Stock assessment of Queensland east coast red emperor (*Lutjanus sebae*), Australia, with data to June 2021

March 2022

Queensland Government

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

[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

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

This stock assessment indicates that biomass declined between 1953 and 2005 to 55% unfished spawning biomass. Following a period of fluctuation, the stock level at the beginning of 2022 was estimated to be 58%.

Red emperor (*Lutjanus sebae*) is a species of tropical snapper that inhabits Queensland waters. Research suggests a single Australian genetic population, with a panmictic population structure throughout northern Australia. They are gonochoristic (born male or female and do not change sex) and spawn primarily during the summer months. On Queensland's east coast, they can attain lengths of at least 100 cm (total length) and live for up to 43 years.

This is the first stock assessment of Queensland east coast red emperor.

The stock assessment was conducted on financial years and included input data through to June 2021. All assessment inputs and outputs will be referenced on a financial year basis (that is, '2021' means July 2020–June 2021). The assessment used a two-sex, age-structured population model, fit to age and length data, constructed within the Stock Synthesis modelling framework.

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

Over the last five years (2017 to 2021), the Queensland total retained catch averaged 113 tonnes per year, including 35 tonnes by the commercial sector, and 78 tonnes by the charter, recreational, and Indigenous sectors combined (Figure 1). The commercial and charter harvest were based on logbook reporting whereas the recreational and Indigenous harvest were based on survey estimates and interpolated between survey years. The recreational, Indigenous and charter estimates were recorded in numbers of fish and converted to weight in kilograms by the population model. The commercial harvest was recorded in kilograms.

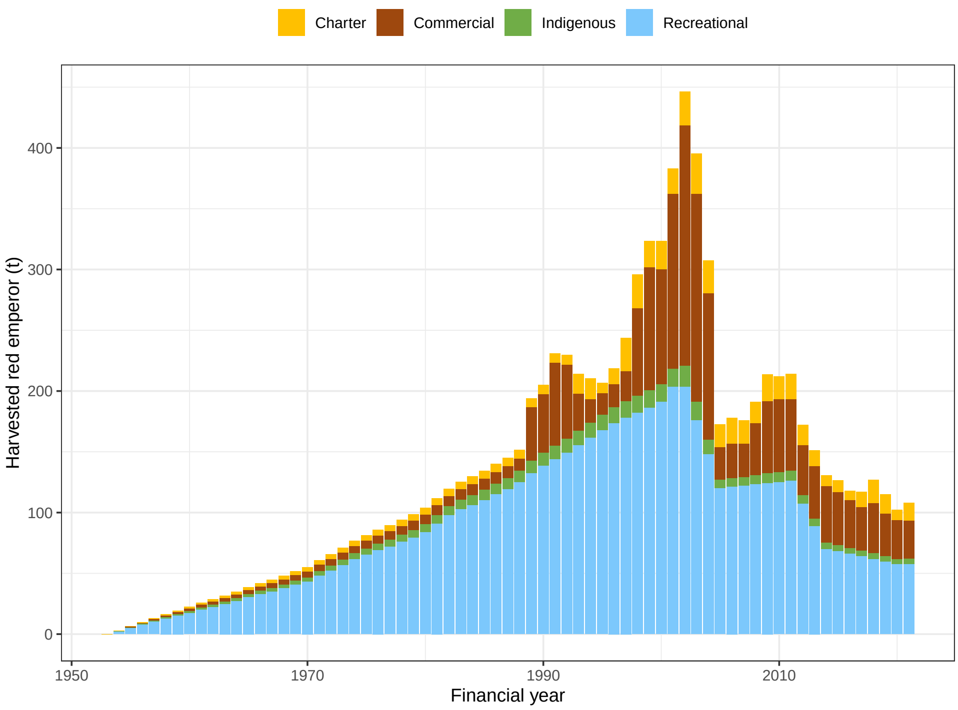

Figure 1: Annual estimated harvest (retained catch) from commercial, recreational, charter and Indigenous sectors between 1953 and 2021 for red emperor—recreational, charter and Indigenous sectors were modelled as a single fleet

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

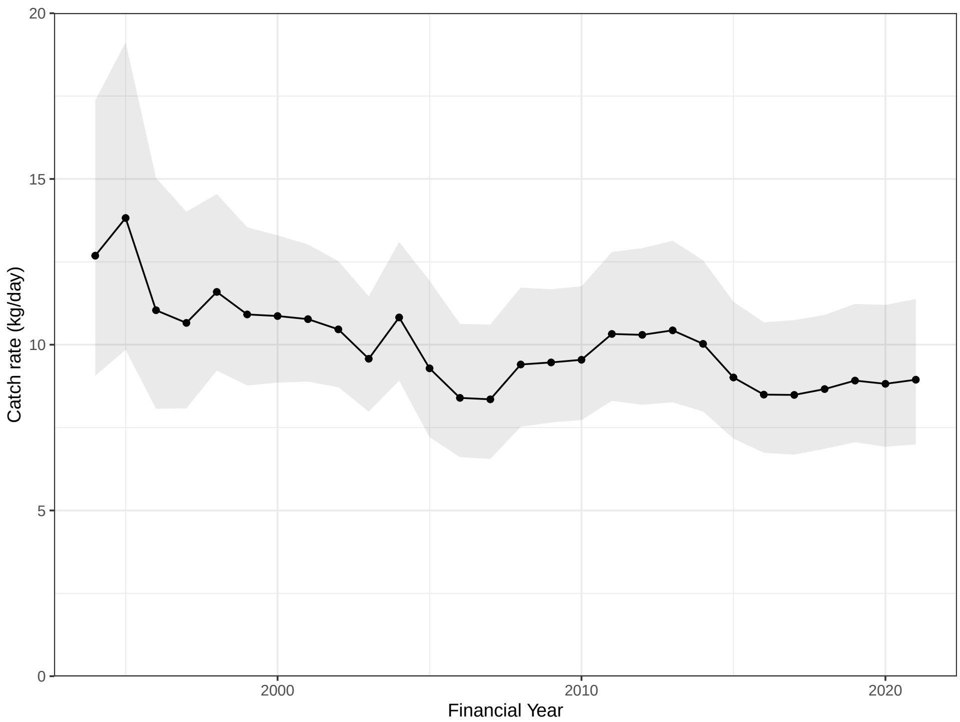

Figure 2: Annual standardised catch rates (95% confidence intervals) for commercial line caught red emperor between the years of 1994 and 2021

Twenty-four model scenarios were run, covering a range of modelling assumptions and sensitivity tests. Base case (most plausible) scenario results suggested that the Queensland east coast red emperor stock experienced a decline in the period 1953–2005 to reach 55% of unfished spawning biomass. This was followed by a period of fluctuation between 55% and 60% of unfished spawning biomass from 2005 to present. At the beginning of 2022, the stock level was estimated to be 58% (56–65% range across scenarios) of the unfished spawning biomass (Figure 3).

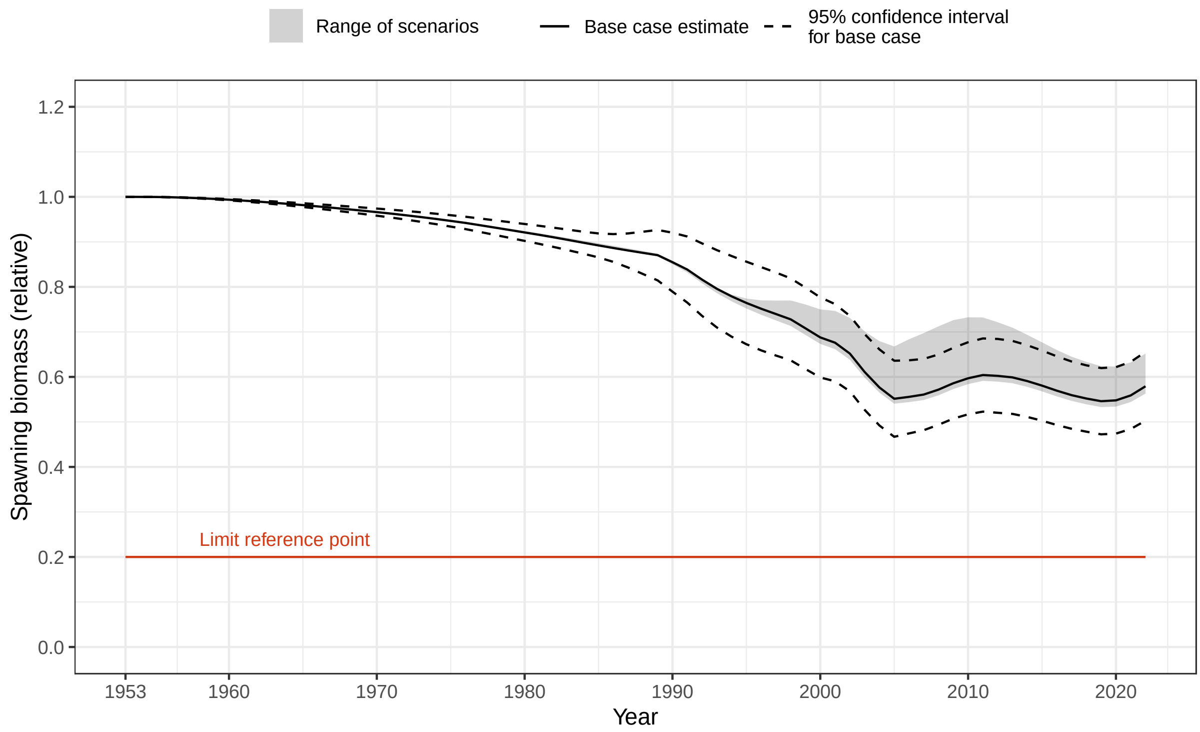

Figure 3: Predicted spawning stock biomass trajectory relative to unfished, from 1953 to 2022

The Reef line harvest strategy 2020–2025 sets out a fishery objective for all species in the fishery to be maintained at, or returned to, a target spawning biomass level that aims to maximise economic yield (MEY) for the fishery. The assessment recommends a biological catch of 115 t for 2022, with a retained component of 114 t (Table 1), to allow the stock to rebuild to 60% unfished spawning biomass (proxy for maximum economic yield). This will allow the longer-term biological retained catch target of 124 t to be reached.

The suggested uncertainty discount factor for this assessment is 0.83.

Table 1: Current and target indicators for Queensland east coast red emperor—60% biomass target

Indicator	Estimate
Biomass◇ (relative to unfished) at the start of 2022	58% (56% to 65%)
Target biomass (relative to unfished)	60%
Biomass (relative to unfished) at MSY⋆	25%
MSY⋆	185 t
Retained catch component of MSY⋆	183 t
Retained catch in 2021	108 t
Retained catch at 60% biomass target	124 t
RBC† for 2022 to achieve target	115 t
Retained component of RBC	114 t
Time to achieve target	3 years

◇ Biomass is defined to be spawning stock biomass.
⋆ MSY (maximum sustainable yield) is defined to be the maximum sustainable dead catch. That is, retained catch plus catch that dies following discarding.
† RBC (recommended biological catch) is defined to be the recommended biological dead catch. That is, retained catch plus catch that dies following discarding.

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, Eddie Jebreen, Robyn Lovett, Chad Lunow, Amos Mapleston, Tyson Martin, Anthony Roelofs, Darren Roy and Sam Williams. The role of the committee was collaborative to share interpretation and decision making on data inputs, assessment methods and results.

In addition to their roles on the committee, we would like to thank Carlie Heaven for assistance with the Queensland commercial harvest data; Tyson Martin for the provision of, and assistance with, the Queensland boat ramp survey data; Rachel Janes and Daniella Teixeira for the provision of, and assistance with the Queensland recreational statewide survey data and Lucas Sumpter and Amos Mapleston for the assistance with, the biological age and length monitoring data.

In addition to her role on the committee we thank Robyn Lovett for her constructive feedback which has led to a stronger assessment and report.

Sincere thanks to the stock assessment scientists outside of the project team who provided input on a range of technical and conceptual challenges. We thank Dr Alex Campbell for providing assistance with modelling using the Stock Synthesis software, as well as his guidance and insight on many challenges throughout the assessment.

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, Cassandra Peters, Andrew Prosser, Robert Prosser, Emily Purton, Tom Roberts, Peta Schofield, Darren Smallwood, Nick Stratford, Jonathon Staunton Smith, Lucas Sumpter, 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, Chad Lunow and Sue Reilly.

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

We would also like to acknowledge the Australian National Sportfishing Association (ANSA) for the tag-recapture data on released Red emperor (*L.sebae*) below minimum legal size. These data assisted greatly in informing the length distribution of released fish in the recreational sector.

Finally, we would like to thank Alex Campbell and Eddie Jebreen, 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

B_{40}	40% of unfished spawning biomass, a proxy for biomass at maximum sustainable yield
B_{60}	60% of unfished spawning biomass, a proxy for biomass at maximum economic yield
biomass	spawning biomass, the total weight of all adult (reproductively mature) fish in a population, an indicator of the status of the stock and its reproductive capacity
CI	confidence interval
CFISH	Commercial Fisheries Information System, which is the compulsory commercial logbook database managed by Fisheries Queensland
dead catch	retained catch ('harvest') plus catch that dies following discarding
fishing year	for red emperor, fishing year is defined to be the same as financial year
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
FL	fork length, measured from the tip of fish's nose to the fork in its tail
GBR	Great Barrier Reef
GBRMP	Great Barrier Reef Marine Park
GBRMPA	Great Barrier Reef Marine Park Authority
green zone	associated with reefs that were closed to fishing at the introduction of the Representative Areas Program
harvest	see 'retained catch'
MLS	minimum legal size
MSY	maximum sustainable yield, is defined to be the maximum sustainable dead catch—that is, retained catch plus catch that dies following discarding.
NRIFS	the National Recreational and Indigenous Fishing Survey conducted by the Australian Department of Agriculture, Fisheries and Forestry
fisher-day	a day of fishing by a fishing operator, corresponding to a single daily logbook record (commercial)
RAP	Representative Areas Program
RBC	recommended biological catch, is the recommended catch according to the control rule. This is dead catch: retained catch plus catch that dies following discarding.
retained catch	component of the catch that is kept by fishers, also referred to as 'harvest' and 'landed catch'
RFish	recreational fishing surveys conducted by Fisheries Queensland
RLF	Reef Line Fishery
SFS	Sustainable Fisheries Strategy
SRFS	Statewide Recreational Fishing Survey
SS	Stock Synthesis
TL	total length, measured from the tip of fish's nose to the end of its tail

1 Introduction

Red emperor (*Lutjanus sebae*) is a secondary target species in the Reef Line Fishery (formerly the Coral Reef Fin Fish Fishery) with a current annual retained catch of approximately 108 t across all sectors combined. The Reef Line Fishery (RLF) operates largely within the Great Barrier Reef Marine Park (GBRMP), but extends from the northern tip of Cape York to 24°30' S (south of Brisbane).

Red emperor are a widespread species of tropical snapper or lutjanid (family *Lutjanidae*). They are found throughout the Indo-Pacific region, from tropical Australian waters (Newman et al. 2000a) westward to East Africa and the Red Sea, and northward to southern Japan (Allen 1985). Within Australian waters, red emperor are distributed from Geraldton in Western Australia, across the north of the continent and occasionally reaching as far south as Sydney, New South Wales on the east coast (Newman et al. 2010). Research into the biological stock structure of red emperor by Herwerden et al. (2009) suggests a single Australian genetic population, with a panmictic population structure throughout northern Australia. However, multiple fishery management units for red emperor exist within the spatial extent of their genetic population. These units are often referred to as 'stocks' in the context of fishery management and stock status (FRDC 2021b). They include Gascoyne, Kimberley and Pilbara regions (Western Australia), Arafura Sea, Gulf of Carpentaria, Joseph Bonaparte Gulf and Timor Sea (Northern Territory), and East coast (Queensland) (FRDC 2021b).

Red emperor are found in depths to at least 160 m (McPherson et al. 1992b), inhabiting coastal and offshore reefs, shoal ground and flat bottom in the vicinity of reefs, associated epibenthos or vertical relief (Carpenter 2001; Newman et al. 2002). For red emperor, it is generally true that the deeper the water, the larger the fish—with juveniles commonly seen in shallow, inshore waters (Williams et al. 1994). They can be found in mixed shoals with saddletail snapper (*Lutjanus malabaricus*) and crimson snapper (*Lutjanus erythropterus*) (McPherson et al. 1992b). Their diet comprises a wide range of prey including fish, crustaceans and cephalopods (Carpenter 2001).

Red emperor are gonochoristic (Newman et al. 2010), meaning they are born male or female and do not change sex throughout their lives. They are long-lived, and grow slowly after becoming sexually mature (Newman et al. 2000a). In Great Barrier Reef (GBR) waters, the fork length of females at 50% maturity was estimated to be 54.8 cm (McPherson et al. 1992b). Spawning is thought to occur for up to 10 months of the year on the GBR (Hillcoat and Russ, unpublished data). Red emperor can reach a maximum total length of at least 100 cm (Allen 1985; McPherson et al. 1992b) and live for up to 43 years (Section 3.1.3, DAF, unpublished data). This recent age estimate of a 43 year old individual exceeds the current known maximum age of 40 years from Western Australia (see Newman et al. (2010)). Further, this almost doubles the previously recorded longevity for red emperor in Queensland (22 years, see Newman et al. (2000b)).

Tag recapture data collected by members of the Australian National Sportfishing Association (ANSA) between 1986 and 2003 indicated that red emperor had a notably higher recapture rate than other commonly caught coral reef fish, at 19.9% (Sumpton et al. 2008). Of those recaptured individuals, the maximum distance moved was in excess of 120 km, however 98.8% indicated a movement of less than 19 km from their original location (Sumpton et al. 2008). Red emperor exhibit low rates of post-release mortality, with an acute (3 days) post-release mortality rate of 1.6% found in Brown et al. (2008, Chapter 1). This is significantly lower than other closely related lutjanids. Using the same methods to investigate the influence of barotrauma on post-release mortality, Brown et al. (2008) found saddletail snapper (*L.malabaricus*) and crimson snapper (*L.erythropterus*) had acute post-release mortality rates of 50% and 16% respectively. Barotrauma resilience is likely to contribute significantly to this disparity between species, as Brown et al. (2008) noted red emperor have a relatively low susceptibility to barotrauma.

The RLF is Queensland's second most profitable fishery, with an estimated Gross Value of Production of $27 million (Fisheries Queensland 2020). This report considers four sectors in the Reef Line Fishery: Indigenous, commercial, charter and recreational. While coral trout (for the live export market) are the main target of the commercial sector, commercial fishers also harvest redthroat emperor and other coral reef species, including red emperor (see Appendix E for a full list of other species). Red emperor are one of the most highly sought after secondary target species by the commercial fishery and are a primary recreational target species. Often, fishers in the RLF target red emperor in tandem with saddletail snapper (*L.malabaricus*) and crimson snapper (*L.erythropterus*). While species specific individual transferable quotas (ITQs) are in place for coral trout and redthroat emperor, red emperor and other line caught reef fish species are managed using a combined ITQ for 'Other Species' (OS) (Fisheries Queensland 2020). Many of the species comprising the 'Other Species' (OS) quota group are targeted using different fishing techniques compared to coral trout.

Key management measures in the fishery that pertain to red emperor include minimum size limits, compulsory logbook catch reporting for commercial fishers, total allowable commercial catch limits (TACC), ITQs, gear restrictions, vessel and tender restrictions and possession limits for recreational fishers (Fisheries Queensland 2020). Red emperor are also subject to two five-day spawning closures annually, which are applicable to all coral reef fin-fish. The history of red emperor fishery management is provided in Table 1.

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

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

Table 1.1: History of red emperor management in Queensland

Year	Management
1957	Minimum legal size (MLS) of 12 inches (30.48 cm) for red emperor (*Lutjanus sebae*) *Fisheries Act 1957*
1975	Inclusion of no-fishing zones in the Great Barrier Reef *Great Barrier Reef Marine Park Act 1975*

Continued on next page

Table 1.1 – *Continued from previous page*

Year	Management
1976	MLS of 35 cm for red emperor *Fisheries Act 1976*
1981	Zoning of Capricornia Section of GBRMP (Capricorn-Bunker reefs) *GBR Marine Park Management*
1982	Section 35 permit allows recreational fishers to sell excess catch *Fishing Industry Organisation and Marketing Regulation*
1983	Zoning of Cairns Section of GBRMP (Lizard Island to Innisfail) *GBR Marine Park Management*
Oct 1987	Zoning of Central Section of GBRMP (Innisfail to Mackay) *GBR Marine Park Management*
Aug 1988	Zoning of Mackay-Capricorn Section of GBRMP (Mackay to Swains Reefs) *GBR Marine Park Management*
1988	Introduction of compulsory commercial logbook reporting
1990	Permits under Section 35 allowing recreational fishers to sell catch were repealed *Fishing Industry Organisation and Marketing Regulation*
Apr 1992	Second zoning of Cairns Section of GBRMP *GBR Marine Park Management*
1993	MLS of 45 cm for red emperor. Recreational possession limits of a combined total of 30 coral reef fish covering 26 species. Charter vessel possession limit arrangements: extended charters in excess of 48 hrs allowed double the prescribed possession limit. Restructure of commercial line fishery into regional endorsements—the existing L symbol was introduced into legislation with the numbers L1–L9 depicting different regions of operations. New format for landed fish, where a fish has been filleted there must be two fillets equal to one whole fish. Skin not to be removed from fillets by recreational fishers, except in the case of charter vessels in excess of 48 hours where the majority of the skin may be removed provided a minimum is left for identification. *Fishing Industry Organisation and Marketing Regulation*
May 1997	Investment warning issued
Apr 2002	Second zoning of Far Northern Section of GBRMP *Fishing Industry Organisation and Marketing Regulation*
Sep 2003	Fisheries (Coral Reef Fin Fish) Management Plan implemented. MLS for red emperor increased to 55 cm; recreational in-possession limits reduced to a total of 5 red emperor, and 20 reef fish (all reef fish species combined) *Fisheries (Coral Reef Fin Fish) Management Plan 2003 (Queensland)*

Continued on next page

Table 1.1 – *Continued from previous page*

Year	Management
Jul 2004	All commercial vessels must hold an RQ licence. RQ licence holders must hold appropriate line units (OS units) to take red emperor, 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 introduced for commercial fishermen. *Fisheries (Coral Reef Fin Fish) Management Plan 2003 (Queensland)*
Jul 2004	Representative Area Program (RAP) - comprehensive rezoning of whole GBR; proportion of GBR closed to fishing increases from about 5% to 33%. *Great Barrier Reef Marine Park Zoning Plan 2003*
Oct 2004	Seasonal fishery closures commence across the GBR for nine days around the new moon period in October, November and December each year. *Fisheries (Coral Reef Fin Fish) Management Plan 2003 (Queensland)*
Oct 2009	Seasonal fishery closures (Coral Reef Fish) reduced to two five-day closures in October and November. December closure removed. *Fisheries (Coral Reef Fin Fish) Management Plan 2003 (Queensland)*
Jul 2010	Management plan amended removing ability to appeal. Available OS Quota in fishery after all appeals heard is 1 064 405 units. *Fisheries (Coral Reef Fin Fish) Management Plan 2003 (Queensland)*
Jul 2013	Department of Environment and Heritage surrender quota units. As a result 955,604 OS units remain. *Fisheries (Coral Reef Fin Fish) Management Plan 2003 (Queensland)*
Sep 2019	Fisheries (Coral Reef Fin Fish) Management Plan repealed Fisheries (General) Regulation 2019 (Queensland), Fisheries (Commercial Fisheries) Regulation 2019 (Queensland), Fisheries Declaration 2019 (Queensland) and Fisheries Quota Declaration 2019 (Queensland) enacted.
2019	Line Fishery (Reef): The fishery symbols for the fishery are 'L1', 'L2', 'L3' and 'L8' provide access to fishing areas in Queensland while RQ quota provides access to fish and both are required. Fish may be taken only by using fishing lines. A person must not use more than 3 fishing lines at the same time. The total number of hooks or lures attached to the lines must not be more than 6 per person. A primary boat longer than 20 m must not be used. The permitted distance for an assistant fisher to be under direction of a commercial fisher is 5 nautical miles. A tender boat must not be used more than 5 nautical miles from its primary boat. This does not apply if the tender boat and its primary boat are located on the same reef. *Fisheries (Commercial Fisheries) Regulation 2019 (Queensland)*
Sep 2020	'Primary' vessels to be up to 25 m long, 'tender' vessels to be up to 10 m long and the number of tenders that can operate in different fisheries clarified. Distance requirements for tenders and assistant fishers removed now that vessel tracking is required on all commercial fishing vessels. These matters are regulated under national marine safety legislation.

In 2021, the Queensland Department of Agriculture and Fisheries commissioned a stock assessment for red emperor 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 (Department of Agriculture and Fisheries 2017), and inform the Status of Australian Fish Stocks (SAFS) process.

2 Methods

2.1 Data sources

Data sources included in this assessment (Table 2.1) were used to determine catch rates, age and length compositions, and estimate 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 1953 up until and including 2021 based on available information.

Table 2.1: Data used in the Queensland east coast red emperor stock assessment

Type	Financial year	Source
Commercial harvest	1989–2021	Logbook data collected by Fisheries Queensland
Recreational harvest	2002, 2005	Recreational fishing surveys (RFish) conducted by Fisheries Queensland (Higgs et al. 2007; McInnes 2008)
	2011, 2014, 2020	Statewide Recreational Fishing Survey (SRFS) conducted by Fisheries Queensland) (Taylor et al. 2012; Webley et al. 2015; Teixeira et al. 2021)
	2001	Recreational fishing surveys conducted by the Australian Department of Agriculture, Fisheries and Forestry (the National Recreational and Indigenous Fishing Survey, NRIFS) (Henry et al. 2003)
	2017–2021	Boat ramp survey, conducted by Fisheries Queensland, providing catch and length information
	1953–2002	Australian historical population statistics (for the state of Queensland), conducted by the Australian Bureau of Statistics, providing a proxy for fishing effort (ABS 2014)
Charter harvest	1989–2021	Logbook data collected by Fisheries Queensland
Indigenous harvest	2001	Indigenous fishing survey conducted by the Australian Department of Agriculture, Fisheries and Forestry (the National Recreational and Indigenous Fishing Survey, NRIFS) (Henry et al. 2003)
Biological data	2018–2021	Biological monitoring (sex, age and length of red emperor from the commercial line fishery) undertaken by Fisheries Queensland (Fisheries Queensland (In Prep.) 2012)

Continued on next page

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

Table 2.1 – *Continued from previous page*

Type	Financial year	Source
Biological data	2017–2021	Collaborative collection of regional demographic data by Fisheries Queensland and James Cook University. Age, length and sex data 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. Additional information was provided on maturity and sex-specific growth rates of *L.sebae* as part of this collaboration
	2017–2021	Boat ramp survey, conducted by Fisheries Queensland, providing length and discard information
	2004–2008	Length information of tagged red emperor caught by the recreational sector, collected by Australian National Sportfishing Association (ANSA). Used to inform length structure of red emperor below MLS. Subset of 2004 onward used to ensure MLS of 55cm was consistent with period of boat ramp survey discard information

2.1.1 Commercial

Commercial harvests of red emperor were recorded in the Queensland logbook system. The logbook system consists of daily retained catches (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 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 retained 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 2001, 2011, 2014 and 2020 (financial years) had more effective follow-up contact procedures with diarists resulting in less dropout of participants compared to the other survey years using RFish methodology (Lawson 2015). This was taken into account when reconstructing recreational harvest estimates. For more detail, see Section 2.2.

2.1.2.2 Boat ramp survey

Recreational data were collected by Fisheries Queensland in 18 different regions on the east coast, 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 2017). The length data was used as input in the model, and discards were used to infer discard rates of red emperor for the recreational sector.

2.1.3 Charter

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

2.1.4 Indigenous

The National Recreational and Indigenous Fishing Survey in 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 discards for Indigenous communities followed similar procedures (Henry et al. 2003). Indigenous harvests were combined with recreational harvests for modelling 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 (given as increment count, or number of annuli present on transverse-sectioned saggital otoliths) and sex of fish (male, female or unknown). The age-at-length relationship of recreationally caught fish were assumed to be of the same distribution per length class, as those from the commercial fishery, in each region sampled.

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

2.2 Harvest estimates

Commercial, charter, recreational and Indigenous catch data were analysed to reconstruct the history of harvest from 1953 until 2021. Prior to 1953, red emperor harvest was assumed to be negligible. This section describes how these data were combined to create the history of red emperor harvest (Figure 2.1).

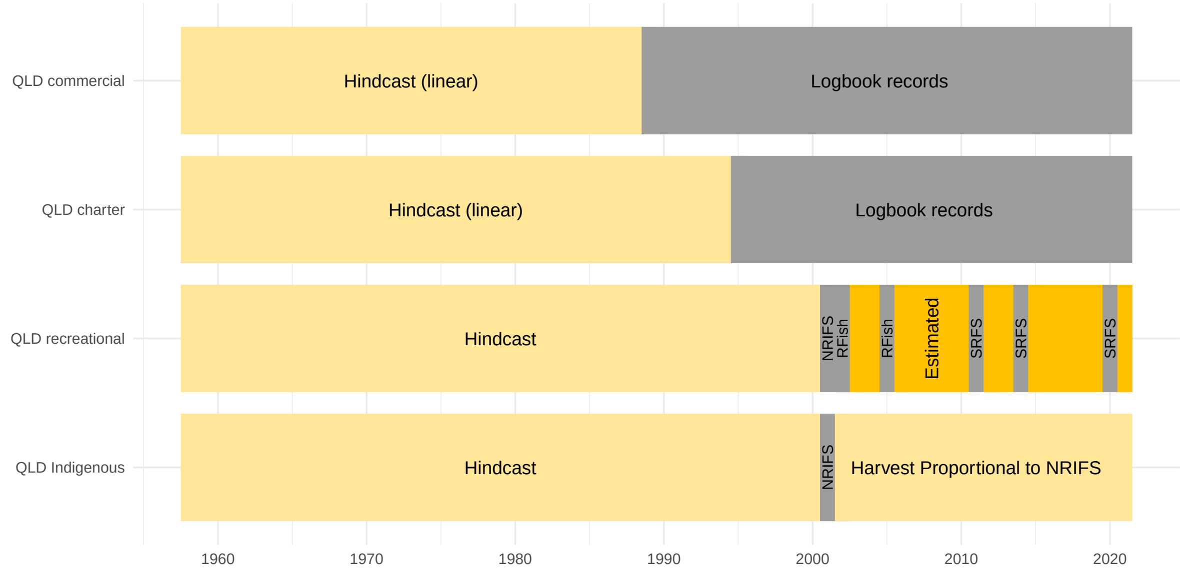

Figure 2.1: Overview of the methods used to reconstruct the history of red emperor harvest

Commercial harvest:

- **1989–2021:** A baseline harvest of red emperor was set to the retained weight of whole red emperor (in kilograms, CAAB code 37346004) recorded against the line (LI) and mixed fishery (MF) codes in the CFISH logbooks. A minority of logbook records (0.7%) existed where retained weight of whole red emperor was not given, but the retained number of red emperor was provided. For these records, the retained number of red emperor was multiplied by the average weight of red emperor sampled from the commercial sector by Fishery Monitoring (5.077 kg, n = 5925).
- **1953–1989:** Harvest was linearly hindcast to 0 t in 1953.

Charter harvest:

- **1995–2021:** A baseline harvest of red emperor was set to the retained number of whole red emperor (CAAB code 37346004) recorded the charter fishery (CV) code in the CFISH logbooks.
- **1953–1994:** Harvest was linearly hindcast to 0 t in 1953.
- Measured in numbers of fish as opposed to weight.

Recreational harvest:

- **1953–2002:** Assumed zero in 1953 and increased proportionally to Queensland population growth through the time series to reach a rescaled RFish estimate in 2002. The rescaling factor applied to obtain this estimate was calculated as the 2002 estimate divided by the NRIFS estimate for the year 2001.
- **2001, 2011, 2014, 2020:** Set to equal the values reported in the NRIFS (2001) and SRFS (2011, 2014 and 2020) surveys.
- **2002, 2005:** Set to the rescaled RFish estimates.
- **2021:** Estimate for 2021 set to equal the value reported in the 2020 SRFS survey.
- **2003–2004, 2006–2010, 2012–2013 and 2016–2019:** “Missing” records were set to values linearly interpolated between the estimates from the survey years listed above.

- Estimates for all years were entered into the population model as retained numbers of fish, and converted to weights by the model itself.

Indigenous harvest:

- **2001:** Equalled the estimated number of fish harvested by Indigenous fishers from the NRIFS survey
- **1953–2000:** Assumed zero in 1953 and increased proportionally to Queensland population growth through the time series to reach the NRIFS estimate in 2001.
- **2002–2021:** The proportion of the total harvest of red emperor represented by the Indigenous sector was calculated in 2001. This proportion was then applied to the total harvest of red emperor in each subsequent year to give annual estimates of Indigenous harvest for this period.
- Added to the recreational and charter harvest for input to the population model.

2.3 Standardised index of abundance

Queensland logbook data on commercial catches of red emperor (kg whole weight) per boat per day were used as an index of legal-sized fish abundance. These data were reported per primary vessel (rather than per dory or tender). 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 fish logbook records:

1. The data set was restricted to east coast, line fishery records where the number of crew was recorded and the catch was reported for a single date per day.
2. In the situation where multiple locations were fished on a single day, the catch was summed over all records, and the location was set to the location where the greatest amount of catch was taken.
3. The data set excluded all records outside the spatial extent of the L1 fishery (Figure 2.2).
4. The data set was restricted to records where kilograms of red emperor caught was greater than zero.
5. The data set excluded records where the weight of the daily catch reported was less than the weight of one legal-sized red emperor. Conversion equations for expressing the relationship between total length (TL) and fork length (FL), as well as FL and total weight were sourced from McPherson et al. (1992a) and McPherson et al. (1992b) respectively (Section 2.5). The inverse of the TL-FL conversion equation was used to find the FL of a fish whose TL equalled the applicable MLS for the given year. The FL-weight equation was then used to convert this FL to a weight. Daily catch records of less than this weight were excluded from the data set.
6. The data set was filtered to include records associated with fishers that had (a) at least two years of catch history and (b) were in the subset of fishers that accounted for 95% of the total red emperor catch when ordered by contribution (in total whole weight). These steps were taken to ensure a consistent, comparable subset of fishers were included in the standardisation process across the time series. This helped to reduce the influence of factors unrelated to fish abundance, such as fisher dropout, market drivers, changes in targeting behaviour and incidental catches. The resulting subset comprises logbook records from 359 fishers.

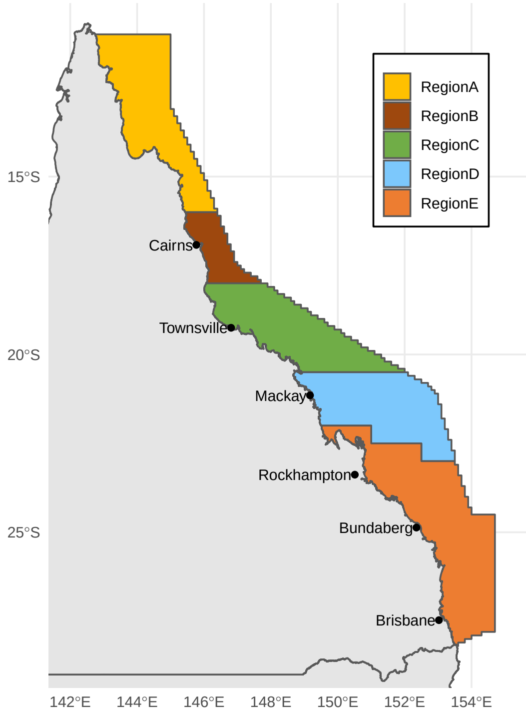

Figure 2.2: Map of regions used for catch rate analysis

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

The form of the model was:

$$\log(RedEmperor) \sim Year * Quarter * Region + Fisher + Crew + CTRTE + OS^2 \tag{2.1}$$

where the variables considered were:

- *RedEmperor*: retained catch of red emperor per boat, per day (kilograms)
- *Year*: financial year (factor)
- *Quarter*: 3-month time blocks, ordered according to financial month (factor)
- *Region*: spatial region, aggregated into broader regions 'Region A', 'Region B', 'Region C', 'Region D' and 'Region E' from Fishery Monitoring regions (Figure 2.2; factor)
- *Fisher*: fisher license identifier (authority chain number, factor)
- *Crew*: number of crew recorded (factor)
- *CTRTE*: retained catch of coral trout and redthroat emperor (kilograms)
- *OS^2*: retained catch of coral reef 'other species' (excluding red emperor, see list in Appendix E; kilograms). A quadratic transformation was applied to this variable to improve diagnostics.

While spatial regions were used to structure the catch rate analysis, ultimately a single catch rate for the whole fishery was analysed through time. Regional catch rate contributions to the unified final catch rate were 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^2' and 'CTRTE') were included following project team discussions on the complex nature of identifying targeting of red emperor in the Reef Line Fishery (RLF). Including these variables provides the catch rate model with the ability to standardise by the degree to which a given trip targeted red emperor. For example, a large quantity of co-caught coral trout and/or redthroat emperor ('CTRTE', primary target species of the RLF) may indicate the operation was in fact targeting these species, and any catch of red emperor on that trip was incidental. Conversely, a large quantity of co-caught coral reef 'other species' ('OS') may indicate that the operation was not targeting coral trout or redthroat emperor, and hence there is a greater chance that red emperor was one of the target species on that trip.

2.4 Discards and post-release mortality

For many species, greater than half of the fish caught by recreational anglers are released (discarded) (McLeay et al. 2002). Generally these released fish are under the MLS which, for red emperor, is 55 cm total length for all sectors. As per Campbell et al. (2021), it is hypothesized that a large proportion of released 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 (Campbell et al. 2021). However, releasing fish due to being below the MLS is just one reason that fish may be released. For some species, other factors such as desirability, eating quality, recreational in-possession limits and the practice of 'catch and release' fishing can result in legal-sized fish being released.

Commercial discarding of red emperor is negligible due to the absence of an in-possession limit, the offshore focus of commercial fishers (Campbell et al. 2021) and the desirability of red emperor. Discarding within the commercial fleet was therefore assumed negligible. Conversely, boat ramp survey data confirmed that a significant fraction of the recreational red emperor catch was released. The project team discussed what proportion of red emperor catch in the recreational sector was discarded due to reasons other than not meeting MLS. Discarding of legal-sized red emperor in the recreational sector was considered to be negligible, due to factors such as their high desirability as a target of recreational fishing and esteemed eating quality. Therefore, it was assumed that all discarded red emperor were discarded due to being below the MLS.

In order to model discards optimally, the model requires information on the total quantity of discards and their length distribution. Boat ramp survey data included information from recreational anglers on the number of discarded red emperor, though the length distribution of these discarded fish is unknown. The following procedure was used to produce a length distribution of red emperor in the recreational sector (including both retained and discarded fish), for input to the model.

1. The length distribution of retained recreational red emperor 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. As length information from Fisheries Queensland was only available for retained fish, length information of tagged and released red emperor collected by members of the Australian National Sportfishing Association (ANSA) was used to construct the length distribution of undersized red emperor. These fish were caught, measured and tagged by recreational anglers, and included a large quantity of individuals below MLS.
2. The length distribution of undersized fish from the ANSA data was created in terms of proportions within each length bin per year (see Figure 3.6, Section 3.1.4)
3. This length distribution was then applied to the numbers of released red emperor in each year, according to boat ramp survey data. This ensured that the relative magnitude of released and

retained recreational red emperor length distributions reflected what was observed in boat ramp surveys. This was achieved by sampling from the undersized length distribution, such that the total number of samples generated was the total number released (from the boat ramp survey estimates of this quantity). The resulting recreational length distribution including both discarded and retained fish can be seen in Figure 3.7, Section 3.1.4.

Total estimates of discards from the recreational sector were input separately to the reconstruction (Taylor et al. 2012; Webley et al. 2015; Teixeira et al. 2021). The pattern of discarding between 2017 and 2021 from the boat ramp survey data were scaled to meet the absolute number discarded from the Statewide Recreational Fishing Survey in 2020.

Discard mortality was set at 1.6% (i.e. 98.4% survival), based on rates of acute (3 days) discard mortality from Brown et al. (2008, Chapter 1). As stated in Brown et al. (2008) however, a number of other factors can impact whether short-term resilience translates into long-term post release survival, such as the occurrence of 'deep-hooking' (fish hooked in either the throat or gut). As such, an additional model scenario was explored, under the 'Discard mortality' sensitivity test (Section 2.7.4) where an additional 7.64% discard mortality was applied—this is equivalent to the proportion of total tagged red emperor that were 'deep-hooked' in Brown et al. (2008, Chapter 4).

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 discard modelling and calculating FL at minimum legal size (given as TL), a conversion to total length was required. The following conversions were applied where necessary (McPherson et al. 1992a):

$$TL_{mm} = 1.07 \times FL_{mm} - 0.21, FL_{mm} = \frac{1}{1.07} \times TL_{mm} + \frac{0.21}{1.07}$$

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:

$$mat = \frac{1}{(1 + \exp(-intercept \times (FL_{mm} - L_{50})))}$$

where mat is maturity, $intercept$ is a coefficient of the logistic function (0.027, Hillcoat and Russ, unpublished data), FL_{mm} is fork length in millimetres and L_{50} (or size at first maturity) is the fork length at which 50% of fish have reached maturity (529.548 mm, Hillcoat and Russ, unpublished data).

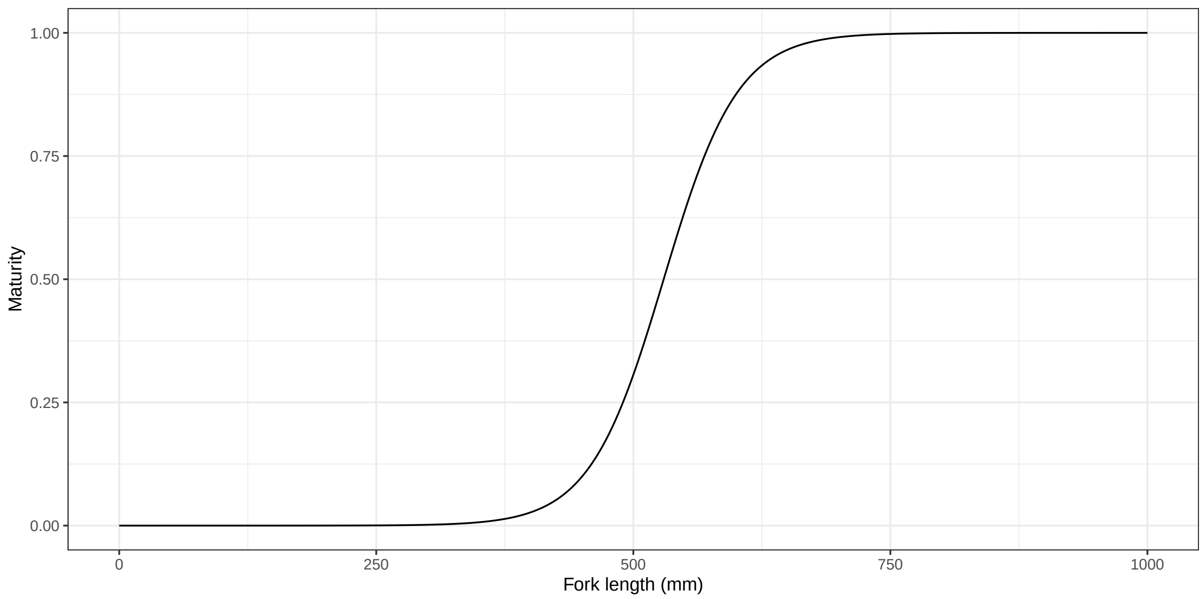

Figure 2.3: Maturity curve input into the model, produced using coefficients from Hillcoat and Russ, unpublished data

No information was available on the fecundity for red emperor. For this assessment the number of eggs produced by a female red emperor was set to the total weight of that individual.

2.5.3 Weight and length

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

$$W_{kg} = \exp(-11.18 + 3.10 \times \log(FL_{cm}))$$

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

2.6 Length and age data

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

2.7 Population model

A population model was fitted to the data to determine the number of red emperor in each year and each age group using the software package Stock Synthesis (SS; version 3.30.16.00). A full technical description of SS is given in Methot et al. (2021).

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

Unpublished data associated with a doctoral thesis at James Cook University indicated a growth difference between the sexes with males growing significantly larger, but slower than females (Hillcoat and Russ, unpublished data). However, sex-specified biological monitoring data (from the commercial sector) were limited, due to the majority of red emperor being measured as whole fish (not filleted) at the point of vessel unload. Using sex-specific growth parameter information from Hillcoat and Russ (unpublished data), a two-sex model was able to be constructed using Stock Synthesis' parameter offset method. The procedure used to produce a two-sex model in this assessment is as follows:

1. Initially, the model was run as a one-sex model, producing pooled-sex (combined male, female and unknown) growth parameter estimates for the whole data set (L_at_Amin, L_at_Amax, VonBert_K).
2. The difference was calculated between sex-specific growth parameters for male and female red emperor from Hillcoat and Russ (unpublished data) by subtracting each of the female parameters from the male equivalent.
3. This difference was halved and applied to the pooled growth parameter estimates from the one-sex model. The value was subtracted from the one-sex parameter estimates to produce estimates of the female growth parameters, which were then used as priors during parameter estimation.
4. Using Stock Synthesis' parameter offset method, male growth parameters are estimated as offsets from the female growth parameter estimates. A detailed description of the parameter offset method is provided in Methot et al. (2021). The male growth parameter offsets must be given in exponential terms, and were calculated by solving for x below:
$$M_{cm} = F_{cm} \times e^x$$
where M_{cm} is the one-sex growth parameter estimate for male fish plus half of the difference between male and female estimates from Hillcoat and Russ (unpublished data), F_{cm} is the one-sex growth parameter estimate for female fish minus half of the difference between male and female estimates from Hillcoat and Russ (unpublished data), and x is the required male parameter offset, expressed as an exponent.
5. For each of the three male growth parameters, x from the equation above is used as the prior for parameter estimation.
6. The model was then run as a two-sex model, with all data input as 'unknown' sex. The default sex ratio in Stock Synthesis between male and female fish at recruitment is 50:50, and parameter estimation was executed accordingly with the sex-specific growth parameters calculated in the steps above. Unpublished data from Hillcoat and Russ also support a sex ratio of 50:50 for red emperor.

2.7.1 Model assumptions

The main assumptions underlying the model are given below:

- The fishery began from an unfished state in 1953.
- 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 Queensland east coast stock is reproductively isolated.
- 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 red emperor are parametric functions of their size.
- The first mature age is 5, after which the proportion of mature fish depends on size.
- The instantaneous natural mortality rate does not depend on size, age, year or sex.
- Deterministic annual recruitment is a Beverton-Holt function of stock size.

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, and known as *uniform priors*. 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 fixed at a specified value. Steepness is a metric relating to the productivity of the stock. Specifically, steepness refers to the fraction of recruitment from a virgin population that is obtained when the population is at 20% of virgin spawning biomass (Lee et al. 2012). For the base case, steepness was set to the (natural scale) initial value of 0.70, based on the meta-analysis by Thorson (2020). Lower and higher 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 with moderately informative normal priors. The male-specific parameters were estimated as an offset from the female-specific parameters using Stock Synthesis' parameter offset method (Section 2.7). These parameters, their priors and the associated prior standard deviations can be seen in Table 2.2.

Table 2.2: Sex-specific growth parameters with associated priors, prior standard deviations and prior types

Parameter	Prior	Prior SD	Prior Type
L_at_Amin_Fem	14.996	1	Normal
L_at_Amax_Fem	65.932	2.5	Normal
VonBert_K_Fem	0.2199	0.01	Normal
L_at_Amin_Mal	-0.0656	0.1	Normal
L_at_Amax_Mal	0.1648	0.05	Normal
VonBert_K_Mal	-0.0349	0.05	Normal

Coefficients of variation for both young and old fish were also estimated for females, but without priors (CV_young_Fem, CV_old_Fem). The male equivalents were assumed not to differ from the female estimates, and hence their parameter offset was fixed at zero (CV_young_Mal, CV_old_Mal).

Natural mortality (NatM) was estimated in the model, with a lognormal prior. This prior had a (natural scale) median value of 0.125 and a standard deviation of 0.05. This prior was based on the meta-analytical approach from Hamel (2015) and Then et al. (2015), where the prior is defined as a log-normal distribution with a median value (corresponding to the mean in log-space) equal to $5.40/A_{max}$. The maximum age across all samples is 43 years, giving $5.4/43 = 0.125$. The log-scale standard deviation was set to 0.05. While information on sex-specific growth was available from (Hillcoat and Russ, unpublished data), no information was available on sex-specific natural mortality. Accordingly, natural mortality was assumed to be the same for males and females with the parameter offset for male NatM fixed to zero.

Logistic length-based selectivity parameters were estimated in the model for both fleets (Size_inflection_Commercial, Size_95%width_Commercial, Size_inflection_Recreational, and Size_95%width_Recreational). Separate selectivity curves were estimated for the commercial fleet and the recreational-charter-Indigenous fleet.

Recruitment deviations between 1980 and 2021 improved fits to composition data and abundance indices as variability in recruitment annually allowed for changes in the population on shorter time-scales than fishing mortality alone.

Finally, all scenarios involved catchability being calculated rather than estimated.

2.7.3 Model weightings

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

2.7.4 Sensitivity tests

A number of 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:

- **Catch rates:** The catch rate analysis was either inclusive of all data defined in Section 2.3, or only inclusive of records where > 20 kg/day of red emperor was caught. Scenarios with only records above > 20 kg/day were executed to indicate whether the catch rates trends of more targeted red emperor operations differed from the overall catch rate trend. The rate of 20 kg/day was decided as an appropriate split after completing a 'breakpoint' analysis (Appendix A.1) using the R function 'breakpoints', from the *"strucchange"* package (Zeileis et al. 2019).
  - "All": Catch rates modelled using all data defined in Section 2.3
  - "Upper": Catch rates modelled using only data (defined in Section 2.3) where >20kg/day of red emperor was caught
- **Steepness:** Natural-scale median of the steepness prior altered based on study by Thorson (2020)
  - "Mid": 0.70
  - "High": 0.80
  - "Low": 0.60
- **Discard mortality:** Discard mortality defined as 1.6% as per acute discard mortality in Brown et al. (2008, Chapter 1) (Section 2.4), or discard mortality equal to 1.6% plus an additional 7.64% (9.24%), equivalent to the percentage of red emperor that were deep-hooked in Brown et al. (2008, Chapter 4).
  - "Acute": 1.6% discard mortality
  - "Alt": 9.24% discard mortality
- **Recruitment deviations:** Recruitment deviations applied over a long or short time scale
  - "Full": Recruitment deviations applied from 1980 to 2021
  - "Short": Recruitment deviations applied from 1980 to 2016

Twenty-four combinations of these sensitivities were tested, as outlined in Table 2.3. Scenario 1 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	Catch rates	Steepness	Discard mortality	Recruitment deviations
1 (Base case)	All	0.7	Acute	Full
2	All	0.7	Alt	Full
3	All	0.7	Acute	Short
4	All	0.7	Alt	Short
5	Upper	0.7	Acute	Full
6	Upper	0.7	Alt	Full
7	Upper	0.7	Acute	Short
8	Upper	0.7	Alt	Short
9	All	0.6	Acute	Full
10	All	0.6	Alt	Full
11	All	0.6	Acute	Short
12	All	0.6	Alt	Short
13	Upper	0.6	Acute	Full
14	Upper	0.6	Alt	Full
15	Upper	0.6	Acute	Short
16	Upper	0.6	Alt	Short
17	All	0.8	Acute	Full
18	All	0.8	Alt	Full
19	All	0.8	Acute	Short
20	All	0.8	Alt	Short
21	Upper	0.8	Acute	Full
22	Upper	0.8	Alt	Full
23	Upper	0.8	Acute	Short
24	Upper	0.8	Alt	Short

2.7.5 Harvest control rule

Stock Synthesis's forecast sub-model was used to provide forward projections of spawning biomass and future harvest targets, following a harvest control rule (Fisheries Queensland 2021). This rule has a linear ramp in fishing mortality between 20% spawning biomass, where fishing mortality is set at zero, and a target spawning biomass, where fishing mortality is set at the equilibrium level that achieves the target spawning biomass (F_{Btarg}). Below 20% spawning biomass fishing mortality remains set at zero, and above the target spawning biomass fishing mortality remains set at F_{Btarg} (Figure 2.4).

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

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

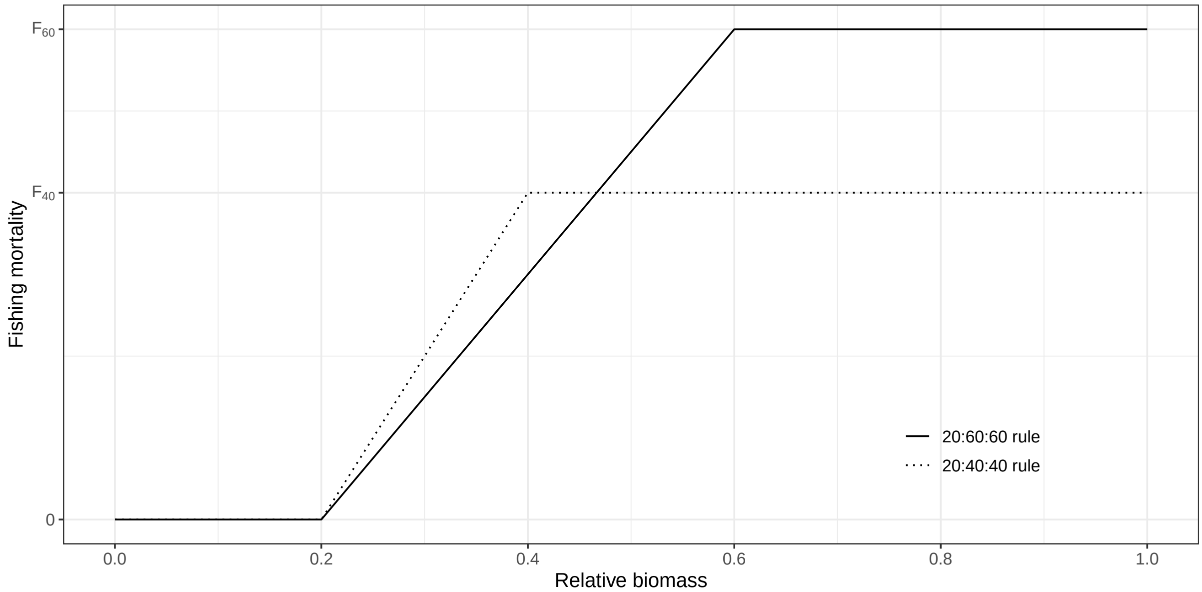

Figure 2.4: The 20:60:60 and 20:40:40 harvest control rules

3 Results

These model inputs and outputs relate to Scenario 1—the 'base case' (defined in Table 2.3). Results for all other scenarios can be found in Appendix C and Appendix D.

3.1 Model inputs

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

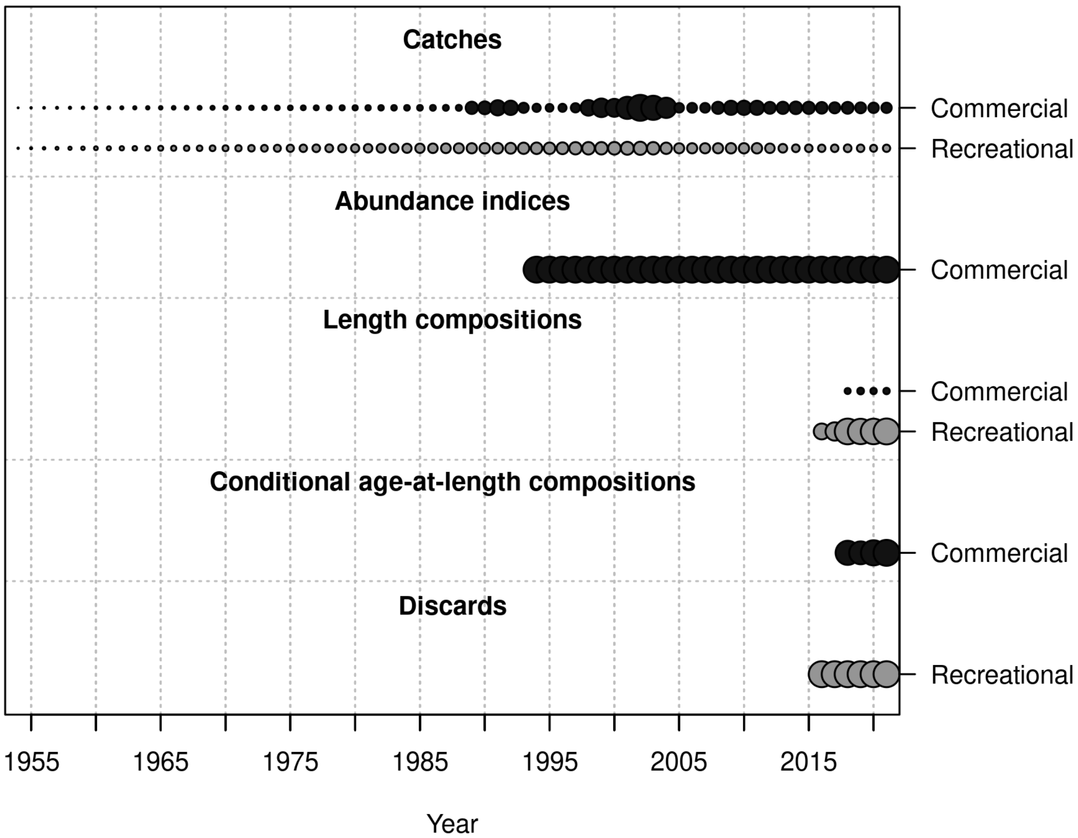

Figure 3.1: Data presence by year for each category of data type and Stock Synthesis fleet
Note: Stock Synthesis uses the term 'fleet' to distinguish data sets (and model processes) associated with different selectivity curves (proportions of fish at different lengths vulnerable to the fishing gear). This assessment 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 between separate data types should not be compared.

3.1.1 Harvest estimates

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

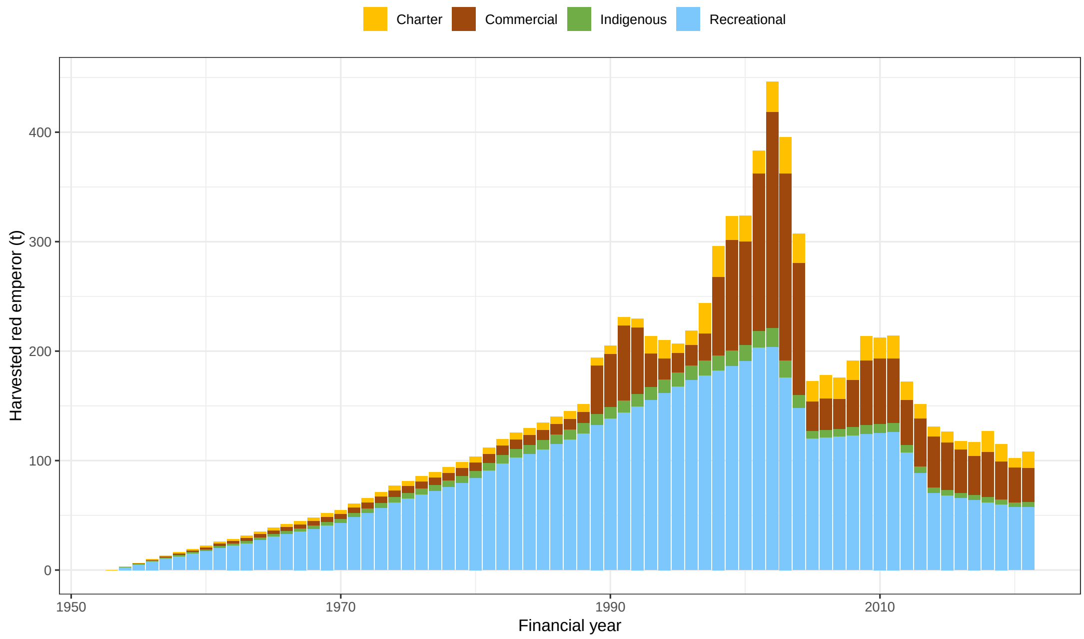

Figure 3.2: Annual estimated harvest (retained catch) from commercial, recreational, charter and Indigenous sectors between 1953 and 2021 for red emperor—recreational, charter and Indigenous sectors were modelled as a single fleet

3.1.2 Standardised index of abundance

The annual standardised commercial catch rates exhibited a slight decline on average (Figure 3.3). There was greater uncertainty in 1994 and 1995 which reduced notably thereafter. The trend in annual standardised commercial catch rates for the upper catch rates scenario (using records where daily catch > 20 kg/day) did not differ noticeably from the base case. Results for the upper catch rates scenario can be seen in Appendix C.

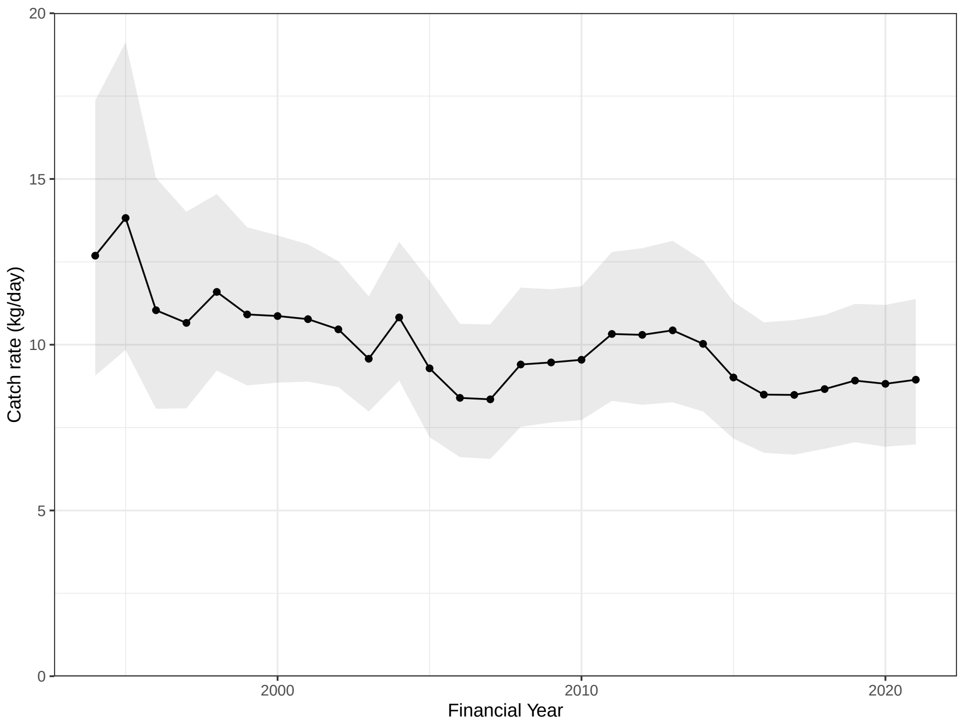

Figure 3.3: Annual standardised catch rates (with 95% confidence intervals) for commercial line caught red emperor between the years of 1994 and 2021

3.1.3 Age composition

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

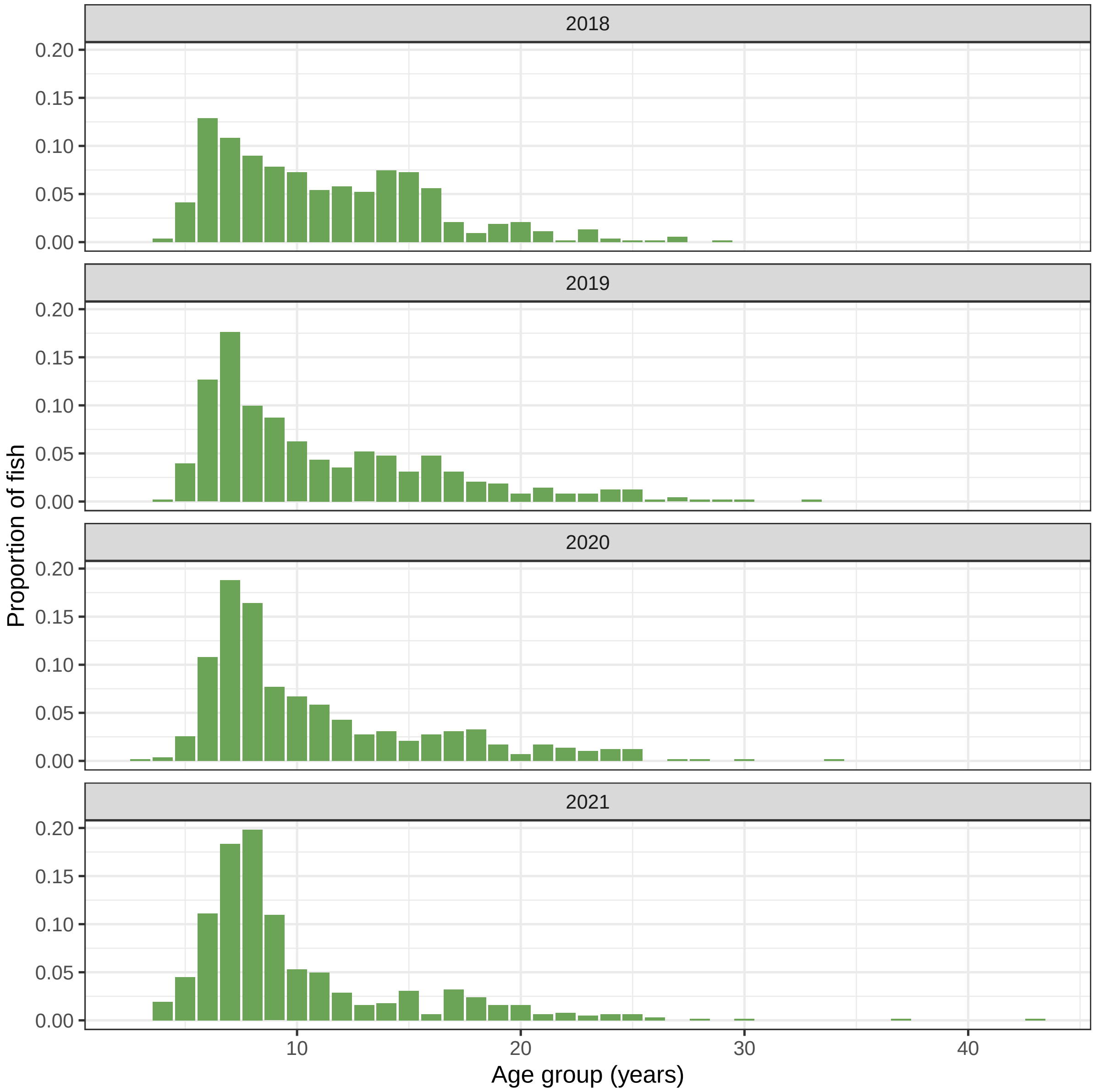

Figure 3.4: Annual age compositions of red emperor for commercial line caught fish between 2018 and 2021

3.1.4 Length composition

Fishery length compositions were input to the population model for the commercial fleet (Figure 3.5) and the recreational fleet (Figure 3.7). Discarded recreational length compositions were generated by the method described in Section 2.4.

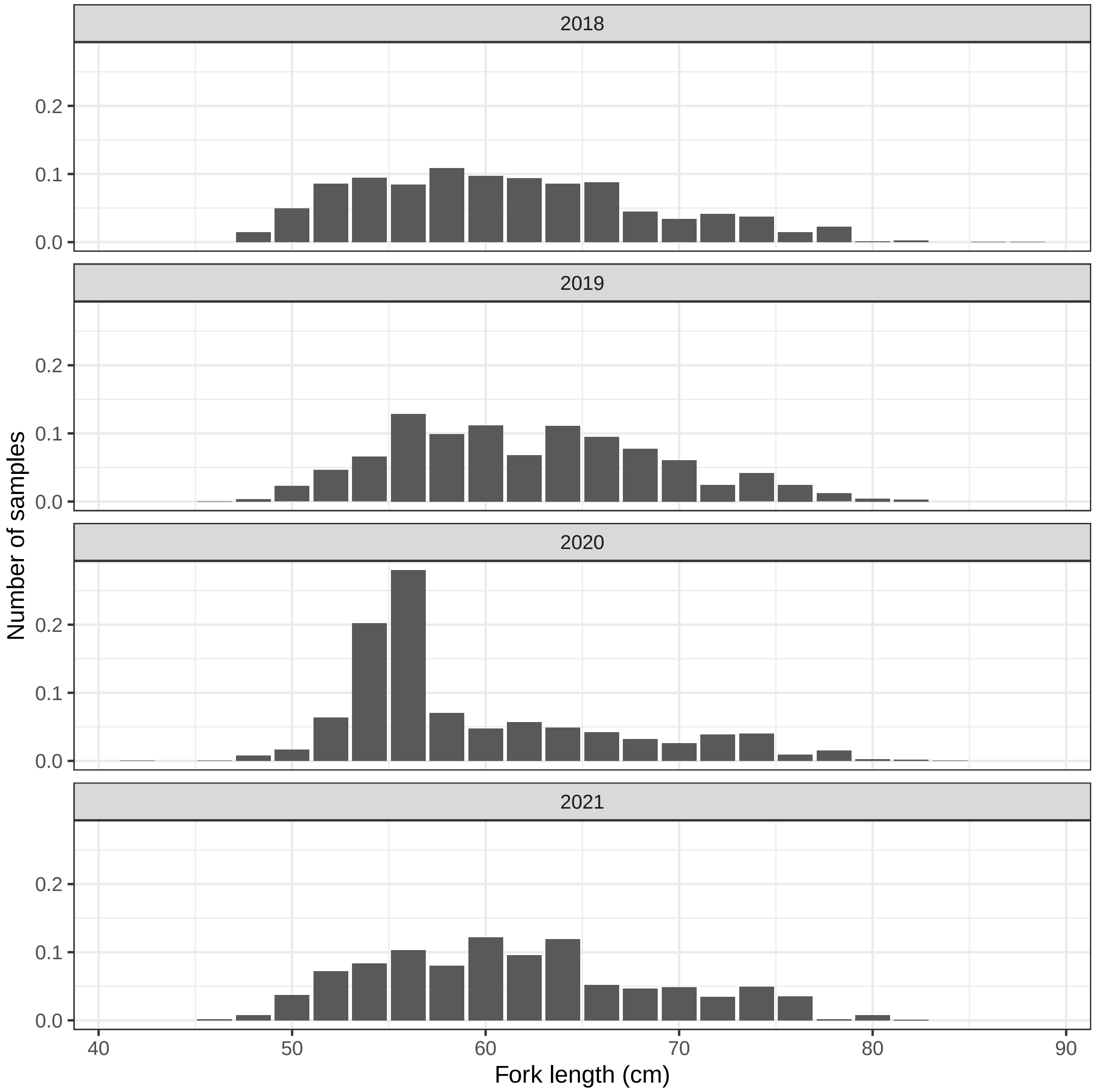

Figure 3.5: Annual length compositions of red emperor for commercial line caught fish between 2018 and 2021

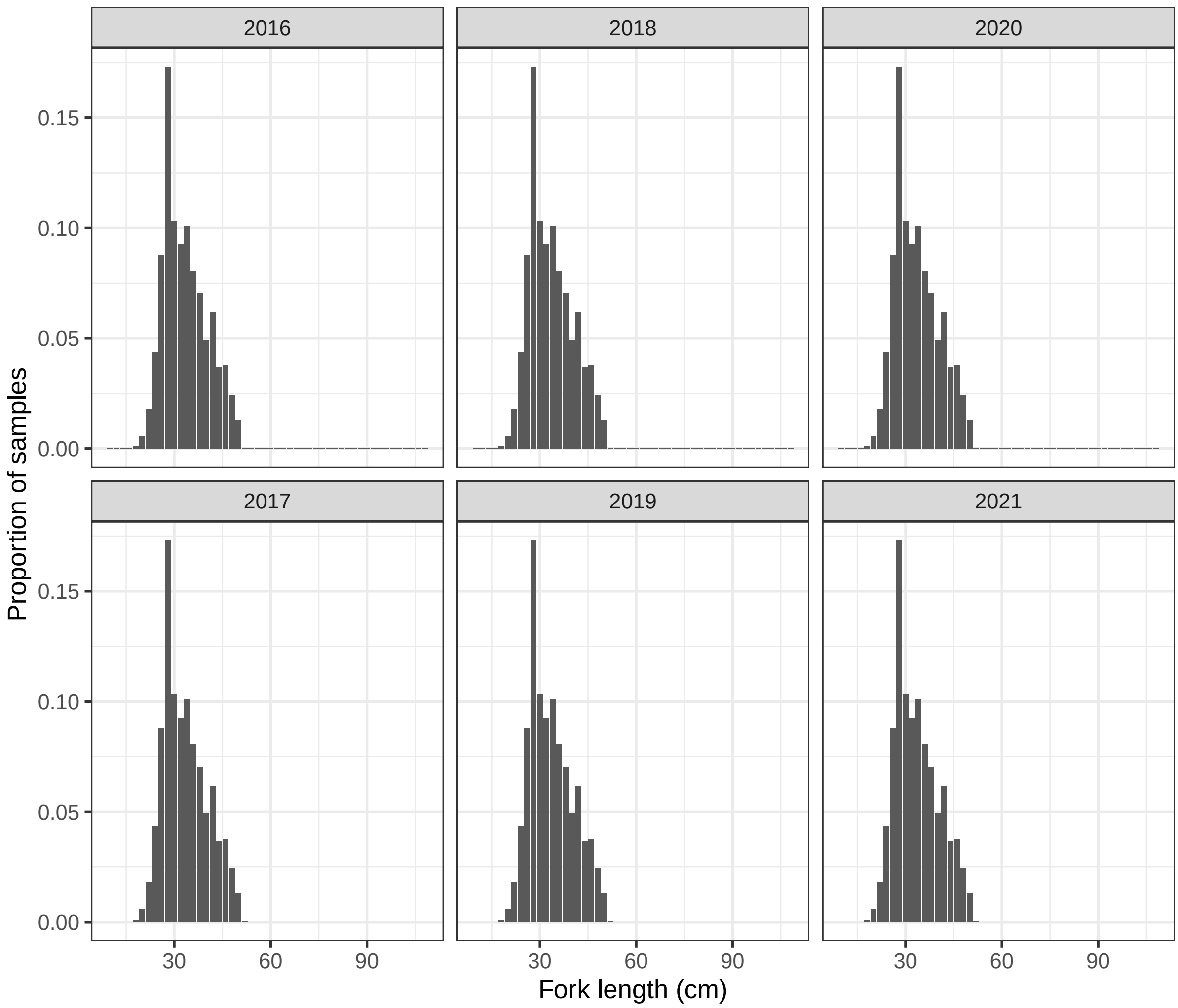

Figure 3.6: Estimated annual length compositions of discarded red emperor for recreational line-caught fish between 2016 and 2021

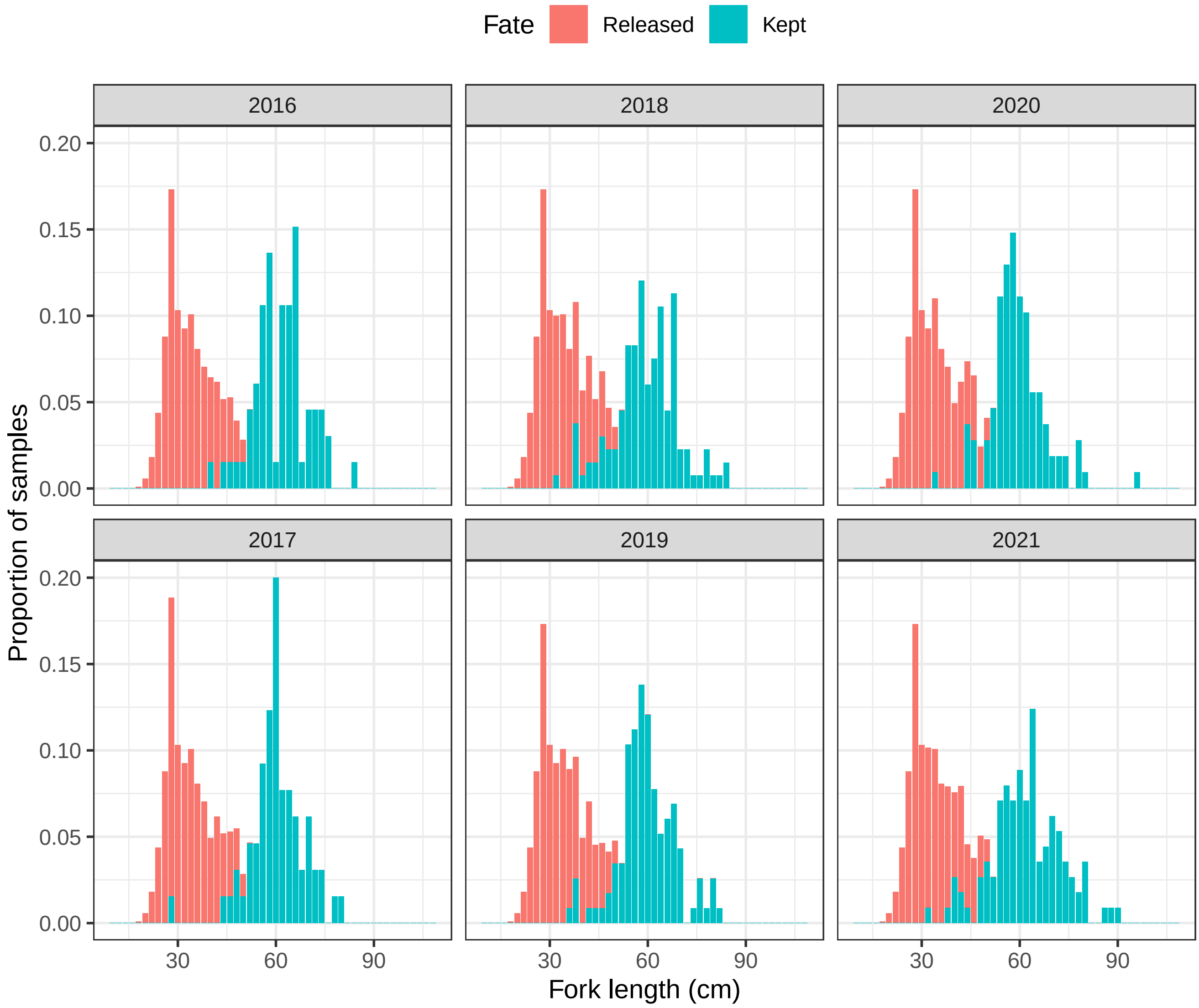

Figure 3.7: Estimated annual length compositions of both retained and discarded red emperor for recreational line-caught fish between 2016 and 2021

3.1.5 Discards

In addition to the discarded length composition data (above), total numbers of discards from the recreational sector were input to the model. The pattern of discarding between 2016 and 2021 from the boat ramp survey data was scaled to meet the absolute number discarded from the Statewide Recreational Fishing Survey in 2020. The total number of fish discarded for the recreational-charter-Indigenous fleet, input to the model are summarised in Table 3.1.

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

Year	Number of discards
2016	21 000
2017	25 850
2018	25 366
2019	28 465
2020	24 623
2021	23 725

3.2 Model outputs

3.2.1 Model parameters

A number of parameters were estimated within the base case model (Table 3.2). Male growth parameters below are given as offsets from the equivalent female parameter estimates, with the detailed method described in (Section 2.7). Male growth parameter offset values are denoted with asterisks, and the resulting absolute values are denoted in the table footnote. The full list of estimated parameters for the base and sensitivity runs is given in Appendix B.1, Table B.1. Boxplots that show the variation in parameter estimates across all sensitivity runs are given in Appendix C, Figure C.

Table 3.2: Summary of parameter estimates for red emperor from the base population model

Parameter	Estimate	Standard deviation
Natural mortality	0.160	0.006
Length at age 1 (Female)	15.584	0.424
Length at age 43 (Female)	67.065	0.515
von Bertalanffy growth parameter (Female)	0.187	0.005
Coefficient of variation in length at age 1	0.090	0.006
Coefficient of variation in length at age 35	0.085	0.06
Length at age 1 (Male)	-0.135*	0.050
Length at age 43 (Male)	0.164*	0.013
von Bertalanffy growth parameter (Male)	-0.054*	0.037
Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1953)	13.350	0.162
Commercial selectivity inflection (cm)	52.526	0.431
Commercial selectivity width (cm)	3.258	0.600
Recreational selectivity inflection (cm)	23.631	0.276
Recreational selectivity width (cm)	2.507	0.280

Note: *Absolute values for male growth parameters: Length at age 1 (Male) = 13.615; Length at age 43 (Male) = 79.016; von Bertalanffy growth parameter (Male) = 0.177

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

In Scenarios 5–8, 13–16 and 21–24, standardised annual catch rates were run with only records above > 20 kg/day. In these scenarios, estimates of Beverton-Holt unfished recruitment were slightly higher than in the other scenarios (Figure C).

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

3.2.2 Model fits

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

3.2.3 Selectivity

Selectivity of red emperor was estimated within the model. The recreational and commercial fleets had significantly different selectivity (Figure 3.8). Patterns of discarding, retention and discard mortality for red emperor in the recreational sector are shown in (Figure 3.9).

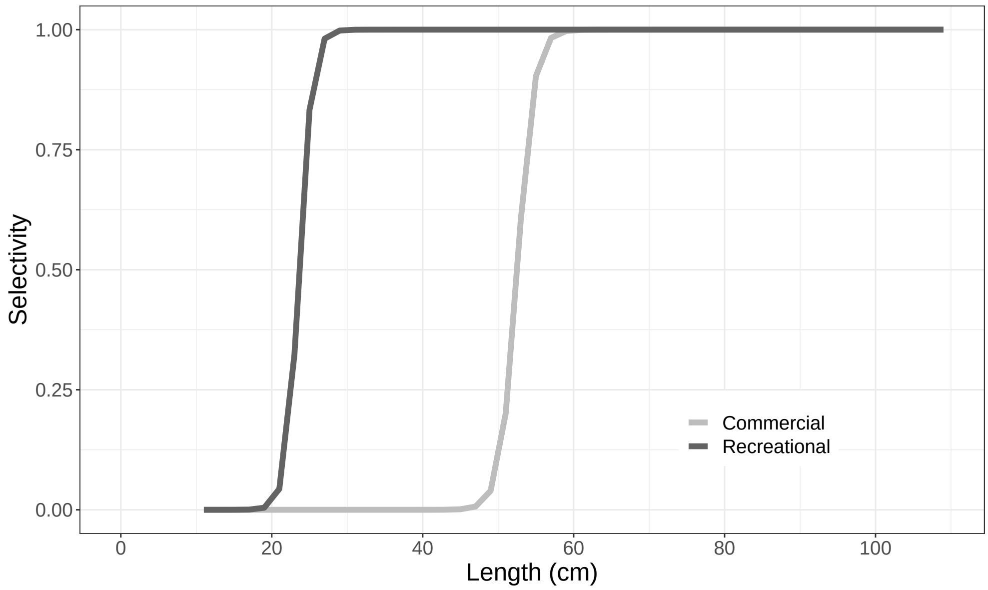

Figure 3.8: Model estimated size-based selectivity for red emperor by fleet—note that the recreational fleet includes retained and discarded fish

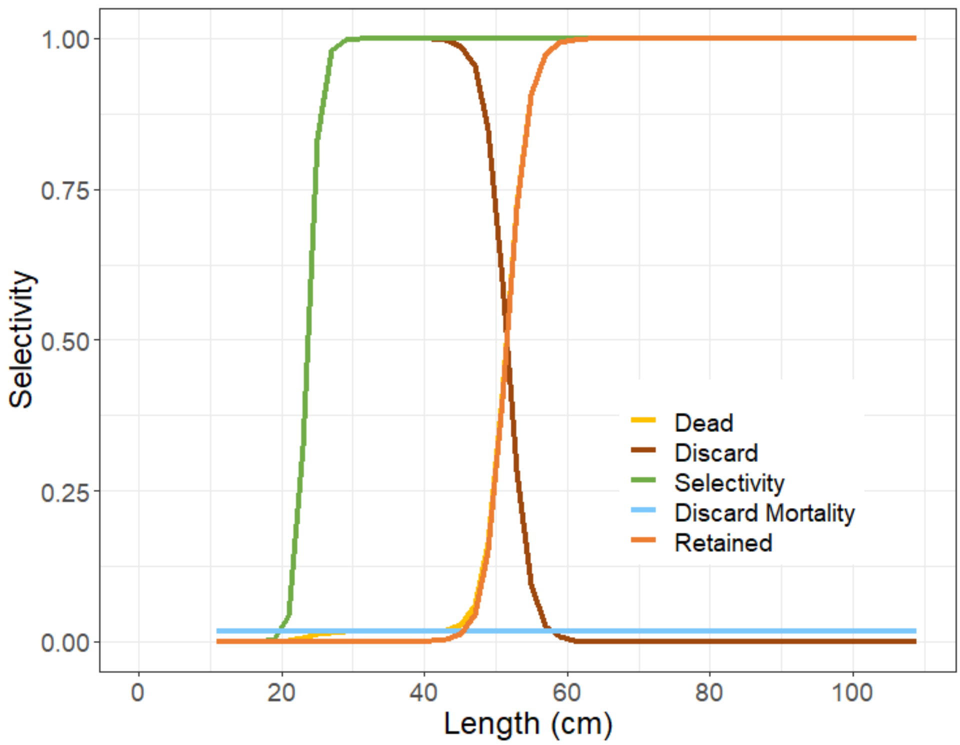

Figure 3.9: Model estimated retention, discard mortality and selectivity for red emperor in the recreational fleet. Discard mortality was set at a constant 1.6% as described in Section 2.4. Note the 'Dead' curve begins to mirror the 'Retained' curve as it approaches MLS, and is hereafter obscured by this curve.

3.2.4 Biology

The von Bertalanffy growth curve, including coefficients of variation of old and young fish, was estimated within the model (Table 3.2, Figure 3.10).

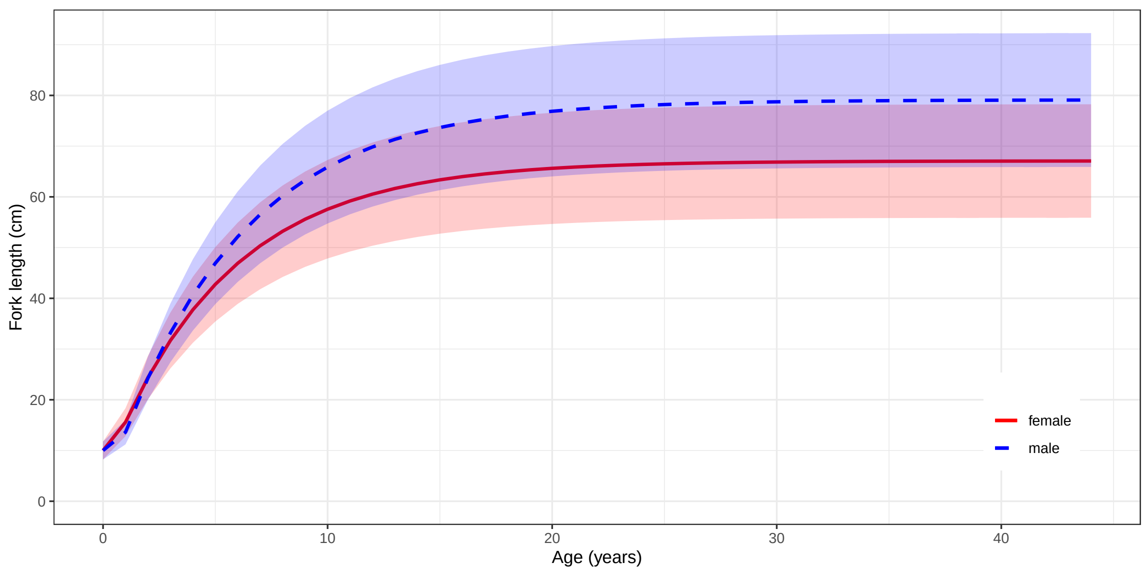

Figure 3.10: Model estimated von Bertalanffy growth curves for female and male red emperor

3.2.5 Biomass

The base case model predicted spawning stock biomass declined between 1953 and 2005 to 55% unfished spawning biomass. In 2022[1], the stock level was estimated to be 58% of the unfished spawning biomass (56–65% range across scenarios) (Figure 3.11). Relative spawning biomass trajectories for all sensitivity scenarios are presented in Figure 3.12.

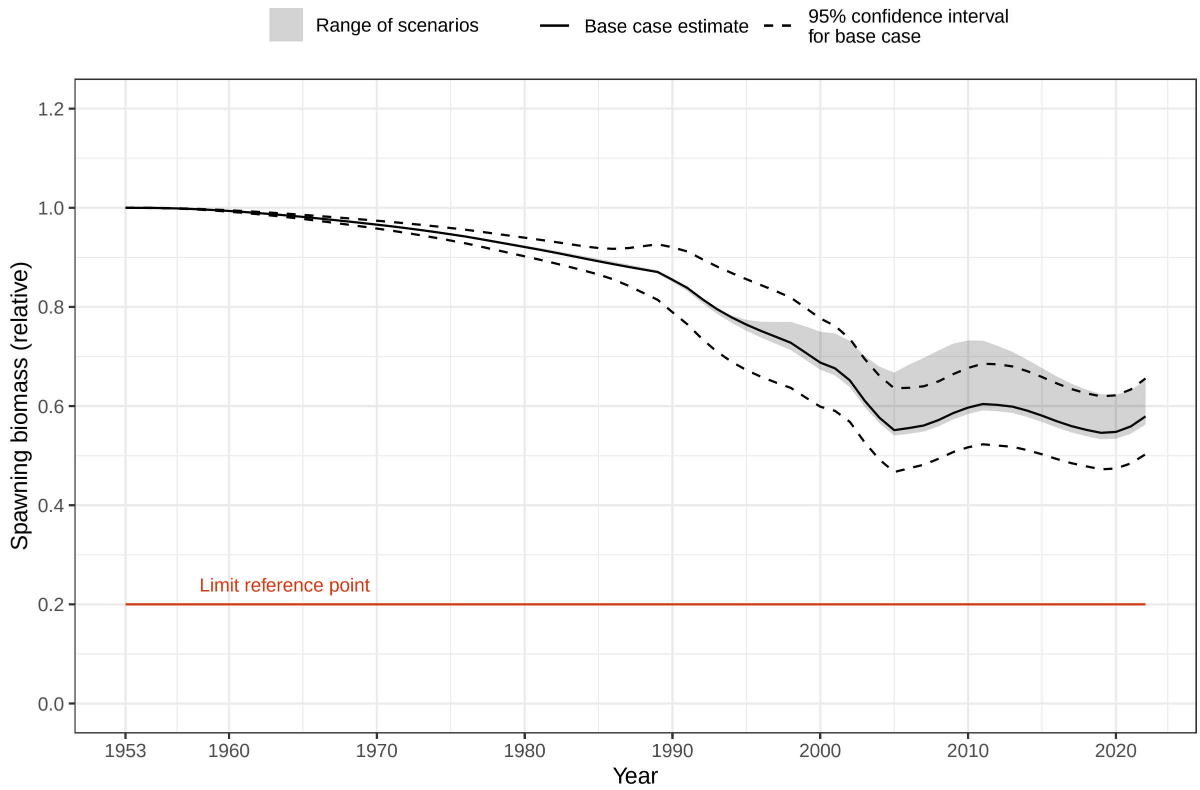

Figure 3.11: Predicted spawning stock biomass trajectory relative to unfished, from 1953 to 2022

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

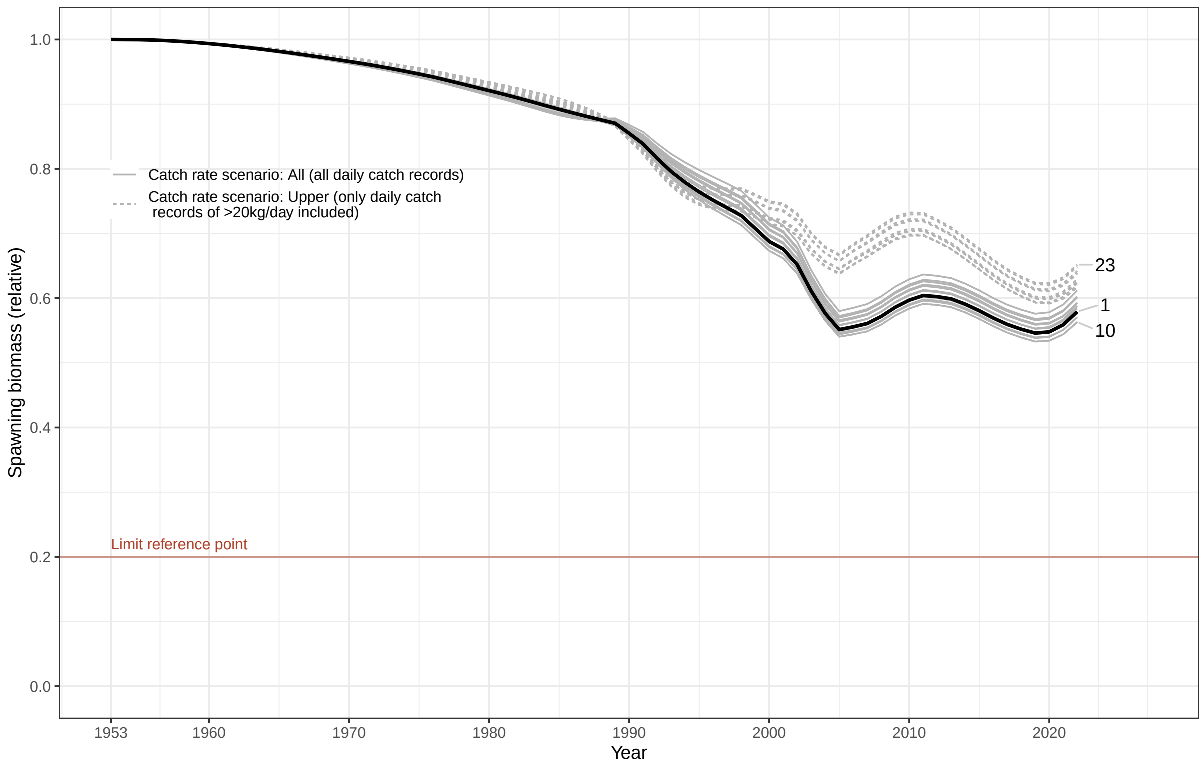

Figure 3.12: Predicted spawning biomass trajectory relative to virgin for red emperor from 1953 to 2022, for all scenarios — labelled scenarios are the base case (1, in black), the highest (23) and lowest (10) scenarios in terms of 2022 biomass

The relationship between the spawning biomass estimate and fishing mortality are presented in a phase plot (Appendix B.3.1, Figure B.1). The equilibrium yield curve informs on the productivity of the stock at different spawning biomass levels (Figure 3.13). Recommended biological catches (RBCs) are derived from the equilibrium yield curve, representing the total dead catch that can be extracted from the stock at equilibrium, including both retained catch and dead discards. The retained component of the RBC is derived from the equilibrium retained catch curve, representing the total retained catch that can be extracted from the stock at equilibrium. The retained component of the RBC does not include dead discards.

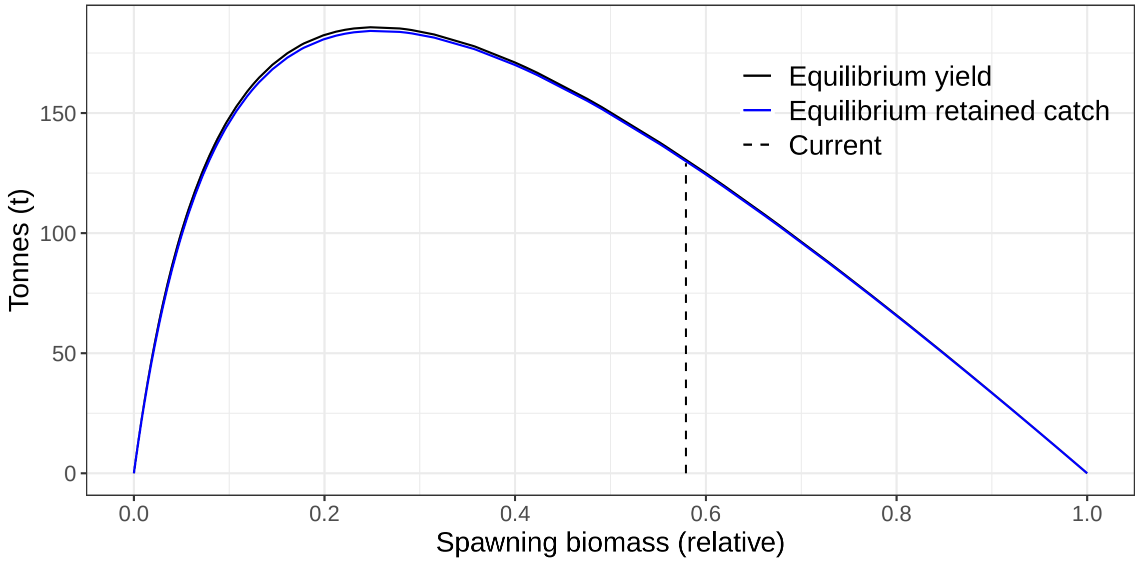

Figure 3.13: Equilibrium yield and equilibrium retained catch curves for red emperor

3.2.6 Harvest targets

Harvest targets have been calculated to maintain spawning biomass at the two target reference points for the base model—60% spawning biomass and 40% spawning biomass (as a proxy for maximum sustainable yield, MSY). Using a target reference point of 60% spawning biomass, the RBC for 2022 is 115 t with a retained catch component of 114 t. For a target reference point of 40% spawning biomass, the RBC for 2022 is 238 t with a retained catch component of 236 t. These RBCs are the second in a schedule of projected recommended harvests following a 20:60:60 or 20:40:40 harvest control rule. The schedules are presented here for the base case in Table 3.3. Note that these RBC values have not had an uncertainty discount factor applied. For discounted harvest values see Section 4.3.2.

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

	20:60:60 control rule		20:40:40 control rule	
Year	**Harvest (t)**	**Spawning biomass ratio**	**Harvest (t)**	**Spawning biomass ratio**
2022	114	0.579	236	0.579
2023	125	0.598	234	0.564
2024	134	0.63	241	0.568
2025			251	0.582
2026			257	0.594
2027			255	0.596
2028			247	0.586
2029			236	0.567
2030			226	0.545
2031			217	0.523
2032			209	0.504
2033			203	0.488
2034			199	0.475
2035			195	0.465
2036			192	0.456
2037			189	0.449
2038			187	0.443
2039			185	0.438
2040			183	0.434

4 Discussion

These results represent the first assessment of the Queensland east coast red emperor stock. The base case results discussed below should also be considered in the context of stock status variation amongst the full suite of scenarios investigated.

Results from this assessment suggest the red emperor population on Queensland's east coast experienced a substantial decline in the period 1953–2005 to reach 55% of unfished spawning biomass. This was followed by a period of fluctuation between 55% and 60% of unfished spawning biomass from 2005 to present. The results suggest that catch levels have slightly exceeded those consistent with a 60% spawning biomass target from 2003 to 2011, and again from 2013 to present. The current population level is estimated at 58% of unfished spawning biomass (56–65% range across scenarios).

4.1 Performance of the population model

Across the twenty-four scenarios (Figure 3.12), 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 all scenarios performed well in the sense described above, there was still a degree of variation in scenario outcomes, however this variation is notably less than in some previous assessments of closely related species (see Campbell et al. (2021) and Fox et al. (2021)). The majority of this variation stems from the catch rate sensitivity tests and is not an artifact of population modelling compromises or otherwise poor population model performance.

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

- **Targeting and catch rates.** Two different scenarios pertaining to the catch rate analysis were run: the base including all catch records for the catch rate analysis and the alternative only including catch records above $>$ 20 kg/day. This sensitivity test was the most significant contributor to the overall variability in unfished spawning biomass among all scenarios. The rationale and decisions behind these scenarios are given below.

  The RLF is a diverse and complex fishery, with a wide range of viable target species. The species that comprise the primary focus of a fisher can differ greatly between fishers, between trips, or even from day to day within a trip. As a result, identifying and isolating targeted red emperor fishing within the data can be challenging. For example, many vessels within the fishery primarily target live coral trout, encountering a small quantity of red emperor as incidental catch. Other vessels specifically target Reef OS species, often in deeper waters. These specialist Reef OS fishers typically land greater quantities of red emperor per day. However, the delineation between these two styles of operation is not necessarily clear. For instance, some vessels may spend the early portion of their trip targeting Reef OS species such as red emperor, before shifting their focus to live coral trout for the remainder of the trip.

As can be seen in Figure A.1, the majority of daily catch records report relatively low quantities of red emperor. This is despite filtering the data to include top 95% of fishers (Section 2.3) prior to the catch rate standardisation process, which took the total number of fishers in the data from 1245 to 359. Conversely, the higher daily catch records (likely associated with specialist Reef OS fishers) are quite few in number.

A consideration raised in project team discussion was whether the trend in annual standardised catch rates may be different for more specialist Reef OS fishers (higher daily catch records) as opposed to the whole dataset. It was decided that this was an important comparison to make in additional scenario runs. Accordingly, statistical separation of low and high catch rates was obtained from the breakpoint analysis (20 kg/day, Section 2.7.4), and additional scenarios were run where only daily catch records of $>$ 20 kg/day of red emperor were included. The catch rate trend in these scenarios was then compared to that of the overall data to determine whether divergent catch rate trends were present in the fishery. Ultimately, it was agreed that the base case should include all catch records in the catch rates analysis (not filtered by daily catch), as both the incidental and targeted harvest of red emperor represent important components of the fishery. Trends in the annual standardised catch rates did not differ notably between scenarios (Figure A.2), which worked to further justify the chosen base case. Overall magnitude of the annual standardised catch rates did differ however, and higher estimates of unfished spawning biomass were obtained for the 'upper' catch rates scenarios. This introduced a degree of variability to the overall suite of outcomes across scenarios.

Looking further than the assessment methodology, additional sources of catch rate uncertainty were intrinsic to the logbook catch records. The GBRMP rezoning and concurrent introduction of ITQs in 2004 were identified as significant drivers of both catch rate data shortages and catch rate uncertainty in previous assessments of other Reef OS species (Campbell et al. 2021; Fox et al. 2021). For the preceding assessments of saddletail and crimson snapper, the effects were noteworthy enough to warrant multiple scenarios where the time series was split at 2004 for catch rate standardisation. For this assessment, it was decided that this approach was not required for red emperor, due to sufficient annual sample sizes of logbook catch records and a subsequent lesser degree of catch rate uncertainty throughout the time series. While the same impacts were not seen in this assessment, the rezoning of the GBRMP and the introduction of ITQs represent fundamental changes for the fishery, and have likely influenced red emperor fishing practices in a similar manner to other Reef OS species. Hence, they remain an important consideration in the context of catch rate uncertainty. See Campbell et al. (2021) for more on these influences.

- **Recreational harvest and discard mortality.** A significant component of the harvest is taken by the recreational sector. The full extent of both retained and discarded fish within the recreational harvest is subject to considerable uncertainty. The specifics of the recreational harvest, however, were better informed in this assessment than for some previous species, with additional information available on the size frequency of fish below MLS (collected by ANSA) and rates of post-release survival (Brown et al. 2008). However, rates of post-release survival in Brown et al. (2008) did not capture potential rates of shark depredation upon release, and no data are available on pre-capture rates of shark depredation (between being hooked and landed). Coupled with concern regarding the overall magnitude of recreational harvest, these factors present a key source of uncertainty.

4.2 Unmodelled influences

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

- **Fishing power.** Fishing power over and above that incorporated through the current catch rate standardisation variables has not been explicitly modelled. Significant changes to fishing technology have occurred in recent years, including depth sounders with side-imaging and improved deep water performance, electric motors with GPS 'spot-lock' capability, readily available bathymetry maps and information sharing on social media platforms. For deeper-water species such as red emperor, these factors have the capacity to artificially inflate catch rates as, with this technology, fishers are able to find and fish isolated and/or virgin habitat far more easily. Recording and sharing fishing spots is easier with improved GPS technology, maritime chart apps for smartphones, and the advent of social media. Finally, acquiring the knowledge and skills required to find quality fishing ground has become considerably easier, with online courses available on how to find isolated habitat such as 'wonky holes'. The culmination of these factors means that the remaining red emperor stock is significantly easier to find and capture than in previous years. This presents a challenge for stock assessment, as without quantifiable data on fishing power, it will remain a factor unrelated to fish abundance that has the capacity to positively bias catch rates. Quantifiable measures of contemporary fishing power are required, and need to be included in the catch rate standardisation process of future assessments.

- **Climate change.** Red emperor are not solely reef-associated, and make use of habitat in a wide range of depths (from 1 m to at least 150 m, Newman et al. (2002)). Thus, they may not be considered as directly vulnerable to coral bleaching and other forms of climate-induced coral reef degradation as, for example, coral trout. Nevertheless climate impacts on the GBR are a significant concern. Loss of coral habitat and complexity has been found to result in reductions in fisheries productivity (Rogers et al. 2017), and since 2014 there have been two mass bleaching events, one severe tropical cyclone, and two crown-of-thorns outbreaks on the GBR (Australian Institute of Marine Science 2021). For example, it is possible that changes in environmental conditions could affect recruitment, growth, reproduction, or mortality rates of red emperor. While the precise mechanisms by which climate change may impact red emperor remain unclear, and any impacts to date remain unknown, this may be an additional influence to be modelled in future assessments. Due to a lack of available research on the impacts of climate change upon red emperor, it cannot be taken into account at this time.

- **Shark depredation.** Shark depredation usually refers to the situation where a shark partially or completely consumes an animal caught by fishing gear before it can be retrieved to the fishing vessel, however it can also refer to 'post-release predation' where released fish are predated before they recover (Mitchell et al. 2018). While there are numerous anecdotal reports of shark depredation in Queensland fisheries, there are no quantitative data available to use in the assessment at this stage. As a result, neither form of depredation has been explicitly modelled. This only represents a limitation of the model if there have been significant fluctuations in the shark population or shark behaviour over time, or if there have been changes to release patterns through time. Some shark depredation research is currently being undertaken that may provide data for use in future assessments.

- **GBRMP zoning and ITQ management shift.** The impact of the DAF fishery management arrangements and GBRMP rezoning in 2004 led to many changes in fishery dynamics, with resulting changes to fishing practice, areas fished and catch reporting. As discussed in Section 4.1, this had a number of quantifiable impacts upon the data in previous stock assessments of other Reef OS species (Campbell et al. 2021; Fox et al. 2021). Since these same impacts were not seen in the data for red emperor, GBRMP zoning and management changes of 2004 were not modelled explicitly. A better understanding of changes in fishing behaviour and targeting from the perspective of the fishery could better inform the catch rate analysis, other model inputs and interpretation of model outputs.

- **Regional variation in demography.** Regional variations in demography have been reported on the GBR for coral trout (Bergenius 2007; Carter et al. 2014; Carter et al. 2017) and redthroat emperor (Williams 2003; Williams et al. 2006). Preliminary studies indicate that there may be latitudinal differences in growth rates of red emperor in Queensland east coast waters. Greater variations in growth and size were observed between sexes, however (Hillcoat and Russ, unpublished data). Such variations in age-based demographics, if verified, may be modelled in future assessments.

4.3 Recommendations

4.3.1 Research and monitoring

Research and monitoring recommendations for red emperor focus on prioritising reduction in model uncertainty and the rectification of caveats. These recommendations are given below:

- **Length and age monitoring.** The biological age and length monitoring data are crucial and without them the assessment would not have been possible. Each additional year of samples from the fishery monitoring program under the same survey design parameters should reduce the overall stock status uncertainty. Higher quantities of sex-specific samples (where sex of the fish is identified and recorded) would be helpful for growth parameter estimation or, in the absence of this, the development of a sex-length key.
- **Fishing power.** Past studies on fishing power (O'Neill et al. 2007) should be updated to account for new technologies, resources and information sharing, and their impact on standardised catch rates for future assessments. Identifying a number of key variables as indicators of fishing power, and incorporating data collection on these variables through DAF's boat ramp survey program would provide an invaluable source of data for future assessments.
- **Fishery targeting behaviour.** A survey of commercial and recreational fishers may provide additional information on shifting targeting behaviour that could help interpret model outputs. Such a survey may also yield additional inputs or model terms that may help to separate targeted and incidental catch more reliably in the catch rate standardisation process. This could aid in reducing model uncertainty.

- **Mortality estimates.** Improved estimates and quantification of other sources of mortality such as shark depredation and post-release survival will reduce assessment uncertainty. A survey investigating rates of shark depredation would prove to be a valuable resource to better inform overall rates of mortality in future assessments of line-caught species in Queensland.
- **Reproduction.** Another key model input is the relationship between size or age of fecundity. Currently, no fecundity data relative to size or age of red emperor is available in Queensland east coast waters. Future research is needed to investigate relationships of fecundity by size and age. This may provide an invaluable source of data for future assessments.
- **Fishery independent surveys.** As mentioned in Campbell et al. (2021) and Fox et al. (2021) there is a lack of information on abundance of numerous Reef OS species (including red emperor) in green zones, following the rezoning in 2004. The Great Barrier Reef Foundation's 'Integrated Monitoring and Reporting' project intends to expand and/or initiate monitoring for many species, including *Lutjanus sebae*, across blue and green zones (Great Barrier Reef Foundation 2019). This may prove useful for estimating the magnitude of post-rezone abundance density divergence between zones, in addition to providing fishery independent metrics.
- **Stock structure.** Research on the biological stock structure of red emperor is limited. There is a need for updated information on stock structure and connectivity throughout Queensland waters.
- **Environmental influences.** Latitudinal differences in temperature and habitat are likely drivers of population dynamics. Furthermore, environmental influences are likely to differ regionally. Each region of the GBR differs in breadth of the continental shelf, mean water depth, sediment type, distance of coral reefs from shore, tidal flow, currents, and marine plant diversity and distribution (Wolanski 1994; Pitcher et al. 2007; Lough 1994; Kerrigan et al. 2010). Determining any potential impacts on population dynamics from variations in drivers such as these, requires future research.

4.3.2 Management

Currently red emperor is a secondary species in the reef line fishery, managed through an ITQ as part of the OS quota group. To provide options for management now that there is a red emperor biomass estimate, harvest control rules for B_{60} and B_{40} (a proxy for B_{MSY}) targets have been generated. For secondary species in a multi-species fishery, the Queensland harvest strategy policy requires a minimum objective of maximum sustainable yield (40% unfished spawning biomass is used as a proxy). To achieve this goal the assessment recommends a biological catch of 238 t, with a retained component of 236 t (Table 4.1), to bring the stock to 40% unfished biomass. This will allow a longer-term biological retained catch target of 170 t to be reached.

Table 4.1: Current and target indicators for Queensland east coast red emperor—40% biomass target

Indicator	Estimate
Biomass* (relative to unfished) at the start of 2022	58% (56% to 65%)
Target biomass (relative to unfished)	40%
Biomass (relative to unfished) at MSY⋆	25%
MSY⋆	185 t
Retained catch component of MSY⋆	183 t
Retained catch in 2021	108 t
Retained catch at 40% biomass target	170 t
RBC† for 2022 to achieve target	238 t
Retained component of RBC	236 t
Time to achieve target	> 20 years

* Biomass is defined to be spawning stock biomass.
⋆ MSY (maximum sustainable yield) is defined to be the maximum sustainable dead catch. That is, retained catch plus catch that dies following discarding.
† RBC (recommended biological catch) is defined to be the recommended biological dead catch. That is, retained catch plus catch that dies following discarding.

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

- **Uncertainty.** The base case scenario estimated the 2022 east coast red emperor stock to be 58% of unfished spawning biomass. Note that this estimate is across the full spatial extent of the stock, not just for the GBRMP zones that have been open to fishing since July 2004. While from 2005 onward (post-rezone) the analysis is drawing upon data from a smaller spatial area, in terms of abundance *density*, the relevant metric for the catch rate on any given fishing trip, the index remains a valid indicator of overall (stock-wide) relative abundance. The full range of biomass estimates from model outputs (scenarios range from 56 to 65%) should be considered when applying this assessment in any management process. No discount factor has been applied to the harvest control rule in this assessment.
- **Uncertainty discount factor.** The recommended discount factor for this assessment (Fisheries Queensland 2021) is 0.83 based on a qualitative tier assignment process and Ralston et al. (2011) (σ is 0.72, P^* (risk aversion) is 0.4) (Fisheries Queensland 2021). Under the 20:60:60 harvest control rule, applying this discount factor results in an adjusted 2022 RBC of 95.4 t with a retained catch component of 94.6 t. For the 20:40:40 harvest control rule, this results in an adjusted 2022 RBC of 197.5 t with a retained catch component of 195.8 t.
- **Harvest weights.** Accurate harvest weights (using calibrated scales) by species for each reef-line trip would significantly improve data for future assessments. The potential for this has been improved with the new reporting requirements introduced in September 2021.
- **Recreational management arrangements.** The recreational sector is a significant contributor to overall red emperor fishing mortality and this should be taken into account when considering any management changes. Of the last six financial years where a recreational fishing survey was conducted (e.g. years containing SRFS, RFish or NRIFS data), the average relative contributions of the recreational, commercial, charter and Indigenous sectors to total harvest were 56%, 32%, 8% and 4%, respectively.
- **Size limit.** The MLS for red emperor was set at 55 cm in 2004, based on their length at 50% maturity (54.8 cm (FL) McPherson et al. (1992b)). Coupled with their low rates of post-release

mortality (Brown et al. 2008), this has likely had a positive impact on the numbers of fish reaching maturity and hence, the stock status.

4.3.3 Assessment

Future assessments could be improved by:

- **Catch rates.** This is probably the single largest source of uncertainty and should be the primary focus of assessment improvement efforts. There are three main issues here: targeting, fishing power and impacts relating to the GBRMP rezoning and fishery management changes of 2004. The complexities surrounding targeting and the 2004 fishery changes were detailed in Section 4.1, whereas fishing power is discussed in 4.2. Additional data may enable these factors to be modelled in more detail. Understanding ongoing shifts in targeting behaviour is difficult to define for Reef OS species. Methods proposed in Campbell et al. (2021) for saddletail snapper and in Fox et al. (2021) for crimson snapper are also relevant for red emperor: to incorporate fisher knowledge directly into catch rate analysis. This should be done in tandem with the use of Vessel Monitoring System data to obtain the information necessary to disentangle the effects of abundance and non-abundance related impacts upon catch rates.
- **Fishing power.** Pending the future availability of data on fishing power, methodologies should be developed to incorporate these data into the catch rate standardisation process. This would give future assessments the potential to identify any possible catch rate increases due to improved technology, and further eliminate non-abundance related impacts on abundance indices.
- **Mortality estimates.** Pending the future availability of data on shark depredation (detailed in Section 4.2), these data should incorporated into estimates of total mortality; both post-release, and pre-capture.
- **Regional demography.** Finally, if more data become available on regionally varying demographics, these should be investigated, either for improved regional data set weighting or potentially for incorporating spatial structure in the population model itself.

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

4.4 Conclusions

This assessment was commissioned to establish the stock status of red emperor on Queensland's east coast and inform the Sustainable Fisheries Strategy. The base case model scenario suggested spawning biomass is currently around 58% of unfished levels. Some recommendations for management and a repeat assessment have been made.

References

ABS (2014). *Australian Historical Population Statistics*. Tech. rep. Catalogue no. 3105.0.65.001. Canberra: Australian Bureau of Statistics. URL: http://www.abs.gov.au/ausstats/abs@.nsf/cat/3105.0.65.001.

Allen, Gerald R (1985). "Snappers of the world: an annotated and illustrated catalogue of lutjanid species known to date". In: *FAO fisheries synopsis*. Vol. 6. 125. Rome, Italy: Food and Agriculture Organization of the United Nations.

Australian Institute of Marine Science (2021). *Long-term Reef Monitoring Program - Annual Summary Report on coral reef condition for 2020/21*. Tech. rep. Australian Institute of Marine Science, Australian Government.

Bergenius, Mikaela 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, Ian W., Wayne D. Sumpton, Mark F. McLennan, David J. Welch, John M. Kirkwood, Adam R. Butcher, Amos Mapleston, David G. Mayer, Gavin A. Begg, Matthew D. Campbell, Ian Halliday, and W. Sawynok (July 2008). *National Strategy for the Survival of Released Line-caught Fish: Tropical Reef Species. Final report of FRDC project 2003/019.* Tech. rep. Brisbane: Queensland Department of Primary Industries and Fisheries. URL: http://frdc.com.au/research/Documents/Final_reports/2003-019-DLD.pdf.

Campbell, Alexander B., A. R. Fox, K. B. Hillcoat, and L. Sumpter (2021). *Stock assessment of Queensland east coast saddletail snapper* (Lutjanus malabaricus)*, Australia*. Tech. rep. Brisbane, Australia: Department of Agriculture and Fisheries. URL: https://era.daf.qld.gov.au/id/eprint/8225/.

Carpenter, KE (2001). "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)". In: ed. by K.E. Carpenter and Niem V. Rome: FAO, p. 2892.

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, Alex B., Campbell R. Davies, Bruce D. Mapstone, Garry R. Russ, Andrew J. Tobin, and Ashley 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.

Commonwealth of Australia (2017). *Assessment of the Queensland Coral Reef Fin Fish Fishery 2017, Commonwealth of Australia 2017*. Tech. rep. URL: https://www.environment.gov.au/system/files/pages/c8f3f7b7-fd3b-4cac-b4c9-c26cd0afd2d5/files/coral-reef-fin-fish-assessment-2017.pdf.

Department of Agriculture and Fisheries (2017). *Queensland Sustainable Fisheries Strategy 2017-2027*. Vol. 2018. 11 September.

Fisheries Queensland (2017). *Fisheries Queensland Boat Ramp Survey Sampling Protocol: Section 2*. Tech. rep. Brisbane, Australia.

— (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. Sustainable Fisheries Strategy 2017–2027*. Tech. rep. Brisbane, Australia: Department of Employment, Economic Development and Innovation. URL: https://www.environment.

gov.au/system/files/consultations/b6a43fdb-0fbf-47dc-92c0-7bb1fd7cceb1/files/line-fishery-reef-wto-submission-july-2020.pdf.

Fisheries Queensland (2021). *Draft Harvest Strategy Policy*. Tech. rep. Brisbane, Australia: Department of Agriculture and Fisheries. URL: https://daf.engagementhub.com.au/draft-harveststrategy-policy.

Fisheries Queensland (In Prep.) (2012). *DRAFT Fisheries Long Term Monitoring Program Sampling Protocol - Coral Reef Fin Fish: (2005-2007) Section 2. Department of Agriculture, Fisheries and Forestry*. Tech. rep. Brisbane, Australia.

Fisheries Research and Development Corporation (2021a). *How are the Status of Australian Fish Stocks Reports done?* URL: https://www.fish.gov.au/about/how-are-the-status-of-australian-fish-stock-reports-done (visited on 11/10/2021).

— (2021b). *Red Emperor (2020)*. URL: https://www.fish.gov.au/report/354-Red-Emperor-2020 (visited on 11/25/2021).

Fox, A.R., A.B. Campbell, L.I. Sumpter, and K.B. Hillcoat (2021). *Stock assessment of Queensland east coast crimson snapper* (Lutjanus erythropterus)*, Australia*. Tech. rep. Brisbane, Australia: Department of Agriculture and Fisheries. URL: https://era.daf.qld.gov.au/id/eprint/8438/.

Francis, R. I. C. Chris (2011). "Data weighting in statistical fisheries stock assessment models". In: *Canadian Journal of Fisheries and Aquatic Sciences* 68.6, pp. 1124–1138. URL: http://dx.doi.org/10.1139/f2011-025.

Great Barrier Reef Foundation (2019). *Reef Trust Partnership: Annual Work Plan 2019–2020*. URL: https://www.barrierreef.org/uploads/RTP_Annual%5C%20Work%5C%20Plan%5C%202019-2020_FINAL.pdf.

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, Gary W. and Jeremy M. Lyle (2003). *The National Recreational and Indigenous Fishing Survey*. Tech. rep. Canberra: Australian Government Department of Agriculture, Fisheries and Forestry. URL: http://eprints.utas.edu.au/2526/1/Henry_Lyle_Nationalsurvey.pdf (visited on 11/10/2016).

Herwerden, Lynne van, William J Aspden, Stephen J Newman, Graham G Pegg, Leica Briskey, and William Sinclair (2009). "A comparison of the population genetics of Lethrinus miniatus and Lutjanus sebae from the east and west coasts of Australia: evidence for panmixia and isolation". In: *Fisheries Research* 100.2, pp. 148–155.

Higgs, Jim, Len Olyott, and Kirrily McInnes (2007). *Experimental Results from the Third Statewide Recreational Fishing Information System Diary Program (2002)*. Tech. rep. Brisbane: Queensland Department of Primary Industries and Fisheries.

Kerrigan, BA, Daniel Breen, Glenn De'ath, Jon Day, Leanne Fernandes, Renae Tobin, and Kirstin Dobbs (2010). "Classifying the biodiversity of the Great Barrier Reef World Heritage Area for the classification phase of the representative areas program". In.

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

Lee, Hui-Hua, Mark N. Maunder, Kevin R. Piner, and Richard D. Methot (Aug. 2012). "Can steepness of the stock–recruitment relationship be estimated in fishery stock assessment models?" In: *Fisheries Research* 125–126, pp. 254–261. URL: http://www.sciencedirect.com/science/article/pii/S0165783612001099 (visited on 04/28/2016).

Lough, JM (1994). "Climate variation and El Niño-Southern Oscillation events on the Great Barrier reef: 1958 to 1987". In: *Coral Reefs* 13.3, pp. 181–185.

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

McLeay, Lachlan J, Geoffrey Keith Jones, and Timothy Mark Ward (2002). *National strategy for the survival of released line-caught fish: a review of research and fishery information*. 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, Richard D., Chantel R. Wetzel, Ian G. Taylor, Kathryn L. Doering, and Kelli F. Johnson (2021). *Stock Synthesis User Manual Version 3.30.17*. Tech. rep. Seattle, WA: National Oceanic and Atmospheric Administration, U.S. Dept. Commer.

Mitchell, JD, DL McLean, SP Collin, and TJ Langlois (2018). "Shark depredation in commercial and recreational fisheries". In: *Reviews in Fish Biology and Fisheries* 28.4, pp. 715–748.

Newman, S. J., C. L. Skepper, and C. B. Wakefield (2010). "Age estimation and otolith characteristics of an unusually old, red emperor snapper (Lutjanus sebae) captured off the Kimberley coast of north-western Australia". In: *Journal of Applied Ichthyology* 26.1, pp. 120–122. eprint: `https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1439-0426.2009.01362.x`. URL: `https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1439-0426.2009.01362.x`.

Newman, S.J. and I.J. Dunk (2002). "Growth, Age Validation, Mortality, and other Population Characteristics of the Red Emperor Snapper, Lutjanus sebae (Cuvier, 1828), off the Kimberley Coast of North-Western Australia". In: *Estuarine, Coastal and Shelf Science* 55.1, pp. 67–80. URL: `https://www.sciencedirect.com/science/article/pii/S027277140190887X`.

Newman, Stephen J., Michael Cappo, and David McB. Williams (2000a). "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, pp. 1–14. URL: `http://dx.doi.org/10.1016/S0165-7836(00)00115-6`.

— (2000b). "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, pp. 1–14.

Northrop, Amanada, Michael F. O'Neill, George M. Leigh, and Chad Lunow (2018). *Monitoring requirements for common coral trout*. Tech. rep. Brisbane: Queensland Department of Agriculture and Fisheries.

O'Neill, Michael F. and George M. Leigh (2007). "Fishing power increases continue in Queensland's east coast trawl fishery, Australia". In: *Fisheries Research* 85.1–2, pp. 84–92.

Pitcher, Roland, Peter Doherty, Peter Arnold, John Hooper, Neil Gribble, Susan Chalmers, Rob Coles, Barry Ehrke, Norm Good, and Sarah Kistle (2007). "Seabed biodiversity on the continental shelf of the Great Barrier Reef World Heritage Area". In.

Punt, André E, Anthony DM Smith, David C Smith, Geoffrey N Tuck, and Neil L Klaer (2014). "Selecting relative abundance proxies for B MSY and B MEY". In: *ICES Journal of Marine Science* 71.3, pp. 469–483.

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

Ralston, Stephen, André E Punt, Owen S Hamel, John D DeVore, and Ramon J Conser (2011). "A meta-analytic approach to quantifying scientific uncertainty in stock assessments." In: *Fishery Bulletin* 109.2.

Rogers, Alice, Julia L. Blanchard, and Peter J. Mumby (2017). “Fisheries productivity under progressive coral reef degradation”. In: *Journal of Applied Ecology* 55.3, pp. 1041–1049.

Sumpton, Wayne, David Mayer, Ian Brown, Bill Sawynok, Mark McLennan, Adam Butcher, and John Kirkwood (2008). “Investigation of movement and factors influencing post-release survival of line-caught coral reef fish using recreational tag-recapture data”. In: *Fisheries Research* 92.2, pp. 189–195. URL: https://www.sciencedirect.com/science/article/pii/S0165783608000398.

Taylor, Stephen, James Webley, and Kirrily McInnes (2012). *2010 Statewide Recreational Fishing Survey*. Tech. rep. Brisbane: Department of Agriculture, Fisheries and Forestry. URL: http://era.daf.qld.gov.au/id/eprint/6926/2/2010%20SWRFS-Final%20V4.pdf (visited on 12/19/2019).

Teixeira, Daniella, Rachel Janes, and James Webley (2021). *2019/20 Statewide Recreational Fishing Survey Key Results*. Project Report. Brisbane, Australia. URL: http://era.daf.qld.gov.au/id/eprint/7879/.

Then, Amy Y., John M. Hoenig, Norman G. Hall, and David 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, James A. C., Kirrily McInnes, Daniella Teixeira, Ashley Lawson, and Ross Quinn (2015). *Statewide Recreational Fishing Survey 2013–14*. Tech. rep. Brisbane: Department of Agriculture and Fisheries. URL: http://era.daf.qld.gov.au/id/eprint/6513/1/2013-14SRFS%20Report.pdf (visited on 12/19/2019).

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

Williams, AJ, CR Davies, and BD 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, David McB. and Garry R. Russ (July 1994). *Review of Data on Fishes of Commercial and Recreational Fishing Interest in the Great Barrier Reef*. Tech. rep. Townsville: Great Barrier Reef Marine Park Authority, Research Publication No. 33, p. 103. URL: http://www.gbrmpa.gov.au/__data/assets/pdf_file/0018/5535/Review-of-Data-on-Fishes-of-in-the-GBR-vol1-1994.pdf.

Wolanski, Eric. (1994). *Physical oceanographic processes of the Great Barrier Reef / Eric Wolanski ; with an introduction by G.L. Pickard*. English. CRC Press Boca Raton, 194 p. :

Zeileis, Achim, Friedrich Leisch, Kurt Hornik, Christian Kleiber, Bruce Hansen, and Edgar C. Merkle (2019). *Package 'strucchange'*. URL: https://cran.r-project.org/web/packages/strucchange/strucchange.pdf (visited on 11/26/2021).

Appendix A Model inputs

A.1 Abundance indices

In Scenarios 5–8, 13–16 and 21–24, annual standardised catch rates were calculated on a subset of the daily catch records where daily catch of red emperor exceeded 20 kg/day. The rate of 20 kg/day was decided as an appropriate split after completing a 'breakpoint' analysis using the R function *"breakpoints"*, from the *"strucchange"* package (Zeileis et al. 2019). Figure A.1 shows the number of daily catch records within each category of daily catch (kg/day). The '20–25 kg' category indicated the point at which the data were split to define the 'upper' and 'all' scenarios for the catch rates analysis. Figure A.2 compares the trend in annual standardised catch rates between scenarios including all daily catch records ("All"), and scenarios only including records where > 20 kg/day of red emperor was reported ("Upper").

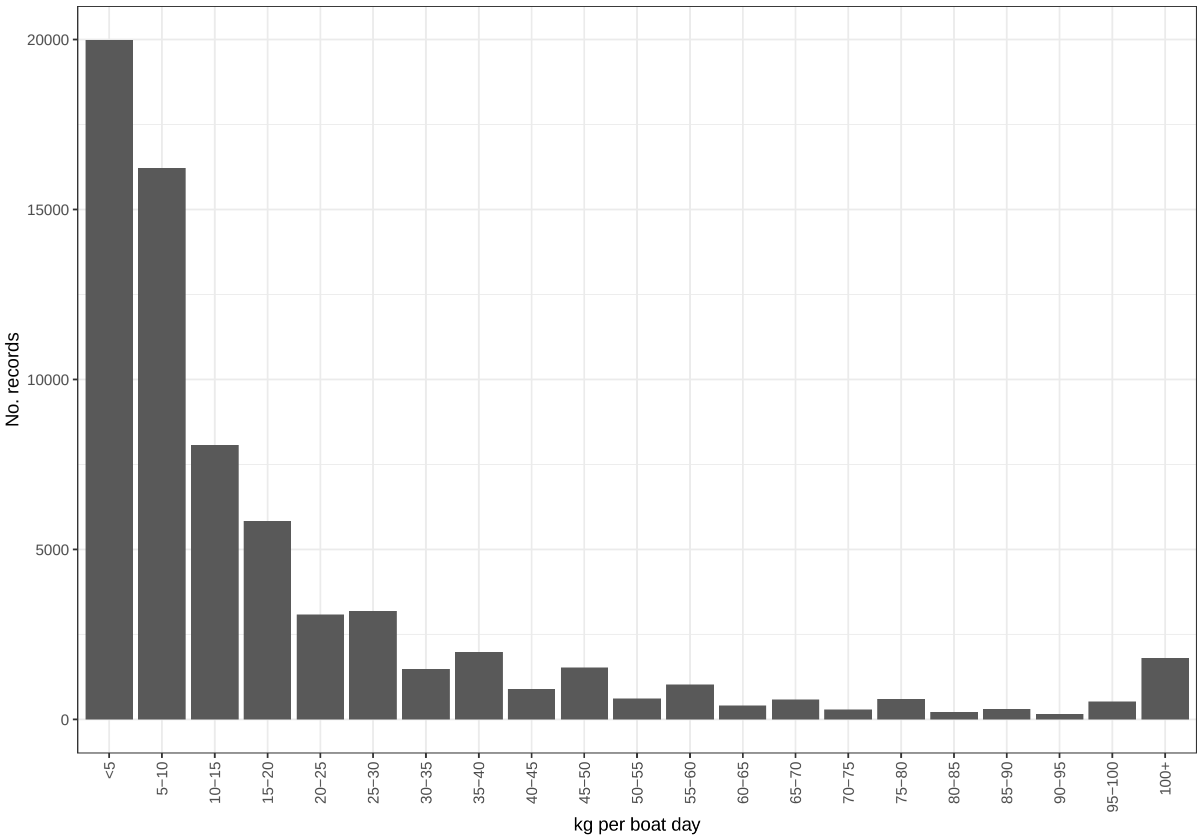

Figure A.1: Number of catch records by kilograms per boat day for red emperor, categorised to 5 kg/day bins between 1994 and 2021

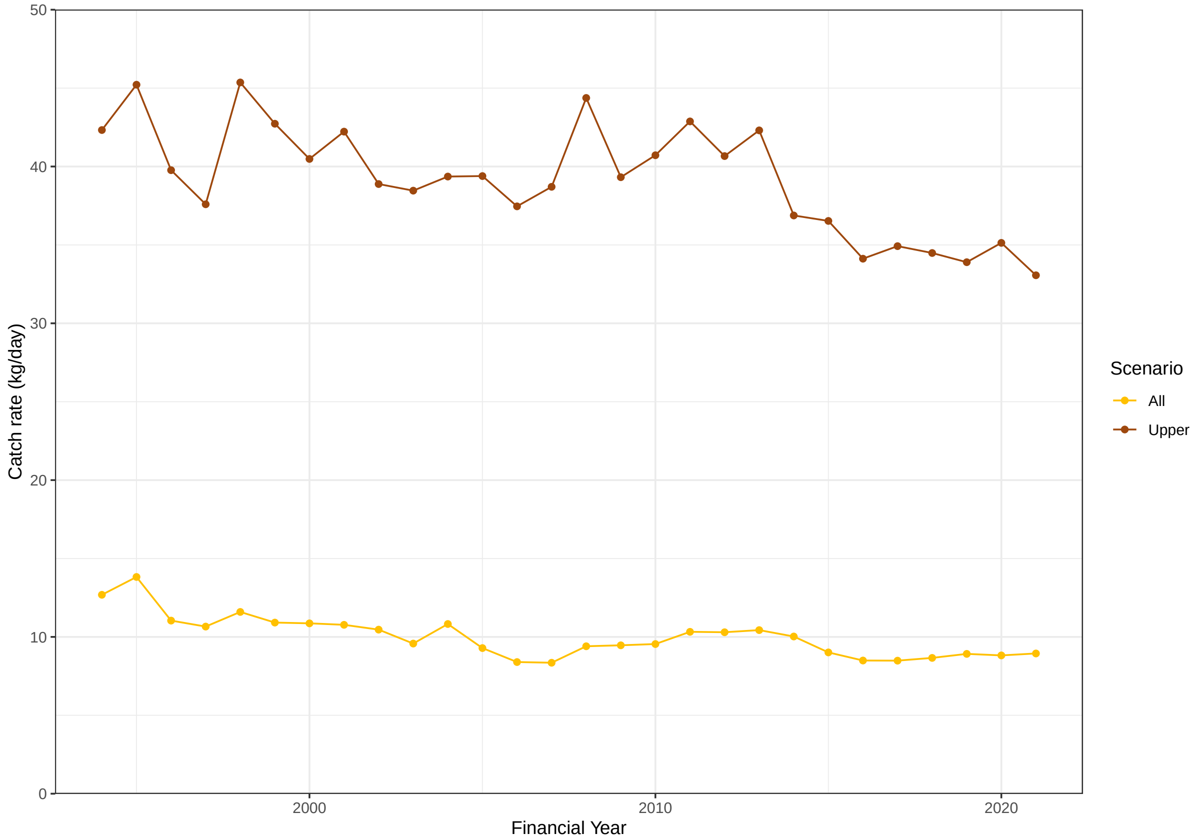

Figure A.2: Annual standardised catch rates by catch rates scenarios in which "All" includes the whole data set of daily catch records and "Upper" only includes daily catch records of above 20 kg/day—both scenarios show annual standardised catch rates for commercial line caught red emperor between the years of 1994 and 2021

A.2 Age and length sample sizes

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

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

Year	Recreational length	Commercial length	Commercial age
2016	66		
2017	65		
2018	133	1428	536
2019	116	1380	482
2020	108	952	585
2021	113	1146	621

A.3 Conditional age-at-length

Conditional age-at-length composition data were input to the population model (Figure A.3).

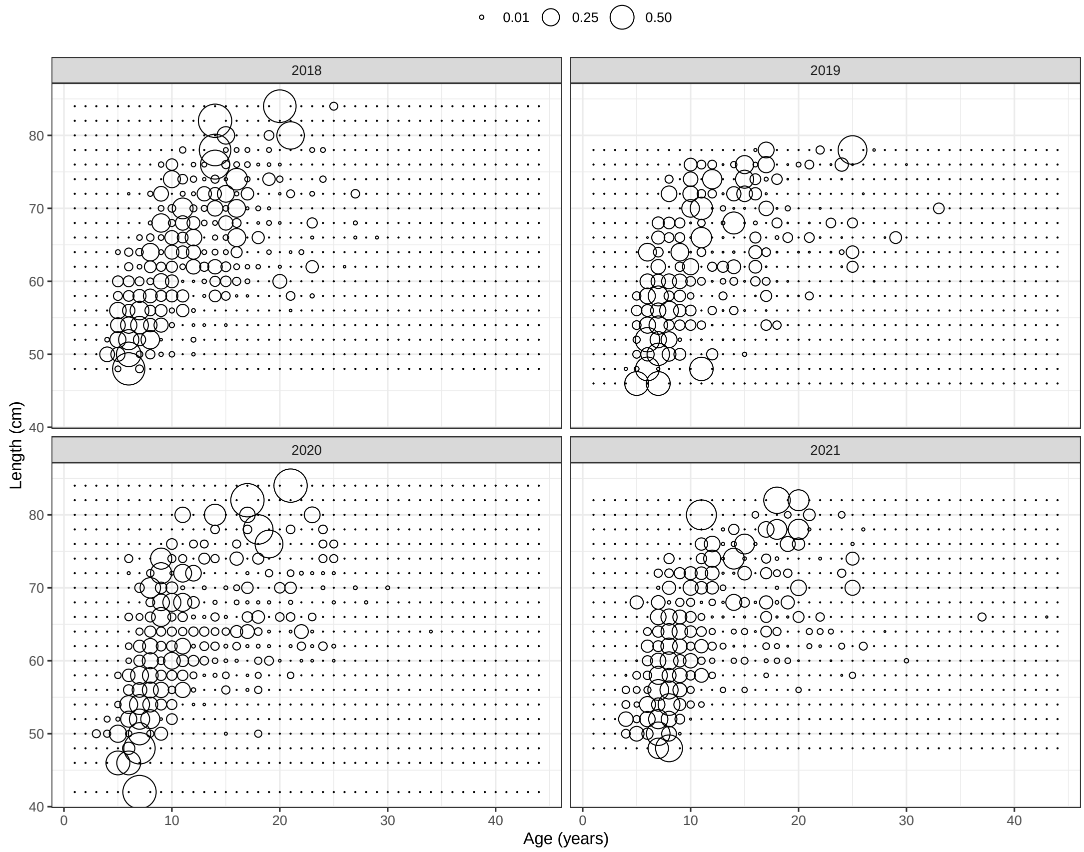

Figure A.3: Conditional age-at-length compositions of red emperor between 2018 and 2021—circle size is proportional to relative sample size in each bin across rows (i.e. for a given length bin)

A.4 Biological data

A.4.1 Fecundity and maturity

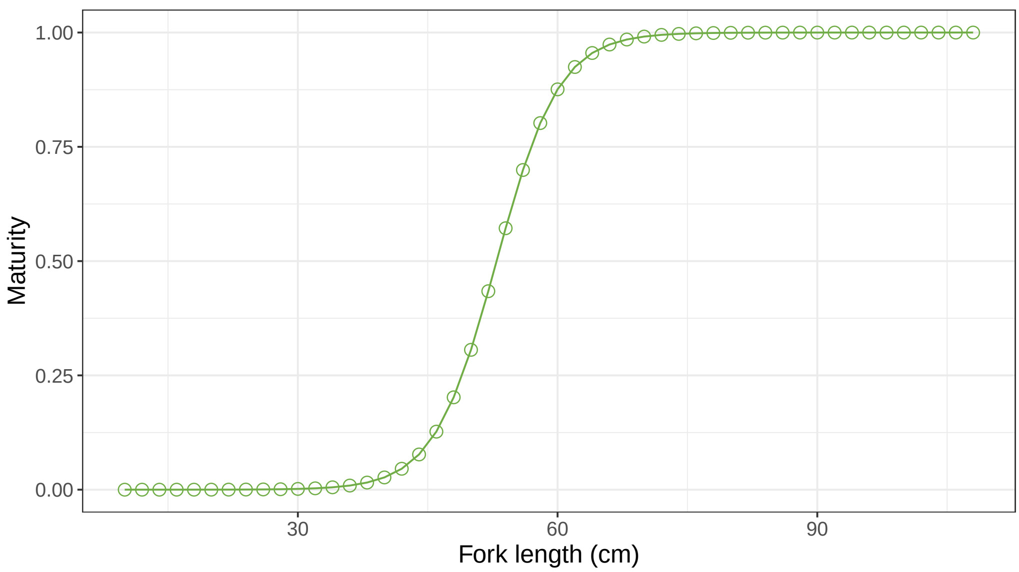

Figure A.4: Maturity at length for red emperor

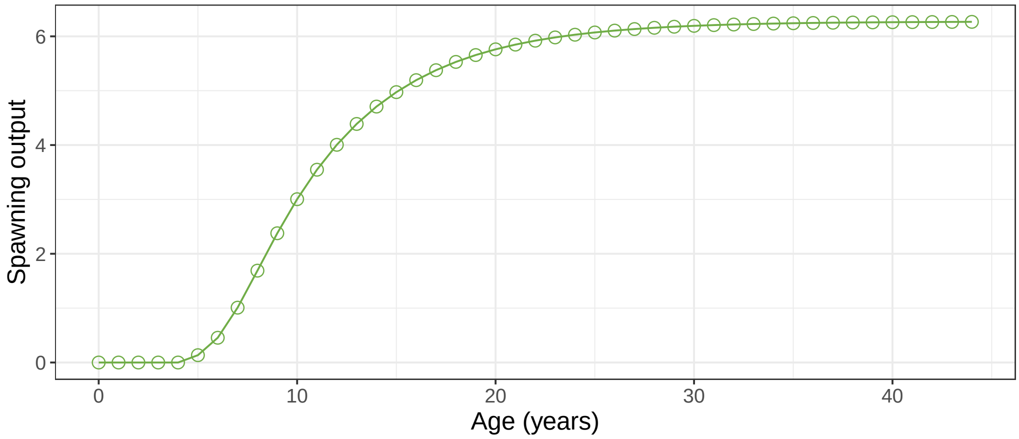

Figure A.5: Spawning output (maturity multiplied by fecundity) at age for red emperor

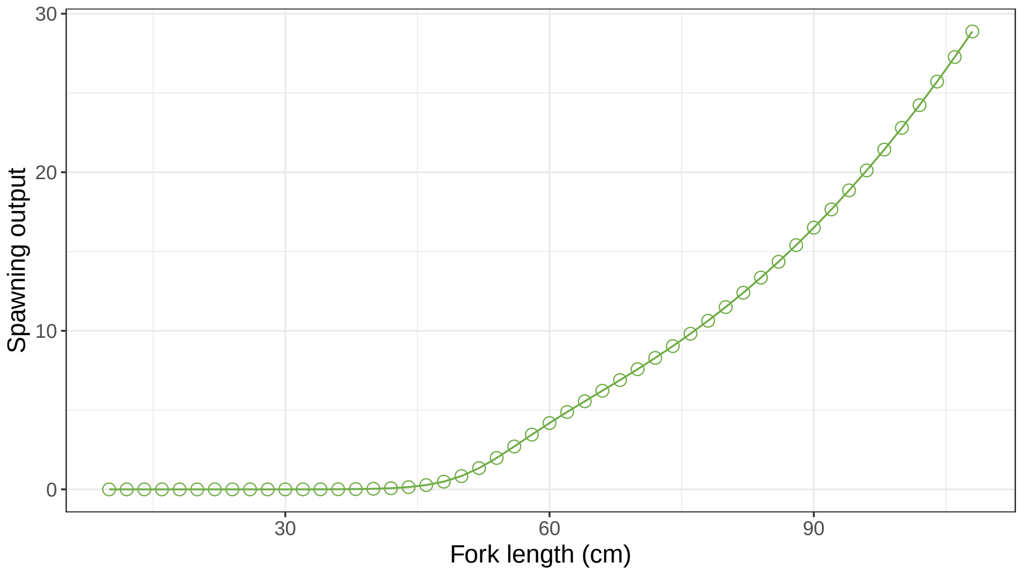

Figure A.6: Spawning output (maturity multiplied by fecundity) at length for red emperor

A.4.2 Weight and length

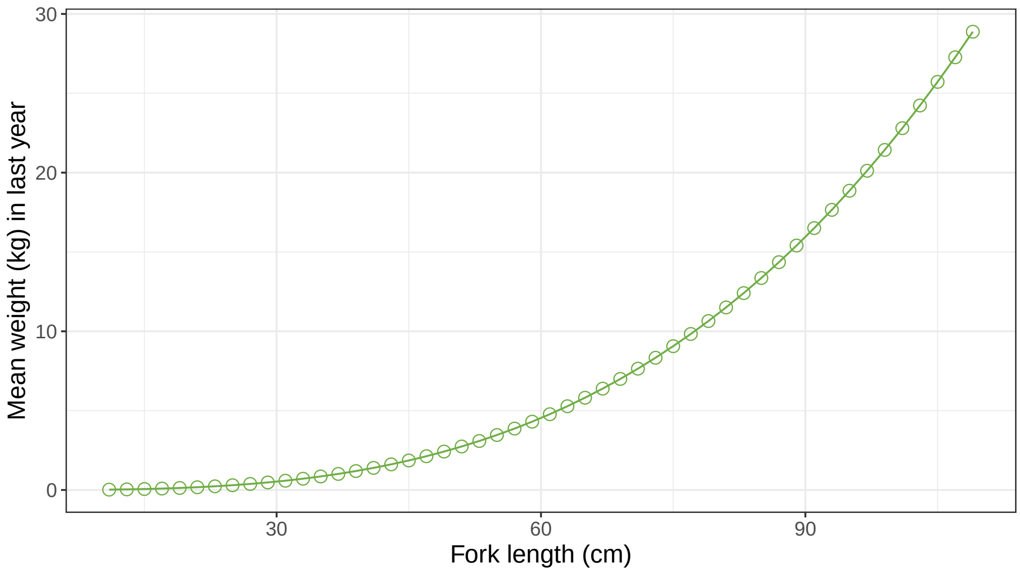

Figure A.7: Weight-length relationship for red emperor

Appendix B Model outputs

B.1 Parameter estimates

Model parameters contained in Table B.1 were estimated by Stock Synthesis, and parameter labels follow a Stock Synthesis specific naming convention. Note that some model parameters included in the population model were fixed at certain values rather than estimated. Similarly, some male equivalents of female-specific parameters given below were assumed the same as the female estimates, with offsets fixed at zero. Any parameters that were fixed (not estimated) are not listed below. Male-specific growth parameter estimates are model-estimated offsets from the equivalent female parameters, rather than absolute values. These are labelled with asterisks, and the resulting absolute values are denoted in the footnote of Table B.2. For a detailed explanation of all model parameters, see Section 2.7.

Table B.1: Stock Synthesis parameter label explanation for red emperor

Stock Synthesis Parameter Label	Explanation
NatM_Fem	Natural mortality (female)
L_at_Amin_Fem	Length at age 1 (female)
L_at_Amax_Fem	Length at age 43 (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 43 (female)
L_at_Amin_Mal	Length at age 1 (male), given as parameter offset
L_at_Amax_Mal	Length at age 43 (male), given as parameter offset
VonBert_K_Mal	von Bertalanffy growth parameter (male)
SR_LN(R0)	Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1953)
Size_inflection_Commercial	Commercial selectivity inflection (cm)
Size_95%width_Commercial	Commercial selectivity width (cm)
Size_inflection_Recreational	Recreational selectivity inflection (cm)
Size_95%width_Recreational	Recreational selectivity width (cm)

Table B.2: Stock Synthesis parameter estimates for the base population model for red emperor

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
NatM_Fem	0.1602	1	0.01	0.5	0.160	0.006
L_at_Amin_Fem	15.584	3	1	50	15.500	0.420
L_at_Amax_Fem	67.065	3	40	90	65.932	0.510
VonBert_K_Fem	0.187	3	0.1	0.4	0.219	0.005
CV_young_Fem	0.090	5	0.05	0.3	0.223	0.006
CV_old_Fem	0.085	5	0.01	0.2	0.091	0.006
L_at_Amin_Mal	-0.135*	3	-1	1	-0.065	0.050
L_at_Amax_Mal	0.164*	3	-1	1	0.164	0.013
VonBert_K_Mal	-0.054*	3	-1	1	-0.034	0.037
SR_LN(R0)	13.35	2	3	15	13.00	0.162
Size_inflection_Commercial	52.526	4	30	60	51.865	0.431
Size_95%width_Commercial	3.258	4	1	20	2.919	0.600
Size_inflection_Recreational	23.631	4	20	60	23.500	0.276
Size_95%width_Recreational	2.507	4	0.01	10	3.033	0.280

Note: *Absolute values for male growth parameters: L_at_Amin_Mal = 13.615; L_at_Amax_Mal = 79.016; VonBert_K_Mal = 0.177

In addition, recruitment deviations were estimated between 1980 and 2021.

B.2 Goodness of fit

B.2.1 Abundance indices

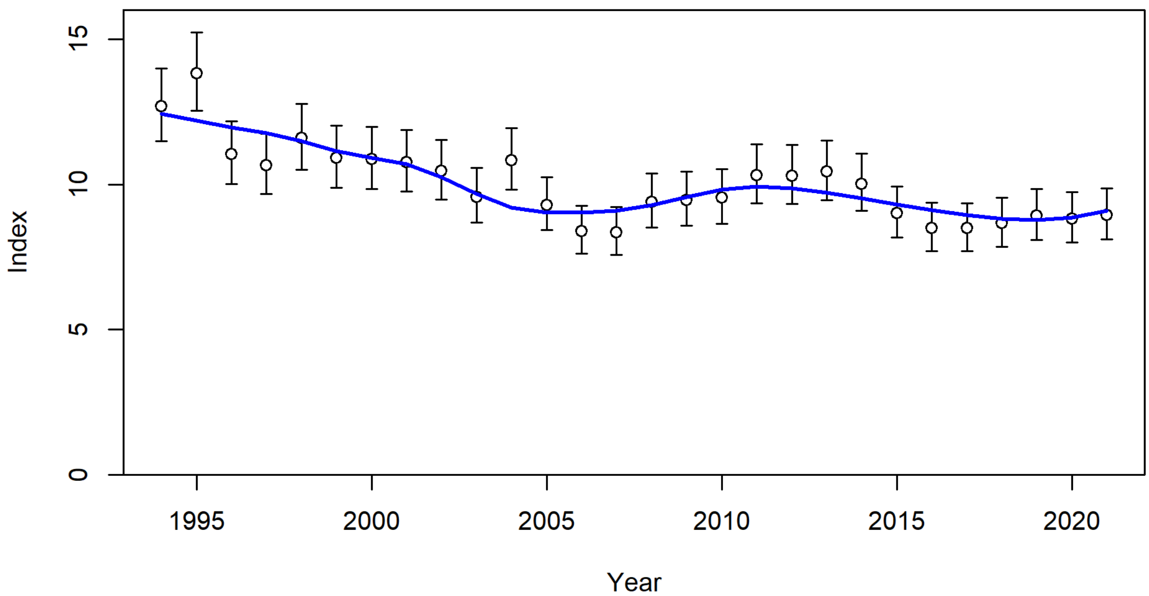

Figure B.1: Model predictions (blue line) to commercial catch rates for red emperor

B.2.2 Length compositions

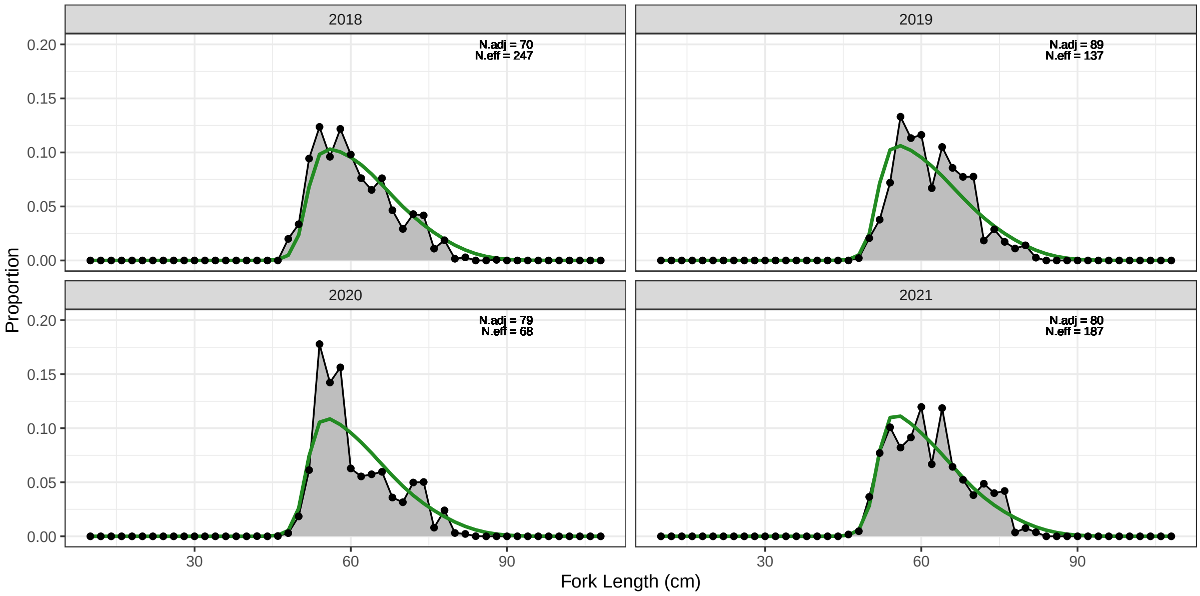

Figure B.2: Length structure for the commercial fleet for red emperor

'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

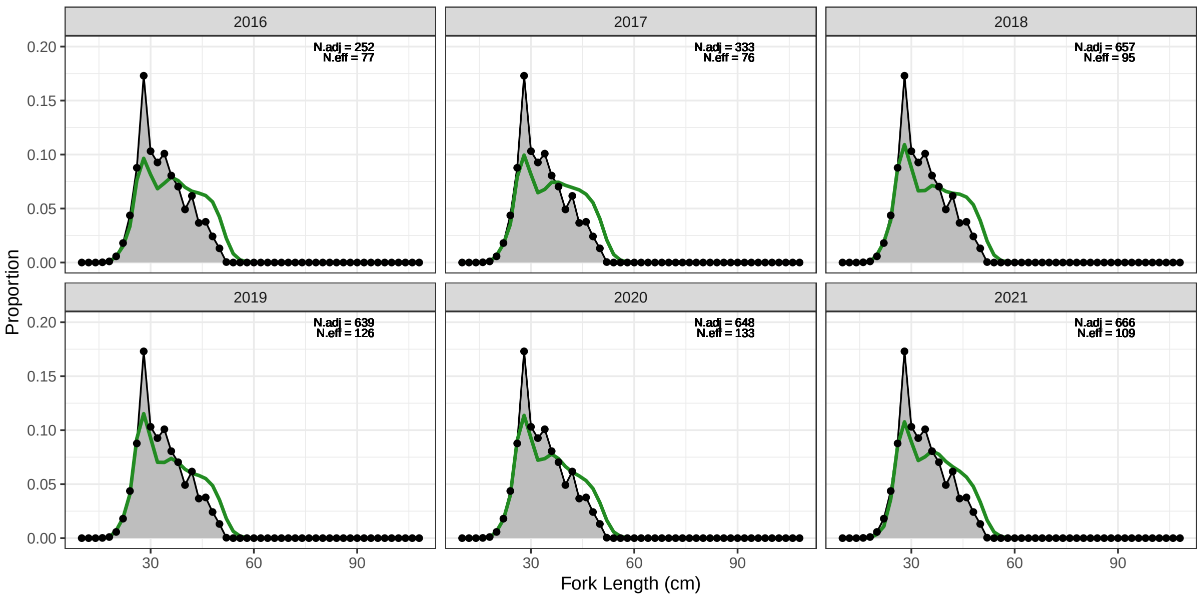

Figure B.3: Length structure for the recreational fleet for discarded red emperor

'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

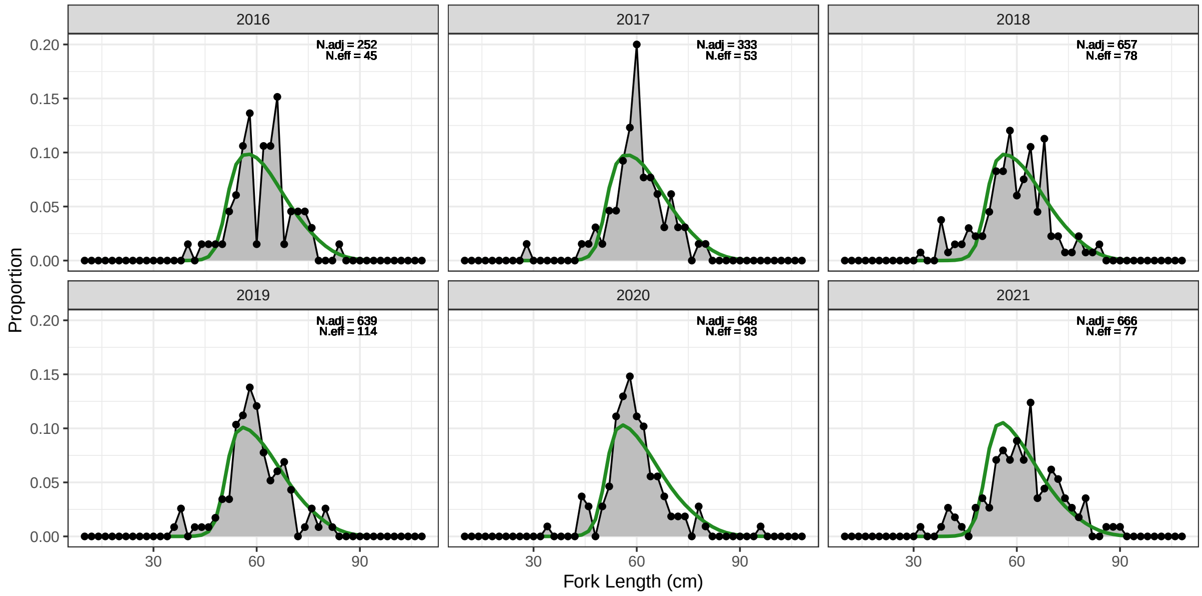

Figure B.4: Length structure for the recreational fleet for retained red emperor

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

B.2.3 Conditional age-at-length compositions

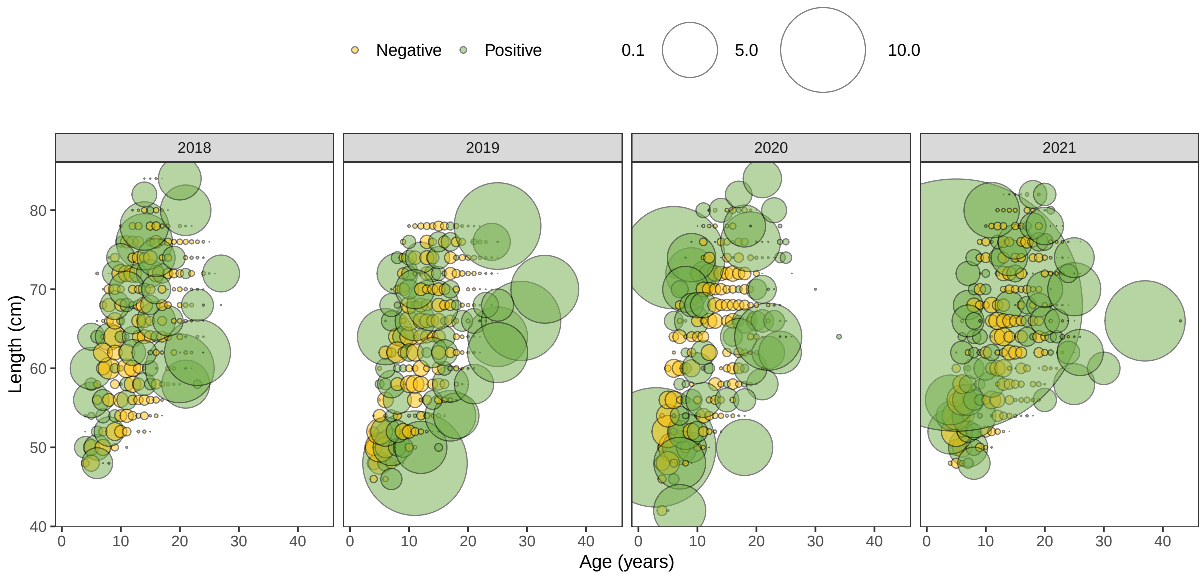

Figure B.5: Pearson residuals for age-at-length compositions for the commercial fleet for red emperor—circle size represents the magnitude of the Pearson residual

B.2.4 Discard fraction

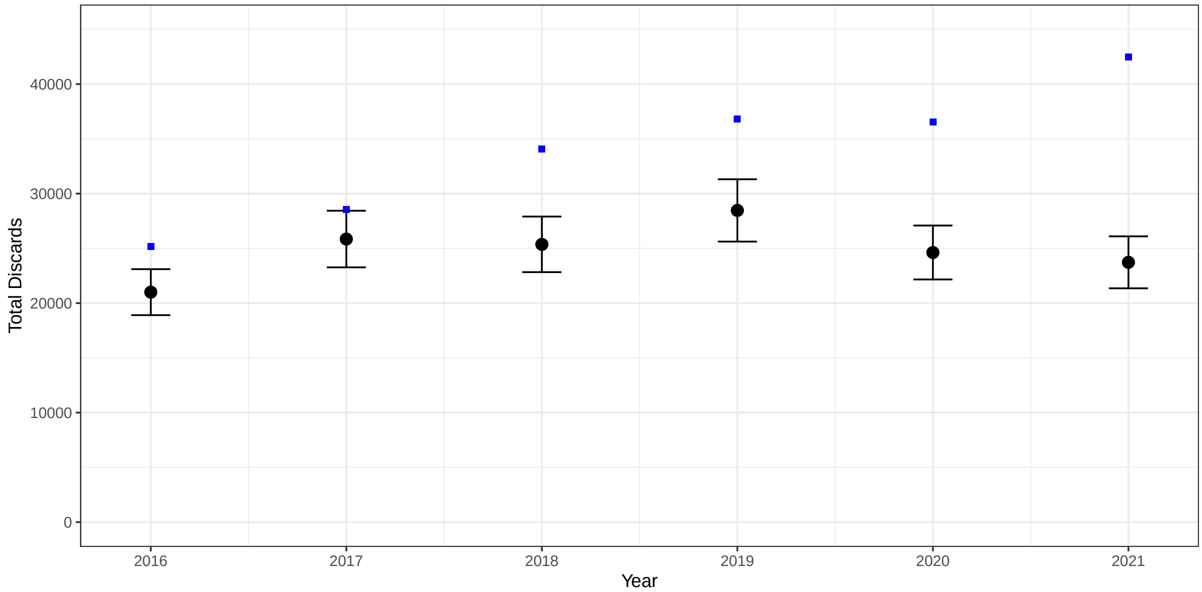

Figure B.6: Model fit to total discards for recreational-charter-Indigenous fleet—circles and error bars represent input data and their associated coefficients of variation and blue points represent the model predictions

B.3 Other outputs

B.3.1 Phase plot

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

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

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

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

A phase plot assists in defining SAFS stock status relative to limit reference points for biomass and fishing mortality (FRDC 2021a). The plot tracks the annual stock biomass ratio relative to the unfished level, and fishing mortality relative to the target reference point for the biomass limit (Figure B.1).

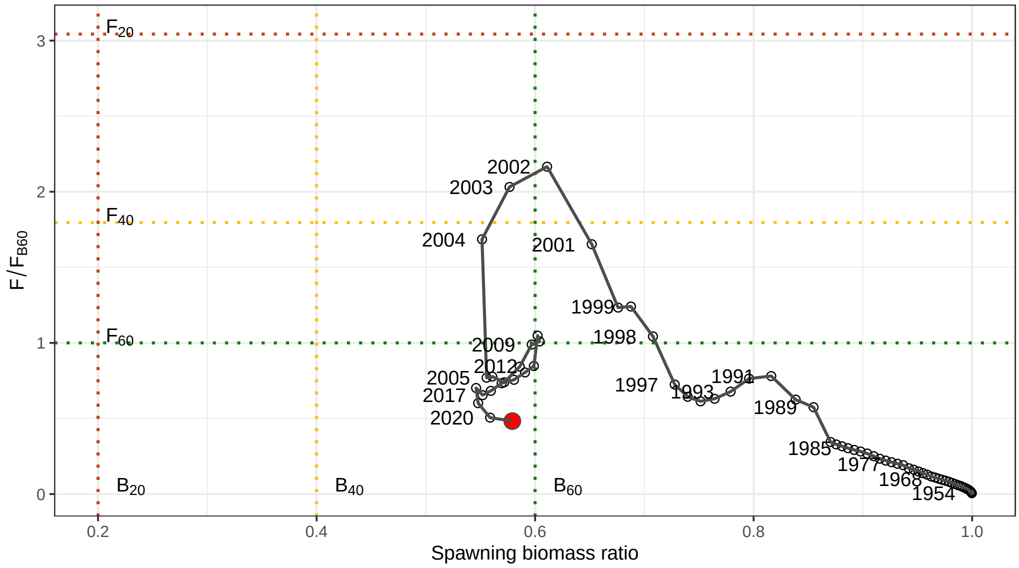

Figure B.7: Phase plot for red emperor

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

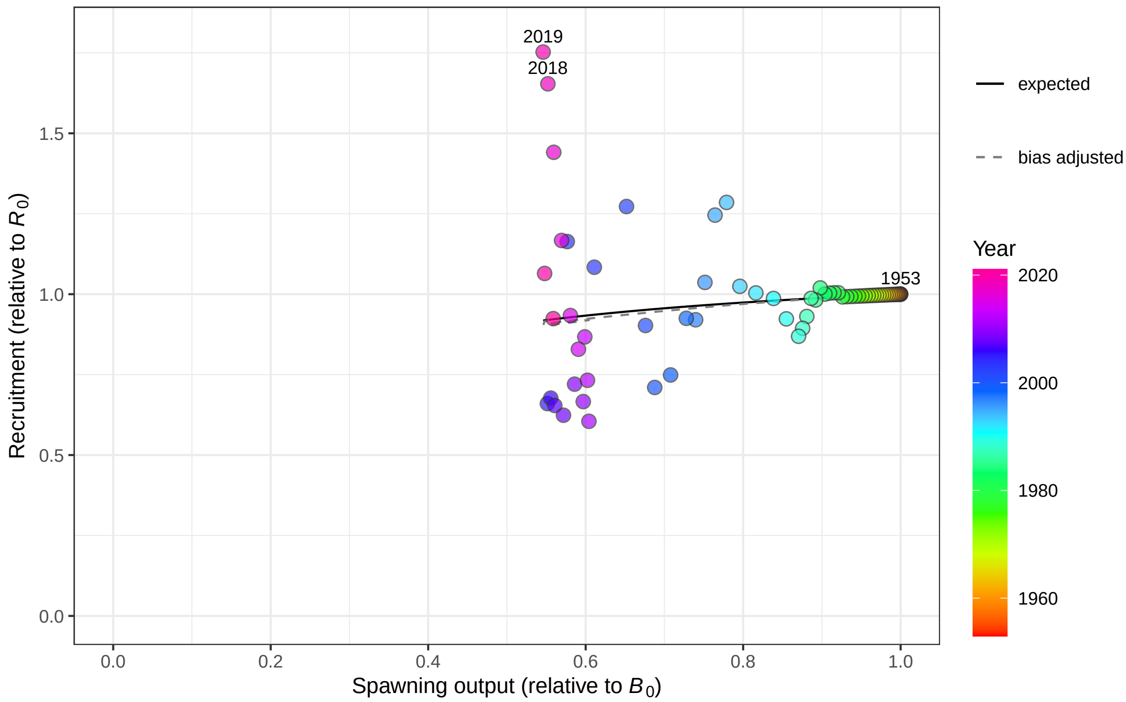

Figure B.8: Stock-recruit curve for red emperor

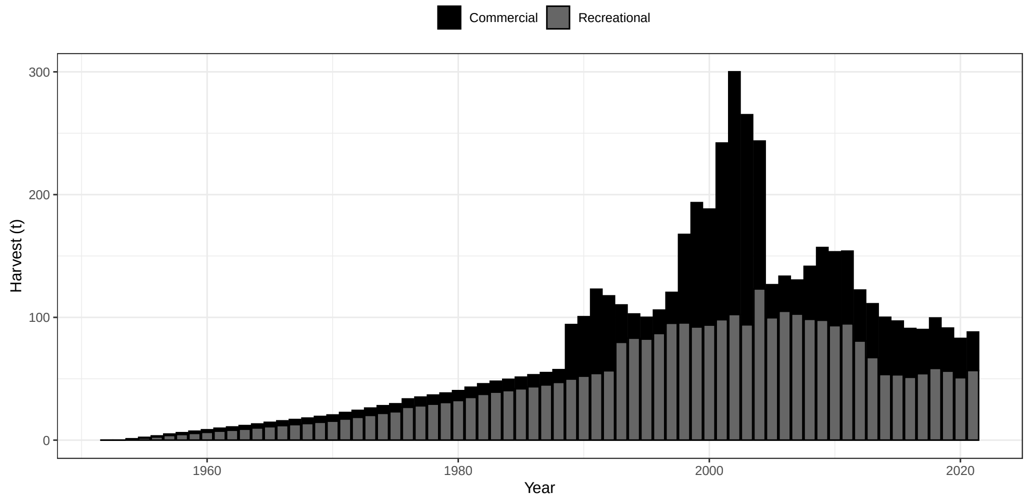

Figure B.9: Modelled harvest of red emperor

Appendix C Sensitivity tests: model outputs

Parameter estimates

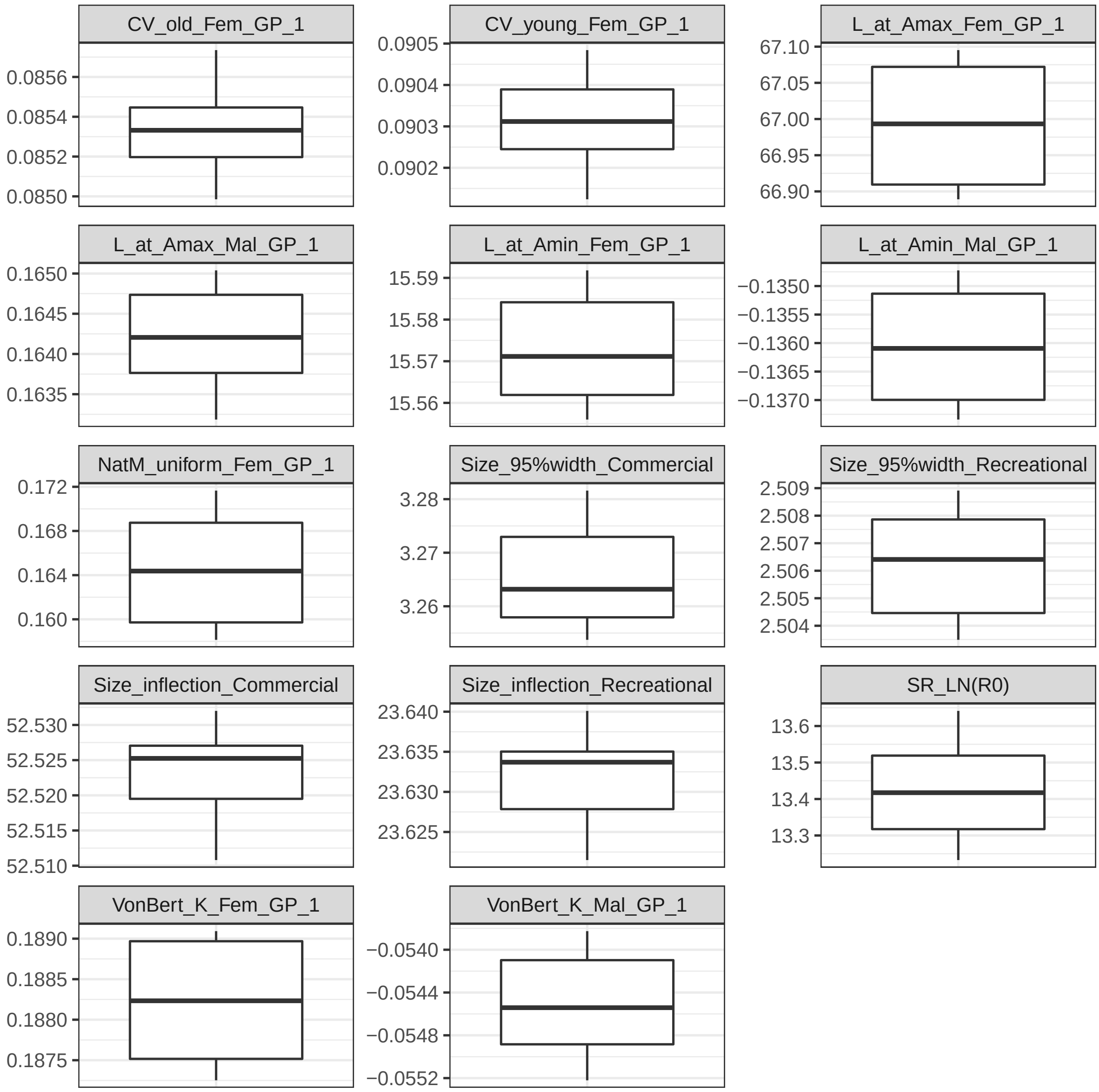

Figure C.1: Visualisation of parameter estimates for all 24 sensitivity tests

Scenario 2

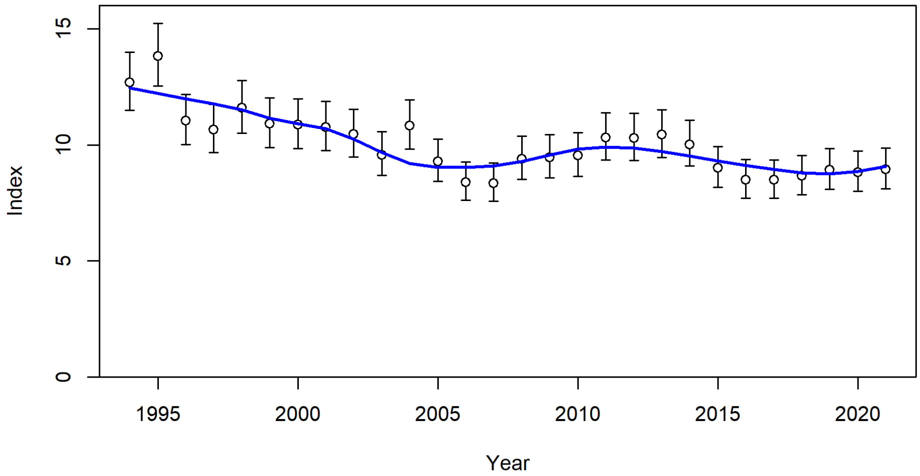

Figure C.2: Scenario 2 model predictions (blue line) to commercial catch rates for red emperor prior to rezoning

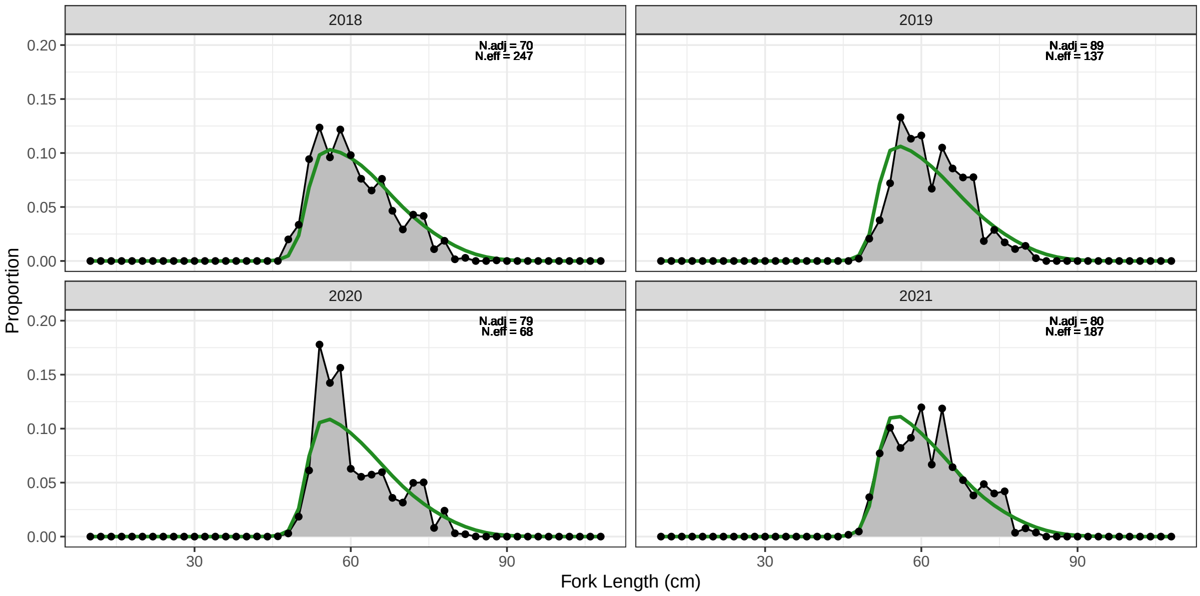

Figure C.3: Scenario 2 length structure for the commercial fleet for red emperor

'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

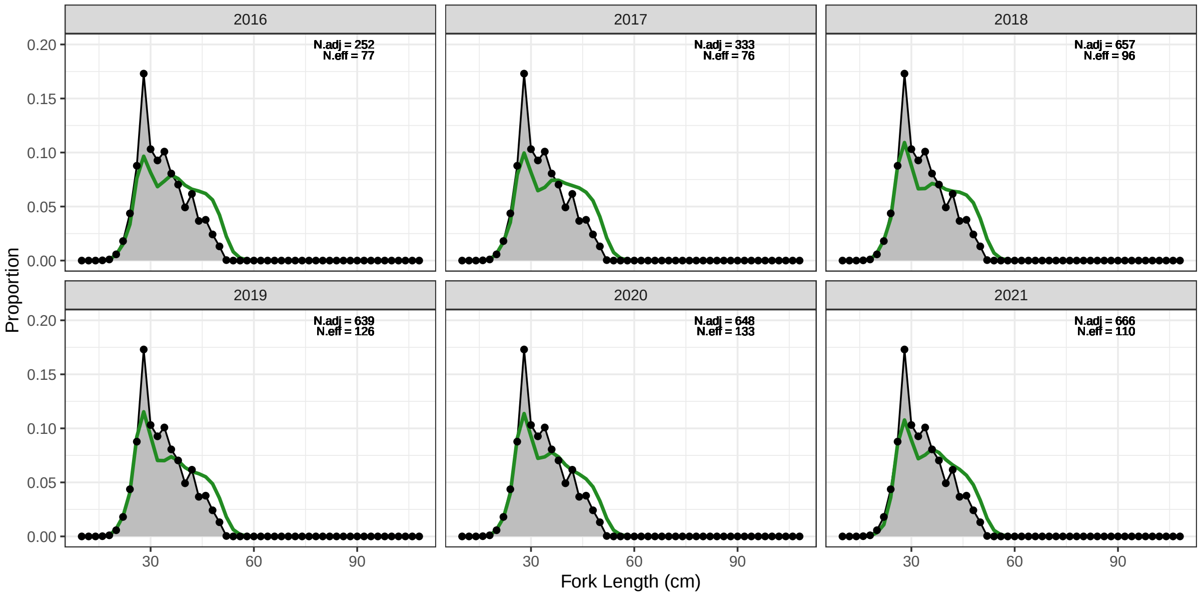

Figure C.4: Scenario 2 length structure for the recreational fleet for discarded red emperor

'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

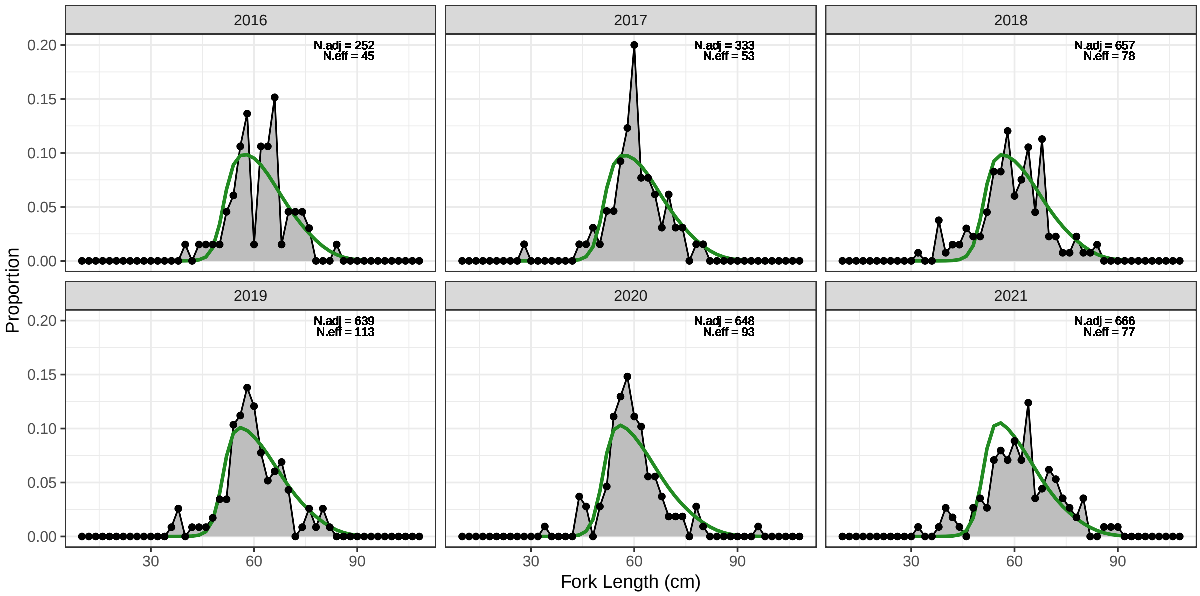

Figure C.5: Scenario 2 length structure for the recreational fleet for retained red emperor

'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

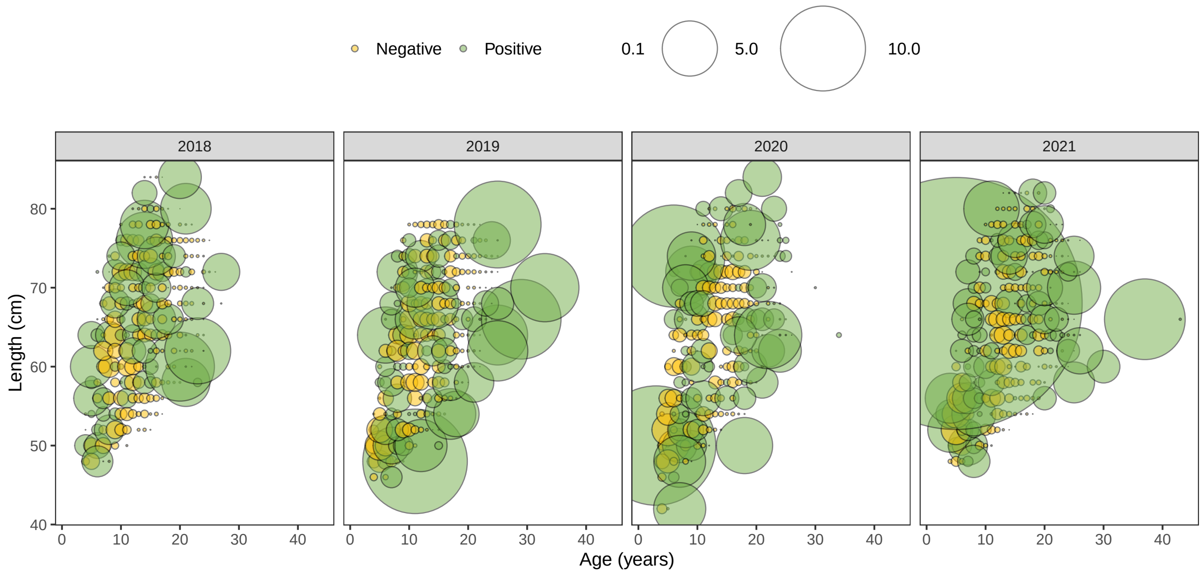

Figure C.6: Scenario 2 Pearson residuals for age-at-length compositions for the commercial fleet for red emperor—circle size represents the magnitude of the Pearson residual

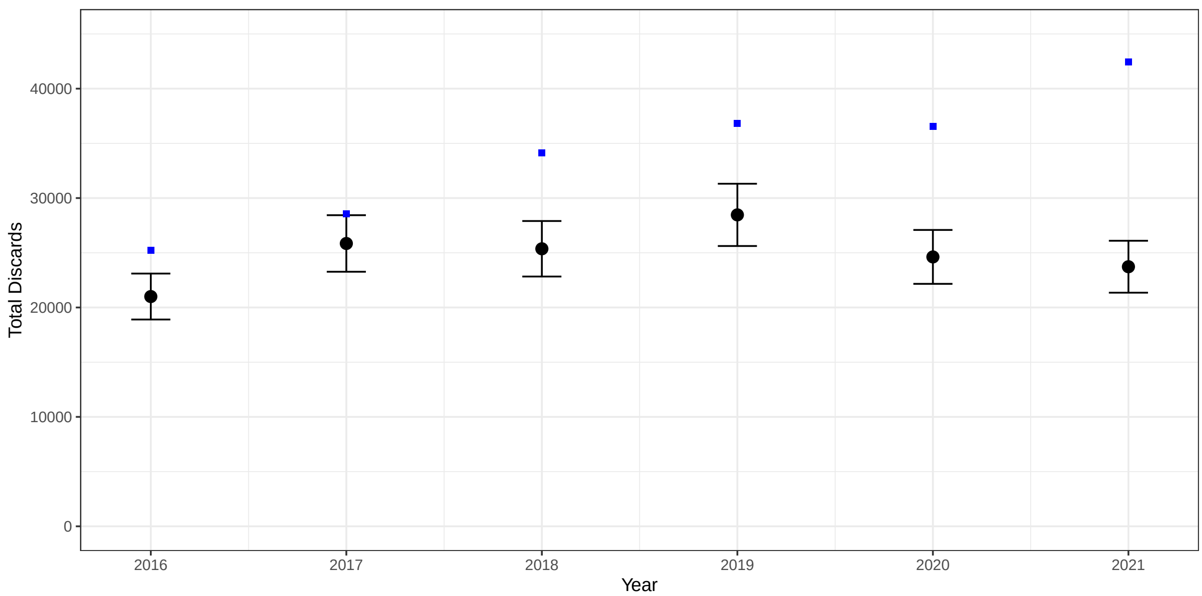

Figure C.7: Scenario 2 model fit to total discards for recreational-charter-Indigenous fleet—circles and error bars represent input data and their associated coefficients of variation and blue points represent the model predictions

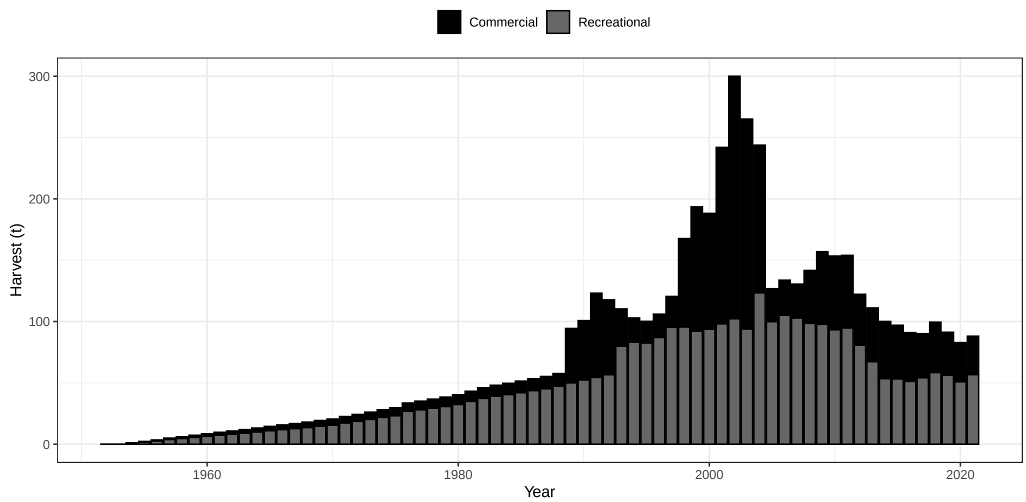

Figure C.8: Scenario 2 modelled harvest of red emperor

Scenario 3

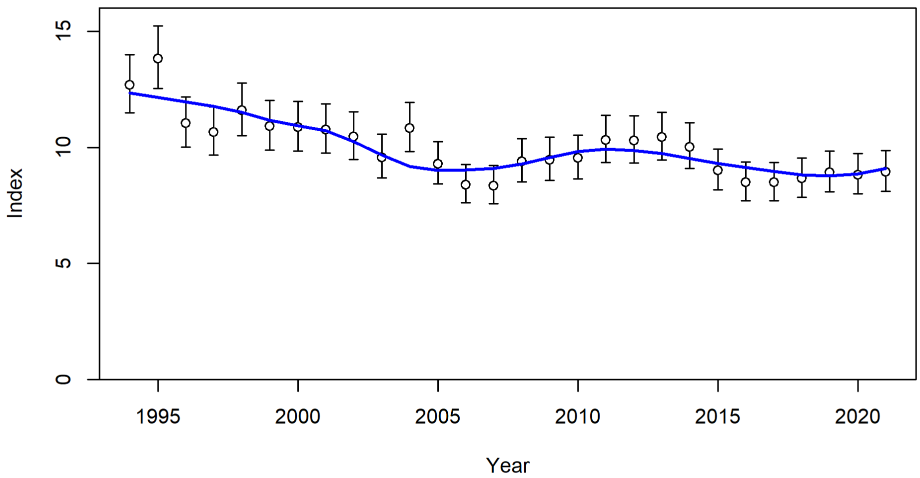

Figure C.9: Scenario 3 model predictions (blue line) to commercial catch rates for red emperor prior to rezoning

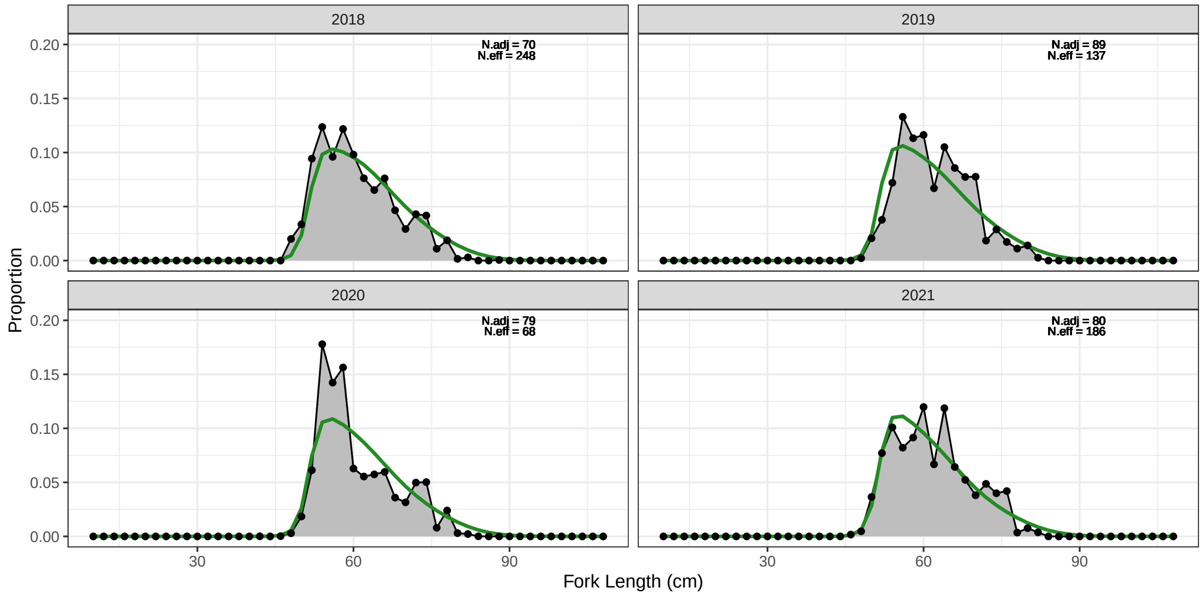

Figure C.10: Scenario 3 length structure for the commercial fleet for red emperor

'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

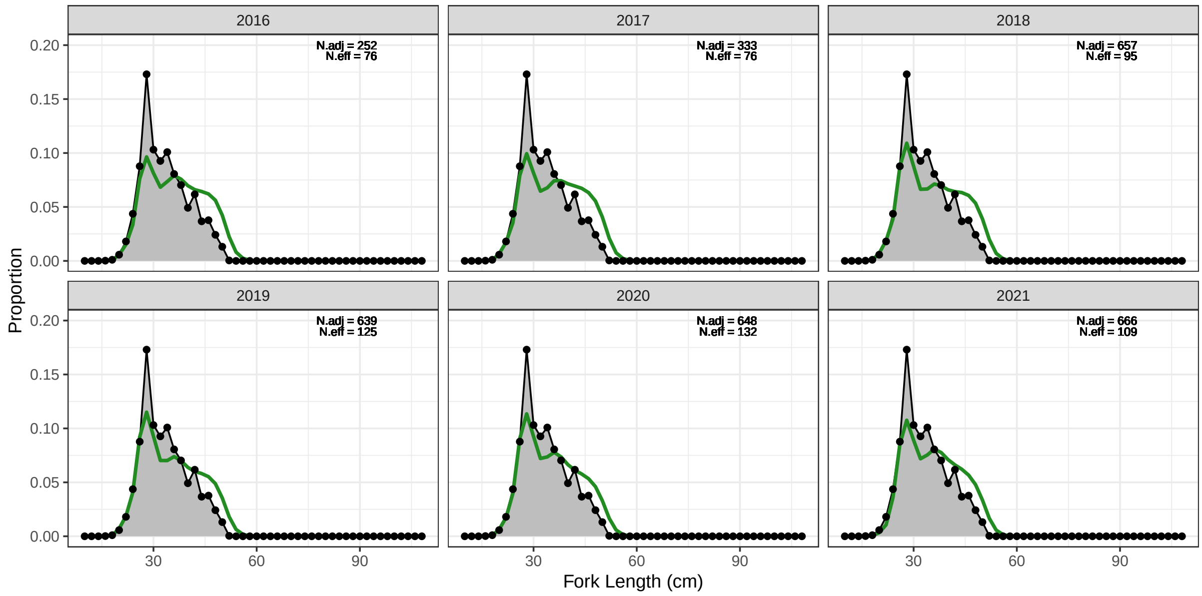

Figure C.11: Scenario 3 length structure for the recreational fleet for discarded red emperor

'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

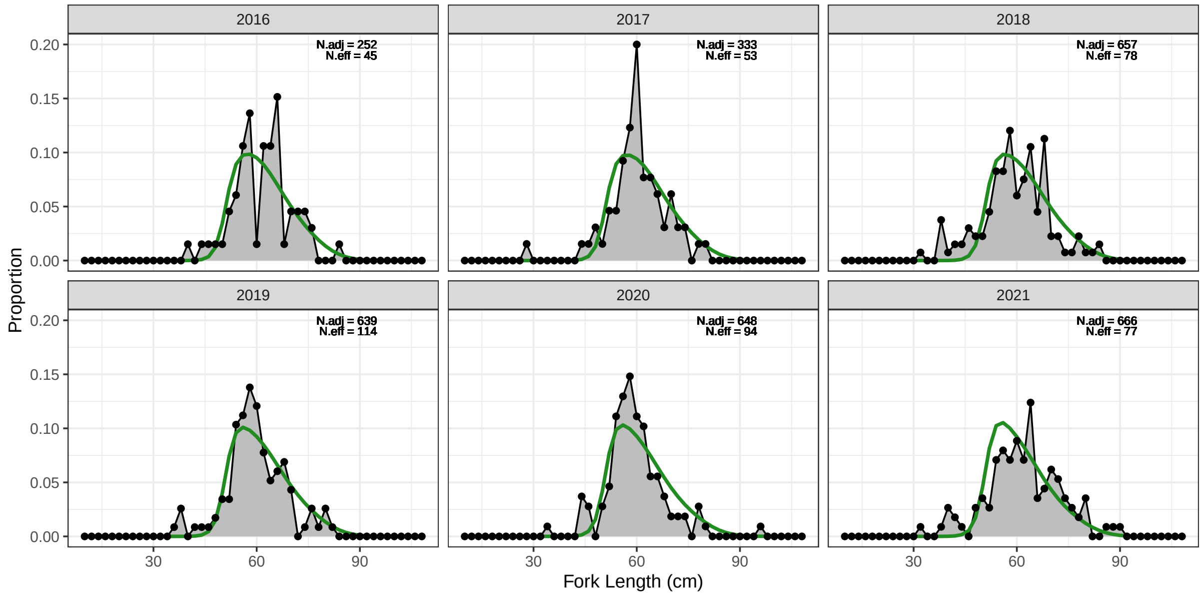

Figure C.12: Scenario 3 length structure for the recreational fleet for retained red emperor

'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

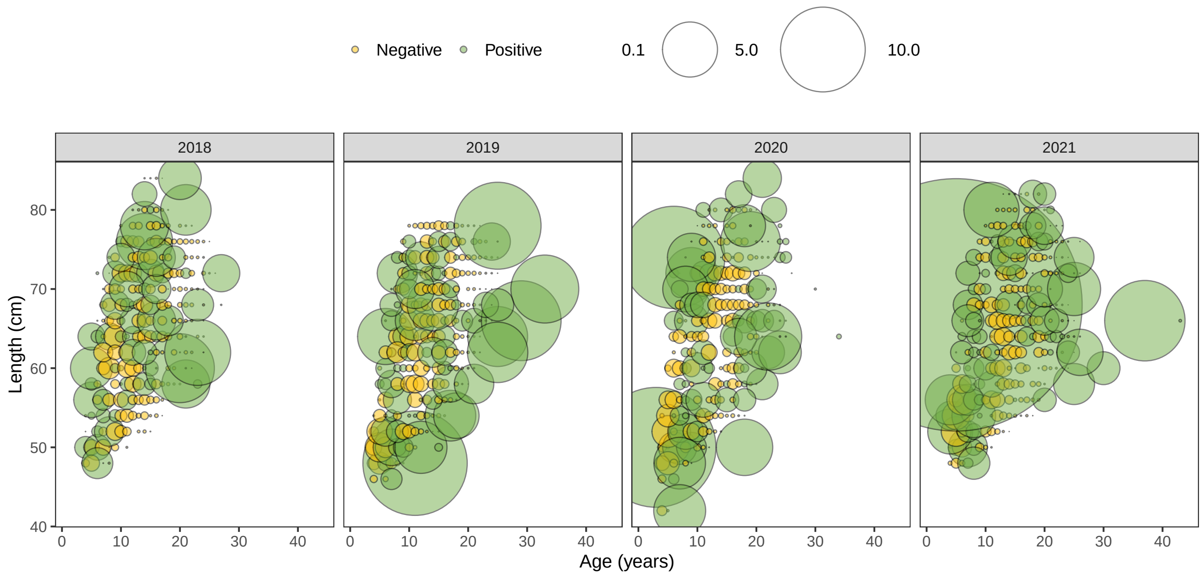

Figure C.13: Scenario 3 Pearson residuals for age-at-length compositions for the commercial fleet for red emperor—circle size represents the magnitude of the Pearson residual

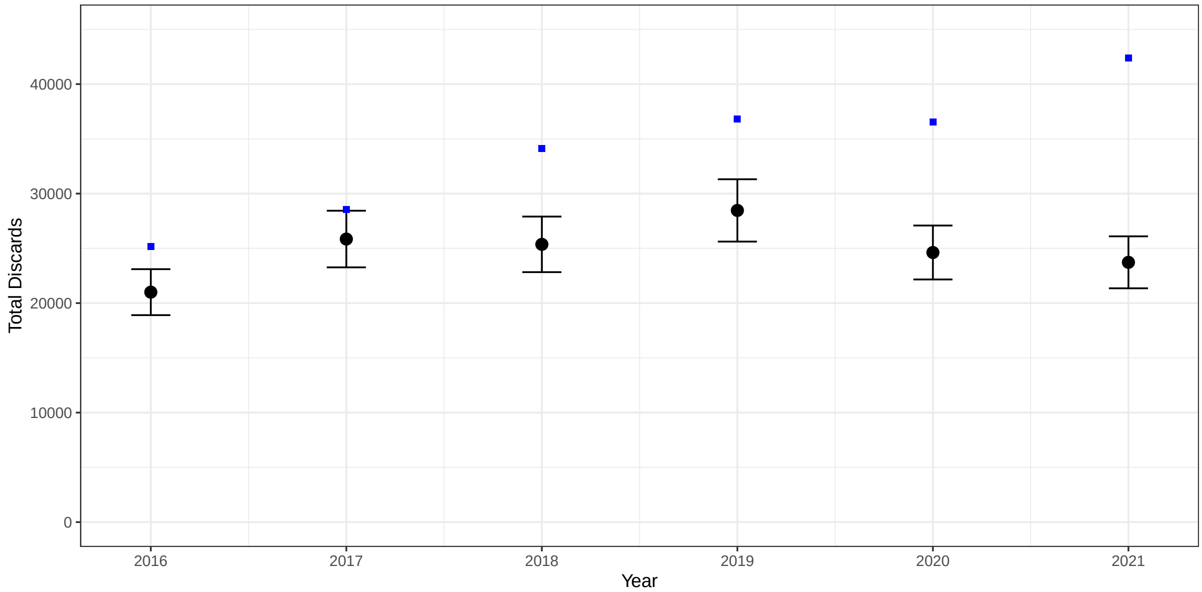

Figure C.14: Scenario 3 model fit to total discards for recreational-charter-Indigenous fleet—circles and error bars represent input data and their associated coefficients of variation and blue points represent the model predictions

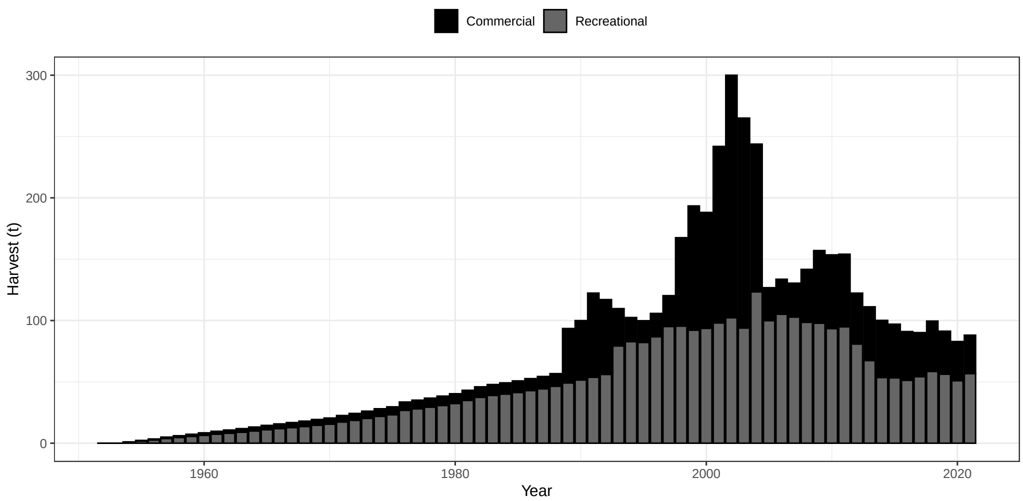

Figure C.15: Scenario 3 modelled harvest of red emperor

Scenario 4

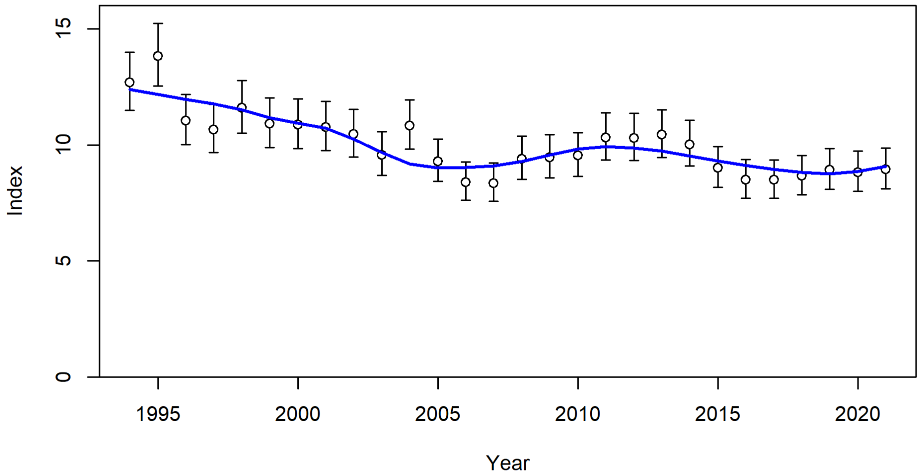

Figure C.16: Scenario 4 model predictions (blue line) to commercial catch rates for red emperor prior to rezoning

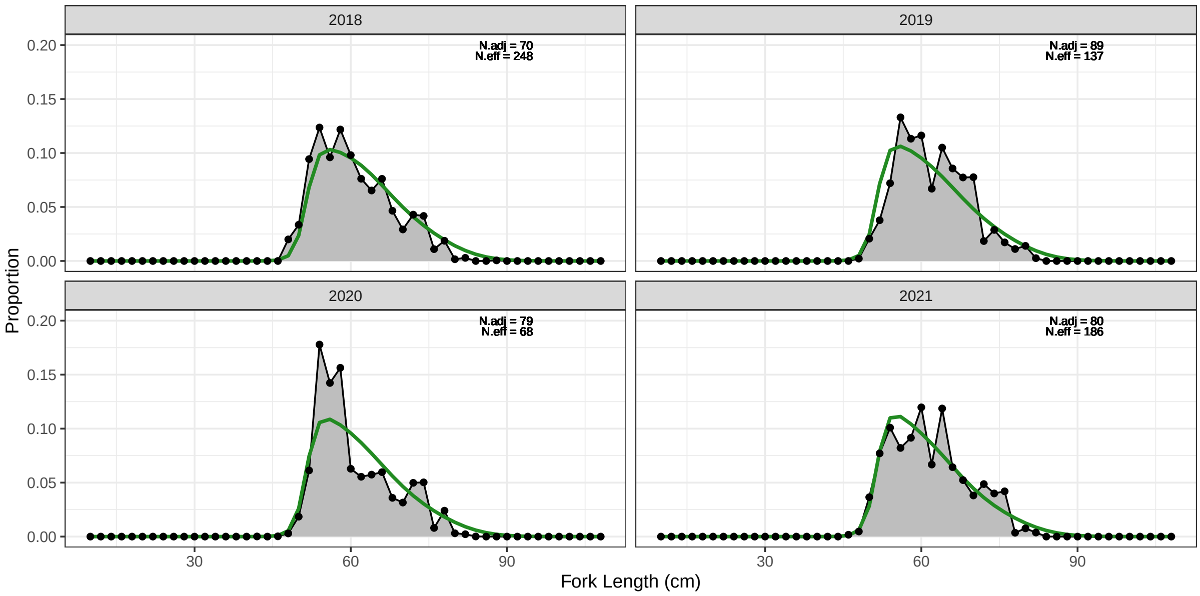

Figure C.17: Scenario 4 length structure for the commercial fleet for red emperor

'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

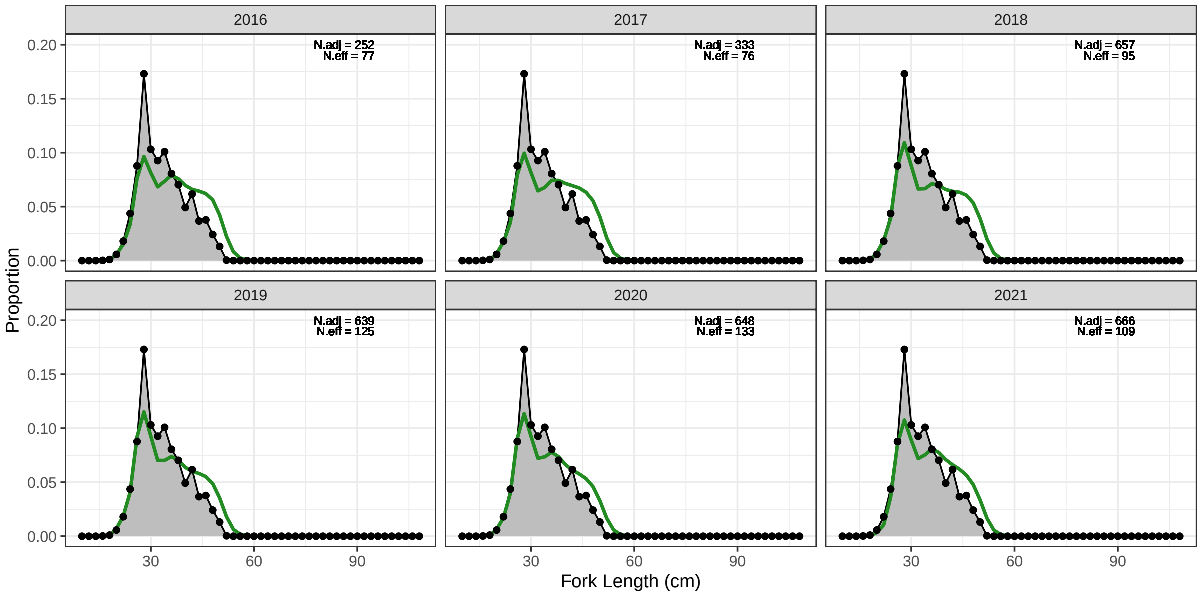

Figure C.18: Scenario 4 length structure for the recreational fleet for discarded red emperor

'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

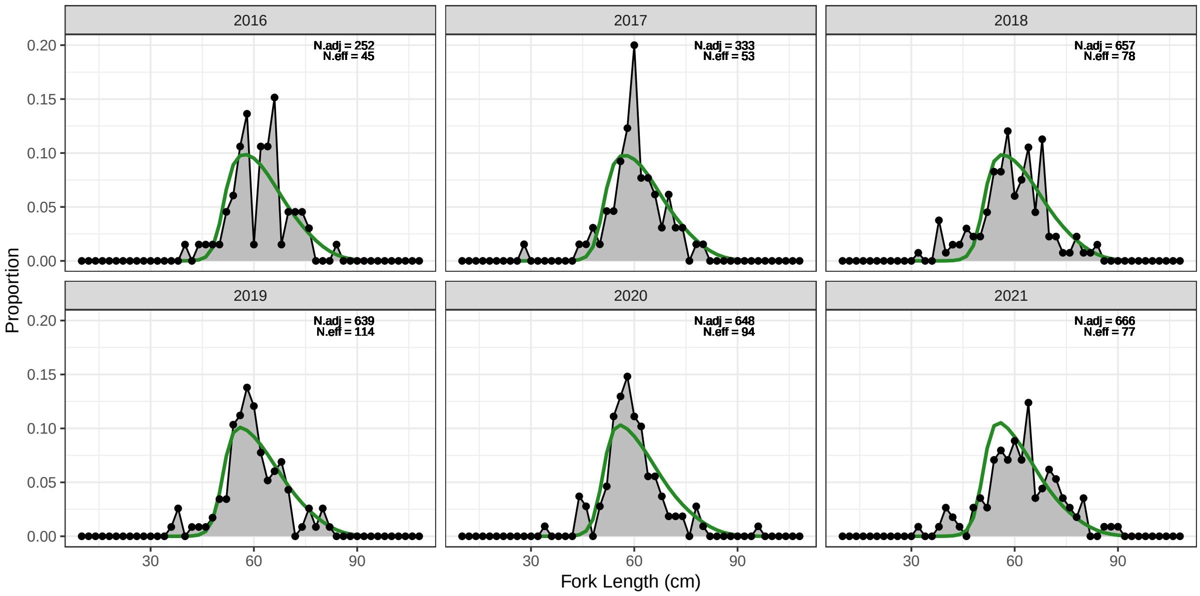

Figure C.19: Scenario 4 length structure for the recreational fleet for retained red emperor

'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

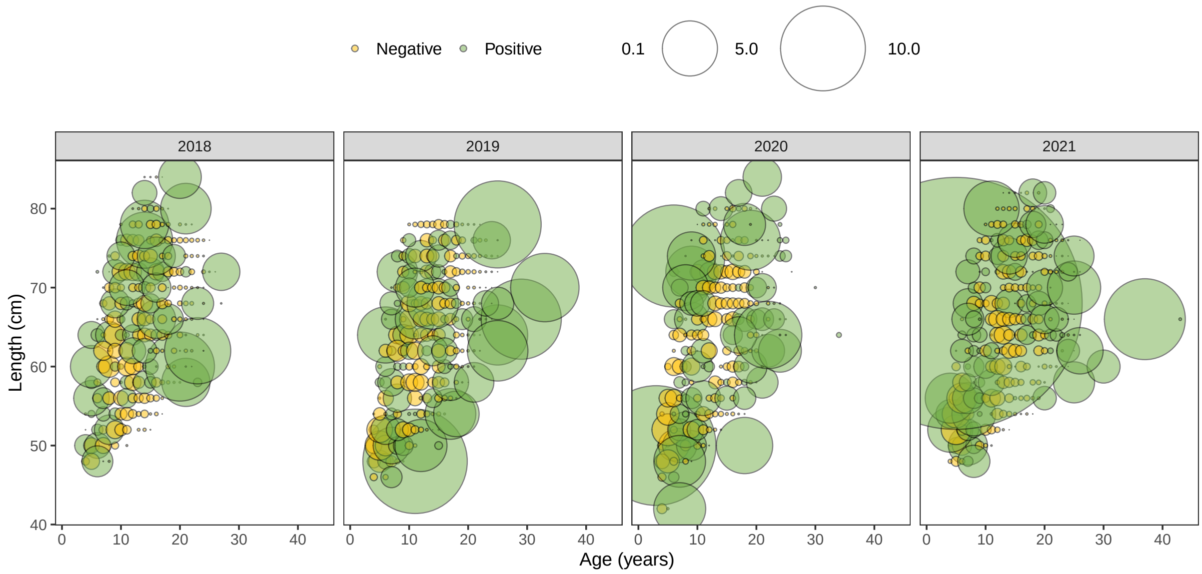

Figure C.20: Scenario 4 Pearson residuals for age-at-length compositions for the commercial fleet for red emperor—circle size represents the magnitude of the Pearson residual

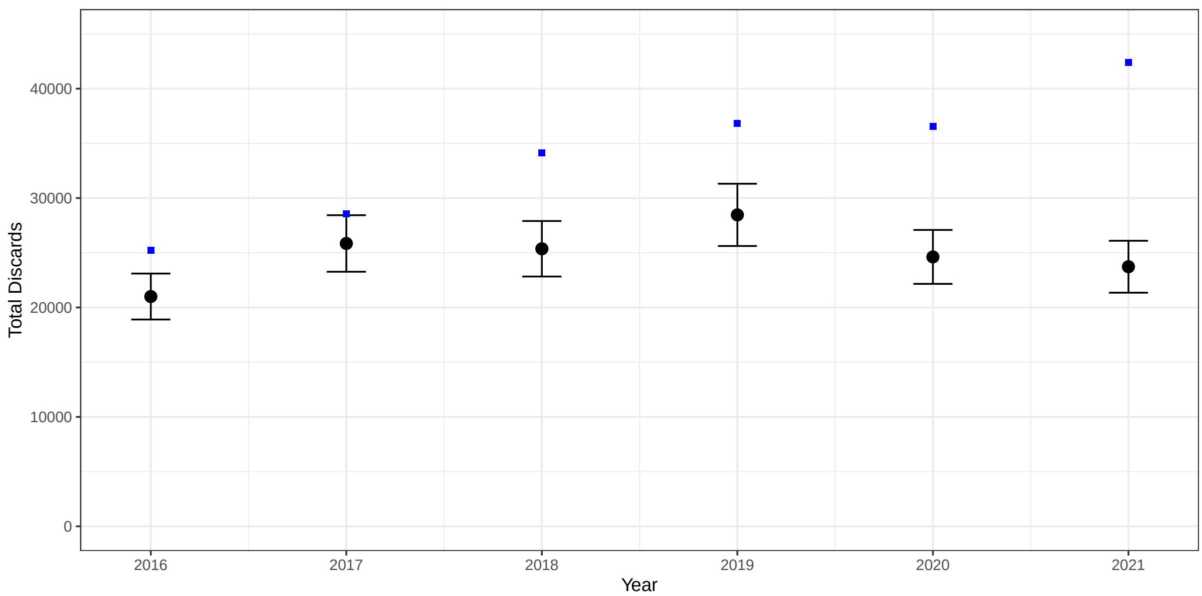

Figure C.21: Scenario 4 model fit to total discards for recreational-charter-Indigenous fleet—circles and error bars represent input data and their associated coefficients of variation and blue points represent the model predictions

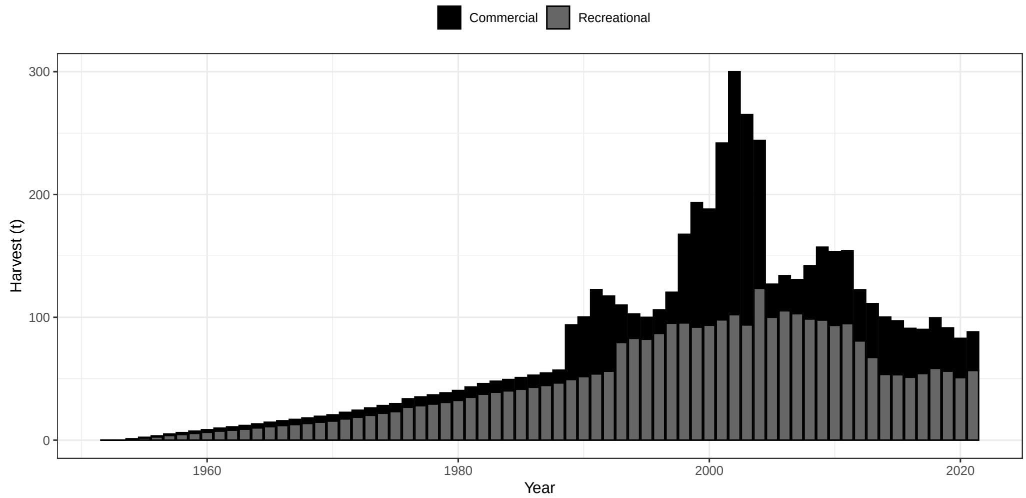

Figure C.22: Scenario 4 modelled harvest of red emperor

Scenario 5

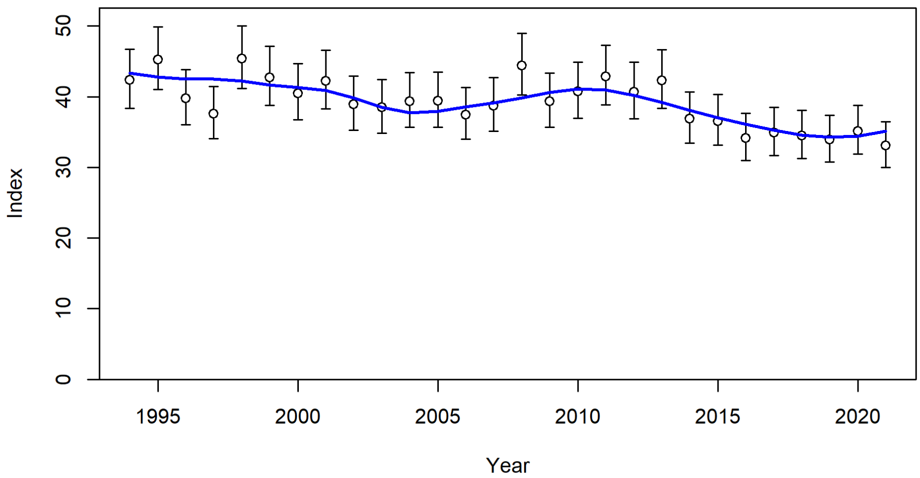

Figure C.23: Scenario 5 model predictions (blue line) to commercial catch rates for red emperor prior to rezoning

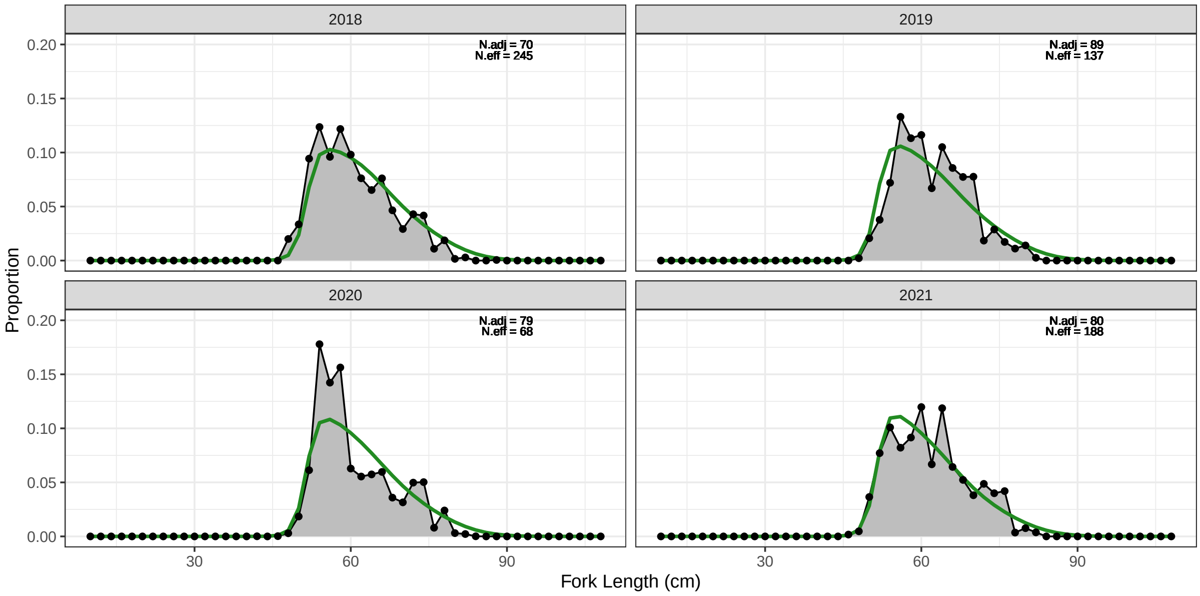

Figure C.24: Scenario 5 length structure for the commercial fleet for red emperor

'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

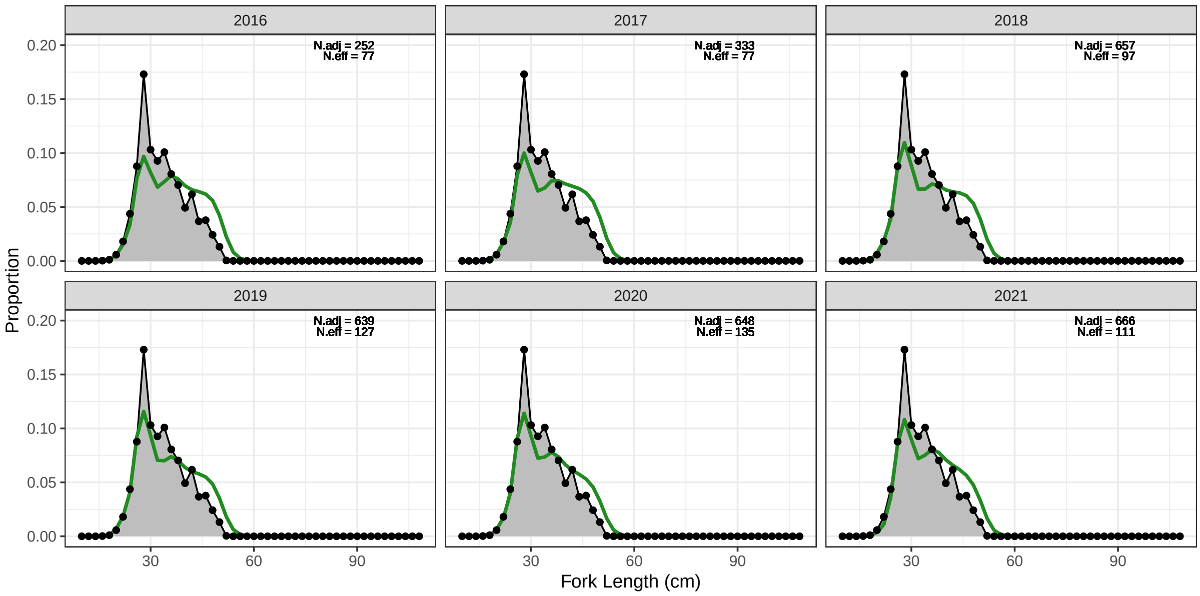

Figure C.25: Scenario 5 length structure for the recreational fleet for discarded red emperor

'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

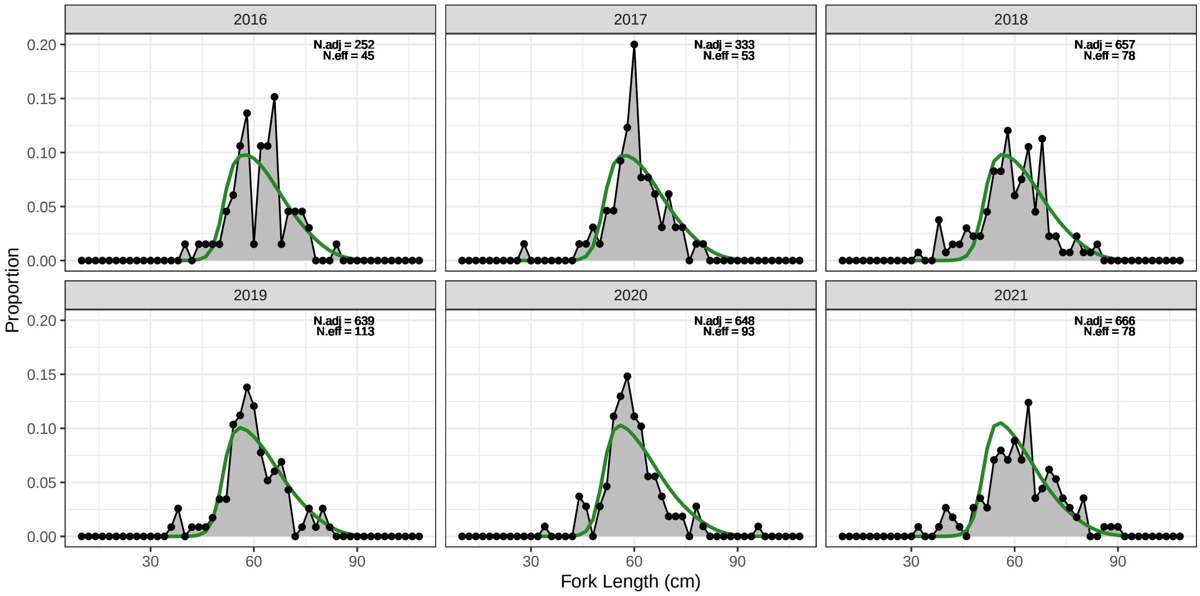

Figure C.26: Scenario 5 length structure for the recreational fleet for retained red emperor

'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

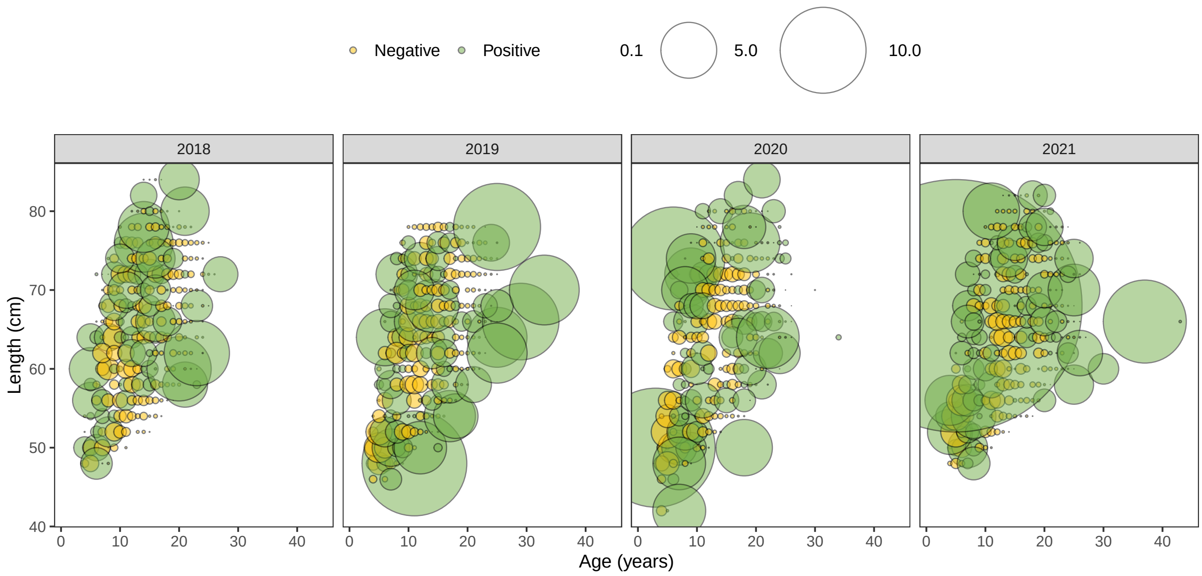

Figure C.27: Scenario 5 Pearson residuals for age-at-length compositions for the commercial fleet for red emperor—circle size represents the magnitude of the Pearson residual

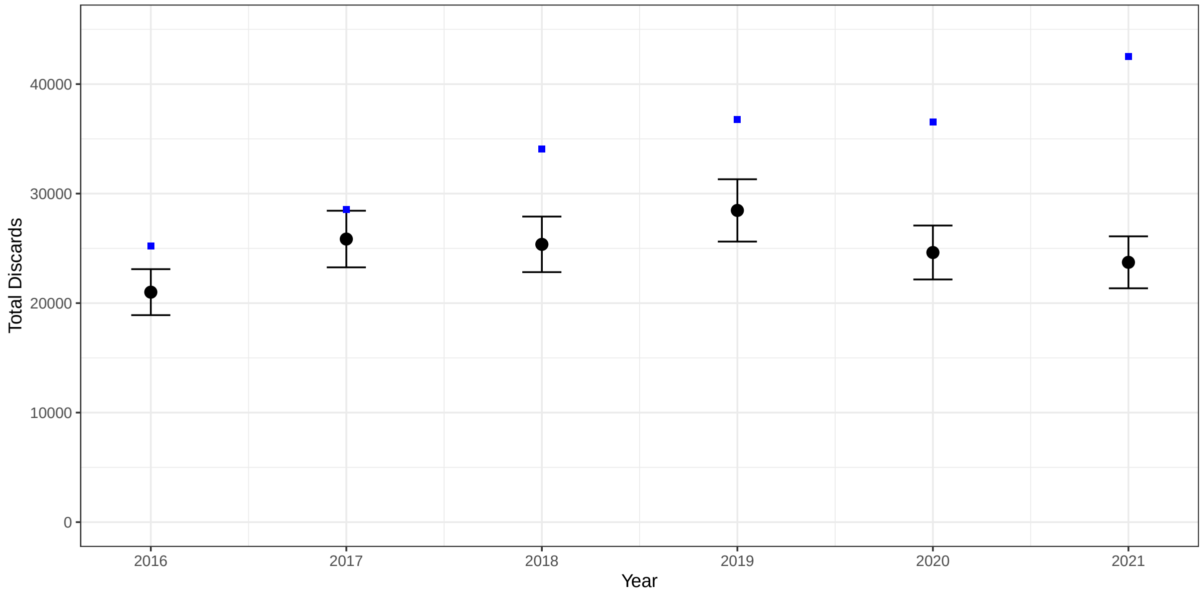

Figure C.28: Scenario 5 model fit to total discards for recreational-charter-Indigenous fleet—circles and error bars represent input data and their associated coefficients of variation and blue points represent the model predictions

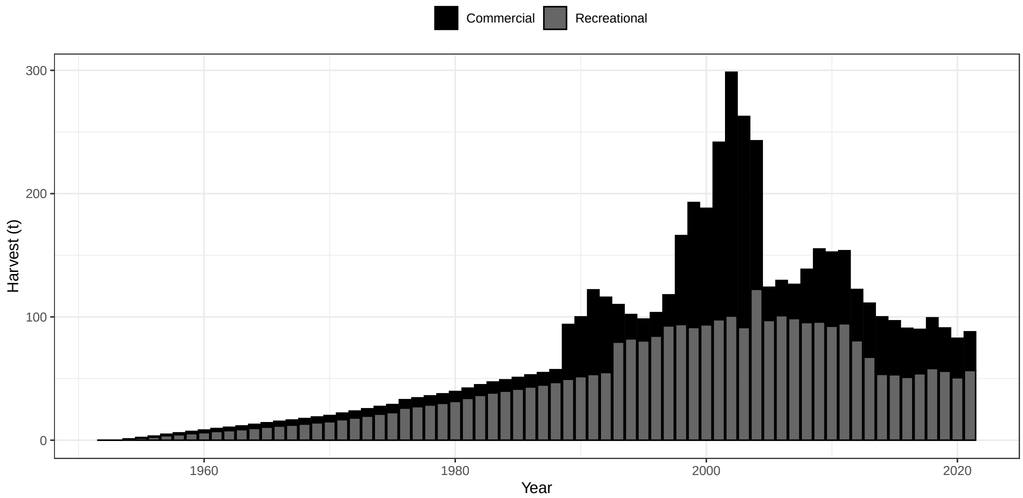

Figure C.29: Scenario 5 modelled harvest of red emperor

Scenario 6

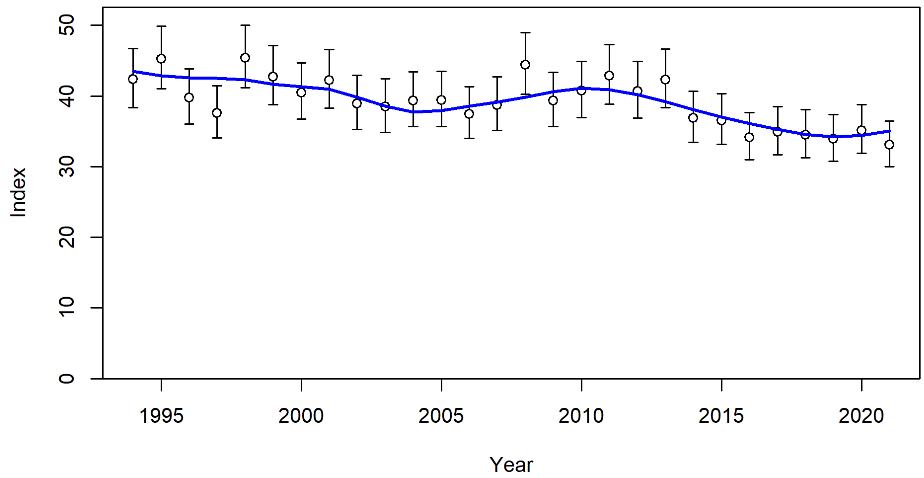

Figure C.30: Scenario 6 model predictions (blue line) to commercial catch rates for red emperor prior to rezoning

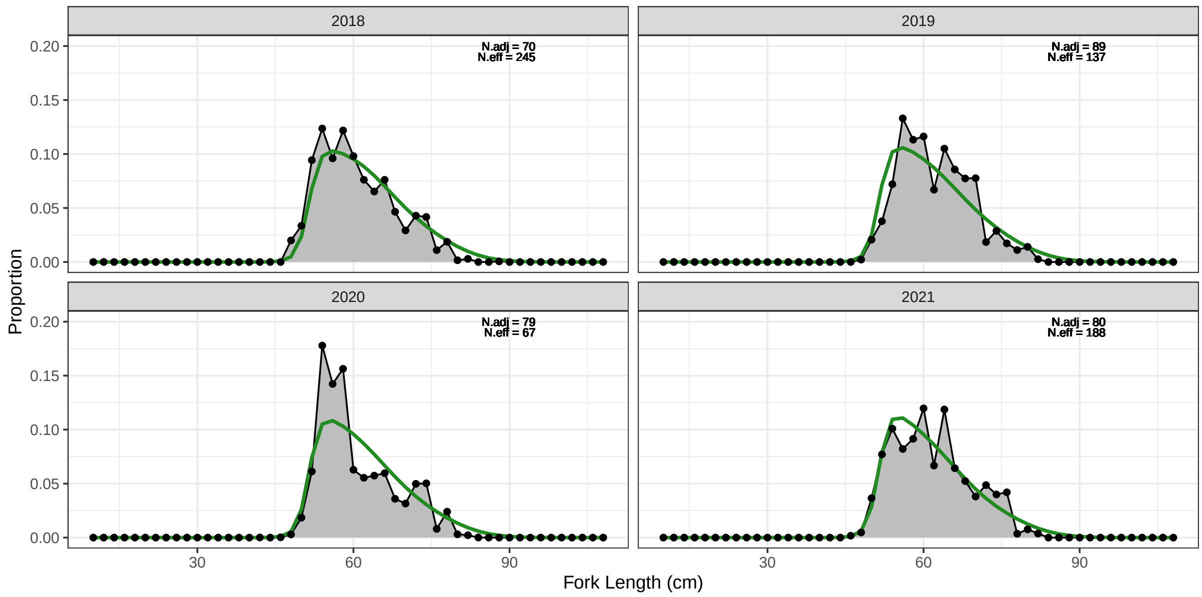

Figure C.31: Scenario 6 length structure for the commercial fleet for red emperor

'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

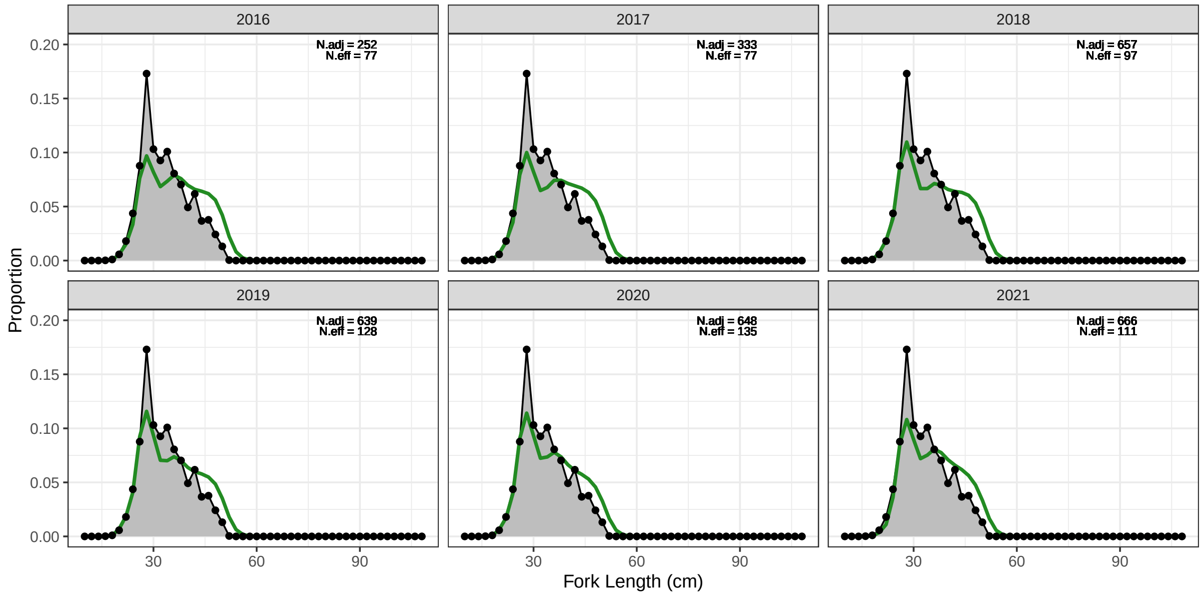

Figure C.32: Scenario 6 length structure for the recreational fleet for discarded red emperor

'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

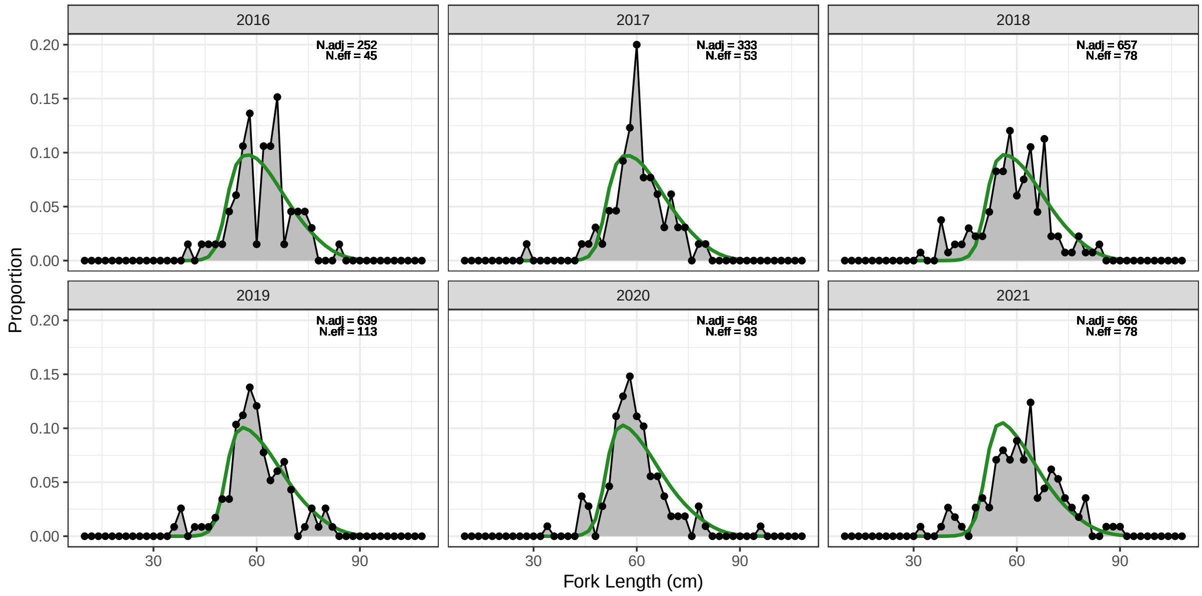

Figure C.33: Scenario 6 length structure for the recreational fleet for retained red emperor

'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

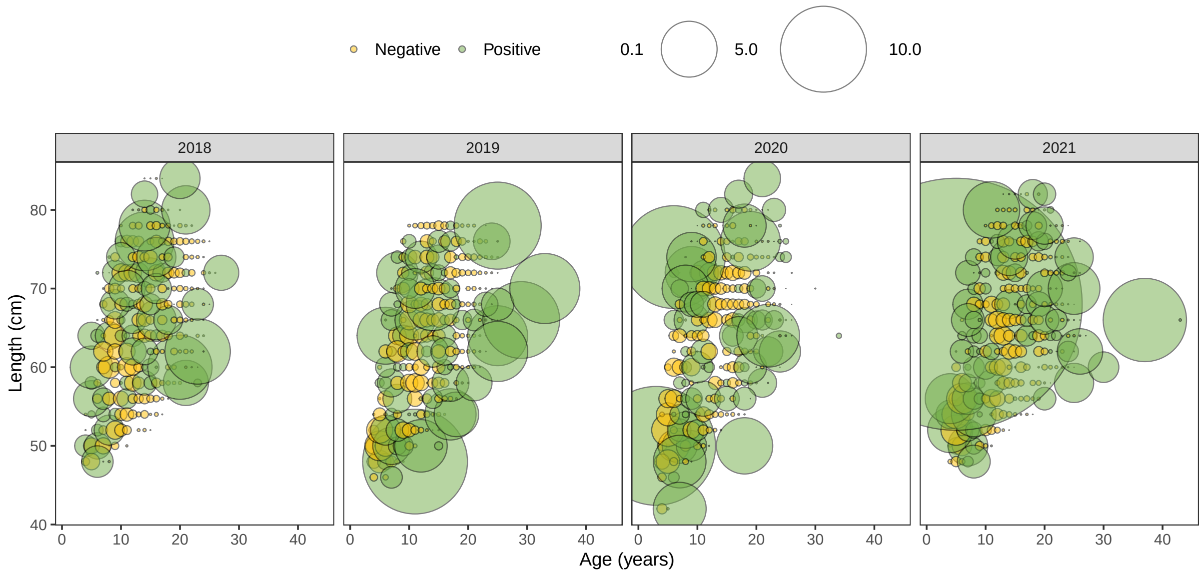

Figure C.34: Scenario 6 Pearson residuals for age-at-length compositions for the commercial fleet for red emperor—circle size represents the magnitude of the Pearson residual

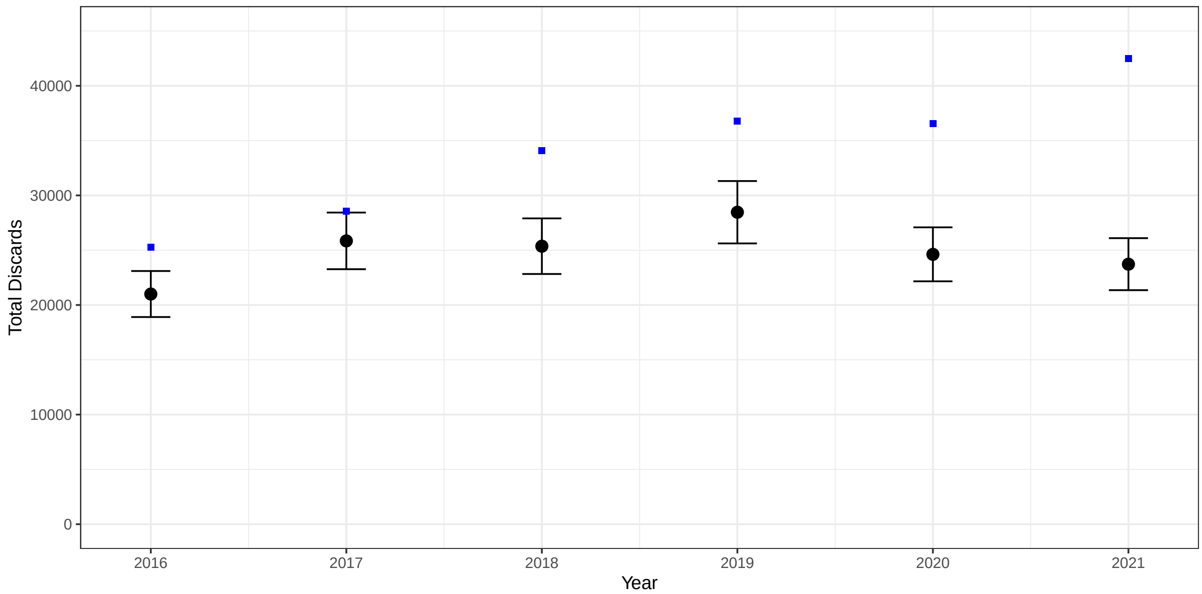

Figure C.35: Scenario 6 model fit to total discards for recreational-charter-Indigenous fleet—circles and error bars represent input data and their associated coefficients of variation and blue points represent the model predictions

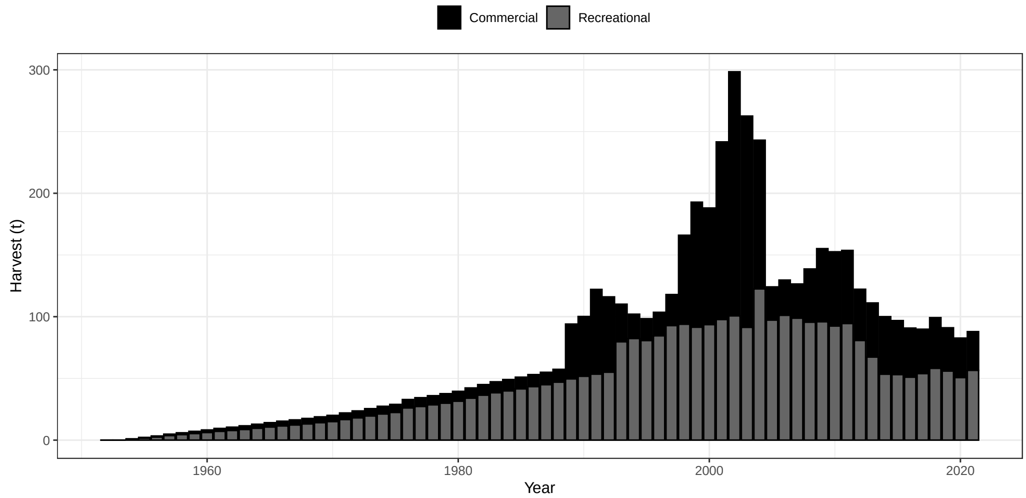

Figure C.36: Scenario 6 modelled harvest of red emperor

Scenario 7

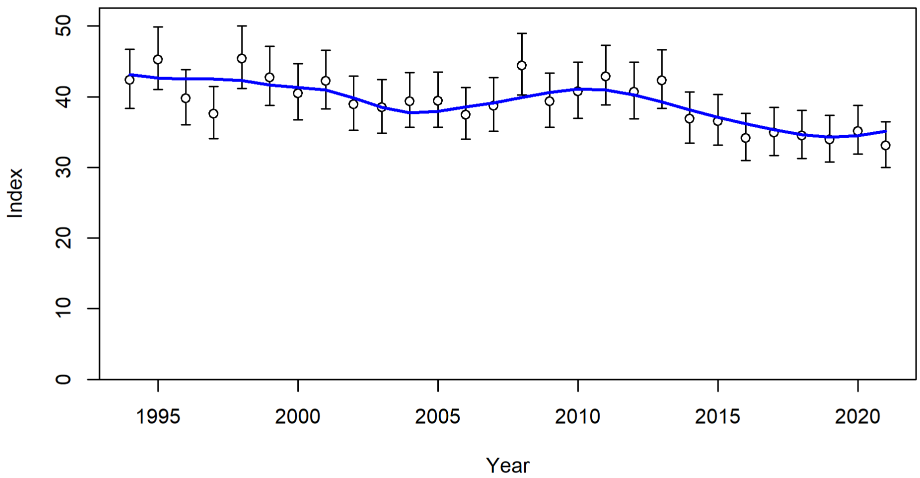

Figure C.37: Scenario 7 model predictions (blue line) to commercial catch rates for red emperor prior to rezoning

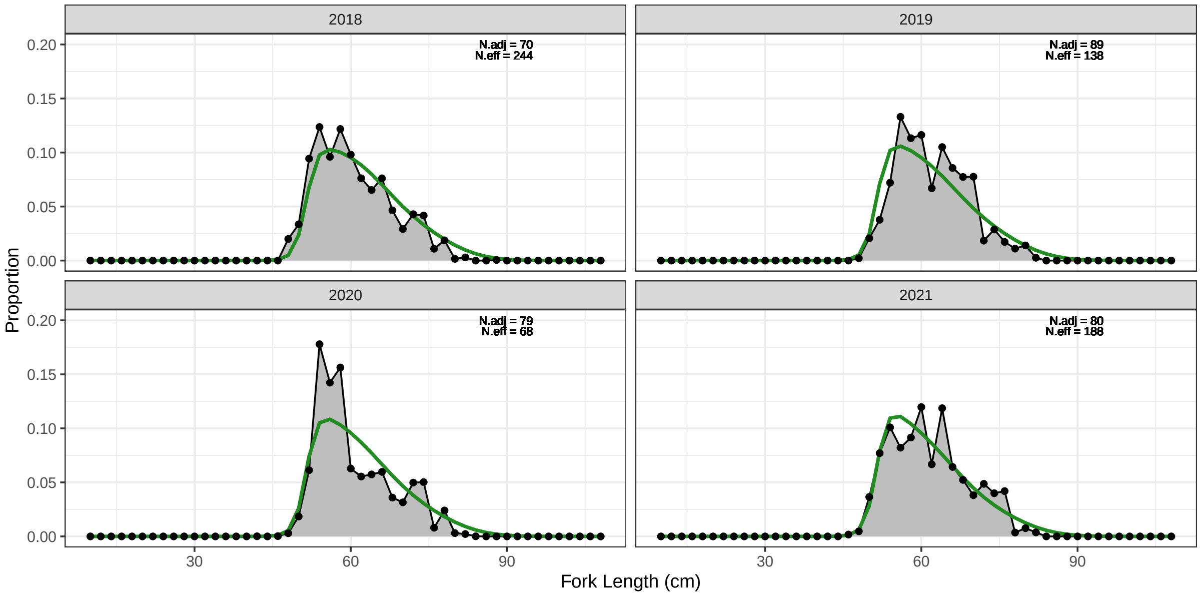

Figure C.38: Scenario 7 length structure for the commercial fleet for red emperor

'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

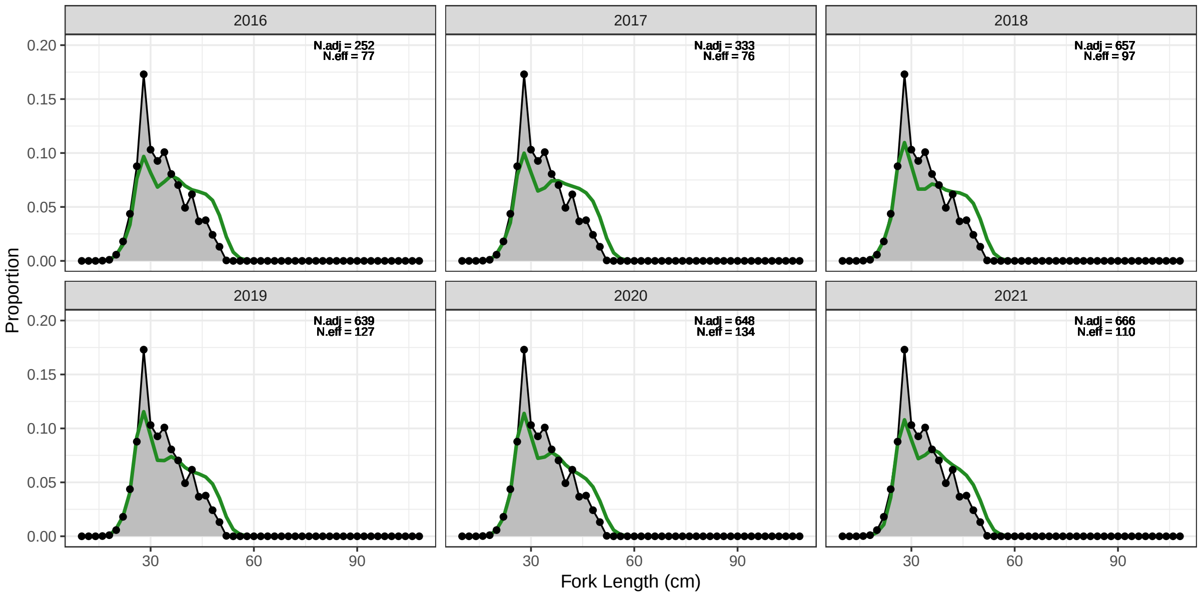

Figure C.39: Scenario 7 length structure for the recreational fleet for discarded red emperor

'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

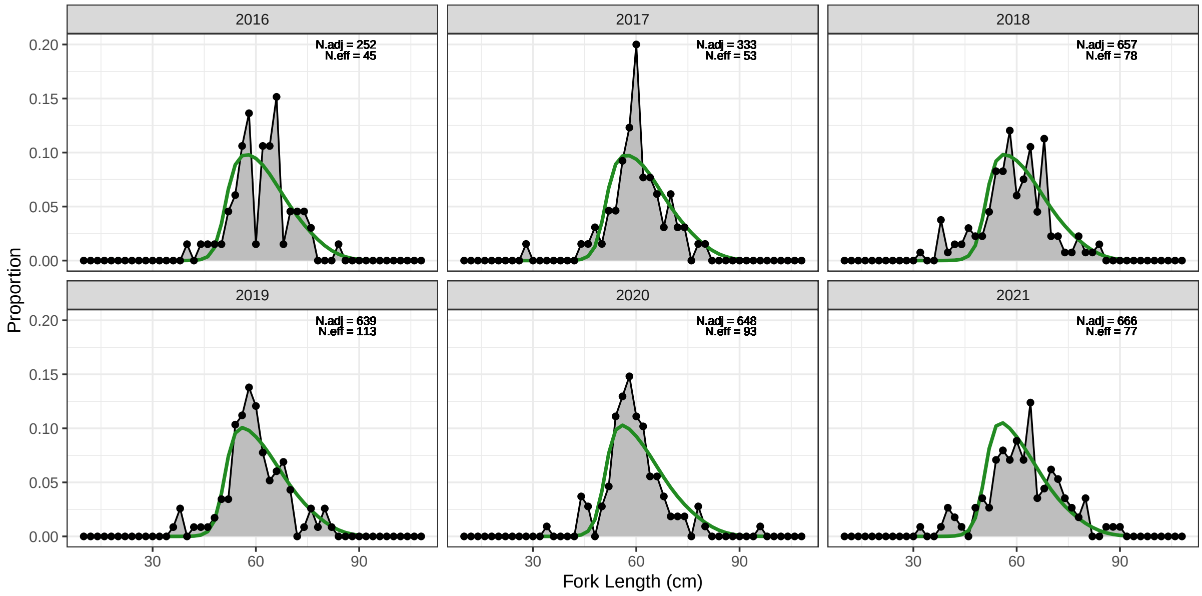

Figure C.40: Scenario 7 length structure for the recreational fleet for retained red emperor

'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

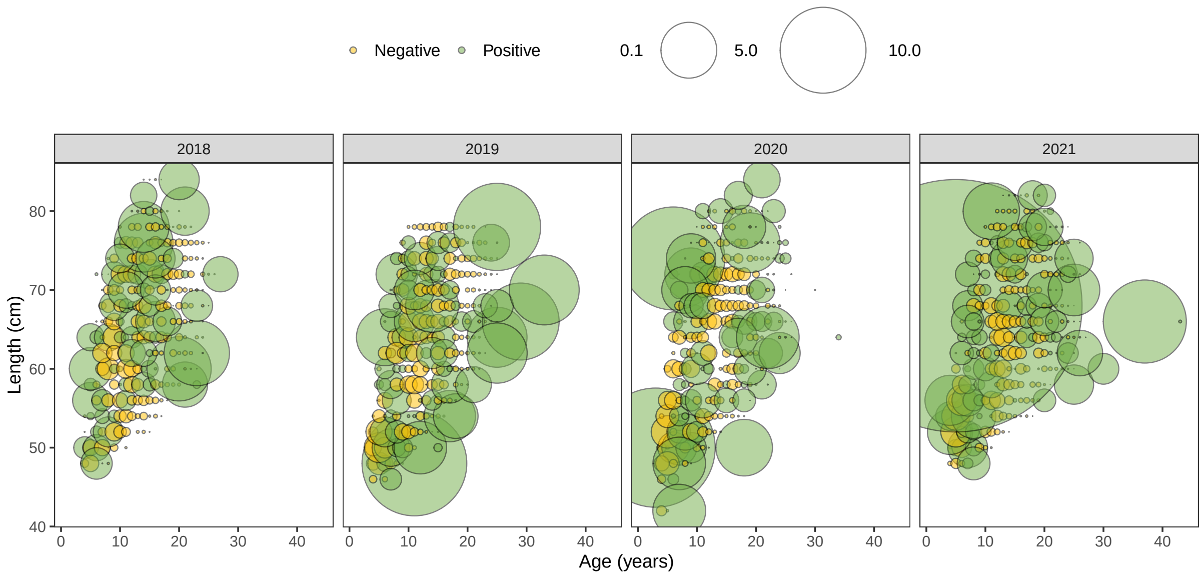

Figure C.41: Scenario 7 Pearson residuals for age-at-length compositions for the commercial fleet for red emperor—circle size represents the magnitude of the Pearson residual

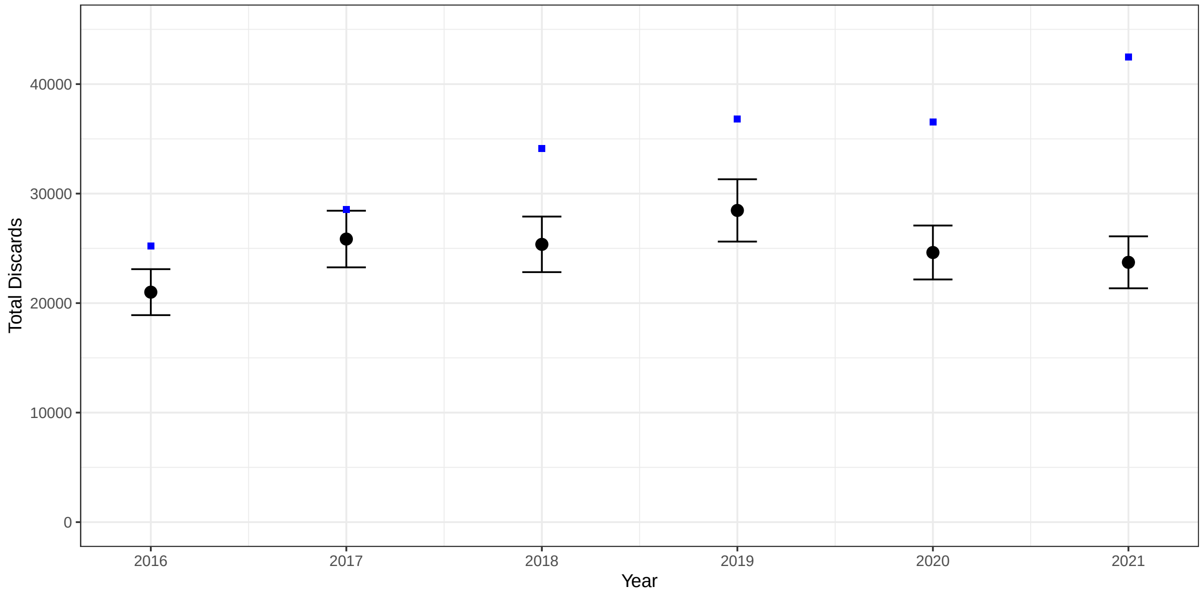

Figure C.42: Scenario 7 model fit to total discards for recreational-charter-Indigenous fleet—circles and error bars represent input data and their associated coefficients of variation and blue points represent the model predictions

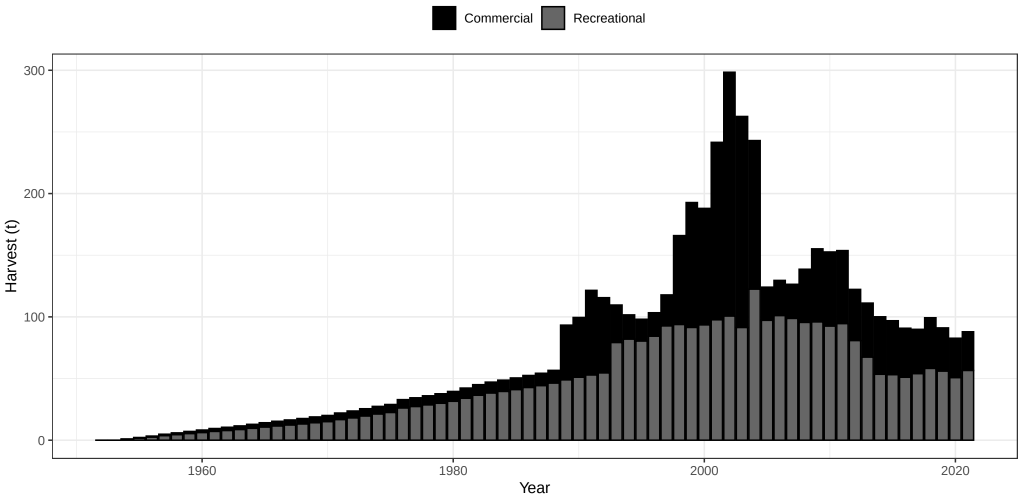

Figure C.43: Scenario 7 modelled harvest of red emperor

Scenario 8

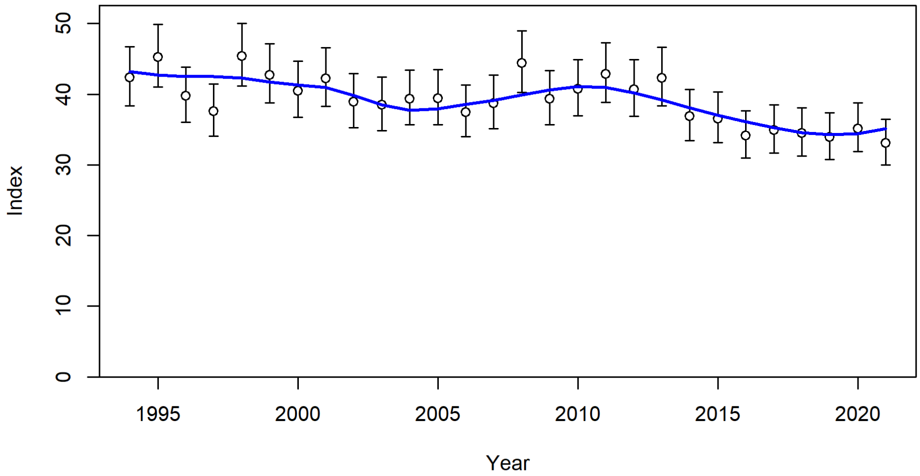

Figure C.44: Scenario 8 model predictions (blue line) to commercial catch rates for red emperor prior to rezoning

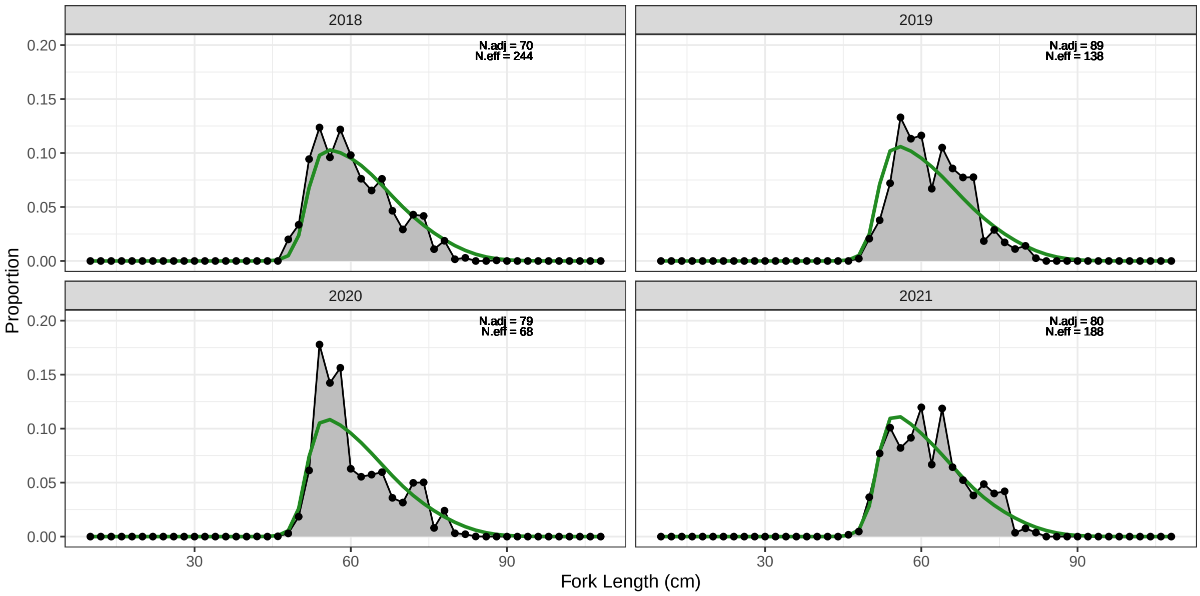

Figure C.45: Scenario 8 length structure for the commercial fleet for red emperor

'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

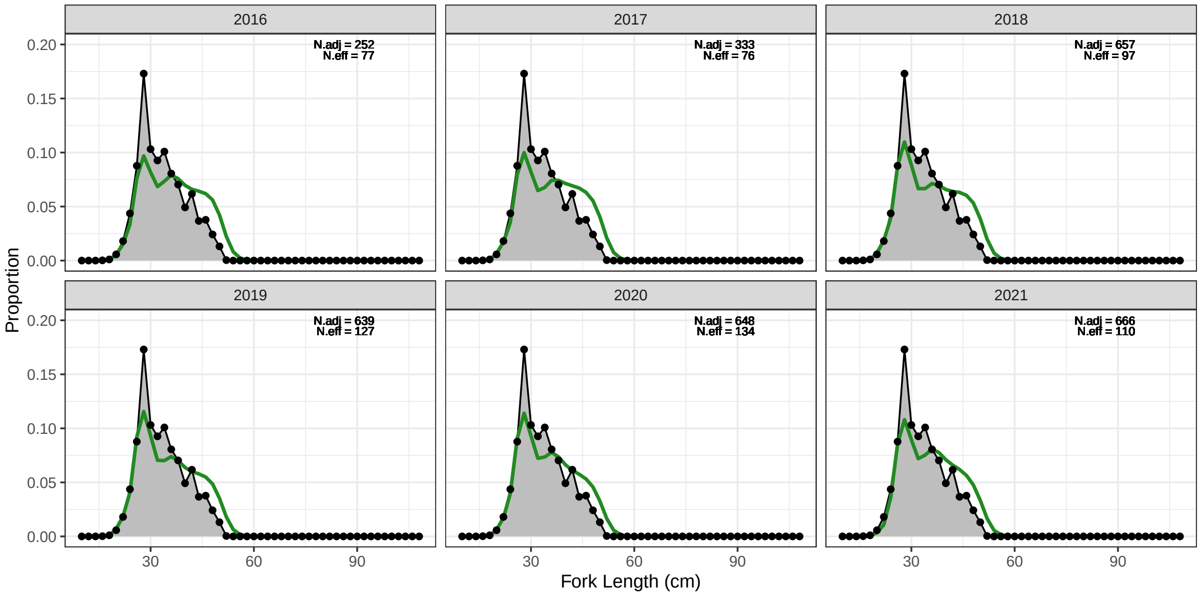

Figure C.46: Scenario 8 length structure for the recreational fleet for discarded red emperor

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

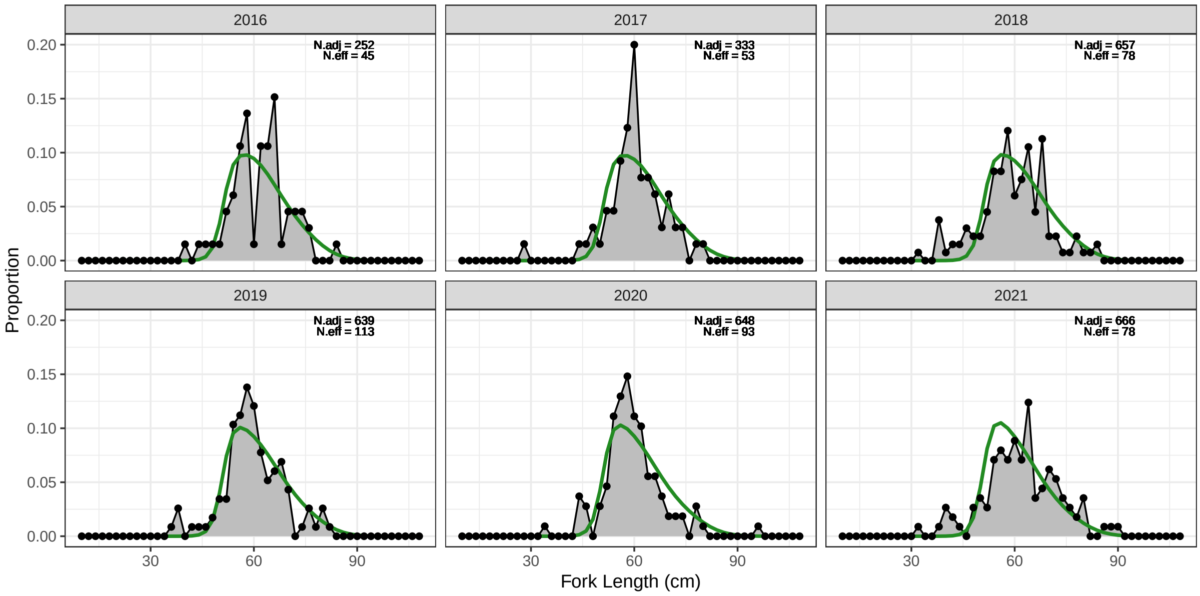

Figure C.47: Scenario 8 length structure for the recreational fleet for retained red emperor

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

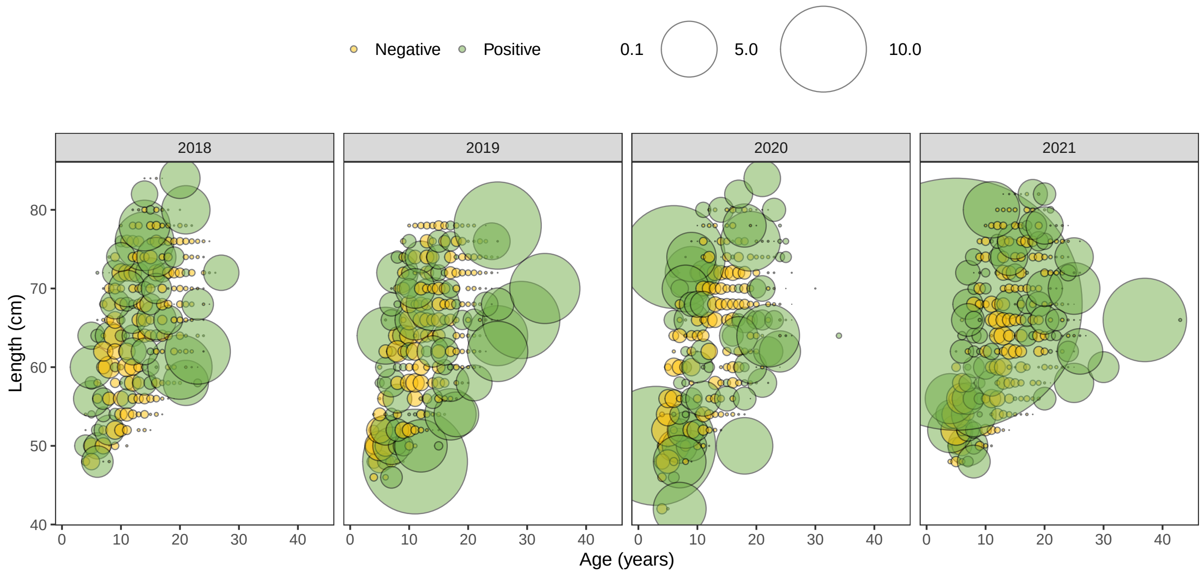

Figure C.48: Scenario 8 Pearson residuals for age-at-length compositions for the commercial fleet for red emperor—circle size represents the magnitude of the Pearson residual

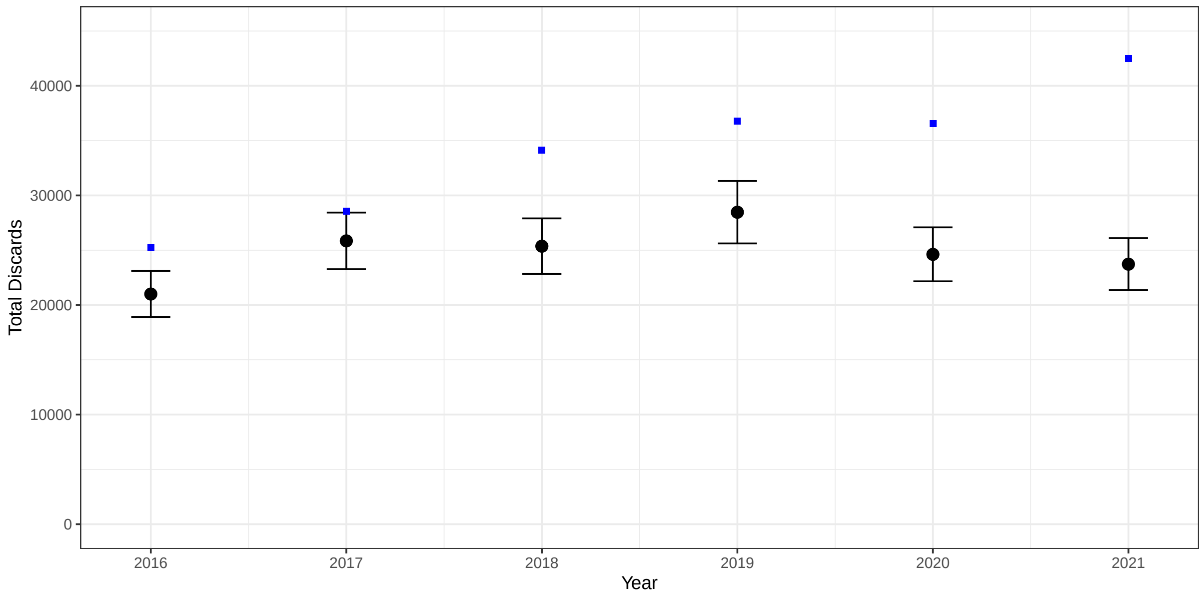

Figure C.49: Scenario 8 model fit to total discards for recreational-charter-Indigenous fleet—circles and error bars represent input data and their associated coefficients of variation and blue points represent the model predictions

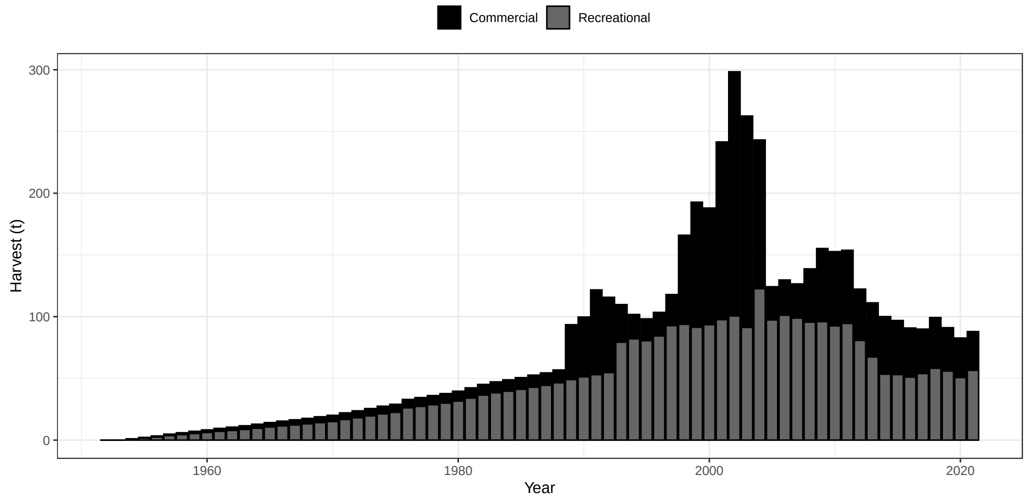

Figure C.50: Scenario 8 modelled harvest of red emperor

Scenario 9

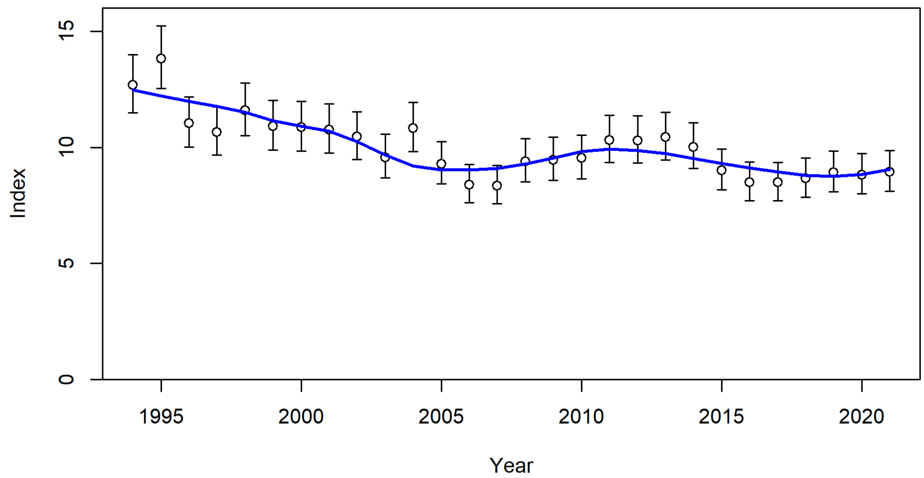

Figure C.51: Scenario 9 model predictions (blue line) to commercial catch rates for red emperor prior to rezoning

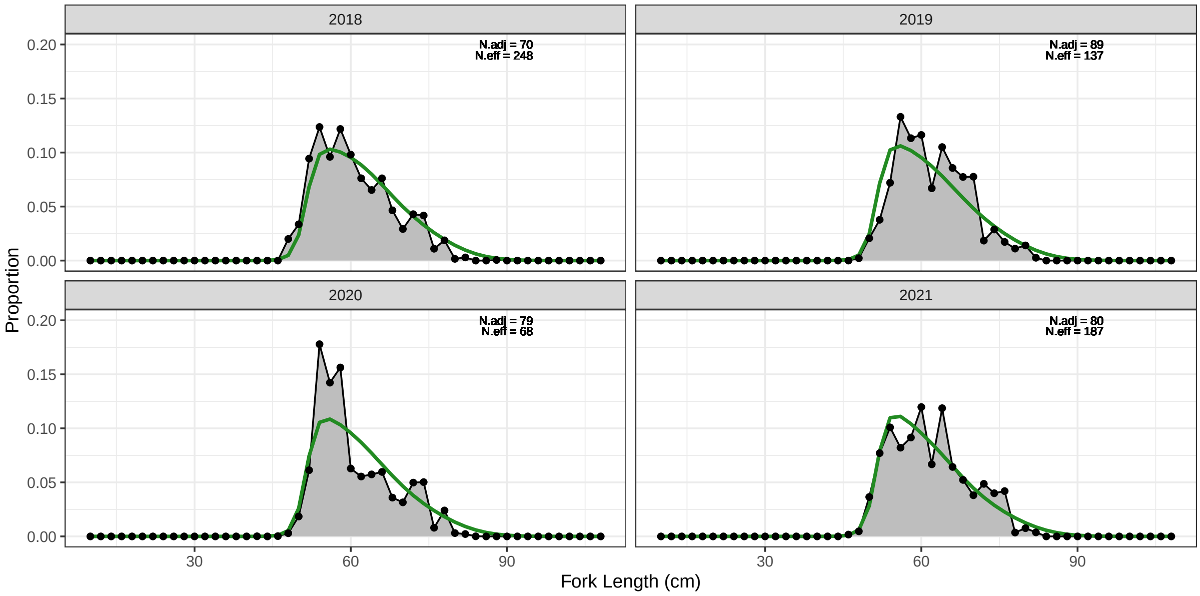

Figure C.52: Scenario 9 length structure for the commercial fleet for red emperor

'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

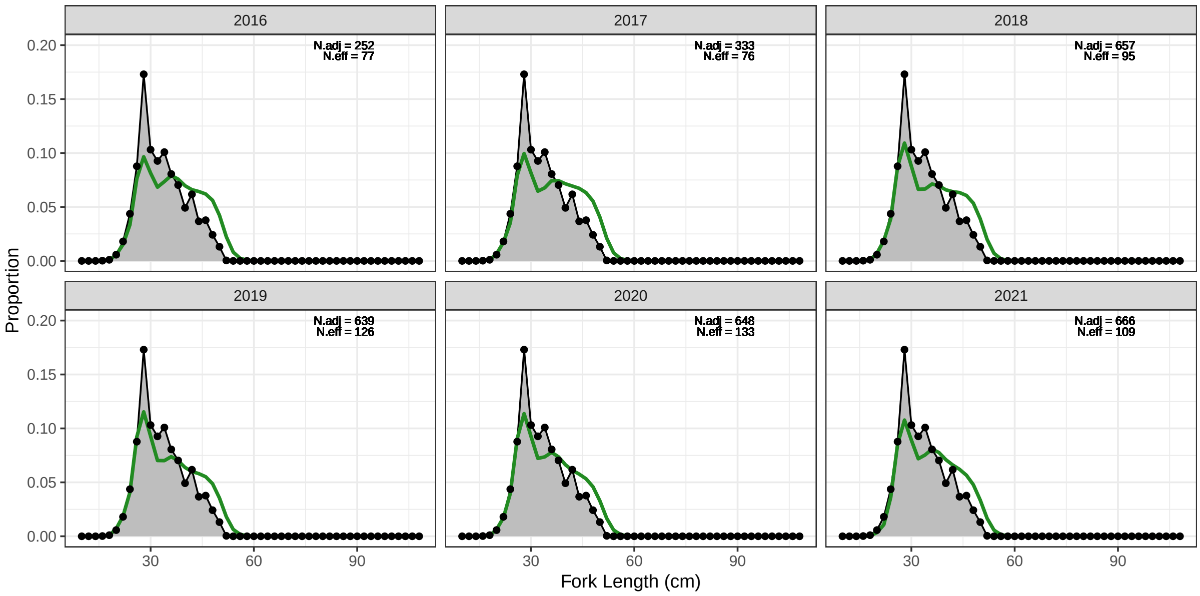

Figure C.53: Scenario 9 length structure for the recreational fleet for discarded red emperor

'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

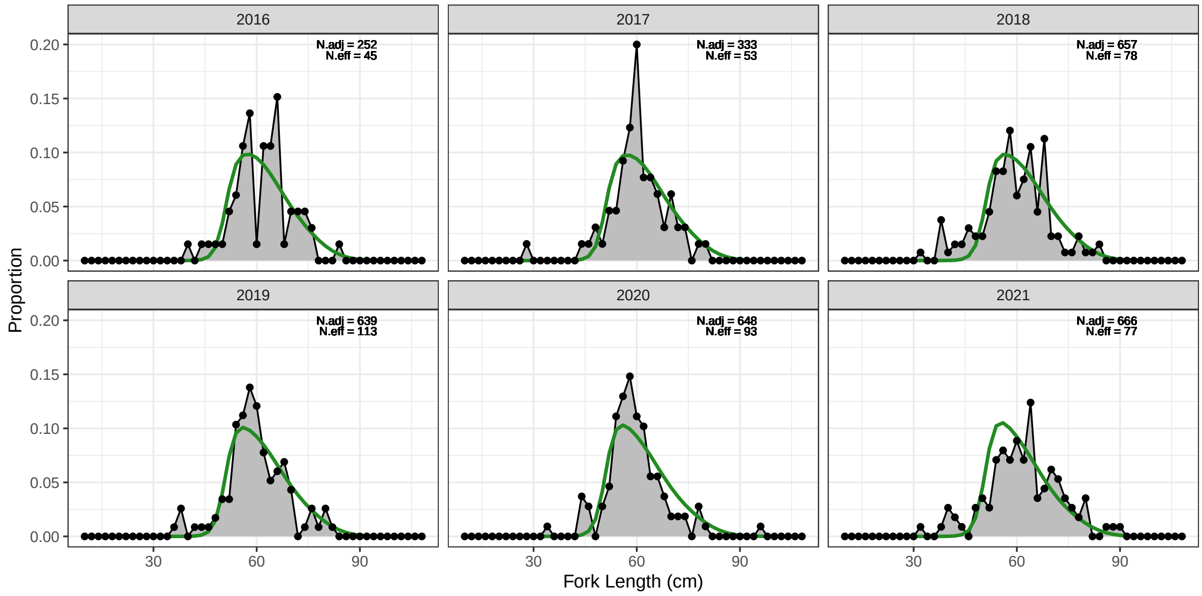

Figure C.54: Scenario 9 length structure for the recreational fleet for retained red emperor

'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

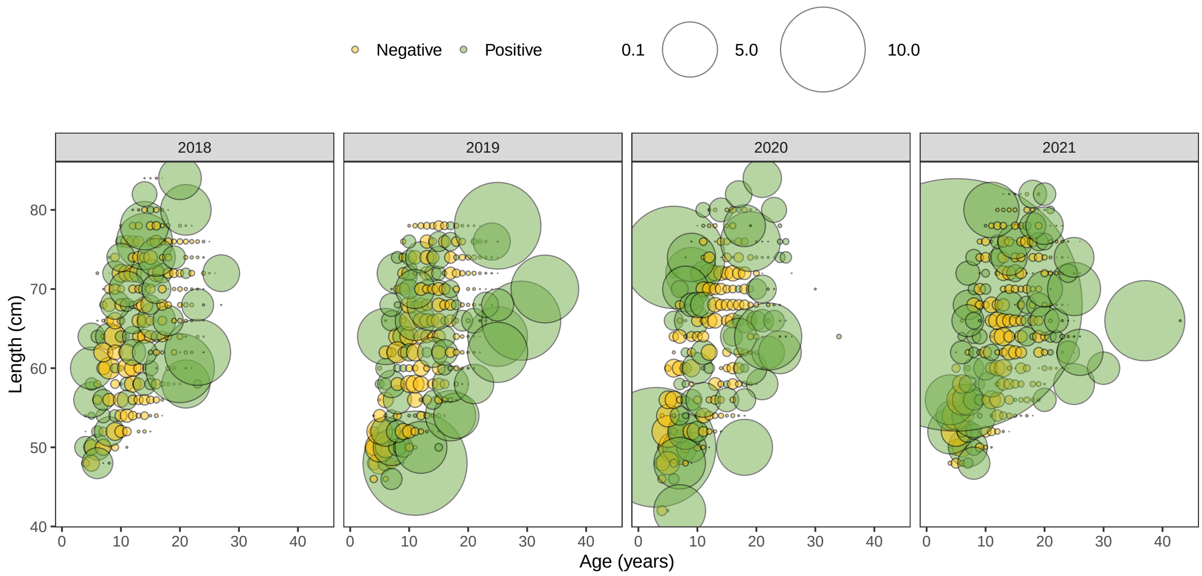

Figure C.55: Scenario 9 Pearson residuals for age-at-length compositions for the commercial fleet for red emperor—circle size represents the magnitude of the Pearson residual

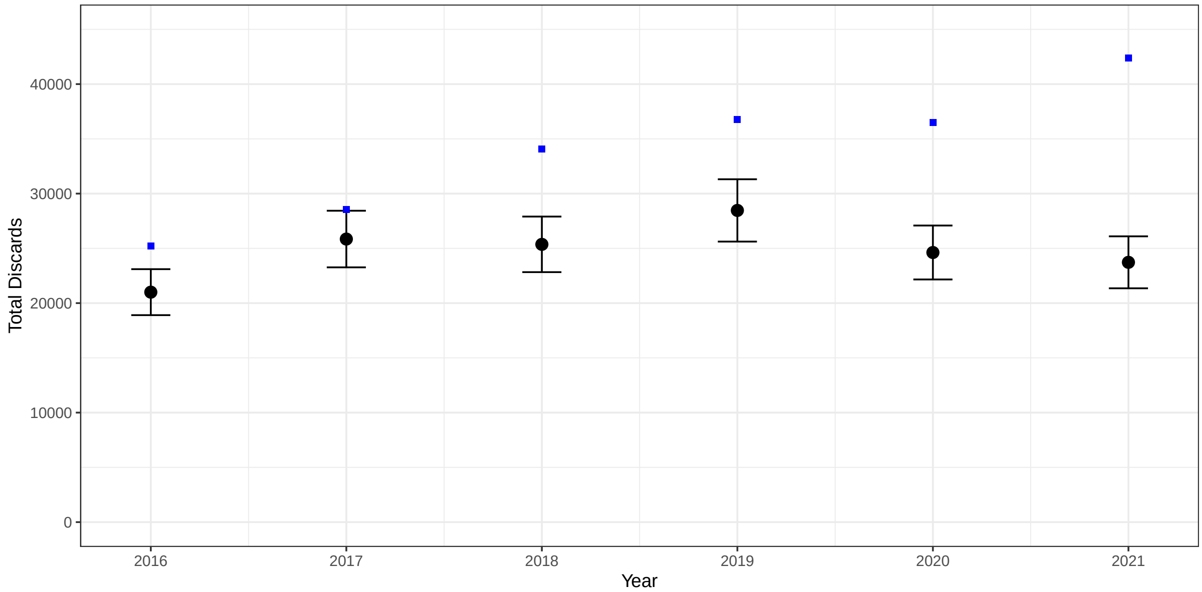

Figure C.56: Scenario 9 model fit to total discards for recreational-charter-Indigenous fleet—circles and error bars represent input data and their associated coefficients of variation and blue points represent the model predictions

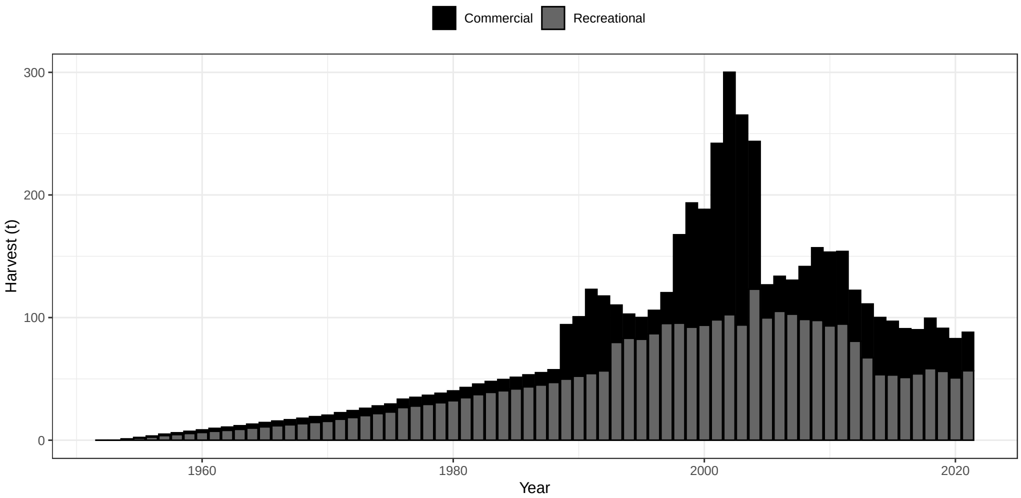

Figure C.57: Scenario 9 modelled harvest of red emperor

Scenario 10

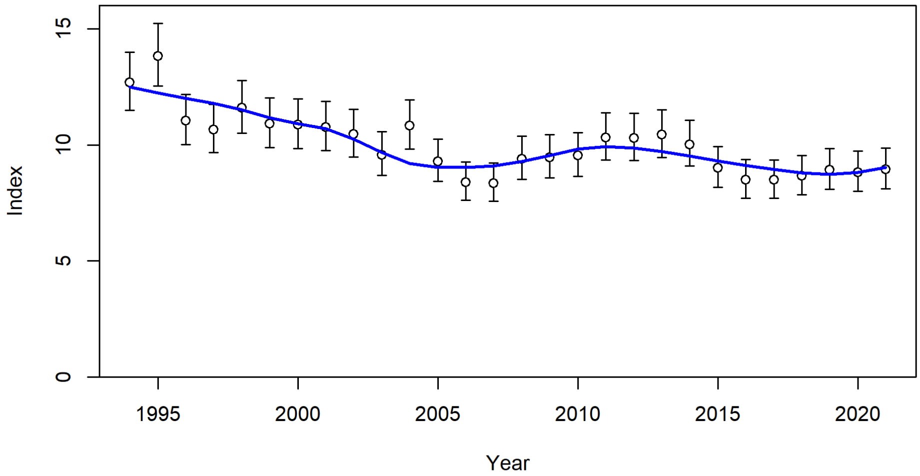

Figure C.58: Scenario 10 model predictions (blue line) to commercial catch rates for red emperor prior to rezoning

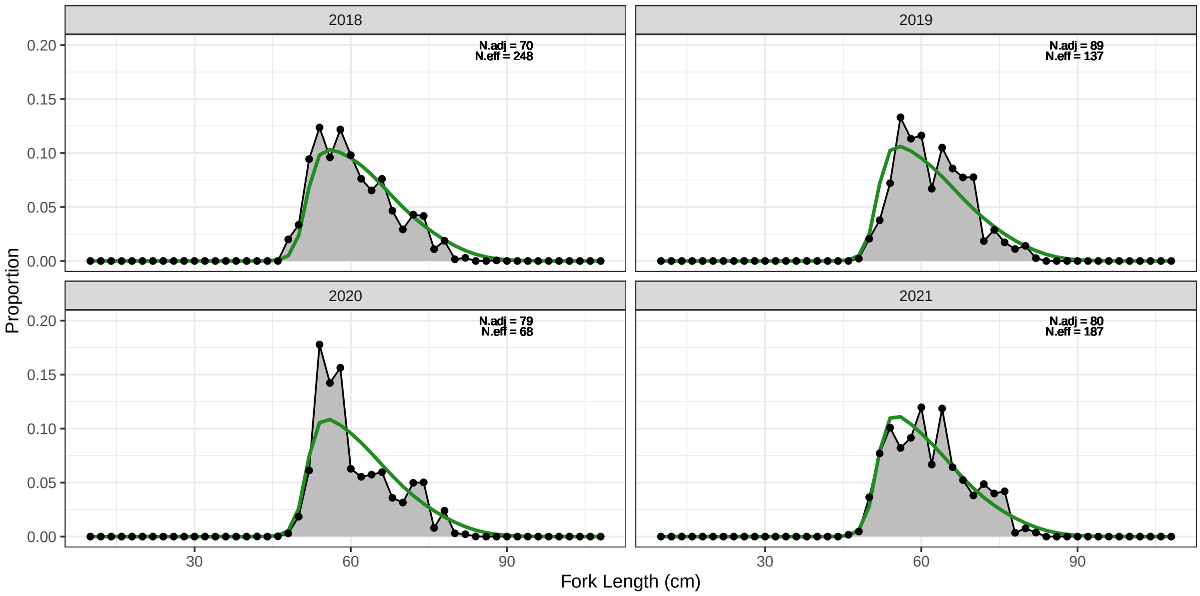

Figure C.59: Scenario 10 length structure for the commercial fleet for red emperor

'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

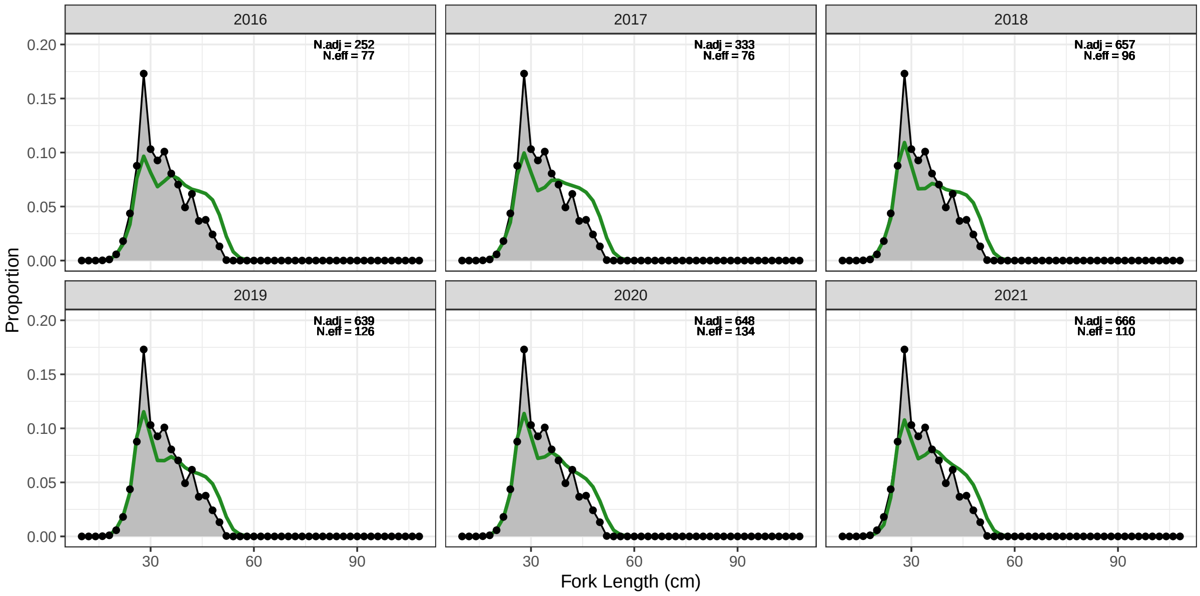

Figure C.60: Scenario 10 length structure for the recreational fleet for discarded red emperor

'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

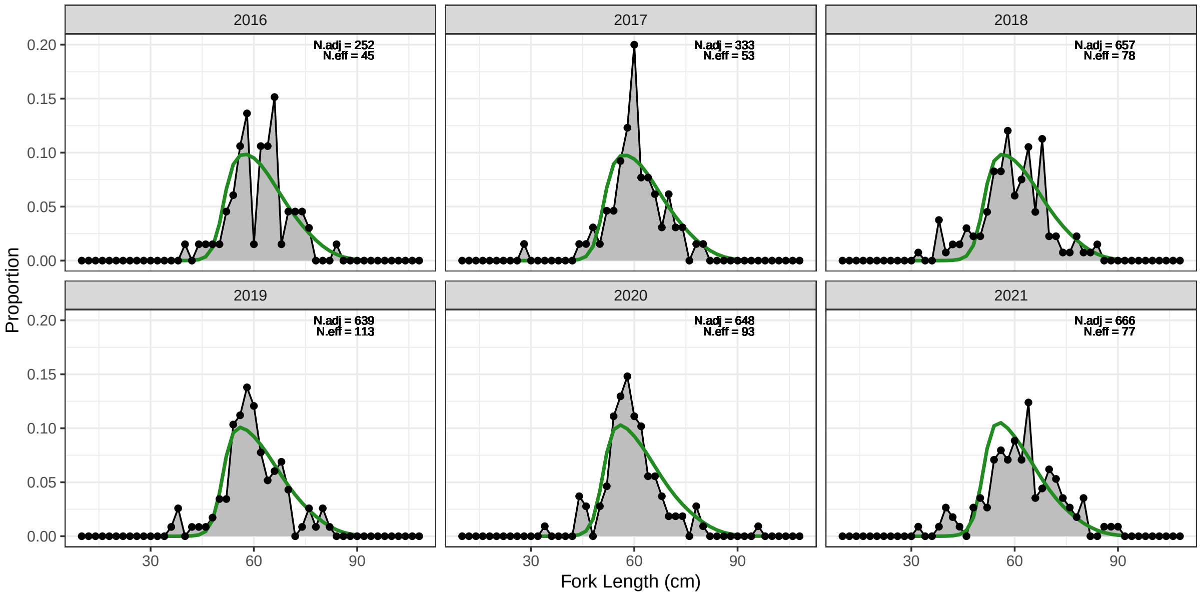

Figure C.61: Scenario 10 length structure for the recreational fleet for retained red emperor

'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

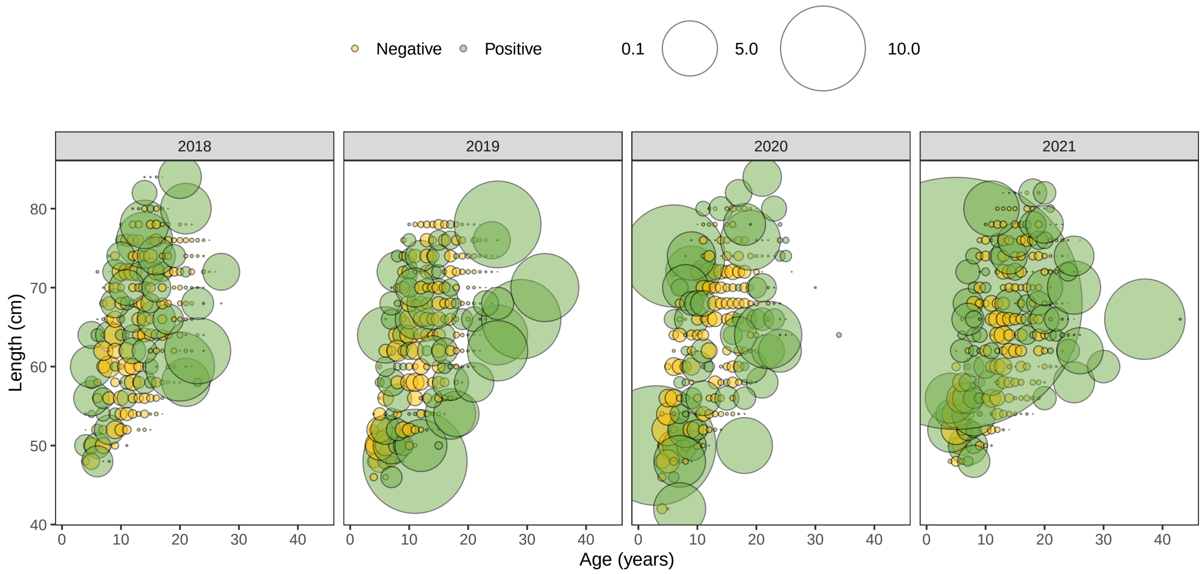

Figure C.62: Scenario 10 Pearson residuals for age-at-length compositions for the commercial fleet for red emperor—circle size represents the magnitude of the Pearson residual

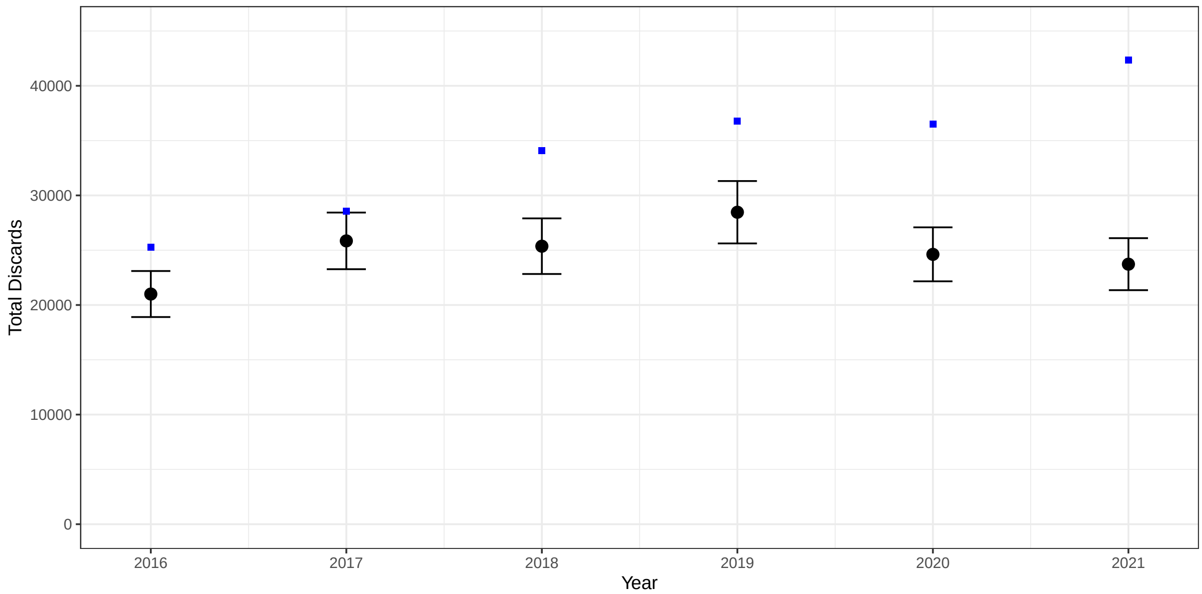

Figure C.63: Scenario 10 model fit to total discards for recreational-charter-Indigenous fleet—circles and error bars represent input data and their associated coefficients of variation and blue points represent the model predictions

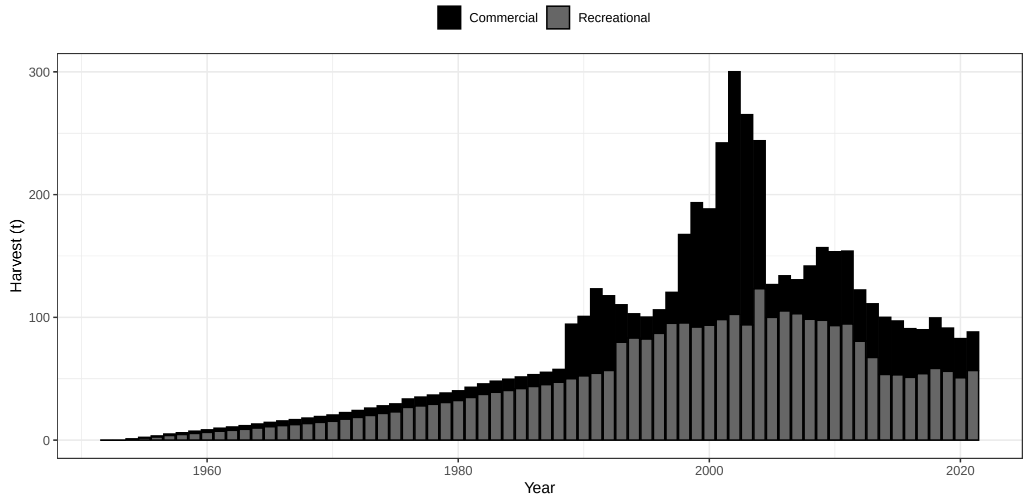

Figure C.64: Scenario 10 modelled harvest of red emperor

Scenario 11

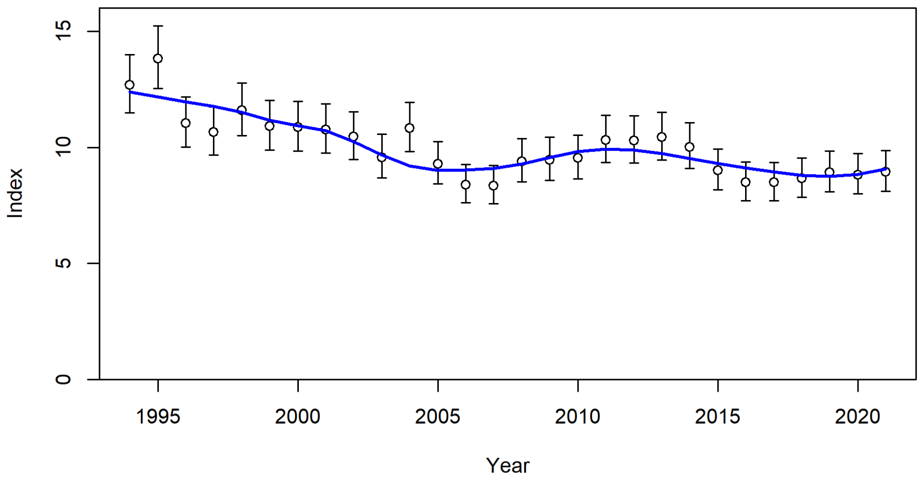

Figure C.65: Scenario 11 model predictions (blue line) to commercial catch rates for red emperor prior to rezoning

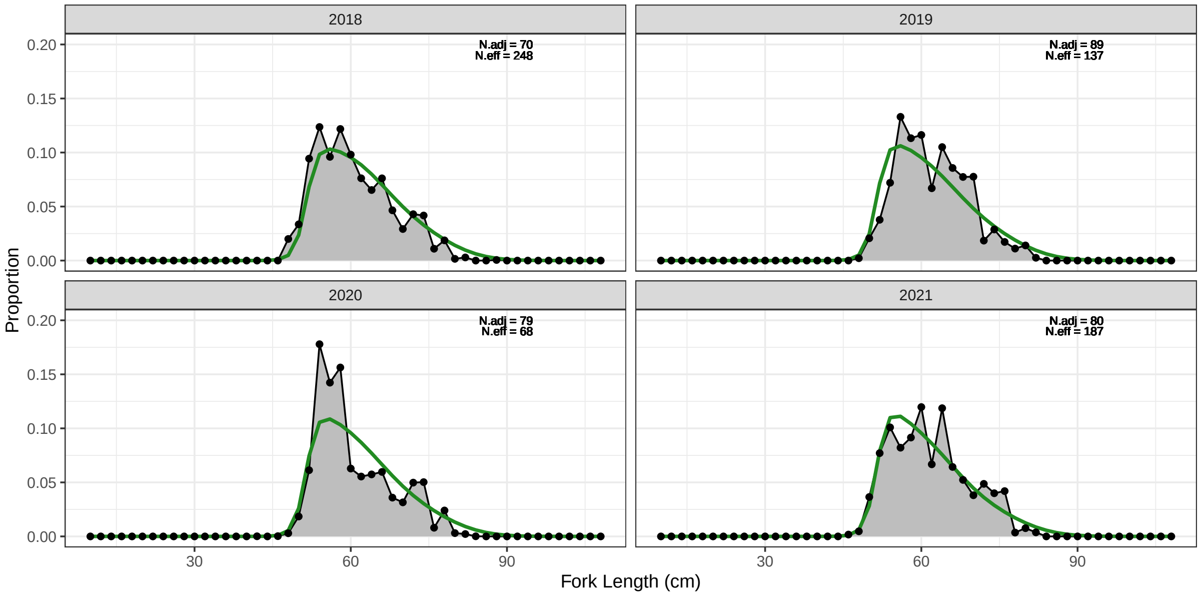

Figure C.66: Scenario 11 length structure for the commercial fleet for red emperor

'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

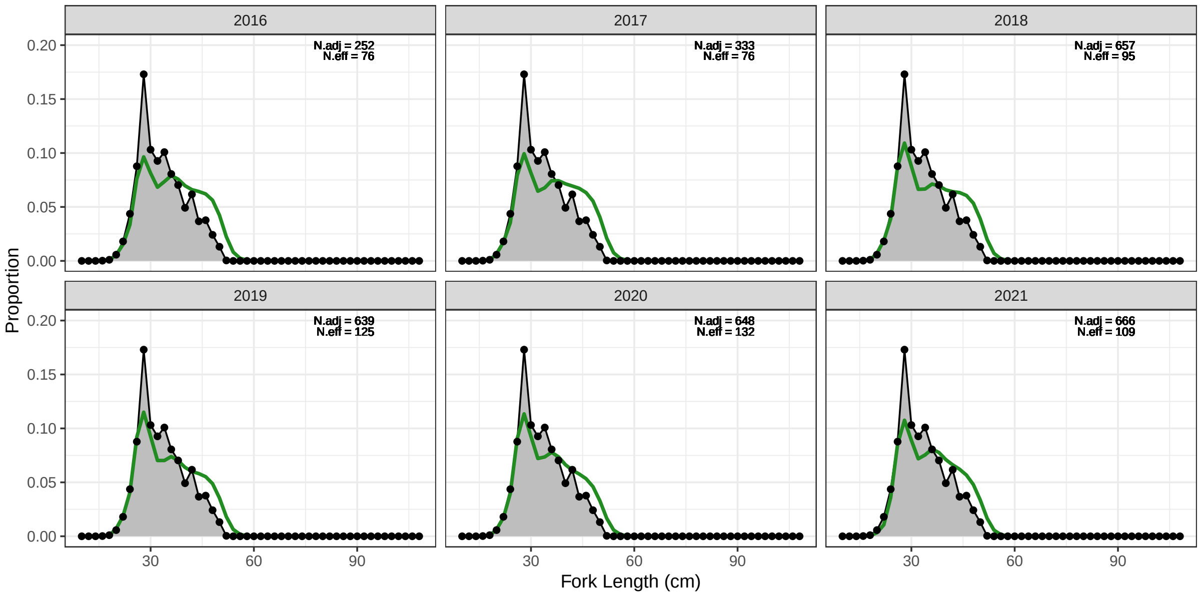

Figure C.67: Scenario 11 length structure for the recreational fleet for discarded red emperor

'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

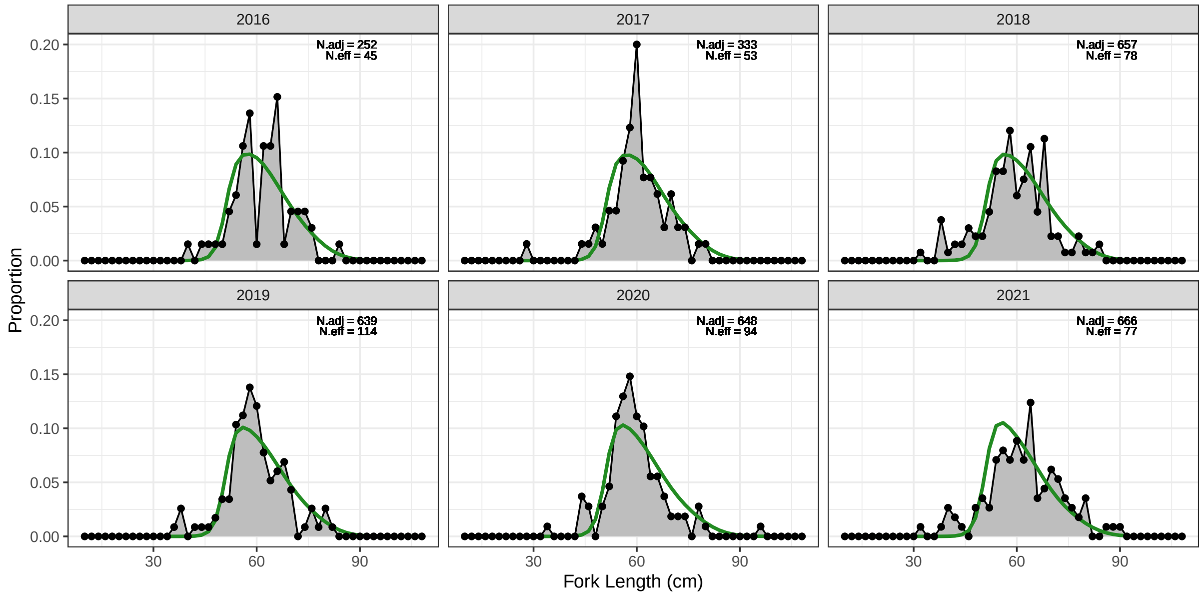

Figure C.68: Scenario 11 length structure for the recreational fleet for retained red emperor

'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

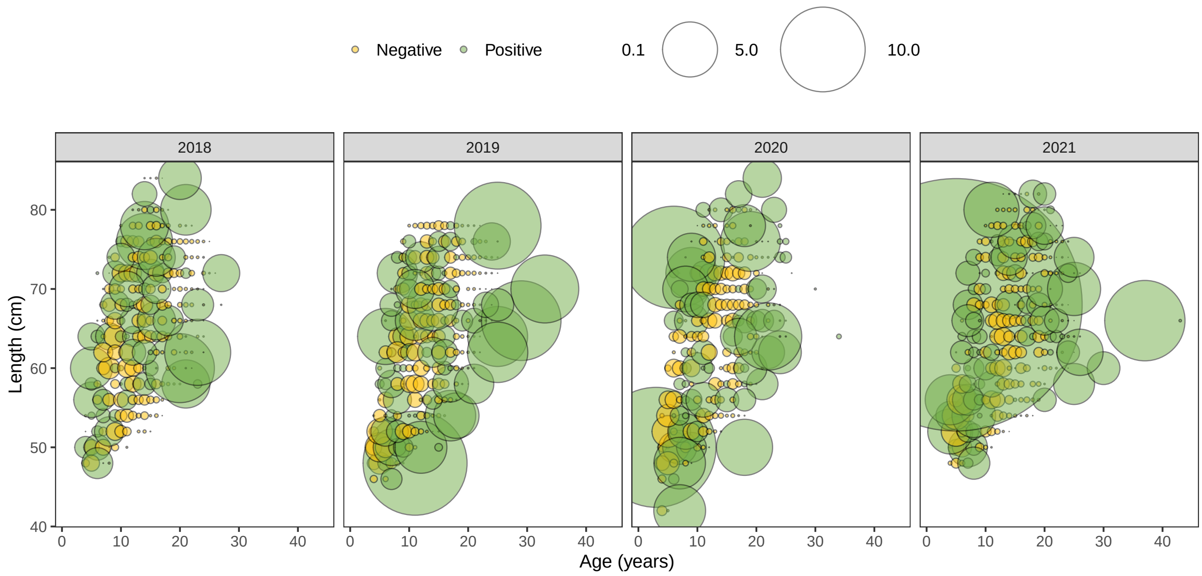

Figure C.69: Scenario 11 Pearson residuals for age-at-length compositions for the commercial fleet for red emperor—circle size represents the magnitude of the Pearson residual

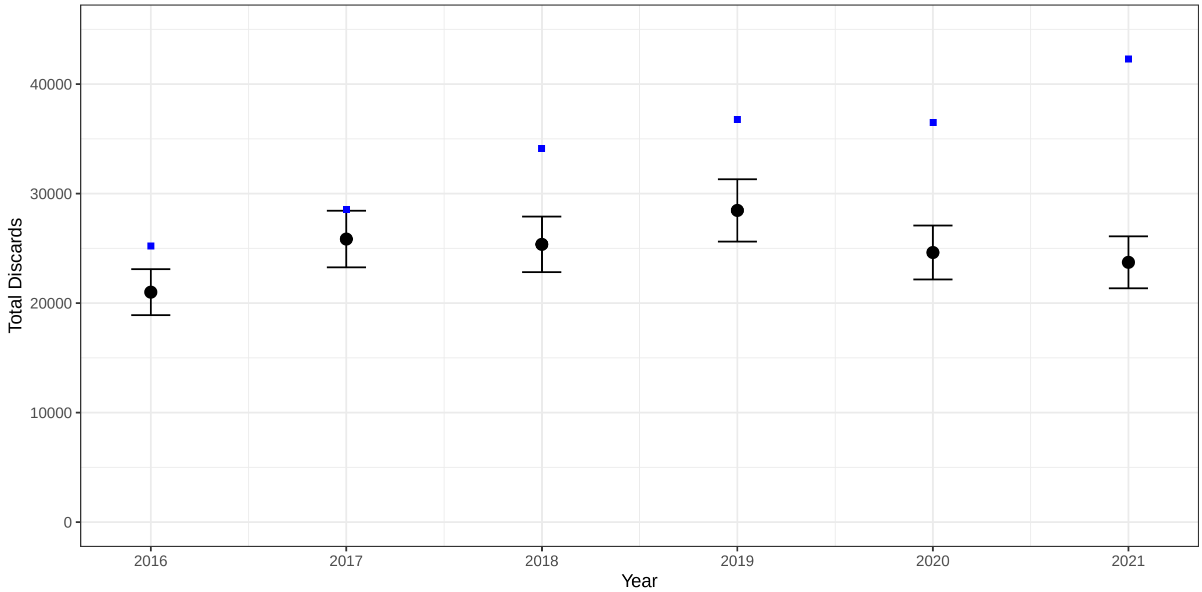

Figure C.70: Scenario 11 model fit to total discards for recreational-charter-Indigenous fleet—circles and error bars represent input data and their associated coefficients of variation and blue points represent the model predictions

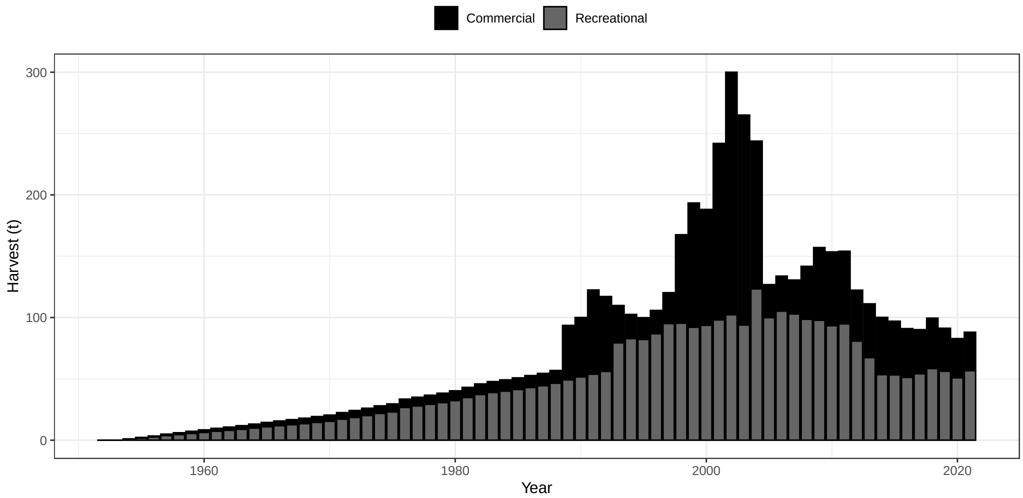

Figure C.71: Scenario 11 modelled harvest of red emperor

Scenario 12

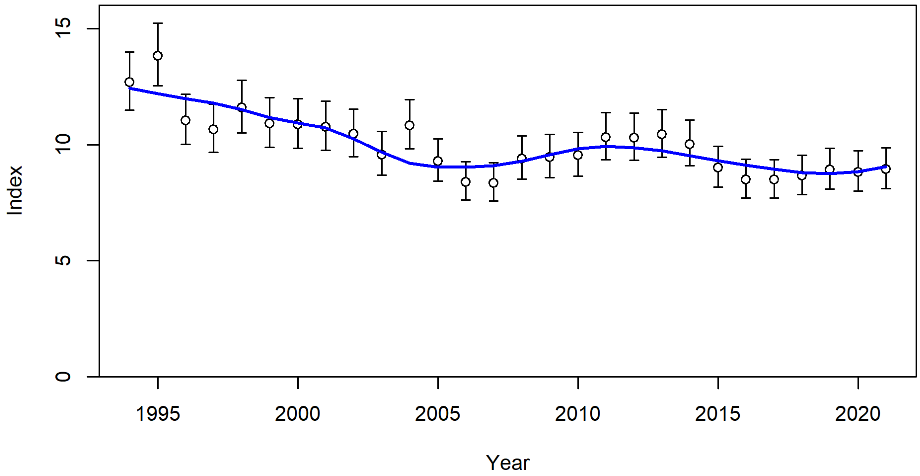

Figure C.72: Scenario 12 model predictions (blue line) to commercial catch rates for red emperor prior to rezoning

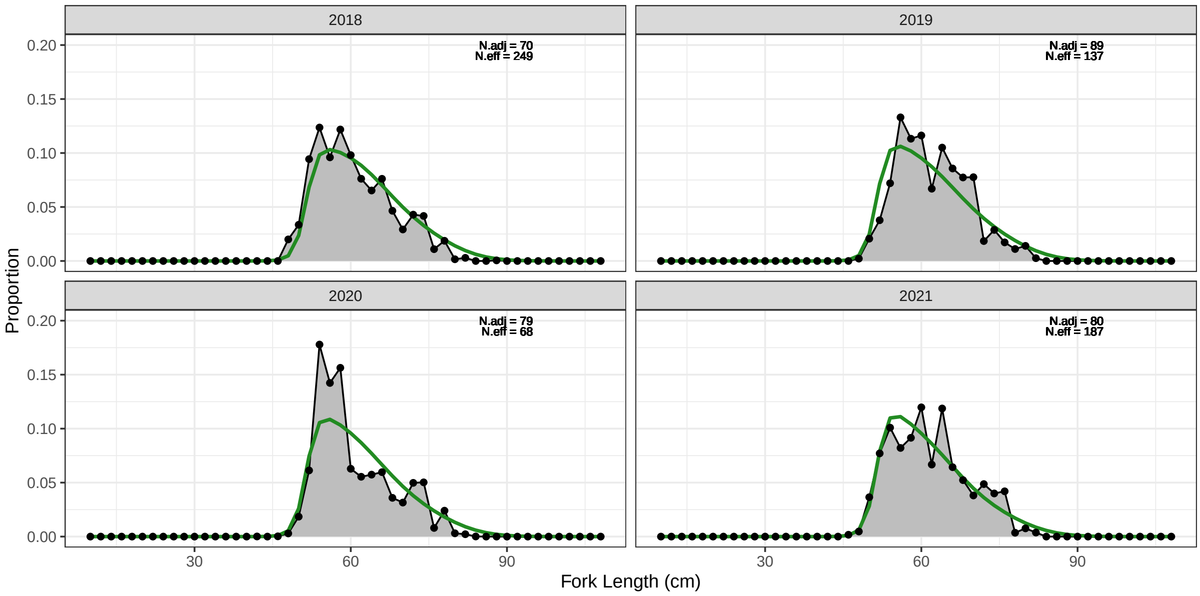

Figure C.73: Scenario 12 length structure for the commercial fleet for red emperor

'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

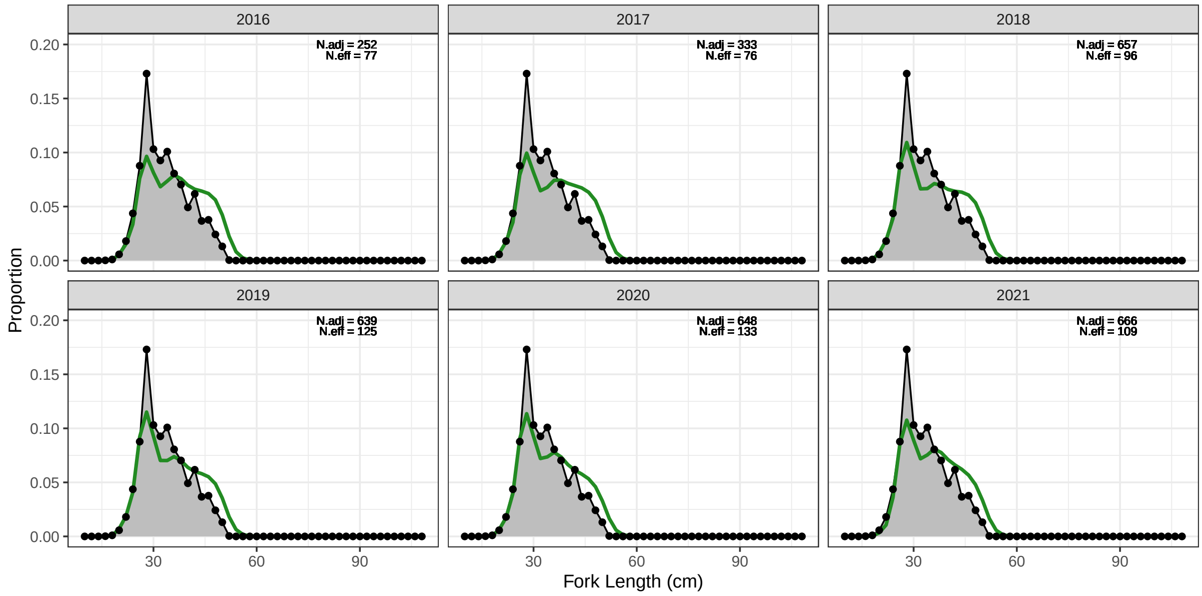

Figure C.74: Scenario 12 length structure for the recreational fleet for discarded red emperor

'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

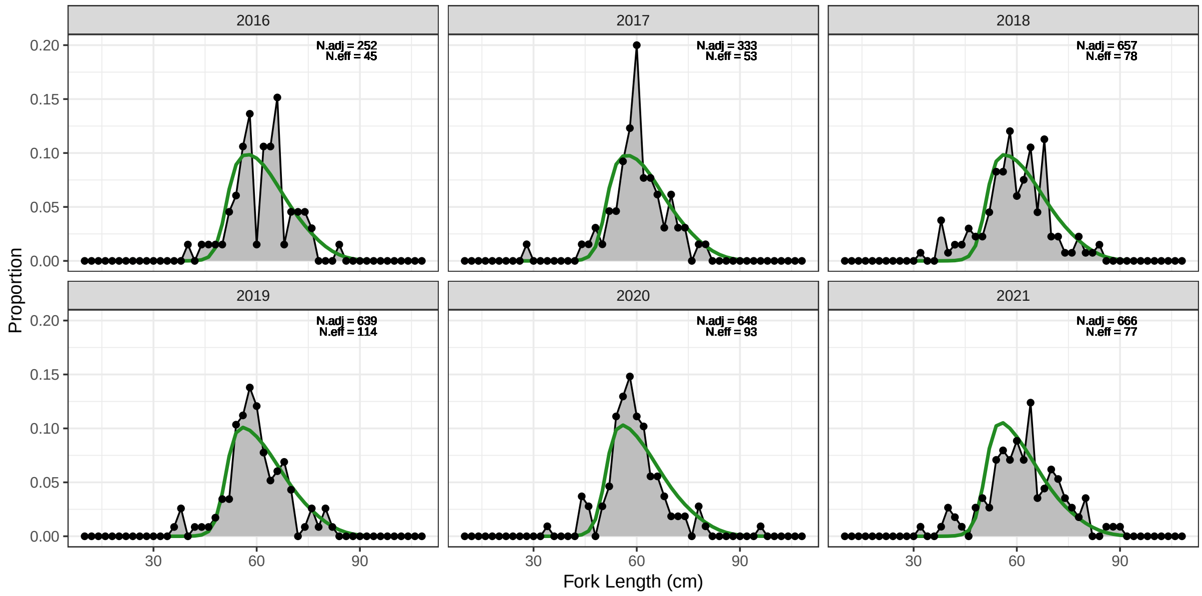

Figure C.75: Scenario 12 length structure for the recreational fleet for retained red emperor

'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

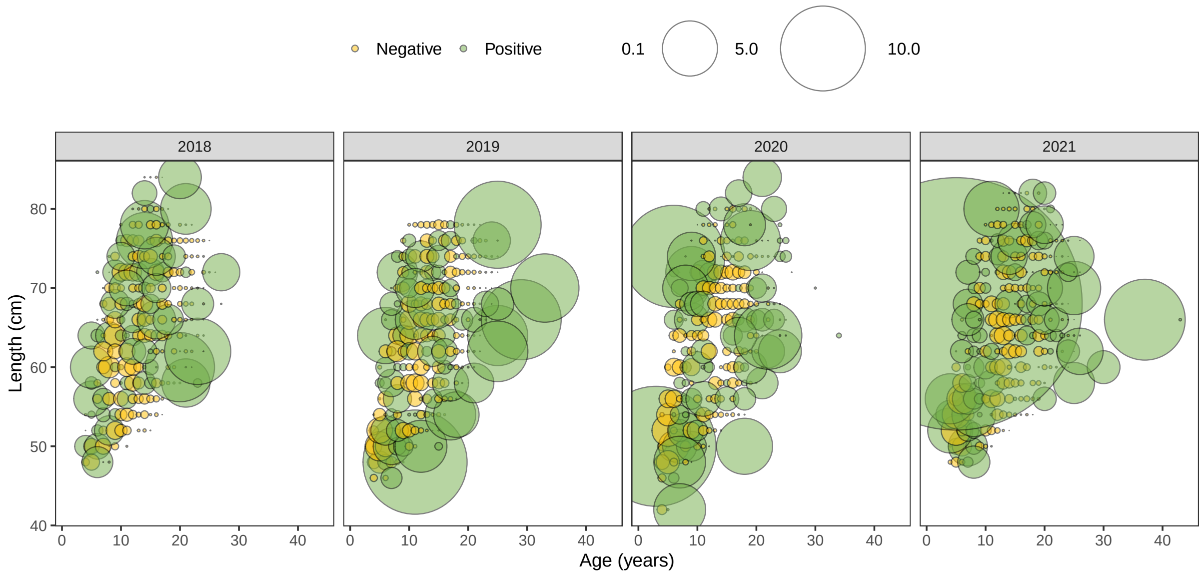

Figure C.76: Scenario 12 Pearson residuals for age-at-length compositions for the commercial fleet for red emperor—circle size represents the magnitude of the Pearson residual

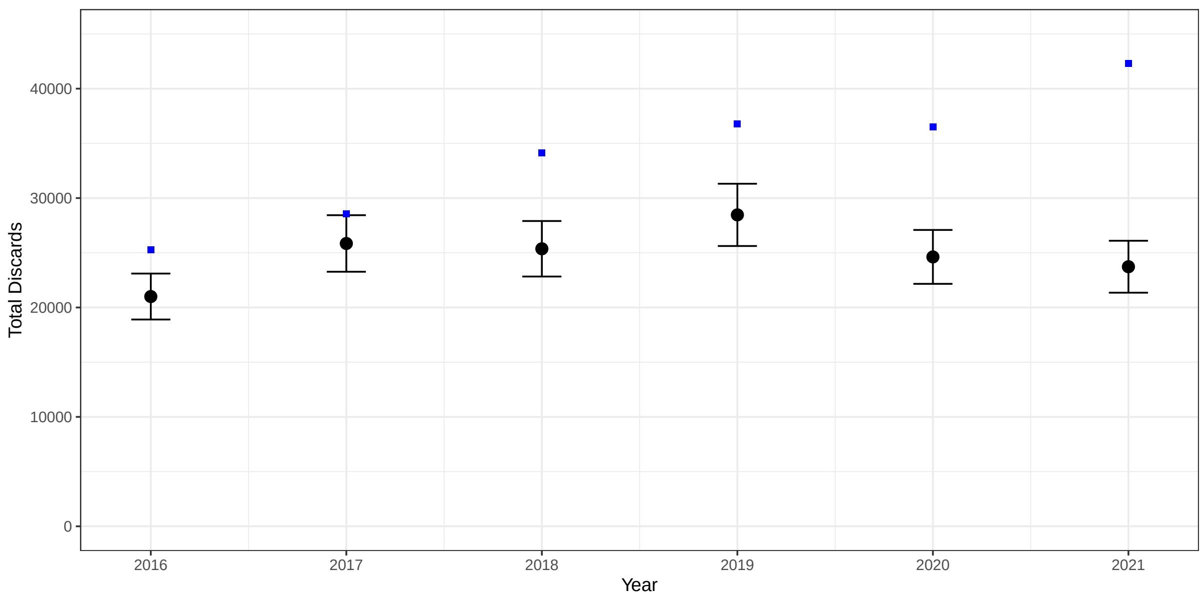

Figure C.77: Scenario 12 model fit to total discards for recreational-charter-Indigenous fleet—circles and error bars represent input data and their associated coefficients of variation and blue points represent the model predictions

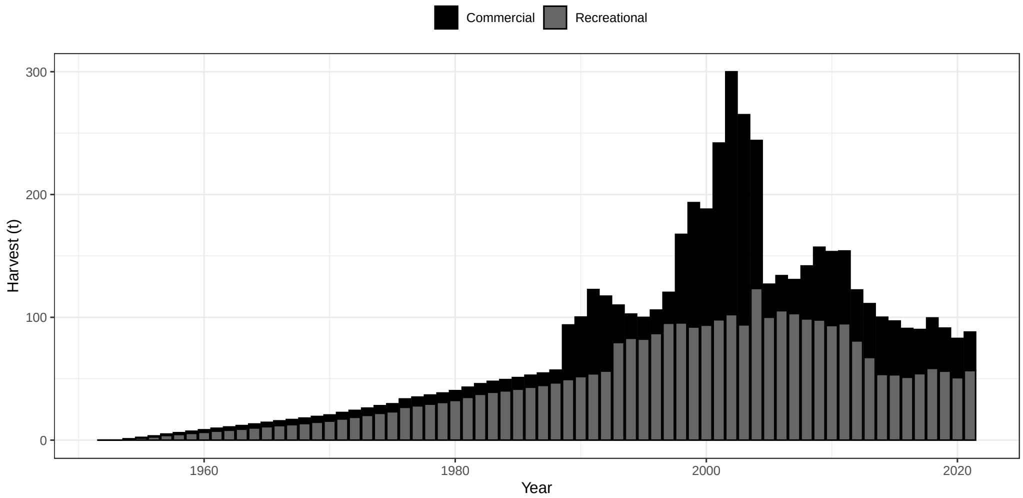

Figure C.78: Scenario 12 modelled harvest of red emperor

Scenario 13

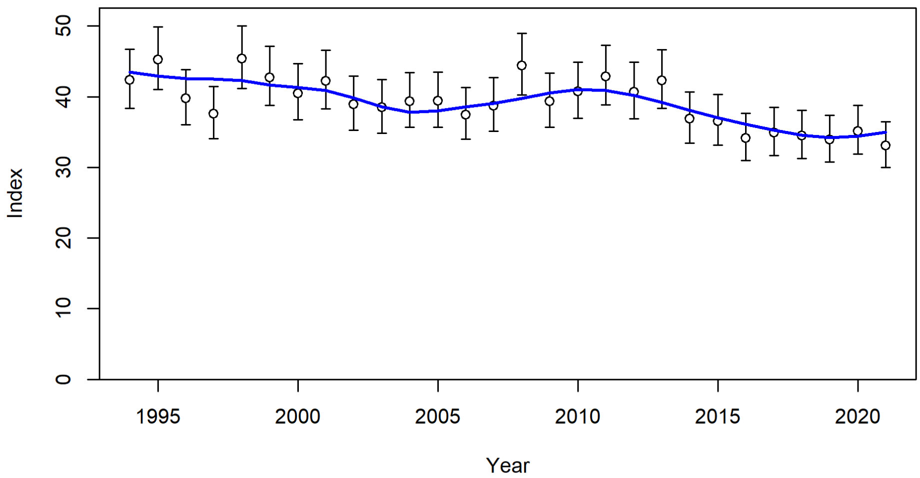

Figure C.79: Scenario 13 model predictions (blue line) to commercial catch rates for red emperor prior to rezoning

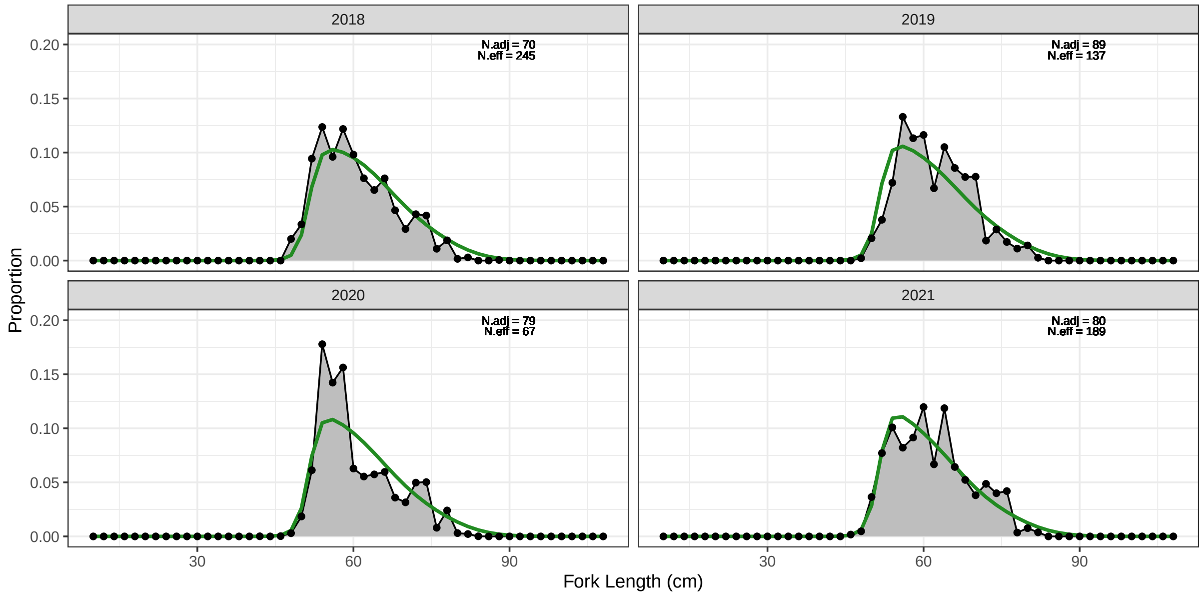

Figure C.80: Scenario 13 length structure for the commercial fleet for red emperor

'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

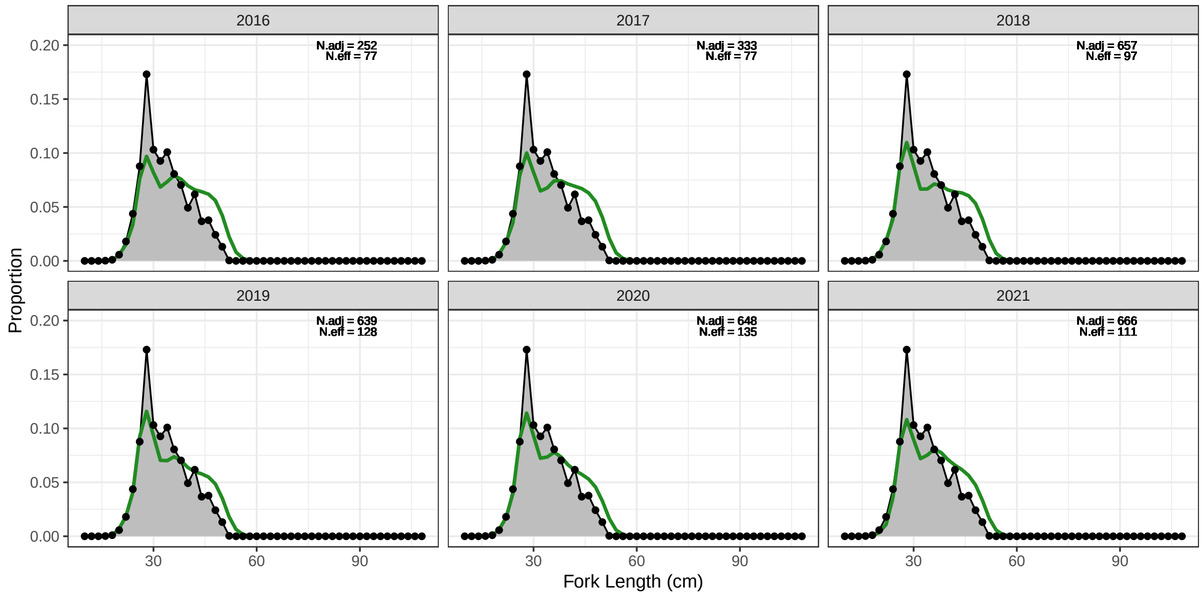

Figure C.81: Scenario 13 length structure for the recreational fleet for discarded red emperor

'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

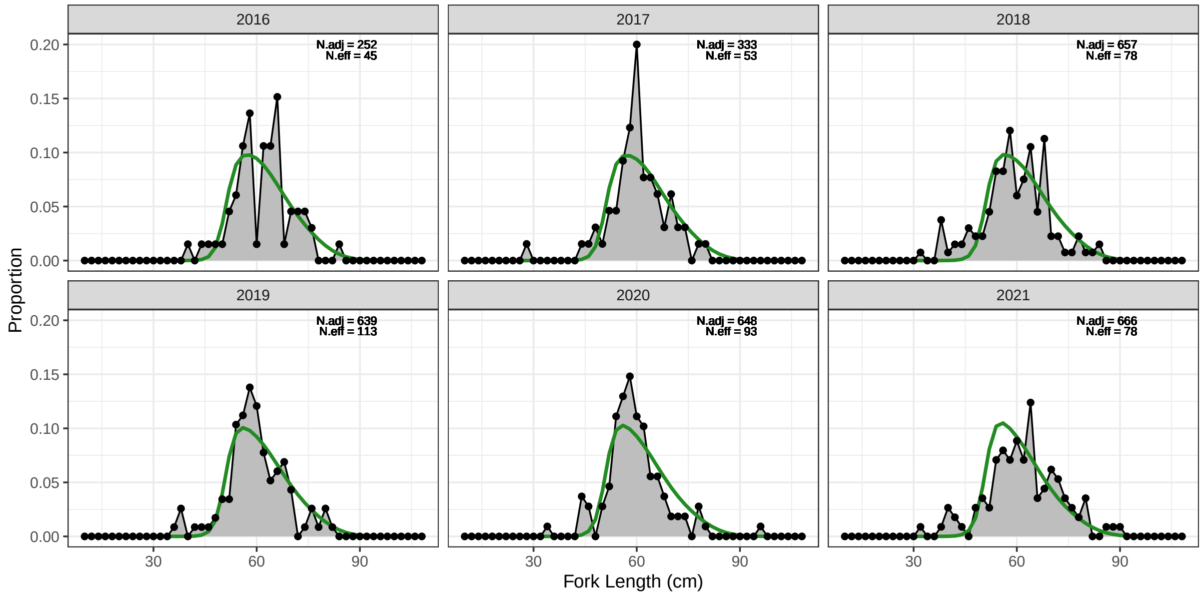

Figure C.82: Scenario 13 length structure for the recreational fleet for retained red emperor

'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

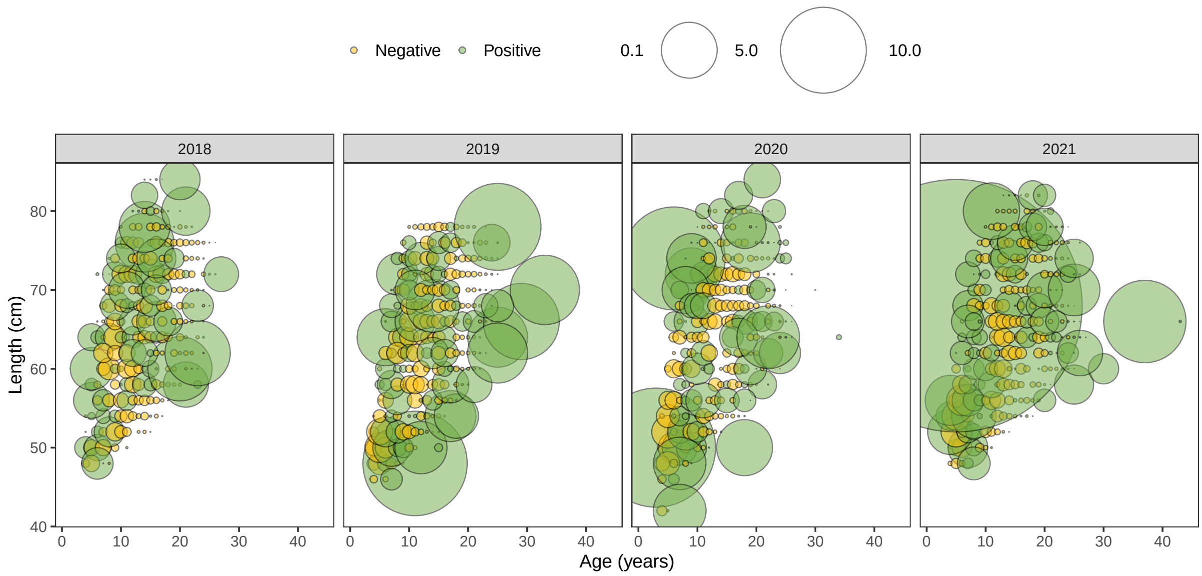

Figure C.83: Scenario 13 Pearson residuals for age-at-length compositions for the commercial fleet for red emperor—circle size represents the magnitude of the Pearson residual

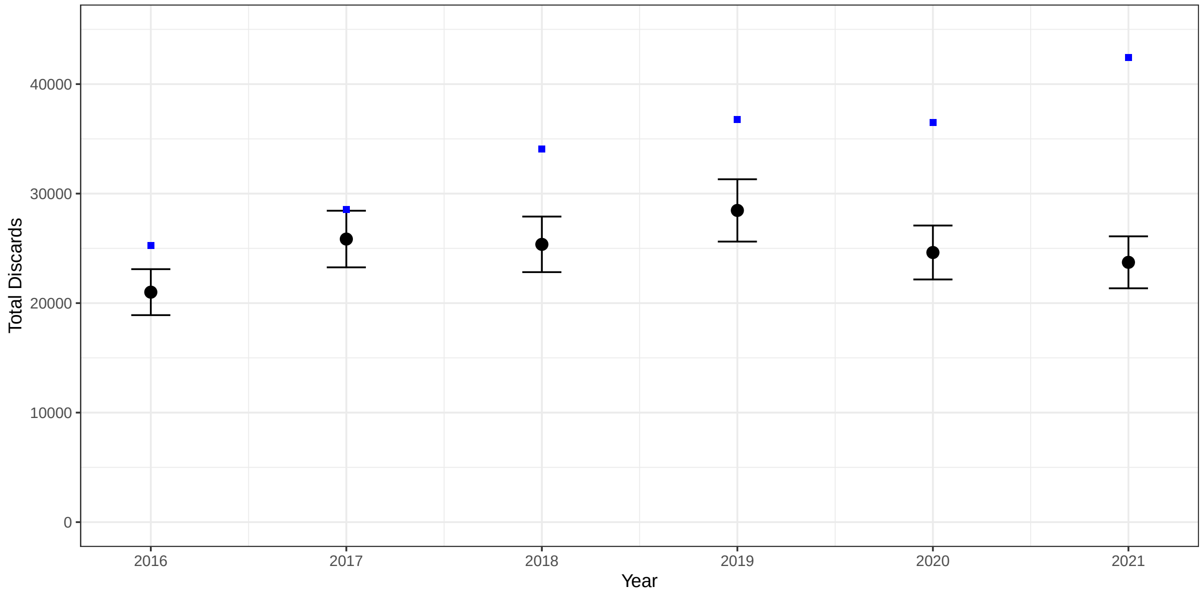

Figure C.84: Scenario 13 model fit to total discards for recreational-charter-Indigenous fleet—circles and error bars represent input data and their associated coefficients of variation and blue points represent the model predictions

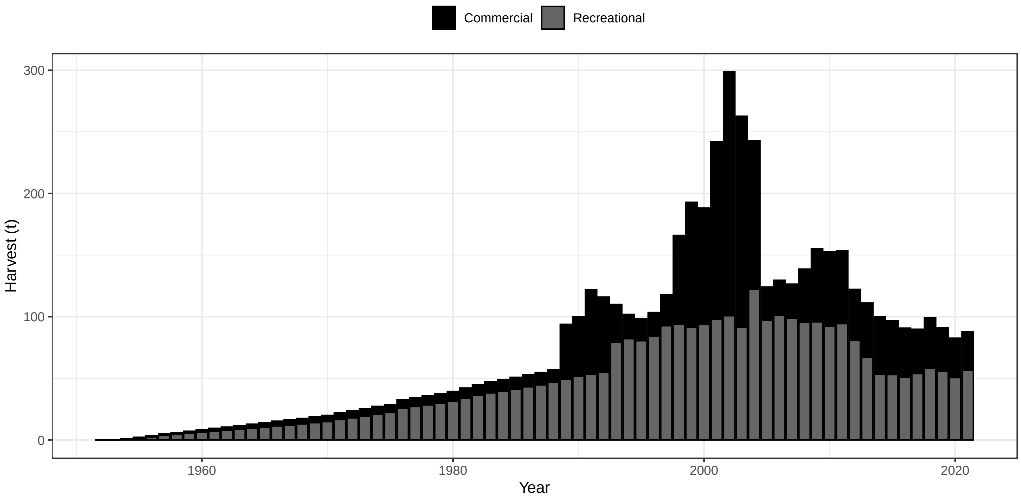

Figure C.85: Scenario 13 modelled harvest of red emperor

Scenario 14

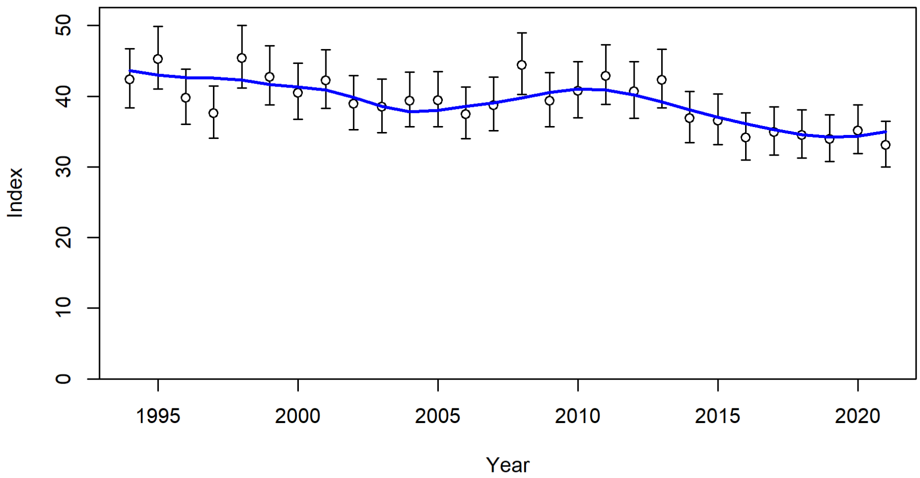

Figure C.86: Scenario 14 model predictions (blue line) to commercial catch rates for red emperor prior to rezoning

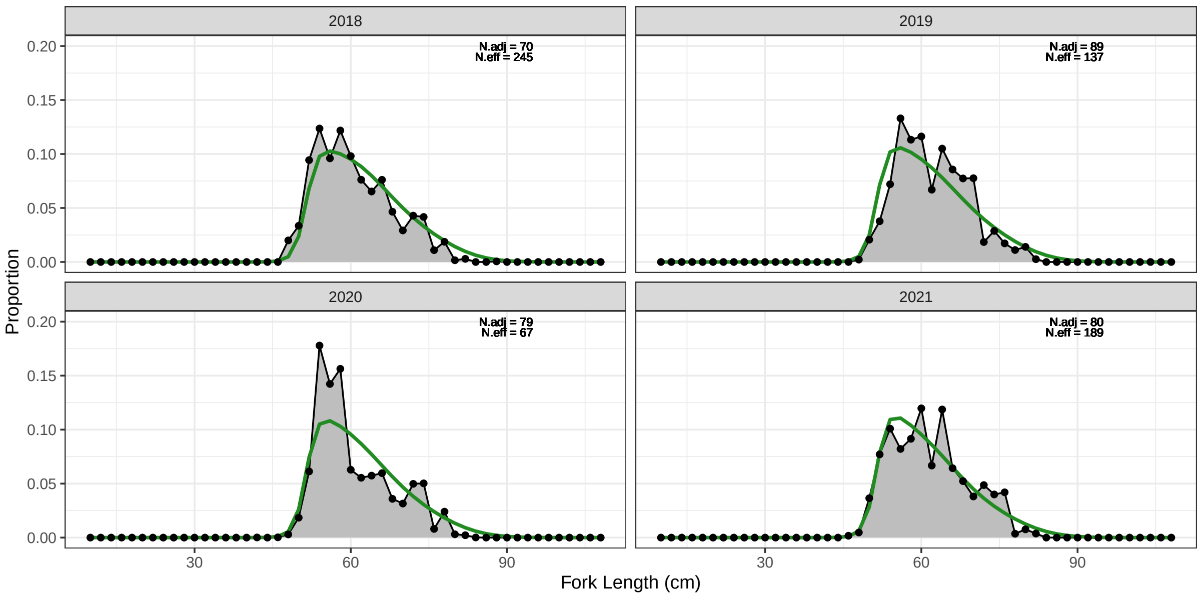

Figure C.87: Scenario 14 length structure for the commercial fleet for red emperor

'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

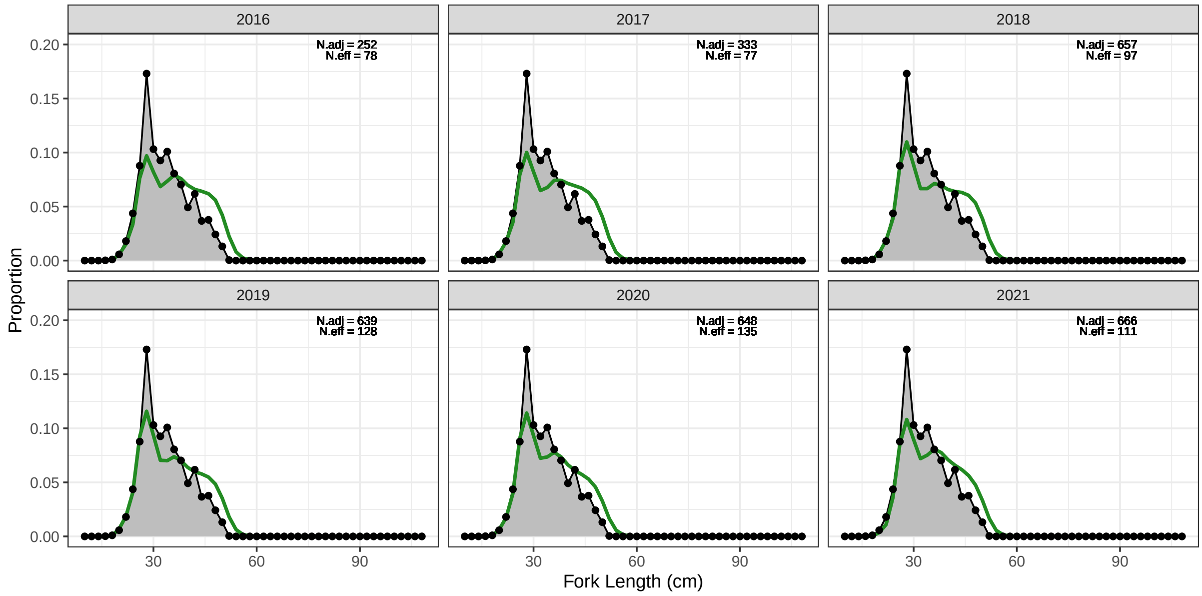

Figure C.88: Scenario 14 length structure for the recreational fleet for discarded red emperor

'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

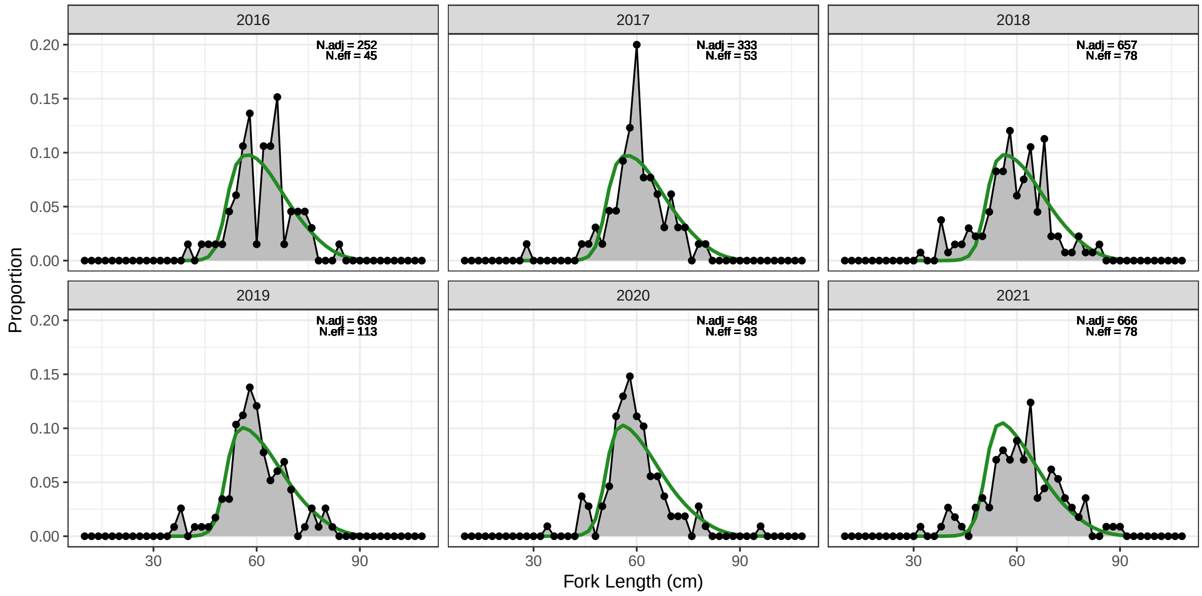

Figure C.89: Scenario 14 length structure for the recreational fleet for retained red emperor

'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

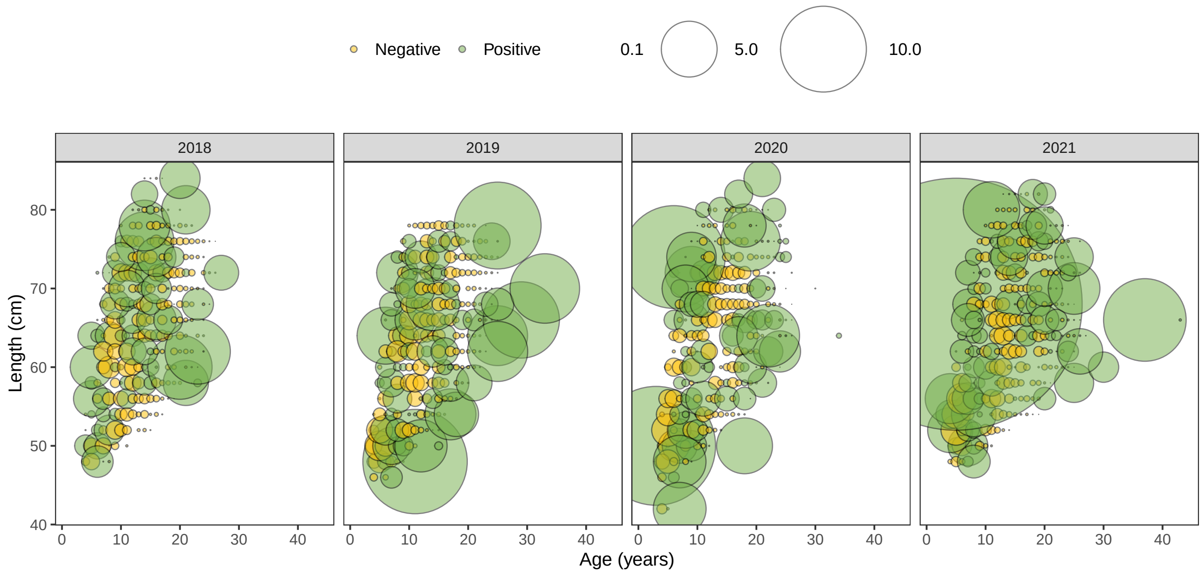

Figure C.90: Scenario 14 Pearson residuals for age-at-length compositions for the commercial fleet for red emperor—circle size represents the magnitude of the Pearson residual

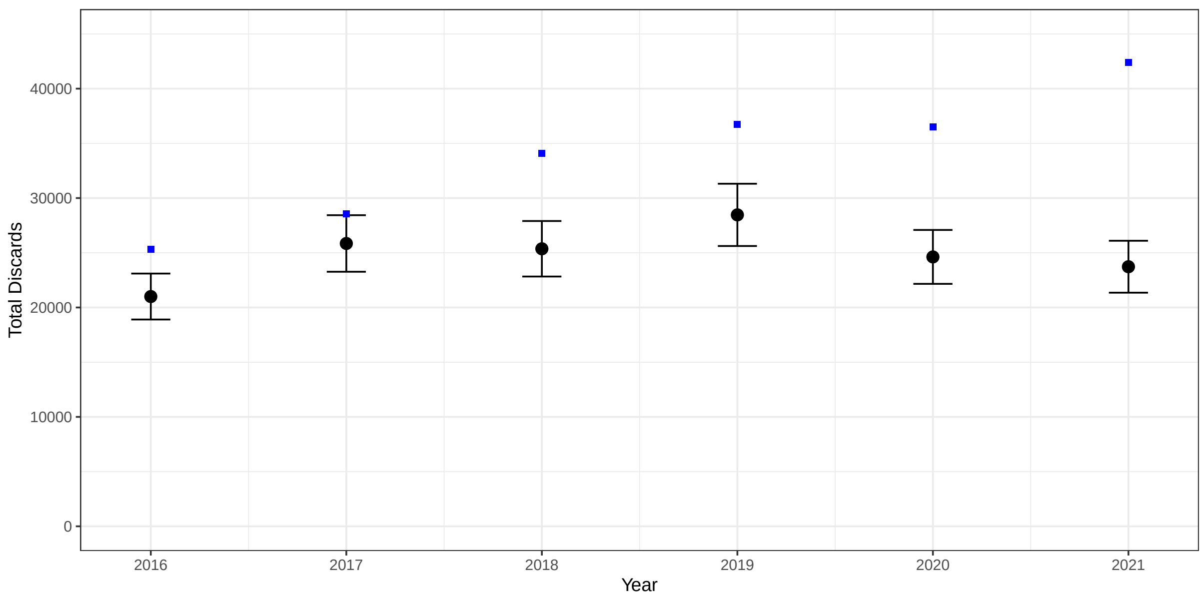

Figure C.91: Scenario 14 model fit to total discards for recreational-charter-Indigenous fleet—circles and error bars represent input data and their associated coefficients of variation and blue points represent the model predictions

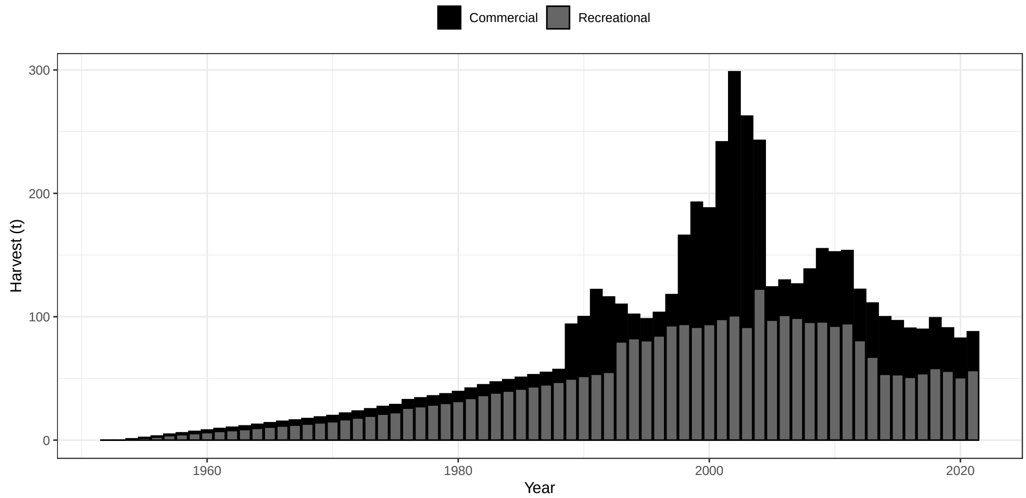

Figure C.92: Scenario 14 modelled harvest of red emperor

Scenario 15

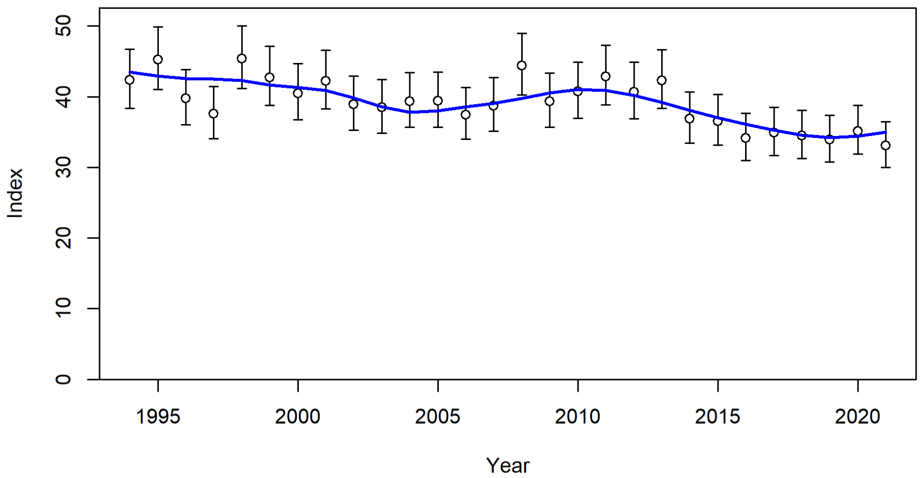

Figure C.93: Scenario 15 model predictions (blue line) to commercial catch rates for red emperor prior to rezoning

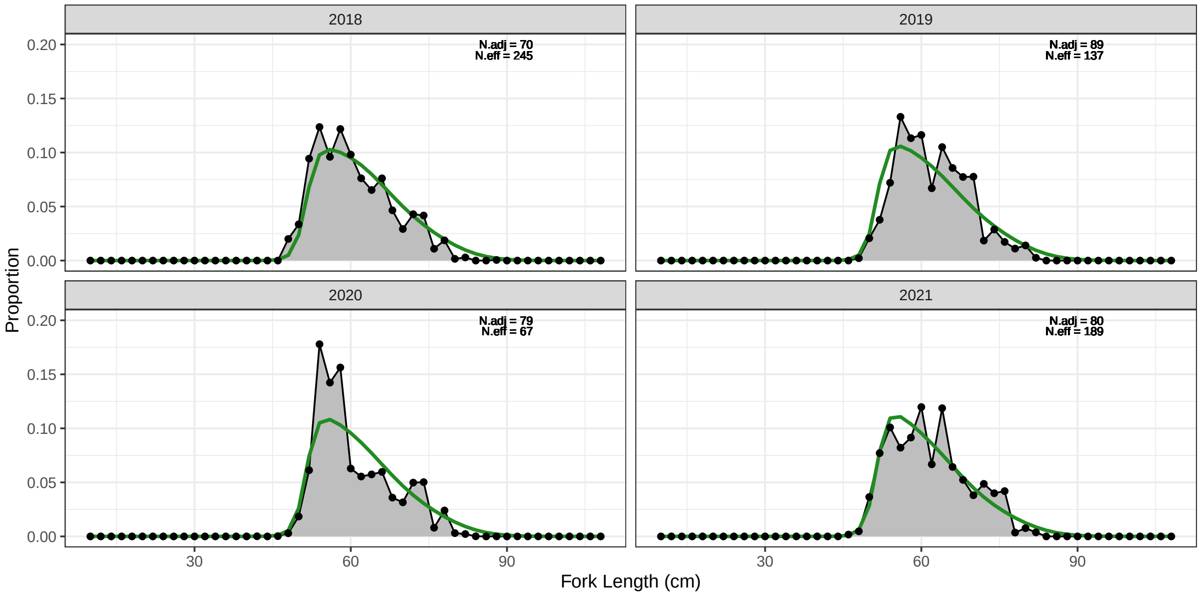

Figure C.94: Scenario 15 length structure for the commercial fleet for red emperor

'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

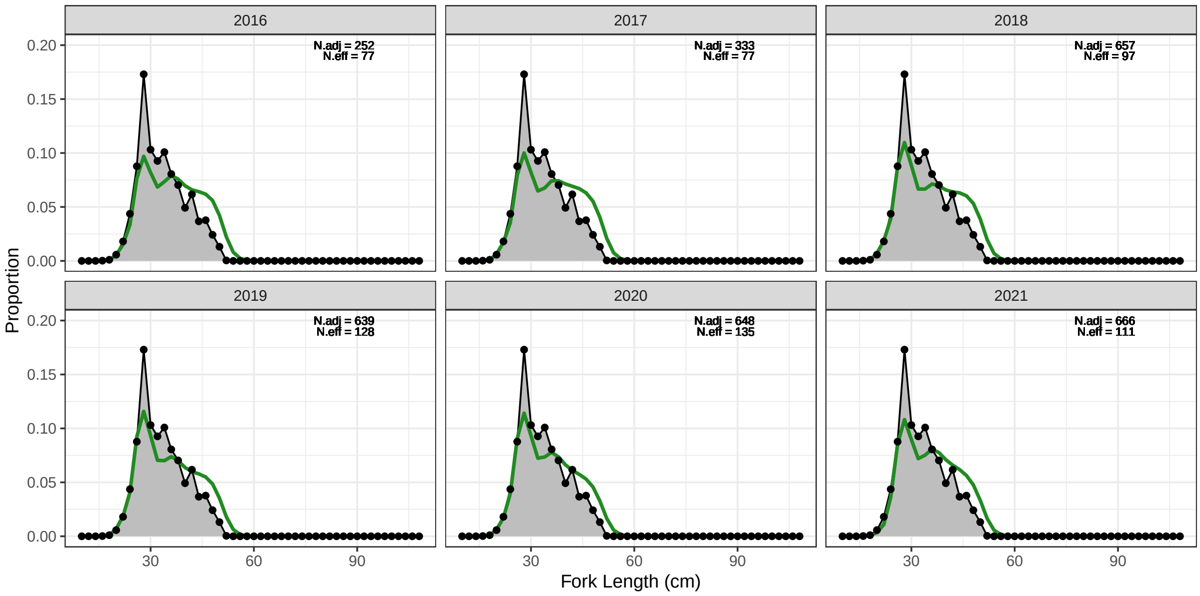

Figure C.95: Scenario 15 length structure for the recreational fleet for discarded red emperor

'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

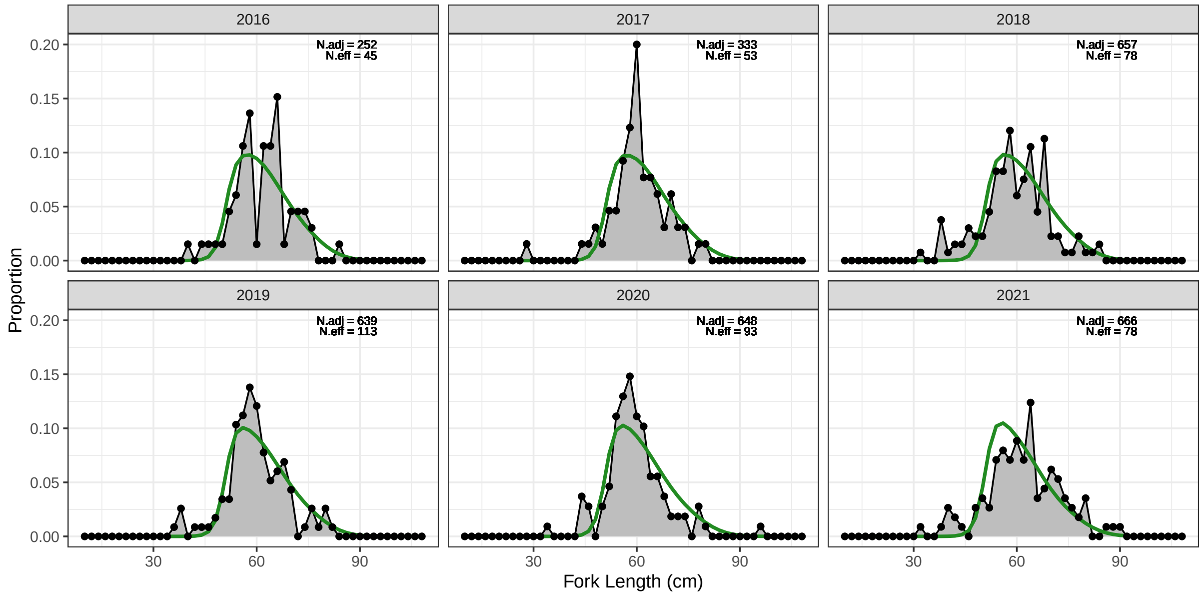

Figure C.96: Scenario 15 length structure for the recreational fleet for retained red emperor

'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

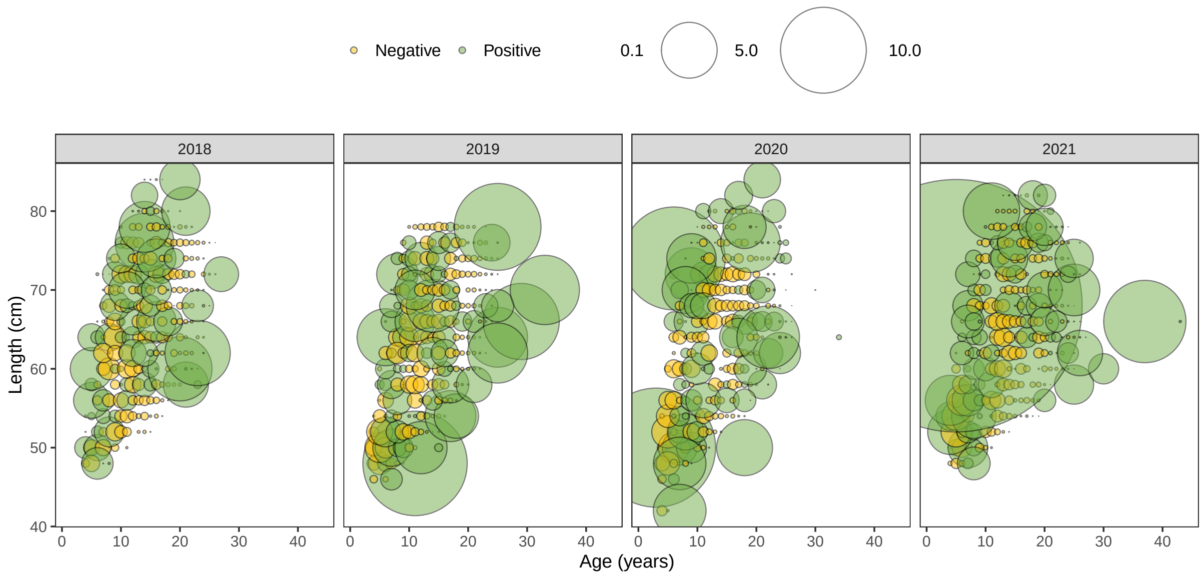

Figure C.97: Scenario 15 Pearson residuals for age-at-length compositions for the commercial fleet for red emperor—circle size represents the magnitude of the Pearson residual

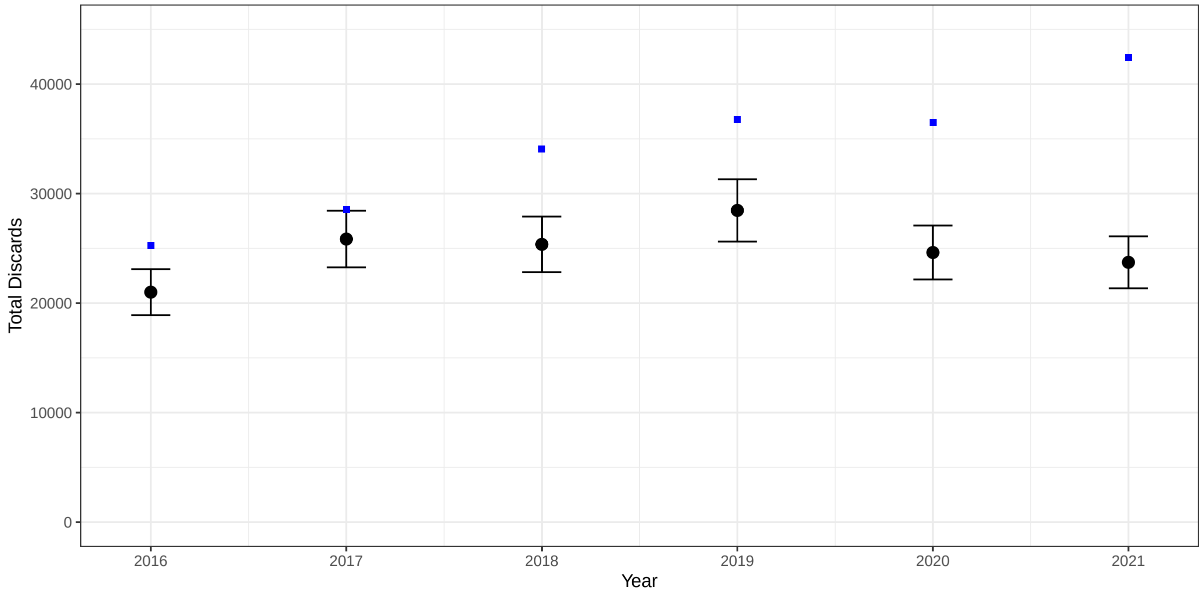

Figure C.98: Scenario 15 model fit to total discards for recreational-charter-Indigenous fleet—circles and error bars represent input data and their associated coefficients of variation and blue points represent the model predictions

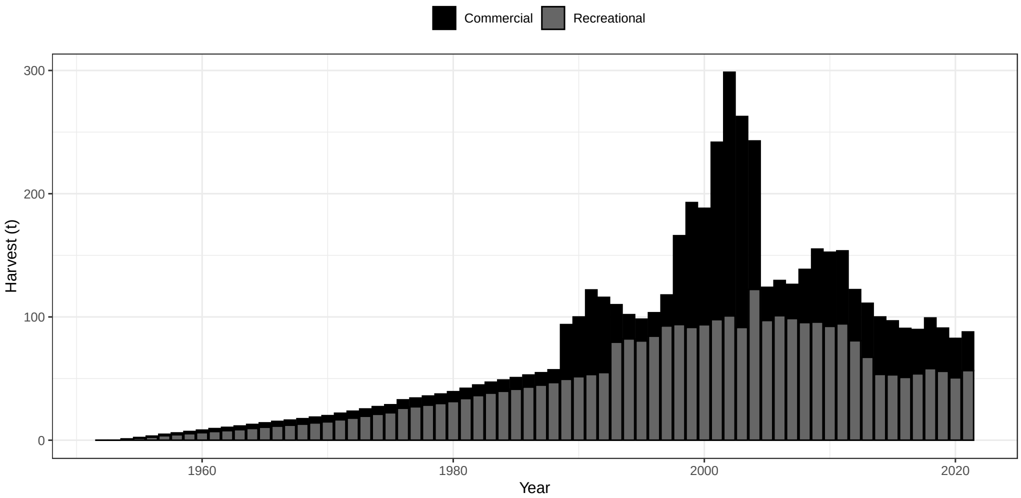

Figure C.99: Scenario 15 modelled harvest of red emperor

Scenario 16

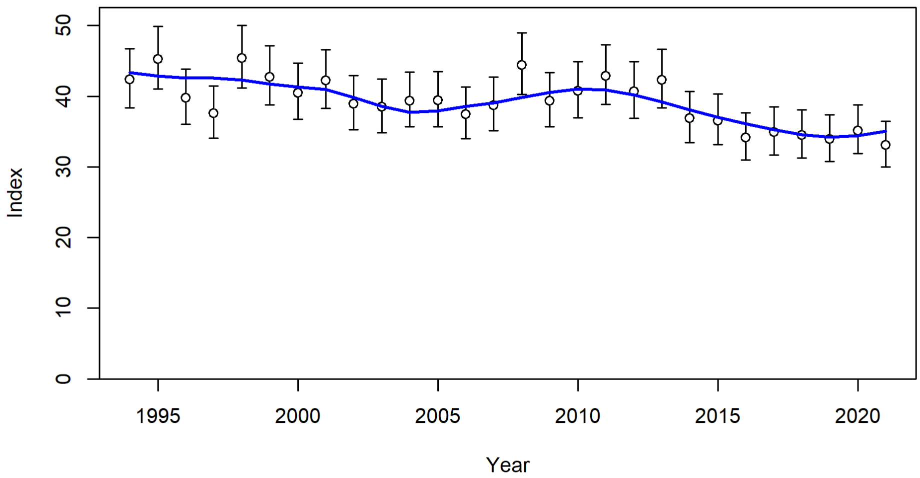

Figure C.100: Scenario 16 model predictions (blue line) to commercial catch rates for red emperor prior to rezoning

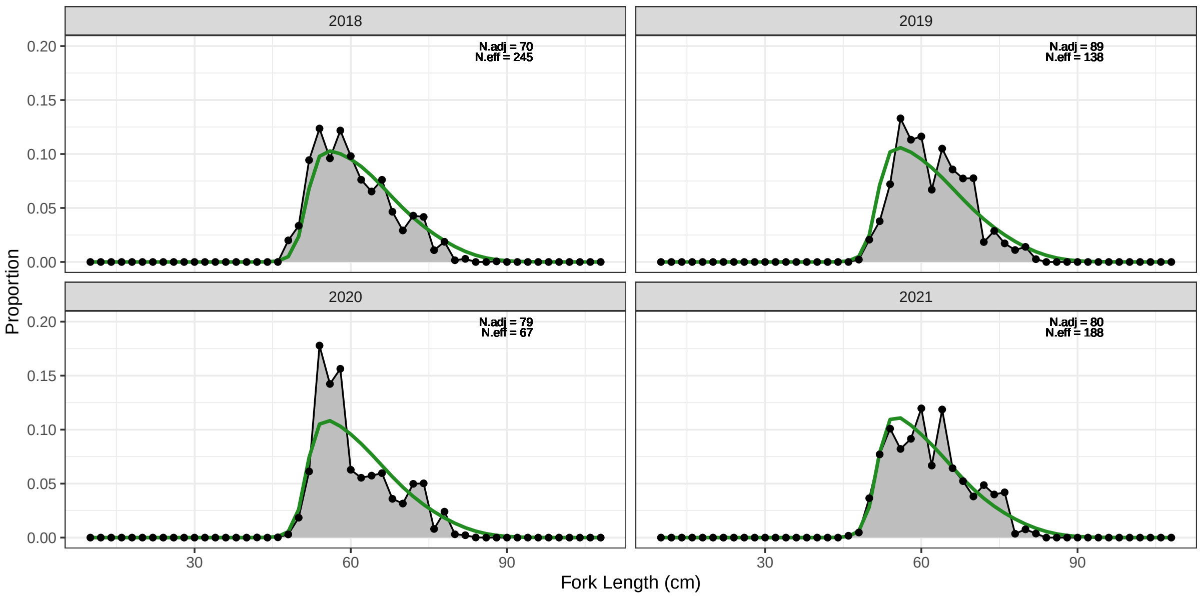

Figure C.101: Scenario 16 length structure for the commercial fleet for red emperor

'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

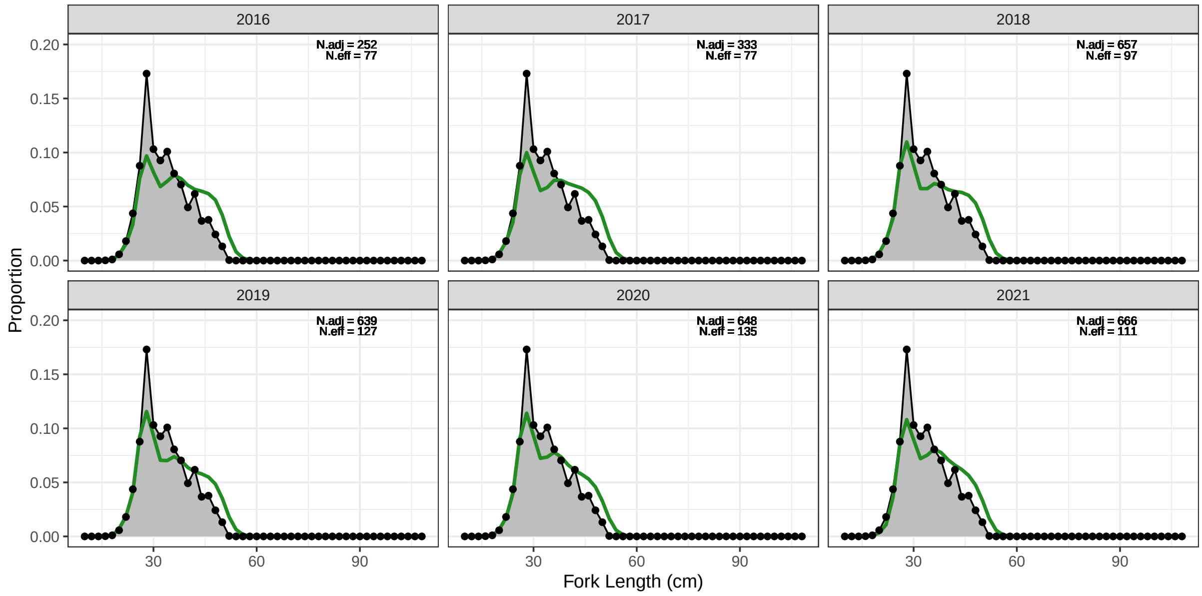

Figure C.102: Scenario 16 length structure for the recreational fleet for discarded red emperor

'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

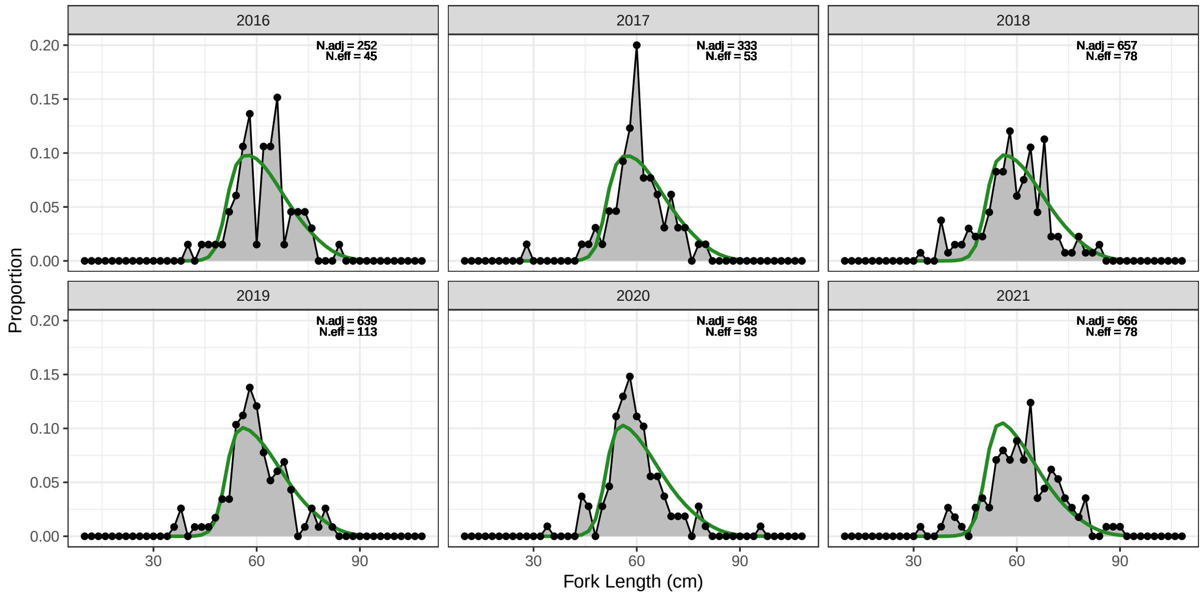

Figure C.103: Scenario 16 length structure for the recreational fleet for retained red emperor

'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

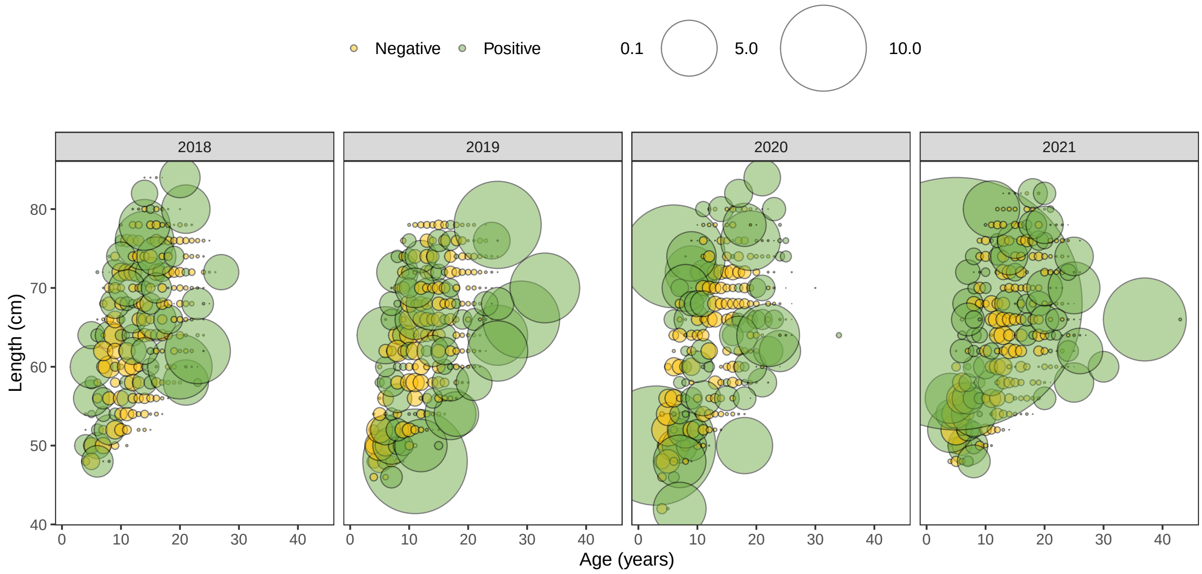

Figure C.104: Scenario 16 Pearson residuals for age-at-length compositions for the commercial fleet for red emperor—circle size represents the magnitude of the Pearson residual

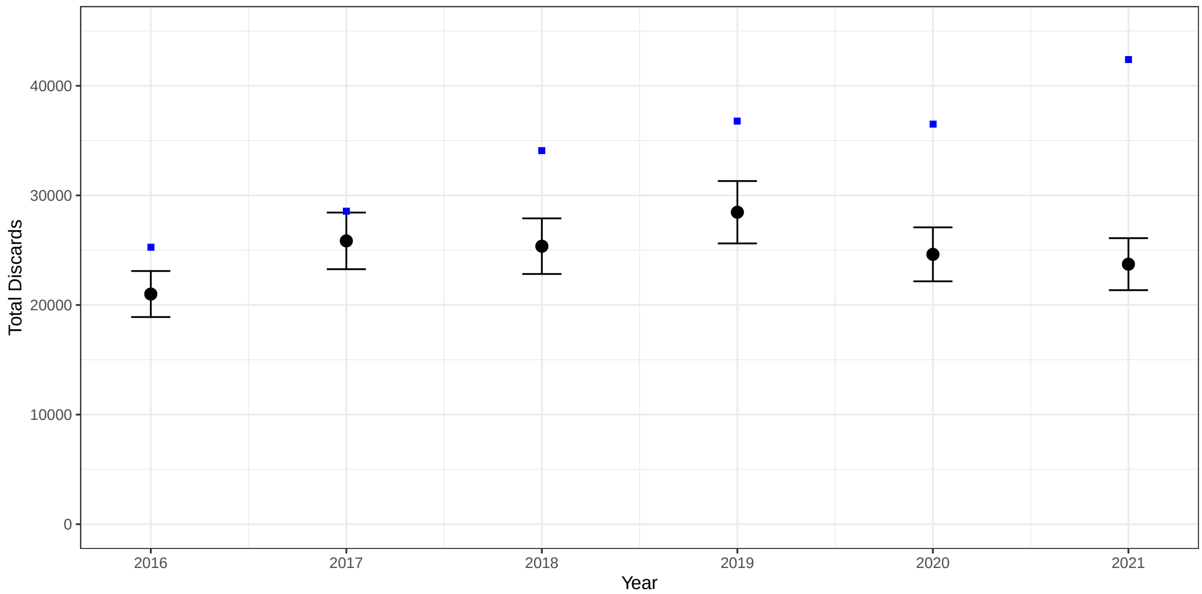

Figure C.105: Scenario 16 model fit to total discards for recreational-charter-Indigenous fleet—circles and error bars represent input data and their associated coefficients of variation and blue points represent the model predictions

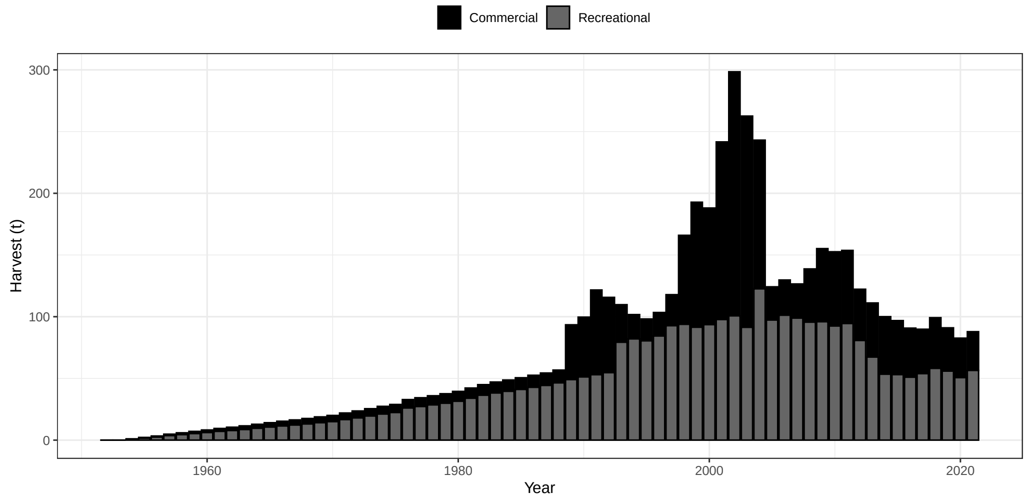

Figure C.106: Scenario 16 modelled harvest of red emperor

Scenario 17

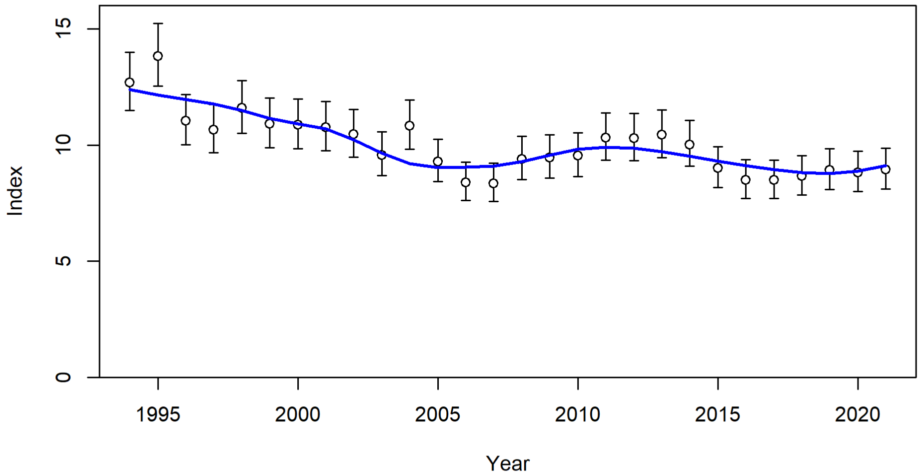

Figure C.107: Scenario 17 model predictions (blue line) to commercial catch rates for red emperor prior to rezoning

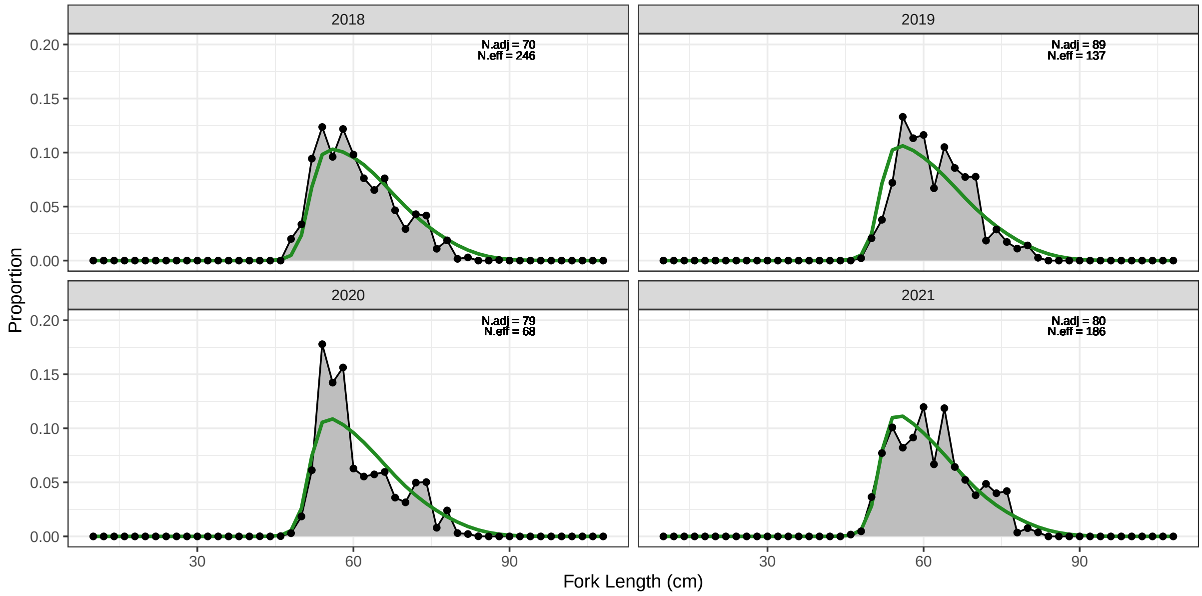

Figure C.108: Scenario 17 length structure for the commercial fleet for red emperor

'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

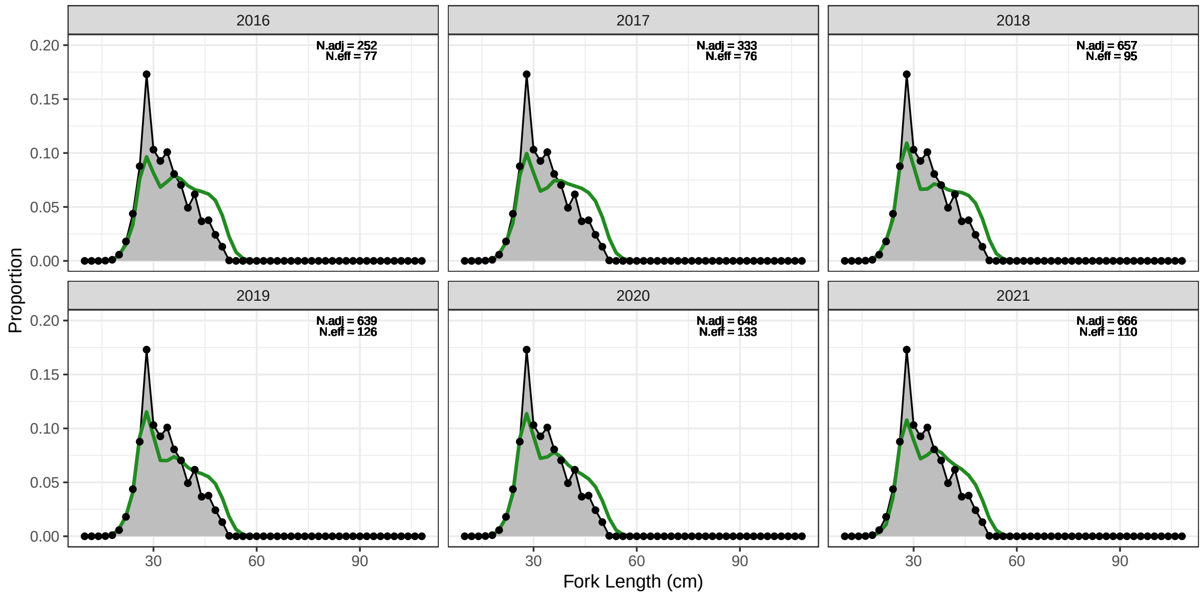

Figure C.109: Scenario 17 length structure for the recreational fleet for discarded red emperor

'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

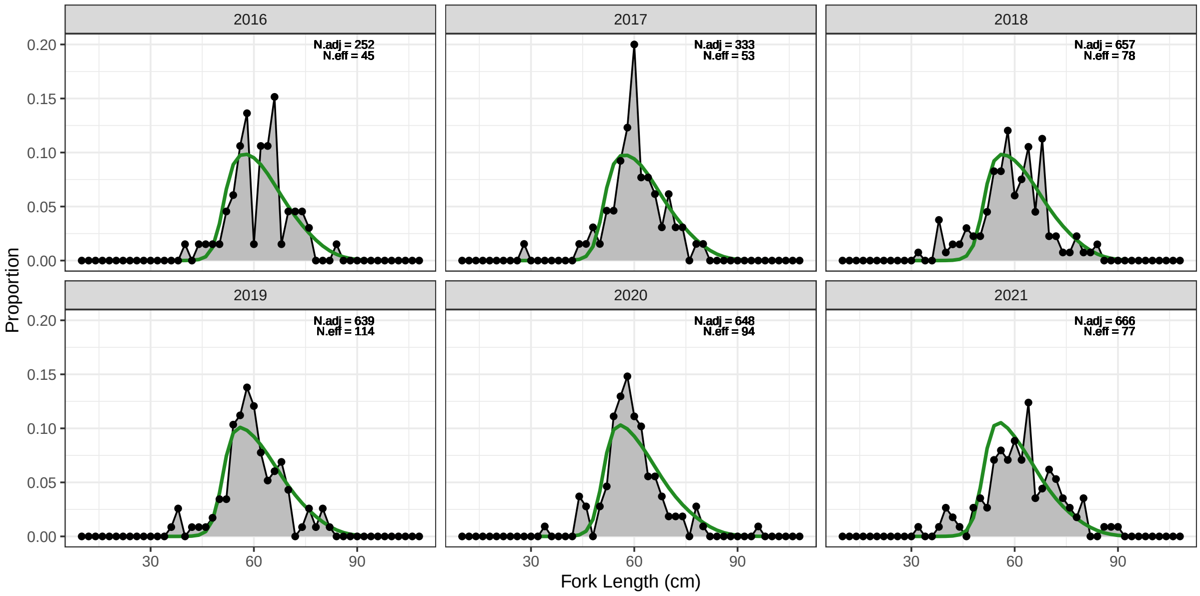

Figure C.110: Scenario 17 length structure for the recreational fleet for retained red emperor

'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

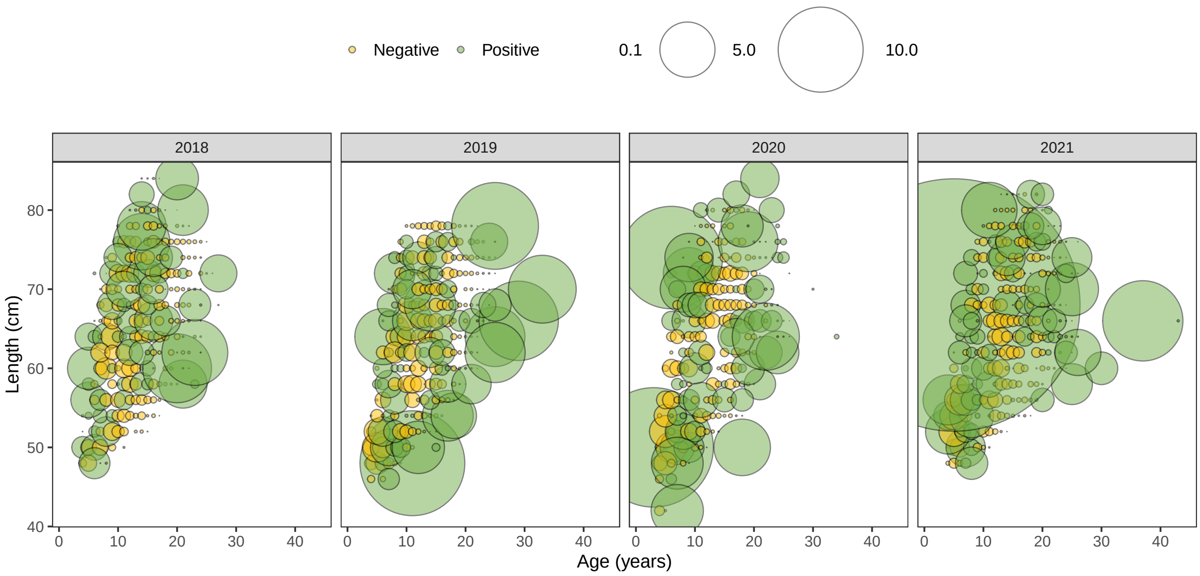

Figure C.111: Scenario 17 Pearson residuals for age-at-length compositions for the commercial fleet for red emperor—circle size represents the magnitude of the Pearson residual

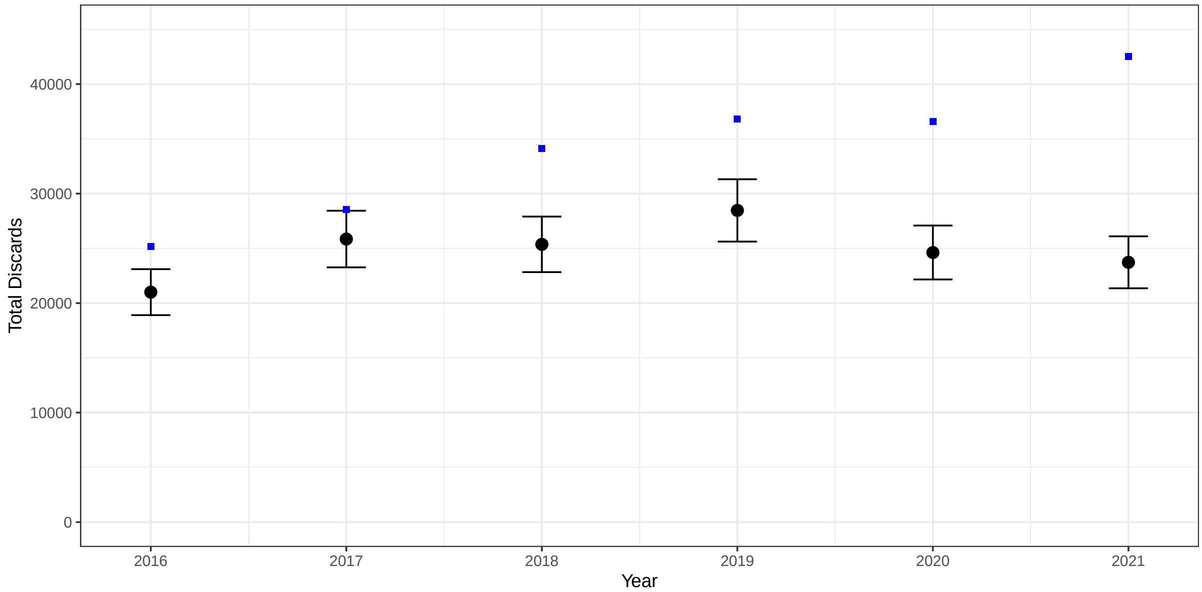

Figure C.112: Scenario 17 model fit to total discards for recreational-charter-Indigenous fleet—circles and error bars represent input data and their associated coefficients of variation and blue points represent the model predictions

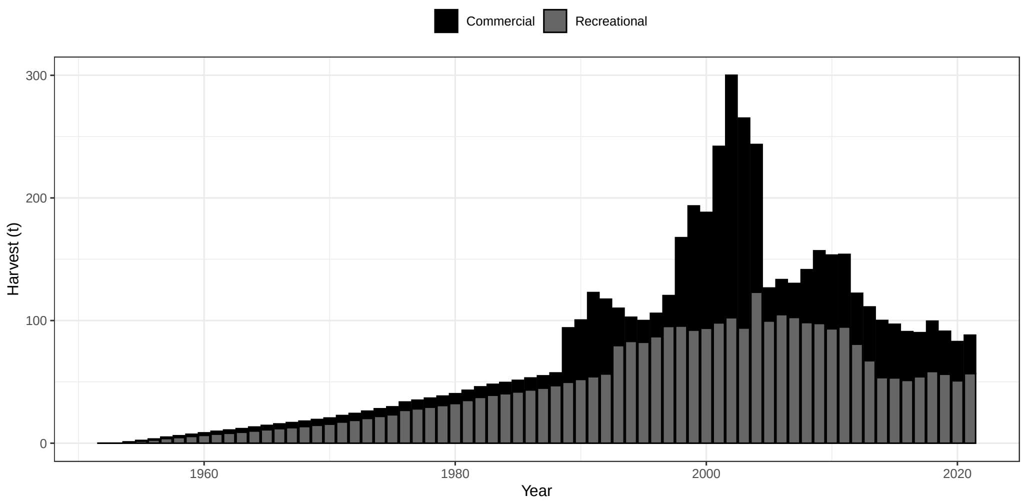

Figure C.113: Scenario 17 modelled harvest of red emperor

Scenario 18

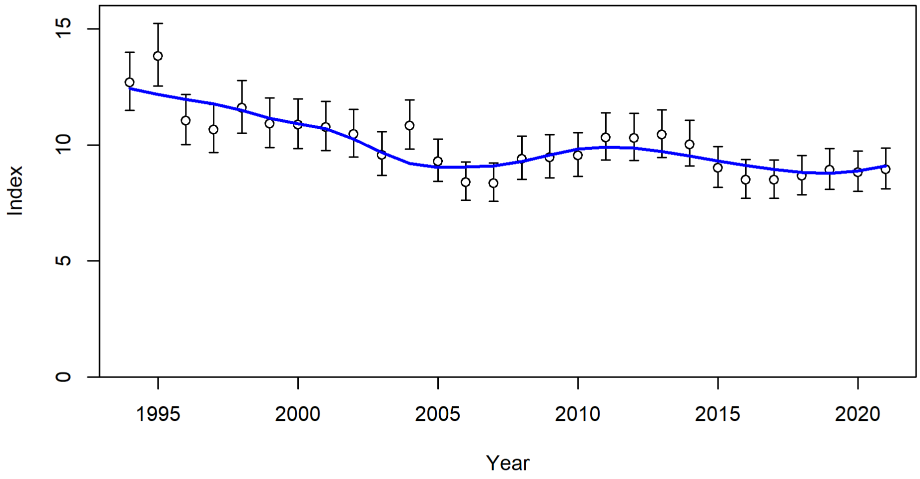

Figure C.114: Scenario 18 model predictions (blue line) to commercial catch rates for red emperor prior to rezoning

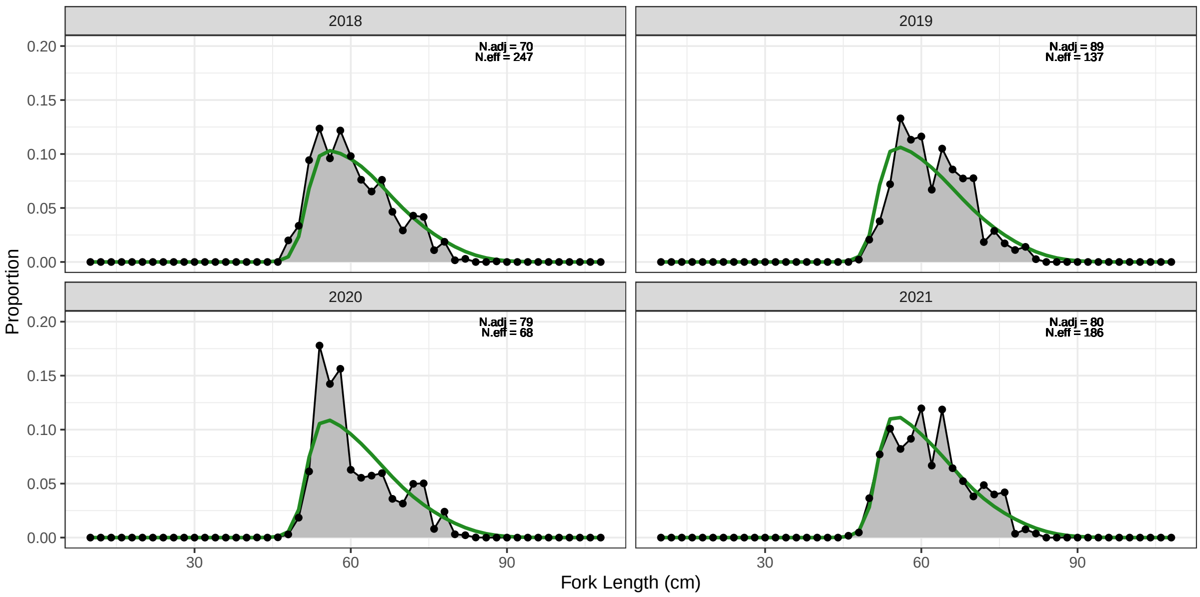

Figure C.115: Scenario 18 length structure for the commercial fleet for red emperor

'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

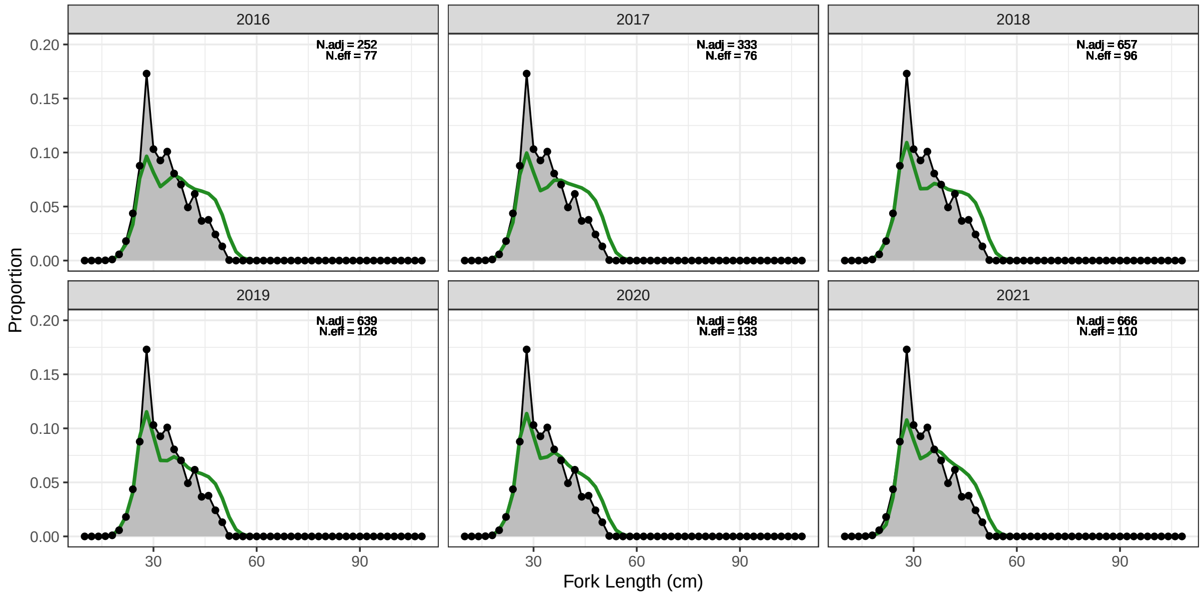

Figure C.116: Scenario 18 length structure for the recreational fleet for discarded red emperor

'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

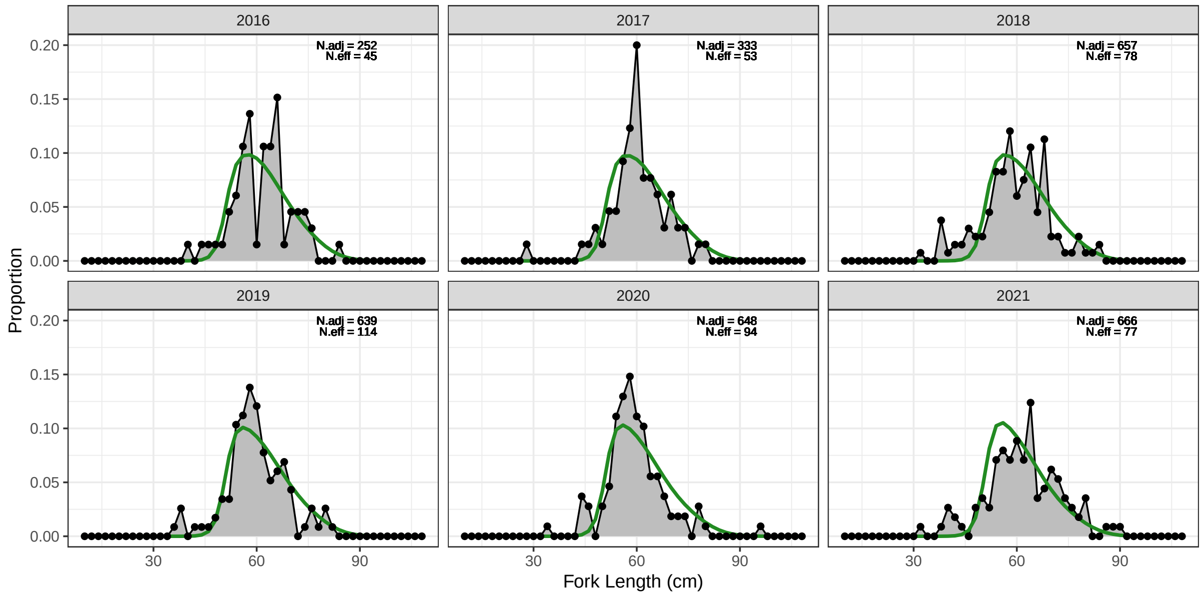

Figure C.117: Scenario 18 length structure for the recreational fleet for retained red emperor

'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

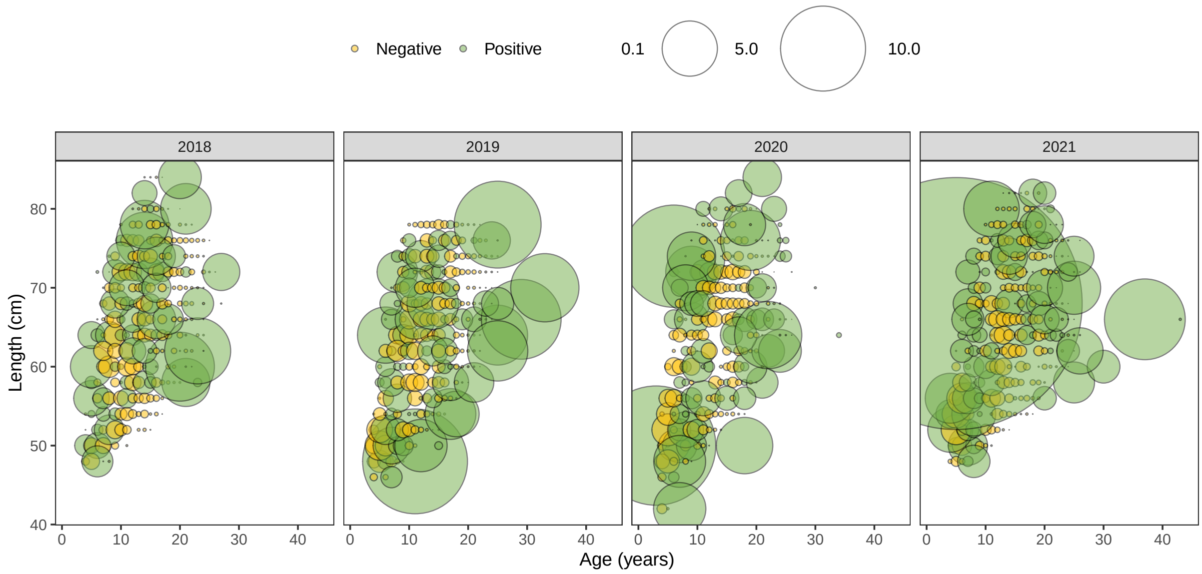

Figure C.118: Scenario 18 Pearson residuals for age-at-length compositions for the commercial fleet for red emperor—circle size represents the magnitude of the Pearson residual

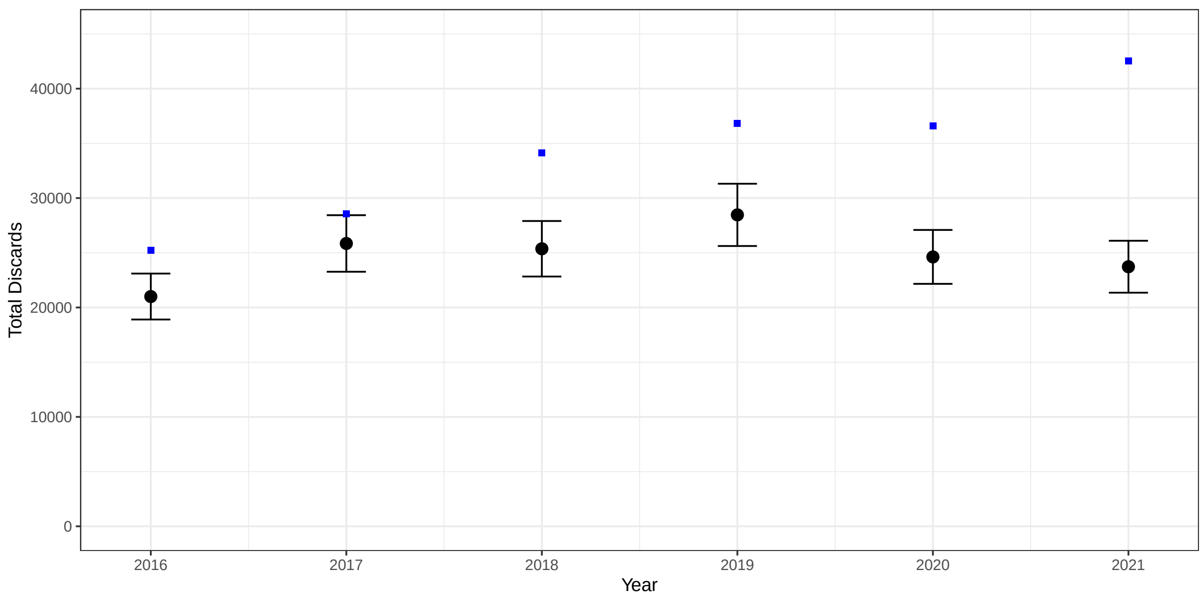

Figure C.119: Scenario 18 model fit to total discards for recreational-charter-Indigenous fleet—circles and error bars represent input data and their associated coefficients of variation and blue points represent the model predictions

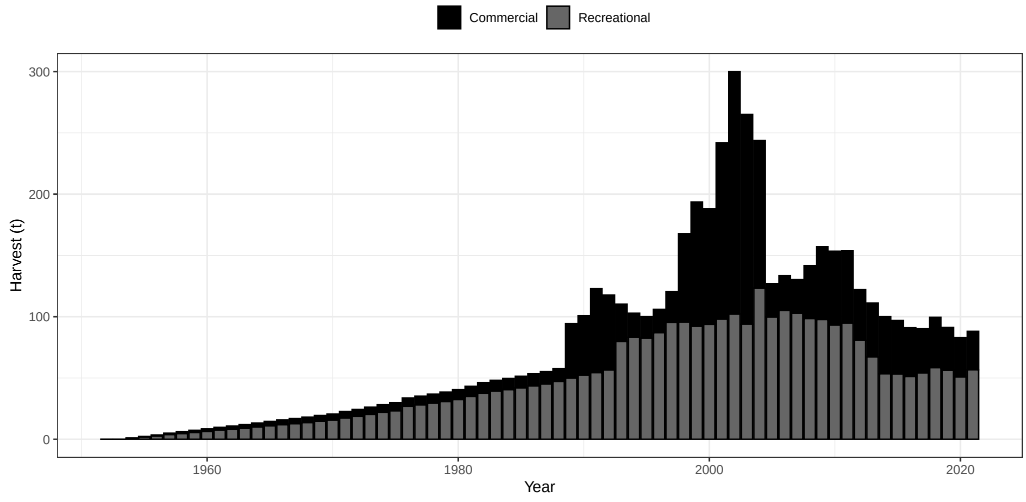

Figure C.120: Scenario 18 modelled harvest of red emperor

Scenario 19

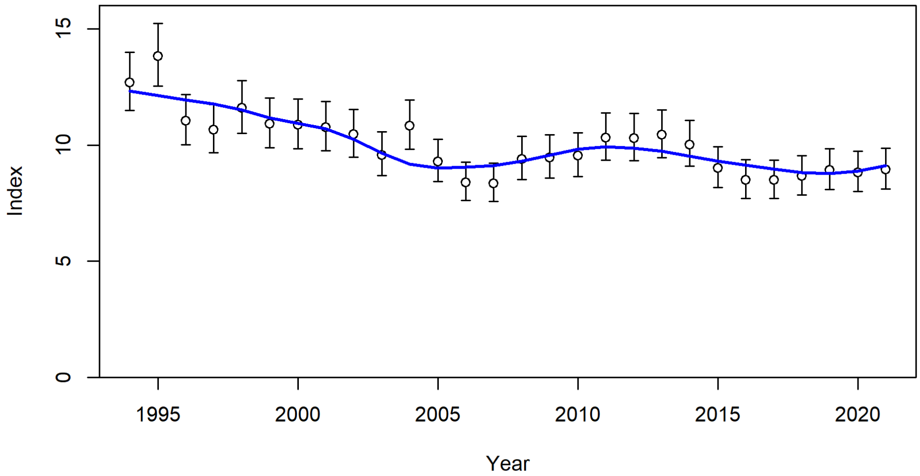

Figure C.121: Scenario 19 model predictions (blue line) to commercial catch rates for red emperor prior to rezoning

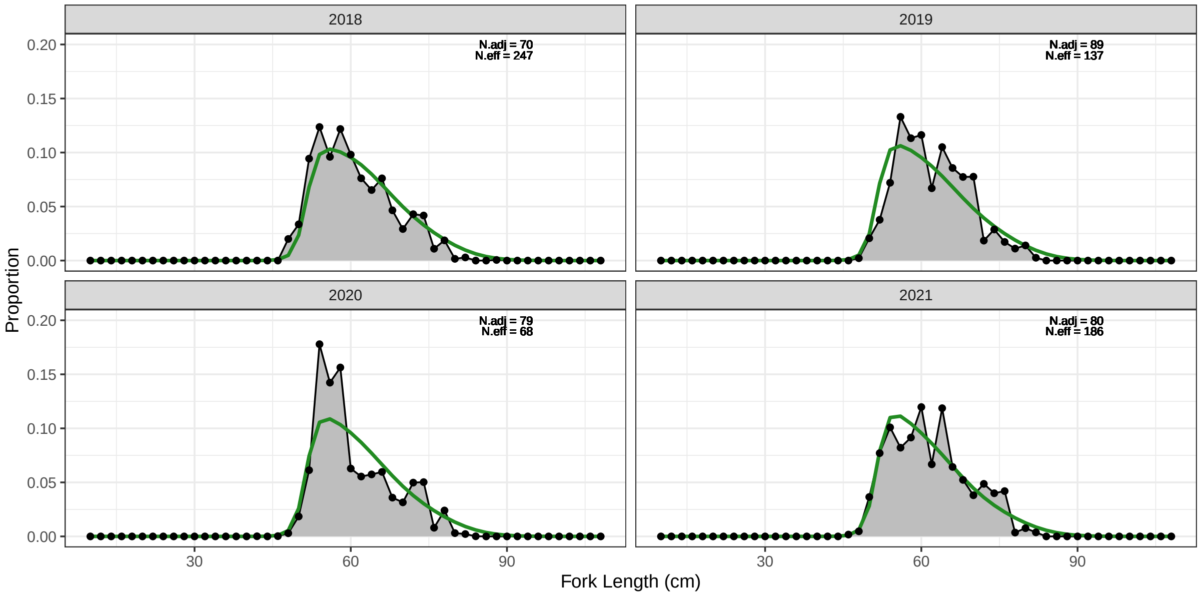

Figure C.122: Scenario 19 length structure for the commercial fleet for red emperor

'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

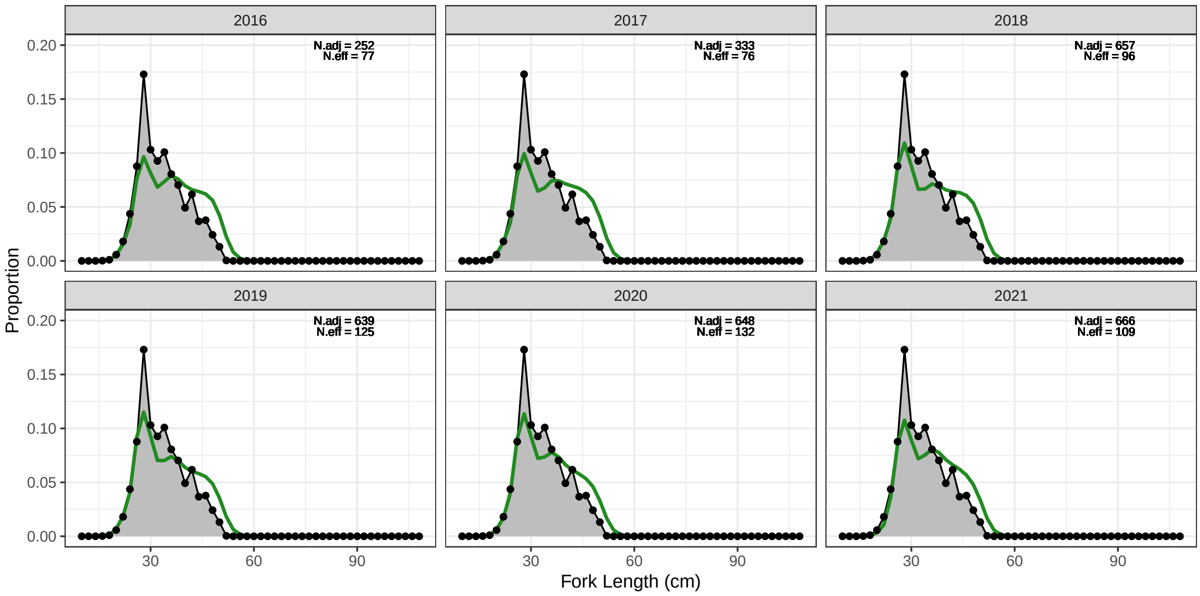

Figure C.123: Scenario 19 length structure for the recreational fleet for discarded red emperor

'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

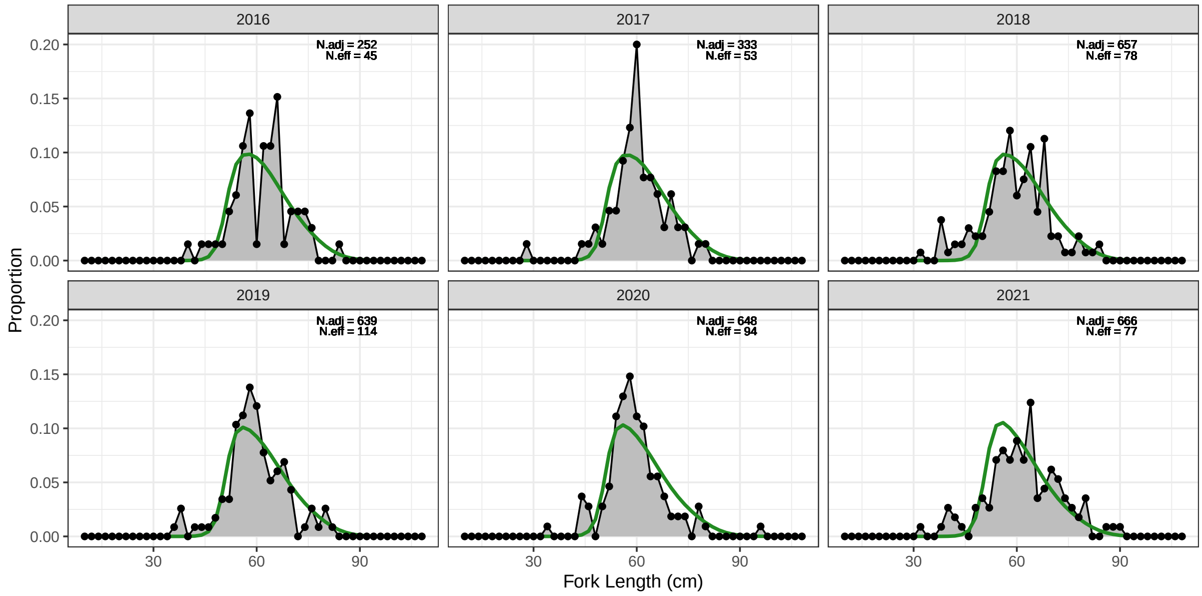

Figure C.124: Scenario 19 length structure for the recreational fleet for retained red emperor

'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

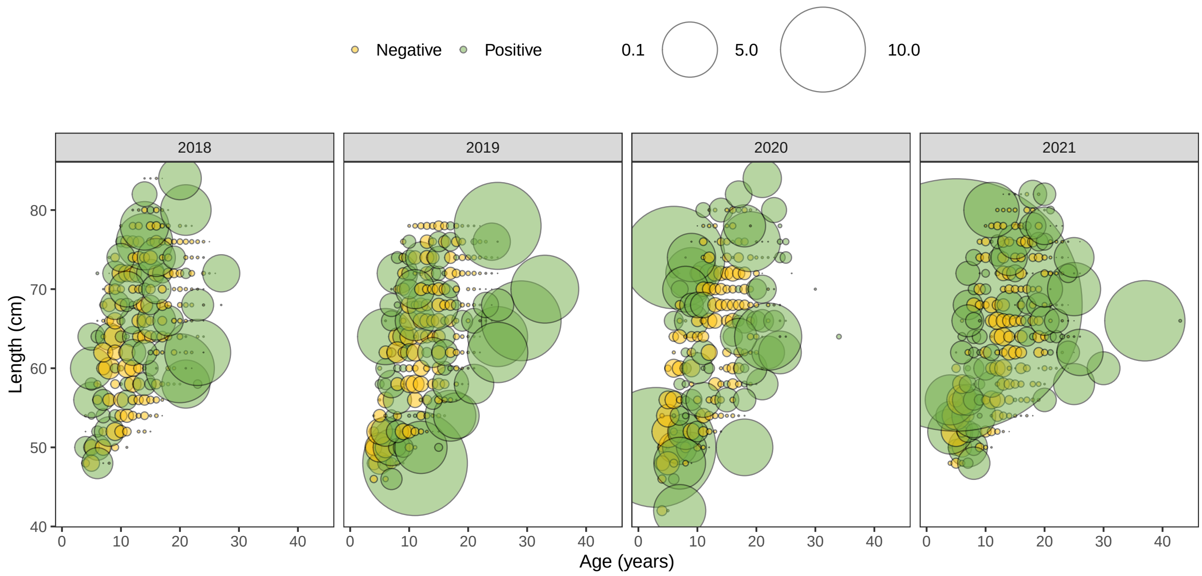

Figure C.125: Scenario 19 Pearson residuals for age-at-length compositions for the commercial fleet for red emperor—circle size represents the magnitude of the Pearson residual

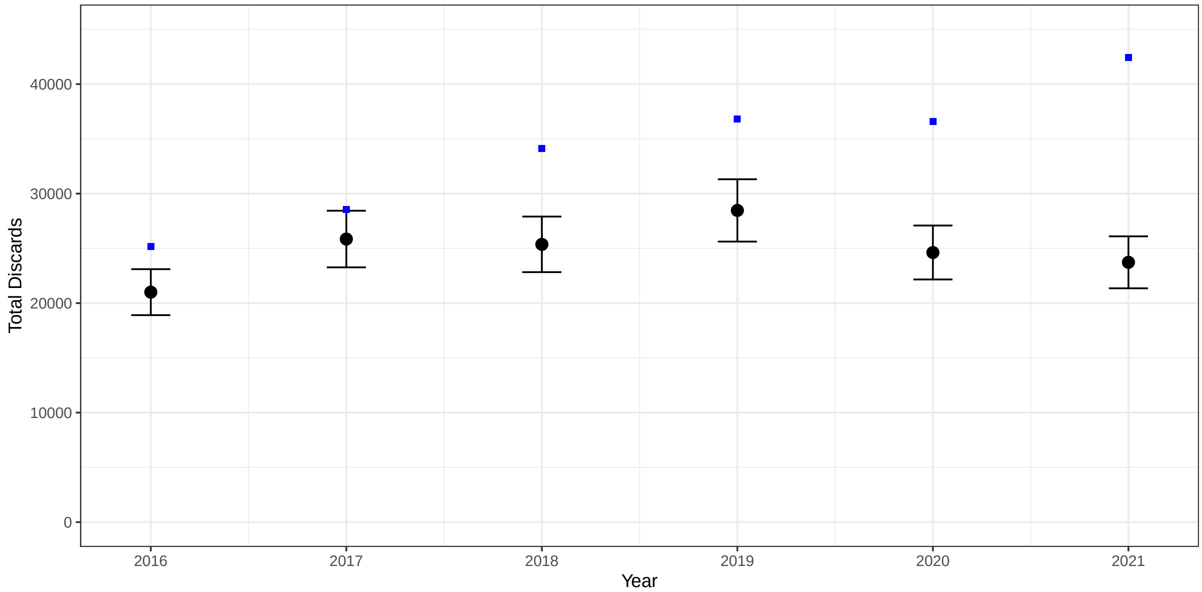

Figure C.126: Scenario 19 model fit to total discards for recreational-charter-Indigenous fleet—circles and error bars represent input data and their associated coefficients of variation and blue points represent the model predictions

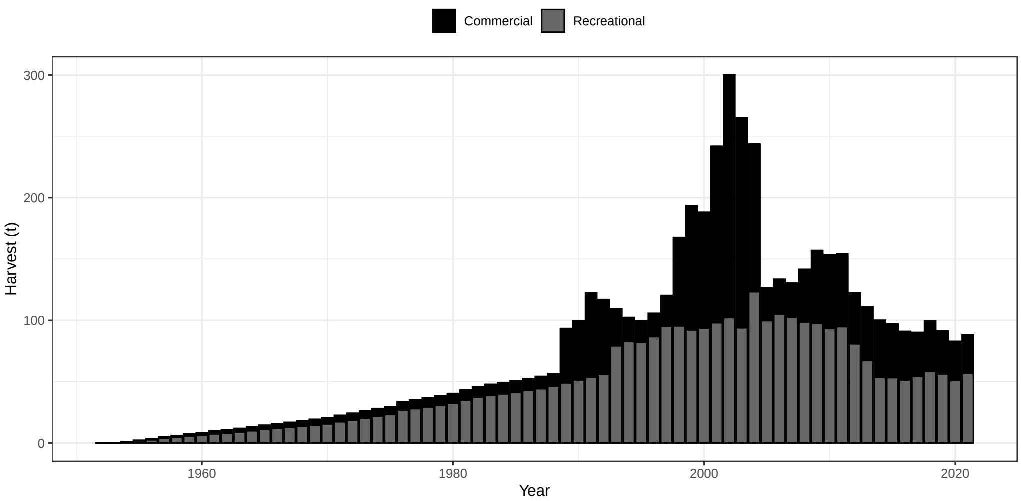

Figure C.127: Scenario 19 modelled harvest of red emperor

Scenario 20

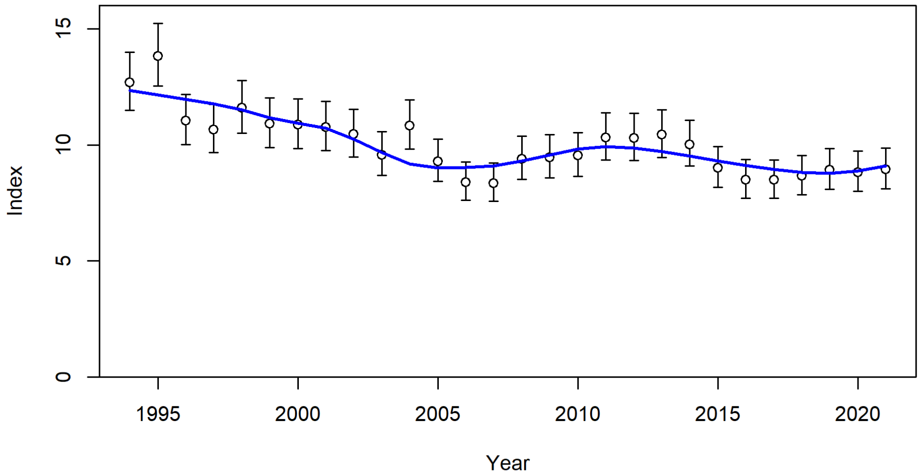

Figure C.128: Scenario 20 model predictions (blue line) to commercial catch rates for red emperor prior to rezoning

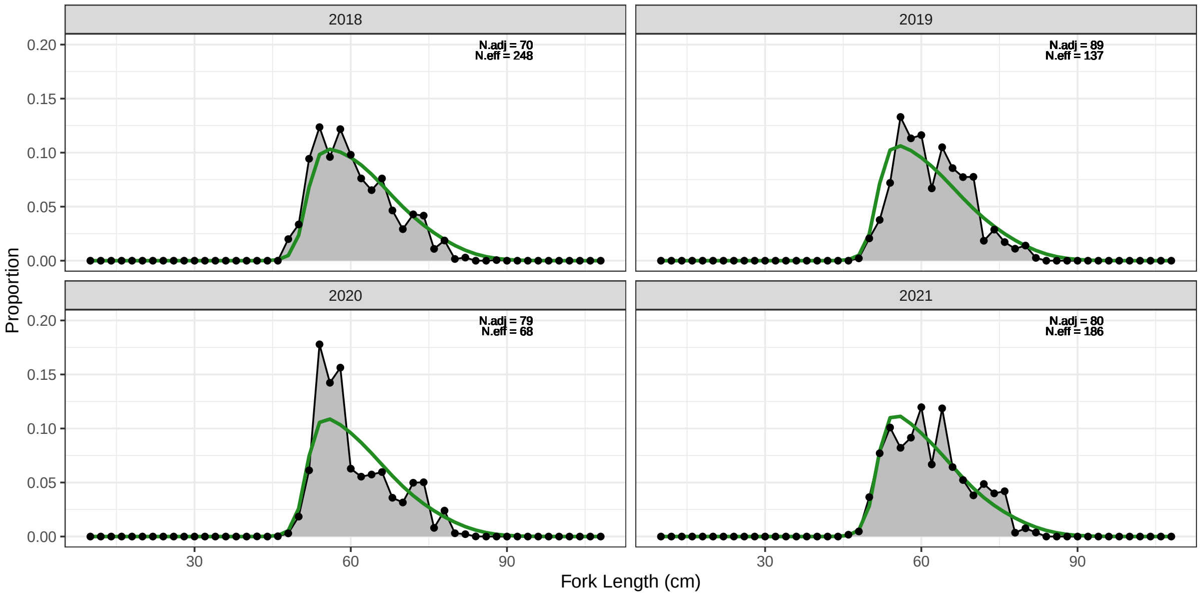

Figure C.129: Scenario 20 length structure for the commercial fleet for red emperor

'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

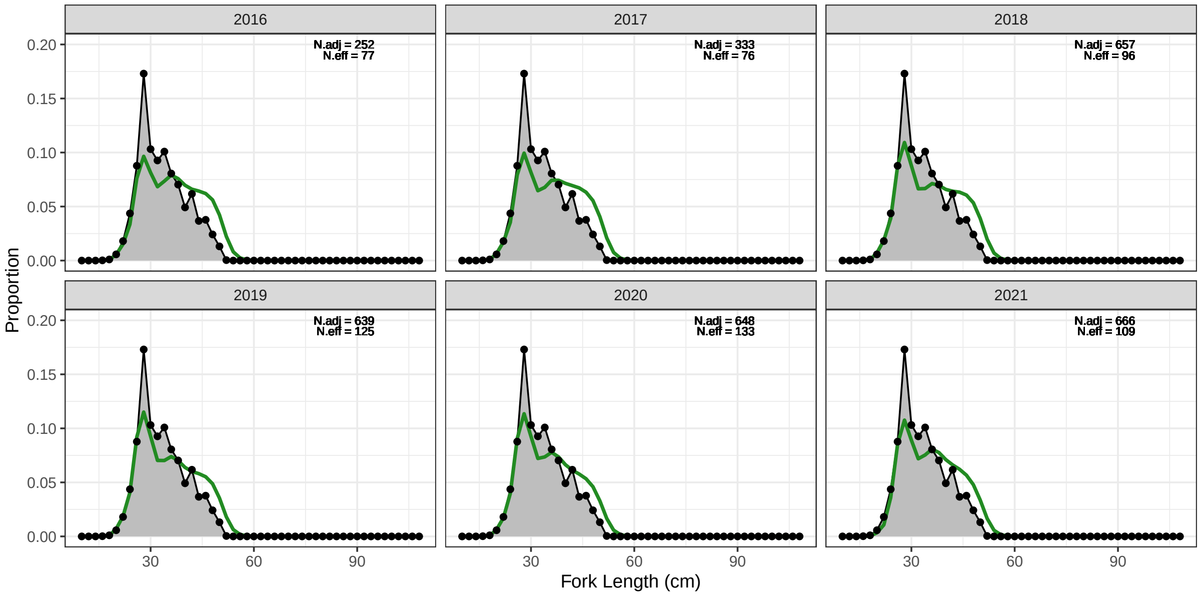

Figure C.130: Scenario 20 length structure for the recreational fleet for discarded red emperor

'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

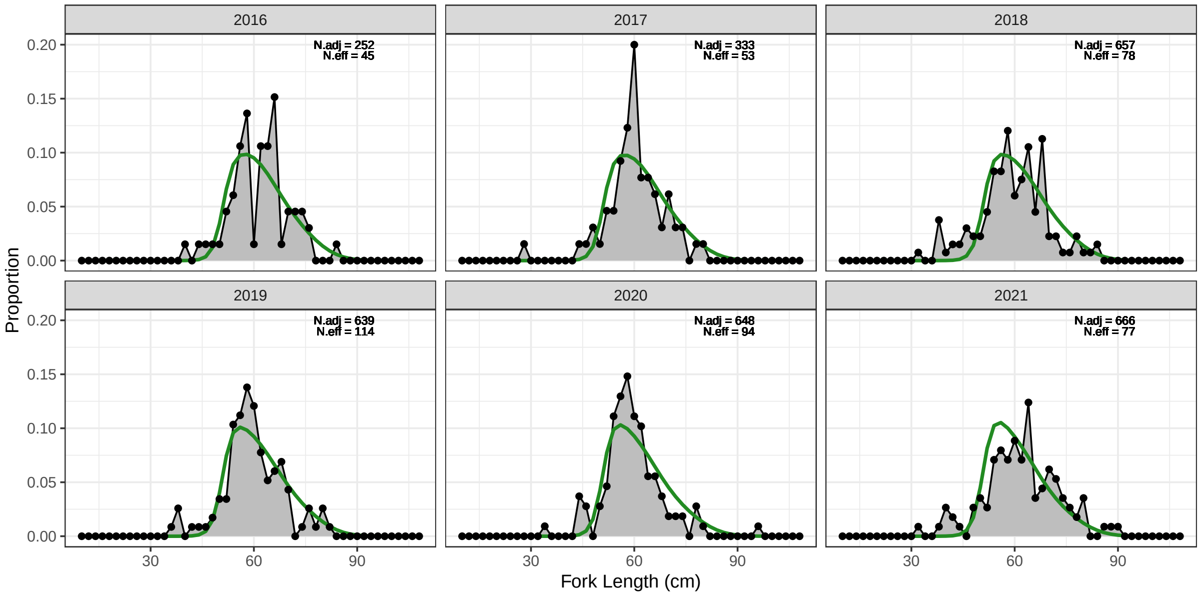

Figure C.131: Scenario 20 length structure for the recreational fleet for retained red emperor

'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

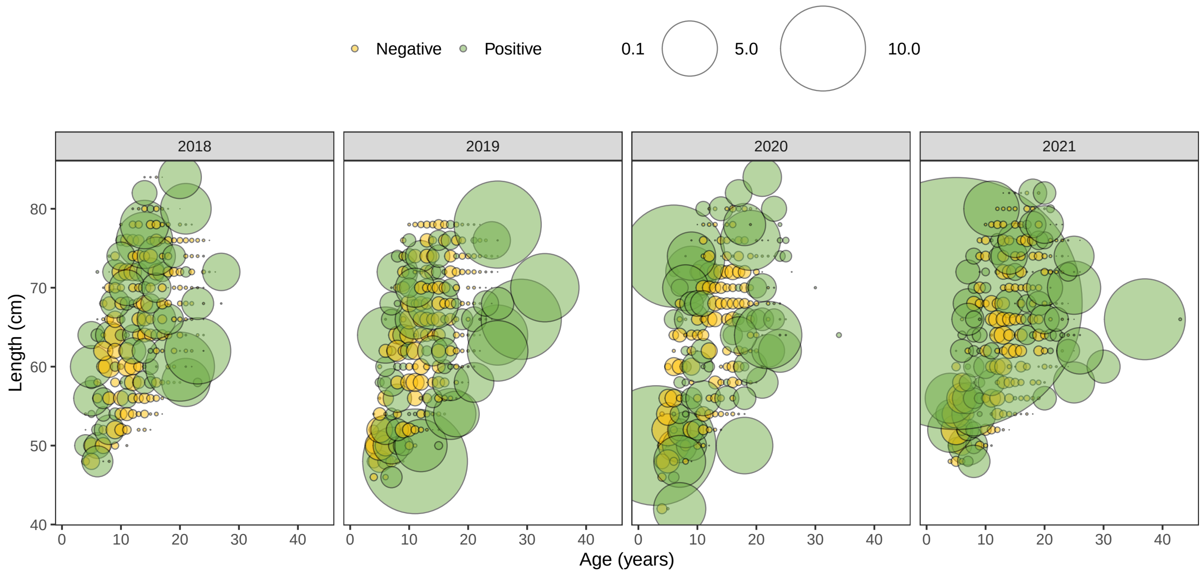

Figure C.132: Scenario 20 Pearson residuals for age-at-length compositions for the commercial fleet for red emperor—circle size represents the magnitude of the Pearson residual

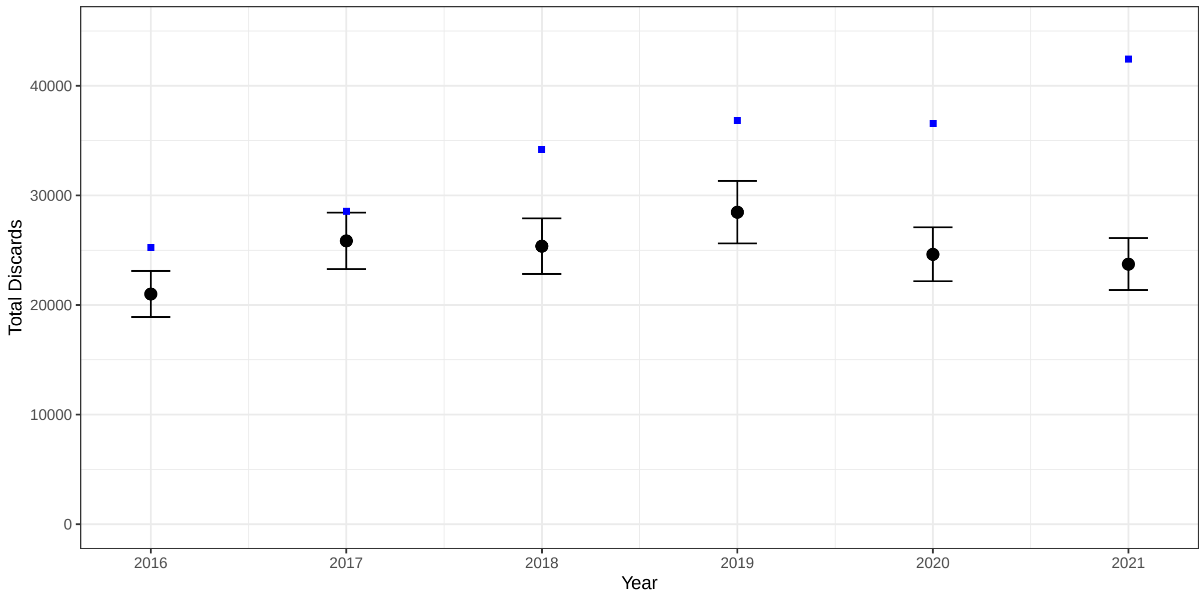

Figure C.133: Scenario 20 model fit to total discards for recreational-charter-Indigenous fleet—circles and error bars represent input data and their associated coefficients of variation and blue points represent the model predictions

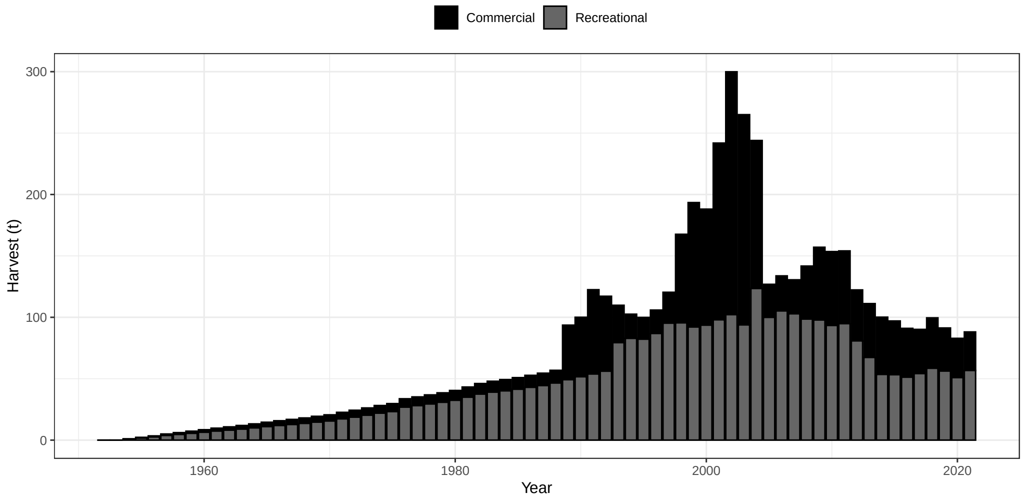

Figure C.134: Scenario 20 modelled harvest of red emperor

Scenario 21

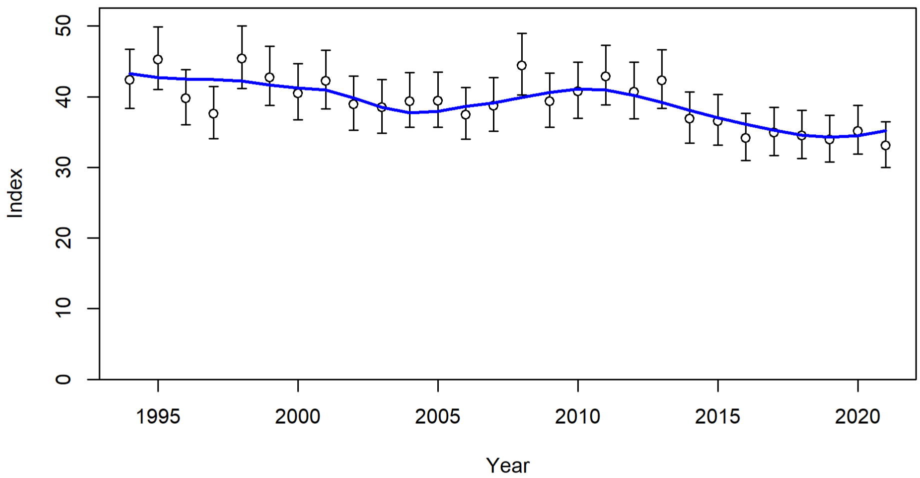

Figure C.135: Scenario 21 model predictions (blue line) to commercial catch rates for red emperor prior to rezoning

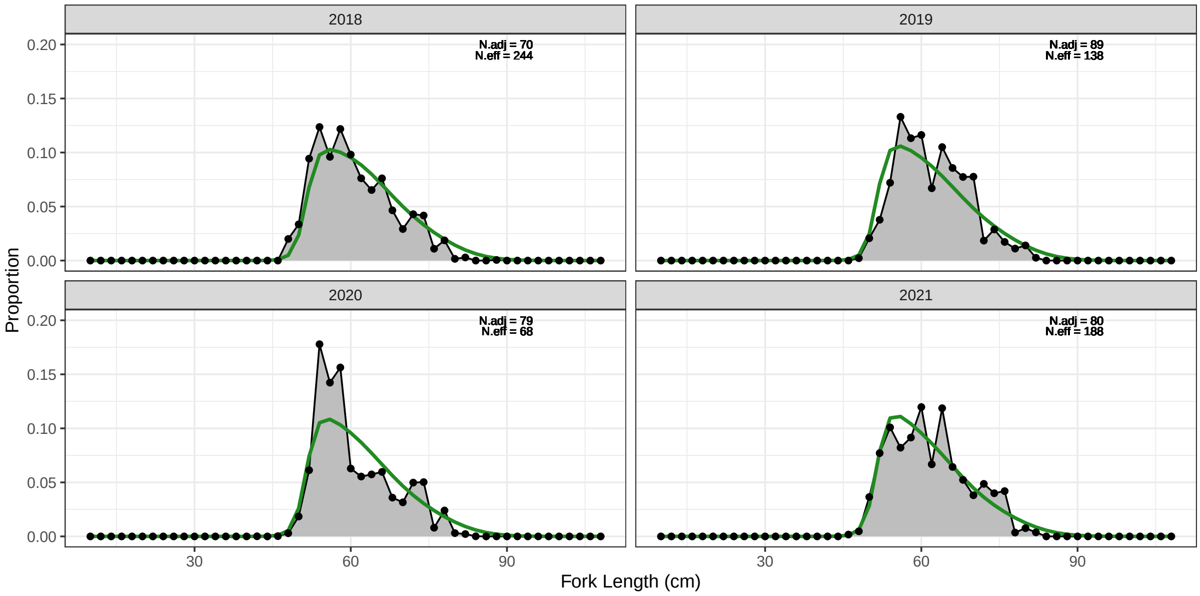

Figure C.136: Scenario 21 length structure for the commercial fleet for red emperor

'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

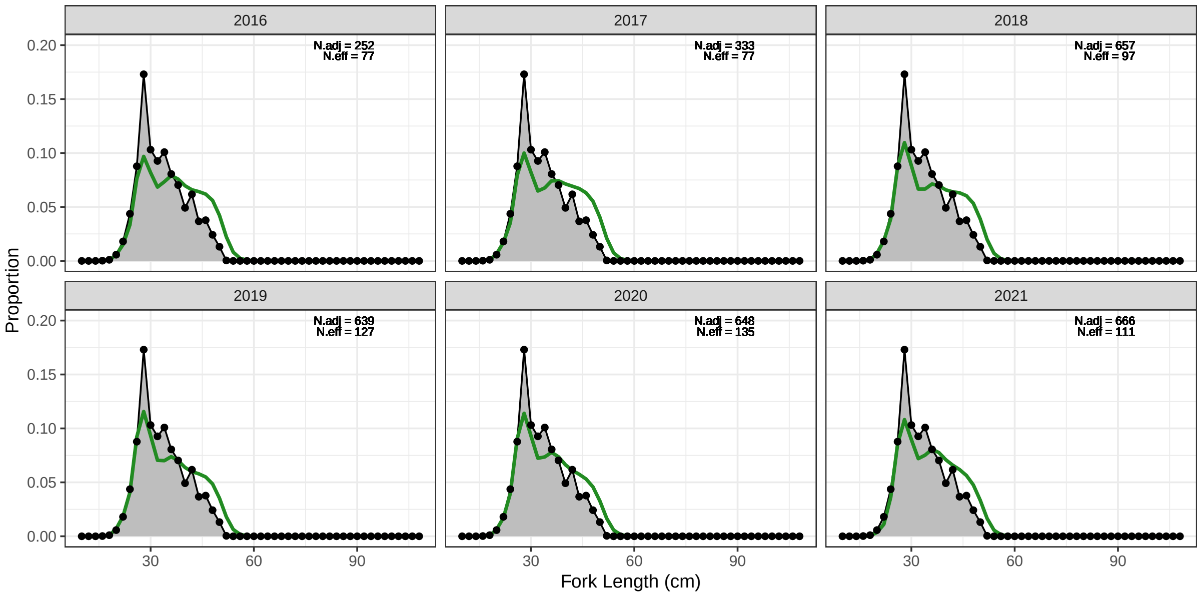

Figure C.137: Scenario 21 length structure for the recreational fleet for discarded red emperor

'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

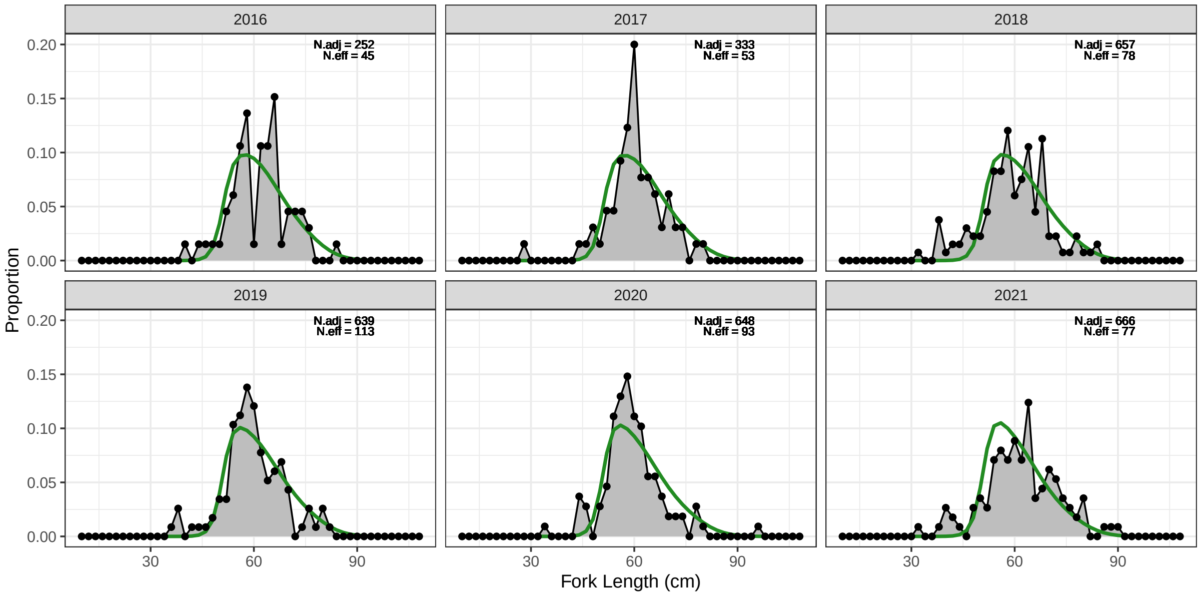

Figure C.138: Scenario 21 length structure for the recreational fleet for retained red emperor

'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

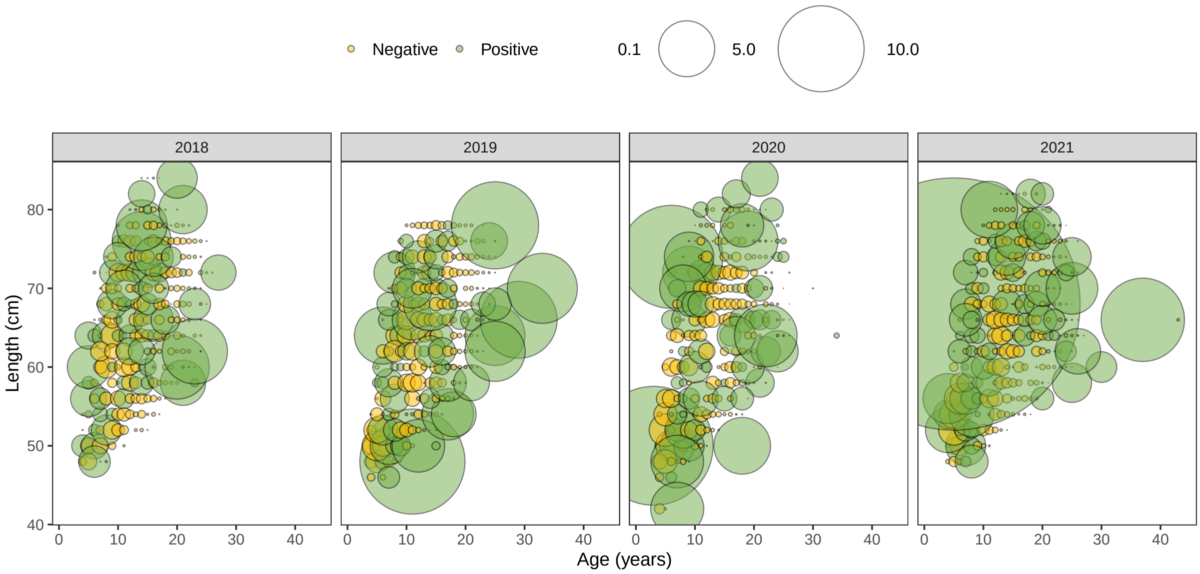

Figure C.139: Scenario 21 Pearson residuals for age-at-length compositions for the commercial fleet for red emperor—circle size represents the magnitude of the Pearson residual

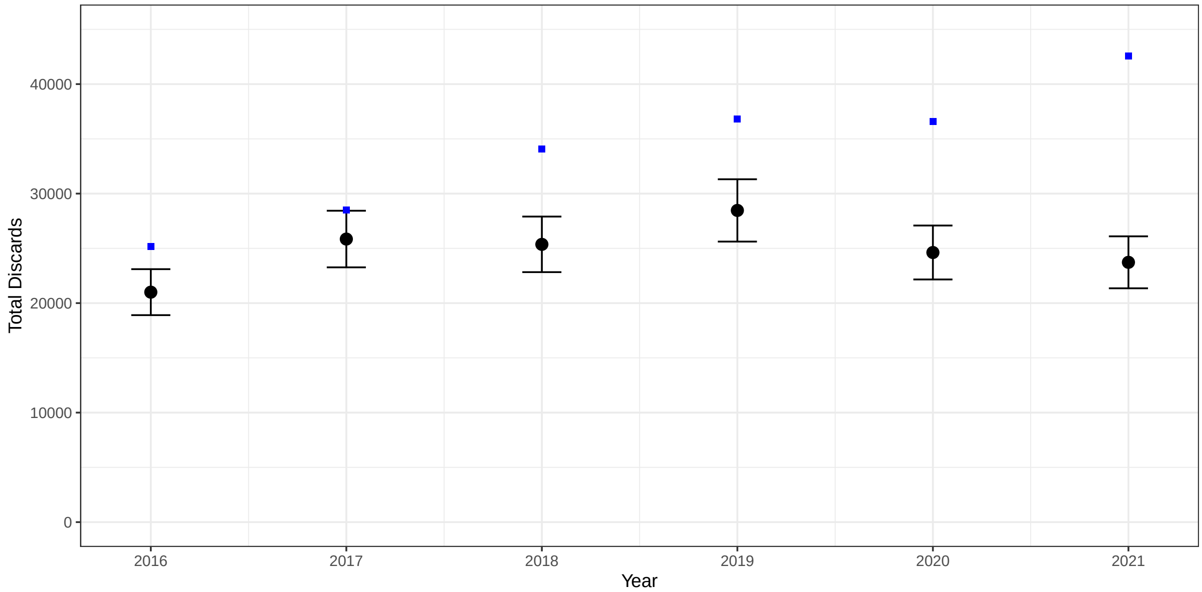

Figure C.140: Scenario 21 model fit to total discards for recreational-charter-Indigenous fleet—circles and error bars represent input data and their associated coefficients of variation and blue points represent the model predictions

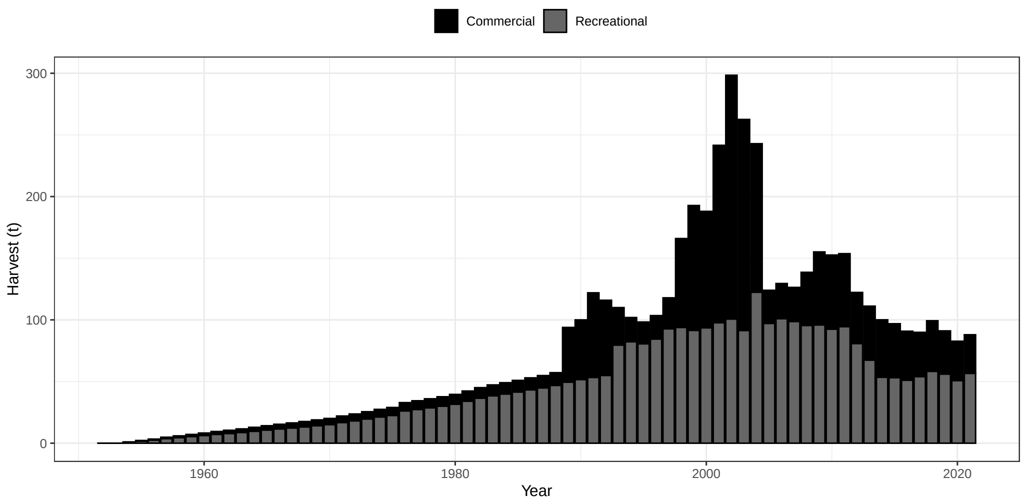

Figure C.141: Scenario 21 modelled harvest of red emperor

Scenario 22

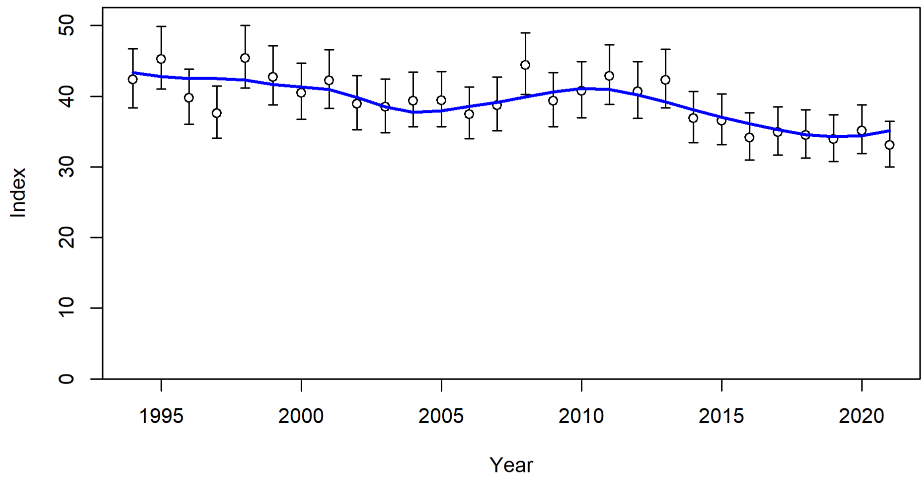

Figure C.142: Scenario 22 model predictions (blue line) to commercial catch rates for red emperor prior to rezoning

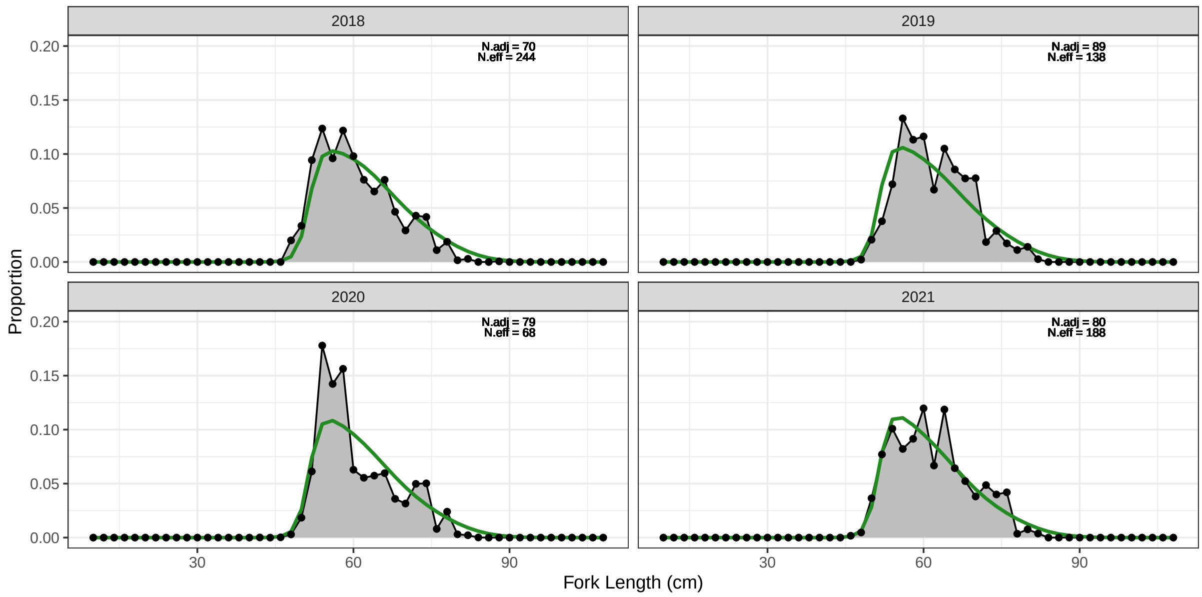

Figure C.143: Scenario 22 length structure for the commercial fleet for red emperor

'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

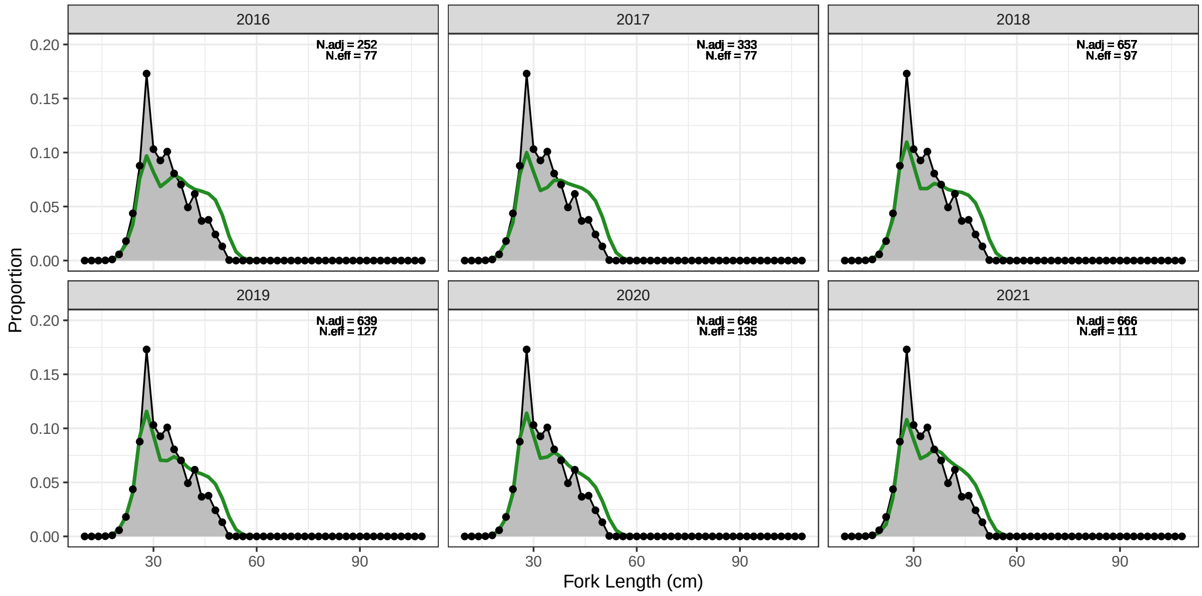

Figure C.144: Scenario 22 length structure for the recreational fleet for discarded red emperor

'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

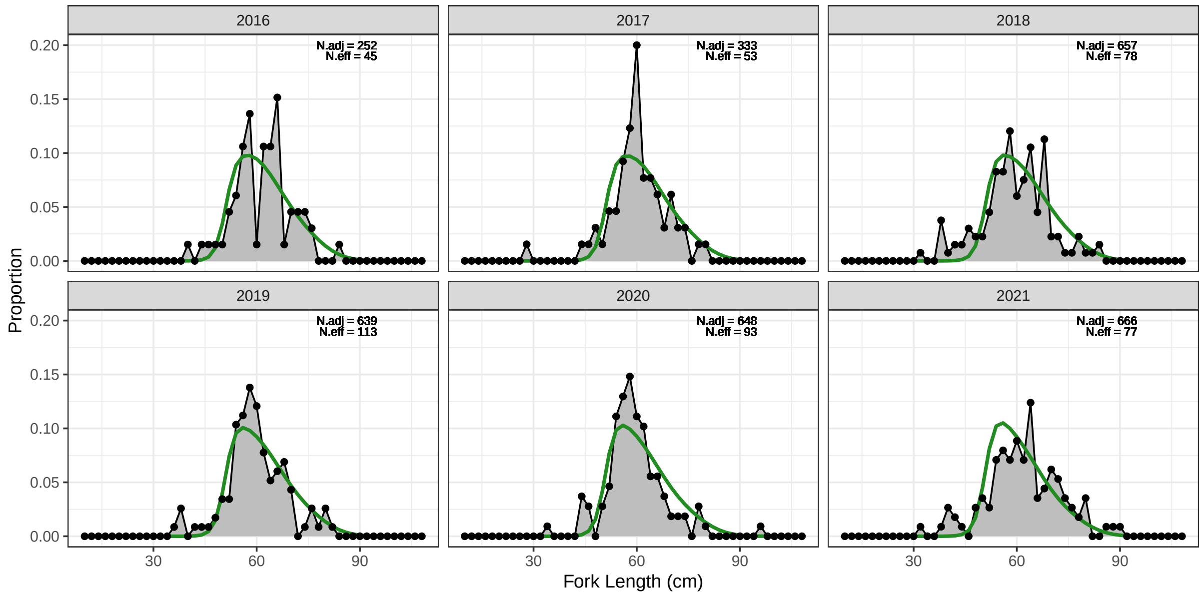

Figure C.145: Scenario 22 length structure for the recreational fleet for retained red emperor

'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

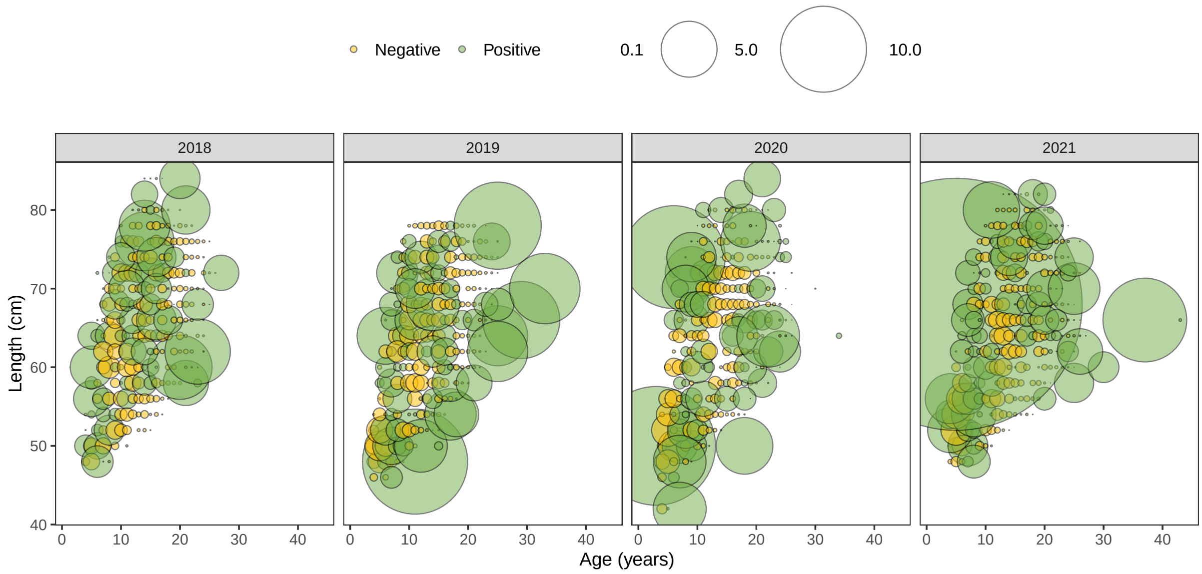

Figure C.146: Scenario 22 Pearson residuals for age-at-length compositions for the commercial fleet for red emperor—circle size represents the magnitude of the Pearson residual

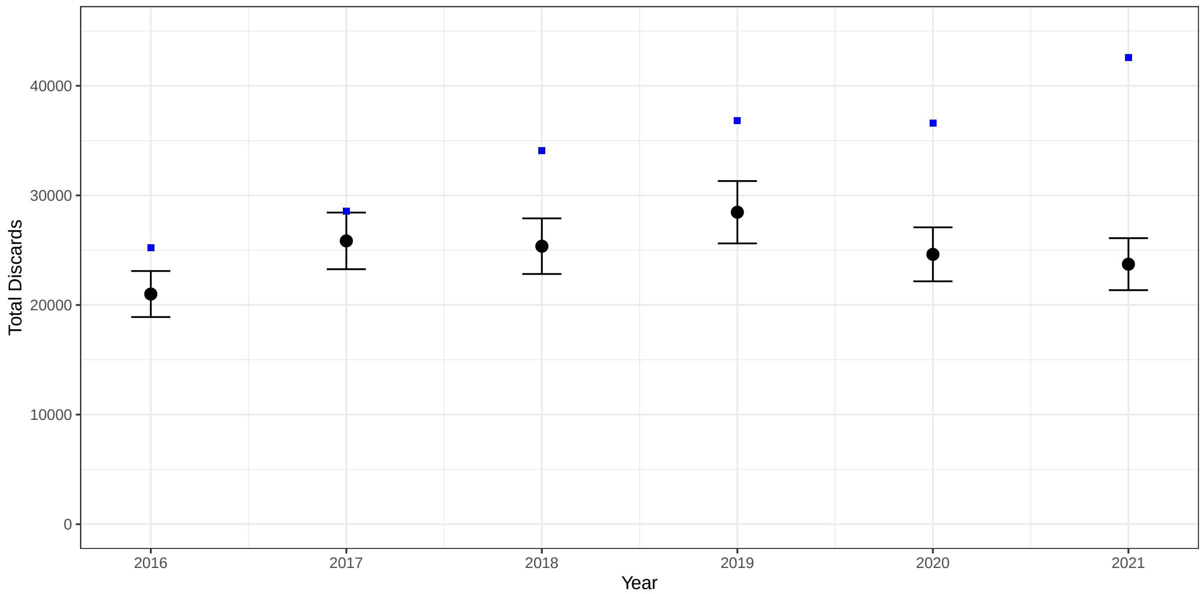

Figure C.147: Scenario 22 model fit to total discards for recreational-charter-Indigenous fleet—circles and error bars represent input data and their associated coefficients of variation and blue points represent the model predictions

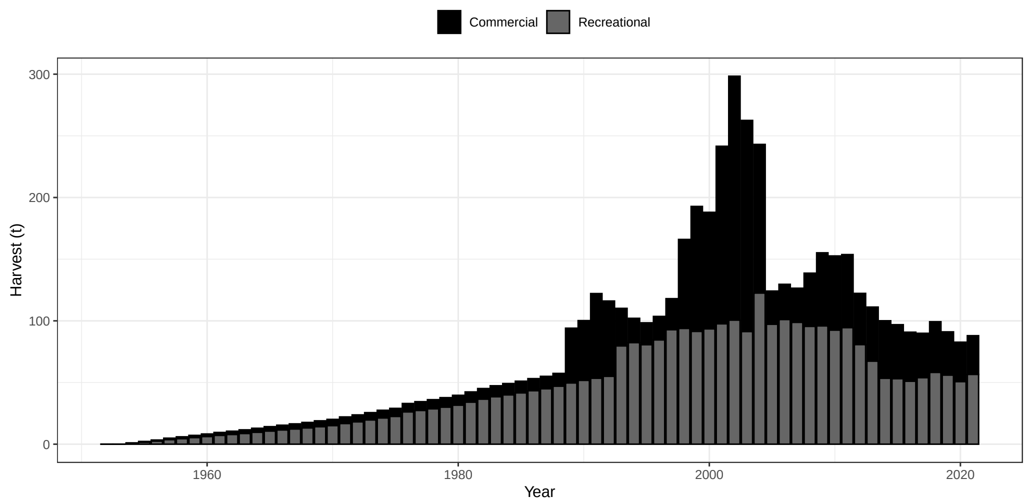

Figure C.148: Scenario 22 modelled harvest of red emperor

Scenario 23

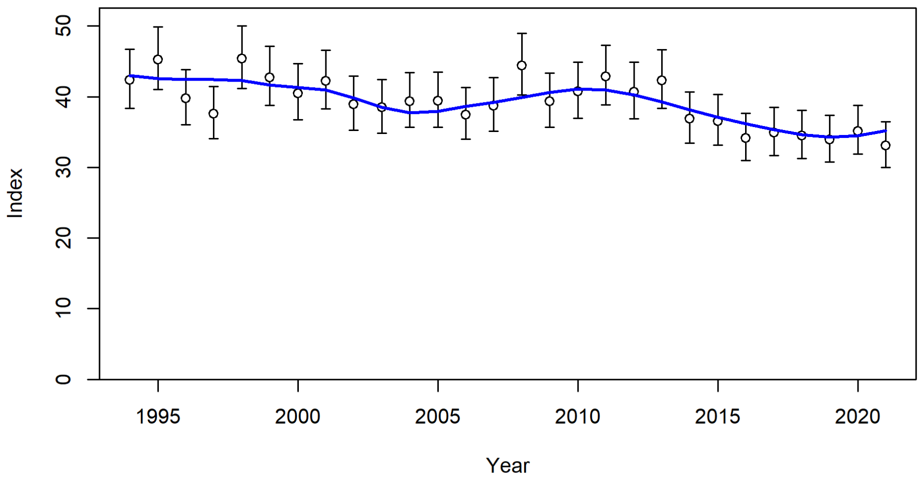

Figure C.149: Scenario 23 model predictions (blue line) to commercial catch rates for red emperor prior to rezoning

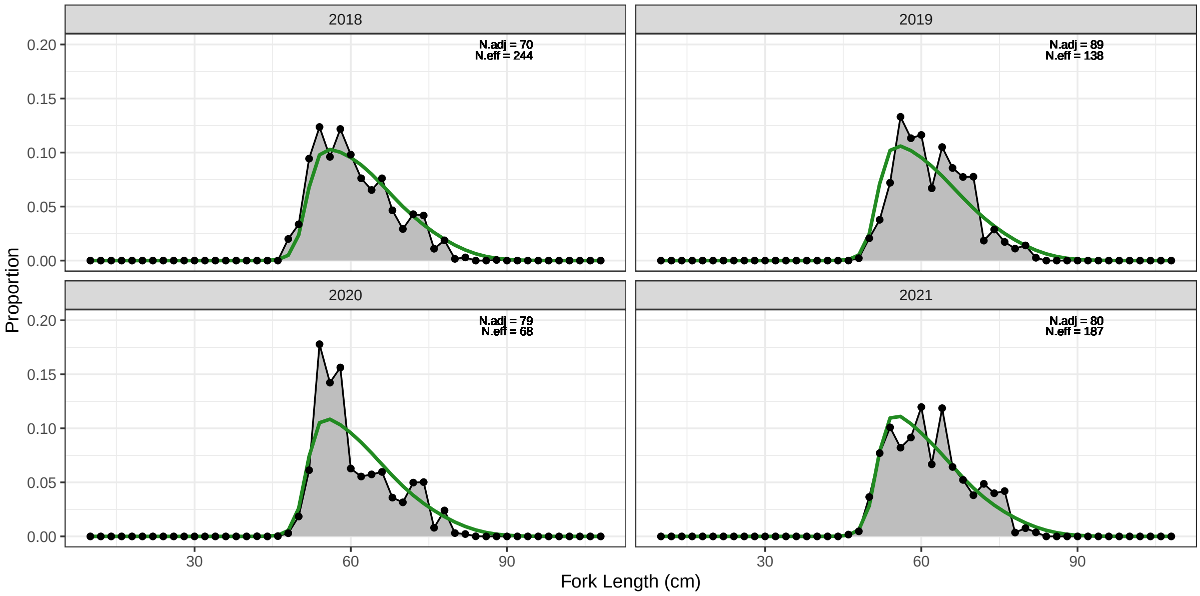

Figure C.150: Scenario 23 length structure for the commercial fleet for red emperor

'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

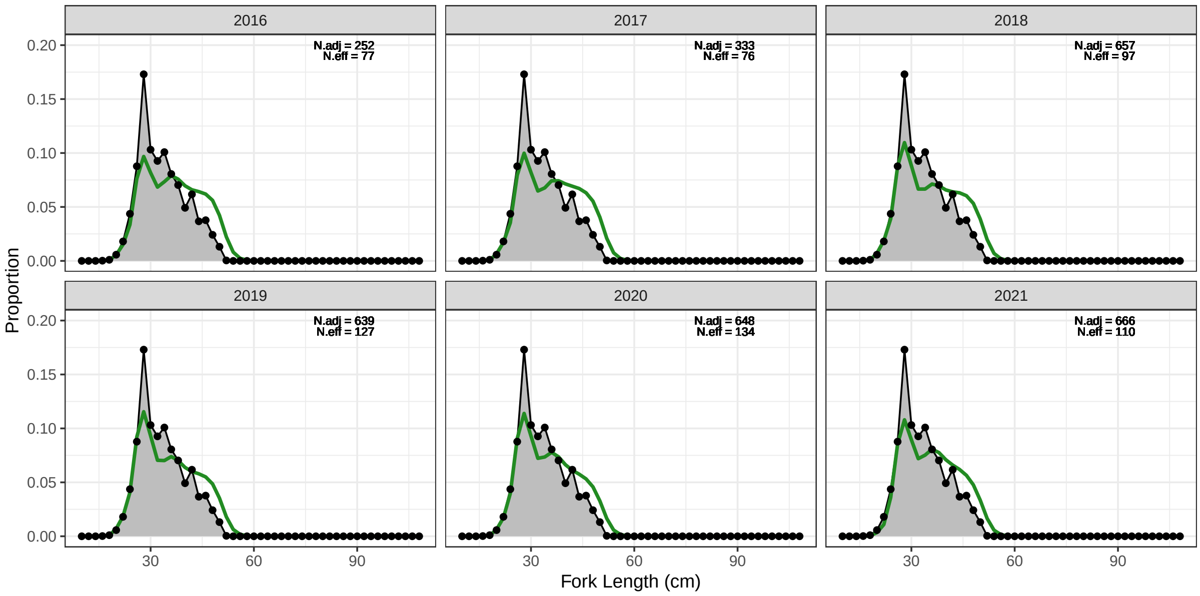

Figure C.151: Scenario 23 length structure for the recreational fleet for discarded red emperor

'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

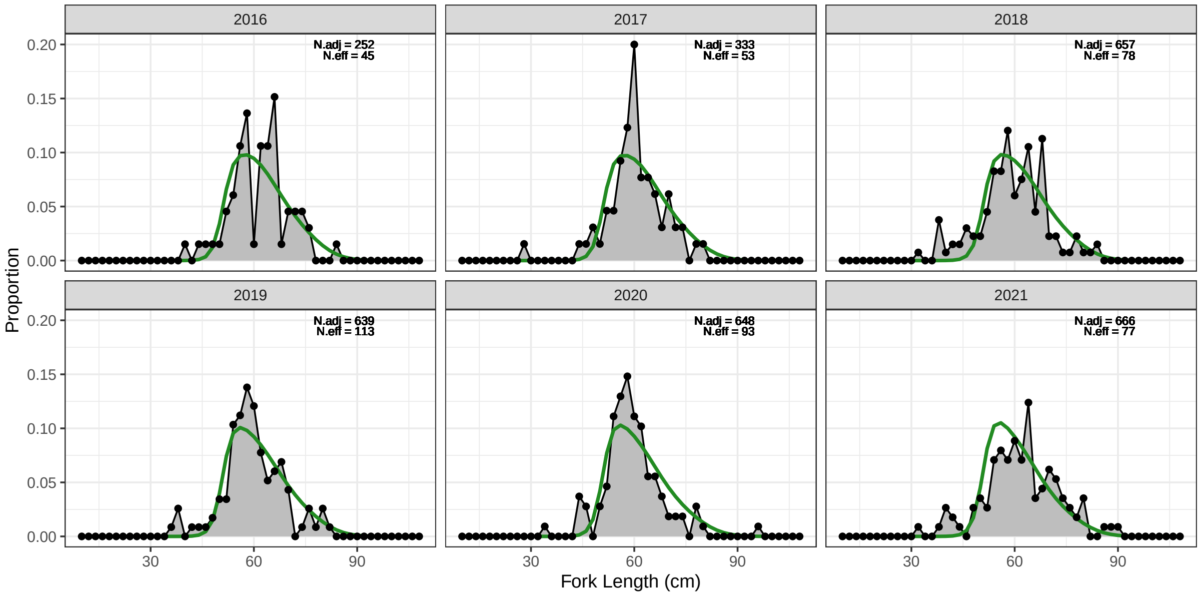

Figure C.152: Scenario 23 length structure for the recreational fleet for retained red emperor

'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

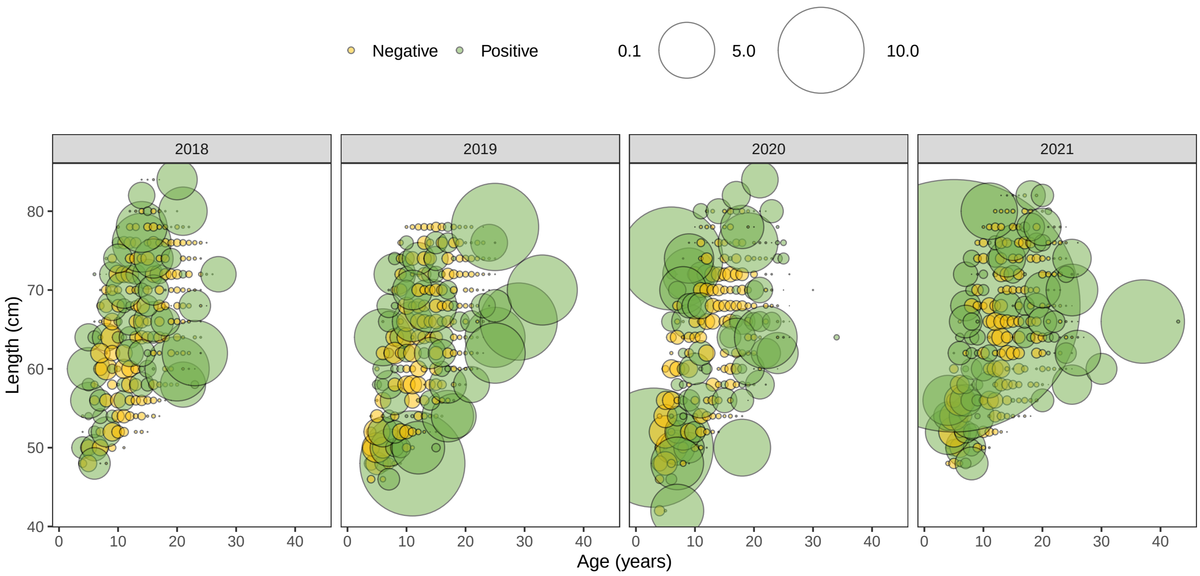

Figure C.153: Scenario 23 Pearson residuals for age-at-length compositions for the commercial fleet for red emperor—circle size represents the magnitude of the Pearson residual

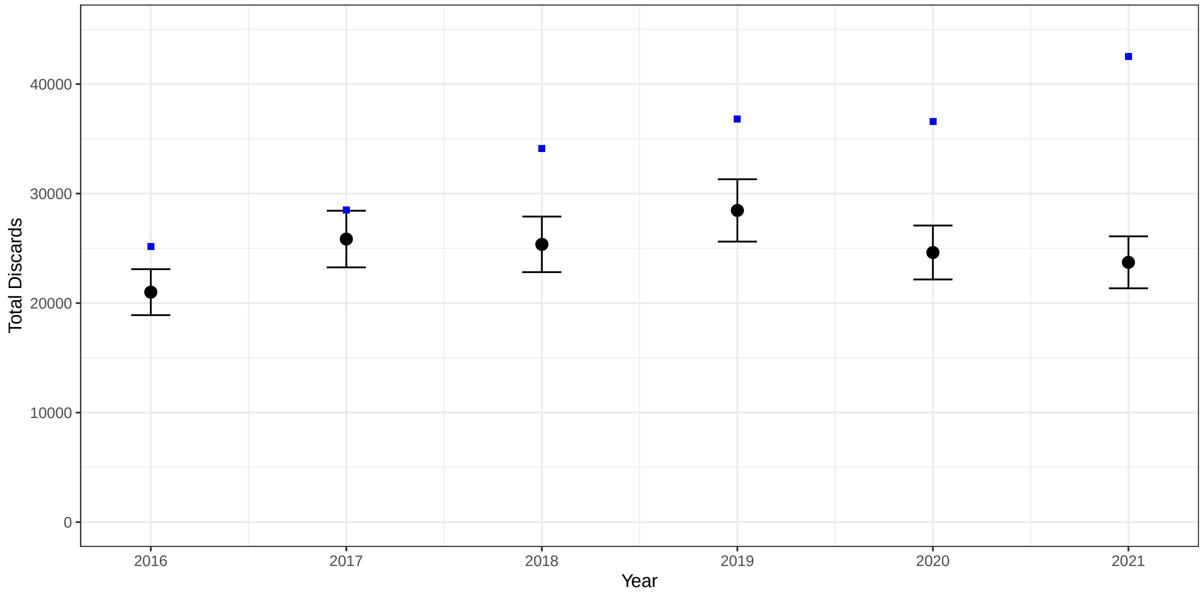

Figure C.154: Scenario 23 model fit to total discards for recreational-charter-Indigenous fleet—circles and error bars represent input data and their associated coefficients of variation and blue points represent the model predictions

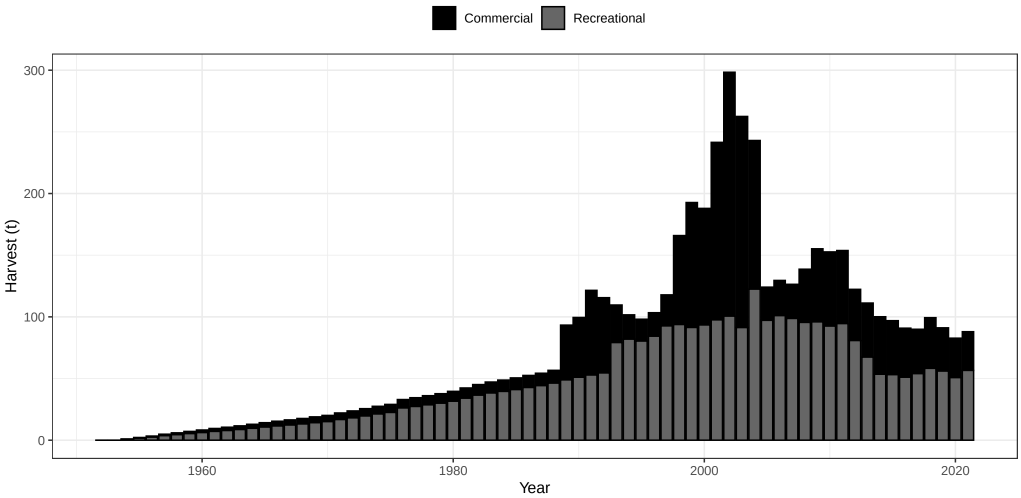

Figure C.155: Scenario 23 modelled harvest of red emperor

Scenario 24

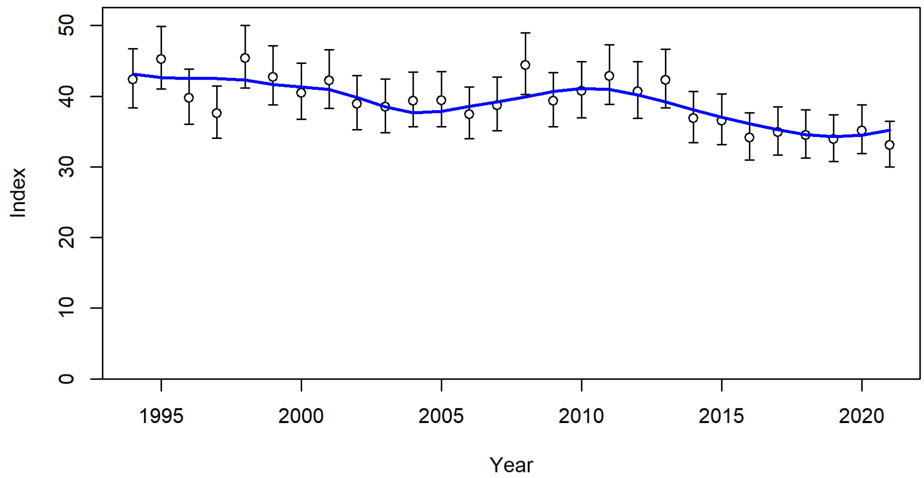

Figure C.156: Scenario 24 model predictions (blue line) to commercial catch rates for red emperor prior to rezoning

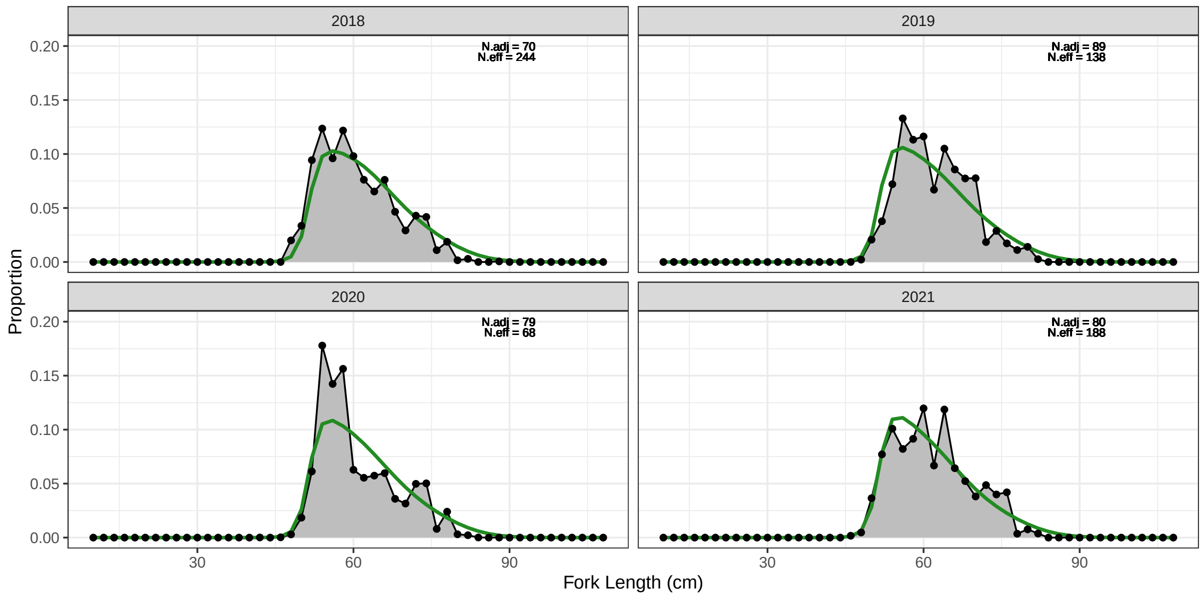

Figure C.157: Scenario 24 length structure for the commercial fleet for red emperor

'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

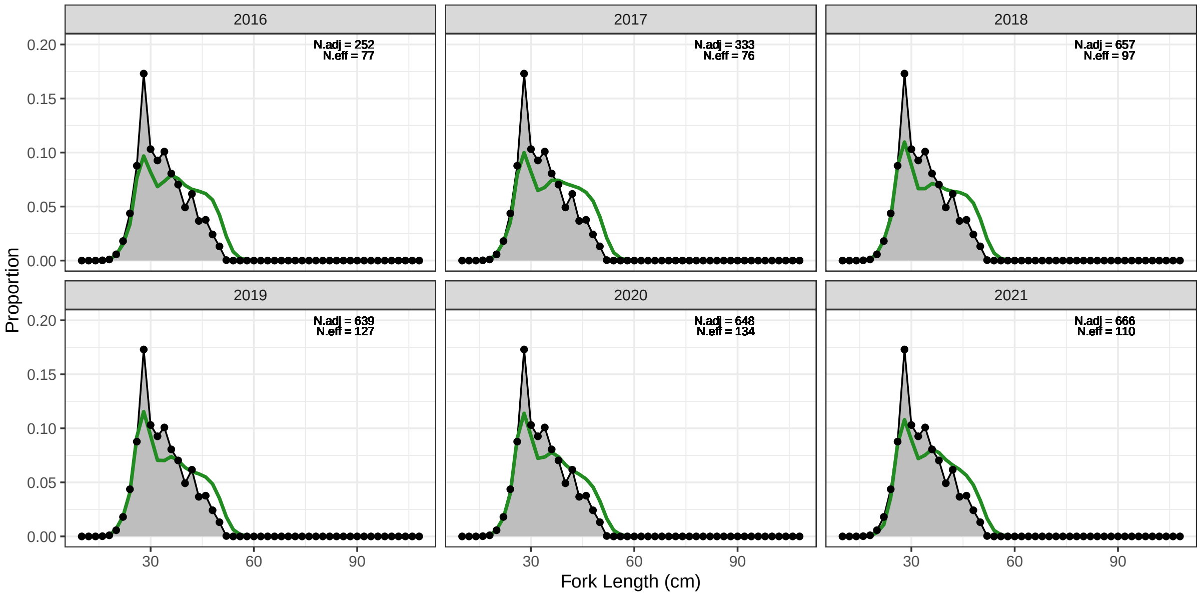

Figure C.158: Scenario 24 length structure for the recreational fleet for discarded red emperor

'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

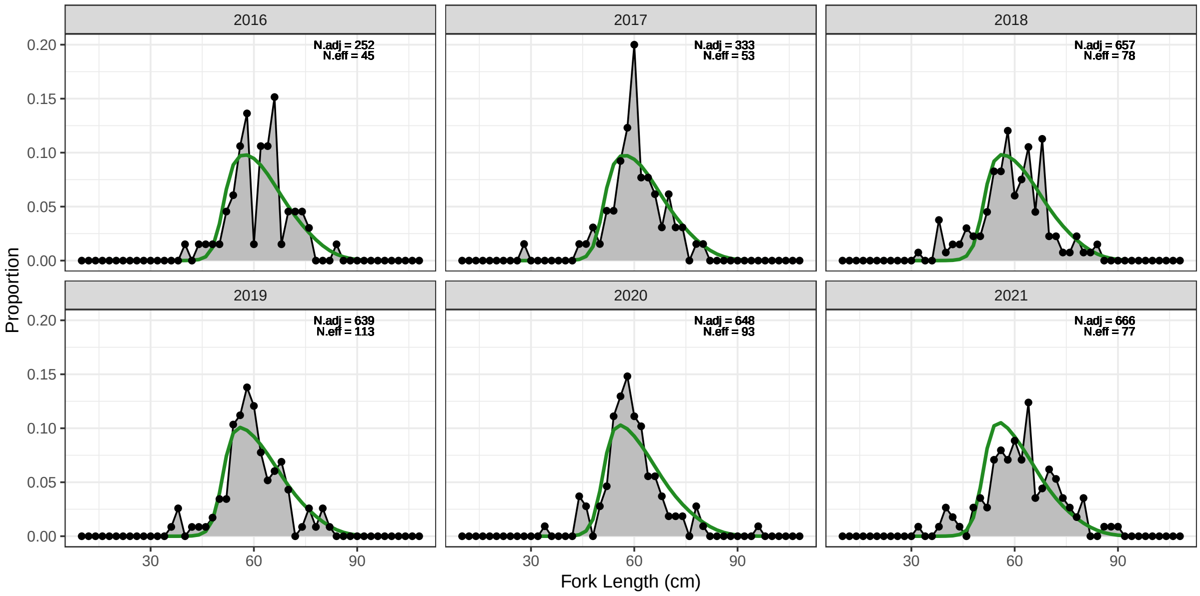

Figure C.159: Scenario 24 length structure for the recreational fleet for retained red emperor

'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

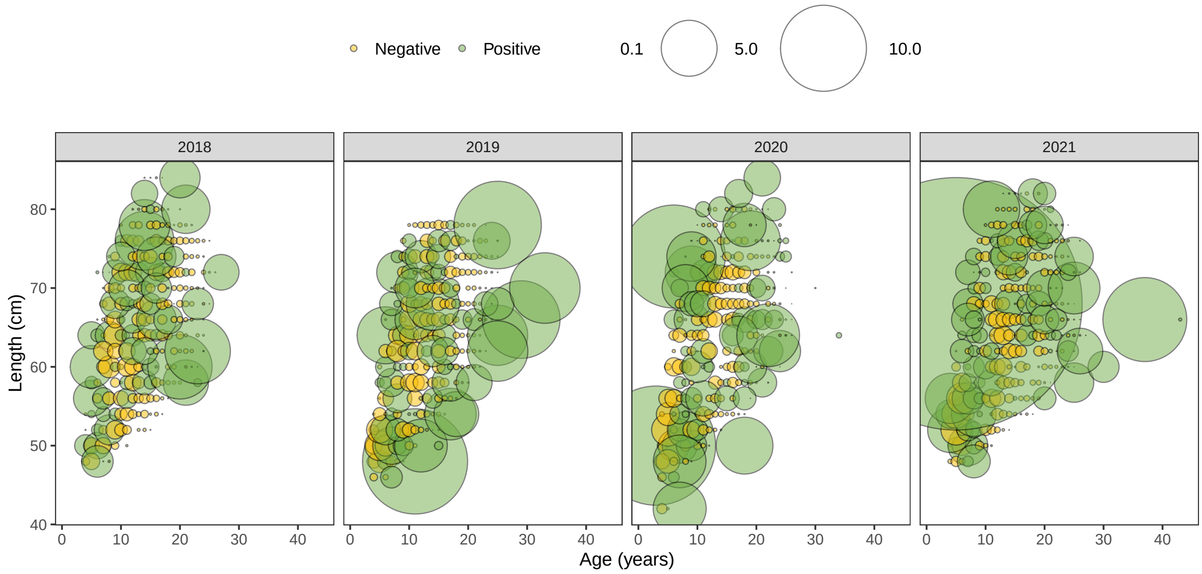

Figure C.160: Scenario 24 Pearson residuals for age-at-length compositions for the commercial fleet for red emperor—circle size represents the magnitude of the Pearson residual

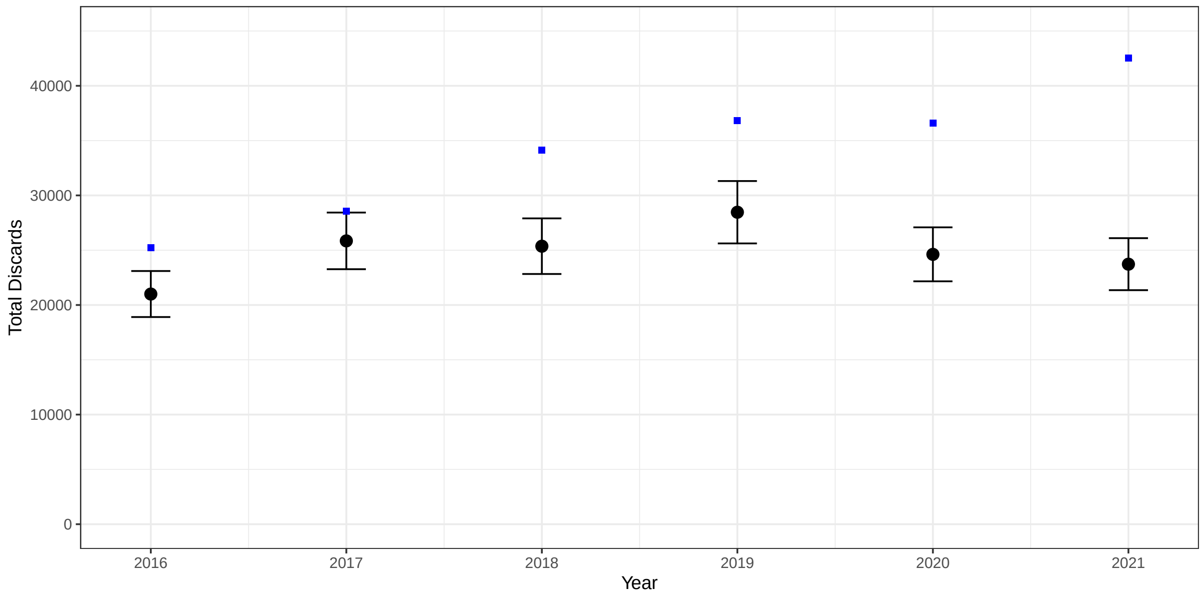

Figure C.161: Scenario 24 model fit to total discards for recreational-charter-Indigenous fleet—circles and error bars represent input data and their associated coefficients of variation and blue points represent the model predictions

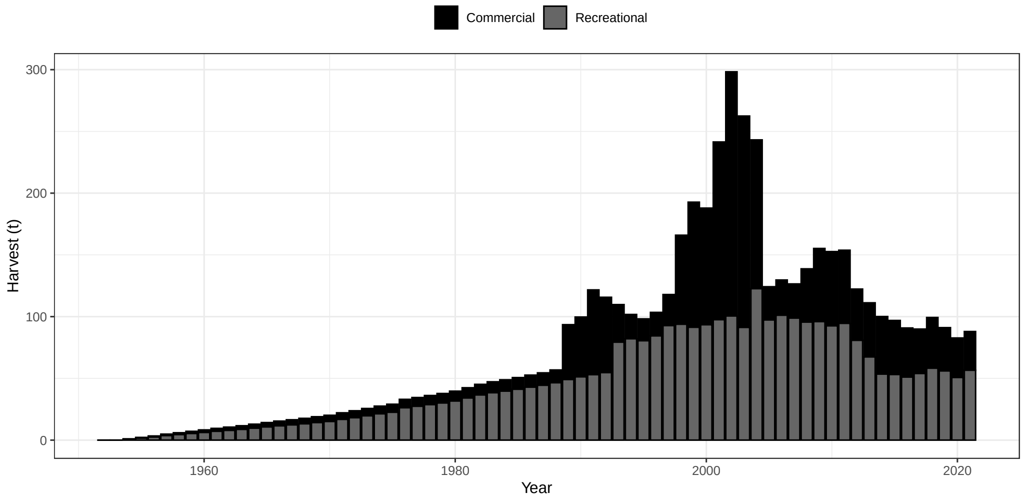

Figure C.162: Scenario 24 modelled harvest of red emperor

Appendix D Sensitivity tests: other outputs

Scenario 2

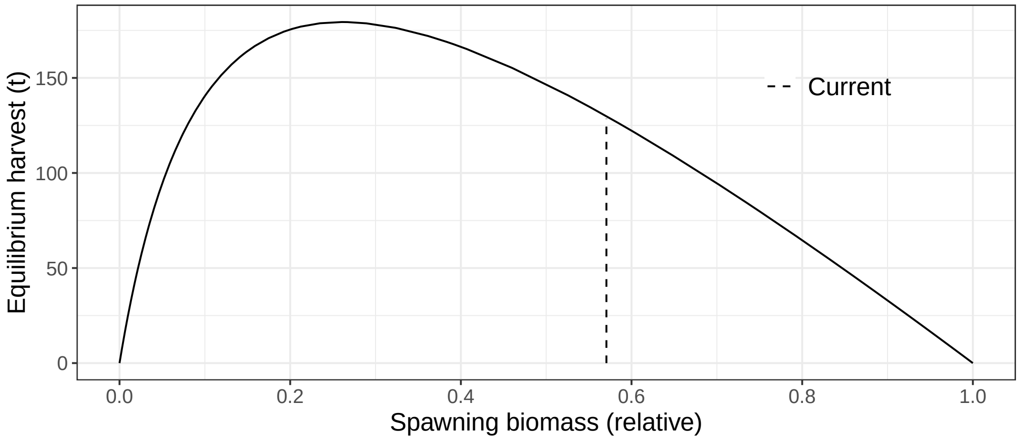

Figure D.1: Scenario 2 equilibrium harvest curve for red emperor

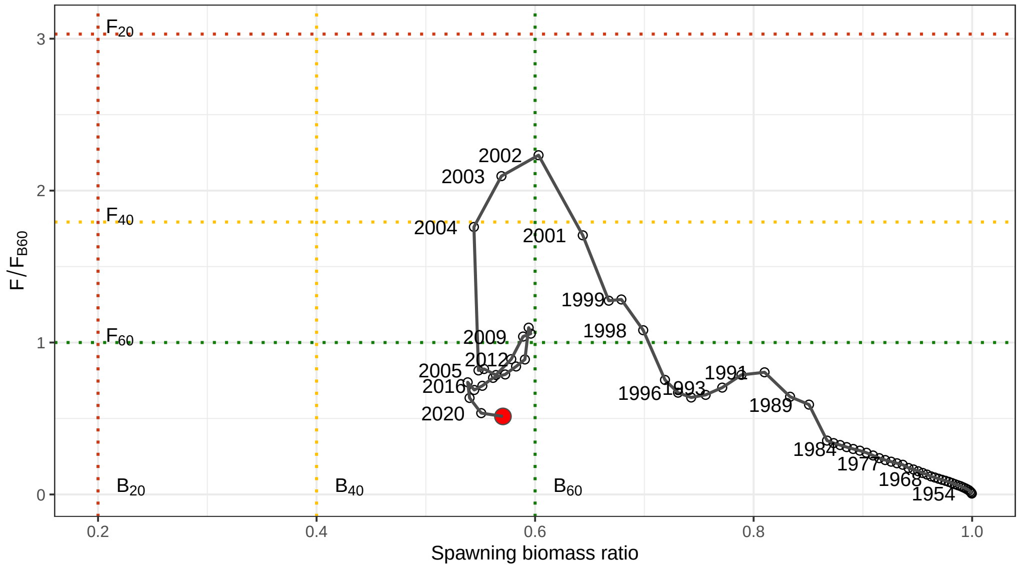

Figure D.2: Scenario 2 phase plot for red emperor

Scenario 3

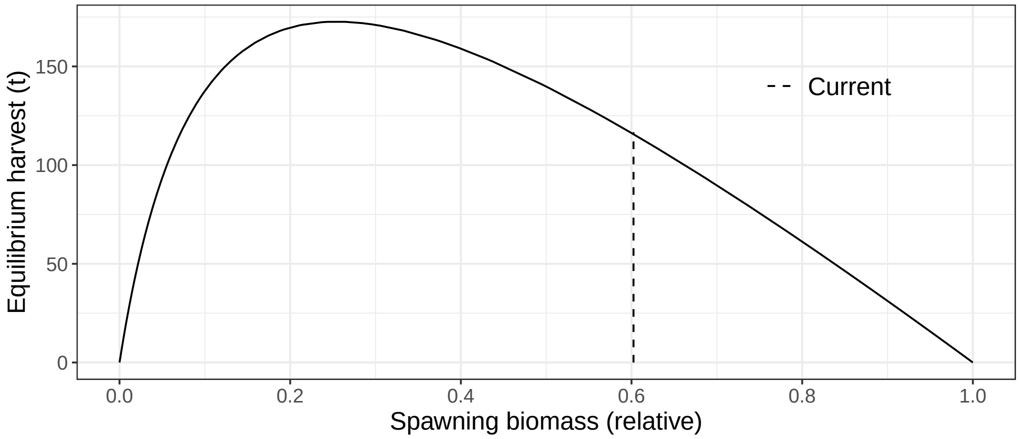

Figure D.3: Scenario 3 equilibrium harvest curve for red emperor

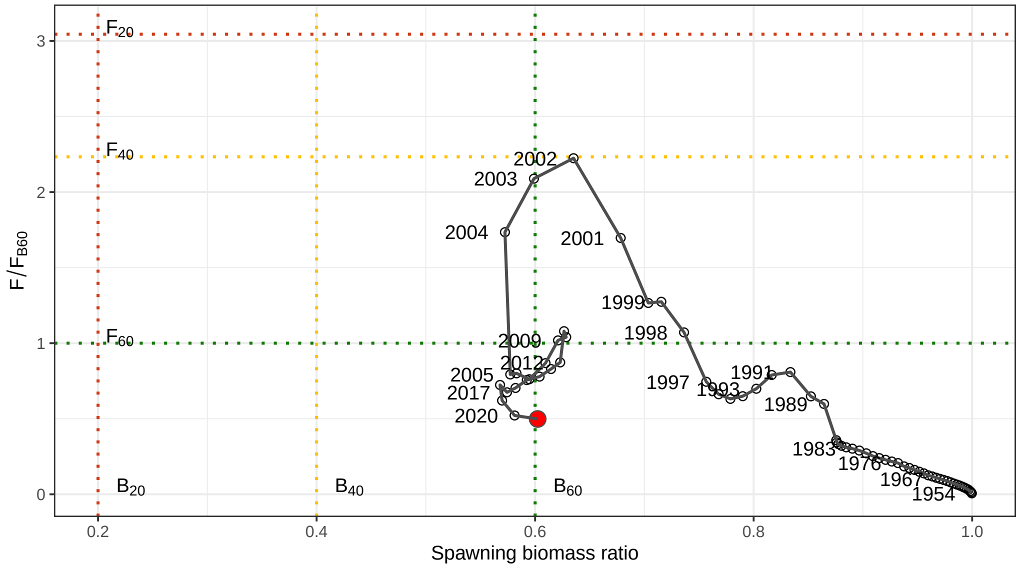

Figure D.4: Scenario 3 phase plot for red emperor

Scenario 4

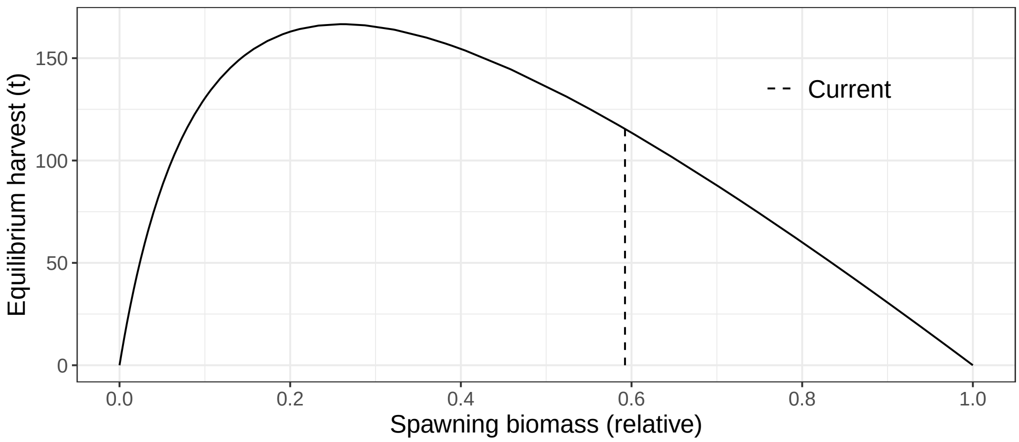

Figure D.5: Scenario 4 equilibrium harvest curve for red emperor

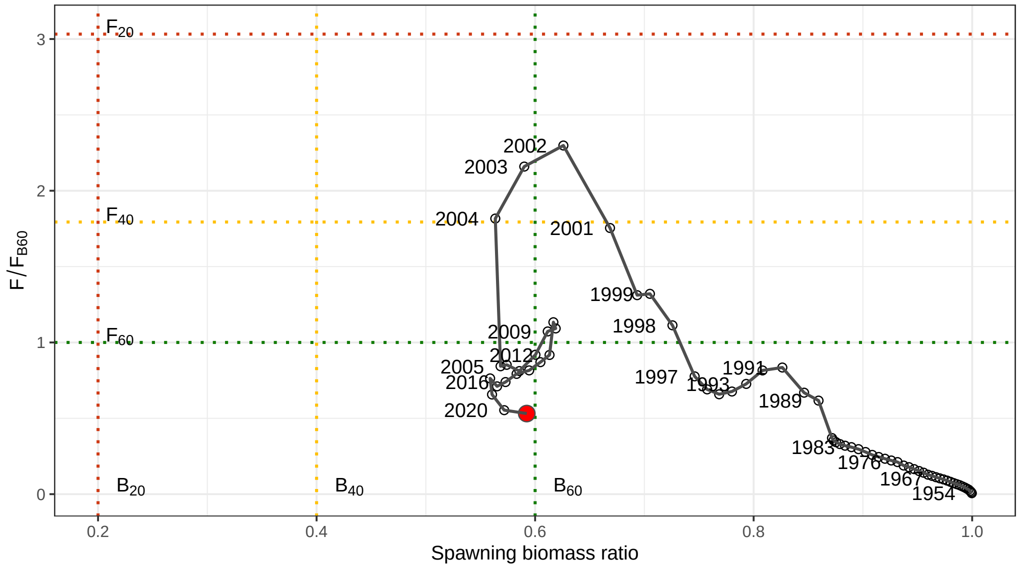

Figure D.6: Scenario 4 phase plot for red emperor

Scenario 5

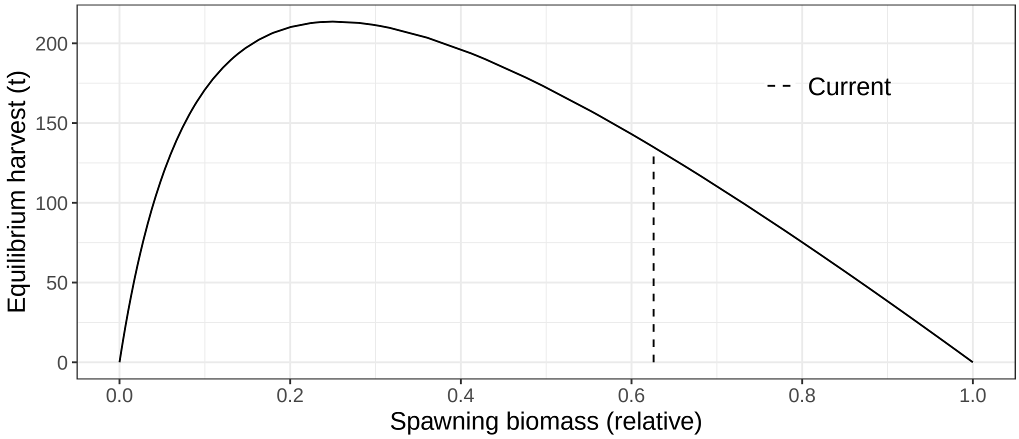

Figure D.7: Scenario 5 equilibrium harvest curve for red emperor

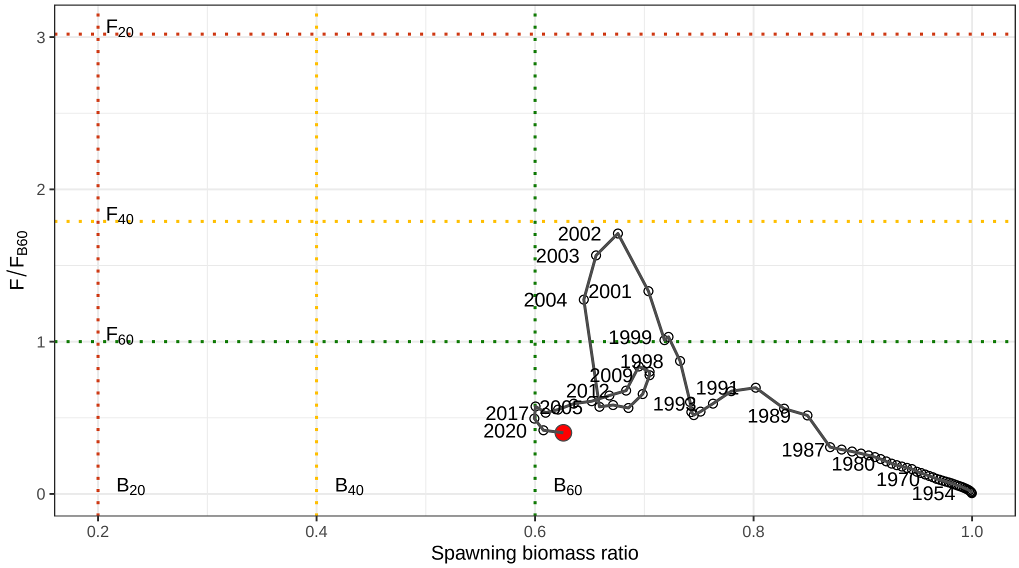

Figure D.8: Scenario 5 phase plot for red emperor

Scenario 6

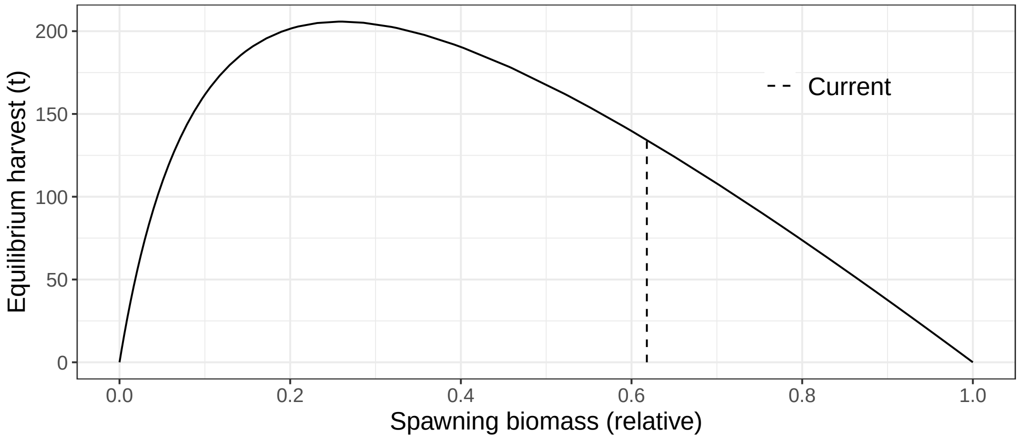

Figure D.9: Scenario 6 equilibrium harvest curve for red emperor

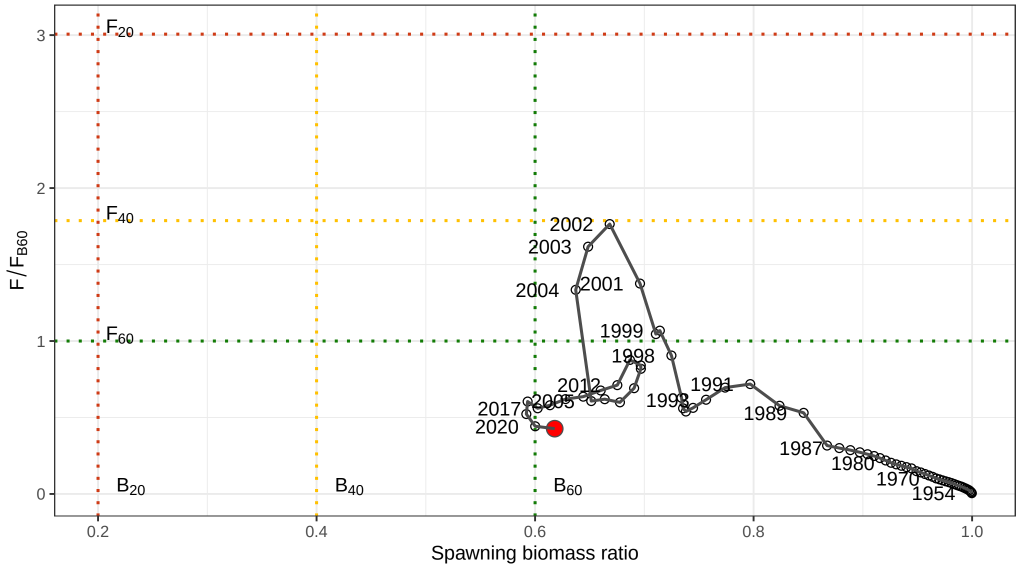

Figure D.10: Scenario 6 phase plot for red emperor

Scenario 7

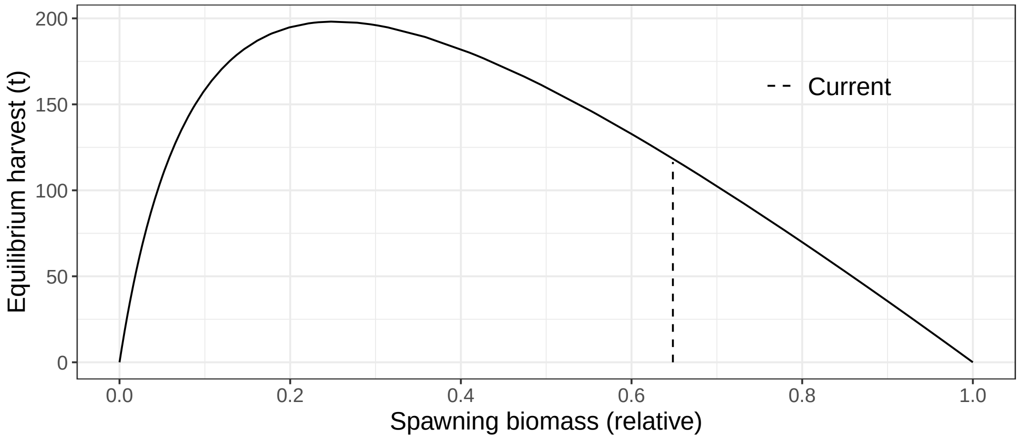

Figure D.11: Scenario 7 equilibrium harvest curve for red emperor

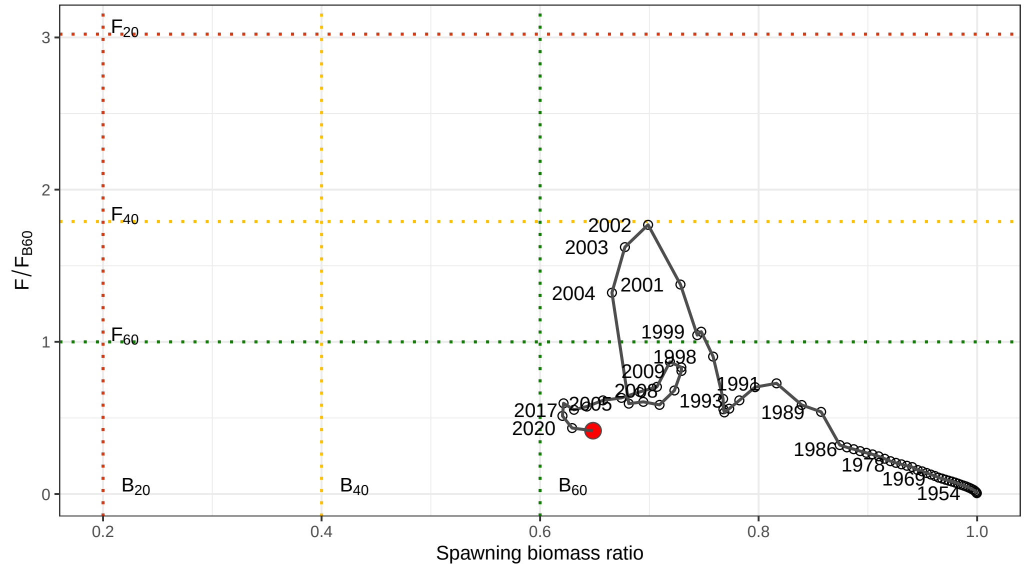

Figure D.12: Scenario 7 phase plot for red emperor

Scenario 8

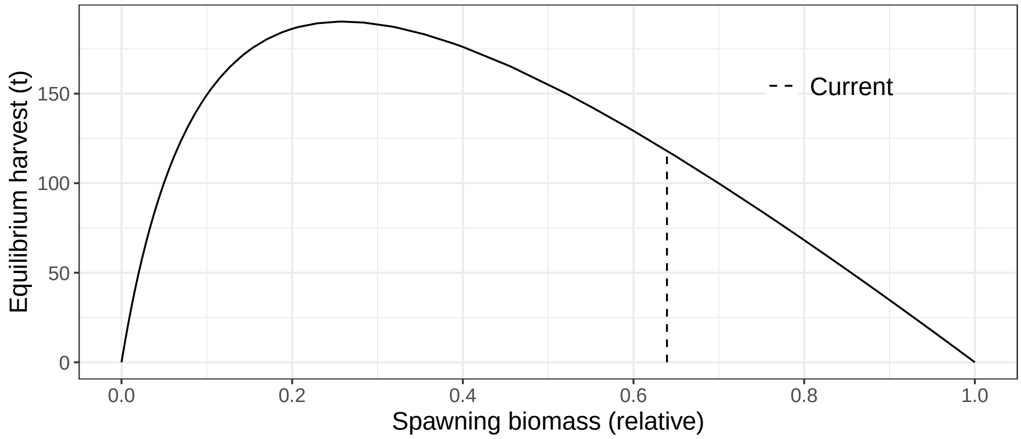

Figure D.13: Scenario 8 equilibrium harvest curve for red emperor

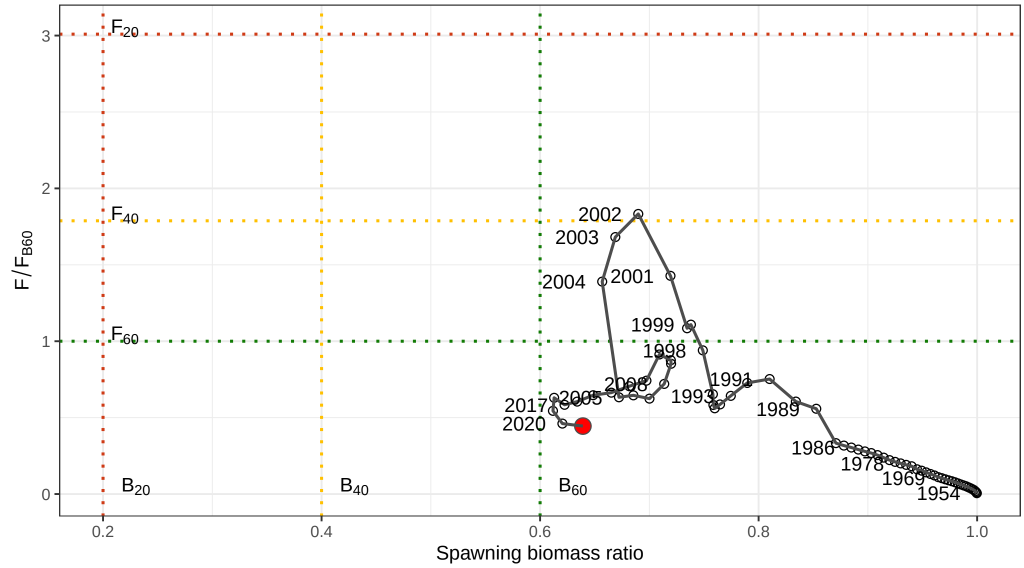

Figure D.14: Scenario 8 phase plot for red emperor

Scenario 9

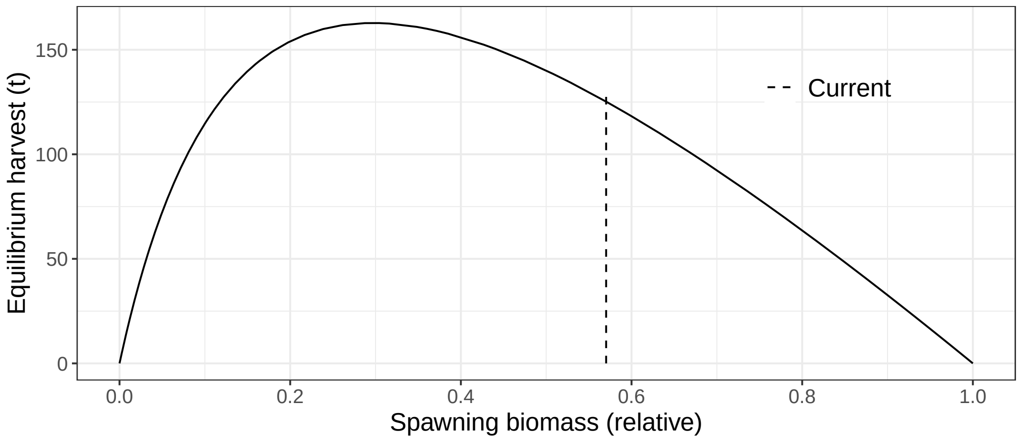

Figure D.15: Scenario 9 equilibrium harvest curve for red emperor

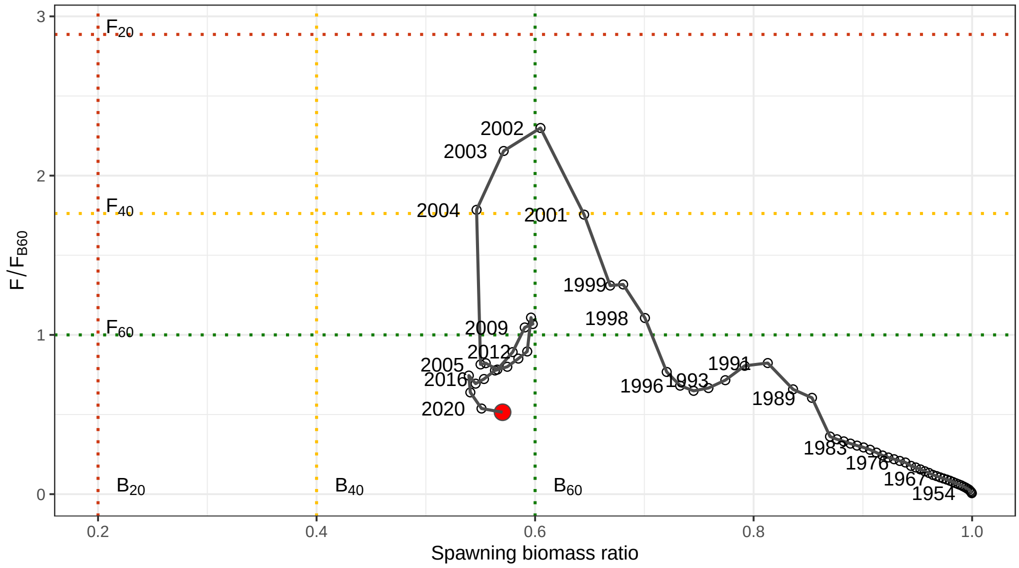

Figure D.16: Scenario 9 phase plot for red emperor

Scenario 10

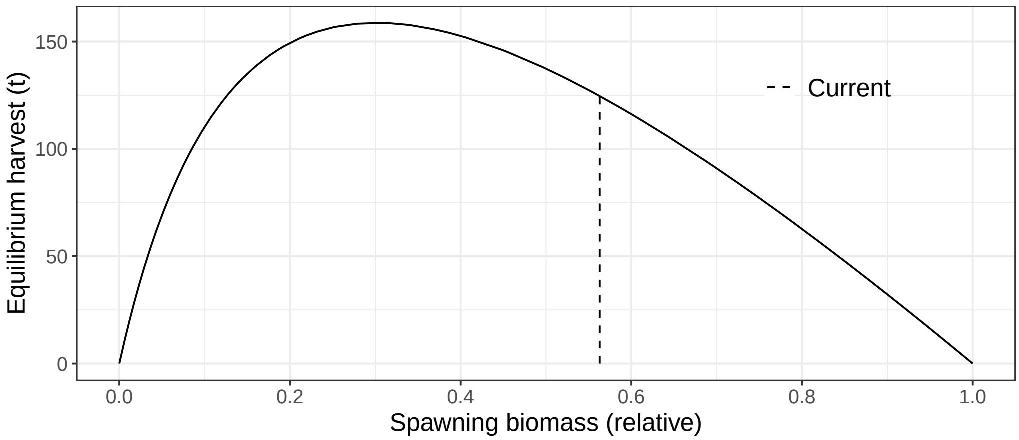

Figure D.17: Scenario 10 equilibrium harvest curve for red emperor

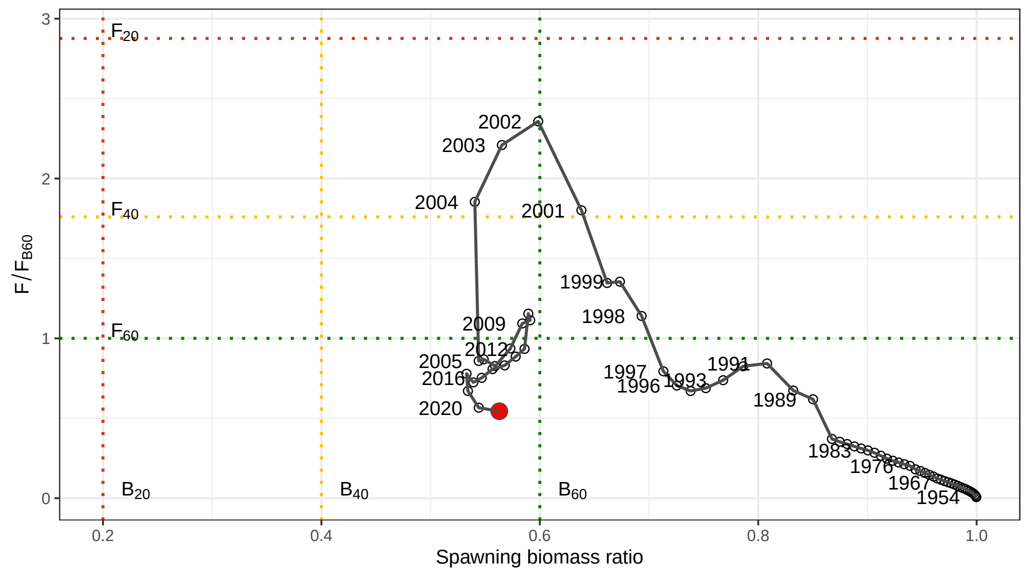

Figure D.18: Scenario 10 phase plot for red emperor

Scenario 11

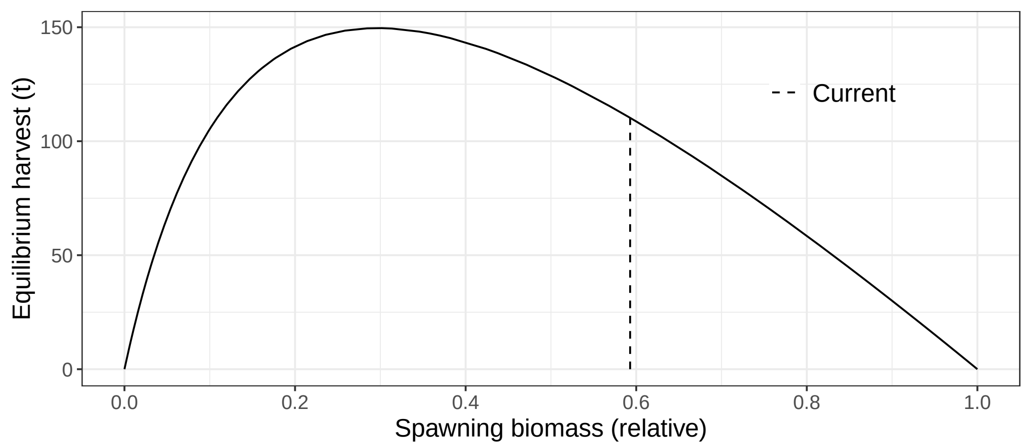

Figure D.19: Scenario 11 equilibrium harvest curve for red emperor

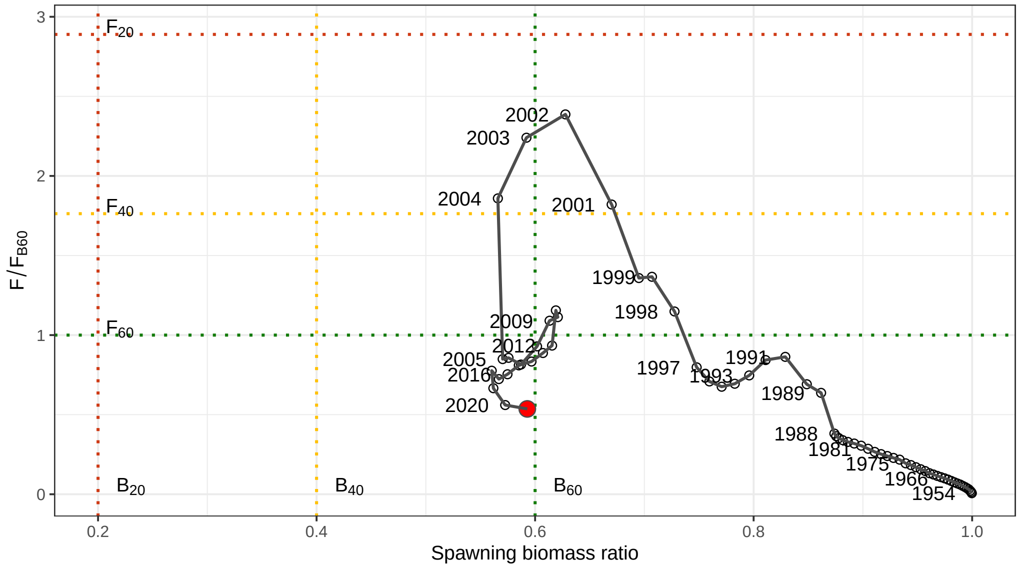

Figure D.20: Scenario 11 phase plot for red emperor

Scenario 12

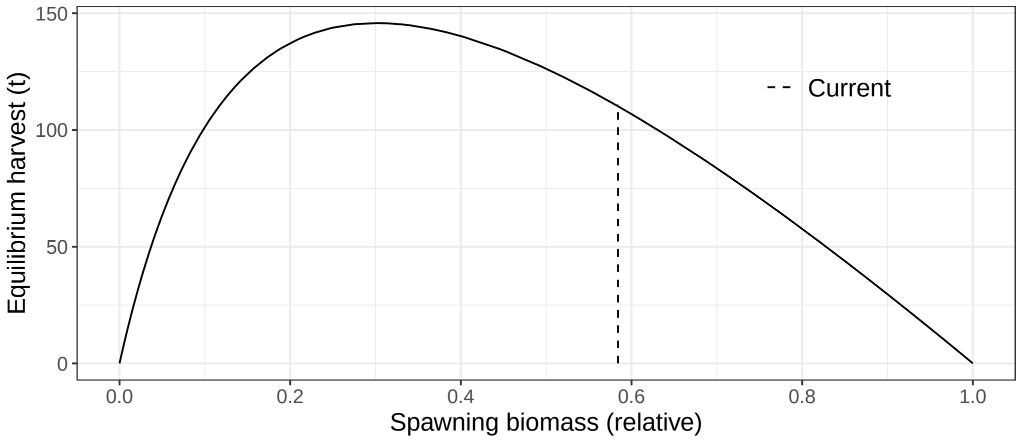

Figure D.21: Scenario 12 equilibrium harvest curve for red emperor

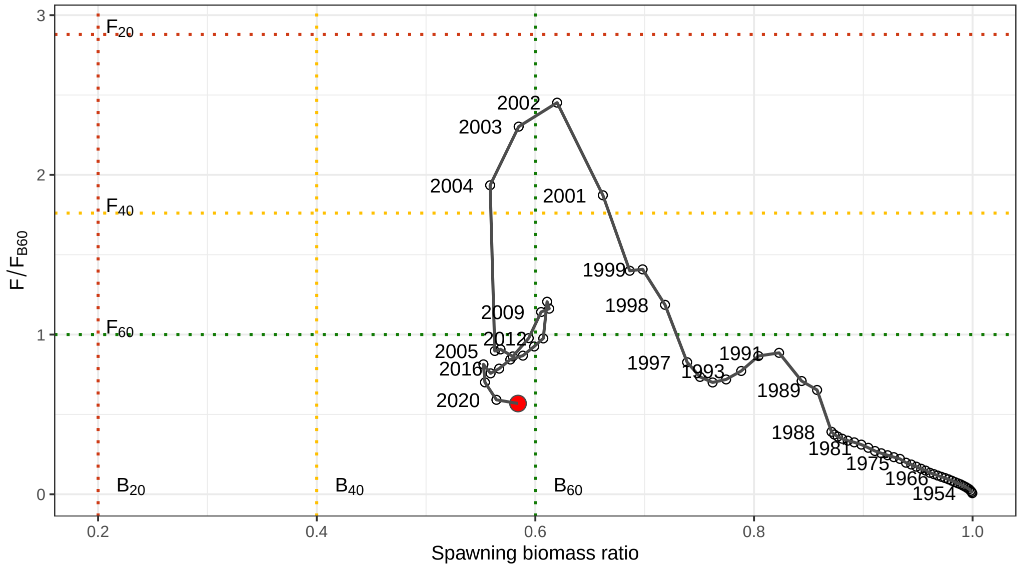

Figure D.22: Scenario 12 phase plot for red emperor

Scenario 13

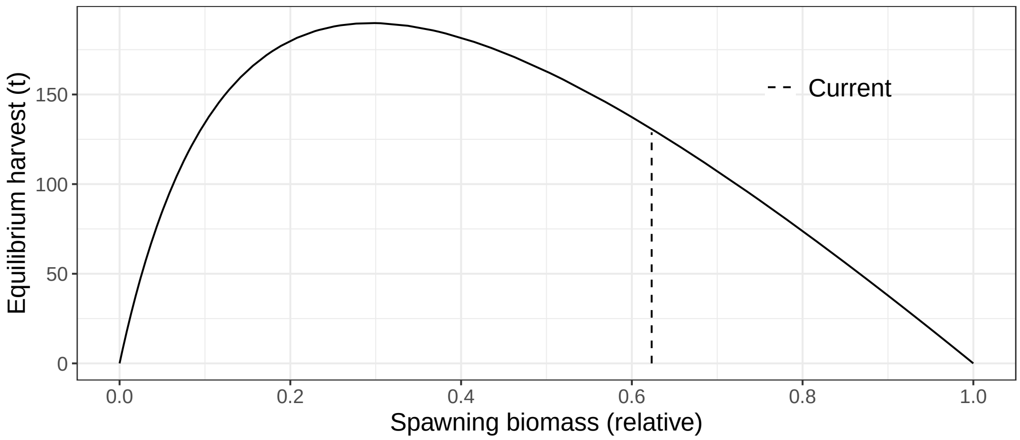

Figure D.23: Scenario 13 equilibrium harvest curve for red emperor

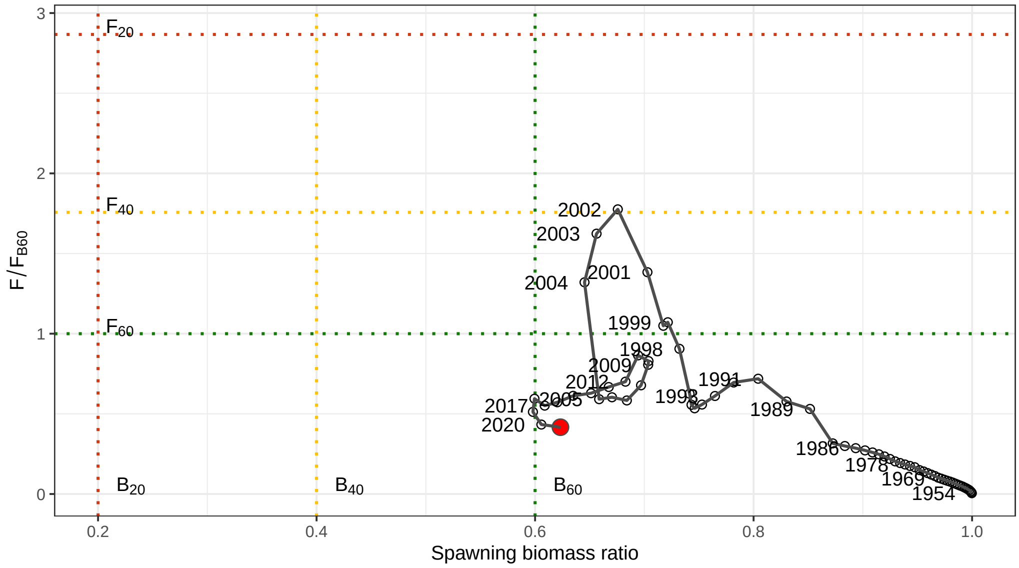

Figure D.24: Scenario 13 phase plot for red emperor

Scenario 14

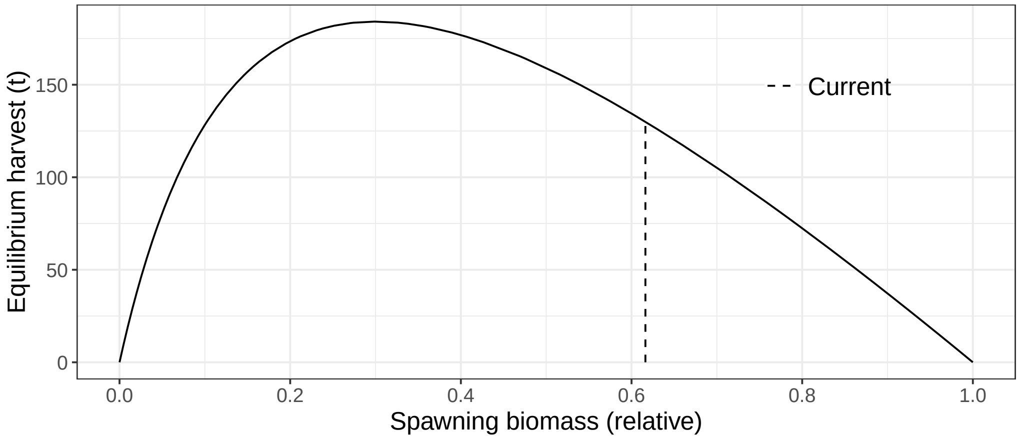

Figure D.25: Scenario 14 equilibrium harvest curve for red emperor

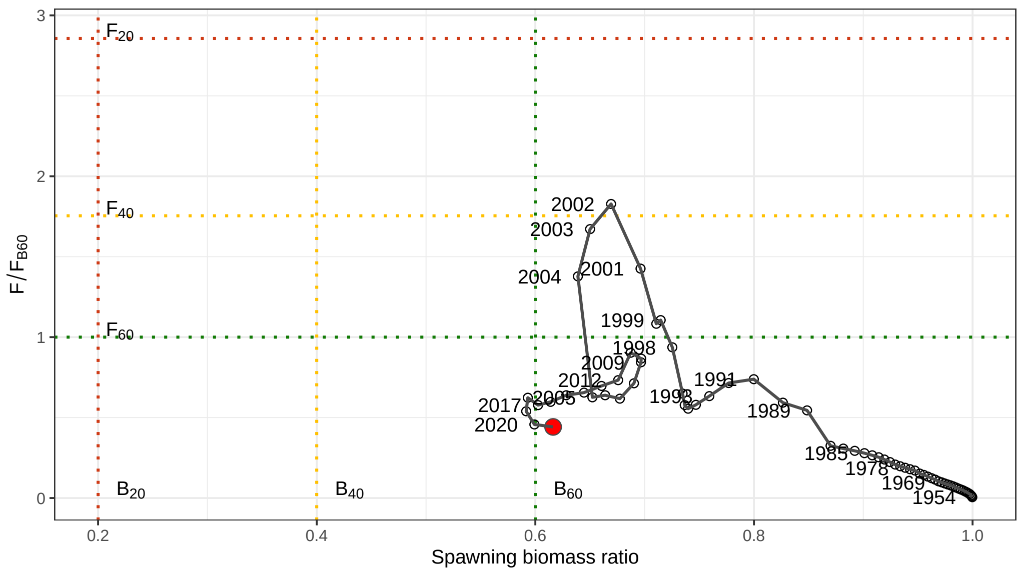

Figure D.26: Scenario 14 phase plot for red emperor

Scenario 15

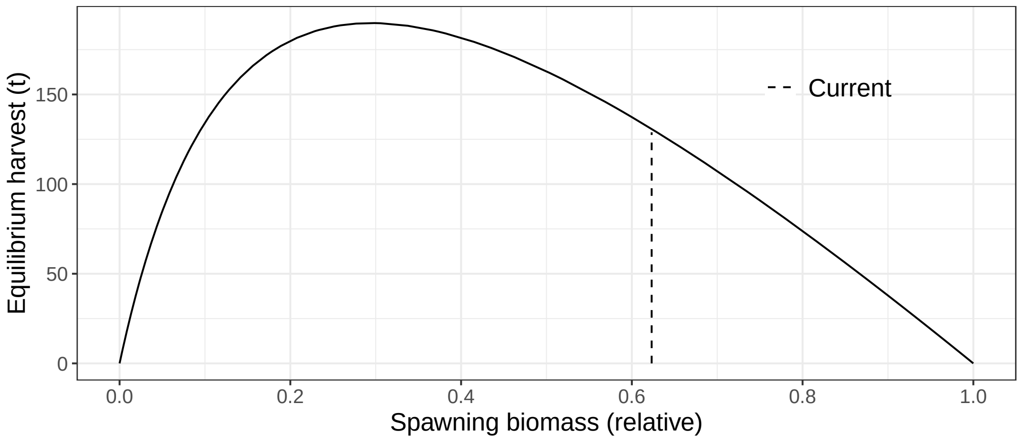

Figure D.27: Scenario 15 equilibrium harvest curve for red emperor

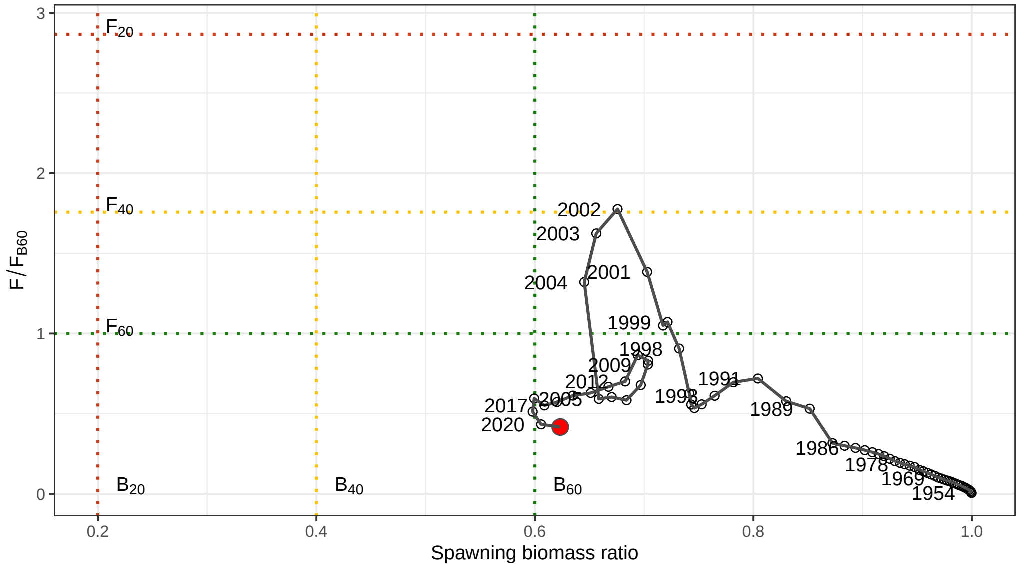

Figure D.28: Scenario 15 phase plot for red emperor

Scenario 16

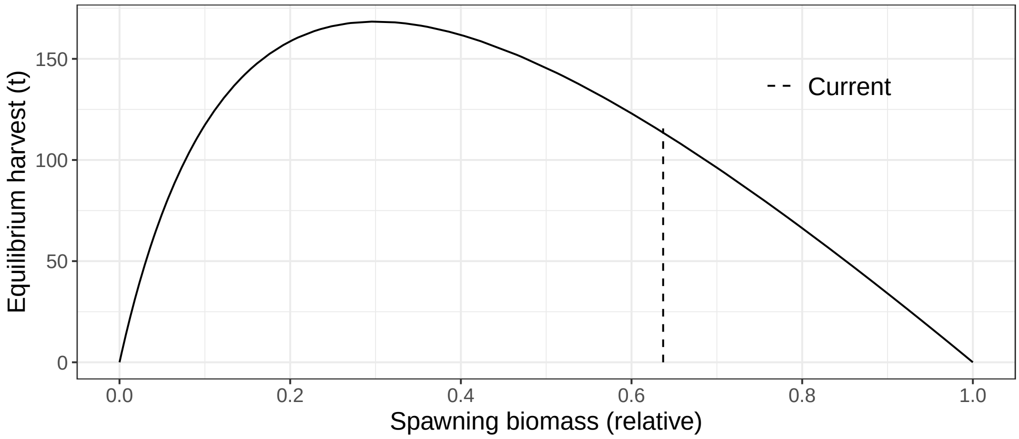

Figure D.29: Scenario 16 equilibrium harvest curve for red emperor

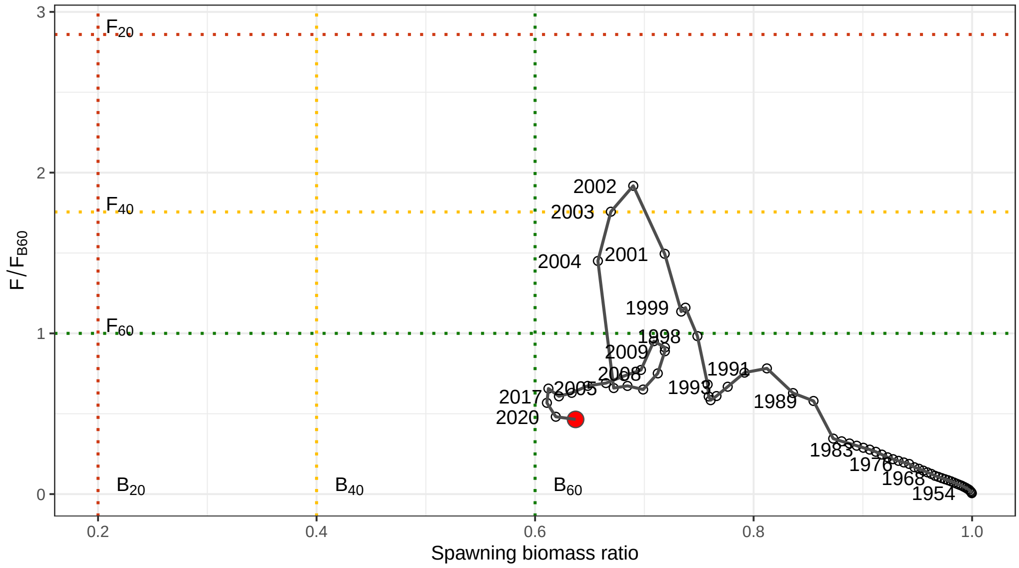

Figure D.30: Scenario 16 phase plot for red emperor

Scenario 17

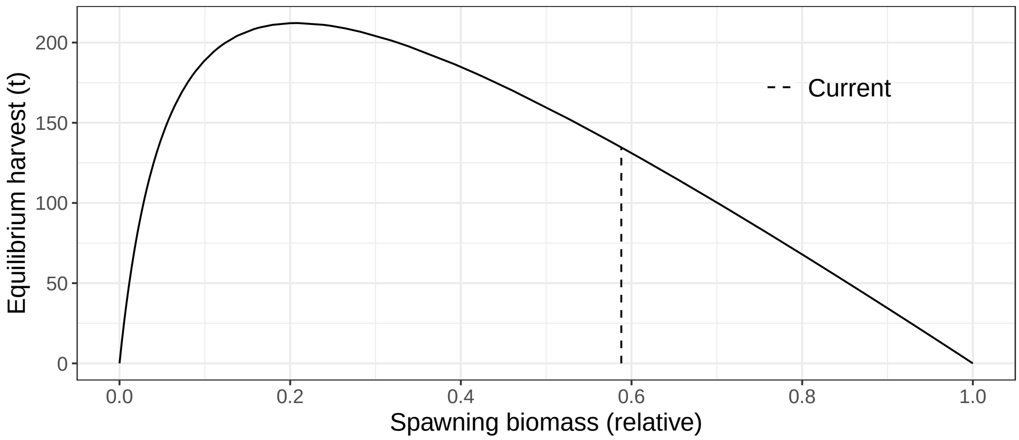

Figure D.31: Scenario 17 equilibrium harvest curve for red emperor

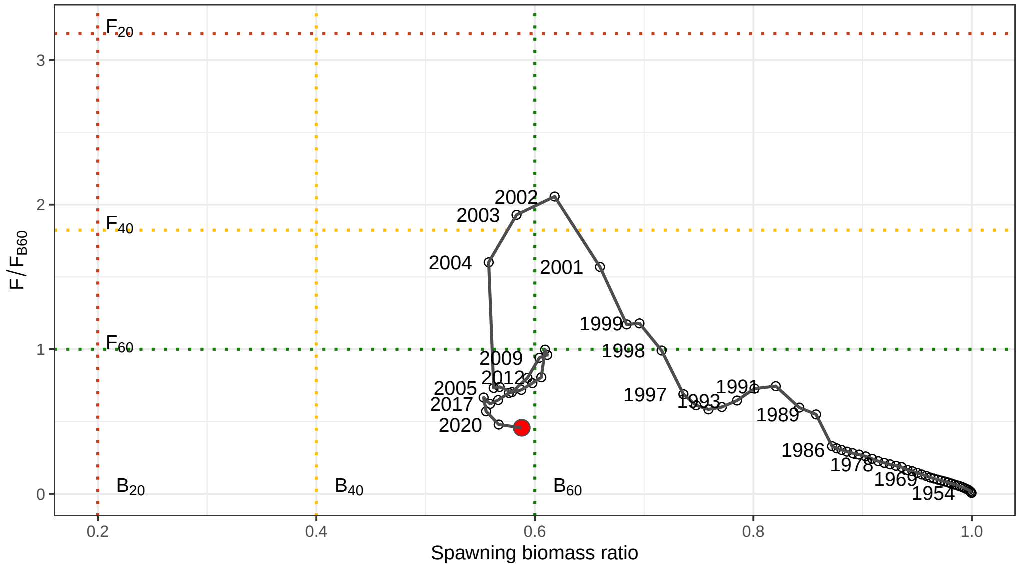

Figure D.32: Scenario 17 phase plot for red emperor

Scenario 18

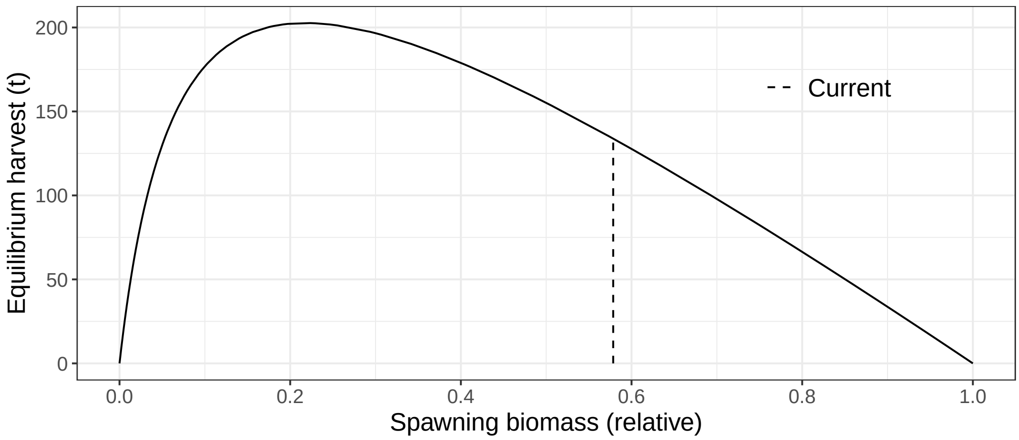

Figure D.33: Scenario 18 equilibrium harvest curve for red emperor

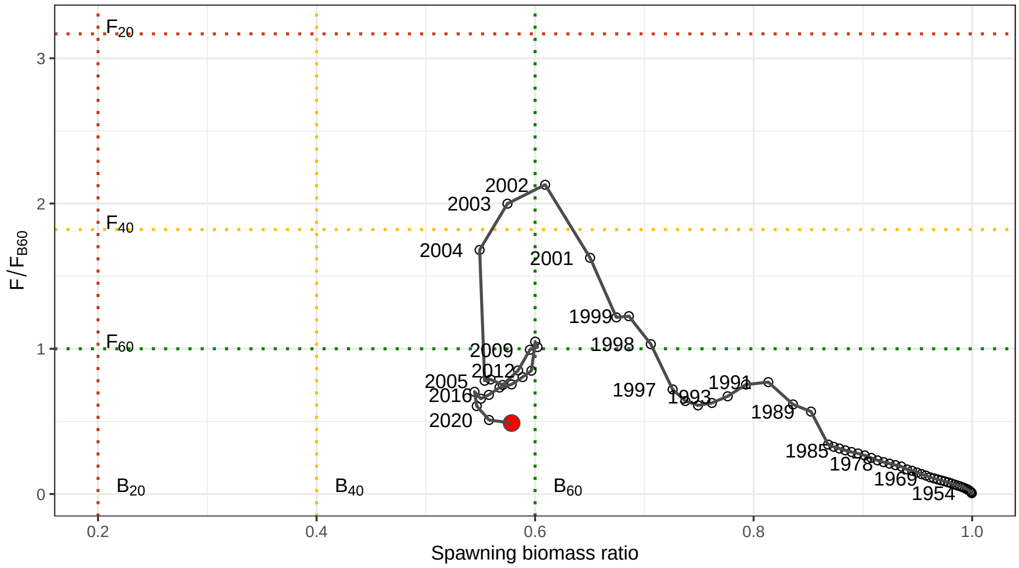

Figure D.34: Scenario 18 phase plot for red emperor

Scenario 19

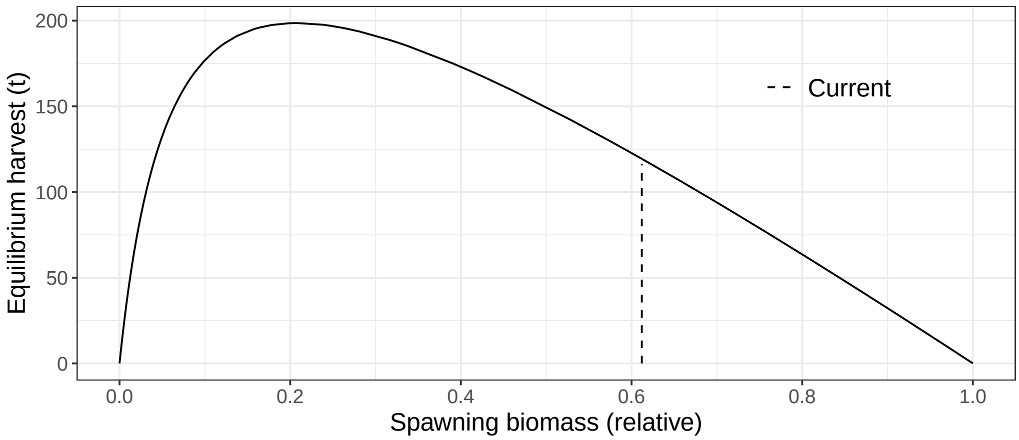

Figure D.35: Scenario 19 equilibrium harvest curve for red emperor

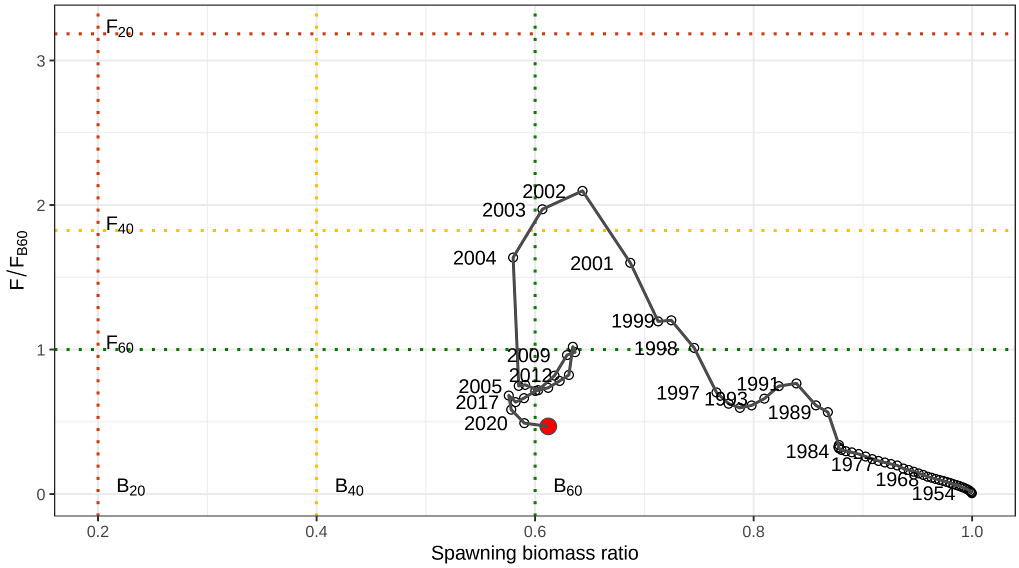

Figure D.36: Scenario 19 phase plot for red emperor

Scenario 20

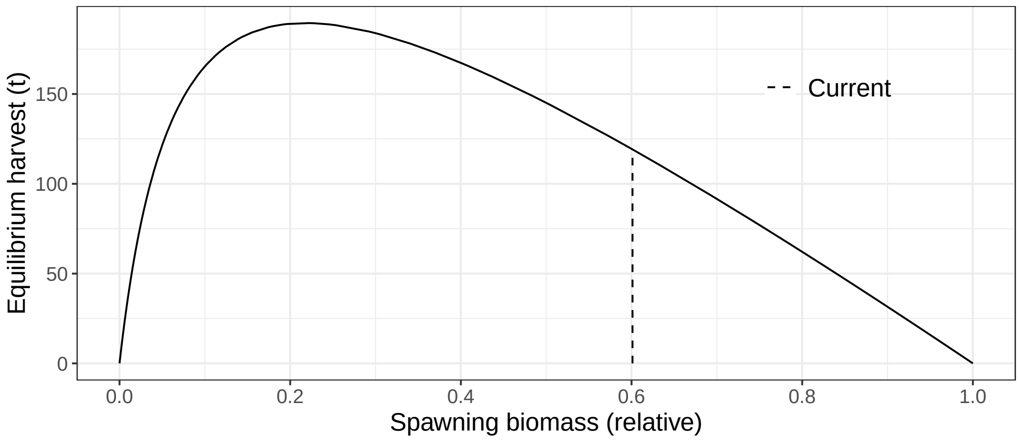

Figure D.37: Scenario 20 equilibrium harvest curve for red emperor

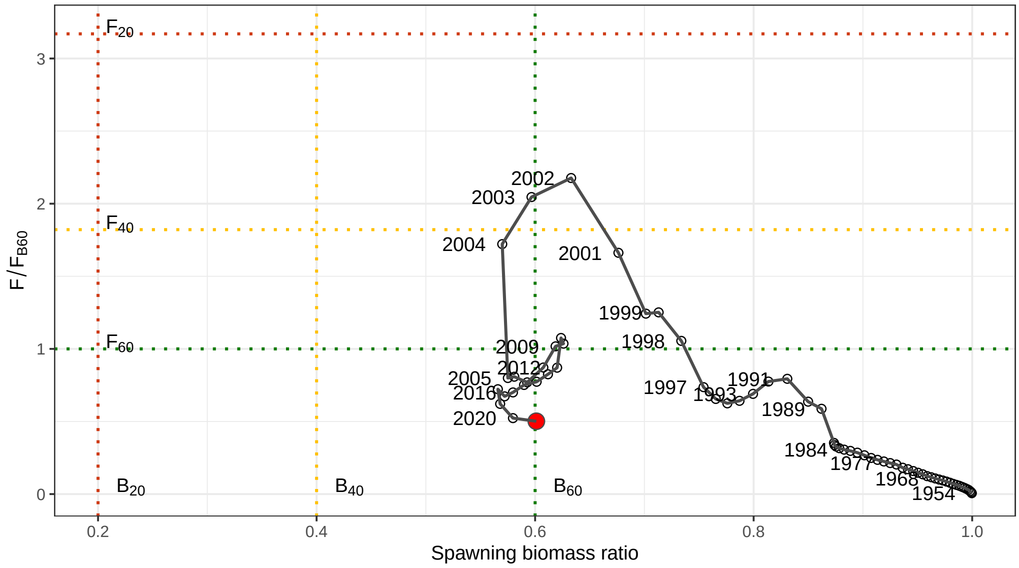

Figure D.38: Scenario 20 phase plot for red emperor

Scenario 21

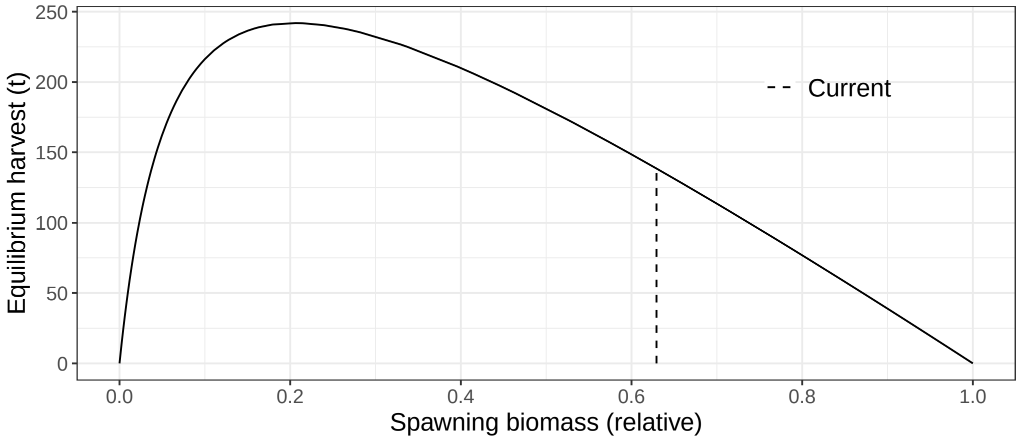

Figure D.39: Scenario 21 equilibrium harvest curve for red emperor

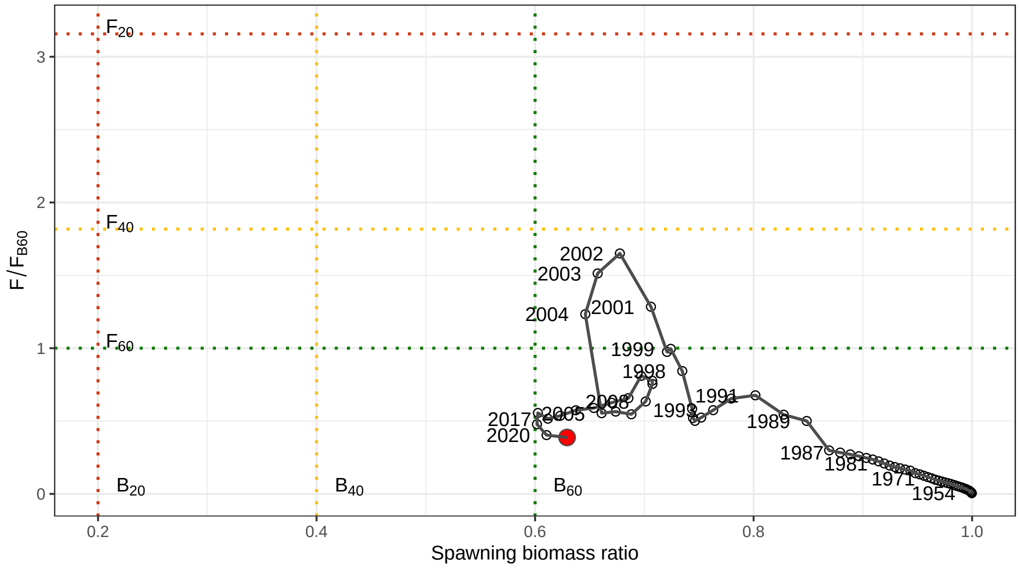

Figure D.40: Scenario 21 phase plot for red emperor

Scenario 22

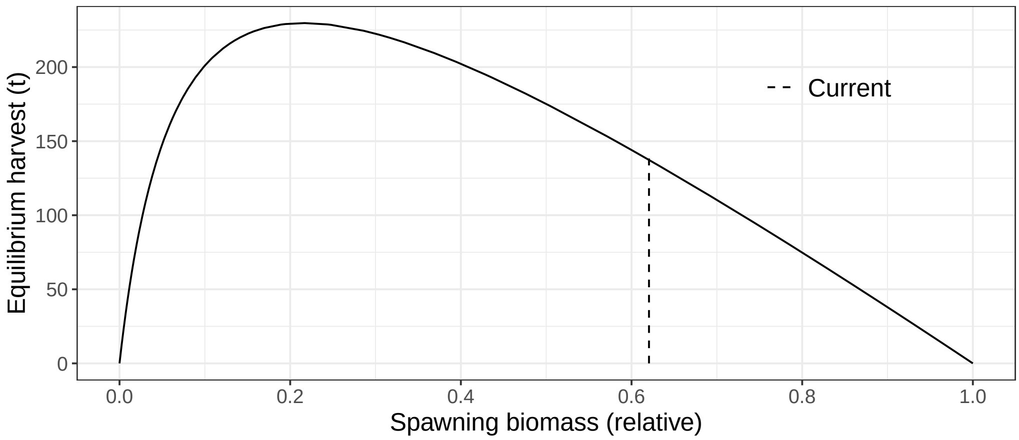

Figure D.41: Scenario 22 equilibrium harvest curve for red emperor

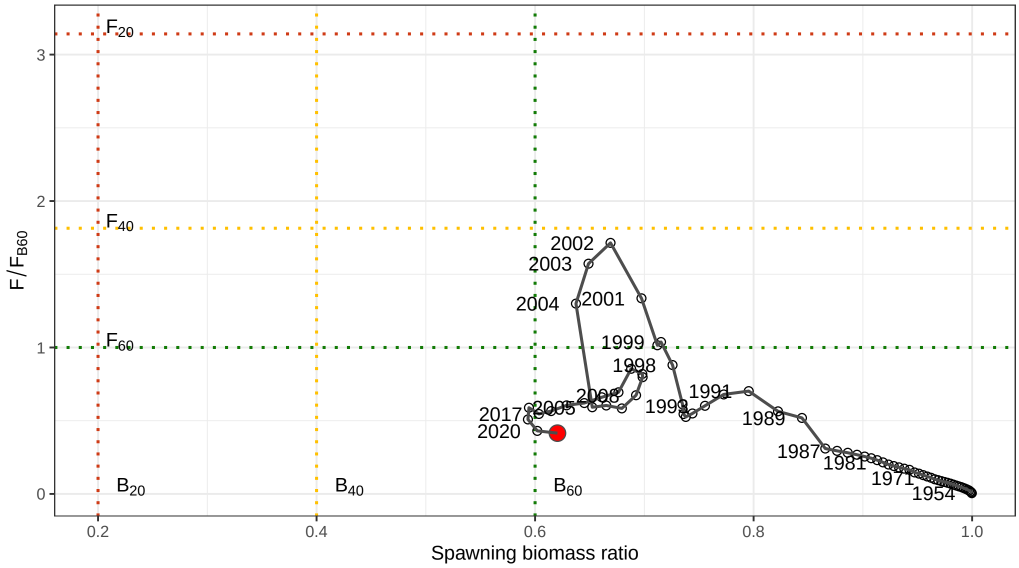

Figure D.42: Scenario 22 phase plot for red emperor

Scenario 23

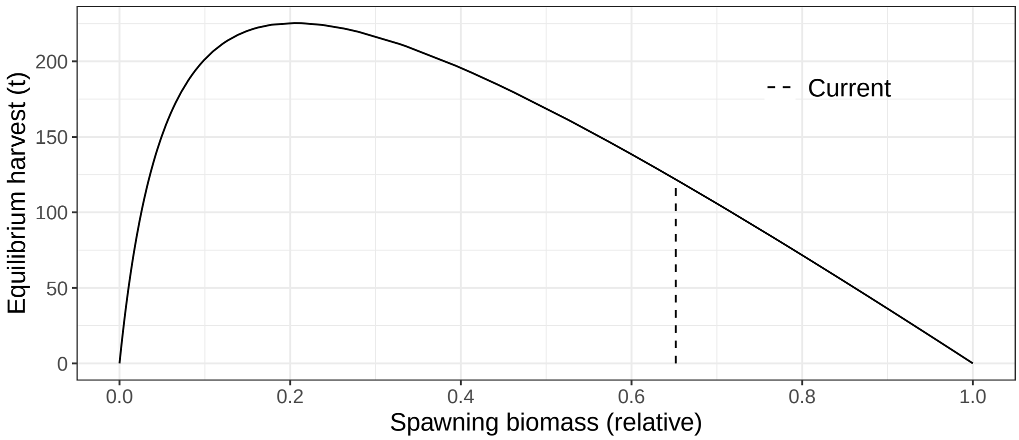

Figure D.43: Scenario 23 equilibrium harvest curve for red emperor

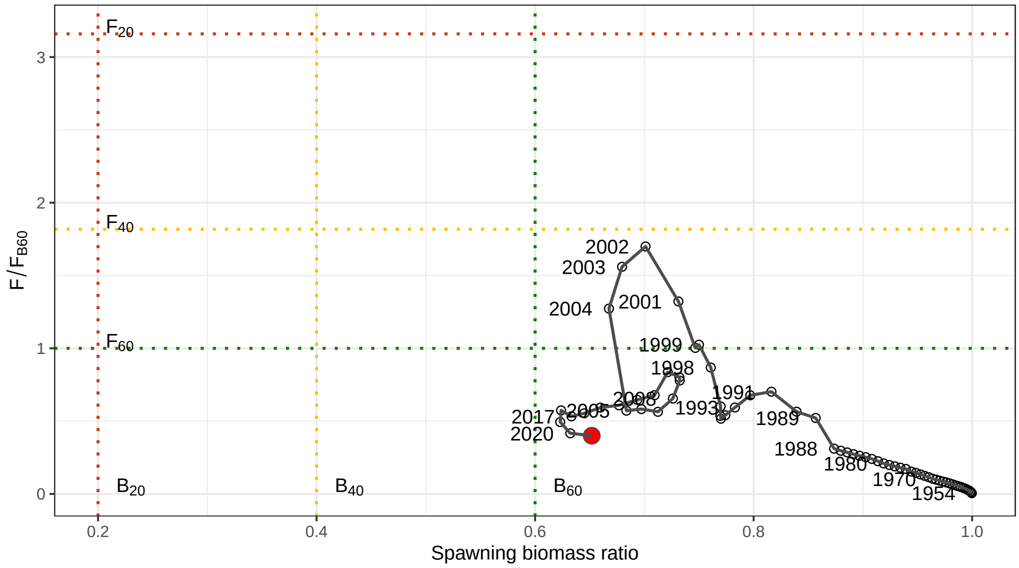

Figure D.44: Scenario 23 phase plot for red emperor

Scenario 24

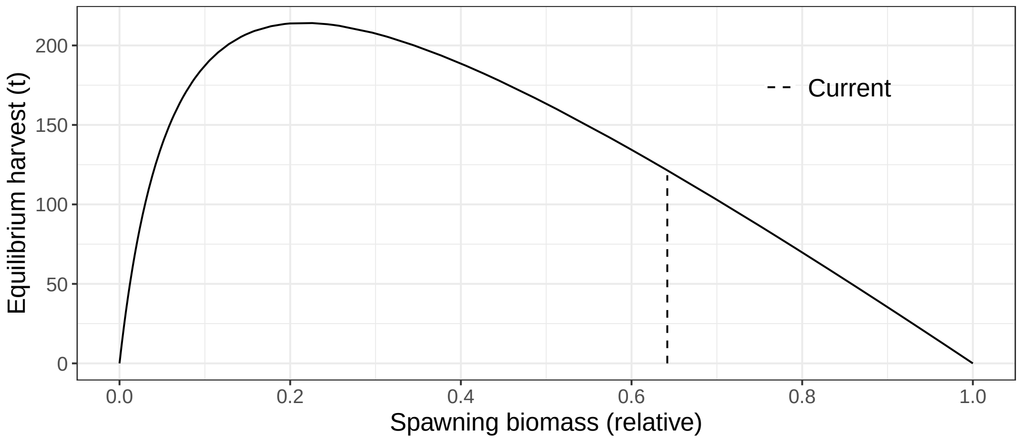

Figure D.45: Scenario 24 equilibrium harvest curve for red emperor

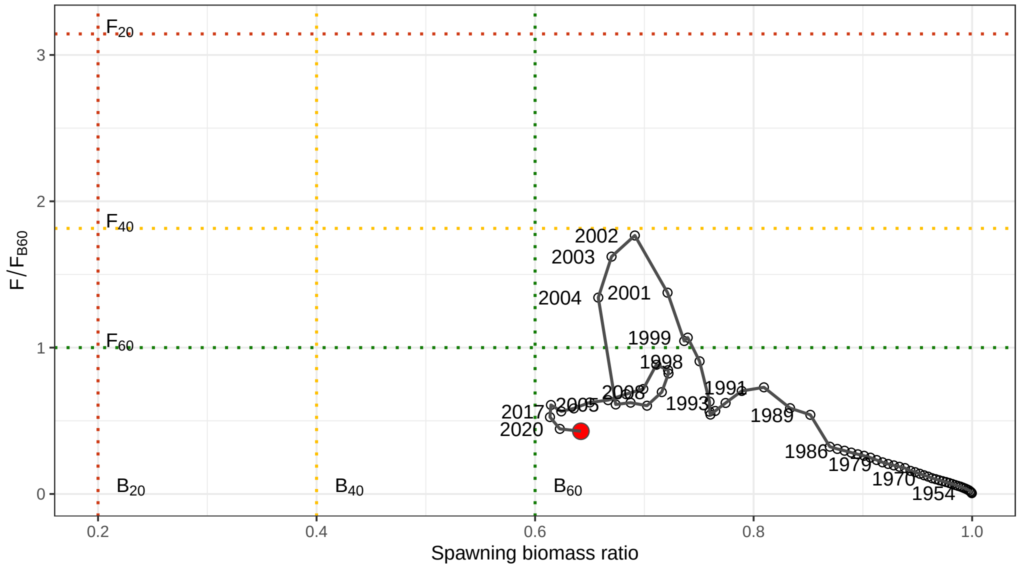

Figure D.46: Scenario 24 phase plot for red emperor

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