stocks to localised depletion cannot be discounted, despite this low vulnerability score.
Redfish (Pilbara and Shark Bay)	Redfish assumed to have a relatively short life span (maximum age around 12 years), and mature at 2 years of age. With a productivity score of 1.5 and susceptibility score of 1.88, the overall derived PSA score is 2.4 (MSC score > 80)

9.3.7 Fishery-Independent Data Analyses

9.3.7.1 Sandfish (Pilbara)

For sandfish, a parametric resampling analysis (*n* = 5,000 resamples; Manly 1997) was undertaken to provide an estimate of biomass with associated uncertainty, based on data collected during fishery independent surveys in 2017 and 2020, and given the area of the stock encompassed by the strata. The analysis assumed the data conformed to delta-lognormal distribution given knowledge of the area of the stock (Section 8.2.6). The abundance data were collected at 183 sites in 2017 and 110 sites in 2020 (Section 8.2.6; Table 8.2), and estimates from this were applied in a population model (Section 9.3.8).

The original survey design in 2015 involved a total of 183 sites spread across 15 strata (Figure 8.8). At completion of the survey it was established that 13 of the 15 strata had negligible populations of sandfish. The two strata that did contain significant populations of sandfish were Karratha Bay on West Lewis Island, and Enderby South Bay on Enderby Island. A third high density stratum was established within Enderby South, resulting in a total of three strata used for population assessment. This design was improved in 2020, with the 110 sites targeting sandfish-specific habitat.

Mean length of sandfish in the Pilbara region in 2017 was 225 (±32 SD) mm, with a range between 90 and 300 mm (Figure 9.17a). Mean weight was 712 (± 182 SD) grams, with a range between 100 and 1200 g (Figure 9.17b).

In 2017, the estimated population biomass of sandfish at the surveyed strata in the Pilbara varied between 98 and 181 tonnes whole weight (95% CL), with a median estimate of 134 t (Figure 9.18a).

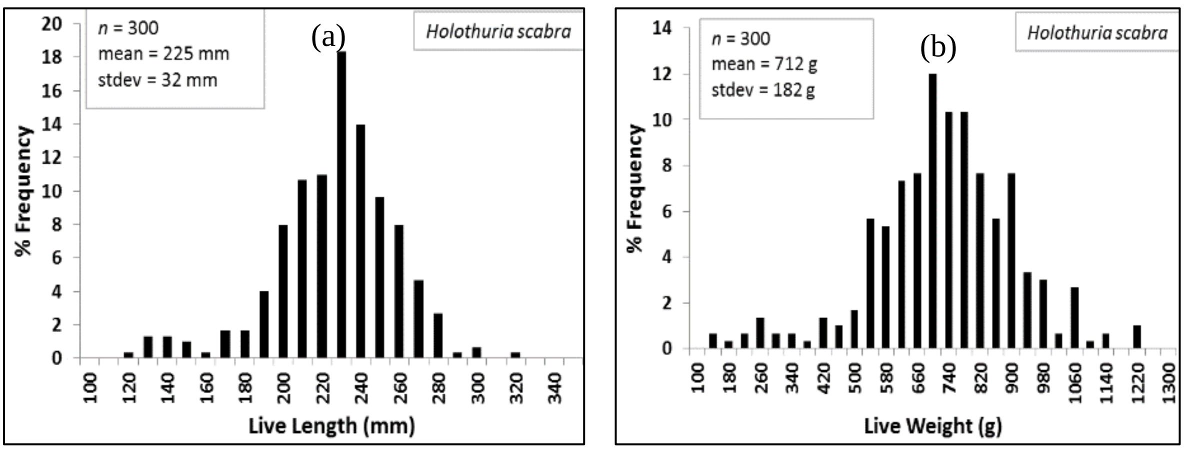


Figure 9.17. (a) Length (mm) and (b) whole weight (g) frequency distribution of sandfish at the Dampier Archipelago (Karratha Bay on West Lewis Island). Data from 2017 surveys

Looking closely at the individual strata in 2017, the surveyed population of sandfish in the Pilbara is largely confined to Karratha Bay (Table 9.4). Median population biomass estimates were 10 tonnes in Enderby South Bay, and 122 tonnes in Karratha Bay (Table 9.4). Median biomass density ranged from 2 to 92 tonnes per km^2. Over 50% of the Enderby South Bay population is contained within a high density strata (22 t per km^2) of low area (0.27 km^2), and the rest spread across the bay at lower densities (2.09 t per km^2). See Table 9.4 and Table 9.5.

In 2020, the estimated population biomass of sandfish at the surveyed strata in the Pilbara varied between 14 and 47 tonnes whole weight (95% CL), with a median estimate of 27 t (Figure 9.19).

Looking closely at the individual strata in 2020, the population of sandfish in the Pilbara remained largely confined to Karratha Bay, however there had been significant declines in density (Table 9.5). Median population biomass estimates were < 1 tonne in Enderby South Bay, and only 27 tonnes in Karratha Bay (Table 9.5). Overall, declines of 100 tonnes were observed by the FIS surveys between 2017 (Figure 9.18a) and 2020 (Figure 9.19a).

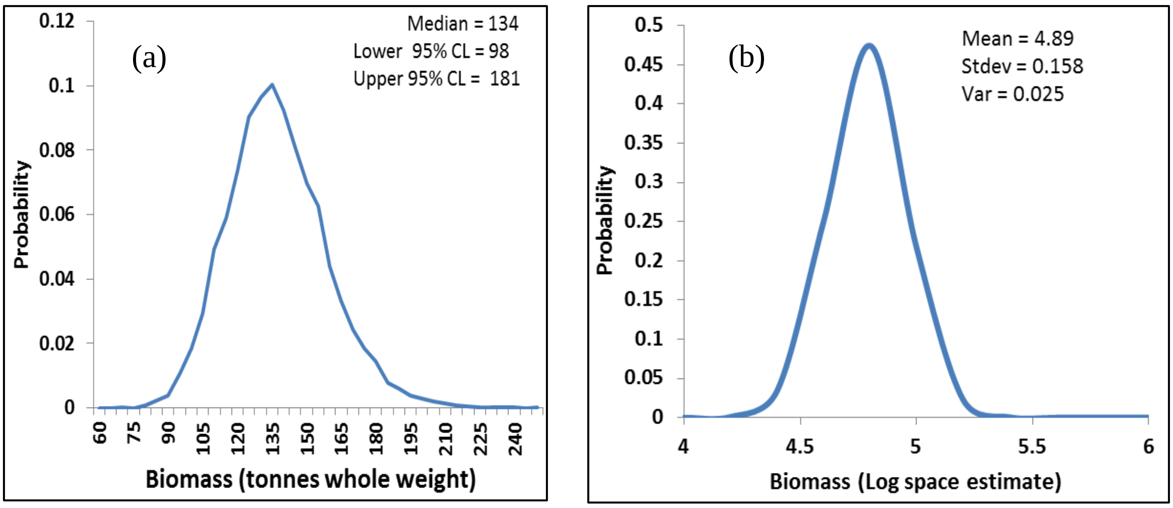


Figure 9.18. Probability estimates of biomass for the sandfish (*Holothuria scabra*) stock in 2017 in the Pilbara region. (a) Distribution in normal units (numbers x 1000) with statistical parameters; (b) Distribution in log-transformed space with statistical parameters. Parameters from (b) were used in the biomass dynamics model (see section 9.3.8.8).

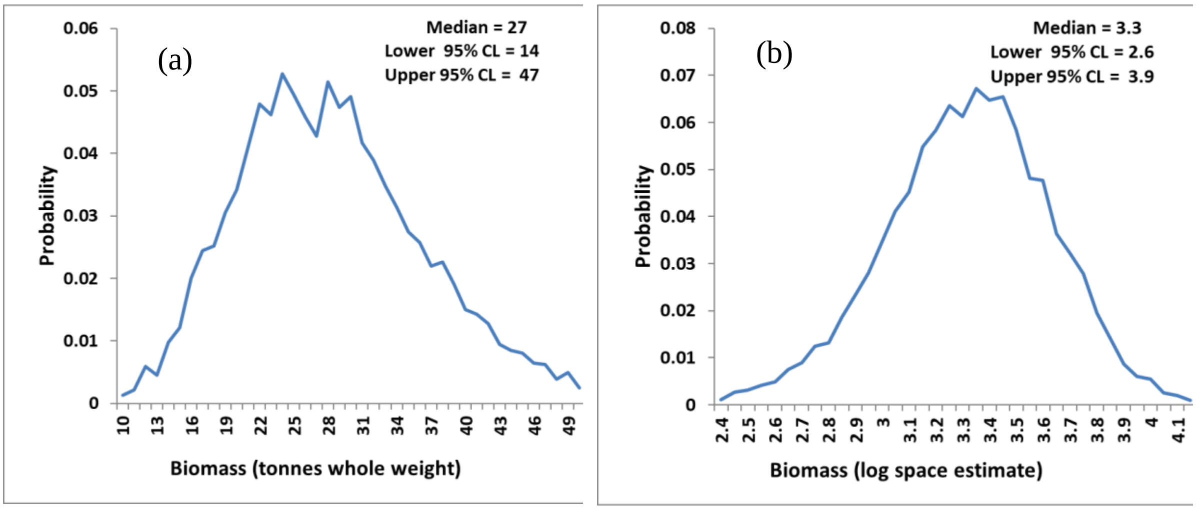


Figure 9.19. Probability estimates of biomass for the sandfish (*Holothuria scabra*) stock in 2020 at surveyed areas in the Pilbara region. (a) Distribution in normal units (numbers x 1000) with statistical parameters; (b) Distribution in log-transformed space with statistical parameters. Parameters from (b) were used in the biomass dynamics model (see section 9.3.8.8).

Table 9.4. Population biomass in 2017 for individual strata within the *Holothuria scabra* fishery in the Pilbara region. See Figure 8.8 for a spatial map of strata.

Strata	Area (km^2)	Population biomass (t; whole weight)			Median biomass density (tonnes per km^2)
		Median	Lower 60% CL	Upper 60% CL	
Enderby South	1.962	4.11	2.23	6.48	2.09
Enderby South High Density	0.27	5.6	3.82	7.99	20.7
Karratha Bay	1.303	122.7	106.8	140.8	94.2

Table 9.5. Population biomass in 2020 for individual strata within the *Holothuria scabra* fishery in the Pilbara region. See Figure 8.8 for a spatial map of strata.

Strata	Area (km^2)	Population biomass (t; whole weight)			Median biomass density (tonnes per km^2)
		Median	Lower 60% CL	Upper 60% CL	
Enderby South	1.962	<1	<1	<1	<0.1
Enderby South High Density	0.27	<1	<1	<1	<0.1
Karratha Bay	1.303	27.2	21.0	34.7	20.8

9.3.7.2 Sandfish (Kimberley)

For sandfish, a parametric resampling analysis (n = 5,000 resamples; Manly 1997) was undertaken to provide an estimate of biomass with associated uncertainty, based on data collected during fishery independent surveys in 2019, and given the area of the stock encompassed by the strata. The analysis assumed the data conformed to delta-lognormal distribution given knowledge of the area of the stock (Section 8.2.6). The abundance data were collected at 161 survey sites (Section 8.2.6; Figure 8.3), and estimates from this were applied in a population model (Section 9.3.8).

In 2019, the estimated population biomass of sandfish at surveyed sites in the Kimberley region (Grid 1426) varied between 127 and 300 tonnes whole weight (95% CL), with a median estimate of 199 t (Figure 9.20).

Based on historical catches, Grid 1426 is estimated to contain 30% of the Kimberley sandfish populations. This figure was used when scaling up from the surveyed areas to the whole of the stocks (see section 9.3.8.3).

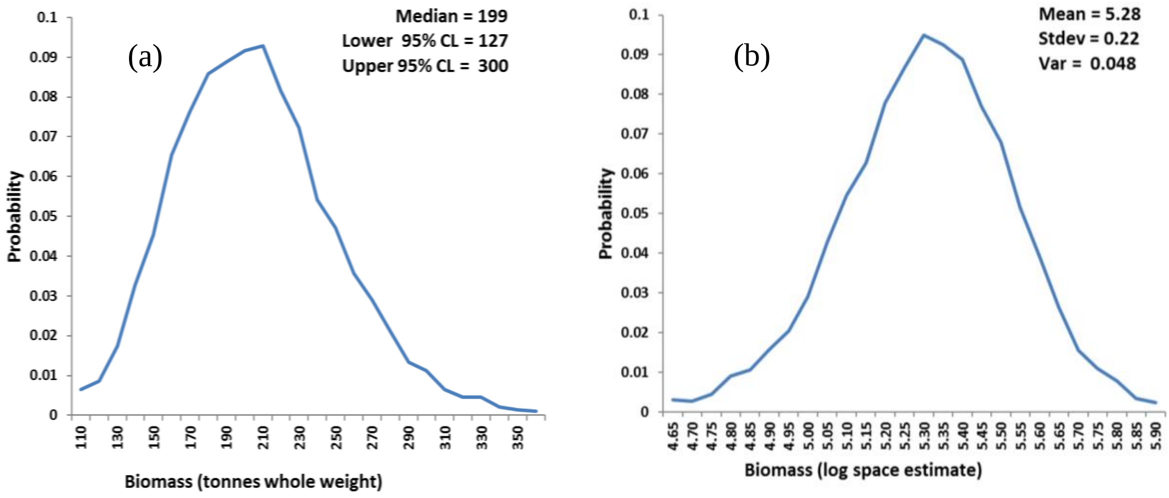


Figure 9.20. Probability estimates of biomass for the sandfish (*Holothuria scabra*) stock in Grid 1426 (see Figure 8.1) of the Kimberley region. Grid 1426 is estimated to contain 30% of the Kimberley sandfish populations. (a) Distribution in normal units (tonnes) with statistical parameters; (b) Distribution in log-transformed space with statistical parameters. Parameters from (b) were used in the biomass dynamics model (see section 9.3.8.8).

9.3.7.3 Redfish (Pilbara)

For redfish, a parametric resampling analysis (n = 5,000 resamples; Manly 1997) was undertaken to provide an estimate of biomass with associated uncertainty, based on data collected during fishery independent surveys in 2015 and 2020, and given the area of the stock encompassed by the strata. The analysis assumed the data conformed to delta-lognormal distribution given knowledge of the area of the stock (Section 8.2.6). The abundance data were collected at 122 sites in 2015 and 96 sites in 2020 (Section 8.2.6; Table 8.2).

The original survey design in 2015 for the Montebello Island population involved a total of 122 sites spread across 10 strata, with two strata receiving a higher intensity of sampling (Strata G and F), and the others receiving a lower intensity of sampling (Figure 8.3). At completion of the survey, it was established that six of the low intensity strata had negligible populations of redfish. These were A, B, DS, E, and H. These strata were excluded from the 2015 population assessment. The final assessment was based on 4 strata; 2 × high density (G and F), and 2 x low density (DN; GN + GS). The total area of habitat of these strata was 59.35 km^2 (or 59,351,939 m^2). Based on these results, an improved survey design was applied in 2020 to the Montebello Island population, with 96 sites targeting only two strata.

Mean length of redfish in the Pilbara region was 178 (±32 SD) mm, with a range between 90 and 300 mm (Figure 9.21a). Mean weight was 395 (±201 SD) grams, with a range between 100 and 1200 g (Figure 9.21b).

In 2015, the estimated population biomass of redfish in the Pilbara region varied between 1000 and 7400 tonnes whole weight (95% CL), with a median estimate of 2221 t (Figure 9.22).

In 2015, the population is spread across the four main strata (Table 9.6). Median population biomass ranged from 311 tonnes in Strata C to 623 tonnes in Strata F (Table 9.6). Median biomass density ranged from 22 to 48 tonnes per km^2.

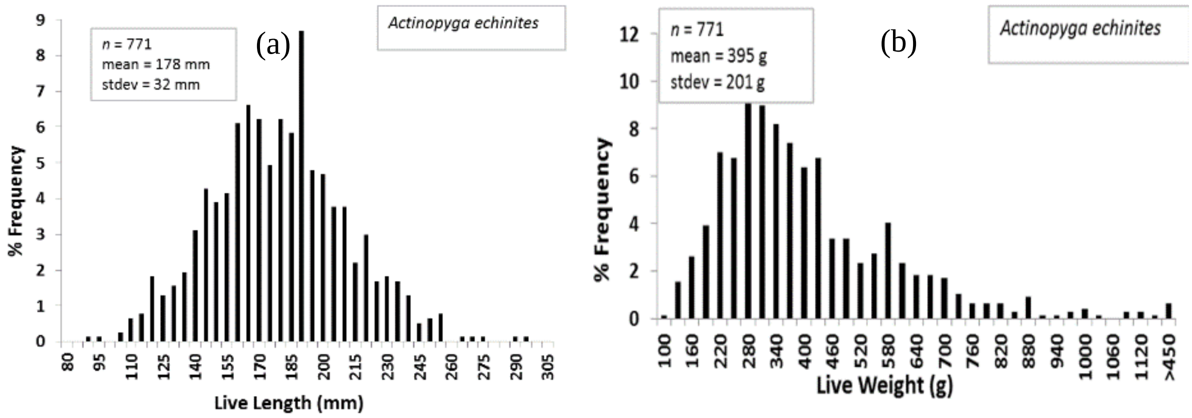


Figure 9.21. (a) Length (mm) and (b) whole weight (g) frequency distribution of redfish at the Montebello Islands.

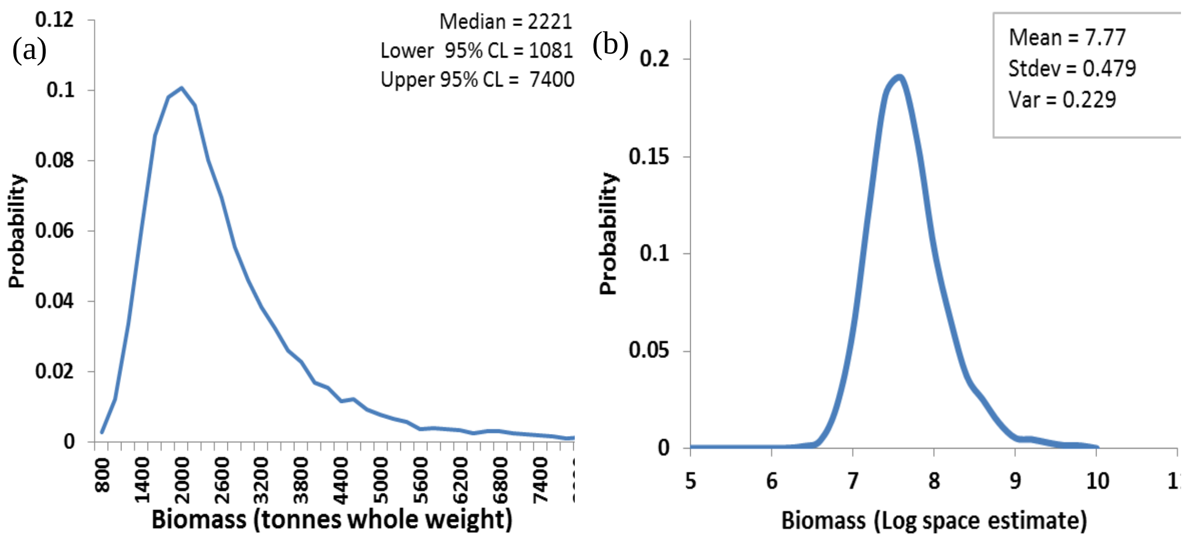


Figure 9.22. Probability estimates of biomass for the redfish stock in 2015 in the Pilbara region. (a) Distribution in normal units (tonnes) with statistical parameters; (b) Distribution in log-transformed space with statistical parameters. Parameters from (b) were applied in the biomass dynamics model (see Section 9.3.8.8).

Table 9.6. Population biomass in 2015 (t; whole weight) for individual strata within the *Actinopyga echinites* fishery in the Pilbara region. See Figure 8.3 for a spatial map of strata.

Strata	Area (km²)	Population biomass (t; whole weight) Median	Lower 60% CL	Upper 60% CL	Median biomass density (tonnes per km²)
C	12.87	311	207	462	24.2
F	14.53	623	389	1004	42.9
DN+DS	12.81	615	233	1564	48.0
GN+GS	19.15	422	268	656	22.0
Total	59.4				

In 2020, the estimated population biomass of redfish in the Pilbara varied between 1467 and 5015 tonnes whole weight (95% CL), with a median estimate of 2581 t (Figure 9.23).

In 2020, the population was examined in three main strata (Table 9.7). Median biomass density ranged from 20 tonnes per km^2 in the Barrow South Strata, to 90 tonnes per km^2 in the Rosemary Island strata.

Median estimated biomass of redfish (*Actinopyga echinites*) increased in 2020, relative to 2015. The two reasons for this were: 1) discovery of a new redfish stock at Rosemary Island in the Dampier Archipelago, 2) an improved sampling design based on findings of the 2015 survey, which resulted in higher overall densities, for a smaller overall area surveyed. It is expected that the 2020 sampling design will be retained for future surveys.

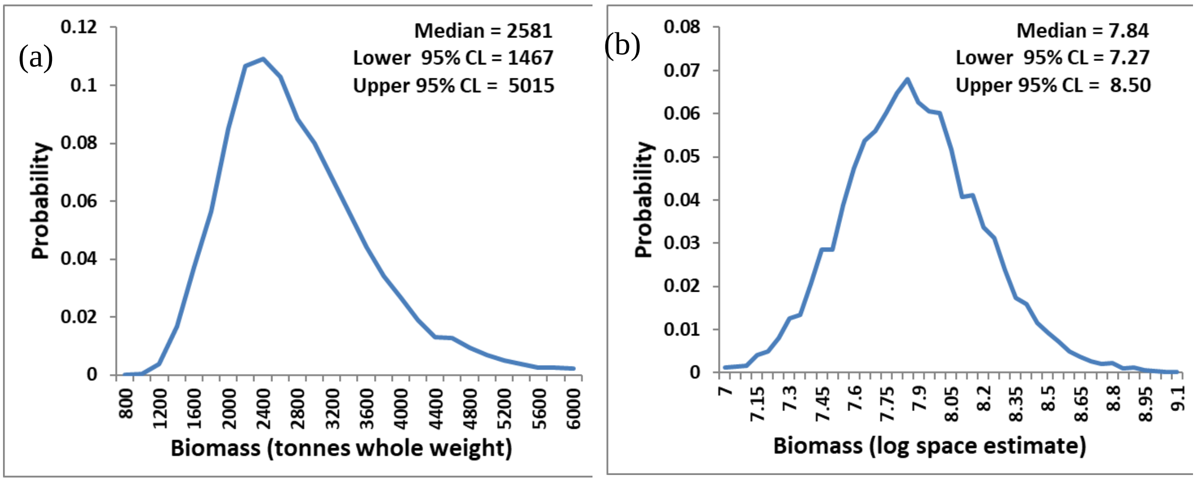


Figure 9.23. Probability estimates of biomass for the redfish stock in 2020 in the Pilbara region. (a) Distribution in normal units (tonnes) with statistical parameters; (b) Distribution in log-transformed space with statistical parameters. Parameters from (b) were applied in the biomass dynamics model (see Section 9.3.8.8).

Table 9.7. Population biomass in 2020 (t; whole weight) for individual strata within the *Actinopyga echinites* fishery in the Pilbara region. See Figure 8.4 for a spatial map of strata.

Strata	Area (km^2)	Population biomass (t; whole weight)			Median biomass density (tonnes per km^2)
		Median	Lower 60% CL	Upper 60% CL	
Barrow North	16.7	1,292	811	1,997	77.4
Barrow South	20.1	415	331	518	20.6
Rosemary Island	8.6	766	537	1092	89.1
Total	45.4				

9.3.7.4 Redfish (Shark Bay)

In 2021, the estimated population biomass of redfish in Shark Bay varied between 47 and 130 tonnes whole weight (95% CL), with a median estimate of 82 t (Figure 9.23). This was the first estimate for this population and is considered preliminary.

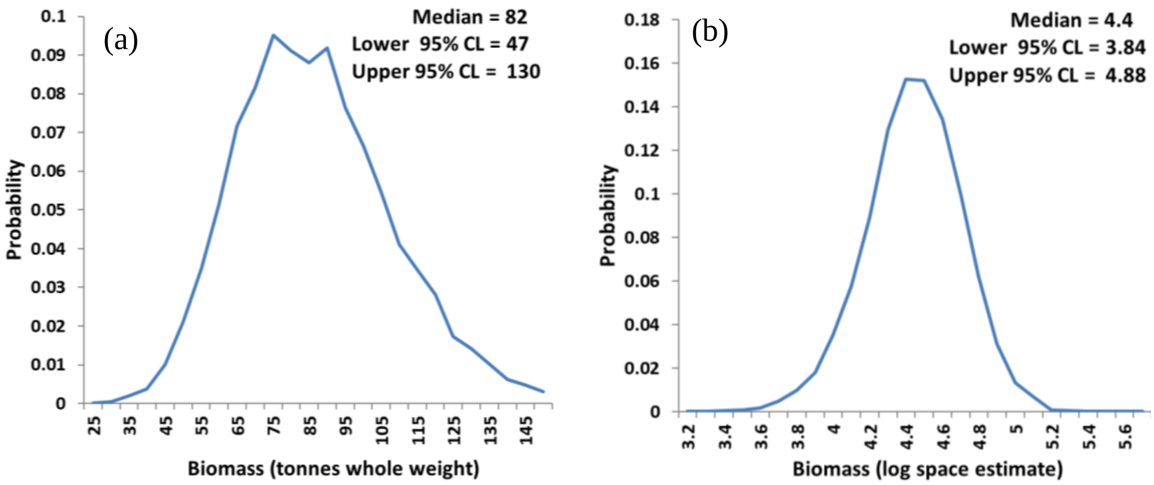


Figure 9.24. Probability estimates of biomass for the redfish stock in 2021 in the Shark Bay region. (a) Distribution in normal units (tonnes) with statistical parameters; (b) Distribution in log-transformed space with statistical parameters. Parameters from (b) were applied in the biomass dynamics model (see Section 9.3.8.8).

9.3.7.5 Conclusion

Sandfish (Kimberley)	The median biomass estimate for sandfish in Grid 1426 of the Kimberley was 199 t (95% CL: 127 - 300 t). Scaled up by 3.33 (see section 9.3.8.3), this equates to 663 t for the Kimberley.
Sandfish (Pilbara)	The median biomass estimate for sandfish in the Pilbara declined from 134 t in 2017 (95% CL: 98 to 181 t) to 27 t in 2020 (95% CL: 14 to 47 t).
Redfish (Pilbara)	The median biomass estimate for redfish in the Pilbara was 2221 t in 2015 (95% CL: 1000 to 7400 t) and 2581 t in 2020 (95% CL: 1467 to 5015 t)
Redfish (Shark Bay)	The median biomass estimate for redfish in Shark Bay in 2021 was 82 t (95% CL: 47 to 130 t)

9.3.8 Biomass Dynamics Model

9.3.8.1 Overview

A discrete version of the surplus production model with an annual time step (or biomass-dynamics model), applying the Schaefer (1954) production equation, was fitted to the catch, catch rate and fishery-independent survey biomass data for sandfish and redfish.

9.3.8.2 Model Description

B_{t+1}, the biomass in year $t+1$, is:

$$B_{t+1} = B_t + rB_t\left(1 - \frac{B_t}{K}\right) - C_t$$

where B_t is the biomass in year t, C_t is the catch in year t, r is the intrinsic rate of in increase and K is the carrying capacity. $\hat{U}_t$, the estimated catch rate in year t, is calculated as

$$\hat{U}_t = qB_t,$$

where q is the catchability coefficient.

The model was fitted by maximising the sum of numerous log-likelihood components. λ_1, the log-likelihood associated with the catch rate data, was calculated as

$$\lambda_1 = -\frac{n}{2}[\ln(2\pi) + 2\log_e(\hat{\sigma}) + 1]$$

where the maximum likelihood estimate of the variance was derived from the sum of squared residuals between the natural logarithms of the observed (U_t) and expected annual catch ($\hat{U}_t$) rates. In the Kimberley sandfish fishery, there were two log-likelihood components for catch

rate data (λ_1 and $\lambda_{1.1}$), as there were two catch rate indices from different periods (1995-2006; 2007 - 2021). These had different units (kg./day vs number / hour) and thus different q's.

λ_2, the log-likelihood associated with the fishery independent survey (FIS) estimate of biomass (see section 9.3.7.1 for sandfish and section 9.3.7.3 for redfish), was calculated from the probability density function for the lognormal distribution, i.e.

$$\lambda_2 = \ln\left\{\frac{1}{\hat{B}\sigma\sqrt{2\pi}} \exp\left[-\frac{\ln\left(\hat{B}-\mu\right)^2}{2\sigma^2}\right]\right\}$$

where $\hat{B}$ is the model estimate of biomass for the years in which the surveys were carried out. These years were 2015 and 2020 for Pilbara redfish, 2017 and 2020 for Pilbara sandfish, 2019 for Kimberley sandfish and 2021 for Shark Bay redfish. The parameter μ is the mean of the lognormal distribution for the fishery independent survey biomass estimate in a given year, and σ is the standard deviation for that estimate, thus there is a μ and an σ for each year of an FIS. The values for μ and σ were obtained by fitting a lognormal distribution to the resampled estimates of biomass, determined from the resampling analysis of the FIS data. The resampling analysis is summarised in Figure 9.18b and Figure 9.19b for Pilbara sandfish, Figure 9.20b for Kimberley sandfish, Figure 9.22b and Figure 9.23b for Pilbara redfish, and Figure 9.26b for Shark Bay redfish.

The overall log-likelihood associated with the biomass model fit to all data sets (λ) is a summation of all individual log-likelihood estimates:

$\lambda = \lambda_1 + \lambda_2$ (for 1 cpue trend and 1 FIS estimates – Shark Bay redfish)

$\lambda = \lambda_1 + \lambda_2 + \lambda_{2.1}$ (for 1 cpue trend and 2 FIS estimates – Pilbara sandfish and redfish)

$\lambda = \lambda_1 + \lambda_{1.1} + \lambda_1$ (for 2 cpue trends and 1 FIS estimates) – Kimberley sandfish

A parametric resampling approach was employed to account for uncertainty in the observed annual catch rate values. This involved generating 5000 random values for each mean annual catch rate, based on the value of that mean and its associated standard error. These values were employed to generate 5000 random catch rate time series, to each of which the model was fitted, and for which the estimated parameters and biomass values (and ratios of current / unfished biomass) were recorded. The 95% confidence limits associated for each parameter or biomass measure were taken as the upper 97.5 and lower 2.5 percentiles of the 5000 estimates for that respective parameter or biomass measure.

9.3.8.3 Scenarios for sandfish

In the Kimberley and Pilbara regions, two biomass modelling scenarios were investigated to account for the fact that fishery independent surveys (FIS) of sandfish biomass did not cover 100% of the known area of catch and populations.

Scenario 1, or "conservative", assumed that the area covered by the FIS strata (3.53 km^2 in the Pilbara, and 53.3 km^2 in Kimberley) included all known stocks. This was overly-conservative and represents a minimal scenario.

Scenario 2 or "realistic" used the knowledge of the % of populations that occurred in the strata covered by the FIS surveys. To calculate this, investigations of historical catch were made, particularly within the early years of the fishery, which generally involved more exploratory fishing. For the Pilbara region, 65% of the populations were covered by the FIS surveys. For the Kimberley region, 30% of the populations were surveyed by FIS. For these scenarios, the FIS biomass estimate was multiplied by (1/0.65 = 1.54) for the Pilbara stocks, and (1/0.30 = 3.33) for the Kimberley stocks (Table 9.8).

Table 9.8. Input data and estimated parameters for the sandfish (*Holothuria scabra*) biomass dynamics models for Western Australia. Different scenarios were investigated, as defined by the *SF* (scaling factor). Scenarios are found in section 9.3.8.3

Parameter/ Data	Description	Values/Estimation
SF	Scaling factor	Scenario 1 = 1; Scenario 2 = 1.56 for Pilbara and 3.33 for Kimberly. See section 9.3.8.3 for more detail.
K	Carrying Capacity/ Virgin Biomass	Estimated in model
r	Intrinsic rate of population increase	From equation $r = 2M$. M assumed to be normally distributed, with a mean of 0.35 and SD of 0.1.
q	Catchability coefficient	Estimated in model
$\hat{U}_t$	Estimated catch rate	Estimated in model
U_t	Observed catch rate	Output from fishery dependent CPUE analysis (see Section 9.3.4.1).
C_t	Catch (tonnes) in year *t*	Catch records from fishery (1996 to 2021)
B_t	Biomass (tonnes) in year t	Estimated in model
MSY	Maximum sustainable yield (tonnes)	$=rK$
B_{MSY}	Biomass at maximum sustainable yield	$=K/2$
μ_{2017}	Mean of the lognormal distribution for the observed biomass in 2017	Output from fishery independent population surveys - Pilbara (see Figure 9.18b)
σ_{2017}	Standard deviation of the lognormal distribution for the observed biomass in 2017	Output from fishery independent population surveys - Pilbara (see Figure 9.18b)
μ_{2020}	Mean of the lognormal distribution for the observed biomass in 2020	Output from fishery independent population surveys - Pilbara (see Figure 9.19b)
σ_{2020}	Standard deviation of the lognormal distribution for the observed biomass in 2020	Output from fishery independent population surveys - Pilbara (see Figure 9.19b)
μ_{2019}	Mean of the lognormal distribution for the observed biomass in 2019	Output from fishery independent population surveys - Kimberley (see Figure 9.20b)
σ_{2019}	Standard deviation of the lognormal distribution for the observed biomass in 2019	Output from fishery independent population surveys - Kimberley (see Figure 9.20b)

9.3.8.4 Results and Diagnostics – Sandfish (Pilbara)

Model outputs for Scenario 1 are summarised in Figure 9.25. Unfished biomass in 1996 was estimated at 150 t, with a range from 140 to 175 t. Biomass was reduced by around 40% in the first 5 years of fishing but recovered to virgin levels in 2008 following the cessation of fishing (Figure 9.25d). The model estimated that it was unlikely that biomass was reduced below $0.5B_0$ prior to 2017, but showed significant declines and recovery between 2017 and 2021. Only four years of useful catch rate data were available, but showed a signal between 2016 and 2019, when it declined by around 40% (Figure 9.25e).

Model outputs for Scenario 2 are summarised in Figure 9.26. Unfished biomass in 1996 was estimated at 210 t, with a range from 180 to 240 t. Biomass was reduced by around 20% in the first 5 years of fishing, but recovered to virgin levels in 2008 following the cessation of fishing (Figure 9.26d). The model estimated that it was highly unlikely that biomass was reduced below 0.5 B_0 at any time during the 25 year history of the fishery.

9.3.8.5 Results and Diagnostics – Sandfish (Kimberley)

Model outputs for Scenario 1 (Grid 1426 only) are summarised in Figure 9.27. Unfished biomass in Grid 1426 in 1995 was estimated at 320 t, with a range from 270 to 400 t (Figure 9.27c). Biomass was reduced by around 50% in the first 7 years of fishing, but recovered to almost B_0 levels in 2020 following a much reduced harvest (Figure 9.27d). The model estimated that it was unlikely that biomass was reduced below 0.5 B_0 at any time during the 24-year history of the fishery (Figure 9.27d). Current biomass estimated by the model was higher than that estimated by the FIS (Figure 9.27c).

Model outputs for Scenario 2 (whole of Kimberley) are summarised in Figure 9.28. Unfished biomass in the Kimberley in 1995 was estimated at 900 t, with a range from 790 to 1100 t (Figure 9.28a). Biomass was reduced by 60% in the first 5 years of fishing, largely because 1200 tonnes was harvested between 1995 and 2002 (Figure 9.28f). Kimberley sandfish biomass recovered to 90% of virgin levels by 2011 following a much reduced harvest (Figure 9.28d). The model estimated that biomass was reduced below B_{MSY} in the first five years of the fishery, but has recovered to be well above B_{MSY} since then (Figure 9.28c). Both the biomass dynamics model, and the FIS estimated current biomass to be above B_{MSY} (Figure 9.28c), and catch has been well below MSY for 20 years (Figure 9.28f).

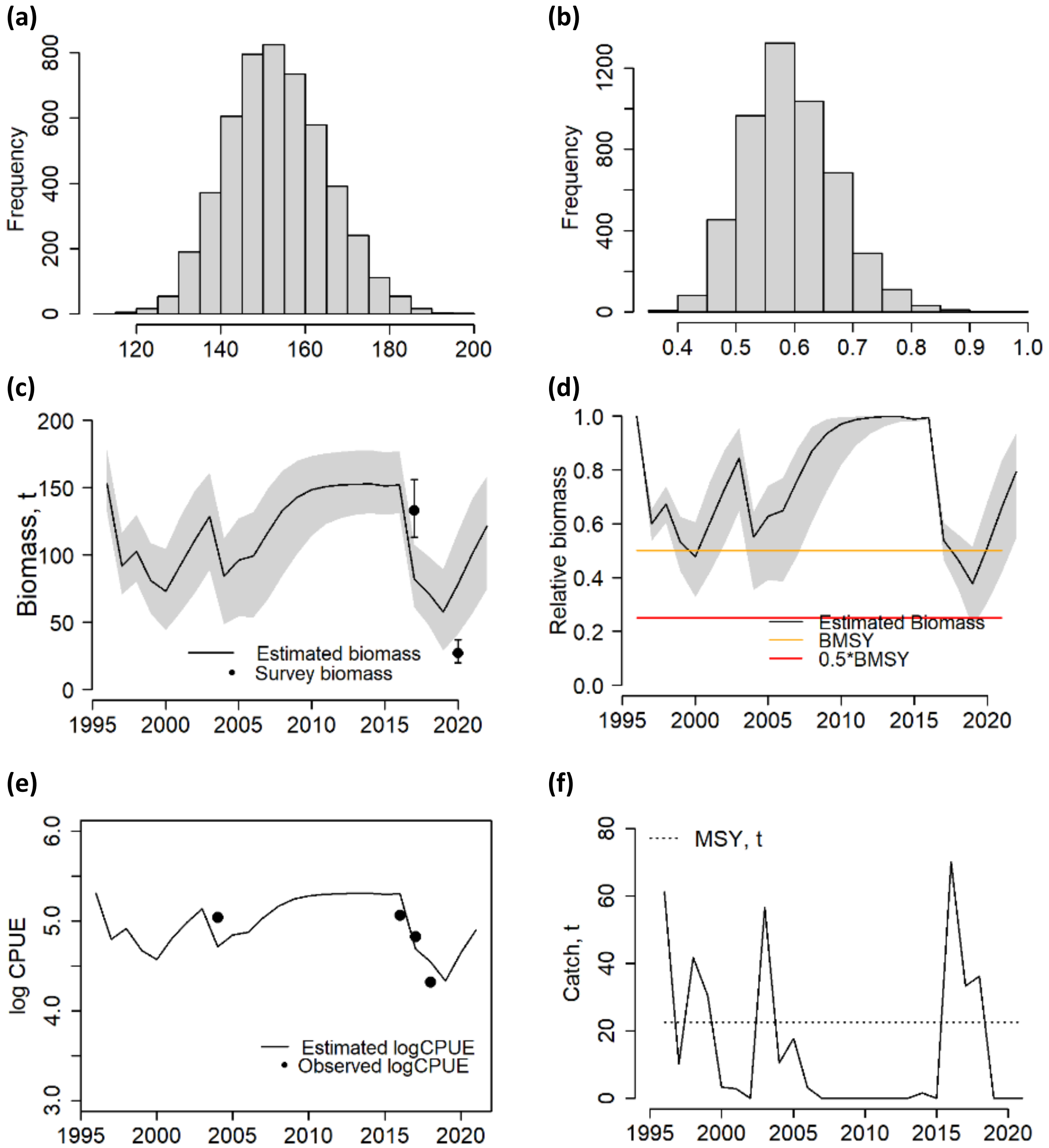


Figure 9.25. ***Holothuria scabra*-Pilbara region. (Scenario 1). Estimates of key model parameters and outputs for sandfish stocks in the Pilbara region. (a) Unfished Biomass (K or B_0) in tonnes, (b) Intrinsic rate of population increase (*r*), (c) Estimated biomass from 1995 to 2021 and observed biomass from FIS in 2017 and 2020, (d) Relative biomass (B/B_0), (e) estimated and observed SCPUE, (f) Catch vs estimated MSY. Outputs from *n* = 5000 model runs.**

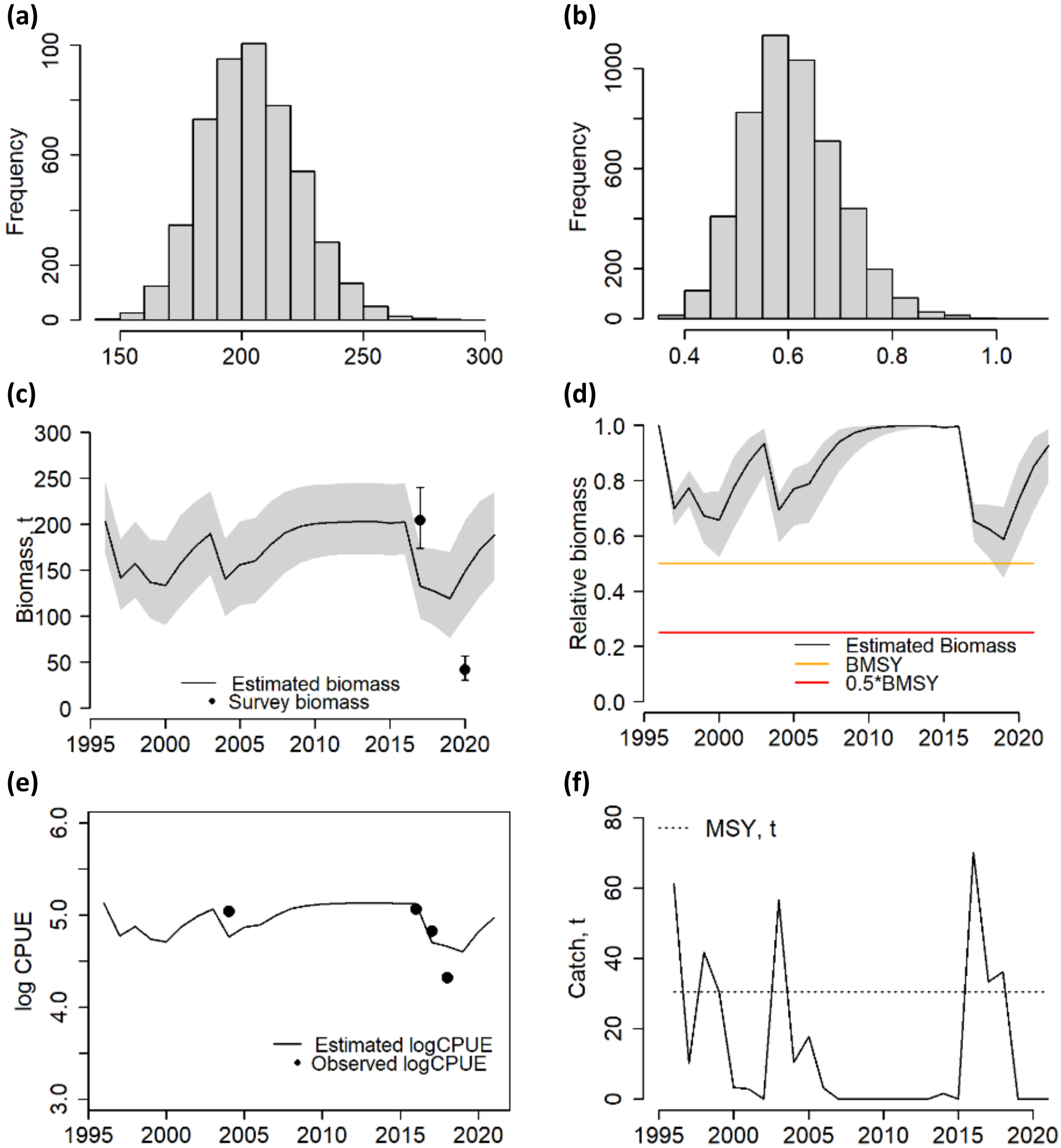


Figure 9.26. ***Holothuria scabra*** **– Pilbara region (Scenario 2). Estimates of key model parameters and outputs for sandfish stocks in the Pilbara region. (a) Unfished Biomass (K or B0) in tonnes, (b) Intrinsic rate of population increase (r), (c) Estimated biomass over from 1995 to 2021 and observed biomass from FIS in 2017 and 2020, (d) Relative biomass (B/B0) with reference points, (e) estimated and observed SCPUE, (f) Catch and estimated MSY. Outputs from n = 5000 model runs.**

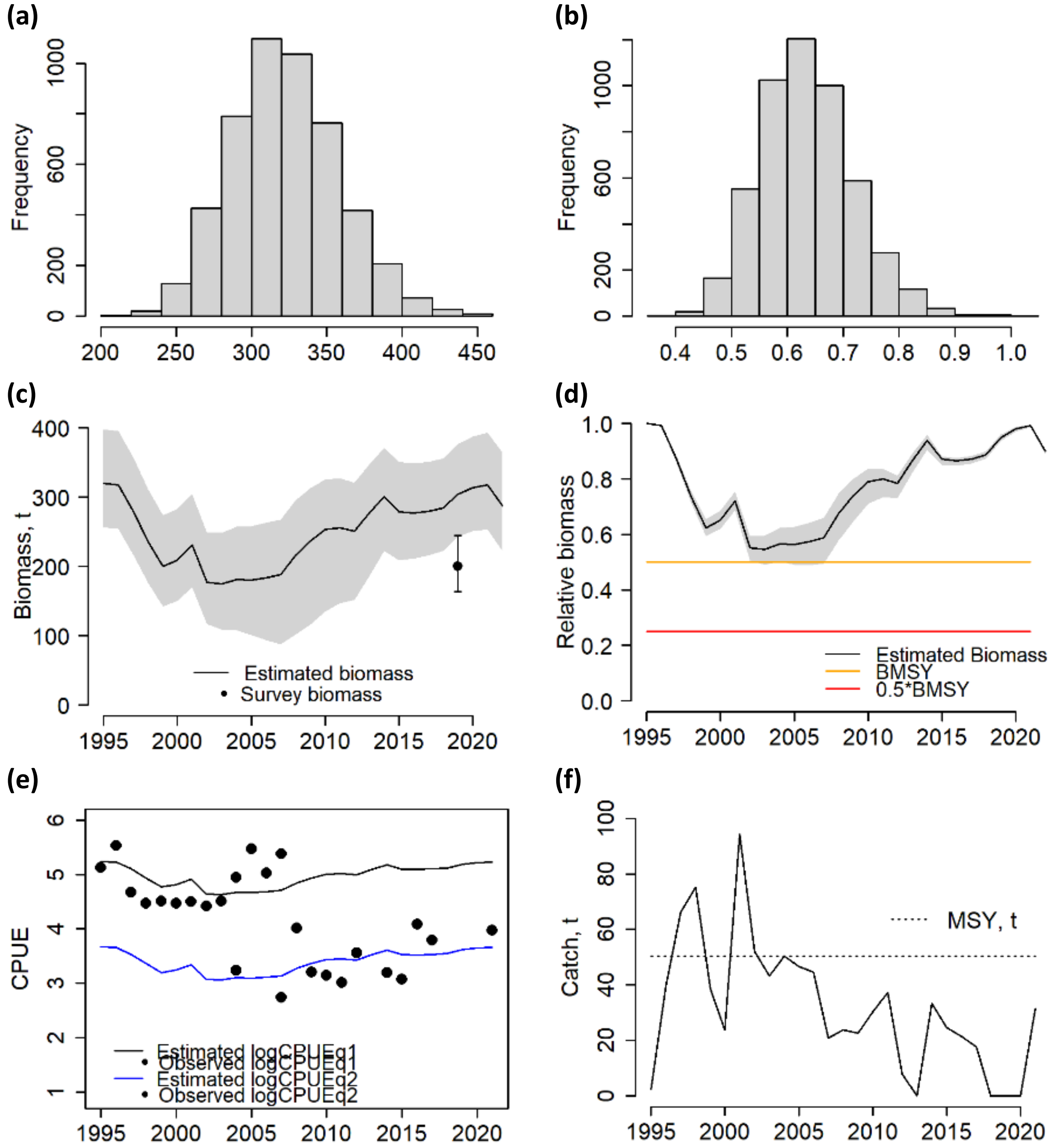


Figure 9.27. ***Holothuria scabra*** **- Kimberley (Scenario 1). Estimates of parameters and outputs for sandfish stocks in Grid 1426 of the Kimberley region (see Figure 8.1). (a) Unfished Biomass (K or B_0), (b) Intrinsic rate of population increase (*r*), (c) Estimated biomass from 1995 to 2021 and observed biomass from FIS in 2019, (d) Relative biomass (B/B0) with target and limit reference points, (e) estimated and observed SCPUE, (f) Catch vs estimated MSY. Outputs from *n* = 5000 model runs.**

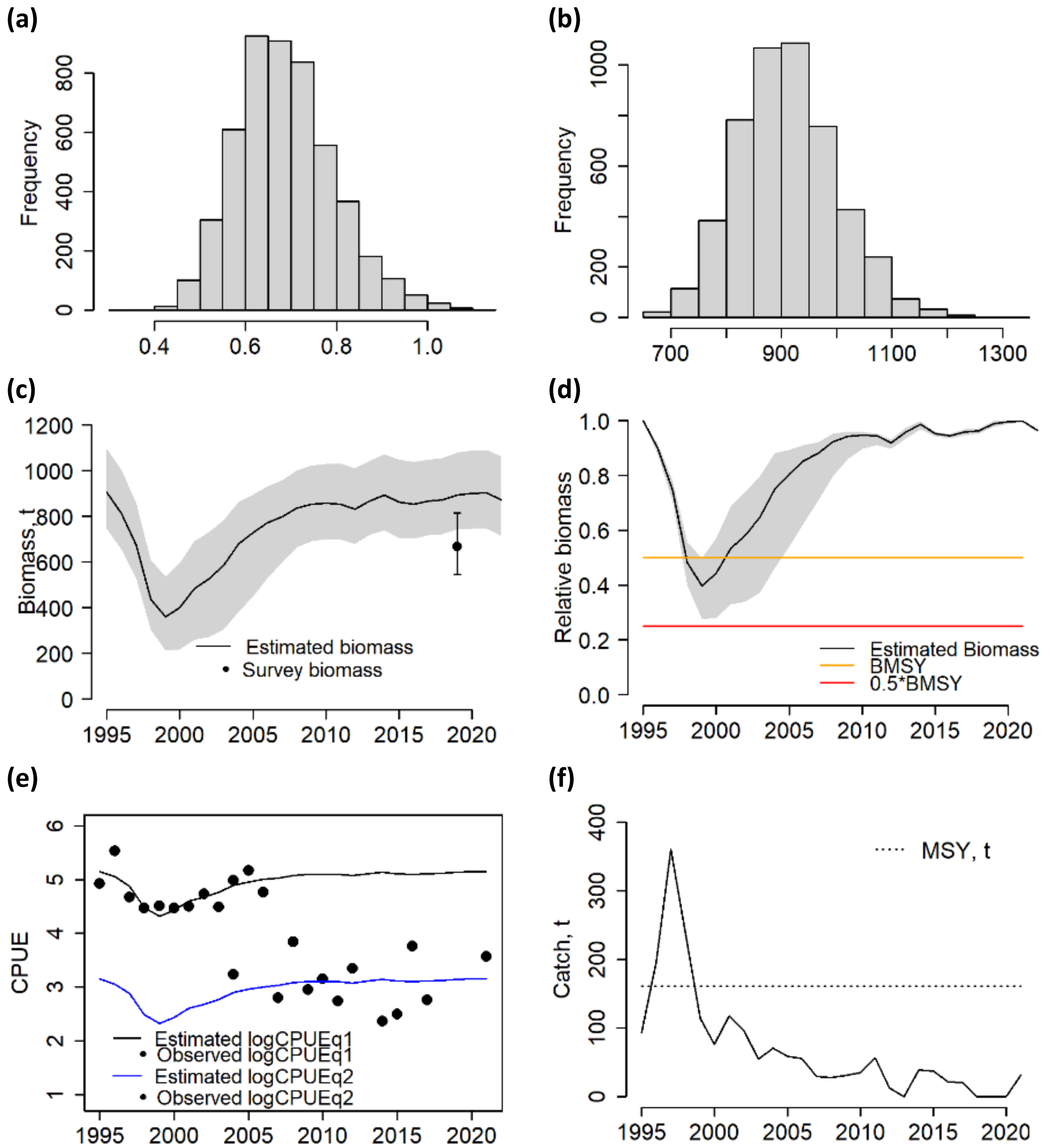


Figure 9.28. ***Holothuria scabra*** **– Kimberley region. (Scenario 2). Estimates of key model parameters and outputs for sandfish stocks in the Kimberley. (a) Unfished Biomass (K or B0) in tonnes, (b) Intrinsic rate of population increase (r), (c) Estimated biomass from 1995 to 2021 and observed biomass from FIS in 2019, (d) Relative biomass (B/B0), (e) estimated and observed SCPUE, (f) Catch vs estimated MSY. Outputs from n = 5000 model runs.**

Table 9.9. Input data and estimated parameters for the redfish (*Actinopyga echinites*) biomass dynamics models

Parameter/ Data	Description	Values/Estimation
K	Carrying Capacity/ Virgin Biomass	Estimated in model
r	Intrinsic rate of population increase	From equation $r = 2M$. M assumed to be normally distributed, with a mean of 0.35 and SD of 0.1.
q	Catchability coefficient	Estimated in model
$\hat{U}_t$	Estimated catch rate	Estimated in model
U_t	Observed catch rate	Output from fishery dependent CPUE analysis (see section 9.3.4).
C_t	Catch (tonnes) in year t	Catch records from fishery
B_t	Biomass (tonnes) in year t	Estimated in model
MSY	Maximum sustainable yield (tonnes)	$=rK$
B_{MSY}	Biomass at maximum sustainable yield	$=K/2$
μ_{2015}	Mean of the lognormal distribution for the observed biomass in 2015	Output from fishery independent population surveys – Pilbara (see Figure 9.22)
σ_{2015}	Standard deviation of the lognormal distribution for the observed biomass in 2015	Output from fishery independent population surveys – Pilbara (see Figure 9.22)
μ_{2020}	Mean of the lognormal distribution for the observed biomass in 2020	Output from fishery independent population surveys - Pilbara (see Figure 9.23)
σ_{2020}	Standard deviation of the lognormal distribution for the observed biomass in 2020	Output from fishery independent population surveys – Pilbara (see Figure 9.23)
μ_{2021}	Mean of the lognormal distribution for the observed biomass in 2021	Output from fishery independent population surveys – Shark Bay (see Figure 9.24)
σ_{2021}	Standard deviation of the lognormal distribution for the observed biomass in 2021	Output from fishery independent population surveys – Shark Bay (see Figure 9.24)

9.3.8.6 Results and Diagnostics – Redfish (Pilbara)

Model outputs are summarised in Figure 9.29. Unfished biomass in 2006 was estimated at 1800 t, with a range from 1500 to 2200 t (Figure 9.29c). Biomass was reduced between 2007 and 2010 by approximately 20%. Total catch during this period was 587 tonnes (Figure 9.29f). Biomass recovered to near virgin levels between 2010 and 2016, during which time only 62 tonnes was removed. The model estimated that it was highly unlikely that biomass was reduced below 0.8K at any time during the 15-year history of the fishery (Figure 9.29d). Minimal signal was found in the catch rates, with SCPUE in 2016 and 2017 being very similar to catch rates at the inception of the fishery (Figure 9.29e). MSY was estimated at a median of 305 tonnes, however MSY has never been harvested in this fishery (Figure 9.29f).

9.3.8.7 Results and Diagnostics – Redfish (Shark Bay)

Model outputs are summarised in Figure 9.30. Unfished biomass in 2018 was estimated at 90 t, with a range from 60 to 140t (Figure 9.30c). With only 3 years of fishing, the stock has been only lightly impacted so far, and in 2022 was estimated at 0.9 B_0 (Figure 9.30d). Total catch during this period was 15 tonnes, and the MSY was estimated at 15 tonnes (Figure 9.30f). Minimal signal was found in the catch rates, with SCPUE increasing slowly between 2020 and 2022 (Figure 9.30e). As the fishery is new, and catch has not so far achieved the annual SCPUE, no sustainability issues have arisen thus far.

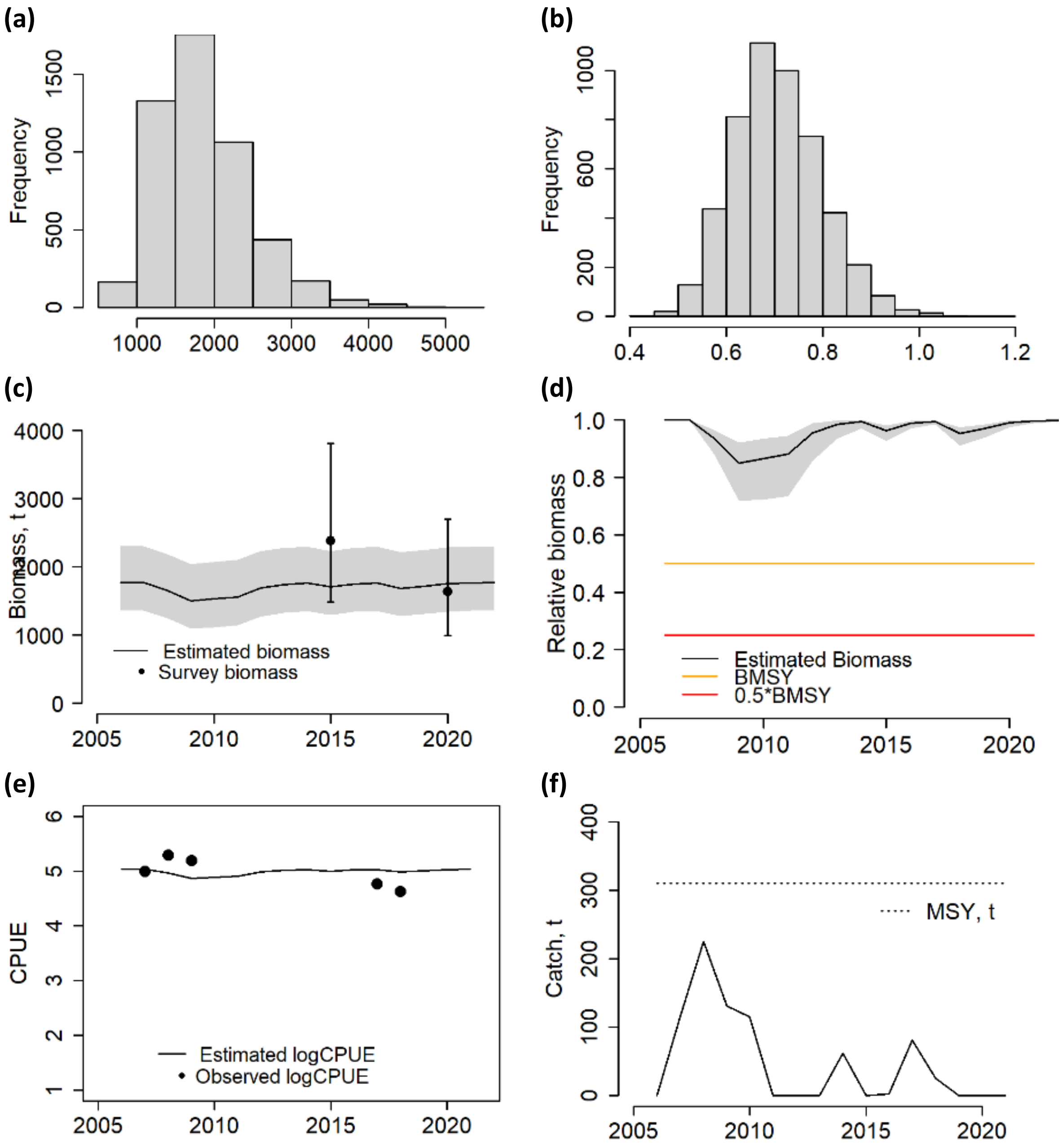


Figure 9.29. ***Actinopyga echinites*** **(Pilbara). Estimates of key model parameters and outputs for redfish stocks in the Pilbara. (a) Unfished Biomass (K or B0) in tonnes, (b) Intrinsic rate of population increase (r), (c) Biomass over the history of the fishery (2007 to 2012) with FIS (Fishery Independent Survey) estimate in 2017 and 2021, (d) Relative biomass (B/B0), (e) estimated and observed SCPUE, (f) Catch vs estimated MSY. Outputs from n = 5000 model runs.**

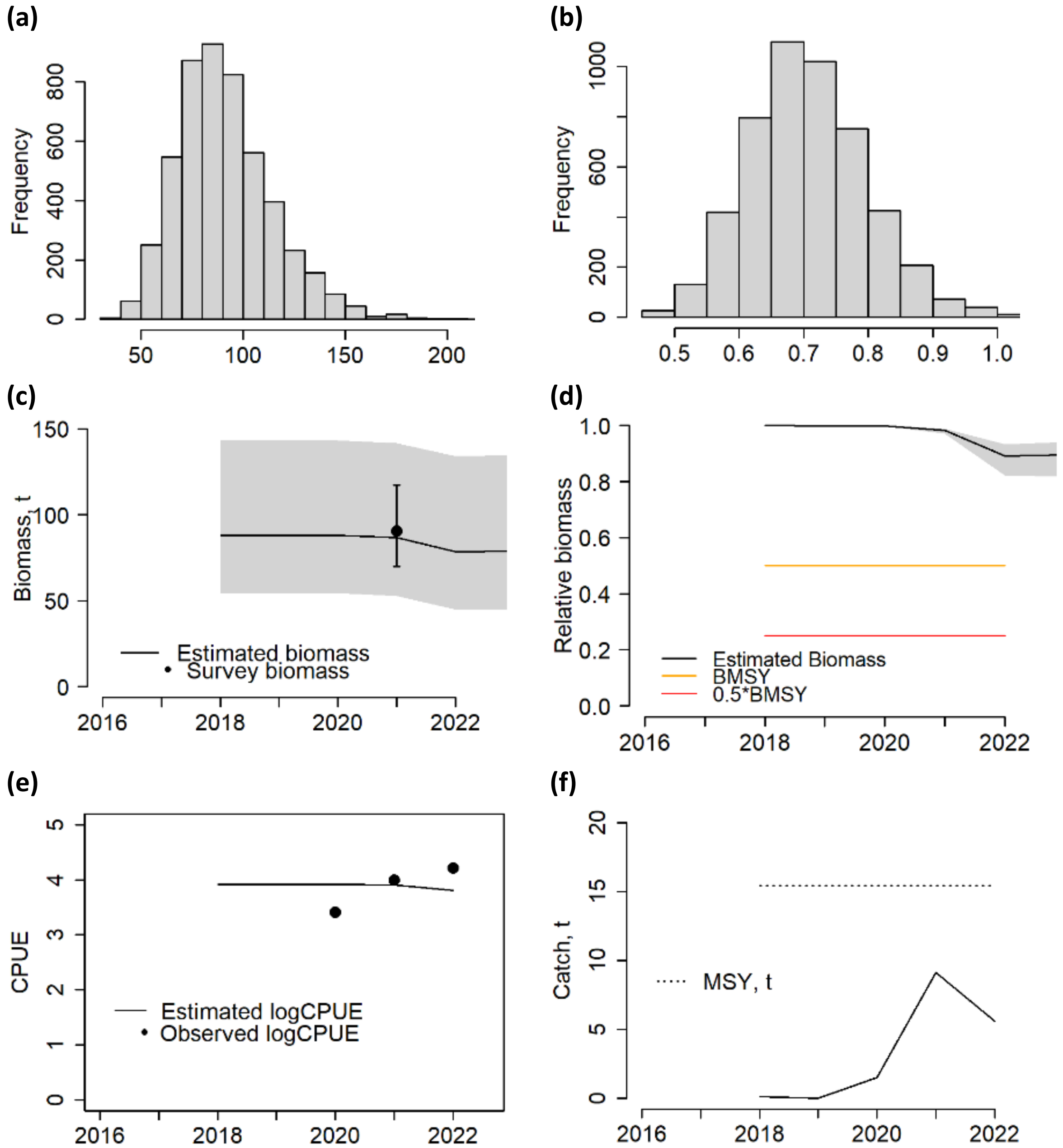


Figure 9.30. ***Actinopyga echinites*** **(Shark Bay). Estimates of key model parameters and outputs for redfish in Shark Bay (a) Unfished Biomass (K or B0) in tonnes, (b) Intrinsic rate of population increase (r), (c) Biomass over the history of the fishery (2018 to 2022) with FIS (Fishery Independent Survey) estimate in 2021, (d) Relative biomass (B/B0), (e) estimated and observed SCPUE, (f) Catch vs estimated MSY. Outputs from n = 5000 model runs.**

9.3.8.8 Accounting for Uncertainty

Resampling approaches were employed to account for uncertainty in key data/parameter inputs associated with generating biomass estimates. These data include:

Natural Mortality (M) and intrinsic rate of population increase (r): M was assumed to be normally distributed with a conservative mean of 0.35 for sandfish and redfish, with a standard deviation of 0.1. This figure has been previously used to model sea cucumber population dynamics (Skewes et al. 2014). Parametric resampling was employed to generate 5000 values for *M*, which in turn were used to estimate *r* using the formula $r = 2M$ (Zhou et al. 2016).

Observed catch rate (U_t): Parametric resampling was used to generate 5000 random values for each observed annual catch rate, given the estimated mean and standard errors for each year (for the estimates in log space). The model was fitted to each of the 1000 random values for r, and mean annual catch rate, to produce estimates of uncertainty for each estimated parameter and annual biomass value.

Observed Biomass (2015, 2017, 2019,2020 and 2021 FIS Surveys) (B_t)*:* Parametric resampling was used to generate 5000 random values for the sandfish and redfish fishery independent survey biomass estimates. The uncertainty associated with the survey biomass estimated was incorporated into the model likelihood function. In the case of sandfish, an additional source of uncertainty was the proportion of total stock enumerated by the fishery independent surveys. This uncertainty was modelled using multiple scenarios with different assumptions about the ratio of current known area to historically fished areas of stock and have been included in the model outputs.

9.3.8.9 Conclusion

Sandfish (Kimberley)	The biomass dynamics model estimated that an initial decline occurred to 0.4 B_0 (unfished biomass) during 1995 - 1999, but it was highly unlikely that biomass was reduced below 0.8B_0 (unfished biomass) between 2006 and 2021.
Sandfish (Pilbara)	The biomass dynamics model estimated that it was highly unlikely that biomass was reduced below 0.5 B_0 at any time during the 25 year history of the fishery.
Redfish (Pilbara)	The biomass dynamics model estimated that it was highly unlikely that biomass was reduced below 0.8 B_0 at any time during the 15-year history of the fishery.
Redfish (Shark Bay)	The biomass dynamics model estimated that it was highly unlikely that biomass was reduced below 0.8 B_0 at any time during the 3-year history of the fishery.

9.4 Stock Status Summary

Presented below is a summary of the available lines of evidence considered in the overall weight of evidence assessment of the indicator species' stocks for the WA Sea Cucumber Resource, followed by the management advice and recommendations for future monitoring of these species.

9.4.1 Sandfish (Kimberley)

9.4.1.1 Weight of Evidence Risk Assessment

Category	Lines of evidence (Consequence / Status)
Catch (Section 9.3.2)	Catch and effort in this fishery has followed a typical fishery developmental path, with initial large catch and effort and reductions thereafter, instigated largely by conditions from assessments (e.g. under the EPBC Act), which required the development of fine-scale catch and effort records, and changes in industry practices, such as use of smaller boats (i.e. a reduction in holding capacity), smaller crews, shorter trips and rotational fishing strategies. There is no indication within the catch data of unacceptable stock depletion..
Catch distribution (Section 9.3.3)	The spatial distribution of catch has remained largely consistent over the history of the Kimberley sandfish fishery. The fishery is widespread, with catch coming from a few high productivity areas, and a variable number of lower productivity areas. Catch distribution is also managed by rotational harvest strategies. There is no indication that catch levels have been maintained by a progressive shifting of the areas fished that would be indicative of unacceptable serial stock depletion.
Catch rates (Section 9.3.4)	The SCPUE in the Kimberley sandfish fishery has oscillate widely, but with a clear upward trend. In 2021, the SCPUE was at its 2nd highest level on record There are no indications from catch rates of unacceptable stock depletion since 2007.
Trends in size structure (Section 0)	Average weight of sandfish harvested in the Kimberley in the period 2004 to 2021 was > 3 times than the estimated size-at-maturity and stable over time. There are no indications from average size fished of unacceptable stock depletion during the history of the fishery.
Vulnerability (PSA) (Section 9.3.6)	Sandfish are assumed to have a relatively short life span (maximum age around 10-14 years), and mature at 2 years of age. With a productivity score of 1.33 and susceptibility score of 1.88, the overall derived PSA score is 2.3 (MSC score > 80). This level of vulnerability indicates there is a relatively low chance of overfishing occurring at current levels of effort. However the significant risk of sea cucumber stocks to localised depletion cannot be discounted, despite this low vulnerability score.
Fishery Independent Surveys	The median biomass estimate for sandfish in Grid 1426 of the Kimberley was 199 t (95% CL: 127 - 300 t). Scaled up by 3.33 (see section 9.3.8.3), this equates to 663 t for the Kimberley
Biomass dynamics model	The biomass dynamics model estimated that an initial decline occurred to 0.4 B0 (unfished biomass) during 1995 - 1999, but it was highly unlikely that biomass was reduced below 0.8B0 (unfished biomass) between 2006 and 2021.

Kimberley sandfish risk matrix					
Consequence (stock depletion) Level	Likelihood				
	L1 Remote (<5%)	L2 Unlikely (5-<20%)	L3 Possible (20-<50%)	L4 Likely (≥50%)	**Risk Score**
C1 Minor				X	4
C2 Moderate		X			4
C3 High	X				3
C4 Major	NA				-

C1 (Minor Depletion): **Likely L4** – The primary performance indicator for this stock (biomass) was above the target reference level in 2021 with >95% confidence limit. This is supported by all lines of evidence, so it is likely (L4) that sandfish in the Kimberley has experienced only a minor (C1) depletion.

C2 (Moderate Depletion): **Unlikely L2 –** The primary performance indicator for this stock (biomass) was above the target reference level in 2021 with >95% confidence limit. Based on all lines of evidence, it is unlikely (L2) that sandfish in the Kimberley has experienced a moderate (C2) depletion.

C3 (High Depletion): **Remote L1** – The primary performance indicator for this stock (biomass) was above the target reference level in 2021 with >95% confidence limit. Based on all lines of evidence, it is unlikely (L2) that sandfish in the Kimberley has experienced a moderate (C2) depletion.

C4 (Major Depletion): **NA** – Not plausible based on current evidence.

9.4.1.2 Current Risk Status

Based on the information and analyses available, the current risk level for Kimberley sandfish was estimated to be LOW (C2 × L2). The LOW risk (see Appendix 2) is an improvement of the MEDIUM risk status of the 2018 assessment. Therefore, the overall Weight of Evidence assessment indicates the status of the Kimberley sandfish stock is adequate and that current management settings are maintaining risk at acceptable levels.

9.4.1.3 Future Monitoring

Information on size-at-maturity for the Kimberley sandfish would be desirable from the point of view of understanding more of the biology. However, the plasticity of morphological metrics in sea cucumbers offsets the efficacy of minimum legal lengths in protecting the breeding stock. More viable strategies will be those that maintain low levels of catch and effort, such as harvest strategies based on fishery-independent estimates of biomass.

9.4.2 Sandfish (Pilbara)

9.4.2.1 Weight of Evidence Risk Assessment

Category	Lines of evidence (Consequence / Status)
Catch (Section 9.3.2)	Catch and effort in this fishery has followed a similar pattern to the Kimberley stock, although effort has been more intermittent, with minimal effort on sandfish over the past ten years. In 2016 a sandfish stock was discovered and fished between 2016 and 2018, with declining catches There is some indication within the catch data of unacceptable stock depletion between 2016 and 2018.
Catch distribution (Section 9.3.3)	Effort in the Pilbara has historically been focused on redfish and has involved fishing in places where sandfish are not abundant. The rediscovery of lightly exploited high-density populations of sandfish (such as those fished in the Dampier Archipelago in 2016 and 2017) may influence effort distribution in the Pilbara in the future. There is no indication that catch levels have been maintained by a progressive shifting of the areas fished that would be indicative of unacceptable serial stock depletion.
Catch rates (Section 9.3.4)	The SCPUE in the Pilbara sandfish fishery declined during the years 2016 to 2018, but there has been no fishing since 2019. There is an indication from catch rates of potentially unacceptable stock depletion during 2015 to 2019. No fishing in 2020 and 2021 may have allowed a recovery, but evidence is not yet available
Trends in size structure (Section)	Average weight of sandfish harvested in the Pilbara has been increasing since 2004 and is > 3 times than the estimated size-at-maturity. There are no indications from average size fished of unacceptable stock depletion during the history of the fishery
Vulnerability (PSA) (Section 9.3.6)	Sandfish are assumed to have a relatively short life span (maximum age around 10-14 years), and mature at 2 years of age. With a productivity score of 1.33 and susceptibility score of 1.88, the overall derived PSA score is 2.3 (MSC score > 80). This level of vulnerability indicates there is a relatively low chance of overfishing occurring at current levels of effort. However the significant risk of sea cucumber stocks to localised depletion cannot be discounted, despite this low vulnerability score.
Fishery Independent Surveys	The median biomass estimate for sandfish in the Pilbara declined from 134 t in 2017 (95% CL: 98 to 181 t) to 27 t in 2020 (95% CL: 14 to 47 t).
Biomass dynamics model (Section 9.3.8)	The biomass dynamics model estimated that it was highly unlikely that biomass was reduced below 0.5 B_0 at any time during the 25 year history of the fishery.

Pilbara sandfish risk matrix					
Consequence (stock depletion) Level	Likelihood				
	L1 Remote (<5%)	L2 Unlikely (5-<20%)	L3 Possible (20-<50%)	L4 Likely (≥50%)	**Risk Score**
C1 Minor				X	4
C2 Moderate			MEDIUM		6
C3 High		X			6
C4 Major	NA				-

C1 (Minor Depletion): **Likely L4** – The primary performance indicator for this stock (biomass) was above the target reference level in 2021 with >95% confidence limit, but not in in 2019 and 2018. This is supported by all lines of evidence, so it is likely (L4) that sandfish in the Pilbara has experienced a minor depletion.

C2 (Moderate Depletion): **Possible L4 –** The primary performance indicator for this stock (biomass) was above the target reference level with 95% certainty in 2021, but not in 2019 and 2020. Also, the FIS data suggested a >50% depletion between 2015 and 2020. Thus, it is possible that redfish in the Pilbara has experienced a moderate depletion.

C3 (High Depletion): **Unlikley L1** – The primary performance indicator for this stock (biomass) was above the target reference level in 2021 with >95% confidence limit, and no harvest has been taken for 3 years. Thus it is unlikely that sandfish in the Pilbara have experienced a high level of depletion.

C4 (Major Depletion): **NA** – Not plausible based on current evidence.

9.4.2.2 Current Risk Status

Based on the information and analyses available, the current risk level for Pilbara sandfish was estimated to be MEDIUM (C2 × L3). Therefore, the overall Weight of Evidence assessment indicates the status of the Pilbara sandfish stock is adequate and that current management settings are maintaining risk at acceptable levels.

9.4.2.3 Future Monitoring

Information on size-at-maturity for the Pilbara sandfish would be desirable from the point of view of understanding more of the biology. However, the plasticity of morphological metrics in sea cucumbers reduces the efficacy of minimum legal lengths in protecting the breeding stock. More viable strategies will be those that maintain low levels of catch and effort, such as catch-based harvest strategies based on fishery-independent estimates of biomass.

9.4.3 Redfish (Pilbara)

9.4.3.1 Weight of Evidence Risk Assessment

Category	Lines of evidence (Consequence / Status)
Catch (Section 9.3.2)	Catches from this stock were initially large (587 t in first 4 years), however, minimal catch in the past 6 years (63 t). Stock is exploited on a rotational basis by commercial contractual agreements within Industry. There is no indication within the catch data of unacceptable stock depletion.
Catch distribution (Section 9.3.3)	The fishery is primarily based on the discovery of an unexploited stock in 2007 at Montebello Islands. Effort has been re-focused on the same spatial areas, although there is considerable fine-scale variation in the harvested areas. Stocks have been targeted 5 times in from 2014 to 2018, but not since then. There is no indication that catch levels have been maintained by a progressive shifting of the areas fished that would be indicative of unacceptable serial stock depletion.
Catch rates (Section 9.3.4)	Catch rates in the Pilbara redfish fishery have oscillated over time, with no clear overall trend upwards or downwards, but there has been no fishing since 2018. There are no indications from catch rates of unacceptable stock depletion during the history of the fishery.
Trends in size structure (Section 0)	Average weight of redfish harvested in the WASCF in the period 2007 to 2021 was > 3 times greater than the estimated size-at-maturity. This provides protection of the spawning stock, and fishing mortality is likely to be low. There are no indications from average size fished of unacceptable stock depletion during the history of the fishery.
Vulnerability (PSA) (Section 9.3.6)	Redfish assumed to have a relatively short life span (maximum age around 12 years), and mature at 2 years of age. With a productivity score of 1.5 and susceptibility score of 1.88, the overall derived PSA score is 2.4 (MSC score > 80). This level of vulnerability indicates there is a relatively low chance of overfishing occurring at current levels of effort. However the significant risk of sea cucumber stocks to localised depletion cannot be discounted, despite this low vulnerability score.
Fishery Independent Surveys	The median biomass estimate for redfish in the Pilbara was 2221 t in 2015 (95% CL: 1000 to 7400 t) and 2581 t in 2020 (95% CL: 1467 to 5015 t).
Biomass dynamics model (Section 9.3.8)	The biomass dynamics model estimated that it was highly unlikely that biomass was reduced below 0.8 B0 at any time during the 15-year history of the fishery.

Pilbara redfish risk matrix					
Consequence (stock depletion) Level	Likelihood				
	L1 Remote (<5%)	L2 Unlikely (5-<20%)	L3 Possible (20-<50%)	L4 Likely (≥50%)	**Risk Score**
C1 Minor				LOW	4
C2 Moderate		X			4
C3 High	X				3
C4 Major	NA				-

C1 (Minor Depletion): **Likely L4** – Based on the lines of evidence, with biomass estimates (and 95% CLs) being well above the Target level (i.e. > 40% unfished levels), it is highly likely that the Pilbara redfish stock has only experienced minor depletion to date.

C2 (Moderate Depletion): **Unlikely L2 –** Catches and catch rates increased during the first four years of exploitation, when most of the catch was taken. Average size fished is significantly higher than size-at-maturity. As biomass estimates (and 95% CLs) are well above the Target level, it is unlikely that the fishery is operating at maximum acceptable level of depletion, i.e. spawning biomass < Target level but > Threshold level (B_{MSY}).

C3 (High Depletion): **Remote L1** – High average size fished, low catches, relatively high biomass, and considerable rest periods imposed a by a rotational fishing strategy mean that there is only a remote likelihood that the level of depletion is unacceptable and is affecting recruitment levels of stock.

C4 (Major Depletion): **NA** – Not plausible based on current evidence.

9.4.3.2 Current Risk Status

Based on the information and analyses available, the current risk level for Pilbara redfish was estimated to be LOW (C1 × L4). Therefore the overall Weight of Evidence assessment indicates the status of the Pilbara redfish stock is adequate and that current management settings are maintaining risk at low levels.

9.4.3.3 Future Monitoring

Information on size-at-maturity for the Pilbara redfish would be desirable from the point of view of understanding more of the biology. However, the plasticity of morphological metrics in sea cucumbers reduces the efficacy of minimum legal lengths in protecting the breeding stock.

9.4.1 Redfish (Shark Bay)

9.4.1.1 Weight of Evidence Risk Assessment

Category	Lines of evidence (Consequence / Status)
Catch (Section 9.3.2)	Catches from this stock in 2020 - 2022 constituted the first 3 years of the fishery. There is not sufficient data to detect if there is unacceptable stock depletion.
Catch distribution (Section 9.3.3)	Catch distribution data from this stock in 2020-2022 constituted the first 3 years of the fishery. There is not sufficient data to detect changes in catch distribution that would indicate stock depletion.
Catch rates (Section 9.3.4)	Catch rates in the Shark Bay redfish fishery increased between 2020 and 2022. There are no indications from catch rates of unacceptable stock depletion during the history of the fishery.
Trends in size structure (Section 0)	Average weight of redfish harvested in the WASCF in the period 2007 to 2016 was > 3 times greater than the estimated size-at-maturity. This provides protection of the spawning stock, and fishing mortality is likely to be low. There are no indications from average size fished of unacceptable stock depletion during the history of the fishery.
Vulnerability (PSA) (Section 9.3.6)	Redfish assumed to have a relatively short life span (maximum age around 12 years), and mature at 2 years of age. With a productivity score of 1.5 and susceptibility score of 1.88, the overall derived PSA score is 2.4 (MSC score > 80). This level of vulnerability indicates there is a relatively low chance of overfishing occurring at current levels of effort. However the significant risk of sea cucumber stocks to localised depletion cannot be discounted, despite this low vulnerability score.
Fishery Independent Surveys	The median biomass estimate for redfish in Shark Bay in 2021 was 82 t (95% CL range: 47 to 130 t).
Biomass dynamics model (Section 9.3.8)	The biomass dynamics model estimated that it was highly unlikely that biomass was reduced below 0.8 B0 in the 3-year history of the fishery.

Shark Bay redfish risk matrix					
Consequence (stock depletion) Level	Likelihood				
	L1 Remote (<5%)	L2 Unlikely (5-<20%)	L3 Possible (20-<50%)	L4 Likely (≥50%)	**Risk Score**
C1 Minor				LOW	4
C2 Moderate		X			4
C3 High	X				3
C4 Major	NA				-

C1 (Minor Depletion): **Likely L4** – The primary performance indicator for this stock (biomass) was above the target reference level in 2021 with >95% confidence limit and it has been harvested between 2018 and 2022. So it is likely (L4) that redfish in Shark Bay have experienced a minor (C1) depletion.

C2 (Moderate Depletion): **Unlikely L2 –** The primary performance indicator for this stock (biomass) was above the target reference level in 2021 with >95% confidence limit. With only 3 years of fishing, and harvest not reaching MSY in any of those year, it is unlikely (L2) that redfish in Shark Bay have experienced a moderate (C2) depletion.

C3 (High Depletion): **Remote L1** – The primary performance indicator for this stock (biomass) was above the target reference level in 2021 with >95% confidence limit. Based on all lines of evidence, it is a remote (L2) chance that redfish in Shark Bay have experienced a moderate (C2) depletion.

C4 (Major Depletion): **NA** – Not plausible based on current evidence.

9.4.1.2 Current Risk Status

Based on the information and analyses available, the current risk level for Shark Bay redfish was estimated to be LOW (C1 × L4). The LOW risk (see Appendix 2) indicates the status of the Shark Bay redfish stock is adequate and that current management settings are maintaining risk at acceptable levels.

9.4.1.3 Future Monitoring

Shark Bay redfish stocks have only recently been discovered. More years of fishing and fishery independent surveys are needed to gauge the true extent of the stock.

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Appendix 1

Justification for Harvest Strategy Reference Levels

The harvest strategy for the sea cucumber resource has been based around the behaviour of various metrics during a particular period of the fishery, defined here as the reference period or a reference point. This can be a range of years, or a single year, depending on the nature of the indicator (Table A1.1).

Various fishery-dependent and fishery-independent information and monitoring data were used to establish performance indicators and reference levels for the assessment of the sea cucumber resource. For a detailed description of the overall harvest strategy, see DPIRD (2018). However, note that performance indicators and reference levels for the sea cucumber resource have been updated since the harvest strategy was published.

Sandfish (*Holothuria scabra*) and Redfish (*Actinopyga echinites*)

The principal performance indicator for the sandfish and redfish stocks is a biomass index estimated from a biomass dynamics model based on the Schaefer production curve (Hilborn and Walters, 1992). The index accounts for spatial variability and changes in fishing efficiency over the history of the fishery (Table A1.1). Associated biomass-based (target, threshold and limit) reference points have been set based on the MSC standard, which defines the "Threshold" reference point of $0.4B_0$ as equivalent to B_{MSY} (Table A1.1).

The principal performance indicator for these resources is derived from a model that incorporates catch data from the beginning of each fishery, catch rate data from the inception of the daily logbook program, and one or more fishery-independent survey biomass estimates. The performance indicator is compared annually against reference levels that been set using the estimate of unfished biomass (B_0) at the beginning of each fishery. Reference levels defined as: Target (50% B_0), threshold (40% B_0) and limit (30% B_0) (Table A1.1). These levels are consistent with current internationally accepted benchmarks (Mace 1994; Caddy and Mahon 1995; Gabriel and Mace 1999; Wise et al. 2007).

Comparison of old and new reference levels for Pilbara sea cucumber stocks

In the period 2017 to 2021, significant new information became available to improve the harvest strategy and assessment for the main species under exploitation. This new information included additional Fishery Independent Surveys (FIS) of Pilbara sea cucumber stocks, both sandfish and redfish, and a redefinition of reference levels for the Pilbara resource. A comparison of the old and new reference levels is provided in Figure A1.1.

Table A1.1. Performance indicators (PIs) and, where applicable, reference periods used for setting reference levels for each PI in the Sea Cucumber Resource. These have been updated since the publication of the Harvest strategy (DPIRD, 2018)

Species (Area)	Performance indicator (PI)	Reference Period	Justification
Sandfish (Kimberley)	Biomass	1995	Unfished biomass (B0) estimated for 1995. Reference levels defined as: Target (50% B0), threshold (40% B0) and limit (30% B0) in relation to this
Sandfish (Pilbara)	Biomass	1996	Unfished biomass (B_0) estimated for 1996. Reference levels defined as: Target (50% B0), threshold (40% B0) and limit (30% B0) in relation to this.
Redfish (Pilbara)	Biomass	2006	Unfished biomass (B_0) estimated for 2006. Reference levels defined as: Target (50% B0), threshold (40% B0) and limit (30% B0) in relation to this
Redfish (Shark Bay)	Biomass	2018	Unfished biomass (B_0) estimated for 2018. Reference levels defined as: Target (50% B0), threshold (40% B0) and limit (30% B0) in relation to this

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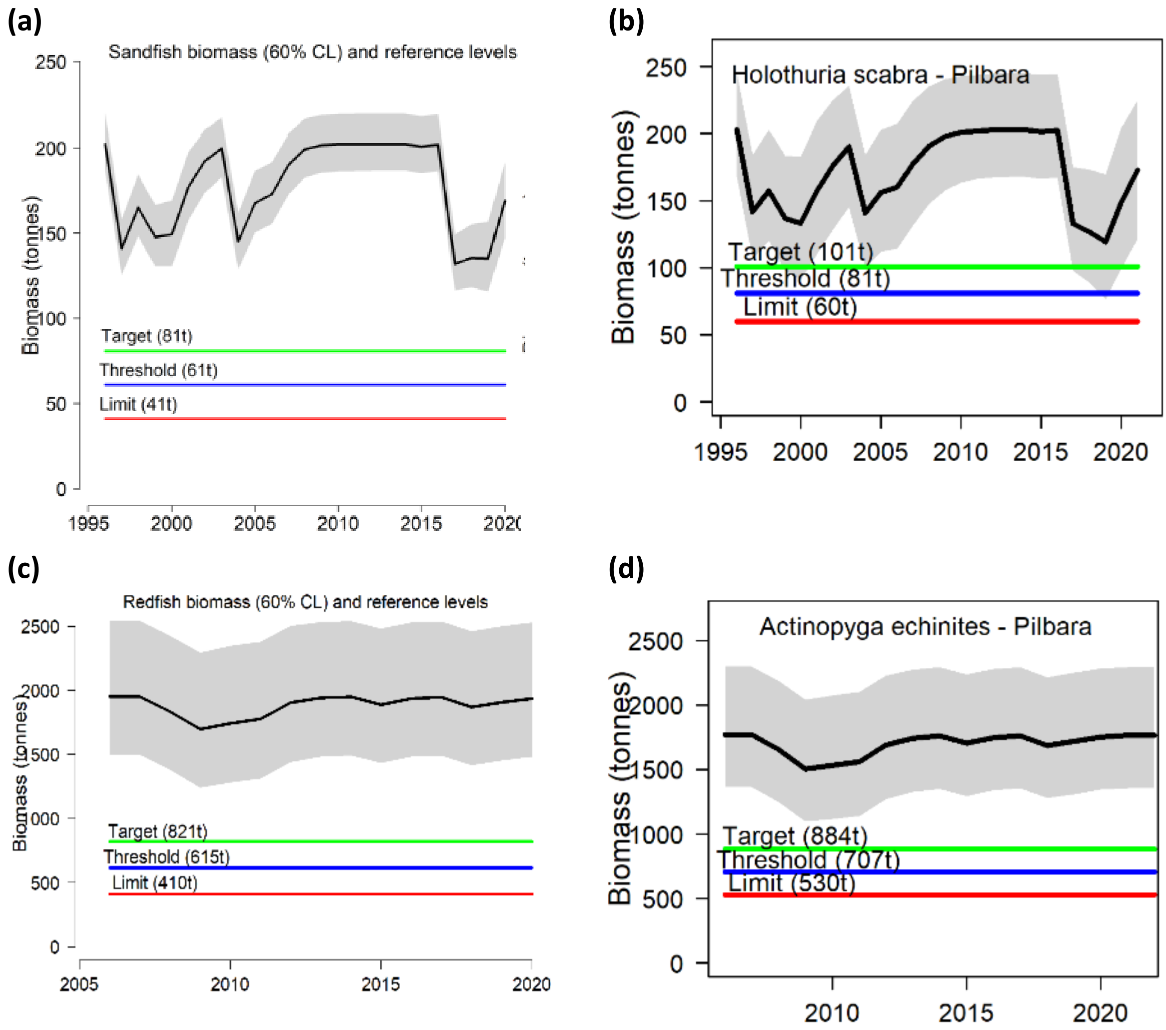

Figure A1.1. Comparison of old (a,c) and new reference levels (b,d) for the Pilbara sea cucumber resources.

Appendix 2

Consequence, Likelihood and Risk Levels (based on AS 4360 / ISO 31000) modified from Fletcher et al. (2011) and Fletcher (2015).

CONSEQUENCE LEVELS

As defined for major target species

1. Minor – Fishing impacts either not detectable against background variability for this population; or if detectable, minimal impact on population size and none on dynamics

   Spawning biomass > Target level (B_{MEY})

2. Moderate – Fishery operating at maximum acceptable level of depletion

   Spawning biomass < Target level (B_{MEY}) but > Threshold level (B_{MSY})

3. High – Level of depletion unacceptable but still not affecting recruitment levels of stock

   Spawning biomass < Threshold level (B_{MSY}) but >Limit level (B_{REC})

4. Major – Level of depletion is already affecting (or will definitely affect) future recruitment potential/ levels of the stock

   Spawning biomass < Limit level (B_{REC})

LIKELIHOOD LEVELS

These are defined as the likelihood of a particular consequence level actually occurring within the assessment period (5 years was used)

1. Remote – The consequence has never been heard of in these circumstances, but it is not impossible within the time frame (Probability of <5%)
2. Unlikely – The consequence is not expected to occur in the timeframe but it has been known to occur elsewhere under special circumstances (Probability of 5 - <20%)
3. Possible – Evidence to suggest this consequence level is possible and may occur in some circumstances within the timeframe. (Probability of 20 - <50%)
4. Likely – A particular consequence level is expected to occur in the timeframe (Probability of >50%)

Consequence × Likelihood Risk Matrix		Likelihood			
		Remote (1)	Unlikely (2)	Possible (3)	Likely (4)
Consequence	Minor (1)	Negligible	Negligible	Low	Low
	Moderate (2)	Negligible	Low	Medium	Medium
	High (3)	Low	Medium	High	High
	Major (4)	Low	Medium	Severe	Severe

Risk Levels	Description	Likely Reporting & Monitoring Requirements	Likely Management Action
1 Negligible	Acceptable; Not an issue	Brief justification – no monitoring	Nil
2 Low	Acceptable; No specific control measures needed	Full justification needed – periodic monitoring	None specific
3 Medium	Acceptable; With current risk control measures in place (no new management required)	Full Performance Report – regular monitoring	Specific management and/or monitoring required
4 High	Not desirable; Continue strong management actions OR new / further risk control measures to be introduced in the near future	Full Performance Report – regular monitoring	Increased management activities needed
5 Severe	Unacceptable; If not already introduced, major changes required to management in immediate future	Recovery strategy and detailed monitoring	Increased management activities needed urgently

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Appendix 3

Productivity Susceptibility Analysis (PSA) Scoring Tables

Productivity attribute	**High productivity** **Low risk** **Score = 1**	**Medium productivity** **Medium risk** **Score = 2**	**Low productivity** **High risk** **Score = 3)**
Average maximum age	<10 years	10-25 years	>25 years
Average age at maturity	<5 years	5-15 years	>15 years
Average maximum size (not to be used when scoring invertebrates)	<1000 mm	1000-3000 mm	>3000 mm
Average size at maturity (not to be used when scoring invertebrates)	<400 mm	400-2000 mm	>2000 mm
Reproductive strategy	Broadcast spawner	Demersal egg layer	Live bearer
Fecundity	>20,000 eggs per year	100-20,000 eggs per year	<100 eggs per year
Trophic level	<2.75	2.75-3.25	>3.25
Density dependence (only to be used when scoring invertebrates)	Compensatory dynamics at low population size demonstrated or likely	No depensatory or compensatory dynamics demonstrated or likely	Depensatory dynamics at low population sizes (Allele effects) demonstrated or likely

Susceptibility attribute	**Low susceptibility** **Low risk** **Score = 1**	**Medium susceptibility** **Medium risk** **Score = 2**	**High susceptibility** **High risk** **Score = 3)**
Areal overlap (availability) i.e. overlap of fishing effort with stock distribution	<10% overlap	10-30% overlap	>30% overlap
Encounterability i.e. the position of the species / stock within the water column / habitat relative to the position of the fishing gear	Low encounterability / overlap with fishing gear	Medium overlap with fishing gear	High encounterability / overlap with fishing gear (Default score for target species in a fishery)
Selectivity of gear type i.e. potential of gear to retain species	a) Individual < size at maturity are rarely caught	a) Individual < size at maturity are regularly caught	a) Individual < size at maturity are frequently caught
	b) Individual < size can escape or avoid gear	b) Individual < half the size can escape or avoid gear	b) Individual < half the size are retained by gear
Post-capture mortality i.e. the chance that, if captures, a species would be released and that it would be in a	Evidence of majority released post-capture and survival	Evidence of some released post-capture and survival	Retained species or majority dead when released

condition permitting subsequent survival			

Appendix 4

Western Australian Sea cucumber Daily Catch and Effort Log Book
HOW TO FILL IN YOUR DAILY CATCH AND EFFORT LOG SHEETS

The form is divided into two main sections. The top is for recording information from individual effort units (e.g. diving, wading or snorkeling) within a day's fishing for Sea cucumber, the bottom is for the information at the end of a day's catch. All relevant sections must be completed. Species codes for Sea cucumber are on the flip side of every log book page. If any aspects of the forms are unclear please contact the catch and effort returns officer (Dave Murphy 08 9203 0111).

Administration details Record all details on a minimum of one record per month. Record date and LFB for every days fishing.

Vessel name The name of the vessel from which you fished. If the name of your vessel changed during the month please make a comment on the bottom of the form.

Date The day to which the catch return relates, e.g. 12/10/2006.

Anchorage Location where vessel was on anchor for the previous night(s).

No. days fished Only record when filling out the unload record (see below).

Fishing Boat Licence (FBL) this 4 digit number is found on the licence issued by the Department of Fisheries if you operate a Licenced Fishing Boat. Example: FBL1234 please enter 1234. A return is required even if you do not have a vessel attached to your FBL - in this case the Boat Rego and Boat Name field is left blank.

Boat registration Also referred to as Licenced Fishing Boat or LFB. Enter the registration number of your vessel. If your vessel has licenced dinghies, as part of its fishing unit, **and** these dinghies always fish alongside the main vessel, please record all information on one catch return for the main vessel. Example: A96, A96A, A96B record all catch as A96 on one return.

Sea cucumber (MFL) When the Sea cucumber fishery becomes an official managed fishery, each operator will be required to indicate their Managed Fishery Licence (MFL). Presently this field is inactive.

Crew numbers Record total number involved in fishing for Sea cucumber, including the skipper.

Unload Port or Anchorage Location where vessel unloads catch.

Unload Record Only fill out this information on the day in which the vessel is unloaded. In days fished record the total number of days fished, and the total kg, which is the total catch being unloaded.

Catch and Effort For each unit of effort (up to 6 maximum in one day), circle whether it is a Dive (D), Wade (W), or Snorkel (S).

GPS Latitude Enter the start GPS latitude of each dive/wade/ snorkel. Decimal points for minutes are optional, but information down to individual minutes is required.

GPS Longitude Enter the start GPS longitude of each dive/wade/ snorkel. Decimal points for minutes are optional, but information down to individual minutes is required.

Start time Enter the start time of each dive/wade/ snorkel (e.g. 0800, 1450).

Number of Ds/Ws/Sn Enter the number of people that are diving, wading, or snorkeling for Sea cucumber.

Depth (m) Enter the depth (in metres) of each dive.

Duration of D/W/S Enter the time spent fishing for Sea cucumber (in minutes).

Distance waded Enter the average distance waded by individual harvesters. E.g. If 2 people are wading, the first wades approx 500 m, and the other 200 m, the average distance waded is 350 m.

Catch Select the main species caught (S – Sandfish, WT – White teatfish, BT – Black teatfish, R – Deepwater Redfish) and record the approximate number caught.

Other species catch Select the other species (of Sea cucumber) caught and record the approximate Number caught for each species after each dive/wade/snorkel. Species codes are found on the log sheet.

Daily weight estimates (kg) Enter the measured weight of the day's catch (after processing) for each of the main species.

Daily weight estimates (other species) Enter the measured weight (kg) of the day's catch (after processing) for each of the other species caught. If more than 3 different species have been caught, enter the information in the Comments section.

Processing Record processing details for boiling time (in minutes) and circle the processing method, e.g. GB for gutted and boiled, WW for whole wet weight. Specify if processing method differs from common types.

Protected species interactions The implementation of the *Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)* means that fishers need to record interactions with all listed marine and migratory species and threatened species in Commonwealth waters (whales, dolphins, dugongs, sea turtles, seals, pipefishes, seasnakes and many species of seabird – see website http://www.deh.gov.au). Consequently, we have included a special section to record interactions with protected species. For example, if you ran over or bumped a sea turtle with a dory, circle Yes to the first question (i.e. did you have an interaction?), and if it swam away alive, circle Yes to the second question (i.e. was the animal released?). An officer from the Department of Fisheries will contact you if any further details are required regarding the interaction.

Western Australian Sea cucumber Daily Catch and Effort Log Sheet

Vessel Name	Daze Off	Fishing Boat License (FBL)	5423	**UNLOAD RECORD** (record only when unloading vessel)				OFFICE USE
Date (dd/mm/yyyy)	12 / 10 / 2007	Boat Registration (LFB)	F101	Unload Port	Darwin	Weight (kg)	4010.5	
Anchorage	Admiralty Gulf	Sea Cucumber (MFL) (if known)		Master Name	James Brown			
No. days fished		Crew numbers (inc. master)	5	Crew names (specify)	John Strickland, Matt Dodge, Bill Letter, Rod Budge			

EFFORT

Dive/Wade/Snorkel (please circle)	1			2			3			4			5			6		
	(D)	W	S	D	(W)	S	(D)	W	S	D	W	S	D	W	S	D	W	S
GPS **Latitude** (eg 13°47')	13° 47. 86			13° 48. 00			13° 47. 9											
Start **Longitude** (eg 127°30')	128' 30. 20			128' 29. 5			128' 30. 8											
Start Time (eg 1350)	0800			1100			1400											
Number of Divers/Waders	3			3			3											
Depth (m)	5			—			7											
Duration of D/W/S (mins)	150			90			180											
Distance waded (m)				900														

CATCH

Main species (circle type)	(S)	WT	BT	R	S	WT	BT	(R)	(S)	WT	(BT)	R	S	WT	BT	R	S	WT	BT	R	S	WT	BT	R
Number caught (approx.)	600							200	200		10													
Other species (write down)									CV															
Number caught (approx.)									100															

DAILY WEIGHT ESTIMATES	S	WT	BT	R	OTHER SPECIES*
Estimated weight (kg)	350		10		30

PROCESSING			
Boiling time (mins)	20		
Condition: (please circle)	(GB)	WW	Other (specify) Curryfish

PROTECTED SPECIES INTERACTION (please circle)		
Have you had an interaction with a protected species?	(YES)	NO
If yes, was the animal released alive?	(YES)	NO

COMMENTS (Include general and species interaction)

Dory 4 (Sticko) struck a green turtle but it swam away okay.
Good fishing day.
All Blackteat were salted only (no boiling).

I certify that the information on this form is correct. (Master, authorisation holder or agent)	Signature: James Brown
	Date Signed: 12/10/2007

* If multiple other species, separate daily wts.

Note: TEAR OUT and RETURN the ORIGINAL and keep the DUPLICATE in the book for your personal use. Please submit returns to Fisheries Research, PO Box 20, North Beach, WA 6920.