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New South Wales Stock Assessment Report 2026. Snapper (*Chrysophrys auratus*).

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More information

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Summary

This stock assessment report presents the outcomes from the first fully integrated population model for Snapper (*Chrysophrys auratus*, CAAB 37 353001) done using just data from New South Wales (NSW). The stock assessment was done to support harvest strategy development for the Snapper fishery in NSW and utilised an age-structured population model using the software package Stock Synthesis (SS; version SS-V3.30.16), see Methot et al. (2019).

The stock assessment model was based on 4 catch fleets, being commercial trap, commercial line, recreational and historical. The fishery was assumed to have begun from an unfished state in 1880. In addition to catch, inputs to the model included length compositions from the commercial trap and line fleets with selectivity estimated, age-at-length data from the commercial trap fishery, standardised catch rates from the commercial trap and line fleets, and biological parameters. The base-case model was developed using a pre-specified value for natural mortality (*M*) of 0.167 and a stock-recruitment steepness parameter (*h*) of 0.75. Recruitment was estimated by the model until 2020, after which a recent (5-year) average of recruitment deviations was applied to the recruitment specified by the stock-recruitment relationship. Five alternative model scenarios were developed varying *M* (0.135 and 0.2), *h* (0.65 and 0.85) and levels of historical recreational catch, to examine the impact of these on the model outputs.

The base-case model estimated the unfished female spawning biomass (SSB_0) at 10,640 t and female spawning biomass at the beginning of 2023 to be 2,386 t, producing a biomass depletion estimate of 22.4% (17.3% - 27.5% approximate 95% confidence interval) of unfished levels. The biomass trajectory indicated a steady decline from around 1950 to 1990, followed by around 30 years of increase to the final year in the model 2022/23.

The alternative model scenarios tested all showed similar biomass trajectories to the base-case, but with deviations evident after the early 1980s when the model commenced estimation of recruitment variations. The model was most sensitive to the value of *M*, with the high-*M* value of 0.2 estimating depletion to be 31.7% of unfished levels and the low-*M* value of 0.135 estimating depletion to be as low as 15% of unfished levels in 2022/23. Lower *h* (0.65) produced a slightly lower depletion estimate (-1.7%) and the higher *h* (0.85) a slightly higher estimate (+2.4%) compared to the base-case. The lower historical recreational harvest scenario was very similar to the base-case.

Biomass trajectories were forecast for the next 40 years using a range of constant catch scenarios (current at 263 t, low at 150 t and high at 400 t) and assuming recent average recruitment would continue in future. Constant catch was required to achieve forecasting while implementing deviation from the stock-recruitment relationship. Forecasting was also completed using a draft harvest control rule developed for Snapper in the Line and Trap Harvest Strategy; however, this can only be achieved using long-term average recruitment. All forecast models showed continued increases in biomass. Forecasts using the harvest control rule and average long-term recruitment showed rapid increase and asymptote, with the target reference level of 50% unfished biomass not being attained for 40+ years. Forecasts of biomass using constant catches and recent average recruitment all increased, with faster biomass rebuilding under lower catch.

Future stock assessments of Snapper in NSW waters may benefit from improved estimates of *M*, revised growth modelling, improved estimates of the recreational harvest (historically and currently), reviewed ageing protocols and a spatially compartmentalised model.

Introduction

This stock assessment report for Snapper (*Chrysophrys auratus*, CAAB 37 353001) was developed to inform the harvest strategy for Snapper in New South Wales (NSW). Given the purpose of the assessment is to inform NSW processes, the assessment includes only data from NSW despite the biological stock extending northwards into Queensland waters. This was deemed reasonable based on the understanding that Snapper on the east-coast are largely resident with limited mixing between Queensland and NSW (Rogers et al., 2023).

Snapper in NSW are a high priority species for management and assessment, supporting considerable commercial and recreational fisheries. Snapper supported a substantial line-fishing fleet, including recreational charter boats, from the late 1880s and early 1900s (Thurstan et al., 2018). Commercial fish trapping was developed during the 1940s and rapidly became the dominant method catching Snapper in NSW. Commercial Snapper landings peaked during 1974/75 at 960 t; however, the size of the commercial fleet has diminished considerably since that time, and during the past decade approximately 60% of the catch has been from commercial fishing (trapping 50% and line fishing 10%), and 40% from the recreational sector.

Management history

Snapper in NSW have been managed historically largely through commercial input controls and recreational bag and size limits. The current minimum legal length (MLL) of 30 cm total length (TL) was introduced in July 2001, an increase from 28 cm. The MLL of 28 cm (or equivalent in inches) appears to have been in place since 1939 (Table 1).

The recreational daily bag limit for snapper is 10 fish per person and was introduced in 1990.

The introduction of several marine parks including various management zones during the 1990s and 2000s will have reduced the available fishing grounds for snapper, however to what extent remains unknown.

Contemporary commercial fishery management has included limited entry, minimum shareholdings, boat lengths, trap sizes and numbers, and a MLL of 30 cm TL.

Table 1. Selected management measures through time impacting the fishery for Snapper in NSW. MLL is minimum legal length as total length.

Date	Management measure
pre-1881	MLL of 8 oz (~25 cm)
1881	MLL of 16 oz (~32 cm)
1884	MLL of 12 oz (~29 cm)
1903	MLL of 6 oz (~23 cm)
1914	MLL of 9 inches (~23 cm)
1939	MLL of 11 inches (~28 cm)
1990	MLL of 28 cm, introduced recreational bag limit of 10 snapper per person. Fisheries Management Act

Date	Management measure
1994	Lord Howe Island Marine Park introduced, with some areas closed to fishing
1997	Restricted fishery introduced for the Ocean Trap and Line Fishery
1997	Change to commercial logbooks. Monthly reports linking method to catch
1998	Solitary Islands Marine Park introduced, with some areas closed to fishing
1998	Jervis Bay Marine Park introduced, with some areas closed to fishing
2001	MLL of 30 cm, recreational bag limit of 10 snapper per person
2002	Cape Byron Marine Park introduced, with some areas closed to fishing
2005	Port Stephens–Great Lakes Marine Park introduced, with some areas closed to fishing
2006	Ocean Trap and Line Fishery Environmental Impact Statement Published. Number of demersal fish trap endorsements at 277
2006	Fishery Management Strategy for the NSW Ocean Trap and Line Fishery published. Implications for Snapper management: • Objective 1.2(b) recommended that escape panels be implemented in traps with 50 x 75 mm mesh Objective 2.3(a(i)) recommended implementing a maximum trap number of 30 per endorsement holder
2007	Share management introduced for Ocean Trap and Line Fishery: Shareholding changes: • Minimum shareholding of 1 demersal fish trap share for 'original shareholders' • Minimum shareholding of 40 upon transfer • Trap limit changes: • Maximum of 30 fish traps per demersal fish trap endorsed fishing business Number of demersal fish trap endorsements at 235
2007	Batemans Bay Marine Park introduced, with some areas closed to fishing
2008	'Escape' panels of 50 x 75 mm mesh in the 'back' of demersal fish traps were introduced
2009	Change to daily reporting for commercial logbooks
2015	New minimum shareholding requirement of 40 shares for a demersal fish trap endorsement (for all shareholders)
2017	NSW commercial business adjustment program implemented: Shareholding changes: • New minimum shareholding requirement of 50 shares for a demersal fish trap endorsement • Trap limit changes: • A maximum of 30 fish traps for the first 50 demersal fish trap shares held • Maximum number of traps increased by 10 traps, for every additional 20 shares held
2024	Current progress with Snapper fishing and management: • Number of demersal fish trap endorsements at 111 NSW Snapper Harvest Strategy under development by the Line & Trap Harvest Strategy Working Group

Previous stock assessments

The most recent published stock assessment for east-coast Snapper was done on data up to 2016 (Wortmann et al., 2018). That assessment was done using data from Queensland and NSW and was a full age-structured population model estimated using Matlab (MathWorks 2017). Model scenarios using NSW trap CPUE ranged between 20% and 45% of unfished levels, with most estimates above 30%. Scenarios modelled using Queensland line CPUE data were generally below 20% of unfished levels.

Prior formal stock assessments were done based on Queensland data only (Allen et al. 2006, Campbell et al., 2009), with the earlier study inconclusive whether the stock was overfished and the later study estimating depletion levels likely to be less than 35%. Historical assessments were more limited, although some yield-per-recruit analyses were done on data from NSW and Queensland (Ferrell and Sumpton, 1997).

An unpublished stock assessment was done during 2021 on data to 2019 using data from Queensland and NSW. This assessment was developed using the stock synthesis framework (SS; version SS-V3.30.16. Methot et al. 2019). Model outputs were consistent with the published assessment of Wortmann et al. (2018) for both Queensland and NSW scenarios, and aspects of model development greatly assisted the current NSW assessment.

Biology and stock structure

The Eastern Australian Snapper stock extends from Rockhampton, Queensland to Eden, NSW (Morgan et al., 2019). There is an overlap with a more southern biological stock around Eden (Morgan et al., 2019) that is not considered as part of this assessment. Results from tagging studies indicate that east-coast snapper are generally resident as sub-adults and adults; however, some individuals have been recorded to move large distances to more than 1,000 kms (Sumpton et al., 2003, Harasti et al., 2015, Stewart et al., 2019). The majority of commercial landings in New South Wales are thought to consist of fish that recruit from local estuaries (Gillanders, 2002).

There are considerable latitudinal variations in life-history traits of east-coast Snapper. Snapper grow faster, and mature at smaller sizes and younger ages in more northern latitudes (Stewart et al., 2019, Stewart et al., 2010). Spawning occurs earlier in the year towards the northern end of their distribution (Ferrell and Sumpton, 1997).

The limited movements with latitudinal variation in biological traits has justified previous stock status assessments for east-coast Snapper being done at the jurisdictional level (Rogers et al., 2023). Similar logic is used in the present stock assessment, which is to service NSW management needs, and is limited to the NSW part of the biological stock.

Methods

Data Sources

Catches

Commercial fisheries

Reported commercial landings were available from 1940. These data were obtained from the Departmental databases H_Catch (1940 to 1983), ComCatch (1984 to 2008) and FishOnline (2009 to 2022). Data were compiled by financial year, with year being denoted as the first calendar year (e.g. 2009/10 is denoted as 2009). Almost the entire (97%) of the NSW commercial Snapper catch is taken in the Ocean Trap and Line Fishery (since 2009). Approximately 83% of Snapper are reported as being taken in demersal traps, 16% by line-fishing methods and 1% by other methods including fish trawl and mesh netting. These data were compiled into the relevant assessment fleets being commercial trap and commercial line, with catch from other minor methods being included in the commercial line fleet.

Recreational fisheries

Estimates of any recreational harvests are lacking prior to 2000/01 when the National Recreational and Indigenous Fishing Survey (NRIFS) was done. Since that time there have been 4 more surveys to estimate recreational harvest in NSW, in 2013/14 (West et al., 2015), 2017/18, 2019/20 and 2021/22 (Murphy et al., 2020, 2022, 2023).

Hindcasting the recreational harvest prior to 2000/01 was done using estimates of recreational marine fishing effort nationally as reported by Kleisner et al. (2015). That study used coastal population statistics from the Australian Bureau of Statistics with linear interpolation between census years. A recreational fishing participation rate of 19.5% was used between 1950 and 1970, after which participation was modelled to increase linearly to 34% in 1980 based on survey data (Anon. 1984) to account for an agreed increase during that time. Participation rate was constant at 34% between 1980 and 1990, after which it declined linearly to 19.5% in 2000 based on the NRIFS (Henry and Lyle, 2003) to account for perceived declines in recreational fishing effort.

Recreational fishing effort relative to 2000/01 was indexed using data in Kleisner et al. (2015). Estimates of recreational harvest were made by applying the recreational fishing effort each year relative to 2000 by the estimated harvest in 2000/01 of approximately 246 t. This estimate was made using the numbers as reported in the NRIFS and NSW DPI unpublished estimates of the average weights in estuarine and oceanic waters. Between 1940 and 1950 recreational harvest was estimated by continuing the linear relationship between 1950 and 1970. After 2000, harvest was estimated to follow a linear path between each survey, with the estimate in 2022/23 being set as the same as in 2021/22.

Recreational fishing surveys during 2013/14, 2017/18, 2019/20 and 2021/22 were done as part of the NSW DPI Recreational Fisheries Monitoring Program (https://www.dpi.nsw.gov.au/fishing/recreational/rfmp). The surveys use a sampling frame of long-term (1- or 3-year) NSW recreational fishing licence holders and do not cover the fishing activities of short-term (3-day or 1-month) licence holders, or people exempt from requiring a fishing licence, unless residing in the surveyed household. Therefore, a scaling factor to convert survey estimates into estimates of total recreational harvest was estimated from concurrent surveys done during 2013/14 that included a survey of all recreational fishers using a white-pages sampling approach, and the sub-sampled diary frame survey as currently used. The scaling estimate for Snapper was estimated to be x 1.69 (NSW DPI Unpublished). Charterboat catch is estimated as part of the recreational harvest in the surveys.

Discards

Various studies have reported discard rates of Snapper including the charterboat sector (52%, Gray and Kennelly, 2016), fish trapping (33%, Stewart et al. 2003), commercial line fishing (18%, Macbeth and Gray, 2016), and the recreational sector (65%, Murphy et al., 2020). These discard rates are in numbers of fish and mortality rates unknown. Given the available estimates vary considerably and were made under multiple management eras and with unknown survival rates, we applied a constant rate of 6% discard mortality for each catch fleet and added this to the totals. This was the same approach used in the last joint stock assessment with Queensland (unpublished).

Historical Catch

Snapper fishing was well established by the early 1900s (Thurstan et al., 2016, 2018), with a reported approximate 100 t harvest in NSW by 1900 (Anon). Catch prior to available commercial logbook data in 1940 was therefore modelled back to 1880 as an exponential function fitted to 100 t in 1900 and harvest data 1940 to 1946 (after which a substantial increase in harvest was reported).

Standardized CPUE series

New South Wales commercial logbooks provided data on kgs of snapper per fishing-operation-day. These were standardized separately for monthly aggregated data from the ComCatch database (1984/85 to 1996/97 using records when only fish trapping was reported, 1997/98 to 2008/09 using all Snapper records), and daily reported data from the FishOnline database (2009/10 to 2022/23).

CPUE was standardised for year, latitude, fisher and month in each series, and also depth of capture in the more recent FishOnline data.

Catch-per-unit-effort data were standardised using general linear models in the R package 'cede' (v. 0.0.4, Haddon 2018). Variables used included authorised fisher (as a proxy for boat), latitude (one degree band as reported), month, and also depth of capture (median depth fished on the day) in the more recent FishOnline data. Interaction terms were included. Data were natural log-transformed prior to analysis and model terms were selected and ordered using Akaike's Information Criterion (AIC) and their influence on the adjusted r^2 value (Appendix 1). Model residuals were visually inspected for adherence to normality (Appendix 1). Trends in catch rates were compared to those generated using generalised linear models using the gamma distribution with a log link. Minimal differences were observed between the two standardisation models; therefore, the general linear models were retained.

These analyses produced timeseries of CPUE for:

1. Commercial trap 1984 to 2008
2. Commercial trap 2009 to 2022
3. Commercial line 1997 to 2008
4. Commercial line 2009 to 2022

Length data

Monitoring data on the lengths of commercially landed Snapper are available via port monitoring since 1993. Catches are sampled directly at ports of landing and at the Sydney Fish Markets, with statewide distributions estimated by scaling samples to reported landings by month and latitudinal zone. Details of the monitoring program are in Stewart et al. (2024).

The number of length measurements by fleet and year used in the base case assessment is provided in Table 2.

Table 2. Number of length measurements and number of catches sampled by year and fleet for the Snapper stock assessment.

	Commercial Trap		Commercial Line	
Year	Number	Catches	Number	Catches
1993	11644	167		
1994	22846	312		
1995	11178	232		
1996	9767	249		
1997	10764	162		
1998	25104	323		
1999	17334	309		
2000	21279	328		
2001	17560	353		
2002	6340	148		
2003	1312	38		
2004	863	13		
2005	9431	189	259	30
2006	12337	243	1030	57
2007	19335	336	1858	73
2008	15879	282	990	49
2009	15661	266	778	36
2010	20338	273	1773	71
2011	16712	221	1052	51
2012	18217	300	1670	68
2013	10477	231	1925	88
2014	13521	260	2125	85
2015	14353	280	1927	100
2016	13060	220	1856	82
2018	14258	255	940	68
2020	14803	198	595	35
2022	11749	195	656	42

Age data

Age-at-length data from the commercial trap fishery are available sporadically since 1993 and were collected during routine port monitoring and dedicated snapper research projects. These data were treated as conditional age-at-length in the model. Note that the age-at-length data from 2018, 2020 and 2022 conflicted with the observed length frequency data for those years, causing the model to estimated radically low recruitment deviations. These recent age-at-length data were subsequently removed from the base-case model pending investigation of otolith interpretations and fishery sampling from those years.

Table 3. Number of age-at-length estimates for the Commercial Trap fleet for the Snapper stock assessment.

Year	Number
1993	2296
1994	1586
1995	1616
1997	531
1998	2104
1999	1164
2000	1335
2001	1284
2002	300
2003	267
2005	478
2008	645
2010	790
2011	204
2012	223
2013	209
2014	462
2018	703
2020	853
2022	785

Selectivity

Selectivity of Snapper in the NSW demersal trap fishery is assumed to be dome-shaped, with relatively knife-edged selectivity on the left hand side of the selectivity-at-length plot due to mesh selectivity of the trap, and a more gradual decline in selectivity on the right-hand side due to the narrow trap entrance and avoidance behaviour of larger-bodied Snapper (Stewart and Ferrell, 2002, 2003). Therefore, selectivity for the Commercial trap fleet was estimated as a double-normal curve; whereas selectivity of the Commercial line fleet was estimated as a logistic curve. Selectivity of the Recreational and Historical fleets were also assumed to be logistic and were mirrored to the Commercial line fleet.

Biological parameters

The pre-specified biological parameters used in the assessment and their sources are provided in Table 4. Male and female Snapper have the same biological parameters, including natural mortality (*M*), growth and length-weight relationship.

Growth

Growth was estimated by fitting a von Bertalanffy growth function to the 13,730 size-at-age data points in the NSW DPIRD age database. The coefficient of variation (CV) around the growth curve was set at 0.15 based on the observed CVs for length at ages 2, 3, 4 and 5.

Stock recruitment relationship

There was no information to inform the value of the steepness of the Beverton-Holt stock recruitment relationship so a value of h = 0.75 was chosen for the base case. This value is consistent with averages for marine demersal stocks (Shertzer and Conn 2012). Sensitivities to h = 0.65 and h = 0.85 were done.

Natural Mortality

Natural mortality of Snapper was pre-specified at 0.167 yr^{-1} in the base case. This was estimated based on a maximum age of 40 years and the approach in Then et al. (2015):

$$M = 4.899 t_{max}^{-0.916}$$

This value was similar to the values of *M* estimated in the last four stock assessments for east-coast Snapper being *M* = 0.15 to 0.2 (Allen et al., 2006), *M* = 0.15 to 0.19 (Campbell et al., 2009), *M* = 0.163 to 0.21 (Wortmann et al., 2018) and *M* = 0.16 to 0.2 (Unpublished stock assessment). Previous assessments have reported a large effect of varying *M* and sensitivity scenarios are done in the current assessment varying *M* from a lower value of 0.135 (derived using the recommended approach in Maunder et al. 2023 and a maximum age of 40 years) to a high of 0.2 being the upper values used in previous assessments.

Estimates of *M* for Snapper have varied considerably amongst stock assessments and regions. *M* is estimated at around 0.05 to 0.075 in South Australian and New Zealand stock assessments (Langley, 2021, Drew et al., 2022), substantially lower than estimates uses on the east-coast of Australia. In Western Australia values of *M* between 0.12 and 0.144 are currently used based on a maximum age of 30 years (Fairclough et al., 2021).

Table 4. Values of pre-specified biological parameters for Snapper. Length refers to fork length.

Parameter	Value
Natural mortality M (yr-1)	0.167
Beverton Holt Steepness (h)	0.75
Growth parameters	
von Bertalanffy K (yr-1)	0.057
length (cm) t0	-3.73
asymptotic length L∞ (cm)	85.6
Growth CV	0.15
Length-weight parameters	
Scalar a	0.0000618
Power b	2.7108
Maturity	
length 50% (cm)	24.8
length 95% (cm)	34
Fecundity	
scalar a	0.0000618
power b	2.7108

Population model

An annual age-structured population model was fitted to the data to determine the number of Snapper in each year and each age group using the software package Stock Synthesis (SS; version SS-V3.30.16). see Methot et al. (2019).

Model assumptions

- The fishery began from an unfished state in 1880.
- The fraction of fish that are female at birth is 50% and remains so throughout an individual's life.
- Growth occurs according to the von Bertalanffy growth curve.
- The weight and fecundity of snapper are parametric functions of their size.
- The instantaneous natural mortality rate does not depend on age, size or sex.

- Deterministic annual recruitment is a Beverton-Holt function of stock size.

Base case model

The base case model was specified as:

- A single stock comprising catches from NSW 1880 to 2022.
- Four catch fleets: Commercial Trap, Commercial Line, Recreational, Historical.
- Time varying catchability parameters Q before and after 2008.
- Length data for Commercial Trap and Commercial Line fleets, with selectivity estimated.
- Age-at-length data from 1993 from Commercial Trap fleet.
- Pre-specified biological parameters described in Table 4.
- Estimated recruitment deviations from 1984-2020.
- Recent (5-year) average of recruitment deviations applied from 2021 onward.
- Francis weighted length and age data.
- Bias adjusted recruitment.

Tuning description

Models were tuned using the following procedure:

- All variance adjustment factors were set to 1.
- The model was run and the fits and the Francis weights were examined.
- Variance adjustments were made to the length and age data according to Francis weighting estimation and the model rerun. This continued until Francis weights reached 1 within two 2 d.p.
- The bias-ramp was tuned, as was sigmaR (using suggested value from r4ss)
- Bias ramp tuning continued until there was no change in the year inputs.
- Sigma R tuned until no change to 2 d.p.
- Extra SD was enabled for CPUE indices, but estimates for these parameters indicated this was not required (estimated extra Q <0.2), so these were disabled again.
- A final check of the weights on the length and age data was made.

Sensitivity tests and alternative scenarios

- Several additional model runs were undertaken to determine sensitivity to pre-specified parameters, assumptions and model inputs. Sensitivities were tested regarding natural mortality, steepness and recreational harvests. Each component was varied from the base case to test the difference such a change would make.
- Natural mortality (*M*) pre-specified at 0.135
- Natural mortality (*M*) pre-specified at 0.2
- Steepness (*h*) pre-specified at 0.85
- Steepness (*h*) pre-specified at 0.65

- Recreational harvest lower 10th percentile estimate for 2000/01 survey used to examine potential for over-estimation in that survey. Hindcasting from 2000/01 and interpolation between 2000/01 and 2013/14 survey estimates were redone.

Biomass Projections

Biomass trajectories under a range of future catch scenarios were modelled using the base case and alternative scenario models. Projections were done using the recent average recruitment from the base case, which is only possible with constant catch values across all forecast years, rather than a harvest control rule. Three constant catch scenarios were investigated, being current catch (2022) of 263 t, a higher catch of 400 t and a lower catch of 150 t. Forecasting was also done by applying the draft harvest control rule being developed in the NSW Snapper harvest strategy (Fig. 1), which required an assumption of long-term average recruitment. Projections were done for 40 years beyond the model end year (2022/23).

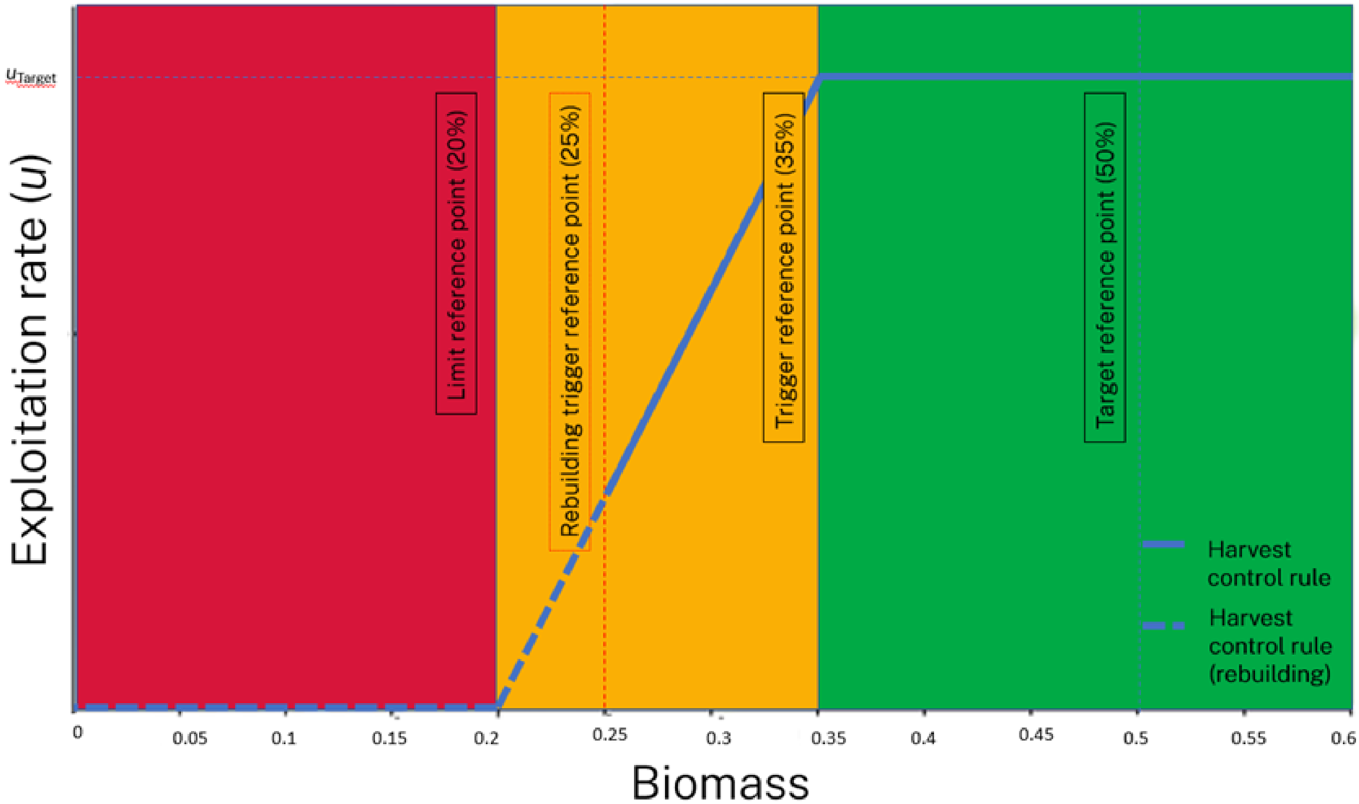

Figure 1. The draft harvest control rule for Snapper.

Results

Model inputs

The data sources available and used in the model are in Fig. 2.

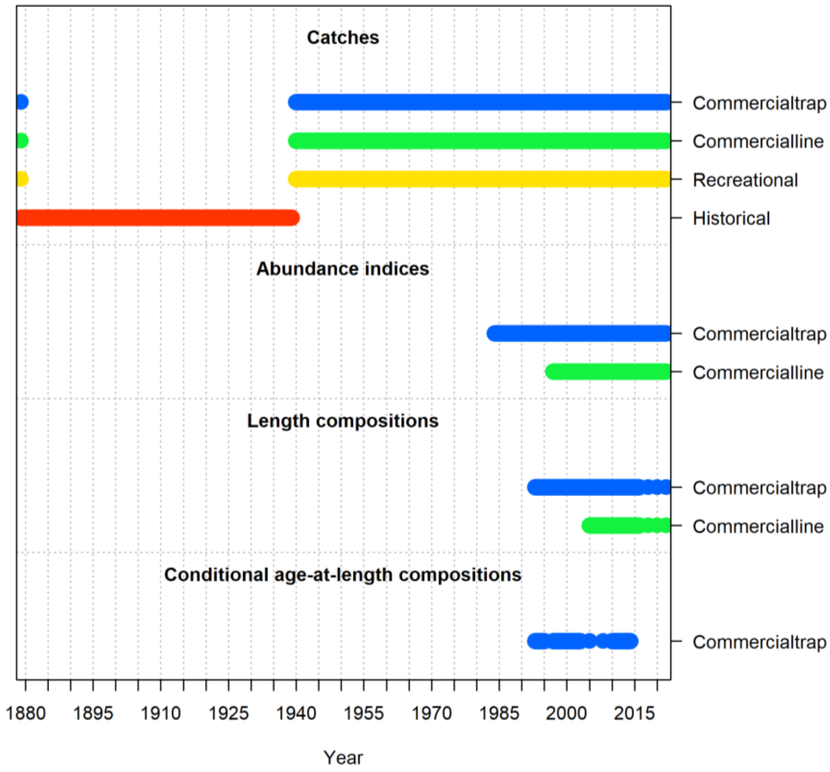

Figure 2. A summary of the input data used in the Snapper stock assessment by fleet.

Catches

The distribution of Snapper harvests amongst the four fleets are shown in Fig. 3. The catch reconstruction indicates that harvests peaked at more than 1,300 t p.a. during the early 1980s followed by a decline to current levels of approximately 263 t in 2022.

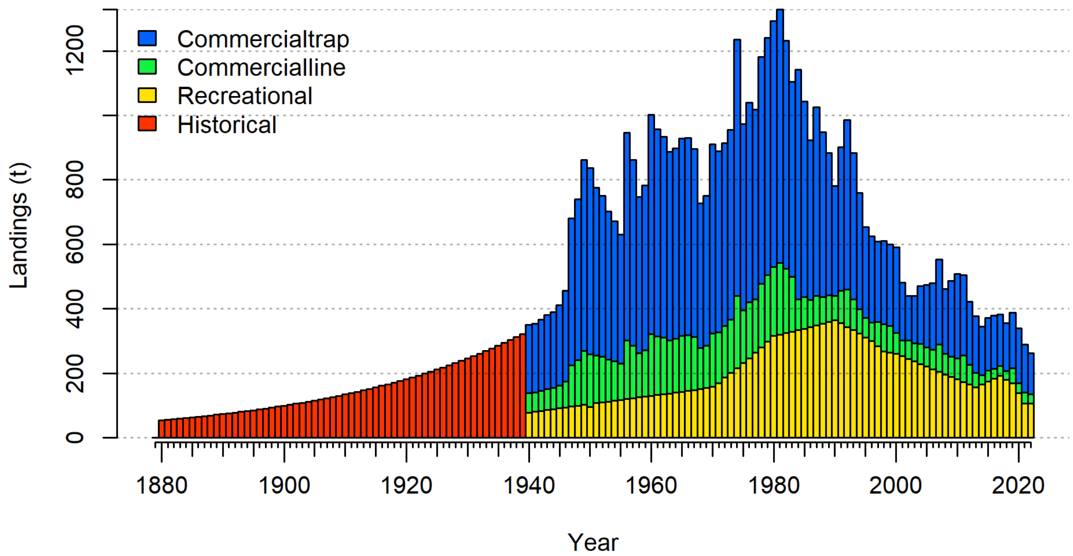

Figure 3. Estimated harvest (tonnes) for the commercial trap, commercial line, recreational and historical fleets used in the stock assessment.

Standardized CPUE series

The standardized CPUE series for the commercial trap fishery indicated some cyclical but overall increasing trend for the 1984 to 2008 logbook data (Fig. 4). The 2009 onwards series also has evidence of some cyclical pattern but showed no overall increase or decrease during that time (Fig. 4). The standardized CPUE series for the commercial line fishery showed a similar increase between 1997 and 2008 to the trap fishery, with less obvious cyclical variation (Fig. 5). The pattern in CPUE from 2009 to 2022 was similar to the trap fishery with corresponding relatively higher and lower points in each year and no overall trends, noting a gradual increase from a low in 2013 to 2021 (Fig. 5).

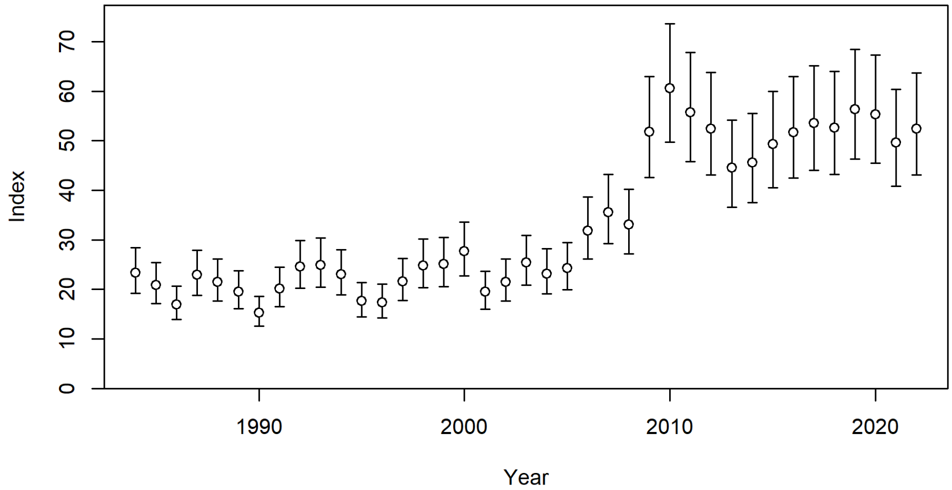

Figure 4. Standardized catch rates for the commercial trap fleet. Lines indicate 95% uncertainty intervals. Note that time-varying catchability coefficients were used in the stock assessment model to separate early and late periods of the time-series of logbooks, being 1984 to 2008 and 2009 to 2022.

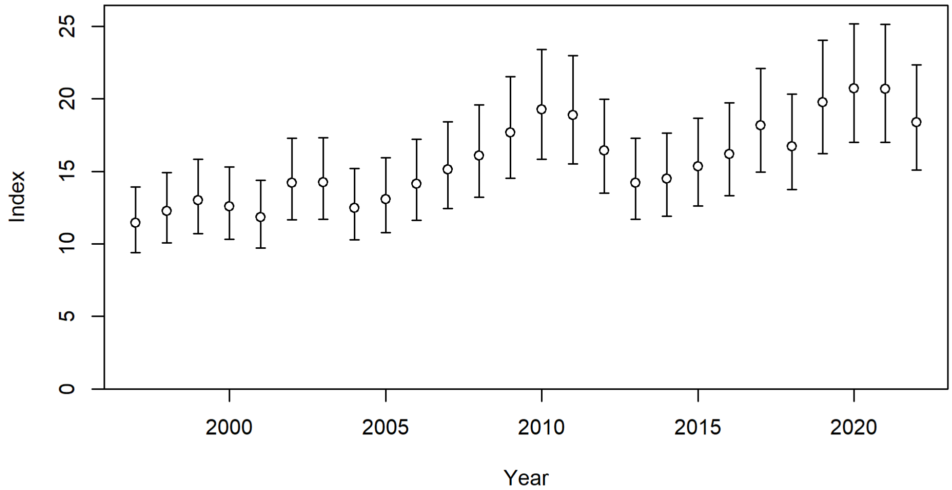

Figure 5. Standardized catch rates for the commercial line fleet. Lines indicate 95% uncertainty intervals. Note that time-varying catchability coefficients were used in the stock assessment model to separate early and late periods of the time-series of logbooks, being 1997 to 2008 and 2009 to 2022.

Length data

Length frequency distributions of the landed commercial catch have remained remarkably stable since the early 1990s, particularly for the commercial trap fishery (Fig. 6). A management change increasing the minimum legal length to 30 cm TL (~25.4 cm FL) in 2007 being the only obvious change, with the vast majority of fish being less than ~ 49 cm FL. The lengths of Snapper landed from the commercial line fishery comprised substantially more fish greater than ~ 40 cm FL, noting the small effective sample sizes in many years (Fig. 7).

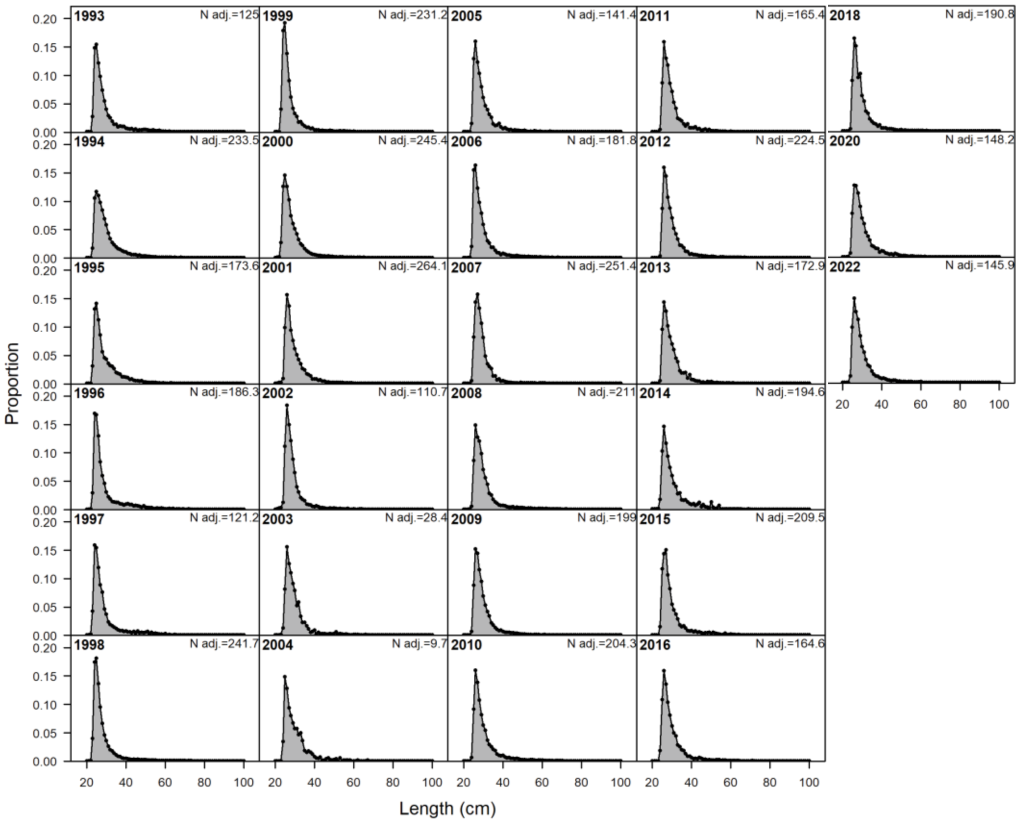

Figure 6. Length frequency distribution data of landed catch for the commercial trap fleet each year.

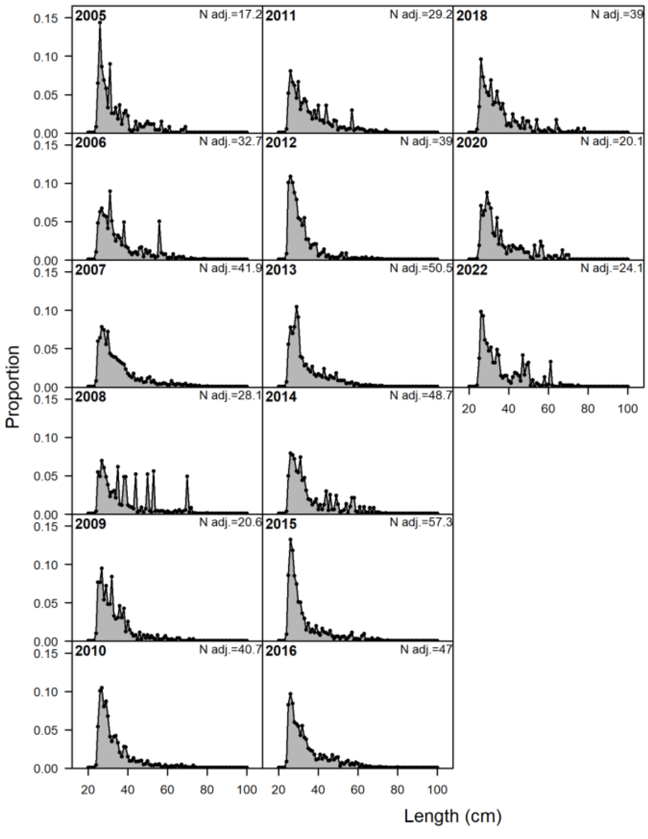

Figure 7. Length frequency distribution data of landed catch for the commercial line fleet each year.

Age data

The age-at-length data were from the commercial trap fleet and therefore reflected an increase in minimum legal length in 2007 (28 to 30 cm FL) and the selectivity of the fish traps (Fig. 8).

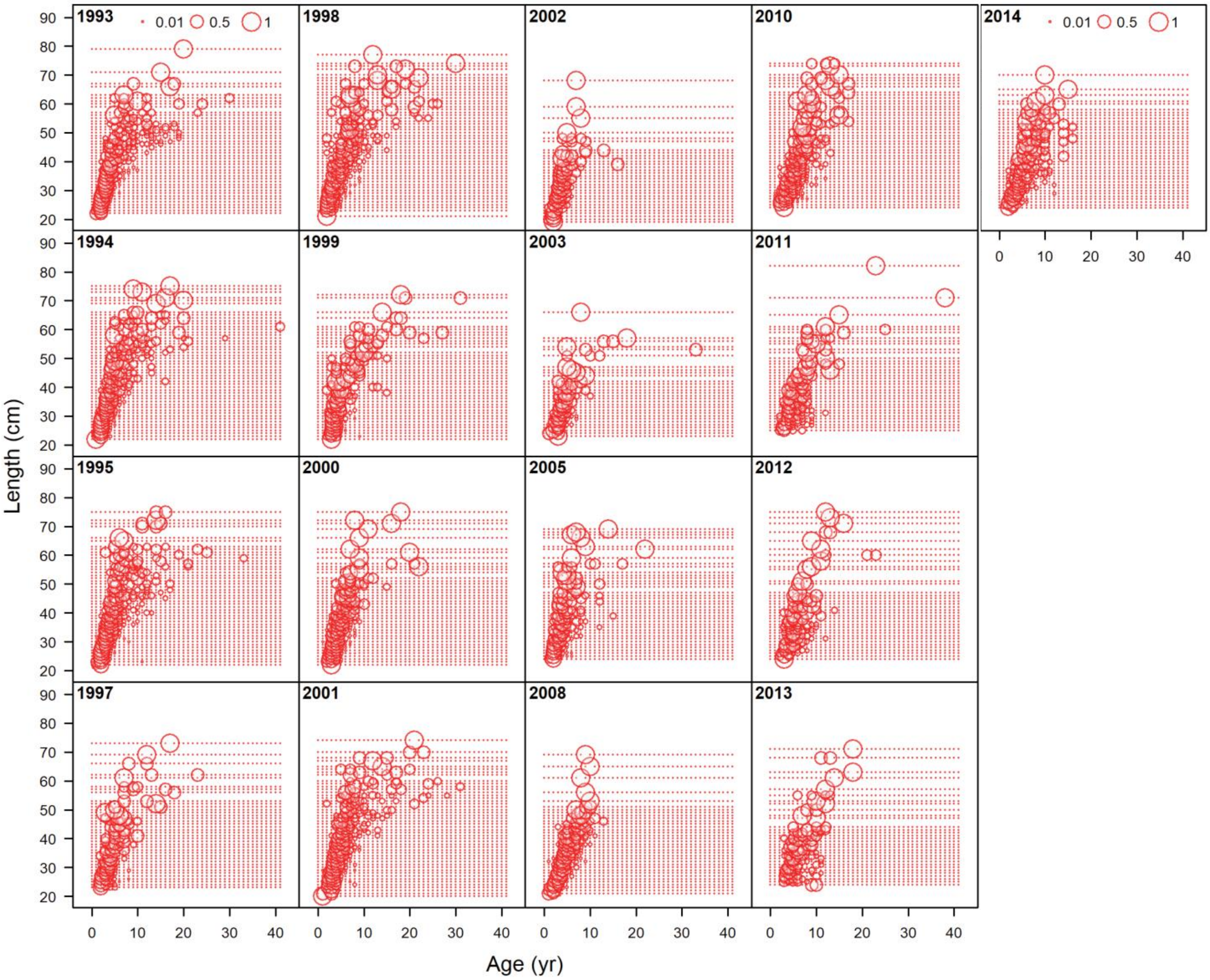

Figure 8. Sampled age-at-length data for the commercial trap fleet 1993 to 2014.

Model outputs

Base case model

Estimated parameter values (with standard deviations) are in Table 5.

Table 5. Estimated parameters and standard deviations for the base-case. Estimates were derived assuming long-term average recruitment.

Parameter	Value	Standard deviation
Unfished equilibrium recruitment (lnR0)	7.99	0.01
Catchability coefficient (lnQ) for trap fleet - pre 2009	-3.93	0.05
Catchability coefficient (lnQ) for line fleet - pre 2009	-5.45	0.08
Catchability coefficient (lnQ) for trap fleet - post 2009	-3.31	0.09
Catchability coefficient (lnQ) for line fleet - post 2009	-5.48	0.12
Trap fleet double normal selectivity peak (cm)	25.86	0.08
Trap fleet double normal selectivity top (logit)	-14.04	21.88
Trap fleet double normal selectivity ascending width	0.76	0.09
Trap fleet double normal selectivity descending width	3.26	0.08
Trap fleet double normal selectivity final length bin (logit)	-1.42	0.08
Line fleet logistic selectivity inflection (cm)	25.19	0.16
Line fleet logistic selectivity width	0.77	0.20

Selectivity

Logistic selectivity curves for the historical, recreational and commercial line fishing fleets, and the dome-shaped selectivity curve for commercial fish traps are in Fig. 9.

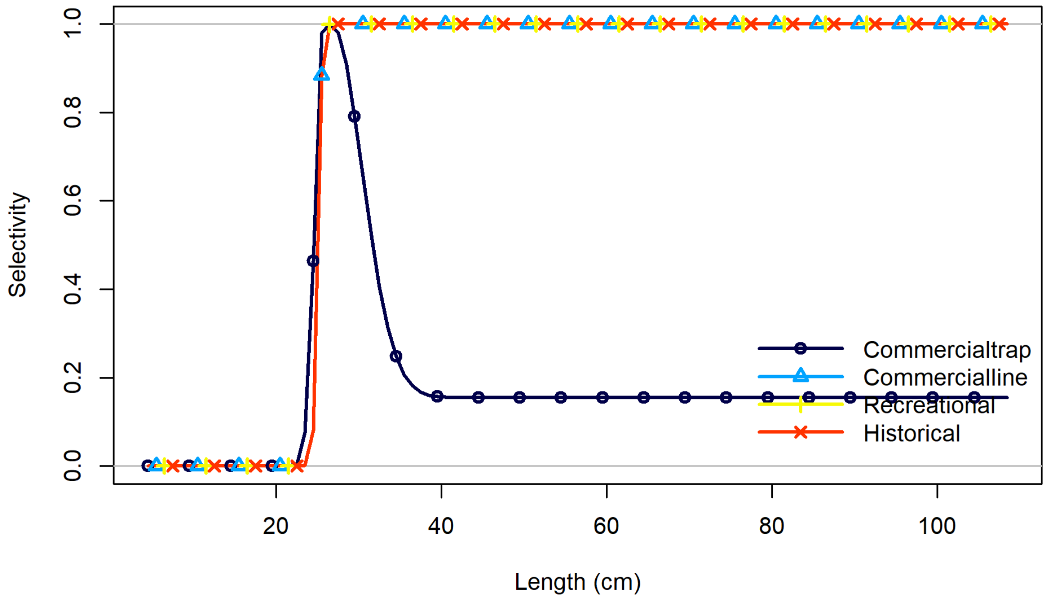

Figure 9. Fitted selectivity curves for the four fleets in the Snapper stock assessment model.

Recruitment

Recruitment was estimated from 1984 to 2020 and indicated generally lower recruitment than predicted by the stock-recruitment relationship (referred to subsequently as 'average' recruitment) during recent years (Fig. 10). Recruitment strength was estimated to be lower than average during 17 of the most recent 24 years. The average of the five most recent estimated recruitment deviations was used in constant catch forecasting (Fig. 10).

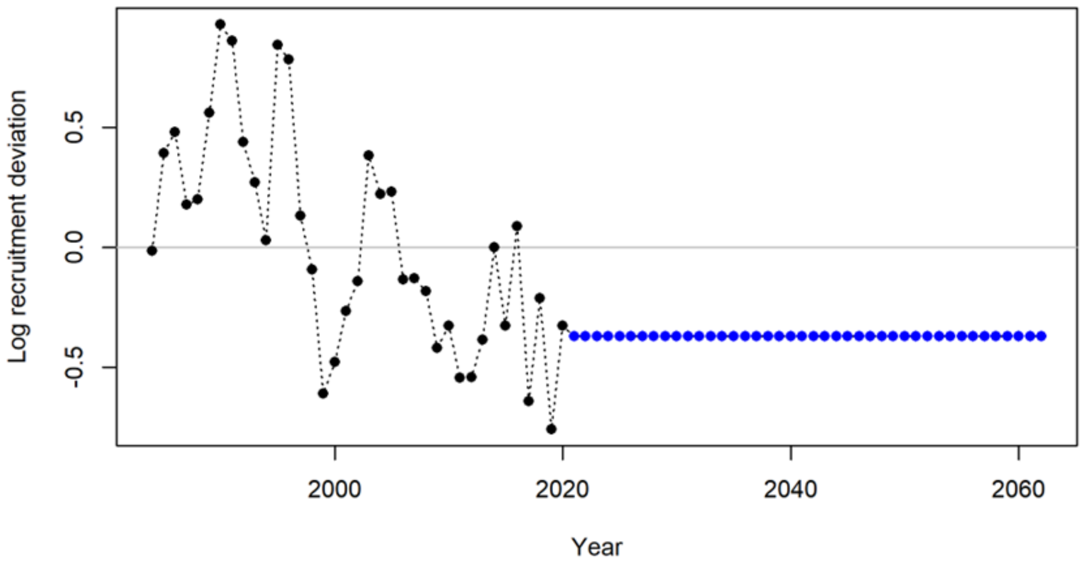

Figure 10. Estimated recruitment deviations 1984 to 2020, and into the forecasting phase, in the Snapper stock assessment model.

Biomass

The base-case model estimated unfished female spawning biomass (SSB_0) was 10,640 t and the 2023 spawning biomass (SSB_{2023}) was estimated to be 2,386 t with stock status (SSB_{2023}/SSB_0) estimated to be 22.4 % (Fig. 11). Spawning biomass declined fairly constantly after around 1950, falling below the limit reference level of 20% of unfished levels in the early 1980s. Biomass has been steadily increasing since the mid-1990s.

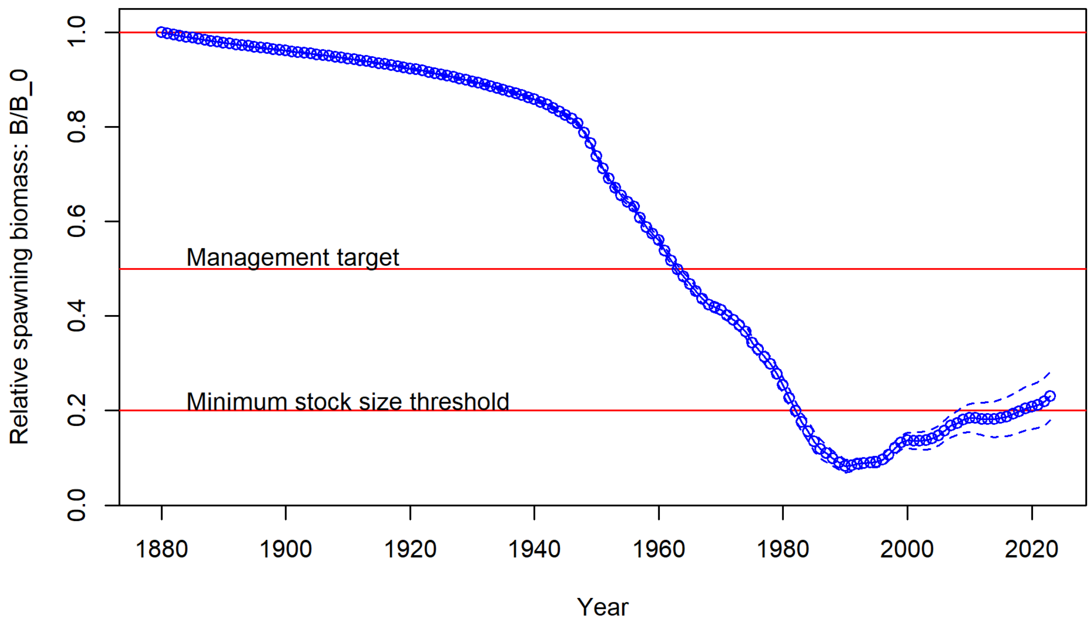

Figure 11. Time-series of relative spawning biomass estimates for the base case Snapper assessment. Dotted lines represent the 95% confidence intervals.

Model fits

Fits to the standardised CPUE, length frequency and age-at-length data series were reasonable with no obvious trends in bias (Figs. 12, 13, 15). The time varying catchability coefficients captured the CPUE changes before and after 2008/09; however the fit to the line CPUE data after 2008/09 was flatter than the trend in the data (Fig. 12). Fits to the trap length data were very good, whereas the fits to the line data under-estimated the proportion of smaller fish in some years (Fig. 14).

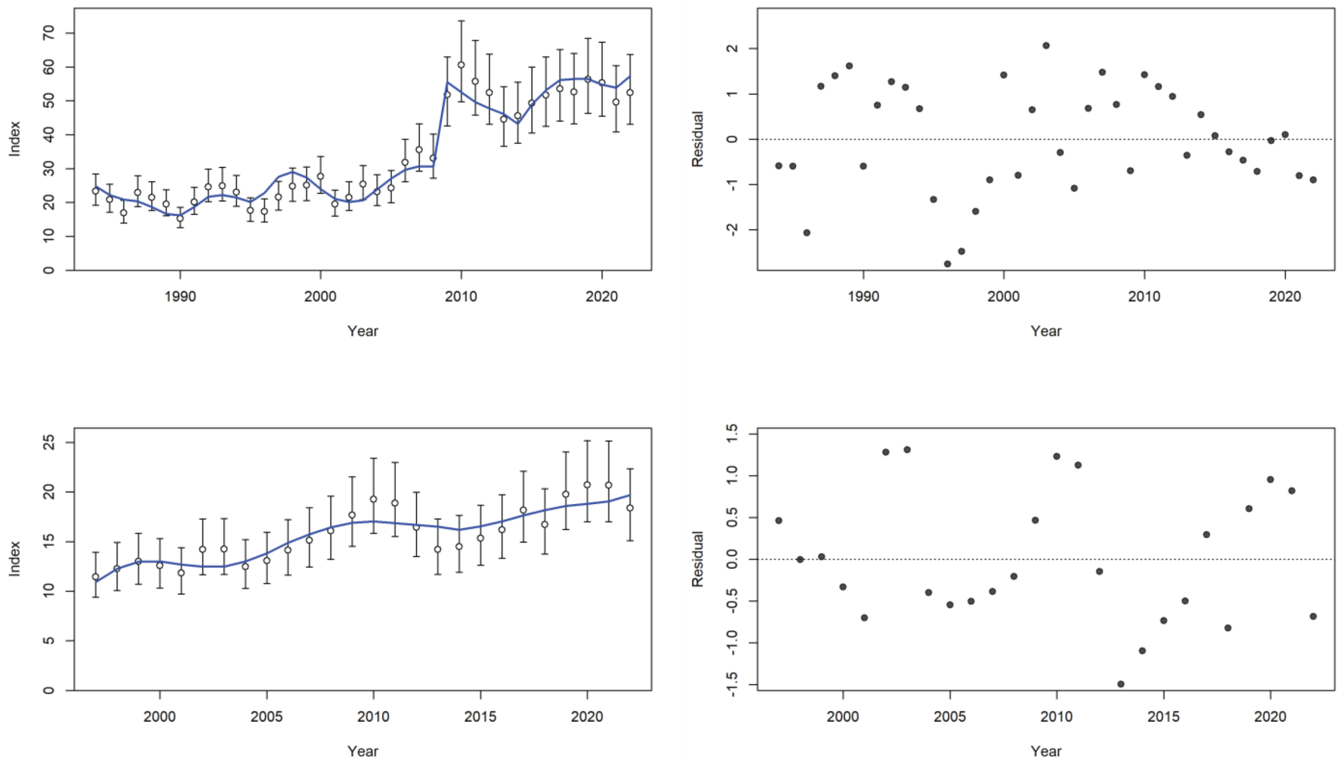

Figure 12. Fits (left) and residuals (right) of standardized CPUE series for commercial trap (top), and commercial line (bottom) for the base case Snapper assessment.

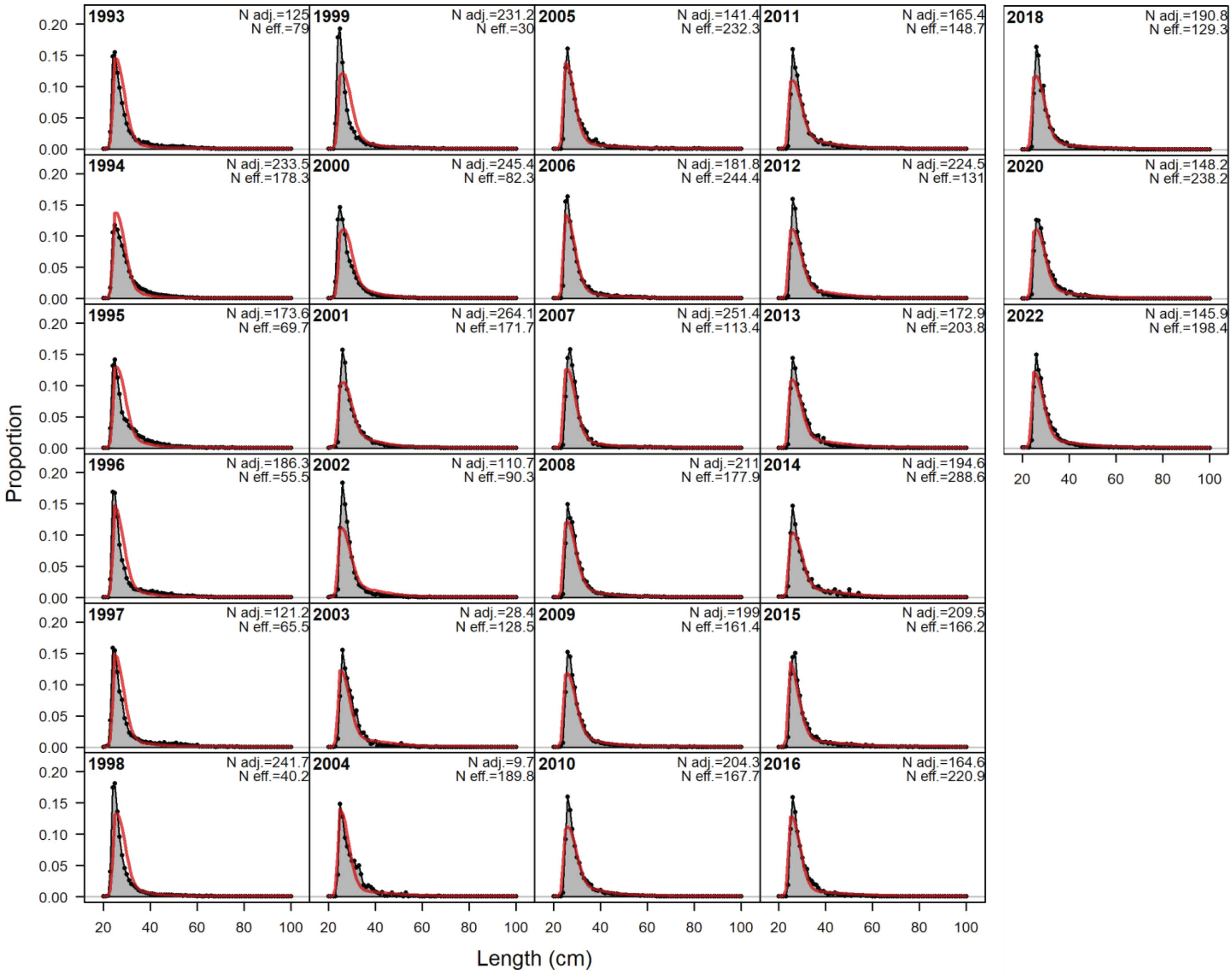

Figure 13. Fits to the annual commercial trap retained length frequency data for the base case Snapper assessment.

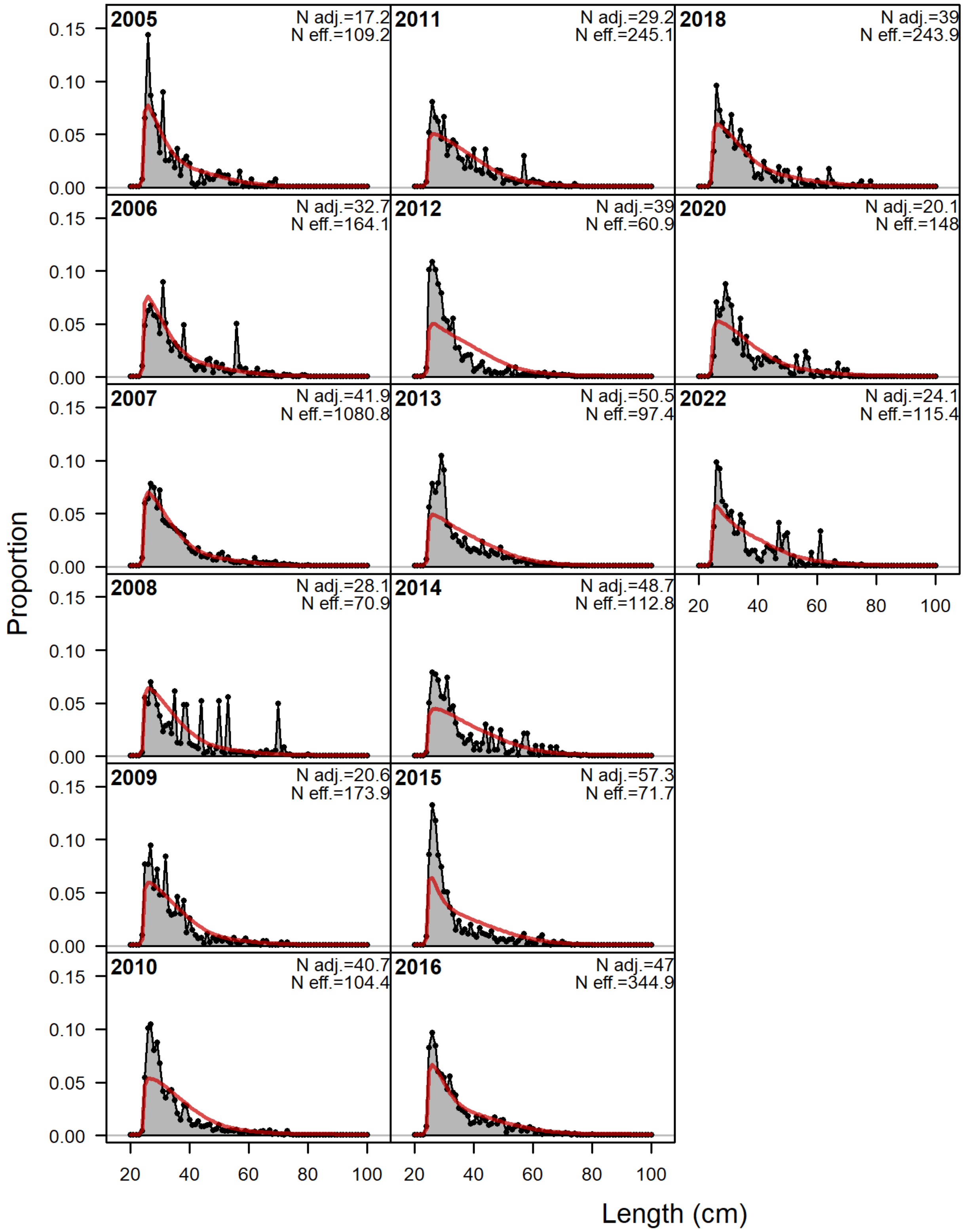

Figure 14. Fits to the annual commercial line retained length frequency data for the base case Snapper assessment.

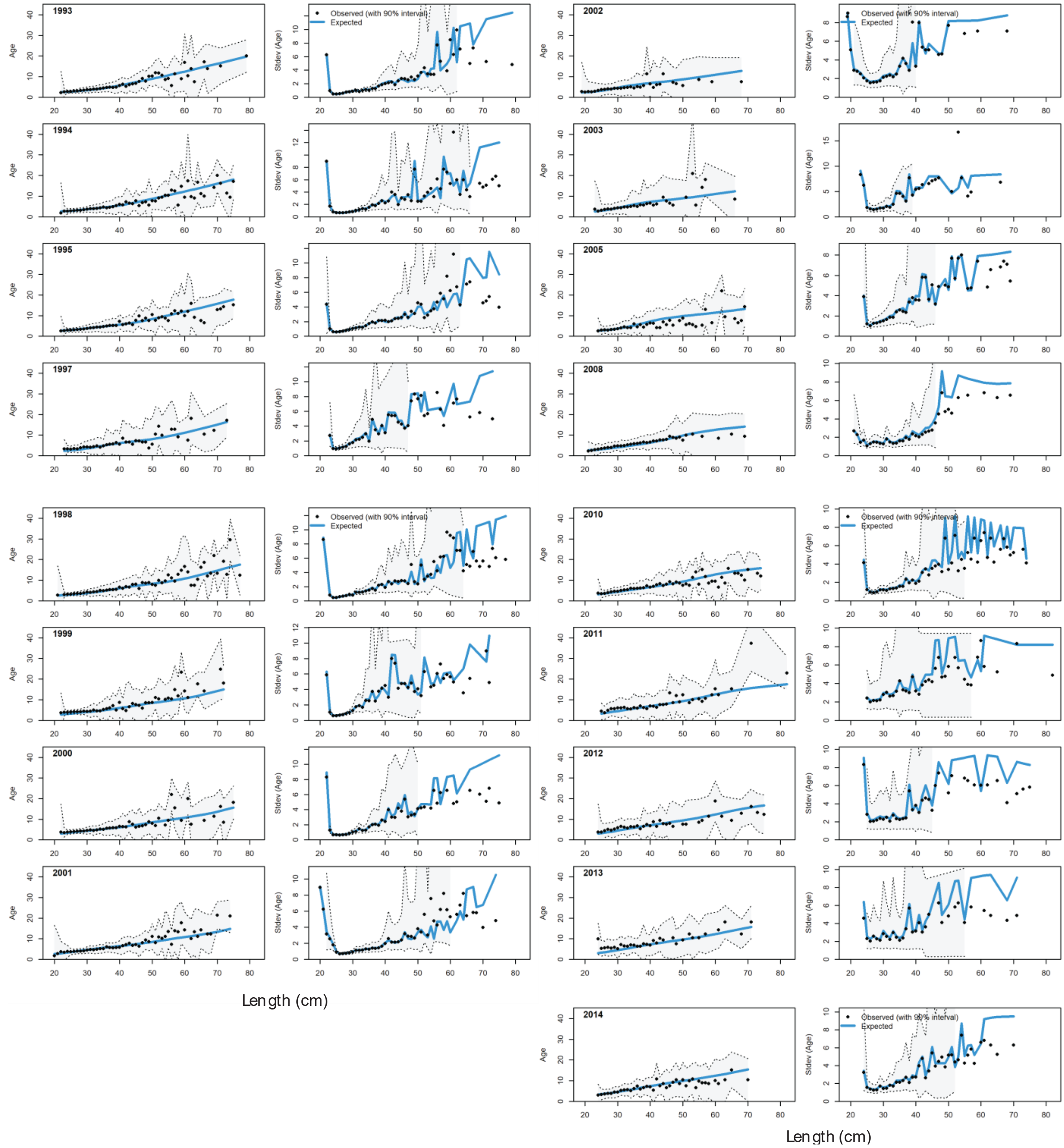

Figure 15. Fits to the mean (left) and standard deviation (right) of age-at-length data for the commercial trap fleet for the base case Snapper assessment.

Sensitivity tests and alternative scenarios

The base case depletion trajectory was quite robust to the variations examined (Table 6, Appendix 2). All models indicated a steady decline in biomass until around 1990, followed by around 30 years of a steady increase (Fig. 16). The model was most sensitive to the value of natural mortality, with the high-*M* value of 0.2 estimating depletion to be 31.7% of unfished levels and the low-*M* value of 0.135 estimating depletion to be as low as 15% of unfished levels. The scenario that included a lower recreational catch hindcast from the national survey in 2000/01 was similar to that of the base case.

Table 6. Absolute and relative spawning biomass estimates from sensitivity scenarios compared to the base-case result. SSB_0 indicates unfished spawning biomass (t), SSB_{2023} indicates spawning biomass at the beginning of the first year after the data period, SSB_{2023}/SSB_0 indicates relative spawning biomass at the beginning of 2023 and $\Delta SSB_{2023}/SSB_0$ indicates the difference in relative spawning biomass to the base case.

Scenario	SSB_0	SSB_{2023}	SSB_{2023}/SSB_0 (%)	Δ SSB_{2023}/SSB_0 (%)
Base case	10,640	2,386	22.4	0.0
Steepness of the stock recruitment relationship				
Low *h* (0.65)	11,424	2,363	20.7	-1.7
High *h* (0.85)	10,027	2,483	24.8	2.4
Natural mortality (*M*)				
Low *M* (0.135 yr^{-1})	12,825	1,924	15.0	-7.4
High *M* (0.200 yr^{-1})	9,094	2,884	31.7	9.3
Low recreational catch	10,426	2,276	21.8	-0.6

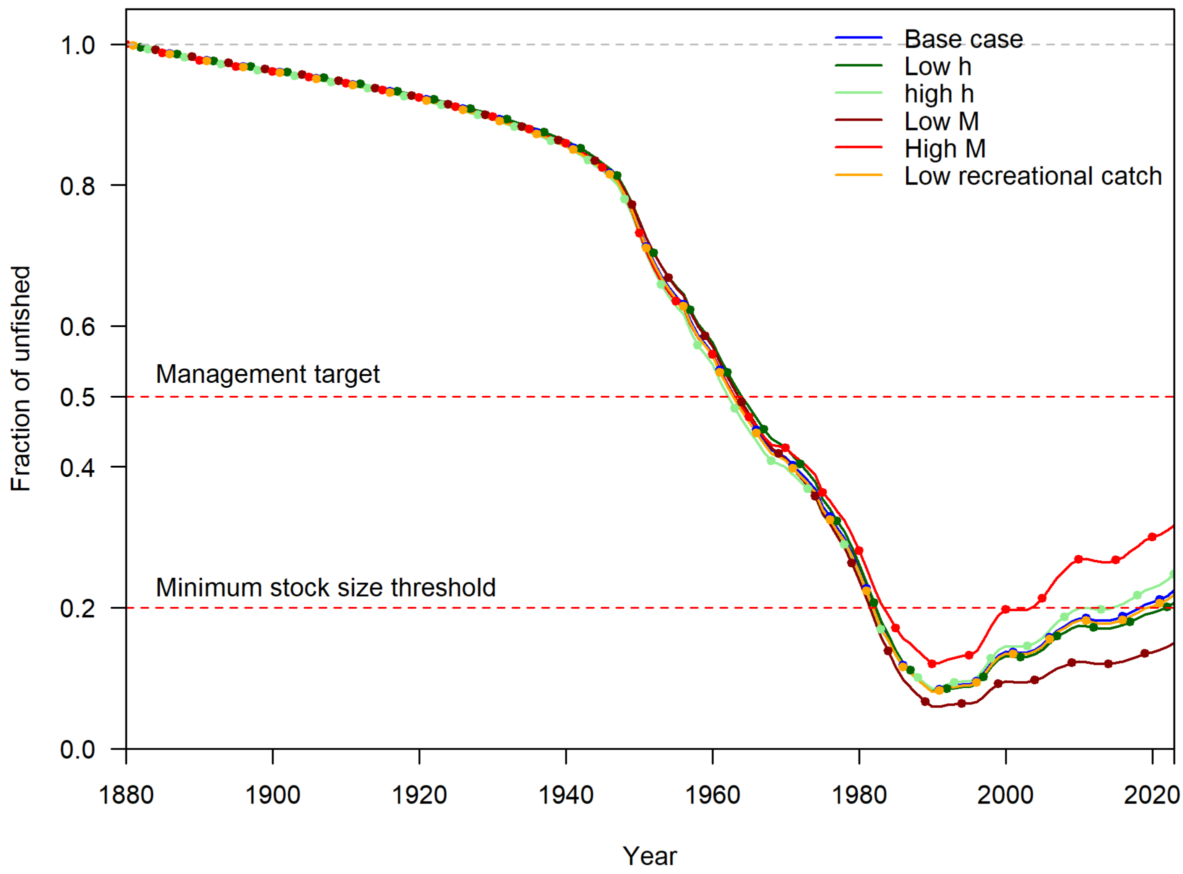

Figure 16. Time series of relative biomass for each of the alternative scenarios modelled.

Biomass projections

Biomass was predicted to increase using the base case model under various constant catch scenarios assuming recent (5 years) average recruitment and application of the draft harvest control rule assuming long-term average recruitment (Figs. 17, 18). Projections using the alternative model scenarios showed similar trajectories of increasing biomass through time under constant current (263 t) catch and assuming recent average recruitment (Fig. 19).

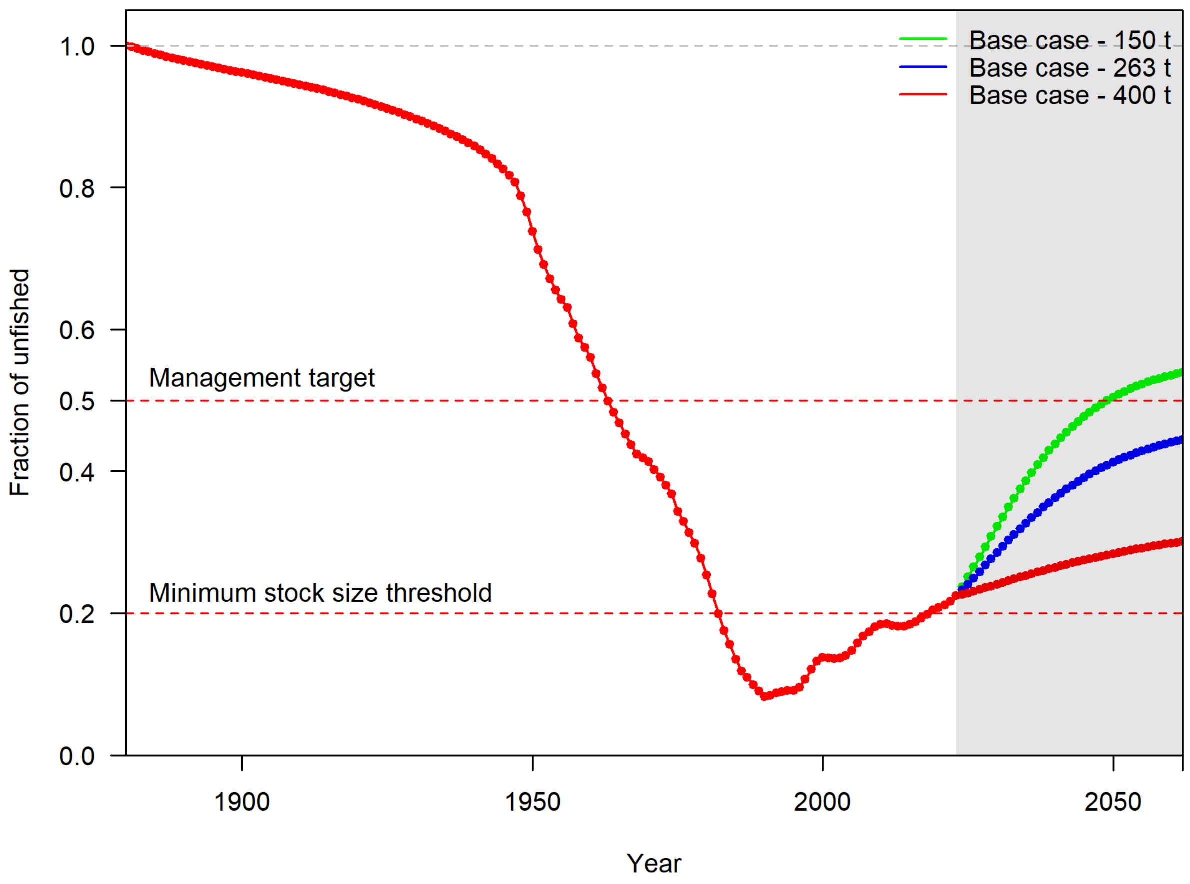

Figure 17. Projections of relative biomass for three constant catch scenarios. Projections used the base-case model and assumed recent (5 years) average recruitment throughout the projection period.

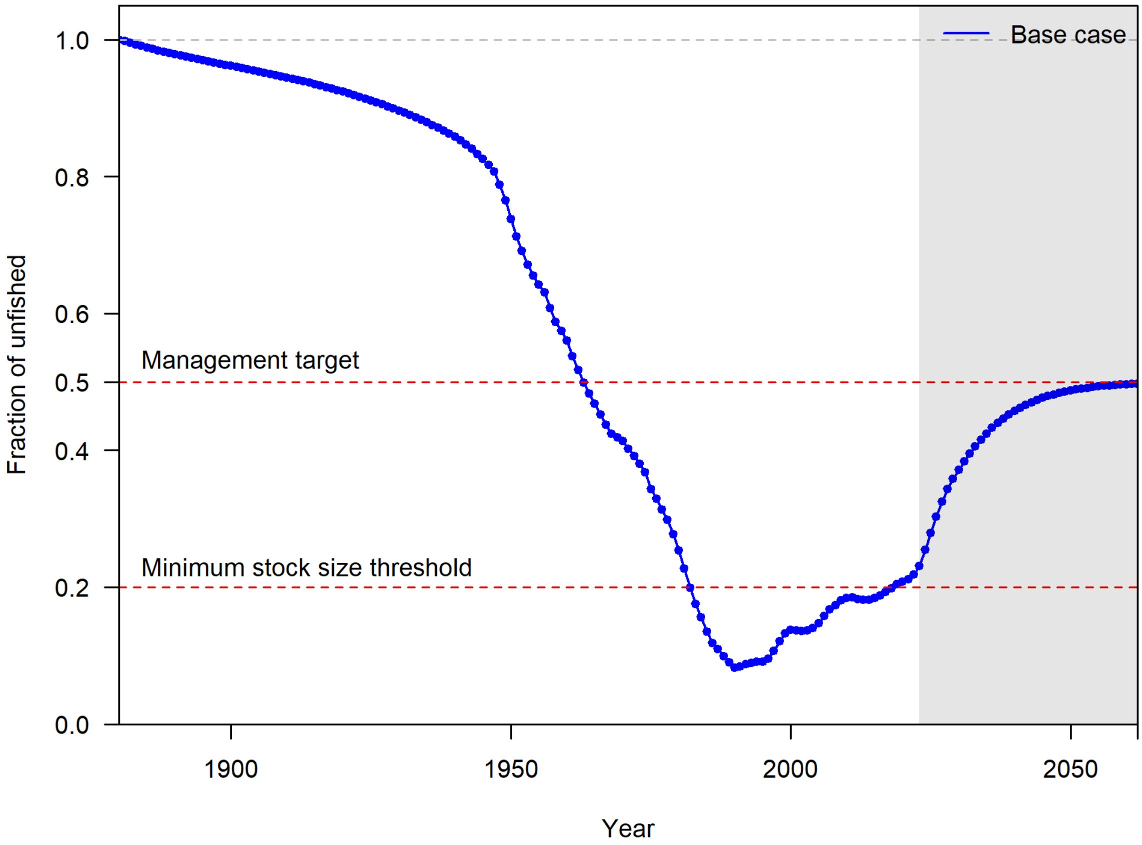

Figure 18. Projections of relative biomass following application of the draft NSW Snapper harvest control rule. Projections used the base-case model and long-term average recruitment.

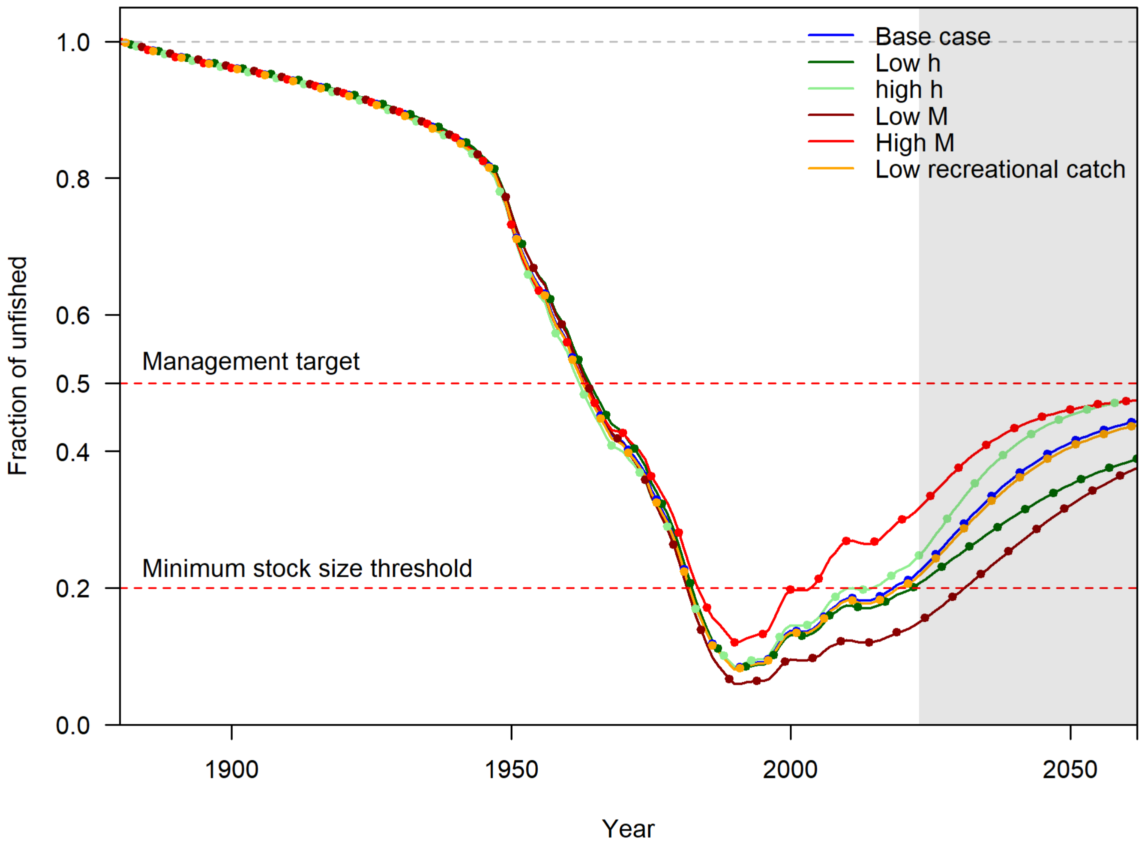

Figure 19. Projections of relative biomass for each model scenario and current (263 t p.a.) constant catch. Projections were done assuming recent (5 years) average recruitment.

Discussion

This stock assessment is the first fully integrated model for Snapper using just NSW data. The base case model estimated the unfished female spawning biomass (SSB_O) at 10,640 t and female spawning biomass in the first year following the data series (2023) to be 2,386 t. That produced a depletion estimate to be 22.4% of unfished levels.

The stock assessment was most sensitive to the value of natural mortality, with the high-*M* value of 0.2 estimating depletion to be 31.7% of unfished levels and the low-*M* value of 0.135 estimating depletion to be as low as 15% of unfished levels. Lower stock recruitment steepness parameter *h* (0.65) produced a slightly lower depletion estimate (-1.7%) and the higher *h* (0.85) a slightly higher estimate (+2.4%). The scenario to examine the effect of potential over-estimated recreational harvest in 2000/01, an important data point given the entire hindcasted recreational harvest is anchored at that catch level, produced very similar results to the base case (just -0.6% change). We used the lower 10^{th} percentile of the recreational harvest estimate from that survey; however, the estimates were relatively precise from that survey and future scenarios should examine more extreme variations in recreational harvest.

Importantly all the scenarios tested showed similar biomass trajectories of steady decline until around 1990 followed by around 30 years of increase. Biomass trajectories of all scenarios were almost identical until the early 1980s after which recruitment deviations were estimated, and trajectories differed after this time.

The model estimated below average recruitment for many of the past 20 years, something observed in other stock assessments of regional stocks (e.g. Burch et al., 2023). This lends support to a precautionary approach when projecting estimated biomass under future management arrangements by assuming that future recruitment will be similar to recent years rather than the long-term average estimated in the model. Consequently, we applied the most recent 5 years average recruitment in some biomass projections under constant catch management scenarios. Biomass recovery in these scenarios was slower than a scenario that applied the draft harvest control rule, likely because the latter scenario assumed higher (long-term average) recruitment.

Averaging the most recent 5 years of recruitment may be too short a timeframe given the longevity of Snapper, the potential for autocorrelation in recruitment strength and the variable recruitment patterns observed in other Australian stocks of Snapper (Drew et al., 2022). Suitable recent reference years for assumed future recruitment may require further consideration, for all species, however we note the lower recruitment during the last 20 years in the current assessment meaning the number of years over which to average recruitment are unlikely to markedly effect projections in our assessment.

Implications for harvest strategy development

Biomass projections using the draft harvest control rule in the developing Snapper harvest strategy, with long-term average recruitment forecast, showed a rapid increase and asymptote, with the target reference level of 50% unfished biomass not being attained for 40+ years. The biomass projections using the more precautionary average recent recruitment levels in the forecast and constant annual catches (low, current and high) all increased, with faster biomass rebuilding under lower catch. Given the very low harvests governed by the harvest control rule for several years due to the relatively low biomass, direct application may in effect close the commercial fishery and severely limit recreational harvest opportunities. Application of some constant catch for a period of time may be prudent given the stability it would afford the fishery and given the observed and predicted stock rebuilding under current and larger harvests, noting that the stock may rebuild even faster than projected under a constant catch scenario if relative recruitment strength improves toward the long-term average.

It is important to note that the projected current constant catch of 263 t p.a. is actually constant mortality and includes an estimated 6% release mortality. In effect the 263 t constant kill equates to 248 t of retained catch by all sectors.

Uncertainties and future research and development

Being the first attempt at a fully integrated stock assessment model for NSW Snapper in the Stock Synthesis framework this work has provided considerable insights into potential improvements in future iterations. We eventually simplified the model into just 4 fleets after considerable efforts to model 9 different fleets that separated recreational and charter fleets, a standalone dead discard fleet, and commercial fleets split by old, recent and current logbook formats. Outputs were broadly similar between the 9 and 4 fleet models, but having fewer fleets resulted in far greater model performance in terms of convergence.

The robustness of the model is related to the standardized CPUE series, and whether they adequately index changes in abundance of Snapper. Factors that may influence these CPUE series include changes to fishing power through time, and the potential for hyperstability that may mask declines or increases in stock abundance. We have no evidence that either of these factors unduly influence the trapping catch rates; however future assessments would benefit from an in-depth study into fishing power and hyperstability in both the trap and line fisheries for Snapper.

The major effect of natural mortality (*M*) in the stock assessment as a pre-specified parameter aligns with all previous attempts at stock assessment for east-coast snapper and similar species regionally. The potential to estimate *M* in the model appears limited given the dome-shaped selectivity of the trap fishery from which the age-at-length data are derived. Until improvements are developed in ways to estimate *M* for Snapper, using a similar value in iterative stock assessments will at least make each assessment comparable.

Growth was pre-specified in the model using parameters derived from age-at-length data from fishery dependent sampling. Similar selectivity biases that limit estimation of *M* relate to estimating growth in the model. The growth parameters include t_0 at -3.73 years, which suggests the model does not fit early growth well. It is recommended that the NSW Snapper growth curve be reviewed for future stock assessments.

The NSW Snapper stock was modelled as a single NSW-wide population. This decision was driven in part by the desire to keep the model as simple as possible. Current assumptions are that there is limited mixing of Snapper at any life-history stage between NSW and QLD, so compartmentalising NSW as a single assessable stock is logical. However, we also know that Snapper are largely residential and that life-history traits, including growth rates, size and age at maturity and spawning peaks, vary substantially with latitude. There is evidence of latitudinal differences in fishery performance with latitude, with more northern (southern QLD and northern NSW) areas showing declines in harvest and relative abundance, while southern NSW has seen increases in harvest. We hypothesise that changing environmental conditions along eastern Australia are having considerable impacts on the distribution, abundance and biological traits of Snapper. These factors all suggest that stock assessment that includes smaller spatial scales than the entire waters of NSW would be useful. Further research on Snapper movements, at all life-history stages, is needed to identify appropriate spatial scales for model structure.

Total Snapper harvests remain uncertain, especially for the recreational fishing sector. Our single alternative model scenario that considered a slightly lower estimate of recreational catch in 2000/01, an important pivot point for all the hindcast years, indicated very little impact on the model outputs, however the lower 10th percentile estimate we used was only 9% lower than the median estimate and perhaps insufficient to understand the impact of uncertainty around the recreational harvest. Future work is needed to improve the method of hindcasting recreational catch prior to 2000/01, and of estimating current harvests of the entire fishing population rather than the 1-3 year licence holders currently surveyed.

A review of the method of ageing Snapper may be required given our difficulty in being able to use age-at-length data for the most recent 3 years of age sampling. Apparent differences in the age-at-length data between these recent years and historically are being reviewed, however initial results indicate no changes in otolith interpretation. It may be that the dynamics of the commercial fishery have changed in recent years due to vastly reduced number of fishers in most ports, and the rapid increase in south-coast harvests of likely slower-growing Snapper. Collaboration with the Snapper ageing team in QLD is recommended and is being investigated.

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Appendices

Appendix 1 - Diagnostic plots and summaries for CPUE standardisations.

Fish trapping 2009/10 to 2022/23

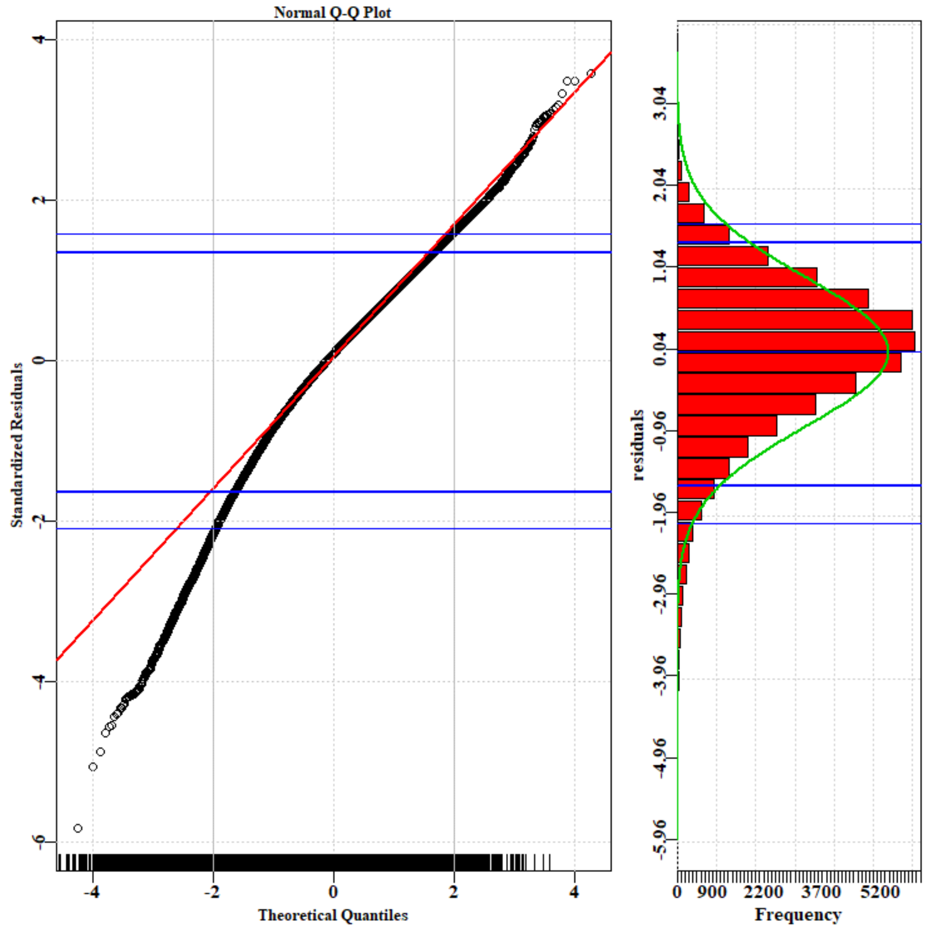

Figure A1. Distribution of residuals relative to expected normality for the CPUE standardisation model for fish trapping during 2009/10 to 2022/23.

Table A1. Selection of model terms for standardisation of fish trapping CPUE during 2009/10 to 2022/23. AIC: Akaike's Information Criterion, RSS: residual sum-of-squares, MSS: model sum-of-squares, Nobs: number of observations, Npar: number of parameters, adj. r^2: adjusted r^2, and inc. r^2: change in r^2.

	adjR^2	incR^2	RSS	MSS	Npar	nobs	AIC
Year	0.0	NA	63003.7	340.5	14.0	47470	13466.6
AuthorisedFisherID	0.3	0.3	44614.2	18730.0	233.0	47470	-2479.3
LatitudeDegrees	0.3	0.0	43437.3	19907.0	242.0	47470	-3730.4
Month	0.3	0.0	42835.9	20508.3	253.0	47470	-4370.2
DepCat	0.3	0.0	42086.9	21257.3	261.0	47470	-5191.5
LatitudeDegrees:Month	0.4	0.0	40514.2	22830.0	360.0	47470	-6801.4
Month:DepCat	0.4	0.0	40178.4	23165.8	445.0	47470	-7026.4
LatitudeDegrees:DepCat	0.4	0.0	39590.0	23754.2	494.0	47470	-7628.8

Line fishing 2009/10 to 2022/23

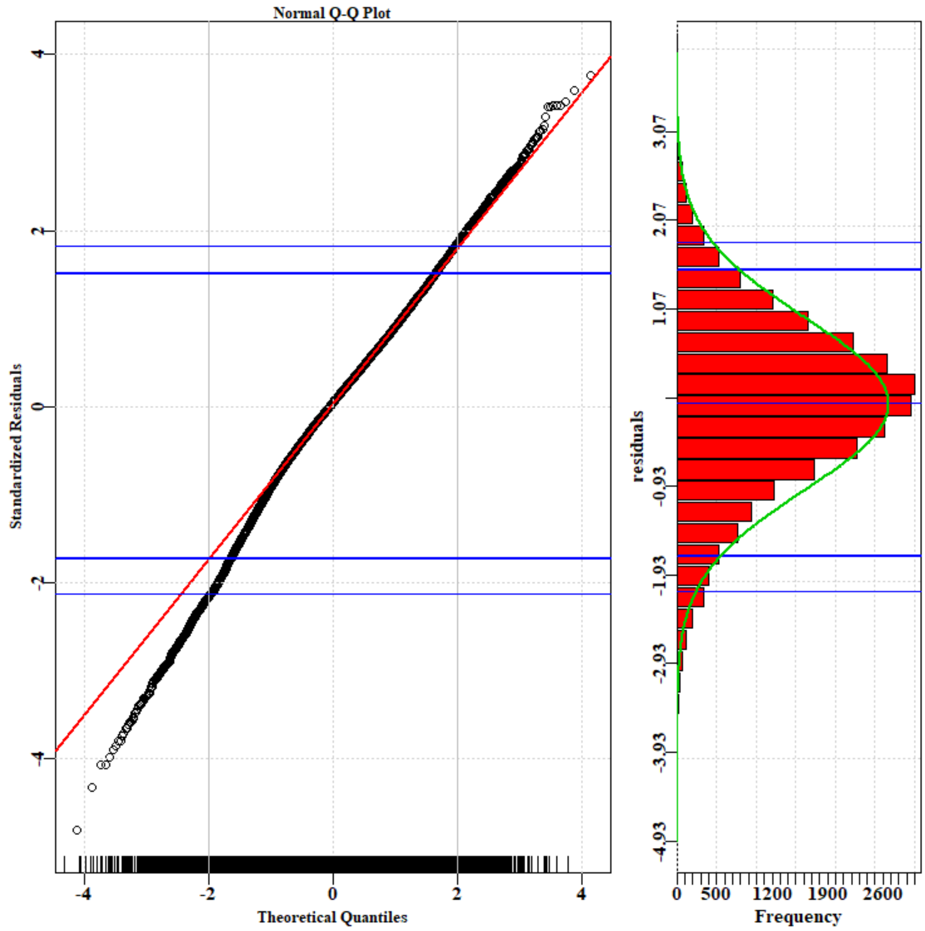

Figure A2. Distribution of residuals relative to expected normality for the CPUE standardisation model for line fishing during 2009/10 to 2022/23.

Table A2. Selection of model terms for standardisation of line fishing CPUE during 2009/10 to 2022/23. AIC: Akaike's Information Criterion, RSS: residual sum-of-squares, MSS: model sum-of-squares, Nobs: number of observations, Npar: number of parameters, adj. r^2: adjusted r^2, and inc. r^2: change in r^2.

	adjR^2	incR^2	RSS	MSS	Npar	nobs	AIC
Year	0.0	NA	42482.7	1162.1	14.0	26965.0	12285.1
AuthorisedFisherID	0.4	0.35	26820.7	16824.1	432.0	26965.0	719.3
LatitudeDegrees	0.4	0.00	26680.7	16964.1	441.0	26965.0	596.2
Month	0.4	0.01	26154.2	17490.6	452.0	26965.0	80.7
DepCat	0.4	0.00	26014.6	17630.2	460.0	26965.0	-47.5
LatitudeDegrees:Month	0.4	0.01	25623.1	18021.7	559.0	26965.0	-258.5
Month:DepCat	0.4	0.00	25456.8	18188.0	647.0	26965.0	-258.0
LatitudeDegrees:DepCat	0.4	0.01	25131.8	18513.0	702.0	26965.0	-494.5

Trapping 1997/98 to 2008/09

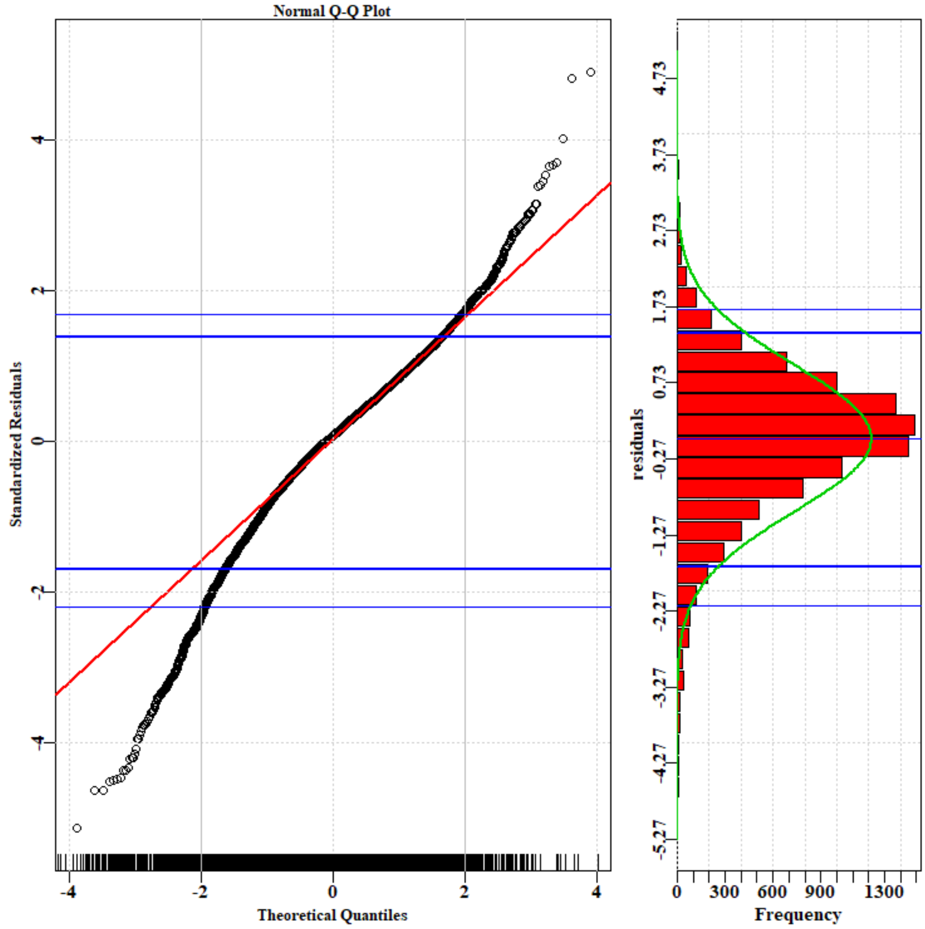

Figure A3. Distribution of residuals relative to expected normality for the CPUE standardisation model for fish trapping during 1997/98 to 2008/09.

Table A3. Selection of model terms for standardisation of fish trapping CPUE during 1997/98 to 2008/09. AIC: Akaike's Information Criterion, RSS: residual sum-of-squares, MSS: model sum-of-squares, Nobs: number of observations, Npar: number of parameters, adj. r^2: adjusted r^2, and inc. r^2: change in r^2.

	$adjR^2$	$incR^2$	RSS	MSS	Npar	nobs	AIC
Year	0.0	NA	18312.6	231.7	10.0	10454.0	5880.6
AuthorisedFisherID	0.4	0.42	10166.6	8377.6	397.0	10454.0	502.6
AreaID	0.4	0.00	10083.6	8460.7	407.0	10454.0	436.9
Month	0.4	0.01	9924.1	8620.2	418.0	10454.0	292.2
AreaID:Month	0.5	0.01	9594.1	8950.1	527.0	10454.0	156.7

Line fishing 1997/98 to 2008/09

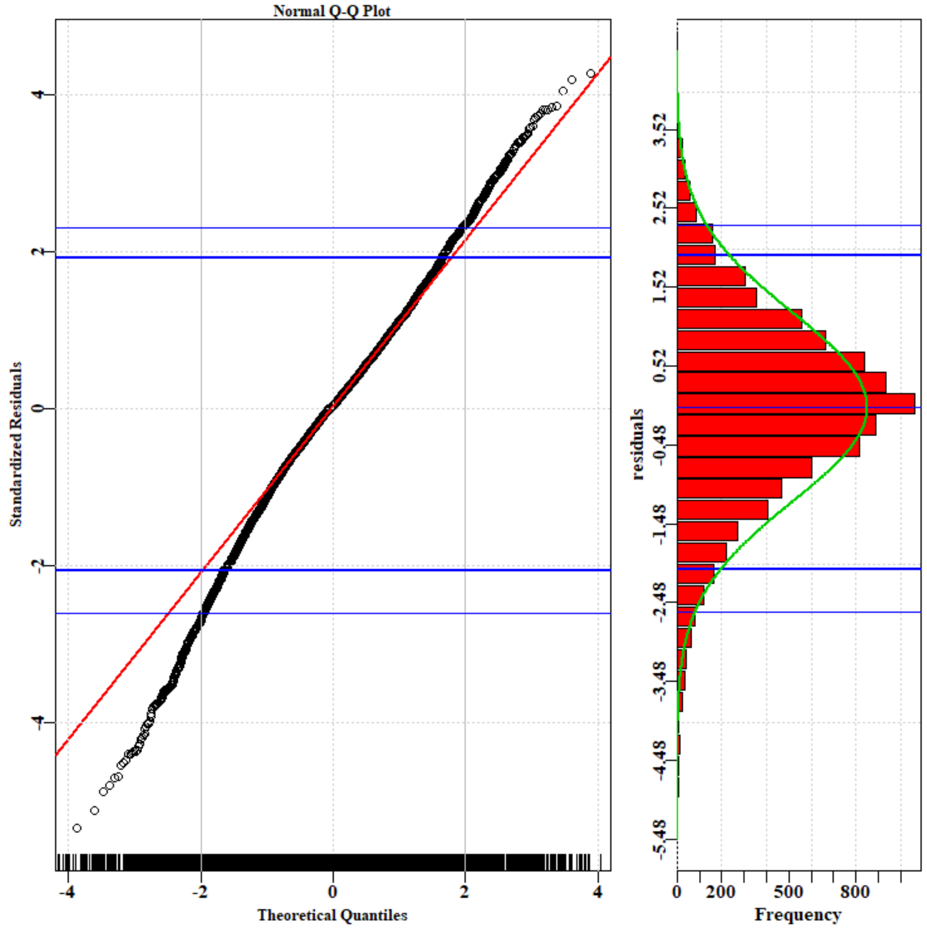

Figure A4. Distribution of residuals relative to expected normality for the CPUE standardisation model for line fishing during 1997/98 to 2008/09.

Table A4. Selection of model terms for standardisation of line fishing CPUE during 1997/98 to 2008/09. AIC: Akaike's Information Criterion, RSS: residual sum-of-squares, MSS: model sum-of-squares, Nobs: number of observations, Npar: number of parameters, adj. r^2: adjusted r^2, and inc. r^2: change in r^2.

	adjR^2	incR^2	RSS	MSS	Npar	nobs	AIC
Year	0.0	NA	22043.9	52.3	10.0	9478.0	8020.0
AuthorisedFisherID	0.3	0.29	14746.2	7350.0	577.0	9478.0	5343.4
AreaID	0.3	0.01	14543.7	7552.5	587.0	9478.0	5232.3
Month	0.3	0.02	14028.3	8067.9	598.0	9478.0	4912.3
AreaID:Month	0.3	0.01	13629.6	8466.6	708.0	9478.0	4859.1

Fish trapping 1984/85 to 1996/97

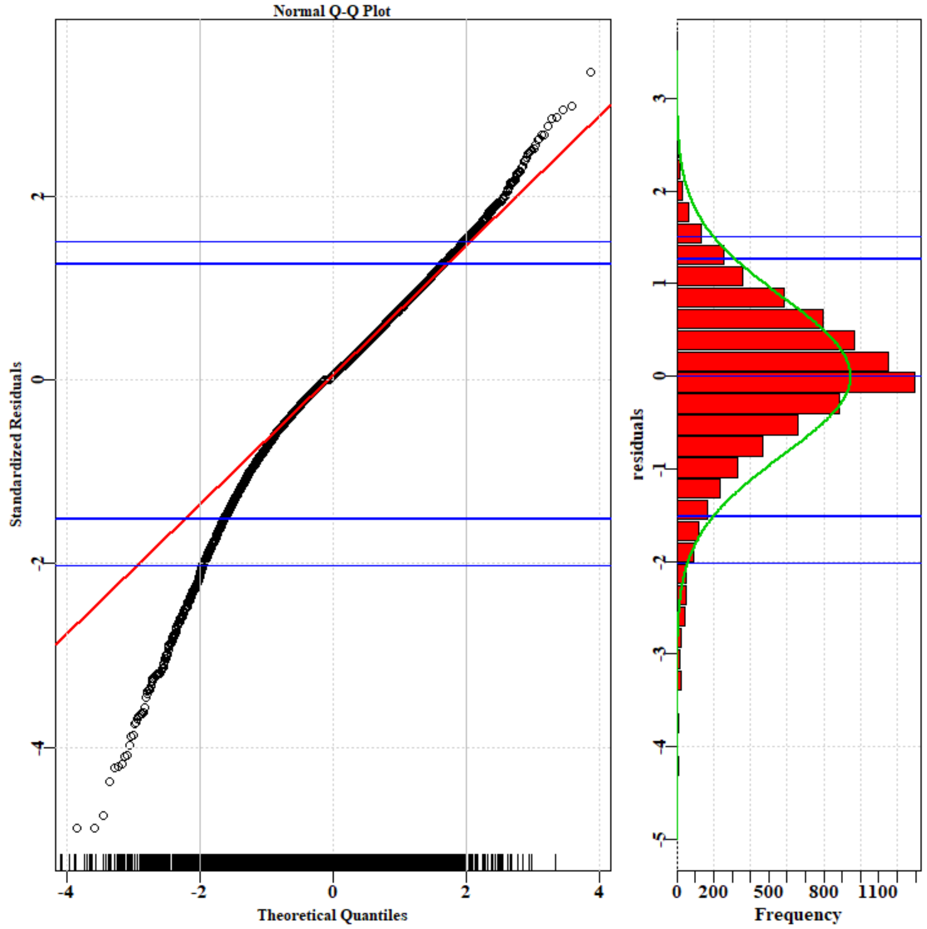

Figure A5. Distribution of residuals relative to expected normality for the CPUE standardisation model for fish trapping during 1984/85 to 1996/97.

Table A5. Selection of model terms for standardisation of fish trapping CPUE during 1984/85 to 1996/97. AIC: Akaike's Information Criterion, RSS: residual sum-of-squares, MSS: model sum-of-squares, Nobs: number of observations, Npar: number of parameters, adj. r^2: adjusted r^2, and inc. r^2: change in r^2.

	adjR^2	incR^2	RSS	MSS	Npar	nobs	AIC
Year	0.0	NA	14944.4	297.3	13.0	8832.0	4671.2
AuthorisedFisherID	0.5	0.49	6889.6	8352.1	751.0	8832.0	-691.6
AreaID	0.5	0.00	6852.5	8389.3	761.0	8832.0	-719.3
Month	0.5	0.00	6803.7	8438.1	772.0	8832.0	-760.4
AreaID:Month	0.5	0.02	6463.9	8777.8	859.0	8832.0	-1038.8

Appendix 2 - Additional model diagnostics

The base-case model fits to the CPUE data were good, showing random and uncorrelated residuals for both data sets (Fig. A6).

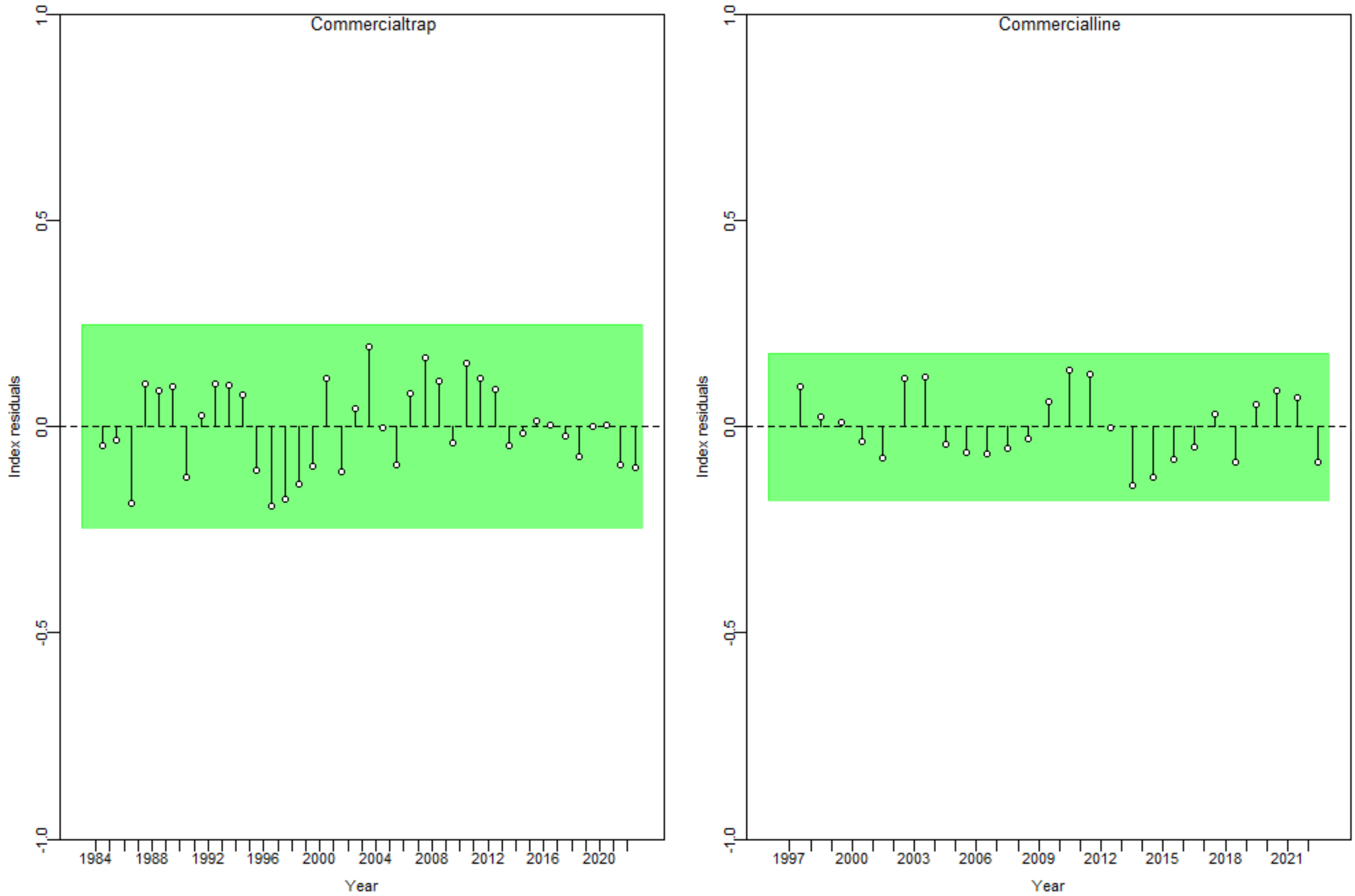

Figure A6. Residuals for base-case model fits to the trap and line CPUE data. The green indicates the fits passed the runs test (P > 0.05) for randomness.

Various model runs excluding CPUE, length and age data from the base-case indicated that the age and length data were influential in the more recent biomass trajectories (Fig. A7). Data weighting and likelihoods from the base-case are in Table A7.

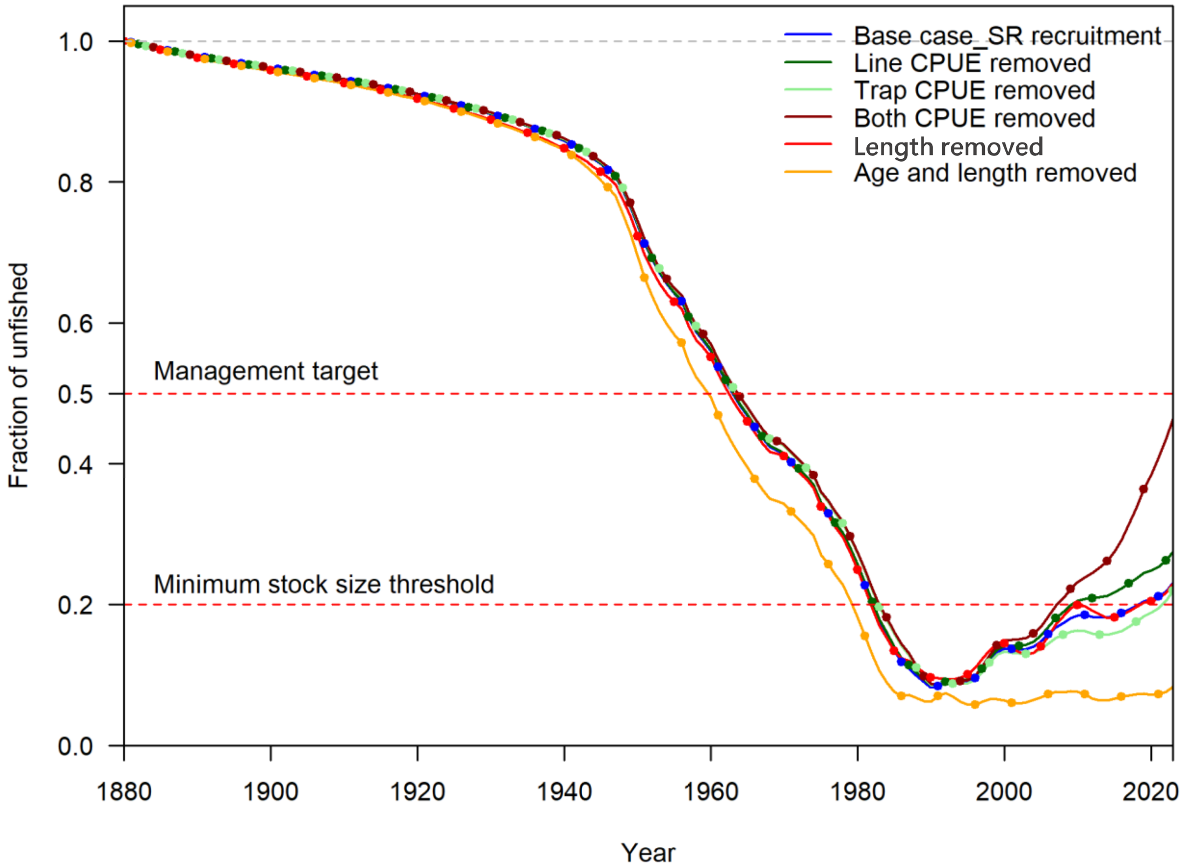

Figure A7. Base-case snapper model sensitivity analysis of data time-series

Table A7. Likelihood components and lambda weights from the base-case model

Component	logL*Lambda	Lambda
TOTAL	1721.75	NA
Catch	0.00	NA
Equil_catch	0.00	NA
Survey	-120.91	NA
Length_comp	668.74	NA
Age_comp	1170.52	NA
Recruitment	-7.64	1
InitEQ_Regime	0.00	1
Forecast_Recruitment	11.03	1
Parm_priors	0.00	1
Parm_softbounds	0.01	NA
Parm_devs	0.00	1
Crash_Pen	0.00	1

Likelihood profile on unfished equilibrium recruitment R_0

A likelihood profile undertaken on R_0 suggests the value estimated in the assessment of 7.99 is plausible (Fig. A8).

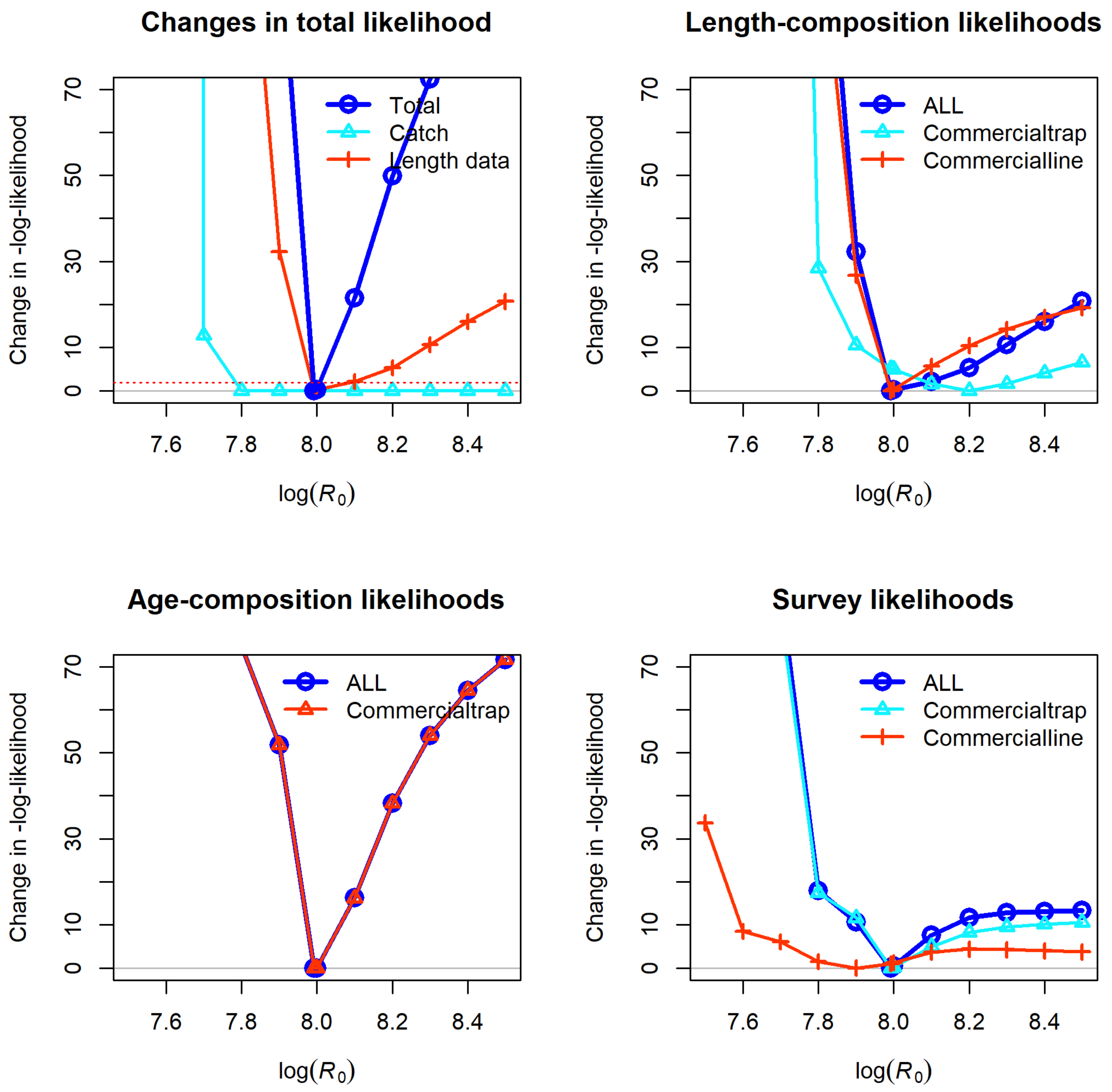

Figure A8. Likelihood profiles for unfished equilibrium recruitment R_0 in the base-case model.

Retrospective analyses

Retrospective analyses were done by sequentially removing 1 to 5 years of data (Fig. A9). The Mohn's rho statistic indicates the severity of retrospective patterns, with values beyond the range of -0.15 to 0.2 indicating the need for further model exploration (Hurtado-Ferro et al., 2015). Mohn's rho was calculated for spawning stock biomass, recruitment, fraction of unfished biomass, and fishing mortality (Table A8). Only the value for recruitment exceeded the acceptable range, suggesting there may be some misspecification of recruitment within the model.

Table A8. Mohn's Rho values for retrospective analyses for spawning stock biomass (SSB), Recruitment, Fraction unfished biomass and Fishing mortality (*F*).

Quantity	Mohn's Rho
SSB	0.08
Recruitment	2.70
Fraction unfished	0.08
F	-0.07

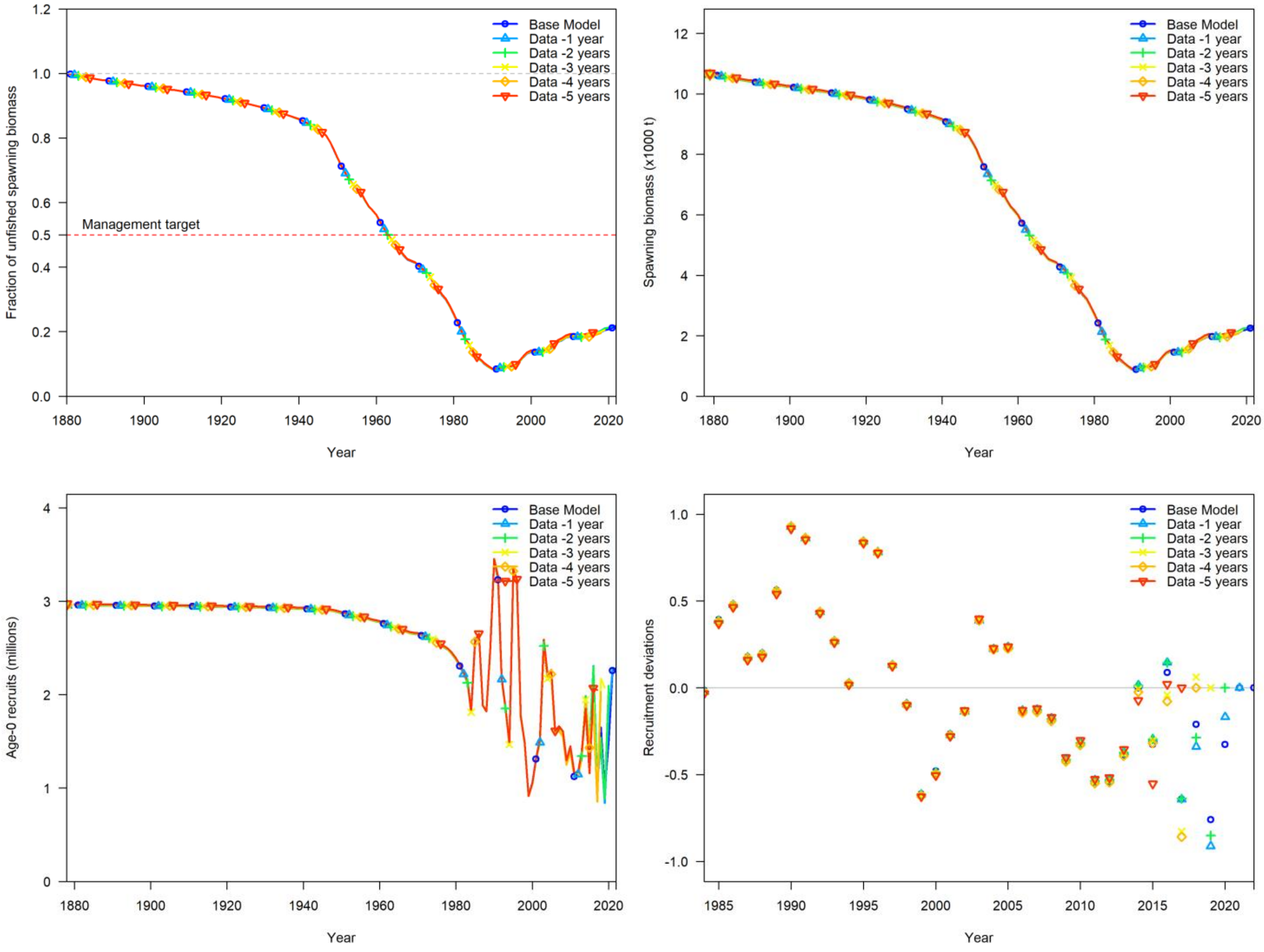

Figure A9. Retrospective analyses for depletion, spawning stock biomass, age-0 recruits and recruitment deviations.

Sensitivities to the base-case model

The likelihood components for the base case and sensitivity scenarios are presented in Table A9.

Table A9. Summary of likelihood components for the base case and sensitivity scenarios.

Scenario	TOTAL	Catch	Survey	Length comp	Age comp	Recruitment
Base case	1721.75	0.00	-120.91	668.74	1170.52	-7.64
Steepness of the stock recruitment relationship						
Low *h* (0.65)	1724.78	0.00	-120.75	667.96	1170.93	-4.40
High *h* (0.85)	1721.31	0.00	-120.61	669.77	1170.17	-9.05
Natural mortality (*M*)						
Low *M* (0.135 yr^{-1})	1675.89	0.00	-117.79	632.11	1149.99	0.55
High *M* (0.200 yr^{-1})	1752.49	0.00	-121.83	715.12	1159.34	-11.17
Low recreational catch	1721.88	0.00	-121.48	667.36	1172.74	-7.78

Appendix 3 - NSW fishing zones and regions

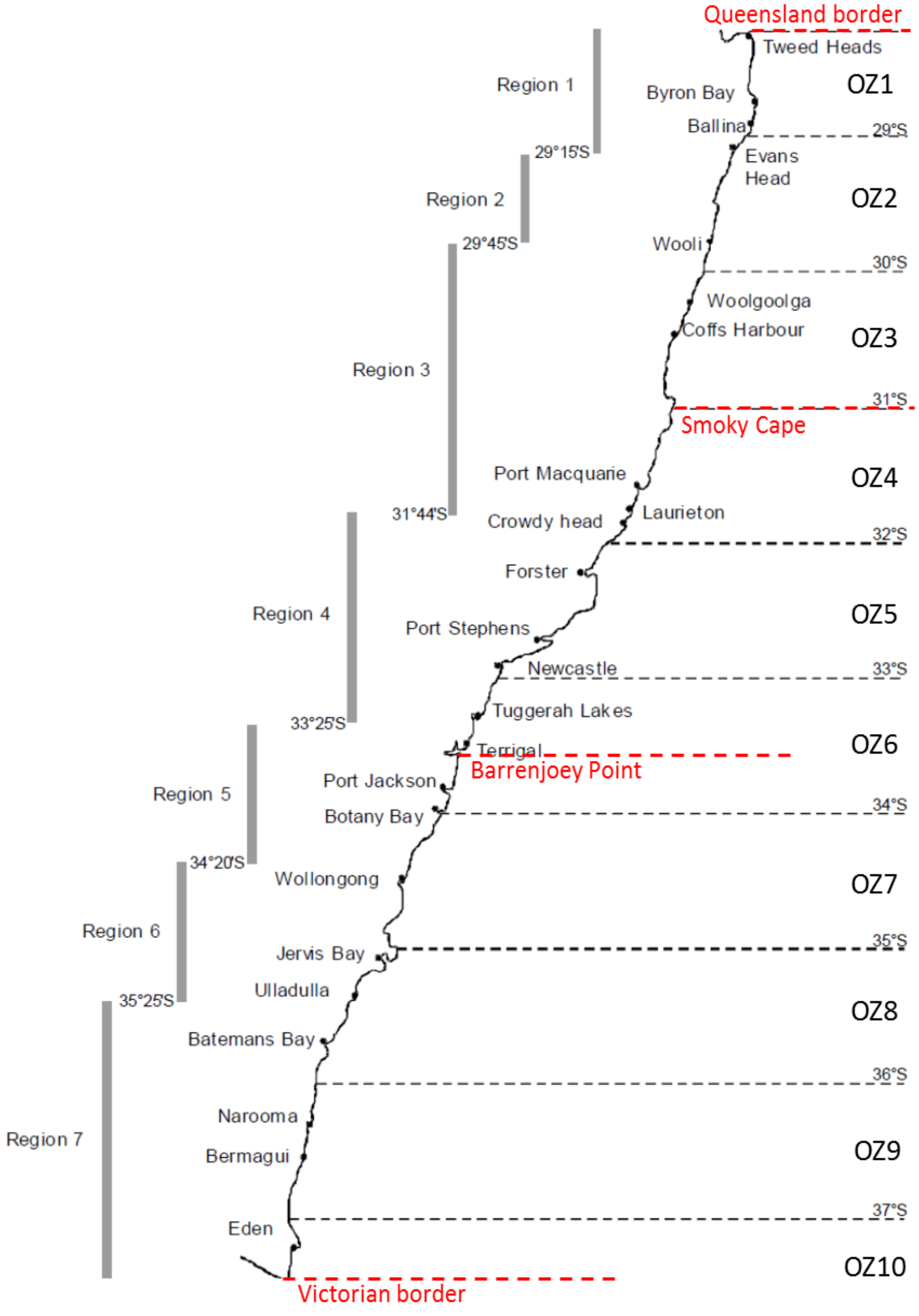

Figure A10. Map of NSW coastline indicating the main ports of landing, broad ocean fishing zones (OZ1 to OZ10) and estuary fishing regions (Regions 1 to 7) for catch and effort reporting. Important management landmarks, including Smoky Cape, Barrenjoey Point and the Queensland and Victorian borders are also indicated by dashed red lines.