Stock assessment of Queensland east coast crimson snapper (*Lutjanus erythropterus*), Australia

2021

Queensland Government

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Contents

List of figures

List of tables

Summary

Crimson snapper (*Lutjanus erythropterus*) is a species of tropical snapper that inhabits Queensland waters, forming one population (stock) on Queensland's east coast. This stock is primarily harvested by line fishing. Crimson snapper are gonochoristic (born male or female and do not change sex) and spawn primarily during spring and summer. They can grow to 79 cm (fork length) and live for at least 35 years (DAF, unpublished data).

This is the first stock assessment of the Queensland east coast stock of crimson snapper. It implemented a one-sex population model fit to age and length data, constructed within the Stock Synthesis modelling framework.

The model incorporated data spanning the period from 1989 to 2021 including commercial harvest (1989–2021), recreational harvest (2001–2019), boat-ramp surveys (2017–2021) and age-length monitoring (2018–2021).

Over the last five years, 2017 to 2021, the Queensland total harvest averaged 34 tonnes per year, including 12 tonnes by the commercial sector, and 22 tonnes by the charter, recreational, and Indigenous sectors combined (Figure 1). The commercial and charter harvest were based on logbook reporting whereas the recreational and Indigenous harvest were estimated from surveys and interpolated between survey years. The recreational, Indigenous and charter estimates were recorded in numbers of fish and converted to weight in kilograms by the population model. The commercial harvest was recorded in kilograms. The fishery was modelled using two fleets: commercial and 'recreational' (which included charter and Indigenous catch).

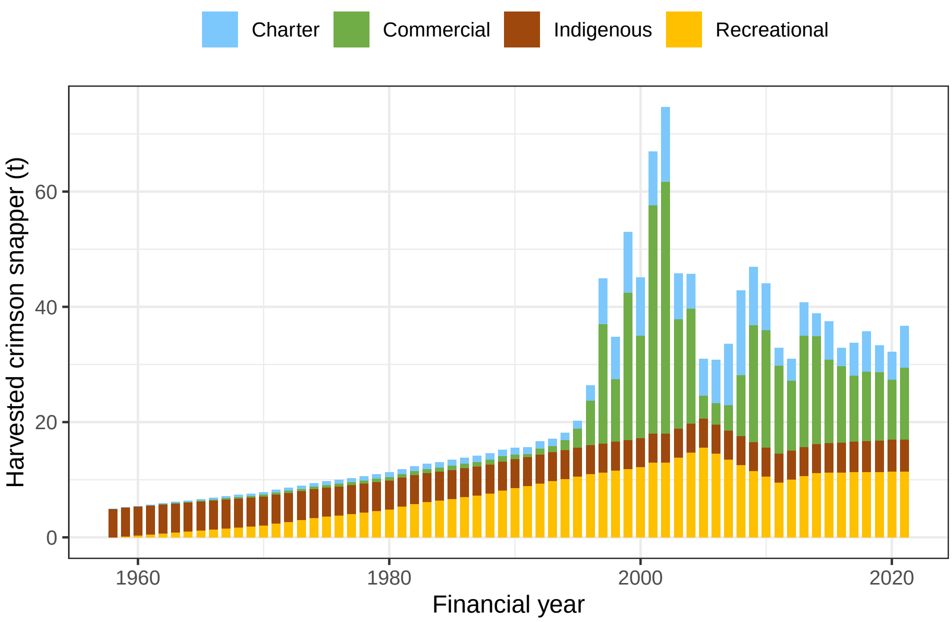

Figure 1: Annual estimated harvest (retained catch) from commercial, recreational, charter and Indigenous sectors between 1958 and 2021 for crimson snapper—the latter three sectors were modelled as a single fleet

Commercial catch rates were standardised to estimate an index of crimson snapper abundance through time (Figure 2). The unit of standardisation was kilograms of crimson snapper per boat per day. Explanatory terms used in the standardisation model included year, region, fisher, number of crew members, weight of co-caught coral trout and redthroat emperor, and weight of all other commonly co-caught reef species.

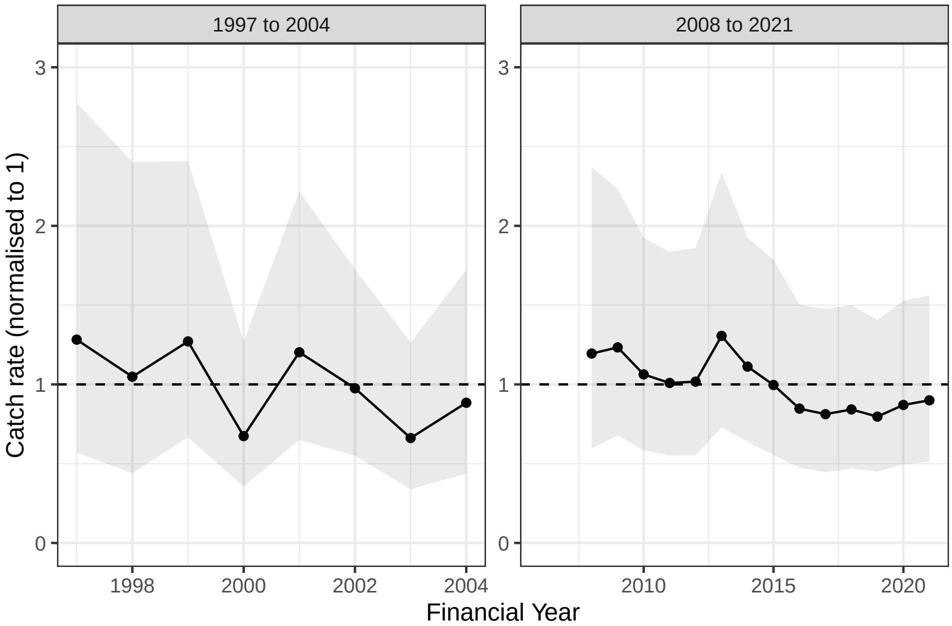

Figure 2: Annual standardised catch rates (with 95% confidence intervals) for commercial line caught crimson snapper between the years of 1997 and 2021

Fourteen model scenarios were run, covering a wide range of modelling assumptions. Base case (preferred) scenario results suggested that spawning biomass declined between 1958 and 2019 to 35% unfished spawning biomass. In 2021, the stock level was estimated to be 44% (21–45% range across scenarios) unfished spawning biomass (Figure 3).

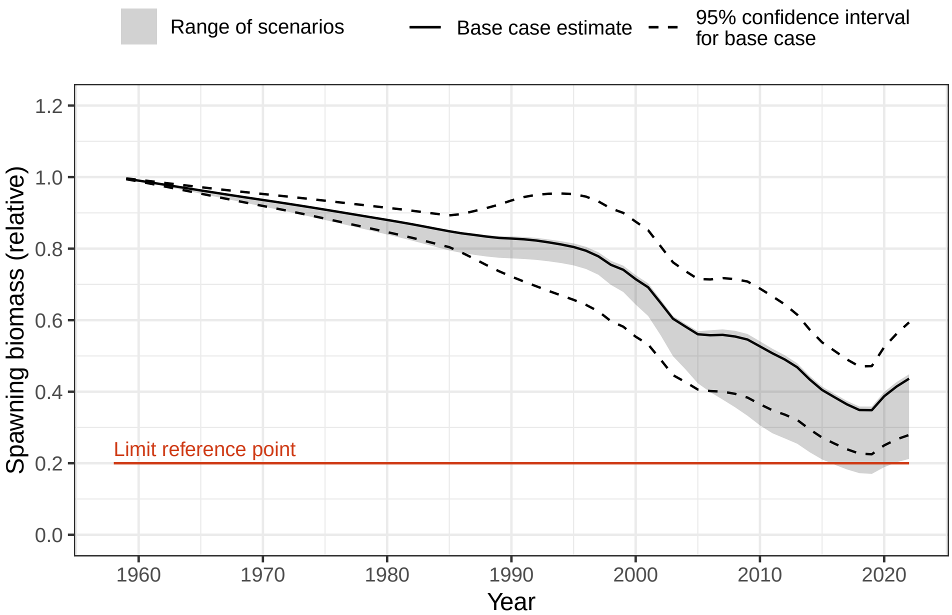

Figure 3: Predicted spawning biomass trajectory relative to unfished for crimson snapper for the 'base case' scenario, from 1958 to 2021

The harvest consistent with a spawning biomass ratio of 60%, the reef line harvest strategy objective for species with a published stock assessment, was estimated at 34 t (24–36 t range across scenarios; all sectors). The recommended harvest in the 2022 financial year is 16 t (0–16 t range across scenarios) in order to achieve this target by 2031.

For secondary species in a multi-species fishery, the Queensland harvest strategy policy requires a minimum objective of maximum sustainable harvest. The harvest consistent with a spawning biomass ratio of 40%, a proxy for biomass at maximum sustainable harvest, was estimated at 45 t (32–48 t range across scenarios; all sectors). The recommended harvest in the 2022 financial year is 51 t (0–54 t range across scenarios) in order to achieve this target by approximately 2041.

Table 1: Current and target indicators

Parameter	**Estimate**
Current (2021) spawning biomass (relative to unfished)	44% (21–45%)
Biomass at maximum sustainable harvest	26% (26–30%)
Current (2021) harvest	30.2 t
Commercial	12.5 t
Recreational + Charter + Indigenous	17.7 t
Sustainable harvest at spawning $B_{40\%}$	45 t (32–48 t)
Maximum sustainable harvest	48 t (34–52 t)
Proposed harvest (2022) to achieve $B_{40\%}$ target	51 t (0–54 t)
Time to reach target	10 years (9–20+ years)

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Glossary

B_{40}	40% of unfished spawning biomass, a proxy for biomass at maximum sustainable yield
B_{60}	60% of unfished spawning biomass, a proxy for biomass at maximum economic yield
biomass	spawning biomass, the total weight of all adult (reproductively mature) fish in a population, an indicator of the status of the stock and its reproductive capacity
blue zone	associated with reefs in the Great Barrier Reef Marine Park that remained open to fishing after the introduction of the Representative Areas Program in 2004, and all areas on the Queensland east coast outside the Great Barrier Reef Marine Park
CFISH	Commercial Fisheries Information System, which is the compulsory commercial logbook database managed by Fisheries Queensland
fleet	a population modelling term used to distinguish types of fishing activity: typically a fleet will have its own selectivity curve that characterises the likelihood that fish of various sizes (or ages) will be caught by the fishing gear
GBR	Great Barrier Reef
GBRMP	Great Barrier Reef Marine Park
GBRMPA	Great Barrier Reef Marine Park Authority
green zone	associated with reefs that were closed to fishing at the introduction of the Representative Areas Program
FL	fork length, measured from the tip of fish's nose to the fork in its tail
McMC	Markov chain Monte Carlo, a statistical computer simulation method for estimating population model parameters and their variance
MLS	minimum legal size
MSH	maximum sustainable harvest
NRIFS	the National Recreational and Indigenous Fishing Survey conducted by the Australian Department of Agriculture, Fisheries and Forestry
fisher-day	a day of fishing by a fishing operator, corresponding to a single daily logbook record (commercial)
RAP	Representative Areas Program
RFish	recreational fishing surveys conducted by Fisheries Queensland
RLF	Reef Line Fishery
SFS	Sustainable Fisheries Strategy
SRFS	Statewide Recreational Fishing Survey
SS	Stock Synthesis
TL	total length, measured from the tip of fish's nose to the end of its tail
year	modelled according to financial year (July–June)

1 Introduction

Crimson snapper (*Lutjanus erythropterus*) is a secondary target and by-product species in the Reef Line Fishery (formerly the Coral Reef Fin Fish Fishery) with an annual harvest of approximately 30 t across all sectors combined. The Reef Line Fishery (RLF) operates largely within the Great Barrier Reef Marine Park (GBRMP), extending from the northern tip of Cape York to 24°30' S (south of Brisbane).

Crimson snapper are widespread, found in the Indo-West Pacific from Australia and New Guinea to the Gulf of Oman, and northward to southern Japan (Allen 1985). Research on the biological stock structure of this species in Australian waters has only occurred in northern Australia, including the Timor Sea, the Arafura Sea and the Gulf of Carpentaria (Salini et al. 2006). It is considered that the species has five genetic stocks—in Western Australia (North Coast Bioregion), off the east coast of Queensland, in the Joseph Bonaparte Gulf, in the Timor and Arafura seas, and in the Gulf of Carpentaria (Salini et al. 2006; Saunders et al. 2018)—however there is limited information on the stock structure of crimson snapper for the east coast of Australia.

The limited tag recapture data that have been collected from the central Queensland coast indicate that crimson snapper have a recapture rate of 5.1% (Platten et al. 2007). Of those recaptured individuals, the maximum distance moved was 8 km, while 95% indicated no movement from their initial location (Platten et al. 2007).

Crimson snapper are found in trawling grounds and reefs to depths of at least 100 m (Newman 2002). They are present over shoals, rubble, corals, large epibenthos, hard or sandy mud substrates and off-shore reefs (Kailola et al. 1993). They frequently form mixed shoals with saddletail snapper (*Lutjanus malabaricus*) (Allen 1985; Newman 2002). They feed on a broad range of prey dominated by fish, as well as small amounts of crustaceans, cephalopods and other benthic invertebrates (Kailola et al. 1993).

Crimson snapper are gonochoristic, meaning they are born male or female and do not change sex throughout their lives. They are relatively long-lived, and grow slowly after becoming reproductively mature (Newman et al. 2000). In Great Barrier Reef (GBR) waters, the fork length of females at 50% maturity was estimated to be 48.5 cm (McPherson et al. 1992b). Crimson snapper can reach an estimated maximum fork length of 79 cm in east coast Queensland waters (McPherson et al. 1992b) and live to at least 35 years.

Crimson snapper suffer from barotrauma when released. Brown et al. (2008) reported a post-release survival rate for crimson snapper of 84%, however this decreased to 10% survival if fish were in the lowest category for release condition in their study. This study was conducted on an inshore wreck near Townsville, Queensland at a depth of approximately 22 m with a high proportion of individuals under the minimum legal size (MLS). Juvenile crimson snapper (below the MLS) are more likely to inhabit inshore shallow waters (< 25 m) (Jones et al. 1988). Conversely, larger individuals (above the MLS) generally inhabit deeper waters (Williams et al. 1994). Therefore, an ontogenetic shift in post-release survival is likely, however not proven scientifically.

Crimson snapper are one of three large species of lutjanids (tropical snappers) that are prevalent secondary target species in the Reef Line Fishery, alongside saddletail snapper and red emperor (*L. malabaricus* and *L. sebae*, respectively). Due to their similar appearance, crimson snapper are sometimes misidentified as saddletail snapper (*Lutjanus malabaricus*) (Allen 1985). Crimson snapper (*L. erythropterus*) has previously been known as saddletail sea perch or small mouth nannygai, and saddletail snapper (*L. malabaricus*) have previously been known as scarlet sea perch or large mouth nannygai (McPherson et al. 1992b).

The Reef Line Fishery is Queensland's second most profitable (behind the East Coast Otter Trawl Fishery), with an estimated Gross Value of Production of $27 million (Fisheries Queensland 2020).

This report considers four sectors in the Reef Line Fishery: Indigenous, commercial, charter and recreational. While coral trout for a live export market are the main target of the fishery, commercial fishers also harvest redthroat emperor and other coral reef species, including crimson snapper (see Appendix E for a full list of other species). Different 'Other Species' (OS) species are targeted using different fishing techniques compared to live trout. While species specific individual transferable quotas (ITQs) are in place for coral trout and redthroat emperor, crimson snapper and other targeted species are managed using a 'Other Species' (OS) combined/basket ITQ (Fisheries Queensland 2020).

Additional management measures in the fishery that pertain to crimson snapper include spawning closures, minimum size limits, compulsory logbook catch reporting, gear restrictions, vessel and tender restrictions and possession limits for recreational fishers (Fisheries Queensland 2020). The history of crimson snapper fishery management is provided in Table 1.

The fishing season is 1 July to 30 June annually, with two five-day spawning closures between October and November each year (Commonwealth of Australia 2017). Vessel length is restricted to a maximum of 25 m and tenders are limited by number and size (Fisheries Queensland 2020). In the commercial sector, gear is restricted to three fishing lines at a time with no more than six hooks per person (Fisheries Queensland 2020). Recreational fishers accessing the fishery can use hook and line, rods and reels, and spearfishing gear (excluding hookah/scuba) (Fisheries Queensland 2020).

The RLF is managed under the *Fisheries Act 1994* and its subordinate legislation. The Indigenous sector of the fishery is managed in consideration of the *Native Title Act 1993*, which allows Indigenous fishers to use prescribed traditional and non-commercial gear, and removes restrictions on size, possession limits and seasonal closures (Fisheries Queensland 2020).

Table 1.1: History of crimson snapper management in Queensland

Year	Management
1957	Minimum size of 14 inches (35.56 cm) (listed as "Scarlet Sea-Perch (*Lutjanus malabaricus*)"). No MLS explicitly listed for *Lutjanus erythropterus* although it is assumed this applied to both nannygai species. *The Fisheries Acts, 1957 to 1962*
1975	Inclusion of no-fishing zones in the Great Barrier Reef. *Great Barrier Reef Marine Park Act 1975*
1981	Zoning extended to Capricornia Section of GBRMP (Capricorn–Bunker reefs). *GBR Marine Park Management*
1982	Section 35 permit allows recreational fishers to sell excess catch.
1983	Zoning extended to Cairns Section of GBRMP (Lizard Island to Innisfail).
1987	Zoning extended to Central Section of GBRMP (Innisfail to Mackay).

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Table 1.1 – *Continued from previous page*

Year	Management
1988	Zoning extended to Mackay–Capricorn Section of GBRMP (Mackay to the Swains).
1988	Introduction of compulsory commercial logbooks.
1990	Permits under section 35 allowing recreational fishers to sell catch was repealed. *Fishing Industry Organisation and Marketing Regulation*
1993	Recreational possession limits of a combined total of 30 coral reef fish covering 26 species. Charter vessel possession limit arrangements: extended charters in excess of 48 hrs allowed double the prescribed possession limit. Restructure of commercial line fishery into regional endorsements—the existing L symbol was introduced into legislation with the numbers L1–L9 depicting different regions of operations. New format for landed fish, where a fish has been filleted there must be two fillets equal to one whole fish. Skin not to be removed from fillets by recreational fishers, except in the case of charter vessels in excess of 48 hours where the majority of the skin may be removed provided a minimum is left for identification. *Fishing Industry Organisation and Marketing Regulation*
May 1997	Investment Warning is issued.
Apr 2002	Second zoning of Far Northern Section of GBRMP. *GBR Marine Park Management*
2003	*Fisheries (Coral Reef Fin Fish) Management Plan 2003* implemented. Minimum size limit increased to 40 cm total length. Recreational in-possession limits reduced to a total of 9 nannygai (crimson and saddletail snapper combined).
July 2004	All commercial vessels must hold an RQ licence. RQ licence holders must hold appropriate line units (OS units) to take crimson snapper, which take the form of individual transferable quotas. The total yearly catch of Other Species available for allocation is 902.2 t.
Jul 2004	Representative Area Program (RAP), a comprehensive rezoning of whole GBR, introduced. Proportion of GBR closed to fishing increases from about 5% to 33%, protected through closed green zones within which extractive uses are restricted. *Great Barrier Reef Marine Park Zoning Plan 2003*
Oct 2004	Seasonal fishery closures commence across the GBR for nine days each around the new moon period in October, November and December each year. *Fisheries (Coral Reef Fin Fish) Management Plan 2003 (Queensland)*
Oct 2009	Seasonal fishery closures reduced to two 5-day closures in October and November. December closure removed. *Fisheries (Coral Reef Fin Fish) Management Plan 2003 (Queensland)*
Jul 2010	Management plan amended removing ability to appeal. OS Quota in fishery after all appeals heard is 1 064 405 units. *Fisheries (Coral Reef Fin Fish) Management Plan 2003 (Queensland)*

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Year	Management
Jul 2013	Department of Environment and Heritage surrender quota units. As a result 955 604 OS units remain. *Fisheries (Coral Reef Fin Fish) Management Plan 2003 (Queensland)*
Sep 2019	Fisheries (Coral Reef Fin Fish) Management Plan repealed. *Fisheries (General) Regulation 2019 (Queensland)*, *Fisheries (Commercial Fisheries) Regulation 2019 (Queensland)*, *Fisheries Declaration 2019 (Queensland)* and *Fisheries Quota Declaration 2019 (Queensland)* enacted.
2019	Line Fishery (Reef): The fishery symbols for the fishery are ‘L1’, ‘L2’, ‘L3’ and ‘L8’ provide access to fishing areas in Queensland while RQ quota provides access to fish and both are required. Fish may be taken only by using fishing lines. A person must not use more than 3 fishing lines at the same time. The total number of hooks or lures attached to the lines must not be more than 6 per person. A primary boat longer than 20 m must not be used. The permitted distance for an assistant fisher to be under direction of a commercial fisher is 5 nautical miles. A tender boat must not be used more than 5 nautical miles from its primary boat. This does not apply if the tender boat and its primary boat are located on the same reef. Vessel tracking required on all commercial primary vessels and tenders with an engine size greater than 3KW. *Fisheries (Commercial Fisheries) Regulation 2019 (Queensland)*
Sep 2020	‘Primary’ vessels to be up to 25 m long, ‘tender’ vessels to be up to 10 m long and the number of tenders that can operate in different fisheries clarified. Distance requirements for tenders and assistant fishers removed now that vessel tracking is required on all commercial fishing vessels. These matters are regulated under national marine safety legislation.

In 2021, the Queensland Department of Agriculture and Fisheries commissioned a stock assessment for crimson snapper off the east coast of Queensland in order to fulfill a requirement from the Wildlife Trade Organisation. This stock has not previously been assessed. This assessment aims to determine current spawning stock biomass relative to an unfished state, provide estimates of sustainable harvests to support Queensland’s *Sustainable Fisheries Strategy 2017–2027* (Department of Agriculture and Fisheries 2017), and inform the Status of Australian Fish Stocks (SAFS) process.

2 Methods

2.1 Data sources

Data sources included in this assessment (Table 2.1) were used to determine catch rates, age and length compositions, and create annual harvests. Data sets were compiled by financial year[1] and all references to year should be assumed to be financial year. The assessment period began in 1958 up until and including 2021 based on available information.

Table 2.1: Data used in the Queensland east coast crimson snapper stock assessment

Type	Financial year	Source
Commercial harvest	1989–2021	Logbook data collected by Fisheries Queensland
Recreational harvest	2002, 2005	Recreational fishing surveys (RFish) conducted by Fisheries Queensland (Higgs et al. 2007; McInnes 2008)
	2011, 2014, 2020	Statewide Recreational Fishing Survey (SRFS) conducted by Fisheries Queensland) (Taylor et al. 2012; Webley et al. 2015; Teixeira et al. 2021)
	2001	Recreational fishing surveys conducted by the Australian Department of Agriculture, Fisheries and Forestry (the National Recreational and Indigenous Fishing Survey, NRIFS) (Henry et al. 2003)
	2017–2021	Boat ramp survey, conducted by Fisheries Queensland, providing harvest information
	1958–2002	Australian historical population statistics (for the state of Queensland), conducted by the Australian Bureau of Statistics, providing a proxy for fishing effort (ABS 2014)
Charter harvest	1989–2021	Logbook data collected by Fisheries Queensland
Indigenous harvest	2001	Indigenous fishing survey conducted by the Australian Department of Agriculture, Fisheries and Forestry (the National Recreational and Indigenous Fishing Survey, NRIFS) (Henry et al. 2003)
Biological data	2018–2021	Biological monitoring (sex, age and length from the commercial line fishery) undertaken by Fisheries Queensland (Fisheries Queensland 2012)
	2017–2019	Collaborative collection of regional demographic data (age, length and sex) sourced from both commercial and recreational fisheries (biological monitoring as above undertaken by Fisheries Queensland) and supplemented by additional recreational fishery catches as part of doctoral thesis at James Cook University
	2017–2021	Boat ramp survey, conducted by Fisheries Queensland, providing length and discard information

[1] Financial year naming convention is to reference the calendar year during which the financial year ended, that is, FY 2021 is July 2020 to June 2021.

2.1.1 Commercial

Commercial harvests of crimson snapper were recorded in the Queensland logbook system. The logbook system consists of daily harvests (landed weight in kilograms) of all fish species or species groups from each individual fishing operator (license) since 1989. In addition to landed weight, logbooks also record the location of the catch (30 minute or 6 minute grid identifier), the number of boats (dories) that were fishing, and the number of crew.

2.1.2 Recreational

2.1.2.1 Recreational fishing surveys

All recreational surveys provided estimates of the number of fish kept and released per trip, and combined this with demographic information to estimate annual totals for each species (or species group) at national, state and regional scales. See the references listed in Table 2.1 for more detail.

Surveys conducted in 2001, 2011, 2014 and 2020 (financial years) had more effective follow-up contact procedures with diarists resulting in less dropout of participants compared to the other survey years using RFish methodology (Lawson 2015).

2.1.2.2 Boat ramp survey

Recreational data were collected by Fisheries Queensland in 18 different regions, extending from Cooktown to the Gold Coast. Staff trained in the survey protocol, and identifying fish, interviewed recreational fishers at boat ramps during a survey shift. The surveys recorded day and location fished, catch of key species (including discards) and length of retained key species (Fisheries Queensland 2017). The length data were used as input in the model, and discards were used to infer discard rates of crimson snapper for the recreational sector.

2.1.3 Charter

Charter harvests of crimson snapper were recorded in the Queensland logbook system. This provided the operator identifier, the date, the location fished, retained catch by species (including discards) and the number of guests on the trip.

2.1.4 Indigenous

The National Recreational and Indigenous Fishing Survey in 2001 attempted to redress the lack of Indigenous fishing information on a national scale by involving Indigenous communities in the gathering of fisheries statistics. Estimates of total harvest and discard for Indigenous communities followed similar procedures to those in the recreational component of the survey (Henry et al. 2003).

2.1.5 Age and length compositions

Biological monitoring of sex, age and length information from the commercial and recreational sector has been undertaken by Fisheries Queensland. Information provided included: date of capture, region, fork length (cm), age class (number of birthdays a fish has had at date of capture, where the nominal birthday for crimson snapper is 1 October), age group (maximum age class the fish would attain during the sampling season, where the sampling season 1 July to 30 June) and sex of fish (male, female or unknown). The age-at-length relationship of recreationally caught fish were assumed to be of the same distribution per length class, as those from the commercial fishery, in each region sampled.

In addition, boat ramp surveys of recreational anglers contributed length frequency information for recreationally caught fish from 2017 to 2021.

2.2 Harvest estimates

Commercial, charter, recreational and Indigenous harvest data were analysed to reconstruct the history of harvest from 1958 until 2021. Prior to 1958 crimson snapper harvest is assumed to be negligible. This section describes how these data were combined to create the history of crimson snapper harvest (Figure 2.1).

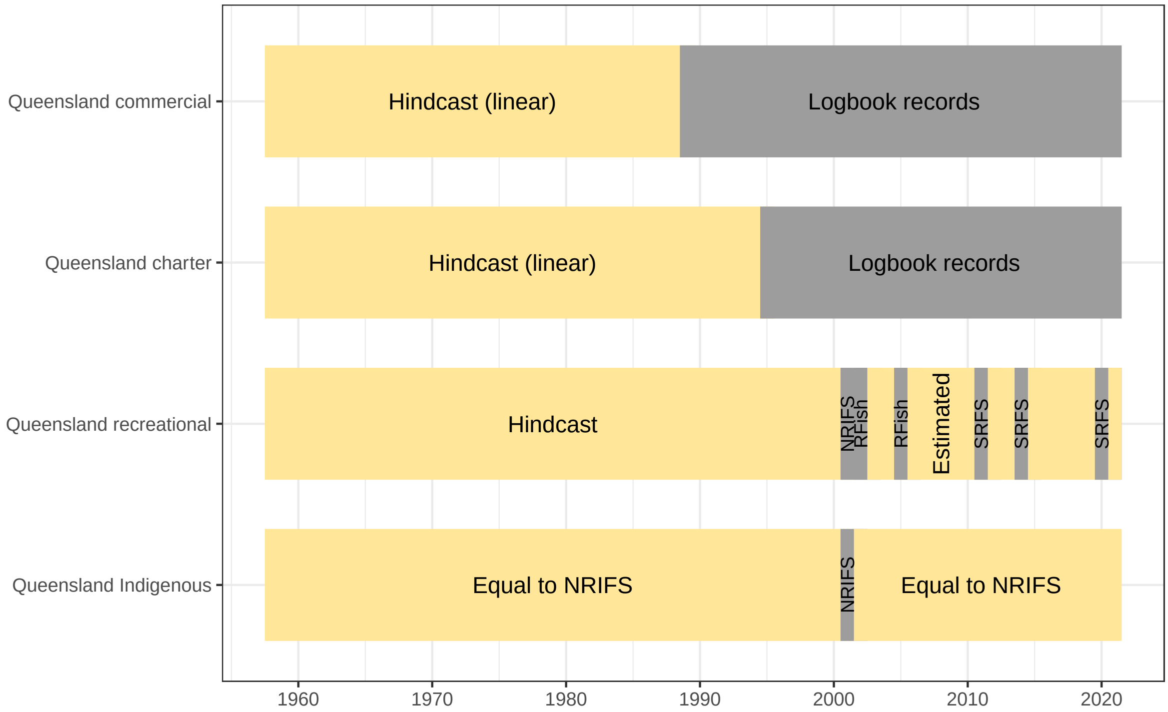

Figure 2.1: Overview of the methods used to reconstruct history of crimson snapper harvest

Commercial harvest:

- **1989–2021:** A baseline harvest of crimson snapper was set to the weight of whole crimson snapper (in kilograms, CAAB code 37346005) recorded against the line (LI) and mixed fishery (MF) codes in the CFISH logbooks.
- **1989–2009:** CFISH logbooks also contain an 'unspecified nannygai' label which is an ambiguous mixture of small mouth nannygai (crimson snapper) and large mouth nannygai (saddletail snapper). This was handled as follows:
  - **Between 2009 and 2021** very small amounts of crimson and saddletail snapper harvest was recorded as unspecified—approximately 0.01% per year. As such, the proportion of crimson snapper reported in the logbooks (approximately 20% of the combined crimson and saddletail snapper harvest) was used as the estimated proportion of the 'unspecified nannygai' category in the proceeding years from **1989 to 2009** and added to the logbook records for crimson snapper in those years.
- **1958–1989:** Harvest was linearly hindcast to 0 t in 1958.

Charter harvest:

- **1995–2021:** A baseline harvest of crimson snapper was set to the number of whole crimson snapper (CAAB code 37346005) recorded the charter fishery (CV) code in the CFISH logbooks. Approximately 20% of the 'unspecified nannygai' harvest was allocated to the crimson snapper harvest, using the method described for the commercial harvest.
- **1958–1994:** Harvest was linearly hindcast to 0 t in 1958.
- Measured in numbers of fish as opposed to weight.

Recreational harvest:

- **1958–2002:** Assumed zero in 1958 and increased proportionally to Queensland population growth through to reach a rescaled RFish estimate in 2002, where this rescaled estimate was calculated as the 2002 estimate divided by the NRIFS estimate for the year 2001.
- **2001, 2011, 2014, 2020:** Set to equal the values reported in the NRIFS (2001) and SRFS (2011, 2014 and 2020) surveys.
- **2002, 2005:** Set to the rescaled RFish estimates.
- **2021:** Estimate for 2021 set to equal the value reported in the 2020 SRFS survey.
- **2003–2004, 2006–2010, 2012–2013 and 2016–2019:** "Missing" records were set to values linearly interpolated between the estimates from the survey years listed above.
- Estimates for all years were converted from retained numbers of fish to harvested weight by the population model itself (they were entered into the model as numbers, not weights). This was done for scenarios which accounted for discards, and scenarios that did not.

Indigenous harvest:

- **2001:** Equalled the estimated number of fish harvested by Indigenous fishers from the NRIFS survey
- **1958–2000, 2002–2021:** Equal to the estimate in 2001 as no other data are available.
- Added to the recreational and charter harvest for input to the population model.

2.3 Standardised index of abundance

Queensland logbook data on commercial catches of crimson snapper (kg whole weight) per fishing-day were used as an index of legal-sized fish abundance. The index was standardised to remove the influence of a number of factors not related to abundance. This section outlines the standardisation procedure.

From the initial logbook data set, including all coral reef logbook records:

1. The data set was restricted to east coast, line fishery records where the number of crew was recorded and the catch was reported for a single date per day.
2. In the situation where multiple locations were fished on a single day, the catch was summed over all records, and the location was set to the location where the greatest amount of catch was taken.
3. The data set excluded all records outside of the L1 fishery (Figure 2.2).
4. The data set was restricted to records associated with fishers that had (a) at least two years of catch history and (b) were in the subset of fishers that accounted for 99% of the total crimson snapper catch when ordered by contribution (in total whole weight).

5. The data set was restricted to records where kilograms of crimson snapper caught was greater than zero.
6. The data from 2005 to 2007 were omitted due to small sample size (< 100 records per year).

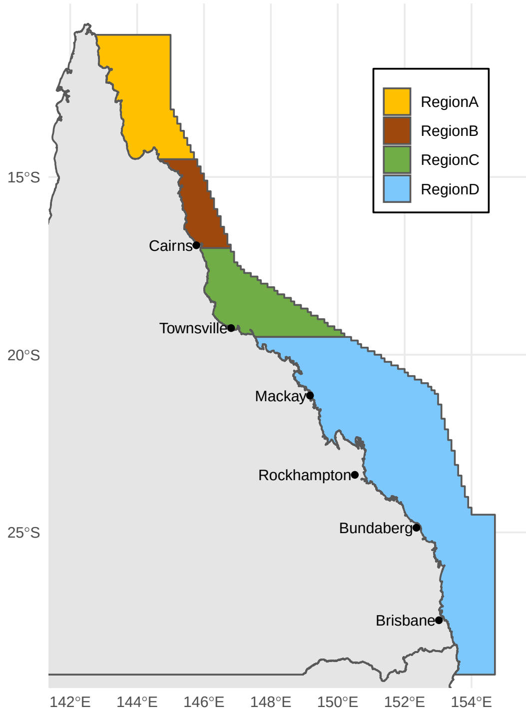

Figure 2.2: Map of regions used for catch rate analysis

The statistical model used was a linear model with the response being a log-transform of the crimson snapper catch. The analysis was carried out using the software R (version 4.0.5, R Core Team (2020)).

The form of the model was:

$$\log(Crimson) \sim Year * Region + Year : Month + Region : Month + Month + Fisher + Crew + CTRTE + OS \quad (2.1)$$

where the variables considered were:

- *Crimson*: daily harvest of crimson snapper (kilograms)
- *Year*: financial year (factor)
- *Month*: financial month (factor)
- *Region*: spatial region, aggregated into broader regions 'Region A', 'Region B', 'Region C' and 'Region D' from Fishery Monitoring regions (Figure 2.2; factor)
- *Fisher*: fisher license identifier (authority chain number, factor)
- *Crew*: how many crew were recorded (factor)
- *CTRTE*: harvest of coral trout and redthroat emperor (kilograms)
- *OS*: harvest of coral reef 'other species' (excluding crimson snapper, see list in Appendix E; kilograms)

While spatial regions were used to structure and standardise the catch rate analysis, ultimately a single catch rate for the whole fishery was produced. Regional catch rate contributions to the unified final catch rate was handled through a sample-size based (sometimes referred to as 'natural') weighting procedure that ensured sub-regional catch rate uncertainty was propagated into unified catch-rate uncertainty.

Targeting is the term used to refer to the fact that effort was made to target a specific species of fish, as opposed to it being caught incidentally. Co-caught species variables ('OS' and 'CTRTE') were included following project team discussions on the complex nature of targeting of crimson snapper in the Reef Line Fishery.

2.4 Discards and discard mortality

For many species, greater than half of the fish caught by recreational anglers are released (McLeay et al. 2002). Generally these released fish are under the MLS which, for crimson snapper, is 40 cm total length (TL) for the recreational and commercial fisheries. Following Jones et al. (1988) it was hypothesized that a large proportion of discarded fish are undersized and from inshore waters, the typical focus of smaller recreational boats. Larger recreational and commercial vessels typically fish further offshore in deeper waters where the chance of encountering individuals above the MLS is higher, so there will be less discarding due to the MLS. Lower rates of survival for larger fish in deeper water seems logical, however. This is important as these fish can additionally be released when above the MLS, due to being unwanted (low quality) by some fishers, so they are consequently exposed to increased post-release mortality from barotrauma. Boat ramp survey data confirmed that a significant fraction of the recreational crimson catch was released, and it was therefore important to model discarding explicitly for the recreational-charter-Indigenous fleet. Commercial discarding however is uncommon due to the absence of a bag limit and the offshore focus of commercial fishers (T Roberts 2020, pers. comm.) and so for the commercial fleet discarding was assumed negligible.

In order to model discards optimally, the model requires information on the total quantity of discards and their size distribution. As size information was only available for retained fish, the following procedure was used to generate a synthetic released recreational length distribution for input to the model.

1. Fish under 20 cm total length were excluded from the discard selectivity curve.
2. An expert elicitation (Morgan 2014) strategy was then devised whereby an R Shiny (Chang et al. 2020) application was constructed to prompt two members of the project team with relevant expertise to set values for the following three parameters:
   (a) The proportion of discards that are under the MLS (α)
   (b) The curvature of selectivity between 20 cm and the 40 cm (β_1)
   (c) The degree of 'elbow' in undersized selectivity (β_2)

   An average of the two expert's chosen values resulted in a value of 80% for α and an undersized selectivity curve (Figure 2.3).
3. The length distribution of retained recreational crimson snapper was formed from boat ramp survey records, with the total number of fish released on each trip appended to the length records for that trip.
4. The distribution of legal-sized released fish was generated from this data set by sub-sampling the fraction equal to $1 - \alpha$ (the proportion that are not undersized).
5. The distribution of undersized released fish was generated by sampling from a beta distribution with domain 20–40 cm and parameters (β_1, β_2) such that the total number of samples generated was the total number released (from the boat ramp survey estimates of this quantity) minus the fraction already allocated to the legal size component of the distribution. Total numbers of discards from the recreational sector were input to the reconstruction. The pattern of discarding between

2017 and 2020 from the boat ramp survey data were scaled to meet the absolute number discarded from the 2019 Statewide Recreational Fishing Survey in 2020.

The resulting released size distribution data sets can be seen in Appendix B.2.

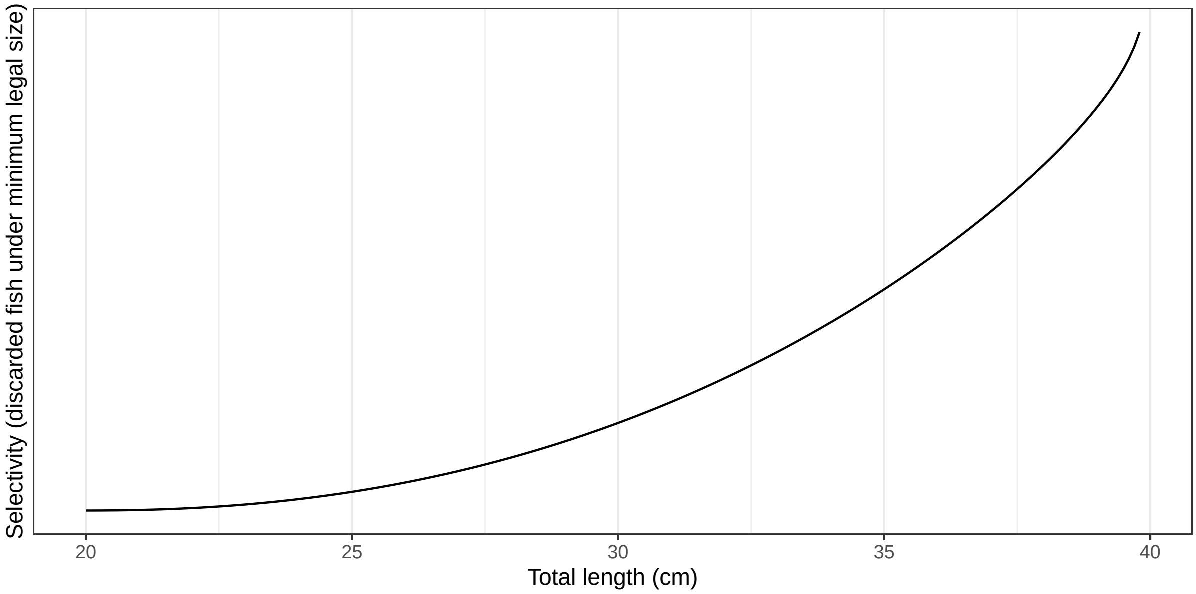

Figure 2.3: Selectivity curve for discarded crimson snapper under minimum legal size

Discard mortality was set at 58% (i.e. 42% survival), based on Brown et al. (2008) and feedback from the project team. This feedback took into account the following factors:

- the best (84%) and worst (10%) survival rates from Brown et al. (2008)
- that there were few discards above the MLS for all sectors
- that Brown et al. (2008) studied predominantly under-sized individuals from shallow waters.

2.5 Biological relationships

2.5.1 Fork length and total length

All length measurements were provided in fork length (FL) and the population model was run using FL. For expert elicitation and MLS we required a conversion to total length. The following conversions were applied where necessary (McPherson et al. 1992a):

$$TL_{mm} = 1.05 \times FL_{mm} - 0.06,$$
$$FL_{mm} = 0.95 \times TL_{mm} + 0.06$$

where TL_{mm} is total length (mm) and FL_{mm} is fork length (mm).

2.5.2 Fecundity and maturity

Maturity values in the model were length-based, following a logistic function fit to data extracted from Figure 6 of McPherson et al. (1992a) and reproduced in Figure 2.4.

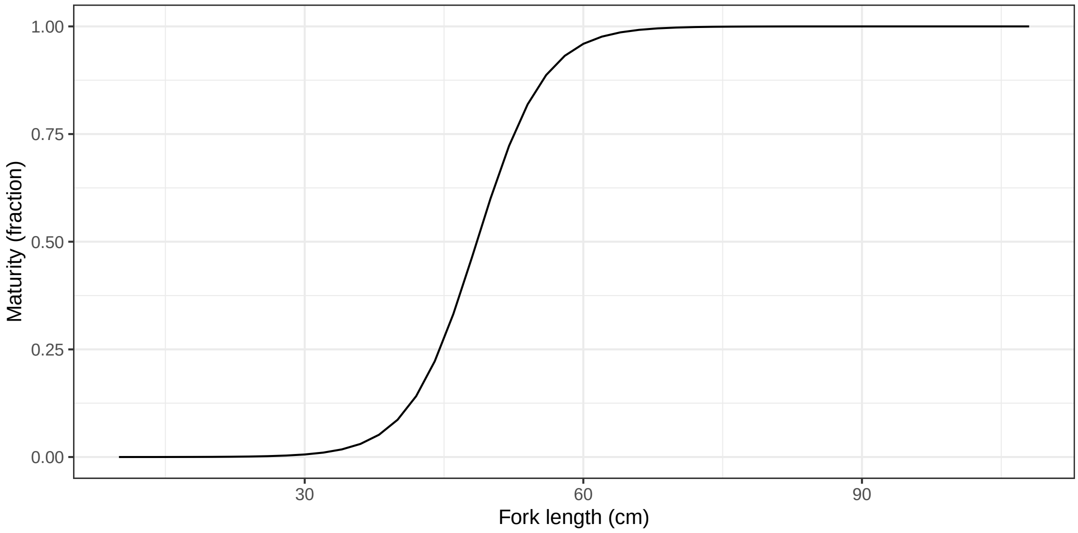

Figure 2.4: Maturity curve input into the model as extracted from Figure 6 of McPherson et al. (1992a)

No information was available on the fecundity for crimson snapper. For this assessment the number of eggs produced by a female crimson snapper was set to the total weight of mature females. Minimum observed length at first maturity is 50 cm FL for crimson snapper (McPherson et al. 1992a). To convert this to age of first maturity, fish of 50 cm were averaged by age from data herein. This led to a minimum age of first maturity at 4.5 years for crimson snapper.

2.5.3 Weight and length

The weight-length relationship was taken from McPherson et al. (1992b):

$$W_{kg} = \exp(-10.62 + 2.87 \times \log(FL_{cm}))$$

where W_{kg} is weight (kg) and FL_{cm} is fork length (cm).

2.6 Length and age data

Length data were input to the population model in two-centimetre length bins. Age data were input as conditional age-at-length samples.

2.7 Population model

A population model was fitted to the data to determine the number of crimson snapper in each year and each age group using the software package Stock Synthesis (SS; version 3.30.17.01). A full technical description of SS is given in Methot et al. (2020).

The model used three fleets: two for the commercial sector (for before and after the rezoning of the GBRMP), and one for the recreational, Indigenous and charter sectors combined. Ideally the charter sector would have been modelled as its own fleet, however limitations in length data meant that an additional selectivity curve could not be estimated.

Sex-specific biological monitoring data (from the commercial sector) were limited, so the population model was set up as a one-sex model. Differences in growth of males and females were investigated using 95% bivariate data ellipses of bootstrapped K (growth rate) and L_{inf} (mean maximum asymptotic size) estimates. Differences were assessed by the degree of ellipse overlap (Section A.4.3). Females reached significantly larger sizes (L_{inf}) than males, however when a shared sex growth model was fit, this was not significantly different to either the separate male or female von Bertalanffy growth functions. Ideally, separate growth curves for males and females would be preferred, however this was not possible with the current data. The large number of records of fish with undetermined sex limited the creation of sex-specific age-length keys.

2.7.1 Model assumptions

The main assumptions underlying the model are that:

- The Queensland east coast stock is reproductively isolated from all other stocks (Elliott 1996; Salini et al. 2006).
- The fishery began from an unfished state in 1958.
- 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 crimson snapper are parametric functions of their size.
- The first mature age is 4.5 years, after which the proportion of mature fish depends on size.
- The instantaneous natural mortality rate does not depend on size, age, year or sex.
- Deterministic annual recruitment is a Beverton-Holt function of stock size.
- Regarding spatial mixing, either:
  - Fish swim freely and mix rapidly across the entire area, so that the different fleets compete for the same fish rather than targeting different sub-populations. This corresponds to the 'Continuous' catch rates scenario under the Rezoning sensitivity test (Section 2.7.4), or
  - there is limited spatial movement so that blue zone and green zone populations will have diverged after July 2004 (GBRMP rezone). This corresponds to the 'Split' catch rates scenario under the 'Rezoning' sensitivity test (Section 2.7.4).

2.7.2 Model parameters

A variety of parameters were included in the model, with some of these fixed at specified values and others estimated.

Unfished recruitment (logarithmic scale, SR_LN(R0)) was estimated within the model.

Beverton-Holt stock recruitment steepness (SR_BH_steep) was estimated using a strongly informative lognormal prior. In the base case, the (natural scale) median of the prior was 0.70, based on the meta-analysis by Thorson (2020). The standard deviation was tight at 0.08. Lower and higher values for the median of the prior were chosen in the sensitivity analysis (details in Section 2.7.4).

Parameters of the von Bertalanffy growth curve (L_at_Amin, L_at_Amax, VonBert_K) were estimated within the model, including coefficients of variation for both young and old fish (CV_young, CV_old).

Natural mortality (NatM) was estimated in the model, with a lognormal prior. This prior had a (natural scale) median value of 0.154 and standard deviation of 0.2. This prior was based on the meta-analytical approach from Hamel (2015) and Then et al. (2015). The prior is defined as a log-normal distribution with a median value (corresponding to the mean in log-space) equal to $5.40/A_{max}$ and log-scale standard deviation equal to 0.2. The maximum age across all samples is 35 years, giving $5.4/35 = 0.154$.

Logistic length-based selectivity parameters were estimated in the model for both fleets (Size_inflection_Commercial, Size_95%width_Commercial, Size_inflection_Recreational, and Size_95%width_Recreational). Separate selectivity curves were estimated for the commercial fleet and the recreational-charter-Indigenous fleet. The base case involved a partitioning of the commercial catch rate around the time of the GBRMP Representative Areas Program rezoning (July 2004). This split the commercial sector into two fleets. In these scenarios, selectivity parameters were still estimated for two fleets (pre-rezoning commercial and recreational) with the selectivity for commercial post-rezoning set up to mirror the selectivity for commercial pre-rezoning.

All scenarios involved catchability being calculated rather than estimated. Catchability was calculated for each fleet that had an associated index of abundance.

Recruitment deviations between 1982 and 2021 improved fits to composition data and abundance indices as variability in recruitment annually allowed for changes in the population on shorter time-scales than fishing mortality alone.

2.7.3 Model weightings

A Francis adjustment (Francis 2011) was applied to all the age and length compositions fits, to attempt to achieve a suitable effective sample size (and thus relative weighting).

2.7.4 Sensitivity tests

Several additional model runs were undertaken to determine sensitivity to fixed parameters, assumptions and model inputs. The sensitivities, and notations used to denote variations, were as follows:

- **Rezoning:** Catch rates either split into two separate time series for before (through to 2004) and after (2008–2021) GBRMP rezoning, or modelled as one continuous time series
  - “Continuous”: Catch rates modelled as one continuous time series
  - “Split”: Catch rates split into two separate time series for before and after GBRMP rezoning
- **Steepness:** Natural-scale median of the steepness prior altered based on study by Thorson (2020)
  - “Mid”: 0.70
  - “High”: 0.80
  - “Low”: 0.60
- **Discards:** Discarding for the recreational sector modelled as described in Section 2.4, or a ‘short-cut’ applied where the input catches are increased to match the total number retained and discarded and it is assumed that all discarded fish follow the same selectivity curve as those retained
  - “Base”: Discarding modelled
  - “Alt”: Discarding short-cut
- **Recruitment deviations:** Recruitment deviations applied over a long or short time scale
  - “Full”: Recruitment deviations applied from 1982–2021
  - “Short”: Recruitment deviations applied from 1982–2015
- **Recreational harvest:** Recreational harvest at 100%, 80% or 120% of total as described in Section 2.2; thresholds were determined using confidence intervals of survey results
  - “Base”: 100% of recreational harvest
  - “High”: 120% of recreational harvest
  - “Low”: 80% of recreational harvest

Fourteen combinations of these sensitivities were tested, as outlined in Table 2.2. Scenario 1 was selected by the project team as the base case scenario.

Table 2.2: Scenarios tested to determine sensitivity to parameters, assumptions and model inputs

Scenario	Rezoning	Steepness	Discards	Recruitment deviations	Recreational harvest
1 (Base case)	Split	0.7	In model	Full	Base
2	Split	0.7	In model	Full	High
3	Split	0.7	In model	Full	Low
4	Split	0.7	In model	Short	Base
5	Split	0.7	Out of model	Full	Base
6	Split	0.6	In model	Full	Base
7	Split	0.8	In model	Full	Base
8	Continuous	0.7	In model	Full	Base
9	Continuous	0.7	In model	Full	High
10	Continuous	0.7	In model	Full	Low
11	Continuous	0.7	In model	Short	Base
12	Continuous	0.7	Out of model	Full	Base
13	Continuous	0.6	In model	Full	Base
14	Continuous	0.8	In model	Full	Base

2.7.5 Harvest control rule

Stock Synthesis's forecast sub-model was used to provide forward projections of spawning biomass and future harvest targets, following a harvest control rule (Fisheries Queensland 2021). This rule has a linear ramp in fishing mortality between 20% spawning biomass, where fishing mortality is set at zero, and a target spawning biomass, where fishing mortality is set at the equilibrium level that achieves the target spawning biomass (F_{Btarg}). Below 20% spawning biomass fishing mortality remains set at zero, and above the target spawning biomass fishing mortality remains set at F_{Btarg} (Figure 2.5).

Crimson snapper is currently classified as a secondary species in a multi-species fishery, so two harvest control rule scenarios have been applied:

- a 20:60:60 control rule, in which the spawning biomass target is set to 60%, as per the current reef line harvest strategy objective, and
- a 20:40:40 control rule, in which the spawning biomass target is set to 40%, as a proxy for the biomass at maximum sustainable harvest.

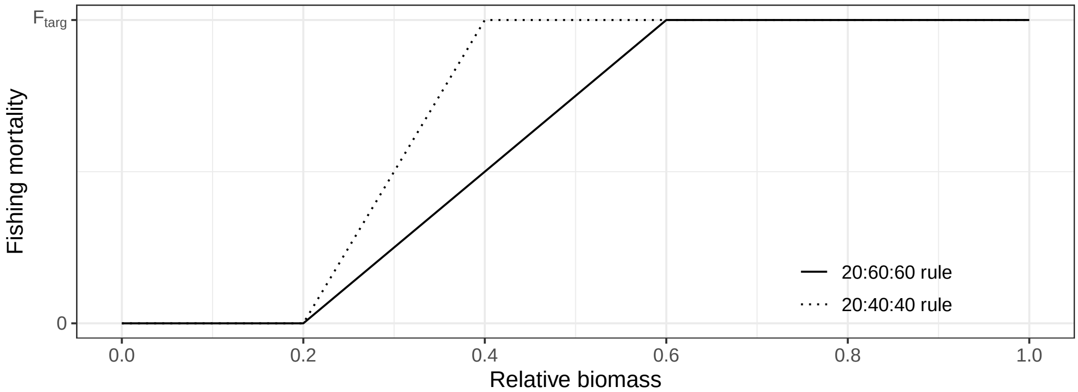

Figure 2.5: The 20:60:60 and 20:40:40 harvest control rules—note that F_{targ} for B_{40} is not the same as F_{targ} for B_{60} (i.e. vertical axis scale is not consistent between harvest control rules)

3 Results

These model inputs and outputs relate to Scenario 1—the 'base case' (defined in Table 2.2). Results for all other scenarios can be found in Appendix C and Appendix D.

3.1 Model inputs

Figure 3.1 summarises the assembled data sets input to the model.

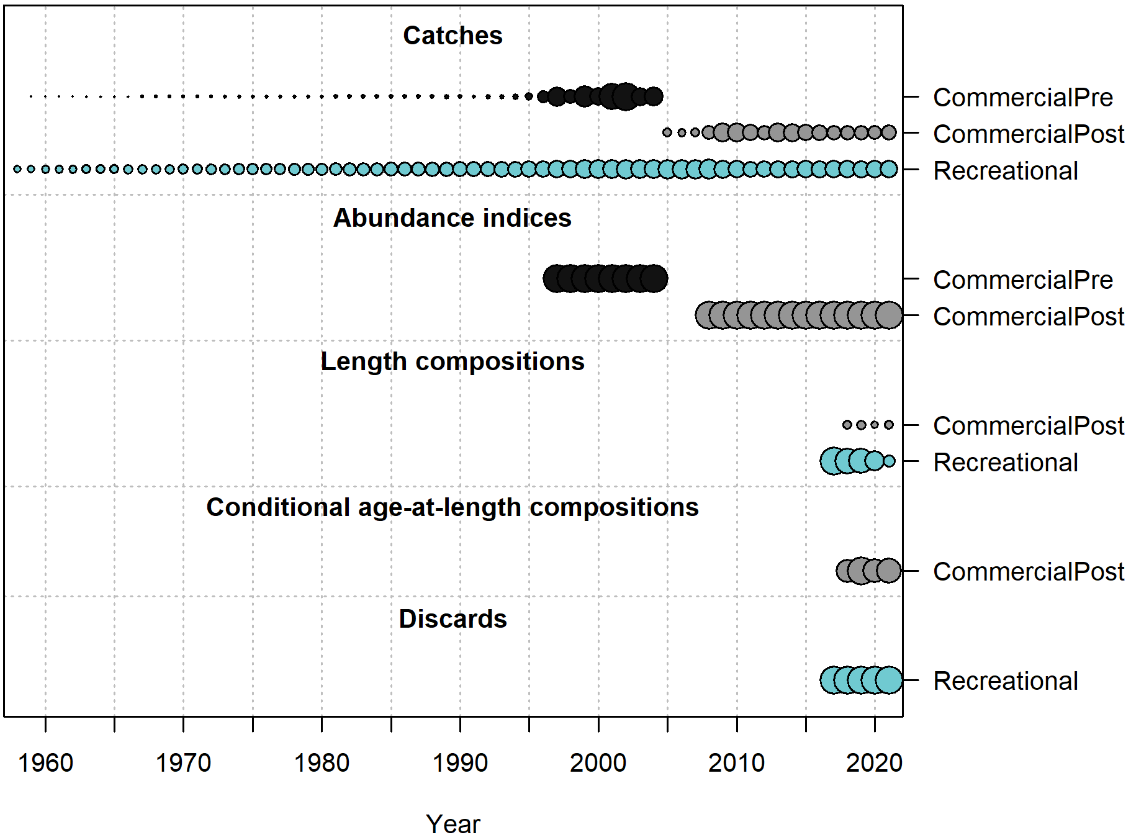

Figure 3.1: Data presence by year for each category of data type and Stock Synthesis fleet
Note: Stock Synthesis uses the term 'fleet' to distinguish data sets (and model processes) associated with different selectivity curves (proportions of fish at different lengths vulnerable to the fishing gear). This assessment generally involves two fleets: one for the commercial sector and one for all other sectors combined. In some scenarios (including the base case) the commercial fleet has been split into 'pre' and 'post' rezoning of the GBRMP. This plot shows data presence by year for each fleet, where circle area is relative within a data type. Circle areas are proportional to total harvest for harvests; to precision for indices and discards; and to total sample size for compositions. Note that since the circles are scaled relative to maximums within each data type, the scaling within separate plots should not be compared.

3.1.1 Harvest estimates

Total harvest (landed catch) combined harvest from commercial, recreational, charter and Indigenous sectors is shown in Figure 3.2.

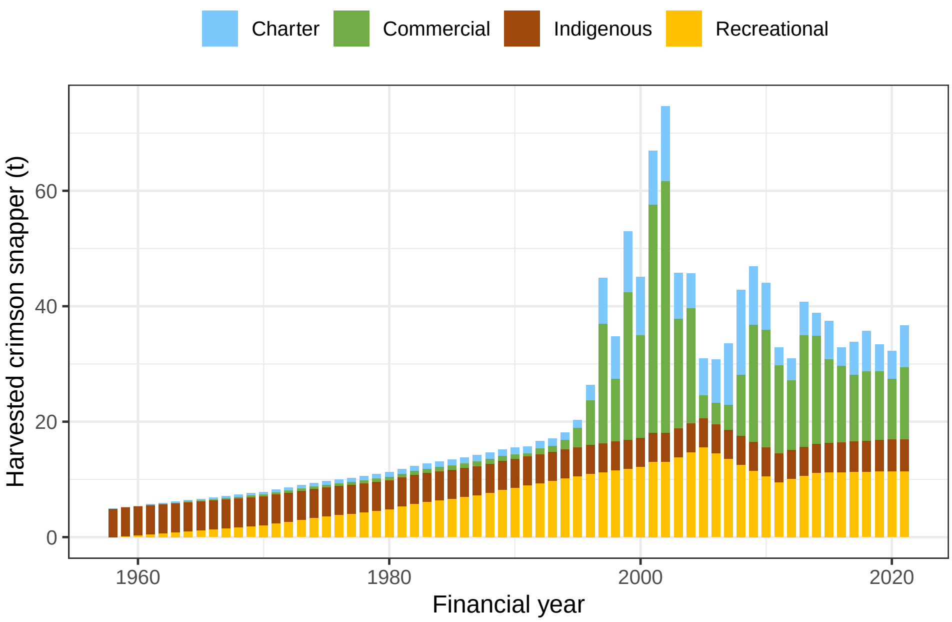

Figure 3.2: Annual estimated harvest (retained catch) from commercial, recreational, charter and Indigenous sectors between 1958 and 2021 for crimson snapper—the latter three sectors were modelled as a single fleet

3.1.2 Standardised index of abundance

Both the 1997–2004 and 2008–2021 time series of annual standardised commercial catch rates declined on average (Figure 3.3). There was greater uncertainty in early years of 1997–2004 time series.

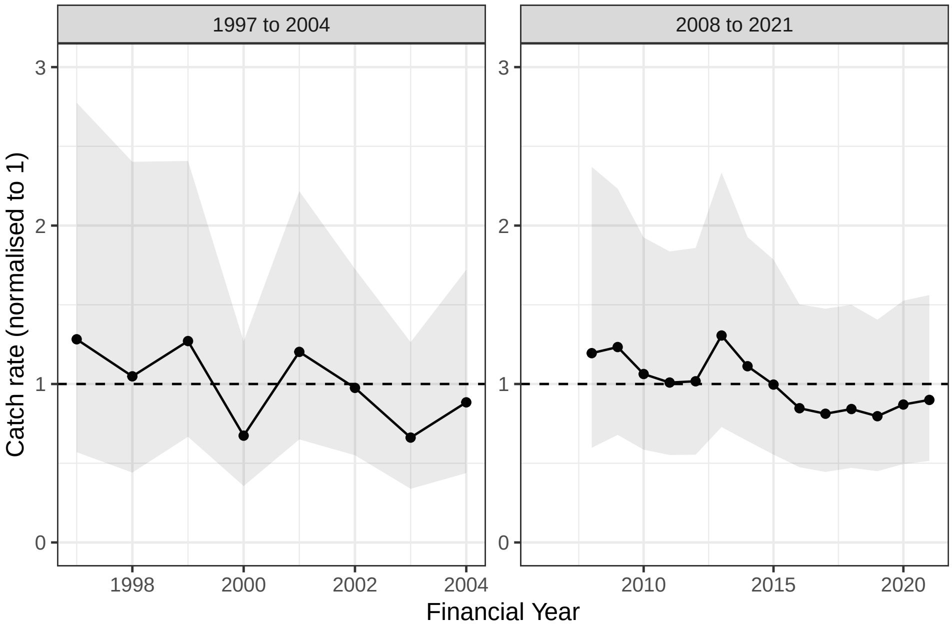

Figure 3.3: Annual standardised catch rates (95% confidence intervals) for commercial line caught crimson snapper between the years of 1997 and 2021

3.1.3 Age composition

Fishery age composition data were input to the population model, as part of age-at-length compositions. For visualisation purposes, the age composition is shown in Figure 3.4.

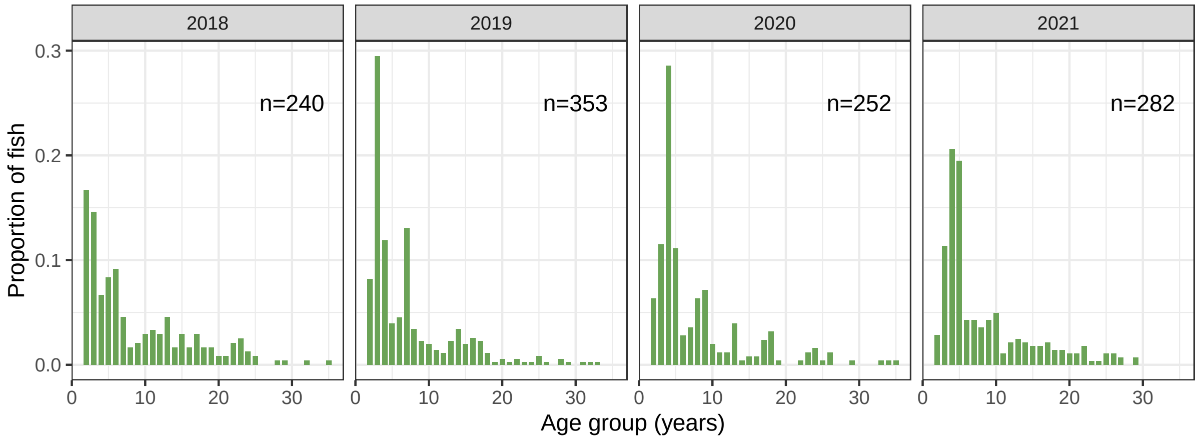

Figure 3.4: Annual age compositions of crimson snapper for line caught fish between 2018 and 2021

3.1.4 Length composition

Fishery length compositions were input to the population model for the commercial fleet (Figure 3.5) and the recreational fleet (Figure 3.6). Discarded recreational length compositions were generated by the method described in Section 2.4.

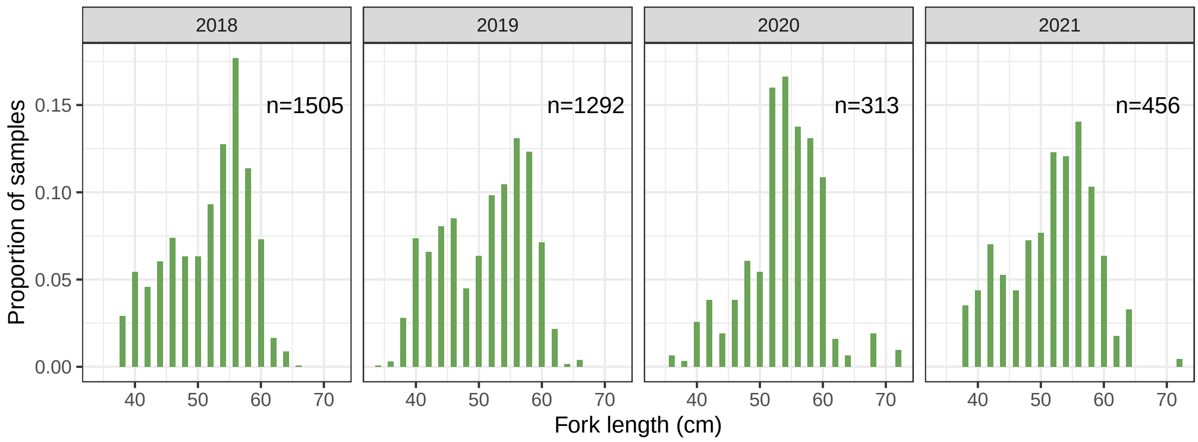

Figure 3.5: Annual length compositions of crimson snapper for commercial line caught fish between 2018 and 2021

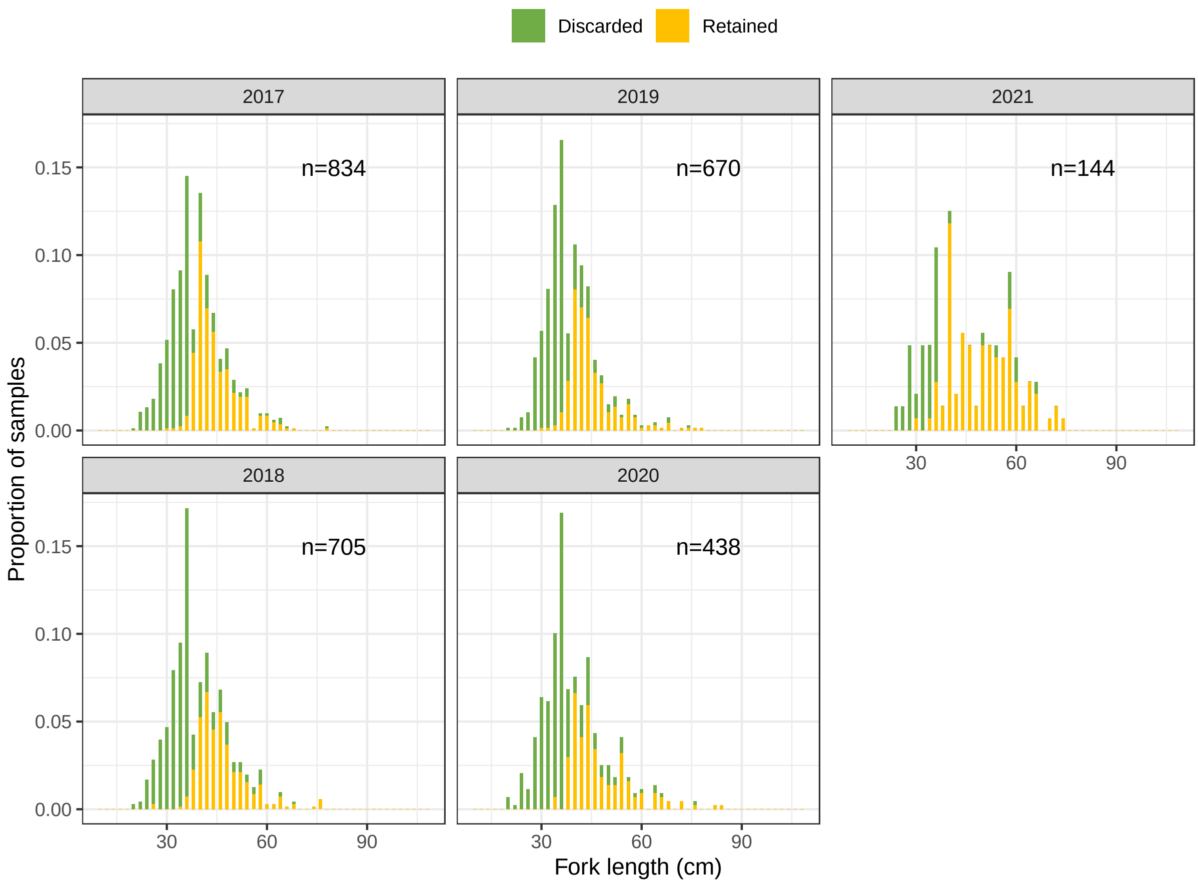

Figure 3.6: Estimated annual length compositions of crimson snapper for recreational line caught-and-discarded and caught-and-retained fish between 2017 and 2021

3.1.5 Discards

In addition to the discarded length composition data (above), total numbers of discards from the recreational sector were input to the model. The pattern of discarding between 2017 and 2020 from the boat ramp survey data was scaled to meet the absolute number discarded from the 2019 Statewide Recreational Fishing Survey in 2020. The total number of fish discarded for the recreational-charter-Indigenous fleet, input to the model are summarised in Table 3.1.

Table 3.1: Estimated number of discards by the recreational-charter-Indigenous fleet

Year	Number of discards
2017	20 056
2018	22 714
2019	23 739
2020	17 711
2021	12 358

3.2 Model outputs

3.2.1 Model parameters

Several parameters were estimated within the base case model (Table 3.2). The full list of estimated parameters for the base and sensitivity runs is given in Appendix B.1, Table B.1. Boxplots that show the variation in parameter estimates across all sensitivity runs are given in Appendix C, Figure C.1.

Table 3.2: Summary of parameter estimates for crimson snapper from the base population model

Parameter	Estimate	Standard deviation
Natural mortality	0.14	0.02
Length at age 1	33.9	0.5
Length at age 35	61.63	1.09
von Bertalanffy growth parameter	0.14	0.01
Coefficient of variation in length at age 1	0.12	0.01
Coefficient of variation in length at age 35	0.12	0.01
Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1958)	11.69	0.23
Beverton-Holt steepness	0.7	0.06
Commercial selectivity inflection (cm)	51	1.51
Commercial selectivity width (cm)	11.29	1.39
Recreational selectivity inflection (cm)	26.24	0.44
Recreational selectivity width (cm)	3.57	0.53

All fourteen scenarios described in Section 2.7.4 had parameters that were estimated cleanly (none were near their bounds), and final parameter gradients were small, implying no convergence problems.

In Scenarios 5 and 12, discards were calculated outside of the Stock Synthesis modelling framework. In these scenarios, estimates for the von Bertalanffy growth parameters and selectivity curve parameters differed from the other scenarios (Figure C.1).

For all other scenarios, there was little difference between parameter estimates.

3.2.2 Model fits

Good fits were achieved for all data sets, including abundance indices, length compositions, age compositions and conditional age-at-length compositions (Appendix B.2). Reasonable fits were obtained for all data sets with the exception of the total discard amount (Appendix B.2).

3.2.3 Selectivity

Selectivity of crimson snapper was estimated within the model. The recreational and commercial fleets had significantly different selectivity (Figure 3.7).

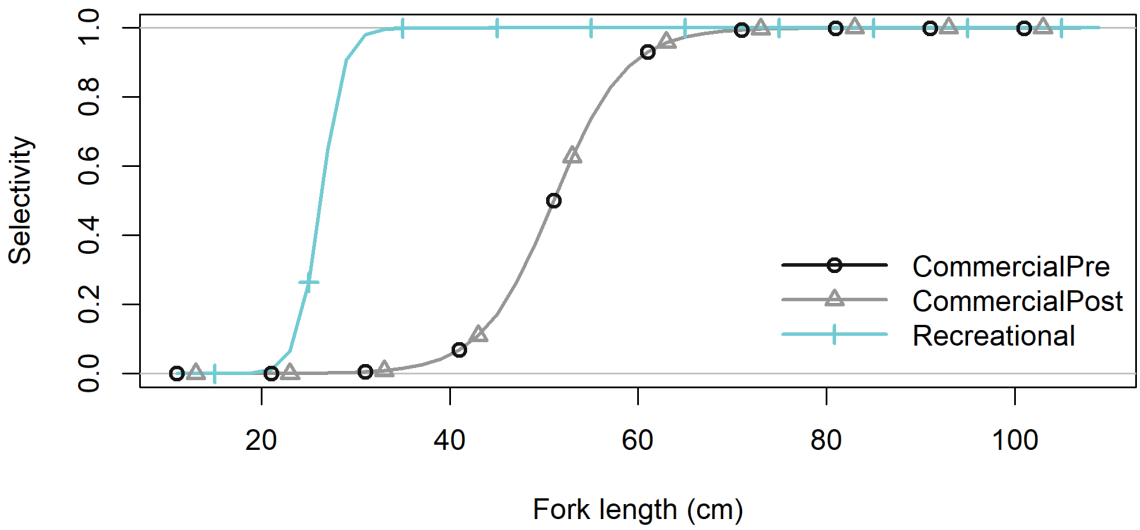

Figure 3.7: Model estimated length-based selectivity for crimson snapper by fleet in 2021

3.2.4 Growth curve

The von Bertalanffy growth curve, including coefficients of variation of old and young fish, was estimated within the model (Table 3.2, Figure 3.8).

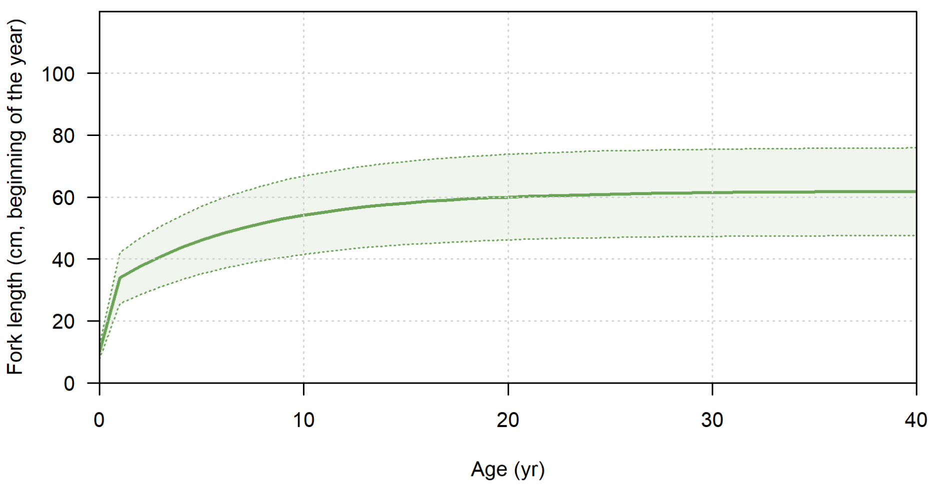

Figure 3.8: Model estimated growth curve for crimson snapper in 2021

3.2.5 Biomass

The base case model predicted spawning stock biomass declined between 1958 and 2019 to 35% unfished spawning biomass. In 2022[1], the stock level was estimated to be 44% unfished spawning biomass (Figure 3.9). Relative spawning biomass trajectories for all sensitivity scenarios are presented in Figure 3.10.

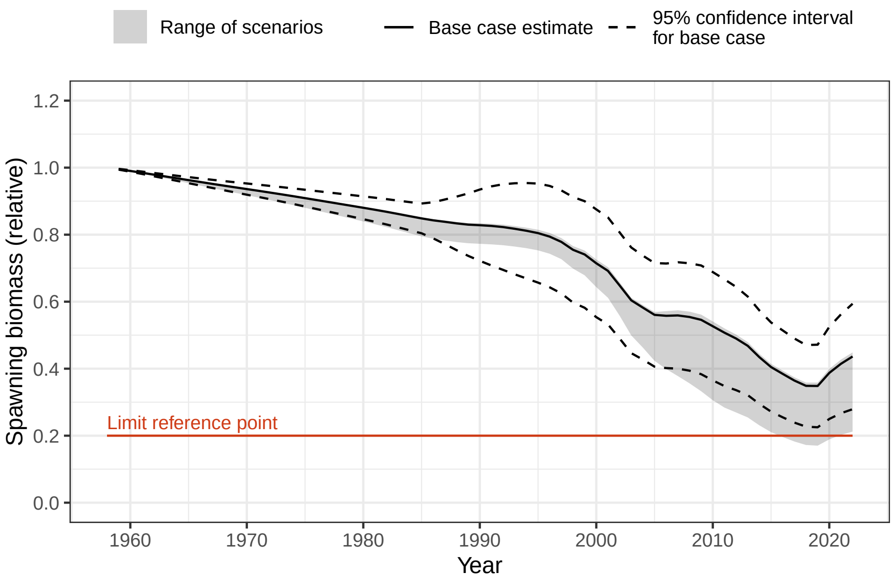

Figure 3.9: Predicted spawning biomass trajectory relative to virgin for crimson snapper with 95% confidence intervals (dotted lines) and the range of scenarios (grey) from 1958 to 2021

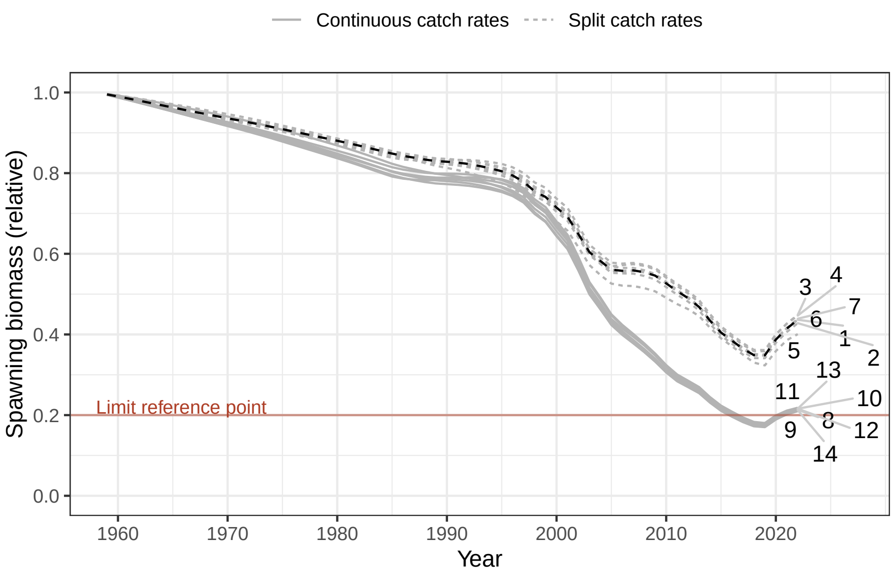

Figure 3.10: Predicted spawning biomass trajectory relative to virgin for crimson snapper, from 1958 to 2021, for all scenarios (as described in Section 2.7.4) with the base case highlighted in black—'Split catch rates' refers to scenarios in which GBRMP rezoning was modelled using separate fleets

[1] Stock Synthesis reports spawning stock biomass at the beginning of each year, so following this convention the spawning stock biomass estimate is reported for the year after the input data end. In this case, the model inputs end at 2021, so spawning stock biomass for 2022 is reported.

The relationship between the spawning biomass estimate and fishing mortality are presented in a phase plot (Appendix B.3.1, Figure B.7). The equilibrium harvest informs on the productivity of the stock at different spawning biomass levels (Figure 3.11).

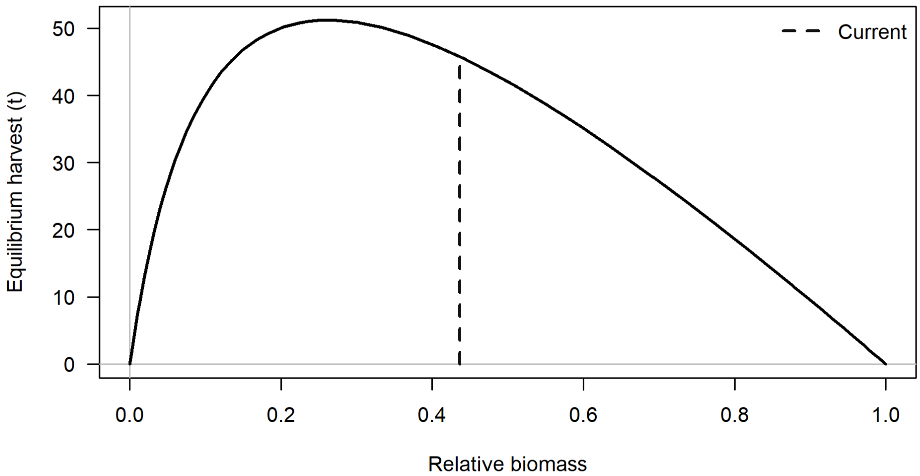

Figure 3.11: Equilibrium harvest curve for crimson snapper

3.2.6 Harvest targets

Harvest targets have been calculated to maintain spawning biomass at the two target reference points for the base model—60% spawning biomass and 40% spawning biomass (as a proxy for maximum sustainable harvest, MSH)—resulting in recommended biological harvests (RBH) of 16 t and 51 t respectively for 2022. These RBHs are the first in a schedule of projected recommended harvests following a 20:60:60 or 20:40:40 harvest control rule. The schedules are presented here for the base case in Table 3.3. Note that these RBH values have not had an uncertainty discount factor applied. For discounted harvest values see Section 4.3.2.

Table 3.3: Estimated total harvests and spawning biomass ratios of crimson snapper for the base case to rebuild and maintain the stock at the target reference point of 60% unfished spawning biomass or 40% unfished spawning biomass, following a 20:60:60 or 20:40:40 control rule respectively

	20:60:60 control rule		20:40:40 control rule	
Year	**Harvest (t)**	**Spawning biomass ratio**	**Harvest (t)**	**Spawning biomass ratio**
2022	16	0.44	51	0.44
2023	19	0.46	51	0.44
2024	23	0.5	51	0.45
2025	26	0.53	51	0.46
2026	28	0.55	51	0.46
2027	30	0.56	50	0.46
2028	31	0.58	50	0.45
2029	32	0.58	50	0.45
2030	32	0.59	49	0.45
2031	33	0.59	49	0.44
2032	33	0.59	48	0.44
2033	33	0.6	48	0.43
2034	33	0.6	48	0.43
2035	33	0.6	47	0.43
2036	33	0.6	47	0.42
2037	34	0.6	47	0.42
2038	34	0.6	47	0.42
2039	34	0.6	47	0.42
2040	34	0.6	46	0.41
2041	34	0.6	46	0.41

4 Discussion

The results above represent the first assessment of the Queensland east coast crimson snapper stock, which is a relatively data-poor species and historically part of a species complex including saddletail snapper. The results should be viewed considering this understanding. The base case results discussed below should also be considered in the context of stock status variation amongst the full suite of scenarios investigated.

Results from this assessment suggest the crimson snapper population on the Queensland east coast experienced a large decline in the period 1958–2019, followed by a short period of recovery.

The results suggest that catch levels have been in excess of those consistent with a 60% spawning biomass target (34 t) since 2003. The base case model suggests the current population level is around 44% of unfished spawning biomass.

4.1 Performance of the population model

The fourteen scenarios in Figure 3.10 all performed well. All parameters that were attempted to be estimated were estimated cleanly (none hit their bounds), final parameter gradients were small (likely a genuine optimal point was found), and reasonable fits were obtained for all data sets with the exception of the total discard amount.

All scenarios appeared to have a unimodal posterior, meaning each model consistently converged to its own single optimal point. A Markov chain Monte Carlo algorithm was run on the base case scenario, which supported this observation (Section B.4).

While fourteen scenarios performed well in the sense described above, they constitute a wide range of outcomes. A lot of this uncertainty stems directly from catch rate uncertainty and is not an artifact of population modelling compromises or otherwise poor population model performance.

Scenario 1 was chosen by the project team to be the base case (preferred) model, however other scenarios are also considered plausible. This is best understood by considering the following two key contributors to the overall uncertainty:

- **Catch rates.** One source of uncertainty arises from the GBRMP rezoning and the concurrent introduction of ITQs in 2004. This disruption impacted commercial logbook records over several years, which were unable to be analysed due to low sample sizes (2005–2007). Standardised catch rates from 2007 onward were lower in comparison to prior to 2004. While there are many possible reasons for this (e.g. changes in reporting behaviour), there is a lack of information on which to test hypotheses, and thus in general it is not possible to incorporate this issue directly into the standardisation. The GBRMP rezoning in 2004 reduced the spatial access of the fishing fleet. There is a possibility that, post-rezoning, the relative abundance density of crimson snapper may have diverged between blue and green zones, however the extent to which this will have occurred depends on the degree of spatial mixing of the stock. Because there is very limited information on the spatial mixing of crimson snapper (Platten et al. 2007), and no information on relative abundance of fish in green zones, it is important to consider implications under both scenarios (i.e. modelling catch rates as a ‘Continuous’ or ‘Split’ under the Rezoning sensitivity test as defined in

Section 2.7.4).

Under the scenario where there is significant spatial mixing (the ‘Continuous’ scenario), the catch rate standardisation should be used without modification. This is because, while from 2005 onward the analysis is drawing on data from a smaller spatial area, in terms of abundance *density*, the relevant metric for the catch rate on any given fishing trip, the index remains a valid indicator of overall (stock-wide) relative abundance.

Under the scenario where spatial mixing is somehow limited, the situation is more complex. In the absence of fishery independent indicators from green zones or any detailed understanding of movement, the approach used was to allow the population model to choose a different catchability for the two periods (pre- and post-rezone). In Stock Synthesis this was achieved through the introduction of a second fleet for the post-rezone commercial sector. Because selectivity was forced to be the same for both fleets (but still estimated), this is equivalent to deriving a catchability difference from the model’s ability to fit the various data sets and then re-running the model with a single fleet that has the derived catchability difference factored into the single long-term catch rate. The ‘model adjusted’ standardised catch rate can be seen plotted against the original standardised catch rate in Figure A.1.

Under the hypothesis that spatial mixing is limited and that abundance density in green zones is higher post-rezone, the *direction* of the model-derived catchability difference makes sense: you would expect an unadjusted index to be biased downwards.

Ultimately the project team took the adjusted standardised catch rate scenario as the preferred base case because catch rates were considered to have been downwardly impacted by the GBRMP rezoning and introduction of ITQs in ways that were unlikely to be abundance-related. For example, the crimson snapper targeting of the commercial fishing sector may have been reduced after the rezone as the fishery moved to focus on live coral trout. This implies some degree of adjustment is required. The magnitude of the required adjustment should be the subject of future research.

Note that the population model has no spatial structure: i.e. under both of the continuous and split scenarios the index of abundance is of the entire stock, and that in the split scenario an adjustment has been made to account for non-abundance related declines.

Additional sources of catch rate uncertainty for this species relate to targeting and fishing power, for the same reasons as saddletail snapper. See Campbell et al. (2021) for more on these aspects.

- **Recreational harvest and discarding.** A significant component of the harvest is taken by the recreational sector, however the full extent is subject to considerable uncertainty. This is of concern when coupled with uncertainty around the length structure of recreational discards and post-release survival. Significant effort was put into reconstructing plausible length frequency data for legal-sized and discarded recreational fish. While this was judged preferable to the alternative (increasing the recreational harvest by a presumed dead-discard amount and assuming both mortality components are equally size-distributed) it remains a key source of uncertainty. Both methods of modelling discards (either explicitly modelled in Stock Synthesis, or accounted for in the harvest reconstruction) resulted in similar indicators of stock status.

4.2 Unmodelled influences

There are a number of possible drivers of the crimson snapper population that have not been directly modelled, but which should be taken into consideration when interpreting model outputs and considering future management arrangements. These include environmental impact of climate changes, potential regional variation in population demography, depredation, fishing power, GBRMP rezoning and previous management arrangement changes, as discussed below.

- **Climate change.** Crimson snapper are not solely reef-associated, nor known to be dependent on live coral cover. Thus, they may not be considered as directly vulnerable to coral bleaching and other forms of climate-induced coral reef degradation as, for example, coral trout. Nevertheless climate impacts on the GBR are a significant concern. Loss of coral habitat and complexity has been found to result in reductions in fisheries productivity (Rogers et al. 2017), and since 2014 there have been two mass bleaching events, one severe tropical cyclone, and two crown-of-thorns outbreaks on the GBR (Australian Institute of Marine Science 2021). For example, it is possible that changes in environmental conditions could affect recruitment, growth, reproduction, or mortality rates of crimson snapper. While the precise mechanisms by which climate change may impact crimson snapper remain unclear, and any impacts to date remain unquantified, this may be an additional source of uncertainty that would need to be quantified at a later date and cannot be taken into account at this time.
- **Regional variation in demography.** Regional variations in demography have been reported on the GBR for coral trout (Bergenius 2007; Carter et al. 2014; Carter et al. 2017) and redthroat emperor (Williams 2003; Williams et al. 2006). At the time of this assessment no data were available to determine if regional variation exists for crimson snapper. Preliminary studies indicate that there are no significant differences in growth rates of crimson snapper between sampling regions (DAF, unpublished data). If regional variation in age-based demographics are identified in future, they could be modelled in future assessments.
- **Shark depredation.** Shark depredation usually refers to the situation where a shark partially or completely consumes an animal caught by fishing gear before it can be retrieved to the fishing vessel, however it can also refer to ‘post-release predation’ where released fish are predated before they recover (Mitchell et al. 2018). While there are numerous anecdotal reports of sharks taking other species of fish whilst it’s being landed, there are no quantitative data at this stage. As a result, neither form of depredation has been explicitly modelled. This only represents a limitation of the model if there have been significant fluctuations in the shark population or shark behaviour over time, or if there have been changes to release patterns through time. There is some depredation research currently being undertaken that may provide data for use in future assessments, however depredation mortality remains an unquantified uncertainty in this assessment.
- **Fishing power.** Fishing power over and above that incorporated through the current catch rate standardisation variables (year, month, region, fisher, number of crew, quantity of coral trout and red throat emperor caught, quantity of other species (see list in Appendix E) caught) has not been explicitly modelled. Recent significant changes to high definition sounders, anchor lock electric motors, availability of ‘wonky hole’ fishing training courses, information sharing on social media platforms and significantly advances bathymetry mapping and on-board computer storage capabilities needs to be quantified within fishing power considerations and included in future assessments.
- **GBRMP zoning and ITQ management shift.** The impact of the DAF fishery management arrangements and GBRMP rezoning in 2004 has been handled through hypotheses on catch rates.

See Table 2.2 and scenarios with 'Split' or 'Continuous' in the 'Rezoning' column, and a more detailed explanation in Section 4.1. As discussed, a better understanding of fleet fishing behaviour and targeting changes requires more work to better inform the catch rate analysis, other model inputs and interpretation of model outputs.

4.3 Recommendations

4.3.1 Research and monitoring

Research and monitoring recommendations for crimson snapper focus on prioritising reduction in model uncertainty:

- **Length and age monitoring.** The biological age and length monitoring data are crucial and without them the assessment would not have been possible. Each additional year of samples from the fishery monitoring program under the same survey design parameters should reduce the overall stock status uncertainty. Recreational relative catch rate indices derived from the boat ramp survey data would also be helpful in reducing uncertainty.
- **Stock structure.** Research on the biological stock structure of crimson snapper is limited. There is a need for updated information on stock structure and connectivity throughout Queensland waters.
- **Fishery targeting behaviour.** A survey of commercial and recreational fishers may provide additional information on shifting targeting behaviour that could help interpret model outputs, inform the magnitude of the required adjustment of post-rezone catch rates or even provide additional inputs that may reduce model uncertainty.
- **Fishery independent surveys.** As discussed in Section 4.1 there is a lack of information on abundance of crimson snapper in green zones following the rezoning in 2004. The Great Barrier Reef Foundation's 'Integrated Monitoring and Reporting' project intends to expand and/or initiate monitoring for many species, including *Lutjanus erythropterus*, across blue and green zones (Great Barrier Reef Foundation 2019). This may prove useful for estimating the magnitude of post-rezone abundance density divergence, in addition to providing fishery independent metrics.
- **Discards.** Additional information on the size distribution of discards would inform the way fishing mortality affects different cohorts.
- **Fishing power.** Past studies on fishing power (O'Neill et al. 2007) should be updated to include new technologies, training and information sharing on standardised catch rates of Reef OS species for future assessments.
- **Harvest weights.** Accurate harvest weights (using calibrated scales) for each reef-line trip would significantly improve data for future assessments. The potential for this has been improved with the new reporting requirements introduced in September 2021.
- **Mortality estimates.** Improved estimates and quantification of other sources of mortality such as that potentially from depredation or post-release mortality will reduce assessment uncertainty.
- **Environmental influences.** Determine any potential impacts of changing environmental conditions such as increasing sea surface temperature, or other potential impact on population parameters.
- **Reproduction.** Another key model input is the relationship between size or age of fecundity. A study by Fry et al. (2009) reported fecundity by length, with no clear relationship. Future studies investigating fecundity by age may alleviate this uncertainty.

4.3.2 Management

Currently crimson snapper is a secondary (non-target) species in the reef line fishery, managed through an ITQ as part of the OS quota group. To provide options for management now that there is a crimson snapper biomass estimate, harvest control rules for B_{60} and B_{40} (a proxy for B_{MSH}) targets have been generated (Table 4.1).

The harvest consistent with a spawning biomass ratio of 60%, the reef line harvest strategy objective for species with a published stock assessment, was estimated at 34 t (24–36 t range across scenarios; all sectors). The recommended harvest in the 2022 financial year is 16 t (0–16 t range across scenarios) in order to achieve this target by 2031.

For secondary species in a multi-species fishery, the Queensland harvest strategy policy requires a minimum objective of maximum sustainable harvest. The harvest consistent with a spawning biomass ratio of 40%, a proxy for biomass at maximum sustainable harvest, was estimated at 45 t (32–48 t range across scenarios; all sectors). The recommended harvest in the 2022 financial year is 51 t (0–54 t range across scenarios) in order to achieve this target by approximately 2041. B_{40} is often considered a more reliable target than B_{MSH} itself due to its sensitivity to the steepness and natural mortality parameters.

Table 4.1: Current and target indicators, including B_{60}

Parameter	Estimate
Current (2021) spawning biomass (relative to unfished)	44% (21–45%)
Biomass at maximum sustainable harvest	26% (26–30%)
Current (2021) harvest	30.2 t
Commercial	12.5 t
Recreational + Charter + Indigenous	17.7 t
Sustainable harvest at spawning $B_{60\%}$	34 t (24–36 t)
Sustainable harvest at spawning $B_{40\%}$	45 t (32–48 t)
Maximum sustainable harvest	48 t (34–52 t)
Proposed harvest (2022) to achieve $B_{60\%}$ target	16 t (0–16 t)
Proposed harvest (2022) to achieve $B_{40\%}$ target	51 t (0–54 t)
Time to reach target	10 years (9–20+ years)

Additional factors to consider when applying the results of this stock assessment to the management process include:

- **Uncertainty.** The base case scenario estimated the 2021 east coast crimson snapper stock to be 44% of unfished spawning biomass. Note that this estimate is across the full spatial extent of the stock, not just for the GBRMP zones that have been open to fishing since July 2004 (this point is made in more detail in Section 4.1). The full range of biomass estimates from model outputs (scenarios range from 21–45%) should be considered when applying this assessment in any management process. In particular there is uncertainty surrounding the relative adjustment (via the catchability coefficient) when modelling the catch rates before and after the GBRMP rezoning. No discount factor has been applied to the harvest control rule in this assessment.
- **Uncertainty discount factor.** The recommended discount factor for this assessment (Fisheries Queensland 2021) is 0.83 based on a qualitative tier assignment process and Ralston et al. (2011) (σ is 0.72, P^* (risk aversion) is 0.4). Applying this discount factor, the recommended biological

harvest results in a discounted 2022 harvest of 13.3 t and 42.3 t for the 20:60:60 or 20:40:40 harvest control rules, respectively.

- **Recreational and charter management arrangements.** The recreational and charter sectors are a significant contributor to overall crimson snapper fishing mortality and this should be taken into account when considering any management changes. Over the last five financial years, the relative contributions of the commercial, recreational, charter and Indigenous sectors to total harvest were 34%, 33%, 17% and 16%, respectively.
- **Size limit.** With approximately 50% of crimson snapper mature around 49 cm (FL) (Figure A.3), an increase in the MLS should be considered. This species exhibits relatively low levels of barotrauma-related mortality (16%) when compared to related tropical snappers (e.g. saddletail snapper at 50%) (Brown et al. 2008). As such, an increase in size limit and corresponding increase in released fish and with a level of post-release mortality is likely to provide an overall population benefit. This may be able to be quantified in a future assessment.

4.3.3 Assessment

Future assessments could be improved by:

- **Catch rates.** This is probably the single largest source of uncertainty and should be the primary focus of assessment improvement efforts. There are three main issues here: rezoning impacts, fishing power, and targeting. The impact of rezoning has been discussed already. Additional data may enable this to be modelled in more detail. This is also likely to be true for fishing power. Understanding ongoing shifts in targeting behaviour is difficult to define for Reef OS species. Methods proposed by Campbell et al. (2021) for saddletail snapper and by Mitchell et al. (in prep) for Spanish mackerel are also relevant for crimson snapper to incorporate fisher knowledge directly into catch rate analysis. This should be done in tandem with the use of Vessel Monitoring System data to obtain high resolution information necessary to disentangle the effects of abundance and non-abundance related impacts.
- **Discard mortality.** A key missing element is an understanding of the size-distribution of discards to better define discard mortality. The next assessment should consider additional sensitivity runs and alternative discard modelling setups to improve model fits.
- **Regional demography.** Finally, if more data are available on regionally varying demographics, these should be investigated, either for improved regional data set weighting or potentially for incorporating spatial structure in the population model itself.

A second assessment in two years time is recommended. This will incorporate updated base data sets and any additional data arising from the recommendations in Section 4.3.1.

4.4 Conclusions

This assessment was commissioned to establish the stock status of crimson snapper on Queensland's east coast and inform the Sustainable Fisheries Strategy. The base case model scenario suggested spawning biomass is currently around 44% of unfished levels. Some recommendations for management and a repeat assessment have been made.

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Appendix A Model inputs

A.1 Abundance indices

In Scenarios 1–7, the catch rates were input to the model as two independent time series (representing before and after the GBRMP rezoning in July 2004), and a constant catchability coefficient was calculated for each. For Scenarios 8–14, the catch rates were input as one fleet with one constant catchablity coefficient calculated for the entire continuous time series. Figure A.1 shows each catch rate time series multiplied by its respective catchability coefficient (then normalised to one), to demonstrate the effective catch rates as imposed by calculated catchability coefficient and allow for comparison between scenarios. The implications of this effect are discussed in Section 4.1.

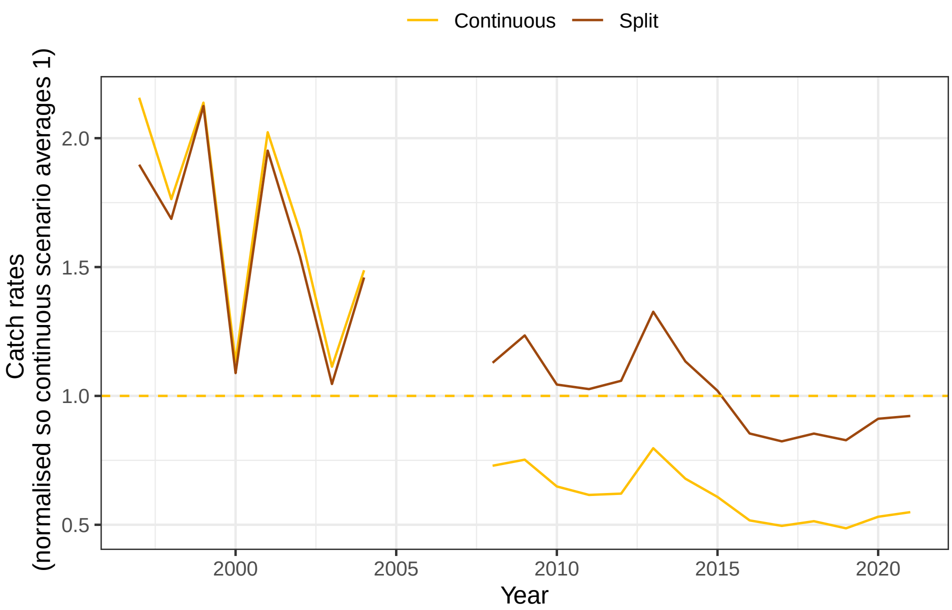


Figure A.1: Annual standardised catch rates multiplied by their calculated catchability coefficient and normalised to one, for commercial line caught crimson snapper between the years of 1997 and 2021

A.2 Age and length sample sizes

These sample sizes are input to the model and form a starting point for data set weighting.

Table A.1: Raw sample sizes measured and aged input to the model for crimson snapper

Year	Recreational length	Commercial length	Commercial age
2017	305		
2018	224	1423	245
2019	195	1158	366
2020	137	283	254
2021	73	397	289

A.3 Conditional age-at-length

Conditional age-at-length composition data were input to the population model (Figure A.2).

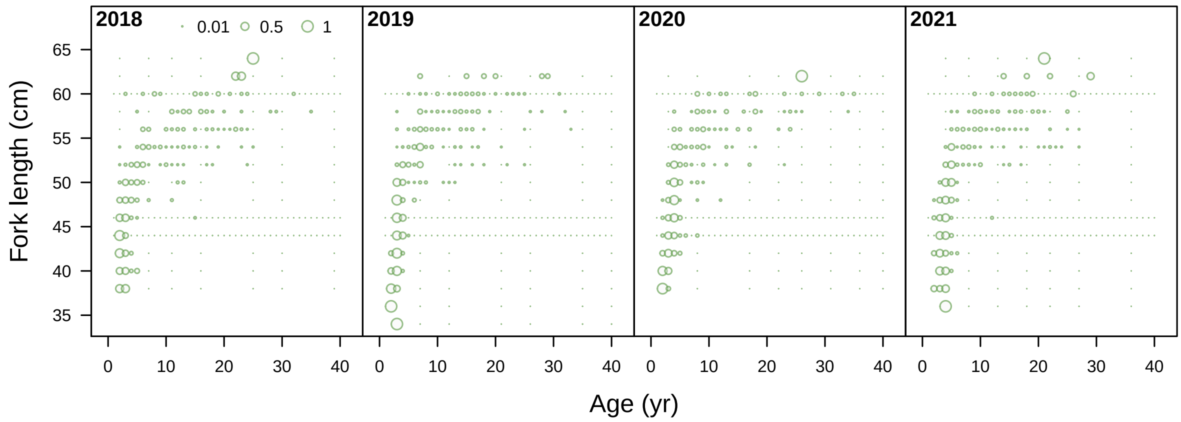


Figure A.2: Conditional age-at-length compositions of crimson snapper between 2018 and 2021—circle size is proportional to relative sample size in each bin across rows (i.e. for a given length bin)

A.4 Biological data

A.4.1 Fecundity and maturity

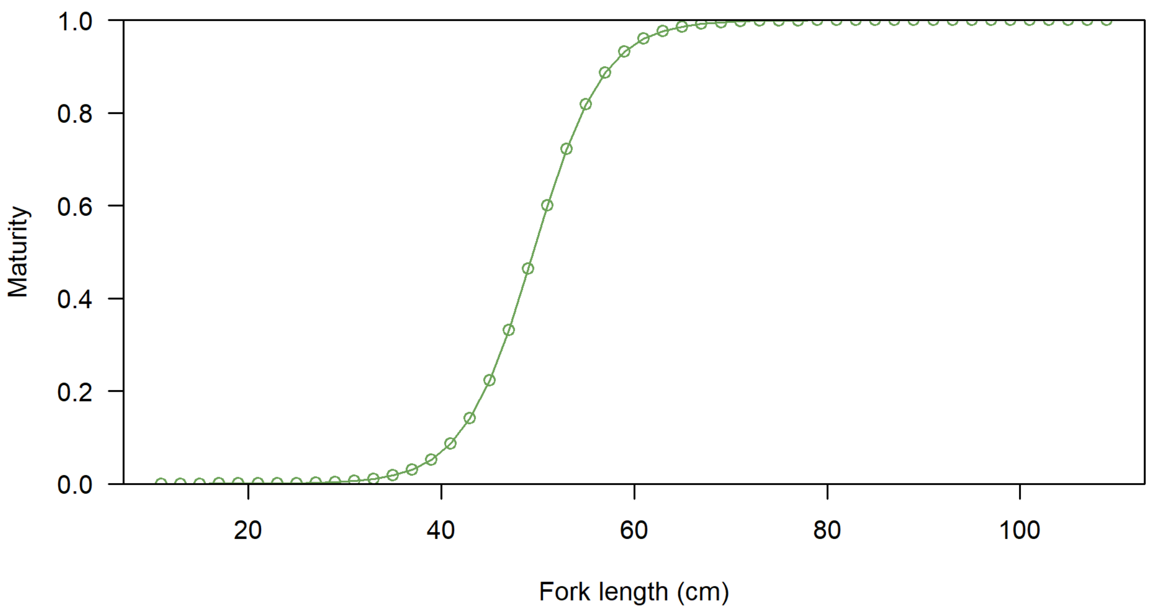


Figure A.3: Maturity at length for crimson snapper

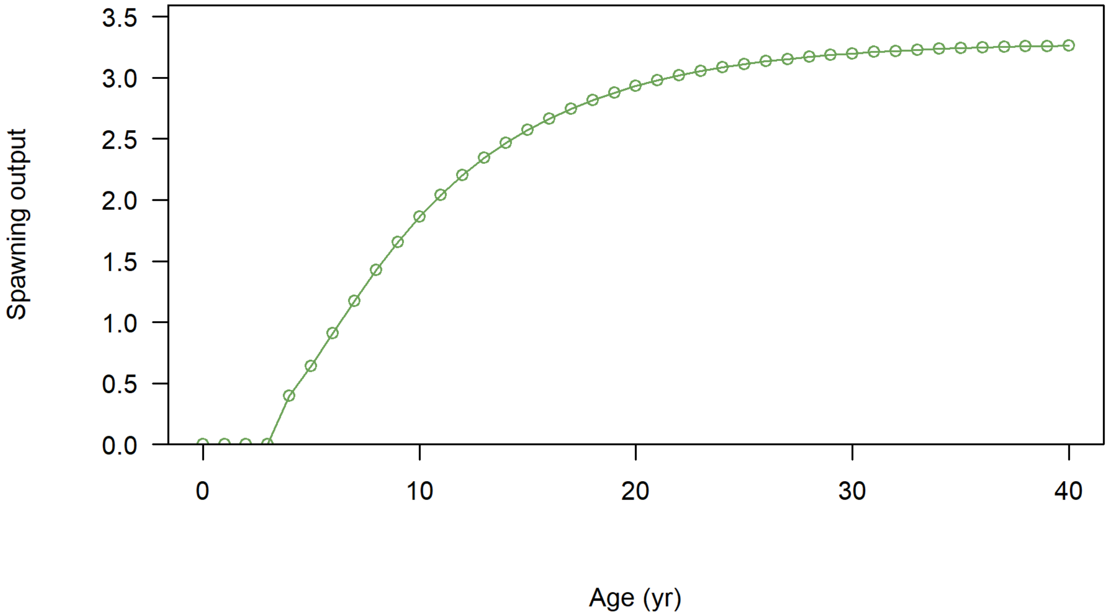


Figure A.4: Spawning output (maturity times fecundity) at age for crimson snapper

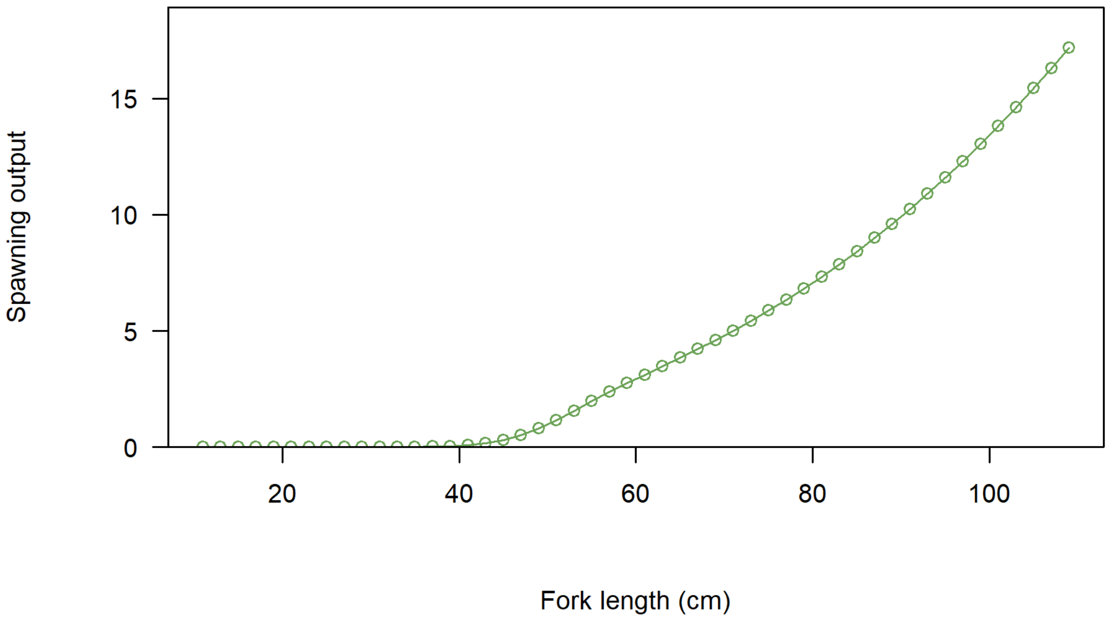


Figure A.5: Spawning output (maturity times fecundity) at length for crimson snapper

A.4.2 Weight and length

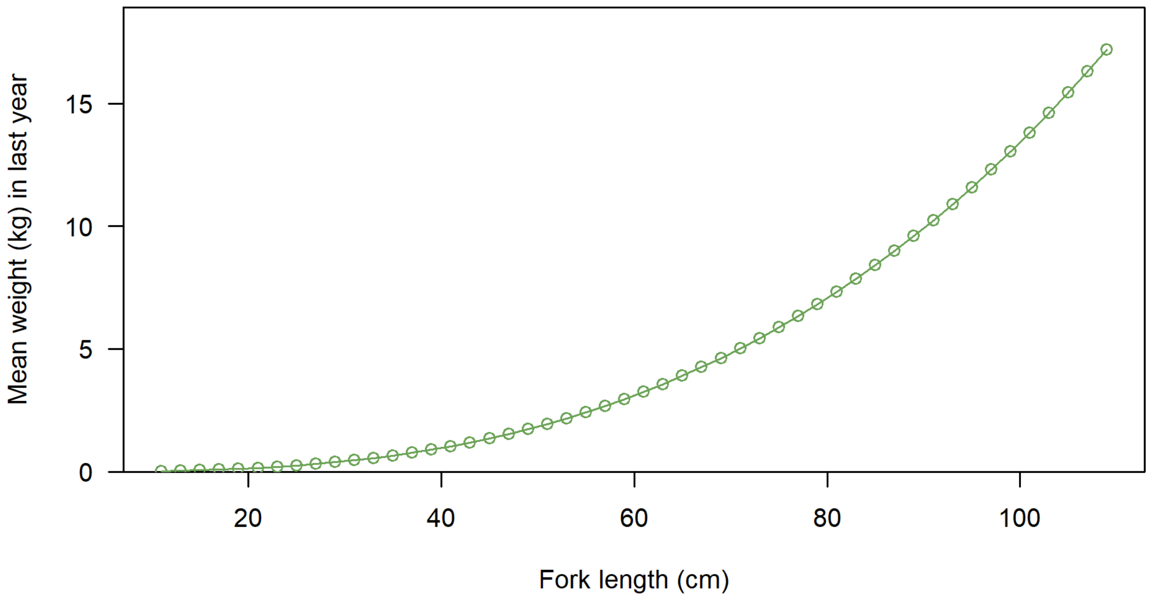


Figure A.6: Weight-length relationship for crimson snapper

A.4.3 Differences in growth between sexes

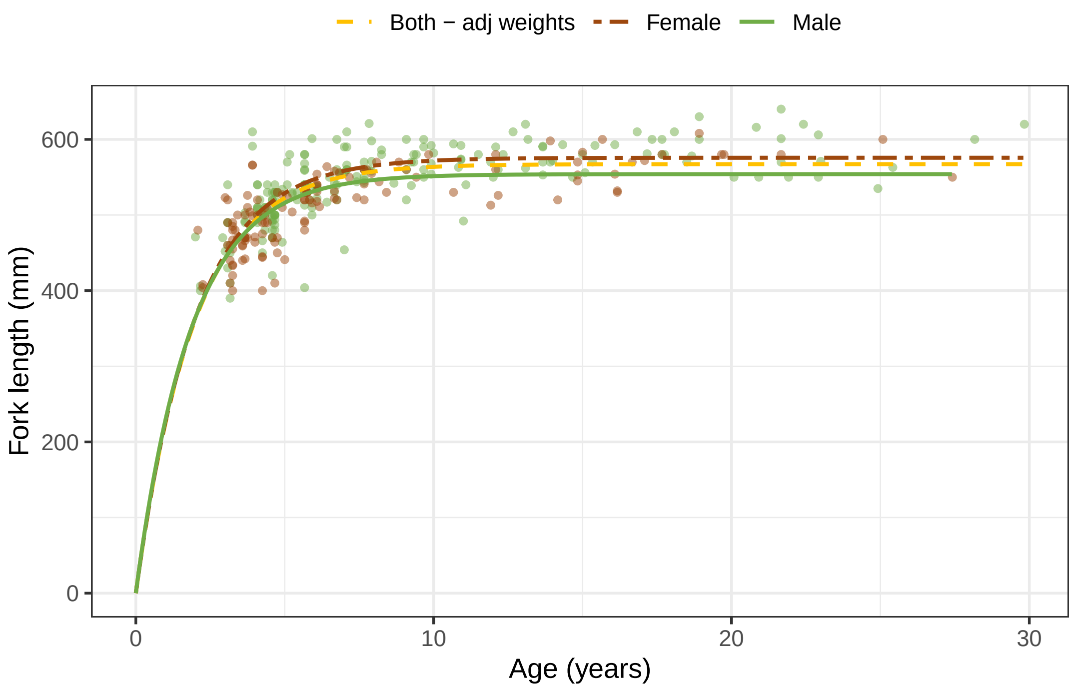


Figure A.7: von Bertalanffy growth curves for male, female and combined crimson snapper in Lockhart and Cooktown regions—combined sexes were weighted to account for differences in male and female sample sizes

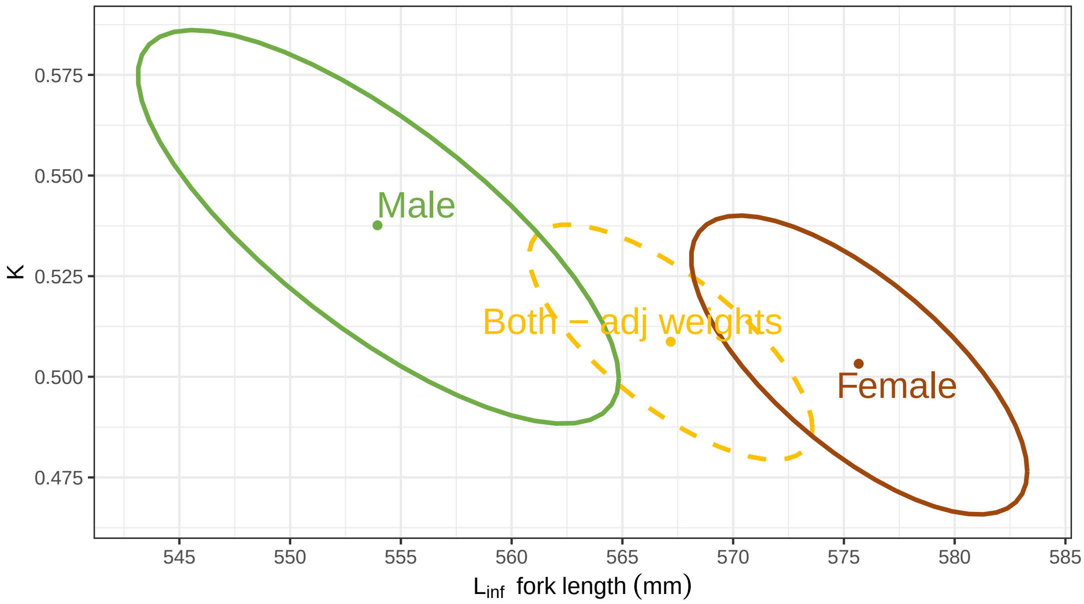


Figure A.8: 95% bivariate data ellipses of bootstrapped K (growth rate) and L_{inf} (mean maximum asymptotic size) estimates for male, female and combined crimson snapper in Lockhart and Cooktown regions—combined sexes were weighted to account for differences in male and female sample sizes

Appendix B Model outputs

B.1 Parameter estimates

Model parameters were estimated by Stock Synthesis, and parameter labels follow a Stock Synthesis specific naming convention (Table B.1).

Table B.1: Stock Synthesis parameter label explanation for crimson snapper

Stock Synthesis Parameter Label	Explanation
NatM	Natural mortality
L_at_Amin	Length at age 1
L_at_Amax	Length at age 35
VonBert_K	von Bertalanffy growth parameter
CV_young	Coefficient of variation in length at age 1
CV_old	Coefficient of variation in length at age 35
SR_LN(R0)	Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1958)
SR_BH_steep	Beverton-Holt steepness
Size_inflection_Commercial	Commercial selectivity inflection (cm)
Size_95%width_Commercial	Commercial selectivity width (cm)
Size_inflection_Recreational	Recreational selectivity inflection (cm)
Size_95%width_Recreational	Recreational selectivity width (cm)

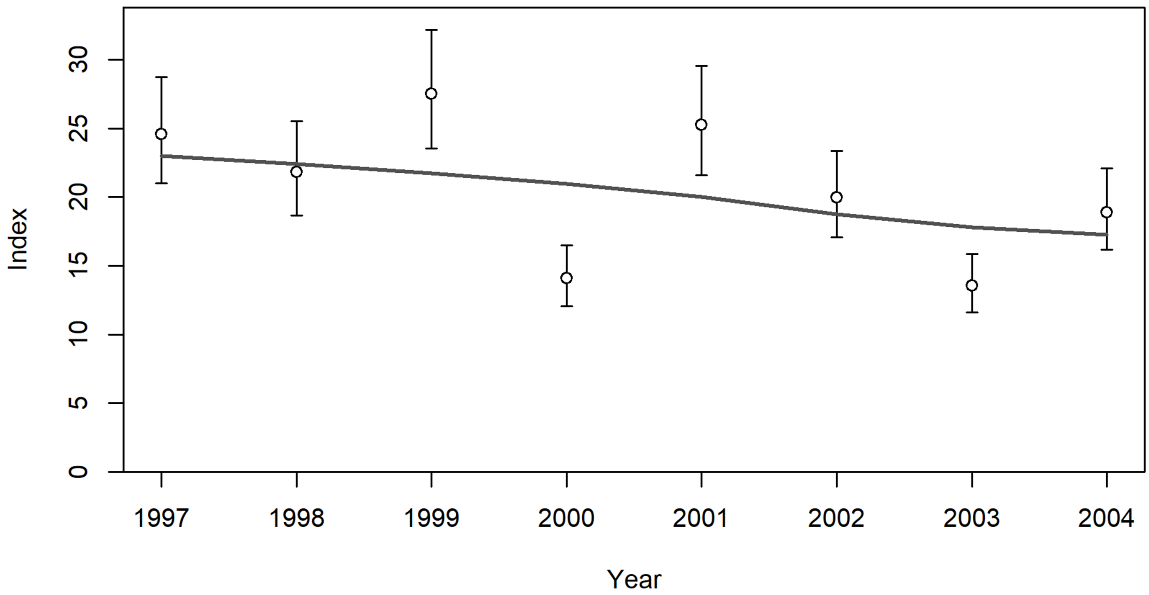
Table B.2: Stock Synthesis parameter estimates for the base population model for crimson snapper

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
NatM	0.14	2	0.01	0.5	0.15	0.02
L_at_Amin	33.9	3	10	40	34	0.5
L_at_Amax	61.63	3	40	90	62	1.09
VonBert_K	0.14	3	0.1	0.4	0.13	0.01
CV_young	0.12	5	0.1	0.3	0.13	0.01
CV_old	0.12	5	0.01	0.2	0.11	0.01
SR_LN(R0)	11.69	1	3	19	11.64	0.23
SR_BH_steep	0.7	6	0.2	1	0.7	0.06
Size_inflection_Commercial	51	4	30	60	50	1.51
Size_95%width_Commercial	11.29	4	1	20	11.5	1.39
Size_inflection_Recreational	26.24	4	20	45	26	0.44
Size_95%width_Recreational	3.57	4	0.01	10	3.7	0.53

In addition, recruitment deviations were estimated between 1982 and 2021.

B.2 Goodness of fit

B.2.1 Abundance indices



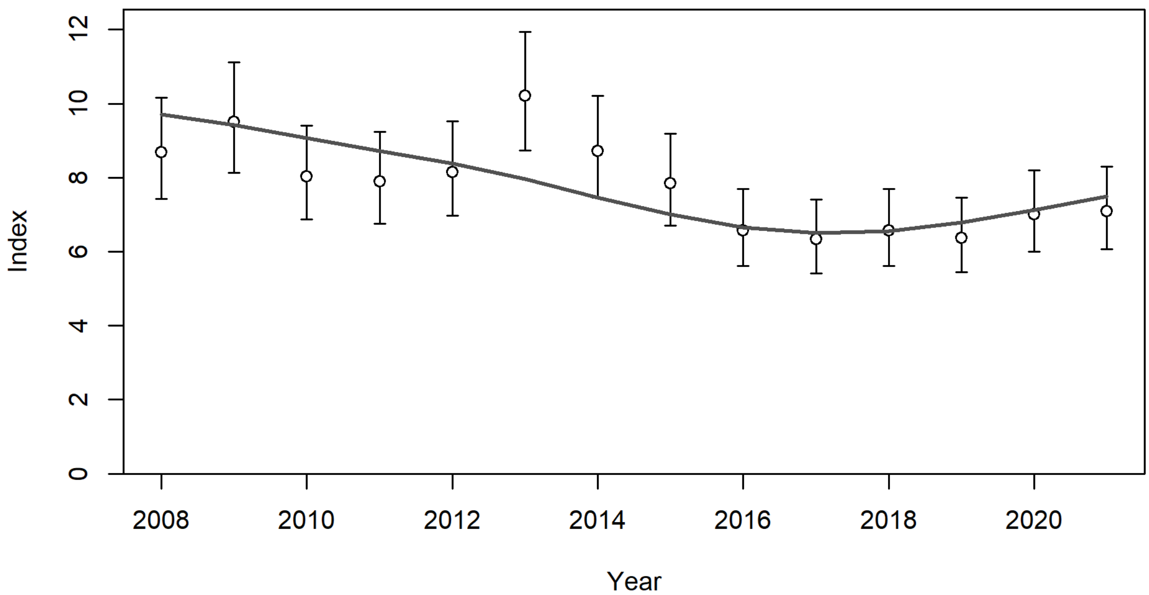


Figure B.1: Model predictions (grey line) to commercial catch rates for crimson snapper

B.2.2 Length compositions

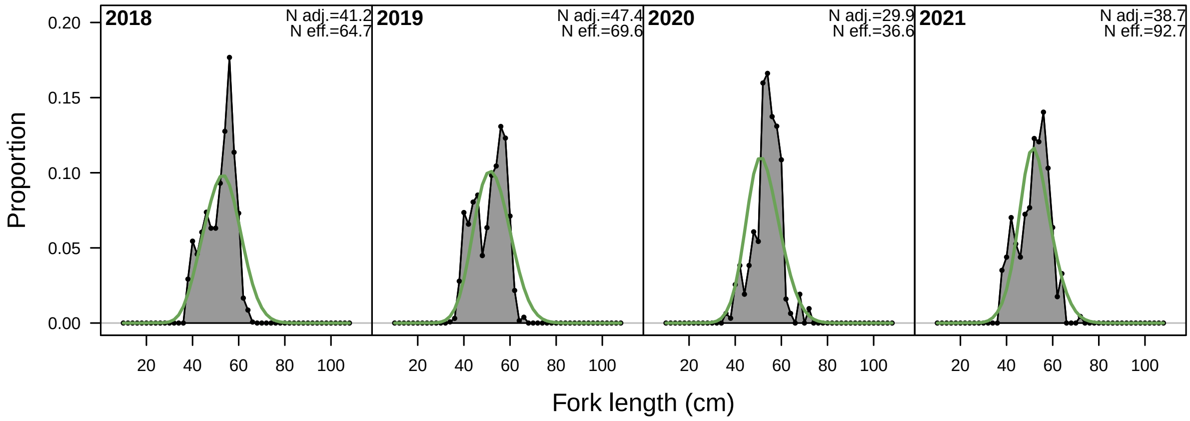


Figure B.2: Length structure for the commercial fleet for crimson snapper
'N adj.' is the input sample size after data-weighting adjustment. 'N eff.' is the calculated effective sample size used in the McAllister-Iannelli tuning method

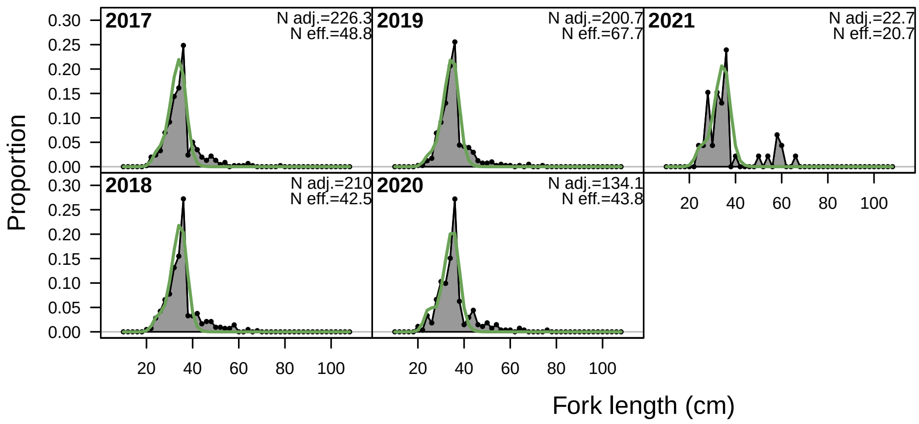


Figure B.3: Length structure for the recreational fleet for discarded crimson snapper
'N adj.' is the input sample size after data-weighting adjustment. 'N eff.' is the calculated effective sample size used in the McAllister-Iannelli tuning method

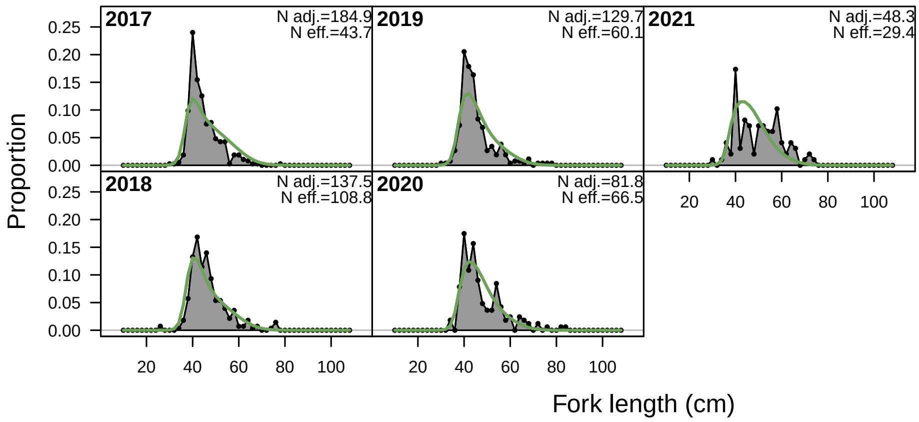


Figure B.4: Length structure for the recreational fleet for retained crimson snapper

'N adj.' is the input sample size after data-weighting adjustment. 'N eff.' is the calculated effective sample size used in the McAllister-Iannelli tuning method

B.2.3 Conditional age-at-length compositions

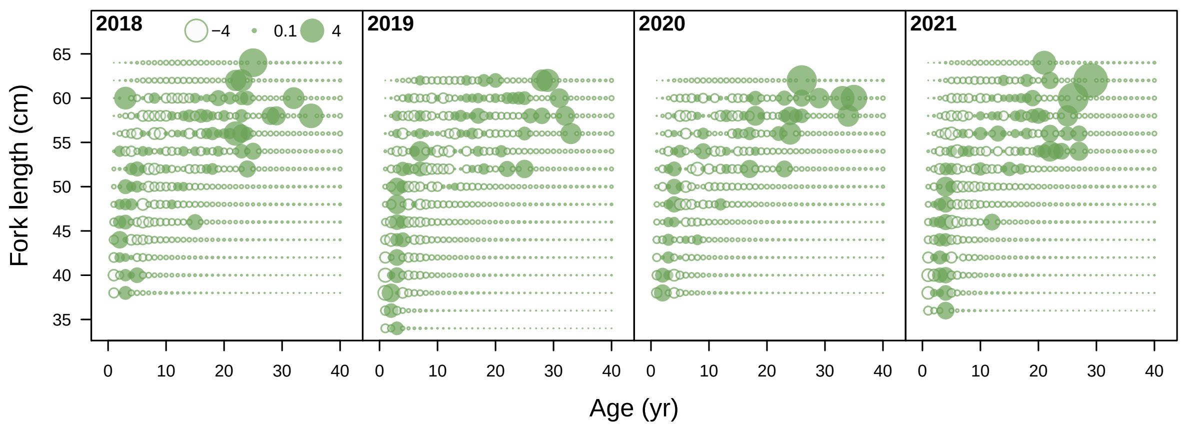


Figure B.5: Pearson residuals for age-at-length compositions for the commercial fleet for crimson snapper—circle size represents the magnitude of the Pearson residual

B.2.4 Discard fraction

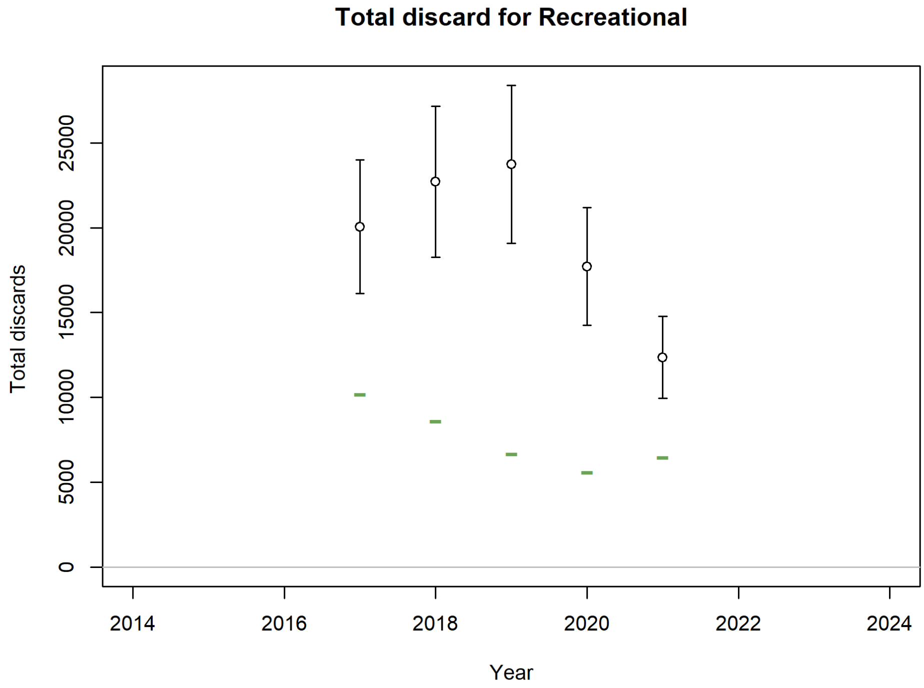


Figure B.6: Model fit to total discards for recreational-charter-Indigenous fleet—circles and error bars represent input data and their associated coefficients of variation and green dashes represent the model predictions

B.3 Other outputs

B.3.1 Phase plot

The purpose of this stock assessment was to report on the health of the stock and provide information to support fishery management. Results were assessed and classified against fishery target and limit reference points outlined in the harvest strategy and harvest strategy policy for Queensland.

Separate to this report and other Queensland government reporting, stock assessment results may be used and cited in separate 'Status of Australian Fish Stocks' (SAFS) reports (www.fish.gov.au). The SAFS classification system applies different inferences and reference points.

The SAFS classification system was designed by the Status of Australian Fish Stocks Reports Advisory Group. The classification system evaluates the status of a stock based on the fishing mortality (F) and biomass (B) relative to a 20% biological limit reference point. The status of a stock is classified as sustainable, depleting, depleted, recovering, negligible or undefined. The terms 'sustainable stock' and 'stock status' in the Status of Australian Fish Stocks Reports 2020 refer specifically to the biological status against the limit reference point.

Broader biological, economic or social considerations are not yet classified in SAFS, such as biomass reference points at maximum sustainable yield (B_{MSY}) or biomass at maximum economic yield (B_{MEY}). B_{MSY} generally ranges 35–40%, when harvest from surplus production (the annual amount by which the fish population would increase from growth and recruitment) is maximized (Punt et al. 2014). B_{MEY} generally ranges 50–60%, minimising potential loss in profit (Punt et al. 2014).

A phase plot assists in defining SAFS stock status relative to limit reference points for biomass and fishing mortality (FRDC 2021). The plot tracks the annual stock biomass ratio relative to the unfished level, and fishing mortality relative to the target reference point for the biomass limit (Figure B.7).

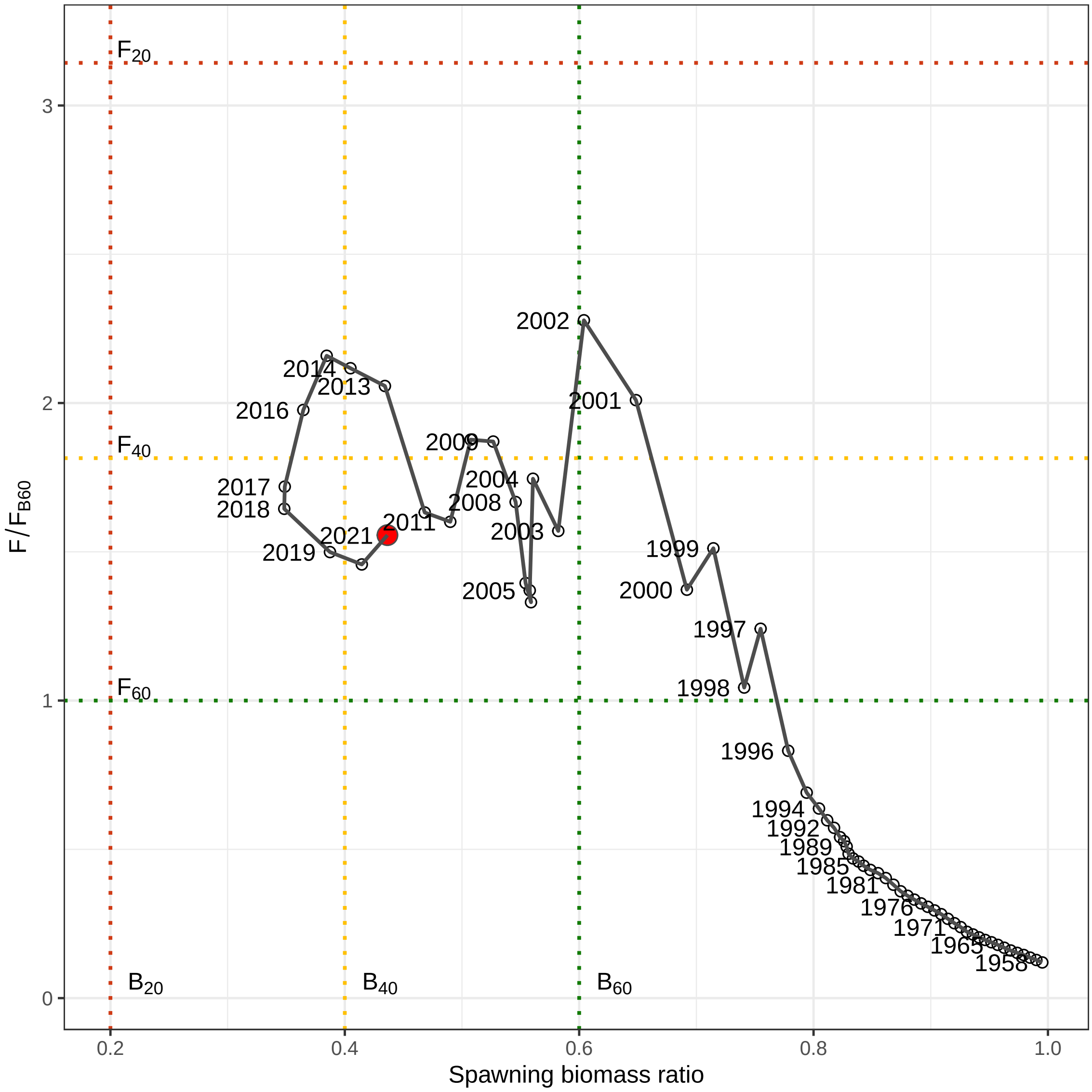


Figure B.7: Phase plot for crimson snapper

The horizontal axis is the spawning biomass ratio of Queensland crimson snapper relative to unfished and the vertical axis is the fishing mortality relative to the fishing mortality which would produce the SFS spawning biomass target of 60%. The red dotted vertical line is the limit reference point (20% relative spawning biomass) and the green and yellow dotted vertical lines are the potential target reference points (60% and 40% relative spawning biomass)

B.3.2 Stock-recruit curve

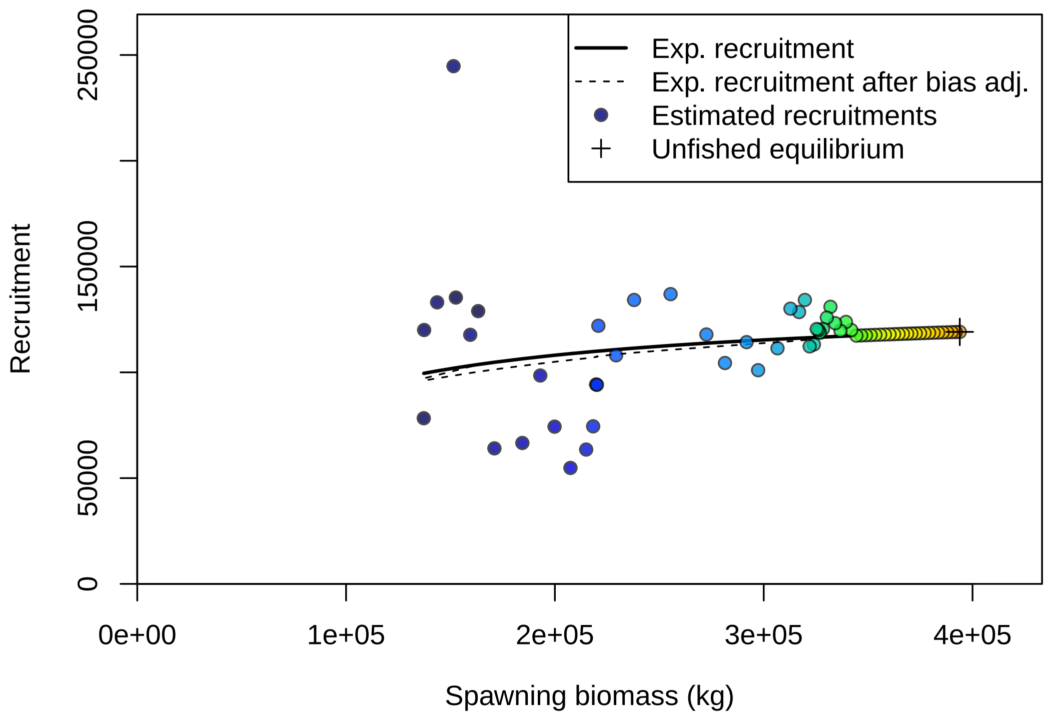


Figure B.8: Stock-recruit curve—point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years.

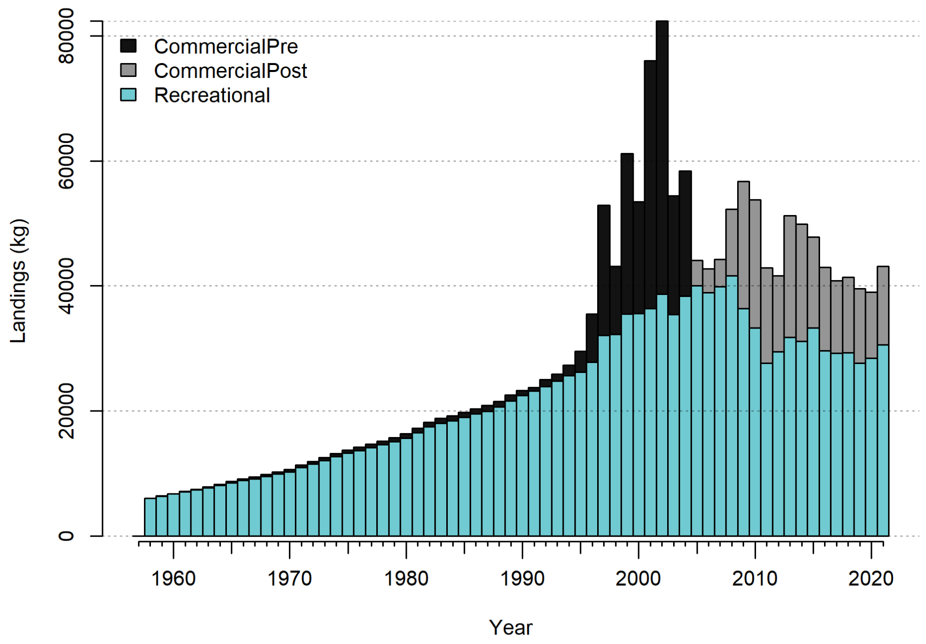


Figure B.9: Modelled harvest for crimson snapper

B.4 Markov chain Monte Carlo

A Markov chain Monte Carlo (McMC) was run on the base case scenario (Scenario 1) for over 4 000 000 iterations to investigate the posterior and ensure a global minimum was found by Stock Synthesis.

Convergence of the McMC was monitored using a factor ($\hat{R}$) by which the scale of the distribution at the end of the chain might be reduced if the simulations were continued infinitely (Gelman et al. 1995).

This value was calculated to be $\hat{R} = 0.9998 \sim 1$ which does not indicate non-convergence. The calculation was performed using the *rhat* function in the R package "*posterior*" (Bürkner et al. 2020; Vehtari et al. 2020). Further McMC diagnostic plots are shown in Figures B.10, B.11 and B.12.

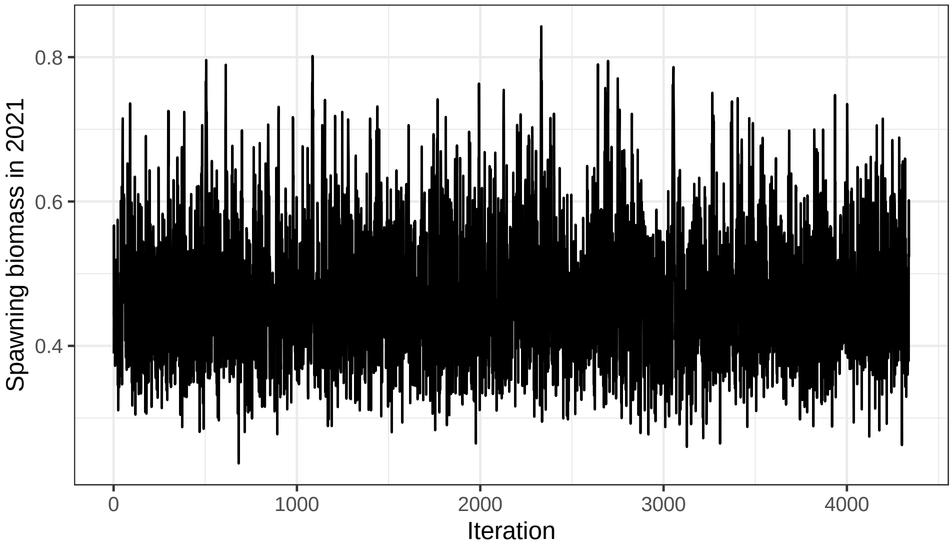


Figure B.10: Trace plot for final spawning biomass after a Markov chain Monte Carlo for crimson snapper

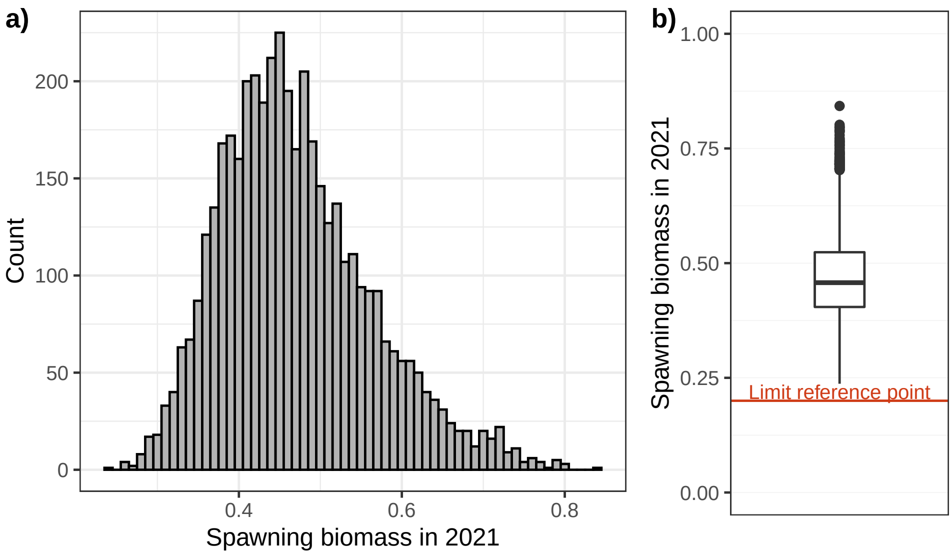


Figure B.11: Histogram and boxplot for final spawning biomass after a Markov chain Monte Carlo for crimson snapper

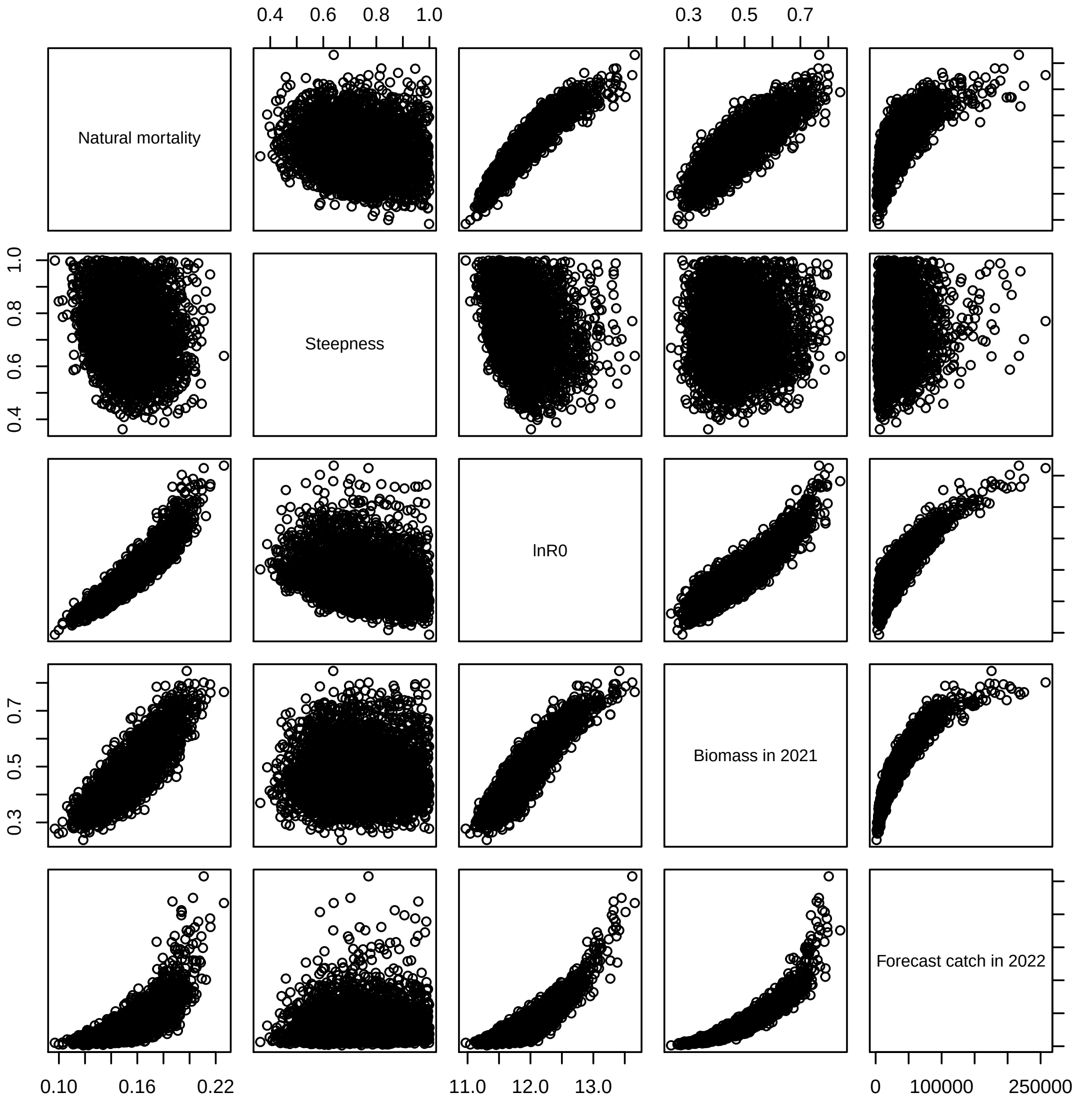


Figure B.12: Pairs plot for key parameters and model outputs after a Markov chain Monte Carlo for crimson snapper

Appendix C Sensitivity tests: model outputs

Parameter estimates

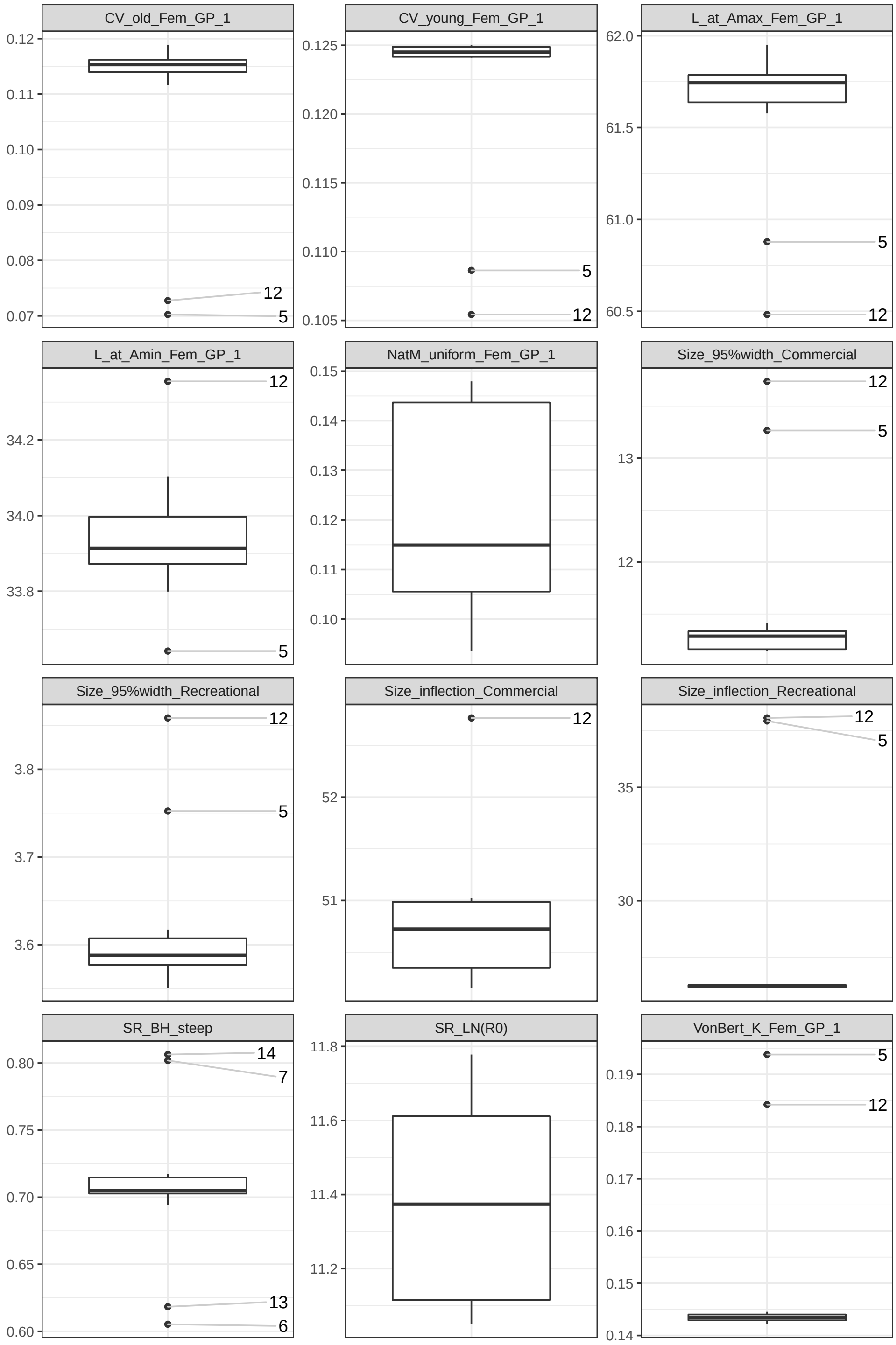


Figure C.1: Visualisation of parameter estimates for all 14 sensitivity tests

Outliers are labelled with the corresponding sensitivity test identifier, as defined in Section 2.7.4

Figure C.1 shows that the growth parameters estimated for Scenarios 5 and 12 (in which discards were modelled outside of Stock Synthesis) are outliers compared to the estimates from other scenarios. The von Bertalanffy growth curves, as defined by these estimated parameters and shown in Figure C.2, are not dissimliar across all scenarios.

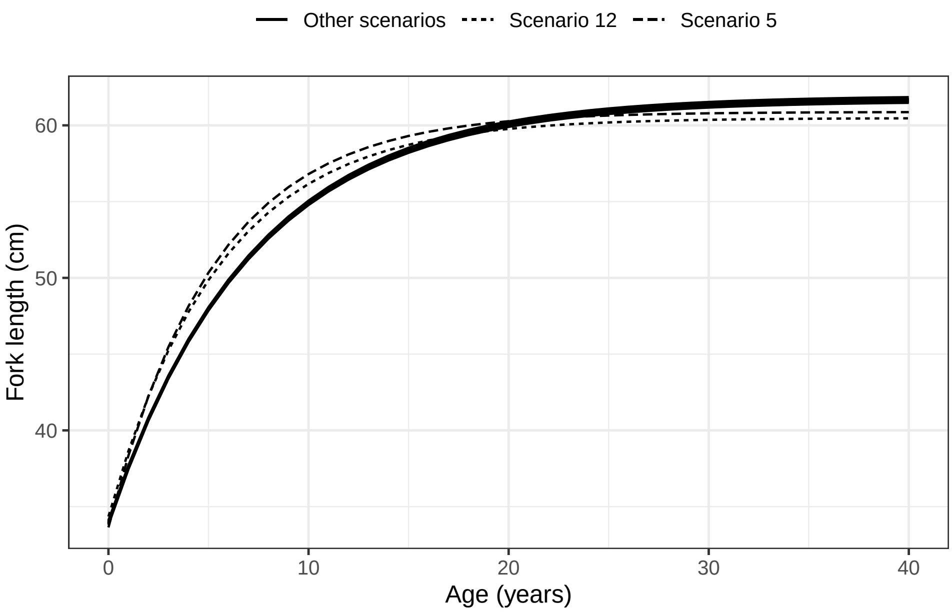


Figure C.2: Comparison of von Bertalanffy growth curves as defined by estimated growth parameters for all scenarios for crimson snapper

Scenario 2

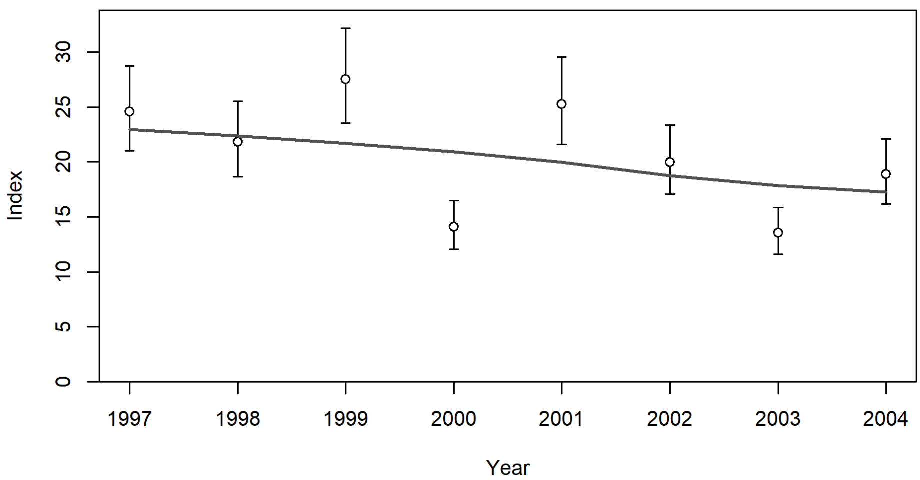


Figure C.3: Scenario 2 model predictions (grey line) to commercial catch rates for crimson snapper prior to rezoning

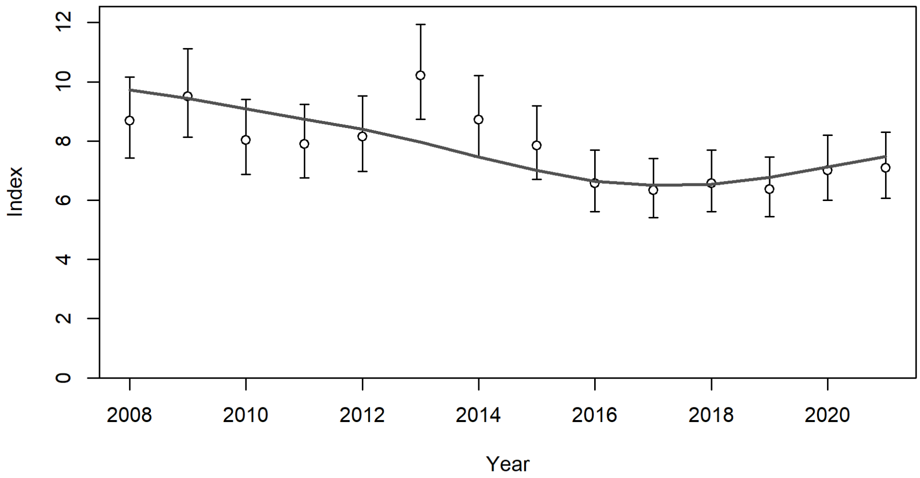


Figure C.4: Scenario 2 model predictions (grey line) to commercial catch rates for crimson snapper after rezoning

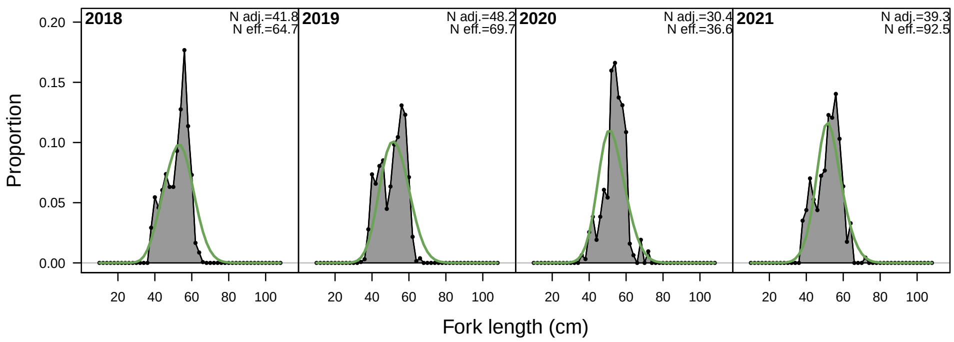


Figure C.5: Scenario 2 length structure for the commercial fleet for crimson snapper

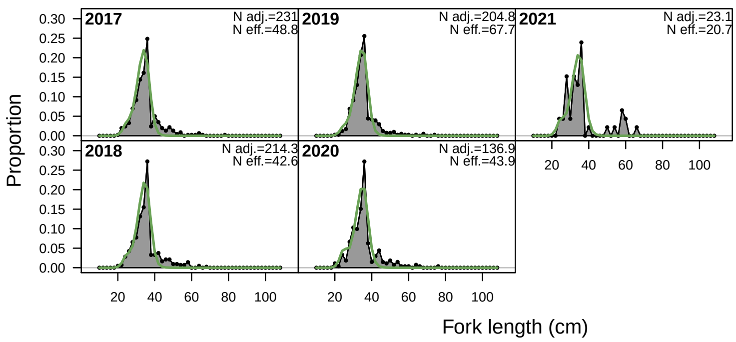


Figure C.6: Scenario 2 length structure for the recreational fleet for discarded crimson snapper

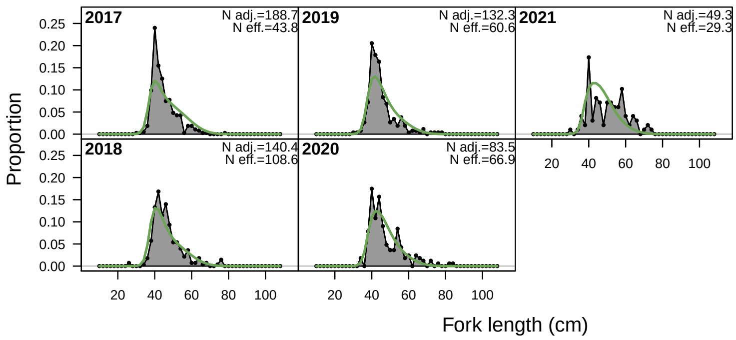


Figure C.7: Scenario 2 length structure for the recreational fleet for retained crimson snapper

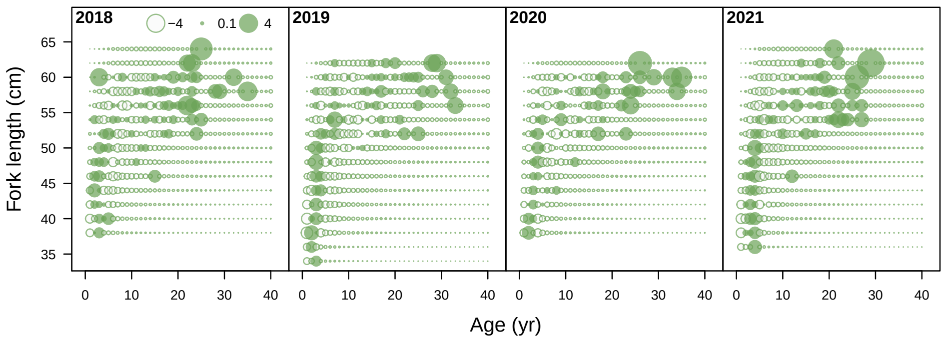


Figure C.8: Scenario 2 Pearson residuals for age-at-length compositions for the commercial fleet for crimson snapper—circle size represents the magnitude of the Pearson residual

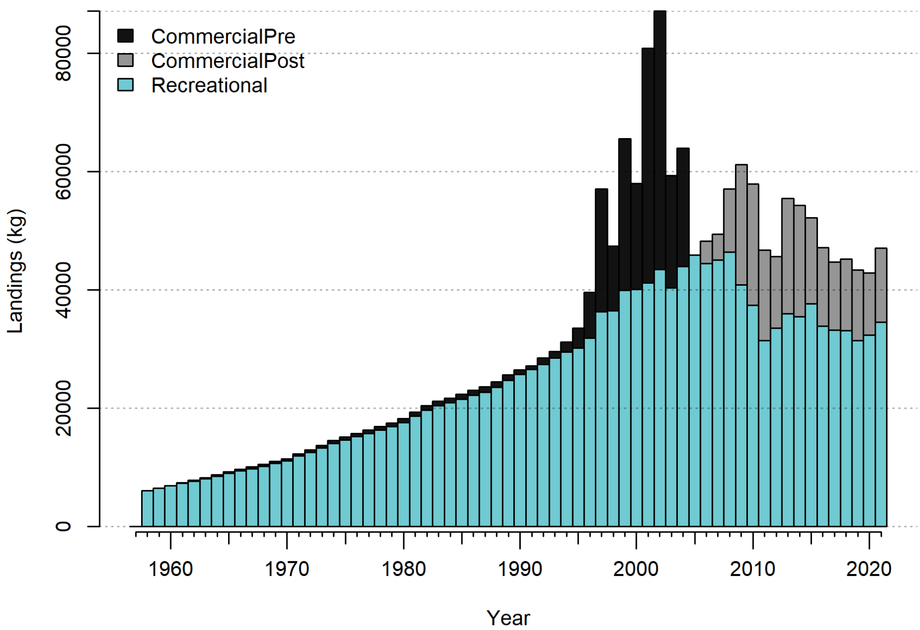


Figure C.9: Scenario 2 modelled harvest

Scenario 3

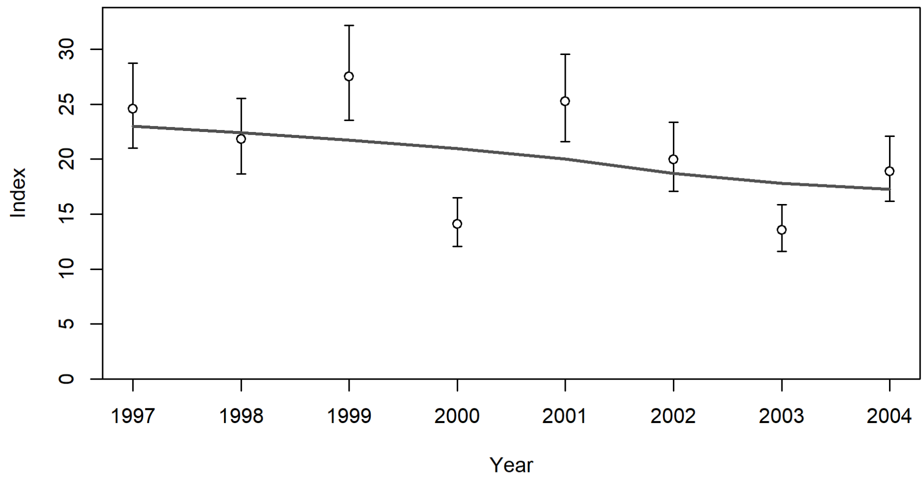


Figure C.10: Scenario 3 model predictions (grey line) to commercial catch rates for crimson snapper prior to rezoning

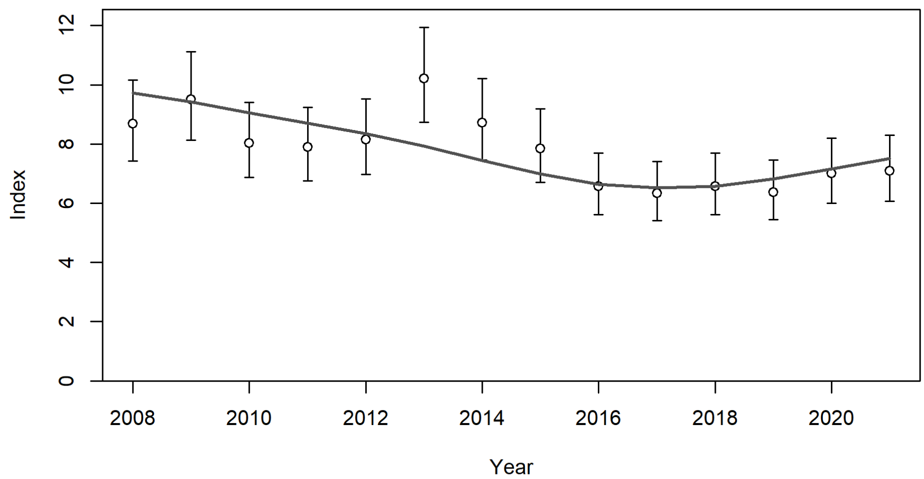


Figure C.11: Scenario 3 model predictions (grey line) to commercial catch rates for crimson snapper after rezoning

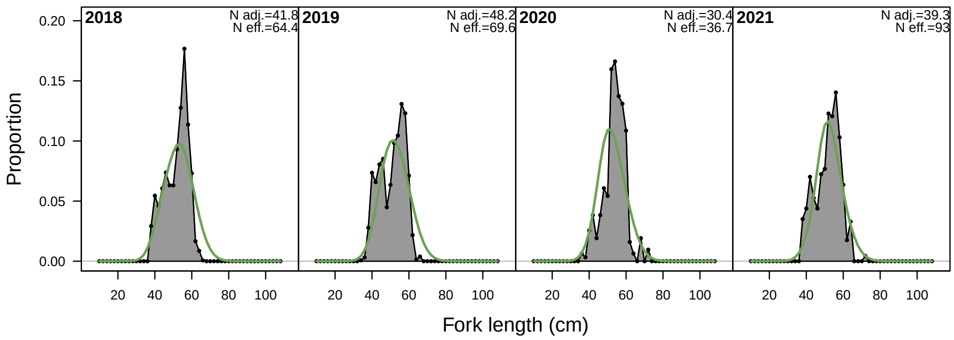


Figure C.12: Scenario 3 length structure for the commercial fleet for crimson snapper

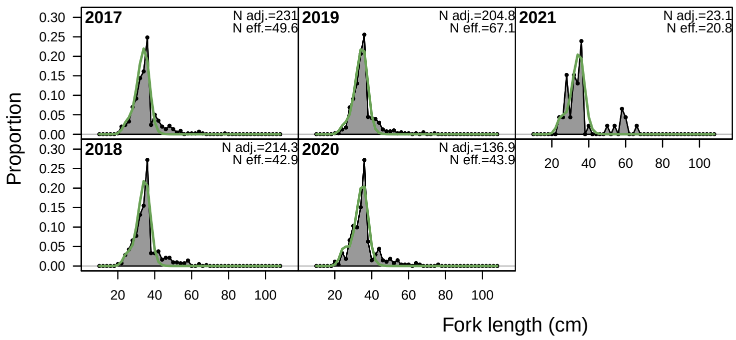


Figure C.13: Scenario 3 length structure for the recreational fleet for discarded crimson snapper

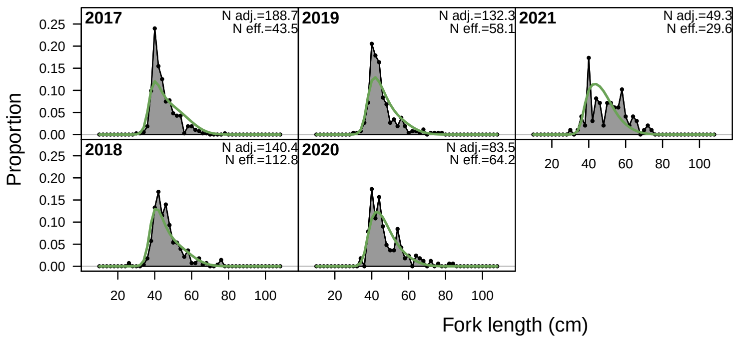


Figure C.14: Scenario 3 length structure for the recreational fleet for retained crimson snapper

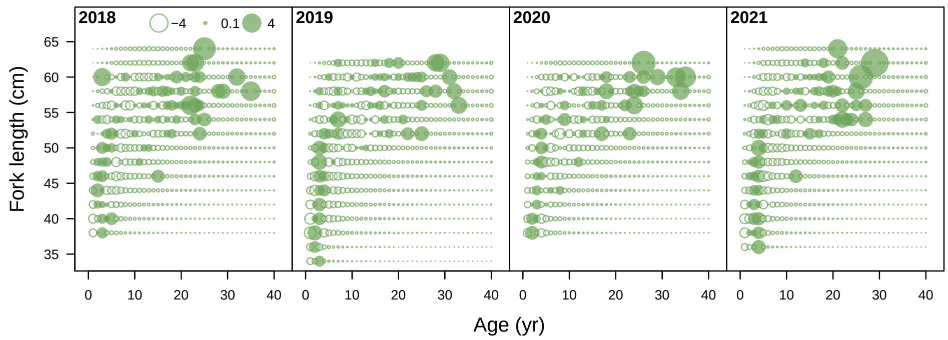


Figure C.15: Scenario 3 Pearson residuals for age-at-length compositions for the commercial fleet for crimson snapper—circle size represents the magnitude of the Pearson residual

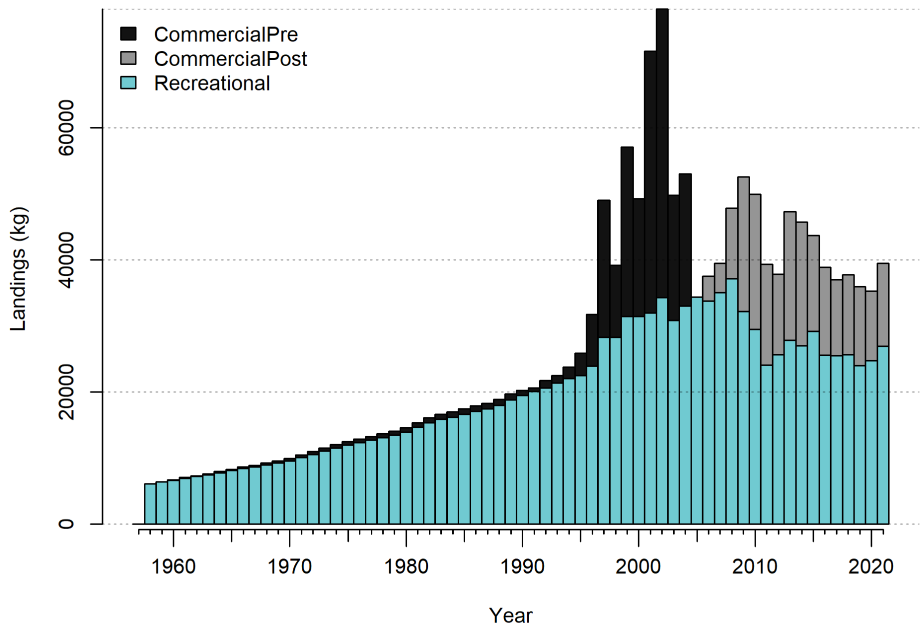


Figure C.16: Scenario 3 modelled harvest

Scenario 4

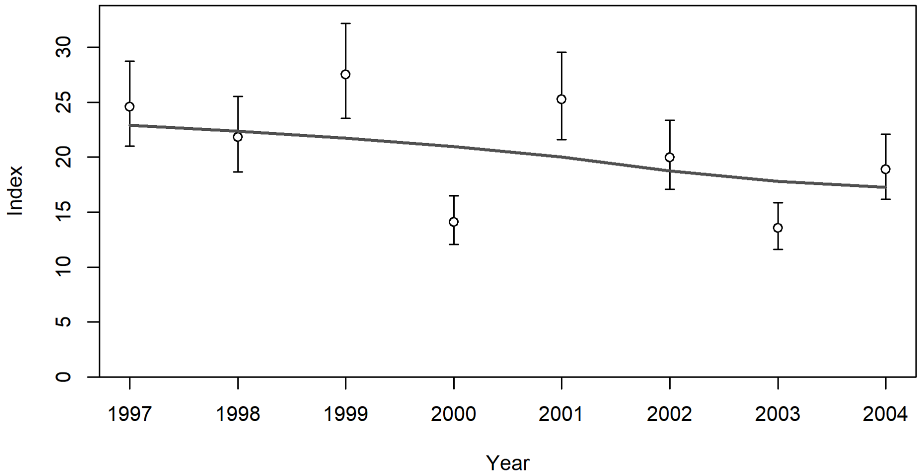


Figure C.17: Scenario 4 model predictions (grey line) to commercial catch rates for crimson snapper prior to rezoning

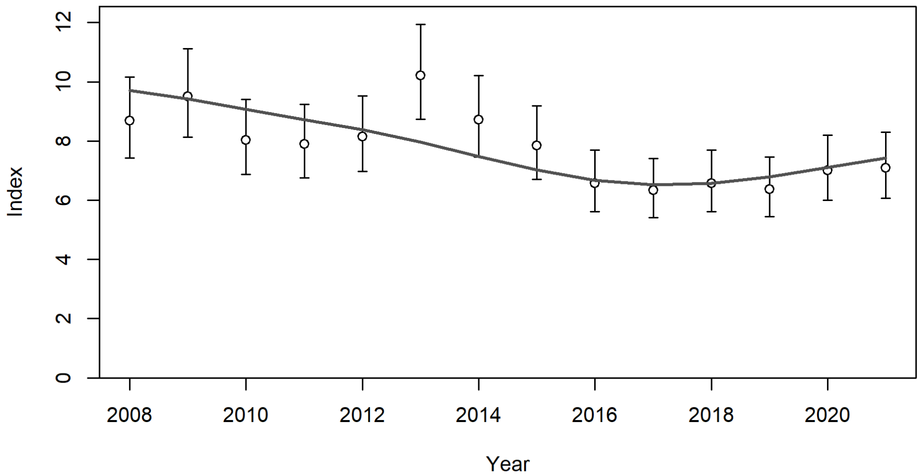


Figure C.18: Scenario 4 model predictions (grey line) to commercial catch rates for crimson snapper after rezoning

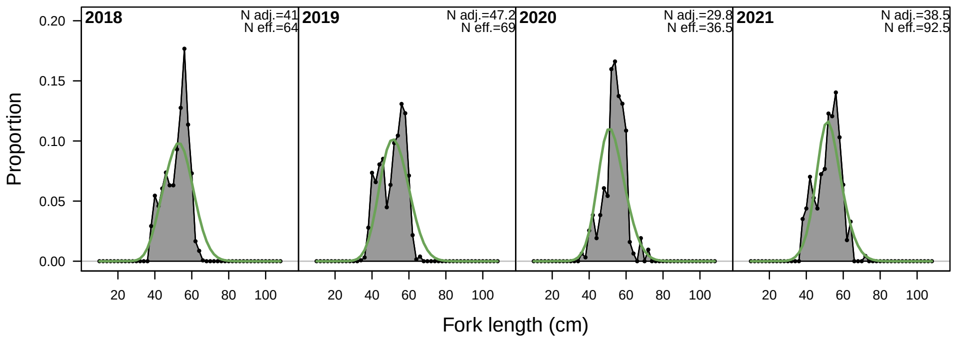


Figure C.19: Scenario 4 length structure for the commercial fleet for crimson snapper

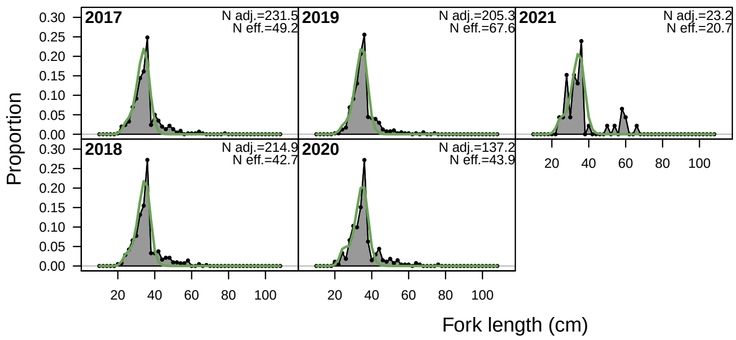


Figure C.20: Scenario 4 length structure for the recreational fleet for discarded crimson snapper

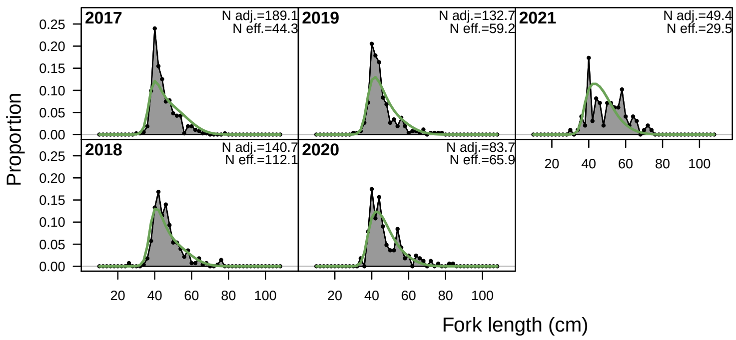


Figure C.21: Scenario 4 length structure for the recreational fleet for retained crimson snapper

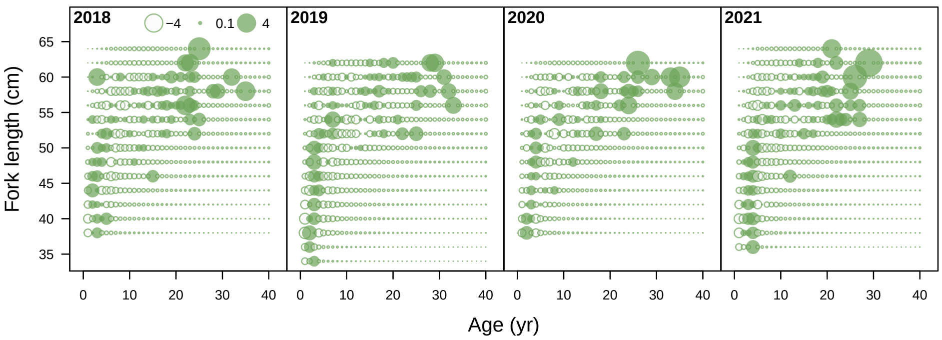


Figure C.22: Scenario 4 Pearson residuals for age-at-length compositions for the commercial fleet for crimson snapper—circle size represents the magnitude of the Pearson residual

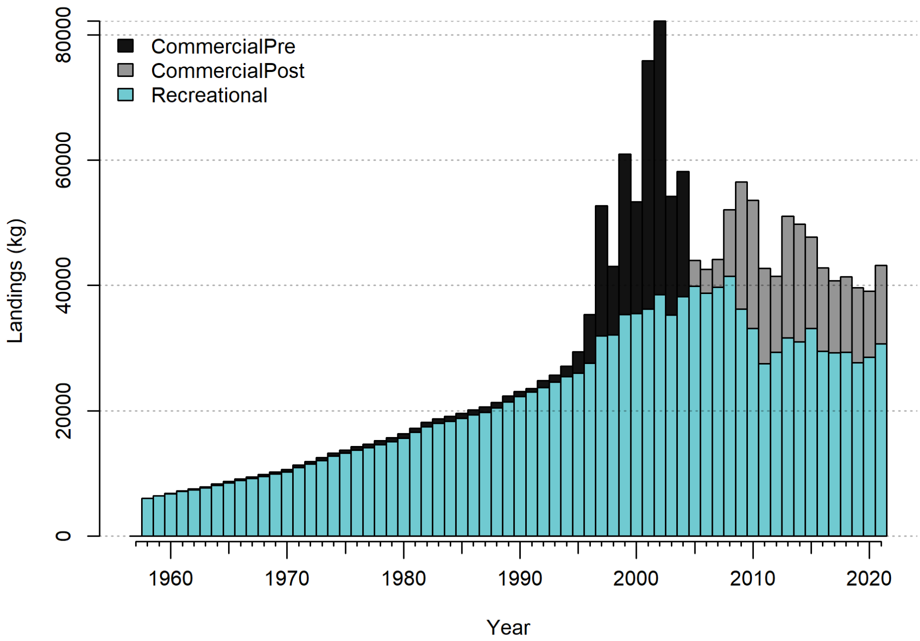


Figure C.23: Scenario 4 modelled harvest

Scenario 5

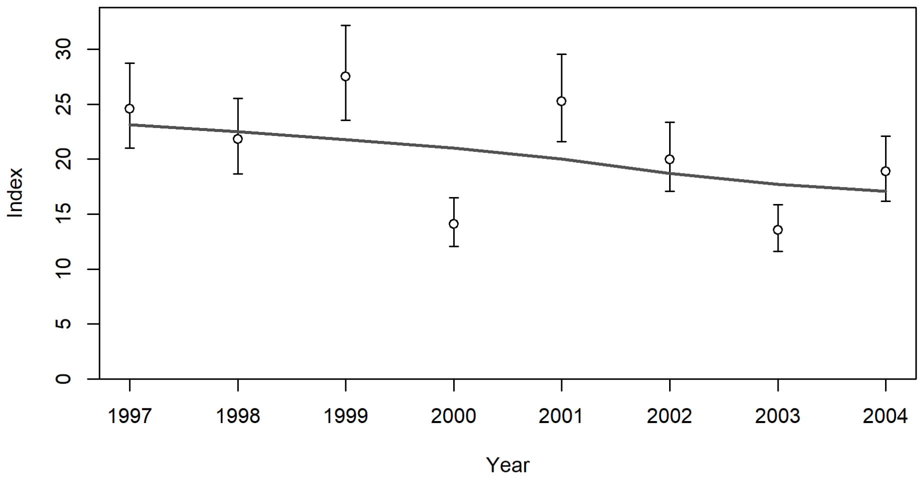


Figure C.24: Scenario 5 model predictions (grey line) to commercial catch rates for crimson snapper prior to rezoning

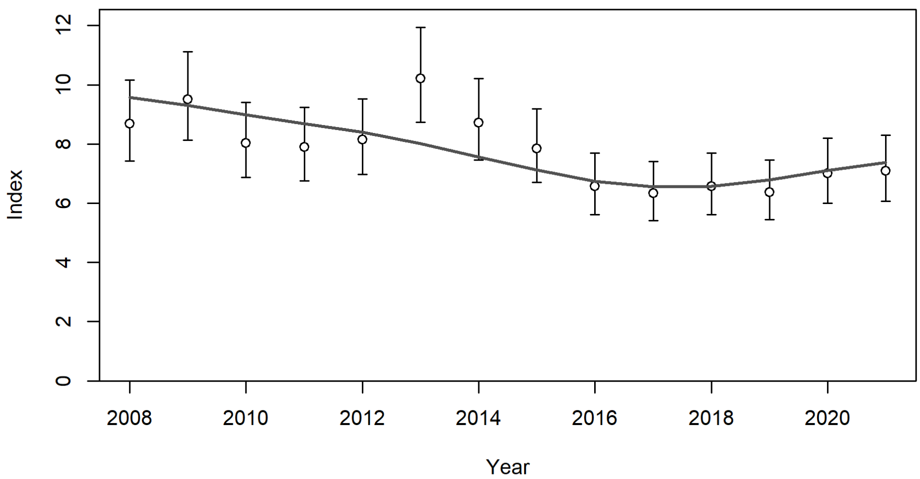


Figure C.25: Scenario 5 model predictions (grey line) to commercial catch rates for crimson snapper after rezoning

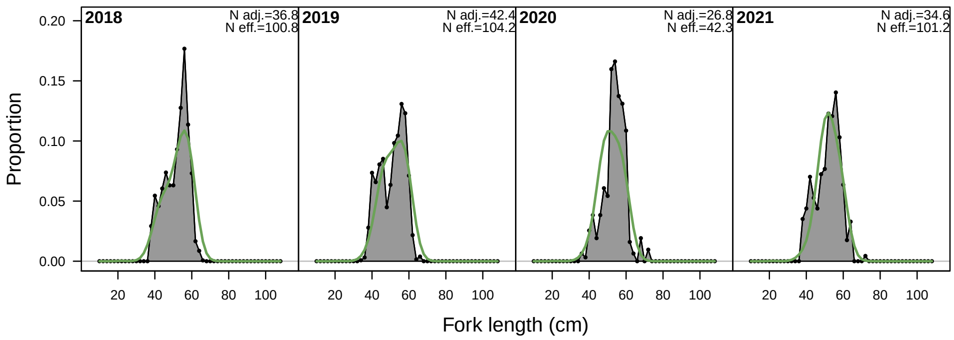


Figure C.26: Scenario 5 length structure for the commercial fleet for crimson snapper

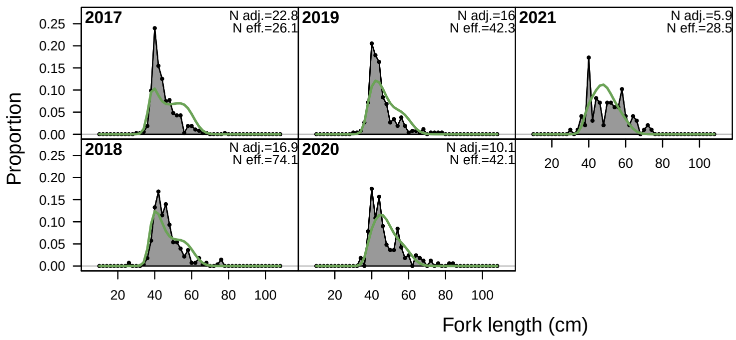


Figure C.27: Scenario 5 length structure for the recreational fleet for retained crimson snapper

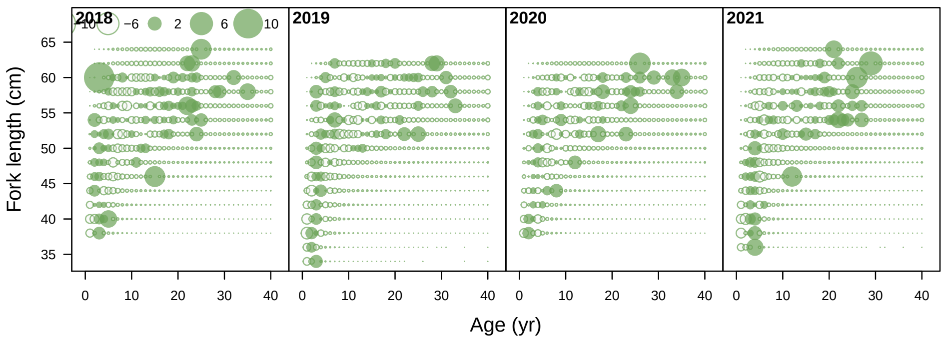


Figure C.28: Scenario 5 Pearson residuals for age-at-length compositions for the commercial fleet for crimson snapper—circle size represents the magnitude of the Pearson residual

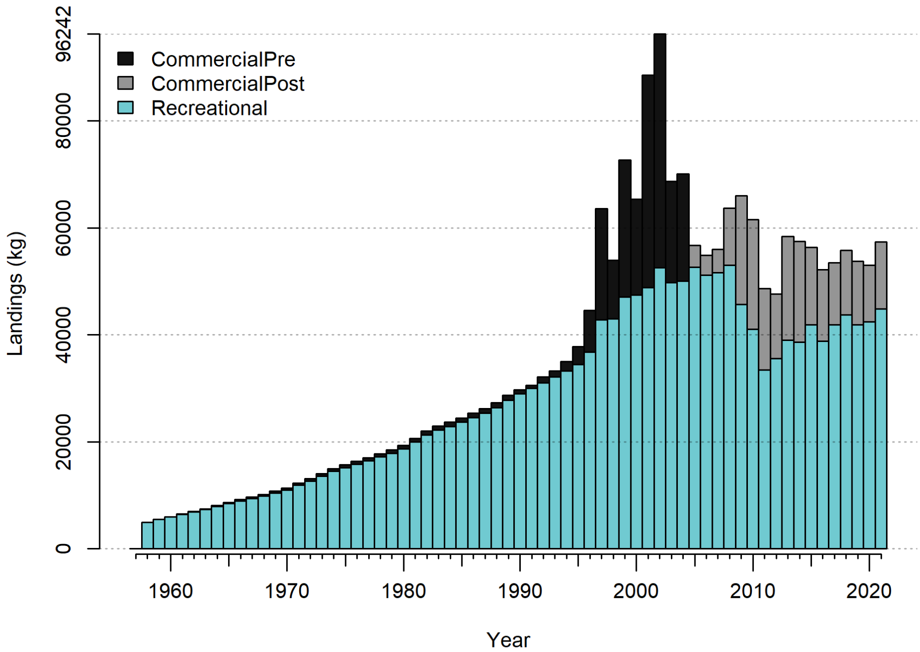


Figure C.29: Scenario 5 modelled harvest

Scenario 6

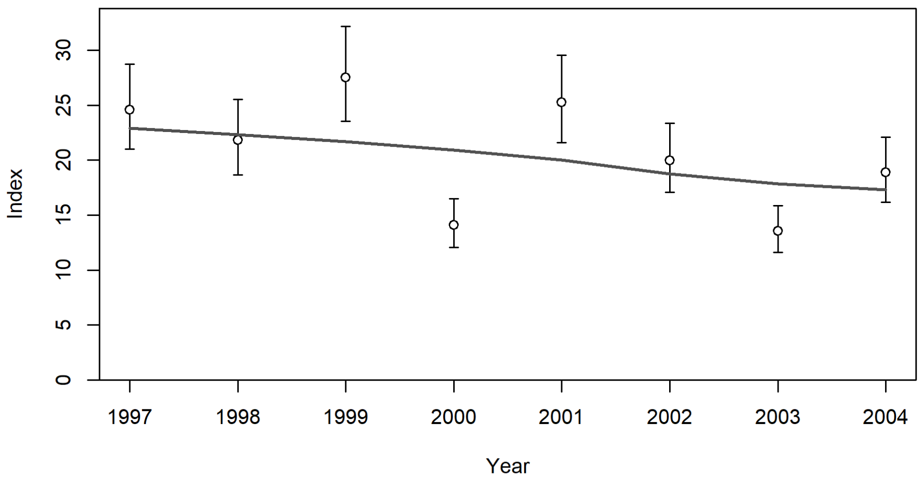


Figure C.30: Scenario 6 model predictions (grey line) to commercial catch rates for crimson snapper prior to rezoning

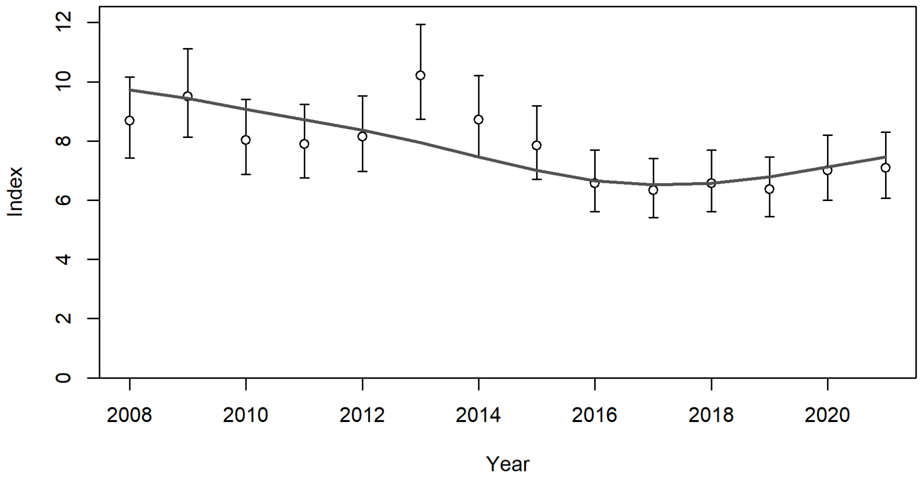


Figure C.31: Scenario 6 model predictions (grey line) to commercial catch rates for crimson snapper after rezoning

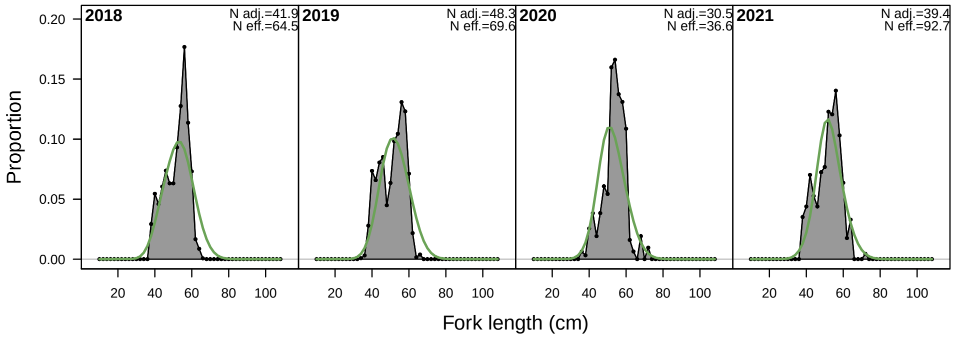


Figure C.32: Scenario 6 length structure for the commercial fleet for crimson snapper

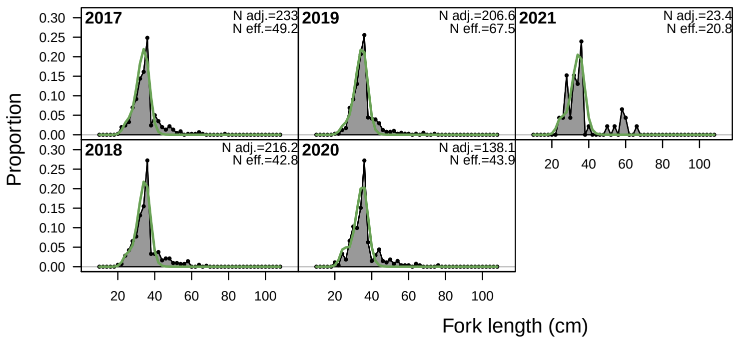


Figure C.33: Scenario 6 length structure for the recreational fleet for discarded crimson snapper

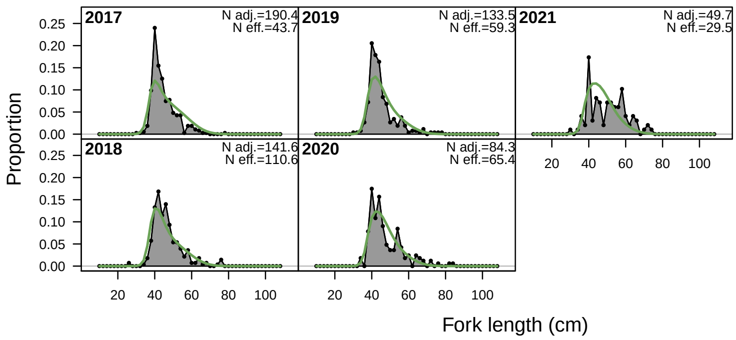


Figure C.34: Scenario 6 length structure for the recreational fleet for retained crimson snapper

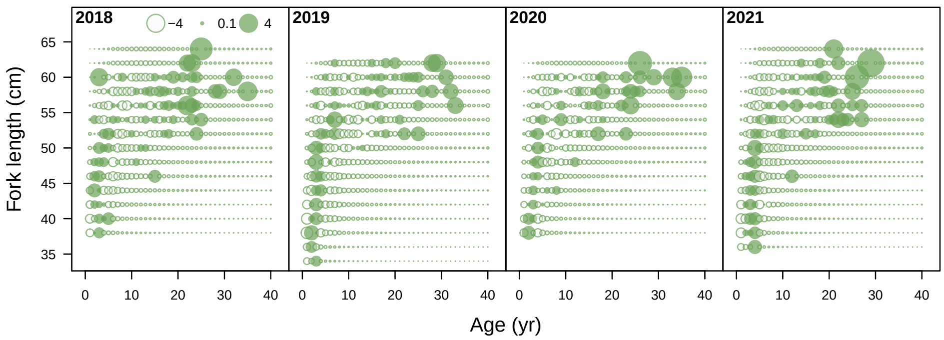


Figure C.35: Scenario 6 Pearson residuals for age-at-length compositions for the commercial fleet for crimson snapper—circle size represents the magnitude of the Pearson residual

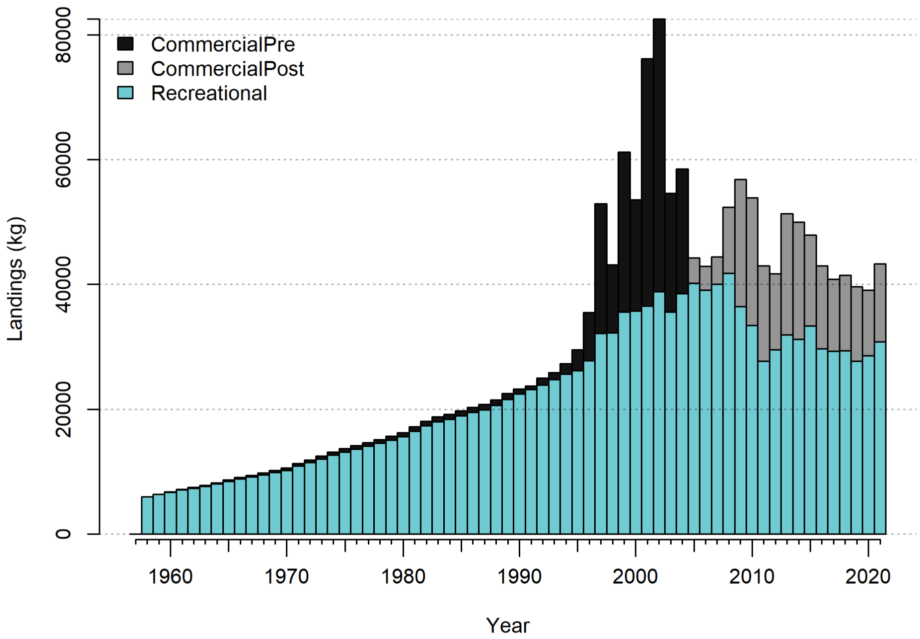


Figure C.36: Scenario 6 modelled harvest

Scenario 7

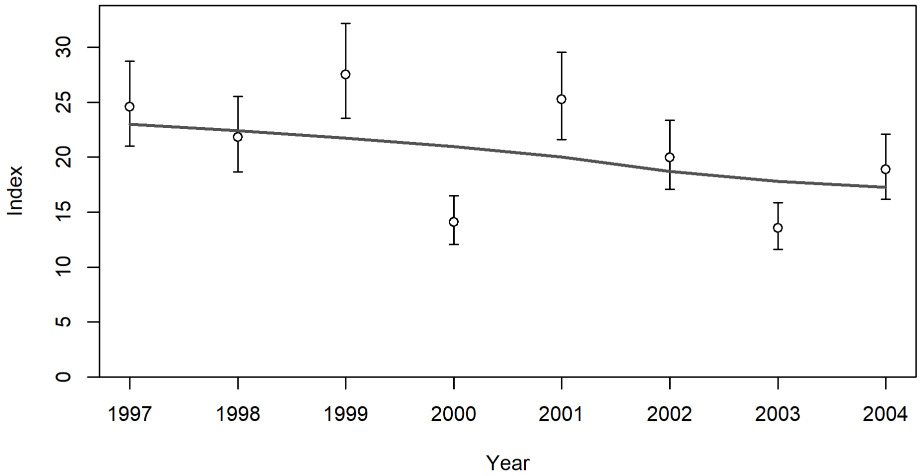


Figure C.37: Scenario 7 model predictions (grey line) to commercial catch rates for crimson snapper prior to rezoning

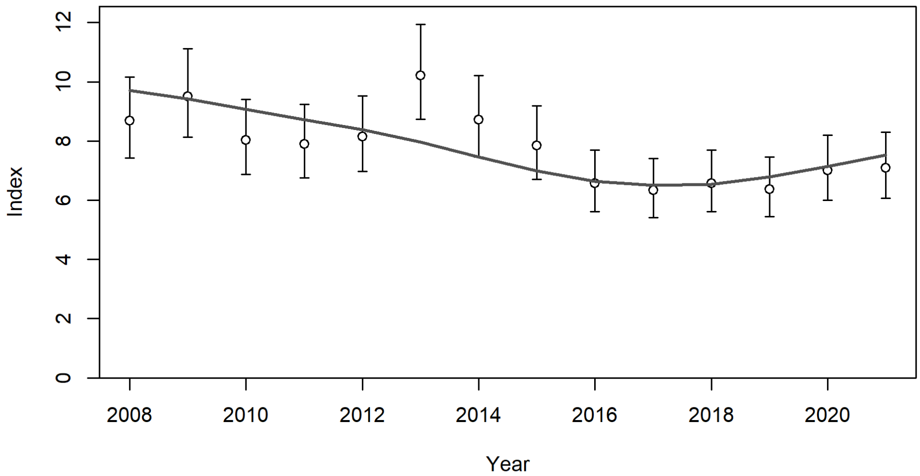


Figure C.38: Scenario 7 model predictions (grey line) to commercial catch rates for crimson snapper after rezoning

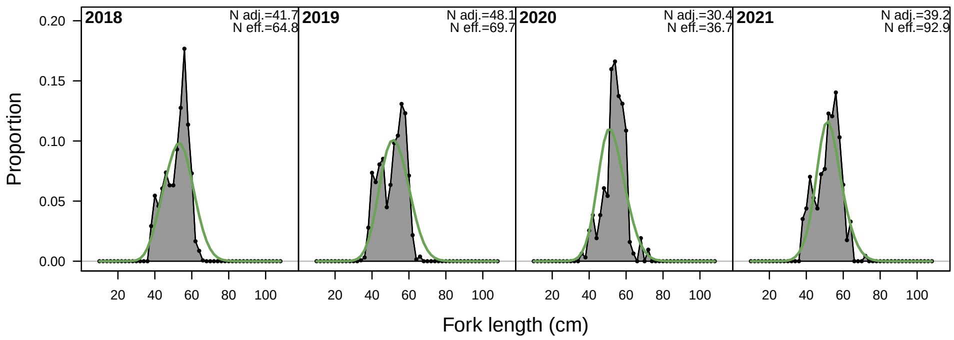


Figure C.39: Scenario 7 length structure for the commercial fleet for crimson snapper

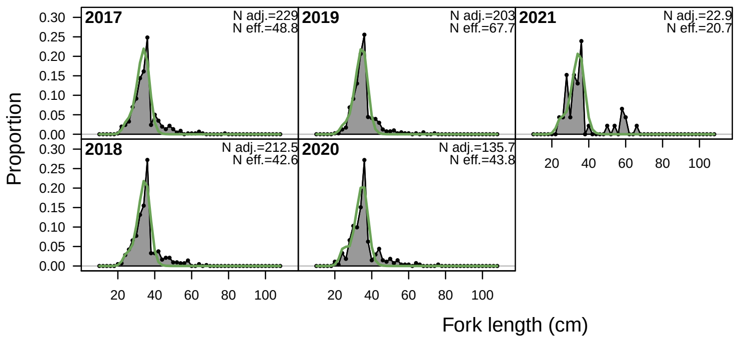


Figure C.40: Scenario 7 length structure for the recreational fleet for discarded crimson snapper

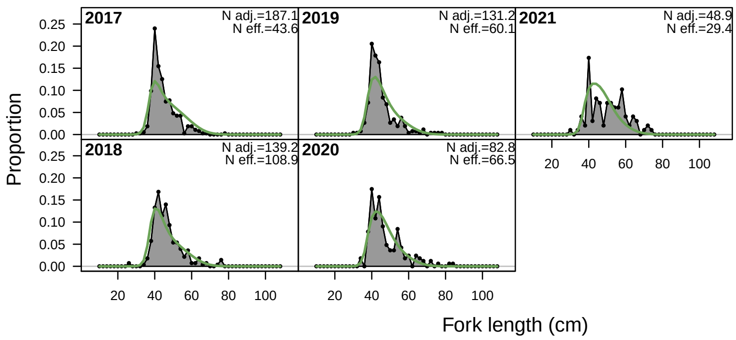


Figure C.41: Scenario 7 length structure for the recreational fleet for retained crimson snapper

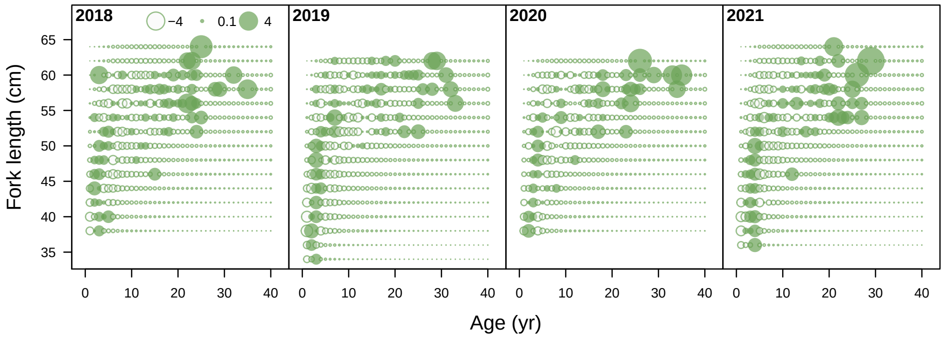


Figure C.42: Scenario 7 Pearson residuals for age-at-length compositions for the commercial fleet for crimson snapper—circle size represents the magnitude of the Pearson residual

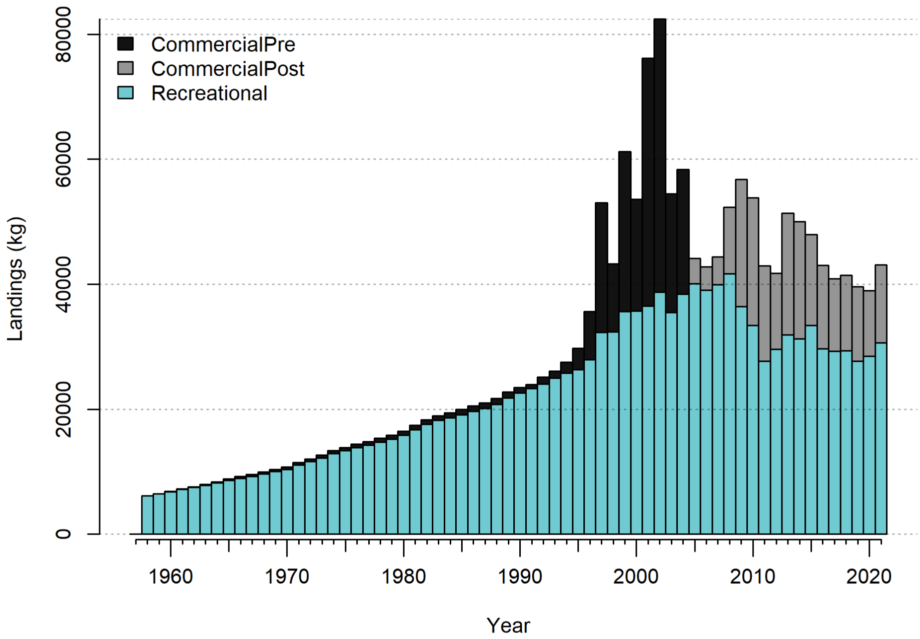


Figure C.43: Scenario 7 modelled harvest

Scenario 8

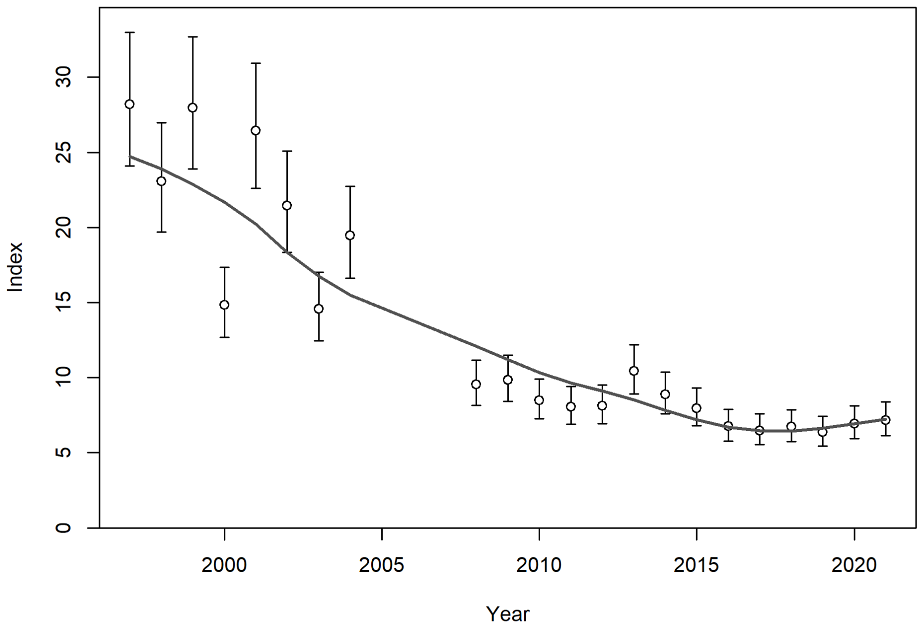


Figure C.44: Scenario 8 model predictions (grey line) to commercial catch rates for crimson snapper

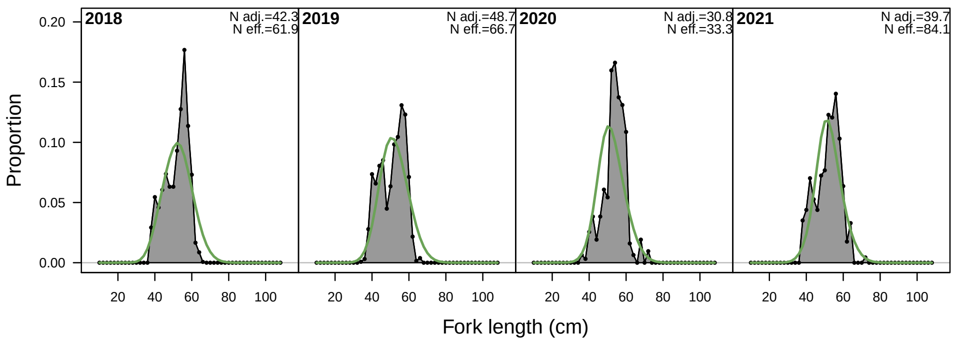


Figure C.45: Scenario 8 length structure for the commercial fleet for crimson snapper

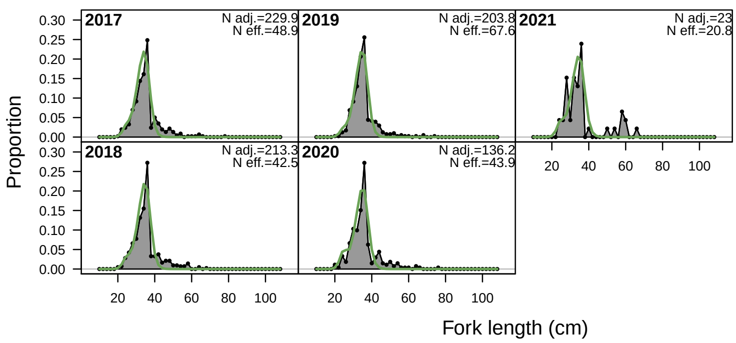


Figure C.46: Scenario 8 length structure for the recreational fleet for discarded crimson snapper

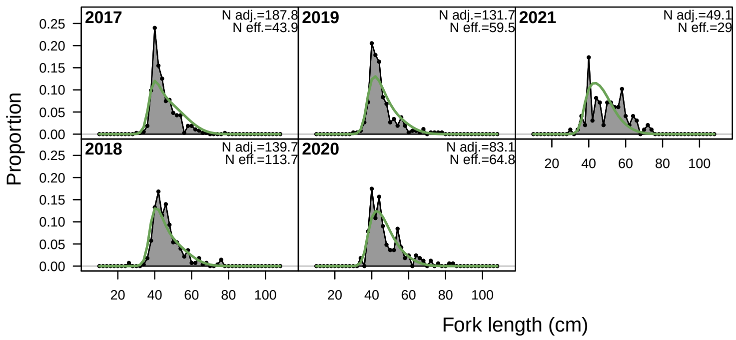


Figure C.47: Scenario 8 length structure for the recreational fleet for retained crimson snapper

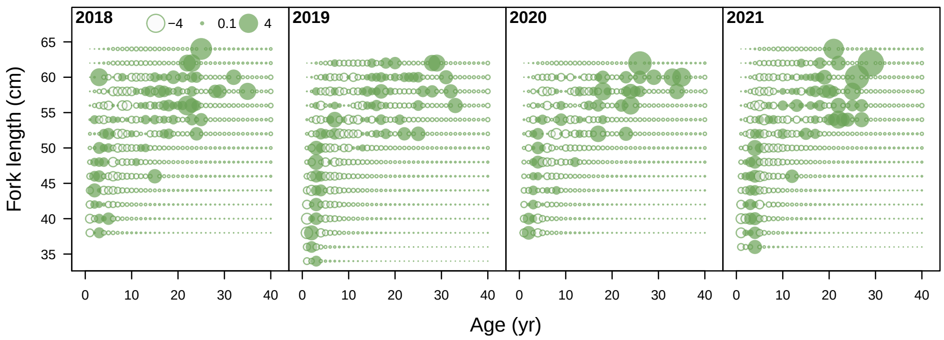


Figure C.48: Scenario 8 Pearson residuals for age-at-length compositions for the commercial fleet for crimson snapper—circle size represents the magnitude of the Pearson residual

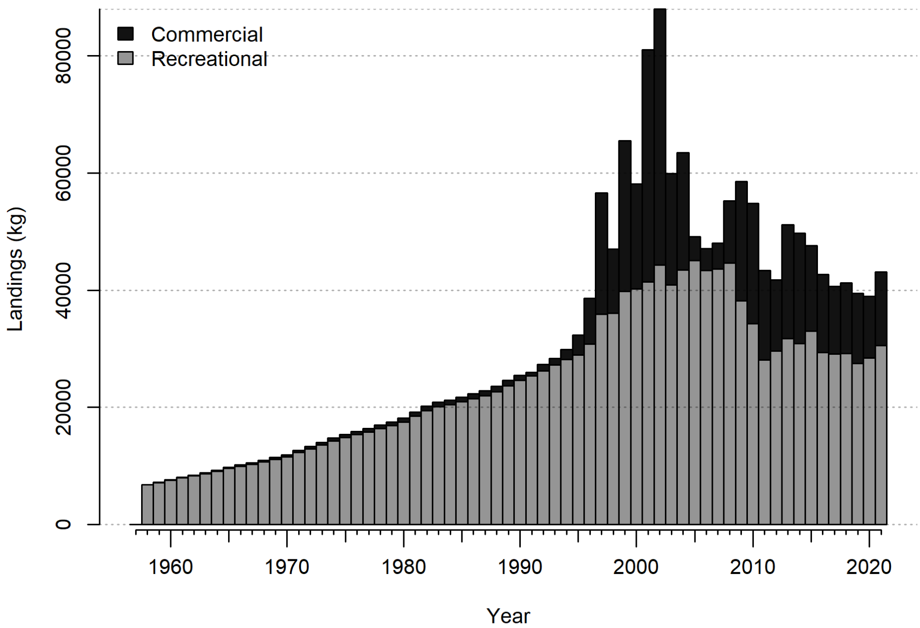


Figure C.49: Scenario 8 modelled harvest

Scenario 9

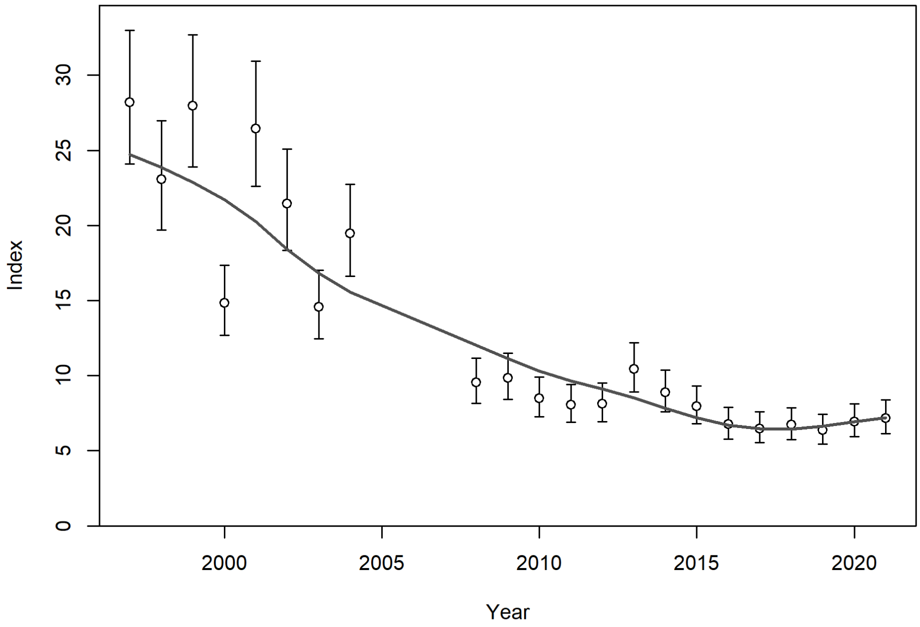


Figure C.50: Scenario 9 model predictions (grey line) to commercial catch rates for crimson snapper

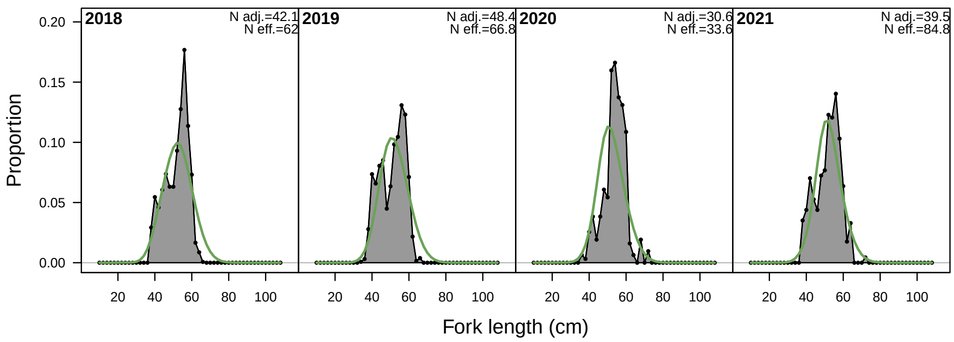


Figure C.51: Scenario 9 length structure for the commercial fleet for crimson snapper

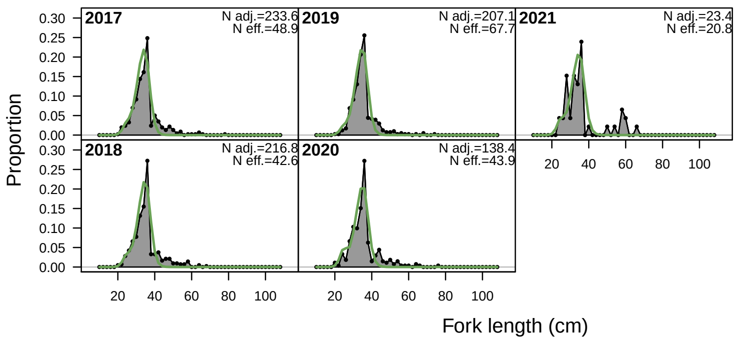


Figure C.52: Scenario 9 length structure for the recreational fleet for discarded crimson snapper

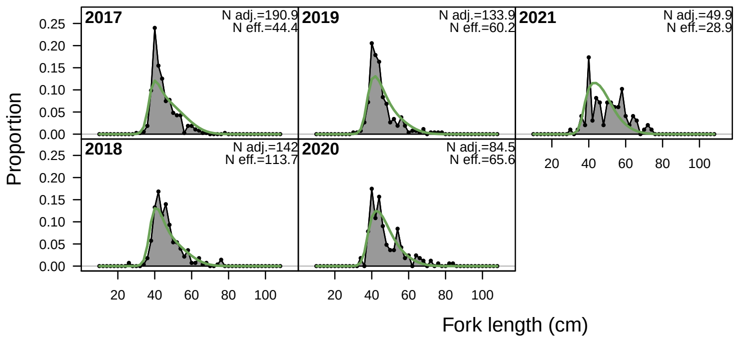


Figure C.53: Scenario 9 length structure for the recreational fleet for retained crimson snapper

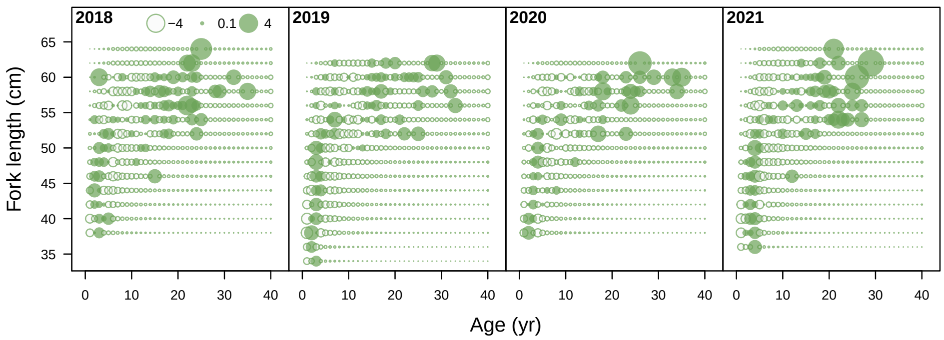


Figure C.54: Scenario 9 Pearson residuals for age-at-length compositions for the commercial fleet for crimson snapper—circle size represents the magnitude of the Pearson residual

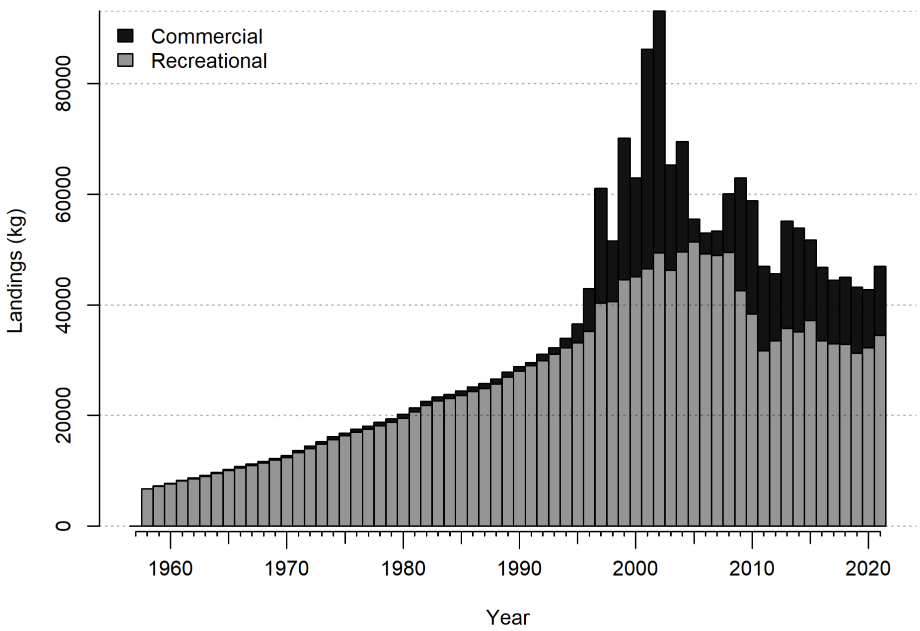


Figure C.55: Scenario 9 modelled harvest

Scenario 10

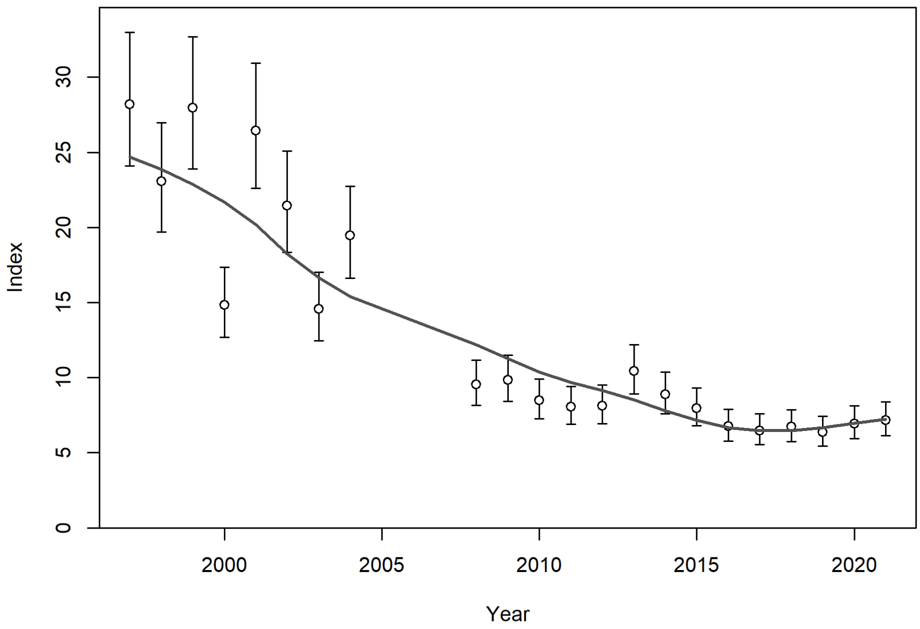


Figure C.56: Scenario 10 model predictions (grey line) to commercial catch rates for crimson snapper

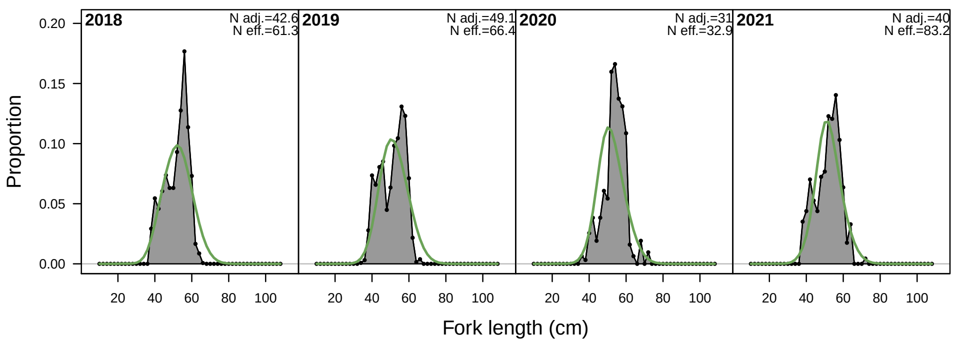


Figure C.57: Scenario 10 length structure for the commercial fleet for crimson snapper

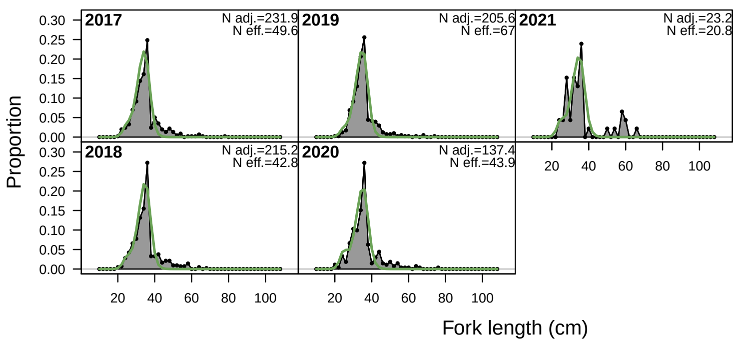


Figure C.58: Scenario 10 length structure for the recreational fleet for discarded crimson snapper

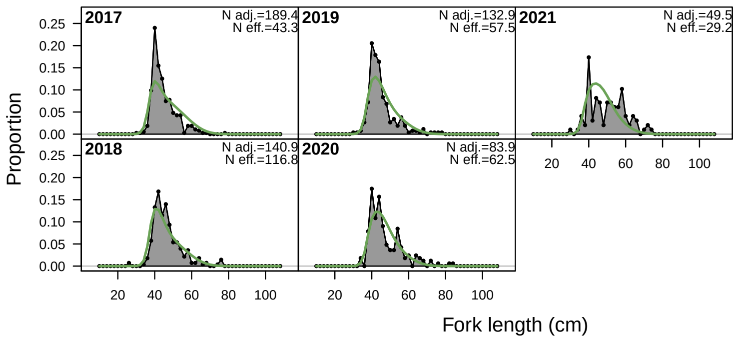


Figure C.59: Scenario 10 length structure for the recreational fleet for retained crimson snapper

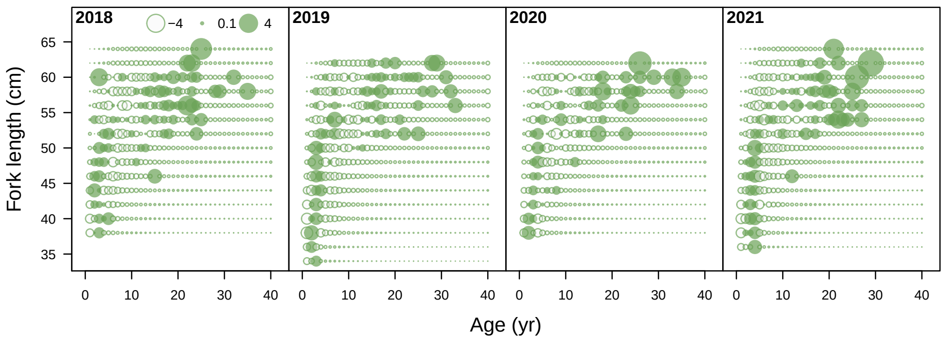


Figure C.60: Scenario 10 Pearson residuals for age-at-length compositions for the commercial fleet for crimson snapper—circle size represents the magnitude of the Pearson residual

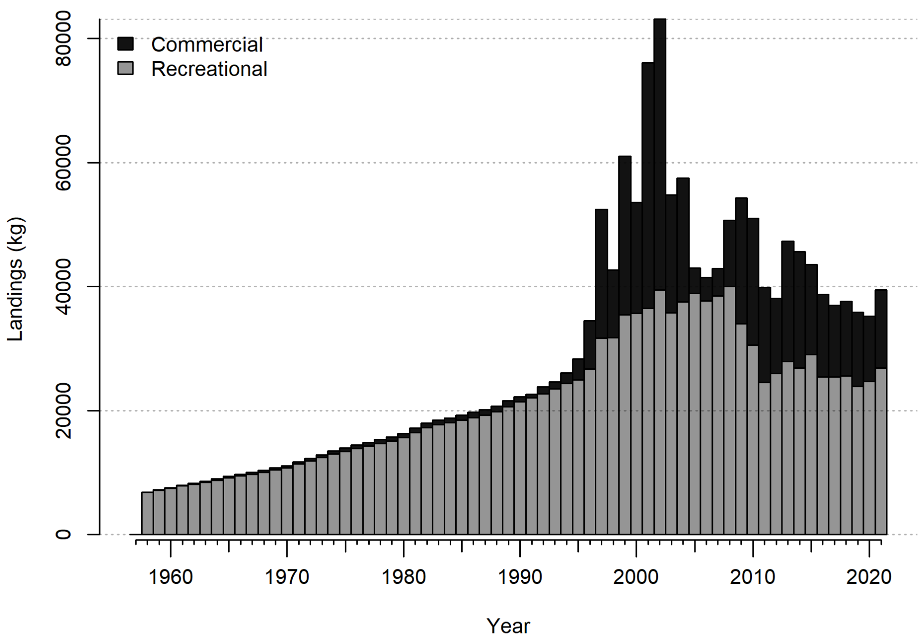


Figure C.61: Scenario 10 modelled harvest

Scenario 11

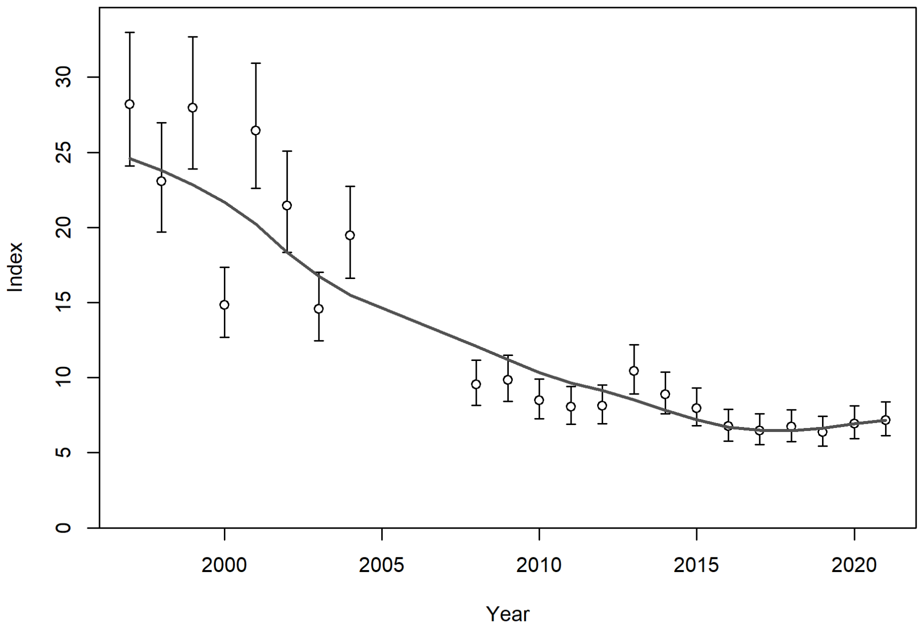


Figure C.62: Scenario 11 model predictions (grey line) to commercial catch rates for crimson snapper

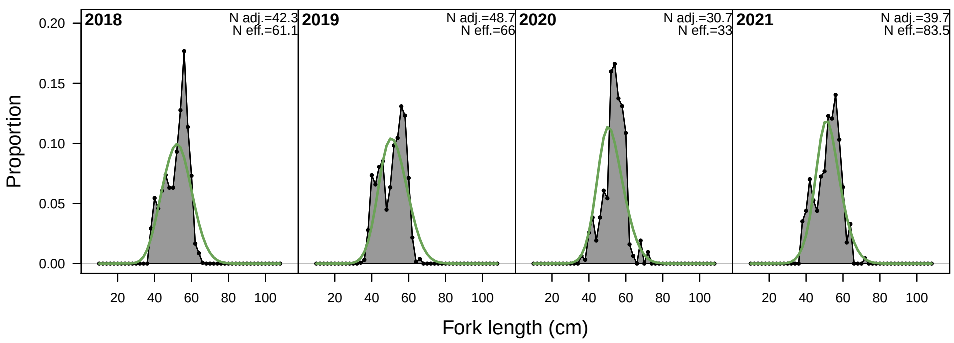


Figure C.63: Scenario 11 length structure for the commercial fleet for crimson snapper

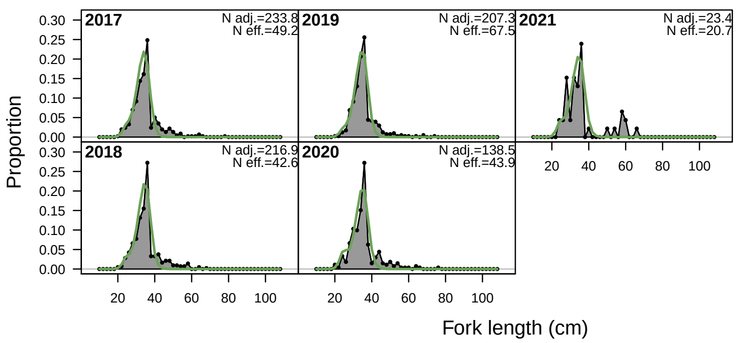


Figure C.64: Scenario 11 length structure for the recreational fleet for discarded crimson snapper

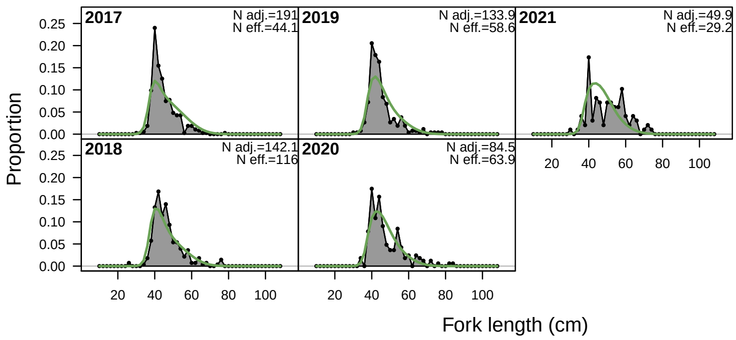


Figure C.65: Scenario 11 length structure for the recreational fleet for retained crimson snapper

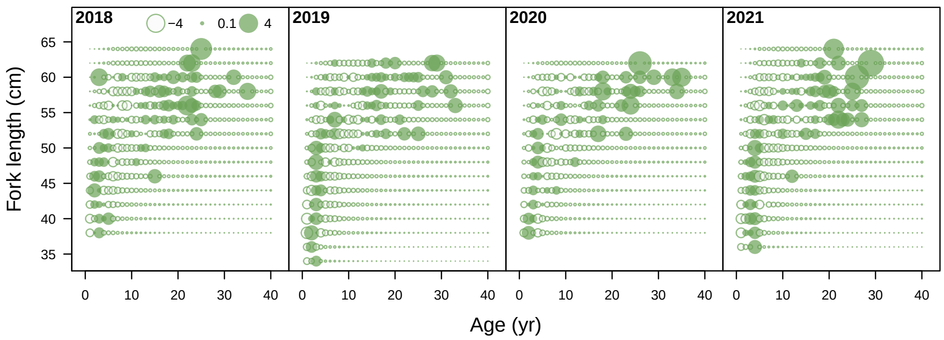


Figure C.66: Scenario 11 Pearson residuals for age-at-length compositions for the commercial fleet for crimson snapper—circle size represents the magnitude of the Pearson residual

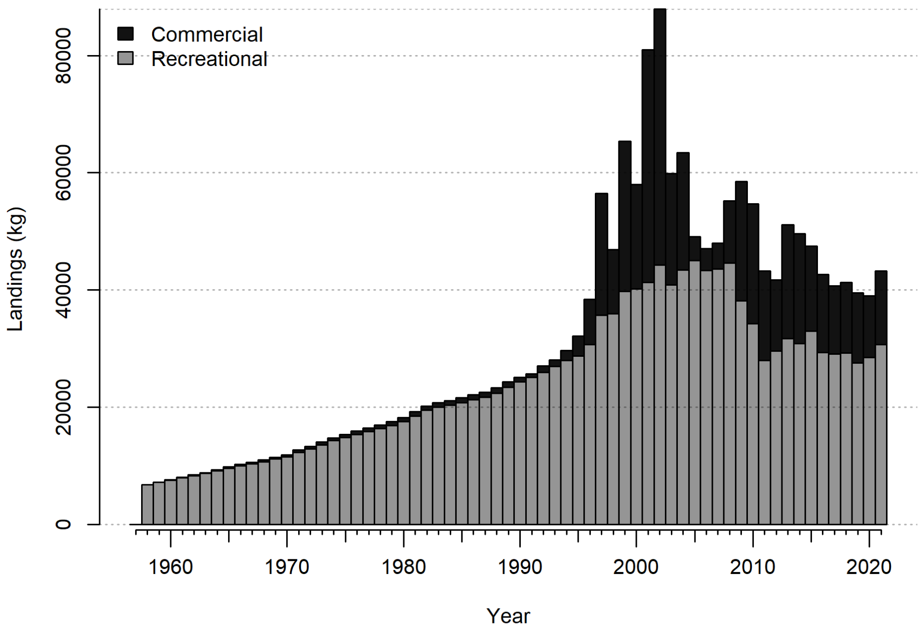


Figure C.67: Scenario 11 modelled harvest

Scenario 12

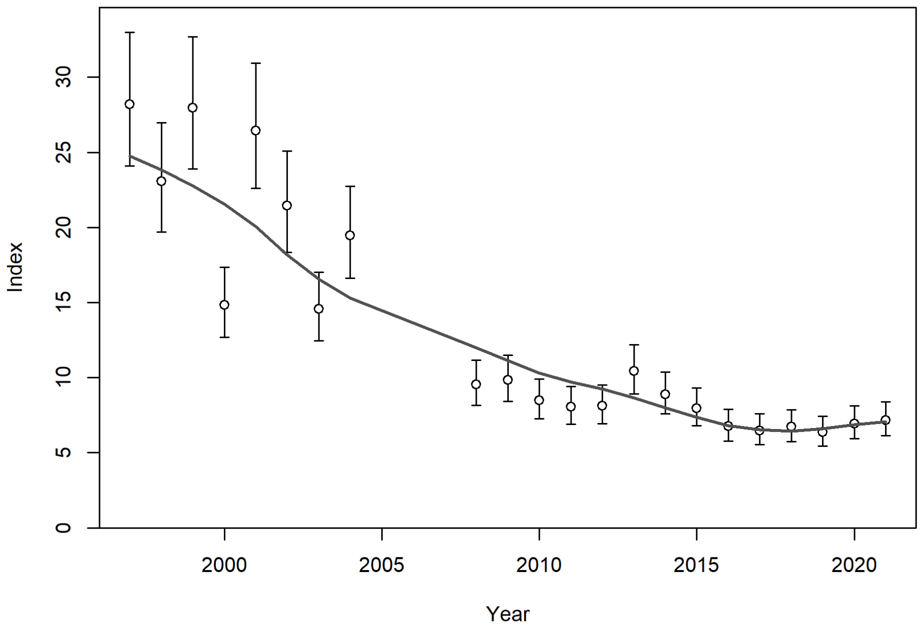


Figure C.68: Scenario 12 model predictions (grey line) to commercial catch rates for crimson snapper

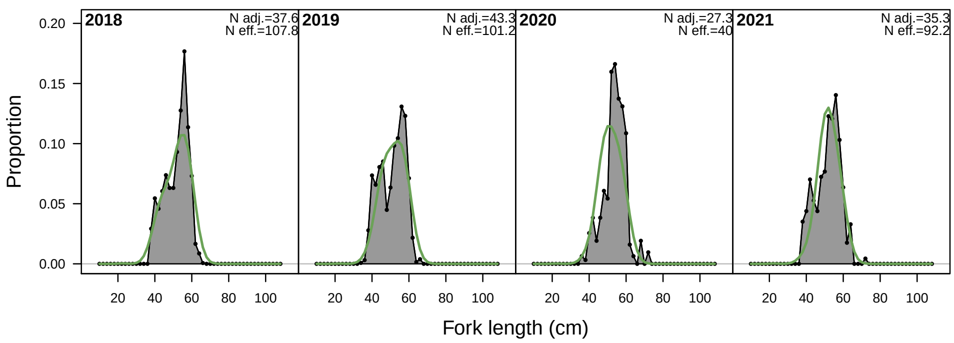


Figure C.69: Scenario 12 length structure for the commercial fleet for crimson snapper

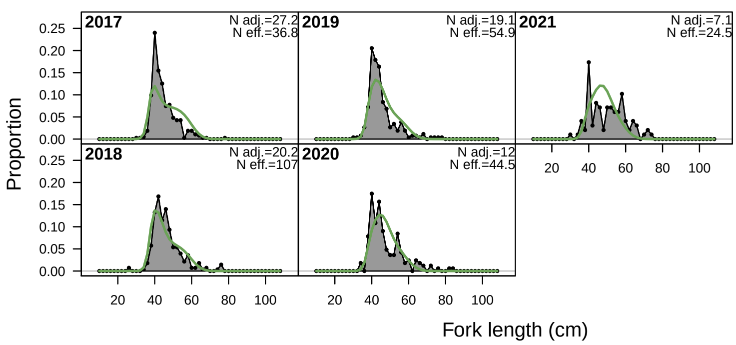


Figure C.70: Scenario 12 length structure for the recreational fleet for retained crimson snapper

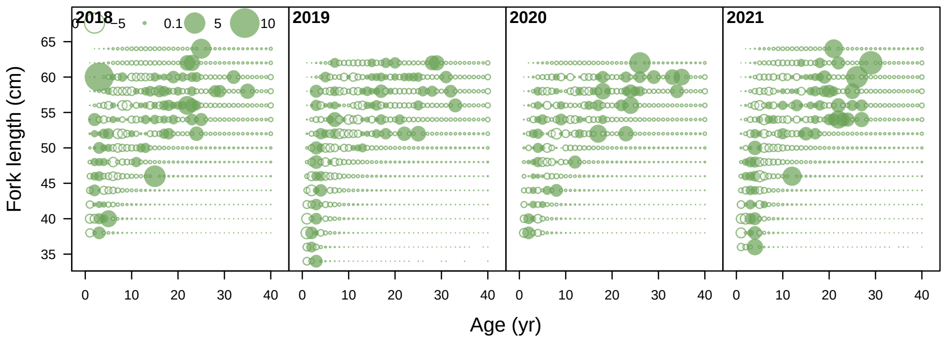


Figure C.71: Scenario 12 Pearson residuals for age-at-length compositions for the commercial fleet for crimson snapper—circle size represents the magnitude of the Pearson residual

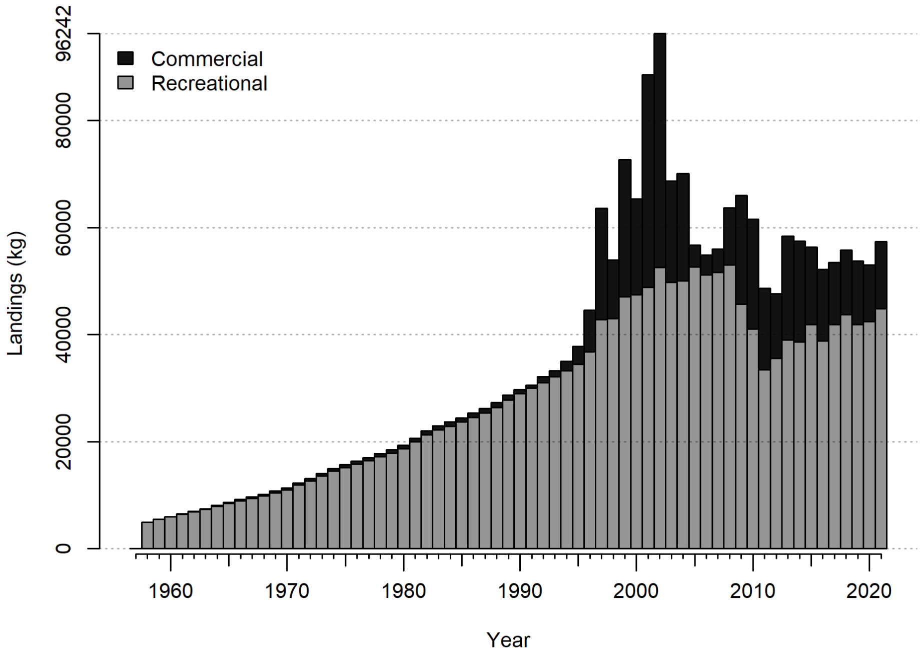


Figure C.72: Scenario 12 modelled harvest

Scenario 13

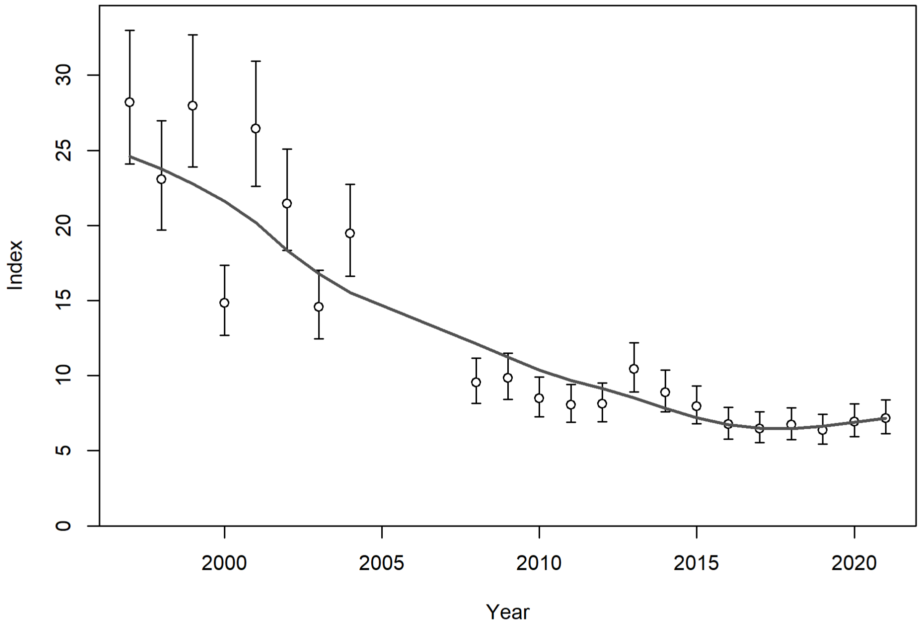


Figure C.73: Scenario 13 model predictions (grey line) to commercial catch rates for crimson snapper

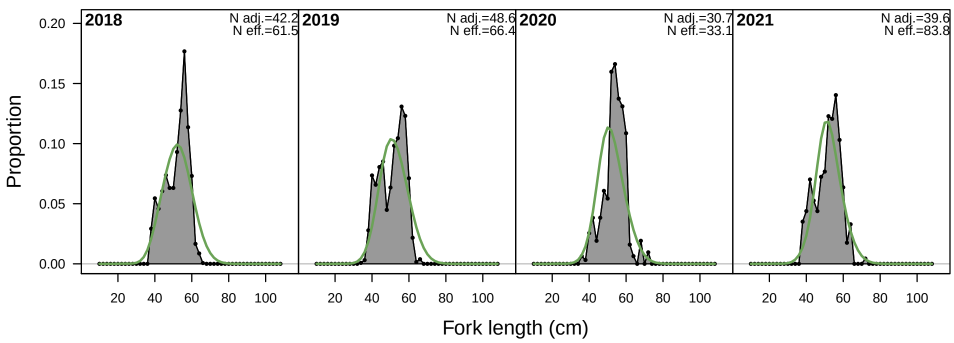


Figure C.74: Scenario 13 length structure for the commercial fleet for crimson snapper

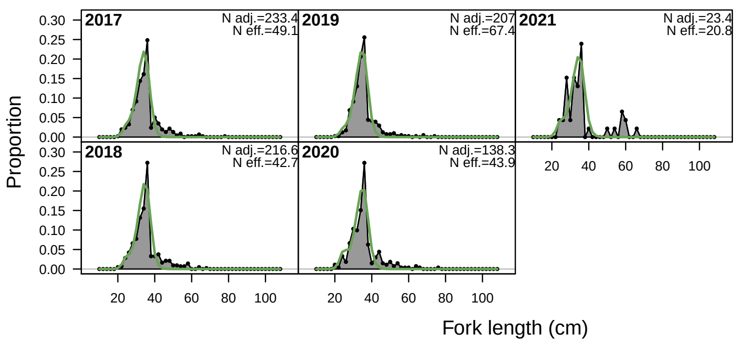


Figure C.75: Scenario 13 length structure for the recreational fleet for discarded crimson snapper

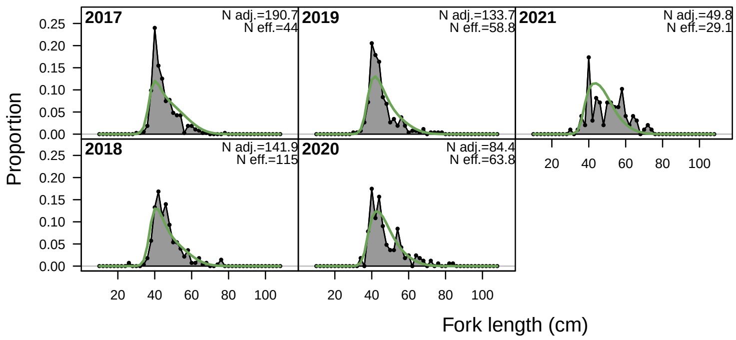


Figure C.76: Scenario 13 length structure for the recreational fleet for retained crimson snapper

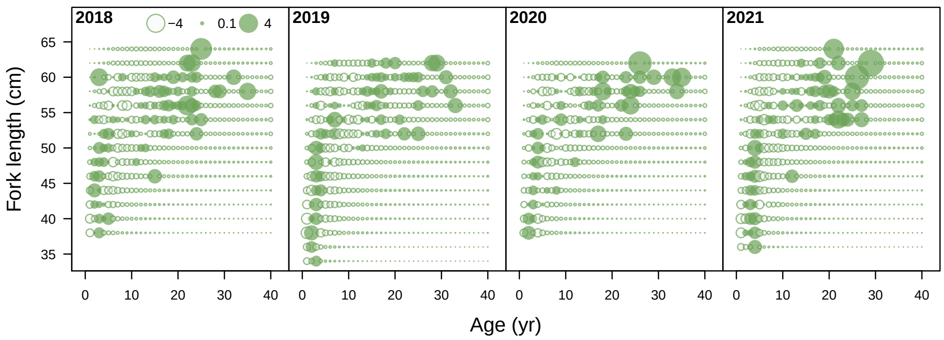


Figure C.77: Scenario 13 Pearson residuals for age-at-length compositions for the commercial fleet for crimson snapper—circle size represents the magnitude of the Pearson residual

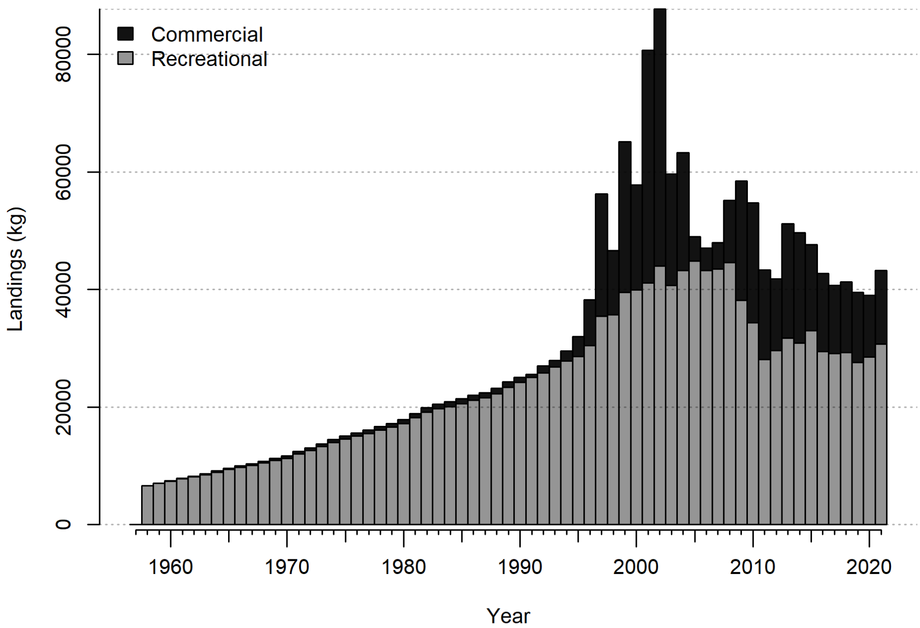


Figure C.78: Scenario 13 modelled harvest

Scenario 14

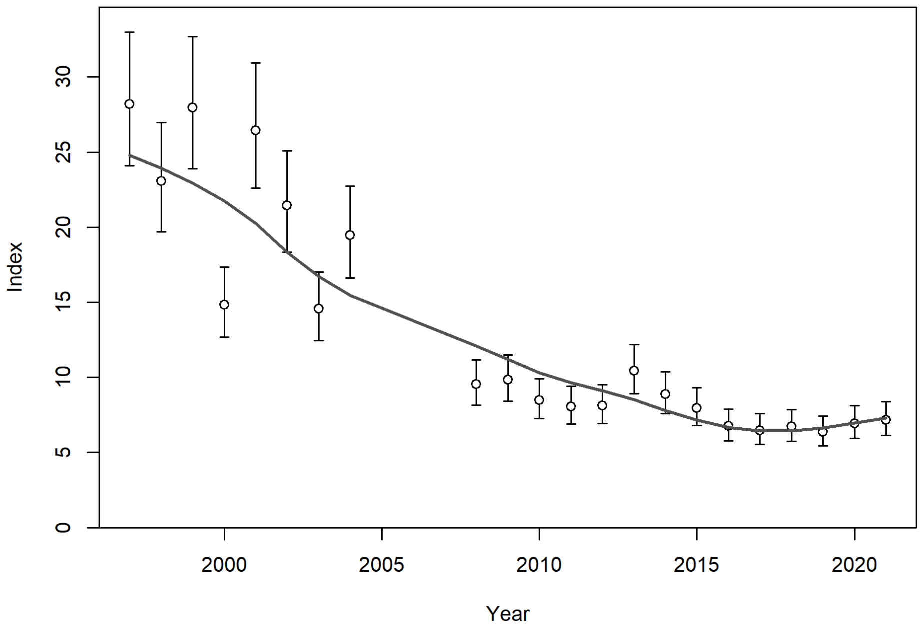


Figure C.79: Scenario 14 model predictions (grey line) to commercial catch rates for crimson snapper

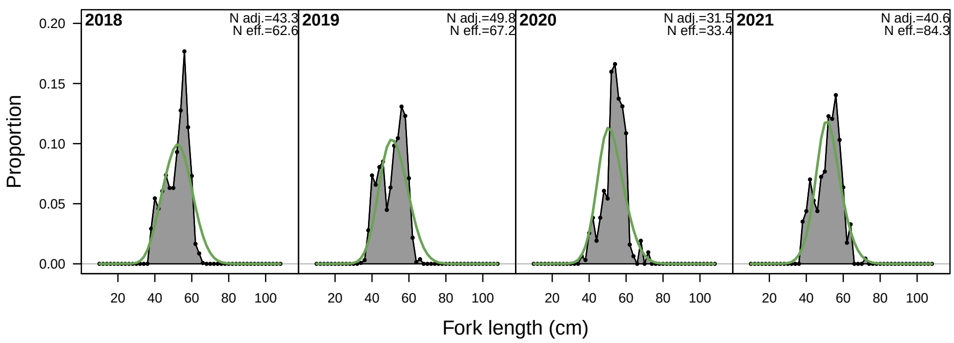


Figure C.80: Scenario 14 length structure for the commercial fleet for crimson snapper

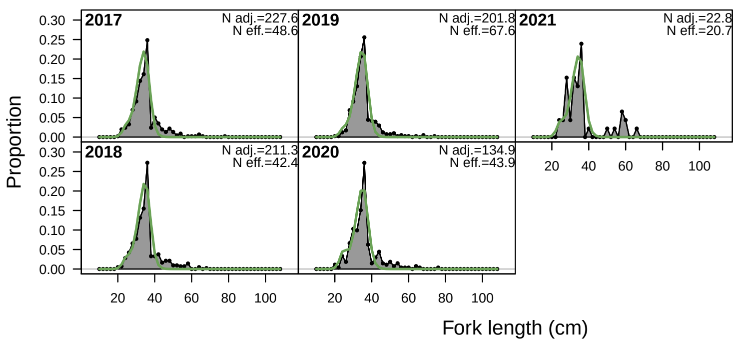


Figure C.81: Scenario 14 length structure for the recreational fleet for discarded crimson snapper

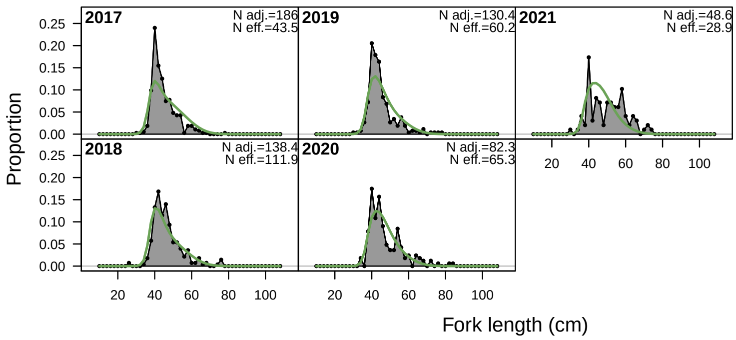


Figure C.82: Scenario 14 length structure for the recreational fleet for retained crimson snapper

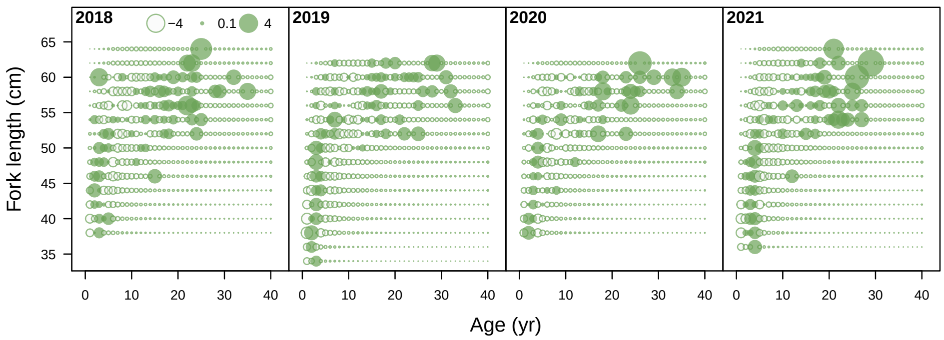


Figure C.83: Scenario 14 Pearson residuals for age-at-length compositions for the commercial fleet for crimson snapper—circle size represents the magnitude of the Pearson residual

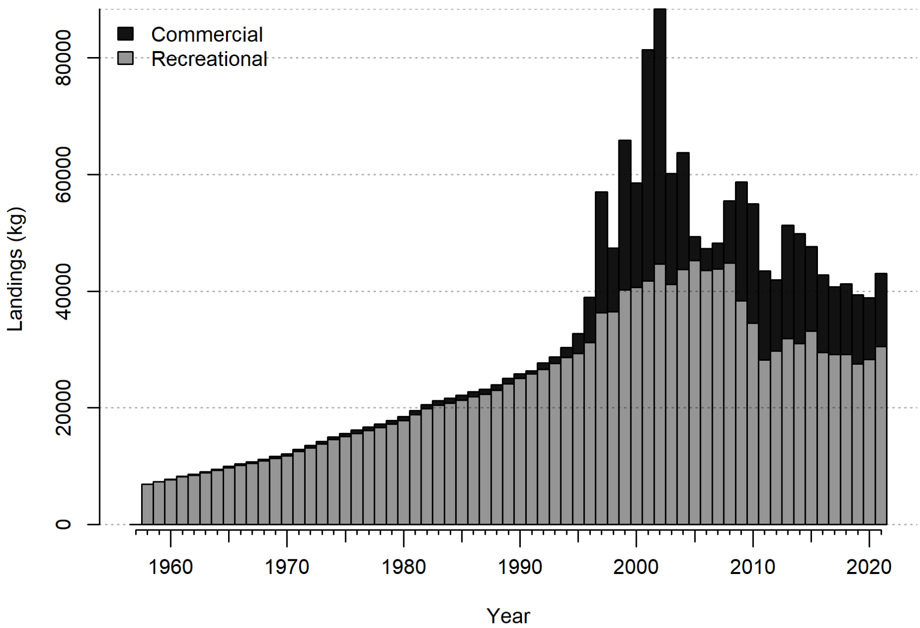


Figure C.84: Scenario 14 modelled harvest

Appendix D Sensitivity tests: other outputs

Scenario 2

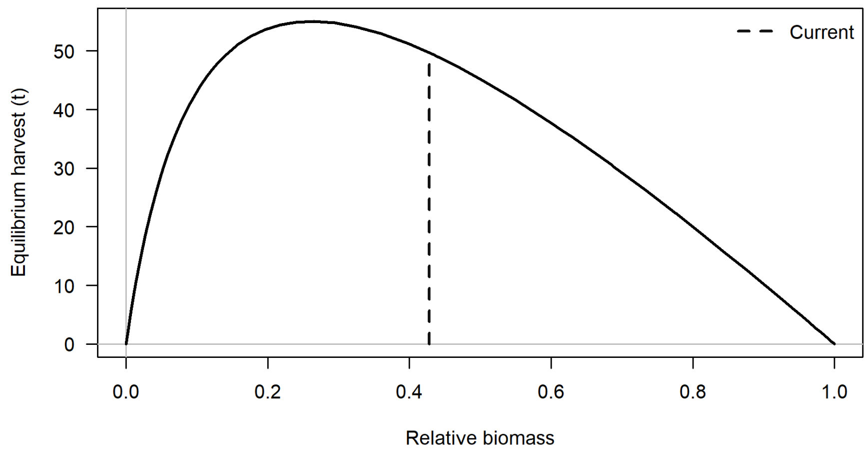


Figure D.1: Scenario 2 equilibrium harvest curve for crimson snapper

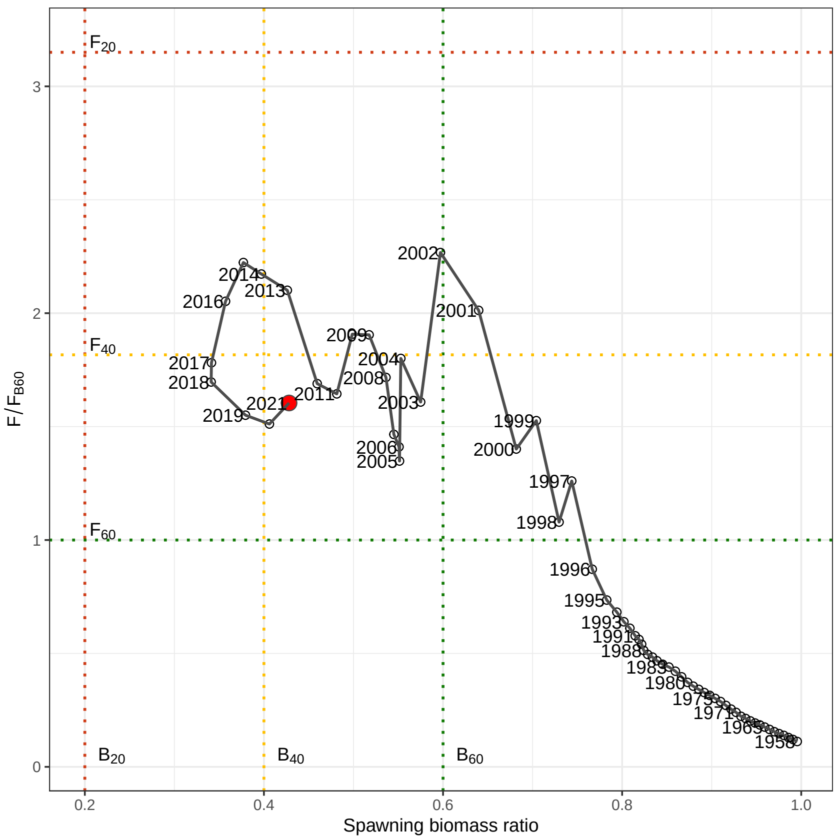


Figure D.2: Scenario 2 phase plot for crimson snapper

Scenario 3

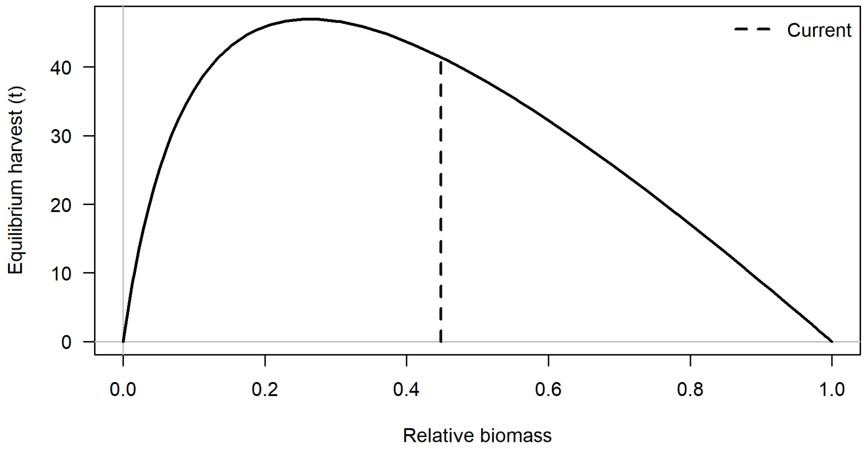


Figure D.3: Scenario 3 equilibrium harvest curve for crimson snapper

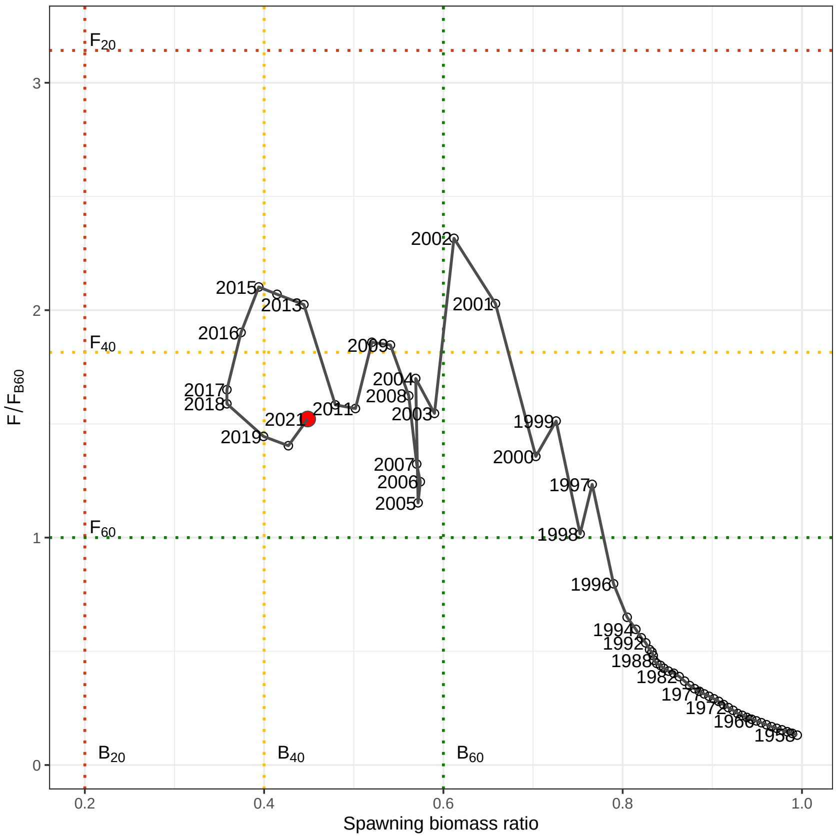


Figure D.4: Scenario 3 phase plot for crimson snapper

Scenario 4

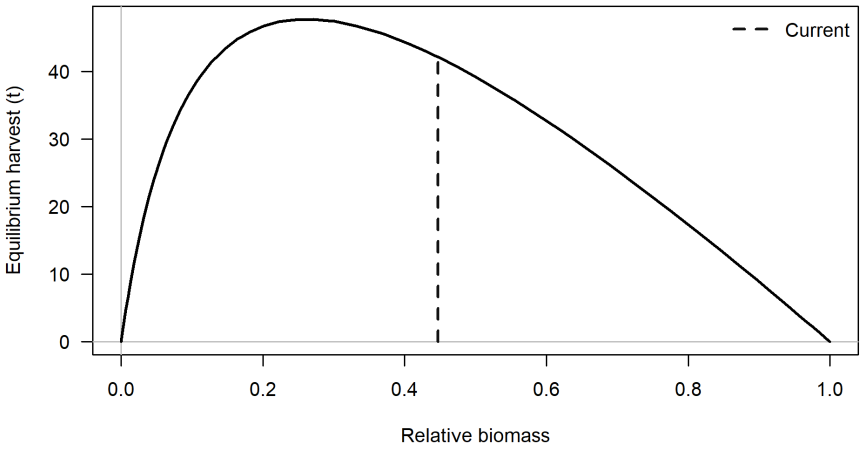


Figure D.5: Scenario 4 equilibrium harvest curve for crimson snapper

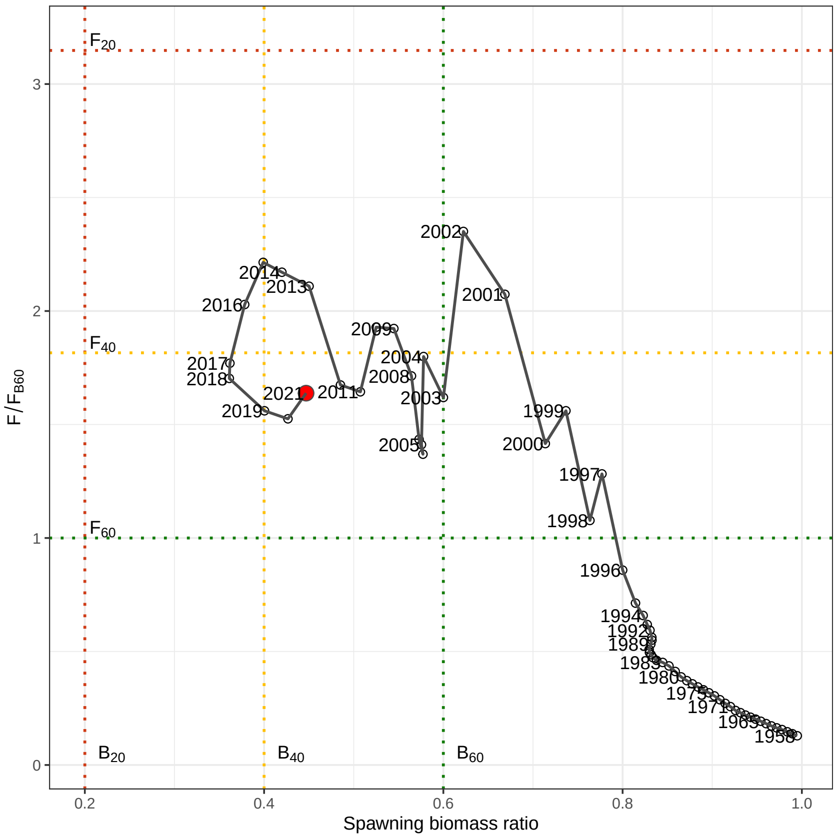


Figure D.6: Scenario 4 phase plot for crimson snapper

Scenario 5

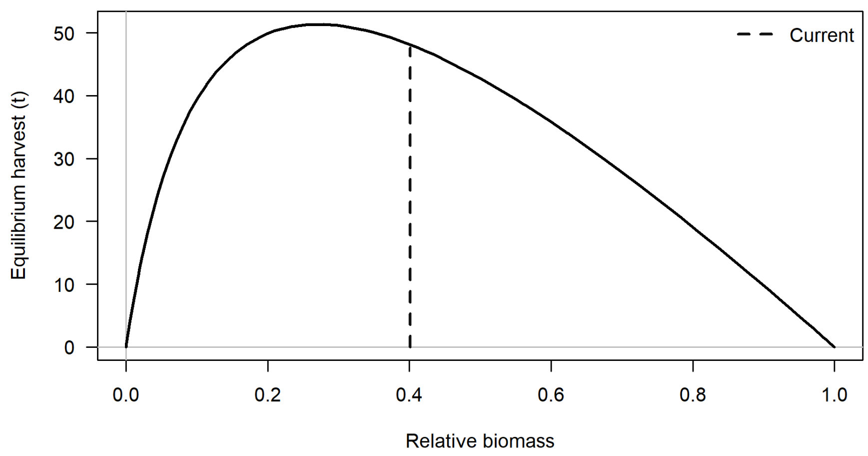


Figure D.7: Scenario 5 equilibrium harvest curve for crimson snapper

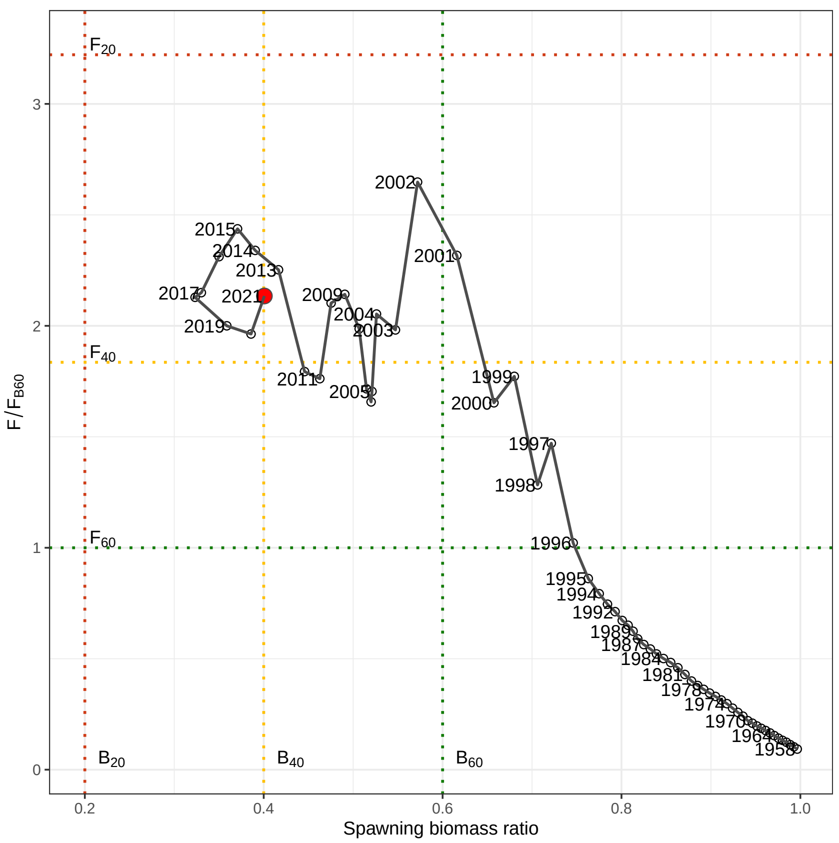


Figure D.8: Scenario 5 phase plot for crimson snapper

Scenario 6

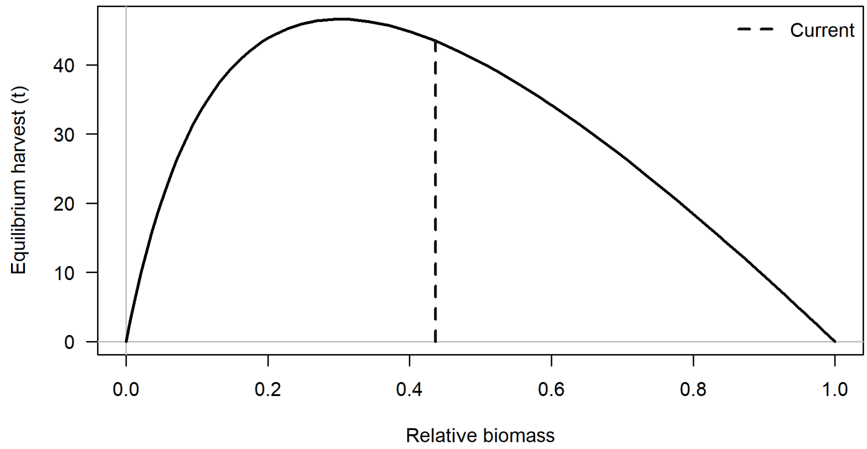


Figure D.9: Scenario 6 equilibrium harvest curve for crimson snapper

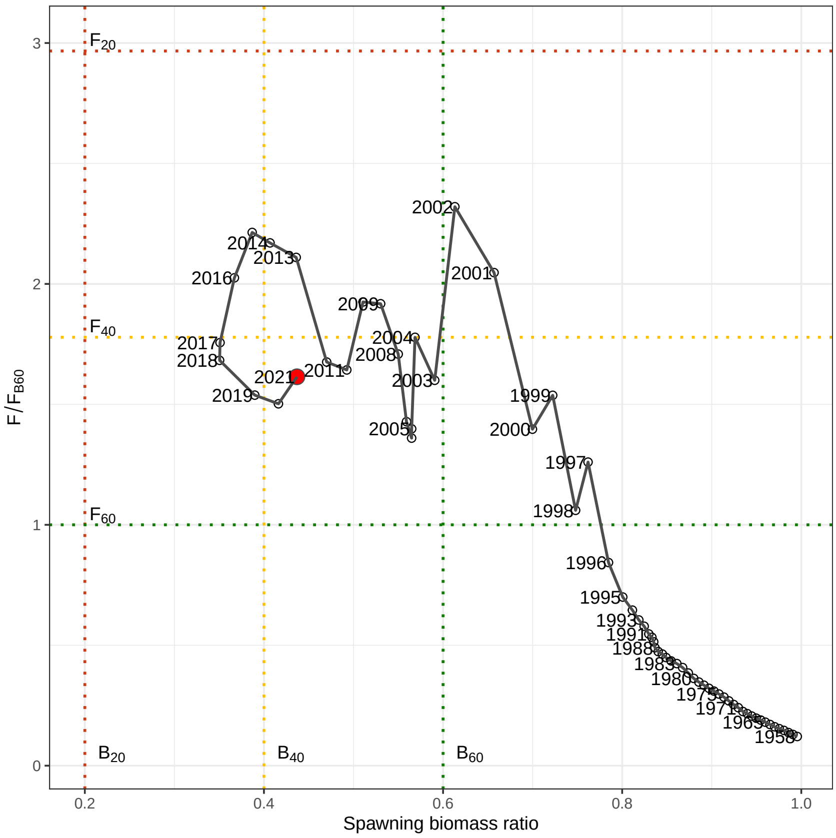


Figure D.10: Scenario 6 phase plot for crimson snapper

Scenario 7

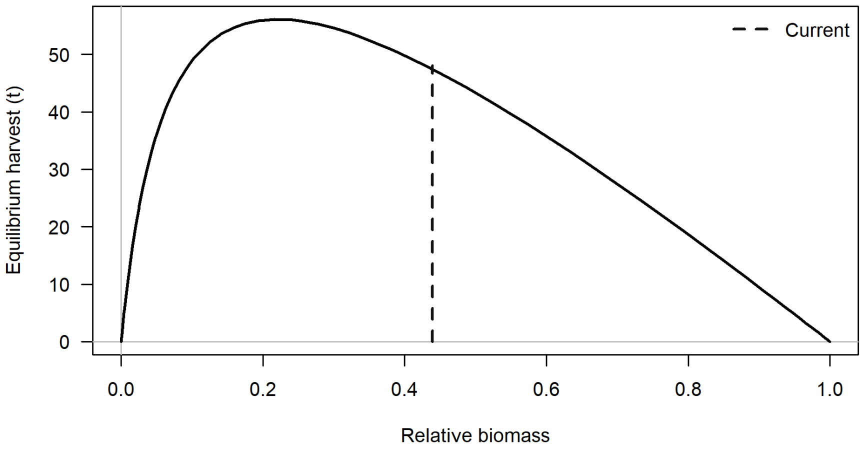


Figure D.11: Scenario 7 equilibrium harvest curve for crimson snapper

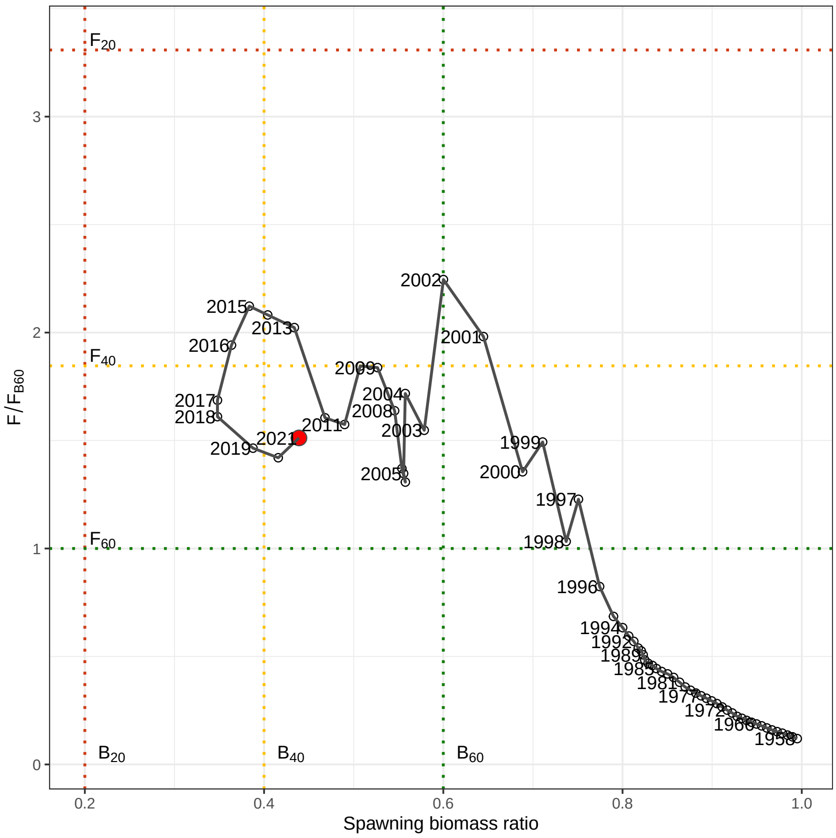


Figure D.12: Scenario 7 phase plot for crimson snapper

Scenario 8

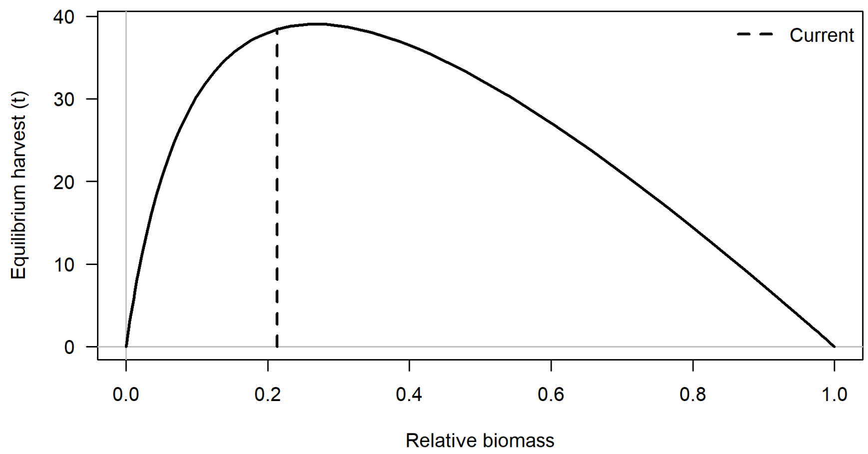


Figure D.13: Scenario 8 equilibrium harvest curve for crimson snapper

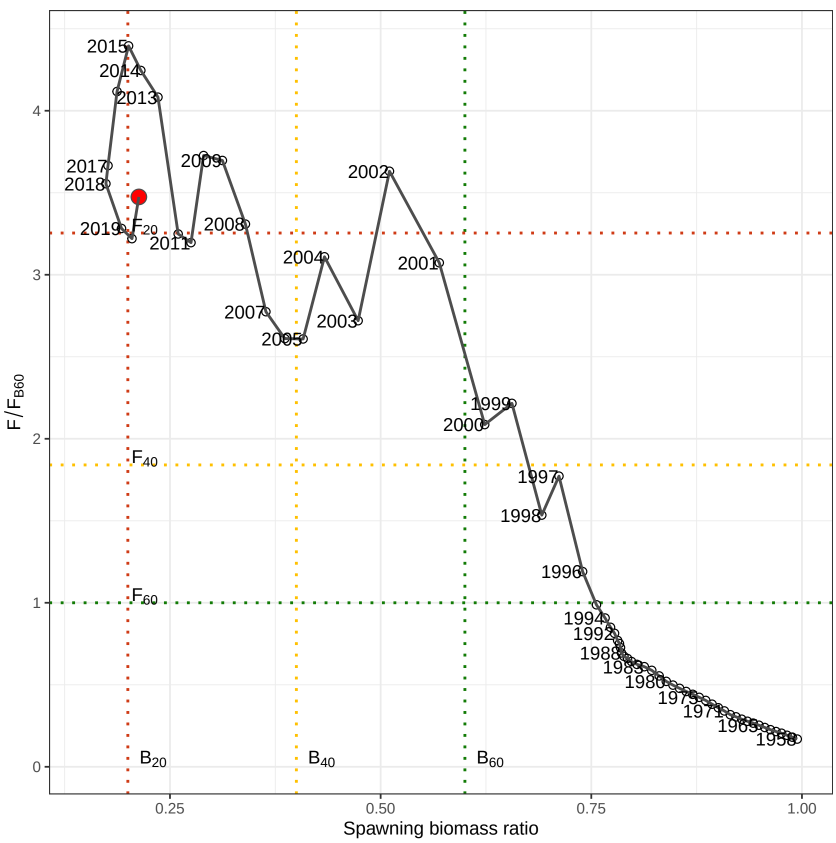


Figure D.14: Scenario 8 phase plot for crimson snapper

Scenario 9

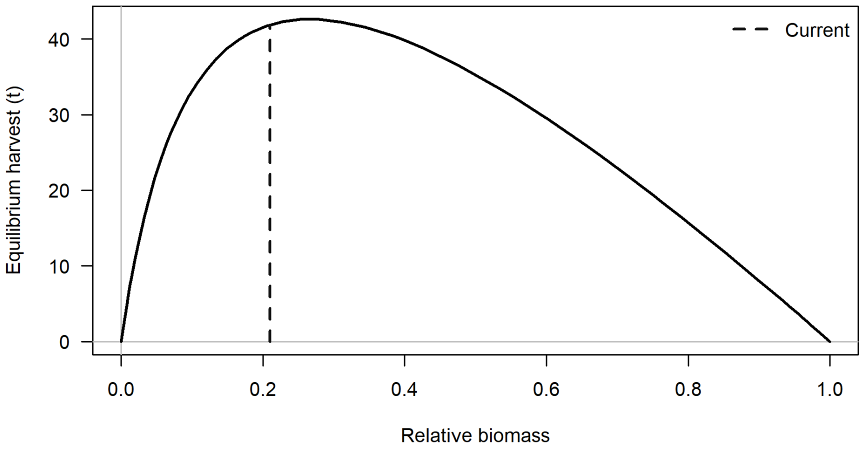


Figure D.15: Scenario 9 equilibrium harvest curve for crimson snapper

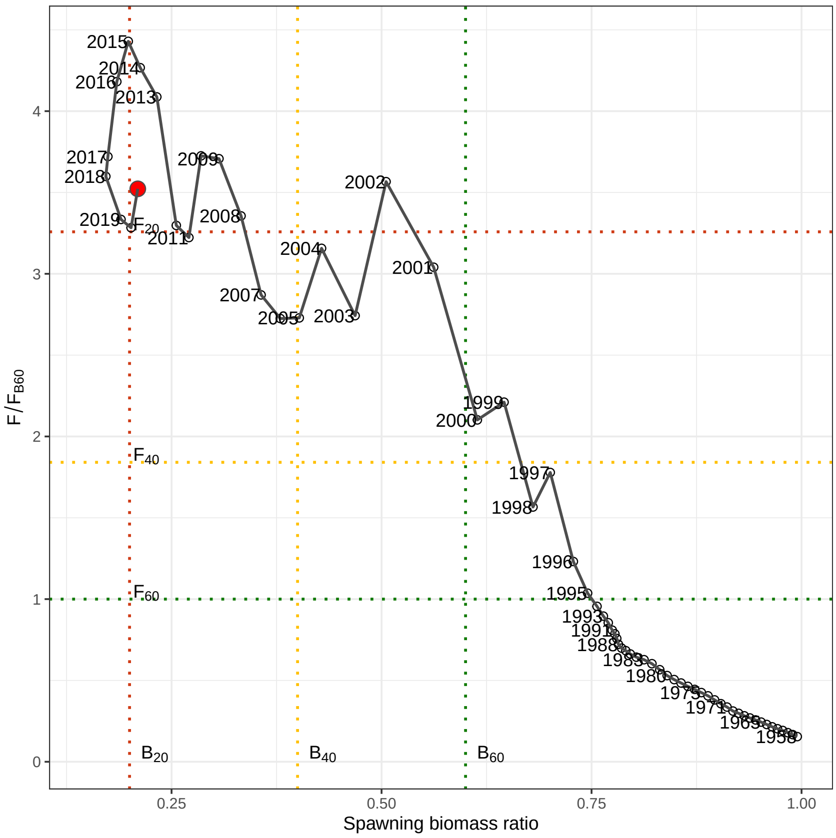


Figure D.16: Scenario 9 phase plot for crimson snapper

Scenario 10

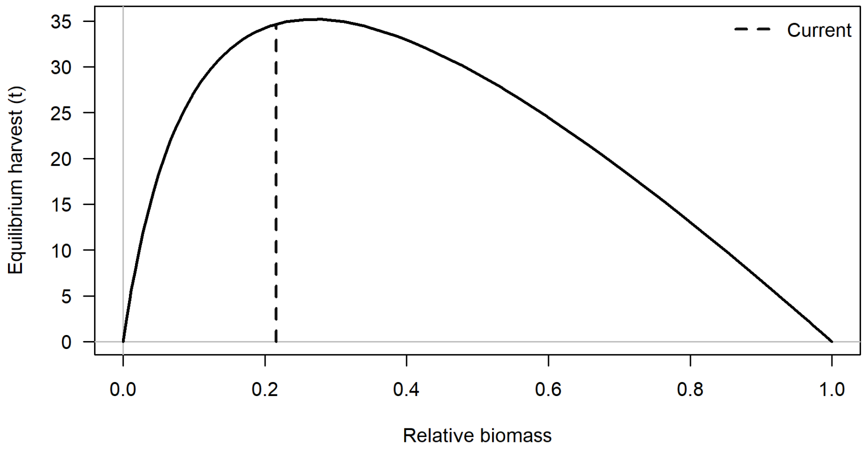


Figure D.17: Scenario 10 equilibrium harvest curve for crimson snapper

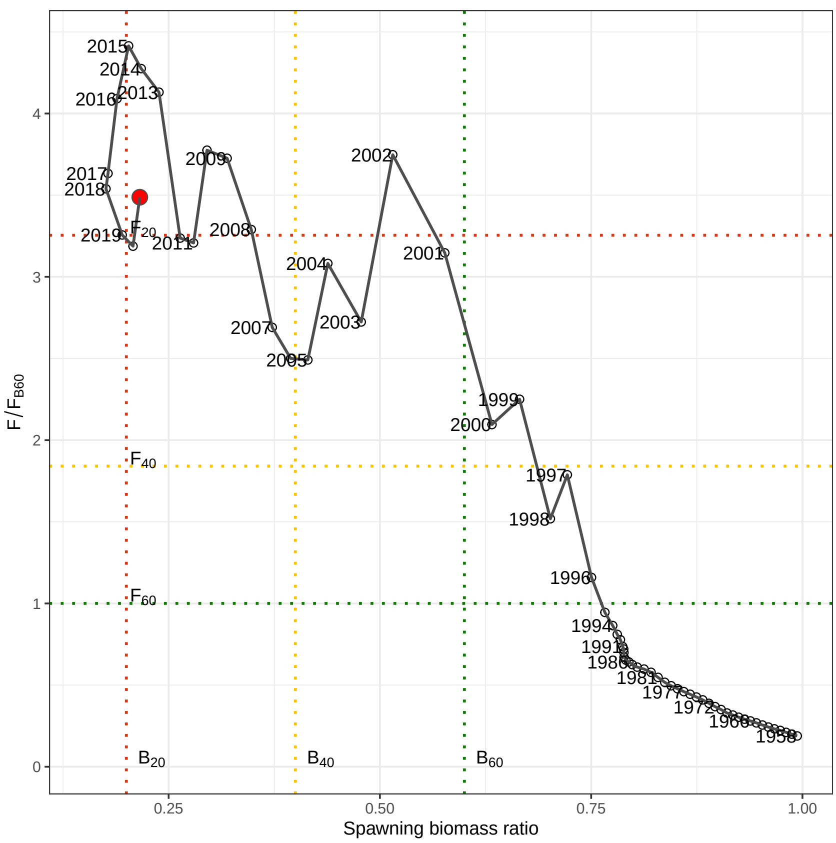


Figure D.18: Scenario 10 phase plot for crimson snapper

Scenario 11

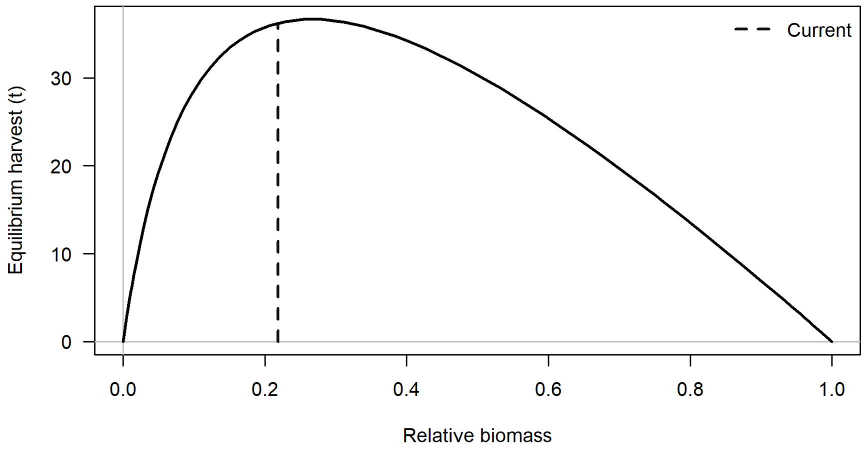


Figure D.19: Scenario 11 equilibrium harvest curve for crimson snapper

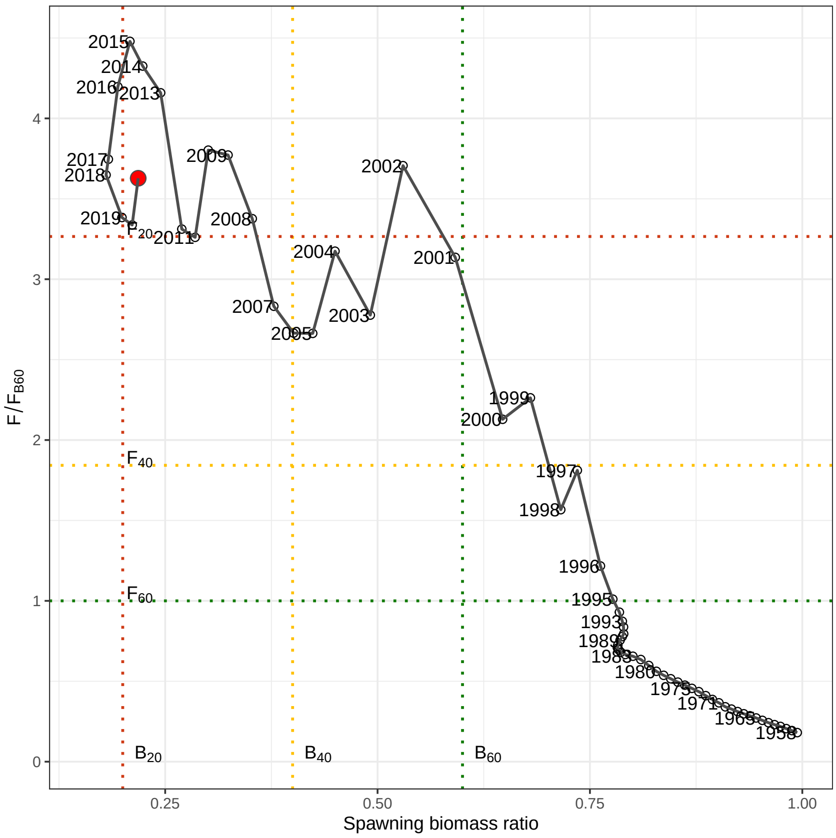


Figure D.20: Scenario 11 phase plot for crimson snapper

Scenario 12

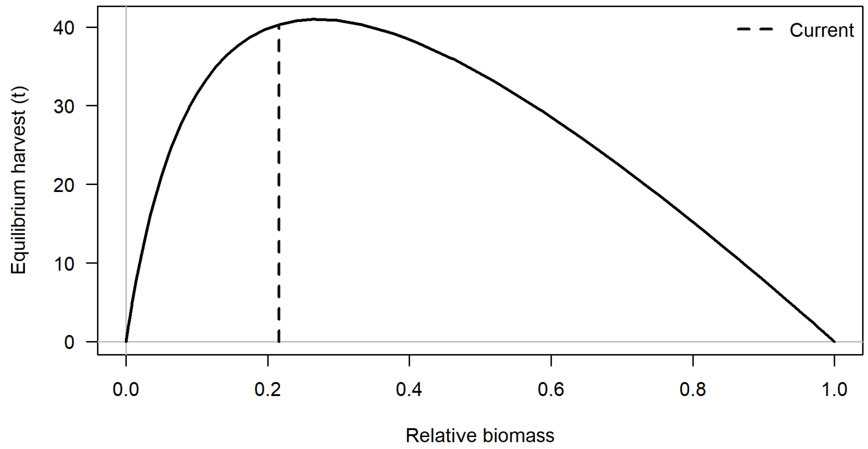


Figure D.21: Scenario 12 equilibrium harvest curve for crimson snapper

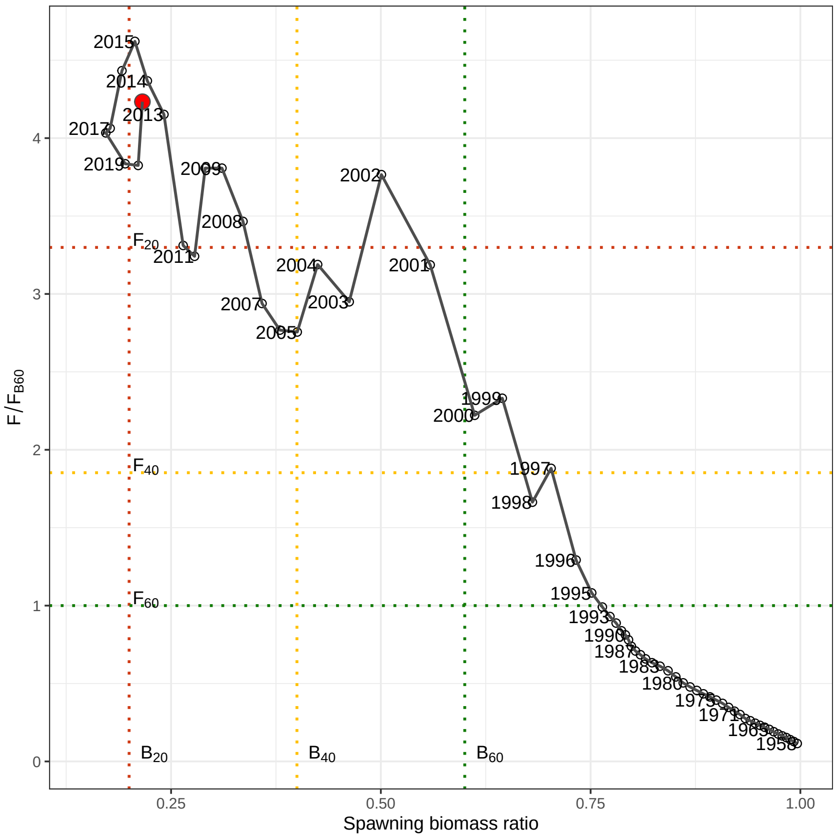


Figure D.22: Scenario 12 phase plot for crimson snapper

Scenario 13

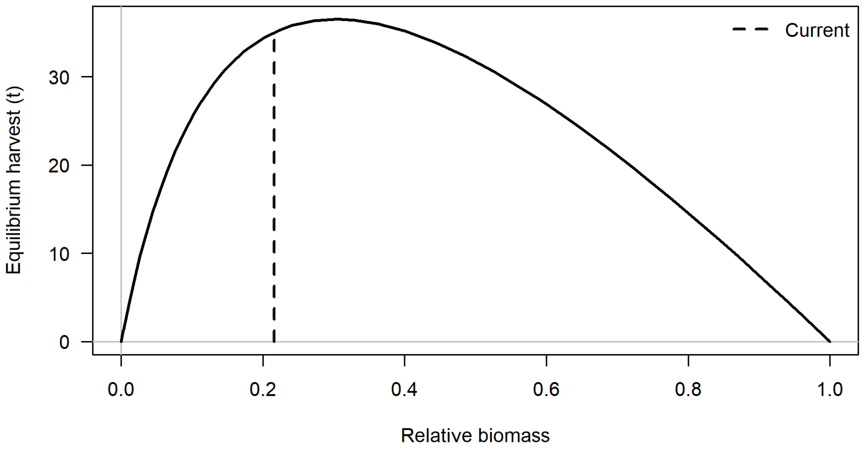


Figure D.23: Scenario 13 equilibrium harvest curve for crimson snapper

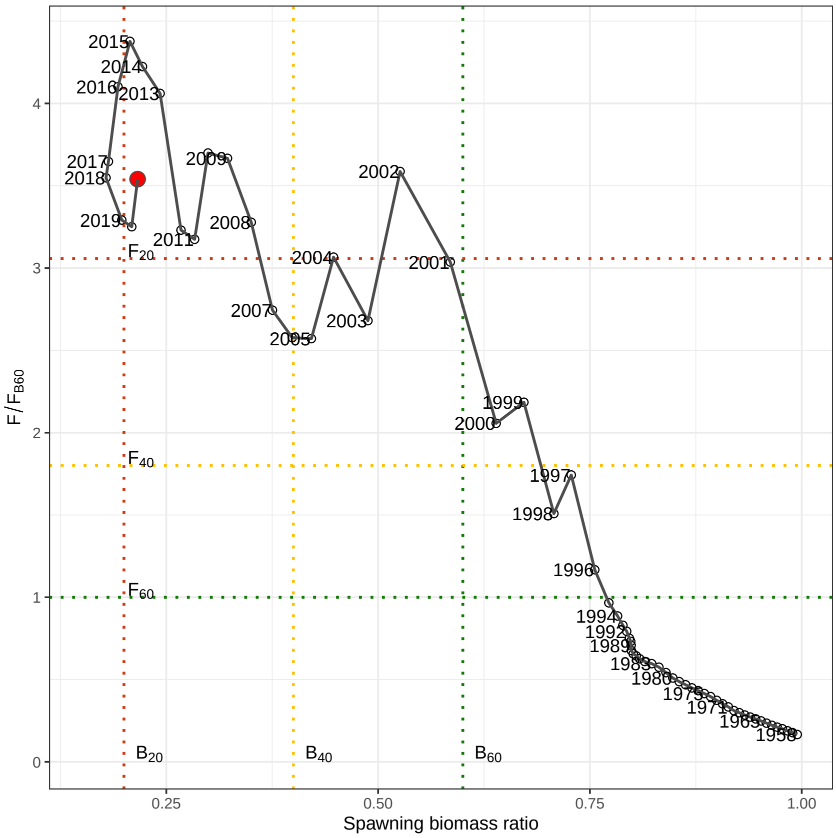


Figure D.24: Scenario 13 phase plot for crimson snapper

Scenario 14

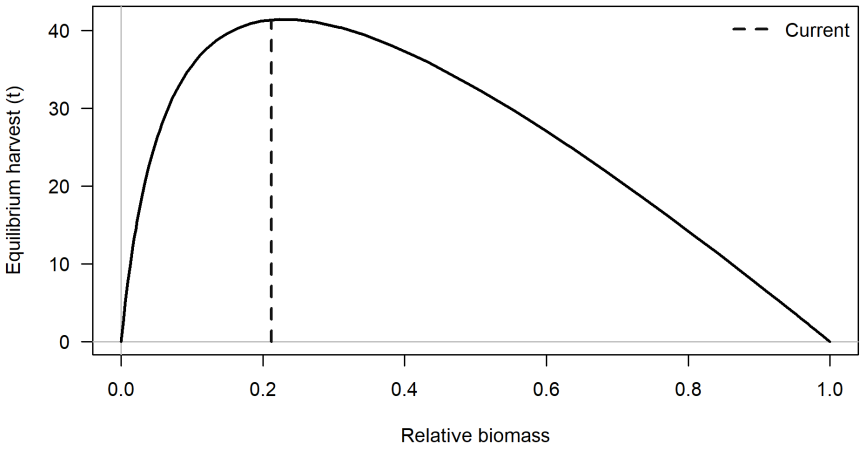


Figure D.25: Scenario 14 equilibrium harvest curve for crimson snapper

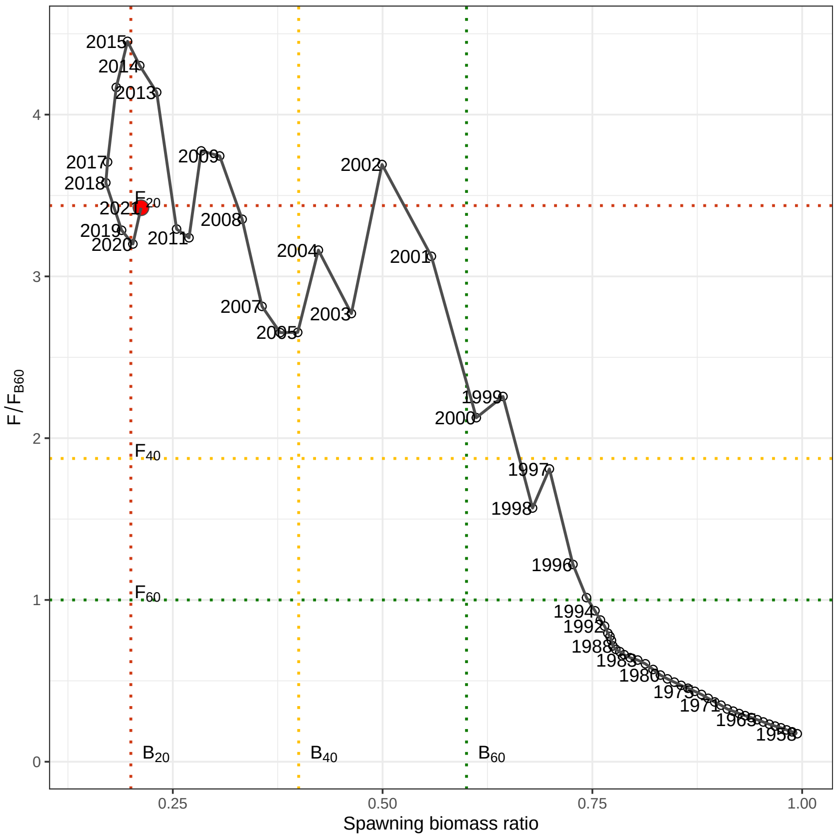


Figure D.26: Scenario 14 phase plot for crimson snapper

Appendix E List of 'other species' in fishery

- Cod - greasy
- Camouflage rockcod
- Cod - flowery
- Cod - bar
- Cod - white lined
- Radiant rockcod
- Cod - black-tipped rock
- Peacock cod
- Cod - black-finned
- Cod - tomato
- Cod - birdwire
- Cod - coral
- Cod - yellow spotted rock
- Cod - speckled fin
- Cod - blue maori
- Cod - hapuku
- Cod - red rock
- Cod - maori
- Cod - red flushed
- Cod - blue spot rock
- Cod - long finned
- Banded Rockcod
- Blacksaddle Rockcod
- Chinaman Rockcod
- Cod - brown banded
- Cod - leopard rock
- Cod - strawberry rock
- Cod - barramundi
- Cod - potato
- Cod - groper unspecified
- Cod - reef unspecified
- Cod - unspecified
- Speckled grouper
- Grouper - eight bar
- Grouper - comet
- Bass groper
- Whitespotted Grouper
- Emperor - spangled
- Emperor - Unspecified
- Lancer
- Emperor - long nose
- Emperor - pink-eared
- Emperor - red ear
- Emperor - yellow tailed
- Emperor - variegated
- Emperor - reticulated
- Emperor - orange striped
- Emperor - yellow lipped
- Bream - japanese large-eye
- Emperor - yellow spotted
- Smalltooth Emperor
- Ornate Emperor
- Longfin Emperor
- Bream - mozambique
- Bream - blubber lip
- Bream - sea
- Bream - japanese large-eye
- Bream - maori
- Seabream - Collar
- Sea bream - big eye
- Emperor - red
- Stripey - spanish flag
- Jobfish - gold banded
- Nannygai - small mouth
- Nannygai - large mouth
- Nannygai - unspecified
- Jobfish - rosy
- Jobfish - green
- Rusty jobfish
- Jobfish - small-toothed
- Jobfish - unspecified
- Hussar
- Hussar - unspecified
- Snapper - unspecified tropical
- Snapper - ruby
- Snapper - flame tail
- Snapper - onespot
- Snapper - pale
- Snapper - saddleback
- Olbique-banded snapper
- Midnight Snapper
- Ornate snapper
- Snapper - indonesian
- Goldeneye snapper
- Sharptooth snapper
- Lavender snapper
- Snapper - black and white
- Fiveline Snapper
- Snapper - black spot
- Cocoa snapper
- Tropical snapper
- Perch - moses
- Perch - dark tailed sea
- Perch - maori sea
- Bass - red
- Seaperch - swallowtail
- Paddle tail
- Chinaman
- Wrasse - unspecified
- Wrasse - sling-jaw
- Wrasse - humphead maori
- Foxfish
- Redbreast Maori Wrasse
- Reefcrest Parrotfish
- Pigfish - gold spot
- Eastern Pigfish
- Tusk fish - venus
- Tusk fish - unspecified
- Tusk fish - black spot
- Tusk fish - blue
- Tusk fish - purple
- Painted sweetlip
- Sweetlip - clown
- Oriental Sweetlips
- Sweetlip - striped
- Surgeon fish - convict
- Fusilier - yellow tail
- Fusilier - southern
- Fish - mixed reef b
- Fish - mixed reef a
- Fish - mixed reef