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North Coast Demersal Scalefish Resource: Kimberley

2025 Assessment

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Resource Assessment Report No. 4

North Coast Demersal Scalefish Resource - Kimberley

2025 Assessment

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Important disclaimer

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Executive Summary

The North Coast Demersal Scalefish Resource (NCDSR) comprises ecological suites of tropical demersal fish species that occur predominantly in inshore waters (20–250 m deep) and offshore waters (> 250 m deep) of the North Coast Bioregion (NCB). More than 60 demersal species are landed by fisheries operating in the Kimberley and Pilbara regions of the NCB each year, including high-value snappers (Lutjanidae), groupers (Epinephelidae), and emperors (Lethrinidae). As outlined in the NCDSR Harvest Strategy (DPIRD, 2017), the Kimberley resource is currently monitored through annual reviews of total removals and catch rate trends of indicator species, as well as periodic (every 4–5 years) model-based stock assessments of each indicator species, and occasional assessments of non-indicator species to validate the indicator species approach and ensure that the status of other retained species remains at acceptable levels. The assessment and harvest strategies of these species are primarily based on estimates of spawning stock biomass (or an appropriate proxy for biomass), relative to internationally accepted target, threshold, and limit reference levels. Based on the inherent vulnerability and risk to the sustainability of the major species within the suite of inshore demersal scalefish in the NCB, the stocks of indicator species selected for assessing the status of the resource within the Pilbara and Kimberley include red emperor, bluespotted emperor, Rankin cod, and goldband snapper.

The demersal fish resources of the Kimberley region of the NCDSR (NCDSR-Kimberley) supports the second highest annual total retained catch of demersal scalefish in Western Australia, with the commercial fisheries taking the vast majority of the catch share (i.e., 99%) compared with the charter and recreational (<1%) sectors. The commercial fishery principally targets higher-value species such as goldband snapper and red emperor, resulting in an economic value of $10–20 million. This indicates that this fishery has a high social amenity value and is an important asset locally. Since 2008, annual commercial catches have exceeded 1,000 t. Annual catches have ranged from 1,378 to 1,544 tonnes over the last 5 years. In 2025, management actions were implemented to reduce effort within specific Zones of the fishery by 10%.

The 2025 NCDSR-Kimberley assessment of the two indicator species, red emperor and goldband snapper, presented in this report incorporates catch and effort information collected up to 2024 (inclusive), as well as biological data on the sizes and ages of fish sampled from fisheries independent sampling up until 2021 (inclusive) for the two indicator species.

Red Emperor

The 2025 integrated model (Level 5) assessment of the red emperor stock in the NCDSR-Kimberley estimated the female B_{rel} in 2024 to be above the limit reference level of 0.2 (B_{rel} = 0.24, 60% CI: 0.22–0.25), with recent trends in B_{rel} estimates indicating a declining spawning biomass. The estimated F for red emperor in 2024 (F = 0.22 yr^{-1}; 60% CI: 0.20–0.23 yr^{-1}) was above the proxy limit reference point and thus exceeded the acceptable level. The red emperor stock in the NCDSR-Kimberley is classified as **Inadequate** and the risk to this stock is assessed as **High**. Model projections based on the 2024 catch level suggest a very low probability of the stock recovering to B_{MSY} by 2035.

Goldband Snapper

The 2025 integrated model (Level 5) assessment of the goldband snapper stock in the NCDSR-Kimberley estimated the female B_{rel} in 2024 to be just below the target reference level of 0.4 (B_{rel} = 0.38; 60% CI: 0.32–0.43), with recent trends in B_{rel} estimates indicating a declining spawning biomass. The estimated *F* for goldband snapper in 2024 ($F = 0.18\ yr^{-1}$; 60% CI: 0.14–0.22 yr^{-1}) was at the proxy threshold point. The goldband snapper stock in the NCDSR-Kimberley is classified as **Sustainable-adequate** and the risk to the stock is assessed as **Medium**. Model projections based on current catch suggest that the stock would continue to decline to around the threshold level by 2035.

Ecological Components

As a result of the gear design, these fisheries have little impact on the habitat overall, although there may be some rare interactions with coral habitats, which are not common in areas where these fisheries operate. Trap fishing is the main fishing method used in the NDSMF for demersal species, which has little physical impact on the benthic environment and hence there is a **low** risk to benthic habitats. Hall and Wise (2011) demonstrated that there has been no reduction in either mean trophic level or mean maximum length in the finfish catches recorded within the Kimberley (i.e., no fishing down of the food web) over the past 30 years. The need to maintain relatively high levels of biomass for the species caught in this fishery to meet stock recruitment requirements results in a **low** risk to the overall ecosystem from the fishery.

Socio-Economic Components and External Drivers

Seven vessels fished in the 2024 fishing season, and at least 25 people (3–4 crew per vessel) were directly employed in the NDSMF. Approximately half the fish from this fishery are supplied to Perth metropolitan markets, while the other half is supplied to east coast metropolitan markets. There is currently a **medium** level of risk to these values. The NDSMF principally targets the higher-value species such as goldband snapper and red emperor, resulting in an economic value of $10–20 million (Level 4). This indicates that this fishery has a high social amenity value and is an important asset locally. There is currently a **medium** risk to this level of return. Recreational fishing attracts many visitors to the NCB, particularly in inshore areas over the winter dry season (April – October). This provides employment through local charter fishing services and fishing tackle outlets around key population centres, as well as more remote charter operations offering wilderness fishing experiences in the northern Kimberley region, including offshore locations such as the Rowley Shoals.

Assessment Overview

Target Stocks

Species/Stock	Risk	Fishing Mortality	Relative Biomass	Status
Red emperor	High	*F* > Limit	Limit < *B* < Threshold	Inadequate
Goldband snapper	Medium	*F* ~ Threshold	Threshold < *B* < Target	Sustainable-Adequate

Ecological Components

Feature	Risk	Comments
Other Retained Species	High	Following indicator species approach, based on the highest risk for indicator species.
Bycatch Species	Low	There is a limited quantity of non-retained bycatch.
ETP Species	Low	Rarely interacts with listed species, mostly released alive.
Habitats	Low	Minor physical impact on the benthic habitat.
Ecosystem	Low	No evidence to suggest a reduction in mean trophic level.

Although the overall risk to other retained species is assessed as High (following the indicator species approach, based on the highest risk for target stocks), risks to other ecological components affected by fishing activities targeting the NCDSR-Kimberley is assessed as **Acceptable**. In line with the harvest strategy, management should continue to focus on meeting objectives relating to the sustainability of target stocks.

Socio-Economic Components and External Drivers

Feature	Risk	Comments
Economic	Medium	Level 4: GVP $10-20 million.
Social	Low-Medium	Level 3: Locally important to the recreational sector.
External Drivers (Climate)	Medium	Low-medium sensitivity for inshore and offshore species.
External Drivers (Other)	Low risk	Commonwealth marine parks restricting access to fishing by all sectors. Commonwealth trawl fishing may operate in waters in depths greater than 200 m isobath.

1 Background

1.1 Resource Overview

A range of commercial and recreational fisheries target demersal scalefish resources in the North Coast Bioregion (NCB) of Western Australia (WA). The major demersal fish species in the NCB (i.e., > 100 tonnes, in order of gross tonnage) are goldband snapper (*Pristipomoides multidens*), bluespotted emperor (*Lethrinus punctulatus*), saddletail snapper (*Lutjanus malabaricus*), red emperor (*Lutjanus sebae*), Rankin cod (*Epinephelus rankini*), crimson snapper (*Lutjanus erythropterus*), rosy threadfin bream (*Nemipterus furcosus*), and brownstripe snapper (*Lutjanus vitta*).

Commercial fisheries accessing demersal scalefish resources in the NCB include the Northern Demersal Scalefish Managed Fishery (NDSMF) in the Kimberley, and the Pilbara Demersal Scalefish Fisheries (PDSF) in the Pilbara. These fisheries are managed in accordance with the *North Coast Demersal Scalefish Resource Harvest Strategy 2017-2021* (NCDSR Harvest Strategy; DPIRD 2017).

The permitted methods in the NDSMF (Area 2 – offshore area) include handline, dropline, and fish traps, but since 2002 it has essentially been a trap-based fishery, which uses gear time access and spatial zones as the primary management measures. The main species landed by this fishery in the Kimberley are goldband snapper and red emperor. The inshore area of the NDSMF (Area 1) permits line fishing only, between the high-water mark and a line approximating the 30 m isobath. The commercial sector is managed primarily through input controls in the form of total allowable effort (TAE) and since 2006, has been allocated to three separate Zones within Area 2 of the fishery and is monitored and enforced using a satellite-based vessel monitoring system (VMS).

Recreational fishing activities in the NCB are mostly line-based fishing from private boats and charter vessels with effort concentrated around key population centres. The recreational fishery for demersal fish is managed through the use of input controls (e.g., recreational licences) and output controls (e.g., bag and/or boat limits, size limits). The recreational (including charter) sector do not catch significant quantities of most demersal scalefish species targeted by the commercial fisheries.

1.2 Assessment Approach

The different methods used by the Department to assess the status of aquatic resources in WA have been categorised into five broad levels, ranging from relatively simple analysis of catch and effort information, through to the application of more sophisticated analyses and models that incorporate biological data (e.g., Braccini et al. 2021; Newman et al. 2024). The relevance and applicability of each assessment level varies among stocks and is determined based on the level of ecological risk, the biology and population dynamics of the relevant species, the characteristics of the fisheries exploiting the species, and data availability.

Irrespective of the types of assessment methods used, all stock assessments undertaken by the Department apply a risk-based, weight-of-evidence approach. This requires the consideration of each available line of evidence, including outputs from quantitative (empirical and/or model-based) analyses, as well as qualitative lines of evidence such as biological and fishery information that describe the inherent vulnerability of the species to fishing. For each stock, all the lines of evidence are considered within the Department's ISO 31000 based risk assessment framework to derive an overall risk status from the combinations of consequence and likelihood scores (Fletcher 2015).

1.3 Scope

This report provides a benchmark assessment for the NCDSR-Kimberley, following the principles of ecosystem-based fisheries management (EBFM; Fletcher 2015). The document provides information relevant to monitoring of the broader resource (Section 2), as well as more detailed stock assessment outputs for key target species (Section 3). Additional information relevant to assessing the risk to other ecological components affected by fishing activities targeting the NCDSR-Kimberley is presented in Section 4.

As outlined in the NCDSR harvest strategy, the resource is currently monitored through annual reviews of available catch information for the demersal suite and key species/groups, as well as periodic assessments of stock status for each indicator species (DPIRD 2017). The annual catch review process considers estimates of the total removals of species in the NCDSR-Kimberley.

Stock assessments are conducted periodically for the key NCDSR-Kimberley indicator species (red emperor and goldband snapper), as well as other important inshore or offshore species when data are available. Level 3 and Level 5 assessments (see Appendix 1) provide estimates of relative female spawning biomass (B_{rel}) and fishing mortality (F). These estimates are compared to internationally-recognised biological reference points to assess status and risk to stocks, and for overfished stocks, to help ensure the rate of recovery is sufficient for these to rebuild within the recovery timeframe.

This 2025 assessment provides estimates of B_{rel} and F for the two demersal indicator species (red emperor and goldband snapper). Level 5 assessment results for both species are provided as single-area integrated models (i.e., for entire Kimberley), and by two-area integrated models based on a North / South divide at the 15 degrees latitude parallel. The models were developed using the Stock Synthesis framework (Methot and Wetzel, 2013). The North / South divide is based on knowledge regarding ecosystem and habitat associations, species biodiversity, and fishing practices within these areas. While current management arrangements are applied at the Kimberley scale, it is important to understand the impact of fishing at a regional level.

Appendix 1 provides a broad description of the key empirical and model-based analyses undertaken as part of this assessment. Appendix 2 show model fits to data and outputs from model sensitivity analyses, respectively. The 2025 assessment provides catch and effort information collected up to 2024 (inclusive), as well as biological data on the sizes and ages of fish sampled from fisheries-independent sampling up until 2021 (inclusive).

2 Resource Level

2.1 Catch

Demersal scalefish have been commercially fished in Kimberley waters since at least the 1970s (Figure 2.1). Taiwanese pair-trawl fishery commenced within the Pilbara in 1972 and expanded into the Kimberley region soon afterwards. Vessels typically operated in pairs, towing a 30 m headline net on 850 m of wire cable. Cod-end mesh sizes of about 45 mm were common until the introduction of 60 mm minimum mesh size in 1981, in depths between 30 and 140 m. The retained catch mostly comprised the genera *Nemipterus* (threadfin breams), *Saurida* (lizard fishes), *Lutjanus* (tropical snappers), and *Lethrinus* (emperors). The species catch composition changed markedly from 1984 to 1990, with the proportions of lutjanids and *Pristipomoides* species increasing in the overall catch. Available data on the history of foreign fishing show that Taiwanese pair-trawl catches in the Kimberley peaked at approx. 7,166 t in late 1970s (CSIRO Marlin database). Japanese droplining occurred from 1976–1982 in two main areas of Northern Australia, in the vicinity of Ashmore reef (Northern Kimberley) and Troubadour shoal (NT) and a reported 500–1500 tonnes of scalefish were caught annually across these two regions. The catch was predominately *Pristipomoides* species followed by tropical snappers. Chinese pair trawlers operated across NW Australia in 1989. While a quota of 4800 tonnes was allocated, catches of only 1,387 t were recorded, with the majority of the catch being reported within the Kimberley region (approx. 916 t), and mostly comprised the genera *Lethrinus*. Research vessels undertaking voyages around the Australian continent, such as the Russian stern trawlers (1967–1977) and CSIRO trawlers (1978–2017) have reported catches in the Kimberley region but all were relatively minor compared to the commercial Taiwanese and Japanese operations.

Domestic commercial fishing operations in the Kimberley largely began in 1988 when trap fishing was made an exempt fishing method. While line fishing was occurring before 1988, it was mainly focused in inshore areas and only increased post-1988 alongside the trap sector into offshore areas. However, the trap sector has proceeded to land the majority of catches in this region and by 2002, the fishery essentially became trap based. Total annual commercial catches from the domestic fishery in the Kimberley peaked at 959 t in 1996 then declined to 434 t in 2002. Total commercial catches have been increasing since 2002, exceeding 1000 t in 2008 and 1500 t in 2019, and have since peaked at 1544 t in 2021, before reducing to 1379 t in 2024 (Figure 2.2). Charter and recreational catches have remained minor (<1%) compared to commercial catches, due to the low number of fishers and the remoteness of the area. Although there is currently no estimate of the total Kimberley recreational boat-based demersal catch, the top 15 demersal species contributed 52 t to retained catches across the whole NCB in 2020/21 (Ryan et al. 2022). However, demersal species are unlikely to contribute a major proportion to catches in the Kimberley, with nearshore species likely dominating the recreational catch (Table 2.1). The total 2024 commercial catches were above the **acceptable** catch tolerance range, which would require a review.

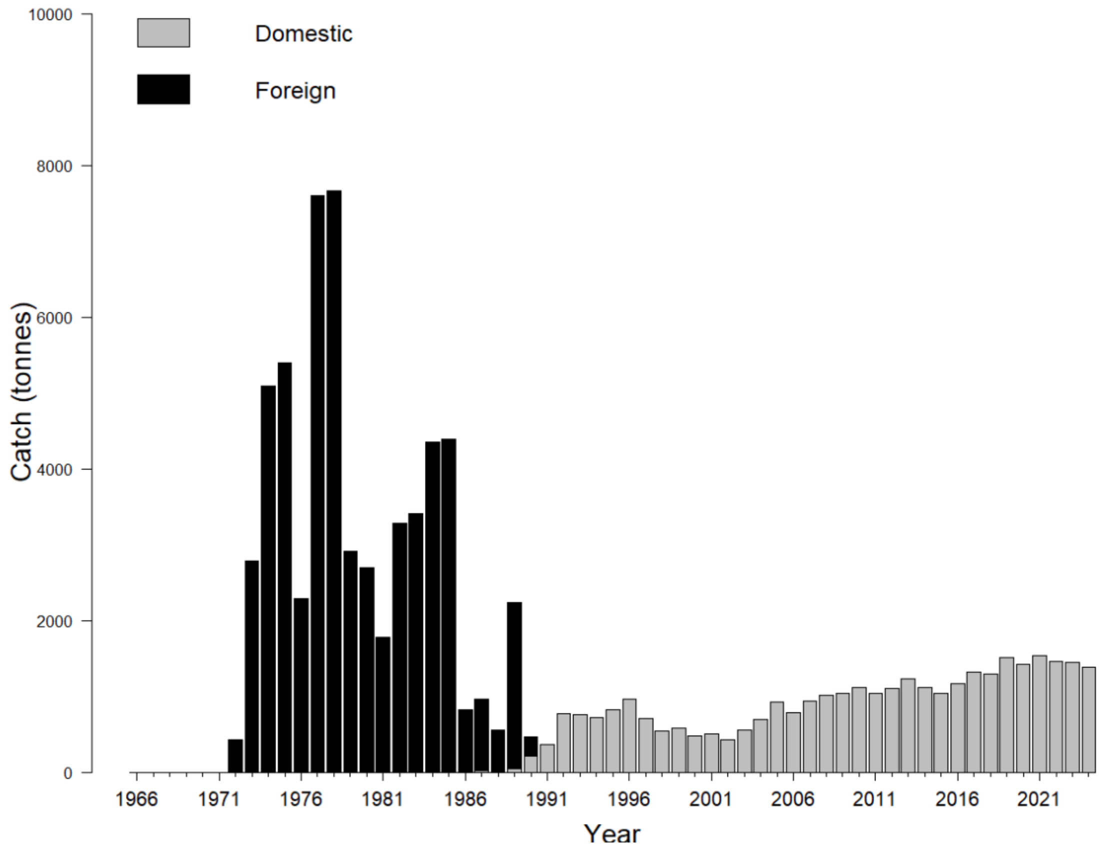


Figure 2.1. Total demersal scalefish catches landed by foreign and domestic commercial fishers in the Kimberley from 1966 to 2024.

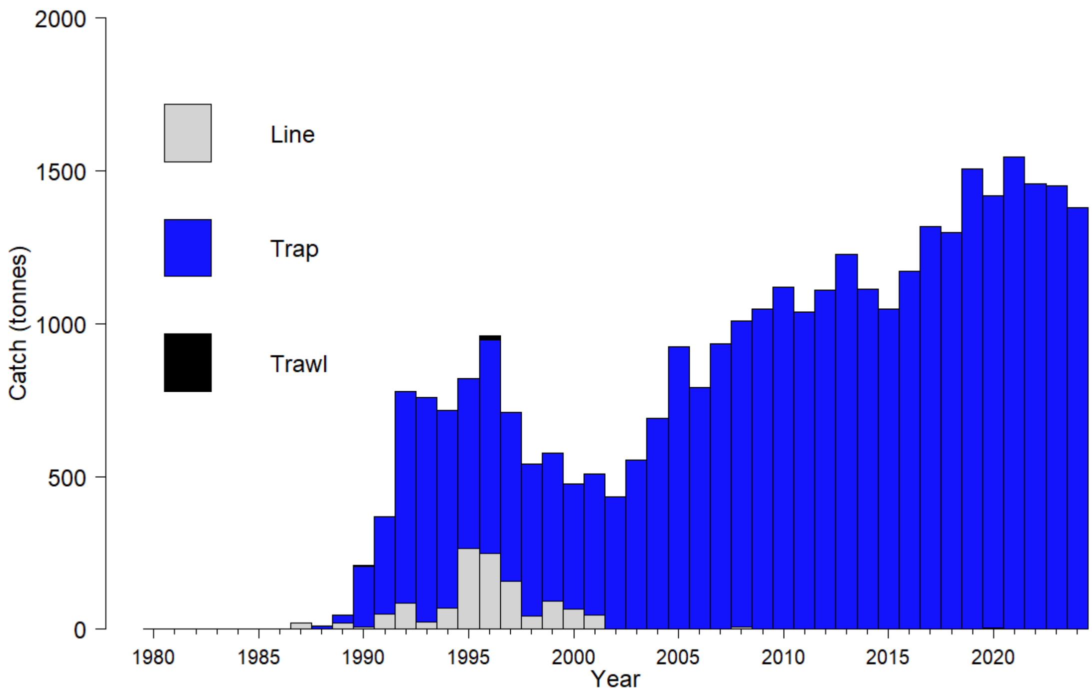


Figure 2.2. Annual commercial domestic catch (tonnes) of demersal scalefish from the line, trap and trawl fisheries in the Kimberley from 1980 to 2024.

Table 2.1. Retained catches (tonnes, t) of demersal scalefish landed by commercial, charter and recreational fishers in the Kimberley in 2024 (commercial and charter) or 2020–21 (recreational; see Ryan et al. 2022). Note that catches have been rounded and may not add up to totals.

Species	Commercial	Charter	Recreational
Goldband snapper (adjusted)**	429	<0.1	
Red emperor	151	<0.1	
Bluespotted emperor	39	1	
Saddletail snapper	249	2	
Rankin cod	56	0.2	
Crimson snapper	57	0.8	
Rosy threadfin bream	<0.1	0	
Brownstripe snapper	14	<0.1	
Frypan snapper	<0.1	0	
Spangled emperor	25	<0.1	
Moses snapper	15	0	
Longnose emperor	16	0	
Barcheek coral trout	6	0.4	
Ruby snapper	1	<0.1	
Other demersal scalefish	323	12	
Total demersal scalefish	1,379	16.6	52*

*NCB recreational catch estimate of top 15 demersal species. **The 91% adjustment made from all jobfish (all species group) to goldband snapper only (Appendix 1: Level 1 assessment).

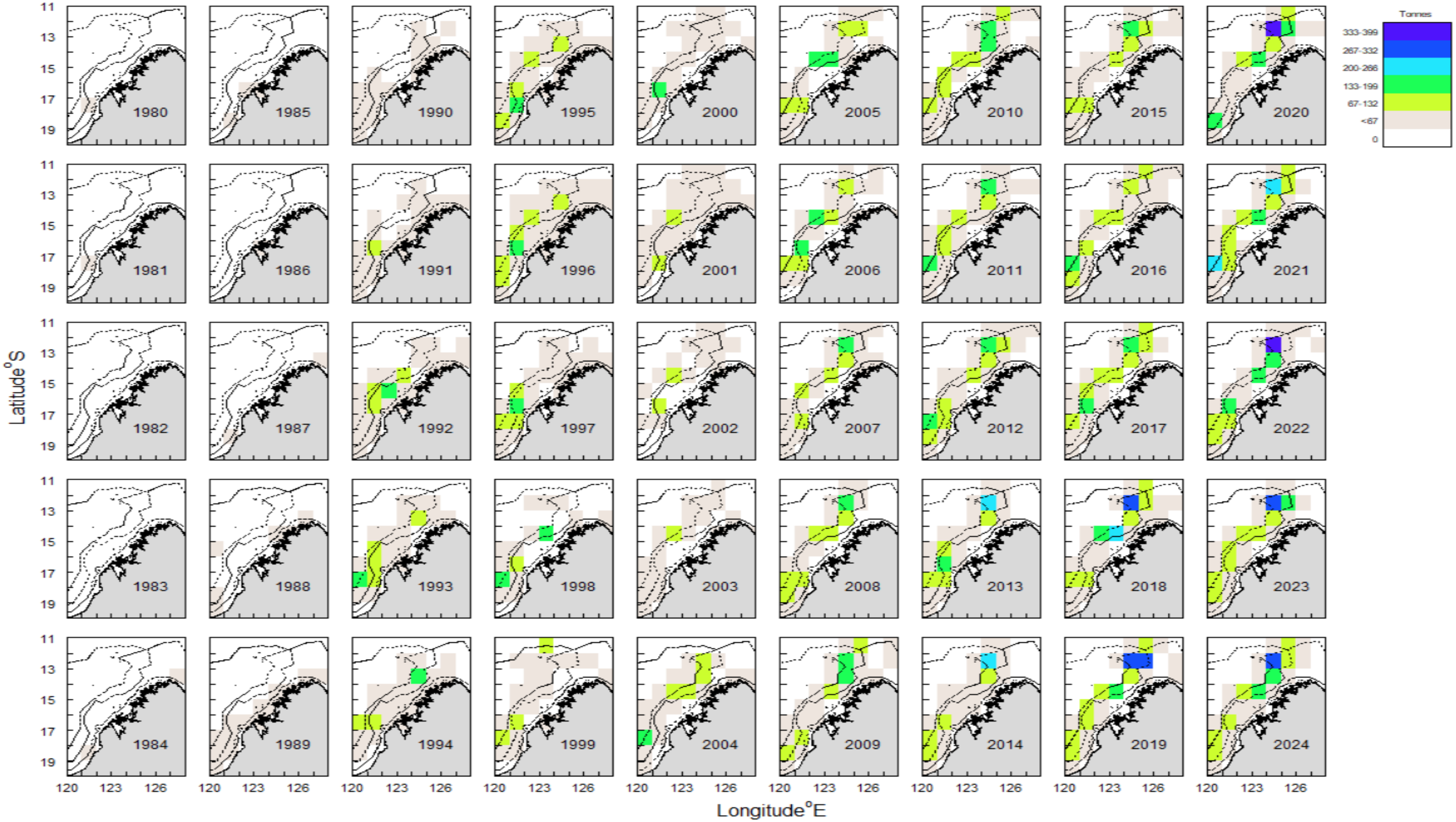


Figure 2.3. Distribution of NDSMF catch (tonnes) from fisher logbooks by calendar year, from all methods combined, and 60 x 60 nm block from 1980 to 2024.

2.2 Effort

Domestic line, trap, and trawl fishing operations in the Kimberley largely began in the 1980s, with the trap sector expending the majority of effort in this region. Total annual commercial effort (logbook days) from the contemporary fisheries in the Kimberley peaked in 1996, then declined in 1998 when the fishery became formally recognised as the NDSMF and effort management via standard boat days was formally implemented within a TAE system. In 1998, VMS monitoring was also introduced to all commercial vessels. By 2002, essentially the fishery became trap based. Total commercial effort has been relatively stable since 2005 (Figure 2.4). From 1998 to 2005, TAE was managed solely over all of Area 2, whereas in 2006, Area 2 was divided into 3 zones; A, B, and C and each zone was managed with separate effort allocations (Figure 2.5; Table 2.2). Total effort by 60 x 60 NM block demonstrates the development of the domestic fishery from close to Broome and then expanding to cover the entire region. Effort has since occurred in most blocks with no discernible contraction in the area fished (Figure 2.6). Line fishing effort started inshore and expanded northwards until effort entitlements became constrictive and line fishing largely ceased (Figure 2.7). Trap fishing occurred largely in the south until the early 2000s then expanded to cover the entire area, with the landing of catch in Darwin allowing for a greater opportunity to fish in the north (Figure 2.8; Figure 2.9). Domestic trawl effort is insignificant in the region and is not considered in any further analyses.

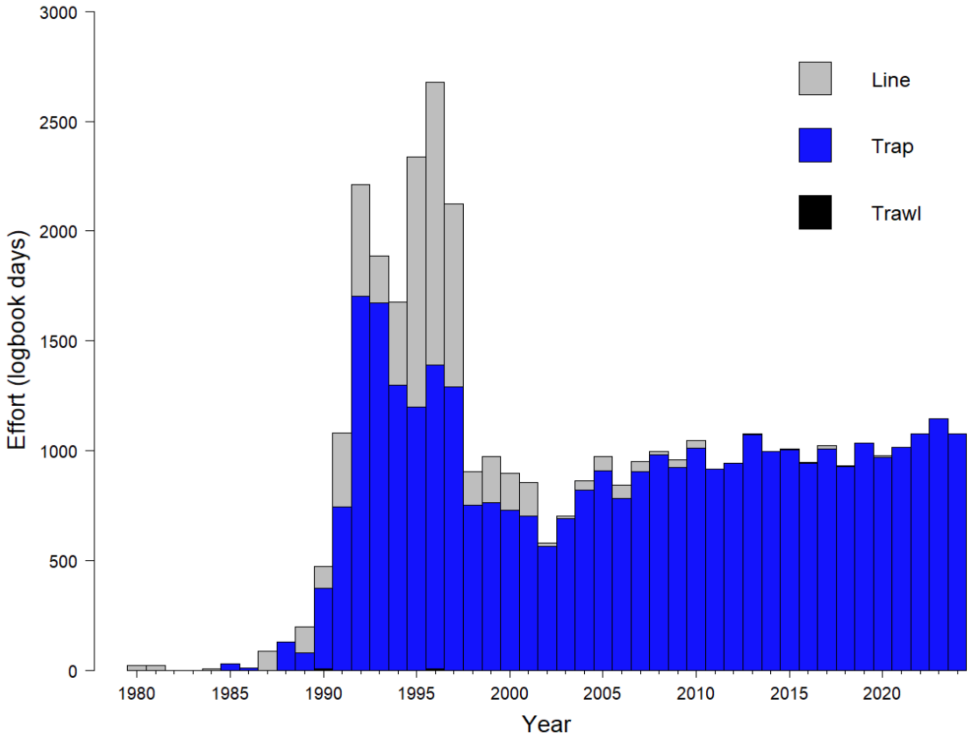


Figure 2.4. Total logbook effort (days) within the NDSMF by method from 1980 to 2024.

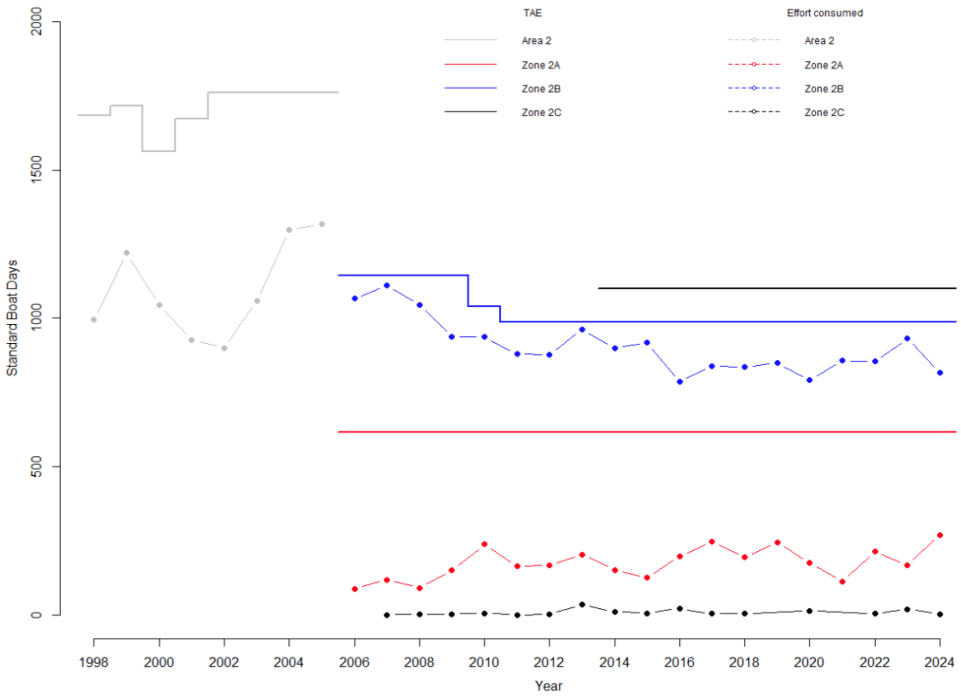


Figure 2.5. Total allowable effort (TAE) allocation (VMS standard boats days by zone) and effort consumed in the NDSMF from 1998 to 2024.

Table 2.2. Total allowable effort (TAE) allocation (VMS standard boats days by zone) and usage in the NDSMF from 1998 to 2024.

Year	Management Area/Zone SFDs				Management Allocated SFD				Proportion of Allocation			
	Area 2	A	B	C	Area 2	A	B	C	Area 2	A	B	C
1998	995				1684				59%			
1999	1220				1716				71%			
2000	1045				1562				67%			
2001	1064				1672				64%			
2002	900				1760				51%			
2003	1060				1760				60%			
2004	1299				1760				74%			
2005	1317				1760				75%			
2006		88	1066	0		616	1144			14%	93%	
2007		118	1110	0.4		616	1144			19%	97%	
2008		90	1044	3		616	1144			15%	91%	
2009		149	939	3		616	1144			24%	82%	
2010		237	938	4		616	1038			39%	90%	
2011		163	879	0.1		616	986			26%	89%	
2012		167	878	1		616	986			27%	89%	
2013		202	963	34		616	986			33%	98%	
2014		151	899	10		616	986	1100		25%	91%	0.9%
2015		125	917	6		616	986	1100		20%	93%	0.5%
2016		198	785	21		616	986	1100		32%	80%	1.9%
2017		247	838	4		616	986	1100		40%	85%	0.4%
2018		195	837	4		616	986	1100		32%	85%	0.4%
2019		243	849	0		616	986	1100		39%	86%	0.0%
2020		174	790	13		616	986	1100		28%	80%	1.2%
2021		113	857	0		616	986	1100		18%	87%	0.0%
2022		214	854	4		616	986	1100		35%	87%	0.4%
2023		168	932	19		616	986	1100		27%	95%	1.8%
2024		269	815	3		616	986	1100		44%	83%	0.2%

Table 2.3. Performance statistics relating to fishing effort (fishing days/trips, number of active vessels) of the key fishing sectors targeting the Kimberley.

Sector	Previous season	Current season	Further description
Commercial (WCDSIMF)	2023: 1,144 days (8 active vessels)	2024: 1,077 days (7 active vessels)	
Charter	2023: 2,331 trips (50 vessels)	2024: 1,520 trips (39 vessels)	Trips fished in marine waters catching demersal scalefish only. Excludes spearfishing while diving.
Recreational	NCB, 2017–18: 8,434 – 17,211 boat days	NCB, 2020–21: 12,215 – 23,842 boat days	Days fished in NCB (95% CLs) Boat-based fishing only (Ryan et al. 2022).

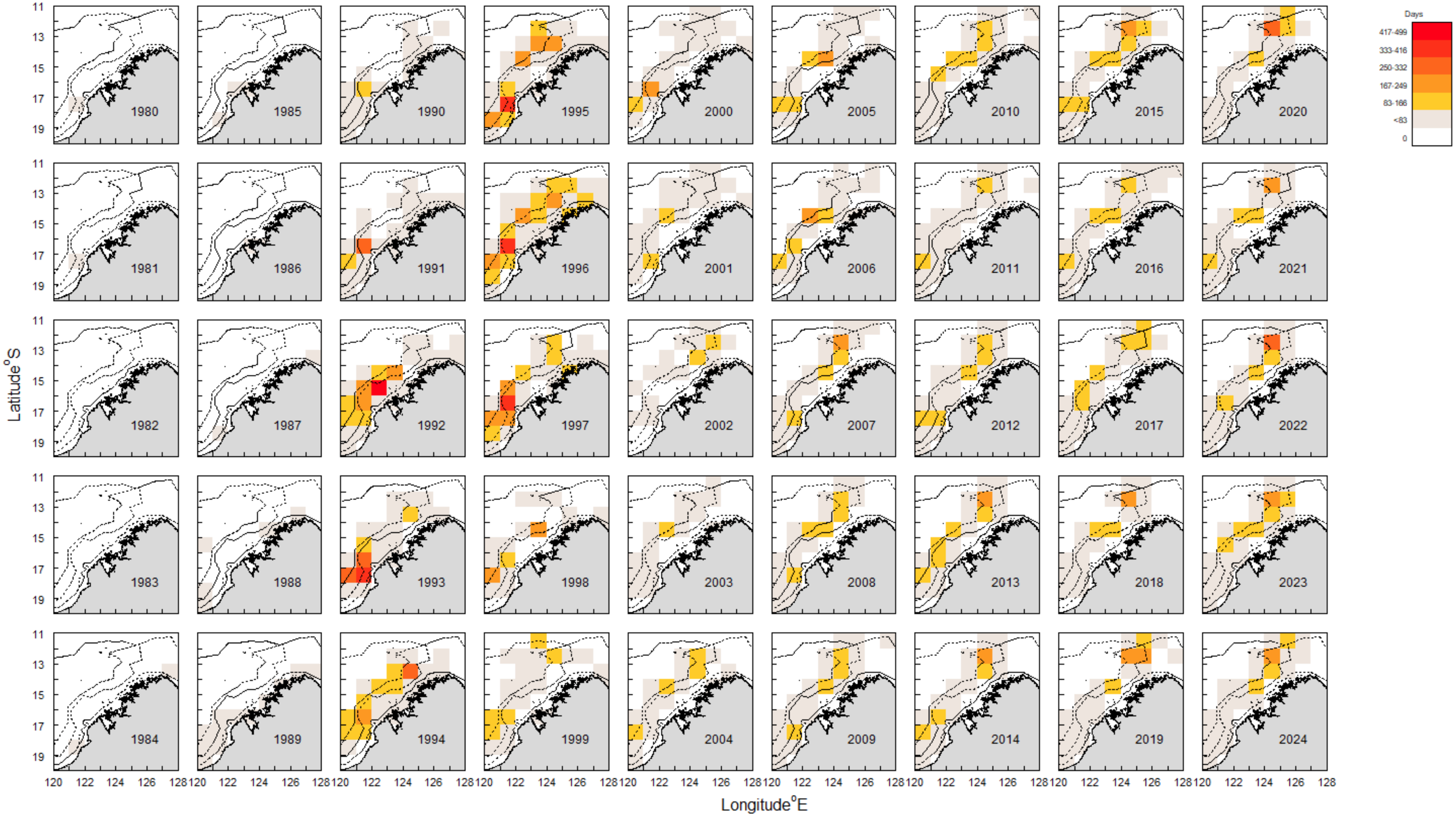


Figure 2.6. Distribution of NDSMF effort (days fished) from fisher logbooks by calendar year, from all methods combined, and 60 x 60 nm block from 1980 to 2024.

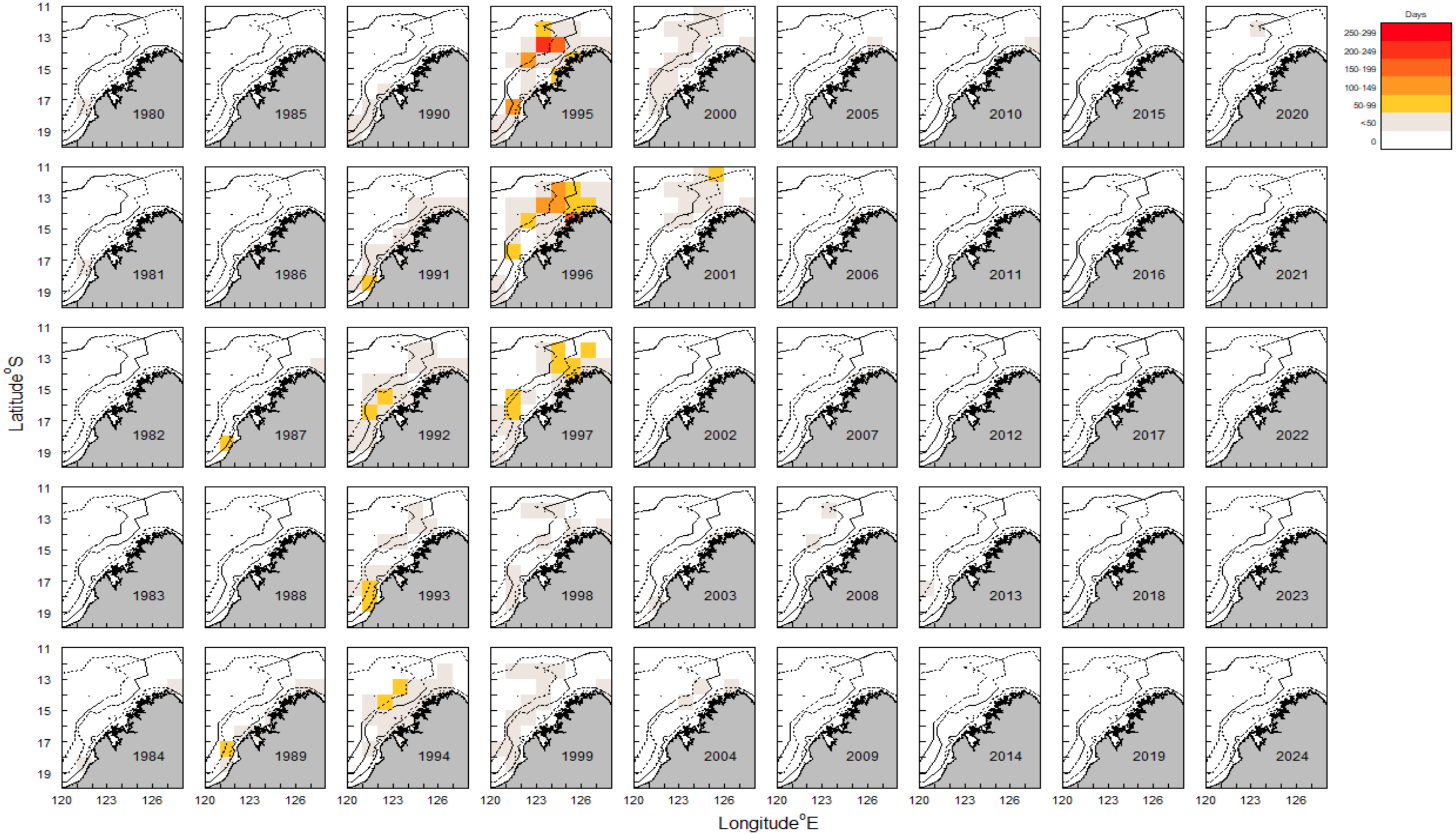


Figure 2.7. Distribution of NDSMF effort (days fished) from fisher logbooks by calendar year, from line fishing method, and 60 x 60 nm block from 1980 to 2024.

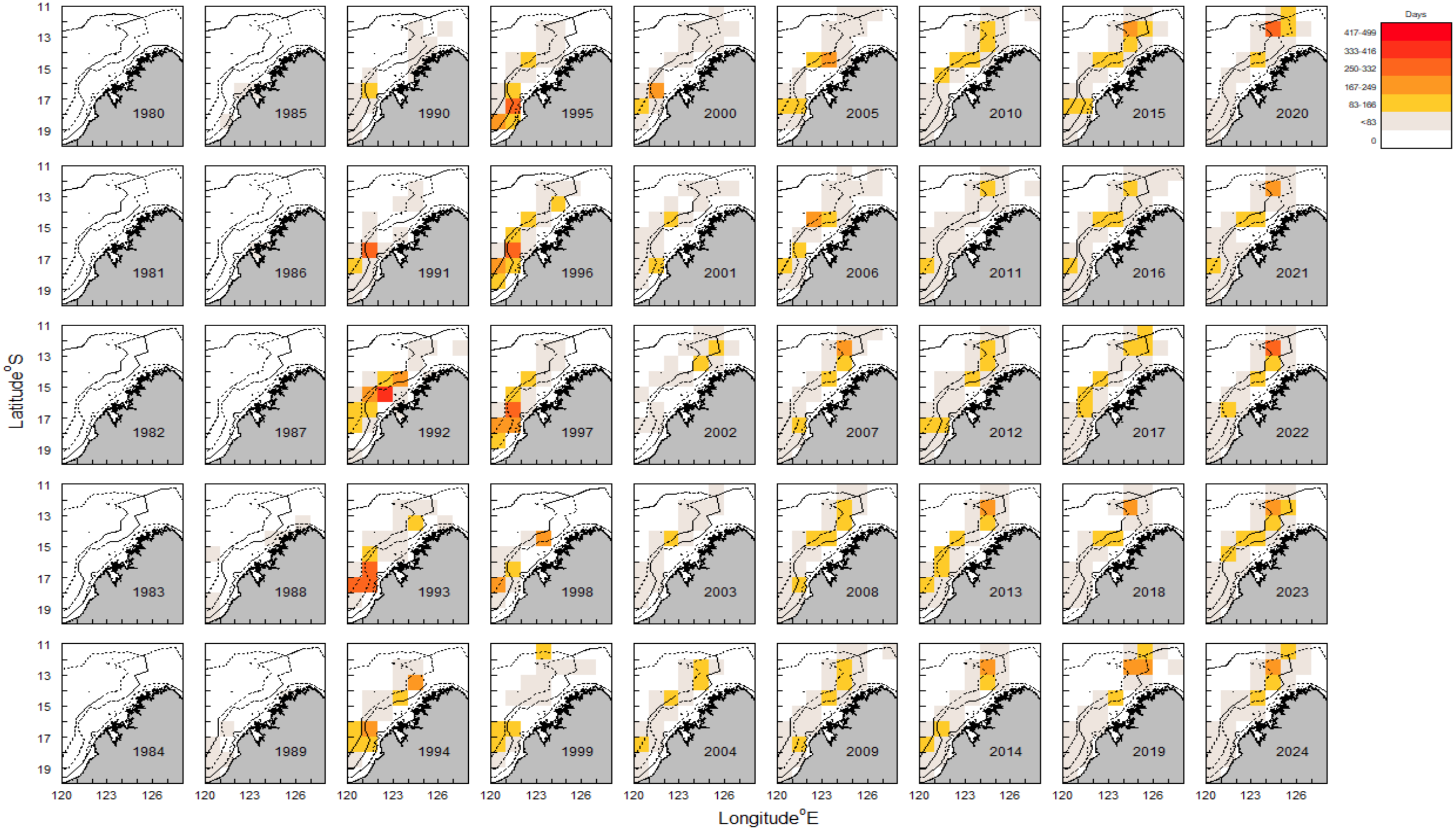


Figure 2.8. Distribution of NDSMF effort (days fished) from fisher logbooks by calendar year, from trap fishing method, and 60 x 60 nm block from 1980 to 2024.

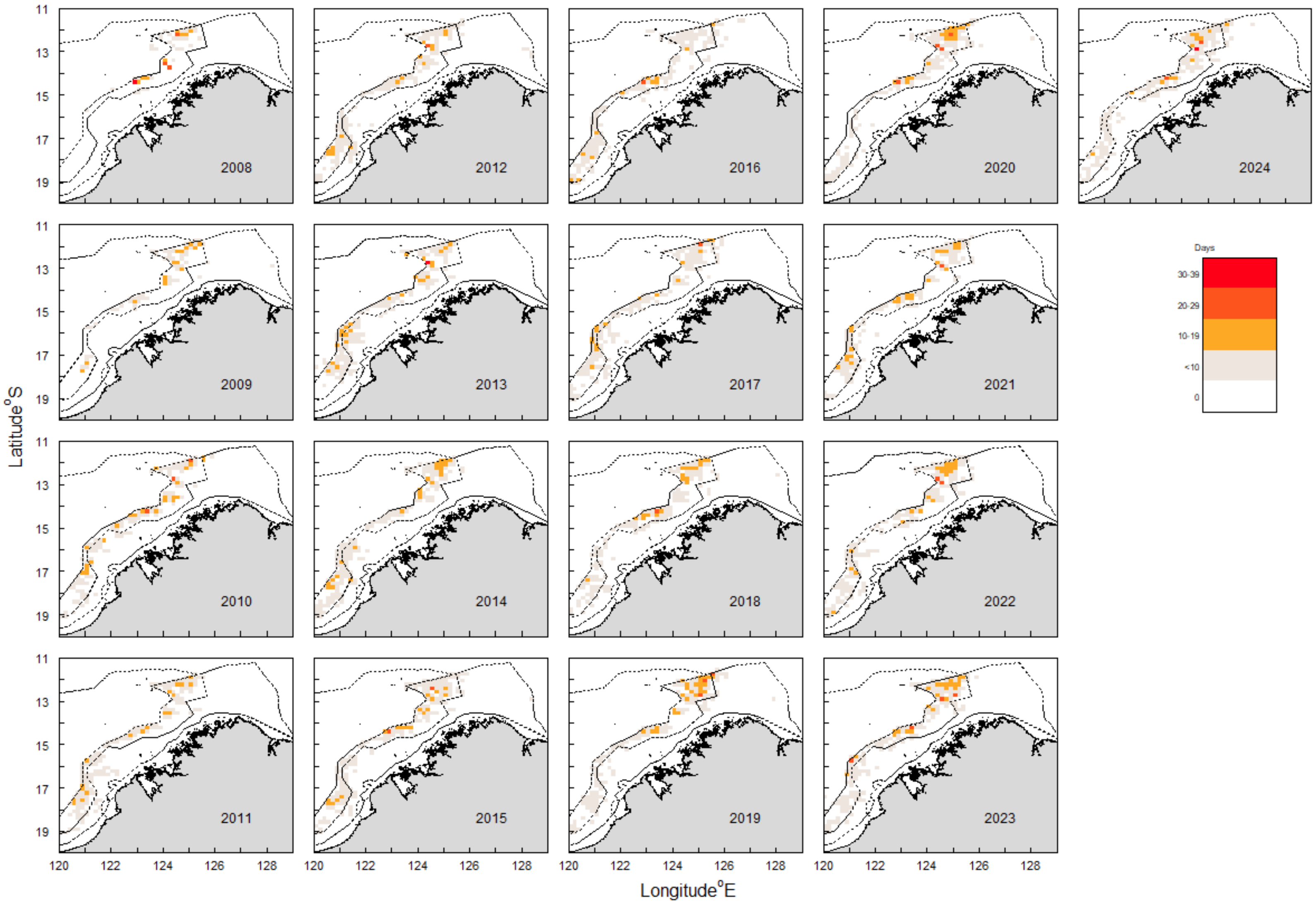


Figure 2.9. Distribution of NDSMF reported effort (days fished) from daily logbooks by calendar year, all methods combined, and 10 x 10 nm block. Logbooks with 10 x 10 nm blocks were first introduced in 2008 and were fully integrated into the fishery by 2010.

2.3 Social and Economic

Seven vessels fished in the 2024 fishing season, and at least 25 people (3–4 crew per vessel) were directly employed in the NDSMF. Approximately half the fish from this fishery are supplied to Perth metropolitan markets, while the other half is supplied to east coast metropolitan markets. There is currently a **medium** level of risk to these values.

The NDSMF principally targets the higher-value species such as goldband snapper and red emperor, resulting in an economic value of $10–20 million (Level 4). This indicates that this fishery has a high social amenity value and is an important asset locally. There is currently a **medium** risk to this level of return.

The NCDSR provides a high social amenity to recreational fishing and diving and to consumers via commercial fish supply to markets and restaurants. Recreational fishers make a significant contribution to WA's economy and support economic activity in many regional towns on the coast and near inland fishing spots. The value of recreational fishing in WA was estimated at $1.1 billion per year (Moore et al. 2023). There is currently a **low** level of risk to these values.

3 Species Assessment

3.1 Red Emperor

3.1.1 Catch

Annual catches of red emperor from the Kimberley prior to 1972 were <1 tonne annually (Figure 3.1), catches first peaked at 179 t in 1978 from foreign fishing, but had declined to 20 t by 1988 with the removal of the foreign fleet within Australia and the transition to a domestic only commercial industry. Catches then increased to a peak of 229 t in 1993, the highest annual catch recorded for this stock. They subsequently declined following the introduction of effort management measures, and a reduction in line fishing after 1998. Catches then peaked again in 2005, before stabilising between 140–150 t per year from 2010 onwards. Notable exceptions to this trend occurred in 2019, 2021, 2023, and 2024, when catches exceeded this range. During the foreign fishing period, most red Emperor catches occurred in the northern Kimberley. However, with the development of the domestic commercial sector, primarily based out of Broome, the majority of catches shifted to the southern Kimberley. Since 2010, approximately equal proportions of the catch are derived from the North and South (Figure 3.2). Charter and recreational catches have remained minimal (<1%) compared to commercial catches, due to the low number of fishers and the remoteness of the area (Figure 3.3). There has been no evidence of spatial contraction in red emperor catches in the Kimberley (Figure 3.4; Figure 3.5).

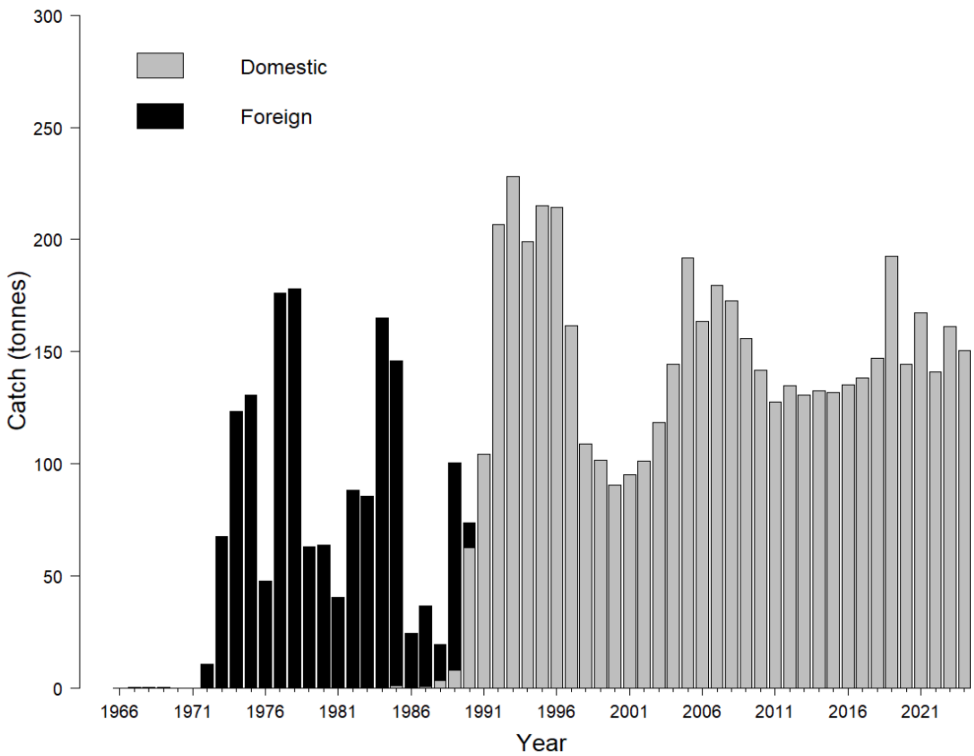


Figure 3.1. Annual catch (tonnes) of red emperor from the foreign (black) and domestic (grey) commercial fisheries taken in the Kimberley from 1966 to 2024.

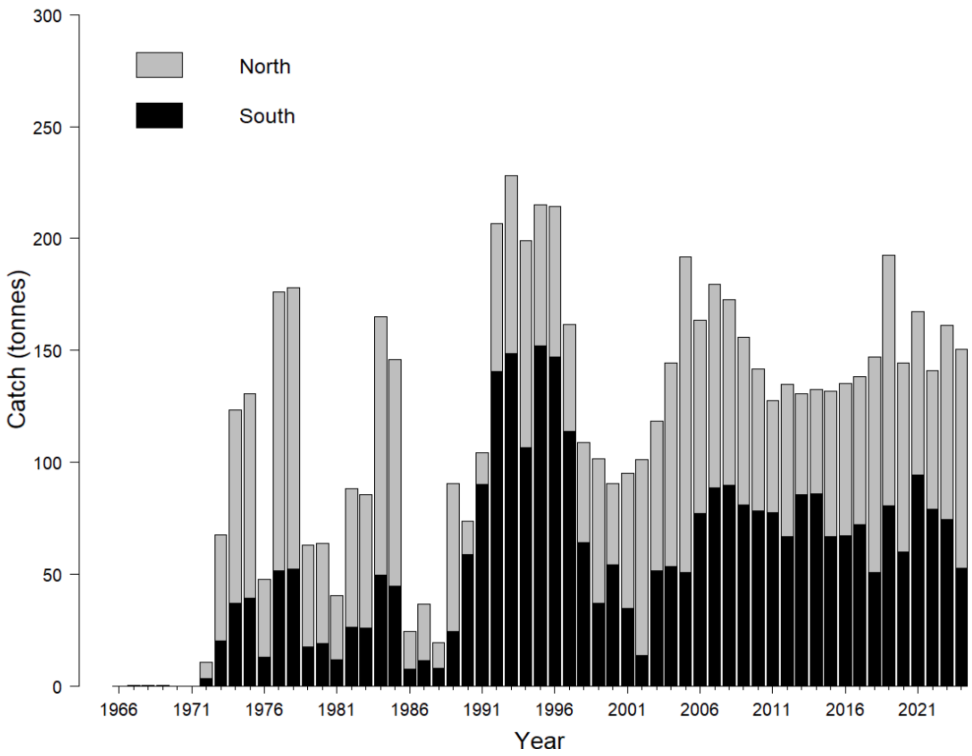


Figure 3.2. Annual catch (tonnes) of Red emperor taken in the Kimberley by spatial zones. North, catch north of 15°S latitude; South, catch south of 15°S latitude.

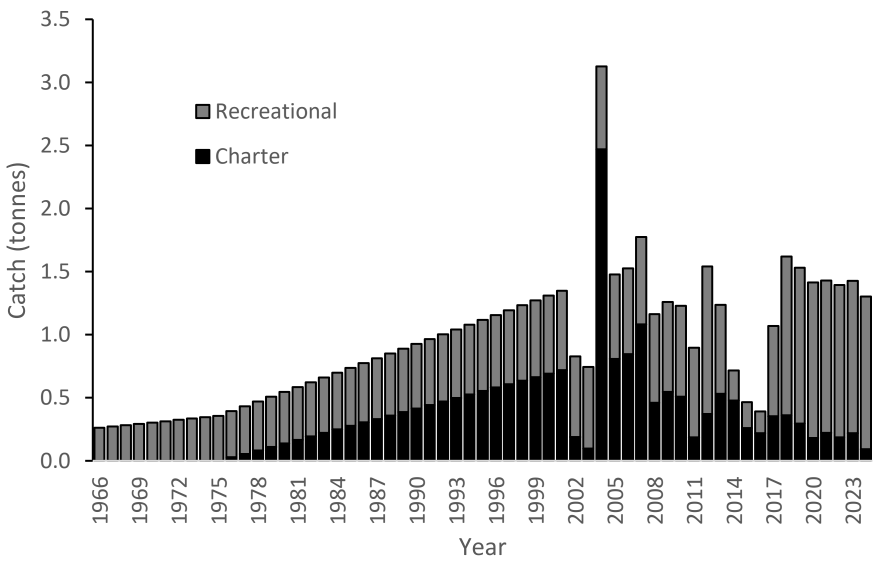


Figure 3.3. Total annual catches (tonnes) of red emperor taken by the charter (black) and recreational (grey) fisheries in the Kimberley.

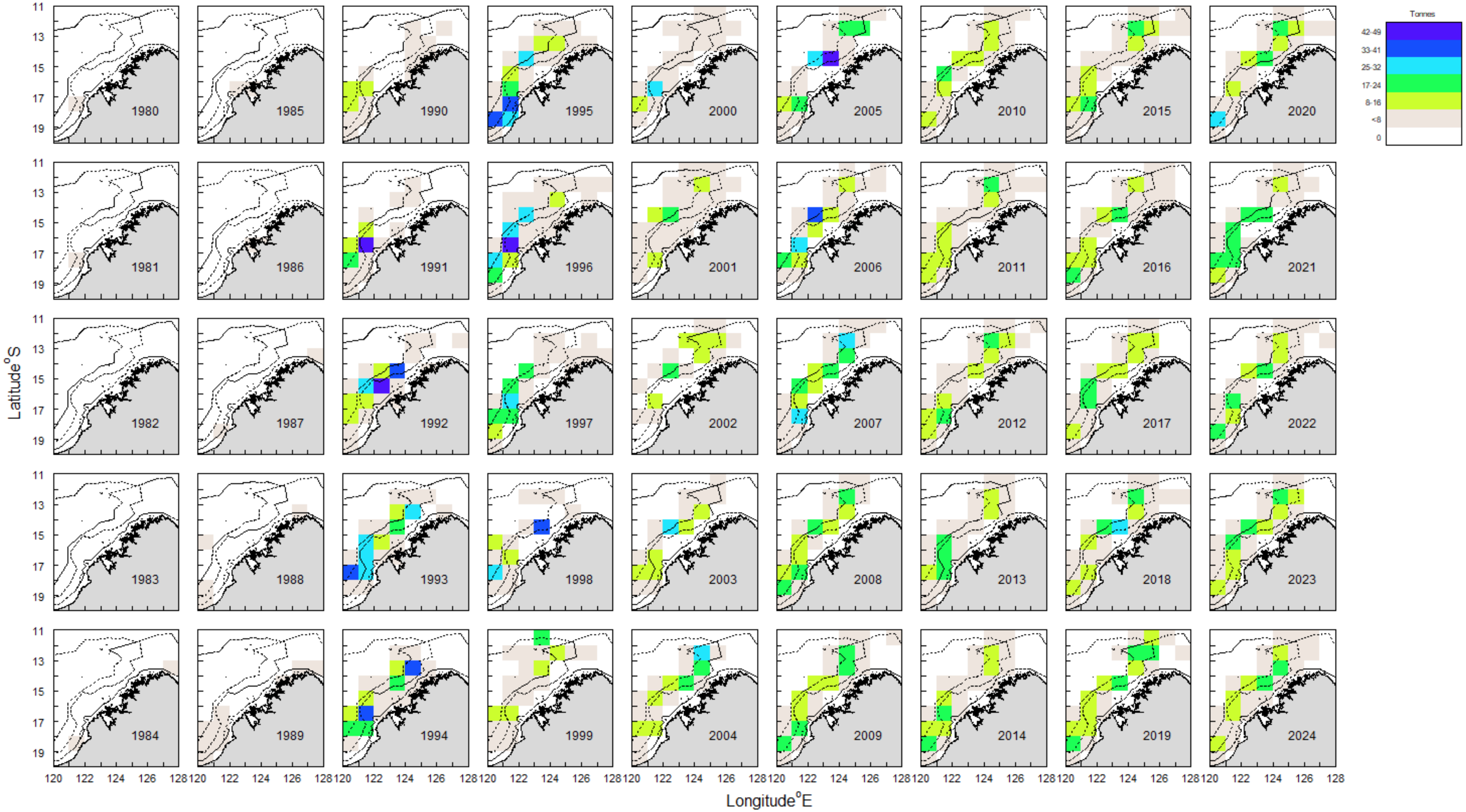


Figure 3.4. Distribution of red emperor reported catches (tonnes) by calendar year, all fishing methods combined, and 60 NM blocks in the NDSMF from 1980 to 2024.

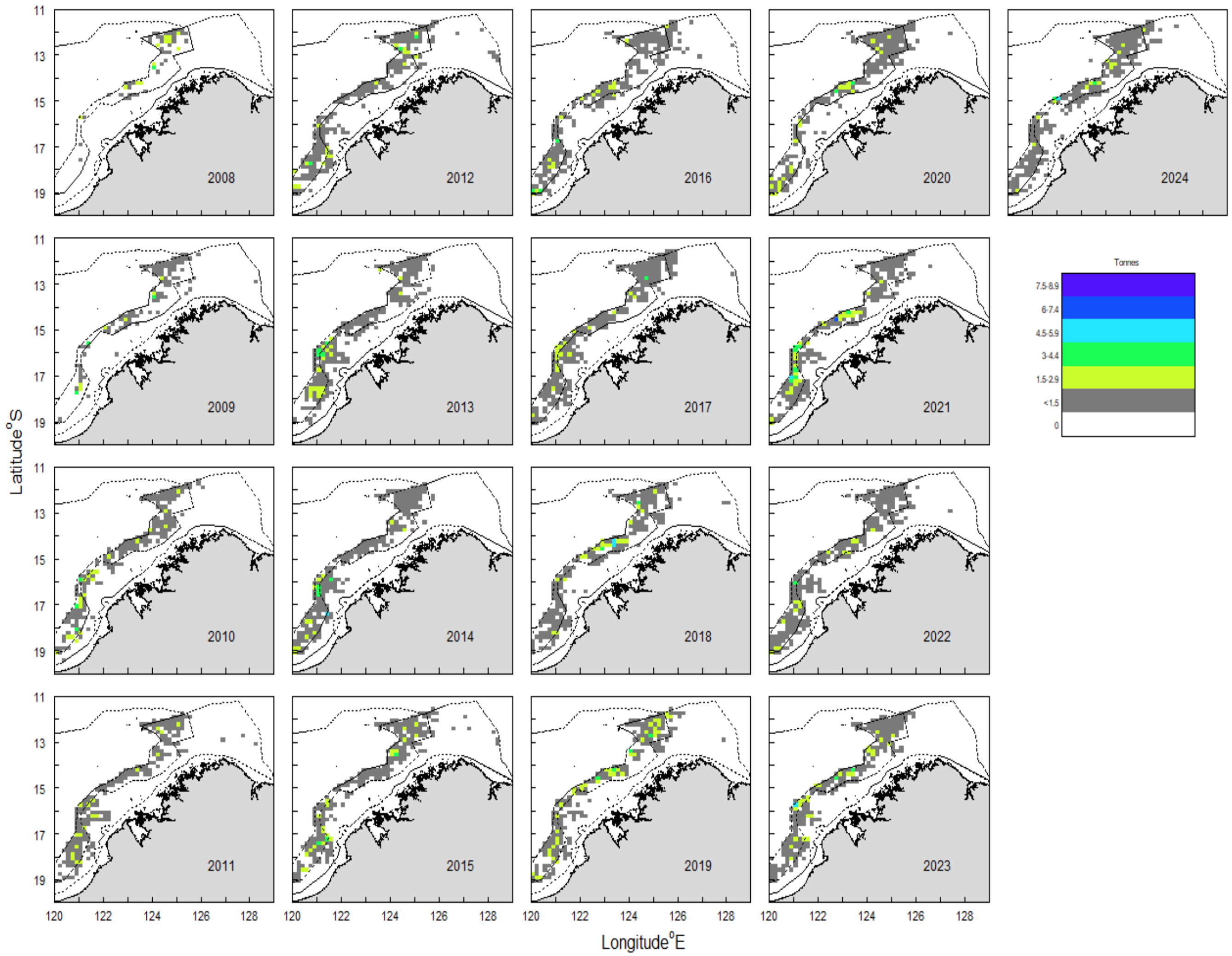


Figure 3.5. Distribution of red emperor reported daily logbook catches (tonnes) by calendar year, all methods combined, and 10 x 10 NM blocks in the NDSMF. Daily logbooks with 10 x 10 NM blocks were first introduced in 2008 and were fully integrated into the fishery by 2010.

3.1.2 Catch Per Unit Effort (CPUE)

Standardised catch per unit effort (CPUE) for red emperor from monthly logbooks, adjusted for a 2% efficiency creep, showed a relatively stable trend between 1996 and 2001, followed by an increase that remained stable from 2002 to 2009, though with high uncertainty around the point estimates. The CPUE from daily logbooks declined from 2010 to 2017, with relatively low uncertainty, then increased to a peak in 2019, before declining to pre-2017 CPUE levels by 2022, and has remained stable through to 2024 (Figure 3.6). CPUE from the FIS survey at nine fixed sites declined from 2006 to 2021, consistent with trends observed in CPUE from monthly and daily logbooks. Nominal CPUE trends using all available CPUE data is provided alongside the monthly and daily SCRs trends to demonstrate the effect of the standardisation process (Appendix 1: Level 2 Assessment).

Due to inconsistent spatial and temporal cover in the monthly logbook data, monthly CPUE could not be calculated at the regional level. In the Northern region, daily logbook CPUE remained relatively stable until 2019, then declined until 2022, and has since stabilised at this lower level. FIS survey CPUE show a less consistent trend to the daily CPUE but also demonstrate a decline in catch rates from 2006 to 2021. The nominal and CPUE trends were highly correlated in the northern daily logbook data. In the South, daily CPUE have remained relatively stable through the time series, with a peak in catch rates in 2019. FIS survey CPUE time series is consistent with the daily CPUE but indicates a decline from 2006 to 2012.

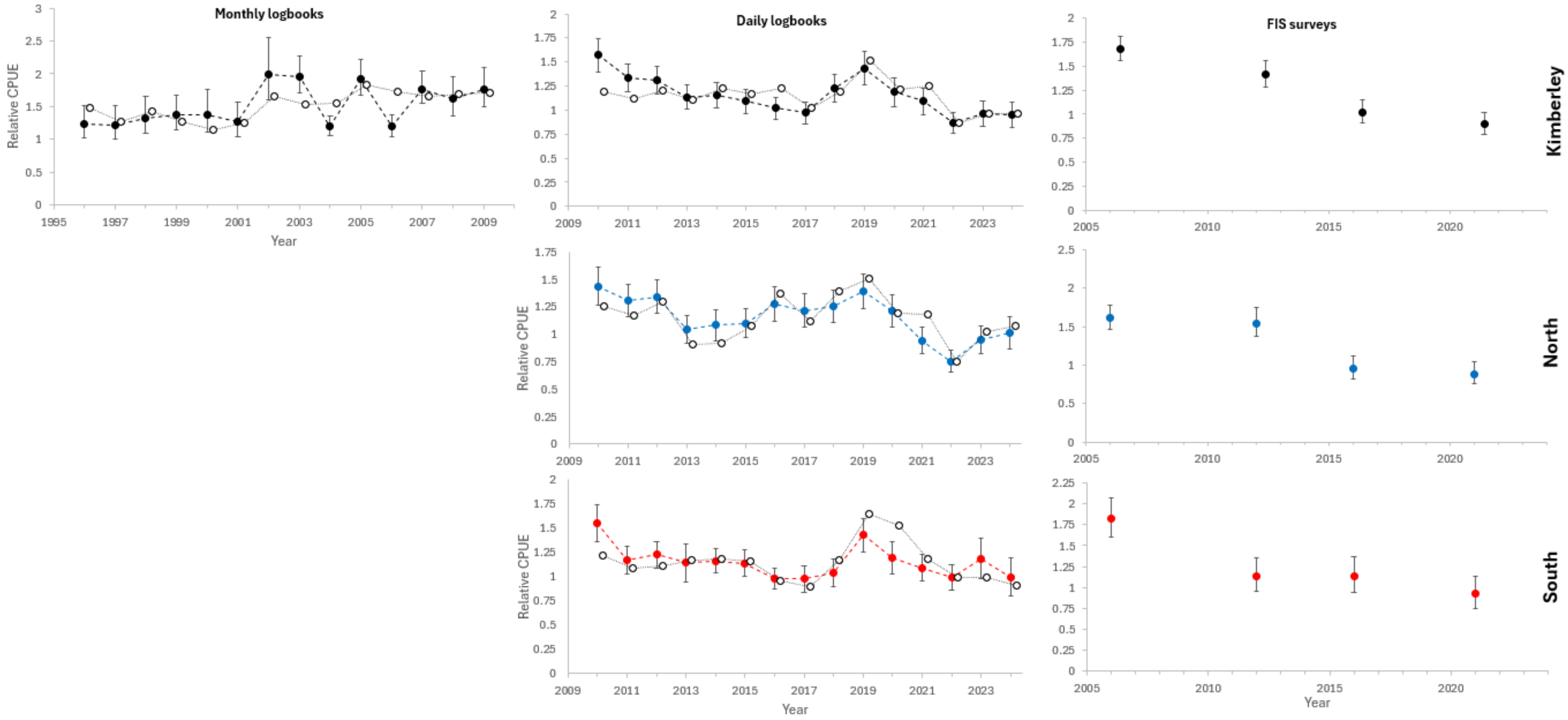


Figure 3.6. Relative annual standardised catch per unit effort (CPUE) (mean and ±95% CI) (filled dots), and nominal catch rates (open dots) for red emperor by trap fishing in the Kimberley, and by North and South regions from 1996–2024. Monthly logbooks, daily logbooks, and FIS sampling catch rates Each series has separately been normalised to a mean of 1, and a 2% efficiency creep applied retrospectively to the normalised CPUE time series.

3.1.3 Size Composition

The maximum recorded fork length of red emperor in the Kimberley during FIS surveys conducted between 2006 to 2021 was 717 mm. Mean fork lengths of all measured individuals for each survey year were 464 mm, 478 mm, 451 mm, 442 mm, and 442 mm for 2006, 2008, 2012, 2016/17, and 2021, respectively. When comparing annual samples for fish at or above the MLL (380 mm FL), the mean lengths were 477 mm, 488 mm, 480 mm, 480 mm, and 472 mm for 2006, 2008, 2012, 2016/17, and 2021 respectively (Figure 3.7). The higher mean lengths observed in 2006 and 2008 likely reflect an underrepresentation of smaller red emperor in those years. It is unknown why this occurred. In 2021, there was a decline in larger red emperor (>600 mm FL) compared to previous years (Figure 3.8), although the 2006 and 2021 mean lengths (>MLL) are similar.

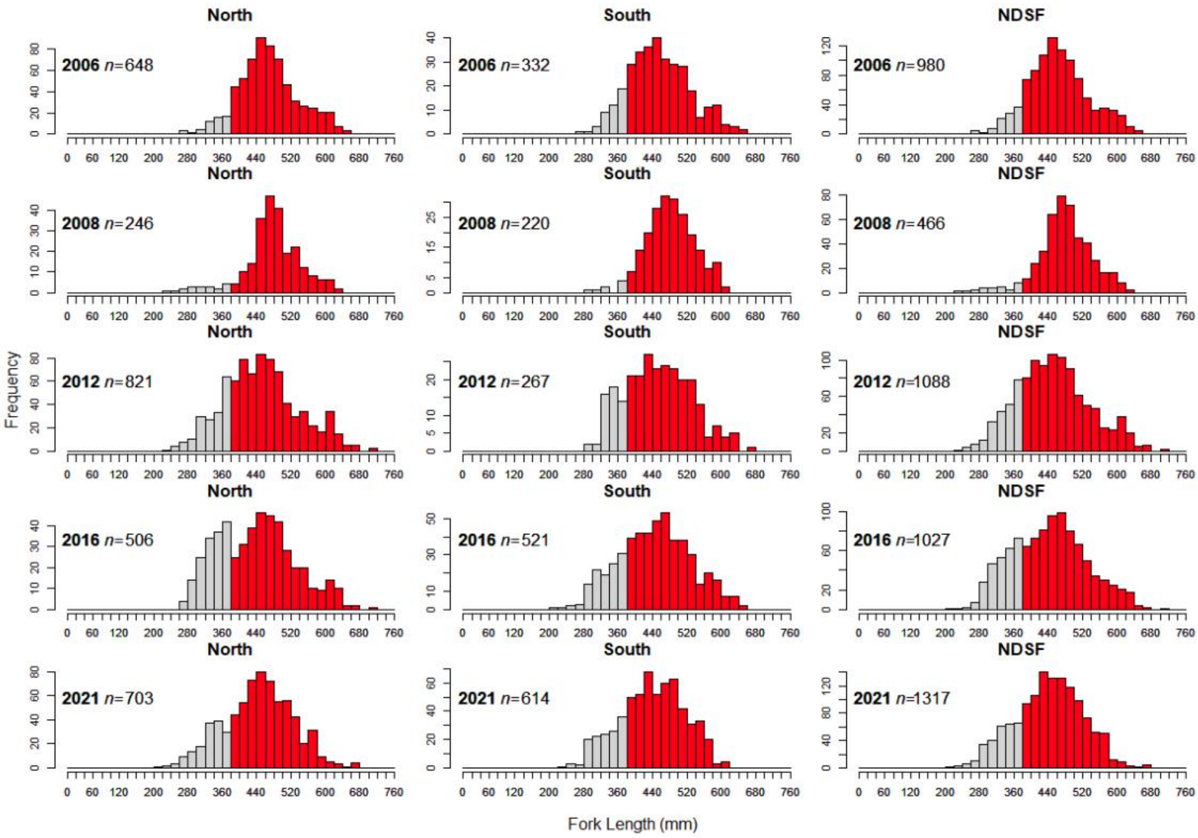


Figure 3.7. Length frequency (fork length) plots for all captured red emperor from fisheries-independent survey sampling in the Kimberley (NDSMF), and by North and South regions. Grey bars represent fish below the MLL of 380 mm FL, and red bars indicate frequencies of fish above the MLL.

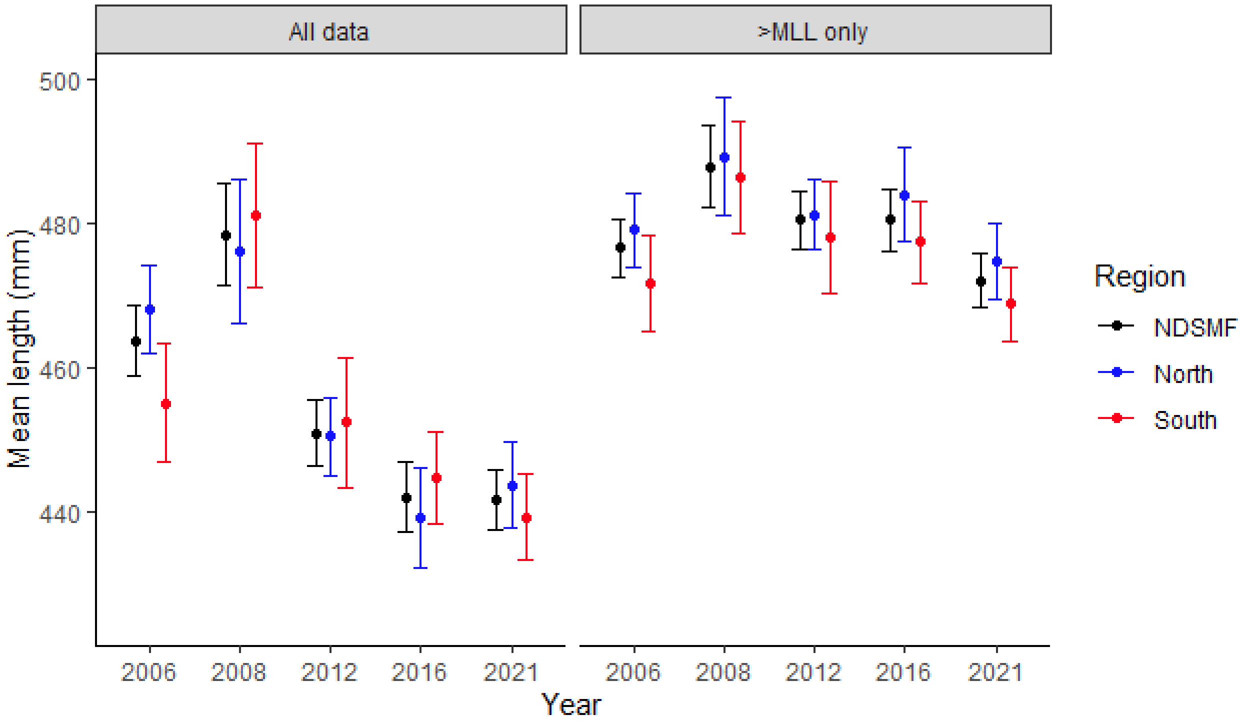


Figure 3.8. Mean fork lengths (with 95% CIs) of red emperor from fisheries-independent survey sampling in the Kimberley (NDSMF), and by North and South regions. All animals captured (left) only animals >MLL (380 mm FL) (right).

3.1.4 Age Composition

The maximum recorded age for this species in the Kimberley from the FIS surveys is 41 years. The peak age class of red emperor from traps (>MLL) in the NDSMF in all years is 6 years of age but varied between 5 and 6 years of age, depending on year and sex (Figure 3.9; Figure 3.10). The mean age of red emperor for each survey year from all animals aged were 7.9, 9.0, 8.2, 8.6, and 8.1 years for 2006, 2008, 2012, 2016/17, and 2021, respectively (Figure 3.11). The vast majority of red emperor sampled in all years are relatively young (~90% of fish < 15 y). The proportion of older fish (i.e., ≥ 15 years) recorded in the age compositions has fluctuated across the survey years showing no clear trend, from ~8% to 14% (Figure 3.12). As the number of sites sampled in FIS surveys has increased over time (from 8 sites in 2006 and 2008 to 12 sites in 2012, and 16 sites in 2016 and 2021, the recent age information is likely to be more representative of the population age structure. The overall age composition is more truncated in 2021 than 2016. Note also that males grow larger than females and the age composition is more truncated than for females across all survey years. This suggests that, on average, males may be more susceptible than females to being caught by the trap gear.

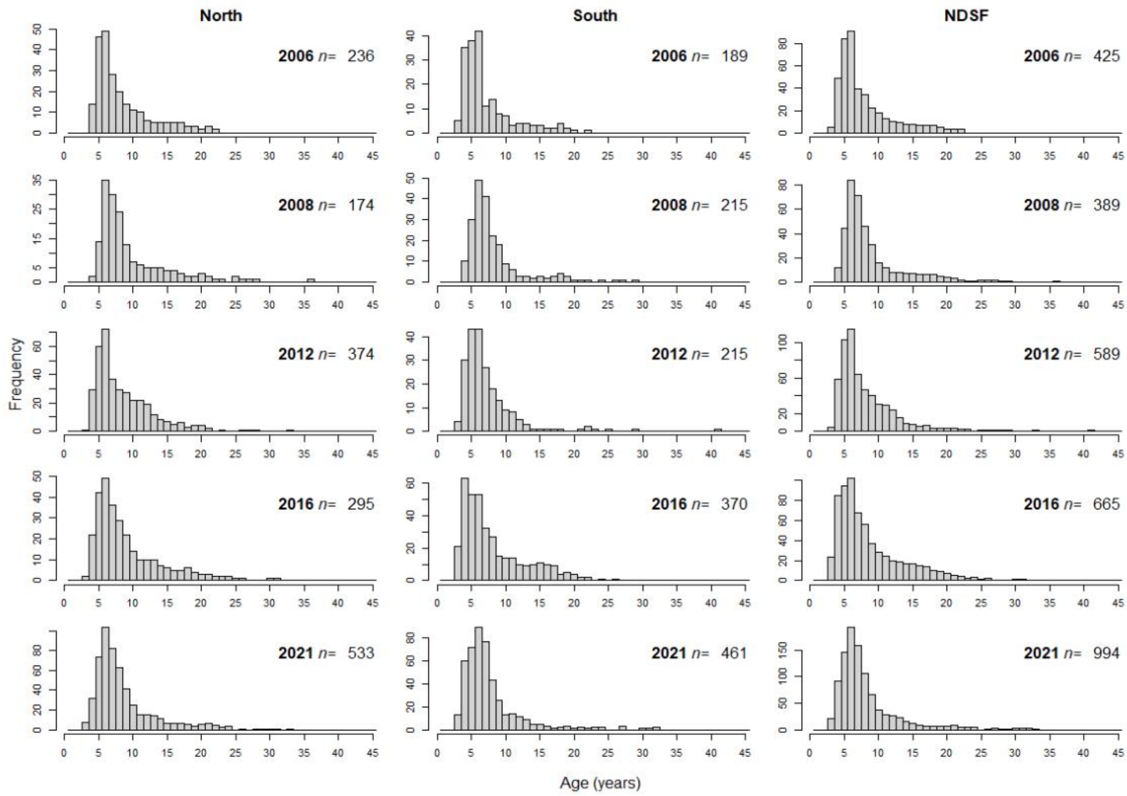


Figure 3.9. Age frequency (numbers) histograms for Red emperor from fisheries-independent survey sampling in the Kimberley (NDSMF) (*n*, sample sizes), and by North and South regions.

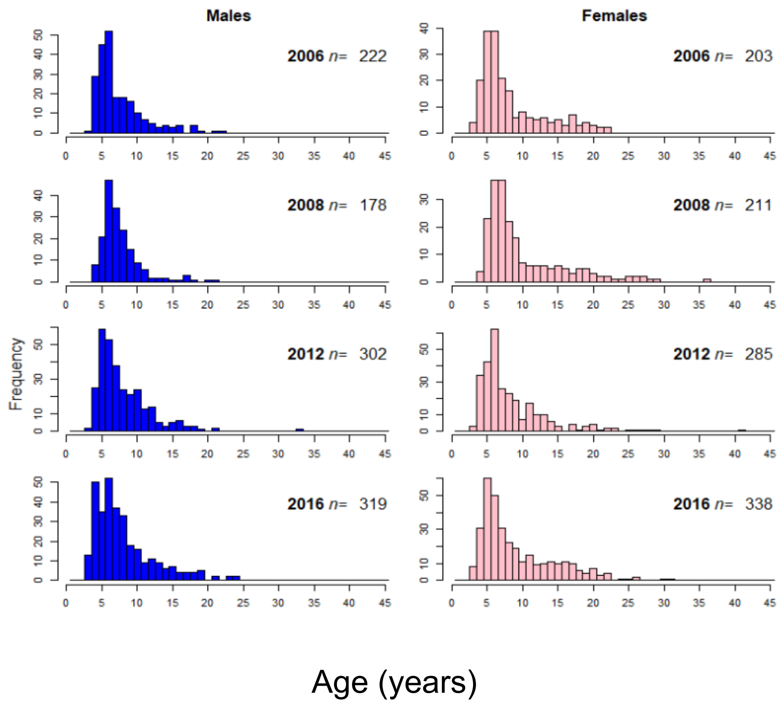


Figure 3.10. Age frequency (numbers) histograms for red emperor, by sex and all data combined, from fisheries-independent survey sampling in the Kimberley (*n*, sample sizes).

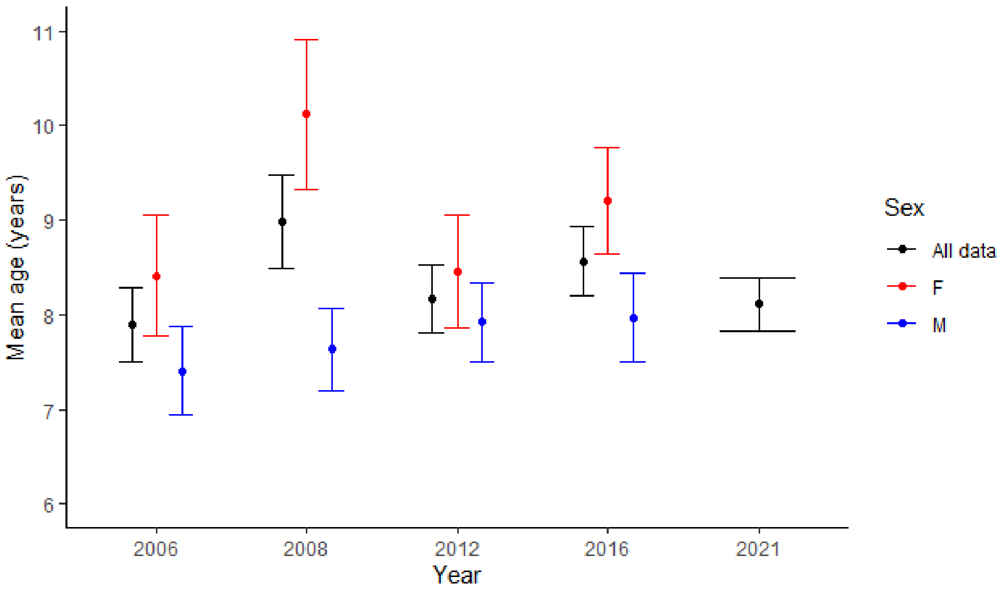


Figure 3.11. Mean age (years) for red emperor >MLL (with 95% CIs), by sex and all data combined, from fisheries-independent survey sampling in the Kimberley.

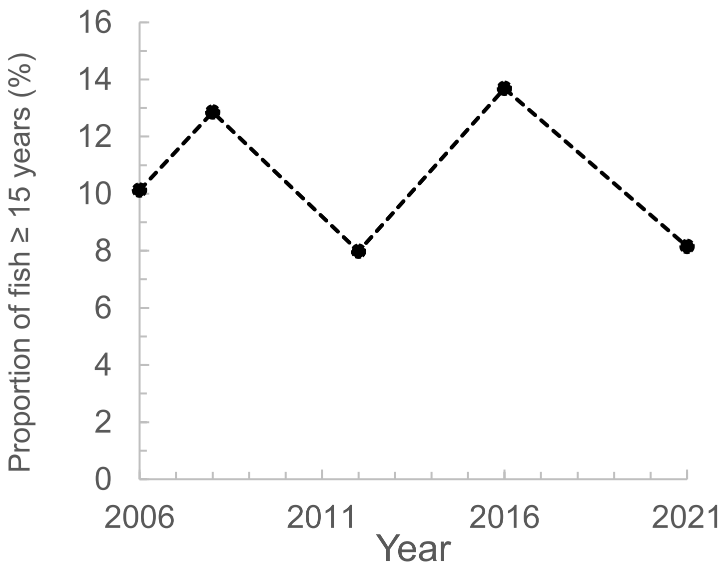


Figure 3.12. Percentage of older (i.e., ≥ 15 years) red emperor in the age compositions from fisheries-independent survey sampling in the Kimberley.

3.1.5 Environmental Impacts

Climate projections for WA (Pilbara to Albany) include increases in sea surface temperature, number of marine heatwave days, sea level increases, ocean acidification, intense and variable storms and rainfall decreases (Chandrapavan and Jackson 2025). Climate change and climate variability has the potential to impact fish stocks in a range of ways including influencing their recruitment, spawning and geographic distribution (e.g., latitudinal shifts in distribution). However, it is currently unclear how much climate change may affect sustainability of NCDSR-Kimberley demersal resources.

red emperor is a tropical species and based on its abundance, distribution and phenological characteristics in the NCDSR - Kimberley stock, it has been assessed as having **Medium** sensitivity to the effects of climate change (Newman et al. 2024).

3.1.6 Model Assessment

3.1.6.1 Level 3 Assessment

The level 3 assessment involved analysis of trends in age and length data, application of catch curve analyses for estimating (long-term average) fishing mortality and length and age-based equilibrium analyses for calculating female relative biomass. The biological parameters (e.g., growth and maturity) have been updated since the previous assessment of red emperor from the Kimberley region in 2018. For more detail of the parameters, model analyses and assumptions; see Appendix 1: Level 3 assessment.

The oldest red emperor captured from FIS surveys is 41 yrs old (based on large samples), however no fish have been caught between 36 yrs (the second oldest fish) and 41 yrs of age. For the catch curve and per-recruit analyses, natural mortality is currently based on the second oldest fish and the natural mortality equation of Hoenig (1983), which predicts a value of M=0.115 y^{-1} and indicates that ~1.5% of the population reaching this age (Hewitt & Hoenig, 2005; see also Dureuil et al., 2021; Dureuil & Froese, 2021).

For 2021, the estimates of total mortality, Z, and fishing mortality, F (with M = 0.115 y^{-1}) for the Kimberley red emperor stock were generally considerably higher using age-based analyses (catch curve with logistic selectivity, CCLS) and the Chapman & Robson (1960) mortality estimator, CR), compared to estimates from the linear analysis (linear catch curve, LCC) (Table 3.1; Figure 3.13). The majority of age-based catch curve point estimates of F from CR and CCLS, were above the threshold reference point (F=M) of 0.115 y^{-1}, whereas the point estimates from the LCC analysis were at or above the target reference point (F = 2/3M) of 0.077 y^{-1}). As growth of red emperor is sexually dimorphic (males grow larger than females), and the 2021 age data are not sex-specific, it was not possible to fit a more sophisticated catch curve method (age and length-based catch curve, ALCC), which estimates F, selectivity, and sex-specific growth using length and age data.

For 2016, estimates of Z, and F using age-based catch curve analyses were very similar across all methods, including CCLS, CR, LCC, and ALCC (which could be applied to these data as sex was known) (Table 3.1; Figure 3.13). The point estimates of F from the first three methods were just above the target reference point (F=2/3M) of 0.077 y^{-1} whereas those from LCC were just below the target reference point, although the confidence limits for the various methods overlapped.

Table 3.1. Fishing mortality estimates *F* y^{-1}, and associated upper and lower 95% confidence limits, from various catch curve methods based on 2016 and 2021 data for red emperor. CCLS, age-based catch curve with logistic selectivity; CR, Chapman & Robson (1960) method; LCC, linear catch curve; ALCC, age and length-based catch curve.

Region	North		South		NDSMF	
Year	2016	2021	2016	2021	2016	2021
Catch curve analysis						
CCLS	0.090	0.133	NA	0.166	0.087	0.145
(low,upp)	(0.068,0.120)	(0.110,0.162)		(0.135,0.205)	(0.071,0.107)	(0.124,0.167)
CR	0.086	0.120	0.089	0.149	0.080	0.132
(low,upp)	(0.058,0.115)	(0.094,0.146)	(0.064,0.115)	(0.114,0.183)	(0.059,0.100)	(0.111,0.152)
LCC	0.062	0.073	0.059	0.109	0.079	0.083
(low,upp)	(0.039,0.085)	(0.0.039,0.107)	(0.024,0.094)	(0.058,0.159)	(0.051,0.108)	(0.050,0.116)
ALCC	0.075	NA	0.083	NA	0.081	NA
(low,upp)	(0.054,0.104)		(0.061,0.111)		(0.066,0.099)	

When comparing estimates of *F* between North, South, and the combined NDSMF, estimates are higher in the South compared to the North, with the combined NDSMF generally centred between the two region estimates. The Level 3 catch curve results indicate that, in 2021, the Kimberley red emperor stock had experienced overfishing, with estimates of *F* from CR and CCLS breaching the proxy threshold value (*F*=*M*). Age-based linear catch curve estimates are presented but are considered less statistically robust compared with CR and CCLS. In comparison with 2021, the results for 2016 suggest that the stock at that time was only moderately exploited, with *F* estimates below the threshold value. Note that CCLS could not be successfully applied to 2016 age data for the south region.

Key results and implications for estimating female relative biomass:

For both 2016 and 2021, the two alternative equilibrium biomass models (age-based equilibrium analysis, ABEA, and length-based equilibrium analysis, LBEA) provided similar results of relative female biomass, B_{rel}. These models extend traditional equilibrium per recruit analysis by incorporating a stock recruitment relationship to account for potential impacts of fishing on recruitment, through reducing spawning biomass (Table 3.2; Figure 3.13).

The B_{rel} point estimates for the South were generally lower than the point estimates in the North, whilst noting that the confidence limits for the two regions often overlap. If not accounting for post-release mortality, in 2021, the B_{rel} estimates in each region, and for the NDSMF overall, are above the threshold (0.3) reference point. Allowing for post-release mortality (assuming 100% of released fish die), as is most appropriate for this species, the B_{rel} point estimates were generally below the threshold level (0.3), whereas for 2016 the B_{rel} point estimates were typically above the target level (0.4). In the South, the estimates are closer to the limit (0.2) than threshold reference point. For the above analysis, the steepness of the (Beverton-Holt) stock recruitment relationship was set to 0.75.

In summary, the results of the Level 3 equilibrium biomass analyses incorporating catch curve estimates of fishing mortality, indicate that the overall Kimberley red emperor spawning stock has declined between 2016 and 2021. Equilibrium analysis results are impacted by increased uncertainty associated with strong equilibrium assumptions associated with mortality and recruitment. If a stock is in decline, the level of decline may be underestimated using models with these equilibrium assumptions.

Table 3.2. Relative spawning biomass estimates and associated upper and lower 60% confidence limits for red emperor, derived using an age-based equilibrium biomass model (ABEA) and a length-based equilibrium biomass model (LBEA) and, for the North, South, and NDSMF regions, that incorporated fishing mortality estimates from 2016 and 2021 data.

Region		North		South		NDSMF	
Year	**Discard**	**2016**	**2021**	**2016**	**2021**	**2016**	**2021**
Model	**mortality**						
ABEA	0%	0.486	0.402	0.459	0.309	0.485	0.362
(low,upp)		(0.42,0.56)	(0.33,0.48)	(0.40,0.53)	(0.25,0.38)	(0.41,0.55)	(0.30,0.44)
ABEA	100%	0.422	0.321	0.395	0.229	0.444	0.282
(low,upp)		(0.36,0.49)	(0.26,0.39)	(0.34,0.46)	(0.18,0.29)	(0.38,0.51)	(0.23,0.34)
LBEA	0%	0.535	0.369	0.497	0.304	0.503	0.347
(low,upp)		(0.47,0.60)	(0.30,0.44)	(0.43,0.57)	(0.24,0.37)	(0.44,0.57)	(0.22,0.34)
LBEA	100%	0.468	0.298	0.455	0.232	0.450	0.273
(low,upp)		(0.41,0.53)	(0.24,0.36)	(0.38,0.52)	(0.18,0.29)	(0.39,0.51)	(0.28,0.42)

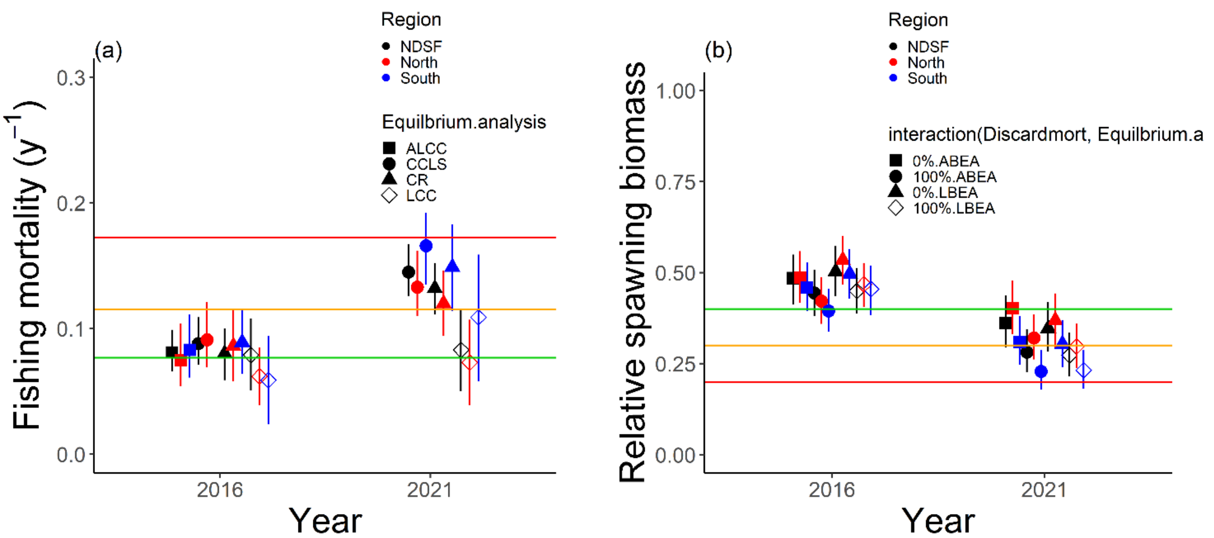


Figure 3.13. Comparison of estimates (with 60% confidence intervals) of a) fishing mortality (*F*) and b) female relative spawning biomass (B_{rel}) for the Kimberley red emperor stock based on 2016 and 2021 age data. *F* estimates in a) are estimated using a linear catch curve (LCC), the Chapman and Robson (1960) method (CR), a catch curve with logistic selectivity (CCLS), and a length and age-based catch curve (ALCC). B_{rel} estimates in b) are from an age-based equilibrium analysis (ABEA) using *F* estimates from age-based catch curves, and a length-based equilibrium analysis (LBEA) using *F* estimates from ALCC and applying 0 and 100% post release mortality. Limit (red lines), threshold (orange lines) and target reference points (green lines) are as follows: F_{limit}=1.5M, $F_{threshold}$=M, F_{target}=0.67M, B_{limit}=0.2, $B_{threshold}$=0.3, B_{target}=0.4.

3.1.6.2 Level 5 Assessment

Integrated models for red emperor were fitted to annual catch, standardised and adjusted CPUE (monthly and daily logbook returns, FIS surveys), and marginal length and conditional age-at-length composition data, up to 2024. Models with two alternative area structures were developed and compared, i.e., a single-area model, and a two-area (north-south) model. The key attributes of each model type are outlined in Appendix 1: Level 5 Assessment.

Single-area model key results

Biomass and fishing mortality

The estimated trends for both absolute (Figure 3.14a) and relative spawning biomass (B_{rel}) (Figure 3.14b) exhibit a general declining trend over the history of the fishery. Thus, estimated B_{rel} declines from ~1.0 in 1970 (i.e., just prior to commencement of known foreign fishing for demersal fish in the Kimberley) to around the target level (0.4) in the early to mid-2000s and to 0.24 (60% CIs: 0.22–0.25) by 2024. The decline in estimated biomass levels coincide with an increasing trend for fishing mortality (F), rising to its highest level in 2024 (Figure 3.14c). At this time, F is 0.22 yr^{-1} (60% CIs: 0.20–0.23) and thus about twice the level of natural mortality (0.115 y^{-1}) considered for the base case model, consistent with overfishing.

Model simulation projections for spawning biomass over the history of the fishery, for the hypothetical scenario of no fishing (i.e., no catches) throughout this period, indicate a relatively stable biomass trend (Figure 3.14e). The difference between this trend vs the estimated biomass trend accounting for fishing indicates that the estimated decline in spawning biomass is mainly attributable to fishing effects, rather than to environmental changes.

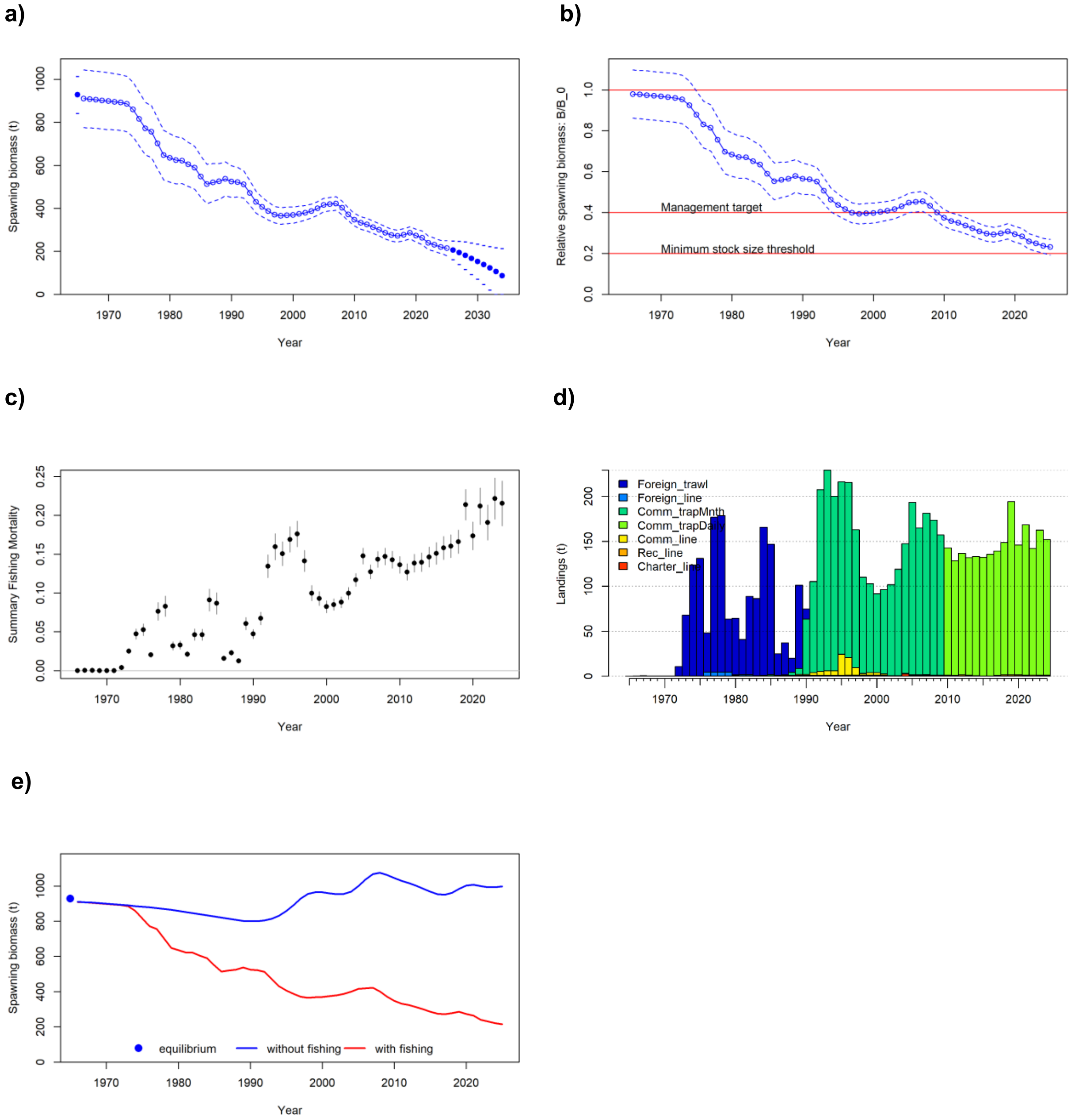


Figure 3.14 Trends for red emperor in: a) estimated absolute biomass, b) estimated relative spawning biomass (with 95% CIs), c) estimated fishing mortality, d) observed catches, and f) 'dynamic B_0 plot', which compares estimated relative spawning biomass to that which would have been expected for the stock in the absence of fishing, with all variations due to environmental changes.

Stock projections

Model forecasts for alternative scenarios of future catch indicate that if catches were to remain at the level recorded in 2024, female B_{rel} would continue to decline to below the limit (0.09, 60% CIs 0.04-0.15) by 2034 (Figure 3.15a). If catches were reduced by 25% from the 2024 level, B_{rel} is predicted to remain just above the limit level (0.26, 60% CIs 0.21–0.30), and with a 50% reduction, B_{rel} is predicted to rebuild towards the target (0.4, 60% CIs 0.35–0.44) by just after 2035. In 2024, the estimate for fishing mortality (*F)* exceeds the proxy limit reference point (*F*=3/2*M*). Beyond 2024, *F* is predicted to exceed the limit and increase to very high levels (0.51 y^{-1}, 60% CIs 0.22–0.79 y^{-1}) if catches were to remain at the 2024 level. For the projection period, *F* is predicted to decrease slightly below the proxy limit level (0.15 y^{-1}, 60% CIs 0.13–0.18 y^{-1}) with a 25% catch reduction. With a 50% catch reduction, however, *F* is predicted to decrease substantially, reaching the proxy target (*F*=2/3*M*) by about 2035 (0.07 y^{-1}, 60% CIs 0.06–0.08 y^{-1}) (Figure 3.15b). Note that, if management is aimed at stock rebuilding, then the level of fishing mortality that is desirable relates to a level of exploitation low enough to allow the stock biomass to rebuild within a specified time frame. This would need to be substantially lower than the proxy threshold *M* and best determined by model projection analysis.

a) **b)**

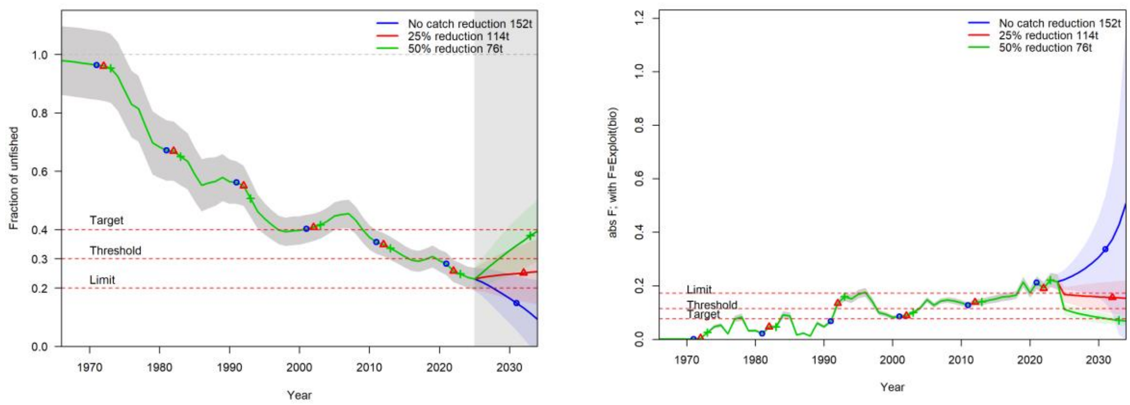


Figure 3.15: a) Relative biomass, and b) fishing mortality trends for red emperor, with 95% confidence intervals, including predicted values extending to 2035 (end of the model forecast period) under three future catch scenarios: i) constant future catch at observed 2024 catch level, ii) 25% less than the 2024 catch level, and iii) 50% less than the 2024 catch level.

Two-area model key results

Biomass, fishing mortality and recruitment

The trends exhibited by the estimates of absolute (female) red emperor spawning biomass and relative female spawning biomass are very similar between the single-area and two-area models. In 2024, both models estimate relative spawning biomass (B_{rel}) to be just above the limit, although the lower 95% confidence limit for B_{rel} is at the limit (Figure 3.16a, b). At the start of the time period the estimated spawning biomass is noticeably greater in the south (~550 t) than north area (~450 t) (Figure 3.16c). Relative spawning biomass in the southern area is estimated to have declined dramatically from about 0.6 (well above target) to just above 0.2 (limit) in the 1990s (Figure 3.16d), associated with high catches in that region during this period (Figure 3.16e). In contrast, B_{rel} is estimated to have declined more gradually in the north, not dipping below the target (0.4) until ~ 2010. Estimates of B_{rel} for 2024, however, are very similar for the two areas. If future catches were to remain at the 2024 level for each area, B_{rel} is to decline in the northern area, and increase slightly in the south to 2035 (Figure 3.16f). The estimated recruitment patterns are similar between the two areas, suggesting a high level of larval connectivity between the northern and southern areas (Figure 3.16e).

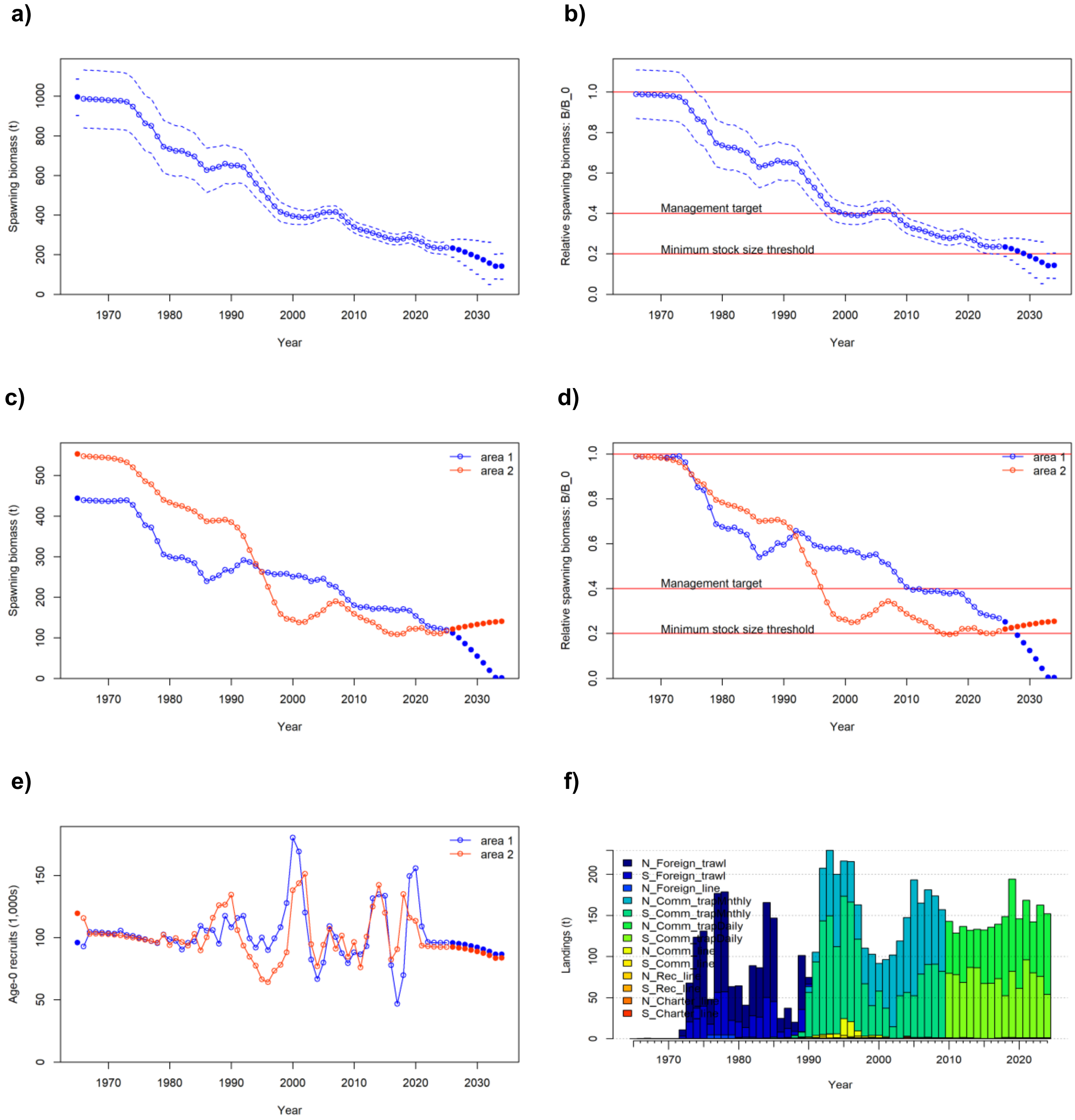


Figure 3.16: Trends associated with the two-area model for red emperor in: a) combined areas estimated absolute biomass, b) combined areas estimated relative spawning biomass (with 95% CIs), c) separate area absolute biomass, d) separate area relative biomass, e) separate area recruitment, and f) observed catches by area-specific fleets.

3.1.7 Risk-based weight of evidence assessment

Category	Line of evidence
Biology and vulnerability	Red emperor has a long lifespan (~41 years) and reaches maturity at ~5 years of age. For this species, a minimum legal length of 410 mm total length (~380 mm FL) has been in place since 1991, resulting in fish being retained in commercial catches when they reach ~6 years of age. In the NDSMF (which is primarily a commercial trap fishery), discarded, undersized individuals represent about 9% of the red emperor catch by weight (23% by numbers), with associated mortality likely to be very high due to predation (from sharks) and effects of barotrauma. Thus, red emperor is highly vulnerable to fishing pressure.
Catch	Red emperor have been captured almost exclusively by commercial fleets since the early 1970s with foreign fleets fishing the Kimberley until 1990, and the domestic line fishing occurring inshore since at least 1980. Effort management measures were introduced in 1998, which by 2002 had resulted in line fishing being replaced by trap fishing. Since 2010, red emperor catches have been relatively high at around 140–150 t per year, with higher catches in 2019, 2021, and 2023. The relatively high catches in all years since the mid-2000s may be resulting in high current fishing pressure.
Spatial catch distribution	Adult red emperor exhibit a relatively even distribution across mid-shelf depths, to a maximum of at least 180 m. In the initial stages of the developing domestic commercial fishery, red emperor catches were taken by fishers operating in inshore waters. As the NDSMF expanded between 1988 and 1993, catches were recorded across the full distribution of the stock (depth and latitude). The consistent spatial distribution of catches in recent decades throughout the full stock distribution indicates that all of the stock area is fished. There is no evidence of spatial contraction of the stock, which might otherwise suggest unacceptable stock depletion.
Level 1 Assessment: The lines of evidence based on catch indicate it is possible that red emperor is currently experiencing overfishing. As similar levels of catch have been sustained for the last two decades, and there is no evidence of marked spatial stock contraction, this suggests that the stock is unlikely to be heavily depleted.	
Catch per unit effort (CPUE)	Annual standardised catch rate (SCR) indices for red emperor are calculated for the commercial trap fishery through monthly logbooks (1996–2009), daily logbooks (2010–2024), and fisheries independent surveys (FIS; 2006, 2008, 2012, 2016, 2021). All CPUE trends are adjusted assuming that fishing efficiency has increased by 2% each year. The adjusted monthly SCR does not show a clear trend and is highly variable. The

	adjusted daily logbook SCR shows an overall declining trend (~33%) with a temporary increase in 2018–19. The adjusted FIS SCR declined steadily from 2006 to 2021.
Level 2 Assessment: The declining trends in daily logbook SCR and FIS SCR indicate that there has been a decline in stock biomass over the past couple of decades.	
Length composition	The mean size of red emperor above the MLL caught in periodic FIS surveys between 2006 and 2021 has remained relatively stable over time. This trend suggests that the impacts of fishing mortality on the size distribution of red emperor have not increased since 2006.
Age composition	The maximum age for a red emperor is ~41 yrs but few animals have been recorded above 30 y of age. As the numbers of fish in samples peak at about 6 yrs of age, individuals recruit into the fishery, and thus become exposed to fishing pressure, early in life. The vast majority (86–92%) of fish caught in periodic FIS surveys between 2006 and 2021 are young (<15 years), which indicates that the stock has been heavily fished. The age structures are somewhat inconsistent between surveys (possibly representing differences in sampling), with the 2016 sample less truncated than for other years.
Catch Curve	Catch curve results for 2021 indicate that the red emperor stock is currently over-exploited, with (equilibrium) *F* estimates breaching the threshold reference level. The estimates of *F* estimated from the 2021 age sample are higher than from 2016 data, which may reflect increasing fishing pressure in recent years. Reliability of the *F* estimates is potentially impacted by sampling effects and equilibrium assumptions.
Equilibrium biomass analysis	The Level 3 equilibrium analyses for estimating relative female biomass (B_{rel}), incorporating catch curve estimates of mortality and a range of biological information for the stock, indicate that the red emperor stock is now over-exploited, with all estimates for B_{rel} breaching the threshold reference level (Appendix E).
Level 3 Assessment: The age structures in association with the 2021 estimates of *F* and B_{rel} all indicate that the stock is over exploited. As most of the growth of red emperor, in terms if length, occurs early in life, heavy fishing pressure is not expected to impact on mean size. Note that the Level 3 analyses make strong equilibrium assumptions, increasing the uncertainty of results.	
Integrated Model	In 2024, the point estimate for B_{rel} from the single-area integrated assessment model is just above the limit (0.2), although the associated 95% lower confidence limit is below the limit. The estimate of *F* in 2024 from this model is above the limit, strongly indicating that overfishing was occurring. Projection analyses from the single-area model indicate that if future catches were to remain at the 2024 catch level, this would

	result in further stock decline. The model indicates that a 50% reduction in catch from the 2024 level is predicted to result in stock levels approaching the target (0.4) over the next decade (assuming average recruitment levels over this period). Results from a preliminary two-area model are somewhat uncertain, as several diagnostic analyses indicated potential issues with the model, possibly associated with a lack of data.
Level 5 Assessment: The single-area integrated model indicates that the stock is overfished, and current fishing mortality is too high.	
Environmental impacts	Red emperor has been assessed as having **Medium** sensitivity to the effects of climate change based on its abundance, distribution, and phenological characteristics in the NCDSR - Kimberley stock. However, the impacts of climate change on red emperor and its environment are uncertain.

Final Risk

C1 (Minor depletion): There is a REMOTE (0-5%) chance that the stock is above the target. This is consistent with sustained high catches in recent years, declining catch rates, truncated age structures, high F, and low B_{rel} estimates.

C2 (Moderate depletion): There is a REMOTE (0-5%) chance that the stock is between the threshold and target. As above for C1.

C3 (High depletion): It is LIKELY (>50%) that the stock is between the threshold and limit. As above for C1, and as the upper 95% CL B_{rel} from the integrated model is below the threshold and the lower 95% CL B_{rel} is fractionally below the limit.

C4 (Major depletion): There is a REMOTE (0-5%) chance that the stock is below the limit. As above for C1, and the lower 95% CL B_{rel} is fractionally below the limit. There is also no evidence of marked spatial stock contraction or a decline in mean size over time.

Based on the risk matrix, the overall risk to the red emperor stock in the Kimberley region is assessed as **High (C3 × L4).** On the basis of this evidence, the stock is classified as **Inadequate**.

Consequence (Stock level)	Likelihood			
	1 Remote (<5%)	2 Unlikely (5-20%)	3 Possible (20-50%)	4 Likely (>50%)
1 Minor (above Target)	X			
2 Moderate (between Target and Threshold)	X			
3 High (between Threshold and Limit)				High
4 Major (below Limit)	X			

3.1.8 Assessment Advice

The single-area integrated model indicates that the stock is overfished, with current fishing mortality rates exceeding sustainable levels. Model projections based on catches maintained at current levels indicate that the stock biomass is likely to continue to decline to below the limit reference point by 2035. In contrast, model projections indicate that a 50% reduction in catch from the 2024 levels is likely to result in the stock biomass level approaching the target reference point within the next decade.

3.2 Goldband Snapper

3.2.1 Catch

Annual catches of goldband snapper (91% adjusted from all combined jobfish species (Appendix 1: Level 1 Assessment) from the Kimberley since 1966 have fluctuated from 37 to 598 t (Figure 3.17). Catches first peaked at 418 t in 1977–78, and again in 1984 from foreign fleets, catches then declined to 37 t by 1990, with the removal of the foreign fleet. Catches have been increasing periodically, with peaks in 1996, 2005, 2010, and 2020. The maximum catch within a year for this species is 595 tonnes. From 2009 to 2018, catches stabilised within the 400–450 t range, and catches have since returned to within this catch range in 2024. The majority of goldband snapper have been caught in the Northern region of the Kimberley, with the exception of the earlier years when the domestic commercial sector began in the South before expanding to the North (Figure 3.18).

Charter and recreational catches of goldband snapper in the Kimberley has been minimal (<1%) compared to the commercial catches, due to the low number of fishers and remoteness of the area (Figure 3.19).

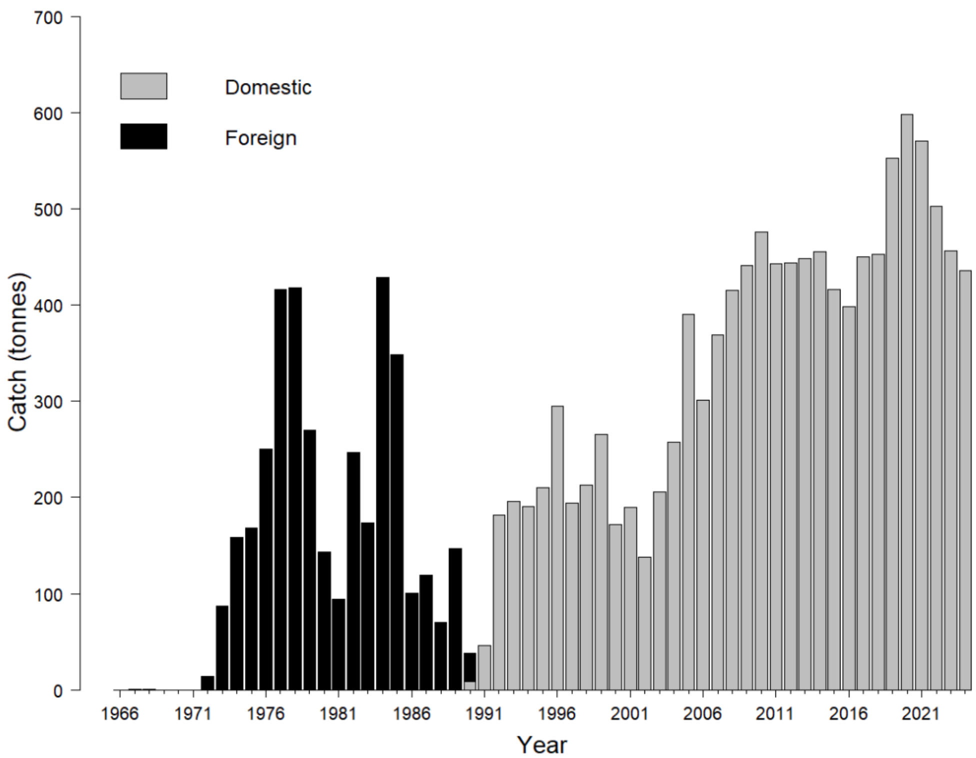


Figure 3.17. Annual catch (tonnes) of goldband snapper (91% adjusted) (below) from the foreign (black) and domestic (grey) commercial fisheries taken in the Kimberley from 1966 to 2024.

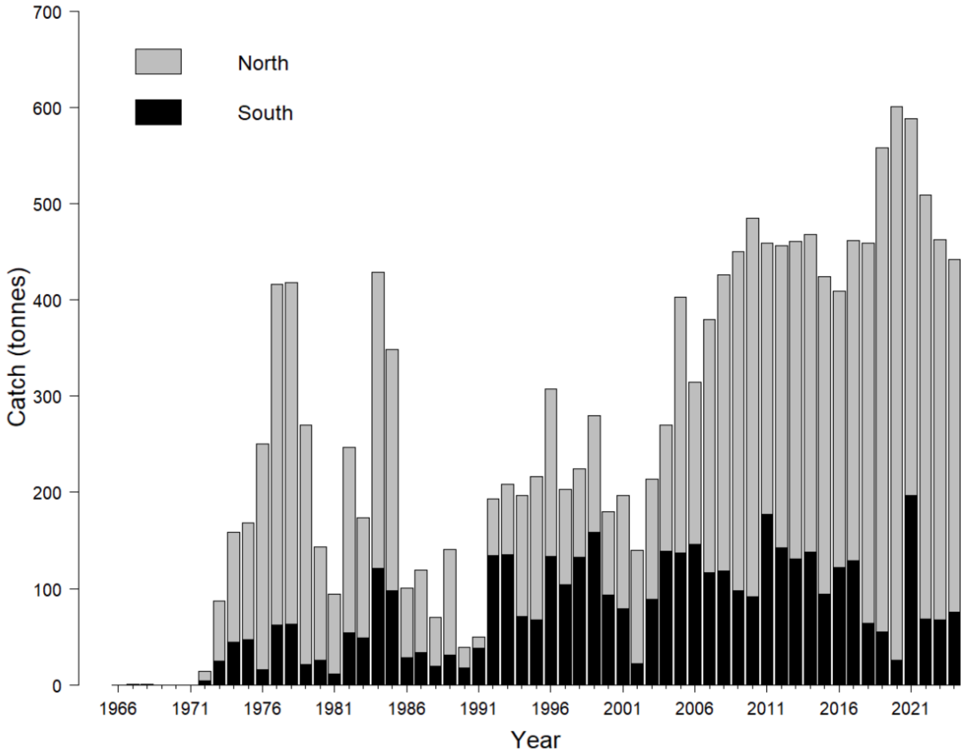


Figure 3.18. Annual catch (tonnes) of goldband snapper (91% adjusted) (below) taken in the Kimberley by spatial regions. North, catch north of 15°S latitude; South, catch south of 15°S latitude.

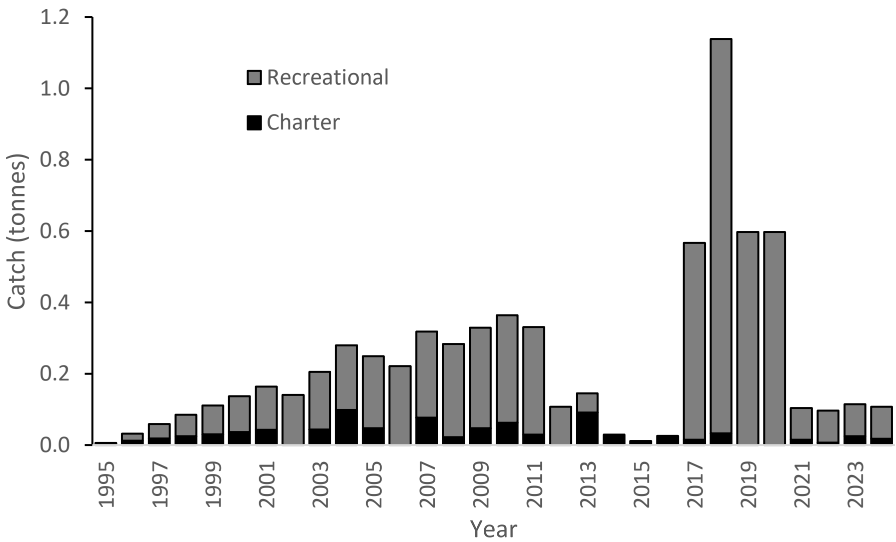


Figure 3.19. Total annual catches (tonnes) of goldband snapper (below) taken by the charter (black) and recreational (grey) fisheries in the Kimberley.

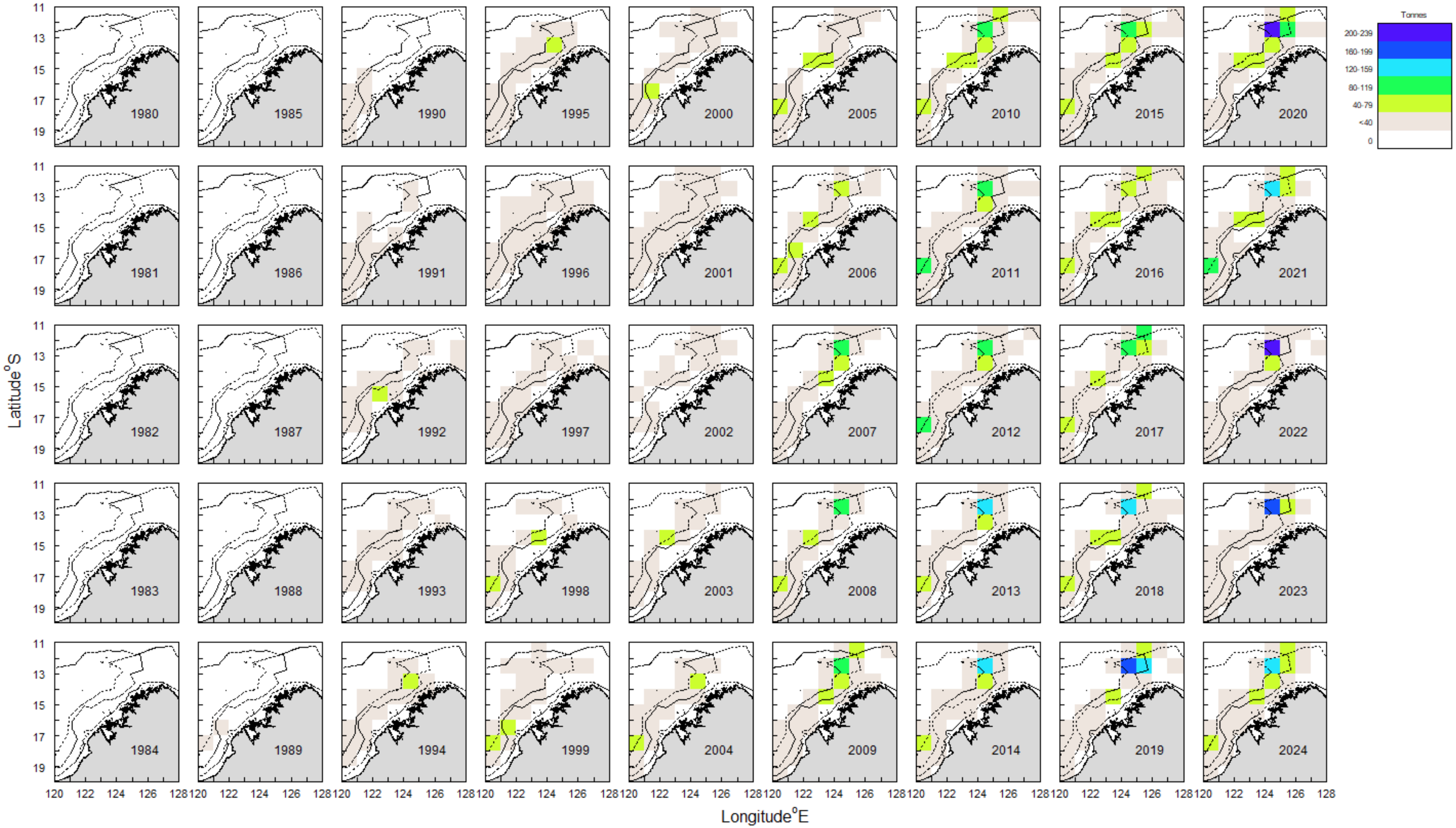


Figure 3.20. Distribution of goldband snapper reported catches by calendar year, all methods combined, and 60 NM block in the NDSMF from 1980 to 2024.

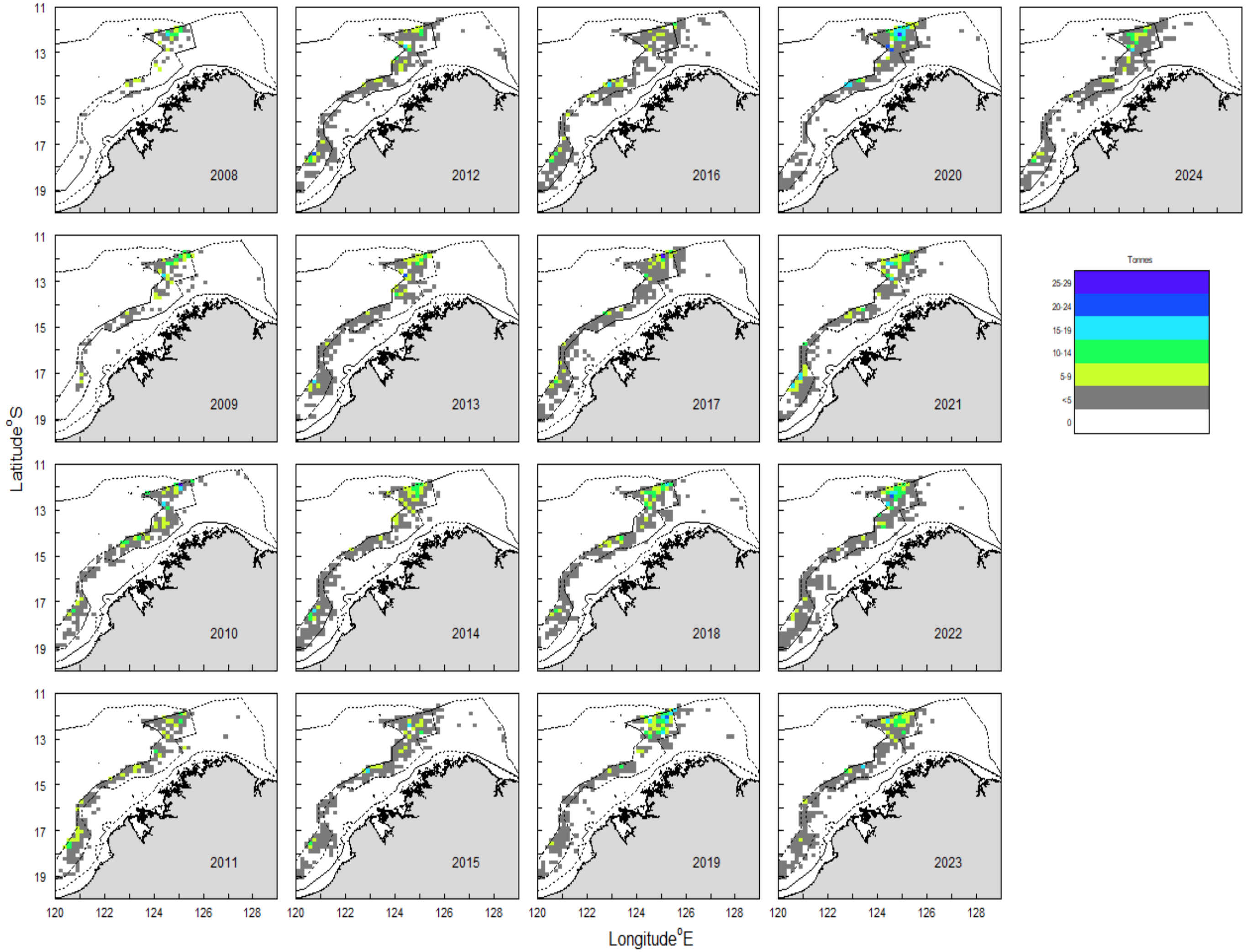


Figure 3.21. Distribution of goldband snapper reported daily logbook catches by calendar year, all methods combined, and 10 x 10 NM block in the NDSMF. Daily logbooks with 10 x 10 NM blocks were first introduced in 2008 and were fully integrated into the fishery by 2010.

3.2.2 Catch Per Unit Effort (CPUE)

Standardised CPUE for goldband snapper from monthly logbooks with 2% efficiency creep applied showed a relative stable trend from 1996–2009, but with high uncertainty around the point estimates. The CPUE from daily logbooks showed a gradual decline over the period from 2010–2024, with low uncertainty (Figure 3.22). The FIS survey CPUE showed an increasing trend from 2006 to 2016, then a marked decline (~50%) in 2021 at the nine fixed sites, which is inconsistent with trends in the monthly and daily logbook CPUE. The standardisation resulted in a more stable monthly catch rate time series compared to an increasing time series observed in the nominal catch rates and remained relatively consistent within the daily catch rate time series.

Due to inconsistent spatial and temporal cover in the monthly logbook data, monthly CPUE could not be calculated at the regional level. In the northern region, daily logbook CPUE showed a gradual decline over the period from 2010–2024, with low uncertainty. The FIS survey CPUE showed a less consistent trend compared to the daily CPUE, with a relatively stable trend with the exception of considerably higher CPUE in 2016. The standardisation resulted in a relatively consistent daily catch rate time series with the nominal catch rate. In the south, daily CPUE was more variable than in the north, but showed a declining trend over the period from 2010–2024. The FIS survey CPUE time series is less consistent than the daily CPUE, with an increasing trend then declining in 2021. The FIS survey in 2021 in the south was markedly different from the daily logbooks, catches were at a record peak in 2021 and catch rates were considerably higher than previous years, but the catches and subsequent catch rates were much lower in the FIS survey. The standardisation resulted in a reduced decline in daily catch rates than was observed in the nominal time series and varied considerably in 2020–2021 resulting in less variability in abundance during this period.

Some of the changes in mean CPUE between successive FIS surveys are very large. For example, in the south region, the mean survey declined from about 1.5 in 2016 to 0.25 in 2021, representing more than an 80% decrease. Such a decrease over just 5 years is not realistic; that is, if CPUE is considered proportional to abundance, then this implies that the stock level has declined by more than 80% in just 5 years. The reliability of the FIS CPUE, and associated methods for standardising these data, is being further investigated.

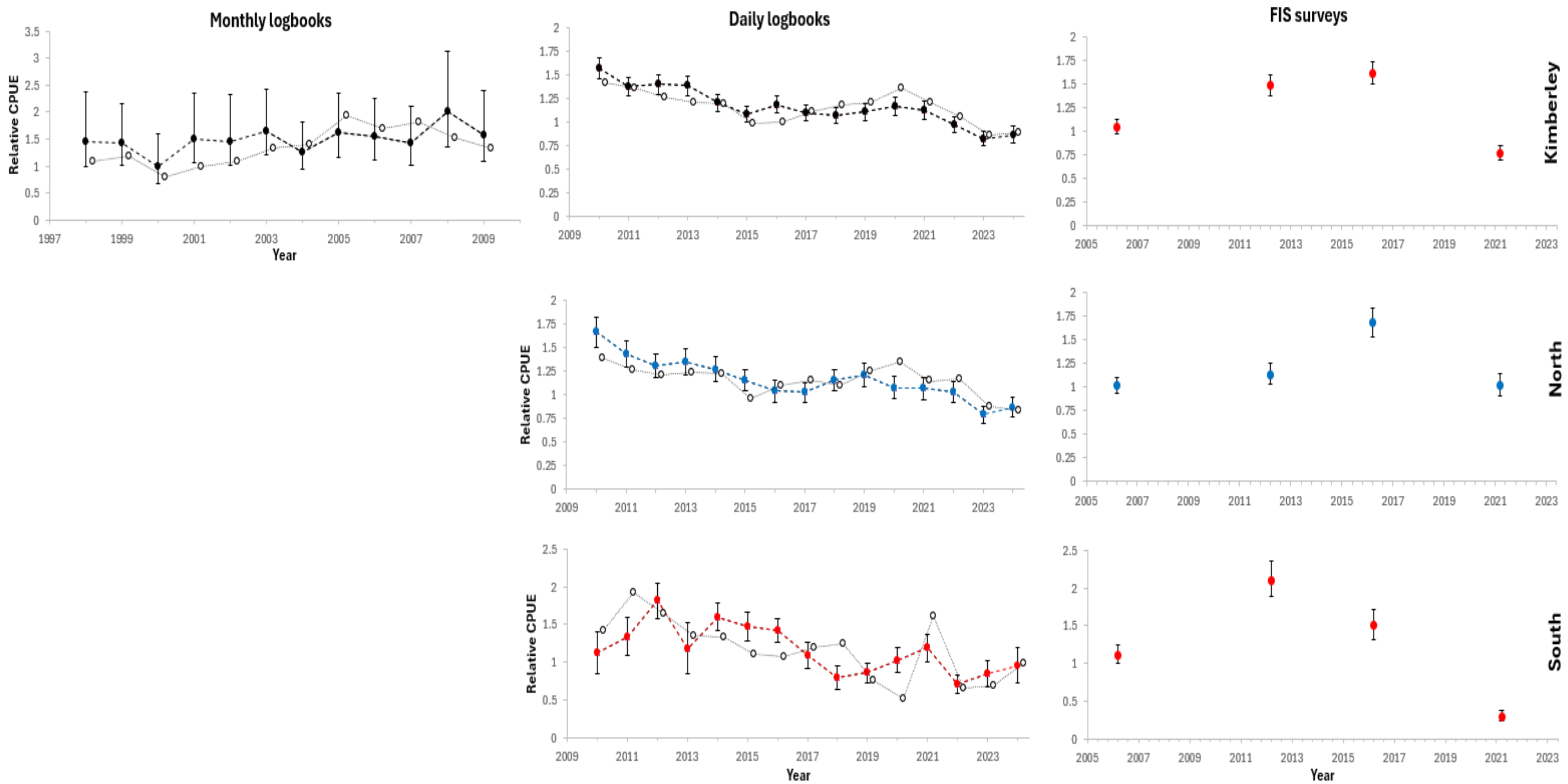


Figure 3.22. Relative annual standardised catch per unit effort (CPUE) (mean and ±95% CI) (filled dots), and nominal catch rates (open dots) for goldband snapper by trap fishing in the Kimberley, and the North and South regions from 1996–2024. Monthly logbooks, daily logbooks, and FIS sampling. Each series has separately been normalised to a mean of 1, with a 2% efficiency creep applied retrospectively to the normalised CPUE time series.

3.2.3 Size Composition

The maximum recorded length for goldband snapper in the Kimberley from the FIS surveys is 703 mm FL (Figure 3.23). The mean fork lengths of goldband snapper for each survey year were 484 mm, 485 mm, 478 mm, 483 mm, and 452 mm for 2006, 2008, 2012, 2016/17, and 2021, respectively (Figure 3.24). For goldband snapper, based on all captured fish), mean length in the South, North, and both regions combined, was lower in 2021 compared with all other years (Figure 3.24), with the values similar among regions in that year. Note, a legal-size limit does not apply for this species.

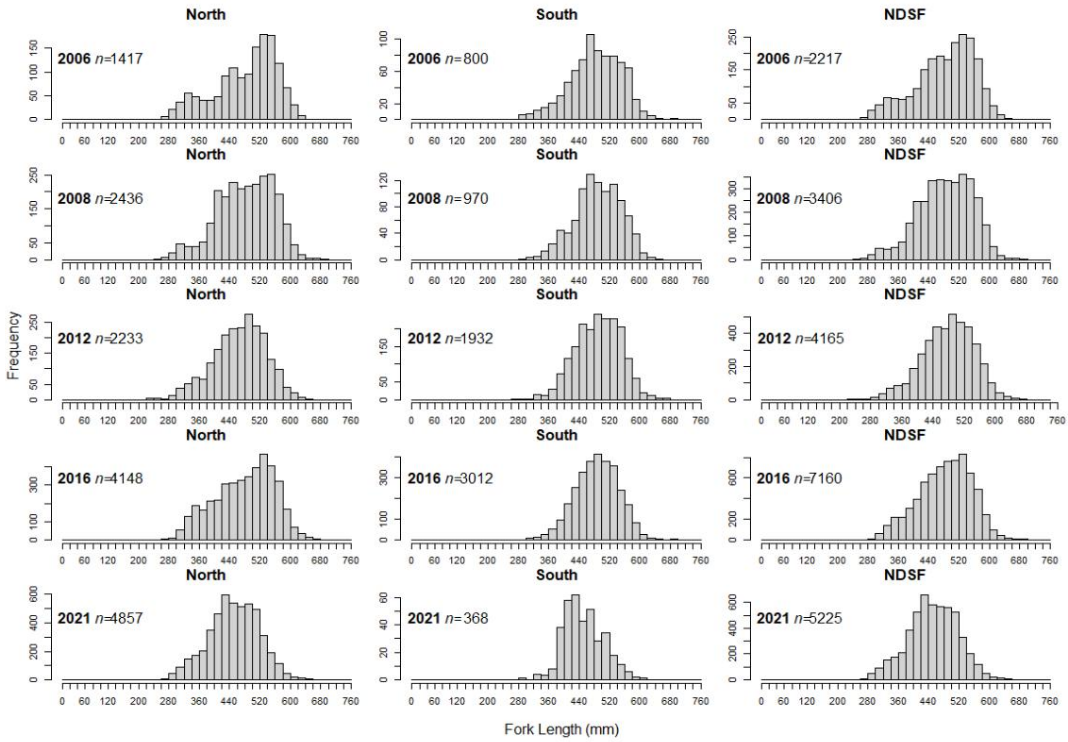


Figure 3.23. Length frequency (fork length) plots for all captured goldband snapper from fisheries-independent survey sampling in the Kimberley, and by North and South regions.

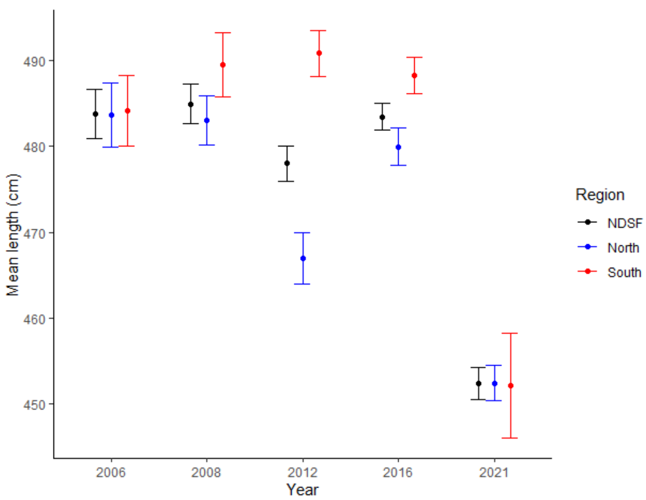


Figure 3.24. Mean lengths with 95% CIs for all captured goldband snapper from fisheries-independent survey sampling in the Kimberley, and by North and South regions.

3.2.4 Age Composition

The maximum recorded age for this species from the Kimberley FIS surveys is 28 years (Figure 3.25). The peak age class of goldband snapper from traps in the NDSMF in all years in each area (North and South of 15-degree latitude) is 5 years of age, with the exception of 2008 in the South Kimberley, with a peak age of 4 years. Males and females show no major differences in their age frequencies, reaching similar peak ages and maximum ages (Figure 3.26). The mean age of goldband snapper for each survey year from all animals aged were 6.1, 5.9, 6.9, 7.0, and 7.0 years for 2006, 2008, 2012, 2016/17, and 2021, respectively (Figure 3.27). The proportion of older fish (i.e., ≥ 10 years) recorded in the age compositions has increased across the survey years from ~10% to ~18% (Figure 3.28). Note that the number of survey sites has increased over time, and therefore the samples from the most recent years are likely to be the most representative.

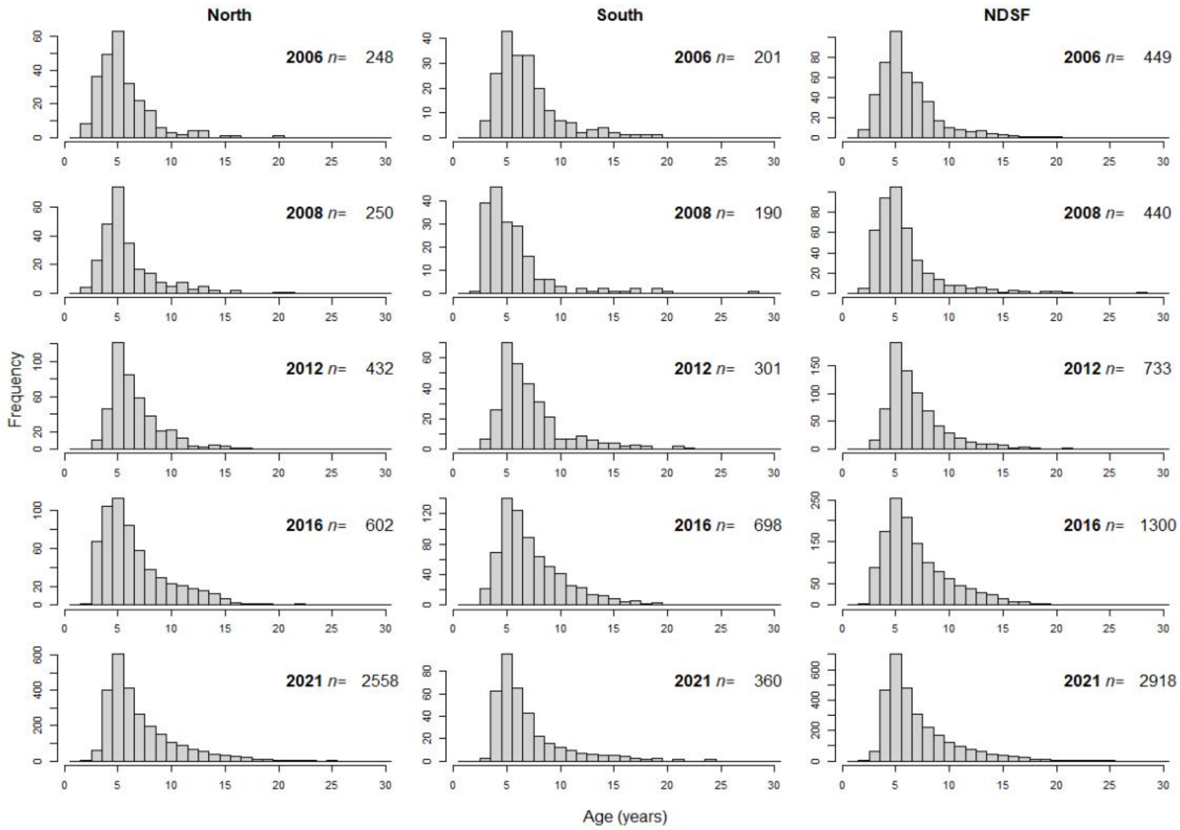


Figure 3.25. Age frequency (numbers) histograms for goldband snapper in the Kimberley, and by North and South regions from fisheries-independent survey sampling (*n*, sample sizes).

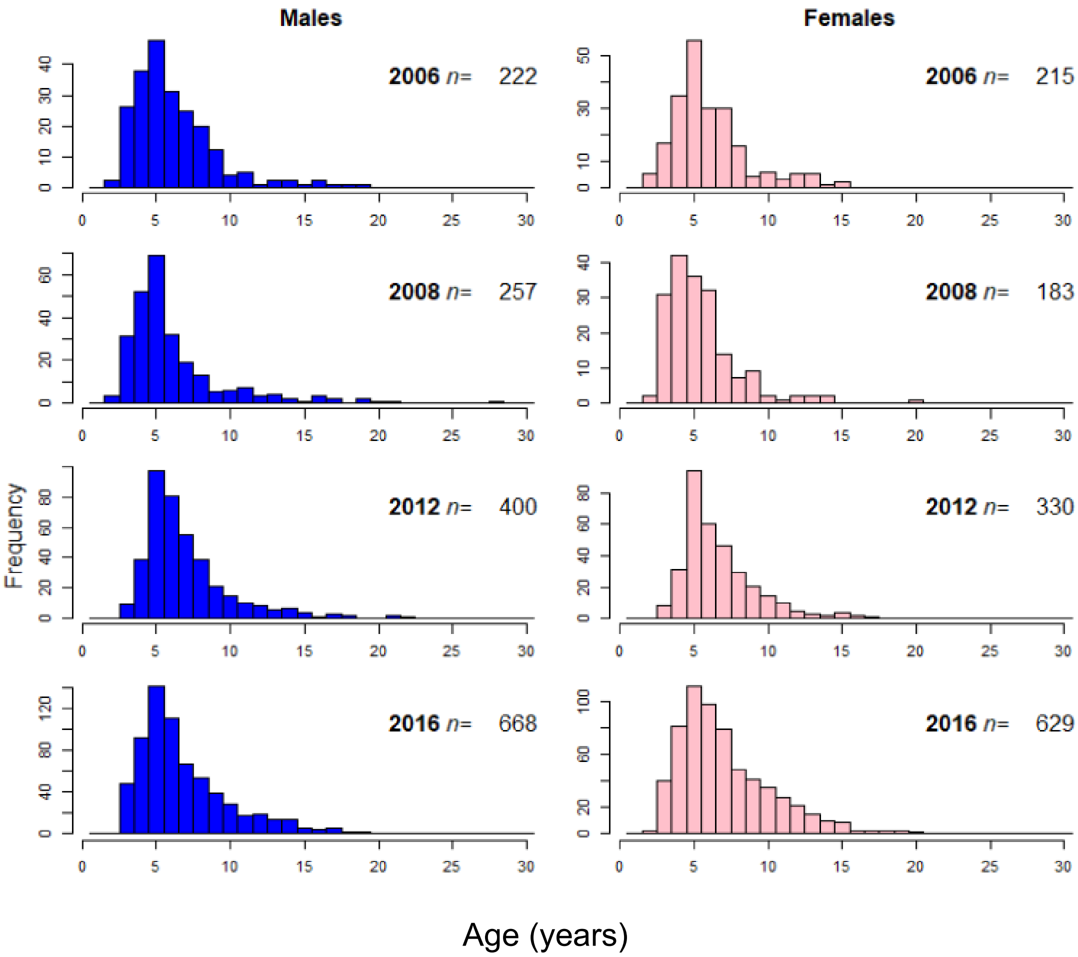


Figure 3.26. Age frequency (numbers) histograms for goldband snapper by sex in the Kimberley from fisheries-independent survey sampling (*n*, sample sizes).

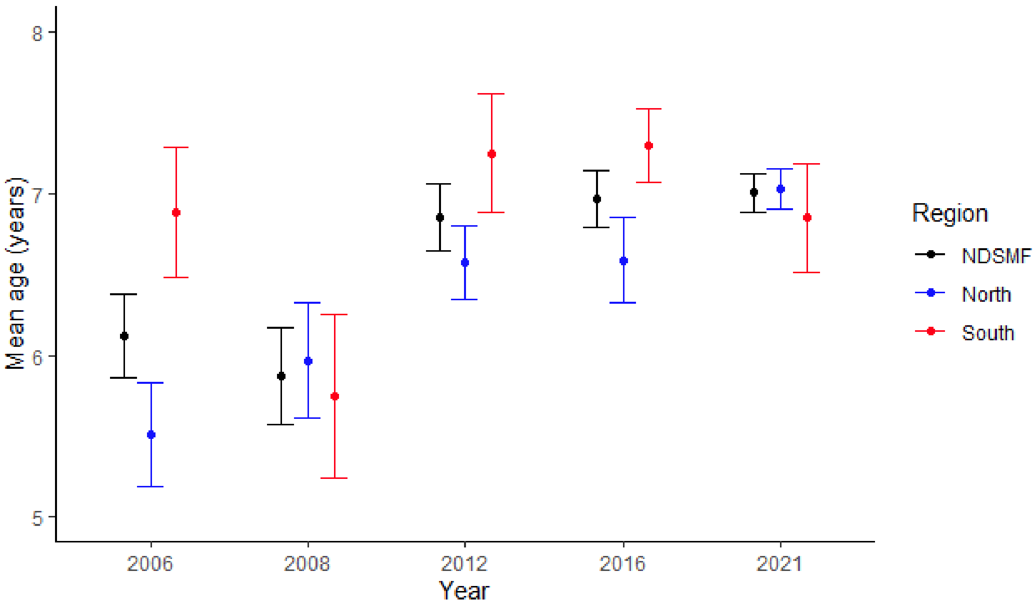


Figure 3.27. Mean age (years) for goldband snapper, with 95% CIs, from fisheries-independent survey sampling in the Kimberley (NDSMF), and by North and South regions.

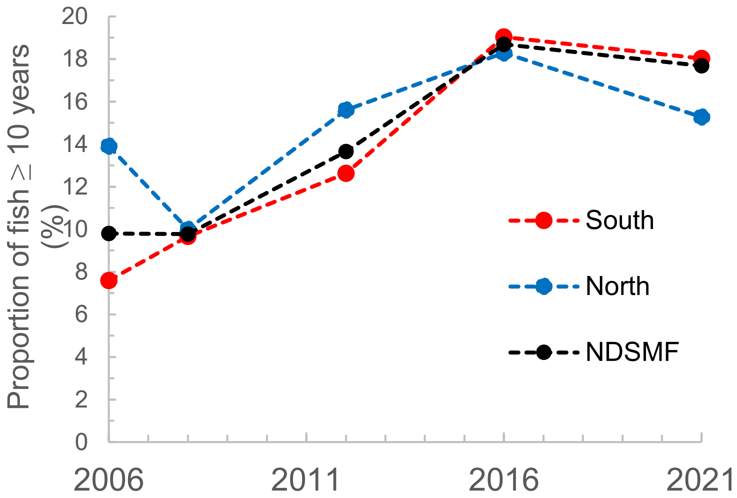


Figure 3.28. Percentage of older (i.e., ≥ 10 years) goldband snapper in the age compositions from fisheries-independent survey sampling in the Kimberley (NDSMF), and by North and South regions.

3.2.5 Environmental Impacts

Climate projections for WA (Pilbara to Albany) include increases in sea surface temperature, increases in the number of marine heatwave days, sea level increases, ocean acidification, intense and variable storms, and rainfall decreases (Chandrapavan and Jackson 2024). Climate change and climate variability has the potential to impact fish stocks in a range of ways including influencing their recruitment, spawning, and geographic distribution (e.g., latitudinal shifts in distribution). However, it is currently unclear how much climate change may affect the sustainability of NCDSR-Kimberley demersal resources.

Goldband snapper is a tropical species and based on its abundance, distribution, and phenological characteristics in the NCDSR-Kimberley stock, it has been assessed as having **Low** sensitivity to the effects of climate change (Jackson et al. 2024).

3.2.6 Model Assessment

3.2.6.1 Level 3 Assessment

The biological parameters (e.g., growth and maturity) have been updated since the previous assessment of goldband snapper from the Kimberley region in 2018. For more detail of the model analyses and assumptions see section (Appendix 1: Level 3 assessment).

The oldest goldband snapper captured from FIS surveys is 28 years of age (based on large samples). However, no individuals have been caught between 23 (the second oldest fish) and 28 years of age. For catch curve and equilibrium biomass analyses, natural mortality is currently calculated based on the second oldest fish and the natural mortality equation of Hoenig (1983), which predicts a value of M=0.181 y^{-1} and indicates that ~ 1.5% of the population reaching this age (Hewitt & Hoenig, 2005; see also Dureuil et al., 2021; Dureuil & Froese, 2021).

In 2021, the points estimates of total mortality, Z, and fishing mortality, F (using M = 0.181 y^{-1}) for the goldband snapper were generally slightly lower using age-based catch curve analyses (catch curve with logistic selectivity, CCLS and Chapman and Robson (1960) method, CS), than from linear catch curves (LCC), and these were less than from an age and length-based catch curve (ALCC) (Table 3.3; Figure 3.29). Point estimates of *F* from the age or length-based methods were at or above the target reference point (*F*=2/3M) of 0.123 y^{-1}, whereas the point estimates from the ALCC analysis were at or above the threshold reference point (*F* = *M*) of 0.181 y^{-1}). A similar pattern was observed for 2016, with the mortality estimates from a given method being at a similar level between the two periods (Table 3.3; Figure 3.29).

Table 3.3. Fishing mortality estimates *F* y^{-1}, and associated upper and lower 95% confidence limits, from various catch curve methods based on the 2016 and 2021 data for goldband snapper. CLSL, age-based catch curve with logistic selectivity; CR, Chapman & Robson (1960) method; LCC, linear catch curve; ALCC age and length-based catch curve.

Region	North		South		NDSMF	
Year	2016	2021	2016	2021	2016	2021
Catch curve analysis						
CCLS	0.095	0.133	0.153	0.162	0.128	0.137
(low,upp)	(0.071,0.127)	(0.120,0.148)	(0.123,0.191)	(0.126,0.208)	(0.108,0.152)	(0.124,0.151)
CR	0.117	0.122	0.149	0.139	0.132	0.124
(low,upp)	(0.087,0.147)	(0.106,0.137)	(0.116,0.182)	(0.094,0.183)	(0.110,0.154)	(0.109,0.138)
LCC	0.151	0.148	0.14	0.092	0.161	0.152
(low,upp)	(0.100,0.202)	(0.122,0.173)	(0.102,0.178)	(0.053,0.131)	(0.123,0.199)	(0.131,0.173)
ALCC	0.156	0.205	0.21	0.187	0.185	0.199
(low,upp)	(0.108,0.222)	(0.178,0.234)	(0.150,0.286)	(0.143,0.241)	(0.157,0.217)	(0.176,0.223)

The estimates of *F* between the North and NDSMF (entire Kimberley) as a whole were more similar than between the South and NDSMF, noting that the majority of fish were caught in the North. Catch curve results indicate that the goldband snapper stock is moderately to fully exploited, with most estimates suggesting that exploitation has increased, at least in the North and across the NDSMF compared with results based on the 2016 samples. There is greater uncertainty around the estimates for the South, due to the lower sample sizes for this region. There is uncertainty regarding whether the long-term average mortality estimates from catch curve analyses, assuming the stock is at equilibrium with respect to mortality and recruitment, adequately reflect mortality in recent years. Age-based linear catch curve (LCC) estimates are presented but are considered less statistically robust compared with CR and CCLS.

Equilibrium analyses for estimating female relative biomass:

Estimates of relative female spawning biomass B_{rel}, for 2016 and 2021, from age-based equilibrium biomass analysis (ABEA), and length-based equilibrium biomass analysis (LBEA) are similar (Table 3.4; Figure 3.29). The point estimates for B_{rel} in the South were generally lower than those in the North but noting that their associated 60% confidence limits often overlapped. The estimates of B_{rel} for 2021 were around or above the target level (0.4), whereas in 2016, the SPR estimates were at or above the target level.

Table 3.4. Relative spawning biomass estimates and associated upper and lower 60% confidence limits for goldband snapper, derived using an age-based equilibrium biomass model (ABEA) and a length-based equilibrium biomass model (LBEA) and, for the North, South, and NDSMF regions, that incorporated fishing mortality estimates from 2016 and 2021 data.

Region	North		South		NDSMF	
Year	**2016**	**2021**	**2016**	**2021**	**2016**	**2021**
Equilibrium analysis						
ABEA	0.534	0.45	0.455	0.402	0.483	0.442
(low,upp)	(0.469,0.595)	(0.378,0.520)	(0.381,0.528)	(0.332,0.480)	(0.412,0.552)	(0.377,0.518)
LBEA	0.528	0.402	0.47	0.401	0.497	0.395
(low,upp)	(0.456,0.607)	(0.326,0.480)	(0.391,0.554)	(0.329,0.470)	(0.422,0.580)	(0.322,0.474)

The Level 3 equilibrium analysis results incorporating catch curve estimates of mortality indicate that the Kimberley goldband snapper spawning stock had declined from the previous age structure analysis and is at least moderately exploited. Equilibrium analysis results are impacted by increased uncertainty associated with equilibrium assumptions and the possible impacts of recruitment variability on catch curve results.

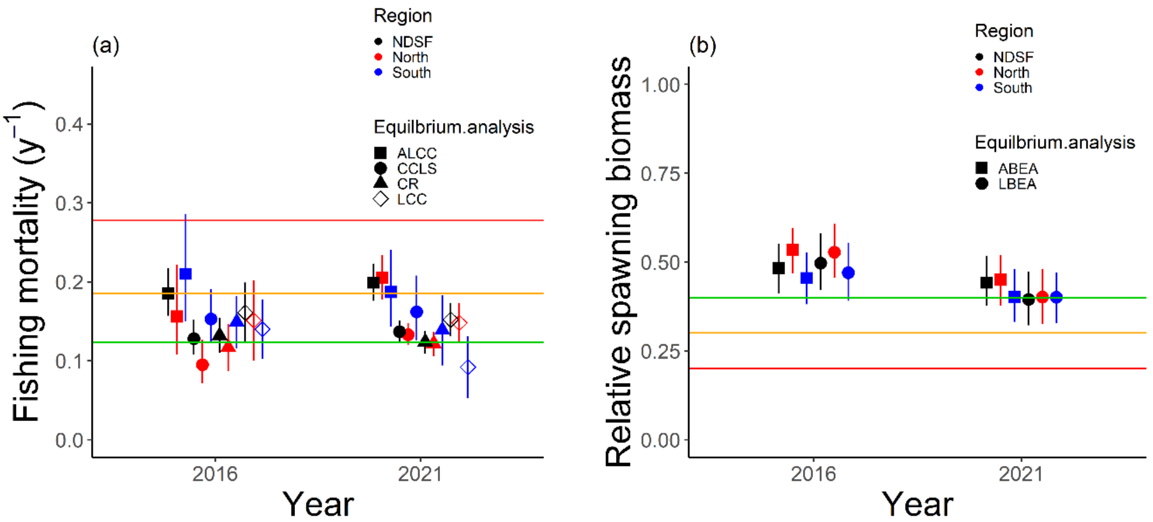


Figure 3.29. Comparison of estimates (with 60% confidence intervals) of: a) fishing mortality (*F*), and b) female relative spawning biomass (B_{rel}) for the Kimberley goldband snapper stock based on the 2016 and 2021 age data. Estimates of *F* in a) are estimated using a linear catch curve (LCC), the Chapman and Robson (1960) method (CR), a catch curve with logistic selectivity (CCLS), and a length and age-based catch curve (ALCC). Estimates of B_{rel} in b) are from an age-based equilibrium analysis (ABEA) using *F* estimates from age-based catch curves, and a length-based equilibrium analysis (LBEA) using *F* estimates from ALCC and applying 0 and 100% post release mortality. Limit (red lines), threshold (orange lines), and target reference points (green lines) are as follows: F_{limit}=1.5*M*, $F_{threshold}$=*M*, F_{target}=0.67*M*, B_{limit}=0.2, $B_{threshold}$=0.3, B_{target}=0.4.

3.2.6.2 Level 5 Assessment

Integrated models for goldband snapper were fitted to annual catch, CPUE (monthly and daily logbook returns, FIS surveys), and marginal length and conditional age-at-length composition data up to 2024. Models with two alternative area structures were developed and compared, i.e., a single-area model, and a two-area (north-south) model. The key attributes of each model type are outlined in Appendix 2: Level 5 Assessment.

Single-area model key results

Biomass and fishing mortality estimates

Similar to red emperor, the estimated trends for both absolute (Figure 3.30a) and relative female spawning biomass (B_{rel}) (Figure 3.30b) exhibit a general decline over the history of the fishery. Median B_{rel}, for example, declines from 1.0 in 1970 (i.e., just prior to commencement of known foreign fishing for demersal fish in the Kimberley) to around the target level (0.4) by 2022, to just below that level in 2024 (B_{rel} =0.38, 60% CIs 0.32-0.43). The decline in estimated biomass levels coincide with an increasing trend for fishing mortality (F), rising to historically high levels from 2020–2024 (F=0.18 y^{-1}, 60% CIs 0.14-0.22 y^{-1}) (Figure 3.30c). At this time, F is close to the level of natural mortality (M=0.181 y^{-1}) considered for the base case model, consistent with the view that the stock is now fully exploited (such that if F were to increase any further, this would translate to overfishing).

Model simulations for female spawning biomass over the history of the fishery, for the hypothetical scenario of no fishing (i.e., no catches) throughout this period, do not show any notable decreases. Rather, the trend for unfished biomass is relatively stable until around 2005, and then increases by ~20% by 2010, and then remains at a similar level through to 2024 (Figure 3.30e). The predicted increase relates to a period of above average recruitment deviations (see further below). The comparison between the predicted unfished biomass trend vs estimated biomass trend strongly indicates that the estimated decline in spawning biomass is mainly attributable to effects of fishing, rather than to environmental changes (Figure 3.30e).

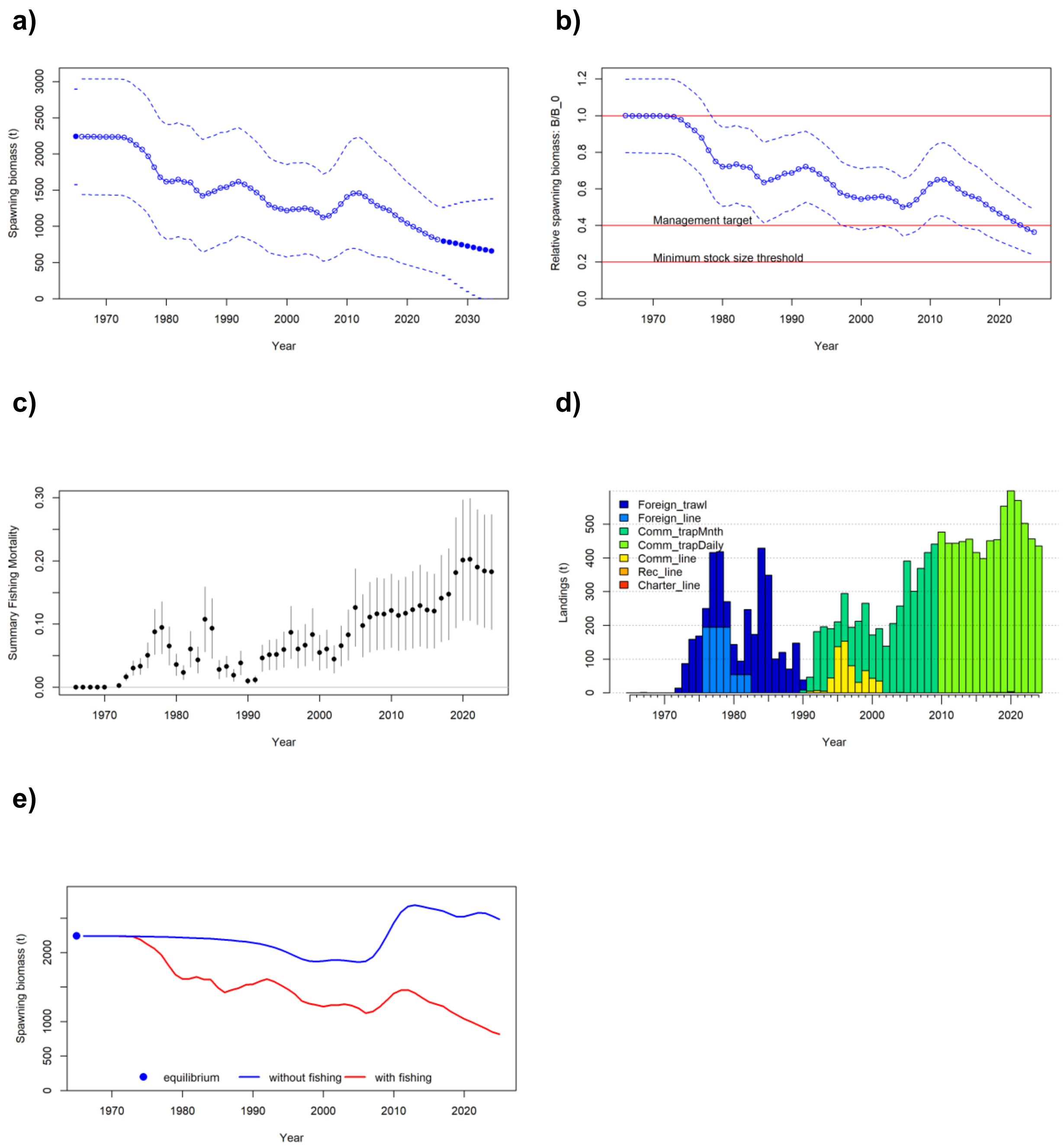


Figure 3.30: Trends associated with the single-area model for goldband snapper in: a) estimated absolute biomass, b) estimated relative spawning biomass, c) estimated fishing mortality, d) observed catches, and e) 'dynamic B0 plot', which compares estimated relative spawning biomass to that which would have been expected for the stock in the absence of fishing, with all variations due to environmental changes. 95% confidence intervals are shown for a), b), and c).

Stock projections

Results of model forecasts for alternative scenarios of future catch indicate that if catches were to remain at the level recorded in 2024, female B_{rel} would decline to just below the threshold level of 0.3 (B_{rel}=0.29, 60% CIs 0.18–0.41) by 2034. If catches were reduced by 25% from the 2024 level, B_{rel} is predicted to remain above the target level of 0.4 (B_{rel}=0.43, 60% CIs 0.33–0.53), and with a 50% reduction, B_{rel} is predicted to increase to well above the target (B_{rel}=0.56, 60% CIs 0.47–0.65) by 2034. In 2024, the estimate for fishing mortality (*F)* is at the proxy threshold reference point (*F*=*M*). Beyond 2024, if catches were to remain at the 2024 level, *F* is predicted to increase progressively to 0.22 y^{-1} (60% CIs 0.13–0.31 y^{-1}) by 2034, which is between the threshold and limit proxy reference points. Reducing the 2024 catch level by 25% is predicted to result in fishing mortality declining to the proxy target level (*F*=0.12 y^{-1}, 60% CIs 0.09–0.16 y^{-1}). With a 50% catch reduction, *F* is predicted to decrease to well below the proxy target level (*F*=0.07 y^{-1}, 60% CIs 0.05–0.08 y^{-1}) (Figure 3.31).

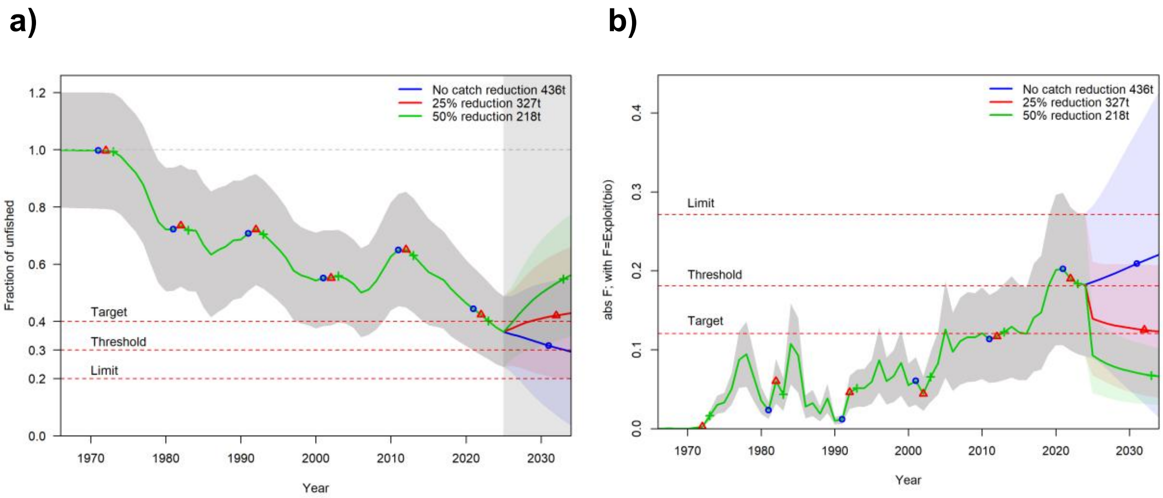


Figure 3.31: a) Relative biomass, and b) fishing mortality trends (with 95% confidence intervals) for goldband snapper, included predicted values extending to 2035 (end of the model forecast period) for different future catch scenarios. The constant catch projections include the following assumptions: i) constant future catch in maintained at the observed 2024 catch level, the catch is 25% less than the 2024 catch level, and the catch is 50% less than the 2024 catch level.

Two-area model key results

Biomass, fishing mortality and recruitment

The biomass trajectory estimated by the two-area model for goldband snapper is slightly more positive than for the single-area model, indicating a slightly greater stock size (Figure 3.32a and Figure 3.30a) and marginally higher relative biomass in 2024 (Figure 3.32b and Figure 3.30b). The model estimates that the goldband snapper biomass has always been far greater in the north than the south (Figure 3.32c). The model results indicate that the B_{rel} trends for this species for the two areas diverged greatly around the mid-1990s, with substantially lower values for the south than the north area (Figure 3.32d). In the north, B_{rel} is currently estimated to be around the target level. In the south, B_{rel} declined to the limit in 2021, following several years of low recruitment (Figure 3.32e) combined with substantial catch (for that area) (Figure 3.32f). With increasing recruitment and relatively low catch, B_{rel} in the south is now estimated to be increasing, but still below the threshold. At current catch levels, B_{rel} is projected to remain around the target level in both areas.

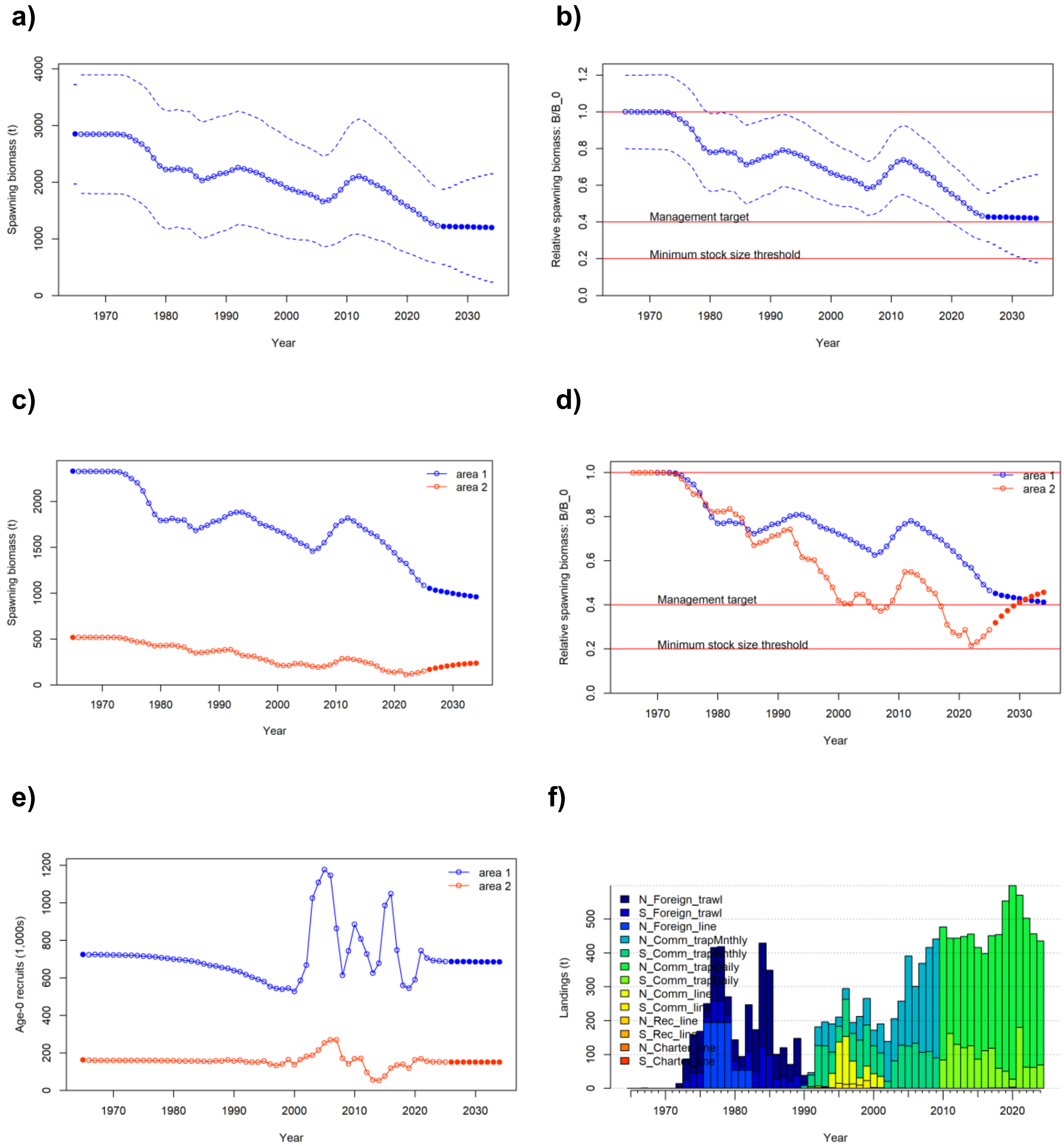


Figure 3.32: Trends associated with the two-area model for goldband snapper in: a) combined areas estimated absolute biomass, b) combined areas estimated relative spawning biomass, c) separate area absolute biomass, d) separate area relative biomass, e) separate area recruitment, and f) observed catches by area-specific fleets. 95% confidence intervals are shown for a) and b). North = area 1; South = area 2.

3.2.7 Risk-based weight of evidence assessment

Category	Line of evidence
Biology and vulnerability	Goldband snapper has a relatively long lifespan (~28 years) and reaches maturity at ~4.5 years of age. There is no minimum legal length for goldband snapper and discarding of fish is considered negligible. While goldband snapper are fully retained by the commercial fishery when they reach ~5 years of age, they first become vulnerable to being captured by fishers prior to reaching maturity, which makes them more vulnerable to fishing pressure.
Catch	Goldband snapper have been captured almost exclusively by commercial fleets since the early 1970s with foreign fleets fishing the Kimberley until 1990, and domestic catches increasing rapidly with the introduction of trap fishing in the Kimberley in 1988. Effort management measures were introduced in 1998, which by 2002 had resulted in line fishing being replaced by trap fishing. Catches of goldband snapper have been increasing periodically, with increasing peaks in 1996, 2005, 2010, and 2020 (a historical high of 599 t). The high catches in recent years may be resulting in high current fishing pressure. Catches in 2021–2024 were, however, lower than the 2020 peak.
Spatial catch distribution	Goldband snapper have a depth range of ~60 to 200 m, with their highest relative abundance in depths of 90 to 140 m (within Zone B). Goldband snapper were not initially recorded in domestic commercial fishery catches until the introduction of trap fishing in 1988. As the NDSMF expanded between 1988 and 1993, catches were recorded across the entire Kimberley region. The consistent spatial distribution of catches in recent decades throughout the full stock distribution indicates that all of the stock area is fished. There is no evidence of spatial contraction of the stock, which might otherwise suggest unacceptable stock depletion.
Level 1 Assessment: The lines of evidence based on catch indicate it is possible that goldband snapper is currently fully exploited or experiencing overfishing, associated with high catches in recent years. There is no evidence of marked spatial stock contraction. This suggests that the stock is unlikely to be heavily depleted.	
Catch per unit effort (CPUE)	Annual standardised catch rate (SCR) indices for goldband snapper are calculated for the commercial trap fishery through monthly logbooks (1998–2009), daily logbooks (2010–2024), and fisheries independent surveys (FIS; 2006, 2008, 2012, 2016, 2021). All CPUE trends are adjusted assuming that fishing efficiency has increased by 2% each year. The adjusted monthly SCR was relatively stable but is highly variable. The adjusted daily logbook SCR gradually declined over the 15-

	year period. Standardised FIS survey catch rates increased steadily from 2006 to 2016, then declined from 2016 to 2021. The level of decline over this 5-year period appears biologically unrealistic raising the possibility that the FIS CPUE time series may not constitute a reliable abundance indice.
Level 2 Assessment: The declining trends in daily logbook SCR and FIS SCR indicate that there has been a decline in stock biomass over the past 15 years.	
Length composition	The mean size of goldband snapper caught in periodic FIS surveys between 2006 and 2021 has declined over time. There is no current evidence as to whether this is a direct impact of fishing or associated with changes in growth.
Age composition	The maximum age for a goldband snapper is ~28 yrs of age, but few animals have been recorded above 20 yrs of age. As the numbers of fish in the representative samples peak at about 5 yrs of age, individuals recruit into the fishery, and thus become exposed to fishing pressure, relatively early in life. The proportion of older fish (i.e., ≥ 10 years) recorded in these age compositions has generally increased across the survey years from ~8% in 2006 to 18% in 2021. There is some uncertainty regarding the representativeness of FIS sampling in the early years.
Catch curve	Catch curve results indicate that the goldband snapper stock is moderately exploited, with estimates of fishing mortality derived from different catch curve methods breaching the target or threshold reference levels. The estimates of *F* estimated from the 2021 age sample are higher than from 2016 data, which may reflect increasing fishing pressure in recent years. Reliability of the *F* estimates is potentially impacted by sampling effects and equilibrium assumptions of the analyses.
Equilibrium biomass analysis	The Level 3 equilibrium analysis results for estimating relative female biomass (B_{rel}), incorporating catch curve estimates of mortality and a range of biological information for the stock, indicate that the goldband snapper stock is fully exploited, with all estimates for B_{rel} likely at or breaching the target reference level.
Level 3 Assessment: The age structures and the 2021 estimates of *F* and B_{rel} all indicate that the stock is fully exploited. Note that the Level 3 model-based analyses make several relatively strong assumptions (particularly constant recruitment and mortality), which increases the uncertainty of the assessment results.	
Integrated Model	In 2024, the point estimate for B_{rel} from the single-area, integrated assessment model for goldband snapper is just below the target (0.4). The point estimate for B_{rel} from a preliminary two-area, integrated assessment model, for areas combined, being just above the target. B_{rel} in 2024 is estimated to be substantially lower in the southern area (~0.3) than the

	northern area (above target), reflecting different catch histories and carrying capacities (amounts of suitable habitat for goldband snapper) for the two areas. Results suggest recent overfishing in the southern area (up to ~2021), but not in the northern area. The single-area and two-area models produce estimates of *F* that, for recent years, are approaching M, suggesting that the overall stock is close to being fully exploited. Single area model projection analyses indicate that if future catches were to remain at the 2024 catch level, B_{rel} would continue to decline. Assuming the same 2024 catch for each area, B_{rel} in the southern area is predicted to increase to around the target, and in the northern area, remain around the target level.
Level 5 Assessment: The single-area and two-area integrated assessment models indicate the Kimberley stock is close to full exploitation, and that overall, overfishing is not occurring. Recent fishing mortality has, however, increased to around the natural mortality level and there is evidence of recent overfishing in the southern area. Differing signals between the commercial and FIS CPUE data creates some tension in the integrated models, which increases the uncertainty of results.	
Environmental impacts	Goldband snapper has been assessed as having **Low** sensitivity to the effects of climate change based on its abundance, distribution, and phenological characteristics in the NCDSR - Kimberley stock. However, the impacts of climate change on goldband snapper and its environment are uncertain.
Final Risk C1 (Minor depletion): There is a POSSIBLE (20-50%) chance that the stock is above the target. This is consistent with sustained high catches in recent years, declining catch rates, truncated age structures, high *F*, and low B_{rel} estimates. C2 (Moderate depletion): There is a LIKELY (>50%) chance that the stock is between the threshold and target. As above for C1. C3 (High depletion): There is a REMOTE (<5%) chance that the stock is between the threshold and limit. The lower 95% CL of B_{rel} from the integrated model is above the threshold. C4 (Major depletion): There is a REMOTE (<5%) chance that the stock is below the limit. As above for C3, and the lower 95% CL of B_{rel} is above the threshold. There is also no evidence of marked spatial stock contraction or a decline in mean age over time. Based on the risk matrix, the overall risk to the goldband snapper stock in the Kimberley region is assessed as **Medium (C2 × L4).** On the basis of this evidence, the stock is classified as **Sustainable-Adequate**.	

	Likelihood

Consequence (Stock level)	1 Remote (<5%)	2 Unlikely (5-<20%)	3 Possible (20-50%)	4 Likely (>50%)
1 Minor (above Target)			X	
2 Moderate (between Target and Threshold)				Medium
3 High (between Threshold and Limit)	X			
4 Major (below Limit)	X			

3.2.8 Assessment Advice

The 2024 integrated model assessment of the goldband snapper stock in the Kimberley indicates that fishing mortality has increased above the target level (2/3*M*) and the biomass has reduced to just below the target level of 0.4. Model projections based on maintaining the 2024 level of catch indicate that the stock would likely decline within the next 5 years.

4 Ecological Assessment

An Ecological Risk Assessment (ERA) for the North Coast Scalefish Resource was undertaken in 2025 (Smith et al. 2025). The current risk to ecological components other than the target stocks of this resource are reviewed annually as part of the Department's annual Status Reports of the Fisheries and Aquatic Resources of Western Australia (State of the Fisheries, e.g., Newman et al. 2024).

4.1 Other Retained Species

Following the indicator species approach, the risk to other retained species is assessed as **High** (based on the highest risk, red emperor).

4.2 Bycatch Species

There is a limited quantity of non-retained bycatch in these fisheries. The most common bycatch species is the starry triggerfish (*Abalistes stellatus*), but the numbers taken are considered to pose a **Low** risk to the sustainability of this species.

4.3 ETP Species

Mandatory reporting of listed species interactions by commercial NDSMF and charter fishers suggest these interactions are relatively rare. In 2024, 115 sea snakes were reported by the NDSMF, and all are likely to be the olive sea snake. All trap-caught sea snakes are released alive and appear uninjured, suggesting high post-release survival. Potato cods rarely enter traps because most individuals encountered are large in size and girth, which limits their capacity to pass through the entrance funnel into the traps, 4 Potato cods were captured and released. The level of interactions with these listed species is therefore considered a **Low** risk.

4.4 Habitats

As a result of the gear design, these fisheries have little impact on the habitat overall, although there may be some rare interactions with coral habitats, which are not common in areas where these fisheries operate. Trap fishing is the main fishing method used in the NDSMF for demersal species, which has little physical impact on the benthic environment and hence is a **Low** risk to benthic habitats.

4.5 Ecosystem

Hall and Wise (2011) demonstrated that there has been no reduction in either mean trophic level or mean maximum length in the finfish catches recorded within the Kimberley (i.e., no fishing down of the food web) over the past 30 years. Removals are spread over a relatively wide area in each region. The commercial trap and line fishers move around to maintain their catch rate at an economic level, and do not visit the same fishing grounds on consecutive fishing trips. This rotation of fishing activity seeks to avoid any localised depletion of a fishing area. The need to maintain relatively high levels of biomass for the species caught in this fishery to meet stock recruitment requirements results in a **Low** risk to the overall ecosystem from the fishery.

4.6 Assessment Advice

In line with the harvest strategy (based on the High risk to retained species), management should continue to focus on meeting objectives relating to the sustainability of target stocks.

References

Braccini, M. Denham, A., O'Neill, M.F., and Lai, E. 2021. Spatial and temporal patterns in catch rates from multispecies shark fisheries in Western Australia. *Ocean & Coastal Management.* 213: 105883. https://doi.org/10.1016/j.ocecoaman.2021.105883.

Chandrapavan A and Jackson G. 2024. WA Ocean climate summary 2023. In: Status Reports of the Fisheries and Aquatic Resources of Western Australia 2023/2024: The State of the Fisheries eds. Newman, S.J., Santoro, K.G. and Gaugan, D.J. Department of Primary Industries and Regional Development. Western Australia. pp. 24–29.

Chapman, D.G. and Robson, D.S. 1960. The analysis of a catch curve. *Biometrics* 16: 354–368.

DPIRD. 2017. North Coast Demersal Scalefish Resource Harvest Strategy 2017–2021. Version 1.0 Fisheries Management Paper No. 285. Department of Primary Industries and Regional Development, Government of Western Australia, Perth, Australia. 35p.

Dureuil, M. and Froese, R., 2021. A natural constant predicts survival to maximum age. *Communications Biology*, *4*(1), p.641.

Dureuil, M., Aeberhard, W.H., Burnett, K.A., Hueter, R.E., Tyminski, J.P., and Worm, B. 2021. Unified natural mortality estimation for teleosts and elasmobranchs. *Marine Ecology Progress Series*. 667. 113-129.

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

Hall, N.G. and Wise, B.S. 2011. Development of an ecosystem approach to the monitoring and management of Western Australian fisheries. FRDC Report – Project 2005/063. Fisheries Research Report, No. 215. Department of Fisheries, Western Australia. 112p.

Hamel, O.S. and Cope, J.M. 2022. Development and considerations for application of longevity-based prior for natural mortality rate. *Fisheries Research* 256: 106477. https://doi.org/10.1016/j.fishres.2022.106477.

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

Hewitt, D.A. and Hoenig, J.M. 2005. Comparison of two approaches for estimating natural mortality based on longevity. *Fishery Bulletin*. 103:2, 433.

Hoenig, J.M. 1983. Empirical Use of Longevity Data to Estimate Mortality Rates. *Fishery Bulletin*: vol. 82:1.

Lenth, R. 2024. Emmeans: Estimated Marginal Means, aka Least-Squares Means. R Package versin 1.10.0, https://CRAN.R-project.org/package=emmeans.

Methot, R.D. and Wetzel, C.R. 2013. Stock Synthesis: A biological and statistical framework for fish stock assessment and fishery management. *Fisheries Research* 142: 86–99. https://doi.org/10.1016/j.fishres.2012.10.012.

Moore A, Schirmer J, Magnusson A, Keller K, Hinten G, Galeano D, Woodhams J, Wright D, Maloney L, Dix A. 2023. National Social and Economic Survey of Recreational Fishers 2018-2021, FRDC Project 2018-161. 274p.

Newman, S.J., Moore, J., Gaughan, D.J. (eds.). 2024. Status Reports of the Fisheries and Aquatic Resources of Western Australia 2023/24: The State of the Fisheries. DPIRD, WA.

Nowara, G.B. and Newman, S.J. 1996. The Kimberley Demersal Scalefish Fishery: Extent and Nature of the Resource and the Ability of a Trap Fishery to Exploit It. Part 1: A history of fishing activities in the region. FRDC final report March 1996. Project 94/026. 104 p.

Palomares, M.L.D. and Pauly, D. 2019. On the creeping increase of vessels' fishing power. *Ecol. Soc*., 24 (2019), p. 31.

Ryan, K.L., Lai, E.K.M., Smallwood, C.B. 2022. Boat-based recreational fishing in Western Australia 2020/21. Fisheries Research Report No. 327 Department of Primary Industries and Regional Development, Western Australia. 221pp.

R Core Team. 2024. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.r-project.org

Shertzer, K.S., Williams, E.H. and Sagarese, S.R. 2022. Modeling Discards in Stock Assessments: Red Grouper *Epinephelus morio* in the Gulf of Mexico. *Fishes* 7:7. https://doi.org/10.3390/fishes7010007

Smith KA, Crisafulli B, Mitsopoulos G, Trinnie F, Grosse T, Thompson T and Newman SJ. 2025. Ecological Risk Assessment for the North Coast Demersal Scalefish Resource. Fisheries Research Report *In press*. Department of Primary Industries and Regional Development, Western Australia.

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

Stephens, A., and MacCall. 2004. A multispecies approach to subsetting logbook data for purposes of estimating CPUE. Fisheries Research 70: 299–310.

Tour Operators Fishing Working Group. 1998, *Final report: Future management of the aquatic charter industry in Western Australia*. Tour Operators Fishing Working Group., Perth. Article No. 116. https://library.dpird.wa.gov.au/fr_fmp/111

Wakefield, C.W., Denham, A., Trinnie, F., Hesp, S.A., Boddington, D., and Newman, S.J. 2024. Assessment of the status of the Pilbara Demersal Scalefish Resource. Fisheries Research Report No. 338. Department of Primary Industries and Regional Development, Western Australia. 103 p.

Wang, S-P., Maunder, M.N., Nishida, T. and Chen, Y-R. 2015. Influence of model misspecification, temporal changes, and data weighting in stock assessment models: Application to swordfish (Xiphias gladius) in the Indian Ocean. Fisheries Research, 166: 119-128, https://doi.org/10.1016/j.fishres.2014.08.004.

Wood, S. 2025. Mgcv: Mixed GAM Computation Vehicle with Automatic Smoothness Estimation. R Package version 1.9.3, https://CRAN.R-project.org/package=mgcv.

Appendix 1: Assessment Description

Level 1 Assessment

Trends in catch over time provide important inputs to the assessment of each key demersal species in the Kimberley and can be important for understanding changes in fishery dynamics and recruitment of key stocks. Analyses of commercial and charter catch information also consider the spatial extent of catches (by reporting blocks) and how these change over time.

Demersal scalefish catches by commercial fishers are reported in weight (kg), while recreational and charter catches are reported in numbers. To monitor the overall demersal scalefish catch in the Kimberley, annual retained catches of key species, or groups of species, by charter and recreational fishers are converted to weight using available length and weight information. Length-weight relationships for the key species (e.g., Smallwood et al. 2018) are applied to calculate average weights from the lengths of retained fish derived from charter logbooks and recreational boat-ramp surveys. Annual catches of each key species are then calculated from the number of retained fish in each year and the estimated average weights of those fish. Where the annual average weight is based on less than 100 fish, the long-term average weight is applied using all available data for the species. As long-term average weights are updated when new data become available, annual charter and recreational catches can vary slightly between reporting years.

As required for assessments of key demersal species in the Kimberley, available data on charter catches since 2002, and periodic survey estimates of boat-based recreational catches since the early-2010s have been used to derive time series of retained catches going back to 1966. Linear 'ramping' has been used to extend the charter and recreational catches back to the start of the time series. To reconstruct charter and recreational catches for each demersal species, the following process has been applied:

1. Charter catch was 'ramped' downwards, from 2001, to zero in 1975 (red emperor), as little to no charter catch had occurred prior to 1975 (TOFWG, 1998), and 1995 (goldband snapper) as deepwater charter fishing was unlikely to exist.
2. The recreational catch was ramped downwards, from 2012 to 1966, with the catch in 1975 being 50% of the 2012–2019 mean catch, based on the assumption that recreational catches are proportional to the WA human population, which has doubled since 1975, based on estimated residential population in WA from the Australian Bureau of Statistics.
3. Recreational catches between successive recreational surveys were calculated as the mean of the two surveys, with catches in years since the last survey assumed to have remained the same.

For red emperor, the foreign fleet was divided into North and South based ona 70% and 30% split, respectfully, based on catch reported by 60 x 60 nm blocks in Nowara and Newman (1996). For goldband snapper, the foreign fleet is divided into North and South based on 71.9% and 28.1% split, respectfully, based on catch reported by 60 x 60 nm blocks in Nowara and Newman (1996). With no available evidence of spatial distribution of catches, it is assumed the recreational catch is split 50:50 in the North and South regions for both red emperor and goldband snapper.

Foreign fleets only recorded jobfish (genus *Pristipomoides*) on their logsheets and not specifically report goldband snapper. The domestic commercial fleets also recorded either jobfish (or king snapper, another common name for the jobfish group) sporadically in the early years of the fishery. There is also uncertainty as to whether the species caught were recorded correctly, with higher proportions of rosy snapper caught in the 1990s, with little to no sharptooth snapper, then neither species being recorded in the early 2000s, and then little to no rosy snapper but higher proportions of sharptooth snapper in the late 2000s onwards (Figure A1.1). This uncertainty in species identity has required that the total catch to be adjusted to represent a more justifiable goldband snapper catch time series. Based on analyses of species compositions from fisheries-independent sampling (FIS) surveys, goldband snapper constituted approximately 91% of the total jobfish catch (Table A1.1). While catches of rosy snappers are small in the FIS surveys, the proportions were adjusted to 1% to reflect the sampling bias of the FIS surveys, which target demersal species assemblages along the continental shelf. This proportion has been applied to the entire time series.

Table A1.1. Catch proportions of jobfishes (*Pristipomoides sp.*) from fisheries-independent sampling (FIS) surveys in the Kimberley pooled across years 2006–2021. FIS surveys potentially underrepresent the true rosy snapper catch proportions, which have been adjusted to a more representative catch proportion.

Species	Species name	Proportion	
		Number	Weight (adjusted value)
Goldband snapper	*Pristipomoides multidens*	89.6%	91.2% (**91%**)
Sharptooth snapper	*Pristipomoides typus*	10.1%	8.5% (**8%**)
Rosy snapper	*Pristipomoides filamentosus*	0.3%	0.3% (**1%**)
Total		100%	100%

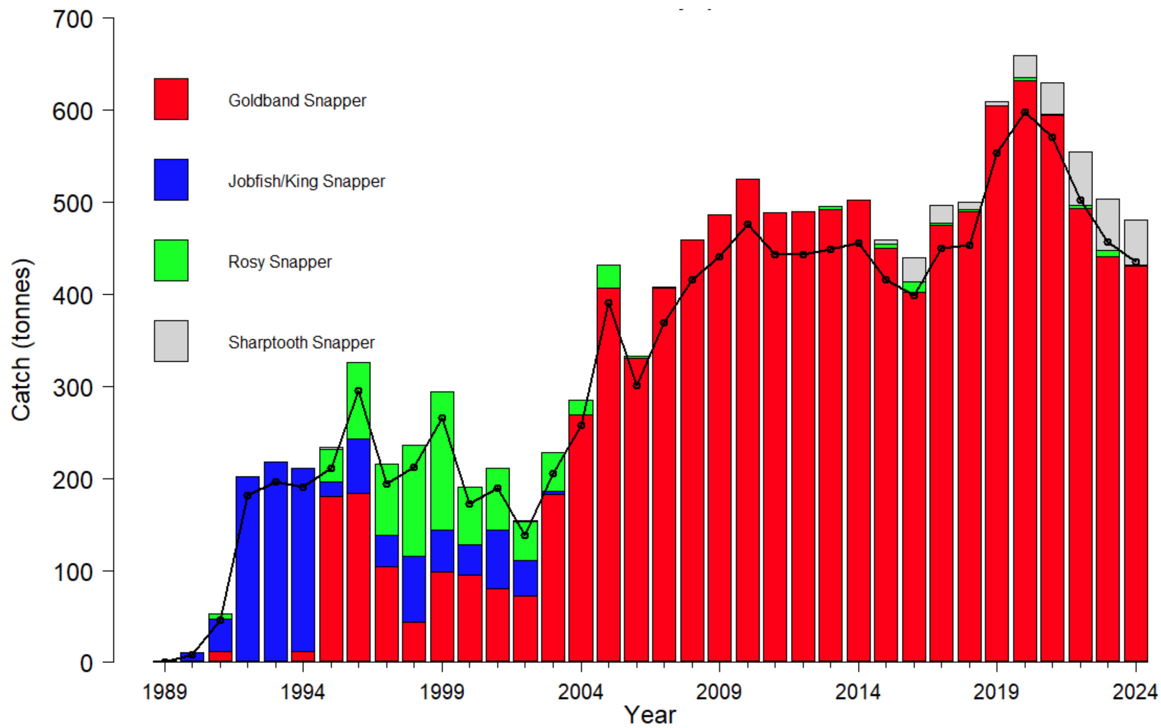


Figure A1.1. Reported domestic commercial logbook catches of the category jobfishes (*Pristipomoides sp.*) separated by species in the Kimberley. Black line represents the 91% adjustment made from all jobfish to goldband snapper only.

Level 2 Assessment

Effort variable

For the CPUE analyses, the unit of effort was defined as days fished for both daily and monthly logbook data, and as individual traps effort for FIS surveys data. For daily logbooks, when fishing by a vessel occurred in more than one 10x10 nm block on the same day, the effort (one day) was divided equally among the blocks i.e. if two blocks were recorded on a single day, each block was assigned 0.5 days of effort. For monthly logbooks, when more than one 60x60 nm block was reported in a given month by a particular vessel and catch or effort were not assigned to individual blocks, both catch and effort were divided equally among the blocks recorded, i.e., if two blocks were recorded, each was assigned 50% of the total monthly catch and effort. In a small number of monthly records, the sum of block-days exceeded the total number of fishing days reported for the month, presumably due to fishing across multiple blocks on the same day. In these cases, the additional block-days were retained and each treated as a full fishing day.

Data filtering

For the daily logbook CPUE, data were filtered to include only Zone B within Area 2, as goldband snapper are generally not found in the shallower waters of Zone A. While red emperor are found across Zones A and B, Zone A is not fished consistently enough to warrant inclusion. For monthly logbooks, spatial resolution within Area 2 was only available from 2006 onward. Given the coarser spatial scale, where multiple trips are aggregated into a single record across 60 x 60 nm blocks, all 60 x 60 nm blocks located within or adjacent to Zone B were included in the SCR analysis for both indicator species (Figure A1.2).

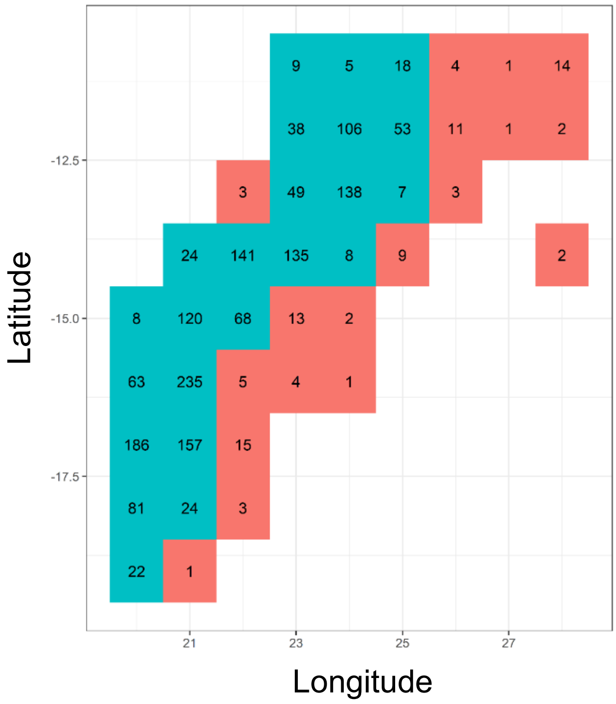


Figure A1.2. Blocks included in monthly logbook data selection for Area 2, Zone B for monthly CPUE analysis. Numbers represent total number of monthly records in each block pooled across all years. Blue indicates blocks that are retained in analysis, red blocks are omitted from analysis.

To identify daily logbook records indicative of targeting either of the two indicator species, a logistic regression approach was applied as described in Stephens and MacCall (2004). This method used the daily 10 x 10 nm block logbook entries to infer whether fishing effort was directed toward suitable habitat for the “target” species. Species compositions from each daily catch record were used to estimate the logistic regression parameters, which were then used to calculate the probability that the target species would have been encountered, based on the composition of the catch. For both species, the logistic regression was parameterised to account for differences between the North and South Kimberley regions. For red emperor, the analysis also incorporated differences between management Zones A and B. Records with probabilities exceeding a defined threshold (critical value) were retained for inclusion in the CPUE analysis (Figure A1.2, Figure A1.3) improving the reliability of abundance indices by reducing the influence of non-targeted effort. The critical probability is the value at which the difference between the observed and expected number of encounters with the target species is minimised, ensuring the most accurate classification of targeted effort for CPUE analysis.

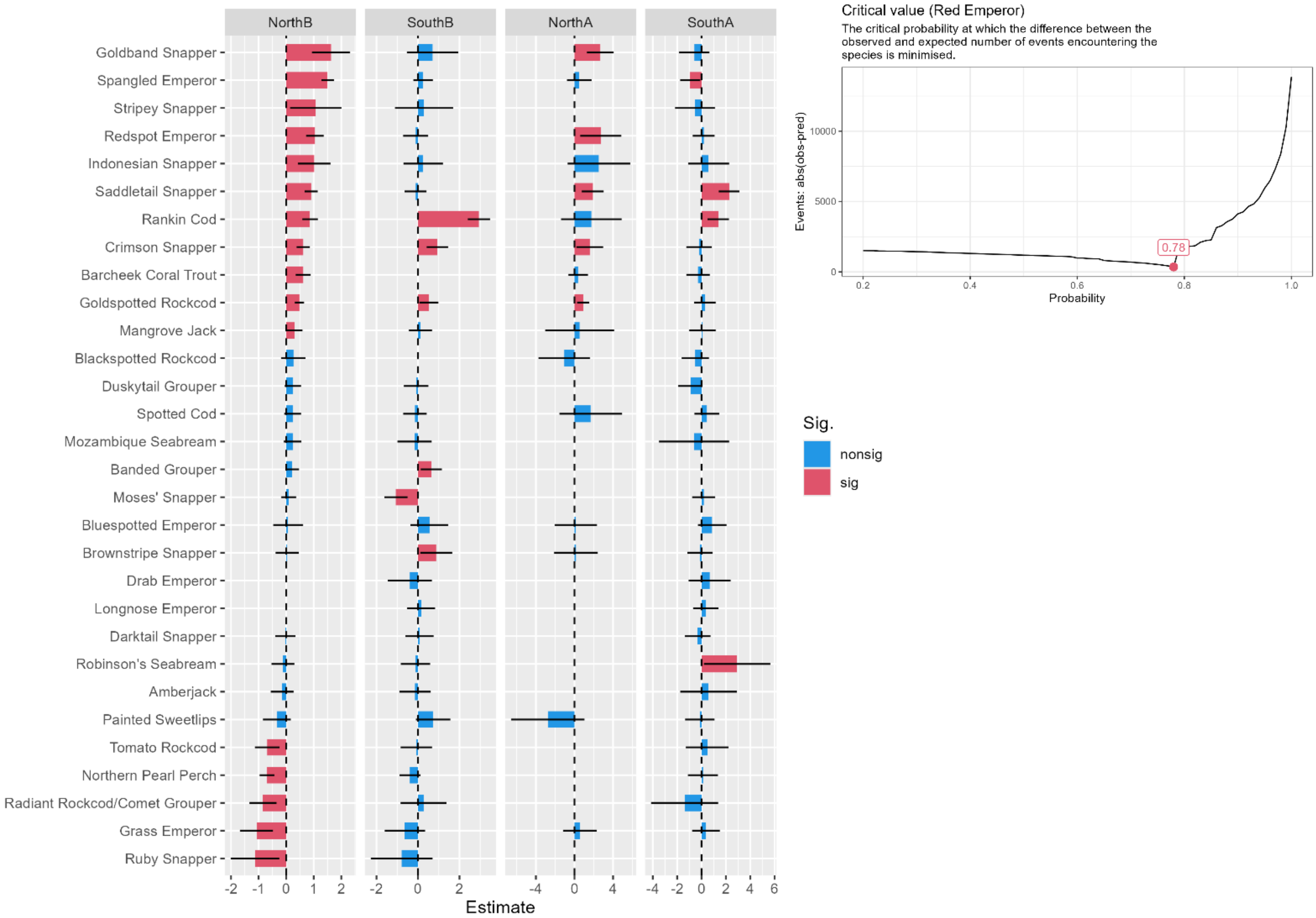


Figure A1.3. Stephens & MacCall (2004) logistic regression coefficients and critical value for red emperor in the Kimberley, split by North and South regions and fishing Zones A and B.

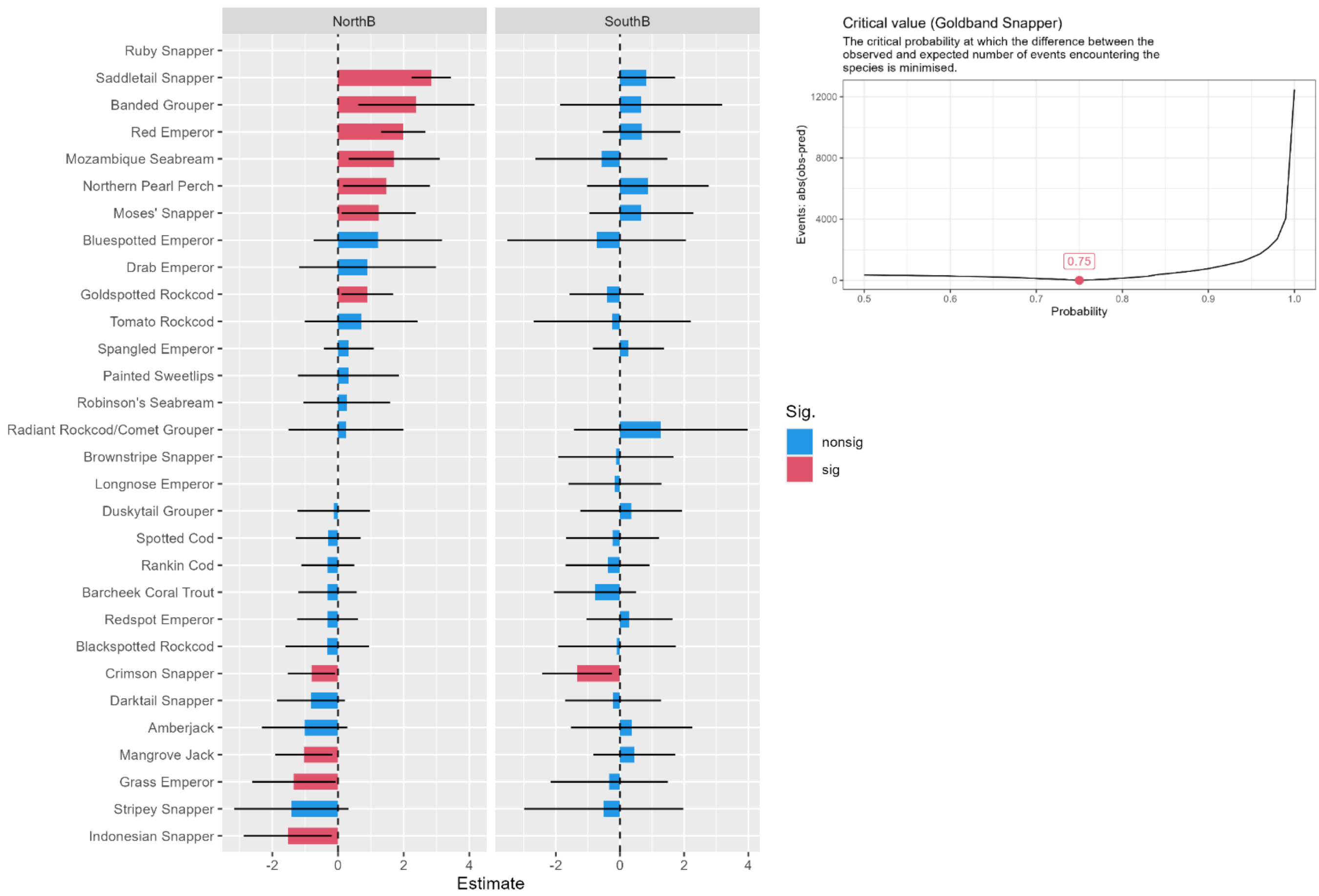


Figure A1.4. Stephens & MacCall (2004) logistic regression coefficients and critical value for goldband snapper in the Kimberley, split by North and South regions within Zone B.

Due to the inherent nature of monthly logbooks (coarse temporal and spatial resolution and the aggregation of multiple fishing events), the Stephens-MacCall method is not generally appropriate. The monthly logbook records which contained zero catch for the indicator species were deemed to be fishing in an area where the target species is not found and were removed from any further analysis.

For the FIS surveys, the survey design was to sample only zone B and represents only zone B for both indicator species. For the FIS surveys, sites were either designated fixed or random, where fixed sites are repeated each survey period and random sites are randomly chosen each survey period. Nine fixed sites have been sampled continuously each survey year (except for 2008, where some fixed sites were not repeated) and to avoid the complexity of dealing with increasing random sites across survey years, only the fixed sites are used in the SCR analysis. Note that for a given site, multiple traps were deployed and lifted within a defined area (approx. 5 nm). For CPUE analyses, each trap is considered to be an individual replicate (i.e., autocorrelation between traps was not considered, and as such, the errors for each annual mean may be underestimated).

For monthly CPUE analysis, vessel was chosen as the independent variable in the SCR to represent fisher activity over time. For daily CPUE analysis, the combination of vessel and unique fisher, or vessel-fisher, was chosen as an independent variable in the SCR as this represents the fisher’s ability on a particular vessel of operation, given that each vessel has different fishing capabilities regarding gear, technology, and potential area of operations. To avoid over-parameterisation and approximate a balanced design, vessel-fishers that did not meet the criteria of a minimum of three years in the fishery and a minimum of 20 records for each of the years of participation (daily logbooks) or a minimum of 7 years and 6 records (monthly logbooks) were discarded. For monthly logbook records using 60 x 60 spatial blocks, blocks which were minimally fished were combined into the nearest associated block.

Preliminary analysis of the monthly logbook data showed an unbalanced design for years prior to 1998, where another inherent condition of SCR analysis is the requirement of overlap between vessels, i.e., years where vessels are together in the fishery, regardless of when they enter or leave the fishery. In the monthly records, vessels occurring from pre-1998 had very little overlap with the fishers found from 1999 onwards. In pre-1998, there were also too few trap fishers in too few 60 x 60 nm blocks across the entire fishery, which would provide unreliable catch rates and all data prior to 1998 was removed from the SCR analysis. There was also effort and catch reported in 2008–2010 transitioned from monthly to daily logbooks and if included would result in systematic underrepresentation of effort in both of the logbook types temporally and spatially for both indicator species. Therefore, the years 2008 and 2009 were removed from the daily analysis and 2010 from the monthly analysis.

Catch per unit effort standardisation

To produce standardised indices of abundance, catch rate data were modelled using generalised additive models (GAMs) using the gam function (package *mgcv,* Wood, S. 2025) in R (R Development Core Team, 2024) to account for temporal, spatial, and operational variation. Separate analyses were conducted for daily and monthly logbook data. These models allowed for non-linear relationships between CPUE and the explanatory variables, which included:

- Year
- Month (fitted as a cyclic cubic spline with 12 knots)
- Vessel-fisher (fitted as random effect, daily) or vessel (monthly)
- A spatial proxy:
    - latitude-longitude interaction (smoothing term, daily)
    - 60 x 60 nm block (categorical, monthly)
    - survey site (categorical, FIS)

Model error distributions were selected based on the presence of zero CPUE values. For monthly logbooks which contained records with only non-zero CPUE, a gamma distribution model was chosen with a log link, but for daily logbook and FIS records which contained records with a zero CPUE, a Tweedie distribution with a log link was chosen. The Tweedie family accommodates both zero and positive continuous data. The function emmeans (package *emmeans,* Lenth, R (2024)) was used to calculate the CPUE from the gam model coefficients. A direction for future research is to extend the GAM analysis for the FIS CPUE to account for within-site autocorrelation.

Efficiency

To account for advances in fishing efficiency over time, the multiple time series of standardised CPUE were retrospectively adjusted by 2% per year from 2024. This adjustment accounts for increases in vessel size and operational range, the adoption of new technologies, and enhanced fishers' knowledge of stock distributions and behaviour. The 2% rate has been applied in previous assessments for these stocks and is broadly consistent with an estimated global 2.4% annual increase (Braccini et al, 2021; Palomares and Pauly, 2019). This approach also aligns with methods used in assessments of indicator species in the Pilbara managed fisheries (Wakefield et al, 2024). (Figure A1.5)

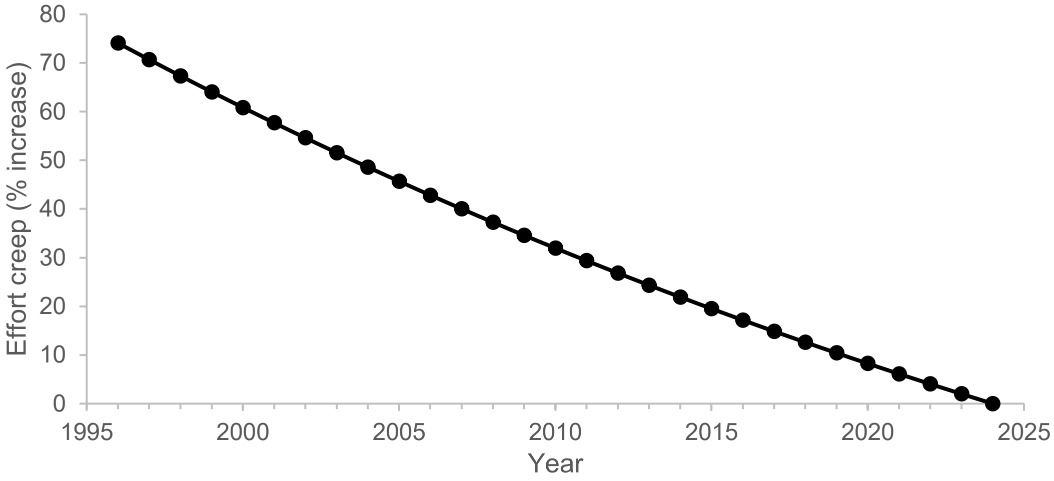


Figure A1.5. Assumed fishing efficiency applied retrospectively to the standardised CPUE for both indicator species.

Level 3 Assessment

Description of analysis (catch curve)

Mortality estimates have been derived using several catch curve methods applied to age composition data, length composition data, or both length and conditional age-at-length composition data collected in 2016 and 2021 (using the L3Assess package; Hesp, 2023). These methods make several strong assumptions, including constant recruitment and mortality (over the life spans of the fish in the samples). Note that the values of *F* calculated from this type of analysis represent the average level of fishing mortality experienced by fish in the sample over their life spans, which may differ from the very recent mortality experienced by fish just prior to sampling (that is, if mortality was changing). Values for this long-term (equilibrium) measure of fishing pressure from catch curve analysis may be interpreted as providing a measure of the overall “health” of the population age structure.

Most ‘simple’ catch curve methods applied to age composition data for fish are assumed to be at or above the age at full recruitment into the fishery. For medium (e.g., > 15 years) and long-lived species, such as red emperor and goldband snapper, it is typically assumed that the age at full recruitment is the age corresponding to one year above the age at peak frequency, hereafter referred to as the “peak age+1” recruitment assumption. This is generally used in preference to the age at peak frequency, hereafter termed the “peak age” recruitment assumption, to avoid under-estimation of mortality (i.e., if fish are not fully recruited into the fishery by the peak age). Some catch curve methods have also been developed to estimate changes in selectivity of fish with age or size, assuming that this process can be described using an asymptotic logistic curve. These latter methods are fitted to fish of all ages collected (using a particular fishing gear type). The catch curve methods applied in this assessment include: i) age-based linear catch curves (LCC), ii) the age-based method of Chapman and Robson (1960) (CR), iii) an age-based catch curve assuming logistic selectivity (CCLS), and iv) and a catch curve fitted to length and conditional age-length data (ALCC) (Hesp, 2023). LCC and CR provide an estimate for total mortality, *Z* (from which F can be derived), CCLS estimates F and selectivity parameters, and ALCC estimates F, selectivity parameters, and growth parameters. The "peak age+1" recruitment assumption was used for both LCC and CR.

Equilibrium analyses for estimating female relative biomass

The mortality estimates from the above were incorporated, together with biological information (Table A1.2; A1.3), in an age-based equilibrium analysis (ABEA) and a length-based equilibrium analysis (LBEA) to provide estimates of female relative biomass (B_{rel}). These analyses extend traditional per recruit analyses by incorporating a Beverton-Holt stock recruitment relationship (steepness, h = 0.75) to account for potential impacts of fishing on recruitment, expected due to reductions in spawning biomass from fishing. The primary performance indicator, B_{rel}, corresponds to the level of depletion of female spawning biomass relative to that expected for an unfished stock (accounting for stock-recruitment dynamics). The estimates of B_{rel} have been produced incorporating several sources of uncertainty (using parametric resampling), including for values of F, and h, with each of these parameters assumed to be normally distributed with specified values for their standard deviations, and M to be lognormally distributed (Hamel and Cope 2022).

Both species are demersal fish species and thus likely susceptible to significant mortality from depth-related injuries if caught and then released (i.e., for fish that are caught below a minimum legal length, MLL). For goldband snapper, however, the numbers of fish that are discarded is understood to be negligible. Estimates of B_{rel} for red emperor are compared for model runs prior to and after accounting for post-release mortality, where applicable (as this is the first level 3 assessment exploring this issue for this stock). Effects of post-release mortality are modelled using a 'retention function' approach (e.g., Shertzer et al., 2021), which applies separate functions for describing changes in gear selectivity, fish retention, and selectivity of fish landings with age.

Estimates of yield per recruit and equilibrium catch (i.e., yield calculated after allowing for stock-recruitment dynamics), corresponding to the mortality values estimated from catch curve analysis, are also shown. Mortality from the CCLS were used as a preference over other age-based catch curve analyses because selectivity is likely to have changed across FIS surveys due to the use of different vessels in the collections, and the direct estimation of age-based selectivity required within the ABEA.

Table A1.2. Estimates of parameters used for per recruit analysis for red emperor.

Parameter	Female	Male	Comments
Growth			von Bertalanffy (L_∞, k, t_0)
L_∞ (mm FL)	484	600	Estimated from ALCC
k (yr^{-1})	0.453	0.453	
t_0 (yrs)	0	0	
CV	0.057	0.057	
Max. age (yrs)	41		Both sexes
Max. length (mm FL)	842		Both sexes
Natural mortality, M (yr^{-1}) (stddev)	0.115 (0.31)		Based on second oldest fish (36 yr^{-1})
Length-weight (g, mm FL)			Power (a, b) W = a(FL)^b
a	1.251e-05	1.251e-05	

b	3.0918	3.0918	
Maturity			Symmetric_logistic (L_{50}, L_{95}, A_{50}, A_{95})
L_{50} (mm)	403		
L_{95} (mm)	482		
A_{50} (yrs)	4.8		
A_{95} (yrs)	7.3		
Steepness (stddev)	0.75 (0.025)		Beverton-Holt
Sex Ratio Female	0.5		

Table A1.3. Estimates of parameters used for per recruit analysis for goldband snapper.

Parameter	Both sexes	Comments
Growth		von Bertalanffy (L_∞, k, t_0)
L_∞ (mm FL)	532	Estimated from ALCC
k (yr^{-1})	0.298	
t_0 (yrs)	0	
CV	0.075	
Max. age (yrs)	28.8	
Max. length (mm FL)	703	
Natural mortality, M (yr^{-1}) (stddev)	0.181 (0.31)	Based on second oldest fish (23 yr^{-1})
Length-weight (g, mm FL)		Power (a, b) W = *a*(FL)^b
a	2.472e-05	
b	2.9498	
Maturity	Females	Symmetric_logistic (L_{50}, L_{95}, A_{50}, A_{95})
L_{50} (mm FL)	417	
L_{95} (mm FL)	528	
A_{50} (yrs)	4.6	
A_{95} (yrs)	7.3	
Steepness (stddev)	0.75 (0.025)	Beverton-Holt
Sex Ratio Female	0.5	

Level 5 Assessment

Stock Synthesis Integrated Model

For this assessment, integrated (L5) models were implemented in the software Stock Synthesis (SS) (Methot and Wetzel, 2013), developed by a team of international stock assessment experts in the US National Oceanic and Atmospheric Administration (NOAA). DPIRD has now adopted SS as the primary modelling software platform for integrated assessments, this aligns with the direction being taken by other Australian State and Commonwealth fisheries agencies. A key advantage of using SS, compared with DPIRD continuing to maintain its own 'bespoke' models, is that SS is highly flexible, allowing many more modelling options to be explored within a given timeframe. Some of these options include alternative spatial structures (e.g., single vs two-area), models incorporating additional types of data (e.g., fish lengths in addition to ages, thereby allowing for length-based selectivity, and internal estimation of growth which can be constant or time-varying). Further, as the SS modelling framework has been used by many fisheries agencies globally, the associated computer code has been tested heavily, reducing the risk of coding errors. There are also many 'add on' features, such as r4SS, an R package including a wide variety of model diagnostic tools, to allow researchers to diagnose and fix potential issues with stock assessment models developed within SS. Finally, as SS is so widely used, this enables external experts to more easily undertake assessment reviews. Stock synthesis is implemented in AD Model Builder, and run using R.

Alternative model structures for red emperor

For each species, models with two alternative area structures were developed and compared, i.e., a single-area model, and a two-area (north-south) model. The key attributes of each model type are outlined in Table A1.4.

Table A1.4. Key assumptions of the single-area and two-area integrated models for red emperor.

Attribute	Single-area model	Two-area model
Sex structure	Sex structured	Same
Fleet structure	8 fleets including 2 x foreign fleets (trawl, line), 3 x commercial fleets (trap monthly and daily, line), and recreational and charter	16 fleets – Same as 1 area but split by area (north and south)
Observed data	Catch, fishery dependent cpue (commercial), and fishery independent survey (FIS) cpue, lengths (FIS + commercial), conditional lengths at age (FIS) and 'ghost fleet' of marginal ages (FIS).	Same, but split by area (north and south) Note: commercial monthly cpue not used for north or south areas
Initial fishing mortality	Estimated for Foreign_trawl fleet with weak normally distributed prior around natural mortality (*M*) for this species. Prior mean = 0.115 and sd=0.2	Same, but split by area (north and south)
Equilibrium catch	Initial value for Foreign_trawl of 0.134 t (mean of the first 5 years of catch) with catch_se set to 0.2	Initial value for N_Foreign_trawl of 0.087 with catch_se set to 0.2. Initial value for S_Foreign_trawl of 0.047 with catch_se set to 0.2.

	(Note: setting se=666 led timeseries of relative biomass starting at 0).	
Natural mortality	M = 0.115 y^{-1} for both sexes. Sensitivity analyses: M = 0.095 y^{-1} and M = 0.135 y^{-1}.	Same (Natural mortality common to both areas)
Maturity	Specified, age-based logistic function. First mature age 2	Same (maturity common to both areas)
Growth	Growth option 1, vonBert with L1 = 3 & L2 = 10 (where sufficient ages where available). Estimating L_at_Amin, L_at_Amax, VonBert_K, CV_young and CV_old for both males and females. Note: time varying growth was not considered for this assessment as external analyses did not indicate substantive growth changes for this species.	Same (growth common to both areas)
Stock recruitment relationship	Standard Beverton-Holt	Same
R0	Estimated. Initial value of 8.5	Same
Steepness	Specified at 0.85 Sensitivity analyses: h = 0.75 and h = 0.95.	Same
sigmaR - stdev of ln of rec devs	sigmaR = 0.3 Sensitivity analyses: sigmaR = 0.2, 0.4, & 0.6 Lower than often used sigmaR = 0.6. Tropical fish species may have less variable recruitment due to more consistent environmental conditions.	Same
Bias correction	Using SS ‘ramp’ function	Same
Recruitment distribution proportion	NA	RecrDist parameter for area 1 is not estimated. RecrDist for area 2 is estimated and time varying between the model start (1966) and end year (2024).
RecDev option	Option 2 = deviations (R=F(SSB)+dev)	Same
RecDev types	No ‘early’ recdevs First year set to 1950, i.e. including an early burn in period	Same
Fishing efficiency changes	Cumulative and multiplicative, 2% fishing efficiency applied across the time series, including FIS cpue.	Same
Age data weighting	Dirichlet weighting	Same
Ageing error	Default (-1 and 0.001), i.e. essentially not considered	Same
Discarding – proportion released	Not specified (i.e. discarding levels are predicted by the model, based on difference between selectivity and retention curves). Discards only estimated for the commercial trap fleets, as 1) catches are minimal for other fishing sectors in	Same

	current fishery and 2) information is not available to inform discarding for early foreign fleets, except with knowledge that no size limit regulations were in place at the time, allowing all fish to be kept.	
Discarding – proportion that die	100%	Same
Gear selectivity	Asymptotic length-based logistic curve (constant over time), estimated within the model, using FIS undersized (discarded) fish. Gear selectivity is mirrored to all other fleets. Sensitivity analysis: with time varying selectivity. Whilst it is inappropriate to have time varying selectivity for a *bona fide* survey, the Kimberley FIS are undertaken using commercial skippers and boats, with some degree of 'searching' for fishing locations within a specified area (5 nm) for a site. The numbers and locations of sampling sites have changed over time, from 8 (in 2008) to 16 (in 2021). Recent surveys include sites from more inshore waters than in the past.	Same
Retention	Asymptotic length-based logistic curve (constant over time). Estimated within the model, using FIS sized (retained) fish. Retention is mirrored to the commercial daily trap fleet. Estimated for the Commercial monthly fleet using historical length comps.	Asymptotic length-based logistic curve (constant over time). Estimated within the model, using FIS sized (retained) fish. Retention is mirrored to all fleets as historical commercial trap data (1996-1999) is not available at this spatial scale.

Alternative model structures for goldband snapper

For each species, models with two alternative area structures were developed and compared, i.e., a one area model, and a two-area (north-south) model. The key attributes of each model type are outlined in Table A1.5.

Table A1.5. Key assumptions of the single-area and two-area integrated models for goldband snapper.

Attribute	Single-area models	Two-area models
Sex structure	Single sex Ngenders = -1 (SSB multiplied by female_frac parameter = 0.5)	Same
Fleet structure	8 fleets including 2 x foreign fleets (trawl, line), 3 x commercial fleets (trap monthly and daily, line), and recreational and charter	16 fleets – Same as 1 area but split by area (north and south)
Observed data	Catch, fishery dependent cpue (commercial), and fishery independent survey (FIS) cpue, lengths (FIS +	Same, but split by area (north and south)

	commercial), conditional lengths at age (FIS) and 'ghost fleet' of marginal ages (FIS).	Note: commercial monthly cpue not used for north or south areas
Initial fishing mortality	Estimated for Foreign_trawl fleet with weak normally distributed prior around natural mortality (*M*) for this species. Prior mean = 0.181 and sd=0.2	Same, but split by area (north and south)
Equilibrium catch	Initial value for Foreign_trawl of 0.215 t (mean of the first 5 years of catch) with catch_se set to 0.2 (Note: setting se=666 led timeseries of relative biomass starting at 0).	Initial value for N_Foreign_trawl of 0.139 with catch_se set to 0.2. Initial value for S_Foreign_trawl of 0.076 with catch_se set to 0.2.
Natural mortality	M = 0.181 y^{-1} for both sexes. Sensitivity analyses: M = 0.161 y^{-1} and M = 0.201 y^{-1}.	Same (natural mortality common to both areas)
Maturity	Specified, age-based logistic function. First mature age 2	Same (maturity common to both areas)
Growth	Growth option 1, vonBert with L1 = 3 & L2 = 10 (where sufficient ages where available). Estimating L_at_Amin, L_at_Amax, VonBert_K, CV_young and CV_old for both males and females. Note: time varying growth was not considered for this assessment as external analyses did not indicate substantive growth changes for this species.	Same (growth common to both areas)
Stock recruitment relationship	Standard Beverton-Holt	Same
R0	Estimated. Initial value of 8.5	Same
Steepness	Specified at 0.85 Sensitivity analyses: *h* = 0.75 and *h* = 0.95.	
sigmaR - stdev of ln of rec devs	sigmaR = 0.4 Sensitivity analyses: sigmaR = 0.2 & 0.6 Lower than often used sigmaR = 0.6. Tropical fish species may have less variable recruitment due to more consistent environmental conditions.	Same
Bias correction	Using SS 'ramp' function	Same
Recruitment distribution proportion	NA	RecrDist parameter for area 1 is not estimated. RecrDist for area 2 is estimated and time varying between the model start (1966) and end year (2024).
RecDev option	Option 2 = deviations (R=F(SSB)+dev)	Same
RecDev types	No 'early' recdevs First year set to 1950, i.e. including an early burn in period	Same
Fishing efficiency changes	Cumulative and multiplicative, 2% fishing efficiency applied across the time series, including FIS cpue.	Same

Age data weighting	Francis weighting. R4ss function (SStunecomps) used for suggested tunning values.	Same
Ageing error	Default (-1 and 0.001), i.e. essentially not considered	Same
Discarding – proportion released	NA – no minimum legal length for this species	Same
Discarding – proportion that die	NA – no minimum legal length for this species	Same
Gear selectivity	Asymptotic length-based logistic curve (constant over time), estimated within the model from the FIS trap data (2006-2021) and commercial trap data (1996-1999). Gear selectivity from the FIS is mirrored to all other fleets. Sensitivity analysis: with time varying selectivity. Whilst it is inappropriate to have time varying selectivity for a *bona fide* survey, the Kimberley FIS are undertaken using commercial skippers and boats, with some degree of 'searching' for fishing locations within a specified area (5 nm) for a site. The numbers and locations of sampling sites have changed over time, from 8 (in 2008) to 16 (in 2021). Recent surveys include sites from more inshore waters than in the past.	Same Gear selectivity from the FIS is mirrored to all fleets as historical commercial trap data (1996-1999) is not available at this spatial scale.
Retention	NA – no minimum legal length for this species	Same

Appendix 2: Assessment Diagnostics

Red emperor

Level 3 Assessment

Diagnostic plots generated by the L3Assess R package (Hesp 2023a).

Kimberley **North Kimberley** **South Kimberley**

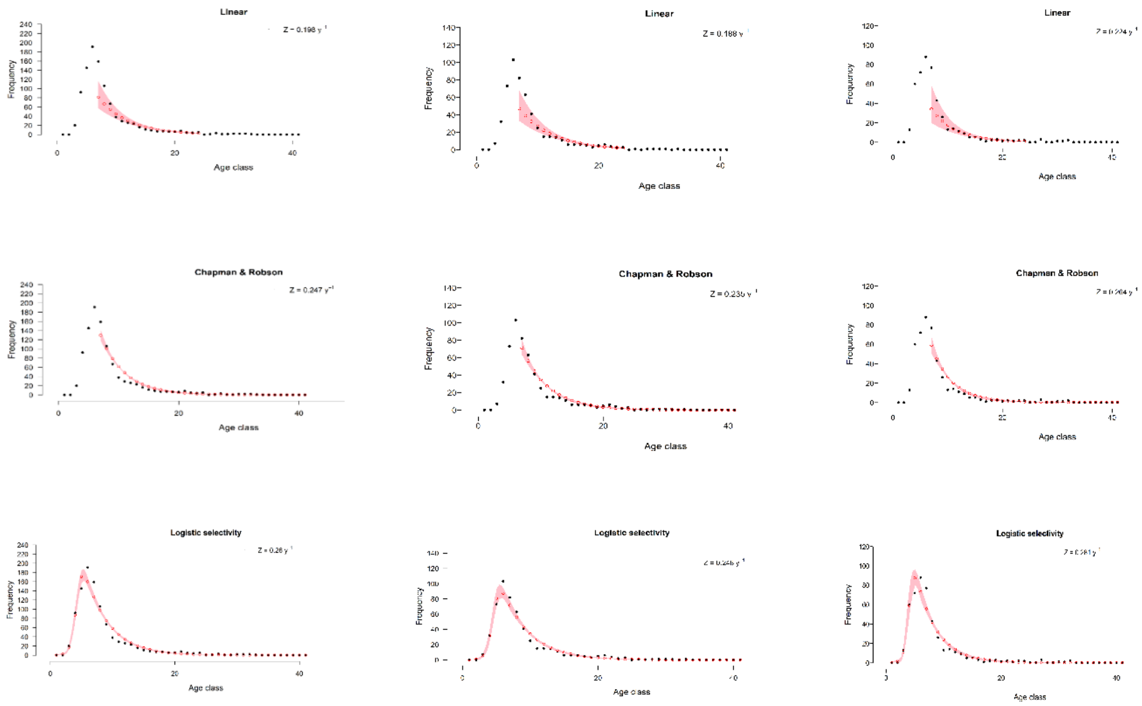


Figure A2.1. Estimates of total mortality (Z) for the red emperor stock, and by North and South Kimberley, derived using linear catch curve analysis, the method of Chapman and Robson (1960), and a catch curve assuming (asymptotic) logistic selectivity. The assumed age at full recruitment into the fishery was taken as one year above the age at peak frequency.

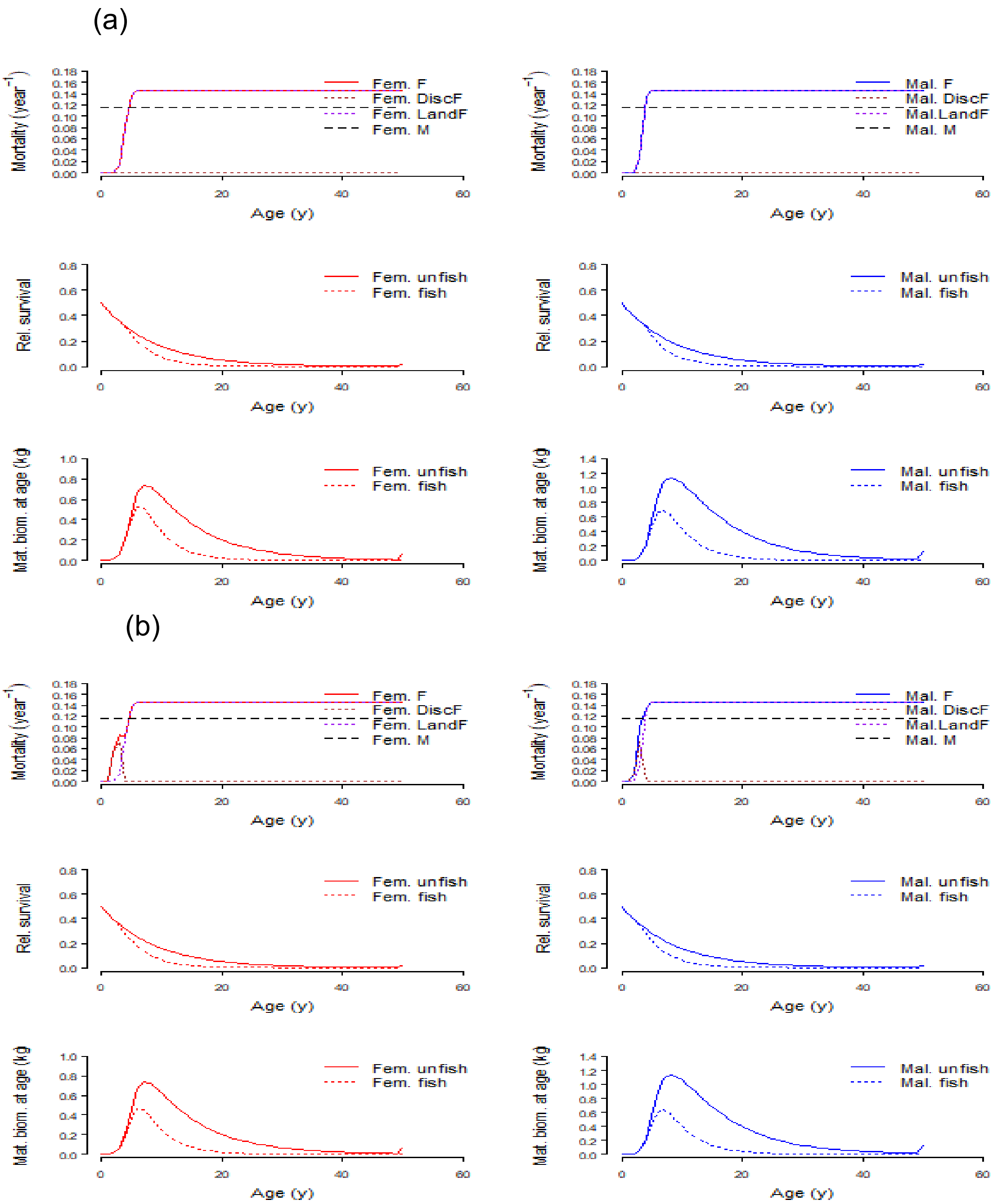


Figure A2.2. Mortality at age associated with fishing (from landings, discards and combined) vs natural mortality, expected relative survival, and biomass at age for the stock at the current level of fishing vs when unfished for the Kimberley red emperor stock in 2021. Relationships are plotted for both females (red) and males (blue). Results are plotted for the model scenario that assumes no discard mortality (a), and 100% discard mortality (b).

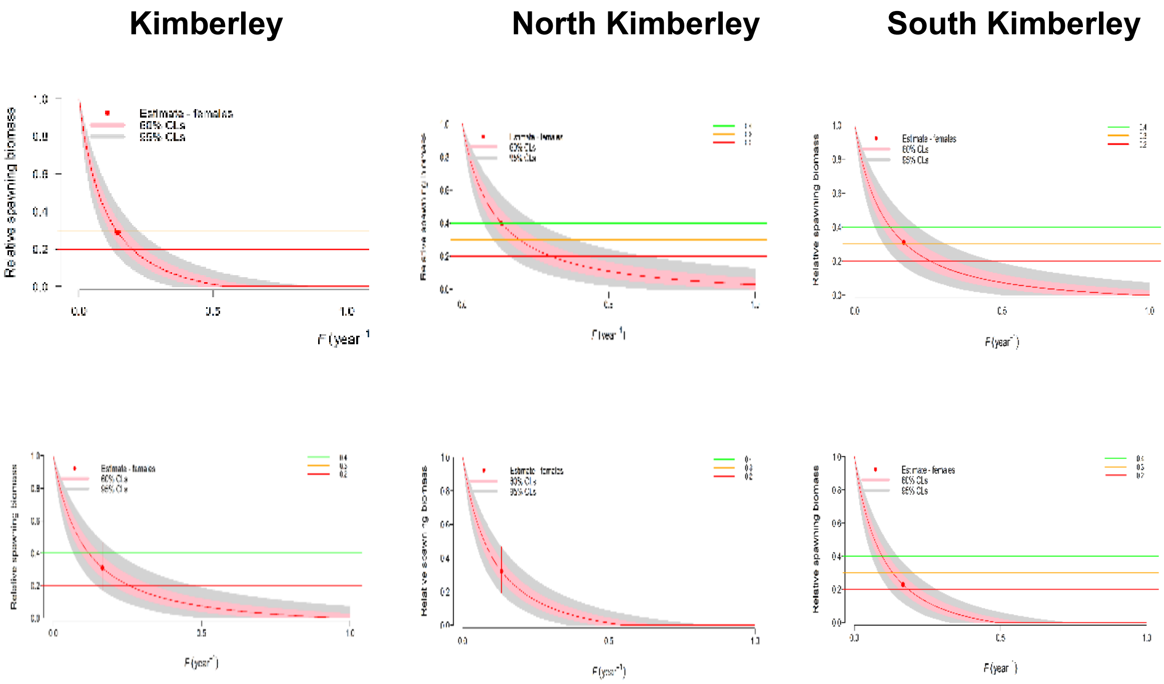


Figure A2.3. Estimated relative spawning biomass (with 60% and 95% CL) from aged-based equilibrium analysis for the Kimberley female red emperor stock. Results are plotted for the model scenario that assumes no discard mortality (a), and 100% discard mortality (b).

Level 5 Assessment

Single-area model (data, outputs and diagnostics)

Data inputs

The data inputs to the red emperor single-area model are summarised in Figure A2.4. Broadly, the model includes all known catches taken from the fishery, which date back to 1966. Early catches were taken by foreign fishing fleets (mainly trawl fishing and limited line fishing), whereas in later years, commercial catches were taken mainly from commercial trap fishing, and limited commercial, recreational and charter line fishing. Abundance indices are available from FIS (2006–2021), and commercial monthly logbooks (1996–2009) and daily logbooks (2010–2024). The model is also informed by marginal length and conditional age-at-length data available from the FIS surveys starting in 2006, and marginal length data from the commercial trap fishery from 1997–1999.

Some historical age data also exist but are not included in the model, primarily due to concerns regarding the accuracy of age estimates (derived from thicker otoliths sections in which growth zones are less discernible than in the thinner sections used today, and evidence of systematic ageing bias, with overestimates of age for earlier years). Although marginal length data are available for these years, sampled from commercial fleets, there is some lack of clarity regarding sampling protocols for this historical period. For example, although there was a minimum size limit at the time, the samples included fish below this length, possibly reflecting some targeted fish collection by researchers, amongst other sampling, for various biological analyses.

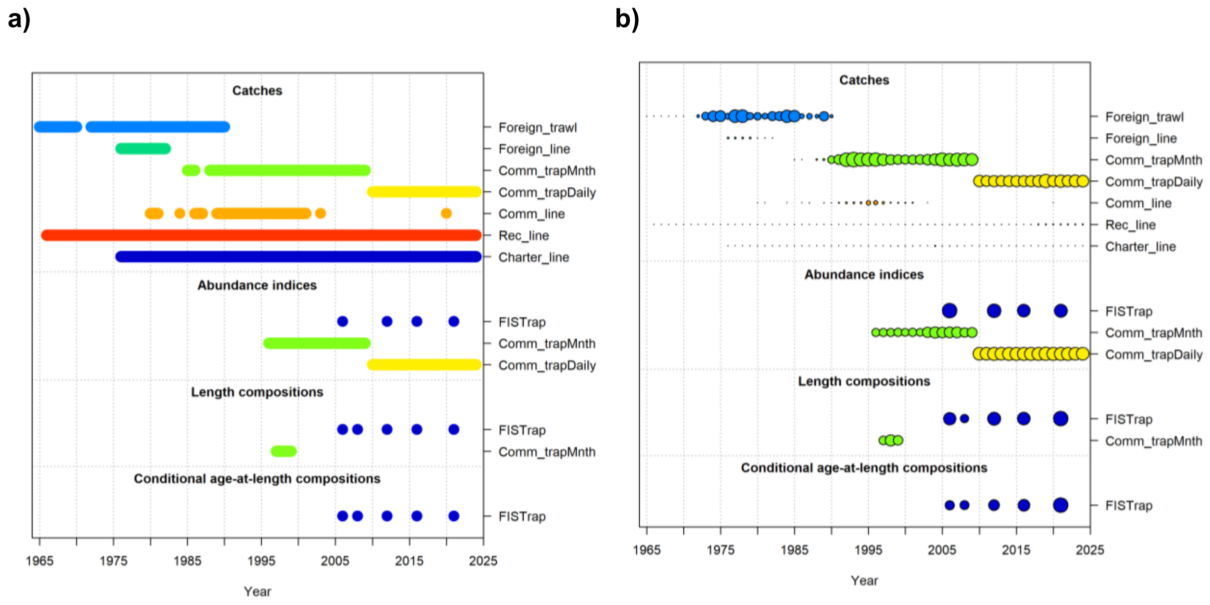


Figure A2.4. Data sources by year for each fleet for the single-area red emperor model. In figure b, circle areas for: i) catch data are proportional to catch magnitude, ii) those for abundance index data are proportional to precision, and iii) those for composition data to input sample size.

Model fits

The model for red emperor provides relatively good visual fits to the FIS data and daily commercial trap CPUE data (Figure A2.5a, c). In each case, the observed and expected CPUE indices exhibit declining trends. The trends exhibited by the observed monthly CPUE commercial trap data are somewhat inconsistent, showing relatively large changes in magnitude in some successive years with non-overlapping confidence intervals (Figure A2.5c). Not surprisingly, the model has difficulty in matching these trends (which imply large changes in population over short time periods, which is not biologically realistic). There is thus high uncertainty regarding the reliability of this monthly CPUE series as an index of population abundance. Preliminary analyses involving excluding these data when fitting the model, however, did not substantially change results.

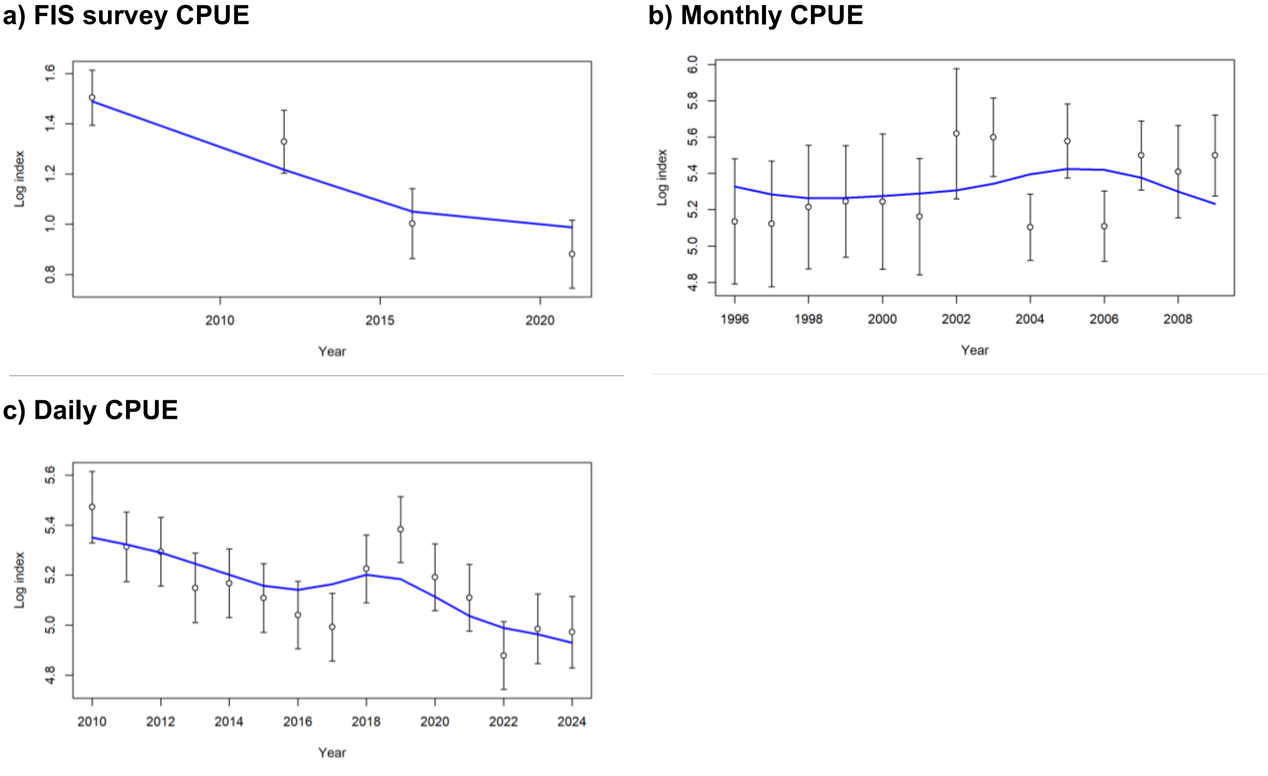


Figure A2.5. Fits of the single-area red emperor model to a) fishery independent survey CPUE, b) commercial trap monthly CPUE, and c) and commercial trap daily CPUE.

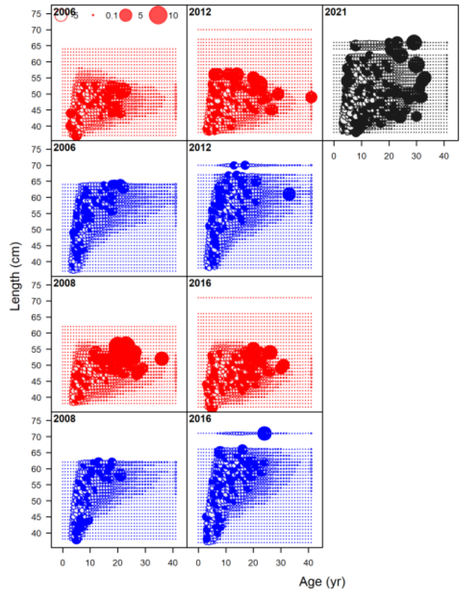
For all years of FIS sampling apart from the most recent survey (2021), the sex of each red emperor was recorded (Figure A2.6a). In each year, the residuals associated with the model fit to the FIS conditional age-at-length data are of similar magnitudes across the full ranges of ages and lengths, although perhaps a little less so for males than females. These results provide a general indication that the sex-specific von Bertalanffy growth curves (constant growth, estimated within the model) adequately describe the available conditional age-at-length data (Figure A2.6a).

The observed mean ages of fish (> MLL) range from just below 9 years to just below 10 years, across the suite of surveys, with the lowest values associated with the first (2006) and last (2021) survey years (Figure A2.6b). The expected mean age for 2021 did not match the observed mean age for that year, underestimating the observed mean by about a year. These results provide an indication that the FIS composition data for 2021 are somewhat inconsistent with those for earlier years. Although, potentially, these results could be affected by growth variation, an attempt to incorporate time-varying growth (annual variation in *k*) caused issues when fitting the integrated model (diagnostic model output suggesting issues with the model). Alternatively, the inconsistent data may relate to sampling differences between surveys.

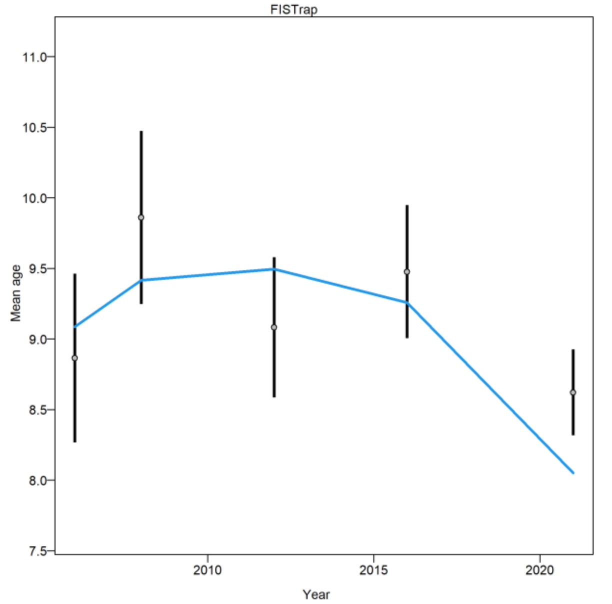
For the final survey year, sex-specific age-at-length data are not available. Note that this species is sexually dimorphic (males grow to a large size than females).

The expected marginal age distributions match well those associated with the observed marginal age data (used as a ‘ghost fleet’) (Figure A2.6c). As these observed data are not used in the model fitting process, this provides an indication the population dynamics specified in the model are internally consistent, and also that the estimated length-based selectivity patterns within this model are generally consistent with the age data.

a) Pearson residuals



b) Conditional age retained fish (D-M weighting)



c) Marginal age (ghost fleet)

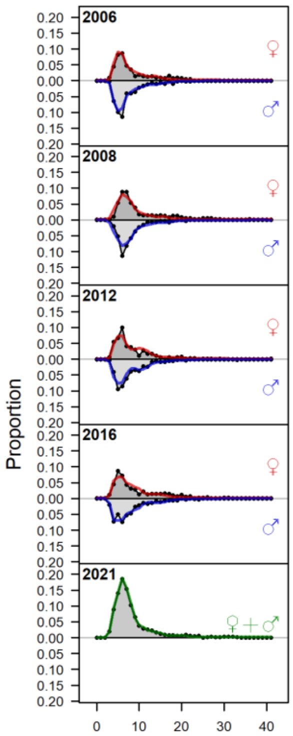


Figure A2.6. Single-area red emperor model outputs associated with conditional age-at-length data from fishery independent surveys including a) residuals, b) Pearson residuals for observed vs expected mean age, and c) expected vs observed marginal age compositions (i.e., whereby observed marginal age data are used as a ‘ghost fleet’, and thus not used in the model fitting process).

The visual fits provided by the red emperor single-area model to the overall FIS trap survey length data (for fish above and below the MLL) are good (Figure A2.7a) and reasonable for the earlier commercial trap data. Thus, the expected proportions of legal-sized fish at length, across years, match well the corresponding observed proportions at length of legal-size fish, and the same is true for sub legal-size fish (Figure A2.7a). Likewise, the model matches well the size distributions for each of these categories of length samples, when separated by year (Figure A2.7b).

An issue that has not yet been resolved is that application of the self-weighting Dirichlet multinomial function does not resolve in any marked change in weighting to the marginal length composition data. Currently, the input sample sizes are inputted into the data as the 'number of fish', and thus the weighting towards these data is high. Preliminary investigation using 'number of trips' (resulting in poor fits to the length data), and also 'number of traps deployed' (resulting in correlated parameters, with SS warnings). In addition, the Dirichlet multinomial weighting was fixed at half for the marginal length data, which resulted in similar results to the base model. The Francis weighting method could not be successfully applied (increased weight towards the marginal length data and reduced weight on age data almost to zero, affecting model fit). Therefore, aspects relating to data-weighting in the SS red emperor models is an area requiring further work.

The observed mean length of fish in 1999 is conspicuously less than for the previous 2 years, and this is overestimated by the model (Figure A2.7c). The observed mean lengths for red emperor caught in the FIS decline by about 1cm between 2016 and 2021, which is not matched well by the model.

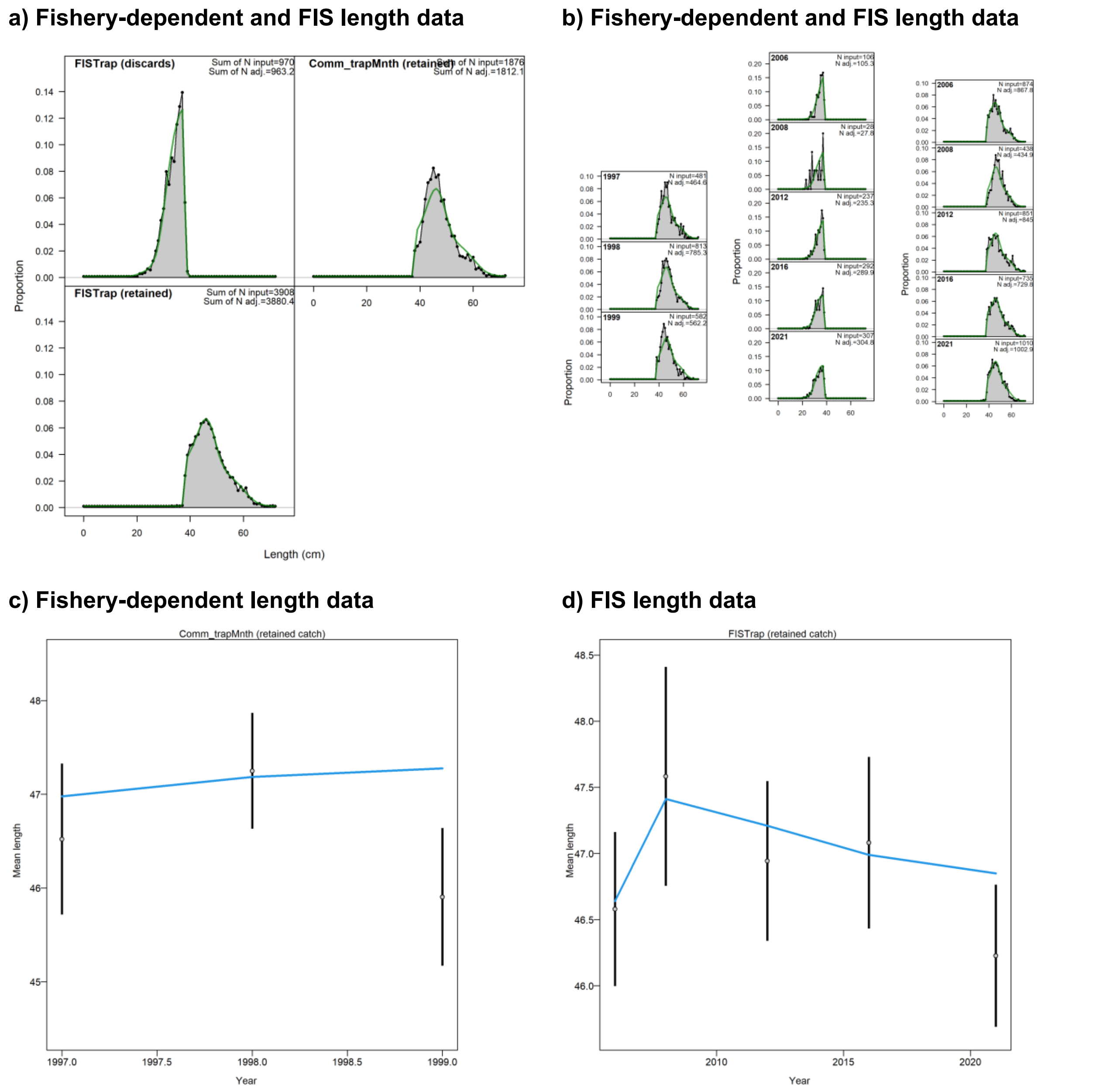


Figure A2.7. Single-area red emperor model outputs associated with marginal length data from fishery independent surveys including: a) fit to combined data for all survey years, b) fit to length data for sub-legal size fish (i.e., fish of lengths discarded by the fishery), and fit to length data for legal size fish (i.e., fish of lengths retained by the fishery), c) observed vs mean size from fishery-dependent length data and d) observed vs estimated mean size from FIS length data.

Selectivity

The single-area model red emperor estimates logistic length-based selectivity from FIS trap data for sub-legal size fish, with selectivity then being mirrored to other fleets (i.e., selectivity is assumed to be the same for all fleets). The is deemed appropriate as the vast majority of the catch taken from the fishery has been from commercial trap operators who employ the same fishing gear and fishing methods as used in the survey. Fish are estimated to be 50% selected by the trap gear at just over 30 cm, which corresponds to ~3 years of age (Figure A2.8a, b).

The length-based retention curve is very steep, reflecting the effect of the minimum size limit for this fishery (Figure A2.8c). With fish being caught in deep water, 100% mortality is assumed for all discarded fish. Over time, the estimated proportions for fish that are discarded has ranged between just below 0.05 to ~ 0.1, corresponding to total discard catch biomass of up to ~16 tonnes (Figure A2.8d, e). The estimated levels of discarding in recent years are higher relative to earlier years. Discarding is not considered for the early foreign fishing fleets, given that a minimum size limit was not in place at the time. Without further information, it is not possible to rule out that some discarding occurred during this early period.

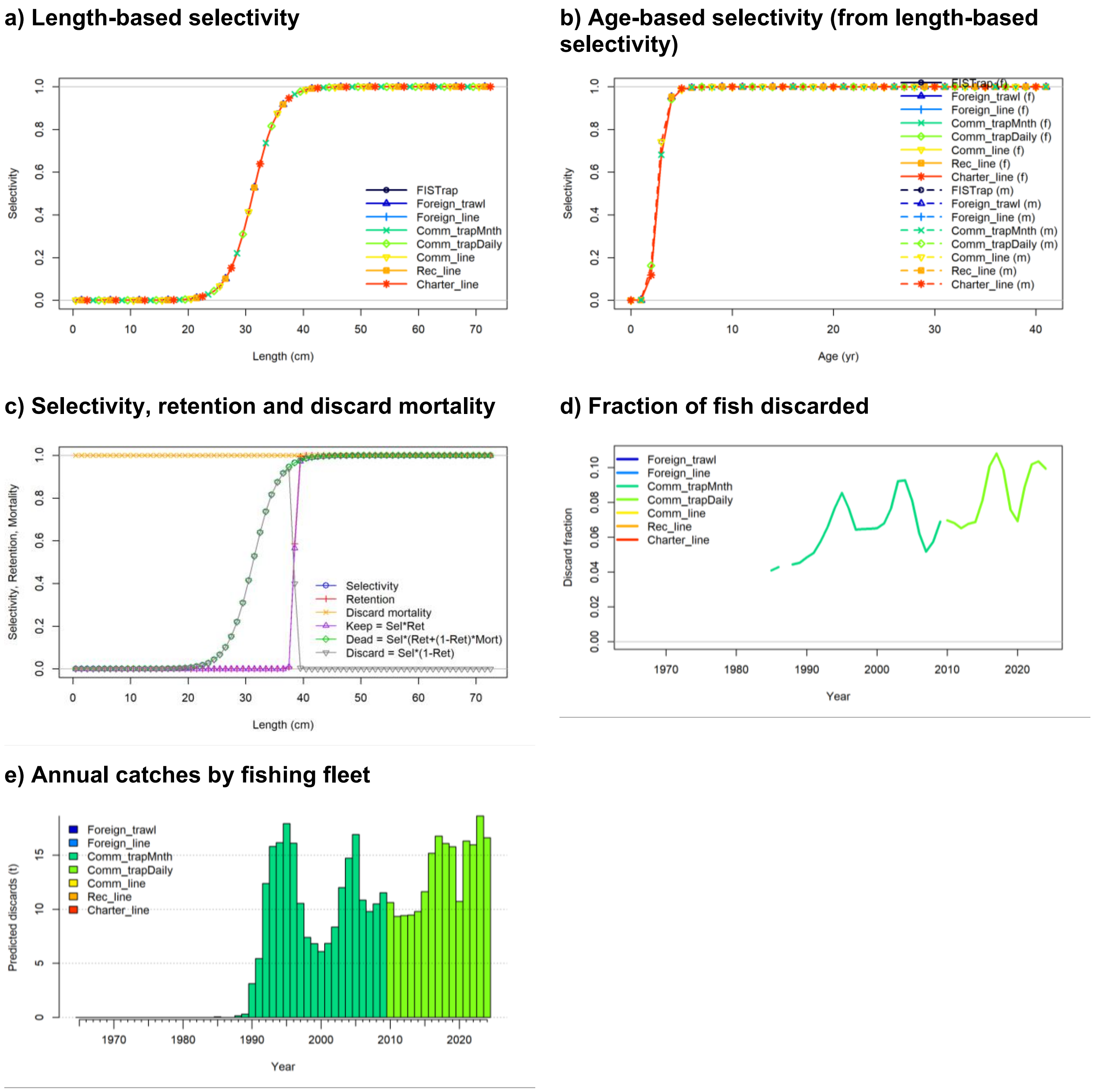


Figure A2.8. NDSMF red emperor single-area model outputs including a) estimated logistic length-based gear selectivity, b) corresponding gear selectivity at age values, c) length-based specified level of length-based discard mortality together with curves associated with selectivity, retention, and calculations for retained and discarded catches, d) fraction of fish discarded, and e) estimated annual discard proportions and discard biomass arising from fishing.

Recruitment

The estimated annual recruitment deviations for early years, when the model is only informed by annual catch data show a declining trend for the early years of the fishery, although this trend is not marked. Lowering the level of recruitment variation from SigmaR = 0.6 to 0.3 reduced this trend (see section below on model diagnostics and further discussion of this issue). In later years (from late 1990s), as expected, recruitment deviations fluctuate around zero (in log space) (Figure A2.9a). Increasing the value for steepness from 0.75 to 0.85 slightly improved the pattern further. The plot showing annual changes in recruitment deviation variance exhibits the expected pattern of increased variance for early and very late years when recruitment is poorly informed by observed data, and lower variance during the period when recruitment is informed by the data available for these years (Figure A2.9b). The 'bias ramp' plot demonstrates that the model has been appropriately tuned, with respect to the variances associated with the estimated annual recruitment deviations (Figure A2.9c). Broadly, the diagnostic plots associated with estimated recruitment deviations indicate minor structural issues with the single-area model for red emperor that have not fully been able to be resolved.

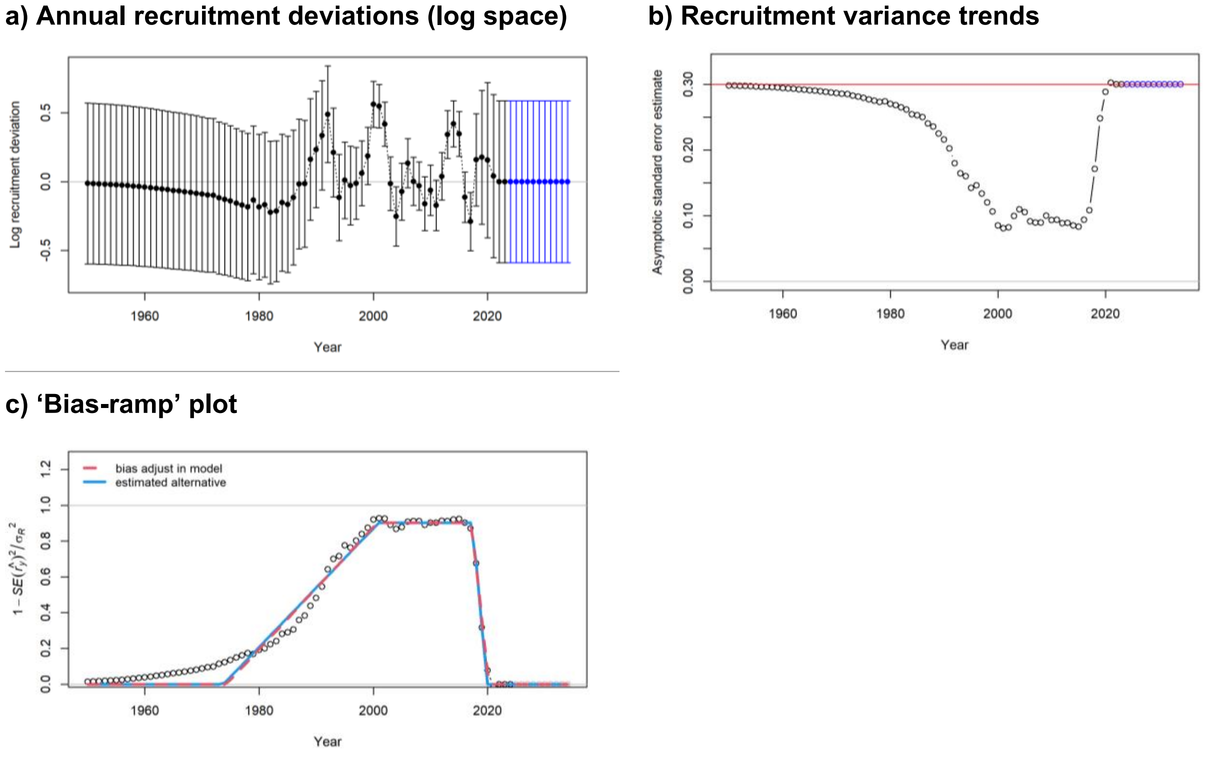


Figure A2.9. NDSMF red emperor single-area model outputs including a) estimated annual recruitment deviations, b-c) diagnostic plots relating to variance assumptions associated with bias corrections for the lognormally-distributed, estimated annual recruitment deviations.

Jitter, likelihood profile, and retrospective analyses

Results of a jitter analysis with 25 alternative sets of starting values for estimated model parameters show that the model is relatively stable (Figure A2.10a). Whilst the resultant negative log-likelihood (NLL) values for five 'jitter runs' were lower than the base model, the maximum difference was ~1.1 (indicating little difference in level of model fit). The remaining jitter runs led to a poorer fit that the base model.

A likelihood profile analysis for initial recruitment (R0) highlights that there is some tension in the model data between likelihood components contributing to the overall model fit (Figure A2.10b). The plot indicates that the minimum for the overall NLL is to the right of the minima for the survey, length and age likelihood components, due to the influence of the recruitment likelihood component.

A likelihood profile analysis for natural mortality (*M*), which is fixed in the model at *M*=0.115 year^{-1}, for values ranging from *M*=0.055 year^{-1} to *M*=0.175 year^{-1}, has a minimum that is slightly lower than the assumed (fixed) value, driven largely by the impact of the age composition data (Figure A2.10c). No attempt has yet been made to estimate M internally due to the relatively data-limited nature of the assessment, in particular, presence of only a declining trend (one-way trip) in CPUE. Given that this profile analysis indicates some information exists in the data does for estimating *M*, this may be useful to explore for future assessments, e.g., to allow for its uncertainty.

A likelihood profile analysis for the steepness parameter (h) in the Beverton-Holt stock recruitment relationship, fixed in the model at h=0.85, for values ranging between h=0.55 to h=0.95, shows no clear minimum for the overall log-likelihood, across this range of values for this parameter (Figure A2.10d). This result suggests that there is currently insufficient information in the available data to estimate this parameter.

A likelihood profile analysis for current depletion indicates that the survey data, length data and, to a lesser extent, age data, are consistent with the estimate for this derived parameter (Figure A2.10e).

A retrospective analysis showed little change in estimated B_{rel} for recent years (2021-2024), but lower estimated biomass trajectories for the two preceding years (Figure A2.10f). As age data are collected at intervals of several years, the pattern is likely associated with the effect of the latest composition sample being included in the analysis (and possible tension between the CPUE and composition data).

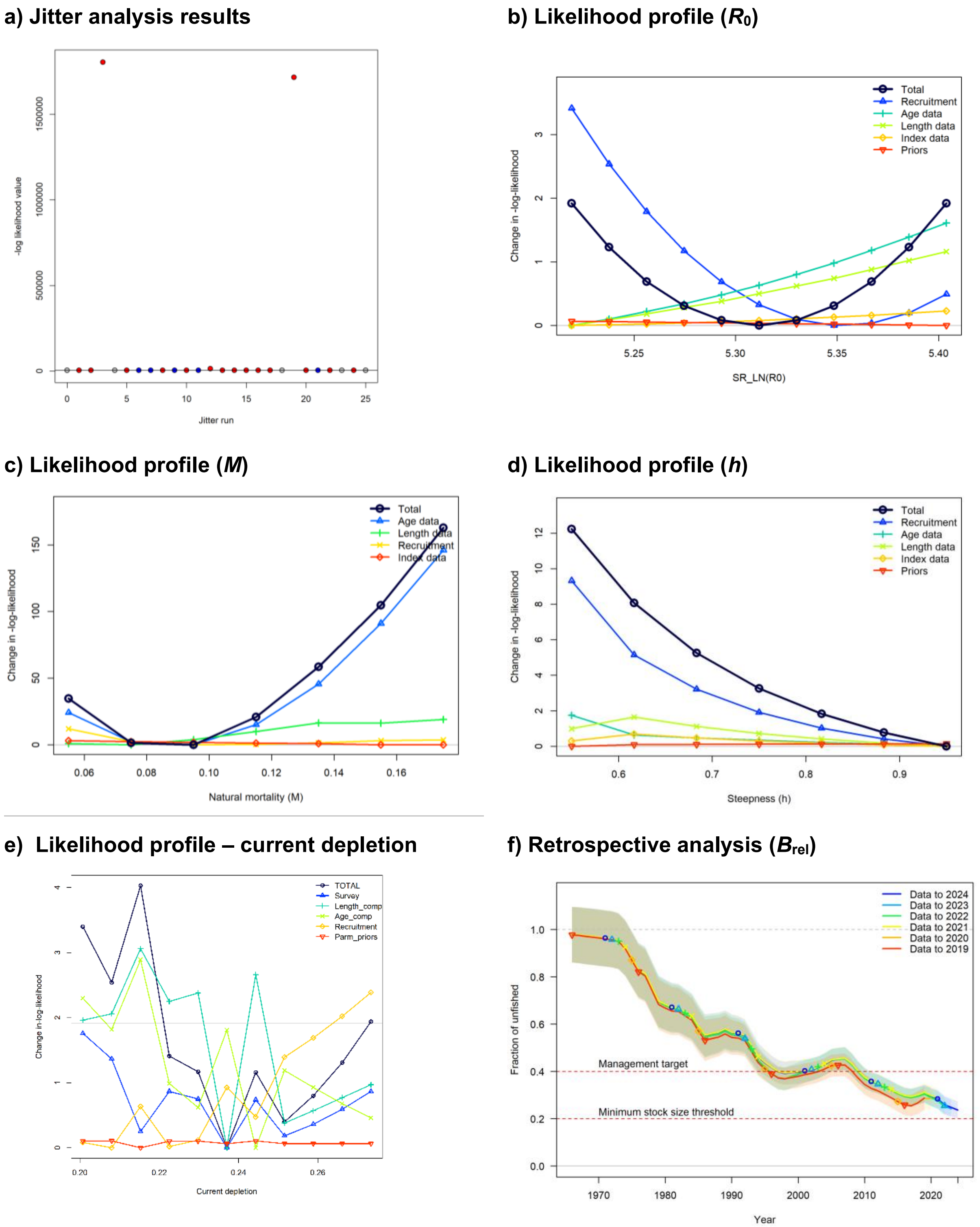


Figure A2.10. Model diagnostics for the single-area red emperor model, including: a) jitter analysis, b) likelihood profiles for R0, c) likelihood profiles for *M*, natural mortality, d) likelihood profiles for h, steepness, e) likelihood profiles for current depletion estimates, and f) a retrospective analysis, displaying results for relative female biomass (B_{rel}) levels.

Fixed parameter sensitivity analysis

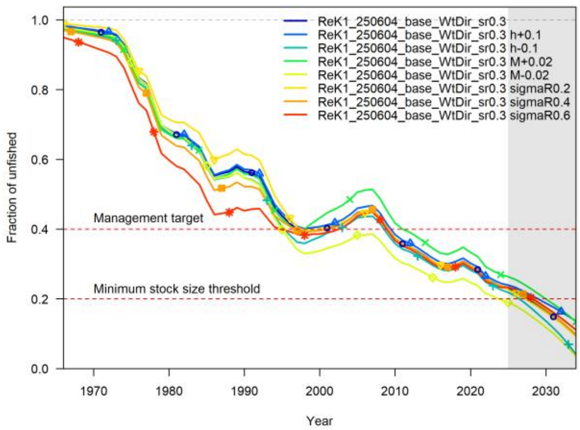
Increasing steepness from h=0.85 to h=0.95 and decreasing steepness to h=0.75 had limited effect on the trends for B_{rel} (Figure A2.11a), *F* (Figure A2.11b) and c) annual recruitment deviations (Figure A2.11c). The same was true for *M*; increasing *M* from the base level (*M*=0.115 y^{-1}) to *M*=0.0.135 y^{-1} or down to *M*=0.095 y^{-1} had only a minor effect on the trends for each of these model-derived variables.

Changing the level of assumed error for recruitment deviations (reducing from SigmaR=0.3 to 0.2 or increasing to 0.6) had a conspicuous effect on trends for B_{rel}, F, and annual recruitment deviations in early years. Lowering SigmaR led to higher B_{rel} and lower F, whereas reducing SigmaR to 0.2 caused the opposite effect, i.e., lower B_{rel} and higher F values. Lowering SigmaR reduced F throughout the time series, whereas increasing SigmaR increased F (Figure A2.11b).

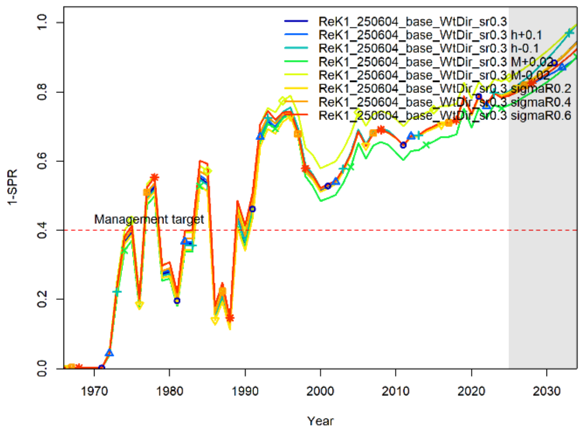
With a SigmaR value set to 0.6, there is a relatively strong decreasing pattern in recruitment deviations in all early years covering the period of relatively non-informative data (prior to the first available CPUE data and composition data). Such a pattern for recruitment deviations is indicative of a level of model misspecification, i.e. and thus far from ideal. In a recent assessment for red emperor in the WA Pilbara region, on advice from an external expert reviewer (Evans-Powell et al., in prep.), this same type of issue was able to be overcome by specifying a weak prior on initial fishing mortality and increasing the standard error of the initial equilibrium catch. This same approach was tried for the current assessment but was not successful (resulting in unrealistically low B_{rel} values for the early years of the time series). Related to this issue is the possibility of missing early catches affecting model results. A very detailed review of early catches taken by foreign fishing fleets was undertaken for this assessment, resulting is some additional catch being identified, which are now included in the model.

The undesirable negative recruitment pattern is reduced greatly, however, when SigmaR is lowered, with this sensitivity analysis showing the effect becomes minimal effect when SigmaR is lower to 0.2. SigmaR=0.2 is, however, outside the range typically considered in integrated model-based assessments and possibly unrealistically low for this species, despite it being a tropical deepwater demersal fish species (spawning most months of the year with two distinct peaks at about 6 months apart). A slightly higher value and more biologically realistic value of SigmaR=0.3 was selected for the base case model. This reduced the strength of this non-desirable negative recruitment deviation pattern during the 1980s.

a) Parameter sensitivity analysis (B_{rel})



b) Parameter sensitivity analysis (*F*)



c) Parameter sensitivity analysis (SigmaR)

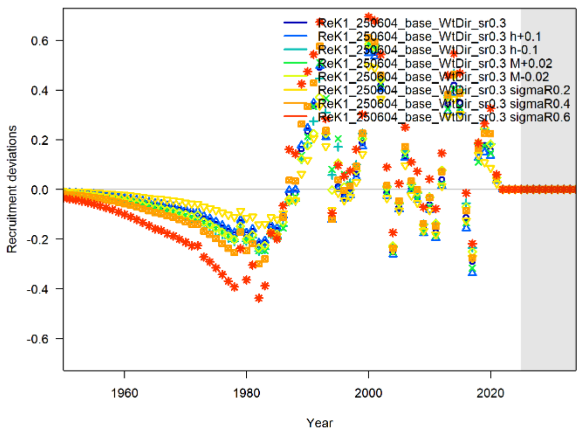


Figure A2.11. Results of sensitivity analyses for the single-area model for red emperor exploring alternative fixed values of steepness (h), natural mortality (M) and SigmaR. Comparisons among these model sensitivity runs are shown for: a) relative female biomass, b) fishing mortality, and c) recruitment deviation pattern.

Two-area model (data, outputs and diagnostics)

Data inputs

In comparison with the red emperor single-area model, the input data to the two-area model, as to expected, are split by the north and south areas (where possible) (Figure A2.12a, b). Some of the early data used in the one-area model data could not be used the two-area model, including fishery-dependent length data from the early 1990s (as the locations of fishing are not known) and monthly CPUE time series (as these data were considered too sparse for area-specific indices to likely be reliable as stock abundance indices). Broadly, the amount of available data, and periods for which data are available, are similar for each area.

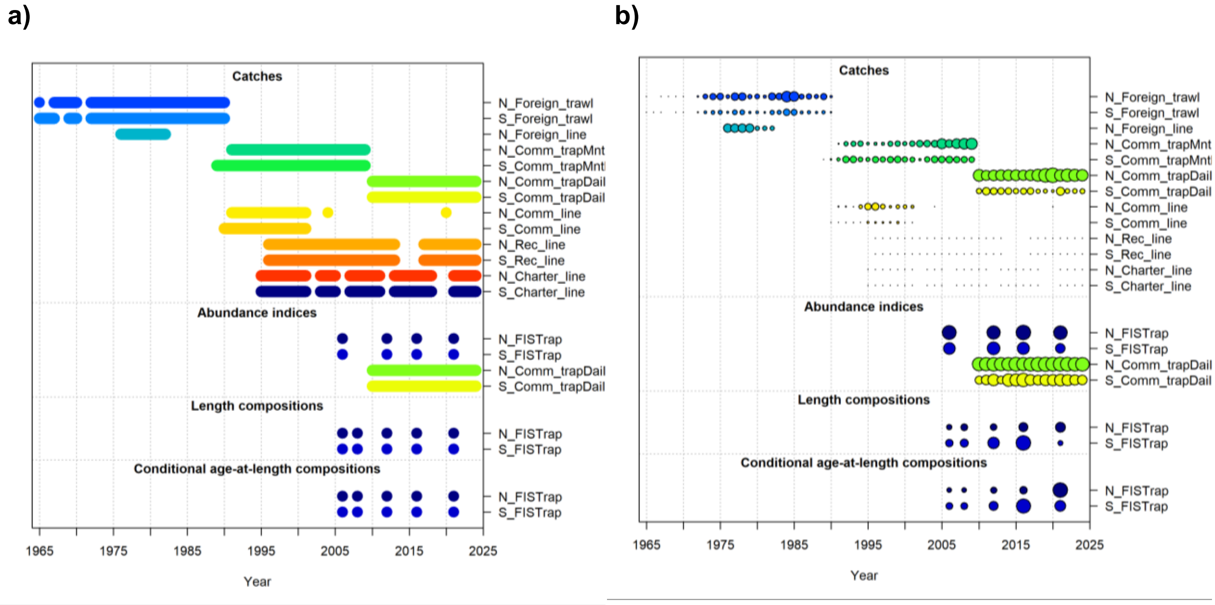


Figure A2.12. Data sources by year for each fleet for the two-area red emperor model. In figure b, circle areas for: i) catch data are proportional to catch magnitude, ii) those for abundance index data are proportional to precision, and iii) those for composition data to input sample size.

Model fits

The fits of the model to the FIS CPUE, and daily commercial trap CPUE in each area are shown below (Figure A2.13a-d). Note, the two-area model was not fitted to earlier monthly CPUE as the data, when separated by area, were considered too sparse to be reliable.

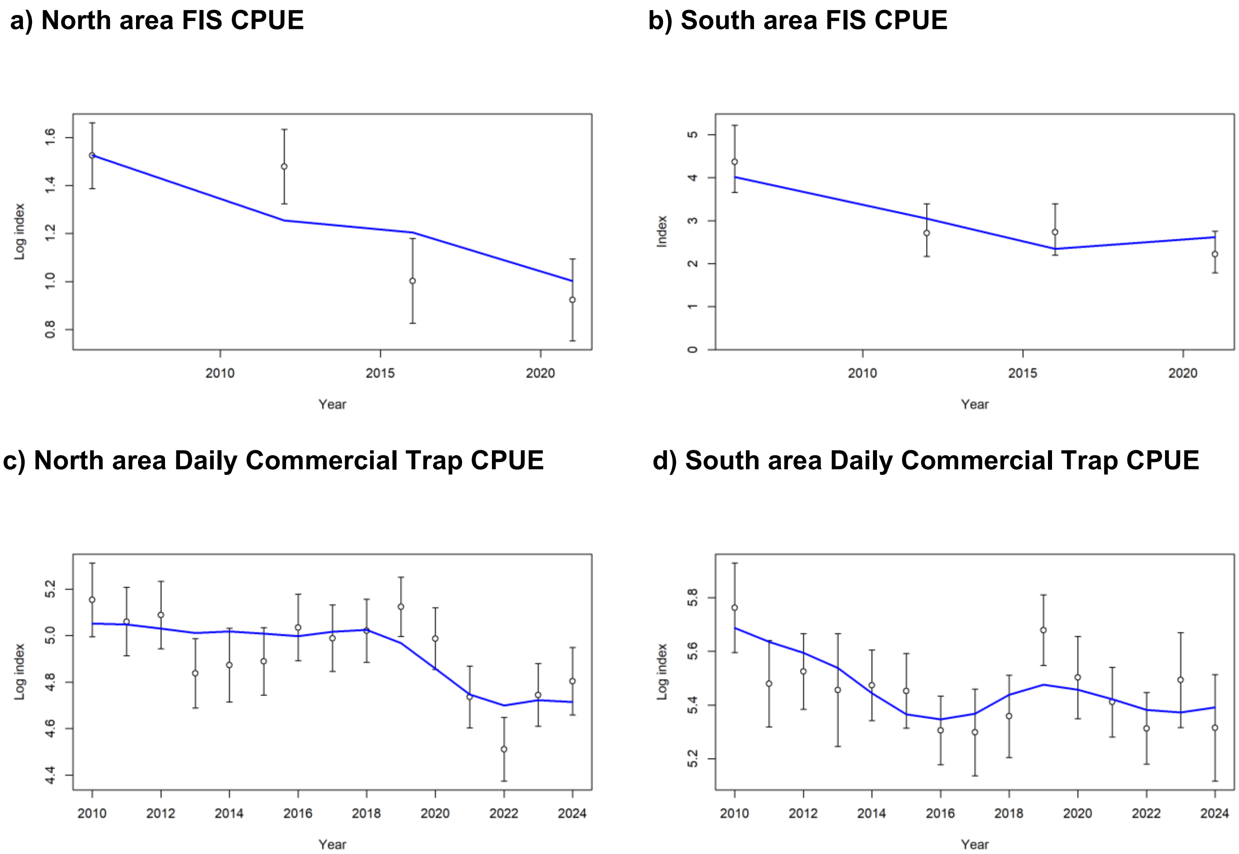
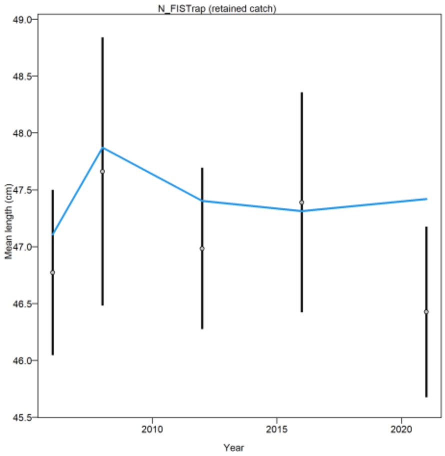


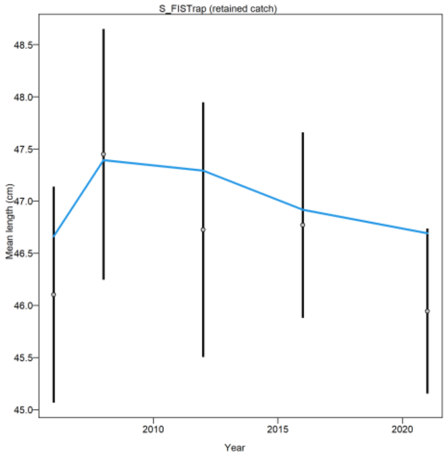
Figure A2.13. Fits of the two-area red emperor model to fishery independent survey CPUE in a) the north area, b) south area; and to commercial trap daily CPUE in c) the north area, and d) south area.

In each area, the FIS mean length of red emperor is least in the final (2021) survey, followed by the first year (2006), and the same pattern occurs with mean age in each area (Figure A2.14a-d). The model overestimates the mean length of red emperor in each area in 2021, and underestimates mean age, in each area, in that year. Similar to the results for the single-area model, the results imply that the data for 2021 are somewhat inconsistent with those for earlier year, which as discussed earlier, may relate to sampling differences between surveys, and also potentially be affected by growth changes (but an attempt to model time-varying growth for this species was not successful).

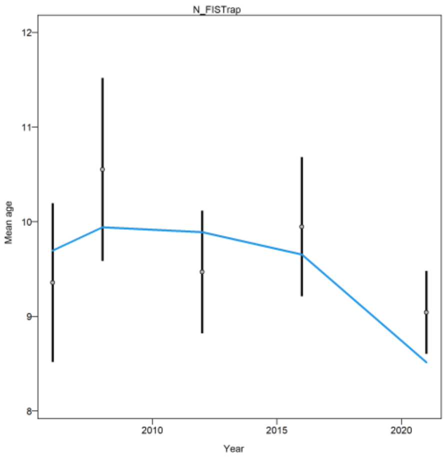
a) North area length > MLL (D-M weighting)



b) South area length > MLL (D-M weighting)



c) North area conditional age (D-M weighting)



d) South area conditional age (D-M weighting)

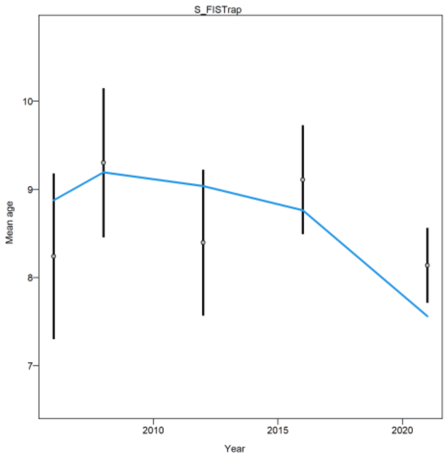
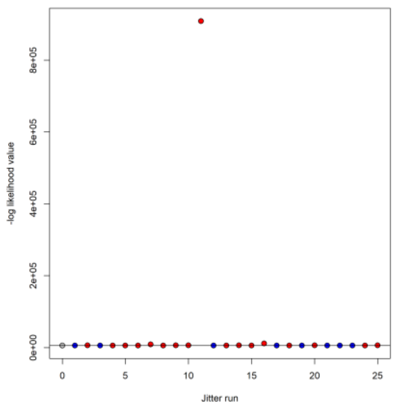


Figure A2.14. Fits of the two-area red emperor model to fishery independent survey length data in a) the north area, b) south area; and to conditional age data in c) the north area, and d) the south area.

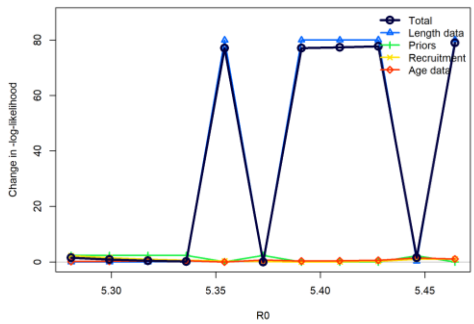
Jitter, likelihood profile and retrospective analysis

The results of a jitter analysis indicated that the preliminary two-area model for Red emperor is not highly stable, with the overall negative log-likelihood (NLL) values for 8 of the 25 model runs with alternative starting parameter values being lower (i.e., better) than the base model (Figure A.2.15a). The differences were often considerable (above 70-80), with much of the differences associated with the fit of the model to the likelihood component associated with the marginal length composition data, whilst noting that several of the model runs for this analysis relate to non-converged models. This is evident with the results of the initial recruitment (R0) likelihood profile analysis (Figure A2.15b) and also steepness (h) likelihood profile analysis (Figure A2.15d). The likelihood profile analysis for natural mortality (*M*) suggests a global minima for natural mortality, at about M=0.09 yr^{-1}, consistent with both the length and age data, which is less than the assumed value of M=0.115 yr^{-1}. The retrospective analysis for the two-area red emperor model did not highlight any strong retrospective patterns (Figure A2.15e). Further work is required with this model for red emperor focusing on potential factors leading to model instability. One contributing factor for the reduced stability, relative to the single-area model, is that although there is less input data to inform the two-area model, more parameters are required to be estimated.

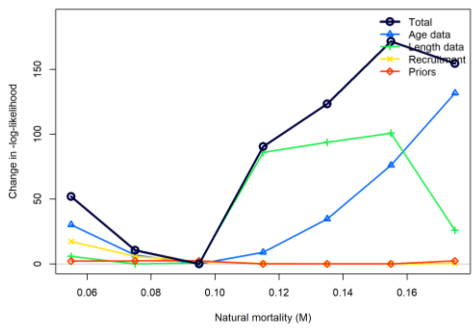
a) Jitter analysis results



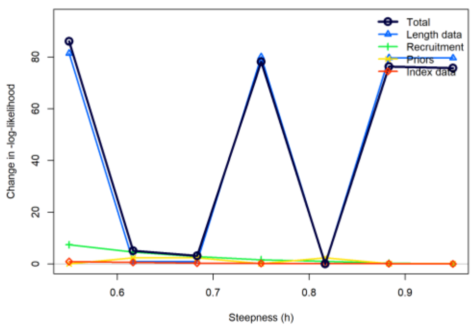
b) Likelihood profile (R_0)



c) Likelihood profile (M)



d) Likelihood profile (h)



e) Retrospective analysis (B_{rel})

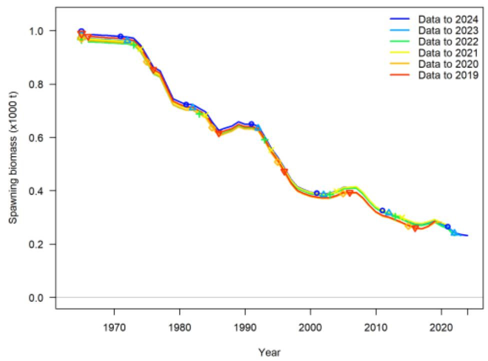


Figure A2.15. Model diagnostics for the two-area red emperor model, including: a) jitter analysis, b) likelihood profiles for R0, initial recruitment, c) likelihood profiles for M, natural mortality, d) likelihood profiles for h, steepness, and e) a retrospective analysis displaying results for relative female biomass (B_{rel}) levels.

Goldband Snapper

Level 3 Assessment

Kimberley **North Kimberley** **South Kimberley**

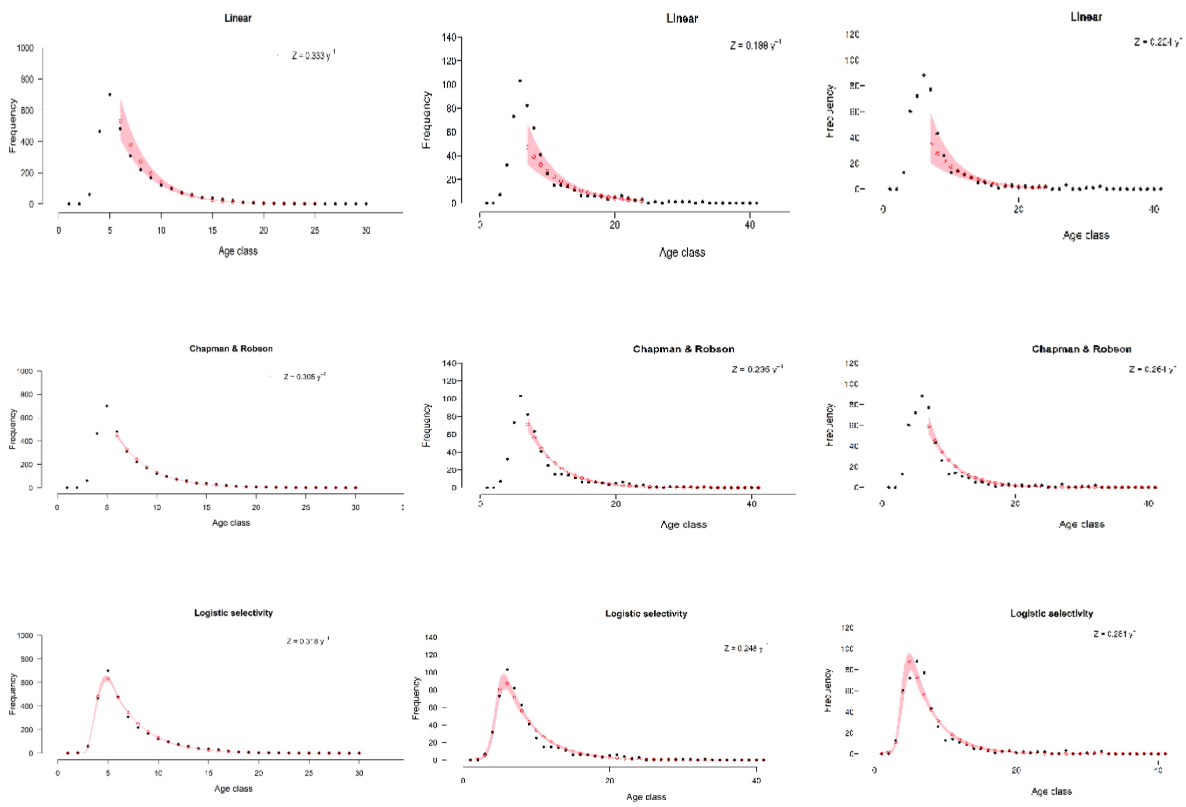


Figure A2.16. Estimates of total mortality (Z) for the Kimberley goldband snapper stock, and by North and South, in 2021, derived using linear catch curve analysis, the method of Chapman and Robson (1960), and a catch curve assuming (asymptotic) logistic selectivity. The assumed age at full recruitment into the fishery was taken as one year above the age at peak frequency.

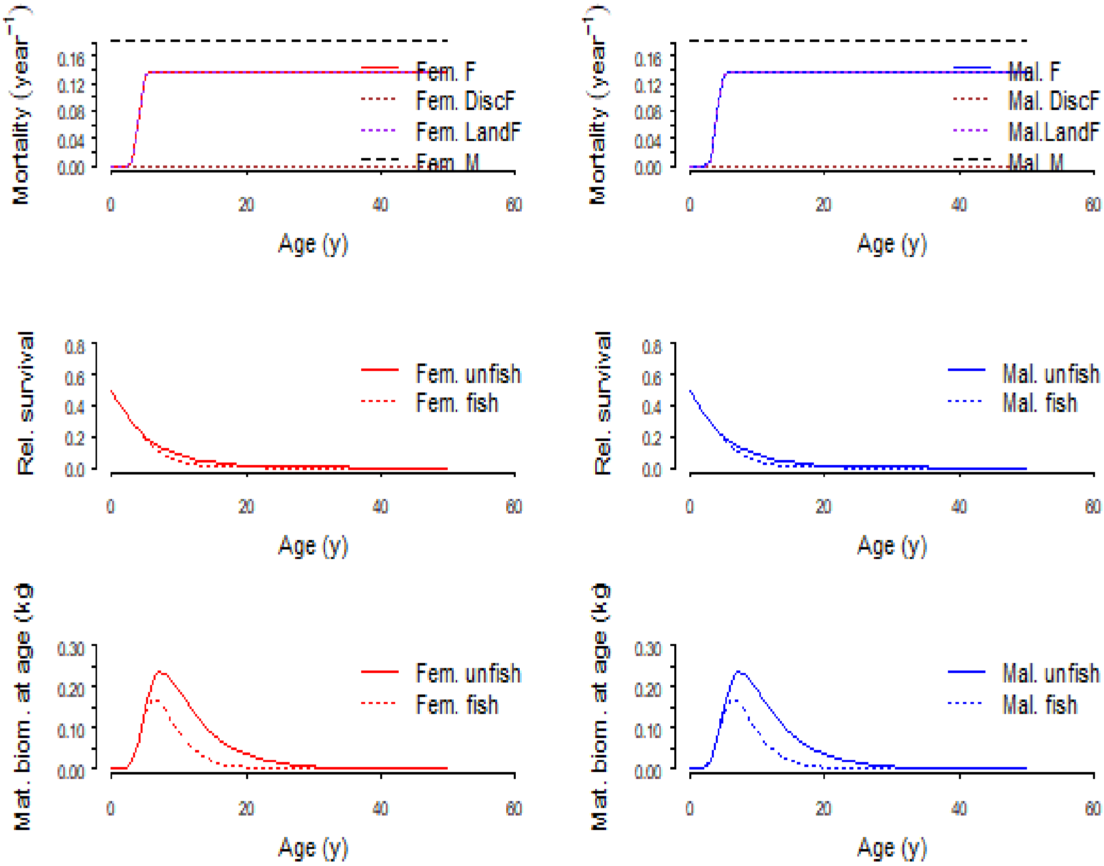


Figure A2.17. Mortality at age associated with fishing (from landings, discards and combined) vs natural mortality, expected relative survival, and biomass at age for the stock at the current level of fishing vs when unfished in 2021. Relationships are plotted for both females (red) and males (blue), for the Kimberley goldband snapper stock.

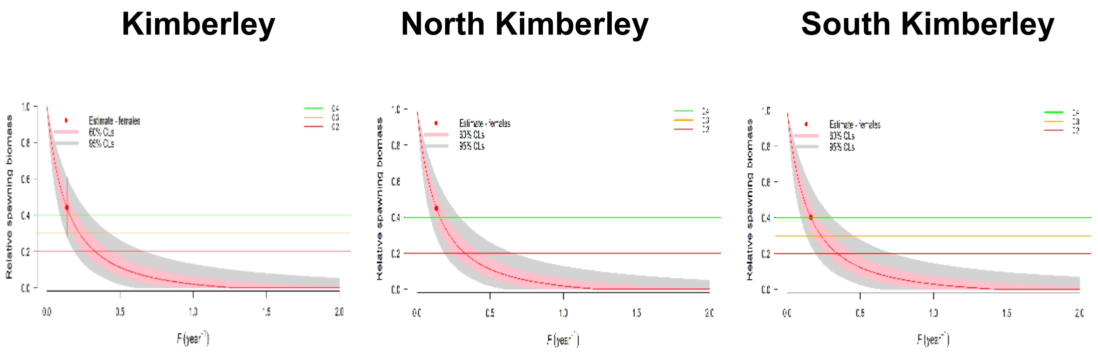


Figure A2.18. Estimated relative spawning biomass (with 60% and 95% CL) from aged-based equilibrium analysis for the Kimberley female goldband snapper stock in 2021.

Level 5 Assessment

Single-area model (data, outputs and diagnostics)

Data inputs

The data inputs to the goldband single-area model are summarised below (Figure A2.19). The broad characteristics of data inputs for goldband snapper closely resemble those described above for the red emperor single-area model, i.e., including all known catches taken from the fishery, starting in 1966, with i) earliest catches from foreign fishing fleets (mainly trawl fishing and limited line fishing) followed by commercial catches from commercial trap fishing, and limited commercial, recreational, and charter line fishing. Abundance indices are available for four years from FIS (between 2006–2021), and annually from commercial monthly logbooks (1998–2009), and daily logbooks (2010–2024). The model is also informed by marginal length and conditional age-at-length data available from the FIS surveys.

Some historical age data also exist from the mid-late 1990s that are not included in the current model, primarily due to concerns regarding the accuracy of age estimates (derived from thicker otoliths sections in which growth zones are less discernible than in the thinner sections used today, and evidence of systematic ageing bias, with overestimates of age for samples collected in earlier years). A priority for future assessments is to revisit ageing for the biological samples collected in earlier years. Marginal length data available for these years, sampled from commercial fleets are, however, included in the model.

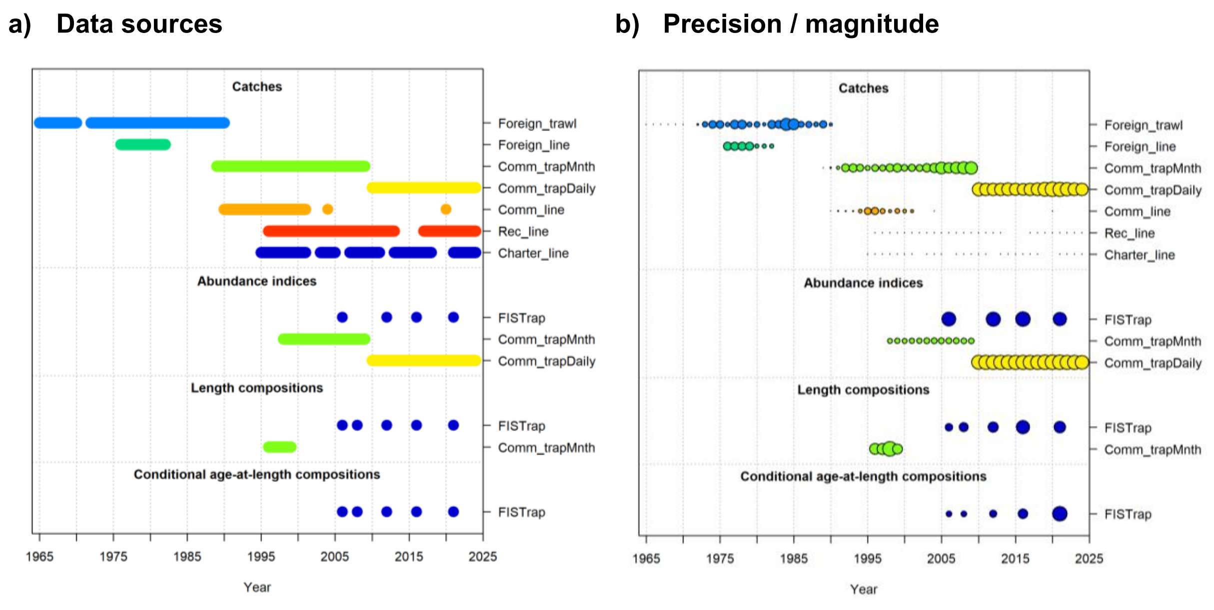


Figure A2.19. Data sources by year for each fleet for the single-area goldband snapper model. In figure b, circle areas for: i) catch data are proportional to catch magnitude, ii) those for abundance index data are proportional to precision, and iii) those for composition data to input sample size.

Model fits

The single-area model matches relatively well the observed FIS CPUE data points for the first two years (2006 and 2012), but not latter two years, with the estimated values (in log space) being substantially lower and higher, respectively, than the observed values (in log space) for 2016 and 2021 (Figure A2.20a). In normal space (figure not shown), it is clear there is about a halving of observed FIS CPUE between 2016 and 2021 which does not appear biologically realistic; therefore, it is not surprising that this level of change in CPUE (possibly associated with sampling issues) cannot be matched by the model. Furthermore, the increase in FIS CPUE between 2012 and 2016 is in the opposite direction to the trend exhibited by the Daily CPUE for those years. The extent to which the different trends in these CPUE time series creates "tension" in the model (that, in turn, could affect model outputs, see Wang et al, 2015) requires further investigation.

The observed monthly commercial trap CPUE data exhibits a relatively flat trend, which is well matched by the model (Figure A2.20b). The daily commercial trap CPUE, in contrast to the monthly commercial CPUE, exhibits a progressive declining trend, which is also relatively well matched by the model.

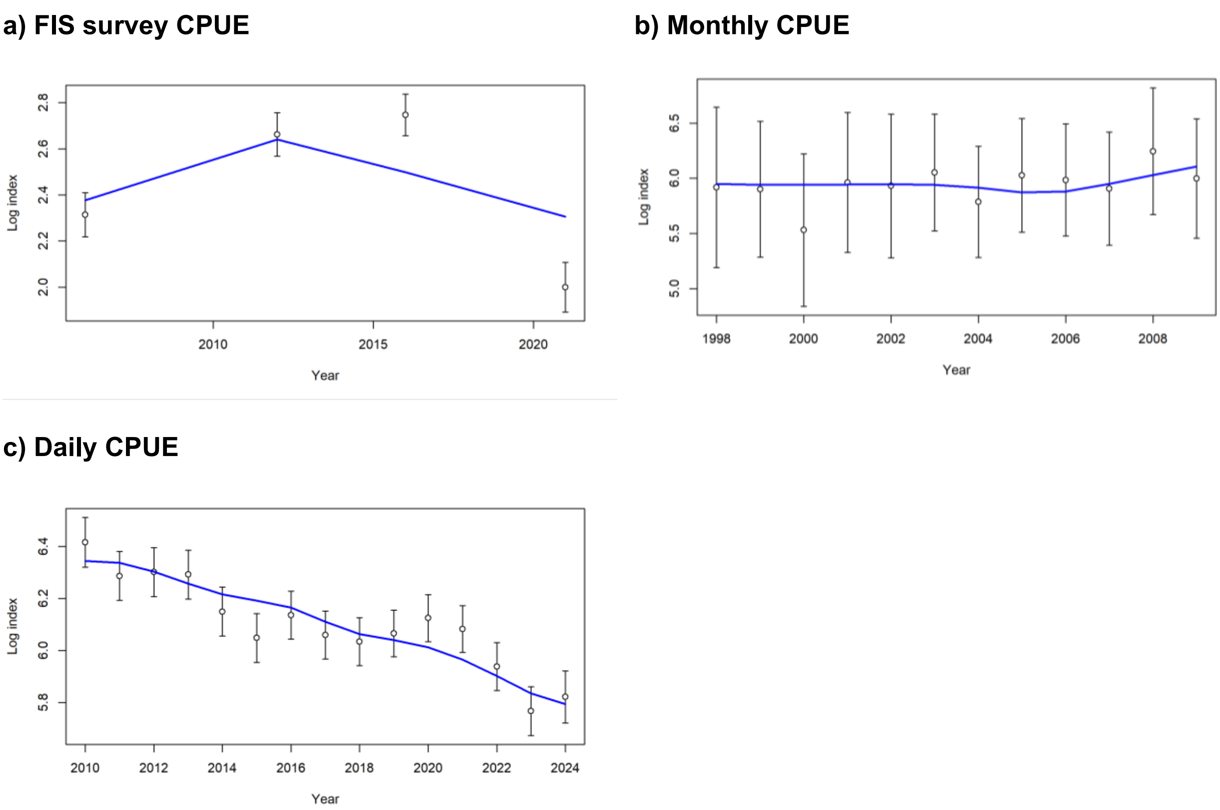


Figure A2.20. Fits by the single-area goldband snapper model to a) fishery independent survey CPUE, b) commercial trap monthly CPUE, and c) and commercial trap daily CPUE.

Growth is estimated internally in the model, based on all years of conditional age-at-length and marginal length data from FIS sampling, and assumed to be constant. The residual patterns from the conditional age-at-length data exhibit some structural deviations in several years (Figure A2.21a). For example, in 2006 and 2008, at a given length class, residuals of greatest magnitudes are typically for younger ages, and in 2021, at a given length class, residuals are typically larger at older ages. Whilst it is possible that growth may be time-varying, it is also possible that interannual differences in residual patterns reflect spatial sampling differences over time, associated with the FIS. Over time, additional sampling sites have been added to the survey to increase representativeness of sampling from the population, from 8 key sites in 2006 and 2008, to 12 sites in 2011 and 2016, and 16 sites in 2021. Also, at a given site, commercial skippers (who operate with researchers on board) can search for new locations within a 5 nm radius, such that precisely the same locations are not sampled each year. Time-varying growth was considered in some preliminary models, but this resulted in issues with the models (poor diagnostics) that could not be resolved.

The observed mean ages of goldband snapper in FIS samples have remained relatively constant between 2006–2016 (~6–7 years), with uncertainty decreasing substantially in later years, reflecting greater sampling intensity (Figure A2.21b). The model predicts a decline in mean age from ~8.5 years in 2006 to ~ 6.5 years in 2021. The predicted marginal age compositions match relatively well the observed marginal age compositions from the FIS (Figure A2.21c), which are specified in the model as a ‘ghost fleet’, i.e., these data do not influence the model fitting process.

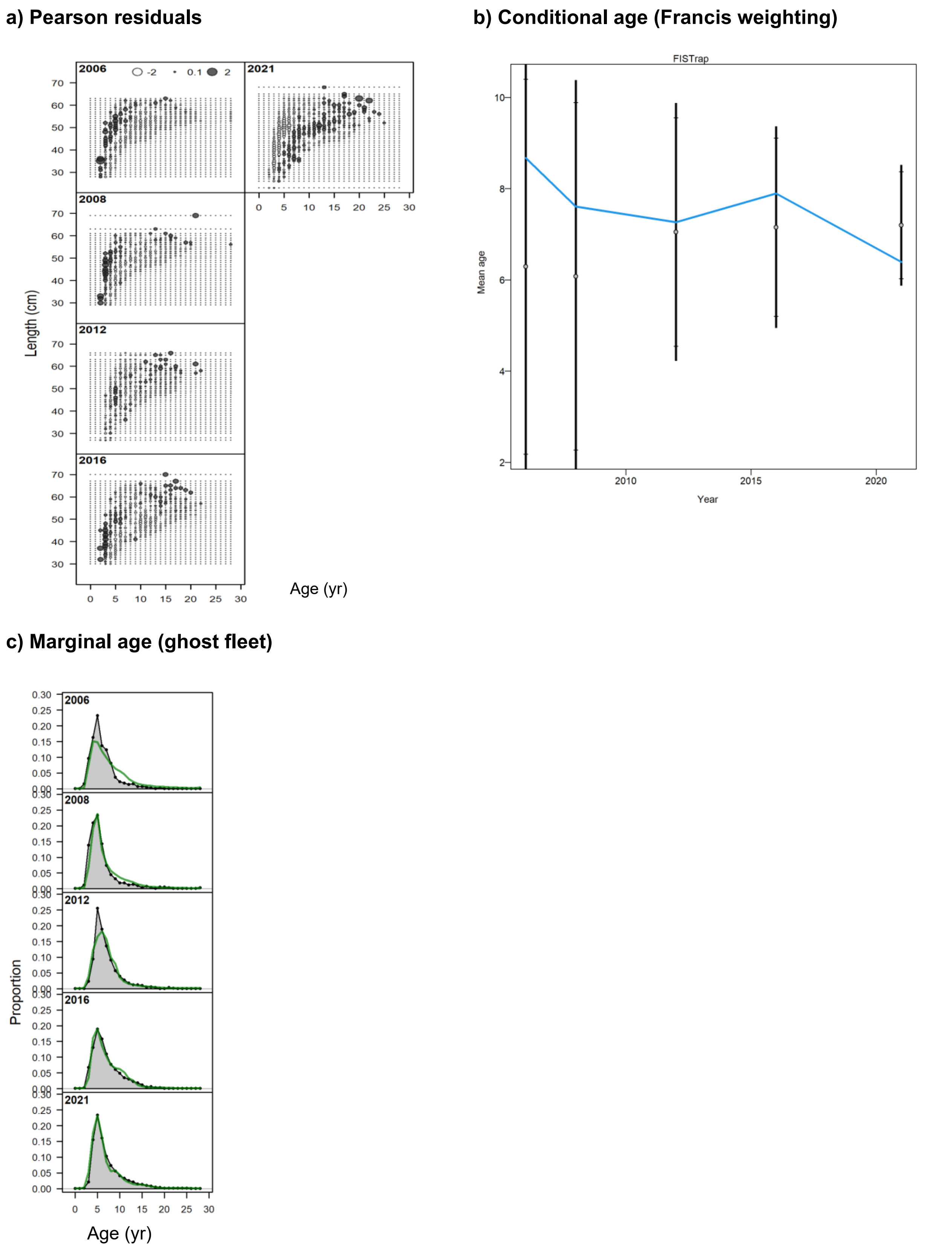
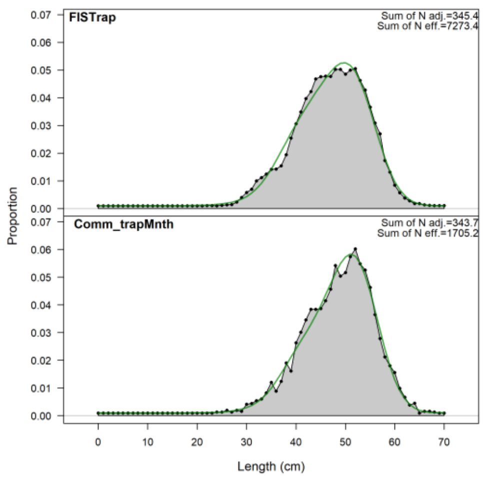


Figure A2.21. Single-area goldband snapper model outputs associated with conditional age-at-length data from fishery independent surveys including: a) residuals, b) observed vs expected mean age, and c) expected vs observed marginal age compositions (i.e., whereby observed marginal age data are used as a 'ghost fleet', and thus not used in the model fitting process).

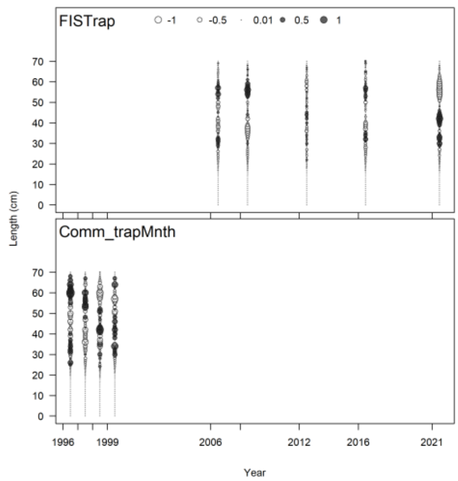
The visual fits provided by the goldband snapper single-area model to the FIS trap surveys (between 2006–2021) and early commercial trap length data (1997–1999) are good (Figure A2.22a), as also indicated by the lack of obvious residual patterns associated with observed vs expected length distributions (Figure A2.22b). Note that as there is no minimum size limit for goldband snapper. The marginal length distributions thus represent all catches taken by the survey, and also by the fishery.

The single-area integrated model for goldband snapper, assuming constant growth, provides relatively good visual fits to the marginal length data from the fishery, and FIS since 2006 (Figure A2.22c, e). The observed mean lengths from commercial sampling decline slightly from ~48-49 mm in 1996–1997 to about 46–47 mm in 1998–1999, which is partly matched by the model (Figure A2.22d). The observed mean length from FIS sampling shows a stable trend from 2006–2016 at about 46–47 mm (i.e., same as earlier commercial samples), before declining substantially to about 44 mm in 2021, a decline that was not matched by mean age in the 2021 FIS sample (Figure A2.22e). The reason for this sudden decline is not well understood but may reflect to some extent sampling differences between surveys and/or growth variation. Changes in growth may be related to environmental variation, although this needs to be investigated further. This inconsistency in trends between mean age vs mean length has implications for modelling (potentially creating ‘tension’ when fitting to the multiple data sets).

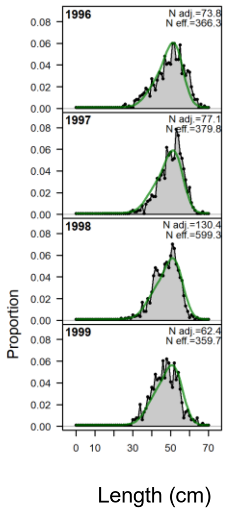
a) Commercial and FIS marginal length



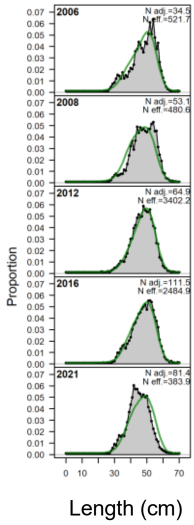
b) Pearson residuals



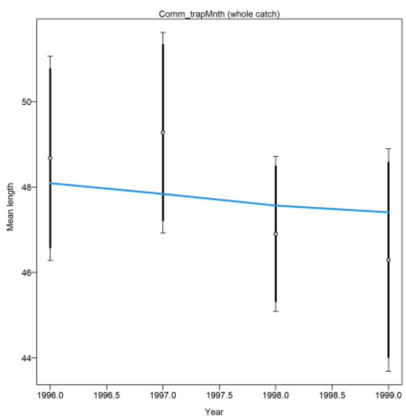
c) Commercial marginal length



d) FIS marginal length



e) Commercial length (Francis weighting)



f) FIS length (Francis weighting)

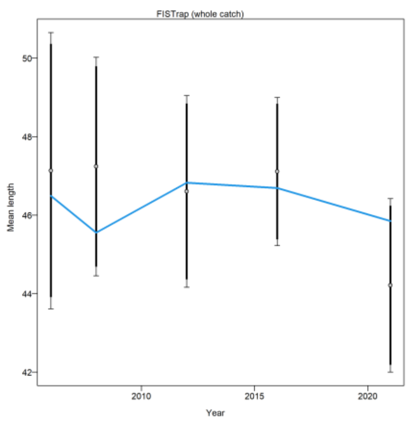


Figure A2.22. NDSMF goldband snapper single-area model outputs associated with marginal length data from fishery independent surveys including: a) fits to combined data for all survey years, b) residual patterns associated with observed vs expected lengths, c) fits to length data for fish of lengths retained by the fishery, d) fits to length data from FIS,

e) observed vs estimated mean size from fishery-dependent length data, and f) observed vs estimated mean size from FIS length data.

Selectivity

The single-area model for goldband snapper estimates asymptotic logistic length-based selectivity from FIS trap data (2006–2021) years, and commercial trap data (1996–1999). These time-specific selectivity estimates, which are very similar, are mirrored to the other fleets, given that the vast majority of the catch taken from the fishery has been from commercial trap operators. Fish are estimated to be 50% selected by the trap gear at about 38 cm, corresponding to 4–5 years of age (Figure A2.23a, b). It is assumed that there is no discarding (i.e., retention set to 1.0 for all lengths), and thus no post-release mortality.

a) Length-based selectivity **b) Age-based selectivity (from length-based selectivity)**

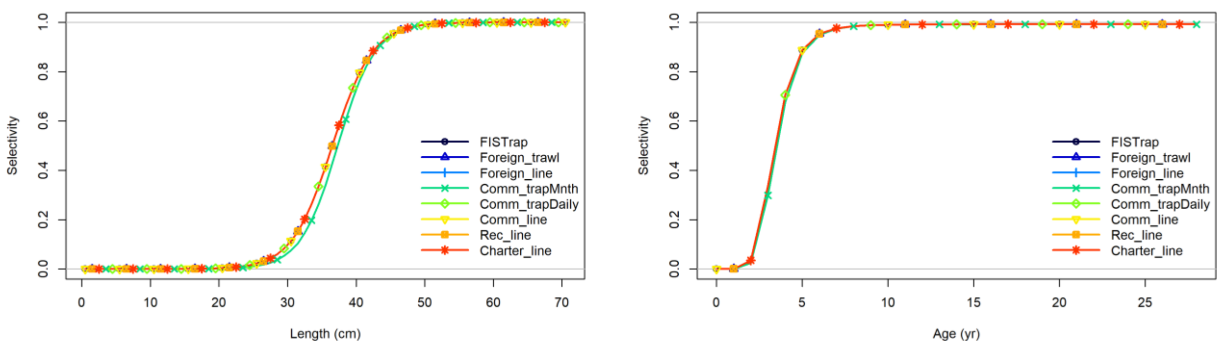
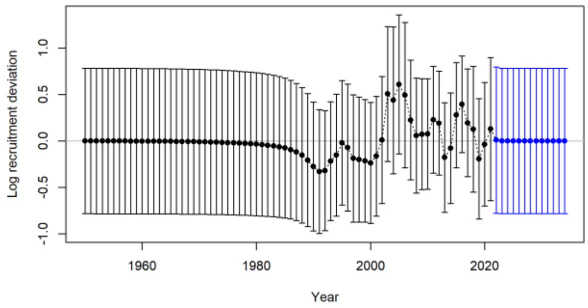


Figure A2.23. Single-area goldband snapper model outputs for selectivity, including a) estimated logistic length-based gear selectivity, and b) corresponding gear selectivity at age curves.

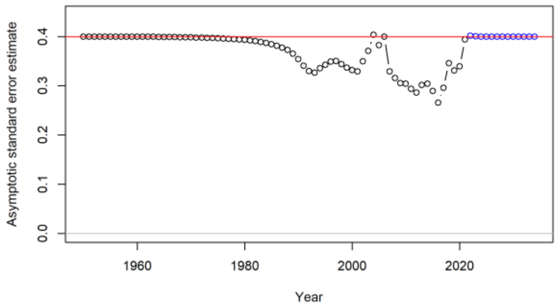
Recruitment

As should be expected, the estimated annual recruitment deviations for early years, when the model is only informed by annual catch data, remain at essentially zero. The model subsequently estimates below-average recruitment during the 1990s, above-average recruitment mainly in the early 2000s and late 2010s), and below average recruitment in a couple of other years (Figure A2.24a). The recruitment deviation variance is typically lower in years where data CPUE and composition data exist (Figure A2.24b). The increase in variance in the early 2000s likely relates to limited data for this period to inform the model, i.e., occurs around when CPUE indices change from monthly to daily data, and a period when neither length or age-at-length data exist. The ‘bias ramp’ plot demonstrates that the model has been appropriately tuned, with respect to the variances associated with the estimated annual recruitment deviations (Figure A2.24c). Broadly, the diagnostic plots associated with estimated recruitment deviations do not indicate major structural issues with the single-area model for this species.

a) Annual recruitment deviations (log space)



b) Recruitment variance trends



c) 'Bias-ramp' plot

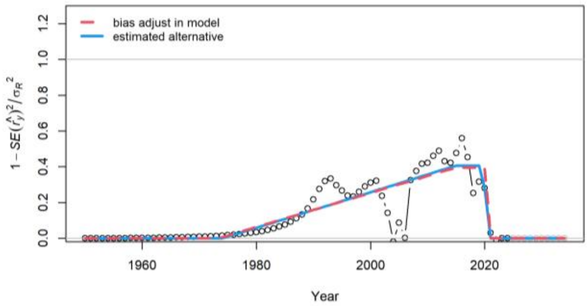


Figure A2.24. Single-area goldband snapper model outputs including a) estimated annual recruitment deviations, b-c) diagnostic plots relating to variance assumptions associated with bias corrections for the lognormally-distributed, estimated annual recruitment deviations.

Jitter, likelihood profile and retrospective analyses

The jitter analysis with 25 alternative sets of starting values for estimated model parameters show that none of the resultant negative log-likelihood (NLL) values for alternative 'jitter runs' were lower than the base model (Figure A2.25a).

Similar to the situation with red emperor, a likelihood profile analysis for initial recruitment (R0) highlights that there is tension in the model data between likelihood components contributing to the overall model fit (Figure A2.25b). Similar to red emperor, the likelihood associated with recruitment has a relatively strong effect on the overall model fit, which is not desirable, but the minimum for the overall NLL does not align with that for recruitment due. Thus, other components in the model (in particular, length data) are reducing its effect. The overall NLL is largely consistent with the signal in the age data, but not with the CPUE index (suggesting a lower R0 value).

Using, in the base model, the Francis weighting function, as might be expected, the effect of index data on the model fit is more dominant than composition data. For goldband snapper, use of the alternative Dirichlet multinomial (self-weighting) function implemented in SS, led to an unrealistic pattern for recruitment deviations (i.e., mostly positive deviations for the period of informative data), and thus not used as the base case model.

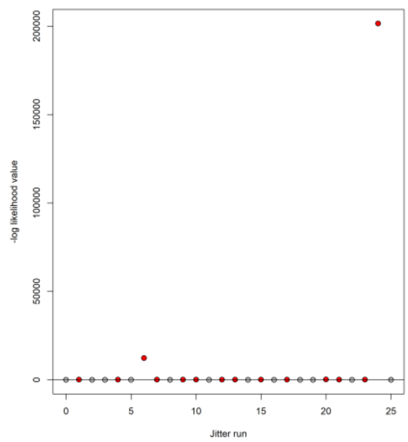
A likelihood profile analysis for natural mortality (M), which is fixed in the model at M=0.18 year^{-1}, for values ranging from M=0.121 year^{-1} to M=0.241 year^{-1} shows declining trend for the overall NLL over this M range (Figure A2.25c). This suggests that there is likely to be limited information in the data for estimating this parameter (assuming the values of *M* explored covers the biologically feasible range).

Likelihood profile analysis for the steepness parameter (h) in the Beverton-Holt stock recruitment relationship, fixed in the model at h=0.85, for values ranging between h=0.55 to h=0.95, increases over this h range (Figure A2.25d). It is concluded that there is currently insufficient information in the data to estimate this parameter.

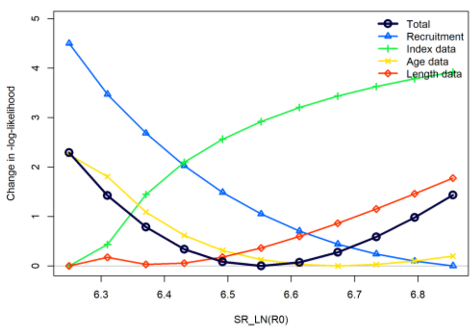
A likelihood profile analysis for current depletion indicates some differing signals in the data for estimating this parameter, with the depletion levels at the minimum for the likelihood component associated with the age data slightly higher than the over minimum, and the index data (labelled as 'survey') being well to the left of the overall minimum (Figure A2.25e).

A retrospective analysis showed little change in estimated Brel for data including recent years (up to 2021 to up to 2024), but higher estimated biomass trajectories with data up to only 2019 or 2020 (Figure A2.25f). As discussed for red emperor, FIS age data are collected at intervals of several years. The above pattern is likely associated with the effect of the latest composition sample being included in the analysis (and tension between the CPUE and latest composition sample).

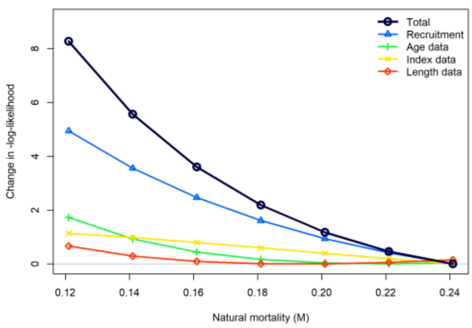
a) Jitter analysis results



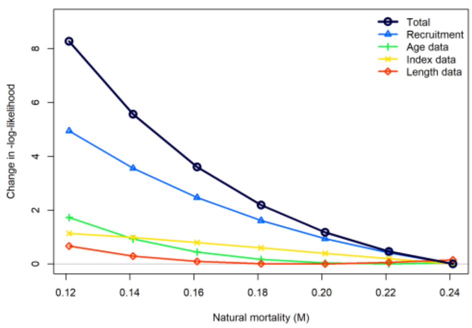
b) Likelihood profile (R_0)



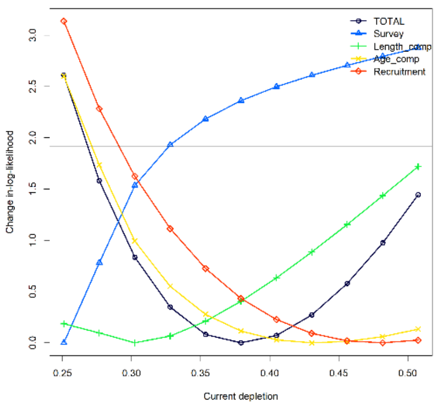
c) Likelihood profile (*M*)



d) Likelihood profile (*h*)



e) Likelihood profile (current depletion)



f) Retrospective analysis (*B*rel)

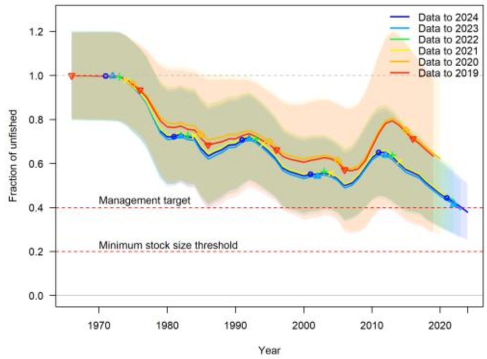


Figure A2.25. Model diagnostics for the single-area goldband snapper model, including a) jitter analysis, b) likelihood profiles for R0, initial recruitment, c) likelihood profiles for M, natural mortality, d) likelihood profiles for h, steepness, e) likelihood profiles for current depletion estimates, and f) a retrospective analysis, displaying results for relative female biomass (B_{rel}) levels.

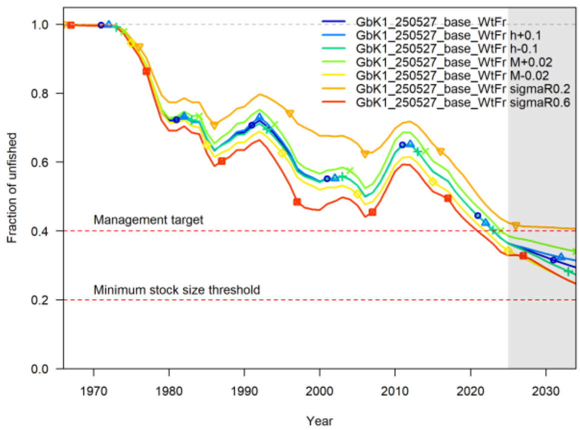
Fixed parameter sensitivity analyses

Increasing steepness from h=0.85 to h=0.95 and decreasing steepness to h=0.75 had limited effect on the trends for B_{rel} (Figure A2.26a), F (Figure A2.26b) and c) annual recruitment deviations (Figure A2.26c). Similarly, increasing M from the base level (M=0.180 y^{-1}) to M=0.200 y^{-1} or down to M=0.160 y^{-1} had a minor effect on the trends for each of these model-derived variables.

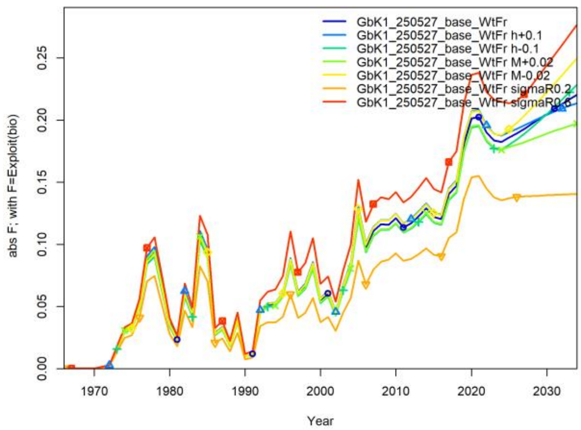
Changing the level of assumed error for recruitment deviations (reducing from SigmaR=0.4 to 0.2 or increasing to 0.6) had a substantive effect on trends. Lowering SigmaR to 0.2 lead to higher B_{rel} and lower F throughout most of the time series, whereas increasing SigmaR to 0.6 resulted in lower B_{rel} levels and higher F (Figure A2.26b). With a SigmaR value set to 0.6, there is a relatively strong decreasing pattern in recruitment deviations during the 1980s, a period of still relatively non-informative data few years, prior to the first available CPUE data and composition data. Such a pattern for recruitment deviations is indicative of a level of model misspecification, i.e., it is not ideal. This pattern is reduced greatly when SigmaR is lowered, becoming a minimal effect when SigmaR is set to 0.2. As SigmaR=0.2 is, however, outside the range typically considered in integrated model-based assessments and also potentially unrealistically low for this species, despite it being tropical deepwater demersal fish species. Thus, the intermediate value and potentially more biologically realistic value of SigmaR=0.4 was selected for the base case model. This reduced the strength of this non-desirable negative recruitment deviation pattern during the 1980s, prior to when the model input data start to become more informative, whilst still being considered biologically realistic. Note that the alternative approach for overcoming this issue, of specifying a weak prior on initial equilibrium catch, was tried but not successful (resulting in unrealistically low B_{rel} values for the early years of the time series).

It is likely that the cause of the above-mentioned model misspecification is due to factors not relating to recruitment assumptions. This aspect requires further investigation.

a) Parameter sensitivity analysis (B_{rel})



b) Parameter sensitivity analysis (*F*)



c) Parameter sensitivity analysis (SigmaR)

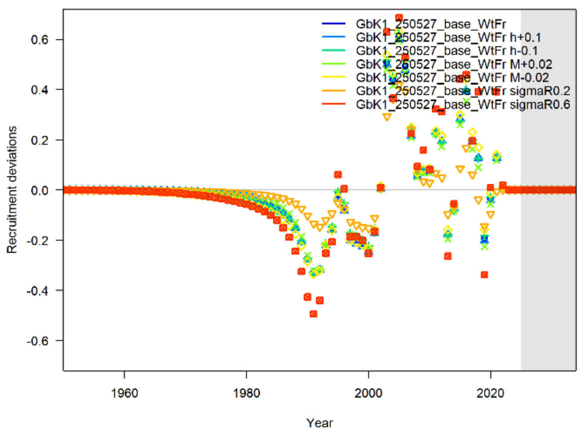


Figure A2.26. Results of sensitivity analyses for the single-area model for goldband snapper exploring alternative fixed values of steepness (h), natural mortality (*M*) and SigmaR. Comparisons among these model sensitivity runs are shown for: a) relative female biomass, b) fishing mortality and c) recruitment deviation pattern.

Two-area model (data, outputs and diagnostics)

As with red emperor, the input data used in the one-area model for goldband snapper have, for the associated two-area model, been split by the north and south areas (where possible) (Figure A2.27a, b). Likewise, the early fishery-dependent 1990s data and monthly CPUE were not used in the two-area model, due to the locations of fishing are being known for the length data, and the monthly CPUE data being too sparse for area-specific indices to constitute reliable stock abundance indices.

Similar to the situation with the single-area for goldband snapper, the two-area model for was unable to match well the trends in observed FIS CPUE. With the observed FIS and commercial CPUE trends differing (e.g., between 2012 and 2016), this likely creates some tension in the model, an aspect requiring further investigation.

Data inputs

a) b)

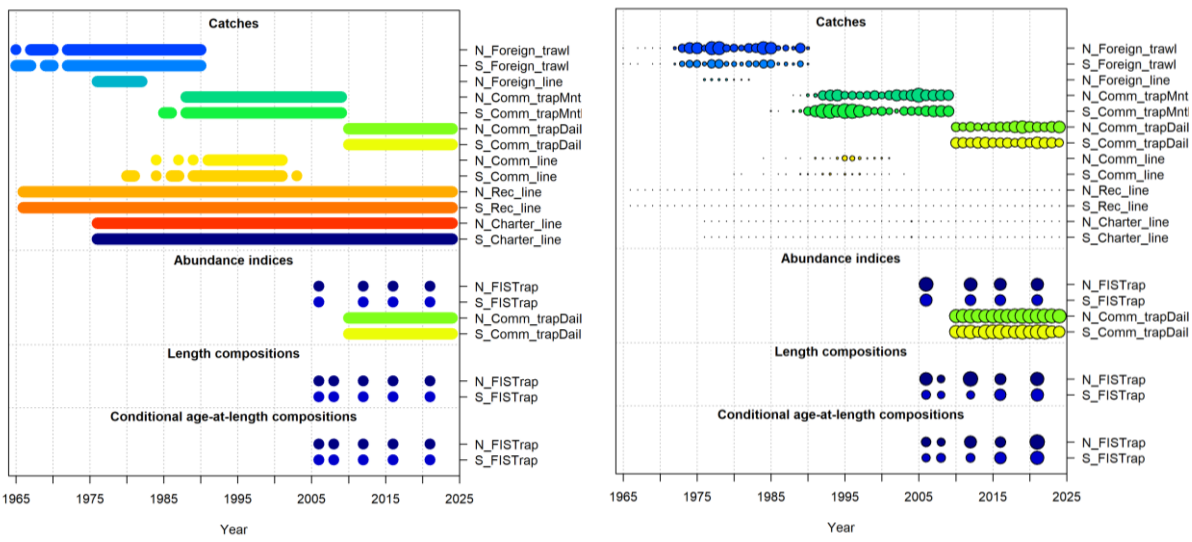
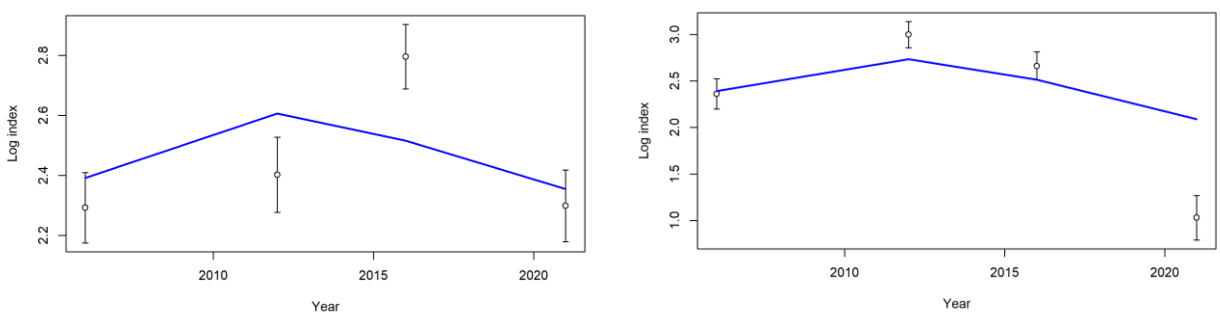


Figure A2.27. Data sources by year for each fleet for the two-area goldband snapper model. In figure b, circle areas for i) catch data are proportional to catch magnitude, ii) those for abundance index data are proportional to precision, and iii) those for composition data to input sample size.

Model fits

a) North area FIS CPUE **b) South area FIS CPUE**



c) North area Daily Commercial Trap CPUE **d) South area Daily Commercial Trap CPUE**

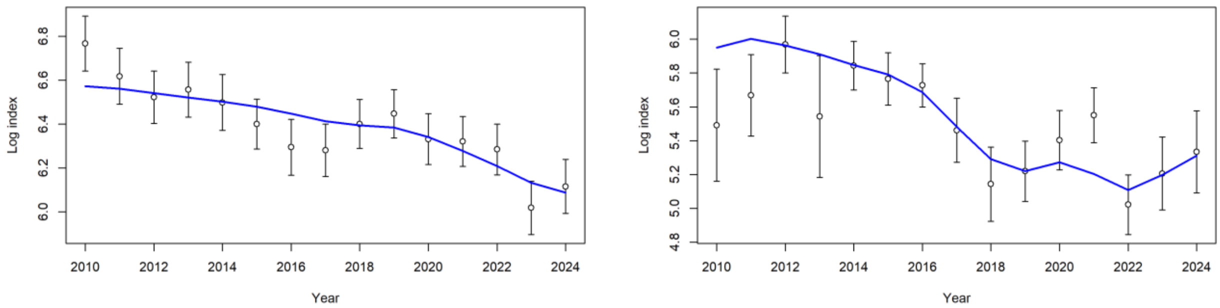


Figure A2.28. Fits of the two-area goldband snapper model to fishery independent survey CPUE in a) the north area, b) the south area, and to commercial trap daily CPUE in c) the north area, and d) the south area.

a) North FIS length (Francis weighting) **b) South FIS length (Francis weighting)**

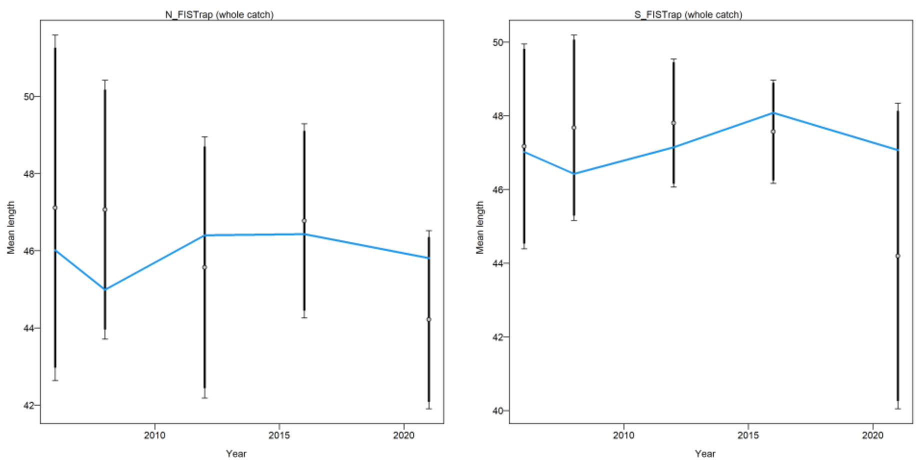
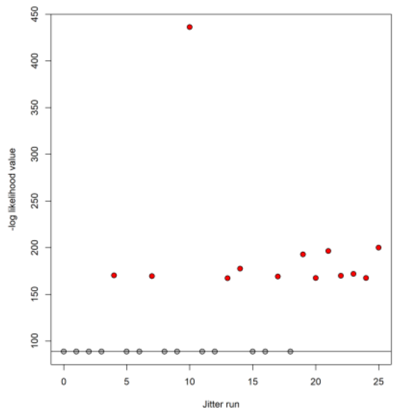


Figure A2.29. Fits of the two-area goldband snapper model to observed vs estimated mean size from FIS length data a) north area, b) south area.

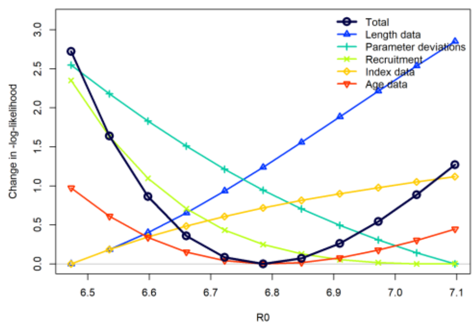
Jitter, likelihood profile and retrospective analysis

The results of a jitter analysis (25 model runs) for the two-area Goldband snapper model show that none of those models had a lower overall NLL (better solution) than the base model (Figure A2.30a). The overall NLL associated with the R0 profile shows a clear minimum. Whilst the NLL likelihood component for the age data is very consistent with the overall NLL pattern, there is inconsistency with other components, e.g., length and parameter deviations, highlighting a level of tension in the model (Figure A2.30b). The likelihood profiles for M and h show no overall minimum, indicating insufficient information in the data to estimate either of these parameters (Figure A2.30c-d). There is limited retrospective pattern among relative female spawning biomass trends for models with varying amounts of data (Figure A2.30e).

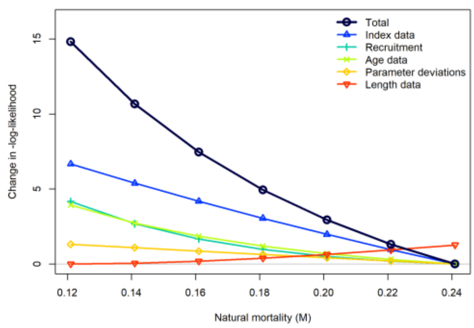
a) Jitter analysis results



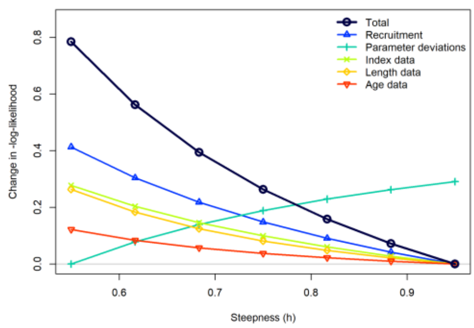
b) Likelihood profile (R_0)



c) Likelihood profile (*M*)



d) Likelihood profile (*h*)



e) Retrospective analysis (B_{rel})

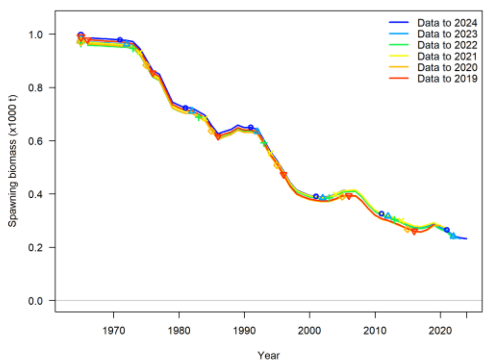


Figure A2.30. Model diagnostics for the two-area goldband snapper model, including: a) jitter analysis, b) likelihood profiles for R0, initial recruitment, c) likelihood profiles for M, natural mortality, d) likelihood profiles for h, steepness, and e) a retrospective analysis, displaying results for relative female biomass (B_{rel}) levels.