Stock assessment of Queensland east coast saddletail snapper (*Lutjanus malabaricus*), Australia

2021

Queensland Government

This publication has been compiled by A.B. Campbell [1], A.R. Fox [1], K. B. Hillcoat [2] and L. Sumpter [1]

[1] Fisheries Queensland, Department of Agriculture and Fisheries.
[2] College of Science and Engineering, James Cook University, Townsville, Qld, 4811, Australia
ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, Qld, 4811, Australia.

Enquiries and feedback regarding this document can be made as follows:

Email:	info@daf.qld.gov.au
Telephone:	13 25 23 (Queensland callers only)
	(07) 3404 6999 (outside Queensland)
	Monday, Tuesday, Wednesday and Friday: 8 am to 5 pm, Thursday: 9 am to 5 pm
Post:	Department of Agriculture and Fisheries GPO Box 46 BRISBANE QLD 4001 AUSTRALIA
Website:	daf.qld.gov.au

Interpreter statement

Interpreter

The Queensland Government is committed to providing accessible services to Queenslanders from all culturally and linguistically diverse backgrounds. If you need an interpreter to help you understand this document, call **13 25 23** or visit **daf.qld.gov.au** and search for 'interpreter'.

Contents

Summary i

Acknowledgements iv

Glossary v

1 Introduction 1

2 Methods 5

2.1 Data sources . . . 5

2.1.1 Commercial . . . 5

2.1.2 Recreational . . . 6

2.1.2.1 Recreational fishing surveys . . . 6

2.1.2.2 Boat ramp survey . . . 6

2.1.3 Charter . . . 6

2.1.4 Indigenous . . . 6

2.1.5 Age and length compositions . . . 6

2.2 Harvest estimates . . . 7

2.3 Abundance indices . . . 7

2.3.1 Zero-based catch rate analysis . . . 9

2.4 Discards and discard mortality . . . 9

2.5 Biological relationships . . . 11

2.5.1 Fork length and total length . . . 11

2.5.2 Fecundity and maturity . . . 11

2.5.3 Weight and length . . . 12

2.6 Length and age data . . . 12

2.7 Population model . . . 12

2.7.1 Model assumptions . . . 12

2.7.2 Model parameters . . . 13

2.7.3 Model weightings . . . 13

2.7.4 Sensitivity tests . . . 14

2.7.5 Harvest control rule . . . 15

3 Results 17

3.1 Model inputs . . . 17

3.1.1 Harvest estimates . . . 17

3.1.2 Abundance indices . . . 18

3.1.3 Age composition . . . 18

3.1.4 Length composition . . . 20

3.1.5 Discards . . . 22

3.2 Model outputs . . . 23

3.2.1 Model parameters . . . 23

3.2.2 Model fits . . . 24

3.2.3 Selectivity . . . 24

3.2.4 Growth curve . . . 25

3.2.5 Biomass 25
3.2.6 Harvest targets 27

4 Discussion **28**
4.1 Stock status 28
4.2 Performance of the population model 28
4.3 Unmodelled influences 29
4.4 Recommendations 30
4.4.1 Research and monitoring 30
4.4.2 Management 30
4.4.3 Assessment 31
4.5 Conclusions 31

References **34**

Appendix A Model inputs **35**
A.1 Age and length sample sizes 35
A.2 Conditional age-at-length 35
A.3 Biological data 36
A.3.1 Fecundity and maturity 36
A.3.2 Weight and length 37

Appendix B Model outputs **38**
B.1 Parameter estimates 38
B.2 Goodness of fit 40
B.2.1 Abundance indices 40
B.2.2 Length compositions 41
B.2.3 Age compositions 42
B.2.4 Conditional age-at-length compositions 43
B.2.5 Discard fraction 44
B.3 Other outputs 45
B.3.1 Phase plot 45

Appendix C Sensitivity tests: model outputs **46**

Appendix D Sensitivity tests: other outputs **101**

Appendix E List of ‘other species’ in fishery **122**

List of figures

1	Annual estimated harvest (retained catch) from commercial and 'recreational' (includes charter and Indigenous) sectors between 1961 and 2020 for saddletail snapper	i
2	Annual standardised catch rates (95% confidence intervals) for commercial line-caught saddletail snapper between the years of 1993 and 2020	ii
3	Estimated and predicted biomass trajectory relative to unfished for saddletail snapper for the 'base case' scenario, from 1961 to 2040	ii
2.1	Map of regions used for catch-rate analysis	8
2.2	Size selectivity curve for discarded saddletail under minimum legal size	11
2.3	The 20:60:60 harvest control rule	16
3.1	Data presence by year for each category of data type and Stock Synthesis fleet	17
3.2	Annual estimated harvest (retained catch) from commercial and 'recreational' (includes charter and Indigenous) sectors between 1961 and 2020 for saddletail snapper	18
3.3	Annual standardised catch rates (95% confidence intervals) for commercial line-caught saddletail snapper between the years of 1993 and 2020	18
3.4	Annual age compositions of female saddletail snapper for line-caught fish between 2018 and 2020	19
3.5	Annual age compositions of male saddletail snapper for line-caught fish between 2018 and 2020	19
3.6	Annual age compositions of sex-unknown saddletail snapper for line-caught fish between 2018 and 2020	20
3.7	Annual length compositions of female saddletail snapper for commercial line-caught fish between 2018 and 2020	20
3.8	Annual length compositions of male saddletail snapper for commercial line-caught fish between 2018 and 2020	21
3.9	Annual length compositions of unknown-sex saddletail snapper for commercial line-caught fish between 2018 and 2020	21
3.10	Annual length compositions of saddletail snapper for recreational line-caught-and-retained fish between 2017 and 2020	22
3.11	Annual estimated length compositions of saddletail snapper for recreational line-caught-and-discarded fish between 2017 and 2020	22
3.12	Model estimated length-based selectivity for saddletail snapper by fleet in 2020	24
3.13	Model estimated length-based selectivity for saddletail snapper by sex in 2020	25
3.14	Predicted spawning biomass trajectory relative to virgin for saddletail snapper, from 1961 to 2040	25
3.15	Estimated and predicted spawning biomass trajectory relative to virgin for saddletail snapper, from 1961 to 2020, for all sensitivity runs (as described in Section 2.7.4)	26
3.16	Equilibrium harvest curve for saddletail snapper	27
A.1	Conditional age-at-length compositions of saddletail snapper between 2018 and 2020	35
A.2	Maturity at length for saddletail snapper	36
A.3	Spawning output (maturity times fecundity) at age for saddletail snapper	36
A.4	Spawning output (maturity times fecundity) at length for saddletail snapper	37
A.5	Weight-length relationship for saddletail snapper	37

B.1 Model predictions (green line) to commercial catch rates for saddletail snapper 40
B.2 Length structure for the commercial fleet for saddletail snapper for each sex 41
B.3 Length structure for the recreational fleet for discarded saddletail snapper 41
B.4 Length structure for the recreational fleet for retained saddletail snapper 42
B.5 Age structure for saddletail snapper 42
B.6 Pearson residuals for age-at-length compositions for the commercial fleet for saddletail snapper 43
B.7 Model fit to total discards for recreational-charter-Indigenous fleet 44
B.8 Phase plot for saddletail snapper 45

C.1 Visualisation of parameter estimates for all 21 sensitivity tests 46

List of tables

1 Current and target indicators . . . iii

1.1 History of saddletail snapper management in Queensland . . . 3

2.1 Data sources used in stock assessment . . . 5
2.2 Aggregation of FM regions for catch rate analysis . . . 8
2.3 Scenarios tested to determine sensitivity to parameters, assumptions and model inputs . 15

3.1 Estimated number of discards by the recreational-charter-Indigenous fleet . . . 23
3.2 Stock Synthesis parameter estimates for the base population model . . . 23
3.3 Estimated total harvests and biomass ratios to rebuild and maintain the stock . . . 27

A.1 Age and length sample sizes . . . 35

B.1 Stock Synthesis parameter label explanation . . . 38
B.2 Stock Synthesis parameter estimates for the base population model—detailed . . . 39

Summary

In Queensland, east coast saddletail snapper (*Lutjanus malabaricus*) are mostly line-caught by commercial and recreational fishers, with some recreational spearfishing take. Saddletail snapper are believed to be a single stock (population) off Queensland's east coast. Saddletail snapper are gonochoristic (born male or female and remain that way) and spawn primarily during spring and summer. They can grow to more than 13 kg, 100 cm and live for at least 39 years (DAF, unpublished data).

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

The model incorporated data spanning the period from financial years 1988 to 2020 including commercial logbook harvest (1988–2020), recreational, charter and Indigenous survey harvest estimates (2000–2019), length distribution data from boat-ramp surveys (2017–2020) and age-length (2018–2020). Fishing was assumed negligible in 1960 and harvest during the period 1961–1987 was modelled (interpolated).

Over the last five years, 2016 to 2020, the Queensland total harvest averaged 239 tonnes (t) per year, including 75 t by the commercial sector, and 165 t by the charter, recreational, and Indigenous sectors combined (Figure 1). These estimates were interpolated between survey years and converted to weight in kilograms by the population model.

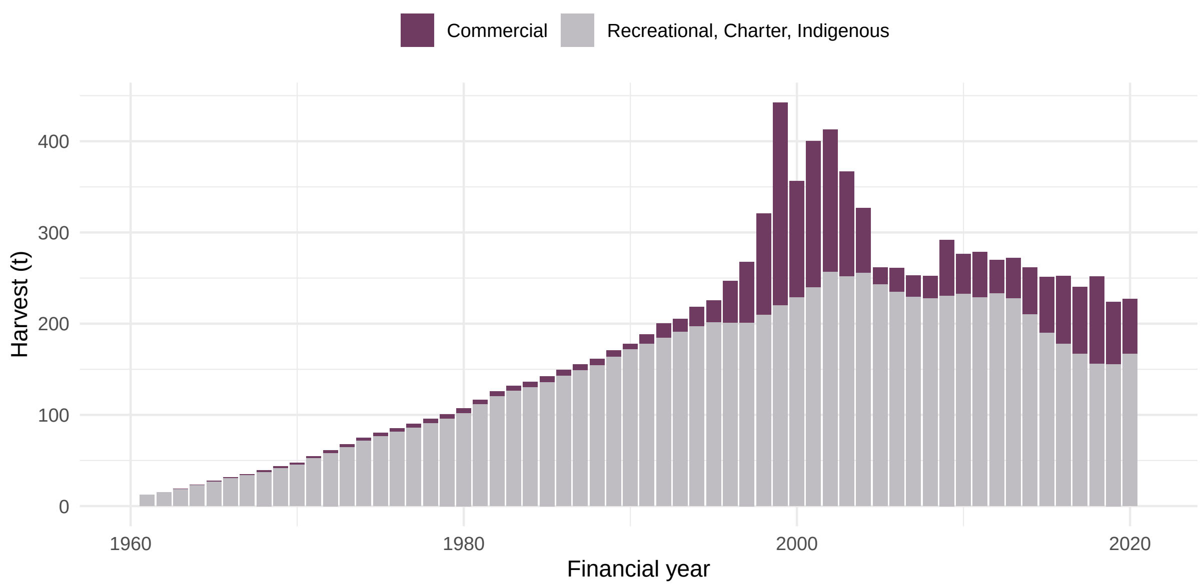

Figure 1: Annual estimated harvest (retained catch) from commercial and 'recreational' (includes charter and Indigenous) sectors between 1961 and 2020 for saddletail snapper

Commercial catch rates were standardised to estimate an index of saddletail snapper abundance through time (Figure 2). The unit of standardisation was kilograms per boat per day. Year, bimester (two-month period), fisher, number of crew, weight of co-caught coral trout and redthroat emperor, and weight of a combination of other commonly co-caught species were included as explanatory terms in the standardisation model.

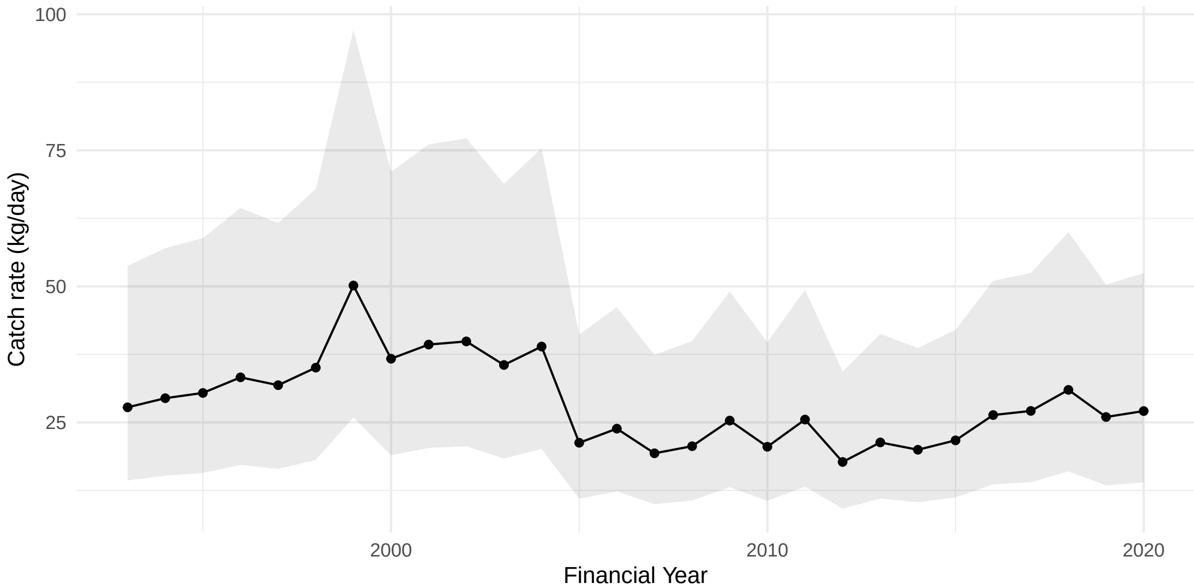

Figure 2: Annual standardised catch rates (95% confidence intervals) for commercial line-caught saddletail snapper between the years of 1993 and 2020

Twenty-one model scenarios were run, covering a wide range of modelling assumptions. Base case (preferred) scenario results suggested that biomass declined between 1961 and 2017 to 19% unfished biomass. In 2020, the stock level was estimated to be 23% (13–73% range across scenarios) unfished biomass (Figure 3).

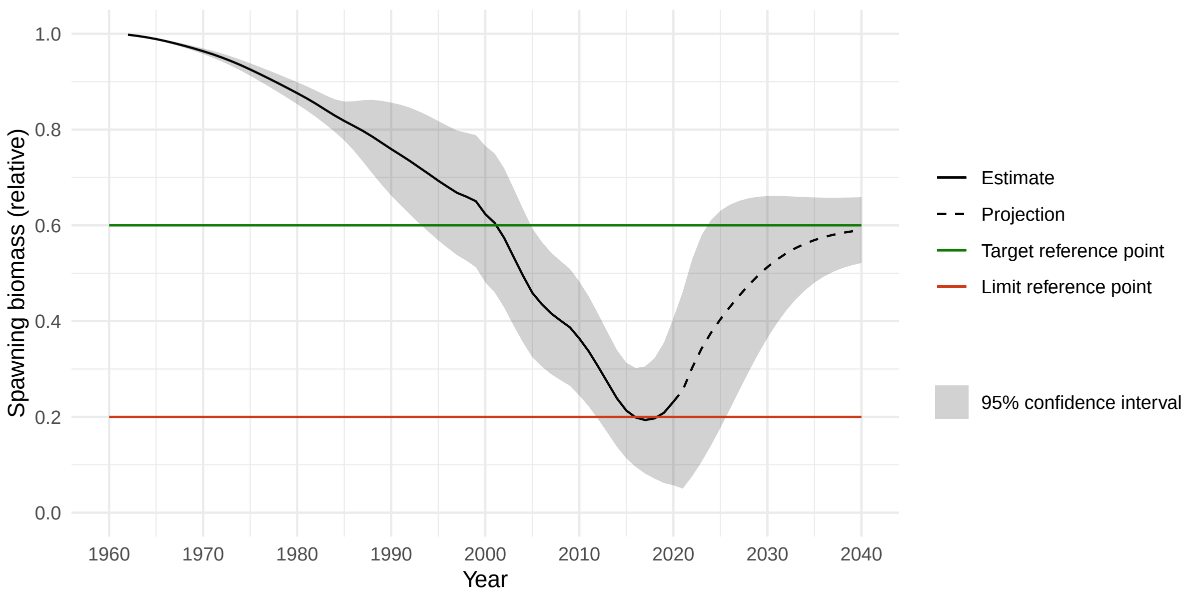

Figure 3: Estimated and predicted biomass trajectory relative to unfished for saddletail snapper for the 'base case' scenario, from 1961 to 2040

The harvest consistent with a biomass ratio of 60%, the Sustainable Fisheries Strategy longer-term target, was estimated at 159 t (146–348 t range across scenarios and all sectors). The recommended harvest in the 2021 financial year is 12 t (0–494 t range across scenarios) in order to achieve this target by 2040.

While the base case model scenario suggested biomass is currently around 23% of unfished levels and the stock is in need of rebuilding, significant uncertainty is associated with this conclusion, evidenced by the wide range of current biomass predictions (13–73%) across sixteen plausible model scenarios. Caution is recommended in applying stock assessment outputs into the management process and this assessment should not be the sole basis for management decisions.

Table 1: Current and target indicators

Parameter	Estimate	Range of scenarios
Current (2020) biomass (relative to unfished)	23%	13–73%
Current (2020) harvest	227 t	
Commercial	60 t	
Recreational + Charter + Indigenous	167 t	
Sustainable harvest at biomass target (60%)	159 t	146–348 t
Proposed harvest (2021) to achieve target	12 t	0–494 t
Time to reach target	19 years	(0–19) years

Acknowledgements

The work was overseen by a project team committee that consisted of the authors and the following scientists, data specialists and managers: Carlie Heaven, Sue Helmke, Ashley Lawson, Chad Lunow, Tyson Martin, Jason McGilvray, Michael O'Neill, Amanda Northrop, Tom Roberts, Anthony Roelofs and Darren Roy. The role of the committee was collaborative to share interpretation and decision making on data inputs, assessment methods and results.

In addition to their role on the committee, we want to acknowledge Carlie Heaven and Ashley Lawson for the provision of, and assistance with, the Queensland commercial harvest data; Tyson Martin for the provision of, and assistance with, the Queensland boat ramp survey data; Lucas Sumpter and Jason McGilvray for the provision of, and assistance with, the biological age and length monitoring data; and Daniella Teixeira and James Webley for the provision of, and assistance with, the Queensland recreational statewide survey data.

In addition to their role on the committee we thank Amanda Northrop for numerous constructive critiques and discussions, and for assistance with Stock Synthesis, and Michael O'Neill for his expertise with catch rate analyses and stock assessment challenges in general. Their constructive feedback has led to a stronger assessment and report.

Many thanks to commercial fishers Chris Bolton and Jake Kingdon for sharing their experiences and providing input on commercial catch rates, particularly in relation to the complex nature of targeting.

We also thank the many Fisheries Queensland staff involved over the years in motivating, designing, implementing and managing the Reef OS (Other Species) program, and in collecting, processing and analysing otolith and length data: Lachlan Barter, John Cavallaro, Megan Daly, Peter Graham, Wayne Hagedoorn, Sue Helmke, Shirin Hyatt, Sophie Johns, Katrina Kaposi, Chad Lunow, Jason McGilvray, Daniel McInnes, Ricky Midgely, Jamie Nicolson, Malcolm Pearce, Cassandra Peters, Andrew Prosser, Robert Prosser, Emily Purton, Tom Roberts, Peta Schofield, Darren Smallwood, Nick Stratford, Jonathon Staunton Smith, Jack Walsh, Shannon White and Jayden Zieth.

We would like to thank Professor Garry Russ for his supervision, guidance and support of the doctoral thesis of Kyle Hillcoat at James Cook University (JCU). We also acknowledge those who provided supervision, funding, assistance and support for the Hillcoat thesis, including the ARC Centre of Excellence for Coral Reef Studies at JCU, Professor Howard Choat, Sue Reilly, Kylie Cuthbertson, Lit Chien Cheah and Nikolaos Andreakis.

We thank all the fishers who donated fish frames and also thank them for their great devotion to research and their commitment to the future of the fishery.

Finally, we would like to thank Eddie Jebreen and Jacqui King, in addition to members of the committee, for reviewing and providing comments on the draft report. The assessment was supported by the Queensland Department of Agriculture and Fisheries.

Glossary

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
GLM	generalised linear model
GSI	gonosomatic index: the ratio between gonad weight and body weight
FL	fork length, measured from the tip of fish's nose to the fork in its tail
LTMP	Long Term Monitoring Program
MLS	minimum legal size
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)
RFish	recreational fishing surveys conducted by Fisheries Queensland
RLF	Reef Line Fishery
SFS	Sustainable Fisheries Strategy
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

Saddletail snapper (*Lutjanus malabaricus*) are a key species targeted in the Reef Line Fishery (formerly the Coral Reef Fin Fish Fishery). Alternative names for the species include large mouth nannygai, scarlet sea-perch, Malabar blood snapper, red jew or saddletail. 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).

Saddletail snapper are widespread, found in the Indo-West Pacific from Fiji to the Arabian Sea and Persian Gulf, and from Australia to southern Japan (Allen 1985). Around Australia, the species can be found from Shark Bay in Western Australia, across northern Australia to the east coast of Queensland (Newman 2002). The species is comprised of three biological stocks, located in the North Coast Bioregion (Western Australia), northern Australia (including the Timor Sea, Arafura Sea and the Gulf of Carpentaria) and the east coast of Queensland (Elliott 1996; Salini et al. 2006). The latter is the focus of this stock assessment. Elliott (1996) suggests little, if any, movement of genes through the Torres Strait since its opening about 8000 years ago. Salini et al. (2006) suggest a genetic boundary exists between Kupang and Sape (districts in Indonesia).

Recapture data collected from the central Queensland coast indicate that saddletail snapper have a high recapture rate of 13.5% (Platten et al. 2007). Of those recaptured individuals, the maximum distance moved was 5 km, while 97% indicated no movement from their initial location (Platten et al. 2007). The number of recaptures in this study was low, and the majority tagged were under-sized, so this is a very rough indication of movement behaviour.

Saddletail snapper are found in coastal and offshore reefs, shoal grounds, and areas of flat bottom with occasional epibenthos or vertical relief (Newman 2002). They are found at depths between 12 and 140 m and frequently form mixed shoals with crimson snapper (*Lutjanus erythropterus*) (Allen 1985; Newman 2002). They feed mainly on finfish and benthic crustaceans (Carpenter 2001).

McPherson et al. (1992b) reported that spawning activity occurs during the spring and summer months in the Great Barrier Reef (GBR) waters, with a 5 month spawning period that peaks during November–January and also add that this could be an overestimation. Histology data collected and analysed by one of the authors suggest October as the middle of the spawning on the GBR (Hillcoat, unpublished)). There is no apparent relationship between spawning activity and lunar cycle (McPherson et al. 1992b).

Saddletail snapper are one of three large species of lutjanids that have historically dominated the Other Species quota category within the Reef Line Fishery, alongside red emperor and crimson snapper (*L. sebae* and *L. erythropterus* respectively). Due to their similar appearance, saddletail snapper are sometimes misidentified as crimson snapper (Allen 1985).

Saddletail snapper are gonochoristic (O'Neill et al. 2011). They are relatively long-lived, and grow slowly after becoming reproductively mature (Newman et al. 2000; Fry et al. 2009). In GBR waters, the fork length of females at 50% maturity was estimated to be 57.6 cm (McPherson et al. 1992b). Saddletail snapper can reach an estimated maximum fork length of 102 cm and weight of 13.2 kg in GBR waters (McPherson et al. 1992b). This is substantially larger than those found in northern and western Australia (McPherson et al. 1992b). Earlier work indicated that saddletail snapper in the Queensland east coast stock can live for up to 20 years (Newman et al. 2000). However, biological age data collected and used in this assessment show that, in the Queensland east coast stock, saddletail snapper can live for at least 39 years (DAF, unpublished data).

Saddletail snapper suffer greatly from barotrauma when released; even in shallow waters less than 10 m (Hillcoat, personal observation). Brown et al. (2008) reported a post-capture released survival rate for saddletail snapper just above 50%, however this decreased to 10% survival if fish were in the lowest category for release condition in their study. It is important to note that 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 MLS. Juvenile saddletail snapper (below the MLS) are more likely to be found in this habitat as they inhabit inshore shallow waters (< 25 m). Both saddletail snapper and crimson snapper (*Lutjanus erythropterus*) form part of a 'coastal' assemblage of species found only in the shallowest stations sampled (15–24 m) in the Central GBR (Jones et al. 1988). Conversely, larger individuals (above the MLS) generally inhabit deeper waters with the exception of shallow (usually) depressions where freshwater flows seasonally ('wonky holes'). The deeper the water, the larger the fish (Williams et al. 1994).

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 saddletail 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.

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 $27–31 million (Fisheries Queensland 2020). The saddletail snapper component is estimated to be $0.6–0.9 million (BDO EconSearch 2020). A number of key target species for commercial fishers in the RLF are also targeted by recreational anglers and charter operators (Fisheries Queensland 2020). Saddletail snapper are also harvested by Aboriginal peoples and Torres Strait Islander peoples. Limited data exist for catch and effort in the Indigenous sector, however it is expected that this sector has comparatively low levels of effort, with fishing activities aligning closely with the recreational fishing sector (Fisheries Queensland 2020).

Key management measures in the fishery that pertain to saddletail snapper include spawning closures, minimum size limits, compulsory log books, total allowable commercial catch limits (TACC), individual transferable quotas (ITQs), gear restrictions, vessel and tender restrictions and possession limits for recreational fishers (Fisheries Queensland 2020). The history of saddletail snapper 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. These closures apply to all line fishers targeting coral reef fin fish (commercial, charter, recreational) between latitude 10° 41'S and 24° 50'S to the eastern boundary of the GBRMP. Vessel length is restricted to a maximum of 25 m and tenders are limited by number, size and proximity to the primary vessel. In the commercial sector, gear is restricted to three fishing lines at a time with no more than six hooks total. Recreational fishers accessing the fishery can use hook and line, rods and reels, and spearfishing gear (excluding hookah/scuba). Species specific individual transferable quotas (ITQs) are in place for coral trout and redthroat emperor, however saddletail snapper and other targeted species are managed using a combined/basket ITQ.

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 saddletail snapper management in Queensland

Year	Management	Legislation
1957	Minimum size of 14 inches (35.56 cm) (listed as Scarlet Sea-Perch (*Lutjanus malabaricus*))	*The Fisheries Acts, 1957 to 1962*
1975	Inclusion of no-fishing zones in the Great Barrier Reef	*Great Barrier Reef Marine Park Act 1975*
1982	Section 35 permit; issued to recreational fishers who had caught more fish than they could use, and therefore were allowed to sell that portion of their catch that was deemed surplus to their requirements.	*Fishing Industry Organization and Marketing Act 1982 (Qld) (FIOMA)*
1993	Recreational possession limits of a combined total of 30 coral reef fish covering 26 species. Skin not to be removed from fillets by recreational fishers, except in the case of charter vessels in excess of 48 hrs where the majority of the skin may be removed provided a minimum is left for identification. Minimum size limit of 40 cm. 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.	*Fishing Industry Organisation and Marketing Regulation 1993*
1994	Section 35 permits to sell recreationally caught fish repealed.	*Fisheries Act 1994*

Continued on next page

Table 1.1 – *Continued from previous page*

Year	Management	Legislation
2003	Fisheries (Coral Reef Fin Fish) Management Plan implemented. Recreational in-possession limits reduced to a combined total of 9 crimson and saddletail snapper. The fishery symbols for the commercial 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. RQ licence holders must hold appropriate line units (OS units) to take saddletail snapper, which take the form of individual transferable quotas. The total yearly catch of Other Species available for allocation is 902.2 t. New reporting requirements. Seasonal closures across the GBR for nine days around the new moon period in October, November and December each year. Fish may be taken only by using fishing lines. A commercial fisher must not use more than 3 fishing lines at the same time, and the total number of hooks or lures attached to the lines must not be more than 6. 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 n miles. A tender boat must not be used more than 5 n miles from its primary boat. This does not apply if the tender boat and its primary boat are located on the same reef.	*Fisheries (Coral Reef Fin Fish) Management Plan 2003 (Queensland)*
2004	New Fisheries Management implemented (ITQ and RQ) and GBRMPA implemented new zoning arrangements for the Great Barrier Reef Marine Park. Under the rezoning approximately 33% of the marine park area is protected through closed green zones within which extractive uses are restricted.	*Great Barrier Reef Marine Park Zoning Plan 2003*
Sept. 1 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	The total quota entitlement for the commercial reef line fishery for each line year for OS line unit is 955.597 t	*Fisheries Quota Declaration 2019 (Queensland)*

In 2020, the Queensland Department of Agriculture and Fisheries commissioned a stock assessment for saddletail snapper off the east coast of Queensland. This stock has not previously been assessed. This assessment aims to determine current stock biomass relative to an unfished state, provide estimates of sustainable harvests to support Queensland's Sustainable Fisheries Strategy 2017–2027 (Fisheries Queensland 2017b), and inform the Status of Australian Fish Stocks 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 1961 up until and including 2020 based on available information.

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

Type	Year	Source
Commercial	1989–2020	Logbook data collected by Fisheries Queensland
Recreational	2000	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)
	2002, 2005	Recreational fishing surveys (RFish) conducted by Fisheries Queensland (Higgs et al. 2007; McInnes 2008)
	2011, 2014, 2019	Statewide Recreational Fishing Survey (SWRFS) conducted by Fisheries Queensland) (Taylor et al. 2012; Webley et al. 2015; Teixeira et al. 2021)
	2017–2020	Boat ramp survey, conducted by Fisheries Queensland, providing harvest information
Indigenous	2000	Indigenous fishing survey conducted in 2000 by the Australian Department of Agriculture, Fisheries and Forestry (the National Recreational and Indigenous Fishing Survey, NRIFS)(Henry et al. 2003)
Biological data	2017–2020	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
	2017–2020	Boat ramp survey, conducted by Fisheries Queensland, providing discard information
	2018–2020	Biological monitoring (sex, age and length from the commercial line fishery) undertaken by Fisheries Queensland (Fisheries Queensland)

2.1.1 Commercial

Commercial harvests of saddletail snapper were recorded in the Queensland logbook system. The logbook system consists of daily harvests (landed weight in kilograms) of all fish species from each individual fishing operator (license) since 1988. In addition to landed weight, logbooks also record the

[1] Financial year naming convention is to reference the calendar year during which the financial year ended, that is, FY 2020 is July 2019 to June 2020.

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 harvested and discarded 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 2000, 2011, 2014 and 2019 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 (Northrop et al. 2018; Fisheries Queensland 2017a). The length data were used as input in the model, and discards were used to infer discard rates of saddletail snapper for the recreational sector.

2.1.3 Charter

Charter logbooks provided an operator identifier, date, location fished, number of each species caught including fate (retained or discarded) and the number of guests on the trip.

2.1.4 Indigenous

The National Recreational and Indigenous Fishing Survey in 2000 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 (Henry et al. 2003). Indigenous harvests were combined with recreational harvests for reporting purposes.

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; birthday for saddletail snapper 1 October), age group (maximum age class the fish would attain during the sampling season; sampling season 1 July to 30 June) and sex of fish. Sex could be unknown. Age distribution 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 from 2017 to 2020.

2.2 Harvest estimates

Commercial, charter, recreational and Indigenous harvest data were analysed to reconstruct the history of harvest from 1961 until 2020. Prior to 1961 saddletail snapper harvest is assumed to be negligible based on low catches in the early years of the logbook system and overall catch reconstruction procedure.

Commercial:

- Between 1988 and 2020 a baseline harvest of saddletail snapper was set to the weight of saddletail snapper recorded against the line (LF) and mixed fishery codes in the CFISH logbooks.
- CFISH logbooks also contain an 'unspecified nannygai' label which is an ambiguous mixture of large mouth nannygai (saddletail snapper) and small mouth nannygai (crimson snapper) and this was handled as follows:
  - Between 2009 and 2020 the proportion of combined large and small mouth nannygai harvest that were large mouth nannygai was calculated (during this period very small amounts of nannygai harvest were recorded as unspecified, approximately 0.01% per year).
  - The average of this proportion (averaged over the years 2009–2020; approximately 0.80) was then applied to all unspecified nannygai harvest in the logbooks, and added to the baseline.

Recreational and charter harvest:

- was assumed zero in 1961 and increased proportionally to Queensland population growth through to reach a re-scaled RFish estimate in 2002, where this re-scaled estimate was calculated as the 2002 estimate divided by the NRIFS estimate for the year 2000.
- estimates for 2000, 2011 and 2014 were set to equal the values reported in the NRIFS (2000) and SRFS (2011 and 2014) surveys.
- estimates for 2019 and 2020 were set to equal the value reported in the 2019 SRFS survey.
- "missing" recreational harvests in 2001, 2003–2010, 2012–2013 and 2016–2019 were set to values linearly interpolated between the above estimates.
- estimates for all years were converted from retained numbers to harvested weight by the population model itself (they were entered into the model as numbers, not weights).

While charter sector data were also available from logbooks, we preferred to use the National and Statewide survey data sets for this component so as to maintain a consistent reconstruction strategy for the entire recreational sector.

Indigenous harvest:

- equalled the NRIFS estimate from 2000 for all years from 1961 onwards.
- was added to the recreational and charter harvest for input to the population model.

2.3 Abundance indices

Queensland logbook data on commercial catches of saddletail 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 duration of the trip was a single date.
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 was restricted to records where location was a Fishery Monitoring region (Table 2.2, Figure 2.1).
4. The data set was restricted to records associated with fishers that had (a) at least two years of history and (b) were in the subset of fishers that accounted for 95% of the total saddletail catch when ordered by contribution (in total whole weight).
5. The data set was restricted to records where kilograms of saddletail caught was greater than zero.

Table 2.2: Aggregation of FM regions for catch rate analysis

North
Lockhart Region
Cooktown Region
Cairns Region
Mission Beach Region
Mid
Lucinda Region
Bowen Region
Coral Sea Region
South
Mackay Region
Swains Region
Stanage Region
Rockhamption Estuarine
Rockhampton Offshore
Rockhampton Region
Fraser Inshore
Fraser Offshore
Fraser Region
Sunshine Coast Offshore

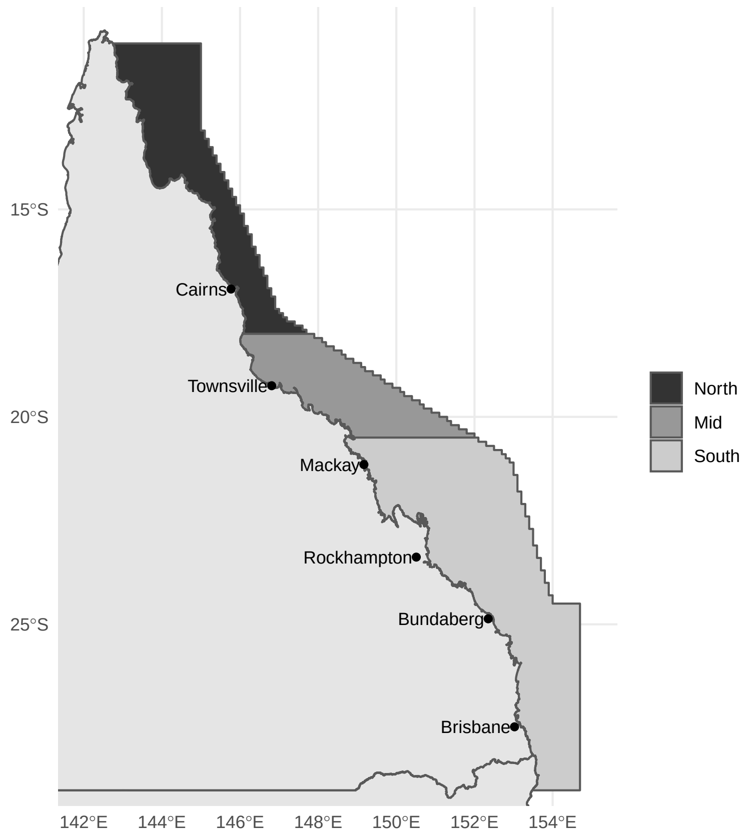

Figure 2.1: Map of regions used for catch-rate analysis

The statistical model used was a linear model with the response being a log transform of the saddletail catch. The analysis was carried out using the software R (version 4.0.2, R Core Team (2020)).

The form of the model was:

$$\log(Saddletail) \sim Year * Bimester * Region + Fisher + Crew + OS + CTRTE \qquad (2.1)$$

where the variables considered were as follows:

- *Saddletail*: daily harvest of saddletail (kilograms)
- *Year*: financial year (factor)
- *Bimester*: two-month period (factor)

- *Region*: spatial region, aggregated into broader regions 'North', 'Mid' and 'South' from Fishery Monitoring regions (Table 2.2, Figure 2.1; factor)
- *Fisher*: fisher license identifier (factor)
- *Crew*: how many crew were recorded (factor)
- *CTRTE*: harvest of coral trout and redthroat emperor (kilograms)
- *OS*: harvest of coral reef 'other species' (see list in Appendix E; kilograms)

While spatial regions were used to structure 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 and stakeholder discussions on the complex nature of targeting in the saddletail fishery. Due to this complexity, it was decided to conduct a 'zero-based' analysis.

2.3.1 Zero-based catch rate analysis

In addition to the baseline catch rate analysis, an alternative approach was investigated with the objective of including 'zero catches' (a record in which no saddletail were retained). A zero-based catch rate analysis can be a more reliable indicator of abundance when schooling-related hyperstability is a concern (Campbell et al. 2012, Appendix D), or when external factors are driving targeting behaviour.

The statistical model used was a negative-binomial generalized linear model with estimated fish dispersion and aggregation parameters. The model's variance was a quadratic function of the mean. The analysis was carried out using the software R (version 4.0.2, (R Core Team 2020)). The analyses used the 'glm' function, with with a log link.

The form of the model was:

$$Saddletail \sim Year * Bimester * Region + Fisher + Crew \tag{2.2}$$

This model did not include CTRTE and OS as additional explanatory variables because, following on from discussions with commercial fishers and members of the project team, it was unclear the role they should play in the zero-based analysis and there was a concern they would introduce spurious signals.

This zero-based catch-rate analysis was used only for a single population model sensitivity scenario (Section 2.7.4).

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 minimum legal size (MLS) which, for saddletail snapper, is 40 cm total length (TL) for both 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. Lower rates of survival for larger fish in deeper water seems logical, however, these fish are not generally released when above the MLS suggesting limited discard mortality. Boat ramp survey data confirmed that a significant fraction of the recreational saddletail 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. This was supported by unpublished data collected when targeting individuals under the MLS did not report any individuals less than 183 mm FL (Hillcoat, unpublished data).
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 application sliders to their favoured 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 90% for α and an undersized selectivity curve (Figure 2.2).
3. The length distribution of retained recreational saddletail 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 diary survey in 2019.

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

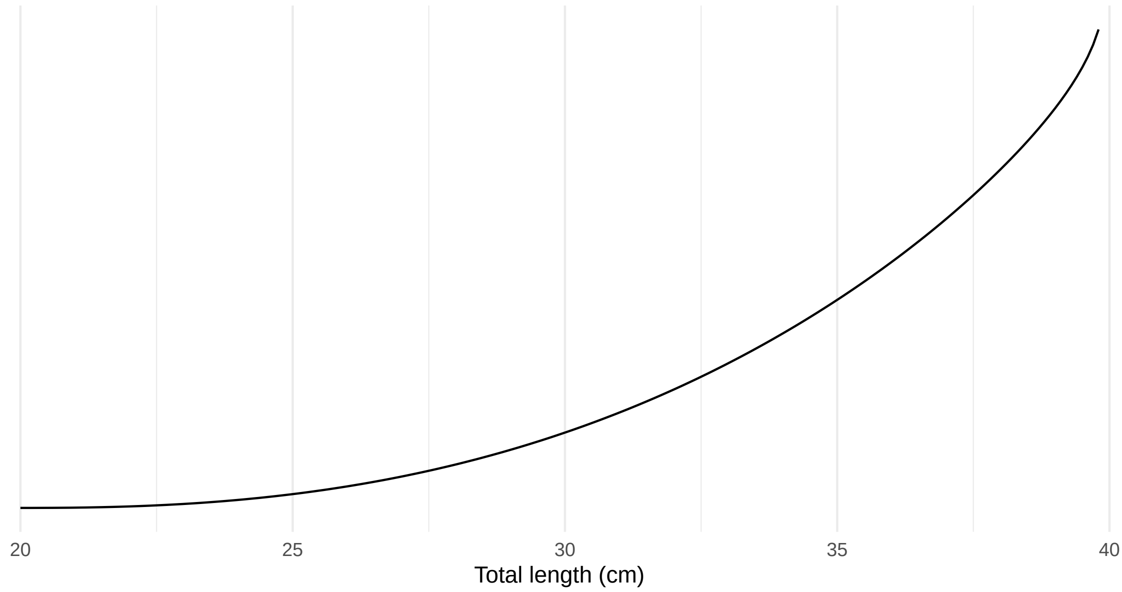

Figure 2.2: Size selectivity curve for discarded saddletail under minimum legal size—vertical axis extends from 0 to 100% selectivity

Discard mortality was set conservatively at 0.75, based on Brown et al. (2008) and feedback from the project team. An average of the best (50%) and worst (10%) case of survival overall (30%) was taken for discards below the MLS based upon Brown et al. (2008) with few discards above the MLS for all sectors. (Brown et al. 2008) studied predominantly under-sized individuals from shallow waters, and therefore the average mortality of 70% was considered an underestimate.

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 the purpose of extracting selectivity curve estimates from Project Team members with relevant experience, and in order to account for minimum legal size (recorded in legislation in total length (TL)) in the model, we required a conversion to total length. The following conversion was applied where necessary (McPherson et al. 1992a):

$$TL_{mm} = 1.04 \times FL_{mm} - 0.45$$

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 with coefficients supplied from unpublished data associated with a doctoral thesis at James Cook University:

$$mat = \frac{1}{(1 + exp((57.3 - FL_{cm})/3.72))}$$

where mat is maturity and FL_{cm} is fork length in centimetres.

Spawning period was indicated by early hydrating egg stages (in which eggs become a clear pink colour, and enlarged) which assumes eggs are spawned within the month. Maturity was based upon the most advanced egg stage present, with mature fish staged as vitellogenic III or above (Brown-Peterson et al. 2011).

No information was available on the fecundity for saddletail snapper. For this assessment we assumed that the number of eggs produced by a female saddletail snapper was equal to her weight.

2.5.3 Weight and length

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

$$W_{kg} = \exp(-10.5 + (2.83 * (\log(FL_{cm}))))$$

where W_{kg} is weight of a saddletail in kilograms.

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 in accordance with Fishery Monitoring sampling design.

In addition, age-only data were entered into a 'ghost fleet' in the model, to simulate goodness-of-fit plots for age frequencies. While this makes no contribution to the model likelihood it does provide a useful visual diagnostic. Age frequency data for the ghost fleet were constructed by multiplying the length frequency data from the commercial fleet by the conditional age-at-length data in 'transition matrix' form (matrix contributions sum to one along the age axis). Ghost fleet age frequency goodness-of-fit plots can be seen in Appendix B.2.

2.7 Population model

A population model was fitted to the data to determine the number of saddletail snapper in each year and each age bin using the software package Stock Synthesis (SS; version 3.30.16.00). A full technical description of SS is given in Methot et al. (2020).

Biological monitoring data indicated a growth difference between the sexes with males growing larger than females. The population model was therefore set up as a two-sex model.

2.7.1 Model assumptions

The main assumptions underlying the model included:

- The Queensland east coast stock is reproductively isolated from the North Coast Bioregion and northern Australian stock (Elliott 1996; Salini et al. 2006)
- 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.
- The fishery began from an unfished state in 1961.
- 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 saddletail snapper are parametric functions of their size.
- The first possible mature age is 3, after which the proportion of female 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.

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. Uniform priors were used unless stated otherwise.

The (natural logarithm of) unfished recruitment (SR_LN(R0)) was estimated within the model.

Beverton-Holt stock recruitment steepness (SR_BH_steep) was estimated using a strongly informative log-normal prior. In the base case, the (natural scale) median of the prior was 0.73, based on the meta-analysis by Thorson (2020). The standard deviation was tight at 0.08. Lower values for the median of the prior were chosen in the sensitivity analysis (details in Section 2.7.4).

Sex-specific parameters of the von Bertalanffy growth curve (L_at_Amin_Fem, L_at_Amax_Fem, VonBert_K_Fem, L_at_Amin_Mal, L_at_Amax_Mal, VonBert_K_Mal) were estimated within the model, including coefficients of variation for both young and old fish (CV_young_Fem, CV_old_Fem, CV_young_Mal, CV_old_Mal).

Natural mortality (NatM) was estimated in the model, with a log-normal prior. This prior had a (natural scale) median value of 0.135 and standard deviation of 0.438. 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 0.438. The maximum age across all samples is 40 years, giving $5.4/40 = 0.135$.

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). For the base case, separate selectivity curves were estimated for the commercial fleet and the recreational-charter-Indigenous fleet. Sensitivity scenarios that involved a partitioning of the commercial catch rate around the time of the GBRMP Representative Areas Program rezoning (July 2004) split the commercial sector into two fleets, and in these scenarios selectivity parameters were still estimated for two fleets 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; usually there is no cause to estimate catchability as it is not free to move independently given the data and standard model parameterisations. However, some scenarios involved the estimation of a parameter governing the behaviour of the standard deviation associated with catchability (Q_extraSD).

Recruitment deviations between 1981 and 2020 improved fits to composition data (length and conditional age-at-length frequency 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).
- The standard error associated with the catch rate time series was generally input to the model based on the value estimated during the catch rate analysis, however some scenarios involved this value being fixed. It should be noted that the standard error emerging from the catch rate

analysis was large, which had the consequence that for those scenarios which relied on it (which ultimately included the base case), the population model was effectively 'down-weighting' catch rate fits in favour of fits to other data sets (principally length and conditional age-at-length). This is not standard practice for a stock assessment but was a deliberate choice given the uncertainties associated with the catch rate analysis (elaborated on in Section 2.3 and Chapter 4).

- Closely related to the catch rate standard error is the Q_extraSD parameter which attempts to 'auto-tune' the catch rate weighting. Some scenarios included this parameter, others did not.
- One scenario involved an explicit 'lambda' weighting, wherein a particular likelihood component (the one associated with the discard data fit) was given more weight.

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:

- **CPUE:** Catch rates modelled with or without 'zero-catches', as described in Section 2.3
  - "Base": Base case analysis
  - "Alt": Zero-based analysis
- **Catch:** Recreational harvest at 100% or 50% of total as described in Section 2.2
  - "1.0": 100%
  - "0.5": 50%
- **SR_BH_steep:** Natural-scale median of the steepness prior altered based on study by Thorson (2020)
  - "High": 0.73
  - "Mid": 0.63
  - "Low": 0.53
- **Rezoning:** Catch rates either split into two separate time series for before and after management changes associated with a shift to quota management and GBRMPA rezoning in 2004, or modelled as one continuous time series
  - "Full": Catch rates modelled as one continuous time series
  - "Split": Catch rates split into two separate time series for before and after GBRMPA rezoning
  - "Post": Catch rates split into two separate time series but only the second of the two (i.e. after rezoning) was used
- **Q_extraSD:** Extra standard deviation on catchability
  - "0": Not included
  - "1": Included
- **λ:** Explicit 'lambda' weighting on discard data fitting
  - "0": None
  - "1": On
- **Devs:** Recruitment deviations applied over a long or short time scale
  - "Full": Recruitment deviations applied from 1981–2020
  - "Short": Recruitment deviations applied from 1981–2015
- **Error:** Standard error of the catch rate time series input to SS directly from the catch rate analysis (> 0.1), or set to 0.1
  - "Mod": Based on catch rate model
  - "Set": Set to 0.1

- **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

From these sensitivities, 21 different scenarios were tested, as outlined in Table 2.3. Scenario 6 was selected by the project team as the base case scenario.

Table 2.3: Scenarios tested to determine sensitivity to parameters, assumptions and model inputs—scenario 6, the chosen base case, has been highlighted

	CPUE	Catch	SR_BH_steep	Rezoning	Q_extraSD	λ	Devs	Error	Discards
1	Base	1.0	High	Full	0	0	Full	Mod	Base
2	Base	1.0	Mid	Full	0	0	Full	Mod	Base
3	Base	0.5	High	Full	0	0	Full	Mod	Base
4	Base	0.5	Mid	Full	0	0	Full	Mod	Base
5	Base	1.0	High	Full	1	0	Short	Mod	Base
6	Base	1.0	High	Split	0	0	Full	Mod	Base
7	Base	1.0	High	Split	1	0	Short	Mod	Base
8	Base	1.0	Mid	Split	1	0	Short	Mod	Base
9	Base	1.0	Low	Split	1	0	Short	Mod	Base
10	Alt	1.0	High	Full	0	0	Full	Mod	Base
11	Base	1.0	High	Split	0	1	Full	Mod	Base
12	Base	1.0	High	Post	0	0	Full	Mod	Base
13	Base	1.0	High	Full	1	0	Full	Mod	Base
14	Base	1.0	High	Split	1	0	Full	Mod	Base
15	Base	1.0	Mid	Split	1	0	Full	Mod	Base
16	Base	1.0	Low	Split	1	0	Full	Mod	Base
17	Base	1.0	Mid	Full	0	0	Full	Set	Base
18	Base	1.0	High	Split	0	0	Full	Set	Base
19	Base	1.0	High	Post	0	0	Full	Set	Base
20	Base	1.0	Mid	Full	0	0	Full	Mod	Alt
21	Base	1.0	High	Split	0	0	Full	Mod	Alt

2.7.5 Harvest control rule

Stock Synthesis's forecast sub-model was used to provide forward projections of biomass and future harvest targets, following a harvest control rule (Fisheries Queensland 2021). This rule has a linear ramp in fishing mortality between 20% exploitable biomass, where fishing mortality is set at zero, and 60% exploitable biomass, where fishing mortality is set at the equilibrium level that achieves 60% biomass (F_{B60}). Below 20% exploitable biomass fishing mortality remains set at zero, and above 60% exploitable biomass fishing mortality remains set at F_{B60} (Figure 2.3). This shifting rate starts out small, which enables the stock to recover much more quickly and means that harvests are not impacted for as long.

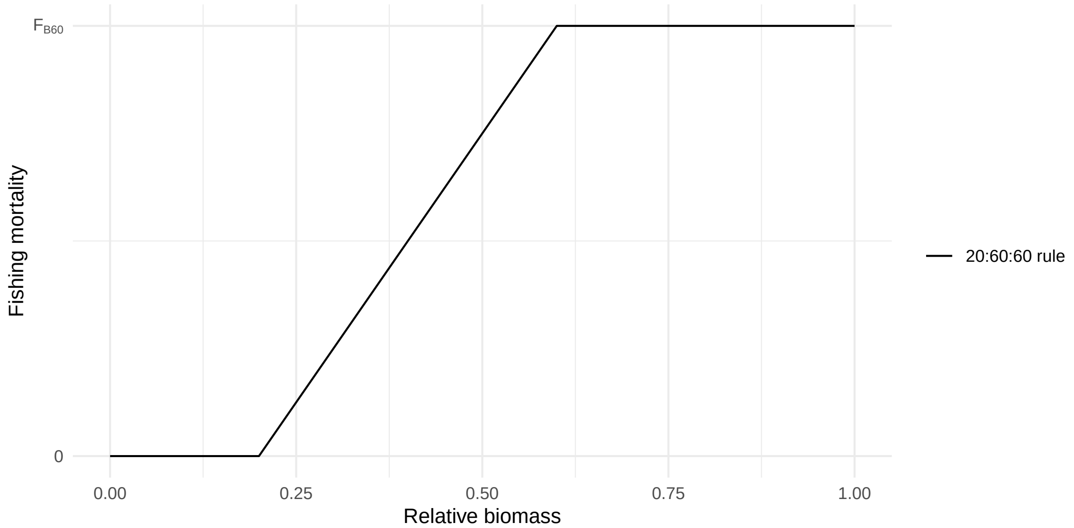

Figure 2.3: The 20:60:60 harvest control rule

3 Results

These model inputs and outputs relate to scenario six—the scenario chosen by the project team to be the 'base case' (defined in Table 2.3). Results for all scenarios can be found in Apppendix C and Appendix D.

3.1 Model inputs

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

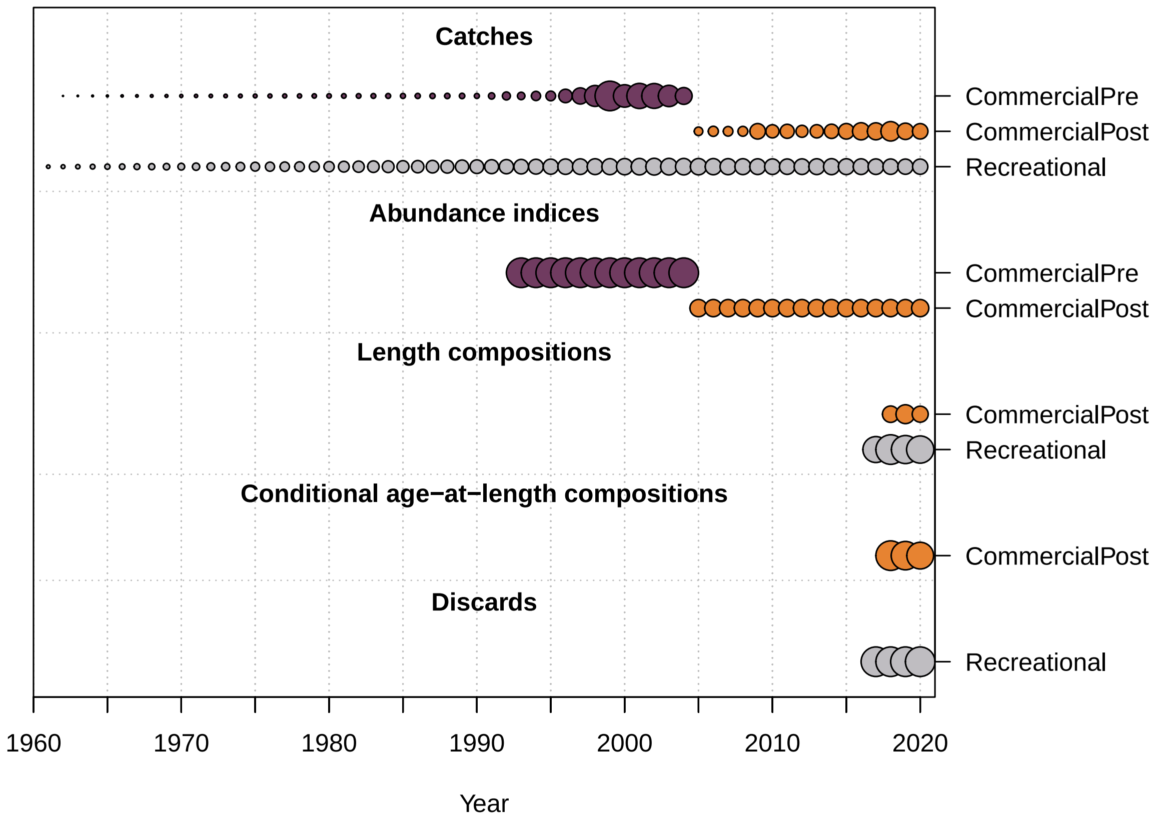

Figure 3.1: Data presence by year for each category of data type and Stock Synthesis fleet
Note: This assessment involves two fleets—one for the commercial sector and one for all other sectors combined. This plot shows data presence by year for each fleet, where circle area is relative within a data 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.

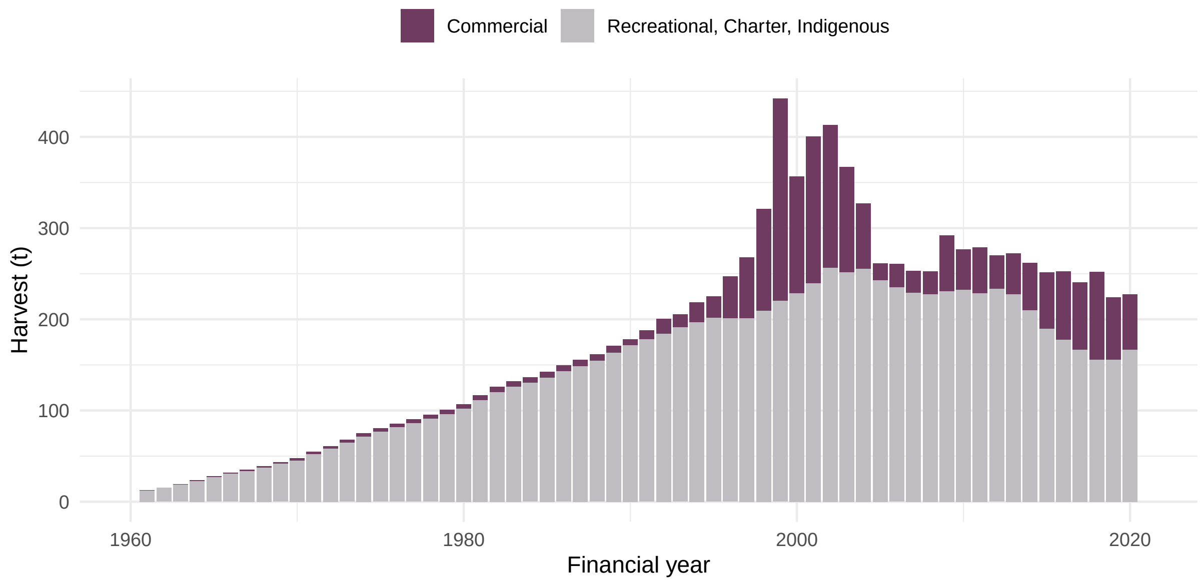

Figure 3.2: Annual estimated harvest (retained catch) from commercial and 'recreational' (includes charter and Indigenous) sectors between 1961 and 2020 for saddletail snapper

3.1.2 Abundance indices

The standardised commercial catch rate averages about 27 kg per operation-day with a minimum of 17 kg per operation-day in 2012 and a maximum of 48 kg per operation-day in 1999 (Figure 3.3).

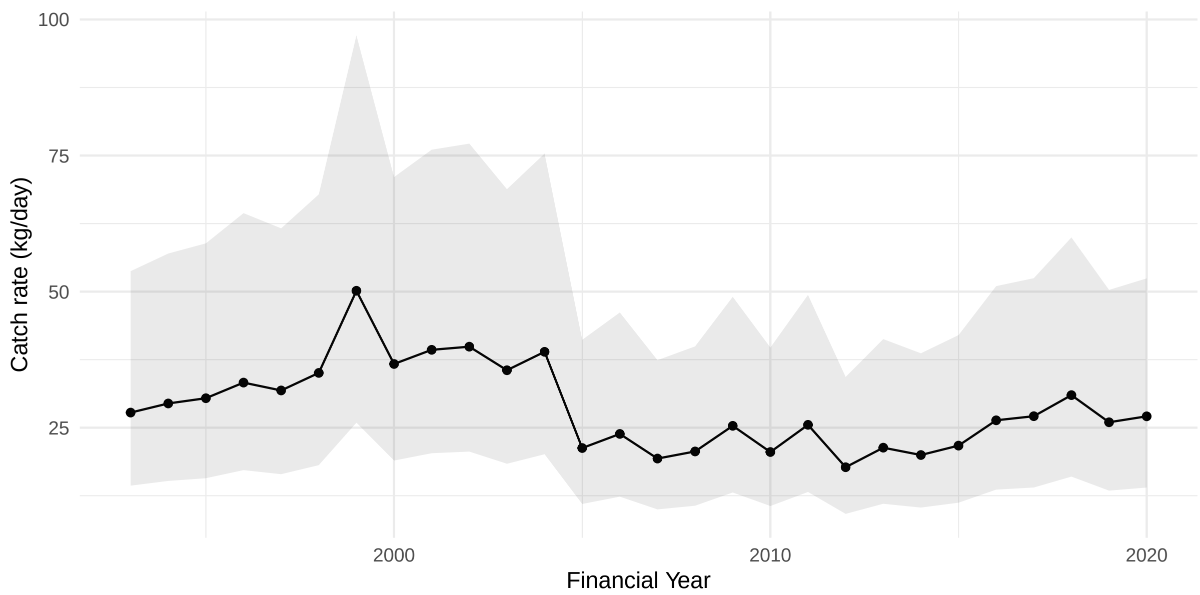

Figure 3.3: Annual standardised catch rates (95% confidence intervals) for commercial line-caught saddletail snapper between the years of 1993 and 2020

3.1.3 Age composition

Fishery age composition data were input to the population model, as part of age-at-length compositions, for the commercial fleet (Figures 3.4–3.6). The actual input to the model for 'live' fleets is conditional age-at-length data (Appendix B.2.4). Sample sizes are given in Appendix A.1, Table A.1.

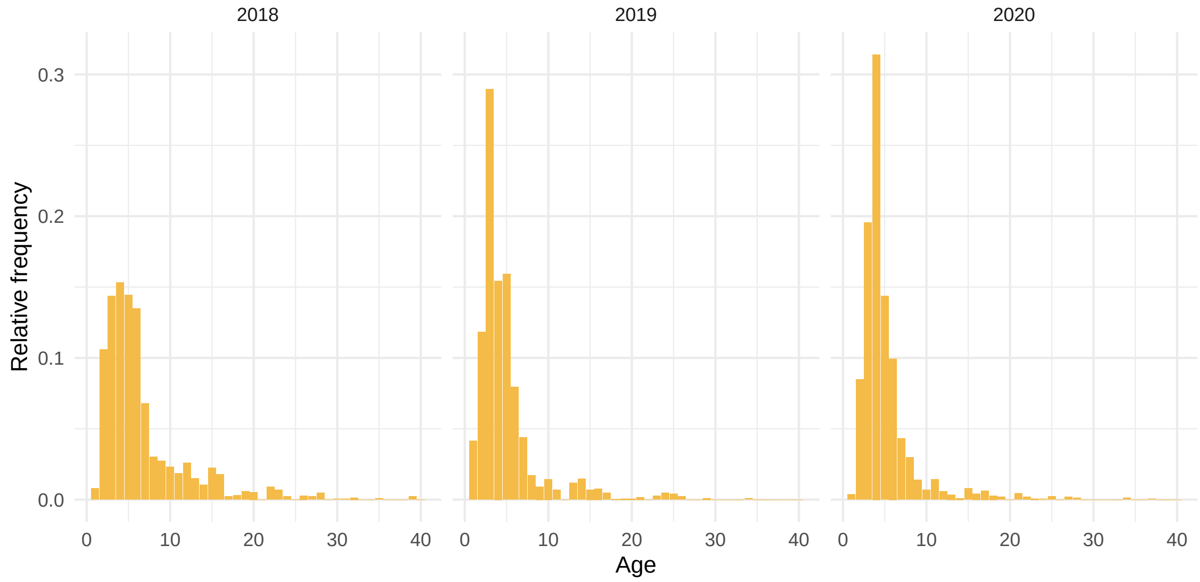

Figure 3.4: Annual age compositions of female saddletail snapper for line-caught fish between 2018 and 2020

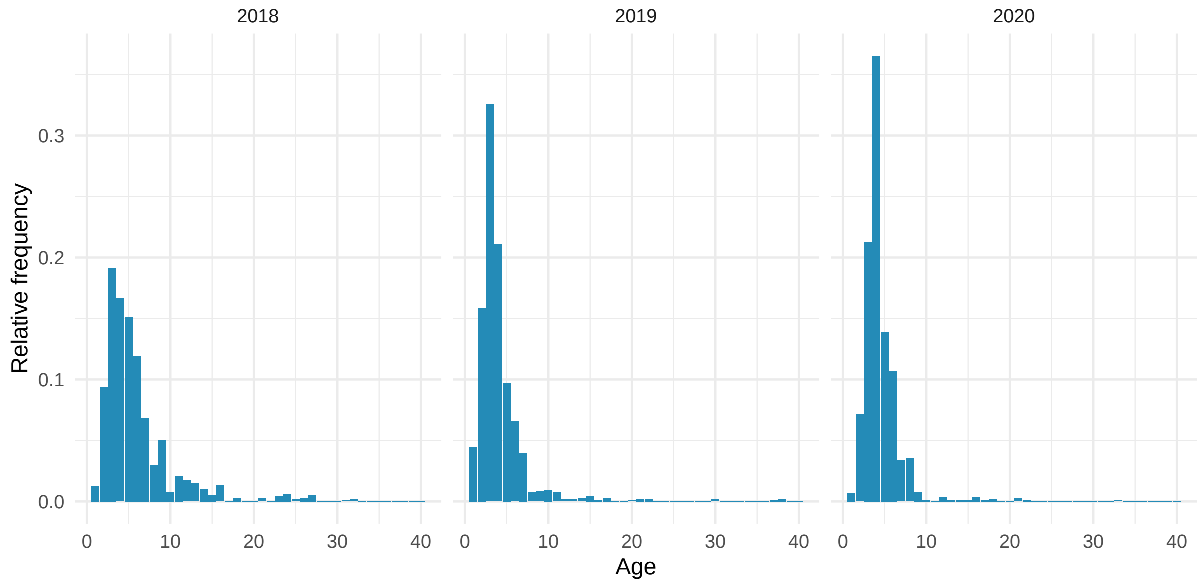

Figure 3.5: Annual age compositions of male saddletail snapper for line-caught fish between 2018 and 2020

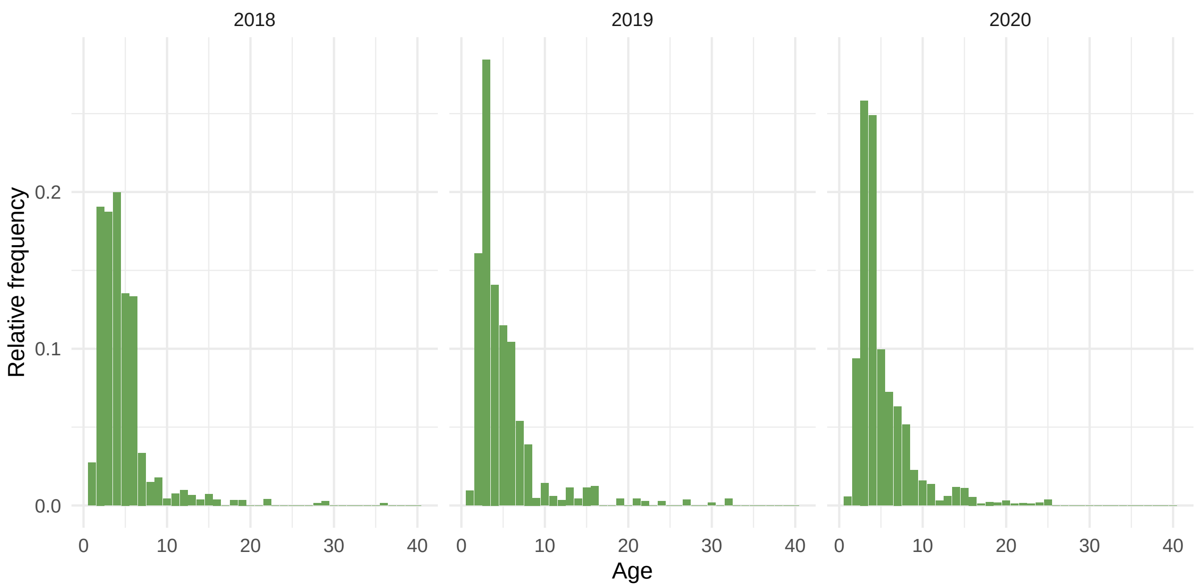

Figure 3.6: Annual age compositions of sex-unknown saddletail snapper for line-caught fish between 2018 and 2020

3.1.4 Length composition

Fishery length compositions were input to the population model for the commercial fleet (Figures 3.7–3.9) and the recreational fleet (Figures 3.10 and 3.11). Discarded recreational length compositions were generated using the method described in Section 2.4.

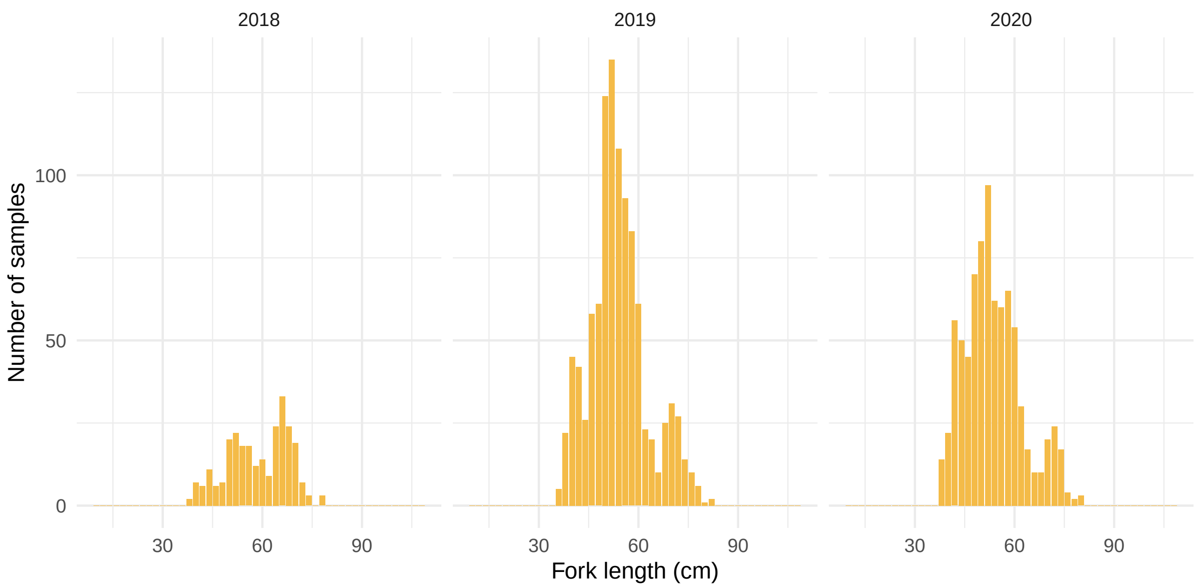

Figure 3.7: Annual length compositions of female saddletail snapper for commercial line-caught fish between 2018 and 2020

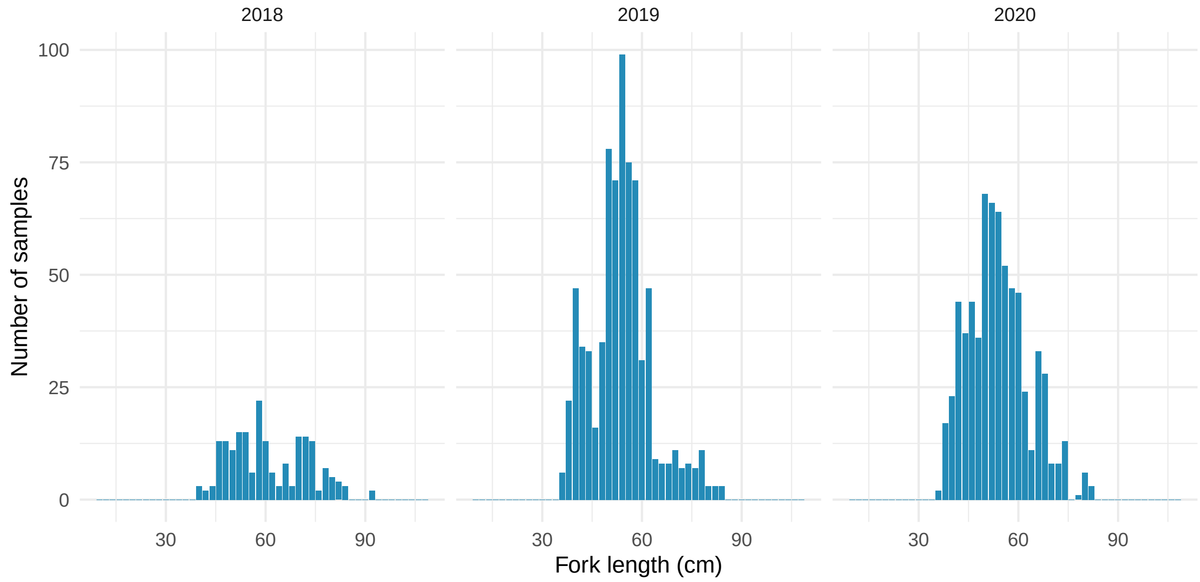

Figure 3.8: Annual length compositions of male saddletail snapper for commercial line-caught fish between 2018 and 2020

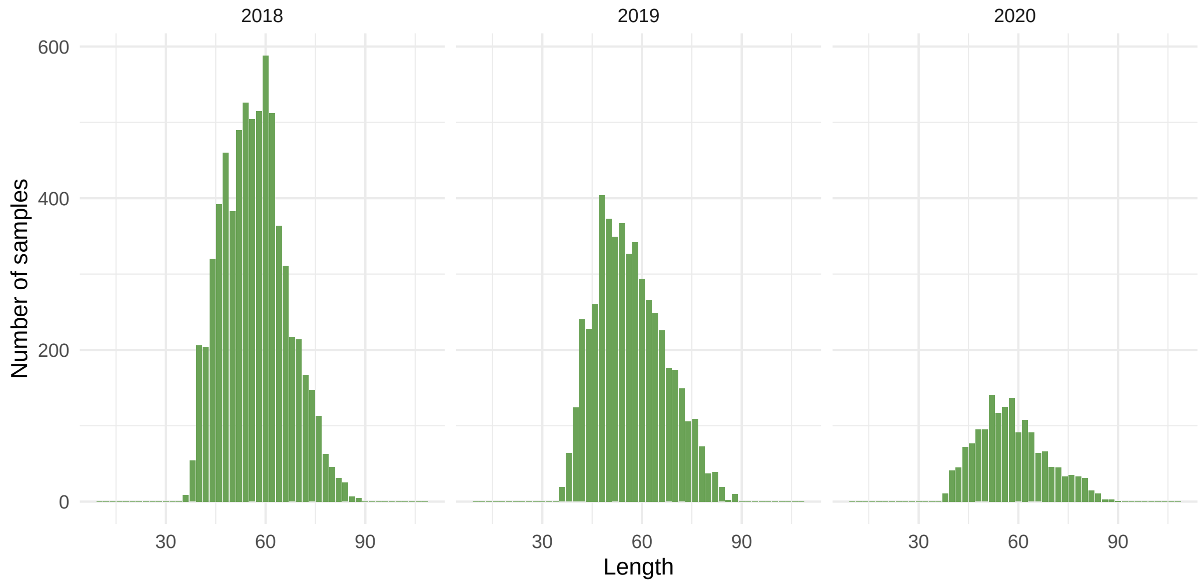

Figure 3.9: Annual length compositions of unknown-sex saddletail snapper for commercial line-caught fish between 2018 and 2020

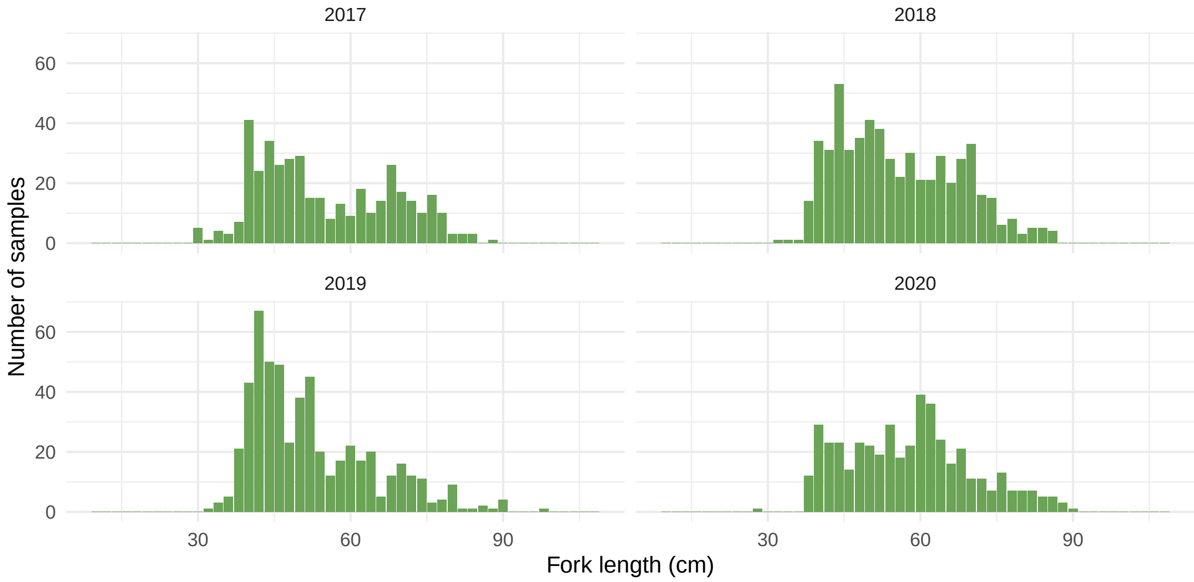

Figure 3.10: Annual length compositions of saddletail snapper for recreational line-caught-and-retained fish between 2017 and 2020

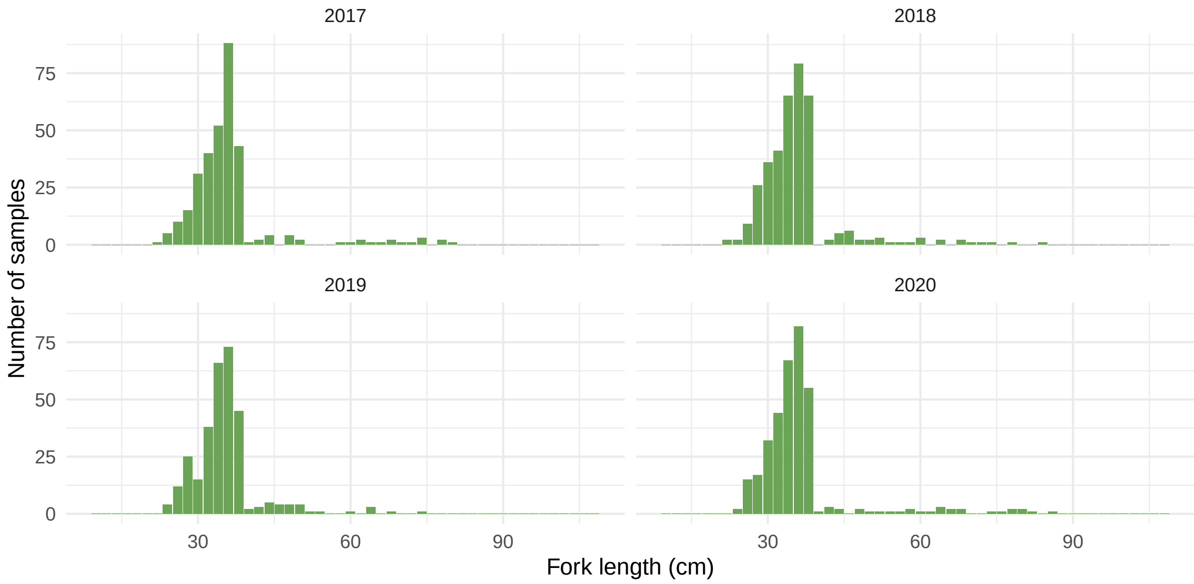

Figure 3.11: Annual estimated length compositions of saddletail snapper for recreational line-caught-and-discarded fish between 2017 and 2020

3.1.5 Discards

The total number of fish discarded for the recreational-charter-Indigenous fleet, input to the model was:

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

Year	Number
2017	44 466
2018	59 459
2019	52 145
2020	46 880

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 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 saddletail snapper from the base population model

Parameter	Estimate	Standard deviation
Natural mortality	0.13	0.01
Length at age 1 female	28.46	0.92
Length at age 35 female	74.42	0.72
von Bertalanffy growth parameter female	0.22	0.01
Coefficient of variation in length at age 1 female	0.18	0.01
Coefficient of variation in length at age 35 female	0.07	< 0.01
Length at age 1 male	25.49	1.00
Length at age 35 male	83.8	0.86
von Bertalanffy growth parameter male	0.21	0.01
Coefficient of variation in length at age 1 male	0.19	0.01
Coefficient of variation in length at age 35 male	0.06	< 0.01
Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1961)	12.47	0.2
Beverton-Holt steepness	0.76	0.06
Commercial selectivity inflection (cm)	43.78	1.17
Commercial selectivity width (cm)	7.24	1.69
Recreational selectivity inflection (cm)	28.32	0.68
Recreational selectivity width (cm)	4.54	0.82

The sixteen scenarios in Figure 3.15 (scenarios 1–9, 11–13, 17 and 19–21) all had parameters that were estimated cleanly (none hit their bounds), and final parameter gradients were small implying no convergence problems. The other five scenarios (Scenarios 10, 14, 15, 16 and 18) all had one or more parameters hit a bound (in particular the Beverton-Holt unfished recruitment parameter wanted to move higher than was plausible given the implication that this has, namely that fishing has had little or no impact on the stock). These scenarios were considered not plausible, and are omitted from Figure 3.15.

Other important categorisations across the full scenario result set include:

- Scenarios 1–5, 10, 13, 17 and 20 assumed catch rates were a single continuous data set, whereas in Scenarios 6–9, 11, 12, 14–16, 18, 19 and 21 catch rate data were split into 2 fleets; either preor post GBR rezoning. Goodness of fit is not markedly better or worse in either group, and no consistent theme emerges with respect to stock status.

- Scenarios 5, 7–9 and 13–16 all had Q_extraSD switched on. These result sets were highly divergent in terms of stock status, depending on the hypothesis on annual recruitment deviations:
  - Scenarios 5, 7, 8 and 9 used a 'short' set of annual recruitment deviations (1981–2015), and all showed stock status below 20% in 2020.
  - Scenarios 13–16 used the 'full' set of deviations (1981–2020), and all showed stock status above 60% in 2020.

  No consistent trend emerges with regards to goodness of fit.
- Scenarios 3 and 4 assumed recreational harvest was half its reported values, and can be compared directly with scenarios 1 and 2. Very little impact on stock status is observed, and very little difference in goodness of fit is observed.
- Scenarios 17–19 set the catch rate error term at a fixed value, whereas all the other scenarios used the error value obtained from the standardised catch rate analysis. Scenarios 17–19 all resulted in stock status above 65% in 2020.

3.2.2 Model fits

Reasonable fits were obtained for all data sets with the exception of the total discard amount (Appendix B.2), and to some extent, the catch rates. As discussed in Section 2.7.3, for the majority of scenarios, close fits to catch rates were not insisted upon. Scenario 11 was an attempt to force a better fit to the discard totals, however it degraded the catch rate fit to the extent that this was not deemed a preferable scenario.

3.2.3 Selectivity

Selectivity of saddletail snapper was estimated within the model. The recreational and commercial fleets had significantly different selectivity (Figure 3.12).

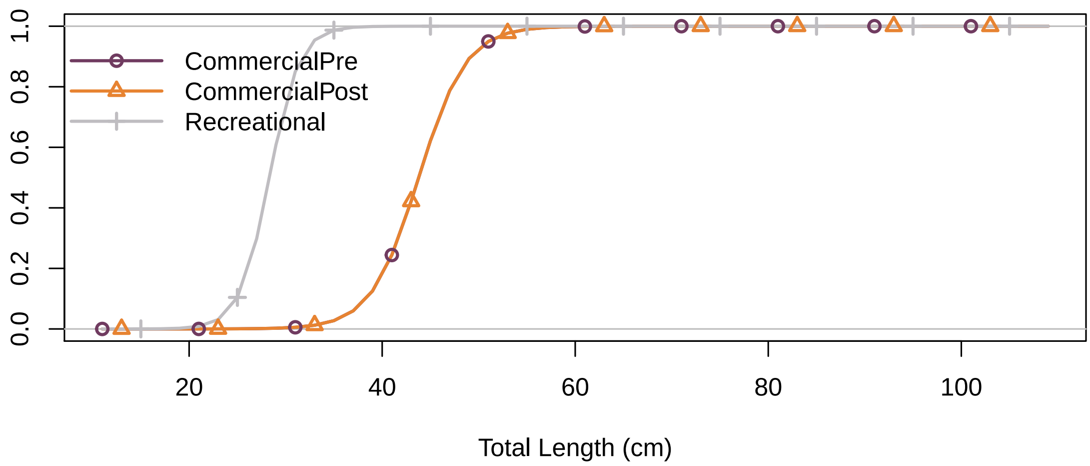

Figure 3.12: Model estimated length-based selectivity for saddletail snapper by fleet in 2020

3.2.4 Growth curve

The von Bertalanffy growth curve, including coefficients of variation of old and young fish, was estimated within the model for both males and females (Table 3.2, Figure 3.13).

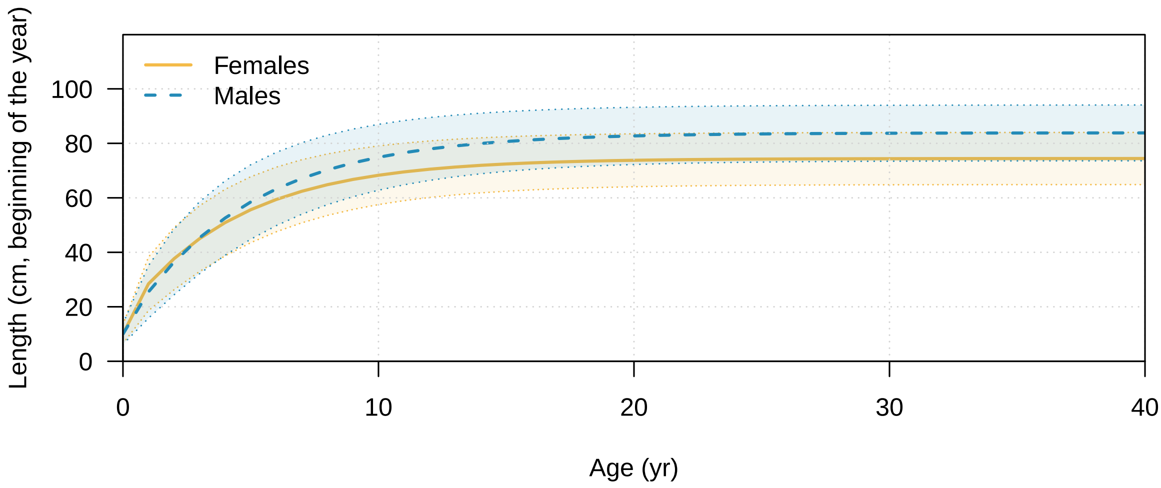

Figure 3.13: Model estimated length-based selectivity for saddletail snapper by sex in 2020

3.2.5 Biomass

The base case model predicted spawning stock biomass declined between 1961 and 2017 to 19% unfished biomass. In 2020, the stock level was estimated to be 23% unfished total biomass (Figure 3.14).

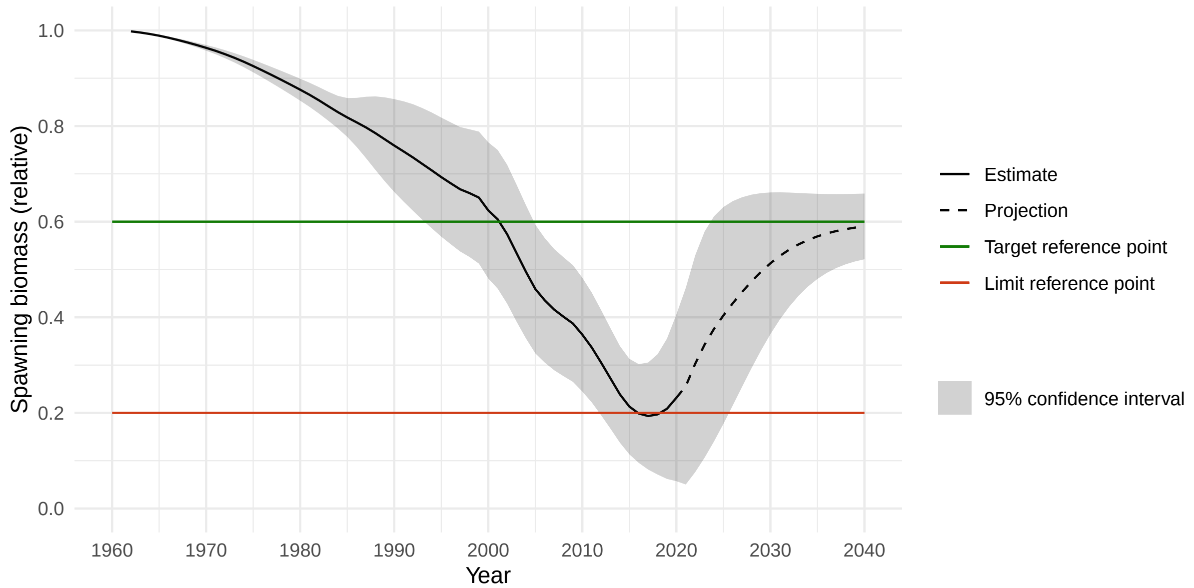

Figure 3.14: Predicted spawning biomass trajectory relative to virgin for saddletail snapper, from 1961 to 2040

Relative biomass trajectories for all sensitivity scenarios that resulted in parameters estimating freely of their bounds are presented in Figure 3.15.

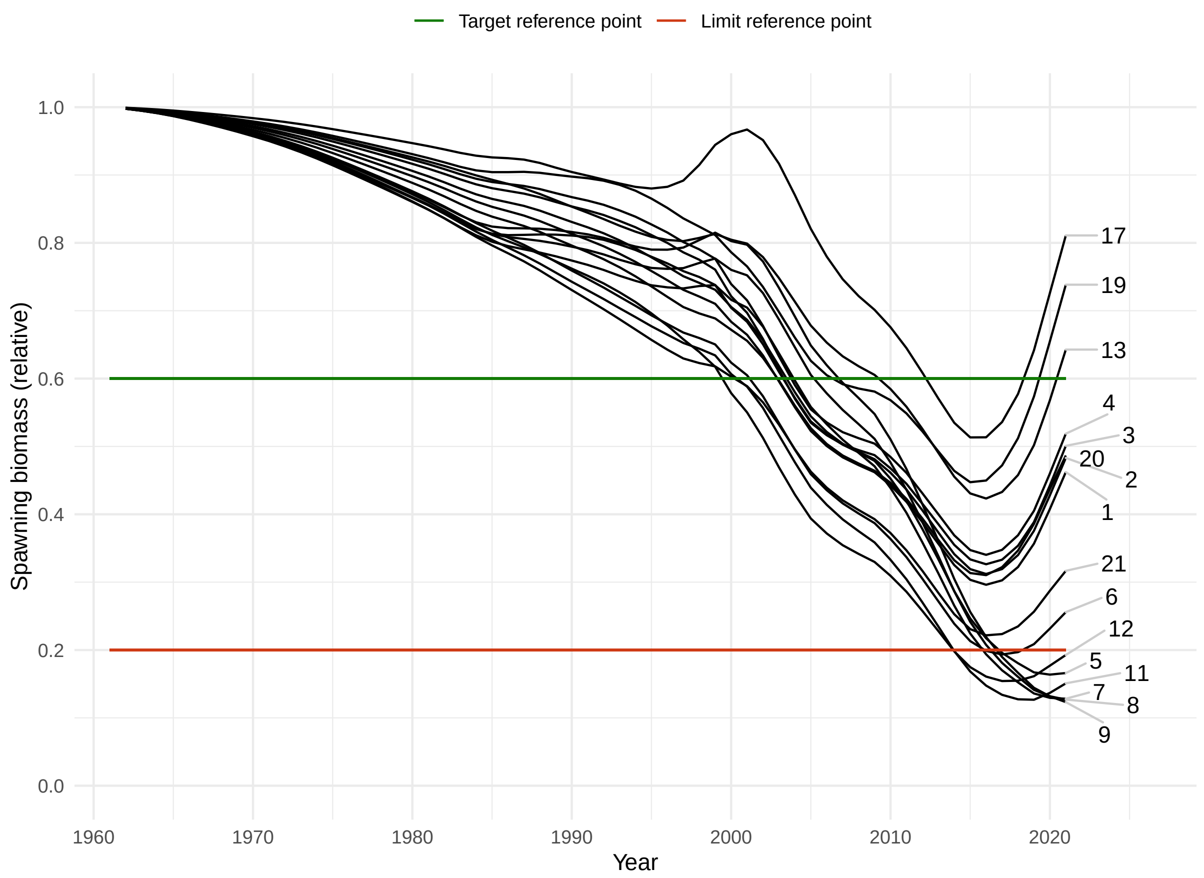

Figure 3.15: Estimated and predicted spawning biomass trajectory relative to virgin for saddletail snapper, from 1961 to 2020, for all sensitivity runs (as described in Section 2.7.4)

The relationship between the biomass estimate and fishing mortality are presented in Appendix B.3.1.

The equilibrium harvest informs on the productivity of the stock at different biomass levels (Figure 3.16).

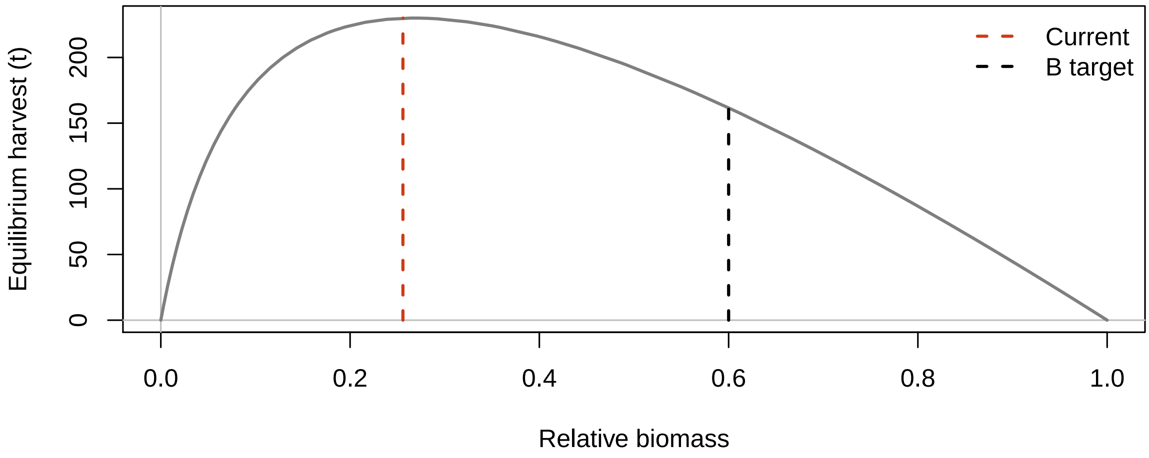

Figure 3.16: Equilibrium harvest curve for saddletail snapper

3.2.6 Harvest targets

Table 3.3: Estimated total harvests and biomass ratios of saddletail snapper for the base case to rebuild and maintain the stock at the target reference point of 60% unfished spawning biomass, following the harvest control rule

Year	Harvest (t)	Biomass ratio
2021	12	0.26
2022	24	0.3
2023	37	0.34
2024	48	0.38
2025	59	0.4
2026	70	0.43
2027	81	0.45
2028	92	0.48
2029	102	0.5
2030	111	0.51
2031	119	0.53
2032	126	0.54
2033	132	0.55
2034	137	0.56
2035	141	0.57
2036	145	0.58
2037	147	0.58
2038	150	0.58
2039	152	0.59
2040	153	0.59

4 Discussion

4.1 Stock status

These base case results discussed below should be considered in the context of significant stock status variation amongst the full suite of scenarios investigated. Results from this assessment suggest the saddletail snapper population on the Queensland east coast experienced a large decline in the period 1961–2017, followed by a short period of recovery. All models except for scenarios 5, 7, 8 and 9 display recent recovery. It is not possible to identify the cause of such a recovery from the model. The current (2020) population level is around 23% of unfished biomass.

The results suggest that catch levels have been in excess of those consistent with a 60% biomass target (159 tonnes) since before 1990. Management reforms appear necessary to rebuild the stock.

4.2 Performance of the population model

Scenario 6 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.** A relatively small number of fishers catch significant quantities of saddletail. Even for those that do, the extent to which they were actively targeting the fish is unclear. As a result, significant uncertainty is associated with the standardised catch rate trend. A decision was made to ensure this uncertainty flowed through to the population model in most scenarios, and this provided flexibility in how closely the catch rate trends were fit, which translated into several different fitting 'strategies' and biomass trajectories. The alternative, explored in Scenarios 17–19, was to place greater confidence in the catch rate by setting the catch rate error term at a lower fixed value. Neither approach is necessarily superior, however the wide range of outcomes across the sixteen scenarios that had all their parameters successfully estimated is likely a reasonable reflection of the uncertainty range of the assessment. Three sub-components of catch rate uncertainty include:
  - Influence of the GBR rezoning and the introduction of ITQ on catch rates. Was this a temporary impact or did it result in a persistent behavioural shift?
  - Influence of the catchability standard deviation parameter on data set weighting. This parameter can be used to automatically 'tune' the closeness of the catch rate fit, however due to the large baseline standard deviation (taken from the output of the catch rate standardisation procedure) it merely served to highlight the sensitivities involved. In particular, when the parameter was switched on, biomass ratio was strongly dependent on which of two equally plausible hypotheses on recruitment deviations was active: a 'short' recruitment deviation hypothesis (with deviations finishing in 2015) led to biomass ratios all below 20% in 2020, whereas the 'full' hypothesis (deviations finishing in 2020) led to biomass ratios all above 60% in 2020. For this reason scenarios with catchability standard deviation switched on were not considered suitable candidates for the base case choice.
  - Influence of fishing power on catch rates. Has fishing power been rising in ways not captured through the current standardisation?
- **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 con-

cern 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, and 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.

The sixteen scenarios in Figure 3.15 all performed well in the following ways: 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.

While sixteen 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.

4.3 Unmodelled influences

There are a number of possible drivers of the saddletail snapper population that have not been directly modelled due to a lack of available data, but which should be taken into consideration when interpreting model outputs, future management arrangements and future research needs.

- **Climate change.** Saddletail snapper are not solely reef-associated, nor known to be dependent on live coral cover. They are thus thought to be less vulnerable to coral bleaching and other forms of climate-induced coral reef degradation as, for example, coral trout. However, climate change related habitat degradation of deep inter-reefal areas has not been investigated, and loss of coral habitat and complexity may lead to reductions in fisheries productivity in generalised reef fish assemblages (Rogers et al. 2017).
  It is also possible that increases in sea surface temperature will affect growth, recruitment, reproduction and mortality rates. While the precise mechanisms by which climate change may impact saddletail snapper remain unclear, and any impacts to date remain unquantified[1], this is an additional source of uncertainty that needs to be taken into account.
- **Regional variation in demography.** Management and conservation efforts are often based upon limited information from only a portion of a species' range, or at best a combination of spatially limited studies (Cappo et al. 2013; Williams et al. 2006). 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). Regional variation in age-based demographics were not modelled in this assessment and are another source of uncertainty that needs to be taken into account. At the time of this assessment no data were available to confirm or deny regional variation exists for saddletail snapper. Current research is investigating this question to better inform future assessments.
- **Shark depredation.** Shark depredation 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 and can also refer to 'post-release predation' where released fish are taken (Mitchell et al. 2018). Neither form of depredation has been explicitly modelled in this assessment. While there are numerous

[1] A recent study by Brown et al. (2020) explored the potential impact of a 'productivity decline', such as might result from coral reef degradation, for a range of coral reef species including saddletail snapper. The use of surplus production models and raw catch rates limit the inferences that can be drawn, and moves the bulk of the explanatory work onto the choice of prior for productivity. It is interesting to note that while the *Lutjanidae* family from which the prior was taken, based on the meta-analysis by Thorson (2020), produced a 'low' productivity, the same family had a 'high' steepness, highlighting the importance of age data and explicitly age-structured population models.

anecdotal reports of sharks taking fish whilst they are being landed, there is no quantitative data at this stage. This is only an issue for 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. Both are likely to have occurred to some extent, and this is an additional source of uncertainty to be considered.

- **Fishing power.** As mentioned above, increases in fishing power beyond those that were incorporated implicitly through the current catch rate standardisation variables (in particular fisher and number of crew) have not been modelled.
- **Zoning.** While some attempt has been made to capture the impact of the 2004 GBRMP rezoning through hypotheses on catch rates (see Table 2.3 and scenarios with 'Split' or 'Post' in the 'Rezoning' column), there has been no explicit modelling of any spatial variation in population dynamics that may have arisen as a result of the rezone, nor of the impact of spatial changes in availability from the perspective of the fishery.

4.4 Recommendations

4.4.1 Research and monitoring

The biological age and length monitoring data have been invaluable and without them the assessment would not have been possible. Another two years of samples from these programs under the same survey design parameters should narrow the overall stock status uncertainty appreciably. Recreational catch rates derived from the boat ramp survey data may also be helpful in this regard.

A key missing data component is information on the size distribution of discards, which is needed to inform the way fishing mortality affects different cohorts.

A study on the effects of fishing power on the abundance of Reef OS species would improve the catch rate standardisation in future assessments.

Accurate saddletail snapper harvest weights (using calibrated scales) for each reef-line trip would also significantly improve data for future assessments. Currently this is not possible because for the purposes of quota, Reef OS is considered a single entity and only a single weight is recorded during unload regardless of the combined Reef OS species composition.

Shark depredation and the potential impacts of temperature change are also important areas of focus for future research.

4.4.2 Management

Considering that the biomass estimates ranged from 13% to 73%, caution is recommended when applying assessment outputs into the management process. The results from this stock assessment should not be the sole information considered when discussing management options. Uncertainty will be reduced in future years when more length and age data become available, and the assessment recommendations are implemented.

With regards to the commercial sector, there is no species-specific ITQ for saddletail snapper, however there are a number of other management measures already in place which could be adapted to allow for the recovery of the saddletail snapper stock. The evidence presented in this assessment suggests that the recreational sector is a more significant contributor to overall saddletail snapper fishing mortality and this should be taken into account when considering any management changes.

Given that about 50% of saddletail snapper are mature around 58 cm FL (Figure A.2), a significant increase in the MLS may be warranted, however, this species suffers high levels of baratruma related discard mortality (Brown et al. 2008), which may offset the benefits of a size-limit increase.

4.4.3 Assessment

Future assessment 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. Key to this is the question of targeting—has a fish been caught because specific efforts were made to target saddletail snapper, or was it caught incidentally? During this assessment two commercial fishers shared their targeting knowledge and expertise directly through a structured feedback session. For this targeting information to be incorporated into catch-rate modelling it would have to be set within a protocol that balanced the effort-verified, low sample size data sets against the unverified, higher sample size current data. This may be the only reliable way to get an informed picture of saddletail-specific (and Reef OS in general) effort and should be pursued.
- **Parameter sensitivity and full Bayesian posteriors.** Even if catch rate confidence can be increased it seems likely that a full Bayesian posterior will display marked differences between mode, mean and median. It is recommended that the next assessment uses posterior integration techniques to produce a full posterior to bring greater transparency to this issue. The point of maximum posterior probability *density* (from which all current model outputs are derived) is not necessarily where the weight of probabilistic evidence sits.
- **Discard mortality.** Discard mortality fits were relatively poor and more work is needed here. As noted above, a key missing element is an understanding of the size-distribution of discards, but even with the information currently available more sensitivity runs and alternative discard modelling setups should be considered in the next assessment.
- **Age data.** Neither age class nor age group are ideal for direct input to a population model as they fail to account for intra-annual recruitment delays. An alternate age estimate that accounts for the delay between sampling year and recruitment is something that should be considered for the next assessment.
- **Regional demography.** Finally, if more data are available on regionally varying demographics this should be investigated, either for improved regional data set weighting or potentially for incorporating spatial structure in the population model itself.

4.5 Conclusions

This assessment was commissioned to estimate the current biomass of saddletail snapper on Queensland's east coast and inform the Sustainable Fisheries Strategy. The base case model scenario suggested biomass is currently around 23% of unfished levels and that the stock is in need of rebuilding. Significant uncertainty is associated with this conclusion, evidenced by the wide range of current biomass predictions (13–73%) across sixteen plausible model scenarios. This assessment should not be the only information considered when discussing management options.

References

Allen, G. R. (1985). *Snappers of the world: an annotated and illustrated catalogue of* Lutjanid *species known to date*. Rome: Food and Agriculture Organization of the United Nations.

BDO EconSearch (2020). *Economic and Social Indicators for the Queensland Coral Reef Fin Fish Fishery, 2017/18 and 2018/19*. A report to Fisheries Queensland. Adelaide.

Bergenius, M. A. J. (2007). "Stock structure of a coral reef fish, *Plectropomus leopardus*: identification and implications for harvest strategy evaluation". PhD thesis. James Cook University.

Brown, C. J., W. Taylor, C. C. C. Wabnitz and R. M. Connolly (2020). "Dependency of Queensland and the Great Barrier Reef's tropical fisheries on reef-associated fish". In: *Scientific reports* 10.1, pp. 1–11.

Brown, I. W., W. D. Sumpton, M. F. McLennan, D. J. Welch, J. M. Kirkwood, A. R. Butcher, A. Mapleston, D. G. Mayer, G. A. Begg, M. D. Campbell, I. Halliday and W. Sawynok (2008). *National Strategy for the Survival of Released Line-caught Fish: Tropical Reef Species*. Final report of FRDC project 2003/019. Brisbane: Queensland Department of Primary Industries and Fisheries.

Brown-Peterson, N. J., D. M. Wyanski, F. Saborido-Rey, B. J. Macewicz and S. K. Lowerre-Barbieri (2011). "A standardized terminology for describing reproductive development in fishes". In: *Marine and Coastal Fisheries* 3.1, pp. 52–70.

Campbell, A. B., M. F. O'Neill, J. Staunton-Smith, J. Atfield and J. Kirkwood (2012). *Stock assessment of the Australian East Coast Spanish mackerel (*Scomberomorus commerson*) fishery*. Brisbane: Queensland Department of Agriculture, Fisheries and Forestry.

Cappo, M., R. J. Marriott and S. J. Newman (2013). "James's rule and causes and consequences of a latitudinal cline in the demography of John's Snapper (*Lutjanus johnii*) in coastal waters of Australia". In: *Fishery Bulletin* 111.4, pp. 309–324.

Carpenter, K. E. (2001). "*Lethrinidae*. Emperor (emperor snappers)". In: *FAO Species identification guide for fishery purposes. The living marine resources of the Western Central Pacific. Vol 5: Bony Fishes Part 3 (*Menidae *to* Pomacentridae*)*. Ed. by K. E. Carpenter and Niem V. Rome: Food and Agriculture Organization of the United Nations, pp. 2791–3380.

Carter, A. B., C. R. Davies, M. J. Emslie, B. D. Mapstone, G. R. Russ, A. J. Tobin and A. J. Williams (2017). "Reproductive benefits of no-take marine reserves vary with region for an exploited coral reef fish". In: *Scientific reports* 7.1, pp. 1–12.

Carter, A. B., C. R. Davies, B. D. Mapstone, G. R. Russ, A. J. Tobin and A. J. Williams (2014). "Effects of region, demography, and protection from fishing on batch fecundity of common coral trout (*Plectropomus leopardus*)". In: *Coral Reefs* 33.3, pp. 751–763.

Chang, W., J. Cheng, J. J. Allaire, Y. Xie and J. McPherson (2020). *shiny: Web Application Framework for R*. URL: `https://CRAN.R-project.org/package=shiny`.

Elliott, N. G. (1996). "Allozyme and mitochondrial DNA analysis of the tropical saddle-tail sea perch, *Lutjanus malabaricus* (Schneider), from Australian waters". In: *Marine and Freshwater Research* 47.7, pp. 869–876.

Fisheries Queensland (2017a). *Fisheries Queensland Boat Ramp Survey Sampling Protocol: Section 2*. Brisbane: Queensland Department of Agriculture and Fisheries.

— (2017b). *Queensland Sustainable Fisheries Strategy 2017-2027*. Queensland Department of Agriculture and Fisheries.

Fisheries Queensland (2020). *Coral Reef Fin Fish Fishery (Line Fishery Reef): Status report for reassessment and approval under protected species and export provisions of the Environment Protection and Biodiversity Conservation Act 1999*. Queensland Department of Agriculture and Fisheries.

— (2021). *Draft Harvest Strategy Policy*. URL: `https://daf.engagementhub.com.au/draft-harvest-strategy-policy` (visited on 25/06/2021).

Francis, R. I. C. C. (2011). "Data weighting in statistical fisheries stock assessment models". In: *Canadian Journal of Fisheries and Aquatic Sciences* 68.6, pp. 1124–1138.

Fry, G. C. and D. A. Milton (2009). "Age, growth and mortality estimates for populations of red snappers *Lutjanus erythropterus* and *L. malabaricus* from northern Australia and eastern Indonesia". In: *Fisheries Science* 75.5, pp. 1219–1229.

Hamel, O. S. (2015). "A method for calculating a meta-analytical prior for the natural mortality rate using multiple life history correlates". In: *ICES Journal of Marine Science* 72, pp. 62–69.

Henry, G. W. and J. M. Lyle (2003). *The National Recreational and Indigenous Fishing Survey*. FRDC project 99/158. Canberra: Australian Government Department of Agriculture, Fisheries and Forestry.

Higgs, J., L. Olyott and K. McInnes (2007). *Experimental Results from the Third Statewide Recreational Fishing Information System Diary Program (2002)*. Brisbane: Queensland Department of Primary Industries and Fisheries.

Jones, C. M. and K. Derbyshire (1988). "Sampling the demersal fauna from a commercial penaeid prawn fishery off the central Queensland coast". In: *Memoirs of the Queensland Museum* 25.2, pp. 403–415.

Lawson, A. (2015). *An Investigative Analysis of Queensland's Statewide Recreational Fishing Surveys: Identifying Bias in Self-reported Catch and Effort Data*. Brisbane: Department of Agriculture and Fisheries.

McInnes, K. (2008). *Experimental Results from the Fourth Queensland Recreational Fishing Diary Program (2005)*. Brisbane: Department of Primary Industries and Fisheries.

McLeay, L. J., G. K. Jones and T. M. Ward (2002). *National strategy for the survival of released line-caught fish: a review of research and fishery information*. FRDC report 2001/101. South Australian Research and Development Institute (Aquatic Sciences).

McPherson, G. R. and L. Squire (1992a). "Age and growth of three dominant *Lutjanus* species of the Great Barrier Reef inter-reef fishery". In: *Asian Fisheries Science* 5.1, pp. 25–36.

McPherson, G. R., L. Squire and J. O'Brien (1992b). "Reproduction of three dominant Lutjanus species of the Great Barrier Reef inter-reef fishery". In: *Asian Fisheries Science* 5.1, pp. 15–24.

Methot, R. D., C. R. Wetzel, I. G. Taylor and K. Doering (2020). Stock Synthesis *User Manual: Version 3.30.15*. NOAA Processed Report NMFS-NWFSC-PR-2020-05. U.S. Department of Commerce.

Mitchell, J. D., D. L. McLean, S. P. Collin and T. J. Langlois (2018). "Shark depredation in commercial and recreational fisheries". In: *Reviews in Fish Biology and Fisheries* 28.4, pp. 715–748.

Morgan, M. G. (2014). "Use (and abuse) of expert elicitation in support of decision making for public policy". In: *Proceedings of the National academy of Sciences* 111.20, pp. 7176–7184.

Newman, S. J. (2002). "Growth rate, age determination, natural mortality and production potential of the scarlet seaperch, *Lutjanus malabaricus* Schneider 1801, off the Pilbara coast of north-western Australia". In: *Fisheries Research* 58.2, pp. 215–225.

Newman, S. J., M. Cappo and D. M. Williams (2000). "Age, growth, mortality rates and corresponding yield estimates using otoliths of the tropical red snappers, *Lutjanus erythropterus*, *L. malabaricus* and *L. sebae*, from the central Great Barrier Reef". In: *Fisheries Research* 48.1.

Northrop, A., M. F. O'Neill, G. M. Leigh and C. Lunow (2018). *Monitoring requirements for common coral trout*. Brisbane: Queensland Department of Agriculture and Fisheries.

O'Neill, M. F., G. M. Leigh, J. M. Martin, S. J. Newman, M. S. Chambers, C. M. Dichmont and R. C. Buckworth (2011). *Sustaining productivity of tropical red snappers using new monitoring and reference points*. FRDC Project 2009-037. Brisbane: Queensland Department of Employment, Economic Development and Innovation.

Platten, J. and B. Sawynok (2007). *Tagged fish recaptures, movement and growth: Tagging of key reef species in Central Queensland*. Infofish Services.

R Core Team (2020). *R: A language and environment for statistical computing*. Vienna. URL: `http://www.R-project.org/`.

Rogers, A., J. L. Blanchard and P. J. Mumby (2017). "Fisheries productivity under progressive coral reef degradation". In: *Journal of Applied Ecology* 55.3, pp. 1041–1049.

Salini, J. P., J. R. Ovenden, R. Street, R. Pendrey, Haryanti and Ngurah (2006). "Genetic population structure of red snappers (*Lutjanus malabaricus* Bloch & Schneider, 1801 and *Lutjanus erythropterus* Bloch, 1790) in central and eastern Indonesia and northern Australia". In: *Journal of Fish Biology* 68, pp. 217–234.

Taylor, S., J. Webley and K. McInnes (2012). *2010 Statewide Recreational Fishing Survey*. Brisbane: Queensland Department of Agriculture, Fisheries and Forestry.

Teixeira, T., R. Janes and J. Webley (2021). *2019/20 Statewide Recreational Fishing Survey Key Results*. Brisbane: Queensland Department of Agriculture and Fisheries.

Then, A. Y., J. M. Hoenig, N. G. Hall and D. A. Hewitt (2015). "Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species". In: *ICES Journal of Marine Science* 72.1, pp. 82–92.

Thorson, J. T. (2020). "Predicting recruitment density dependence and intrinsic growth rate for all fishes worldwide using a data-integrated life-history model". In: *Fish and Fisheries* 21.2, pp. 237–251.

Webley, J. A. C., K. McInnes, D. Teixeira, A. Lawson and R. Quinn (2015). *Statewide Recreational Fishing Survey 2013–14*. Brisbane: Queensland Department of Agriculture and Fisheries.

Williams, A. J. (2003). "Spatial patterns in population biology of a large coral reef fish: what role can movement play?" PhD thesis. James Cook University Townsville.

Williams, A. J., C. R. Davies and B. D. Mapstone (2006). "Regional patterns in reproductive biology of Lethrinus miniatus on the Great Barrier Reef". In: *Marine and Freshwater Research* 57.4, pp. 403–414.

Williams, D. M. and G. R. Russ (1994). *Review of Data on Fishes of Commercial and Recreational Fishing Interest in the Great Barrier Reef*. Research Publication No. 33. Townsville: Great Barrier Reef Marine Park Authority.

Appendix A Model inputs

A.1 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 saddletail snapper

Year	Boat ramp survey (Length)	LTMP (Length)	LTMP (Age)
2017	721		
2018	934	120	1428
2019	843	146	1321
2020	793	102	1168

A.2 Conditional age-at-length

Conditional age-at-length composition data were input to the population model (Figure A.1).

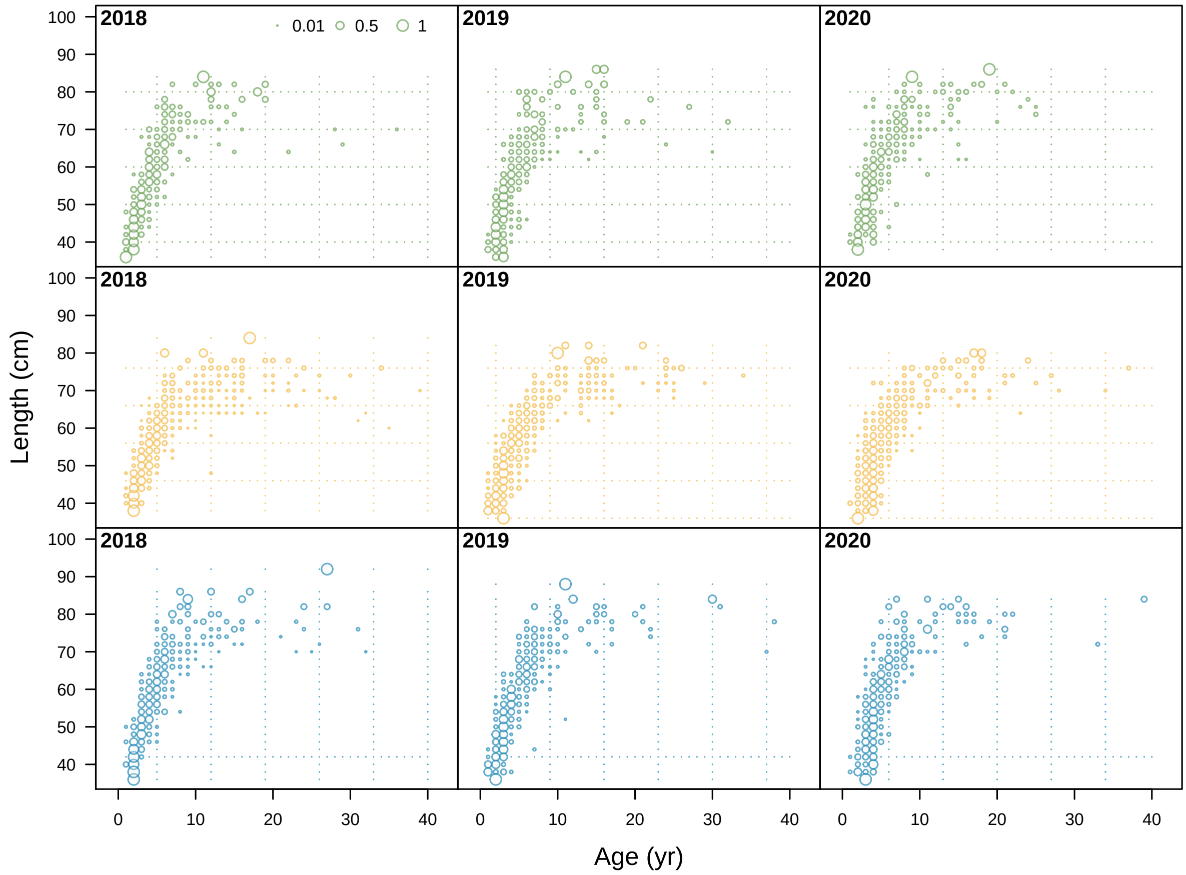

Figure A.1: Conditional age-at-length compositions of saddletail snapper between 2018 and 2020
Note: Circle size is proportional to relative sample size in each bin across rows (i.e. for a given length bin). From top to bottom, the rows represent sex-unknown (green), female (gold) and male (blue).

A.3 Biological data

A.3.1 Fecundity and maturity

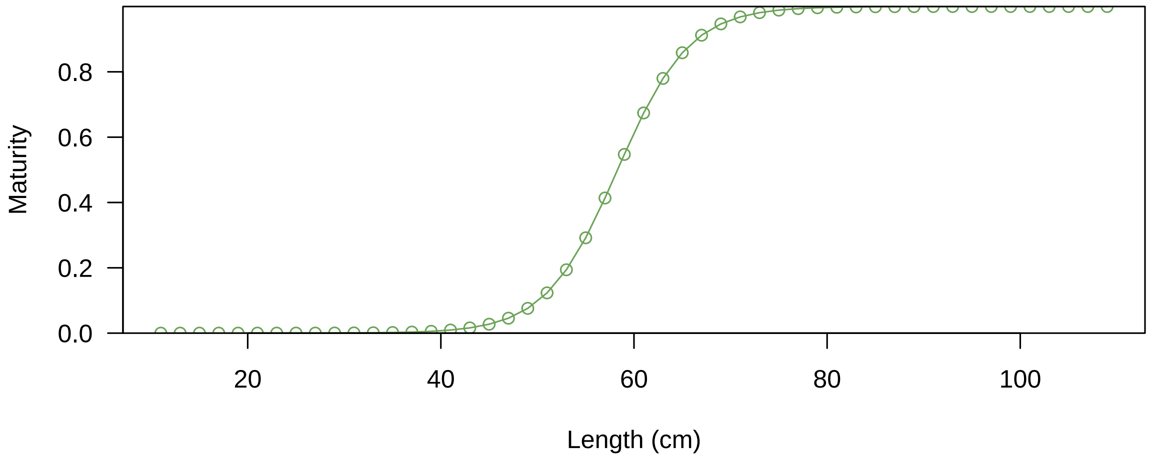

Figure A.2: Maturity at length for saddletail snapper

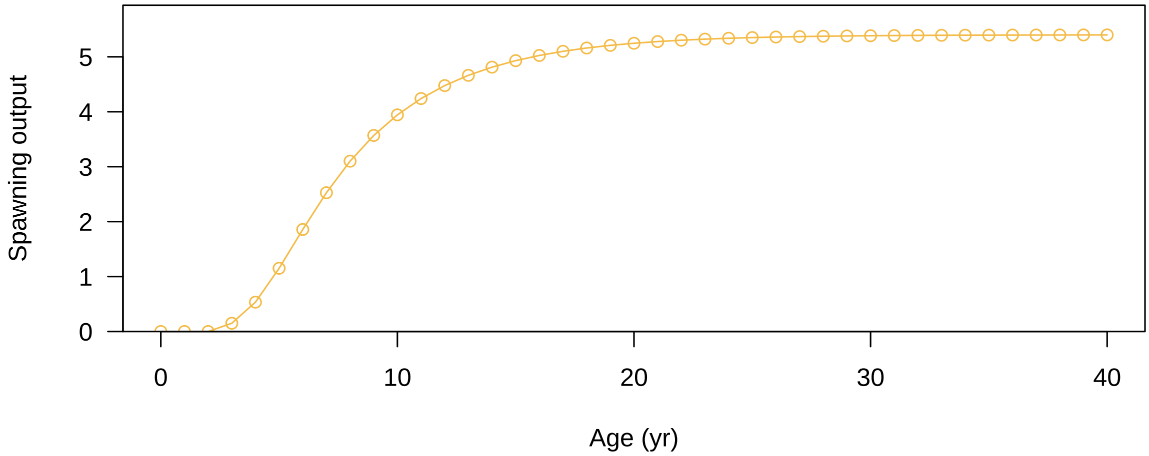

Figure A.3: Spawning output (maturity times fecundity) at age for saddletail snapper

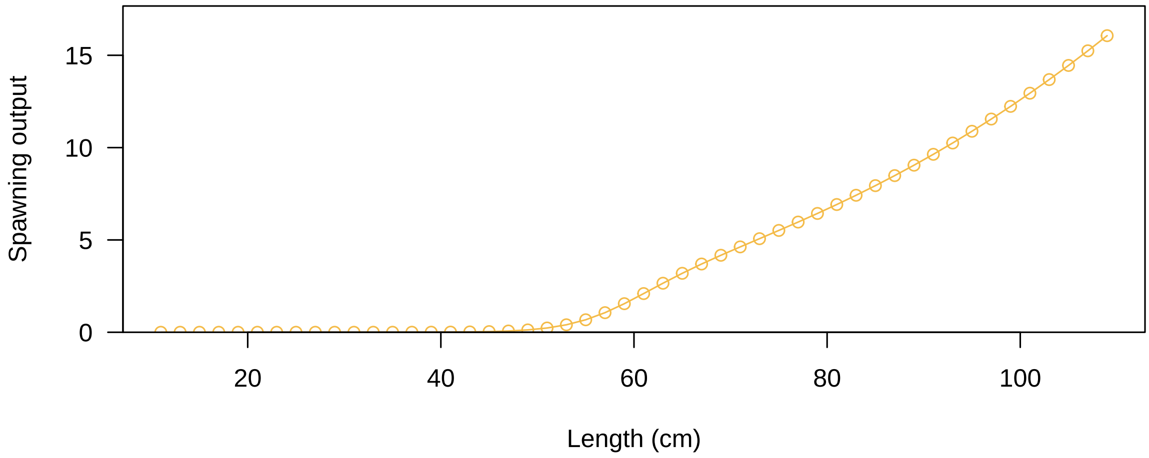

Figure A.4: Spawning output (maturity times fecundity) at length for saddletail snapper

A.3.2 Weight and length

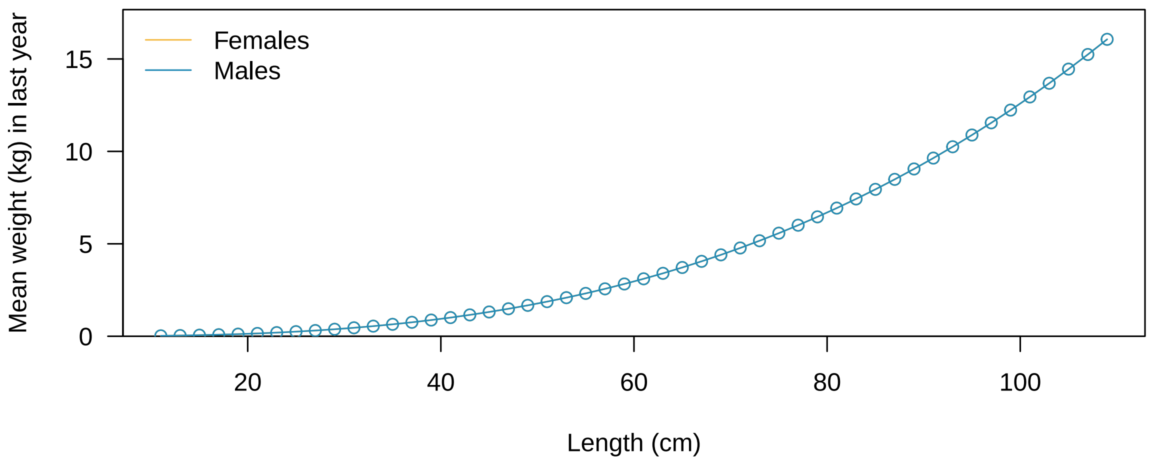

Figure A.5: Weight-length relationship for saddletail snapper

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 saddletail snapper

Stock Synthesis Parameter Label	Explanation
NatM	Natural mortality
L_at_Amin_Fem	Length at age 1 female
L_at_Amax_Fem	Length at age 35 female
VonBert_K_Fem	von Bertalanffy growth parameter female
CV_young_Fem	Coefficient of variation in length at age 1 female
CV_old_Fem	Coefficient of variation in length at age 35 female
L_at_Amin_Mal	Length at age 1 male
L_at_Amax_Mal	Length at age 35 male
VonBert_K_Mal	von Bertalanffy growth parameter male
CV_young_Mal	Coefficient of variation in length at age 1 male
CV_old_Mal	Coefficient of variation in length at age 35 male
SR_LN(R0)	Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1961)
SR_BH_steep	Beverton-Holt steepness
Size_inflection_CommercialPre	Commercial selectivity inflection (cm)
Size_95%width_CommercialPre	Commercial selectivity width (cm)
Size_inflection_Recreational	Recreational selectivity inflection (cm)
Size_95%width_Recreational	Recreational selectivity width (cm)

Biological parameters were estimated within the model for both female and male fish, denoted by ‘Fem’ or ‘Mal’ respectively.

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

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
NatM	0.13	4	0.01	0.5	0.15	0.01
L_at_Amin_Fem	28.46	2	20.00	40.0	30.00	0.92
L_at_Amax_Fem	74.42	2	70.00	90.0	80.00	0.72
VonBert_K_Fem	0.22	2	0.10	0.3	0.20	0.01
CV_young_Fem	0.18	5	0.10	0.3	0.20	0.01
CV_old_Fem female	0.07	5	0.01	0.2	0.10	< 0.01
L_at_Amin_Mal	25.49	2	20.00	40.0	30.00	1.00
L_at_Amax_Mal	83.80	2	70.00	90.0	80.00	0.86
VonBert_K_Mal	0.21	2	0.10	0.3	0.20	0.01
CV_young_Mal	0.19	5	0.10	0.3	0.20	0.01
CV_old_Mal	0.06	5	0.01	0.2	0.10	< 0.01
SR_LN(R0)	12.47	1	10.00	19.0	12.00	0.20
SR_BH_steep	0.76	6	0.20	1.0	0.73	0.06
Size_inflection_CommercialPre	43.78	3	40.00	60.0	50.00	1.17
Size_95%width_CommercialPre	7.24	3	1.00	20.0	8.00	1.69
Size_inflection_Recreational	28.32	3	20.00	45.0	40.00	0.68
Size_95%width_Recreational	4.54	3	0.01	10.0	3.00	0.82

B.2 Goodness of fit

B.2.1 Abundance indices

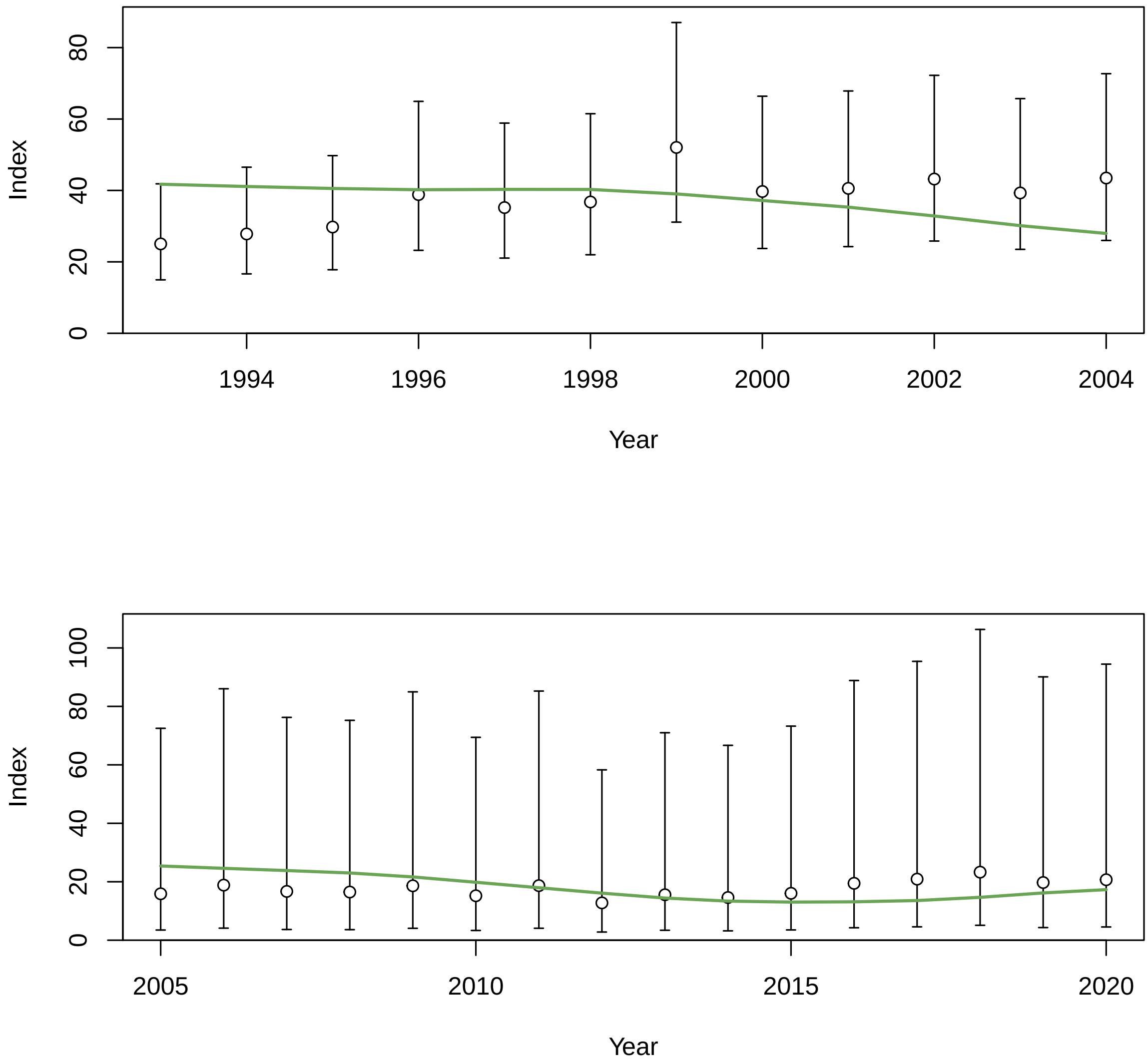

Figure B.1: Model predictions (green line) to commercial catch rates for saddletail snapper

B.2.2 Length compositions

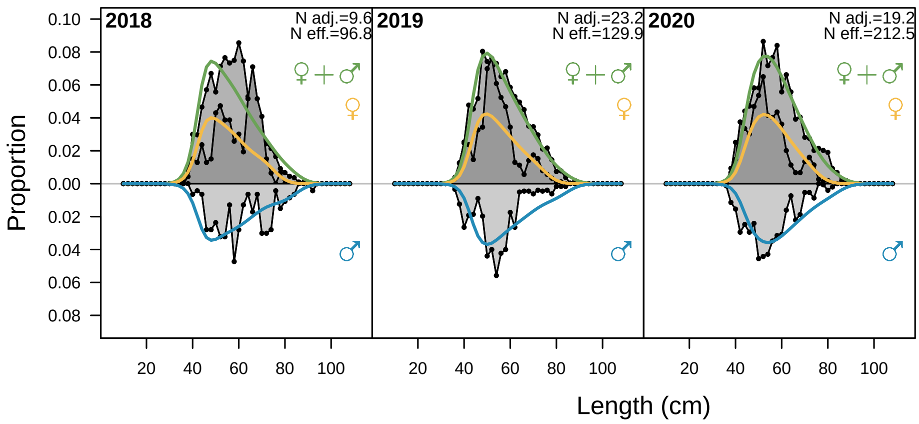

Figure B.2: Length structure for the commercial fleet for saddletail snapper for each sex
'N adj.' is the input sample size after data-weighting adjustment. 'N eff.' is the calculated effective sample size used in the McAllister-Iannelli tuning method

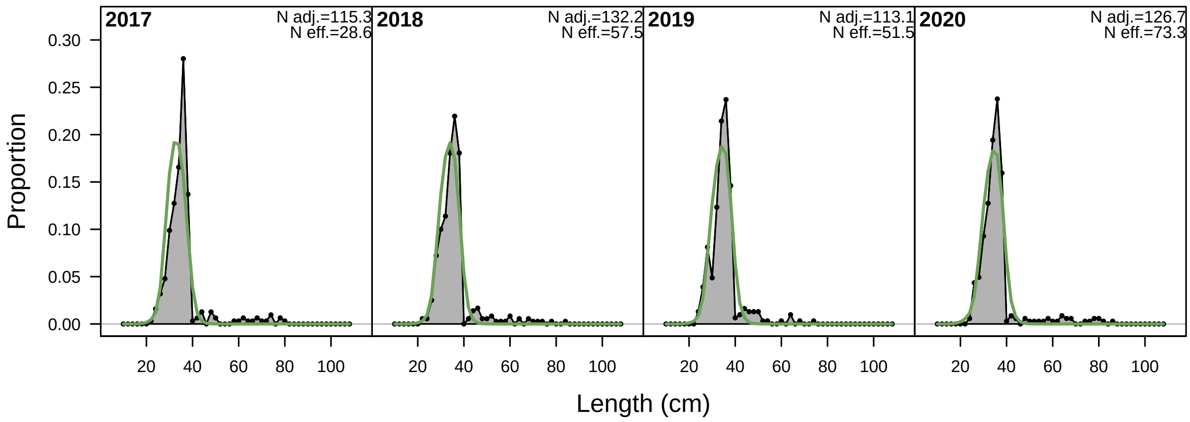

Figure B.3: Length structure for the recreational fleet for discarded saddletail snapper
'N adj.' is the input sample size after data-weighting adjustment. 'N eff.' is the calculated effective sample size used in the McAllister-Iannelli tuning method

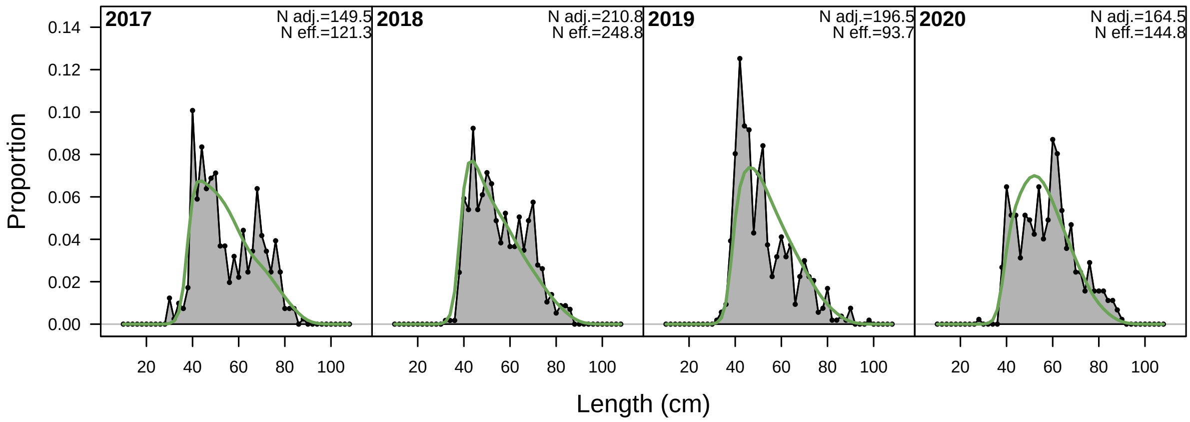

Figure B.4: Length structure for the recreational fleet for retained saddletail snapper
'N adj.' is the input sample size after data-weighting adjustment. 'N eff.' is the calculated effective sample size used in the McAllister-Iannelli tuning method

B.2.3 Age compositions

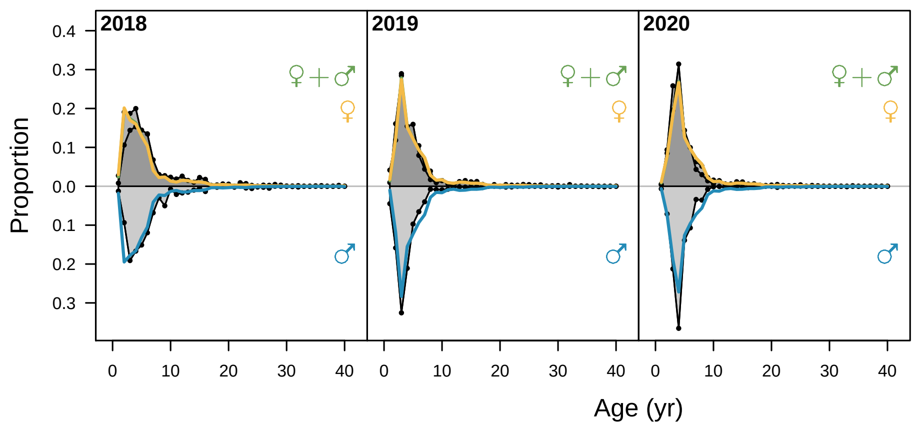

Figure B.5: Age structure for saddletail snapper

B.2.4 Conditional age-at-length compositions

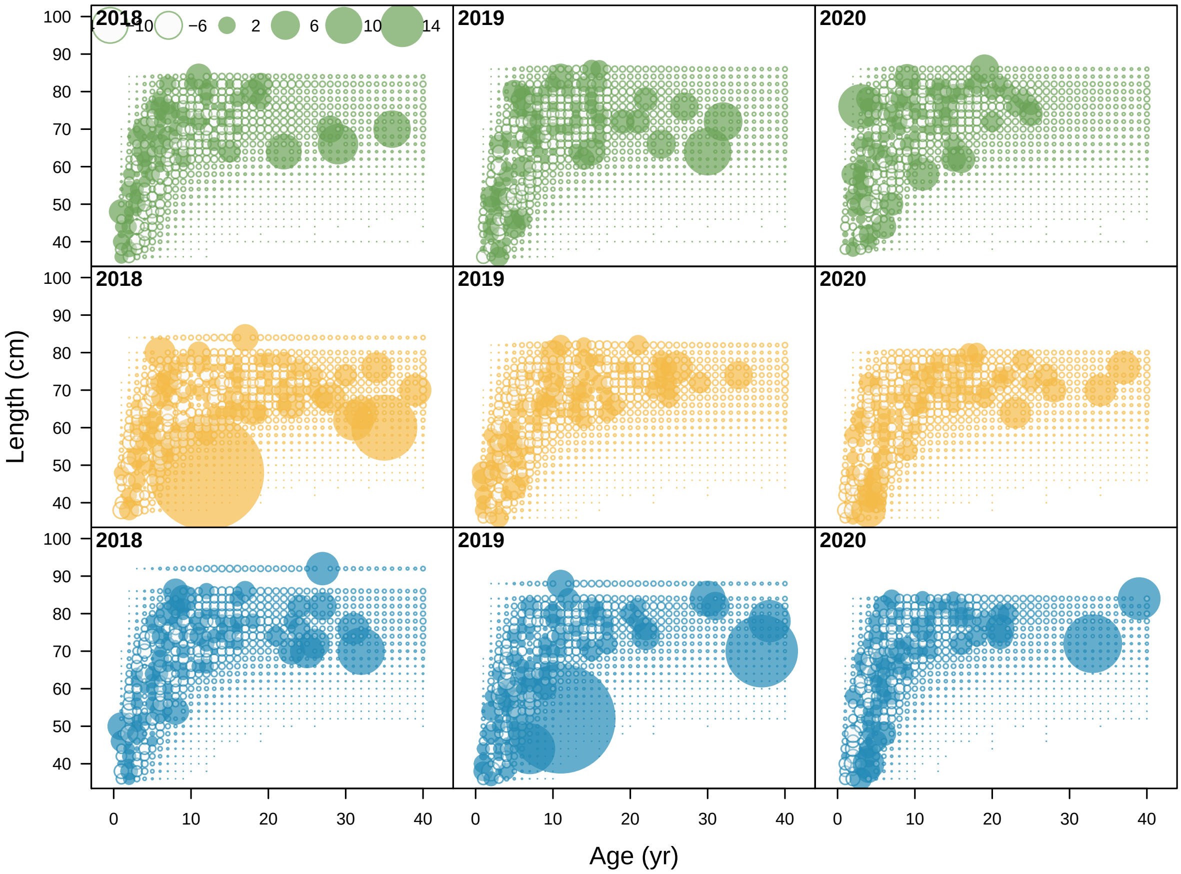

Figure B.6: Pearson residuals for age-at-length compositions for the commercial fleet for saddletail snapper From top to bottom, the rows represent sex-unknown (green), female (gold) and male (blue).

B.2.5 Discard fraction

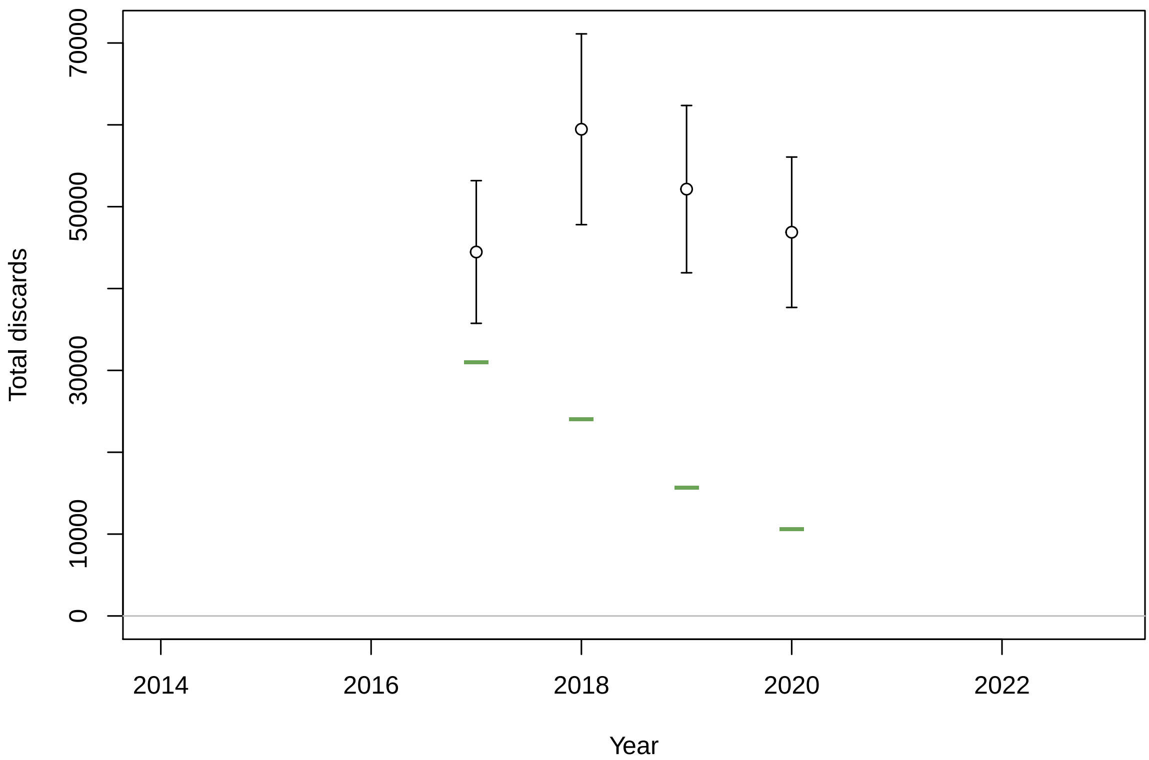

Figure B.7: Model fit to total discards for recreational-charter-Indigenous fleet

B.3 Other outputs

B.3.1 Phase plot

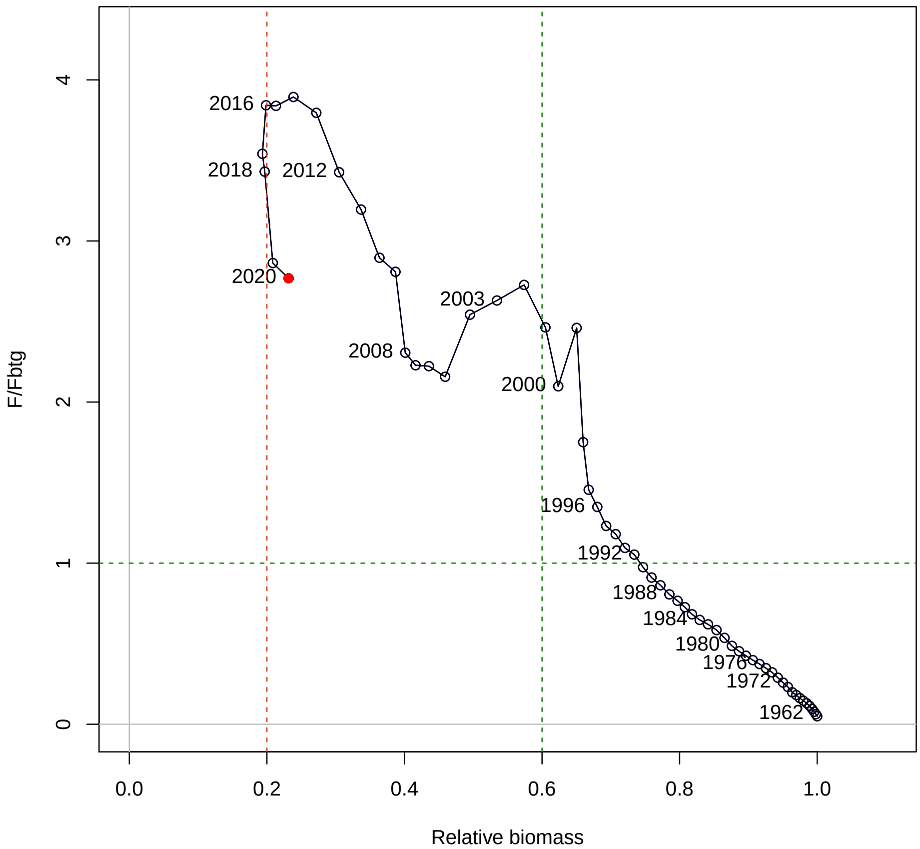

Figure B.8: Phase plot for saddletail snapper

The horizontal axis is the biomass ratio of Queensland saddletail snapper relative to unfished and the vertical axis is the fishing mortality relative to the fishing mortality which would produce the SFS biomass target of 60%. The red dashed vertical line is the limit reference point (20% relative biomass) and the blue dashed vertical line is the target reference point (60% relative biomass)

Appendix C   Sensitivity tests: model outputs

Parameter estimates

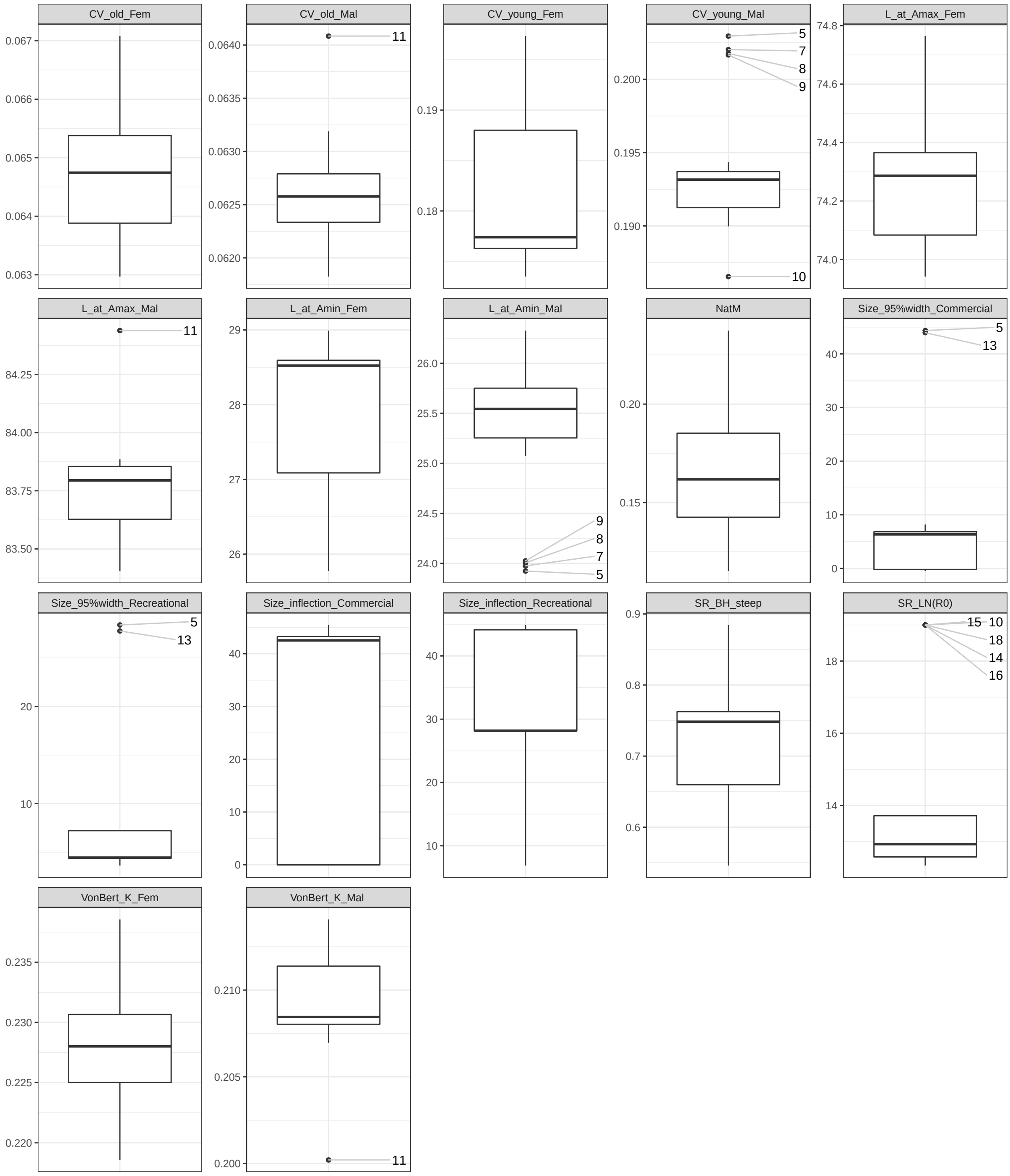

Figure C.1: Visualisation of parameter estimates for all 21 sensitivity tests

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

Scenario 1

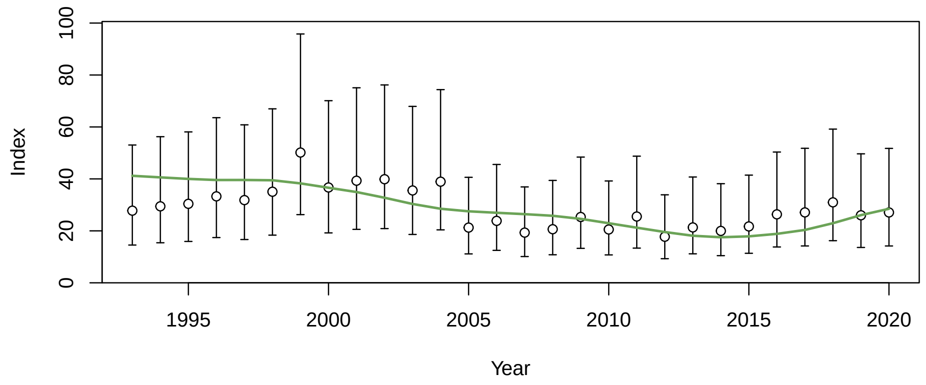

Figure C.2: Scenario 1 model predictions (green line) to commercial catch rates for saddletail snapper

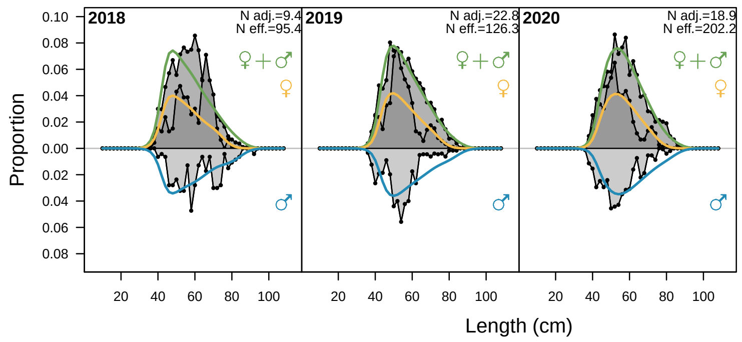

Figure C.3: Scenario 1 length structure for the commercial fleet for saddletail snapper for each sex

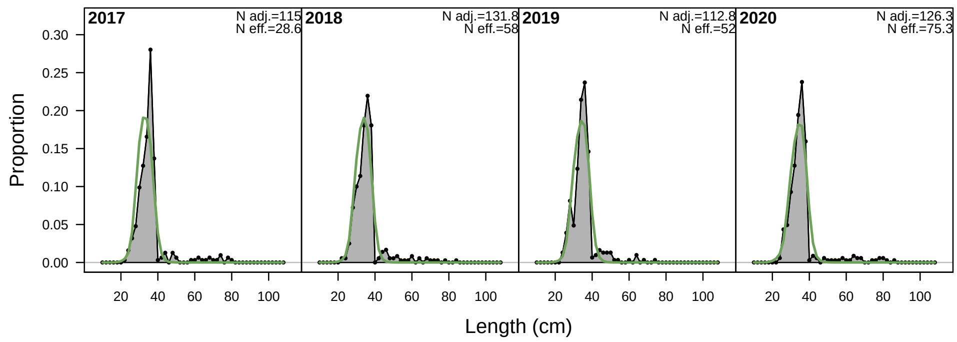

Figure C.4: Scenario 1 length structure for the recreational fleet for discarded saddletail snapper

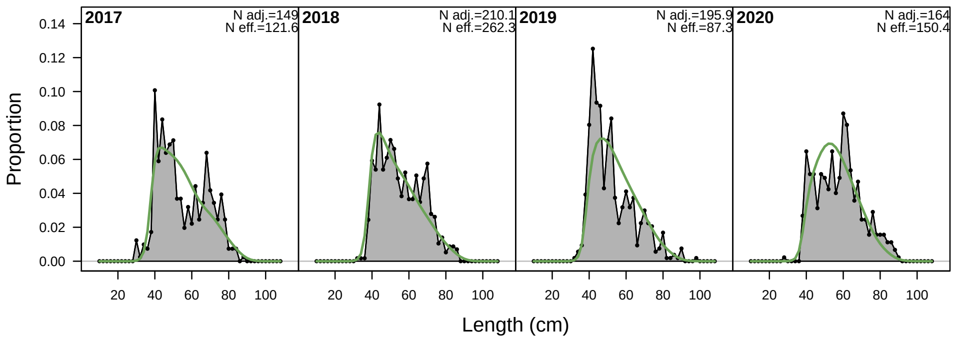

Figure C.5: Scenario 1 length structure for the recreational fleet for retained saddletail snapper

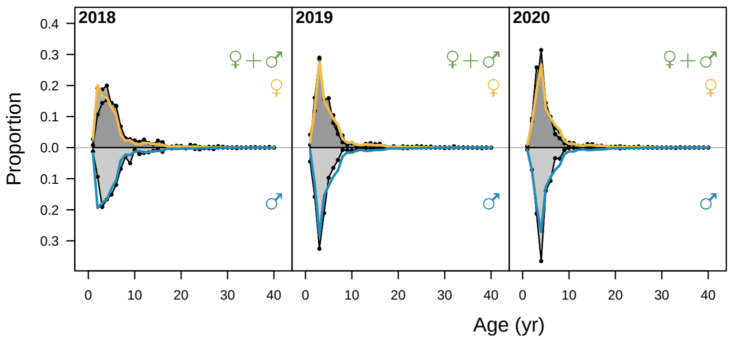

Figure C.6: Scenario 1 age structure for saddletail snapper

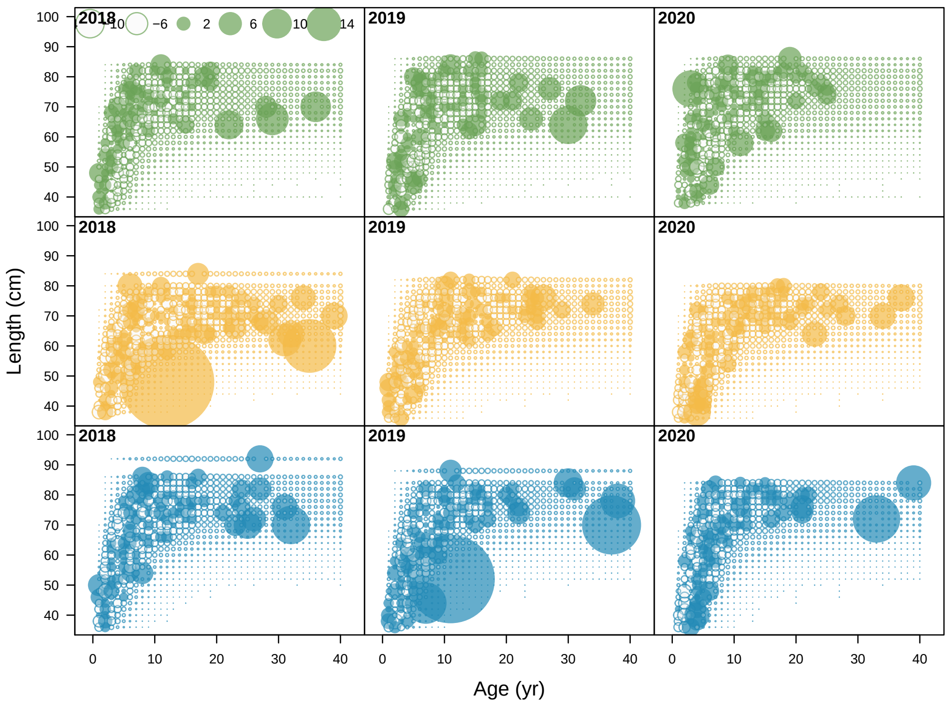

Figure C.7: Scenario 1 Pearson residuals for age-at-length compositions for the commercial fleet for saddletail snapper

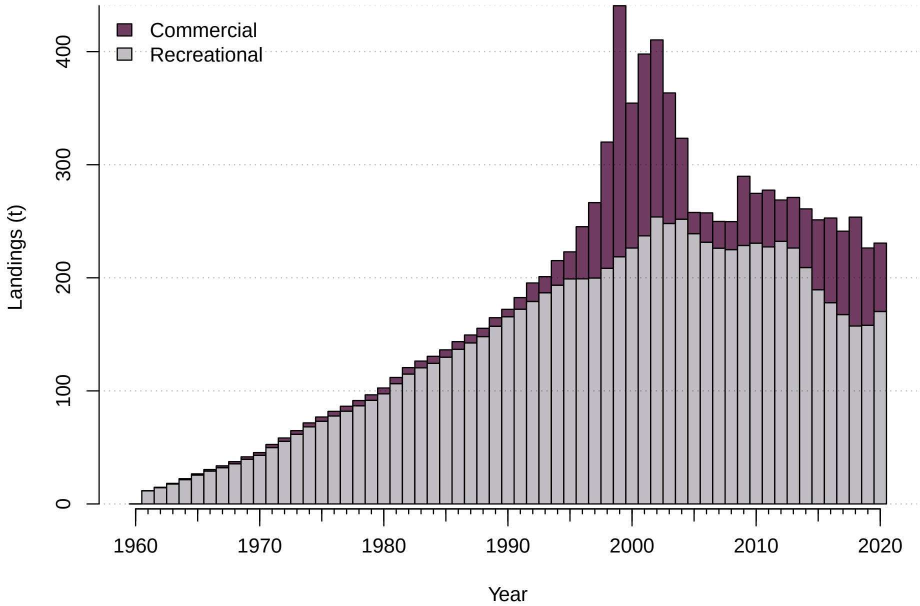

Figure C.8: Scenario 1 modelled harvest

Scenario 2

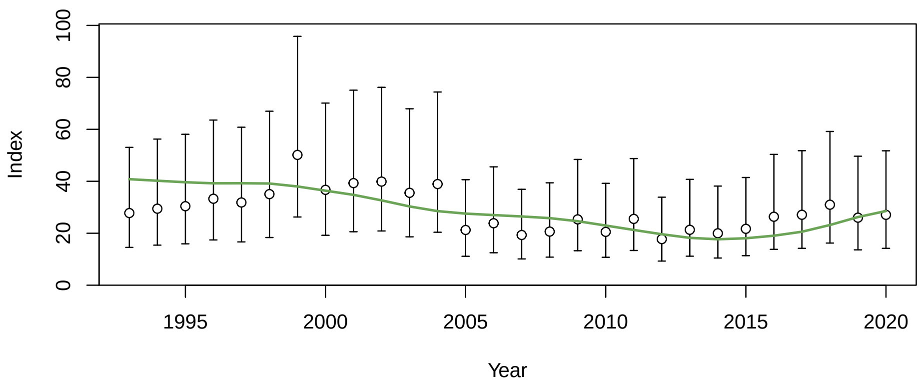

Figure C.9: Scenario 2 model predictions (green line) to commercial catch rates for saddletail snapper

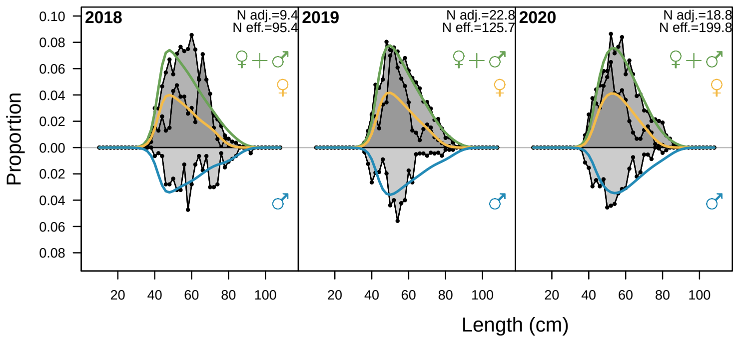

Figure C.10: Scenario 2 length structure for the commercial fleet for saddletail snapper for each sex

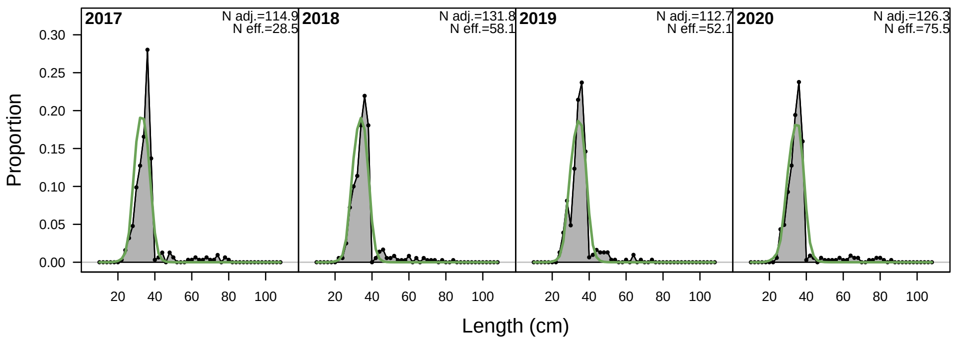

Figure C.11: Scenario 2 length structure for the recreational fleet for discarded saddletail snapper

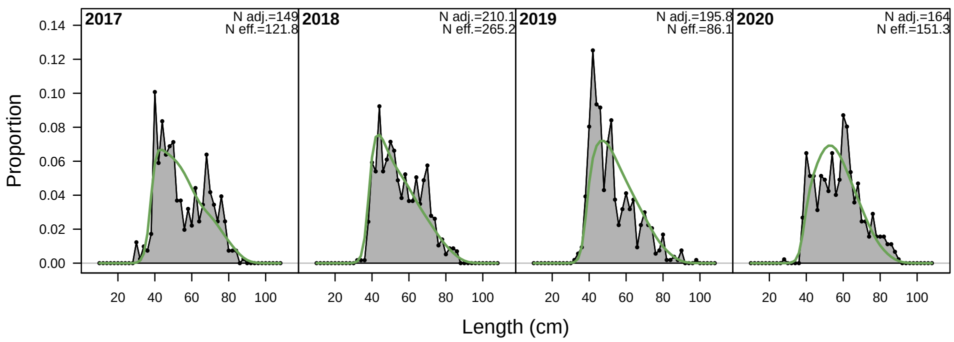

Figure C.12: Scenario 2 length structure for the recreational fleet for retained saddletail snapper

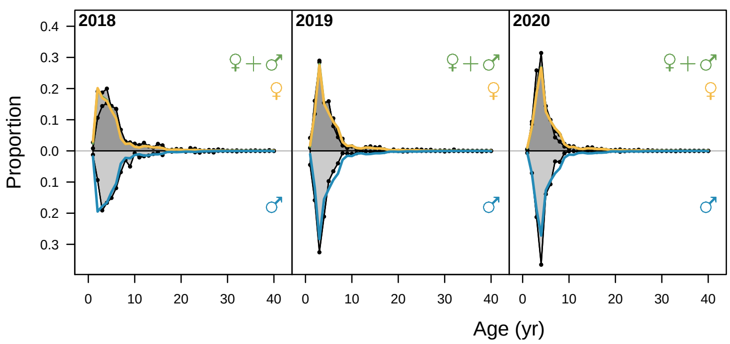

Figure C.13: Scenario 2 age structure for saddletail snapper

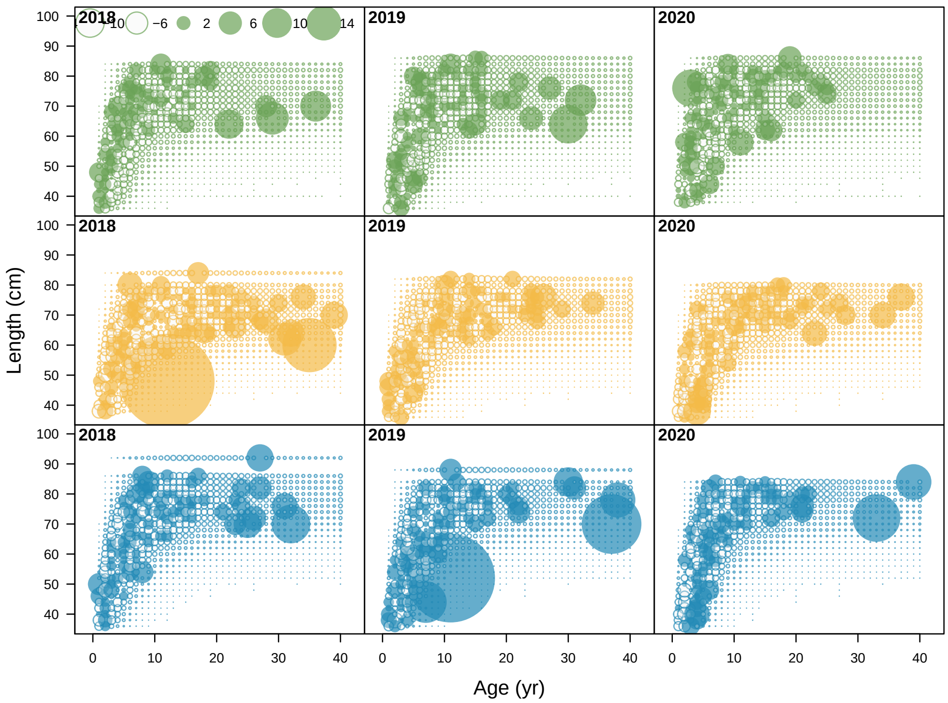

Figure C.14: Scenario 2 Pearson residuals for age-at-length compositions for the commercial fleet for saddletail snapper

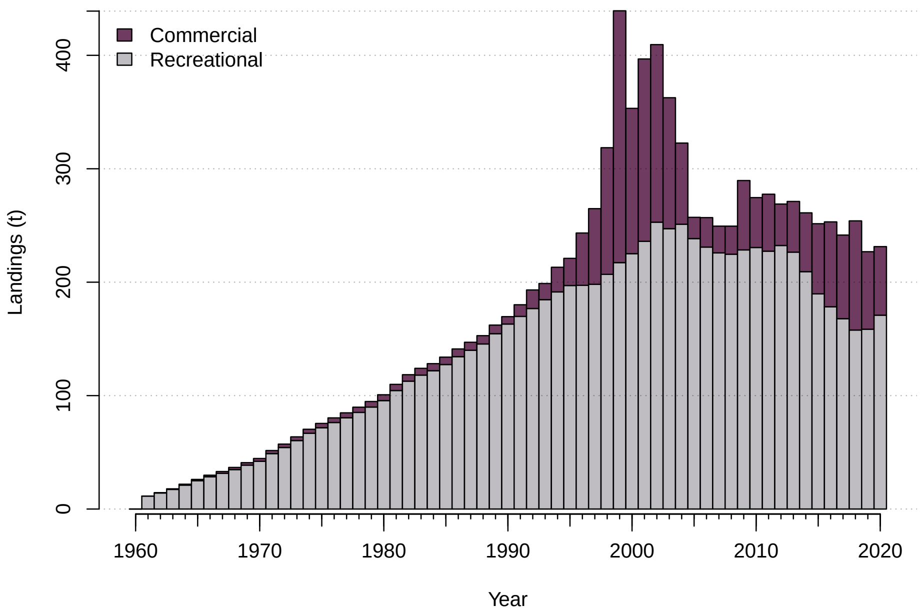

Figure C.15: Scenario 2 modelled harvest

Scenario 3

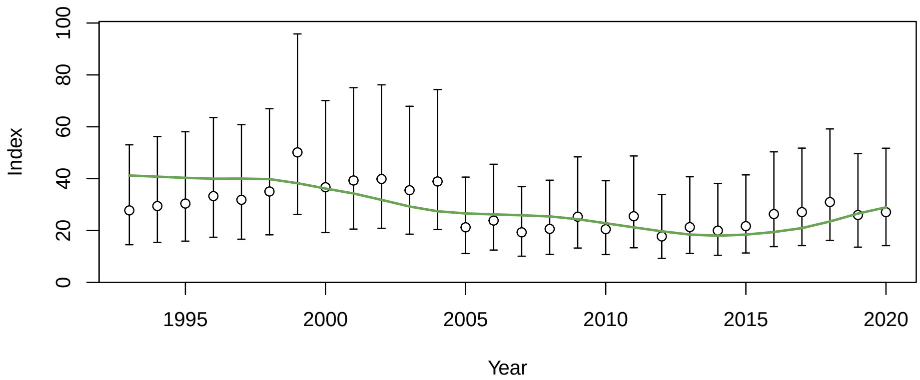

Figure C.16: Scenario 3 model predictions (green line) to commercial catch rates for saddletail snapper

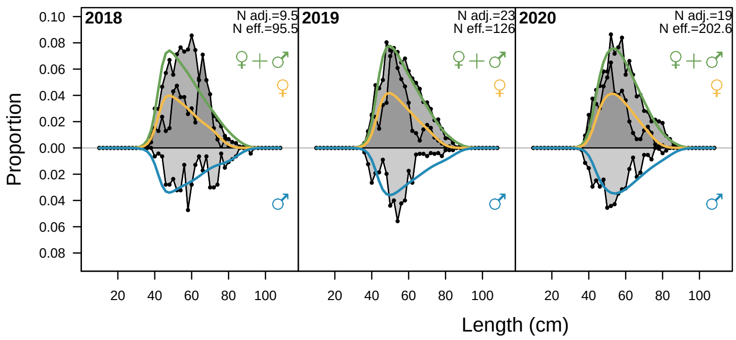

Figure C.17: Scenario 3 length structure for the commercial fleet for saddletail snapper for each sex

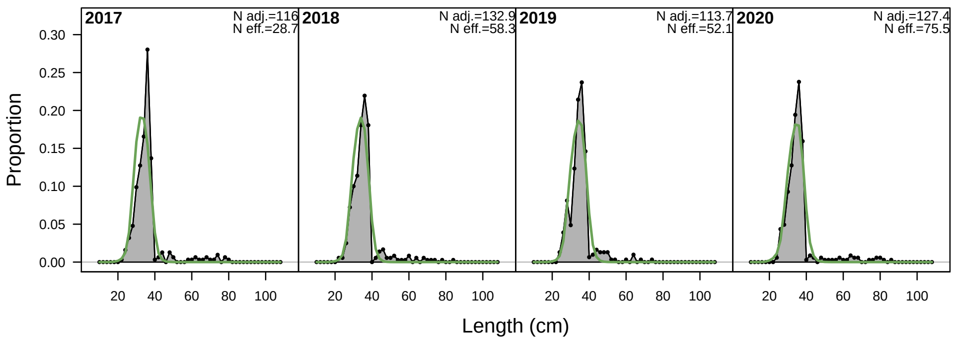

Figure C.18: Scenario 3 length structure for the recreational fleet for discarded saddletail snapper

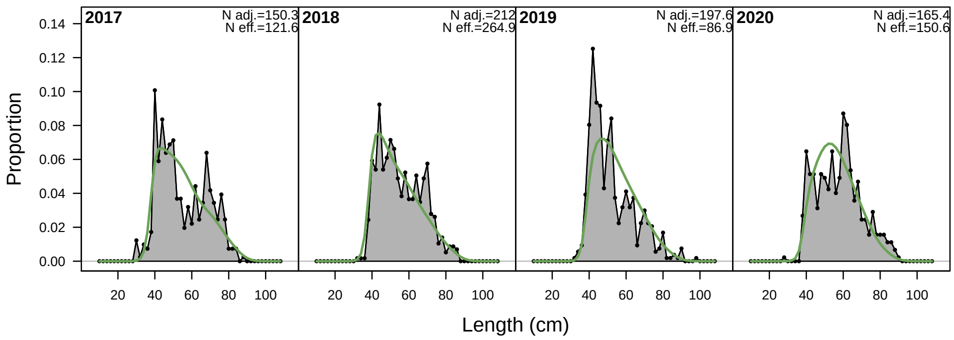

Figure C.19: Scenario 3 length structure for the recreational fleet for retained saddletail snapper

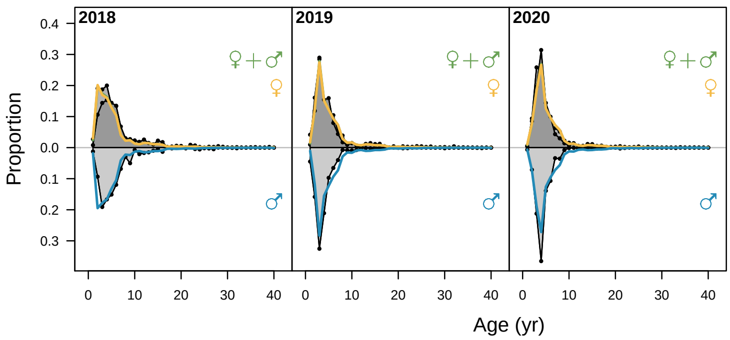

Figure C.20: Scenario 3 age structure for saddletail snapper

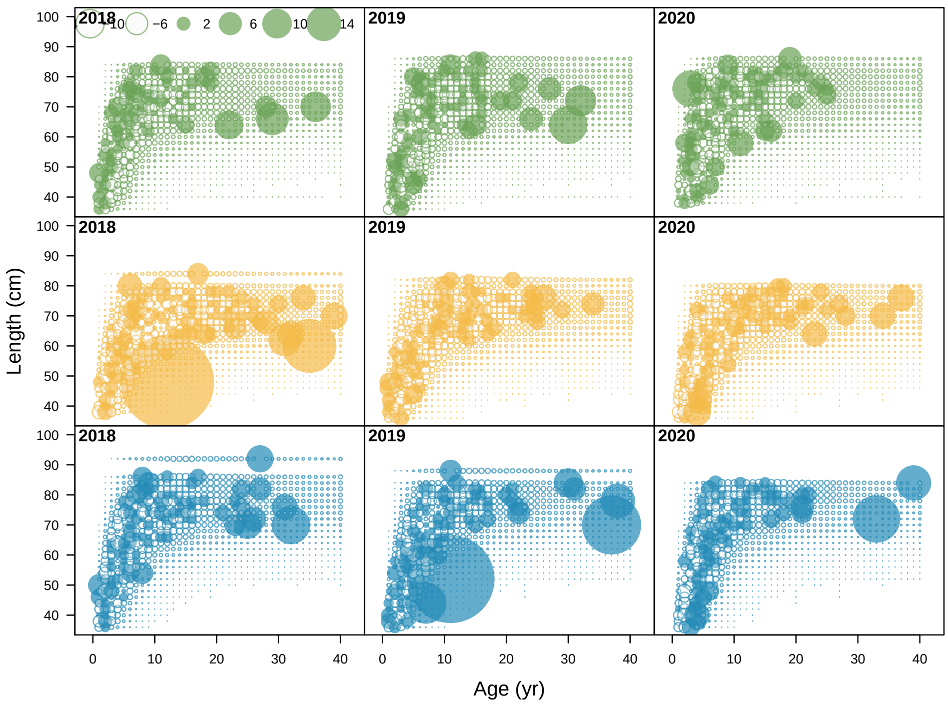

Figure C.21: Scenario 3 Pearson residuals for age-at-length compositions for the commercial fleet for saddletail snapper

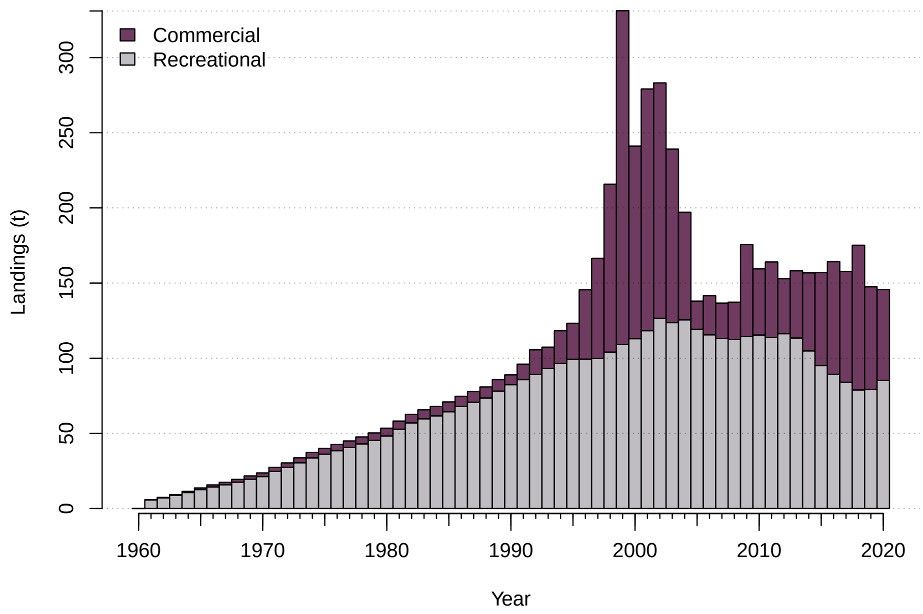

Figure C.22: Scenario 3 modelled harvest

Scenario 4

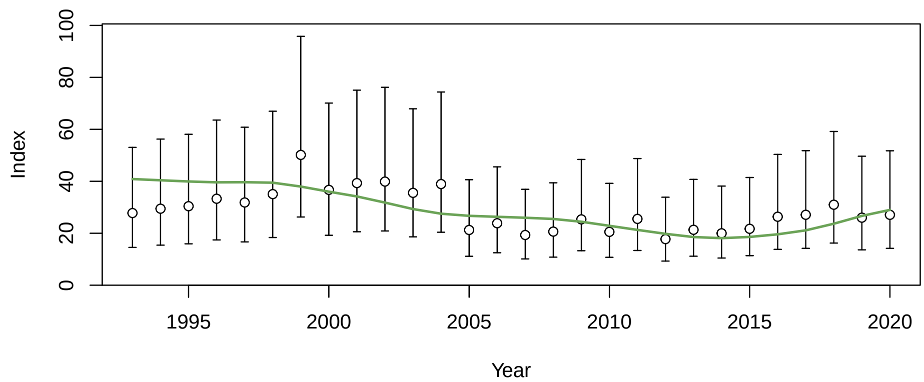

Figure C.23: Scenario 4 model predictions (green line) to commercial catch rates for saddletail snapper

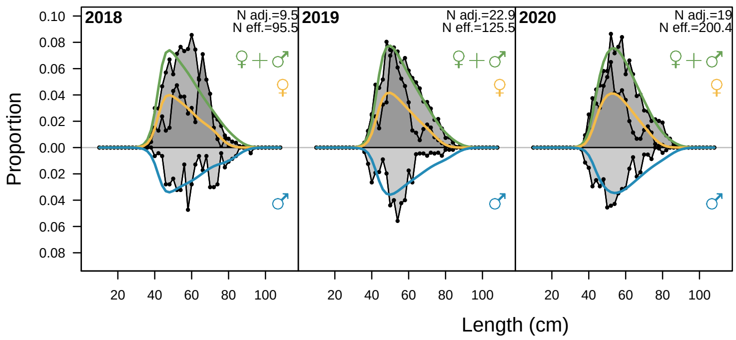

Figure C.24: Scenario 4 length structure for the commercial fleet for saddletail snapper for each sex

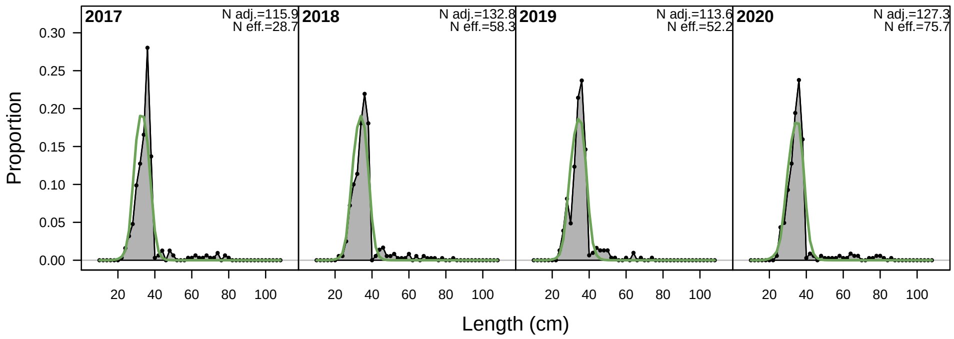

Figure C.25: Scenario 4 length structure for the recreational fleet for discarded saddletail snapper

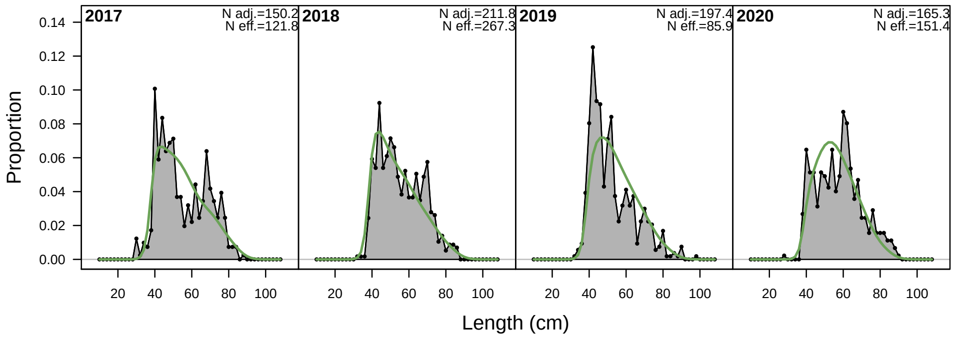

Figure C.26: Scenario 4 length structure for the recreational fleet for retained saddletail snapper

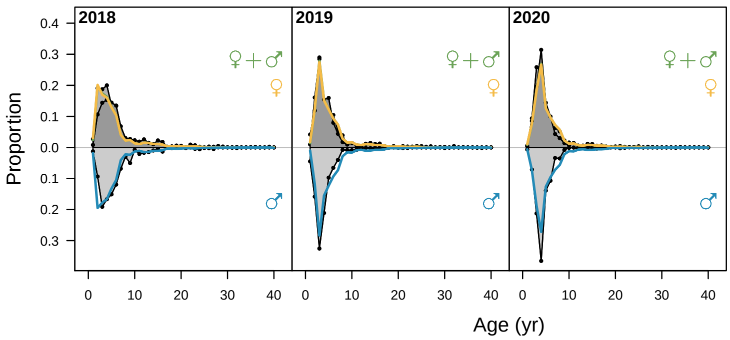

Figure C.27: Scenario 4 age structure for saddletail snapper

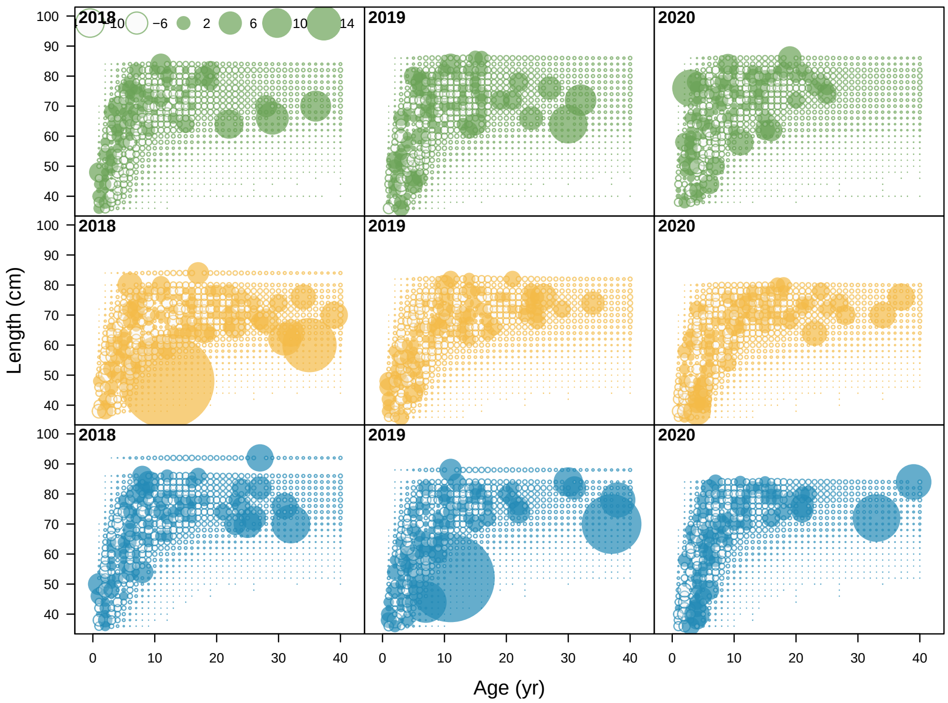

Figure C.28: Scenario 4 Pearson residuals for age-at-length compositions for the commercial fleet for saddletail snapper

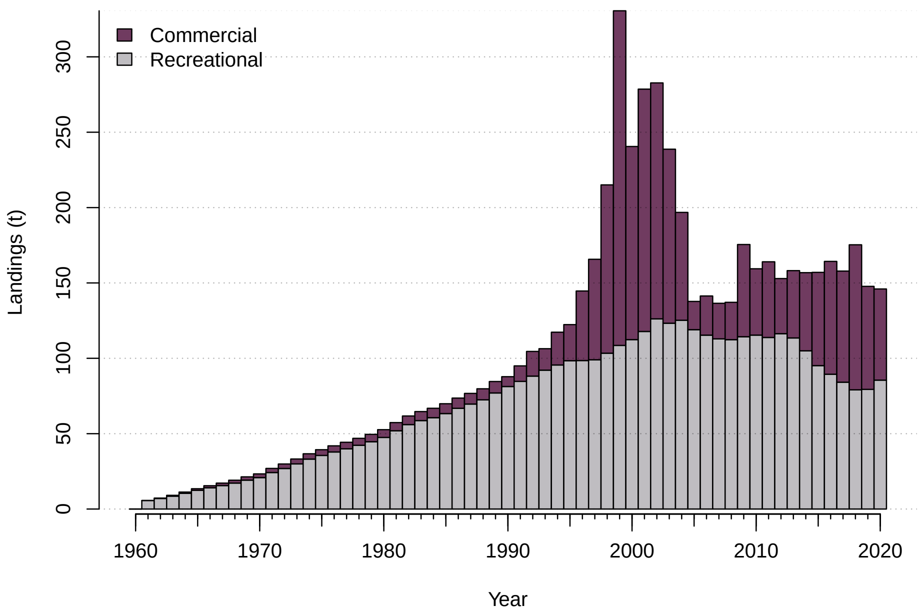

Figure C.29: Scenario 4 modelled harvest

Scenario 5

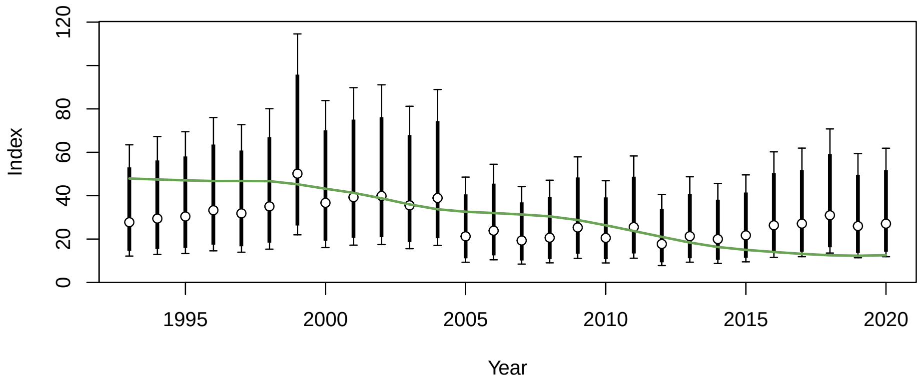

Figure C.30: Scenario 5 model predictions (green line) to commercial catch rates for saddletail snapper

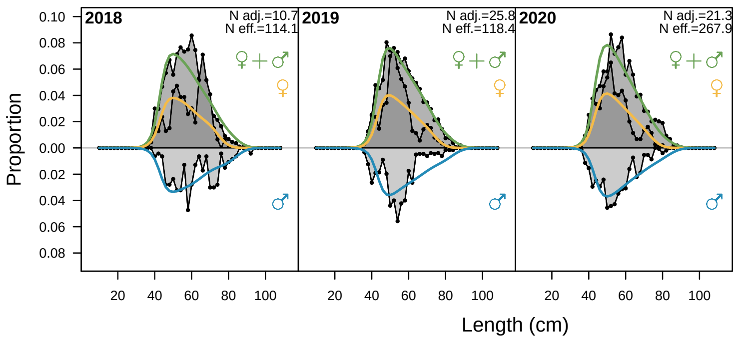

Figure C.31: Scenario 5 length structure for the commercial fleet for saddletail snapper for each sex

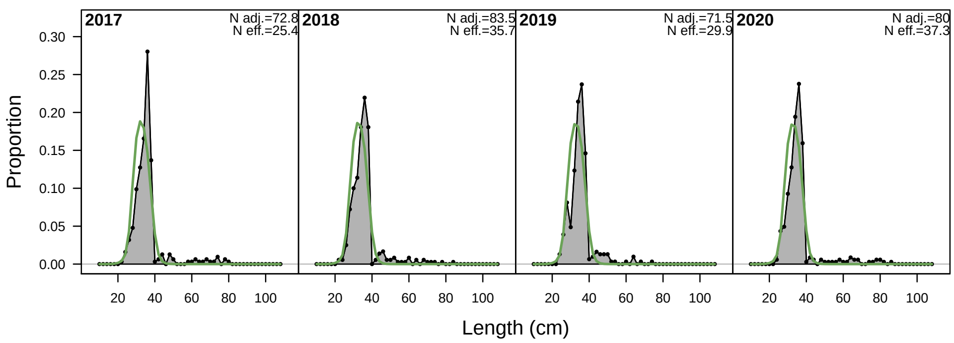

Figure C.32: Scenario 5 length structure for the recreational fleet for discarded saddletail snapper

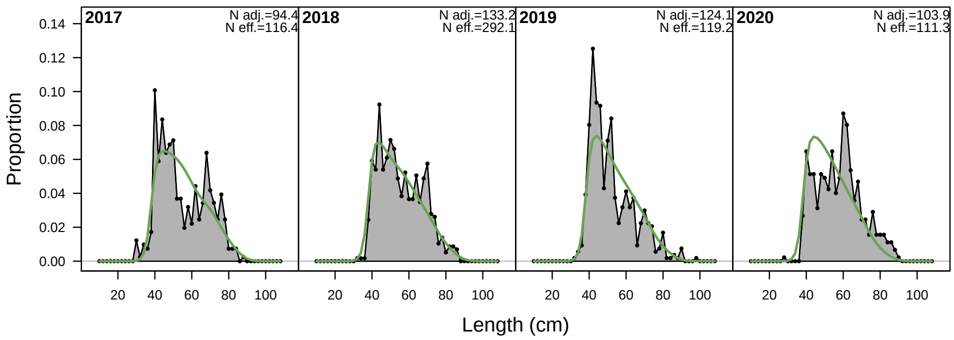

Figure C.33: Scenario 5 length structure for the recreational fleet for retained saddletail snapper

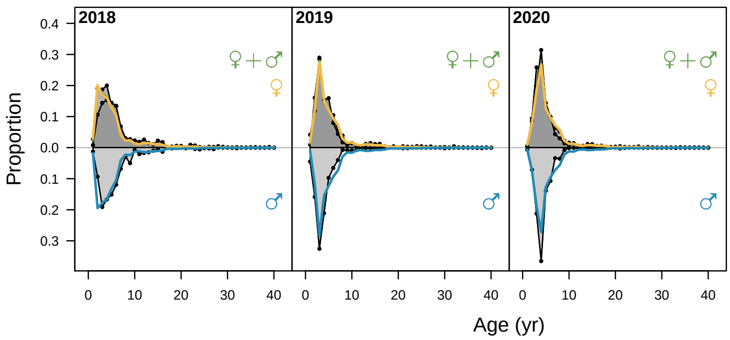

Figure C.34: Scenario 5 age structure for saddletail snapper

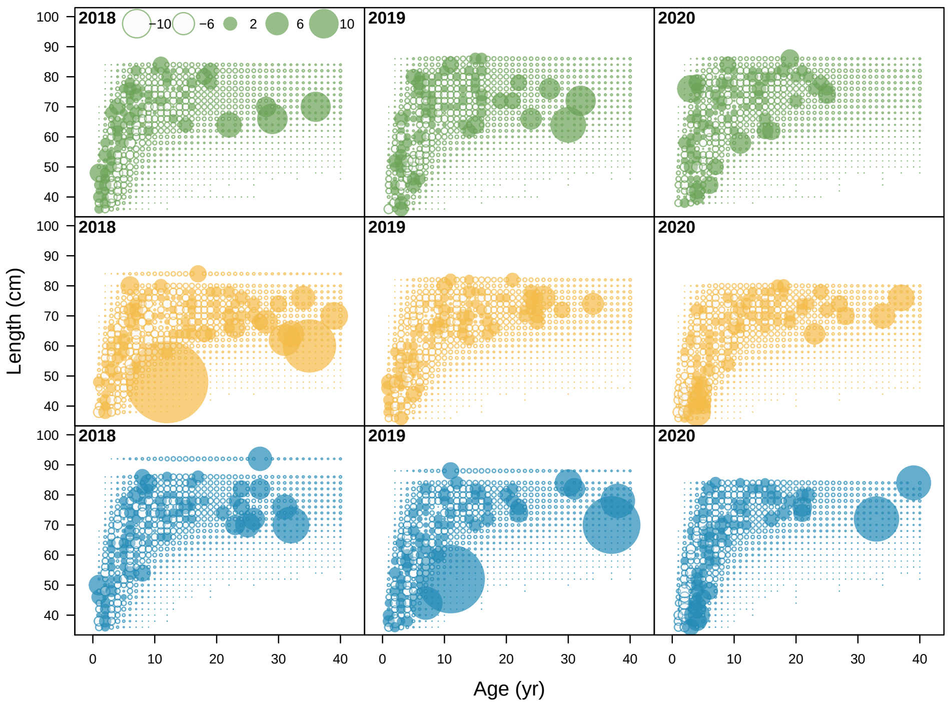

Figure C.35: Scenario 5 Pearson residuals for age-at-length compositions for the commercial fleet for saddletail snapper

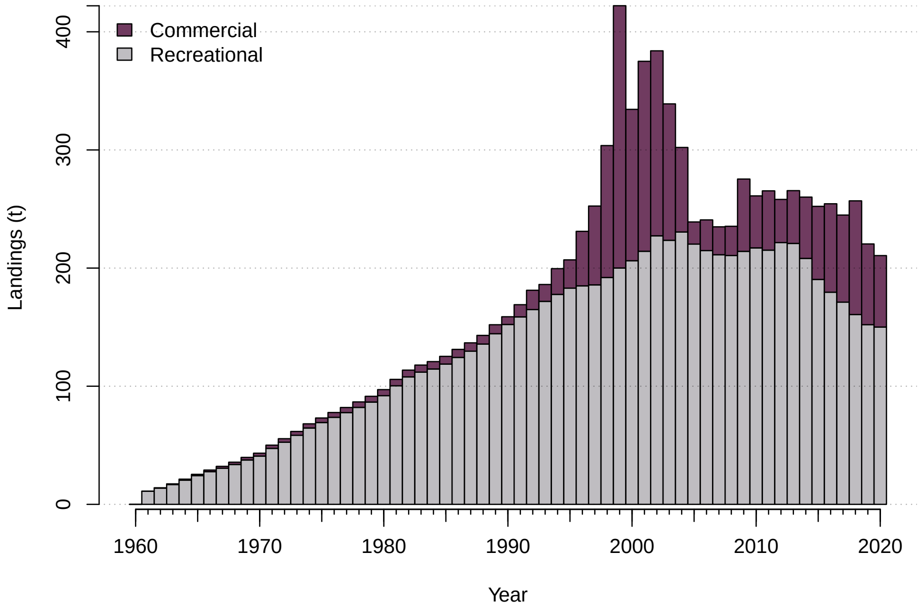

Figure C.36: Scenario 5 modelled harvest

Scenario 7

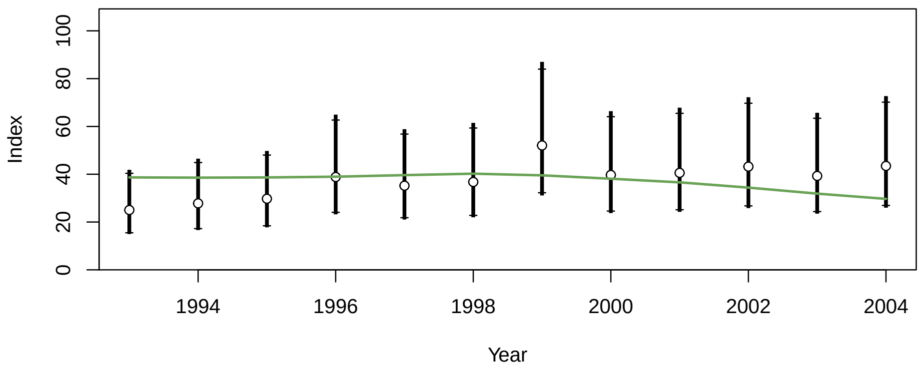

Figure C.37: Scenario 7 model predictions (green line) to commercial catch rates for saddletail snapper

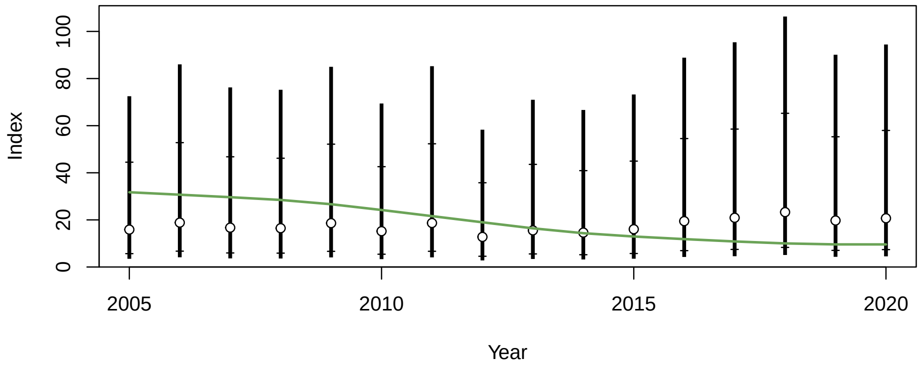

Figure C.38: Scenario 7 model predictions (green line) to commercial catch rates for saddletail snapper

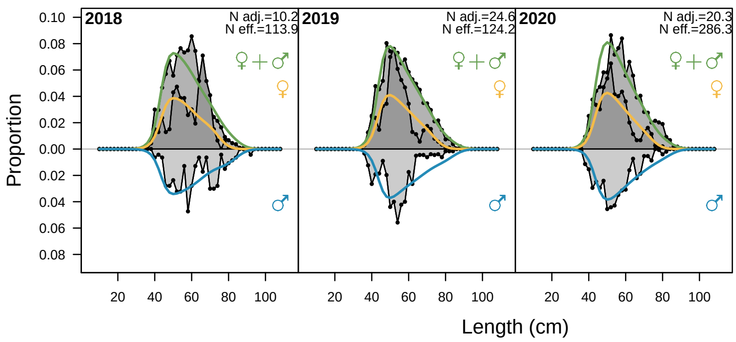

Figure C.39: Scenario 7 length structure for the commercial fleet for saddletail snapper for each sex

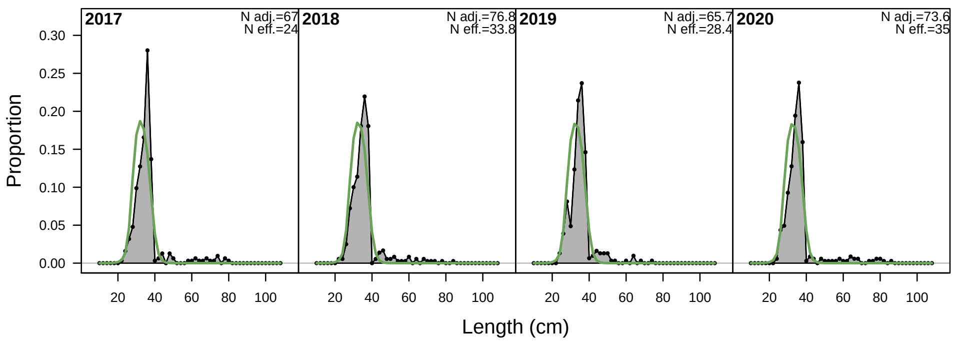

Figure C.40: Scenario 7 length structure for the recreational fleet for discarded saddletail snapper

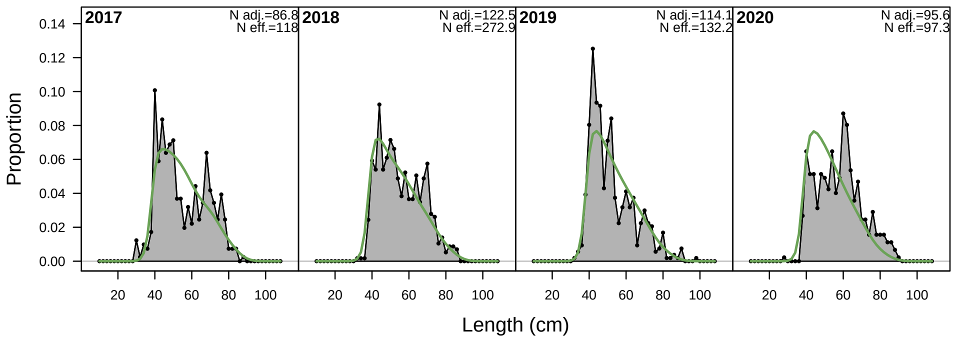

Figure C.41: Scenario 7 length structure for the recreational fleet for retained saddletail snapper

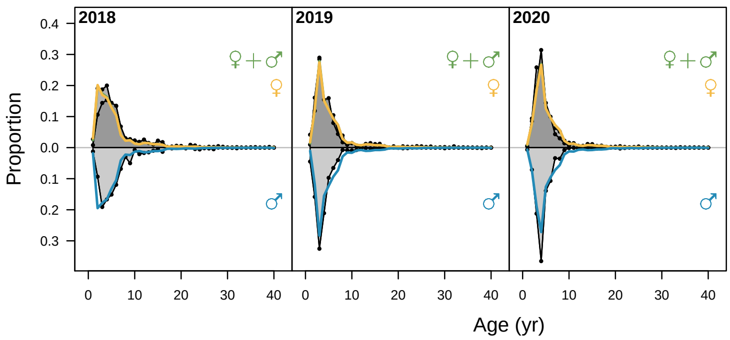

Figure C.42: Scenario 7 age structure for saddletail snapper

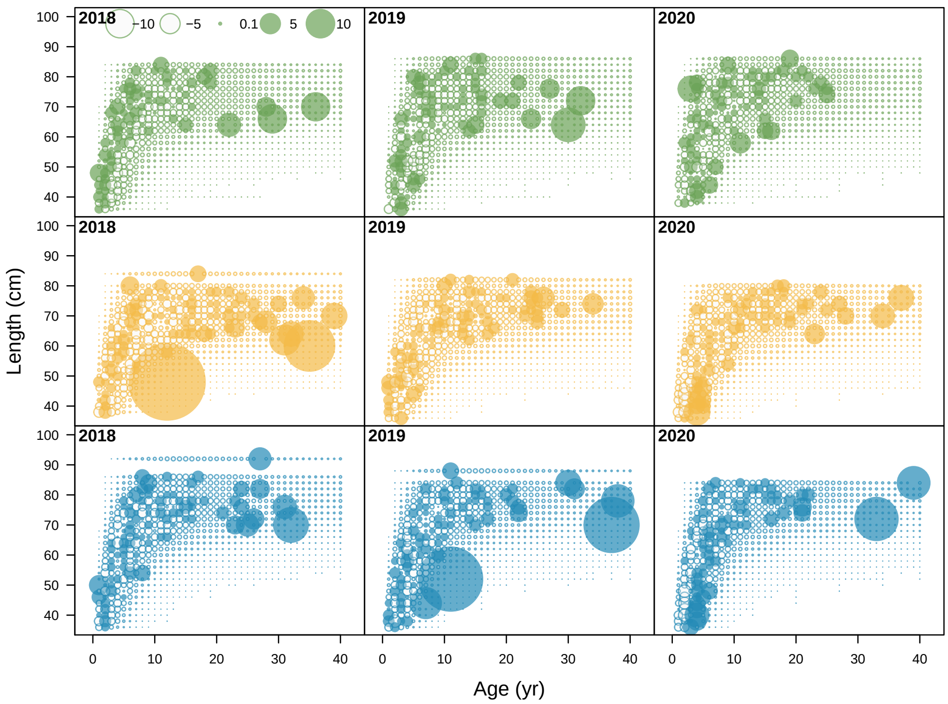

Figure C.43: Scenario 7 Pearson residuals for age-at-length compositions for the commercial fleet for saddletail snapper

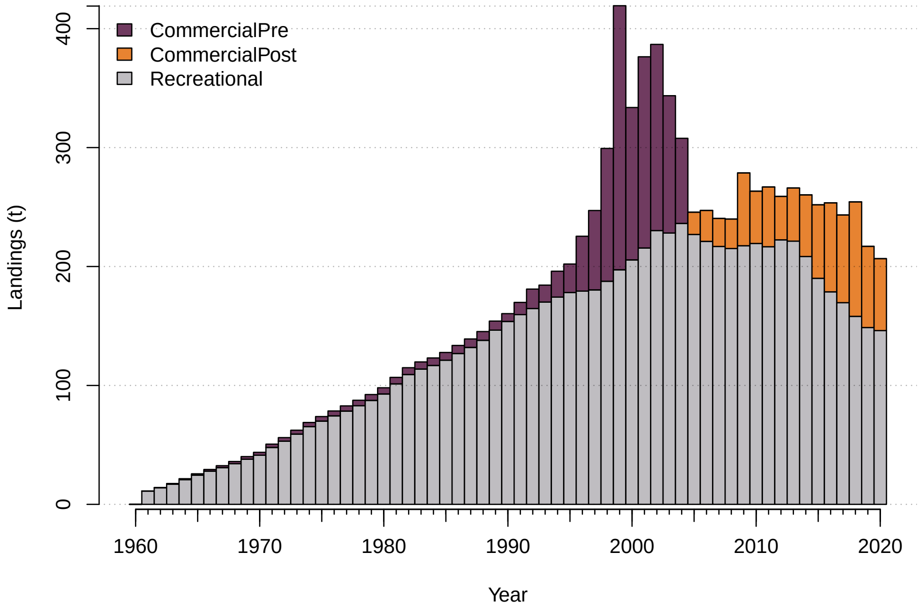

Figure C.44: Scenario 7 modelled harvest

Scenario 8

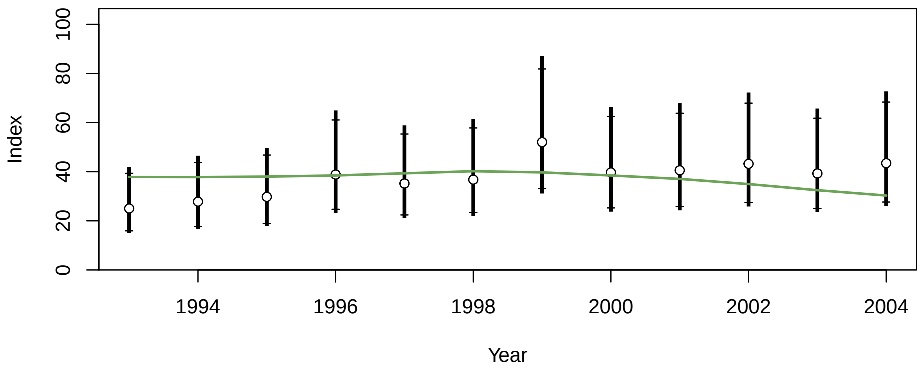

Figure C.45: Scenario 8 model predictions (green line) to commercial catch rates for saddletail snapper

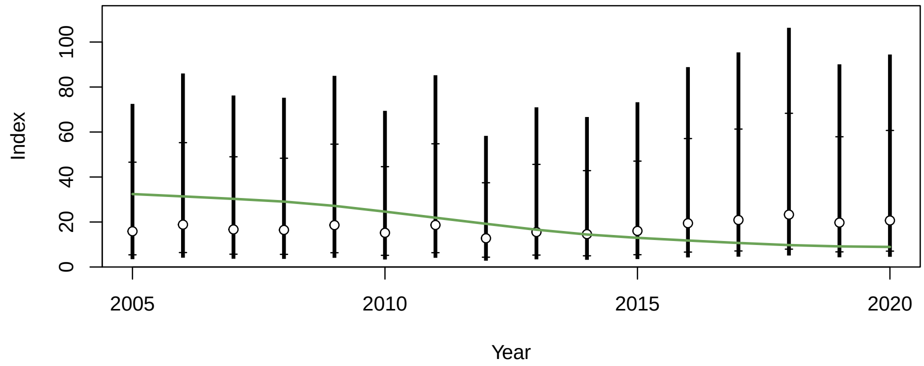

Figure C.46: Scenario 8 model predictions (green line) to commercial catch rates for saddletail snapper

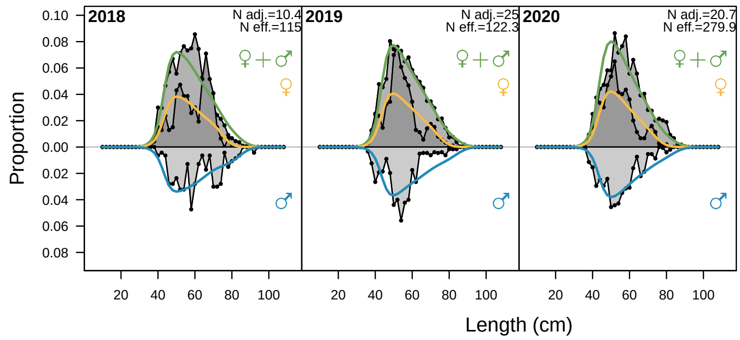

Figure C.47: Scenario 8 length structure for the commercial fleet for saddletail snapper for each sex

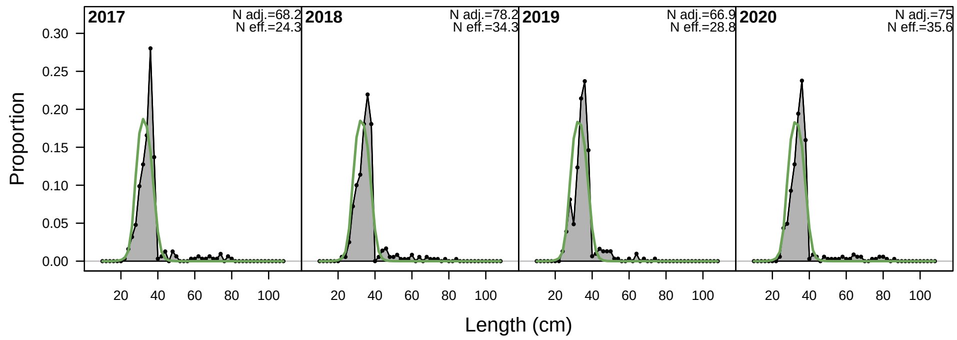

Figure C.48: Scenario 8 length structure for the recreational fleet for discarded saddletail snapper

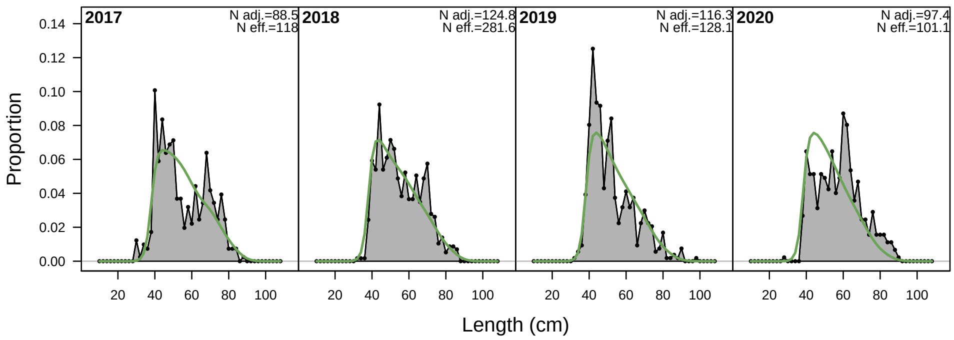

Figure C.49: Scenario 8 length structure for the recreational fleet for retained saddletail snapper

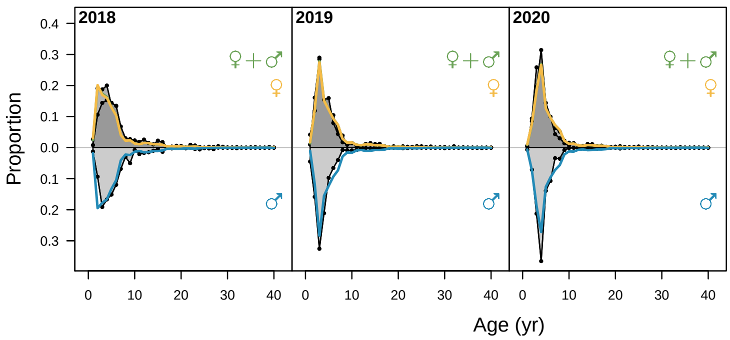

Figure C.50: Scenario 8 age structure for saddletail snapper

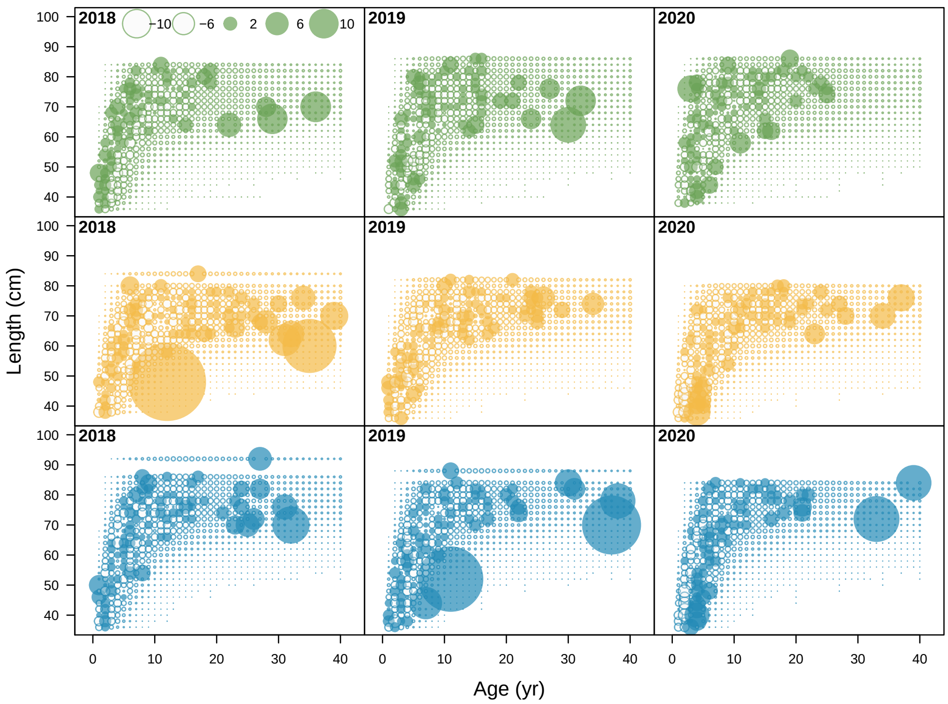

Figure C.51: Scenario 8 Pearson residuals for age-at-length compositions for the commercial fleet for saddletail snapper

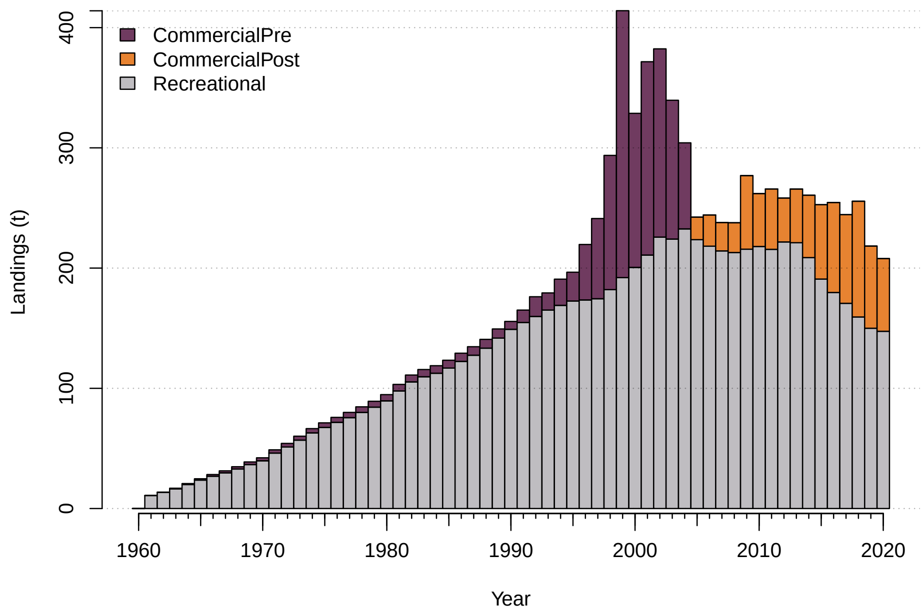

Figure C.52: Scenario 8 modelled harvest

Scenario 9

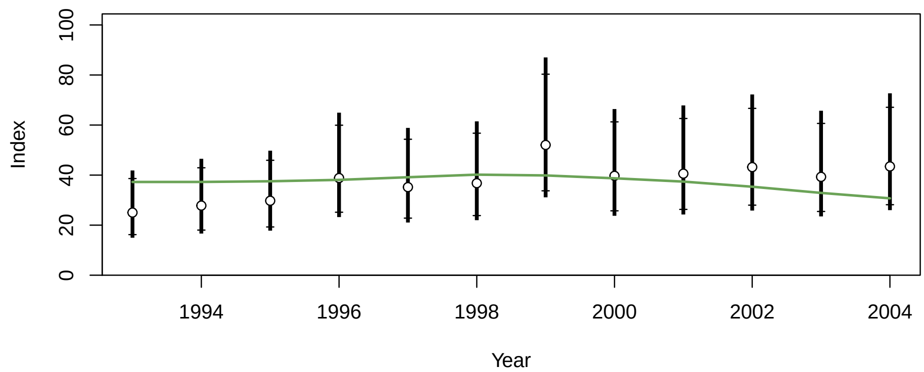

Figure C.53: Scenario 9 model predictions (green line) to commercial catch rates for saddletail snapper

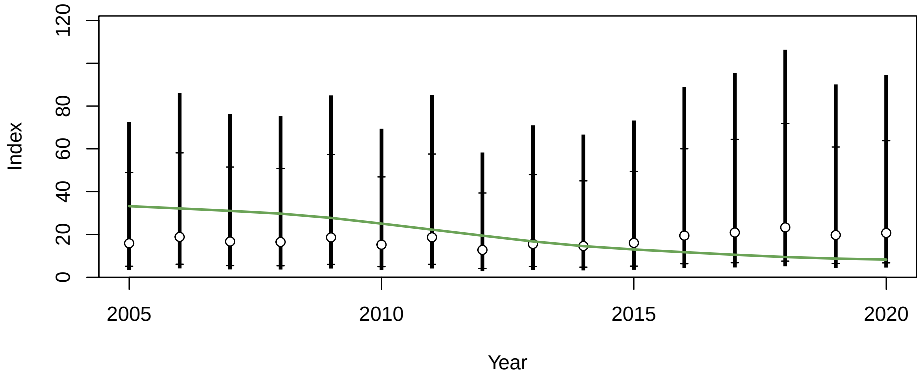

Figure C.54: Scenario 9 model predictions (green line) to commercial catch rates for saddletail snapper

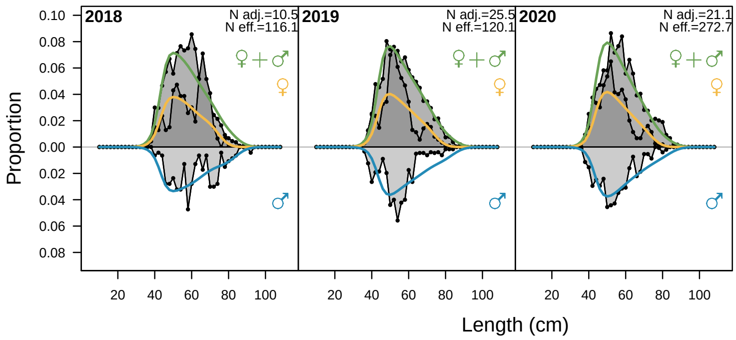

Figure C.55: Scenario 9 length structure for the commercial fleet for saddletail snapper for each sex

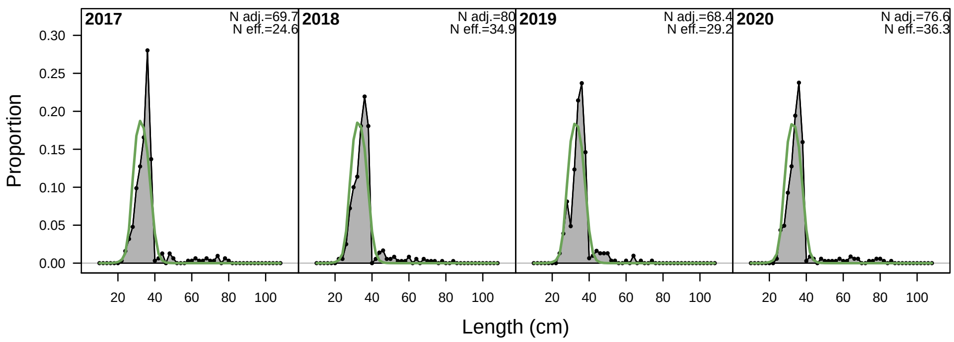

Figure C.56: Scenario 9 length structure for the recreational fleet for discarded saddletail snapper

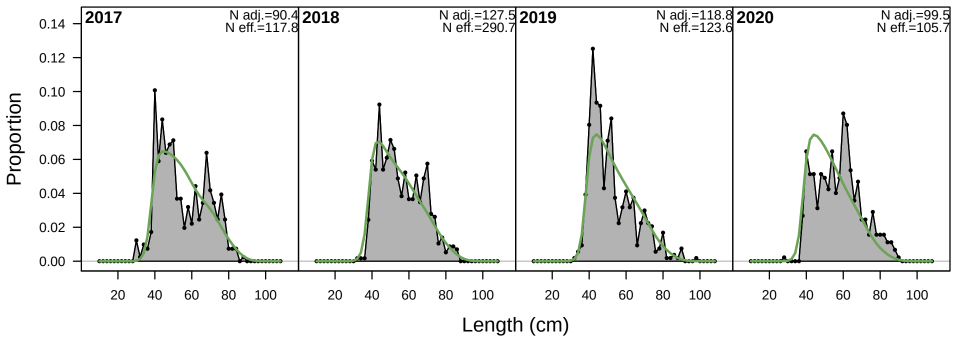

Figure C.57: Scenario 9 length structure for the recreational fleet for retained saddletail snapper

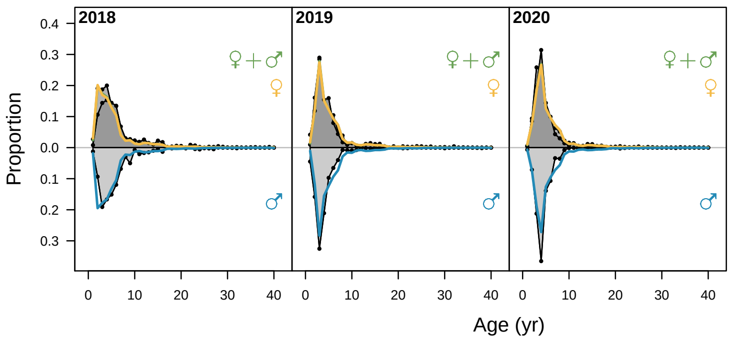

Figure C.58: Scenario 9 age structure for saddletail snapper

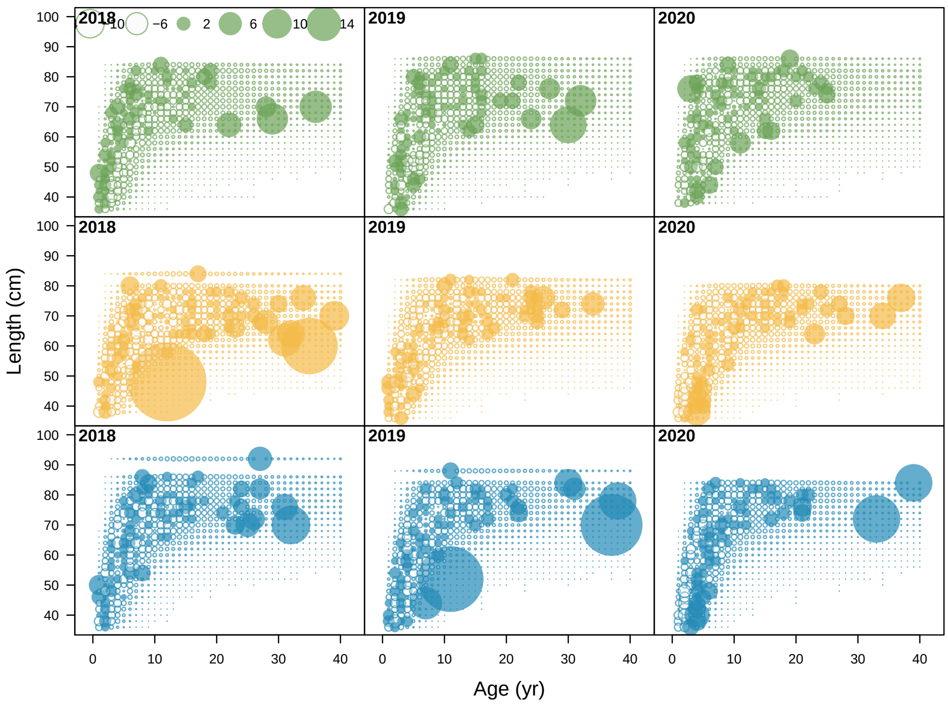

Figure C.59: Scenario 9 Pearson residuals for age-at-length compositions for the commercial fleet for saddletail snapper

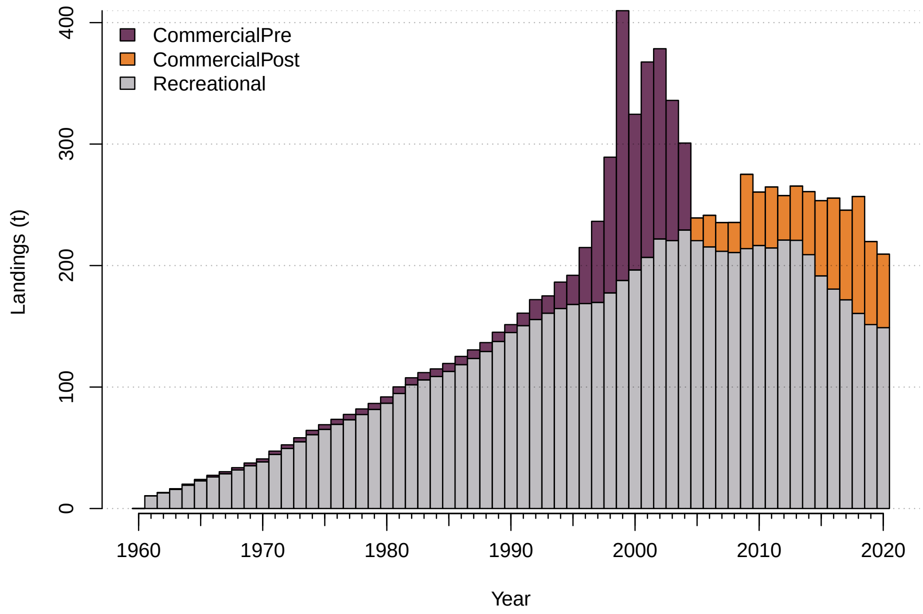

Figure C.60: Scenario 9 modelled harvest

Scenario 10

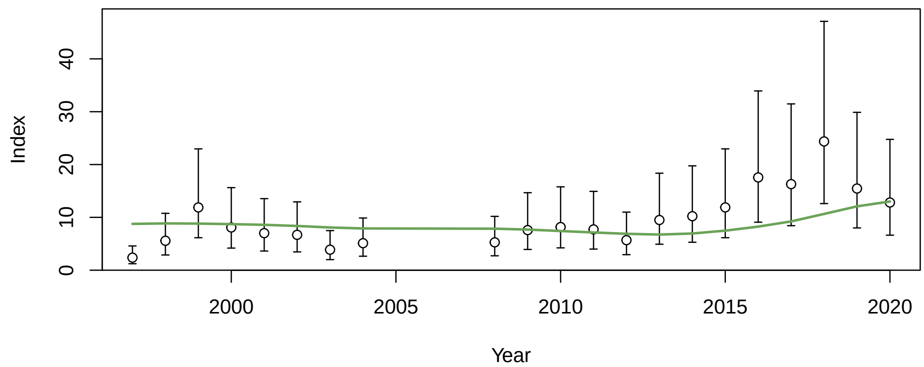

Figure C.61: Scenario 10 model predictions (green line) to commercial catch rates for saddletail snapper

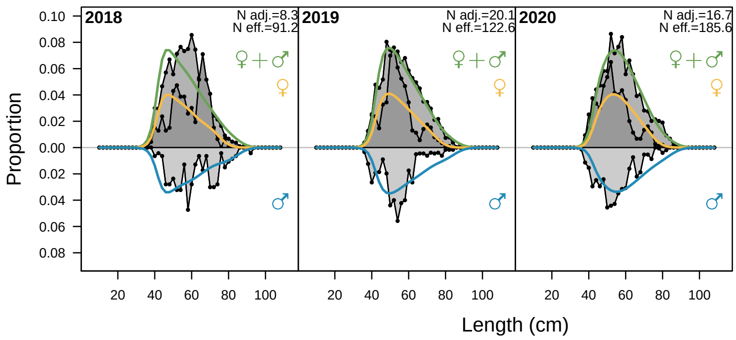

Figure C.62: Scenario 10 length structure for the commercial fleet for saddletail snapper for each sex

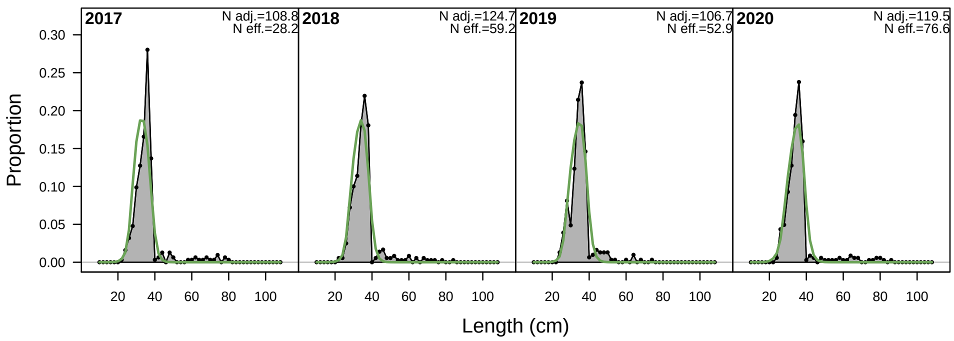

Figure C.63: Scenario 10 length structure for the recreational fleet for discarded saddletail snapper

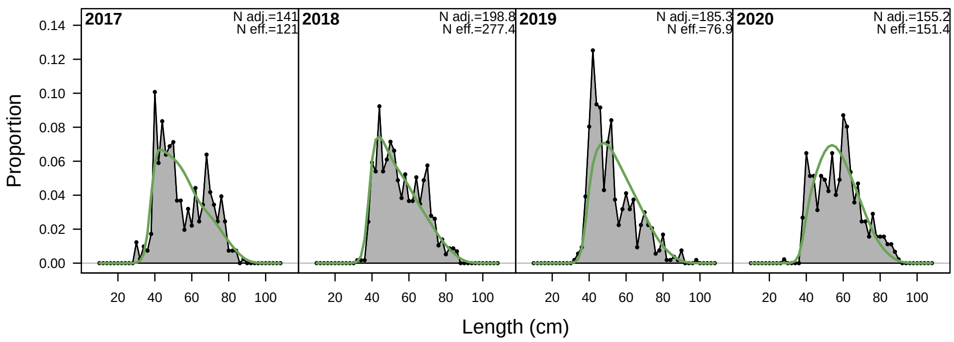

Figure C.64: Scenario 10 length structure for the recreational fleet for retained saddletail snapper

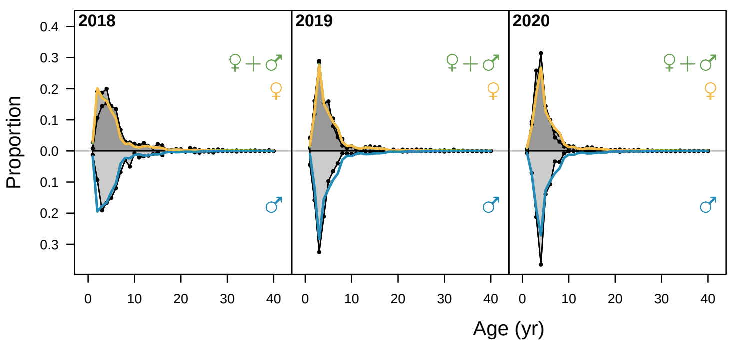

Figure C.65: Scenario 10 age structure for saddletail snapper

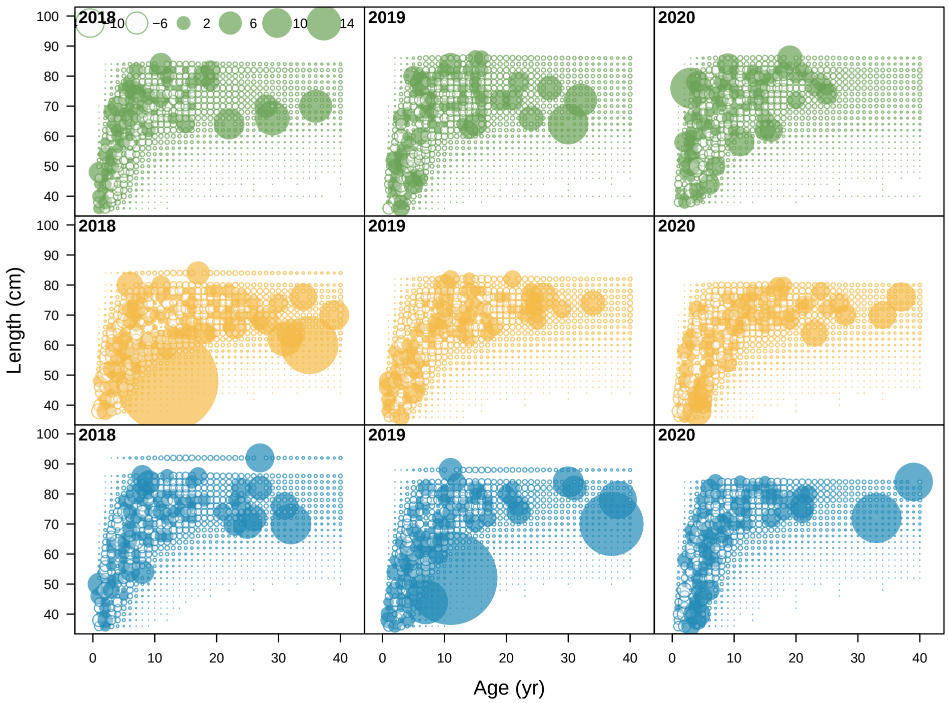

Figure C.66: Scenario 10 Pearson residuals for age-at-length compositions for the commercial fleet for saddletail snapper

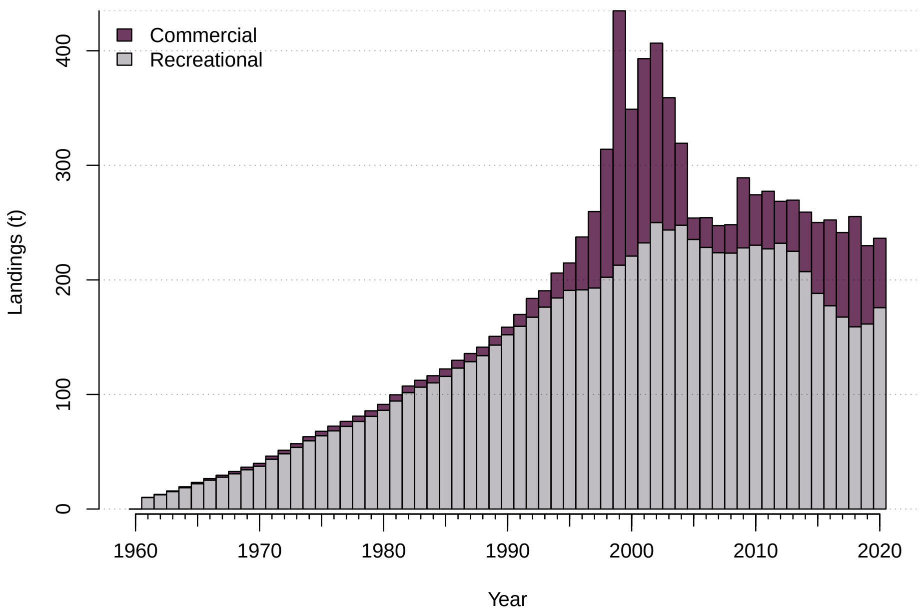

Figure C.67: Scenario 10 modelled harvest

Scenario 11

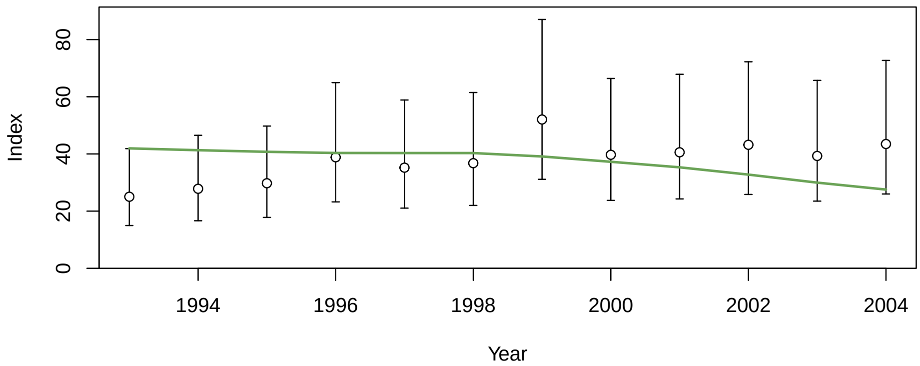

Figure C.68: Scenario 11 model predictions (green line) to commercial catch rates for saddletail snapper

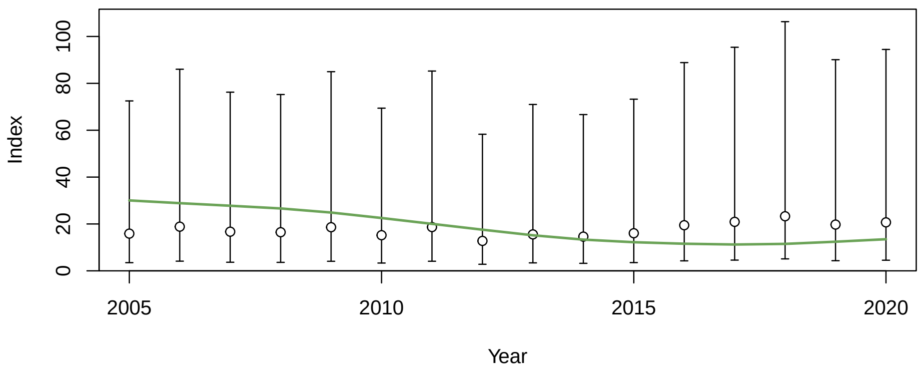

Figure C.69: Scenario 11 model predictions (green line) to commercial catch rates for saddletail snapper

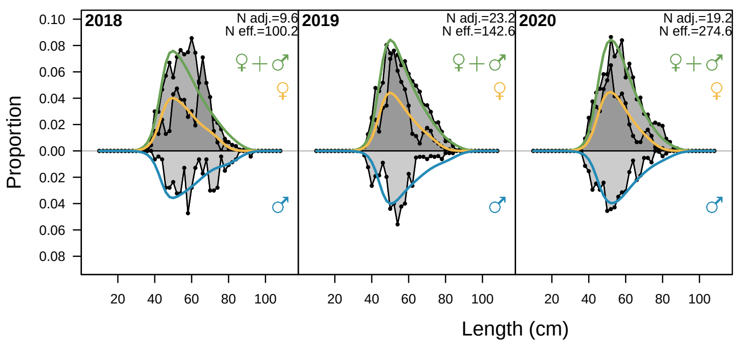

Figure C.70: Scenario 11 length structure for the commercial fleet for saddletail snapper for each sex

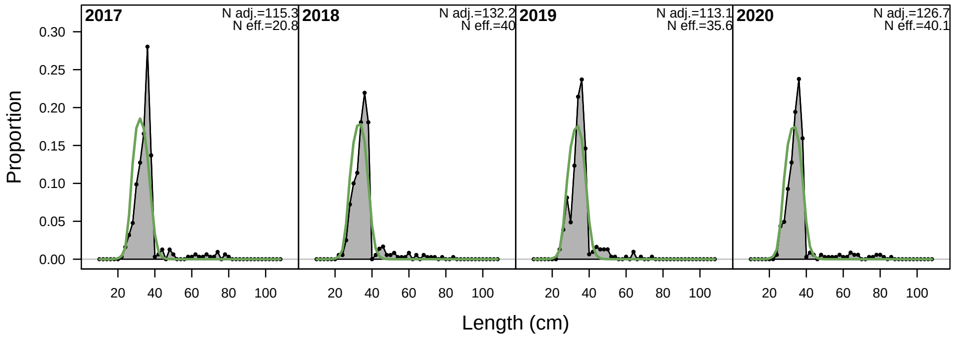

Figure C.71: Scenario 11 length structure for the recreational fleet for discarded saddletail snapper

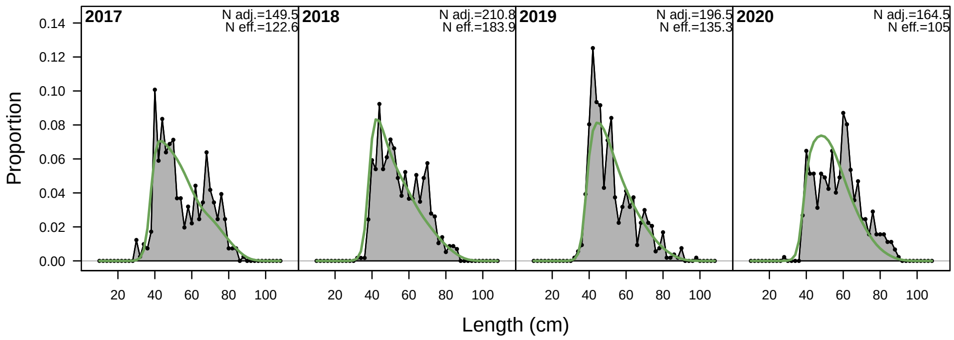

Figure C.72: Scenario 11 length structure for the recreational fleet for retained saddletail snapper

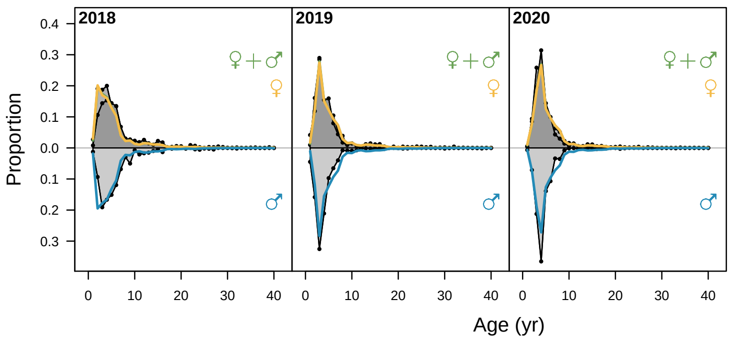

Figure C.73: Scenario 11 age structure for saddletail snapper

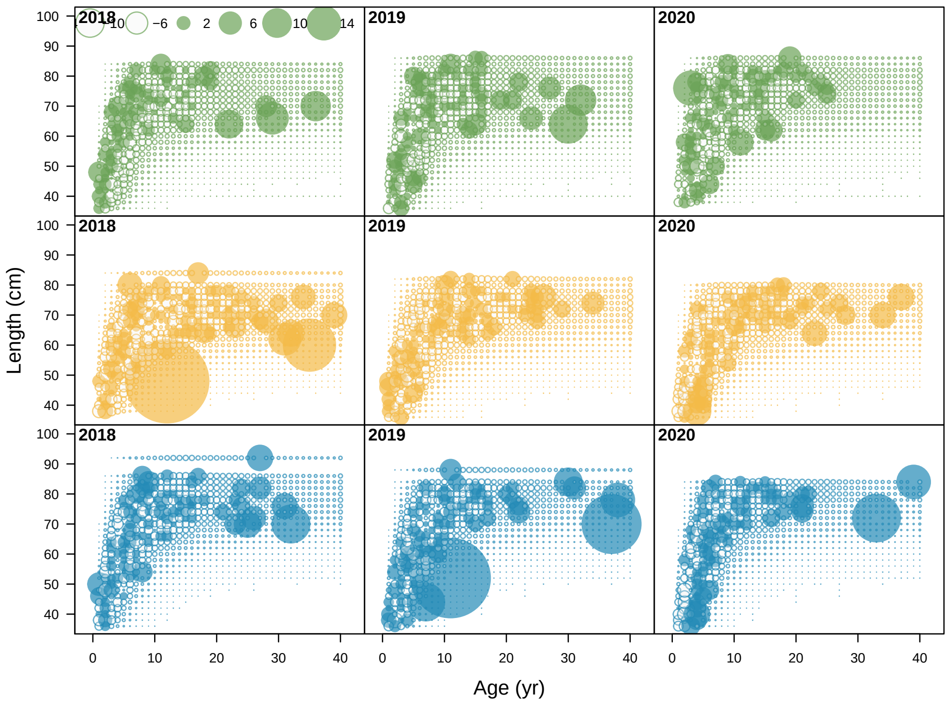

Figure C.74: Scenario 11 Pearson residuals for age-at-length compositions for the commercial fleet for saddletail snapper

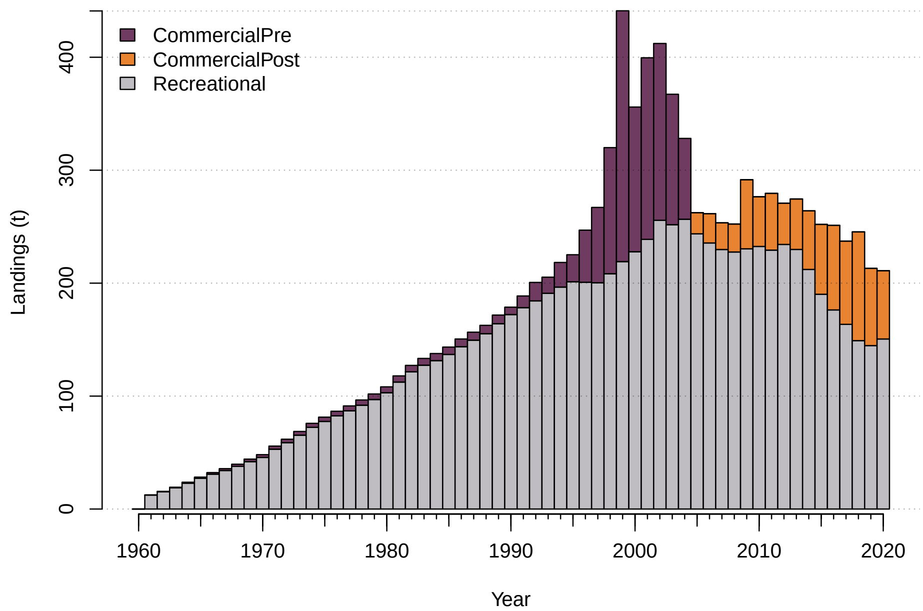

Figure C.75: Scenario 11 modelled harvest

Scenario 12

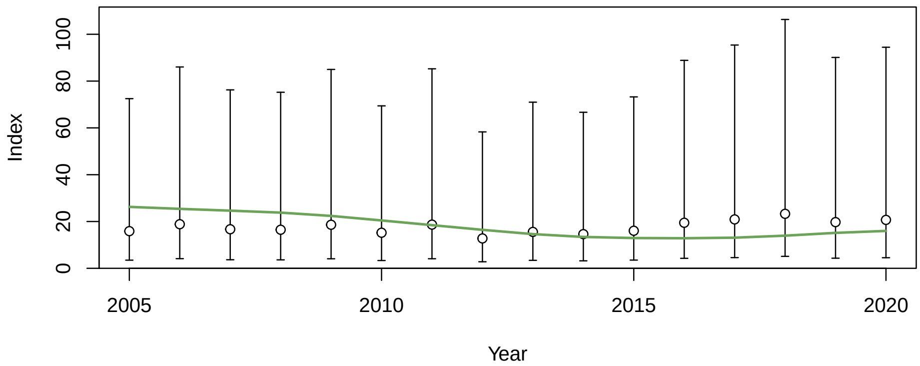

Figure C.76: Scenario 12 model predictions (green line) to commercial catch rates for saddletail snapper

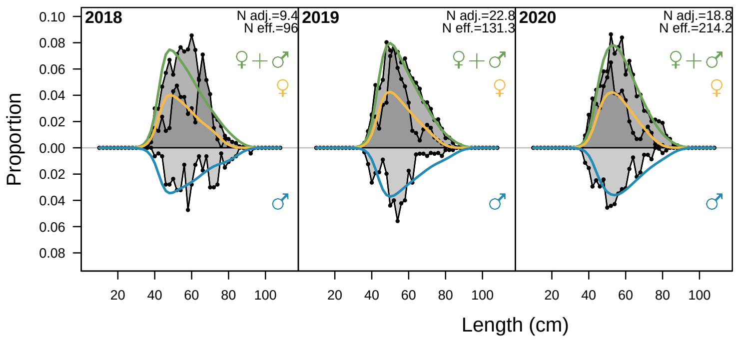

Figure C.77: Scenario 12 length structure for the commercial fleet for saddletail snapper for each sex

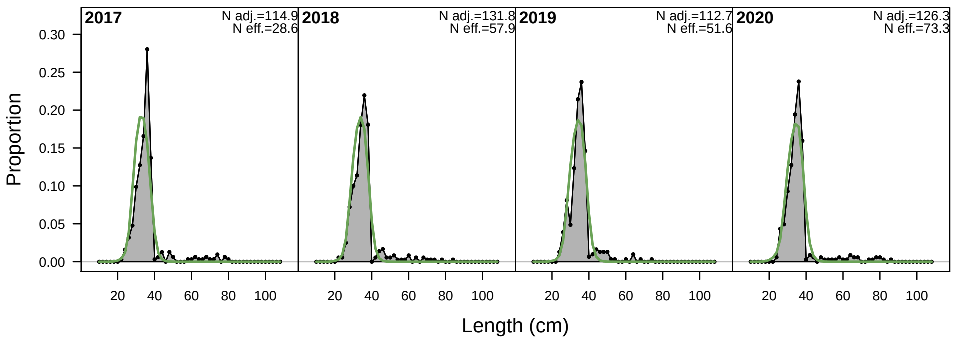

Figure C.78: Scenario 12 length structure for the recreational fleet for discarded saddletail snapper

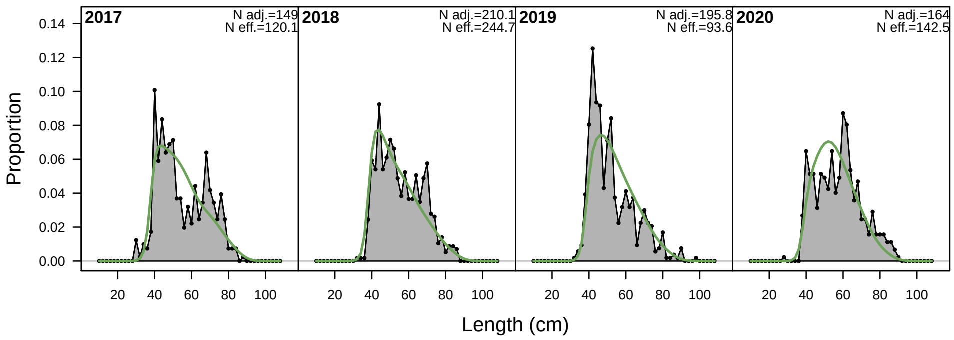

Figure C.79: Scenario 12 length structure for the recreational fleet for retained saddletail snapper

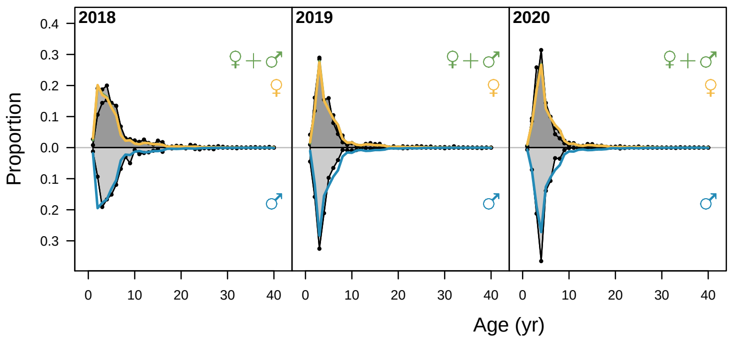

Figure C.80: Scenario 12 age structure for saddletail snapper

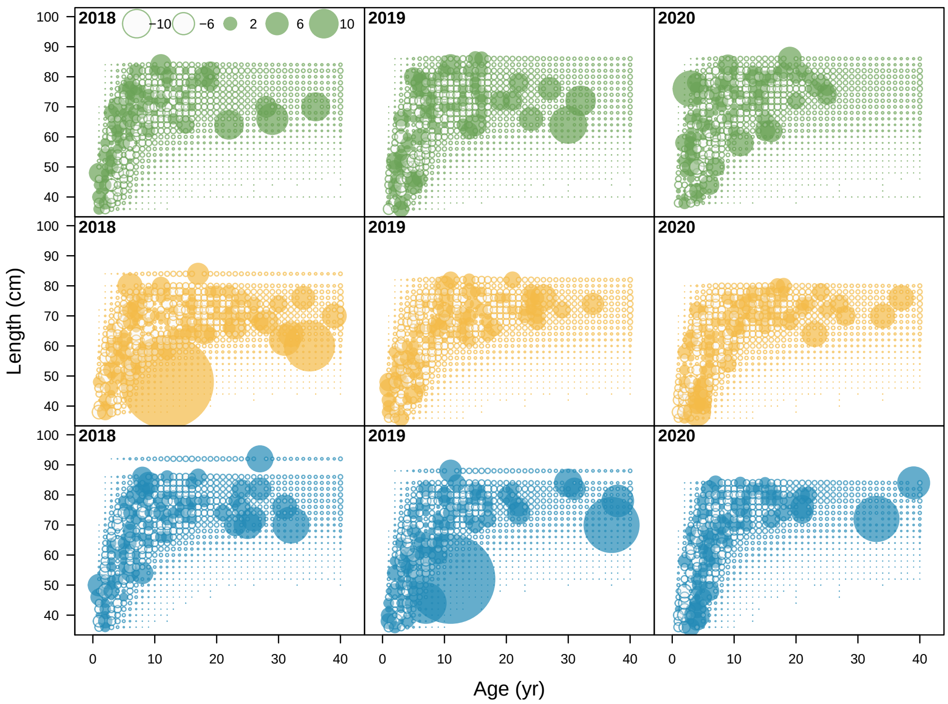

Figure C.81: Scenario 12 Pearson residuals for age-at-length compositions for the commercial fleet for saddletail snapper

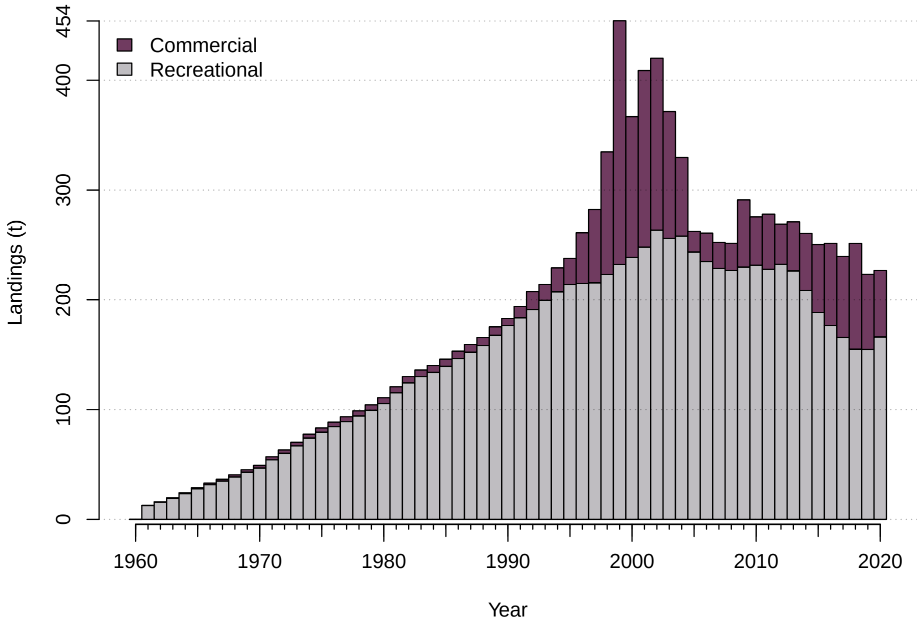

Figure C.82: Scenario 12 modelled harvest

Scenario 13

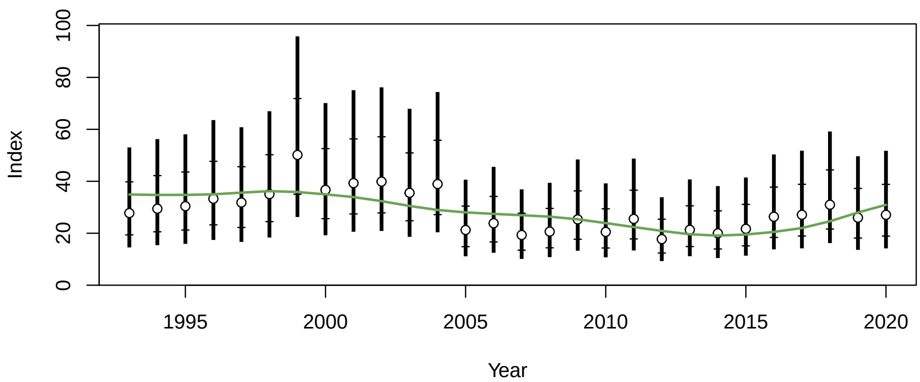

Figure C.83: Scenario 13 model predictions (green line) to commercial catch rates for saddletail snapper

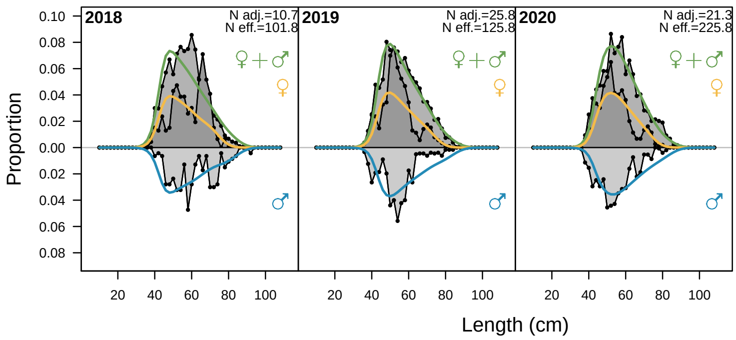

Figure C.84: Scenario 13 length structure for the commercial fleet for saddletail snapper for each sex

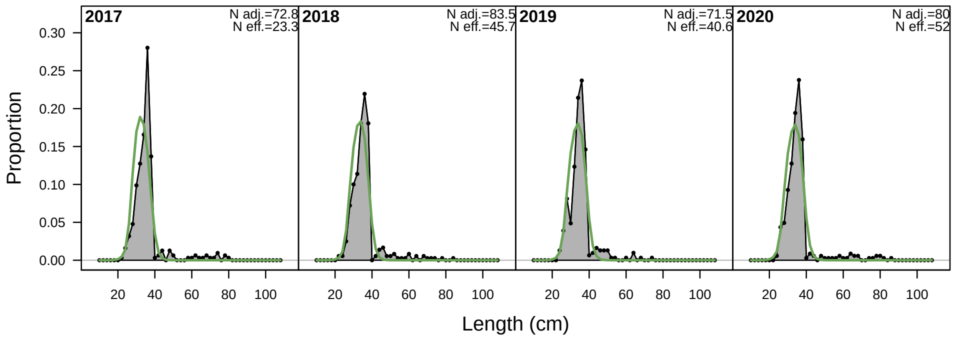

Figure C.85: Scenario 13 length structure for the recreational fleet for discarded saddletail snapper

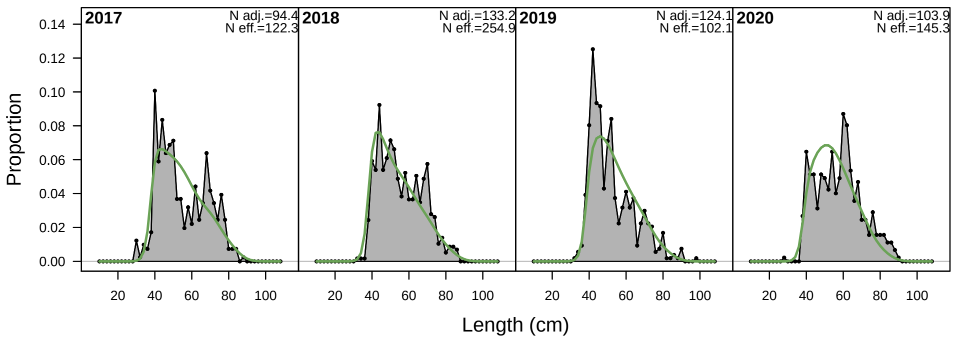

Figure C.86: Scenario 13 length structure for the recreational fleet for retained saddletail snapper

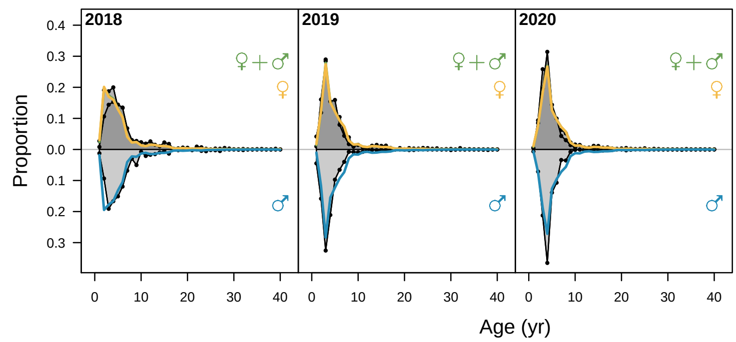

Figure C.87: Scenario 13 age structure for saddletail snapper

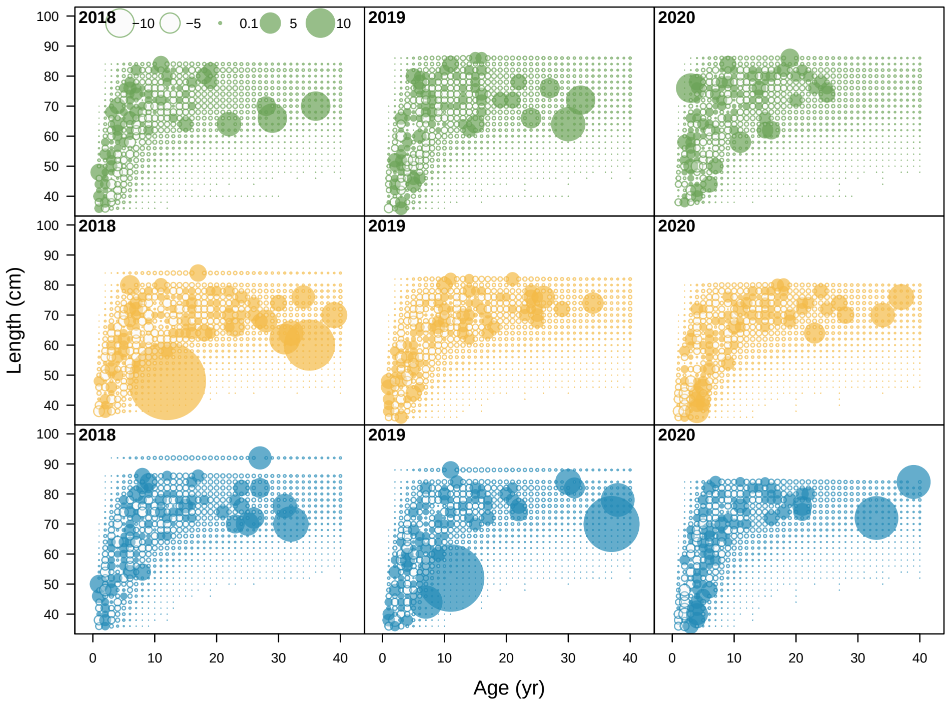

Figure C.88: Scenario 13 Pearson residuals for age-at-length compositions for the commercial fleet for saddletail snapper

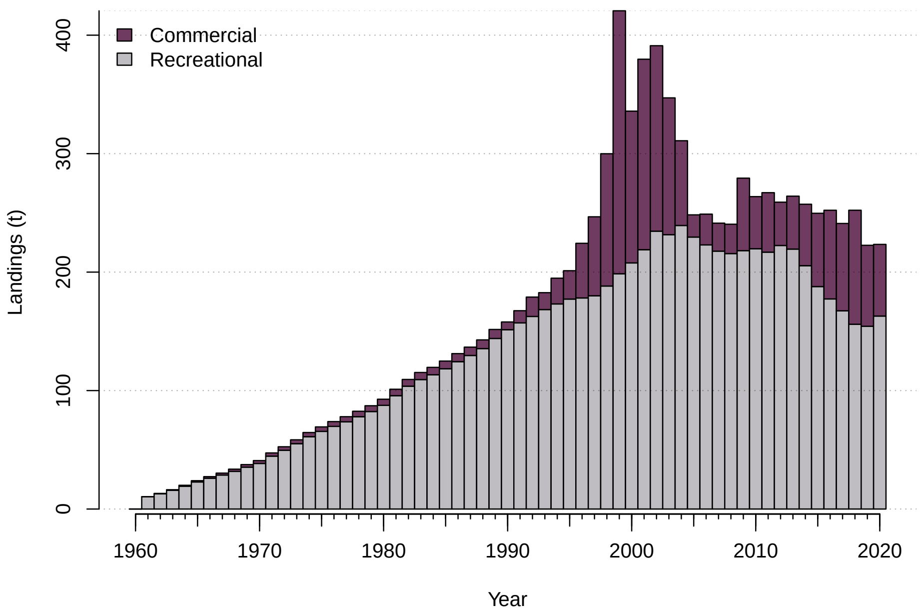

Figure C.89: Scenario 13 modelled harvest

Scenario 14

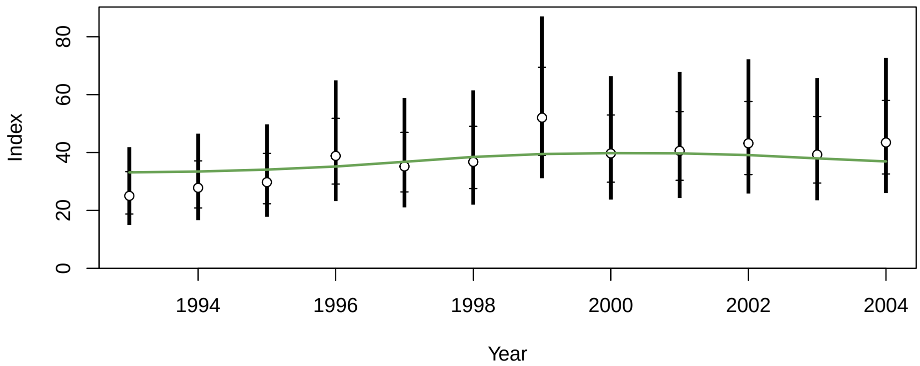

Figure C.90: Scenario 14 model predictions (green line) to commercial catch rates for saddletail snapper

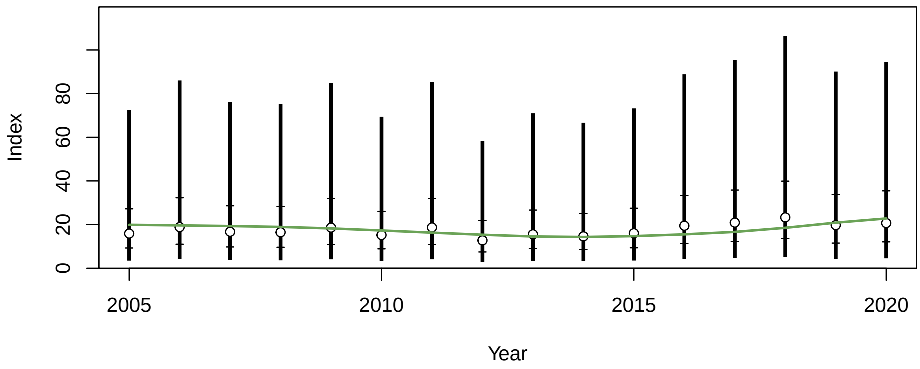

Figure C.91: Scenario 14 model predictions (green line) to commercial catch rates for saddletail snapper

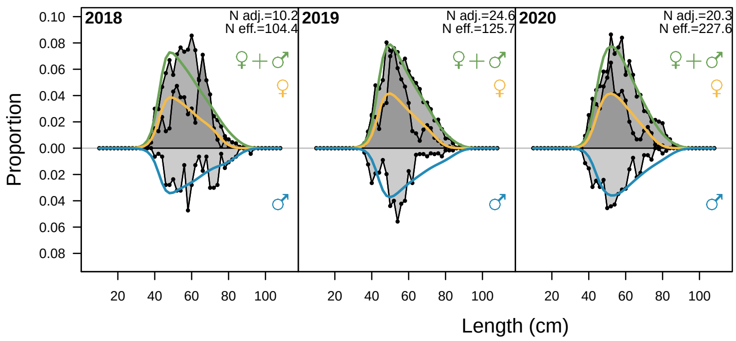

Figure C.92: Scenario 12 length structure for the commercial fleet for saddletail snapper for each sex

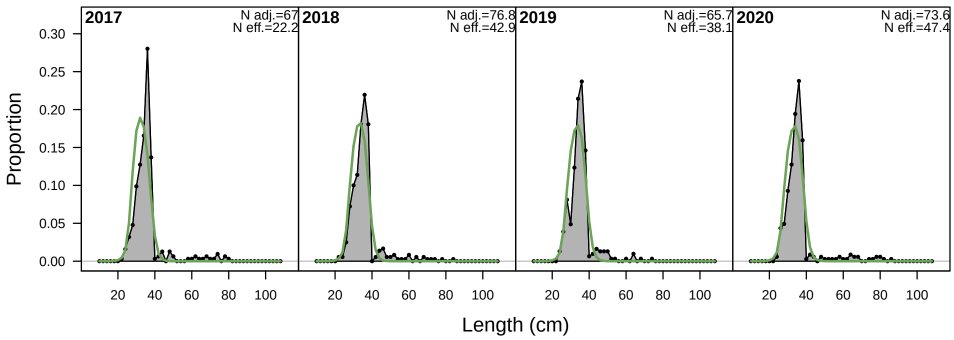

Figure C.93: Scenario 14 length structure for the recreational fleet for discarded saddletail snapper

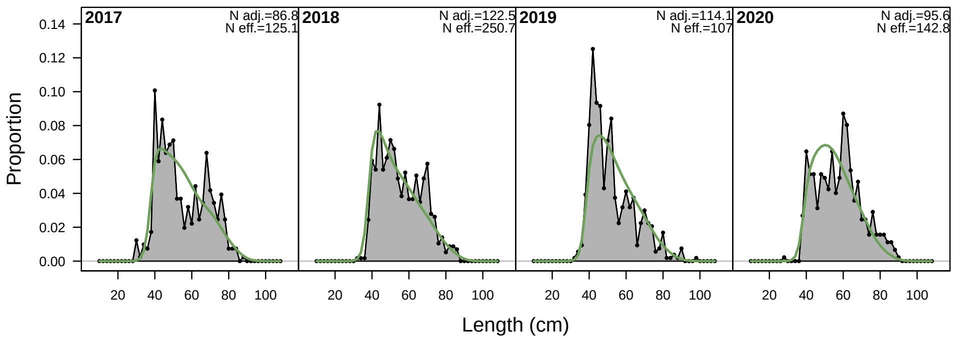

Figure C.94: Scenario 14 length structure for the recreational fleet for retained saddletail snapper

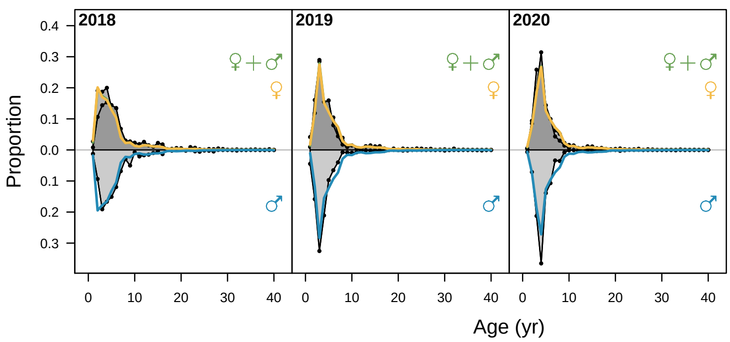

Figure C.95: Scenario 14 age structure for saddletail snapper

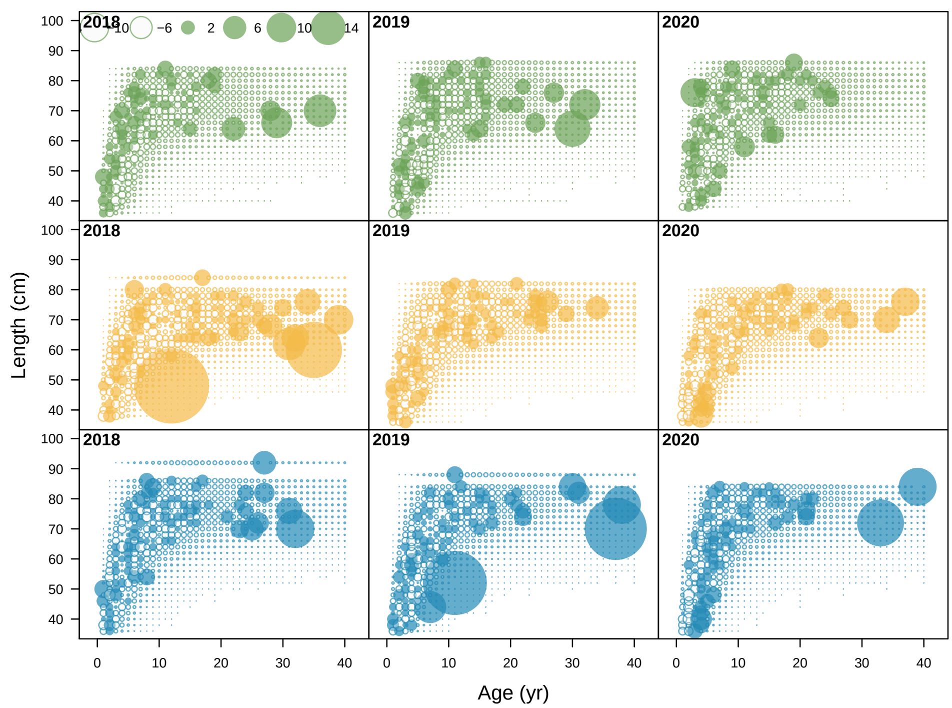

Figure C.96: Scenario 14 Pearson residuals for age-at-length compositions for the commercial fleet for saddletail snapper

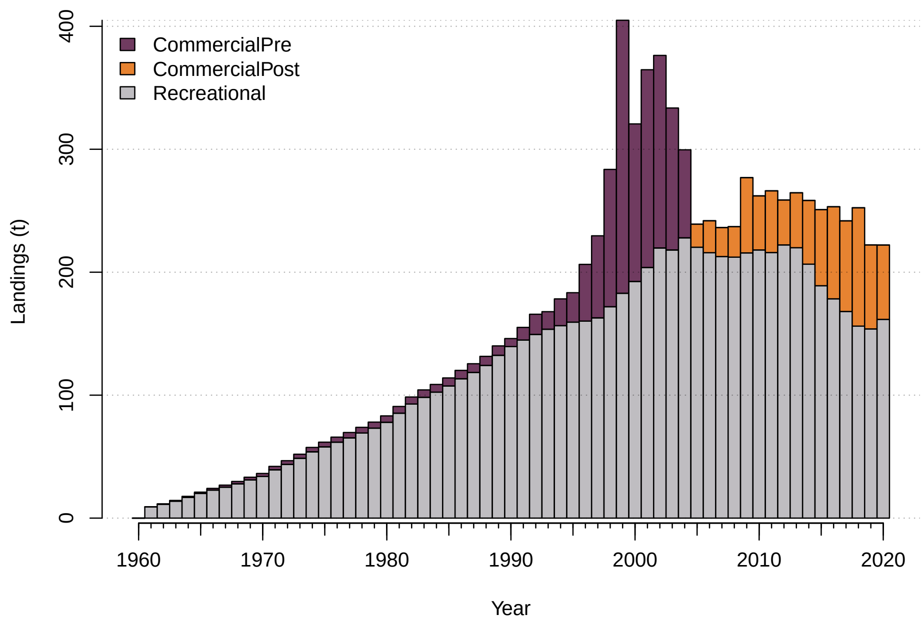

Figure C.97: Scenario 14 modelled harvest

Scenario 15

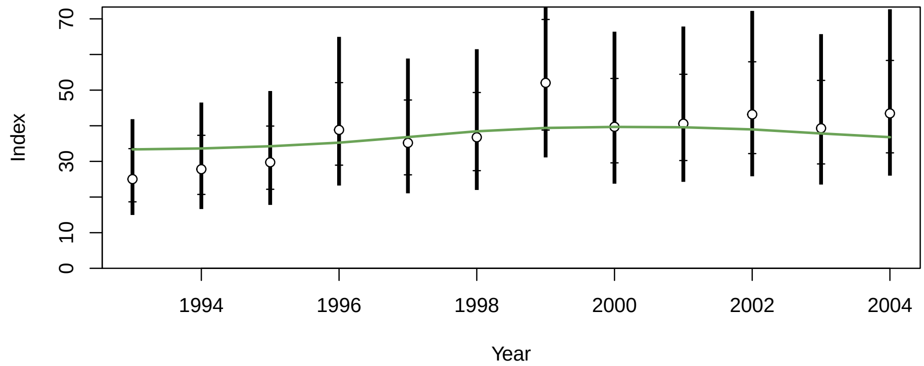

Figure C.98: Scenario 15 model predictions (green line) to commercial catch rates for saddletail snapper

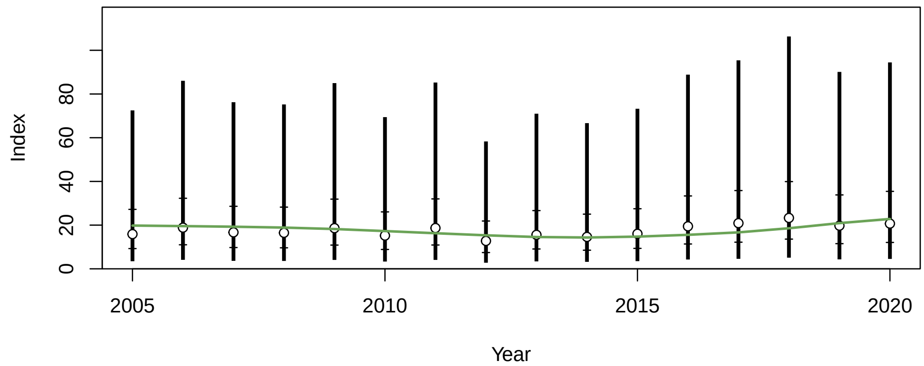

Figure C.99: Scenario 15 model predictions (green line) to commercial catch rates for saddletail snapper

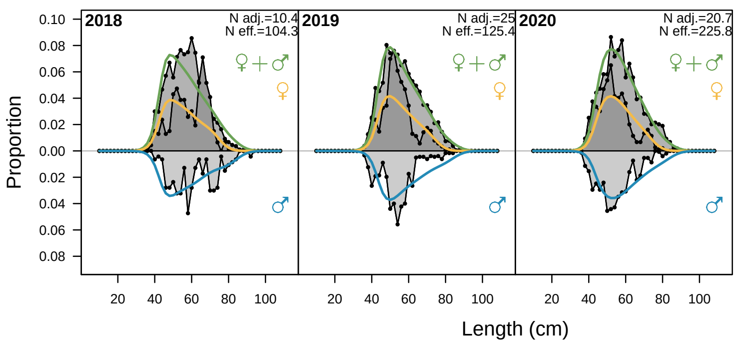

Figure C.100: Scenario 15 length structure for the commercial fleet for saddletail snapper for each sex

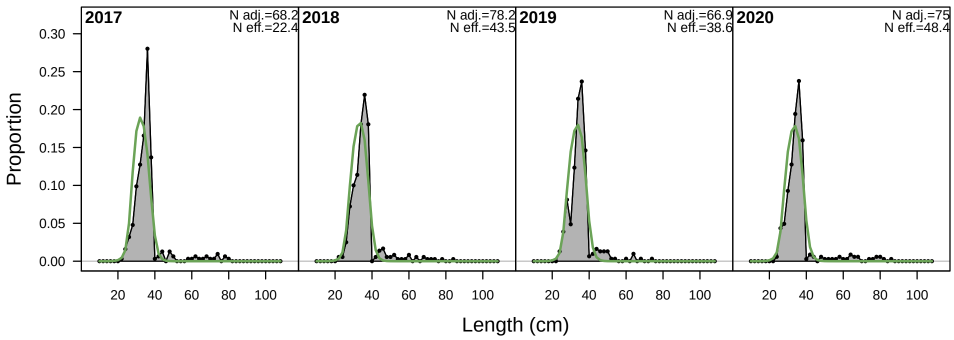

Figure C.101: Scenario 15 length structure for the recreational fleet for discarded saddletail snapper

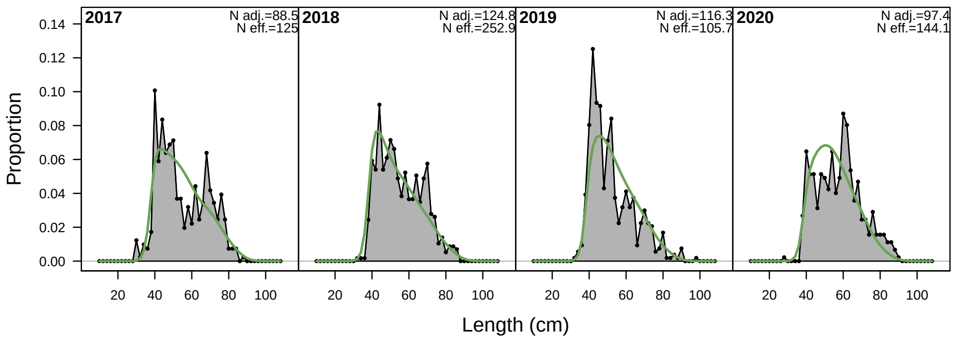

Figure C.102: Scenario 15 length structure for the recreational fleet for retained saddletail snapper

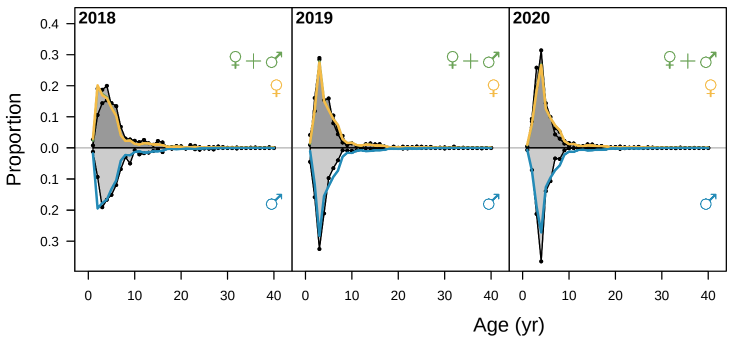

Figure C.103: Scenario 15 age structure for saddletail snapper

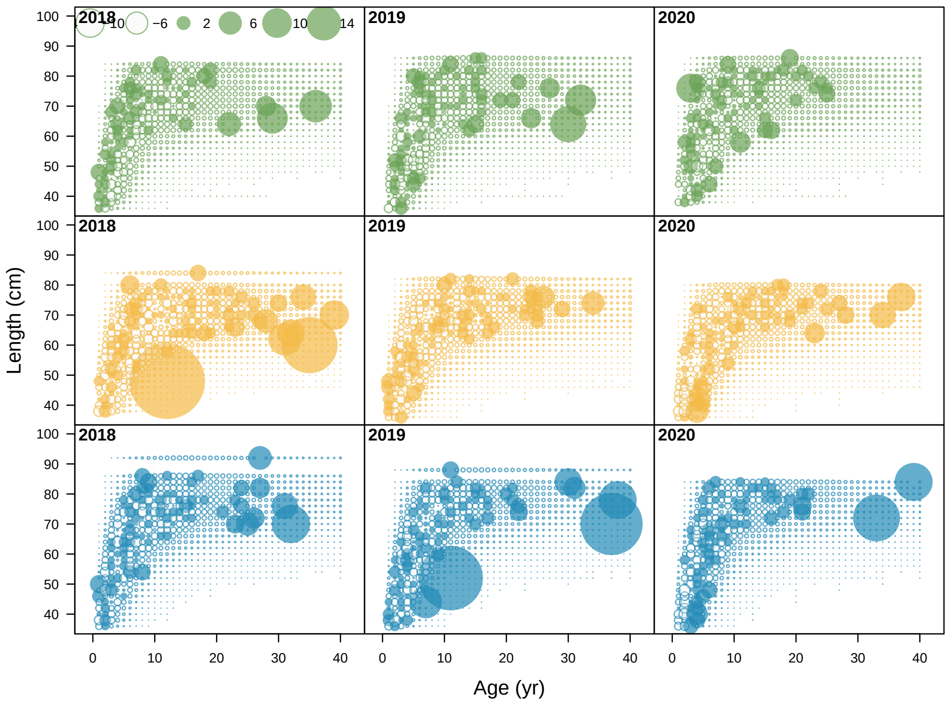

Figure C.104: Scenario 15 Pearson residuals for age-at-length compositions for the commercial fleet for saddletail snapper

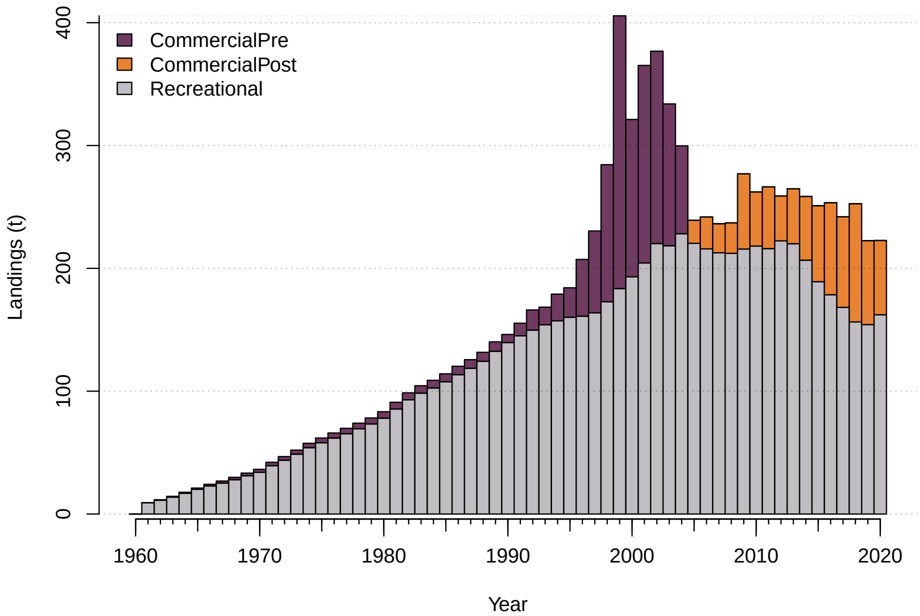

Figure C.105: Scenario 15 modelled harvest

Scenario 16

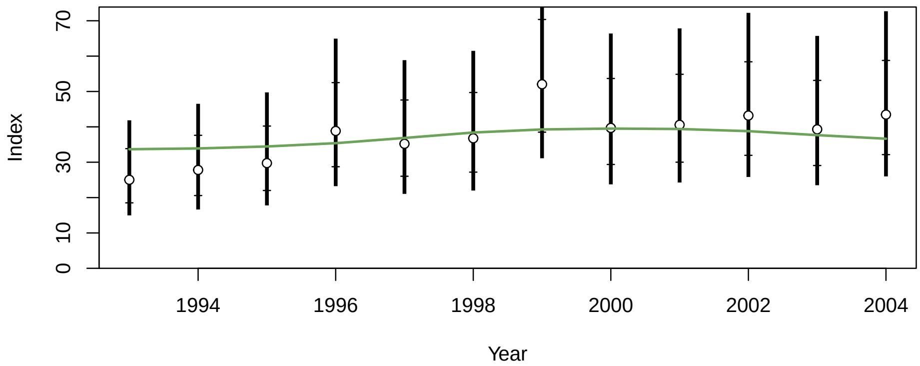

Figure C.106: Scenario 16 model predictions (green line) to commercial catch rates for saddletail snapper

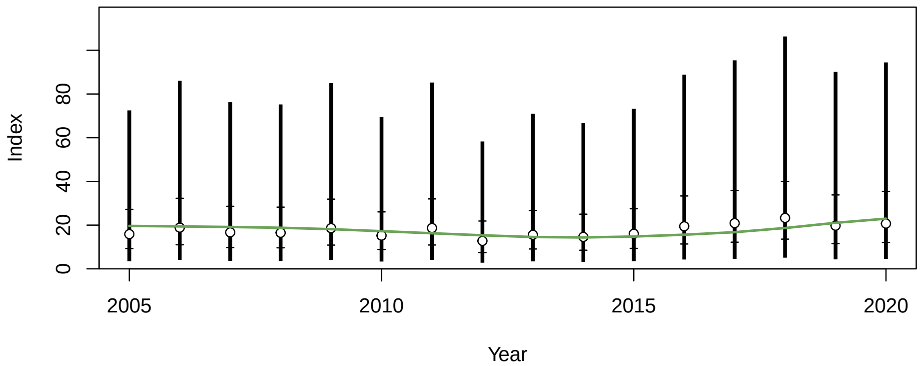

Figure C.107: Scenario 16 model predictions (green line) to commercial catch rates for saddletail snapper

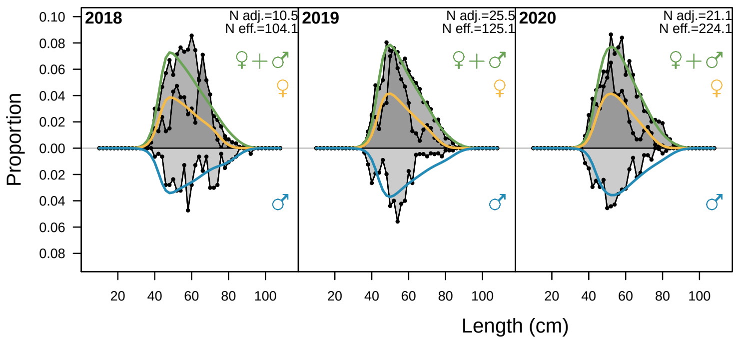

Figure C.108: Scenario 16 length structure for the commercial fleet for saddletail snapper for each sex

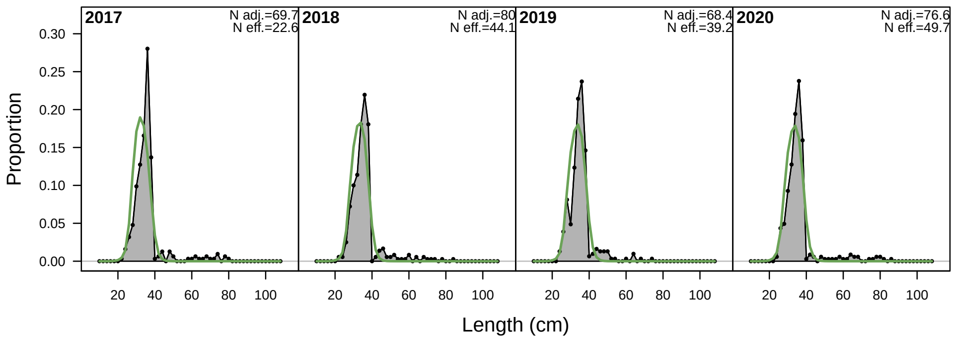

Figure C.109: Scenario 16 length structure for the recreational fleet for discarded saddletail snapper

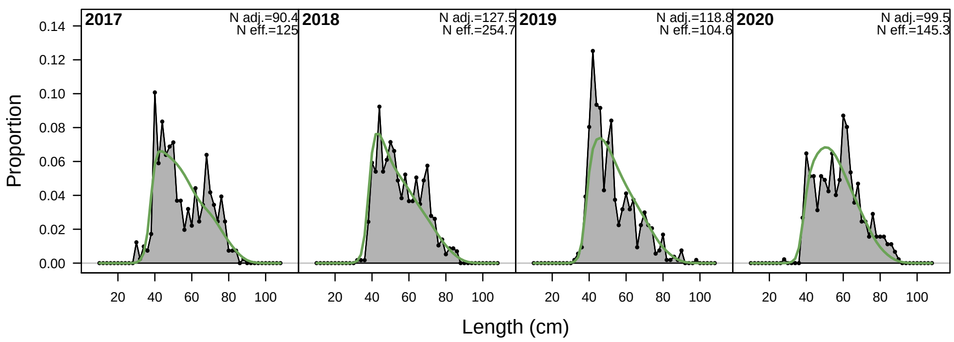

Figure C.110: Scenario 16 length structure for the recreational fleet for retained saddletail snapper

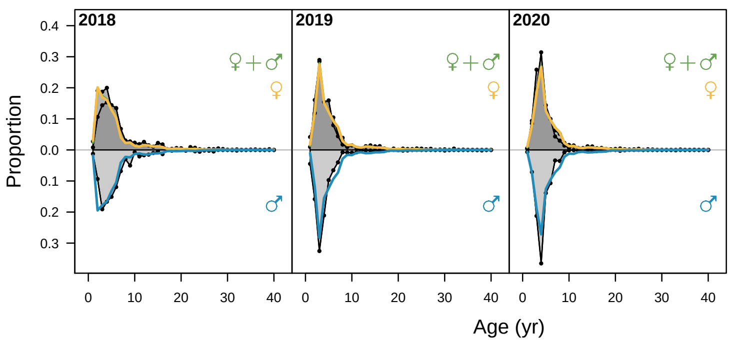

Figure C.111: Scenario 16 age structure for saddletail snapper

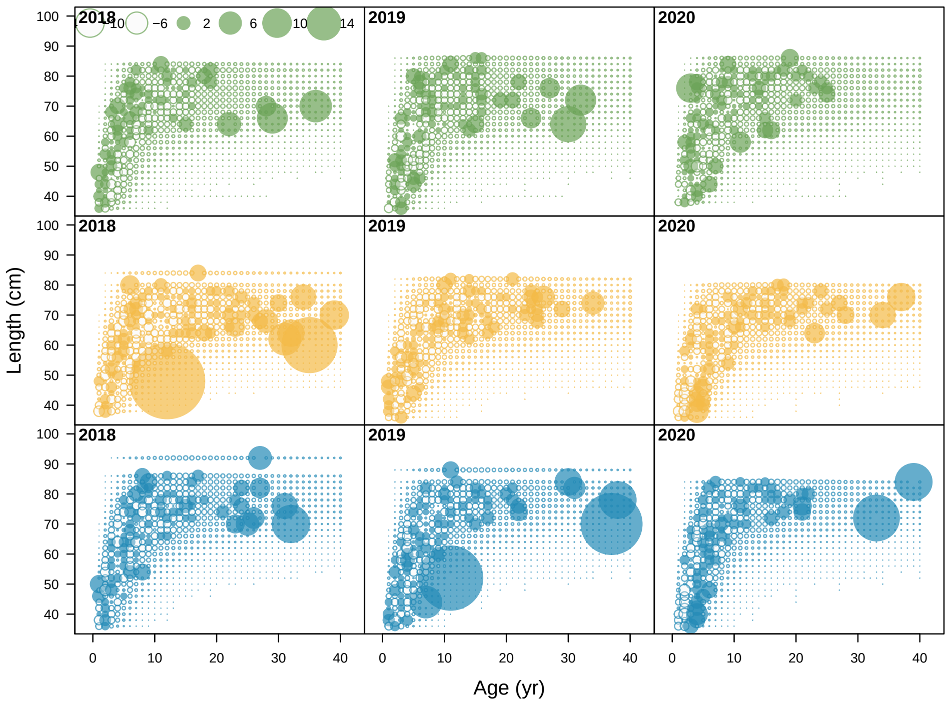

Figure C.112: Scenario 16 Pearson residuals for age-at-length compositions for the commercial fleet for saddletail snapper

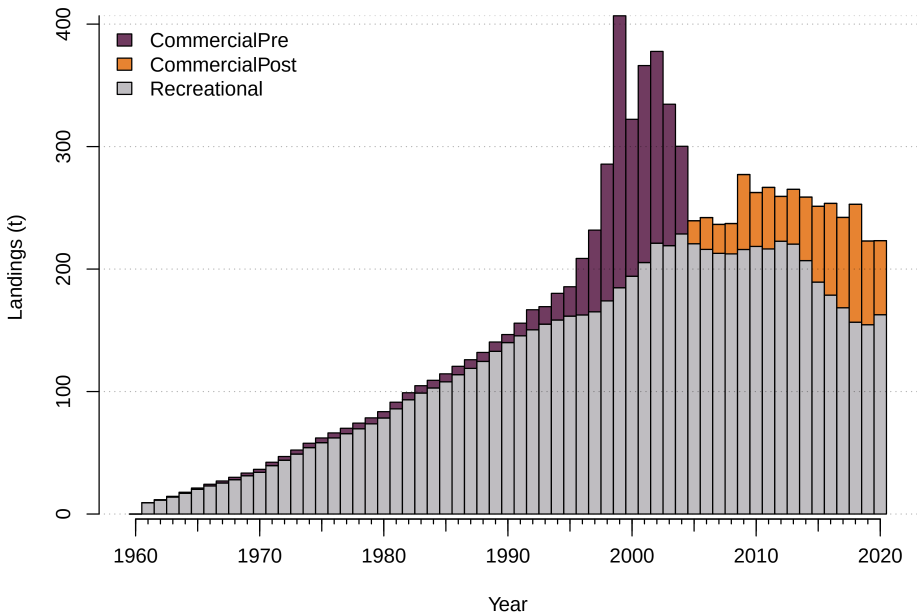

Figure C.113: Scenario 16 modelled harvest

Scenario 17

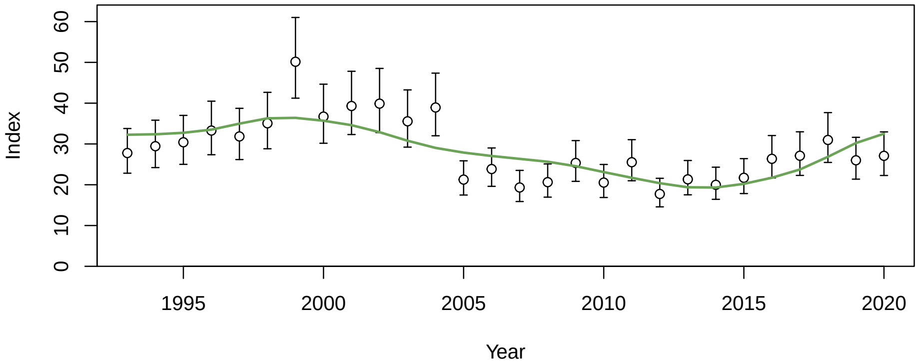

Figure C.114: Scenario 17 model predictions (green line) to commercial catch rates for saddletail snapper

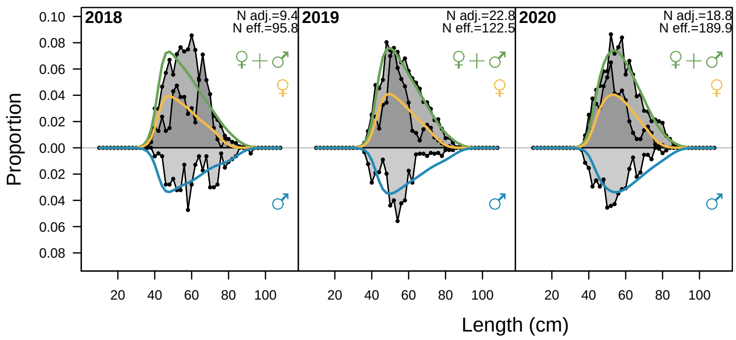

Figure C.115: Scenario 17 length structure for the commercial fleet for saddletail snapper for each sex

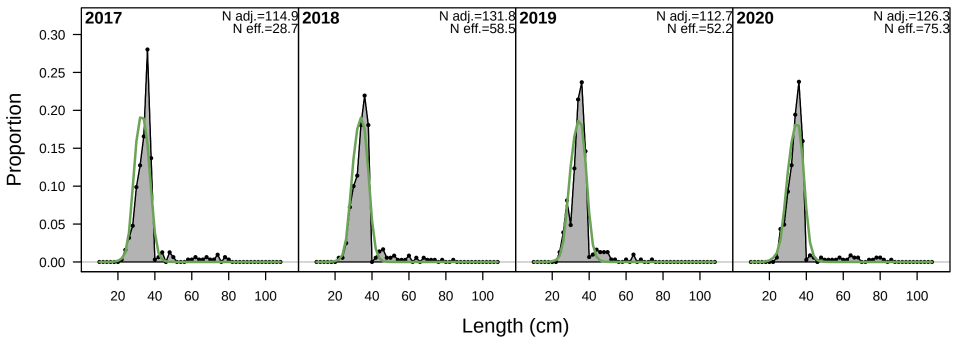

Figure C.116: Scenario 17 length structure for the recreational fleet for discarded saddletail snapper

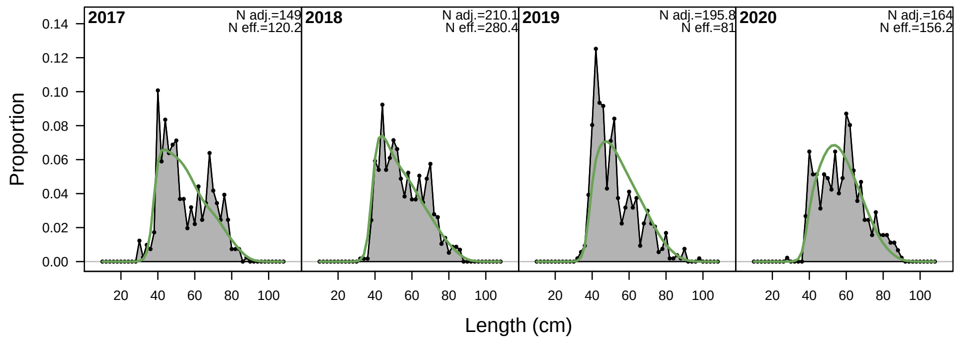

Figure C.117: Scenario 17 length structure for the recreational fleet for retained saddletail snapper

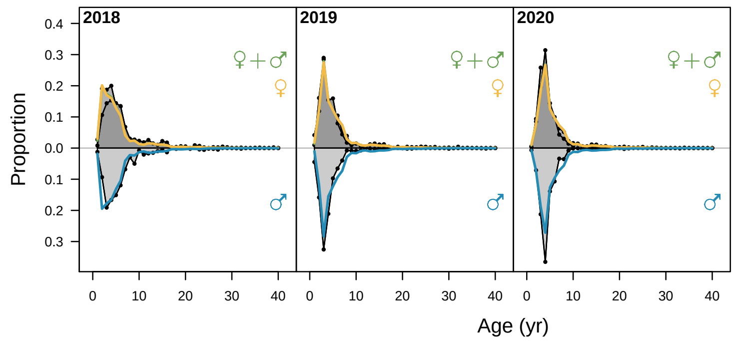

Figure C.118: Scenario 17 age structure for saddletail snapper

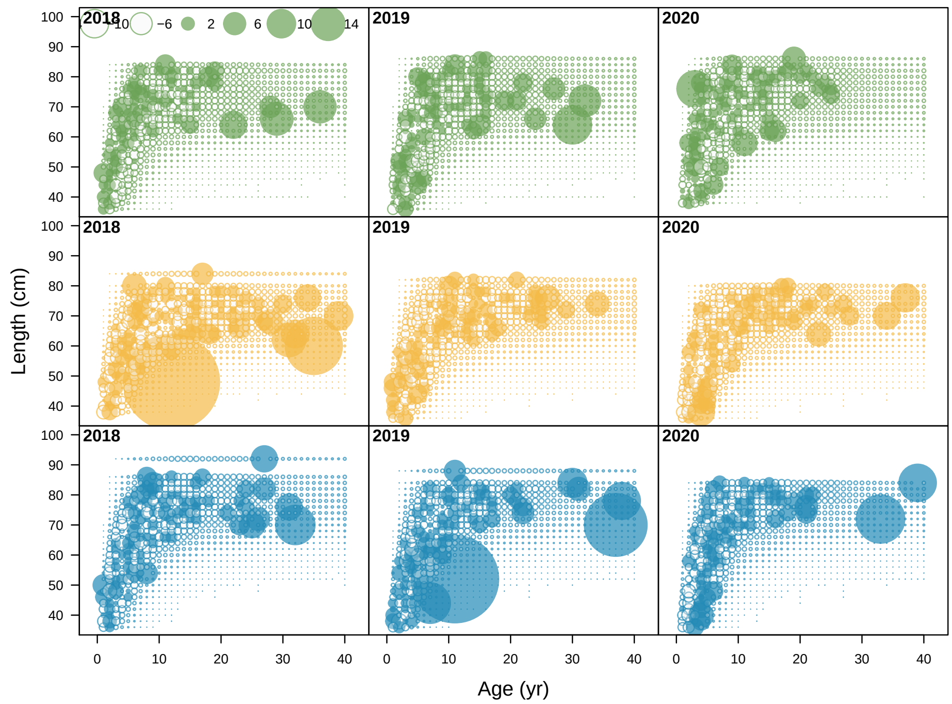

Figure C.119: Scenario 17 Pearson residuals for age-at-length compositions for the commercial fleet for saddletail snapper

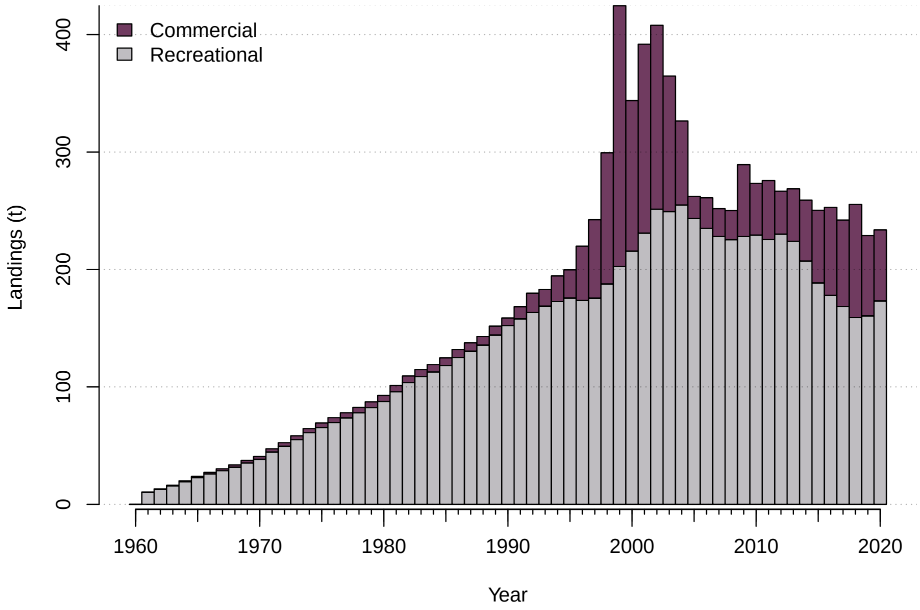

Figure C.120: Scenario 17 modelled harvest

Scenario 18

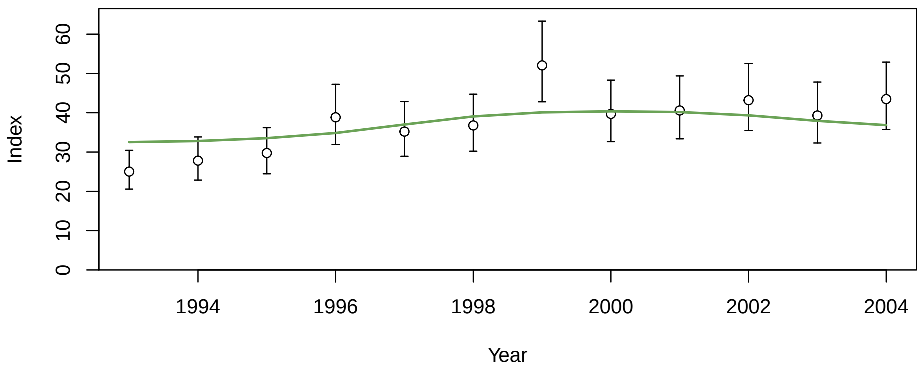

Figure C.121: Scenario 18 model predictions (green line) to commercial catch rates for saddletail snapper

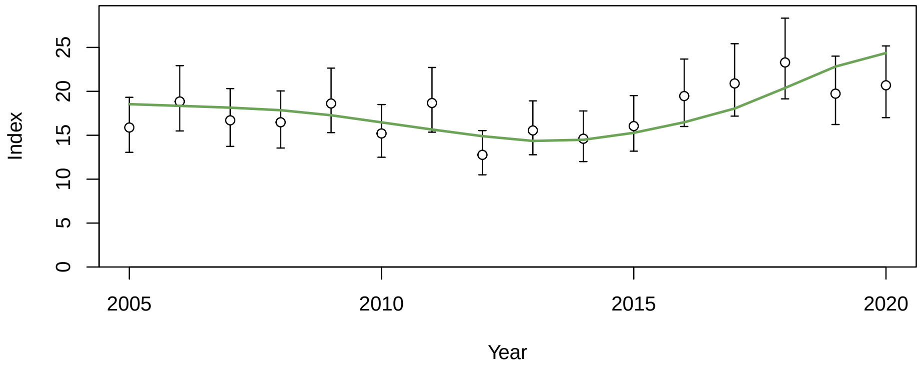

Figure C.122: Scenario 18 model predictions (green line) to commercial catch rates for saddletail snapper

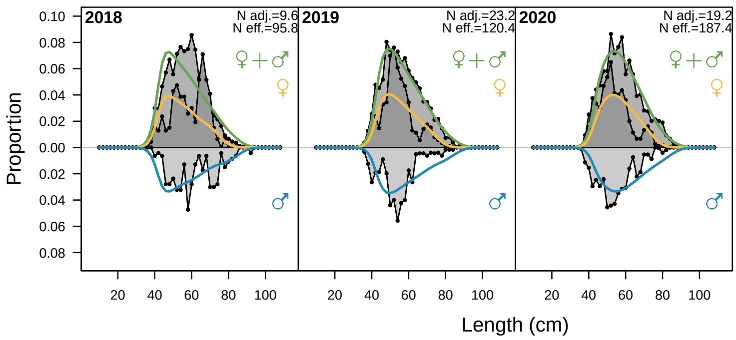

Figure C.123: Scenario 18 length structure for the commercial fleet for saddletail snapper for each sex

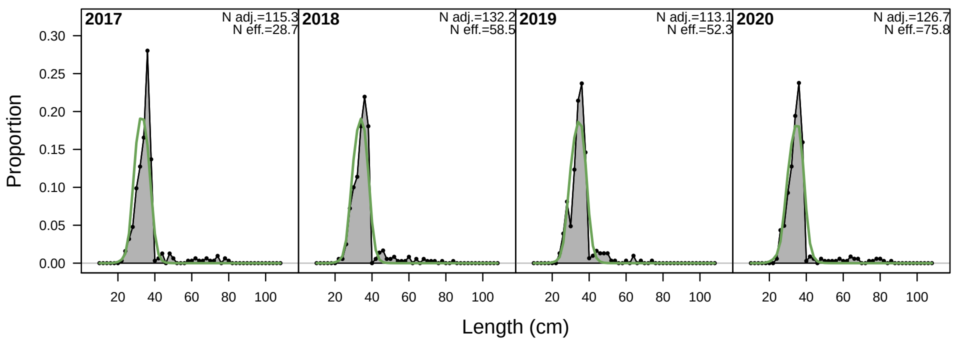

Figure C.124: Scenario 18 length structure for the recreational fleet for discarded saddletail snapper

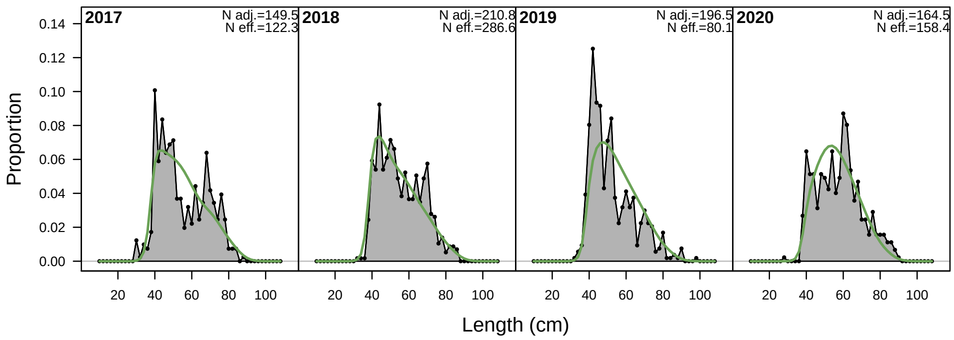

Figure C.125: Scenario 18 length structure for the recreational fleet for retained saddletail snapper

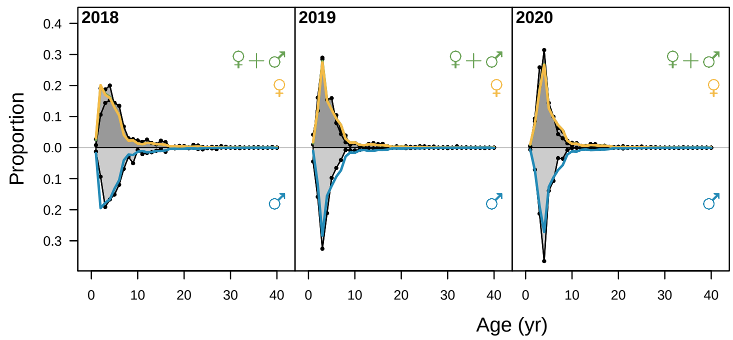

Figure C.126: Scenario 18 age structure for saddletail snapper

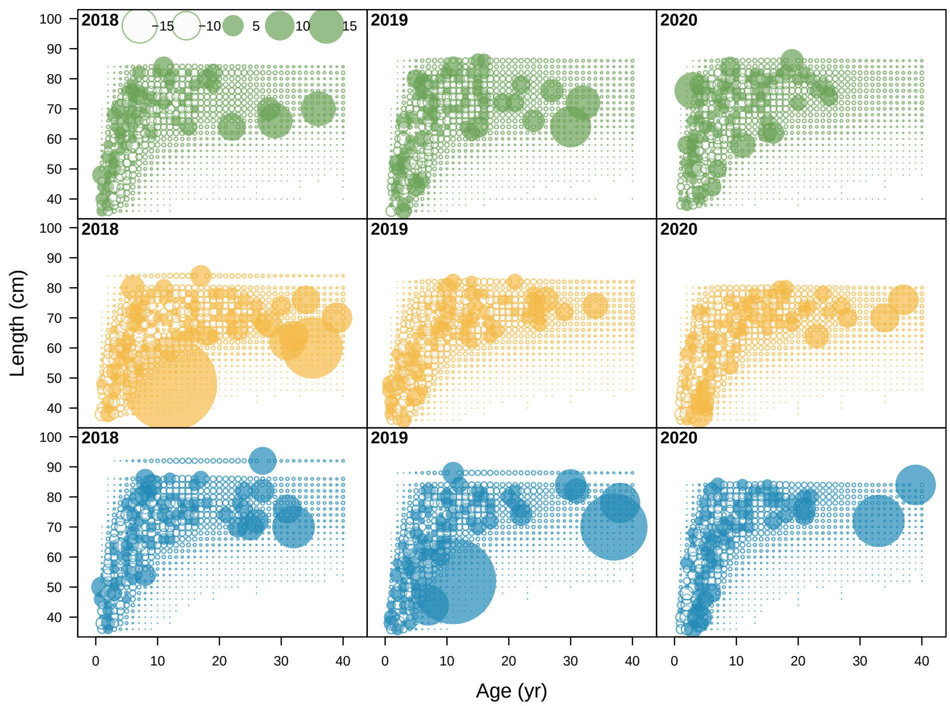

Figure C.127: Scenario 18 Pearson residuals for age-at-length compositions for the commercial fleet for saddletail snapper

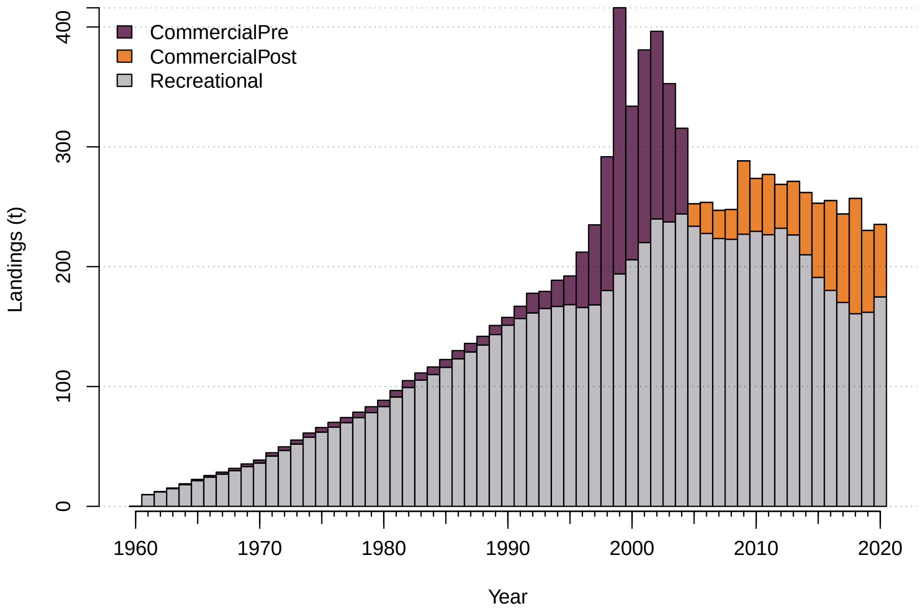

Figure C.128: Scenario 18 modelled harvest

Scenario 19

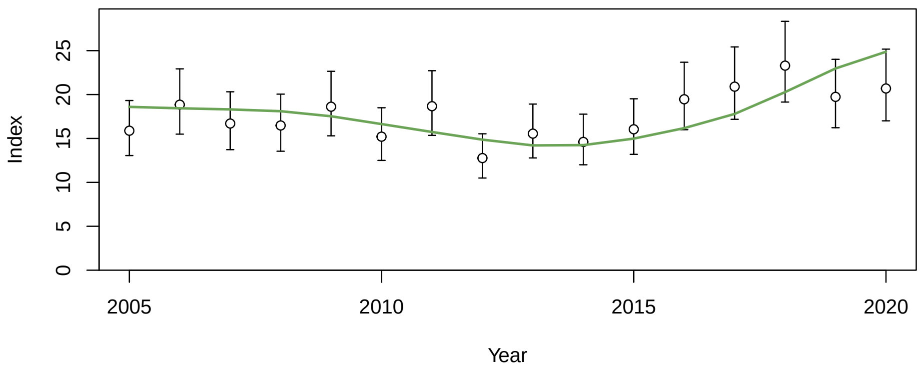

Figure C.129: Scenario 19 model predictions (green line) to commercial catch rates for saddletail snapper

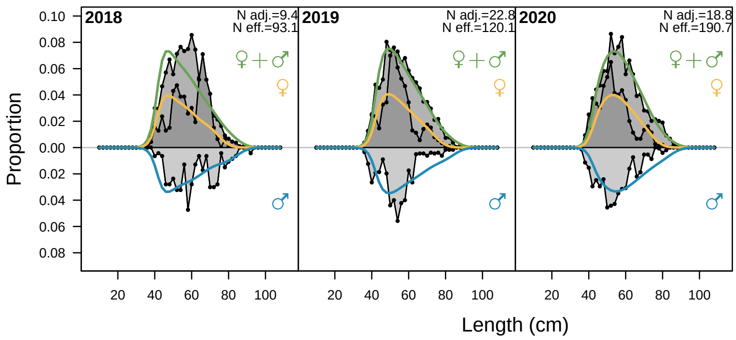

Figure C.130: Scenario 19 length structure for the commercial fleet for saddletail snapper for each sex

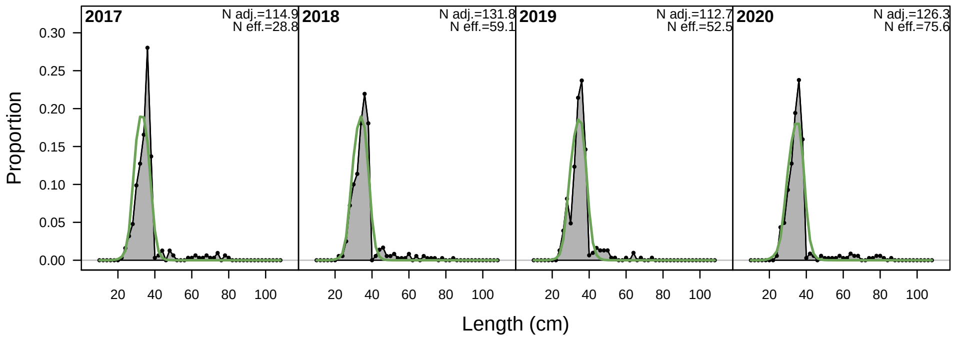

Figure C.131: Scenario 19 length structure for the recreational fleet for retained saddletail snapper

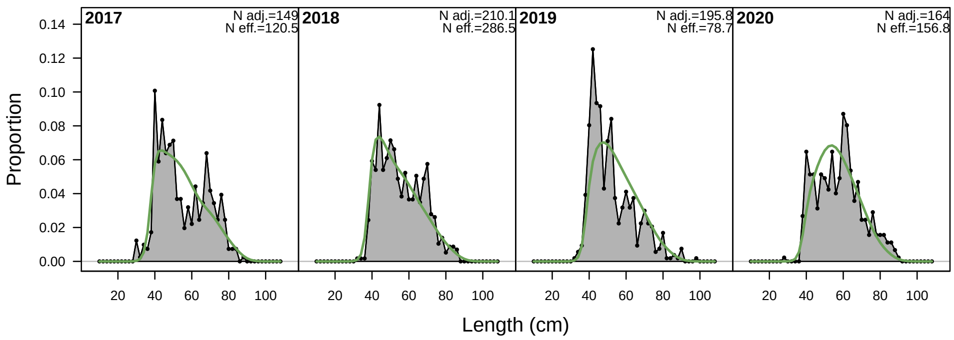

Figure C.132: Scenario 19 length structure for the recreational fleet for retained saddletail snapper

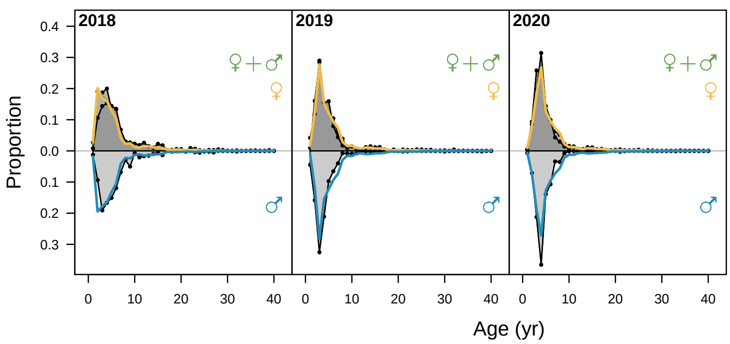

Figure C.133: Scenario 19 age structure for saddletail snapper

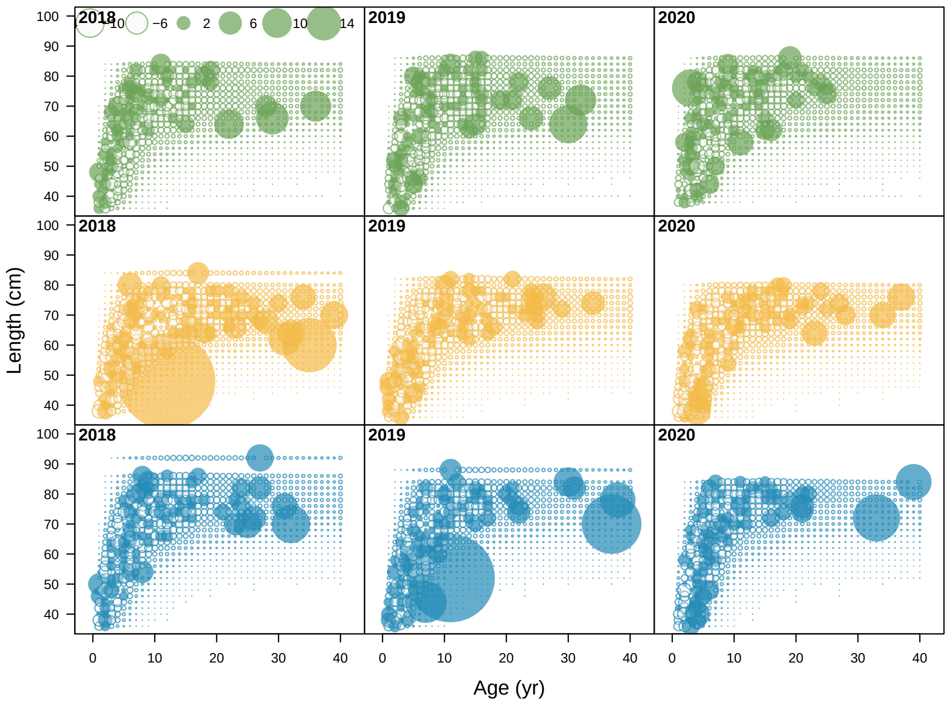

Figure C.134: Scenario 19 Pearson residuals for age-at-length compositions for the commercial fleet for saddletail snapper

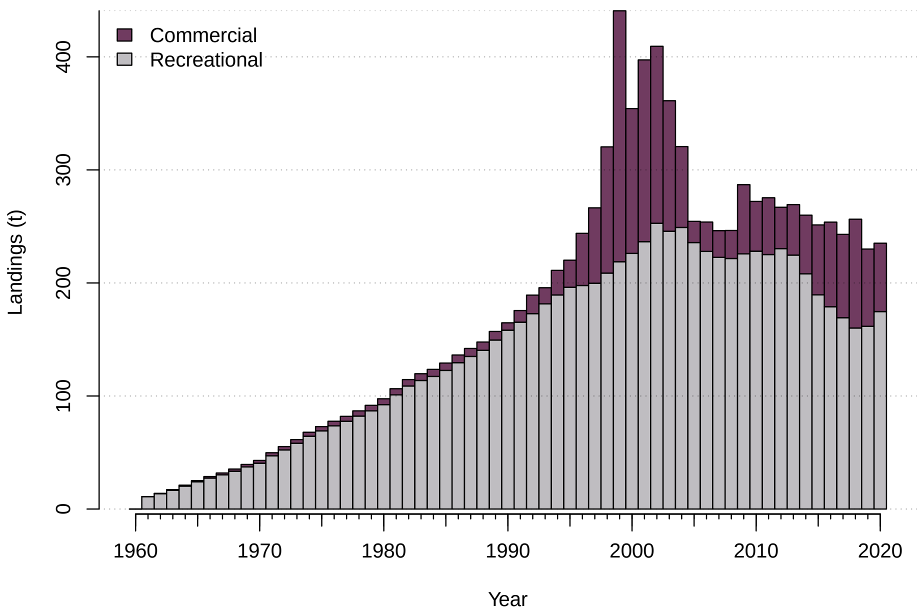

Figure C.135: Scenario 19 modelled harvest

Scenario 20

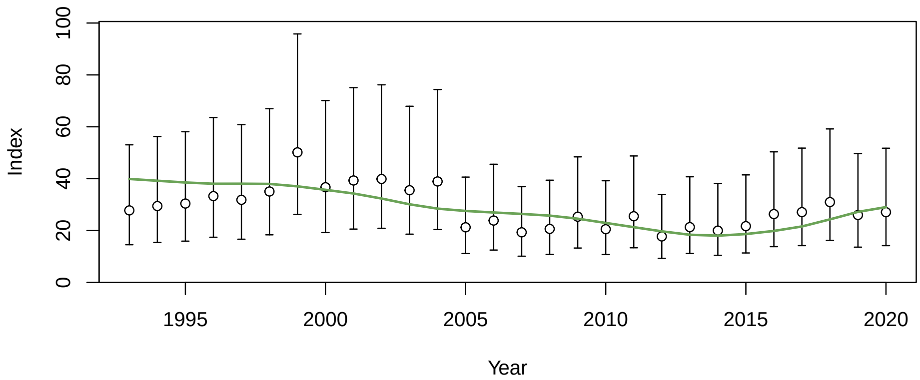

Figure C.136: Scenario 20 model predictions (green line) to commercial catch rates for saddletail snapper

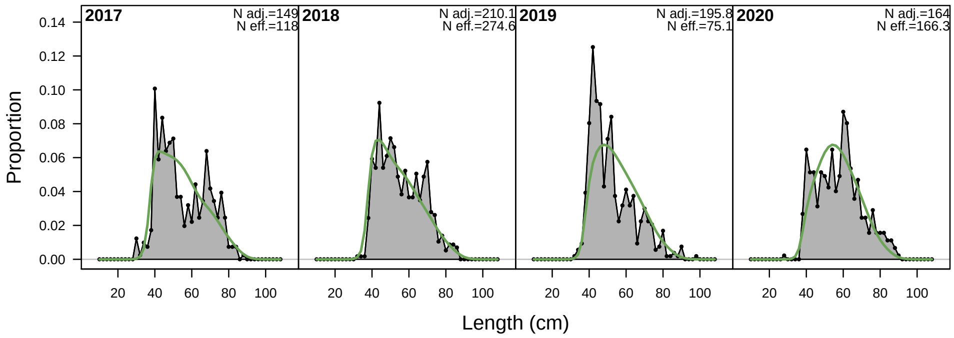

Figure C.137: Scenario 20 length structure for the commercial fleet for saddletail snapper for each sex

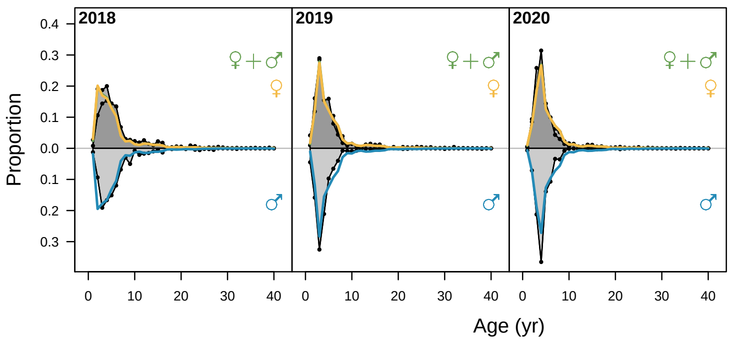

Figure C.138: Scenario 20 age structure for saddletail snapper

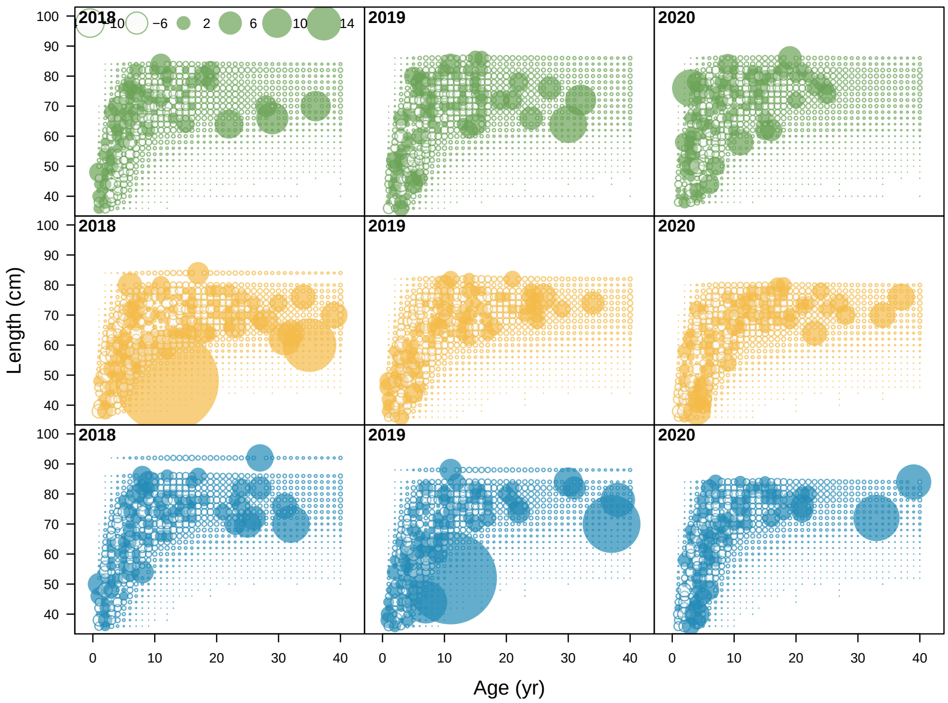

Figure C.139: Scenario 20 Pearson residuals for age-at-length compositions for the commercial fleet for saddletail snapper

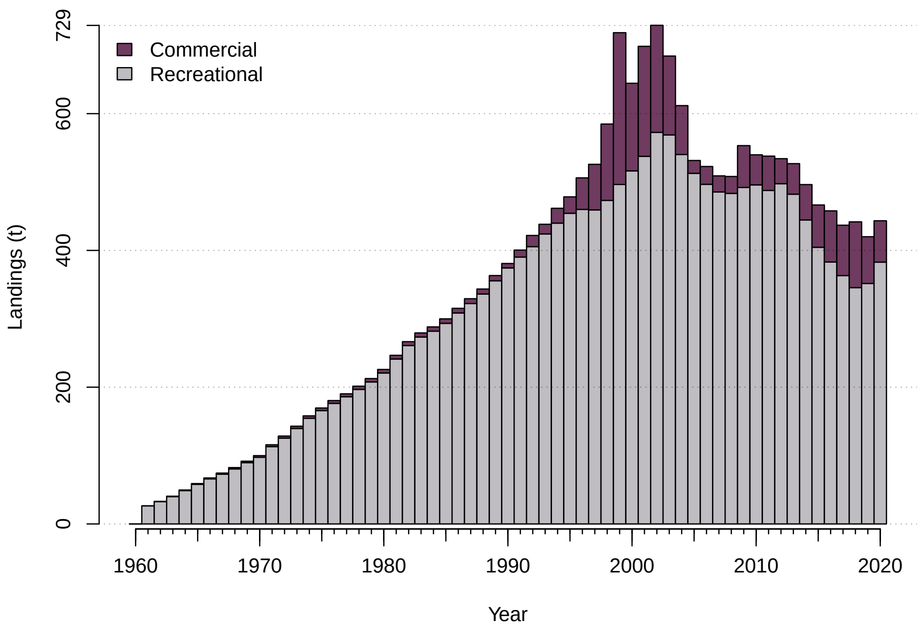

Figure C.140: Scenario 20 modelled harvest

Scenario 21

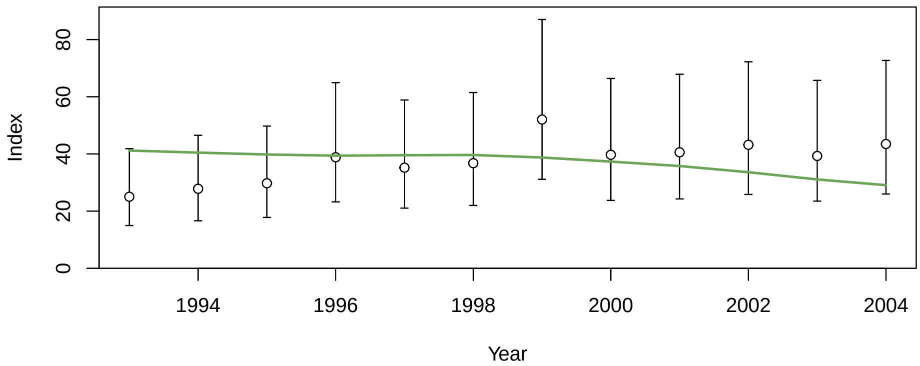

Figure C.141: Scenario 21 model predictions (green line) to commercial catch rates for saddletail snapper

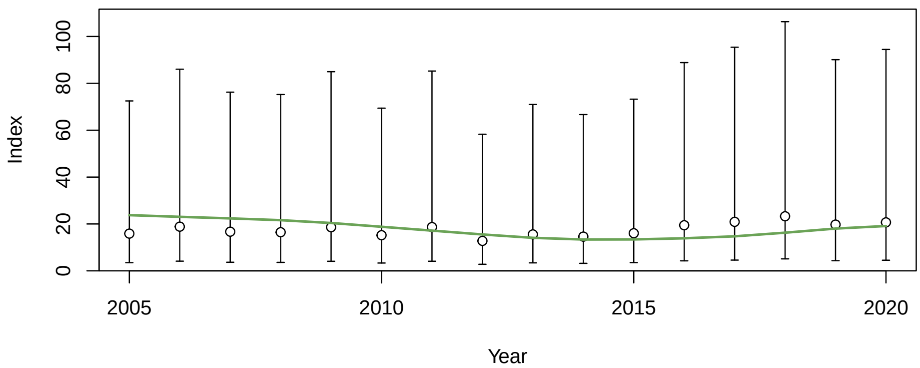

Figure C.142: Scenario 21 model predictions (green line) to commercial catch rates for saddletail snapper

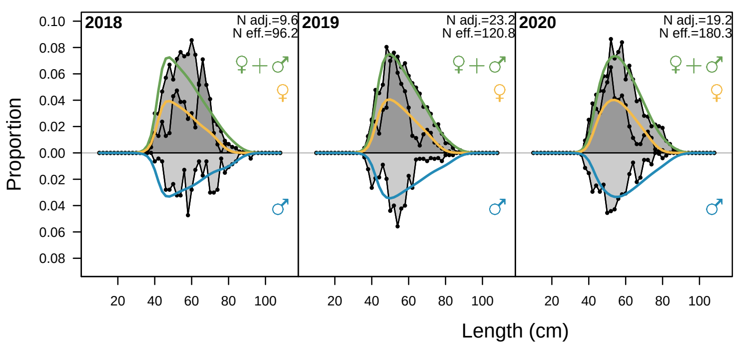

Figure C.143: Scenario 21 length structure for the commercial fleet for saddletail snapper for each sex

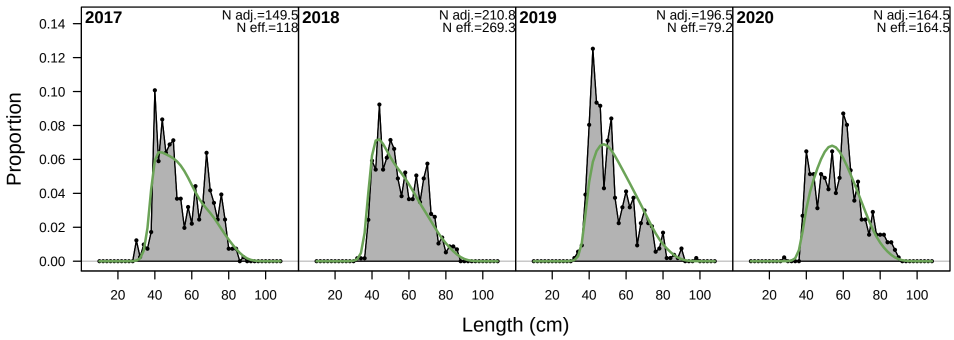

Figure C.144: Scenario 21 length structure for the recreational fleet for retained saddletail snapper

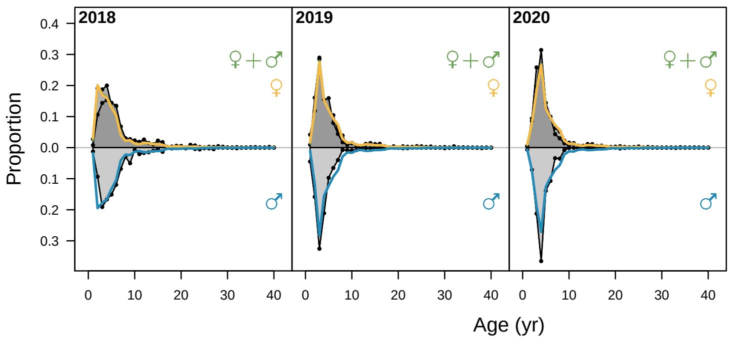

Figure C.145: Scenario 21 age structure for saddletail snapper

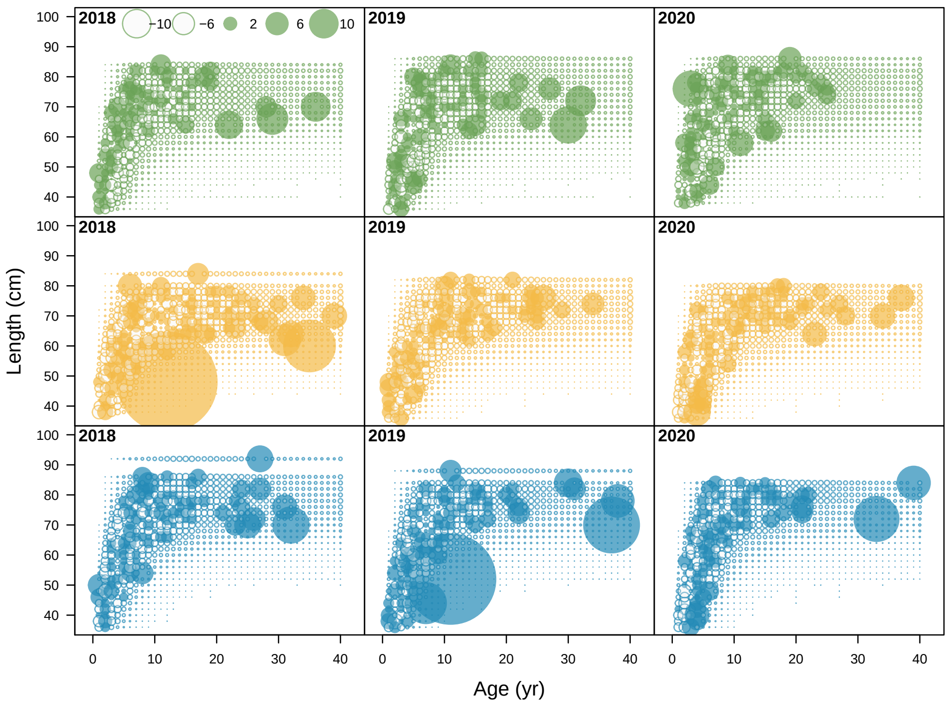

Figure C.146: Scenario 21 Pearson residuals for age-at-length compositions for the commercial fleet for saddletail snapper

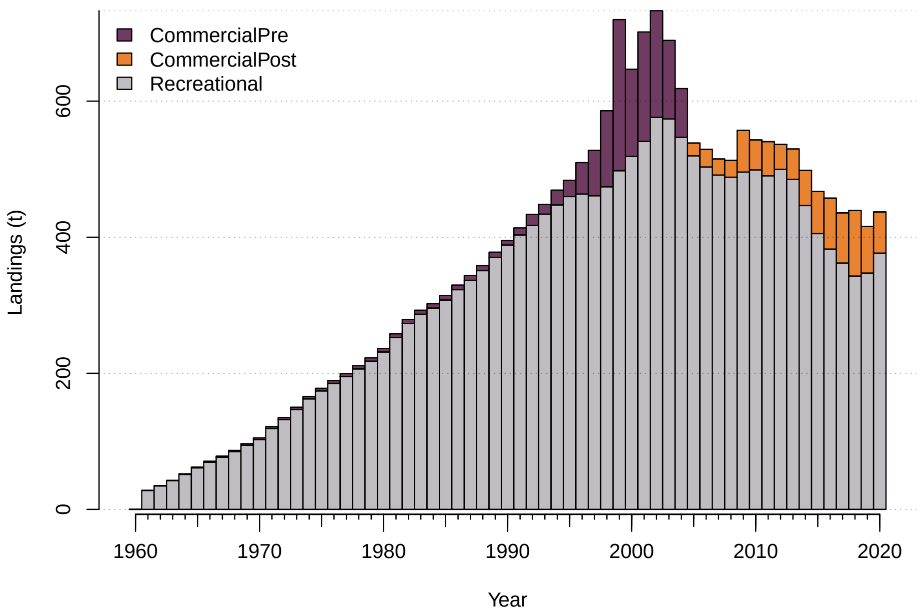

Figure C.147: Scenario 21 modelled harvest

Appendix D Sensitivity tests: other outputs

Scenario 1

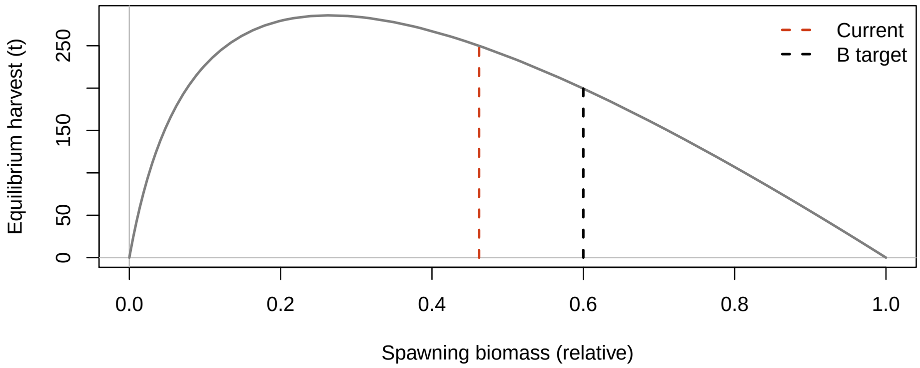

Figure D.1: Scenario 1 equilibrium harvest curve for saddletail snapper

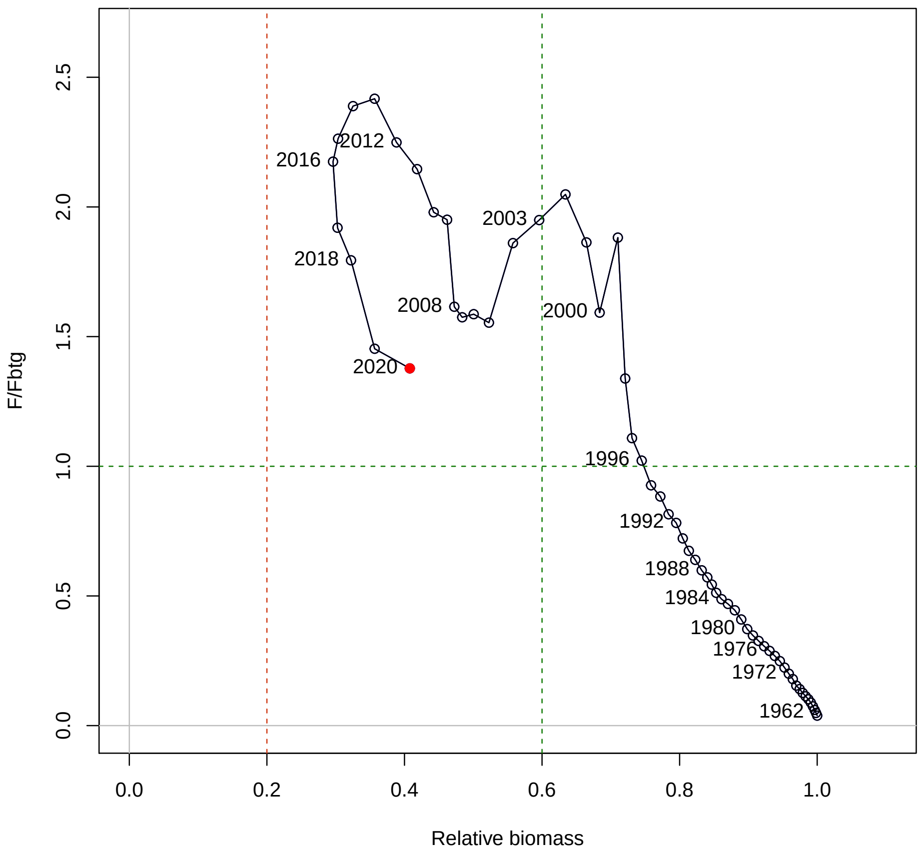

Figure D.2: Scenario 1 phase plot for saddletail snapper

Scenario 2

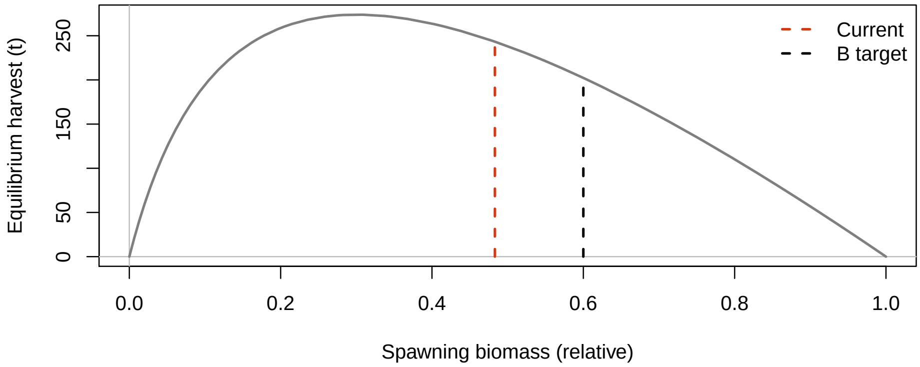

Figure D.3: Scenario 2 equilibrium harvest curve for saddletail snapper

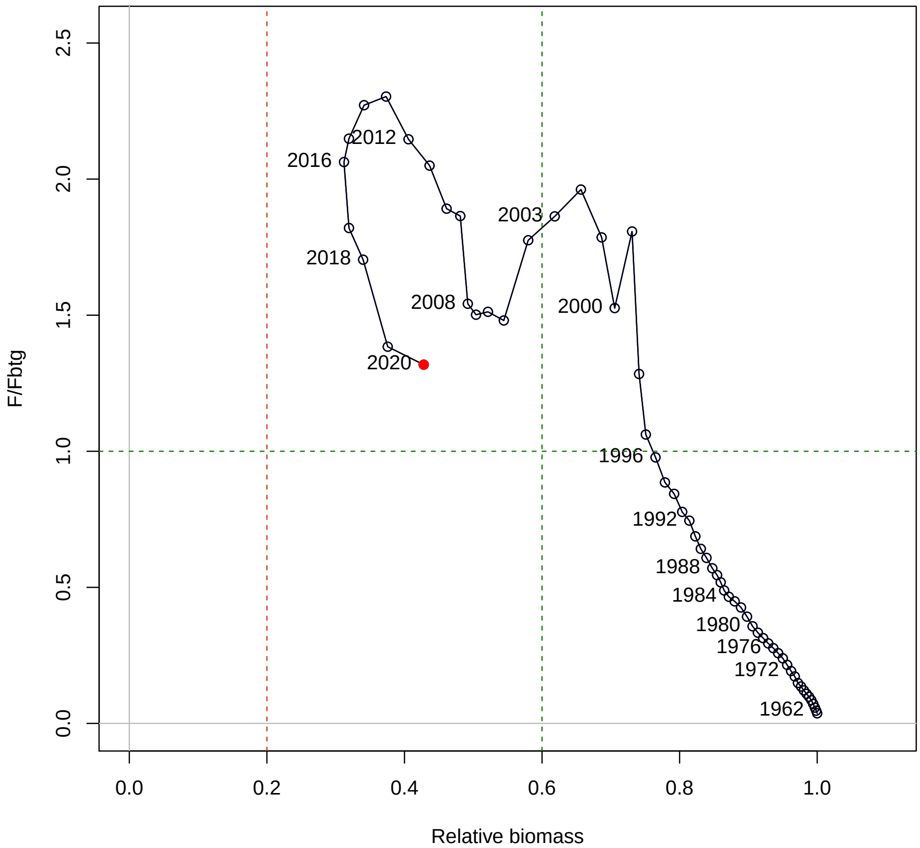

Figure D.4: Scenario 2 phase plot for saddletail snapper

Scenario 3

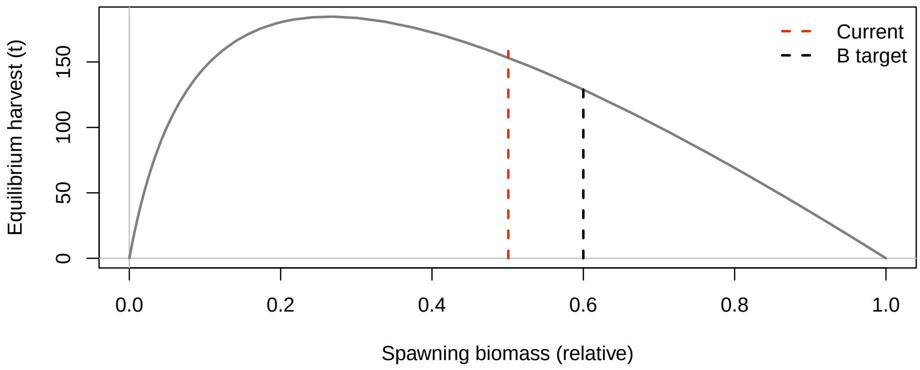

Figure D.5: Scenario 3 equilibrium harvest curve for saddletail snapper

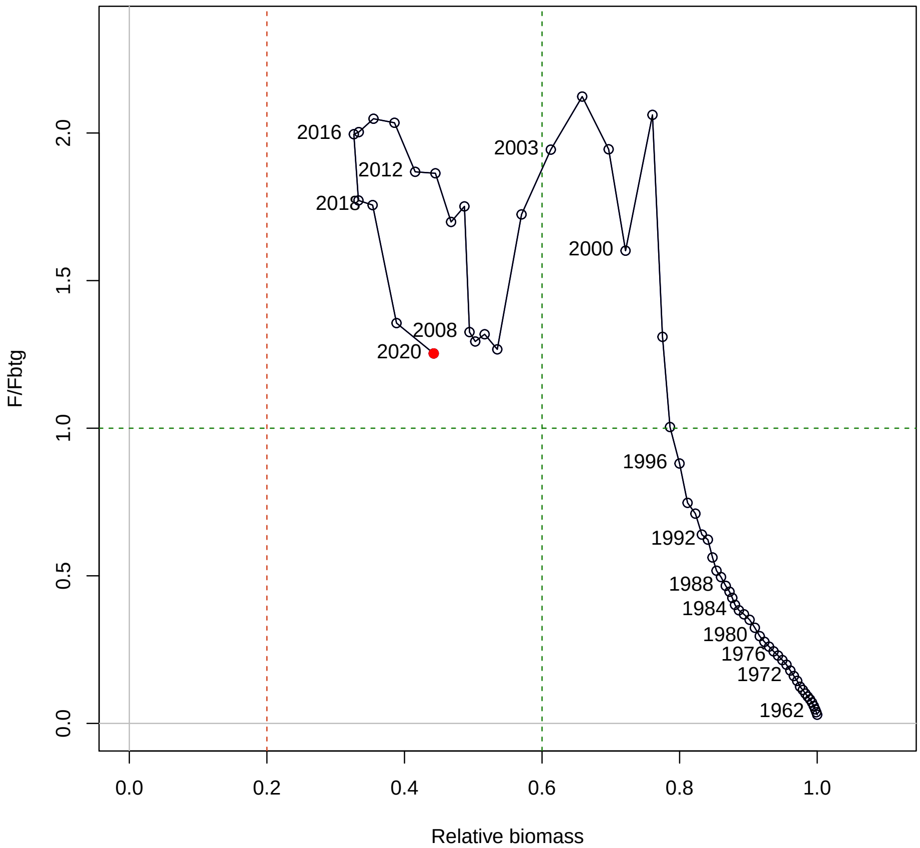

Figure D.6: Scenario 3 phase plot for saddletail snapper

Scenario 4

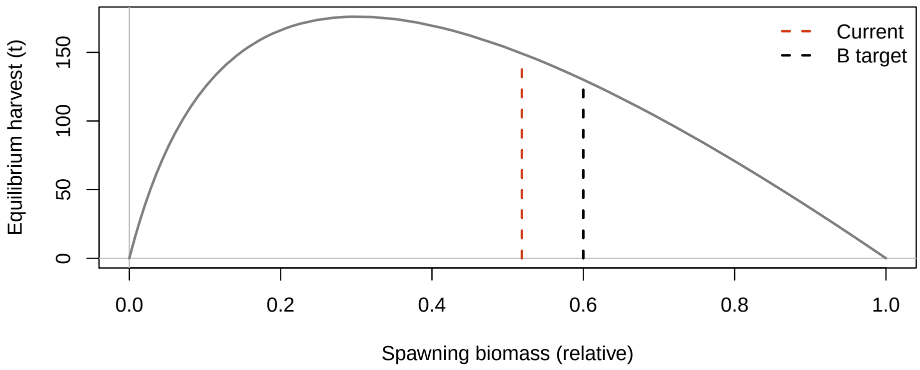

Figure D.7: Scenario 4 equilibrium harvest curve for saddletail snapper

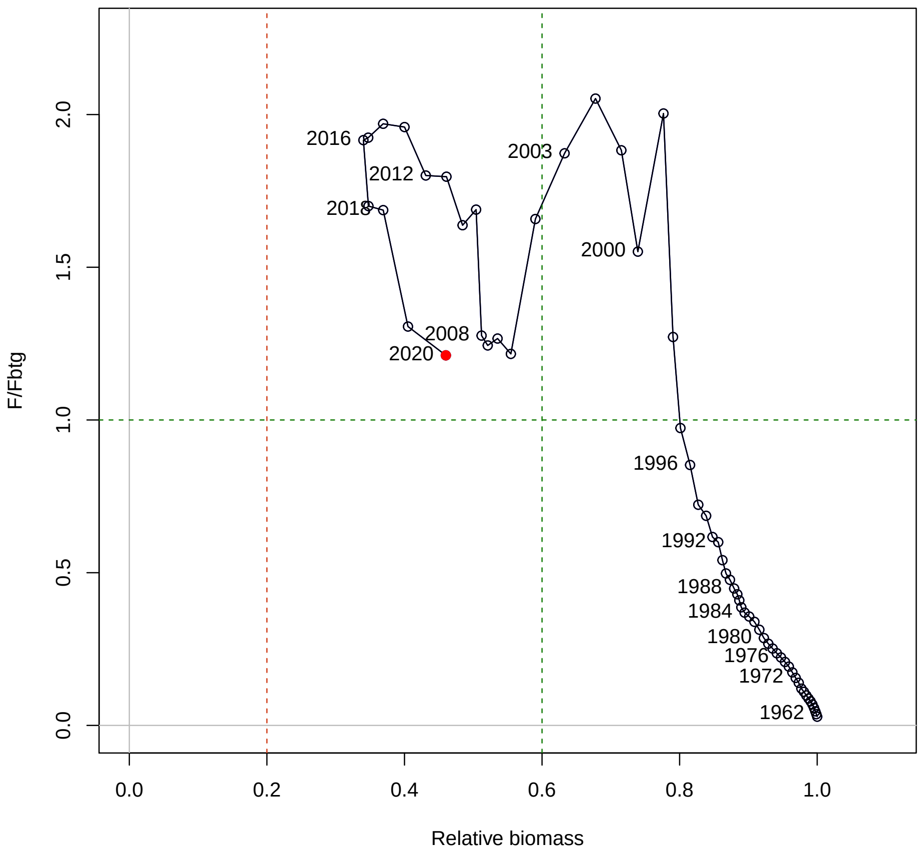

Figure D.8: Scenario 4 phase plot for saddletail snapper

Scenario 5

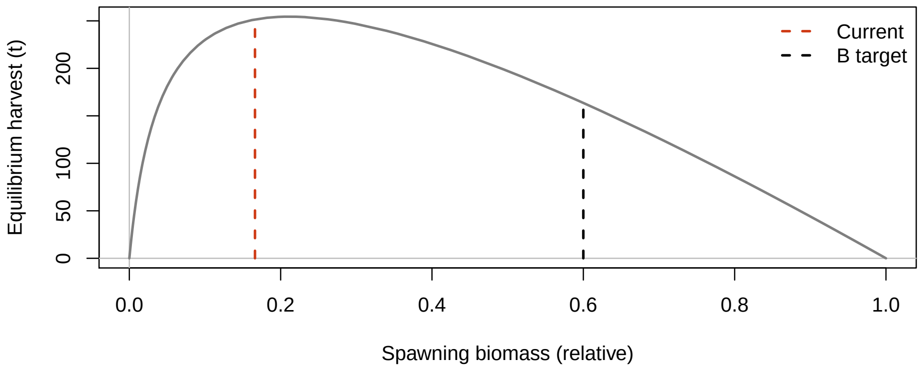

Figure D.9: Scenario 5 equilibrium harvest curve for saddletail snapper

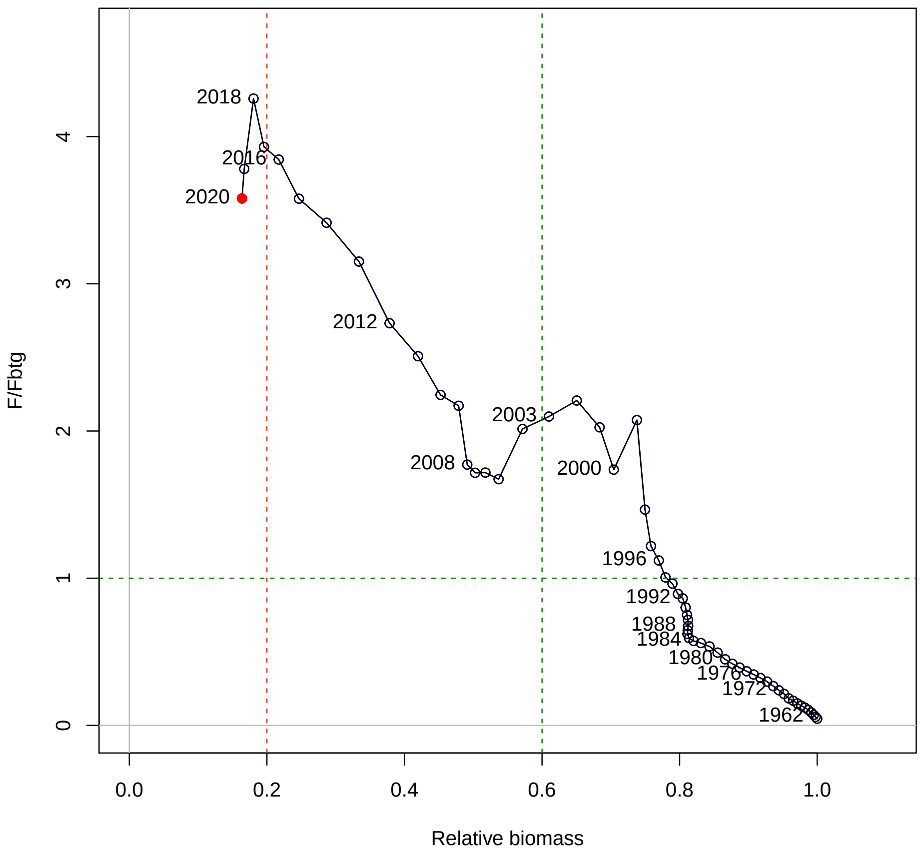

Figure D.10: Scenario 5 phase plot for saddletail snapper

Scenario 6

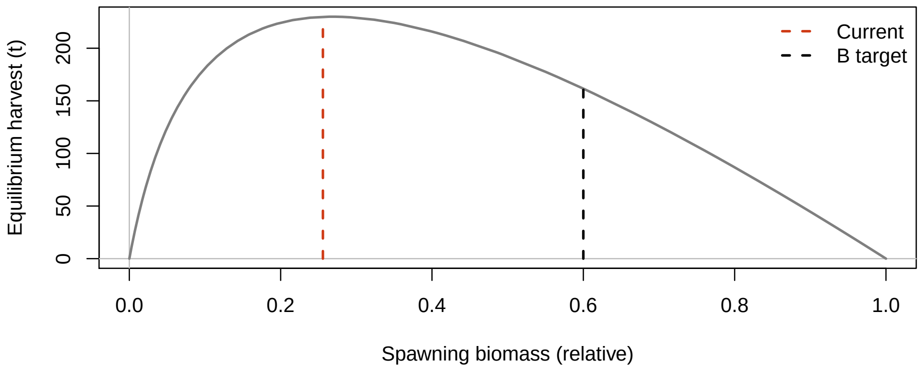

Figure D.11: Scenario 6 equilibrium harvest curve for saddletail snapper

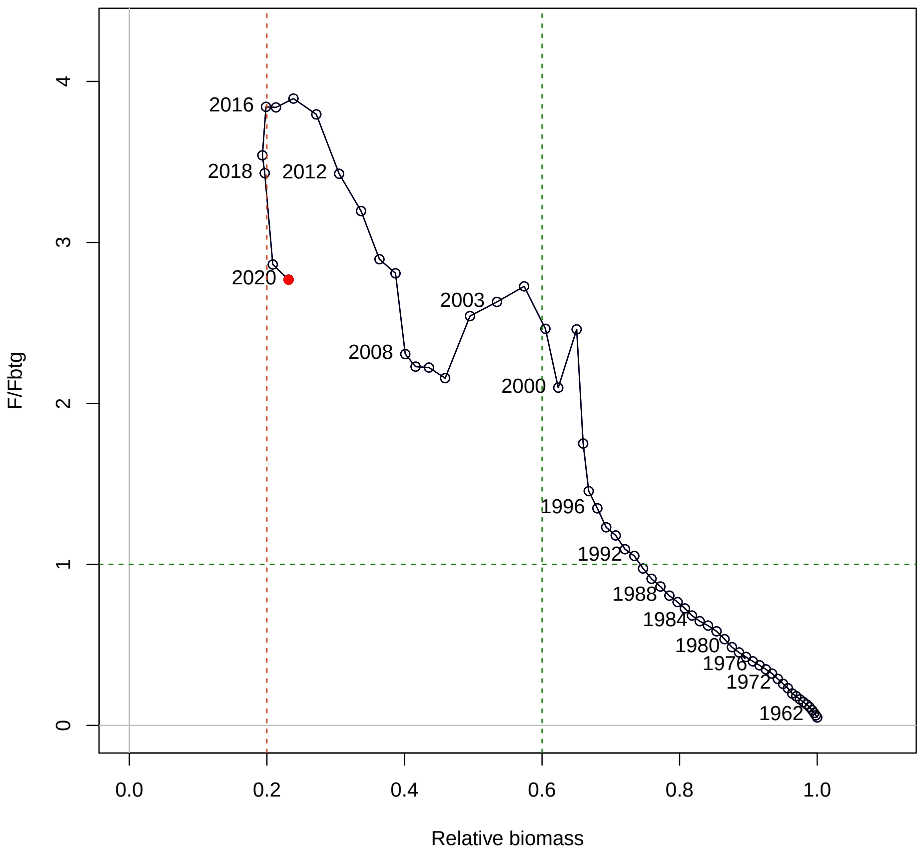

Figure D.12: Scenario 6 phase plot for saddletail snapper

Scenario 7

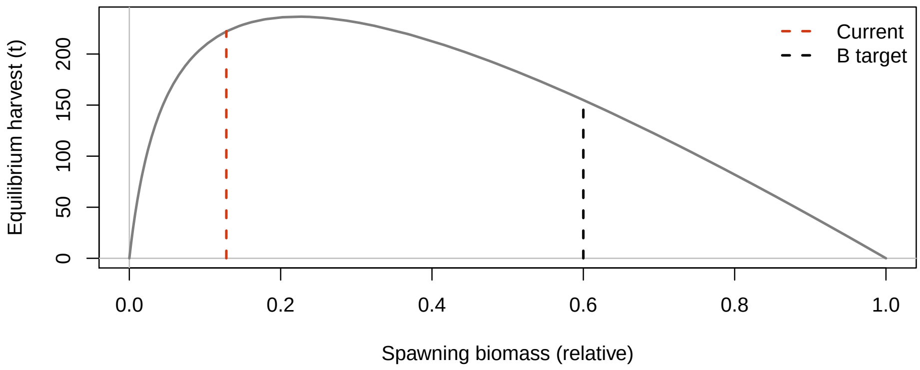

Figure D.13: Scenario 7 equilibrium harvest curve for saddletail snapper

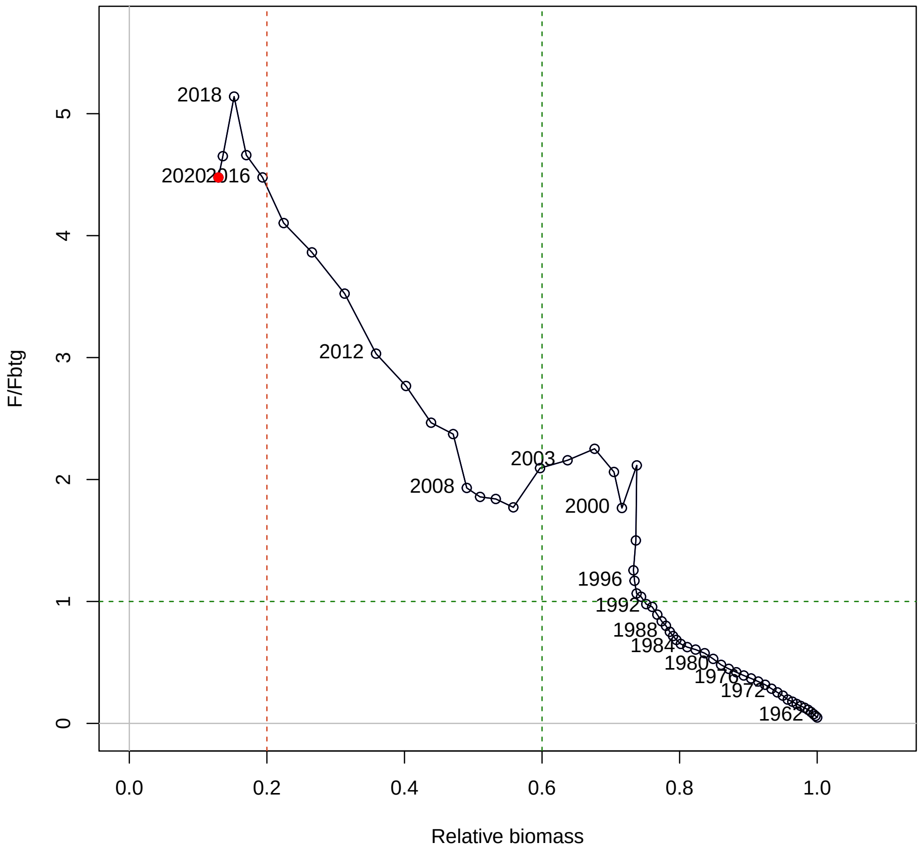

Figure D.14: Scenario 7 phase plot for saddletail snapper

Scenario 8

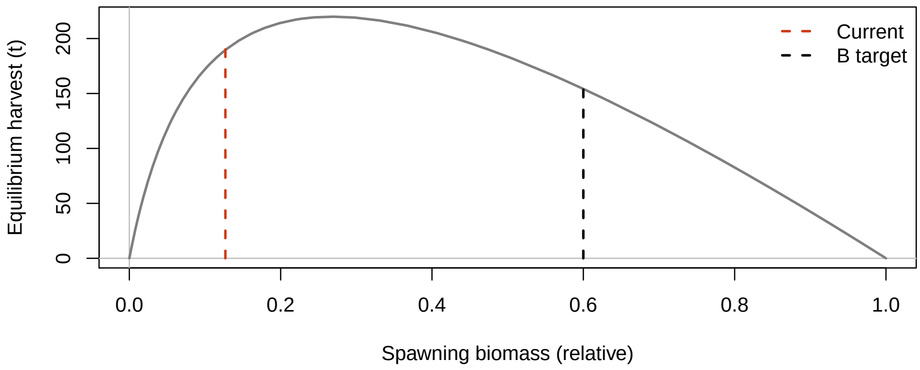

Figure D.15: Scenario 8 equilibrium harvest curve for saddletail snapper

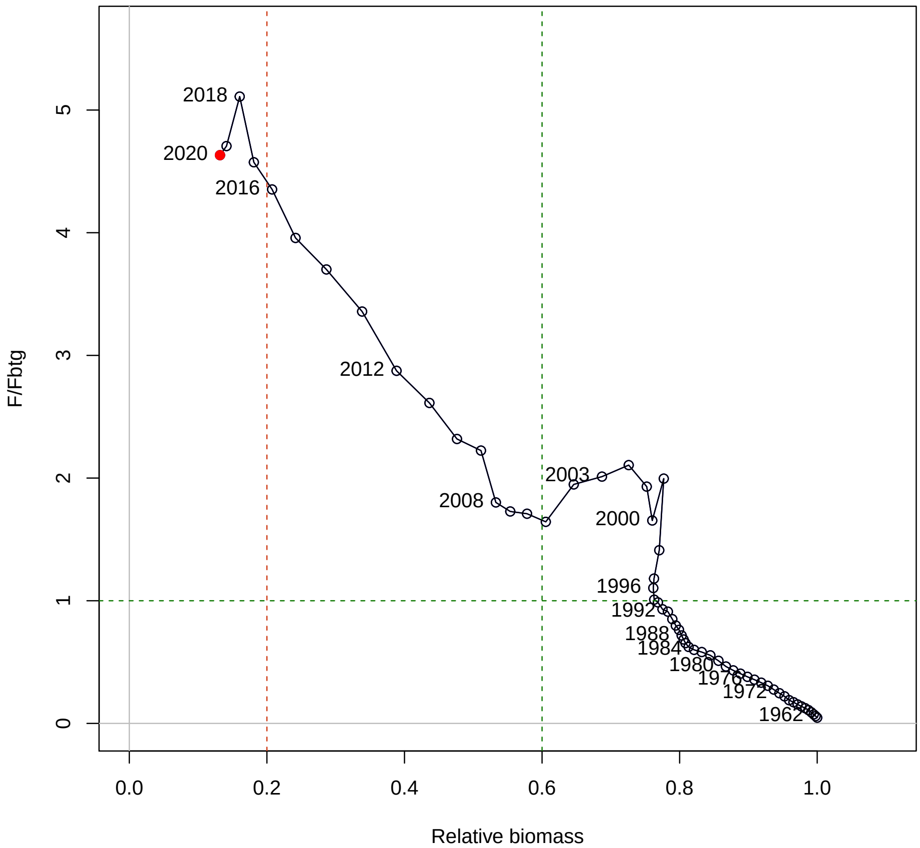

Figure D.16: Scenario 8 phase plot for saddletail snapper

Scenario 9

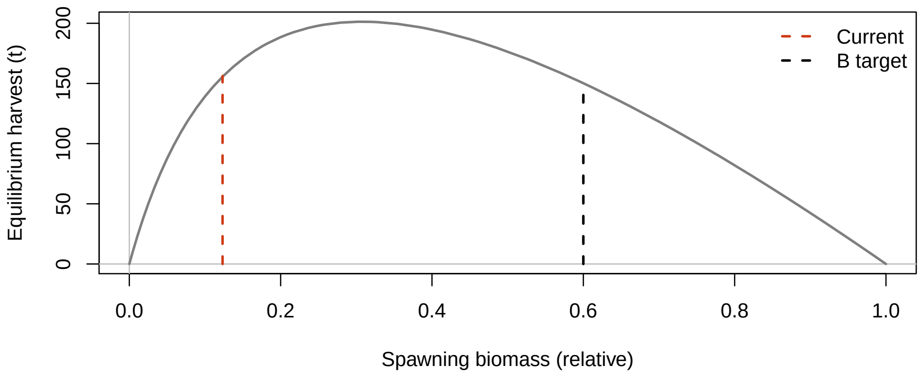

Figure D.17: Scenario 9 equilibrium harvest curve for saddletail snapper

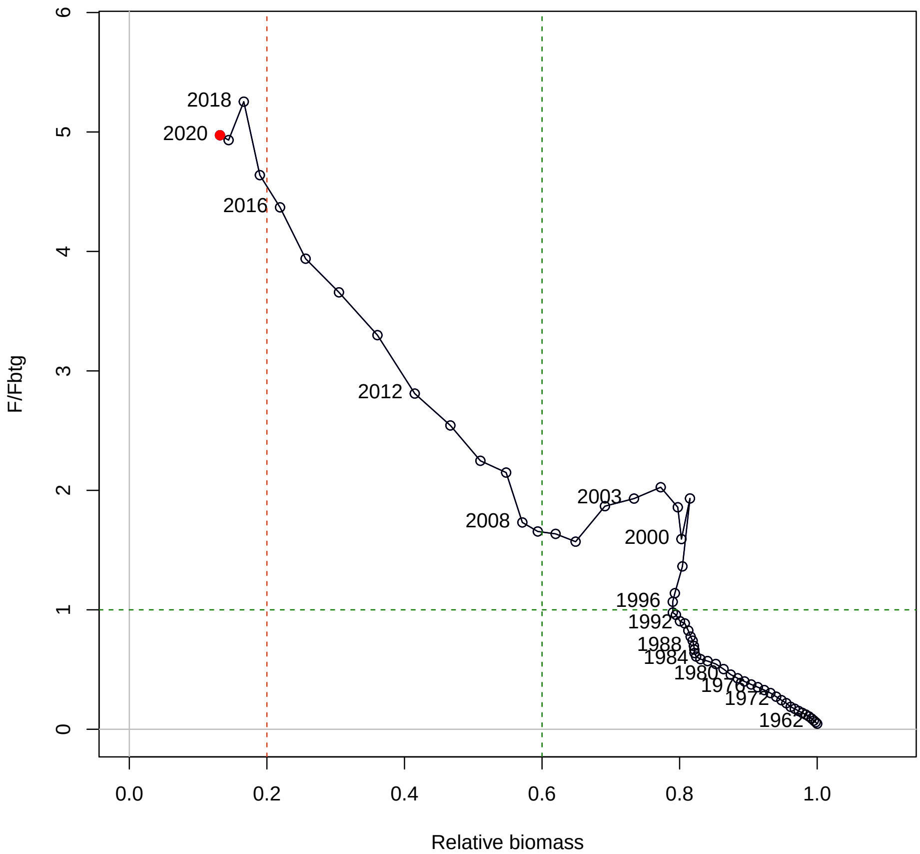

Figure D.18: Scenario 9 phase plot for saddletail snapper

Scenario 10

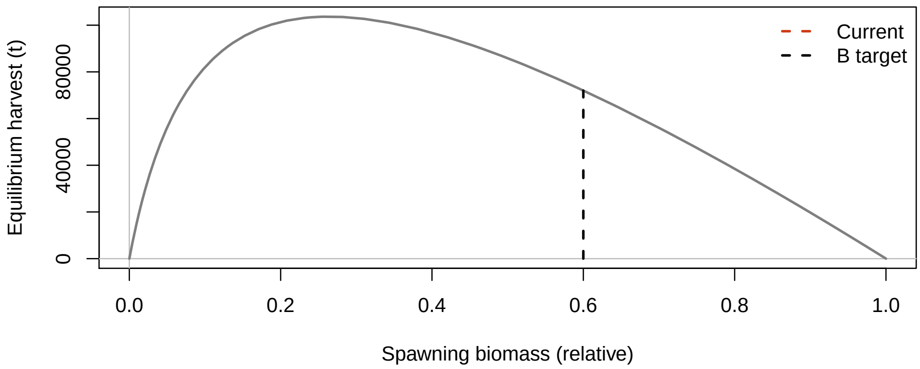

Figure D.19: Scenario 10 equilibrium harvest curve for saddletail snapper

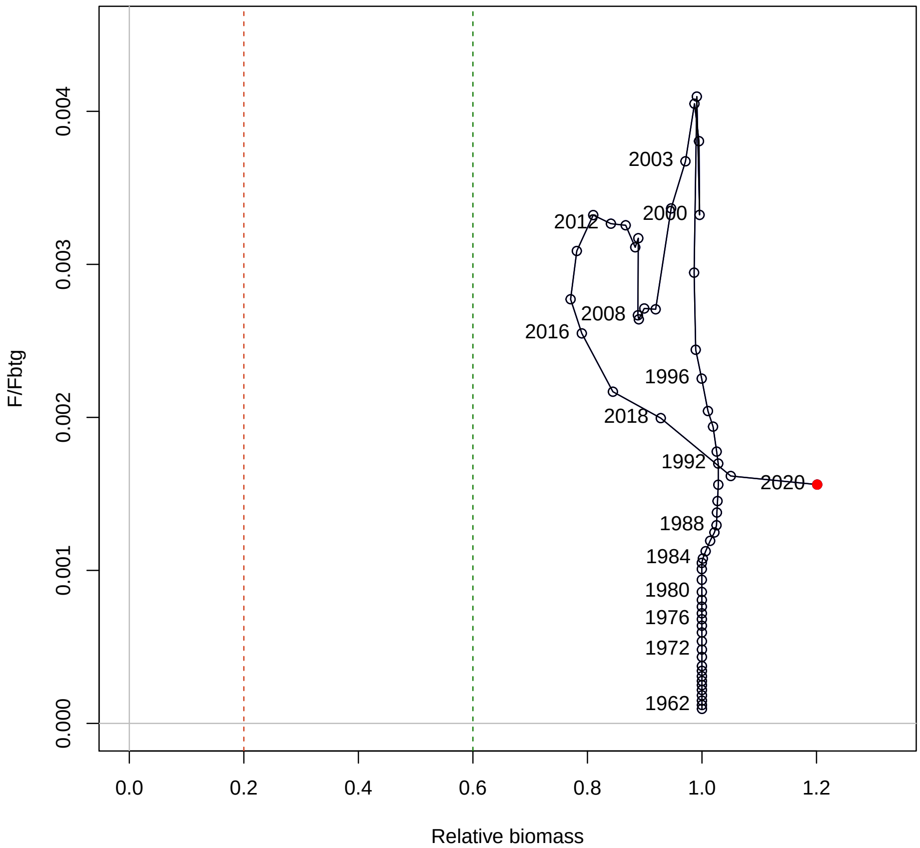

Figure D.20: Scenario 10 phase plot for saddletail snapper

Scenario 11

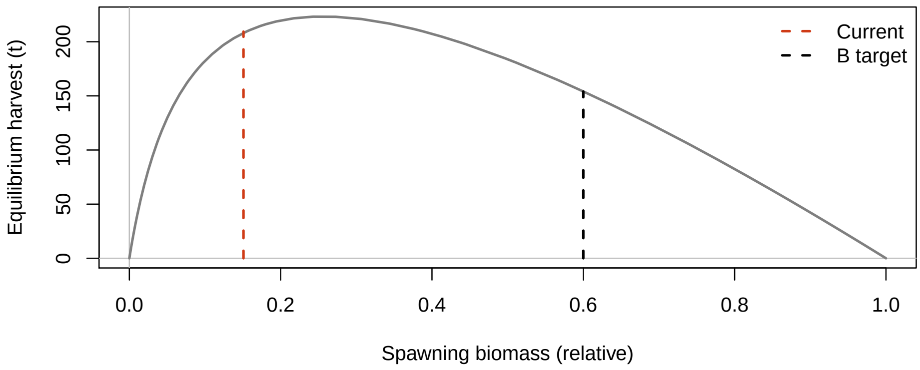

Figure D.21: Scenario 11 equilibrium harvest curve for saddletail snapper

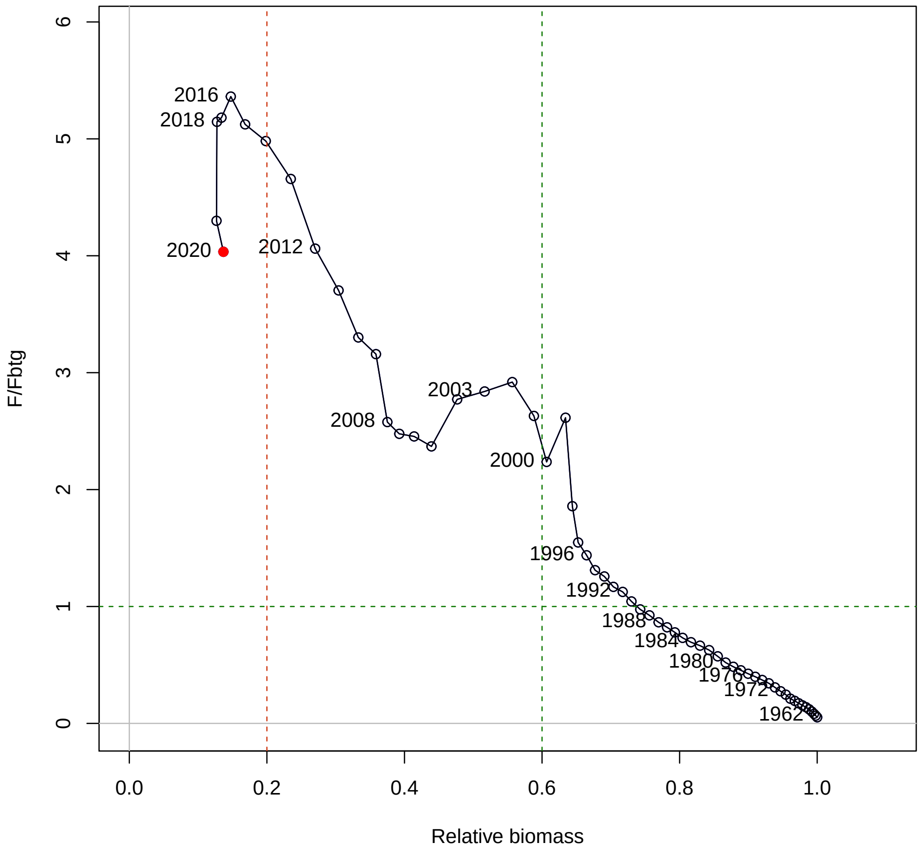

Figure D.22: Scenario 11 phase plot for saddletail snapper

Scenario 12

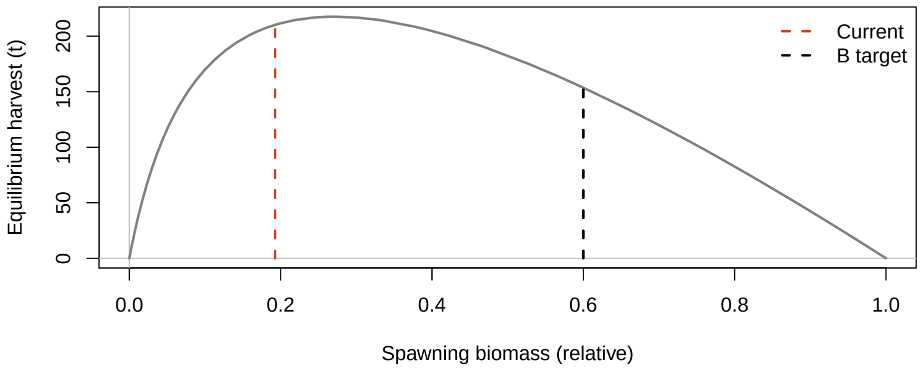

Figure D.23: Scenario 12 equilibrium harvest curve for saddletail snapper

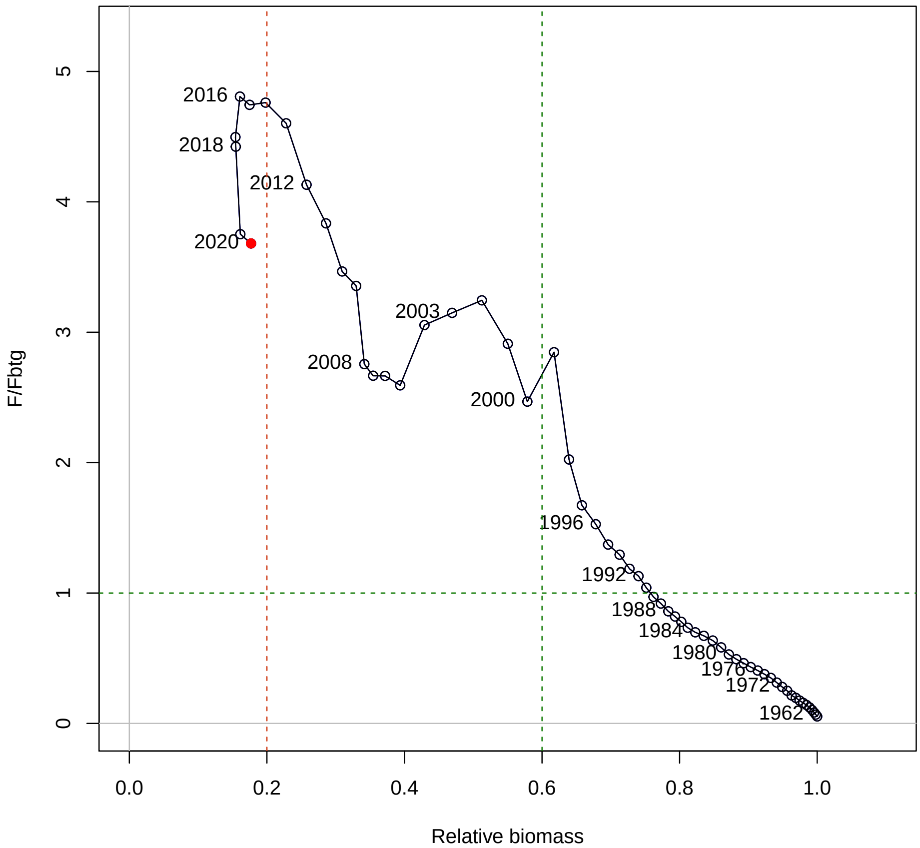

Figure D.24: Scenario 12 phase plot for saddletail snapper

Scenario 13

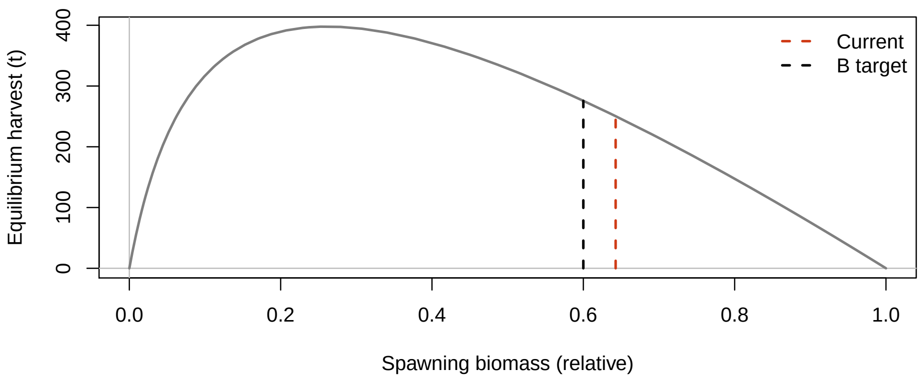

Figure D.25: Scenario 13 equilibrium harvest curve for saddletail snapper

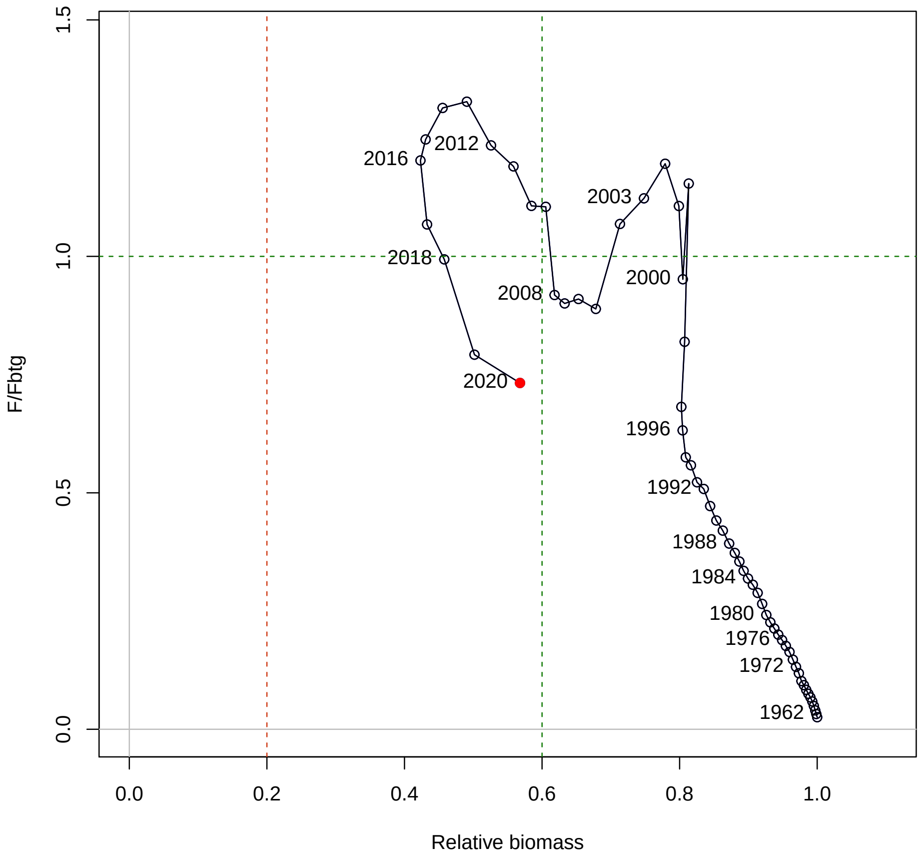

Figure D.26: Scenario 13 phase plot for saddletail snapper

Scenario 14

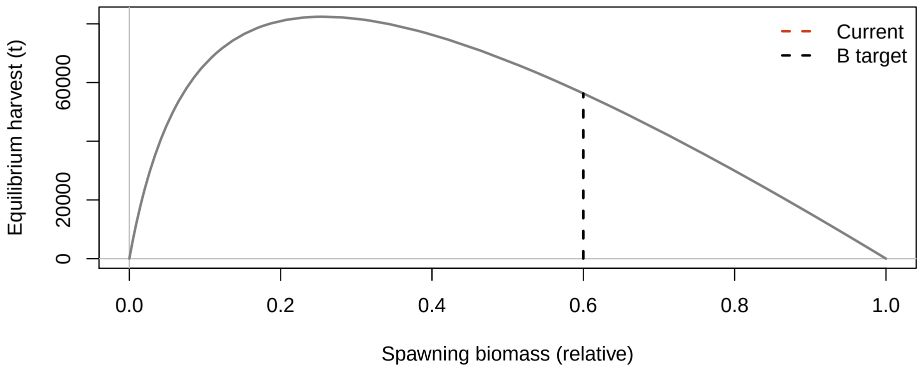

Figure D.27: Scenario 14 equilibrium harvest curve for saddletail snapper

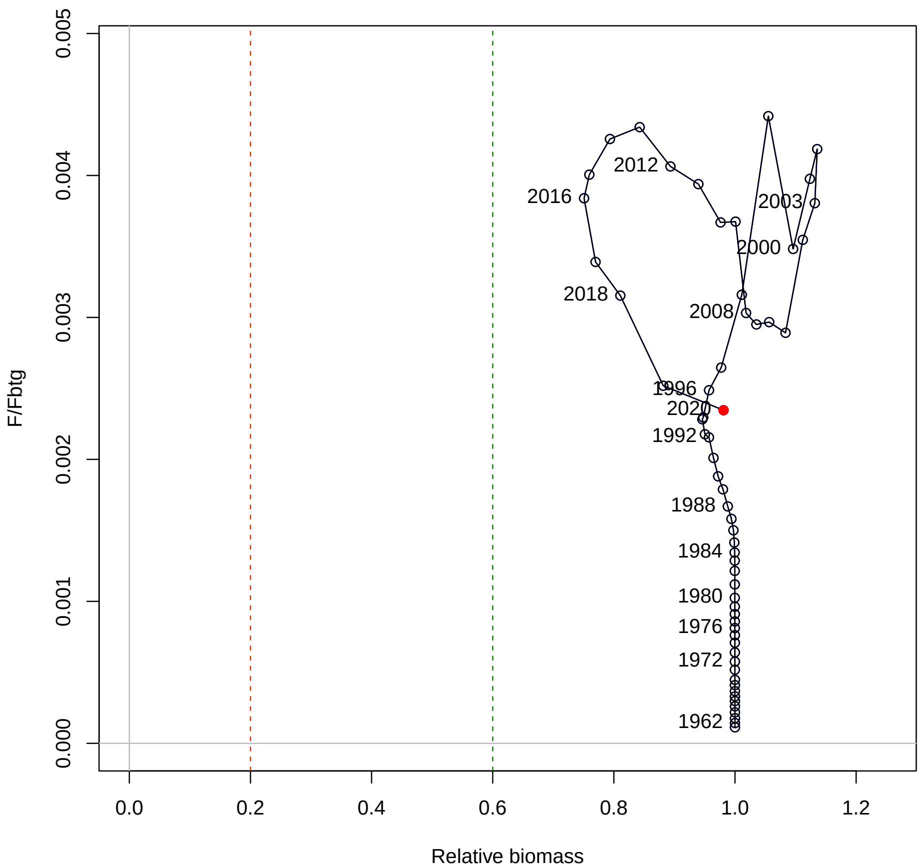

Figure D.28: Scenario 14 phase plot for saddletail snapper

Scenario 15

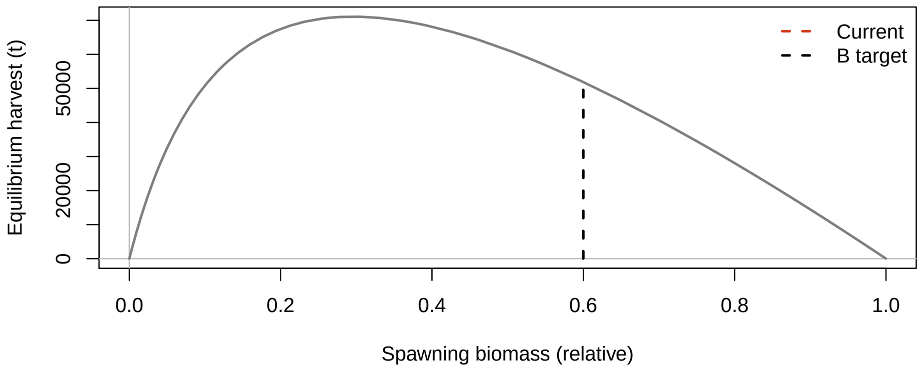

Figure D.29: Scenario 15 equilibrium harvest curve for saddletail snapper

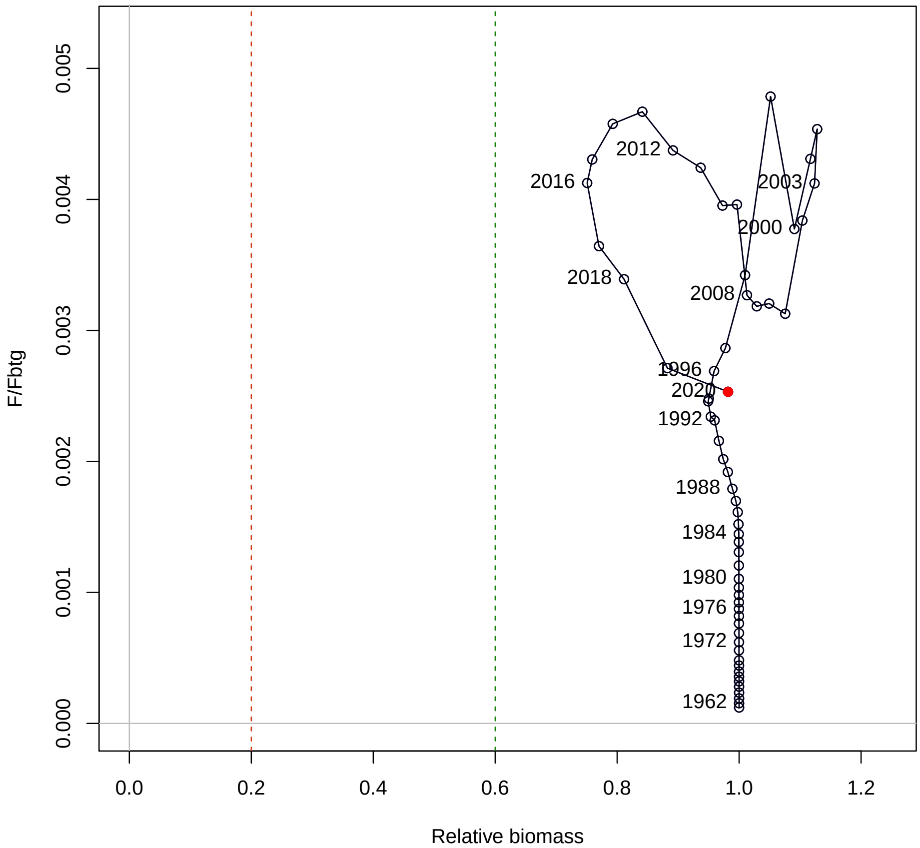

Figure D.30: Scenario 15 phase plot for saddletail snapper

Scenario 16

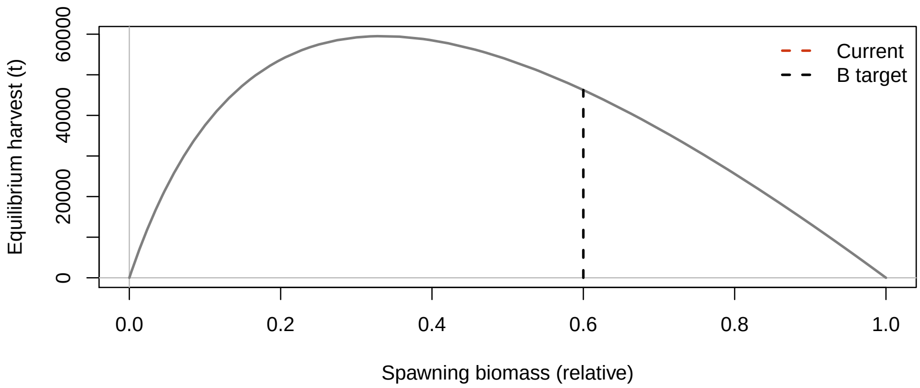

Figure D.31: Scenario 16 equilibrium harvest curve for saddletail snapper

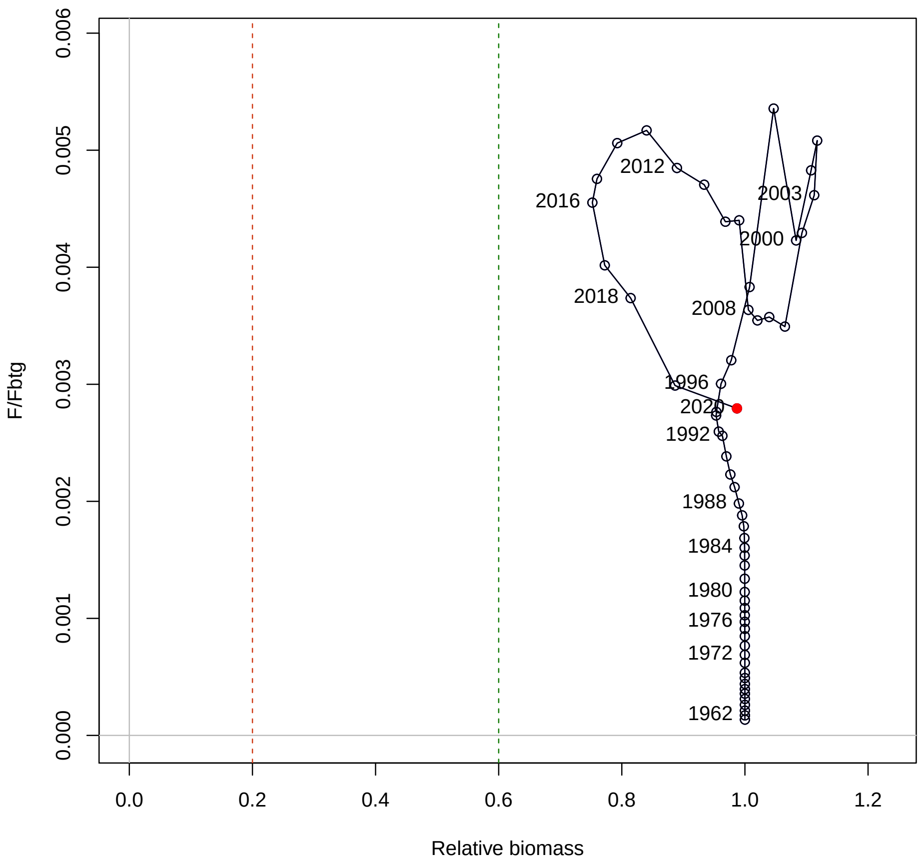

Figure D.32: Scenario 16 phase plot for saddletail snapper

Scenario 17

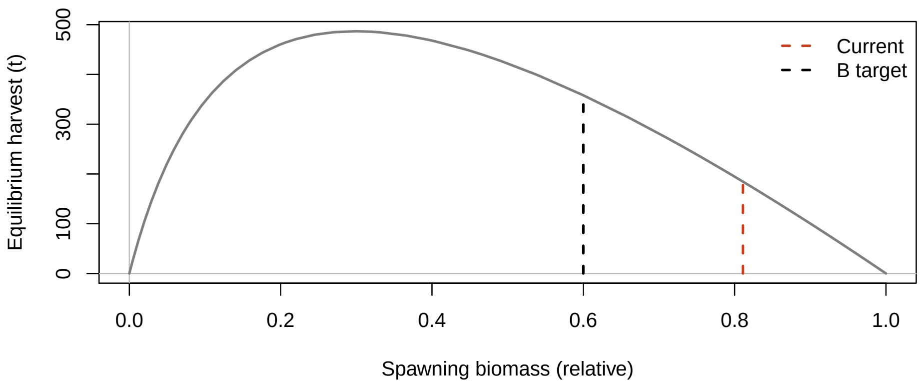

Figure D.33: Scenario 17 equilibrium harvest curve for saddletail snapper

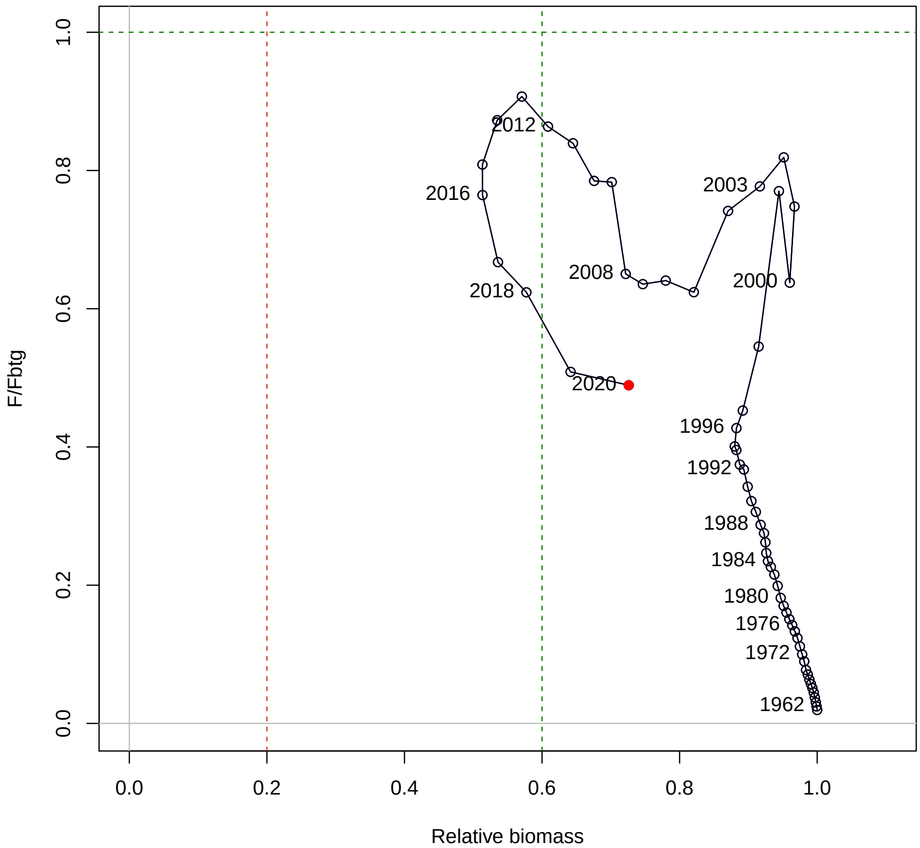

Figure D.34: Scenario 17 phase plot for saddletail snapper

Scenario 18

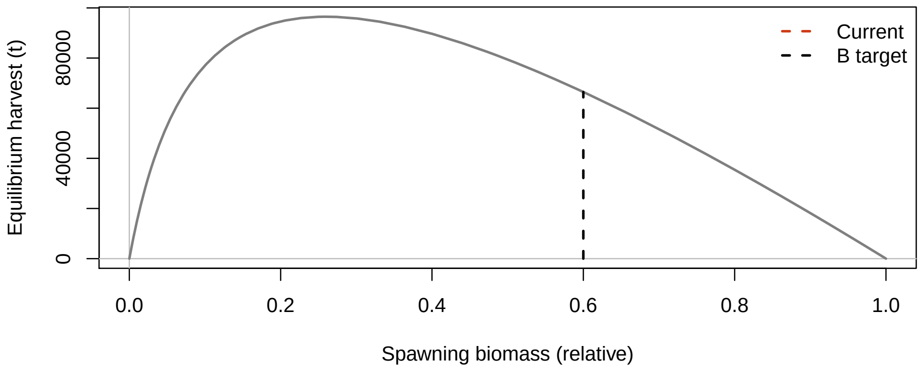

Figure D.35: Scenario 18 equilibrium harvest curve for saddletail snapper

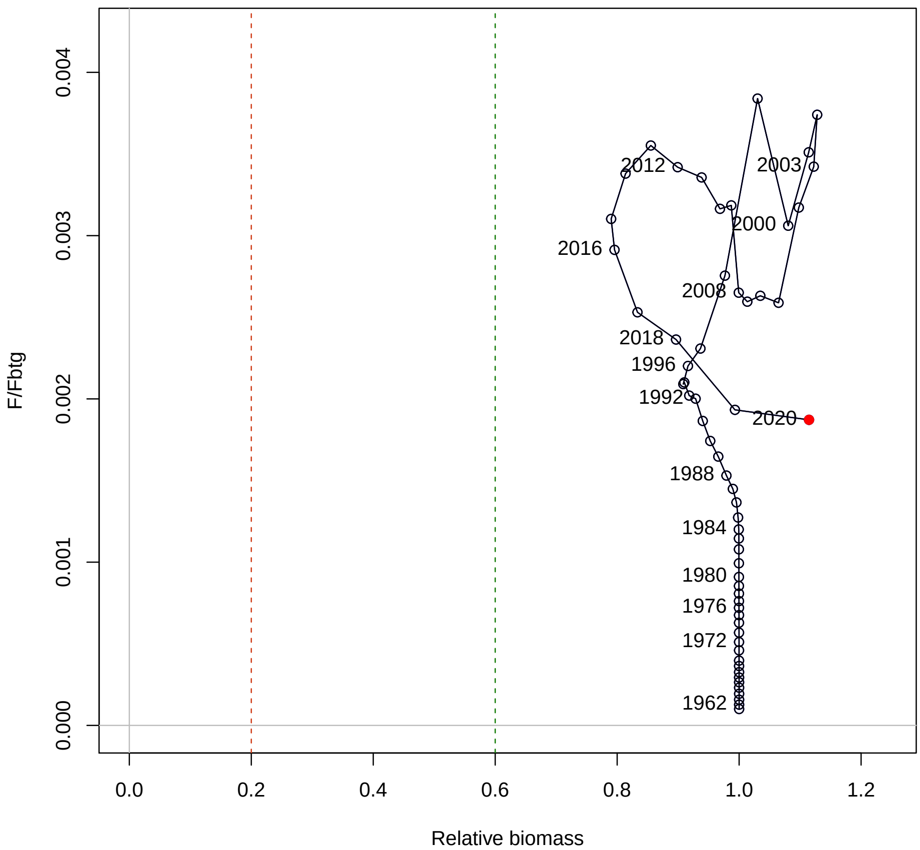

Figure D.36: Scenario 18 phase plot for saddletail snapper

Scenario 19

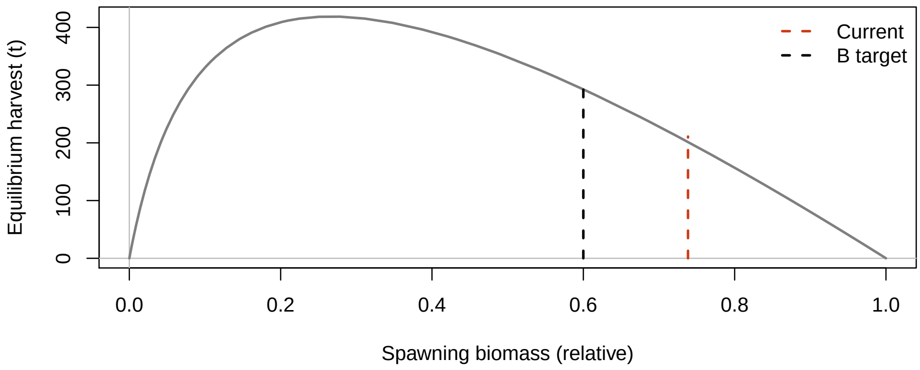

Figure D.37: Scenario 19 equilibrium harvest curve for saddletail snapper

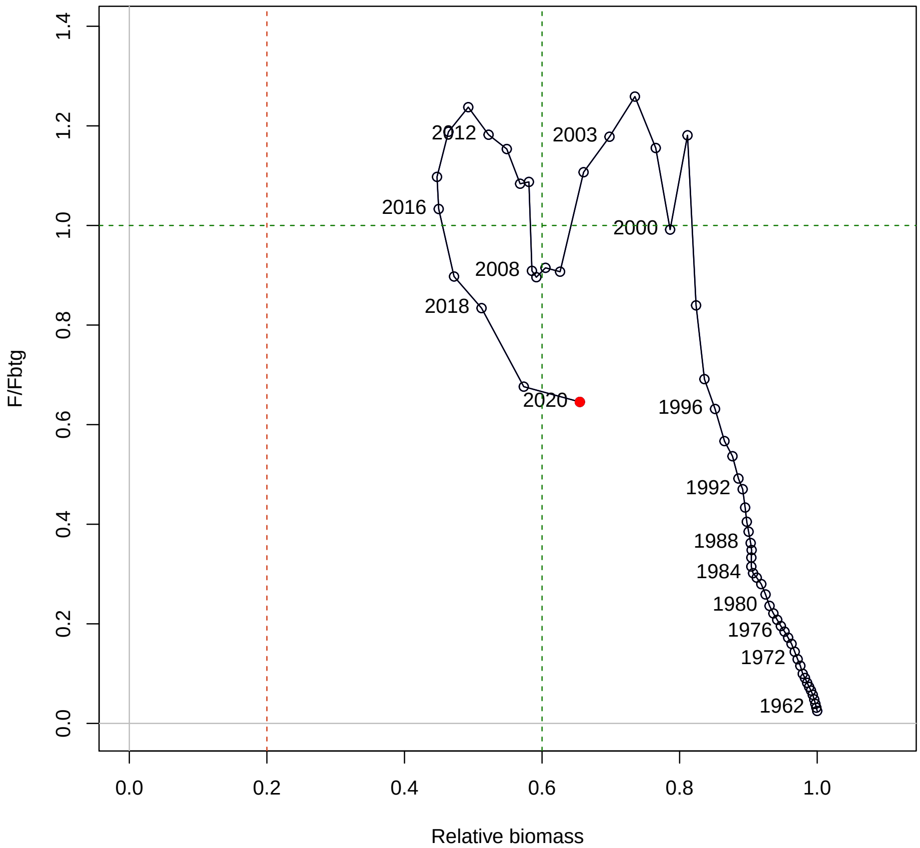

Figure D.38: Scenario 19 phase plot for saddletail snapper

Scenario 20

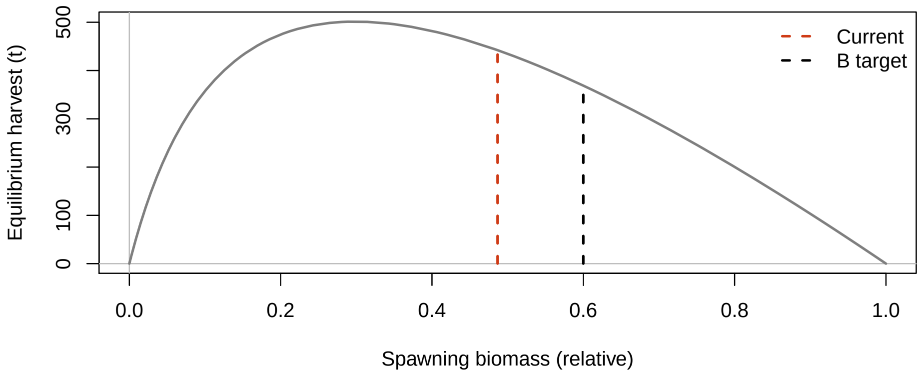

Figure D.39: Scenario 20 equilibrium harvest curve for saddletail snapper

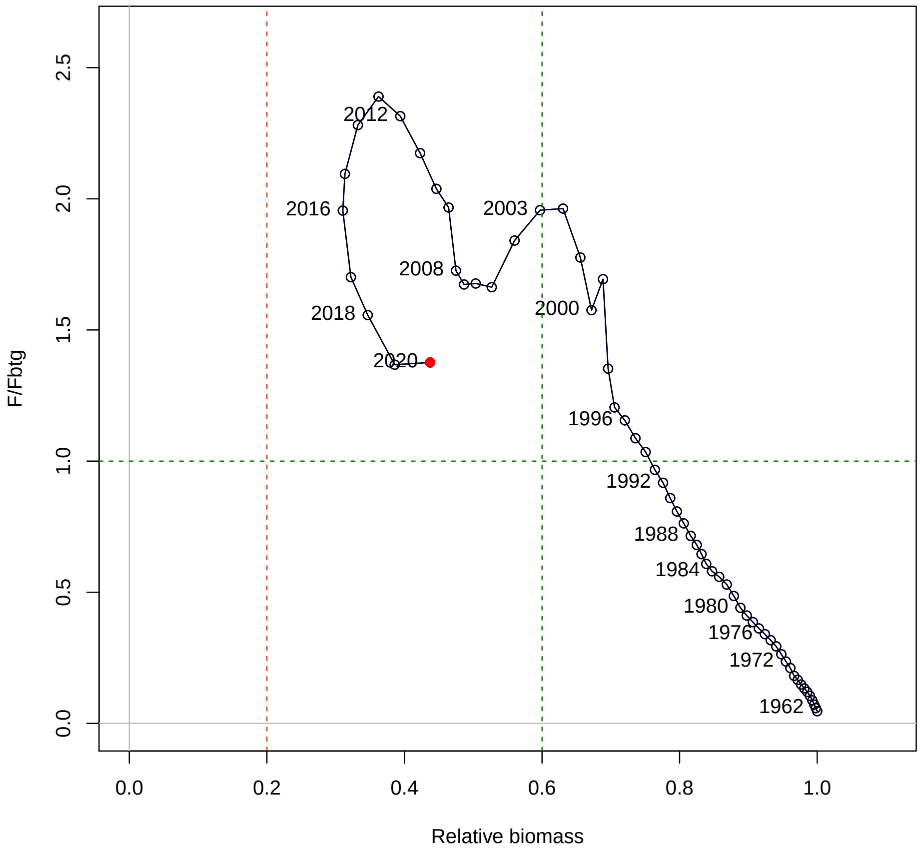

Figure D.40: Scenario 20 phase plot for saddletail snapper

Scenario 21

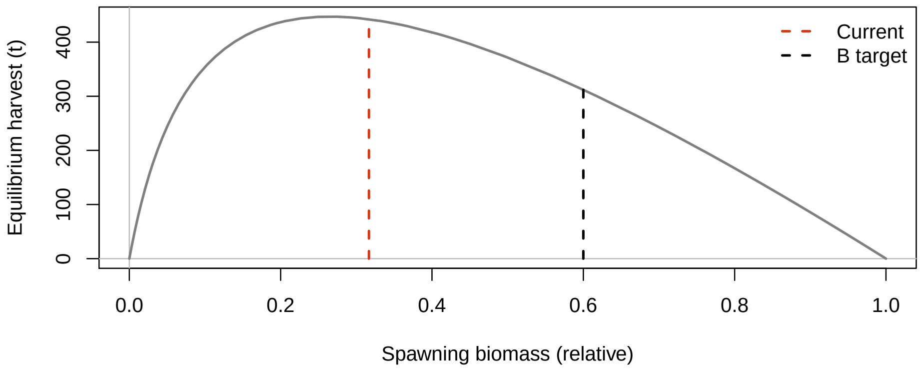

Figure D.41: Scenario 21 equilibrium harvest curve for saddletail snapper

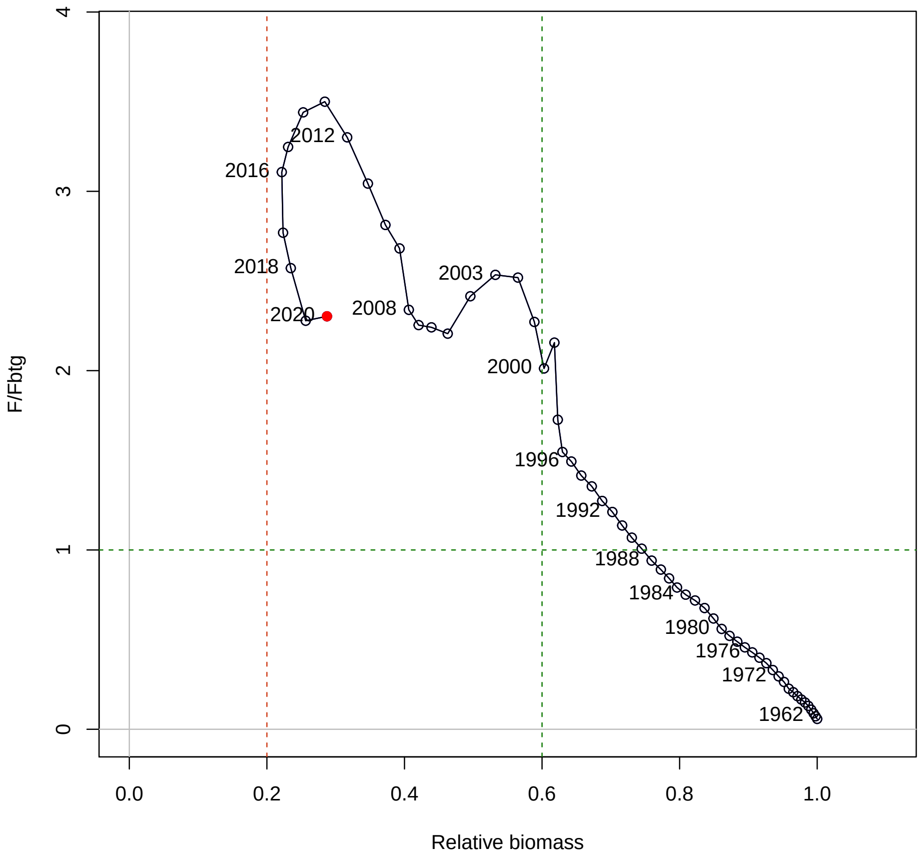

Figure D.42: Scenario 21 phase plot for saddletail snapper

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