4-2022

South-West Estuarine and Nearshore Finfish Resource Part 1: Sea Mullet and Yellowfin Whiting

Rodney Duffy Dr.
Department of Primary Industries and Regional Development, Western Australia,
rodney.duffy@dpird.wa.gov.au

David Harris
Department of Primary Industries and Regional Development, Western Australia,
david.harris@dpird.wa.gov.au

Emily Fisher
Department of Primary Industries and Regional Development, Western Australia,
Emily.Fisher@dpird.wa.gov.au

Kim Smith
Department of Primary Industries and Regional Development, Western Australia,
kim.smith@dpird.wa.gov.au

Danielle Johnston
Department of Primary Industries and Regional Development, Western Australia,
danielle.johnston@dpird.wa.gov.au

See next page for additional authors

Recommended Citation

Duffy, R., Harris, D., Fisher, E., Smith, K., Johnston, D., Denham, A., Hesp, S.A., Hodgson, B., Quinn, A. and Newman, M. 2022. South-West Estuarine and Nearshore Finfish Resource Part 1: Sea Mullet and Yellowfin Whiting. Fisheries Research Report No. 322 Department of Primary Industries and Regional Development, Western Australia. 142pp.

Authors
Rodney Duffy Dr., David Harris, Emily Fisher, Kim Smith, Danielle Johnston, Ainslie Denham, Alex Hesp, Blaine Hodgson, Amber Quinn, and Marcus Newman

Department of
Primary Industries and
Regional Development
GOVERNMENT OF
WESTERN AUSTRALIA

We're working for Western Australia.

Fisheries Research Report No. 322

Resource Assessment Report

South-West Estuarine and Nearshore Finfish Resource

Part 1: Sea Mullet and Yellowfin Whiting

Duffy, R., Harris, D., Fisher, E., Smith, K., Johnston, D., Denham, A., Hesp, S.A., Hodgson, B., Quinn, A. and Newman, M.

April 2022

Correct citation:

Duffy, R., Harris, D., Fisher, E., Smith, K., Johnston, D., Denham, A., Hesp, S.A., Hodgson, B., Quinn, A. and Newman, M. 2022. South-West Estuarine and Nearshore Finfish Resource Part 1: Sea Mullet and Yellowfin Whiting. Fisheries Research Report No. 322 Department of Primary Industries and Regional Development, Western Australia. 142pp.

Enquiries:

WA Fisheries and Marine Research Laboratories,
PO Box 20,
North Beach, WA 6920

Tel: +61 8 9203 0111
Email: library@fish.wa.gov.au
Website: fish.wa.gov.au

A complete list of Fisheries Research Reports is available online at **fish.wa.gov.au**

Important disclaimer

Department of Primary Industries and Regional Development
Gordon Stephenson House
140 William Street
PERTH WA 6000
Telephone: (08) 6551 4444
Website: dpird.wa.gov.au
ABN: 18 951 343 745

ISSN: 1035-4549 (Print) ISBN: 978-1-921258-99-2 (Print)

ISSN: 2202-5758 (Online) ISBN: 978-1-921845-00-0 (Online)

Table of Contents

Executive Summary

Nearshore marine and estuarine resources of south-west Australia have been sustainably harvested by Aboriginal people for thousands of years. We acknowledge that we have yet to acquire detailed information on the traditional fishing practices of Aboriginal people in Western Australia so are currently unable to include an adequate description of historical and cultural fishing practices in this report.

More recently, finfish have been commercially targeted by net fishers in estuarine and nearshore waters of south-west Western Australia (WA) since the early years of colonisation. Annual catches peaked in the early 1990s but have since declined, mainly due to a substantial reduction in fishing effort resulting from a number of Voluntary Fishery Adjustment Schemes (VFAS) and a declining demand for bait used in the western rock lobster fishery. Currently, several small-scale commercial fisheries annually land a total of 300 to 700 t, mostly using haul nets, beach seines and gillnets.

Four commercial fisheries target finfish in nearshore waters in the West Coast Bioregion: West Coast Beach Bait Managed Fishery, Cockburn Sound (Fish Net) Managed Fishery, South West Coast Salmon Managed Fishery and the South West Beach Seine Fishery. Additionally, the West Coast Estuarine Managed Fishery (WCEMF) captures significant quantities of nearshore finfish.

In the South Coast Bioregion, the South Coast Salmon Managed Fishery targets WA salmon while the South Coast Estuarine Managed Fishery captures various nearshore finfish species.

The main commercial fisheries targeting nearshore finfish in the Gascoyne Coast Bioregion are the Shark Bay Beach Seine and Mesh Net Managed Fishery (SBBSMNMF) and the Exmouth Gulf Beach Seine Managed Fishery.

Two main commercial fisheries target estuarine finfish species: the WCEMF and the South Coast Estuarine Managed Fishery.

Recreational fishing for nearshore finfish is undertaken in coastal waters and the lower parts of estuaries by shore- and boat-based fishers using rod and line, while minor quantities are also harvested by netting and spear fishing. The sector has relatively high participation rates, with a corresponding high socio-economic value to WA.

The commercial and recreational fisheries targeting this resource are managed using a range of input and output controls. Commercial effort is typically constrained by a cap on the number of licences/vessels operating in each fishery (limited entry) and restrictions on fishing gear (net length and mesh sizes), while recreational fishing effort is managed through such measures as gear controls (e.g., number of lines per fisher, length of nets) and daily bag and boat limits.

The resource comprises more than 15 species that mostly inhabit waters up to 20 m in depth. Based on the inherent vulnerability and risk to the sustainability of the key species within this suite, the following indicator species have been identified:

- Australian herring (*Arripis georgianus*)

- West Australian salmon (*Arripis truttaceus*)
- sea mullet (*Mugil cephalus*)
- tailor (*Pomatomus saltatrix*)
- southern garfish (*Hyporhamphus melanochir*)
- whitebait (*Hyperlophus vittatus*)
- ‘whiting’ (*Sillago* spp.; *Sillaginodes punctata*)
- black bream (*Acanthopagrus butcheri*)
- estuarine cobbler (*Cnidoglanis macrocephalus*)
- Perth herring (*Nematalosa vlaminghi*)

In line with the current harvest strategy for the resource, this report focuses on one of the primary target species for which biomass-based stock assessments are periodically undertaken - sea mullet. Although not considered a primary species for the purpose of this harvest strategy, the report also includes a recent stock assessment for yellowfin whiting (*Sillago schomburgkii*) due to concerns regarding substantial increases in catch relative to historic levels. Separate harvest strategies are being developed for estuarine and nearshore finfish in the Gascoyne Coast Bioregion, and also for Australian herring (*Arripis georgianus*) and West Australian salmon (*Arripis truttaceus*).

Stocks of several estuarine and nearshore finfish species in south-west WA, including sea mullet, extend to the coastal waters off the South Coast Bioregion and northwards to Shark Bay in the Gascoyne Coast Bioregion. The main breeding stock for sea mullet occurs primarily in Shark Bay (SBBSMNMF) and juveniles migrate south and recruit into the Peel-Harvey Estuary (WCEMF). Consequently, this Resource Assessment Report (RAR) focuses on the two main commercial fisheries that target sea mullet and yellowfin whiting stocks relevant to south-west WA: the WCEMF and SBBSMNMF.

The annual catch of sea mullet in 2020 was 87 t for the WCEMF and 55 t for the SBBSMNF, compared with mean annual catches of 93 (± 8.7) t and 46 (± 8.5) t, respectively, between 2015-19. The annual catch of yellowfin whiting in 2020 was 17 t for the WCEMF and 50 t for the SBBSMNF compared with mean catches of 25 (± 8.3) t and 57 (± 20.1) t respectively between 2015-19.

Harvest Strategy, Monitoring and Assessment

The status of primary target species of the estuarine and nearshore finfish resource in south-west WA is assessed periodically using a risk-based weight-of-evidence approach of all available data. If an increase in risk is identified for other species, e.g. increased catches of yellowfin whiting in 2013 & 2014, additional analyses are undertaken. The current harvest strategy for sea mullet is primarily based on estimates of B_{rel}, the ratio of current biomass (B) to unfished biomass (B_0), (sea mullet), relative to B_{MSY}, i.e. the estimated biomass expected to achieve maximum sustainable yield, MSY, or a suitable proxy reference point for B_{MSY}, as outlined in the Department’s Harvest Strategy Policy.

Status of stock(s)

Sea mullet

Results from a Schaefer biomass dynamic model was applied to commercial catches and catch rates indicate that the sea mullet stock has largely been maintained above the level of B_{MSY}. Based on adjusted catch rate data from Shark Bay, the relative biomass (B/B_0) of sea mullet in 2020 was estimated as 0.90 (95% CLs 0.89-0.91) and the B/B_{MSY} estimate of 1.80 (95% CLs 1.50-2.11) indicate the stock is likely to be well above the threshold level. Estimates of F in 2020 were well below F_{MSY}, indicating that overfishing of the stock is unlikely.

The current stock level is considered to be acceptable, and the current level of fishing mortality is unlikely to deplete the stock to a level at which recruitment could be impaired. On the basis of the evidence provided above, the sea mullet stock in south-west WA is classified as **Sustainable**.

Based on all available lines of evidence, the current risk level for sea mullet in south-west WA is estimated to be **Medium**, with current management measures considered to be maintaining the stock at an acceptable level.

Yellowfin whiting

Most lines of evidence, including the age structure, and estimates of F and spawner potential ratio (SPR), are consistent with the stock level of yellowfin whiting likely to be at an acceptable level, being close to the maximum level of acceptable depletion. The point estimate for relative stock biomass in 2019 was high at 0.87 of the unfished level (95% CLs 0.78-0.95). The above evidence indicates that the biomass of this stock is unlikely to be depleted and that recruitment is unlikely to be impaired. Furthermore, the above evidence indicates that the current level of fishing mortality is unlikely to cause the stock to become recruitment impaired. On the basis of this evidence, the yellowfin whiting stock in south-west WA is classified as **Sustainable**.

Based on all available lines of evidence, the current risk level for yellowfin whiting in south-west WA is estimated to be **Medium**, with current management measures considered to be maintaining the stock at an acceptable level.

List of Abbreviations

ADMB	AD Model Builder
CAES	Commercial Catch and Effort Statistics
DOF	Department of Fisheries (Western Australia)
DPIRD	Department of Primary Industries and Regional Development (Western Australia) (formerly Department of Fisheries (DoF))
EBFM	Ecosystem-Based Fisheries Management
ENSO	El Niño Southern Oscillation
ESD	Ecologically Sustainable Development
EPBC	Environment Protection and Biodiversity Conservation (Act)
ETP	Endangered, Threatened and Protected
FRMA	Fish Resources Management Act
GCB	Gascoyne Coast Bioregion
GSI	Gonadosomatic Index
HCR	Harvest Control Rules
IMCRA	Integrated Marine and Coastal Regionalisation for Australia
LML	Legal Minimum Length
MSC	Marine Stewardship Council
MSY	Maximum Sustainable Yield
PSA	Productivity Susceptibility Analysis
RAP	Research Angler Program
RAR	Resource Assessment Report
RFBL	Recreational Fishing from Boat Licence
RIP	Recruitment Index Project
SAFS	Status of Australian Fish Stocks
SBBSMNMF	Shark Bay Beach Seine and Mesh Net Managed Fishery
SCB	South Coast Bioregion
SPR	Spawning Potential Ratio
SWBSF	South West Beach Seine Fishery
TL	Total Length
VFAS	Voluntary Fishery Adjustment Schemes
WA	Western Australia
WCB	West Coast Bioregion

WCEMF	West Coast Estuarine Managed Fishery
WOE	Weight of Evidence
YFW	Yellowfin Whiting

1 Scope

This document provides a cumulative description and assessment of the south-west estuarine and nearshore finfish resource and all of the fishing activities (i.e., fisheries / fishing sectors) affecting this resource in Western Australia (WA). The overall resource comprises around 15 targeted species of temperate fish that inhabit the nearshore waters and estuaries in the West Coast and South Coast Bioregions and, in some cases, extend into the southern part of the Gascoyne Coast Bioregion.

This report focuses on sea mullet (*Mugil cephalus*), in addition, it also includes a recent assessment of yellowfin whiting (*Sillago schomburgkii*) stocks. These species are primarily captured in estuarine and nearshore waters by commercial netting (gill/haul/seine) fisheries, and recreational line fishing by shore- and boat-based fishers.

The report contains information relevant to assist the assessment of the resource against the Marine Stewardship Council (MSC) Principles and Criteria for Sustainable Fishing, Environment Protection and Biodiversity Conservation (EPBC) Act export approval requirements (for Western Australian salmon), and for other reporting requirements, e.g., Status of Australian Fish Stocks (SAFS).

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's Risk Register, 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 planning annual 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 (DoF 2015) has been designed to ensure that the harvest strategies cover the broader scope EBFM and thus considers 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).

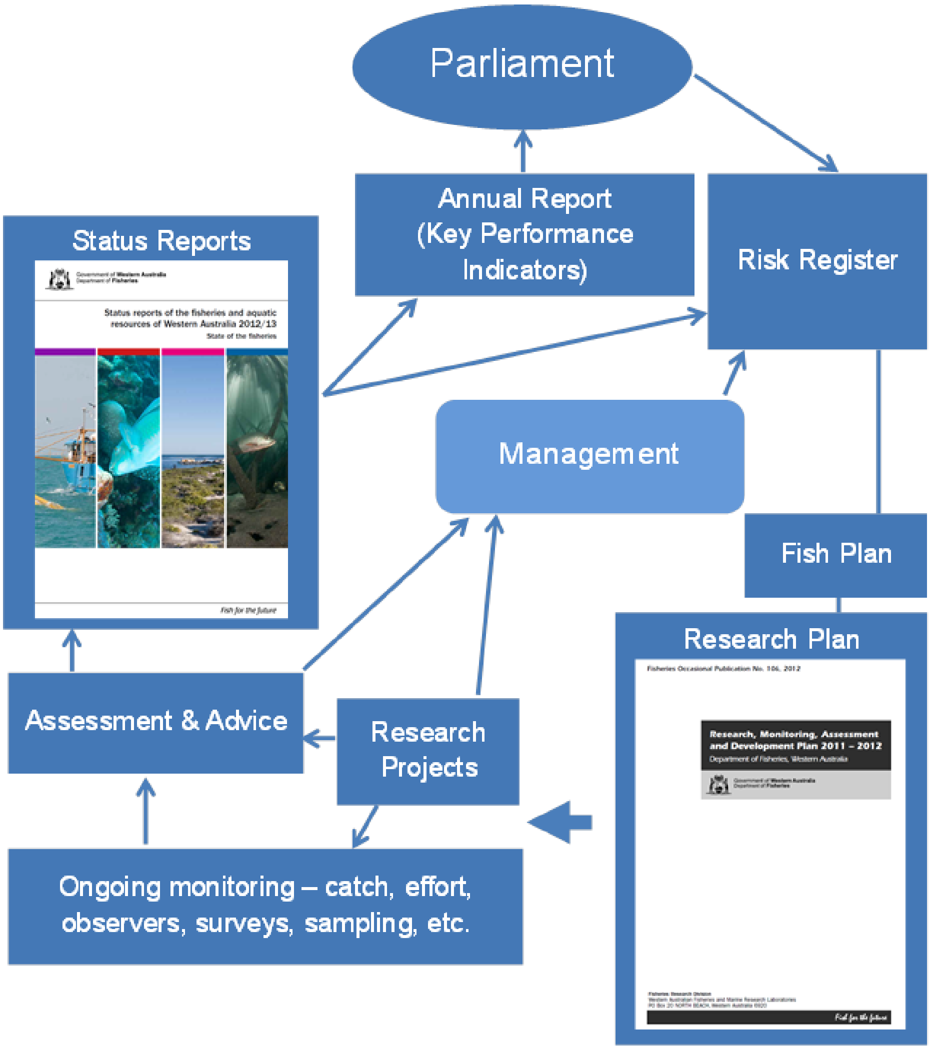


Figure 2.1. An outline of the risk-based planning cycle used for determining Departmental priorities and activities

3 Aquatic Environment

The marine environment of south-west WA is predominantly a temperate zone, with most rainfall occurring during the winter months. This region is heavily influenced by

the Leeuwin Current that transports warm tropical water southward along the edge of the continental shelf. Coastal water temperatures range from 18° C to about 24° C in the West Coast Bioregion (WCB; Kalbarri to Augusta), and between approximately 15° C and 21° C in the South Coast Bioregion (SCB; Augusta to the South Australian border). The Integrated Marine and Coastal Regionalisation for Australia (IMCRA V 4.0) scheme divides the region into a number of meso-scale regions, which are depicted in Figure 3.1.

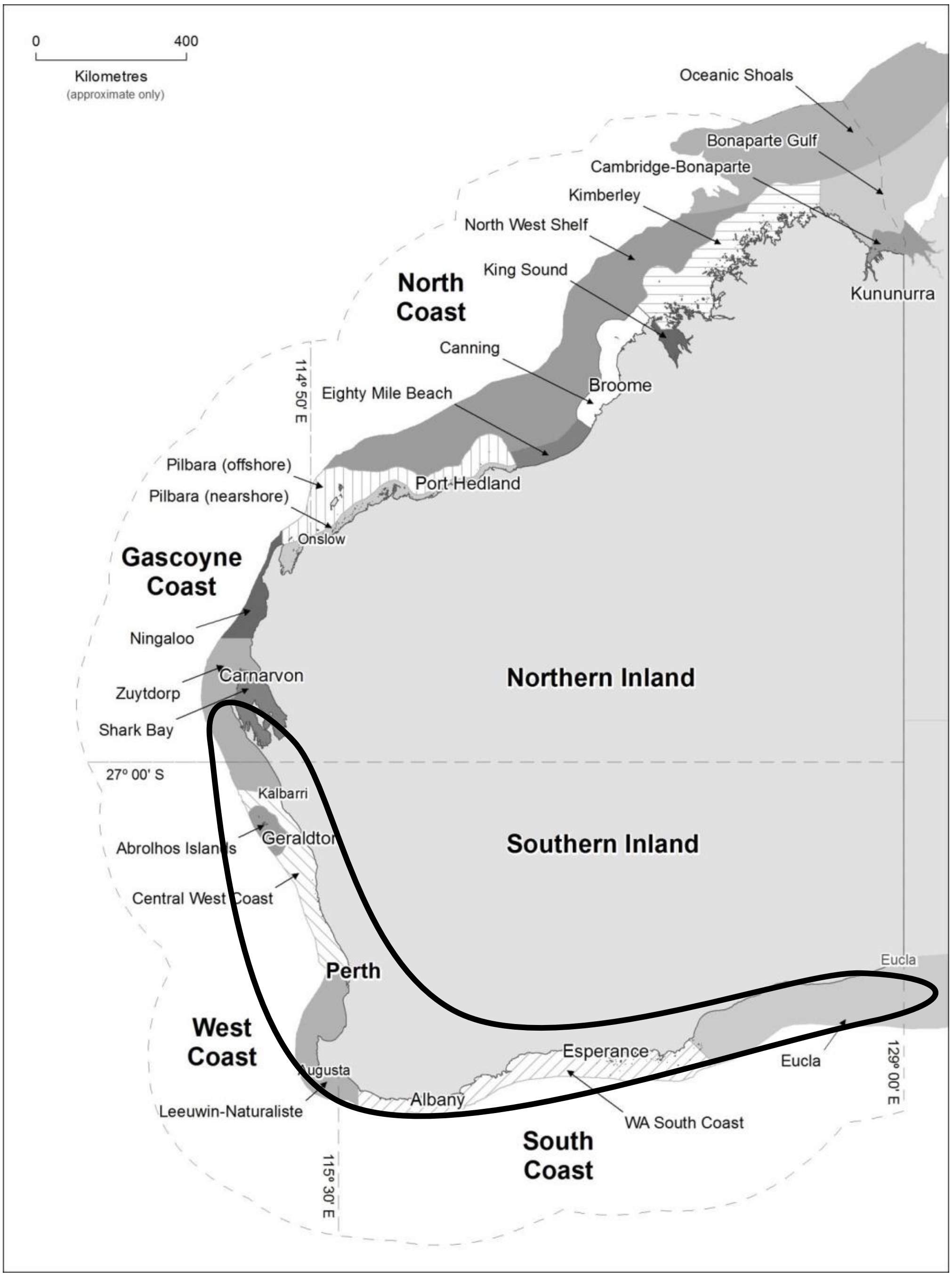


Figure 3.1. Locality of the south-west estuarine and nearshore finfish resource within WA.

The WCB is characterised by exposed sandy beaches and a limestone reef system that creates surface reef lines, often about 5 kilometres off the coast. The most significant impact of the clear, warm, low-nutrient waters of the Leeuwin Current is on the growth and distribution of temperate seagrasses. These form extensive meadows in protected coastal waters of the WCB, generally in depths of 20 m (but up to 30 m), and act as major nursery areas for many fish species. Shoreward of the Leeuwin Current, weaker counter-currents such as the Capes Current, which flows northward from Cape Leeuwin to Shark Bay, also influence the distribution of many of the coastal finfish species.

Within the WCB, there are two major marine embayments (Cockburn Sound and Geographe Bay) and four significant estuarine systems (the Swan-Canning, Peel-Harvey and Leschenault estuaries, and Hardy Inlet). All of these estuaries are permanently open to the sea and form an extension of the marine environment, except when freshwater run-off displaces the oceanic water for a short period in winter and spring. In the SCB, some estuaries in the west are fed by winter-flowing rivers and remain permanently open, whilst many others are closed by sandbars and only open seasonally after heavy winter rains. The number of rivers and estuaries decreases to the east as the coastline becomes more arid.

The shallow estuarine and nearshore waters of south-west WA support extensive stands of macroalgae and seagrasses, which play an important role in nutrient and carbon cycling. These plants support large populations of small invertebrate animals, which in turn form the basis of a food chain that supports a number of fish, other invertebrates, mammals and birds. The Peel-Harvey Estuary is considered an internationally significant habitat for waterbirds, and it has been listed as part of the larger Peel-Yalgorup Wetland System, as a Ramsar Wetland of International Importance.

South-west WA is predicted to be heavily influenced by the impacts of climate change (e.g., increasing sea temperatures and declines in rainfall). Estuaries within the West Coast Bioregion have also been identified as being at significant risk due to high nutrient runoff from surrounding catchments, which coupled with climate change has the potential to markedly affect fish and other communities. Fish mortality events have been periodically reported in Cockburn Sound and from within the Peel-Harvey and Swan-Canning estuaries.

4 Resource Description

4.1 South-West Estuarine and Nearshore Finfish Resource

The estuarine and nearshore finfish resource in south-west WA comprises more than 15 species that mostly inhabit waters up to 20 m in depth. These include species that occur exclusively in estuaries (e.g., estuary cobbler and black bream), with each estuary containing distinct breeding stocks. Others are primarily marine species that may spend a significant part of their life within estuarine waters (e.g., mullet and whiting). The stocks of many species extend over large areas, with individuals

undertaking significant west- and north-ward migrations to spawn and then relying on coastal currents to disperse eggs and larvae back to their nursery grounds.

4.2 Selection of Indicator Species for Resource

Since the adoption of the ESD policy (Fletcher 2002) by the Department in 2002, the process for monitoring and assessing WA finfish resources has involved allocating the species within each bioregion into one of five suites – Estuarine, Nearshore, Inshore Demersal, Offshore Demersal and Pelagic (DoF 2011). A risk-based approach is used to quantify the risks to sustainability of the stocks based on biological and other criteria to develop a risk matrix. From the list of species within a suite for a given bioregion, indicator species are identified based on their vulnerability to fishing, and other considerations such as whether they are target species in major fisheries, and their economic and social values (Lenanton et al. 2006).

The status of these indicator species is assumed to represent the status of the entire suite, and therefore the resource. This concept has also been applied to determine appropriate indicator species for various WA invertebrate resources. In practice, for nearshore and estuarine environments, this is unlikely to be true as the interaction between fisheries, methods, and the complex suite of species with different migratory and life stage related habitat use patterns, means that the status of one species is unlikely to reflect the status of another. Therefore, indicator species in the nearshore and estuarine environment may be better thought of as those species that are important to the fisheries operating in these environments; or those that are more susceptible to fishing due to inherent biological traits or environmental change.

Based on the inherent vulnerability and risk to the sustainability of the key species within the suite of nearshore and estuarine finfish in south-west WA, the following indicator species have been identified:

- Australian herring (*Arripis georgianus*)
- West Australian salmon (*Arripis truttaceus*)
- sea mullet (*Mugil cephalus*)
- tailor (*Pomatomus saltatrix*)
- southern garfish (*Hyporhamphus melanochir*)
- whitebait (*Hyperlophus vittatus*)
- ‘whiting’ (*Sillago* spp.; *Sillaginodes punctata*)
- black bream (*Acanthopagrus butcheri*)
- estuarine cobbler (*Cnidoglanis macrocephalus*)
- Perth herring (*Nematalosa vlaminghi*)

Due to a limit on the resources required to undertake stock assessments for all indicator species, assessment of the majority is based on annual risk assessments using available information on catches and the species’ inherent vulnerability to

fishing. In line with the current harvest strategy for the resource (see Section 7.2), this Resource Assessment Report is currently focused on one of the primary target species for which biomass-based stock assessments are undertaken periodically - sea mullet.

Although not considered a primary species for the purpose of the harvest strategy for this resource, the report also includes a recent stock assessment for yellowfin whiting (*Sillago schomburgkii*). This assessment was triggered by a significant increase in commercial catches in the Peel-Harvey Estuary in 2013 and 2014, suggesting that the risk to the stock may have increased. It is anticipated that future versions of this report will include biomass-based assessments of additional indicator species.

5 Species Description

5.1 Sea mullet (*Mugil cephalus*)

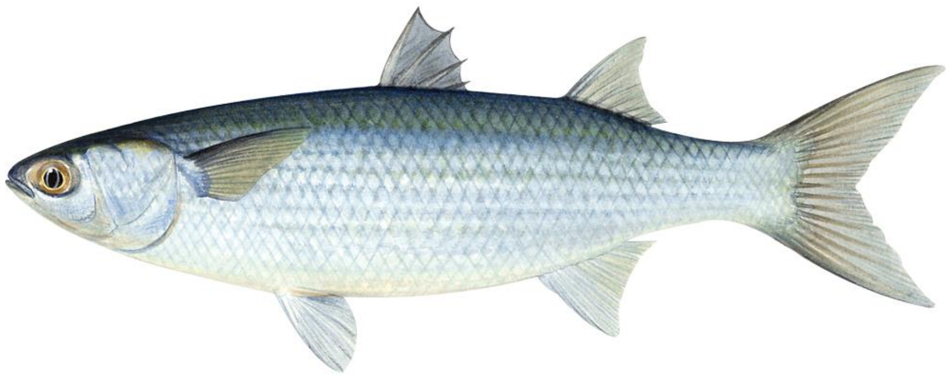


Figure 5.1. The sea mullet, *Mugil cephalus*. Illustration © R. Swainston (www.anima.net.au)

5.1.1 Taxonomy and Distribution

Sea mullet (*Mugil cephalus*; Figure 5.1) are members of the Family Mugilidae which contains at least 22 other species in Australian waters. Distinguishing features of sea mullet include a transparent fatty eyelid that covers most of the eye, an anal fin with three spines and eight (rarely nine) soft rays in adults, widely separated dorsal fins, an absence of dark spots at the base of the pectoral fin, and second dorsal and anal fins with scales restricted to the anterior and basal parts of the fins (Harrison and Senou 1999, Yearsley et al. 2001).

Sea mullet was formerly regarded as a single species with a global distribution, mostly occurring between the latitudes of ~ 42°N and 42°S (Thomson 1963, Rossi et al. 1998). However, recent genetic evidence indicates that 'sea mullet' is actually a complex of species across its global range, and potentially multiple species within Australia (Durand et al. 2012, Krück et al. 2013). It is likely the Western Australian stock is different from the Eastern Australian stock (Durand et al. 2012), particularly

given the geographic separation of the stocks. In Australia, sea mullet appears to be most abundant from approximately 25°S to 35°S.

5.1.2 Stock Structure

The stock structure of sea mullet within WA is yet to be confirmed. The dispersal of eggs and larvae by ocean currents, combined with adult movement (see sections below), may be sufficient to maintain a genetically homogeneous population of sea mullet along the south-western coast. Although sea mullet also occurs further north of Shark Bay, these are assumed to represent a different stock, or possibly even a different species. Further work is required to confirm stock structure, however for this assessment, the stock is assumed to be a single stock.

5.1.3 Life History

Table 5.1. Summary of biological parameters for WCB & SCB sea mullet (n/a=not available)

Parameter	Value(s)	Comments / Source(s)
Growth parameters		$L_t = L_\infty (1 - \exp(-k (t - t_0)))$
L_∞ (mm)	Females 509, Males 398 (WCB) Females 588, Males 447 (SCB)	(Gaughan et al*.* 2006)
k (year^{-1})	Females 0.590, Males 0.793 (WCB) Females 0.352, Males 0.552 (SCB)	
t_0 (years)	Both sexes fixed at zero	
Maximum age (years)	12 (WCB) 8 (SCB)	(Gaughan et al*.* 2006)
Maximum size (mm)	790	(Hutchins and Swainston 1983)
Natural mortality, *M* (year^{-1})	0.5 y^{-1}	$M_{est} = 4.899 t_{max}^{-0.916}$ (Then et al*.* 2016)
Length-weight parameters	4.72 x 10^{-6} x $TL^{3.15}$	Weight in g and TL in mm (Gaughan et al*.* 2006)
Reproduction	Gonochoristic; isochronal broadcast spawner.	
Maturity parameters		
A_{50} (years)	3-4	Approximate, under review
A_{95} (years)	n/a	
L_{50} (mm)	Both sexes 373	Logistic (Gaughan et al. 2006)
L_{95} (mm)	n/a	
Fecundity	0.5-5 million (at sizes 300-800mm)	Annual fecundity
Size-fecundity parameters		e.g., ln(*BF*)=*a*(ln*CW*)+*b*
a	n/a	
b	n/a	
Spawning frequency	n/a	Multiple batches spawned over a short period (few days) (McDonough et al. 2005)

5.1.3.1 Life Cycle

Sea mullet reach sexual maturity at approximately 3 – 4 years of age (Chubb et al*.* 1981, Virgona et al*.* 1998), at which point they typically undergo a migration during late summer from estuaries to open waters to spawn during autumn/winter (Figure 5.2). The eggs of sea mullet are pelagic and hatch after approximately 48 hours (Thomson 1963, Smith and Deguara 2002). After hatching, larvae sink for the first 10 days and then undergo positive phototaxis towards surface waters (Liao 1975). Leis and Carson-Ewart (2000) provide a description of the larval stages of sea mullet. At 20 – 30 mm TL, juveniles typically enter estuaries where they remain until the onset of maturity (Figure 5.2).

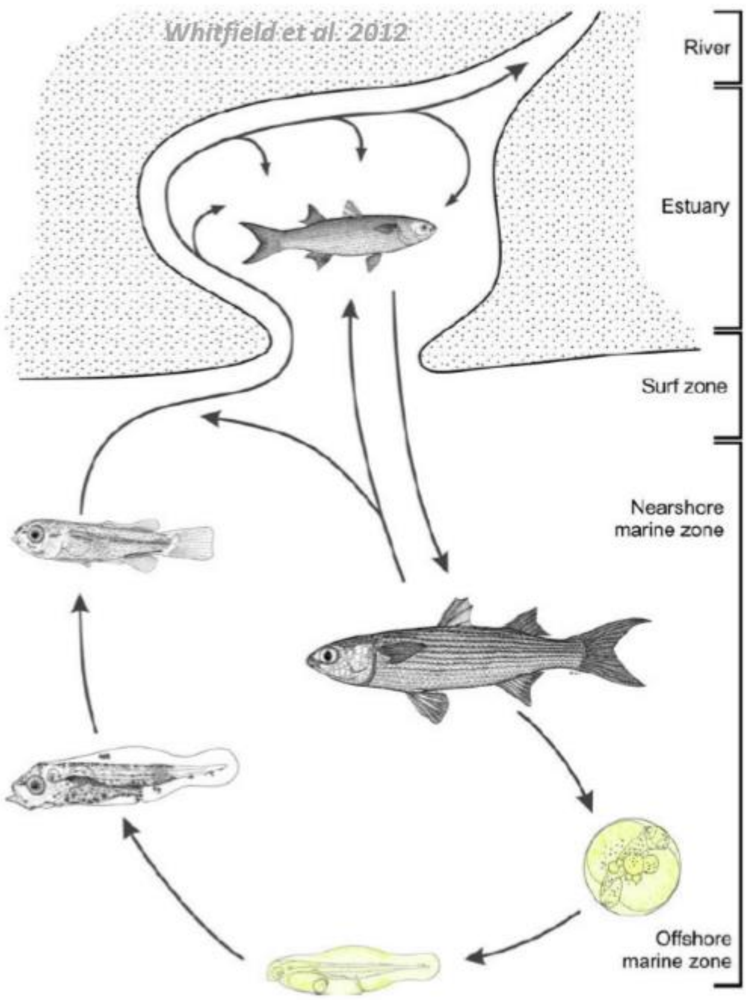


Figure 5.2. Generalised lifecycle diagram for sea mullet (Whitfield et al. 2012).

5.1.3.2 Habitats and Movements

Sea mullet occur in marine, estuarine and freshwater habitats, tolerating salinities of 0-80 ppt (Thomson 1963). Juvenile sea mullet typically inhabit estuaries and freshwater where they associate with shallow weed beds and bare substrate, while adults are found in estuaries, shallow coastal waters and marine embayments

(Chubb et al*.* 1981, Harrison and Senou 1999, Smith 2006). Due to the tolerance of this species to a wide range of salinities, sea mullet can occur in the upper reaches of estuaries (Chubb et al*.* 1981).

Globally, sea mullet spawning is reported to occur in a wide range of marine locations (estuary mouths, ocean beaches, offshore), depending on the region (Nash and Shehadeh 1980). Spawning can occur over a wide temperature range (between 10-30^{o} C) but is apparently restricted to normal ocean salinity (i.e., 32-36 ppt).

In most regions, mature sea mullet undergo a pre-spawning migration, which may be short or long depending on local topography and currents (Nash and Shehadeh 1980, Whitfield et al*.* 2012). On the east and west coasts of Australia, this usually involves moving from an estuary to coastal waters in large schools and then traveling northwards, against the prevailing current, along the open coastline to their spawning site. Eggs and larvae are then dispersed southwards with the current. The migration pattern has presumably evolved to maintain the species' distribution. Differences in spawning location and length of migration between sea mullet populations globally may be explained in terms of fish travelling only as far as required to compensate for larval drift.

In Australia, the northwards movement of sea mullet during autumn is more visible on the east coast due to the larger size of the population (resulting in bigger and more numerous schools migrating along the coast), but it also occurs along the west coast where it is well known to fishers. The cue to commence the spawning migration is reported to be persistent offshore winds during late summer/autumn, i.e., blowing from the east on the south-west coast and from the west on the east coast (Fraser 1953, Thomson 1955). Since the 1970s, the timing of the sea mullet migration along the WCB coast has gradually shifted by 1-2 months, as indicated by a shift in the peak of commercial beach landings from February to May (Figure 5.3). This coincides with a shift in the onset of cool season weather, e.g., the onset of winter rainfall in this region occurs 2-3 months later than in the 1970s.

Annual alongshore migrations up to 724 km have been recorded by tagged sea mullet on the east coast, although <100 km is a more typical distance (Smith and Deguara 2002). In WA, tagging studies were conducted during the 1940s and 1950s (Thomson 1951, 1955). Most fish were tagged in the lower west coast estuaries and were aged 1 to 3 years at release. Apart from two fish, all recaptures were within the same estuary or at an adjacent ocean beach, i.e., distances of <30 km. The two exceptions were Collie River to Geraldton (~550 km in 485 days) and Mandurah to Swan River (~80 km in 310 days).

The direction of movement in ocean waters by tagged fish is predominantly northwards, with only small movements southward. There is no evidence of a return migration. Fish are assumed to remain at the same latitude after spawning (either moving into an estuary or remaining at sea). A small proportion of age 1+ and 2+

juveniles migrate between estuaries. On the east coast a run of juveniles known as the ‘hard-gut migration’ sometimes occurs in early summer (Thomson 1955). Only some adults migrate every year. Many fish appear to migrate less often, perhaps doing so only a few times in their lifetime.

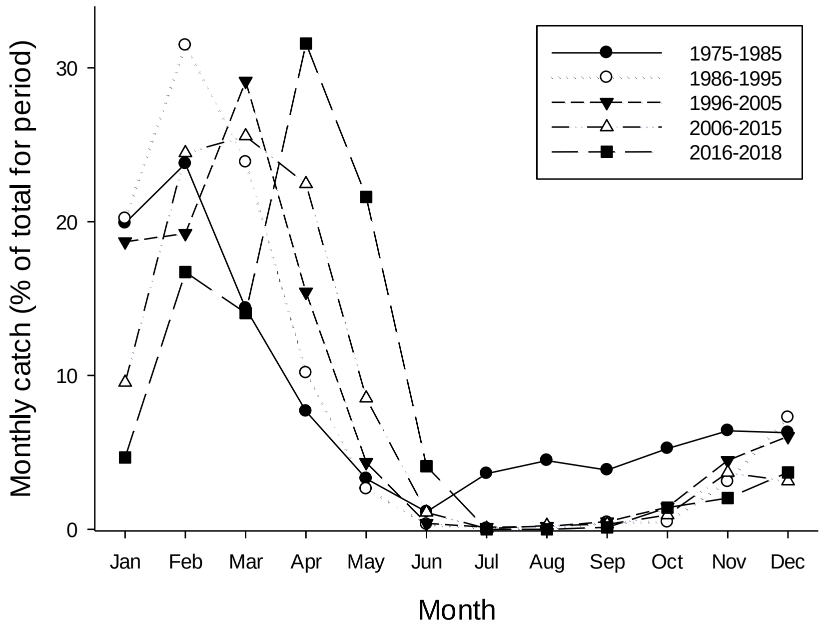


Figure 5.3. Ocean beach-based commercial catches of sea mullet in mid-west WCB (open access fishery), monthly distribution of catch by decade, showing 1 to 2 month shift since 1970s.

5.1.3.3 Age and Growth

Sea mullet grow to a maximum size of ~80 cm (Gomon et al. 2008). The maximum observed age in WA waters is 12 years (Gaughan et al. 2006), although this is based on limited sampling, and is substantially less than eastern Australia where the maximum observed age of sea mullet is 18 years (Stewart et al. 2018).

Sea mullet were sampled in waters off south-western WA between 1999 and 2002 as part of a study to develop a recruitment index for several commercially and recreationally important fish species (Gaughan et al. 2006). Fish were aged by counting opaque zones in sectioned otoliths. The annual periodicity of otolith increments has been validated in eastern Australian sea mullet (Smith and Deguara 2003). Sex and spatial differences in size have been observed for sea mullet in WA. Females grow substantially larger than males (Figure 5.4). Whilst fish on the south coast grow to a larger size than on the west.

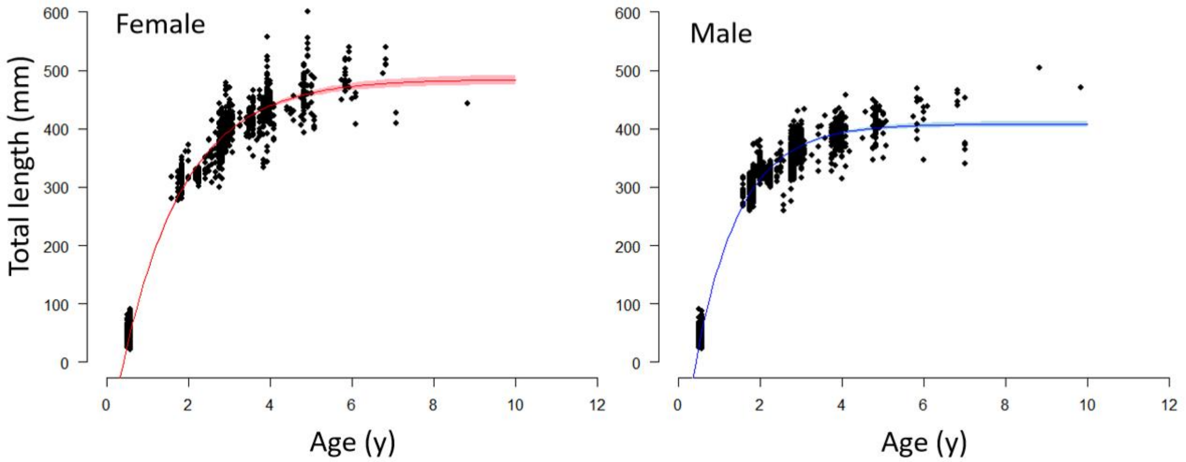


Figure 5.4. von Bertalanffy growth curves and age length data for female and male sea mullet.

5.1.3.4 Natural Mortality

A value of *M* for sea mullet of 0.5 year^{-1} was calculated using the empirical life-history equation by Then et al. (2015) based on the maximum age (t_{max}) of 12 years, where $M = 4.899t_{max}^{-0.916}$. A preliminary exploration of mortality estimates for lightly fished stocks in WA has suggested that this method may be more appropriate than the Hoenig (1983) method for more productive, shorter-lived species with a maximum age under 15 years (DPIRD unpublished data).

5.1.3.5 Reproduction

Spawning occurs in ocean waters only and does not occur in estuaries. Prior to spawning, mature fish aggregate to the lower parts of estuaries and then migrate out to sea. Adults with developed gonads that are unable to reach ocean waters (e.g., trapped in an estuary by a sand bar) will resorb their gonads (Wallace 1975, Chubb et al. 1981). Successful spawning and egg fertilisation only occurs in seawater and optimal egg and larvae survival occurs at 36 ppt (Walsh et al. 1991).

In any given year, the gonads of a significant proportion of adults remain undeveloped. ‘Skipped spawning’ (i.e., non-spawning by adults in at least some years) appears to be a common trait in sea mullet stocks (Fowler et al. 2016). Furthermore, interrupted feeding in the months prior to the spawning migration may result in some fish of mature age not producing ripe gonads and not participating in the spawning run (Thomson 1955).

Globally, sea mullet populations spawn over multiple months each year (Render et al. 1995). Spawning amongst populations on the east coast of Australia occurs between April and July, while sea mullet spawn between February and September on the lower west coast of WA (Thompson 1951, Chubb et al. 1981, Orr 2000, Potter et al. 2000, Gaughan et al. 2006). However, recent data showing the presence of 20-25 mm fish (estimated to be ~1 month old) in the WCB and SCB between April and

December, and between June and October in the GCB, suggests a WA spawning period from April to November (DPIRD unpublished data).

The timing of beach-based catches in the mid-west zone of the WCB indicate the timing of the spawning migration in this area (Figure 5.3). Fishers in this region target pre-spawning schools as they migrate northwards along the coast and have reported relatively consistent annual catches since 1975. During 1975-2018, the main catch period has shifted from January-April to February-May, with the peak shifting from February to April (Figure 5.3). Furthermore, gonadosomatic Index (GSI) in males and females is elevated during April-June in the (Metro/Midwest) WCB (Figure 5.5). It is believed that spawning amongst sea mullet stocks is restricted to nearshore marine waters, with no spawning activity identified within estuaries (Orr 2000, Crisafulli 2008).

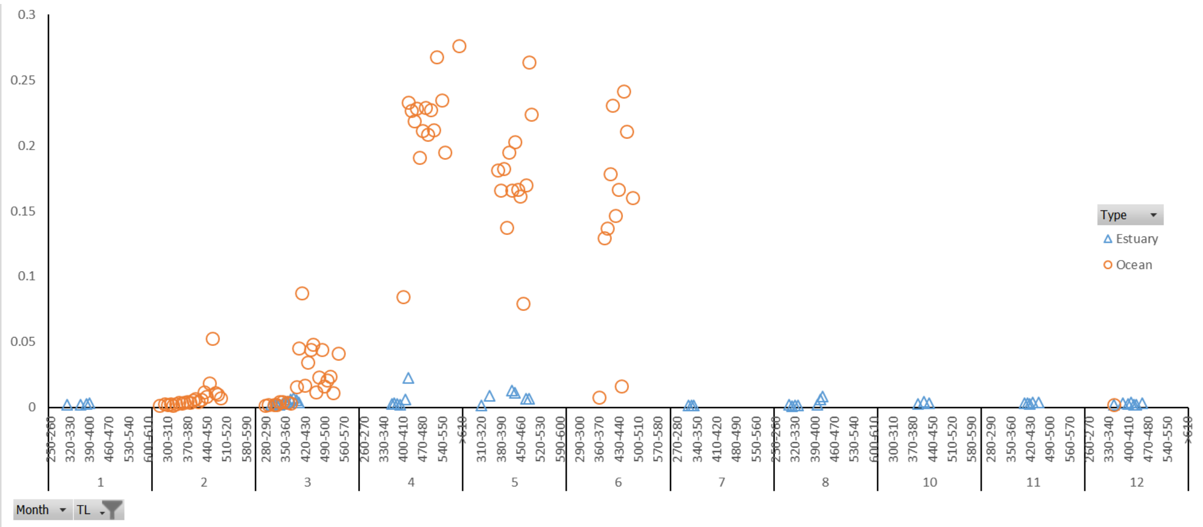


Figure 5.5. Average GSI of female sea mullet caught from 2016-2018, WCB, by month and length (mm TL). Estuary = Peel-Harvey; Ocean = Midwest. 38 cm TL is smallest female with elevated (i.e., >5%) GSI.

5.1.3.6 Factors Affecting Year Class Strength and Other Biological Parameters

There is no published information about factors affecting the juvenile recruitment of sea mullet. As sea mullet spawn outside of estuaries, the strength of ocean currents such as the Leeuwin Current is likely to have an influence on recruitment of this species.

5.1.3.7 Diet and Predators

Sea mullet feed either by sucking up the surface layer of mud, often ingesting a large amount of substrate in the process, or by grazing on submerged surfaces such as rocks or seagrass. Fine organic and inorganic particles are selectively ingested, and then ground within the gizzard-like pyloric stomach before moving further along the

digestive tract (Odum 1963). The diet of sea mullet consists of detritus, diatoms, algae and occasionally crustaceans and bivalves (Lenanton 1978, Orr 2000). The trophic level of sea mullet is estimated as 2.5 (Froese and Pauly 2022).

Sea mullet do not feed while migrating (Thomson 1951). For this reason, the migration by older juveniles that sometimes occurs in early summer on the east coast is known as the 'hard-gut migration'.

5.1.3.8 Parasites and Diseases

There are no known issues in WA.

5.1.4 Inherent Vulnerability

Despite being highly vulnerable to netting, sea mullet are regarded as relatively resilient to fishing pressure due to their biological traits. They can utilise a wide range of habitats and are tolerant of salinities ranging from 0 to at least 60 ppt. Although they often occur in estuaries, they are not dependent on these environments and can complete their whole life cycle in ocean waters (Lenanton and Potter 1987). Sea mullet mainly feed on detritus.

Adult sea mullet move between estuarine and nearshore environments and undertake significant alongshore migrations in ocean waters prior to spawning. Eggs and larvae are likely to be dispersed substantial distances by ocean currents. For these reasons, each stock is distributed over a relatively wide area with high levels of connectivity throughout this area.

Sea mullet attain maturity in approximately 3 years, and have a very high fecundity, capable of producing millions of eggs.

Adults form large seasonal aggregations in shallow areas, making them highly vulnerable to commercial netting; juveniles are rarely caught. Due to their schooling behaviour, there is a possibility of hyperstability in commercial catch rates.

5.2 Yellowfin whiting (*Sillago schomburgkii*)

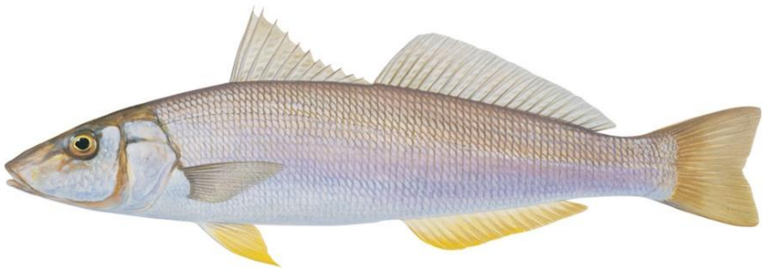


Figure 5.6. The yellowfin whiting, *Sillago schomburgkii*. Illustration © R. Swainston (www.anima.net.au)

5.2.1 Taxonomy and Distribution

Yellowfin whiting (*Sillago schomburgkii*; Figure 5.6), also known as western sand whiting, is a member of the family Sillaginidae.

Adults have no distinguishing body markings and are best identified by their yellow ventral and anal fins and a weakly forked caudal fin. Juveniles have faint black blotches on the body and may be confused with western trumpeter whiting (*S. burrus*). They are best distinguished from this species by the lack of markings on the pectoral fin muscle (Hutchins and Swainston 1986).

Yellowfin whiting (YFW) is endemic to south-western Australia, extending from WA (Exmouth) to South Australia (Gulf St Vincent). Within WA, it has historically been found mainly between Exmouth and Albany, with low abundance further east along the south coast. Records of this species occurring north of Exmouth (e.g., Onslow, Port Hedland) are disputed (J. Brown, DPIRD *pers. comm*.). There appears to have been a range extension of this species in WA in recent years, with increasing abundance on the south coast (Smith et al. 2019), which may be due to the 2011 extreme marine heatwave.

5.2.2 Stock Structure

The population structure in WA is currently being assessed using genetic techniques, however the following evidence suggests low connectivity between populations at small scales. Populations separated by small distances (e.g., 10's of km) display different demography (size/age structure), recruitment and growth patterns, which imply low connectivity between these populations (Ferguson 2000, DoF data in this report).

Eggs and larvae are pelagic, and therefore could potentially be dispersed by ocean currents. However, spawning occurs in very shallow (<5 m) coastal waters and estuaries, well inshore of the influence of major alongshore currents, which greatly limit the extent of alongshore advection (Hyndes and Potter 1997).

The 'southern' (WCB and SCB) and 'northern' (GCB) populations of this species are likely to have limited connectivity, and so are regarded as separate management units. There may be further subdivisions within bioregions, but this is yet to be confirmed (DPIRD in prep.). Based on the possibility of discontinuous distribution, WA and SA are assumed to host separate breeding stocks.

5.2.3 Life History

Table 5.2. Summary of biological parameters for yellowfin whiting in West Coast Bioregion. (based on data from Metro zone in the WCB).

Parameter	Value(s)	Comments / Source(s)
Growth parameters		$L_t = L_\infty (1 - \exp(-k\ (t - t_0)))$
L_∞ (mm, TL)	Females 328, Males 294	(DoF data)
k (year^{-1})	Females 0.57, Males 0.51	
t_0 (years)	Females -0.01, Males -0.04	
Maximum age (years)	12 y	(Hyndes and Potter 1997)
Maximum size (mm)	420 mm TL	(Hutchins and Swainston 1988)
Natural mortality, M (year^{-1})	0.35	(Hoenig 1983 equation for fish)
Length-weight parameters		$\ln(W) = a \ln(TL) - b$
a	3.078	(DoF data)
b	12.174	
Reproduction	Gonochoristic, broadcast spawner.	
Maturity parameters		
A_{50} (years)	Females 2, Males 2	Knife-edge (DoF data)
L_{50} (mm, TL)	Females 205, Males 182	Logistic (DoF data)
L_{95} (mm, TL)	Females 257, Males 220	
Fecundity	30,000 to 600,000	Batch fecundity (Lenanton 1970)
Size-fecundity parameters	n/a	
Spawning frequency	n/a	Multiple (batch) spawner, frequency unknown, spawning period extends over several months

Table 5.3. Summary of biological parameters for yellowfin whiting in Gascoyne Coast Bioregion.

Parameter	Value(s)	Comments / Source(s)
Growth parameters		$L_t = L_\infty (1 - \exp(-k(t - t_0)))$
L_∞ (mm, TL)	Females 340, Males 283	(Coulson et al. 2005)
k (year^{-1})	Females 0.60, Males 0.81	
t_0 (years)	Females -0.03, Males 0.00	
Maximum age (years)	12 y	(Hyndes and Potter 1997)
Maximum size (mm)	420 mm TL	(Hutchins and Swainston 1988)
Natural mortality, M (year^{-1})	0.35	(Hoenig 1983 equation for fish)
Length-weight parameters		$\ln(W) = a \ln(TL) - b$
a	3.005	(DoF data)
b	11.783	
Reproduction	Gonochoristic, broadcast spawner etc.	
Maturity parameters		
A_{50} (years)	Both sexes 2	Knife-edge (Coulson et al. 2005)
L_{50} (mm, TL)	Females 223, Males 196	Logistic (Coulson et al. 2005)
L_{95} (mm, TL)	Females 254, Males 219	
Fecundity	30,000 to 600,000	Batch fecundity (Lenanton 1970)
Size-fecundity parameters	n/a	
Spawning frequency	n/a	Multiple (batch) spawner, frequency unknown, spawning period extends over several months

5.2.3.1 Habitats and Movements

Yellowfin whiting occur on sheltered, sand flats in shallow (<5 m) coastal waters and the lower saline parts of estuaries (Lenanton 1970, Hyndes and Potter 1997). Adults and large juveniles form schools over sandy habitats, whereas small juveniles use a range of shallow nursery habitats including sand, silt, mangrove, and seagrass. The

species can tolerate a wide range of salinities of up to 50 ppt and can enter the limits of brackish water (1 ppt) in tidal creeks (Kailola et al. 1993, Lenanton 1982).

Small juveniles display a preference for sheltered waters. In the WCB metro zone, small juveniles of <100 mm TL are common in the sheltered waters of Mangles Bay, but rare along more exposed beaches such as Becher Point and Pinnaroo Point (DoF beach seine recruitment surveys 1995-2015). In the WCB south-west zone, small juveniles are relatively common in Leschenault Inlet, but rare along the adjacent ocean beach in Koombana Bay.

Adults may move out of estuaries to spawn, however there is no evidence of extensive alongshore movements by adults in ocean waters in WA, which suggests mixing of adults between regions is limited. In SA, tagged adults were recaptured after moving distances of up to ~200 km (Ferguson 1999). Recaptures of fish tagged in Shark Bay have all occurred within the Bay (Lenanton 1970).

5.2.3.2 Age and Growth

Yellowfin whiting grow to a maximum total length (TL) of 420 mm (Hutchins and Swainston 1986) and both female and males can reach a maximum age of 12 years (Hyndes and Potter 1997). The maximum ages reported in each region are:

- WA WCB (metro zone): 12 y female (Hyndes and Potter 1997); 8 y male (DoF),
- WA WCB (south-west zone): 9.8 y female (DoF); 11.8 y male (DoF),
- WA GCB: 10.4 y female (DoF), 9 y male (Coulson et al. 2005, DoF),
- SA: 12 y female, 9 y male (Ferguson 1999).

Females attain a larger size-at-age than males. Recent von Bertalanffy growth parameters have been estimated from data collected by DoF in each region of WA (Table 5.4), with some historical data also available from Coulson et al. (2005).

Table 5.4. von Bertalanffy growth parameters (with 95% confidence intervals in parentheses) determined for yellowfin whiting in the West Coast Bioregion (WCB) and the Gascoyne Coast Bioregion (GCB) from various datasets.

Bioregion-Zone	Year(s)	Sex	L¥ (mm)	k (y-1)	t0 (y)
WCB-metro zone	2015-2016[1]	Female	328 (325-330)	0.57 (0.55-0.59)	0.02 (-0.00 – 0.04)
		Male	294 (290-299)	0.51 (0.48-0.54)	-0.07 (-0.10 - -0.04)
	1992-1995[2]	Female	333 (317-334)	0.53 (0.53-0.61)	-0.16 (-0.11 - -0.18)
		Male	325 (301-328)	0.54 (0.49-0.59	-0.20 (-0.16 - -0.24)
Gascoyne (DoF)	2014[3]	Female	340 (334-346)	0.60 (0.56-0.65)	-0.03 (-0.09 - 0.03)
		Male	283 (278-287)	0.81 (0.75-0.87)	0 (-0.06 – 0.06)
	2002-2003[4]	Female	345 (337-355)	0.48 (0.45-0.51)	-0.01 (-0.04 - 0.03)
		Male	290 (281-299)	0.59 (0.55-0.63)	0.01 (-0.02 - 0.05)

Growth shows seasonal variation in some regions. Slower juvenile growth in winter is evident in the metro zone of the WCB (Table 5.4). Slower juvenile growth in winter is also evident in SA (Ferguson 2000). A seasonal von Bertalanffy growth model provided a better statistical fit to the age/length data from this zone (

[1] DoF unpubl data.
[2] Hyndes & Potter (1997) and reanalysed by Coulson *et al.* (2005). The more recent DoF data is regarded as more representative as it is larger and has a greater proportion of older fish.
[3] Brown (2014) internal DoF report and DoF unpubl. data from Shark Bay.
[4] Coulson et al. (2005) Shark Bay data

Table 5.5, Figure 5.7).

Table 5.5. Values used to calculate seasonal growth curve.

Parameter	**Starting values**	**Lower**	**Upper**
L_∞	300	324.9665	330.165
k	0.6	0.5546922	0.5903623
t_0	0	-001013208	0.04141609
C	0.5	1.000197	0.9998048
ts	0.5	0.9741626	0.9378107

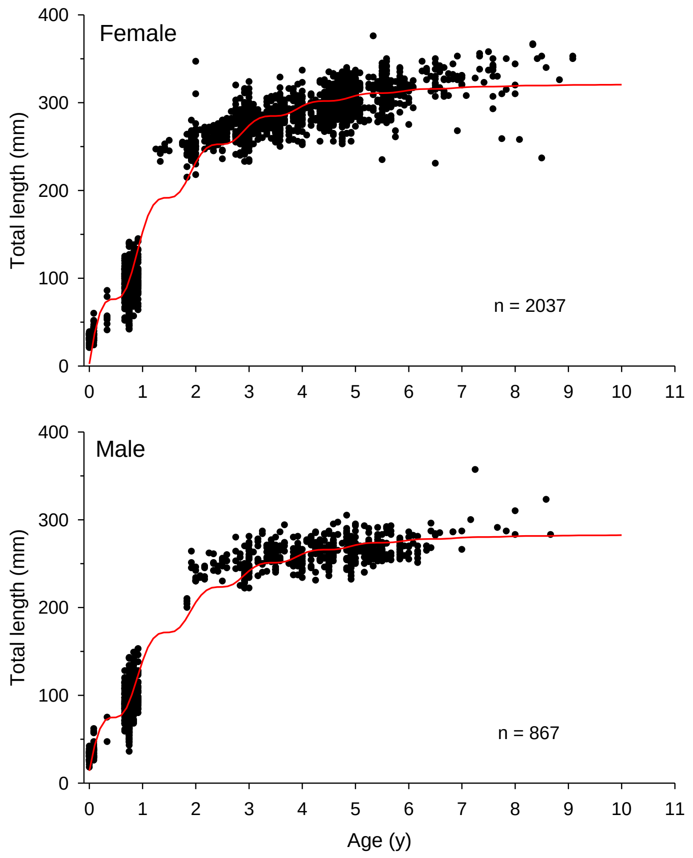


Figure 5.7. Length versus age (black dots) of yellowfin whiting sampled in the Metro Zone of WCB, with seasonal growth curve (red line) fitted. (*note: all data were collected in 2015 and 2016 except for age 0 fish which collected over multiple years 1999-2016*).

Morphometrics for WCB metro zone (DoF data):

TL = (1.0462 x FL) + 2.9306 (R^2 = 0.984, n = 2623)

ln(W) = 3.0781 x ln(TL) - 12.174 (R^2 = 0.9955, n = 735)

where TL – total length (in mm); FL – caudal fork length (in mm); W – whole body weight (in g).

5.2.3.3 Natural Mortality

Natural mortality (*M*) = 0.35y^{-1}, calculated using the estimator of Hoenig (1983, equation for fish), assuming a maximum age of 12 years. Using the more recent equation of Then et al. (2015), $M = 4.899 t_{max}^{-0.916}$, yields an *M* estimate of 0.50 y^{-1}. The *M* estimate is presented here to highlight that alternative values exist, and the impacts of using different values should be explored in future assessments. Note, use of the lower estimate from the Hoenig (1983) equation will lead to more conservative (precautionary) estimates of stock status.

5.2.3.4 Reproduction

Yellowfin whiting is a multiple batch spawner, with asynchronous development and indeterminate fecundity (Hyndes and Potter 1997, Ferguson 2000, Coulson 2003). Individuals do not change sex.

Total annual (absolute) fecundity is expected to be variable, depending on the length of the spawning season. Thomson (1957) estimated a batch fecundity of 170,000 to 217,000 eggs, based on a macroscopic examination of gonads from 20 fish collected from Shark Bay. This is consistent with batch fecundities estimated for other sillaginids of similar body size (e.g., Gray et al. 2014). In Shark Bay, Lenanton (1970) estimated batch fecundity ranging from 30,000 to 600,000 for fish 220 to 370 mm in length. However, given the protracted spawning season (Figure 5.12), annual fecundity is much greater than batch fecundity.

Spawning occurs in very shallow (<5 m) coastal waters and the lower parts of estuaries (Jones 1981, Hyndes and Potter 1997). In Shark Bay, spawning is preceded by an inshore movement to sheltered bays and inlets (Lenanton 1970). In the Peel-Harvey Estuary, data suggests that there is limited spawning inside the estuary, however, there is some spawning activity near the entrance (i.e., Dawesville Cut) (DoF data, Figure 5.10).

Fertilisation is external. Eggs (0.6 mm diameter) and larvae are planktonic. The larval duration is 3-4 weeks (Ferguson 2000). Larval settlement (into a benthic habitat) occurs at ~13mm TL (Neira et al. 1998).

There are differences in the timing and duration of spawning between regions, presumably in response to different temperature regimes. In WA, the spawning period is August-December in Shark Bay (25° S) (Coulson et al. 2005) and November-March in the cooler waters of the WCB metro zone (~32° S)(Figure 5.8, 5.9 and 5.11). In SA, spawning generally occurs between October-January, with slight differences in timing and duration between regions (Ferguson 1999, 2000).

In the WCB metro zone, almost all individuals attain maturity in their 2nd year. For females, L_{50} = 205 mm TL (192-216 mm 95% C.I.) and L_{95} = 257 mm TL (L_{95}) (DoF data)[5]. For males, L_{50} = 182 mm TL (171-193 mm 95% C.I.) and L_{95} = 220 mm TL (DoF data). These estimates of size- and age-at-maturity based on recent DoF data are similar to those previously reported by Hyndes and Potter (1997).

In the GCB, fish mature at a larger size and age than in the WCB (Coulson et al. 2005). For females, L_{50} = 223 mm TL (219-229 mm 95% C.I.) and L_{95} = 254 mm TL (237-269 mm 95% C.I.). For males, L_{50} = 196 mm TL (189-201 mm 95% C.I.) and L_{95} = 219 mm TL (209-226 mm 95% C.I.). In the GCB, 35/70% of females/males attain maturity by the end of their 2nd year, and all are mature by the end of their 3rd year.

In SA, fish attain maturity in their 2nd year, L_{50} = 238/223 mm TL (female/male) in northern Spencer Gulf and 221/207 mm TL in Gulf St Vincent (Ferguson 1999).

[5] Fish defined as 'mature' at macroscopic gonad stages 3-8 and 'immature' at stage 1 or 2 during the spawning period (Nov-Mar).

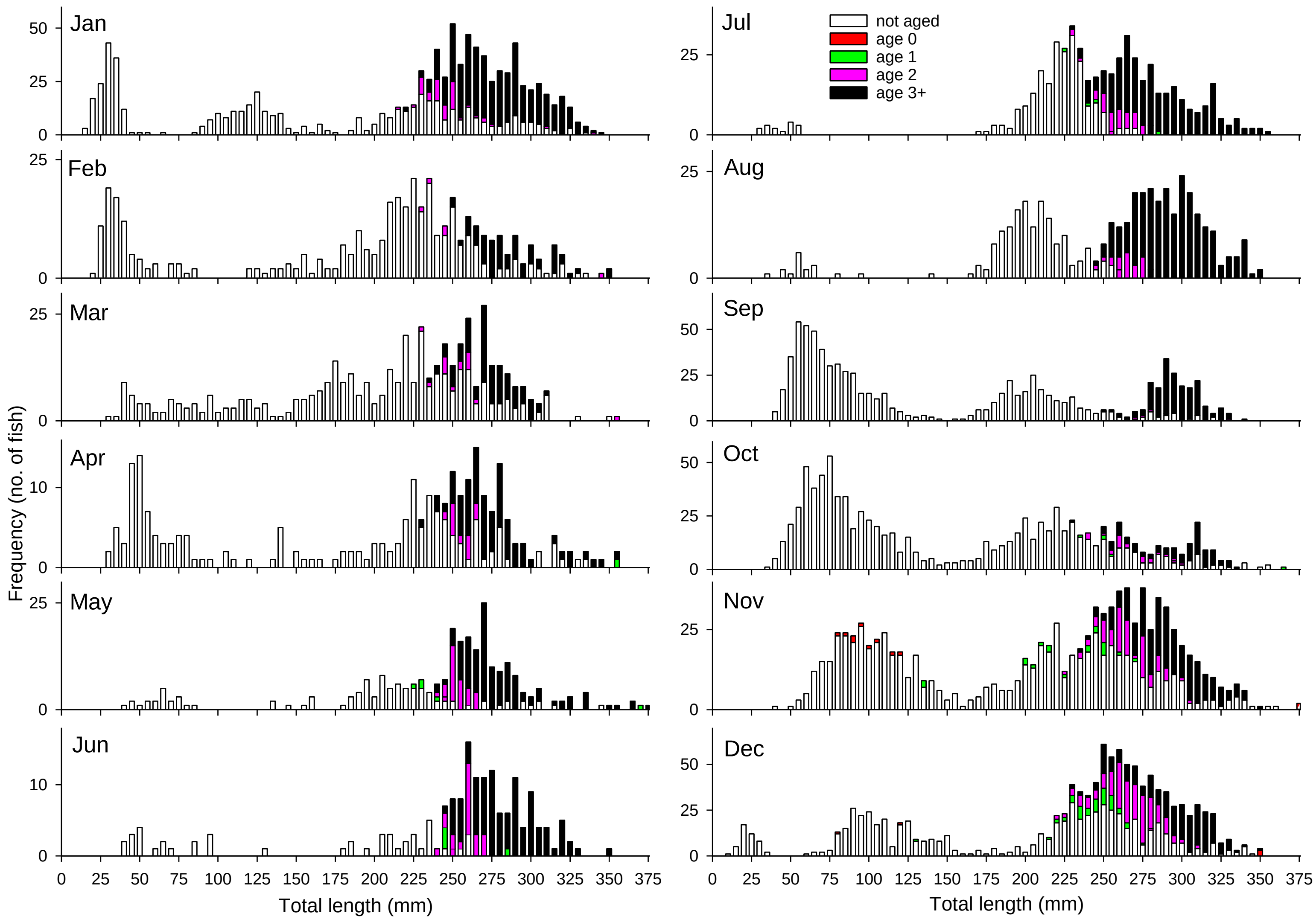


Figure 5.8. Monthly length frequency distribution of yellowfin whiting sampled by fishery-independent and fishery-dependent surveys in the Metro Zone of the WCB during 1999-2016 (DoF data).

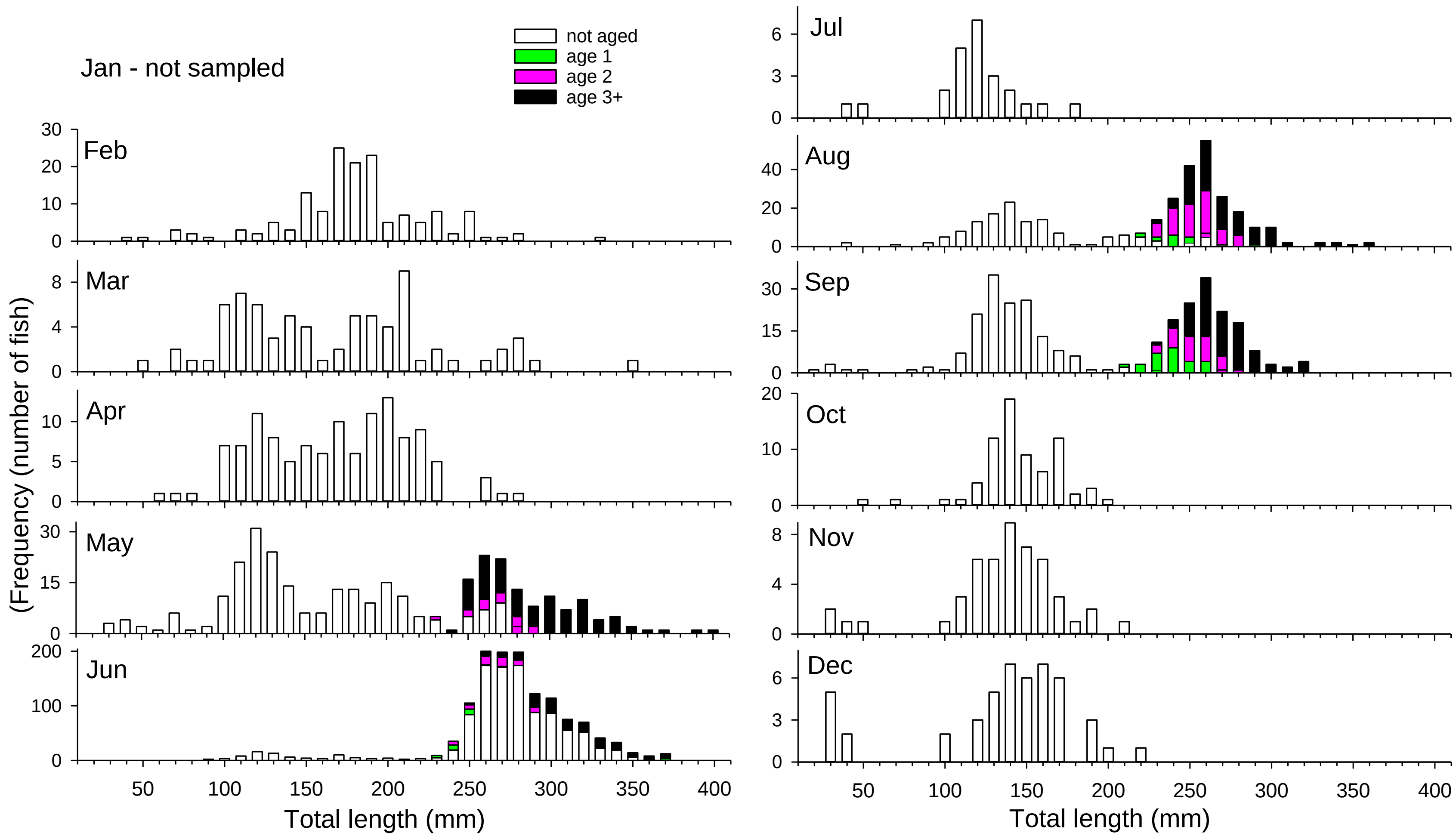


Figure 5.9. Monthly length frequency distribution of yellowfin whiting sampled by fishery-independent and fishery-dependent surveys in the Gascoyne Coast Bioregion during 1995-2014 (DoF data).

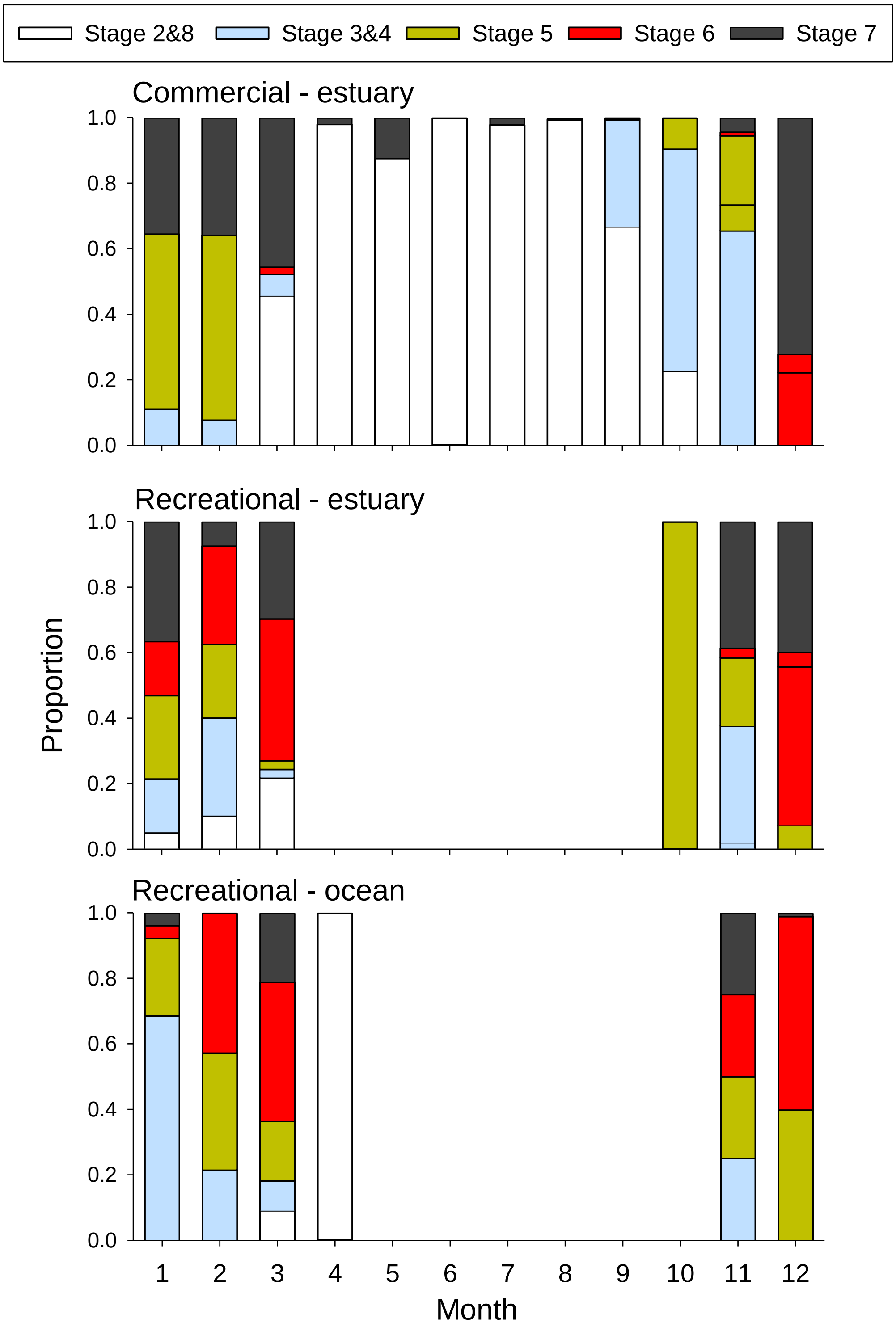


Figure 5.10. Monthly proportions of adult yellowfin whiting (fish >=200 mm TL only) at each macroscopic gonad stage, samples from commercial and recreational fishery catches in the Peel-Harvey Estuary and ocean waters in the Metro Zone of the WCB in 2010-2016* (*majority sampled in 2015-2016, but monthly trends same in earlier years, so all years are included). No recreational data available in cooler months. Note: ~85% of fish in spawning condition (stages 5-7) caught in the estuary by recreational fishers were taken within the Dawesville Cut (i.e., the estuary entrance).

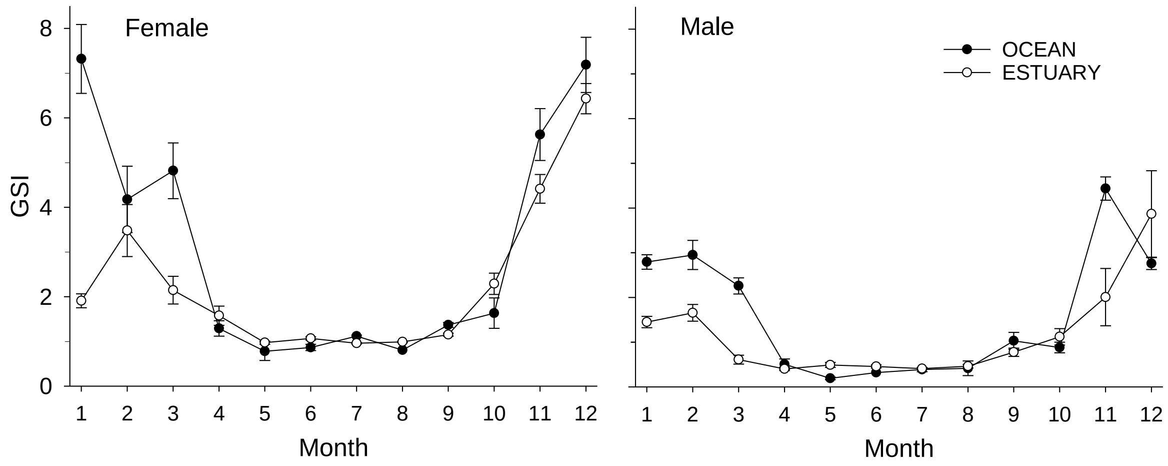


Figure 5.11. Monthly mean (+ s.e.) gonadosomatic index (GSI) for female and male yellowfin whiting (fish >=200 mm TL only), sampled from the Metro Zone of the WCB in 1999-2016* (*majority sampled in 2015-2016, but monthly trends same in earlier years, so have included all years).

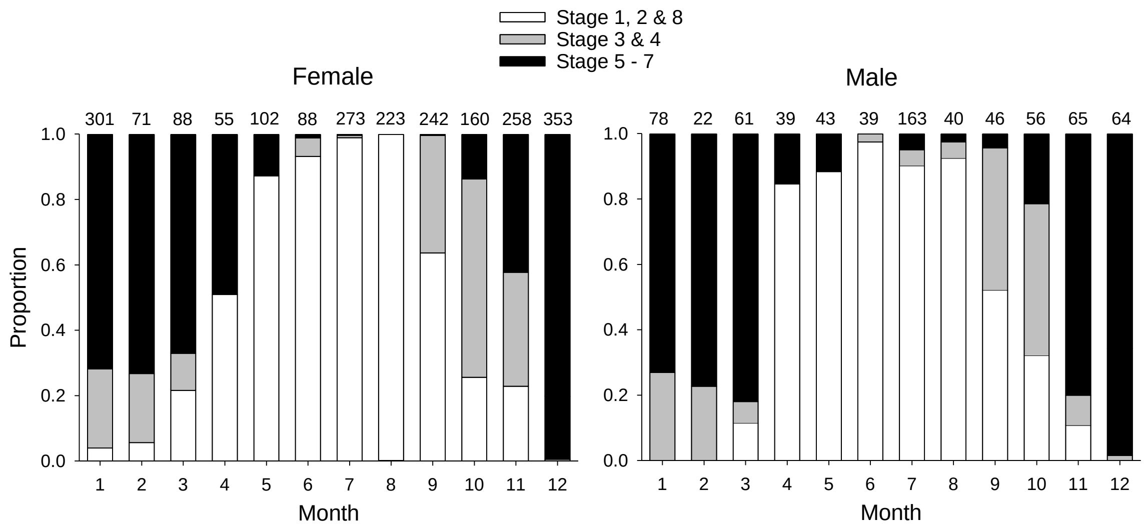


Figure 5.12. Monthly proportions of adult yellowfin whiting (fish >=200 mm TL only) at each macroscopic gonad stage, sampled from the Metro Zone of the WCB in 1999-2016* (*majority sampled in 2015-2016, but monthly trends same in earlier years, so all years are included). *Note: Gonads were assigned to the following macroscopic stages (based on Laevastu 1965): 1: Virgin; 2: Maturing virgin/resting adult; 3: Developing; 4: Maturing; 5: Mature; 6: Spawning; 7: Spent; 8: Recovering spent. Since individual fish spawn multiple times in a spawning season, it can be difficult to differentiate macroscopically between stages 5, 6 and 7. Therefore, stages were grouped into 'immature/resting' (stage 1, 2 and 8), 'developing' (stage 3 and 4) and 'mature/spawning' (stage 5, 6 and 7).*

5.2.3.5 Sex Ratio

The sex ratio tends to be biased towards females in fishery catches. However, the sex ratio of juveniles captured in fishery-independent recruitment surveys is approximately 50:50 (Ferguson 2000) and there is no evidence from the age structure of higher mortality for males. The bias in catches may reflect higher catchability of females due to movement or behaviour, or higher selectivity due to their greater size.

The strength of the bias varies by region. In WA, commercial and recreational catches within the WCB metro zone (all samples from the Peel-Harvey Estuary) are strongly biased towards females in most months of the year (DoF data, Figure 5.13). Furthermore, other fishery landings in WA are also biased towards females, but less strongly (Figure 5.13). Similarly, commercial catches in SA are also strongly biased towards females (Ferguson 2000).

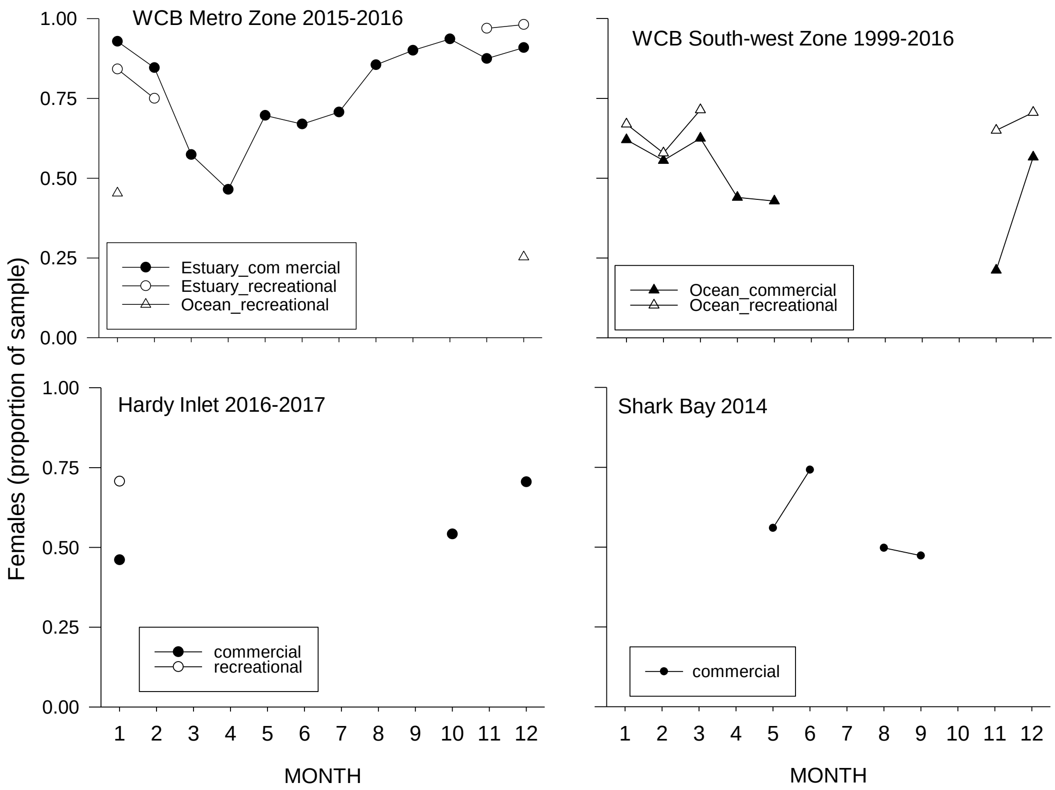


Figure 5.13. Proportion of females in monthly commercial and recreational fishery landings at key fishery locations within WA. (Note: estuary samples from WCB metro zone are from Peel-Harvey Estuary).

5.2.3.6 Factors Affecting Year Class Strength and Other Biological Parameters

Stock-recruitment relationship for this species has not been investigated. In this stock assessment, the Beverton-Holt relationship has been applied, with steepness value of 0.75.

Year class strength is assumed to be influenced by temperature during the spawning period, as observed during the 2011 marine heatwave event. In the WCB, recruitment by the year class spawned in summer 2010/11 was exceptionally strong, following record high temperatures during the spawning period. It is unclear whether a longer spawning period results in greater egg production or if there is higher growth and survival by immature stages.

5.2.3.7 Diet and Predators

Yellowfin whiting are benthic carnivores, consuming predominantly polychaete worms, with some copepods, amphipods and bivalves also taken. The trophic level of this species is estimated to be 3.1 - 3.2 (Froese and Pauly 2022). There is currently no available information on predators of yellowfin whiting.

5.2.3.8 Parasites and Diseases

There are no known issues in WA.

5.2.4 Inherent Vulnerability

The biology and behaviour of yellowfin whiting makes them moderately vulnerable to fishing. Yellowfin whiting attains maturity after 2 years. Longevity is medium (12 years). Annual fecundity is medium-high.

Eggs and larvae are planktonic, with a likely planktonic duration of 3-4 weeks. However, given the shallow location of spawning, there is probably limited dispersal of larvae by currents. Also, adults appear to undertake limited (10’s of km) movements in ocean waters and so there is probably limited connectivity between populations at scales of >200 km. Thus, there is the possibility of localised depletion.

The shallow distribution and predictable behaviour of YFW makes them highly vulnerable to commercial netting and recreational line fishing. Fish form loose aggregations in shallow areas. Catches (and catchability) in each region are seasonal, peaking during the spawning period. There is a moderate risk of hyperstability in catch rates. Males typically comprise a lower proportion of the catch and so appear to be less vulnerable to capture than females.

While recent recruitment data from long-term beach-seine surveys has yet to be analysed for this species, the stability in long-term fishery catch levels suggests relatively consistent annual recruitment, interspersed with the occasional year of stronger recruitment associated with environmental fluctuations such as the 2011 marine heatwave (Smith et al. 2019).

6 Fishery Information

6.1 Fisheries / Sectors Capturing Resource

Finfish have been commercially targeted by net fishers in estuarine and nearshore waters of south-west WA since the early years of colonisation (Walker and Clarke 1987). Annual catches peaked in the early 1990s but have since declined, mainly

due to substantial reductions in fishing effort resulting from a number of Voluntary Fishery Adjustment Schemes (VFAS) and a declining demand for bait used in the western rock lobster fishery (Pearn and Cappelutti 1999).

A number of small-scale commercial fisheries still operate in these waters today, mostly using haul nets (including beach seines) and gillnets to target this resource. Estuarine and nearshore finfish catches now typically fluctuate between 300 and 700 t annually and there has been a strong shift in recent years to catching fish for human consumption, with improvements in handling and processing leading to increases in unit value of the product.

Estuarine and nearshore finfish species are also targeted by shore- and boat-based recreational fishers in south-west WA. The most targeted estuarine and nearshore finfish by recreational line fishing (angling) in this region include Australian herring, WA salmon, whiting, tailor and black bream. Some shore-based recreational net fishing for finfish such as sea mullet is also undertaken by licenced fishers within some of the estuarine waters of south-west WA. Although recreational catch information is uncertain, the catch of estuarine and nearshore finfish by this sector is likely to exceed that of commercial fisheries.

Overall commercial effort in southern nearshore and estuarine fisheries peaked in the 1960s and 1970s. Since 1980 there has been a substantial reduction in commercial effort in these fisheries, via several VFAS. Driving factors included excessive latent effort, conflict with other stakeholders and sustainability concerns. In the period 1987-1997, the number of fishing units was reduced by 41% in the WCB and SCB estuarine fisheries, due to natural attrition and licence buyback. Between 1997 and 2005, the number of licenced fishing units was reduced by >50% in the WCB and SCB nearshore fisheries (Millington and Cranley, date unknown). The number of fishing units has been relatively stable since the early 2000s. Refer to DoF (1999) for further discussion about effort reductions in estuarine and embayment fisheries. Although the number of licenced fishing units has been relatively stable since 2000, the effort (number of active vessels) has continued to decline in each fishery.

The landings of indicator species comprise ~95% of total annual commercial landings (historically and currently) of southern nearshore finfish. Since 2000, there have been notable declines in the commercial catches of most of these; in particular Australian herring, WA salmon, sea mullet, yellow-eye mullet, whitebait and southern garfish; resulting in a substantial decline in total nearshore finfish catch (Figure 6.1, Figure 6.2). However, whiting and tailor catches have remained relatively stable. The total annual catch of southern nearshore finfish fell from approximately 4000 t during the 1970s, 1980s and 1990s to the current level of approximately 500 t. The catch declines were mainly due to effort reduction (licence buybacks and reduced targeting due to low market demand), with some reduction in stock levels (see Section 9).

In the WCB, four commercial fisheries target finfish in nearshore waters: West Coast Beach Bait Managed Fishery, Cockburn Sound (Fish Net) Managed Fishery, South West Coast Salmon Managed Fishery and the South West Beach Seine fishery.

Additionally, the West Coast Estuarine Managed Fishery (WCEMF) captures significant quantities of nearshore finfish.

In the SCB, the main commercial fishery targeting finfish in nearshore waters is the South Coast Salmon Managed Fishery, which exclusively targets WA salmon. Until its closure in 2015, the Herring Trap Net (or G-trap) fishery also operated in the SCB, where it exclusively targeted Australian herring. Additionally, the South Coast Estuarine Managed Fishery captures significant quantities of nearshore finfish.

In the Gascoyne Coast Bioregion, the main commercial fisheries targeting nearshore finfish are the Shark Bay Beach Seine and Mesh Net Managed Fishery (SBBSMNMF) and the Exmouth Gulf Beach Seine Managed Fishery.

Two main commercial fisheries target estuarine finfish: the WCEMF and the South Coast Estuarine Managed Fishery.

Sections below provide more detailed information about the main fisheries that target nearshore finfish on which this report is focused: the WCEMF and the SBBSMNMF.

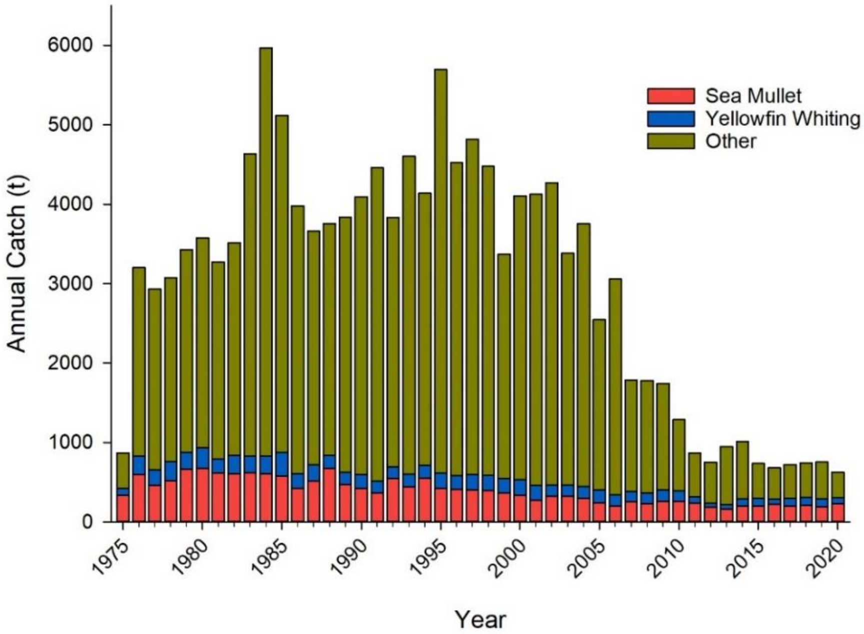


Figure 6.1. Annual Western Australian total catch (tonnes) of sea mullet, yellowfin whiting, and all other indicator species identified for the southwest WA finfish resource combined (WA salmon, Australian herring, black bream, estuary cobbler, Perth herring, whitebait, southern garfish, tailor, and other whiting spp.) between 1975 and 2020.

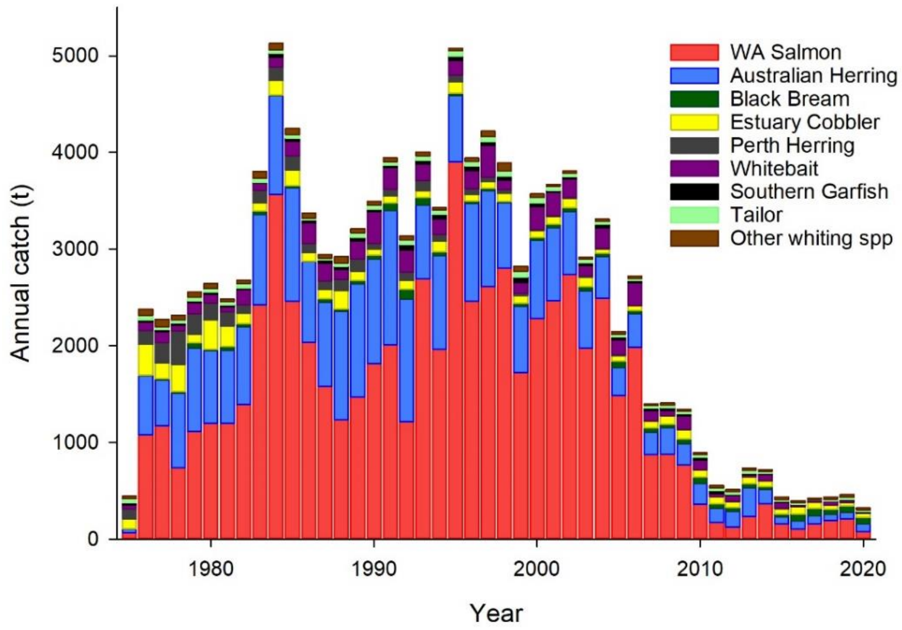


Figure 6.2. Annual Western Australian total catch (tonnes) for each of the remaining indicator species identified for the southwest WA finfish resource: WA salmon, Australian herring, black bream, estuary cobbler, Perth herring, whitebait, southern garfish, tailor, and other whiting spp. between 1975 and 2020.

6.1.1 Susceptibility to commercial and recreational fishing

Tables 6.1 and 6.2 below provide a brief outline of susceptibility of each indicator species to the commercial (all fisheries combined) and recreational fishing sectors, using the following 4 criteria:

- What is the area overlap (i.e., spatial distribution of fishing effort compared to the distribution of the exploited stock)?
- What is the encounterability of the stock within the water column relative to the fishing gear (typically high for target species)?
- What is the selectivity of the gear type used (i.e., individuals < size at maturity are rarely/regularly/frequently caught)?
- Is there evidence for survival following capture and release, or is this species always retained?

Table 6.1. Susceptibility of each indicator species to the commercial fishing sector

Sea mullet	1. medium overlap of spatial distribution of fishing effort with stock distribution 2. high encounterability with the fishing gear (high inshore, low offshore). 3. low selectivity of immature fish. 4. post-release survival of haul netted fish is believed to be relatively high, low for gill netted; species generally not discarded.
Yellowfin whiting	1. medium overlap of spatial distribution of fishing effort with stock distribution. 2. high encounterability with the fishing gear (haul nets used in shallow water) 3. low selectivity of immature fish; net mesh sizes limit retention of small fish 4. post-release survival of haul netted fish is believed to be relatively high

Table 6.2. Susceptibility of each indicator species to the recreational fishing sector

Sea mullet	Not recreationally targeted
Yellowfin whiting	1. high overlap of spatial distribution of fishing effort with stock distribution. 2. high encounterability with the fishing gear. 3. low selectivity of immature fish; juveniles make up a low proportion of the catch. 4. post-release survival of line-caught fish is believed to be relatively high.

6.2 West Coast Estuarine Managed Fishery

6.2.1 History of Development

There are four main (i.e., relatively large) estuaries in the WCB: the Swan-Canning, Peel-Harvey and Leschenault estuaries, and Hardy Inlet. Catch and effort records are available from the Swan-Canning Estuary since 1912, and from the other three estuaries since 1941 (Lenanton 1984; Figure 6.3). The Vasse-Wonnerup Inlet and Toby Inlet are the only other WCB estuaries open to commercial fishing, but catches are small (mainly sea mullet and black bream).

The Leschenault Estuary was closed to commercially fishing in 2001. In 2003, the West Coast Estuary Interim Managed Fishery Management Plan was implemented, incorporating the Swan-Canning (Area 1 of the fishery) and Peel-Harvey (Area 2) estuaries. In 2014, the West Coast Estuary Managed Fishery Management Plan was formalised, which also included the Hardy Inlet (Area 3). Since 1999, a single licencee has operated in Hardy Inlet, targeting finfish (Figure 6.3). Since 2009, a single licencee has operated in the Swan-Canning Estuary, primarily targeting blue swimmer crabs (only crabs have been retained since 2013).

Throughout the history of the fishery, the Peel-Harvey Estuary has been the area of the fishery with the highest finfish production (Figure 6.3). The number of vessels operating in this estuary declined substantially from about 45 to about 10 between 1980 and 2000, resulting in a decline in annual finfish landings from ~700 t to ~150 t

over the same period. In addition to this major reduction in vessels, commercial effort and finfish landings in this estuary have also been affected by several other major events: i) major environmental changes (eutrophication leading to algal blooms in 1980s and 1990s, then implementation of Dawesville Cut in 1994 leading to increased marine influence) which affected catchability and species composition; ii) change from gill nets to pots to target crabs in the period 1996-1999 which eliminated the finfish by-product that had previously been taken while targeting crabs; iii) implementation of the first formal Harvest Strategy for finfish in 2015.

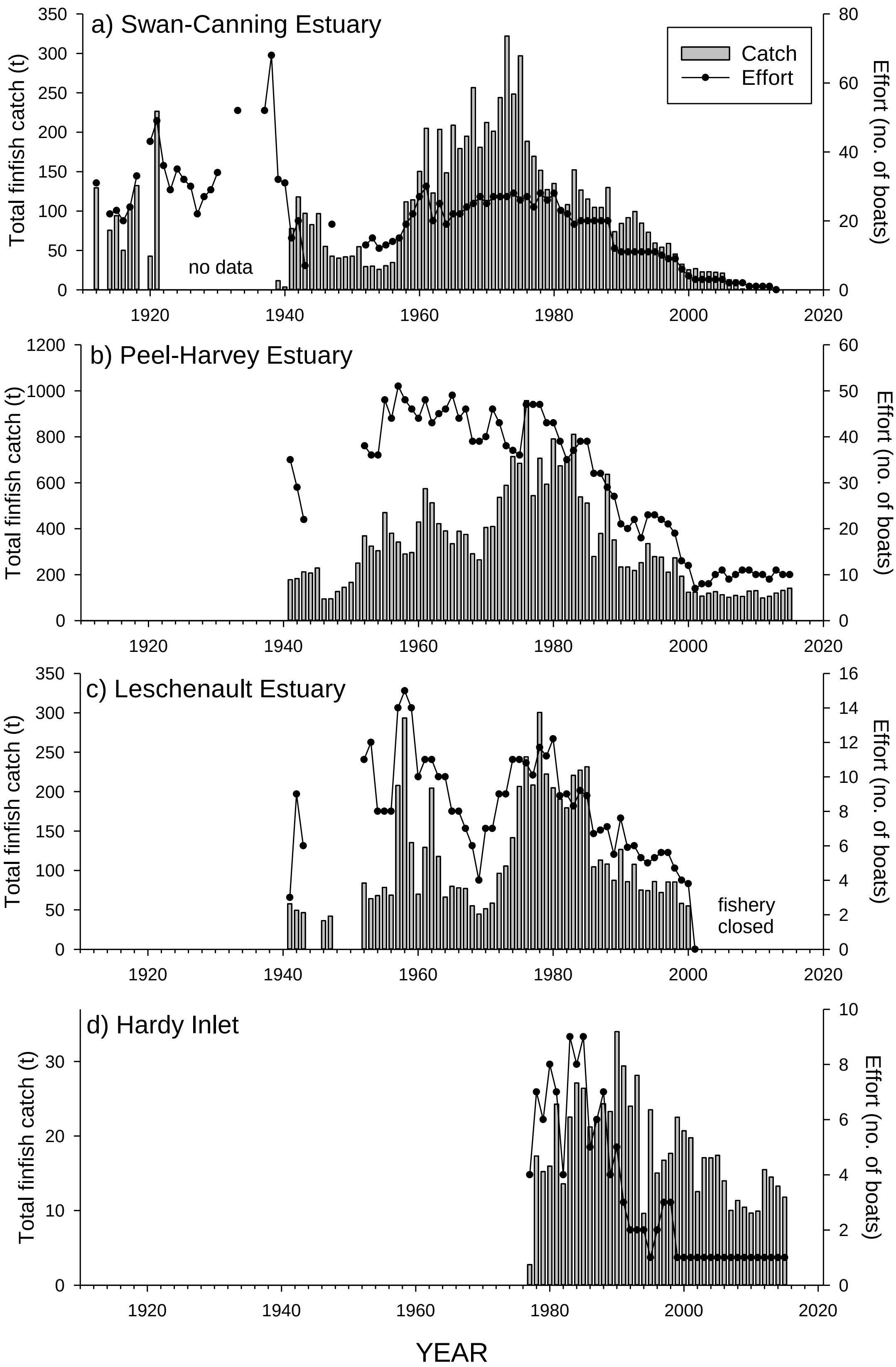


Figure 6.3. Annual total retained finfish catches (tonnes) and fishing effort (number of active boats) in each area of the commercial West Coast Estuarine Managed Fishery between 1912 to 2015, the year of the first formal Harvest Strategy.

6.2.2 Current Fishing Activities

The WCEMF currently comprises the Swan-Canning Estuary (Area 1), the Peel-Harvey Estuary (Area 2), and the Hardy Inlet (Area 3) (Figure 6.4). The fishery operates in all months. The finfish catch is sold on domestic markets. The Peel-Harvey Estuary commercial fishery operates in accordance with a formal Harvest Strategy and sea mullet landings in this estuary received Marine Stewardship Council (MSC) certification in June 2016 (DoF 2015, Johnston et al. 2015).

Table 6.3. Summary of key attributes of the WCEMF in 2020

Attribute	
Fishing methods	Haul net, set net, prawn net, beam trawl net, crab pot
Fishing capacity	Area 1: 4000 m of haul net, 6000 m of set net. Area 2: 12000 m of haul net, 12000 m of set net, 96 m of beam trawl, 420 crab pots. Area 3: 1000 m of net (haul or set)
Number of licences	1 (Area 1); 8 (Area 2); 1 (Area 3)
Number of vessels	1 (Area 1); 8 (Area 2); 1 (Area 3)
Number of people employed	1 (Area 1); ~12 (Area 2); 2 (Area 3)
Value of fishery	Level 1 (< $1million)

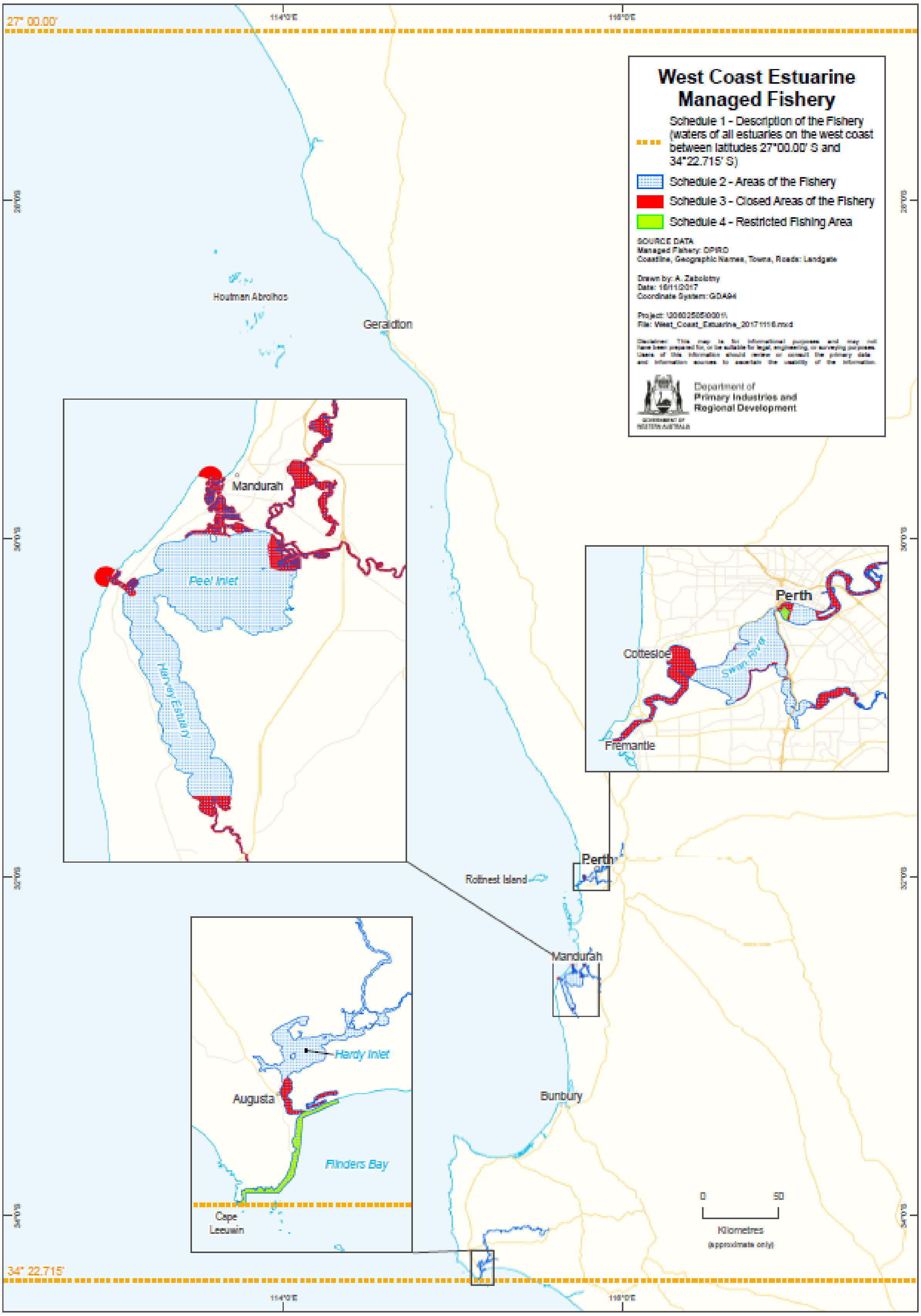


Figure 6.4. Boundaries of the West Coast Estuarine Managed Fishery and its closed areas.

6.2.3 Fishing Methods and Gear

Haul nets and gill nets are used to capture finfish in the Peel-Harvey Estuary and the Hardy Inlet, while the Swan-Canning Estuary licencee uses set nets.

6.3 Shark Bay Beach Seine and Mesh Net Managed Fishery

6.3.1 History of Development

Commercial beach seining for scalefish in the inner gulfs of Shark Bay dates to the early 1900s (Lenanton 1970, Cooper 1997). Pearling commenced in the mid-1800s but declined during the 1920s and 1930s as pearl stocks became depleted. Initially, pearl fishers supplemented their income with beach seining. After the Second World War, pearling was abandoned, and beach seining became the sole source of income. As is the case today, whiting were the primary target species.

During the early years of the fishery, some of the product was exported to Singapore and to eastern Australian states. In the 1940s and 1950s, the building of roads and the introduction of freezer trucks and frozen storage facilities allowed the fishery to expand into local markets. Effort and catches progressively increased until the mid-1960s, when catches began to decline as a result of the combined effects of overfishing (of whiting and bream) and a decline in market demand. Following the decline of the fishery in the 1960s, catch and effort stabilised at lower levels during the 1970s and 1980s due mainly to self-regulation by the licensees and processors, before again declining in the early 1990s (Figure 6.5). In 1992, the fishery which is one of the longest running commercial fisheries in WA, came under formal management for the first time with the creation of the Shark Bay Beach Seine and Mesh Net Fishery Managed Fishery (SBBSMNF) (See *Shark Bay Beach Seine and Mesh Net Management Plan 1992*). Following the formalisation of the Management Plan, effort in the fishery was consistent through to 2011 before a further decline was evident.

The SBBSMNF operates from Denham and uses a combination of beach seine and haul net gears to mainly take four species/groups: whiting (mostly yellowfin whiting, *Sillago schomburgkii*, with some golden-lined whiting, *S. analis*), sea mullet (*Mugil cephalus*), tailor (*Pomatomus saltatrix*) and western yellowfin bream (*Acanthopagrus latus*) (Jackson et al. 2012).

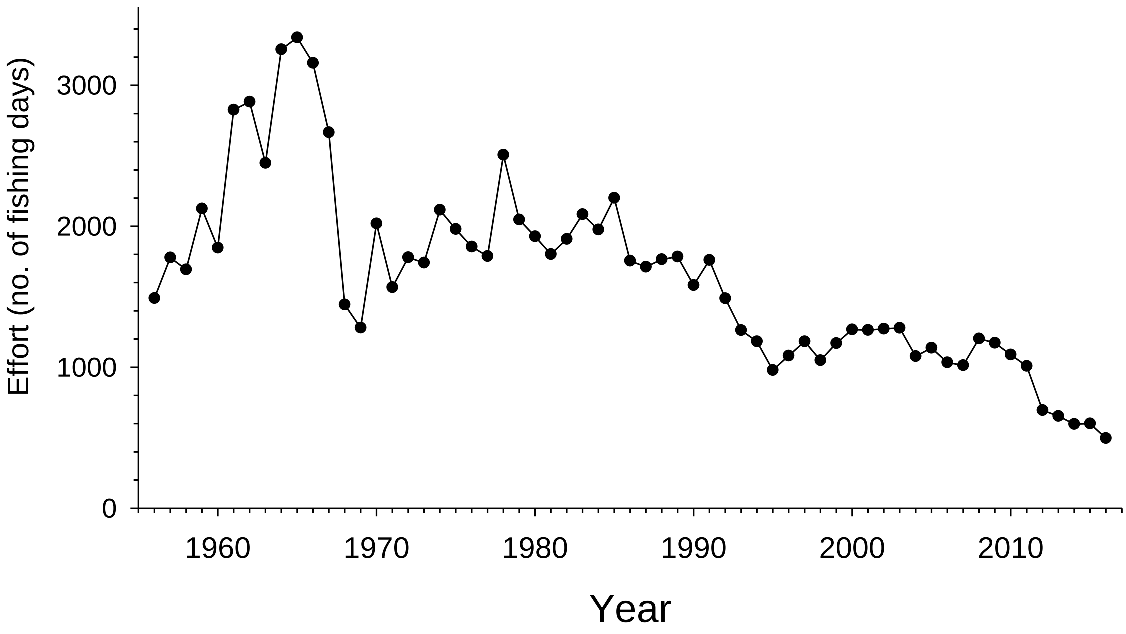


Figure 6.5. Annual effort (number of days) in the commercial SBBSMNMF between 1956 and 2016.

6.3.2 Current Fishing Activities

The current fishery covers the inner gulfs of Shark Bay (Figure 6.6) and operates all year round with catch and effort peaking in autumn/winter and reaching a minimum in October-December. Most of the catch is processed locally (Denham), which sets weekly quotas and commercially acceptable size limits. The processor supplies the local market, with product also sent to markets in Perth and eastern Australia. There are 12 licences in the fishery, but only ~7 vessels have been active in recent years.

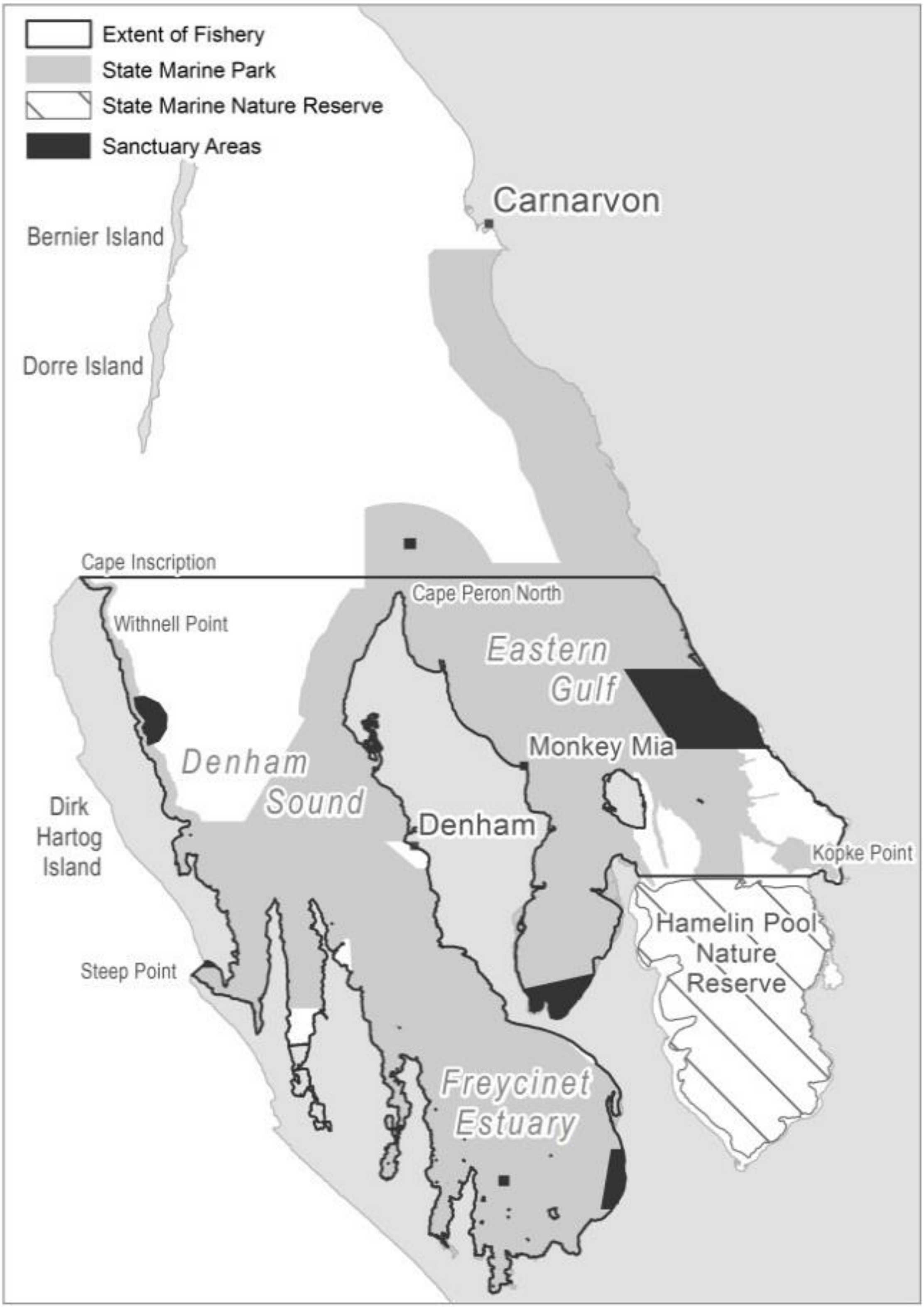


Figure 6.6. Shark Bay Beach Seine and Mesh Net Managed Fishery boundaries and Shark Bay Marine Park boundaries in inner Shark Bay.

Table 6.4. Summary of key attributes of the SBBSMN commercial fishery in 2015

Attribute	
Fishing methods	Beach seine, haul net, gill net
Fishing capacity	n/a
Number of licences	12
Number of vessels	12 (~7 active)
Size of vessels	<12 m
Number of people employed	~14
Value of fishery	Level 2 ($1-5million)

6.3.3 Fishing Methods and Gear

Two net types are used in the SBBSNMF. Beach seines usually consist of two long panels of net ("wings") and a loose section of net to concentrate fish ("bunt"). Haul nets usually consist of a straight panel of gill net, which may incorporate a pocket or bunt of a different mesh size. Haul nets are deployed from, and retrieved to, a boat. Haul nets may be used to capture at the surface only, in deeper waters, or in the entire water column in shallow waters.

Deployment and retrieval of both haul and seine nets are active (i.e., nets are not set for long periods), and fishers must be in attendance while the net is set. Each species is targeted under specific conditions. For example, fishing for whiting occurs on incoming tides. For all species, fishing occurs during daylight hours.

A large proportion of fishing time is spent searching for schools of fish. Fishers will search for fish from boats or from shore (either standing on the beach or from an elevated position). Historically, when searching for whiting fishers travelled slowly, either spotting fish or observing feeding marks in the sediment. From such marks, fishers could estimate the size of the school and the direction of travel. Since the early 1980s, jet boats have been used that allow fishers to travel quickly and search large areas. The disadvantage of jet boats is that they scare fish more easily. However, fishers try to avoid this by moving the boat into deeper water where fishing does not occur. Nets may be hauled to shore or to a boat. In both cases, the net is deployed from a boat to rapidly encircle the school. The tide and behaviour of each species determines how the net is deployed. For example, when targeted during an incoming tide, whiting will run towards the shore. However, if targeted during an outgoing tide, or when resting, whiting will run towards deeper water (Lenanton 1970).

The net is hauled manually whether it is being retrieved to a beach or to a boat. Winches are not used. When a large school is found, the team may target it several times, taking partial quantities on each occasion. Alternatively, several teams may work together to target a large school, which allows them to obtain a large catch in a single net shot. Individual catches may be up to 20 tonnes.

Fishing trip durations by teams may be up to a week. Teams may trailer their vessels when travelling to distant fishing grounds, or travel by sea. Immediately after capture, fish are placed in plastic tubs in refrigerated brine. The catch is generally transported by truck to the processing factory within 24 hours of capture. Most of the catch is marketed through the local fish processing factory in Denham. Fish are sold whole or filleted, both locally and in the eastern states. At present, two trucks per week are employed to transport fish from the factory. Fishers tend to time their catches to coincide with truck departures, to ensure maximum product quality.

Whiting are caught using beach seines. Whiting catches mainly occur from April to September, when tides are high, and fishers can most easily access shallow banks (Lenanton 1970). Also, minimal winds at these times result in calm conditions and allow fish to be observed easily. Sea mullet catches mainly occur from January to May. After this period, sea mullet commence spawning in deeper water (and become inaccessible to fishers) or have completed spawning and are in poor condition (low market value). The processing factory effectively determines the fishing season for sea mullet by refusing to accept catches during the spawning and post-spawning periods. The fishing season for tailor coincides approximately with that of sea mullet. Catch levels are strongly influenced by the processing factory, which sets catch quotas for tailor in order to maintain prices within the limited market demand for this species. Western yellowfin bream catches mainly occur in August, when fish form dense spawning aggregations and thus are highly accessible to fishers.

6.4 Recreational Fishery

6.4.1 History of Development

Since 2 March 2010, all persons fishing from a powered boat anywhere in WA have been required to hold a *recreational fishing from boat licence* (RFBL) or fish in the company of a licence holder. The RFBL provides a state-wide database of recreational boat fishers that can be used for survey purposes. State-wide boat-based fishing surveys now provide regular estimates of the boat-based catch of nearshore finfish in each Bioregion.

Shore-based line fishing does not require a licence. Lack of a suitable licence database has prohibited any comprehensive surveys of shore-based fishing from being undertaken in recent years. There have been some partial surveys of this sector, but no state-wide estimates of annual catch or effort by this sector are currently available.

A major review of recreational fishing management arrangements was completed in February 2013. At this time, a single state-wide (‘resource-based’) system of rules replaced the previous bioregion-based rules. For nearshore finfish, a mixed species total possession limit of 16 fish was implemented.

Refer to Section 7.1.3 for the history of management arrangements for key recreational species.

6.4.2 *Current Fishing Activities*

Recreational fishing for nearshore finfish is undertaken in coastal waters and the lower parts of estuaries, by shore- and boat-based fishers. It is an accessible activity with relatively high participation rates and has high social value in WA.

6.4.3 *Fishing Methods and Gear*

Recreational fishers predominantly target nearshore indicator species using rod and line, from the shore or a boat. Minor quantities are also harvested by other methods such as netting and spear fishing. Bait is used, although soft plastic lures are an increasingly popular replacement for bait.

6.5 Customary Fishing

None known in the WCB and SCB.

6.6 Illegal, Unreported or Unregulated Fishing

Illegal activities (possession and size limit breaches) by recreational fishers are regularly detected by compliance officers. However, the proportion of the total recreational catch/effort represented by illegal activity is unquantified.

---

7 Fishery Management

7.1 Management System

This resource is harvested using a constant exploitation approach, where the annual catch taken is assumed to vary in proportion to variations in the stock abundance.

The Fish Resources Management Act 1994 (FRMA) provides the overarching legislative framework to implement the management arrangements for the fisheries in south-western WA. Management arrangements for each fishery are described in detail in management plans and other legislation. Generally, measures to regulate effort/catch include:

- Limited entry
- Gear restrictions
- Species restrictions
- Minimum legal sizes limits for some species
- Seasonal and time closures
- Spatial closures

7.1.1 *The West Coast Estuarine Managed Fishery*

The West Coast Estuarine Managed Fishery (WCEMF) is a multi-species fishery and encompasses the waters of all estuaries on the west coast of Western Australia between latitudes 27°00.00’S in the north and 34° 22.715’S in the south and all the affluents, rivers, streams and tributaries that flow into those estuaries. The WCEMF

is managed under the *West Coast Estuarine Managed Fishery Management Plan 2014* and is divided into three areas:

- Area 1: incorporating the Swan and Canning Rivers;
- Area 2: incorporating the waters of the Peel Inlet and Harvey Estuary, together with the Murray, Serpentine, Harvey, and Dandalup Rivers and all their tributaries and affluents;
- Area 3: incorporating waters of the Hardy Inlet and Blackwood River.

The majority of the commercial catch of estuarine and nearshore finfish in the West Coast Bioregion is taken by the Peel-Harvey Estuary Fishery (Area 2 of the WCEMF), which has been certified as sustainable against the highly regarded MSC Standard for Sustainable Fishing since 2016. Finfish catches are taken mainly using haul nets to visually target schools of fish, employing different net lengths and mesh sizes to catch fish of different species or sizes throughout the estuary. The fishers in the Peel-Harvey Estuary primarily target sea mullet and yellowfin whiting to supply local markets.

7.1.2 Shark Bay Beach Seine and Mesh Net Managed Fishery

The *Shark Bay Beach Seine and Mesh Net Limited Entry Fishery Notice 1992* permits the use of any net, except otter trawl, to capture fish subject to the following controls:

- Mesh not less than 48 mm for taking whiting
- Mesh not less than 86 mm for taking mullet
- Mesh not less than 26 mm (and maximum 38 mm) and maximum total length 200 m with a pocket of 30 m maximum length, for taking garfish

The fishery is limited entry. A licence may be transferred to a family member. A fishing unit comprises one primary vessel up to 12 m, a maximum of three netting dinghies and a maximum fishing team of three fishers (including the licensee). Jet boats are permitted to be used in the fishery to carry the team and nets. There are no restrictions on engine capacity.

Fishing is prohibited within the sanctuary zones associated with the Shark Bay Marine Park (e.g., Hamelin Pool, Big Lagoon). In addition, the Denham town site was closed to fishing in 2007. Fishers voluntarily avoid areas of high conflict with tourists and other stakeholders.

There are currently no catch or effort quotas in the fishery. Commercial line-fishing for pink snapper and other species has not been permitted in these waters since 1996.

7.1.3 *Recreational / Charter Fishery*

Currently, recreational fishing for a subset of key nearshore finfish is subject to a mixed species daily possession limit of 16 fish[6]. Within this there are size and bag limits for particular species including:

- tailor: size limit 300 mm, bag limit 8 fish (only 2 fish over 500 mm)
- skipjack trevally: 250 mm, bag limit 8
- WA salmon: 300 mm, bag limit 4
- King George whiting: 280 mm, bag limit 12

For the remainder of nearshore finfish (including whiting, mullet and garfish species, and Australian herring) a mixed species daily possession limit of 30 fish applies. Within this there is a bag limit of 12 Australian herring.

Whitebait is classified as a baitfish, for which there is a mixed species daily bag limit of 9 litres.

Since 2 March 2010, all persons fishing from a powered boat anywhere in WA have been required to hold a RFBL or fish in the company of a licence holder. The RFBL provides a state-wide database of recreational boat fishers that can be used for survey purposes.

Since 1992, a recreational fishing licence have been required for all recreational net fishing using set (gill) nets, haul nets or throw nets. Recreational net fishing is only permitted in WA's marine and estuarine waters, not in freshwater. Further, most of WA's estuarine waters are closed to protect juvenile fish stocks. Set netting is now prohibited in all ocean waters of WA except for in the Gascoyne Coast Bioregion.

Recreational netting regulations are complex. Full details are given in the current edition of the '*Recreational Net Fishing Guide'*. Fishers must comply with the numerous spatial closures to netting, especially in close proximity to towns, cities and closed areas such as marine parks. In general, netters must lift and clean their nets of the fish at least once an hour. Fishers must stay within 100 m of their net at all times whilst fishing. There are gear restrictions with respect to the types of permitted net, mesh size, length, and depth/drop:

- Set nets, ocean: 60 m max. length, 75-114 mm mesh size, 25 mesh cells max. depth
- Set nets, inland: 60 m max. length, 63-87 mm mesh size, 25 mesh cells max. depth
- Haul nets: 60 m max. length, 51-114 mm mesh size, 25 mesh cells max. depth
- Throw nets: max. radius 3 m, max. mesh size 25 mm

Western Australian salmon: A legal minimum length (LML) of 300 mm introduced in 1975 (the previous LML in inches was ~25cm). A daily bag limit of 5 salmon was introduced in 1978. In 1991 salmon was defined as a 'prize fish' with bag limit of 4

[6] See http://www.fish.wa.gov.au/Fishing-and-Aquaculture/Recreational-Fishing/Recreational-Fishing-Rules/Bag_And_Size_Limits/Pages/default.aspx for current rules.

salmon within a mixed species bag of 8 fish within this category. In 2013 state-wide rules were introduced (previously bioregional) and salmon was defined as a ‘nearshore fish’ with a bag limit of 4 salmon within a mixed species bag of 16 fish within this category. LML is currently 300 mm.

Australian herring: A LML has applied to herring since at least 1913, with variations as follows: 6 inches (implemented in 1913), 7 inches (1937), 7.875 inches/ 177.8 mm (1973) and 180 mm (1975). These limits applied to both commercial and recreational fishers until 1991 when the LML for recreationally caught herring was removed. There is currently no size limit on herring. In June 1991 herring were placed in a ‘low risk’ finfish category. A mixed species recreational bag limit of 40 applied to this group until October 2009. On 15 October 2009, the daily bag limit for this group was reduced to 30 fish in the WCB, while remaining at 40 fish in the SCB. In February 2013, a state-wide mixed species daily bag limit of 30 ‘other finfish’ (including herring) was implemented in all bioregions. In March 2015 the specific bag limit for herring was reduced to 12, whilst still remaining within the state-wide mixed species daily bag limit of 30 ‘other finfish’.

7.2 Harvest Strategy

The Estuarine and Nearshore Finfish Resource of South-West Western Australia Harvest Strategy 2020 – 2025 (DPIRD 2020) outlines the long- and short-term objectives for management. 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.

This harvest strategy relates to the estuarine and nearshore finfish resource of south-west WA and the fishing activities that impact this resource. For the purpose of this harvest strategy, the estuarine and nearshore finfish resource of south-west WA covers all nearshore and estuarine waters within the West Coast Bioregion (Black Point, east of Augusta, to the Zuytdorp Cliffs, north of Kalbarri, all land and water south of 27° S and west of 115° 30' E) (Figure 3.1). Estuarine and nearshore finfish are targeted by a number of small-scale commercial fisheries and recreational fishers. The majority of commercial catches are taken by haul and gillnetting, whilst recreational catches are taken by line fishing from the shore or from a boat as well as netting.

The estuarine and nearshore finfish resource in the south-west WA resource comprises more than 15 species, however, this harvest strategy is focused on one of the key target species for which biomass-based stock assessments are undertaken periodically — sea mullet (*Mugil cephalus*). Although often referred to as an indicator species, it is recognised that the status of this stock may not be indicative of the status of the overall resource, which includes marine and estuarine species with wide-ranging life history characteristics. Management action will thus be applied at the most appropriate level (area, stock, or broader resource) on a case-by-case basis.

Stocks of several estuarine and nearshore finfish species in south-west WA, including sea mullet, extend to the coastal waters off the South Coast Bioregion and northwards to Shark Bay in the Gascoyne Coast Bioregion. The assessments of these species against relevant ecological objectives are undertaken at the broader stock level, with that for sea mullet primarily considered within this south-west harvest strategy. A separate harvest strategy is being developed for estuarine and nearshore finfish in the Gascoyne Coast Bioregion, which will consider the assessments of stocks caught primarily in that region, as well as fishery-specific performance indicators relevant to the Shark Bay fishery. A separate harvest strategy will also be developed for Australian herring (*Arripis georgianus*) and West Australian salmon (*Arripis truttaceus*), the range of which extends across multiple jurisdictions.

Whilst not considered primary species for the purpose of this harvest strategy, stock assessments are also undertaken occasionally for other estuarine and nearshore species important to commercial and/or recreational fishers in south-west WA, for example yellowfin whiting (*Sillago schomburgkii*). These assessments are typically triggered when annual risk assessments of all retained species (primarily based on catch information and inherent vulnerability to fishing) suggest that the risk to stocks may have increased. A summary of the approach used to determine the reference levels in presented in Appendix 1.

Target Species

The status of primary target species of the estuarine and nearshore finfish resource in south-west WA is assessed periodically (at least every five years) using a weight-of-evidence approach of all available data. The current harvest strategy for sea mullet is primarily based on estimates of biomass (B) relative to the unfished level (B_0), or a suitable proxy (Table 7.1). The estimates of B/B_0 are periodically compared to reference levels as outlined in the Department’s Harvest Strategy Policy (DoF 2015).

Recognising the naturally fluctuating stock levels of many estuarine and nearshore finfish species, this harvest strategy aims to maintain the stock biomass at a level above that at which Maximum Sustainable Yield (MSY) can be achieved, i.e., $B > B_{MSY}$ (Table 7.1). Any stock size above this level is therefore consistent with meeting the objectives for biological sustainability and also satisfy stock status requirements under the MSC standard for sustainable fishing.

Due to the inherent uncertainty around estimates of B_{MSY} and the selection of suitable proxy reference points (e.g., Punt et al. 2014), this is applied as a threshold reference level (i.e., below which exploitation will be reduced) rather than as a target level, to ensure management is more precautionary. Where B_{MSY} can be estimated, the limit reference level for each stock is set at $0.5B_{MSY}$, which is consistent with guidelines for meeting the MSC standard.

All Retained Species

Risk (vulnerability) assessments are undertaken annually for estuarine and nearshore finfish species in south-west WA to identify if there have been any substantial changes, particularly in the catches of these species relative to historic

levels. If an increase in risk is identified, the reasons for the variation will be assessed (Table 7.1).

For example, an increase in the commercial catch of yellowfin whiting in the Peel-Harvey Estuary in 2013 and 2014 triggered the collection of age composition data to determine if the increased catch posed a risk to the sustainability of the broader stock (Smith et al. 2019). The assessment demonstrated that the increase in catch was associated with a period of above-average recruitment to the fishery and the stock was assessed to be at an acceptable level.

Other Ecological Assets

Other ecological assets incorporated in this harvest strategy include bycatch, ETP species, habitats and ecosystem processes that may be affected by commercial and recreational fishing activities in the Peel-Harvey Estuary (Table 7.1). For all ecological components, reference levels have been set to differentiate acceptable fishery impacts from unacceptable fishery impacts according to the risk levels defined in Fletcher (2015). An ecological risk assessment for the Peel-Harvey Estuary fishery was undertaken in September 2020 (Fisher et al. 2020) to inform these components of the harvest strategy, with these risk scores to be reviewed after no more than five years (see Section 3.6.2.3).

Application of Harvest Control Rules

For each ecological performance indicator and reference level, an accompanying Harvest Control Rule (HCR) directs the management needed to meet sustainability objectives (Table 7.1). These HCRs are designed to maintain the resource above the threshold (i.e., in the target area), or rebuild it where it has fallen below the threshold (undesirable) or the limit (unacceptable) levels.

For each primary target species, a decrease in stock levels below the threshold reference level (i.e., B_{MSY}) will trigger a reduction in catch by up to 50% of the current harvest level, applicable to each relevant fishery/sector (Table 7.1). A review will be undertaken within three months to determine the level of reduction that is expected to rebuild the stock to the target area (i.e., above threshold), which will be dependent on the extent by which the threshold has been breached and the required rebuilding rate.

For the commercial sector, the harvest level from which the catch reduction is calculated is the average catch observed in the three years leading up to the breach, to allow for inter-annual variability in catches. The catch reduction may be achieved by setting a nominal catch limit to ensure commercial catches do not exceed the benchmark that is expected to rebuild the stock. Alternatively, an equivalent decrease in catch can be achieved by reducing the fishing effort, for example through gear restrictions or reducing the length of the fishing season through the implementation of temporal closures.

As recreational catch information for the primary target species is often incomplete or uncertain, implementing the HCR as a reduction of current catch estimated for this sector may not be appropriate. A catch reduction for this sector will instead typically be applied indirectly through an equivalent reduction in the current bag/boat limit

and/or the length of the fishing season expected to achieve the required response. Where data are available to suggest the current bag/boat limit is often not achieved by fishers, the review may determine that a stronger management response is necessary to achieve the desired catch reduction. For species where a large proportion of catches are released, temporal closures are more likely to achieve a reduction in recreational fishing pressure that a reduction in bag/boat limits.

If a primary target species falls below the limit reference level (i.e., $0.5B_{MSY}$), measures to reduce the catch (average of last three years) by at least 50% will be implemented as soon as practicable (Table 7.1). Within three months of the breach, the review will then determine what additional management actions are needed to recover the stock within two generation times (see section below on recovering depleted stocks).

For more information on the management tools available to achieve the catch reductions specified by the HCR, and the legal instrument under which the management measure occurs, see Section 7.1.

Recovering Depleted Stocks

A resource that has fallen below the acceptable level, and for which suitable management adjustments have been implemented to reduce catch and/or effort (as outlined in the HCRs), is considered to be in a recovery phase (DoF 2015). For target stocks that fall below the limit reference level, a recovery strategy will be developed and implemented to ensure that the resource can rebuild at an acceptable rate (i.e., within two generations time). Where the environmental conditions have led, or contributed significantly, to the resource being at an unacceptable level, the strategy needs to consider how this may affect the speed and extent of recovery.

Table 7.1. Harvest strategy performance indicators, reference levels and control rules for the estuarine and nearshore finfish resource of south-west WA, and other ecological assets that may be impacted by fishing activities in the Peel-Harvey Estuary.

Component	Management objectives	Resource / Asset	Performance Indicators	Reference Levels	Control Rules
Target species	To maintain spawning stock biomass of each target species at a level where the main factor affecting recruitment is the environment.	Primary target species: Sea mullet	Periodic (at least every five years) estimates of biomass relative to the unfished level (B/B_0)	Target: $> B_{MSY}$	Continue management aimed at achieving ecological, economic, and social objectives.
				Threshold: B_{MSY}	If the threshold level is breached, a review will be completed within three months to develop an appropriate management response. Management action (applicable to all relevant fisheries/sectors) will be taken to reduce catches by up to 50%[7] of the current harvest level to return stock to the target level.

[7] The level of catch reduction to the relevant fisheries/sectors will be dependent on the extent by which the reference level has been breached, and the required rebuilding rate.

Component	Management objectives	Resource / Asset	Performance Indicators	Reference Levels	Control Rules
				Limit: $0.5B_{MSY}$	If the limit level is breached, management action (applicable to all relevant fisheries/sectors) will be taken as soon as practicable to reduce catches by at least 50% of the current harvest level. A review will be completed within three months to determine what additional management actions (up to 100% catch reduction[4]) are required to rebuild the stock to the target level within two generation times (i.e., informing the recovery strategy for the stock).
Retained species	To maintain spawning stock biomass of each retained species at a level where the main factor affecting	All retained species	Annual risk (vulnerability) assessments incorporating: current management arrangements, available data on fishing effort and catch (relative	Target: Fishing impacts are expected to generate an acceptable risk level to all retained species' populations, i.e., medium risk or lower.	Continue management aimed at achieving ecological, economic, and social objectives.

Component	Management objectives	Resource / Asset	Performance Indicators	Reference Levels	Control Rules
	recruitment is the environment.		to MSY or historical levels), fishery-independent recruitment information, species information, and other available research.	Thresholds: A potentially material change to risk levels is identified; or Fishing impacts are considered to generate an undesirable level of risk to any retained species' populations, i.e., high risk.	Review the reasons for this variation within three months and implement an appropriate management response to reduce risk to an acceptable level as soon as practicable. This may include additional monitoring and/or undertaking a biomass-based stock assessment.
				Limit: Fishing impacts are considered to generate an unacceptable level of risk to any retained species' populations, i.e., severe risk.	Initiate an immediate management response to reduce the risk to an acceptable level as soon as practicable.
Bycatch (non-ETP) species	To ensure fishing impacts do not result in serious or irreversible harm to bycatch species' populations.	All (non-ETP) bycatch species in the Peel-Harvey Estuary	Periodic risk assessments incorporating: current management arrangements,	**Target:** Fishing impacts are expected to generate an acceptable risk level to all bycatch species' populations, i.e., medium risk or lower.	Continue management aimed at achieving ecological, economic, and social objectives.

Component	Management objectives	Resource / Asset	Performance Indicators	Reference Levels	Control Rules
			annual commercial fishing effort and catch (including unwanted catch that is discarded), available information on recreational fishing effort and catch (including unwanted catch that is discarded), review of alternative measures to minimise unwanted catch, species information, and other available research	**Thresholds:** A potentially material change to risk levels is identified; or Fishing impacts are considered to generate an undesirable level of risk to any bycatch species' populations, i.e., high risk.	Review the reasons for this variation within three months and implement an appropriate management response to reduce risk to an acceptable level as soon as practicable.
				Limit: Fishing impacts are considered to generate an unacceptable level of risk to any bycatch species' populations, i.e., severe risk.	Initiate an immediate management response to reduce the risk to an acceptable level as soon as practicable.
Endangered, threatened and protected (ETP) species	To ensure fishing impacts do not result in serious or irreversible harm to ETP species' populations	All ETP species in the Peel-Harvey Estuary	Periodic risk assessments incorporating: current management arrangements,	**Target:** Fishing impacts are considered to generate an acceptable level of risk to all ETP species' populations, i.e., medium risk or lower.	Continue management aimed at achieving ecological, economic, and social objectives.

Component	Management objectives	Resource / Asset	Performance Indicators	Reference Levels	Control Rules
			annual commercial fishing effort and catch, available information on recreational fishing effort and catch, number of reported ETP species interactions, species information, and other available research	**Thresholds:** A potentially material change to risk levels is identified; or Fishing impacts are considered to generate an undesirable level of risk to any ETP species' populations, i.e., high risk.	Review the reasons for this variation within three months and implement an appropriate management response to reduce risk to an acceptable level as soon as practicable.
				Limit: Fishing impacts are considered to generate an unacceptable level of risk to any ETP species' populations, i.e., severe risk.	Initiate an immediate management response to reduce the risk to an acceptable level as soon as practicable.
Habitats	To ensure the effects of fishing do not result in serious or irreversible harm to habitat	Benthic and nearshore habitats in the Peel-Harvey Estuary	Periodic risk assessments incorporating: current management arrangements,	**Target:** Fishing impacts are considered to generate an acceptable level of risk to all benthic habitats, i.e., medium risk or lower.	Continue management aimed at achieving ecological, economic, and social objectives.

Component	Management objectives	Resource / Asset	Performance Indicators	Reference Levels	Control Rules
	structure and function		annual commercial fishing effort, available information on recreational fishing effort, extent of area fished, and other available research	**Thresholds:** A potentially material change to risk levels is identified; or Fishing impacts are considered to generate an undesirable level of risk to any benthic habitats, i.e., high risk.	Review the reasons for this variation within three months and implement an appropriate management response to reduce risk to an acceptable level as soon as practicable.
				Limit: Fishing impacts are considered to generate an unacceptable level of risk to any benthic habitats, i.e., severe risk.	Initiate an immediate management response to reduce the risk to an acceptable level as soon as practicable.
Ecosystem	To ensure the effects of fishing do not result in serious or irreversible harm to ecological processes	Trophic interactions Community structure (in the Peel-Harvey Estuary)	Periodic risk assessments incorporating: current management arrangements, annual fishing effort and catch,	**Target:** Fishing impacts are expected to generate an acceptable level of risk to all ecological processes within the ecosystem, i.e., medium risk or lower.	Continue management aimed at achieving ecological, economic, and social objectives.

Component	Management objectives	Resource / Asset	Performance Indicators	Reference Levels	Control Rules
			number of reported ETP species interactions species information, extent of area fished annually, and other available research	**Thresholds:** A potentially material change to risk levels is identified; or Fishing impacts are considered to generate an undesirable level of risk to any ecological processes within the ecosystem, i.e., high risk.	Review the reasons for this variation within three months and implement an appropriate management response to reduce risk to an acceptable level as soon as practicable.
				Limit: Fishing impacts are considered to generate an unacceptable level of risk to any ecological processes within the ecosystem, i.e., severe risk	Initiate an immediate management response to reduce the risk to an acceptable level as soon as practicable.

7.3 External Influences

External influences include other activities and factors that occur within the aquatic environment that may impact on the productivity and sustainability of fisheries resources and their ecosystems. The main external influences included here are environmental factors, introduced pest species, market influences, and non-WA managed fisheries.

7.3.1 Environmental Factors

Landings of WA salmon and Australian herring are strongly influenced by the Leeuwin Current and coastal water temperatures. Commercial fishers in the WCB and SCB report that schools will move offshore (becoming unavailable to beach-based fishers) to avoid patches of warm water near the shore. Low catches in the SWCSMF typically occur during years of strong Leeuwin Current (resulting in warmer water along the west coast of WA).

Over the extensive spatial distribution of southern nearshore finfish (from Shark Bay in the GCB to the SCB) there is a gradient in average ocean temperature. For species which span a large part of this range, growth rates may differ in each region (typically faster growth in north). For example, Australian herring grow faster and attain maturity earlier in the WCB compared to the SCB. Different temperature regimes in each region also result in different spawning times. For example, yellowfin whiting spawn earlier (August-December) in the GCB compared to the WCB (November-March). Water temperature has also been shown to be positively correlated with YFW recruitment (Smith et al. 2019).

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 resulted in increased catches of some species and widespread mortalities of others.

7.3.2 Introduced Pest Species

No known issues directly affecting target species.

Anecdotal evidence suggests the mass mortality of pilchards in the 1990s, due to herpes virus, caused WA salmon to shift from consuming pilchards (formerly an important prey item) to other species, e.g., Australian herring, southern garfish. Thus, the event may have affected growth, condition, natural mortality, etc. of various nearshore species.

7.3.3 Market Influences

During the 1970s and early 1980s, large quantities of sea mullet were sold as bait, primarily for the Western Rock Lobster Managed Fishery. In recent years, sea mullet is primarily sold in smaller quantities for human consumption. A smaller portion of the catch is used as bait by those fishers in the WCEMF Area 2 who are also licenced to catch blue swimmer crabs in the estuary. This market shift and change in demand has substantially influenced catches of sea mullet in the WCEMF Area 2, which are lower than historical levels. Low prices and lack of demand is also cited by commercial fishers as the reason for catch declines for some other nearshore species (e.g., yellow-eye mullet). Whiting species, whitebait and southern garfish are sold for human consumption, with relatively strong and consistent market demand for these species. Catch trends for these species are mainly driven by fish availability. There are limited markets for tailor, which is often taken as a by-product when targeting other species.

7.3.4 Non-WA Managed Fisheries

Many of the nearshore species are caught in other states, but they are thought to be separate breeding stocks to those occurring in WA, with the exception of Australian herring and WA salmon. Herring and salmon are targeted by commercial and recreational fishers in SA. Minor quantities of these species are also taken in Victoria and Tasmania.

7.3.5 Other Activities

Historical and current industrial and urban activities have various impacts on habitats in Cockburn Sound (dredging, groundwater contamination, effluent discharges/spills, vessel movements, etc). Most south-western estuaries are affected to some extent by anthropogenic factors such as eutrophication, altered river flow and habitat loss.

8 Information and Monitoring

8.1 Range of Information

There is a range of information available to support the assessment and harvest strategy for the southern nearshore finfish resource (see Table 8.1).

Table 8.1. Summary of information available for assessing southern nearshore finfish species, specifically the sea mullet (*Mugil cephalus*) and yellowfin whiting (*Sillago schomburgkii*).

Data type	Fishery-dependent or independent	Purpose / Use	Area of collection	Frequency of collection	History of collection
Commercial catch and effort statistics (CAES returns)	Dependent	Monitoring of commercial catch and effort trends, calculation of catch rates and the area fished	Statewide	Monthly	Since 1975. Historic data since 1940.
Recreational catch and effort estimates	Dependent	Monitoring of recreational catch and effort trends	State-wide, boat-based	Biennial	Since 2011
Catch at age data	Dependent	Age structure, estimation of total mortality	WCB, SCB	Periodic	Since ~2000
Recruitment index	Independent	Catch rates (index of recruitment strength) used to predict catches for season	WCB, SCB	Annual	Since 1995 (with periodic breaks)
Biological information	Dependent and independent	Patterns of growth and reproduction, stock structure	WCB, SCB, GCB	Intermittent	Since 1970s
Recreational voluntary daily logbook	Dependent	Monitoring abundance trends & size composition	WCB, SCB	Monthly	Since 2005

8.2 Monitoring

8.2.1 Commercial Catch and Effort

All fishers operating in the WCEMF and SBBSMNF are required to fill out and submit monthly statutory catch and effort statistics (CAES). These data have been used to provide the basis for ongoing stock assessment and are critical to the development of stock performance indices and harvest strategy evaluation.

Under the Fish Resources Management Act 1994 (FRMA), licensees involved in fishing operations and/or the master of every licensed fishing boat must submit an accurate and complete monthly catch and effort return on forms approved by the Department. These returns record the monthly catch totals (to the nearest kilogram) for each retained species, monthly effort (total days fished), estimates of daily effort (e.g., average hours fished per day, average length of net deployed per day) and spatial information by block (60 x 60 nm) fished, along with bycatch and threatened

species interactions, per method used. These data are collected and collated by DPIRD and stored in a Catch and Effort Statistics (CAES) database.

It should be noted that catch records for whiting species in CAES must be interpreted with caution as commercial fishers often do not report catches at the species level on their returns.

Reporting of effort by commercial fishers in their statutory CAES returns is also problematic as nearshore and estuarine commercial fisheries are multi-species and multi-gear. Catch and effort is reported as monthly summaries. Usually, the effort expended towards a particular species cannot be precisely quantified due to the monthly aggregation of data, although it may be possible to obtain a reasonable estimate in situations where the species is known to be the main target and makes up the majority of the catch.

In addition to 'number of days fished', fishers are required to report the 'mesh size', 'net length', 'hours fished per day' 'and 'number of shots per day' for each net type on their monthly returns. However, the single value given for the month does not allow for daily variations (which presumably occur) in each variable and is therefore potentially unreliable.

Also, 'hours fished' is open to interpretation by individual fishers. It could include searching, traveling and/or soak time depending on how fishers choose to quantify their effort. Searching/spotting is an integral part of beach seine and haul net fishing, but it can be difficult to quantify.

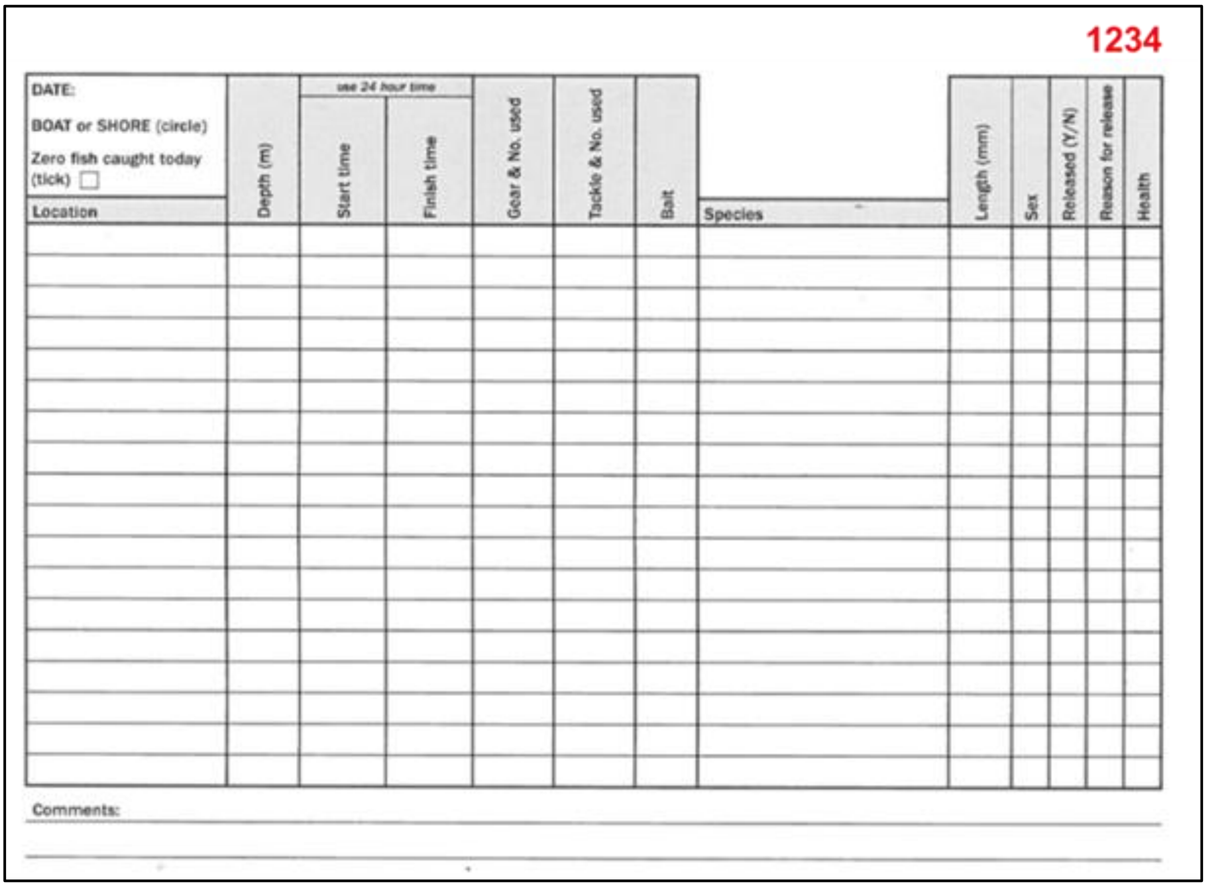
For the above reasons, it is generally not possible to detect fine-scale variations in total effort in commercial netting fisheries. Pre-1975, the number of licenced vessels in the fishery is often the only available measure of effort. Post-1975, 'method day' (the no. of days that a particular gear type was deployed within a block within a month, 'Bday' in CAES) is usually the most reliable measure of effort.

8.2.2 Recreational / Charter Catch and Effort

Since 2011, a biennial state-wide recreational survey has been undertaken to collect information on private (non-charter) recreational boat-based catch and effort in WA (Ryan et al. 2013, 2015, 2017, 2019). This survey uses three complementary components, off-site phone diary surveys, on-site boat ramp surveys and remote camera monitoring, to collect information on catch, effort, location, and other demographic information, every two to three years. The latest 2017/18 survey also collected some information on shore-based recreational fishing by surveyed fishers.

Since 2001, it has been a statutory requirement for boat-based charter fishing operators to submit monthly returns detailing catches and effort.

A voluntary recreational daily logbook scheme (Research Angler Program, RAP) commenced in 2004/05. Contributing fishers record information on their catch (no. of fish), effort (hours and fishing method/gear type and number used) and catch composition (size, sex, discard information), along with generalised spatial data (Figure 8.1). The majority of participants are in the WCB, including shore- and boat-based recreational fishers. The RAP provides some data not currently available from other sources, especially for shore-based fishing.


1234

DATE: BOAT or SHORE (circle) Zero fish caught today (tick) ☐ Location	Depth (m)	Start time (use 24 hour time)	Finish time	Gear & No. used	Tackle & No. used	Bait	Species	Length (mm)	Sex	Released (Y/N)	Reason for release	Health

Comments:

Figure 8.1. Voluntary research log sheet completed by recreational fishers as part of the Recreational Angler Program (RAP).

8.2.3 Fishery-Dependent Monitoring

Information about the age and length composition of fishery landings is collected periodically for a number of indicator species in the south-west estuarine and nearshore finfish resource to inform weight-of-evidence assessments of these stocks. The age of sampled fish is estimated by counting the number of opaque zones in otoliths, following documented quality control protocols for each species. The annual periodicity of opaque zones has been validated for sea mullet (Smith and Deguara 2003) and yellowfin whiting (Hyndes and Potter 1997, Coulson et al. 2005).

Fishery-dependent monitoring of sea mullet for age and length composition in fishery landings were most recently undertaken in the WCB in 2016/17 and 2017/18, and in the GCB (Shark Bay) in 2018 and 2019. Fishery-dependent monitoring of yellowfin whiting for age and length composition in fishery landings was most recently undertaken in the WCB (Peel-Harvey, Bunbury, Hardy Inlet, Wonnerup and Binnigup) between 2015 and 2017, and in 2014 in the GCB (Shark Bay).

Samples of commercially caught sea mullet have been collected from the GCB, WCB and SCB regions during 2020 and 2021 for genetic analysis aimed at determining the stock connectivity of this species along the WA coast. Samples of yellowfin whiting were also collected, along with samples collected opportunistically

during 2020/21 recruitment index surveys in the WCB (Koombana Bay, Warnbro Sound and Mangles Bay), for a South Australian research project aiming to establish the population structure and connectivity of yellowfin whiting on evolutionary scales across the entire southwest Australian range.

8.2.4 Fishery-Independent Monitoring

Fishery-independent seine net surveys have been conducted by DoF at multiple beaches in the WCB and SCB since 1995 (Gaughan et al. 2006) to monitor annual recruitment trends and provide biological information (e.g., growth, reproduction, recruitment, distribution) that could support formal stock assessments for key indicator species (e.g., whiting *spp*., herring, salmon, mullet).

Between 1995 and June 2002, sampling occurred on a monthly basis at six sites: Poison Creek (170 km east of Esperance), Emu Beach (Albany), Koombana Bay (Bunbury), Warnbro Sound, Mangles Bay (Cockburn Sound) and Pinnaroo Point (Perth). Sampling was discontinued from July 2002 due to budgetary constraints, before recommencing in September 2005 with sampling refined to 8 months of the year (September through to April). A site in the Leschenault Estuary was included in 2006, while sampling at the Emu Beach site was discontinued in 2010 due to changing beach conditions prohibiting sampling.

The seine netting program was again discontinued in May 2016, before recommencing in September 2020.

8.2.5 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.

8.2.6 Other Information

Biological parameters and other information used in assessments are available from numerous fishery-independent studies in WA conducted by universities.

---

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 catch levels and standardised catch rates, through to the application of more sophisticated analyses and models that involve estimation of fishing mortality and biomass (Fletcher and Santoro 2015; Table 9.1). 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.

Table 9.1. Summary of information available for assessing southern nearshore finfish species; both sea mullet and yellowfin whiting have been assessed at Level 3.

Level	Description
Level 1	Catch data and biological/fishing vulnerability.
Level 2	Level 1 plus fishery-dependent effort.
Level 3	Levels 1 and/or 2 plus fishery-dependent biological sampling of landed catch (e.g., average size; fishing mortality, etc. estimated from representative samples).
Level 4	Levels 1, 2 or 3 plus fishery-independent surveys of relative abundance, exploitation rate, recruitment; or standardised fishery-dependent relative abundance data.
Level 5	Levels 1 to 3 and/or 4 plus outputs from integrated simulation, stock assessment model.

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 the lines of evidence are then combined within the Department's ISO 31000 based risk assessment framework (see Fletcher 2015) to determine the most appropriate combinations of consequence and likelihood to determine the overall current risk status. The strength of the Weight of Evidence (WoE) risk-based approach is that it explicitly shows which lines of evidence are consistent or inconsistent with a specific consequence level and therefore where there are uncertainties which assist in determining the overall risk level.

9.2 Assessment Overview

The current assessment of sea mullet incorporated estimates of biomass, using a Schaefer biomass dynamic model applied to catch and catch rate data to determine the status of the stock. This performance indicator is periodically (at least every five years) compared to MSY-based reference points specified in the harvest strategy for this resource (DPIRD 2020). In addition, a Catch-MSY model (CMSY; Froese et al. 2017) is used to estimate the Maximum Sustainable Yield (MSY) for sea mullet in the combined South Coast, West Coast and Gascoyne Coast Bioregions, based on a catch history and inputs relating to the assumed productivity of the stock. While the model also estimates trends in biomass (B) and fishing mortality (F), these typically exhibit large uncertainty and can be sensitive to assumptions around the level of final depletion of the stock, required for running the analyses; however a wide prior for

final depletion was specified for sea mullet due to prolonged low catches and in this case had little impact on the results.

The current assessment of yellowfin whiting incorporated estimates of fishing mortality and female spawning potential ratio (SPR), where the latter is a proxy for spawning biomass. An extended per recruit model with a stock-recruitment relationship was also used, accounting for fishing effects on recruitment. The measure of reproductive potential from this extended model is an estimate of 'relative female biomass', B_{rel} (i.e. reproductive potential at a relative equilibrium level of recruitment). Due to the clear evidence for inter-annual variation in recruitment of this species, a catch curve model (referred to as a 'relative abundance analysis') that accounts for such recruitment variability by fitting to several years of consecutive age data and estimating annual 'recruitment deviation' parameters, was chosen as the preferred method. This method has been applied to estimate mortality of a range of other finfish species in WA (see Fairclough et al. 2014, Norriss et al. 2016 for detailed description). In addition to estimating mortality and annual recruitment deviations, the catch-curve model also generates estimates of age-based selectivity.

A weight-of-evidence approach is then applied to all fisheries where fishery-dependent, fishery-independent data and model assessments are considered with the results of a Productivity Susceptibility Analysis (PSA) to evaluate the inherent vulnerability of southwest WA sea mullet and yellowfin whiting stocks to fishing.

9.2.1 Peer Review of Assessment

The weight-of-evidence approach, incorporating a Level 3 age-based assessment, has been applied by the Department to numerous finfish stocks (e.g., Wise et al. 2007, Marriott et al. 2012, Smith et al. 2013a, 2013b, Brown et al. 2013). This assessment approach has been published in peer-reviewed journals (e.g., Marriott et al. 2010).

External, expert reviews were conducted for recent Level 3 assessments of Australian herring (Jones 2013, Haddon 2018), and tailor (Jones 2013). The most recent Level 3 assessment for King George whiting underwent external peer review prior to publication (Fisher et al. 2014).

All nearshore and estuarine finfish fisheries underwent pre-assessment against the Marine Stewardship Council (MSC) standard for sustainable fishing in 2013-14 using a bioregional assessment approach (Bellchambers et al. 2016). Subsequently, the Peel-Harvey Estuary commercial fishery for sea mullet has undergone third party certification against the Marine Stewardship Council (MSC) standard for sustainable fishing (V3.1). During this process, independent assessors reviewed the Level 2 stock assessment methodology for sea mullet. The fishery was recertified in 2021.

9.3 Analyses and Assessments

9.3.1 Data Used in Assessment

CAES
Recreational fishing survey data
Fishery-dependent data

9.3.2 Catch and Effort Trends

9.3.2.1 Commercial Catches

9.3.2.1.1 Sea mullet

Sea mullet is primarily targeted by the commercial net fishing sector, with catches by the recreational sector and customary fishers considered low relative to commercial catches. Recreational fishers are likely to catch sea mullet mainly by gillnetting from the shore, however, no catch estimates are available. Historical records describe how the Noongar people of south-western WA would gather each year around March to trap schools of sea mullet moving up the Serpentine River. Contemporary information-sharing by Noongar Elders and Cultural Advisors has revealed that mullet were also seasonally harvested in the Swan River and estuaries on the south coast.

The commercial catch of sea mullet in the South, West and Gascoyne Coast bioregions shows a gradual increase from 1941 to around 1980, peaking at just under 700 t (Figure 9.1). However, following a reduction in effort and the targeting of sea mullet, catches have since declined to the current annual level of around 200 t. Over the past five years, 62% of the catch has been taken by haul netting, 19% by beach seining and 19% by gillnetting (Figure 9.2).

The distribution of commercial catch among the different bioregions have not changed substantially over the history of the fishery (Figure 9.1). Annual catches have typically been greatest in the West Coast Bioregion, where between 60 and 80% of catches have been landed in the Peel-Harvey Estuary (Area 2 of the WCEMF; Figure 9.3). The remainder are mostly taken by fishers in oceanic waters off Lancelin and Jurien Bay in mid-west WA. Sea mullet catch in the Gascoyne Coast Bioregion has primarily been taken by the Shark Bay Beach Seine and Mesh Net Managed Fishery (Figure 9.3). Although Gascoyne catches briefly exceeded those in the West Coast Bioregion in the early and late 2000s, they currently comprise around 20% of the total annual sea mullet catch. Over the past five years, less than 10% of the total annual catch has been taken in the South Coast Bioregion (Figure 9.1).

Table 9.2. Annual catches (t) of sea mullet and yellowfin whiting retained by the West Coast Estuarine Managed Fishery (WCEMF) and Shark Bay Beach Seine and Managed Net Fishery (SBBSMNF) during 2020 (calendar year) compared to the five-year average (with standard deviation) from 2015–2019.

	Fishery			
	WCEMF		SBBSMNF	
Species	2020	2015-19 Mean (± SD)	2020	2015-19 Mean (± SD)
Sea mullet	87	93 (± 8.7)	55	46 (± 8.5)
Yellowfin whiting	17	25 (± 8.3)	50	57 (± 20.1)

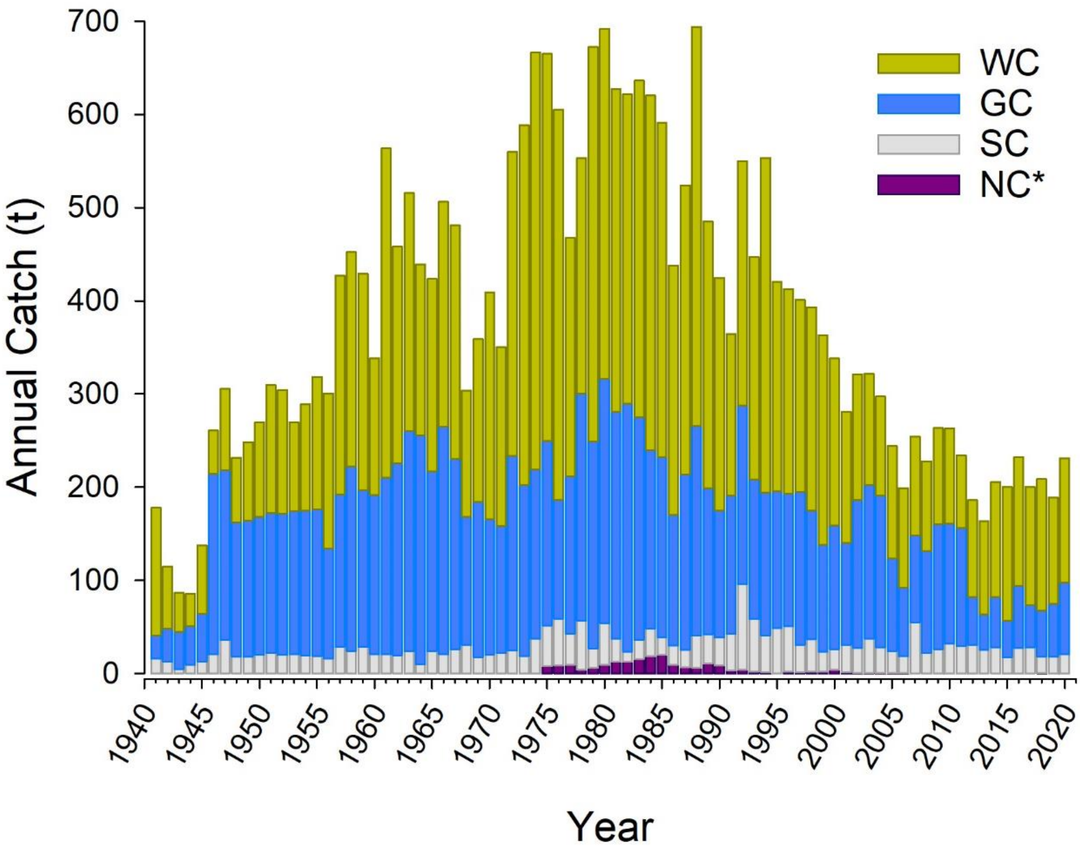


Figure 9.1 Total Western Australian commercial catch of sea mullet by bioregion (WC: West Coast Bioregion; GC: Gascoyne Coast Bioregion; SC: South Coast Bioregion; NC*: North Coast Bioregion) between 1941 and 2020. * North Coast Bioregion data prior to 1975 not available.

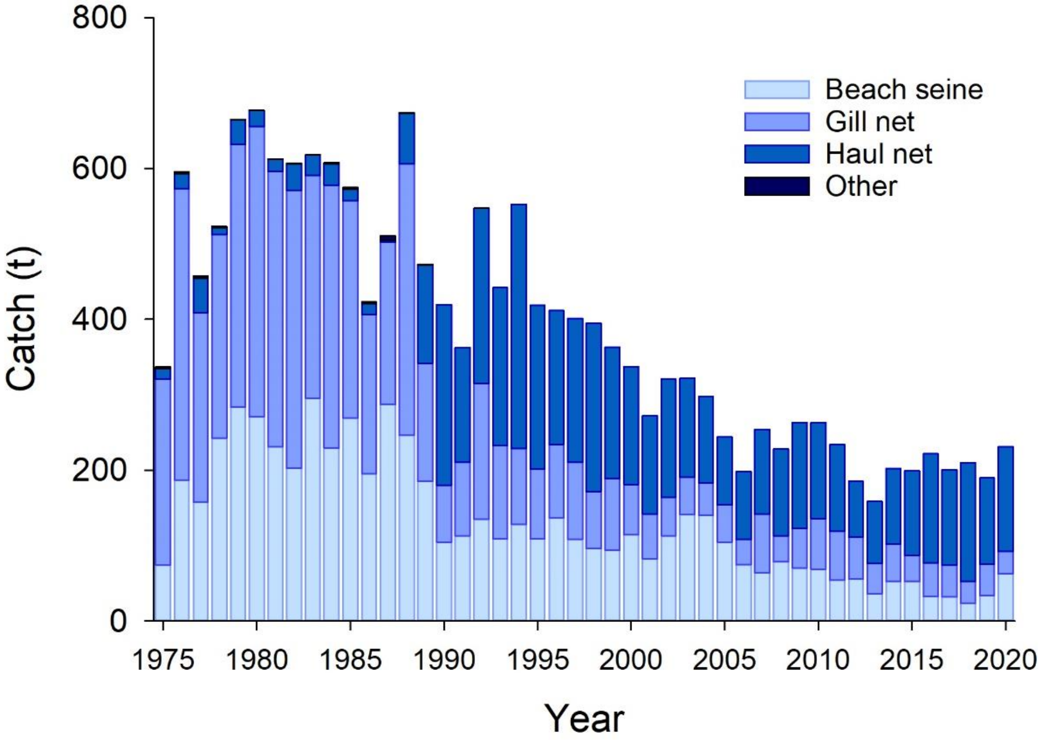


Figure 9.2 Historical Western Australian commercial catch of sea mullet by method between 1975 and 2020.

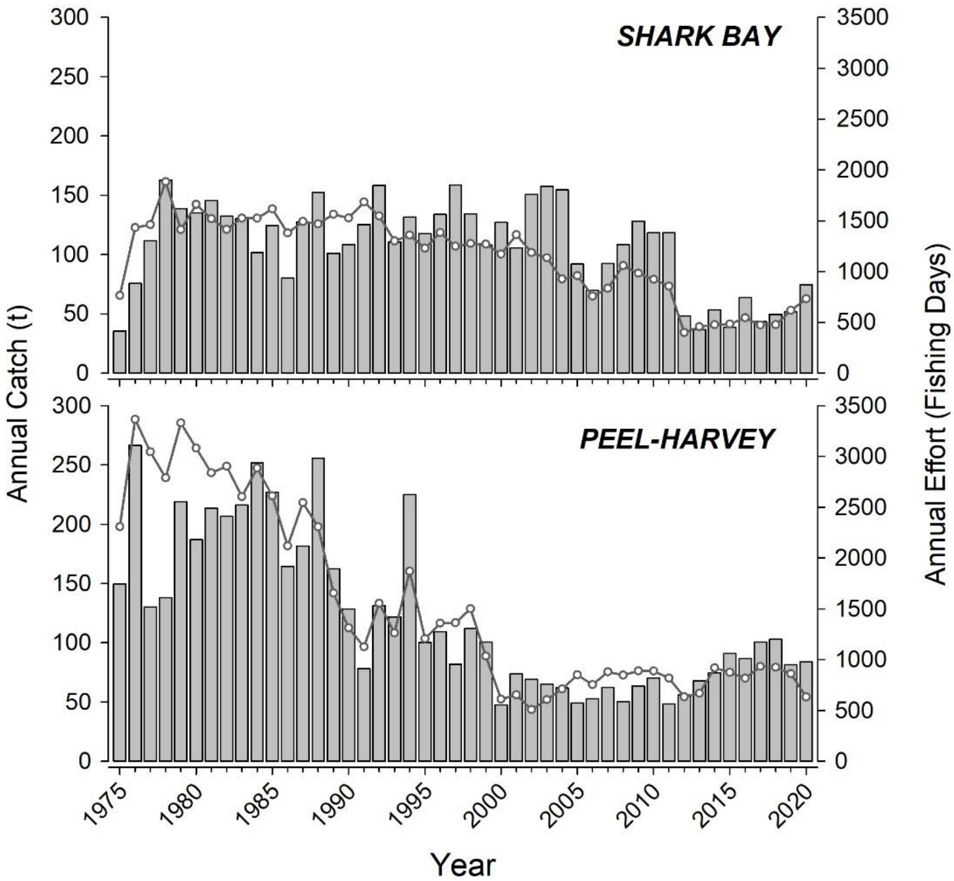


Figure 9.3. Annual catch (tonnes) of sea mullet (bars) and fishing effort (number of fishing days when sea mullet was reported as being caught) (line with points) in Shark Bay and the Peel-Harvey Estuary between 1975 (July onwards) and 2020.

9.3.2.1.2 Yellowfin whiting

The majority of WA commercial landings of yellowfin whiting have been taken in the Gascoyne Coast Bioregion, mainly by the SBBSMNMF (Table 9.2, Figure 9.4). Commercial catches of yellowfin whiting were predominantly caught using beach seine and gill net between 1975 and the mid-1980s, after which beach seine and haul net were used to land most of the catch (Figure 9.5).

The total catch in the SBBSMNMF declined from ~150 t in the late 1970s to ~100 t through the 1990s to 2010. This was followed by an abrupt drop to <~50 t, with some increase in catch in recent years (Figure 9.6).

Since 1980, the total WCB catch has ranged from 17 to 74 t (Figure 9.4). The majority of recent landings in the WCB were taken by the WCEMF (Peel-Harvey Estuary, Hardy Inlet), with minor catches also taken by the SWBSF and the WCBBMF.

From 1941 to 2013, the Peel-Harvey annual catch was 0-22 t. The catch then increased sharply, reaching 25 t in 2014 and 30 t in 2015 (Figure 9.6). These catches were the result of strong recruitment due to prevailing environmental

conditions (see sections below). The catch declined to 19 t in 2016 (Figure 9.6). Yellowfin whiting is taken by gill netting and haul netting in the Peel-Harvey Estuary. Low catches around 1990 coincide with a period of intense algal blooms, which made haul netting difficult. The opening of the Dawesville Cut in 1994 led to a reduction in the algal blooms in the estuary basin.

Annual landings in the Hardy Inlet have been relatively stable, typically around 8-12 t, except for a period of low catches in 2010-2012. These low catches are associated with a period of poor water quality in the lower estuary, including algal blooms, and changes to the sand bar opening.

Since 1980/81, the South West Beach Seine Fishery (SWBSF) catch has been <10 t (and usually <5 t), with the exception of 2001/02 when a peak catch of 34 t was taken. The WCBBMF catch has been <4 t (and usually <2 t), with the exception of 2001/02 when a peak catch of 7 t was taken.

Only minor quantities are taken in the SCB, with less than 2 t taken annually since 1980 (Figure 9.4). The main areas where this species is caught commercially in the SCB are Irwin Inlet, Wilson Inlet, Oyster Harbour, and on ocean beaches east of Albany (CAES blocks 3418 & 3419). Most recently, the SCB total catch increased markedly after 2011 due to increases in Irwin Inlet and CAES block 3418.

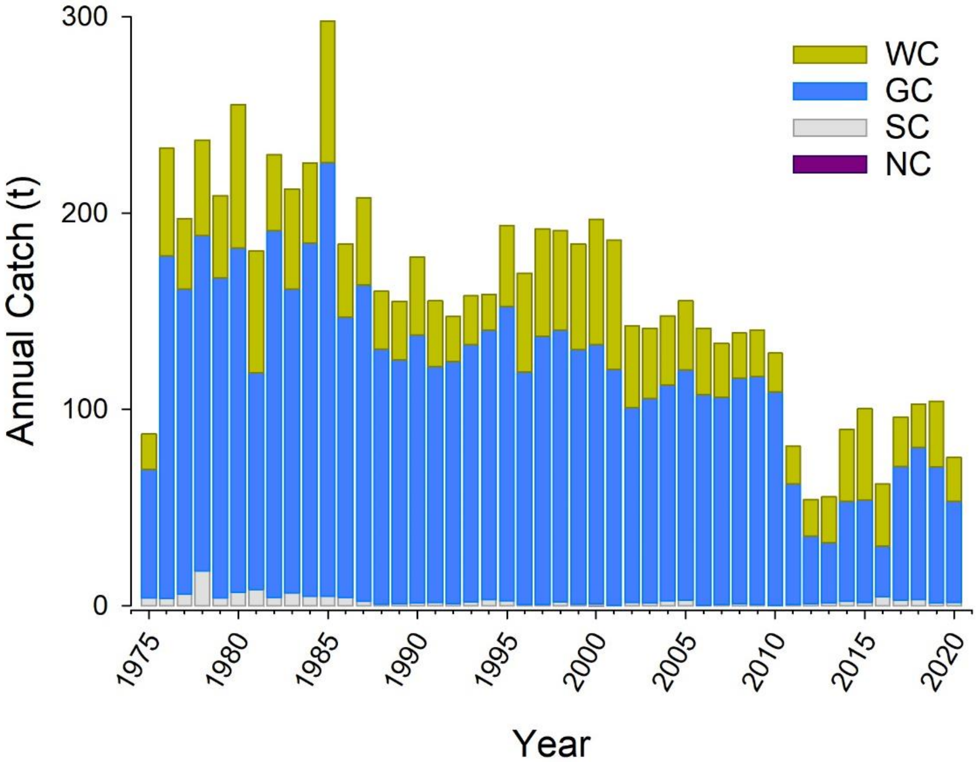


Figure 9.4. Total Western Australian commercial catch of yellowfin whiting by bioregion (WC: West Coast Bioregion; GC: Gascoyne Coast Bioregion; SC: South Coast Bioregion; NC*: North Coast Bioregion) between 1975 (July onwards) and 2020.

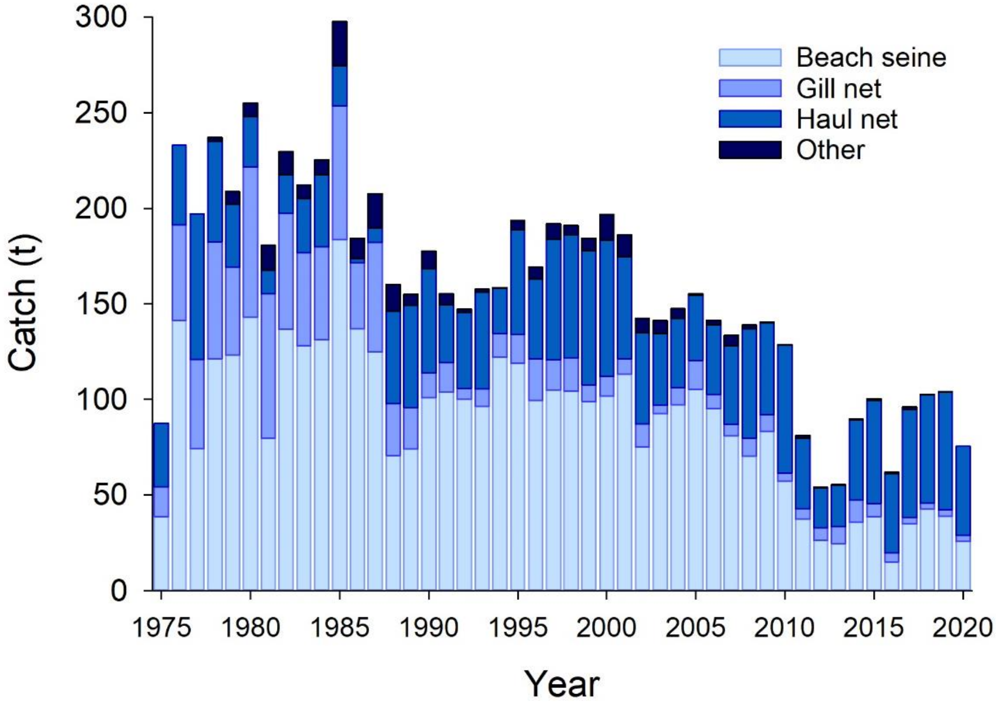


Figure 9.5. Historical Western Australian commercial catch of yellowfin whiting by method between 1975 and 2020.

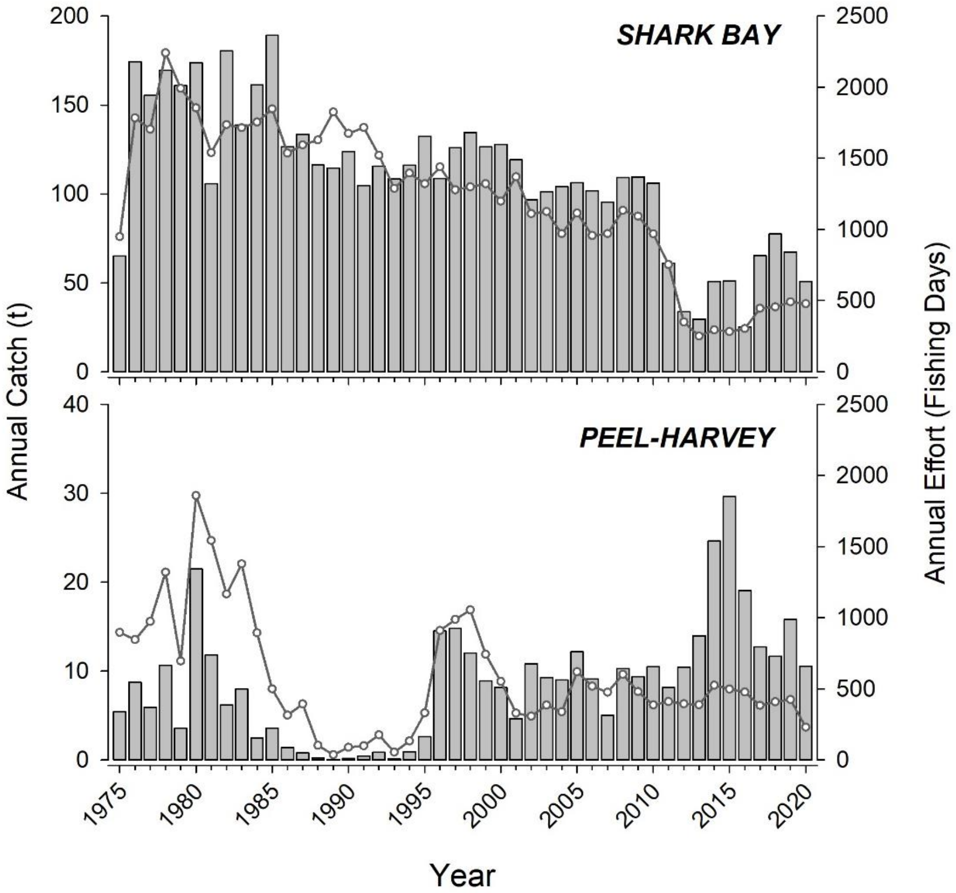


Figure 9.6. Annual catch (tonnes) of yellowfin whiting (bars) and fishing effort (number of fishing days when yellowfin whiting was reported as being caught) (line with points) in Shark Bay and the Peel-Harvey Estuary between 1975 and 2020.

The catches of yellowfin whiting are seasonal in almost all fisheries. Landings occur in the cooler months (April-November) in Shark Bay (the SBBSMNMF) (Figure 9.7), west coast estuaries (Peel-Harvey (Figure 9.7), Leschenault) and south coast estuaries (Irwin Inlet, Oyster Harbour). Landings occur in summer (December-February) in the SWBBF and the WCBBMF (and also the WCB recreational fishery). The patterns in the WCB are likely to reflect the aggregation of spawning fish in shallow ocean waters in summer, and their dispersal back into estuaries and other sheltered waters in other months. Biological sampling has confirmed spawning activity in summer in WCB ocean waters, and around the entrance of the Peel-Harvey Estuary but not deeper waters of the estuary basin. This suggests a seasonal movement of fish in/out of the Peel-Harvey Estuary. The Hardy Inlet is a different situation – fish appear to reside within this estuary all year and spawn here in summer. As a consequence, catches are not seasonal in this system. This could be due to a lack of suitable sheltered habitats in adjacent ocean waters of the SCB.

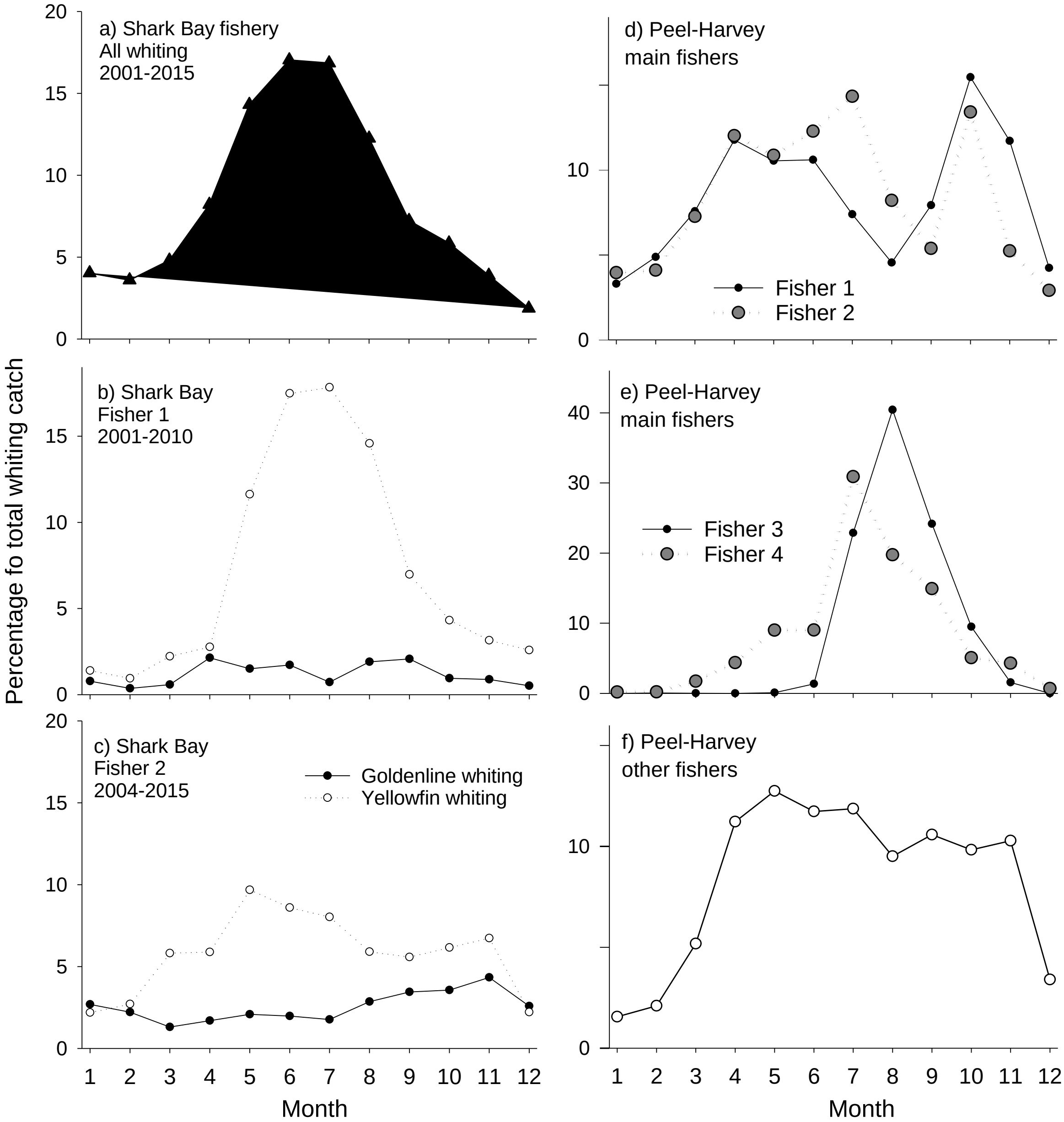


Figure 9.7. Seasonality of commercial yellowfin whiting catches in Shark Bay (a-c) and Peel-Harvey Estuary (d-f).

9.3.2.2 Commercial Effort

9.3.2.2.1 Key fisheries

Peel-Harvey Estuary fishery (Area 2 of the WCEMF): Traditionally, targeting of finfish (using haul nets and gill nets) has tended to increase when blue swimmer crabs were not available. Crabs are the most valuable component of the catch in this fishery. Crab trapping occurs mainly in summer. Hence, gill netting for finfish tends to peak in winter. Also, low availability of crabs in a particular year can result in more netting effort. Haul netting effort traditionally peaked during spring/summer, reflecting the seasonal availability of the main target species (sea mullet).

Total fishery effort measured either by the ‘number of licenced boats’ declined substantially between 1980 and 2000 but has since been stable. However, there has been a shift in the distribution of effort among gear types since 2013, with more days spent using haul nets and less using gill nets (Figure 9.8).

In this estuary, several key events have affected the amount and type of effort expended: i) a major reduction in number of vessels between 1980 and 2000, ii) major environmental changes (eutrophication leading to algal blooms in 1980s and 1990s, then construction of the Dawesville Cut in 1994 leading to increased marine influence) have affected catchability and species composition; iii) changing from gill nets to pots to target crabs in the period 1996-1999 reduced gill netting effort and eliminated the finfish by-product that had previously been taken while targeting crabs; iv) implementation of the first formal Harvest Strategy for finfish and MSC certification of sea mullet has altered fishing behaviour since 2013.

Hardy Inlet fishery: A single licensee has operated in this estuary since 1999. This fisher mainly uses haul nets in October-May, and gill nets in June-September. Total annual effort (in terms of number of boat days) has been relatively stable since 2005.

Shark Bay Beach Seine and Mesh Net Fishery: The main method is beach seine. Effort peaks in winter each year. Total effort (boat days) in this fishery was relatively stable from 1990 to 2000, but then declined to historically low levels in recent years (Figure 9.6).

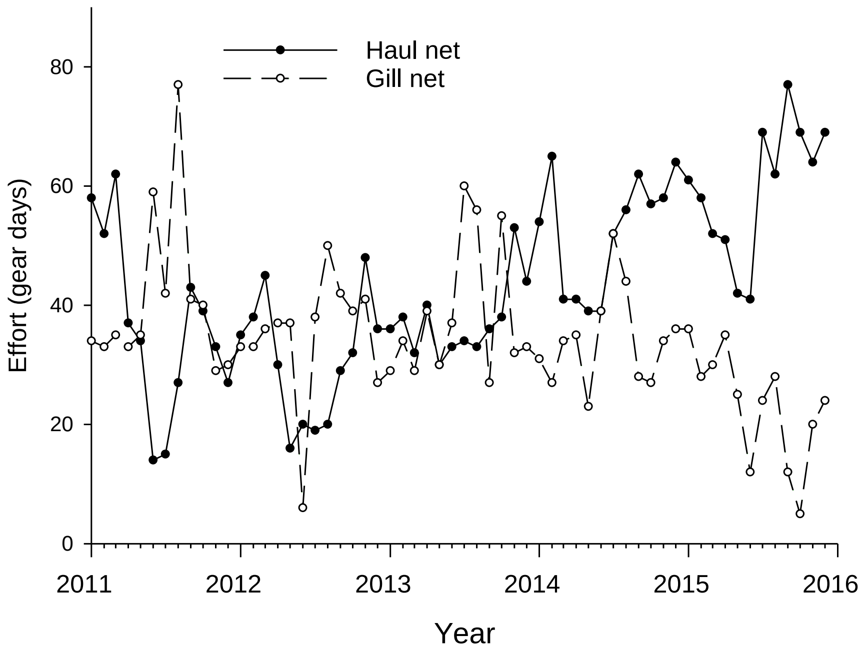


Figure 9.8. Monthly effort (gear days) using haul and gill nets in recent years (2011-2015) in Peel-Harvey Estuary commercial fishery.

9.3.2.3 Recreational / Charter Catches

9.3.2.3.1 Sea mullet

Sea mullet is not usually caught by recreational line fishing methods. A small amount of sea mullet is caught by recreational fishers using nets in WA. These catches are subject to various netting restrictions, as well as a daily bag limit of 30 fish. The recreational catch of sea mullet by boat-based fishers is very low (<1 t) (Ryan et al. 2015). The shore-based catch is not known but is believed to be low in each bioregion.

9.3.2.3.2 Yellowfin whiting

Anecdotal evidence suggests yellowfin whiting is a popular species caught by shore-based recreational fishers during summer in the WCB and GCB. However, estimates of recreational landings of yellowfin whiting are not available due to the absence of recent shore-based recreational fishing surveys in summer. Also, there have been problems with species identification in past surveys. All surveys, including the 2000/01 National Phone Survey, the bi-annual 'iSurvey' of boat-based fishing and the annual autumn (February-June) metro shore-based survey estimate 'whiting' catches only and do not reliably identify individual species of whiting.

Available evidence suggests that the WCB recreational fishery for yellowfin whiting is restricted to summer (December–March) and targets spawning aggregations of fish along ocean beaches and the lower parts of estuaries (including Peel-Harvey Estuary and Hardy Inlet).

9.3.2.4 Recreational / Charter Effort

Boat-based recreational fishing effort is periodically estimated in each bioregion (Ryan et al. 2015). However, this effort has limited relevance to nearshore finfish resource, much of which is harvested recreationally by shore-based fishers.

9.3.2.5 Conclusion

Sea mullet	Sea mullet is primarily caught by the commercial net fishing sector, with catches by the recreational sector (mainly by gillnets) and customary fishers considered to be low relative to commercial catches. The commercial catch of sea mullet in the South, West and Gascoyne Coast bioregions shows a gradual increase from 1941 to around 1980, peaking at just under 700 t. Catches have since declined to the current level of around 200 t, with the majority taken by haul netting. The distribution of commercial catch among the bioregions has not changed substantially over the history of the fishery, with the majority taken in the West Coast Bioregion and, to a lesser extent, in the Gascoyne Coast Bioregion (mainly Shark Bay). Over the last five years, sea mullet has primarily been targeted by the West Coast Estuarine Managed Fishery in the Peel-Harvey Estuary, the Shark Bay Beach Seine and Mesh Net Managed Fishery, and by fishers operating in coastal waters off mid-west WA. **The data is considered to provide possible evidence of unacceptable stock depletion, but decline in catch is likely due to markets and reduced targeting.**
Yellowfin whiting	The majority of commercial and recreational catches of yellowfin whiting in southern WA occur off the Perth metropolitan area. Recreational catches are taken by line by both boat and shore-based fishers, but the current recreational catch is unknown due to lack of recent shore-based fishing surveys. Data for the commercial net and line fisheries show that the long-term commercial catch trends in this region are relatively stable. Recent catches have been above average in the west and south coast due to strong recruitment by a single year class that was spawned during the 2010/11 marine heatwave event [Smith et al. 2019]. Catches have now returned to lower, more typical long-term levels. The heatwave event resulted in catches declining in Shark Bay for some years after this event. The boundaries of each commercial fishery are fixed so there is little scope for within-fishery shifts in catch or effort, but between-fishery shifts could occur. **The data is considered to provide possible evidence of unacceptable stock depletion, but decline in catch is likely due to markets and reduced targeting.**

9.3.3 Catch Distribution Trends

9.3.3.1 Sea mullet

The catch trends in each bioregion appear to be largely driven by changes in effort. However, a range of other factors may also influence catch level. WCB and GCB catch trends changed after 2011, which could reflect an impact (e.g., southwards range shift) of the 2011 heatwave. Alternatively, the sharp decline in the GCB sea mullet catch after 2011 could be due to a shift towards targeting of whiting, a more valuable species that increased in abundance at this time. In the WCB, the increasing catch trend could be due to an increase in targeting due to the MSC certification of this species in the Peel-Harvey Estuary. Since the GCB and WCB fisheries supply the same domestic markets, catch fluctuations in one region could affect catches in another bioregion. An increase in Peel-Harvey production may result in a decline in the GCB.

Catch distribution data is ambiguous, but it could reflect a southward range shift in the ‘sea mullet’ species complex in WA.

9.3.3.2 Yellowfin whiting

The overall catch level of yellowfin whiting in each zone/bioregion has been relatively stable over several decades, suggesting a stable stock level. Since 2011, the GCB catch has decreased slightly (consistent with a decline in effort) while the WCB and SCB catches have increased. There is no evidence from catch distribution data of stock depletion in any region.

9.3.3.3 Conclusion

Sea mullet	The distribution of commercial catch among the different bioregions have not changed substantially over the history of the fishery, however, as highly migratory, stock depletion may not impact its distribution. Annual catches have typically been greatest in the West Coast Bioregion, where between 60 and 80% of catches have recently landed by the West Coast Estuarine Managed Fishery in the Peel-Harvey Estuary. The remainder are mostly taken by fishers in oceanic waters of the mid-west WA, off Lancelin and Jurien Bay. Sea mullet catch in the Gascoyne Coast Bioregion has primarily been taken by the Shark Bay Beach Seine and Mesh Net Managed Fishery. Although Gascoyne catches briefly exceeded those in the West Coast Bioregion in the early and late 2000s, they currently comprise around 20% of the total annual sea mullet catch. Over the past five years, less than 10% of the total annual catch has been taken in the South Coast Bioregion. **There is no evidence from catch distribution data of stock depletion in any region.**

Yellowfin whiting	The boundaries of each commercial fishery are fixed so there is little scope for within-fishery shifts in catch or effort, but between-fishery shifts could occur. The overall catch level in each region has been relatively stable over several decades, suggesting long-term stable stock levels. Since 2011, data suggest increases in the WCB & SCB. **There is no evidence from catch distribution data of stock depletion in any region.**

9.3.4 Fishery-Dependent Catch Rate Analyses

9.3.4.1 Sea mullet

The standardised commercial catch rate of sea mullet in the Peel-Harvey Estuary has been the primary performance indicator used to monitor abundance for this species in this estuary since a harvest strategy was first developed for this fishery in 2015. The catch rate was initially calculated based on "100 m netting hours' as the measure of fishing effort. However, concerns that this could be inaccurate led to the development of a second catch rate time series based on fishing days. Prior to the development of a higher-level stock assessment for sea mullet in WA, these two alternative time series of standardised catch rates have been simultaneously monitored against associated reference levels based on the catch rates observed during a 2000-2011 reference period (Figure 9.9).

Whilst the original catch rate time series indicates a substantial increase in abundance in recent years, the time series based on the broader effort measure remains relatively stable and has broadly fluctuated between 55 and 130 kg/day since 1975 (Figure 9.9). In 2020, the two alternative catch rates (4.4 kg/100 m netting hour and 103.1 kg/day) were lower than in the previous year but remained above their respective lower threshold reference levels, indicating that abundance in the Peel-Harvey Estuary has been maintained at a sustainable level (Figure 9.9). As samples of sea mullet from the Peel-Harvey Estuary catch have shown that the majority is comprised of juveniles, these catch rates effectively indicate variations in recruitment to the stock over time.

Sea mullet samples from catches taken from oceanic waters off mid-west WA (between Lancelin and Jurien Bay) and from Shark Bay comprise a greater proportion of adult fish, with the catch rates from these areas considered to better reflect the spawning abundance of this stock. Catch rates in the mid-west region, whilst only available since 1990, indicate that sea mullet migrating north through this region each year has remained relatively stable or increased over this time (

Figure 9.10). In Shark Bay, nominal catch rates show a decline from more than 60 kg/day in the late 1950s down to 31 kg/day in 1976 (

Figure 9.10). This is followed by an increase in catch rates to levels exceeding 100 kg/day in 1997, between 2002 and 2004, and from 2009 to 2011.

The Shark Bay catch rates are considered the most reliable index of spawning stock abundance for assessing the status of the broader sea mullet stock. For modelling, an adjustment to this CPUE series has been made to account for a potential increase in fishing efficiency when fishers began using jet-powered boats in 1980 (Figure 9.11). No change in fishing efficiency was assumed between 1956 and 1980 as any potential learnings of fishers as the fishery first developed are likely to have occurred prior to the start of the catch rate time series. To account for the likely increase in fishing efficiency as fishers changed over to jet boats, an annual effort creep of 10% was assumed between 1980 and 1985, with no change thereafter (Figure 9.11).

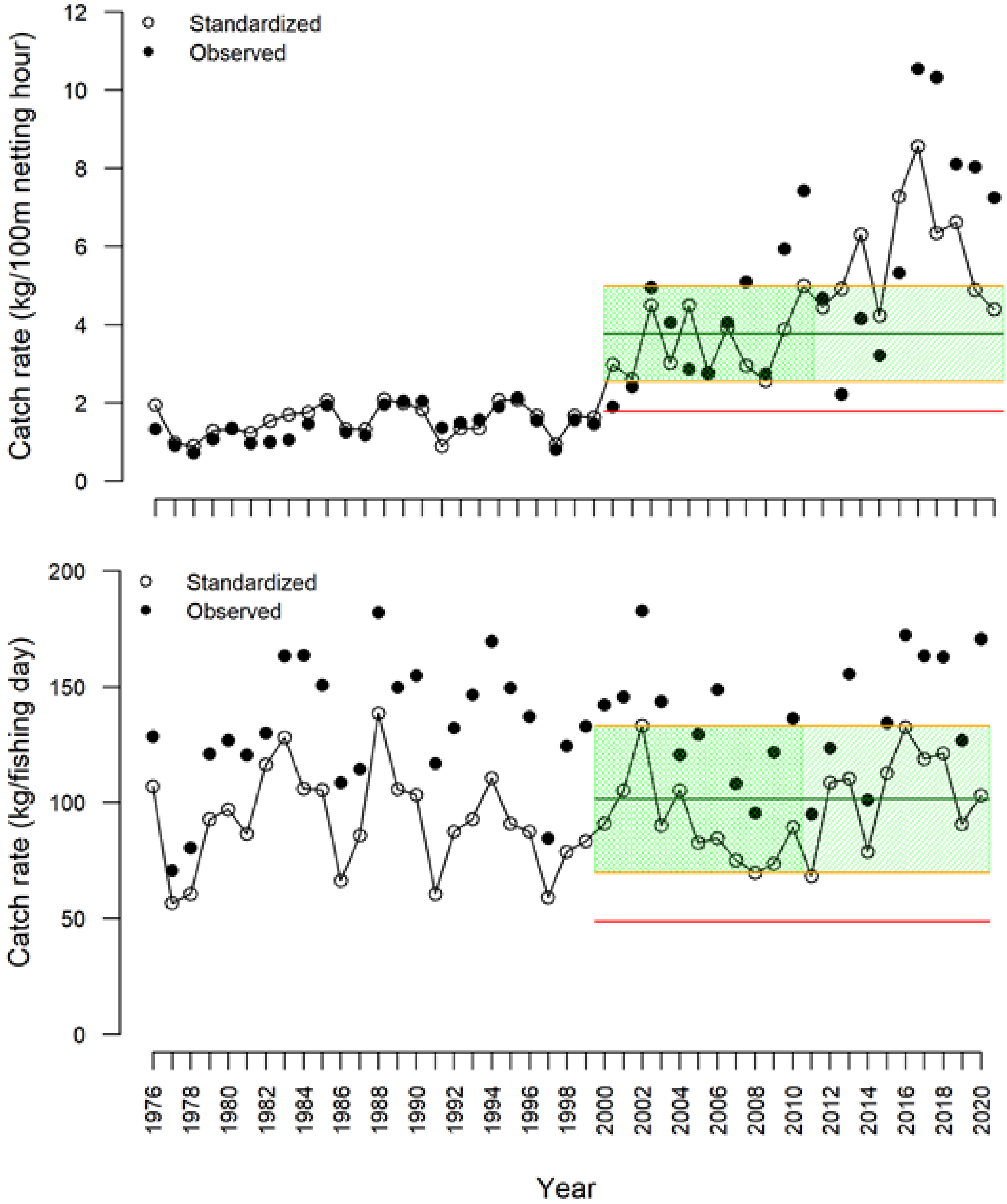


Figure 9.9. Nominal and standardised annual commercial catch rates of sea mullet in the Peel-Harvey Estuary between 1976 and 2020, relative to the target (green range), threshold (orange line) and limit (red line) reference levels. The top plot represents catch rate standardisation based on kg/100 m netting hour, and the bottom plot shows the standardisation based on kg/fishing day (when sea mullet was reported as being retained).

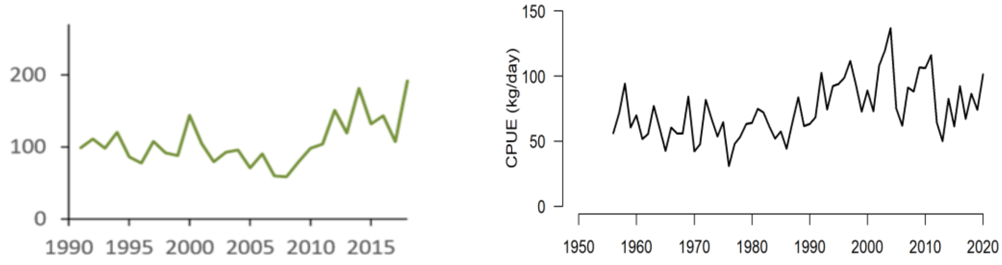


Figure 9.10. Annual nominal commercial catch rate (kg/day) of sea mullet in the mid-west (left) and in Shark Bay (right).

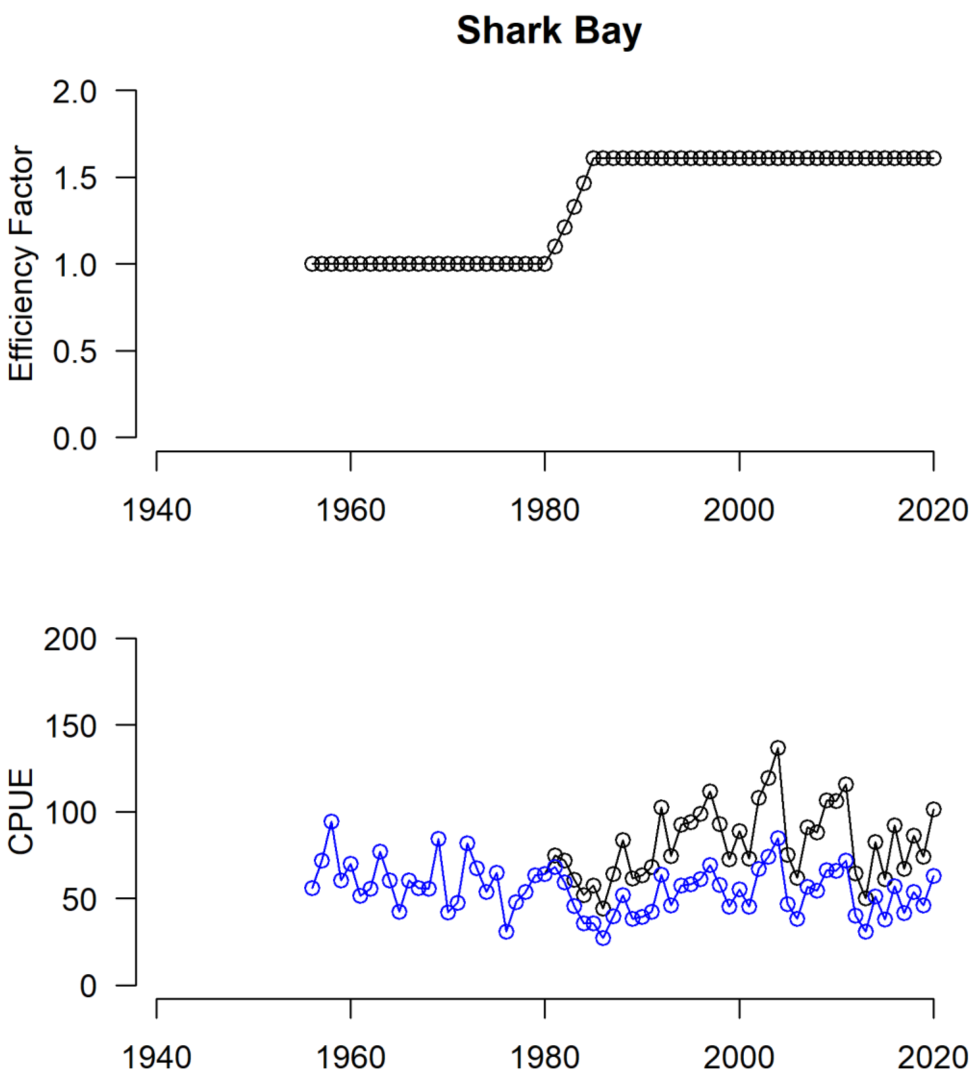


Figure 9.11. Annual fishing efficiency factor applied to adjust catch rates in Shark Bay to account for an assumed increase in efficiency when fishers began using jet-powered boats in 1980 (top plot), and unadjusted (black line) and adjusted (blue line) catch per unit effort (bottom plot).

9.3.4.2 Yellowfin whiting

Commercial fishery catch rates suggest a sudden, large increase in abundance in each Bioregion after the 2011 heatwave, peaking first in the Gascoyne, then West Coast Bioregion, and finally in the South Coast Bioregion (Figure 9.12).

In the GCB, commercial catch rates of yellowfin whiting suggest a gradual increase in abundance during 1990-2012, followed by a rapid increase, peaking in 2013, and remaining relatively high in 2014-2016 (Figure 9.12). In the WCB, catch rates suggests stable abundance from at least the mid-1990s until 2011, followed by a rapid increase, with relatively high levels in 2014-2016 including a peak in 2015. In the early 1990s, the WCB catch rate is probably affected by environmental factors in the Peel-Harvey estuary and so not regarded as a reliable index of abundance. In the SCB, catch rates suggests a gradual increase in abundance during 1990-2013, followed by a rapid increase, peaking in 2016.

Commercial catch rates suggest current abundances are high relative to historical levels, which suggests a low risk to each stock.

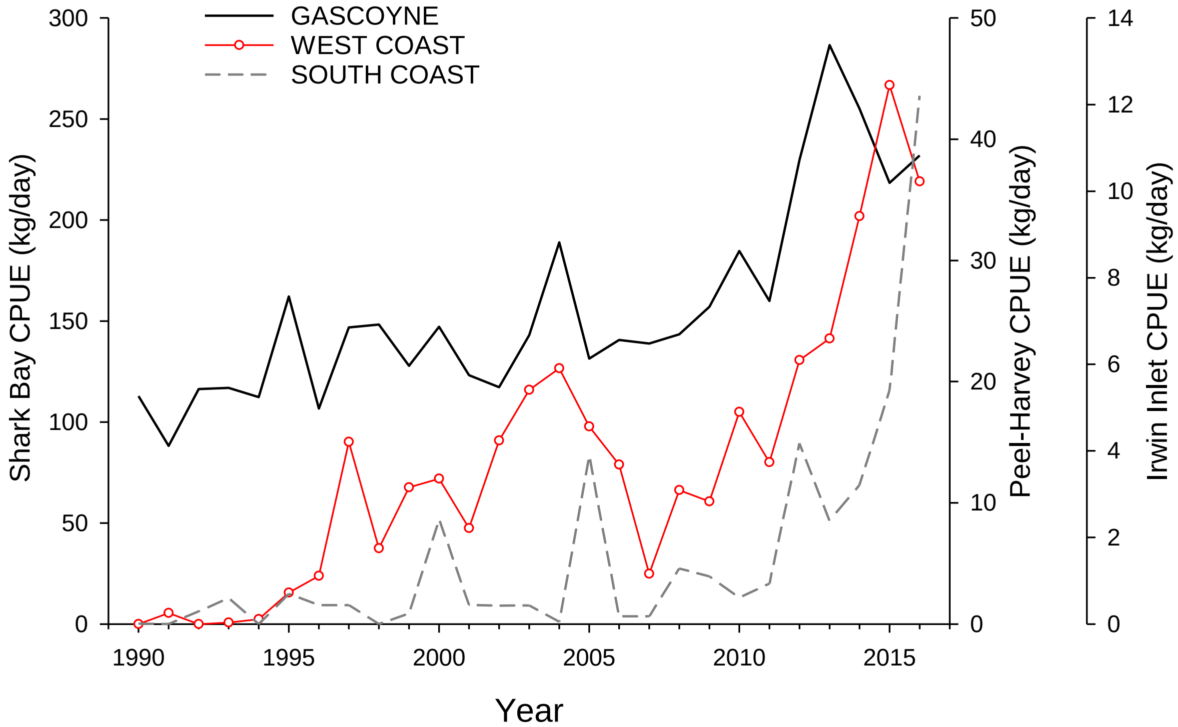


Figure 9.12. Standardised annual catch rate (kg/gear day) of yellowfin whiting in key commercial fisheries that target this species in the Gascoyne Coast (Shark Bay fishery), West Coast (Peel-Harvey Estuary fishery) and South Coast (Irwin Inlet fishery) Bioregions, between 1990 and 2016. Chart reproduced from previous assessment in 2017.

9.3.4.3 Conclusion

Sea mullet	The annual standardised catch rate of sea mullet in the Peel-Harvey Estuary has fluctuated between 55 and 130 kg/day since 1975 and is likely to reflect variations in recruitment to the stock. Catch rates in the mid-west and Shark Bay are considered to better reflect the abundance of spawning sea mullet, however, only a limited time series is available for the mid-west region. Nominal catch rates in Shark Bay declined from more than 60 kg/day in the late 1950s to 31 kg/day in 1976, followed by a slight increase to the current level. Adjusting the Shark Bay catch rates to account for a likely increase in fishing efficiency between 1980 and 1985 as fishers changed to jet-powered boats results in a slightly lower catch rate since that time. Additionally, a new standardised catch rate based on kg/fishing day shows a long stable trend. **The data is considered to provide no evidence of unacceptable stock depletion.**
Yellowfin whiting	Commercial fishery catch rates suggest a sudden, large increase in abundance in each Bioregion after the 2011 heatwave, peaking first in the Gascoyne, then West Coast Bioregion, and finally in the South Coast Bioregion. Catch rates suggest current abundances high relative to historical levels, which suggests a low risk to each stock. **The data is considered to provide no evidence of unacceptable stock depletion.**

9.3.5 Trends in Age/Length Structures

9.3.5.1 Sea mullet

Age composition

Age composition data were collected from commercial catches of sea mullet between 2016 and 2019, however, the final year of samples (from Shark Bay) had not yet been processed at the time of writing. Age samples from the Peel-Harvey Estuary (n=892), collected by both haul nets (2.5-3.25 inch meshes) and gillnets (2.75-3 inch meshes), were dominated by 2 year old fish (Figure 9.13) and only 21% comprised 3+ year old individuals. In contrast, catches taken by beach seines in oceanic waters off the mid-west of WA (n=442, collected using 2-3 inch meshes) and in Shark Bay (n=395, collected using 2-4 inch meshes) contained a greater proportion of adult (≥3+ year old) fish (37 and 99% respectively) (Figure 9.13, Figure 9.14).

The increasing representation of older fish with a decreasing latitude supports observations along both the western and eastern coasts of Australia that sea mullet

move out of the estuarine environment once they reach maturity and undertake a northward migration to spawn (Thomson 1951, Smith and Deguara 2002, Smith and Deguara 2003). Samples from the mid-west and Shark Bay regions are thus likely to better describe the age structure of the spawning population of sea mullet than those in the Peel-Harvey Estuary which are likely to reflect the recruitment to the fishery. The connectivity between sea mullet in the oceanic waters of the mid-west region with those in Shark Bay is more uncertain, with anecdotal evidence suggesting there may be some level of residency in the latter area.

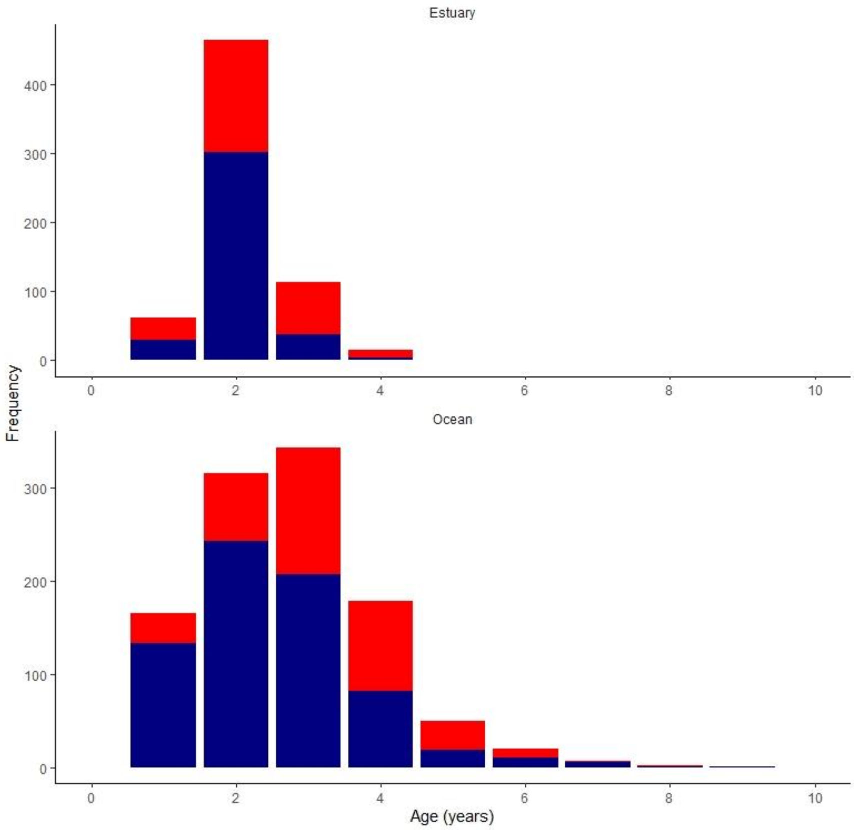


Figure 9.13. Age composition data for male (blue) and female (red) sea mullet sampled from commercial catches in the Peel-Harvey Estuary (top plot) and oceanic waters off the mid-west region of WA (bottom plot).

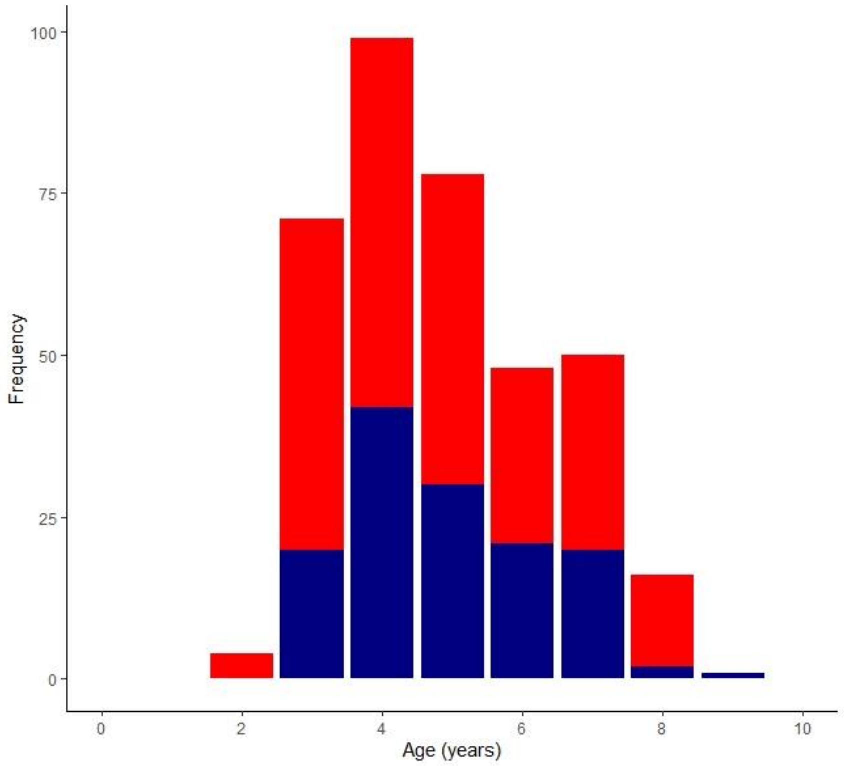


Figure 9.14. Age composition data for male (blue) and female (red) sea mullet sampled from commercial catches in Shark Bay.

Length composition

Length composition samples were collected in 2016/17 and 2017/18 from commercial catches of sea mullet in the Peel-Harvey Estuary (n=894) and oceanic waters off mid-west WA (n=1194). Samples from estuarine waters were collected by both haul nets (2.5-3.25 inch meshes) and gillnets (2.75-3 inch meshes) and ranged in length from 292 to 482 mm total length (TL; Figure 9.15). Samples collected by beach seines (2-3 inch meshes) from the oceanic waters off the mid-west coast ranged from 259 to 601 mm TL (Figure 9.15). The mean length of fish from the Peel-Harvey Estuary (355 mm) was lower than those from the oceanic waters in the mid-west (379 mm). The oceanic sample contained a much larger proportion of fish equal to or greater than 400 mm (28%) compared to the estuarine sample (17%). In both samples, the majority of smaller fish (less than 400 mm) were male, whilst the larger fish were predominantly female (Figure 9.15). This likely reflects, at least in part, differences in the growth of the two sexes (Smith and Deguara 2002).

Sea mullet were also sampled from catches taken by beach seine nets (2-4 inch meshes) in 2018 and 2019 from Shark Bay, with only the first year of samples (n = 400) available at the time of writing. Although based on a limited sample size, the lengths of fish sampled in 2018 ranged from 333 to 468 mm, with a mean size of 400 mm (Figure 9.16). Almost half of the fish in the sample (49%) were 400 mm or larger.

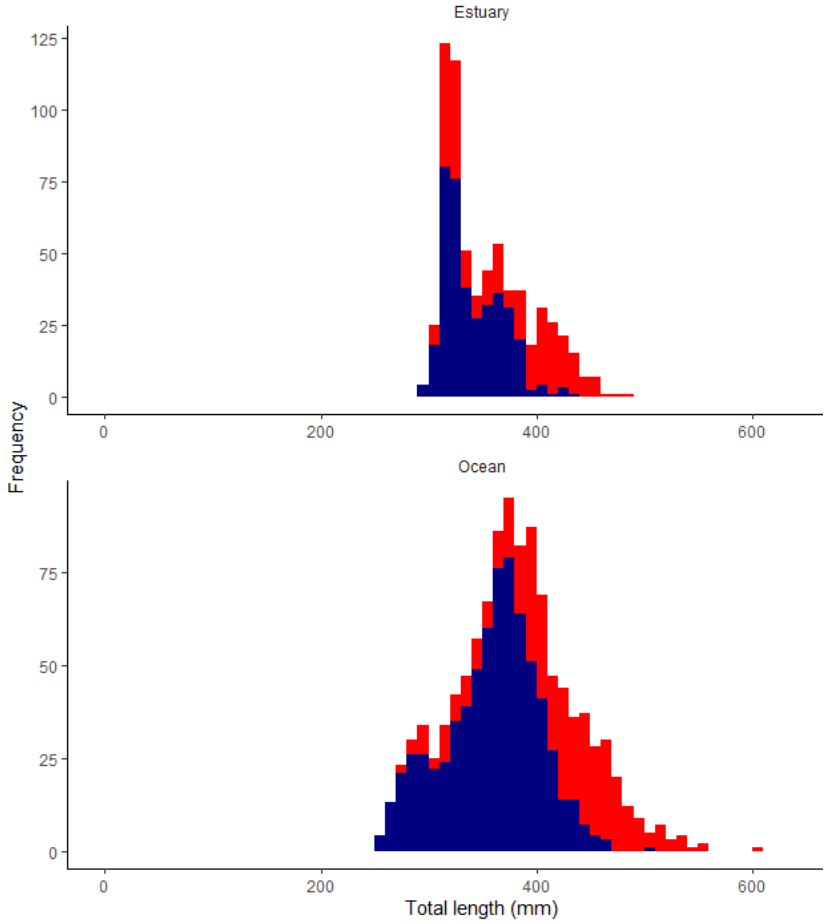


Figure 9.15. Length composition data for male (blue) and female (red) sea mullet sampled from commercial catches in the Peel-Harvey Estuary (top plot) and oceanic waters off the mid-west region of WA (bottom plot).

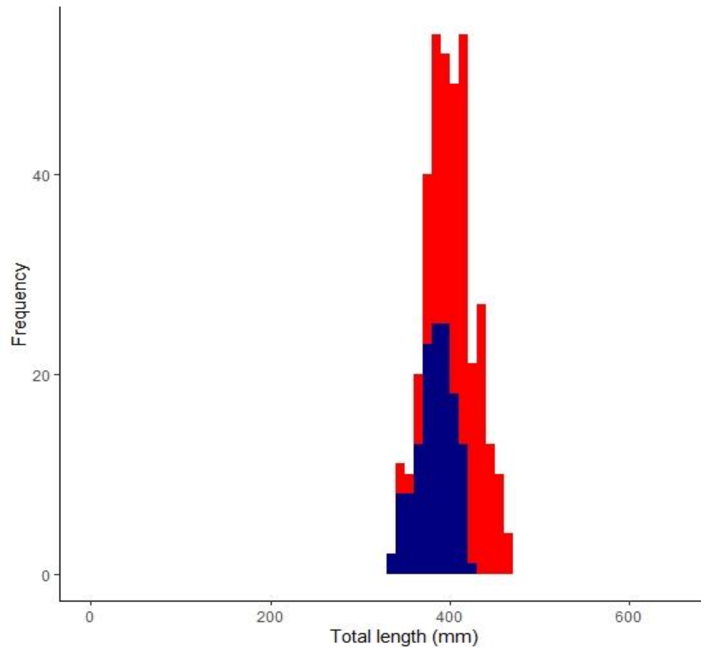


Figure 9.16. Length composition data for male (blue) and female (red) sea mullet sampled from commercial catches in the Shark Bay.

9.3.5.2 Yellowfin whiting

In the West Coast Bioregion, the maximum age of fish sampled in 2015 and 2016 was 9 years in the metro zone and 11 years in south-west zone. In both zones there is evidence of very strong recruitment by 2010/11 and 2012/13 year classes, representing fish spawned during the marine heatwave and their offspring, respectively. Given the maximum observed age for species is 12 years, the age structure in the West Coast Bioregion suggests a relatively low level of truncation due to fishing.

A high proportion of fish in each sample was above the age at 50% maturity of 2 years. Recruitment into the commercial fishery starts at 2 years, with full selection by around 4 years of age. The timing of recruitment by the strong 2010/11 year class thus explains sudden rise in catches from 2013 onwards.

Age sampling of yellowfin whiting in 2015 and 2016 showed that, apart from some differences in the ages at which younger fish (ages 1-3) are selected by the different sectors, the age compositions were similar in all samples, i.e. males vs. females (Figure 9.17), estuary vs. ocean, and commercial vs. recreational (Figure 9.18). All samples show an exceptionally strong year class corresponding to fish spawned in summer 2010/11, which is coincident with a marine heatwave event along the west coast of WA with the subsequent two summers also having above-average water temperatures. Additionally, in 2016, another relatively strong year class was apparent in samples. These fish were spawned in summer 2012/13 and are assumed to include the progeny of the 2010/11 year class.

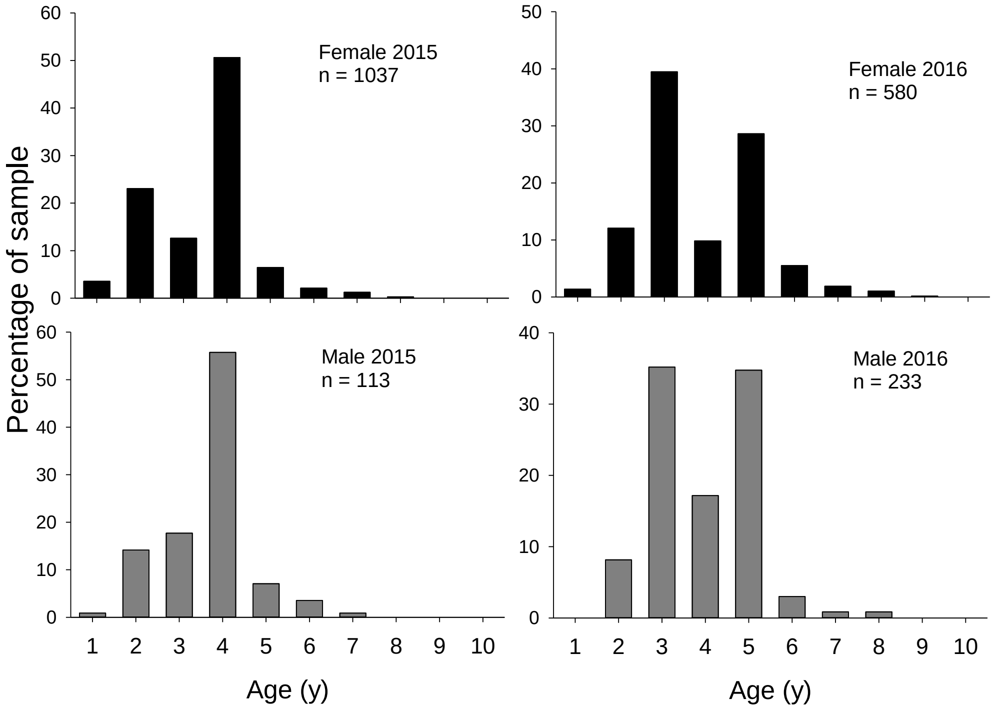


Figure 9.17. Male and female yellowfin whiting age frequency distributions in Peel-Harvey Estuary (WCB Metro Zone) in 2015 and 2016. Sectors/fisheries combined.

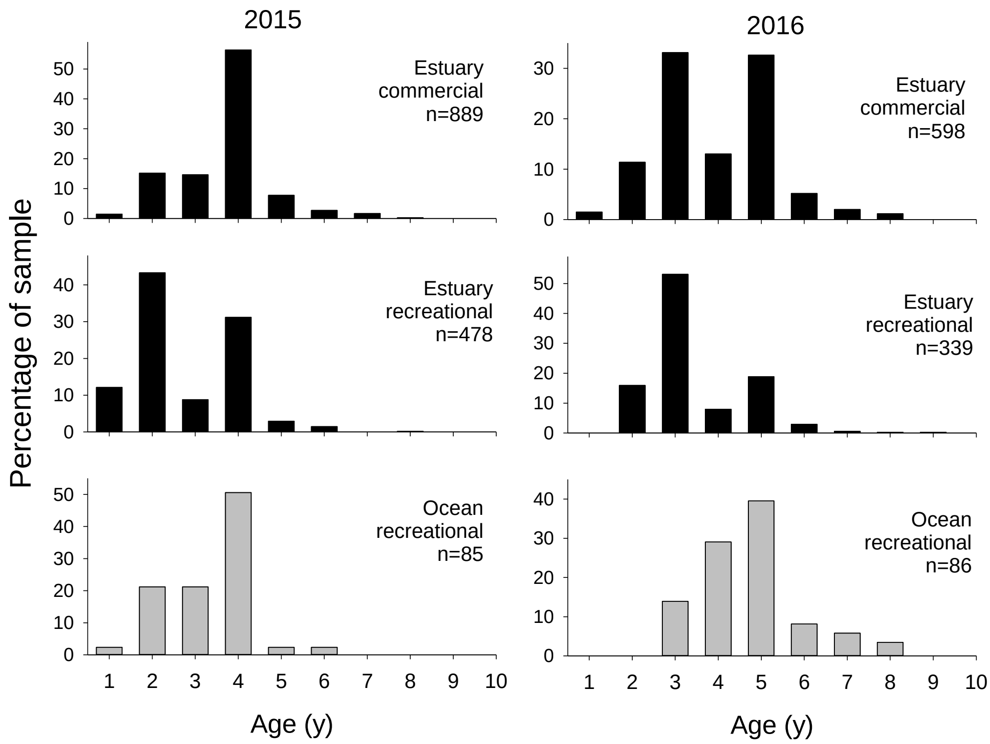


Figure 9.18. Yellowfin whiting age frequency distributions in WCB Metro Zone in 2015 and 2016, comparing commercial versus recreational landings, and estuary (Peel-Harvey) versus ocean landings. Sexes combined.

9.3.5.3 Conclusion

Sea mullet	Age composition data collected from commercial catches of sea mullet (using nets with similar mesh sizes) between 2016 and 2018 show that catches in the Peel-Harvey Estuary were dominated by the 2+ cohort and only 21% comprised adult individuals ≥3 years old. In contrast, catches taken by beach seines in oceanic waters off the mid-west of WA and in Shark Bay contained a greater proportion of adult fish (37 and 99% respectively) as expected for a species that inhabits estuarine environments mostly as juveniles and undertake a northward migration along the coast to spawn. Although uncertainty around the connectivity of sea mullet along the WA coast makes the collection of representative age composition data for the stock challenging, this assessment considered the age composition samples from the mid-west and Gascoyne regions to be the most reliable to describe the age structure of the sea mullet spawning stock. Length composition samples collected from commercial catches of sea mullet (using nets with similar mesh sizes) between 2016 and 2018 show a smaller range of lengths and smaller mean length of catches from the Peel-Harvey Estuary (292-482 mm, mean of 355 mm) compared to oceanic waters off mid-west WA (259-601 mm, mean length of 379 mm). Although based on a limited sample size, the lengths of fish sampled in 2018 ranged from 333 to 468 mm, with a mean size of 400 mm. The proportion of fish equal to or greater than 400 mm was much greater in the sample from Shark Bay (49%), compared to the oceanic waters off mid-west WA (28%) and the Peel-Harvey Estuary (17%). The larger individuals in the samples were predominantly female due to differences in the growth of the two sexes. **The data is considered to provide no evidence of unacceptable stock depletion.**

Yellowfin whiting	In the West Coast Bioregion, the maximum age of fish sampled in 2015 and 2016 was 9 years in metro zone and 11 years in south-west zone. In both zones there is evidence of very strong recruitment by 2010/11 and 2012/13 year classes, representing fish spawned during the marine heatwave and following two years of above-average water temperatures and their offspring. Given the maximum observed age for species is 12 years, the age structure in the West Coast Bioregion suggests a relatively low level of truncation due to fishing. A high proportion of fish in each sample was above the age at 50% maturity of 2 years. Recruitment into the commercial fishery starts at 2 years, with full selection by around 4 years of age. The timing of recruitment by strong 2010/11 year class thus explains sudden rise in catches from 2013 onwards. **The data is considered to provide no evidence of unacceptable stock depletion.**

9.3.6 Productivity Susceptibility Analysis

Productivity Susceptibility Analysis (PSA) is a semi-quantitative risk analysis originally developed for use in 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.

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 sea mullet and yellowfin whiting targeted in each fishing sector; both commercial and recreational, in south-west WA.

9.3.6.1 Productivity

For the purposes of the PSA analysis, productivity scores are attributed to the species, sea mullet (*Mugil cephalus*) and yellowfin whiting *(Sillago schomburgkii)*, and are relevant and applicable to all fisheries. Both the commercial and recreational

sectors are considered in the susceptibility scores and PSA analyses. Key factors influencing the score for productivity for *M. cephalus* include low to moderate longevity (maximum recorded age in WA of 12 years), maturation at approximately 3 to 4 years of age, and a high fecundity. Key factors influencing the score for productivity for *S. schomburgkii* include low to moderate longevity (maximum recorded age in WA of 12 years), maturation at approximately 2 years of age, a broadcast spawning strategy and high fecundity. Therefore, a precautionary approach has been taken and moderate score allocated. The total productivity score averaged 1.14 for *M. cephalus* and 1.29 for *S. schomburgkii* (Table 9.3).

Table 9.3. PSA productivity scores for each indicator species

Productivity attribute	**Sea mullet**	**Yellowfin whiting**
Average maximum age	2	2
Average age at maturity	1	1
Average maximum size	1	1
Average size at maturity	1	1
Reproductive strategy	1	1
Fecundity	1	1
Trophic level	1	2
Total productivity (average)	1.14	1.29

9.3.6.2 Susceptibility

9.3.6.2.1 Sea mullet

Susceptibility scores are provided for the main fisheries (Table 9.4). All fisheries have high vertical overlap and post-capture mortality. However, as sea mullet have a broad distribution, areal overlap scored low for all fisheries. Selectivity for Mid-West and Shark Bay scored low, however Peel-Harvey scored high due to targeting of this species and retention of immature fish.

Table 9.4. PSA susceptibility scores for each fishery that targets sea mullet in Western Australia.

Susceptibility attribute	Peel-Harvey	Mid-West	Shark Bay
Areal overlap	1	1	1
Vertical overlap	3	3	3
Selectivity	3	1	1
Post-capture mortality	3	3	3
Total susceptibility (multiplicative)	1.65	1.2	1.2

9.3.6.2.2 Yellowfin whiting

Susceptibility scores are provided for the commercial and recreational fisheries (Table 9.5). Both sectors scored high for vertical overlap and post-capture mortality. Recreational anglers target this species across its entire range, and commercial fisheries cover much of its range, therefore areal overlap scored a high and medium, respectively. Selectivity scored a low, as both sectors target many different species.

Table 9.5. PSA susceptibility scores for each fishery / sector that impact on yellowfin whiting *(Sillago schomburgkii)* in southwest WA.

Susceptibility attribute	Commercial	Recreational
Areal overlap	2	3
Vertical overlap	3	3
Selectivity	1	1
Post-capture mortality	3	3
Total susceptibility (multiplicative)	1.65	1.65

9.3.6.3 Conclusion

Sea mullet	Sea mullet have a low to moderate longevity (maximum recorded age in WA of 12 years), mature at approximately 3 to 4 years of age and have a high fecundity. Targeted commercial fishing for sea mullet in WA occurs in a relatively small proportion of the overall stock distribution, however, the vertical overlap between the stock and the fishing gear in the water column is likely high. Whilst juvenile sea mullet are frequently caught within estuarine fisheries, catches from oceanic waters of mid-west WA and in Shark Bay comprise a greater proportion of mature individuals. Based on a productivity score of 1.14 and susceptibility scores of the key fisheries ranging from 1.2 to 1.65, the overall PSA score of 1.85 suggests a low risk of overexploiting the stock under current management arrangements and fishing effort. It assumes that the productivity of the stock is constant and not impacted by environmental conditions. **The data is considered to indicate that unacceptable stock depletion could occur without appropriate management.**

Yellowfin whiting	Yellowfin whiting have a low to moderate longevity (maximum recorded age in WA of 12 years), mature at approximately 2 years of age and 180-200 mm in length. This species is a broadcast spawner and while fecundity is likely high, spawning in very shallow (< 5 m) coastal waters may limit the alongshore dispersal of eggs and larvae. Yellowfin whiting form loose aggregations in shallow areas and their distribution makes them highly vulnerable to commercial netting and recreational line fishing. The vertical overlap between the stock and the fishing gear in the water column is high. Commercial and recreational catches comprise mostly mature individuals and are often seasonal, peaking during the spawning period. Based on a productivity score of 1.29 and susceptibility scores of the key fisheries of 1.65, the overall PSA score of 2.09 suggests a low risk of overexploiting the stock under current management arrangements and fishing effort. It assumes that the productivity of the stock is constant and not impacted by environmental conditions. **The data is considered to indicate that unacceptable stock depletion could occur without appropriate management.**

9.3.7 Catch Curve Analysis

9.3.7.1 Overview

Estimates of the instantaneous rate of total mortality (Z, year^{-1}) and associated 95% confidence intervals (i.e., measure of uncertainty in mortality estimates) are determined periodically by fitting catch curve analyses to age composition data. Estimates of fishing mortality (F, year^{-1}) are calculated by subtracting an estimated value of natural mortality (M, year^{-1}) for the species from the estimate of Z, i.e., F = Z – M.

Depending on the characteristics of the age composition data and timeframe for analysis, a range of catch curve models with alternative assumptions may be applied to a given stock to explore the extent to which alternative modelling assumptions impact on assessment results. Catch curve models can be constructed that are fitted solely to age or length composition data, or simultaneously to length and age composition data (e.g., see Norris et al. 2016). For each stock, catch curves are typically fitted separately to data collected from different fishing sectors (commercial/recreational) to ascertain whether the different data sources provide consistent information, after accounting for possible differences in selectivity of the gears used by each sector.

9.3.7.2 Model Description

The catch curve models used for this assessment were implemented in either the R software package or AD Model Builder (ADMB) and the model outputs are typically analysed using R.

Catch curves differ widely with respect to model complexity and assumptions. The age-based mortality estimators range from simple models assuming constant mortality, recruitment, and knife-edge selectivity, i.e., linear catch curve analysis (see Ricker 1975) and a mortality estimator based on the mean age assuming the age composition data have a geometric distribution (Chapman and Robson 1960), to multi-year models assuming age-based (logistic) selectivity with either constant or variable annual recruitment. Length-based methods include a model assuming logistic length-based selectivity with constant recruitment, and another is fitted simultaneously to age and length composition data to estimate growth, (length-based) selectivity and mortality.

A judgement is then made on a stock by stock basis as to which models are most suitable based on a range of criteria including i) their biological traits (e.g. level of inter-annual recruitment variation, growth characteristics), ii) information from diagnostic plots detailing how well the various models fit to the data, iii) degree of model complexity (i.e. a model should only be as complex as it needs to be to account for important factors influencing reliability of results), iv) the likely validity of statistical assumptions made by the each model, and v) information from the published literature regarding the reliability of alternative approaches as determined from simulation studies.

For each assessment, it is important to recognise that although a particular catch curve model was selected for the purpose of providing a single “answer” (on which to assess stock status) and thereby help inform management of the fishery, each of the alternative catch curve models explored has some merit in explaining the trends in the data to which these models are fitted. Moreover, comparisons of the various models, each with their own set of assumptions, provide valuable insights into the factors that, for a given species, are likely to impact most on the reliability of estimates of mortality. More broadly, they also enable an assessment of the extent to which model uncertainty (alternative modelling assumptions) impact on results.

9.3.7.3 Input Data and Parameters

9.3.7.3.1 Sea mullet

Estimates of the instantaneous rate of total mortality (Z, year^{-1}) and associated 95% CLs for sea mullet were derived by fitting an equilibrium catch curve model to age composition data sampled from commercial catches in oceanic waters off the mid-west region of WA between 2016 and 2018. A value of *M* for sea mullet of 0.5 year^{-1} was calculated using the empirical life-history equation by Then et al. (2015) based on the maximum age (t_{max}) of 12 years, where M = 1-exp(-4.899t_{max}-0.916). A preliminary exploration of mortality estimates for lightly fished stocks in WA suggested that this method may be more appropriate than the Hoenig (1983)

equation for more productive, shorter-lived species with a maximum age under 15 years, however more work is required (DPIRD unpublished data).

9.3.7.3.2 Yellowfin whiting

9.3.7.3.2.1 WCB metro zone stock

Analysis of this stock was undertaken subsequent to the data collection completion in 2016, using input parameters current at the time, such as Hoenig's (1983) empirical equation, which yielded a value for natural mortality of $M = 0.35$ y^{-1}, when using a maximum observed age of 12 years for yellowfin whiting. For future assessments, it would be beneficial to explore impacts of applying alternative M values.

The age structure was sampled from recreational (rod and line) and commercial (haul net) fisheries in various months during 2015-2016 (Table 9.6). Commercial samples were obtained in both 2015 and 2016, i.e., two consecutive commercial fishing seasons. In contrast, recreational samples were restricted to the 2015/16 summer only, i.e., a single recreational fishing season. The commercial fishery data was considered most representative of the stock because it was the largest sample and it encompassed two fishing seasons/years.

The catch curve method used in this assessment has been applied to estimate mortality of a range of other finfish species in WA (see Fairclough et al. 2014 and Norriss et al. 2016 for detailed description). In addition to estimating mortality and annual recruitment deviations, this model also generated estimates of age-based selectivity, as described by a logistic curve where the parameters A_{50} and A_{95} represent the ages by which 50 and 95% of fish are selected by fishers, respectively.

Table 9.6. Number of yellowfin whiting aged in WCB Metro Zone each month during 2015-2016 assessment, sampled from commercial and recreational fisheries. ('estuary' = Peel-Harvey). Data used in current assessment.

Year	Month	Estuary-commercial	Estuary- recreational	Ocean-recreational
2015	1			2
	2			
	3	33		
	4	30		
	5	105		
	6	43		
	7	108		
	8	177		
	9	148		
	10	106	4	
	11	107	125	3
	12	32	349	80
2016	1	46	319	86
	2	42	20	
	3	47		
	4	49		
	5	50		
	6	79		
	7	171		
	8	84		
	9	30		
Total		1487	817	171

9.3.7.3.2.2 GCB stock

This stock was assessed by Brown (2014, unpublished DoF report) and a summary presented here.

9.3.7.4 Results and Diagnostics

9.3.7.4.1 Sea mullet

Although a number of simple catch curve models were explored for sea mullet (Models 1-4 described by Norriss et al. 2016), only outputs from the Chapman and Robson (1960) mortality estimator have been presented as they are widely used and have been shown to provide more robust estimates (Dunn et al. 2002). Sea mullet have had relatively stable catches over the last decade, and there is a lack of evidence to suggest the occurrence of marked inter-annual variability in recruitment from the age composition data.

The Chapman and Robson mortality estimator is based on the mean age of fish above the age at which they are assumed to have become fully recruited into the fishery, assuming the age composition in the population has a geometric distribution (Chapman and Robson 1960). The catch curve model was implemented in the R software package and was fitted separately to age composition data for the two sexes due to the different growth of female and male sea mullet, and possible difference in mortality among sexes. The age at full recruitment was assumed to represent the age class at which the peak in the age frequency data was observed.

Based on an age at full recruitment of 3 years (i.e., the peak age in the combined age composition), the catch curve results indicated that the mortality of males was greater than that of females (Figure 9.19). The point estimates (and 95% CLs) of F for females and males were 0.35 (0.31-0.40) and 0.52 (0.48-0.57) year^{-1}, respectively.

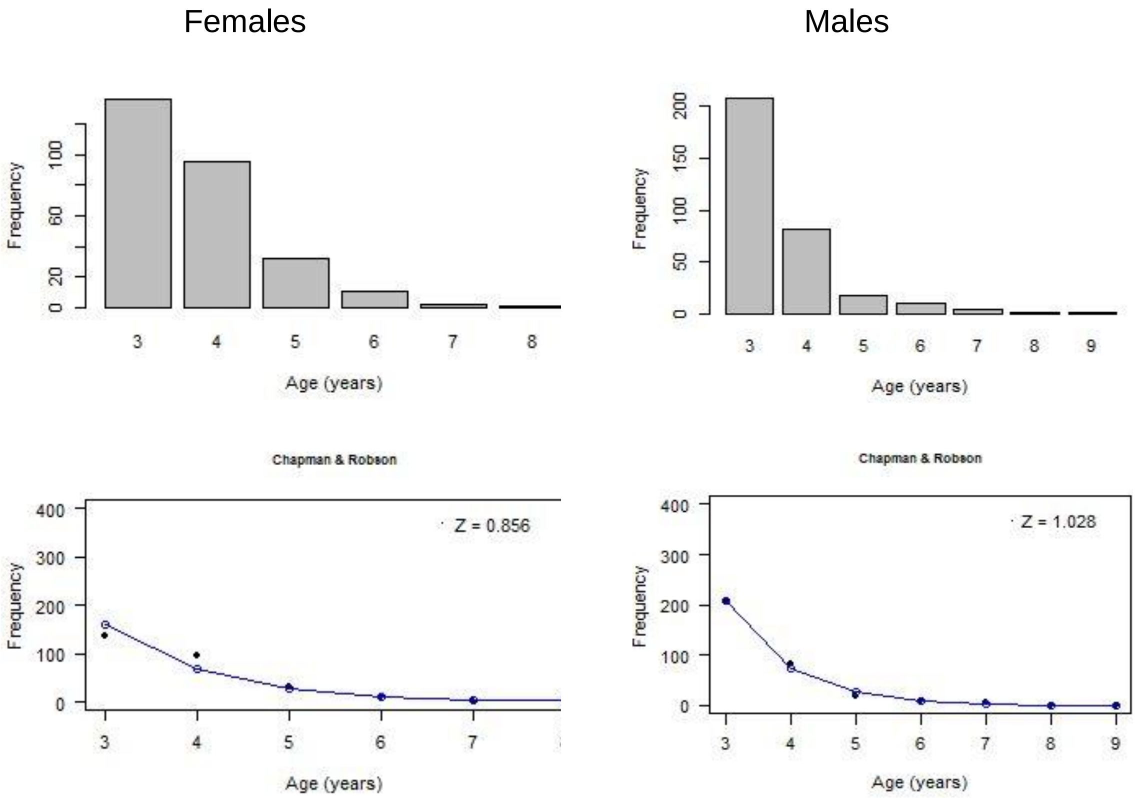


Figure 9.19. Age compositions of fully recruited female and male sea mullet in mid-west WA (top) and the fitted Chapman & Robson catch curve model to these data to estimate total mortality (*Z*) (bottom).

9.3.7.4.2 Yellowfin whiting

9.3.7.4.2.1 WCB metro zone stock

Estimates of the instantaneous rate of total mortality (Z, year^{-1}) for yellowfin whiting were derived from age composition data collected in 2015-16 using catch curve analysis. Due to the clear evidence for inter-annual variation in recruitment of this species, a catch curve model that accounts for such recruitment variability by fitting to several years of consecutive age data was chosen as the preferred method. The catch curve model was fitted separately to the commercial and recreational data, with each year class in the sample data identified in terms of the biological year in which the individuals of that year class were spawned. For yellowfin whiting, the biological year is the twelve-month period following the assumed annual birth date for this species (1 January), which corresponds to the peak of spawning.

Catch curve results showed that the point estimate of F from the commercial data was higher (0.60 year^{-1}) than from the recreational data (0.45 year^{-1}) (Table 9.7). The commercial data were considered more representative of the stock because of the larger sample size and as these data encompassed two fishing seasons/years, to which the model provided a good fit (Figure 9.20). Although the F estimate of 0.60 year^{-1} is greater than the value of M, it is important to note that this represents the

mortality of fully selected fish in the population. As catch curve estimates of selectivity suggest full selectivity into the commercial fishery is at >4.5 years (Table 9.7) which is much later than the age at which this species attains maturity (at 2 years), a considerable portion of the stock is protected from commercial fishing and thus the level of exploitation experienced by fish on average in the mature population is likely to be much lower than 0.60 $year^{-1}$.

Table 9.7. Estimates of fishing mortality and age-based selectivity (±95% confidence intervals) derived from catch curve analysis of age composition data for yellowfin whiting sampled from the commercial and recreational fishery in the West Coast Bioregion in 2015 and 2016.

Parameter	Commercial	Recreational
Fishing mortality (F; $year^{-1}$)	0.60 (0.48-0.72)	0.45 (0.35-0.55)
A_{50} selectivity (years)	3.43 (3.20-3.65)	2.68 (0.48-0.88)
A_{95} selectivity (years)	4.74 (4.36-5.12)	3.90 (3.55-4.26)

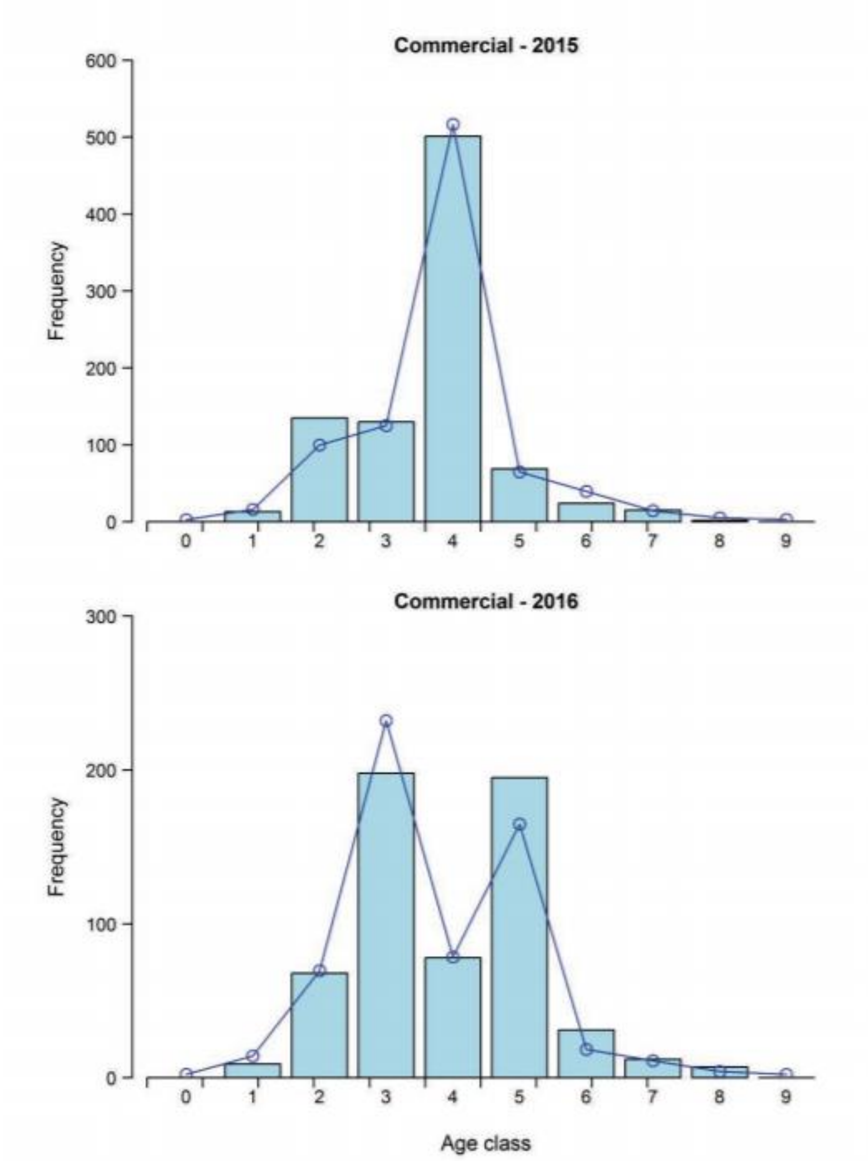


Figure 9.20. Multi-year, variable recruitment catch curve model (blue line) fitted to the age composition data for yellowfin whiting sampled from the recreational and commercial fishery in the West Coast Bioregion in 2015 and 2016.

9.3.7.4.2.2 GCB stock

The age structure was sampled from the commercial beach seine catches in Shark Bay (the SBBSMNF) during April-September 2014. Data were fitted to four catch curve models (Models 1-4). The same models were also fitted to age structure data obtained from the same stock in 2001-2003 by Coulson (2003) using fishery-independent beach seine netting.

The value of natural mortality, M = 0.39 y^{-1}, was estimated by Brown (2014) using Hoenig's (1983) empirical equation for fish and inserting into that equation the maximum observed age of 10.7 years for yellowfin whiting in this region.

An alternative (slightly more conservative) value of natural mortality, $M = 0.35\ y^{-1}$, based on a maximum observed age of 12 years (as used for WCB metro stock) is considered here.

9.3.7.5 Accounting for Uncertainty

The uncertainty associated with modelling assumptions was explored by applying multiple catch curve models. For the WCB metro zone stock, the uncertainty associated with sampling error was explored by comparing age data from two fisheries (commercial/recreational), two years (2015/2016) and two habitats (estuary/ocean).

9.3.7.6 Conclusion

Sea mullet	Assuming a value of natural mortality (*M*) for sea mullet of 0.5 year^{-1}, estimates of fishing mortality (*F*) derived from an equilibrium catch curve model fitted to the age composition sample collected in oceanic waters off mid-west WA between 2016 and 2018 was 0.35 year^{-1} (95%CLs 0.31-0.40 year^{-1}) for females and 0.52 year^{-1} (95% CLs 0.48-0.57 year^{-1}) for males. As part of the decline in the numbers of fish with increasing age may reflect the continued northward migration from the area of sampling, these may be overestimates of *F*. Despite this uncertainty, the results suggest it is possible that the long-term average *F* experienced by fully vulnerable fish has been above the acceptable level of *F*=*M*. **The model outputs are considered to provide no evidence of unacceptable stock depletion.**
Yellowfin whiting	Assuming a value of natural mortality (M) for yellowfin whiting of 0.35 year^{-1}, estimates of fishing mortality (F) derived from a catch curve model fitted to the age composition sample collected in the metropolitan zone of the West Coast Bioregion in 2015-16 was 0.60 year^{-1} for the commercial sector. While this estimate is well above the value of M, a lower level of F is likely affecting younger adults with maturity occurring at 2 years of age and full recruitment into the commercial fishery at 3-4 years of age. Despite this uncertainty, the results suggest it is possible that the long-term average F experienced by fully vulnerable fish has been above the acceptable level of F=M. **The model outputs are considered to provide evidence that unacceptable stock depletion is possible.**

9.3.8 Per-Recruit Analysis and Extended Equilibrium Age-Structured Model

9.3.8.1 Model Description

Two equilibrium age-based population models, including a traditional per-recruit analysis and a similar model that extends the per-recruit analysis to incorporate a

Beverton and Holt stock-recruitment relationship (assuming steepness *h* = 0.75) to account for potential impacts of exploitation on recruitment, were applied to produce estimates of female spawning potential ratio (SPR) and relative female spawning biomass (B_{rel}), respectively, for yellowfin whiting. Detailed mathematical descriptions of the two models are provided in Norriss et al. (2016). The SPR analyses were based on catch curve estimates of *F* and selectivity for the commercial sector, in addition to available biological information for this species (DPIRD unpublished data).

9.3.8.2 Results and Diagnostics

Point estimates of female SPR (and 95% confidence intervals) for yellowfin whiting derived from catch curve outputs for the commercial sector using the traditional and extended per-recruit models were 0.48 (0.45-0.52) and 0.43 (0.40-0.48), respectively (Figure 9.21). As these estimates are all above the SPR target of 0.4 and well above the SPR threshold of 0.3, which is considered to correspond to B_{MSY}, the current level of fishing is considered acceptable.

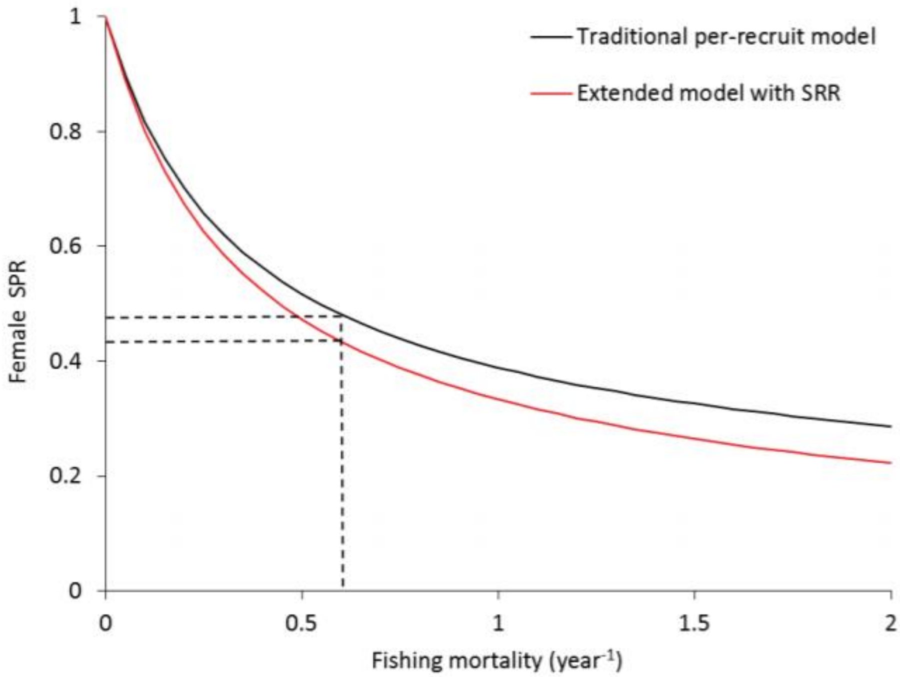


Figure 9.21. Female spawning potential ratio (SPR) for yellowfin whiting at different levels of fishing mortality (*F*, year^{-1}) derived from a traditional per-recruit model (black curve) and an extended model that incorporates a stock-recruitment relationship (SRR) (red curve). The dashed lines indicate the current SPR estimates based on the commercial *F* estimate of 0.6 year^{-1} for 2015-16.

9.3.8.3 Accounting for Uncertainty

Total mortality on the spawning stock is affected by both commercial and recreational fishing, however, the recreational catch level is unknown. Recruitment into the recreational fishery occurs earlier than the commercial fishery. For this reason, the SPR and B_{rel} estimates based on recreational selectivity parameters are more pessimistic than estimates from commercial parameters (e.g., 0.318 versus 0.432 in extended model). However, both scenarios indicate acceptable stock status.

9.3.8.4 Conclusion

Sea mullet	This analysis has not been undertaken for sea mullet.
Yellowfin whiting (WCB metro)	Estimates of female SPR and B_{rel} depend on assumptions about commercial & recreational catch shares. If the recreational catch is assumed to be larger (i.e., recreational selectivity parameters are used in the model), SPR estimates are more pessimistic than when the commercial catch is assumed to be larger (e.g., SPR=0.32 versus 0.43 in extended model). However, in both scenarios SPR lies above Threshold reference levels, indicating acceptable stock status. **The SPR and B_{rel} estimates are considered to provide no evidence of unacceptable stock depletion.**

9.3.9 Biomass Dynamics Modelling

9.3.9.1 Model Description

A Schaefer biomass dynamic model was developed using catch and catch rate data for sea mullet to determine the status of the stock, relative to MSY-based reference points specified in the harvest strategy for this resource (DPIRD 2020). The model was driven by commercial catches from the South Coast, West Coast and Gascoyne Coast bioregions between 1941 and 2020 and fitted to catch rate data from the commercial fishery in Shark Bay (1956-2020), where the latter is assumed to provide an index of spawning stock abundance (Figure 9.22). Note that the time series of catch rate had been adjusted to account for an increase in fishing efficiency when fishers started using jet-powered boats.

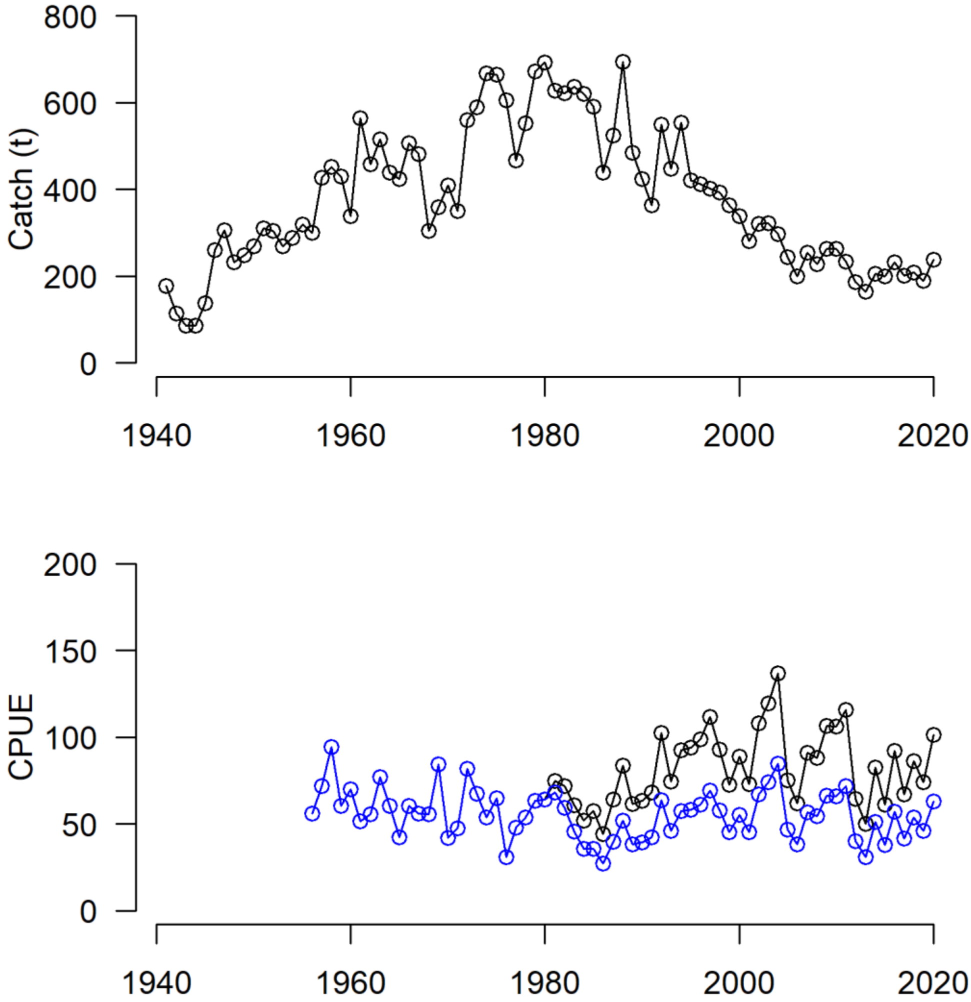


Figure 9.22. (Top plot) Total sea mullet catch (tonnes, t) in WA and (Bottom plot) unadjusted (black line) and adjusted (blue line) catch per unit effort (CPUE; kg/day) in the Shark Bay commercial fishery.

9.3.9.2 Results and Diagnostics

The Schaefer production model provided a reasonable fit to the nominal catch rates of sea mullet in Shark Bay (adjusted for fishing efficiency), except for the most recent period, when the model estimated values were larger than the observed values (Figure 9.23). This could be related to the relatively low effort in the fishery in recent years, affecting the reliability of the catch rate data. Alternatively, it may reflect low abundances of this species in Shark Bay since the marine heatwave in 2011. Given that the Shark Bay catch rates used in the model had been compiled from different sources and have not yet been standardised, the assessment will be re-visited using an updated catch rate time series generated using the same GLM approach applied to the PHE data. Further, an alternative (state space) modelling framework (e.g., see Marks et al. 2021) will be applied when fitting a biomass dynamics model to the

updated data. This type of modelling framework, which allows for both process and observation error, should better capture the interannual variation in catch rate trends, and provide improved estimates of stock status.

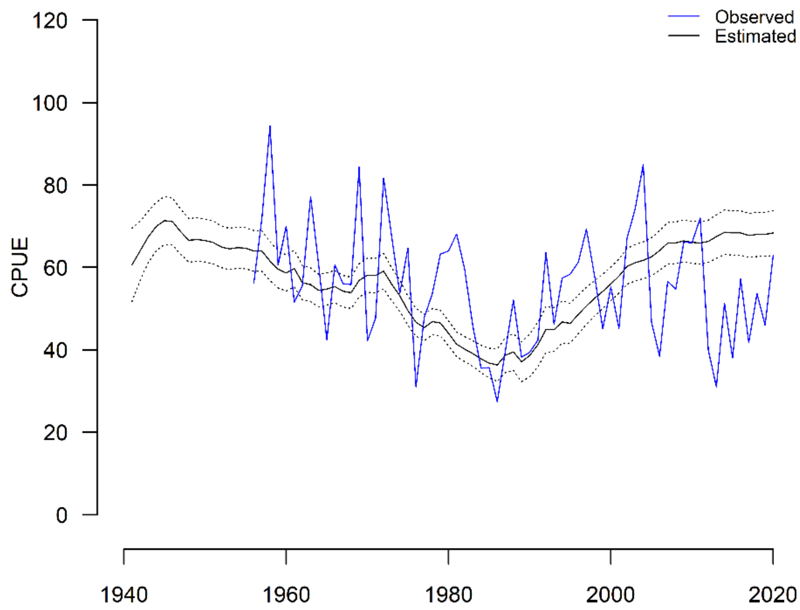


Figure 9.23. Fit of Schaefer ADMB model to nominal, adjusted (for changes in fishing efficiency) catch rate data for sea mullet in Shark Bay. The dashed lines around the estimated catch rates (black) represent the 95% CLs.

Outputs from the sea mullet assessment suggest that current level of catch is well below the estimated Maximum Sustainable Yield (MSY) for the stock of 566 t (95% CLs: 542 – 591 t). Although estimates of *K*, *r* and MSY differ slightly to those estimated by the CMSY model, both analyses indicate that the relative biomass (B/B_0 and B/B_{MSY}) of the broader sea mullet stock in 2020 is highly likely to be above the threshold level. The results from the biomass dynamic model indicate that stock in WA declined to a level around B_{MSY} after a period of historically high catches in the 1970s and early 1980s, before a decrease in catch allowed stock rebuilding to near the unfished level (Figure 9.24). Because of the reduction in catch observed since the late 1980s, estimates of fishing mortality (*F*) in 2020 were well below F_{MSY} (Table 9.8 Figure 9.24), indicating that overfishing of the stock is unlikely.

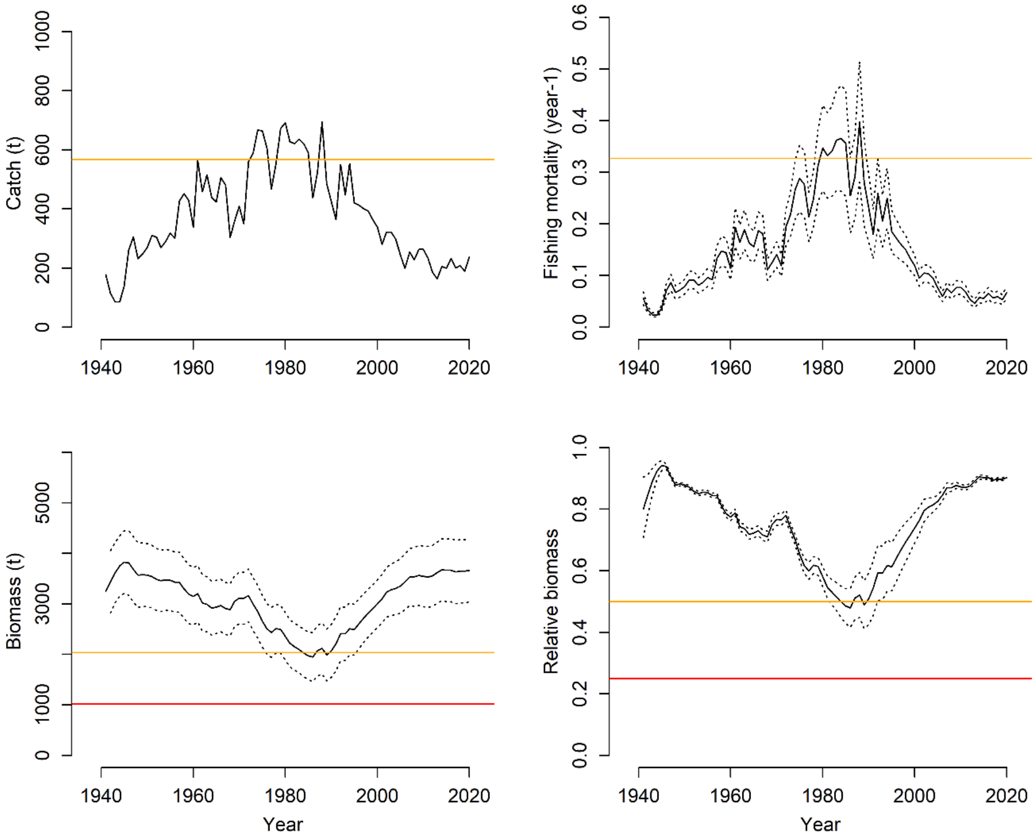


Figure 9.24. Annual time series of catch and estimates of fishing mortality, biomass, and relative biomass (proportion of unfished levels) derived from a Schaefer production model fitted using sea mullet catch and catch rate data. The 95% CLs around parameter estimates are shown as dotted lines, with the orange and red horizontal lines corresponding to the threshold and limit reference levels for this stock relating to MSY and 0.5MSY, respectively.

Table 9.8. Estimates (±95% CLs) of K, r, MSY, B_{MSY}, F_{MSY} and current (2018) levels of biomass and fishing mortality relative to unfished level and those levels expected to achieve MSY (i.e., B/B_0, B/B_{MSY} and F/F_{MSY}), derived from a Schaefer biomass dynamic model fitted to catch data for sea mullet in south-west WA and adjusted catch rates for the fishery in Shark Bay.

Parameter	Estimate (95% CLs)
K (tonnes)	4,064 (3,420-4,830)
r	0.56 (0.46-0.67)
MSY (tonnes)	567 (542-591)
B_{MSY} (tonnes)	2,032 (1,681-2,383)
F_{MSY} (year^{-1})	0.33 (0.26-0.40)
B/B_0 (in 2020)	0.90 (0.89-91)
B/B_{MSY} (in 2020)	1.80 (1.50-2.11)
F/F_{MSY} (in 2020)	0.21 (0.17-0.24)

9.3.9.3 Conclusion

Sea mullet	Results from a Schaefer biomass dynamic model fitted to commercial catches and catch rates indicate that the sea mullet stock has largely been maintained above the level of B_{MSY}. Based on adjusted catch rate data from Shark Bay, the relative biomass (B/B_0) of sea mullet in 2020 was estimated as 0.90 (95% CLs 0.89-0.91) and the B/B_{MSY} estimate of 1.80 (95% CLs 1.50-2.11) indicate the stock is likely to be above the threshold level. Estimates of F in 2020 were well below F_{MSY}, indicating that overfishing of the stock is unlikely. **The results are considered to provide no evidence of unacceptable stock depletion.**
Yellowfin whiting	This type of analysis has not been undertaken for yellowfin whiting.

9.3.10 Catch-MSY Modelling

9.3.10.1 Model Description

A Catch-MSY model (CMSY; Froese et al. 2017) was fitted using catch data for sea mullet in south-west WA to estimate the Maximum Sustainable Yield (MSY) for the stock. The Catch-MSY model is a “data-poor” stock assessment method that produces estimates of maximum population size (K), intrinsic population growth rate (r) and MSY ($rK/4$), based on a catch history and inputs relating to the assumed productivity of the stock. It also estimates trends in biomass (B) and fishing mortality

(*F*); however, these typically exhibit large uncertainty and are sensitive to assumptions around the depletion of the stock required for running the analyses.

The CMSY model was fitted to the annual commercial catches of sea mullet combined from the South Coast, West Coast and Gascoyne Coast Bioregions from 1941 to 2020, assuming a medium level of resilience of the stock (Table 9.9). The analyses assumed that the stock had only experienced minor depletion prior to the start of the time series in 1941, whilst priors for depletion at the middle and end of the time series were set to 0.1-1.0 to ensure results were not constrained (Table 9.9).

Table 9.9. Assumed prior distributions specified as input for CMSY analyses of sea mullet data from south-west WA.

Parameter	Assumed prior	Source/Comment
Resilience (*r*)	0.2-0.8	Froese et al. 2017
Initial depletion (B/B_0)	0.7-1.0	In 1941
Intermediate depletion (B/B_0)	0.1-1.0	In 2000
Final depletion (B/B_0)	0.1-1.0	In 2020

9.3.10.2 Results and Diagnostics

Whilst outputs from the CMSY model were uncertain (Table 9.10, Figure 9.25), the results suggest that annual catches have largely remained below the estimated MSY of 642 t over the history of the fishery (Figure 9.25). The model indicates that stock biomass gradually decreased from 1941 to the early 1980s as a result of increasing catches and exploitation up to, and briefly exceeding, the level expected to achieve MSY. The analysis suggests that a subsequent reduction in catches resulted in the biomass rebuilding to near the unfished level in 2020 (Figure 9.25).

Table 9.10. Estimates (±95% CLs) of *K*, *r*, MSY and current (2020) levels of biomass and fishing mortality relative to the levels expected to achieve MSY (i.e., B/B_{MSY} and F/F_{MSY}) derived from a catch-only model (CMSY; Froese et al. 2017) fitted to catch data for sea mullet in south-west WA.

Parameter	Estimate (±95%CLs)
K (tonnes)	5,132 (3,020-8,721)
r ($year^{-1}$)	0.52 (0.30-0.88)
MSY (tonnes)	642 (475-1,066)
B/B_{MSY} (in 2020)	1.82 (1.66-1.91)
F/F_{MSY} (in 2020)	0.20 (0.19-0.22)

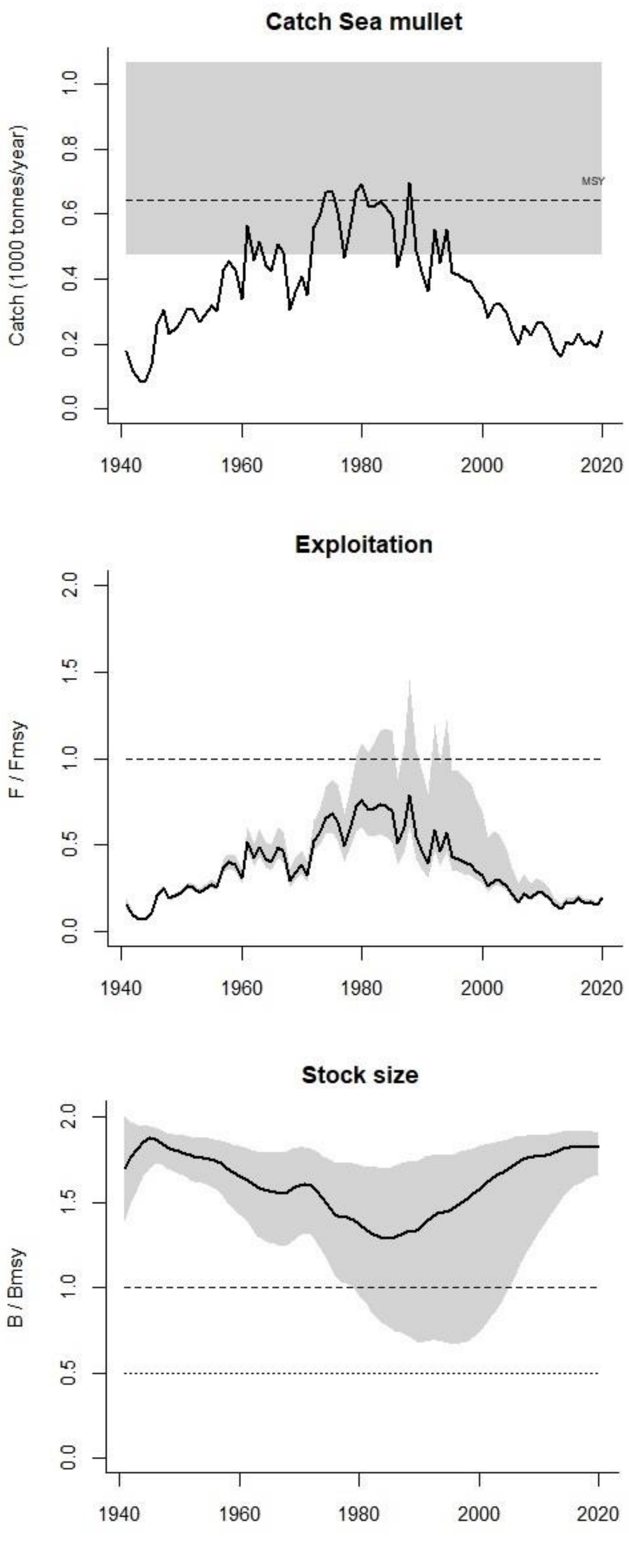


Figure 9.25. Annual time series of sea mullet catch and estimates of fishing mortality *F* and biomass *B*, relative to the levels corresponding to the estimated Maximum Sustainable Yield (MSY), derived from a catch-MSY model (CMSY; Froese et al. 2017) fitted to catch data for this stock. The 95% CLs around parameter estimates are shown in grey, with the dashed and dotted horizontal lines corresponding to commonly used threshold and

limit reference levels, respectively.

9.3.10.3 Conclusion

Sea mullet	Assuming that sea mullet has a moderate level of productivity (*r* = 0.2 – 0.8), outputs from a catch-only model (CMSY; Froese et al. 2017) fitted to the time series of commercial catches suggest that annual catches have largely remained below the estimated MSY of 642 t over the history of the fishery. The modelling results indicate that stock biomass gradually decreased from 1941 to the early 1980s as a result of increasing catches and exploitation up to, and briefly exceeding, the level expected to achieve MSY. A subsequent reduction in catches has resulted in the biomass rebuilding to near the unfished level in 2020. **The modelling results are considered to provide no evidence of unacceptable stock depletion in recent years.**
Yellowfin whiting	Analysis not done for yellowfin whiting

9.4 Stock Status Summary

Presented below is a summary of each line of evidence considered in the overall weight of evidence assessment of the stocks that comprise the southwest nearshore and estuarine finfish resource (specifically sea mullet and yellowfin whiting), followed by the management advice and recommendations for future monitoring of the species.

9.4.1 Sea mullet

9.4.1.1 Weight of Evidence Risk Assessment

Category	Lines of evidence (Consequence / Status)
Catch and effort	Sea mullet is primarily caught by the commercial net fishing sector, with catches by the recreational sector (mainly by gillnets) and customary fishers considered to be low relative to commercial catches. The commercial catch of sea mullet in the South, West and Gascoyne Coast bioregions shows a gradual increase from 1941 to around 1980, peaking at just under 700 t. Catches have since declined to the current level of around 200 t, with the majority taken by haul netting. The distribution of commercial catch among the bioregions has not changed substantially over the history of the fishery, with the majority taken in the West Coast Bioregion and, to a lesser extent, in the Gascoyne Coast Bioregion (mainly Shark Bay). Over the last five years, sea mullet has primarily been targeted by the West Coast Estuarine Managed Fishery in the Peel-Harvey Estuary, the Shark Bay Beach Seine and Mesh Net Managed Fishery, and by fishers operating in coastal waters off mid-west WA. **The data is considered to provide evidence of unacceptable stock depletion is possible, but decline in catch is likely due to markets and reduced targeting.**
Catch distribution	The distribution of commercial catch among the different bioregions have not changed substantially over the history of the fishery. Annual catches have typically been greatest in the West Coast Bioregion, where between 60 and 80% of catches have recently landed by the West Coast Estuarine Managed Fishery in the Peel-Harvey Estuary. The remainder are mostly taken by fishers in oceanic waters of the mid-west WA, off Lancelin and Jurien Bay. Sea mullet catch in the Gascoyne Coast Bioregion has primarily been taken by the Shark Bay Beach Seine and Mesh Net Managed Fishery. Although Gascoyne catches briefly exceeded those in the West Coast Bioregion in the early and late 2000s, they currently comprise around 20% of the total annual sea mullet catch. Over the past five years, less than 10% of the total annual catch has been taken in the South Coast Bioregion. **There is no evidence from catch distribution data of stock depletion in any region.**

Catch rates	The annual standardised catch rate of sea mullet in the Peel-Harvey Estuary has fluctuated between 55 and 130 kg/day since 1975 and is likely to reflect variations in recruitment to the stock. Catch rates in the mid-west and Shark Bay are considered to better reflect the abundance of spawning sea mullet, however, only a limited time series is available for the mid-west region. Nominal catch rates in Shark Bay declined from more than 60 kg/day in the late 1950s to 31 kg/day in 1976, followed by a slight increase to the current level. Adjusting the Shark Bay catch rates to account for a likely increase in fishing efficiency between 1980 and 1985 as fishers changed to jet-powered boats results in a slightly lower catch rate since that time. **The data is considered to provide no evidence of unacceptable stock depletion.**

Age and / or size composition	Age composition data collected from commercial catches of sea mullet (using nets with similar mesh sizes) between 2016 and 2018 show that catches in the Peel-Harvey Estuary were dominated by the 2+ cohort and only 21% comprised adult individuals ≥3 years old. In contrast, catches taken by beach seines in oceanic waters off the mid-west of WA and in Shark Bay contained a greater proportion of adult fish (37 and 99% respectively). These data support the theory that sea mullet inhabit estuarine environments mostly as juveniles and undertake a northward migration along the coast to spawn. Although uncertainty around the connectivity of sea mullet along the WA coast makes the collection of representative age composition data for the stock challenging, this assessment considered the age composition samples from the mid-west and Gascoyne regions to be the most reliable to describe the age structure of the sea mullet spawning stock. Length composition samples collected from commercial catches of sea mullet (using nets with similar mesh sizes) between 2016 and 2018 show a smaller range of lengths and smaller mean length of catches from the Peel-Harvey Estuary (292-482 mm, mean of 355 mm) compared to oceanic waters off mid-west WA (259-601 mm, mean length of 379 mm). Although based on a limited sample size, the lengths of fish sampled in 2018 ranged from 333 to 468 mm, with a mean size of 400 mm. The proportion of fish equal to or greater than 400 mm was much greater in the sample from Shark Bay (49%), compared to the oceanic waters off mid-west WA (28%) and the Peel-Harvey Estuary (17%). The larger individuals in the samples were predominantly female due to differences in the growth of the two sexes. **The data is considered to provide no evidence of unacceptable stock depletion.**

Vulnerability (PSA)	Sea mullet have a low to moderate longevity (maximum recorded age in WA of 12 years), mature at approximately 3 to 4 years of age and have a high fecundity. Targeted commercial fishing for sea mullet in WA occurs in a relatively small proportion of the overall stock distribution, however, the vertical overlap between the stock and the fishing gear in the water column is likely high. Whilst juvenile sea mullet are frequently caught within estuarine fisheries, catches from oceanic waters of mid-west WA and in Shark Bay comprise a greater proportion of mature individuals. Based on a productivity score of 1.14 and susceptibility scores of the key fisheries ranging from 1.2 to 1.65, the overall PSA score of 1.85 suggests a low risk of overexploiting the stock is low under current management arrangements and fishing effort. It assumes that the productivity of the stock is constant and not impacted by environmental conditions. **The data is considered to indicate that unacceptable stock depletion could occur without appropriate management.**
Catch Curve Analysis	Assuming a value of natural mortality (*M*) for sea mullet of 0.5 year^{-1}, estimates of fishing mortality (*F*) derived from an equilibrium catch curve model fitted to the age composition sample collected in oceanic waters off mid-west WA between 2016 and 2018 was 0.35 year^{-1} (95%CLs 0.31-0.40 year^{-1}) for females and 0.52 year^{-1} (95% CLs 0.48-0.57 year^{-1}) for males. As part of the decline in the numbers of fish with increasing age may reflect the continued northward migration from the area of sampling, these may be overestimates of *F*. Despite this uncertainty, the results suggest it is possible that the long-term average *F* experienced by fully-vulnerable fish has been above the acceptable level of F=M. **The model outputs are considered to provide no evidence of unacceptable stock depletion.**
Biomass Dynamic Modelling	Results from a Schaefer biomass dynamic model fitted to commercial catches and catch rates indicate that the sea mullet stock has largely been maintained above the level of B_{MSY}. Based on adjusted catch rate data from Shark Bay, the relative biomass (B/B0) of sea mullet in 2020 was estimated as 0.90 (95% CLs 0.89-0.91) and the $B/\ B_{MSY}$ estimate of 1.80 (95% CLs 1.50-2.11) indicate the stock is likely to be above the threshold level. Estimates of F in 2020 were well below FMSY, indicating that overfishing of the stock is unlikely. **The results are considered to provide no evidence of unacceptable stock depletion.**

Catch-MSY modelling	Assuming that sea mullet has a moderate level of productivity (r = 0.2 – 0.8), outputs from a catch-only model (CMSY; Froese et al. 2017) fitted to the time series of commercial catches suggest that annual catches have largely remained below the estimated MSY of 642 t over the history of the fishery. The model indicate that stock biomass gradually decreased from 1941 to the early 1980s as a result of increasing catches and exploitation up to, and briefly exceeding, the level expected to achieve MSY. A subsequent reduction in catches has resulted in the biomass rebuilding to near the unfished level in 2020. **The modelling results are considered to provide no evidence of unacceptable stock depletion in recent years.**

Consequence (Stock Depletion) Level	Likelihood				Risk Score
	L1 Remote (<5%)	L2 Unlikely (5- <20%)	L3 Possible (20- <50%)	L4 Likely (≥50%)	
C1 Minor			X		**2**
C2 Moderate				X	**8**
C3 High	X				**3**
C4 Major	X				**4**

C1 (Minor Depletion): **Possible L3 -** Estimates of biomass produced by the Schaefer biomass dynamic model suggest that the sea mullet stock is currently above the threshold level of B_{MSY}. Based on the overlap of the 95% CLs of biomass estimates with the proxy target level of $1.2B_{MSY}$, and due to the very low estimate of current fishing mortality relative to F_{MSY}, it is considered **Possible** that the stock has only experienced a Minor depletion to date.

C2 (Moderate Depletion): **Likely L4 -** Estimates of current biomass and associated 95% CLs produced by the Schaefer biomass dynamic model are well above the threshold level of B_{MSY}. Based on these results and a truncated age structure consistent with that expected for a fished stock, a moderate level of stock depletion is considered **Likely**.

C3 (High Depletion): **Remote L1 -** The estimates of current biomass and fishing mortality (and associated 95% CLs) relative to the levels expected to achieve MSY suggest that a high depletion of the stock is **Remote**.

C4 (Major Depletion): **Remote L1 –** Annual commercial catch rates of juvenile sea mullet in the Peel-Harvey Estuary since 1975 provide no evidence of recruitment impairment of the stock to date. The likelihood of major depletion of the sea mullet stock is considered **Remote**.

9.4.1.2 Current Risk Status

Based on the information available, the current risk level for sea mullet in south-west WA for the next 5 years is estimated to be MEDIUM (C2 × L4). The medium risk (see Appendix 2) reflects acceptable levels of fishing mortality and estimates of relative spawning biomass. All the lines of evidence are generally consistent with a medium level of risk; hence the overall Weight of Evidence assessment indicates the status of the south-west WA sea mullet stock is adequate and that current management settings are maintaining risk at acceptable levels.

This score assumes the total catch will be maintained at near current levels which could require the development and implementation of a suitable set of management arrangements for all sectors to ensure this is maintained and that the stock status is monitored at regular intervals into the future. It should also be noted that the information in the lines of evidence for *F* and SPR presented in the above analyses indicate that a significant increase in annual catch levels would increase the likelihood of the stock declining to an unacceptable level.

9.4.1.3 Future Monitoring

Annual monitoring of catch and effort information and standardised commercial CPUE is ongoing. Sampling of length and age composition data will be undertaken to inform the next benchmark assessment. An assessment of the environmental factors affecting the spawning and recruitment should be undertaken. A review/update of this assessment will be undertaken annually, with the next benchmark assessment due in 2025.

9.4.2 Yellowfin whiting

9.4.2.1 Weight of Evidence Risk Assessment

Category	Lines of evidence (Consequence / Status)
Catch and effort	The majority of commercial and recreational catches of yellowfin whiting in southern WA occurs off the Perth metropolitan area. Recreational catches are taken by line by both boat and shore-based fishers, but the current recreational catch is unknown due to lack of recent shore-based fishing surveys. Data for the commercial net and line fisheries show that the long-term commercial catch trends in this region are relatively stable. Recent catches have been above average in the west and south coast due to strong recruitment by a single year class that was spawned during the 2010/11 marine heatwave event [Smith et al. 2019]. Catches have now returned to lower, more typical long-term levels. The heatwave event results in catches declining in Shark Bay for some years after this event. The boundaries of each commercial fishery are fixed so there is little scope for within-fishery shifts in catch or effort, but between-fishery shifts could occur. **The data is considered to provide possible evidence of unacceptable stock depletion, but decline in catch is likely due to markets and reduced targeting.**
Catch distribution	The boundaries of each commercial fishery are fixed so there is little scope for within-fishery shifts in catch or effort, but between-fishery shifts could occur. The overall catch level in each region has been relatively stable over several decades, suggesting long-term stable stock levels. Since 2011, data suggest increases in the WCB & SCB. **There is no evidence from catch distribution data of stock depletion in any region.**
Catch rates	Commercial fishery catch rates suggest a sudden, large increase in abundance in each Bioregion after the 2011 heatwave, peaking first in the Gascoyne, then West Coast Bioregion, and finally in the South Coast Bioregion. Catch rates suggest current abundances high relative to historical levels, which suggests a low risk to each stock. **The data is considered to provide no evidence of unacceptable stock depletion.**

Age and / or size composition	In the West Coast Bioregion, the maximum age of fish sampled in 2015 and 2016 was 9 years in metro zone and 11 years in south-west zone. In both zones there is evidence of very strong recruitment by 2010/11 and 2012/13 year classes, representing fish spawned during the marine heatwave and their offspring, respectively. Given the maximum observed age for species is 12 years, the age structure in the West Coast Bioregion suggests a relatively low level of truncation due to fishing. A high proportion of fish in each sample was above the age at 50% maturity of 2 years. Recruitment into the commercial fishery starts at 2 years, with full selection by around 4 years of age. The timing of recruitment by strong 2010/11 year class thus explains sudden rise in catches from 2013 onwards. **The data is considered to provide no evidence of unacceptable stock depletion.**
Vulnerability (PSA)	Yellowfin whiting have a low to moderate longevity (maximum recorded age in WA of 12 years), mature at approximately 2 years of age and 180-200 mm in length. This species is a broadcast spawner and while fecundity is likely high, spawning in very shallow (< 5 m) coastal waters may limit the alongshore dispersal of eggs and larvae. Yellowfin whiting form loose aggregations in shallow areas and their distribution makes them highly vulnerable to commercial netting and recreational line fishing. The vertical overlap between the stock and the fishing gear in the water column is high. Commercial and recreational catches comprise mostly mature individuals and are often seasonal, peaking during the spawning period. Based on a productivity score of 1.29 and susceptibility scores of the key fisheries of 1.65, the overall PSA score of 2.09 suggests a low risk of overexploiting the stock is low under current management arrangements and fishing effort. It assumes that the productivity of the stock is constant and not impacted by environmental conditions. **The data is considered to indicate that unacceptable stock depletion could occur without appropriate management.**

Catch Curve Analysis	Assuming a value of natural mortality (M) for yellowfin whiting of 0.35 year-1, estimates of fishing mortality (F) derived from a catch curve model fitted to the age composition sample collected in the metropolitan zone of the West Coast Bioregion in 2015-16 was 0.60 year-1 for the commercial sector. While this estimate is well above the value of M, a lower level of F is likely affecting younger adults with maturity occurring at 2 years of age and full recruitment into the commercial fishery at 3-4 years of age. Despite this uncertainty, the results suggest it is possible that the long-term average F experienced by fully vulnerable fish has been above the acceptable level of F=M. **The model outputs are considered to provide evidence that unacceptable stock depletion is possible.**
Spawning biomass	SPR was estimated for the WCB metro zone in 2015-2016. Estimates depend on assumptions about commercial & recreational catch shares. If the recreational catch is assumed to be larger (i.e., recreational selectivity parameters are used in the model), SPR estimates are more pessimistic than when the commercial catch is assumed to be larger (e.g., SPR=0.318 versus 0.432 in extended model). However, in both scenarios SPR lies between Target and Threshold reference levels, indicating acceptable stock status. **The SPR and B_{rel} estimates are considered to provide no evidence of unacceptable stock depletion.**

Consequence (Stock Depletion) Level	Likelihood				Risk Score
	L1 Remote (<5%)	**L2 Unlikely (5- <20%)**	**L3 Possible (20- <50%)**	**L4 Likely (≥50%)**	
C1 Minor		X			**2**
C2 Moderate				X	**8**
C3 High		X			**6**
C4 Major	X				**4**

C1 (Minor Depletion): **Unlikely L2 –** Based on the catch history, current age structure and fishing mortality estimates, it is **Unlikely** that the level of current stock depletion is still only minimal.

C2 (Moderate Depletion): **Likely L4 –** Most lines of evidence, including the age structure, and estimates of *F* and SPR, are consistent with the stock level of yellowfin whiting **Likely** to be at an acceptable level, being somewhere close to the maximum level of acceptable depletion. These lines of evidence also suggest that if

the current total levels of annual capture are maintained, the stock level is likely to remain within this band during the next five years.

C3 (High Depletion): **Unlikely L2 -** All of the lines of evidence are consistent with it being **Unlikely** that at the current (historic) levels of fishing that the stock depletion has or will become unacceptably high within the next five years.

C4 (Major Depletion): **Remote L1 –** Given there is no evidence that recruitment levels have been affected at any point over the history of the fishery, it is not plausible that the stock has experienced major depletion. There remains a **Remote** likelihood of this occurring within the next 5 years based on the potential for unknown factors.

9.4.2.2 Current Risk Status

Based on the information available, the current risk level for yellowfin whiting in south-west WA for the next 5 years is estimated to be MEDIUM (C2 × L4), i.e., the stock is maintained between the threshold and target level. This level of risk is acceptable under current control measures and with the ongoing level of stock status monitoring set out by the harvest strategy for this stock (DPIRD 2020). All the lines of evidence are consistent with a medium level of risk; hence the overall Weight of Evidence assessment indicates the status of the south-west WA yellowfin whiting stock is adequate and that current management settings are maintaining risk at acceptable levels.

This score assumes the total catch will be maintained at near current levels which could require the development and implementation of a suitable set of management arrangements for all sectors to ensure this is maintained and that the stock status is monitored at regular intervals into the future. It should also be noted that the information in the lines of evidence for F and SPR presented in the above analyses indicate that a significant increase in annual catch levels would increase the likelihood of the stock declining to an unacceptable level.

9.4.2.3 Future Monitoring

Annual monitoring of commercial catch information, particularly in relation to environmental conditions such as marine heatwaves, is ongoing and used to inform periodic risk assessments of key fisheries targeting this stock. Sampling of length and age composition data to inform the next benchmark assessment will be undertaken in response to indications that the risk to the stock has changed, as triggered by the harvest strategy. Ongoing fishery-independent surveys sampling recruitment recommenced in September 2020.

10 References

Bellchambers, L.M., Fisher, E.A., Harry, A.V. and Travaille, K.L. (2016). Identifying and mitigating potential risks for Marine Stewardship Council assessment and certification. *Fisheries Research* 182: 7-17.

Brown, J., Dowling, C., Hesp, A., Smith, K. and Molony, B. (2013). Status of Nearshore Finfish Stocks in South-western Western Australia. Part 3. Whiting (Sillaginidae). Fisheries Research Report No. 248.

Brown, J. (2014) Shark Bay Beach Seine and Mesh Net Managed Fishery Stock Status Report. December 2014. Unpublished report. Department of Fisheries, WA. 19pp.

Caputi, N., Feng, M., Pearce, A., Benthuysen, J., Denham, A., Hetzel, Y., Matear, R., Jackson, G., Molony, B., Joll, L. and Chandrapavan, A. (2015). Management implications of climate change effect on fisheries in Western Australia. Part 1. Environmental change and risk assessment. Department of Fisheries, WA.

Chapman D.G. and Robson D.S. (1960). The analysis of a catch curve. *Biometrics* 16(3): 354-368.

Chubb, C.F., Potter, I.C., Grant, C.J., Lenanton, R.C.J. and Wallace, J. (1981). Age, structure, growth rates and movements of sea mullet, *Mugil cephalus* L., and yellow-eye Mullet, *Aldrichetta forsteri* (Valenciennes), in the Swan-Avon River system, Western Australia. *Marine and Freshwater Research* 32(4): 605-628.

Cooper, R. (1997). Shark Bay Legends. First Edition. Rawlinsons Publishing.

Coulson, P. (2003). *Comparisons between the biology of two species of whiting (Sillaginidae) in Shark Bay, Western Australia.* Honours thesis, Murdoch University.

Coulson, P.G., Hesp, S.A., Potter, I.C. and Hall, N.G. (2005). Comparisons between the biology of two co-occurring species of whiting (Sillaginidae) in a large marine embayment. *Environmental Biology of Fishes:* 73: 125-139.

Crisafulli, B. (2008). *Biology of two fish species of mullet (Mugilidae) in five estuaries on the south coast of Western Australia.* Honours thesis, Murdoch University.

Department of Fisheries. (1999). Management Directions for Western Australia's Estuarine and Marine Embayment Fisheries. A strategic approach to management. Fisheries Management Paper 131. Department of Fisheries Government of Western Australia, Perth, Australia.

DoF. (2011). Resource Assessment Framework (RAF) for finfish resources in Western Australia. Fisheries Occasional Publication No. 85. Department of Fisheries, WA.

DoF. (2015). Harvest Strategy Policy and Operational Guidelines for the Aquatic Resources of Western Australia. Fisheries Management Paper No. 271. Department of Fisheries, WA.

Department of Primary Industries and Regional Development (DPIRD) (2020). Blue Swimmer Crab Resource of Shark Bay Harvest Strategy 2020-2025. Fisheries Management Paper No. 300. DPIRD, WA.

Dunn, A., Francis, R.I.C.C., and Doonan, F.I. (2002). Comparison of the Chapman-Robson and regression estimators of *Z* from catch-curve data when non-sampling stochastic error is present. *Fisheries Research* 59(1-2): 149-159

Durand, J.D., Chen, W.J., Shen, K.N., Jamandre, B.W., Blel, H., and Diop, K. (2012). Systematics of the grey mullets (Teleostei: Mugiliformes: Mugilidae): molecular phylogenetic evidence challenges two centuries of morphology-based taxonomy. *Molecular Phylogenetics and Evolution* 64: 73-92.

Fairclough, D., Brown, J., Carlish, B., Crisafulli, B.M., and Keay, I.S. (2014), Breathing life into fisheries stock assessments with citizen science. *Sci Rep* 4: 7249.

Ferguson, G. (1999). Yellowfin Whiting (*Sillago schomburgkii*). South Australian Fisheries Assessment Series 99/10. 48pp.

Ferguson, G. (2000). Yellowfin whiting (*Sillago schomburgkii*). Fishery Assessment Report to PIRSA for the Marine Scalefish Fishery Management Committee. South Australian Fisheries Assessment Series Report No. 00/10. Adelaide, SA: SARDI.

Fisher, EA., Hesp, SA., Hall, N.G., and Sulin, E.H. (2014). Predicting the impacts of shifting recreational fishing effort towards inshore species, Final report, Fisheries Research and Development Corporation project 2010/001.

Fisher, E.A., Evans, S.N., Desfosses, C.J., Johnston, D.J., Duffy, R., and Smith, K.A. (2020). Ecological Risk Assessment for the Peel-Harvey Estuarine Fishery. Fisheries Research Report No. 311. Department of Primary Industries and Regional Development, WA. 102pp.

Fletcher, W.J. (2002). Policy for the implementation of ecologically sustainable development for fisheries and aquaculture within Western Australia. Fisheries Management Paper No. 157. Department of Fisheries, WA.

Fletcher, W.J. (2015). Review and refinement of an existing qualitative risk assessment method for application within an ecosystem-based fisheries management framework. *ICES Journal of Marine Science* 72: 1043-1056.

Fletcher, W.J. and Santoro, K. (eds.) (2015). Status reports of the fisheries and aquatic resources of Western Australia 2014/15: State of the fisheries. Department of Fisheries, WA.

Fletcher, W.J., Shaw, J., Metcalf, S.J. and Gaughan, D.J. (2010). An Ecosystem Based Fisheries Management framework: the efficient, regional-level planning tool for management agencies. Marine Policy 34: 1226-1238.

Fletcher, W.J., Shaw, J., Gaughan, D.J. and Metcalf, S.J. (2011). Ecosystem Based Fisheries Management case study report – West Coast Bioregion. Fisheries Research Report No. 225. Department of Fisheries, WA. 116 pp.

Fletcher, W.J., Wise, B.S., Joll, L.M., Hall, N.G., Fisher, E.A., Harry, A.V., Fairclough, D.V., Gaughan, D.J., Travaille, K., Molony, B.W. and Kangas, M. (2016). Refinements to harvest strategies to enable effective implementation of Ecosystem Based Fisheries Management for the multi-sector, multi-species fisheries of Western Australia. *Fisheries Research* 183: 594-608.

Fowler, A.M., Smith, S.M., Booth, D.J. and Stewart, J. (2016) Partial migration of grey mullet (*Mugil cephalus*) on Australia's east coast revealed by otolith chemistry. *Marine Environmental Research* 119: 238-44.

Fraser, A.J. (1953). The river or sea mullet of Western Australia. Monthly Service Bulletin (WA Fisheries Department) 2: 183-196.

Froese, R., Demirel, N., Coro, G., Kleisner, K.M., and Winker, H. (2017). Estimating fisheries reference points from catch and resilience. *Fish and Fisheries* 18: 506-526.

Froese, R. and Pauly, D. (eds.) (2022). FishBase. World Wide Web electronic publication. www.fishbase.org, version (02/2022).

Gaughan, D., Ayvazian, S. and Nowara, G. (2006). The Development of a Rigorous Sampling Program for a Long-Term Annual Index of Recruitment for Finfish Species from South-Western Australia. *Final FRDC Report-Project 1999/153*. Fisheries research division, Western Australian fisheries and marine research laboratories.

Gomon, M.F., Bray, D.J., and Kuiter, R.H. (eds.). (2008). *Fishes of Australia's southern coast*. Chatswood, Australia: New Holland.

Gray, C.A., Barnes, L.M., Van der Meulen, D.E., Kendall, B.W., Ochwada-Doyle, F.A. and Robbins, W.D. (2014). Depth interactions and reproductive ecology of sympatric Sillaginidae: *Sillago robusta* and *S. flindersi*. *Aquat Biol* 21: 127-142. https://doi.org/10.3354/ab00578

Haddon, M. (2018). Herring Attachment 8. Stock Reduction Analyses (Catch-MSY Method). In Wise, B. and Molony, B. (eds), Australian Herring and West Australian Salmon Scientific Workshop Report, October 2017. Fisheries Research Report 289. Department of Primary Industries and Regional Development, WA.

Harrison, I.J., and Senou H. (1999). Mugilidae. FAO species identification guide for fishery purposes. *The living marine resources of the Western Central Pacific, Vol 4: bony fishes part 2 (Mugilidae to Carangidae)*. FAO, pp 2069–2108

Hobday, A.J., Smith, A.D.M., Stobutzki, I.C., Bulman, C., Daley, R., Dambacher, J.M.,Deng, R.A., Dowdney, J., Fuller, M., Furlani, D., Griffiths, S.P., Johnson, D., Kenyon,R., Knuckey, I.A., Ling, S.D., Pitcher, R., Sainsbury, K.J., Sporcic, M., Smith, T., Turnbull, C., Walker, T.I., Wayte, S.E., Webb, H., Williams, A., Wise, B.S. and Zhou, S. (2011). Ecological risk assessment for the effects of fishing. *Fisheries Research* 108: 372-384.

Hoenig, J.M. (1983). Empirical use of longevity data to estimate mortality rates. *Fishery Bulletin* 82: 898-903.

Hutchins, B., and Swainston, R. (1986). *Sea fishes of southern Australia: complete field guide for anglers and divers*. Swainston.

Hyndes, G.A. and Potter, I.C. (1997). Age, Growth, and reproduction of *Sillago schomburgkii* in south-western Australian nearshore waters and comparisons of life history styles for a suite of Sillago species. *Environmental Biology of Fishes* 49: 435-447.

Jackson, G., Cheng, Y.W. and Wakefield, C.B. (2012). An evaluation of the daily egg production method to estimate spawning biomass of snapper (*Pagrus auratus*) stocks in inner Shark Bay, Western Australia, following more than a decade of surveys 1997–2007. *Fisheries Research* 117-118: 22–34. doi:10.1016/J.FISHRES.2010.12.009

Johnston, D.J., Smith, K.A., Brown, J.I., Trevaille, K.L., Crowe, F., Oliver, R.K. and Fisher, E.A. (2015). Western Australian Marine Stewardship Council Report Series No. 3: West Coast Estuarine Managed Fishery (Area 2: (Peel-Harvey Estuary) & Peel-Harvey Estuary Blue Swimmer Crab Recreational Fishery. Department of Fisheries, WA. 284pp.

Jones, G.K. (1981). Yellowfin whiting (*Sillago schomburgkii*) studies in South Australian waters. SAFIC 5(4): 20-23.

Jones, K. (2013). Review of report on the "Status of nearshore finfish stocks in south-western Western Australia: Australian herring and tailor" prepared by Keith Jones, Sillago Research Pty Ltd for the Department of Fisheries, Western Australia. Fisheries Occasional Publication No. 116. Department of Fisheries, Western Australia. 52pp.

Kailola, P., Williams, M.J., Stewart, P.C., Reichlet, R.E., McNee, A. and Grieve, C. (1993). Australian fisheries resources. Bureau of Resource Sciences and Fisheries Research and Development Corporation, Canberra.

Krück, N.C., Innes, D.I. and Ovenden, J.R. (2013). New SNPS for population genetic analysis reveal possible cryptic speciation of eastern Australian sea mullet (*Mugil cephalus*). *Molecular Ecology Resources* 13: 715-725. Doi:10.1111/1755-0998.12112

Leis, J.M. and Carson-Ewart, B.M. (eds.). (2000). The larvae of Indo-Pacific coastal fishes: an identification guide to marine fish larvae (Vol. 2). Brill.

Lenanton, R. (1970) *The biology of the commercially fished whiting (Sillago spp.) in Shark Bay, Western Australia*, Phd Thesis, University of Western Australia.

Lenanton R.C.J. (1978). Fish and exploited crustaceans of the Swan – Canning estuary. Department of Fisheries and Wildlife Report. No. 35. Department of Fisheries and Wildlife, WA. 36pp.

Lenanton, R.C.J. (1982). Alternative non-estuarine habitats from some commercially and recreationally important fish species of south-western Australia. *Australian Journal of Marine and Freshwater Research* 33: 881-900.

Lenanton, R.C.J. (1984). The commercial fisheries of temperate Western Australian estuaries: Early settlement to 1975. West. Aust. Dep. Fish. Wildl. Rep. No. 62, 82p.

Lenanton, R., Fletcher, R. and Gaughan, D. (2006). Integrated fisheries management in Western Australia – a significant challenge for fisheries scientists. *In* Phelan, M.J. and Bajhau, H. (eds.), A guide to monitoring fish stocks and aquatic ecosystems. Australian Society for Fish Biology Workshop Proceedings, Darwin, Northern Territory, 11-15 July 2005. Fisheries Incidental Publication No. 25. Northern Territory Department of Primary Industry, Fisheries and Mines, Darwin, pp. 37-43.

Lenanton, R.C.J. and Potter, I.C. (1987). Contribution of estuaries to commercial fisheries in temperate Western Australia and the concept of estuarine dependence. *Estuaries* 10(1): 28-35.

Liao, I.C. (1975). Experiments on induced breeding of the grey mullet in Taiwan from 1963 to 1973. *Aquaculture* 6(1): 31-58.

Marine Stewardship Council (MSC). (2014). MSC Guidance for the Fisheries Certification Requirements, V2.0, 1st October 2014.

Marks, R., Hesp, S.A., Denham, A., Loneragan, N.R., Johnston, D. and Hall, N. (2021). Factors influencing the dynamics of a collapsed blue swimmer crab (*Portunus armatus*) population and its lack of recovery. Fisheries Research 242:106035

Marriott, R.J., Jarvis, N.D.C., Adams, D.J., Gallash, A.E., Norriss, J and Newman S.J. (2010). Maturation and sexual ontogeny in the spangled emperor *Lethrinus nebulosus*. *Journal of Fish Biology* 76(6): 1396-1414. DOI: 10.1111/j.1095-8649.2010.0257.x

Marriott, R., Jackson, G., Lenanton, R., Telfer, C., Lai, E., Stephenson, P., Bruce, C., Adams, D. and Norriss, J. (2012) Biology and stock status of inshore demersal scalefish indicator species in the Gascoyne Coast Bioregion. Fisheries Research Report No. 228. Department of Fisheries, WA. 216pp.

McDonough, C., Roumillat, W., and Wenner, C. (2005). Sexual differentiation and gonad development in striped mullet (*Mugil cephalus* L.) from South Carolina estuaries. Fish. Bull. 103(4): 601-619.

Millington, P. and Cranley, M. A case study on the use of fisheries adjustment schemes to achieve shifts in resource allocations in estuaries and embayments in Western Australia. Department of Fisheries, WA. Unpublished report.

Nash, C.E., and Shehadeh, Z.H. (1980). Review of breeding and propagation techniques for grey mullet, *Mugil cephalus*.

Neira, F.J., Miskiewicz, A.G. and Trinski, T. (1998). Larvae of Temperate Australian Fishes. University of Western Australia Press, Nedlands. 474 pp.

Norriss, J.V., Fisher, E.A., Hesp, S.A., Jackson, G, Coulson, P.G., Leary, T and Thomson, A.W. (2016). Status of inshore demersal scalefish stocks on the South Coast of Western Australia. Fisheries Research Report No. 276, Department of Fisheries, WA. 116 pp.

Odum, E.P. (1963). Primary and secondary energy flow in relation to ecosystem structure. Proc. 16th Int. Congr. Zool. 4: 336-338.

Orr, P. (2000). *The biology of four commercial fish species in a seasonally closed estuary.* PhD Thesis, Murdoch University.

Pearce, A., Lenanton, R., Jackson, G., Moore, J., Feng, M. and Gaughan, D. (2011). The “marine heat wave” off Western Australia during the summer of 2010/11. Fisheries Research Report No. 222. Department of Fisheries, WA.

Pearn, R. and Cappelluti, T. (1999). The South Coast estuarine fishery. A discussion paper. Fisheries Department of Western Australia, Perth, Article No. 126.

Potter, I.C., Chalmer, P.N., Tiivel, P.N., Steckis, R.A. Platell, M.E. and Lenanton, R. (2000). The fish fauna and finfish fishery of the Leschenault Estuary in south –

Western Australia. *Journal of the Royal Society of Western Australia* 83: 481-501.

Punt, A.E., Butterworth, D. S., de Moor, C.L., De Oliveira, J. A. A. and Haddon, M. (2014). Management strategy evaluation: best practices. *Fish and Fisheries* 17(2): 303-334.

Render, J.H., Thompson, B.A., and Allen, R.L. (1995). Reproductive development of striped mullet in Louisiana estuarine waters with notes on the applicability of reproductive assessment methods for isochronal species. *Transactions of the American Fisheries Society* 124(1): 26-36.

Ricker, W.E. (1975). Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada, 191 pg. 382

Rossi, A.R., Capula, M., Crosetti, D., Campton, D.E. and Sola, L. (1998). Genetic divergence and phylogenetic inferences in five species of Mugilidae (Pisces: Perciformes). *Marine Biology* 131: 213-218.

Ryan, K.L., Wise, B.S., Hall, N.G., Pollock, K.H., Sulin, E.H. and Gaughan, D.J. (2013). An integrated system to survey boat-based recreational fishing in Western Australia 2011/12. Fisheries Research Report No. 249. Department of Fisheries, WA.

Ryan, K.L., Hall, N.G., Lai, E.K., Smallwood, C.B., Taylor, S.M. and Wise, B.S. (2015). Statewide survey of boat-based recreational fishing in Western Australia 2013/14. Fisheries Research Report No. 268. Department of Fisheries, WA.

Ryan, K.L., Hall, N.G., Lai, E.K., Smallwood, C.B., Taylor, S.M. and Wise, B.S. (2017). Statewide survey of boat-based recreational fishing in Western Australia 2015/16. Fisheries Research Report No. 287. Department of Primary Industries and Regional Development, WA.

Ryan, K.L., Hall, N.G., Lai, E.K., Smallwood, C.B., Tate, A., Taylor, S.M. and Wise, B.S. (2019). Statewide survey of boat-based recreational fishing in Western Australia 2017/18. Fisheries Research Report No. 297. Department of Primary Industries and Regional Development, WA.

Shark Bay Beach Seine and Mesh Net Limited Entry Fishery Notice 1992 (Fisheries Act 1905, Western Australia).

Smith, K.A. (2006). *Review of fishery resources and status of key fishery stocks in the Swan-Canning Estuary*. Fisheries Research Division, Western Australian Fisheries and Marine Research Laboratories.

Smith, K.A. and Deguara, K. (2002). *Review of biological information and stock assessment for the NSW sea mullet resource*. NSW Fisheries Cronulla Fisheries Centre.

Smith, K.A. and Deguara, K. (2003). Formation and annual periodicity of opaque zones in sagittal otoliths of *Mugil cephalus* (Pisces: Mugilidae). *Marine and Freshwater Research* 54: 57-67.

Smith, K., Brown, J., Lewis, P., Dowling, C., Howard, A., Lenanton, R. and Molony, B. (2013a). Status of nearshore finfish stocks in south-western Western

Australia. Part 1: Australian herring. Final NRM Report - Project No. 09003. Fisheries Research Report No. 246. Department of Fisheries, WA. 200 pp.

Smith, K., Brown, J., Lewis, P., Dowling, C., Howard, A., Lenanton, R. and Molony, B. (2013b). Status of nearshore finfish stocks in south-western Western Australia. Part 2: Tailor. Final NRM Report – Project No. 09003. Fisheries Research Report No.247. Department of Fisheries WA. 112 pp.

Smith, K.A., Dowling, C.E. and Brown, J. (2019). Simmered then boiled: Multi-decadal poleward shift in distribution by a temperate fish accelerates during marine heatwave. *Frontiers in Marine Science* 6: 407.

Stewart, J., Hegarty, A., Young, C and Fowler, A.M. (2018) Gender-specific differences in growth, mortality and migration support population resilience in a heavily exploited migratory marine teleost, *Mugil cephalus* (Linnaeus 1758). *Marine and Freshwater Research* 69: 385-394.

Then, A.Y., Hoenig, J.M., Hall, N.G. and Hewitt, D.A. (2015). Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. *ICES Journal of Marine* Science 72: 82-92.

Thomson, J.M. (1957). The size at maturity and spawning times of some Western Australian estuarine fishes. Western Australian Fisheries Department *Fisheries Bulletin* 8. 8pp

Thomson, J.M. (1951). Growth and Habits of the Sea Mullet, *Mugil dobula* Gunther, in Western Australia. *Marine and Freshwater Research* 2(2): 193-225.

Thomson, J.M. (1955). The movements and migrations of mullet (*Mugil cephalus* L.). *Marine and Freshwater Research* 6(3): 328-347.

Thomson, J.M. (1963). Synopsis of biological data on the grey mullet *Mugil cephalus* Linnaeus 1758.

Virgona, J., Deguara, K., Sullings, D., Halliday, I. and Kelly, K. (1998). Assessment of the stocks of sea mullet in New South Wales and Queensland waters. *NSW Fisheries Research Institute: Sydney, NSW, Australia*.

Walker, J.H. and Clarke, D.P. (1987). The Australian herring fishery in Western Australia, 1973-1985. Western Australian Department of Fisheries Report 76. 43p.

Wallace, J.H. (1975b). The estuarine fishes of the east coast of South Africa III. Reproduction. Invest Rep Oceanogr Res Inst 41: 1-51.

Walsh, W.A., Swanson, C. and Lee, C.S. (1991). Combined effects of temperature and salinity on embryonic development and hatching of striped mullet, *Mugil cephalus*. *Aquaculture* 97(2-3): 281-289.

Whitfield, A.K., Panfili, J., and Durand, J.D. (2012). A global review of the cosmopolitan flathead mullet *Mugil cephalus* Linnaeus 1758 (Teleostei: Mugilidae), with emphasis on the biology, genetics, ecology and fisheries aspects of this apparent species complex. *Reviews in Fish Biology and Fisheries* 22(3): 641-681.

Wise, B.S., St John, J. and Lenanton, R.C.J. (2007). Spatial scales of exploitation among populations of demersal scalefish: implications for management. Part 1:

Stock status of the key indicator species for the demersal scalefish fishery in the West Coast Bioregion. Final report to Fisheries Research and Development Corporation on Project No. 2003/052. Fisheries Research Report No. 163. Department of Fisheries. WA.

Yearsley, G.K., Last, P.R. and Ward, R.D. (eds) (2001). Australian seafood handbook: an identification guide to domestic species. CSIRO Marine Research and FRDC, Canberra, Australia.

11 Appendix 1

Justification for Harvest Strategy Reference Levels

The performance indicator used to evaluate the stock status of indicator species in the [Region] is spawning biomass (*B*), or an appropriate proxy such as spawning potential ratio (SPR) (see Table A1.1). For each stock, the performance indicator is estimated periodically (at least every 5 years) and compared to associated reference levels (Table A1.1). The reference levels are consistent with those used by the Department in other similar assessments and are based on internationally accepted benchmarks for moderate to long-lived fish species (Mace 1994, Caddy and Mahon 1995, Gabriel and Mace 1999, Wise et al. 2007). Note that the threshold level of B_{30} (and SPR_{30}) corresponds to B_{MSY} (Table A1.1).

Table A1.1. Performance indicators and associated reference levels used to evaluate the status of sea mullet in south-west WA

	Reference Levels		
Performance Indicator	**Target**	**Threshold (B_{MSY})**	**Limit**
Biomass (*B*)	$>B_{MSY}$	B_{MSY}	$0.5B_{MSY}$

References

Caddy, J.F. and Mahon, R. (1995). Reference points for fisheries management (Vol. 374). Rome: Food and Agriculture Organization of the United Nations.

Gabriel, W.L. and Mace, P.M. (1999). A review of biological reference points in the context of the precautionary approach. In Proceedings of the fifth national NMFS stock assessment workshop: providing scientific advice to implement the precautionary approach under the Magnuson-Stevens fishery conservation and management act. NOAA Tech Memo NMFS-F/SPO-40 (pp. 34-45).

Mace, P.M. (1994). Relationships between common biological reference points used as thresholds and targets of fisheries management strategies. Canadian journal of Fisheries and aquatic Sciences, 51(1): 110-122.

Wise, B.S., St John, J. and Lenanton, R.C. (eds) (2007). Spatial scales of exploitation among populations of demersal scalefish: implications for management. Part 1. Stock status of key indicator species for the demersal scalefish fishery in the West Coast Bioregion. Final report to Fisheries Research and Development Corporation on Project No. 2003/052. Fisheries Research Report No. 163. Department of Fisheries, WA. 130pp.

12 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

13 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 captured, a species would be released and that it would be in a condition permitting subsequent survival	Evidence of majority released post-capture and survival	Evidence of some released post-capture and survival	Retained species or majority dead when released