Stock Status Summary – 2023/24 (based on data to 2021/22)

NSW Stock Status Summary – Mulloway (*Argyrosomus japonicus*)

Assessment Authors and Year

Hughes, J.M. 2023. Stock status summary 2023/24 (based on data to 2021/22) – Mulloway (*Argyrosomus japonicus*). NSW Department of Primary Industries - Fisheries: 30 pp.

Stock Status

Current stock status	On the basis of the evidence contained within this assessment, Mulloway are currently assessed as **recovering** for the NSW component of the stock.

Stock structure & distribution

Mulloway (*Argyrosomus japonicus*; Temminck & Schlegel 1844) are a large coastal sciaenid species widely distributed in estuaries and near-shore coastal waters (less than 200 m) of the Pacific and Indian Oceans, including subtropical and temperate waters of Australia (Griffiths & Heemstra 1995, Silberschneider & Gray 2008). In Australia it has a wide distribution from the Gascoyne region on the west coast of Western Australia (WA), around the southern coasts of the continent, and up to the Wide Bay–Burnett region on the east coast of Queensland (Kailola et al. 1993, Silberschneider & Gray 2008).

Genetic analyses have shown Mulloway in Australia to be divisible into four large-scale biological stocks – stocks on the eastern and western seaboards, another at the head of the Great Australian Bight, and one encompassing eastern South Australia (SA) – western Victoria (Barnes et al. 2015). However, evidence from otolith morphology and chemistry analyses, and tag-recapture studies suggest population structure likely occurs at much smaller spatial scales (Ferguson et al. 2011, Russell et al. 2021, Hughes et al. 2022).

The data presented in this summary relate to the NSW part of the stock which occurs along eastern Australia.

Biology

Mulloway occur around inshore rocky reefs and ocean beaches in nearshore coastal waters and are often abundant in estuaries and the lower reaches of rivers (Taylor et al. 2006, Silberschneider et al. 2009). Juveniles are found in estuarine and nearshore coastal environments, with estuaries representing a key nursery area (Gray & McDonall 1993, Silberschneider & Gray 2008).

The estimated size at which 50% of females and males are mature is 68 cm and 51 cm total length respectively, corresponding to an age of ~4 years for females (Silberschneider et al. 2009). In eastern Australia, spawning occurs in the lower reaches of estuaries and nearshore coastal waters between November and March (Silberschneider et al. 2009), with pelagic larvae recorded in offshore shelf waters (> 30 km) between January and April (Neira et al. 1998, Smith 2003). Successful recruitment has been shown to be linked to favourable environmental conditions correlated with high rainfall (Stewart et al. 2020).

Initial growth is rapid, reaching on average 34, 52 and 92 cm after 1, 2 and 5 years, respectively, with fish reaching the minimum legal length (MLL) of 70 cm TL (total length) at around 4 years of age (Silberschneider et al. 2009). Mulloway can attain >150 cm TL and can weigh up to 70 kg with

a maximum recorded age of 34 years in eastern Australia (Silberschneider et al. 2009, Hughes et al. 2022).

FISHERY STATISTICS

Catch information

Commercial

Commercial landings of Mulloway in NSW have steadily declined from a peak of almost 400 t in the mid-1970s to a historic low of 37 t in 2008-09, and have been less than 100 t per year since the mid-1990s (Fig. 1). In 2021-22, the total State-wide commercial catch was 79 t.

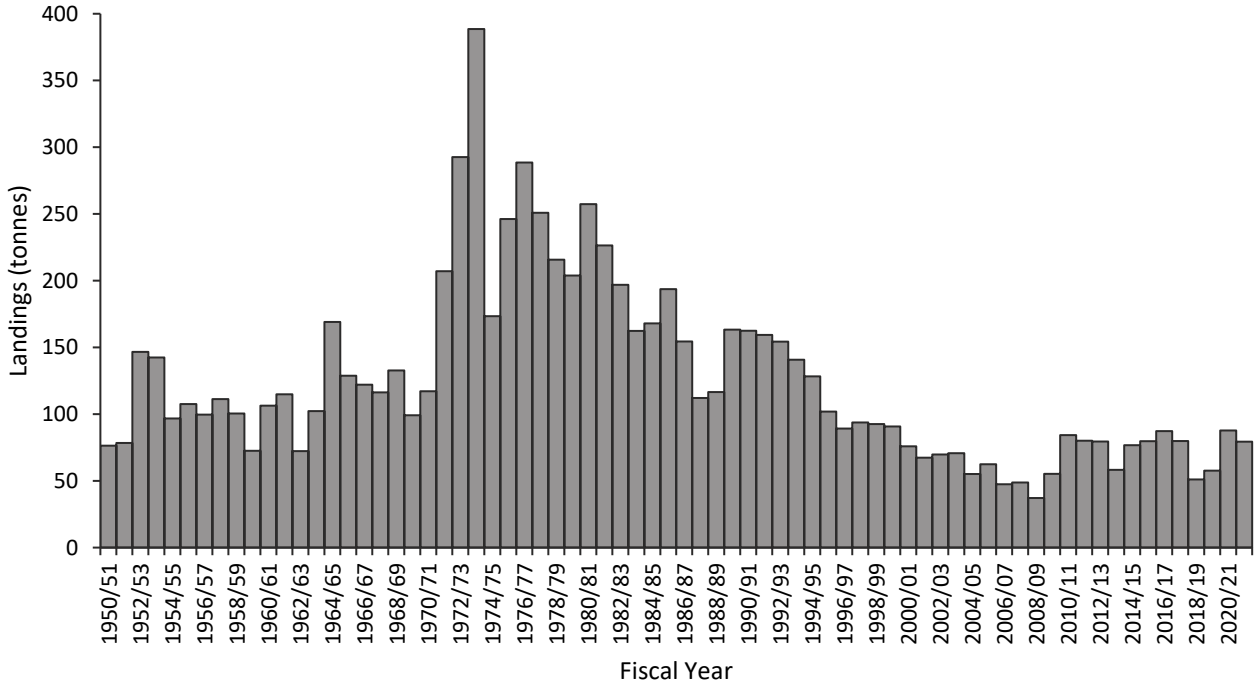

Figure 1. Commercial landings (including available historical records) of Mulloway for NSW from fiscal years 1950-51 to 2021-22 for all commercial fishing methods.

Since 1997-98, the majority (~65%) of the commercial catch of Mulloway has come from the Estuary General (EG) mesh net fishery (Fig. 2). Catches from the Ocean Trap and Line (OTL) fishery made up around 40% of the catch between 1997-98 and 2003-04, but since this time have made a much smaller (10-20%) contribution to the overall catch. Ocean Haul (OH) catches are generally a small component of commercial landings (<10%), but high catches do periodically occur (e.g. 2005-06, 2010-11, 2021-22; Fig. 2).

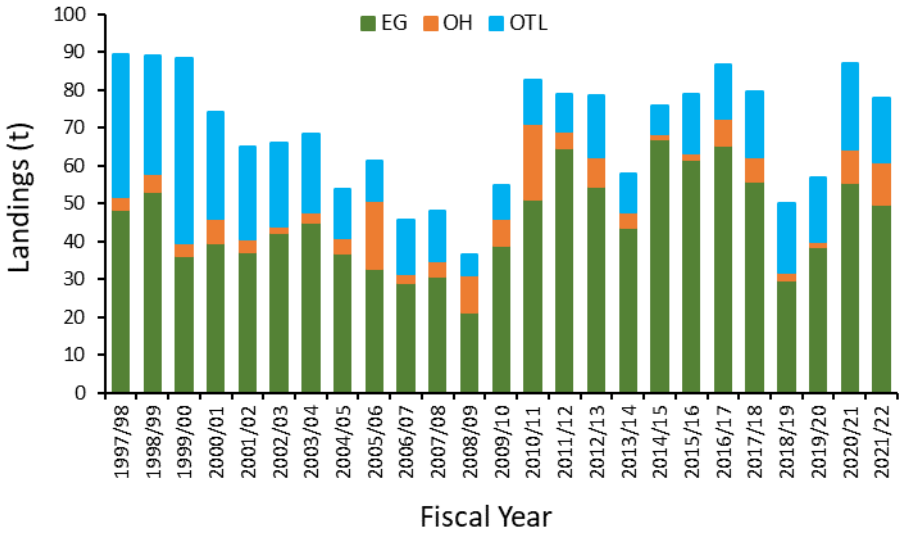

Figure 2. Landings by commercial fishery of Mulloway in NSW for years 1997-98 to 2021-22. EG = Estuary General, OH = Ocean Haul, OTL = Ocean Trap & Line.

Recreational & Charter Fishery

Preliminary data from the most recent recreational fishing survey conducted in NSW estimated that 12,830 (± 4,185 SE) individuals were harvested in 2021-22 (NSW DPI unpublished; Fig. 3). Estimated weight (t) for the recreational harvest for the 2021-22 period was not available at the time this document was prepared. In 2019-20, it was estimated that 6,431 (± 1,888 SE) individuals weighing an estimated 55 t in were retained (Murphy et al. 2022). In 2017-18, 13,641 (± 2,843 SE) individuals weighing an estimated 90 t were estimated harvested (Murphy et al. 2020). These estimates only encompassed harvest from NSW households within which a long-term NSW Recreational Fishing Licence holder resided (RFL household). Re-analysis of the previous survey (West et al. 2015) produced an estimate of 19,319 (± 6,554 SE) individuals weighing an estimated 103 t harvested by RFL households during 2013-14 (Murphy et al. 2020). In 2000-01, estimated recreational harvest by all fishers in NSW waters was 59,029 (± 25,232 SE) individuals weighing an estimated 274 t (Henry & Lyle 2003). While these survey results are not directly comparable due to different sampling frames, they likely represent an overall decline in recreational harvest from 2000-01 to 2019-20, followed by an increase in 2021-22. These estimates also consistently indicate that the recreational harvest is likely to be larger than the commercial catch since 2000-01 (Fig. 1). Harvest from the NSW Charter Fishery is included within the recreational survey estimates. Total historical harvest of Mulloway in NSW was also reconstructed by estimating recreational harvest prior to, and between, survey estimates (Fig. 4).

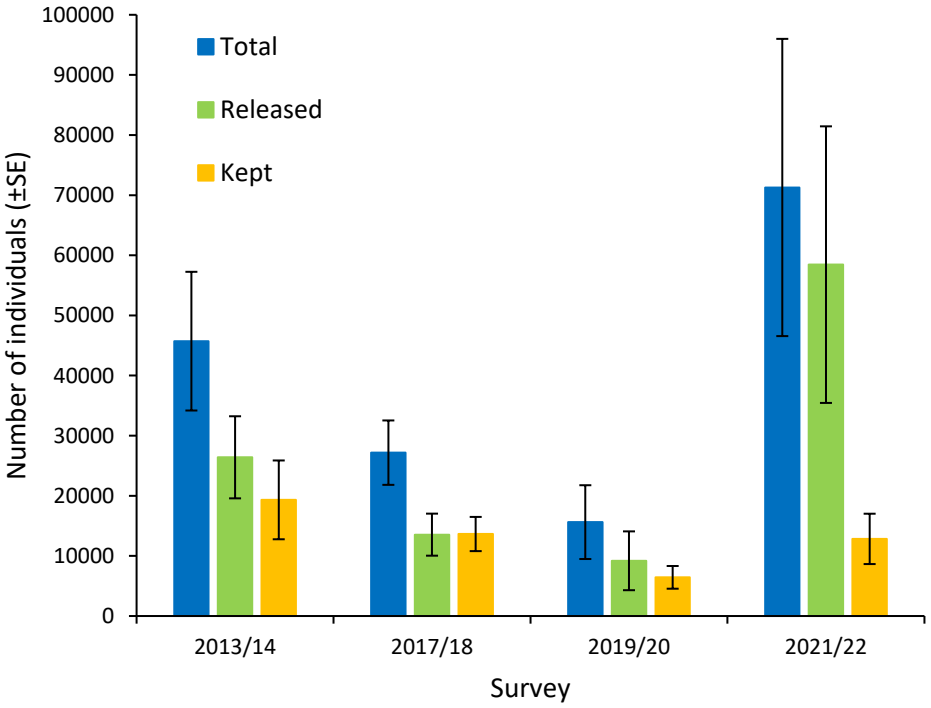

Figure 3. Total (blue bars), released (green bars) and kept (orange bars) Mulloway individuals (± SE) estimated by NSW recreational fishing surveys in 2013-14, 2017-18, 2019-20, with preliminary data from 2021-22.

The total number of Mulloway estimated caught in NSW from recreational fishing surveys has declined steadily from 45,719 individuals (± 11,535 SE) in 2013-14, to 27,173 individuals (± 5,355 SE) in 2017-18 and 15,619 (± 6,135 SE) individuals in 2019-20 (Fig. 3). In 2021-22 however, the total number of Mulloway caught (71,277 (± 24,720 SE) increased by more than 4.5 times that estimated in the previous survey for 2019-20. This was primarily driven by a dramatic increase in the number of released individuals from 9,188 (± 4,890 SE) in 2019-20 to 58,447 (± 23,003 SE) in 2021-22, with corresponding release rates increasing from 50 – 59% for previous surveys to ~82% in 2021-22 (Fig. 3). Previous surveys have indicated that most recreationally caught Mulloway are released because they are smaller than the MLL (West et al. 2015, Murphy et al. 2020, Murphy et al. 2022) and for the 2021-22 survey period, were therefore juveniles (Silberschneider et al. 2009). It is therefore likely that the increase in released catch for Mulloway estimated in 2021-22 may represent evidence for increased abundances of juvenile individuals in NSW, predicted by the influence of favourable environmental condition on successful Mulloway recruitment (Stewart et al. 2020) encompassed by this survey period.

Indigenous

Aboriginal cultural catch of Mulloway has not been quantified in NSW.

Illegal, Unregulated and Unreported

The level of Illegal, Unregulated and Unreported (IUU) fishing has not been quantified.

Total Harvest Estimates

Total historical harvest of Mulloway in NSW was reconstructed by estimating recreational harvest prior to, and between, recreational survey estimates (Fig. 4). Hindcasting the recreational harvest prior to 2000-01 was done using estimates of national recreational marine fishing effort reported in

Kleisner et al. (2015), which used coastal population statistics from the Australian Bureau of Statistics (ABS) with linear interpolation between census years. Estimates of recreational harvest were made by applying the relative recreational fishing effort each year relative to 2000 by the estimated harvest in 2000-01. After 2000-01, harvest was assumed to follow a linear path between each survey, with the estimate for 2020-21 and 2021-22 being set as the same as in 2019-20.

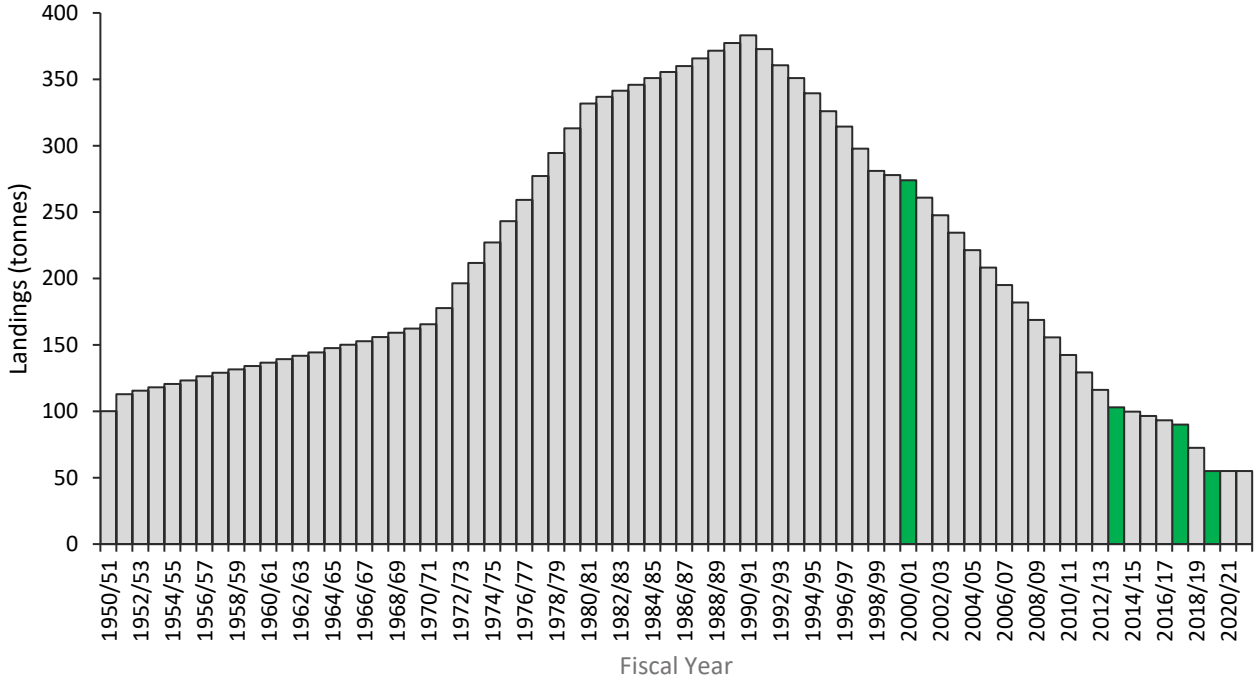

Figure 4. Recreational catch reconstruction for Mulloway in NSW using an estimated recreational catch of 274 t for 2000-01. The green bars represent recreational survey estimates for 2000-01, 2013-14, 2017-18 and 2019-20.

The recreational harvest of Mulloway was estimated to have increased rapidly during the 1970s and 1980s, peaking in 1990-91 (Fig. 4). There was a substantial decline in recreational harvest between the surveys in 2000-01 and 2013-14, and a slight decrease between 2013-14 and 2017-18 (noting that the MLL was increased from 45 to 70 cm TL and the daily bag limit reduced from 5 to 2 fish in 2013). There was another decrease in recreational harvest between the surveys in 2017-18 and 2019-20 (noting that the daily bag limit reduced from 2 to 1 fish in 2018).

Combining the NSW commercial and recreational harvest estimates indicate that the fishery increased rapidly during the early 1970s, peaking at 500-600 t per year until the early 1990s (Fig. 5). Total harvest has declined steadily since with harvest over recent years being among the lowest estimated for the species.

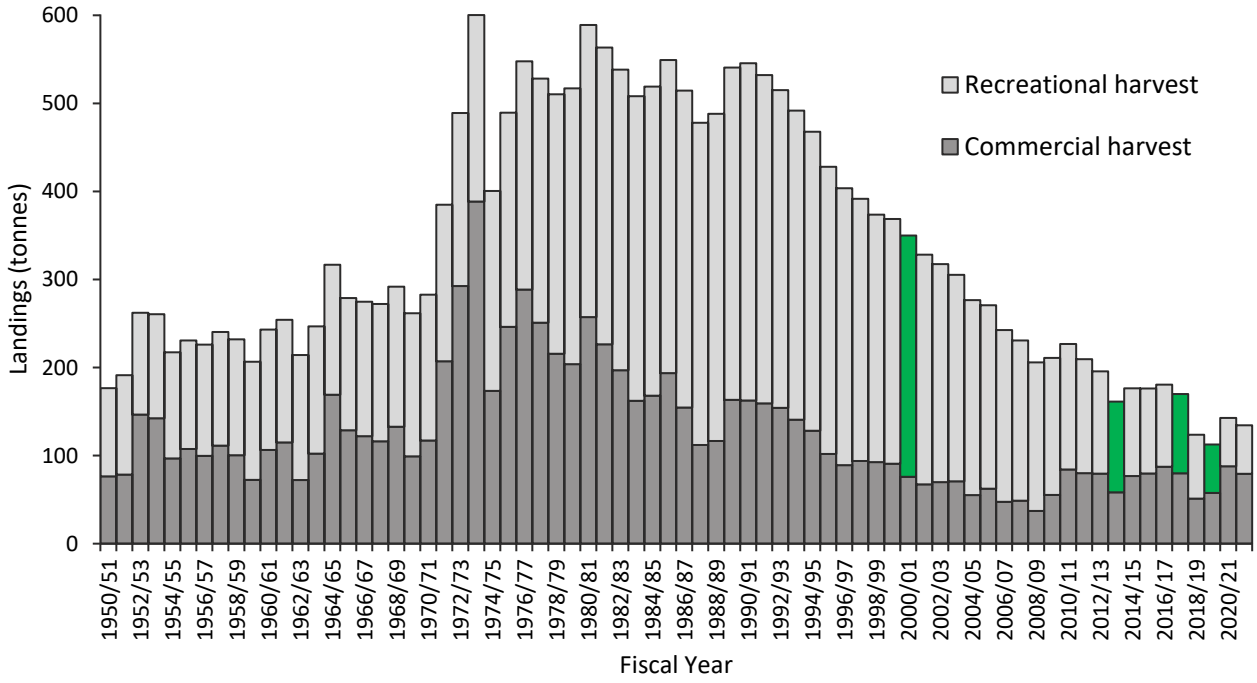

Figure 5. Reconstructed total catch history for Mulloway in NSW 1950-51 to 2021-22.

Fishing effort information

Effort mesh netting for Mulloway in the EG fishery showed an initial increase from 5,600 days fished per year in 2009-10 to 8,800 days in 2014-15, followed by a steady decline to 3,500 days in 2018-19 (Fig. 6). Since this time, effort mesh netting has remained reasonably stable at ~3,250 days fished. In 2021-22, days fished mesh netting for Mulloway was 2,915 days.

Effort handlining for Mulloway in the OTL fishery has been reasonably stable between 2009-10 and 2020-21 at ~1,300 days fished per year (Fig. 6). In 2021-22, days fished handlining for Mulloway was 861 days.

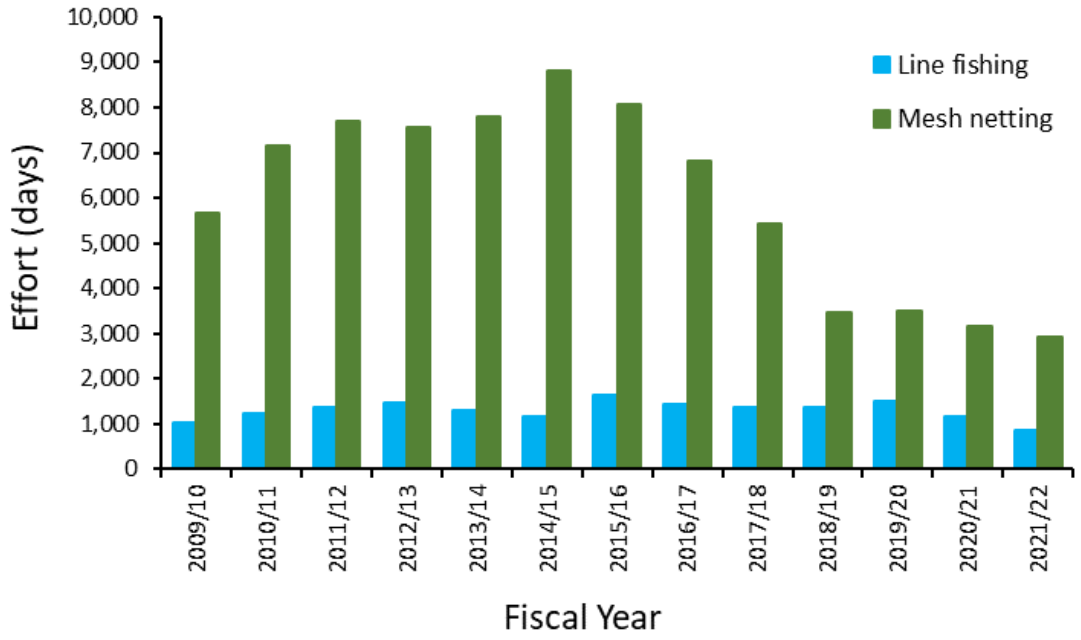

Figure 6. Annual reported days fished for Mulloway from the EGF (mesh netting) and the OTLF (handlining) 2009-10 to 2021-22.

Catch rate trends

Standardised Commercial CPUE

Standardised catch per unit effort (kg.day^{-1}) for commercial EG mesh netting and OTL offshore hand lining for Mulloway, were estimated using a general linear model (LM) constructed using the 'cede' package (Haddon et al. 2018) in 'R' statistical software. CPUE was standardised for variations across months, areas and fishers to a mean estimate of CPUE by year for the periods 1997-98 – 2021-22 and 2009-10 – 2021-22, in order to examine CPUE trends before and after a reporting change (from monthly to daily catch reporting) introduced in 2009.

1997-98 – 2020-21

Mesh netting comprised ~65% of the landed commercial catch of Mulloway during the period 1997-98 – 2021-22 and the resulting standardised CPUE shows an overall ~340% increase between 1997-98 and 2021-22 (Fig. 7). Standardised CPUE was reasonably stable at approximately 5 kg.day^{-1} between 1997-98 and 2008-09, followed by an increase to 13 kg.day^{-1} in 2011-12. CPUE then declined to approximately 9 kg.day-1 in 2013-14, before gradually increasing to 13 kg.day^{-1} in 2019-20. CPUE then increased sharply to just under 20 kg.day^{-1} over the last two years (2020-21 – 2021-22). There was a ~120% increase between 2009-10 and 2021-22.

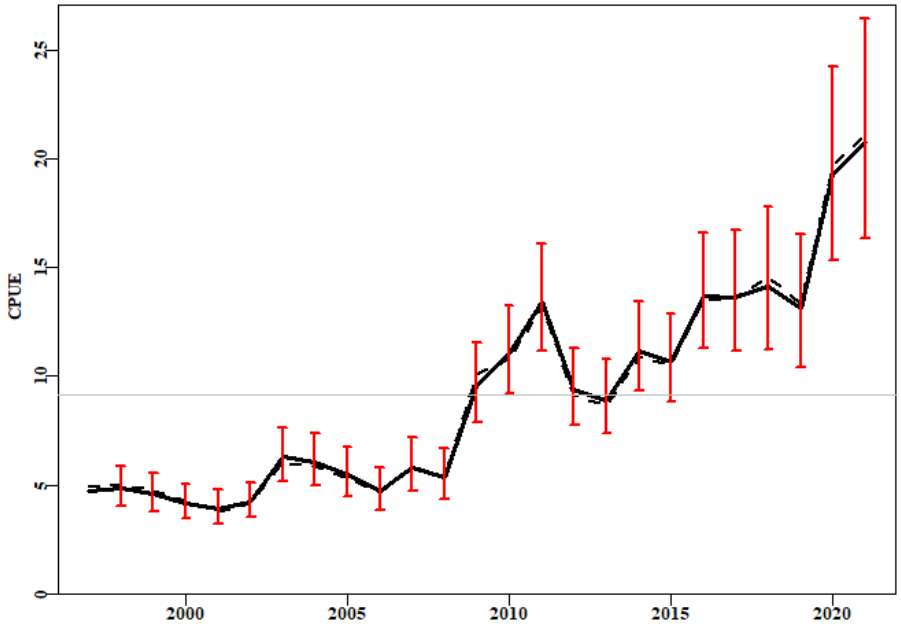

Figure 7. Standardised catch per unit effort in days (kg.day^{-1}) EG mesh netting for Mulloway for years 1997-98 – 2021-22 in NSW. The dashed line is the geometric mean CPUE while the solid line with 95% confidence intervals is the standardised CPUE. The horizontal line represents the average catch rate. Year is fiscal.

Handlining comprised ~26% of the landed commercial catch of Mulloway during the period 1997-98 – 2021-22. The resulting standardised CPUE shows an overall increase of ~65% between 1997-98 and 2021-22 (Fig. 8). It shows an initial decrease from approximately 13 kg.day^{-1} in 1997-98 to ~6 kg.day^{-1} in 2008-09. Standardised CPUE increased sharply to ~13 kg.day^{-1} in 2009-10 and then showed a steady increase to an average of just under 20 kg.day^{-1} in the period 2018-19 – 2021-22. There was a ~60% increase between 2009-10 and 2021-22.

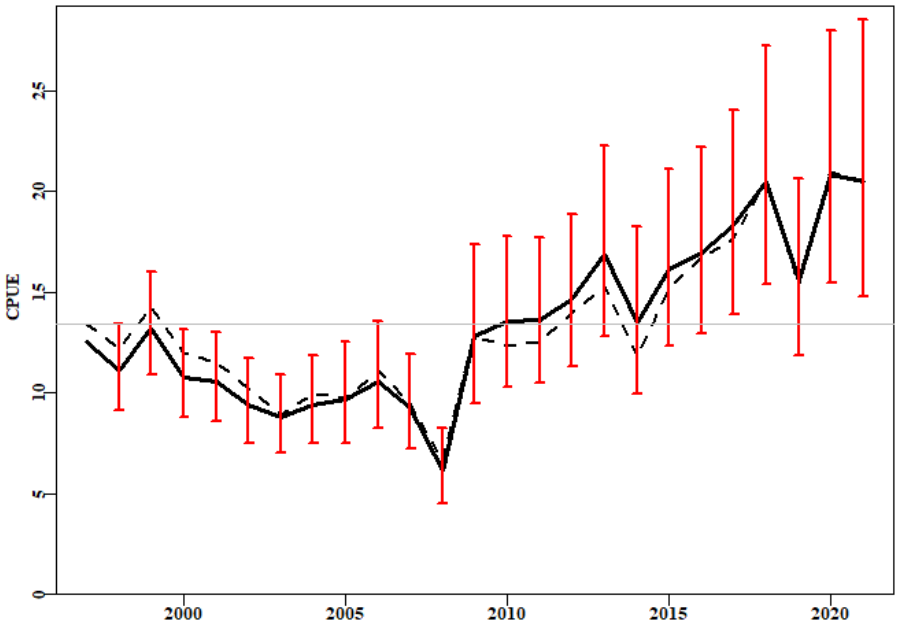

Figure 8. Standardised catch per unit effort in days (kg.day^{-1}) OTL offshore hand lining for Mulloway for years 1997-98 – 2021-22 in NSW. The dashed line is the geometric mean CPUE while the solid line with 95% confidence intervals is the standardised CPUE. The horizontal line represents the average catch rate. Year is fiscal.

Standardised commercial handline CPUE adjusted for fishing power

To account for increases in fishing efficiency (power), standardised hand lining CPUE was also adjusted as described in Wortmann et al. (2018). The resulting time series of catch rates showed a ~70% decrease from 1997-98 to 2008-09 followed by a ~170% increase to 2020-21 (Fig. 8). Overall catch rates adjusted for fishing efficiency have therefore remained reasonably stable (~14% decline with overlapping SEs) between 1997-98 and 2021-22.

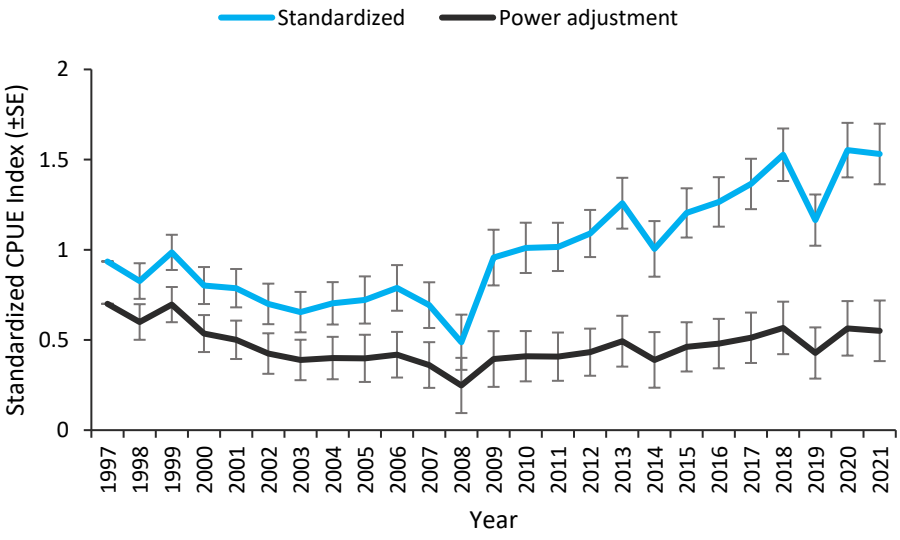

Figure 9. Standardized catch rate indices 1997-98 – 2021-22 (± SE) for OTL offshore handlining for Mulloway (light blue) adjusted for increases in fishing power (black). Years are fiscal.

2009-10 – 2020-21

Standardised catch per unit effort (kg.day^{-1}) was also estimated for commercial EG mesh netting and OTL offshore hand lining using logbook data from the period 2009-10 – 2021-22 in which only days when Mulloway were landed were included. CPUE was standardized for variation across year, months, areas and vessels as described above.

The daily-based standardised CPUE time series for EG mesh netting showed a very similar trend to the monthly-based CPUE standardisation (Fig. 7) with a ~195% increase from ~12 kg.day^{-1} to ~39 kg.day^{-1} between 2009-10 and 2021-22 (Fig. 10). There was a ~70% increase in standardised CPUE between 2018-19 and 2021-22.

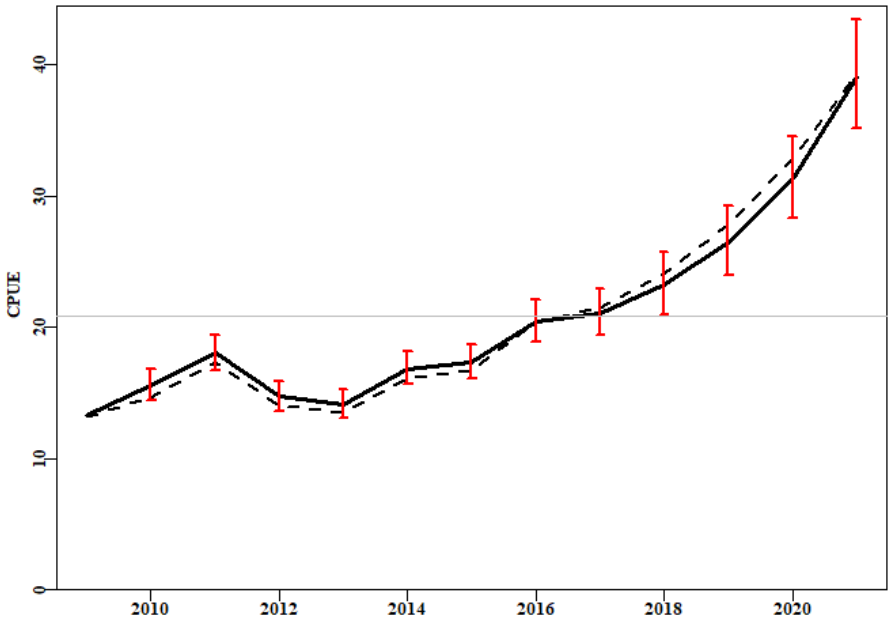

Figure 10. Standardised catch per unit effort (kg.day^{-1}) for EG mesh netting for Mulloway in which only days when Mulloway were landed were included, for years 2009-10 – 2021-22 in NSW. The dashed line is the geometric mean CPUE while the solid line with 95% confidence intervals is the standardised CPUE. The horizontal line represents the average catch rate.

The daily-based standardised CPUE time series for OTL offshore line fishing also showed a very similar trend to the monthly-based CPUE standardisation (Fig. 8) with a ~40% increase from ~32 kg.day^{-1} to ~47 kg.day^{-1} between 2009-10 and 2021-22 (Fig. 11). Standardised CPUE was stable at ~40-50 kg.day^{-1} between 2018-19 and 2021-22 (~5% decrease with overlapping 95% confidence intervals).

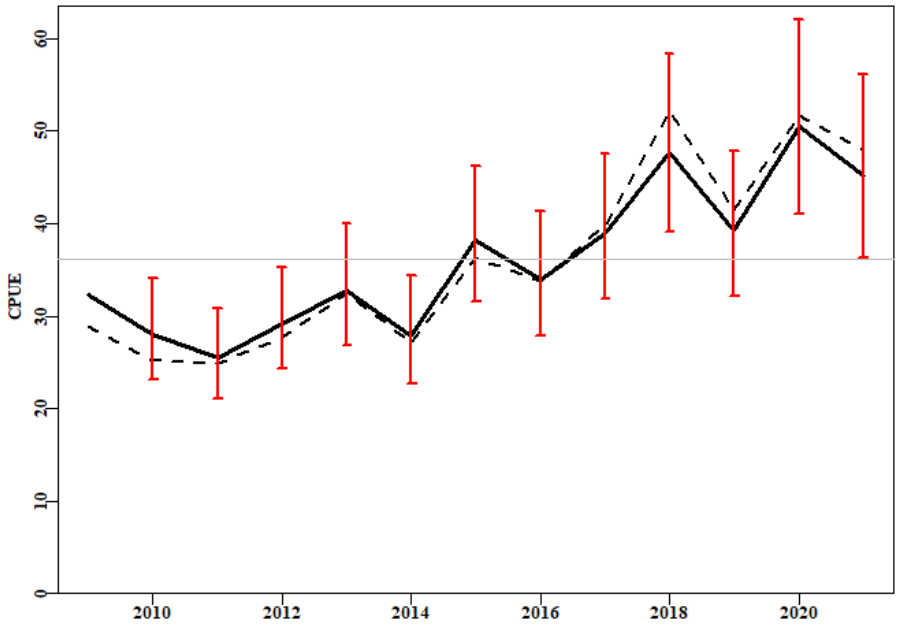

Figure 11. Standardised catch per unit effort (kg.day^{-1}) for OTL offshore line fishing for Mulloway in which only days when Mulloway were landed were included, for years 2009-10 – 2020-21 in NSW. The dashed line is the geometric mean CPUE while the solid line with 95% confidence intervals is the standardised CPUE. The horizontal line represents the average catch rate.

Commercial length composition

The annual average lengths of Mulloway landed by the commercial fishery have been reasonably stable since the mid-2000s except for the effect of increasing the legal minimum length (MLL) from 45 cm to 70 cm in 2013 (Figs 12 & 13). The commercial Mulloway fishery was historically based largely on juveniles with around 80% of the catch <70 cm (Fig. 12), the approximate length at maturity for female Mulloway (Silberschneider et al. 2009). Despite an increase to the MLL in 2013, the commercial fishery continued to be based on juveniles up until 2016-17 as a result of a bycatch allowance for retention of fish smaller than 70 cm taken by EG mesh nets (Figs 12 & 13). Only since 2015-16 has the average size of Mulloway in commercial landings indicated the catch to be based on adults, and has been ~90 cm since 2017-18 (Figs 12 & 13).

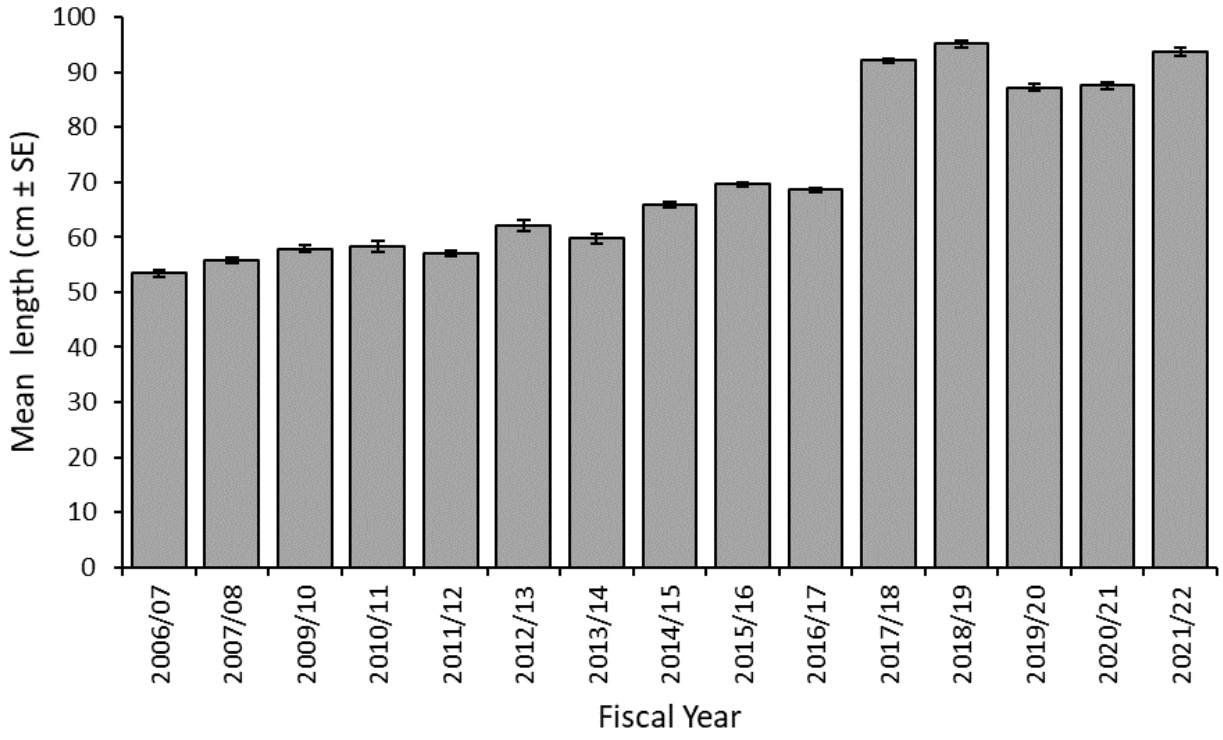

Figure 12. Average total length (cm ± SE) of the NSW commercial catch of Mulloway from 2006-07 to 2021-22.

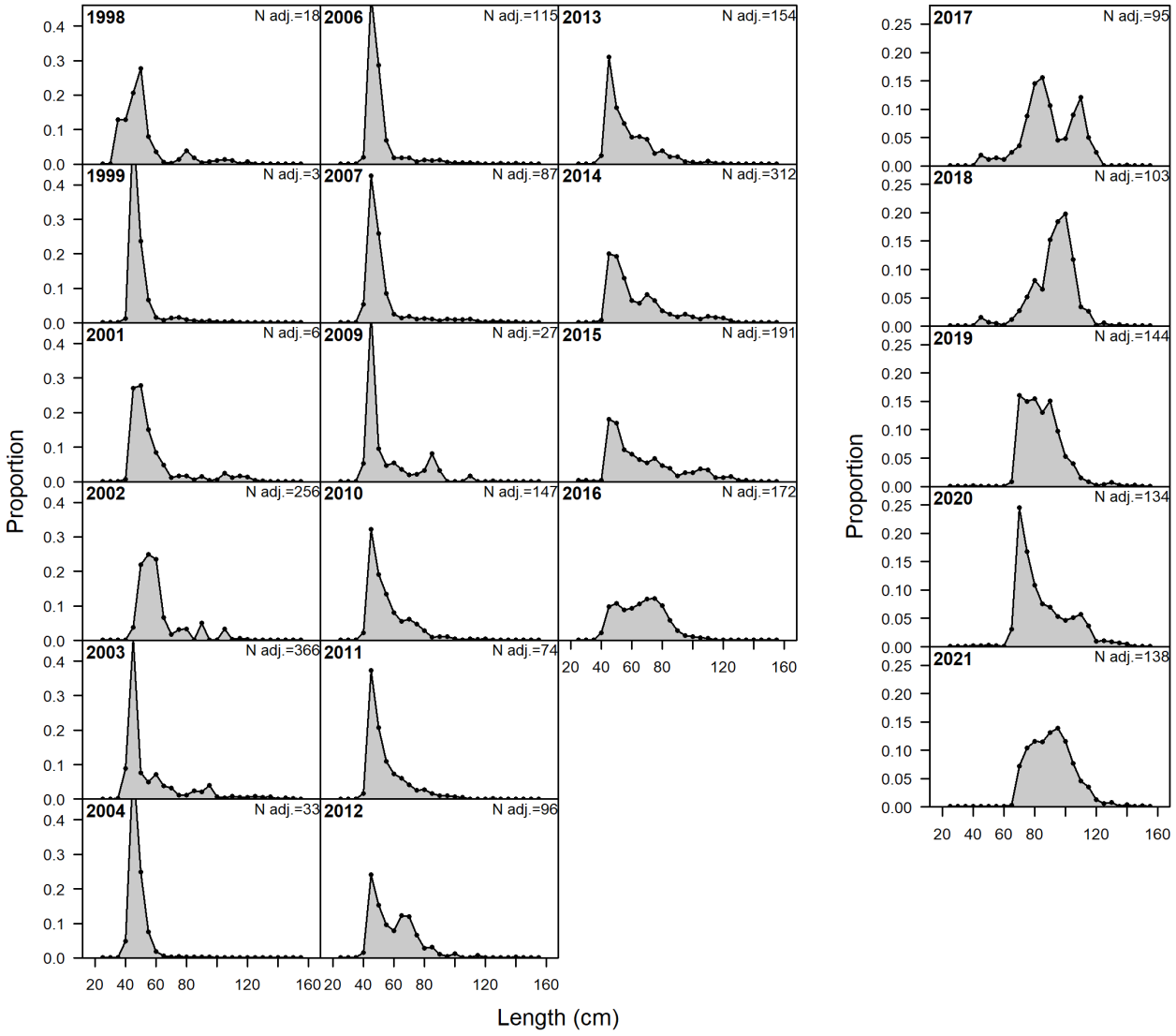

Figure 13. Length compositions of Mulloway from commercial catches in NSW from 1998 to 2016 (nominal MLL = 45 cm), and 2017 to 2021 (MLL = 70 cm). Years are fiscal.

STOCK ASSESSMENT

Stock Assessment Methodology

Year of most recent assessment:

2023 (using data to 2021-22)

Assessment method:

A weight-of-evidence approach has been used to classify the biological status of the NSW Mulloway stock based on:

1) Standardised commercial catch rates (CPUE)
    a. EG mesh netting
    b. OTL offshore hand lining
2) Spawning Potential Ratio (SPR) modelling
3) Catch curve analysis
4) A time-series of commercial length compositions
5) Integrated models under development*
    a. Surplus production modelling
    b. Integrated catch and length-structured modelling

*All results are preliminary as modelling approaches have not been subjected to comprehensive diagnostic evaluation or scenario testing.

Main data inputs:

Standardised Commercial CPUE

- Catch per unit effort (kg.day^{-1}) for commercial EG mesh netting and OTL offshore hand lining standardised for variations across months, areas and vessels to a mean estimate of CPUE by year for the periods 2009-10 – 2021-22 (daily reporting; Figs 10 & 11) and 1997-98 – 2021-22 (monthly reporting; Figs 7 & 8);
- Standardised hand lining CPUE adjusted for fishing efficiency (power) for 1997-98 – 2021-22 (Fig. 9).

SPR model

- Length-composition data from NSW commercial fisheries 1998-99 – 2021-22 (Fig. 13);
- Biological parameters (natural mortality (M), fecundity, maturity, length-weight, growth parameters), selectivity, total (Z) and fishing mortality (F) estimates.

Integrated models under development

Production model

- Historical catch series (Fig. 5), comprising:
  - Commercial landings reported in NSW from 1950-51 – 2021-22 (Fig. 1);
  - Annual estimates of recreational harvest in NSW from 2000 onward imputed from the linear fit between the four available harvest estimates from state-wide telephone diary surveys (Fig. 4);
  - Annual estimates of recreational harvest in NSW during 1950-1999 imputed from the ratio of Mulloway harvest in NSW during the year 2000 to total Australian recreational harvest (Kleisner et al. 2015) (Fig. 4).
- Standardised commercial OTL offshore handlining CPUE adjusted for fishing efficiency (power) for 1997-98 to 2021-22 (Fig. 9). This catch rate series was selected for use in the model because it was considered likely to reflect the abundance of mature fish occurring in offshore waters, past management changes would have had minimal influence on catch rates using this method, and it included adjustment for increased fishing power through time.

Integrated catch and length-structured model

- Historical catch series (Fig. 5), comprising:
  - Commercial landings reported to NSW from 1950-51 – 2021-22 (Fig. 1);
  - Annual estimates of recreational harvest in NSW from 2000 onward imputed from four available harvest estimates from state-wide telephone diary surveys (Fig. 4);
  - Annual estimates of recreational harvest in NSW during 1950-1999 imputed from the ratio of Mulloway harvest in NSW during the year 2000 to total Australian recreational harvest (Kleisner et al. 2015) (Fig. 4).
- Length-composition data from NSW commercial fisheries 1998-99 – 2021-22 (Fig. 13).
- Biological parameters (natural mortality (M), fecundity, maturity, length-weight, growth parameters), selectivity, total (Z) and fishing mortality (F) estimates.

Key model structure & assumptions:

Standardised commercial CPUE

Standardised catch per unit effort (kg.day^{-1}) for offshore handlining was estimated using a general linear model (LM) constructed using the 'cede' package (Haddon et al. 2018) in 'R' statistical software. CPUE was standardised for variations across months, areas and vessels to a mean estimate of CPUE by year for the periods 2009-10 – 2020-21 and 1997-98 – 2021-22, in order to examine CPUE trends before and after a reporting change (from monthly to daily catch reporting) introduced in 2009 (Figs 7-8, 10-11). CPUE was also adjusted according to increases in fishing efficiency (power) for commercial line fishing (Wortmann et al. 2018; Fig. 9).

Assumptions: Annual CPUE is an index of relative abundance and not unduly influenced by other factors that are not accounted for through standardisation or adjustment.

SPR model

SPR modelling was conducted to provide an assessment method that does not rely on catch data or abundance indices (CPUE).

The spawning potential ratio (SPR) of a stock is defined as the proportion of the unfished reproductive potential left at any given level of fishing pressure (Goodyear 1993). The model is age-structured and uses the length composition of the population, biological parameters and current mortality rates to estimate the reproductive output of the fished population relative to the reproductive output of the population in the absence of fishing.

Total mortality estimates (Z) were made using age-based catch curve analysis (Chapman & Robson 1960) by applying an annual age-length key (ALK) to commercial length frequency distributions to generate annual age frequency distributions.

Assumptions: The size composition of commercial landings is assumed to arise from logistic gear selectivity and is representative of the size composition of the stock. Sampling is from a population not affected by immigration or emigration, mortality is constant across ages and years, and sampling is not biased regarding any age classes.

Integrated models under development

Production model

Production modelling was conducted to provide a complementary assessment method that integrates catch data and abundance indices (CPUE), and does not rely on length or age composition data.

CMSY++ (Catch-Maximum Sustainable Yield++; Froese et al. 2021).

CMSY++ is an advanced Bayesian state-space implementation of a modified Schaefer surplus production model (BSM). The BSM method relies on catch time series and relative abundance data, such as catch/effort (CPUE) data. The BSM method generates estimates of the intrinsic growth rate of a population (r) along with an estimate of its carrying capacity (k); from these, time series of biomass (B) and fishing mortality (F) can be computed, including the biomass (B_{MSY}) from which maximum sustainable yield (MSY) can be extracted given F_{MSY}. The model was conditioned on catch and calibrated using a time-series index of abundance (standardised handlining CPUE; Fig. 9). The main advantage of BSM compared to other implementations of surplus production models is the focus on informative priors and the acceptance of short and incomplete (fragmented) CPUE data (Froese et al. 2017).

Assumptions: Productivity models assume average recruitment across all stock sizes, including stock sizes below half of B_{MSY}. However, if recruitment is indeed reduced at lower stock sizes, then production models and CMSY will overestimate production of new biomass and will underestimate exploitation rates. Priors for initial relative biomass in 1950-51 were 0.4 – 0.8, and for final relative biomass in 2021-22 at 0.1 – 0.5.

Integrated catch and length-structured model

Integrated catch and length-structured modelling was conducted to provide a complementary assessment method that integrates catch and length composition data, and does not rely on abundance indices (CPUE) or age composition.

Modelling was conducted within the Stock Synthesis (SS) framework (Methot & Wetzel 2013). SS provides a statistical framework for calibration of a population dynamics model using a diversity of fishery and survey data. It is designed to accommodate both age and size structure in the population and with multiple stock sub-areas. Selectivity (logistic knife-edged or dome-shaped) can be cast as age specific only, size-specific in the observations only, or size-specific with the ability

to capture the major effect of size-specific survivorship. The overall model contains subcomponents which simulate the population dynamics of the stock and fisheries, derive the expected values for the various observed data, and quantify the magnitude of difference between observed and expected data. SS is most flexible in its ability to utilize a wide diversity of age, size, and aggregate data from fisheries and surveys.

Integrated catch and length-structured modelling for NSW Mulloway was undertaken using the Stock Synthesis Data-Limited Tool (SS-DL; Cope 2021) in R to provide an assessment method that integrates catch (to provide the scale of removals), lengths (to provide a time series index of stock status) and biological information (to provide population productivity parameters). Integrating catch and length has been shown to provided informative estimates of stock status relative to more complex reference models including additional data from abundance indices and age composition (Rudd et al. 2021).

Assumptions: Length frequency data were assumed to arise from dome-shaped selectivity of estuarine mesh nets. Other assumptions include instantaneous length sampling, adequate description of growth by the von Bertalanffy growth function, and that both sexes have the same growth.

Sources of uncertainty evaluated:

Standardised Commercial CPUE

Standardised commercial catch rates for the EG fishery using mesh nets may be confounded due to:

- Changes to management arrangements resulting from the introduction of the Mulloway Recovery Program (MRP) in November 2013 (increased minimum legal length (MLL) from 45 to 70 cm and introduction of bycatch allowance for undersize fish caught in EG mesh nets). Further changes were implemented in September 2018 (removal of bycatch allowance).
- The mesh sizes used by EG mesh net fishers may have changed after September 2018 when net registrations permitting the use of 6-inch mesh was removed, potentially changing the selectivity of the gear used to target Mulloway.
- The above management changes may have also affected targeting of Mulloway.

Standardised commercial catch rates for the OTL fishery using line fishing methods may be confounded due to:

- Changes to management arrangements resulting from the introduction of the MRP in November 2013 (increased MLL).
- The above management changes may have affected targeting of Mulloway.
- Increases in fishing efficiency (power) resulting from rapid recent improvements to gear and technology (GPS, sonar).

SPR model

A 95% confidence interval around the estimate of Z was derived from the uncertainty around the slope of the catch curve. Mortality estimates were made using a plausible range of values for M (range 0.09 – 0.19, median 0.159; Cope & Hamel 2022, Hamel & Cope 2022).

The size composition of commercial catches is used in calculation of mortality rates (catch curve analysis) and subsequent estimates of SPR. If the size composition of commercial landings is not representative of size composition of the stock (i.e. under-represents larger fish), then mortality estimates (Z & F) will be inflated, and SPR models may produce pessimistic SPR estimates. A non-representative commercial length composition could occur if:

1) Fishers selectively target small fish and/or selectively avoid larger fish (e.g. for marketing reasons – price)
2) Large fish are less catchable than smaller fish because of gear selectivity, behaviour or distribution
3) Routine port-based sampling does not sample large fish (e.g. small fish are sent to major markets where they are they are measured, but large fish are sold locally)
4) Age has been systematically underestimated in old age classes (the age-length relationship is incorrect).

Integrated models under development

Production model

Sensitivity of the model to a range of alternative assumptions and model inputs was evaluated by implementing five additional model scenarios, including those that varied recreational catch reconstructions and commercial discard mortality rates. Sensitivity scenarios run for the production model were undertaken using standardised commercial OTL offshore handlining CPUE adjusted for fishing efficiency (power) for 1997-98 – 2021-22, as the abundance index (Fig. 8). This was combined with the following modified catch time series datasets:

1) Reference model (base case) – reconstructed recreational catch time series (Fig. 4), reported commercial time series (Fig. 1)
2) Scenario 2 - reconstructed recreational catch time series (Fig. 4) with catch doubled 1950 – 1970, reported commercial time series (Fig. 1)*
3) Scenario 3 - reconstructed recreational catch time series (Fig. 4) with catch doubled 1950 – 2000, reported commercial time series (Fig. 1) *
4) Scenario 4 - reconstructed recreational catch time series (Fig. 4), reported commercial time series (Fig. 1), with undersize bycatch discard mortality equivalent to 60% of reported catch (based on discard estimates from Gray 2002)#
5) Scenario 5 - reconstructed recreational catch time series (Fig. 4), reported commercial time series (Fig. 1), with undersize bycatch discard mortality equivalent to 30% of reported catch (half that used in scenario 4)#
6) Scenario 6 - reconstructed recreational catch time series (Fig. 4), reported commercial time series (Fig. 1), with undersize bycatch discard mortality equivalent to 10% of reported catch (one third of that used in scenario 5)#

*Scenarios 2 and 3 were undertaken in order to explore the effect of much larger and time-variable possible historical recreational catches on model outputs

#Scenarios 4-6 were undertaken in order to explore the effect of various rates of discarding and discard mortality on model outputs

Integrated model

Sensitivity of the model to a range of alternative assumptions and model inputs was evaluated by implementing five additional model scenarios, including those that varied commercial fishery discard mortality rates and recreational catch reconstructions. Sensitivity scenarios run for the integrated model were undertaken using commercial length composition timeseries data (Fig. 13), combined with the same modified catch time series datasets for the first six scenrios used in the production model (see "*Sources of uncertainty evaluated: Integrated models under development*" above).

Status Indicators - Limit & Target Reference Levels

Biomass indicator or proxy	**Standardised commercial CPUE trends** **Current SPR from SPR model** [Current B/K from production model]* [Current B/B_0 from integrated model]*
Biomass Limit Reference Point	**SPR_{20} (20% of estimated unfished SPR)** [B_{20} (20% of pre-exploitation spawning biomass)]*
Biomass Target Reference Point	NA
Fishing mortality indicator or proxy	**Current F relative to M from catch curve analysis** **Length composition (auxiliary indicator)** [Current F relative to F_{20} from production model]* [Current total harvest relative to MSY from production model]* [Current F relative to M from integrated model]*
Fishing mortality Limit Reference Point	**F >> M from catch curve analysis** [F > F_{20} from production model]* [Harvest > MSY from production model]* [F > M from integrated model]*
Fishing Mortality Target Reference Point	NA

*Indicators and reference points for "Integrated models under development"

Stock Assessment Results

The NSW Mulloway stock is classified as **recovering**. The status is based on:

1) Standardised commercial catch rates:
    a. EG mesh netting CPUE:
        i. Increased by ~340% between 1997-98 and 2021-22 (monthly catch reporting; Fig. 7).
        ii. Increased by ~195% between 2009-10 and 2021-22 (daily catch reporting; Fig. 10).
        iii. Increased by ~70% between 2018-19 and 2021-22 (daily catch reporting; Fig. 10).
    b. OTL offshore line fishing CPUE:
        i. Increased by ~65% between 1997-98 and 2021-22 (monthly catch reporting; Fig. 8).
        ii. Adjusted for fishing power – stable (~14% decrease) between 1997-98 and 2021-22 (monthly catch reporting; Fig. 9).
        iii. Increased by ~40% between 2009-10 and 2021-22 (daily catch reporting; Fig. 11).
        iv. Stable (~5% decrease) between 2018-19 and 2021-22 (daily catch reporting; Fig. 11).
2) Spawning Potential Ratio:
    a. Current SPR is estimated >20% of unfished SPR (SPR_{20}) in the scenario using median M (0.159) in the SPR model – **SPR = 31%** (range 15-39%; Fig. 14).
    b. SPR was estimated to be 21% (range 10-27%) in 2018-19 (Fig. 14).
3) Fishing mortality:
    a. Current F is estimated > median M (0.159) from catch curve analysis – total mortality Z = 0.40 (95% CIs 0.32 – 0.59), current fishing mortality **F = 0.25** (range 0.22 – 0.32).
    b. F was estimated to be 0.35 (range 0.32 – 0.42) in 2018-19 (Hughes 2020).
4) Length composition:
    a. Current commercial **mean length = 93.7 cm** (± 0.8 SE).
    b. The average length has been > size-at-maturity (70 cm) since 2017-18 (Figs 12 & 13).

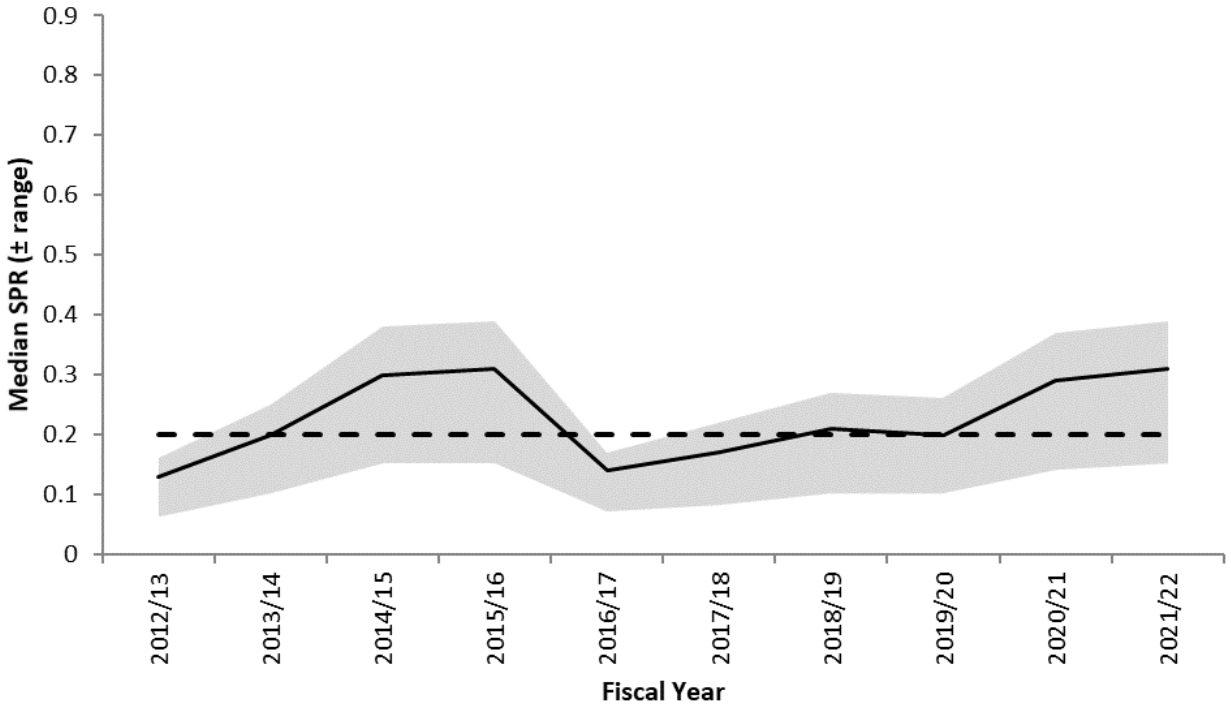

Figure 14. Median spawning potential ratio (SPR) estimates for Mulloway in NSW 2012-13 – 2021-22. The grey shaded area represents SPR range for scenarios using a range of empirical M estimates. The horizontal line represents the 20% SPR limit reference point (SPR_{20}).

Results of uncertainty evaluation

Standardised CPUE confounded by management changes

Increases in CPUE evident for EG mesh netting (Figs 7 & 10) may be confounded by changes to management as part of the MRP in November 2013 and removal of bycatch allowances in September 2018, and subsequent changes to fishery operations. However, given the increase to the MLL, the relative abundance of spawning biomass may have increased substantially more than these CPUE trends suggest.

Standardised commercial handline CPUE adjusted for fishing power

To account for increases in fishing efficiency (power), standardised handlining CPUE was also adjusted as described in Wortmann et al. (2018). The resulting time series of catch rates showed a ~70% decrease from 1997-98 to 2008-09 followed by a ~185% increase to 2020-21 (Fig. 9). Overall catch rates adjusted for fishing efficiency have therefore remained relatively stable overall (~14% decline) between 1997-98 and 2021-22.

SPR model

Sensitivity scenarios run for the SPR model using a range of M estimates (0.09-0.19) produced SPR estimates of 15-39% of unfished, which spans the biomass limit reference point of SPR_{20} (20% of unfished; Fig. 14).

It is considered that two of the four scenarios which may produce a non-representative length frequency are likely to occur for commercially-caught Mulloway in NSW (1. Selective targeting of small fish, 2. Dome-shaped selectivity of the primary gear). Mortality rates derived from catch curve analysis are therefore likely to be inflated, and SPR estimates are likely to be pessimistic.

Stock Assessment Result Summary

Biomass status in relation to Limit	**~70% increase in standardised EG mesh netting CPUE between 2018-19 and 2021-22** **Standardised OTL hand lining CPUE stable between 2018-19 and 2021-22** **SPR model (base case, last series value [2021-22]): SPR = 31%** Production model (base-case, last series value [2021-22]): B/K = 31%* Integrated model (base case, last series value [2021-22]): B/B_0 = 25%*
Biomass status in relation to Target	NA
Fishing mortality in relation to Limit	**Catch curve analysis – F > M (last series value [2021 – 22] = 0.25)** **Length composition – Mean length > size-at-maturity (last series value [2021 – 22] = 93.7 cm)** Production model – F/F_{20} < 1 (base-case, last series value [2021 – 22] = 0.39)* Production model – Harvest < MSY (base-case, last series value [2021 – 22]) = 134 t (MSY= 365 t)* Integrated model – F < M (base-case, last series value [2021 – 22] = 0.06) from integrated model*
Fishing mortality in relation to Target	NA
Previous SAFS stock status	"Overfished" in NSW assessments 2004/05 – 2014/15 New South Wales stock "Overfished" SAFS 2014 New South Wales stock "Overfished" SAFS 2016 New South Wales stock "Depleted" SAFS 2018 New South Wales stock "Depleted" SAFS 2020

Current SAFS stock status	Recovering (NSW)

*See Appendix 1 for results from "Integrated models under development".

Summary

While some analyses estimate that biomass may be greater than the 20% limit reference point in recent years, due to high variance surrounding estimates of all biomass indicators, none do so with high certainty, and recruitment impairment may therefore still be occurring. However, all fishing mortality and biomass indicators show reductions in fishing pressure and increases in biomass in recent years with a high degree of certainty. For the period 2019-20 – 2021-22, these indicators therefore suggest a recovering stock.

The above evidence indicates that the current level of fishing mortality should allow the stock to continue to recover from its recruitment impaired state, however the rate of recovery will depend on the magnitude of future harvest.

On the basis of the evidence provided above, Mulloway in New South Wales is classified as a **recovering stock**.

Fishery interactions

Mulloway are fished in the adjacent jurisdictions of Victoria and Queensland.

Stakeholder engagement

NSW DPI Fisheries presented the current stock assessment to stakeholders in the Mulloway Harvest Strategy Working Group on 18th March 2024, to outline the assessment process and provide an opportunity for feedback.

All stakeholders welcomed the improved stock status of 'recovering' for NSW Mulloway in 2023. Commercial stakeholders provided commentary on the fishing effort and standardised CPUE series presented, noting that the current series includes Mulloway landed when targeting other species, and suggested a more suitable CPUE series may be one restricted only to fishers specifically targeting Mulloway. Other members highlighted the uncertainty in recreational survey data used to underpin the historical recreational catch reconstruction, and potential underestimation of recent increases in fishing power driven by social media.

DPI expressed to stakeholders that the current weight-of-evidence assessment uses numerous types of data (including catch, CPUE, length and age composition, and species biology) to underpin multiple different analyses, all of which provided consistent signals for biomass and fishing mortality indicators, defensibly justifying the determination of a 'recovering' stock status.

Qualifying Comments

The weight-of-evidence approach used here to assess stock status reveals some uncertainty due to the lack of data on size composition from historical landings (commercial and recreational), the historic recreational harvest, population representative contemporary biological data, and knowledge gaps regarding fine-scale population structure in NSW, and gear selectivity and discard mortality for the main sectors and gears (mesh nets and angling). Results from data-limited assessment methods must therefore be interpreted with caution, given the limited information used to model population parameters and stock status.

Nevertheless, outputs from all modelling approaches indicated that the stock underwent a steady decline to estimated biomass levels likely to be below the limit reference point of 20% unfished biomass ($<B_{20}$) during the 1990s – 2000s, simultaneous with high fishing mortality (>2M) and a fishery that was largely based on juveniles. All modelling approaches have since estimated biomass to have rebuilt such that current biomass is likely to be around B_{20} with reasonable probability, simultaneous with declining fishing mortality, a fishery increasingly based on adults and evidence of good recent recruitment.

Factors other than fishing, including climate change and other environmental processes, may also affect changes in the abundance and biological functioning of the Mulloway stock through time (e.g. rainfall – Stewart et al. 2020, temperature – Nicolle et al. 2022).

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Appendix 1 – Integrated models under development

Stock Assessment Results*

1) Production model
    a. Current biomass is estimated >20% of pre-exploitation biomass in base case scenario – B/K = 31% (95% CIs 23-42%; Appendix 1, Figs 15 & 19, Table 1).
        i. B/K > 20% in all model scenarios (Appendix 1, Figs 15 & 19, Table 1)
    b. Current F is estimated < F_{20} in the base case scenario of the production model – F/F_{20} = 0.39 (Appendix 1, Fig. 16).
    c. Current harvest (134 t) < MSY (365 t) in the base case scenario of the production model (MSY range 365 – 616 t).
2) Integrated model
    a. Current biomass is estimated >20% of pre-exploitation biomass in base case scenario – B/B_0 = 25% (95% CIs 5-40%; Appendix 1, Fig 17 & 20, Table 1).
        i. B/B_0 > 20% in all model scenarios (Appendix 1, Fig 17 & 20, Table 1)
    b. Current F is estimated < median M (0.159) in the base case scenario of the integrated model – F = 0.06 (95% CIs 0.03 – 0.09; Appendix 1, Fig. 18).

*All results are preliminary as modelling approaches have not been subjected to comprehensive diagnostic evaluation or scenario testing.

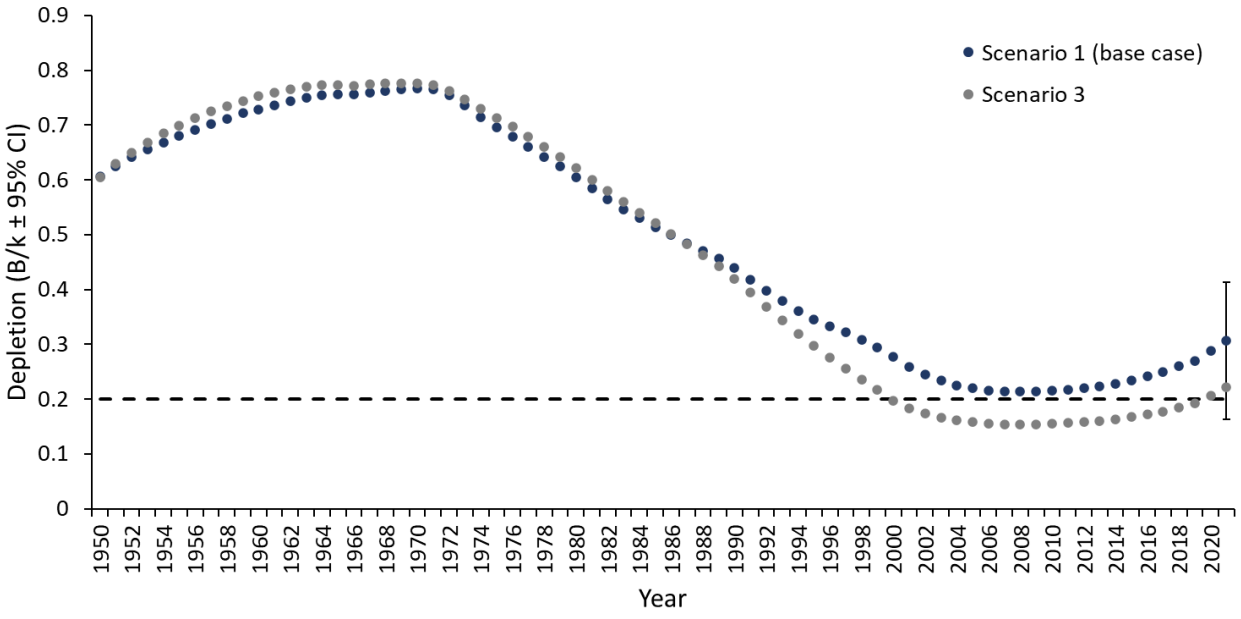

Figure 15 Biomass depletion trajectories (B/K) for two catch and CPUE timeseries scenarios (Scenario 1 (base case) – dark blue, and Scenario 3 – grey; see Table 1) used in the production model for the period 1950-51 – 2021-22. A 95% CI is given for the current (2021-22) estimate for each scenario. The dashed black horizontal line indicates the limit reference point of 20% B/K. Years are fiscal.

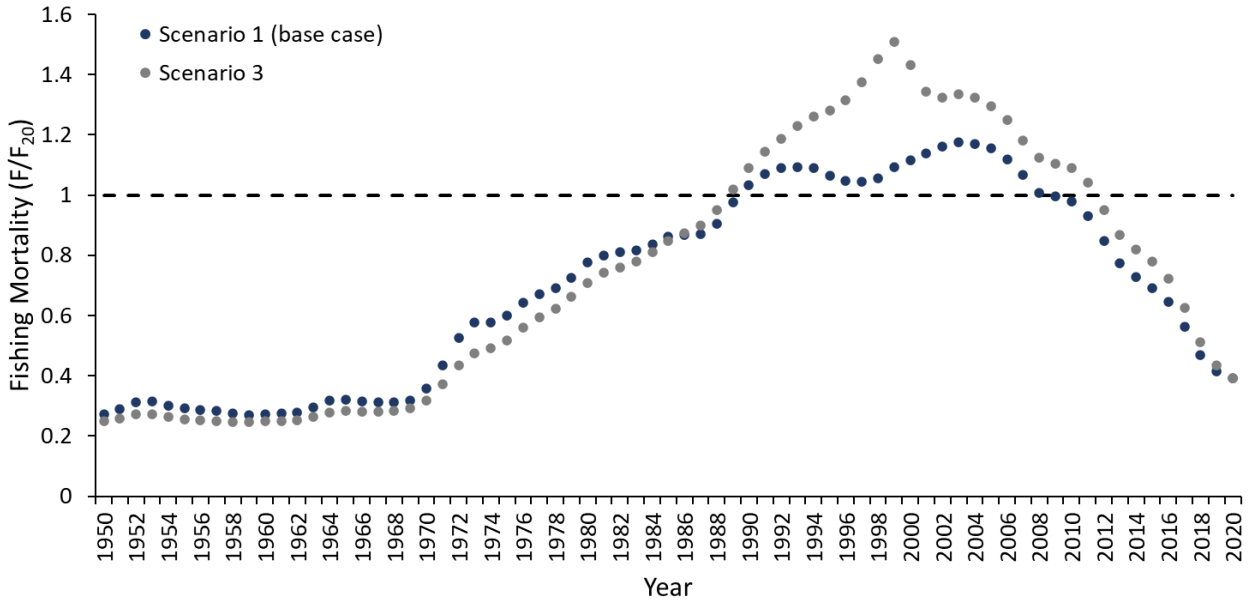

Figure 16 **F/F_{20} trajectories for two catch and CPUE timeseries scenarios (Scenario 1 (base case) – dark blue, and Scenario 3 – grey; see Table 1) catch and CPUE timeseries used in the production model for the period 1950-51 – 2021-22. The dashed black horizontal line indicates F/F_{20} = 1, above which F was greater than that predicted to drive biomass below B_{20}. Years are fiscal.**

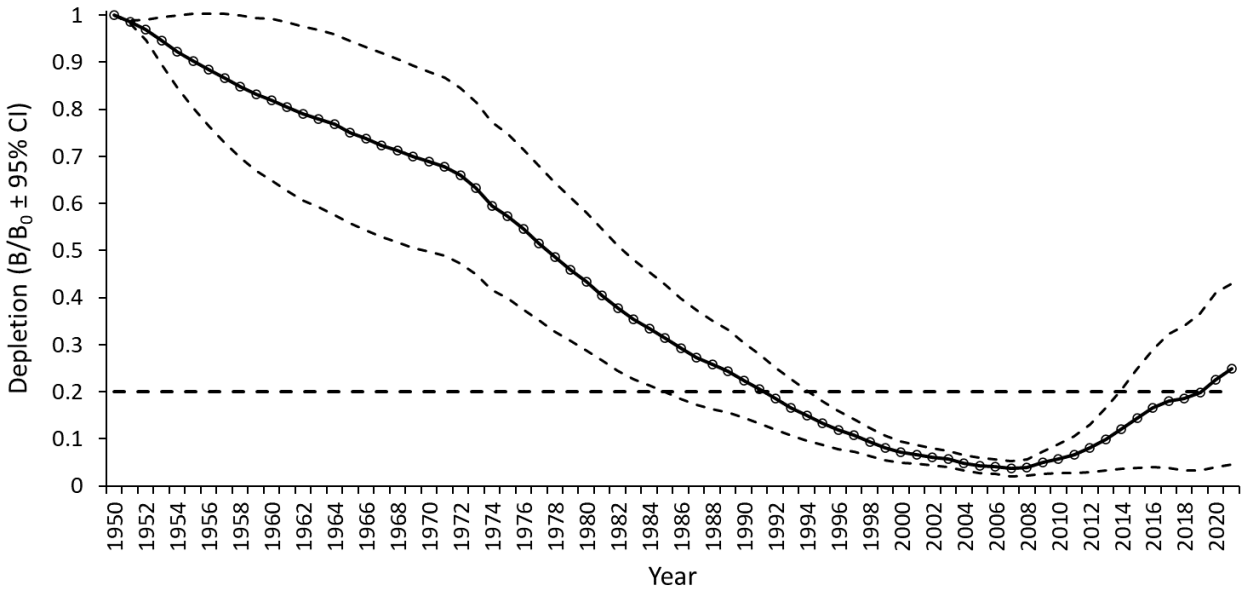

Figure 17 **Biomass depletion trajectory (B/B_0) for the base case catch and length composition timeseries used in the integrated model for the period 1950-51 – 2021-22. The dashed lines above and below indicate the 95% confidence intervals around the estimates. The dashed black horizontal line indicates the limit reference point of 20% B/B_0. Years are fiscal.**

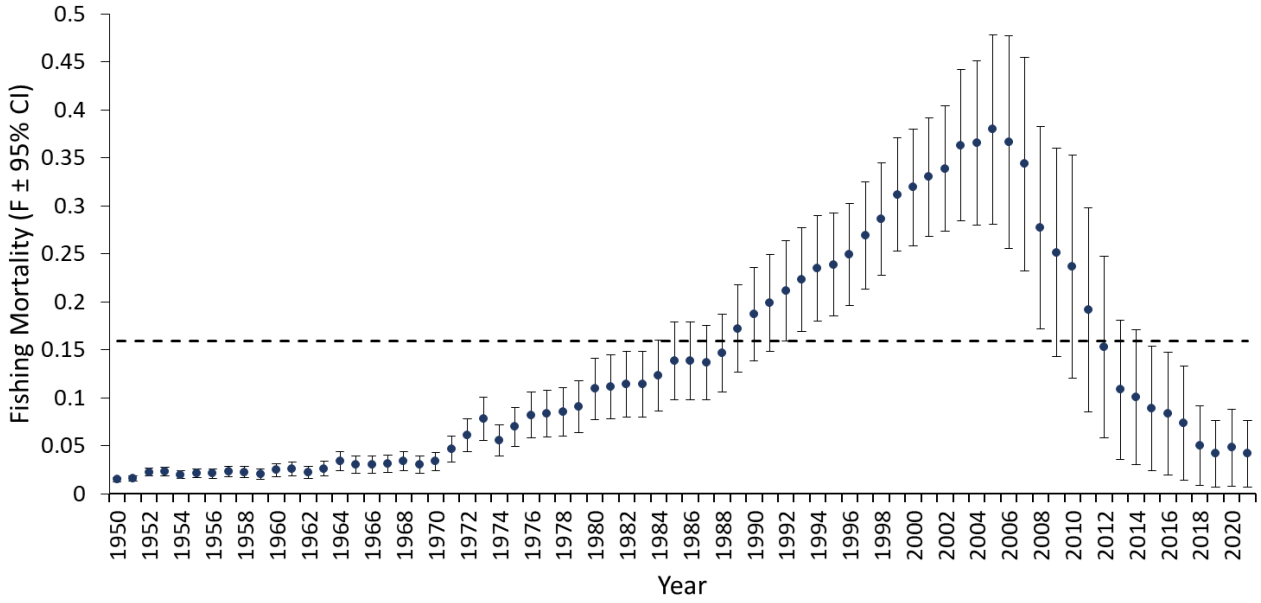

Figure 18 Fishing mortality (F ± 95% CI) trajectory for the base case catch and length composition timeseries used in the integrated model for the period 1950-51 – 2021-22. The dashed black horizontal line indicates median natural mortality rate (M; Cope & Hamel 2022, Hamel & Cope 2022). Years are fiscal.

Results of uncertainty evaluation

Production model

Sensitivity scenarios consistently estimated the current depletion of biomass to be above the limit reference point of B_{20} using various reconstructed recreational catch reconstructions and commercial discard mortality rates (Table 1, Fig. 19). Estimates from the base case and all five sensitivity scenarios were greater than the limit reference poit of B_{20}. However, B_{20} was encompassed by the 95% CI around two of the scenario estimates (2 & 3), and for the other four, the lower bound of the 95% CI was within 3% of B_{20} (Table 1, Fig. 19).

Integrated model

Sensitivity scenarios run for the integrated model consistently estimated the current depletion of biomass to be above the limit reference point of B_{20} in the base case and five recreational catch reconstruction and discard mortality rate scenarios, but B_{20} was encompassed by the 95% CI around all estimates (where variance was estimated; Fig. 20, Table 1).

Table 1. Estimated biomass depletion in 2021-22 for the six CPUE and reconstructed catch and discarding scenario timeseries used in the integrated models under development (production model (B/K), integrated model (B/B_0)) for the period 1950-51 – 2021-22. The limit reference point is 20% B/K or B/B_0.

Sensitivity scenario	Description	Current estimated biomass (2021-22)	
		Production model – B/K (± 95% CI)	*Integrated model – B/B_0 (± 95% CI)*
1 (base case)	Reconstructed recreational catch time series (Fig. 4), reported commercial time series (Fig. 1)	0.306 (± 0.097)	0.249 (± 0.204)
2	Reconstructed recreational catch time series (Fig. 4) with catch doubled 1950 – 1970, reported commercial time series (Fig. 1)*	0.288 (± 0.091)	0.239 (± 0.202)
3	Reconstructed recreational catch time series (Fig. 4) with catch doubled 1950 – 2000, reported commercial time series (Fig. 1)*	0.221 (± 0.071)	0.230 (± 0.204)
4	Reconstructed recreational catch time series (Fig. 4), reported commercial time series (Fig. 1) with bycatch discard mortality equivalent to 60% of reported catch#	0.298 (± 0.110)	0.221 (NA^)
5	Reconstructed recreational catch time series (Fig. 4), reported commercial time series (Fig. 1) with bycatch discard mortality equivalent to 30% of reported catch#	0.306 (± 0.103)	0.219 (NA^)
6	Reconstructed recreational catch time series (Fig. 4), reported commercial time series (Fig. 1) with bycatch discard mortality equivalent to 10% of reported catch#	0.303 (± 0.099)	0.236 (NA^)

*Scenarios 2 and 3 were undertaken in order to explore the effect of much larger and time-variable possible historical recreational catches on model outputs

#Scenarios 4-6 were undertaken in order to explore the effect of various rates of discard mortality on model outputs

^Variance components were not estimated for these scenarios of the integrated model

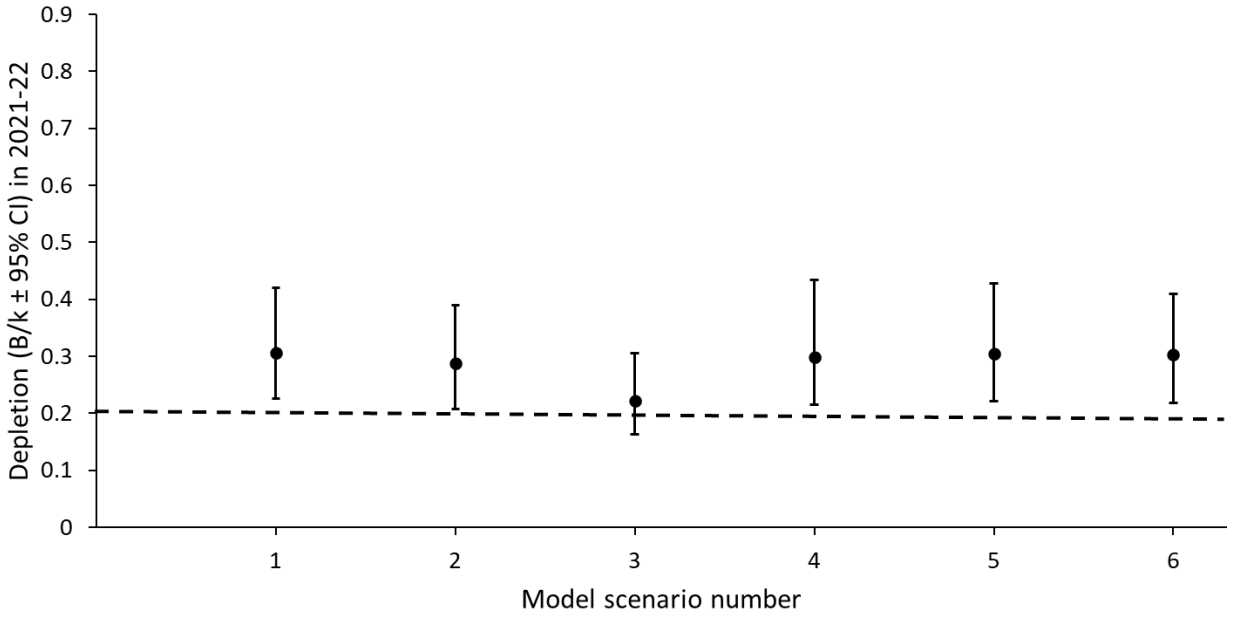

Figure 19 **Estimated biomass depletion (B/K ± 95% CI) in 2021-22 for the six CPUE and reconstructed catch and discarding scenario timeseries used in the production model for the period 1950-51 – 2021-22. The dashed black horizontal line indicates the limit reference point of 20% B/B_0. Years are fiscal.**

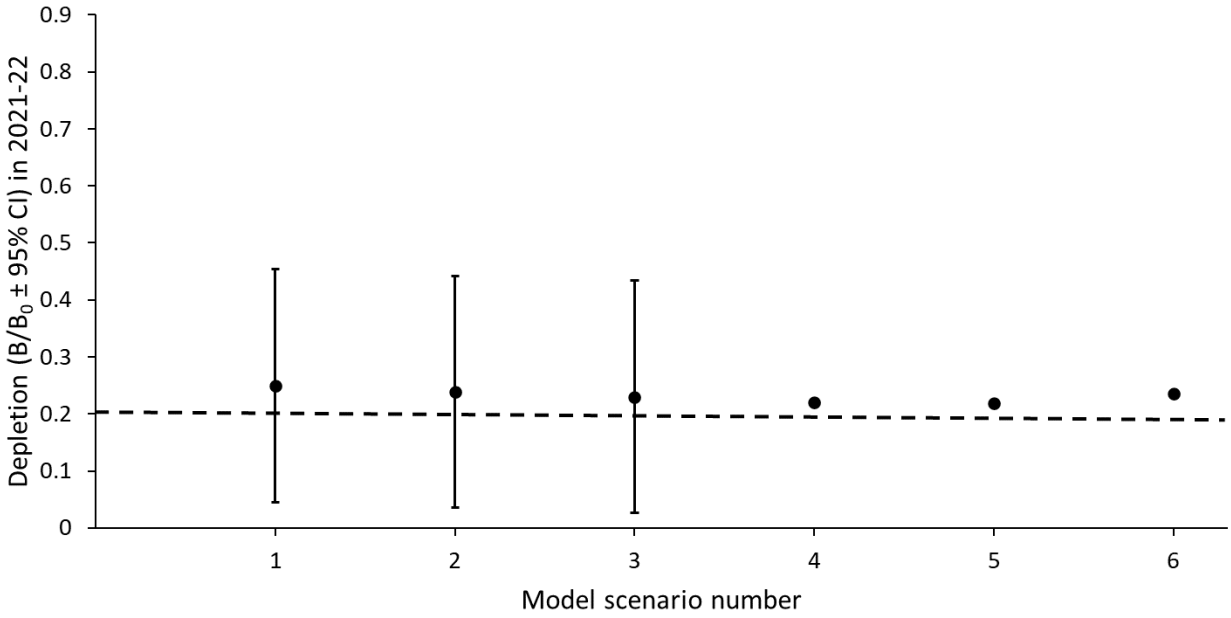

Figure 20 **Estimated biomass depletion (B/B_0 ± 95% CI) in 2021-22 for the six length composition and reconstructed catch and discarding scenario timeseries used in the integrated model for the period 1950-51 – 2021-22. The dashed black horizontal line indicates the limit reference point of 20% B/B_0. NB: variance components were not estimated for scenarios 4-6.**