Department of
Primary Industries and Regional Development

GOVERNMENT OF WESTERN AUSTRALIA

Resource Assessment Report

Gascoyne Demersal Scalefish Resource

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Executive Summary

- The Gascoyne Demersal Scalefish Resource comprises ecological suites of tropical and some temperate demersal fish species that occur predominantly in inshore waters (20-250 m deep) and offshore waters (> 250 m deep) of the Gascoyne Coast Bioregion (GCB). More than 60 demersal species are regularly landed by commercial and recreational fisheries operating in these waters, including pink snapper (Sparidae), tropical snappers (Lutjanidae), emperors (Lethrinidae), and cods (Epinephelidae). In 2016/17, the commercial catch of demersal scalefish species in the GCB was ~ 280 t compared with recreational catch (including charter) ~160 t.
- Demersal scalefish in open marine waters are primarily harvested by line-fishing by the commercial Gascoyne Demersal Scalefish Managed Fishery and the recreational and charter fishing sectors. A small number of operators in the Pilbara Line Fishery, which fish in the northern part of the GCB that borders with the North Coast Bioregion, also target deepwater demersal species such as ruby snapper (*Etelis carbunculus*).
- Due to the resource comprising many species, several indicator species have been selected from the suite of demersal scalefish (based on their inherent vulnerability and overall risk to sustainability) for assessing the status of the overall resource. The two main demersal indicator species for the oceanic waters of the GCB are pink snapper (*Chrysophrys auratus*, Gascoyne oceanic stock) and goldband snapper (*Pristipomoides multidens*).
- For the oceanic stock of pink snapper in the Gascoyne region, a level 5 (integrated model) assessment is produced periodically (every ~3-5 years). An age-structured integrated model is 'conditioned' on catch and fitted simultaneously to age composition and catch per unit effort (CPUE) data to estimate a range of quantities including fishing mortality (F) and female spawning stock biomass (B), and used as the primary indicator of stock status. The L5 assessment for pink snapper is supported by additional analyses L3 (catch curve and per recruit) analyses. Goldband snapper is assessed periodically using L3 assessment analyses, where estimates of F are derived from catch curve analysis and a suitable proxy for female spawning biomass, i.e. spawning potential ratio (SPR), produced from per recruit analysis. For each assessment, the relevant performance indicator is compared to specified biological (target, threshold and limit) reference points to determine stock status.
- A risk-based, weight of evidence approach was used to assess the current status of pink snapper (oceanic stock) and goldband snapper as follows:

  Pink snapper – latest L5 assessment (in 2017) and supporting analyses indicated B is around the limit level (B_{20}). Risk level is estimated as **Severe**. As this risk level is **unacceptable,** continued strong management measures (TAC reductions and area closures) are required to reduce the risk to an acceptable level within the next 5 years.

  Goldband snapper – latest assessment (in 2017) indicated that female SPR is above the threshold level (SPR_{30}). Risk level is estimated to be **Low**. This is **acceptable** and current management arrangements are adequate. As goldband snapper is an indicator species, it is inferred that the status of all other species in the demersal suite is also acceptable.

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List of Abbreviations

DPIRD	Department of Primary Industries and Regional Development (Western Australia, formerly Department of Fisheries)
EBFM	Ecosystem-Based Fisheries Management
ESD	Ecologically Sustainable Development
EPBC	Environment Protection and Biodiversity Conservation (Act)
FRMA	Fish Resources Management Act
GCB	Gascoyne Coast Bioregion
GDSFR	Gascoyne Demersal Scalefish Resource
GDSMF	Gascoyne Demersal Scalefish Managed Fishery
MSC	Marine Stewardship Council
SAFS	Status of Australian Fish Stocks
WA	Western Australia

1 Scope

This document provides a cumulative description and assessment of the Gascoyne Demersal Scalefish Resource (GDSFR) and all of the fishing activities (i.e. fisheries / fishing sectors) affecting this resource in Western Australia (WA). The resource comprises around 60 demersal scalefish species that inhabit the inshore waters of the Gascoyne Coast Bioregion (GCB), including Shark Bay.

The report is focused on the two main indicator species used to assess the suites of demersal scalefish that comprise this resource (pink snapper and goldband snapper), which constitute a large portion of the total catches in this region. The species are primarily captured by the commercial Gascoyne Demersal Scalefish Managed Fishery (GDSMF) and recreational and charter fishing activities that operate in the GCB. The report contains information relevant to assist the assessment of the resource against the Environment Protection and Biodiversity Conservation (EPBC) Act export approval requirements, the Marine Stewardship Council (MSC) Principles and Criteria for Sustainable Fishing 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 of Primary Industries and Regional Development (DPIRD, hereafter referred to as the Department) Risk Register for fisheries resources, which is an integral component of the annual planning cycle for assigning activity priorities (research, management, compliance, education etc.) across each bioregion. A summary of the Department's risk-based planning annual cycle that is delivering EBFM in the long-term is provided in Figure 1.1.

To ensure that management is effective in achieving the relevant ecological, economic and social objectives, formal harvest strategies are being developed for each resource. These harvest strategies outline the performance indicators used to measure how well objectives are being met and set out control rules that specify the management actions to be taken in situations when objectives are not being met. The WA harvest strategy policy (Department of Fisheries 2015a) 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).

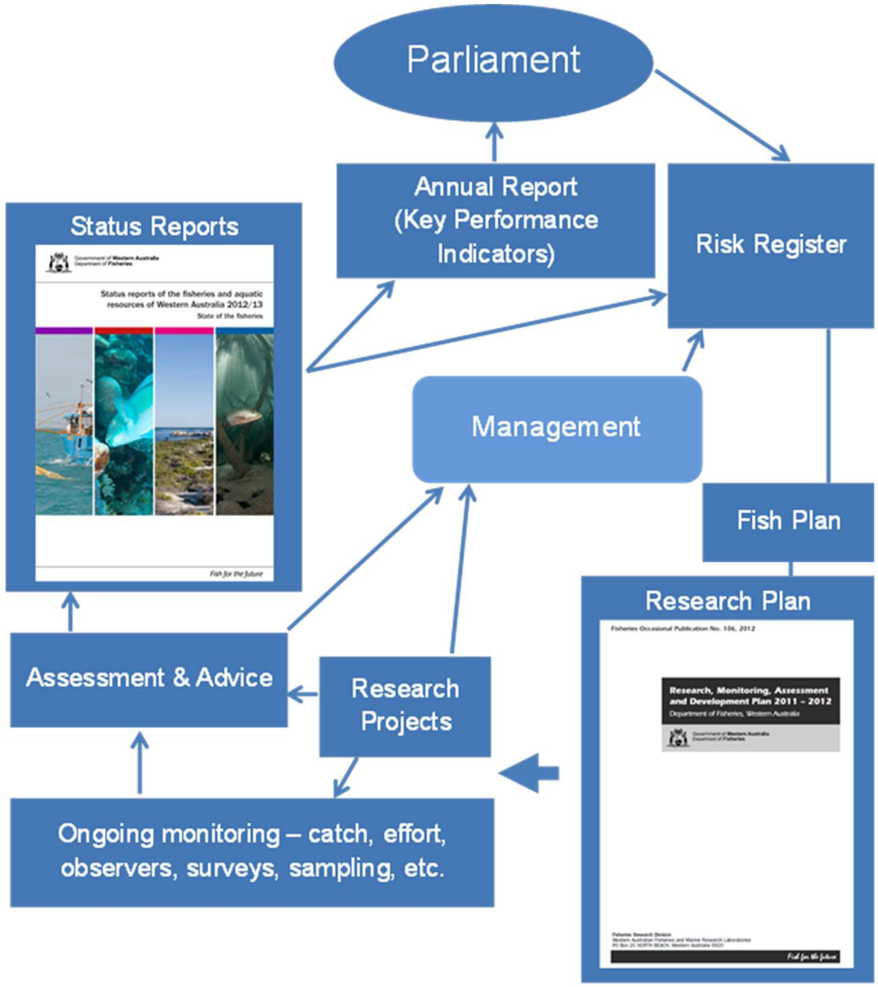


Figure 1.1. An outline of the risk-based planning cycle used for determining Departmental priorities and activities for fishery resource management

3 Aquatic Environment

The marine environment of the GCB (Figure 3.1) represents a transition between the fully tropical waters of the North West Shelf of the North Coast Bioregion and the temperate waters of the West Coast Bioregion. Offshore ocean temperatures range from about 22° C to 28° C, while the inner areas of Shark Bay regularly fall to around 15° C in winter. The major fish stocks are generally tropical in nature, with the exceptions of the temperate species, pink snapper, whiting and tailor, which are at the northern end of their range around Shark Bay.

The coastline is characterised by high cliffs in the southern half changing to fringing coral reefs in the north. Coastal waters are generally high-energy in terms of wave action due to the strong trade wind system. The Exmouth Gulf section of the GCB is seasonally influenced by extreme tropical summer cyclones, while the Shark Bay end of the Bioregion receives infrequent cyclones, but is affected at times by river outflows from inland cyclone-based summer rainfall. The limited local rainfall comes mostly from the northern edge of winter storm fronts.

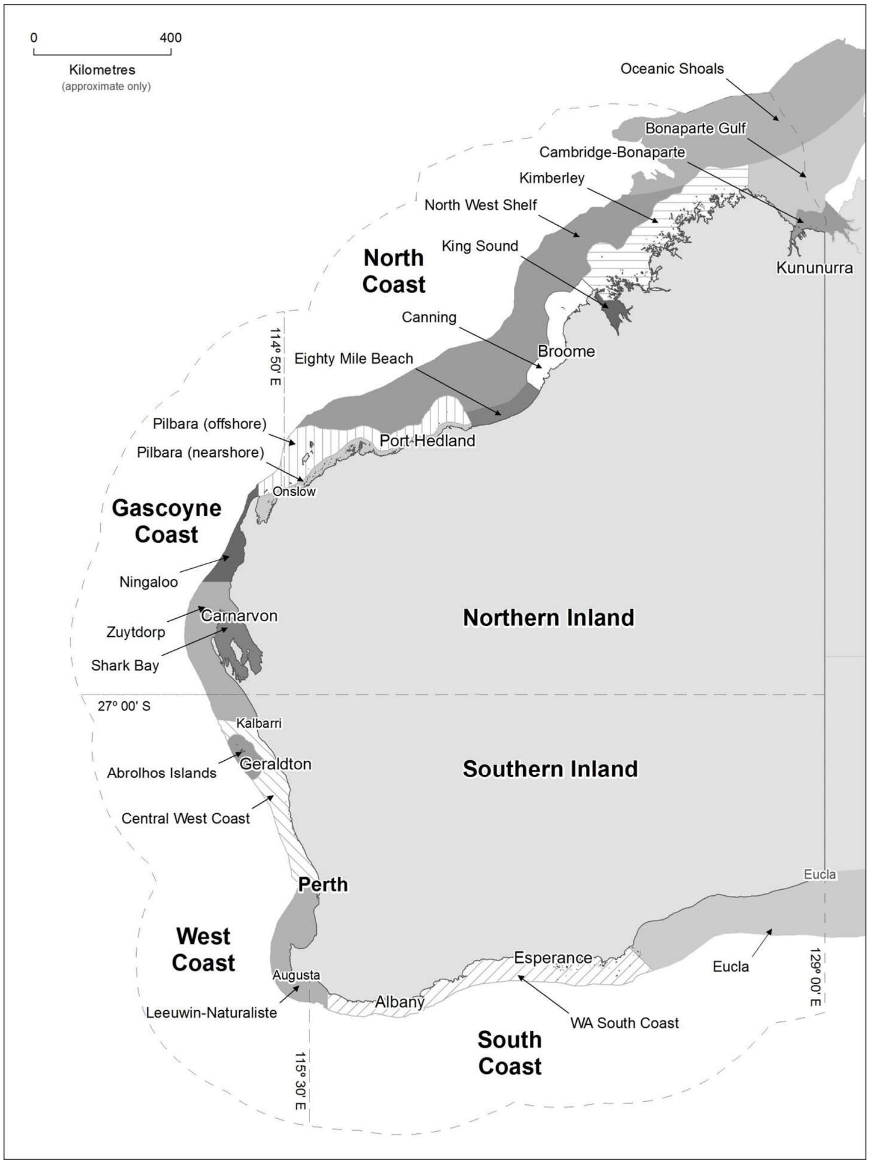


Figure 3.1. Locality of the Gascoyne Coast Bioregion within WA and boundaries of the different IMCRA ecosystems identified along the coast

The waters off the Gascoyne coast are also strongly influenced by the southward-flowing Leeuwin Current, generated by flow from the Pacific through the Indonesian archipelago. This tropical current becomes evident in the North West Cape area and flows along the edge of the narrow continental shelf where, coupled with low rainfall and run-off plus the north flowing Ningaloo Current, it supports the highly diverse Ningaloo Reef marine ecosystem.

The outer area of the large marine embayment of the World Heritage-listed Shark Bay is also influenced by the warm winter current. The inner waters of the embayment are hypersaline, owing to the high evaporation and low rainfall of the adjacent terrestrial desert areas. The sea floor of both Shark Bay and the continental shelf is typically sandy compared to Exmouth Gulf, which has more mud areas and greater turbidity.

The GCB has been identified as one of 18 global 'hotspots' in terms of tropical reef endemism and the second most diverse marine environment in the world in terms of tropical reef species. The Ningaloo reef in the north of the bioregion is the largest continuous reef in WA and is one the most significant fringing reefs in Australia. The bioregion also has some stands of mangroves, mostly in Exmouth Gulf, while extensive seagrass beds are located in a number of areas (e.g. Shark Bay).

4 Resource Description

4.1 Gascoyne Demersal Scalefish Resource

The Gascoyne Demersal Scalefish Resource (GDSFR) comprises ecological suites of demersal fish species that occur predominantly in inshore waters (20-250 m deep) and offshore waters (> 250 m deep) of the GCB. More than 60 demersal species are landed by commercial and recreational fisheries operating in the GCB each year, including pink snapper (Sparidae), tropical snappers (Lutjanidae), emperors (Lethrinidae), and cods (Epinephelidae). The species are widespread throughout this region, from nearshore coastal habitats to the deeper-water outer shelf habitats. Snappers and cods tend to be caught in the vicinity of reef structures, hard bottom areas, epibenthic communities or vertical reef (e.g. pinnacles, ledges and bommies), while emperors tend to occur over sand and mud bottom (Department of Fisheries 2000).

The biological characteristics of the species that comprise the GDSR typically include extended longevity (> 30 years) and correspondingly low natural mortality, relatively large maximum sizes (> 500 mm total length) that are approached relatively slowly (von Bertalanffy growth coefficient for females, k =0.21 year^{-1}), and reproductive strategies which may include spawning aggregation behaviour. Such factors make these species inherently vulnerable to exploitation.

4.2 Selection of Indicator Species for Resource

Following the adoption by the Department in 2002 of the ESD policy (Fletcher 2002), the process for monitoring and assessing the finfish resources of WA has involved allocating the species within each bioregion into one of five suites – Estuarine, Nearshore, Inshore Demersal, Offshore Demersal and Pelagic (Department of Fisheries 2011). A risk-assessment based approach is used to quantify the risks to sustainability of the stocks based on biological and other criteria to develop a risk matrix (Newman et al. 2017). From the list of species within a suite for a given bioregion, indicator species are then 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; Newman et al. 2017). The status of these indicator species is assumed to represent the status of the entire suite and therefore the resource (Newman et al. 2017).

Based on the inherent vulnerability and risk to the sustainability of the major species within the suite of demersal scalefish in the GCB, six indicator species' stocks are currently monitored and assessed by the Department. These include four stocks of pink snapper (*Chrysophrys auratus*, oceanic stock and three separate inner Shark Bay stocks) and the single stocks of goldband snapper (*Pristipomoides multidens*) and spangled emperor (*Lethrinus nebulosus*). This report is currently focused only on those two indicator species' stocks that are primarily targeted by the GDSMF, namely

- pink snapper (oceanic stock only); and
- goldband snapper.

Note that future version of this report may also include information and assessments of selected non-indicator species, where vulnerability assessments have indicated a need for a higher level of monitoring (spot-check) of the species. These species would typically make up significant proportions of the total demersal scalefish catch in the GCB and thus higher level assessments are occasionally undertaken for these species as a form of validation of the indicator species approach. Higher-level stock assessments of non-indicator species will also be initiated if annual reviews of the vulnerability (productivity and annual catches) of all retained species provide an indication of changes to targeting etc. See Table 4.1 for an example of such a vulnerability assessment for the main species retained by the GDSMF.

Table 4.1. Assessment of vulnerability and management risk for the main retained species in the Gascoyne Demersal Scalefish Managed Fishery (i.e. contribute ≥ 1 % of total retained catch) to identify key indicator species. Here categories 'Inherent vulnerability' and 'Current risk to wild stock' are each scored 1 (low risk) to 5 (severe risk) and then multiplied to give an 'Overall risk to sustainability' score. Various management criteria are also each scored 1 (low)-5 (severe) then summed to give 'Management Risk". This then added to 'Overall risk to vulnerability' to give 'Indicator Value' (see Newman et al. 2017 for more details)

Common name	Species name	Inherent Vulnerability (Productivity)	Current Risk to Wild Stock	Overall risk to sustainability	Current Management requirements	GVP	Recreational Importance	Customary Importance	Community Significance	Management Risk Sum	Indicator Value Attributes
Pink Snapper	*Chrysophrys auratus*	4	3	24	4	4	5	1	4	18	42
Goldband Snapper	*Pristipomoides multidens*	4	3	24	4	3	1	0	0	8	32
Red Emperor	*Lutjanus sebae*	4	3	24	2	2	4	0	1	9	33
Rosy Snapper	*Pristipomoides filamentosus*	4	2	16	2	2	1	0	0	5	21
Sharptooth Snapper	*Pristipomoides typus*	4	2	16	2	2	1	0	0	5	21
Mulloway	*Argyrosomus japonicus*	3	2	12	2	1	3	1	1	8	20
Rankin Cod	*Epinephelus multinotatus*	4	3	24	2	2	4	0	1	9	33
Ruby Snapper	*Etelis* sp.	4	3	24	2	1	1	0	0	4	28
Redthroat Emperor	*Lethrinus miniatus*	3	3	18	2	1	2	0	1	6	24
Goldspotted Rockcod	*Epinephelus coioides*	4	3	24	2	1	2	0	1	6	30
Blackspotted Rockcod	*Epinephelus malabaricus*	4	3	24	2	1	1	0	1	5	29
Northern Pearl Perch	*Glaucosoma buergeri*	3	2	12	2	1	1	0	1	5	17
Eightbar Grouper	*Hyporthodus octofasciatus*	4	3	24	2	1	3	0	0	6	30
Spangled Emperor	*Lethrinus nebulosus*	3	3	18	3	1	4	1	3	12	30
Amberjack	*Seriola dumerili*	3	2	12	2	1	1	0	1	5	17

5 Species Description

5.1 Pink snapper

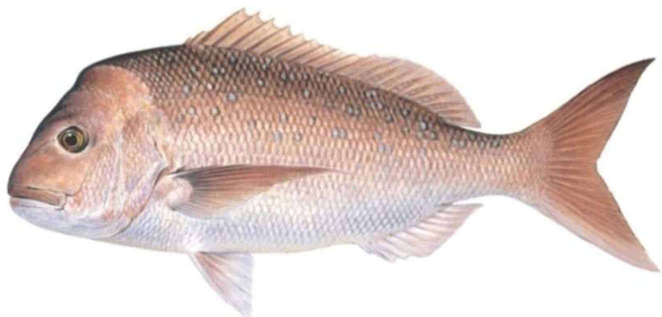


Figure 5.1. Pink snapper, *Chrysophrys auratus*. Illustration © R. Swainston (www.anima.net.au)

5.1.1 Taxonomy and Distribution

The pink snapper is a member of the family Sparidae (sea breams and porgies). Distinguishing features include largish head, pale pink to dark red upper body colouration and scattered, small, bright turquoise-blue spots on dorsal surfaces.

The species occurs across southern Australia (south of ca 18°S), at Norfolk and Lord Howe Islands and in northern New Zealand (Gomon et al. 2008; Parsons et al. 2014).

5.1.2 Stock Structure

In WA, pink snapper is divided into six management units, some at small geographic scales (e.g. three separate biological stocks located inside Shark Bay) and others that cover greater areas of oceanic waters in the Gascoyne (oceanic stock), West and South Coast bioregions (e.g. Johnson et al. 1986; Moran et al. 2003; Fowler et al. 2018). The three inshore Shark Bay biological stocks in the inner gulfs are predominantly fished by the recreational and charter sectors while the Gascoyne oceanic stock is mostly fished by a commercial line-fishery.

5.1.3 Life History

The sub-sections below provide an overview of the life history characteristics of pink snapper, with a summary of the relevant biological parameters used in stock assessments presented in Table 5..

Table 5.1. Summary of biological parameters for pink snapper (oceanic stock) in the Gascoyne Coast Bioregion

Parameter	Value(s)	Comments / Source(s)
Growth parameters		$L_t = L_\infty (1 - \exp(-K (t - t_0)))$
L_∞ (mm TL)	691 (females), 648 (males)	Wakefield et al. (2016)
k (year^{-1})	0.21 (females), 0.25 (males)	Wakefield et al. (2016)
t_0 (years)	-0.33 (females), -0.25 (males)	Wakefield et al. (2016)
Maximum age (years)	32	In Gascoyne (40 years in WA)
Maximum size (mm TL)	914	
Natural mortality, M (year^{-1})	0.144	Estimated using the method described by Quinn & Deriso (1999), based on a maximum age of 32
Total-fork length parameters		FL (mm) = a TL (mm) + b
a	0.897 (females), 0.892 (males)	Wakefield (2006)
b	23.058 (females), 23.797 (males)	Wakefield (2006)
Length-weight parameters		W (g) = a FL (mm)^b
a	5.61×10^{-5} (both sexes)	Wakefield et al. (2016)
b	2.827 (both sexes)	Wakefield et al. (2016)
Reproduction	Gonochoristic, broadcast spawner	
Maturity parameters		Logistic
A_{50} (years)	4.0	Wakefield et al. (2015)
A_{95} (years)	6.0	Wakefield et al. (2015)
L_{50} (mm TL)	~350	Wakefield et al. (2015)
L_{95} (mm TL)	~480	Wakefield et al. (2015)
Fecundity (batch)	Up to 653,000 (at 710 mm FL)	Mackie et al. (2009)
Size-fecundity parameters		$BF = a\ FL^b$
a	9.436×10^{-4}	Jackson (2007)
b	3.359	Jackson (2007)
Spawning frequency	Multiple spawners, spawn around new and full moons between May-August in Gascoyne. Form spawning aggregations.	

5.1.3.1 Habitats and Movements

Across the species' Australian range, juveniles typically inhabit sheltered inshore waters such as bays and inlets, often over mud and seagrass (Kailola et al. 1993). Sub-adults and adults may be associated with offshore rocky reefs but are also found over mud and sand out to depths of 200 m (Kailola et al. 1993).

In the Gascoyne region, information on the distribution and abundance of juvenile pink snapper (i.e. 0+, 1+ age classes) from the oceanic stock is limited compared with the inner gulf stocks (Moran & Kangas 2003; Jackson et al. 2007). Adults and sub-adults from the oceanic stock inhabit waters of the continental shelf out to depths of 300+ m.

Tagging studies of pink snapper in Australia and New Zealand indicate that the majority of individuals are essentially resident and undertake only localised movements associated with feeding and spawning with a small number of adults and older juveniles moving large distances (Sanders 1974; Coutin et al. 2003; Moran et al. 2003; Norriss et al. 2012).

In Shark Bay oceanic waters, during summer, sub-adult and adult fish are dispersed over the continental shelf and upper slope to depths of 300+ m. During winter, adults move inshore from deeper waters to spawn over inshore reefs before dispersing again over the continental shelf during the non-spawning season (Moran et al. 2003). Most individuals undertake seasonal movements of 10's of km while a small number can move 100's of km (Moran et al. 2003). In contrast, snapper in inner Shark Bay demonstrate highly restricted movement patterns (Norriss et al. 2012).

5.1.3.2 Age and Growth

Pink snapper is long-lived and relatively slow growing. The maximum age recorded for pink snapper in Australia is 40 years (Norriss and Crisafulli 2010) and around 30 years in the Shark Bay region (Jackson et al. 2010), compared with 55-60 years in New Zealand (Francis et al. 1992).

Growth of pink snapper varies between the sexes, with females growing to a larger size (Wakefield et al. 2016; Table 5.). The high values of k for the Gascoyne oceanic stock (0.20-0.27) compared to values for snapper from the Perth region and south coast of WA (0.11-0.15, see Wakefield 2016) indicates growth is rapid for young fish, with fish reaching about 60% of their asymptotic length (i.e. from the estimated von Bertalanffy growth curve) by about 4 years, and 90-95% by ~ 10-15 years of age.

The ages of snapper in Australia are determined using counts of annuli in sectioned sagittal otoliths (see Section 8.2.5 for a description of ageing protocols). The periodicity of increment formation in snapper otoliths from waters of the Gascoyne has been validated as annual using marginal increment analysis and oxytetracycline/calcein marking of otoliths (Jackson 2007; Wakefield 2016). Opaque zones are generally formed during late autumn to early spring, and these zones typically become delineated from the otolith edge by August-September in oceanic waters (Jackson 2007; Wakefield 2016). For determining ages for the oceanic stock, the mean birth date of pink snapper is assumed to be June 1 (Wakefield 2016).

Parameters describing the relationships between fork length and total length, and between fork length and weight, were estimated by Wakefield et al. (2016) and are provided in Table 5..

5.1.3.3 Natural Mortality

The estimated value of the instantaneous rate of natural mortality (*M*) for pink snapper of 0.144 $year^{-1}$ (Table 5.) was derived from the method described by Quinn and Deriso (1999), based on the assumption that 1% of fish survive to the maximum age (32 years for pink snapper in the Gascoyne).

5.1.3.4 Reproduction

Pink snapper are functional gonochorists with pre-maturational, protogynous sex change occurring in some individuals (Francis and Pankhurst 1988). Size and age at maturity vary between locations in WA (Jackson et al. 2010; Wakefield et al. 2015). In oceanic waters off Shark Bay, pink snapper typically mature at 4 years of age and approximately 350 mm in total length (Wakefield et al. 2015; Table 5.).

Pink snapper are batch spawners that are capable of spawning multiple times during an extended spawning season. Broadcast spawning is highly synchronised with pelagic eggs released and fertilized within the upper layers of the water column (Jackson 2007). Spawning in oceanic waters off Shark Bay occurs over a 5-month period between late autumn (May) through to mid-spring (September) (Wakefield et al. 2015). The peak in spawning occurs around June-July although the timing of this peak can vary slightly between years. Adults from the oceanic stock form spawning aggregations over inshore reefs in depths of 15-80 m to the north and west of the islands that bound Shark Bay (Moran et al. 2003).

Estimates of batch fecundity are not available for the oceanic stock but are available for pink snapper in the inner gulfs of Shark Bay (Mackie et al. 2009; Jackson et al. 2010). Estimates of batch fecundity ranged from 2,750 hydrated oocytes for a 172 mm FL female to 653,000 hydrated oocytes for a 710 mm FL female (Mackie et al. 2009). Estimated parameters describing the positive non-linear relationship between batch fecundity and female length are provided in Table 5..

Egg development is influenced by environmental conditions, particularly water temperature, with hatching taking place after ~ 20-30 hours inside Shark Bay (Norriss and Jackson 2002). A pelagic larval phase of ca. 20-25 days (Tapp 2003; Fowler and Jennings 2003) occurs prior to metamorphosis and settlement when the juveniles are ~ 8-12 mm in length (TL) (Fukuhara 1991; Battaglene and Talbot 1992; Fowler and Jennings 2003).

5.1.3.5 Factors Affecting Year Class Strength and Other Biological Parameters

High levels of inter-annual variability in 0+ snapper recruitment occur in some regions of Australia and New Zealand. The temperature either during the spawning season, or shortly thereafter has been found to be positively correlated with recruitment in New Zealand (Francis 1993) and southern Australia (Fowler and Jennings 2003; Hamer and Jenkins 2004; Saunders 2009).

Determining an index of relative juvenile abundance that can be used to assess annual recruitment variation has been attempted in the inner gulfs of Shark Bay using trawl surveys (Moran and Kangas 2003) and trap surveys (Jackson et al. 2007). Similar research has been less successful with juveniles from the oceanic pink snapper stock in waters of northern Shark Bay off Carnarvon (Marriott et al. 2012).

Juvenile recruitment with oceanic pink snapper has been indirectly investigated using cohort analysis (Moran et al. 2005) using Pope's approximation (Pope 1972) and catch-at-age data from the commercial fishery for the period 1982-2003. Results showed a period of high recruitment in early 1990s (possibly related to a period of cooler water temperatures) followed by low recruitment through the mid-late 1990s (Moran et al. 2005).

5.1.3.6 Diet and Predators

Pink snapper are highly opportunistic carnivores with a broad ranging diet that can include a wide variety of mainly benthic organisms such as crustaceans, bivalves, cephalopods, marine worms, starfish, sea urchins and fish, depending on availability (Colman 1972; Coutin et al. 2003). Ontogenetic differences in diet shown on west coast related to body size and season (French et al. 2012). The trophic level of pink snapper is 3.6 (Fishbase).

Predators of juvenile and adult demersal scalefish in the Gascoyne / Shark Bay region include other larger teleosts such as cod (Serranidae), dolphins and sharks. There are anecdotal reports from all sectors of increased shark depredation in the Gascoyne region in recent years (Ryan et al. 2019).

5.1.3.7 Parasites and Diseases

A didymozoid trematode, *Gonapodasmius williamsoni*, was found in the flesh of pink snapper from oceanic waters off Shark Bay with 5 to 8 year olds most frequently infected (Williams et al. 1993). A nematode *Philometra lateolabracis*, that has been observed to infect pink snapper gonads in New Zealand (Hine and Anderson 1981), and in the ovaries of Western Australian dhufish, *Glaucosoma hebraicum*, on the west coast of WA (Hesp et al. 2002), may also occur in the GCB.

5.1.4 Inherent Vulnerability

The biology and spawning behaviour of pink snapper makes them highly vulnerable to fishing in the absence of appropriate management. Pink snapper are a moderately fast growing, with most individuals reaching spawning age and exploitation size by 3-5 years but with potential longevities in excess of 30 years. They are highly fecund. Adults undergo spawning-related migrations. They form spawning aggregations in highly accessible locations.

The most common method of capture is by baited lines close to reefs or other structures. There is a high risk of hyper-stability in catch rates during the spawning season. Successful long-term management has been recorded for fisheries in WA (e.g. Jackson and Moran 2012). Stock declines that have occurred in snapper fisheries have followed extended periods of high exploitation, these can, however, recover in moderate timeframes (~ 10-12 years) once corrective management actions are implemented. There is evidence that recruitment levels are maintained even following significant reductions in spawning biomass. Further, whilst the level of recruitment often varies annually, associated with environmental conditions, there is generally some recruitment in most years.

5.2 Goldband snapper (*Pristipomoides multidens*)

Figure 5.1. Goldband snapper, *Pristipomoides multidens*. Illustration © R. Swainston (www.anima.net.au)

5.2.1 Taxonomy and Distribution

The goldband snapper (Figure 5.1) is a member of the family Lutjanidae. Goldband snapper are widely distributed throughout the tropical Indo-Pacific from Samoa to the Red Sea and from southern Japan to Australia (Allen 1985). In WA, goldband snapper are found from Cape Pasley (east of Esperance), west and northwards to the Northern Territory border (Newman and Dunk 2003).

5.2.2 Stock Structure

Goldband snapper are widely distributed throughout northern Australia and likely represent a single biological (genetic) stock (Ovenden et al. 2002). In WA, based on analysis of otolith stable isotopes (Newman et al. 2000), separate management units are recognised in Gascoyne, Pilbara and Kimberley regions (Saunders et al. 2018).

5.2.3 Life History

The sub-sections below provide an overview of the life history characteristics of goldband snapper in WA, with a summary of the relevant biological parameters used in stock assessments presented in Table 5.1.

Table 5.1. Summary of biological parameters for goldband snapper in WA

Parameter	Value(s)	Comments / Source(s)
Growth parameters		$L_t = L_\infty (1 - \exp(-k(t - t_0)))$
L_∞ (mm FL)	590 (both sexes)	Updated in 2016
k (year^{-1})	0.26 (both sexes)	Updated in 2016
t_0 (years)	-0.46 (both sexes)	Updated in 2016
Maximum age (years)	28	
Maximum size (mm FL)	701	
Natural mortality, M (year^{-1})	0.164	Estimated using the method described by Quinn & Deriso (1999)
Length-weight parameters		W (g) = a TL (mm FL)^b
a	2.483×10^{-5}	Newman & Dunk (2003)
b	2.9501	Newman & Dunk (2003)
Reproduction	Gonochoristic, broadcast spawner	
Maturity parameters		Logistic, based on available data for north-western WA
A_{50} (years)	4.8 (females), 4.8 (males)	Updated in 2016
A_{95} (years)	13.2 (females), 10.7 (males)	Updated in 2016
L_{50} (mm FL)	441 (females), 442 (males)	Updated in 2016
L_{95} (mm FL)	574 (females), 559 (males)	Updated in 2016
Fecundity	No estimates available	
Size-fecundity parameters	No estimates available	
Spawning frequency	Multiple spawners	

Goldband snapper inhabit hard bottom areas and areas of vertical relief and large epibenthos from depths of 60 to at least 200 m and are concentrated in depths from 80 to 150 m (Allen 1985; S. J. Newman, unpubl. data).

All life stages of this species may be relatively sedentary (Ovenden et al. 2004). Genetic and otolith isotope analyses indicate that adults remain sedentary on individual reefs, with no evidence of longshore movement (Lloyd et al. 1996; Newman et al. 2000b; Ovenden et al. 2002).

Goldband snapper exhibit moderate growth (attaining ~60 and 80% of the estimated asymptotic length, from the von Bertalanffy growth curve, by 3 and 6 years of age, respectively), with no significant difference in the growth of the two sexes in WA. The maximum age of goldband snapper in north-western WA has recently been revised from 30 years to 28 years following improvements made to the ageing of this species, now using much thinner sections of otoliths.

Updated estimates for the von Bertalanffy growth parameters for fish sampled in the Gascoyne, Pilbara and Kimberley (pooled across regions) are presented in Table 5.1.

The value for the instantaneous rate of natural mortality (*M*) for goldband snapper of 0.164 $year^{-1}$ (Table 5.1) was derived from the method described by Quinn and Deriso (1999), based on the assumption that 1% of fish survive to the maximum age (28 years for goldband snapper).

Goldband snapper are gonochoristic (i.e. sexes are separate throughout life). Peak spawning in the Gascoyne occurs from March to May, although females with 'ripe' ovaries were sampled over many months, from January to August and in November (Marriott et al. 2012). Goldband snapper are capable of spawning multiple times during a spawning season and over a long reproductive lifespan (Newman et al. 2001).

During spawning, sperm and eggs are released into the water and fertilisation takes place externally. Larvae are planktonic and it is possible that they may be dispersed via currents. Although there have been no studies of post-larval dispersal or recruitment of this species, in Indonesia genetic subdivision was apparent over relatively small spatial scales, suggesting that all life stages of this species (including planktonic larvae) may be relatively sedentary (Ovenden et al. 2004).

The length at which 50% of goldband snapper in WA have reached maturity was estimated to be 441 mm FL for females and 442 mm FL for males, which corresponds to a mean age of 4.7 years for both females and males (Table 5.1). The estimates were updated in 2016 to include samples of goldband snapper from the Gascoyne, Pilbara and Kimberley collected between 2010 and 2016. These are the values currently used in the integrated model assessment for the Kimberley goldband snapper, as well as in the per-recruit analyses of the Pilbara goldband snapper.

No reliable estimates of fecundity exist for goldband snapper.

5.2.4 Factors Affecting Year Class Strength and Other Biological Parameters

Spatial studies of population genetics suggest that larval dispersal may be restricted to hundreds of kilometres (Ovenden et al. 2004) and studies of otolith stable isotopes suggest that post-larval individuals are relatively sedentary, with movements occurring over much smaller distances (Newman et al. 2000). Given these findings, it is therefore likely that any effects on recruitment from potential overfishing of, or other anthropogenic or environmental effect on, the spawning stock are likely to be relatively localised at the spatial scale of impact(s).

The diet of related *Pristipomoides* species is dominated by zooplankton in particular crustaceans, pteropods and large, pelagic, colonial urochordates (e.g. salps) (Haight et al. 1993). The trophic level of goldband snapper is listed as 3.8 in Fishbase.

Predators of juvenile and adult demersal scalefish in the Gascoyne/Shark Bay region include other larger teleosts such as cods/groupers (Epinephelidae), dolphins and sharks.

Little is known of the extent of the parasitic fauna of goldband snapper in northern Australia. A preliminary survey of larval anisakid parasites in fish from north-western Australia reported a high prevalence (100 %) of *Anisakis* spp. infection but a low prevalence (7%) of *Terranova* spp. from their small sample size of goldband snapper (n = 15) (Doupe et al. 2003).

5.2.5 Inherent Vulnerability

Goldband snapper are considered to have a high level of inherent vulnerability to fishing (Newman et al. 2017), based on aspects of their life history such as their relatively long lifespan of 28 years. Although they have a wide distribution within and outside Australian waters, the movement of adult goldband snapper is limited making them relatively vulnerable to localised depletion and requiring management at appropriate spatial scales.

6 Fishery Information

6.1 Fisheries / Sectors Capturing Resource

Line fishing has been the main method used to catch pink snapper in the waters off Shark Bay since the fishery commenced in the early 1900s (Moran and Jenke 1989; Moran et al. 2005). Sailing vessels came north from Geraldton to fish the winter spawning aggregations each year, forming convoys and drifting over the aggregating fish.

The fishery developed significantly in the 1950s, with rock lobster boats heading north during winter from Geraldton and Fremantle to fish alongside local, Denham-based vessels. Trap fishing for pink snapper began around 1957, however, following years of conflict between the line and trap fishing sectors and the overall poor quality of the trap-caught product, trap fishing effort was progressively reduced between 1961 and 1987 (Moran and Jenke 1989). With the formalisation of the Shark Bay Snapper Managed Fishery in 1987, the fishery effectively became line-only.

During the late 1980s to mid-1990s, fishing efficiency improved significantly with the adoption of new technologies including mechanised hand lines (hydraulic reels), colour sounders and GPS (Marriott et al. 2011). As the snapper fishery developed into a more year-round fishery, it moved offshore from the more traditional inshore fishing grounds to explore deeper waters (greater than 120-150 m). Consequently, a wider range of demersal species (including goldband snapper) began to contribute to the overall catch and, in 2010 the Shark Bay Snapper Managed Fishery formally became the Gascoyne Demersal Scalefish Managed Fishery (GDSMF, see below).

The sections below provide more detailed information about the main fisheries that currently target the GDSR, i.e. the GDSMF and the recreational and charter fishing sectors.

6.2 Gascoyne Demersal Scalefish Managed Fishery

6.2.1 History of Development

The GDSMF came into operation in November 2010, incorporating the pre-existing quota-managed Shark Bay Snapper Fishery (SBSF), plus open-access 'wetline' fishing that was previously permitted in waters between 23º34' S and 23º07'30 S (Figure 6.1). This consolidated all state-based commercial line-based fishing operations in Gascoyne waters under a single management framework. The fishery primarily targets pink snapper and goldband snapper but also catches a range of other demersal species including ruby snapper, red emperor (*Lutjanus seabae*), redthroat emperor (*Lethrinus miniatus*), various cod species (Serranidae), trevallies (Carangidae), and mulloway (*Argyrosomus japonicus*).

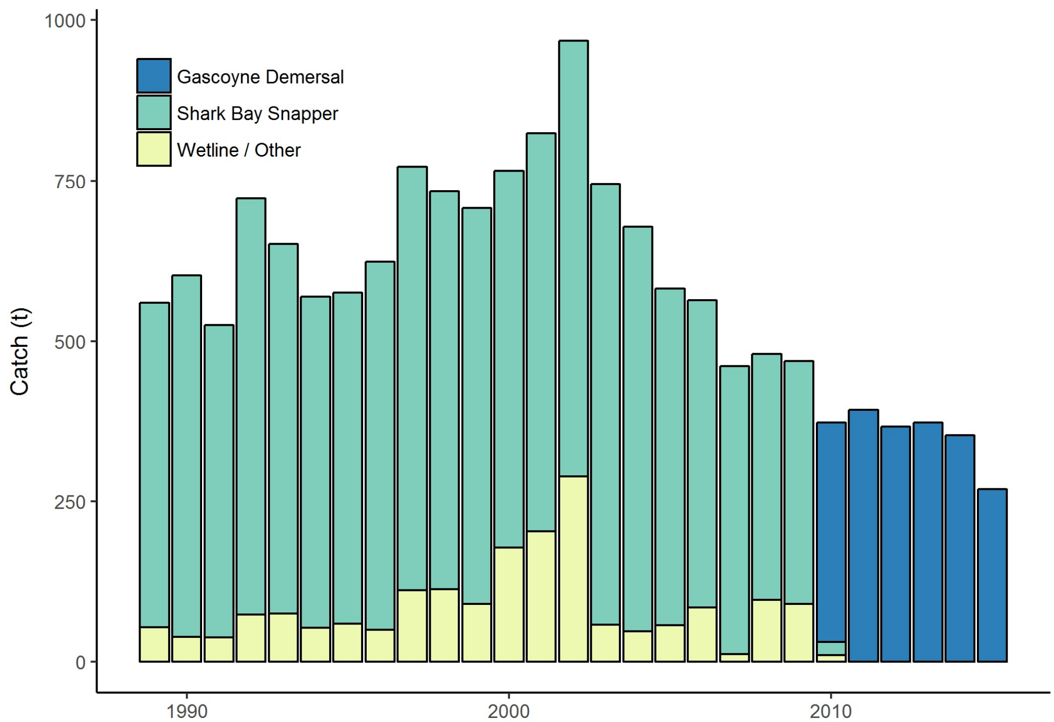
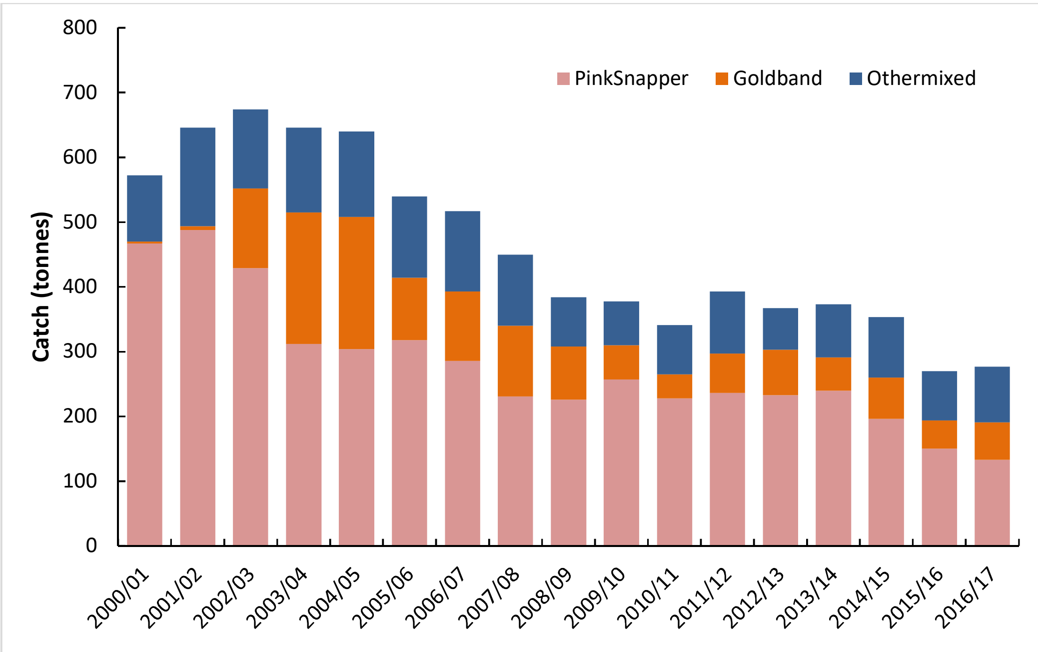


Figure 6.1. Time series of total annual commercial catches of demersal scalefish taken by the current Gascoyne Demersal Scalefish Managed Fishery, the previous Shark Bay Snapper Managed Fishery, and other wetline catches

The total annual commercial catch of demersal scalefish taken by line-fishing in the Gascoyne region has steadily declined from around 2002-present in part reflecting reduction in the overall effort in the fishery from ~1,700 to ~ 800 boat days over the same period (Figure 6.1, Figure 6.2). The TACC for pink snapper was significantly reduced in 2004 (by 40% to 338 t) following the first integrated model-based stock assessment of the (oceanic) pink snapper stock in 2002 which showed that the spawning stock was depleted. After an updated assessment in 2006 indicated that the stock was rebuilding more slowly than expected, the TACC was further reduced to 277 t in 2007 and has been maintained at this level. The TACC for other demersal scalefish species was set at 227 t. While nominal effort in the fishery has remained stable at around 700-800 boat days since 2008, the total catch in 2016/17 of 277.1 t was the second lowest on record (was 269.5 t in 2015/16) (Figure 6.2).



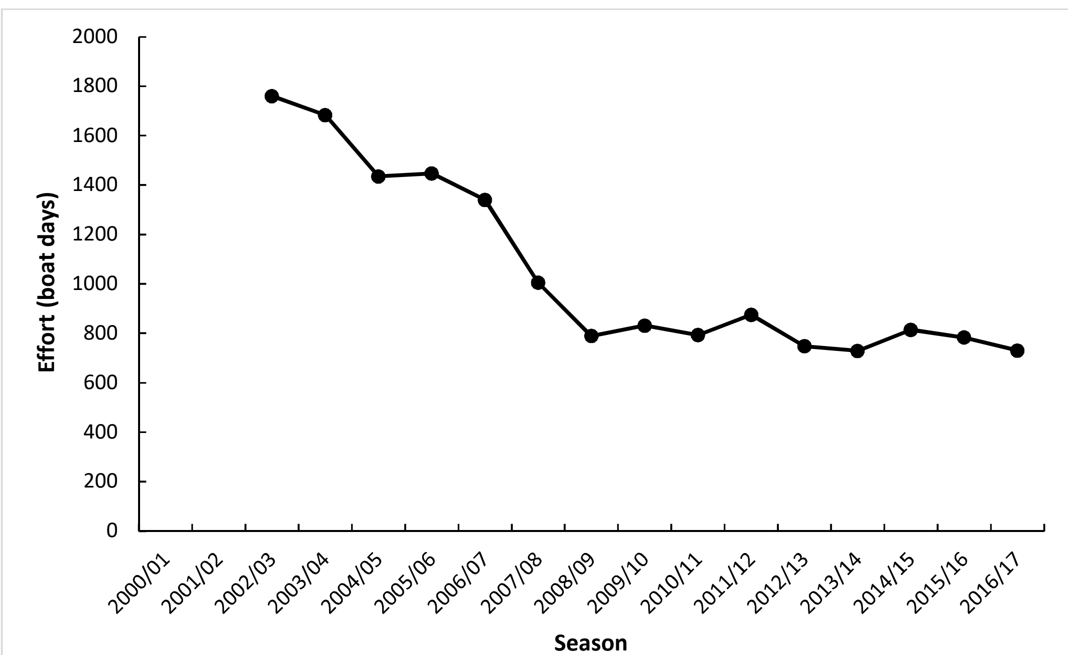


Figure 6.2. Annual total retained catches (tonnes) and nominal fishing effort (boat days) in the Gascoyne Demersal Scalefish Managed Fishery between 2000/01 and 2016/17

Table 6.1. Retained catches (t) of all species/groups reported in the Gascoyne Demersal Scalefish Managed Fishery for the 2012/13 – 2016/17 fishing seasons (1 September – 30 August).

Species	2012/13	2013/14	2014/15	2015/16	2016/17
Pink Snapper	232.8	240.0	195.8	149.8	133.3
Goldband Snapper	69.5	50.9	63.5	43.6	58.2
Other Jobfish	3.8	3.4	4.3	4.4	6.2
Red Emperor	8.0	10.1	10.9	10.0	13.5
Ruby Snapper	2.8	4.2	5.1	1.2	1.8
Other Snappers	1.0	1.1	1.7	1.5	2.5
Spangled Emperor	2.3	2.0	2.5	2.6	2.3
Redthroat Emperor	5.0	6.1	10.9	8.0	9.3
Other Emperors	0.2	0.3	1.3	0.6	<1.0
Rankin Cod	6.2	6.9	8.0	10.5	10.8
Other Cods	8.3	11.2	11.3	10.7	12.1
Eightbar Grouper	4.3	3.5	1.9	1.6	2.2
Mulloway	4.0	8.6	9.0	6.4	4.6
Trevallies	4.6	6.8	7.9	3.6	2.4
Other Species	13.9	18.0	18.6	15.1	17.2
Total	366.7	373.1	352.7	269.5	277.2

6.2.2 Current Fishing Activities

A summary of key attributes of the current GDSMF and the fishing fleet is provided in Table 6.2.

The GDSMF encompasses the waters between 26°30'S and 23°07'30"S, out to 200 nautical miles (see Figure 6.3). Licensed vessels are not permitted to fish in a number of closed waters that include (i) inside Bernier and Dorre Islands, (ii) waters of the Shark Bay Beach Seine and Mesh Net Managed Fishery (i.e. the inner gulfs), (iii) Point Quobba Fish Habitat Protection Area, (iv) Commonwealth waters of the Ningaloo Marine Park, (v) Denham, Carnarvon and Coral Bay port areas, (vi) waters of Point Maud-Tantabiddi Well commercial fishing closure and (vii) waters to the south of 26°30'S.

The GDSMF fishing season runs from 1 September to 30 August (i.e. the quota-year), however, fishing for pink snapper is mainly focused on the winter months (May-August) when the species aggregates to spawn. The current market demand for both pink snapper and goldband snapper is for whole fish. The catch is supplied mostly to Perth markets, with some pink snapper catch sold to the east coast of Australia during the peak season for this species.

Table 6.2. Summary of key attributes of the Gascoyne Demersal Scalefish Managed Fishery for 2016/17

Attribute	
Fishing methods	Mechanised lines
Fishing capacity	TACC for pink snapper: 277 t TACC for other demersal scalefish species: 227 t
Number of licences	55
Number of vessels	17 (10 active for > 10 days)
Size of vessels	~12-23 m
Number of people employed	~50 (fishing, assuming three crew per vessel)
Value of fishery	$1 – 5 million (Level 2)

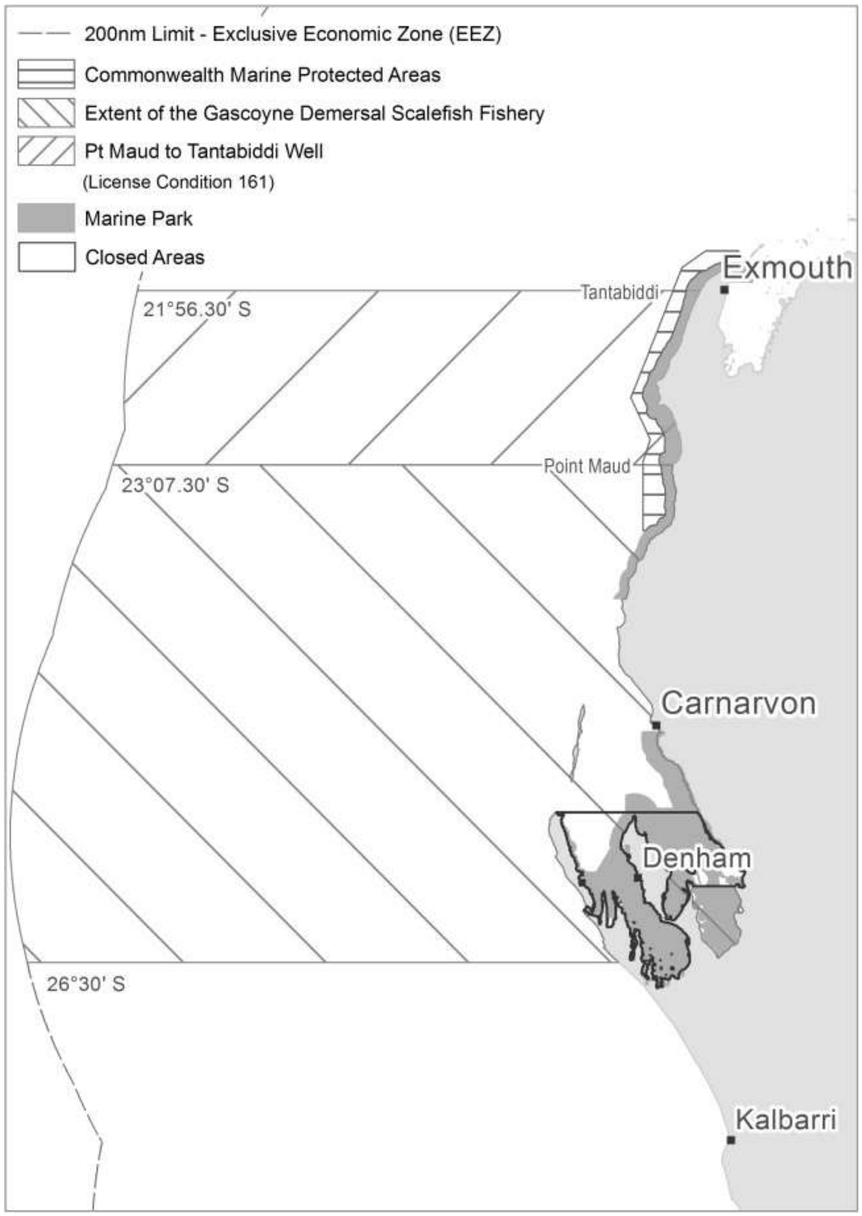


Figure 6.3. Boundaries of the Gascoyne Demersal Scalefish Managed Fishery and areas closed to commercial fishing, including the Point Maud – Tantabiddi Well commercial fishing closure

6.2.3 Fishing Methods and Gear

Demersal scalefish caught by the GDSMF using gunwhale-mounted hydraulic or electric powered reel lines usually rigged with 15-30 snoods, with each having one or several terminal circle hooks baited with mullet, sardines or squid. Fishing vessels are typically equipped with 3-4 of these hydraulic reels (Figure 6.4).

A fishing trip typically ranges from two to three days to over a week in duration, but will vary among operators and is weather-dependent. At sea, landed catch are killed using the iki-jimi method and then quickly placed in an seawater-ice-slurry. The catch is landed at designated ports in Denham, Carnarvon or Coral Bay.

Figure 6.4. Fishing gear used to catch demersal scalefish in the Gascoyne Demersal Scalefish Managed Fishery; (a) Hydraulic gunwhale mounted reel, (b) snoods attached to main line, (c) hook types used for targeting different species, (d) goldband snapper being retrieved using the gunwhale mounted hydraulic reel

6.2.4 Susceptibility

Pink snapper are distributed over the continental shelf and upper slope to depths of 300+ m. During winter, adults move inshore to spawn over reefs (20-80 m) before dispersing again over the shelf during the non-spawning season (Moran et al. 2003). Other inshore demersal species such as emperors and cods are caught in similar water depths as pink snapper during spawning season. Goldband snapper inhabit hard bottom areas and areas of vertical relief mostly in water depths 80-150 m. Deeper-water species are found in waters 200-300 m and greater.

The commercial fishery operates over the most of the distribution of the two key indicator species (Figure 6.5).

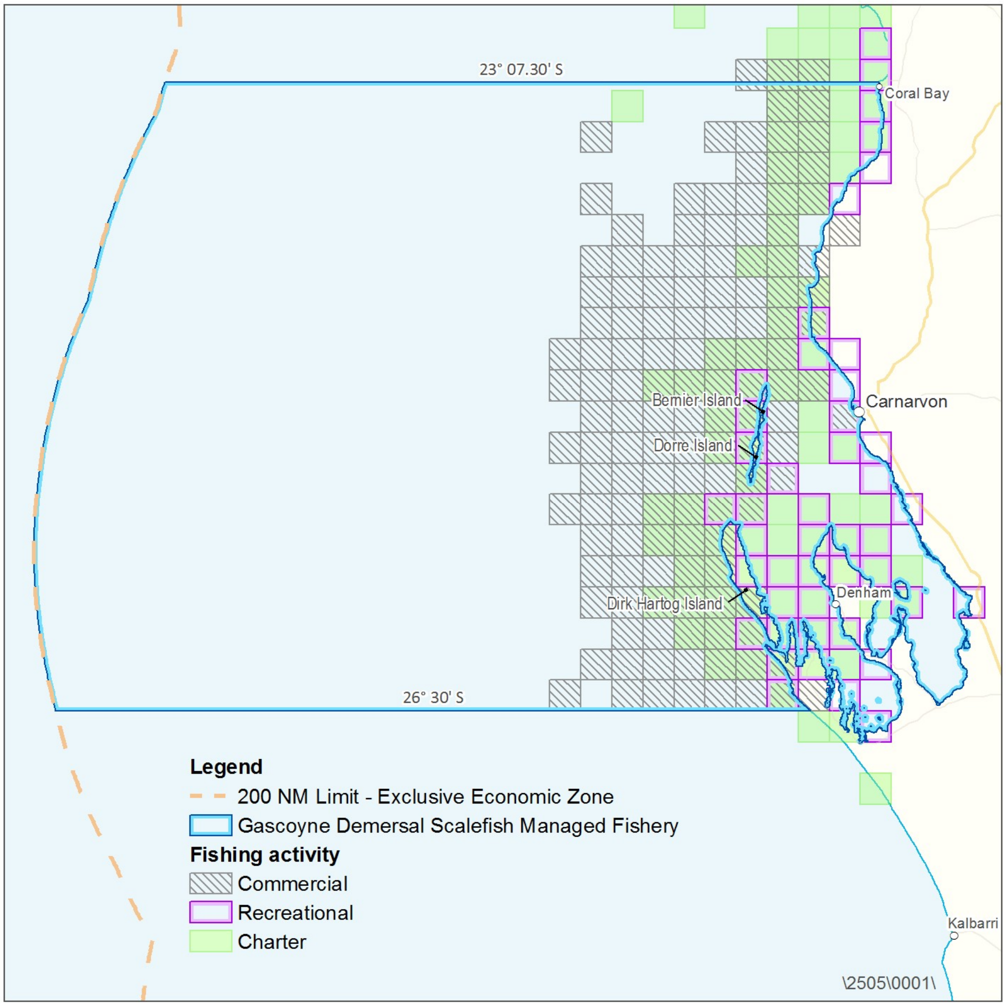


Figure 6.5 Areas fished by the Gascoyne Demersal Scalefish Managed Fishery and charter sector (2011-2015), and randomly selected Recreational Fishing Boat Licence holders during the 2011-12 and 2013-14 state-wide recreational surveys.

6.3 Recreational & Charter Fishery

6.3.1 History of Development

Recreational fishing is a popular activity in WA, with the estimated number of recreational fishers in the State more than doubling since 1990 to over 700,000 participants in 2014/15 (Department of Fisheries 2015b).

The special features of the GCB, coupled with the warm, dry winter climate and accessible fish stocks, have made it a focal point for winter recreation by the Western Australian community. Fishing during this season is a key component of many tourist visits. A full range of angling activities is available, including beach and cliff fishing (e.g. Steep Point and Quobba), embayment and shallow-water boat angling (e.g. Shark Bay, Exmouth Gulf and Ningaloo lagoons), and offshore boat angling for demersal and larger pelagic species (e.g. off Ningaloo).

There is limited historic data on recreational and charter catches of demersal scalefish species in WA. A survey of boat-based recreational fishers in 2015/16 reported ~50 demersal species caught in the GCB (Ryan et al. 2017). The most common species represented in the recreational catches (by numbers) were pink snapper, spangled emperor, grass emperor, red emperor, goldband snapper and redthroat emperor. An annual recreational catch of 103 t (± 7.8 t) of the top 10 demersal scalefish species in the GCB was estimated for 2015/16 (Ryan et al. 2017). A summary of available recreational and charter catch information for demersal scalefish in the GCB is presented in Section 9.3.2.3.

6.3.2 Current Fishing Activities

Recreational and charter fishing for demersal scalefish species is undertaken in all Gascoyne waters, with the exception of Sanctuary Zones, Marine Nature Reserves and Conservation Areas within the Ningaloo and Shark Bay Marine Parks. The majority of boat-based fishing effort occurs during autumn and winter, peaking in April-May (Ryan et al. 2013, 2015, 2017). In 2015/16, recreational boat-based fishers fished for an estimated 43,237 (± 3,152) boat days (=169,312 hours) in the GCB (does not include tour boat/charter based fishing) (Ryan et al. 2017).

6.3.3 Fishing Methods and Gear

Recreational (and charter) fishing for demersal scalefish in the GCB are mostly line-based fishing from boats. Hooks are typically baited with squid, pilchards or other types of scalefish.

Similar range of species are also taken by free-diving spearfishers (Ryan et al. 2017)

6.3.4 Susceptibility

Charter vessels operate in similar waters as GDSMF. In contrast, recreational vessels operate closer inshore nearer ports of Denham, Carnarvon and Coral Bay. Charter and recreational vessels catch many of the same species as taken by the GDSMF.

6.4 Customary Fishing

See 8.2.3.

6.5 Illegal, Unreported or Unregulated Fishing

Under-reporting of pink snapper catches (‘leakage’) during the period 1990-2006, including catch being landed illegally at Kalbarri (not a designated port of landing), was identified as feature of the fishery in the past, and following extensive discussions with industry (November-December 2006), it has been accounted for in stock assessments (via modified catch designated as ‘foreign’) since 2006. With the small number of operators in current GDSMF fleet, only three designated landing ports (Coral Bay, Carnarvon and Denham), and the use of a Vessel Monitoring System (VMS) for monitoring of fishing effort, there is no longer likely to be any significant illegal commercial fishing of the resource.

7 Fishery Management

7.1 Management System

The regulatory harvesting system for the GDSFR is based on a *constant catch approach* (where catch is kept constant) when a stock is in recovery, and a *constant exploitation approach* (where the catch varies in proportion to variations in stock abundance) when a stock is above B_{MSY} (i.e. the threshold).

In line with this harvesting approach, the main commercial fishery that targets this resource (GDSMF) is primarily managed using output controls via an ITQ system. There are two types of quota in the GDSMF; a separate pink snapper Total Allowable Commercial Catch (TACC), and a combined TACC for other non-pink snapper demersal scalefish species. Given the multi-species nature of the fishery, the two quota systems are linked to ensure fishers cannot target one quota group in isolation of the other.

A licence cannot be operated unless there is a minimum of 100 units of usual or current entitlement of each quota group on the licence, and a person must not operate in the fishery unless there is unexhausted pink snapper and combined species quota remaining on a licence. Furthermore, a 'minimum debit rule' of 50 kilograms of pink snapper quota per fishing day applies to reduce any incentive to discard pink snapper while targeting non-pink snapper species demersal scalefish, particularly in deeper offshore waters where barotrauma issues are more prevalent. Fishers must also comply with gear restrictions, spatial closures and applicable species size limits.

The recreational and charter fishery in the GCB is primarily managed using output controls, including size limits for some species, and daily bag and possession limits. Recreational fishers operating from a boat are required to hold a current Recreational Fishing from Boat Licence (RFBL). Unlicensed fishers on boats can fish if at least one other person on board has an RFBL, provided the total catch of everyone on board stays within the bag limits of the licensed fisher(s). Charter operators are required to hold a Fishing Tour Operators Licence. The decision-making process required to ensure the objectives are being met is framed around a series of linked procedures within the operational part of this harvest strategy.

7.2 Harvest Strategy

A harvest strategy for the GDSFR outlines the long- and short-term objectives for management (DPIRD 2017). 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.

A summary of the management objectives, performance indicators, reference levels and control rules for the resource is provided in Table 7.1. The focus of the harvest strategy is on the target stocks of the two indicator species for the commercial fishery in the GCB, i.e. pink snapper and goldband snapper. Periodic assessments of selected non-indicator species are also occasionally undertaken to validate the indicator species approach and ensure that the status of other retained species remains at acceptable levels (see Section 9.2). The assessment and harvest strategies of these species are primarily based on estimates of fishing mortality and spawning stock biomass (or an appropriate proxy for biomass), relative to internationally accepted target, threshold and limit reference levels. A summary of these reference levels is presented in Appendix 1.

Table 7.1. Summary of the key performance indicators, reference levels and control rules for the indicator species (pink snapper and goldband snapper) of the Gascoyne Demersal Scalefish Resource

Management Objective	Performance Indicator(s)	Reference Levels	Control Rules
To maintain spawning stock biomass of each retained species above B_{MSY} at a level where the main factor affecting recruitment is the environment	Periodic estimates of spawning stock biomass (B, or appropriate proxy)	**Target:** B_{Target}	Continue management aimed at achieving ecological, economic and social objectives.
		Threshold: $B_{Threshold}$	If the Threshold is breached[1] by either indicator species, a management review will be completed within 3 months to develop a management response. Appropriate management action will be taken as soon as is practicable to reduce the total mortality by 10-50%, applicable to all fishing sectors, to enable a return to above the Threshold within one generation.
		Limit: B_{Limit}	If the Limit[1] is breached by either indicator species, a review will be initiated immediately and completed within 1 month to develop a management response. Appropriate management action will be taken as soon as is practicable to reduce the total mortality by 50-100%, applicable to all fishing sectors, to enable a return to above the Threshold within one generation. If a severe risk is identified then fishing will cease immediately while the initial review process is undertaken.

[1] For pink snapper the Threshold and Limit levels are considered breached when there is greater than 20% probability that these levels have been exceeded. That is, the 20th percentile of a distribution of the estimated performance indicator (i.e. the lower bound of a 60% confidence interval) falls below the Threshold or Limit level).

7.3 External Influences

External influences include other activities and factors that occur within the aquatic environment that may or may not impact on the productivity and sustainability of fisheries resources and their ecosystems. The main external influences included here are environmental factors and non-WA managed fisheries that also catch demersal scalefish in the GCB.

7.3.1 Environmental Factors

Environmental change such as warming water temperature has the potential to impact temperate species such as pink snapper in the GCB, which is towards the northern extent of the species range on the west coast of Australia. Spawning in pink snapper is highly related to temperature, mostly occurring around 19-21º C (Wakefield et al. 2015). While there is no firm evidence of spawning omission due to elevated water temperatures (related to marine heatwave in 2010/11 and subsequent years) in the Gascoyne, maintained increases in water temperatures during the winter spawning season will likely affect temporal and spatial spawning patterns and subsequently, recruitment.

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. 2015a). 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. 2015a). In 2010/11, a very strong Leeuwin Current resulted in unusually warm ocean temperatures in coastal waters of south-western WA (Pearce et al. 2011). This "marine heatwave" altered the distribution and behaviour (e.g. spawning activity and migration) of some species and caused widespread mortalities of others. Pink snapper have been identified as highly sensitive to climate change and at high risk, in particular in the Gascoyne that is towards the northern extent of the species distribution in WA (Caputi et al. 2015b).

7.3.2 Non-WA Managed Fisheries

The Commonwealth-managed Western Deepwater Trawl Fishery operates in WA outside the 200 m isobath, between Exmouth and Augusta. The small number of vessels involved fish out of Carnarvon and Fremantle, primarily targeting deepwater bugs (*Ibacus* spp.) but also retain minor quantities of deepwater demersal scalefish species such as ruby snapper (Chambers and Bath 2015).

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 Gascoyne Demersal Scalefish Resource (see Table 8.1).

Table 8.1. Summary of information available for assessing the Gascoyne Demersal Scalefish Resource

Data type	Fishery-dependent or independent	Purpose / Use	Area of collection	Frequency of collection	History of collection
Commercial catch and effort statistics (CAES returns and logbooks)	Dependent	Monitoring of commercial catch and effort trends and calculation of catch rates	60 × 60 nm (CAES) 10 × 10 nm (logbooks)	Monthly (CAES) Daily / trip (logbook)	1950-2007 (Monthly returns since 1950, CAES since 1975) 2008 onwards (logbook)
Catch Disposal Records (CDRs)	Dependent	Quota monitoring, validation of catch returns / logbooks	GDSMF	By trip	Since 2001
VMS data	Dependent	Verification of boat locations for logbook analysis	GDSMF	Daily	Since 2008
Recreational catch and effort estimates	Dependent	Monitoring of recreational catch and effort trends	Gascoyne Coast Bioregion	Periodic (biennial since 2011)	Since 1998
Charter catch and effort statistics	Dependent	Monitoring of charter catch and effort trends	Gascoyne Coast Bioregion	Monthly	Since 2001
Age composition	Dependent	Age structure, estimation of total mortality	Gascoyne Coast Bioregion	Periodic	1992, 1995-1996, 1999-2000, 2004-2015
Biological information	Dependent and independent	Patterns of growth and reproduction, stock structure	Gascoyne Coast Bioregion	Opportunistic	Since early 1980s

8.2 Monitoring

8.2.1 Commercial Catch and Effort

Information on commercial fishing effort (days fished) and retained species catches (kg) in the Gascoyne is available from monthly catch and effort (Deep Sea Fisherman's returns 1949 onwards, CAES since 1975) returns, daily/trip logbooks and catch disposal records (CDRs).

The statutory reporting requirements have changed through time. The Department's monthly catch and effort statistics (CAES) database comprises commercial catch and effort data from 1975. The data include fishing gears, number of days fished, and retained catches of different species and species groups by statistical reporting blocks (approximately 60 × 60 nautical miles). Although catches in earlier years were often reported by fishers as groups of species (e.g. goldband snapper often reported as 'jobfish', Marriot et al. 2012), the majority of catches are now recorded accurately at the species level.

Daily/trip logbooks were introduced in the GDSMF in 2008 to collect more comprehensive and finer-resolution (approximately 10 × 10 nautical mile reporting blocks) catch and effort data for use in assessment of the key target species. The daily catch and effort logbook data are reconciled against the compulsory CDRs that are independently submitted by fishers at the end of each trip (for quota monitoring).

VMS was introduced in the GDSMF in 2008 to monitor effort levels and ensure compliance to the management arrangements.

8.2.2 Recreational / Charter Catch and Effort

Estimates of recreational fishing effort and demersal scalefish catches in the GCB are available from a number of recreational fishing surveys undertaken by the Department, including two boat-ramp creel surveys undertaken in 1998/99 (Sumner et al. 2002) and 2007/08 (Marriott et al. 2012). There is negligible shore-based catch of the demersal scalefish species that are the focus of this RAR and therefore estimated boat-based recreational catches (see below) are taken to represent the total recreational catch.

A state-wide survey was implemented in 2011 to collect information on private (non-charter), boat-based recreational fishing in WA (Ryan et al. 2013, 2015, 2017). This probability-based survey uses three complementary components, off-site phone-diary surveys, on-site boat ramp surveys and remote camera monitoring, to collect information on fishing catch, effort, location and other demographic information every two years.

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

8.2.3 Customary Catch

The only available estimates of customary catches of demersal scalefish in northern WA are from the 2000/01 National Recreational and Indigenous Fishing Survey (Henry and Lyle 2000).

8.2.4 Illegal, Unreported or Unregulated Catch

After concerns by fishers in the mid-2000s of under-reporting and the illegal landing of demersal scalefish at the port of Kalbarri, the Department attempted to quantify the effect on the time series of commercial pink snapper catches. These were then presented to industry for comment and subsequently used to develop two different time series of catches for the fishery, a ‘base case’ and a ‘modified case’ that were incorporated into the updated stock assessment in January 2007 (see 9.13.1.2). The ‘modified case’ catch data that were agreed to by the industry are now used routinely in each stock assessment.

8.2.5 Fishery-Dependent Monitoring

Random samples of pink snapper for otolith-based ageing have been collected periodically from commercial fishers and processors in the Gascoyne since the early 1990s. Since 2004, following recommendations by Moran et al. (2005), age composition sampling for pink snapper has been more comprehensive and is undertaken periodically using a stratified sampling design. For pink snapper, this sampling design is based on the seasonality of catches, with larger numbers of otolith samples collected during the winter months of highest catch. A total of ~500-600 otoliths (minimum of 300) are collected in each sampling year, based on a target of 25-30 otoliths from 20 separate catches per fishing season.

Methods for biological processing of fish samples in the laboratory and sectioning of otoliths follow those of Jenke (2002), Lewis and Mackie (2002) and Newman and Dunk (2003). All otoliths are sectioned transversely (0.3-0.5 mm thick) and ages are estimated from alternating translucent and opaque growth zones counted using a dissecting microscope with reflected light at approximately 30× magnification. Prior to reading a new sample of otoliths, an experienced reader reads a subset of sections randomly selected from a reference collection and the counts compared with those previously agreed upon. Bias and precision in the ageing is measured using age-bias plots and indices of average per cent error (IAPE, e.g. Campana 2001). In cases of clear bias or low precision (IAPE < ~5 %), another subset of otolith sections from the reference collection are read. Once the required levels of accuracy and precision have been achieved, the 'new' otolith sections are all read once, and a random selection (25%) read for a second time, to obtain a final measure of bias and precision (Marriott et al. 2012).

Ages at capture of the sampled fish are calculated using counts of opaque zones, otolith margin categories, and assumed birth date of June 1.

8.2.6 Environmental Monitoring

Databases with environmental variables (e.g. SST, wind direction/strength and sea level height) 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. 2015a). Analyses of correlations between key environmental variables and biological parameters (e.g. growth, recruitment) for the key demersal species in then Gascoyne (e.g. pink snapper, goldband snapper) remain to be undertaken.

9 Stock Assessment

9.1 Assessment Principles

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

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

9.2 Assessment Overview

As described in Section 4.2, assessment of the GDSFR is focused on evaluating stock status of the representative indicator species. While the assessment of indicator species is the primary method for inferring stock status of the large number of species comprising this resource, periodic monitoring and assessment is undertaken for a number of secondary indicator species that comprise a significant proportion of the total commercial catch, and/or that have life history characteristics that make them inherently vulnerable to fishing impacts. Such assessments are undertaken to validate the indicator species approach and ensure that the status of secondary indicator species remains at acceptable levels.

The stock status of two demersal indicator species in the Gascoyne (pink snapper and goldband snapper) is primarily assessed based on estimates of spawning stock biomass (or a proxy for biomass) relative to reference levels 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). Fishing mortality (*F*) and spawning biomass (*B*) for the oceanic stock of pink snapper is estimated periodically (every 3-5 years) using an age-structured, integrated assessment model which is conditioned on catch, and fitted to available time series of catch rates and age composition data (see Section 0). The model takes into account the major features of the biology of the species, including growth characteristics, the lengths and ages at which individuals mature, and the selectivity characteristics of the fishing gear used to catch these species.

In the absence of direct estimates of spawning stock biomass for goldband snapper, appropriate proxies for biomass are used as the primary performance indicator for monitoring of their stocks. These include estimates of fishing mortality and spawning potential ratio (*SPR*) from catch curve and per-recruit analyses, which are periodically compared to specified reference levels to determine the status of each stock (see Section 9.3.7 and 9.3.8).

9.2.1 Peer Review of Assessment

The stock assessment of the indicator species in the Gascoyne Coast Bioregion has been externally reviewed on two occasions; oceanic pink snapper by David J. Gilbert (National Institute of Water and Atmospheric Research, New Zealand) in June 2006 and all three species (pink snapper, goldband snapper and spangled emperor) by Sandy Morison (Morison Aquatic Sciences) in 2011 (Morison 2012). Both reviewers generally supported the assessment approaches used.

9.3 Analyses and Assessments

9.3.1 Data Used in Assessment

CAES / Logbook / VMS data Recreational fishing survey data Charter returns data Fishery-dependent data

9.3.2 Catch and Effort Trends

Since the most recent reductions in pink snapper TACC in 2006/07, commercial catches of demersal scalefish taken by the GDSMF have ranged from between 269 t and 532 t (Table 9.1). A more extensive and detailed time series of all catches of pink snapper is presented in Section 0. Minor commercial catches of demersal scalefish species, potentially including pink snapper, are retained by the Commonwealth-managed Western Deepwater Trawl Fishery (average catch all demersal species combined over past 5 years < 1 tonne per year).

The total commercial catch taken by the GDSMF in the 2016/17 fishing season was 277 t (Table 9.1). The catch comprised 133 t of pink snapper (oceanic stock, TACC = 277 t), plus 144 t of other species including 58 t of goldband snapper, 2 t of spangled emperor and 84 t of other scalefish species (Table 9.1).

Table 9.1. Total commercial catches (in tonnes) of indicator species (in grey) and other major demersal species taken by mechanised line fishing in GDSMF (2007/08-2016/17)

Species	2007/ 2008	2008/ 2009	2009/ 2010	2010/ 2011	2011/ 2012	2012/ 2013	2013/ 2014	2014/ 2015	2015/ 2016	2016/ 2017
Pink snapper	229.1	226.5	257.1	236.5	235.5	232.8	239.7	195.8	149.8	133.3
Goldband snapper	121.1	143.8	104.6	53.2	64.2	73.2	50.9	63.5	43.6	58.2
Red emperor	12.8	11.7	9.8	8.2	13.1	7.9	10.1	10.9	10.0	13.5
Spangled emperor	7.0	3.3	3.8	3.7	4.3	2.3	2.0	2.5	2.6	2.3
Other emperors	26.8	13.8	9.2	10.4	11.6	5.1	6.4	12.2	8.6	10.0
Cods	15.0	9.5	13.4	11.4	21.1	14.0	15.6	19.3	21.2	22.9
Other	65.8	64.8	72.9	50.7	38.9	30.8	51.2	57.5	32.6	37.0
Total	**477.6**	**473.4**	**470.8**	**374**	**388.5**	**366.2**	**372.9**	**352.7**	**269.5**	**277.2**

There were 55 licences with pink snapper quota in the GDSMF in the 2016/17 season, with 16 vessels actively fishing through the season. These vessels (all are required to hold a minimum of 100 units of pink snapper quota to be able to operate in the waters of the GDSF) fished for a total of 730 days (783 days in 2015/16). Since 2007/2008, overall nominal effort in this fishery has been stable at ~700-800 days, considerably lower than during the period 1990s to early 2000s (see Figure 6.2).

The level of effort targeted at pink snapper varies on a seasonal basis, historically peaking in June–July, when the oceanic stock aggregates to spawn. Pink snapper catch rates are assessed annually using 'standard boat days', i.e. days fished by quota-holding vessels that caught more than 4 t each of pink snapper by line during the period June–July. GDSMF vessels fished for a total of 325 boat days during June-July in 2016/17.

Historical recreational and charter catches of demersal scalefish in the GCB prior to the first creel survey of boat-based recreational fishing in 1998/99 are unknown. Summaries of catch information collected during the 1989/99 and 2007/08 creel surveys of recreational boat-based fishing, and of available charter boat catches in the region for these same years, are presented in Marriott et al. (2012). More recently, from boat-based recreational fishing surveys since 2011/12, estimated annual catches of pink snapper (oceanic and Shark Bay's inner gulfs combined) have been relatively stable at ~ 20-30 t while catches of goldband snapper have increased slightly to ~15 t (Ryan et al. 2017).

The most recent boat-based recreational fishing survey undertaken in 2015/16 estimated annual catches of 32.3 t (27.3-37.3 t) pink snapper (oceanic stock), 14.9 t (11-18.8 t) goldband snapper and 12.4 t (10.5-14.3 t) of spangled emperor (Ryan et al. 2017). Charter vessel catch of these three demersal scalefish in the Gascoyne in 2016 was estimated to be 9.6 t (oceanic stock) pink snapper, 8.2 t goldband snapper and 2.2 t spangled emperor.

Total recreational boat fishing effort across the entire GCB between 2011/12 and 2015/16 varied between 43,237 and 58,123 boat days (Table 9.2) (Ryan et al. 2017).

Table 9.2. Annual fishing effort in Gascoyne, expressed as boat days and hours fished, for boat-based recreational fishing in WA during 2011/12, 2013/14 and 2015/16 (se=standard error) (source Ryan et al. 2017).

Year	Boat Days	se	Hours Fished	se
2011/12	58,123	3,672	253,930	17,245
2013/14	53,832	3,603	211,967	15,671
2015/16	43,237	3,152	169,312	12,914

9.3.3 Catch Distribution Trends

Based on daily/trip logbook data (approximately 10 × 10 nautical mile reporting blocks, data available only since 2008) there has been no marked change in spatial pattern of oceanic pink snapper catches: most of the commercial catch continues to be taken between May-August from the well-known marks over inshore reefs to the north and west of Bernier, Dorre and Dirk

Hartog Islands (Fig. 9.1)[2]. Over similar timescales, there has also been no marked change in the pattern of charter and recreational boat-based catches of oceanic pink snapper, with charter catches taken from similar areas to commercial fishery and private vessels catching pink snapper from a wider range of locations including fishing grounds closer inshore (Fig. 6.5).

Based on daily/trip logbook data, there has been no marked change in spatial pattern of commercial goldband snapper catches that continue to come from deeper waters of ~80-150 m depth further offshore to main pink snapper fishing areas (Fig. 9.2)

[2] Based on the pink snapper assessment reported in this RAR, a number of changes to the management arrangements were subsequently introduced in May 2018, to protect spawning aggregations in waters off northern Bernier Island. Details of this and corresponding changes in spatial patterns of snapper will be reported in next version of the RAR.

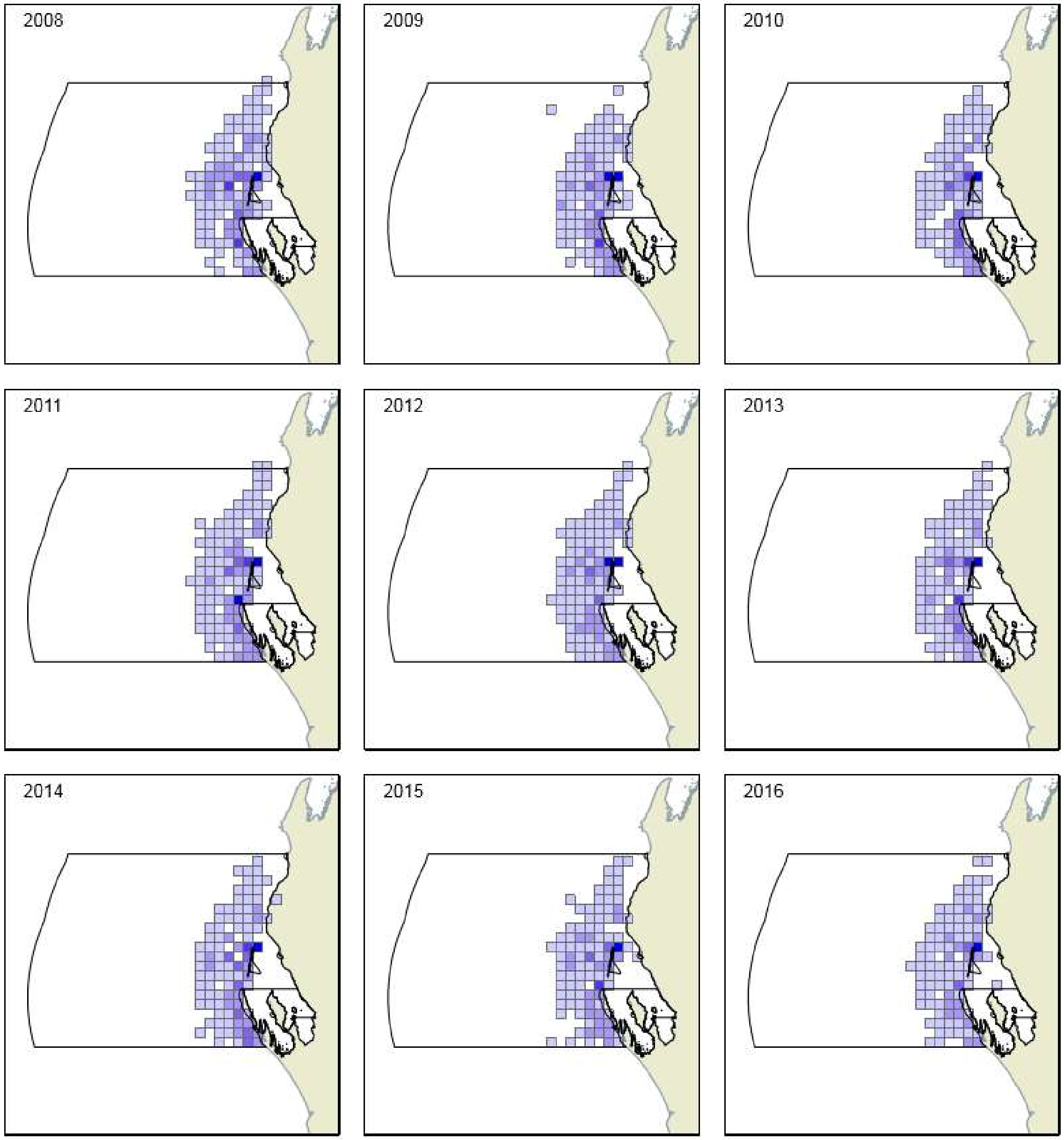


Figure 9.1. Spatial distribution of commercial pink snapper catches in GDSMF from daily/trip logbooks from 2007/08 to 2015/16 (10 x 10 blocks) (units are kg, lowest values = pale blue, highest values = dark blue).

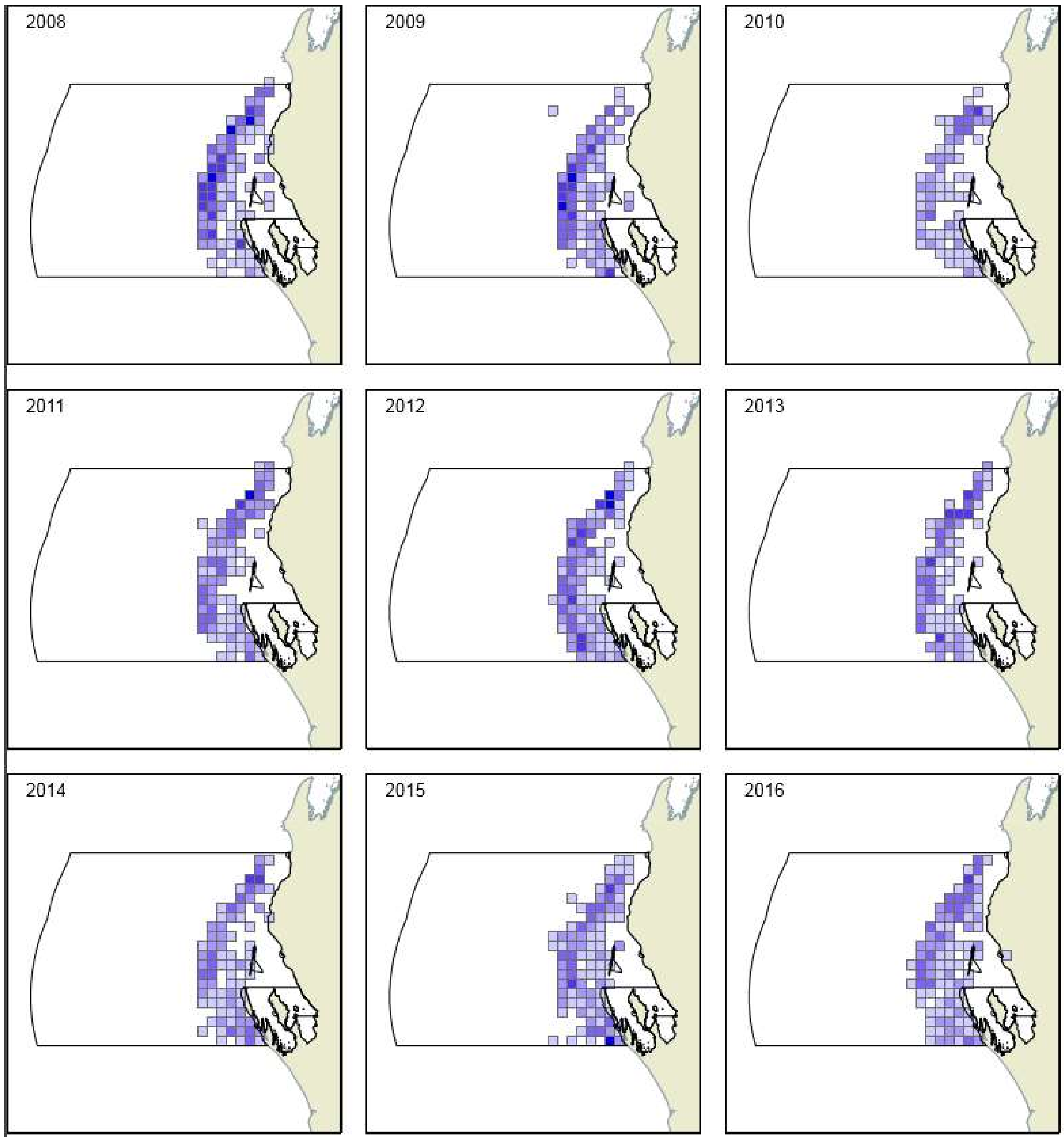


Figure 9.2. Spatial distribution of commercial goldband snapper catches in GDSMF from daily/trip logbooks from 2007/08 to 2015/16 (10 x 10 blocks) (units are kg, lowest values = pale blue, highest values = dark blue).

9.3.4 Fishery-Dependent Catch Rate Analyses

Although various fishing operations and gears have been used over the recorded history of the commercial pink snapper fishing in the GCB, handline has been the predominant method (Moran et al. 2005). Nominal catch rates are highest during winter months, peaking in June-July, when fish from the oceanic pink snapper stock aggregate to spawn. Based on these characteristics of the commercial fishery and in recognition of the need to identify targeted fishing effort, a commercial pink snapper catch rate (kg/boat day) has been calculated since the 1990s based on handline catches and effort during the months of June and July only (Moran et al. 2005). This approach was further refined to take into account issues arising from the boundaries of the fishery dissecting CAES reporting blocks and differences in skipper experience. A time series of pink snapper catch rates calculated using the following criteria (referred to as the 'Moran method') were incorporated into an age-structured integrated stock assessment model for the first time in 2002 (Moran et al. 2005):

- GDSMF vessels fishing by handline that caught >4 t total ('high-catch vessels') of pink snapper during months June and July only; and
- Catches from whole CAES blocks only within proscribed waters of GDSMF (dissected blocks at northern and southern margins excluded).

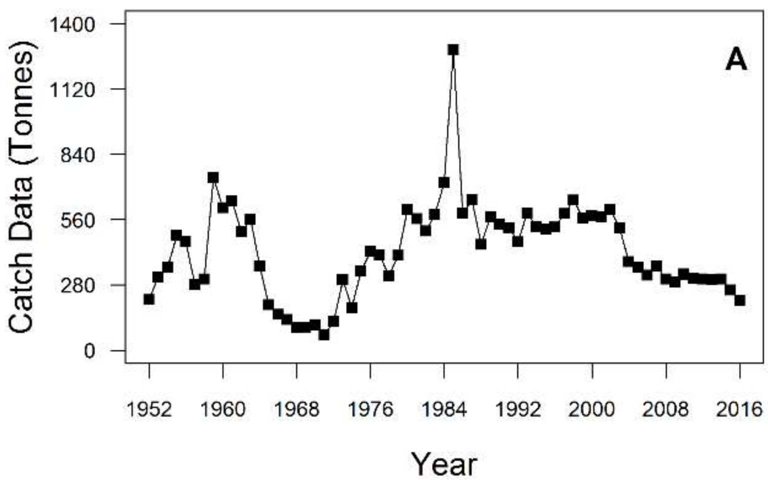
In 2006, a generalised linear modelling (GLM) approach for calculating pink snapper catch rates was explored (see Marriott et al. 2012 for details), however, the resultant catch rate trends were not noticeably different to that obtained using the 'Moran method'. In the same year, following discussions between the Department and industry, at which the merits of the various methods of estimating catch rates were discussed at length, it was agreed that the 'Moran method' would be continued with as the standard method for estimating pink snapper catch rates. Since then, catch rates calculated using effort measured as 'standard boat days', i.e. days fished by vessels that caught more than 4 t each of pink snapper by handline during June and July each year, were incorporated in the integrated stock assessment model used to periodically assess the oceanic pink snapper stock (see Section 0). This catch rate was also used as an annual performance indicator for the commercial pink snapper fishery, with the target level set at 500 kg pink snapper per standard boat day.

More recently, following a sharp decline in the annual commercial pink snapper catch rate in 2014/15 and 2015/16 quota seasons, and concern raised by GDSF fishers, another review of catch rates used in the oceanic pink snapper assessment was undertaken that included the first-time analysis of daily logbook data (logbooks were introduced in 2008). This analysis also attempted to quantify the effect of changes in fishing efficiency on pink snapper catch rates since 1990. The observed catch rates of pink snapper from catch and effort data recorded in the daily logbooks in the GDSF for the period 2007/08-2015/16 were standardised for temporal and spatial shifts in fishing effort that occur from month to month in each season for 30' x 30' blocks, and also for the influences of skipper, vessel and additional effects e.g. number of hooks used.

Marriott et al. (2012) undertook some preliminary work to explore whether the CAES catch and effort data could be used to develop an index of relative abundance for goldband snapper in the GCB. More recently, using the same method as with pink snapper, an analysis attempted to standardise the observed catch rates of goldband snapper from catch and effort data recorded in the GDSF daily logbooks.

The annual standardised pink snapper catch rate for 1990-2008 (monthly CAES data) after adjusting for changes in fishing efficiency, shows a gradual, progressive decline, from ~400 kg/day in 1990 to ~200 kg/day in 2008 (Figure 9.3).

The annual catch rate for 2009-2016 (daily logbook data) increases progressively from ~ 17 kg/line/hour in 2009-2010 to ~24 kg/line/hour in 2012 before declining progressively to just below 10 kg/line/hour in 2016 (Figure 9.4).



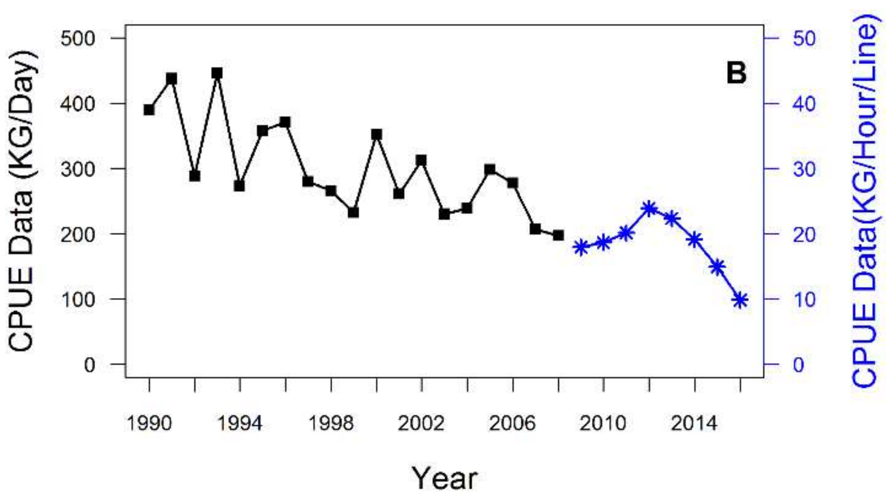


Figure 9.3 A) commercial pink snapper catch data for Gascoyne Demersal Scalefish Fishery from 1952-2016. B) Adjusted (i.e. for assumed changes in fishing efficiency) and standardised (i.e. from GLM analysis) pink snapper CPUE data for period 1990-2016.

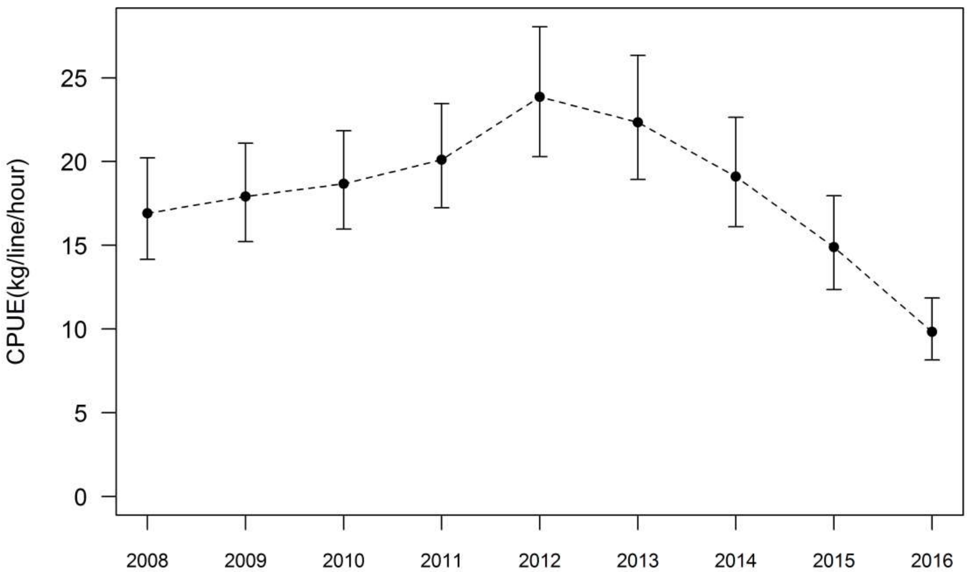


Figure 9.4. Annual mean pink snapper catch rate (kg/line/hour) in the GDSF standardised for month of fishing, 30' x 30' spatial block, skipper-vessel and number of hooks. The analysis included daily logbook records for "primary" skipper-vessels fishing in 3 or more seasons across the main 30' x 30' spatial blocks in the GDSF during the peak fishing months (May, June, July and August) for the quota seasons 2007/08 to 2015/16. Note that 2008 on the figure refers to the fishing season 2007/08.

The annual catch rate for 2009-2016 (daily logbook data) fluctuated between ~ 10 and 15 kg/line/hour. There is a high level of uncertainty whether the available fishery-dependent, multi-species catch rate data (CAES and daily logbook) can be used to provide a reliable index of abundance for goldband snapper.

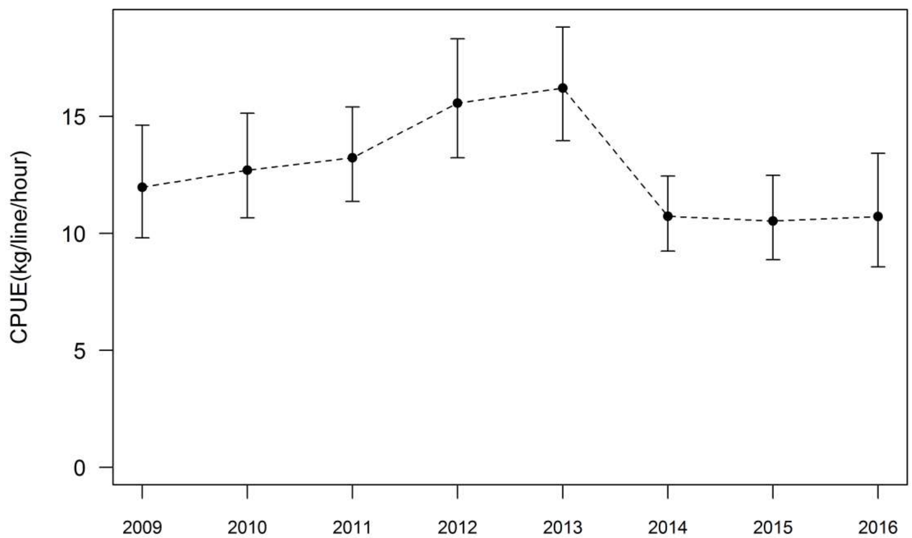


Figure 9.5. Annual mean goldband snapper catch rate (kg/line/hour) in the GDSF standardised for month of fishing, 30' x 30' spatial block, skipper-vessel and number of hooks. The analysis included daily logbook records for "primary" skipper-vessels fishing in 3 or more seasons across the main 30' x 30' spatial blocks in the GDSF during all months (Sept-Aug) for the quota seasons 2007/08 to 2015/16. Note that 2009 on the figure refers to the quota fishing season 2008/09.

9.3.5 Trends in Age and Size Structures

Fishery-dependent age composition data for pink snapper have been collected since 1991 (Figure 9.6). These data are used as input to the integrated age-structured assessment model (and catch curve analyses) for pink snapper (see Section 0). Data indicate that catches in the GDSMF have primarily comprised of relatively young fish, i.e. between 4-8 years of age, with a lack of older fish between 9-30 years of age.

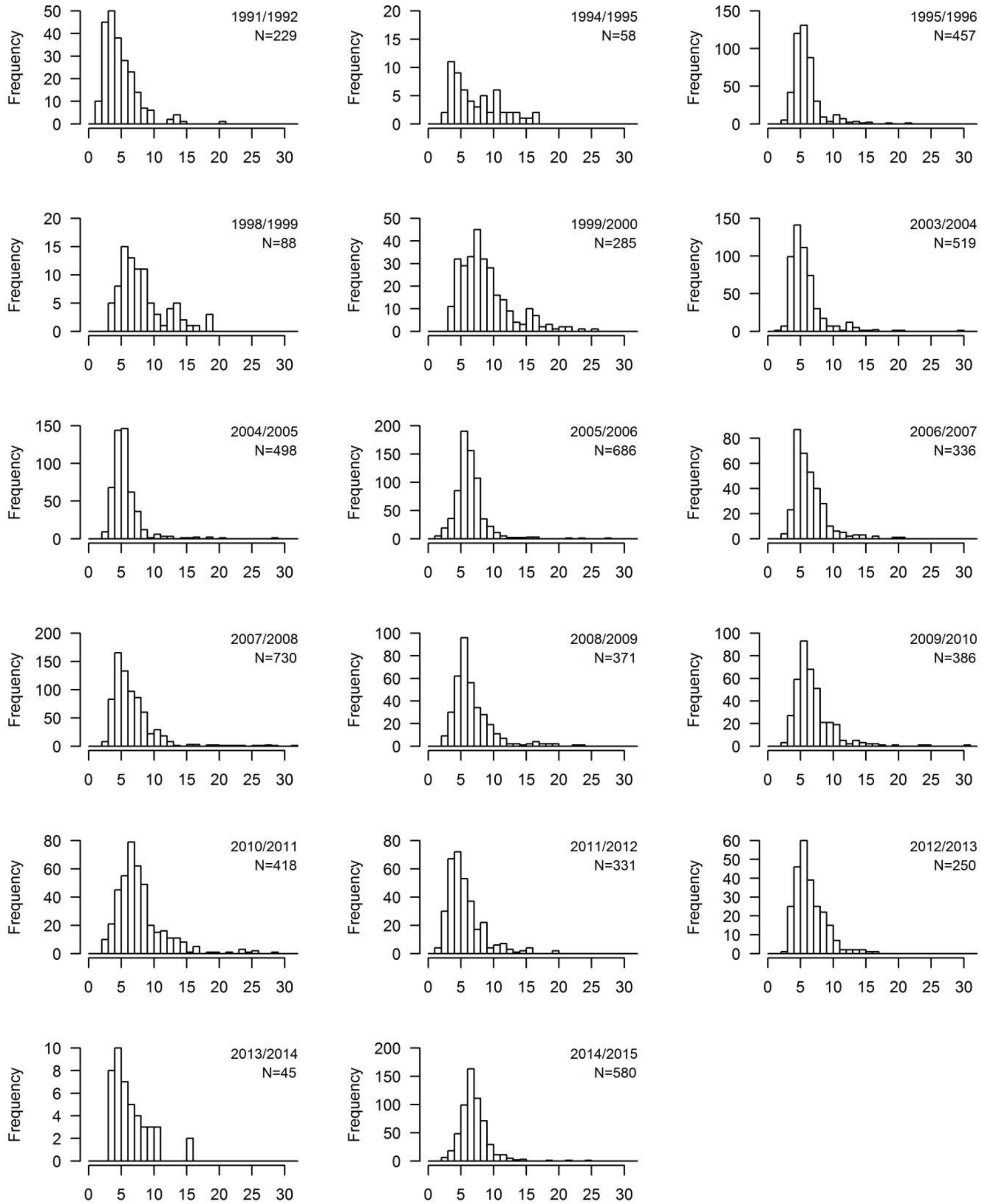


Figure 9.6. Age compositions of pink snapper (oceanic stock) in the Gascoyne between 1991/92 and 2014/15.

The most recent goldband snapper age composition data collected in 2010/11 and 2012/13 show that almost all age classes above 4 years up to a maximum observed age class of 28 years are represented in the catches (Figure 9.7). The modal ages of the age frequency distributions were 5 and 6 years for the samples collected in 2010/11 and 2012/13, respectively. The bimodal characteristics of the age composition data, particularly in the sample collected in 2012/13, suggest that this species exhibits substantial variation in recruitment between years in the Gascoyne (Figure 9.).

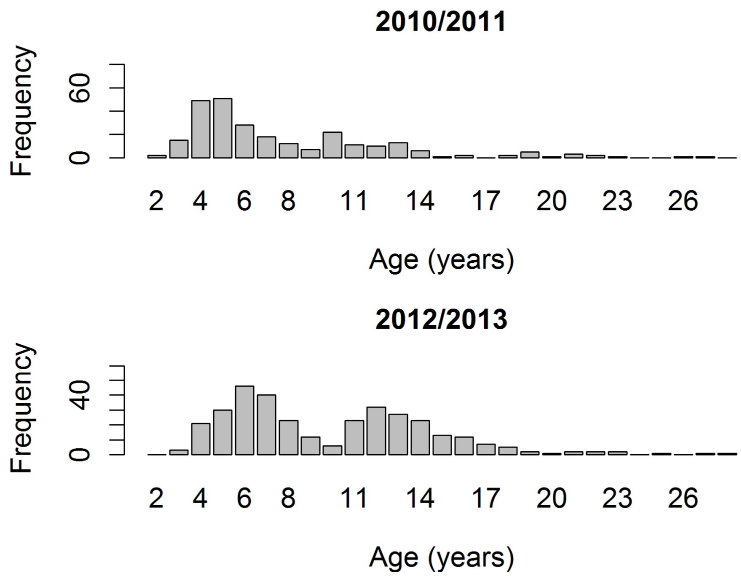


Figure 9.7. Age composition of goldband snapper in the Gascoyne in 2010/11 and 2012/13.

9.3.6 Productivity Susceptibility Analysis

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

Although a valuable tool for determining the overall inherent vulnerability of a stock to fishing, the PSA is limited in its usefulness for providing stock status advice. This is because of the simplicity and prescriptiveness of the approach, which means that risk scores are very sensitive to input data and there is no ability to consider management measures implemented in fisheries to reduce the risk to a stock. 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 the two indicator species of the Gascoyne Coast Demersal Scalefish Resource.

Based on available life history information for pink snapper and goldband snapper reported in Section 5, the scores for the different productivity attributes considered in the PSA were identical for the two species (Table 9.3). Scores for individual attributes ranged from low risk, for characteristics such as reproductive strategy and fecundity, to high risk, for the longevity and trophic level of both species.

Table 9.3. PSA productivity scores for pink snapper and goldband snapper in the oceanic waters of the Gascoyne Coast Bioregion

Productivity attribute	Pink snapper	Goldband snapper
Average maximum age	3	3
Average age at maturity	2	2
Average maximum size	1	1
Average size at maturity	2	2
Reproductive strategy	1	1
Fecundity	1	1
Trophic level	3	3
Total productivity (average)	1.86	1.86

9.3.6.1 Pink Snapper & Goldband Snapper

For the key fisheries targeting pink snapper in the oceanic waters of the GCB (i.e. the GDSMF and the recreational/charter fishery), total susceptibility scores of 1.88 were obtained (Table 9.4). Lower total susceptibility scores of 1.43 were obtained for the fisheries that only retain minor catches of pink snapper (i.e. Commonwealth-managed Western Deepwater Trawl Fishery). The only difference in susceptibility scoring was for the attribute 'Areal overlap', which considers the spatial overlap of effort in the fishery relative to the distribution of the stock (defined as the oceanic waters of the GCB for pink snapper). The areal overlap is greater (likely 10-30%) for the main fisheries that directly target this stock, compared with the fisheries that retain pink snapper as a byproduct (likely < 10% overlap).

Table 9.4. PSA susceptibility scores for each fishery/sector that catches pink snapper and goldband snapper in the oceanic waters of the Gascoyne Coast Bioregion

Susceptibility attribute	GDSMF	Western Deepwater Trawl Fishery	Recreational Fishery
Areal overlap	2	1	2
Vertical overlap	3	3	3
Selectivity	2	2	2
Post-capture mortality	3	3	3
Total susceptibility (multiplicative)	1.88	1.43	1.88

Based on the productivity and susceptibility scores, the overall weighted PSA scores for the both indicator species of the Gascoyne Coast Demersal Scalefish Resource were 2.64.

9.3.7 Catch Curve Analysis

For each indicator species in the Gascoyne, periodic estimates of the instantaneous rate of total mortality (Z, year^{-1}) are derived from age composition data using catch curve analysis. While assessments of the oceanic pink snapper stock have focused on using available age composition data (and catch and catch rate time series) in an integrated assessment model to obtain estimates of spawning stock biomass (Section 0), results of catch curve analysis recently undertaken are presented here as part of the overall weight of evidence approach. For both pink snapper and goldband snapper, catch curve outputs are also used as input for subsequent per-recruit analyses to estimate the reproductive potential of stocks relative to an unfished state (see Section 9.3.8).

Four catch curve methods (see below) have been applied to explore the extent to which model uncertainty impacts on the assessment results. For goldband snapper, a fifth model that accounts for variability in annual recruitment was also fitted to the data. Estimates of fishing mortality (F) are calculated by subtracting the estimated value of natural mortality (M) for the species from the catch curve estimate of Z, i.e. $F = Z - M$. Values of M for the species were obtained using the mortality equation described by Quinn and Deriso (1999), where $M = ln(0.01)/A_{\max}$. The M estimates produced by this method (see Section 5 for more information) are based on the assumption that 1% of fish in the population survive to the maximum observed age $A_{\max}$.

For each species, the four methods of catch curve analysis were applied to available age composition data included linear catch curve analysis (method 1), the mortality estimator of Chapman & Robson (1960) (method 2), and two methods whereby a catch curve model is fitted to proportion-at-age data assuming that those proportions conform to a multinomial distribution, but with differing assumptions regarding the age at which fish become selected into the fishery (methods 3-4). Methods 1-3 assume knife-edge selection, with the age at which fish become fully selected into the fishery corresponding to one year above the age with the greatest frequency of fish in samples (i.e. "peak age +1"), and method 4 assumes that selectivity at age may be described by an asymptotic, logistic selectivity function. Full descriptions of these four methods are provided in Fairclough et al. (2014) and Norriss et al. (2016). When applying linear catch curve analysis, the upper end of the age frequency distribution was truncated such that the minimum frequency for any age above the specified age at full recruitment into the fishery was three.

As age composition data for goldband snapper indicated that this species exhibits considerable variation in annual recruitment between years in the Gascoyne, an alternative method that accounts for recruitment variability by tracking cohorts of fish (see Fairclough et al. 2014; Norriss et al. 2016) was also fitted simultaneously to the data for the two sampling periods.

To account for uncertainty around estimates of mortality, the catch curve estimates of Z and associated standard errors for each method were resampled to produce 1000 Z values. Point estimates of mortality and the 95% confidence intervals from each catch curve method were taken as the median, 2.5 percentile and 97.5 percentiles, respectively, of these 1000 Z values.

Catch curves were fitted to available age composition samples for pink snapper from 2014/15 (n = 580 fish), noting that only a small sample of pink snapper were available from the 2013/14 fishing season (n = 45 fish). Analyses demonstrated that the mortality and selectivity estimates obtained from catch curve analysis using the combined sample for 2013/14 and 2014/15 (n = 625 fish) were very similar to those based on 2014/15 data alone (Table 9.).

For goldband snapper, catch curves were fitted to available age composition samples from the southern area of the Gascoyne from 2010/11 (n = 263 fish) and 2012/13 (n = 335 fish).

9.3.7.1 Pink snapper

Catch curve estimates of Z derived from the 2014/15 age composition sample for pink snapper were very similar across the alternative catch curve models, ranging between 0.59 and 0.63 year^{-1} (Figure 9.8). As the importance of estimating selectivity in catch curve analysis has been demonstrated by simulation (Thorson and Prager 2011), method 4 was chosen as the most appropriate of the four models. The estimates of age-based selectivity produced by this catch curve method were also used in subsequent per-recruit analyses (see Section 9.3.8).

Assuming a value for natural mortality (M) of 0.144 year^{-1} (based on equation $M = -\ln(0.01)/A_{\max}$ from Quinn and Deriso (1999) and assuming a maximum age $A_{\max}$ of 32 years), the estimated fishing mortality (F) derived from catch curve method 4 is several times larger than the value of M (9.5). Selectivity estimates from this method suggest that 50% of individuals are selected by the line fishery at an age of around 6-7 years.

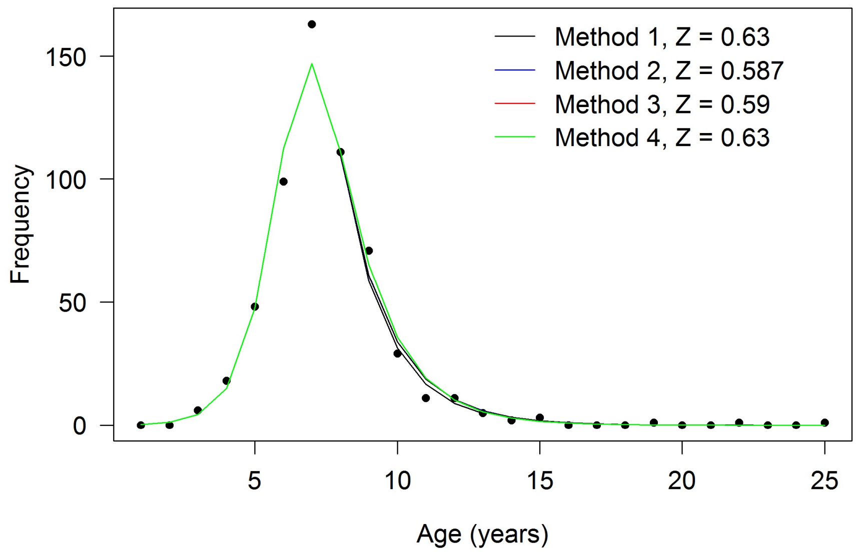


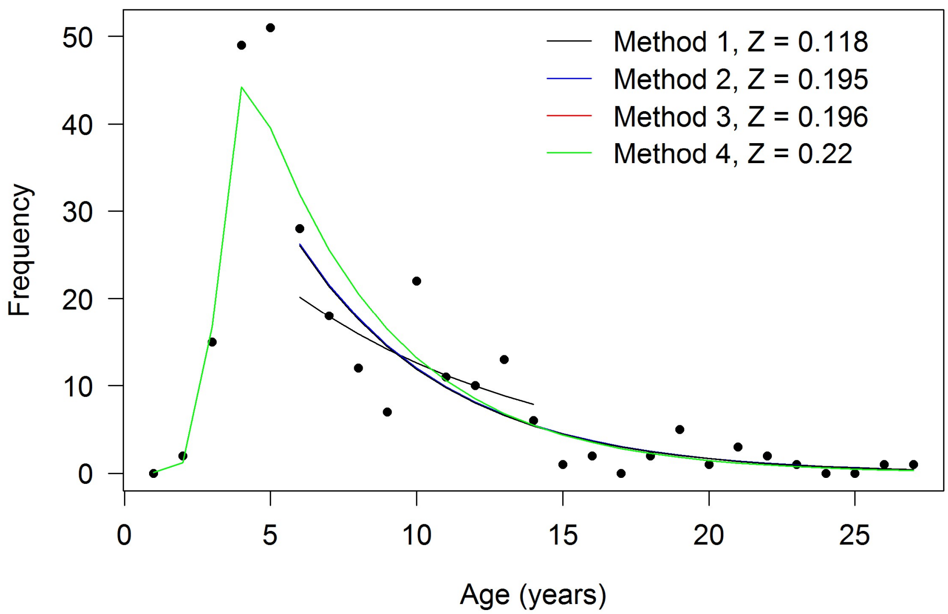
Figure 9.8. Fits of the four catch curve methods to age composition data (black dots) for pink snapper collected in the Gascoyne Demersal Scalefish Fishery in 2014/15. *Z* = total mortality (year^{-1}). Method 1, linear catch curve; 2, Chapman & Robson (1960); 3, multinomial catch curve with knife edge selectivity; 4, multinomial catch curve with logistic selectivity.

Table 9.5. Estimates of fishing mortality and age-based selectivity parameters (± lower and upper 95% confidence limits) for pink snapper in the Gascoyne Demersal Scalefish Fishery derived by fitting catch curve method 4 to age composition data collected in 2014/15 and combined data for 2013/14-2014/15.

Year	Sample size	Fishing mortality (F; year^{-1})	Selectivity A_{50} (years)	Selectivity slope
2014/15	580	0.49 (0.40-0.56)	6.7 (6.3-7.0)	1.4 (1.2-1.6)
2013/14 – 2014/15	625	0.46 (0.39-0.54)	6.6 (6.2-6.9)	1.4 (1.2-1.6)

9.3.7.2 Goldband Snapper

The four basic catch curve models that assume constant recruitment did not fit well to the age composition data for goldband snapper, thus indicating that recruitment of this species in the Gascoyne varies markedly between years (Figure 9.9). Although the Z estimates produced by catch curve methods 2-4 were relatively similar (0.20-0.22 year^{-1} in 2010/11 and 0.18 year^{-1} in 2012/13), the linear catch curve (method 1) produced much lower estimates of Z (Figure 9.9).



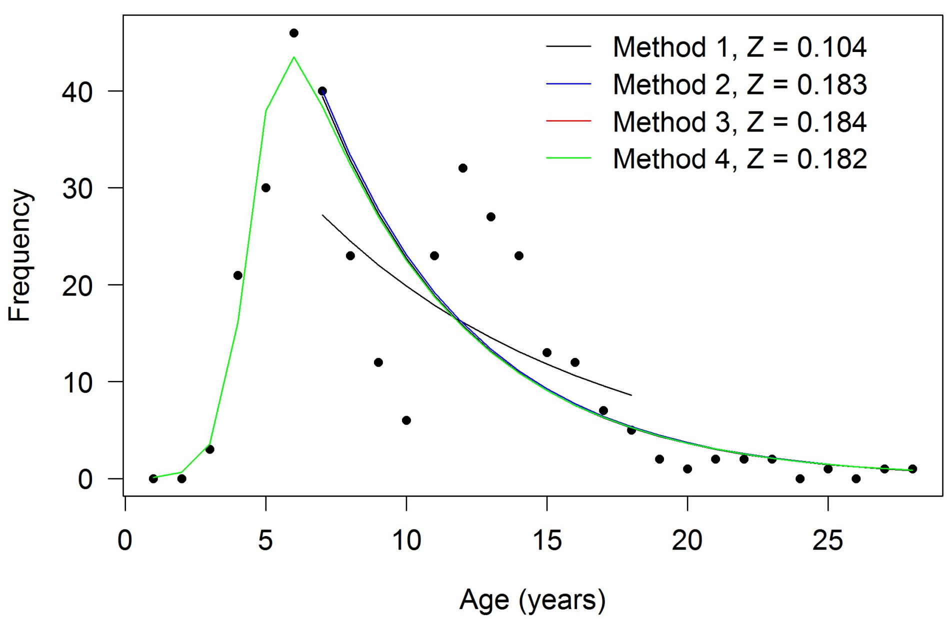


Figure 9.9. Fits of the four basic catch curve methods to age composition data (black dots) for goldband snapper collected in the Gascoyne Demersal Scalefish Fishery in 2010/11 (top) and 2012/13 (bottom). *Z* = total mortality (year^{-1}). Method 1, linear catch curve; 2, Chapman & Robson (1960); 3, multinomial catch curve with knife edge selectivity; 4, multinomial catch curve with logistic selectivity.

The catch curve model that accounts for variability in recruitment between years provided an improved fit to the age composition data (Figure 9.9) compared to the methods assuming constant recruitment between years, however, the *Z* estimate of 0.18 year^{-1} was the same as to those generated by Methods 2-4 for the 2012/13 sample. Assuming a value for *M* of 0.164 year^{-}

[1], the point estimate of fishing mortality (and associated 95% confidence limits) derived from the catch curve analysis was much lower than the value of *M* (Table 9.), indicating that the stock has only experienced a very low level of exploitation to date, which is consistent with the presence of considerable numbers of relatively old (> 15 y) fish in samples. Selectivity estimates suggest that 50% of individuals are selected by the line fishery at an age of around 3-4 years (Table 9.).

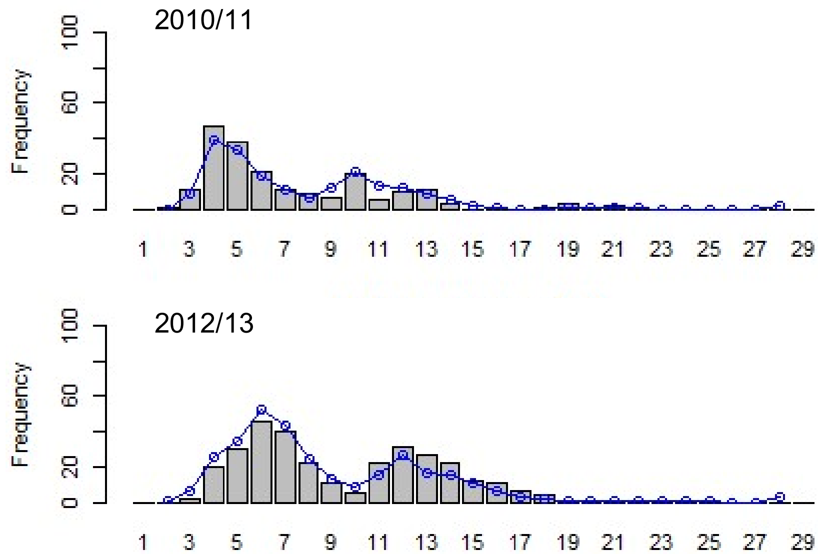


Figure 9.10. Fits of the catch curve method that accounts for recruitment variability to age composition data (grey bars) for goldband snapper collected in the Gascoyne Demersal Scalefish Fishery in 2010/11 and 2012/13. *Z* = total mortality (year^{-1}).

Table 9.6. Estimates of fishing mortality and age-based selectivity parameters (± 95% confidence limits) for goldband snapper in the Gascoyne Demersal Scalefish Fishery derived by fitting the catch curve method accounting for inter-annual variability in recruitment to age composition data collected in 2010/11 and 2012/13.

Year	Sample size	Fishing mortality (F; year^{-1})	Selectivity A_{50} (years)	Selectivity A_{95} (years)
2010/11-2012/13	598	0.018 (0.002-0.038)	3.7 (3.4-4.0)	4.6 (3.9-5.2)

In all of the catch curve assessments, 95% confidence intervals have been calculated to quantify the level of uncertainty in estimates of mortality associated with the catch curve analysis (applying a fixed value for *M*). Moreover, in each case, mortality has been estimated employing several catch curve models with different assumptions to explore model uncertainty.

9.3.8 Per Recruit Analysis

For each indicator species, estimates of female spawning potential ratio (SPR) were calculated from catch curve estimates of mortality and age-based selectivity (see Section 9.3.7) using two equilibrium age-based population models. The models included a traditional per-recruit analysis and a similar model (hereafter termed the "extended model") which incorporates a Beverton and Holt stock-recruitment relationship to account for potential impacts of exploitation on recruitment (e.g. Punt et al., 1993; see also Wakefield *et al.* in press).

Estimates of SPR provide a measure of the extent to which the spawning biomass of a population in equilibrium, at a given level of exploitation, has declined from the estimated level for an unfished population. In the case of goldband snapper, for which no dynamic assessment model is available to estimate relative female spawning biomass for the stock, SPR is used as the primary performance indicator in the harvest strategy and is compared against associated reference points (SPR_{Target} = 0.4, $SPR_{Threshold}$ = 0.3, SPR_{Limit} = 0.2). Note that these values translate directly to a value of fishing mortality (F). As per recruit analysis assumes the stock is in equilibrium, managing a stock to female *SPR* would be equivalent to managing based on F. This, of course, is not the case when using a dynamic assessment model (e.g. production model or integrated model).

For pink snapper, where undersized individuals are discarded by both the commercial and recreational fishing sectors due to the MLL of 410 mm TL, using per recruit analysis, a sensitivity analysis was undertaken to explore the impact on assessment results. To account for post-release mortality of undersized pink snapper that are released by fishers, the catch curve estimates of age-based selectivity were assumed to represent the retention of fish (as age composition samples included only landed fish), and assuming a gear selectivity curve where 50% of individuals are caught at an age of 3 years (Table 9.). Of the fish that are assumed to be selected by the fishing gear but not of a size at which they are retained, 25% were assumed to suffer post-release mortality. It was assumed that there is no discarding of goldband snapper as there is no MLL for this species.

Detailed mathematical descriptions of the two equilibrium, age-based population models applied to these analyses are provided in Norriss et al. (2016). Both population models provide a basic description of fish population dynamics based on the assumption that the population was at equilibrium (i.e. constant recruitment and mortality) at the time of sampling. They incorporate a range of available information on the biology of the stock including on growth, probability of maturity at age, selectivity pattern, and mortality estimates. Both models applied an annual time step and assumed deterministic growth of individuals, with an initial a sex ratio of 1:1.

Summaries of input parameter values used in the per-recruit analyses are provided for pink snapper in 9.7 and for goldband snapper in Table 9.8.

Table 9.7. Biological parameters applied in per-recruit analysis and the extended model with a stock-recruitment relationship, used to calculate female spawning potential ratio for the oceanic pink snapper stock in the Gascoyne.

Parameter	Value	Source
Natural mortality	0.144 $year^{-1}$	Based on equation by Quinn and Deriso (1999), with assumed maximum age of 32 years
Steepness stock-recruitment parameter for extended model, h	0.75	Myers et al. (1999) - meta analysis for steepness, Francis (2009) - recommendations for steepness
von Bertalanffy growth (females)		Wakefield et al. (2016)
L_∞	691 mm TL	
k	0.21 $year^{-1}$	
t_0	-0.33 years	
Retention at age		
A_{50}	6.57 years	
slope	1.38	
Gear selectivity (sensitivity analysis)		Assumed
A_{50}	3 years	
slope	1.38	
Proportion of caught and released fish that die (sensitivity analysis)	0.25	Assumed
Maturity at age (females)		Wakefield et al. (2015)
A_{50}	4.0 years	
A_{95}	6.0 years	
FL-TL relationship (females)	0.897 TL + 23.058	Wakefield (2006)
Weight-FL relationship (both sexes)	0.0000561 $FL^{2.827}$	Wakefield (2006)

Table 9.8. Biological parameters applied in per-recruit analysis and the extended model with a stock-recruitment relationship, used to calculate female spawning potential ratio for goldband snapper in the Gascoyne.

Parameter	Value	Source
Natural mortality (*M*)	0.164 year^{-1}	Based on equation by Quinn and Deriso (1999), with assumed maximum age of 28 years
Steepness stock-recruitment parameter for extended model (h)	0.75	Myers et al. (1999) - meta analysis for steepness, Francis (2009) - recommendations for steepness
von Bertalanffy growth (females)		Updated in 2016
L_∞	590 mm FL	
k	0.26 year^{-1}	
t_0	-0.46 years	
Selectivity at age		Estimated by catch curve that assumes variable recruitment
A_{50}	3.68 years	
A_{95}	4.56 years	
Maturity at length (females)		Updated in 2016
L_{50}	441 mm FL	
L_{95}	574 mm FL	
Weight-FL relationship (both sexes)	0.00002483 FL $^{2.9501}$	Newman and Dunk (2003)

9.3.8.1 Pink snapper

Based on estimates of fishing mortality estimated for pink snapper using catch curve analysis, the point estimates of female SPR derived by the traditional per-recruit analysis (0.26-0.27; see Table 9. for associated estimates of uncertainty) were between the limit and threshold reference points, suggesting that the spawning potential has been reduced to ~20-30% of that estimated for an unfished stock. When that analysis is extended to incorporate a stock-recruitment relationship (with steepness set to 0.75) to account for the possibility that recruitment may be impacted by fishing, the point estimates were around the limit reference point (Table 9.).

Assuming 25% mortality of fish below legal size that are caught and discarded, the point estimates for SPR from the traditional per-recruit analysis and the extended analysis were all below the limit (Table 9.).

Table 9.9. Estimates of female spawning potential ratio (SPR) and associated 95% confidence limits (i.e. accounting for uncertainty in *F*) for oceanic pink snapper derived from per-recruit analysis and an extended analysis incorporating a stock recruitment relationship. Results of sensitivity analysis accounting for effects of mortality associated with capture and release of "undersize" fish are also provided.

Sample	SPR (traditional)	SPR (extended with SRR)
2014/15	0.26 (0.24-0.29)	0.19 (0.17-0.22)
Combined	0.27 (0.24-0.30)	0.20 (0.17-0.23)
Sensitivity analyses – post-release mortality = 25%		
2014/15	0.18 (0.16-0.22)	0.11 (0.08-0.15)
Combined	0.19 (0.17-0.22)	9.12 0.09-0.15)

9.3.8.2 Goldband snapper

At the level of fishing mortality estimated for goldband snapper from age composition data collected in 2010/11 and 2012/13, the point estimate of female SPR and associated 95% confidence intervals derived from both the traditional per-recruit analysis and the extended model were above 0.8 and thus more than double the target reference point of 0.4 (Table 9.). This suggests that the goldband snapper spawning stock in the Gascoyne has only experienced minor depletion to date.

Table 9.10. Estimates of female spawning potential ratio (SPR) and associated 95% confidence limits (i.e. accounting for uncertainty in *F*) for goldband snapper derived from per-recruit analysis and an extended analysis incorporating a stock recruitment relationship.

Sample	SPR (traditional)	SPR (extended with SRR)
Combined	0.86 (0.73-0.98)	0.84 (0.71-0.98)

The above catch curve and per recruit assessment for pink snapper and goldband snapper has been extended to incorporate a range of available biological information (parameters) for these species. These analyses included a per-recruit analysis and an extension to that analysis (equilibrium age-structured model) that incorporates a stock-recruitment relationship to account for effects of fishing on recruitment. Thus these analyses explore the impact of alternative model assumptions on estimates of spawning potential ratio. Uncertainty around point estimates of SPR was calculated by inputting each of the 1000 bootstrapped estimates of fishing mortality from the catch curve analysis into the per-recruit and extend models.

9.3.9 Age-Structured Integrated Model

The age-structured integrated assessment model used for assessing the status of the oceanic stock of pink snapper in the Gascoyne is fitted to available time series of observed catch data, commercial catch rates (assumed to be an index of abundance) and age composition data. The model also incorporates biological parameters that have been separately estimated and pre-specified, e.g. for describing growth, weight-at-length relationships and size at maturity of fish. A general description of the model, the input data and pre-specified parameters used for the most recent assessment undertaken in 2017 are presented below.

This section provides a general description of the integrated assessment model, with details of the model equations for pink snapper assessments provided in Appendix 4.

The age-structured population model starts with an assumed age distribution of fish based on the numbers of fish reducing in each age class as a result of an initial specified fishing mortality F_0. The population dynamic model consists of:

The population dynamic model consists of:

1. A Beverton-Holt stock-recruitment relationship with steepness either fixed or estimated under an assumed prior distribution. Log-normal recruitment deviations with a mean of zero are estimated to account for annual variation in recruitment around the value predicted by the Beverton-Holt stock-recruitment relationship.
2. A deterministic, logistic maturity-age relationship, calculated external to the assessment model (Wakefield et al., 2015), pre-specified in the assessment.
3. A deterministic weight-at-age relationship, calculated external to the assessment model (Wakefield, 2006), pre-specified in the assessment.
4. A logistic function with median age and slope at the inflection point estimated in the model, which is used to calculate the vector of vulnerability at age.
5. Values of natural mortality M and the steepness h of the stock-recruitment relationship are pre-specified.
6. The annual age composition data, which were observed for each species, were assumed to be drawn from a multinomial distribution, with estimated effective sample sizes. The observed age composition data was fitted to model estimated age composition data assuming a multinomial model. Effective sample size, i.e. the size of a random sample producing the same precision of estimates as obtained using the observed sample and thus adjusting for correlation of lengths or ages among individual fish, was calculated and used to scale the observed sample sizes. The approach used to calculate the effective sample size was that described by McAllister and Ianelli (1997) or Francis (2011, Eq. TA1.8).

7. Two log-transformed, commercial catch rate time series (based on monthly CAES data, and daily logbook data), standardised using an external GLM model and adjusted for changes in fishing efficiency.
8. Two catchability parameters, q_1 and q_2, estimated in the model.
9. Available time series of total catch removals form all sectors.
10. Harvest rate (H), estimated as the quotient of observed catch and estimated vulnerable biomass. Approximate values of fishing mortality were calculated as $-\ln(1-H)$.
11. The overall log-likelihood has contributions from the recruitment deviations, log-likelihood for age composition data, and log-likelihood of log-transformed catch rates.

The stock assessment model was run using the software package AD Model Builder (ADMB) with point estimates and their associated upper and lower 95% confidence limits determined for the quantities of interest (unfished spawning biomass, annual spawning biomass, annual spawning biomass as a % of unfished spawning biomass, annual fishing mortality, annual fishing mortality as a % of natural mortality, and annual recruitment).

Several key changes were made to the integrated model and underlying assumptions in the most recent assessment (2017) as follows:

i. CPUE data were split into two separate time series, i.e. pre and post 2009, to account for the monthly CAES data period and more recent daily logbook data period. The model now estimates two catchability coefficients (one for each time series) whereas previously the model only estimated a single catchability coefficient for a single, combined catch rate series for monthly CAES and daily logbook data combined.

ii. Changes in annual fishing efficiency due to changes in technology were explicitly incorporated for the first time and were assumed to be the same as those estimated for commercial fishing operations in the West Coast Demersal Scalefish Fishery (Marriot et al., 2011). This fishery, which is located adjacent to the Gascoyne Demersal Scalefish Fishery, also targets pink snapper, using essentially the same methods.

iii. CPUE data were adjusted to account for the impacts, on fishing efficiency, associated with an assumed increased level of shark depredation in recent years. Commercial fishers had advised that fishing efficiency is likely to have declined by ~15% because of shark depredation. The model was run for a range of alternative assumptions regarding the effect of fishing efficiency on shark depredation with the 15% level taken as the base case scenario.

iv. Mortality of snapper in recent years due to shark depredation was considered by increasing annual catches by 10 t in 2008, 20 t in 2009, 30 t in 2010 and 40 t in 2011-2016.

v. The process leading to post-release mortality of discarded undersize fish was modelled explicitly by imposing an assumed asymptotic logistic curve for gear selectivity (currently set at A_{50} = 3.0 y (~300 mm TL), slope = 2.0) and estimating a separate retention curve, when fitting the model to commercial age composition data. A value for the proportion of undersize fish that die after capture and discard was specified, based on previous empirical work in WA and elsewhere in eastern Australia.

vi. The age data weighting scheme was changed to that described by McAllister and Ianelli (1997) was modified to be consistent with models used for other similar fisheries (Pilbara and Northern Demersal Scalefish Fishery).

vii. Age at maturity and growth parameters were set to those published by Wakefield et al. (2015) and Wakefield et al. (2016). Growth was described in terms of length (traditional von Bertalanffy growth model) and then converted to weight, employing the weight vs length and fork length vs total length relationships presented in Wakefield (2006).

viii. Recruitment deviation parameters were estimated for the entire modelling period (all years with observed and projected catches) to account for uncertainty associated with annual recruitments in all years.

ix. Recruitment deviation parameters were no longer constrained to have a slope of zero, as this is no longer considered appropriate (given the relatively long time series of data).

Table 9.11. Catch data used as input to the most recent assessment (2017) of the oceanic pink snapper stock in the Gascoyne from 1951/52 to 2015/16

Season	SBSF	Wetline	foreign	charter	recreational	total
1951/52	216.3					216.3
1952/53	314.3					314.3
1953/54	353.2					353.2
1954/55	491.2					491.2
1955/56	465.3					465.3
1956/57	282.5					282.5
1957/58	304.2					304.2
1958/59	740.9					740.9
1959/60	611.2					611.2
1960/61	642.2					642.2
1960/62	507.5					507.5
1960/63	561.5					561.5
1960/64	358.7					358.7
1960/65	193.9					193.9
1960/66	153.7					153.7
1960/67	130.7					130.7
1960/68	96.9					96.9
1960/69	98.3					98.3
1969/70	108.7					108.7
1970/71	66.7					66.7
1971/72	121.7					121.7
1972/73	300.8					300.8
1973/74	182.3					182.3
1974/75	339.8					339.8
1975/76	423.0					423.0
1976/77	409.0					409.0
1977/78	318.7					318.7
1978/79	406.4					406.4
1979/80	601.2					601.2
1980/81	564.3					564.3
1981/82	512.0					512.0
1982/83	582.0					582.0
1983/84	717.0					717.0
1984/85	1287.0					1287.0
1985/86	588.0					588.0
1986/87	646.0					646.0
1987/88	454.0					454.0
1988/89	511.9	40.5		10	10	572.4
1989/90	487.8	33.0		10	10	540.8
1990/91	477.0	29.1		10	10	526.0
1991/92	429.7	14.7		10	10	464.4
1992/93	482.8	85.5		10	10	588.2
1993/94	463.3	46.7		10	10	529.9
1994/95	468.3	31.2		10	10	519.4
1995/96	463.9	34.1		20	10	528.0

1996/97	518.6	36.3		20	10	584.9
1997/98	557.3	51.0		20	15	643.3
1998/99	477.6	52.1		20	17.1	566.8
1999/00	487.4	31.9	20	20	17	576.3
2000/01	479.3	34.9	20	20	17	571.2
2001/02	488.4	53.4	20	24	17	602.9
2002/03	440.8	35.9	0	27	20	523.7
2003/04	322.4	12.5	0	25	20	379.9
2004/05	305.0	9.5	0	21	20	355.5
2005/06	275.9	8.2	0	18	20	322.1
2006/07	305.3	15.9	0	20.2	20	361.4
2007/08	231	24	0	19.2	21.5	295.7
2008/09	224.8	6.8	0	21.5	21	274.1
2009/10	257.1	5.8	0	12.9	21	296.8
2010/11	236.4	0	0	11.6	21	269.0
2011/12	235.3	0	0	11.3	26.7	273.3
2012/13	232.8	0	0	11	26.7	270.5
2013/14	239.7	0	0	11	21.1	271.8
2014/15	195.8	0	0	8.5	21.1	225.4

Table 9.12. Summary of input data and parameters used in the 2017 assessment of pink snapper in the Gascoyne

Input Data / Parameters	Pink snapper
Observed catch (t)	Years 1952 - 2016
Catch rates and associated standard errors	Years 1993 - 2016
Age compositions (catch in numbers at age)	Years 1992-2015
Growth parameters for weight-at-age relationship (kg, years)	See Section 1.1
Median and inflection point of female maturity ogive λ_{50} λ_s	See Section 1.1
Steepness parameter h,	$h = 0.75$
Standard deviation of future *M* deviations σ_M	$\sigma_M = 0.02$
Initial fishing mortality prior to first year Fo	0.03

9.3.9.1Pink Snapper

For the latest assessment, the revised model was run using the catch and catch rate data to 2015/16 and age-composition data to 2014/15.

Integrated modelling: Key results

The results produced by the model vary considerably (in terms biomass estimates for recent years) depending whether it is fitted to the available catch rate data (i.e. after standardisation and adjustments for changes in fishing efficiency). Thus, results were presented based on separate model runs that either included or excluded catch rate data.

The current version of the assessment model provided a relatively good visual fit to the available age composition data for most years (Figure 9.12). When the model was fitted to these data (base case scenario), the model fitted relatively well to the catch rate data in many years, but diverges conspicuously from the observed data particularly in the late 1990s (Figure 9.12). It also did not match the observed trend well over the past five years, with the mean expected catch rate being higher than the mean observed catch rate in 2016 (but with 95% confidence limits almost overlapping).

Integrated model fitted to commercial catch rate data (base case scenario):

Between 1952-1970, estimates of annual F ranged from close to zero to just above M. F progressively increased from just above zero in 1970 to well above M (~0.2 year^{-1}) in 1984 (Figure 9.12). Subsequently, F was estimated to have remained at ~0.2 year^{-1} before declining to ~ M (0.14 year^{-1}) in 2016. The point estimates for relative female spawning biomass (i.e. current/unfished level) declined from ~80% in 1952 to ~ 20% (limit reference point) in 2004, and then remained at this level until 2016.

Integrated model not fitted to commercial catch rate data (alternative integrated modelling scenario):

Between 1952 and 2004, the trend in annual F estimates were essentially the same, regardless of whether or not the model was fitted to catch rate data (Figure 9.11). The trends diverged after 2004, with F progressively decreasing from ~0.2 year^{-1} to below 0.1 year^{-1} (*i.e.* well below M) in 2016, coinciding with reduced catches in recent years. The trend in the relative female biomass estimates were virtually the same as that described above (for when the model was fitted to catch rate data). The trends diverged around 2004, after which, for the model not fitted to catch rate data, it increased progressively to reach the threshold level in 2013, and remained at about this level until 2016.

Of the above two scenarios, the more pessimistic set of results derived from the model being fitted to catch rate data was most consistent with the catch curve/per recruit assessment results, and recent anecdotal information from fishers that current abundance of pink snapper in the Gascoyne region is very low.

Additional results: Integrated model fitted to commercial catch rate data (base case scenario)

Estimates of annual (juvenile) recruitment exhibited a gradual declining trend over the history of the fishery (Figure 9.13). This reflects, at least to some extent, the estimated decline in spawning biomass between 1952 and 2016, which on the basis of the stock-recruitment curve (with an assumed steepness value of 0.75), resulted in reductions in predicted (average) recruitment levels. In 2011, estimated juvenile recruitment was relatively low, which may be associated with negative impacts on spawning success/larval survival due to an extreme marine heatwave event at that time. The estimated low juvenile recruitment may be an important contributing factor to the relatively very low catch rates in 2015 and 2016, i.e. low levels of juvenile recruitment in 2011 would be expected to translate into low levels of recruitment into the fishery several years later.

Applying the base case model, several analyses were undertaken involving 5-year projections with alternate catch levels (Figure 9.14). The results of these runs indicated a high probability of the stock rebuilding to the threshold level (relative female spawning biomass = 0.3) with (effectively) no catch over that period. Results suggested ~50% probability of rebuilding to the threshold level in 5 years with catches set at 100 t. With catches set at 200 t, the stock was predicted to rebuild slowly, with a low probability of attaining the threshold level in 5 years. The stock is not projected to rebuild if catches over the next 5 years are set at 300 t.

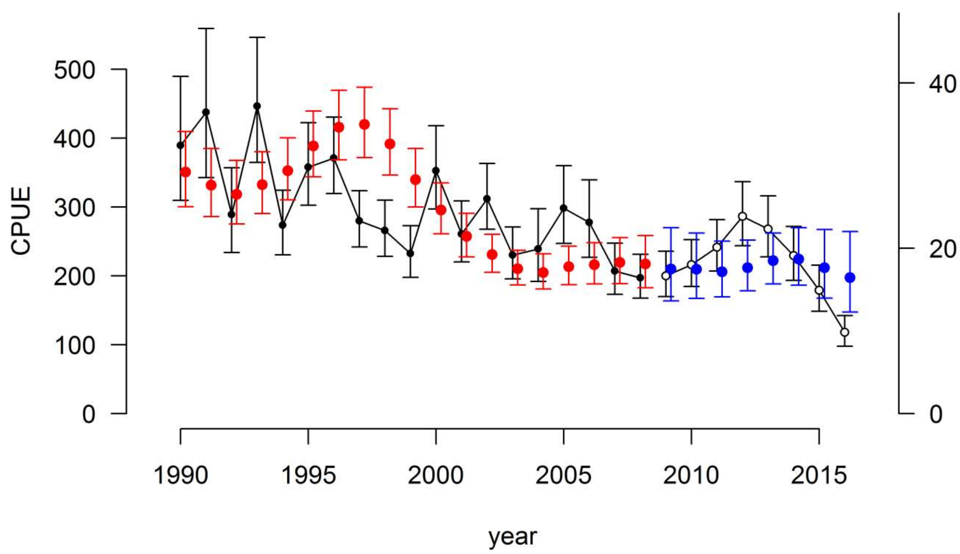


Figure 9.11. Observed (black line, closed circles - CAES, open circles – daily log books) and expected catch per unit effort (applying the "base case model") (red dots CAES, blue dots daily log books) for Pink Snapper collected from the Gascoyne Demersal Scalefish Fishery between 1992 and 2015. The catch rate data have been standardised and adjusted for annual changes in fishing efficiency associated with advances in technology and assumed effects of shark depredation.

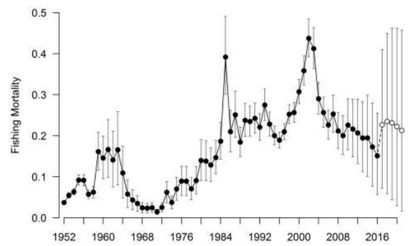
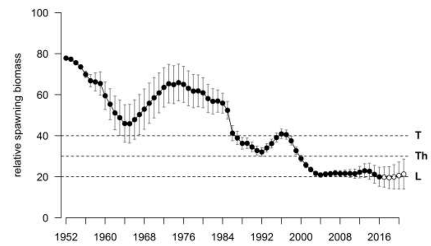
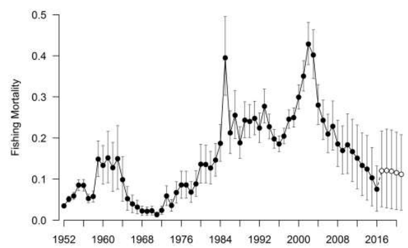
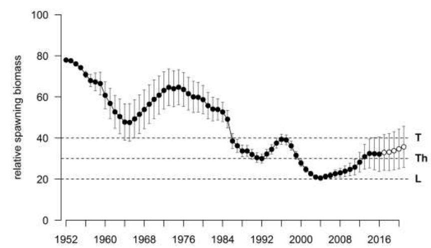
	Fishing mortality	Relative spawning biomass
Base case model: fitted to CPUE data (proj. 300t)		
Alternative model: not fitted to CPUE data (proj. 300t)		

Figure 9.12. Estimated annual trends in fishing mortality and relative female spawning biomass, when fitting the integrated model to the available catch rate data (base case model) compared with those obtained when not fitting the model to these data.

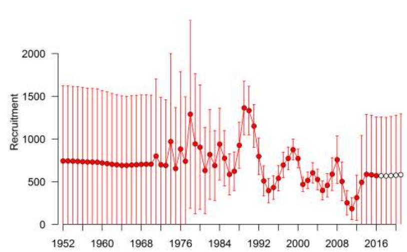
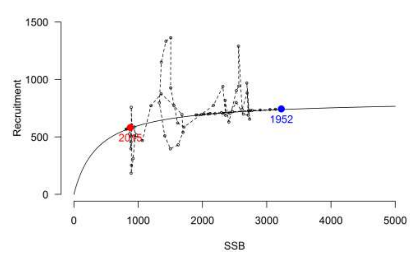
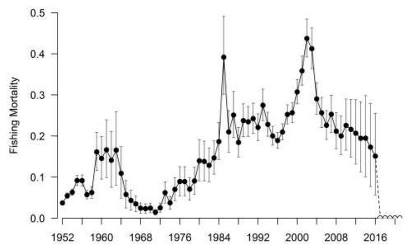
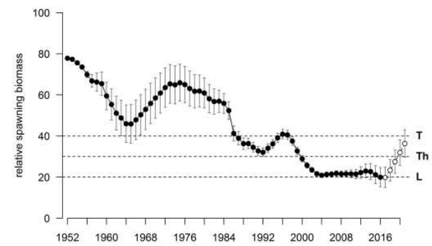
	Annual recruitment	Stock recruitment relationship
Base case model: fitted to CPUE data (proj. 300 t)		

Figure 9.13. Estimated annual recruitment trend and stock recruitment relationship (with assumed steepness = 0.75) when fitting the integrated model to the available catch rate data (based case model). The estimated recruitment and biomass values for each year, after accounting for recruitment deviations, are overlaid on the stock-recruitment plot, with the respective values for 1952 and 2016 highlighted.

<table>
<tr><th></th><th>Fishing mortality</th><th>Relative spawning biomass</th></tr>
<tr><td>Base case model: fitted to CPUE data (proj. 1 t)</td><td>
</td><td>
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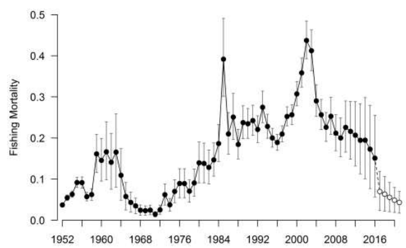
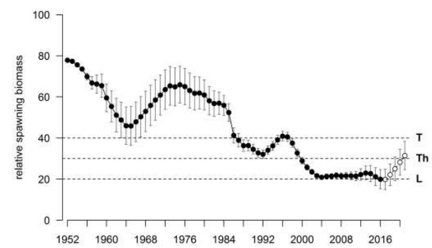
<tr><td>Base case model: fitted to CPUE data (proj.100 t)</td><td>
</td><td>
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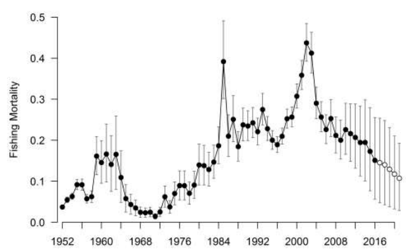
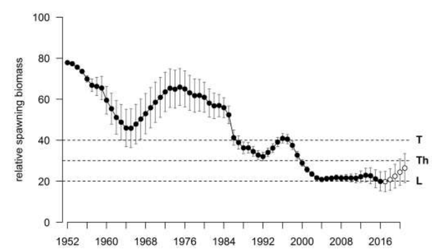
<tr><td>Base case model: fitted to CPUE data (proj. 200 t)</td><td>
</td><td>
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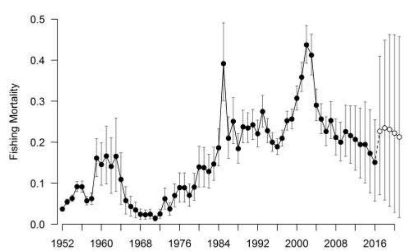
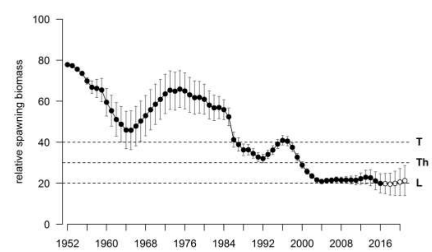
<tr><td>Base case model: fitted to CPUE data (proj. 300 t)</td><td>
</td><td>
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Figure 9.14. Estimated annual trends in fishing mortality and relative female spawning biomass, when fitting the integrated model to the available catch rate data (based case model). Results are presented for 5-year model projection periods assuming constant catches of 1, 100, 200 or 300 t.

There are various ways in which uncertainty is included in the analysis. The variation in the calculated commercial catch rates is incorporated into the integrated model, which also allows for additional variation when fitting to the catch rates. Sensitivity analyses have also been conducted for varying values of natural mortality, steepness and catch level (not presented here). Confidence intervals are calculated for all parameters of interest estimated in the model, and these estimates of uncertainty to quantify the probablity that spawning biomass lay above the defined reference ponts for that primary performance indicator.

9.13 Stock Status Summary

Presented below is a summary of each line of evidence considered in the overall weight of evidence assessment of pink snapper (oceanic stock) and goldband snapper that are the two key indicator species that comprise the Gascoyne Demersal Scalefish Resource, followed by the management advice and recommendations for future monitoring of the species.

9.13.1 Pink Snapper

9.13.1.1 Weight of Evidence Risk Assessment

Category	Lines of evidence (Consequence/Status)
Catch	Currently ~80% of the total retained catch of pink snapper (oceanic stock) in the Gascoyne Coast Bioregion (GCB) is taken by the commercial Gascoyne Demersal Scalefish Managed Fishery (GDSMF). While there is little information on retained recreational catches prior to the early 1980s, catches were likely <10 t per year. Retained recreational catches over the last two decades have been ~20-25 t and charter catches ~10-20 t. Commercial snapper fishing in the region dates to the early 1900s. Catches rose steadily to reach ~200 t by 1950 and then varied between ~100-400 t during the 1960s-1970s. An increase to an all-time peak of ~1,300 t in 1985 triggered creation of a limited entry managed fishery in 1987. Catches in the 1980s-1990s ranged from ~450-550 t. The fishery became fully quota managed in 2001 with a Total Allowable Commercial Catch (TACC) initially set at 564 t. Following the first integrated age-based assessment in 2002, that indicated that the spawning stock had been reduced to below the threshold level (30% unfished biomass) following nearly a decade of below average recruitment, the TACC was reduced in 2003 from 564 t to 338 t and then again in 2007, to 277 t, to assist stock rebuilding. For operational and economic reasons, the entire TACC cannot be caught in a quota season. Hence, while TACC is currently set at 277 t, the landed catch in recent years between 230-240 t has been considered the level where the TACC has effectively been reached. Catches of 196 t landed in 2014/15 and 150 t in 2015/16 were substantially lower than this. Preliminary analysis of CDRs indicates that landed catch in the 2016/17 season will be ~130 t, i.e. the lowest on record. Discussions with fishers at the end of the 2015/16 quota year provided anecdotal information for the recent low catches, including low fish abundance, loss of experienced skippers to the fishery, changes in fishing operations, low peak season prices leading to decreased effort, increased interaction with sharks and current management arrangements (minimum debit rule). **Catches in the two most recent quota seasons, i.e. 2014/15 and 2015/16, and based on preliminary information, in the 2016/17 season, provide some indication of unacceptable stock depletion.**
Catch distribution	Most of the pink snapper catch is taken over inshore reefs to the north and west of islands that bound Shark Bay during winter months (June-August) when snapper aggregate to spawn. While the spatial distribution of commercial catches changed over the period of the fishery's earliest development, it has not changed substantially over the last three decades. Anecdotal information from commercial fishers suggests that fish still aggregate on the same reefs as have historically been fished since the 1980s. Spatial analysis of daily logbook data since 2008 provides no evidence of marked expansion/contraction in areas fished in recent years. Charter vessels operate in some of the areas where the commercial fleet operates, whereas most recreational fishing tends to occur closer inshore, nearer the ports of Carnarvon and Denham. More recent anecdotal information from some commercial fishers suggests sharks are disrupting snapper fishing at some

	traditional locations to a greater extent than is usual such that the total area fished during the peak season may have contracted in recent years. **Catch distribution over the past 30 years provides no indication of any marked expansion/contraction in areas fished in recent years and is therefore not indicative of unacceptable stock depletion**
Catch rates	For assessments undertaken 2002-2016, commercial pink snapper catch rates were estimated using the “Moran method”, which only includes vessels that catch >4 t during June-July when snapper are aggregated to spawn. Since the TACC reductions in 2003/04 and 2006/07, mean catch rates calculated using the Moran method exhibited an increasing trend, and were taken to indicate that the stock was slowly rebuilding. However, a recent review of this catch rate analysis has identified high uncertainty (i.e. large confidence intervals) in the calculated mean catch rate and therefore overall trend in catch rates. For this current assessment (2017), monthly CAES data (1990-2007) and daily logbook data (2008-present) were standardised using generalised linear modelling (see Appendix 2). Exploration of alternative effort measures available in the daily logbook data (e.g. number of hooks per line, number of hours and lines per fishing session) indicated an appropriate measure of effort is line hours, adjusted for the effects of number of hooks and other variables (spatial block, month and skipper/vessel). Monthly and daily catch rate time series were also adjusted for estimated increases in historical fishing efficiency associated with new technology (e.g. hydraulic reels, GPS, colour sounders) and assumed recent reductions in efficiency associated with increased shark depredation (as reported by industry). The annual standardised catch rate for 1990-2008 (monthly CAES data) after adjusting for changes in fishing efficiency, exhibits a gradual, progressive decline, from ~400 kg/day in 1990 to ~200 kg/day in 2008. The annual catch rate for 2009-2016 (daily logbook data) increases progressively from ~ 17 kg/line/hour in 2009-2010 to ~24 kg/line/hour in 2012 before declining progressively to just below 10 kg/line/hour in 2016. Importantly, it is unknown if the available fishery dependent, multi-species catch rate data (monthly CAES and daily logbook) based on fishing directly on spawning aggregations during the peak provides a reliable index of abundance for oceanic pink snapper. However, CPUE trends for oceanic pink snapper caught outside the aggregation period are not dissimilar although these still consist as fishery dependent, multi-species catch rate data. **Catch rates provide some indication of unacceptable stock depletion in recent years.**
Vulnerability (Productivity Susceptibility Analysis [PSA])	Pink snapper in the Gascoyne are moderately long-lived (maximum recorded age ~30 years). Individuals typically mature at ~340-380 mm TL and ~3-4 years of age. As the current minimum legal length (MLL) of 410 mm TL is higher than that at which fish typically mature, this management measure provides limited protection to the breeding stock. Most commercial fishing for pink snapper is concentrated on spawning aggregations over a relatively small area (during the spawning season) compared with the full spatial distribution of the oceanic snapper stock (outside the spawning season).

	With a productivity score of 1.86 and susceptibility scores ranging between 1.43 and 1.88 for the different fisheries/sectors that target the Gascoyne stock, the derived PSA score is 2.64 (MSC score = 80). **This level of vulnerability would indicate that unacceptable stock depletion is possible if there was no effective management of the fisheries in the region**.
Age composition	Fishery-dependent age composition data collected since 1992 show that pink snapper catches in the GDSMF have primarily comprised relatively young fish between 4-8 years of age. These samples indicate the lack of older fish between 8-30 years suggesting that the population has experienced high levels of exploitation over several decades. While samples of fish aged between 4-8 years provides evidence of regular annual recruitment into this stock over the last 4-8 years, the very low numbers of fish 3-4 years of age in 2015 suggests relatively poor recruitment derived from the 2011 and 2012 spawning seasons. During those years, fish in Gascoyne region experienced very high water temperatures associated with an extreme marine heatwave event that may have negatively impacted recent recruitment. **Age composition provides some indication of unacceptable stock depletion in recent years and there is some evidence of recent lower recruitment possibly associated with the effects the marine heatwave event.**
Fishing mortality	Estimates of fishing mortality (*F*) are available from an equilibrium, catch curve assessment (L3), and a dynamic integrated model assessment (L5). For all analyses, natural mortality (*M*) was assumed as 0.144 year^{-1} for pink snapper (oceanic). Catch curve: The point estimate of *F* from catch curve analysis using a logistic age-based selectivity was 0.49 year^{-1} in 2014/15. As this *F* estimate is substantially higher than *M*, this indicates that the population has experienced much higher than target levels of exploitation. Integrated model: two (2) scenarios were considered: I. Integrated model fitted to commercial catch rate data, total catches and age composition data (S1 - base case integrated model scenario): Between 1952-1970, estimates of annual *F* ranged from close to zero to just above *M*. *F* progressively increased from just above zero in 1970 well above *M* (~0.2 year^{-1}) in 1984. Subsequently, *F* is estimated to have remained at ~0.2 year^{-1} before declining to ~ *M* (0.144 year^{-1}) in 2016. The high *F* values indicate overfishing in recent years; although there is a decline in *F* in the last couple of years, the confidence intervals are wide. II. Integrated model not fitted to commercial catch rate data however fitted to total catches and age composition data (S2 - alternative integrated model scenario): Between 1952 and 2004, the trend in annual *F* estimates are essentially the same, regardless of whether or not the model was fitted to catch rate data. The trends diverge after 2004, with *F* progressively decreasing from ~0.2 year^{-1} to below 0.1 year^{-1} (*i.e.* well below *M*) in 2016, coinciding with reduced catches in recent years. The low *F* values indicate rebuilding in recent years.

	The results of equilibrium-based catch curve analyses and dynamic integrated modelling incorporating commercial catch rate data both provide some indication of unacceptable stock depletion in recent years. **In contrast, results of dynamic integrated modelling excluding commercial catch rate data provide some indication of rebuilding of the stock in recent years.**
Spawning biomass	Per-recruit estimates of female spawning potential ratio (SPR), based on the catch curve estimate of F (0.49 year^{-1}) ranged between 0.26 and 0.19 in 2015 (Appendix 3). Applying a 25% mortality of undersized fish that are returned to the water, estimates of SPR ranged between 0.18 and 0.11, which are below the limit level (20%SPR). Age-based integrated model conditioned on catch fitted to commercial catch rate data and age composition data (base case integrated model scenario 1): The point estimates for relative female spawning biomass (i.e. current/unfished level) declined from ~80% in 1952 to ~ 20% in 2004, and then remained at this level until 2016 (Appendix 5). These indicate the level of spawning biomass is at the limit level (B_{20}). Integrated model conditioned on catch not fitted to age composition data only (base case integrated model scenario 2): The earlier trend in the relative female biomass estimates is virtually the same as for when the model was fitted to catch rate data (as above). The trends diverge around 2004, after which, for the model not fitted to catch rate data, relative female spawning biomass increases progressively to reach the threshold level (B_{30}) in 2013, and remains at about this level until 2016. **The results of equilibrium-based catch curve analyses and dynamic integrated modelling incorporating commercial catch rate data both provide some indication of unacceptable stock depletion in recent years.** **The results of dynamic integrated modelling excluding commercial catch rate data provide some indication of rebuilding of the stock in recent years.**

Pink snapper (Gascoyne oceanic stock) risk matrix					
Consequence (stock depletion) Level	Likelihood				
	L1 Remote (<5%)	L2 Unlikely (5-20%)	L3 Possible (20-50%)	L4 Likely (≥50%)	**Max Risk Score**
C1 Minor (above target)					NP
C2 Moderate (below target, above threshold)		X			4
C3 High (below threshold, above limit)				X	12
C4 Major (below limit)			X		12

C1 (Minor Depletion): **Not plausible**. No lines of evidence are consistent with the stock currently having only a minor level of depletion.

C2 (Moderate Depletion): **Unlikely L2** – The overall likelihood that there is currently a moderate level of depletion (i.e. stock below target but above threshold) for this stock is Unlikely (L2). This is based on the results from the integrated model where commercial catch rates were excluded (S2). This estimated that fishing mortality would be decreasing and spawning biomass increasing such that the stock is continuing to rebuild, albeit more slowly than previously estimated, but still could now be above the threshold. The likelihood is however downgraded based on the results of the integrated model where commercial catch rates are included (S1) which suggest that there is minimal likelihood of stock being above the threshold. Similarly, the recent low catches are also inconsistent with the stock currently being above the threshold.

C3 (High Depletion): **Likely L4** – Multiple lines of evidence including recent commercial catches well below the TACC, marked declines in commercial catch rates, age structures with very few old fish (with possible impacts of marine heatwave on recent recruitment), high estimates of fishing mortality and low estimates of SPR/relative biomass from catch curve analysis and integrated model assessments for S1 (commercial catch rates included) suggest there is a **Likely** (L4) likelihood that the stock has experienced a high level of depletion (i.e. stock is below threshold but above the limit). Even the outputs from the integrated model results where commercial catch rates are excluded suggest that the stock may still be below the threshold.

C4 (Major Depletion): **Possible L3** – A number of lines of evidence including recent commercial catches well below the TACC, marked declines in commercial catch rates, age structures with very few old fish (with possible impacts of marine heatwave on recruitment), high estimates of fishing mortality and low estimates of SPR/relative biomass from catch curve analysis and integrated model assessments for S1 (commercial catch rates included) suggest that it is **Possible** (L3) that the stock has experienced a major level of depletion (i.e. stock is below the limit). The only line of evidence that suggests a major level of stock depletion is unlikely is from the integrated model results for S2 (commercial catch rates excluded).

The current risk level for the oceanic pink snapper stock is estimated to be **Severe** (C4 × L3). This is **unacceptable** and **requires additional management action** in the immediate future to reduce the risk to an acceptable level (see Appendix 2).

9.13.1.2 Previous Assessments – Pink snapper

During the early decades of the fishery, i.e. 1950s to 1980s, prior to the introduction of formal management in 1987, while the commercial catches were monitored, no formal stock assessments were undertaken. Between 1987 and 2000, a nominal TACC of 550 tonnes applied, and the fishery was managed using a mix of individual quotas and effort controls (e.g. fishing closure in June-July). The first quantitative assessment of the oceanic pink snapper stock and associated fishery was an MSY-type assessment completed in 1986 (Moran *et al.* 2005). Based on this assessment, a TACC of 563.7 tonnes was introduced in 2001 and the fishery managed entirely by quota. The fishery was monitored each year using the catch rates during the peak season (June-July). It was recognised that a more robust stock assessment of the oceanic stock that could also incorporate recreational catches (thought at that time to be around 10 tonnes per year) was required.

In 2002, an integrated age-structure model was developed for the first time, to assess the status of the oceanic stock (Oceanic Pink Snapper Assessment June 2003). In 2004, a cohort analysis (using Pope's approximation) was undertaken and the integrated age-structured model updated (Moran et al. 2005). The cohort analysis estimated the numbers of fish at age removed from the stock 1982-2003; for years where no age data were available, numbers at age were imputed (Moran et al. 2005). The same catch-at-age data were used in both approaches with a high level of agreement found between the results from the two methods. The outcomes of these assessments indicated that that the stock had become depleted (i.e. below the threshold level) and were consistent with a marked decline observed in CPUE. Following discussions with industry, the TACC was reduced by approximately 40% in 2003/04.

In 2006, the integrated age-structured model was updated (revised sampling strategy for age composition data based on recommendations in Moran et al. 2005 adopted from 2004 onwards) with the addition of catch and catch rate data from the period 2004-2006. This assessment indicated that the spawning biomass had declined from 1997 to 2005, and that the median value was at 27% of the 1952 level (target level: 40% of that in 1952, limit level 30% of the 1952 level). The assessment indicated that with a TAC of 250 tonnes (all sectors), the median value of the spawning biomass would be expected to rebuild to the target level by 2014. Recreational daily bag limit of oceanic pink snapper was reduced from 6 to 4 in January 2016.

A review of the 2006 model-based assessment was undertaken by David Gilbert from NIWA, New Zealand (see Appendix 5). The main points of discussion were the level of natural mortality used, the steepness of the stock-recruitment relationship, and the method of calculation of the catch rate. The model had used the method of calculation CPUE referred to as the 'Moran method' (Moran et al. 2005). Gilbert applied an alternative approach that used the catch and effort by vessel as inputs to a GLM based statistical analysis to determine standardized catch rates. Using a similar methodology, the Department also re-calculated catch rates with no significant differences between the approaches. Following discussions with industry, in January 2007, there was strong agreement to adopt the 'Moran method' for estimating CPUE as it was easy to understand (by industry) and unlike the GLM method of calculation, was more consistent with the previous values when new data points are added to the dataset.

During these same discussions with industry (late 2006 to early 2007), when the stock assessment methodology was being heavily scrutinised, concerns were raised in relation to under-reporting of pink snapper catches and leakage (catch landed illegally at port of Kalbarri) such that the data available likely represented underestimates of true catches in each year and that the overall mortality had been significantly greater than the stock assessment model was allowing for. Based on documents available, the Department attempted to quantify the effects on the time series of commercial snapper catches attributable to a range of factors including drip loss, high grading, wetline fishing mortality and 'leakage' out of Kalbarri. These were then presented to industry leaders for comment and subsequently used to develop two different time series of catches for the fishery, a 'base case' and a 'modified' case that were incorporated in the updated model in January 2007. Based on this assessment, the TACC was reduced to 297 tonnes for the 2006-07 season and subsequently further reduced to 277 tonnes for the 2007/08 season. Given the management arrangements and trends in effort at that time, the catch from the other sectors (recreational and charter) were assumed to be in the range of 50-60 tonnes per year at that time.

In 2009, the age-structured statistical model was re-run with the addition of 2007 and 2008 catch and catch rate data, and age-composition data for 2007 and 2008. In addition, the model incorporated information on length-age relationship by sex and improved length at sexual maturity from research by Wakefield (2006). The new data indicated snapper mature at a smaller length than that incorporated in the previous assessment. The assessment indicated that with a total catch in the fishery of around 303 tonnes, the median value of the spawning biomass would be above the target level by 2015. This assessment assumed there was a snapper catch prior to 1952. In the 2009 assessment only age-composition data from the years actually sampled were used. The age structured model was re-run again in 2011 and 2014 (assessment included catch, catch rate and age-composition up to 2012/13 season) and most recently in 2017 (see 9.3.9.3 for details).

Catch and commercial catch rate of pink snapper will be routinely monitored and an updated assessment (integrated model) will be completed in 5 years (i.e. 2022). Additional research will be undertaken to address areas of greatest uncertainty in the assessment, in particular, questions around the fishery-dependent catch rates, low recruitment in recent years and impact of sharks on stock abundance and behaviour of snapper in spawning aggregations.

9.13.2 Goldband Snapper

9.13.2.1 Weight of Evidence Risk Assessment

Category	Lines of evidence (Consequence/Status)
Catch	Around 70-80% of the current total catch of goldband snapper in the Gascoyne Coast Bioregion (GCB) is taken by the commercial Gascoyne Demersal Scalefish Fishery (GDSF). Commercial catches of goldband snapper reported through the 1980s-1990s were low (< 10 t) and mostly incidental with line-fishing vessels mainly targeting pink snapper and other inshore demersal species in waters ~30-80 m depth. Goldband snapper catches increased rapidly from around 1998/99 as vessels moved offshore to fish deeper waters (~100-250 m), peaking at ~300 t in 2003/04. Given this rapid increase, and sustainability concerns around the vulnerability of deeper water species, management measures were introduced in 2009 to reduce effort in offshore deeper waters. Goldband catches subsequently decreased to ~100 t by 2005/06 and have since ranged between ~50-100 t. The commercial catch in 2015/16 was 43.6 t. Historical recreational catches are unknown but are unlikely to have been significant as the species is found in deeper offshore waters that were not routinely accessed by recreational vessels in the past. The most recent estimate of recreational boat-based catch in the GCB was 14.7 t in 2013/14 and charter catch reported in 2015/16 was 8.2 t. **As the reductions in catch of goldband snapper in recent years are due to management actions taken to manage this and other deeper-water species, there is no indication of unacceptable stock depletion within the catch data.**
Catch distribution	Goldband snapper are associated with limited areas of suitable habitat type, i.e. hard structure with vertical relief in waters ~80-150 m depth. As commercial fishers began targeting deeper water species, the spatial distribution of commercial catches was observed to expand over a relatively short period from the late 1990s to the mid-2000s but has been stable over the last decade. Goldband are a minor component of the total recreational catch in the GCB and the species was only recorded during recreational boat ramp surveys for first time in 2007/08. **Following development of the fishery in deeper waters of the Gascoyne, there is no indication that current catch levels have been maintained by a subsequent progressive shifting of the areas fished that would be indicative of unacceptable stock depletion.**
Catch rates	Daily logbook data (2008-present) were subjected to a formal standardisation procedure (generalised linear modelling) to account for unbalanced data and thereby provide more reliable estimates of the annual mean catch rate values and associated uncertainty. Following exploration of alternative effort measures based on all variables available in the daily logbook data (e.g. number of hooks per line, number of hours and lines per fishing session), the recommended measure of effort for the daily logbook data is line hours, adjusted for the effects of number of hooks and other variables (spatial block, month and skipper/vessel). The annual catch rate for 2009-2016 (daily logbook data) fluctuated between ~ 10 and 15 kg/line/hour. There is a high level of uncertainty whether the available fishery dependent, multi-species catch rate data (CAES and daily logbook) can be used to provide a reliable index of abundance for goldband snapper. **The lack of a marked upward or downward trend in annual catch rates from 2009-2016 (daily logbooks), suggesting there is no indication of unacceptable changes to stock abundance during this period.**

Vulnerability (Productivity Susceptibility Analysis [PSA])	Goldband snapper have a relatively long lifespan (~30 years) and mature at ~5 years of age. With a productivity score of 1.71 and susceptibility scores ranging between 1.43 and 1.88 for the different fisheries/sectors that target the Gascoyne stock, the overall derived PSA score is 2.53 (MSC score > 80). **This level of vulnerability would indicate that unacceptable stock depletion could be possible if there was no management of the fishery in this region.**
Age composition	The most recent age composition of samples for goldband snapper collected from the GDSF catches in 2010/11 and 2012/13 contains a large number of relatively old individuals (>15 years) up to a maximum of 28 years of age, close to the maximum recorded age of this species in the GCB of 30 years. This indicates that this stock has only been lightly exploited. The distribution of ages in these samples suggests that this species exhibits considerable variation in annual recruitment between years. **The age composition data from the most recent samples provide no evidence of recruitment impairment.**
Fishing mortality	Assuming a value for natural mortality of 0.164 year^{-1} for goldband snapper, the point estimate of fishing mortality (F) produced by a catch curve analysis that accounts for variable recruitment by fitting simultaneously to the age composition data for 2010/11 and 2012/13 was 0.018 year^{-1}. Due to the equilibrium assumptions of catch curve analysis, the F estimates reflect the fishing mortality experienced, on average, by all fish in the sample. As these F estimates are less than the $F_{40\%SPR}$ (target level) of 0.13 year^{-1}, this suggests that, on average, the level of exploitation experienced by Gascoyne goldband snapper over the past two decades (since the fishery developed) has been low. **The estimates of *F* provide no evidence of unacceptable exploitation.**
Spawning biomass (Spawning Potential Ratio)	Point estimates of female spawning potential ratio (SPR) derived from per-recruit analysis and an extended analysis (equilibrium age-structured model accounting for possible impacts of fishing on recruitment), based on catch curve estimates of F and selectivity-at-age parameters from 2010/11 and 2012/13, were 0.86 and 0.84, respectively. It is assumed that there is no discarding of this species as there is no MLL. Accounting for uncertainty in estimates of F, there is a 100% probability that the stock is above the target level of 0.4 at the time of most recent sampling. **Estimates of SPR provide no evidence of unacceptable stock depletion.**

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

C1 (Minor Depletion): **Likely L4** – With estimates of female SPR (and associated 95% confidence intervals) for goldband snapper well above the target level of 40%SPR, and as catches have remained relatively stable over the past decade, it is likely that goldband snapper has only experienced minor depletion in the Gascoyne.

C2 (Moderate Depletion): **Unlikely L2 –** Although the catch history demonstrates that the stock experienced a short period of relatively high catches (~300 t), SPR analyses demonstrated with a high probability that the stock level at the time of sampling was above the threshold level of 30%SPR (i.e. B_{MSY}). As catches have remained at around 50-100 t over the past decade, it is unlikely that the stock has since been depleted to below this level and may have increased.

C3 (High Depletion): **Remote L1** – All of the lines of evidence suggest that there is only a remote likelihood of the stock being depleted below B_{MSY}.

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

The current risk level for the goldband snapper stock is estimated to **Low** (C1 × L4) (see Appendix 1).

The current status of the goldband snapper stock is **acceptable** and the current management settings are **adequate.** As goldband snapper is an indicator species, this means the current status of all other demersal species can be considered acceptable and the current management settings are adequate.

Catches of goldband snapper will routinely monitored and updated assessment (F/SPR) will be completed in ~ 5 years (2021-2022).

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11 Appendix 1

Justification for Harvest Strategy Reference Levels

The performance indicator used to evaluate the stock status of indicator species in the Gascoyne is spawning biomass (*B*), or an appropriate proxy (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).

Table A1.1. Performance indicators and associated reference levels used to evaluate the status of indicator species and secondary indicator species in the Gascoyne

	Reference Levels		
Performance Indicator	**Target**	**Threshold**	**Limit**
Spawning biomass (*B*)	B_{40}	B_{30}	B_{20}
Spawning potential ratio (SPR)	SPR_{40}	SPR_{30}	SPR_{20}
Fishing mortality (*F*), relative to natural mortality (*M*)	2/3*M*	*M*	1.5*M*

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_{MEY}) 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 Potential of gear to retain species	a) Individual < size at maturity are rarely caught	a) Individual < size at maturity are regularly caught	a) Individual < size at maturity are frequently caught
	b) Individual < size can escape or avoid gear	b) Individual < half the size can escape or avoid gear	b) Individual < half the size are retained by gear
Post-capture mortality i.e. the chance that, if captures, a species would be released and that it would be in a 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

14 Appendix 4

Description of Age-Structured Integrated Model

This section provides a detailed mathematical description of the age-structured integrated model (see Table A4.1 for symbols) used to assess the status of the oceanic pink snapper stock in the Gascoyne.

Table A4.1. List of symbols, parameters, input data and derived variables used in the model

Symbols		
s	Sex	
y	Year	
y_Ω	First year	
y_Ψ	Last year of data	
a	Age (years)	
A	Maximum age (years)	
$N_{a,y}^{s}$	Number of fish in the population	

Parameters		
L_∞, k, t_0	von Bertalanffy growth parameters (mm FL, year^{-1} and years, respectively)	Pre-specified:
$\omega_1\ \omega_2$	Median and inflection point of female maturity ogive	Pre-specified:
$F_{p,y}$	Annual rate of fishing mortality (year^{-1}) in year *y*	Estimated.
M	Natural mortality (year^{-1})	Pre-specified
h	Steepness parameter	Pre-specified
σ^R	Recruitment deviation standard deviation	Pre-specified
ε_y	Recruitment deviations	Estimated with penalty $\varepsilon_y \sim N\left(0, \sigma_R^2\right)$
R^I	Initial recruitment	Estimated
a, b	Weight-at-length (kg, mm)	Pre-specified
q_1	Catchability (monthly CAES data)	Estimated
q_2	Catchability (daily logbook data)	Estimated
l_{50}	Length at 50% vulnerable	Estimated
l_s	Slope of vulnerability ogive	Estimated
F_0	Initial fishing mortality prior to first year	Pre-specified

Table A4.1. Continued

Input data variables	
$U_{p,y}$	Catch rate
$C_{p,y}$	Observed catch (t)
σ_y^U	Catch rate standard error
$C_{p,y,a}^A$	Catch in numbers-at-age

Derived quantities	
α_p, β_p	Beverton and Holt recruitment parameters
$R_{p,y}$	Annual recruitment
ω_a	Female maturity
v_a^s	Vulnerability to capture
$\hat{C}_{p,y,a}^A$	Model estimated catch in numbers-at-age
$F_{p,y,a}$	Fishing mortality at age a in year y
$Z_{p,y,a}$	Total mortality (year^{-1}) at age a in year y
$S_{p,y}$	Spawning biomass (mass of sexually mature females)
$\rho_{p,y,a}$	Observed proportion at age n year y and age a
$\hat{\rho}_{p,y,a}$	Model derived proportion at age a in year y
ϕ	Over-dispersion parameter

Weight at age

The weight-at-age vectors for each sex s are assumed to be known without error and are calculated from published length-at-age and weight-at-length relationships.

Sexual maturity of females at age

The probability ω_a that a female fish of age a (years) is mature is described by the logistic function $\omega_a = 1/\{1 + \exp(-\ln(19)[(a - A_{50})/(A_{95} - A_{50})]\}$, where A_{50} and A_{95} are the ages at which 50 and 95% of fish have attained maturity, respectively. The relationship was fitted outside the model and the parameter estimates were fixed in the model (i.e. assumed to be known without error).

Recruitment

The numbers of annual recruits (thousands of fish, female and male combined) are expected to vary among years due to different environmental conditions. They are also expected to vary according to the stock size. For these species, for which there is a long series of catch data, but short time series of catch rate and age composition data, the most parsimonious description of the relationship between annual recruitment and stock size is the Beverton and Holt stock-recruitment relationship $R_{y+1} = \frac{S_y}{\alpha+\beta S_y}$, where α and β are constants, R_y is the number of 1-year-old fish (both sexes combined) that recruit to the stock in year y and S_y is the spawning biomass of females (tonnes) in year y, i.e. the total biomass of females that are mature at the time of spawning. Note that the model considers only the fish from age 1 year to a maximum age of A years; fish of age 0 years are considered to be unfished and, at that age, cannot contribute to the spawning potential of the stock.

The numbers of fish $\widetilde{N}_a$ at ages a = 1 to A years, in the unfished equilibrium population, are determined as

$$\widetilde{N}_{a+1} = \widetilde{N}_a \exp(-M)$$

where M is the instantaneous rate of natural mortality (year^{-1}) and $\widetilde{N}_1 = R^*$, the initial recruitment when the stock is unfished and at equilibrium. R^* is a parameter that is estimated when the model is fitted to the observed data. The number of fish of age a and sex s may be calculated as $\widetilde{N}_a^s = \rho^s \widetilde{N}_a^s$, where ρ^s is the proportion of 1-year-old recruits that are of sex s.

The spawning biomass (of females) for the unfished equilibrium population is

$\tilde{S} = \sum_{a=1}^{A} \rho^f W_a^f \widetilde{N}_a^f \, \omega_a$ and from the stock-recruitment relationship, $R^* = \frac{\alpha\tilde{S}}{\alpha+\beta\tilde{S}}$.

The values of the Beverton-Holt stock-recruitment parameters, α and β, can be estimated from R^* and $\tilde{S}$ and the steepness h of the stock-recruitment relationship, where steepness is defined as the proportion of the initial equilibrium recruitment that would be produced at equilibrium when the initial unfished equilibrium spawning biomass is reduced to 20% of its initial level.

Thus, for a given value of h, α and β are calculated as $\alpha = \frac{\tilde{S}}{R^*}\left(1 - \frac{h-0.2}{0.8h}\right)$ and $\beta = \frac{h-0.2}{0.8h \quad {}^*}$.

At the beginning of the first year considered within the model, the population is assumed to be at an exploited equilibrium, with a fishing mortality for fully-vulnerable fish of F_{I}. The vulnerability of fish of age a years is denoted by v_a, and is described by the logistic function $v_a = 1/\{1 + \exp[v_1(a - v_2)]\}$ where v_1 and v_2 are estimated parameters for the slope and inflection point, respectively. It is assumed that the harvest ratio for fish of age a is $F_{\mathrm{I}}a$. For each 1-year-old recruit to the initial population, the expected number of fish surviving to ages $a = 1$ to A in the initial population is given by

$$\breve{N}_a = \begin{cases} 1 & \text{for } a = 1 \\ \exp\left(-(M + F_{\mathrm{I}} v_a)(a-1)\right) & \text{for } 2 \le a \le A \end{cases}$$

The spawning biomass of females per 1-year-old recruit of this equilibrium population with exploitation F_{I} is therefore given by $\breve{S} = \sum_{a=1}^{A} \rho^f \, W_a^f \, \breve{N}_a \omega_a$. Using this, an estimate of the numbers of fish at age a = 1 in the initial population may be calculated.

Population dynamics

Let us denote the first and last years for which there are data as y_Ω and y_Ψ, respectively, and the number of fish, of sex s and age a, at the beginning of year y, as $N_{a,y}^s$. Then, if the form of the Beverton-Holt stock-recruitment relationship is $R_{y+1} = \frac{S_y}{\alpha + \beta S_y}$, the initial number of 1-year-old fish of sex s at the beginning of year y_Ω is $N_{1,y}^s = \rho^s \left[\frac{\breve{S} - \alpha}{\beta \breve{S}}\right]$.

The initial number of a-year-old fish at the beginning of this year may then be calculated as $N_{a+1,y_\Omega}^s = N_{a,y_\Omega}^s \exp(-M - F_{\mathrm{I}} v_a)$.

The annual spawning biomass (of mature females at the time of spawning, i.e. at the beginning of the year) is $S_y = \sum_{a=1}^{A} \rho^f W_a^f N_a \, \omega_a$.

The expected number of 1-year-old fish R_y which were produced by the spawning females in area p, year y, and which will recruit to the fishery in year y+1, was calculated, from the Beverton-Holt stock recruitment-relationship as $R_{y+1} = \frac{S_y}{\alpha + \beta S_y}$.

It is assumed, however, that the annual recruitment varies from the expected value due to natural environmental variation, and that the annual recruitment deviations conform to a lognormal distribution. That is, it is assumed that

$N_{1,y+1} = R_{y+1} \exp(\varepsilon_y - 0.5\sigma_R^2)$ where the 'recruitment deviations' (in log-space) are normally distributed with a mean of zero and specified standard deviation of σ_R. Note that, when calculating the factor by which the expected recruitment is multiplied, an adjustment is made to future deviations to take the inter-annual variability of recruitment into account such that the expected value of the factor is 1.

Although in previous assessments, σ_R was set at 0.2, a higher value, e.g. 0.6, has been recommended as appropriate for teleosts (Smith and Punt 1998, citing the estimates obtained by Beddington and Cook 1983) and thus, in this assessment, σ_R was increased to 0.6. The recruitment deviations ε_y where $\varepsilon_y \sim N(0, \sigma_R^2)$ are parameters that are estimated when fitting the model. The recruitment deviations for the future projection period are assumed to have the same variances of those in the estimation period.

The vulnerable biomass, B_y, is given by $B_y = \sum_s \sum_{a=1}^{A} N_{a,y}^{s} \exp(-MW_a v_a)$, where the vulnerability to capture v_a at age is described by the logistic function

$$v_a = 1/\{1 + \exp[v_1(a - v_2)]\}$$

where v_1 and v_2 are estimated parameters for the slope and inflection point, respectively.

The instantaneous rate of fishing mortality in year y is calculated as $F_y = -\ln(1 - H_y)$, where H_y is the annual harvest rate, calculated as $H_y = C_y/B_y$.

The number of animals surviving after natural and fishing mortality is then calculated as $N_{a+1,y+1}^{s} = N_{a,y}^{s} \exp\left(-v_a H_y M\right)$ for a = 1, 2, … $A - 1$.

The estimated catch rate is then be calculated as $\overline{U}_y^1 = q_1 B_y$ for the monthly CAES catch rate data and as $\overline{U}_y^2 = q_2 B_y$ for the daily logbook data.

Parameterization and objective function

The parameters of the population dynamics model are either pre-specified or freely estimated. The list of all of the parameters of model, both pre-specified and estimated, is shown in Table A4.1.

Natural mortality is assumed not to vary over time from the first year y_Ω to last year y_Ψ, for which catch data are available. *M* is pre-specified and the vulnerability at age is based on constant selectivity, noting that over time there have been no management changes to either minimum or maximum legal size over the assessment period (although it is possible that growth could have changed).

There are three components that contribute to the overall log-likelihood in the objective function

A. age-composition negative log-likelihood: L^A

B. penalty for the annual recruitment deviation parameters: L^D

C. catch rate log-likelihood: L^U

The approach is based on the assumption that the observed age-composition $C_{a,y}^{A}$ represent a multinomial sample of the catches-at-age (Hasselblad 1966), i.e.

$$L^A = -\emptyset N_y \sum_{a=1}^{A} \sum_{y=y_\Omega}^{y=y_\Psi} p_{a,y} \ln\left(\hat{p}_{a,y}\right)$$

where $\emptyset$ is the over-dispersion multiplier calculated applying the data weighting routine of McAllister and Ianelli (1997), N_y is the observed sample size in year y, and $p_{a,y}$ and $\hat{p}_{a,y}$ are the observed and model-estimated proportions at age, given by $p_{a,y} = \frac{C^A_{a,y}}{\sum_a C^A_{a,y}}$ and $\hat{p}_{a,y} = \frac{\sum_s N^S_{a,y} v_a}{\sum_s \sum_a N^S_{a,y} v_a}$. In the years where no age sample was collected, $N^S_{a,y}$ and thus $L^A = 0$.

The component of the objective function for the recruitment deviations is

$L^D = \frac{\varepsilon^2_y}{\sigma^2_R} + 0.5\ln(2\pi\sigma^2_R)$.

Negative log likelihoods, L^U, were calculated separately for the two catch rate series (monthly CAES data and daily logbook data) as

$$L^U = \sum_{y=y^F}^{y^L} \frac{\left[\left(\ln(U^A_y) - \ln(\hat{U}^A_y)\right)\right]^2}{2\left((\sigma^A_y)^2 - (\sigma^U)^2\right)} + \ln\left[2\pi\left((\sigma^A_y)^2 - (\sigma^U)^2\right)\right]$$

where $\hat{U}^A_y$ is the model determined catch rate given by $\hat{U}^A_y = \frac{B_{y,a}}{q}$, σ^A_y is the calculated standard error for the estimate of U^A_y which was determined when standardizing the catch rate, and which represents the measurement error for this "observed" value, adjusted for the efficiency increase. and σ^U is the additional standard deviation for the process error, estimated as a model parameter, and y^F and y^L are the first and last years in the catch rate time series. A penalty, implemented using the posfun function in AD Model Builder, was added to robustify the model by preventing negative values of stock biomass when the model is being fitted.

The overall objective function is $L^A + L^D + L^U + Pen$.

15 Appendix 5

Review of Shark Bay Oceanic Snapper Stock Assessment

For: **Western Australian Marine Research Laboratory**

Department of Fisheries

Government of Western Australia

By: **D. J. Gilbert**

National Institute of Water and Atmospheric Research

New Zealand

Date: **26 June 2006**

Summary

I carried out a review of a stock assessment of the oceanic stock of snapper (pink snapper *Pagrus auratus*) off Shark Bay at the Western Australian Marine Research Laboratory between 12th and 16th June 2006. The original assessment indicated that the population had been declining in recent years and was now well below its target level of 40% of virgin size. I made various checks on the input data and the model structure, which led to changes and a new "Base case" run. A series of runs was carried out in which sensitivity to various assumptions was estimated. This model has many small differences from that of the original assessment, but their net effect is not to change the results a great deal. In my view the new Base case, which is broadly similar to the original assessment, gives a good estimate of the current state of the stock and expected stock sizes under various projected catches.

In my view the Base case steepness parameter is too low and the Base case natural mortality rate is too high, but these inaccuracies cancel. In the sensitivity runs we changed each parameter to what I consider to be more reasonable values. Increasing steepness to h=0.9 made the assessment more optimistic and reducing natural mortality to M=0.08 y^{-1} made it less so. If these two changes were made together their effects would approximately cancel and take us back to the Base case and the original assessment results. Therefore, I think that the Base case results could be used as a basis for decision making.

I consider the target and limit biomasses and the time to rebuild to be questions of management choice. I do not believe that there is any increased risk of catastrophic recruitment failure at the

current stock size. However, the target of 40% virgin stock size has the benefits of high catch rates and of lesser ecosystem disturbance, both of which are valid goals. Time to rebuild is a question of balancing short term pain with long term gain. Alternative scenarios should be discussed with fishers. A sequence of small changes instead of a few large jumps may be less economically disruptive and therefore more acceptable. The model should be used to obtain projections under alternative catch scenarios and Monte Carlo Markov chains should be used, preferably with $h = 0.9$ and $M = 0.08$ y^{-1}, to obtain estimates of the probabilities of particular outcomes under various projected scenarios.

Introduction

I carried out a review of a stock assessment of the oceanic stock of snapper (pink snapper *Pagrus auratus*) off Shark Bay at the Western Australian Marine Research Laboratory between 12th and 16th June 2006. The original assessment had been carried out by Peter Stephenson and Gary Jackson. It indicated that the population had been declining in recent years and was now well below its target level of 40% of virgin size. As a consequence, management action to reduce catch until the stock was rebuilt was under consideration. I reviewed three aspects of the original assessment: the data, the model structure and the sensitivity of the assessment to assumptions. Peter Stephenson and I decided on a "Base case" and I used the results from this and the sensitivity runs to draw conclusions as to the stock status and the expected effects of various future catch scenarios.

Data

There were three data types: the catch history, several years of catch at age estimates and a catch per unit effort (CPUE) abundance index. I was not in a position to investigate the validity of the catch history and assumed it to be accurate. Inaccuracy in the catch history would cause error in the assessment except in so far as a systematic proportional understatement would cause an underestimate in the stock size and sustainable yield of the same proportion. Provided the catch continued to be understated, the assessment would be a valid basis for management decisions.

The catch at age data had several apparent deficiencies. Age class strengths were implausibly regular from year to year, and where there was a strong or weak age class, the data did not show any consistency from one year's estimate to the next. Mean age at length for the 2001–05 sampling was systematically at least one year younger than for the 1991-2000 sampling. It is clear that ageing fish from this population of pink snapper is difficult. I therefore concluded that there was too much inconsistency in these catch at age data and that they should be given little or no weight in the assessment. A consequence of this is that it was not possible to obtain useful estimates of year class strengths or their variability.

The CPUE abundance index had been obtained as the June–July handline catch recorded by high-catch vessels divided by their corresponding number of days fished. These months are the period where fish aggregate to spawn and therefore produce the highest catch rates. I was provided with the catch and effort data (from monthly returns) from the database and confirmed that the index had been correctly calculated. However, I also investigated a better approach to obtaining a CPUE index. Because the make-up of the fleet and the number of crew per vessel may have changed over time, a standardised index is more likely to reliably reflect abundance. I obtained a standardised index by fitting a linear model to the logarithm of monthly catch, with year, vessel, month, days fished and crew number as covariates. The standardised index was then the exponential of the year coefficient. This allowed all months' data to contribute to the index. The inclusion of each of the covariates was highly significant. The pattern of the estimated coefficients was also quite plausible. For example the June and July coefficients gave catch rates three times higher than those of the summer months. Two options for removing non-pink snapper target fishing records were tested; monthly catches of zero or of less than 500 kg were removed. These options also removed records where fishers have, for some reason, recorded catch of pink snapper on separate forms from that of other species, with the effort apparently duplicated. The indices for the two options were very similar and both were similar to the index that had been used in the original assessment. I therefore concluded that there was considerable consistency in the catch and effort data. This lends support to its use to provide an index of abundance.

Model structure

Two models had been used in the original assessment: a cohort analysis and an integrated age-structured model. The method of cohort analysis dates from a time of limited computing capability and requires the strong assumption that the catch at age estimates are without error (a particularly poor assumption here). Its estimates of population size are least reliable for the most recent years. I consider that integrated age-structured models produce more reliable stock assessments. I therefore examined only the age-structured model.

The general approach used in the original assessment was sound, but the model had several undesirable, *ad hoc* features. A number of changes were made to the model structure at my suggestion. The catch equation was simplified to a single, mid-year form, which ensures that the recorded catch weight is exactly removed each year. The model had allowed removals to differ somewhat from the recorded catches for some years. A constant estimated catchability was assumed (the proportionality constant between population size and the CPUE index). It had been assumed that the CPUE index was hyper-stable, i.e. that the index would decline more slowly than the stock when this was high, implying an increasing catchability. A somewhat arbitrary adjustment to catchability had been applied. Arguments can be propounded for both hyper-stability and hyper-depletion hypotheses, as well as for other distortions of a proportional relationship. In the case of New Zealand orange roughy where hyper-stability had been hypothesised, analysis showed that the data tended to support hyper-depletion. In my opinion, unless there is evidence supporting either hypothesis, strict proportionality should be assumed. If hypotheses like hyper-stability are applied, they allow assessments to be made arbitrarily pessimistic or optimistic. Such arbitrariness is undesirable and reduces the credibility of assessments in the eyes of the fishing industry. The vulnerability curve (the relationship between relative probability of capture and age) had been assumed to vary over time. This had been used to help explain earlier estimates in which the most recent catch at age data contained substantially more young fish. The ages in these data had been re-estimated, giving older ages. This fact, together with the problems discussed above regarding the age data meant that a time-variant vulnerability curve was not justified. I therefore proposed that a constant (estimated) vulnerability curve should be used.

During my checking of the model source code, I suggested some minor modifications, which had small effect on the results. As a consequence of these examinations and the effects of these changes I became fairly confident that overall the model had been doing what was intended. Minor changes included: weight at age made consistent with the von Bertalanffy growth curve, stock sizes always reported as mid-year, stock size reported as a percentage of the year prior to fishing (virgin biomass) not the first fished year, mid-year stock sizes applied in the stock recruitment relationship and the CPUE lognormal likelihood corrected so that the expectation of the index was equal to the model prediction rather than expectation of the log of the index being equal to the log of the model prediction. The modified model was run so as to produce estimates of maximum sustainable yield (*MSY*), stock size at *MSY* (S_{MSY}) and the year in which the stock would return to 40% of its virgin size (on average) under various constant future catch regimes.

Model results and sensitivity to assumptions

The third aspect of the original assessment that I examined was the sensitivity of the model estimates to various assumptions. Firstly, a “Base case” was decided on and then individual assumptions were altered to determine the sensitivity of the model to them.

The key Base case assumptions were:

1. Steepness, $h = 0.7$, i.e. mean recruitment at 20% virgin stock size is 70% of mean virgin recruitment.
2. Natural mortality, $M = 0.13$ y^{-1}.
3. Include 1991-2005 age frequency data, but with low weighting.
4. Standardised CPUE index based on monthly catches exceeding 500 kg.
5. CPUE catchability constant.
6. No plus group, i.e. all fish die at their 21st birthday.

7. Vulnerability curve to be logistic and constant.

The results of the Base case run (Figure 1 and Table 1) are similar to those of the original assessment. This appears to be because the standardised CPUE index differs only slightly from that used in the original assessment, the catch at age data were not very influential (partly because they were not internally consistent) and the net effect of all the other changes was small. Historical catches had fluctuated between the start of the fishery in the early 1950s and the early 1980s and the stock had been necessarily reduced from its virgin size. An unusually large annual catch in 1985 saw a sharp decline to about 40% of its virgin size and since then catches have been systematically somewhat higher than the stock could sustain. As a result the stock has gradually declined to around 20% of virgin size. Only in 2004 and 2005 has the annual catch fallen below a sustainable level, the latter year's catch as a result of a lowered TAC. The CPUE index shows a slight increase in these years, which is matched by the model biomass estimates.

The results were moderately sensitive to the steepness parameter (Table 1). In my view the steepness, h = 0.7, used in the original assessment was unduly pessimistic. Whilst many fisheries scientists believe that there is a positive relationship between stock size and recruitment for marine spawning, bony fishes, the evidence for this is weak. Hence the steepness parameter is notoriously difficult to estimate and is generally just assumed. The lowest value used for New Zealand stocks is 0.75 and for snapper h = 1 is assumed (i.e. no relationship). The main effect of the more reasonable assumption of h = 0.9 (run HIH), is that the stock can recover to target 40% somewhat sooner than the Base case predicts for the same level of catch.

In my view the assumed natural mortality rate, $M = 0.13$ y^{-1}, is somewhat too high. The effective mean natural mortality modelled in the virgin stock is even higher because the no plus group assumption implies an infinite mortality rate for the 21-year-olds. The natural mortality parameter is difficult to estimate, but good catch at data from an early period in one New Zealand stock gave an estimate of 0.051 y^{-1}. The environment of Shark Bay is clearly very different and fish there appear to have somewhat lesser longevity. Even though the ageing of these fish is problematic I understand that fish have been aged as old as 30 y, about half the maximum age recorded for New Zealand snapper. Therefore, the combined assumptions of $M = 0.08$ y^{-1} and no plus group seem to me to be reasonable. These assumptions (run LOM) are more pessimistic than those of the original assessment (Table 1).

None of the other sensitivity runs produced results that differed substantially from the Base case and they therefore do not warrant any discussion.

The combined effects of h = 0.9 and M = 0.08 y^{-1} would approximately cancel, producing results similar to those of the Base case. The Base case best estimate of the 2005 spawning stock biomass is 23% virgin size, which is below the proposed limit of 30% and well below the proposed target of 40%. It predicts that a TAC of 250 t would, with average recruitment, rebuild the stock to 40% virgin size by 2013, a result very close to that produced in the original assessment. Once this is reached a TAC of about 450 t could be sustained. Of course the 40% target could be reached under a multitude of alternative catch scenarios.

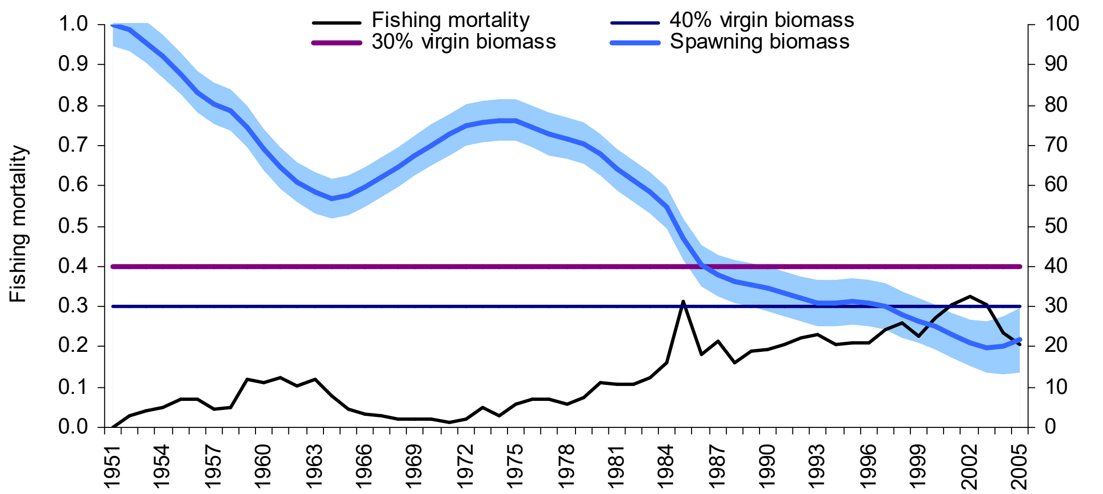

Figure 1. Time series of Shark Bay oceanic snapper Base case model mid-year spawning biomass estimates showing proposed target (40% virgin) and limit (30% virgin) biomasses as well as fishing mortality.

Table 1. Shark Bay oceanic snapper model estimates with projections at various total annual catches. (*S* denotes spawning stock biomass and – indicates a value that was not calculated).

					Year to reach 40% of virgin biomass at various TACs					
Run name	**Change from Base case**	**S_{2005} (% of virgin)**	**S_{MSY} (% of virgin)**	***MSY* (t)**	**50 t**	**200 t**	**250 t**	**300 t**	**350 t**	**400 t**
BASECASE	–	23	36	460	2009	2011	2013	2015	2018	2029
LOM	*M* = 0.08	18	37	430	2012	2015	2018	2023	–	–
HIH	*h* = 0.9	26	25	510	–	2009	2009	2010	2012	2015
MORAN	Use original CPUE	22	35	460	2009	2011	2013	2015	2019	2031
NEWAGE	Omit 1991–2000 age data	22	36	460	2009	2011	2013	2015	2018	2030
NOAGE	Omit age data	23	34	460	2010	2012	2013	2015	2019	2031
CATCHAB	Use original time varying catchability	22	35	460	2009	2011	2013	2015	2019	2032

Conclusions

My review of the Shark Bay oceanic snapper stock assessment led me to assist Peter Stephenson in the development a modified version of the model that had been used for the original assessment. Both data and model structure were changed. However, the combined effects of these changes produced estimates that were quite close to those of the original assessment. The important parameters of stock-recruitment steepness and natural mortality are difficult to estimate. I proposed what I considered to be more realistic values of these parameters than had been used. These values produced opposite effects, so that their combined effect would be again similar to the original assessment. Therefore, although I proposed a modified stock assessment, the results were very similar to those originally obtained. My conclusion is that the original assessment was essentially a satisfactory basis for decision-making.

As for the target and limit biomasses and the time that should be taken to rebuild the stock, I consider these to be questions of management choice. I do not believe that there is any increased risk of catastrophic recruitment failure at the current stock size. Recruitment collapses are essentially caused by environmental change. The target of 40% virgin biomass is more than double the level that New Zealand snapper stocks have been managed at for quite a few years without perceptible effects on recruitment levels. However, 40% virgin biomass is a valid target which would achieve high catch rates and lesser ecosystem disturbance. Time to rebuild is a question of balancing short term pain with long term gain. Presumably the intention is to increase the TAC once the rebuild is complete. There are many possible scenarios that would produce the desired outcome and these should be discussed with fishers. A sequence of small changes instead of a few large jumps may be less economically disruptive and therefore more acceptable. The model should be used to obtain projections under alternative catch scenarios and Monte Carlo Markov chains should be used, preferably with h = 0.9 and M = 0.08 y^{-1}, to obtain estimates of the probabilities of particular outcomes under various projected scenarios.

Acknowledgments

I received assistance in reviewing the original assessment from Gary Jackson and Peter Stephenson who at all times provided me with the explanations and information I sought. They were a pleasure to work with, even though the situation of my reviewing their work was one that could have been a little prickly. I also received important explanations regarding the catch and effort data from Marie Wapnah and Eva Lai. Eva also extracted data allowing me to do my own CPUE analysis. Without their help my review would have been considerably weaker.