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2021 assessment of the status of the West Coast Demersal Scalefish Resource

Fairclough, D.V., Hesp, S.A., Denham, A., Fisher, E.A., Marks, R., Ryan, K.L., Lek, E., Allen, R., Crisafulli, B.M.

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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

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

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Executive Summary

A recovery program for the West Coast Demersal Scalefish Resource was introduced between late 2007 and early 2010, based on the maintenance of retained catches of demersal species (overall suite and each indicator species) by both the commercial and recreational sectors below 50% of the catches reported in 2005/06 (*original catch recovery benchmarks*).

Catch reductions were aimed at reducing exploitation levels (*F*, long-term fishing mortality of the key indicator species' stocks) to below the threshold reference point ($F = M$, the natural mortality rate), which would then allow stocks to recover to above the long-term biomass threshold level. It was expected this recovery would take at least 20 years and be achieved by 2030 at the earliest.

Estimates of *F* (from age structures) in the 2007 assessment that underpinned the management response to reduce catches by at least 50% accounted for all sources of mortality, not just mortality observed as retained catch. This assessment provides comparison of current catches (of the demersal suite and indicator species) against original catch recovery benchmarks, which assumed total fishing mortality was characterised by retained catches and that fishing behaviour remains unchanged after implementation of the recovery program.

This assessment also provides comparison of the catches of indicator species against recovery benchmarks in the 2021 Harvest Strategy for the West Coast Demersal Scalefish Resource, which were based on total fishing mortality and included retained catches and post-release mortality.

This 2021 assessment provides updates in terms of fishery performance and indicator species status. Risk-based weight of evidence assessments of stock status were undertaken for WA dhufish and Snapper, as indicator species of the WCDSR, using ISO 31000-based risk assessment methods. Specific objectives are as follows:

Objective 1. Overall performance of the commercial and recreational sectors based on total catches vs management objectives (catch recovery benchmark) at the bioregion and area level and estimates of fishing effort.

Objective 2. Weight of evidence report comprising levels 1 to 5 assessments of WA dhufish.

Objective 3. Weight of evidence report comprising levels 1 to 5 assessments of Snapper.

The results of risk assessment at the bioregion level were consistent across the different levels of assessment, i.e. Level 1 (Catch MSY), Level 3 (Spawning Potential Ratio), Level 4 (state space biomass dynamic model) and Level 5 (integrated biomass model), where applicable. The level 5 integrated biomass models provide the most comprehensive outputs. Four scenarios were considered using the L5 assessments, however, scenarios 3 and 4 which use fine scale, daily (standardised) CPUE data are considered more reliable in estimating recent trends in stock status, as trends in CPUE are consistent with knowledge of recruitment variation. These scenarios also account for post-release mortality, as additional catch in Scenario 3 and by applying it to undersize fish using a gear-selection curve in Scenario 4.

Analyses in this assessment were initially conducted using internationally accepted reference points of B_{MSY} and $0.5B_{MSY}$ for the threshold and limit, respectively. The 2021 Harvest Strategy for the WCDSR adopted B_{20}, rather than $0.5B_{MSY}$ as the limit reference point. L5 assessments involved consideration of both $0.5B_{MSY}$ and B_{20} limit reference points.

Objective 1. Overall performance

Total catches of demersal species by the commercial sector have been below the original catch recovery benchmark since the commencement of the recovery plan between 2008 and 2010 and are considered ACCEPTABLE. Total catches of the top 15 demersal species by the recreational sector were above the catch recovery benchmark at the time of the last estimate (2017/18) and are considered UNACCEPTABLE.

Objective 2. Assessment of WA dhufish

Retained catches of WA dhufish by the commercial sector were below the original catch recovery benchmark in 2020 and are deemed ACCEPTABLE, while the estimated recreational catch range (95% CI) in 2017/18 was close to or above the catch recovery benchmark. Considering the additional increases in recreational release rates (and thus associated mortality) after management changes, the recreational catch range exceeds the catch recovery benchmark and is deemed UNACCEPTABLE.

Based on all available lines of evidence and using internationally accepted reference points, the current risk to sustainability of WA dhufish at the bioregion level is estimated to be High (C3×L4). In the L5 assessment, there was a 20-49% or ≥ 50% probability of estimated relative biomass (B_{rel}) at the bioregion level being between the limit (B_{Lim}) and threshold ($B_{Threshold}$) reference points used in this assessment in scenarios 3 and 4, respectively. However, current risk (L5) in Scenarios 3 and 4 was estimated to be HIGH in the northern areas and MEDIUM/HIGH in southern areas.

Projected levels of relative biomass (based on future retained catches being equivalent to original catch recovery benchmarks, plus estimated release mortality and average recruitment) suggest that in Scenario 3, the median biomass (B_{rel}) would recover to above the target in both the northern and southern areas, while in Scenario 4, B_{rel} in the northern areas would not be greater than the threshold by 2030, but would recover to above the target in the southern areas.

The current risk to sustainability of WA dhufish at the bioregion level is HIGH.

Objective 3. Assessment of Snapper

Retained catches of Snapper by the commercial sector were below the original catch recovery benchmark in 2020 and are deemed ACCEPTABLE, while the estimated recreational catch range (95% CI) has been above the catch recovery benchmark since 2011/12. Considering the additional increases in recreational release rates (and thus associated mortality) after management changes, the recreational catch range exceeds the catch recovery benchmark and is deemed UNACCEPTABLE.

Based on all available lines of evidence, and using internationally accepted reference points, the current risk to sustainability of Snapper at the bioregion level is estimated to be SEVERE (C4×L4). In the L5 assessment, there was a ≥50% probability of estimated relative biomass (B_{rel}) at the bioregion level being below the limit (B_{Lim}) in 2020 in Scenarios 3 and 4. The current risk to sustainability of Snapper in the northern and southern areas in each of those scenarios in the L5 analysis was SEVERE.

Projected levels of median relative biomass (based on future retained catches being equivalent to original catch recovery benchmarks, plus estimated release mortality and average recruitment) suggest that in Scenarios 3 and 4, the median biomass (B_{rel}) in both the northern and southern areas would not exceed the threshold by 2030.

<u>The current risk to sustainability of Snapper at the bioregion level is SEVERE.</u>

1.0 Introduction

The West Coast Demersal Scalefish Resource (WCDSR) comprises over 100 species in inshore (20-250 m deep) and offshore (>250 m) demersal habitats of the West Coast Bioregion (WCB) which are exploited by both commercial and recreational (including charter) boat-based line fishers (Figure 1.1). The indicator species for inshore waters include West Australian dhufish, Snapper and Baldchin groper (for the Mid-west Area only), while indicators for offshore waters include Hapuku, Blue-eye trevalla and Bass groper (DPIRD 2021).

Following an assessment in 2007 that demonstrated overfishing of the indicators for the inshore demersal resource (Wise et al., 2007), a recovery program for the WCDSR was introduced between late 2007 and early 2010. This was based on the maintenance of retained catches of demersal species (overall suite and each inshore indicator species) by each of the commercial and recreational sectors in the West Coast Bioregion below 50% of their catches in 2005/06 (*original catch recovery benchmarks*). This catch reduction aimed to reduce exploitation levels (long-term fishing mortality, F, of the key indicator species' stocks) to below the threshold reference point ($F = M$, the natural mortality rate), which would then allow these stocks to recover to above the long-term biomass threshold level and is expected to take at least 20 years, i.e. by 2030 at the earliest.

The estimates of F (from age structures) in the 2007 assessment that underpinned the management response to reduce catches by at least 50% account for all sources of mortality, not just mortality observed as retained catch.

Since the assessment in 2007, fishery performance data (catch and effort of commercial and recreational sectors) and biological data (e.g. age compositions from fishery-dependent collection of fish frames) have continued to be collected to improve the time series of information of data available for assessments and the levels of assessment able to be conducted. Subsequent assessments of performance levels and indicator species status in 2011, 2014 and 2017 have monitored recovery progress and demonstrated varying levels of recovery across the WCB (Fairclough et al., 2014a; Fairclough and Walters, 2021). The 2017 assessment identified that stocks of WA dhufish and Snapper were at high risk of future depletion (Fairclough and Walters, 2021).

This 2021 assessment uses the time series of data collected in a risk-based, weight of evidence approach, which examines multiple data sets (lines of evidence) related to fishery performance and stock status with respect to catch recovery benchmarks and biological reference points (Table 1.1). The likelihood of each possible consequence (level of depletion of stocks) is determined for each line of evidence where possible via the results of appropriate models (Table 1.1). From this, the risk of future depletion of each indicator species is determined, which informs any need for management action.

Specifically, the 2021 assessment provides comparison of recent catch estimates (of the demersal suite and indicator species) against the original catch recovery benchmarks (50% of 2005/06 catches), which assumed changes in all sources of mortality are characterised by changes in retained catches. It also provides comparison of indicator species catches to the recovery benchmarks in the 2021 Harvest Strategy for the West Coast Demersal Scalefish Resource, which are based on total fishing mortality and specifically include estimated retained catches and post-release mortality.

The assessment of status of stocks of indicator species uses internationally accepted methods previously applied to WA dhufish and Snapper in the WCB and for Snapper in the GCB (Fairclough et al., 2014a; Marriott et al., 2012). In this 2021 assessment, methods adopted have been extended from the independently reviewed level 3 assessments of WA dhufish and Snapper in the WCB in 2007, 2014 and 2017 (M. Haddon in Wise et al., 2007; O'Neill, 2009; Fisher, 2012), to level 5 methods adopted and reviewed for Snapper in the Gascoyne Coast Bioregion (Morison, 2012). These methods have produced rigorous assessments deemed acceptable for providing advice on the status and management of these types of species. This 2021 assessment provides updates of fishery performance and indicator species status as follows:

1. Overall performance of the commercial and recreational sectors based on total catches of demersal species vs catch recovery benchmarks at the bioregion and area level and estimates of effort.

2. Weight of evidence report comprising level 1 to level 5 assessments of WA dhufish

3. Weight of evidence report comprising level 1 to level 5 assessments of Snapper.

Analyses in this assessment were initially conducted using internationally accepted reference points of B_{MSY} and $0.5B_{MSY}$ for the threshold and limit, respectively. The 2021 Harvest Strategy for the WCDSR adopted B_{20}, rather than $0.5B_{MSY}$ as the limit reference point. L5 assessments involved consideration of both $0.5B_{MSY}$ and B_{20} limit reference points.

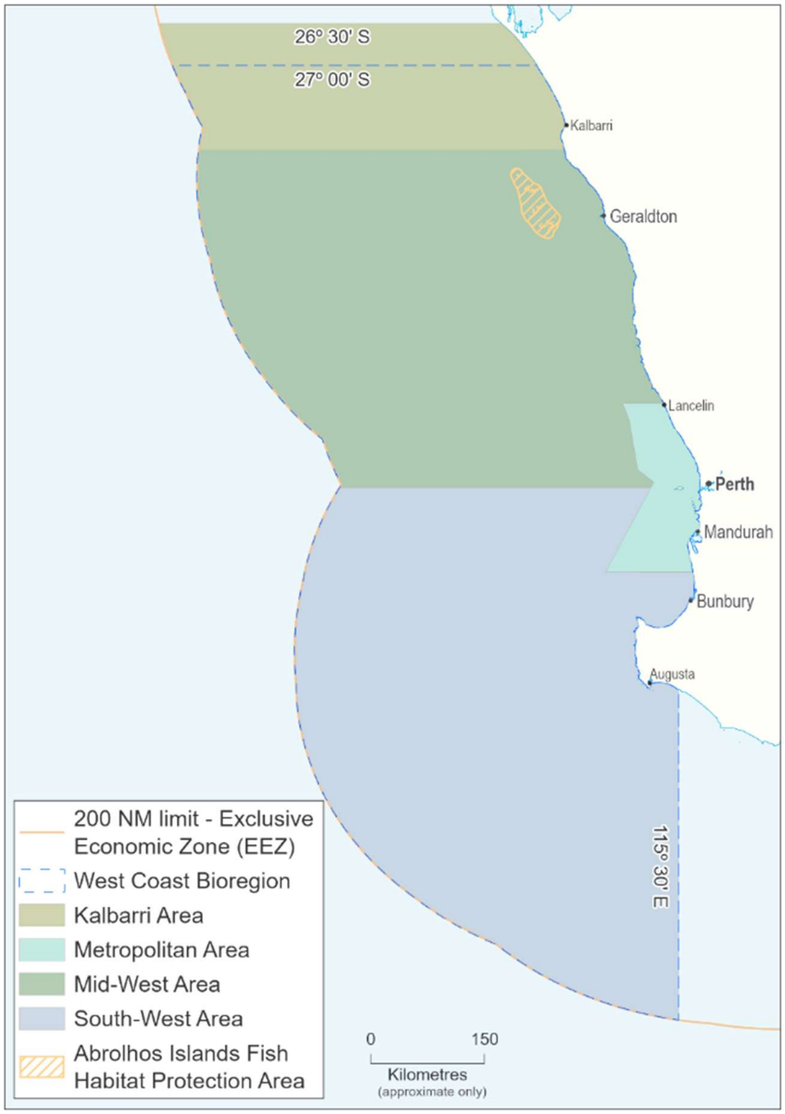


Figure 1.1. Map showing boundaries of the West Coast Bioregion (27°S to 115°30′E) that applies to the recreational sector and of the West Coast Demersal Scalefish Interim Managed Fishery (26°30′S to 115°30′E) and its management areas.

TABLE 1.1. Levels and descriptions of the categories of assessment methods/models and the biological reference points used in this assessment (Gaughan and Santoro, 2021). The 2021 Harvest Strategy for the WCDSR adopted B_{20}, rather than $0.5B_{MSY}$ as the limit reference point. Level 5 assessments involved consideration of both $0.5B_{MSY}$ and B_{20} limit reference points.

Level	**Description**	**Method/Model**	**Biological reference points (Section 2.2.2)**
Level 1	Catch data and biological/fishing vulnerability.	Catch MSY model of relative biomass	Threshold: B_{MSY} = $0.5B_0$ Limit: $0.5B_{MSY}$
Level 2	Level 1 plus fishery-dependent effort.	N/A	N/A
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).	Fishing mortality and spawning potential ratio	Target: $F = 0.67M$, SPR = 0.4, Threshold: $F = M$, SPR = 0.3, Limit: $F = 1.5M$, SPR = 0.2
Level 4	Levels 1, 2 or 3 plus fishery-independent surveys of relative abundance, exploitation rate, recruitment; or standardised fishery-dependent relative abundance data.	Biomass dynamics model (Schaefer)	Threshold: B_{MSY} = $0.5B_0$ Limit: $0.5B_{MSY}$
Level 5	Levels 1 to 3 and/or 4 plus outputs from integrated simulation, stock assessment model.	Integrated simulation model of relative biomass	Target: $1.2B_{MSY}$, Threshold: B_{MSY}, Limit

2.0 Methods

2.1 Catch and effort data

Compulsorily reported catch and effort data from each commercial fishery that retained demersal scalefish including West Australian dhufish and Snapper in the WCB since 1975 were obtained from DPIRD databases. These fisheries include the West Coast Demersal Scalefish (Interim) Managed Fishery, the Temperate demersal gillnet and long-line fisheries (i.e. West Coast Demersal Gillnet and Demersal Longline Managed Fishery and Southern Demersal Gillnet and Demersal Longline Managed Fishery, West Coast Rock Lobster Managed Fishery, South-west Trawl Managed Fishery and the Cockburn Sound Line and Pot Managed Fishery. Charter catch and effort data were obtained from compulsory logbooks introduced in 2001/02. Catch and effort data of private boat-based recreational fishers were derived from periodic surveys at boat ramps (creel surveys) prior to 2011/12 (Lai et al., 2019) and from integrated phone-diary surveys from 2011/12 onwards (see Ryan et al. 2019).

2.2 Biological data and stock assessment

2.2.1 *Sampling regime and laboratory processing*

Biological samples of WA dhufish (*Glaucosoma hebraicum*) and Snapper (*Chrysophrys auratus*) have been collected from the recreational and/or commercial sectors in the West Coast Bioregion since 2002/03 (Wise et al., 2007; Fairclough et al., 2014a). Biological data used in analyses also include those collected by Hesp et al. (2002) and Wakefield et al. (2015, 2017). Since management changes were made between late 2007 and early 2010, both species have been collected from each sector in each management area where they are abundant in catches, noting that commercial line fishing is prohibited in the inshore Metropolitan Area (Fig. 1.1). The skeletons (frames) of legal-sized WA dhufish (≥ 500 mm) and Snapper (≥ 410 mm in the Kalbarri and Mid-west areas; ≥ 500 mm in the Metropolitan and South-west areas) were sampled monthly where possible from commercial catches via commercial fishers and wholesale/retail processors and from recreational catches via voluntary donations (see Fairclough et al., 2014b), fishing competitions and boat ramps.

Biological data including total length (TL), sex and gonadal development stage were obtained from each frame following standard methods (see Fairclough et al., 2014a). Sagittal otoliths were also removed to determine the ages of each fish using counts of opaque zones in sections, average birthdates, otolith margin categories, collection date and the time of year when opaque zones become delineated (see Fairclough et al., 2014a for greater detail including quality control processes for opaque zone counting) (Campana, 2001; O'Sullivan, 2007).

2.2.2 *Assessment analyses*

The analyses conducted in this assessment follow a weight of evidence approach, comprising the five different levels of complexity (Table 1.1). Assessments were conducted at the stock (bioregion) level and in the northern (Kalbarri and Mid-west) and southern (Metropolitan and South-west) areas separately, if possible. Analyses in this assessment were initially conducted using internationally accepted reference points of B_{MSY} and $0.5B_{MSY}$ for the threshold and limit, respectively. The 2021 Harvest Strategy for the WCDSR adopted B_{20}, rather than $0.5B_{MSY}$ as the limit reference point. L5 assessments involved consideration of both $0.5B_{MSY}$ and B_{20} limit reference points.

2.2.2.1 *Level 1 – Catch, effort, productivity and susceptibility and Catch MSY*

Catches of the demersal suite and of each indicator species by the commercial and recreational sectors were compared to original catch recovery benchmarks derived from 50% of 2005/06 levels. Vulnerability of WA dhufish and Snapper was estimated using a productivity-susceptibility analysis (PSA; Marine Stewardship Council, 2014). Note, PSA scores are provided for all indicator and other key species in the WCDSR in the Appendix (DPIRD 2021).

Catch MSY models were used to estimate fishing mortality rates and levels of depletion for WA dhufish and Snapper, based on knowledge of species biology and catch history, using the datalowSA package in R (https://rdrr.io/github/haddonm/datalowSA/; Haddon et al., 2019). For both species, analyses assumed a low resilience of the stock (r=0.1-0.6), initial depletion range of 0.5-0.8 for the start of the catch time series in 1975 and final depletion range of 0.05-0.5 for 2021 (program default calculation), and available catch information, including estimated post-release mortality. Retained catch data were derived as described in Section 2.1. As catch estimates of private boat-based recreational fishers were only available from periodic surveys, they were linearly interpolated for intermediate years. Prior to the first recreational survey of boat-based fishing in the WCB in 1996/97, annual estimates from 1975 to 1996 were linearly interpolated as a function of the annual percentage change in WA population size derived from the Australian Bureau of Statistics. This assumes that fishing catch, effort and participation changed at the same rate. Estimated catches from boat ramp creel surveys prior to 2011/12 were increased by 30% for the purposes of modelling. This is consistent with the recommendation by the Integrated Fisheries Allocation Advisory Committee (Department of Fisheries, 2013) that they were underestimated due to the creel surveys being conducted during daylight hours (either 900-1700 or 800-1600). Estimated charter catches between 1975 and prior to the first year of logbook data being available in 2001/02 were linearly interpolated based on the change in number of operators per year (Tour Operators Fishing Working Group, 1998). Estimated release mortality was also added to retained catch using the same approach described in Section 2.2.2.5. Note, for this model, the maximum final depletion of 0.5 is equivalent to B_{MSY} and therefore assumes the stock could not have recovered to a biomass greater than B_{MSY} by 2021.

2.2.2.2 *Level 2 – Raw catch rates*

Raw catch rates for WA dhufish and Snapper were determined for both the commercial line fishery (WCDSIMF) from 2008 to 2020 and the charter fishery from 2001/02 to 2019/20. Catch rates (CPUE) for each year in each management area were calculated as the mean of the ratios of catch and effort ($\frac{C}{E}$) for each fishing session for the WCDSIMF (kg $hour^{-1}$) and for each trip for charter fishers (kg block-$trip^{-1}$). Commercial CPUE for WA dhufish was calculated for the Mid-west Area using both drop-line and hand-line methods and for the South-west Area using hand-line. Charter data for the Kalbarri and Mid-west areas were combined, due to limited effort in the Kalbarri Area.

2.2.2.3 *Level 3 – Fishing mortality and spawning potential ratio*

Estimates of fishing mortality (F $year^{-1}$) for WA dhufish and Snapper were determined using a method that fits catch curves to multiple years of successive age composition data and accounts for recruitment variation. This approach was adapted from Fisher (2012) and used in previous assessments of indicator species for the WCDSR (see Fairclough et al., 2014a).

Estimates of female Spawning Potential Ratio (SPR) were derived from a traditional and an extended form of per-recruit analysis (Fairclough et al., 2014a; Norris et al. 2016). SPR is considered to represent a more informative indicator of stock status compared to F due to the inclusion in per-recruit models of other known biological information for the species, such as growth and maturity (Goodyear, 1993). The extended approach accounts for expected effects of fishing mortality on recruitment through its impact on female spawning biomass (according to a stock-recruitment relationship) and uses the catch curve estimates of 'long-term' F and age-based selectivity curves. Sensitivity analyses using the extended per recruit model were also conducted to explore the effects on results of (1) assuming a 50% mortality of fish < MLL released after capture and (2) changes in growth of individuals as indicated by recent length-at-age data (see Appendix).

The F and SPR values for each species were compared to target (F = 0.67M, SPR = 0.4), threshold ($F = M$, SPR = 0.3) and limit (F = 1.5M, SPR = 0.2) reference points, where M values of 0.11 and 0.12 $year^{-1}$ for WA dhufish and Snapper, respectively, were as estimated by Wise et al. (2007) using the empirical equation for fish of Hoenig (1983), relating mortality to maximum age.

2.2.2.4 *Level 4 – Standardised commercial catch rates and biomass dynamics models*

Standardised commercial catch rates were calculated for WA dhufish and Snapper in the northern (Kalbarri/Mid-west) and southern (Metropolitan/South-west) areas separately, dependent on where each species is important in catches. Data were derived from monthly logbooks from open access line fishing between 1975-2007 and from the daily logbooks of the WCDSIMF from 2008 onwards. Details of methods for standardising commercial catch rates are described in the Appendix.

A state space Schaefer biomass dynamics model (i.e. incorporating both observation and process errors) was fitted to the standardised CPUE and catch data for WA dhufish in the northern and southern areas and for Snapper in only the northern areas (due to limited time series of data for southern areas) (see Appendix for full detail). Retained catch data and estimated release mortality (as additional catch) are as described in Sections 2.1, 2.2.2.1 and 2.2.2.5.

Different scenarios were considered for both species for this modelling, in terms of additional annual efficiency increases (i.e. in addition to increases estimated due to adoption of GPS, colour sounders and hydraulic reels). For WA dhufish, the additional efficiency increases were set at (1) 3% for CPUE prior to 2008 (monthly data) and 1% for CPUE from 2008 onwards (daily data; base case scenario) and (2) at 2% and 1%, respectively, for an alternative scenario. For snapper, the efficiency scenarios for monthly and daily data, respectively, were (1) 2% and 1%, (2) 1% and 1% and (3) 0% and 0%. Estimated fishing mortality and relative biomass from different scenarios are compared to threshold and limit reference points.

2.2.2.5 *Level 5 – Integrated simulation model of relative biomass*

Two-area, two-sex, age-structured, dynamic population models for WA dhufish and Snapper were fitted to available catch and age composition data for each species in different scenarios (time series with and without catch rate, and assumptions relating to post catch and release mortality) to estimate fishing mortality and relative biomass at the stock (bioregion) and area (north, south) levels. Historical retained catch data are as described in Section 2.1. Future retained catches were assumed to be constant at 50% of 2005/06 catches (the original recovery catch benchmark). Different scenarios and methods of determining post-release mortality (PRM) are as follows:

Scenarios included (1) a base case with post-release mortality (PRM) included as additional catch, with model not fitted to CPUE indices, (2) PRM on selected undersize fish at a rate of 0.5 for WA dhufish and 0.25 for Snapper, with model not fitted to CPUE indices, (3) PRM as additional catch, with model fitted to CPUE indices, and (4) PRM of undersize fish at a rate of 0.5 for WA dhufish and 0.25 for Snapper, with model fitted to CPUE indices.

PRM included as additional catch was estimated as follows (further detail in DPIRD, 2021):

Commercial line fishing: Estimated catch × 25% (release rate) × PRM rate (as release rates are not required to be recorded by commercial fishers). The estimated release rate of 25% of the catch is based on limited data recorded by an individual commercial line fisher and, for future assessments, requires further fishery-wide evaluation.

Commercial gillnet/long-line fishing: Estimated catch × 10% (release rate) × 100% (it is assumed that any released fish that were caught by gill-net or long-line do not survive).

Post-release mortality from commercial line fishing for Snapper in Cockburn Sound, bycatch of Western Rock lobster fishery pots and trawling by the South-west Trawl fishery or Abrolhos Islands Managed Trawl Fishery is likely very small and is assumed to be zero for the purpose of modelling.

Recreational/charter line fishing: estimated/reported numbers of fish released × average weight of released fish × PRM rate (estimated numbers of fish released by private recreational fishers are derived from each iSurvey [Ryan et al., 2019], numbers of released by charter fishers are reported in trip logbooks).

PRM rate = 50% for WA dhufish and 25% for Snapper (DPIRD, 2021).

Average weight of released WA dhufish and Snapper is assumed to be 1.5 kg and 0.82 kg, respectively, based on conversion from the average lengths of released fish of 443 mm and 400 mm, as derived from the Recreational Angler Program database (Smith et al., 2007).

Details of methods for constructing integrated models of relative biomass and model outputs are provided in the Appendix. Estimated fishing mortality and relative biomass from different scenarios are compared to target, threshold and limit reference points.

2.2.3 *Risk Assessment*

Lines of evidence where stock status was compared against reference points was used to assess the likelihood (probability) of potential future levels of depletion of biomass (or proxies of biomass), based on AS 4360 / ISO 31000 standards modified from Fletcher et al. (2011) and Fletcher (2015). Thus, risk assessments were conducted on Level 1 Catch MSY models, Level 3 spawning potential ratios, Level 4 biomass dynamics models and Level 5 integrated models. The risk score is determined from the product of the consequence and likelihood (C×L) (Tables 2.1-2.3). The most precautionary risk level from risk assessment of each line of evidence is used to indicate the likely level of management action required (Table 2.4).

Table 2.1 Levels of consequence in terms of depletion of stocks of an indicator species.

Consequence level	Description	Level of biomass (*B*)
Minor	Fishing impacts either not detectable against background variability for this population; or if detectable, minimal impact on population size and none on dynamics	B > Target (B_{MEY})
Moderate	Fishery operating at maximum acceptable level of depletion	Threshold (B_{MSY}) < B < Target (B_{MEY})
High	Level of depletion unacceptable but still not affecting recruitment levels of stock	Limit (B_{REC}) < B < Threshold (B_{MSY}) but >Limit (B_{REC})
Major	Level of depletion is already affecting or will definitely affect future recruitment potential/ levels of the stock	B < Limit (B_{REC})

Table 2.2. Levels of likelihood (probability) of depletion of stocks of an indicator.

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

Table 2.3. Scoring (1-4) of Consequence × Likelihood of depletion of an indicator species and risk level outcome.

Consequence × Likelihood Risk Matrix		Likelihood			
		Remote (1)	Unlikely (2)	Possible (3)	Likely (4)
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

Table 2.4. Interpretation of risk levels and potential management action.

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

3.0 Results and Discussion

3.1 Objective 1. Overall fishery performance

Catch and effort data for the demersal suite

Category	Line of evidence
Commercial retained and released catch	**Retained catch** *Retained catches of demersal species by all commercial fisheries in the West Coast Bioregion (WCB, Fig. 1.1) in 2019/20 (latest season either 2019/20 or 2020) and by the West Coast Demersal Scalefish (Interim) Managed Fishery (WCDSIMF) in 2020 were below respective original catch recovery benchmarks (50% of 2005/06 catches) of 450 t and 410 t (Fig 3.1), as they have been since 2008 when management commenced to recover stocks.* The total retained catches of demersal species by commercial fisheries in the WCB in the most recent season (2019/20 or 2020) was 247 t and is below the original catch recovery benchmark of 450 t (Fig. 3.1). Retained catches are also well below the proposed 2021 Draft Harvest Strategy's lower tolerance level for total mortality (retained catch plus release mortality) of 360 t (75% of the benchmark). Adding estimates of release mortality to retained catch would not result in total mortality exceeding the tolerance level. The WCDSIMF retained 213 t of demersal species (227 t of all fishes) in 2020, which was also well below the original catch recovery benchmark of 410 t and lower tolerance level of 332 t in the 2021 harvest strategy. The Temperate Demersal Gillnet and Demersal Longline fisheries (TDGDLF), the Cockburn Sound Line and Pot Managed Fishery, South-west Trawl Managed Fishery and West Coast Rock Lobster Managed Fishery landed 31 t, 1 t, 0 t and 2.6 t, respectively, in either 2019/20 or 2020. Total mortality (retained catches plus release mortality) of these other fisheries would thus be between the total mortality tolerance level and recovery benchmark of 43 t. Catches of demersal species by the WCDSIMF in 2020 in the Kalbarri Area (74 t) declined from 96 t in 2019, while they have been increasing in the Mid-west Area since 2017, i.e. from 76 t to 100 t in 2020 (Figs 1.1, 3.2). The increase in 2020 was due in part to a rapid increase in effort and catch in the Mid-west in February, following the COVID outbreak. A loss of market for Western rock lobster fishers resulted in numerous fishers shifting to fishing for demersal species. The majority of this additional catch was of WA dhufish and Snapper. In the South-west Area, catches of WA dhufish declined from 55 t in 2019 to 38 t in 2020. Thus, catches in each area were below respective original catch recovery benchmarks, i.e. Kalbarri: 141 t, Mid-west: 177 t, South-west: 82 t. Reductions in entitlements to fish (ITE, hours) in the Kalbarri and Mid-west areas in 2015 to reduce Snapper catches below original catch recovery benchmarks have also contributed to reduced total catches (Fig. 3.2). Catches of demersal species by the WCDSIMF comprise predominantly inshore demersal species (>91% per year), with Snapper, Redthroat emperor, WA dhufish, Bight redfish and Baldchin groper contributing 70-84% per year to total catches (see individual Weight of Evidence reports for more detail).

Landings of offshore species have remained below the original catch recovery range for this suite (20-40 t) since 2008. While catches off offshore demersal species in the Kalbarri and Mid-west Areas have never exceeded 2 and 4 t, respectively, they have increased from 2 t to 16 t from 2008 to 2019 in the South-west Area, then declined to 10 t in 2020 (Fig. 3.2), with Hapuku typically comprising the majority of the catch (e.g. 7 t in 2020). Offshore demersal species are sometimes also caught by the Commonwealth Western Deepwater Trawl Fishery. However, reported effort and estimated annual catches of offshore demersal species have remained very low in recent years (< 1 t) (http://data.gov.au/dataset/reported-retained-annual-catch-from-commonwealth-fisheries-logbooks).

Released catch

WCDSIMF fishers are not required to report released fish in their logbooks, but have anecdotally indicated they do not continue fishing an area if they are catching undersize fish. Voluntarily reported release rates by a single fisher in the South-west Area in 2019 indicated very low release rates (~5%), as most fish caught are above minimum legal lengths (MLL). Similar data from a single fisher in the Kalbarri Area indicated a diverse range of species released and highly variable release rates (20% of fish caught overall). Ninety five percent of fish released in the Kalbarri Area were Snapper, due to them being below the MLL.

The proposed generic logbook (for all fisheries) would allow released catches to be reported, but would also require on-board validation.

The recent retained catch data for inshore demersal species and effort levels of the WCDSIMF and TDGDLF may reflect reductions in entitlements in 2015 and thus would not provide indication of further stock depletion at the resource level. However, uncertainty regarding release rates and any associated release mortality pose additional risk. Retained catches of offshore demersal species do not currently indicate that fishing levels would result in stock depletion.

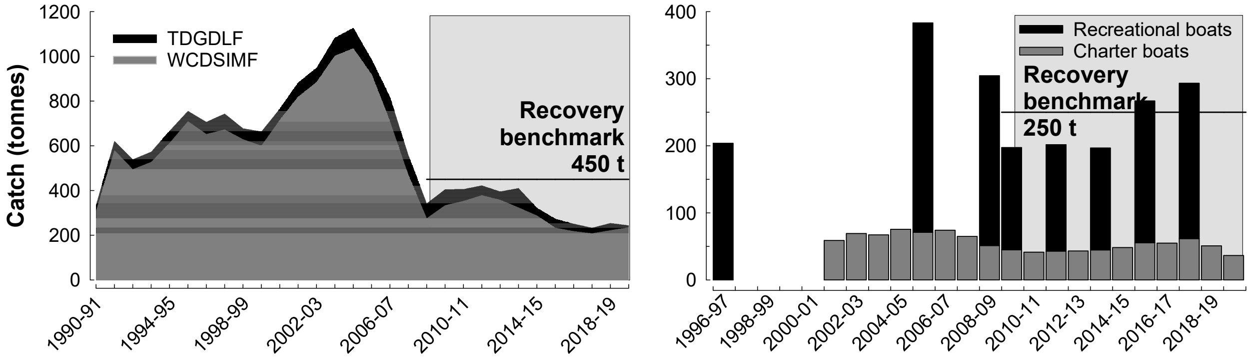


Figure 3.1. Estimated retained catches of demersal species in the West Coast Bioregion by the commercial and recreational sectors vs original catch recovery catch benchmarks, introduced between 2008 and 2010 (light grey shading). Note: Estimated recreational sector retained catches combine data for financial year for charter (since logbooks were introduced in 2001/02) and survey year for private recreational boats. Estimated retained catches of private boat-based recreational fishers do not show uncertainty (95% CIs), with estimates derived from boat ramp surveys from 1996/97-2009/10 (revised by Lai et al. 2019) and statewide phone diary surveys from 2011/12-2017/18 (Ryan et al., 2019). TDGDLF = Temperate Demersal Gill-net and Longline fisheries; WCDSIMF = West Coast Demersal (Interim) Managed Fishery. Small catches of other commercial fisheries are not shown (e.g. Cockburn Sound Line and pot Managed Fishery and West Coast Rock Lobster Managed Fishery). *Estimates of catch from the two different recreational fishery survey methods are not directly comparable. Estimates from boat-ramp surveys (1996/97-2009/10) are not adjusted upwards to account for underestimation due to time of day of surveys and catches at the Abrolhos Islands, as adopted by FMP247.*

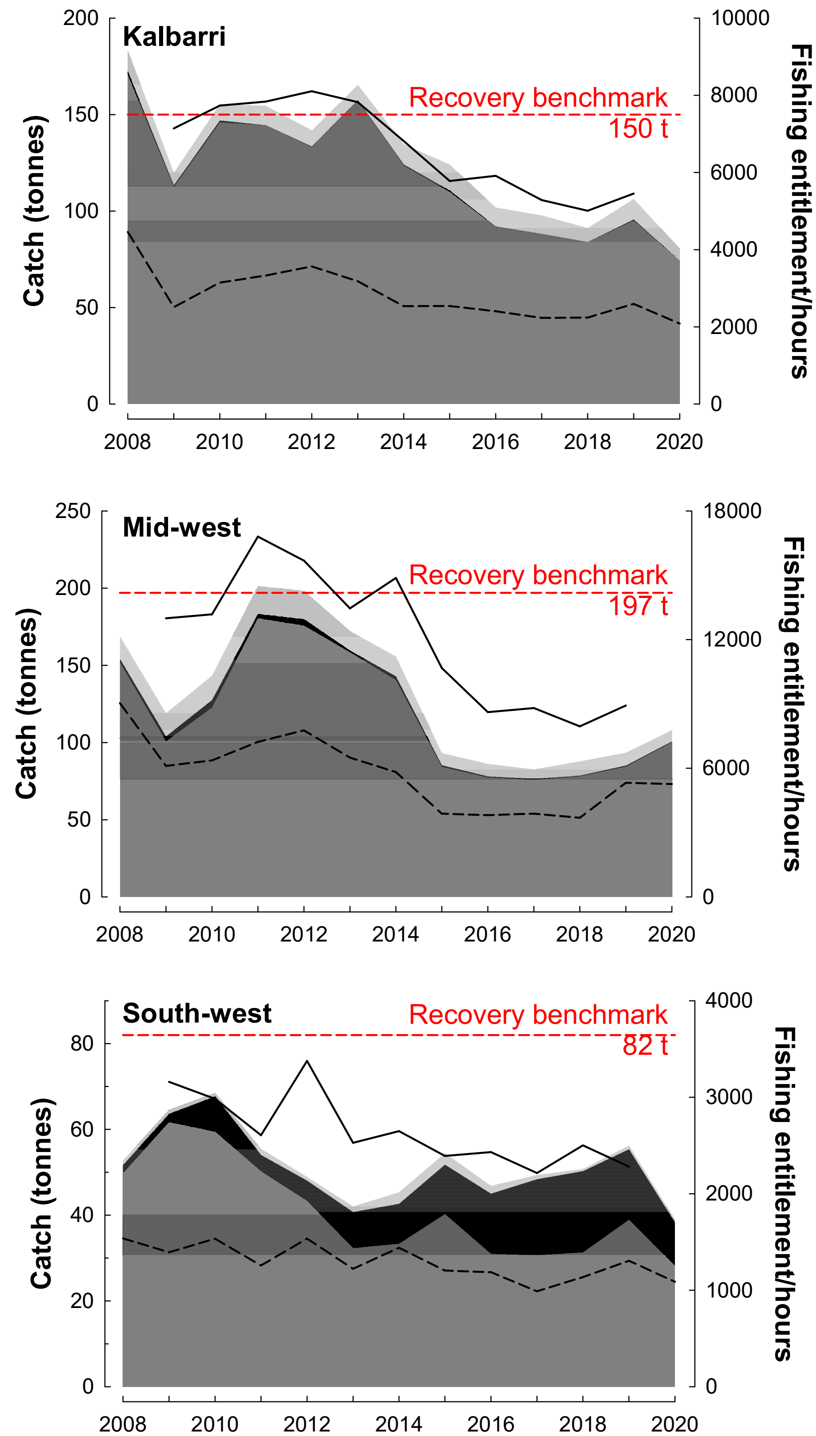


Figure 3.2. Retained catches by the WCDSIMF of inshore demersal species (dark grey), offshore demersal species (black) and non-demersal species (light grey) and effort (hours, dashed line) and entitlement consumed (solid line) in the Kalbarri, Mid-west and South-west Management Areas of the West Coast Bioregion vs original catch recovery benchmarks for all species in each area. Entitlement information for 2020 was not available at the time of analysis.

Commercial (WCDSIMF) effort and entitlement consumption	The WCDSIMF fished for 8,440 hours in 2020, a decline from ~9,160 hours in 2019, but both years represented increases from effort expended between 2015 and 2018, i.e. 7,060-7,600 h, following entitlement reductions in the Mid-west and Kalbarri areas in 2015. The majority of the effort occurred in the Mid-west (~5,260 h), followed by the Kalbarri (2,100 h) and South-west areas (1,100 h) (**Fig. 3.2**). Effort in each area declined from that in 2019. In 2020, effort was at its lowest level in the Kalbarri and South-west areas, since the fishery commenced in 2008, while it was just below average in the Mid-west. The spatial distribution of effort indicates less effort in inshore waters of the Mid-west area in the last three years and effort to be more focused south of Cape Leeuwin in the South-west area in the last 5 years (**Fig. 3.3**). Since 2009, annual entitlement to fish (hours) consumed by the WCDSIMF in the Kalbarri, Mid-west and South-west areas has ranged from 68-77%, 53-69% and 36-51% of the maximum, respectively (**Fig. 3.2**). Entitlement consumption has thus always been below the tolerance range in the 2021 Harvest Strategy for the WCDSR. After entitlements were introduced, the hours fished reached maxima in 2012 in the Kalbarri (3,569 h), Mid-west (7,763 h) and South-west (1,534 h) areas, but have since been lower (**Fig. 3.2**). The reduction in hours fished in the Kalbarri and Mid-west areas after 2014 is influenced by 25% and 33% entitlement reductions in those areas in 2015 to reduce retained Snapper catches to below recovery benchmarks. Entitlements are not fully consumed in each year as, anecdotally, it is not economically viable to do so. **Entitlement consumed and effort expended since the WCDSIMF commenced in 2008 were consistent with total demersal suite catches not exceeding the control rule for stock recovery (50% of 2005/06 catches) in almost all years in each area. Catches of some indicator species reached or exceeded such control rules in some years, which may have been related to stock abundance. Effort (fishing hours) and entitlement have both continued to decline since 2015 in the Kalbarri/Mid-west areas (when entitlements were reduced to manage snapper catches), consistent with anecdotal evidence from commercial fishers of declining catch rates and estimated CPUE, which may indicate ongoing depletion. Similar declines have occurred in the South-west Area since 2012. Any increase in entitlement use could result in retained catches exceeding benchmarks and further depletion.**

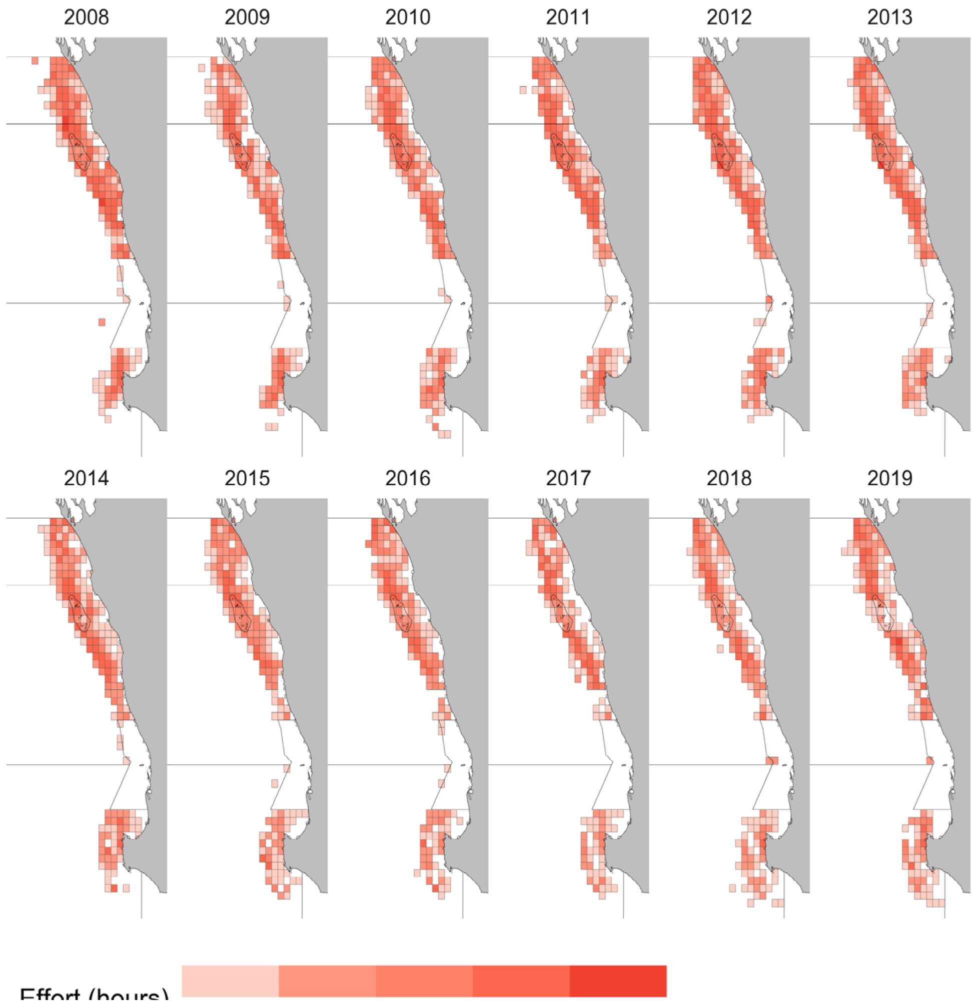


Figure 3.3. Total effort (hours fished) by WCDSIMF fishers in the West Coast Bioregion per 10nm block from 2008 to 2019.

Recreational retained and released catch	**Retained catch in the West Coast Bioregion** *The most recent estimated retained catch of the top 15 demersal species (and groups of species) by the recreational sector in the WCB (private boat-based fishers and charter fishers in 2017/18) was 271-314 t. This was above the original catch recovery benchmark of 250 t and the higher 270 t in the WCDSR Harvest Strategy (DPIRD 2021), which allows for post-release mortality (Fig. 3.1).* The estimated retained catch of the top 15 species in 2017/18 by private boat-based fishers was 231 t (95% CI 210–253 t; Ryan et al., 2019) and by charter fishers was 61 t. The total of the lower 95% CL of boat-based catches and the estimated charter catch (210+61 t) was above the original catch recovery benchmark (of 250 t) and equivalent to the total recovery benchmark in the *WCDSR Harvest Strategy (DPIRD 2021)* of 270 t (which also includes estimated post-release mortality). While the point estimate of retained catches by private boat-based recreational fishers in 2017/18 (231 t) was equivalent to their harvest strategy catch recovery benchmark (230 t, which includes estimated post-release mortality), the confidence interval ranges from below that (210 t) to above it (253 t). However, considering there is likely to be additional release mortality, the total of retained catch and post-release mortality may exceed the harvest strategy catch recovery benchmark. The point estimate of retained catches by charter fishers was 61 t in 2017/18. Thus, retained catches plus estimated PRM would be well above the harvest strategy catch recovery benchmark for charter fishers of 40 t (which also includes estimated post-release mortality; Figs 3.1, 3.4). The estimated retained catch of the top 15 demersal species (or groupings) in the WCB by private boat-based fishers was steady in 2017/18 compared with the 213 t (95% CI 194–231 t) in 2015/16 (Ryan et al., 2017), but has increased from 152 t (139-166 t) in 2013/14 and 159 t (145-173 t) in 2011/12 (Ryan et al., 2015) (Figs 3.1, 3.4). The estimated retained catch of the top 15 demersal species by charter fishers in the WCB increased from 41 t in 2010/11 to 61 t in 2017/18 and then decreased to 36 t in 2019/20, following possible impacts of COVID restrictions on charter fishing (Fig. 3.1). Of the top 15 species caught by private fishers, retained catches of offshore demersal species comprised 8 t in 2017/18 by private boat-based fishers (Ryan et al., 2019) and 3 t in 2018/19 by charter fishers. Less than 2 t of these species was estimated to have been retained by private boat-based fishers in each of the three prior surveys in 2011/12, 2013/14 and 2015/16. Similarly, low retained catches were reported by charter fishers per year since 2001/02, but increased rapidly to 7 t in 2017/18. They have since declined to <1 t again in 2019/20, possibly due to COVID related impacts. **Retained catches of private and charter vessels in each management area** **Mid-west/Kalbarri areas:** *Overall, estimated recreational sector catches have remained steady since management changes in the Mid-west/Kalbarri areas (Fig. 3.4).* Retained catches of the top 15 demersal species by private boat-based fishers in

the Mid-west/Kalbarri areas since management changes were completed did not exhibit any directional trend and ranged from 55-78 t per year (iSurveys 2011/12-2017/18; Fig. 3.4, 3.5). Estimated charter catches in the Mid-west/Kalbarri areas have been similar in the last 10 years (19-34 t) after management changes to those prior to management changes (20-40 t), i.e. between the introduction of logbooks in 2001/02 and immediately prior to management changes in 2008/09 (Figs 3.4, 3.5).

Metropolitan Area: *Overall, estimated recreational sector catches have increased since management changes in the Metropolitan Area (Fig. 3.4).*

Retained catches of the top 15 species by private boat-based fishers in the Metropolitan Area since management changes have increased from 53 to 98 t per year (iSurveys 2011/12-2017/18; Figs 3.4, 3.5). Estimated charter catches in the Metropolitan Area of 13 to 28 t per year in the 10 years after management changes (2009/10-2019/20), have been generally less than the 24-43 t per year between the introduction of logbooks in 2001/02 and immediately prior to management changes in 2008/09. While charter catches gradually increased from 2010/11 to 2017/18, they have since declined, particularly in 2019/20, possibly as a result of COVID-related impacts (Fig. 3.5).

South-west Area: *Overall, estimated recreational sector catches have increased since management changes in the South-west Area (Fig. 3.4).*

Retained catches of the top 15 species by private boat-based fishers in the South-west area since management changes were completed have increased from 26 t in 2011/12 to 56 t in 2017/18 (iSurvey estimates; Fig. 3.4, 3.5). Annual estimated charter catches in the South-west Area of 1-3 t in the 10 years after management changes (2009/10-2018/19), were typically less than the 1-7 t per year between the introduction of logbooks in 2001/02 and immediately prior to management changes in 2008/09 (Fig. 3.5).

Retained vs released catches of private boat-based fishers and charter fishers

Of the top 15 demersal species caught by private recreational boat-based fishers prior to management changes for recreational fishing in 2009/10, the percentage retained decreased from ~75% in 1996/97 to 51% in 2008/09 (Lai et al., 2019; Fig. 3.6). Following management changes, 37-41% have been retained (see Ryan et al., 2015, 2017, 2019; Fig. 3.6). Similar patterns occurred in each management area, with 36-48%, 33-41% and 33-46% of fish caught after management changes being retained in the Mid-west/Kalbarri, Metropolitan and South-west areas, respectively, in comparison to 57-84%, 44-72% and 56-69% before management changes.

WA dhufish, Snapper, Baldchin groper and Breaksea cod have comprised 84-88% and 85-93% of the respective retained and released catches (in numbers) and 91-93% of the retained catch by weight (see individual Weight of Evidence reports for more detail on variation among management areas).

Of the top 15 species caught by charter fishers between 2001/02 and 2019/20, the mean (±95%CI) percentage of fish retained was lower after management changes than before, i.e. 56 ± 2% vs 71 ± 3% (Fig. 3.7). A similar decrease was observed in the Mid-west/Kalbarri (53 ± 3% vs 62 ± 4%) and Metropolitan areas (58 ± 3% vs 79 ± 3%), but not in the South-west area (79 ± 9% vs 89 ± 4%)

	(Fig. 3.7). However, at the bioregion level and in the Mid-west//Kalbarri and Metropolitan areas, the percentage of fish retained has gradually increased in the 10 years since management changes, i.e. from 49 to 59%, 44 to 56% and 54 to 63% (Fig. 3.7). In the South-west Area, retention rates have been highly variable in the last 10 years, i.e. 47-93%, due to limited fishing effort in that area (Fig. 3.7) **The most recent estimate of the total retained catch of the top 15 species in the WCDSR by the recreational sector exceeded the stock recovery catch benchmark. In addition to high release rates and any associated post-release mortality, this could result in further depletion and the expected rate of stock recovery could be impacted.**

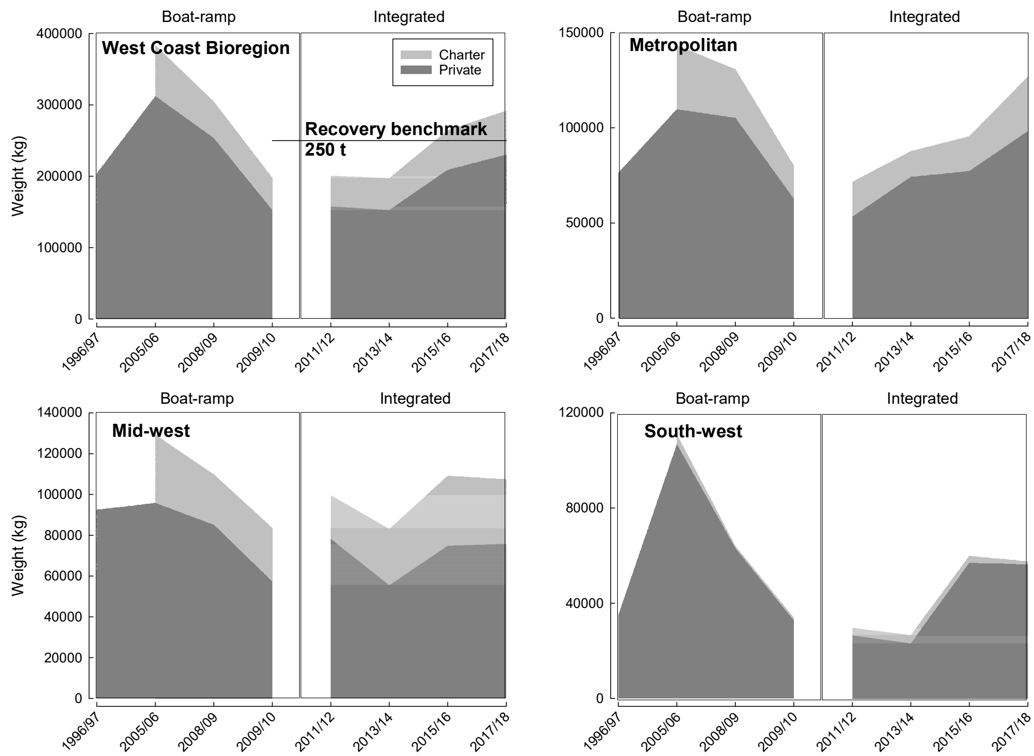


Figure 3.4. Estimated retained catches of the top 15 demersal species by private boat-based recreational fishers and charter fishers at the West Coast Bioregion level (vs the stock recovery benchmark) and in each management area (Table 6a FMP 247). Private boat-based recreational catches estimated during boat-ramp surveys from 1996/97-2009/10 and integrated surveys from 2011/12-2017/18. Catches by charter fishers are reported for the financial year overlapping the time of recreational surveys.

Note: *surveys of private boat-based fishers were estimated using two different methods (creel and integrated) and catches by weight may not be directly comparable; Boat ramp survey estimates have not been adjusted to account for the underestimation of catch from this method or the limited inclusion of catches from the Abrolhos Islands (FMP 249). Confidence intervals for estimates are not shown; catches are not estimated for all members of the top 15 species in each area, either because they were not encountered during surveys, not caught or there were less than 30 diarists (Ryan et al., 2019); mandatory reporting for charter fishers commenced in 2001/02.*

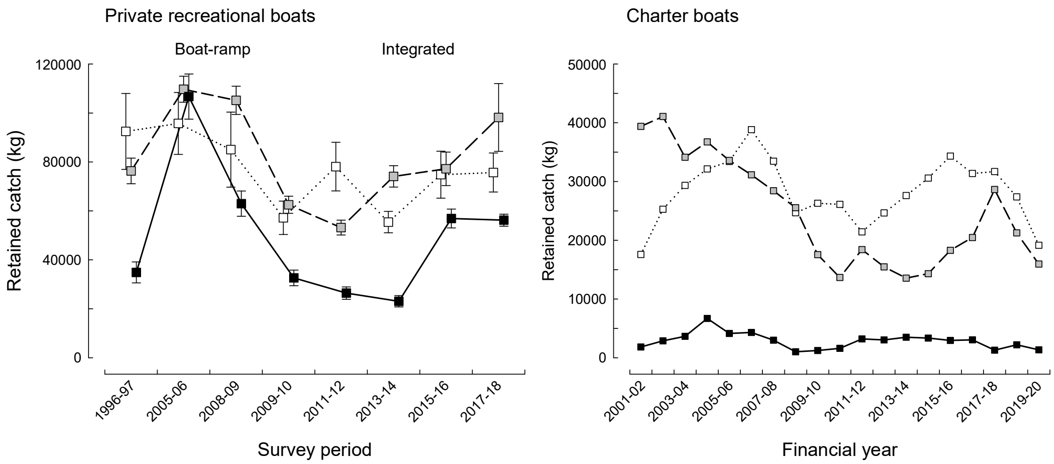


Figure 3.5. Estimated retained catches of the top 15 demersal species (Table 6a FMP 247) in each management area by private boat-based recreational fishers (estimated during boat-ramp surveys from 1996/97-2009/10 and integrated boat-based surveys from 2011/12-2017/18, ± 95% confidence intervals), and charter fishers (in each financial year). Mid-west/Kalbarri: white squares; Metropolitan Area: grey squares; South-west Area: black squares. **Note**: surveys of private boat-based fishers were estimated using two different methods (creel and integrated) and catches by weight are not directly comparable; catches by private recreational boats are not estimated for all members of the top 15 species in each area, either because they were not encountered during surveys, not caught or there were less than 30 diarists during integrated surveys (Ryan et al., 2019).

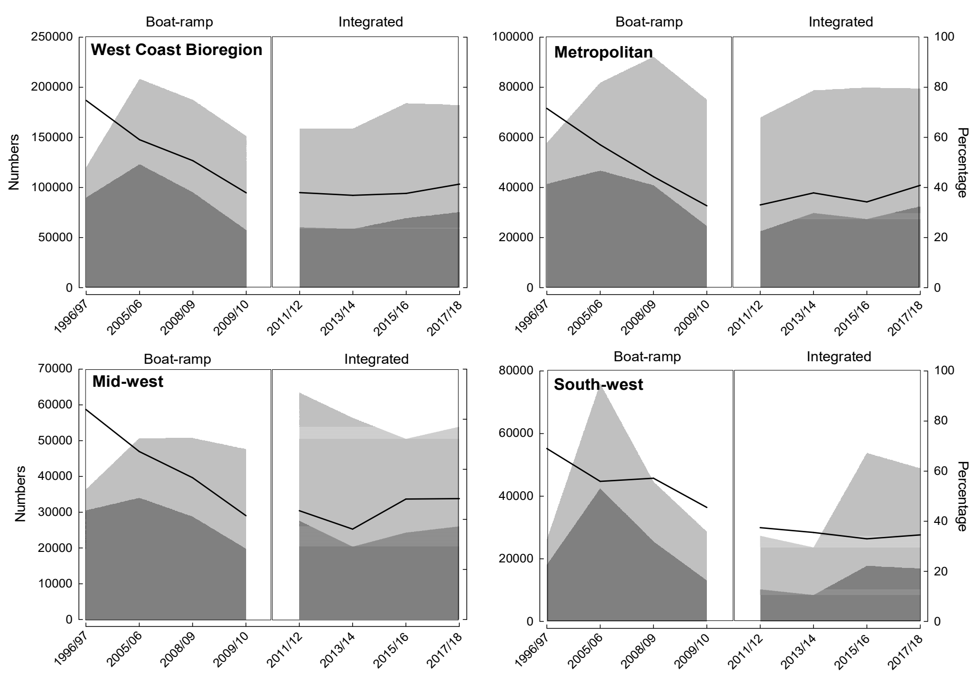


Figure 3.6. Estimated numbers of the top 15 demersal species (Table 6a FMP 247) retained (dark grey) and released (light grey) and percentage retained (black line) by private boat-based recreational fishers, derived from recreational boat-ramp surveys between 1996/97 and 2009/10 and integrated boat-based surveys in the West Coast Bioregion between 2011/12 and 2017/18. **Note:** Catches of the top 15 species represented > 90% of estimated catches of demersal species in 2005/06 (FMP 247); catches by private boat-based fishers were estimated using two different survey methods (boat ramp and integrated) and are not directly comparable.

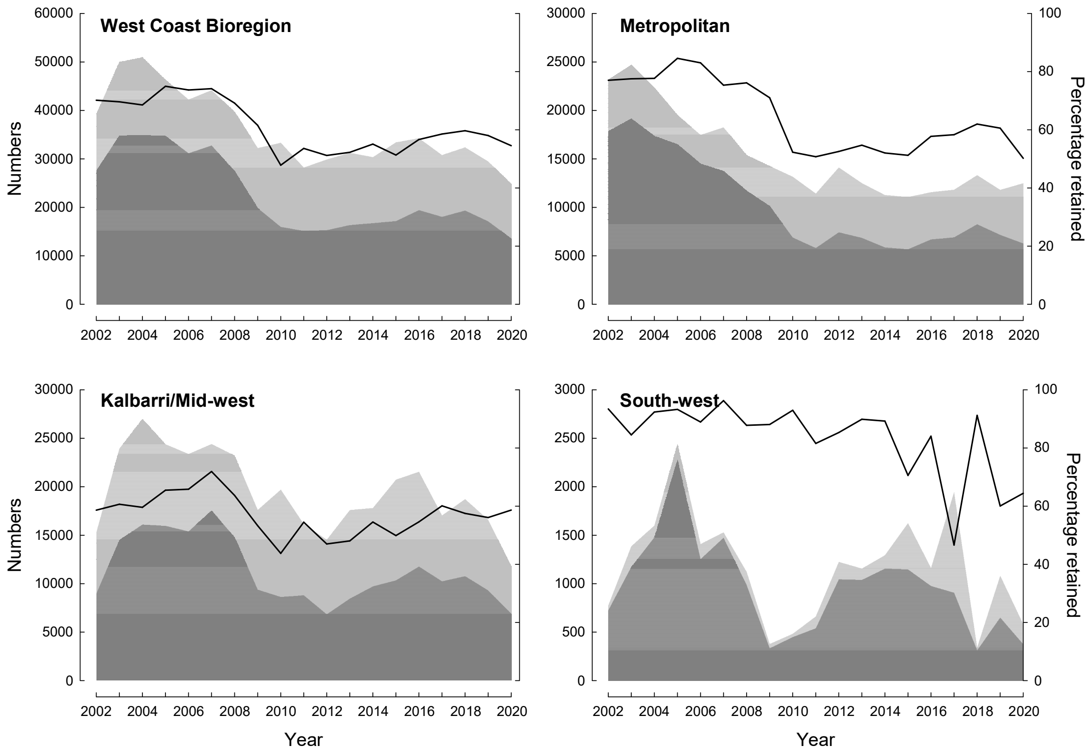


Figure 3.7. Total numbers of the top 15 species retained (dark grey) and released (light grey) and the percentage retained by charter fishers in the West Coast Bioregion and in each management area in each financial year since 2001/02 (shown as 2002).

Recreational sector effort trends	**Boat-based recreational fishers** *The annual estimated recreational fishing effort (private boat-based) in the West Coast Bioregion was steady in 2017/18 (311,495 boat days, 95% CI: 287,726-335,264) compared with 2015/16 (271,311 boat days, 95% CI: 249,688-292,934) (Ryan et al. 2019) and 2011/12 (293,112 boat days, 95% CI: 272,164–314,060), but was higher than 2013/14 (249,719 boat days, 95%CI: 229,016-270,423). The number of trips reported by charter fishers increased since management changes were introduced to recover stocks, from about 1,400 in 2010/11 to 1,860 in 2017/18, but declined to 1,330 in 2019/20, due to the COVID pandemic.* Although the point estimate of boat-based recreational fishing effort (boat days) in 2017/18 was greater than in previous survey years, 95% confidence intervals overlapped those for 2011/12 and 2015/16, indicating no significant differences among those survey years (Table 3.1). The majority of recreational boat-based effort in each survey occurred in nearshore (<20 m; 52-62%) or inshore waters (20-250 m, 22-24%), with at least half of the effort in all habitats attributed to line fishing (50-58% of boat days). The number of Recreational Fishing from a Boat Licenses (RFBL) in the four major Regional Commission boundaries (Metropolitan, Peel, South-west and Mid-west) that abut the coastline of the WCB increased from about 90,000 in 2010/11 to 109,000 in 2015/16, but has since decreased slightly (Table 3.2; Ryan et al. 2013, 2015, 2017, 2019). An average of 63% of licences held are by residents of the Metropolitan region, followed by the South-west (17%), Peel (13%) and Mid-

	west (7%) regions. **Charter fishers** The annual total number of charter trips when fishing was reported increased after management changes, from ~1,540 in 2010/11 to ~1,960 in 2016/17, but have since declined, including as a result of COVID impacts on charter activities in 2019/20 (**Fig. 3.8**). The average annual number of trips in the Metropolitan and South-west Areas has been lower after management changes in comparison to prior to those changes (i.e. 1285 to 834 and 157 to 79 trips, respectively), with concomitant reductions in the numbers of licences operating (i.e. 45 to 27 and 11 to 5) (**Fig. 3.8**). In contrast, in the Kalbarri/Mid-west areas, the average number of trips per year and licences operating increased (700 to 812 trips and 30 to 33 licences). The number of trips remained low (≤ 106) in the South-west Area and highly variable in the Metropolitan Area after management changes (742 to 918) (**Fig. 3.8**). The number of trips in the Kalbarri/Mid-west area increased from 624 trips in 2010/11 to a peak of 1018 trips in 2016/17 and 2017/18, before declining to 764 by 2019/20. The number of licences per year reporting fishing in the Kalbarri/Mid-west area also increased from 28 in 2010/11 to 42 in 2018/19, before declining to 32 in 2019/20, following COVID impacts to charter impact activities (**Fig. 3.8**). Charter trips between 2002 and 2019 occurred in focal areas of the West Coast Bioregion, e.g. Kalbarri, the Abrolhos Islands, the lower Mid-west (e.g.) Jurien, the Metropolitan Area around Rottnest and Mandurah and the South-west Area around Cape Naturaliste (**Fig. 3.9a, b**). The number of trips that reported fishing in blocks between the southern Metropolitan and South-west areas decreased after management changes. Similarly, in some recent years (2016-2018) fishing occurred across blocks from the northern Metropolitan Area to the southern Mid-west (**Fig. 3.9b**). **Effort levels of private recreational fishers in the WCB have not increased since 2011/12, while catches of the top 15 species have increased, which may reflect increasing abundance and/or efficiency. Increasing effort levels (numbers of trips) of charter fishers overall are consistent with their increasing catch levels. As current effort levels have resulted in total catches of the recreational sector exceeding stock recovery benchmarks, plus there is additional release mortality, and most of the increase in charter effort/catch has occurred in the Kalbarri/Mid-west area, this may lead to further depletion, particularly in northern areas.**

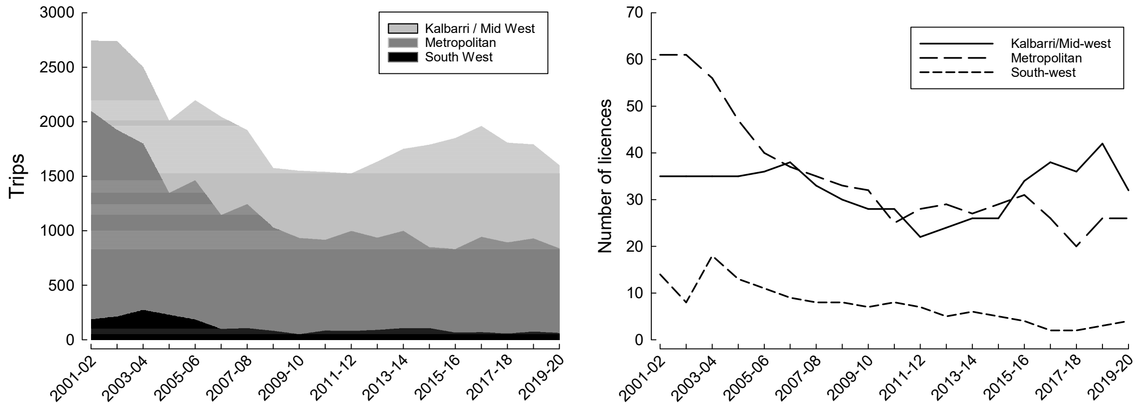


Figure 3.8. Number of trips by charter vessels when fishing occurred in each area of the West Coast Bioregion and number of charter licences that reported fishing activity since 2001/02.

Table 3.1. Range of number of boat days fished (estimate and 95% confidence limits) by recreational boat-based fishers and percentage of effort by habitat and fishing method (by boat days) in the West Coast Bioregion estimated during integrated phone diary surveys (since 2011/12) from Ryan et al. (2019). Note: effort estimated in historical creel surveys (prior to 2011/12) may not be directly comparable and is not presented here (Sumner et al., 1999; Sumner et al., 2008).

Survey year	Boat days (Est. & 95%CL)	Habitat (% of boat days)				Method (% of boat days)		
		Offshore demersal	Inshore demersal	Nearshore	Other	Line fishing	Diving	Other
2011/12	293,112 (272,164-314,060)	5	22	52	21	58	4	38
2013/14	249,719 (229,016-270,422	2	23	57	18	56	5	39
2015/16	271,311 (249,688-292,934)	2	23	62	13	52	4	44
2017/18	311495 (287,726-335,264)	2	24	61	12	50	6	44

Table 3.2. Numbers of RFBL holders within each of the four major Regional Development Commission Boundaries (Metropolitan, Peel, South-west and Mid-west) that abut the coastline of the West Coast Bioregion (Ryan et al., 2013, 2015, 2017, 2019).

Year	Metropolitan	Peel	SW	MW	Total
2010/11	56,608	11,530	15,806	6,445	90,389
2011/12	59,174	11,953	15,941	6,205	93,273
2012/13	65,537	11,900	17,108	7,074	101,619
2013/14	66,784	13,149	17,835	7,356	105,124
2014/15	68,028	14,146	18,682	7,578	108,434
2015/16	68,946	13,940	18,457	7,698	109,041
2016/17	67,696	13,829	18,075	7,461	107,061
2017/18	66,923	14,072	18,294	7,239	106,528

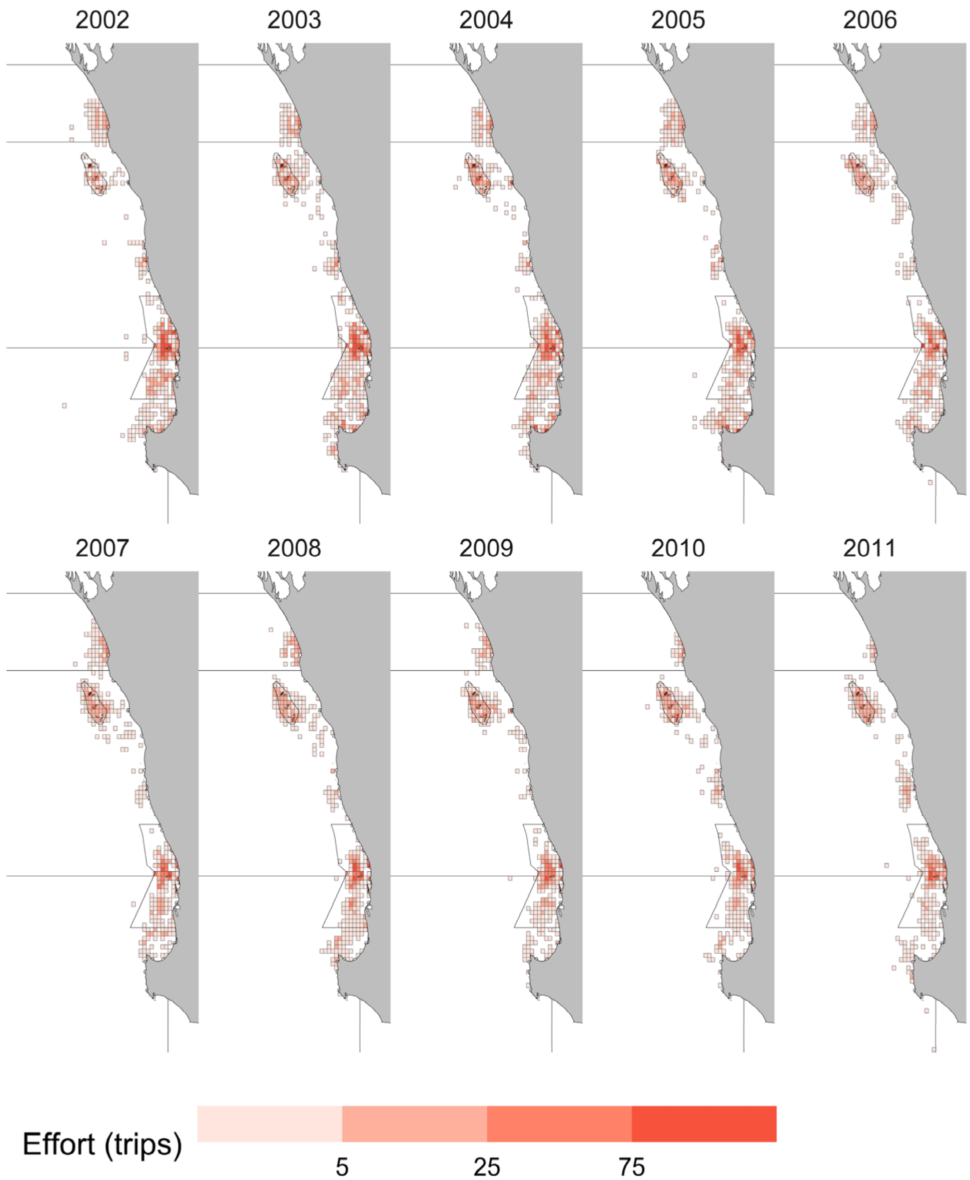


Figure 3.9a. Number of trips reported by charter fishers in each block of the West Coast Bioregion in each financial year from 2002 to 2011 (e.g. 2002 = 2001/02).

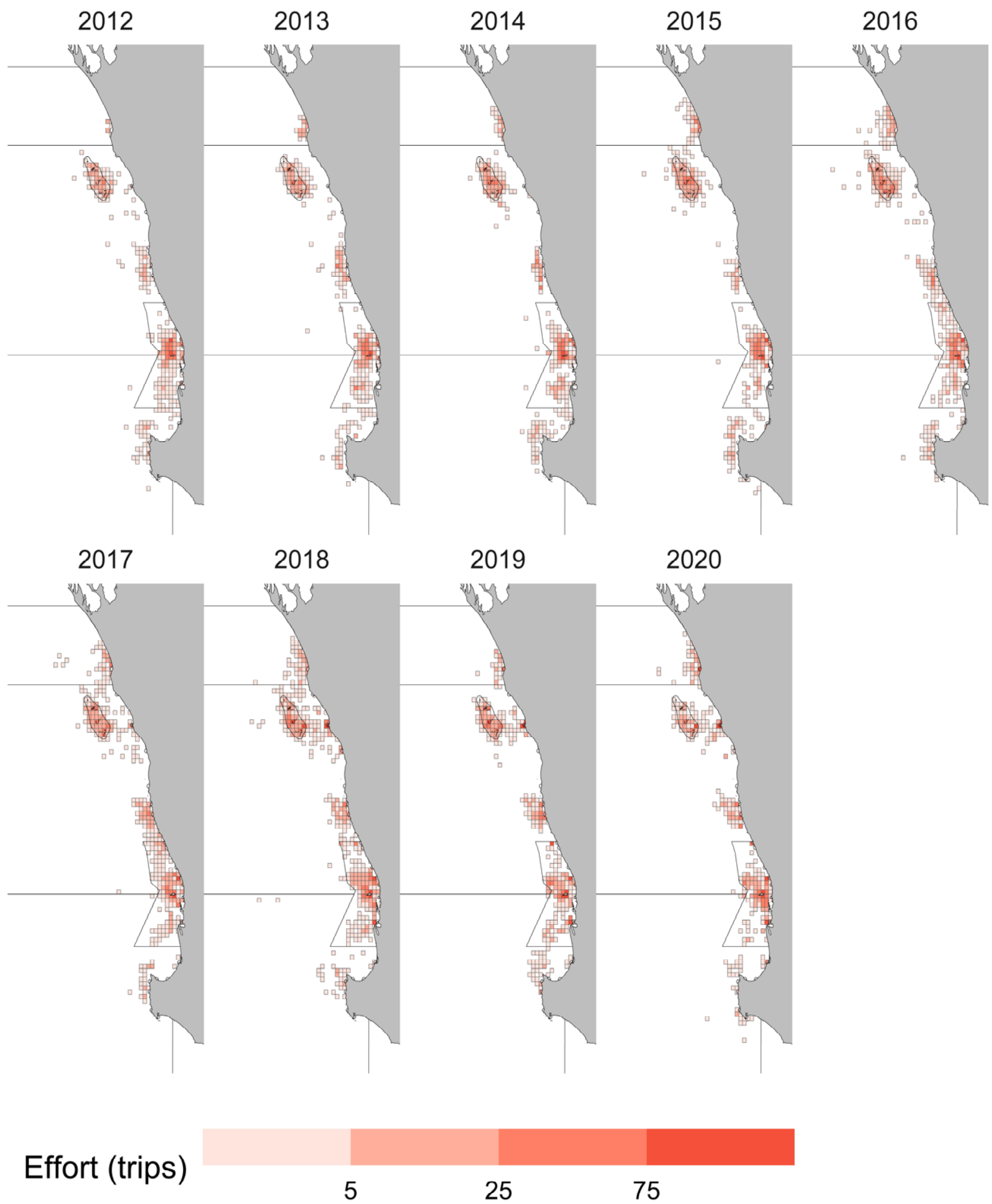


Figure 3.9b. Number of trips reported by charter fishers in each block of the West Coast Bioregion in each financial year from 2011/12 to 2019/20 (e.g. 2012 = 2011/12).

3.2 Objective 2. Weight of evidence assessment of WA dhufish

The L1 Catch-MSY analyses indicated that for dhufish in the northern and southern areas, current *F* (i.e. in 2020) has declined to around F_{MSY}. Point estimates for current B_{rel} (the depletion level) were above the limit ($0.5B_{MSY}$) but still well below the threshold (B_{MSY}) for both areas and thus, the risk of recruitment impairment is reduced. The L1 analyses indicate B_{rel} has been increasing since about 2010 in both areas, suggesting that the population is starting to recover. Catch-MSY assessments are designed for data-poor fisheries and estimates of stock status are imprecise, thus more weight should be given to L3-L5 assessments in interpreting stock status.

The L3 catch curve point estimate for long-term *F* at the stock (bioregion) level from 2015-17 age data (0.18 y^{-1}) is above the limit reference point of 1.5*M* (i.e. 0.165 y^{-1}). Although the 2015-17 *F* was lower than the estimated 0.22 y^{-1} for 2012-14 biological data, overfishing may still be occurring and there is still a risk of recruitment impairment. Long-term *F* in the northern areas increased between 2012-14 and 2015-17 (using age data from commercial and/or recreational fishers), and was well above the limit (i.e. 0.33 or 0.28 vs 0.165). Estimates of long-term *F* have been lower in southern than northern areas and decreased in 2015-17 to be between the threshold and limit (F = 0.14 y^{-1}). However, this is driven primarily by lower *F* in the South-west Area than the Metropolitan Area.

The L3 SPR point estimate of 0.23 at the stock (bioregion) level in 2015-17 was between the threshold and limit and increased from 2012-14. In the northern areas in 2015-17, SPR declined and was below the limit (SPR = 0.15), while in the southern areas, SPR increased to 0.29 and thus was around the threshold. Analyses allowing for temporal variations in growth of dhufish, for which there is increasing evidence, yield slightly more optimistic results.

The L3 analyses indicate that fishing mortality has been too high to allow stock recovery in the northern areas since management changes in 2008-10. Identified recovery at the stock level is driven by recovery in the southern areas and more specifically, the South-west Area, as indicated by greater relative abundances of older fish in 2015-17.

Results of L4 biomass dynamics modelling are influenced by the assumed level of fishing efficiency increase over time applied to CPUE indices. Assuming a 3%/1% (pre 2008/post 2008) efficiency increase, estimated *F* for dhufish in the north in 2020 was close to F_{MSY} and B_{rel} was between the limit and threshold ($0.5B_{MSY}$ and B_{MSY}), but had increased slightly from the mid-2010s. As recent catches have been below estimated MSY in the northern areas, this indicates that this stock is beginning to recover from its depleted status and not currently at risk of recruitment impairment. Note that the 3%/1% efficiency increase relate to increases in addition to those associated with adoption of GPS, colour sounders and hydraulic reels, and that 3% was the minimum required for this model to produce meaningful results for WA dhufish. Biomass dynamics models did not produce realistic outcomes for southern areas (e.g. for values of intrinsic increase r and MSY), with little contrast in CPUE.

Results from two L5 integrated model scenarios (Scenarios 3 and 4), which included CPUE indices applying the same efficiency assumptions as for L4 analyses, and (i) PRM as additional catch (Scenario 3) or (ii) with PRM on undersize gear-selected fish (Scenario 4), indicated that in 2020, *F* in both the northern and southern areas was likely to be around or above F_{MSY} in both scenarios. Although *F* was predicted to continue declining with future catches set at the original recovery benchmarks, median *F* in the northern areas only declines below F_{MSY} by around 2028 in Scenario 3 and does not decline below F_{MSY} in Scenario 4 by 2030, which limits the rate of recovery of B_{rel}. *F* in the southern areas reaches F_{MSY} by 2030, allowing greater recovery.

In Scenario 3, B_{rel} at the bioregion level was around the threshold (B_{MSY}) in 2020, while in Scenario 4, it was between the limit and threshold level in 2020. While B_{rel} in the northern areas was between the limit and threshold in Scenario 3 and around the limit in Scenario 4, in the southern areas, it was between the target and threshold in Scenario 3 and around the threshold in the Scenario 4.

The results of risk assessment at the bioregion level were consistent across the different levels of assessment, i.e. Level 1 (Catch MSY), Level 3 (Spawning Potential Ratio), Level 4 (state space biomass dynamic model) and Level 5 (integrated biomass model). The level 5 integrated biomass models provide the most comprehensive outputs.

Based on all available lines of evidence and using internationally accepted reference points, the current risk to sustainability of WA dhufish at the bioregion level is estimated to be High (C3×L4). In the L5 assessment, there was a 20-49% or ≥ 50% probability of estimated relative biomass (B_{rel}) at the bioregion level being between the limit (B_{Lim}) and threshold ($B_{Threshold}$) reference points used in this assessment (in scenarios 3 and 4, respectively). However, current risk (L5) in Scenarios 3 and 4 was estimated to be HIGH in the northern areas and MEDIUM/HIGH in southern areas. Projected levels of relative biomass (based on future retained catches being equivalent to original catch recovery benchmarks, plus estimated release mortality and average recruitment) suggest that in Scenario 3, the median biomass (B_{rel}) would recover to above the target in both the northern and southern areas, while in Scenario 4, B_{rel} in the northern areas would not be greater than the threshold by 2030, but would recover to above the target in the southern areas.

<u>The current risk to sustainability of WA dhufish at the bioregion level is HIGH.</u>

<table>
<tr><th>Category</th><th>Line of evidence</th></tr>
<tr><td>L1 Biology and vulnerability</td><td>WA dhufish is a long-lived gonochorist (separate sexes), with a maximum recorded age of 41 years and an average age at maturity of around 3-4 years. This species is endemic to south-western WA and the majority of catches are taken in the West Coast Bioregion, where there is high overlap of targeted fishing effort with the stock range. There is likely high site residency among adult fish, and locations are readily targeted by fishers with GPS. The minimum legal length (MLL) of 500 mm is well above the L_{50} at maturity (around 330 mm) and while immature fish are rarely caught, released individuals above and below the MLL are likely to have a relatively high post-release mortality (assumed 50% based on StJohn and Syers, 2005; Memo 31.10.2017; 6016/16). Although dhufish begin spawning at a relatively young age/small size, older/larger fish spawn longer and thus likely make a disproportionately greater contribution to population replenishment than these young/small fish (DPIRD & Murdoch University, unpublished data). Also, dhufish exhibit group spawning behaviours with a social hierarchy among males. As male sperm output is low (associated with small gonad size), selective removal of many large males may lead to sperm limitation/incomplete fertilization of released eggs (Mackie et al., 2009). As fishing is targeted towards these individuals, this increases the vulnerability of this species.</td></tr>
<tr><td colspan="2">L1 Productivity Susceptibility Analysis (PSA)

Based on a productivity score of 1.71 and susceptibility scores of 2.33 for the fishing sectors that catch this species, the overall PSA score of 2.89 suggests a medium risk of overexploiting the stock (see Appendix).</td></tr>
<tr><td>L1 Catch</td><td>Commercial catch

Retained catches of WA dhufish in the WCB by all commercial fisheries and by the WCDSIMF have been around or below respective original catch recovery benchmarks of 82 t and 72 t, since inception of the current management regime in 2008 (Fig. 3.10).
WCDSIMF catches have increased steadily from 27 t in 2016 to 48t in 2020, with all commercial fisheries landing 55 t of WA dhufish in 2019/20 (Fig. 3.10).
Total estimated biomass removed (retained catch plus estimated release mortality) by the commercial sector across the WCB was close to or between the lower catch tolerance level (68 t) and catch recovery benchmark (91 t) in the 2021 Draft harvest strategy for the WCDSR between 2009 and 2013 (Fig. 3.11). It has since been below the lower tolerance level, but gradually increasing from 39 t in 2016 to 62 t in 2020). Note: this assumes release rates of 25% of fish by the WCDSIMF and 10% by the TDGDLF (by weight), respective mortality rates of 50% and 100% and an average released fish length of 442 mm and weight of 1.2 kg.
The majority of commercial catch of WA dhufish is landed in the Mid-west Area. In the Mid-west and South-west areas, retained catches by the WCDSIMF have remained around or below their respective original recovery benchmarks of 44 t and 19 t since 2008, with 35 t and 12 t landed in 2020 (Fig. 3.12). Increased landings in recent years are mostly due to increases in the Mid-west Area. In 2020 this was related partly to increased effort by WCRLF fishers with permits to fish in the WCDSIMF, due to impacts on lobster exports during COVID.
Catches in the Kalbarri Area have remained low (< 5 t) and steadily</td></tr>
</table>

	decreased since 2008. • Between 2008 and 2019, the frequency of blocks with moderate to high catches (> 1 t per year) of WA dhufish by the WCDSIMF has decreased in the Kalbarri and Mid-west Areas (**Fig. 3.13**). The number of blocks in which catches were recorded has decreased at the northern extent of the Kalbarri Area and to some extent along the coast of the Mid-west Area. • These reductions may be related to decreases in effort in the northern areas (cf. **Figs 3.3, 3.13**). However, anecdotal reports from fishers are of declining catch rates resulting in reduced effort, and may reflect localised reduction in abundance observed in catch maps. **Recreational catch** Estimated retained catches of WA dhufish in the WCB by the recreational sector (private boat-based and charter fishers) have increased since 2011/12 to be close to or above the original catch recovery benchmark of 126 t in 2015/16 (127 t; 95%CLs 110-144 t) and 2017/18 (135 t; 95%CLs 116-154 t) (**Fig. 3.10**). • Retained catch of WA dhufish in the WCB by private boat-based recreational fishers in 2017/18 was 123 t (95% CL: 105-141 t; Ryan *et al.* 2019) and by charter fishers in 2019/20 was 8 t (**Fig. 3.10, 2.5**). Charter catches declined from 12 t in 2018/19 due to restrictions related to COVID. • Total estimated biomass removed (retained catches plus estimated release mortality) in 2015/16 and 2017/18 by the recreational sector in the WCB was above the catch recovery benchmark (136 t) proposed in the WCDSR draft Harvest Strategy (**Fig 3.11**). Note: Release mortality is derived from the estimated numbers of fish released by boat-based fishers and reported numbers released by charter fishers multiplied by an assumed mortality rate of 50% and an average length of dhufish released of 442 mm/1.4 kg. • In the Metropolitan and South-west areas, point estimates of retained catch for the recreational sector have increased over time, i.e. 28 t in 2011/12 to 58 t in 2017/18 and 15 t in 2011/12 to 37 t in 2017/18, respectively. In the Kalbarri/Mid-west Area, retained catches have remained steady since 2011/12 (35-46 t) (**Fig. 3.14**). • The percentage of WA dhufish retained by private boat-based recreational fishers in the WCB in 2017/18 was 41% of the 63,068 (SE=5,842) caught (point estimate of retained and released) (**Fig. 3.15**). • Retention rates by private boat-based fishers in the Metropolitan and Mid-west areas increased in 2017/18 compared to previous years, but decreased in the South-west areas (**Fig. 3.15**). The percentage of WA dhufish retained by private boat-based fishers in 2017/18 were 51% of 13,997 fish caught in the Mid-west Area, 45% of 24,310 fish caught in the Metropolitan Area and 30% of 24,761 fish caught in the South-west Area (**Fig. 3.15)**. • The percentage of WA dhufish caught that are retained by charter fishers in the WCB has steadily increased from 42% in 2011/12 to 64% in 2019/20. This is due to increases in retention rates in the Metropolitan (37 to 57%) and Mid-west areas (40 to 65%). Retention rates in the south-west Area have been highly variable since 2011/12, with low numbers of fish caught (51 to 87%) (**Fig. 3.16**). • The vast majority (75-92%) of catches by charter vessels in each block in each year were less than 100 kg (**Fig. 3.17a, b**). Reported catches in each management area in each year were from particular focal areas, e.g. Kalbarri, the Abrolhos islands, Jurien, Rottnest and Cape Naturaliste. WA dhufish were caught in a greater frequency of blocks between the southern

	Metropolitan and South-west areas prior to management changes than after. Similarly, greater catches were reported in blocks between the northern Metropolitan Area and the southern Mid-west in some years. Both of these changes are related to changes in the extent of vessel activity in some regions of the coast and did not provide evidence of serial depletion. **Commercial catches of WA dhufish have remained below original catch recovery benchmarks and do not alone indicate further depletion of the stock. However, reductions in catches at the northern edges of the species range (Kalbarri) and coastal waters of the Mid-west may reflect localised reduction in abundance in these areas. Recent estimates of retained catches by the recreational sector have exceeded the West Coast Bioregion original catch recovery benchmark for this sector. In addition to post-release mortality associated with releasing fish (and any unknown release mortality by the commercial sector), this could increase overall fishing mortality and thus the expected rate of stock recovery could be impacted.**

Level 1 Assessment

Results suggest that annual catches in the northern and southern management areas of the WCB have exceeded the estimated MSY of 176 t (95% CI=140-205 t) and 164 t (95% CI = 129-194 t), respectively, for extended periods over the history of the fishery (**Figs 3.18, 3.19**). Although recent catches in the northern areas have been below MSY, as required to ensure stock recovery, catches in the south have been around the lower 95% CL for MSY, which may impact the rate of recovery (**Figs 3.18, 3.19**).

Annual estimates of stock biomass fell below the estimated level of B_{MSY} in the early 2000s in the north (B_{MSY}: 1689 t; 915-2338 t) and mid 2000s in the south (B_{MSY}: 1350 t; 740-1998 t), with the stock in the north depleting to below B_{lim} of 0.25 (mean ~0.2 of unfished biomass), lower than that in the south (mean ~0.25 of unfished biomass) (**Figs 3.18, 3.19; Tables 3.3, 3.4**). Current *F* (i.e. in 2020) is around F_{MSY} and point estimates for current B_{rel} (the depletion level) were above the limit ($0.5B_{MSY}$), but still well below the threshold (B_{MSY}) for both areas.

The Catch-MSY results indicate that since management action from 2008 to reduce catches of WA dhufish, which has been largely achieved, biomass has slowly been rebuilding in both regions. It must be recognised that Catch-MSY analysis is a data poor stock assessment method and, as such, there is large uncertainty associated with the results and they should be treated with a level of caution.

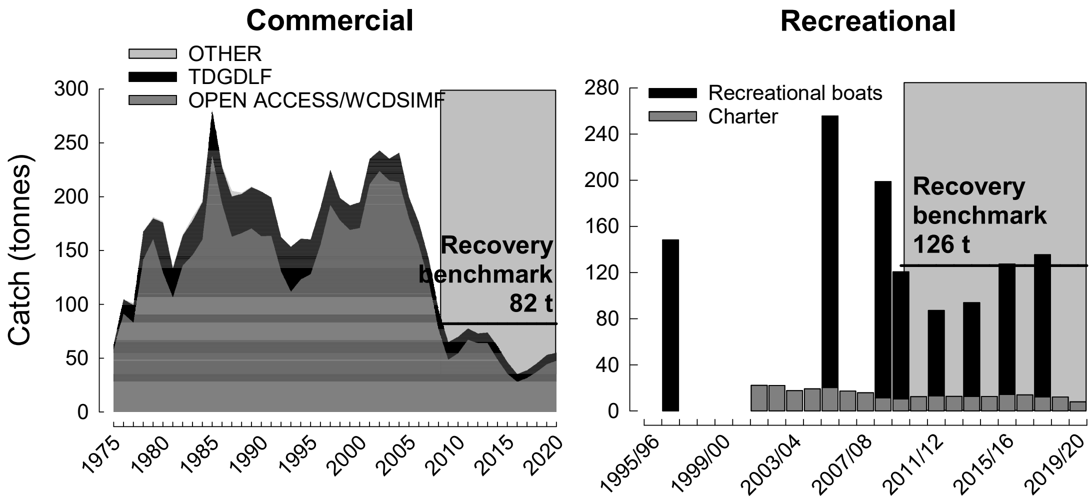


Figure 3.10. Total commercial and recreational estimated retained catches of West Australian dhufish vs 50% of 2005/06 catch benchmarks for stock recovery. Private boat-based recreational catches are estimates of the retained catch and do not show uncertainty (95% CIs), with 2011/12-2017/18 estimates derived from integrated phone diary surveys (Ryan et al., 2019) and prior estimates derived from boat ramp creel surveys (Lai et al., 2019).

Note: catches by private boat-based recreational fishers estimated from boat ramp surveys (1996/97-2009/10) are not adjusted to account for the assumed underestimation due to the time of day of the survey and catches at the Abrolhos Islands (FMP249). TDGDLF = Temperate Demersal Gill-net and Longline fisheries; Open access and WCDSIMF [West Coast Demersal (Interim) Managed Fishery] are hand-line/drop-line fisheries.

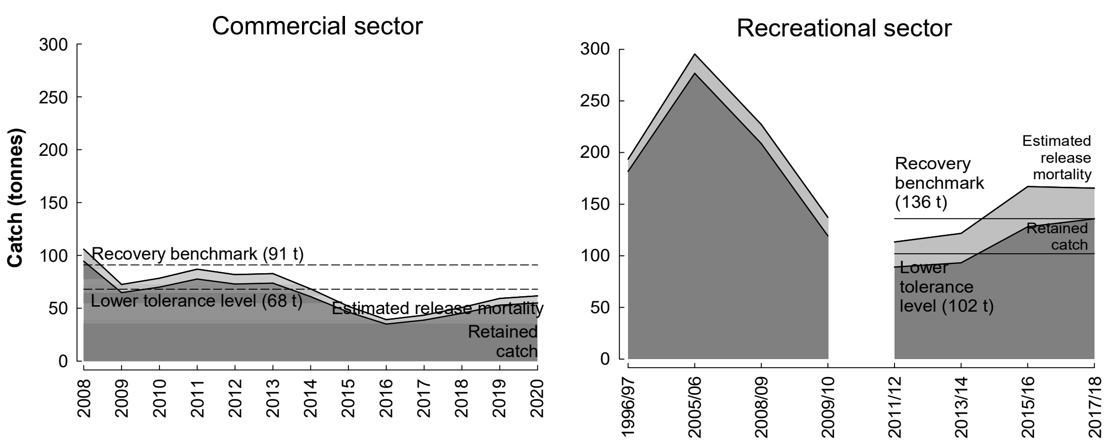


Figure 3.11. Total reported retained catch (dark grey) and estimated release mortality (light grey); i.e. total estimated biomass removed from the population) of West Australian dhufish by the commercial sector (includes WCDSIMF, TDGDLF, WCRLF, CSLPF, SWTMF) and the recreational sector (private recreational boats and charter vessels) in the West Coast Bioregion vs the recovery benchmark and lower catch tolerance levels proposed by the Draft Harvest Strategy for the WCDSR. Note: recreational retained catch estimates from 1996/97 to 2009/10 were adjusted upwards by 30% to account for the assumed underestimation due to the time of day of the survey and catches at the Abrolhos Islands (FMP249).

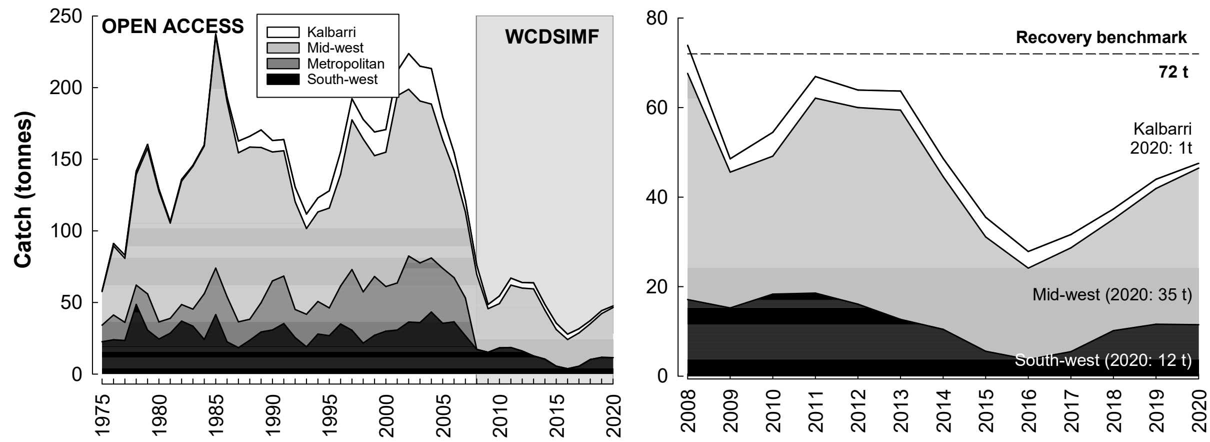


Figure 3.12. Retained commercial catches of West Australian dhufish reported by open access fishers (1975-2007) and the West Coast Demersal Scalefish (Interim) Managed Fishery (2008-2020) in the Kalbarri, Mid-west, Metropolitan and South-west Areas (left panel) and by the WCDSIMF in each area vs original stock recovery benchmark for the WCB (right panel).

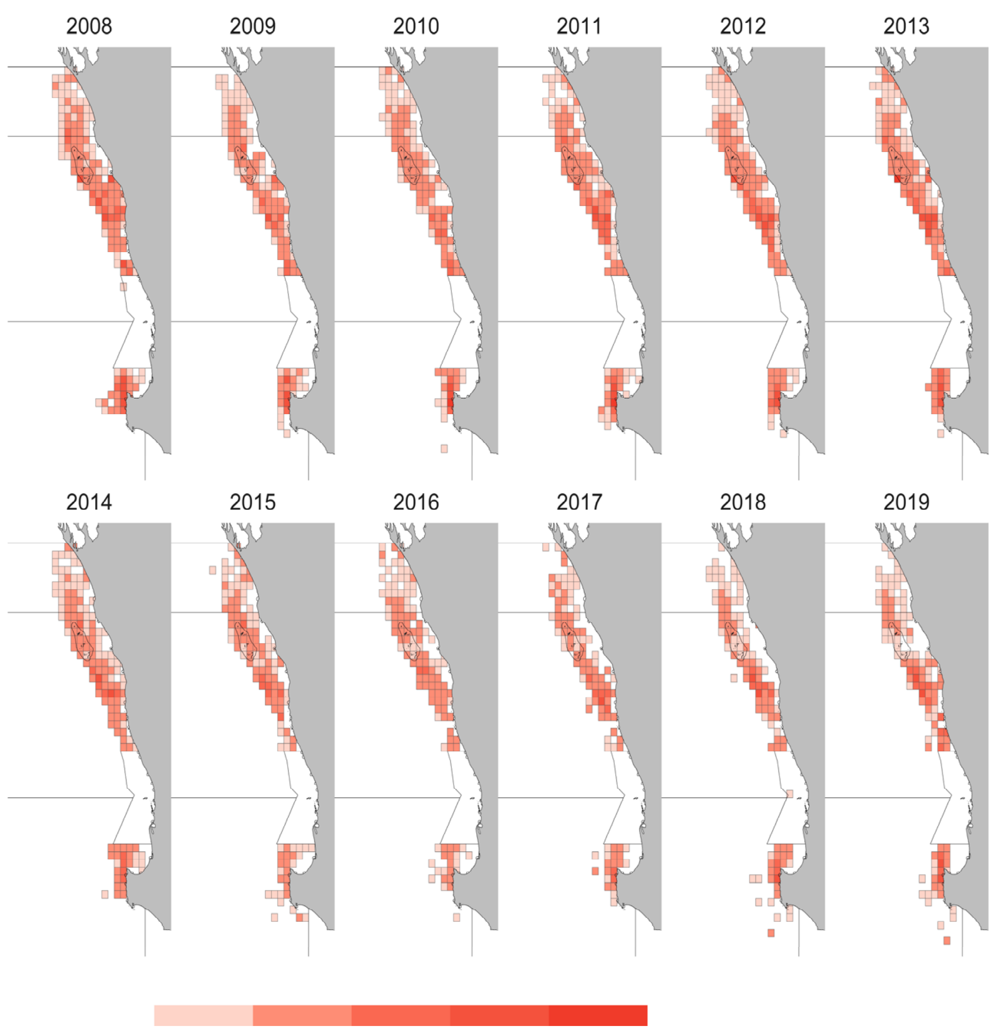


Figure 3.13. Retained catches of WA dhufish by the WCDSIMF in each 10nm block in each year since 2008.

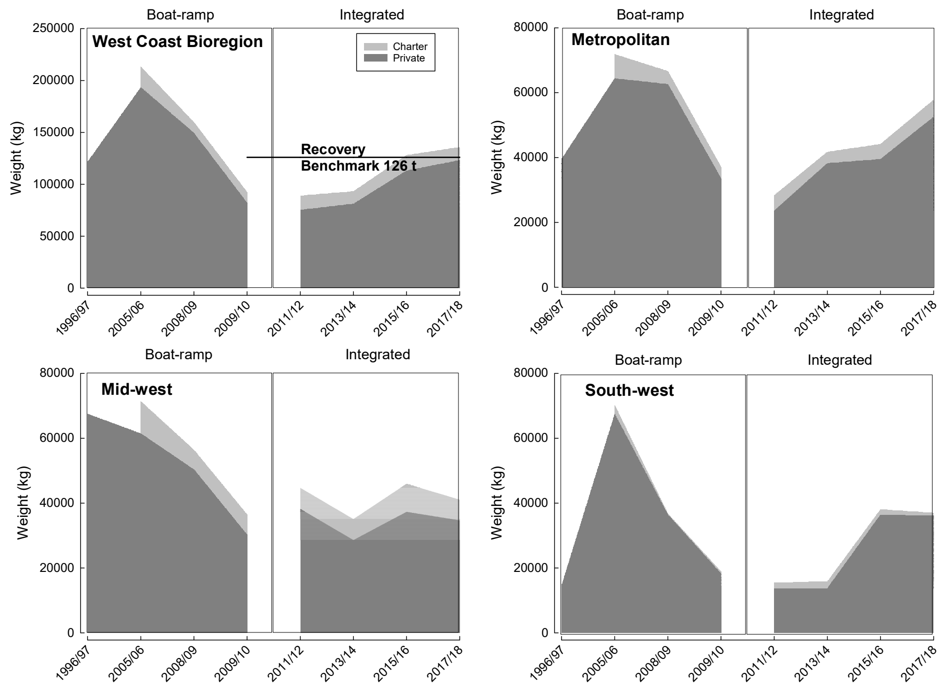


Figure 3.14. Estimated retained catches (kg) of West Australian dhufish by private boat-based recreational fishers (dark grey) and charter fishers (light grey) during each survey year.

Note: recreational surveys were conducted with boat-ramp surveys prior to 2011/12 and integrated surveys from 2011/12 onwards and may not be directly comparable. Catches by private recreational fishers estimated from boat ramp surveys (1996/97-2009/10) were not adjusted to account for the presumed underestimation due to the time of day of the survey and catches at the Abrolhos Islands (FMP249). Charter logbooks became compulsory in 2001/02, hence there are no data for 1996/97.

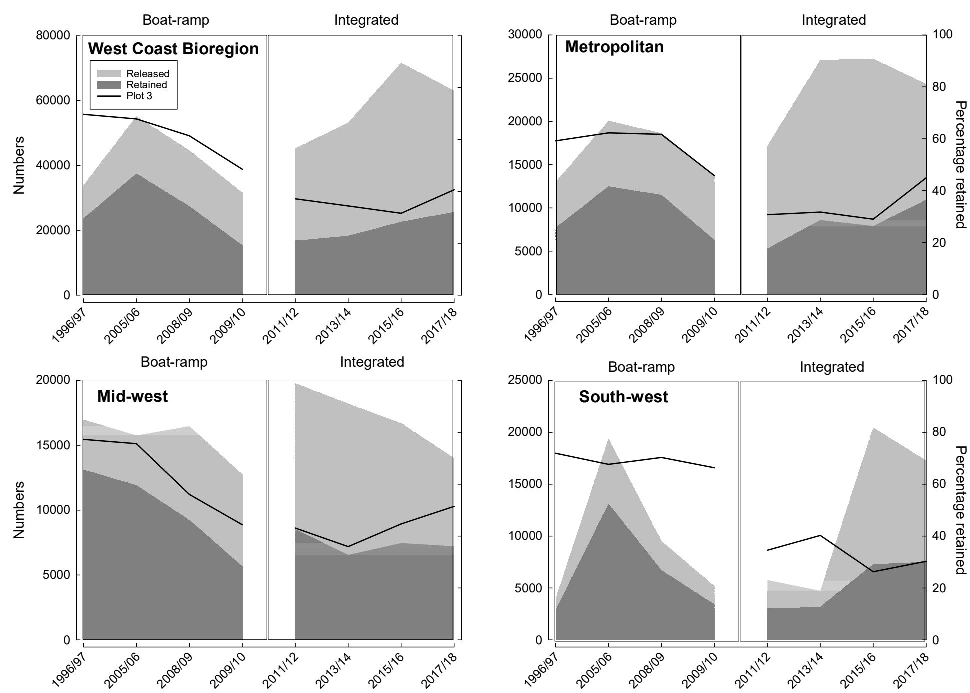


Figure 3.15. Estimated numbers of WA dhufish retained (dark grey) and released (light grey) by private boat-based fishers in each recreational fishing survey since 1996/97 and the percentage of the catch retained (black line) in the West Coast Bioregion and each management area each year.

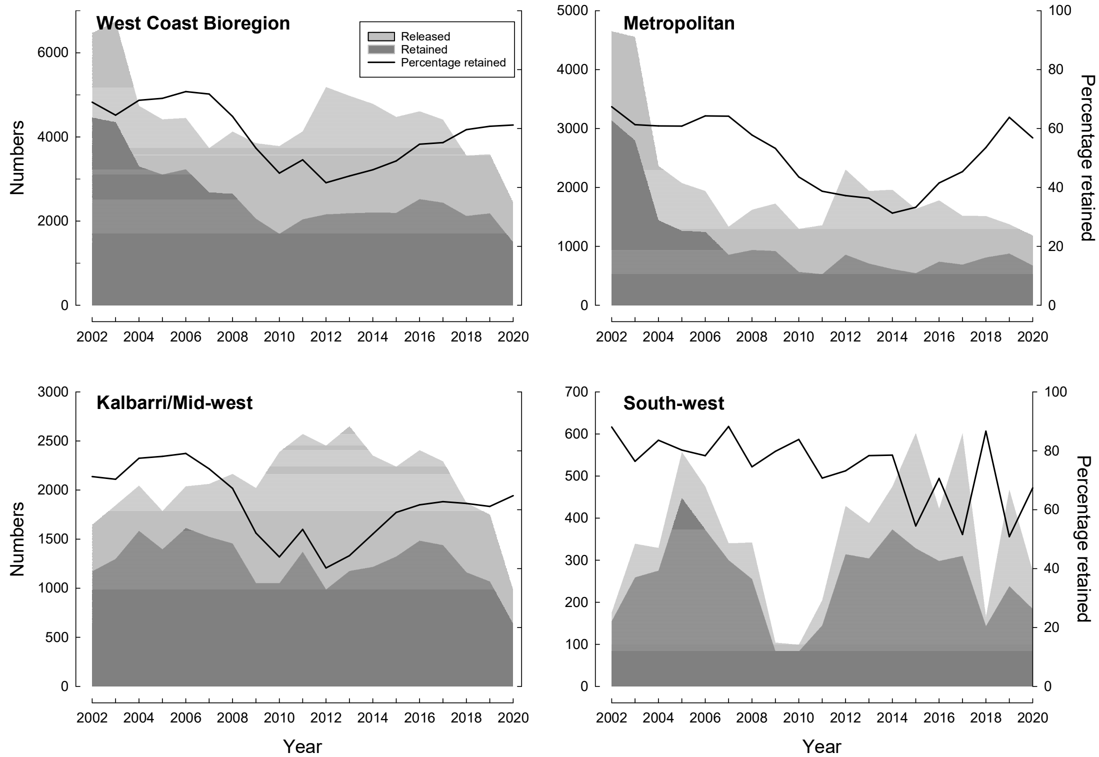


Figure 3.16. Estimated numbers of WA dhufish retained (dark grey) and released (light grey) by charter fishers since 2001/02 (shown as 2002) and the percentage of the catch retained (black line) in the West Coast Bioregion and each management area each year in each year.

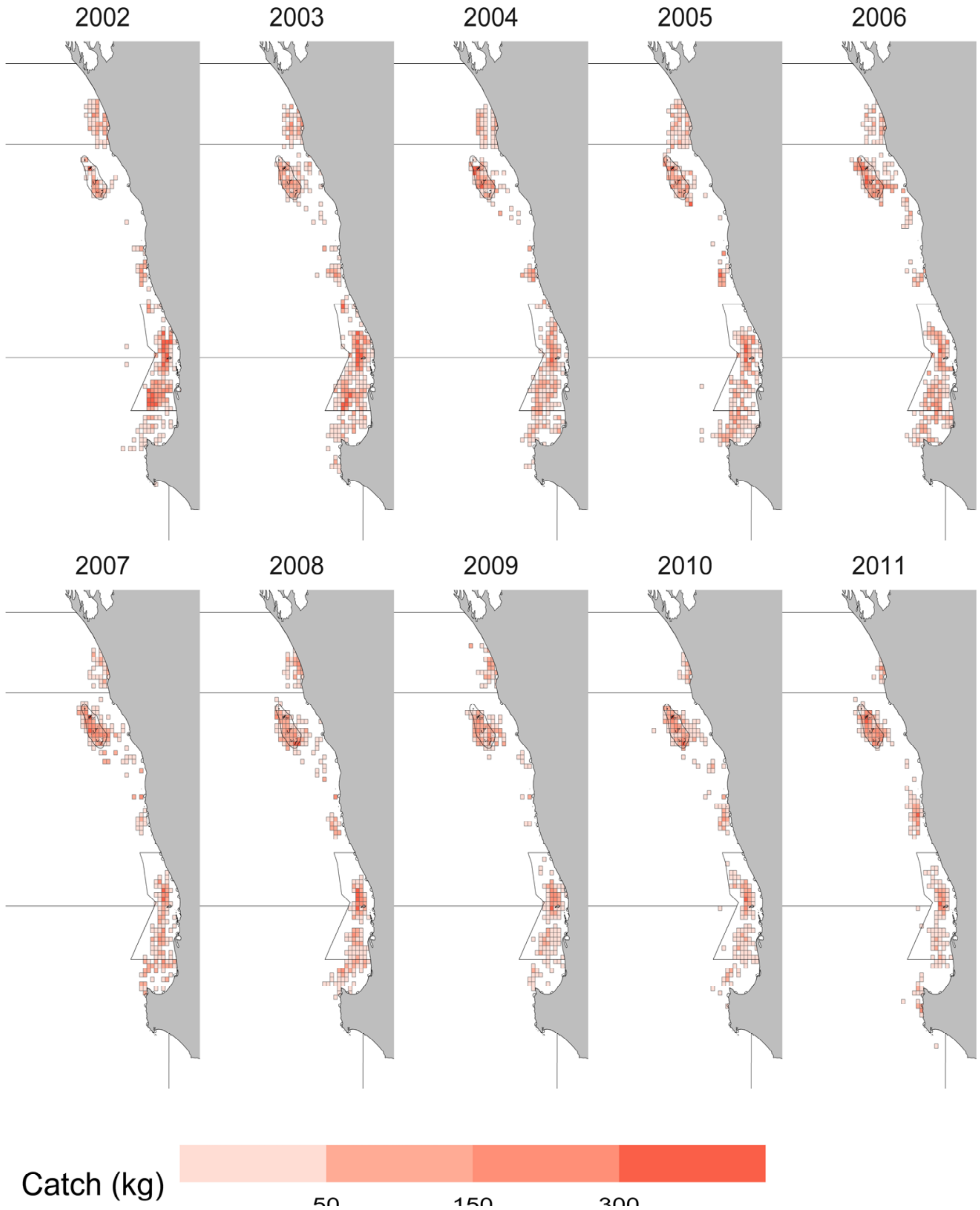


Figure 3.17a. Retained catches of WA dhufish by charter vessels in each 10nm block of the West Coast Bioregion in each financial year between 2001/02 and 2010/11 (label 2002 = 2001/02).

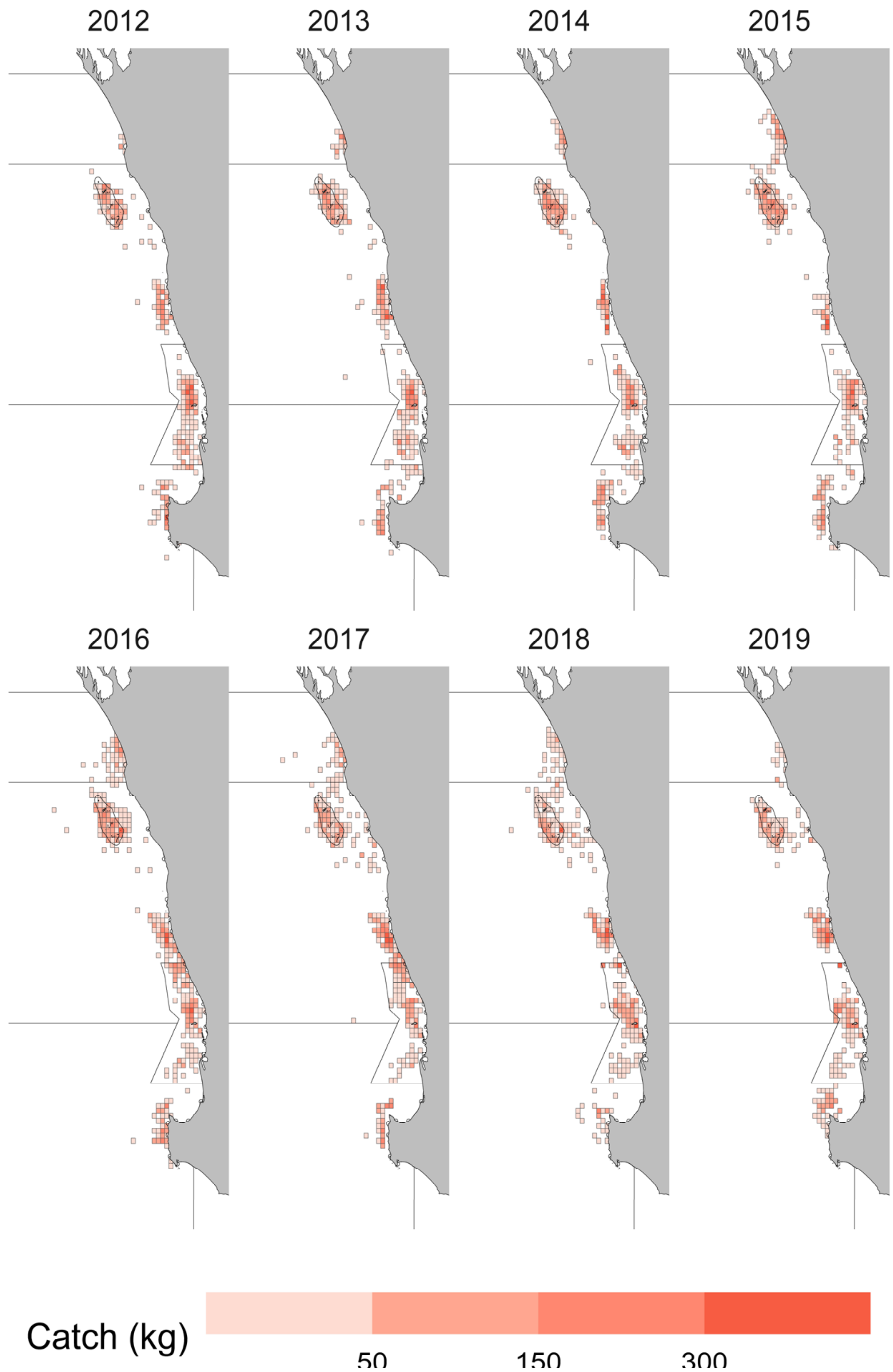


Figure 3.17b. Retained catches of WA dhufish by charter vessels in each 5 nm block of the West Coast Bioregion in each financial year between 2011/12 and 2018/19 (label 2012 = 2011/12).

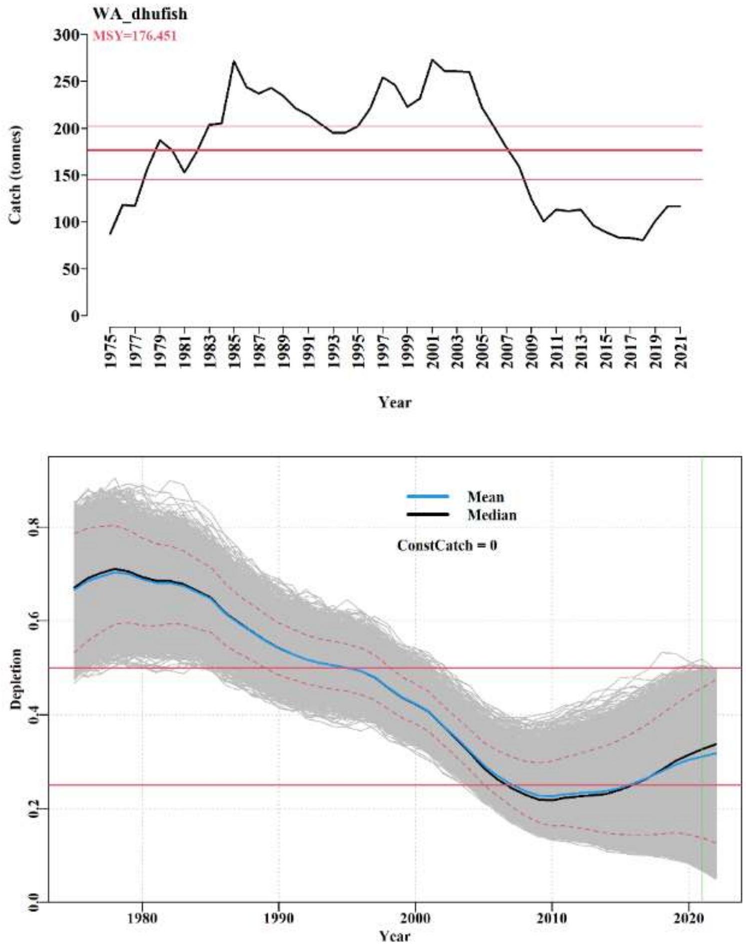
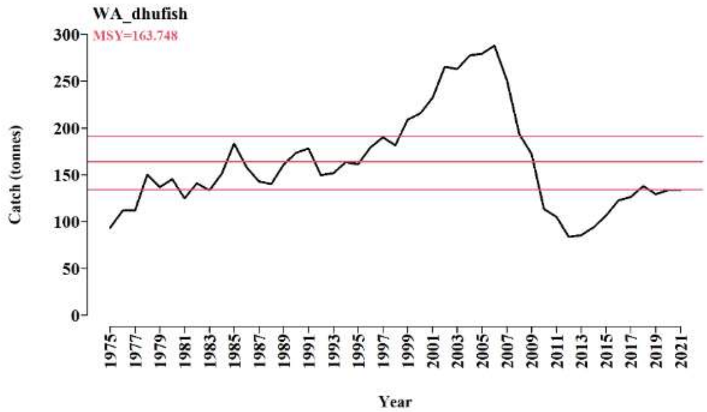


Figure 3.18. Northern areas: Total estimated/reported retained and projected catches (top) of WA dhufish by all sectors vs estimated MSY (± 95%CLs) and estimated depletion level (bottom).

Table 3.3. Northern areas: Outputs of catch MSY analyses for WA dhufish. MSY, maximum sustainable yield; r, intrinsic increase, K, carrying capacity, Brel (relative biomass, or 'current stock depletion' level); B_{MSY} (biomass at MSY), F_{MSY} (fishing mortality at MSY).

Stock	Resilience	Parameter	Mean	Lower	Upper
WA dhufish (northern areas)	low	MSY	176.45	140.11	205.06
		r	0.21	0.13	0.44
		K	3,377.48	1,829.73	4,676.33
		Brel	0.32	0.07	0.49

Resilience	Parameter	Mean	Lower	Upper
low	Biomass	1179	253	2143
	Harvest Rate	0.1	0.05	0.46
	F	0.1	0.06	0.62
	BMSY	1689	915	2338
	FMSY	0.1	0.06	0.22



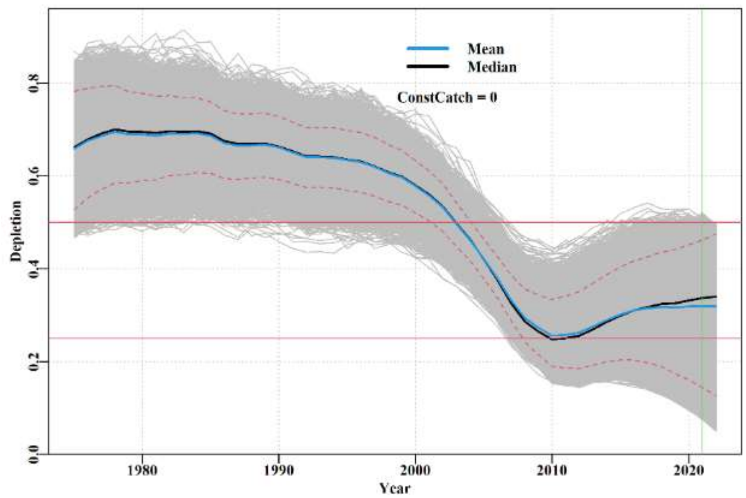


Figure 3.19. Southern areas: Total estimated/reported retained and projected catches (top) of WA dhufish by all sectors vs estimated MSY (± 95%CLs) and estimated depletion level (bottom).

Table 3.4. Southern areas: Outputs of catch MSY analyses for WA dhufish. MSY, maximum sustainable yield; r, intrinsic increase, K, carrying capacity, Brel (relative biomass, or 'current stock depletion' level); B_{MSY} (biomass at MSY), F_{MSY} (fishing mortality at MSY).

Stock	Resilience	Parameter	Mean	Lower	Upper
WA dhufish (southern areas)	low	MSY	163.75	128.80	194.45
		r	0.24	0.14	0.52
		K	2,699.95	1,479.93	3,996.77
		Brel	0.32	0.07	0.49

Resilience	Parameter	Mean	Lower	Upper
low	Biomass	965	206	1824
	Harvest Rate	0.14	0.07	0.65
	F	0.15	0.08	1.05
	BMSY	1350	740	1998
	FMSY	0.12	0.07	0.26

Level 2	
Effort	It is not possible to distinguish effort associated specifically with WA dhufish and other species for commercial and charter fishers, as commercial fishers report target species inconsistently and charter fishers do not report target species. Targeting information is reported by recreational boat-based fishers during phone diary surveys, but has not yet been used to inform effort trends. Therefore, only total effort is reported (**Figures 3.2, 3.3** and **Tables 3.1, 3.2**).
Raw catch rate	**Commercial** Catch rate estimates for WA dhufish calculated using non-differentiated effort may not reflect abundance, because changing species composition and targeting will bias trends in ‘inferred relative biomass of WA dhufish. This limitation was considered in estimating standardised CPUE (L4 assessment), by using a vessel/catch qualification procedure. In addition, entitlements to fish (hours) were introduced in 2009 and may influence catch rates in early years of the WCDSIMF as fishers adjusted their businesses. Raw mean catch rates of dhufish by WCDSIMF fishers derived from drop-line methods in the Mid-west Area and hand-line methods in the South-west area declined after 2010 or 2011 (**Fig. 3.20**). This is consistent with anecdotal reports of declining catch rates. In contrast, CPUE derived from hand-line methods did not differ greatly among years. CPUE for each area was determined from only a small number of boats that fished relatively consistently between 2008 and 2019. While the decline in CPUE may reflect reported declines in effort and/or natural variation in stock abundance as a function of recruitment variation, raw catch rates in each area do not currently indicate increasing stock abundance. **Recreational - Private boat-based** CPUE were not determined for the recreational sector, given the uncertainty around how estimates of boat-based fishing effort in this multi-species fishery relate to targeted effort for WA dhufish. **Recreational - Charter** Raw mean charter catch rates (CPUE; kg/block-trip based on all licences) were greater in the South-west area than both the Kalbarri/Mid-west and Metropolitan areas and greater in the Kalbarri/Mid-west area than the Metropolitan Area (**Fig. 3.21a**). Mean CPUE also differed among years in each area of the WCB. Charter CPUE in the South-west area may not be meaningful as an index of abundance, as effort and catches of WA dhufish in that area are low (64-83 trips in the last 5 years and 1-2 t caught per year). Mean CPUE in the Kalbarri/Mid-west and Metropolitan areas decreased from the early/mid 2000s to 2014 (**Fig. 3.21 a, b**). After 2013/14, CPUE in the Mid-west increased until around 2016/17 and then decreased slightly by 2019/20. CPUE in the Metropolitan area also increased after 2013/14 through until 2017/18 (from about 3.4 to 6.7 kg/block trip), increasing only slightly after that, with effort (number of trips) declining slightly in the last three years (**Fig. 3.8**).
Level 2 Assessment **Lower raw commercial CPUE in the Mid-west and South-west areas in recent years may be influenced by reduced effort and/or natural variation in abundance, but are consistent with anecdotal reports of lower catch rates. This may indicate declining abundance. Although charter CPUE increased after 2014 in the Mid-west and Metropolitan areas, it declined and steadied, respectively, after about 2017, suggesting any increases in abundance had not continued.**	

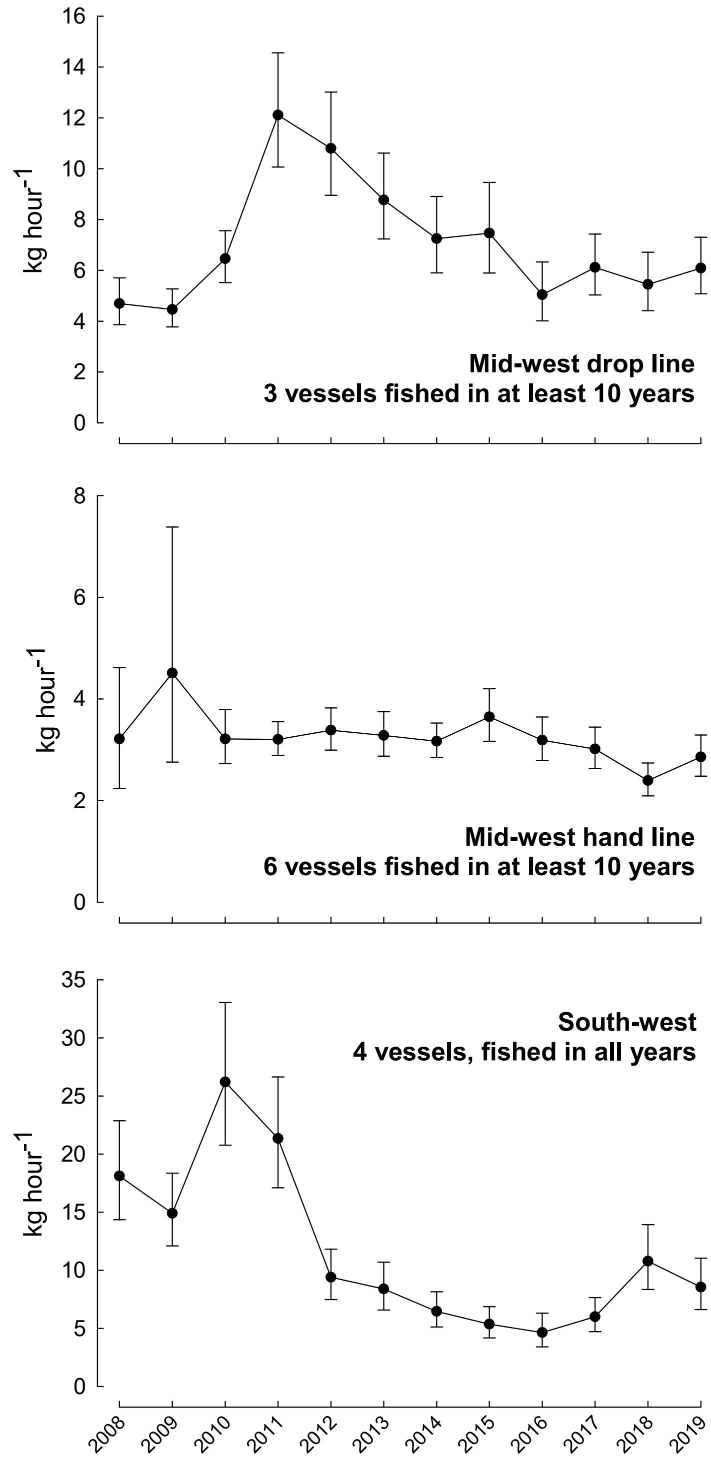
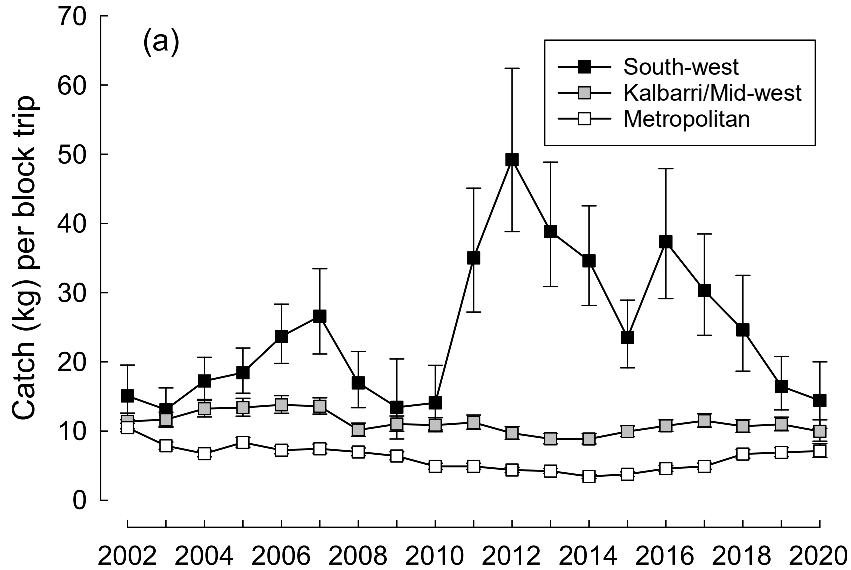


Figure 3.20 Mean raw catches (kg) of WA dhufish per hour (± 95% confidence intervals) by WCDSIMF fishers in the Mid-west and South-west management areas of the West Coast Bioregion. Means are back-transformed marginal means from one-way analysis of variance (results not shown).



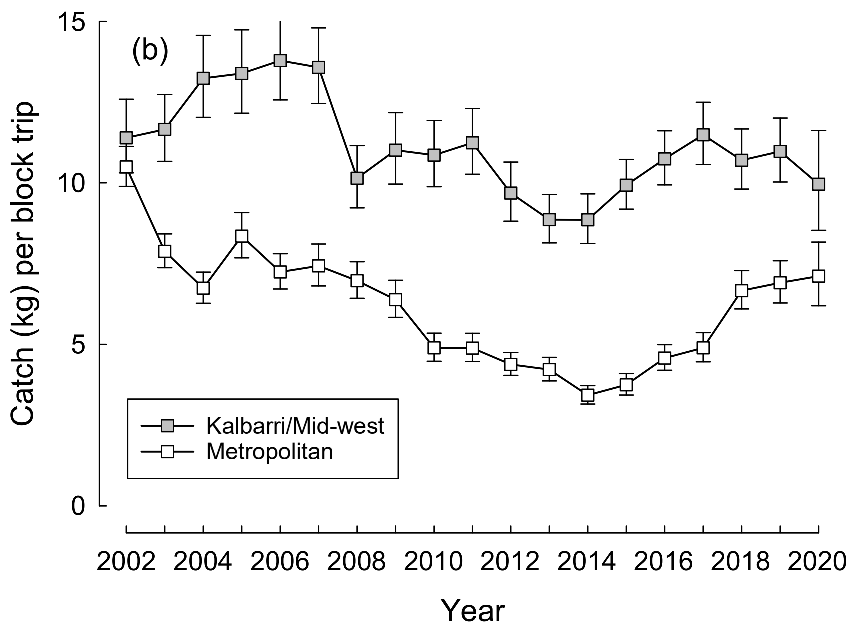


Figure 3.21. Mean raw catches of WA dhufish per block-trip (± 95% confidence intervals) by charter fishers in (a) each management area of the West Coast Bioregion and (b) in only the Kalbarri/Mid-west and Metropolitan management areas of the WCB. Year represents financial year, e.g. 2002 = 2001/02. Means are back-transformed marginal means from one-way analysis of variance (results not shown).

Level 3	
Length composition	**Northern areas** The percentage of large WA Dhufish (≥ 800 mm TL) in commercial samples has varied over time, potentially reflecting recruitment variation. In the northern areas (Kalbarri and Mid-west), the percentage of fish ≥ 800 mm decreased from 21% in the mid-1990s to 11% by 2009-11, but has since increased to 14% in 2015-17 and 33% in 2018-20, noting the small sample size of 208 fish in 2018-20 (**Fig. 3.22**). The percentage of large fish in length frequency distributions from recreational samples in the northern areas has decreased from 19% in 2006-08 to 12% in 2015-17. The percentage of large fish in catches of charter fishers in northern areas has been highly variable, declining from an average of 18% per year between 2006 and 2010 to 15% between 2011 and 2015, and then increasing to 25% between 2016 and 2020 (**Figure 3.23**). This may be influenced by a greater frequency of catches in northern areas between 2016 and 2020 being taken in the lower part of the Mid-west Area, where length distributions may be more similar to those in the Metropolitan Area (**cf Figs 3.17a, b**). **Southern areas** There has been a greater percentage of very large fish (≥ 1000 mm) in samples of recreational catches in the southern areas than northern areas in the different years since management changes, i.e. 1.4-3% vs ≤ 0.4% (**Fig. 3.22**). The percentage of large fish (≥ 800 mm TL) in recreational samples in the southern areas increased from 21% in 1996-1998 to 32% in 2009-11, but then declined to 17% in 2018-20 (**Fig. 3.22**). This may reflect the substantial interannual variation in recruitment that occurs in southern areas, particularly the South-west area. The percentage of large fish in catches of charter fishers in the southern areas has declined from an average of 27% per year between 2006 and 2015 to 16% between 2016 and 2020 (**Figure 3.23**). While the percentage of very large fish (≥ 1000 mm) has been typically greater than northern areas (2-10% vs 0.1-1%) since 2011, it has decreased to ≤ 0.5% in 2019 and 2020 (**Fig. 3.23**). **The change in the relative proportions of WA dhufish in each length class over time are influenced by inter-annual recruitment variation, which is greatest in the southern region. The typically smaller percentage of large fish (≥ 1000 mm) in the northern vs. southern areas could reflect (i) greater depletion in the northern areas, (ii) differences in recruitment variation and/or (iii) spatio-temporal changes in growth patterns. Recent declines in the percentage of large fish in southern areas could reflect increasing depletion in the region (associated with increasing catches).**
Age composition	**Northern areas** The relative abundance of WA dhufish >15 years old in age compositions from commercial catches in the northern areas declined from 11% in the mid-1990s to 5% in 2009-11, when management changes were being made. They have since decreased further, i.e. to 1.6% in 2015-17 (**Fig. 3.24**). In addition, the contribution of fish ≥ 20 years of age to age compositions has decreased from 4.6% in 1996-98 to 0.3% in 2015-17 (**Fig. 3.24**). The percentage of fish in age distributions from recreational samples in northern

areas has remained low from 2003-05 to 2015-17, increasing slightly from 2.3% in 2003-05 to 3.2% in 2009-11, then declining to 2.5% in 2015-17. In addition, fish above 20 years of age have contributed ≤1% to age compositions since the early 2000s (**Fig. 3.24**).

Southern areas

The percentage of WA dhufish above 15 years old in the southern areas has been greater than in the northern areas in each period. The relative abundance of such fish decreased from 15.4% in 1996-98 to 4.8% in 2006-08, before management changes were made. Their contribution has since increased to 9.9% by 2015-17. The percentage of WA dhufish above 20 years also follows a similar trend, declining from 7% in 1996-98 to 1% by 2012-14, but increasing to 1.9% in 2015-17 (**Fig. 3.24**). Trends may be influenced by the occurrence of strong cohorts on the stock.

The greater proportion of older (> 15 years) fish in age distributions of WA dhufish in southern vs northern areas likely reflects better stock status in the former areas. The trends exhibited by the age distributions in the northern areas do not indicate substantive stock recovery since management changes. For the southern areas, substantive increases in the percentages of fish >15 years since 2006-08 suggest a level of stock recovery in those areas. Although this species can live to > 40 y, there are relatively very few fish > 20 years old in either area, which would be expected in a recovered stock.

Level 3 Assessment

Estimates of fishing mortality (*F*) of WA dhufish produced by a multi-year catch curve method that accounts for inter-annual variability in recruitment show that the 'long-term' average *F* of fully selected individuals at the stock (bioregion) level has remained high since management changes, i.e. above or around the limit reference level of 0.17 y^{-1} (1.5 times assumed natural mortality (*M*) of 0.11 y^{-1}) (**Fig. 3.25; Table 3.5**).

However, the bioregion level *F* estimate for 2015-17 of 0.18 (95% CLs = 0.17-0.19) y^{-1} was lower than the estimated 0.22 y^{-1} (95% CLs = 0.20-0.23) in 2012-14. This was driven by a decrease in *F* in the combined southern management areas (Metropolitan and South-west), but specifically the South-west Area (**Fig. 3.25**). *F* in the South-west area declined to just above the threshold, while the *F* in the Metropolitan Area remained steady above the limit. *F* estimates for the northern management areas (Kalbarri and Mid-west) have increased since 2009-11 and remain well above the limit (**Fig. 3.25**).

Estimates of female Spawning Potential Ratio (SPR) were derived from an extended form of per-recruit analysis which accounts for effects of fishing on recruitment (according to a stock-recruitment relationship) and uses the catch curve estimates of 'long-term' *F* and age-based selectivity curves. At the bioregion scale, SPR increased from just below the limit in 2012-14 to between the limit and threshold in 2015-17 (**Fig. 3.25; Table 3.6**).

This was due to the increase in SPR in the south from 0.24 in 2012-14 to be just below the threshold in 2015-17 (0.29), with a lower 60% CL of 0.28. This was primarily as a result of an increase in the South-west Area from 0.29 to 0.33 (i.e. above the threshold). However, SPR in the South-west is lower than prior to management changes (**Fig. 3.25**). In the Metropolitan Area, SPR remained around the limit (95% CLs: 0.17-0.23) and has not increased since management changes.

SPR in the north has continued to decrease to levels lower than before management changes and was below the limit in 2015-17 (**Fig. 3.25; Table 2.4**).

Estimates of SPR ± 95% CLs in the northern areas in 2015-17 were below the limit in analyses of data from both commercial (0.13; 0.11-0.17) and recreational samples (0.16; 0.14-0.18) (**Fig. 3.25; Table 2.4**).

Estimates of SPR derived from a traditional per-recruit model in 2015-17 are somewhat more optimistic (i.e. 0.06-0.07 greater than estimates generated by the more conservative extended SPR model), but this approach does not account for impacts of fishing mortality on recruitment (**Table 2.4**).

Sensitivity analyses using the extended per recruit model, exploring the effect on results of assuming a 50% mortality of fish < MLL released after capture, reduced bioregional SPR estimates by 0.06 in 2015-17 (i.e. SPR = 0.17, 95% CLs: 0.15-0.18), which is below the limit. In contrast, by adopting the assumption that growth of individuals has increased in recent years (as appears to be evident in recent length-at-age data), estimated SPR increased in 2015-17 by 0.05 (SPR = 0.28, 95%CLs: 0.27-0.30). (See Appendix for all F and SPR estimates by area and scenario).

Based on estimated fishing mortality rates and extended SPR, there is evidence of some recovery of WA dhufish at the stock level between 2012-14 and 2015-17 (biological years). However, this like.ly reflects improvements only for the South-west Area. Steady *F* (above the limit) and SPR (around the limit) in the Metropolitan Area do not provide evidence of recovery occurring and both increases in *F* and decreases in SPR in the northern areas provide evidence of further depletion. Including effects of release mortality for sublegal sized fish would reduce SPR at the stock level below the limit, while recent increased growth rates would increase SPR to between the limit and threshold.

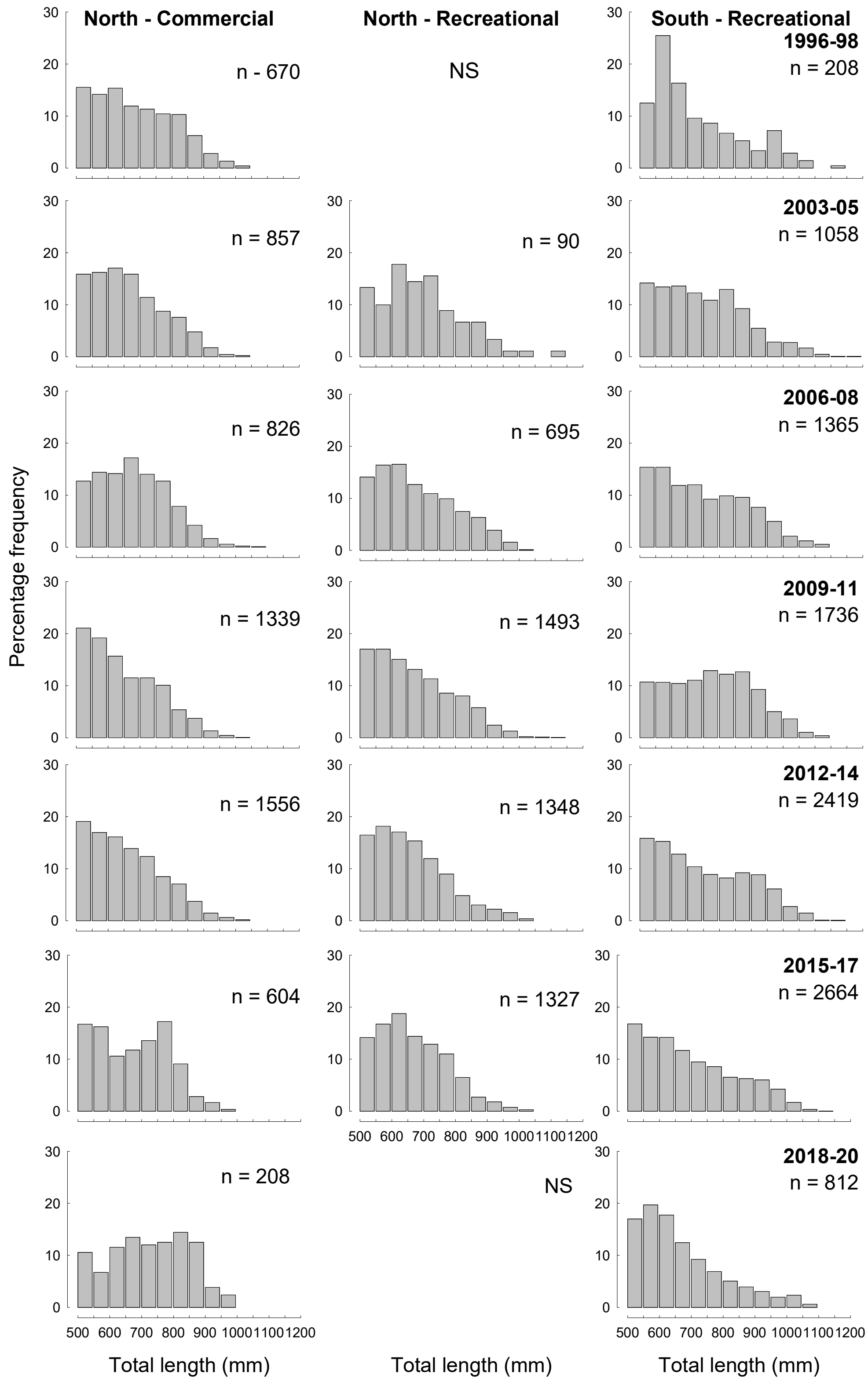


Figure 3.22. Length-frequency distributions of WA dhufish ≥500 mm (minimum legal length) in the northern and southern areas from each sector sampled in each biological year group (Biological year = 1 Feb-31 Jan; North: Kalbarri and Mid-west Areas; South: Metropolitan and South-west areas).

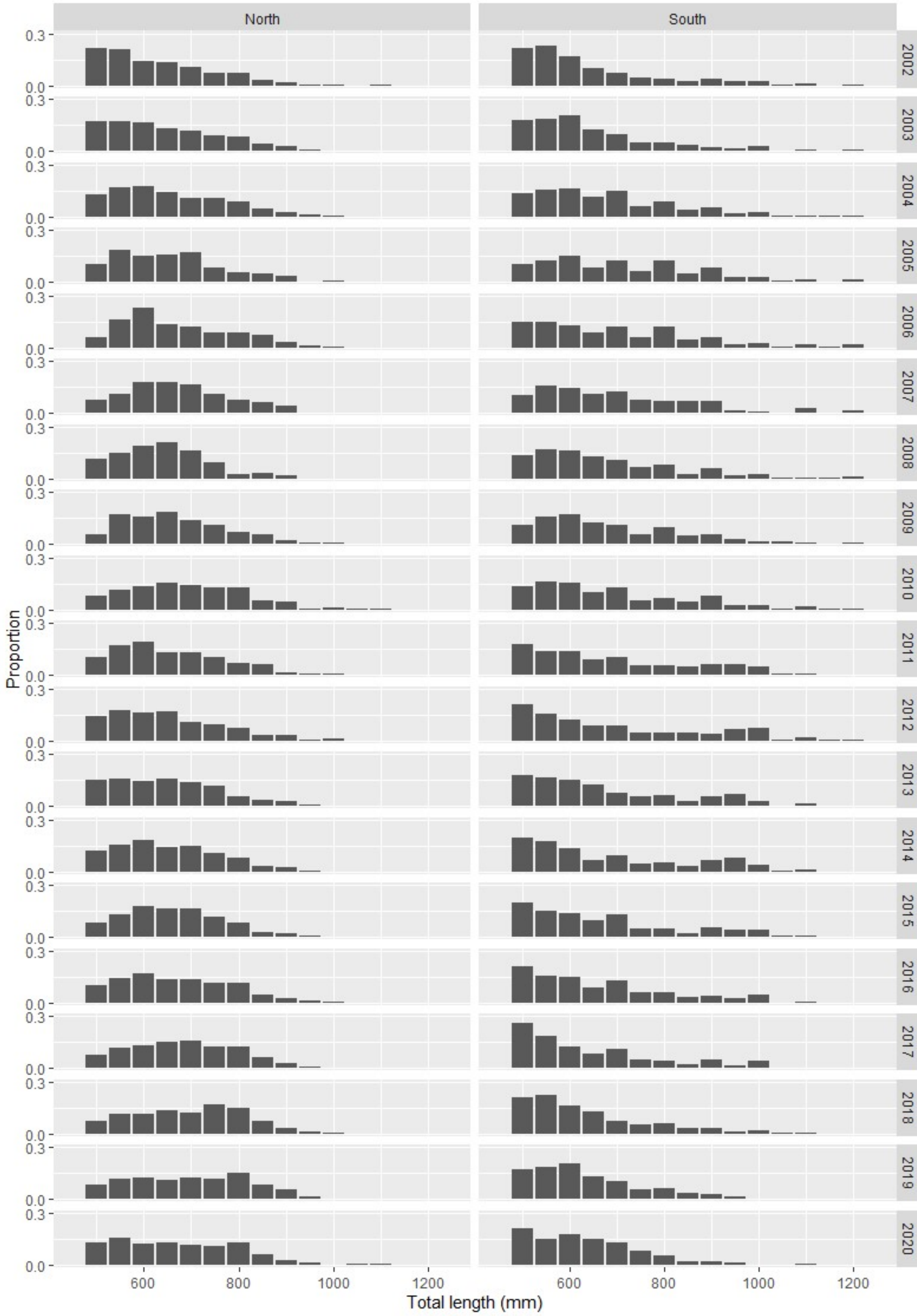


Figure 3.23. Length-frequency distributions of retained WA dhufish reported by charter fishers in the northern and southern management areas of the WCB by year.

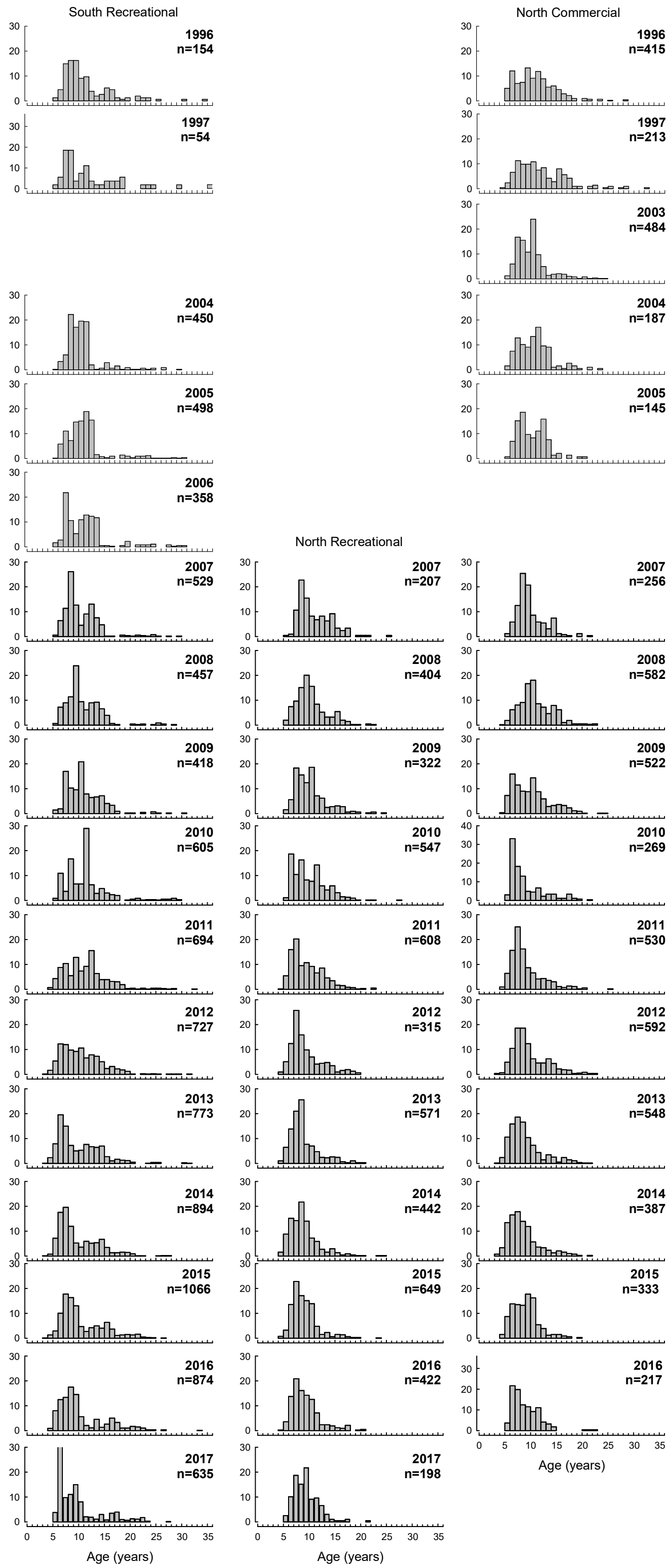


Figure 3.24. Age-frequency distributions of WA dhufish ≥500 mm (minimum legal length) in the northern and southern areas sampled from each sector in each biological year group from 1996/97 to 2017/18 (Biological year = 1 Feb-31 Jan; North: Kalbarri and Mid-west Areas; South: Metropolitan and South-west areas).

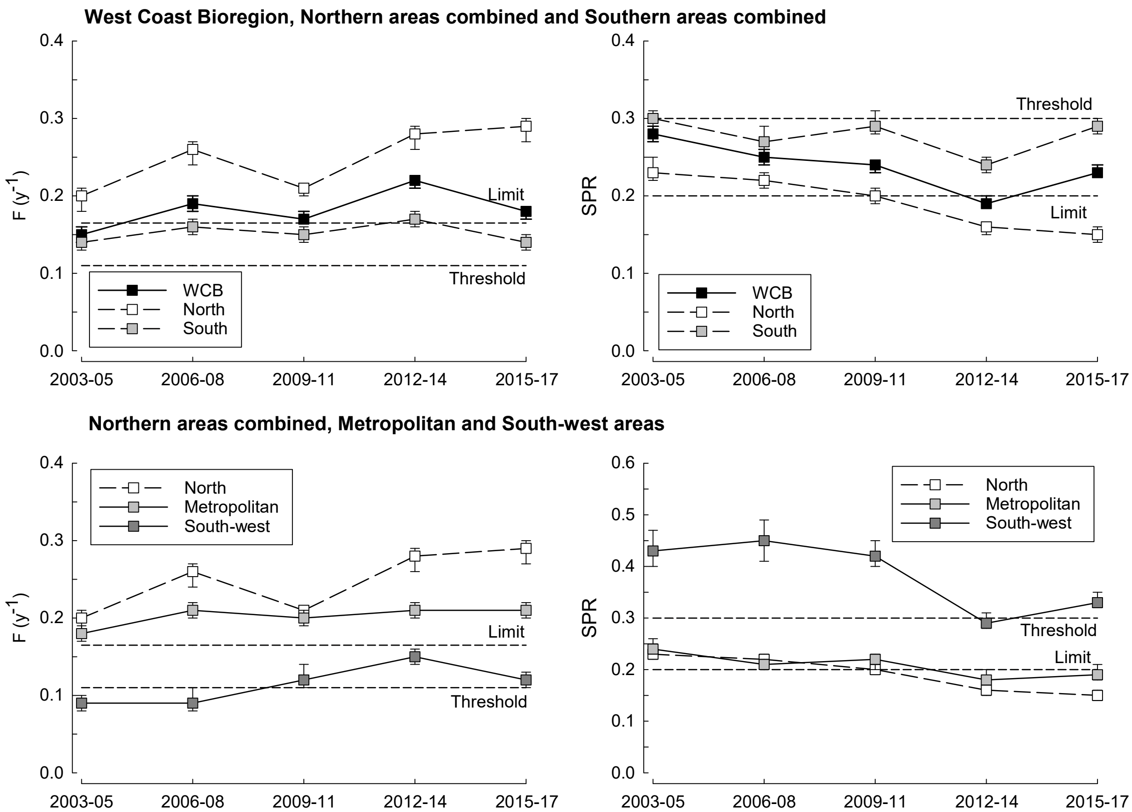


Figure 3.25. Estimates (and 60% confidence intervals) of 'long-term' fishing mortality (*F*, year^{-1}) and female spawning potential ratio (SPR) for WA Dhufish between 2003-05 and 2015-17, based on data from combined commercial and recreational catches in the West Coast Bioregion and Northern management areas (Kalbarri/Mid-west) and from recreational catches in the Southern management areas (Metropolitan/South-west). Estimates of female SPR were derived from an extended model that accounts for the impact of fishing on recruitment. Note the Target reference level (not shown) determined in the Draft Harvest Strategy for the WCDSR is $SPR_{0.5}$.

Table 3.5. Estimates of 'long-term' fishing mortality, *F* (year^{-1}, ±95% confidence intervals) for West Australian Dhufish based on catch curve analysis of age composition data collected in 2015-17 from commercial and/or recreational catches in the West Coast Bioregion (WCB), the combined northern (Kalbarri/Mid-west) and southern (Metropolitan/South-west) management areas and the separate Metropolitan and South-west areas. Point estimates were compared to reference levels relating the value for natural mortality (*M*), where orange denotes *F* ≥ the limit level of 1.5*M* (0.165 year^{-1}) and yellow denotes *F* ≥ the threshold level of *M* (0.11 year^{-1}).

Area	Combined sectors	Commercial	Recreational
WCB	0.18 (0.17-0.19)		
North		0.33 (0.26-0.4)	0.28 (0.24-0.31)
South			0.14 (0.12-0.15)
Metro			0.21 (0.18-0.24)
South-west			0.12 (0.10-0.14)

Table 3.6. Estimates of spawning potential ratio, SPR (±95% confidence intervals) for West Australian Dhufish based on per-recruit analyses of fishing mortality estimates from 2015-17 for the commercial and/or recreational sectors in the West Coast Bioregion (WCB), the combined northern (Kalbarri/Mid-west) and southern (Metropolitan/South-west) management areas and the separate Metropolitan and South-west areas. Point estimates were compared to reference levels relating the spawning potential to that of an unfished stock, where orange denotes SPR ≤ the limit level of 0.2, yellow denotes SPR ≤ the threshold level of 0.3 and green denotes SPR > the threshold level. Note Target reference point adopted by Draft Harvest Strategy for the WCDSR is SPR = 0.5.

Area	Combined sectors		Commercial		Recreational	
	Traditional per recruit	Extended per recruit	Traditional per recruit	Extended per recruit	Traditional per recruit	Extended per recruit
WCB	0.30 (0.28-0.31)	0.23 (0.22-0.25)				
North	0.22 (0.21-0.24)	0.15 (0.13-0.17)	0.21 (0.18-0.24)	0.13 (0.11-0.17)	0.23 (0.21-0.25)	0.16 (0.14-0.18)
South					0.35 (0.33-0.38)	0.29 (0.27-0.32)
Metro					0.26 (0.24-0.29)	0.19 (0.17-0.23)
South-west					0.39 (0.36-0.42)	0.33 (0.3-0.37)

Level 4	
Fishery-dependent abundance index and biomass dynamics model	In the northern areas, standardised drop-line (DL) and handline (HL) CPUEs increased over time. In the southern areas, standardised DL CPUE also increased over time, but HL CPUE did not (**Fig. 3.26a**). However, after accounting for fishing efficiency increases associated with adoption of GPS, colour sounders and hydraulic reels (Marriott et al., 2011), adjusted standardised DL CPUE initially declined in the northern areas in the 1980s, followed by a gradual increase for both DL and HL (**Fig. 3.26b**). This was also the case for CPUE derived from data for fishers that met the minimum qualification rule (**Fig. 3.28**). DL and HL CPUE remained relatively steady after initial declines in the late 1980s/early 1990s in southern areas, as did those derived from data meeting the minimum qualification rule (**Fig. 3.28**). Note that fishing efficiency may have increased further during this period than from that estimated for the introduction of GPS, colour sounders and hydraulic reels, e.g. from other technological changes or levels of fisher knowledge and skill, which would result in further decreases in CPUE. Daily CPUE trends were similar for mean, nominal and standardised CPUE in the northern areas (**Fig. 3.27**). In the southern areas, the standardised CPUE trend was less variable than either mean or nominal CPUE. Daily standardised DL and HL CPUE for the northern areas have remained relatively stable between 2008 and 2020, suggesting little change in abundance over this period (**Fig. 3.27**). In the southern areas, where only HL methods are currently used, there was a pronounced decline in standardised CPUE from 2011 to 2016, after which CPUE has been relatively steady, providing little evidence of recent increases in abundance (**Fig. 3.27**). Trends were similar for CPUE derived from data for vessels that met the minimum qualification rule. Note that it is likely that fishing efficiency will also have had some effect on daily CPUE trends due to further advances in fishing technology/fisher experience etc. since 2008. The reliability of the monthly CPUE trends as indices of abundance is highly uncertain due, in particular, to lack of knowledge of how fishing efficiency has changed over time and impacts of targeting of particular fish species in certain areas as certain times (within this multi-species fishery) by fishers. While fishing efficiency would have also changed since management changes, it is likely to have changed less in the relatively short period of time (2008-2020). Future research should focus on analyses/data collections that might reduce this uncertainty.

Level 4 Assessment (Biomass dynamics model)

North, base case:

The estimated relative biomass of WA dhufish in the northern areas declined from a specified level of 0.8 in 1975 to between 0.25 (0.5B_{MSY} = limit) and 0.5 (B_{MSY} = threshold) from the early 1990s to 2020 (**Fig. 3.29**). This occurred following increases in catch above estimated MSY (164 t) in the mid-1980s and exploitation exceeding F_{MSY}, which were both sustained until the mid-2000s. Therefore, this analysis indicates that the stock was slightly overfished during that period. However, since management changes in 2008-2010, the results provide evidence of recent increases in relative biomass. Estimates for absolute biomass are highly uncertain, likely due to the nature of the CPUE data (so-called 1-way trip, of overall decreasing CPUE trend).

North, alternative case:

When additional fishing efficiency increase was set at 2% for the monthly CPUE, the model was not able to fit well to the CPUE and catch data as indicated by extremely large estimates of uncertainty. Consequently, the results from this analysis are considered unreliable (figures not shown). This set of modelling results suggests either that (1) it is necessary to account for substantial fishing efficiency increases over time for the CPUE and catch trends to provide a consistent stock status signal, or (2) there is insufficient signal in the CPUE data for this form of modelling.

South, base case:

Estimated median relative biomass declined to around the limit ($0.5B_{MSY}$) in the mid-1990s and has remained below it in recent years (**Fig 3.30**). Although the model could be fitted to both the Catch and CPUE data, and provides a feasible trajectory for stock biomass, the level of contrast in the data is very limited (i.e. 1-way trip). This, in turn reduces the reliability of estimated model parameters (e.g. unfeasibly low estimates for r, annual exploitation rates and MSY. The results also indicate that other data are likely required (e.g. age data and/or another abundance indices) to provide more reliable results.

South, alternative case:

Results are similar to the base case scenario, with estimated relative biomass declining below the limit reference point in the mid-2010s (**Fig. 3.31**). As above, several of the results for this scenario do not appear reliable.

The results of biomass dynamics models highlight large uncertainties associated with limited signal in the CPUE data. In each case, the estimated annual relative biomass trends suggested that current relative biomass is between the threshold (B_{MSY}) and limit ($0.5B_{MSY}$) reference points in the northern areas and below the limit reference point in the southern areas. Also, relative biomass has exhibited little or no increase in recent years. Results from these production modelling analyses are uncertain and should be treated with a level of caution.

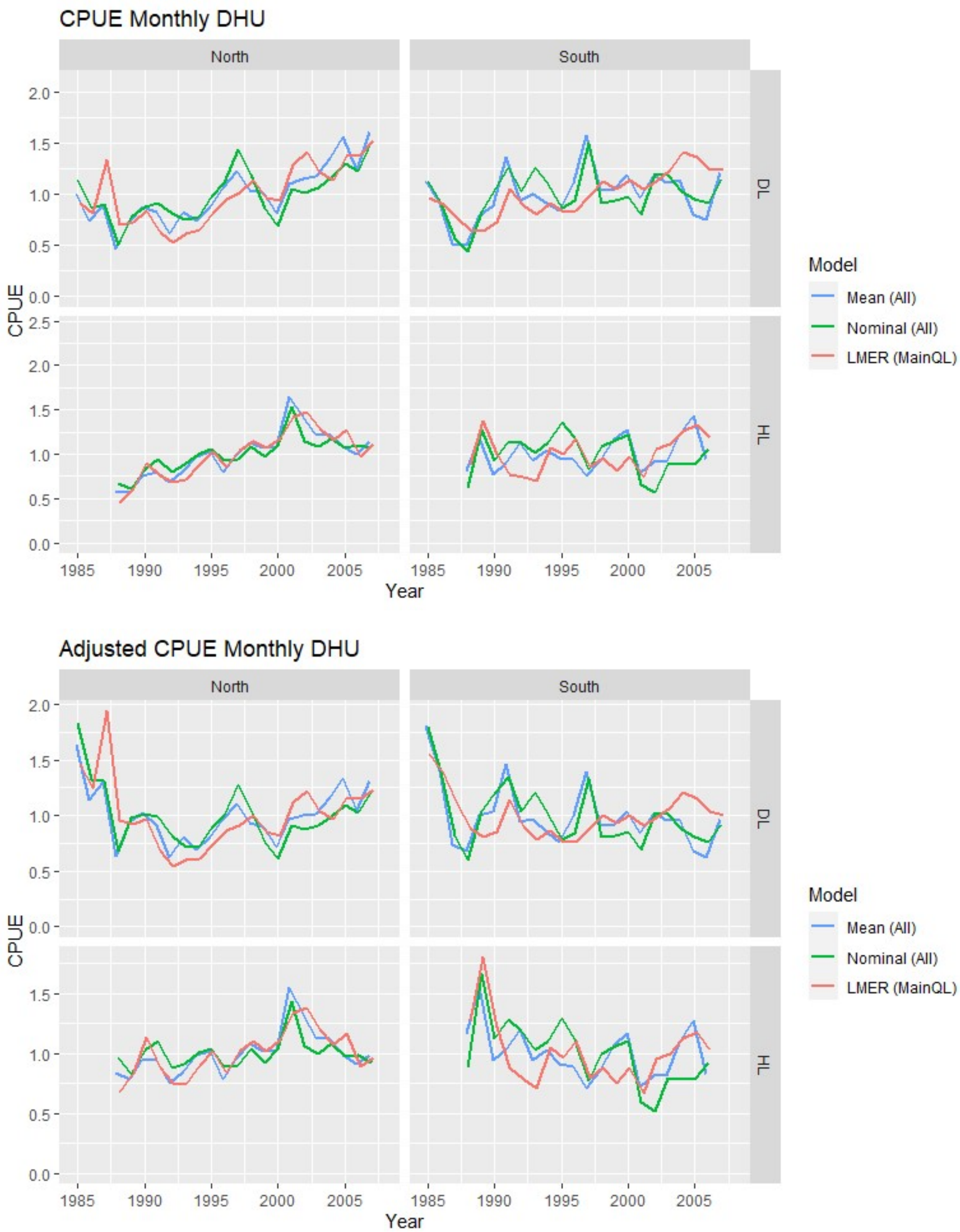


Figure 3.26. a) Raw (mean and nominal) CPUE trends and standardised CPUE (LMER) trends and b) adjusted raw and standardised CPUE, for monthly dhufish records in the north and south regions using DL or HL methods.

Figure 3.27. Raw (mean and nominal) CPUE trends and standardised CPUE (LMER) trends for daily dhufish records in the north and south regions using DL or HL methods. Note there is no daily data for DL methods in the southern region.

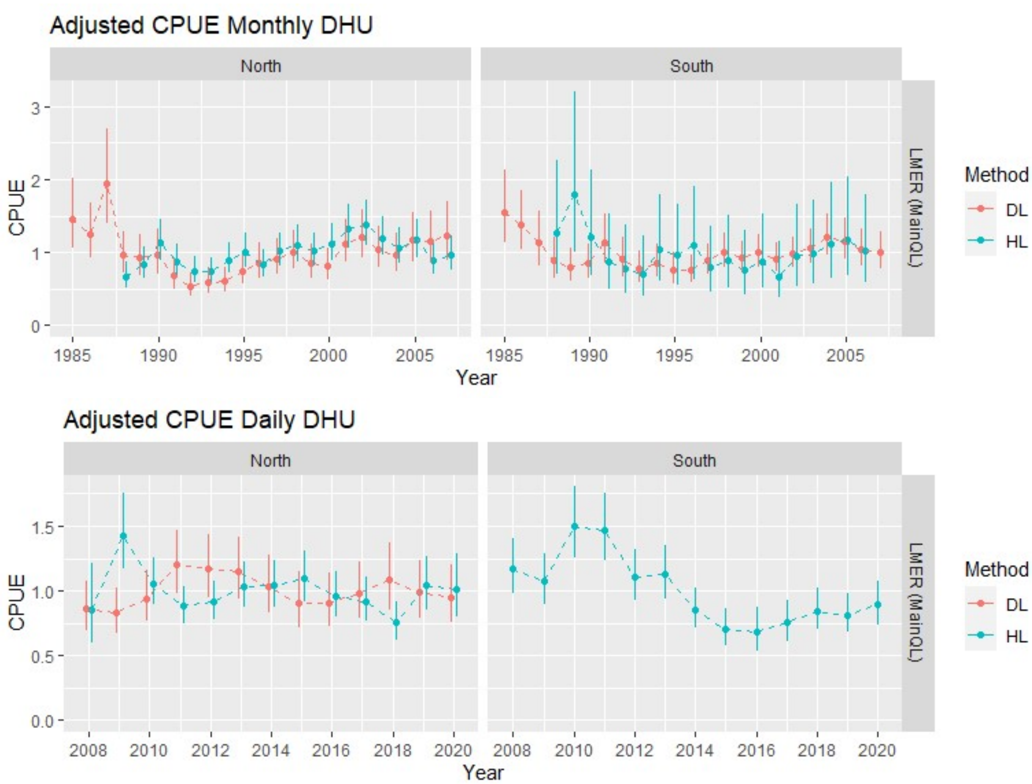


Figure 3.28. Adjusted monthly (top) and daily (bottom) standardised CPUE (± 95% CI) for WA dhufish by DL or HL in the northern and southern areas, using data for vessels that met a qualification rule for targeting dhufish.

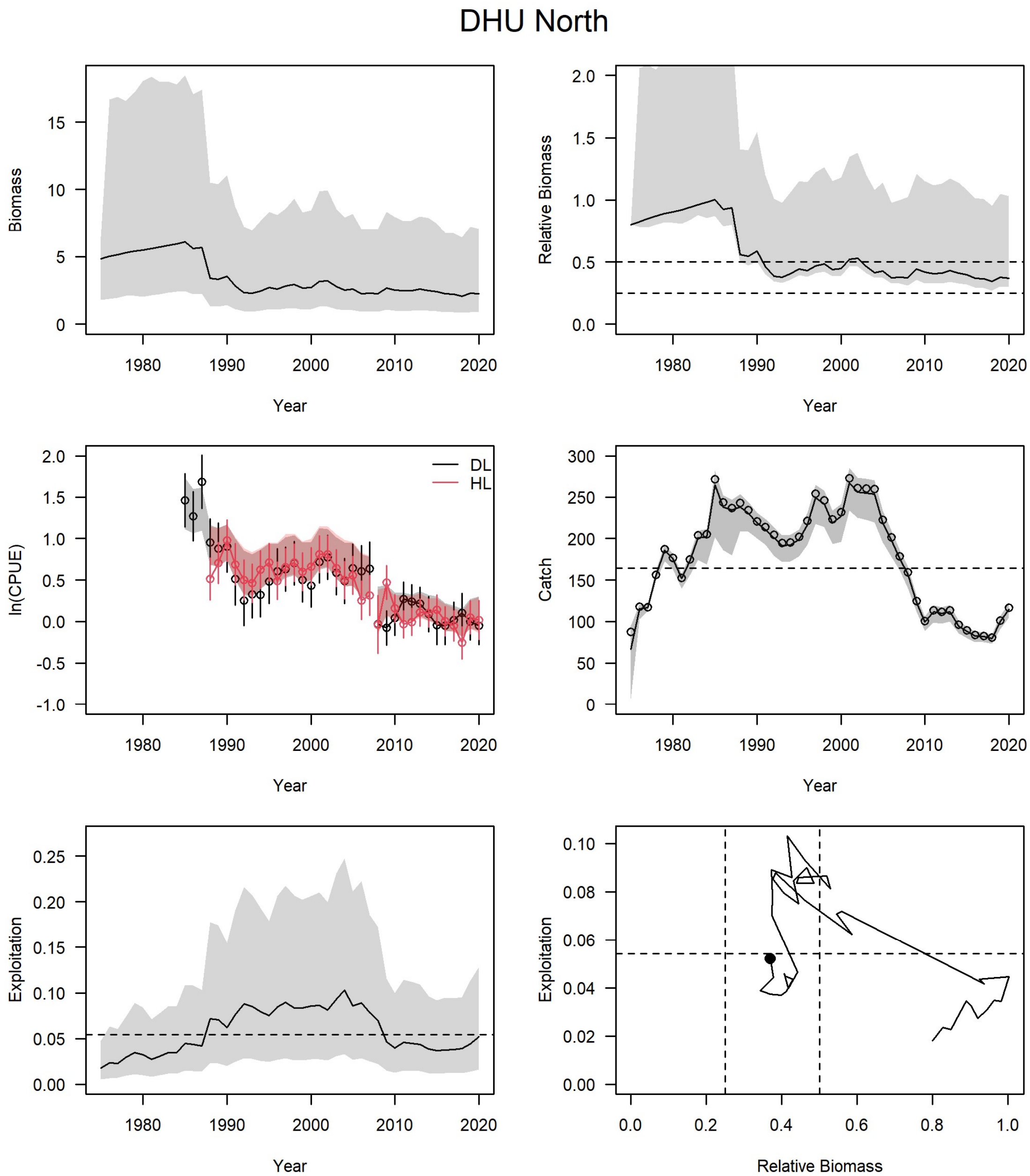


Figure 3.29. Absolute biomass (1000 tonnes) trajectory, b) estimates of relative biomass with internationally accepted threshold (0.5) and limit (0.25) reference levels, c) observed (lines) and expected (shading) annual CPUE for each method type, d) estimated annual catch with estimated MSY (dotted line), e) annual exploitation rates with FMSY, and f) trajectory of exploitation rate as a function of relative biomass, for the northern dhufish resource with an additional 3% efficiency increase of the monthly CPUE and 1% increase on daily CPUE data.

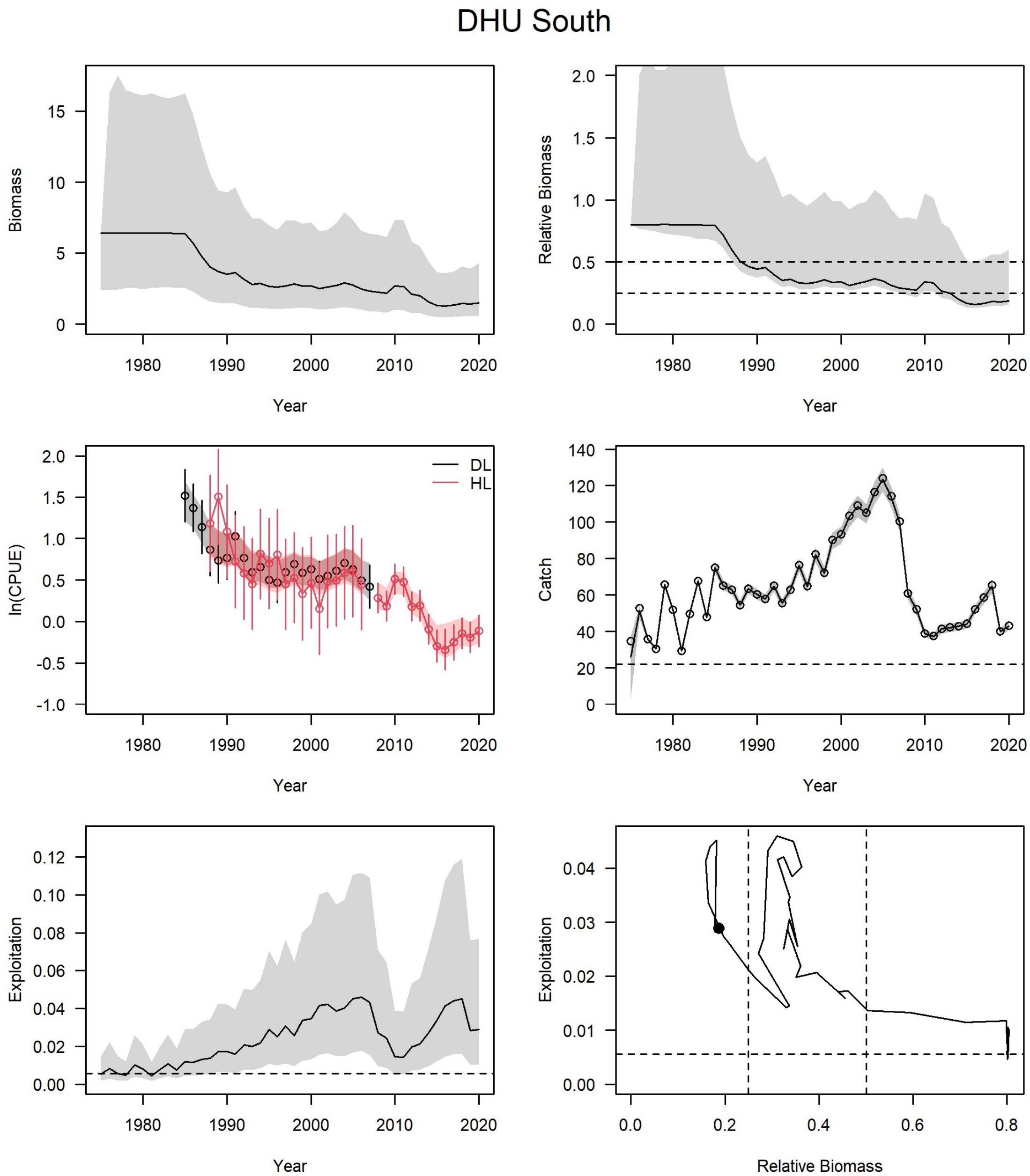


Figure 3.30. Absolute biomass (1000 tonnes) trajectory, b) estimates of relative biomass and internationally accepted threshold (0.5) and limit (0.25) reference levels, c) observed (lines) and expected (shading) annual CPUE for each method type, d) estimated annual catch with estimated MSY (dotted line), e) annual exploitation rates with FMSY, and f) trajectory of exploitation rate as a function of relative biomass, for the southern dhufish resource with an additional 3% efficiency increase of the monthly CPUE and 1% increase on daily CPUE data.

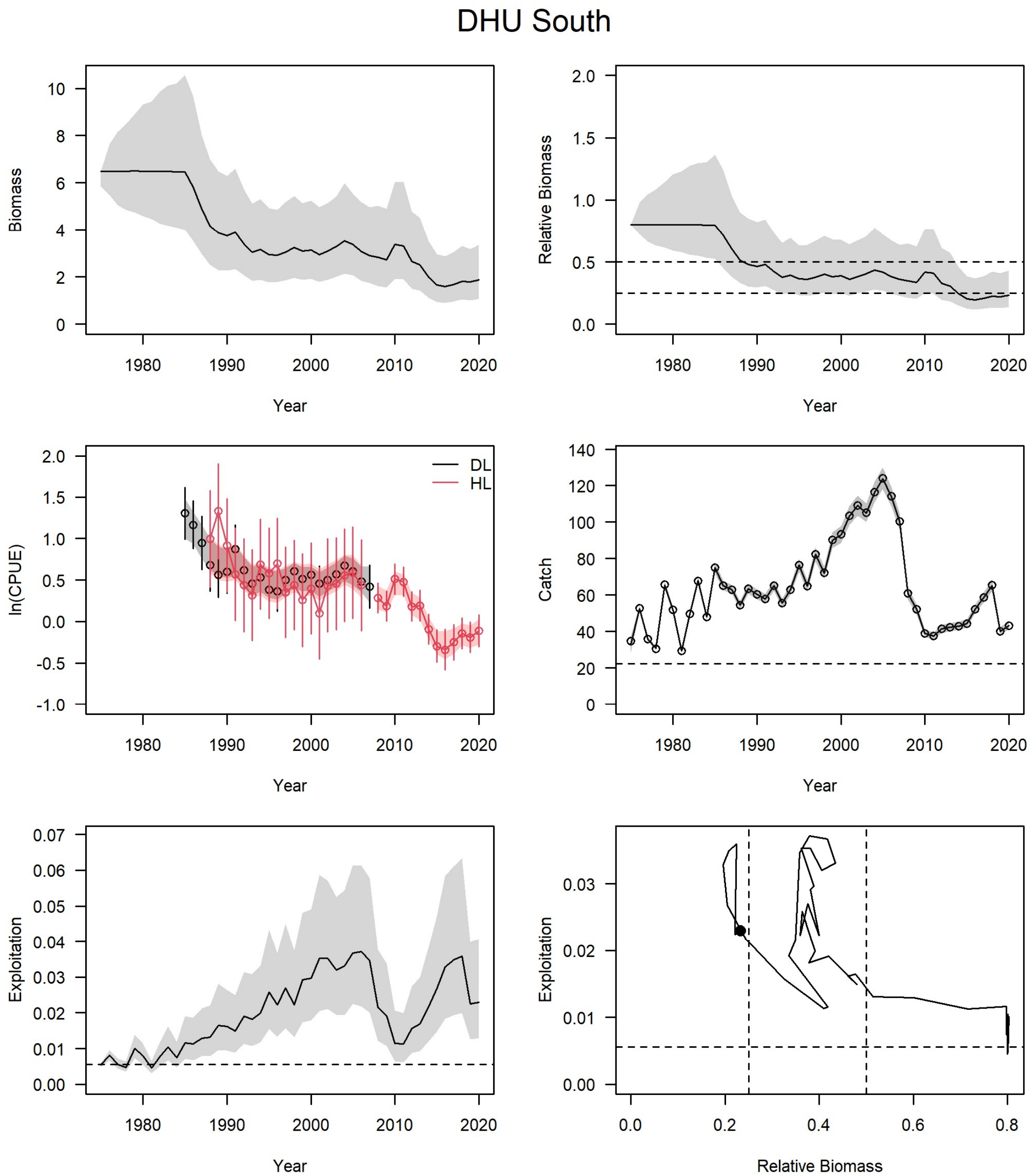


Figure 3.31. Absolute biomass (1000 tonnes) trajectory, b) estimates of relative biomass and internationally accepted threshold (0.5) and limit (0.25) reference levels, c) observed (lines) and expected (shading) annual CPUE for each method type, d) estimated annual catch with estimated MSY (dotted line), e) annual exploitation rates with FMSY, and f) trajectory of exploitation rate as a function of relative biomass, for the southern dhufish resource with an additional 2% efficiency increase of the monthly CPUE and 1% increase on daily CPUE data.

Level 5

Integrated Model

Scenarios included (1) a base case with post-release mortality (PRM) included as additional catch, with model not fitted to CPUE indices and (2) PRM on selected undersize fish at a rate of 0.5, with model not fitted to CPUE indices (3) PRM as additional catch, with model fitted to CPUE indices, and (4) PRM of undersize fish at a rate of 0.5, with model fitted to CPUE indices.

In scenarios 1 and 2, median relative biomass of females at the bioregion level was predicted to have recovered to between the threshold (B_{MSY}) and target level ($1.2B_{MSY}$) by 2020 and well above the target by 2030 (**Figs. 3.32, 3.33**). Recovery was predicted for each of the northern and southern areas, with fishing mortality expected to remain below F_{MSY} through to 2030. As a result, the lower 60% CL of B_{rel} in 2020 in Scenario 1 was expected to be above the limit in the northern areas and the threshold in the southern areas and both would be above the target by 2030 (**Figs. 3.32, 3.33**).In Scenario 2, the lower 60% CL of B_{rel} in 2020 was expected to be above the limit in the northern areas and the target in the southern areas and both would be above the target by 2030 (**Figs. 3.32, 3.33**).

Scenarios 3 and 4, which included CPUE as an index of abundance, resulted in B_{rel} (±60% CI) at the bioregion level in 2020 being around the threshold in Scenario 3 and between the limit and threshold in Scenario 4 (**Figs 3.34, 3.35**). Median B_{rel} at the bioregion level recovered to above the target by 2030 in Scenario 3 and to be between the threshold and target in Scenario 4.

In Scenario 3, fishing mortality did not decrease to below F_{MSY} until 2030 in the northern and southern areas and B_{rel} in 2020 was between the target and threshold in the southern areas and between the threshold and limit in the northern areas. B_{rel} recovered to above the target in both areas by 2030 (**Fig. 3.34**). In Scenario 4, F did not decrease below F_{MSY} in the northern areas by 2030, but reached F_{MSY} in the southern areas. Thus, B_{rel} was around the threshold in the southern areas in 2020 and median B_{rel} recovered to above the target by 2030, but B_{rel} was around the limit in the northern areas in 2020 and median B_{rel} did not exceed the threshold by 2030 (**Fig. 3.35**). Scenario 4 thus yields the most conservative estimates of stock status for the four model scenarios.

Scenarios 2 and 4 represent a more conservative, possibly more appropriate method for accounting for post-release mortality, which assumes that all post-release mortality is associated with mortality of undersize fish. This may be pessimistic, as some released fish are likely to be above the MLL. In contrast, scenarios 1 and 3 ignore mortality of undersize fish. As WA dhufish are known to start becoming vulnerable to fishing gear at a size (~ 300 mm) well below the minimum legal length, recreational release rates indicate many undersize fish are likely to be caught and released, Furthermore, release rates in commercial fisheries are not well known.

For all four model scenarios, projections beyond 2020 are dependent on assumed average recruitment levels (i.e. as predicted from the stock-recruitment relationship). For those models not fitted to CPUE indices, the last available information on recruitment is provided mainly by the age composition data collected up to 2017. Noting that WA dhufish do not become recruited into the fishery until they are on average 6-8 years old, there is limited information in the age composition data in relation to recruitment for the previous decade. Thus, for scenarios without CPUE, results for 2010-2020 largely reflect model projections based on catches and average expected recruitment. Furthermore, as model results from scenarios 1 and 2 are informed by limited data (i.e. no abundance index) this means the estimates of current stock status for these scenarios are highly uncertain.

Inclusion in the model of CPUE data provides the model with more information on changes in stock abundance, particularly for recent years. As noted above in relation to L4 production modelling, however, there is considerable uncertainty with the CPUE indices, and particularly the monthly data, in relation to fishing efficiency changes, and the level of signal in the data is not strong (i.e. the trend is a 1-way trip).

The L5 model results are subject to a number of key modelling assumptions, including stock productivity (i.e. natural mortality and stock-recruitment steepness values), various biological assumptions (e.g.

temporal growth changes), and assumptions about the fishery (changes in fishing efficiency) and fishing impacts associated with PRM. It is recommended that future research focus to reduce these uncertainties in future assessments.

Although the usefulness of the monthly CPUE data is somewhat questionable, it did not impact greatly on estimates of stock status for WA dhufish at around the time of management changes (2008-10), across the various modelling scenarios.

Across the 4 modelling scenarios, stock status of WA dhufish for the northern and southern areas around the period when management was changed (2008-2010) was similar. Given that lack of data increases modelling uncertainty, results from the model scenarios 3 and 4 making use of available fine scale, daily (standardised) CPUE data appear most reliable in terms of gauging recent trends in stock status. All modelling scenarios indicate a level of stock recovery through to 2030 if catches do not increase, but with consistently better stock status in the southern than northern areas.

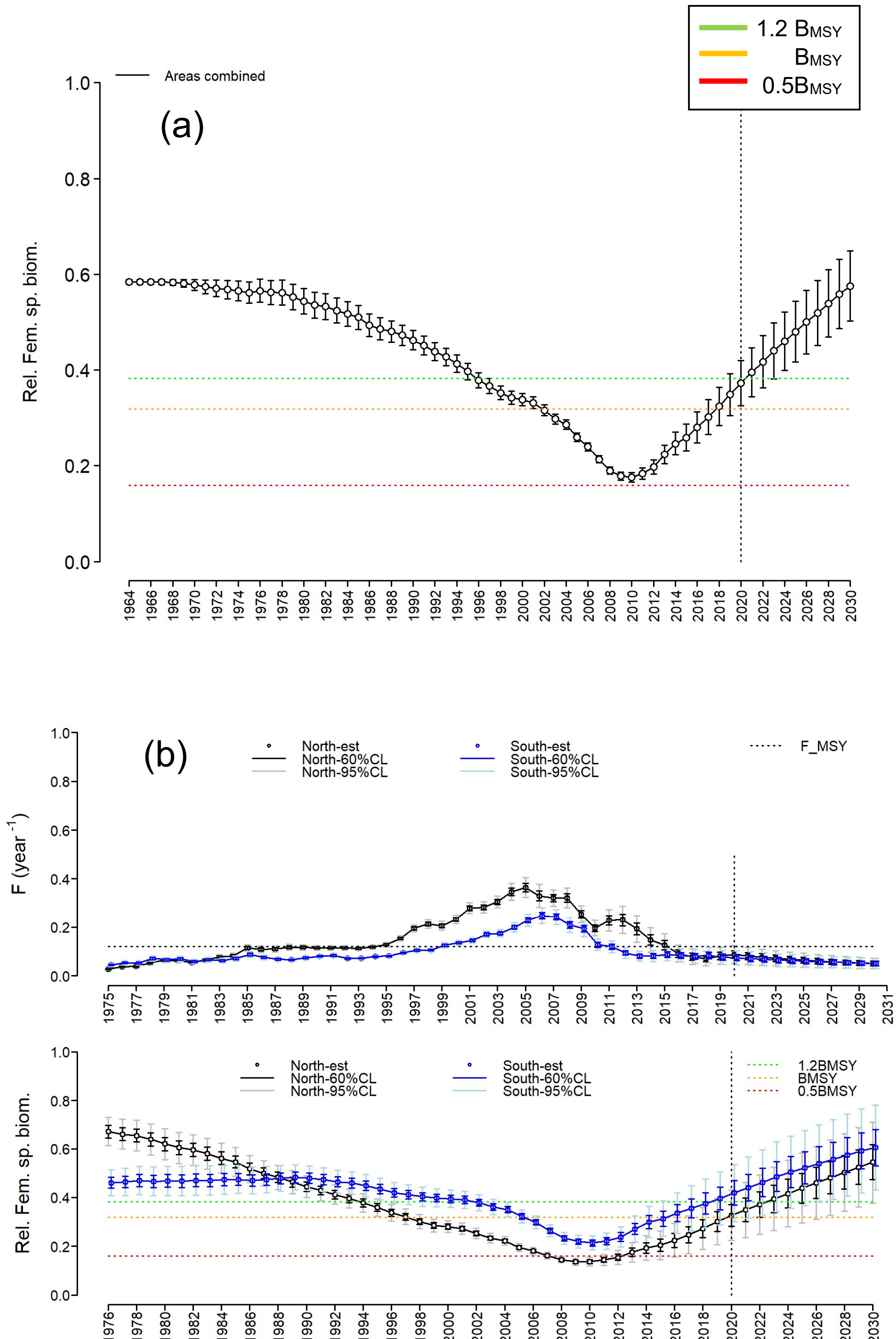


Figure 3.32. **Scenario 1.** Model estimates for (a) relative female spawning biomass B_{rel} (±60% CI) of WA dhufish at the bioregion level (north and south regions combined) and (b) fishing mortality (F, y^{-1}) and relative female biomass B_{rel}, in the north and south areas. Vertical dotted line indicates the year 2020. **Model contains post-release mortality (PRM) as additional catch, but does not include an index of abundance (CPUE). Relative biomass is compared with internationally accepted target, threshold and limit reference points.**

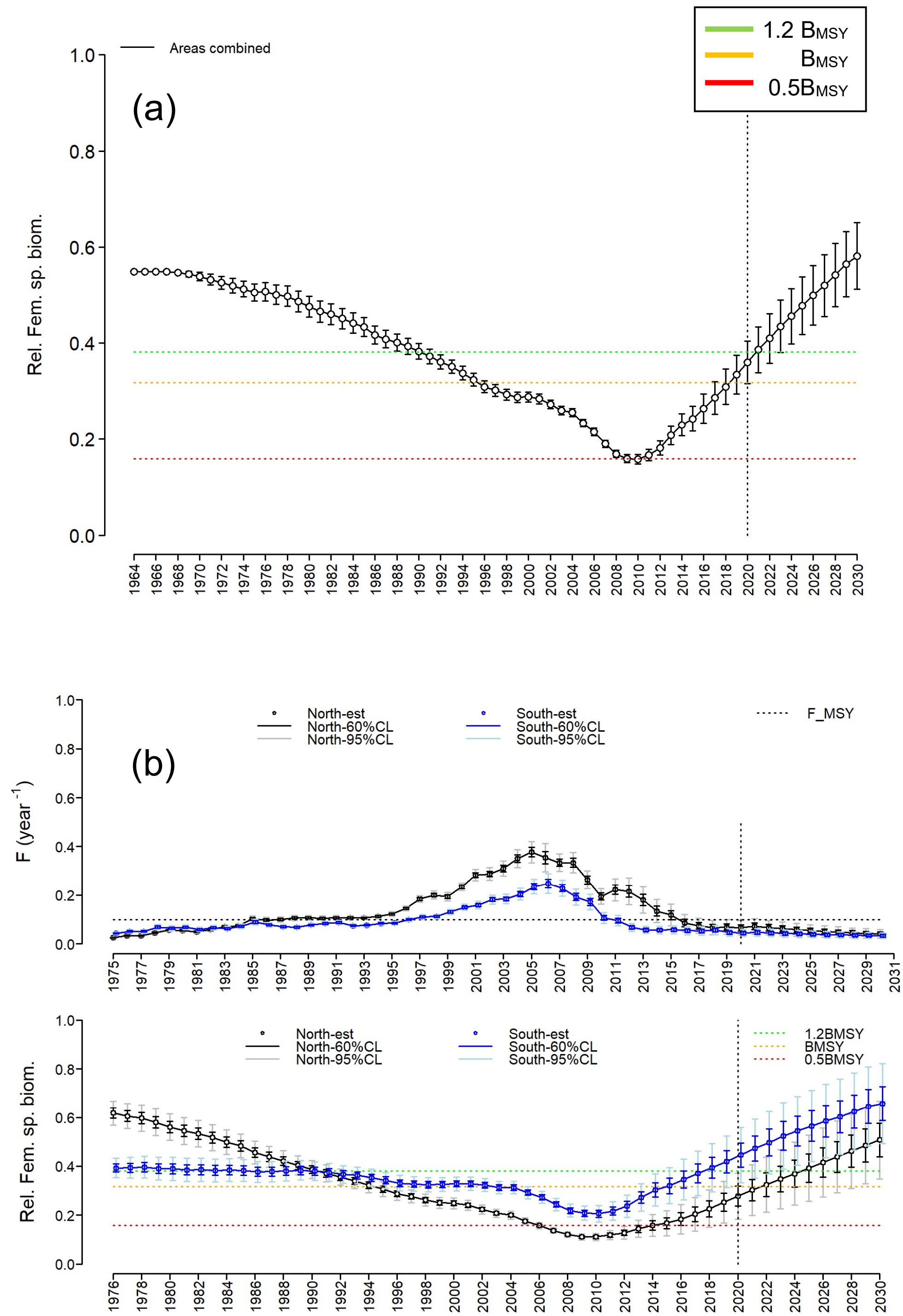


Figure 3.33. **Scenario 2.** Model estimates for (a) relative female spawning biomass B_{rel} (±60% CI) of WA dhufish at the bioregion level (north and south regions combined) and (b) fishing mortality (F, y^{-1}) and relative female biomass B_{rel}, in the north and south areas. Vertical dotted line indicates the year 2020. **Model includes post-release mortality (PRM) of undersize fish = 0.5, but does not include an index of abundance (CPUE). Relative biomass is compared with internationally accepted target, threshold and limit reference points.**

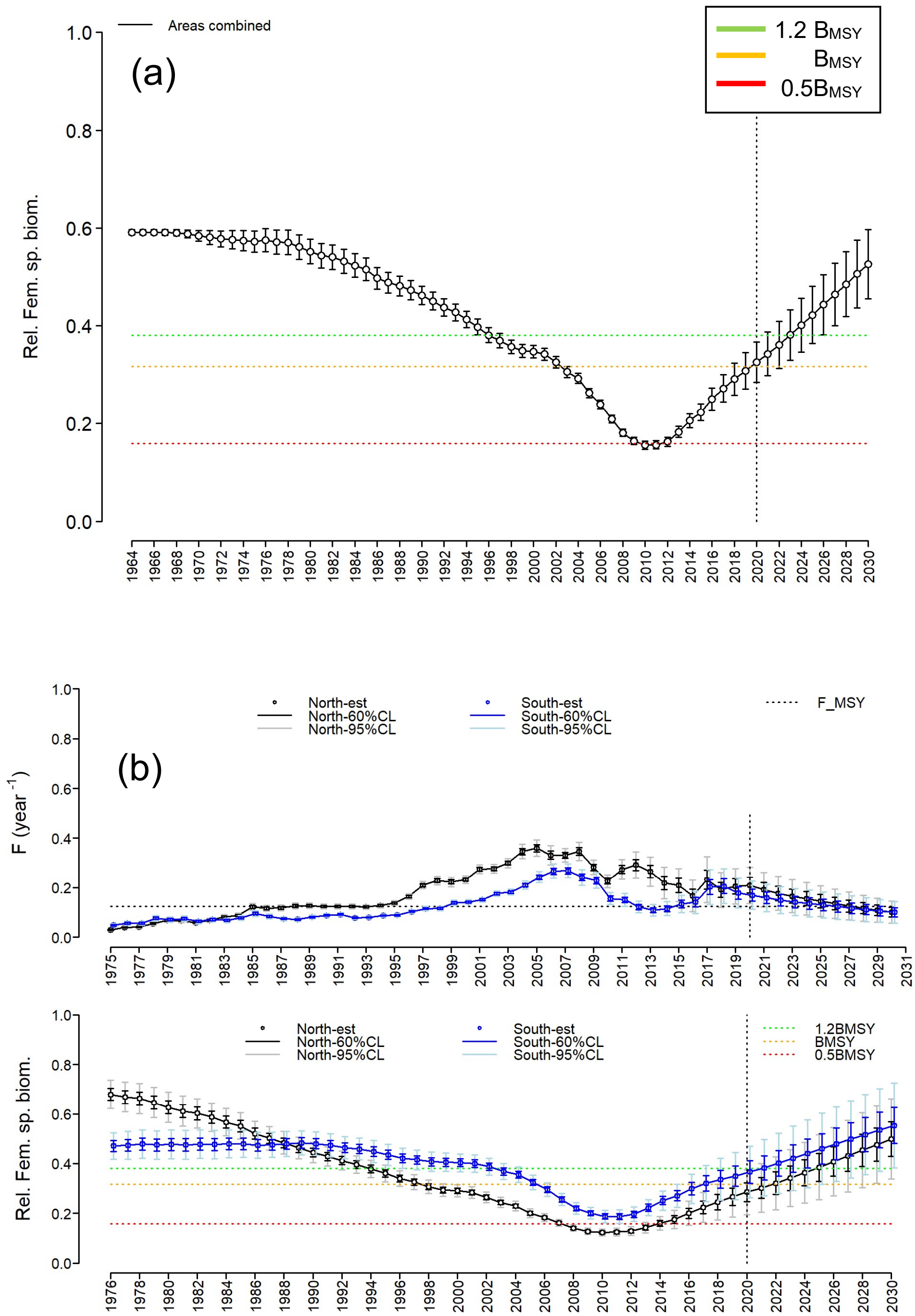


Figure 3.34. **Scenario 3.** Model estimates for (a) relative female spawning biomass B_{rel} (±60% CI) of WA dhufish at the bioregion level (north and south regions combined) and (b) fishing mortality (F, y^{-1}) and relative female biomass B_{rel}, in the north and south areas. Vertical dotted line indicates the year 2020. **Model includes post-release mortality (PRM) as additional catch and CPUE as an index of abundance. Relative biomass is compared with internationally accepted target, threshold and limit reference points.**

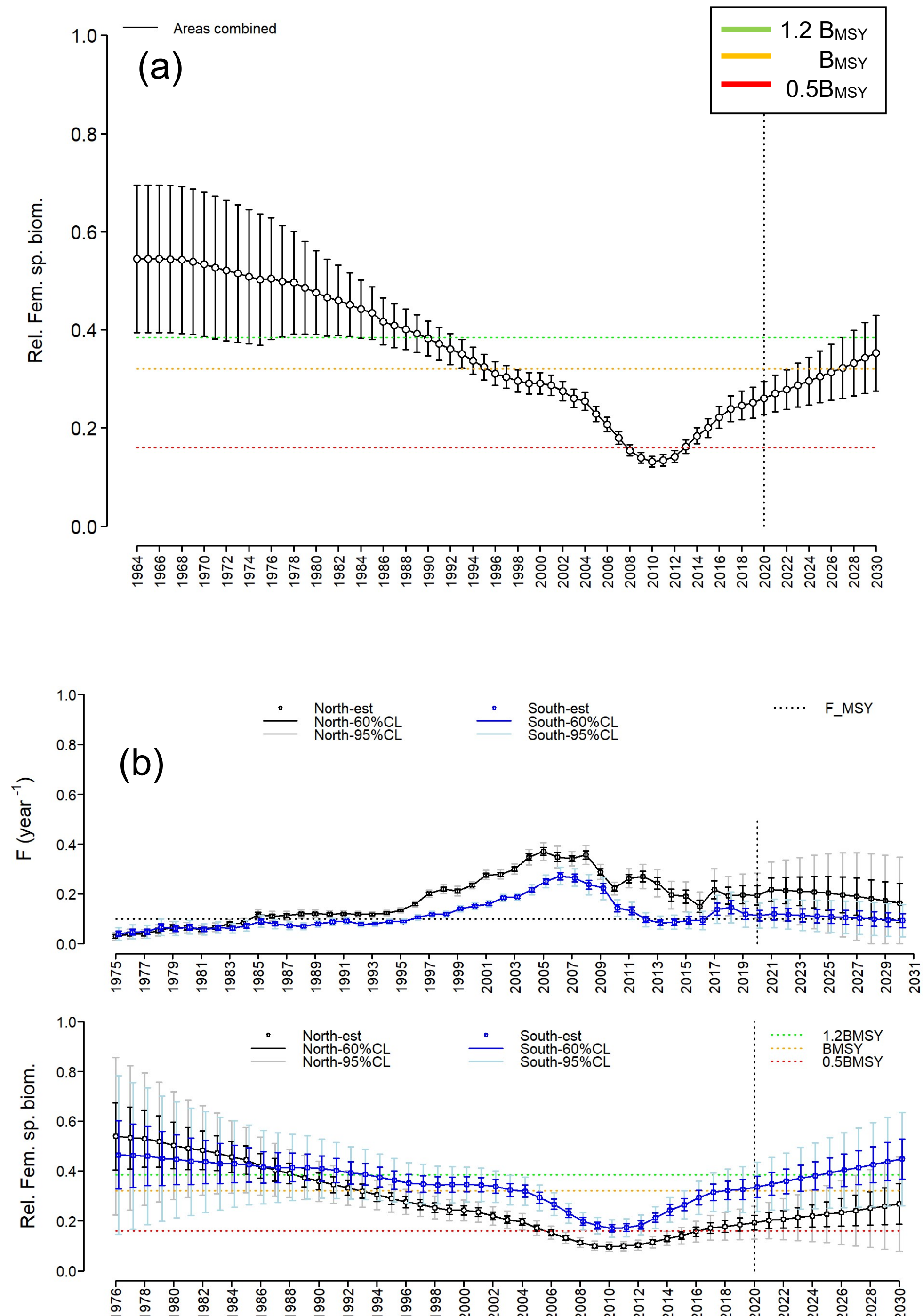


Figure 3.35. **Scenario 4.** Model estimates for (a) relative female spawning biomass B_{rel} (±60% CI) of WA dhufish at the bioregion level (north and south regions combined) and (b) fishing mortality (F, y^{-1}) and relative female biomass B_{rel}, in the north and south areas. Vertical dotted line indicates the year 2020. **Model includes post-release mortality (PRM) of undersize fish = 0.5 and CPUE as an index of abundance. Relative biomass is compared with internationally accepted target, threshold and limit reference points.**

Final Risk

- The L1, L4 and L5 assessments used available catch and CPUE data to 2020, while the L3 risk assessment used biological data to 2017.
- Risk assessment for L4 biomass dynamics models was conducted on the scenario that assumed the greatest increase in fishing efficiency and thus produced the most pessimistic result.
- The most informative scenarios among L5 models would be ones that include some level of post-release mortality and/or CPUE as an index of abundance (scenarios 3 and 4). Thus, risk assessments were only conducted for those.

Considering the different lines of evidence, the expected risk of future depletion at the stock (bioregion) level is estimated to be HIGH (C3×L4) and was consistent among the different levels of assessment.

In the northern areas, the risk is estimated to be HIGH/SEVERE across the different levels of assessment and in the southern areas MEDIUM to SEVERE among different levels.

	Bioregion/management areas		
Assessment level	**Bioregion**	**North**	**South**
L1 CMSY (2025)	N/A	Severe (C4×L3, 12)	Severe (C4×L3, 12)
L3 SPR (2022)	High (C3×L4, 12)	Severe (C4×L4, 16)	High (C3×L4, 12)
L4 Biom dynamics (2025)	N/A	High (C3×L4, 12)	N/A
L5 integrated Scenario 3 (CPUE, PRM = added catch; 2025)	High (C3×L3, 9)	High (C3×L4, 12)	Medium (C2×L3, 6)
L5 integrated Scenario 4 (CPUE, PRM = 0.5; 2025)	High (C3×L4, 12)	High (C3×L4, 12)	High (C3×L3, 9)

3.3 Objective 3. Weight of evidence assessment of Snapper

The L1 Catch-MSY analyses indicated that for snapper in the northern and southern areas, current *F* (i.e. in 2020) has declined to around F_{MSY}. Point estimates for current B_{rel} (the depletion level) were above the limit ($0.5B_{MSY}$) but still well below the threshold (B_{MSY}), for both regions and thus, the risk of recruitment impairment is reduced. The L1 analyses indicate B_{rel} has been increasing since about 2015 in the north and 2010 in the south, suggesting that the population is starting to recover. Catch-MSY assessments are designed for data-poor fisheries and estimates of stock status are imprecise, thus more weight should be given to L3-L5 assessments in interpreting stock status.

The L3 catch curve point estimate for long-term *F* at the stock (bioregion) level from 2015-17 age data (0.2 y^{-1}) is lower than prior to management changes, but still above the limit reference point of 1.5*M* (i.e. 0.18 y^{-1}). This has not changed since the previous assessment of 2012-14 biological data, indicating that overfishing may still be occurring and there is still a risk of recruitment impairment. Similarly, long-term *F* in both the northern and southern areas changed little between 2012-14 and 2015-17 (using age data from either commercial and/or recreational fishers), remaining above the limit and between threshold and limit, respectively. Estimates of long-term *F* have been consistently lower for the southern areas than northern areas, driven primarily by lower *F* in the South-west Area than the Metropolitan Area.

The point estimate of 0.22 for SPR (from L3 analysis incorporating a stock-recruitment relationship) in 2015-17 in the northern areas was between the limit and threshold, increasing slightly from 2012-14 and being higher than prior to management changes. In the southern areas, SPR (0.16) was below the limit, having declined from around the limit in 2012-14, influenced mostly by a decline in the South-west Area and no change in the Metropolitan Area.

The L3 analyses indicate that catch levels have limited the rate of stock recovery in each region since management changes in 2007-10, as would otherwise be evident through substantial improvements to population age structures (i.e. greater relative abundances of older fish). Note that as maximum age for this species may be lower in the northern areas than southern areas (and thus M would be higher), *F* and SPR results may be pessimistic.

Results of L4 biomass dynamics modelling are influenced by the assumed level of fishing efficiency increase over time applied to CPUE indices. Assuming a 2%/1% (pre 2008/post 2008) efficiency increase, estimated *F* for Snapper in the north in 2020 was above F_{MSY} and B_{rel} was around the limit ($0.5B_{MSY}$), but had increased slightly from 2018. As recent catches were below MSY, this indicates the northern stock is beginning to recover from its depleted status and not currently at risk of recruitment impairment. Note, the 2%/1% efficiency values relate to increases additional to those associated with introduction of GPS, colour sounders and hydraulic reels. Biomass dynamics models could not be fitted to data for southern areas, as there was no recent index of abundance from commercial fishing. Snapper biomass levels (and associated catch rates) are strongly influenced by strong annual recruitment variation, and thus the recent increase may be also associated with recent, strong recruitment.

Results from L5 integrated model scenarios, which included CPUE indices applying the same efficiency assumptions as in the L4 analyses and (i) PRM as additional catch in

Scenario 3 or (ii) with PRM on undersize gear-selected fish in Scenario 4, indicated that in 2020, median F in the northern areas was above F_{MSY} in the two scenarios and in the southern areas it was most just below F_{MSY} in both scenarios. Although F was predicted to continue declining gradually with future catches set at the original recovery benchmarks, median F in the northern areas only reaches F_{MSY} by 2030, which would limit the rate of recovery of B_{rel}. In the southern areas, median F remains below F_{MSY} through to 2030, allowing greater recovery. In both scenarios, median B_{rel} in 2020 was around the limit at the stock (bioregion) level and in both the northern and southern areas.

Based on all available lines of evidence, and using internationally accepted reference points, the current risk to sustainability of Snapper at the bioregion level is estimated to be SEVERE (C4×L4). In the L5 assessment, there was a ≥50% probability of estimated relative biomass (B_{rel}) at the bioregion level being below the limit (B_{Lim}) in 2020 in Scenarios 3 and 4. The current risk to sustainability of Snapper in the northern and southern areas in each of those scenarios in the L5 analysis was SEVERE.

Projected levels of median relative biomass (based on future retained catches being equivalent to original catch recovery benchmarks, plus estimated release mortality and average recruitment) suggest that in Scenarios 3 and 4, the median biomass (B_{rel}) in both the northern and southern areas would not exceed the threshold by 2030.

The current risk to sustainability of Snapper at the bioregion level is SEVERE.

Category	Line of evidence
Biology and vulnerability	Snapper is a long-lived gonochorist (separate sexes), with a maximum recorded age of 41 years and an average age at maturity around 4-6 years. This species occurs across the southern half of Australia and the majority of catches are taken in the Gascoyne and West Coast bioregions, where there is high overlap of targeted fishing effort with the stock range (in this assessment the 'stock' refers to the WCB). The minimum legal lengths (MLL) of 410 mm in the northern areas (Kalbarri/Mid-west) of the WCB and 500 mm in the southern areas (Metropolitan/South-west) are below estimated lengths at which 50% of females mature (CL: 469-506 mm and 567-602 mm, respectively) [Lenanton et al. 2009a]. Released individuals can experience post-release mortality (estimated 25% based on published literature; Lenanton et al. 2009b; Memo 31.10.2017; 6016/16). Snapper spawn widely along the coast from Bremer Bay to the Gascoyne. They also migrate to and aggregate to spawn in embayments on the lower west coast within the Metropolitan Area (protected by seasonal spawning closures), around islands on the Gascoyne coast (some locations currently protected from fishing) and locations on the south coast (two known aggregation locations are not protected).
Productivity Susceptibility Analysis (PSA) Based on a productivity score of 2.00 and susceptibility score of 2.33 for the combined fishing sectors that catch this species, the overall PSA score of 3.07 suggests a medium risk of overexploiting the stock (Appendix).	

Level 1	
Catch	**Commercial catch** Retained catches of Snapper in the WCB by all commercial fisheries and by the WCDSIMF have been below respective stock recovery benchmarks of 126 t and 120 t, since reductions in entitlements in the Kalbarri and Mid-west areas in 2015 (**Fig. 3.36**). • All commercial fisheries landed 79 t of WA Snapper in 2019/20 and, of that, the WCDSIMF landed 72 t in 2020 (**Fig. 3.36**). • Total estimated biomass removed from the population (retained catches plus estimated release mortality) by the commercial sector between 2010 and 2014 exceeded the Recovery benchmark (138 t) in the WCDSR Harvest Strategy (**Fig 3.37**). Reduction to entitlements in 2015 in the northern areas reduced effort and since then estimated biomass removed has remained below the lower tolerance level of 104 t. Entitlements are not being fully utilised as fishers have reported low abundances and uneconomical fishing. Note: this assumes release rates of 25% of fish by the WCDSIMF and 10% by the TDGDL, respective mortality rates of 25% and 100%, and an average length of fish released of 400 mm (DPIRD, 2021). • Following entitlement reductions in the Kalbarri and Mid-west areas of the WCDSIMF in 2015, retained catches have remained below original recovery benchmarks of 65 t and 43 t, with 32 t and 38 t landed in the respective areas in 2020 (**Fig. 3.38**). Catches of Snapper in the South-west Area have remained low since 2008 (< 5 t). • The number of 10nm blocks with low annual catches (< 1000 kg) by the WCDSIMF has increased steadily since 2012, while the proportion with large

catches (≥5000 kg) has decreased (**Fig. 3.39**).

- The number of blocks in which catches were recorded decreased along the coast of the Mid-west Area in 2019. This may be related to decreases in effort in those blocks (see **Fig. 3.3**).

Recreational catch

Estimated retained catches of Snapper in the WCB by the recreational sector (private boat-based and charter fishers) have increased since 2013/14 and were above the original recovery benchmark of 37 t during the period of each integrated survey since 2011/12 (**Fig. 3.36**). In 2017/18, an estimated 70 t was landed (95%CLs 66-77 t) by the recreational sector.

- Total estimated biomass removed in the WCB by the recreational sector (retained catches plus estimated release mortality) has increased since 2013/14 and been above the recovery benchmark (35 t) in the WCDSR Harvest Strategy (**Fig. 3.37**).

Note: Release mortality (by weight) is derived from the estimated numbers of fish released by boat-based fishers and reported numbers released by charter fishers, each multiplied by an assumed post-release mortality rate of 25% and an average weight of Snapper released, converted from an assumed length of released fish of 400 mm (using a known length-weight equation for Snapper in WA) (DPIRD, 2021).

- Retained catch of Snapper in the WCB by private boat-based recreational fishers in 2017/18 was 48 t (95% CL: 40-55 t) and by charter fishers was 22 t (**Fig. 3.36, 3.40**). Landings by charter fishers decreased to 14 t in 2019/20, which may have been influenced by COVID restrictions.
- Point estimates of retained catch of Snapper for the recreational sector (private and charter) have increased in each area of the WCB since 2013/14 (**Fig. 3.40**). In 2017/18, recreational retained catch was 24 t (95% CL: 20-28 t) in the Kalbarri/Mid-west areas, 33 t (28-37 t) in the Metropolitan Area and 14 t (10-18 t) in the South-west Area (**Fig. 3.40**).
- The percentage of Snapper retained by private boat-based recreational fishers in the WCB in 2017/18 was 29% of the 61,446 (SE=4,922) caught (Ryan *et al.* 2019) and by charter fishers in 2018/19 was 45% of the ~12,699 caught (**Fig. 3.41, 3.42**).
- Retention rates of Snapper by private boat-based fishers vary among years and areas (**Fig. 3.41**). Private boat-based fishers typically retain a greater percentage of the catch in the Kalbarri/Mid-west Area than either the Metropolitan or South-west areas. For example, in 2017/18, 40% of 12,095 Snapper were retained in the Mid-west area, 25% of 31,597 in the Metropolitan Area and 28% of 17,753 in the South-west Area (**Fig. 3.41**).
- Retention rates by charter fishers in the Kalbarri/Mid-west and Metropolitan areas increased from 41% and 28% in 2009/10 to 56% and 55% in 2017/18. They have since declined to 52 and 34% in 2019/20. Charter fishers retained 52% of 5,464 snapper caught in 2019/20 in the Kalbarri/Mid-west areas and 34% of 6,570 snapper caught in the Metropolitan Area. Only 134 Snapper were caught in the South-west Area (**Fig. 3.42**).
- The vast majority (76-91%) of catches of Snapper by charter vessels in each block in each year were less than 150 kg (**Fig. 3.43a, b**). Reported catches in each year were from focal areas, e.g. Kalbarri, the Abrolhos Islands, Jurien, and waters around Rottnest and Garden Island in the Metropolitan Area.

	Lower total retained catches of Snapper by the commercial sector since 2015 are influenced by reductions in entitlements to fish in the Kalbarri and Mid-west areas and anecdotal reports of low abundances in those areas. Recreational sector retained catches have exceeded the original West Coast Bioregion catch recovery benchmarks for this sector in the WCB in each surveyed year since 2011/12, demonstrating that current controls on recreational fishing are insufficient to constrain removals of Snapper to the intended levels. In addition, high release rates and any associated post-release mortality (and any unknown release mortality by the commercial sector) could be resulting in further reduction in abundance and the expected rate of stock recovery could be impacted.

Level 1 Assessment

Annual catches in the northern areas of the WCB have exceeded the estimated MSY (in Catch MSY analyses) of 198 t (95% CI=152-240 t) for extended periods over the history of the fishery. They were also above the lower 95% CL of MSY between 2010 and 2014, prior to reductions in commercial entitlements to maintain commercial snapper catches below catch recovery benchmarks in the northern areas. In the southern areas, catches exceeded the MSY of 66 t (95% CI=50-81 t) between the late 1990s and late 2000s and have been below the lower 95% CL in most years since management changes (**Figs 3.44, 3.45**; **Tables 3.7, 3.8**).

Although uncertain, annual estimates of stock biomass fell below the estimated level of B_{MSY} around the mid-1990s in the north (B_{MSY} = 1901 t, 95%CI: 1143-2544 t) and early 2000s in the south (B_{MSY} = 574 t, 95%CI: 315-840t), with the median estimated biomass in the northern and southern areas depleting to the limit around the mid-2010s and just before 2010, respectively (**Figs 3.44, 3.45**).

The Catch-MSY results indicate that since management action was taken in 2008 to reduce catches of Snapper to below the estimated MSY (catch recovery benchmark for both sectors of 163 t vs MSY of 264 t at the bioregion level), biomass in the northern and southern areas has been rebuilding. It must be recognised that Catch-MSY analysis is a data poor stock assessment method and, as such, there is large uncertainty associated with the results and they should be treated with a level of caution.

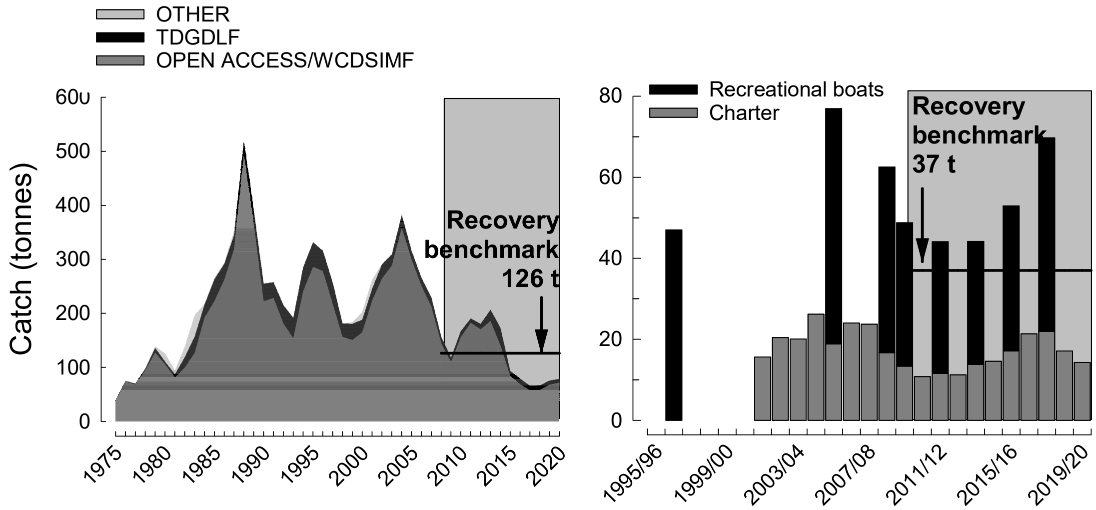


Figure 3.36. Total commercial and recreational retained catches of Snapper vs 50% of 2005/06 catch benchmarks for stock recovery. Private boat-based recreational catches are estimates of the retained catch and do not show uncertainty (95% CIs), with 2011/12-2017/18 estimates derived from integrated phone diary surveys (Ryan et al., 2019) and prior estimates derived from boat ramp creel surveys (Lai et al., 2019). TDGDLF = Temperate Demersal Gill-net and Longline fisheries; Open access and WCDSIMF [West Coast Demersal (Interim) Managed Fishery] are hand-line/drop-line fisheries.

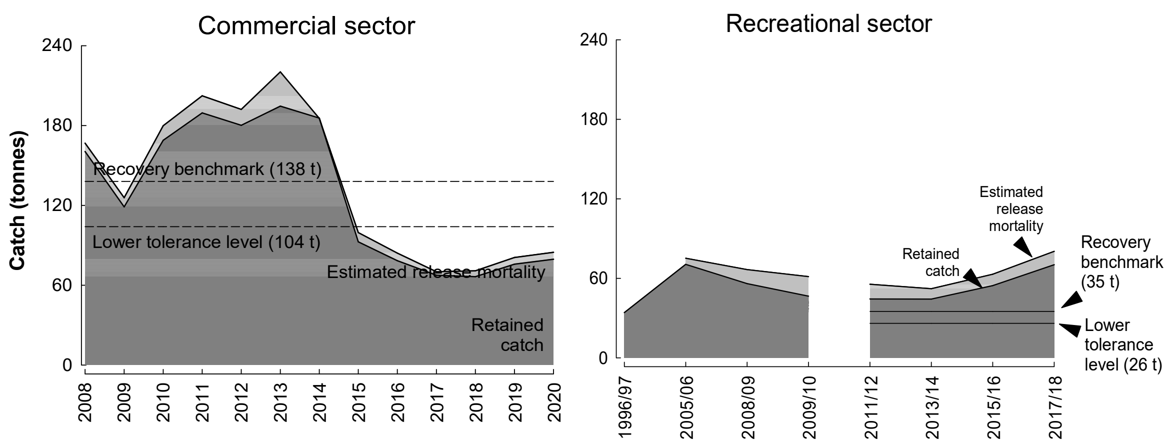


Figure 3.37. Total reported retained catch (dark grey) and estimated release mortality (i.e. total estimated biomass removed from the population (light grey) of Snapper by the commercial sector (includes WCDSIMF, TDGDLF, WCRLF, CSLPF, SWTMF) and the recreational sector (private recreational boats and charter vessels) in the West Coast Bioregion vs the recovery benchmark and lower catch tolerance levels proposed by the Draft Harvest Strategy for the WCDSR. Note: recreational retained catch estimates from 1996/97 to 2009/10 were adjusted upwards by 30% to account for the presumed underestimation due to the time of day of the survey and catches at the Abrolhos Islands (FMP249).

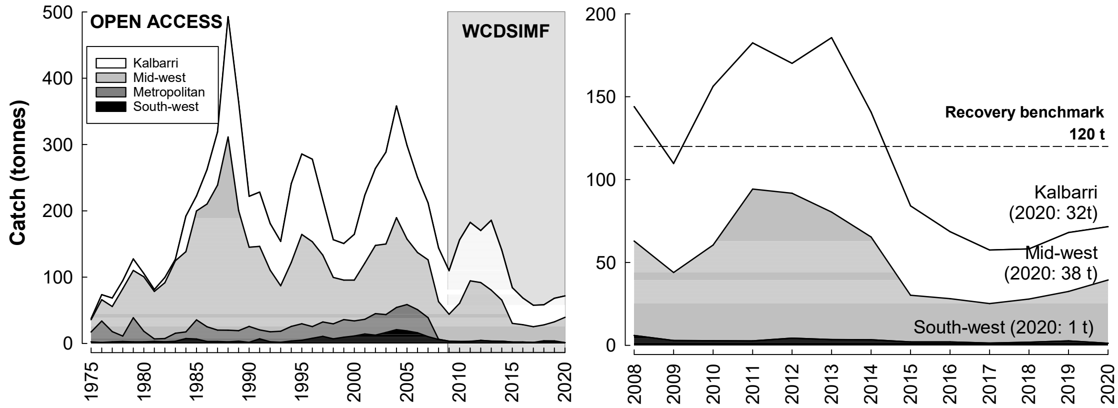


Figure 3.38. Retained commercial catches of Snapper reported by open access fishers (1975-2007) and the West Coast Demersal Scalefish (Interim) Managed Fishery (2008-2020) in the Kalbarri, Mid-west, Metropolitan and South-west Areas (left panel) and by the WCDSIMF in total and each area vs respective catch recovery benchmarks.

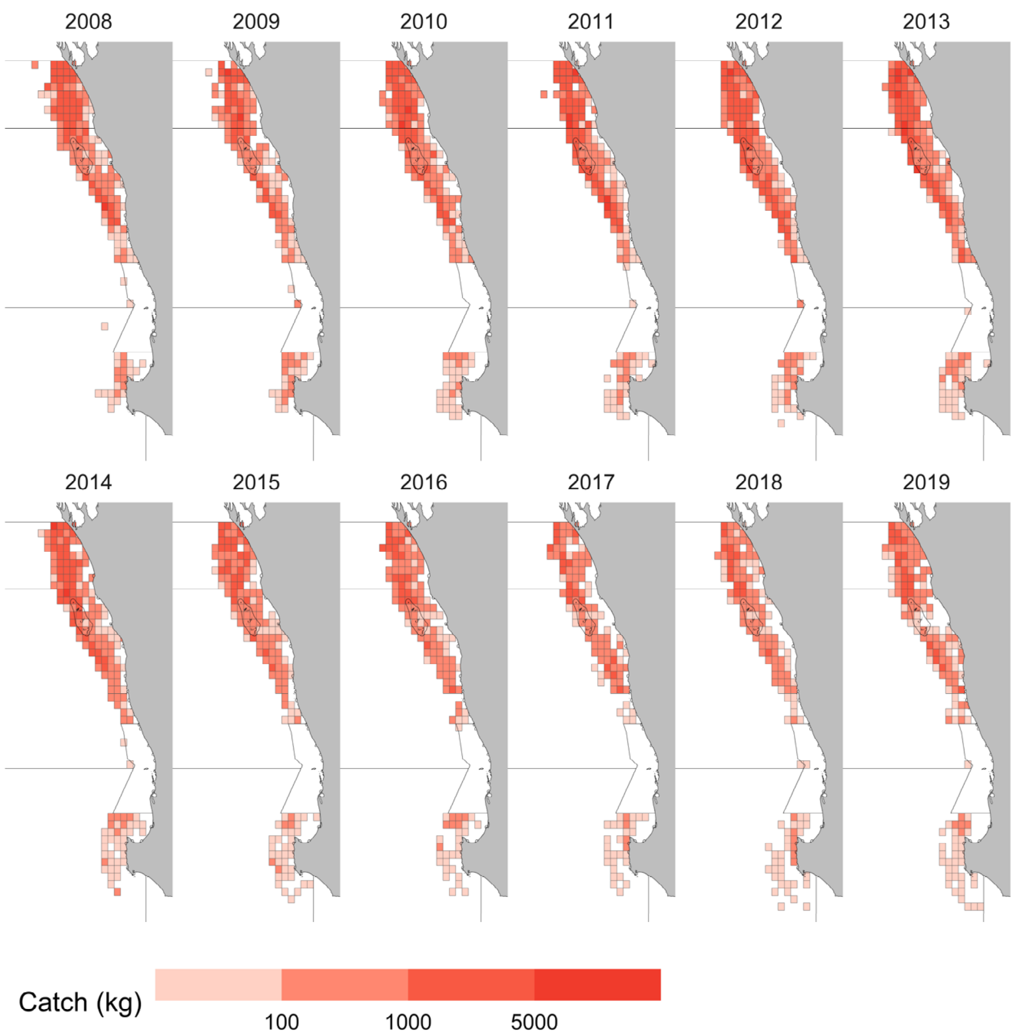


Figure 3.39. Retained catches of Snapper by the WCDSIMF in each 10nm block in each year since 2008.

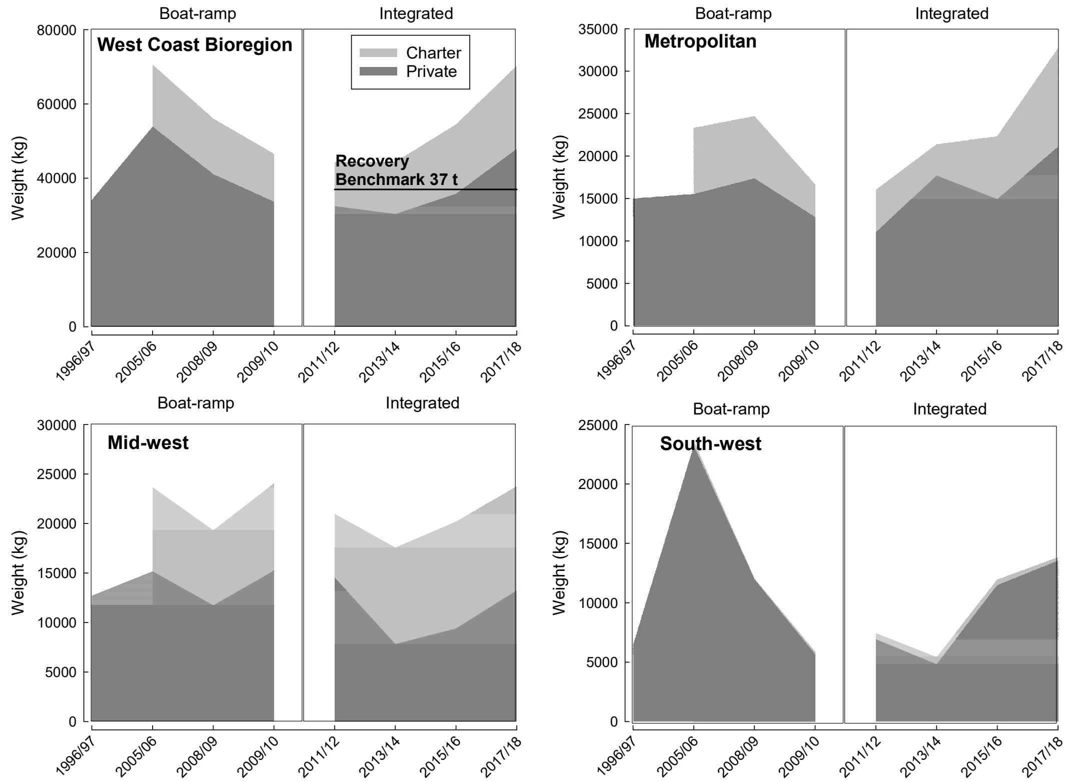


Figure 3.40. Estimated retained catches (kg) of Snapper by private boat-based recreational fishers (dark grey) and charter fishers (light grey) during each survey year.

Note:– recreational surveys were conducted with boat-ramp surveys prior to 2011/12 and integrated surveys from 2011/12 onwards and may not be directly comparable. Catches by private recreational fishers estimated from boat ramp surveys (1996/97-2009/10) were not adjusted to account for the presumed underestimation due to the time of day of the survey and catches at the Abrolhos Islands (FMP249). Charter logbooks became compulsory in 2001/02, hence there are no data for 1996/97.

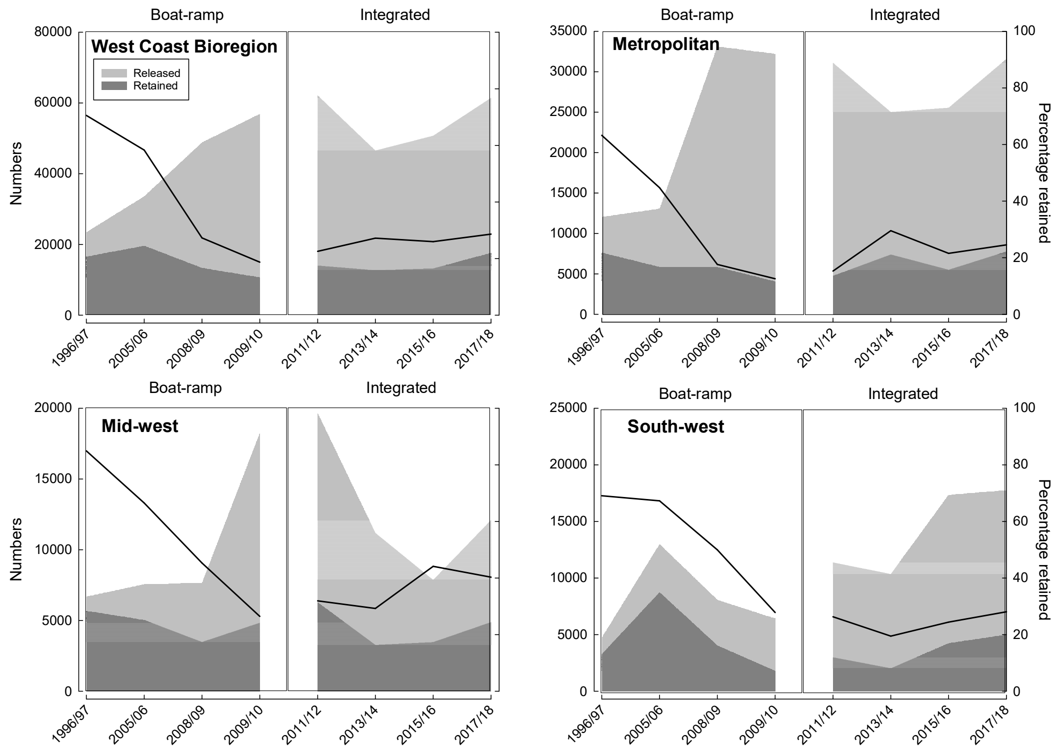


Figure 3.41. Estimated numbers of Snapper retained (dark grey) and released (light grey) by private boat-based recreational fishers in each survey since 1996/97 and the percentage of the catch retained (black line) in each year.

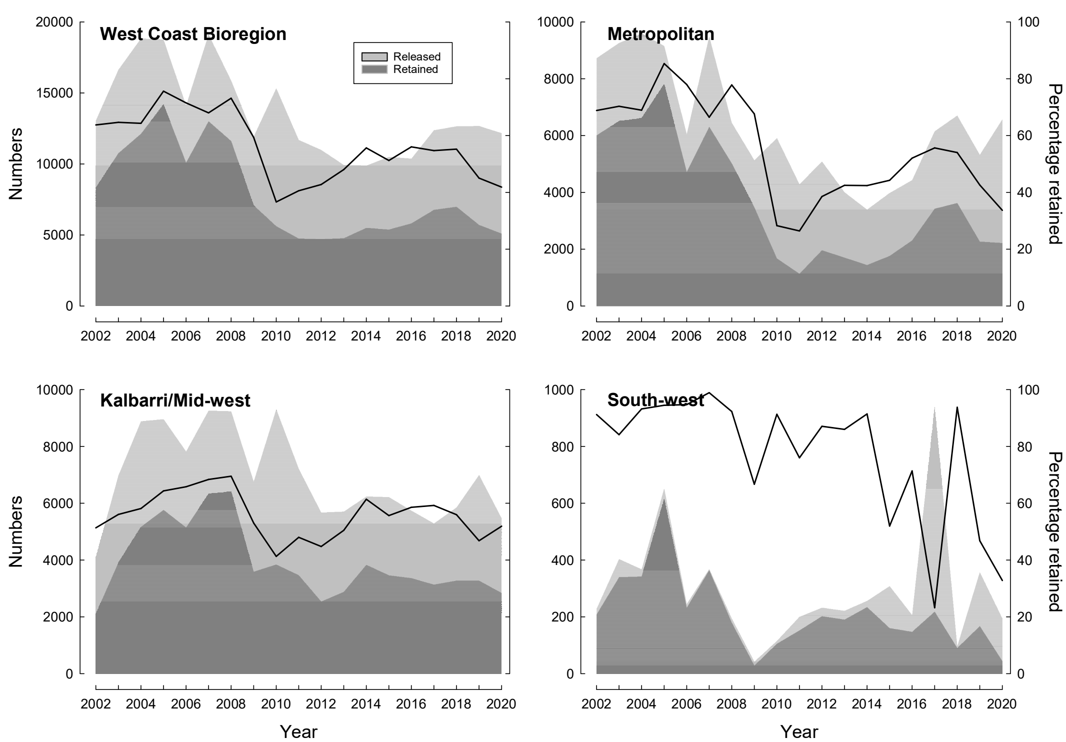


Figure 3.42. Estimated numbers of Snapper retained (dark grey) and released (light grey) by charter fishers since 2001/02 (shown as 2002) and the percentage of the catch retained (black line) in each year.

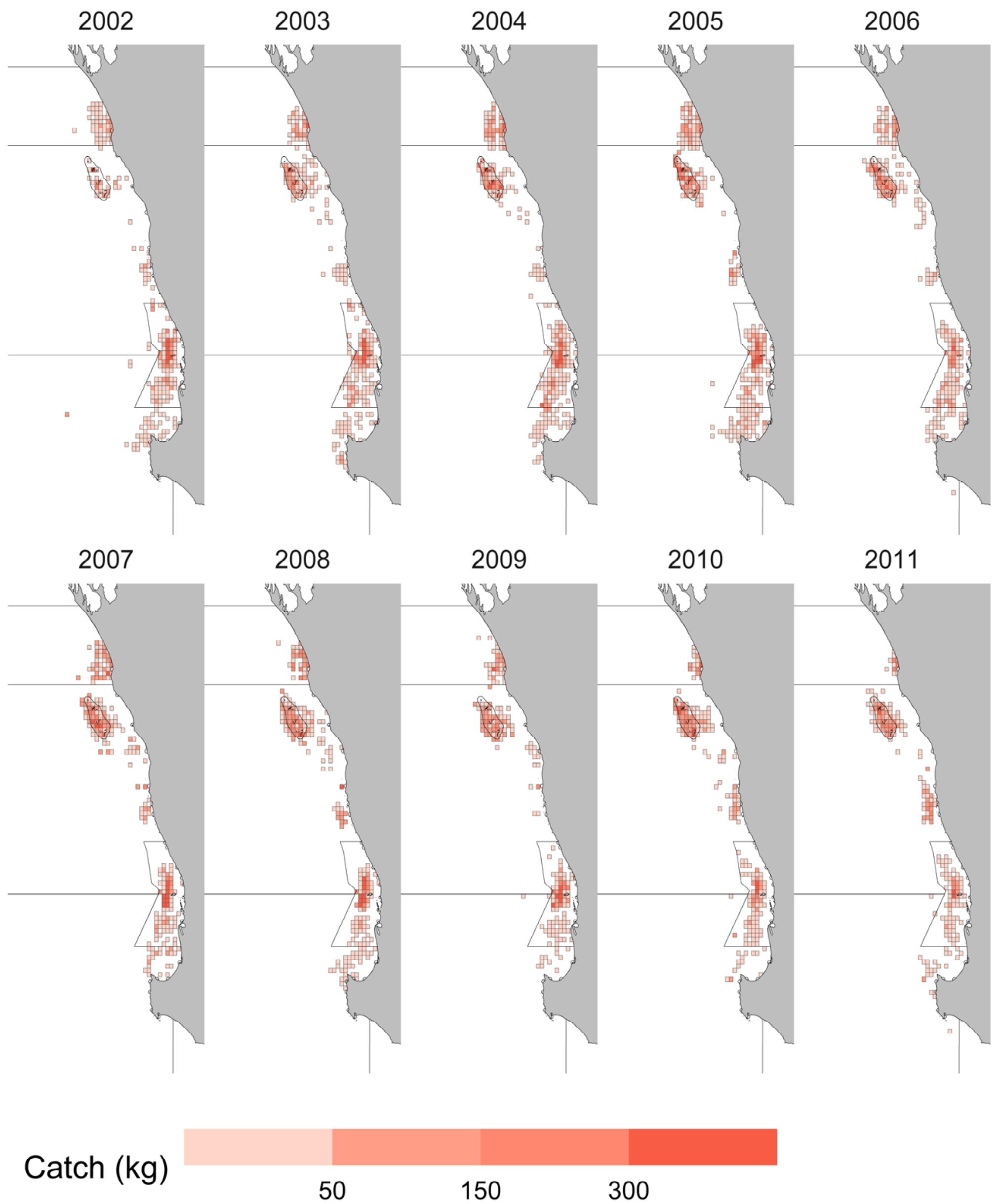


Figure 3.43a. Retained catches of Snapper by charter vessels in each 10nm block of the West Coast Bioregion between 2001/02 and 2010/11 (label 2002 = 2001/02).

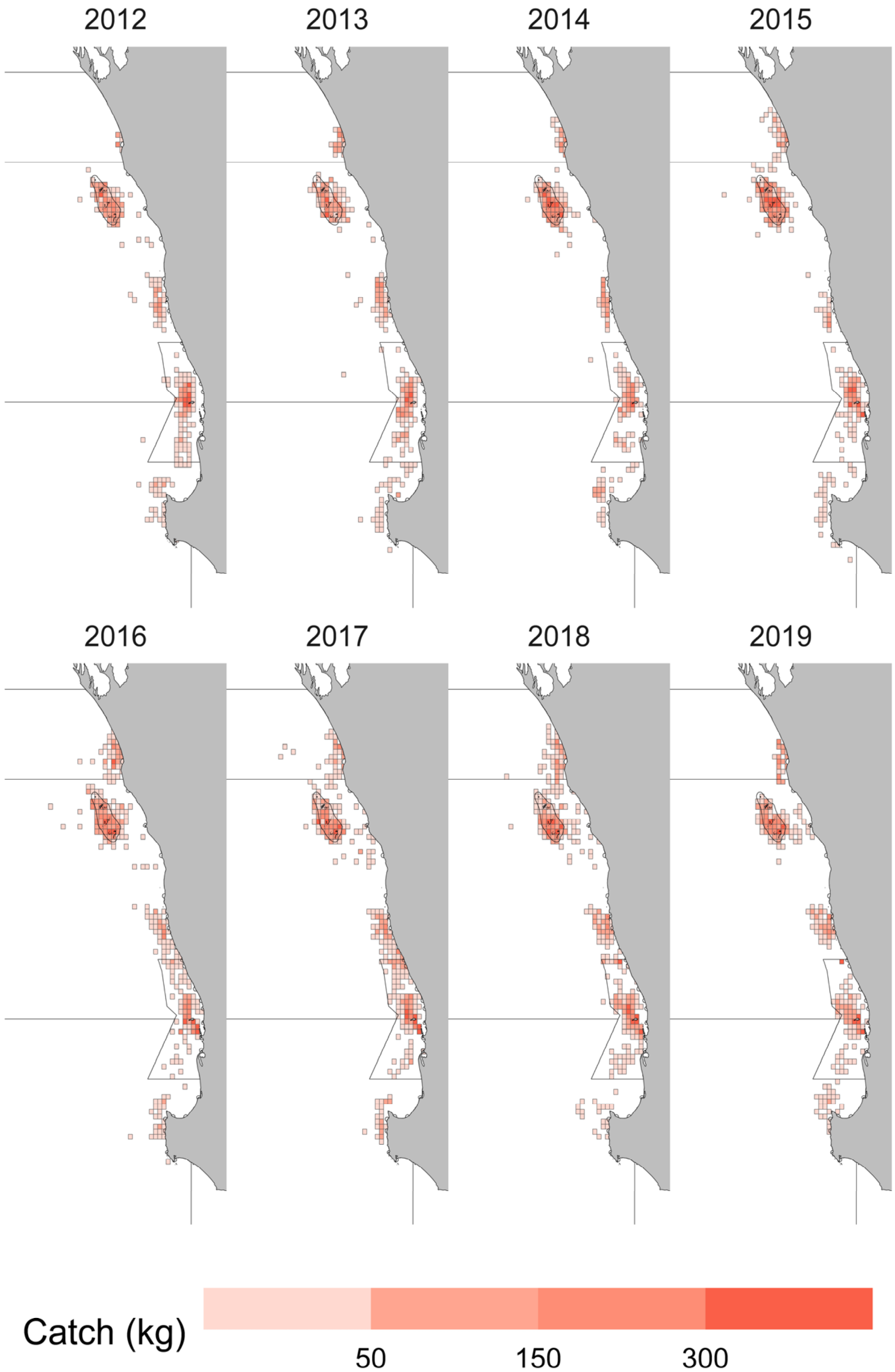


Figure 3.43b. Retained catches of Snapper by charter vessels in each 10nm block of the West Coast Bioregion between 2011/12 and 2018/19 (label 2012 = 2011/12).

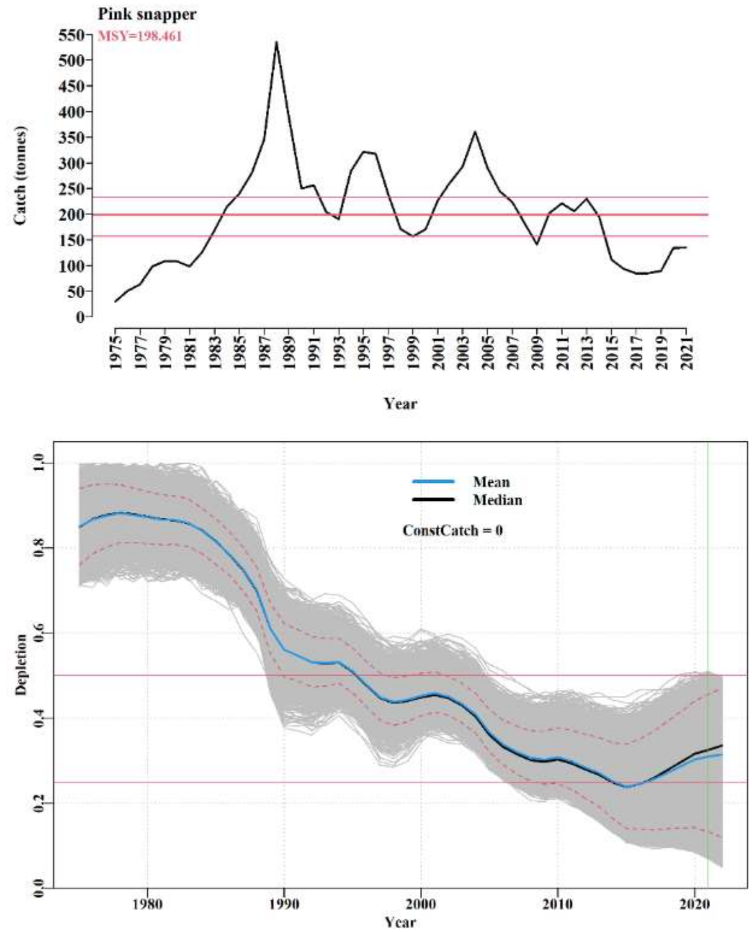


Figure 3.44. Northern areas: Total estimated/reported retained and projected catches (top) of Snapper by all sectors vs estimated MSY (± 95%CLs) and estimated depletion level (bottom).

Table 3.7. Northern areas: Outputs of catch MSY analyses for Snapper. MSY, maximum sustainable yield; r, intrinsic increase, K, carrying capacity, Brel (relative biomass, or 'current stock depletion' level); B_{MSY} (biomass at MSY), F_{MSY} (fishing mortality at MSY).

Stock	Resilience	Parameter	Mean	Lower	Upper
Snapper (northern areas)	low	MSY	198.46	152.22	239.59
		r	0.21	0.12	0.42
		K	3,801.97	2,286.31	5,088.05
		Brel	0.31	0.07	0.49

Resilience	Parameter	Mean	Lower	Upper
low	Biomass	1295	291	2311
	Harvest rate	0.1	0.06	0.47
	F	0.11	0.06	0.63
	B_{MSY}	1901	1143	2544
	F_{MSY}	0.1	0.06	0.21

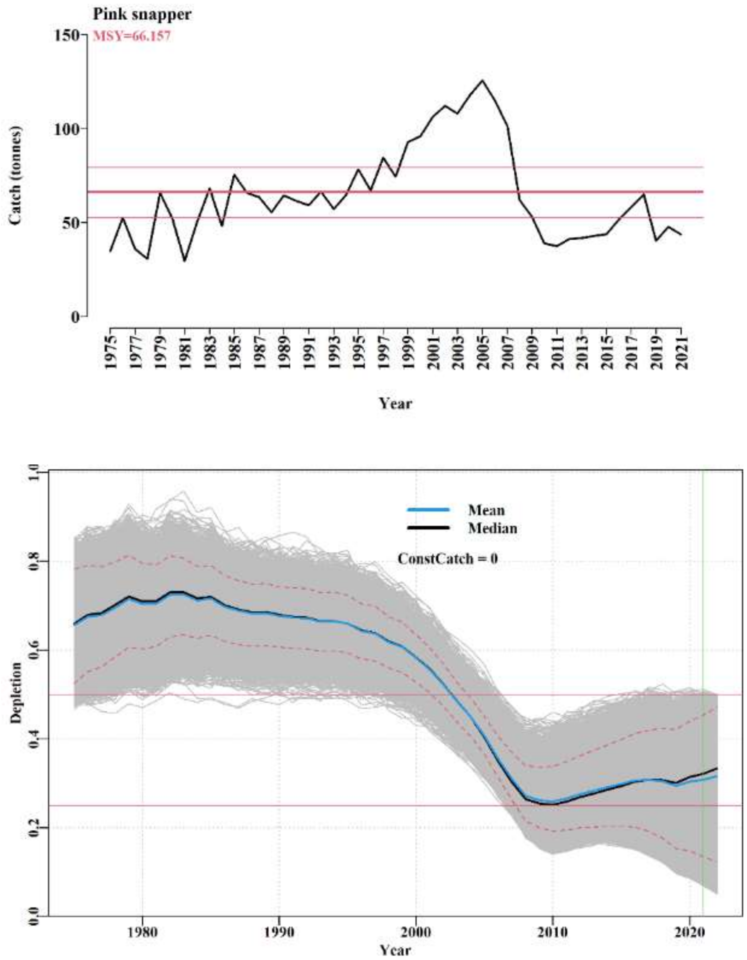


Figure 3.45. Southern areas: Total estimated/reported retained and projected catches (top) of Snapper by all sectors vs estimated MSY (± 95%CLs) and estimated depletion level (bottom).

Table 3.8. Southern areas: Outputs of catch MSY analyses for Snapper. MSY, maximum sustainable yield; r, intrinsic increase, K, carrying capacity, Brel (relative biomass, or 'current stock depletion' level); B_{MSY} (biomass at MSY), F_{MSY} (fishing mortality at MSY).

Stock	Resilience	Parameter	Mean	Lower	Upper
Snapper (Southern areas)	low	MSY	66.16	50.45	81.26
		r	0.23	0.13	0.51
		K	1,148.78	630.62	1,679.53
		Brel	0.32	0.07	0.49

Resilience	Parameter	Mean	Lower	Upper
low	Biomass	405	88	763
	Harvest rate	0.11	0.06	0.5
	F	0.11	0.06	0.68
	B_{MSY}	574	315	840
	F_{MSY}	0.12	0.06	0.26

Level 2	
Effort	It is not currently possible to distinguish effort associated specifically with Snapper and other species for commercial and charter fishers, as commercial fishers report target species inconsistently and charter fishers do not report target species. Targeting information is reported by recreational boat-based fishers during phone diary surveys, but has not yet been used to inform effort trends. Therefore, only total effort is reported (**Figures 3.2, 3.3** and **Tables 3.1, 3.2**).
Catch rate	**Commercial** Catch rate estimates for snapper calculated using non-differentiated effort may not reflect abundance, because changing species composition and targeting will bias trends in 'inferred' relative biomass of snapper. This limitation was considered in estimating standardised CPUE (L4 assessment), by using a vessel/catch qualification procedure. In addition, entitlements to fish (hours) were introduced in 2009 and may influence catch rates in early years of the WCDSIMF as fishers adjusted their businesses. Raw mean catch rates (means of ratios of raw catch and raw effort; CPUE) of Snapper by WCDSIMF fishers derived from hand-line methods in the Kalbarri and Mid-west areas increased from 2008 and remained at elevated levels until 2014 before declining to low levels by 2016. While CPUE has remained low in the Kalbarri Area, they gradually increased again in the Mid-west Area (**Fig. 3.46**). Relative abundance in the Kalbarri area may be influenced by poor recruitment from the Gascoyne Bioregion in recent years, while recent increasing relative abundance in the Mid-west area may be partly influenced by recruitment from further south (e.g. the Metropolitan Area), where stock status is better and a strong cohort has been abundant in catches. CPUE derived from drop-line methods, in the Mid-west Area gradually increased over time, but was more variable than for hand-line methods. This lack of contrast may be due to only a small number of vessels catching snapper using this method consistently. High CPUE derived from hand-line methods in the Kalbarri and Mid-west areas between 2009 and 2014 are consistent with the occurrence of a strong cohort in the population from 2007 and with historical peaks and troughs in commercial catch that may also be driven by recruitment variation in Snapper. CPUE was not estimated for the South-west area, due to the normally low catches in that area (**Fig. 3.46**). **Charter** CPUE in the Kalbarri/Mid-west area were lower in most years following management changes than in several years prior to changes (2004-2008) and there was little change in CPUE among years after management changes (**Fig. 3.47**). In the Metropolitan Area, CPUE decreased from elevated levels after 2008, then increased after 2008 to 2014 to maxima in 2017 and 2018 and then declined (**Fig. 3.47**). CPUE in the South-west Area has varied substantially among years, but may not be meaningful as an index of abundance, as effort and catches of Snapper are low (64-83 trips in the last 5 years and ≤ 1 t caught per year) (**Fig. 3.47**).
Level 2 Assessment **Consistent with anecdotal reports, commercial hand-line CPUE in the Kalbarri and Mid-west areas has been low in recent years. This follows the likely decline in relative abundance of a**	

strong cohort from 2007 and any contributions that may be derived from the Gascoyne Bioregion where stocks are currently depleted. However, a gradual increase in Mid-west hand-line CPUE since 2016 may represent recovery of stocks in that area. Charter CPUE do not provide evidence of increases in abundance in the Kalbarri/Mid-west areas, but do indicate periodic increases and decreases in abundance in the Metropolitan Area, most likely related to periodic strong cohorts in the stock.

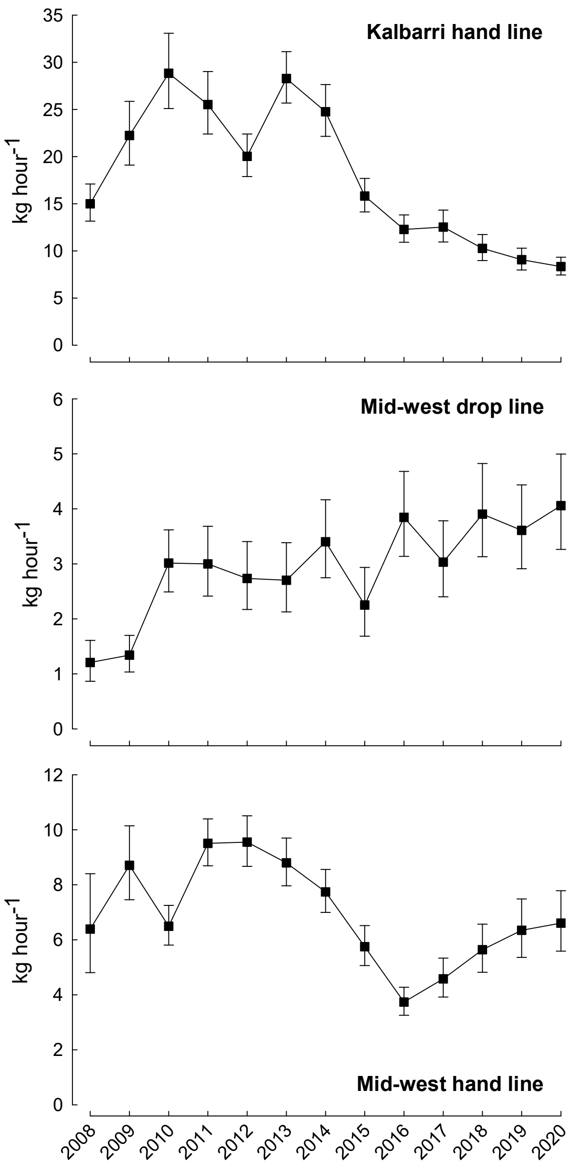


Figure 3.46. Mean raw catch per unit effort (kg h^{-1}) of Snapper by the WCDSIMF in the Kalbarri and Mid-west areas by boats using hand-line and drop-line methods since 2008.

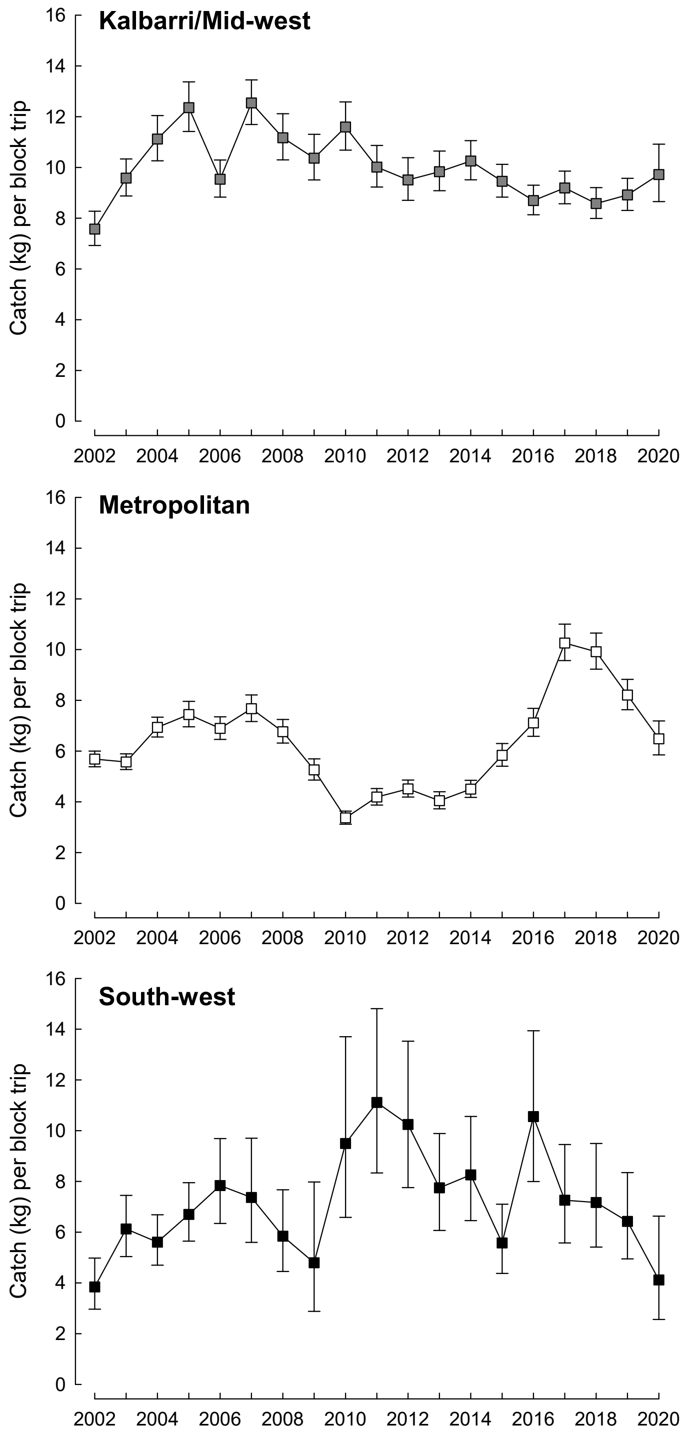


Figure 3.47. Back-transformed marginal means of the raw catches of Snapper per block -trip (± 95% confidence intervals) by charter fishers in each management area of the West Coast Bioregion. Year represents financial year, e.g. 2002 = 2001/02.

Level 3	
Length composition	The percentage of large Snapper (≥ 700 mm TL) in commercial and recreational samples in northern areas has increased from 1-3% and 7-9%, respectively, prior to 2012-14 to 7-12 and 11-13% after 2012-14 (**Fig. 3.48**). This may be influenced by the occurrence of an abundant cohort from 2007 in the stock. This has now declined in relative abundance resulting in a decrease in abundance of large fish in commercial samples from 12% in 2015-17 to 8% in 2018-20 (**Fig. 3.48**). In southern areas, the percentage of large Snapper in recreational catch samples increased from 11% in 2003-05 to 51% in 2009-11 and has remained high (41-54%) since then. While this would be influenced by the occurrence of the 2007 strong cohort in stocks, it would also be influenced by the change in the minimum legal length for retention in the southern areas from 410 to 500 mm by the end of 2009 (**Fig. 3.48**). Similar patterns are present in the percentage frequency of large fish (≥ 700 mm TL) in catches of charter fishers in the northern and southern areas. This reflects the increase and decrease in abundance of the strong 2007 cohort in stocks and the change in minimum legal length to 500 mm in the southern areas (**Fig. 3.49**). **The change in the relative proportions of Snapper in each length class over time are influenced partly by inter-annual recruitment variation, which is more apparent in the southern areas, and an increase in the MLL in southern areas. The typically smaller percentage of large fish (≥ 700 mm) in the northern vs southern areas could reflect i) greater depletion in the north region, (ii) differences in recruitment variation and (iii) the naturally smaller lengths at age of Snapper in northern areas than southern areas due to differences in growth.**
Age composition	Snapper age distributions derived from commercial and recreational catch samples from the northern areas have been dominated by fish < 10 years of age since sampling commenced in 2002, with <10% of fish being greater than 10 years of age in most years (**Fig. 3.50**). In addition, age classes ≥ 10 years old have only been represented intermittently, i.e. older fish are in low abundance. In southern areas, age classes ≥10 years old generally represent a greater component of age classes in each year than in northern areas, but also exhibit cyclicity (**Fig. 3.50**). Thus, the percentage of fish ≥10 years old in age compositions increased from 7% in 2006 to 30% in 2010, then decreased to 8% by 2015, before increasing rapidly to 35% in 2017 (**Fig. 3.50**). These increases and decreases are influenced by the increase and decrease in abundance of strong cohorts in the stock. For example, the latter rapid increase in fish ≥10 years old in 2017 was driven by the 2007 strong cohort reaching 10 years of age. However, the abundance of older fish was relatively much lower than several prior years (e.g. 2011). **Age distributions for the northern areas provide evidence of at least some fish surviving up to 20 years old in recent years that would not be expected if the stock was currently heavily depleted, but the lack of substantial numbers of old fish indicate the stock has not yet recovered in these areas. In southern areas, the age composition plots demonstrate that fishing mortality in recent years has been sufficiently low to allow strong cohorts to persist in the population, required for stock recovery.**

Level 3 Assessment

The long-term average estimates of fishing mortality (*F*±60% CLs) of Snapper produced by a multi-year catch curve method that accounts for inter-annual variability in recruitment of fully selected individuals at the stock (bioregion) level were lower after management changes than prior (**Fig. 3.51**). However, *F* remains above the limit reference level of 0.18 $year^{-1}$, i.e., 1.5 times the assumed natural mortality (*M*) of 0.12 $year^{-1}$ (**Fig. 3.51; Table 3.9**). The bioregional *F* estimates for 2012-14 and 2015-17 remained at 0.20 (95% CI = 0.18-0.21) $year^{-1}$. This pattern was essentially consistent in both the northern and southern areas, but with *F* estimates being above the limit in the northern area and between the limit and threshold in the southern areas. However, only *F* in the Mid-west Area decreased slightly between 2012-14 and 2015-17, indicating it was the only area where recovery continued.

Estimates of female Spawning Potential Ratio (SPR) in the northern and southern areas, derived from the extended per-recruit analyses based on catch curve estimates of *F* and age-based selectivity, have generally improved since 2003-05. However, SPR remains close to the limit in the northern areas (0.22; 95% CI = 0.19-0.24) and below the limit in the southern areas (0.16; 95% CI = 0.13-0.20) (**Table 3.10**).

A slight reduction in the estimated age at which fish are selected by recreational fishers and declines in the relative prevalence of older fish in the South-west and Metropolitan areas, respectively, have resulted in declining and constant SPR in recent periods (**Fig. 3.51**). SPR in the Kalbarri Area similarly has not changed, while that in the Mid-west increased from 2012-2014 to be between the limit and threshold.

While considered less realistic, estimates of SPR derived from a traditional per-recruit model (assuming no impact of fishing on recruitment) were 0.06-0.07 greater than estimates generated by the more conservative model.

Sensitivity analyses exploring the effect on results of assuming a 25% mortality of fish released after capture showed a slight reduction in SPR estimates of 0.01-0.03 for the north and south management areas.

Estimated fishing mortality rates at the stock (bioregion) level indicate some recovery of Snapper since 2009-11. This is due primarily to improvement in the northern areas, which is also reflected in the estimated SPR. However, F and SPR for the northern areas continued to improve only in the Mid-west, to be between the limit and threshold, but remained below the limit in the Kalbarri area, suggesting recovery has not continued in that area. Little change in *F* (between limit and threshold in 2015-17) and SPR (below the limit in 2015-17) in the southern areas also do not provide evidence of ongoing recovery. Including effects of release mortality for sublegal sized fish reduced SPR in the northern and southern areas to around the limit and further below the limit, respectively.

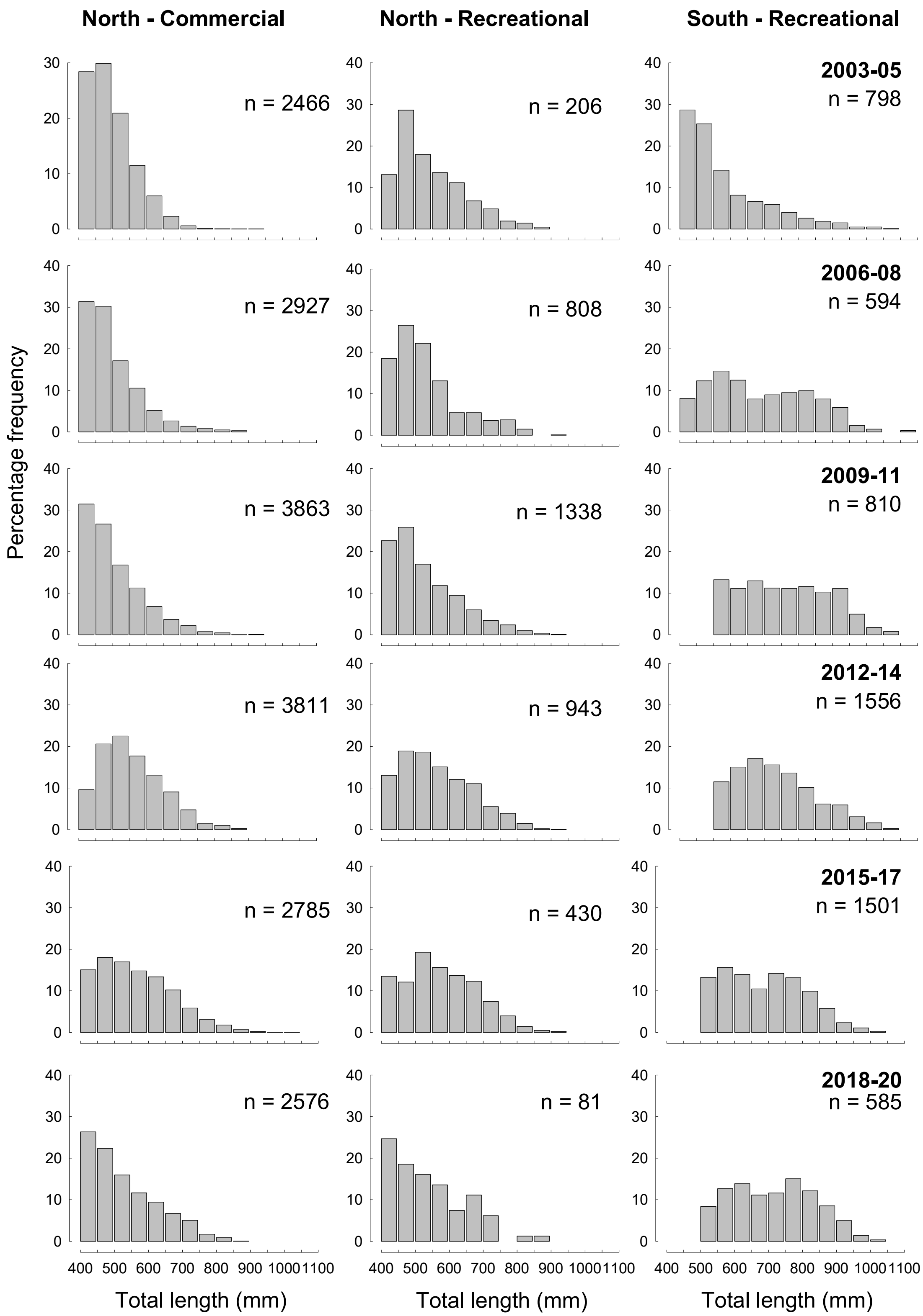


Figure 3.48. Length-frequency distributions of Snapper ≥MLL (410 mm in northern areas; 410 mm in southern areas to 2008, 500 mm after 2008) in the northern and southern areas from each sector sampled in each biological year group (Biological year = 1 Aug-31 Jul; North: Kalbarri and Mid-west Areas; 1 Nov-31 Oct South: Metropolitan and South-west areas).

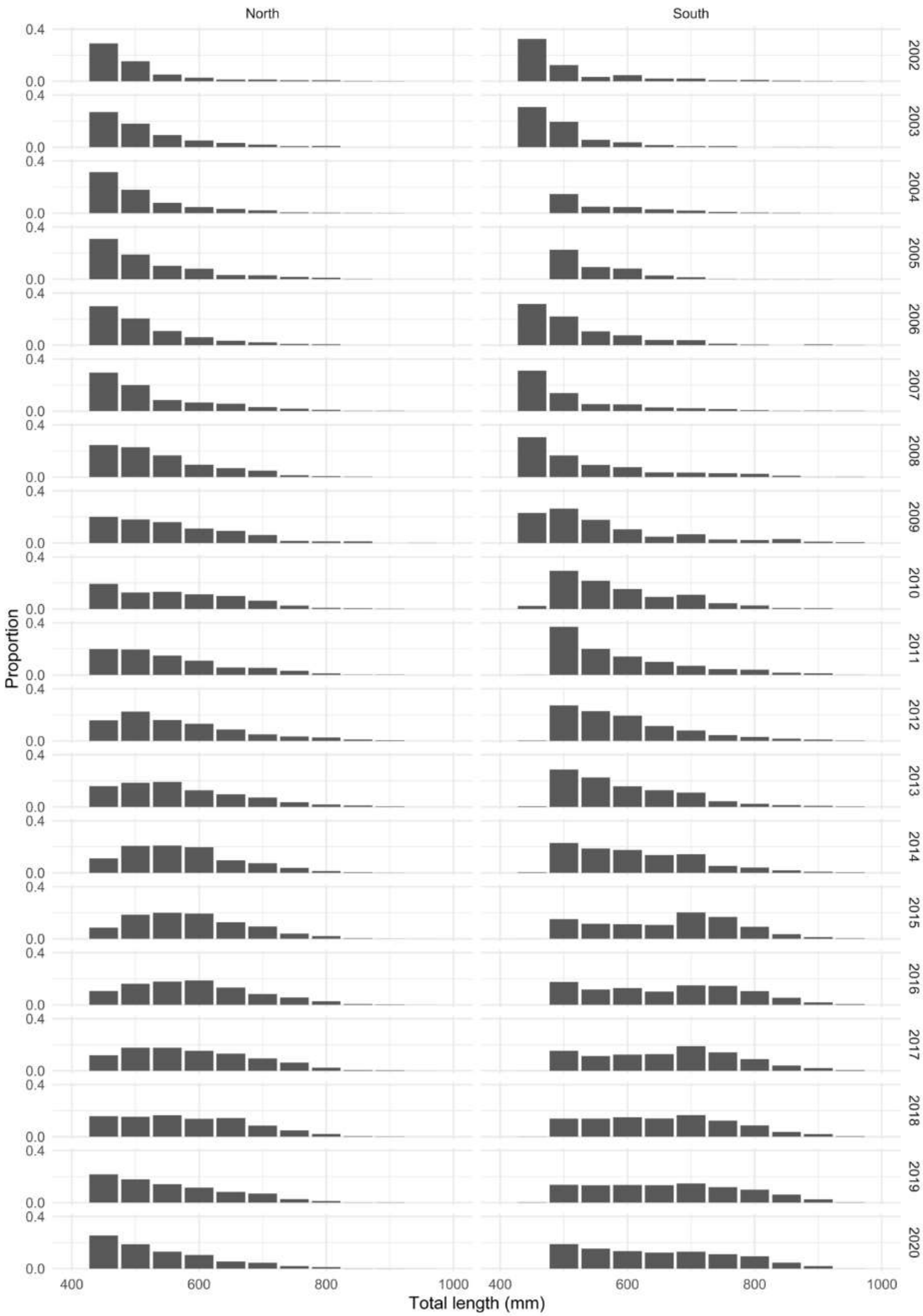


Figure 3.49. Length-frequency distributions of retained Snapper reported by charter fishers in the northern and southern management areas of the WCB by year.

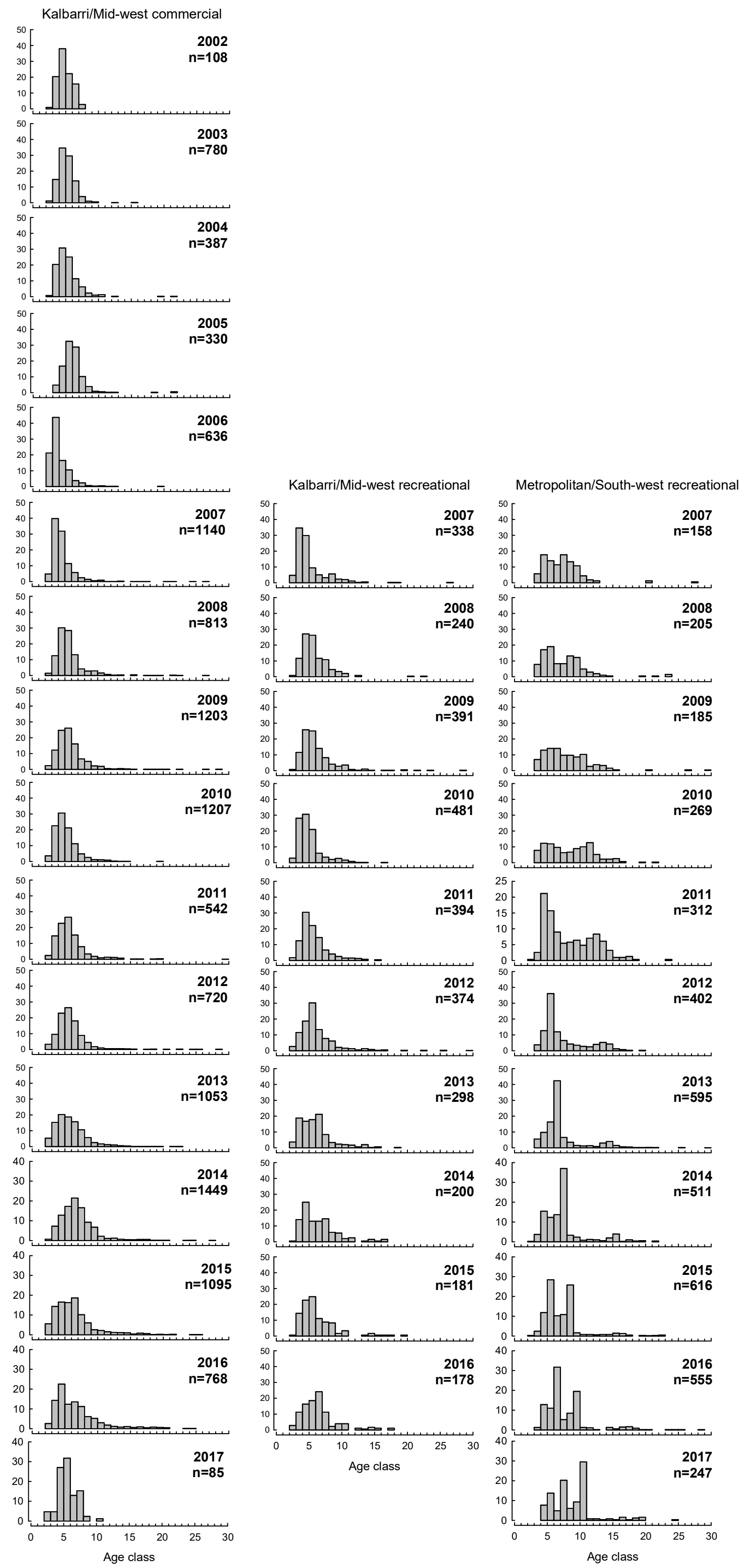


Figure 3.50. Age-frequency distributions of Snapper ≥MLLs in the northern and southern areas from each sector sampled in each biological year group. MLL: 410 mm in northern areas; 410 mm in southern areas to 2008, 500 mm after 2008. Biological year: 1 Aug-31 Jul; North: Kalbarri and Mid-west Areas; 1 Nov-31 Oct South: Metropolitan and South-west areas.

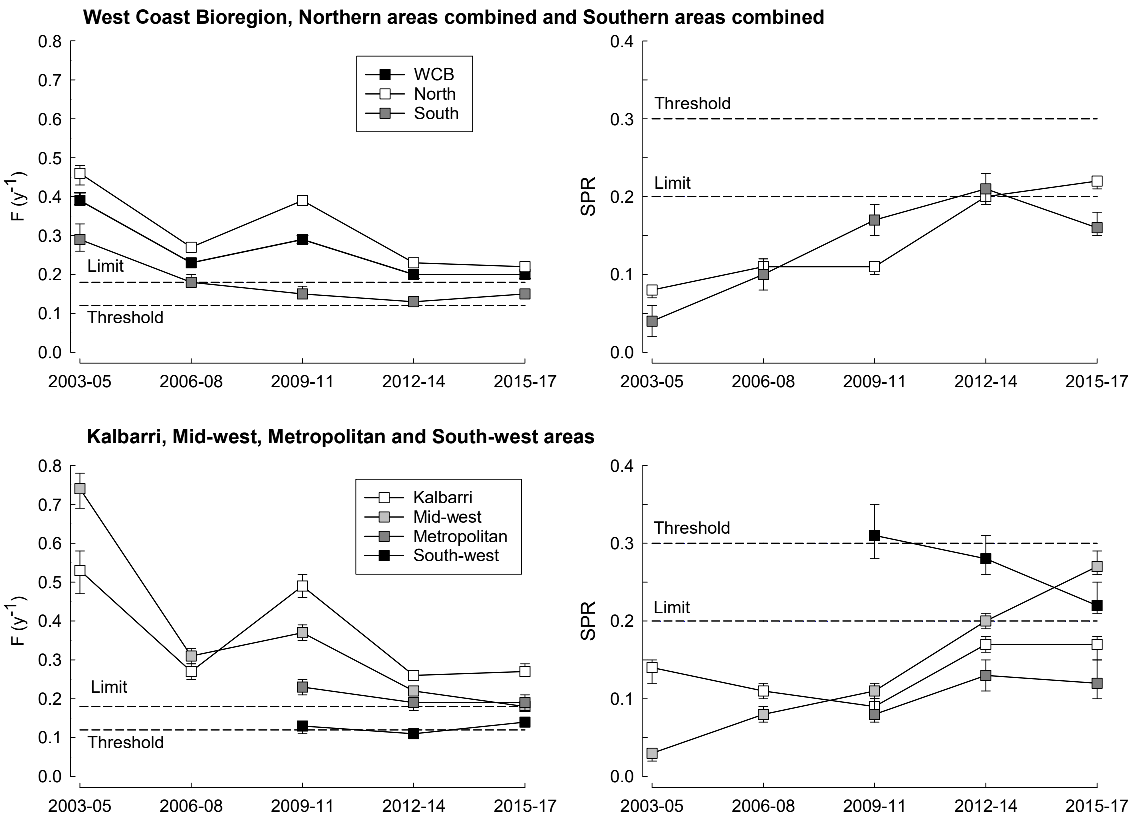


Figure 3.51. Estimates (and 60% confidence intervals) of 'long-term' fishing mortality (*F,* year^{-1}) and female spawning potential ratio (SPR) for Snapper between 2003-05 and 2015-17, based on data from commercial and/or recreational catches in the West Coast Bioregion, combined Northern (Kalbarri/Mid-west) and Southern (Metropolitan/South-west) management areas and for each management area separately. Due to differences in biological characteristics of Snapper in the Northern and Southern areas, there is no combined estimate of SPR for the West Coast Bioregion.

Table 3.9. Estimates of 'long-term' fishing mortality, *F* (year^{-1}, ±95% confidence intervals) for Snapper based on catch curve analysis of age composition data collected in 2015-17 from commercial and/or recreational catches in the West Coast Bioregion (WCB), the combined northern (Kalbarri/Mid-west) and southern (Metropolitan/South-west) management areas and the separate Kalbarri, Mid-west, Metropolitan and South-west areas. Point estimates were compared to reference levels relating the value for natural mortality (*M*), where orange denotes $F \geq$ the limit level of 1.5*M* (0.18 year^{-1}) and yellow denotes $F \geq$ the threshold level of *M* (0.12 year^{-1}).

Area	Combined sectors	Commercial	Recreational
WCB	0.20 (0.18-0.21)		
North		0.22 (0.19-0.24)	0.25 (0.20-0.30)
South			0.15 (0.13-0.17)
Kalbarri		0.27 (0.23-0.31)	
Mid-west		0.18 (0.15-0.21)	0.25 (0.2-0.3)
Metro			0.19 (0.15-0.23)
South-west			0.14 (0.12-0.16)

Table 3.10. Estimates of spawning potential ratio, SPR (±95% confidence intervals) for Snapper based on per-recruit analyses of fishing mortality estimates from 2015-17 for the commercial and/or recreational sectors in the combined northern (Kalbarri/Mid-west) and southern (Metropolitan/South-west) management areas and the separate Kalbarri, Mid-west, Metropolitan and South-west areas. Point estimates were compared to reference levels relating the spawning potential to that of an unfished stock, where orange denotes SPR ≤ the limit level of 0.2, yellow denotes SPR ≤ the threshold level of 0.3 and green denotes SPR > the threshold level.

Area	Combined sectors		Commercial		Recreational	
	Traditional per recruit	Extended per recruit	Traditional per recruit	Extended per recruit	Traditional per recruit	Extended per recruit
North	0.28 (0.26-0.3)	0.22 (0.19-0.24)	0.29 (0.27-0.31)	0.22 (0.20-0.25)	0.25 (0.21-0.29)	0.18 (0.14-0.23)
South					0.23 (0.2-0.27)	0.16 (0.13-0.20)
Kalbarri			0.24 (0.21-0.27)	0.17 (0.14-0.2)		
Mid-west			0.33 (0.30-0.37)	0.27 (0.24-0.32)	0.25 (0.21-0.29)	0.18 (0.14-0.23)
Metro					0.20 (0.15-0.26)	0.12 (0.08-0.19)
South-west					0.29 (0.25-0.34)	0.22 (0.19-0.28)

Level 4	
Fishery-dependent abundance index and biomass dynamic model	Mean, nominal and standardised drop-line (DL) and hand-line (HL) CPUE in the northern areas were highly variable between 1985 and 2007, demonstrating relatively high values in the late 1980s, mid-1990s and mid-2000s and lower values in between, consistent with trends in commercial catches (cf **Figs 3.1, 3.52a**). In southern areas, HL CPUE comprised peaks and troughs consistent with HL methods in the northern areas, while DL CPUE was relatively steady over time, possibly influenced by a limited data set (**Fig. 3.52a**). After accounting for fishing efficiency increases associated with adoption of GPS, colour sounders and hydraulic reels (Marriott et al., 2011), standardised DL and HL CPUE in both areas demonstrated similar peaks and troughs. However, DL CPUE in the northern areas exhibited a substantial decline, whereas HL CPUE did not change dramatically. DL CPUE in the southern areas gradually declined, while HL maintained its un-adjusted trend (**Fig. 3.52b**). Note that fishing efficiency may have increased further during this period than from that estimated for the introduction of GPS, colour sounders and hydraulic reels, e.g. from other technological changes or levels of fisher knowledge and skill. Daily HL CPUE values were high between 2010 and 2014, followed by a decline to low levels by 2016 and a slight increase in 2020 (**Fig. 3.53**). Note that it is likely that fishing efficiency will also have had some effect on daily CPUE trends due to continuing advances in fishing technology and changes in fisher experience within the fishing fleet etc. since 2008. Analyses of monthly and daily CPUE using a subset of vessels considered to be targeting Snapper (identified by a qualification process) reiterated peaks and troughs (**Fig. 3.54**). The reliability of monthly CPUE trends as indices of abundance is uncertain due, in particular, to lack of knowledge of how fishing efficiency has changed over time and impacts of targeting of particular fish species in certain areas at certain times (within this multi-species fishery) by fishers. However, high and low CPUE values are consistent with knowledge of periodic occurrence of high and low recruitment in Snapper. The annual trend in daily HL CPUE data for the northern areas is not consistent with stock recovery. Future research should focus on analyses/data collections that might reduce uncertainty associated with the reliability of available CPUE data as abundance indices.

Level 4 Assessment

With additional efficiency increases of 2% and 1% to the monthly and daily CPUE data, the estimated relative biomass of Snapper in the northern areas declined from the specified level of 0.9 in 1975 to around the limit of 0.25 ($0.5B_{MSY}$ = limit) by 2000. It then increased almost to the threshold by the late 2000s and then declined again to the limit by the late 2010s (**Fig. 3.55**). This low relative biomass would have been influenced by catches being above estimated MSY of 185 t and exploitation being above F_{MSY} in many years since the mid-1980s until 2015.

This indicates that the stock was being overfished during that period, but the increases and decreases in relative biomass would be influenced by the periodic strong cohorts in the stock, which are also reflected in the standardised CPUE trends. Recent catches are well below estimated MSY (185 t), under current management.

When additional fishing efficiency increase was set at 1% or 0%, trends in relative biomass and exploitation estimates were similar to the 2%/1% scenario, but were more optimistic (**Fig. 3.56, 3.57**). In the 1% scenario, final relative biomass and F estimates were between the limit and threshold and around F_{MSY}, respectively, while in the 0% scenario, relative biomass was at the threshold (B_{MSY}) and F was well below F_{MSY}, and had been for several years. Catches in both cases were well below estimated MSY in recent years (194 t and 237 t). However, it is unlikely that additional efficiency increase has remained at 0%, suggesting that the latter scenario would be too optimistic.

Biomass dynamics results model indicate a long history of decline in snapper stocks in northern areas. While there was some evidence of recovery towards the threshold in the 2000s and 2010s, relative biomass in the last 5 years has remained around the limit and its variation is influenced by the occurrence of strong cohorts in the stock (the last one occurring in 2007) and efficiency increases. However, both the 2%/1% and 1%/1% models suggest the stock in northern areas has not yet recovered above B_{MSY}, but that if current estimated exploitation levels are maintained (i.e. $F \leq F_{MSY}$), with catches below MSY, it should allow the stocks to recover.

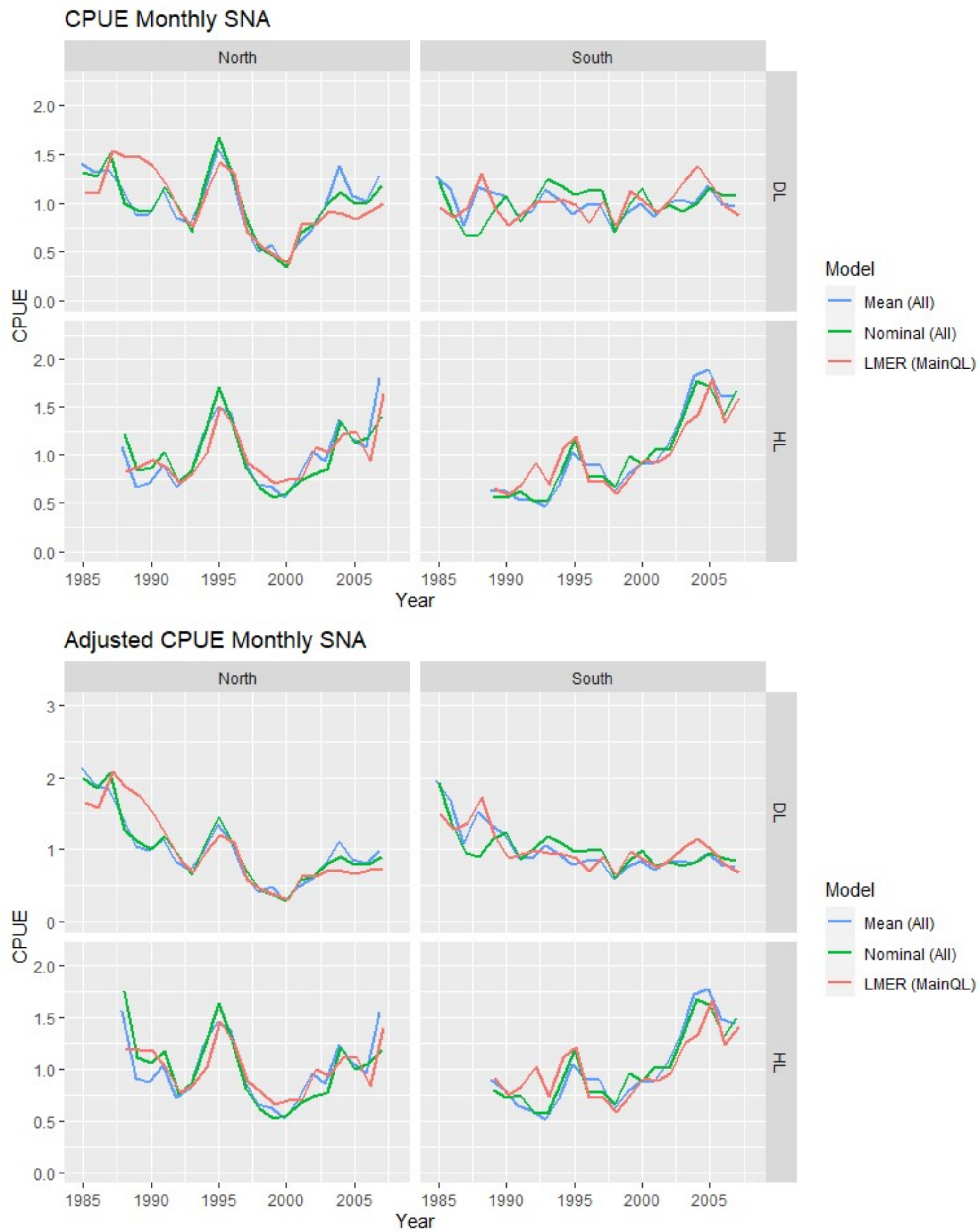


Figure 3.52. Raw (mean and nominal) CPUE trends and standardised (LMER) CPUE trends (top) and adjusted raw and standardised CPUE (bottom), for monthly snapper records in the northern and southern areas using DL or HL methods.

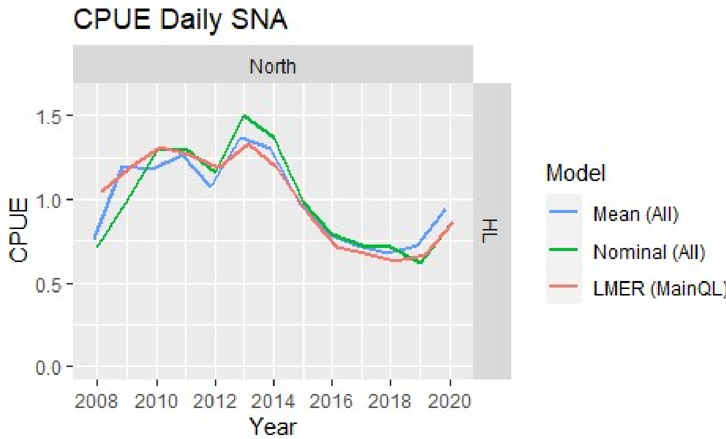


Figure 3.53. Raw (mean and nominal) CPUE and standardised CPUE (LMER) for daily snapper records in the north region using HL methods. Note, there are limited data for DL methods in the northern and southern areas and limited HL data in the southern areas.

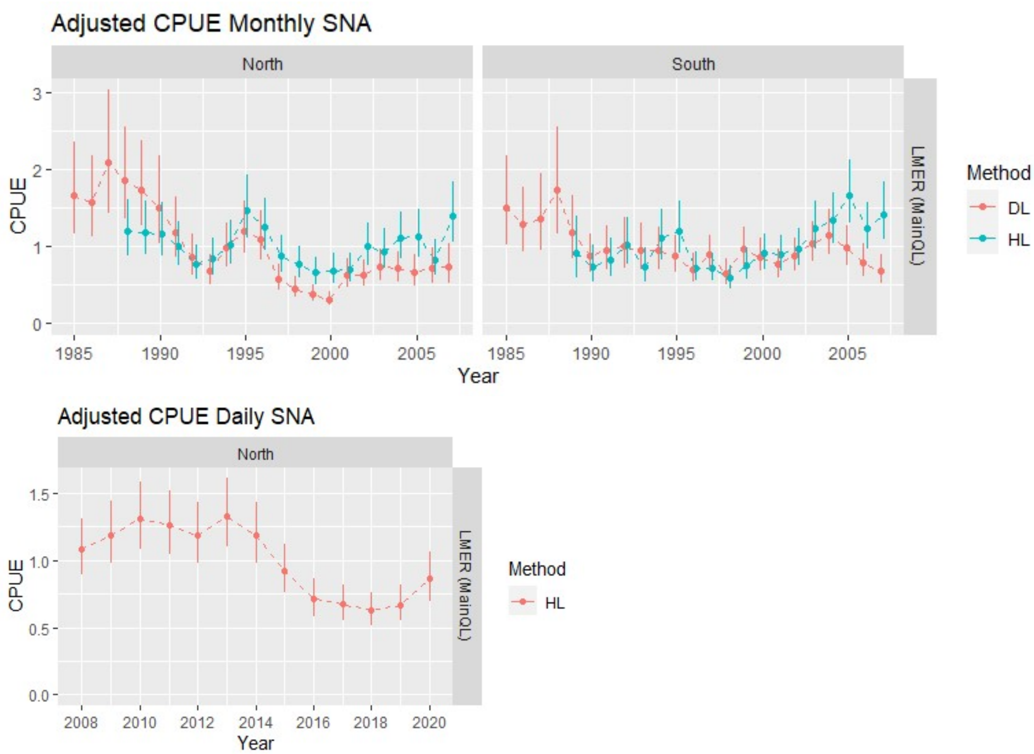


Figure 3.54. Adjusted monthly (top) and daily (bottom) standardised CPUE (± 95% CI) for Snapper by DL or HL in the northern and southern areas based on data for vessels that met a qualification rule for targeting snapper.

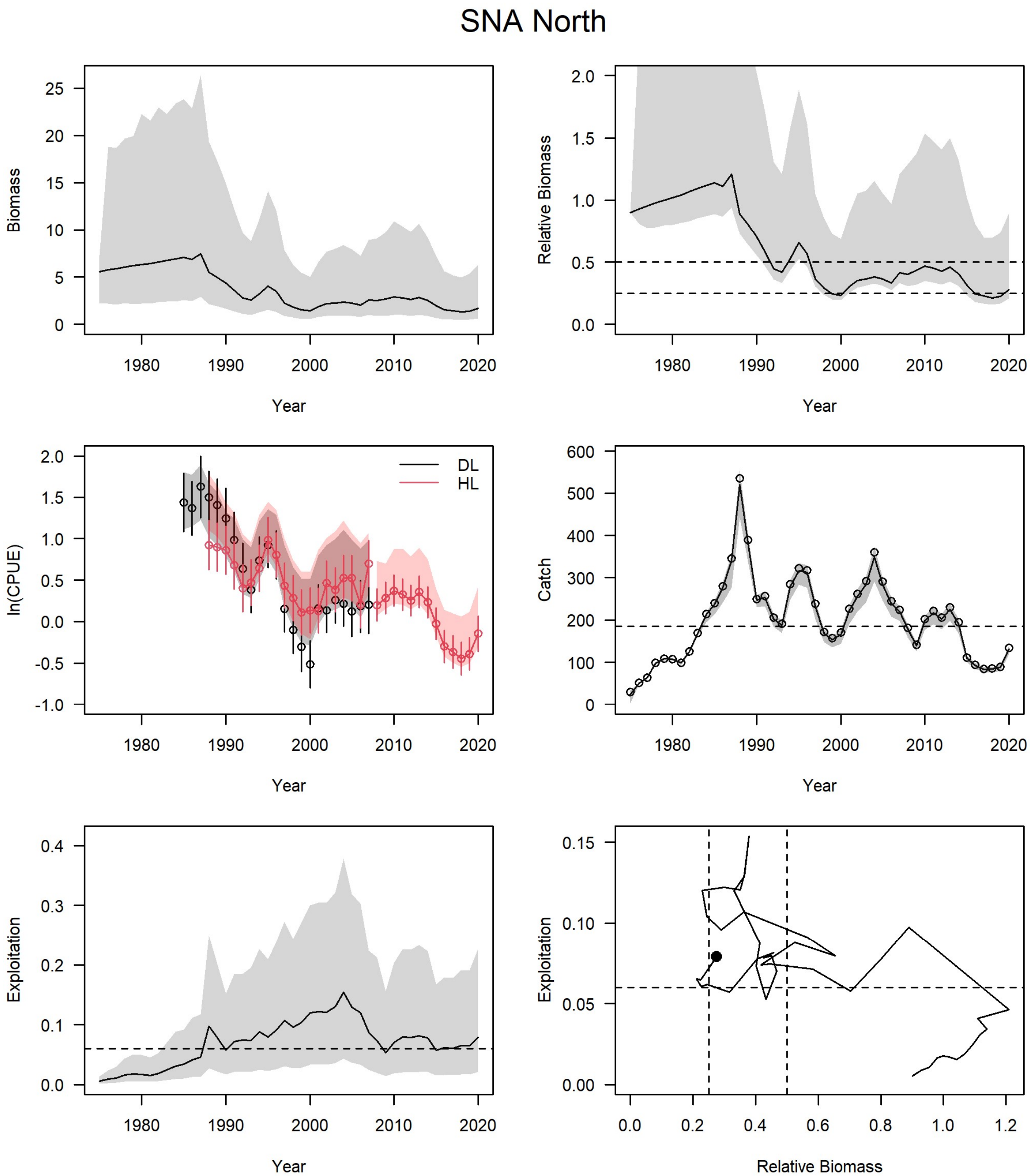


Figure 3.55. a) Absolute biomass (tonnes) trajectory, b) estimates of relative biomass and internationally accepted threshold (0.5) and limit (0.25) reference levels, c) observed (lines) and expected (shading) annual CPUE for each method type, d) estimated annual catch with estimated MSY (dotted line), e) annual exploitation rates with F_{MSY}, and f) trajectory of exploitation rate as a function of relative biomass, for the northern snapper resource with an additional 2% efficiency increase of the monthly CPUE and 1% increase on daily CPUE data.

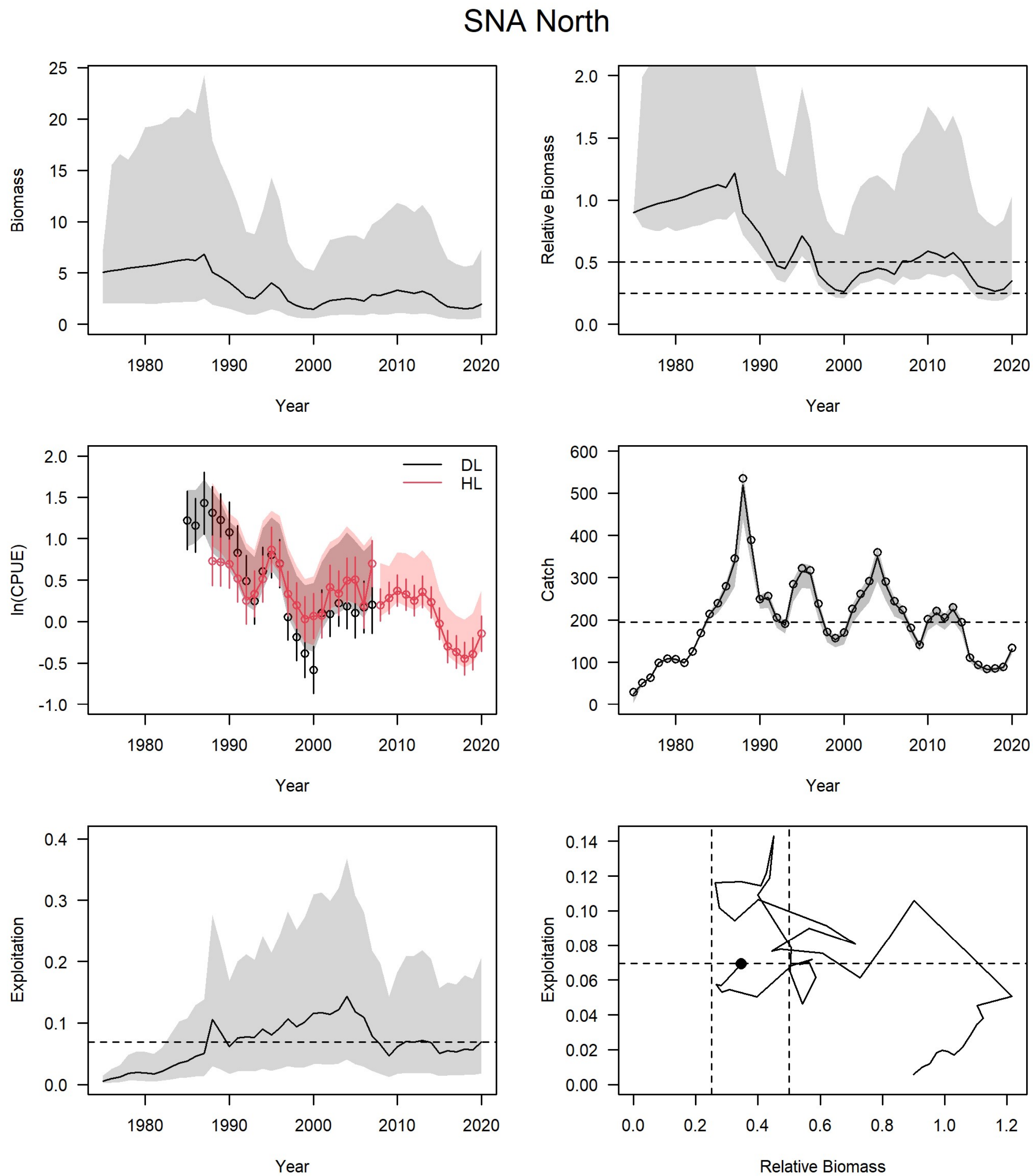


Figure 3.56. a) Absolute biomass (tonnes) trajectory, b) estimates of relative biomass and internationally accepted threshold (0.5) and limit (0.25) reference levels, c) observed (lines) and expected (shading) annual CPUE for each method type, d) estimated annual catch with estimated MSY (dotted line), e) annual exploitation rates with F_{MSY}, and f) trajectory of exploitation rate as a function of relative biomass, for the northern snapper resource with an additional 1% efficiency increase of both the monthly and daily CPUE data.

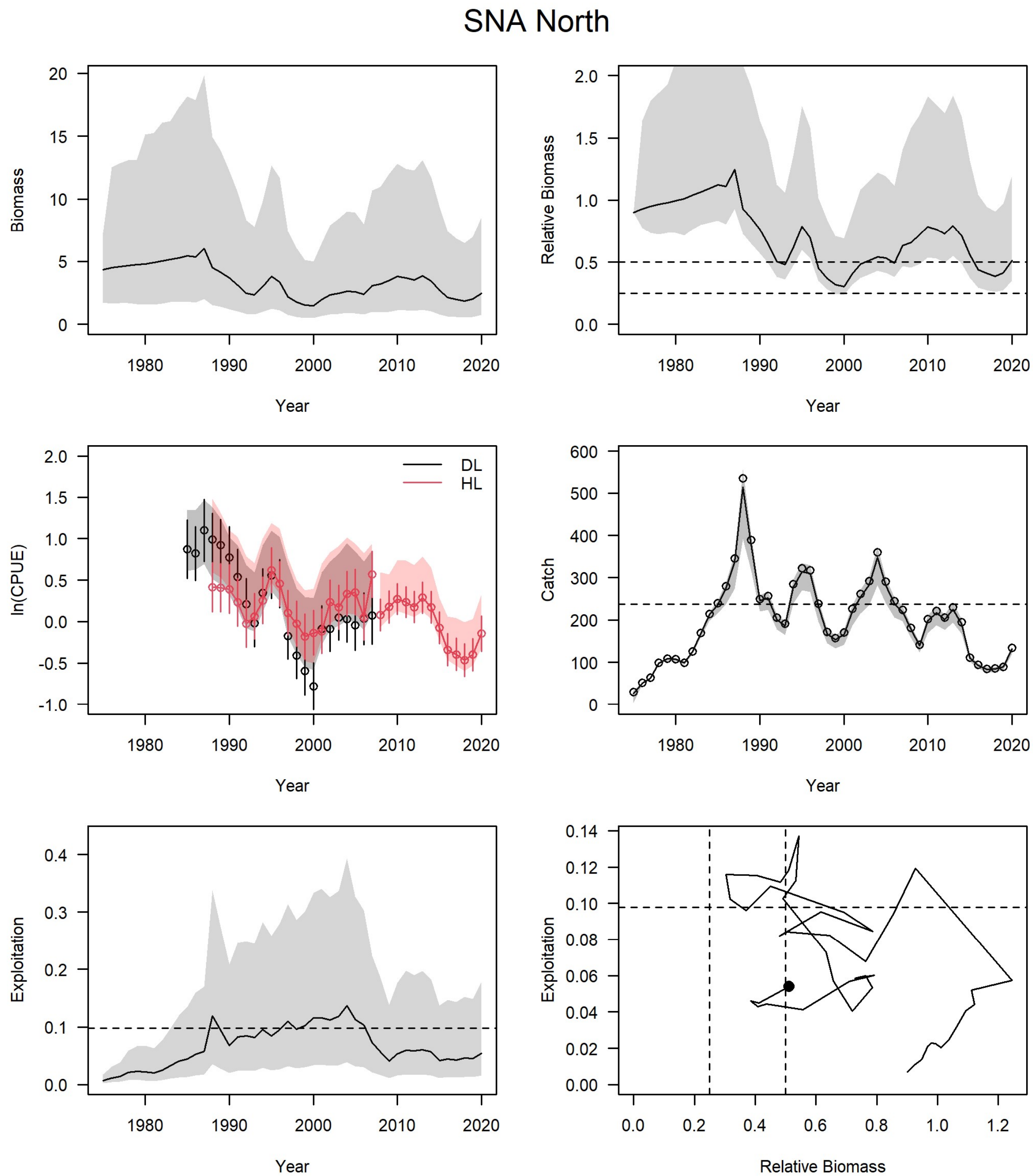


Figure 3.57 a) Absolute biomass (tonnes) trajectory, b) estimates of relative biomass and internationally accepted threshold (0.5) and limit (0.25) reference levels, c) observed (lines) and expected (shading) annual CPUE for each method type, d) estimated annual catch with estimated MSY (dotted line), e) annual exploitation rates with F_{MSY}, and f) trajectory of exploitation rate as a function of relative biomass, for the northern snapper resource with the efficiency schedule as per Marriott et al (2011).

Level 5 assessment
Integrated Model Scenarios included (1) a base case with post-release mortality (PRM) included as additional catch, with model not fitted to CPUE indices, (2) PRM on selected undersize fish at a rate of 25%, with model not fitted to CPUE indices, (3) PRM as additional catch, with model fitted to CPUE indices, and (4) PRM of undersize fish at a rate of 25%, with model fitted to CPUE indices. In scenarios 1 and 2, median relative biomass of females at the bioregion level was predicted to have recovered from below the limit level to be around the limit in 2020, with the lower 60% CL of B_{rel} in 2020 at the stock level being below the limit and the upper 60% CL being between the limit and threshold (B_{MSY}) (**Figs 3.58, 3.59**). B_{rel} in the northern and southern areas was also expected to be around the limit in both scenarios (**Figs 3.58, 3.59**). The model projected that for Scenarios 1 and 2, median B_{rel} at the stock level would be between the limit and threshold by 2030, but there was substantial uncertainty in the estimated projections. Similar recovery trajectories were predicted for both the northern and southern areas, due to F declining gradually to below F_{MSY} by 2030, but with substantial uncertainty. This resulted in median B_{rel} being higher in the northern areas than the southern areas by 2030, but being between the limit and threshold in both scenarios (**Figs 3.58, 3.59**). Scenarios (3 and 4) which included CPUE as an index of abundance, each also resulted in median B_{rel} at the bioregion level in 2020 being around the limit (**Figs 3.60, 3.61**). However, as the upper 60% CL was equivalent to the target reference point in scenarios 3 and 4, it was not as optimistic as in scenarios 1 and 2, in which it was above the target. In scenarios 3 and 4, median B_{rel} was around the limit reference point in 2020 in the northern and southern areas, but was less optimistic in the northern areas. Projections suggested that median F in the northern and southern areas declined after 2020 to reach F_{MSY} and be below F_{MSY} by 2030, respectively. This allowed gradual recovery at the stock level, with median B_{rel} in 2030 being between the limit and threshold, but with substantial uncertainty. Similarly, projected median B_{rel} in the northern and southern areas increased gradually after 2020, but remained between the limit and threshold by 2030. Projected B_{rel} (±60% CI) in 2030 was more optimistic in the southern areas than the northern (**Figs 3.60, 3.61**). Scenarios 2 and 4 represent a more conservative, and possibly more appropriate method for accounting for post-release mortality, which assumes that all post-release mortality is associated with undersize fish, unlike scenarios 1 and 3. As Snapper become vulnerable to fishing gear below the minimum legal length, and release rates are high in at least the recreational sector, it is likely many undersize fish are caught and released. However, this scenario would be slightly pessimistic, as it is likely that not all released snapper are undersize. For all four model scenarios, projections beyond 2020 are dependent on assumed average recruitment levels (i.e. as predicted from the stock-recruitment relationship). For scenarios 1 and 2, which are not fitted to CPUE indices, the last available information on recruitment is provided by the age composition data collected up to 2017. As Snapper do not become recruited into the fishery until about 4-5 years of age in the northern areas and 4-8 years in the southern areas, there is limited information in the age composition data on recruitment since about 2013. Thus, model projections are more uncertain than for scenarios 3 and 4, which used the index of abundance (CPUE) from available data up to 2020. However, there is uncertainty with the CPUE indices, particularly in relation to fishing efficiency changes. Note also that snapper stocks exhibit substantial inter-annual recruitment variation, and a strong recruitment pulse can have a strong, positive effect on future stock abundance levels. The L5 model results are subject to a number of key assumptions, including stock productivity (i.e. natural mortality (*M*) and stock-recruitment steepness values), biological assumptions (e.g. temporal growth changes), fishery changes (e.g. efficiency), impacts associated with bycatch and PRM. It is recommended that research focus on reducing these uncertainties in future assessments. The value used for *M* in the northern areas was based on the same maximum age as in the Gascoyne Bioregion.

This would produce more optimistic results than if the same was used as that in the southern areas (0.12).

The estimated status of Snapper at the bioregion (stock) level and in the northern and southern areas when management was changed (2008-2010) was similar across the four scenarios. Results from scenarios 3 and 4, which use available fine scale, daily (standardised CPUE data (in the northern areas only) are probably most reliable in estimating recent trends in stock status, as trends in CPUE are consistent with knowledge of recruitment variation. These scenarios both indicate a level of stock recovery through to 2030, if retained catches are maintained at or below original catch recovery benchmarks (50% of 2005/06 levels), and noting assumptions in the model and that PRM is not greater than that included. Projected median B_{rel} by 2030 was expected to be between the threshold and limit reference points (noting substantial uncertainty) at the stock level and in both the northern and southern areas.

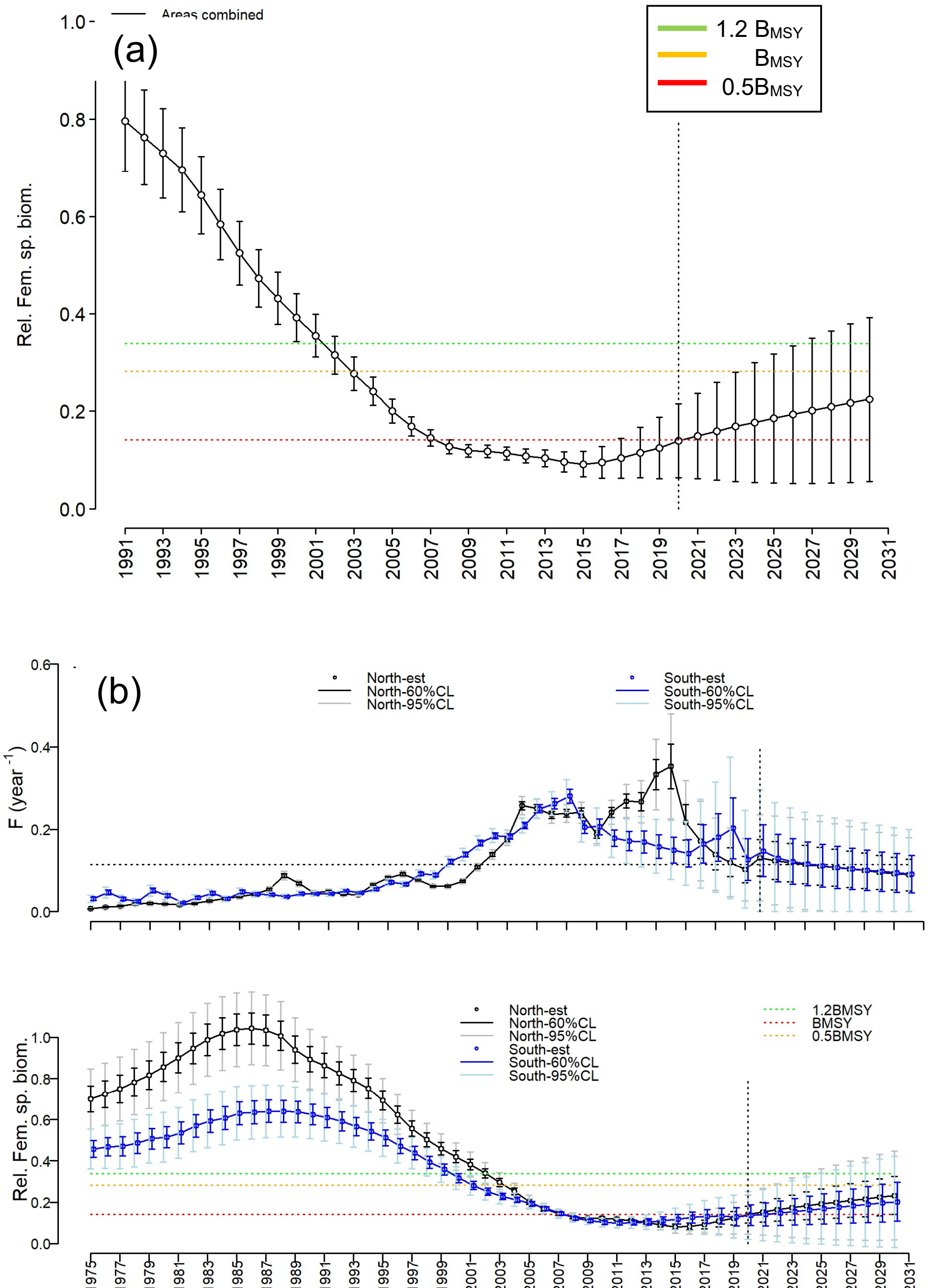


Figure 3.58. **Scenario 1.** Model estimates for (a) relative female spawning biomass B_{rel} (±60% CI) of Snapper at the bioregion level (north and south regions combined) and (b) fishing mortality (F, y^{-1}) and relative female biomass B_{rel}, in the north and south areas. Vertical dotted line indicates the year 2020. **Model contains post-release mortality (PRM) as additional catch, but does not include an index of abundance (CPUE) or account for efficiency gain. Relative biomass is compared with internationally accepted target, threshold and limit reference points.**

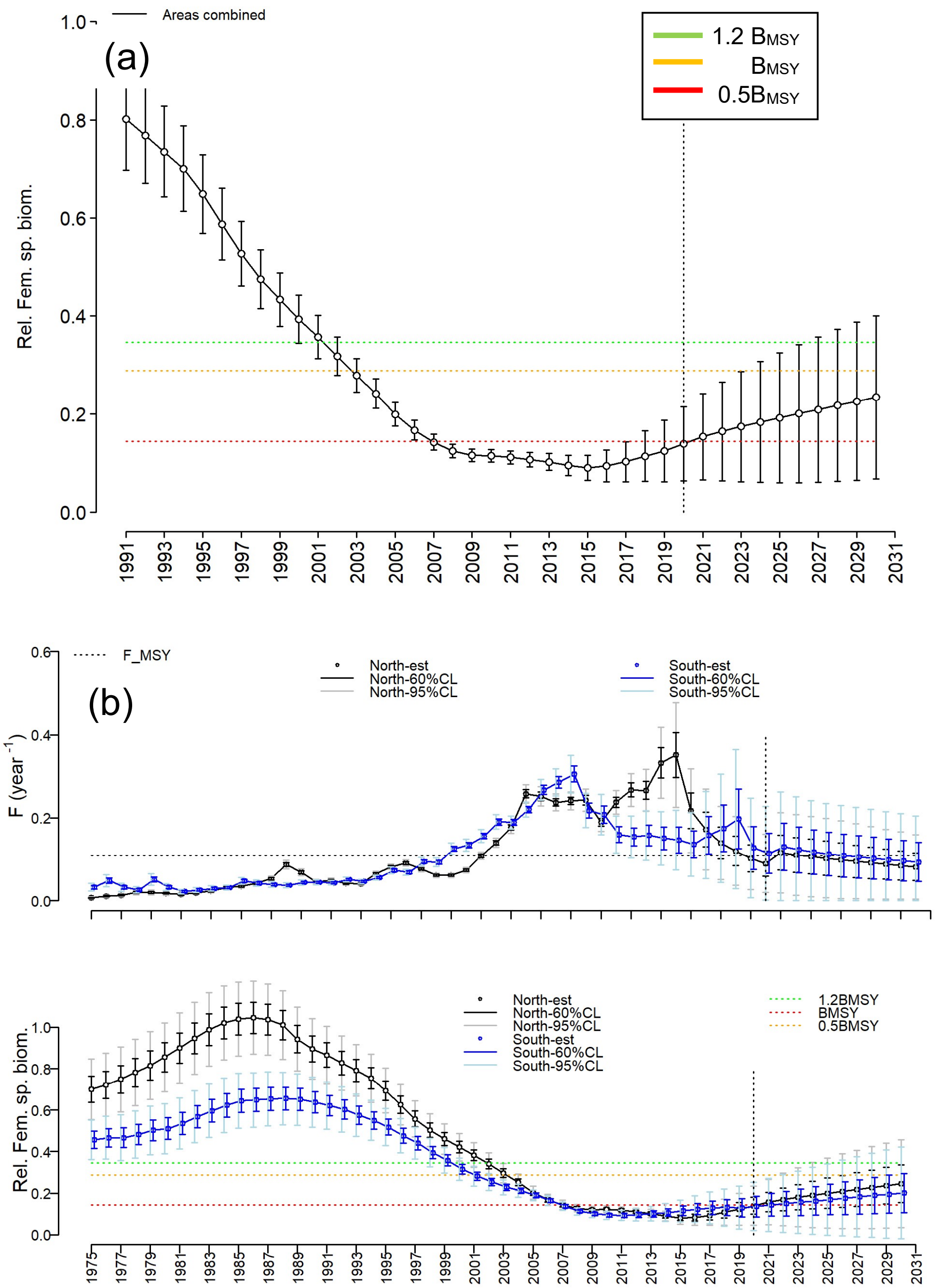


Figure 3.59. **Scenario 2.** Model estimates for (a) relative female spawning biomass B_{rel} (±60% CI) of Snapper at the bioregion level (north and south regions combined) and (b) fishing mortality (F, y^{-1}) and relative female biomass B_{rel}, in the north and south areas. Vertical dotted line indicates the year 2020. **Model includes post-release mortality (PRM) of undersize fish = 0.25, but does not include an index of abundance (CPUE). Relative biomass is compared with internationally accepted target, threshold and limit reference points.**

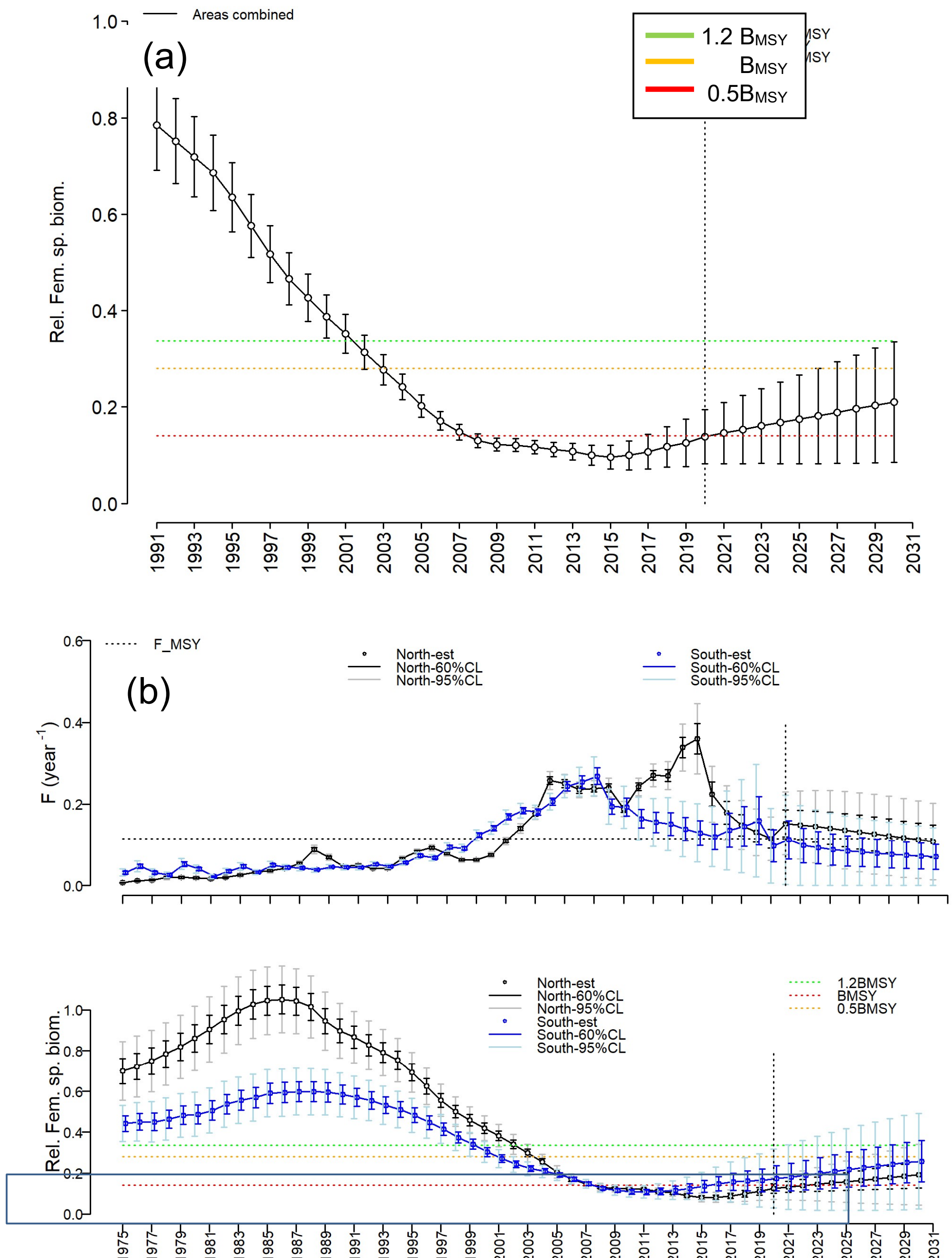


Figure 3.60. **Scenario 3.** Model estimates for (a) relative female spawning biomass B_{rel} (±60% CI) of Snapper at the bioregion level (north and south regions combined) and (b) fishing mortality (F, y^{-1}) and relative female biomass B_{rel}, in the north and south areas. Vertical dotted line indicates the year 2020. **Model includes post-release mortality (PRM) as additional catch and CPUE as an index of abundance. Relative biomass is compared with internationally accepted target, threshold and limit reference points.**

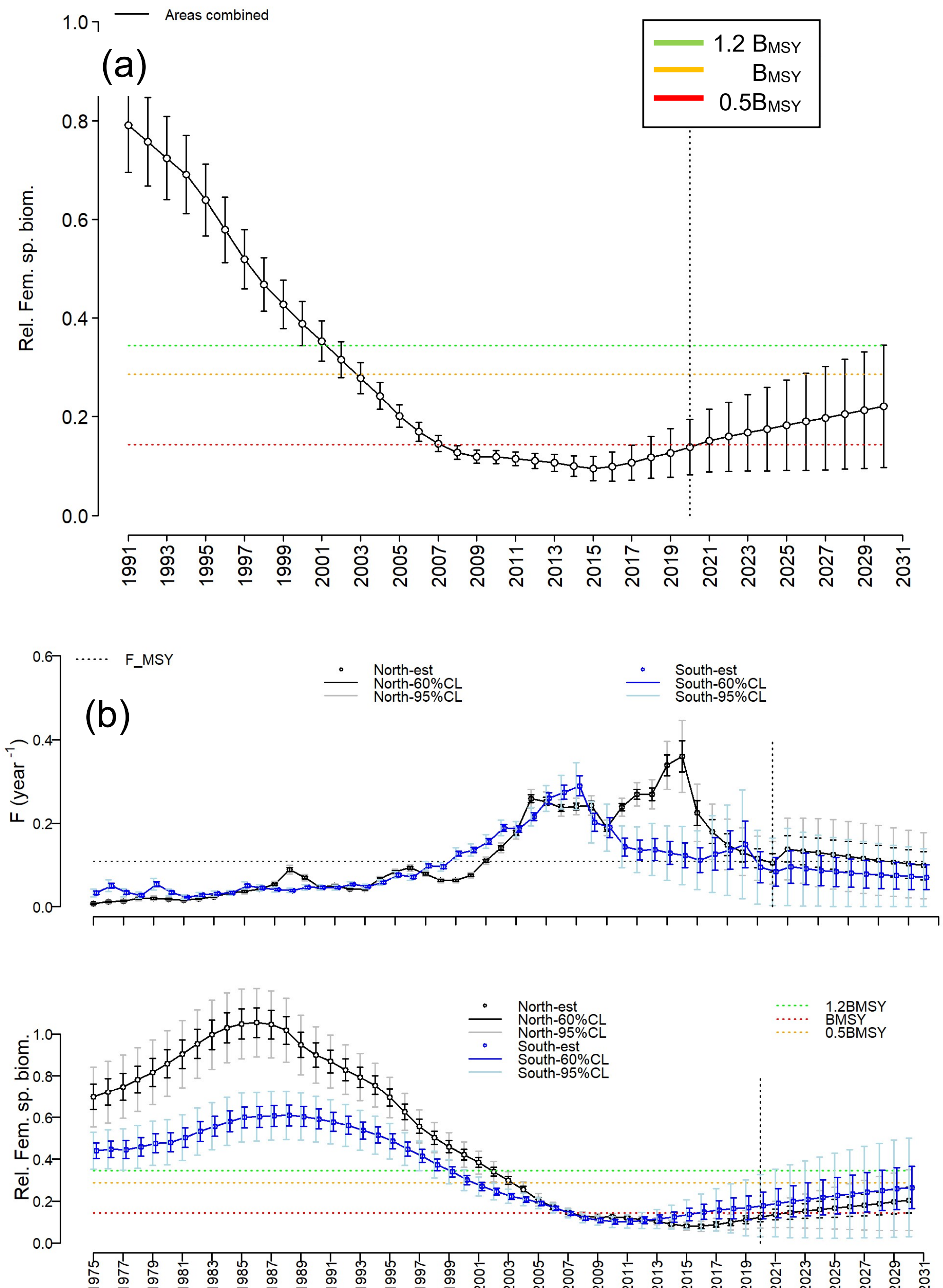


Figure 3.61. **Scenario 4.** Model estimates for (a) relative female spawning biomass B_{rel} (±60% CI) of Snapper at the bioregion level (north and south regions combined) and (b) fishing mortality (F, y^{-1}) and relative female biomass B_{rel}, in the north and south areas. Vertical dotted line indicates the year 2020. **Model includes post-release mortality (PRM) of undersize fish = 0.25 and CPUE as an index of abundance. Relative biomass is compared with internationally accepted target, threshold and limit reference points.**

Risk assessment
• The L1, L4 and L5 assessments used available catch and CPUE data to 2020, while the L3 assessment used biological data to 2017. As biological parameters for Snapper differ between the northern and southern areas, SPR cannot be estimated at the stock level and thus the stock level risk assessment is based on fishing mortality rates. SPR analyses also uses a single value for natural mortality. As the maximum age for this species decreases with decreasing latitude on the lower west coast, *M* may be higher and these results may be pessimistic. • Risk assessment for L4 biomass dynamics models was conducted on the scenario that assumed the greatest increase in fishing efficiency and thus produced the most pessimistic result. • The most likely scenarios among L5 models would be ones that include some level of post-release mortality and CPUE (scenarios 3 and 4) as an index of abundance. Thus, L5 risk assessments were only conducted for those scenarios. Note that the value for *M* in the northern areas used in these analyses was based on a maximum age similar to the Gascoyne Bioregion and thus would produce more optimistic results than if the same maximum age (and thus *M*) was used as for the lower west coast. **Considering the different lines of evidence, the expected risk of future depletion at the bioregion level is estimated to be SEVERE (C4×L4). In the northern areas, the risk is estimated to be SEVERE (when compared to B_{lim} based on B_{MSY} or B_{20}, as per the 2021 WCDSR Harvest Strategy) while it was HIGH/SEVERE in the southern areas (using those respective B_{lim} reference points). The most conservative risk based on B_{lim} = B_{20} is shown below.**

	Bioregion/management areas		
Assessment level	**Bioregion**	**North**	**South**
L1 C_{MSY}	N/A	Severe (C4×L3; 12)	Severe (C4×L3; 12)
L3 *F* or SPR	(*F*) Severe (C4×L4; 16)	High (C3×L4; 12)	Severe (C4×L4; 16)
L4 Biom dynamics	N/A	High (C3×L3; 9)	N/A
L5 integrated Scenario 4 (PRM = 0.5)	Severe (C4×L4; 16)	Severe (C4×L4; 16)	Severe (C4×L4; 16)

4.0 Acknowledgements

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6.0 Appendix

6.1 Level 1 – Productivity – susceptibility analysis

							Productivity Scores [1-3]									Susceptibility Scores [1-3]						Cumulative only								
Scoring element	First of each scoring element	Family name	Scientific name	Common name	Species type	Fishery descriptor	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)
1	First	Sparidae	Chrysophrys auratus	Snapper	Non-invertebrate	WCDSF	2	3	1	2	2	1	3		2.00	3	3	3	2	2.33	**3.07**	120	1.00	3.07	3.07	65	Med	60-79		
2	First	Glaucosomatidae	Glaucosoma hebraicu	West Australian dhufis	Non-invertebrate	WCDSF	1	3	1	2	1	1	3		1.71	3	3	2	3	2.33	**2.89**	170	1.00	2.89	2.89	72	Med	60-79		
3	First	Labridae	Choerodon rubescens	Baldchin groper	Non-invertebrate	WCDSF	1	2	1	1	1	1	3		1.43	3	3	2	3	2.33	**2.73**	50	1.00	2.73	2.73	77	Med	60-79		
4	First	Lethrinidae	Lethrinus miniatus	Redthroat emperor	Non-invertebrate	WCDSF	1	2	1	1	1	1	3		1.43	3	3	1	2	1.43	**2.02**	50	1.00	2.02	2.02	95	Low	≥80		
5	First	Berycidae	Centroberyx gerrardi	Bight redfish	Non-invertebrate	WCDSF	2	3	1	1	1	1	3		1.71	3	3	1	2	1.43	**2.23**	40	1.00	2.23	2.23	91	Low	≥80		
6	First	Polyprionidae	Polyprion oxygeneios	Hapuku	Non-invertebrate	WCDSF	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		
7	First	Polyprionidae	Polyprion americanus	Bass groper	Non-invertebrate	WCDSF	2	3	1	2	2	1	3		2.00	3	3	1	3	1.65	**2.59**	10	1.00	2.59	2.59	82	Low	≥80		
8	First	Centrolophidae	Hyperoglyphe antarcti	Blue-eye trevalla	Non-invertebrate	WCDSF	2	3	1	2	2	1	3		2.00	3	3	1	3	1.65	**2.59**	10	1.00	2.59	2.59	82	Low	≥80		

6.2 Level 3 - Fishing mortality and spawning potential ratio results for all scenarios

WA dhufish

Specie	Sector	ManagementZor	Year	F	Low 60%C	Upp 60%C	Low95CL	Upp95CL	SPR1	Low 60%C	Upp 60%C	Low95CL	Upp95CL	SPR2	Low 60%C	Upp 60%C	Low95CL	Upp95CL
Dhufish	Combined	Combined	2003-05	0.15	0.14	0.16	0.14	0.17	0.34	0.33	0.35	0.32	0.37	**0.28**	0.27	0.29	0.26	0.31
Dhufish	Combined	Combined	2006-08	0.19	0.18	0.20	0.17	0.21	0.31	0.30	0.32	0.29	0.33	**0.25**	0.24	0.26	0.23	0.27
Dhufish	Combined	Combined	2009-11	0.17	0.17	0.18	0.16	0.19	0.30	0.30	0.31	0.29	0.32	**0.24**	0.23	0.24	0.22	0.25
Dhufish	Combined	Combined	2012-14	0.22	0.21	0.22	0.20	0.23	0.26	0.26	0.27	0.25	0.27	**0.19**	0.19	0.20	0.18	0.21
Dhufish	Combined	Combined	2015-17	0.18	0.17	0.18	0.17	0.19	0.30	0.29	0.30	0.28	0.31	**0.23**	0.23	0.24	0.22	0.25
Dhufish	Combined	North	2003-05	0.20	0.18	0.21	0.17	0.23	0.30	0.29	0.31	0.27	0.33	**0.23**	0.22	0.25	0.21	0.27
Dhufish	Combined	North	2006-08	0.26	0.24	0.27	0.22	0.29	0.28	0.27	0.29	0.26	0.31	**0.22**	0.21	0.23	0.20	0.25
Dhufish	Combined	North	2009-11	0.21	0.20	0.21	0.19	0.22	0.27	0.26	0.27	0.25	0.28	**0.20**	0.19	0.21	0.18	0.22
Dhufish	Combined	North	2012-14	0.28	0.26	0.29	0.25	0.30	0.23	0.22	0.23	0.21	0.24	**0.16**	0.15	0.16	0.14	0.17
Dhufish	Combined	North	2015-17	0.29	0.27	0.30	0.26	0.32	0.22	0.21	0.23	0.21	0.24	**0.15**	0.14	0.16	0.13	0.17
Dhufish	Commercial	North	2003-05	0.20	0.19	0.22	0.17	0.23	0.29	0.28	0.30	0.27	0.32	**0.23**	0.21	0.24	0.20	0.26
Dhufish	Commercial	North	2006-08	0.24	0.22	0.26	0.19	0.29	0.30	0.28	0.31	0.27	0.34	**0.23**	0.22	0.25	0.20	0.28
Dhufish	Commercial	North	2009-11	0.20	0.19	0.21	0.18	0.22	0.27	0.26	0.28	0.25	0.29	**0.20**	0.19	0.21	0.18	0.23
Dhufish	Commercial	North	2012-14	0.27	0.25	0.28	0.23	0.30	0.23	0.22	0.23	0.21	0.25	**0.16**	0.15	0.17	0.14	0.18
Dhufish	Commercial	North	2015-17	0.33	0.30	0.36	0.26	0.40	0.21	0.19	0.22	0.18	0.24	**0.13**	0.12	0.15	0.11	0.17
Dhufish	Recreational	North	2003-05															
Dhufish	Recreational	North	2006-08	0.26	0.24	0.28	0.21	0.31	0.28	0.27	0.30	0.26	0.32	**0.22**	0.20	0.23	0.19	0.26
Dhufish	Recreational	North	2009-11	0.23	0.22	0.24	0.21	0.25	0.25	0.24	0.26	0.24	0.27	**0.18**	0.18	0.19	0.17	0.20
Dhufish	Recreational	North	2012-14	0.26	0.25	0.28	0.23	0.30	0.23	0.22	0.24	0.21	0.26	**0.16**	0.15	0.17	0.14	0.19
Dhufish	Recreational	North	2015-17	0.28	0.26	0.29	0.24	0.31	0.23	0.22	0.23	0.21	0.25	**0.16**	0.15	0.16	0.14	0.18
Dhufish	Recreational	South	2003-05	0.14	0.13	0.15	0.12	0.16	0.36	0.34	0.37	0.33	0.40	**0.30**	0.28	0.31	0.26	0.34
Dhufish	Recreational	South	2006-08	0.16	0.15	0.17	0.14	0.18	0.33	0.32	0.34	0.31	0.36	**0.27**	0.26	0.29	0.24	0.31
Dhufish	Recreational	South	2009-11	0.15	0.14	0.16	0.13	0.17	0.35	0.34	0.36	0.33	0.39	**0.29**	0.28	0.31	0.26	0.33
Dhufish	Recreational	South	2012-14	0.17	0.16	0.18	0.16	0.19	0.30	0.30	0.31	0.28	0.32	**0.24**	0.23	0.25	0.22	0.26
Dhufish	Recreational	South	2015-17	0.14	0.13	0.15	0.12	0.15	0.35	0.34	0.36	0.33	0.38	**0.29**	0.28	0.30	0.27	0.32
Dhufish	Recreational	Metro	2003-05	0.18	0.17	0.19	0.15	0.21	0.30	0.29	0.32	0.28	0.34	**0.24**	0.23	0.26	0.21	0.28
Dhufish	Recreational	Metro	2006-08	0.21	0.20	0.22	0.18	0.24	0.27	0.26	0.29	0.25	0.30	**0.21**	0.20	0.22	0.18	0.24
Dhufish	Recreational	Metro	2009-11	0.20	0.19	0.21	0.18	0.23	0.28	0.27	0.29	0.26	0.31	**0.22**	0.20	0.23	0.19	0.25
Dhufish	Recreational	Metro	2012-14	0.21	0.20	0.22	0.18	0.24	0.25	0.24	0.26	0.23	0.28	**0.18**	0.17	0.20	0.16	0.21
Dhufish	Recreational	Metro	2015-17	0.21	0.20	0.22	0.18	0.24	0.26	0.25	0.27	0.24	0.29	**0.19**	0.18	0.21	0.17	0.23
Dhufish	Recreational	South-West	2003-05	0.09	0.08	0.10	0.06	0.12	0.48	0.45	0.52	0.41	0.57	**0.43**	0.40	0.47	0.36	0.54
Dhufish	Recreational	South-West	2006-08	0.09	0.08	0.11	0.07	0.13	0.50	0.46	0.53	0.43	0.58	**0.45**	0.41	0.49	0.38	0.54
Dhufish	Recreational	South-West	2009-11	0.12	0.11	0.14	0.09	0.16	0.47	0.45	0.50	0.42	0.54	**0.42**	0.40	0.45	0.37	0.50
Dhufish	Recreational	South-West	2012-14	0.15	0.14	0.16	0.13	0.17	0.35	0.34	0.37	0.32	0.39	**0.29**	0.28	0.31	0.26	0.33
Dhufish	Recreational	South-West	2015-17	0.12	0.11	0.13	0.10	0.14	0.39	0.38	0.40	0.36	0.42	**0.33**	0.32	0.35	0.30	0.37

Sensitivity analysis																		
Base case (2015-17, WCB)				F	Low60CL	Upp60CL	Low95CL	Upp95CL	SPR1	Low60CL	Upp60CL	Low95CL	Upp95CL	SPR2	Low60CL	Upp60CL	Low95CL	Upp95CL
Dhufish	Combined	Combined	2015-17	0.18	0.17	0.18	0.17	0.19	0.30	0.29	0.30	0.28	0.31	**0.23**	**0.23**	**0.24**	0.22	0.25
Updated growth (higher k)																		
Dhufish	Combined	Combined	2015-17	0.18	0.17	0.18	0.17	0.19	0.34	0.34	0.34	0.35	0.36	**0.28**	**0.28**	**0.29**	0.27	0.30
Post release mortality (50%) of selected, non-retained fish																		
Dhufish	Combined	Combined	2015-17	0.18	0.17	0.18	0.17	0.19	0.24	0.23	0.24	0.22	0.25	**0.17**	**0.16**	**0.17**	0.15	0.18

Snapper

Specie	Sector	ManagementZor	Year	F	Low60CL	Upp60CL	Low95CL	Upp95CL	SPR1	Low60CL	Upp60CL	Low95CL	Upp95CL	SPR2	Low60CL	Upp60CL	Low95CL	Upp95CL
Snapper	Combined	Combined	2003-05	0.39	0.38	0.41	0.35	0.44										
Snapper	Combined	Combined	2006-08	0.23	0.23	0.24	0.21	0.25										
Snapper	Combined	Combined	2009-11	0.29	0.28	0.30	0.27	0.31										
Snapper	Combined	Combined	2012-14	0.20	0.19	0.20	0.18	0.21										
Snapper	Combined	Combined	2015-17	0.20	0.19	0.20	0.18	0.21										
Snapper	Combined	North	2003-05	0.46	0.43	0.48	0.41	0.51	0.15	0.15	0.16	0.14	0.17	0.08	0.07	0.08	0.06	0.09
Snapper	Combined	North	2006-08	0.27	0.26	0.28	0.24	0.29	0.18	0.18	0.19	0.17	0.20	0.11	0.10	0.12	0.09	0.13
Snapper	Combined	North	2009-11	0.39	0.38	0.40	0.36	0.42	0.18	0.18	0.19	0.17	0.19	0.11	0.10	0.11	0.10	0.12
Snapper	Combined	North	2012-14	0.23	0.22	0.24	0.21	0.25	0.27	0.26	0.27	0.25	0.28	0.20	0.19	0.21	0.18	0.22
Snapper	Combined	North	2015-17	0.22	0.21	0.23	0.20	0.24	0.28	0.27	0.29	0.26	0.30	0.22	0.21	0.22	0.19	0.24
Snapper	Commercial	North	2003-05	0.44	0.42	0.46	0.39	0.49	0.16	0.15	0.16	0.14	0.17	0.08	0.07	0.09	0.07	0.10
Snapper	Commercial	North	2006-08	0.29	0.27	0.30	0.26	0.31	0.17	0.16	0.18	0.16	0.19	0.10	0.09	0.10	0.08	0.12
Snapper	Commercial	North	2009-11	0.41	0.40	0.43	0.38	0.45	0.18	0.17	0.18	0.17	0.19	0.10	0.10	0.11	0.09	0.12
Snapper	Commercial	North	2012-14	0.23	0.22	0.24	0.20	0.25	0.27	0.26	0.28	0.25	0.29	0.20			0.18	0.23
Snapper	Commercial	North	2015-17	0.22	0.21	0.23	0.19	0.24	0.29	0.28	0.30	0.27	0.31	0.22	0.21	0.23	0.20	0.25
Snapper	Commercial	Kalbarri	2003-05	0.53	0.47	0.58	0.37	0.66	0.21	0.19	0.22	0.18	0.26	0.14	0.12	0.15	0.11	0.19
Snapper	Commercial	Kalbarri	2006-08	0.27	0.25	0.29	0.23	0.31	0.18	0.17	0.19	0.16	0.21	0.11	0.10	0.12	0.08	0.14
Snapper	Commercial	Kalbarri	2009-11	0.49	0.46	0.52	0.41	0.56	0.16	0.16	0.17	0.15	0.19	0.09	0.08	0.10	0.07	0.11
Snapper	Commercial	Kalbarri	2012-14	0.26	0.25	0.27	0.23	0.29	0.24	0.23	0.25	0.21	0.26	0.17	0.16	0.18	0.14	0.19
Snapper	Commercial	Kalbarri	2015-17	0.27	0.26	0.29	0.23	0.31	0.24	0.22	0.25	0.21	0.27	0.17	0.15	0.18	0.14	0.20
Snapper	Commercial	Mid	2003-05	0.74	0.69	0.78	0.63	0.85	0.11	0.10	0.11	0.10	0.12	0.03	0.02	0.03	0.02	0.04
Snapper	Commercial	Mid	2006-08	0.31	0.29	0.33	0.27	0.35	0.16	0.15	0.17	0.14	0.18	0.08	0.07	0.09	0.06	0.11
Snapper	Commercial	Mid	2009-11	0.37	0.35	0.39	0.33	0.41	0.19	0.18	0.19	0.17	0.20	0.11	0.10	0.12	0.09	0.13
Snapper	Commercial	Mid	2012-14	0.22	0.21	0.23	0.20	0.24	0.27	0.26	0.28	0.25	0.29	0.20	0.19	0.21	0.18	0.22
Snapper	Commercial	Mid	2015-17	0.18	0.17	0.19	0.15	0.21	0.33	0.32	0.35	0.30	0.37	0.27	0.26	0.29	0.24	0.32
Snapper	Recreational	North	2003-05															
Snapper	Recreational	North	2006-08	0.27	0.25	0.30	0.22	0.33	0.21	0.19	0.22	0.18	0.25	0.14	0.12	0.15	0.10	0.18
Snapper	Recreational	North	2009-11	0.35	0.34	0.37	0.31	0.40	0.19	0.18	0.20	0.17	0.21	0.12	0.11	0.13	0.10	0.14
Snapper	Recreational	North	2012-14	0.25	0.24	0.27	0.22	0.29	0.24	0.23	0.25	0.22	0.27	0.17	0.16	0.19	0.15	0.20
Snapper	Recreational	North	2015-17	0.25	0.22	0.27	0.20	0.30	0.25	0.23	0.27	0.21	0.29	0.18	0.16	0.20	0.14	0.23
Snapper	Recreational	Mid	2003-05															
Snapper	Recreational	Mid	2006-08	0.27	0.25	0.30	0.22	0.33	0.20	0.19	0.22	0.17	0.25	0.13	0.11	0.15	0.09	0.19
Snapper	Recreational	Mid	2009-11	0.38	0.36	0.40	0.33	0.42	0.18	0.17	0.19	0.16	0.20	0.10	0.10	0.11	0.09	0.13
Snapper	Recreational	Mid	2012-14	0.26	0.25	0.28	0.22	0.30	0.24	0.23	0.25	0.21	0.27	0.17	0.15	0.18	0.14	0.20
Snapper	Recreational	Mid	2015-17	0.25	0.23	0.27	0.20	0.30	0.25	0.23	0.26	0.21	0.29	0.18	0.16	0.20	0.14	0.23
Snapper	Combined	South	2003-05	0.33	0.29	0.38	0.23	0.44	0.10	0.08	0.12	0.06	0.15	0.01	0.00	0.04	0.00	0.08
Snapper	Combined	South	2006-08	0.18	0.17	0.20	0.15	0.22	0.17	0.16	0.19	0.14	0.22	0.10	0.08	0.12	0.06	0.15
Snapper	Combined	South	2009-11	0.15	0.14	0.16	0.12	0.17	0.25	0.23	0.27	0.21	0.29	0.18	0.16	0.20	0.14	0.23
Snapper	Combined	South	2012-14	0.13	0.12	0.14	0.11	0.15	0.26	0.25	0.28	0.23	0.31	0.20	0.18	0.22	0.16	0.25
Snapper	Combined	South	2015-17	0.15	0.14	0.16	0.13	0.17	0.23	0.22	0.25	0.20	0.27	0.16	0.15	0.18	0.13	0.20
Snapper	Recreational	South	2003-05	0.29	0.26	0.33	0.21	0.38	0.12	0.10	0.14	0.08	0.18	0.04	0.02	0.06	0.00	0.11
Snapper	Recreational	South	2006-08	0.18	0.17	0.20	0.14	0.22	0.17	0.16	0.19	0.14	0.24	0.10	0.08	0.12	0.06	0.17
Snapper	Recreational	South	2009-11	0.15	0.14	0.17	0.13	0.18	0.24	0.22	0.26	0.20	0.28	0.17	0.15	0.19	0.13	0.22
Snapper	Recreational	South	2012-14	0.13	0.12	0.14	0.11	0.15	0.27	0.26	0.30	0.23	0.32	0.21	0.19	0.23	0.16	0.26
Snapper	Recreational	South	2015-17	0.15	0.14	0.16	0.13	0.17	0.23	0.22	0.25	0.20	0.27	0.16	0.15	0.18	0.13	0.20
Snapper	Recreational	Metro	2003-05															
Snapper	Recreational	Metro	2006-08															
Snapper	Recreational	Metro	2009-11	0.23	0.21	0.25	0.18	0.27	0.16	0.14	0.18	0.13	0.21	0.08	0.07	0.10	0.05	0.14
Snapper	Recreational	Metro	2012-14	0.19	0.17	0.20	0.15	0.22	0.20	0.18	0.22	0.16	0.26	0.13	0.11	0.15	0.09	0.19
Snapper	Recreational	Metro	2015-17	0.19	0.17	0.21	0.15	0.23	0.20	0.18	0.22	0.15	0.26	0.12	0.10	0.15	0.08	0.19
Snapper	Recreational	South-West	2003-05															
Snapper	Recreational	South-West	2006-08															
Snapper	Recreational	South-West	2009-11	0.13	0.11	0.14	0.09	0.16	0.37	0.34	0.40	0.31	0.45	0.31	0.28	0.35	0.24	0.40
Snapper	Recreational	South-West	2012-14	0.11	0.10	0.12	0.09	0.14	0.34	0.32	0.37	0.29	0.40	0.28	0.26	0.31	0.22	0.35
Snapper	Recreational	South-West	2015-17	0.14	0.13	0.15	0.12	0.16	0.29	0.27	0.31	0.25	0.34	0.22	0.21	0.25	0.19	0.28

Sensitivity analysis

Base case (2015-17)				F	Low60CL	Upp60CL	Low95CL	Upp95CL	SPR1	Low60CL	Upp60CL	Low95CL	Upp95CL	SPR2	Low60CL	Upp60CL	Low95CL	Upp95CL
Snapper	Combined	North	2015-17	0.22	0.21	0.23	0.20	0.24	0.28	0.27	0.29	0.26	0.30	0.22	0.21	0.22	0.19	0.24
Snapper	Recreational	South	2015-17	0.15	0.14	0.16	0.13	0.17	0.23	0.22	0.25	0.20	0.27	0.16	0.15	0.18	0.13	0.20
Post release mortality (25%) of selected, non-retained fish																		
Snapper	Combined	North	2015-17	0.22	0.21	0.23	0.20	0.24	0.26	0.25	0.27	0.24	0.28	0.19	0.18	0.20	0.17	0.22
Snapper	Recreational	South	2015-17	0.15	0.14	0.16	0.13	0.17	0.22	0.20	0.23	0.19	0.25	0.15	0.13	0.16	0.11	0.19

6.3 Level 4 – Standardised catch rates and biomass dynamics models

Catch and Effort

Catch was based on the landed weight of each species. For fish that were not landed whole e.g. gilled and gutted, landed weight was adjusted according to standard DPIRD conversion codes. For the period of monthly returns, the number of fishing days recorded was used as the measure of effort. For daily data, effort was measured in fishing hours. There are additional effort measures in both data sets, including the number of hooks and number of lines, that could be investigated for use in future analyses after sufficient data validation. CPUE for each unique fishing event (monthly or daily) was calculated as the catch divided by the effort. For monthly data, a fishing event refers to a monthly record of fishing by an individual vessel in an individual 60 x 60 nm block using a unique fishing method. For daily data, a fishing event refers to a daily record of fishing by an individual vessel in an individual 10 x 10 nm block using a unique fishing method.

Season

Analyses were conducted by calendar year (January - December) and by financial year (July - June). For dhufish, calendar year may not be appropriate, with the birthdate residing in the summer months (January- February).

Blocks

Spatially, monthly data is recorded in 60 x 60 nm blocks whilst daily data is recorded in 10 x 10 nm blocks. For analysis, the daily 10 x 10 nm blocks were aggregated to 30 x 30 nm blocks.

Gear methods

There are various fishing methods employed in this fishery. The main species are primarily caught by droplining (DL) and handlining (HL) methods. Due to the nature of the methods, DL records were analysed separately from HL records. There are a number of different hand-line methods, which are considered to be used in a consistent manner, and thus have been pooled for analysis. Mixed methods, i.e. where the method was a combination of DL and HL, were removed from the analysis due to the inability to differentiate between each method. Other methods “JIG”, “SJ”, and “YG” were removed from the analysis as the number of records were minimal and thus only accounted for a small catch of the target species. For monthly data, analysis was limited to years 1985-2007 for droplining and 1988-2007 for handlining, noting that the conversion to daily logbooks occurred in 2008.

Vessels and skippers

There were several vessels operating in this fishery, many of which fished for only a small number of years (Figures 6.1, 6.2). Although data were available from 1975, prior to 1985 there was an increase in the number of vessels reporting dhufish catch by both droplining and handlining methods, thus it was considered to be an exploratory fishing period and therefore catch rates may not be a reliable measure of abundance. Handlining records prior to 1988 also indicated the presence of different fishing tactics due to varying proportions of dhufish in fishing records. Only a small amount of monthly records were available after 2007, due to the conversion to daily logbook reporting.

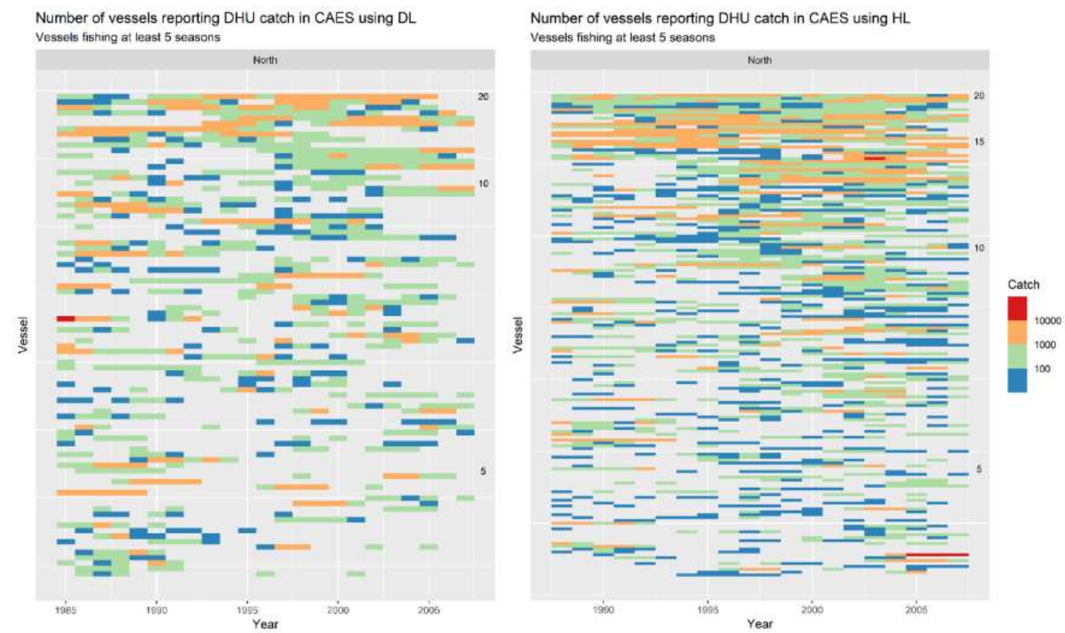

Figure 1. Number of vessels reporting monthly dhufish catches within the north region using DL (left) and HL (right) methods.

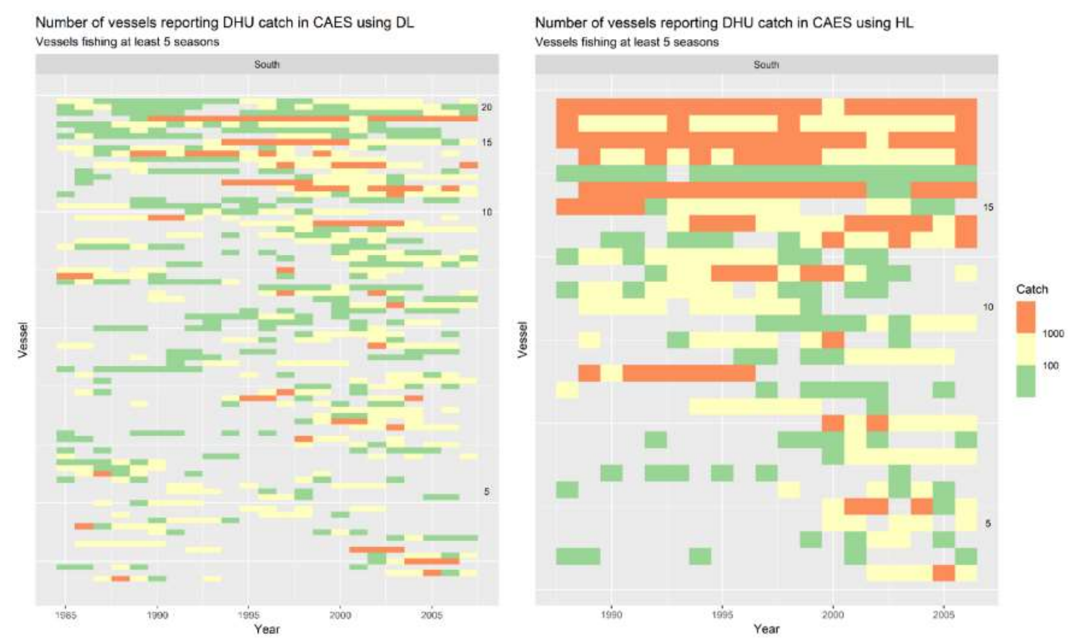

Figure 6.2. Number of vessels reporting monthly dhufish catches within the south region using DL (left) and HL (right) methods.

For daily data, vessel name and skipper are reported, and used in the CPUE analysis. Individual skippers have a wide range of abilities to target and catch particular species based on their avidity (years of experience) and knowledge of the fishery, with only relatively few fishers fishing consistently across all years (Figure 6.3). This fishing knowledge can also be affected by the vessel they use while fishing, e.g. a smaller boat may not fish in deeper waters; gear technology on the boat may change etc. Therefore, a combination of skipper and vessel (boat name) has been used.

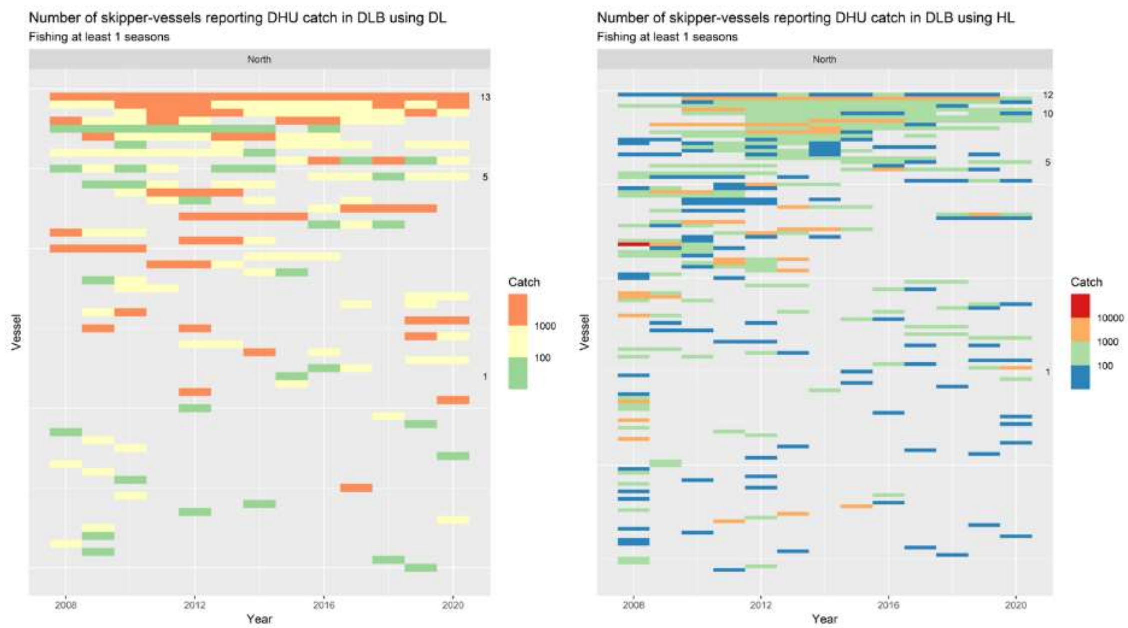

Figure 6.3. Number of vessels reporting daily dhufish catches within the north region using DL (left) and HL (right) methods. Note there were insufficient data for the south region.

Targeting

In daily logbooks for each unique fishing event, fishers are required to state if they are targeting either dhufish or snapper. There are concerns however, whether these targeting variables have been recorded consistently by fishers, and the possible unreliability of their use, therefore have not been used in this analysis. To investigate the influence of targeting in both daily and monthly data, a subset of records were identified as those considered to be targeting the species of interest using a year-specific qualification level (QL). This was calculated as the minimum proportion of that species in an individual record to explain 90% of the cumulative catch of that year.

Analysis of Monthly Data Sets

In the North region, the catch of dhufish across the years of monthly data (1975-2007) were taken primarily from the Midwest zone (DL 95.6%, HL 92.4%) (Figure

6.4). Therefore, the analysis of dhufish CPUE for the North region was limited to the Midwest zone, with CPUEs analysed separately by the HL and DL methods. In the South region, the catch of dhufish across the years of monthly data (1975-2007) by DL method was primarily in the Metropolitan zone (74.2%) and for HL methods reported mainly from the Southwest zone (65.8%) (Figure 6.4), due to high catches in the summer months. The analysis of dhufish CPUE for the South region was analysed separately for the Metropolitan (DL, HL) and Southwest (HL only) zones, with only results for the South-west limited to the summer months (November-February) shown below (Figure 6.4).

For snapper in the North region, CPUE by HL and DL methods were analysed separately using data from the Midwest zone. Similarly, CPUE of snapper in the South region was analysed by both DL and HL methods.

To facilitate the CPUE standardisation process for dhufish and snapper from monthly data, the "main vessels" were identified as those vessels fishing for the species of interest for a minimum of 5 and 10 years during this period for DL and HL, respectively.

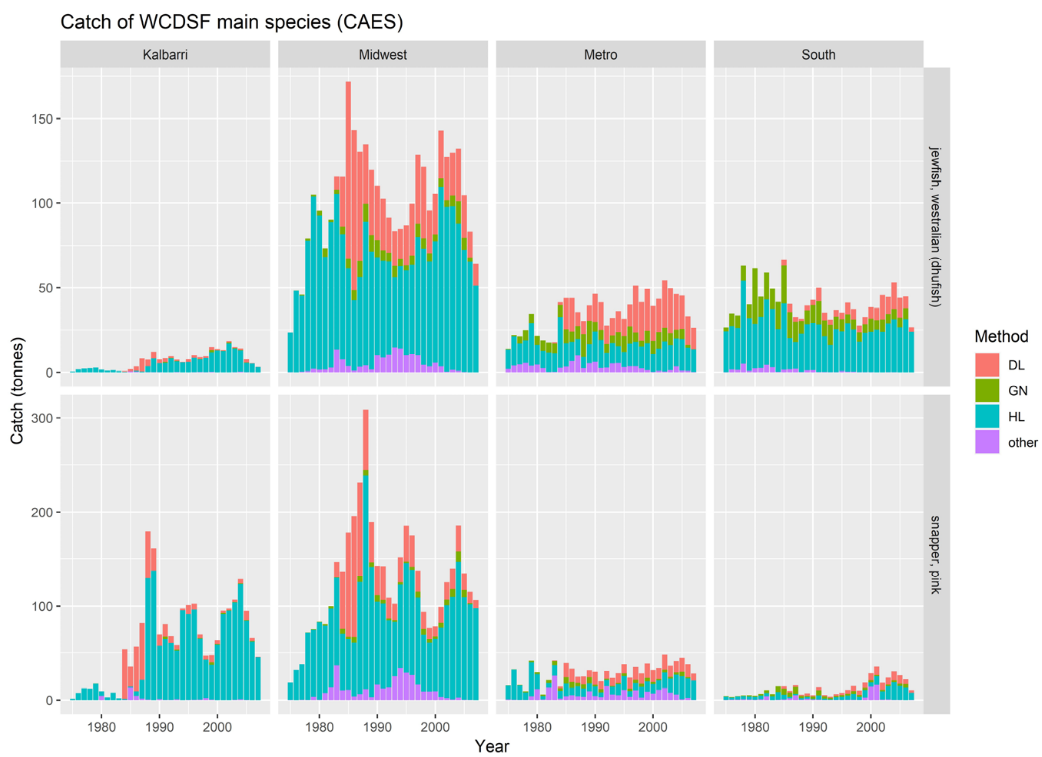

Figure 6.4. Annual catches (tonnes) from monthly records of dhufish and snapper in Kalbarri, Midwest, Metropolitan and Southern fishing zones from 1975-2007.

Analysis of Daily Data Sets

In the North region, daily dhufish CPUE was analysed by both DL and HL methods using data from the Midwest zone. Whilst in the South region, dhufish CPUE was analysed by only DL and HL methods using data from the Southwest zone (Figure 6.5). Note that no commercial fishing is permitted in the Metropolitan zone.

For daily logbook records of snapper in the North region, CPUE by HL method were analysed using data from the Midwest and Kalbarri zones, and CPUE by DL method analysed using data from the Midwest zone only (Figure 6.5). The CPUE of snapper from daily logbooks for the South region (i.e. South-west Area) had insufficient data for consideration of either HL or DL methods.

For CPUE standardisation of dhufish and snapper from daily data, "main skipper-vessels" were identified as those skipper-vessel combinations fishing a minimum of 3 and 5 years during this period for DL and HL, respectively.

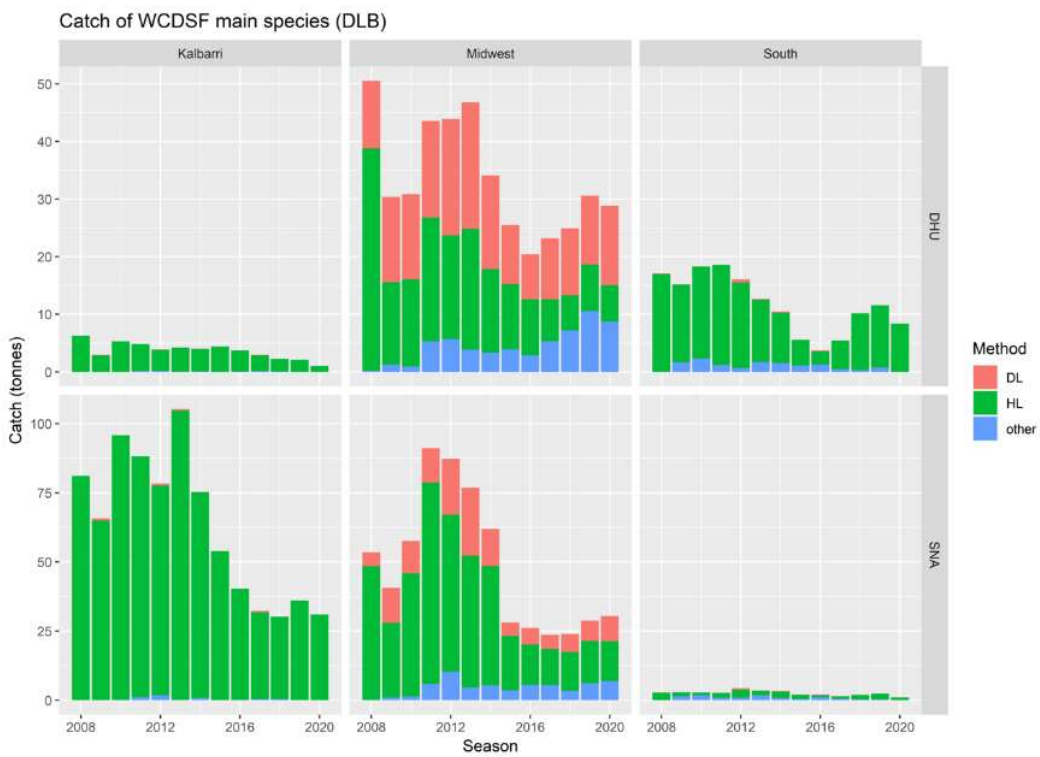

Figure 6.5. Annual catches (tonnes) from daily logbooks of dhufish (DHU) and snapper (SNA) in the Kalbarri, Midwest and South-west areas from 2008-2020. Note that no commercial fishing for demersal species is permitted within the Metropolitan Area.

CPUE Standardisation

Annual time series of raw CPUE for each species were calculated using (a) the mean-of-ratios (MEAN) and (b) ratio-of-means (NOMINAL) estimators using all records, with associated 95% confidence intervals (CIs). The mean-of-ratios estimator is the mean of all CPUE records for a given year, with 95% CIs calculated as $\pm 1.96SE$ where $SE = \frac{\sigma}{\sqrt{n}}$, and σ and n are the standard deviation and count of CPUE records, respectively, for each year. The ratio-of-means estimator is calculated as the mean catch divided by the mean effort, with 95% CIs calculated as $\pm 1.96SE$ where

$$SE = \sqrt{\frac{1}{n}\left(\frac{\overline{C}^2 \sigma_E^2}{\overline{E}^4} + \frac{\sigma_C^2}{\overline{E}^2} - \frac{2\overline{C}\rho_{CE}\sigma_E\sigma_C}{\overline{E}^3}\right)}$$

where $\overline{C}$ and $\overline{E}$ are the mean catch and effort respectively, σ_C and σ_E are the standard deviations of catch and effort respectively, n is the number of data and ρ_{CE} is the correlation between the catch and effort values.

A subset of records, within both monthly and daily data sets, were identified as targeting the species of interest using the QL approach described above. A further subset of records was identified involving "main vessels" or "main skipper-vessels" for monthly and daily data, respectively, which were identified as above. Annual mean CPUE (with 95% CIs) were calculated for the subset of targeted records, and again for the smaller subset of targeted records by main vessels/skipper-vessels.

A Generalised Linear Modelling (GLM) framework was used to derive standardised annual time series of CPUE for each species (dhufish and snapper), within each region, i.e. North and South, using the refined subset of targeted records involving the main vessels, or main skipper-vessel combinations. The log-transformed CPUE for the monthly data set was modelled as a function of year, Y_i, month, M_j, block, B_k (60 x 60 nm) and vessel, V_l, with all factors treated as categorical variables.

$$\ln(CPUE_{ijkl}) \sim Y_i + M_j + B_k + V_l + \epsilon_{ijkl}$$

where $\epsilon_{ijkl} \sim N(0, \sigma^2)$ denotes normally distributed errors. The vessel, or skipper-vessel, effect indicates either a fixed effect or a random effect where $V_l \sim N(0, \sigma_v^2)$. A similar modelling process was undertaken for the log-transformed CPUE from daily logbook records, where the explanatory variables included year, month, block (30 x 30 nm) and skipper-vessel combination. Where spatial blocks contained a low number of records, they were combined with neighbouring blocks, or, where not appropriate, they were omitted from the analysis.

Two separate analyses were undertaken to consider the vessel effect as either a fixed or random effect, with similar results. Therefore, only the model involving vessel (or skipper-vessel) as a random effect has been included in this summary. Preliminary analyses included two-way interactions between year, month and block effects. Whilst some interactions were marginally significant, the resulting annual indices were similar to the model of main effects only. Future work will include further examination of interactions. Standardised annual time series were then calculated as the back-transformed estimated marginal mean of the year effect with associated 95% CIs. To enable comparison between various calculations of CPUE, and between fishing method, CPUE indices were normalised to a mean of one.

After the CPUE standardisation process was complete, the normalised indices from both DL and HL methods were adjusted by an efficiency schedule as per Marriott et al., (2011). This schedule accounts for increased fishing efficiencies by operators within the demersal scalefish fishery in the WCB between 1975-2006 (Marriott et al., 2011), due to, for example, the introduction of GPS and colour sounders, and hydraulic reels. As Marriott et al. (2011) indicated that this schedule was a minimum level, subsequent biomass dynamic modelling also considered additional annual efficiencies which varied by species. For dhufish in both North and South regions, an additional increase of 3% for monthly data, and 1% for daily data were assumed, and for snapper, an increase of 1% for both monthly and daily data were assumed. Initial investigation also explored increases of 2% for monthly data and 1% for daily data for both species in both areas.

Biomass Dynamics Modelling

Biomass dynamics fishery models are relatively simple surplus production models representing stock dynamics in terms of changing levels of annual biomass (B_t), the intrinsic rate of growth (r), the carrying capacity of a population (K), and annual removals by fishers (C_t). The traditional Schaefer (Schaefer, 1954) production model, employing a logistic function, was used with an annual time step t. To account for both observation and process errors, models were implemented in a state-space framework (e.g. Best and Punt, 2020; Punt, 2003; Zhou et al., 2009). The equation for the model is

$$B_{t+1} = (B_t + P_t - \hat{C}_t)e^{\xi_t},$$

where $\hat{C}_t$ is the estimated total annual removals and ξ_t is the extent of the process errors in year t, $\xi_t \sim N(0; \sigma_R^2)$, estimated as a random effect, and the annual production P_t is given by

$$P_t = rB_t\left(1 - \frac{B_t}{K}\right).$$

The predicted catch, $\hat{C}_t$, was estimated from the annual harvest rate, H_t, and biomass, B_t, such that

$$\hat{C}_t = H_t B_t,$$

where $H_t = 1/(1 + e^{-F_t})$, and F_t is a logistic-transformed parameter value for annual exploitation in year t, estimated as a fixed parameter.

The biomass in the first season was assumed to equal $p_I K$, where for snapper, p_I was set to 0.9 and for dhufish, p_I was set to 0.8 as it was assumed that some exploratory fishing had taken place prior to this.

All models were implemented in Template Model Builder (TMB) (Kristensen et al., 2015) and fitted by minimising the sum of the negative log-likelihoods associated with the catch series, the random effects and each CPUE series

$$\lambda_T = \lambda_C + \lambda_R + \sum_i \lambda_{U_i},$$

The negative log-likelihood for each CPUE time series, λ_{U_i}, was calculated as

$$\lambda_{U_i} = \sum_{t \in T_i} \left(0.5\log_e(\sigma^2_{M_{i,t}} + \sigma^2_{P_i}) + 0.5\log_e(2\pi) + \frac{(\log_e(U_t) - \log_e(\widehat{U}_t))^2}{2(\sigma^2_{M_{i,t}} + \sigma^2_{P_i})} \right),$$

where for each CPUE time series, U_t is the standardized CPUE as outlined above, and $\widehat{U}_t$ is the estimated annual CPUE. $\sigma^2_{M_{i,t}}$ is the variance associated with U_t calculated by the catch rate standardisation analysis, and $\sigma^2_{P_i}$ is an additional, unmeasured variance associated with input data.

The catch negative log-likelihood, λ_C, was calculated as

$$\lambda_C = \sum_t \left(0.5\log_e(\sigma^2_c) + 0.5\log_e(2\pi) + \frac{(\log_e(C_t) - \log_e(\hat{C}_t))^2}{2\sigma^2_c} \right),$$

where σ^2_c is the variance associated with the catch time series, assumed to be 0.05.

The random effects negative log-likelihood, λ_ξ, was calculated as

$$\lambda_\xi = \sum_t \left(0.5\log_e(\sigma^2_R) + 0.5\log_e(2\pi) + \frac{\epsilon^2_t}{2\sigma^2_R} \right),$$

where σ_R is the process error. Due to observed periods of high variation in annual snapper CPUE (likely reflecting recruitment variation), σ_R for snapper was set to a higher value (0.3) than for dhufish (0.2), for which the inter-annual variation in CPUE was less pronounced.

Uncertainty associated with model parameters and derived variables was estimated by resampling 1000 samples from a multivariate normal distribution. Estimates of the lower and upper 95% confidence limits were calculated as the 2.5th and 97.5th quantiles of the 1000 sets of sampled estimates.

6.4 Level 5 - Integrated simulation models of relative biomass

Overview of age-structured models applied to WA dhufish and snapper: model features, input data and assumptions

An age-structured dynamic model, similar to that applied in 2018 for 'stock recovery simulations' has been applied to the available catch and age composition and CPUE data for Western Australian dhufish and Snapper.
The models have the following attributes:
- Two sexes
- Two areas (North, including Kalbarri and Mid-west areas, and South, including Metropolitan and South-west areas)
- Single sector. Although dhufish and snapper are caught by several fishing sectors (commercial line, recreational line and other, i.e. commercial TDGDLF, CSLPF), the vast majority of the catch is taken by the commercial and recreational line sectors, which use similar gears.
- The model fitted to 'driven' by catch (1975-2020) and fitted to age composition data (for years when collected) and multiple abundances indices (CPUE time series from commercial handline and dropline fisheries). The CPUE series are based on monthly CAES data (for earlier years) and daily logbook data (since 2008). For sensitivity

analysis, the model is also fitted without using CPUE data.
- The model is set to provide simulation projections of fishing mortality (F) and female relative biomass (B_{rel}) to 2030, i.e. the predicted stock recovery time period for the stocks of both species.
- Growth (estimated outside the model) considered differences between sexes. The growth parameter inputs differ from previous model runs, having some effects on simulation results.
- Growth is assumed to vary temporally. Growth in early years (1996-99) is based on von Bertalanffy growth parameters reported by Hesp et al. (2002) and a 'year effects' growth model (similar to that described by Cottingham et al., 2016) for later years (2002-18), allowing the von Bertalanffy growth coefficient (k) to differ among years.
- The model estimates separate (Beverton & Holt) stock recruitment relationships for each area (h set at 0.75). Thus, recruitment in each area is assumed to be related to the level of female spawning biomass in that area (rather than that for all areas).
- Movement of fish between areas is not considered in the model. Available evidence (e.g. different levels of recruitment variation among regions; otolith microchemistry, mark-recapture) suggests limited movements of adults among regions (Lenanton et al., 2009b; Fairclough et al., 2013; Crisafulli et al., 2019).
- The model for dhufish starts in 1965 (10 year burn-in period with specified, fixed mortality), with the initial population structure is considered to be at a fished equilbrium. For snapper, the model starts in 1960 (15 year burn-in period).
- For dhufish, gear selectivity was estimated outside the model by applying a catch curve analysis that incorporated an (asymptotic) logistic selection curve, using data collected by commercial fishers with permits to retain all sizes in the Mid-west region.

For snapper, reliable data on gear selectivity are not available. For snapper, the A_{50} for gear selectivity is currently offset by a specified amount from the estimated retention curves. For the southern region, this value varies (from 0.5 years, increasing to 2.0 years), to align with increased in the minimum legal length (MLL). - Fish retention curves were estimated for each area for specified time blocks. For dhufish, time periods were set to (1975-2000, 2004 and each year thereafter to 2017), matching periods when growth varied. For Snapper in the north region, the retention curve time blocks (1960-2006, 2007-08, 2009-10, 2011-14, 2015-16, 2017-19) were the same as those in the south except that a separate retention curve was also estimated for 2009. Note that, in the southern region, the minimum legal length for retention (MLL) changed from 410 mm pre-2009, to 450 mm in 2009, and 500 mm after 2009).
- The model incorporates a prior for the amount of variation in annual recruitment levels (i.e. 0.6 for the natural logarithms of the recruitment deviations).
- Estimated model parameters include F_{init} (for WA dhufish), retention curve parameters (A50 and slope) and recruitment deviations for the model 'burn-in' period and years of data (1975-2020 for dhufish, 1960-2020 for snapper) and the future projection period for both species (2021-2030).
- The model uses a 'plus group' calculation when estimating survival. The age corresponding to that plus group was increased (from previous modelling analyses) from 20+ to 30+ years, to allow for effects of increases in size/weight over this age range. The maximum model age was not increased further as, according to the

growth curves, there is limited growth beyond 30 years, allowing the number of 'zeros' needing to be adjusted (to 0.0001) when applying the (self-weighting) Dirichlet likelihood ('self-weighting'), for fitting the model to the age composition data, to be reduced (see Francis, 2014).

- Routines have recently been implemented to estimate values for MSY, FMSY and BMSY, based on either 1) per recruit calculations or 2) model rebuilding simulations with zero fishing mortality. This has allowed calculation of BMSY-related reference points for relative female biomass (i.e. target = 1.2BMSY, threshold = BMSY and limit = 0.5BMSY), rather than relying on proxies (F_{target}=0.4, $F_{threshold}$=0.3 and F_{limit}=0.2). As expected, given a steepness value of 0.75, the values of B_{rel} at BMSY is not dissimilar to the previously-used proxy of 0.3. Results presented are based on estimates from method 1. The two approaches yield similar results, but differ due to the former being based on an equilibrium state with initial growth/selectivity, and the latter being based on the final year prior to the projection period. Which is more appropriate warrants further consideration.
- The age at maturity is fixed across time periods. For snapper, age at maturity for both regions was re-estimated. These estimates differ to some extent (A50 increased) from those used previously (from Lenanton et al., 2009), based on a relatively small data set. This change in input biology parameters has some effect on results.
- Natural mortality (M y^{-1}) is specified as fixed constants for both species, set to 0.11 y^{-1} for dhufish (both areas), 0.144 y^{-1} for snapper in the northern area and 0.12 y^{-1} in the southern area (Wise et al., 2007). The value of 0.144 y^{-1}, based on a maximum observed age of 30 y, is now consistent with the M value applied in stocks assessments for snapper just to the north, in Gascoyne region, but differs from that used for previous assessments of snapper in the northern area of the West Coast Bioregion (0.12 y^{-1}).

Modelling results for WA dhufish

Biological relationships for dhufish

Analysis of available length-at-age data for dhufish indicates substantial temporal variation in mean length at age, with similar patterns in both regions. These differences are most apparent for younger fish, recently recruited into the fishery (i.e. when fish are still exhibiting substantial growth). For example, at ages 6, 7 and 8 years, the mean lengths at age in each region are at their least in the early-mid 2000s, and subsequently increase to values at or above those recorded in the mid 1990s (Figure 1a). The biological basis for these trends are not yet fully clear, but there are some hints as to the factors that could be involved, and others that probably are not.

As growth of dhufish is similar for the north and south regions which span several degrees of latitude (e.g. Hesp, 1996; Lenanton et al., 2009a), growth does not appear to vary markedly according to temperature, although the possibility that extreme temperature changes, such as the 2011 marine heat wave, affects growth cannot be discounted. Heavy exploitation in the mid-2000s will have affected, at least to some extent, the length-at-age trends for dhufish, as fishing with most gears (such as line fishing) disproportionately removes greater numbers of larger, fast-growing individuals at age from a population, and thus reduces mean size at age. Density-dependent effects have also been linked to temporal growth variation in many marine species, with higher densities, particularly early in life, associated with reduced growth size at age due, often due to factors such as competition for space and food. Of note is that the estimated recruitment deviation patterns for dhufish (shown further below) show evidence of well above average recruitment (and thus higher densities of 1+ juveniles) for several later years in the 1990s, whilst the mean size at age of newly-recruited fish (into the fishery) at around six years of age, happens to be least in the early-mid 2000s. Thus, perhaps, high juvenile abundance is associated with reduced growth observed in fish several years later when entering the fishery. There is also some anecdotal support for the view that juvenile recruitment in late 1990s was above average, with several hundred juveniles being be caught in Metropolitan waters by trawling on ‘hard substrate’ near reefs in 1997-1998 (Hesp et al., 2002), but very few such fish were caught by Department researchers in later years during this decade, using similar methods (including a trip to the same location where juveniles had previously been caught, with the same commercial trawl skipper that assisted the earlier study). More research on this aspect of dhufish biology is being undertaken, as it has important implications for assessment results (increased growth rate in recent years leads to increased estimates for annual biomass).

Dhufish growth was modelled employing a traditional von Bertalanffy growth model for early years (1996-98) and a ‘year-effects’ growth model (similar to that described by Cottingham et al., 2016) for latter years (2002-18), which allowed the growth coefficient (k) to vary among years (with the asymptotic length parameter L_∞ kept constant due to limited data for old fish in many years). The analyses indicated that the lengths at age estimated from growth models for each region were similar (consistent with earlier research, e.g. Hesp, 1996; Lenanton et al., 2009), and thus for the preliminary growth analysis undertaken, the data were pooled for the two regions. The growth modelling results indicate an increasing trend in size at age since the early 2000s, as appears evident in the data. This analysis represents a first attempt to model temporal growth changes applying a ‘year effects’ growth model (Figure 2). More investigation, refinement and review of this work would be valuable (Figure 1b).

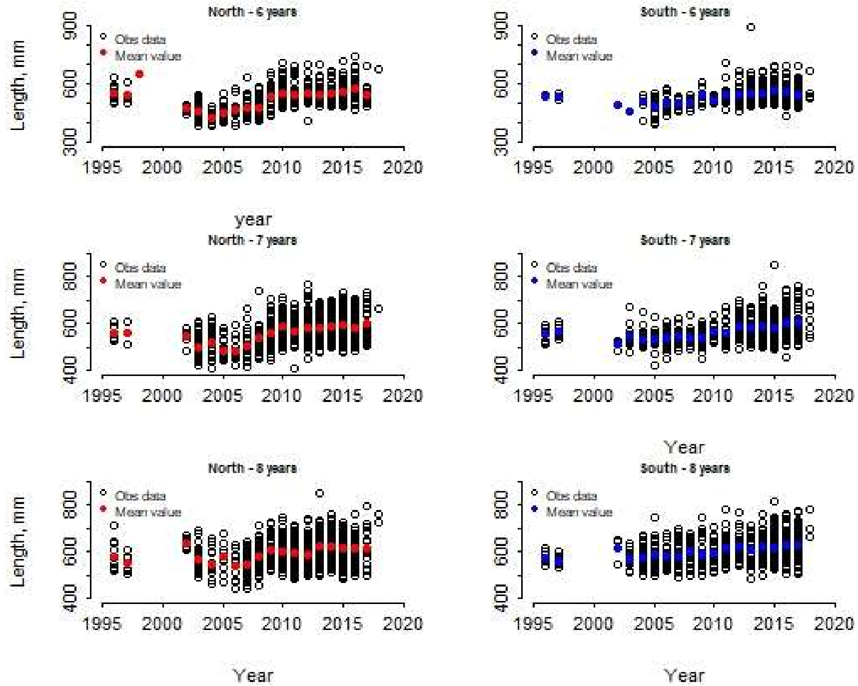

Figure 1a. Observed mean lengths at age of female and male snapper (in each region) at specified ages, plotted over lengths of individuals at those ages.

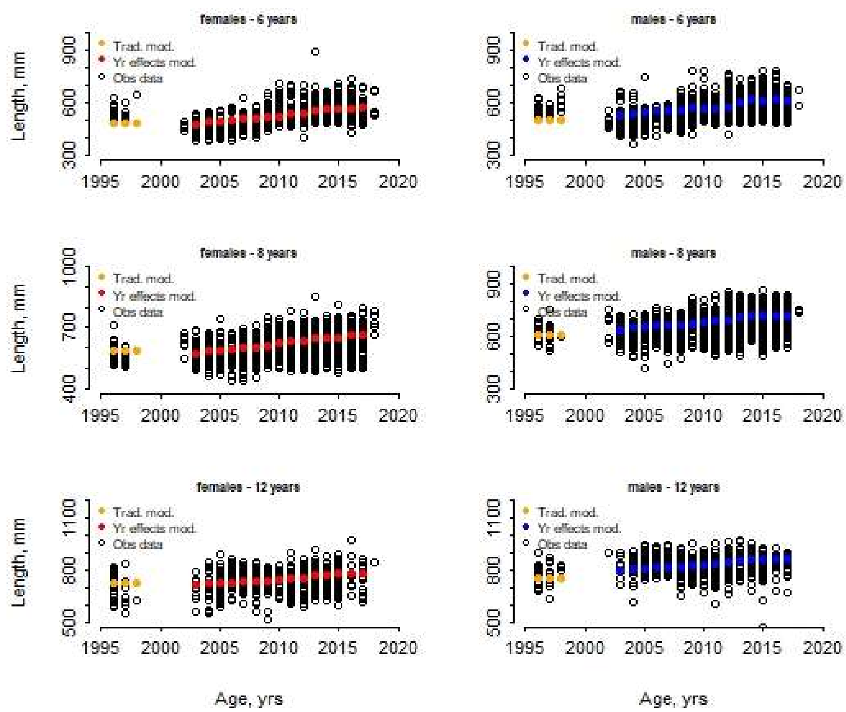

Figure 1b. Estimated lengths at age lengths at age of female and male dhufish (for both regions, combined) at specified ages plotted over lengths of individuals at those ages. Estimated lengths at age were calculated applying a traditional von Bertalanffy growth model for early years (1996-98), and from a 'year-effects growth model', for latter years (2002-2018).

The same trends are more evident in the weight-at-age data inputted into the model. Allowing for increased growth in recent years has a positive impact on recent stock status (see sensitivity analyses, below).

The default assumption in the model for probability of maturity at age for dhufish is that this remains constant. Note, there is an ontogenetic shift in habitat of dhufish as individuals approach maturity (Hesp et al., 2002) which might be expected, at least in part, to be age-related. Currently, there are insufficient maturity data since the early study of Hesp et al. (2002) to re-estimate maturity for recent years, i.e. with fish collected over a wide-enough size/age range.

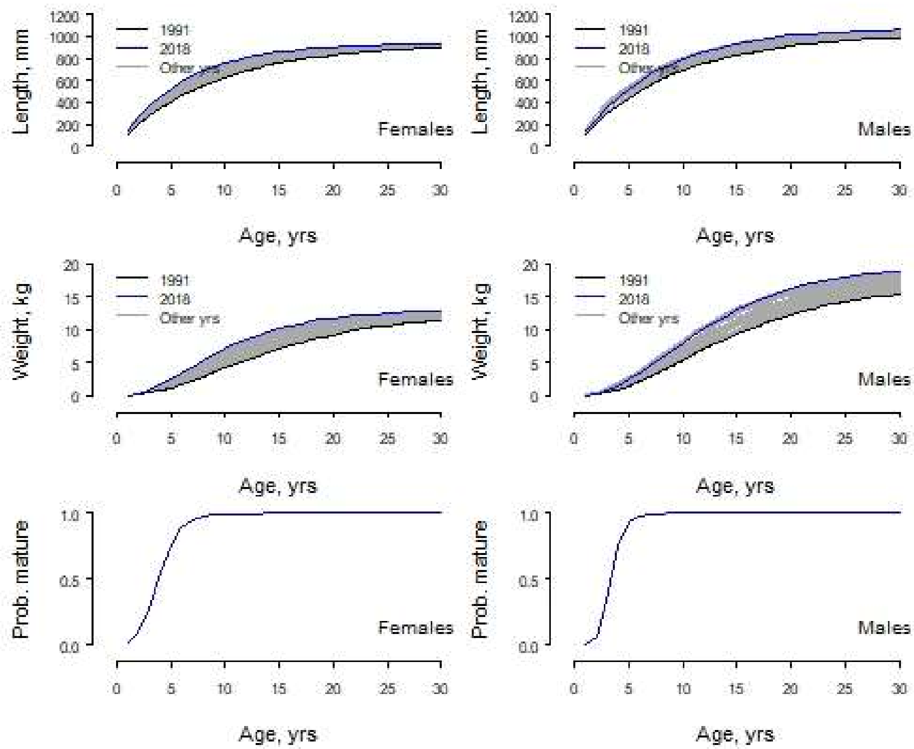

Figure 2. Length at age, weight at age and maturity at age data input data for the dhufish dynamic population model. Note that maturity at age is assumed to remain constant.

Catches

As described for previous assessments of this species, there is substantial uncertainty regarding the accuracy of the catch history for dhufish (and snapper) in the West Coast Bioregion (e.g. very limited data and strong assumptions for recreational catches). In the annual 'State of the Fisheries Reports', the commercial catch time series for dhufish, which was first reported in early 2000s, has always started at 1991, although commercial catch records are available from the Commercial Catch and Effort Statistics (CAES) data base since 1975. There is uncertainty regarding the accuracy of commercial catch records for earlier years (e.g. possible under-reporting, prior to the fishery being formalised in the early

2000s, Crowe et al., 1999; J. Penn pers comm.). There is also further uncertainty in the catch history associated with limited information on recreational catches, available from a small number of recreational surveys. These sources of uncertainty for the catch history impact on the degree of certainty with respect to modelling results.

The extended catch time series for dhufish indicates that, particularly in the northern region, catches were likely substantially lower in the late 1970s than in 1991. The catch histories clearly show the effect of management in the late 2000s, with substantial catch reductions at this time.

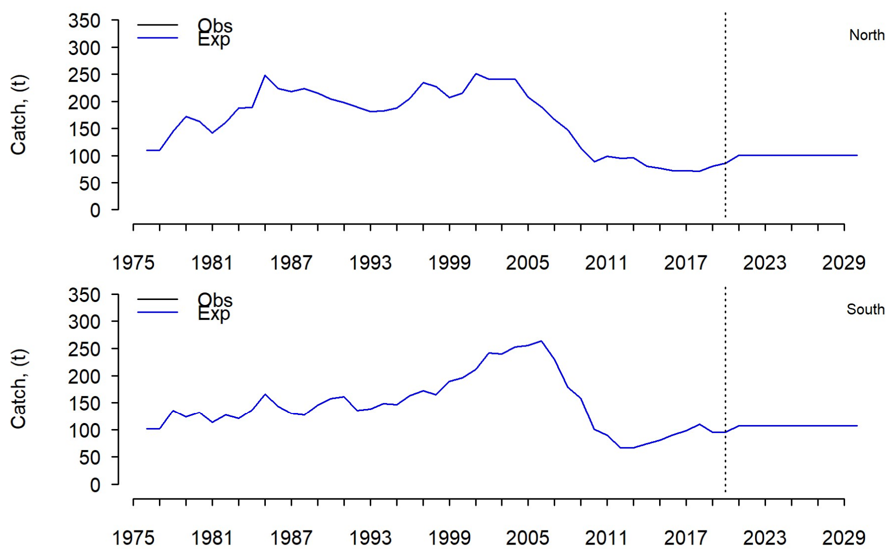

Figure 3. Annual catches for dhufish from 1975-2020, with specified constant catch for the 2021-2013 projection period, in the north and south regions.

Base case scenario (including CPUE indices; undersize post-release mortality = 50%)

For the base case scenario, the annual handline and dropline CPUE indices, and daily handline (south region only) and daily dropline (north region only) CPUE have been included. As consistent with the biomass dynamics modelling (L4), the annual CPUE indices have been adjusted for efficiency increases associated with the introduction of colour sounders, GPS and hydraulic reels, as determined by Marriott et al. (2011), and an additional, assumed annual fishing efficiency increase of 3%. The daily CPUE indices have been adjusted for an assumed 1% annual fishing efficiency increase.

The trends provided by the monthly dropline and handline cpue data for the north region are inconsistent for some years, with in increasing vs steady trend between 1990-2000 for these two indices, respectively (Figure 4a,b). The model better matched the monthly handline data than the monthly dropline data for this region. For the south region, the monthly dropline and handline cpue trends were similar, and thus the model provided a similar fit to both of these indices. Although the model matched well the available daily dropline data for the north region, the fit of the model to the available handline data for the south region was relatively poor (Figure 4a,b).

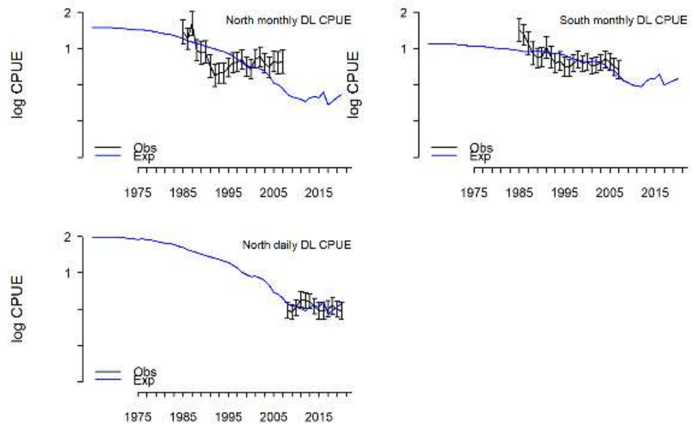

Figure 4a. Observed (black lines and error bars) dropline CPUE (adjusted for fishing efficiency increases) and estimated (blue lines) dropline CPUE trends for dhufish in the north and south regions. The model has been fitted separately to the available monthly (CAES) data and daily (logbook) data.

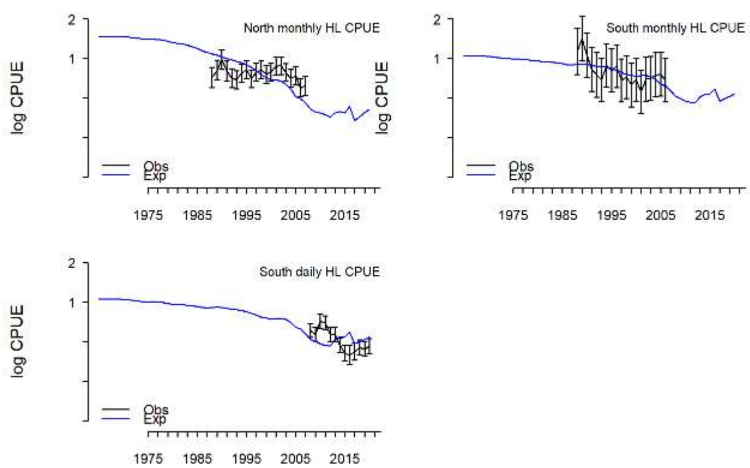

Figure 4b. Observed (black lines and error bars) handline CPUE (adjusted for fishing efficiency increases) and estimated (blue lines) handline CPUE trends for dhufish in the north and south regions. The model has been fitted separately to the available monthly (CAES) data and daily (logbook) data.

Age compositions

In both regions, the age structures are still least truncated in the earliest years (1996-1997) (Figure 5a,b,c). The level of truncation in the expected/observed age samples in recent years is less for the south region (i.e. more fish > 15 y) than in north region.

The model is fitted to both commercial and recreational data for the northern region, but only recreational data for the southern region. This is because commercial data are not available for the Metropolitan region of the West Coast region (i.e. due to commercial fishing area closure), and commercial fishing is more seasonal in the south-west region and likely less representative compared with recreational data for this region. The estimated age compositions match relatively well the available observed age composition data for dhufish in each region for most years (Figure 5a,b,c). The recruitment strengths of some cohorts (e.g. 7 year old fish in 2006, 8 year old fish in 2008 etc.), however, appear to have been underestimated in the south region and over-estimated in the north region. This due to the assumption of common recruitment deviations for the two regions (to improve model stability/convergence), despite indications in the data that annual recruitment is more variable in the south. Although this assumption will have some effects on fishing mortality and biomass estimates, preliminary analyses indicated that the effects are not large.

The age compositions for snapper are projected to be similar (slightly less truncated) in 2030 compared with 2017 (Figure 6a,b) in the both regions.

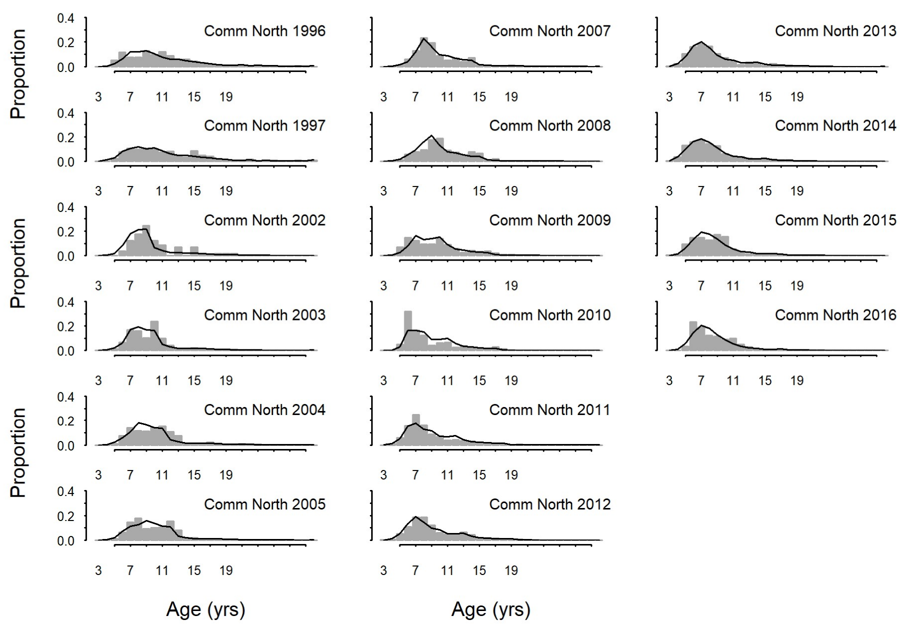

Figure 5a. Fits of the model (black lines) to annual age composition samples caught by commercial fishers in the north region.

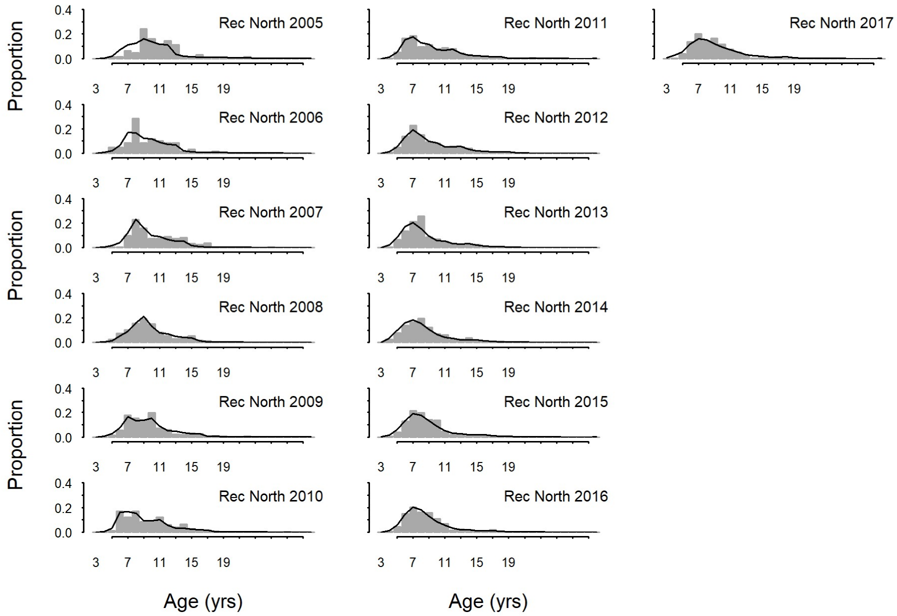

Figure 5b. Fits of the model (black lines) to annual age composition samples caught by recreational fishers in the north region.

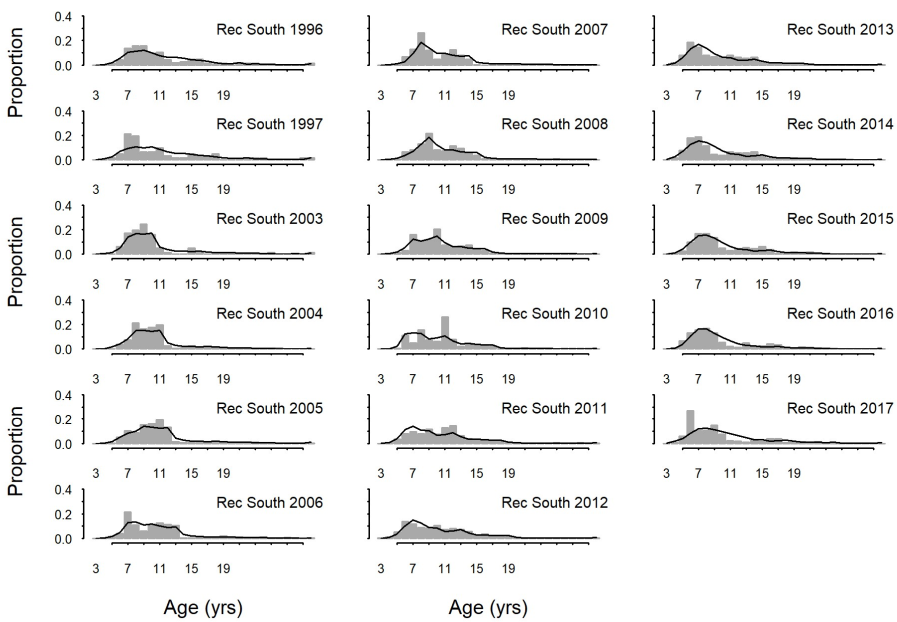

Figure 5c. Fits of the model (black lines) to annual age composition samples caught by recreational fishers in the south region.

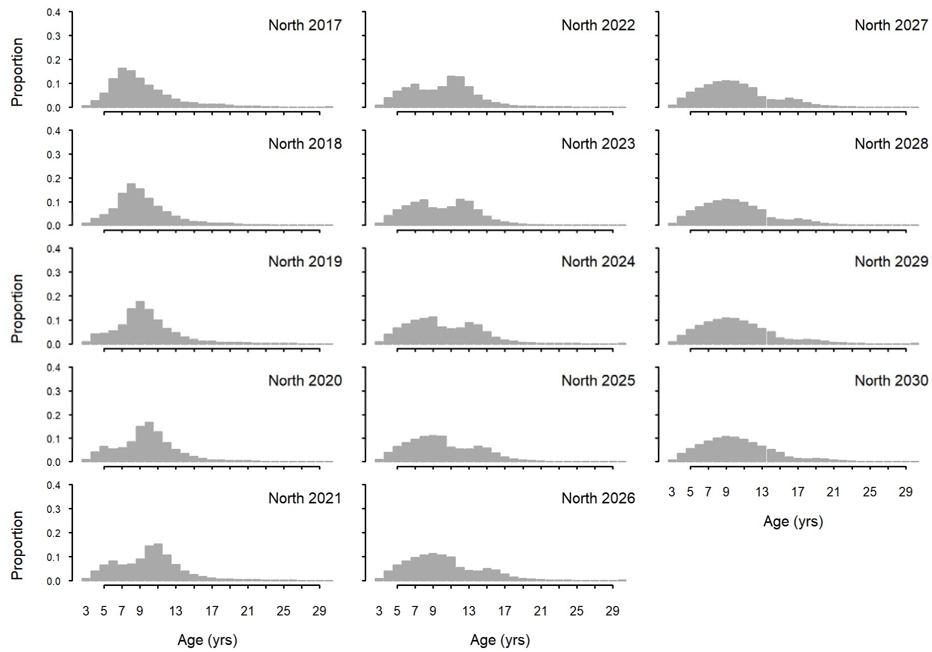

Figure 6a Future projections of annual dhufish age compositions for the north region, assuming mean recruitment (i.e. as calculated from the stock-recruitment relationship) and a specified level for future annual catches.

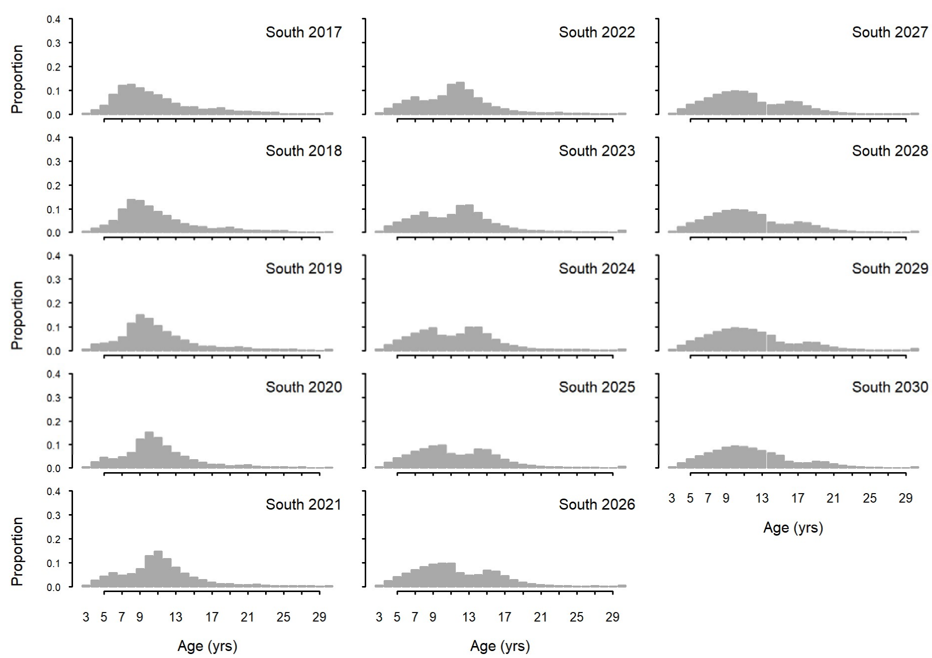

Figure 6b Future projections of annual dhufish age compositions for the south region, assuming average recruitment (i.e. calculated from the stock-recruitment relationship) and a specified level for future annual catches.

Fishing mortality and biomass

Applying the base case model, the estimated fishing mortality, F, increased from very low levels (<0.05 y^{-1}) in 1975 to peaks of almost 0.4 and 0.3 y^{-1}, respectively in the north and south regions, in the mid-late 2000s (Figure 7a). Subsequently, the point estimates for F in the north and south regions declined to around 0.22 and 0.12 y^{-1}, respectively, by 2020, and were projected to remain above F_{MSY} in the northern areas and at about F_{MSY} in the southern areas. Note, 60% confidence limits are shown for estimated fishing mortality and biomass so it can be assessed if, based on a given model, if the probability of being above a particular biological reference point is 80% or more (i.e. if the lower confidence limit is above the line), as consistent with Marine Stewardship Council P1 assessment guidelines).

The estimated relative female biomass levels in the northern areas, B_{rel}, decreased from just under 0.6 in 1975 to around the limit level of 0.16 (equating to $0.5B_{MSY}$) in the mid 2000s, and then to well below the limit over the next few years before increasing to around the limit in 2020. B_{rel} is projected to increase to about midway between the limit and threshold by 2030 in the northern areas. The trend is similar for the southern areas, but with B_{rel} only declining as far as the limit, before increasing to about B_{MSY} by 2020 and above $1.2B_{MSY}$ by 2030.

Assuming 'average' recruitment levels are experienced in the ensuing years, B_{rel} is projected to be about midway between the threshold and target for the overall stock, if catches remain at a similar level to 2020 (Figure 7b).

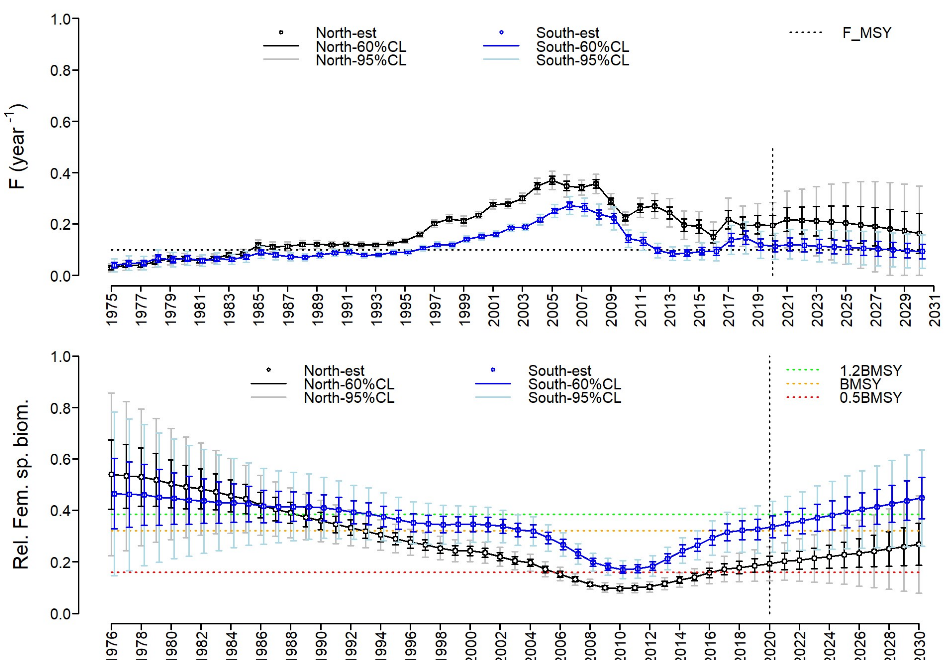

Figure 7a. Model estimates for fishing mortality (F, y^{-1}) and relative female biomass B_{rel}, with associated 60% and 95% confidence intervals, between 1975 and 2030 for dhufish in the north and south regions. Vertical dotted line demarcates the year 2020.

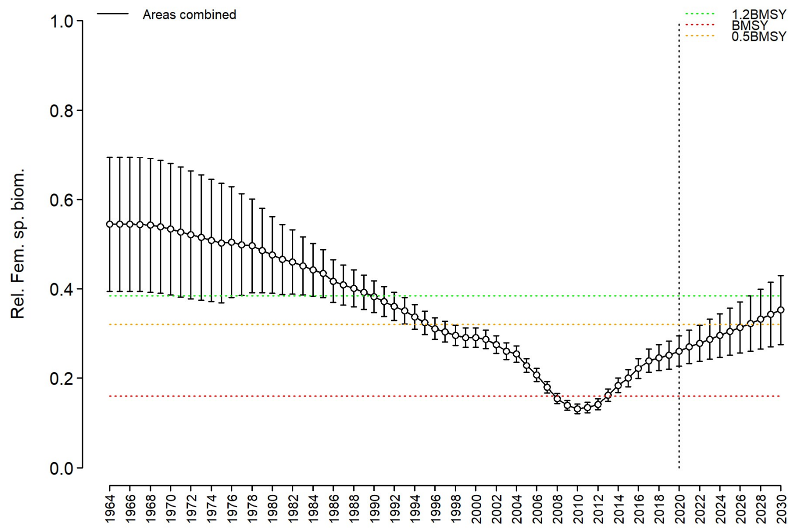

Figure 7b. Model estimates for relative female biomass B_{rel}, with associated 60% confidence intervals, between 1975 and 2030 for dhufish in the northern and southern areas combined. Vertical dotted line demarcates the year 2020.

Assessment summary results

The phase plots show that, in the northern areas region, increasing fishing mortality particularly through the 1980s and 1990s, accompanied by declining female B_{rel}, to below the limit (Figure 8). With subsequent declines in F, estimated B_{rel} levels started to increase in the north region and projected to be midway between the limit and threshold by 2030. Similar trends were exhibited in the south region, but with B_{rel} not declining quite as far. By 2030, B_{rel} in the south is projected to be above the target, with fishing mortality around the threshold level (Figure 8).

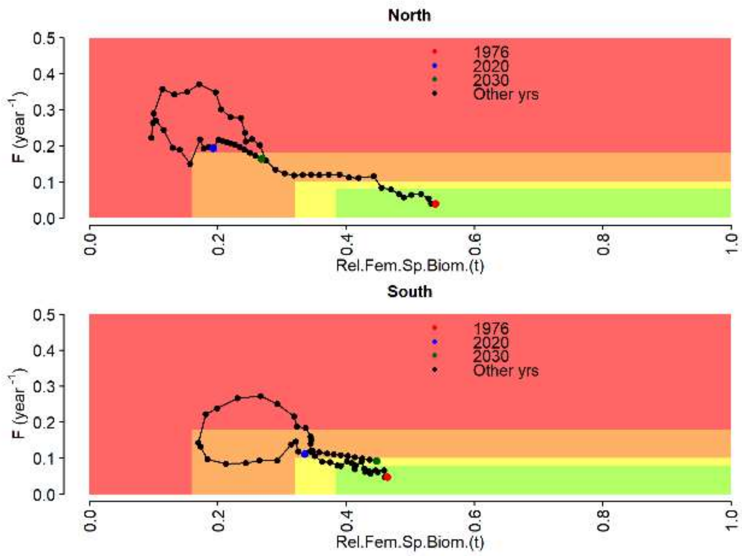

Figure 8. Phase plot showing the relationships between annual model estimates for fishing mortality, F, y^{-1}, and relative female spawning biomass, B_{rel}. Areas shaded red indicate where limit points are exceeded for F and/or B_{rel}. Areas shaded orange are between the limit and threshold, yellow areas are between the threshold and target, and green areas are above the target.

MSY calculations

The estimated equilibrium fishing mortality at B_{MSY} of 0.1 y^{-1}, for the base case model, results in an MSY estimate of 310 t (for regions combined). B_{MSY} is estimated at 1560 t, and B_{rel} at B_{MSY} is 0.32 (Figure 9).

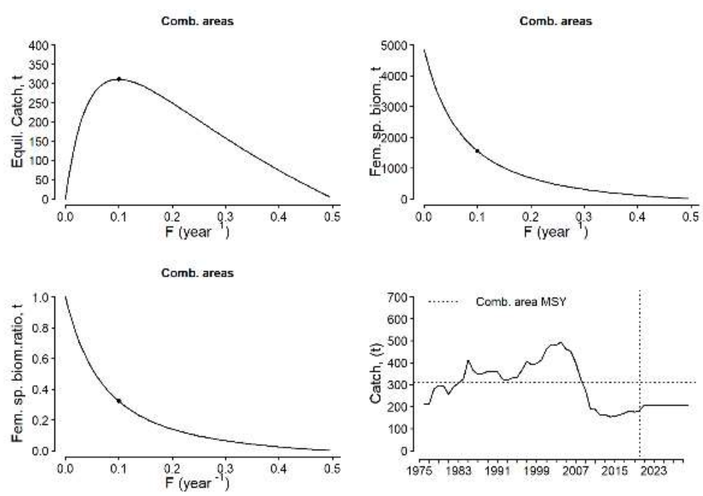

Figure 9. Relationship between fishing mortality and equilbrium catch, equilbrium female spawning biomass and equilbrium relative female spawning biomass (or ratio of fished/unfished female spawning biomass). Black dots highlight the levels of catch and biomass at F_{MSY}.

Recruitment deviations

To reduce model complexity (to assist model fitting), the recruitment deviation parameters for dhufish were assumed to be common to both the northern and southern areas. The recruitment deviation plots for each area show substantial structural patterns prior to the early 2000s, when age composition data are first available, with a continuous decline from the mid 1970s through to the mid 1990s (Figure 10). This pattern probably reflects (at least in part), lack of age data for early years. In later years, when age data are available, the deviation patterns differ between the northern and southern areas, as might be expected if dhufish in these areas are from different stocks. Peaks associated with strong recruitment events are more prominent in the south area. Although preliminary explorations indicated that assuming common vs separate deviation parameters for the two areas would not have a marked impact on results, this aspect should be explored further in future assessments for this species.

The patterns described above are also evident in estimated levels of B_{rel} and recruitment plotted over the estimated stock-recruitment curves, with below average recruitment 1975 to the mid-2000s. In more recent years (i.e. when more data are available to inform the model), estimated annual recruitment levels are more similar to that predicted by the stock recruitment curve, from their respected, estimated levels of B_{rel}.

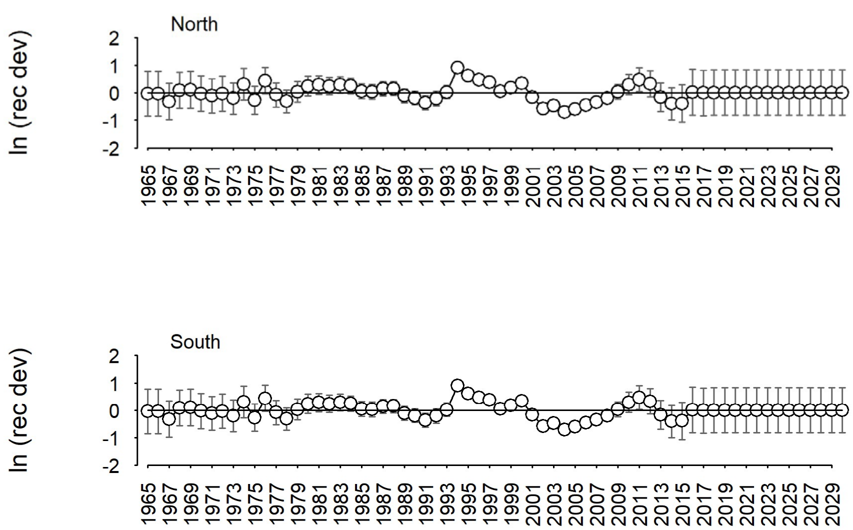

Figure 10. Recruitment deviations and associated 95% confidence intervals (shown in log space) for dhufish in the north and south regions.

Annual recruitment

The estimated levels of annual recruitment for dhufish in the north and south regions are at similar levels throughout the time series, with high recruitment levels in several years during the 1990s and lower levels during the 2000s.

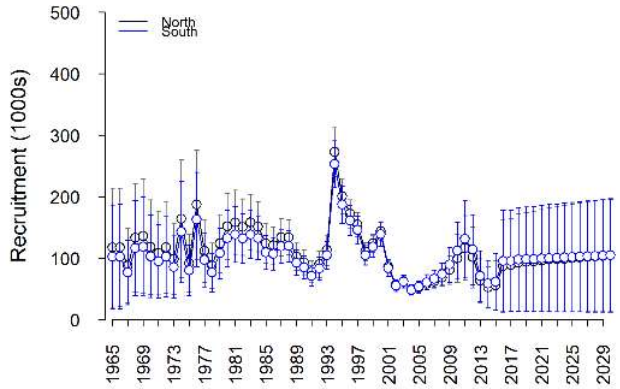

Figure 11. Estimated annual recruitment for dhufish in the north and south regions between 1965 and 2030.

Alternative discard mortality scenario (no discard mortality for undersize fish, model fitted to cpue)

Not allowing for discard mortality of undersize fish (directly in the model) leads to slightly more optimistic results, with lower F, particularly throughout the model projection period, and slightly higher estimates of B_{rel}.

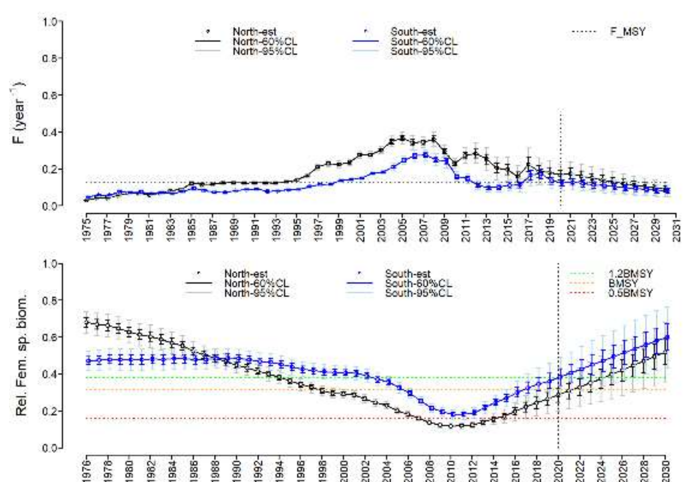

Figure 12. Alternative discard mortality scenario (no discard mortality for undersize fish). Model estimates for fishing mortality (F, y^{-1}) and relative female biomass B_{rel}, with associated 60% confidence intervals, between 1975 and 2030 for dhufish in the north and south regions. Vertical dotted line demarcates the year 2020.

Alternative scenario (discard mortality for undersize fish = 0.5, model not fitted to cpue)

If the model is not fitted to cpue, whilst allowing for discard mortality of undersize fish, the model produces more optimistic results (more rapid stock recovery), with lower estimates for F and substantially higher estimates of B_{rel}, throughout the model projection period. This is associated, at least to some extent, with differences in estimated recruitment deviations, with the addition of cpue data resulting in below average recruitment (from that predicted by the stock-recruitment curve) in 2008-14, compared with average recruitment in most of those years when these data were excluded.

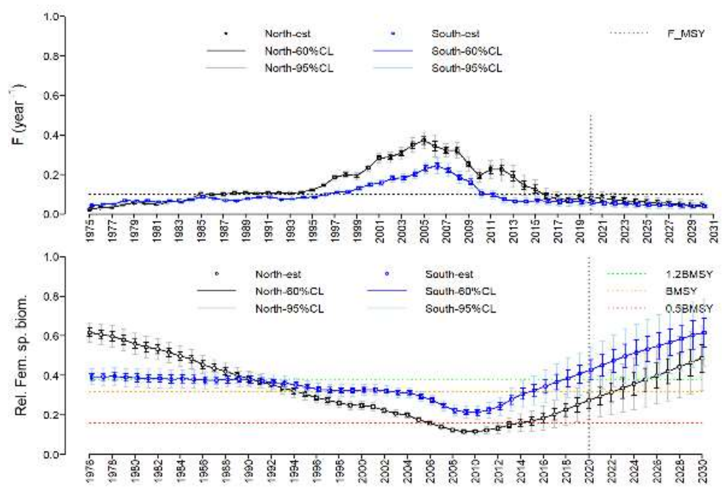

Figure 13. Alternative scenario (model not fitted to cpue, discard mortality for undersize fish = 0.5). Model estimates for fishing mortality (F, y^{-1}) and relative female biomass B_{rel}, with associated 60% confidence intervals, between 1975 and 2030 for dhufish in the north and south regions. Vertical dotted line demarcates the year 2020.

Alternative scenario (no discard mortality for undersize fish, model not fitted to cpue)

The scenario is more optimistic than all other scenarios, indicating that by 2020, the stock had recovered in the south region, and almost recovered to the threshold in the north region.

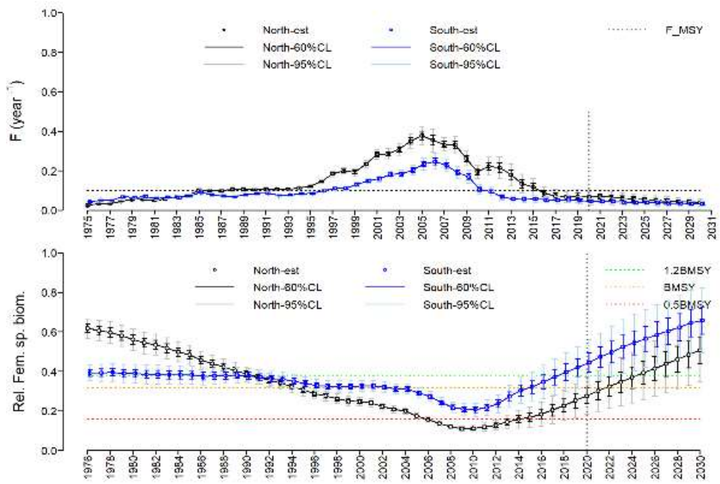

Figure 14. Alternative scenario (model not fitted to cpue, discard mortality for undersize fish = 0). Model estimates for fishing mortality (F, y^{-1}) and relative female biomass B_{rel}, with associated 60% confidence intervals, between 1975 and 2030 for dhufish in the north and south regions. Vertical dotted line demarcates the year 2020.

Alternative growth scenario (fixed growth, fitted to cpue, discard mortality for undersize fish=0.5)

Model results for dhufish are sensitive to growth assumptions. Not allowing for temporal variations in growth, whilst fitting to cpue, and allowing for discard mortality for undersize fish, results in very slow recovery to between the limit and threshold by 2030 for the south region, and no recovery (with declining status) for the north region. The model developed for estimating temporal growth variation for dhufish is preliminary and work is underway to refine this model. Changes in growth estimates from these refinements are likely to have some impact on modelling results in future assessments.

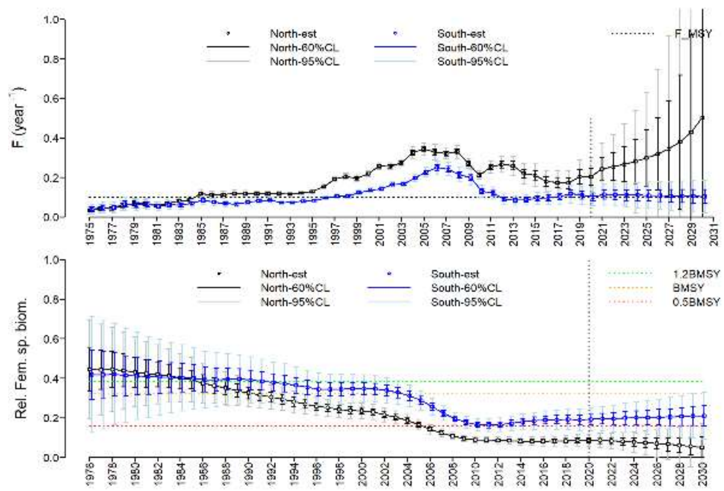

Figure 15. Alternative scenario (fixed growth, model fitted to cpue, discard mortality for undersize fish = 0.5). Model estimates for fishing mortality (F, y^{-1}) and relative female biomass B_{rel}, with associated 60% confidence intervals, between 1975 and 2030 for dhufish in the north and south regions. Vertical dotted line demarcates the year 2020.

Alternative cpue scenario (only fitted to daily cpue, discard mortality for undersize fish=0.5)

There is considerable uncertainty regarding the level of fishing efficiency increases that occurred in earlier years (monthly cpue data up to 2007). For this sensitivity analysis, the model was fitted only to the daily cpue indices. Including just the daily cpue data leads to less optimistic estimates of stock status, compared with removing all the cpue data, but results are slightly more optimistic than when the monthly cpue data (with assumed 3% additional fishing efficiency increase) were included. Thus, the main differences between estimates of current and projected stock status for models with and without cpue data appear mainly due to the influence of the daily cpue series.

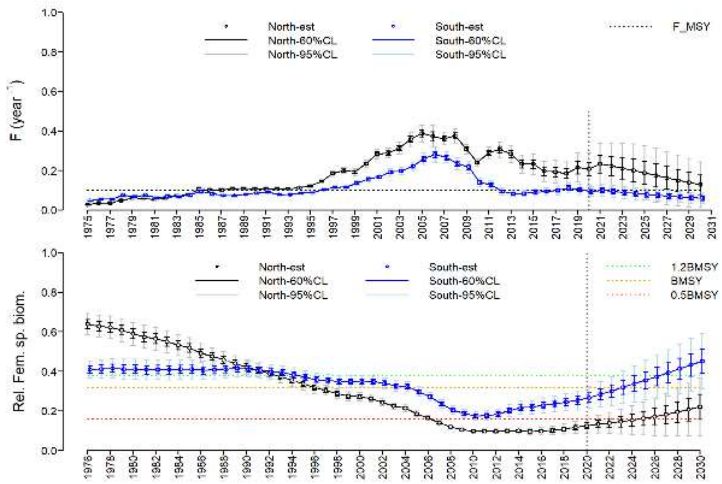

Figure 16. Alternative scenario (model only fitted to daily cpue, discard mortality for undersize fish = 0.5). Model estimates for fishing mortality (F, y^{-1}) and relative female biomass B_{rel}, with associated 60% confidence intervals, between 1975 and 2030 for dhufish in the north and south regions. Vertical dotted line demarcates the year 2020.

Alternative catch history scenarios for dhufish

As described above, there is considerable uncertainty regarding the catch data for dhufish, particularly due to limited recreational survey data, but also potential issues with early commercial data reporting. In preliminary analyses, extending catches back further to only 1991, or to only 1985 (rather than 1976) did not have a marked impact on results (data not shown).

Modelling results for snapper

Biological relationships

Growth

The mean lengths of fish at ages 4, 5 and 6 years, i.e. soon after recruiting into the fishery, show limited variation. The mean lengths of snapper at these ages in the southern region vary slightly more, but the changes are less pronounced than observed for dhufish (Figure 1a). Plots of the mean lengths at ages for different time periods (2002-05, 2006-10, 2011-12, 2012-15, 2016-19) likewise do not indicate substantial growth changes (Figure 1b). Consequently, von Bertalanffy growth curves were fitted to the available data after the data for female and male snapper in each region, after the data for each sex in each region were pooled across all years. As shown previously, growth of the two sexes is very similar, but differs substantially between regions, with fish growing to a larger size in the southern region.

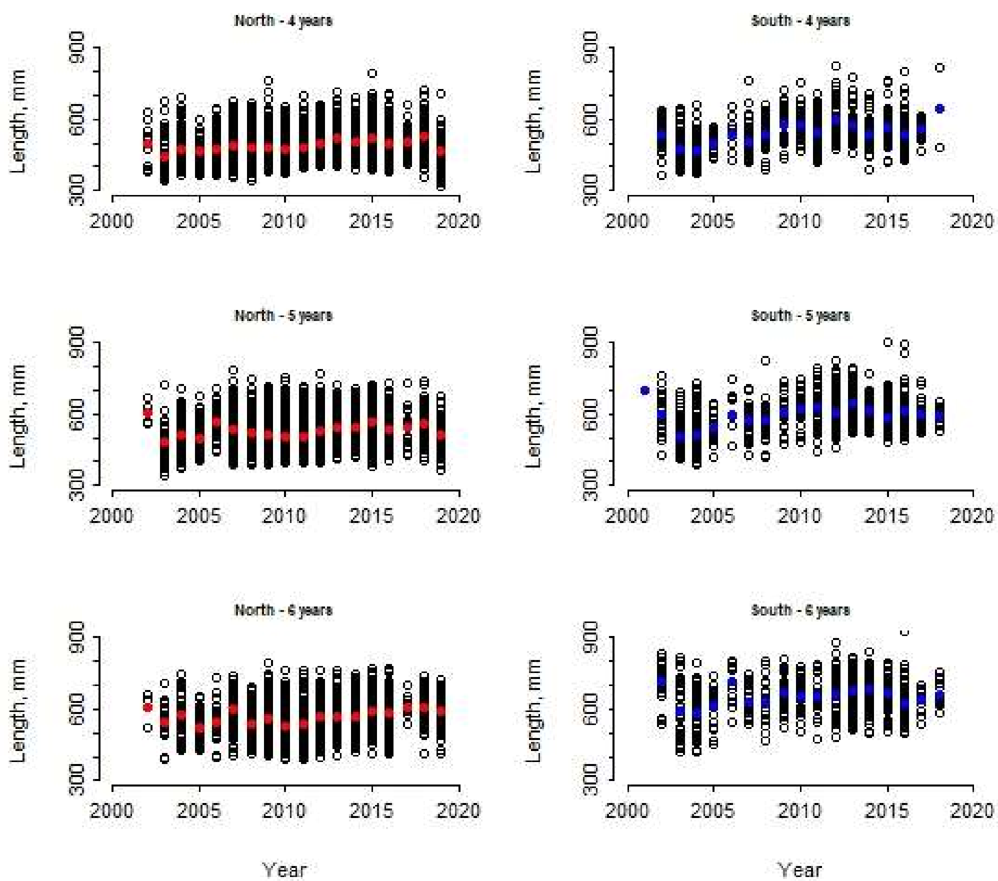

Figure 1a. Observed mean lengths at age of snapper, in each region, at specified ages, plotted over the individual lengths of fish at those ages.

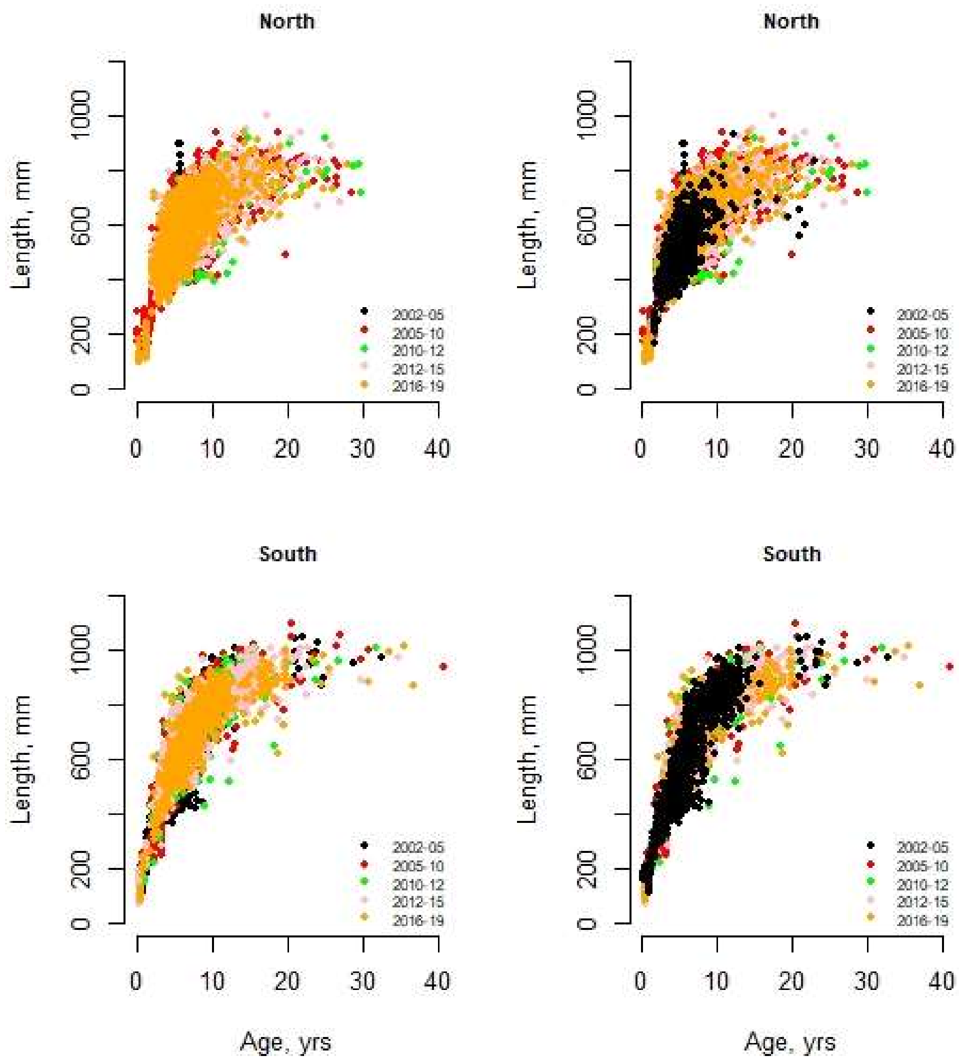

Figure 1b. Observed lengths at age of snapper in each region, with data for different time periods overlaid. On the left, the most recent period (2016-19) is overlaid on top, whereas on the right, the earliest period (2002-05) is overlaid on top.

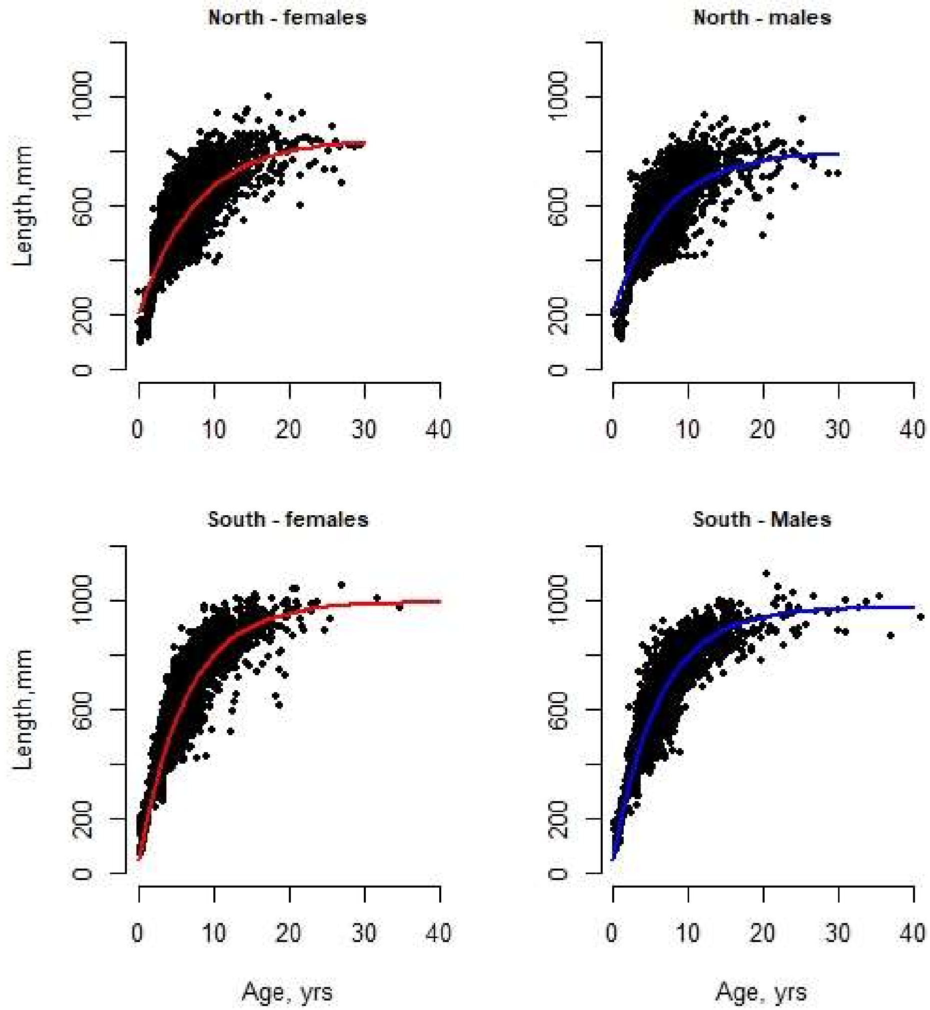

Figure 1c. von Bertalanffy growth curves fitted to all available length-at-age data for female and male snapper in each region.

Maturity relationships

In previous assessment analyses for snapper, input parameters for maturity were those reported in Lenanton et al. (2009a). As the sample sizes available at that time were not large, for this L5 assessment, the analysis was updated using all available data. Some exploratory analyses were undertaken to explore evidence of temporal changes in maturity, however, analyses were impacted by lack of small fish for different time periods, and thus results are based combined data across years.

The maturity data indicate that at least some female snapper mature by 2 years of age in the north region, with half maturing at 5-6 years and 95% maturing by ~15 years. In the south, a few females are mature by 3 years, half are mature by 6-7 years and 95% are mature by ~13 years. The estimated age-at-maturity curves are likely biased to some extent (i.e. overestimating probability of maturity for the youngest fish), particularly for the north region. In the population model, all 1+ year old recruits are assumed to be immature.

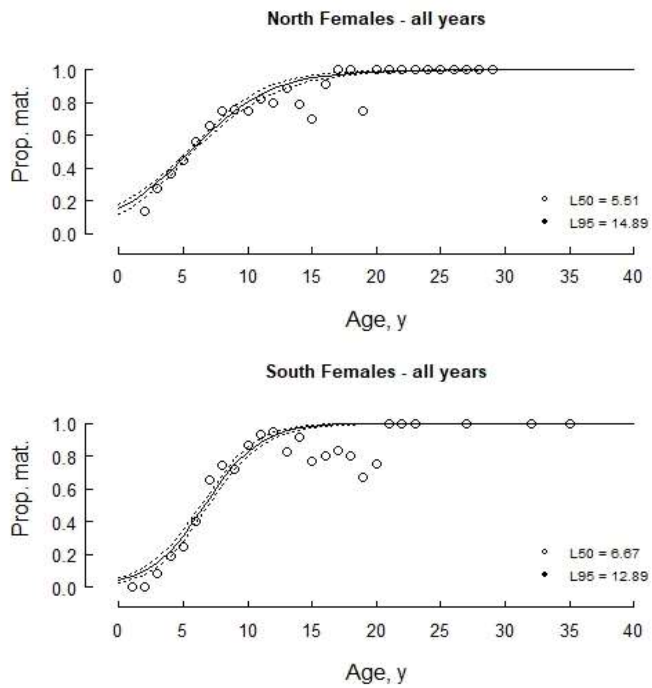

Figure 2. Logistic curves (solid line) describing the probability of maturity at age for female snapper in the northern and southern regions (and associated 95% confidence intervals, dotted lines), and observed proportions of mature females at age (circles).

Biological relationships and retention at age

The von Bertalanffy growth curves for female and male snapper in the north region differ substantially from those for the south region, with fish growing to larger lengths in the south region. This translates to marked differences in weight at age, with much larger weights at age in the south region. In both regions, the ages at which fish typically become recruited into the fishery, i.e. 2-3 years in the north and 2-4 years in the south (depending on time period and, for the south, also changes in MLL) is less than the age at which the majority of fish are recorded as mature during the spawning season (5-6 years in the north and 6-7 years in the south).

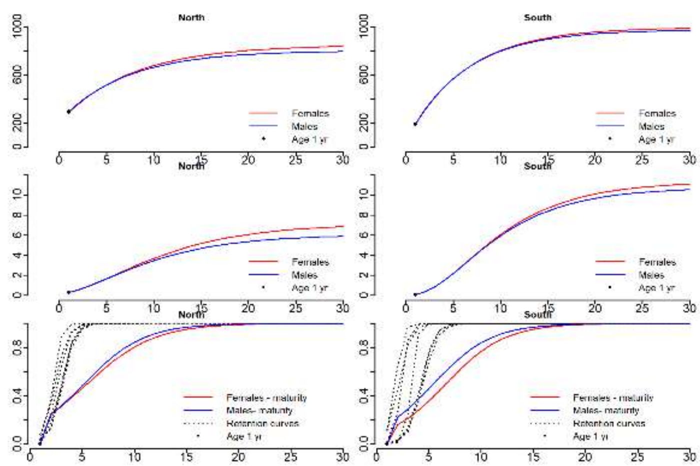

Figure 3. Length at age, weight at age, maturity at age and estimated retention curves for the snapper in the north and south regions.

Catches

As described for previous assessments of this species, there is substantial uncertainty regarding the accuracy of the catch history for snapper (and dhufish) in the West Coast Bioregion (e.g. very limited data and strong assumptions for recreational catches). In the annual ‘State of the Fisheries Reports’, the commercial catch time series for snapper has been reported from ~1989/90, although commercial catch records are available from the Commercial Catch and Effort Statistics (CAES) data base since 1975. For modelling, in 1975, the snapper population was assumed to be at a fished equilibrium with specified fishing mortality. The catch time series for snapper indicates that, particularly in the northern region, catches were likely substantially lower in the late 1970s than in 1991.

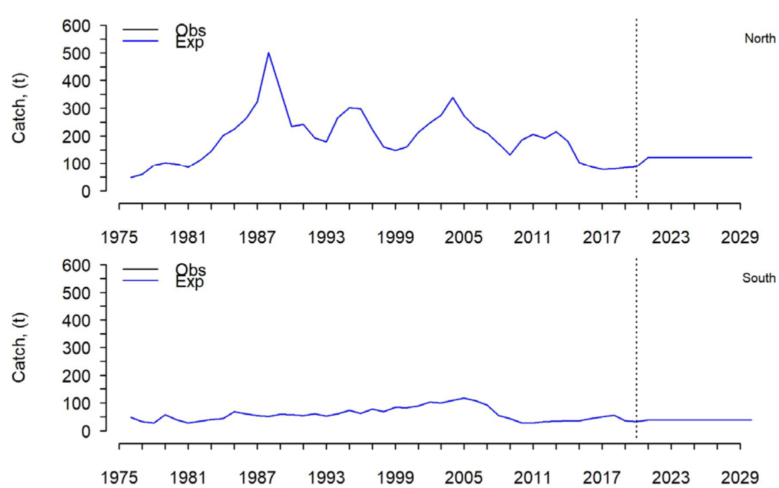

Figure 3. Catch history for snapper (all sectors) in the north and south areas of the West Coast Bioregion.

Base case scenario modelling results (including CPUE indices; undersize post-release mortality = 50%)

For the base case scenario, the annual and daily dropline (DL) CPUE indices were included (Figure 5a) for the north region, and also the monthly DL index for the south region (i.e. as a reliable daily index was not available for this region). As consistent with the biomass dynamics modelling (L4), the annual CPUE indices have been adjusted for calculated efficiency increases associated with the introduction of colour sounders, GPS and hydraulic reels, as determined by Marriott et al. (2011), and an additional, assumed annual fishing efficiency increase of 2% for the monthly data. The daily CPUE indices were also adjusted further for an assumed 1% annual fishing efficiency increase. The HL data were not included due to inconsistent trends between the monthly DL and HL indices (Figure 5a,b). Although the estimated CPUE matched the overall declining trend for the monthly DL series, the fit was somewhat poor, i.e. not matching the peaks and troughs (also evidence in the north HL data).

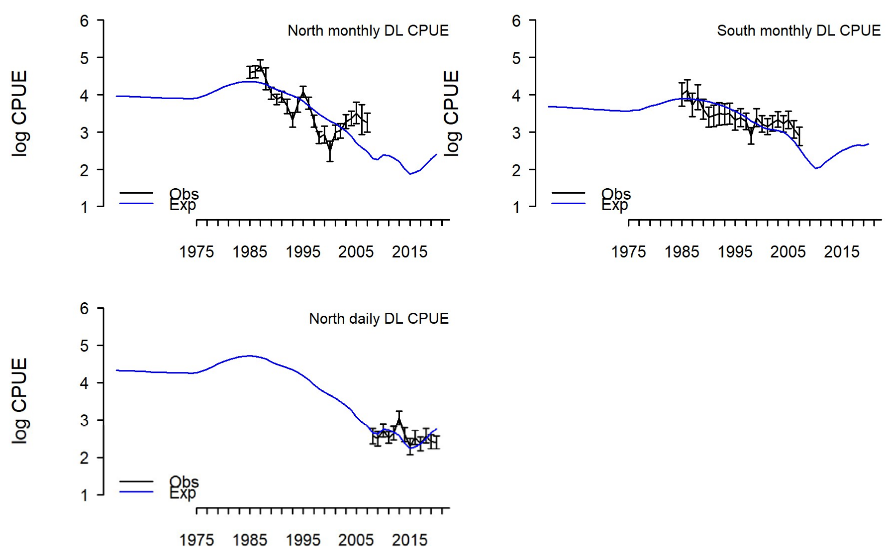

Figure 4a. Observed (black lines and error bars) dropline CPUE (adjusted for fishing efficiency increases) and estimated (blue lines) dropline CPUE trends for snapper in the north and south regions. The model has been fitted separately to the available monthly (CAES) data and daily (logbook) data.

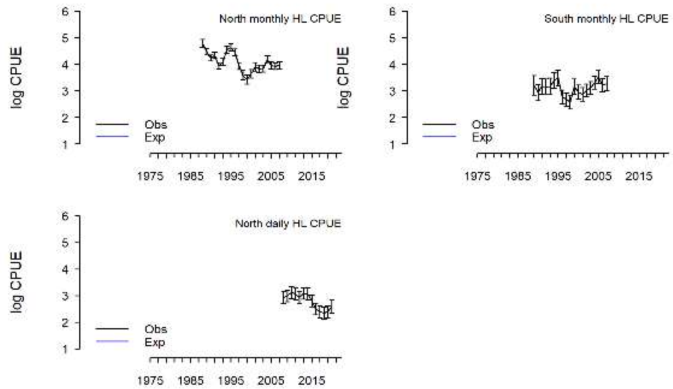

Figure 4b. Observed (black lines and error bars) handline CPUE trends (adjusted for fishing efficiency increases) for snapper in the north and south regions. The model has not been fitted to the HL data for this scenario.

Age compositions

As shown for previous assessments, the model provides relatively good ‘visual fits’ to the available age composition data for snapper in each region for most years (Figure 5a,b,c). Note, the model is fitted to both commercial and recreational data for the northern region, but only recreational data for the southern region. This is because commercial data are not available for the Metropolitan region of the West Coast region (i.e. due to commercial fishing area closure), and commercial fishing is more seasonal in the south-west region and likely less representative compared with recreational data for this region.

The age composition data for the northern and southern regions differ substantially. In particular, recruitment variation is less marked in the north. In this region, the relative numbers of older fish in samples in recent years (2018-19) are similar to those observed in previous years from about 2009. In the southern region, two strong cohorts (one recruiting at age 4 in 2011 and another at age 4 in 2014) have persisted in recreational catches through to 2018, indicating that fishing mortality in the southern region has not been particularly high in recent years. This is consistent with the presence of a higher proportion of older fish (> 10 years) in catch samples collected in this region in recent years, compared with the early 2000s. However, there has been no obvious increase in the relative numbers of older fish in samples since the late 2000s.

In both regions, the age compositions are projected to be less-truncated compared with 2018 (Figure 6a,b), indicative of, albeit slow, stock rebuilding. In 2030, the projected age composition for the north region is similar to that for the south region.

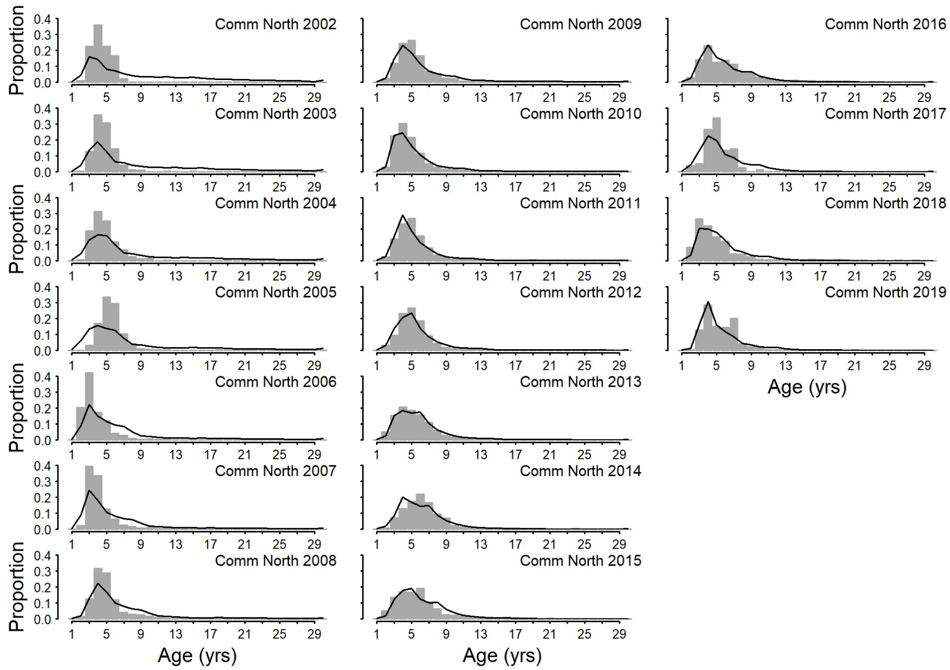

Figure 5a. Fits of the model (black lines) to annual age composition samples in the north region caught by commercial fishers in the north region.

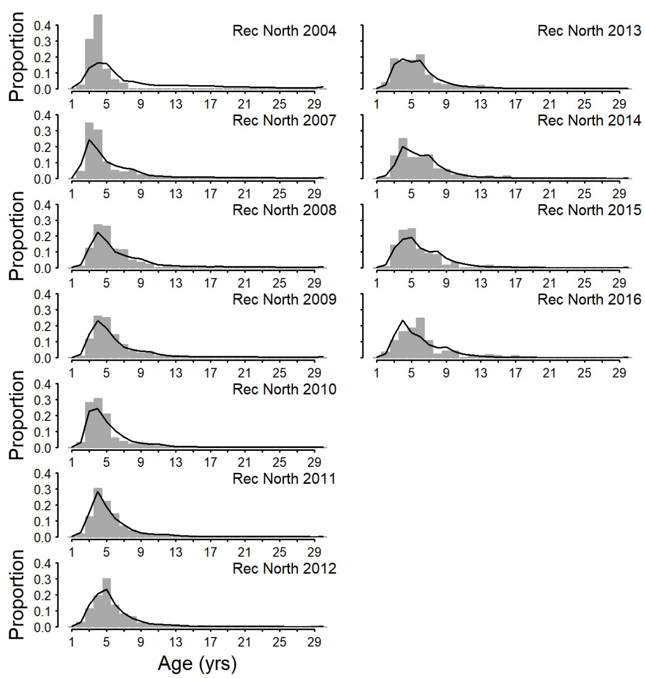

Figure 5b. Fits of the model (black lines) to annual age composition samples in the north region caught by recreational fishers in the north region.

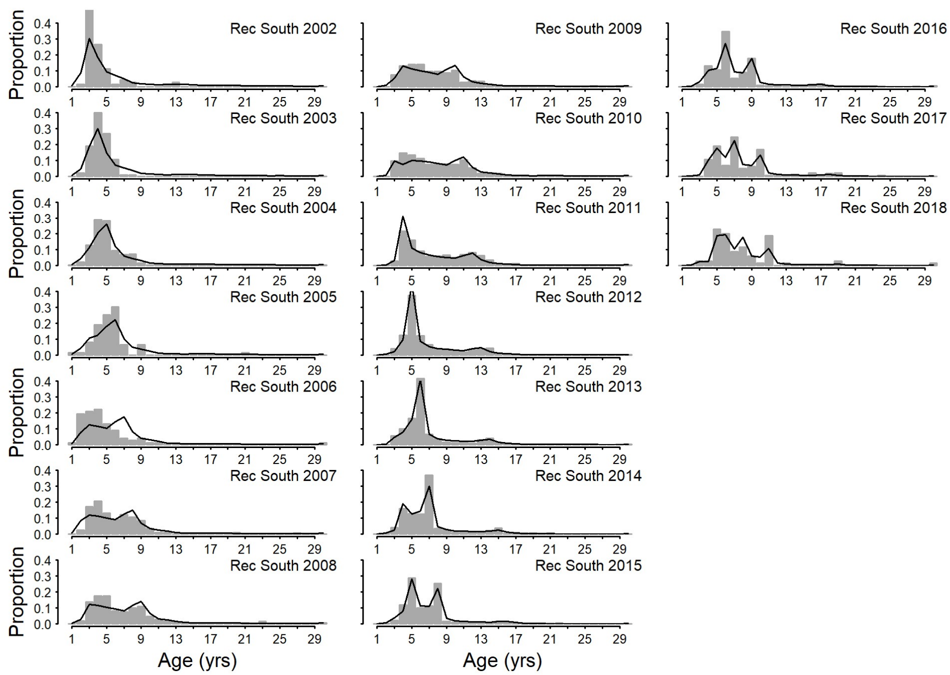

Figure 5c. Fits of the model (black lines) to annual age composition samples caught by recreational fishers in the south region.

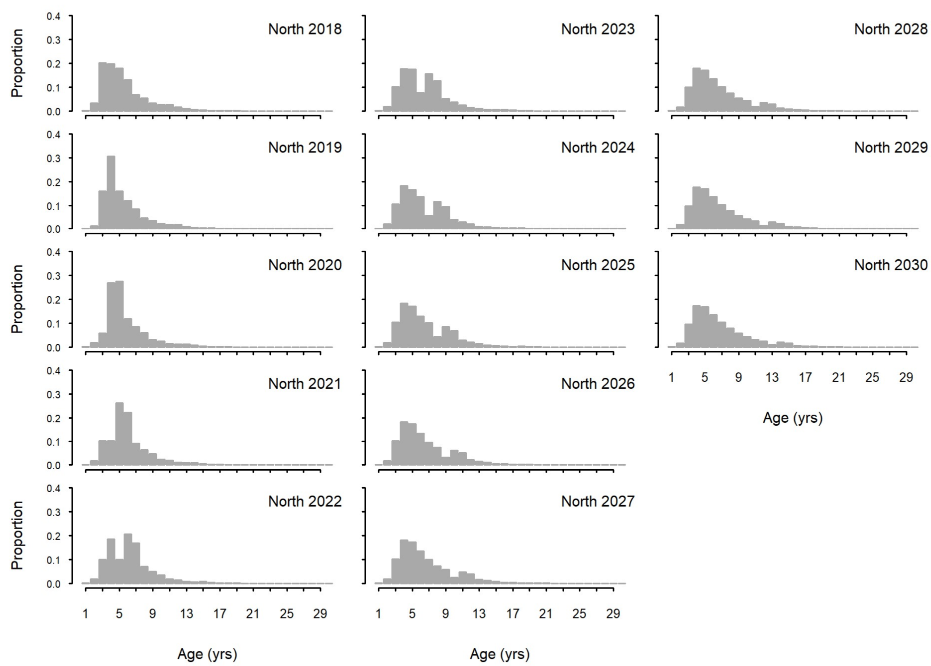

Figure 6a Future projections of annual snapper age compositions for the south region, assuming average recruitment (i.e. calculated from the stock-recruitment relationship) and a specified level for future annual catches.

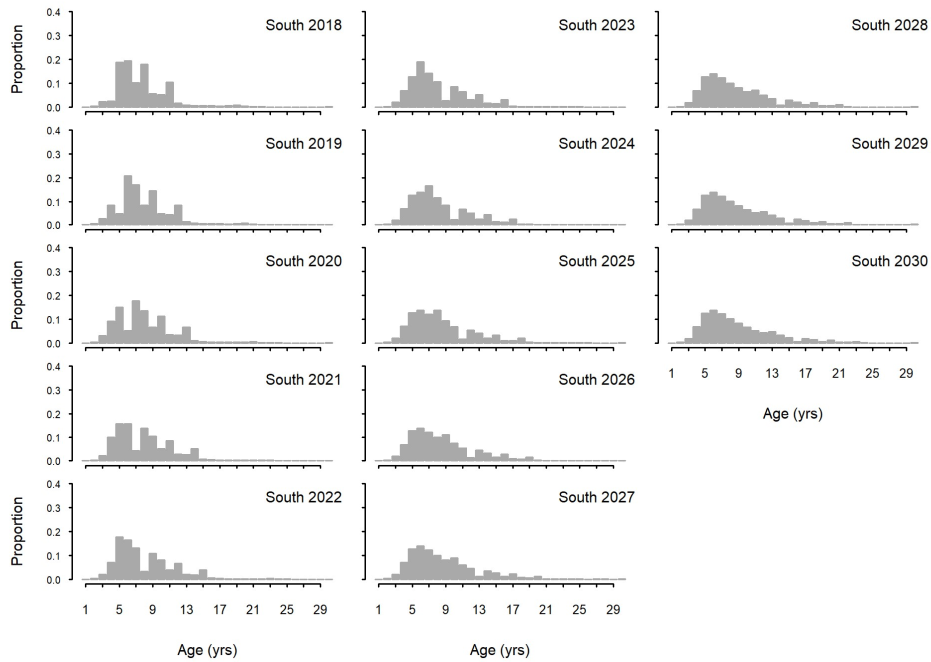

Figure 6b Future projections of annual snapper age compositions for the south region, assuming average recruitment (i.e. calculated from the stock-recruitment relationship) and a specified level for future annual catches.

Fishing mortality and biomass

Applying the base case model, the estimated fishing mortality, F, in the northern areas increased from a very low level <0.05 y^{-1} to a peak of almost 0.4 y^{-1} in the mid-late 2000s. Subsequently, the point estimates of F declined to below 0.2 in 2020, and was projected to decline to around F_{MSY} over the next decade. Note, 60% confidence limits are shown for estimated fishing mortality and biomass so it can be assessed if, based on a given model, if the probability of being above a particular biological reference point is 80% or more (i.e. if the lower confidence limit is above the line), as consistent with Marine Stewardship Council P1 assessment guidelines). The annual fishing mortality trend for the south region is similar, but with the values being lower for most years in recent decades.

The estimated relative female biomass levels in the north region, B_{rel}, decreased from around 0.6 in 1975 to around the limit level of 0.16 (equating to $0.5B_{MSY}$) in the mid 2000s, and then to well below the limit over the next few years before increasing to around the limit in 2020 projected. B_{rel} is projected to increase to about midway between the limit and threshold by 2030 in the north region. The trend is somewhat similar for the south region, but with B_{rel} only declining as far as the limited before increasing to about midway between the limit and threshold by 2020 and to around the threshold by 2030.

The 60% lower confidence limit for B_{rel}, for regions combined in 2020, is around the limit reference point, i.e. ~80% probability that B_{rel} is currently above the limit.

Assuming 'average' recruitment levels are experienced in the ensuring years, B_{rel} is projected to be about midway between the limit and threshold, if catches remain at a similar level to 2020.

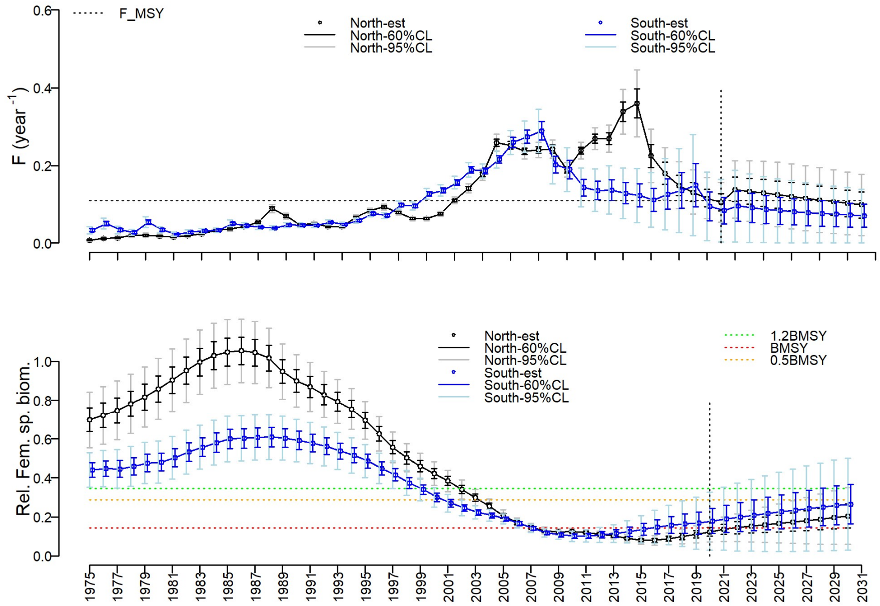

Figure 7a. Model estimates for fishing mortality (F, y^{-1}) and relative female biomass B_{rel}, with associated 60% and 95% confidence intervals, between 1975 and 2030 for dhufish in the north and south regions. Vertical dotted line demarcates the year 2020.

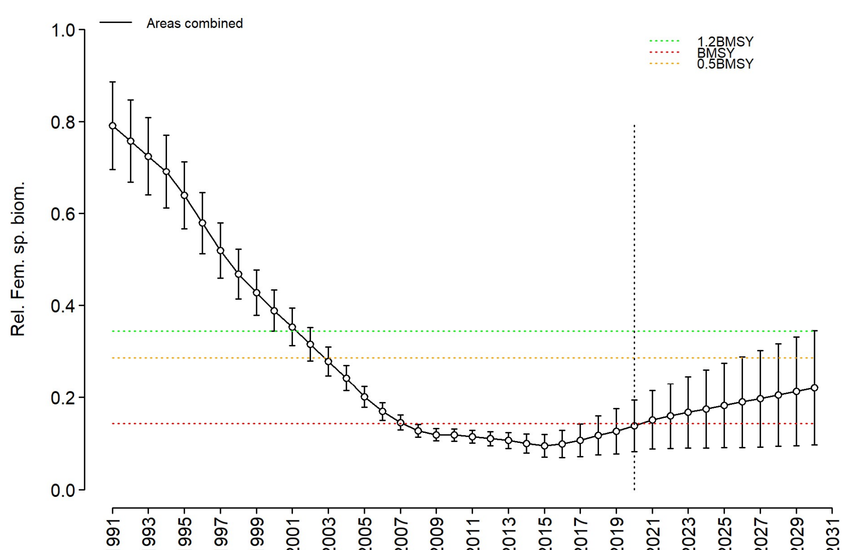

Figure 7b. Model estimates for relative female biomass B_{rel}, with associated 60% confidence intervals, between 1975 and 2030 for dhufish in the north and south regions combined. Vertical dotted line demarcates the year 2020.

Assessment summary results

The phase plots show that, in the north region, increasing fishing mortality particularly through the 1980s and 1990s, accompanied by declining female B_{rel}, to below the limit (Figure 8). With subsequent declines in F, estimated B_{rel} levels started to increase in the north region and projected to be midway between the limit and threshold by 2030. Similar trends were exhibited in the south region, but with B_{rel} not declining quite as far. By 2030, B_{rel} is projected to be just above the threshold, with fishing mortality around the threshold level (Figure 8).

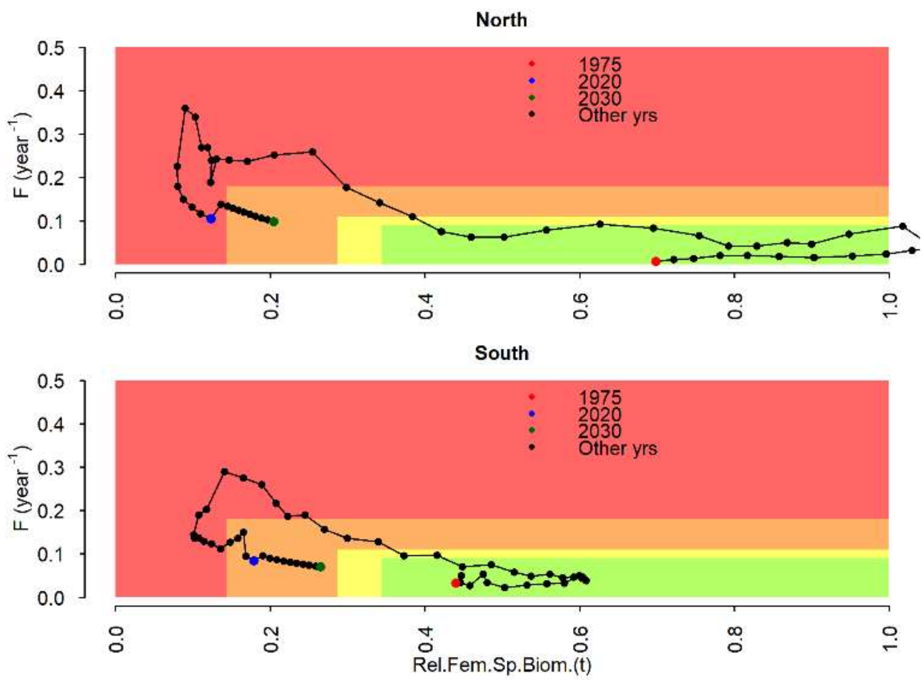

Figure 8. Phase plot showing the relationships between annual model estimates for fishing mortality, F, y^{-1}, and relative female spawning biomass, B_{rel}. Areas shaded red indicate where limit points are exceeded for F and/or B_{rel}. Areas shaded orange are between the limit and threshold, yellow areas are between the threshold and target, and green areas are above the target.

MSY calculations

The estimated equilibrium fishing mortality at B_{MSY} of 0.11, for the base case model, results in an MSY estimate of 300 t (for areas combined). B_{MSY} is estimated at 1036 t, and B_{rel} at B_{MSY} is 0.28 (Figure 9).

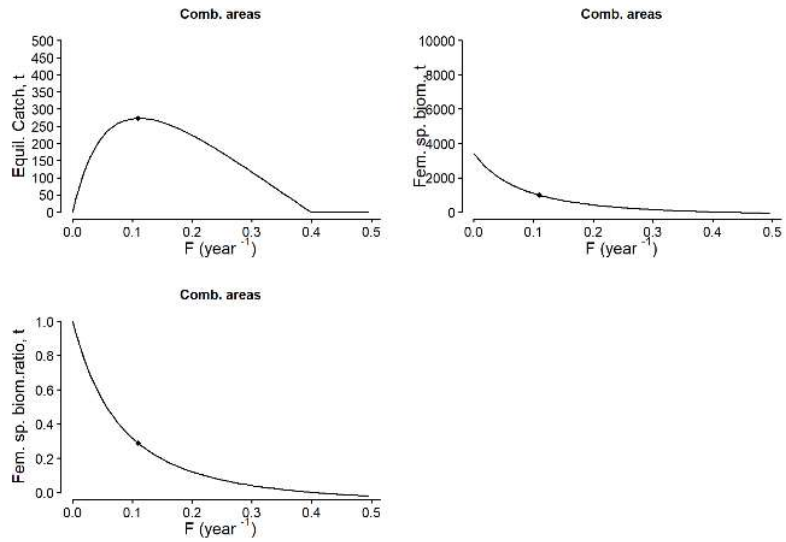

Figure 9. Relationship between fishing mortality and equilbrium catch, equilbrium female spawning biomass and equilbrium relative female spawning biomass (or ratio of fished/unfished female spawning biomass). Black dots highlight the levels of catch and biomass at F_{MSY}.

Recruitment deviations

Visual inspection of the available age composition data for Snapper indicate greater interannual recruitment variation in the southern areas than northern (Figure 10).

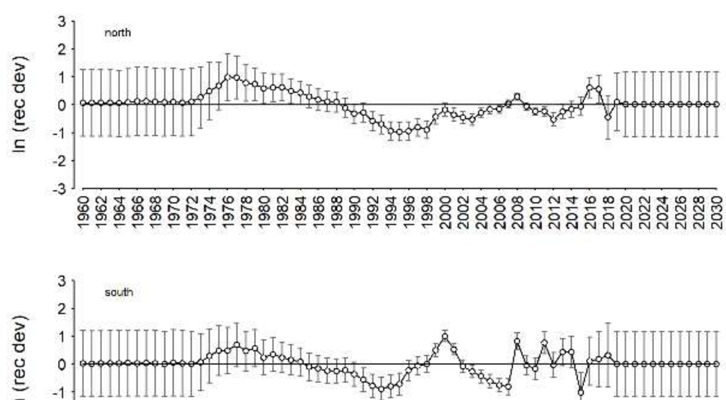

Figure 10. Recruitment deviations and associated 95% confidence intervals (shown in log space) for snapper in the north and south regions.

Recruitment

The estimated levels of annual recruitment for snapper in the north region are far greater than in the south region, reflecting the larger stock size in the former area (Figure 11). Although estimated B_{rel} is far lower in 2020 than in 1975, the estimated annual recruitment levels are well within historical ranges in each region, indicating that recruitment impairment has not occurred (Figure 12).

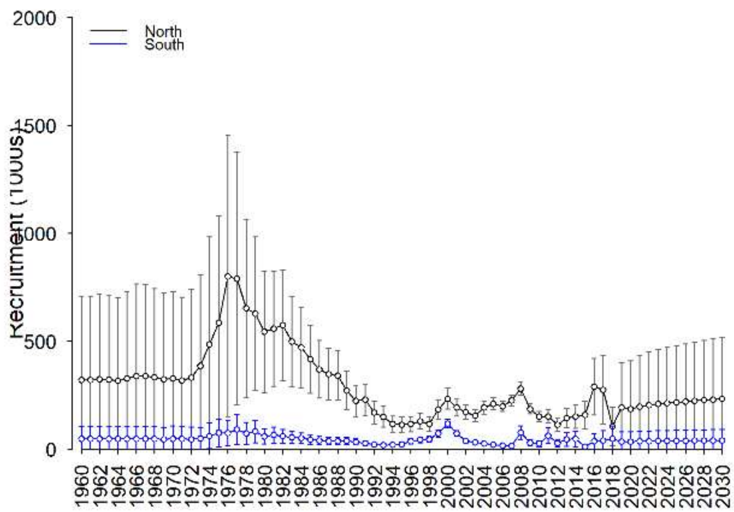

Figure 11. Estimated annual recruitment for snapper in the north and south regions between 1965 and 2030.

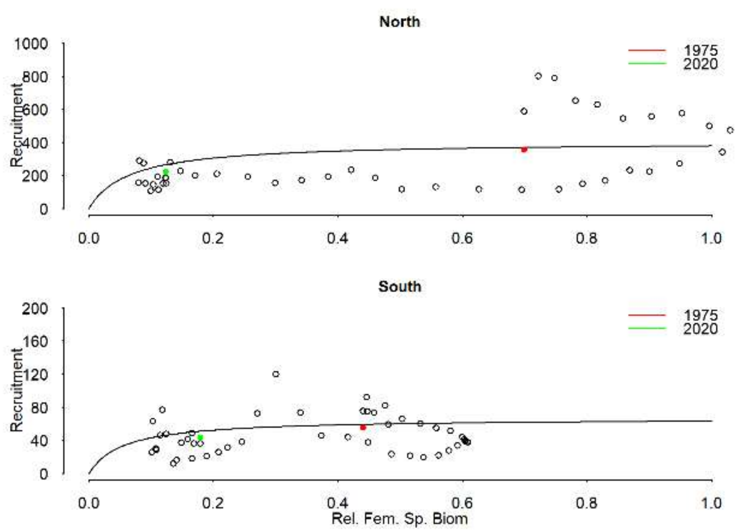

Figure 12. Estimated Beverton-Holt stock-recruitment curves for snapper (with steepness = 0.75) in the north and south regions, and estimates of annual recruitment and relative female spawning biomass between 1991 and 2020.

Alternative discard mortality scenario (no discard mortality for undersize fish, model fitted to cpue)

The annual trends in F and B_{rel}, when not allowing for post-release mortality of undersize fish (i.e. allowing for post-release mortality through increased catches) are very similar to the base case scenario (Figure 13).

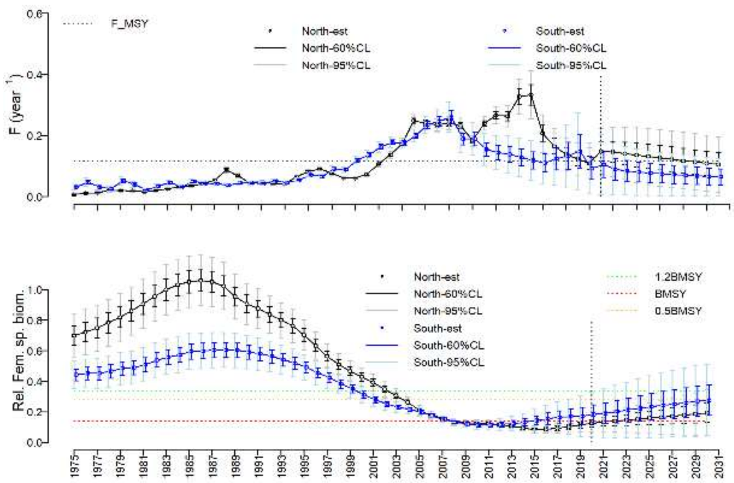

Figure 13. Model estimates for fishing mortality (F, y^{-1}) and relative female biomass B_{rel}, with associated 60% and 95% confidence intervals, between 1975 and 2030 for snapper in the north and south regions. Vertical dotted line demarcates the year 2020.

Alternative scenario (discard mortality for undersize fish = 0.25, model not fitted to cpue)

The annual trends in F and B_{rel}, when not allowing for post-release mortality of undersize fish (i.e. allowing for post-release mortality through increased catches) are similar to the base case scenario except that the levels of B_{rel} in the north region are slightly higher, similar to the estimates for the south region (between threshold and limit) (Figure 14).

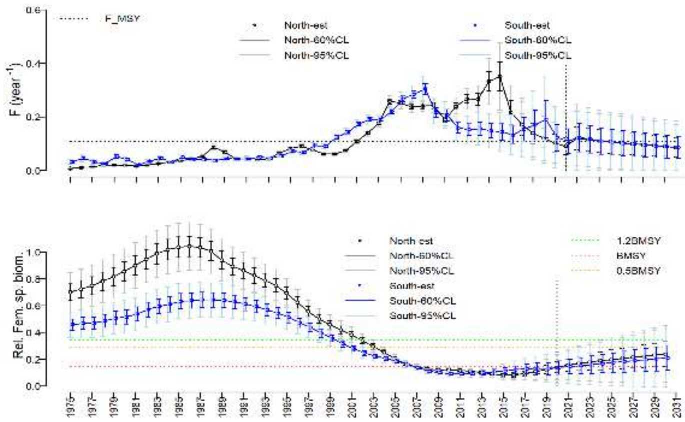

Figure 14. Model estimates for fishing mortality (F, y^{-1}) and relative female biomass B_{rel}, with associated 60% and 95% confidence intervals, between 1975 and 2030 for snapper in the north and south regions. Vertical dotted line demarcates the year 2020.

Alternative scenario (discard mortality for undersize fish = 0, model not fitted to cpue)

The annual trends in F and B_{rel}, when not allowing for post-release mortality of undersize fish (i.e. allowing for post-release mortality through increased catches) are very similar to the previous scenario (Figure 15). Thus, results are slightly more optimistic for the north region when the model is not fitted to monthly and daily CPUE data. Note that there is no daily CPUE index for the south region. As results are very similar with and without daily CPUE data for the south region, this indicates that the monthly CPUE data have little influence on estimates of current stock status for this region. Similar to the modelling for dhufish, the daily CPUE data are more influential.

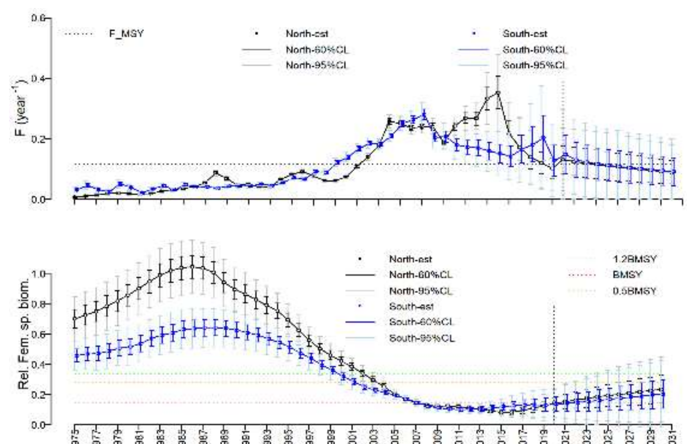

Figure 15. Model estimates for fishing mortality (F, y^{-1}) and relative female biomass B_{rel}, with associated 60% and 95% confidence intervals, between 1975 and 2030 for snapper in the north and south regions. Vertical dotted line demarcates the year 2020.

Modelling uncertainties and future assessments

The modelling results incorporating cpue data indicate that the stock is slowly recovering, following the introduction of management measures in the late 2000s. There are, however, considerable uncertainties with this assessment. Results are highly sensitive to assumptions about growth, in particular, as well as parameters relating to stock productivity. The model projections (2021-2030) are based on the assumption of average recruitment levels throughout this period. Given that the age composition data show considerable recruitment variation exists for this species, stock projections beyond a small number of years will be highly uncertain. There is also further uncertainty associated with effects of recruitment variability on results pertaining to current stock status, particularly for dhufish. This relates to dhufish recruiting into the fishery at about 6-7 years, so the most recent available age composition data can only provide information on recruitment strength back to about 2013-14. Until it can be confirmed that the stock has fully rebuilt, the dhufish stock will need to be monitored closely and the validity, or otherwise, of the current stock projection results continually assessed.

Ideally, a dynamic model such as this should be informed by a reliable abundance index. This is the first time cpue data have been included in a dynamic model for WA dhufish and Snapper (and dhufish). There is considerable uncertainty regarding, in particular, effects of fishing efficiency, and more work is required to better understand how the cpue trends (particularly the monthly data) are impacted by efficiency changes.

Finally, it should be noted that some additional data could become available (other than commercial cpue data) for both species that are potentially useful for informing future assessments. For example, a time series of length composition data exist from charter boat fishing, and perhaps also cpue data from this fishery could prove informative. As this model is age-structured, the commercial and recreational length data are not fully-utilised in this assessment. If both the length and age data were incorporated, this would allow growth to be estimated within the model, which has several advantages over specifying growth as a data input. Incorporating these data would require additional model complexity (i.e. a model that can simultaneously fit to both age and length data). There may be value, for future assessments for these two species, in exploring of the applicability of the stock assessment package, stock synthesis (available from NOAA) for incorporating these data. However, it should be noted there are many complexities to running this package effectively and producing reliable results (requiring substantial knowledge and experience).

Mathematical description

Growth and maturity

Parameters for growth, age at maturity, gear selectivity and length-weight relationships were estimated outside the model. For Snapper, growth was modelled according to a traditional von Bertalanffy growth equation, (i.e. assuming growth curve has not changed over time). The estimated total length $L_{s,y,t}$ of an individual in area a at age t of sex s in year y for Snapper was calculated as:

$$L_{a,s,y,t} = L_{\infty,a,s}\{1 - \exp\left(-\left[k_{a,s}(t - t_{0,a,s})\right]\right\}$$

where $L_{\infty,s}$, k_s and $t_{0,s}$ are the asymptotic total length, growth coefficient and hypothetical age at zero length, respectively, for sex s. Note that the growth of Snapper differs between the two areas, with individuals growing to a larger length-at-age in the South area (Wakefield *et al.*, 2017).

Growth of dhufish was was modelled according to a 'year-effects', to allow for temporal variation in growth evident in the length at age data (based on the model described by Cottingham et al., 2016). Unlike Snapper, growth of dhufish is similar between areas, and assumed not to differ (Hesp *et al.*, 2002; Lenanton *et al.*, 2009a).

For each species, the weight of an individual given its length (using total length for *G. hebraicum* and fork length for *C. auratus*) and its sex, $W_{a,s,y,t}$, was calculated from a weight-length relationship

$$W_{a,s,y,t} = \exp\left(a_s + b_s \log_e L_{a,s,y,t}\right)/1000,$$

where a_s and b_s are the length-weight parameters for each sex.

where j and k are constants (Table 3).

The probability of a fish in area a of sex s being mature in year y at age t, was calculated as

$$P_{a,s,y,t} = 1/\left\{1 + \exp\left[-\log_e(19)\left(L_{a,s,y,t} - L_{50,a,s}\right)/\left(L_{95,a,s} - L_{50,a,s}\right)\right]\right\}$$

where $L_{50,a,s}$ and $L_{95,a,s}$ are the lengths at which 50 and 95% of fish are mature, respectively (with the values being the same for the two areas, for Dhufish).

Gear selectivity, retention, and proportions of retained and released fish

For Dhufish, the vulnerability of an individual, of either sex at age t, to the fishing gear was described as:

$$V_t = 1/\{1 + \exp[-V_\alpha(t - V_{50})]\}$$

where V_α is the slope and V_{50} is the age at which fish are 50% selected by the gear. This relationship was derived using data collected from selected commercial fishers with research permits allowing collection of undersize fish (assumed to be same as for recreational fishers, who use similar gear). (See below for Snapper).

The probability of a fish of either sex at age t being retained if caught in year t, $\psi_{y,t}$, was calculated as

$$\psi_{y,t} = 1/\left\{1 + \exp\left[-\psi_{\alpha,y}\left(t - \psi_{50,y}\right)\right]\right\}$$

where $\psi_{\alpha,y}$ is the slope and $\psi_{50,y}$ is the age at which fish in year y are 50% retained. The values of $\psi_{\alpha,y}$ and $\psi_{50,y}$ were allowed to vary between years to account for possible effects on these parameters of variable growth in Dhufish. The proportion of fish (of either sex) at age t that are retained if caught was calculated as

$$\phi_{y,t} = \psi_{y,t}/V_t$$

and the proportion of fish discarded as

$$\varphi_{y,t} = 1 - \psi_{y,t}/V_t$$

For Snapper, year and area-specific retention curves were calculated to account for differences in retention probabilities associated with variations in minimum legal length (MLL) of this species between areas and over time (i.e. always 410 mm in the North area, vs 410 mm in the South area increasing to 450 mm in 2009 and then 500 mm in 2010. There were insufficient data to reliably estimate gear selectivity for snapper in either area. V_t, for each area was based on the estimated retention curves, reduced by a specified amount (0.5 y for all years in the northern area, 0.5 y prior to 2009 in the south, then 1.5 y in 2009 and 2 y thereafter, to account for the changes in size limit). In future, collection of data on gear selectivity would be valuable for informing future assessments. For both species, age composition data were available from the commercial and recreational line sectors, but were not always available or considered to constitute a reliable sample from both sectors in each area, and age composition data were not available from the minor commercial gillnet sector. The values of $\psi_{y,t,}$ were assumed to be common across fishing sectors.

Mortality

The fishing mortality associated with capture and retention of fish in area a, for sex s in year y at age t, was calculated as

$$F_{a,s,y,t} = V_t \psi_t F_{a,y}$$

where $F_{a,y}$ is the estimated, fully-selected fishing mortality associated with fishing in that area and year. The corresponding fishing mortality associated with capture and discarding was

$$\Lambda_{a,s,y,t} = \varphi_t D V_t F_{a,y}$$

In scenarios that do not allow for post-release mortality of undersize fish, D is set to zero (with release mortality accounted for by increasing annual catches).

The stock in area a in the initial year of the model and preceding burn-in period (i.e. prior to the first year of observed catches, 1960-1975) is assumed to have been fished at F_a^I, the estimated (*G. hebraicum*) or specified (*C. auratus*) equilibrium initial fishing mortality in area a. F_a^I was for *C. auratus* was set to 0.025 y^{-1}. *M* was fixed at 0.11 y^{-1} for *G. hebraicum* for both areas, and to 0.144 and 0.12 y^{-1}, respectively, for *C. auratus* in the north and south areas.

For all subsequent years, $F_{a,y}$ was estimated by applying Newton's algorithm, to search iteratively for the fishing mortality at which the expected and observed catch matched, i.e. in area a, year y).

The annual total mortality for fish of age t in area a was calculated as

$$Z_{a,s,y,t} = F_{a,s,y,t} + \Lambda_{a,s,y,t} + M$$

Stock-recruitment

The model assumes that the recruits in each area are derived from the spawning biomass in that same area. The relationship between annual juvenile recruitment and female spawning stock size in each area was considered to follow a Beverton and Holt (1957) curve. The expected recruitment of 1-year old fish in area a and year y was calculated as

$$R_{y,a} = S_{y-1,s=1,a} / \left(\alpha_a^{SR} + \beta_a^{SR} S_{y-1,s=1,a}\right)$$

where α_a^{SR} and β_a^{SR} are parameters of the Beverton and Holt stock-recruitment curve for area a and $S_{y-1,s=1,a}$ is the female spawning biomass in that area in the previous year. The annual recruitment deviations (estimated as model parameters in log-space) in each area, $\varepsilon_{a,y}$, were assumed to be normally-distributed with a mean of zero and specified standard deviation ($\sigma_R = 0.6$), i.e. $\varepsilon_{a,y} \sim N(0, \sigma_R^2)$, see Smith and Punt (1998) on rationale for σ_R value, who also cite estimates obtained by Beddington and Cook (1983).

The numbers of age 1 fish recruiting in year y in area a were calculated as

$$N_{a,s,y,t=1} = R_{a,y} \exp\left(\varepsilon_{a,y} - 0.5\sigma_R^2\right).$$

The parameter α_a^{SR} was calculated as

$$\alpha_a^{SR} = (S_a^0 / R_a^*)[(1-h)/(4h)]$$

where S_a^0 is the unfished female spawning biomass in area a, R_a^* is the unfished recruitment in that area (estimated as a model parameter) and h is the steepness parameter of the stock-recruitment relationship, specified as a fixed value of 0.75 in the model, as is common in many Australian and New Zealand stock assessments, for reasons given in Francis (1993).
β_a^{SR} was calculated as:

$$\beta_a^{SR} = (h - 0.2)/(0.8 h R_a^*)$$

and S_a^0 as:

$$S_a^0 = R_a^* SBR_a^{F=0}$$

where $SBR_a^{F=0}$ is the unfished female spawning biomass per recruit, determined from the unfished female per recruit numbers at age in each area, $\acute{N}_{a,s=1,t}$, female weight at age, $W_{y=0,s=1,t}$, and female probability of maturity at age for that year, $\psi_{y=0,s=1,t}$. $\acute{N}_{a,s=1,t}$ was calculated as

$$\acute{N}_{a,s=1,t=1} = \varphi \qquad \text{if } (t = 1)$$
$$\acute{N}_{a,s=1,t} = \acute{N}_{a,s=1,t-1}\exp{(-M)} \qquad \text{if } (1 < t < T)$$
$$\acute{N}_{a,s=1,t} = \acute{N}_{a,s=1,t-1}\exp{(-M)}/\big(1-\exp(-M)\big) \qquad \text{if } (t = T)$$

where φ is the proportion of fish that are females at age 1, and T refers to the maximum age of the species considered by the model. The female per recruit numbers at age in each area for the population in its initial equilibrium fished state, $\widetilde{N}_{a,s=1,t}$, were calculated applying the same equation substituting $Z_{a,s=1,y=0,t}$ for M. The female spawning biomass per recruit for the population in its equilibrium unfished state is

$$SBR_a^{F=0} = \sum_{t=1}^{T} \acute{N}_{a,s=1,t} W_{y=0,s=1,t} P_{y=0,s=1,t}$$

The female spawning biomass per recruit for the population in its initial equilibrium fished state, $SBR_a^{F_a^{\text{Init}}}$, was calculated as for $SBR_a^{F=0}$, but replacing $\acute{N}_{a,s=1,t}$ with $\widetilde{N}_{a,s=1,t}$. The estimated initial equilibrium recruitment for the fished population was calculated as

$$R^{\text{Init}} = \left(SBR_a^{F_a^{\text{Init}}} - \alpha_a^{SR}\right) / \left(\beta_a^{SR} SBR_a^{F_a^{\text{Init}}}\right)$$

and the estimated spawning biomass for the population in its initial equilibrium fished state as

$$S_a^{\text{Init}} = SBR_a^{F=F_a^{\text{Init}}} R^{\text{Init}}$$

Population numbers and catches at age

The estimated number of female fish at age 1, in area a and year y, were calculated as

$$N_{a,s=1,y,t=1} = \varphi R_{y,a} \exp(\varepsilon_y - 0.5\sigma_R^2)$$

and with males calculated in the same way, replacing φ with $1-\varphi$. The estimated numbers of fish of sex s, beyond age 1 surviving to age t in area a and year y, were calculated as

$$N_{a,s,y,t} = N_{a,s,y-1,t-1}\exp{(-Z_{a,s,y-1,t-1})} \qquad \text{if } (1 < t < T)$$
$$N_{a,s,y,t} = N_{a,s,y-1,t-1}\exp{(-Z_{a,s,y-1,t-1})}/\left(1-\exp\left(-Z_{a,s,y-1,t-1}\right)\right) \qquad \text{if } (t = T)$$

The estimated catch in area a, year y, of sex s and age t, was calculated from the Baranov catch equation

$$\hat{C}_{a,s,y,t} = \left(F_{a,s,y,t}/Z_{a,s,y,t}\right)\left\{1-\exp\left(-Z_{a,s,y,t}\right)\right\} N_{a,s,y,t} W_{a,s,y,t}$$

Objective function

Age compositions

The age compositions were assumed to conform to a Dirichlet distribution (Schnute and Haigh, 2007). Denoting the observed and estimated proportions of fish, for combined sexes, in age class t caught by sector m in area a and in year y as $P_{m,a,y,t}$ and $\hat{P}_{m,a,y,t}$, respectively, the latter was calculated as

$$\hat{P}_{m,a,y,t} = \hat{C}_{m,a,y,t} \Big/ \sum_{t=1}^{T} \hat{C}_{m,a,y,t}$$

The overall log-likelihood associated with the age composition data is

$$\lambda_1 = \sum_{m=1}^{M} \sum_{a=1}^{A} \sum_{y=1}^{Y} \sum_{t=1}^{T} \{\log_e \Gamma(\varsigma_{m,a,y} \hat{P}_{m,a,y,t}) - \varsigma_{m,a,y} \hat{P}_{m,a,y,t} \log_e(\hat{P}_{m,a,y,t})\} - \log_e \Gamma(\varsigma_{m,a,y})$$

where Γ refers to the gamma function, $\varsigma_{m,a,y}$, the estimated effective sample size for sector m in area a and in year y, depending on Stirling's approximation for the gamma function, was calculated as

$$\varsigma_{m,a,y} \approx \frac{n-1}{2} \left[\sum_{y=1}^{Y} \log_e \left(\frac{\hat{P}_{m,a,y,t}}{P_{m,a,y,t}} \right) \right]^{-1}$$

Any zero values in the age frequency data were replaced by a small number (0.0001) of similar magnitude to the lowest observed proportion in the dataset (Francis, 2014).

Recruitment

The log-likelihood associated with the estimated annual recruitment deviations, λ_2, was calculated as

$$\lambda_2 = \sum_{a=1}^{A} \sum_{y=1}^{Y} 0.5 \frac{\varepsilon_{a,y}^2}{\sigma_R^2}$$

CPUE indices

For scenarios where the model was fitted to CPUE data, these data comprised standardised CPUE indices (dropline and/or handline) for each of the northern and southern areas, calculated separately for monthly and daily data. The estimated CPUE in year y for time series i, was calculated as $\hat{U}_{y,i}, = q_i B_{a,y}$, where q_i is the estimated catchability parameter for CPUE time series i and $B_{a,y}$ is the vulnerable biomass, for area a in year y, calculated as

$$B_{a,y} = N_{t,a,s} \psi_{a,t} W_{a,s,y,t}$$

The negative log-likelihood for each CPUE time series, λ_{U_i}, was calculated as

$$\lambda_{U_i} = \sum_{y \in Y_i} \left(0.5\log_e(\sigma^2_{M_{i,y}} + \sigma^2_{P_i}) + 0.5\log_e(2\pi) + \frac{(\log_e(U_{y,i}) - \log_e(\widehat{U}_{y,i}))^2}{2(\sigma^2_{M_{i,y}} + \sigma^2_{P_i})} \right),$$

where for each CPUE time series, U_y is the standardized CPUE as outlined above, and $\widehat{U}_y$ is the estimated annual CPUE. $\sigma^2_{M_{i,y}}$ is the variance associated with U_y calculated by the catch rate standardisation analysis, and $\sigma^2_{P_i}$ is an additional, unmeasured variance associated with input data. The overall negative log-likelihood associated with CPUE data, denoted λ_3, was determined as the sum of λ_{U_i} for all series included when fitting the model.

Natural mortality and steepness

Recognising that there would be very limited information in the data for estimating M and h, penalty functions were applied to constrain estimates for these parameters to a specified value (with error), i.e.

$$\lambda_4 = 0.5\log_e\sigma^2_M + 0.5\log_e(2\pi) + \frac{(M - \overline{M})^2}{2\sigma^2_M}$$

and

$$\lambda_5 = 0.5\log_e\sigma^2_h + 0.5\log_e(2\pi) + \frac{\left(h - \overline{h}\right)^2}{2\sigma^2_h}$$

The overall log-likelihood, λ was calculated as

$$\lambda = \lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5$$

The model was fitted in AD model builder by minimising the overall negative log-likelihood (Fournier *et al.*, 2012) and outputs plotted in R (R Core Team, 2017). Confidence limits for derived quantities (e.g. relative female spawning biomass, fishing mortality) were calculated based on estimates of asymptotic standard errors outputted by AD model builder. The model was also used to produce projections for future fishing mortality and biomass, based on specified levels of future catch.