Department of
Primary Industries and Regional Development

GOVERNMENT OF WESTERN AUSTRALIA

We're working for Western Australia.

Fisheries Research Report No. 339

Assessment of the status of the South Coast Demersal Scalefish Resource

Norriss, J.V., Hesp, S.A., Fairclough, D.V., Evans-Powell, R.T., Hancock, B., Fisher, E.A., Leary, T., Jarvis, N.

February 2024

Correct citation:

Norriss, J.V., Hesp, S.A., Fairclough, D.V., Evans-Powell, R.T., Hancock, B., Fisher, E.A., Leary, T., Jarvis, N. 2024. Assessment of the status of the South Coast Demersal Scalefish Resource. Fisheries Research Report No. 339 Department of Primary Industries and Regional Development, Western Australia. 125pp.

Enquiries:

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

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

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

Important disclaimer

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

ISSN: 1035-4549 (Print) ISBN: 978-1-921845-35-2 (Print)

ISSN: 2202-5758 (Online) ISBN: 978-1-921845-36-9 (Online)

Table of Contents

Acronyms

BDM	Biomass dynamics model
B_{rel}	Relative spawning biomass
CAES	Catch and effort statistics
CL	Confidence limits
CPUE	Catch per unit effort
F	Fishing mortality
GAB	Great Australian Bight
GABTS	Great Australian Bight Trawl Sector
JABBA	Just Another Bayesian Biomass Assessment
K	Carrying capacity
M	Natural mortality
MLL	Minimum legal length
MSY	Maximum sustainable yield
PRM	Post-release mortality
PSA	Productivity susceptibility analysis
SCB	South Coast Bioregion
SCDSR	South Coast Demersal Scalefish Resource
SCEMF	South Coast Estuarine Managed Fishery
SCLFTMF	South Coast Line and Fish Trap Managed Fishery
SDGDLMF	Southern Demersal Gillnet and Demersal Longline Managed Fishery
SPR	Spawning potential ratio
TL	Total length
WA	Western Australia
WCB	West Coast Bioregion

Executive summary

This document provides the 2023 risk-based weight of evidence stock assessments for snapper, Bight redfish, hapuku, blue morwong, and Western blue groper for 2023 in the South Coast Bioregion (SCB).

The previous benchmark assessment (2016) determined that the risk status for snapper, Bight redfish, and blue morwong was Medium, and for Western blue groper was Low. There was no previous weight of evidence risk assessment for hapuku.

For snapper and Bight redfish, the current assessment (Level 3) is primarily based on estimates of relative female spawning biomass and fishing mortality from catch curve and per recruit models applied to age composition data collected in 2019, and biomass dynamics models (BDM) applied to annual catch and commercial catch per unit effort (CPUE) time series data to 2021-22 (from line fishing for Bight redfish, and demersal gillnet fishing only for snapper). The risk level for SCB snapper and Bight redfish over the next five years is estimated to be **High**.

For Western blue groper the current assessment (Level 3) is primarily based on estimates of female and male relative spawning biomass and fishing mortality from catch curve and per recruit models applied to age composition data collected in 2013-14, and BDM applied to annual CPUE time series data to 2021-22 (from demersal gillnet fishing). Based on weight of all available lines of evidence, the risk level for SCB Western blue groper over the next five years is estimated to be **High**.

For hapuku the current assessment (Level 3) is primarily based on estimates of relative female spawning biomass and fishing mortality from a BDM applied to catch and commercial CPUE data to 2021-22 (from line fishing only). The risk level for SCB hapuku over the next five years is estimated to be **Medium**.

For blue morwong the current assessment (Level 3) is primarily based on estimates of relative spawning biomass (both sexes combined) and fishing mortality from catch curve and per recruit analyses applied to age composition data from 2012-2014, together with trends in annual catch time series data to 2021-22. The risk level for South Coast Bioregion blue morwong over the next five years is estimated to be **Medium**.

1.0 Introduction

The demersal suite of species (depth >20 m) exploited by commercial, recreational and charter fishers in Western Australia's (WA) South Coast Bioregion (SCB; Figure 1.1) are represented by five indicator species for stock assessment purposes: snapper, Bight redfish, hapuku, blue morwong and Western blue groper.

The South Coast Demersal Scalefish Resource (SCDSR) is accessed by the commercial, recreational (including charter) and customary fishing sectors. The majority of the commercial catch is harvested by the South Coast Line and Fish Trap Managed Fishery (SCLFTMF; previously open access line and fish trap fishery), the Southern Demersal Gillnet and Demersal Longline Managed Fishery (SDGDLF), and the South Coast Estuarine Managed Fishery (SCEMF). Recreational sector harvest consist of catches from private boat-based recreational fishers, tour operators and shore-based recreational fishers.

The first dedicated aged-based stock assessments for four of these species (excluding hapuku) were based on comprehensive catch sampling of multiple fisheries from late 2012 to late 2014 (Norriss *et al.* 2016). Other lines of evidence included biology, inherent vulnerability, spatio-temporal distribution of catches, catch rates and length distributions. Snapper and Bight redfish stocks were assessed to have a Medium risk profile, i.e., fully exploited with no capacity for any significant increase to their total catch beyond recent historical levels. There was slightly higher capacity for increased catches of blue morwong (Medium risk) and Western blue groper (Low risk).

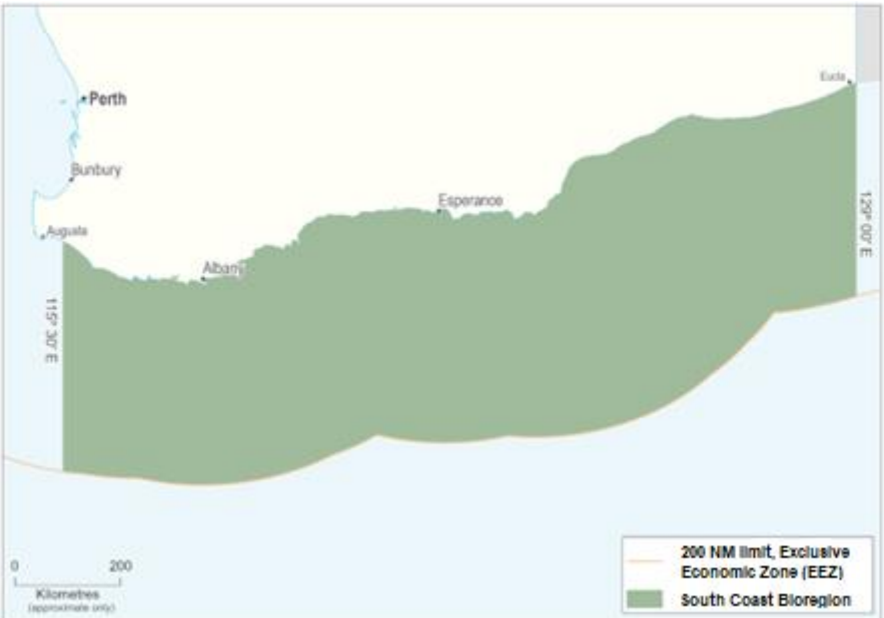


Figure 1.1 Map of the SCB of WA.

For SCB hapuku, the age structure from sampling the 2005 and 2006 commercial line catch was used to estimate the rate of fishing mortality *F* (Wakefield *et al.* 2010). Subsequently an improved catch curve model was used to provide a better estimate of *F*, and relative spawning stock biomass was estimated (Norriss *et al.* 2023). Neither had breached threshold levels at the time of sampling, but catches have increased to record levels in recent years.

The current Level 3 assessment (see Appendix for description of levels of stock assessment used by DPIRD) incorporates additional age data from commercial line catch sampling. For hapuku this includes opportunistic sampling since that reported by Wakefield *et al.* (2010) and a dedicated sampling program from October 2017 to September 2018. For snapper and Bight redfish there was a dedicated sampling program in calendar year 2019. No additional sampling of blue morwong or Western blue groper catches for providing age data has occurred. Previous age-based assessments estimated the rate of natural mortality (*M*) using a method no longer recommended (Hamel and Cope 2022, Maunder *et al*. 2023), so the current assessment applies a recently developed method (Dureuil and Froese 2021) resulting in a slightly less optimistic assessment.

The current assessment provides an updated weight of evidence Level 3 stock assessment for all five indicator species. As with the previous age-based assessment, stock status is compared to target, threshold and limit reference levels (performance indicators, Figure 1.2) for *F* (1.5*M*, *M*, and 0.67*M,* respectively) and relative breeding stock (40%, 30% and 20%, respectively). This assessment also includes a BDM that uses catch and catch rate inputs to estimate relative stock biomass trajectories and biomass at maximum sustainable yield (B_{MSY}). The target, threshold and limit reference points for comparison are 1.2 B_{MSY}, B_{MSY}, and 0.5 B_{MSY}, respectively.

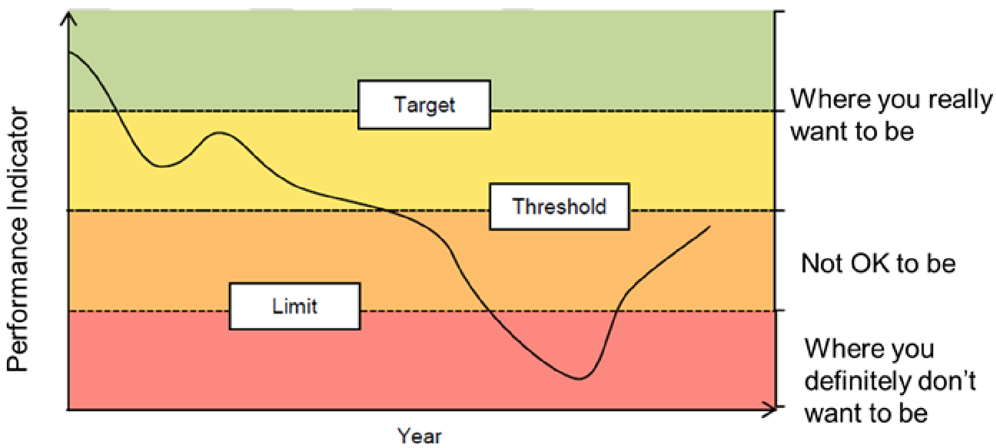


Figure 1.2 Graphical illustration of reference levels in fish stock performance indicators: Target, Threshold and Limit.

Risk profiles are generated by weighting all available lines of evidence to determine the Likelihood (<5%, 5-20%, 20-50% or >50%) of four possible stock depletion levels: above Target, between Target and Threshold, between Threshold and Limit, and below Limit (Table 1.1). The highest risk outcome identified in this Consequence (depletion level) x Likelihood matrix determines the risk score for the fish stock.

Table 1.1 Risk level outcome matrix based on Consequence (depletion level) x Likelihood. B= breeding stock biomass.

Consequence × Likelihood Risk Matrix		Likelihood			
		Remote <5%	Unlikely 5 - 20%	Possible 20 - 50%	Likely >50%
Consequence	Minor (1) (B>Target)	Negligible	Negligible	Low	Low
	Moderate (2) B b/n target & threshold	Negligible	Low	Medium	Medium
	High (3) B between thr & lim	Low	Medium	High	High
	Major (4) B below lim	Low	Medium	Severe	Severe

2.0 Snapper (*Chrysophrys auratus*)

2.1 Snapper summary

WA's SCB population of snapper currently constitutes a jurisdictional stock for management and assessment purposes. Within the south-western stock of snapper from Albany to the Perth metropolitan area, there is evidence of isolation by distance and varying, temporal genetic discontinuity with snapper from around Esperance, suggesting biological separation around the eastern SCB. Throughout its distribution, snapper is relatively long-lived. In the SCB, it has a maximum observed age of 40.3 years and, on average, attains maturity at around 4-5 years and 54 cm total length (TL).

SCB snapper are fished by commercial and recreational fishers in estuaries and coastal waters to the edge of the continental shelf, with most fish taken by oceanic commercial hook and line fishing in the SCLFTMF.

A spatio-temporal assessment of catches to 2021-22 shows no discernible shift in the areas fished from abandoned to new grounds indicative of unacceptable stock depletion. Catch-MSY modelling indicates catches in most years were below MSY and current depletion close to B_{MSY}, i.e., fully exploited. A BDM applied to demersal gillnet catch rates estimated biomass levels to be currently fully exploited (potentially slightly overfished), with biomass in several of the last 5 years just below B_{MSY} (i.e. threshold level) and fishing mortality fluctuating around F_{MSY}. Although there was substantial uncertainty in the model, the prospect of relative biomass breaching the limit reference level ($0.5B_{MSY}$) was remote.

The previous age-based Level 3 stock assessment from 2012-2014 catch sampling, which indicated a medium risk level (Norriss *et al.* 2016), has been revised using an updated method for estimating the rate of natural mortality. The re-assessment showed both the rate of fishing mortality and female spawning biomass had breached the threshold reference level at that time.

Sampling the commercial line catch in 2012-2014 and in 2019 revealed little change in the prevalence of large or old fish. Catch curve analysis of samples indicates the rate of fishing mortality has increased, now exceeding the threshold level, and per-recruit analysis indicates a reduction of spawning stock between sampling periods. The 2019 estimate of relative spawning biomass is between threshold and limit levels.

Consequently, the SCB snapper stock status is **HIGH** risk.

2.2 Risk-based weight of evidence summary table and matrix

Level	Line of evidence
1.1 Biology and vulnerability	SCB snapper are long-lived (up to 40 years) with an average age and length at maturity in the SCB of around 4-5 years and 54 cm TL, respectively. Snapper are found throughout the SCB, but catch and targeted fishing effort mostly occurs west of 120° E where abundance appears to be higher. Stock structure is characterised as isolation by distance in the western SCB and a genetic discontinuity with snapper around Esperance, suggesting biological separation around the eastern SCB. The potential for snapper spawning aggregations to be highly vulnerable to fishing, as known for this species in other bioregions in WA, is not known to be as high in the SCB. Spawning occurs widely along the coast west of about 120° E but is less common to the east. Productivity Susceptibility Analysis (PSA) for snapper generated a productivity score of 1.86 and susceptibility score of 2.33, resulting in an overall score of 2.98, i.e., a medium risk (Appendix).
1.2 Catch	The commercial catch, dominated by the line fishery, has declined since about 2012. Although it is possible that declining oceanic catches by the commercial line and gillnet fisheries are associated, to some extent, with a decline in breeding stock biomass, it would also be consistent with the substantially reduced effort levels in recent years (see Level 2 assessment below). Recreational catches have varied between 5 and 12 t in integrated surveys since 2011-12, and the annual tour operator catches have been <1 t since 2010.
1.3 Spatio-temporal distribution of catch	Catches in the dominant commercial line fishery have been mostly west of 120° E and a smaller component east of 126° E. Within either sub-region there was no evidence that declining catch levels have been associated with a progressive shifting in the areas fished. No unacceptable stock depletion is indicated by the spatio-temporal patterns in catch distribution.
1.4 Catch-MSY analysis SCB	Results of catch-MSY analysis applied to annual catch data (all sectors) suggest that catches had increased from levels below MSY in years prior to 1997, to slightly above MSY in the mid-late 2000s, before declining to around MSY is more recent years. This is consistent with the predicted trend for biomass analysis, which increased in recent years to close to B_{MSY} (i.e. final depletion of ~0.5).
Level 1 assessment The decline in annual commercial catches since about 2012 may be associated with multiple factors, including a level of decline in abundance or reduced fishing	

effort. The spatial distribution of catches in recent years was similar to that of earlier catches. From the catch MSY analysis results, it is plausible that the stock is currently fully exploited but not overfished. As this is a data-limited method with strong assumptions, these results should be treated with caution.	
2.1 Effort and catch rate	The annual demersal gillnet CPUE time series for snapper in the SCB shows a decreasing trend in abundance to 1995, before sharply increasing around 1999. The annual CPUE trends do not show any long-term increasing or decreasing abundance since the early 2000s. For modelling, the CPUE time series have been adjusted with an assumed 2% annual increase in fishing efficiency from 1982-1995.
Level 2 assessment A state space BDM (Winker *et al.* 2018), using the Schaefer production function, was fitted to annual catches and commercial CPUE for snapper in the SCB. Results from the analysis yielded a MSY point estimate of 49 t. In recent years, estimated biomass levels were typically below that corresponding to B_{MSY}. Relative biomass in 2022 was between the limit (0.25) and threshold level (0.5), with the estimated current ratio of biomass to B_{MSY} (B/B_{MSY}) at 0.72 (95% CLs, 0.28-1.53). The corresponding estimates for fishing mortality in recent years were typically above F_{MSY} (F/F_{MSY} = 1.30, 95% CLs = 0.42-3.37), indicating relatively high fishing effort in recent years. A substantial source of uncertainty in this assessment analysis relates to limited understanding regarding changes in fishing efficiency occurring over the history of the fishery. Results from the state space model fitted to annual catch and adjusted nominal commercial CPUE data indicate that the stock is currently being fully exploited (and possibly slightly overfished), with point estimates for biomass in several of the last 5 years just below B_{MSY} (i.e. threshold level), fishing mortality fluctuating around F_{MSY}, and recent catches typically just below MSY. Considering uncertainty in assessment results, the Level 2 assessment suggests a minor depletion Unlikely, a moderate depletion Possible, a high depletion Likely, and a major depletion a Remote likelihood.	
3.1 Length composition	Sample parameters from the commercial line-based catch indicated a slight increase in size from 2012-14 to 2019, giving no indication of unacceptable stock decline.
3.2 Age composition	The prevalence of relatively old (>20 years) snapper in commercial line-based catch samples was little changed between 2012-14 and 2019. Although the age-frequency distributions were significantly different between periods, they provided no evidence of a decline in spawning stock biomass.
3.3 Fishing mortality and per-recruit	All estimates of fully-selected (long term average) fishing mortality *F* over both sample periods breached the threshold reference level. An updated method of estimating natural mortality *M* has resulted in an upward revision of historical *F* estimates. The only *F*

analysis	estimate, based on 2019 data, to breach the limit was from the age-based catch curve assuming logistic selectivity: *F* = 0.17 yr^{-1} (0.14-0.20 yr^{-1}; *F/M* = 1.64). The results of this latter method may be overly-pessimistic due to impacts of recruitment variation on results. The estimate of F from the 'preferred' method of Chapman & Robson (1960), based on 2019 age data, was F=0.14 yr^{-1} (0.11-0.17 yr^{-1}; *F/M*=1.35) and thus between the threshold and limit. All available estimates for female spawning potential ratio (SPR) and relative female spawning biomass (B_{rel}) decreased from 2012-2014 to 2019. The 2019 estimate for B_{rel} of 0.23 (0.17-0.28), based on the preferred Chapman & Robson estimate of F, indicates that female spawning biomass is between the threshold and limit reference point.

Level 3 assessment

SPR, B_{rel} and catch curve estimates of *F* indicate a decline in breeding stock has occurred between 2012-2014 and 2019, associated with high fishing mortality. The stock is likely between the threshold and limit reference point, with the prospect of a breach of the limit close to the margin of Unlikely and Possible.

Final Risk

C1 (Minor depletion – above target): not consistent with Level 1 assessment, Unlikely according to Level 2 assessment and not plausible according to Level 3 assessment.

Likelihood of minor depletion is therefore assessed as **implausible**.

C2 (Moderate depletion – between target and threshold): consistent with Level 1 assessment, possible according to the Level 2 assessment, and not plausible according to Level 3 assessment.

Likelihood of moderate depletion is therefore assessed as **Remote.**

C3 (High depletion- between threshold and limit): consistent with Level 1 assessment and likely according to both Level 2 and 3 assessments.

Likelihood of high depletion is therefore assessed as **Likely**.

C4 (Major depletion – below limit): not consistent with Level 1 assessment, a Remote likelihood according to the Level 2 assessment, and close to the margin of Unlikely and Possible according to the Level 3 assessment.

Likelihood of major depletion is therefore assessed as **Unlikely**.

The SCB snapper risk matrix shows the maximum consequence-likelihood rating to be a **HIGH risk** (C3 x L4)**.**

SCB snapper risk matrix

Consequence (Stock Depletion) Level	Likelihood			
	L1 Remote (<5%)	L2 Unlikely (5-20%)	L3 Possible (20-50%)	L4 Likely (>50%)
C1 Minor (above Target)				
C2 Moderate (below Target, above Threshold)	x			
C3 High (below Threshold, above Limit)				x
C4 Major (below Limit)		x		

2.3 Level 1 assessment: biology, vulnerability and catch

2.3.1 *Biology and vulnerability*

Snapper is a long-lived gonochorist (separate sexes), with a maximum recorded age of 41 years throughout its distribution in WA. It has an average age and length at maturity in the SCB at around 4-5 years and 543 mm TL (both sexes, Norriss et al. 2016), respectively, with the latter being above the current MLL of 410 mm TL. The oldest observed age for this species in the SCB is 40 years. It occurs throughout the SCB but most catches are taken west of 120° E where there is high overlap with targeted fishing effort. In the West Coast and Gascoyne Bioregions snapper are known to form spawning aggregations at predictable times and places making them particularly vulnerable to fishing, but this level of vulnerability is not known in the SCB. Limited data on the recreational catch of spawning snapper near Windy Harbour on the south coast did not indicate a particularly high vulnerability associated with fishing being targeted towards spawning aggregations but the evidence was not conclusive (Norriss et al. 2016). Spawning occurs widely along the coast west of about 120° E but appears less common to the east. Snapper suffer post-release mortality (PRM) from gut-hooking and barotrauma at capture depths >30m (St John et al. 2009), assumed to be 25% for commercial line fishing in the WCB (Fairclough et al. 2021).

Population genetic evidence shows the stock structure of snapper in WA can be characterised as isolation by distance with high connectivity, although a temporally varying genetic discontinuity has been detected in the vicinity of Esperance by two independent studies (Bertram *et al.* 2022, Gardner *et al.* 2022). This suggests the presence of two biological stocks in the SCB.

2.3.2 *Catch*

Annual catches have mostly been taken by the commercial line fishery although its catch has declined substantially since about 2012 when catches became more evenly shared among sectors, including the recreational sector (Figure 2.1). Release rates and discard mortality from the commercial line fishery are considered relatively low based on the low frequency of small fish in landed catches (see section 2.5.1 below). All catches in blocks straddling the WCB boundary at 115°30'E (i.e., between 115°00'E and 116°00'E) have been included if they could not be allocated between bioregions (business rules are being developed to account for allocation of such catches to the appropriate bioregion). Total commercial catch has declined over the same period. Estuarine net catches, normally low, have been relatively high in recent years, almost exclusively from Wilson Inlet. The SDGDLMF (previously known as the Southern Demersal Gillnet and Demersal Longline Managed Fishery) catch has recently increased to near its long term maximum of 17 t in 2021-22, exceeding the commercial line catch in 2020-21 and 2021-22 for the first time since 1995-96 when the latter's catch was low. Observer records of SDGDLMF gillnet operations indicate negligible levels of discarding of snapper and associated PRM in that fishery (Braccini *et al.* 2022). The recent SDGDLMF increase can be attributed to high longline catches which more than compensated for lower concurrent gillnet catches (Figure 2.2). The large majority of the longline increase can be attributed to just one or two vessels, mostly in the far west of the SCB, with no temporal pattern to indicate targeting of spawning aggregations.

Private boat-based recreational retained catches reported during integrated surveys have varied between 6.3 t and 11.6 t between 2011-12 and 2020-21 (Figure 2.1; Ryan *et al.*, 2022), while annual retained tour operator catches have been < 1 t. The numbers of snapper reported as caught during each integrated survey of private boat-based fishers ranged from a minimum of ~10,400 in 2013-14 to a maximum of ~14,100 in 2020-21, with 63-80% of snapper caught being released. Assuming the same released snapper weight of 0.816 kg and PRM rate of 25% as in the WCB (Fairclough *et al.* 2021), the estimated PRM across the integrated surveys ranged from 1.4 to 2.0 t of snapper, with 1.9 t estimated PRM in 2020-21.

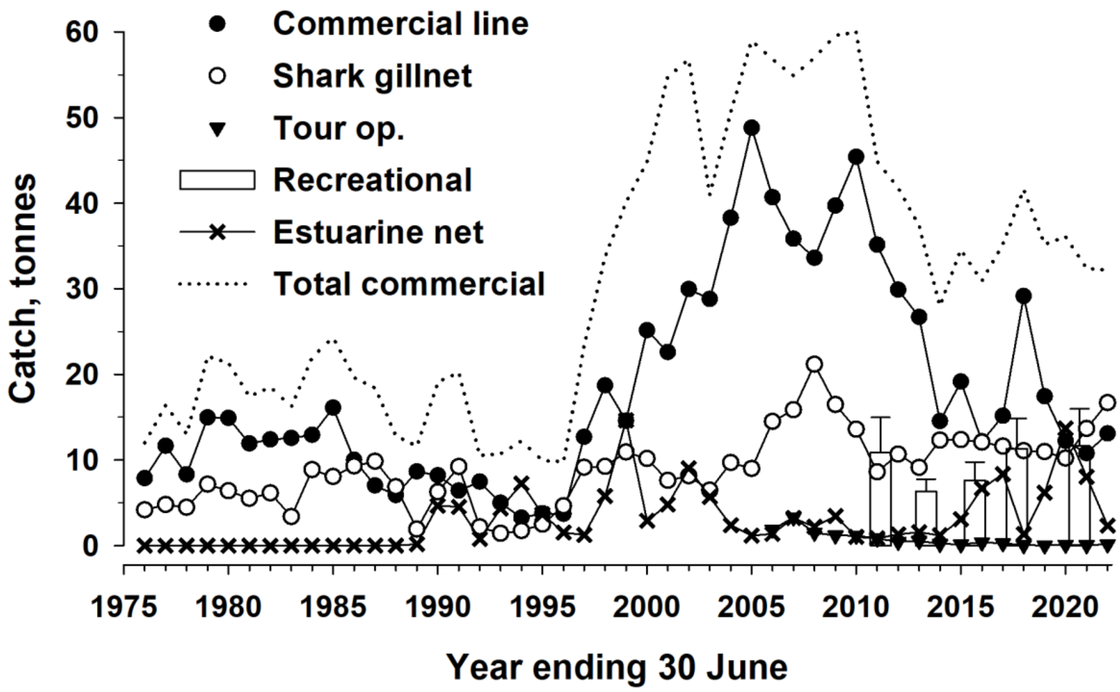


Figure 2.1 Total annual snapper catch in the SCB by fishery from 1975/76 to 2021/22. Commercial line includes open access commercial line, net and trap. Shark gillnet includes catches in the SDGDLMF (gillnet and longline) and prior to its inception in 1988 all longline catches. Recreational catch (±std. err.) is boat-based only.

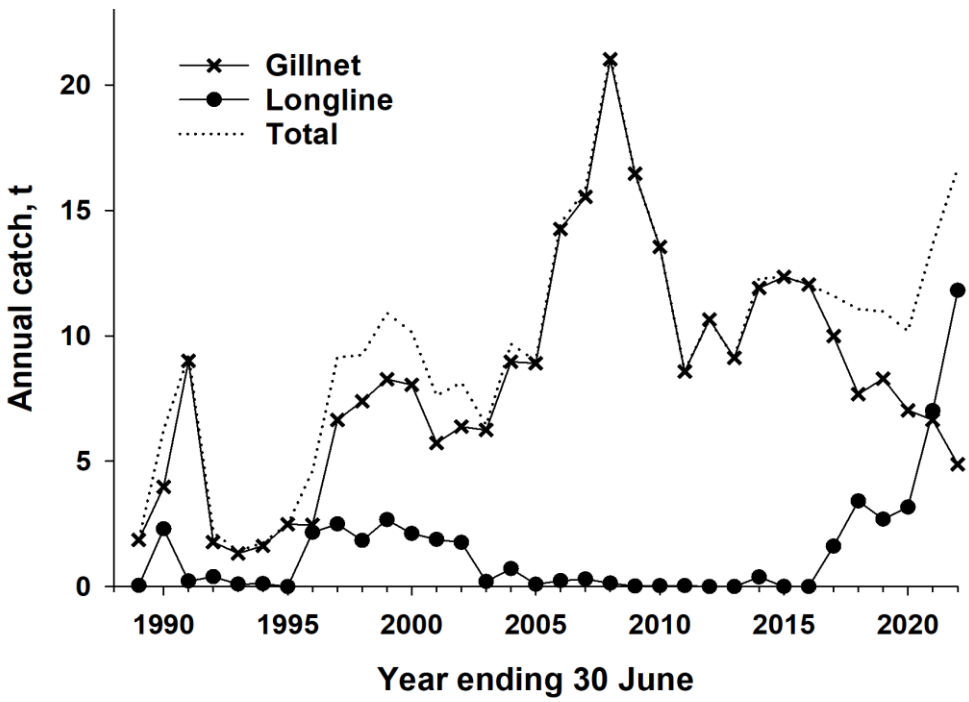


Figure 2.2 Longline and gillnet snapper catch by the SDGDLMF since its inception in 1988-89**.**

2.3.3 *Spatio-temporal distribution of catch*

The spatio-temporal catch distribution by the dominant commercial line fishery can be divided into two broad regions (Figure 2.3):

- west of 120° E, particularly the far west and waters adjacent to Albany and Bremer Bay.
- east of 126° E, the Great Australian Bight (GAB) approaching the South Australian border.

Catches in between these regions (i.e., from 120° to 126° E) have been comparatively low. The west and east components of snapper catches from the SCB likely represent removals from two biological stocks based on evidence of discontinuity in snapper population genetics detected near Esperance but varying temporally (Bertram *et al.* 2022, Gardner *et al*. 2022).

In the eastern component (east of 126° E) no block exceeded 1 t of catch until 1998-99. Since then catches have increased intermittently and the spatial distribution has varied among a relatively small number of blocks.

The western component of the commercial line catch was much higher than the east. The same ocean blocks from which most earlier catches have been sourced continue to dominate despite catches declining from about 2012, albeit at a lower catch level. Around this time the estuarine net catch was historically high, with the vast majority taken from Wilson Inlet about 40 km west of Albany. Wilson Inlet is a nursery area and many snapper, unusually for estuaries, remain in the Inlet and recruit into the fishery. The extent to which Wilson Inlet snapper ultimately emigrate to supplement the ocean population is unknown. The cause of the Inlet's recent high catch is also unknown, e.g., higher targeted effort or above average recruitment event.

The majority of private boat-based recreational catches occurred in the Albany zone of the SCB (i.e. west of 120° E), e.g. 98% of 14,063 snapper caught (retained plus released) in 2020/21 (Ryan *et al.*, 2022).

A finer spatial resolution (10' x 10') facilitated by the inception of the SCLFTMF in 2021-22 shows the relatively low catch in that year was concentrated in the far west of the SCB (Figure 2.4).

In conclusion, across the SCB there was no evidence that declining catch levels have been associated with a progressive shifting in the areas fished. The spatio-temporal catch distributions do not indicate that unacceptable stock depletion has occurred.

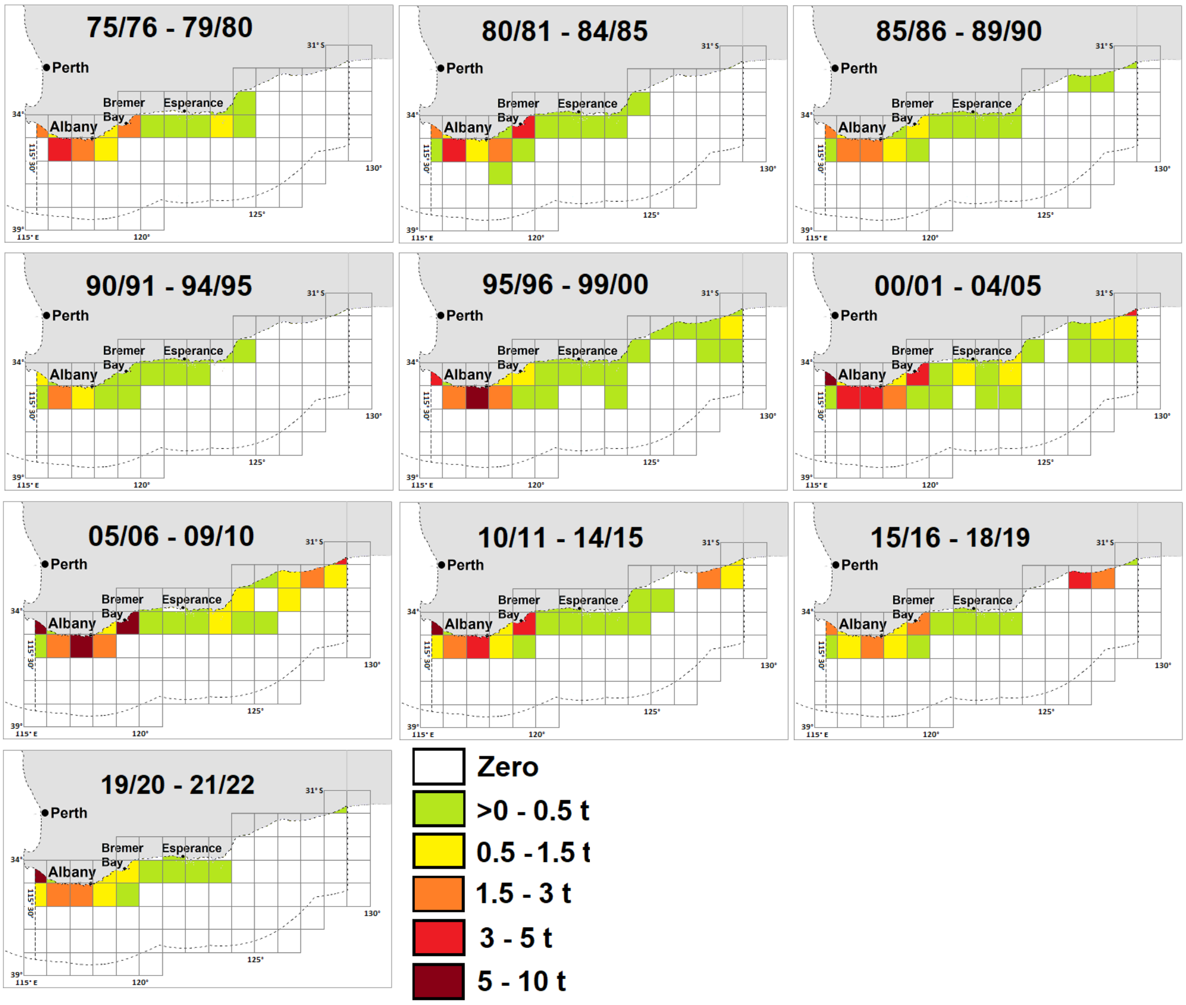


Figure 2.3 Time series of spatial distribution (1°x1° block) of the average annual snapper commercial line catch in the SCB from 1975/76 to 2021/2022. Years ended 30 June.

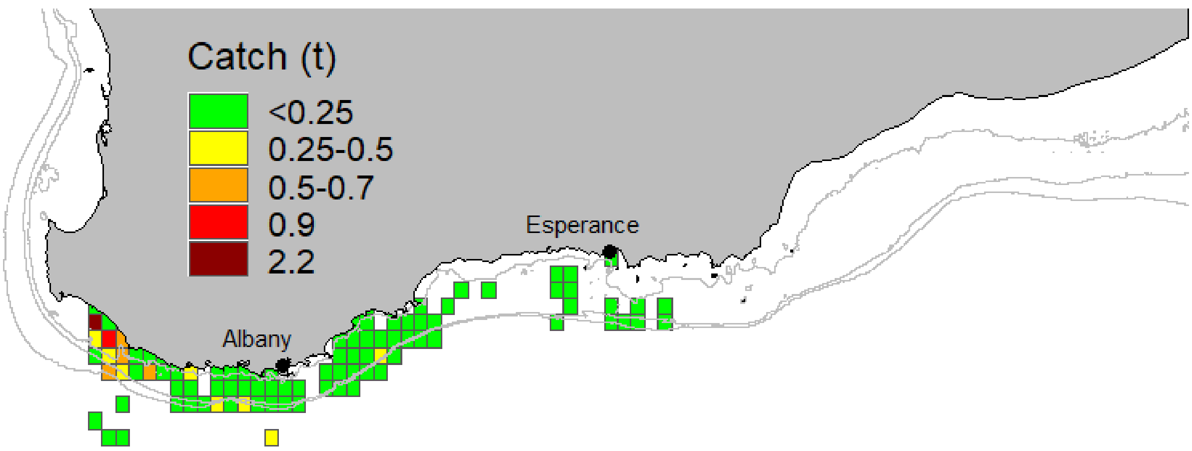


Figure 2.4 Spatial distribution of the SCLFTMF snapper catch (10'x10' block) in its first year of operation, 2021-22. Bathymetry lines correspond to 50m, 100m and 200m.

2.3.4 *Catch-MSY*

Catch-MSY models were used to predict MSY and trends in fishing mortality and stock depletion consistent with available catch data and model assumptions using the datalowSA package in R (Haddon *et al*., 2019). Key model assumptions included a low stock resilience (r=0.1-0.6) initial stock depletion range of 0.5-0.975, and a final stock depletion range of 0.05 – 0.95. This wide range of values for the final depletion 'prior' range was selected following preliminary model analyses indicating that model results were strongly affected by the values of this prior, when the range was not broad.

The catch time series comprised total retained annual catches from all sectors for each year ended 30 June, from 1975-76 to 2021-22. Recreational catch estimates were available from five annual surveys between 2011/12 and 2020/21 (Ryan *et al.* 2022), recently revised and slightly different to earlier published estimates. These surveys did not align exactly with years ending 30 June so were allocated to the nearest such year and linearly interpolated for intermediate years' estimates. Recreational catch estimates for 1975/76 to 2010/11 were calculated as a linear function of the estimated number of registered boats in WA in those years. These estimates were generated from the rate of ownership of boats per head of population in the Perth metropolitan region that increased from 1990 to 2007 (Department for Planning and Infrastructure 2009), extrapolating this increasing rate forward (to 2010/11) and backward (i.e., decreasing rate, to 1975/76) for the total WA population (source: Australian Bureau of Statistics), and assuming catch per boat for 1975/76 to 2010/11 equaled the mean estimate for the years 2011/12 to 2020/21. Tour operator catch estimates were available from 2005/06 to 2021/22, and earlier years, going back to 1975/76, were estimated assuming the same catch per head of the WA population as the mean from 2005/06 to 2021/22.

The set of plausible r-K combinations indicate a MSY ±95%CLs of 50 t (34 – 64 t), with periods of catches both below and above this level (Figure 2.5). Consistent with the catch trend relative to predicted MSY, the stock is predicted to have declined from around 1997-98 to 2011-12 during a period of relatively high catches, and then stabilised since catches declined to mostly around MSY or just below since 2011-12 (Figure 2.6). Note that the Catch-MSY assessment method is designed for data-poor fisheries, is dependent on strong modelling assumptions, and thus results should be treated with caution.

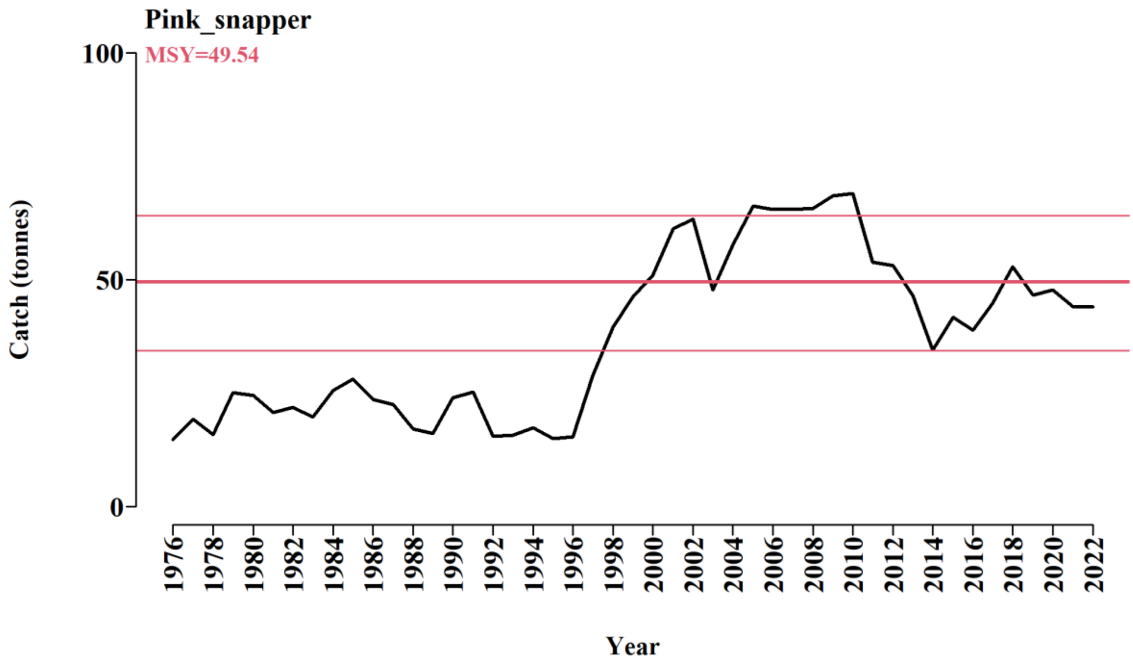


Figure 2.5 Total annual SCB catch (all sectors) from 1975/76 to 2021/22 used for SCB snapper Catch-MSY assessment vs estimated MSY (±95%CLs).

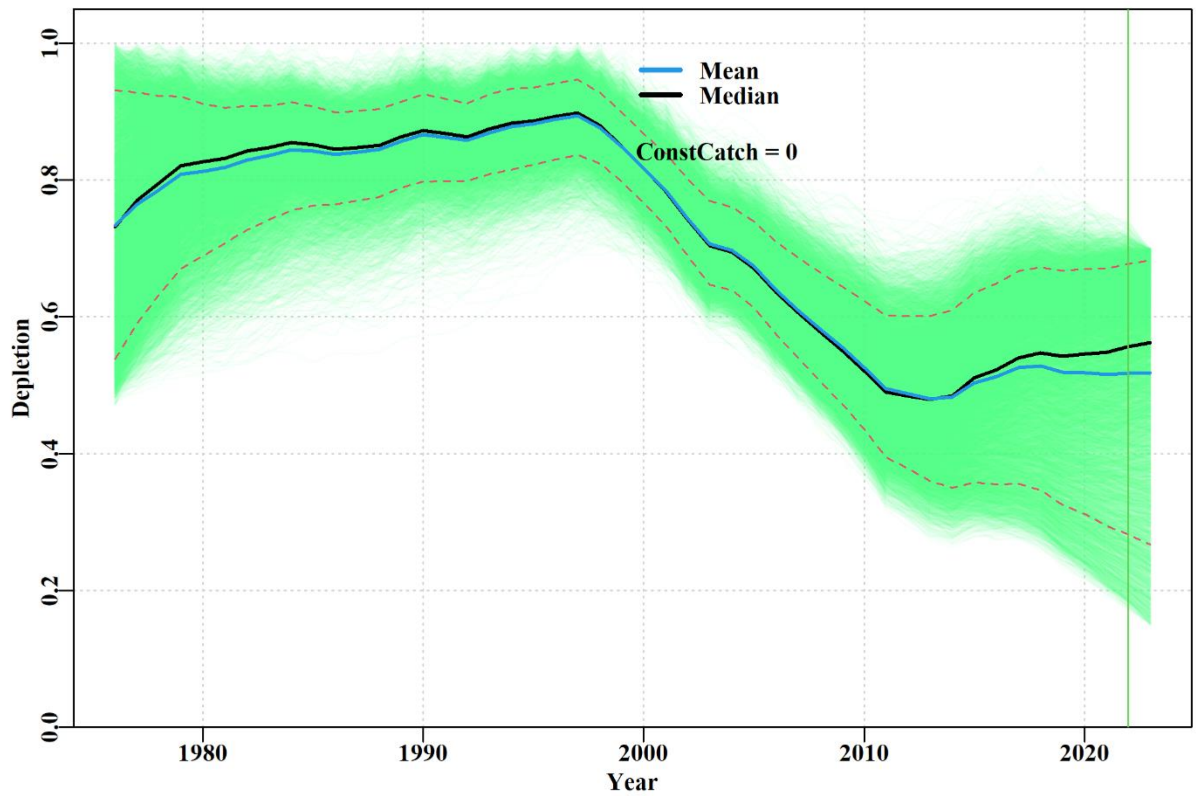


Figure 2.6 Trajectories of SCB snapper stock based on Catch-MSY analysis. Dashed lines are 95% confidence levels.

2.4 Level 2 assessment: effort and catch rate

2.4.1 *JABBA: state-space Schaefer biomass dynamics model*

2.4.1.1 *Model Description*

A state-space Schaefer BDM was applied using catch and commercial CPUE data for snapper in the SCB to provide estimates of biomass and fishing mortality relative to biological reference points. The model was fitted to annual total catches (all sectors) and CPUE data from gillnet fishing by the (SDGDLMF), where the latter is assumed to provide an index of spawning stock abundance (Figure 2.7). State-space BDMs, which account for both observation and process errors, as is now considered best practice for this type of modelling (e.g., Best & Punt, 2020; Punt, 2003; Zhou *et al.*, 2009), were used. The model used for this assessment is JABBA ('Just Another Bayesian Biomass Assessment') (Winker *et al.*, 2018), in R (R Core Team, 2023), which provides a Bayesian implementation of the state-space Schaefer BDM. The following priors were assumed for snapper: a lognormal prior for carrying capacity (K) with mean = log(1000) and sd = 1, a lognormal prior for the intrinsic rate of population increase (r) with mean = log(0.2) and sd = 0.3, a lognormal prior for the initial starting biomass (Ψ) with mean = log(0.7) and sd = 0.3. The initial biomass value assumes light-moderate fishing occurring prior to the first year of recorded catches, noting that fishing activity in the region for this species likely commenced by the 1940s. The assumption of "low resilience" (r=0.2) is considered appropriate for this species given its maximum age (~41 years) and the empirical relationship between r and natural mortality (Zhou *et al.*, 2016). Process error variance was specified as 0.3 with sensitivity runs (not shown in this document) conducted for values of 0.2 and 0.4. Standard fisheries reference points were calculated including MSY (MSY =rK⁄4) and the biomass corresponding to MSY (B_{MSY}=0.5 K) (Carruthers *et al.*, 2014; Froese *et al.*, 2017; Haddon, 2011).

2.4.1.2 *Data Inputs*

The available annual time series of commercial catches of snapper extends from 1976 to 2022 (Figure 2.7a). Investigation of the catch and effort records used to calculate the annual commercial CPUE series for snapper in the SCB suggested that the time series of CPUE data should be split between early monthly (1979-2006) and later years (2008-2022) to account for differences in catch and effort reporting i.e., monthly reporting for earlier years and daily for later years (Braccini *et al.* 2021, (Figure 2.7b). Records for 2007 were omitted due to reporting inconsistencies by fishers immediately following the transition (Braccini *et al.* 2021). A catch rate record was defined as kilograms of retained catch per kilometre of gillnet used per hour. All records of snapper taken in the SCB by gillnet were initially included, then systematically subject to omission by following Braccini *et al.*'s (2021) guidelines for identification of "reliable" and "unreliable" records. Thus records were omitted if:

- hours fished per day was incomplete, zero or >24 h (monthly returns only), or
- net length was incomplete or <100m or >12,000 m, or

- fishing effort < 1 (km of net per hour), or
- number of shots was >3, or
- number of days fished per month was incomplete or >31, or
- catch was in an “estuarine” block other than King George Sound (block 96030).

The first three years of the CPUE time series based on monthly reporting were excluded from the analysis due to exceptionally low catches, which could result in unreliable CPUE values as an index of abundance. Similarly, the first two years of the CPUE time series based on daily reporting have been excluded from the analysis due to issues associated with changes in reporting that may have affected reliability of the CPUE data for those years. Both CPUE time series were adjusted to account for an assumed increase in fishing efficiency of 2% per year until 1994-95. Efficiency was maintained at the 1994-95 value for subsequent years. Note that for this L2 modelling analysis, the ‘years’ for the catch and CPUE time series and model outputs relate to financial years rather than calendar years, e.g. 1976 is the 1975-76 financial year.

2.4.1.3 *Results and Implications*

The JABBA model provided relatively good visual fits to annual catch rate time series for snapper (adjusted for fishing efficiency) (Figure 2.8). Outputs from the snapper assessment suggest that the current level of catch is slightly below the estimated MSY for the stock of 49 t (95% CLs: 26-97t) (Table 2.1).

The results from the BDM indicate that the snapper stock abundance in the SCB has fluctuated around B_{MSY} since the early 2000s, being at B_{MSY} in 2021 and dipping below this level in 2022, to be between the threshold and limit (Figure 2.9). Estimates of fishing mortality (F) increased to above estimated F_{MSY} throughout the 2000s. In more recent years, estimates of F have fluctuated around F_{MSY} (Figure 2.9), increasing from just below F_{MSY} in 2021 to above this level in 2022 (Figure 2.9; Table 2.1).

Fishing efficiency was specified as 2% per year from 1982 to 1995. The assumption of no increase in fishing efficiency was considered infeasible due to the introduction of technology such as GPS in the early 1990s, combined with other factors such as changes in fishing knowledge and experience. An increase of 2% per year after 1995 was considered likely to be too high for this fishery, since the methods of fishing and use of technology are unlikely to have changed rapidly since the mid-1990s and snapper is a non-target species of the fishery.

The results from the state space model fitted to annual catch and CPUE data indicate that the stock is currently fully exploited (potentially slightly overfished), with estimated biomass in several of the last 5 years just below B_{MSY} (i.e. threshold level), fishing mortality fluctuating around F_{MSY}, and recent catches typically just below MSY. The likelihood of stock biomass breaching the threshold generates a High risk score according to the BDM (Figure 2.10).

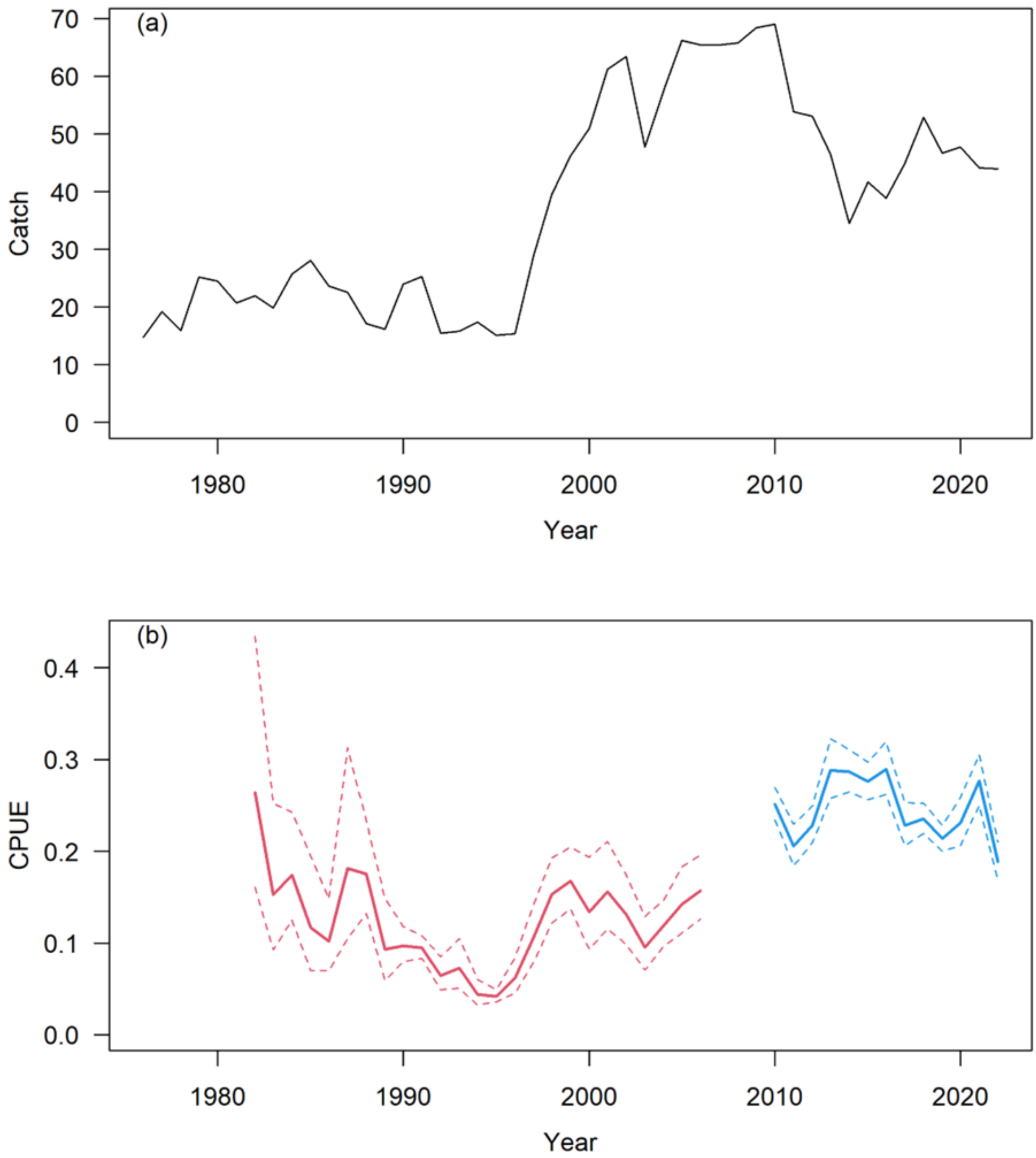


Figure 2.7 (a) Commercial snapper catch (tonnes, t) in the SCB and (b) annual catch per unit effort (CPUE) series for early (1982-2006) and later years (2010-2022) from gillnet fishing by the JASDGDLF. Solid lines denote mean CPUE and dashed lines indicate associated 95% CLs. All CPUE time series have been adjusted for an assumed efficiency increase of 2% per year.

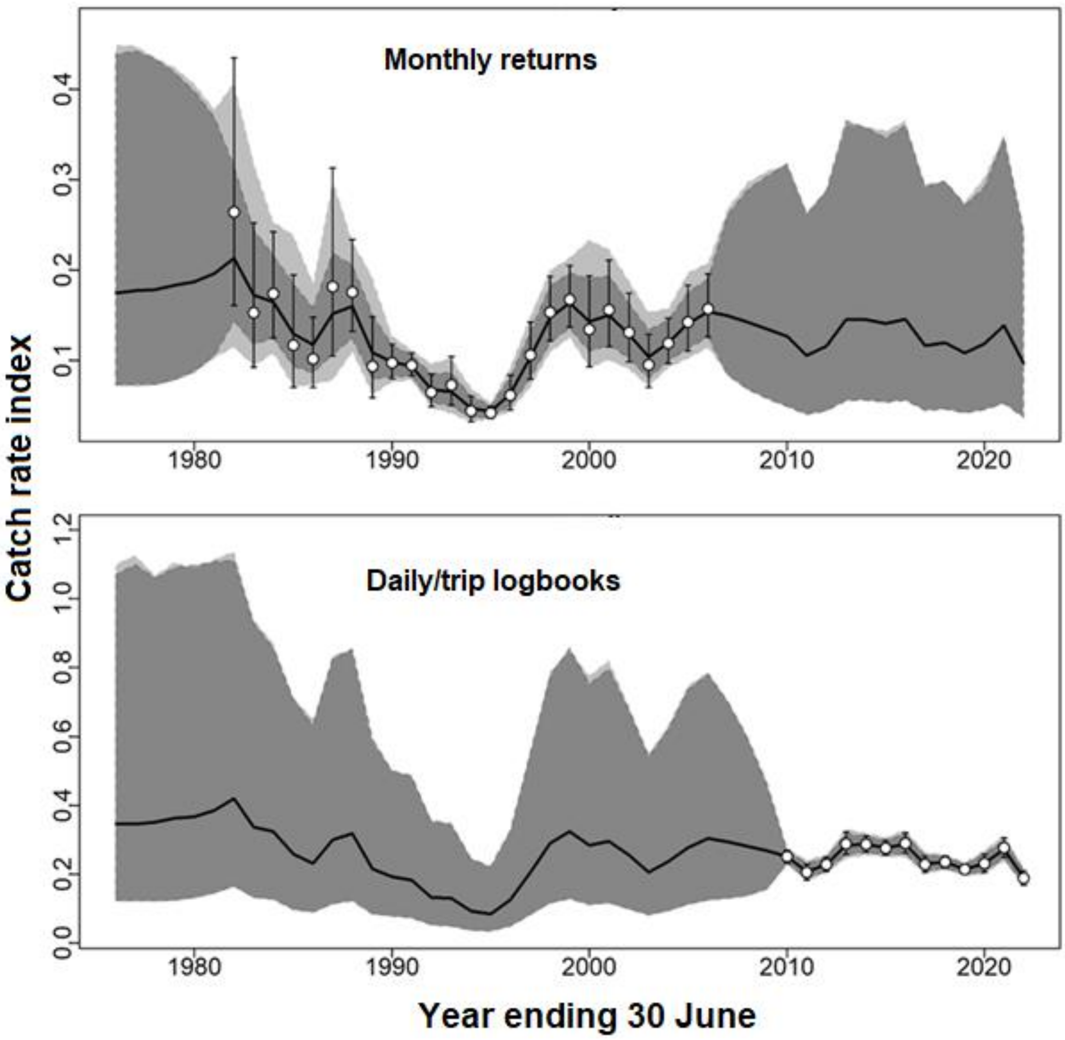


Figure 2.8 Fit of the JABBA Schaefer BDM to the adjusted nominal catch rates (adjusted for assumed changes in fishing efficiency) for snapper from the SCB from the gillnet component of the SDGDLMF from monthly returns and daily/trip logbooks. Observed CPUE and associated 95% CLs are indicated by white circles and error bars, whereas for expected CPUE, these are indicated by solid lines and shading.

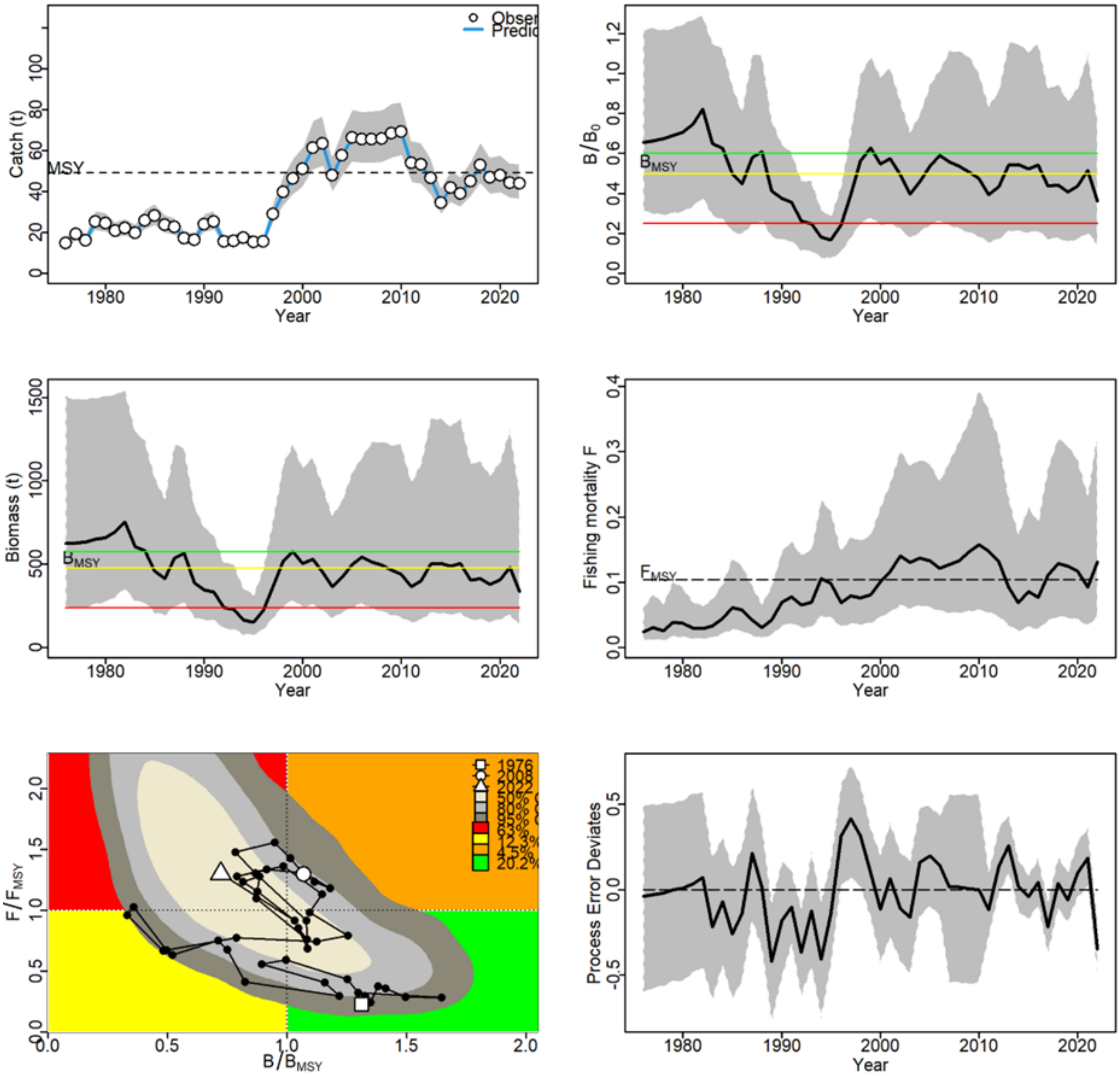


Figure 2.9 Annual time series of (top left) catch and estimates of (top right) relative biomass, (middle left) absolute biomass, (middle right) fishing mortality, (bottom left) KOBE plot tracking the relationship between fishing mortality and biomass over time, and (bottom right) process error deviations, derived from the JABBA Schaefer BDM fitted to snapper catch and catch rate data. The 95% CLs around parameter estimates are shown as shaded regions. B_{MSY} and F_{MSY} refer to the biomass (absolute or relative) and fishing mortality, respectively, expected to achieve MSY. Red, yellow, and green lines represent the limit (0.5 B_{MSY}), threshold (B_{MSY}) and target (1.2 B_{MSY}) reference points respectively.

Table 2.1 Parameter estimates produced by the state space BDM (JABBA) and associated 95% CLs for snapper. Carrying capacity, K; intrinsic increase, r; maximum sustainable yield, MSY; biomass at MSY, B_{MSY}; fishing mortality at MSY, F_{MSY}; ratio of current biomass to unfished biomass, B/B_0; ratio of current fishing mortality to F_{MSY}, F/F_{MSY}.

Parameter	Estimate (95% CLs)
K (tonnes)	959 (507-1842)
r	0.21 (0.12-0.35)
MSY (tonnes)	49 (26-97)
B_{MSY} (tonnes)	480 (254-921)
F_{MSY} ($year^{-1}$)	0.10 (0.06-0.17)
B/B_0 (in 2022)	0.36 (0.14-0.77)
B/B_{MSY} (in 2022)	0.72 (0.28-1.53)
F/F_{MSY} (in 2022)	1.30 (0.42-3.37)

Consequence (Stock Depletion) Level	**Likelihood**			
	L1 Remote (<5%)	**L2 Unlikely (5-20%)**	**L3 Possible (20-50%)**	**L4 Likely (>50%)**
C1 Minor (above Target)		x		
C2 Moderate (below Target, above Threshold)			x	
C3 High (below Threshold, above Limit)				x
C4 Major (below Limit)	x			

Figure 2.10 Risk assessment matrix for snapper based on results of BDM.

2.5 Level 3 assessment: fishery-dependent length and age

Snapper samples for the fishery dependent length and age assessment were derived from commercial line catches west of 120°E. Ages were estimated from sectioned otoliths. Two sampling periods are reported and analysed: November 2012 to November 2014 (Norriss *et al.* 2016), and calendar year 2019. Oceanic caught snapper only (i.e., no estuarine sampling) were collected from throughout the year in each sampling period.

2.5.1 *Length frequency*

Although the MLL for snapper in the SCB is 410 mm TL, less than 10% of the catch was below 500 mm in both sample periods (Figure 2.11). This indicates a low release rate and associated discard mortality for the commercial line fishery because the capture of fish below the MLL is uncommon. This contrasts with the northern area of the WCB where the commercial line fishery has a relatively high frequency of length classes of retained snapper immediately above the same MLL (Fairclough *et al.* 2021). An estimated 24% of SCB snapper are expected to be sexually mature at the MLL (both sexes; Norriss *et al.* 2016). Full recruitment to the SCB fishery occurs at around 56 to 60 cm. The longest fish sampled for this assessment was 103 cm, and for any year by any sector in the SCB was 109 cm. The proportion below the estimated length at maturity (L_{50} = 543 mm, both sexes) was 19% and 20% in 2012-2014 and 2019, respectively. Increases were observed in mean (from 654 to 672 mm) and median (630 to 646 mm) lengths, and in the proportion of large fish (≥ 80 cm TL) from 15% to 22%. In conclusion, length frequency data show no indication of a decline in spawning stock between the two sampling periods.

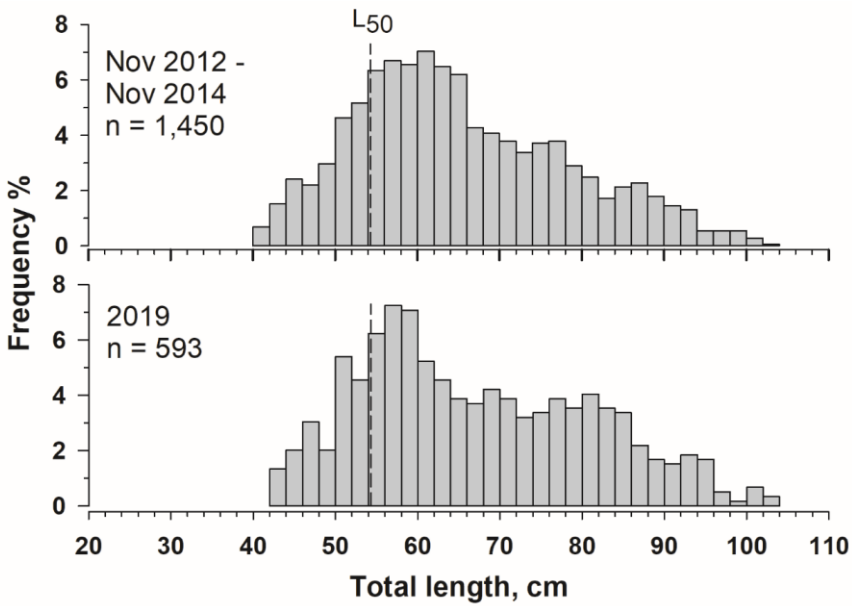


Figure 2.11 Length frequency distribution of snapper sampled from commercial line catch west of 120°E in the SCB from November 2012 to Nov 2014 and in 2019. Dashed lines denote estimated length at which 50% of fish (both sexes) attain sexual maturity in the SCB (L_{50}= 543 mm).

2.5.2 *Age frequency*

Snapper ages ranged from 2 to 37 years in the two sampling periods (Figure 2.12), noting that the oldest fish known from the SCB is 40.3 years (Norriss *et al.* 2016). Over all years, the combined proportion of the catch younger than the estimated age at sexual maturity (A_{50}= 4.3 years, both sexes) was 7%, and modal ages were 6 and 7 years in 2012-14 and 2019, respectively, suggesting full recruitment to the fishery after this age.

The age-frequency distribution was significantly different between the two sample periods (Kolmogorov-Smirnov test statistic D= 0.07, p< 0.05). The proportion of snapper aged 10 – 20 years was unchanged at 26% in both sampling periods, but for relatively old fish aged >20 years the proportion increased slightly from 2% to 3%. The persistence of these old fish in age composition samples demonstrates that, on average over the lifespans of the fish sampled, excessively high fishing pressure has not been sustained throughout this period. The mean and median age did not change substantially between sampling periods, remaining at 8.5 and 7 years, respectively.

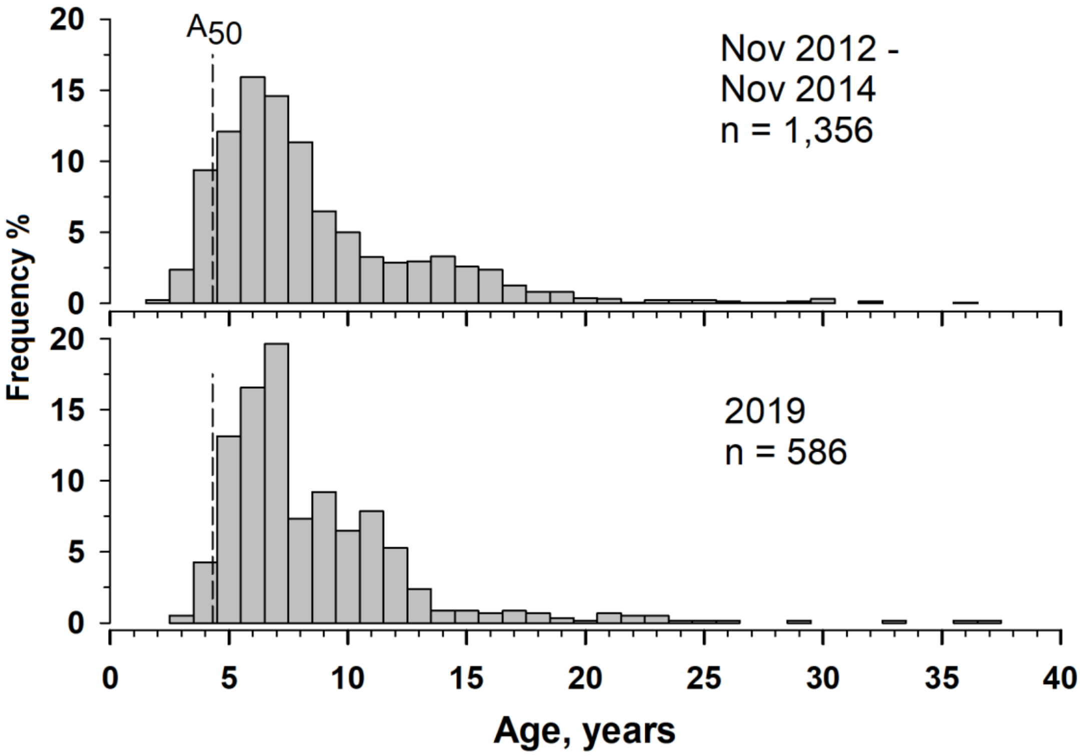


Figure 2.12 Age frequency distributions of snapper sampled from commercial line catch west of 120°E in the SCB from November 2012 to Nov 2014, and during calendar year 2019. Dashed lines denote estimated age at which 50% of fish (both sexes) attain sexual maturity in the SCB (A_{50}= 4.3 years).

In conclusion, although the age-frequency distributions were significantly different, they provide no evidence of a substantial decline in spawning stock biomass from 2012-2014 to 2019.

2.5.3 *Fishing mortality and per-recruit analysis*

Estimates of the instantaneous rate of total mortality (Z, year^{-1} ±95% c.i.) were derived by using the L3Assess catch curve analysis package in R (Hesp 2023a) to assess age-frequency data sets for two sampling time periods: November 2012 to November 2014, and calendar year 2019 (Figure 2.12). Three catch curve models with alternative modelling assumptions (Norriss *et al.* 2016) were fitted to each data set:

1. Linear regression catch curve.
2. Chapman & Robson (1960) estimator.
3. Multinomial catch curve with age-based, logistic selectivity.

The variable recruitment catch curve, considered the most reliable for the 2012-2014 sample (Norriss *et al.* 2016) could not be applied to the 2019 sample due as this method requires multiple years of age data, e.g. for 2 or 3 successive years.

Estimates of the instantaneous rate of fishing mortality (F, year^{-1} ±95% c.i.) were generated by deducting the point estimate of the instantaneous rate of natural mortality (M, year^{-1}) from Z (±95% c.i.). M was estimated using the method of Dureuil and Froese (2021):

$$M = -\log_{e}(0.015)/\mathrm{A}_{\mathrm{max}}$$

where A_{max} was the oldest snapper encountered in the SCB: 40.3 years. The result, M= 0.104 yr^{-1}, is very similar to those derived from alternative M estimators described by Hoenig (1983) (M= 0.103 yr^{-1}) and Hewitt and Hoenig (2005) (M= 0.104 $^{y-1}$), but notably less than the M= 0.135 yr^{-1} estimate used in a previous stock assessment (Norriss *et al.* 2016) based on a method no longer recommended (Hamel and Cope 2022, Maunder *et al*. 2023), i.e. incorporating estimates from Then *et al.* (2015).

The stock was assessed by comparing estimates of F/M to target (0.67, F= 0.07), threshold (1.0, F= 0.10) and limit (1.5, F= 0.16) reference levels. Estimates of (long term average) fishing mortality from catch curves were also used in per-recruit analysis to derive estimates of female spawning potential ratio (SPR) and female relative spawning biomass (B_{rel}) which were then compared to target (0.40), threshold (0.30) and limit (0.20) reference levels. Note that the estimates of SPR were derived from a traditional per-recruit model, whereas those for B_{rel} are from an extended model accounting for the effects of fishing on annual recruitment through incorporation of a stock-recruitment relationship. Models were constructed using the L3Assess per-recruit analysis package in R (Hesp 2023a).

For catch curve models assuming 'knife edge' selectivity, the age at full recruitment to the fishery was specified as the modal age plus one. The mode changed from 6 years in 2012-2014 to 7 in 2019. Pooling the data resulted in modes of 6 and 7 (equal frequencies), so full recruitment was based on the higher mode, i.e., 7 + 1 = 8 years.

For the 2012-2014 sample period the Chapman & Robson, logistic selectivity and the preferred variable recruitment models generated similar estimates of *Z* (Table 2.2). For the 2019 sample, however, all three available point estimates of *Z* were greater than the corresponding 2012-2014 estimates (noting that insufficient data were available for variable recruitment modeling). The 2019 estimates were similar from the linear and Chapman and Robson method, but the value from the method with age-based selectivity was substantially higher. Inspection of the age data from 2019 indicates that the 7+ age cohort likely experienced above-average recruitment, whereas the 8+ cohort may have experienced below-average recruitment (Figure 2.13). It is considered likely that the linear and Chapman and Robson methods are more 'robust' to impacts of recruitment variation, in part, as these methods only fitted to data for fish likely to be fully-recruited into the fishery, and also as they estimate a single parameter (*Z*) compared with three (A_{50}, A_{95} and *Z*) for the method assuming logistic age-based selectivity. Thus, the *Z* estimate from the Chapman Robson method is preferred.

Catch curve estimates of Z were used to calculate estimates of *F* and *F/M* which were compared with fishery performance reference levels (Table 2.3). For the 2019 sample all available point estimates of *F* were greater than the corresponding 2012-2014 estimates, noting that confidence intervals overlapped. Both the linear and Chapman & Robson estimates of *F/M* were between threshold and limit. The estimate of *F* from the catch curve assuming age-based logistic selectivity of *F* = 0.17 yr^{-1} (±95% c.i. 0.14-0.20; *F/M* = 1.64) breached the limit, but this estimate may be biased as discussed above. The catch curve models therefore indicate that the stock has experienced a relatively high level of fishing pressure.

Although previously published estimates of *F/M* for 2012-2014 indicated *F* had not breached the threshold reference level (Norriss *et al.* 2016), a re-assessment using currently accepted methods for estimating *M* suggests that *F* had indeed breached the threshold, but not the limit (Table 2.3) as in 2019 (excluding the age-based logistic selectivity catch curve).

Table 2.2 SCB estimates of the rate of total mortality *Z* (yr^{-1} ±95% c.i.) from commercial line samples taken west of 120°E from Nov 2012 to Nov 2014 and during 2019. NA= not available.

Sample Period	n	Linear	Chapman & Robson	Logistic Selectivity	Variable recruitment
2012-2014	1,356	0.217 (0.182-0.253)	0.227 (0.209-0.244)	0.239 (0.222-0.255)	0.240 (0.22-0.26)
2019	586	0.230 (0.185-0.275)	0.244 (0.214-0.273)	0.274 (0.247-0.304)	NA

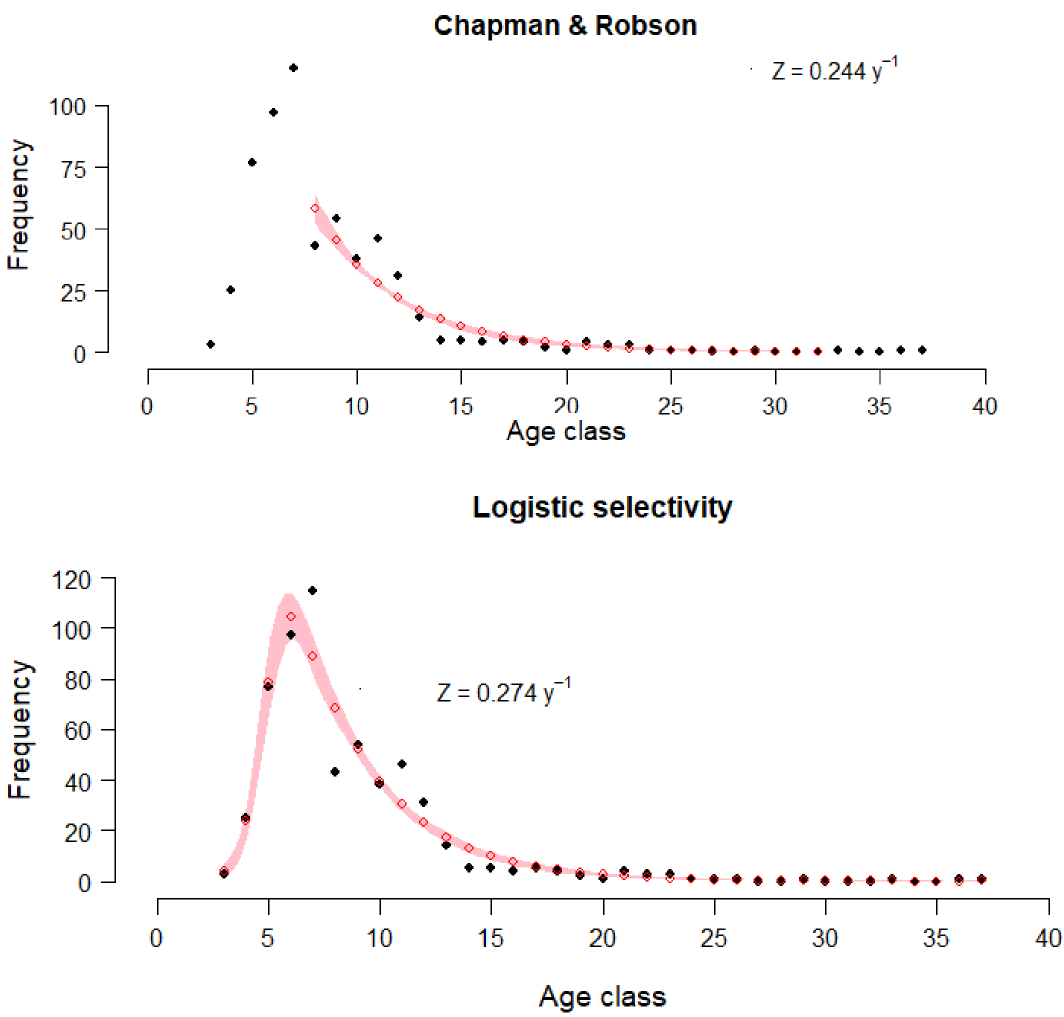


Figure 2.13 Chapman and Robson and logistic selectivity catch curve models fitted to the 2019 snapper age composition (±95% CL, red line) from commercial line catch west of 120°E in the SCB.

Table 2.3 Estimates of fishing mortality F (yr^{-1} ±95% c.i.) from 4 catch curve models for snapper in commercial line catches west of 120°00´E in the SCB. Colours denote fishery reference levels: orange between threshold (F = 0.10) and limit (F = 0.16), and red is above limit. NA= not available.

Sample Period	**Linear**		**Chapman & Robson**		**Logistic Selectivity**		**Variable recruitment**	
2012-2014	0.11	(0.08-0.15)	0.12	(0.10-0.14)	0.13	(0.12-0.15)	0.13	(0.10-0.16)
2019	0.13	(0.08-0.17)	0.14	(0.11-0.17)	0.17	(0.14-0.20)	NA	

Per-recruit analysis parameters for estimating SPR and B_{rel} (±95% CIs) are provided in Table 2.4 (in addition to the Chapman & Robson *F* estimate above), and various diagnostic plot outputs are presented in the Appendix. Confidence intervals were estimated by resampling (n= 300) within probability distributions provided in Table 2.4. Release and discard mortality rates and are unknown for the SCB commercial line fishery and have been excluded from the analysis. However, they are expected to be low given the low frequency of length classes just above the MLL (410 mm TL) in the retained catch (Figure 2.11 and section 2.5.1 above). In contrast, the length distribution of commercially and recreationally line caught snapper in the northern area of the WCB, where the MLL is identical, shows high frequencies for fish immediately above MLL (Fairclough *et al.* 2021). Results of the per-recruit analysis are therefore expected to be marginally optimistic.

All female SPR and B_{rel} estimates decreased from 2012–2014 to 2019, and all estimates from the 2019 sample breached the threshold reference level except the SPR estimate based on linear catch curve results (Table 2.5). The most reliable estimate for 2019, B_{rel} based on the *F* estimate from the Chapman and Robson method, had breached the threshold: B_{rel} = 0.22 (0.17-0.27). The probability of this B_{rel} estimate breaching the limit is estimated to be ~23%, based on the distribution of re-sampled estimates of B_{rel} (n=500).

Although previously published SPR and B_{rel} estimates based on 2012-2014 sampling showed no breach of the threshold (Norriss *et al.* 2016), a re-assessment using an updated method for estimating *M* suggests that they had in fact breached the threshold, but not limit, at that time (Table 2.5).

In conclusion, age-based per-recruit analysis based on the 2019 age composition sample data indicates the snapper spawning stock west of 120° E in the SCB were likely between the threshold and limit reference level (Figure 2.14). The corresponding estimates for 2012–2014 are similar but slightly higher than 2019. Impacts of recruitment variability on catch curve estimates and assumptions of the analyses (including equilibrium mortality and recruitment) increase the level of uncertainty of assessment results. Thus a precautionary approach is taken in considering the likelihood of breaching the limit to be marginally Possible, given per-recruit analysis suggests the likelihood is on the margin of Unlikely and Possible (~20%) and the absence of PRM from the analysis (Figure 2.15).

Table 2.4 Parameters used in SCB snapper per-recruit analysis.

Variable/Parameter	Value	Source
Max age ($A_{max}\ years$)	40.3	Norriss *et al.* (2016)
Natural mortality ($M\ year^{-1}$)	0.104 (sd=0.01)	$-log_e(0.015)/A_{max}$ (Dureuil and Froese 2021)
Growth (females)		von Bertalanffy growth curve fitted (Wakefield *et al.* 2016)
$L_{\infty}(mm\ TL)$	1,013	
$K\ year^{-1}$	0.11	
$t_0\ (years)$	-0.94	
Weight-length (g, mm TL, both sexes)		$W = aTL^b$ (SCB snapper, Smallwood *et al.* 2018)
a	0.000095	
b	2.6734	
Maturity (logistic, females)		Norriss *et al.* (2016)
A_{50} (years) A_{95} (years)	4.6 13.8	
Selectivity of landings (2012–2014, 2019; both sexes)		Age-based logistic selectivity catch curve (Hesp 2023a)
A_{50} (years) A_{95} (years)	4.366, 4.940 6.067, 6.416	
Steepness of Beverton-Holt stock recruitment curve.	0.75 (sd=0.025)	Punt *et al.* (2011).

Table 2.5 Female SPR and B_{rel} estimates (±95% CIs) for snapper taken by commercial line fishing west of 120°00' in the SCB. Colours denote results relative to the reference levels: yellow is point estimate between target (0.40) and threshold (0.30), orange between threshold and limit (0.20), red is below the limit. NA= not available.

Sample Period	Linear		Chapman & Robson		Logistic Selectivity		Variable recruitment	
	SPR1	B_{rel}	SPR1	B_{rel}	SPR1	B_{rel}	SPR1	B_{rel}
2012-2014	0.32 0.27-0.36	0.26 0.20-0.31	0.30 0.25-0.34	0.23 0.17-0.28	0.27 0.23-0.32	0.21 0.15-0.26	0.27 0.23-0.31	0.21 0.15-0.26
2019	0.31 0.26-0.36	0.25 0.19-0.30	0.28 0.23-0.33	0.22 0.17-0.27	0.24 0.21-0.28	0.17 0.13-0.23	NA	NA

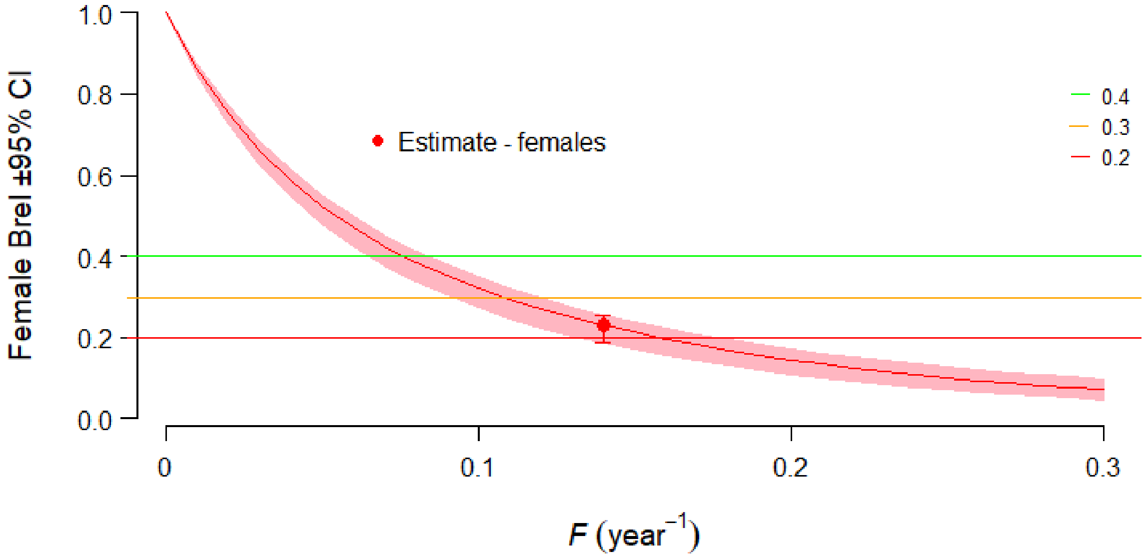


Figure 2.14 Female snapper spawning potential ratio (a proxy for breeding stock biomass relative to unfished biomass) for different levels of fishing mortality using the preferred extended per recruit analysis (B_{rel} ±95% CI)) of 2019 age sample. Point estimate corresponds to the Chapman and Robson estimate of F, considered most reliable. Coloured lines are performance reference levels: target (0.40), threshold (0.30) and limit (0.20).

Consequence (Stock Depletion) Level	**Likelihood**			
	L1 Remote (<5%)	**L2 Unlikely (5-20%)**	**L3 Possible (20-50%)**	**L4 Likely (>50%)**
C1 Minor (above Target)				
C2 Moderate (below Target, above Threshold)				
C3 High (below Threshold, above Limit)				**X**
C4 Major (below Limit)			**x**	

Figure 2.15 Risk assessment matrix based solely on preferred female B_{rel} estimate depicted in Figure 2.14: extended per recruit analysis using Chapman & Robson estimate of *F*. A severe score is indicated (red).

3.0 Bight redfish (*Centroberyx gerrardi*)

3.1 Bight redfish summary

Bight redfish occur across the continental shelf of WA's lower west and south coasts. Similarity in genetic composition and elemental signatures in otoliths in the WCB and SCB, along with likely egg and larval recruitment from the former to the latter, indicate connectivity between the two regions. However, variation in life history parameters between fish in those regions suggest some separation of stocks post-settlement.

In the SCB Bight redfish are exceptionally long lived (maximum observed age 84.6 years) with late maturity. Catches are dominated by the commercial line fishery which have been ranged from 12 to 48 t since the late 1980s. They have been maintained without a discernible progressive shifting of the areas fished from abandoned to new grounds that, otherwise, could be indicative of unacceptable stock depletion. Results of catch-MSY modelling suggest that catches have been mostly below MSY, and therefore, that it is plausible that stock levels have remained above B_{MSY}. A BDM applied to commercial line-based catch rates estimated biomass levels that were at or above that corresponding to B_{MSY} in recent years, although there was a substantial source of uncertainty likely from limited understanding of changes in fishing efficiency over the history of the fishery.

Catch rates by the GABTS (managed by the Australian Government) in the far eastern SCB (east of 126°S) declined from years 2007 to 2018 and catch sampling has shown a progressive reduction in fish size which is consistent with a greater reliance on younger fish. However, the large majority of catch by that GABTS is taken off the South Australian coast, and the GAB stock is independently assessed as adequate and not overfished.

The previous age-based Level 3 stock assessment from 2012-2014 catch sampling, which indicated a medium risk level (Norriss *et al.* 2016), has been updated using a revised method for estimating the rate of natural mortality. The re-assessment indicates the rate of fishing mortality had breached the threshold reference level at that time, and relative spawning biomass (B_{rel}) was between target and threshold. Additional commercial line catch sampling in 2019 showed a reduction in length and increased reliance on younger fish (<20 years) between sample periods, but no discernible change in the proportion of old fish (>40 years). Catch curve modelling of the 2019 sample age-frequency distribution indicates fishing mortality breached the limit reference level. Per-recruit analysis indicates a reduction in relative spawning biomass (B_{rel}) from 2012-2014 to a level in 2019 that breached the threshold but not the limit.

Consequently, the SCB Bight redfish stock status is **HIGH** risk.

3.2 Risk-based weight of evidence summary table and matrix

Level	Line of evidence
1.1 Biology and vulnerability	Bight redfish have a high inherent vulnerability to overfishing due to exceptional longevity and late age at sexual maturity. They are targeted throughout their natural distribution on the continental shelf in southern WA. While eggs and larvae from spawning in the WCB are likely to support SCB recruitment, life history parameters suggest subsequent life stage separation between SCB and WCB stocks. PSA for Bight redfish generated a productivity score of 1.86 and susceptibility score of 2.33, resulting in an overall score of 2.98, i.e. a medium risk (Appendix).
1.2 Catch	The catch is dominated by the commercial line fishery which have landed between 12 and 48 t annually since the late 1980s. Recreational catches have varied between 10 and 15 t in integrated surveys since 2011-12, and the annual tour operator catches have ranged from 2 to 8 t since 2001-02.
1.3 Spatio-temporal distribution of catch	Catches in the dominant commercial line fishery have been mostly west of 120° E and a smaller component east of 126° E. Finer scale spatial information (10’ x 10’ blocks) since the inception of the SCLTMF in 2021-22 shows catches are mainly taken along the outer continental shelf. Across the bioregion there was no evidence that catch levels have been maintained by a progressive shifting in the areas fished from abandoned to new grounds that, otherwise, could be indicative of unacceptable stock depletion.
1.4 Catch-MSY analysis	Catch-MSY modelling indicates catches have been mostly below MSY suggesting that it is plausible that stock levels have remained above B_{MSY} (i.e. above ~0.5). Note that the Catch-MSY assessment method is a data-poor method with very strong assumptions, and results should be treated with caution.
Level 1 assessment Annual catches in the dominant commercial line fishery have been maintained without a discernable shift in the areas fished, providing no evidence of unacceptable stock decline. Catch-MSY modelling indicates catches have been mostly below MSY and that it is plausible that stock levels have remained above B_{MSY} (i.e. above ~0.5). Level 1 assessment is consistent with minor to moderate stock depletion.	
2.1 Effort and catch rate	For modelling, CPUE time series have been adjusted with an assumed 2% annual increase in fishing efficiency per year for both commercial dropline and handline. The adjusted dropline

	CPUE exhibits a declining trend from 1984 through to the mid-late 1990, before fluctuating at relatively lower levels in most subsequent years. Adjusted CPUE in several recent years were at similar levels to those recorded in the late 1980s and early 1990s. The adjusted handline CPUE, which starts in 2001, exhibits similar trends to that just described for adjusted dropline CPUE, although in 2014-2018, the levels were lower than for handline CPUE, when compared to respective values recorded in earlier years. In the far east of the SCB catch rates in the GABTS show a substantial downward trend from an historical high in 2007 to an all-time low in 2018, possibly driven by historical fishing pressure and/or environmental changes, although the GAB stock has been independently assessed as not overfished and not subject to overfishing.
Level 2 assessment A state space BDM (Winker *et al.* 2018), using the Schaefer production function, was fitted to annual catches and commercial CPUE for Bight redfish in the SCB (SCB). Results from the analysis yielded a MSY point estimate of 49 t. In recent years, estimated biomass levels were at or above that corresponding to B_{MSY}. Thus, the estimated current ratio of biomass to B_{MSY} (B/B_{MSY}) was 1.00 (95% CLs, 0.36-2.16) and the estimated fishing mortality in recent years is just below F_{MSY} (F/F_{MSY} = 0.95, 95% CLs = 0.29-2.59). A substantial source of uncertainty in this assessment analysis likely relates to limited understanding regarding changes in fishing efficiency occurring over the history of the fishery. The results produced from the BDM indicate that the Bight redfish stock is currently fully exploited, with estimated current fishing mortality and biomass both at around their respective threshold levels (i.e. B_{MSY} and F_{MSY}). Thus, the stock is not currently estimated to be overfished. Uncertainty in assessment results is increased due to differing CPUE signals in recent years (droplining vs handlining), and so minor, moderate and high depletion levels are possible, but with only a remote prospect of a major depletion. GABTS catch rates in the far east of the SCB indicate a significant downward trend in abundance, possibly driven by historic fishing pressure, although the stock has been independently assessed not overfished and not subject to overfishing.	
3.1 Length composition	Sampling of fish to derive length frequency information was undertaken in various periods from 2010 to 2019. Progressive reductions in the proportions of large fish and the mean and median lengths have occurred over this period, consistent with a progressive reduction of spawning biomass due to high fishing mortality. Trawl surveys in the far west of the GAB show a substantial

<table>
<tr><td></td><td>increase in mean length since 2005, which together with declining abundance (see 2.1 above) may be indicative of poor recruitment to this area.</td></tr>
<tr><td>3.2 Age composition</td><td>Although there has been little change in the proportion of old fish (>40 years) between the 2012–2014 and 2019 catch sampling periods, for ages 20 to 39 there was a decline from 42% to 36% with a concurrent increase from 52% to 59% for ages <20 years. These trends are consistent with impacts of fishing on the stock, but may also reflect, in part, a shift to increased fishing activity in shallower waters (but this was not detected in available data).</td></tr>
<tr><td>3.3 Fishing mortality and per-recruit analysis</td><td>Results from two age-based (equilibrium) catch curve models indicate that long-term average fishing mortality (F yr^{-1} ±95%CI) in 2019 breached the limit reference point: 0.08 (0.06-0.09). Although previously published estimates of F for 2012–2014 indicated that it had not breached the threshold reference level, a re-assessment using a revised methods for estimating natural mortality (M yr^{-1}) shows that F had likely breached the threshold, but not limit, reference level at that time. All available catch curves show that F increased between 2012–2014 and 2019. Catch curve modelling therefore indicates an unacceptably high rate of fishing mortality.

All available estimates for female SPR and relative biomass (B_{rel}) indicate a reduction in breeding stock levels from 2012–2014 to 2019. The most reliable estimate for 2019, B_{rel}= 0.28 (0.21-0.24), indicates a breach of the threshold reference level but not the limit.</td></tr>
<tr><td colspan="2">Level 3 assessment

SPR estimates indicate that a reduction in breeding stock has occurred between 2012-2014 and 2019. This reduction is consistent with a change in the length and age composition and can be explained by the finding of an unacceptably high rate of fishing mortality that breached the limit reference point. The 2019 B_{rel} estimate suggests spawning stock has breached the threshold reference level, with no prospect of a breach of the limit.</td></tr>
<tr><td colspan="2">Final risk

C1 (Minor depletion – above target): consistent with Level 1 assessment, possible according to Level 2 assessments but not plausible according to Level 3 assessment. Likelihood of minor depletion is therefore assessed as Remote.

C2 (Moderate depletion – between target and threshold): consistent with the Level 1 assessment and possible according to both Level 2 and 3 assessments. Likelihood of moderate depletion is therefore assessed as Possible.

C3 (High depletion- between threshold and limit): Not consistent with Level 1 assessment, possible according to Level 2 assessment and likely according to</td></tr>
</table>

Level 3 assessment. Likelihood of high depletion is therefore assessed as **Likely**.

C4 (Major depletion – below limit): not consistent with Level 1 assessment, only a remote possibility according to Level2 assessment, and implausible according to Level 3 assessment. Likelihood of major depletion is therefore assessed as **Implausible**.

The SCB Bight redfish risk matrix shows the maximum consequence-likelihood rating to be a **HIGH risk** (C3 x L4).

SCB Bight redfish risk matrix

Consequence (Stock Depletion) Level	Likelihood			
	L1 Remote (<5%)	L2 Unlikely (5-20%)	L3 Possible (20-50%)	L4 Likely (>50%)
C1 Minor (above Target)	x			
C2 Moderate (below Target, above Threshold)			X	
C3 High (below Threshold, above Limit)				x
C4 Major (below Limit)				

3.3 Level 1 assessment: biology, vulnerability and catch

3.3.1 *Biology and vulnerability*

Bight redfish are naturally distributed across southern Australia's continental shelf. They have a high inherent vulnerability to overfishing due to several contributing biological factors, including an exceptionally high maximum observed age of 84.6 years and a maximum recorded length in WA of 706 mm TL (Norriss *et al.* 2016). Bight redfish are gonochorists (separate sexes) with considerable spatial variation in age and length at sexual maturity and other reproductive parameters (Table 3.1, Coulson *et al.* 2019). Spawning in the lower west coast of WCB is expected to contribute to subsequent recruitment in the SCB, given the likely trajectory of ocean currents for conveying eggs and larvae during the spawning season. Growth curves also differ considerably between regions (Table 3.2), suggesting subsequent life stage population separation between SCB and WCB stocks.

In the SCB Bight redfish are taken in outer shelf waters by the Australian Government managed GABTS (Moore *et al.* 2022). Genetic homogeneity of populations across WA and GAB populations provide no evidence of biological stock separation, but some separation based on otolith chemistry between WA and the main GAB fishing grounds off the South Australian coast has been observed (Norriss *et al.* 2016).

Bight redfish are likely to be strongly resistant to barotrauma based on a tagging study of the closely related *Centroberyx affinis* in a trawl fishery on Australia's east coast (Rowling 1990). Many recaptures were recorded of fish taken from depths ranging from 73 to 360 m. This is also supported for Bight redfish by anecdotal reports from fishers.

Table 3.1 Bight redfish mean age at which 50% (A_{50}) and 95% (A_{95}), and mean length at which 50% (L_{50}) and 95% (L_{95}), become sexually mature. For Cape Naturaliste to Cape Leeuwin in the lower WCB (Capes), and west (WSC) and east (ESC) of 120° E in the SCB. From Coulson *et al*. (2019).

Region	A_{50}, years		A_{95}, years		L_{50}, mm TL		L_{95}, mm TL	
	Female	Male	Female	Male	Female	Male	Female	Male
Capes	5-9	13.6	-	-	307	420	696	697
WSC	11.9	22.2	40.8	71.2	389	482	775	901
ESC	21.0	23.3	34.6	33.9	512	560	560	726

Table 3.2 von Bertalanffy growth parameters (±95% CI) for Bight redfish from the Southern Management Zone of WCB and the adjacent western sub-region of the SCB. Estimates generated using R package by Hesp (2023b). Sexes pooled.

Region	L_{∞}	k (year^{-1})	t_0 (years)
WCB Capes	560 (555-565)	0.11 (0.10-0.12)	-2.0 (-3.1- -0.8)
SCB west of 120° E	596 (587-603)	0.07 (0.07-0.08)	-3.4 (-4.3- -2.5)
SCB east of 120° E	586 (575-598)	0.08 (0.07-0.09)	-1.7 (-2.6- -0.8)

3.3.2 *Catch*

Early attempts to commercially fish Bight redfish in various parts of the GAB date back to at least trawling in 1929, with small mixed catches taken. CAES records since 1975 show some relatively high GAB exploratory trawl catches by foreign vessels operating under State and Australian Government fishing arrangements were recorded between 1975-76 and 1977-78 (Figure 3.1).

Commercial "open access" (not a formally managed fishery) catches, predominantly by line from throughout the continental shelf, but with small quantities by trap and restricted net fishing, started to increase in the early 1980s and since 1995 have far exceeded other fisheries, landing around 60% of the total catch. All catches in blocks straddling the WCB boundary at 115°30'E (i.e., between 115°00'E and 116°00'E) have been included in this assessment if they could not be allocated between bioregions (business rules are being developed to account for allocation of such catches to the appropriate bioregion). This fishery was supplanted by the South Coast Line and Trap Managed Fishery (SCLFTMF) from 1 July 2021. The catch is sometimes reported as "redfishes" and there are also catches of "yelloweye redfish", but extensive sampling indicates >99% to be Bight redfish (Norriss *et al.* 2016). Most is taken in the western part of the SCB, i.e., west of 120°E (Figure 3.2). Since 1997-98 the commercial sector has taken between 20 and 49 t annually, with no apparent long term trend.

Annual catches by the SDGDLMF, which targets sharks, have ranged from a relatively low 2 to 10 t since year 2000. The Australian Government managed GABTS take Bight redfish from the outer continental shelf east of 126°E (about 380 km east of Esperance) (Moore *et al.* 2022, Nitschke *et al.* 2022). The vast majority of GABTS's catch has been from east of the South Australian border, and the WA component has little spatial overlap with the SCLTMF.

The tour operator annual catch ranged from 2 to 8 t since 2001-02. Five estimates of the annual boat-based recreational catch generated between 2011-12 and 2020-21 have ranged from about 10 to 15 t. The numbers of Bight redfish reported as caught during each integrated survey of private boat-based fishers ranged from a minimum of ~8,200 in 2020-21 to a maximum of ~11,400 in 2020-21, with 14-35% of Bight redfish caught being released. Information on the weight of released Bight redfish is unavailable. Post-release mortality rates are unknown but expected to be low based on a tagging study of the closely related *Centroberyx affinis* in a trawl fishery on Australia's east coast (Rowling 1990).

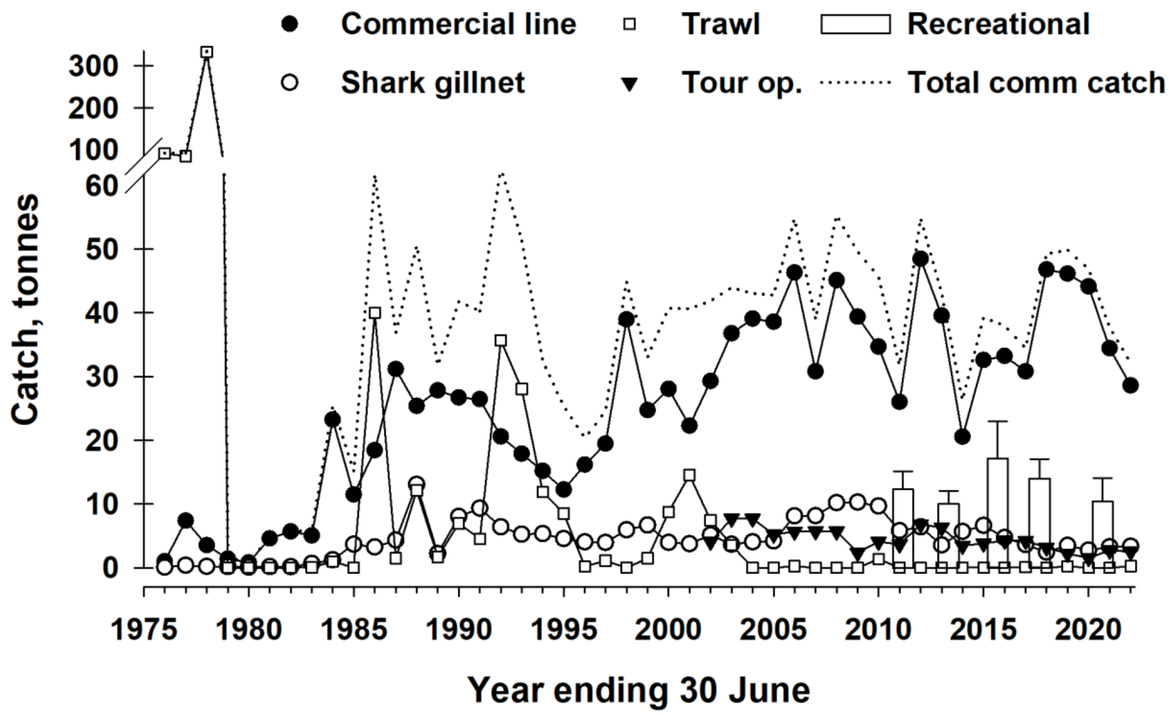


Figure 3.1 Total annual Bight redfish catch in the SCB by sector from 1975-76 to 2021-22, including total annual commercial catch. The federally managed GABTS catch is excluded. Commercial line includes open access commercial line, net and trap, and the SCLFTMF since its inception in 2021-22. Shark gillnet includes catches in the SDGDLMF and prior to its inception in 1988, all longline catches. Private recreational catch (± 1 std. err.) is boat-based only. All catches in blocks straddling the WCB boundary at 115°30'E (i.e., between 115°00'E and 116°00'E) have been included if they could not be allocated between bioregions, e.g., from commencement of West Coast Demersal Interim Managed Fishery in 2008.

3.3.3 *Spatio-temporal distribution of catch*

The spatio-temporal distribution of the dominant commercial line catch in the SCB since 1975/76 shows the large majority was taken from west of 120° E, particularly near the major human population centers of Albany and Bremer Bay, especially the former (Figure 3.2). Some expansion occurred west of 117° E after 2000. Near Esperance, a decline from 2010/11 to 2014/15 was followed by an increase to historically high catches in this area from 2015/16 to 2021/22. A finer spatial resolution (10' x 10') facilitated by the inception of the SCLFTMF in 2021-22 shows higher catches are concentrated along the continental shelf edge (Figure 3.3). A shift in fishing operations between shelf edge and shallower waters may impact the length and age distribution of the catch, but this cannot be detected with the 1°x1° blocks available. Across the SCB, however, there was no evidence that catch levels have been maintained by a progressive shifting in the areas fished from abandoned to new grounds indicative of unacceptable stock depletion.

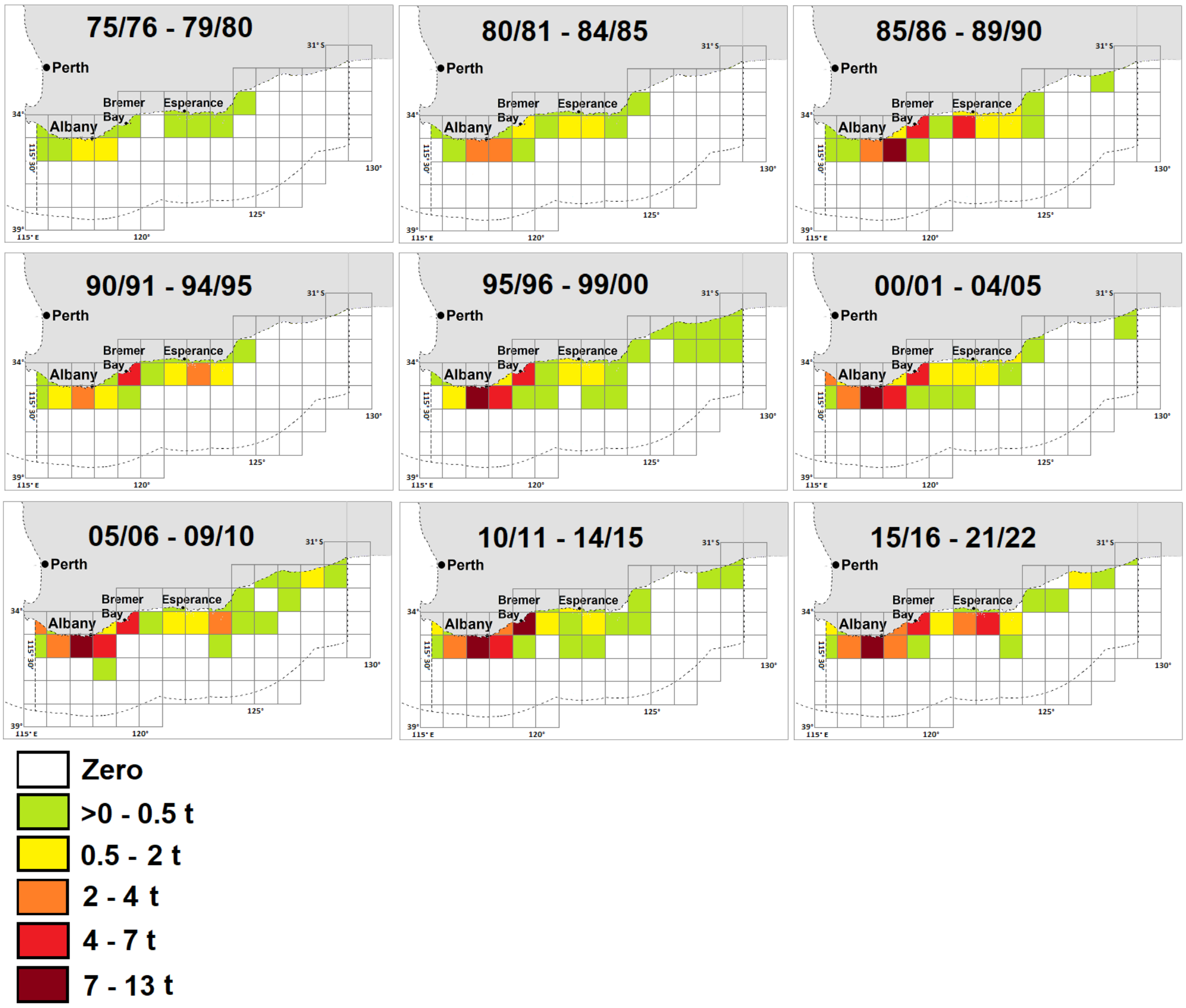


Figure 3.2 Spatial distribution (1°x1° block) of the average annual Bight redfish commercial line catch in the SCB from 1975/76 to 2021/2022. Years ended 30 June.

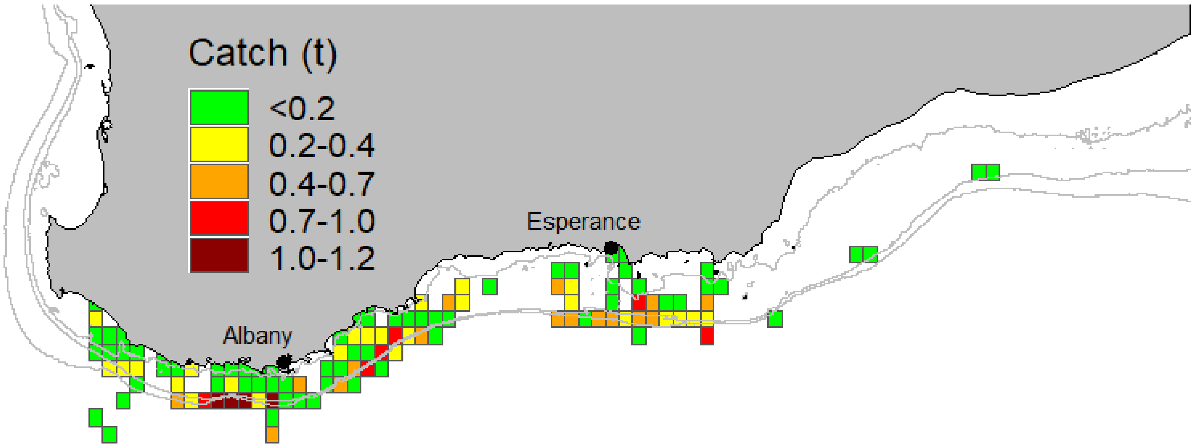


Figure 3.3 Spatial distribution of the SCLFTMF Bight redfish catch for the first year of fine scale (10'x10' block) reporting in 2021-22. Bathymetry lines correspond to 50m, 100m and 200m depth.

3.3.4 *Catch-MSY analysis*

Catch-MSY models were used to predict maximum sustainable trends in fishing mortality and levels of depletion based on knowledge of SCB Bight redfish biology and catch history, using the datalowSA package in R (Haddon *et al.*, 2019). Assumptions included a low stock resilience (r= 0.1 - 0.6), and initial and final depletion ranges of 0.5 – 0.9 and 0.1 – 0.8, respectively. The initial depletion range was set lower than the program default (0.5 – 0.975) to reflect the large GAB exploratory trawl catches between 1975/76 and 1977/78. The very wide final depletion range was chosen after trialing narrower ranges resulted in the model excluding a significant number of possible trajectories. The catch time series for the analysis therefore commenced from 1978/79 and comprised total retained annual catch from all sectors for each year ended 30 June. Recreational catch estimates were available from five annual surveys between 2011/12 and 2020/21 (Ryan *et al.* 2022), recently revised and slightly different to earlier published estimates. These surveys did not align exactly with years ending 30 June so were allocated to the nearest such year and linearly interpolated for intermediate years' estimates. Recreational catch estimates for 1978/79 to 2010/11 were calculated as a linear function of the estimated number of registered boats in WA in those years. These estimates were generated from the rate of ownership of boats per head of population in the Perth metropolitan region that increased from 1990 to 2007 (Department for Planning and Infrastructure 2009), extrapolating this increasing rate forward (to 2010/11) and backward (i.e., decreasing rate, to 1978/79) for the total WA population (source: Australian Bureau of Statistics), and assuming catch per boat for 1978/79 to 2010/11 equaled the mean for the years 2011/12 to 2020/21. Tour operator catch estimates were available from 2001/02 to 2021/22. Earlier years were estimated assuming the same catch per head of the WA population as the mean from 2001/02 to 2021/22.

The set of plausible r-K combinations indicate a MSY (±95%CLs) of 68 t (43 – 102) (Figure 3.4), with catches in most years being below this level. This is consistent with simulated stock depletion levels remaining mainly stable and above B_{MSY} (i.e. above ~0.5) (Figure 3.5). Note that the Catch-MSY is a data poor method with strong assumptions, and thus results should be treated with caution.

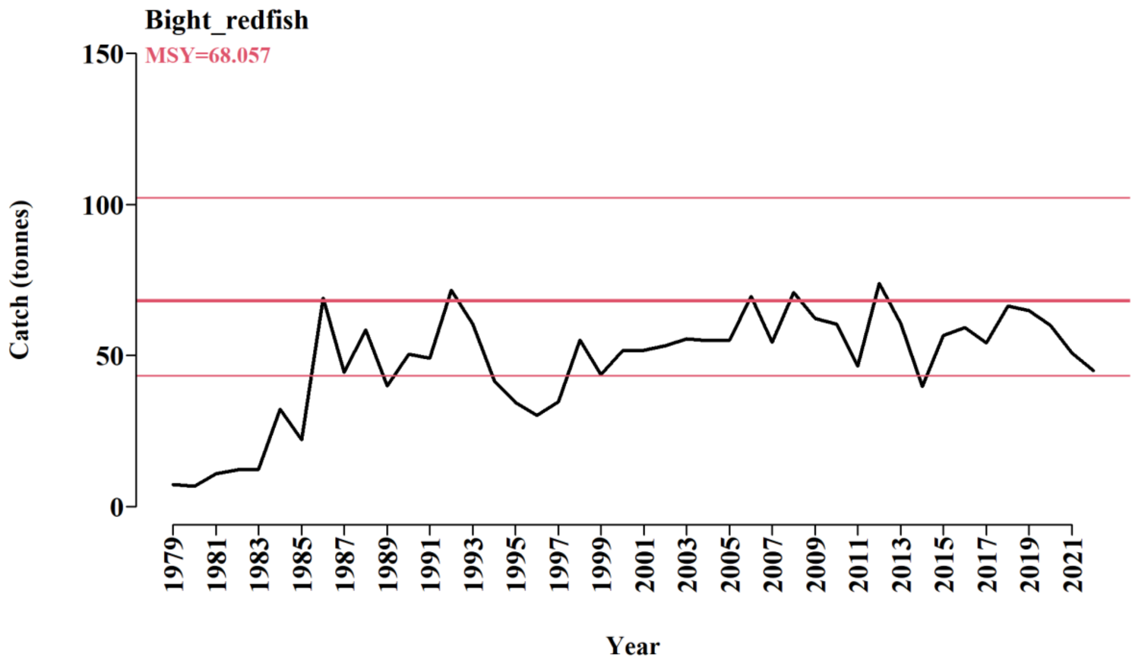


Figure 3.4 Total annual SCB catch (all sectors) from 1978/79 to 2021/22 used for SCB Bight redfish Catch-MSY assessment vs estimated MSY (±95%CLs).

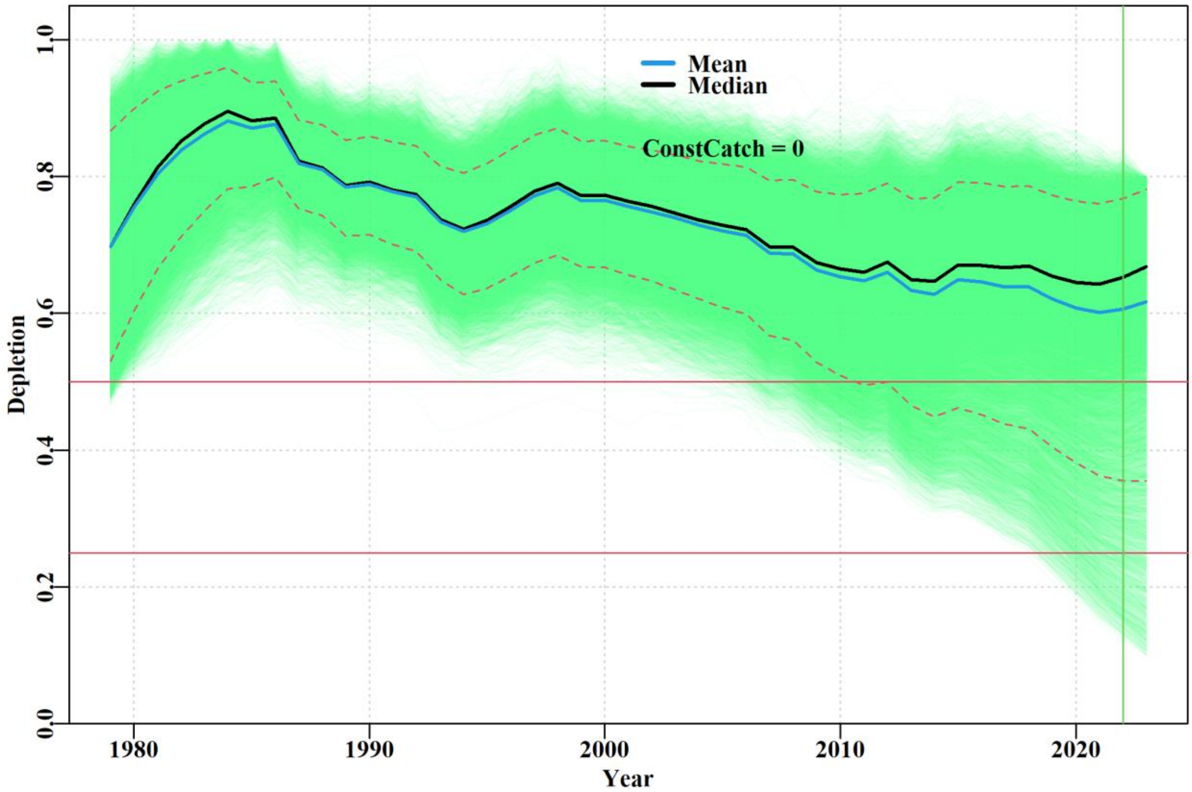


Figure 3.5 Trajectories of SCB Bight redfish stock based on Catch-MSY analysis. Dashed lines are 95% confidence levels.

3.4 Level 2 assessment: effort and catch rate

3.4.1 *JABBA: state-space Schaefer biomass dynamics model*

3.4.1.1 *Model description*

A state-space Schaefer BDM (see section 2.4.1.1) was applied using catch and commercial catch per unit effort (CPUE) data for Bight redfish in the SCB to provide estimates of biomass and fishing mortality relative to biological reference points. The model was fitted to annual total catches (commercial, recreational, charter and historical) and annual CPUE data from commercial line fishing, where the latter is assumed to provide an index of spawning stock abundance. The following priors were assumed for Bight redfish: a lognormal prior for carrying capacity (K) with mean = log(2000) and sd = 1, a lognormal prior for the intrinsic rate of population increase (r) with mean = log(0.1) and sd = 0.2, a lognormal prior for the initial starting biomass (Ψ) with mean = log(0.6) and sd = 0.2. The Initial biomass value assumes light-moderate fishing occurring prior to the first year of recorded catches. The assumption of “low resilience” (r=0.1) is considered appropriate for this species given its maximum age (~84 years) (Norriss *et al.* 2016) and the empirical relationship between r and natural mortality (Zhou *et al.*, 2016). These priors covered assumed biologically feasible ranges for these parameters for Bight redfish. Process error variance was specified as 0.3 with sensitivity runs (not shown in this document) conducted for values of 0.2 and 0.4. Standard fisheries reference points were calculated including MSY ($MSY = rK/4$) and the biomass corresponding to MSY ($B_{MSY} = 0.5\,K$) (Carruthers *et al.*, 2014; Froese *et al.*, 2017; Haddon, 2011).

3.4.1.2 *Data inputs*

The available time series of commercial catch of Bight redfish extends from 1978-79 to 2020-21 (Figure 3.6). CPUE (kg of retained catch per fishing hour) were generated from monthly Catch and Effort Statistics (CAES) returns for line-based methods, which are the predominant methods used to take Bight redfish. Zero to negligible catches by longlining, which is only permitted in the SDGDLMF, were excluded, as were polling and squid jigging as they are not normally used to take demersal fish. Data from 2021-22 was excluded from analysis as it was the first year the fishery transitioned to daily reporting. A catch record was defined as the landing of Bight redfish (kilograms, liveweight) in each block, for each month, for each method, for each licensed fishing boat. The effort for that catch record was hours fished in that block (=block days x hours fished per day) using that method in that month by that vessel. The median CPUE was calculated for each year and 95% confidence intervals estimated from 1,000 bootstrap resamples with replacement. Records of block days and hours fished per day greater than 31 and 24 respectively were excluded, as were records of 400 hours of fishing per month in a block. To reduce the influence of variation in targeting intensity on CPUE, only catch records above the 10% quantile for liveweight in each year were included in the analysis (Norriss *et al.* 2016).

Two CPUE series were included in the model (dropline and handline). In years up to 1983-84, levels of catch and effort associated with handline and dropline fishing for bight redfish were very low, suggesting that CPUE calculated prior to this time may be unreliable. Thus, for modelling, CPUE were only included from 1985. Both CPUE time series were adjusted to account for an assumed increase in fishing efficiency (2% per year from their respective start years, to 2021). Note that for this L2 modelling analysis, the 'years' for the catch and CPUE time series and model outputs relate to financial years rather than calendar years, e.g. 1979 is the 1978/79 financial year.

3.4.1.3 *Results and implications*

The JABBA model provided relatively good visual fits to annual adjusted CPUE time series for Bight redfish for most years (Figure 3.7). In several years from 2014 to 2018, CPUE was underestimated by the model for dropline fishing but overestimated by the model for handline fishing, indicating that, during this period, the two CPUE series were not providing the same signal. For future research, it is recommended that this issue be explored through formal CPUE standardisation analyses (e.g. using GLMs).

Outputs from the Bight redfish assessment suggest that the current level of catch is just below the estimated MSY for the stock of 49 t (95% CLs: 22-156t) (Table 3.3). The results from the BDM indicate the Bight redfish stock abundance fluctuated below B_{MSY} since the start of 1990 until mid-2010's, before showing an increasing trend to be at or above B_{MSY} in recent years (Figure 3.8). Estimates for fishing mortality (F) were below F_{MSY} until 1990, after which they are estimated to have been at or above F_{MSY}.

Fishing efficiency was specified as 2% per year from 1984 to 2021. The assumption of no increase in fishing efficiency was considered infeasible due to the introduction of technology such as GPS in the early 1990s, combined with other factors such as changes in fishing knowledge and experience.

The results produced from the BDM indicate that the bight redfish stock is currently fully exploited, with estimated current fishing mortality and biomass both at around their respective threshold levels (i.e. B_{MSY} and F_{MSY}). Thus, the stock is not currently estimated to be overfished. Uncertainty in assessment results is increased due to differing CPUE signals in recent years (droplining vs handlining). The possibility, from the BDM, that the stock is between the threshold and limit reference points generates a High risk score (Figure 3.9).

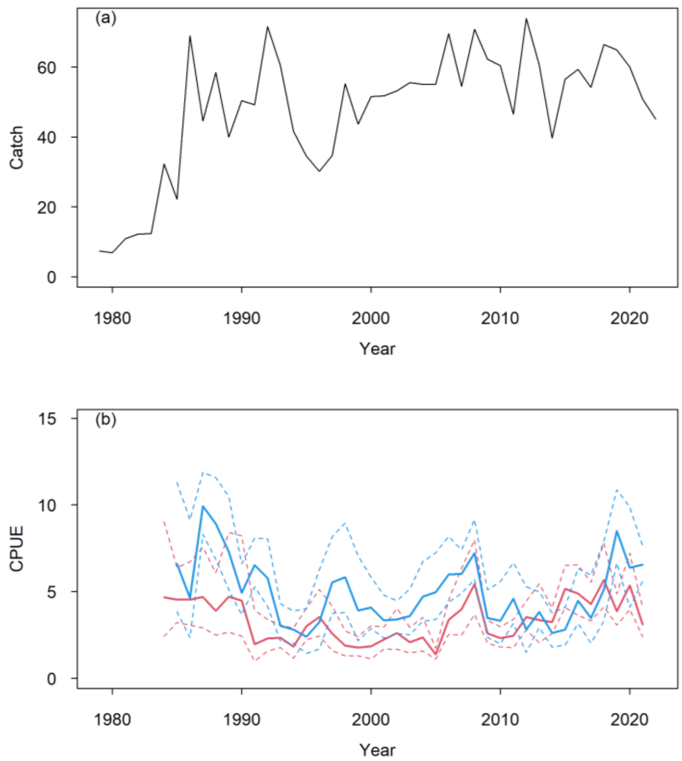


Figure 3.6 Total bight redfish catch (tonnes, t) in the SCB and commercial annual CPUE series for both dropline (red) and handline (blue) fishing. Solid lines denote mean CPUE, and dashed lines indicate associated 95% confidence limits. All CPUE time series have been adjusted for an assumed efficiency increase of 2% per year.

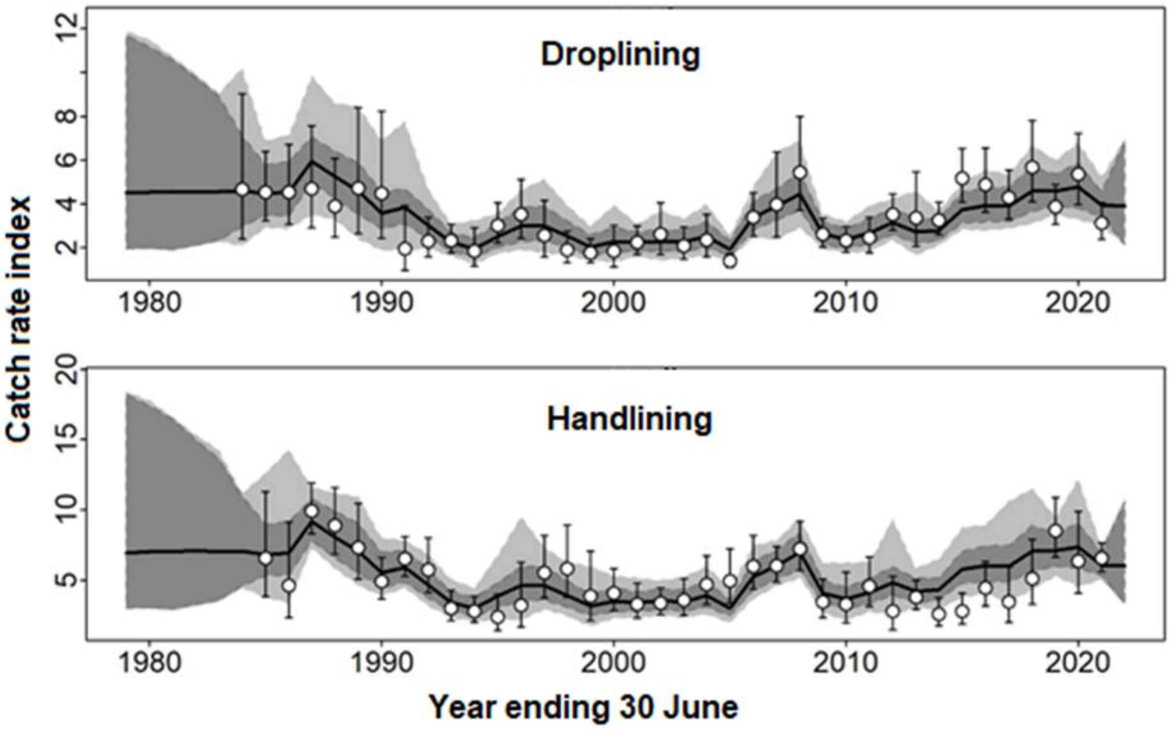


Figure 3.7 Fit of the JABBA Schaefer BDM to the adjusted droplining and handling CPUE (adjusted for changes in fishing efficiency) for Bight redfish from the SCB from commercial line fishing. Observed CPUE and associated 95% confidence limits are indicated by white circles and error bars, whereas for expected CPUE, these are indicated by solid lines and shading. CPUE1, dropline fishing; CPUE2, handline fishing.

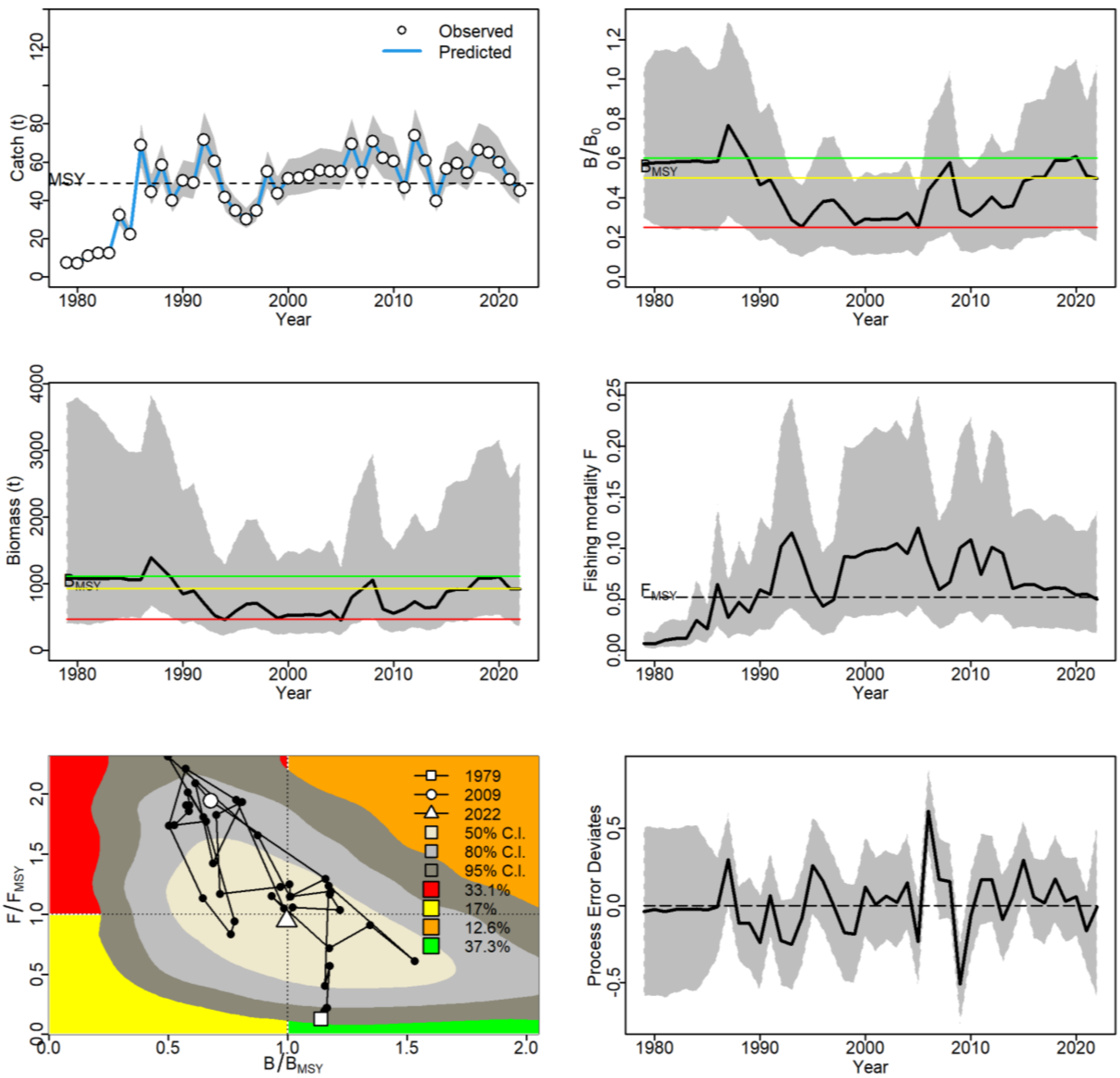


Figure 3.8 Annual time series of (top left) catch and estimates of (top right) relative biomass, (middle left) absolute biomass, (middle right) fishing mortality, (bottom left) KOBE plot tracking the relationship between fishing mortality and biomass over time, and (bottom right) process error deviations, derived from the JABBA Schaefer BDM fitted to Bight redfish catch and CPUE. The 95% CLs around parameter estimates are shown as shaded regions. B_{MSY} and F_{MSY} refer to the biomass (absolute or relative) and fishing mortality, respectively, expected to achieve MSY. Red, yellow, and green lines represent the limit ($0.5B_{MSY}$), threshold (B_{MSY}) and target ($1.2B_{MSY}$) reference points respectively.

Table 3.3 Parameter estimates produced by the state space BDM (JABBA) and associated 95% confidence limits for Bight Redfish. Carrying capacity, *K*; intrinsic increase, r; maximum sustainable yield, MSY; biomass at MSY, B_{MSY}; fishing mortality at MSY, F_{MSY}; ratio of current biomass to unfished biomass, B/B_0; ratio of current fishing mortality to F_{MSY}, F/F_{MSY}.

Parameter	Estimate (95% CLs)
K (tonnes)	1856 (847-6566)
R	0.10 (0.07-0.15)
MSY (tonnes)	49 (22-156)
B_{MSY} (tonnes)	928 (423-3283)
F_{MSY} (year^{-1})	0.052 (0.036-0.077)
B/B_0 (in 2021)	0.498 (0.18-1.08)
B/B_{MSY} (in 2021)	0.997 (0.36-2.16)
F/F_{MSY} (in 2021)	0.945 (0.29-2.59)

Consequence (Stock Depletion) Level	Likelihood			
	L1 Remote (<5%)	L2 Unlikely (5-20%)	L3 Possible (20-50%)	L4 Likely (>50%)
C1 Minor (above Target)			x	
C2 Moderate (below Target, above Threshold)			x	
C3 High (below Threshold, above Limit)			x	
C4 Major (below Limit)	x			

Figure 3.9 Risk assessment matrix based solely on results of BDM.

3.4.2 *Great Australia Bight Trawl Sector standardised catch rates.*

Part of the Australian Government managed GABTS operating in the far east of the SCB (east of 126° E), CPUE maintained a consistent downward trend to 2018 since an historical high in 2007 (Nitschke *et al.* 2022). The result was confirmed by intermittent fishery independent surveys including in 2015 and 2018. Moreover, both fishery dependent and independent data showed a concurrent and substantial increase in mean size, suggesting poor recruitment in this region, where catches are relatively low compared to grounds east of 129° E (WA-SA border). The evidence suggests that fishing pressure has contributed to the decline in abundance. More recent trawl surveys (March 2021) confirmed the biomass decline (Knuckey *et al.* 2021). However, the most recent stock assessment for the whole GAB stock concluded that it is not overfished and not subject to overfishing (Moore *et al.* 2022). Although otolith chemistry suggests Bight redfish taken west of 120° E by WA's SCLTMF are likely to be a separate biological stock to fish from the GABTS main fishing grounds that are off South Australia (Norriss *et al.* 2016), the connectivity with fish from the West and Far West GAB zones is unknown.

3.5 Level 3 assessment: fishery dependent length and age

Bight redfish samples for fishery dependent length and age assessment were from commercial line catches taken west of 120°E following the method described for sampling that fishery by Norriss *et al.* (2016). Samples were sourced from multiple commercial fishers and processors in an attempt to be representative of the total commercial line catch (with exception of 2010–2012- see below). Ages were estimated from sectioned otoliths.

3.5.1 *Length composition*

Three sampling periods for length-frequency data from the SCB are reported and analysed:

- June 2010 to September 2012 – sampling not designed to be representative of catch.
- November 2012 to October 2014, samples collected every month (NRM project 12034, Norriss *et al.* 2016)
- Calendar year 2019, samples collected every month.

Although the MLL is 30 cm TL, very few fish below 35 cm were landed (Figure 3.10), providing no indication of substantial numbers of released fish and consequent PRM. Lack of susceptibility to barotrauma by this species is also indicated by a tagging study of the closely related *Centroberyx affinis* in a trawl fishery on Australia's east coast (Rowling 1990). The longest fish sampled in 2019 was 677 mm, and for any year by any sector in the SCB was 706 mm. The percentage of large fish (≥ 60 cm) was 5% for the first two sample periods and 3% in 2019. The percentage of lengths between 50 and 60 cm progressively declined from 39% to 35% and 23% across the 3 sample periods, respectively. Progressive declines were also observed across the 3 periods for both the median and mean TLs (mm): 491 to 477 to 453, and 491 to 477 to 464, respectively.

The percentages of lengths below the estimated length at which 50% of fish attain sexual maturity (*TL_{50}*) in samples from 2010–2012, 2012–2014 and 2019 was 14%, 6% and 9% for females (<389 mm *TL_{50}*), respectively, and 46%, 52% and 66% for males (<482 mm *TL_{50}*), respectively.

The spatial scale of catch data is insufficient to identify any shift to shallower water that might explain the observed reduction in length. In conclusion and noting that sampling in 2010–2012 was not designed to be representative of the catch, length frequency results are consistent with a progressive reduction in fish length and spawning biomass due to fishing mortality.

Trawl surveys in the far west of the GAB showed a substantial increase in mean length since 2005, which together with declining abundance suggests poor recruitment in this area (Nitschke *et al.* 2022, section 3.4.2 above).

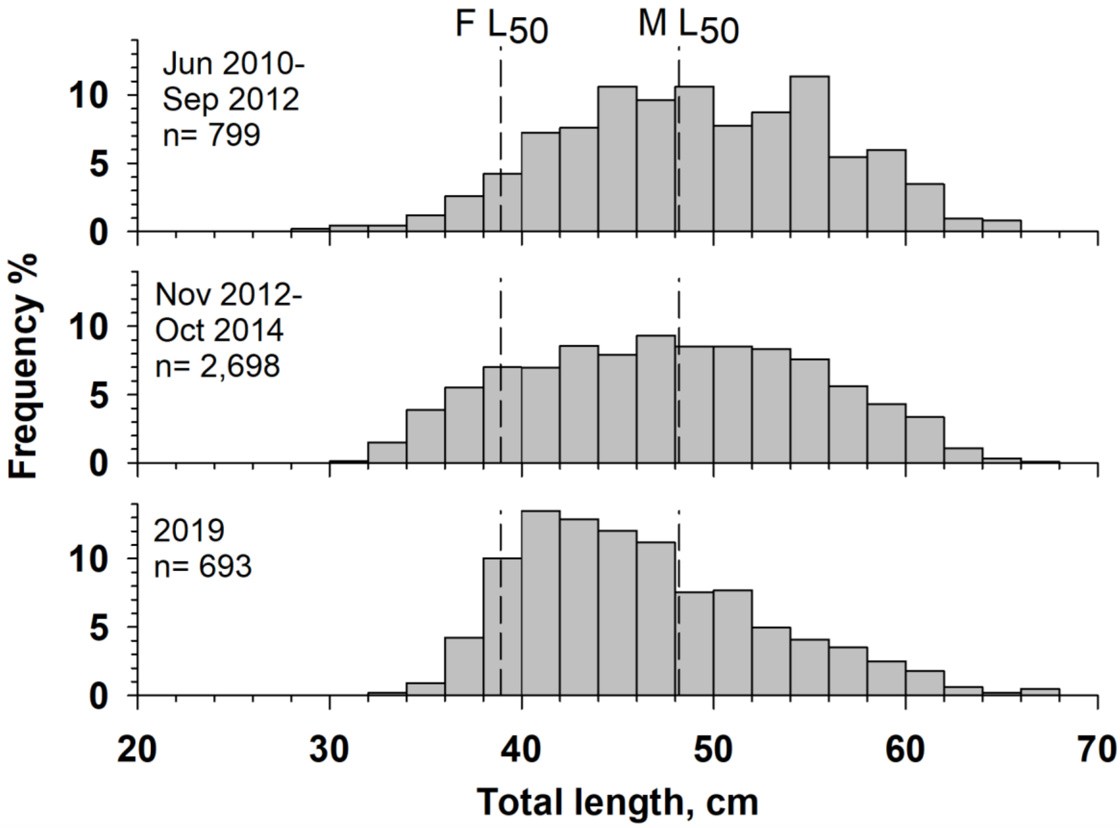


Figure 3.10 Length frequency distribution of Bight redfish sampled from commercial line catch west of 120°E in the SCB for 3 time periods. Dashed lines denote estimated length at which 50% of females (F L_{50}) and males (M L_{50}) attain sexual maturity in SCB west of 120° E.

3.5.2 *Age composition*

Two sampling periods for age-frequency data from the SCB are reported and analysed: November 2012 to October 2014, and calendar year 2019 (Figure 3.11). Age data was generated from samples collected in every month of those sample periods.

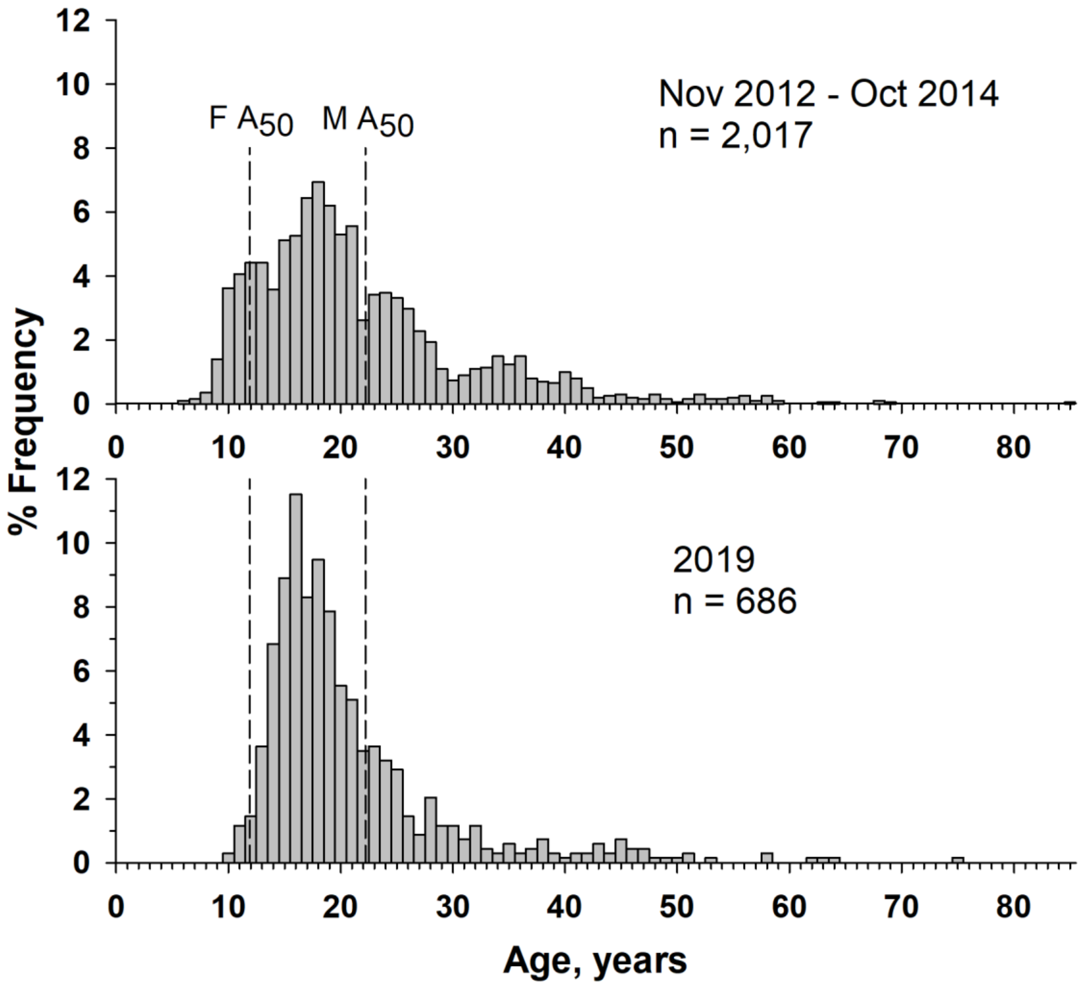


Figure 3.11 Frequency distribution of rounded (to nearest year) ages of Bight redfish sampled from commercial line catch west of 120°E in the SCB from November 2012 to October 2014 and during 2019. Dashed lines denote estimated age at which 50% of females (F A_{50}) and males (M A_{50}) attain sexual maturity in the SCB west of 120° E.

Very few fish of age <10 years were encountered. Modal age classes were 18 and 16 years for 2012–2014 and 2019, respectively. The percentage below the estimated age at which 50% of females attain sexual maturity (7 years) was <1% and zero, respectively. The oldest fish encountered in the SCB was 84.6 years in 2012-14.

A significant difference in the frequency distribution between the two sample periods was observed (Kolmogorov-Smirnov test statistic D= 0.98, p< 0.0001). The change was negligible for old fish: the percentage aged >50 years declined from 2% to 1%, and those aged 40 to 50 years remained at 4%. However, for ages 20 to 39 there was a decline from 42% to 36% with a concurrent increase from 52% to 59% for ages <20 years, consistent with the progressive reduction in fish length described above. The increased proportion of younger fish may have resulted from a shift of fishing effort to shallower waters, but this cannot be confirmed by the relatively spatially coarse (1° x 1°) catch records. The observation is also consistent with a reduction in spawning stock from 2012–2014 to 2019.

3.5.3 *Fishing mortality and per-recruit analysis*

Estimates of the instantaneous rate of total mortality (*Z*, year^{-1} ±95% c.i.) were derived by using the L3Assess catch curve (CC) package in R (Hesp 2023a) to analyse fish taken by hook and line in the commercial sector west of 120°E. Three CC models with alternative modelling assumptions (Norriss *et al.* 2016) were fitted to each data set:

- Linear regression catch curve.
- Chapman & Robson (1960) estimator.
- Multinomial catch curve with age-based, logistic selectivity (logistic CC).

The variable recruitment catch curve, considered the most reliable for the 2012–2014 sample (Norriss *et al.* 2016) was unavailable for 2019 as sample sizes were insufficient after splitting between the pre- and post- 1st April nominal birthdate.

Estimates of the instantaneous rate of fishing mortality (*F*, year^{-1} ±95% c.i.) were generated by deducting the point estimate of the instantaneous rate of natural mortality (*M*, year^{-1}) from Z (±95% c.i.). *M* was estimated using the method of Dureuil and Froese (2021):

$$M = -\log_e(0.015)/\mathrm{A}_{\max}$$

where A_{max} was the oldest fish encountered in the SCB: 84.6 years. This individual, from a total of over 6,000 SCB Bight redfish taken from multiple sectors that have been aged, was 10 years older than the next oldest, so possibly overestimates typical SCB longevity (i.e., underestimates *M*). The result, *M*= 0.050, was very similar to alternative *M* estimates described by Hoenig (1983) and Hewitt and Hoenig (2005) (differences <0.002 in this assessment). Note that this estimate is lower than the 0.067 estimate from a previous stock assessment (Norriss *et al*. 2016) that assumed a uniform distribution between estimates based on methods of Hoenig (1983) and Then *et al.* (2015). The method of Then *et al*. (2015) is no longer recommended in the scientific literature (Hamel and Cope 2022, Maunder *et al*. 2023).

The stock was assessed by comparing estimates of F and relative female breeding stock to reference levels — see section 2.5.3.

Sampling periods for age-based mortality analysis were as above: November 2012 to October 2014, and calendar year 2019 (Figure 3.11). As age modes differed between sample periods, data were pooled to derive a mode of 18 years (when age was rounded to nearest integer), so catch curve analysis assumed age at full recruitment to be mode + 1 = 19 in both sample periods (not applicable for logistic selectivity catch curve).

The Chapman & Robson age-based mortality estimator and the age-based catch curve with logistic selectivity provided virtually identical estimates of *Z* (0.110 yr^{-1}) for the 2012–2014 sample, which were very similar to the estimate derived from the preferred catch curve method allowing for variable recruitment (0.112 yr^{-1}) (Table 3.4). For the 2019 sample, however, *Z* estimates (±95% c.i.) obtained using the former two methods increased to 0.127 yr^{-1} (0.113-0.140 yr^{-1}) and 0.144 yr^{-1} (0.132-0.159 yr^{-1}), respectively. The difference between the two models was influenced by

Table 3.4 SCB estimates of total annual mortality (Z yr^{-1} ± 95% c.i.) from commercial line samples taken west of 120°E from Oct 2012 to Nov 2014 and during 2019. NA= not available.

Sample Period	n	Linear	Chapman & Robson	Logistic Selectivity	Variable recruitment
2012-2014	2,017	0.100 (0.088-0.112)	0.110 (0.103-0.117)	0.110 (0.104-0.118)	0.112 (0.103-0.121)
2019	686	0.105 (0.086-0.125)	0.127 (0.113-0.140)	0.144 (0.132-0.159)	NA

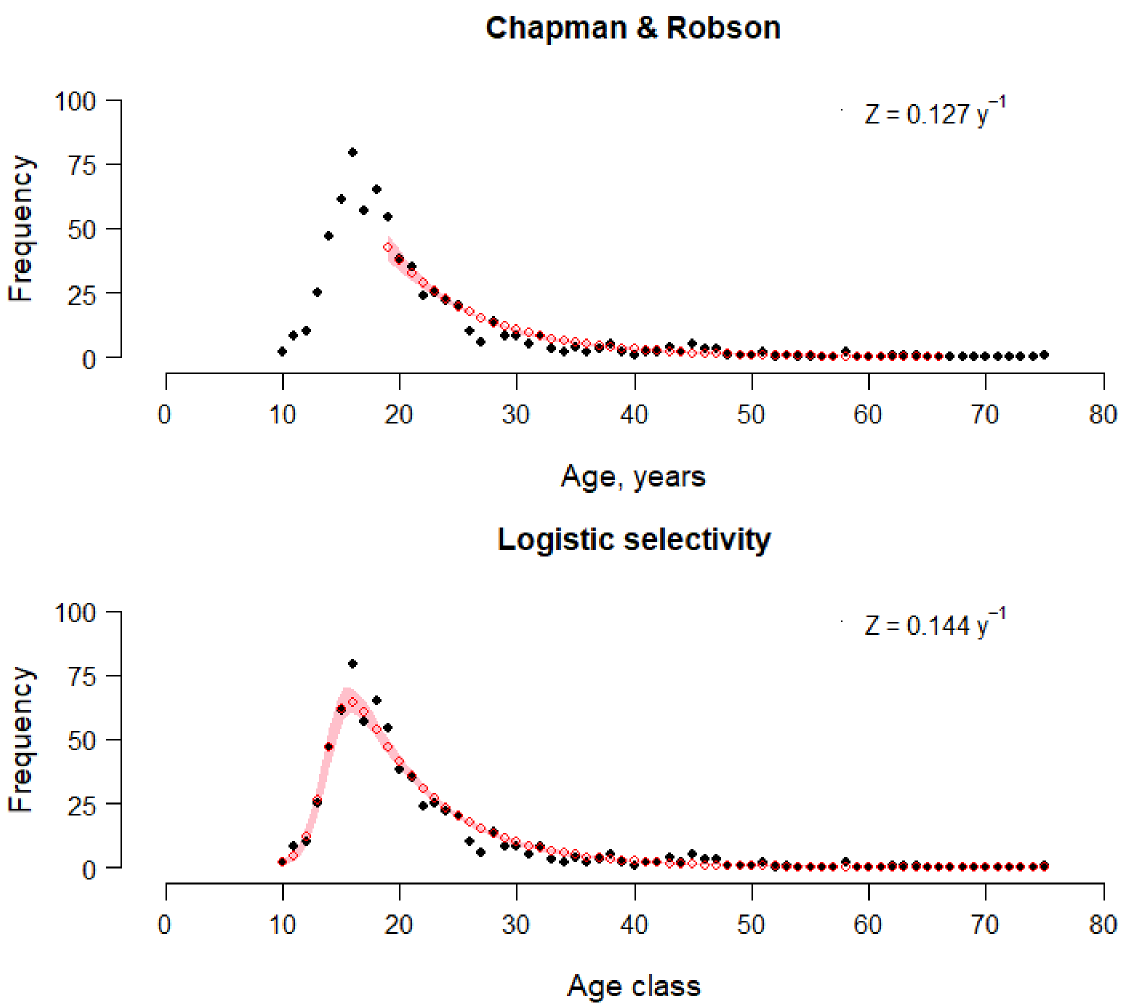


Figure 3.12 Chapman and Robson and logistic selectivity catch curve models fitted to the 2019 age composition (±95% c.i., red line) from commercial line catch west of 120°E in the SCB.

fitting the logistic curve to an age composition with an unusually high relative abundance (mode) of the 16 years age class, considered to reflect above-average recruitment for that year class (Figure 3.12). In contrast the Chapman & Robson model was applied only to age data beyond 19 years, so its estimate is considered more reliable as it was unaffected by the mode at 16 years. The linear model was considered least reliable due to known statistical issues with this method, and also conclusions from published simulation studies comparing this with other catch curve models.

Estimates of *F* from the 2019 sample ranged from 0.06 yr^{-1} (linear) to 0.09 yr^{-1} (logistic selectivity) (Table 3.5). The two most reliable estimates of *F* were 0.08 yr^{-1} and 0.09 yr^{-1} using Chapman & Robson and logistic selectivity catch curves, respectively. Both show the limit reference point was likely breached, with only the former yielding a possibility that *F* was between threshold and limit. Results indicate an unacceptably high rate of stock depletion. *F* estimates were also higher than the F_{MSY}= 0.05 estimate from per recruit analysis (see below), the fishing mortality associated with maximum equilibrium catch.

Although previously published estimates of *F* for 2012–2014 showed *F* had not breached the threshold reference level (Norriss *et al.* 2016), a re-assessment using the updated method for estimating *M* suggests that *F* had indeed breached the threshold of *F* = 0.05 yr^{-1}, but not the limit of *F* = 0.075 yr^{-1} reference levels at that time (Table 3.5). However, all available catch curves show *Z* and therefore *F* increased between 2012-2014 and 2019.

Per-recruit analysis parameters for estimating relative spawning biomass (±95% CIs) are provided in Table 3.6 (in addition to the Chapman & Robson *F* estimate above), and various diagnostic plot outputs are presented in the Appendix. Confidence intervals of SPR and B_{rel} parameter estimates were generated by resampling (n=300) within probability distributions provided in Table 3.6.

All female breeding stock estimates decreased from 2012–2014 to 2019 (Table 3.7). The point estimates based on the 2019 linear catch curve did not breach the threshold reference level (0.30) for either the SPR or B_{rel} estimates. In contrast, both logistic selectivity based estimates breached the threshold, but not limit (0.20). Chapman & Robson based estimates, considered the most reliable, showed SPR to be above the threshold while B_{rel} was between the threshold and limit. The latter estimate, B_{rel}= 0.27 (±95% c.i. 0.21-0.34), is considered the most reliable as it incorporates the effect of fishing of mortality on recruitment. There is no prospect of this B_{rel} estimate breaching the limit (Figure 3.13), so a High risk to the stock is indicated (Figure 3.14).

In conclusion, age-based per-recruit analysis indicates the Bight redfish spawning stock west of 120° E in the SCB was likely between threshold and limit reference levels during the 2019 sample year, and unlikely to have breached the limit. The breeding stock has decreased since the previous estimate from 2012-2014, and the downward trajectory confirmed by an unacceptably high rate of fishing mortality.

Table 3.5 Estimates of fishing mortality *F* (±95% c.i.) from 4 catch curve models for Bight redfish in commercial catches west of 120°00´E in the SCB. Colors denote fishery reference levels: orange between threshold (F = 0.05 yr^{-1}) and limit (F = 0.07 yr^{-1}), and red is above limit. NA= not available.

Sample Period	Linear		Chapman & Robson		Logistic Selectivity		Variable recruitment	
2012-2014	0.050	(0.04-0.06)	0.060	(0.05-0.07)	0.060	(0.05-0.07)	0.062	(0.05-0.07)
2019	0.055	(0.04-0.08)	0.077	(0.06-0.09)	0.094	(0.08-0.11)	NA	

Table 3.6 Parameters used in Bight redfish per-recruit analysis.

Variable/Parameter	Value	Source
Max age (A_{max} years)	84.6	Norriss *et al.* (2016)
Natural mortality ($M\ year^{-1}$) St dev.	0.050 0.005	$log_e(0.015)/A_{max}$ (Dureuil and Froese 2021)
Growth (females)		von Bertalanffy growth curve fitted (Hesp 2023b) to unpublished SCB data
$L_\infty(mm\ TL)$	600.1	
$K\ year^{-1}$	0.07	
$t_0\ (years)$	-2.9	
Weight-length (g, mm TL, both sexes)		$W = log_e a + b * log_e L$ Fitted to unpublished SCB data
ln (a)	-10.320	
b	2.851	
Maturity (logistic, females)		Coulson *et al.* (2019)
A_{50} (years)	11.9	
A_{95} (years)	40.8	
Assumed zero females mature up to age 2.		
Selectivity of landings (2012-2014, 2019; both sexes)		Age-based logistic selectivity catch curve (Hesp 2023a)
A_{50} (years)	13.06, 13.881	
A_{95} (years)	18.691, 16.628	
Steepness (std dev) of Beverton-Holt stock recruitment curve.	0.75 (0.025)	Punt *et al.* (2011). As for *Centroberyx affinis* (Tuck 2015).

Table 3.7 Female SPR and B_{rel} estimates (±95% CIs) for Bight redfish taken by commercial line west of 120°00' in the SCB. Based on a fitted per-recruit model (SPR) and an extended model accounting for the effect of fishing on annual recruitment (B_{rel}). Colors denote the reference levels: green is the point estimate above target (0.40), yellow between target and threshold (0.30) and orange between threshold and limit (0.20). NA= not available.

Sample Period	**Linear**		**Chapman & Robson**		**Logistic Selectivity**		**Variable recruitment**	
	SPR	**B_{rel}**	**SPR**	**B_{rel}**	**SPR**	**B_{rel}**	**SPR**	**B_{rel}**
2012-2014	0.41 0.36-0.47	0.36 0.29-0.42	0.37 0.31-0.42	0.31 0.24-0.37	0.37 0.32-0.43	0.31 0.25-0.38	0.36 0.31-0.42	0.31 0.24-0.37
2019	0.41 0.35-0.46	0.36 0.29-0.42	0.33 0.28-0.39	0.27 0.21-0.34	0.30 0.24-0.34	0.23 0.16-0.29	NA	NA

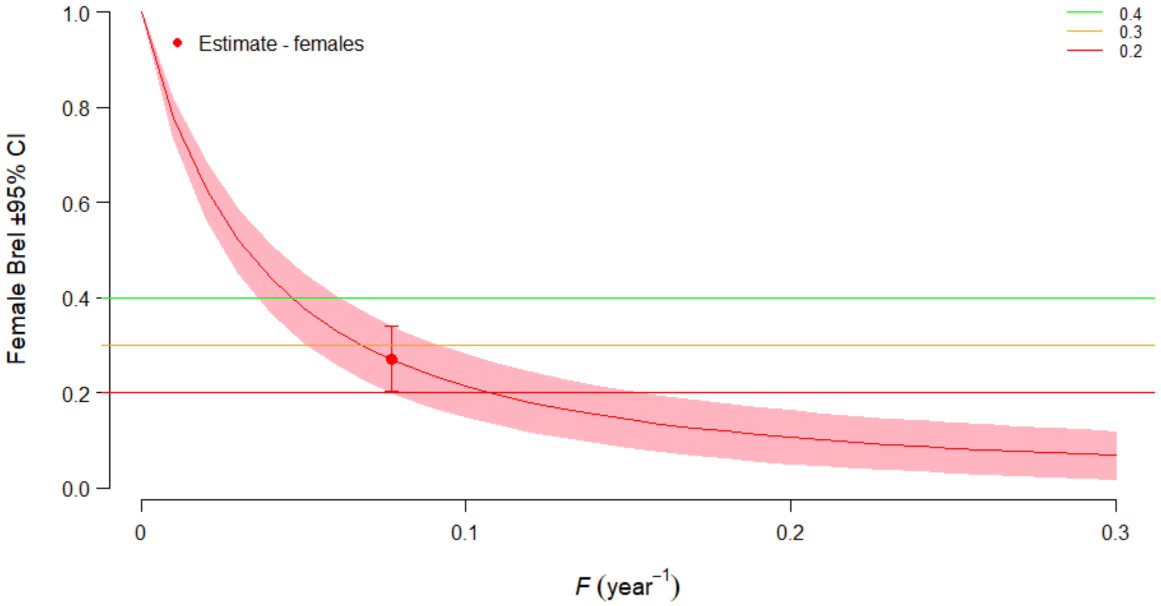


Figure 3.13 Female Bight redfish B_{rel} (±95%CI) at different levels of fishing mortality based on per-recruit analysis of the 2019 age sample. Point estimate corresponds to the Chapman & Robson estimate of *F*, considered most reliable. Coloured lines are performance reference levels: target (0.40), threshold (0.30) and limit (0.20). The probability of breaching of the limit is estimated to be 12%.

Consequence (Stock Depletion) Level	Likelihood			
	L1 Remote (<5%)	L2 Unlikely (5-20%)	L3 Possible (20-50%)	L4 Likely (>50%)
C1 Minor (above Target)				
C2 Moderate (below Target, above Threshold)			x	
C3 High (below Threshold, above Limit)				x
C4 Major (below Limit)				

Figure 3.14 Risk assessment matrix based solely on preferred female B_{rel} estimate depicted in Figure 3.13: extended per recruit analysis using Chapman & Robson estimate of *F*. A high risk score is indicated (orange).

4.0 Hapuku (*Polyprion oxygeneios*)

4.1 Hapuku summary

WA's SCB population of hapuku constitute a jurisdictional stock for fishery management and assessment purposes. Hapuku have an extended pelagic juvenile stage (3 – 5 years) followed by demersal settlement, which in the SCB occurs along the continental shelf edge to depths of about 150 – 500 m. The spatio-temporal pattern of settlement may be influenced by a series of steeply sloping canyons that intersect the shelf edge, facilitating local nutrient upwelling and patchily distributed zones of high benthic productivity. Settlement location preference may therefore result in a spatially complex age composition. In the SCB sexual maturity for females and males is attained at about 76 and 70 cm TL and age 7.1 and 6.8 years, respectively. The maximum observed age was 52 years. Hapuku are gonochorists (separate sexes) and spawn in winter.

Commercial catches, dominated by the line fishery, were first recorded in 1989-90. Initially low at 4 - 13 t, annual catches substantially increased from 2000-01, and although variable maintained a generally upward trend. The highest annual catch was 44 t in 2018-19. Roughly a third of catches came from a 1° x 1° block adjacent to Albany, but since 2017-18 there has also been a marked increase in catches around Esperance. GAB catches have always been negligible. There is no evidence that catch levels have been maintained by a progressive shifting in the areas fished from abandoned to new grounds that, otherwise, would be indicative of serial depletion. Catch-MSY modelling indicates catches were mostly below MSY resulting in stable levels of stock depletion that remain above B_{MSY} (i.e. above ~0.5). The Level 1 assessment was therefore consistent with minor to moderate stock depletion. Results from a BDM applied to line-based commercial catch rates indicate that overfishing may be occurring, but that the stock is not currently overfished as the current ratio of biomass to B_{MSY} (±95% CLs) was estimated at 1.30 (0.52-2.49), and thus likely above the target reference level. However, uncertainty in the model's results suggest moderate and high depletion possible and unlikely, respectively. Catch sampling was undertaken but samples were not accepted as representative of the population, precluding a Level 3 assessment.

Consequently, the SCB hapuku stock status is **MEDIUM** risk.

4.2 Risk-based weight of evidence summary table and matrix

Level	Line of evidence
1.1 Biology and vulnerability	SCB hapuku have a high inherent vulnerability to overfishing due to late age at sexual maturity (~7 years) and substantial longevity (maximum observed age 51.8 years). They are typically found along the edge of the continental shelf in depths of 150-500 m. Their extended pelagic juvenile stage (3 – 5 years) prior to demersal settlement raises the possibility of pan-oceanic mixing between populations which reduces the importance of the status of the SCB breeding stock for local recruitment. Life history parameters indicate post settlement separation between SCB and WCB stocks. The SCB continental shelf is intersected by a series of steeply sloping canyons resulting in sporadic local nutrient upwelling and intermittent zones of high benthic productivity. This may result in spatio-temporal variation in selection of settlement location and consequent length/age composition. PSA for hapuku generated a productivity score of 2.00 and susceptibility score of 2.59, resulting in an overall score of 2.59.
1.2 Catch	Upon demersal settlement hapuku are sufficiently large to be retained by fishers. There is no MLL and they are rarely if ever discarded. The first recorded commercial catch was in 1989-90. Catch is very much dominated by the commercial line fishery. Catches have maintained a generally upward long term trend with the commercial line catch peaking at 44 t in 2017-18.
1.3 Spatio-temporal distribution of catch	Historically about one third of the commercial line catch is taken within a 1° x 1° block adjacent to Albany, but since 2017-18 there has also been marked increase in catches around Esperance. GAB catches have always been negligible. There was no evidence that catch levels have been maintained by a progressive shifting in the areas fished from abandoned to new grounds that, otherwise, would indicate unacceptable stock depletion.
1.4 Catch-MSY analysis SCB	Catch-MSY modelling indicates catches were mostly below MSY resulting in stable levels of stock depletion that remain above B_{MSY} (i.e. above ~0.5). Note that the Catch-MSY assessment method is designed for data-poor fisheries and stock status estimates are imprecise.
Level 1 assessment Although hapuku have a high inherent vulnerability to overfishing, their extended juvenile pelagic phase suggests recruitment from external sources is possible. The spatio-temporal distribution of catches does not indicate progressive shifting of the areas fished from abandoned to new grounds, but there have been	

increased catches in previously lightly fished grounds. Catch-MSY modelling suggests catches have mostly been within MSY, consistent with stock levels above B_{MSY}. Level 1 assessment is therefore consistent with a minor to moderate level of stock depletion.	
2.1 Effort and catch rate	Recent historical highs in the nominal annual CPUE (tonnes per boat day) are likely largely attributable to increased fishing efficiency. For modelling, the CPUE time series have been adjusted with an assumed 2% annual increase in fishing efficiency per year for both the dropline and handline. The adjusted dropline CPUE show a gradual declining trend from 1990 through to the mid-late 2000s, and an increasing trend from about 2014-21. The adjusted handline CPUE, which starts in 2001, exhibits similar trends to adjusted dropline CPUE. The trends for adjusted CPUE are consistent and not indicative of decreasing spawning biomass from 1990, and thereby do not provide evidence of unacceptable stock depletion.
Level 2 assessment A state space BDM (Winker *et al.* 2018), using the Schaefer production function, was fitted to annual catches and adjusted commercial CPUE for hapuku in the SCB. Results from the analysis yielded a MSY point estimate of 16 t. In recent years, estimated biomass levels were above that corresponding to B_{MSY}. For example, using the JABBA model fitted to CPUE data from 1990-2022, the estimated current ratio of biomass to B_{MSY} (B/ B_{MSY}) was 1.30 (95% CLs, 0.52-2.49). Using this same model and data set, the fishing mortality in recent years is estimated above F_{MSY} (F/ F_{MSY} = 1.35, 95% CLs = 0.42-4.15), reflecting relatively high fishing effort in recent years. A substantial source of uncertainty in this assessment relates to limited understanding regarding changes in fishing efficiency occurring over the history of the fishery. Uncertainty in assessment results is further increased due to the possibility that factors such as fishery expansion may be impacting trends in CPUE. The results from the state space model fitted to annual catch and standardised commercial CPUE data indicate that overfishing may be occurring, but that the stock is not currently overfished. There is increased uncertainty in the assessment due to possible impacts of fishery expansion in recent years not accounted for in CPUE analysis. Level 2 assessment therefore suggests minor depletion is most likely, with moderate depletion possible and high depletion unlikely.	
Final risk C1 (Minor depletion – above target): consistent with Level 1 assessment and likely according to Level 2 assessment. Likelihood of minor depletion is therefore assessed as **Likely.**	

C2 (Moderate depletion – between target and threshold): consistent with Level 1 assessment and possible according to Level 2 assessment.

Likelihood of moderate depletion is therefore assessed as **Possible.**

C3 (High depletion- between threshold and limit): inconsistent with Level 1 assessment and unlikely according to Level 2 assessment.

Likelihood of high depletion is therefore assessed as **Unlikely.**

C4 (Major depletion – below limit): not consistent with Level 1 or 2 assessments.

Likelihood of high depletion is therefore assessed as **Implausible.**

The SCB hapuku risk matrix shows the maximum consequence-likelihood rating to be a **MEDIUM** risk (C3 x L2).

SCB Hapuku risk matrix

Consequence (Stock depletion) Level	Likelihood			
	L1 Remote (<5%)	L2 Unlikely (5-20%)	L3 Possible (20-50%)	L4 Likely (>50%)
C1 Minor (above Target)				X
C2 Moderate (below Target, above Threshold)			x	
C3 High (below Threshold, above Limit)		x		
C4 Major (below Limit)				

4.3 Level 1 assessment: biology, vulnerability and catch

4.3.1 *Biology and vulnerability*

The stock structure of Hapuku throughout Australian waters is poorly known. They have an extended pelagic juvenile stage that is strongly associated with floating objects (Roberts, 1996), suggesting the possibility of pan-oceanic mixing between populations. Information on spatial recruitment patterns relevant to the SCB stock is lacking. Movement between post-settlement individuals in the lower WCB and SCB appears restricted as evidenced by faster growth in the former (Armstrong 2013). In New Zealand, tagging demersal hapuku revealed mostly sedentary behaviour but travel of substantial distances up to 1,389 km from release location were observed for some individuals (Beentjes and Francis 1999).

Hapuku settle to a demersal lifestyle at age 3 – 5 years and length of 55 to 63 cm TL, associated with abrupt slowing of growth rate (Wakefield *et al.* 2010). They therefore appear available for capture to the fishery upon settlement. Estimates of the lengths and ages at which 50% of SCB females and males reach sexual maturity were 76 and 70 cm TL and 7.1 and 6.8 years, respectively. Maximum observed age in the SCB is 51.8 years. Hapuku are gonochorists (separate sexes), and spawn in winter in the SCB.

In the SCB Hapuku are taken predominantly by line from depths of about 150 – 500 m along the edge of the continental shelf. A series of steeply sloping canyons intersect the shelf edge and extend to depths >2 km, facilitating local nutrient upwelling and discontinuous zones of high benthic productivity (Exon *et al.* 2005, Kampf 2021, Trotter *et al.* 2022). This patchy habitat distribution may result in a complex population structure with spatial variation in age composition after hapuku select a location to transition from pelagic to demersal life stages.

4.3.2 *Catch*

The commercial fishery for hapuku in the SCB is very much dominated by vessels using dropline and various handline methods (e.g., powered reel) along the edge of the continental shelf. There is no MLL for hapuku which are rarely if ever discarded. Demersal fishing in shallower shelf waters, targeting other species, has minimal spatial overlap with hapuku.

There does not appear to be a particularly long period of exploitation of SCB hapuku as the first commercial catches were recorded in 1989-90 (Figure 4.1). All catches in blocks straddling the WCB boundary at 115°30’E (i.e., between 115°00’E and 116°00’E) have been included in this assessment if they could not be allocated between bioregions (business rules are being developed to account for allocation of such catches to the appropriate bioregion). The annual commercial line catch has been highly variable. Initially at around 4 – 13 t, annual catches increased from 2000/01 and peaked in the mid-2000s at around 27 t. A second higher peak and annual record of 44 t was taken in 2018-19. Typically catches are highest from September to November and lowest May to July. There is no evidence of increased vulnerability associated with spawning (e.g., aggregations) as the spawning season is from May to September, peaking from June to August (Wakefield *et al.* 2010).

Hapuku catches in the 1° x 1° block immediately adjacent to Albany (block 3517) have accounted for 32% of the line catch, summed over all years, and between 31% to 52% of the line catch from 2014/15 to 2020/21 (Figures 4.1 and 4.2).

Moderate catches by the SDGDLMF using demersal gillnets in the early 1990s were associated with atypical shark targeting behaviour on the continental slope off Esperance at that time (Braccini *et al.* 2021).

Recreational boat-based catches were much lower and difficult to estimate with precision but appear to be increasing and were estimated to be around 4 - 5 t in 2020-21 (Ryan *et al*. 2022). Trawl and tour operator catches have been negligible: always < 1 t annually combined. Across all sectors, the fishery for SCB hapuku continues to develop with a trend of increasing catches, but in isolation catch provides no evidence of unacceptable depletion of breeding stock.

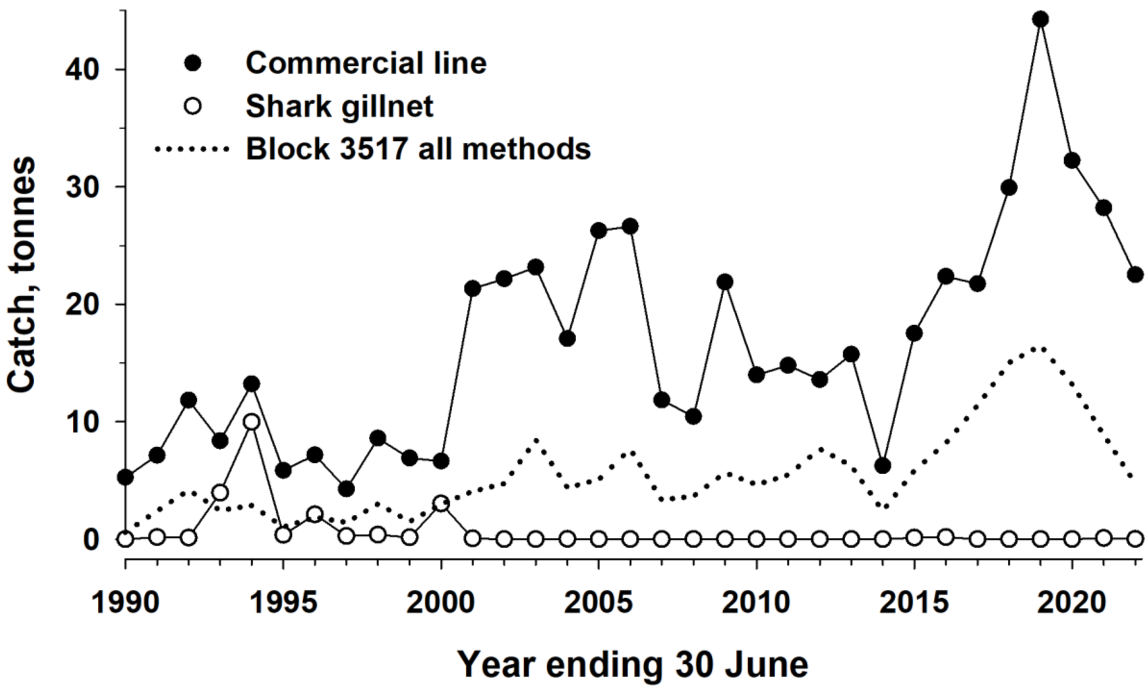


Figure 4.1 Total annual hapuku catch in the SCB by fishery from 1989/90 to 2021/22. Commercial line includes open access commercial line, net and trap. Shark gillnet refers to SDGDLMF catches which include a minor longline component. Negligible trawl and tour operator catches have been omitted for clarity. The recreational boat-based catch, too small to estimate with precision, is also omitted. Commercial catch (all methods) from dominant 1° x 1° block 3517 near Albany also shown.

4.3.3 *Spatio-temporal distribution of catch*

As annual hapuku catches were highly variable (Figure 4.1), they have been grouped into periods of low and high catches for spatio-temporal analysis. The duration of these year groups ranged from two to six years (Figure 4.2).

Historically, the large majority of hapuku catch has been west of 120° E (Figure 4.2). Initially, catches were concentrated around Albany (particularly block 3517 adjacent to Albany – see section 4.3.2 above) and Bremer Bay. Across the SCB, significant contributions to the record high catches from 2017/18 to 2020/21 came not just from higher catches from the regularly fished Albany and Bremer regions, but also from unprecedented catches near Esperance. GAB (*i.e.* east of 124° E) catches have always been negligible. Hapuku abundance in this region is unknown.

A finer spatial resolution (10' x 10') facilitated by the inception of the SCLFTMF in 2021-22 shows catches are concentrated along continental shelf edge and particularly near Albany (Figure 4.3).

In conclusion there was no evidence that catch levels have been maintained by a progressive shifting in the areas fished from abandoned to new grounds that, otherwise, could be indicative of unacceptable stock depletion. Recent catch increases were in part facilitated by contributions from previously lightly fished grounds near Esperance.

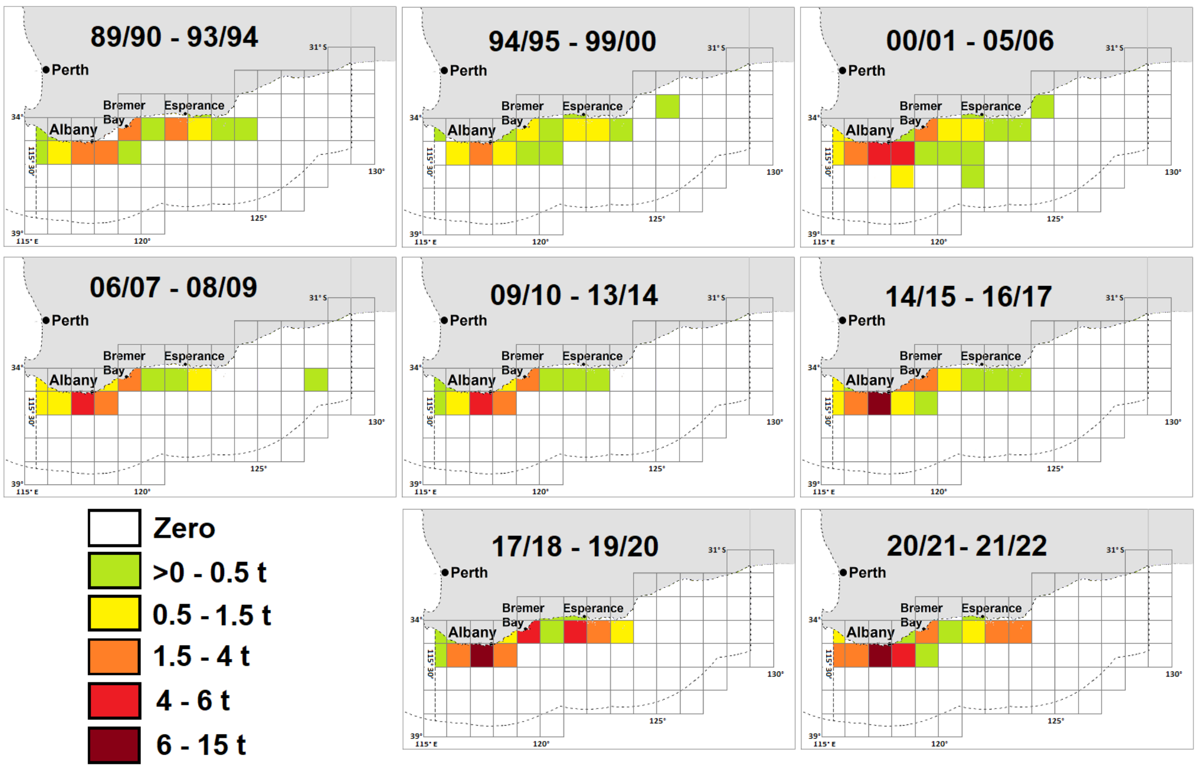


Figure 4.2 Time series of spatial distribution (1°x1° block) of the average annual hapuku commercial line catch in the SCB from 1975/76 to 2021/2022. Years ended 30 June.

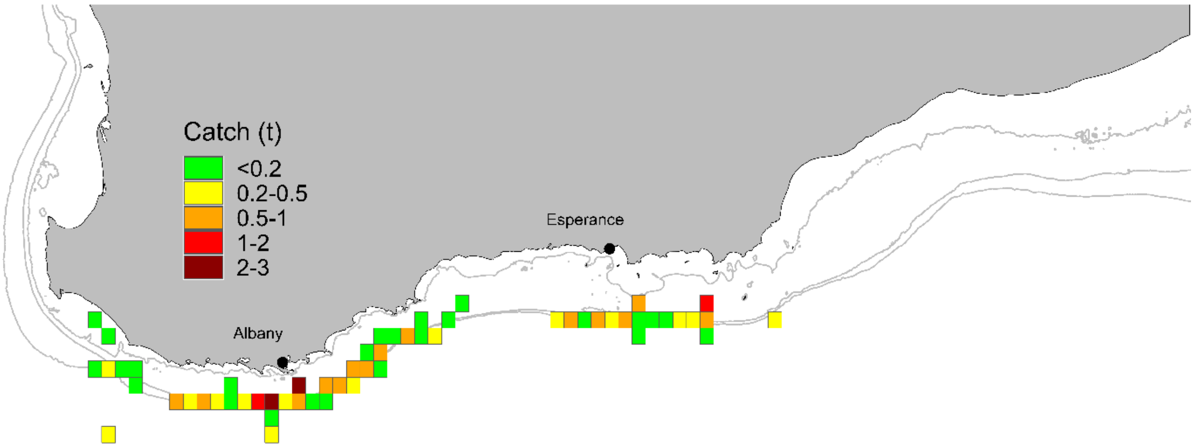


Figure 4.3 Spatial distribution of the SCLFTMF hapuku catch (10'x10' block) in its first year of operation, 2021-22. Bathymetry lines correspond to 50m, 100m and 200m.

4.3.4 *Catch-MSY analysis*

Catch-MSY models were used to predict MSY and trends in fishing mortality and stock depletion consistent with available catch data and model assumptions using the datalowSA package in R (Haddon *et al*., 2019). Assumptions included a low stock resilience (r=0.1-0.6), and an initial depletion range of 0.7 – 0.975 to reflect the fact that although commercial catch reporting for fisheries in WA had commenced by 1975-76, hapuku catches were not first reported until 1989-90 (with the exception of <8 t from the GAB by exploratory trawls between 1977 and 1980 (Walker *et al.* 1982, Walker and Clarke 1989). The final depletion range was set at (0.05 – 0.9), chosen after trialing narrower ranges resulted in the model excluding a significant number of possible trajectories.

The catch time series comprised total retained annual catch from all sectors for each year ended 30 June from when commercial catches were first recorded in 1989/90 to 2020/21. Recreational catch estimates for hapuku, available from five annual surveys between 2011/12 and 2020/21, were insufficiently robust for publication but have been used here as the best available. These surveys did not align exactly with years ending 30 June so were allocated to the nearest such year and linearly interpolated for intermediate years' estimates. Recreational catch estimates for 1989/90 to 2010/11 were calculated as a linear function of the estimated number of registered boats of length >7.5 m in WA in those years. These estimates were generated from the rate of ownership of such boats per head of population in the Perth metropolitan region that increased from 1990 to 2007 (Department for Planning and Infrastructure 2009), extrapolating increasing rate forward (to 2010/11) and backward (i.e., decreasing rate, to 1989/90) for the total WA population (source: Australian Bureau of Statistics), and assuming catch per boat for 1989/90 to 2016/17 was the mean for the years 2011/12 to 2020/21. Tour operator catch estimates were available from 2005/06 to 2020/21, and earlier years, going back to 1989/90, were estimated assuming the same catch per head of the WA population as the mean from 2005/06 to 2020/21.

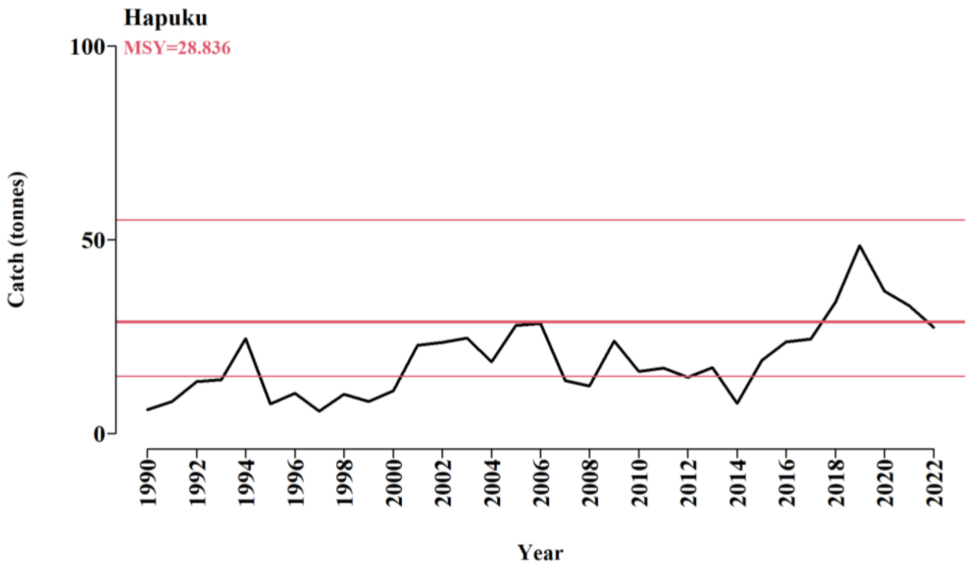


Figure 4.4 Total annual catch from 1989/90 to 2021/22 used for SCB hapuku Catch-MSY assessment vs estimated MSY (±95%CLs).

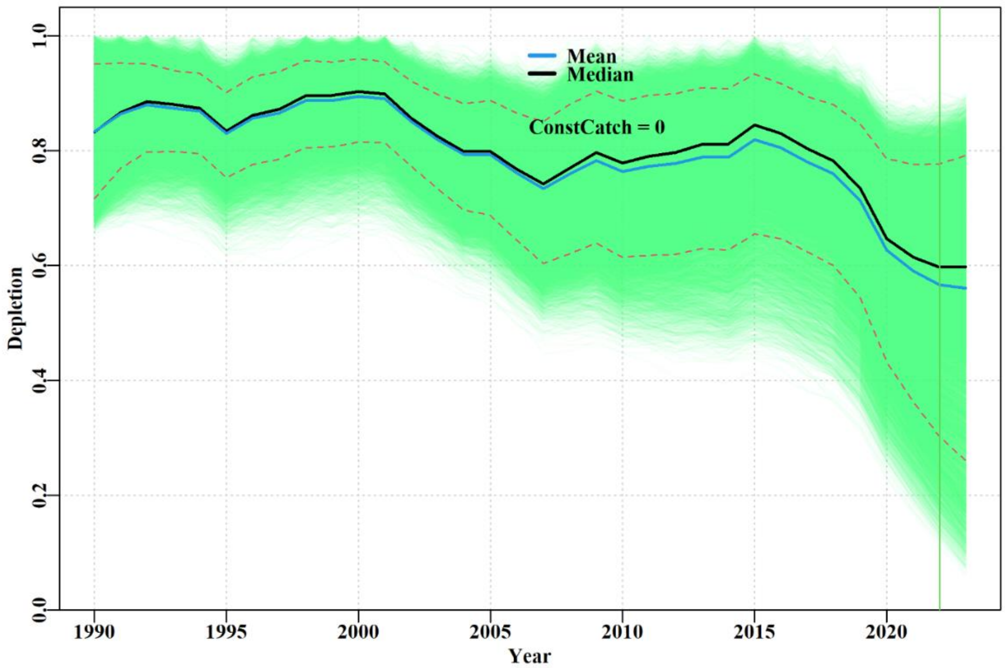


Figure 4.5 Trajectory of SCB hapuku stock based on Catch-MSY analysis. Dashed lines are 95% confidence levels.

The annual catch time series used for the Catch-MSY assessment exhibited considerable fluctuation. The set of plausible r-K combinations indicate a MSY (±95%CLs) of 29 t (15 – 55) (Figure 4.4), with annual catches below this level in all years except 2017-18 to 2019-20. As a result, the stock depletion level has been mainly stable and remains above B_{MSY} (i.e. above ~0.5) (Figure 4.5). Note that the Catch-MSY is a data poor method with strong assumptions, and thus results should be treated with caution.

4.4 Level 2 assessment: effort and catch rate

4.4.1 *JABBA: state-space Schaefer biomass dynamics model*

4.4.1.1 *Model description*

A state-space Schaefer BDM (see section 2.4.1.1) was applied using catch and commercial CPUE data for Hapuku in the SCB to provide estimates of biomass and fishing mortality relative to biological reference points. The model was fitted to annual total catches (commercial, recreational, charter and historical) and annual CPUE from commercial line fishing methods, where the latter is assumed to provide an index of spawning stock abundance. Recreational catches are assumed to have been negligible. The following model priors were assumed for Hapuku: a lognormal prior for carrying capacity (K) with mean = log(600) and sd = 1, a lognormal prior for the intrinsic rate of population increase (r) with mean = log(0.1) and sd = 0.2, a lognormal prior for the initial starting biomass (Ψ) with mean = log(0.7) and sd = 0.1. The initial biomass value assumes relatively light-moderate fishing occurred prior to the first year of recorded catches in 1975, noting that fishing activity in the region likely commenced in the 1940s. The assumption of “low resilience” (r=0.1) is considered appropriate for this species given its maximum age for females (~52 years) (Wakefield *et al.* 2010) and the empirical relationship between r and natural mortality (Zhou *et al.*, 2016). These priors covered assumed biologically feasible ranges for these parameters for Hapuku. Process error variance was specified as 0.3 with sensitivity runs (not shown in this document) conducted for values of 0.2 and 0.4. Employing the Schaefer production equation, standard fisheries reference points are calculated including MSY ($MSY = rK/4$) and the biomass corresponding to MSY (B_{MSY}=0.5 K) (Carruthers *et al.*, 2014; Froese *et al.*, 2017; Haddon, 2011).

4.4.1.2 *Data inputs for modelling*

Although the available time series of commercial catch of Hapuku extends from 1990 to 2022 (Figure 4.6), the final year (2022) in that series encompassed the start of the SCLFTMF. That year was omitted from the analysis due to the new management arrangements and catch reporting parameters. There were two catch rate series included in the model (dropline and handline), with both series ending in 2021. Zero to negligible catches by longlining, which is only permitted in the SDGDLMF, and by auto-jigging and polling were excluded. A catch record was defined as the landing of hapuku (kilograms, liveweight) in each block, for each month, for each method, for each licensed fishing boat. The effort for that catch record was hours fished in that block (=block days * hours fished per day) using that method in that month by that vessel. The median CPUE was calculated for each year and 95% confidence intervals estimated from 1,000 bootstrap resamples. Records of block days and hours fished per day greater than 31 and 24 respectively were excluded, as were records of 400 hours of fishing per month in a block. To reduce the influence of variation in targeting intensity on CPUE, only catch records above the 10% quantile for liveweight in each year were included in the analysis (Norriss *et al.* 2016). Years with less than 10 records were excluded. The dropline CPUE commences in 1990 whereas the handline CPUE commenced in 2001. Both CPUE time series were adjusted to account for an assumed increase in fishing efficiency (2% per year). Note that for this L2 modelling analysis, the 'years' for the catch and CPUE time series and model outputs relate to financial years rather than calendar years, e.g. 1990 is the 1989/90 financial year.

4.4.1.3 *Results and implications*

The JABBA model provided relatively good visual fits to the adjusted annual CPUE time series for Hapuku (Figure 4.7). Outputs from the Hapuku assessment suggest that catches in recent years have been above estimated MSY for the stock of 16 t (95% CLs: 7-40t) (Table 4.1).

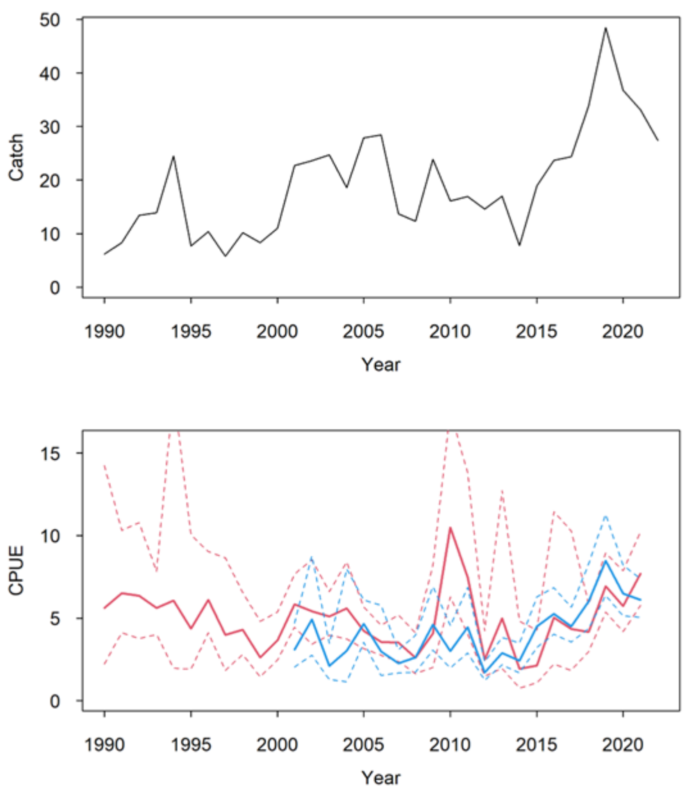


Figure 4.6 Total Hapuku catch (tonnes) in the SCB and commercial annual catch rate series for both dropline (red) and handline (blue). Solid lines denote mean CPUE, and dashed lines indicate associated 95% confidence limits. All CPUE time series have been adjusted for an assumed efficiency increase of 2% per year from 1990 to 2021.

The results from the BDM indicate the hapuku stock abundance fluctuated below BMSY from the mid 1990's to about 2015, before increasing since 2012 to be well above BMSY in 2021 (Figure 4.8). This is consistent with the catch rates which also show an increasing trend since 2012 (Figure 7). Estimates for fishing mortality (F) were below FMSY up until the year 2000 and have generally been at or above FMSY since.

Fishing efficiency was specified as increasing 2% per year from 1990 to 2021. The assumption of no increase in fishing efficiency was considered infeasible due to the introduction of jet-powered boats and GPS in the early 1990s, combined with other factors such as changes in fishing knowledge and experience. It should be noted that the available commercial CPUE data have not yet been subjected to formal CPUE standardisation (e.g. GLM analysis). The progressive increase in CPUE in recent years may reflect, in part, expansion of the fishery into new areas, rather than increasing population abundance. This increases the level of uncertainty of this assessment. For future assessments, it is recommended that the CPUE data are subjected to formal standardisation analysis.

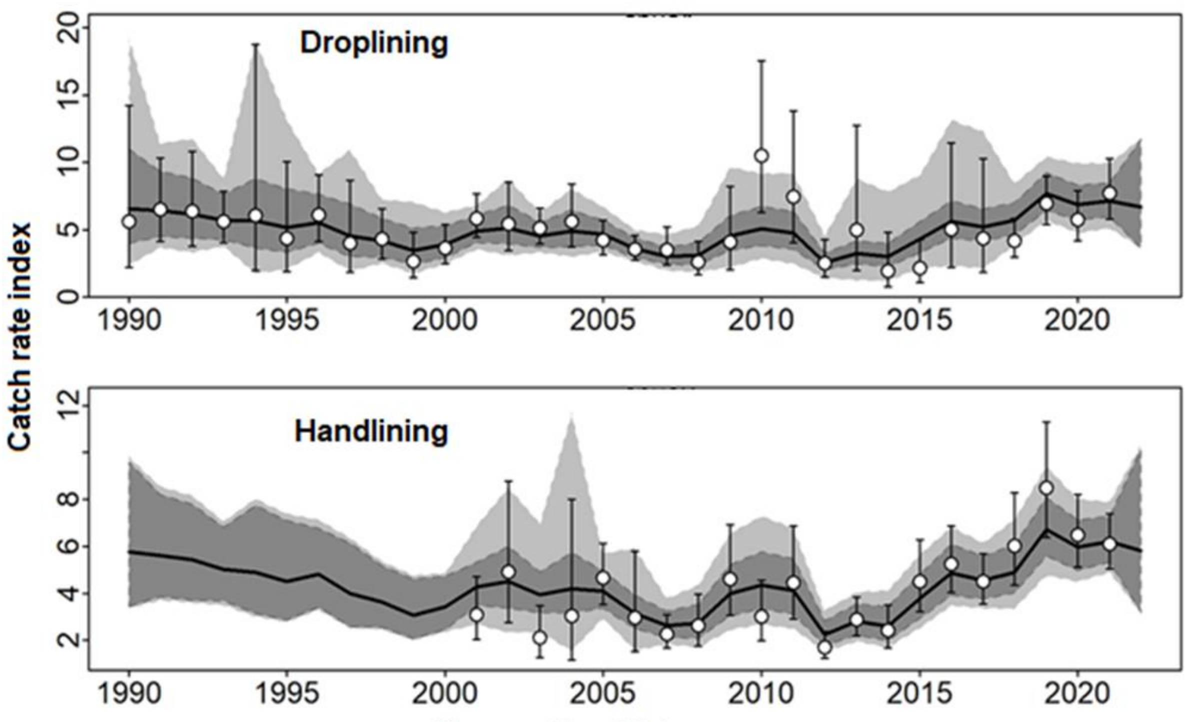


Figure 4.7 Fit of the JABBA Schaefer BDM to the adjusted droplining and handling CPUE (adjusted for changes in fishing efficiency) for hapuku from the SCB from commercial line fishing. Observed CPUE and associated 95% confidence limits are indicated by white circles and error bars, whereas for expected CPUE, these are indicated by solid lines and shading.

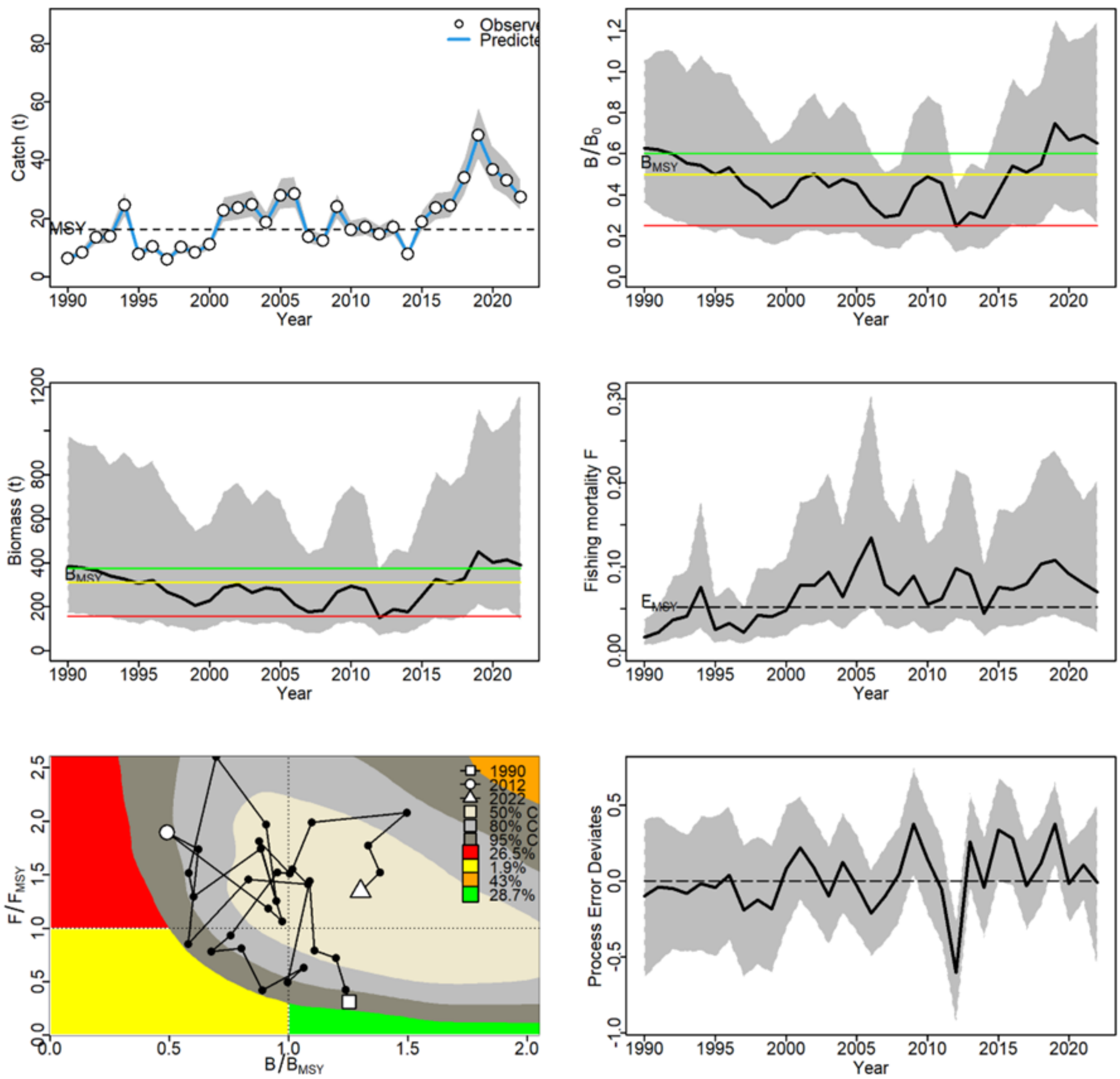


Figure 4.8 Annual time series of (top left) catch and estimates of (top right) relative biomass, (middle left) absolute biomass, (middle right) fishing mortality, (bottom left) KOBE plot tracking the relationship between fishing mortality and biomass over time, and (bottom right) process error deviations, derived from the JABBA Schaefer BDM fitted to hapuku catch and catch rate data. The 95% CLs around parameter estimates are shown as shaded regions. BMSY and FMSY refer to the biomass (absolute or relative) and fishing mortality, respectively, expected to achieve MSY. Red, yellow, and green lines represent the limit (0.5BMSY), threshold (BMSY) and target (1.2 BMSY) reference points respectively.

As the estimate of the ratio of current (2022) biomass to unfished biomass (B/ B0) is as high as 0.6, and the ratio of current biomass to BMSY is thus well above 1 (at 1.30), this indicates that the stock is not overfished (Table 4.1). As current (2022) fishing mortality is above estimated FMSY, this indicates that overfishing may be occurring (Table 4.1). Uncertainty in assessment results is increased due to the possibility that factors such as fishery expansion may be impacting trends in CPUE, which are not yet accounted for in analysis.

The results from the state space model fitted to annual catch and standardised commercial CPUE data indicate that overfishing may be occurring, but the stock is not currently overfished. There is increased uncertainty in the assessment due to possible impacts of fishery expansion in recent years (see section 4.3.3 above) not accounted for in CPUE analysis. Results therefore indicate a minor depletion with a breach of the threshold reference level unlikely, and no prospect of breaching the limit (Figure 4.9).

Table 4.1 Parameter estimates produced by the state space BDM (JABBA) and associated 95% confidence limits for hapuku. Carrying capacity, K; intrinsic increase, r; maximum sustainable yield, MSY; biomass at MSY, B_{MSY}; fishing mortality at MSY, F_{MSY} ; ratio of current biomass to unfished biomass, B/ B_0; ratio of current fishing mortality to F_{MSY}, F/ F_{MSY}.

Parameter	Estimate (95% CLs)
K (tonnes)	624 (280-1505)
r	0.10 (0.07-0.15)
MSY (tonnes)	16 (7-40)
B_{MSY} (tonnes)	312 (140-752)
F_{MSY} (year-1)	0.052 (0.035-0.077)
B/B_0 (in 2022)	0.65 (0.26-1.24)
B/B_{MSY} (in 2022)	1.30 (0.52-2.49)
F/F_{MSY} (in 2022)	1.35 (0.42-4.15)

Consequence (Stock Depletion) Level	Likelihood			
	L1 Remote (<5%)	L2 Unlikely (5-20%)	L3 Possible (20-50%)	L4 Likely (>50%)
C1 Minor (above Target)				x
C2 Moderate (below Target, above Threshold)			x	
C3 High (below Threshold, above Limit)		x		
C4 Major (below Limit)				

Figure 4.9 Risk assessment matrix based solely on results of BDM indicating a Medium risk score (yellow).

4.5 Level 3 assessment: fishery dependent length and age

Hapuku samples for the fishery dependent length and age assessment were collected from commercial fish processors supplemented by a small number of recreationally caught hapuku. Sampling commenced in 2004 (Wakefield *et al.* 2010) and continued intermittently until 2018. For analysis, the data were split into three time periods: for length frequency data they were the years 2004-2008, 2009-2016 and 2017-2018; for age-frequency they were the years 2004-2008, 2012-2016 and 2017-2018. The latter period was from 1 October 2017 to 30 September 2018, when catch locations ranged from the WCB border to Hopetoun.

4.5.1 *Length frequency*

There is no MLL for hapuku which, when taken from demersal habitat, are sufficiently large for retention by fishers because they are already aged 3-5 years when they adopt a demersal lifestyle (Wakefield *et al.* 2010, smallest sampled hapuku was 50 cm TL). Moreover, with a high PRM from barotrauma expected, essentially fishers retain all hapuku.

The length frequency distribution varied greatly among the three time periods (Figure 4.10). The percentage of large fish (≥ 90 cm TL) has temporally varied from 9% in 2004-2008 to 16% in 2009-2016 and 7% in 2017-2018. For fish ≥ 100 cm TL the respective percentages are 2%, 7% and 3%. This parameter is strongly influenced by concurrent variation in the percentage of small fish taken. For example, 51% of the 2004-2008 sample was ≤65 cm TL but this was only 15% and 4% in 2009-2016 and 2017-2018 samples, respectively. As no small fish are released by fishers, temporal variation in their prevalence appears to be associated with recruitment of young, recently settled hapuku becoming available to fishers. If such recruitment is highly variable spatially and temporally, possibly associated with a patchy distribution of productive benthic habitat, then the observed length frequency distributions may poorly represent the SCB hapuku population. In conclusion, the length frequency distribution provides no evidence of unacceptable stock depletion.

4.5.2 *Age frequency*

The age distribution of the SCB catch was examined by estimating ages from sectioned otoliths extracted from line caught hapuku (n= 2,239) collected from commercial fish processors, supplemented by a small number from the recreational sector (n = 62).

The age-frequency distribution varied greatly among the three time periods (Figure 4.11). This included the age at which hapuku fully recruit to the fishery. Using the mode + 1 year estimate, full recruitment was at 5, 7 and 7 years in 2004-2008, 2012-2016 and 2017-2018, respectively. This may reflect changes in the age at which pelagic hapuku settle to their demersal phase (around 2 to 5 years; Wakefield *et al.* 2010) or variation in elapsed time between settlement and capture by the fishery.

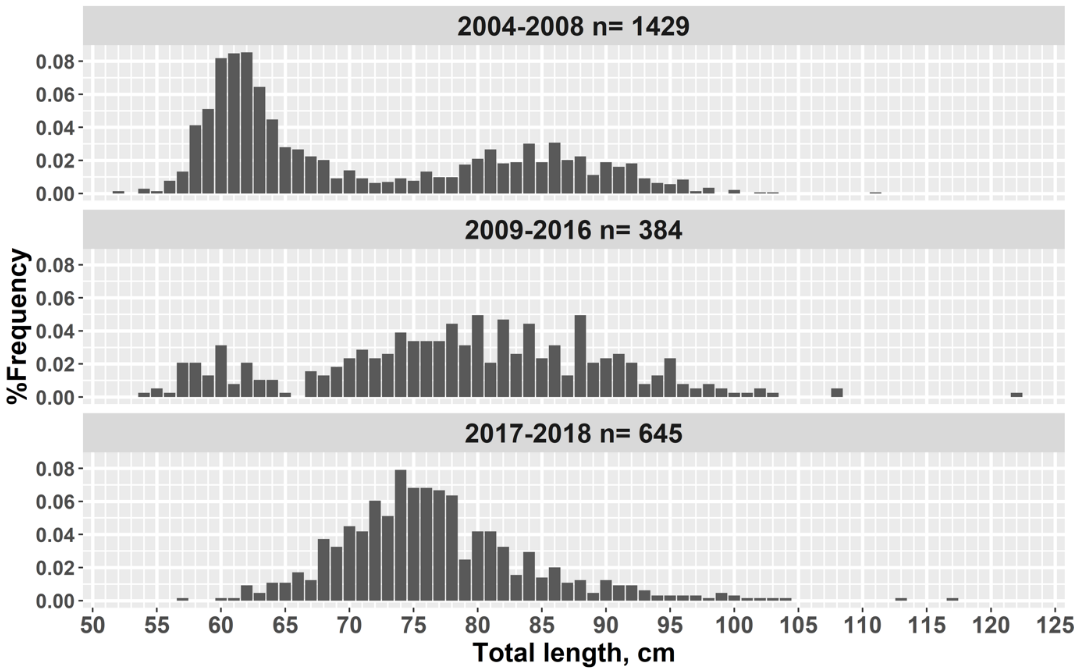


Figure 4.10 Length-frequency distribution of SCB hapuku in three sample periods: 2004-2008, 2009-2016 and 2017-2018. n= sample size.

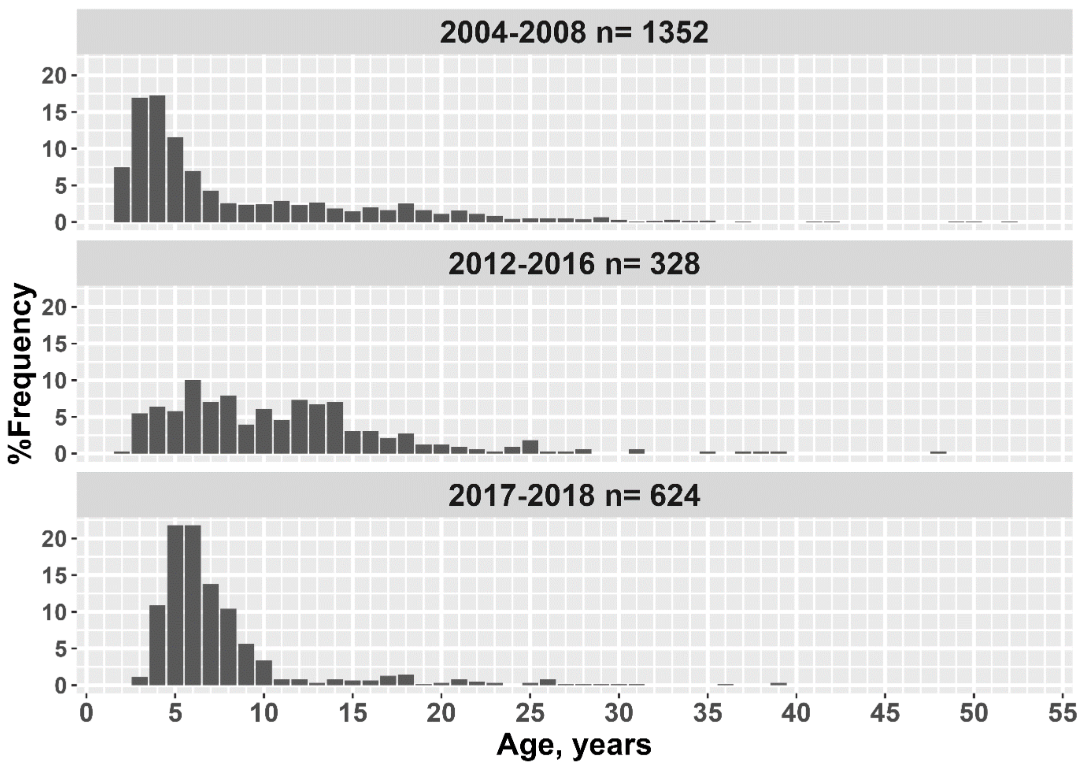


Figure 4.11 Age-frequency distribution of hapuku sampled in SCB grouped into three periods: 2004-2008, 2012-2016 and 2017-2018. n= sample size.

The proportion of young fish (< 10 years) in samples was highly variable and without trend: 71%, 52% and 87% in 2004-2008, 2012-2016 and 2017-2018, respectively. The proportion of intermediate age fish (10 to 20 years, inclusive) was also highly variable: 24%, 47% and 13%, respectively. The proportion of old hapuku (>20 years), however, progressively declined from 9% to 8% to 4%, respectively. The maximum observed age remains the 51.8-year-old taken in 2006 reported by Wakefield *et al*. (2010).

The large temporal variation in the prevalence of young and intermediate aged fish suggests that samples may not be representative of the population for these age groups. This may be due to a strongly spatially heterogenous age structure arising when transitioning from pelagic to demersal phase at age 2 -5 years. Hapuku appear to have considerable choice in location for demersal settlement, which may vary temporally. The likelihood of a spatially heterogenous age structure is enhanced by the SCB's series of steeply sloping canyons intersecting the continental shelf edge resulting in sporadic local nutrient upwelling and intermittent zones of high benthic productivity, e.g., coral gardens, bryozoan and sponge forests (Exon *et al.* 2005, Kampf 2021, Trotter *et al.* 2022). Moreover, consistent targeting by fishers of settlement locations within block 3517 adjacent to Albany, while other locations experience relatively light fishing mortality, may have also contributed to spatial heterogeneity of age structure for young and intermediate aged hapuku (see Figure 4.2 for spatio-temporal variation in catch). The generally sedentary behaviour demonstrated by a New Zealand tagging study (Beentjes and Francis 1999) helps facilitate this outcome. The inability to collect samples representative of the SCB hapuku population therefore undermines catch curve and per-recruit analyses which were not undertaken.

For old hapuku (>20 years) catch samples are expected to be more representative of the population compared to younger fish. This is because as fish age they are likely more dispersed from settlement locations, reducing spatial heterogeneity in age structure. Thus the observed decline in the prevalence of old fish could be reflective of a decrease of breeding stock over the sampling periods due to fishing mortality.

5.0 Western blue groper (*Achoerodus gouldii*)

5.1 Western blue groper summary

WA's SCB population of Western blue groper constitute a jurisdictional stock for management and assessment purposes. The Western blue groper is a protogynous hermaphrodite (some change sex from female to male) that can reach ~40 kg, with exceptional longevity (71 years), late onset of sexual maturity (~17 years) at a large TL (~65 cm), very late sex change (age ~35 years) at a very large total length (~82 cm).

Catches are dominated by the SDGDLMF using demersal gillnets. Since 1989-90 their catch has varied between 16 and 41 t, but progressively declined from 2014-15 to 16.8 t in 2021-22, which was associated with progressively lower fishing effort. SDGDLMF catches are taken from throughout the SCB, with no evidence of a progressive shift in the areas fished from abandoned to new grounds indicative of unacceptable stock depletion. Other commercial sector catches have been minor and tour operator and estimate private boat-based recreational retained catches have been negligible.

Catch-MSY modelling suggests that since 1989-90 catches in most years have been below the estimated annual MSY (±95%CLs) of 31.0 t (21.7 – 43.8), consistent with the stock remaining above B_{MSY}. A BDM applied to demersal gillnet catch rates estimated fishing mortality in recent years to be above F_{MSY} and stock biomass below the threshold reference level, with a breach of the limit considered unlikely. A revised Level 3 assessment of gillnet catch sample data collected in 2013-2014 was undertaken to generate estimates of long-term average fishing mortality from catch curve analysis applied to age composition data. The revised estimate for fishing mortality (year^{-1}) of F= 0.042 (0.029-0.055), was between target and threshold reference levels. Revised estimates for female, male and combined sexes relative spawning stock biomass (B_{rel} ±95%CLs) were 0.49 (0.42-0.53), 0.24 (0.20-0.27) and 0.35 (0.28-0.40), being above target, between threshold and limit, and between target and threshold, respectively. Using a precautionary approach given the unknown potential for sperm limitation, this assessment is based on male B_{rel} which was estimated to be between threshold and limit at the time of sampling (2013-2014), with only a remote likelihood of breaching the limit.

Consequently, the SCB Western blue groper stock status is **HIGH** risk.

5.2 Risk-based weight of evidence summary table and matrix

Category	Line of evidence
1.1 Biology and vulnerability	The Western blue groper is a protogynous hermaphrodite (some change sex from female to male) that can reach ~40 kg, with exceptional longevity (71 years), late onset of sexual maturity (~17 years) at a large TL (~65 cm), very late sex change (age ~35 years) at a very large TL (~82 cm). Western blue groper are generally sedentary making them vulnerable to localised overfishing. PSA for Western blue groper generated a productivity score of 2.14 and susceptibility score of 2.95, resulting in an overall score of 3.65, i.e., a high risk (Appendix).
1.2 Catch	Commercial catches of Western blue groper, first reported in 1976-77, are dominated by the Southern Demersal Gillnet and Demersal Longline Managed Fishery (SDGDLMF) which uses predominantly demersal gillnets. That fishery's catch has varied between 16 and 41 t since 1989-90, and since about 2014-15 has progressively declined to 16.8 t in 2021-22, which was associated with progressively lower fishing effort. Other commercial sector annual catches have been minor (<5.1 t) and tour operator and private boat-based recreational retained catches have been negligible.
1.3 Spatio-temporal distribution of catch	While SDGDLMF catches have been widely distributed across the SCB, they have tended to be higher west of 120°E. There is no evidence of a progressive shifting in the areas fished from abandoned to new grounds indicative of unacceptable stock depletion.
1.4 Catch-MSY analysis SCB	Catch-MSY analysis applied to annual catch data (all sectors) suggest that since 1989-90 catches in most years have been below the estimated annual MSY of 31.0 t (21.7 – 43.8). This is consistent with the stock remaining above B_{MSY} (i.e. relative biomass of 0.5). As this is a data-limited method with strong assumptions, results should be treated with caution.
Level 1 assessment There is no evidence of a progressive shifting in the areas fished from abandoned to new grounds. Catch-MSY modelling indicates catches have been mostly above MSY, consistent with the stock levels remaining above B_{MSY}. Level 1 assessment is therefore consistent with minor to moderate stock depletion.	
2.1 Effort and catch rate	For modelling, the SDGDLMF CPUE time series have been adjusted with an assumed 2% annual increase in fishing efficiency from 1990-1995. The two annual catch per unit effort (CPUE) time series for Western blue groper in the SCB (SCB) both show gradual declining trends and thus indicate a decline in stock abundance over this period.
Level 2 assessment	

A state space BDM (Winker *et al.* 2018), using the Schaefer production function, was fitted to annual catches and commercial CPUE for Western blue groper in SCB (SCB). Results from the analysis yielded a maximum sustainable yield (MSY) point estimate of 25 t. Since around 2009, estimated biomass levels have remained below that corresponding to B_{MSY}. The estimated current (2021-22) ratio of biomass to B_{MSY} (B/B_{MSY}) was 0.69 (95% CLs, 0.18-1.54) and current fishing mortality in recent years is estimated above F_{MSY} (F/ F_{MSY} = 1.24, 95% CLs = 0.38-3.74), indicating relatively high fishing effort in recent years. A substantial source of uncertainty in this assessment analysis relates to limited understanding regarding changes in fishing efficiency occurring over the history of the fishery. The results from the state space model fitted to annual catch and standardised commercial CPUE data indicate that the stock is currently at least slightly overfished, with estimated biomass between the threshold and limit levels, with a breach of the limit unlikely. Although overfishing is estimated to have been occurring in recent years, catch levels have been declining during this time, with fishing mortality also estimated to have been gradually declining to just above F_{MSY} in 2022.	
3.1 Fishery-dependent length and age, fishing mortality and per-recruit analysis	No new catch sampling was conducted for this assessment but a re-assessment of fishing mortality (*F* year^{-1}), spawning potential ratio (SPR) and relative biomass levels (B_{rel}) from commercial gillnet catch sampling between November 2012 and October 2014 using a revised method for estimating the rate of natural mortality (*M* year^{-1}) was undertaken. The revised estimate of *F*= 0.042 (0.029-0.055), based on a multi-year catch curve model that accounts for recruitment variability, was between target and threshold reference levels. Revised relative stock levels were: female SPR= 0.57 (0.52-0.61), B_{rel} = 0.49 (0.42-0.53), above target reference level; male SPR= 0.28 (0.24-0.31) and B_{rel} = 0.24 (0.20-0.27), between threshold and limit; and combined sexes SPR= 0.40 (0.34-0.46) and B_{rel} = 0.35 (0.28-0.40) between target and threshold. Given the possibility of sperm limitation, this assessment is based on male B_{rel} which is below threshold with only a remote likelihood of breaching the limit.
Level 3 assessment A revised assessment of previous catch sampling data from 2012-2014 indicated that fishing mortality was between target and threshold and spawning stock, conservatively based on male B_{rel} given the possibility of sperm limitation, was between threshold and limit with only a remote likelihood of breaching the limit.	
Final Risk C1 (Minor depletion – above target): consistent with Level 1 assessment, Unlikely according to Level 2 assessment and Implausible according to Level 3 assessment. Likelihood of minor depletion is therefore assessed as **Remote**. C2 (Moderate depletion – between target and threshold): consistent with Level 1 assessment, Possible according to Level 2 assessment and Implausible according to Level 3 assessment.	

Likelihood of moderate depletion is therefore assessed as **Unlikely.**

C3 (High depletion- between threshold and limit): Inconsistent with Level 1 assessment and Likely according to both Leve 2 and 3 assessments.

Likelihood of high depletion is therefore assessed as **Likely**.

C4 (Major depletion – below limit): Inconsistent with Level 1 assessment, Unlikely according to Level 2 assessment and a Remote possibility according to Level 3 assessment.

Likelihood of major depletion is therefore assessed as **Remote**.

The SCB Western blue groper risk matrix shows the maximum consequence-likelihood rating to be a **HIGH risk** (C3 x L4)**.**

SCB Western blue groper risk matrix

Consequence (Stock Depletion) Level	**Likelihood**			
	L1 Remote (<5%)	**L2 Unlikely (5-20%)**	**L3 Possible (20-50%)**	**L4 Likely (>50%)**
C1 Minor (above Target)	x			
C2 Moderate (below Target, above Threshold)		x		
C3 High (below Threshold, above Limit)				x
C4 Major (below Limit)	x			

5.3 Level 1 assessment: biology and vulnerability, catch

5.3.1 *Biology and vulnerability*

The Western blue groper (blue groper) is a protogynous hermaphrodite (likelihood of individuals changing sex from female to male increases with age) that can reach ~40 kg, with exceptional longevity (71 years), late onset of sexual maturity (~17 years) at a large total length (~65 cm), very late sex change (age ~35 years) at a very large total length (~82 cm) (Coulson *et al.* 2009). During sub-adulthood there is a migration from inshore protected habitats to deeper (up to 20 m) waters with increasing bottom relief, but they otherwise maintain small home ranges (Shepherd and Brook 2007, Bryars *et al.* 2012), making them vulnerable to localised depletion from overfishing.

In South Australia there was a negative correlation between an index of local fishing intensity and the abundance of sub-adults and adults, and sub-adult length (Shepherd and Brook 2007). Western blue groper are reportedly indifferent to the presence of spear fishers, or even inquisitive, highly enabling size-selective fishing by that sector.

5.3.2 *Catch*

Commercial catches of Western blue groper have been reported since 1976-77 (Figure 5.1), dominated by the Southern Demersal Gillnet and Demersal Longline Managed Fishery (SDGDLMF, also known as the Southern Demersal Gillnet and Demersal Longline Managed Fishery since coming under Western Australian Management) which uses predominantly demersal gillnets but also demersal longlines. Observer records of SDGDLMF gillnet operations indicate negligible levels of discarding of Western blue groper and associated fishing mortality (Braccini *et al.* 2022). All catches in blocks straddling the WCB boundary at 115°30'E (i.e., between 115°00'E and 116°00'E) have been included if they could not be allocated between bioregions.

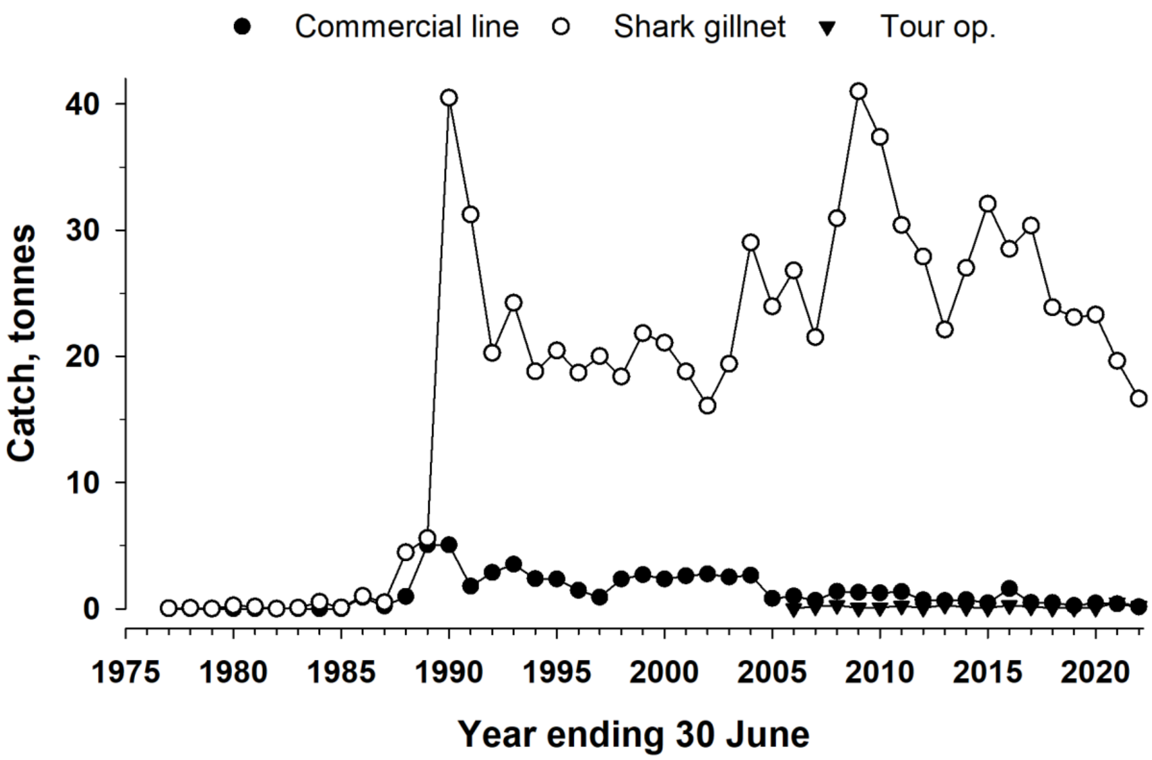


Figure 5.1 Total annual Western blue groper retained catch in the SCB by fishery from 1975-76 to 2021-22. Commercial line includes open access commercial line, net and trap. Shark gillnet includes catches in the SDGDLMF and prior to its inception in 1988 all longline catches. Recreational boat-based catches were too small to estimate with precision in five surveys from 2011-12 to 2020-21.

Initially at very low levels, the reported SDGDLMF catch started to rapidly increase from 1986-87, reaching the second highest annual catch of 40.5 t in 1989-90. The sudden increase may be due in part to increased reporting by fishers. Catches since then have mostly been considerably lower, the lowest at 16.1 t in 2001-02 and the highest at 41.0 t in 2008-09 t. Since about 2014-15 SDGDLMF catches have progressively declined to 16.6 t in 2021-22, which was associated with progressively lower effort levels that were commensurate with the historically low levels in 2007-08 and 2012-13. This decline resulted in catches being at similarly low levels to those during most of the 1990s and early 2000s. The relatively low annual commercial line catch has never exceeded 5.1 t. Private boat-based recreational retained catches have been too small to estimate with precision using integrated surveys (Ryan *et al.*, 2022). Annual tour operator catches have never exceeded 0.5 t.

5.3.3 *Spatio-temporal distribution of catch*

Blue groper catches in the SCB have always been dominated by the SDGDLMF (Figure 5.1). Since the first relatively large catches were reported in1989-90, they were predominantly from west of 120° E, with a somewhat even spatial distribution (Figures 5.2 and 5.3). The highest catches have always been in the far west and in the vicinity of Albany. There is no evidence that catch levels have been maintained by a progressive shifting in the areas fished from abandoned to new grounds that, otherwise, could be indicative of unacceptable stock depletion.

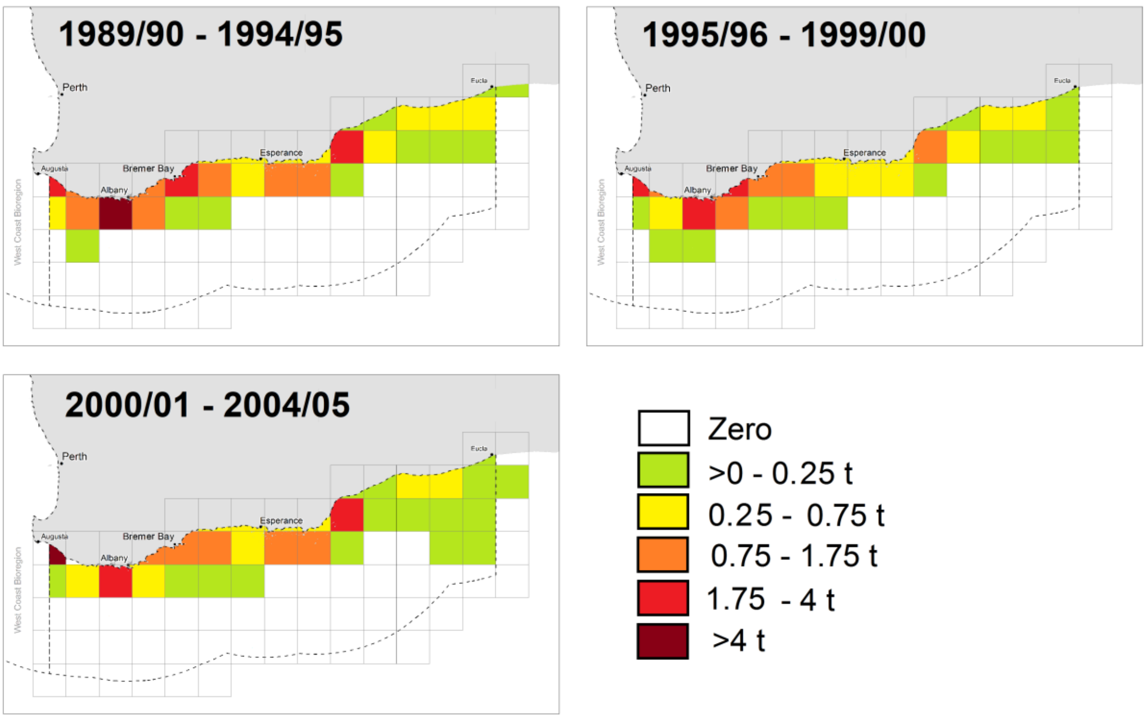


Figure 5.2 Time series of spatial distribution (1°x1° block) of the average annual catch of Western blue groper by the SDGDLMF in the SCB from 1989/1990 to 2004/2005 based on monthly returns.

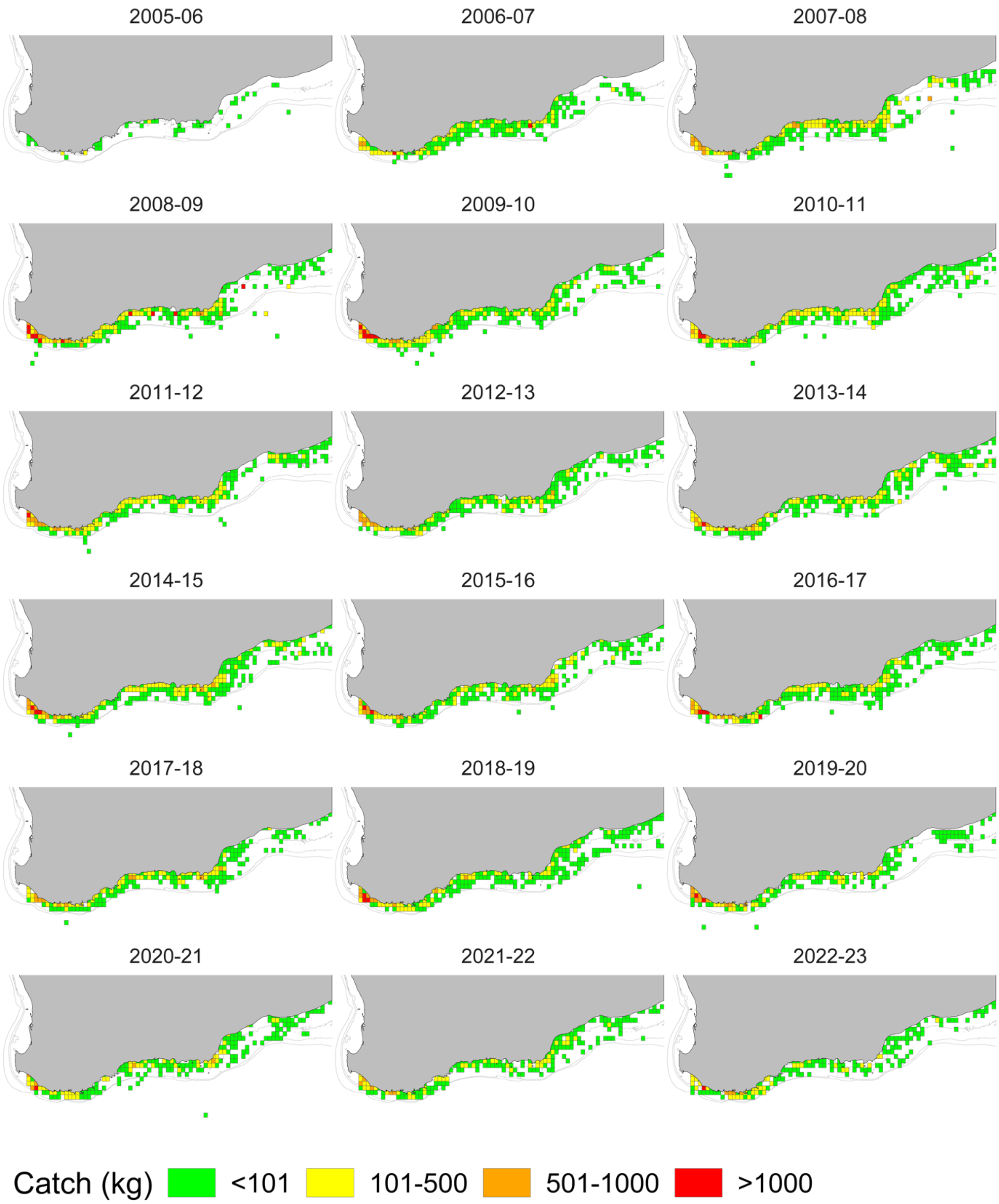


Figure 5.3 Time series of spatial distribution (10' x 10' block) of the catch of Western blue groper by the SDGDLMF in the SCB from 2005-06 to 2022-23. Note there were reporting inconsistencies in 2005-06 after the fishery transitioned to daily/trip logbooks (Braccini *et al.* 2021).

5.3.4 *Catch-MSY*

Catch-MSY models were used to predict MSY and trends in fishing mortality and stock depletion consistent with available catch data and model assumptions using the datalowSA package in R (Haddon *et al*., 2019). Assumptions included a low stock resilience (r=0.1-0.6), and initial and final depletion ranges of 0.7 – 0.975 and 0.15 – 0.80, respectively. The higher initial depletion range (i.e., little depletion had occurred) was because although commercial catch records commenced in 1975/76, very low catches until 1985/86 suggest only minor depletion. The total catch time series comprised total retained annual catch from all sectors for each year ended 30 June from 1975/76 to 2021/22. Recreational catch estimates, available from five annual surveys between 2011/12 and 2020/21 (Ryan *et al.* 2022), were insufficiently robust for publication but have been used here as the best available. The surveys did not align exactly with years ending 30 June so were allocated to the nearest such year and linearly interpolated for intermediate years. Recreational catch estimates for 1976/77 to 2010/11 were calculated as a linear function of the estimated number of registered boats in WA in those years. These estimates were generated from the rate of ownership of boats per head of population in the Perth metropolitan region that increased from 1990 to 2007 (Department for Planning and Infrastructure 2009), extrapolating this increasing rate forward (to 2010/11) and backward (i.e., decreasing rate, to 1976/77) for the total WA population (source: Australian Bureau of Statistics), and assuming catch per boat for 1976/77 to 2010/11 was the mean for the years 2011/12 to 2020/21. Tour operator catch estimates were available from 2005/06 to 2021/22, and earlier years, going back to 1976/77, were estimated assuming the same catch per head of the WA population as the mean from 2005/06 to 2021/22.

Catch-MSY modelling indicated a MSY (±95%CLs) of 31.0 t (21.7 – 43.8), with most years catches below this level since 1989-90 (Figure 5.4), consistent with simulated stock level trajectories remaining above B_{MSY} (i.e. above ~0.5, Figure 5.5). Note that Catch-MSY analysis is a data poor method with strong assumptions and thus results should be treated with caution.

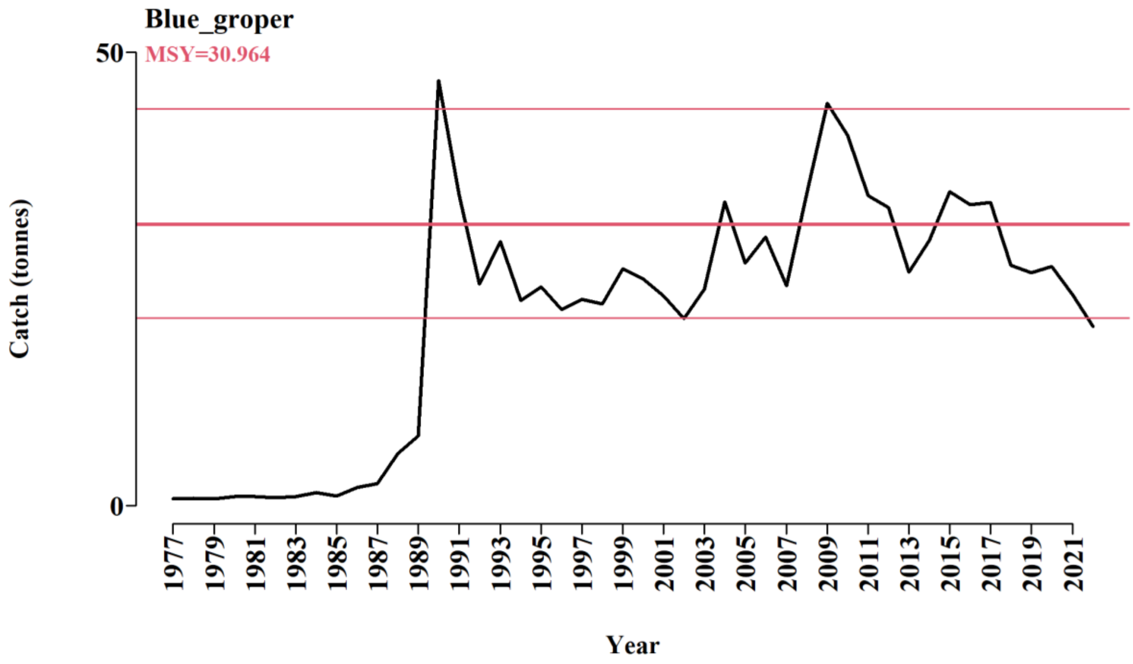


Figure 5.4 Total annual catch from 1976-77 to 2021-22 used for SCB Western blue groper Catch-MSY assessment vs estimated MSY (±95%CLs).

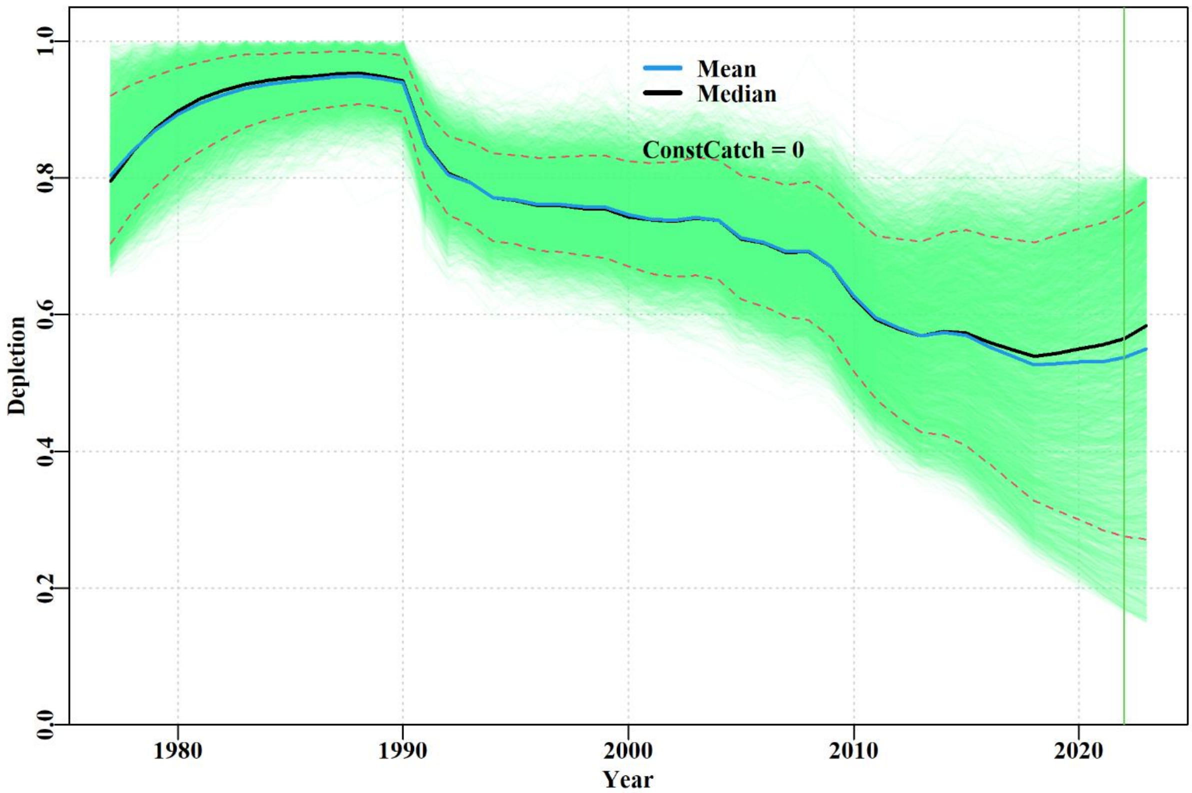


Figure 5.5 Trajectory of depletion levels of SCB Western blue groper stock based on Catch-MSY analysis. Dashed lines are 95% confidence levels.

5.4 Level 2 assessment: effort and catch rate

5.4.1 *JABBA: state-space Schaefer biomass dynamics model*

5.4.1.1 *Model description*

A state-space Schaefer BDM (see section 2.4.1.1) was applied using catch and commercial catch per unit effort (CPUE) data for Western blue groper in the SCB (SCB) to provide estimates of biomass and fishing mortality relative to biological reference points. The model was fitted to annual commercial catches and CPUE data from the gillnet catches of the SDGDLMF, where the latter is assumed to provide an index of spawning stock abundance (Figure 5.6). The following priors were assumed for Western blue groper: a lognormal prior for carrying capacity (K) with mean = log(1000) and sd = 1, a lognormal prior for the intrinsic rate of population increase (r) with mean = log(0.1) and sd = 0.3, a lognormal prior for the initial starting biomass (Ψ) with mean = log(0.7) and sd = 0.3. The Initial biomass value assumes light-moderate fishing occurring prior to the first year of recorded catches, noting that fishing activity for this species in the region likely commenced by the 1940s. The assumption of "low resilience" (r=0.1) is considered appropriate for this species given its maximum age (70 years; Coulson *et al.*, 2009) and the empirical relationship between r and natural mortality (Zhou *et al.*, 2016). Process error variance was specified as 0.3 with sensitivity runs (not shown in this document) conducted for values of 0.2 and 0.4. Standard fisheries reference points were calculated including MSY (MSY =rK⁄4) and the biomass corresponding to MSY (B_MSY=0.5 K) (Carruthers *et al.*, 2014; Froese *et al.*, 2017; Haddon, 2011).

5.4.1.2 *Data inputs*

The available time series of commercial catch of Western blue groper extend from 1978 to 2022 (Figure 5.7). During this assessment, potential issues with available commercial catch and effort data for this species before 1990 were identified that have yet to be resolved (possible species name recording issue). Consequently, this assessment is applied to catch and CPUE data for Western blue groper from 1990 - 2022. Further, investigation of the catch and effort records used to calculate the annual adjusted CPUE series for Western blue groper in the SCB suggested that the time series of CPUE data should be split between early (1990-2006) and later years (2008-2022) to account for differences in catch and effort reporting i.e., monthly reporting for earlier years and daily for later years (Braccini *et al.* 2021, Figure 5.6). Records for 2007 were omitted due to reporting inconsistencies by fishers immediately following the transition (Braccini *et al.* 2021). A catch rate record was defined as kilograms of retained catch per kilometre of gillnet used per hour. All records of Western blue groper taken in the SCB by gillnet were initially included, then systematically subject to omission by following Braccini *et al.*'s (2021) guidelines for identification of "reliable" and "unreliable" records. Thus records were omitted if:

- hours fished per day was incomplete, zero or >24 h (monthly returns only), or
- net length was incomplete or <100m or >12,000 m, or

- fishing effort <1 (km of net per hour), or
- number of shots was >3, or
- number of days fished per month was incomplete or >31, or
- catch was in an “estuarine” block other than King George Sound (block 96030).

The first two years of the CPUE time series based on daily reporting, have been excluded from the analysis due to issues associated with changes in reporting which may have affected reliability of the data. Both CPUE time series were adjusted to account for an assumed increase in fishing efficiency of 2% per year until 1994-95 and maintained at the 1994-95 efficiency value for subsequent years (Braccini *et al.* 2021). Note that for this L2 modelling analysis, the ‘years’ for the catch and CPUE time series and model outputs relate to financial years rather than calendar years, e.g. 1978 is the 1977-78 financial year.

5.4.1.3 *Results and implications*

The JABBA model provided good visual fits to annual adjusted CPUE time series for Western blue groper (adjusted for fishing efficiency) (Figure 5.7). Outputs from the Western blue groper assessment suggest that the current level of catch is just below the estimated MSY of 25 t (95% CLs: 9-65t) (Table 5.1).

The results from the BDM indicate that the Western blue groper stock abundance in the SCB has steadily decreased since the late 1990s and is well below B_{MSY} in recent years (Figure 5.7). Estimates of fishing mortality (F) fluctuated around F_{MSY} until 2003 with estimates since 2007 consistently above estimated F_{MSY} (Figure 5.7). Since 2009, estimates of F have generally shown a decreasing trend, coinciding with declining catch levels. The catch in the current (2022) year was slightly below MSY and *F* was still slightly above F_{MSY} (Figure 5.7; Table 5.1).

Fishing efficiency was specified as 2% per year from 1990 to 1995. The assumption of no increase in fishing efficiency was considered infeasible due to the introduction of technology such as GPS in the early 1990s, combined with other factors such as changes in fishing knowledge and experience. An increase of 2% per year for all years was considered likely to be too high for this fishery, since the methods of fishing and use of technology are unlikely to have changed rapidly since the mid-1990s and Western blue groper is a non-target species of the fishery.

The results from the state space model fitted to annual catch and standardised commercial CPUE data indicate that the stock is currently at least slightly overfished, with estimated biomass between the threshold and limit levels. Although overfishing is estimated to have been occurring in recent years, catch levels have been declining during this time, with fishing mortality also estimated to have been declining to just above F_{MSY} in 2022.

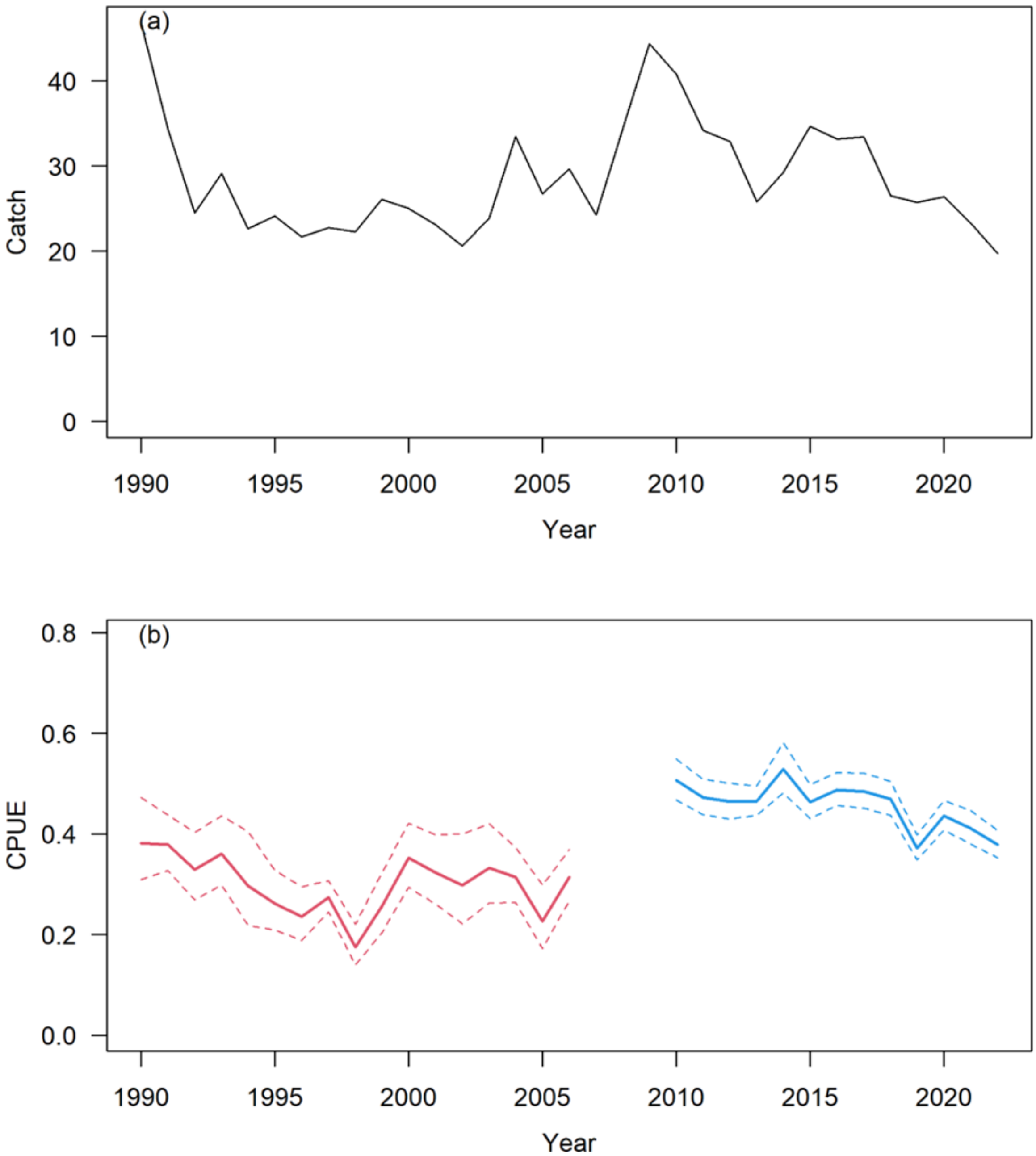


Figure 5.6 (a) Commercial Western blue groper catch (tonnes, t) in the SCB and commercial annual adjusted CPUE series for early (1990-2006) and later years (2010-2022). Solid lines denote mean CPUE, and dashed lines indicate associated 95% confidence limits. All CPUE time series have been adjusted for an assumed efficiency increase of 2% per year.

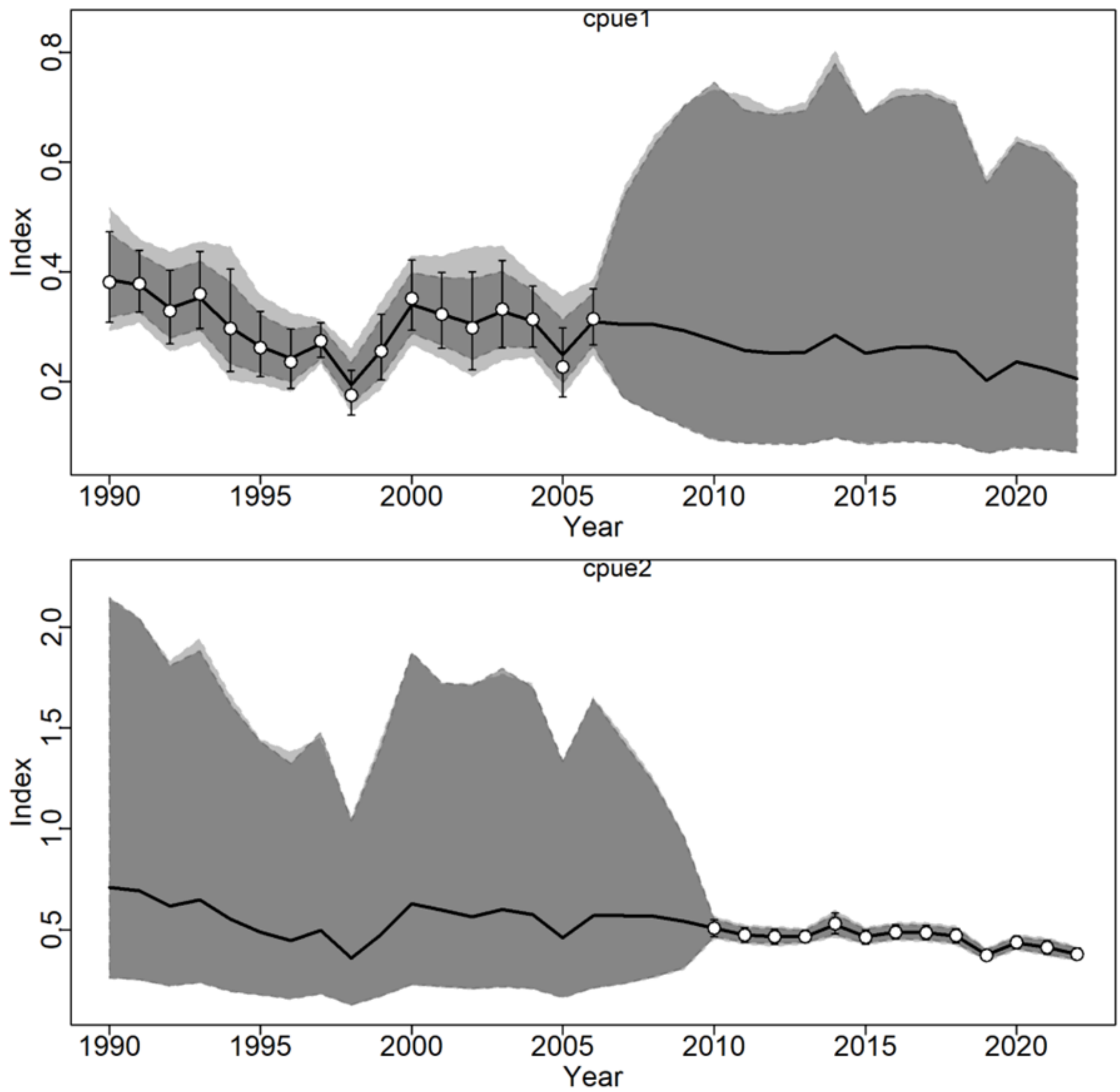


Figure 5.7 Fit of the JABBA Schaefer BDM to the standardised, targeted CPUE (adjusted for assumed changes in fishing efficiency) for Western blue groper from the SCB from the gillnet component of the SDGDLMF based on monthly returns (cpue1) and daily (cpue2). Observed CPUE and associated 95% confidence limits are indicated by white circles and error bars, whereas for expected CPUE, these are indicated by solid lines and shading.

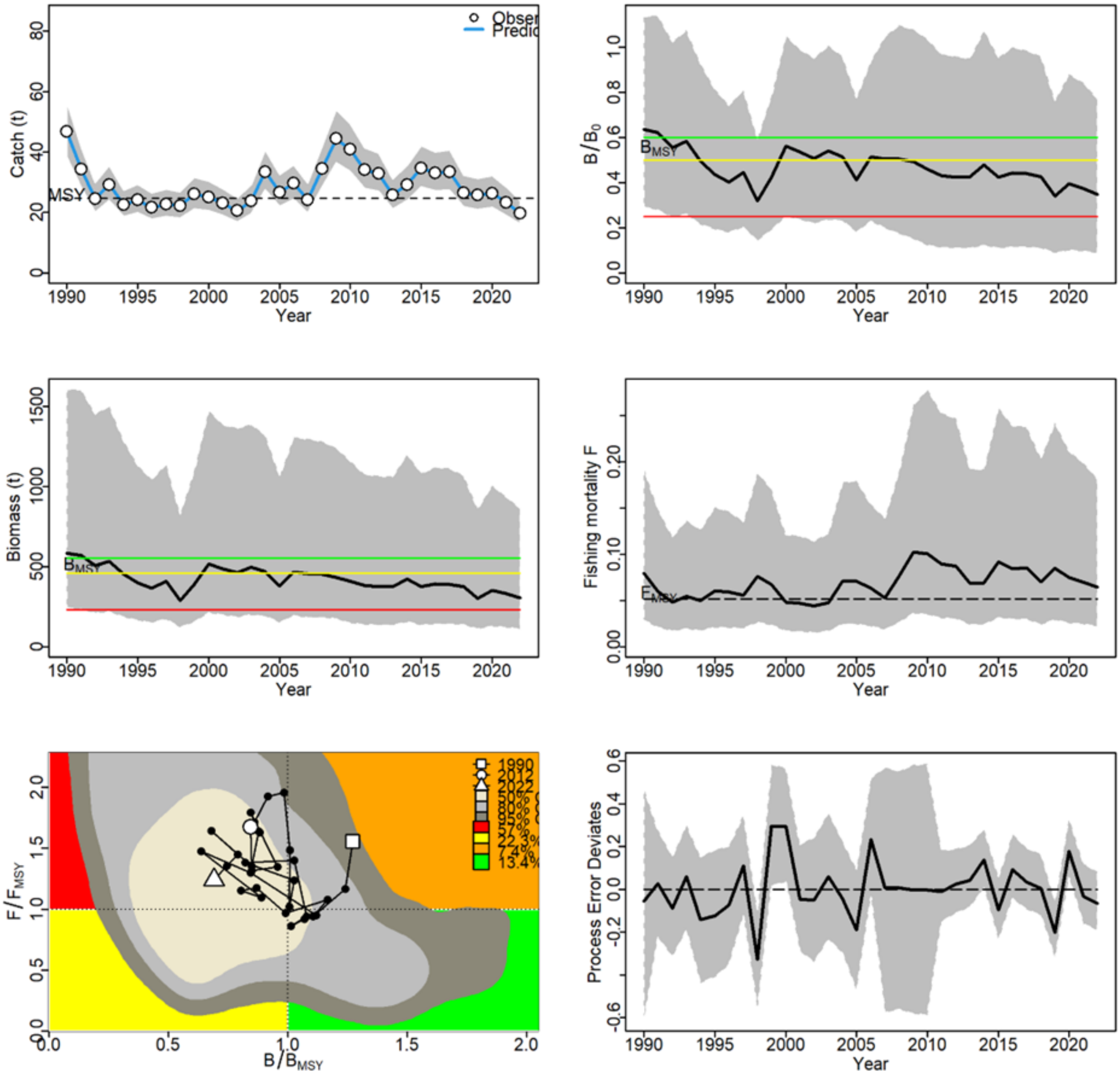


Figure 5.8 Annual time series of (top left) catch and estimates of (top right) relative biomass, (middle left) absolute biomass, (middle right) fishing mortality, (bottom left) KOBE plot tracking the relationship between fishing mortality and biomass over time, and (bottom right) process error deviations, derived from the JABBA Schaefer BDM fitted to Western blue groper catch and CPUE data. The 95% CLs around parameter estimates are shown as shaded regions. B_{MSY} and F_{MSY} refer to the biomass (absolute or relative) and fishing mortality, respectively, expected to achieve MSY. Red, yellow, and green lines represent the limit (0.5BMSY), threshold (B_{MSY}) and target (1.2B_{MSY}) reference points respectively.

Table 5.1 Parameter estimates produced by the state space BDM (JABBA) and associated 95% confidence limits for Western blue groper. Carrying capacity, K; intrinsic increase, r; maximum sustainable yield, MSY; biomass at MSY, B_{MSY}; fishing mortality at MSY, F_{MSY}; ratio of current biomass to unfished biomass, B/B0; ratio of current fishing mortality to F_{MSY}, F/F_{MSY}.

Parameter	Estimate (95% CLs)
K (tonnes)	921 (383-2266)
r	0.10 (0.06-0.19)
MSY (tonnes)	25 (9-65)
B_{MSY} (tonnes)	461 (192-1133)
F_{MSY} (year^{-1})	0.05 (0.03-0.09)
B/B_0 (in 2022)	0.35 (0.09-0.77)
B/B_{MSY} (in 2022)	0.69 (0.18-1.54)
F/F_{MSY} (in 2022)	1.24 (0.38-3.74)

Consequence (Stock Depletion) Level	Likelihood			
	L1 Remote (<5%)	**L2 Unlikely (5-20%)**	**L3 Possible (20-50%)**	**L4 Likely (>50%)**
C1 Minor (above Target)		x		
C2 Moderate (below Target, above Threshold)			x	
C3 High (below Threshold, above Limit)				x
C4 Major (below Limit)		x		

Figure 5.9 Risk assessment matrix based solely on results of BDM.

5.5 Level 3 assessment: fishery-dependent length and age, fishing mortality and per-recruit analysis

An earlier stock assessment for SCB Western blue groper concluded a Low risk rating (Norriss *et al.* 2016). The conclusion relied on an age-based analysis of SDGDLMF gillnet catch sampling from January 2013 to December 2014 (Figures 5.10 and 5.11). No further sampling has been undertaken, but the method for the rate of natural mortality (M year^{-1}) in that analysis was based on a method that assumed a uniform distribution between estimates based on methods of Hoenig (1983) and Then *et al.* (2015) that is no longer recommended, particularly for long-lived species such as Western blue groper (Hamel and Cope 2022, Maunder *et al.* 2023). Here, a reassessment is presented using the method of Dureuil and Froese (2021):

$$M = \log_e(0.015)/A_{\max}$$

where A_{max} is the oldest Western blue groper encountered in the SCB, i.e., 71.1 years. The result, M= 0.059, was very similar to alternative M estimators described by Hoenig (1983; M= 0.058) and Hewitt and Hoenig (2005; M= 0.059). A new estimate for fishing mortality (F, year^{-1} ±95% c.i.) from that sample was also generated based on the estimate of total mortality (Z year^{-1}) using a multi-year catch curve model that accounts for recruitment variability: Z = 0.101 (0.088-0.114) (Norriss *et al.* 2016). The new F estimates were compared to F/M target (0.67, i.e., F= 0.040 year^{-1}), threshold (1.0, i.e., F=0.059 year^{-1}) and limit (1.5, i.e., F=0.089 year^{-1}) reference levels. Note that post-release fishing mortality is negligible based on observer records of SDGDLMF gillnet fishing operations (Braccini *et al.* 2022).

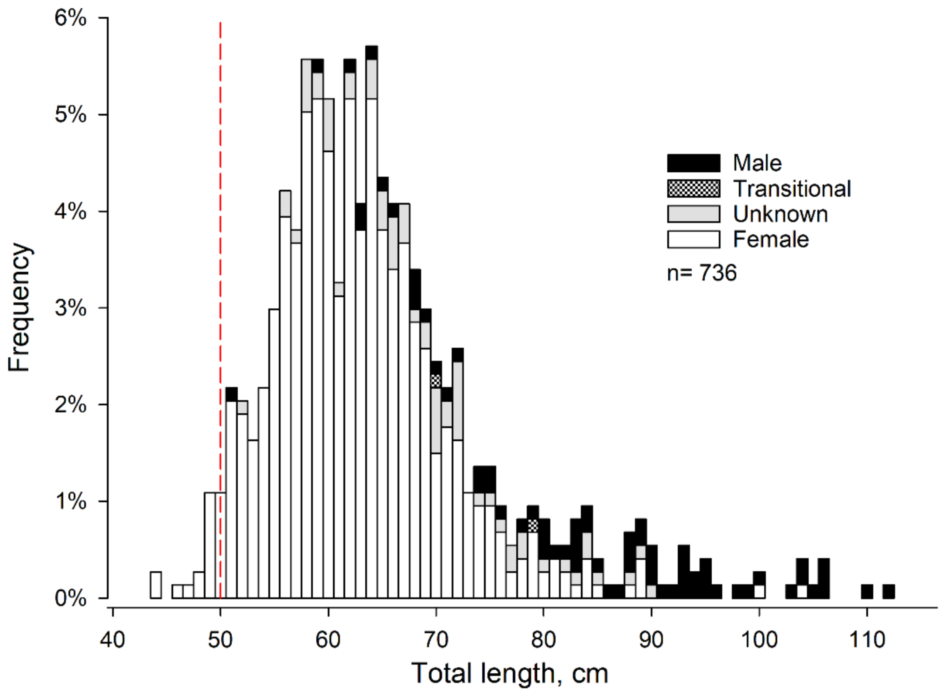


Figure 5.10 Western blue groper length-frequency distribution by sex sampled from the commercial gillnet catch east of 120°E in the SCB from January 2013 to December 2014 (Norriss *et al.* 2016). Dashed red line is the MLL of 500 mm.

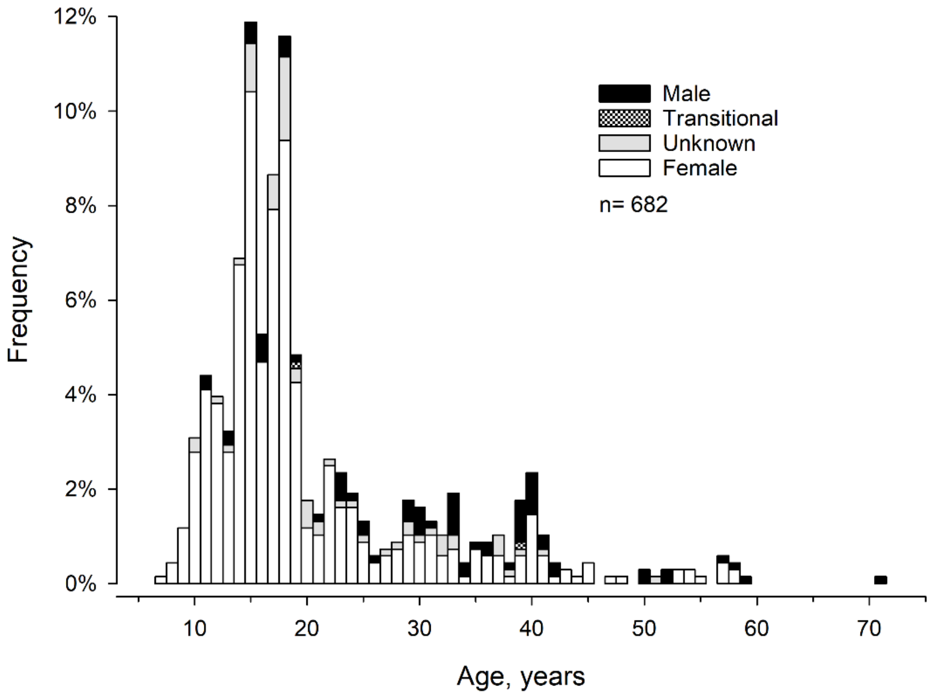


Figure 5.11 Western blue groper age-frequency distribution by sex from commercial gillnet catch sampling from January 2013 to December 2014 that was used for catch-curve and per-recruit assessment (Norriss *et al.* 2016).

New estimates of spawning potential ratio (SPR) and relative spawning biomass (B_{rel}) for females, males, and sexes combined were also generated incorporating the revised *F* estimate using the L3Assess R package (Hesp, 2023a). These analyses used a traditional per-recruit model and a more robust extended model accounting for the effects of fishing on annual recruitment through incorporation of a Beverton-Holt stock-recruitment relationship (Table 5.2). SPR and B_{rel} estimates were compared to target (0.40), threshold (0.30) and limit (0.20) reference levels.

The SDGDLMF gillnet catch along the lower west and south coasts of WA was sampled by Coulson *et al.* (2009) from April 2004 to October 2007. The modal age of 14 years compared with 18 years for the 2013-2014 sample. The proportions aged 15 to 20 years appeared lower, and >20 to 35 years higher, compared to 2013-2014, indicating a possible reduction in stock biomass. The maximum age was similar (~71 years), as was the proportion >50 years: 2.9% in 2004-2007 compared to 2.5% in 2013-2014.

The revised estimate of *F*= 0.042 year^{-1} (0.029-0.055) was between threshold and target levels with no prospect of breaching the threshold (0.059). This was not significantly different to the estimate from Coulson *et al.* (2009) of 0.039 year^{-1} (0.003-0.073). The revised per-recruit results for females was SPR= 0.57 (0.52-0.61; Table 5.3), significantly lower than Coulson *et al.*'s (2009) SPR estimate of 0.88 (0.75-0.99) and suggesting a decline in breeding stock. However the more robust

2013-2014 estimate of B_{rel} = 0.49 (0.42-0.53) indicated female spawning stock was highly likely above the target reference level (Figure 5.12) and subject to only minor depletion at that time. Male spawning stock results were SPR= 0.28 (0.24-0.31) and B_{rel} = 0.24 (0.20-0.27), between threshold and limit. This compares with the 2004-2007 estimate from Coulson *et al.* (2009) of SPR= 0.52 (0.27-0.96). Note that the proportion of males in the catch sample were broadly consistent (~11%). The combined sexes estimate of SPR= 0.40 (0.34-0.46) and B_{rel} = 0.35 (0.28-0.40) were between target and threshold. The possibility of sperm limitation is acknowledged given that facultative sex change has not been demonstrated in this species. Using a precautionary approach, for this assessment spawning stock is based on male B_{rel}, which is between threshold and limit with only a remote likelihood of breaching the limit (Figures 5.12 and 5.13).

Table 5.2 Parameters used in SCB Western blue groper per-recruit analysis.

Variable/Parameter	Value	Source
Max age (A_{max} $years$)	71.1	Norriss *et al.* (2016)
Natural mortality (M $year^{-1}$)	0.059 (sd=0.006)	log_e (0.015)/A_{max} (Dureuil and Froese 2021)
Fishing mortality (F $year^{-1}$)	0.042 (sd=0.013)	From *Z*=0.101 estimate (Norriss *et al.* 2016) and revised *M*
Growth (females)		von Bertalanffy growth curve fitted (Wakefield *et al.* 2016)
$L_\infty (mm\ TL)$	682 (f), 982 (m)	
$K\ year^{-1}$	0.14 (f), 0.08 (m)	
t_0 ($years$	0.06 (f), -0.48 (m)	
Weight-length (g, mm TL, both sexes)		$log_eW = alog_eTL - b$ Coulson *et al.* 2007)
a	11.017	
b	3.041	
Maturity (logistic)		Coulson *et al.* 2009.
L_{50} (mm TL)	653 (females)	
L_{95} (mm TL)	926	
Sex change (logistic)		Norriss *et al.* (2016)
A_{50} (years)	32.71	
A_{95} (years)	47.99	
P_{max}	0.52	
Selectivity (logistic)		
L50 (mm TL)	519.6 (both sexes)	Norriss *et al*. (2016).
Slope δ	0.052 (both sexes)	
Steepness of Beverton-Holt stock recruitment curve.	0.75 (sd=0.025)	Punt *et al.* (2011)

Table 5.3 Estimates of SCB Western blue groper SPR and B_{rel} for female, male and sexes combined based on sampling of gillnet catches from east of 120°E between January 2013 and December 2014. Colors denote results relative to the reference levels: green is point estimate above target, yellow is between target (0.40) and threshold (0.30) and orange between threshold and limit (0.20).

	Female	**Male**	**Combined sexes**
SPR	0.57 (0.52-0.61)	0.28 (0.24-0.31)	0.40 (0.34-0.46)
B_{rel}	0.49 (0.42-0.53)	0.24 (0.20-0.27)	0.35 (0.28-0.40)

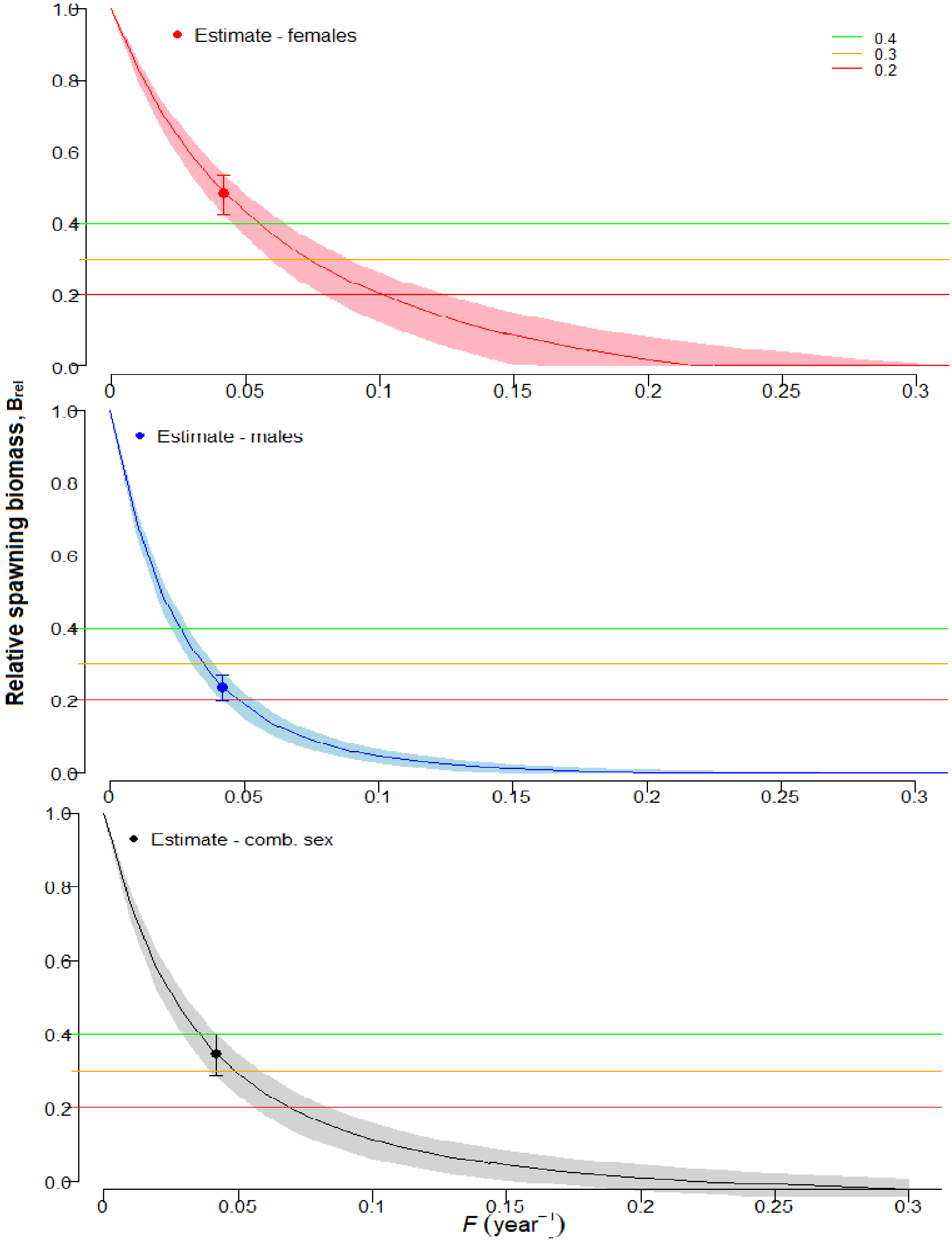


Figure 5.12 Relationship between female, male and combined sexes relative spawning biomass (B_{rel}), a proxy for breeding stock biomass relative to unfished biomass, and fishing mortality F for SCB Western blue groper. Based on sampling of gillnet catches from east of 120°E between January 2013 and November 2014. Coloured lines are performance reference levels: target (green 0.40), threshold (orange, 0.30) and limit (red, 0.20).

Consequence (Stock Depletion) Level	Likelihood			
	L1 Remote (<5%)	L2 Unlikely (5-20%)	L3 Possible (20-50%)	L4 Likely (>50%)
C1 Minor (above Target)				
C2 Moderate (below Target, above Threshold)				
C3 High (below Threshold, above Limit)				x
C4 Major (below Limit)	x			

Figure 5.13 Risk assessment matrix for Western blue groper based solely on preferred estimate of male B_{rel} from the 2013-2014 age sample depicted in Figure 12.

6.0 Blue morwong (*Nemadactylus valenciennesi*)

6.1 Blue morwong summary

WA's SCB population of blue morwong constitute a jurisdictional stock for management and assessment purposes. Blue morwong are gonochorists (do not functionally change sex) with relatively late onset of sexual maturity typically at about age 7 to 8 years when about 70 to 75 cm TL.

Catches are taken mainly by the SDGDLMF using demersal gillnets. Since 1983-84 that SDGDLMF's annual catch has fluctuated between 21 to 65 t and since 2019-20 from 23 to 27 t with low levels of effort. Females are less vulnerable to the fishery than males as their smaller size makes them less vulnerable to gillnets. SDGDLMF catches are taken from throughout the SCB, with no evidence they have been maintained by a progressive shifting in the areas fished from abandoned to new grounds indicative of unacceptable stock depletion. Catch-MSY modelling suggests that since 1993-94 most years' catches, from all sectors, have been below the estimated annual MSY of 59 t (40 – 83), consistent with predicted stock depletion levels being mostly stable and currently above B_{MSY}. SDGDLMF fishing effort in the SCB has fluctuated but since 2017-18 has declined to relatively low levels. Catch rates are consistent with a gradual depletion during early years in the fishery followed by stable abundance since at least 2010-11, except for a decline in the last year observed (2021-22).

An updated Level 3 assessment was undertaken to generate estimates of long-term average fishing mortality from catch curve analysis applied to length and age composition data from commercial gillnet catch sampling between 2012 and 2014. The analysis used a revised estimate for natural mortality (M year^{-1}) (Dureuil *et al*., 2021), to replace previous *M* estimates based on an approach no longer recommended in current scientific literature. Results show blue morwong do not become fully selected to gillnets until a relatively large size, particularly females which attain a smaller size than males. The revised female and male fishing mortality estimates were below and slightly above the threshold reference level, respectively. Estimates of spawning potential ratio (SPR) and relative spawning biomass (B_{rel}) showed females were above target, and males close to threshold, with sperm limitation considered unlikely. A precautionary estimate, based on sexes combined, showed spawning stock was close to target, with moderate depletion level likely.

Consequently, the SCB blue morwong stock status is **MEDIUM** risk.

6.2 Risk-based weight of evidence summary table and matrix

Category	Line of evidence
1.1 Biology and vulnerability	Blue morwong in the SCB are moderately long-lived (maximum age 25 years), are gonochorists (do not functionally change sex) with late onset of sexual maturity typically at about age 7 to 8 years when about 70 to 75 cm TL. Biological stock structure for this species remains to be investigated, but there is evidence of connectivity between populations on the lower west coast and south coast. Females are less vulnerable to the main fishery (demersal gillnet) than males due to their smaller size. PSA for blue morwong generated a productivity score of 1.71 and susceptibility score of 2.76, resulting in an overall score of 3.25, i.e., a high risk (Appendix).
1.2 Catch	Catches are dominated by the SDGDLMF. Since 1983-84 the SDGDLMF's annual catch has ranged from 21 to 65 t, with a recent decline associated with lower fishing effort. Annual boat based recreational catches have varied between 7 and 12 t between 2011-12 and 2020-21 with release rates estimated at 9 - 23%. Anecdotal reports indicate a moderate level of post release mortality from line fishing. Legally undersized blue morwong (<410 mm TL) are commonly found in shallow (<20 m) nearshore SCB waters.
1.3 Spatio-temporal distribution of catch	While SDGDLMF catches have been widely distributed across the SCB since records began in 1975-76, they have tended to be higher in western blocks. There is no evidence that catch levels have been maintained by a progressive shifting in the areas fished from abandoned to new grounds indicative of unacceptable stock depletion.
1.4 Catch-MSY analysis SCB	Catch-MSY analysis of annual catch data (all sectors) suggest that since 1993-94 most years' catches have been below the estimated annual MSY of 59 t (40 – 83). This is consistent with a long term stable level of relative biomass which remains at a level above B_{MSY} (i.e. above 0.5). As this is a data-limited method with strong assumptions, results should be treated with caution.
Level 1 assessment Catch levels have been maintained without a noticeable shift in the areas being fished from abandoned grounds. They have generally been below the MSY estimated by catch-MSY modelling, consistent with simulated stock trajectories remaining above B_{MSY}. The Level 1 assessment therefore indicates the stock depletion to be minor to moderate.	
2.1 Effort and catch	SCB fishing effort in the SDGDLMF has fluctuated but since 2017-18 has declined to relatively low levels. Catch rates, adjusted for

rate	fishing efficiency, are consistent with a gradual depletion during early years in the fishery followed by stable abundance since at least 2010-11, except for a decline in the last year observed (2021-22).
Level 2 assessment Catch rates indicate that abundance declined in the early years of the SDGDLMF but has stabilised since about at least 2010-11, suggesting only a remote likelihood of unacceptable stock decline.	
3.1 Fishery-dependent length and age, fishing mortality and per-recruit analysis	No new catch sampling was conducted for this assessment but a re-assessment of fishing mortality (F year^{-1}), spawning potential ratio (SPR) and relative biomass levels (B_{rel}) from commercial gillnet catch sampling between November 2012 and October 2014 using a revised method for estimating the rate of natural mortality year^{-1} was undertaken. Blue morwong do not become fully selected to gillnets until a relatively large size, particularly females which attain a smaller size than males. Estimates of female and male rates of fishing mortality were below and slightly above the threshold reference level, respectively. Spawning potential ratio (SPR) and relative spawning biomass (B_{rel}) estimates from per-recruit analysis showed females were above target, and males close to threshold. A precautionary estimate, based on sexes combined, indicated spawning stock was close to target, with minor depletion possible and moderate depletion likely.
Level 3 assessment A revised assessment of previous catch sampling data indicated that spawning stock was likely close to target level, with a moderate depletion level likely at the time of catch sampling from 2012 to 2014.	
Final risk C1 (Minor depletion – above target): consistent with Level 1 and 2 assessments. Considered possible according to Level 3 assessment. Likelihood of minor depletion is therefore assessed as **Possible**. C2 (Moderate depletion – between target and threshold): consistent with Level 1, 2 and 3 assessments. Likelihood of moderate depletion is therefore assessed as **Likely** C3 (High depletion- between threshold and limit): not consistent with Level 1 or 3 assessment with only a remote likelihood according to Level 2 assessment. Likelihood of high depletion is therefore assessed as **Implausible**. C4 (Major depletion – below limit): not plausible according to all assessment levels. Likelihood of major depletion is therefore assessed as **Implausible**. The SCB blue morwong risk matrix shows the maximum consequence-likelihood rating to be a **MEDIUM risk** (C1 x L3)**.**	

SCB blue morwong risk matrix

Consequence (Stock Depletion) Level	Likelihood			
	L1 Remote (<5%)	L2 Unlikely (5-20%)	L3 Possible (20-50%)	L4 Likely (>50%)
C1 Minor (above Target)			x	
C2 Moderate (below Target, above Threshold)				x
C3 High (below Threshold, above Limit)				
C4 Major (below Limit)				

6.3 Level 1 assessment: biology, vulnerability and catch

6.3.1 *Biology and vulnerability*

Blue morwong in the SCB are known to reach a maximum age of 25 years, are gonochorists (do not functionally change sex) with late onset of sexual maturity typically at about age 7 to 8 years when about 70 to 75 cm TL (Coulson *et al.* 2010), which is larger than the current MLL of 410 mm TL. Growth is moderately fast: at age 5 years average TL was 55 cm for females and 58 cm for males. Females attain a smaller maximum length than males so the selectivity of gillnets used by the SDGDLMF which takes the majority of the catch, results in a lower fishing mortality compared to males. While biological stock structure for this species remains to be investigated, Coulson *et al.* (2010) suggested lack of juvenile blue morwong and substantial spawning activity along the lower west coast indicates that this area is a source of larval recruits to the SCB where juveniles are relatively abundant. Anecdotal reports indicate a moderate level of post release mortality from line fishing that is associated with depth of capture.

6.3.2 *Catch*

Commercial catches of blue morwong have been reported since at least 1975-76 (Figure 6.1). Since the 1980s most of the catch has been taken by the SDGDLMF which uses predominantly demersal gillnets but also demersal longlines. All catches in blocks straddling the WCB boundary at 115°30'E (i.e., between 115°00'E and 116°00'E) have been included in this assessment if they could not be allocated between bioregions. Annual catches by the SDGDLMF peaked at 65 t in 1989-90, declined to 21 t in 2000-01, then rose again to 53 t in 2008-09, and then gradually declined to range from 23 to 27 t since 2019-20. This recent decline appears to be associated with reduced fishing effort (see Level 2 assessment below).

Private boat-based recreational retained catches reported during integrated surveys have varied between 7 and 12 t between 2011-12 and 2020-21 (Figure 6.1; Ryan *et al.*, 2022), while annual retained tour operator catches have been <1.5 t. The numbers of blue morwong reported as caught during each integrated survey of private boat-based fishers ranged from a minimum of ~3,000 in 2020-21 to a maximum of ~4,900 in 2011-12, with 9-23% of blue morwong caught being released. Information on the weight of released blue morwong is unavailable and PRM rates are unknown. However, blue morwong smaller than the MLL of 410 mm TL, i.e., must be released, are commonly found in shallow (<20 m) nearshore waters (Coulson *et al.* 2010).

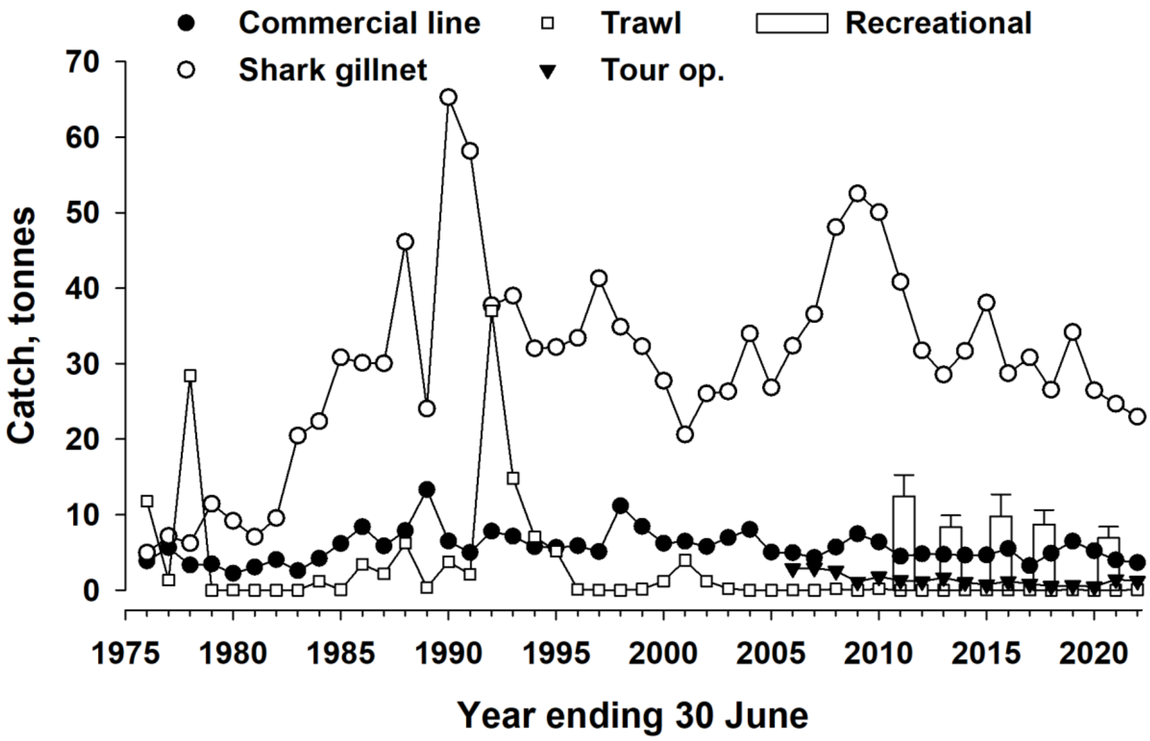


Figure 6.1 Total annual blue morwong catch in the SCB by fishery from 1975-76 to 2021-22. Commercial line includes open access commercial line, net and trap. Shark gillnet includes catches in the SDGDLMF and prior to its inception in 1988 all gillnet and longline catches. Recreational catch (±std. err.) is boat-based only. Tour operator catches available only from 2006.

6.3.3 *Spatio-temporal distribution of catch*

The blue morwong catch is taken predominantly by the SDGDLMF mostly by gillnet but with a small proportion by longline. Since the commencement of commercial catch records from 1975-76 until 2004-05, SDGDLMF catch locations were recorded within 1°x1° blocks in monthly returns. During this period catches were mostly from west of 120° E where the spatial distribution was somewhat even (Figure 6.2). Highest catches were typically in the vicinity of Albany. Catches in blocks east of Esperance were elevated in the late 1980s but then declined.

From 2005-06 catch locations were recorded within 10' x 10' blocks in daily/trip logbooks. Following reporting inconsistencies in 2005-06 immediately following the transition, catches were widely distributed across the continental shelf throughout the SCB (Figure 6.3). They tended to be higher in the west but not in all years, which is consistent with the earlier monthly records (Figure 6.2).

In conclusion there is no evidence that catch levels have been maintained by a progressive shifting in the areas fished from abandoned to new grounds indicative of unacceptable stock depletion.

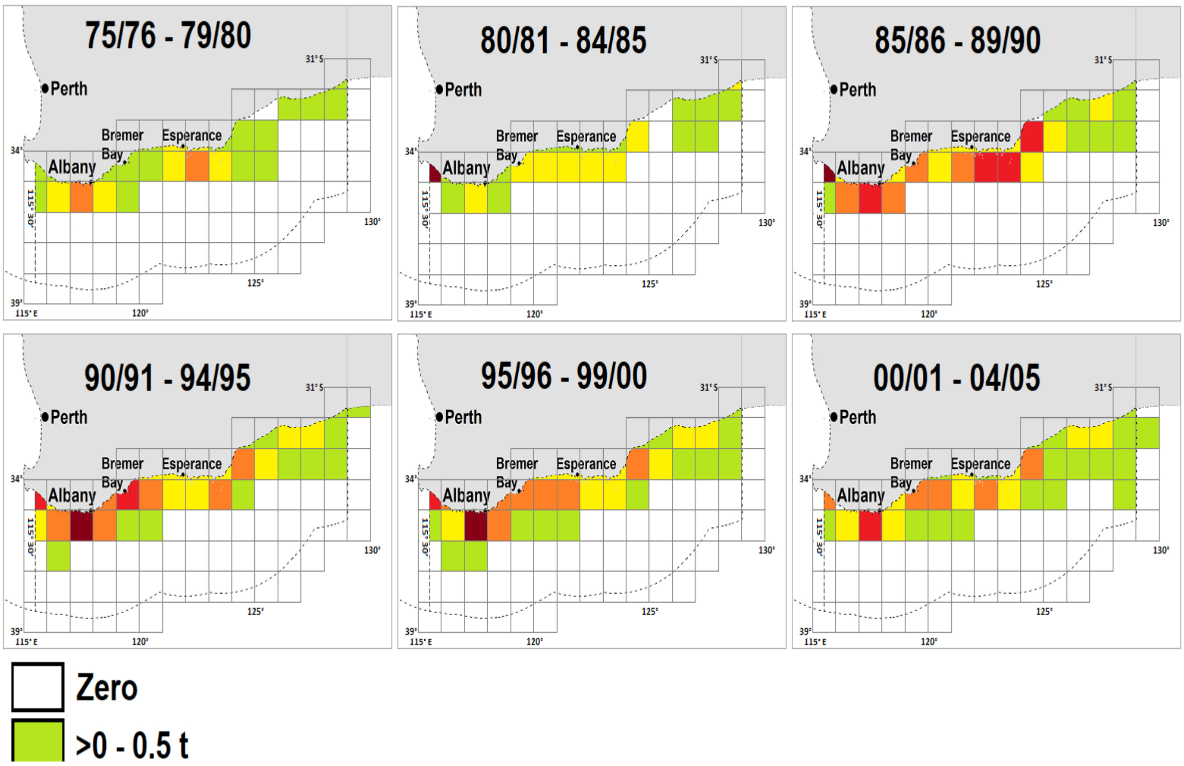


Figure 6.2 Time series of spatial distribution (1°x1° block) of the average annual catch of blue morwong by the SDGDLMF in the SCB from 1975-76 to 2004-2005 based on monthly returns. From 2005-06 the fishery transitioned to daily/trip logbooks reporting 10' x 10' blocks (see Figure 6.3).

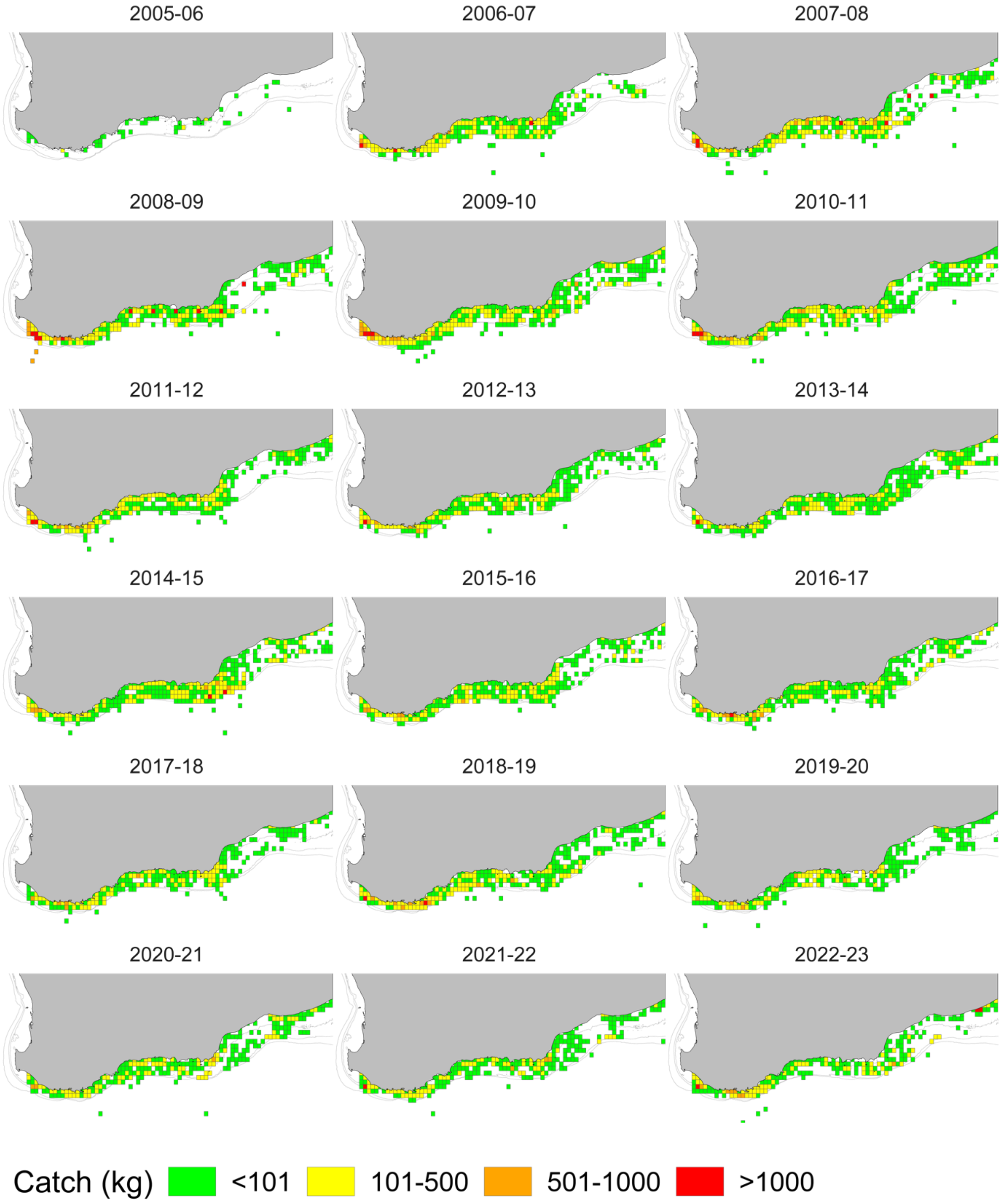


Figure 6.3 Time series of spatial distribution (10’ x 10’ block) of the catch of blue morwong by the SDGDLMF in the SCB from 2005-06 to 2022-23. Note there were reporting inconsistencies in 2005-06 after the fishery transitioned to daily/trip logbooks.

6.3.4 *Catch-MSY analysis*

Catch-MSY models were used to predict MSY and trends in fishing mortality and stock depletion consistent with available catch data and model assumptions using the datalowSA package in R (Haddon *et al*., 2019). Assumptions included a low stock resilience (r=0.1-0.6), and the model default initial depletion range of 0.5 – 0.975 to account for fishing before commercial records commenced in 1975-76. The final depletion range was assumed to be 0.15 – 0.8.

The catch time series comprised total retained annual catch from all sectors for each year ended 30 June, from 1975-76 to 2021-22. Recreational catch estimates were available from five annual surveys between 2011-12 and 2020-21, recently revised and slightly different to earlier published estimates. These surveys did not align exactly with years ending 30 June so were allocated to the nearest such year and linearly interpolated for intermediate years' estimates. Recreational catch estimates for 1975-76 to 2010-11 were calculated as a linear function of the estimated number of registered boats in WA in those years. These estimates were generated from the rate of ownership of boats per head of population in the Perth metropolitan region that increased from 1990 to 2007 (Department for Planning and Infrastructure 2009), extrapolating this increasing rate forward (to 2010-11) and backward (i.e., decreasing rate, to 1975-76) for the total WA population (source: Australian Bureau of Statistics), and assuming catch per boat for 1975-76 to 2010-11 equaled the mean for the years 2011-12 to 2021-22. Tour operator catch estimates were available from 2005-06 to 2021-22, and earlier years, going back to 1975-76, were estimated assuming the same catch per head of the WA population as the mean from 2005-06 to 2021-22.

The annual catch time series used for the Catch-MSY assessment exhibited considerable fluctuation (Figure 6.4). The set of plausible r-K combinations indicate a MSY (±95%CLs) of 59 t (40 – 83), with most years catches close to or below this level since 1993-94. This would be consistent with simulated stock levels being relatively stable with a slight recent increase to above B_{MSY} (i.e. above ~0.5; Figure 6.5). As Catch-MSY analysis is a data-limited method with strong assumptions, results should be treated with caution.

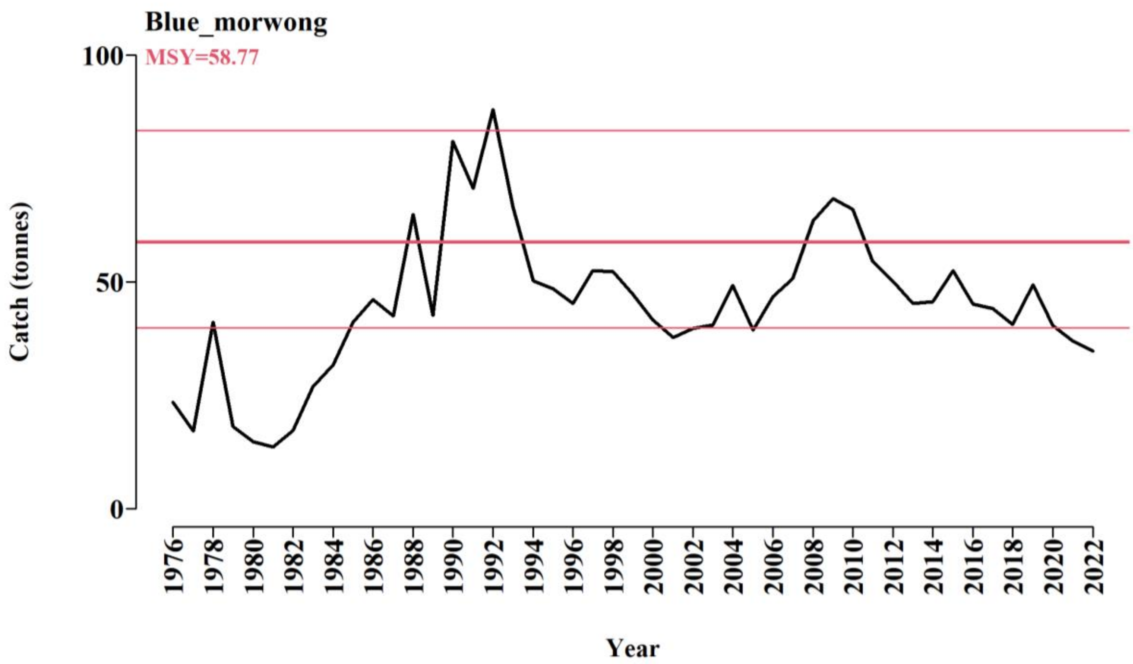


Figure 6.4 Total annual catch from 1989-90 to 2021-22 used for SCB blue morwong Catch-MSY assessment vs estimated MSY (±95%CLs).

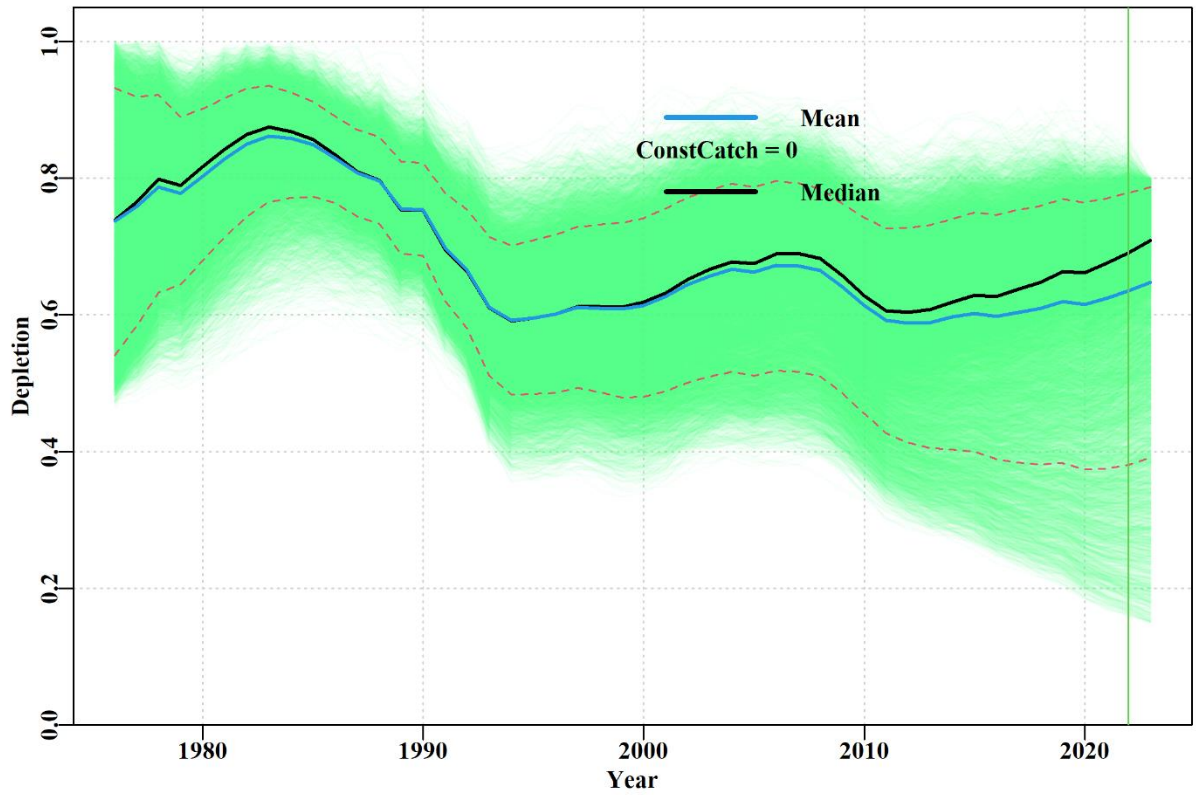


Figure 6.5 Trajectory of SCB blue morwong stock based on Catch-MSY analysis. Dashed lines are 95% confidence levels.

6.4 Level 2 assessment: effort and catch rate

The rate of CPUE (kg of retained blue morwong catch (liveweight) per kilometre of gillnet used per hour), assumed to be an index of abundance, was generated from statutory monthly CAES returns lodged by commercial fishers from 1975-76 to 2005-06, and from daily returns lodged by the SDGDLMF from 2007-08 to 2021-22 (Braccini *et al.* 2021). The 2006-07 year was omitted due to reporting inconsistencies by fishers immediately following the transition (Braccini *et al.* 2021). Following its inception in 1988, only demersal gillnet fishing recorded by the SDGDLMF was used. All records of blue morwong taken in the SCB by gillnet were initially included, then systematically subject to omission by following Braccini *et al.*'s (2021) guidelines for identification of "reliable" and "unreliable" records. Thus records were omitted if:

- hours fished per day was incomplete, zero or >24 h (monthly returns only), or
- net length was incomplete or <100m or >12,000 m, or
- fishing effort < 1 (km of net per hour), or
- number of shots was >3, or
- number of days fished per month was incomplete or >31, or
- catch was in an "estuarine" block other than King George Sound (block 96030).

The CPUE was reduced by 2% yr^{-1} from 1975-76 to 1994-95 (inclusive) to account for assumed increases in fishing efficiency due to technical advancements, then maintained at the 1994-95 value for subsequent years (Braccini *et al.* 2021). The 95% c.i. for each year's median was estimated from 0.025 and 0.975 quantiles of 1,000 random resample estimates of the median with replacement. An attempt to fit catch and CPUE to a BDM was unsuccessful and so that analysis was not undertaken.

The CPUE was initially high and imprecise but steadily declined at a decreasing rate toward the end of the monthly return series as precision improved (Figure 6.6). For the more recent period involving daily log-books (from 2007-08) CPUE initially decreased. For the first few years this may be attributable to reporting bias following the transition from monthly to daily catch returns, as reported by *Braccini et al.* (2021) for several shark species in this fishery which showed a similar decline over the same period. From 2010-11 the daily logbook CPUE remained stable, except for a decline in the last year observed (2021-22). Catch sampling was undertaken during this period (2012-2014) and indicated stock levels were adequate at that time (Norriss *et al.* 2016). Effort levels have fluctuated but since 2017-18 has declined to relatively low levels. In conclusion SDGDLMF CPUE is consistent with a gradual depletion during early years in the fishery followed by stable abundance since at least 2010-11.

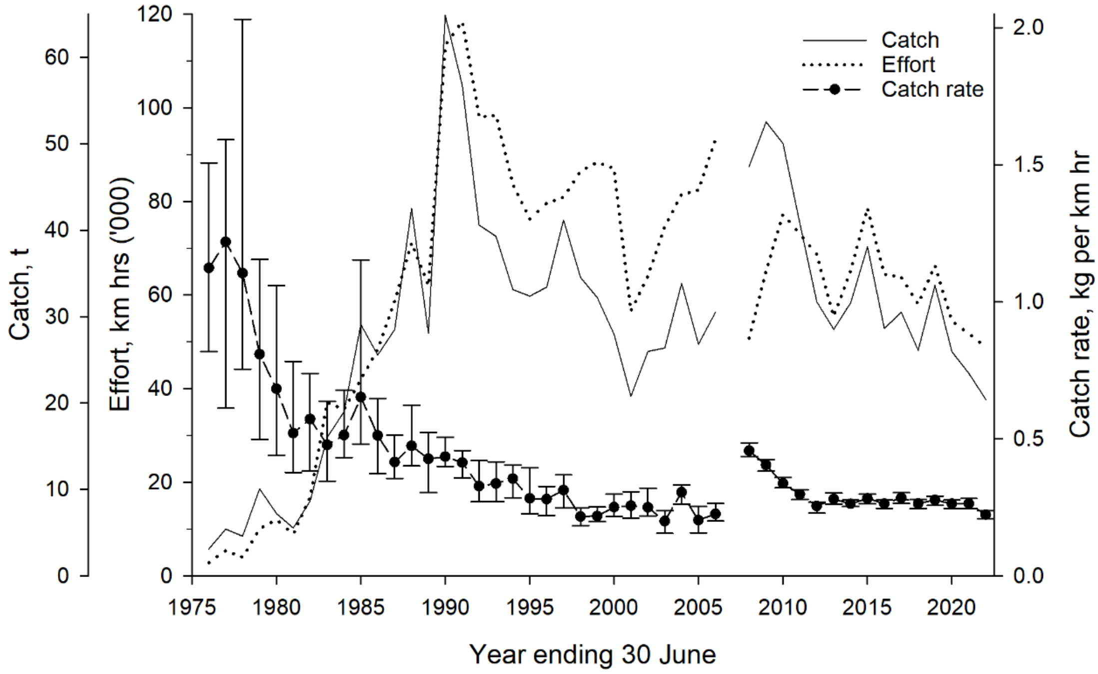


Figure 6.6 Catch, fishing effort and median nominal catch rate (±95% c.i.) for blue morwong taken in SCB by demersal gillnet according to a standardised dataset. Adjusted for 2% annual increase in fishing efficiency until 1994-95 and held constant thereafter. Monthly returns were used until 2005-06 and daily logbooks from 2007-08. The 2006-07 year was omitted due to inconsistencies in effort reporting.

6.5 Level 3 assessment: fishery-dependent length and age, fishing mortality and per-recruit analysis

An earlier stock assessment for SCB blue morwong concluded a Medium risk rating (Norriss *et al.* 2016). The conclusion relied on an age- and length-based analysis of commercial gillnet catches from November 2012 to October 2014 caught east of 120°E in the SCB (Figures 6.7 and 6.8). No further sampling has been undertaken, but the estimate for the rate of natural mortality (M year^{-1}) in that analysis that assumed a uniform distribution between estimates based on methods of Hoenig (1983) and Then *et al.* (2015) is no longer recommended (Hamel and Cope 2022, Maunder *et al*. 2023). Here, a reassessment is presented using the method (Dureuil and Froese 2021):

$$M = \log_e(0.015)/A_{max}$$

where A_{max} is the oldest blue morwong encountered in the SCB, i.e., 24.8 years. The result, M= 0.169, was very similar to alternative M estimators described by Hoenig (1983; M= 0.168) and Hewitt and Hoenig (2005; M= 0.170). New estimates for female and male fishing mortality (F year^{-1} ±95% c.i.) from that sample were also generated, weighted by estimated biomass at age of female and male blue morwong, noting that vulnerability to gillnets is lower for females due to their smaller maximum size compared to males (see 1.1 above). Observer records of SDGDLMF gillnet operations indicate negligible levels of discarding of blue morwong and associated post release fishing mortality (Braccini *et al.* 2022). The catch curve considered most suitable for blue morwong was a model fitted simultaneously to both age and length data (Norriss *et al.* 2016). Resulting estimates of *F*/*M* were compared to target (0.67, i.e., *F* = 0.113), threshold (1.0, i.e., *F* = 0.169) and limit (1.5, i.e., *F* = 0.254) reference levels. New estimates for relative spawning stock at that time were generated using the L3Assess per-recruit analysis package in R (Hesp 2023a): weighted female and male spawning potential ratio (SPR) using a traditional per-recruit model (note that unweighted estimates were previously reported by Norriss *et al.* 2016), and B_{rel} using a more reliable extended model accounting for the effect of fishing on annual recruitment. Input parameters (Table 6.1) were analysed using the L3Assess catch curve analysis package in R (Hesp 2023a). Results were compared to target (0.40), threshold (0.30) and limit (0.20) reference levels.

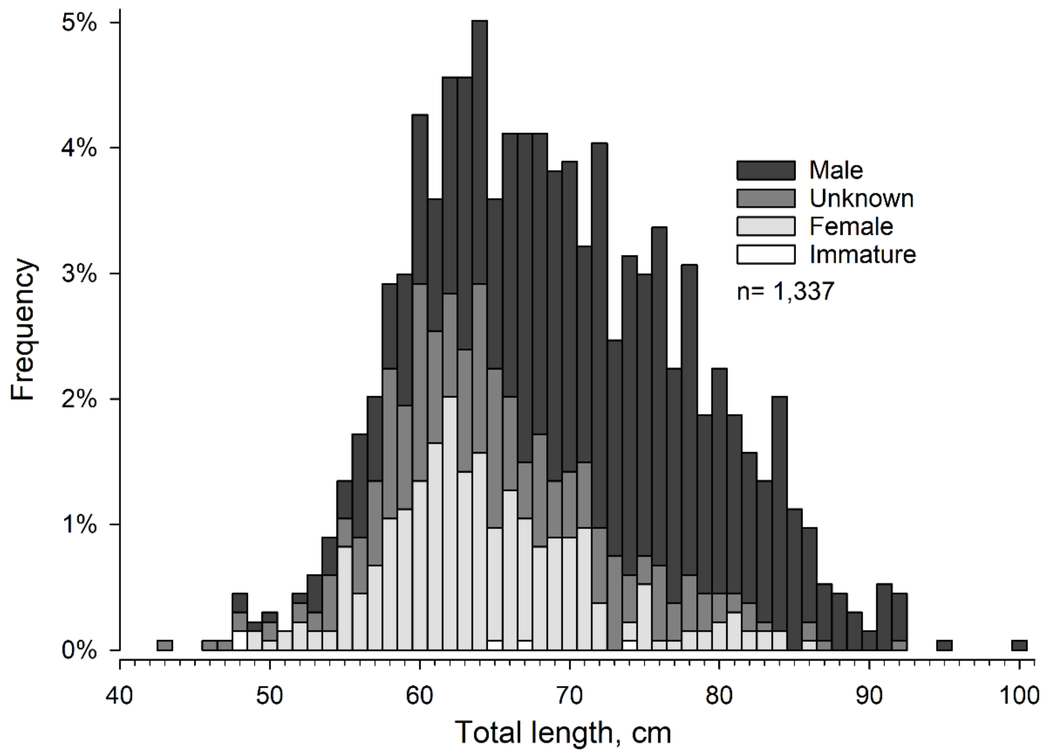


Figure 6.7 Length frequency distribution of blue morwong sampled from gillnet catches taken east of 120° E in the SCB from November 2012 to October 2014.

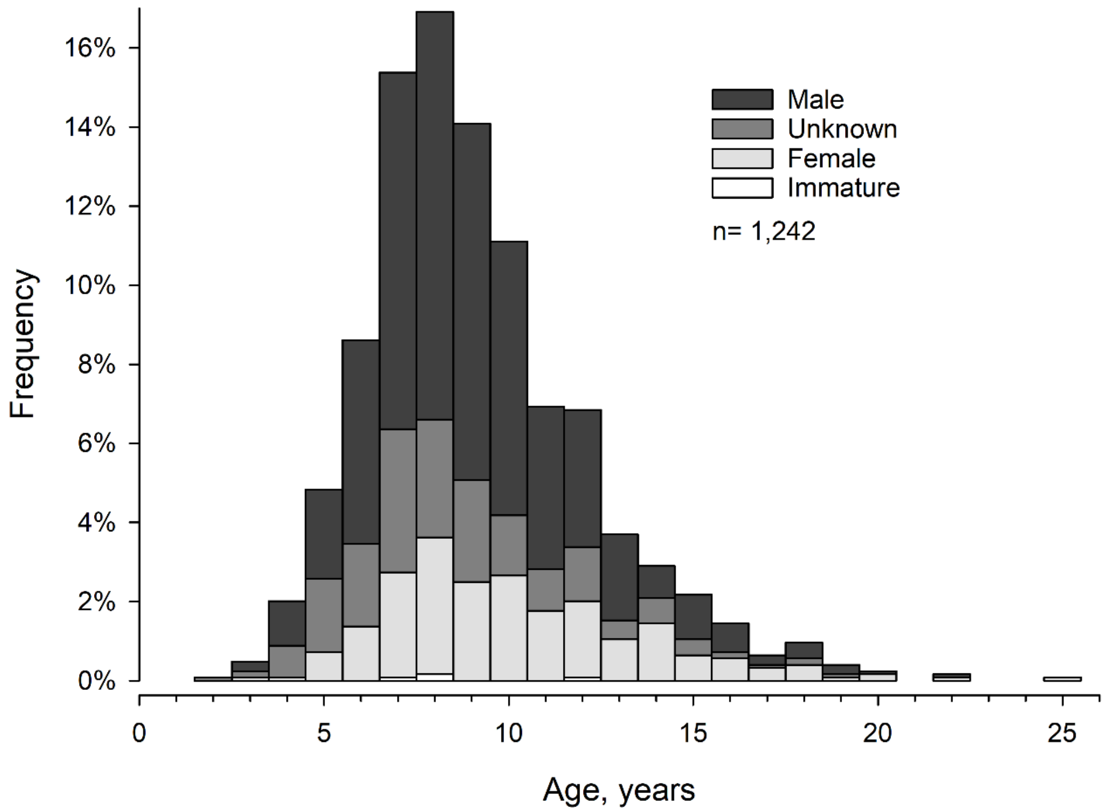


Figure 6.8 Age frequency distribution of blue morwong sampled from gillnet catches taken east of 120° E in the SCB from November 2012 to October 2014.

Results show blue morwong do not become fully selected to gillnets until a relatively large size (Table 6.1). The length at which fish are 50% selected into the fishery (L50 = 622.2 mm TL) is close to the estimated female asymptotic length (696 TL mm), indicating low vulnerability to females in particular. Fishing mortality estimates, weighted by estimated biomass at age, reflect this difference: $F_{females}$ = 0.13 (0.10 – 0.15) is between target and threshold, and F_{males} = 0.21 (0.17-0.25) is between threshold and limit.

Revised estimates for relative spawning stock indicated that the point estimate for female B_{rel} was above target but for males was just below threshold (Table 6.2, Appendix). Sperm limitation appears unlikely given males constitute the majority of both SDGDLMF and SCB recreational line catch samples (Norriss *et al.* 2016). This assessment, based on a precautionary approach where sexes are combined, shows B_{rel} to be just below target with no prospect of breaching the threshold (Figures 6.9 and 6.10).

Table 6.1 Parameters used in SCB blue morwong per-recruit analysis.

Variable/Parameter	Value	Source
Max age ($A_{max}\ years$)	24.8	Norriss *et al.* (2016)
Natural mortality ($M\ year^{-1}$)	0.169 (sd=0.017)	log_e (0.015)/A_{max} (Dureuil and Froese 2021)
Fishing mortality ($F\ year^{-1}$)	0.311 (sd=0.013)	From unweighted *Z*=0.48 estimate (Norriss *et al.* 2016)
Growth (females)		von Bertalanffy growth curve fitted (Coulson *et al.* 2010)
$L_\infty (mm\ TL)$	696 (f), 839 (m)	
$K\ year^{-1}$	0.29 (f), 0.22 (m)	
$t_0\ (years)$	-0.36 (f), 0.52 (m)	
Weight-length (g, mm TL, both sexes)		$log_eW = alog_eTL - b$ Coulson *et al.* (2007)
a	11.154	
b	2.969	
Maturity (asymmetric logistic)		Estimated by fitting, to combined data from Coulson *et al.* (2007) and Norriss *et al.* (2016), an asymmetrical four parameter logistic curve allowing for the possibility that maturity was not obtained by all fish of the largest length classes.
Pmax	0.89602 (f), 1 (m)	
Q	0.00013847(f), 0.22026 (m)	
B	0.010052 (f), 0.0046799 (m)	
v	0.0000011744 (f), 0.010052 (m)	
Selectivity (logistic)		
L50 (mm TL)	622.2 (both sexes)	Length at which fish are 50% selected. Estimated using length- and age-based catch curve, fitted to commercial gillnet data (Norriss *et al.* 2016).
Slope δ	0.029 (both sexes)	
Steepness of Beverton-Holt stock recruitment curve.	0.75 (sd=0.025)	Punt *et al.* (2011)

Table 6.2 Estimates of SCB blue morwong SPR and B_{rel} for female, male and sexes combined based on sampling of gillnet catches from east of 120°E between November 2012 and October 2014. Colors denote results relative to the reference levels: green is point estimate above target, yellow is between target (0.40) and threshold (0.30) and orange between threshold and limit (0.20).

	Female	Male	Combined sexes
SPR	0.53 (0.46-0.60)	0.32 (0.26-0.38)	0.43 (0.36-0.49)
B_{rel}	0.48 (0.41-0.56)	0.29 (0.24-0.36)	0.39 (0.32-0.46)

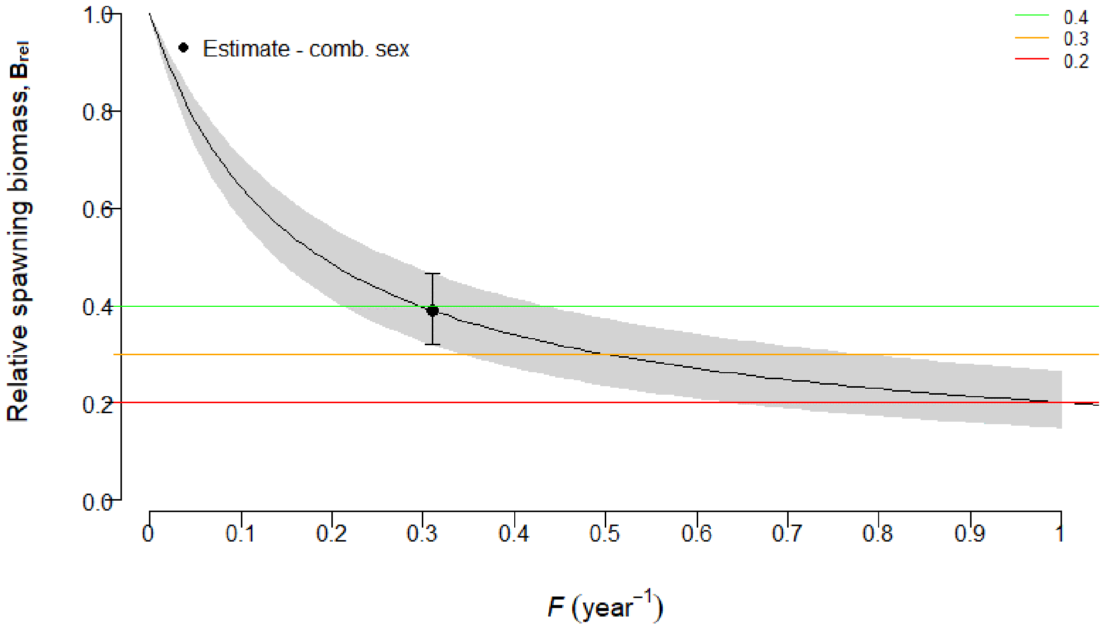


Figure 6.9 Relationship between combined sexes B_{rel}, a proxy for breeding stock biomass relative to unfished biomass, and fishing mortality F for SCB blue morwong. Based on sampling of gillnet catches from east of 120°E between November 2012 and October 2014. Coloured lines are performance reference levels: target (0.40), threshold (0.30) and limit (0.20).

Consequence (Stock Depletion) Level	Likelihood			
	L1 Remote (<5%)	L2 Unlikely (5-20%)	L3 Possible (20-50%)	L4 Likely (>50%)
C1 Minor (above Target)			x	
C2 Moderate (below Target, above Threshold)				x
C3 High (below Threshold, above Limit)				
C4 Major (below Limit)				

Figure 6.10 Risk assessment matrix based solely on preferred combined sexes estimate of B_{rel} from the 2012-2014 age sample depicted in Figure 7.

7.0 References

Armstrong CA. 2013. Differential growth of *Polyprion oxygeneios* between the west and south coast regions of Western Australia. Honours Thesis, Department of Environment and Agriculture, Curtin University, Western Australia.

Beentjes MP and Francis MP. 1999. Movement of hapuku (*Polyprion oxygeneios*) determined from tagging studies. New Zealand Journal of Marine and Freshwater Research, 33: 1–12.

Bertram A, Fairclough DV, Sandoval-Castillo J, Brauer C, Fowler A, Wellenreuther M, Beheregaray L. 2022. Fisheries genomics of snapper (Chrysophrys auratus) along the west Australian coast. Evolutionary Applications, DOI: 10.1111/eva.13439.

Best JK & Punt AE. 2020. Parameterizations for Bayesian state-space surplus production models. Fisheries Research, 222(October 2019), 105411. https://doi.org/10.1016/j.fishres.2019.105411

Braccini M, Bartes S and Coulson PG. 2022. Quantifying teleost discards in the shark fisheries of Western Australia. Journal of Fish Biology, https://doi.org/10.1111/jfb.15193.

Braccini M, Denham A, O'Neill MF and Lai E. 2021. Spatial and temporal patterns in catch rates from multispecies shark fisheries in Western Australia. Ocean and Coastal Management 213, 105883.

Bryars S, Rogers P, Huveneers C, Payne N, Smith I and McDonald B. 2012. Small home range in southern Australia's largest resident reef fish, the Western blue groper (Achoerodus gouldii): implications for adequacy of no-take marine protected areas. Marine and Freshwater Research, 63: 552-563.

Carruthers TR, Punt AE, Walters CJ, MacCall A, McAllister MK, Dick EJ and Cope J. 2014. Evaluating methods for setting catch limits in data-limited fisheries. Fisheries Research, 153, 48–68. https://doi.org/10.1016/j.fishres.2013.12.014

Chapman DG and Robson DS 1960. The analysis of a catch curve. Biometrics, 16, 354-368.

Coulson PG, Hesp, SA, Hall NG and Potter IC. 2009. The western blue groper (*Achoerodus gouldii*), a protogynous hermaphroditic labrid with exceptional longevity, late maturity, slow growth, and both late maturation and sex change. Fishery Bulletin, 107: 57-75.

Coulson PG, Hesp SA, Hall NG and Potter IC. 2010. Life cycle characteristics of the Blue Morwong *Nemadactylus valenciennesi*, compared with those of other species of Cheilodactylidae. Marine and Freshwater Research, 61: 104-118.

Coulson PG, Norriss JV, Jackson G, Fairclough DV. 2019. Reproductive characteristics of the fishery important temperate demersal berycid *Centroberyx gerrardi* indicate greater reproductive output in regions of upwelling. Fisheries Management and Ecology, 26: 236-248.

Coulson PG, Potter IC, Hesp SA and Hall NG. 2007. Biological parameters required for managing Western Blue Groper, Blue Morwong and Yellowtail Flathead. Final report to Fisheries Research and Development Corporation, Project 2004/057, Murdoch University, Western Australia, 167 pp.

Department for Planning and Infrastructure 2009. The Perth Recreational Boating Facilities Study 2008. Technical Report Number 444, Department for Planning and Infrastructure, Fremantle.

Dureuil M and Froese R. 2021. A natural constant predicts survival to maximum age. Communications Biology. https://doi.org/10.1038/s42003-021-02172-4.

Exon NF, Hill PJ, Mitchell C, and Post A. 2005. Nature and origin of the submarine Albany canyons off southwest Australia. Australian Journal of Earth Sciences, 52: 101-115.

Fairclough DV, Hesp SA, Denham A, Fisher EA, Marks R, Ryan KL, Lek E, Allen R and Crisafulli BM 2021. 2021 assessment of the status of the West Coast Demersal Scalefish resource. Fisheries Research Report No. 316. Department of Primary Industries and Regional Development, Western Australia. 158pp.

Froese R, Demirel N, Coro G, Kleisner KM and Winker H. 2017. Estimating fisheries reference points from catch and resilience. Fish and Fisheries, 18(3), 506–526. https://doi.org/10.1111/faf.12190

Gardner MJ, Chaplin, JA, Fairclough DV, Potter IP. 2022. Microsatellite-based assessment of the genetic structure of snapper, *Chrysophrys auratus*, in Australasia. Estuarine, Coastal and Shelf Science, https://doi.org/10.1016/j.ecss.2022.107932.

Haddon M. 2011. Modelling and Quantitative Methods in Fisheries. Second Edition. CRC Press, Taylor Francis Group.

Haddon M, Burch P, Dowling N and Little R. 2019. Reducing the Number of Undefined Species in Future Status of Australian Fish Stocks Reports: Phase Two - training in the assessment of data-poor stocks. FRDC Final Report 2017/102. CSIRO Oceans and Atmosphere and Fisheries Research Development Corporation. Hobart 125 p.

Hamel OS and Cope JM 2022. Development and considerations for application of a longevity-based prior for the natural mortality rate. Fish. Res. https://doi.org/10.1016/j.fishres.2022.106477.

Hesp A. 2023a. L3Assess: Catch curve and per recruit analyses. R package version 0.1.0

Hesp A. 2023b. WAFishBiology: Collection of methods for fish biology. R package version 0.1.0

Hewitt DA and Hoenig JM. 2005. Comparison of two approaches for estimating natural mortality based on longevity. Fishery Bulletin 103: 433-437. https://scholarworks.wm.edu/vimsarticles/566.

Hoenig J. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bulletin, 82, 898–903.

Kampf J 2021. Modelling of physical drivers of a large feeding aggregation of killer whales (*Orcinus orca*) in the western Great Australian Bight, Australia. Deep-Sea Research Part I, 171. https://doi.org/10.1016/j.dsr.2021.103526.

Knuckey I, Koopman M and Hudson R. 2021. Resource Survey of the Great Australian Bight Trawl Sector – 2021. AFMA Project 2019/0837. Fishwell Consulting 40pp.

Maunder MN, Hamel OS, Lee H-H, Piner KR, Cope JM, Punt AE, Ianelli JN, Castillo-Jord´an C, Kapur MS, Methot RD. 2023. A review of estimation methods for natural mortality and their performance in the context of fishery stock assessment. Fisheries Research 257 (2023) 106489. https://doi.org/10.1016/j.fishres.2022.106489

Moore A, Keller K and Tuynman H. 2022. Great Australia Bight Trawl Sector. In: Patterson, H, Bromhead, D, Galeano, D, Larcombe, J, Timmiss, T, Woodhams, J and Curtotti, R, *Fishery Status Reports 2022*, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra. CC BY 4.0. https://doi.org/10.25814/gx9r-3n90.

Nitschke J, Knuckey I, Koopman M, Hudson R, Huveneers C, Grammer G, Ward TM. 2022. Spatio-temporal variability in the demersal fish assemblage on the outer continental shelf of the Great Australian Bight. Estuarine, Coastal and Shelf Science, 271. https://doi.org/10.1016/j.ecss.2022.107852.

Newman, S.J., Santoro, K.G. and Gaughan, D.J. (eds). 2023. Status Reports of the Fisheries and Aquatic Resources of Western Australia 2022/23: The State of the Fisheries. Department of Primary Industries and Regional Development, Western Australia.

Norriss JV, Fisher EA, Hesp SA, Jackson G, Coulson PG, Leary T, and Thomson AW. 2016. Status of inshore demersal scalefish stocks on the south coast of Western Australia. NRM Project 12034 Final Report. Fisheries Research Report, No. 276. Department of Fisheries, Western Australia, 116 pp.

Norriss, J and Walters, S. 2019. South Coast Demersal Scalefish Resource Status Report 2022. In: Status Reports of the Fisheries and Aquatic Resources of Western Australia 2021/22: The State of the Fisheries. Eds. Newman, SJ, Wise, BS, Santoro, KG, and Gaughan, DJ. Department of Primary Industries and Regional Development, Western Australia. pp. 233-237.

Punt AE. 2003. Extending production models to include process error in the population dynamics. Canadian Journal of Fisheries and Aquatic Sciences, 60(10), 1217–1228. https://doi.org/10.1139/f03-105

Punt AE, Smith DC, Smith DM. 2011. Among-stock comparisons for improving stock assessments of data-poor stocks: the “Robin Hood” approach. ICES Journal of Marine Science (2011), 68(5), 972 –981. doi:10.1093/icesjms/fsr039.

R Core Team. 2023. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. https://www.r-project.org

Roberts CD 1996. Hapuku and bass: the mystery of the missing juveniles. Seafood New Zealand, 4: 17–21.

Rowling AK 1990. Estimation of fishing mortality, stock unity and growth of redfish *Centroberyx affinis* by tagging. Final Report of the Redfish Tagging Study, N.S.W. (FIRTA Project 85/71) (New South Wales Department of Agriculture and Fisheries, Fisheries Research Institute: Sydney.)

Ryan KL, Lai EKM, Smallwood CB. 2022. Boat-based recreational fishing in Western Australia 2020/21. Fisheries Research Report No. 327 Department of Primary Industries and Regional Development, Western Australia. 221pp.

Shepherd, S.A. and Brook, J.B. 2007. Distribution and ontogenetic shifts in habitat and abundance of the temperate western blue groper *Achoerodus gouldii*, (Richardson). Journal of Fish Biology 71, 1457-1478.

Smallwood CB, Tate A and Ryan KL. 2018. Weight-length summaries for Western Australian fish species derived from surveys of recreational fishers at boat ramps. Fisheries Research Report No. 278. Department of Primary Industries and Regional Development, Western Australia. 151pp.

St John J, Syers C and Craine M. 2009. The influence of depth, venting and hook type on catch and release angling mortality of snapper, *Pagrus auratus* (Sparidae): implications for management. In ‘Maximising Survival of Released Undersize West Coast Reef Fish’ (Eds Lenanton, R., Wise, B., St John, J., Keay, I. and Gaughan, D.), Final FRDC Report – Project 2000/194, Fisheries Research Report No. 191, pp. 472–478.

Then AY, Hoenig JM, Hall NG and Hewitt DA. 2015. Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. ICES Journal of Marine Science, 72, 82-92.

Trotter JA, Taviani M, Foglini F, Sadekov A, Skrzypek G, Mazzoli C, Remia A, Santodomingo N, Castellan G, McCulloch M, Pattiaratchi C, Montagna P. 2022. Unveiling deep-sea habitats of the Southern Ocean-facing submarine canyons of southwestern Australia. Progress in Oceanography, https://doi.org/10.1016/j.pocean.2022.102904.

Tuck GN (ed.). 2015. Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2014. Part 1. Australian Fisheries Management Authority and CSIRO Oceans and Atmosphere Flagship, Hobart. 170p

Wakefield CB, Newman SJ, Molony BW. 2010. Age-based demography and reproduction of hapuku, *Polyprion oxygeneios*, from the south coast of Western Australia: implications for management. ICES Journal of Marine Science 67(6), 1164-11.

Wakefield CB, Potter IC, Hall NG, Lenanton RCJ and Hesp SA 2016. Timing of growth zone formations in otoliths of the snapper, *Chrysophrys auratus*, in subtropical and temperate waters differ and growth follows a parabolic relationship with latitude. ICES Journal of Marine Science, doi:10.1093/icesjms/fsw137.

Walker MH, Blight, SJ, and Cliff, GM. 1982. Feasibility trawling in the Great Australian Bight by the Korean trawlers Dong Bang 91 and Dong Won 509 during the period 15.11.79 to 12.1.80. Department of Fisheries and Wildlife Western Australia Report No. 50, 59 pp.

Walker MH and Clarke DP 1989. The demersal trawl resources of the Great Australia Bight as indicated by the fishing operations of the stern trawlers Othello, Orsino and Cassio in the period 19.11.77 to 25.8.79. Fisheries Research Report No. 86, Department of Fisheries Western Australia, 65 pp.

Winker H, Carvalho F and Kapur M. 2018. JABBA: Just Another Bayesian Biomass Assessment. Fisheries Research, 204(March), 275–288. https://doi.org/10.1016/j.fishres.2018.03.010

Zhou S, Chen Z, Dichmont CM, Ellis N, Haddon M, Punt AE, Smith D M, Smith DC, and Ye Y. 2016. Catch-based methods for data-poor fisheries (Issue November). Report to FAO. CSIRO.

Zhou S, Punt AE, Deng R, Dichmont CM, Ye Y, and Bishop J. 2009. Modified hierarchical Bayesian BDMs for assessment of short-lived invertebrates: a comparison for tropical tiger prawns. Marine and Freshwater Research, 60(12), 1298. https://doi.org/10.1071/MF09022

8.0 Appendix

8.1 Levels and descriptions of the categories of assessment methods

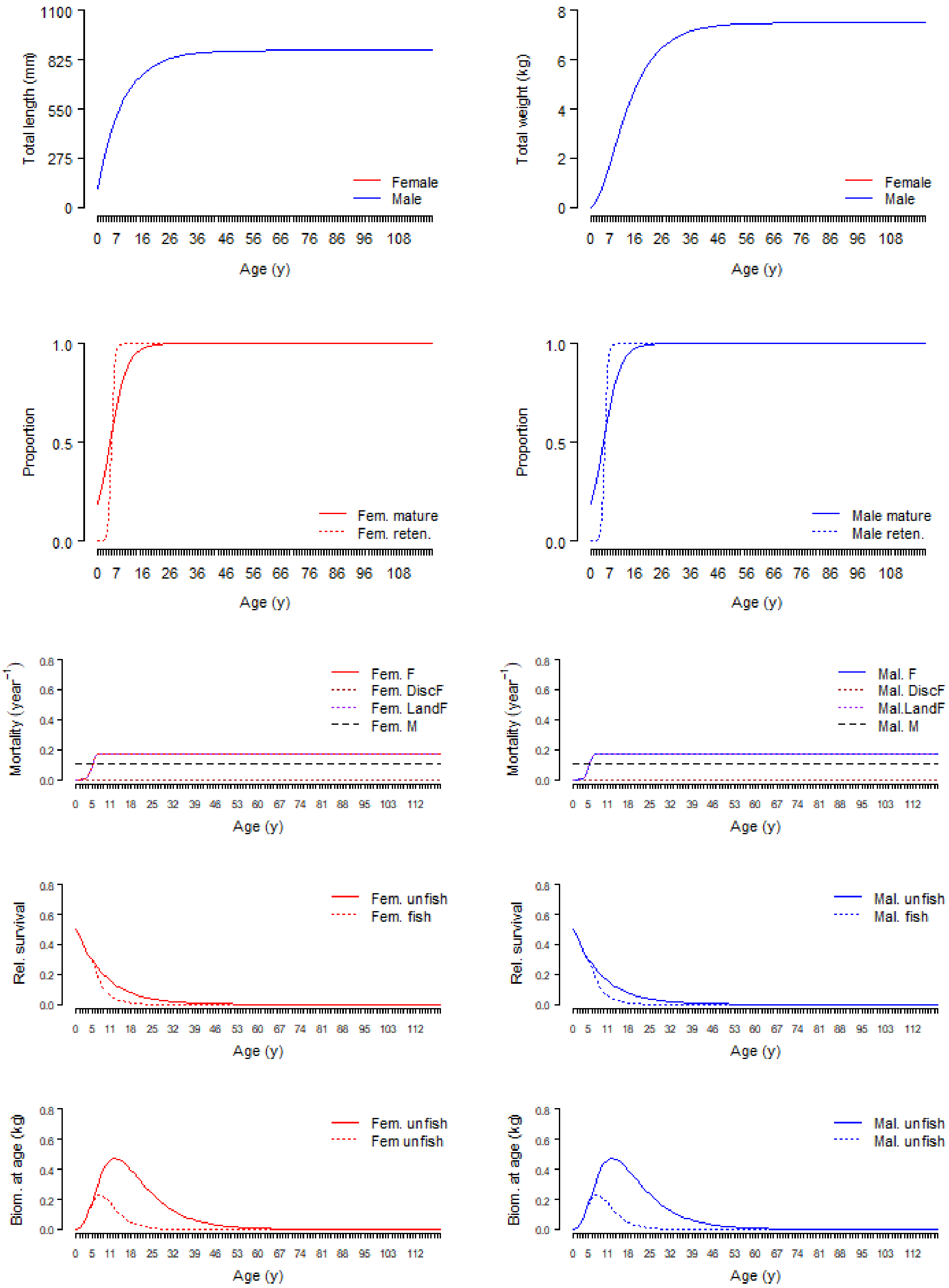
Level	Description
Level 1	Catch data and biological/fishing vulnerability. Catch-MSY analysis (if sufficient data).
Level 2	Level 1 and nominal or standardised fishery-dependent effort. Simple biomass dynamics models, depletion analysis (if sufficient data), or performance-indicator reference levels based on historical catch and/or CPUE time series.
Level 3	Levels 1 and/or 2 plus fishery-dependent biological sampling of landed catch (e.g. average size; fishing mortality, etc. estimated from representative samples). Equilibrium assessment models (e.g. catch curve and per recruit analysis).
Level 4	Levels 1, 2 and (data-permitting) 3 plus reliable/informative abundance time series (e.g. spawning stock and/or recruitment indices from standardised fishery-dependent and/or fishery-independent data). Empirical analyses (e.g. stock-recruitment-environment relationships), dynamic stock assessment models (e.g. state-space production model, age-structured production model, statistical catch-at-age model without abundance information).
Level 5	Levels 1, 2, 3 and 4 plus dynamic, integrated stock assessment model (incorporating biological information, catch, abundance and compositional data, and potentially other information e.g. from tagging).

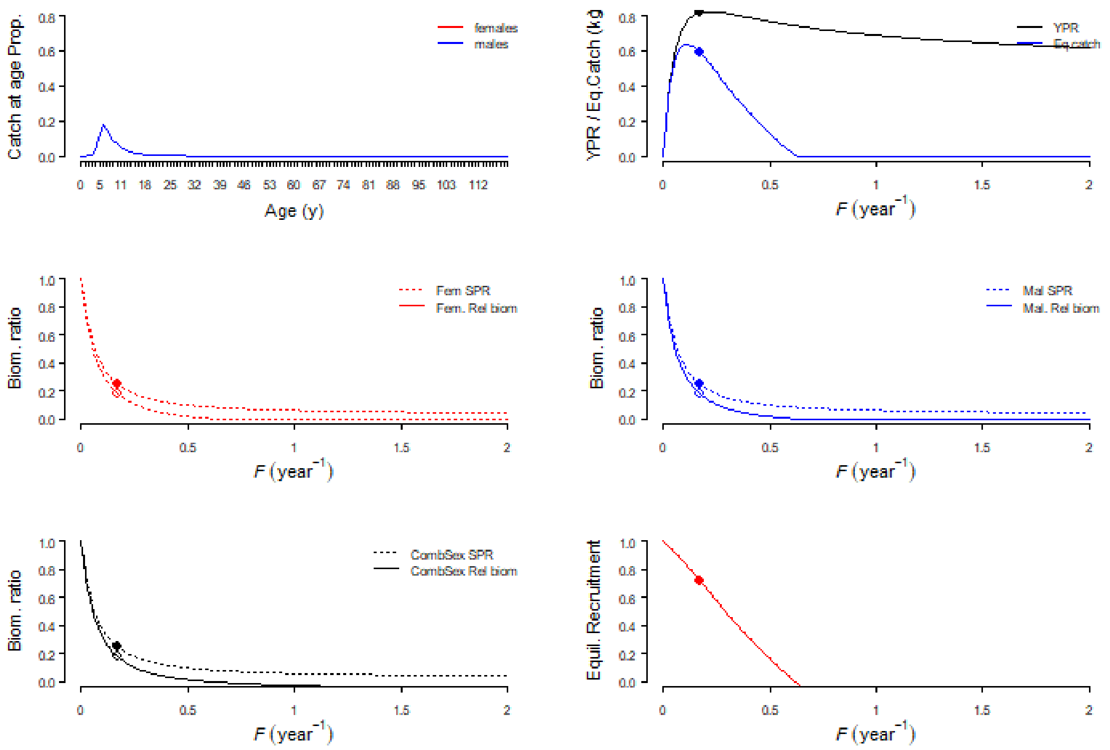
From Newman *et al.* (2023).

8.2 Per-recruit analysis diagnostic plots

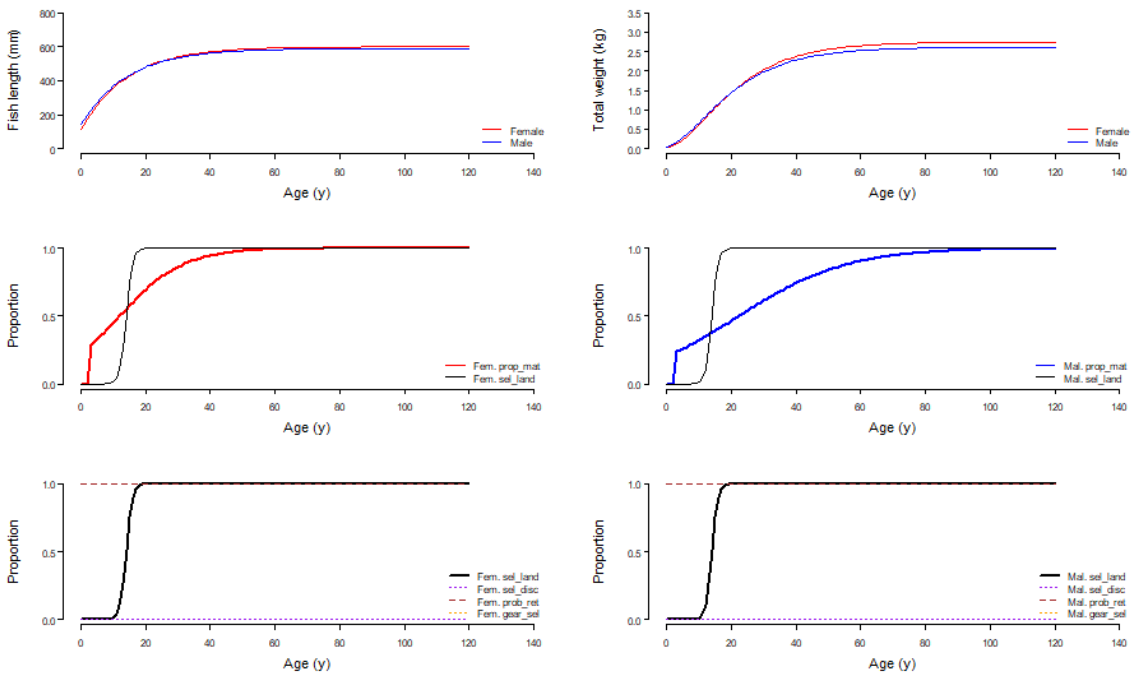
Diagnostic plots generated by the L3Assess per-recruit analysis package in R (Hesp 2023a).

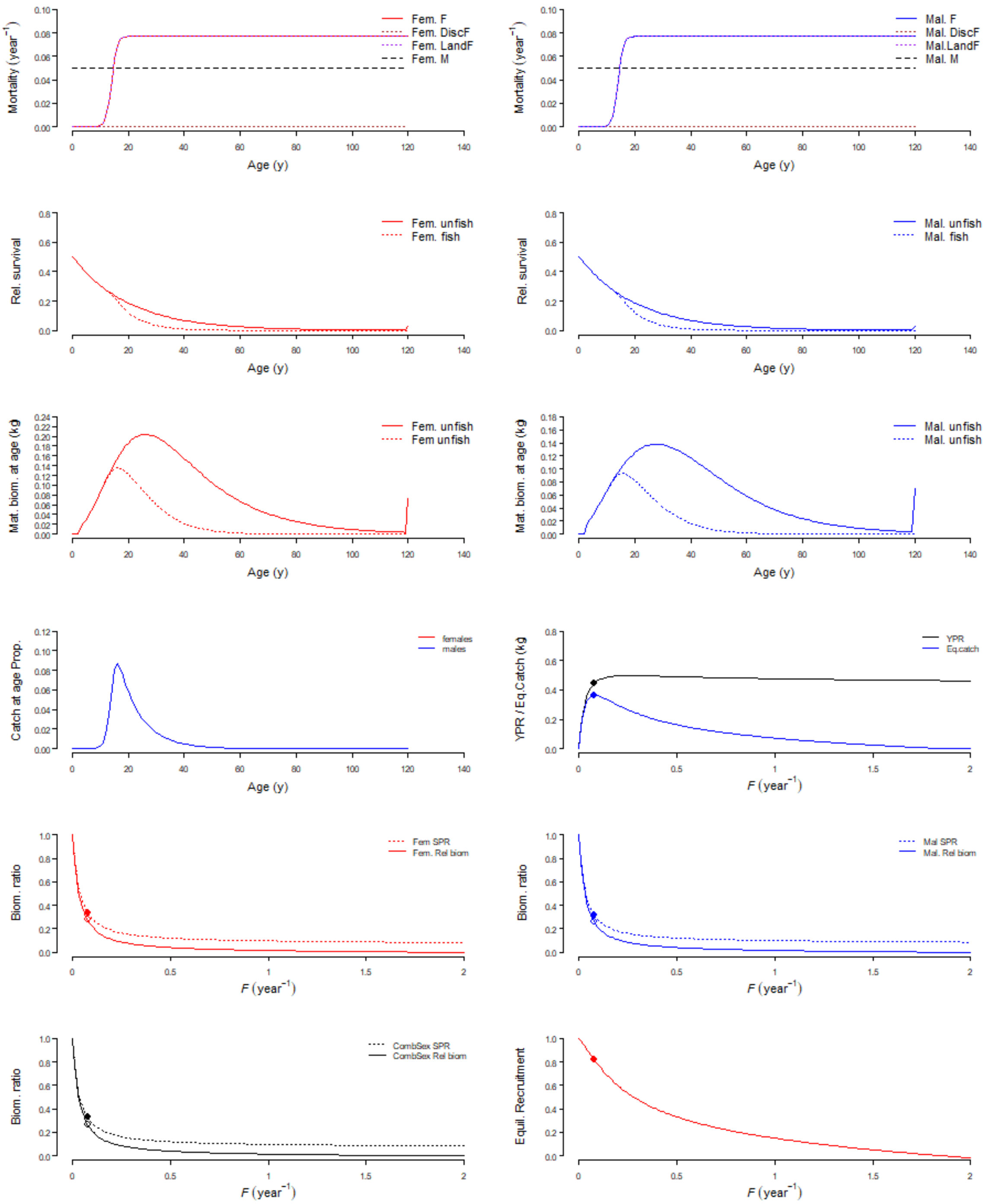
8.2.1 *Snapper*





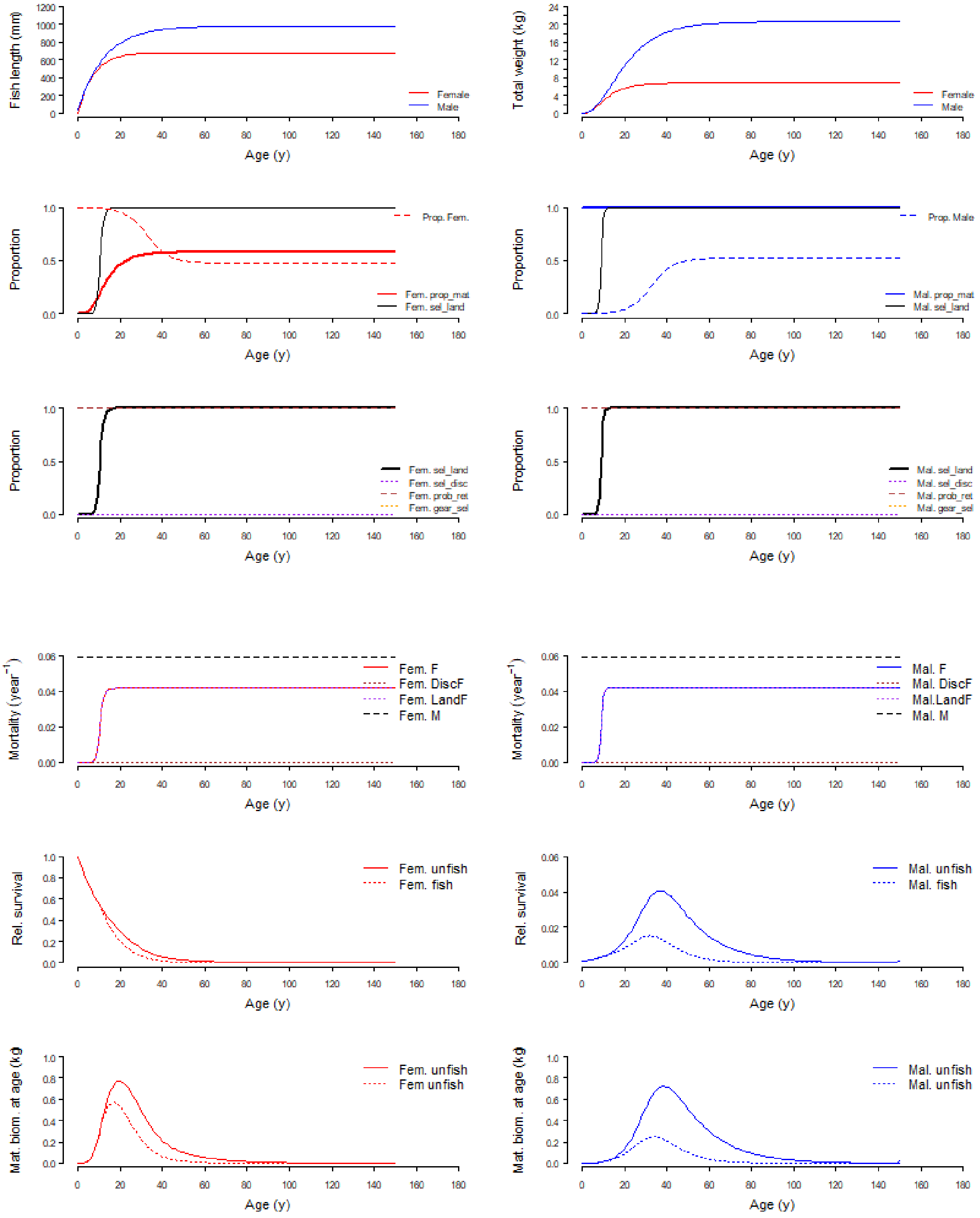
8.2.2 *Bight redfish*

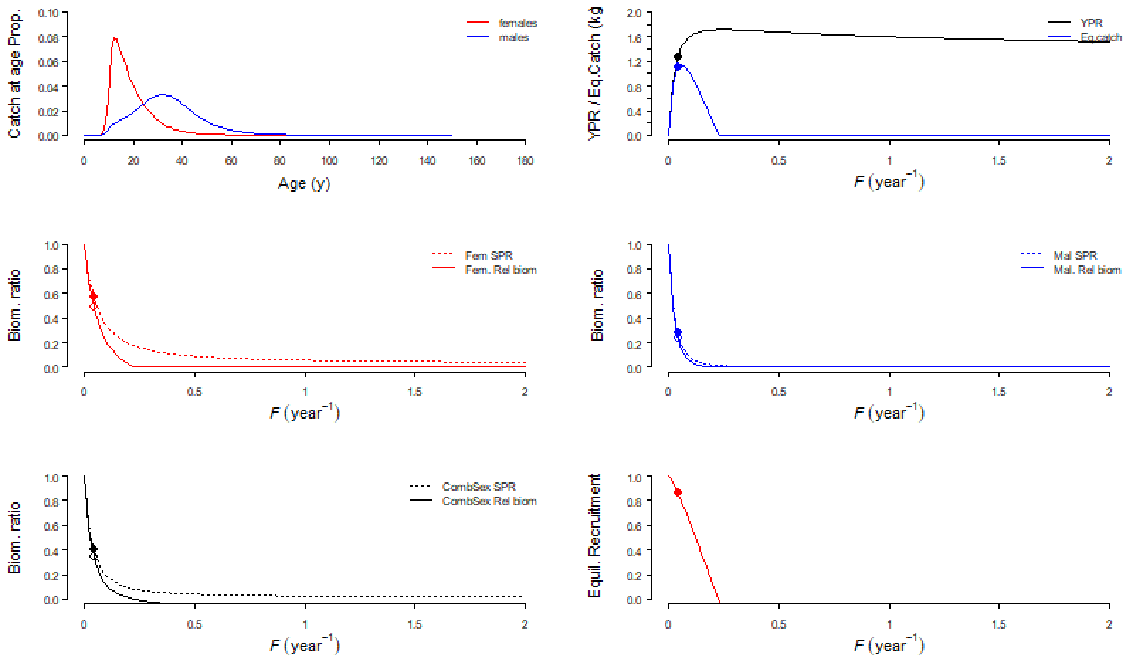




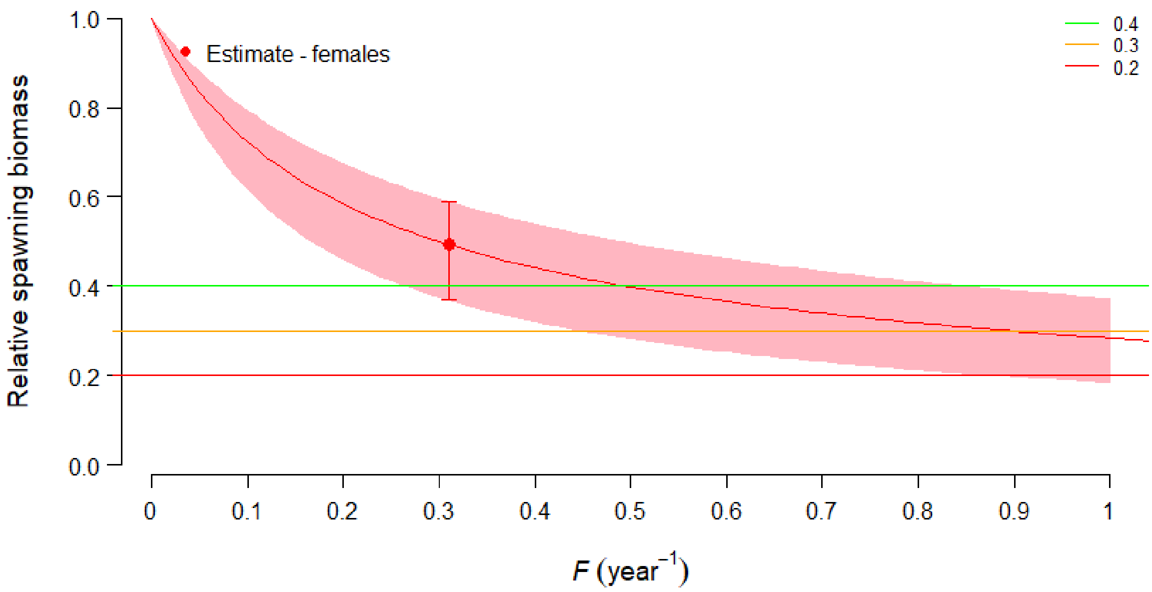
Mortality (year^{-1})
Age (y)
Fem. F
Fem. DiscF
Fem. LandF
Fem. M
Mal. F
Mal. DiscF
Mal.LandF
Mal. M
Rel. survival
Fem. unfish
Fem. fish
Mal. unfish
Mal. fish
Mat. biom. at age (kg)
Fem. unfish
Fem unfish
Mal. unfish
Mal. unfish
Catch at age Prop.
females
males
YPR / Eq.Catch (kg)
YPR
Eq.catch
F (year^{-1})
Biom. ratio
Fem SPR
Fem. Rel biom
Mal SPR
Mal. Rel biom
CombSex SPR
CombSex Rel biom
Equil. Recruitment

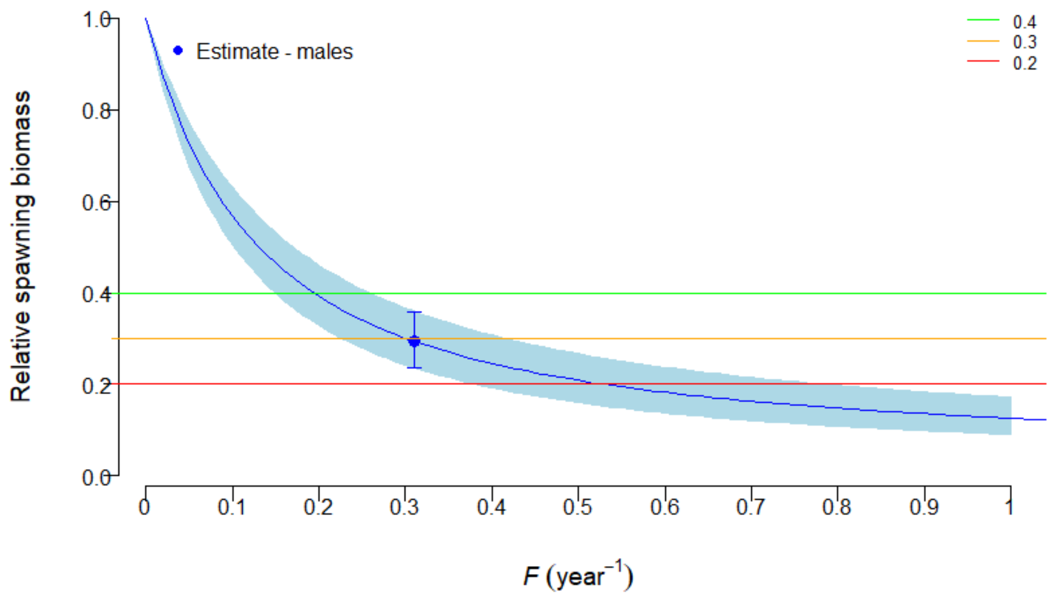
8.2.3 *Western blue groper*

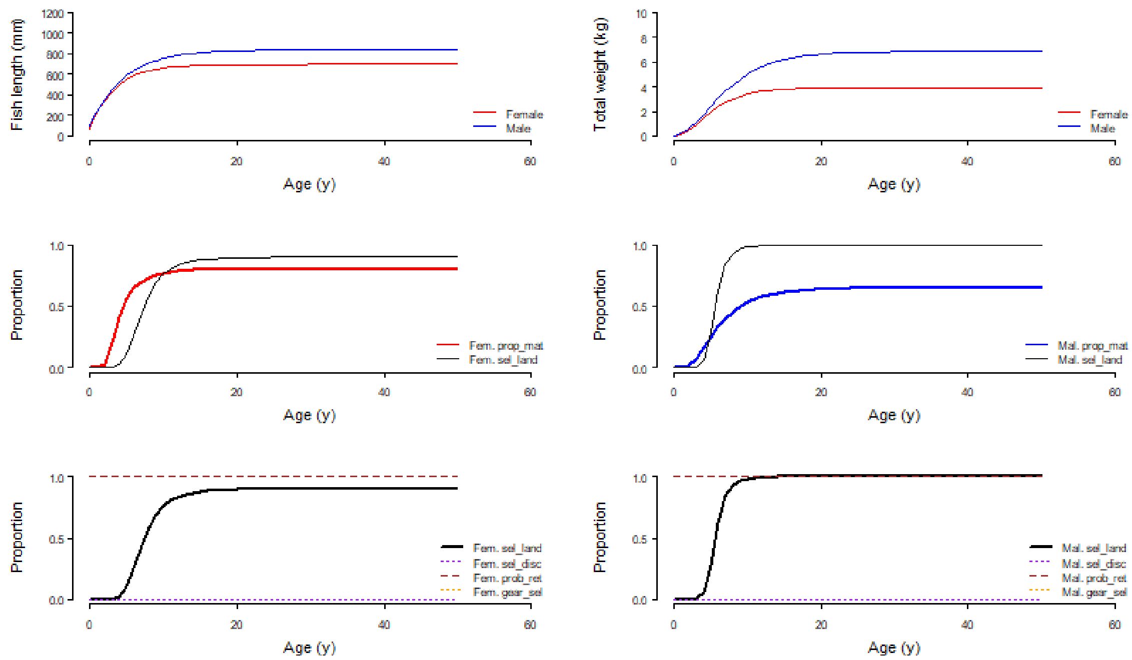


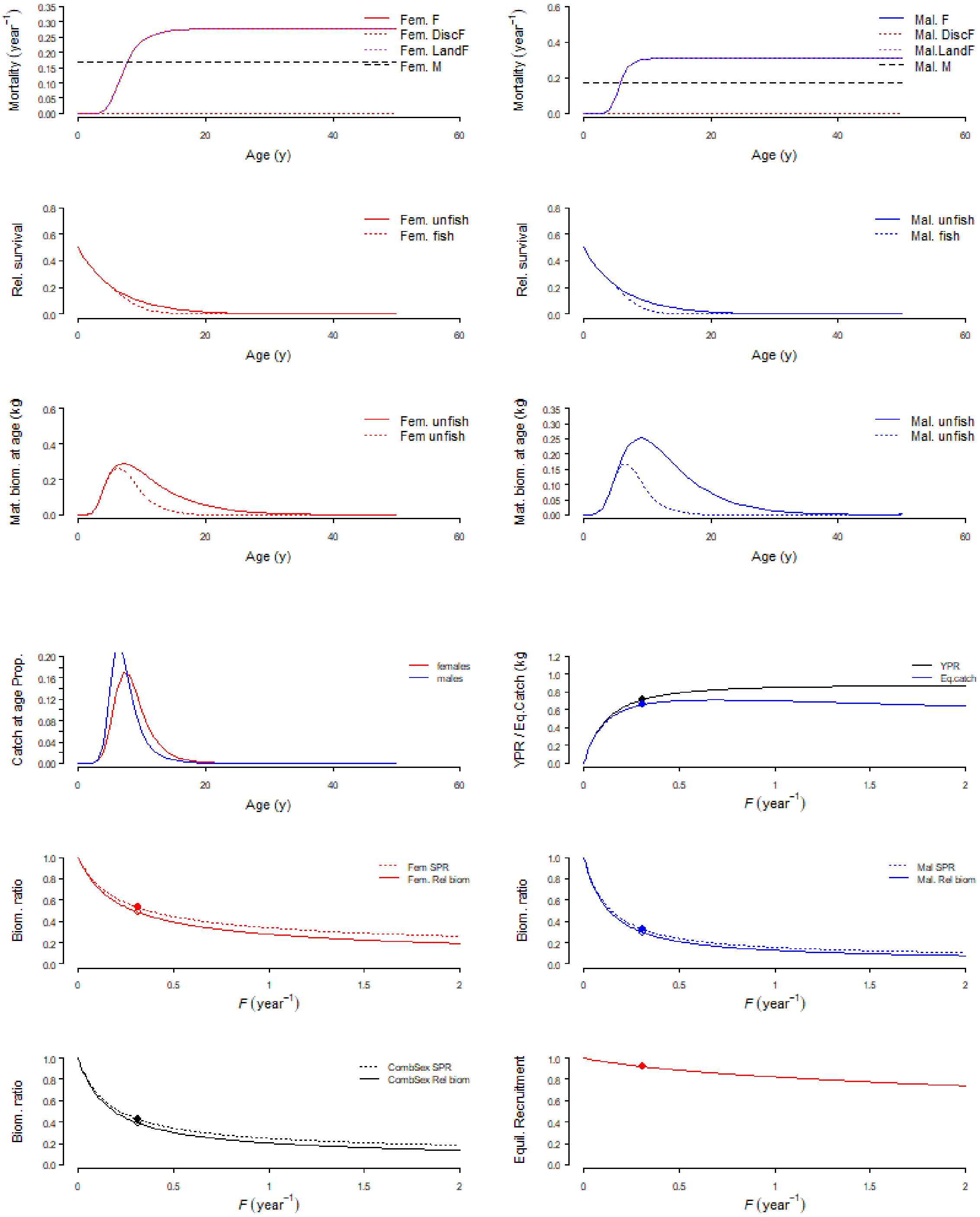


8.2.4 *Blue morwong*




Relative spawning biomass
Estimate - males
0.4
0.3
0.2
F (year⁻¹)


Fish length (mm)
Total weight (kg)
Female
Male
Proportion
Fem. prop_mat
Fem. sel_land
Mal. prop_mat
Mal. sel_land
Fem. sel_disc
Fem. prob_ret
Fem. gear_sel
Mal. sel_disc
Mal. prob_ret
Mal. gear_sel
Age (y)


Mortality (year⁻¹)
Age (y)
Fem. F
Fem. DiscF
Fem. LandF
Fem. M
Mal. F
Mal. DiscF
Mal.LandF
Mal. M
Rel. survival
Fem. unfish
Fem. fish
Mal. unfish
Mal. fish
Mat. biom. at age (kg)
Fem. unfish
Fem unfish
Mal. unfish
Mal. unfish
Catch at age Prop.
females
males
YPR / Eq.Catch (kg
YPR
Eq.catch
F (year⁻¹)
Biom. ratio
Fem SPR
Fem. Rel biom
Mal SPR
Mal. Rel biom
CombSex SPR
CombSex Rel biom
Equil. Recruitment

8.3 Productivity and Susceptibility Analysis

8.3.1 *Snapper PSA*

	Productivity Scores [1-3]								Susceptibility Scores [1-3]				1.1.1 only					PSA scores (automatic)			
GEAR_TYPE (1.1.1)	Average age at maturity	Average max age	Fecundity	Average max size	Average size at Maturity	Reproductive strategy	Trophic level (fishbase)	Total Productivity (average)	Availability	Encounterability	Selectivity	Post-capture mortality	Total (multiplicative)	Catch (tons) (1.1.1)	Weighting (1.1.1)	Weighted Total	Weigted average	PSA Score	MSC Score	Risk Category Name	MSC scoring guidepost
Comm Line	2	3	1	1	2	1	3	1.86	2	3	3	3	2.33	58	0.58	1.35	2.33	2.98	68.4	Med	60-80
Comm Gillnet	2	3	1	1	2	1	3	1.86	2	3	3	3	2.33	25	0.25	0.58					
Rec + Charter line	2	3	1	1	2	1	3	1.86	2	3	3	3	2.33	17	0.17	0.40					

8.3.2 *Bight redfish PSA*

	Productivity Scores [1-3]								Susceptibility Scores [1-3]				1.1.1 only					PSA scores (automatic)			
GEAR_TYPE (1.1.1)	Average age at maturity	Average max age	Fecundity	Average max size	Average size at Maturity	Reproductive strategy	Trophic level (fishbase)	Total Productivity (average)	Availability	Encounterability	Selectivity	Post-capture mortality	Total (multiplicative)	Catch (tons) (1.1.1)	Weighting (1.1.1)	Weighted Total	Weigted average	PSA Score	MSC Score	Risk Category Name	MSC scoring guidepost
Comm Line	2	3	1	1	2	1	3	1.86	2	3	3	3	2.33	60	0.60	1.40	2.33	2.98	68.4	Med	60-80
Comm Gillnet	2	3	1	1	2	1	3	1.86	2	3	3	3	2.33	11	0.11	0.26					
Rec + Charter line	2	3	1	1	2	1	3	1.86	2	3	3	3	2.33	29	0.29	0.67					

8.3.3 *Hapuku PSA*

Productivity Scores [1-3]									Susceptibility Scores [1-3]						Cumulative only								
Average age at maturity	Average max age	Fecundity	Average max size	Average size at Maturity	Reproductive strategy	Trophic level	Density Dependance	Total Productivity (average)	Availability	Encounterability	Selectivity	Post-capture mortality	Total (multiplicative)	**PSA Score**	Catch (tons)	Weighting	Weighted Total	Weighted PSA Score	**MSC PSA-derived score**	Risk Category Name	MSC scoring guidepost	**Consequence Score (CA)**	**Final MSC score (per scoring element)**
2	3	1	2	2	1	3		2.00	3	3	1	3	1.65	**2.59**	20	1.00	2.59	2.59	82	Low	≥80		

8.3.4 *Western blue groper PSA*

GEAR_TYPE (1.1.1)	Productivity Scores [1-3]								Susceptibility Scores [1-3]				1.1.1 only					PSA scores (automatic)			
	Average age at maturity	Average max age	Fecundity	Average max size	Average size at Maturity	Reproductive strategy	Trophic level (fishbase)	Total Productivity (average)	Availability	Encounterability	Selectivity	Post-capture mortality	Total (multiplicative)	Catch (tons) (1.1.1)	Weighting (1.1.1)	Weighted Total	Weigted average	PSA Score	MSC Score	Risk Category Name	MSC scoring guidepost
Comm Line	3	3	1	2	2	1	3	2.14	2	3	3	2	1.88	2	0.02	0.04	2.95	3.65	36.9	High	<60
Comm Gillnet	3	3	1	2	2	1	3	2.14	3	3	3	3	3.00	94	0.94	2.82					
Rec + Charter line	3	3	1	2	2	1	3	2.14	2	3	3	3	2.33	4	0.04	0.09					

8.3.5 *Blue morwong PSA*

	Productivity Scores [1-3]								Susceptibility Scores [1-3]				1.1.1 only					PSA scores (automatic)			
GEAR_TYPE (1.1.1)	Average age at maturity	Average max age	Fecundity	Average max size	Average size at Maturity	Reproductive strategy	Trophic level (fishbase)	Total Productivity (average)	Availability	Encounterability	Selectivity	Post-capture mortality	Total (multiplicative)	Catch (tons) (1.1.1)	Weighting (1.1.1)	Weighted Total	Weighted average	PSA Score	MSC Score	Risk Category Name	MSC scoring guidepost
Comm Line	2	2	1	1	2	1	3	1.71	2	3	3	2	1.88	9	0.09	0.17	2.76	3.25	56.9	High	<60
Comm Gillnet	2	2	1	1	2	1	3	1.71	3	3	3	3	3.00	70	0.70	2.10					
Rec + Charter line	2	2	1	1	2	1	3	1.71	2	3	3	3	2.33	21	0.21	0.49					