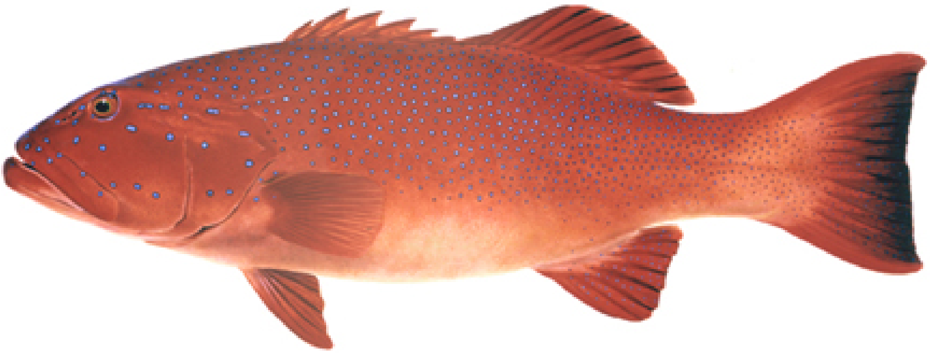

Stock assessment of common coral trout (*Plectropomus leopardus*) in Queensland, Australia

May 2020

Queensland Government

This publication has been compiled by A.B. Campbell and A.R. Northrop of Fisheries Queensland, Department of Agriculture and Fisheries.

Contents

Summary

Queensland's common coral trout (*Plectropomus leopardus*), a species of grouper, is a line-caught fish forming a single population (stock) across the Great Barrier Reef. Common coral trout are protogynous hermaphrodites (born female, many later changing sex to male) and aggregate to spawn during spring and summer. They can grow to more than 5 kg and live for more than 18 years.

The stock extends north from the Great Barrier Reef into the eastern Torres Strait where it is under Australian jurisdiction. There is evidence to suggest that common coral trout stay on the same individual reefs after settlement as larvae, and their larvae do not travel long distances after spawning, so the Torres Strait component of the harvest is not considered in the assessment.

This assessment builds on previous assessments that estimated the stock was at 60% and 68% of unfished biomass in 2012 and 2019 respectively. This stock assessment includes updates to the input data and methods.

This stock assessment used a length-and-age structured population model with a yearly time step. The model contained two subpopulations:

- a "blue region" subpopulation, associated with reefs in the Great Barrier Reef that remained open to fishing after the introduction of the Representative Areas Program in 2004
- a "green region" subpopulation, associated with reefs that have been closed to fishing since the introduction of the Representative Areas Program.

The model incorporated data spanning the period from 1961 to 2019 including commercial harvest (1988–2019), historical commercial harvest (1961–1980), recreational harvest (1995–2014), age-length monitoring (1995–2009), and underwater visual surveys (2005–2018).

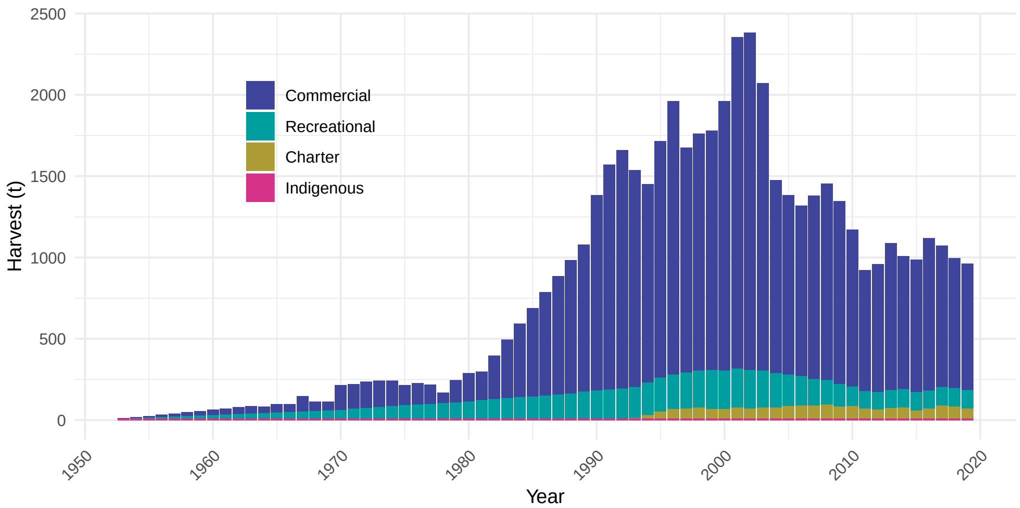

Figure 1: Estimated harvest (retained catch) from commercial recreational, charter and Indigenous sectors between 1953 and 2019

Over the last five years, 2015 to 2019, the Queensland total harvest averaged 1027 tonnes (t) per year, including 839 t by the commercial sector, 65 t by the charter sector, 113 t by the recreational sector, and 11 t Indigenous (Figure 1). The commercial and charter harvest are based in recent years on logbook reporting, whereas recreational and Indigenous harvest is estimated from surveys and interpolated between survey years.

Commercial catch rates were standardised to estimate an index of common coral trout abundance through time (Figure 2). The unit of standardisation was kilograms of coral trout per “operation-day”, defined to be a single day of fishing by a primary vessel. Year, month, stratum (grouped Great Barrier Reef bioregions), spatial grid, vessel, number of dories, number of crew and combinations of these were included explanatory terms.

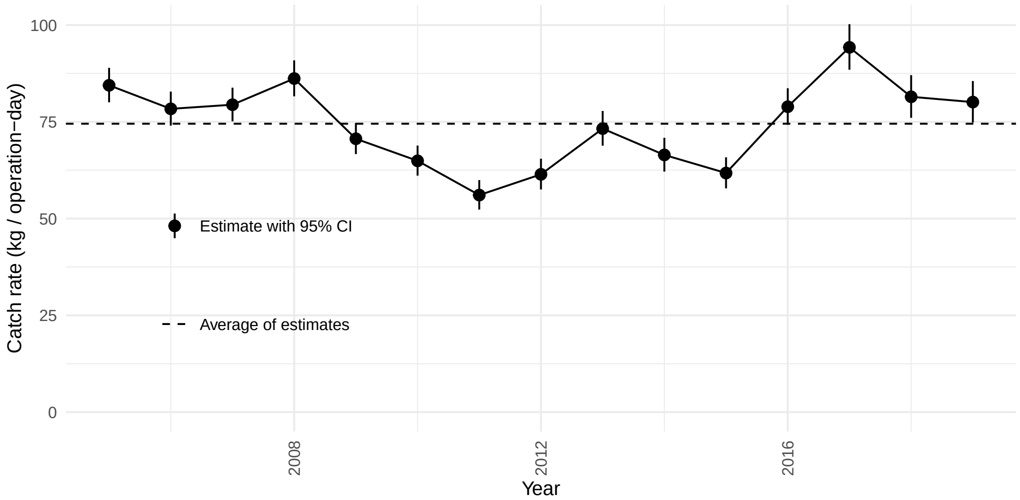

Figure 2: Standardised catch rates for commercial line-caught common coral trout in blue regions (open post-RAP) between the years of 2005 and 2019

Underwater visual survey data were also standardised, to estimate annual indices of common coral trout abundance in the blue region and green region (Figure 3). The unit of standardisation was the number of coral trout observed per underwater transect.

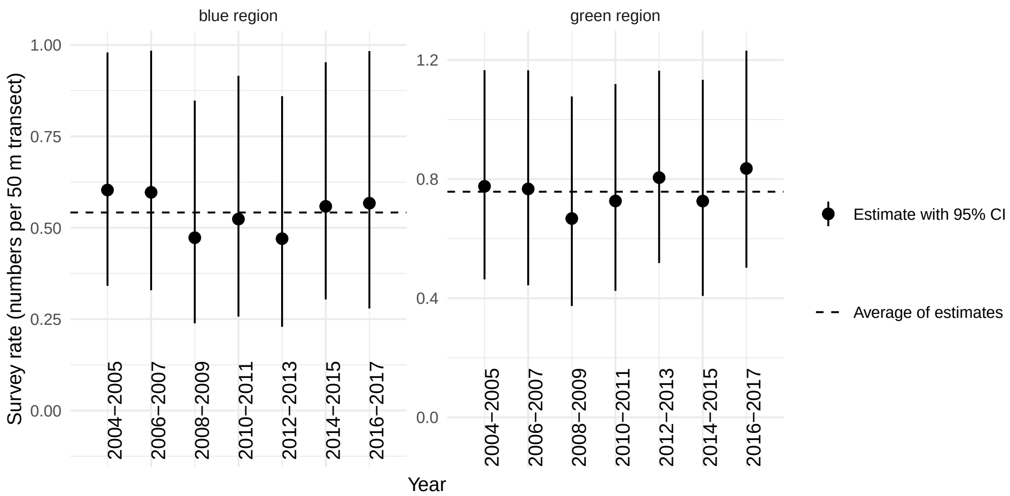

Figure 3: Underwater visual survey standardised index in blue regions (open after the introduction of the Representative Areas Program) and green regions (closed after the introduction of the Representative Areas Program) during two-year periods between 2004 and 2017

Model results suggested that biomass declined between 1953 and 2011 to 51% unfished biomass. In 2020, the stock level was estimated to be 59% unfished biomass (Figure 4).

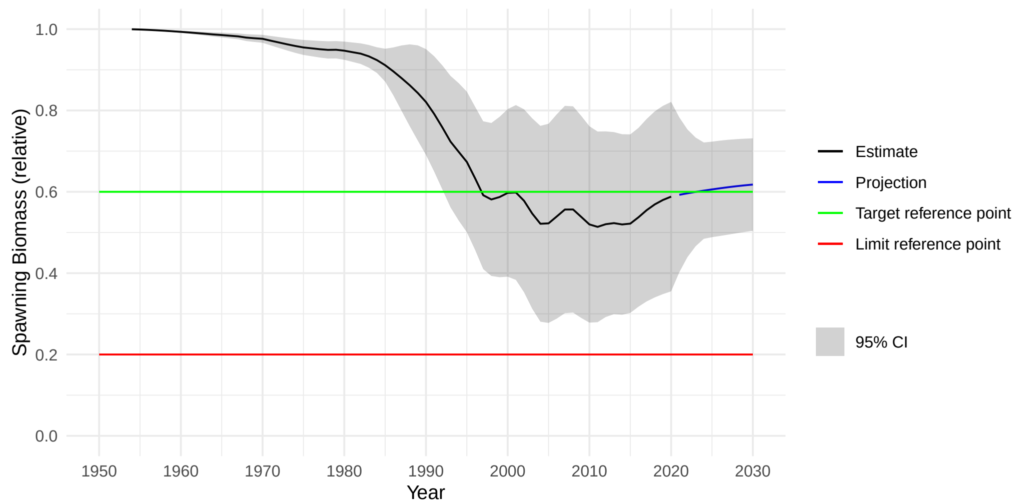

Figure 4: Predicted spawning biomass trajectory relative to virgin, from 1953 to 2030. Refer to Section 2.5.5 for a description of the projection phase (2021–2030)

Maximum sustainable harvest was estimated at 1607 t per year, and the harvest consistent with a biomass ratio of 60% (a proxy for maximum economic harvest) was estimated at 1204 t (all sectors).

The recommended biological harvest in the 2020 calendar year is 1034 t (420–1258 range across models), to achieve the Sustainable Fisheries Strategy longer-term target of 60% unfished. Note this value relates to common coral trout, the species assessed here, not the coral trout species group.

Table 1: Current and target indicators

Parameter	Estimate
Current spawning biomass (relative to unfished)	59%
Maximum sustainable harvest	1607 t
Maximum sustainable harvest biomass (relative to unfished)	33%
Current harvest (2019)	963 t
Equilibrium 60% biomass harvest	1204 t
2020 harvest to achieve 60% biomass	1034 t

Acknowledgements

The work was overseen by a project team committee that consisted of the authors and the following scientists and managers: Lachlan Barter, Pia Bessell-Browne, Sian Breen, Sue Helmke, Ashley Lawson, Tyson Martin, Michael O'Neill, Genevieve Phillips, Tom Roberts, James Webley and Sam Williams. The role of the committee was collaborative to share interpretation and decision making on data inputs, assessment methods and results.

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Thank you to Dr Mike Emslie of the Australian Institute of Marine Science (AIMS) for providing the underwater visual survey data from the AIMS Long Term Monitoring Program, and for making time to discuss it.

Much of the background information for this assessment came from fisher interviews conducted in 2012, many of which were facilitated by Darren Cameron of the Great Barrier Reef Marine Park Authority. Thank you also to data specialists and cartographers from the Great Barrier Reef Marine Park Authority who provided updated mapping data of the Great Barrier Reef.

Researchers from the Effects of Line Fishing (ELF) Project, represented by Dr Bruce Mapstone and Dr Colin Simpfendorfer, provided length and age-frequency data from structured line surveys. The ELF Project field work ran every year from 1995 to 2005. It was undertaken by CRC Reef with funding from the Australian Government's Fisheries Research and Development Corporation (FRDC, Project No. 97/124). Thank you to Dr Mapstone for providing an expanded update of this data and making time to discuss it.

Many thanks to Drs Andre Punt and Jemery Day for input on a range of technical and conceptual challenges, particularly with Stock Synthesis software. Thanks also to Dr Chantel Wetzel for Stock Synthesis advice, and Dr Ian Taylor for r4ss assistance.

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Glossary

AIMS	Australian Institute of Marine Science
blue fishery	associated with the total fishing activity (across all fishing sectors) that has occurred in the blue region
blue region	associated with reefs in the Great Barrier Reef Marine Park that remained open to fishing after the introduction of the Representative Areas Program in 2004, and all areas on the Queensland east coast outside the GBRMP
blue survey	associated with underwater visual surveys that have occurred in the blue region
CI	confidence interval
CRC Reef	Cooperative Research Centre for the Great Barrier Reef World Heritage Area
CRFFF	Coral Reef Fin Fish Fishery
ELF	Effects of Line Fishing
fleet	a Stock Synthesis modelling term used to distinguish types of fishing activity: typically a fleet will have a unique curve that characterises the likelihood that fish of various sizes (or ages) will be caught by the fishing gear, or observed by the survey
FRDC	Fisheries Research and Development Corporation
GBR	Great Barrier Reef
GBRMP	Great Barrier Reef Marine Park
green region	associated with reefs that were closed to fishing at the introduction of the Representative Areas Program
green fishery	associated with the total fishing activity (across all fishing sectors) that has occurred in the green region
green survey	associated with underwater visual surveys that have occurred in the green region
ITQ	individual transferable quota
LMM	linear mixed model
LTMP	Long Term Monitoring Program
MLS	minimum legal size
MSH	maximum sustainable harvest
NRIFS	the National Recreational and Indigenous Fishing Survey conducted by the Australian Department of Agriculture, Fisheries and Forestry
operation-day	a single day of fishing by a primary vessel, with year, month, stratum, number of dories and number of crew and combinations of these as explanatory terms
RAP	Representative Areas Program
RBH	recommended biological harvest
RFish	recreational fishing surveys conducted by Fisheries Queensland
SFS	Sustainable Fisheries Strategy
SS	Stock Synthesis
SST	sea surface temperature
UVS	underwater visual surveys conducted by the Australian Institute of Marine Science

1 Introduction

Coral trout forms a species complex and is part of the family Epinephelidae. The complex is found throughout Australia and is comprised of common coral trout (*Plectropomus leopardus*), barcheek coral trout (*P. maculatus*), bluespotted coral trout (*P. laevis*), passionfruit coral trout (*P. areolatus*), highfin coral trout (*P. oligocanthus*), yellow-edge coronation trout (*Variola louti*) and white-edge coronation trout (*V. albimarginata*).

Common coral trout is the primary target species of the commercial Coral Reef Fin Fish Fishery (CRFFF) on Queensland's east coast. It is a species that is important to Indigenous fishing communities and is also a popular species targeted by recreational line fishers able to travel offshore throughout the Great Barrier Reef (GBR). As common coral trout is the primary target species by all fishing sectors it is the focus of this assessment.

Research suggests that common coral trout forms one stock on the Queensland east coast, including the Torres Strait region (van Herwerden et al. 2006; van Herwerden et al. 2009). van Herwerden et al. (2009) sampled common coral trout from the Torres Strait and the Capricorn-Bunker region and found that there was no significant difference in genetics between the two samples. There is evidence to suggest that common coral trout stay on the same individual reefs after settlement as larvae, and furthermore that their larvae do not travel long distances (generally less than tens of kilometres) after spawning (Bergenius et al. 2005; Bergenius, Begg, and Mapstone 2006; Harrison et al. 2012).

Coral trout are also protogynous hermaphrodites, beginning life as a female, with many later changing sex to male (Ferreira 1995). They spawn in spring and summer months around the new moon (Samoilys 1997).

There are various environmental factors that are thought to influence coral trout or the coral trout fishery, including cyclones, coral bleaching, crown-of-thorns starfish and sea surface temperature. Since 2014, there have been two mass coral bleaching events, one tropical cyclone that severely impacted the GBR, and two crown-of-thorns outbreaks on the GBR (Australian Institute of Marine Science 2018). These have reduced coral cover, which in turn reduces habitat and prey availability for coral trout (Pratchett et al. 2010; Rogers, Blanchard, and Mumby 2017). Bleaching events can also influence coral trout growth rates and spawning output (Hughes 2010; Pratchett, Hoey, and Wilson 2014). These factors are expanded upon in Section 4.

The CRFFF is a line-only fishery, except for a small amount of recreational spear fishing. The fishery targets mainly common coral trout for export live to Asia (Thébaud et al. 2014). Secondary target species include other coral trout species (see above), red throat emperor (*Lethrinus miniatus*), and a large number of reef fish species grouped together into an "Other Species" category for the purposes of management of the commercial fishery. Daily catches are recorded by commercial fishers in logbooks where no distinction is made between coral trout species. According to the logbooks, over 2000 tonnes of coral trout were landed annually by all sectors combined in the early 2000s, before individual transferable quotas (ITQs) were introduced in 2004. Since this time, the estimated total harvest has reduced to around 1000 tonnes annually.

There have been various management changes that have influenced the coral trout fishery (Table 1.1; more detail in Leigh et al. (2014)). The most significant of these changes was in 1988 with the introduction of the compulsory logbook system, and in 2004 with a substantial rezoning of the Great Barrier Reef Marine Park.

Table 1.1: History of coral trout management in Queensland

Year	Management Change
1950	Commercial coral trout fishery begins
1976	*Fisheries Act 1976* implemented a minimum legal size (MLS) of 35 cm for 'coral trout' (nominally *Plectropomus maculatus*)
1983	Replenishment closures of two Capricorn-Bunker reefs: North Reef and Boult Reef
1986	North Reef and Boult Reef reopen
1988	Commercial logbooks implemented
1990	Recreational fishers are prohibited from selling their catch
1992	Replenishment closure of Bramble Reef near Townsville
1993	*Fishing Industry Organisation and Marketing Amendment Regulation* implemented a MLS of 38 cm and a recreational bag limit of 10 for coral trout (all *Plectropomus* species)
1995	Bramble Reef reopens
1997	Investment warning is issued.
2003	12 Sep: *Fisheries (Coral Reef Fin Fish) Management Plan 2003* revised the recreational bag limit to seven coral trout (all *Plectropomus* species) and 20 reef fish.
2004	1 July: Representative Areas Program (RAP) and comprehensive rezoning of the whole GBR; the proportion of GBR closed to fishing increases from about 5% to 33%.
2004	1 July: *Fisheries (Coral Reef Fin Fish) Management Plan 2003* introduced a Total Allowable Commercial Catch (TACC) of 1350 t and Individual Transferable Quotas (ITQs).
2004	9 Oct: First nine-day coral-trout spawning closure begins under the *Fisheries (Coral Reef Fin Fish) Management Plan 2003*, which implements fishery closures around the new moon in October, November and December each year 2004–2008.
2005	TACC reduced to 1288 t by buy-outs under the RAP.
2009	Spawning closures reduced to five-day closures in October and November only.

This is the third stock assessment of common coral trout and builds on information published by Leigh et al. (2014) and Campbell et al. (2019).

The previous stock assessment was based on the financial year and included data up to the end of June 2018 (Campbell et al. 2019). The assessment suggested that in the 2017–18 financial year biomass was at 68% of its unfished state. This assessment improved on the previous assessment in several ways, including:

- moving to calendar years (more appropriate for the population dynamics given spring and summer spawning);
- incorporating length structure in the dynamics and fitting to conditional age-at-length data (made possible by individual age and length data being made available from the Effects of Line Fishing (ELF) project);
- a more sophisticated standardisation of the Australian Institute of Marine Science underwater visual survey (UVS) data; and
- fitting to length frequency information from the UVS.

The assessment used data through to the end of calendar year 2019 and makes a recommendation for total common coral trout harvest in calendar year 2020 to support the harvest strategy (Queensland Department of Agriculture and Fisheries 2020).

2 Methods

2.1 Data sources

A variety of data sources were included in this assessment and are detailed in Table 2.1, Figure 2.1 and are described in more detail in the following sections.

Table 2.1: Data inputs for the population model

Data	Years	Source	Reference
Commercial	1988–2019	Logbook data collected by Fisheries Queensland	N/A
Recreational	1997, 1999, 2000, 2002, 2005, 2011, 2014	Recreational fishing surveys conducted by Fisheries Queensland (RFish, and the Statewide Recreational Fishing Survey) and the Australian Department of Agriculture, Fisheries and Forestry (the National Recreational and Indigenous Fishing Survey, NRIFS)	Higgs (1999), Higgs (2001), Higgs, Olyott, and McInnes (2007), McInnes (2008), Henry and Lyle (2003), Taylor, Webley, and McInnes (2012)
Charter	1988–2019	Logbook data collected by Fisheries Queensland	N/A
Indigenous	1957–2019	Indigenous fishing survey conducted in 2000 by the Australian Department of Agriculture, Fisheries and Forestry (the National Recreational and Indigenous Fishing Survey, NRIFS)	Henry and Lyle (2003)
Historical	1963–1980	Queensland Fish Board data	Halliday and Robins (2007)
Age and length	1995–2009	Biological monitoring (line surveys) undertaken by the ELF project and Fisheries Queensland	Mapstone et al. (2004), Fisheries Queensland (2012)
Underwater visual survey	2004–2017	Underwater visual survey data collected by Australian Institute of Marine Science	Australian Institute of Marine Science (2018), Emslie and Cheal (2018)
Observer	2011	Observer program data collected by Fisheries Queensland	N/A
Boat ramp survey	2015–2019	Boat ramp survey data collected by Fisheries Queensland	Fisheries Queensland (2017)

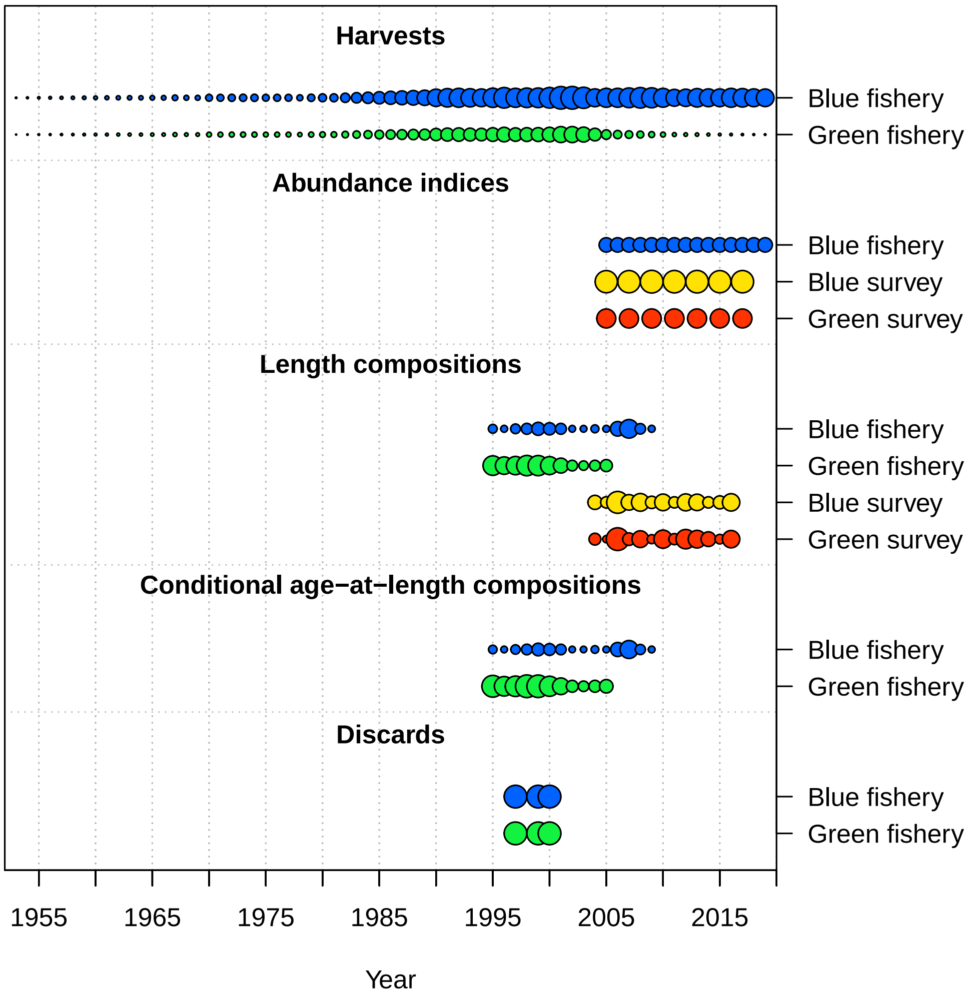

Figure 2.1: Data presence by year for each category of data type and Stock Synthesis fleet
Note: Stock Synthesis uses the term 'fleet' to distinguish data sets (and model processes) associated with different selectivity curves (proportions of fish at different lengths vulnerable to the fishing gear). This assessment involves four fleets: two fleets for the fishery (all sectors combined) corresponding to the two spatial regions ('blue fishery' and 'green fishery'); and two fleets for the underwater visual survey ('blue survey' and 'green survey'). This plot shows data presence by year for each fleet, where circle area is relative within a data type. Circle areas are proportional to total harvest for harvests; to precision for indices and discards; and to total sample size for compositions. Note that since the circles are scaled relative to maximums within each data type, the scaling within separate plots should not be compared.

2.1.1 Regions

The data have been grouped into "regions" for analysis. These regions are based on the GBRMP Representative Areas Program (RAP) zoning introduced in July 2004. For analysis, the "green region" is defined to be the area that was closed to fishing on 1 July 2004 (Figure 2.2). The "blue region" refers to all other areas on the Queensland east coast. Although the GBRMP blue and green *zones* change through time, the *regions* as defined in this stock assessment are fixed: they apply from the beginning of the assessment in 1953 through to the last assessed year in 2019, and through the projection period (2020–2030).

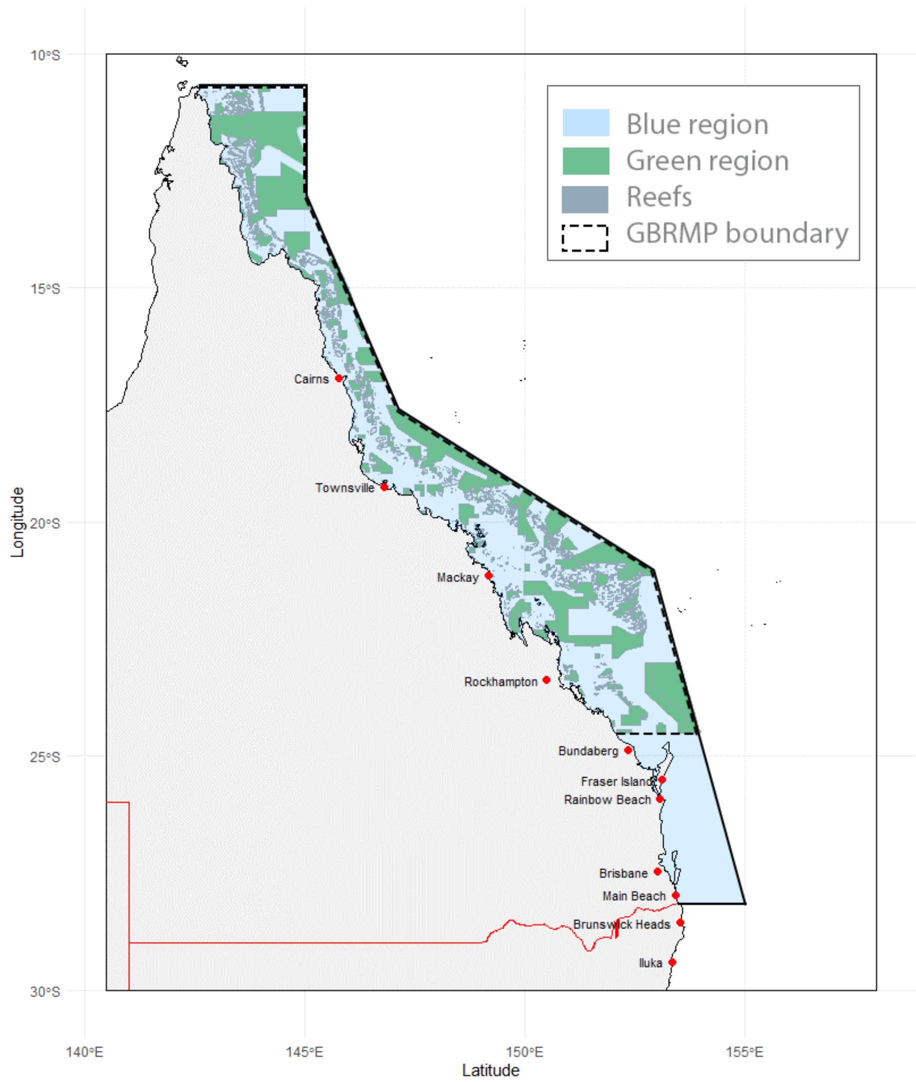

Figure 2.2: Blue and green regions within the Great Barrier Reef Marine Park used to summarise model inputs

2.1.2 Commercial

Commercial harvests of coral trout were recorded in the Queensland logbook system. The logbook system consists of daily harvests (landed weight in kilograms) of all fish species from each individual fishing operator (license) since 1988. Harvests have rarely been recorded to the species level, so only totals for the coral trout species group are available from this source. In addition to landed weight, logbooks also record the location of greatest catch (30 minute or 6 minute grid identifier), the number of boats (dories) that were fishing, and the number of crew.

Since financial year 2004–05, commercial harvest for coral trout have also been available from the quota reporting system where fishers are required to report exact weights, rather than estimated weights (as reported in logbooks).

2.1.3 Recreational

All recreational surveys provided estimates of the number of fish harvested and discarded per trip, and combined this with demographic information to estimate annual totals for each species (or species group) at National, State and regional scales. See the references listed in Table 2.1 for more detail. For coral trout, identification was to the species group level, individual species information was not available.

Surveys conducted in 2000, 2011 and 2014 had more effective follow-up contact procedures with diarists resulting in less dropout of participants compared to the other survey years using RFish methodology (Lawson 2015).

2.1.4 Indigenous

The National Recreational and Indigenous Fishing Survey in 2000 attempted to redress the lack of indigenous fishing information on a national scale by involving indigenous communities in the gathering of fisheries statistics. Estimates of total harvest and discard for Indigenous communities followed similar procedures (Henry and Lyle 2003).

2.1.5 Charter

Charter sector harvest data has been available from the Queensland charter logbook system since 1992. This provided charter daily harvest (landed weight in kilograms) for the coral trout species group.

2.1.6 Historical

Commercially caught fish were by law marketed through the Queensland Fish Board until 1981. Fish Board records compiled by Halliday and Robins (2007) provide estimates of annual coral trout harvest by weight for 37 districts across Queensland from 1963 to 1981.

2.1.7 Age and length compositions

The Effects of Line Fishing (ELF) project was a major research project run by CRC Reef and partly funded by the FRDC. The ELF Project ran from 1995 to 2005 and sampled 24 reefs in the GBR (four clusters each of six reefs) each year. Line fishing catch surveys were conducted in spring of each year to coincide with the spawning period. These line surveys were done via the charter of an active commercial fishing operation with master fisherman and four dory-fishermen, accompanied for the surveys by four research staff. Fishing gear was standardised among fishers and over time to be comparable with standard contemporary gear used in the commercial Reef Line Fishery on the GBR. In addition to age and length data, where possible, the sex of each fish and its weight were also recorded. For more details see Mapstone et al. (2004).

Following on from this program, Fisheries Queensland continued to collect age and length-composition data at thirteen reefs according to a similar protocol from 2005 through 2009 (Fisheries Queensland 2012).

2.1.8 Underwater visual survey

Reef fish communities on 46 reefs were mostly surveyed annually by the Australian Institute of Marine Science (AIMS) from 1994 until 2005. Since then reefs were surveyed as part of their Long Term Monitoring Program (LTMP) in alternating years, within six sectors of the Great Barrier Reef (Cooktown/Lizard Island, Cairns, Townsville, Whitsunday, Swain and Capricorn-Bunker sectors). In each of these sectors, with the exception of the Swain and Capricorn-Bunker sectors, three shelf positions – inner, mid and outer – were identified for sampling (shelf position is determined by the position of the reef relative to the coast and continental slope, with inner shelf reefs closest to the coast).

Since 2006, surveys on 46 different reefs and ten of the initial reefs were conducted in alternate years to LTMP surveys as part of the Representative Areas Program (RAP) to assess the effectiveness of the rezoning of the GBRMP in 2004. RAP surveys were conducted in five offshore latitudinal sectors (reefs >30 km from the coast in the Cairns, Townsville, Pompey, Swain and Capricorn-Bunker sectors) of the GBRMP. This program surveyed No-Take Marine Reserve reefs ("Green Zones") that are paired with similar reefs open to fishing.

In both LTMP and RAP surveys, three sites were surveyed on each reef, each containing five transects lying approximately parallel to the reef crest. Transects were set along the middle of the reef slope, usually at depths between 6 and 9 metres. Counts of large mobile demersal species from a nine families were conducted on 50 metre by 5 metre transects. Estimates of the length of each fish were made to 1 cm, 2 cm or 5 cm bins. For more details of the sampling protocol see Emslie and Cheal (2018).

Each record provided for this stock assessment corresponded to a fish observation and identified the sector, the reef, the shelf position, the site, the transect number, the sample date and the estimated length of the fish (cm).

2.1.9 Observer

In 2011, limited data were collected by Fisheries Queensland on common coral trout discards for commercial fishers. This was used as a proxy for commercial discard proportion and commercial common coral trout fraction of harvest (species composition).

2.1.10 Boat ramp survey

Recreational data were collected by Fisheries Queensland from 2015–2019 in 18 different regions, extending from Aurukun 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). This was used to infer species composition and discard rates of common coral trout.

2.2 Harvest estimates

Commercial, charter, recreational and Indigenous harvest and data (where available) were analysed to reconstruct the history of harvest from 1953 (prior to which common coral trout harvest is presumed to be small) until the end of 2019. This section describes how this data was combined to create the history of common coral trout harvest in the blue and green regions (Figure 2.2). All harvest is retained (landed) unless stated otherwise, coral trout species group (rather than common coral trout) unless stated otherwise, and whole of the Queensland east coast unless stated otherwise.

Commercial sector harvest:

- was assumed zero in 1953, and increased linearly to the value from the Queensland Fish Board in 1963.
- equalled Queensland Fish Board records from 1963 through 1981.
- increased linearly from the last recorded Queensland Fish Board value in 1981 through to the first recorded Queensland logbook value in 1988.
- equalled logbook values from 1988 through the 2004 calendar year.
- equalled quota reporting values from 2005 through 2019 calendar years.
- estimates for all years were multiplied by 0.98, the assumed fraction of the catch that was common coral trout (estimated from Observer program data).

Charter sector harvest:

- estimates equalled Queensland charter logbook values from first records in 1992 through 2019.
- estimates for all years were multiplied by 0.98, the assumed fraction of the catch that was common coral trout (estimated from Observer program data).

Recreational harvest:

- was assumed zero in 1953 and increased proportionally to Queensland population growth through to reach a rescaled RFish estimate in 1997. This rescaled estimate was calculated in the following way:
  - The RFish estimates from 1999 and 2002 were interpolated to obtain a candidate estimate for the year 2000.
  - The rescale factor was calculated as this candidate estimate divided by the NRIFS estimate for the year 2000.
  - This rescale factor was then used to rescale all RFish estimates, including the 1997 value which anchored the series that started from zero in 1953.
- estimates for 1999, 2002, and 2005 were set to equal the values from the rescaled RFish estimates.
- estimates for 2000, 2011 and 2014 were set to equal the values reported in the NRIFS (2000) and SRFS (2011 and 2014) surveys.
- estimates for 2015 through 2019 were set to equal the value reported in the 2014 SRFS survey.
- "missing" recreational harvests in 1998, 2001, 2003, 2004, 2006–2010 were set to values linearly interpolated between the above estimates.
- estimates for all years were converted from numbers to an estimated retained (landed) harvest using the mean common coral trout fish weight from the ELF data set (aggregate mean weight over all years).
- estimates for all years were multiplied by 0.8, the assumed fraction of the catch that was common coral trout (estimated from Boat Ramp Survey program data (Fisheries Queensland 2017)).

Indigenous harvest:

- equalled the NRIFS estimate from 2000 for all years from 1953 onwards.

These annual estimates of harvest by sector through time were assigned to the blue region (2/3 of the GBRMP area) or the green region (1/3 of the GBRMP area) for further analysis by multiplying the overall total by the proportion of the GBRMP, by area, that is unfishable from 1 July 2004 onwards. Catch of common coral trout outside the GBRMP is presumed to be negligible, and the allocation was not adjusted to account for this.

Post 2004, some fishing has occurred in GBRMP Green Zones, and hence in the green region of our analysis. The extent of this illegal fishing is unknown but is presumed to have decreased over time. To account for this, in 2005, 20% of the blue region harvest was instead assigned to the green region. This proportion was then reduced by an 80% every year from 2006 through to 2019 to model an exponentially declining rate of Green Zone fishing.

2.3 Abundance indices

2.3.1 Commercial catch rates

Queensland logbook data on commercial line catches (kg whole weight) of coral trout per fishing-operation-day were used as an index of legal-sized fish abundance, after removing the effects of a number of factors not related to abundance. The methods below outline the concepts and procedures used to achieve this standardisation. In the following, the term “catch rate” refers to a standardised catch rate unless otherwise specified.

The catch rate model included every daily coral trout harvest by each individual license (each operation by a primary vessel). When multiple locations were recorded for a single operation in a day, only the first location was used and all harvest allocated to this location. Records were restricted to 2005 onwards, so all data analysed were “blue region” and post-RAP (this is discussed further in Section 4). Records were further restricted to come from vessels that fished for at least two years (anytime during 2005–2019), and accounted for at least 0.01% of the total catch over the time series. A fishing operation day was defined as a day of fishing by a primary vessel where any one of a suite of commonly co-caught species were landed. This meant that it was possible for 0 kg to be a valid catch of coral trout in an operation-day.

Standardised mean catch rates were modelled using the software R (version 3.5.2, (R Core Team 2020)). The analyses used a linear mixed model (LMM). The LMM was calculated by the ‘glmmTMB’ function, in the glmmTMB package (Brooks et al. 2017), in a restricted maximum likelihood setting (REML = TRUE in the glmmTMB function). The prediction of standardised mean catch rates were determined using the ‘predict.glmmTMB’ function.

In addition to the spatial grid, the twelve strata from the last assessment (Campbell et al. 2019) were used as a medium-scale spatial structure and catch rate predictions were made at this scale before being aggregated to a final scalar time series for the blue region. This aggregation was weighted according to the quantity of catch in that stratum, so strata with higher catches contributed relatively more to the final series. 95% confidence intervals were calculated for all predictions. These strata are groupings of GBRMP bioregions and are described in more detail in Campbell et al. (2019, Section 2.2.1).

The model used a Gaussian distribution with the response variable, $\sqrt[3]{\text{harvest}}$, being kilograms of coral trout harvest per fishing operation per day, transformed with a cube root. The variables modelled included additive categorical effects of:

- “year” (calendar year),
- “month”,
- “stratum”, and
- “excessCrew” (the number of crew in excess of the number of dories, coded as 0 (no excess crew), 1 (1 excess crew) or 2 (2 or more excess crew)).

The full catch rate model was:

$$\begin{aligned}\sqrt[3]{\text{harvest}} \sim\ & \text{year} + \text{month} + \text{stratum} + \text{year:month} + \text{year:stratum} + \text{month:stratum} + \text{excessCrew} + \\ & \text{ndoriescuberoot} + \text{random(vessel)} + \text{random(grid)}\end{aligned}$$

where “doriescuberoot”, the cube root of the number of dories used, was a continuous variable, and “vessel” and “grid” (30 minute spatial grid) were random effects.

2.3.2 Underwater visual survey

Underwater visual survey data collected by the Australian Institute of Marine Science were standardised to produce an index of abundance in blue regions and in green regions.

Several models were run to determine the best way to aggregate reefs over space and time. The outcome of these analyses were that data would be aggregated into two-year blocks, and that only surveys from 2004–2005 onwards would be included. This was because many reefs were only visited every two years, and the total number of reefs surveyed increased from 2005.

Standardised mean survey rates were modelled using the software R (version 3.5.2, (R Core Team 2020)). The analyses used a generalised linear model (GLM). The GLM was calculated by the 'glm' function in base R. The prediction of standardised mean catch rates were determined using the 'predict.glm' function.

Individual reefs were used as a fixed spatial structure, and survey rate predictions were made at this scale before being aggregated to two final scalar time series: on for the blue region and one for the green region. This aggregation was weighted according to total numbers of common coral trout observed on that reef, so reefs with higher abundance contributed relatively more to the final series. 95% confidence intervals were calculated for all predictions.

The full survey abundance index model was:

$$N_{ct} \sim -1 + \text{doubleyear:reef} + \text{offset(log(transects))}$$

where the model response variable, N_{ct}, was the number of common coral trout sighted per 50 m transect per reef-site (each reef had three sites at which transects were carried out) during that *doubleyear* (two-year block). The statistical offset, *transects*, was the number of transects carried out on that reef-site during that double year. A quasi-poisson distribution was used with a log-link.

2.4 Biological information

2.4.1 Fork length and total length

In addition to fork length measurements, the ELF program also recorded some total lengths, and this data was used to estimate a fork length to total length relationship which was then applied to all records to obtain total lengths for further analysis.

The relationship estimated was

$$TL = (FL - 3.8217)/0.9343$$

where TL is total length (mm) and FL is fork length (mm).

2.4.2 Fecundity and maturity

Maturity values in the model were age-based, following the data in Leigh et al. (2014):

- 0% mature at age 1,
- 40% at age 2,
- 70% at age 3,
- 95% at age 4,

- 99% at at 5,
- fully mature from age 6.

The fecundity relationship was based on data in Leigh et al. (2014):

$$fec = W^{1.56}$$

where fec is number of eggs and W is weight (kg).

2.4.3 Weight and length

Length and weight from the ELF program was used to calculate the weight-length relationship:

$$W = 7.3965 \times 10^{-6} \times TL^{3.1236}$$

where W is weight (kg) and TL is total length (cm).

2.5 Population model

A single-sex population dynamic model was fitted to the data to determine the number of common coral trout in each year and each age group using the software package Stock Synthesis (SS; version SS-V3.30.14.0). A full technical description of SS is given in Methot, Wetzel, and Taylor (2019).

2.5.1 Model assumptions

A variety of assumptions were made when formulating inputs to the SS model for the common coral trout assessment. These included:

- The fishery began from an unfished state in 1953.
- 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 common coral trout are parametric functions of their size.
- The proportion of mature fish depends on age and not size.
- The instantaneous natural mortality rate does not depend on age, size or sex.
- The proportions of fish of a given size that are vulnerable to fishing are identical to those proportions during the age and length composition line surveys (ELF and FQ) for all sectors and for all years.
- Fish do not move between the blue region and the green region.
- The number of fish that recruit to each region is a fixed fraction of a Beverton-Holt function of total (whole of stock) spawning biomass.

The assumption that the sex ratio is 50% throughout life is in conflict with known biology, which indicates female to male sex change (protogyny sequential hermaphroditism). This is expanded on in Section 4.2.

2.5.2 Model parameters

A variety of parameters were included in the model, with some of these fixed at specified values and others estimated. Uniform priors were used unless stated otherwise.

The natural logarithm of virgin spawning stock size ($\ln(R_0)$) was estimated within the model.

In the final “base case” model, natural mortality (M) was estimated with log-normal prior to having (natural scale) median value of 0.3 and standard deviation of 0.219. This prior was based on the meta-analytical approach from Hamel (2015) and Then et al. (2015). The prior is defined as a log-normal distribution with median value (corresponding to the mean in log-space) equal to 5.40/maximum age and log-scale standard deviation equal to 0.438. The maximum age across all samples is 18 years, giving $5.4/18 = 0.3$, and the recommended sigma was halved to provide a stronger prior. The sensitivity of the model to this parameter was investigated and is presented in the Results.

Stock recruitment steepness (h) was fixed at 0.50 as a base case. This value is equal to the fixed value for the base case from Campbell et al. (2019) and to the value estimated by Leigh et al. (2014). This value would be low for North American groupers (see Section 1.7 of Leigh et al. (2014)), but is plausible for the less productive Australian waters and serves a precautionary purpose in this assessment, offsetting the potentially non-precautionary consequences of dome-shaped selectivity (see below).

Parameters of the von Bertalanffy growth curve were estimated within the model, including coefficients of variation for both young and old fish.

The proportion of recruitment going to each region was estimated.

Dome-shaped length-based selectivity parameters were also estimated for the fishery fleets, using a double normal curve (pattern 23 in SS). Parameters p1 through p5 (peak, top, ascending width, descending width and initial selectivity) were all estimated. Parameter p6, final selectivity (selectivity in the last bin) was fixed at 0.1. Separate selectivity curves were estimated for each region (blue fishery fleet and green fishery fleet).

For the survey fleets (blue and green), a spline was used for length-based selectivity, with four parameters (in each region) estimated. These parameters correspond to the selectivity at the 1st, 2nd and 4th knots (knots at 17.3951, 36.3434, 42.3821, and 60.3918 cm), in addition to the gradient of the selectivity curve in the first bin. The sensitivity of the model to the assumption that both the fishery and survey fleets had dome-shaped selectivity was investigated, and is presented in the Results.

Undersized fish were subject to a fixed discard mortality of 0.25 across all sizes (based on Brown et al. (2008)), and one parameter of a retention curve was estimated for both fishery fleets. This parameter was the inflection point of an asymptotic (logistic) curve.

Recruitment deviations between 1982 and 2019 improved fits to composition data and abundance indices as variability in recruitment annually allowed for changes in the population on shorter time-scales than fishing mortality alone.

2.5.3 Model weightings

All data inputs were given equal weighting in the model, however a Francis weighting was applied to the age and length compositions within Stock Synthesis (Francis 2011).

2.5.4 Sensitivity tests

Several additional model runs were undertaken to determine sensitivity to fixed parameters and model inputs.

Natural mortality is a key stock assessment parameter and while the base case was able to estimate it with the aid of a strong prior, it was important to test the sensitivity of the outputs to alternative possibilities. The natural mortality sensitivity test involved fixing M at a presumed "worst case" value of 0.2. This value was chosen based on outputs from a range of life-history based proxy methods, including Hoenig (1983) and Jensen (1997), and on estimates from the previous coral trout stock assessments.

Because dome-shaped *selectivity* can lead the model to infer a large number of unfishable older individuals that are not observed, it was important to explore what the model would infer if it does not have this option, and a non-dome shaped (or "asymptotic") selectivity setup was tested. The dome-shaped selectivity sensitivity test involved switching the spline-based selectivity on the survey fleets over to an asymptotic logistic curve. For the latter, the inflection point of the curve was estimated, as well as the width of the ascending portion of the curve.

In addition, a run was conducted where the *standardised commercial catch rates* were dropped from the model fitting. The model fits were relatively poor when the full-time series of standardised catch rates were initially used. With the significant zoning and quota related changes that impacted the fishery around 2004, it was decided to shorten the catch rate time series to the subsequent (2005–2019) period to limit the potential effect of these changes on unmodelled fishing and reporting behaviour. This also had the benefit of simplifying the regional split as all catch rate information after 2004 could be assumed to be associated with the blue region. This made a negligible difference (relative to the base case) and is not reported on further.

A run of the model with *SS's hermaphroditism option* switched on was also conducted. This did not lead to plausible results. The implications are discussed in Section 4.2.

2.5.5 Forward projections

Stock Synthesis's forecast submodel was used to provide forward projections of biomass and future harvest targets, following a 20:60:60 harvest control rule. This rule has a linear ramp in fishing mortality between 20% biomass, where fishing mortality is set at zero, and 60% biomass, where fishing mortality is set at the equilibrium level that achieves 60% biomass ("Fb60"). Below 20% biomass fishing mortality remains set at zero, and above 60% biomass fishing mortality remains set at Fb60 (Figure 2.3). This rule is augmented with a "buffer" to offset model uncertainty. A buffer is a discount factor applied to the control rule to account for risk under uncertainty. For this assessment, a buffer value of 0.87 has been chosen, following Commonwealth Harvest Strategy policy guidelines (Department of Agriculture and Water Resources 2018).

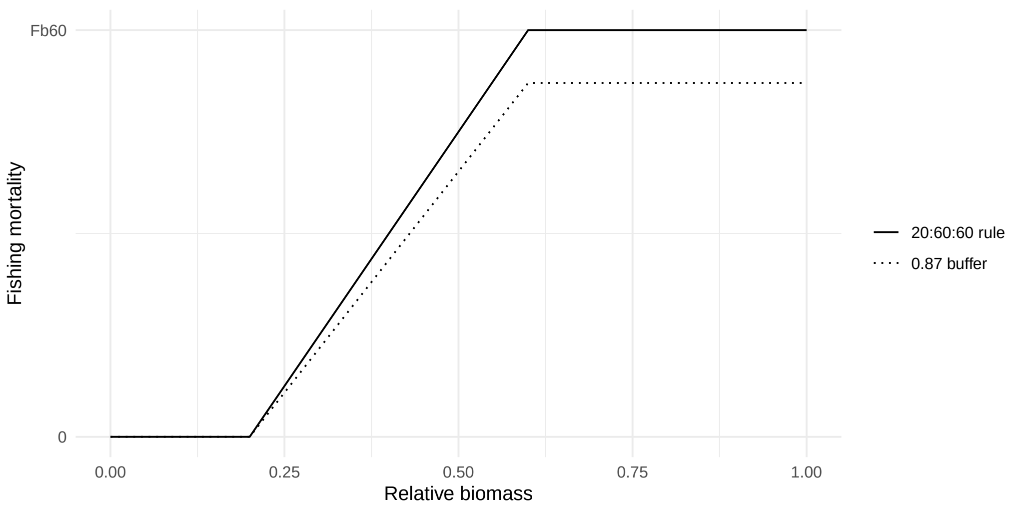

Figure 2.3: The 20:60:60 harvest control rule (solid line) with 0.87 buffer (dashed line)

3 Results

3.1 Model inputs

3.1.1 Harvest estimates

Total harvest (landed catch) combined commercial, recreational, charter and Indigenous sectors (Figure 3.1). The majority of the total harvest can be attributed to the commercial sector. Prior to 1980, the total harvest was relatively low. The harvest estimates indicate that over 2000 tonnes of coral trout were landed annually in the early 2000s before individual transferable quotas (ITQs) were introduced in 2004. Since this time, the estimated total harvest has reduced to around 1000 tonnes annually.

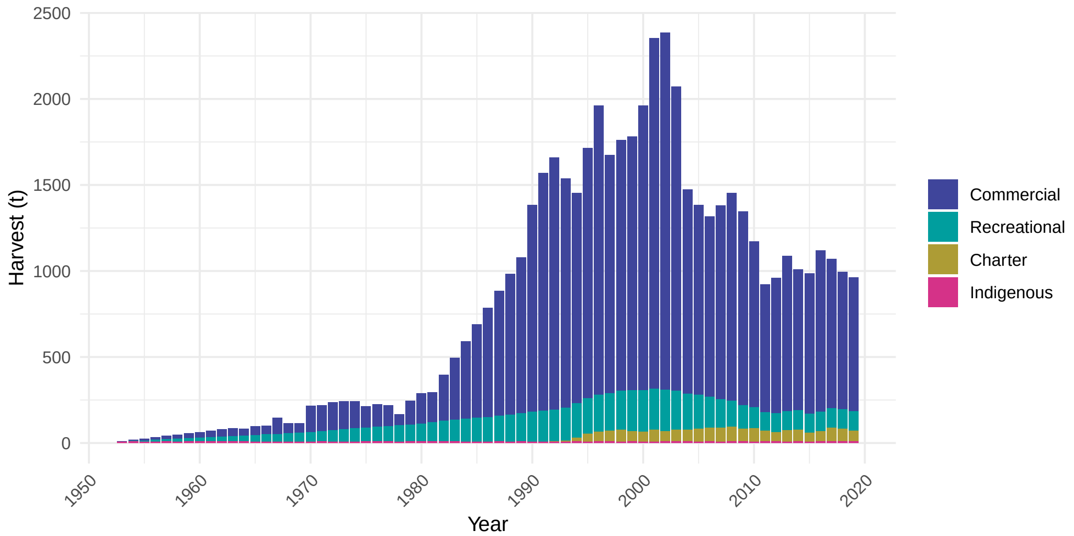

Figure 3.1: Estimated harvest (retained catch) from commercial, recreational, charter and Indigenous sectors between 1953 and 2019

Harvest was input to the population model by region (Figure 3.2). The rapid decline in fishing in the green region can be seen after the rezoning and implementation of the RAP in 2004.

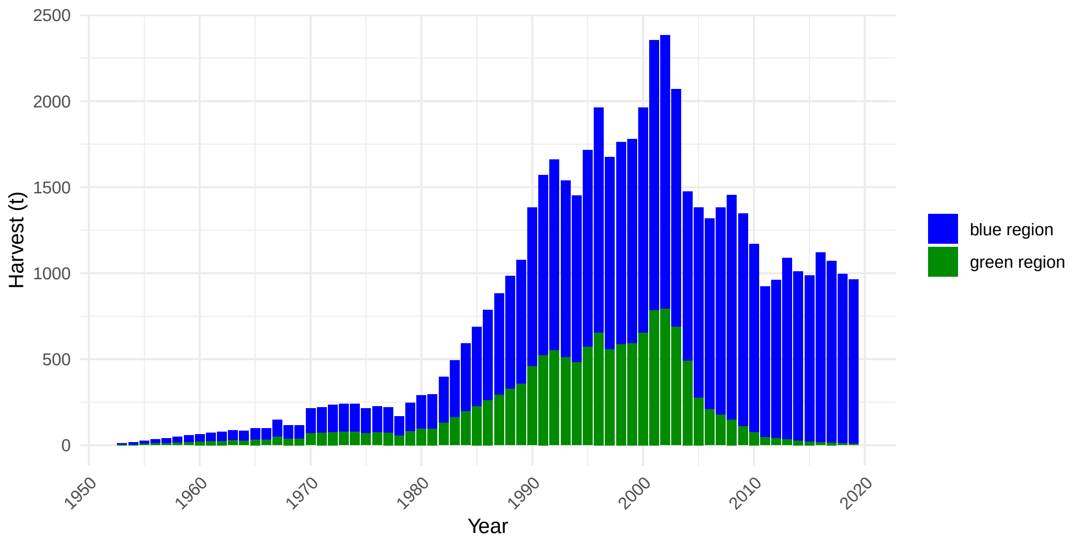

Figure 3.2: Estimated harvest (retained catch) by region between 1953 and 2019

3.1.2 Standardised catch rates

The standardised catch rate declines from around 85 kg per operation-day in 2005–2008, to just under 60 kg per operation-day in 2011 (Figure 3.3). The rate then recovers to around 85 kg per operation-day again over the last four years of the series (2016–2019).

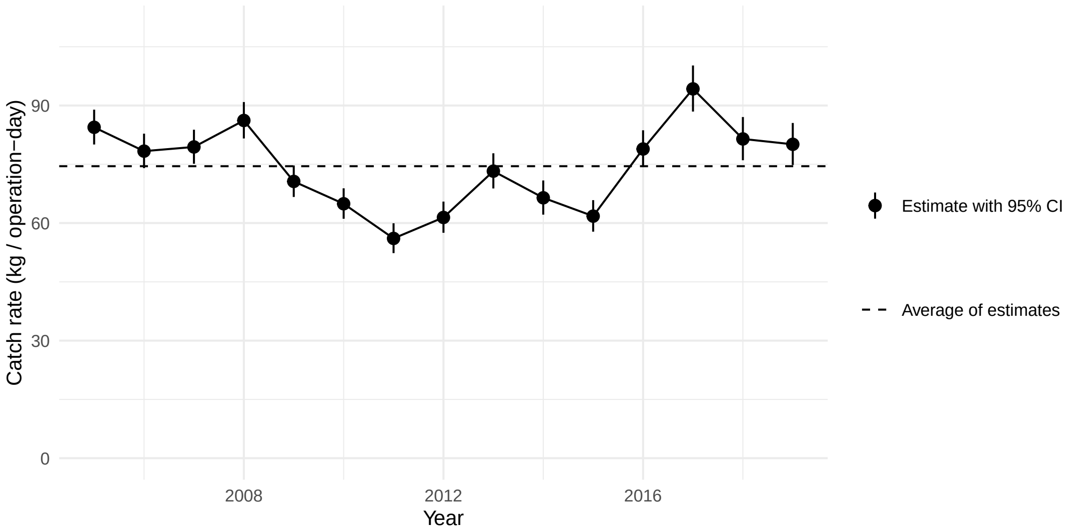

Figure 3.3: Standardised catch rates for commercial line-caught common coral trout in blue regions (open post-RAP) between the years of 2005 and 2019

3.1.3 Standardised underwater visual survey rates

Underwater visual survey rates are markedly higher in the green region than the blue region (Figure 3.4), though for the purposes of population model fitting this is not relevant as abundance indices are rescaled by the estimated catchability. The series are relatively stable, but potentially suggest a similar decline and recovery pattern to the standardised catch rates.

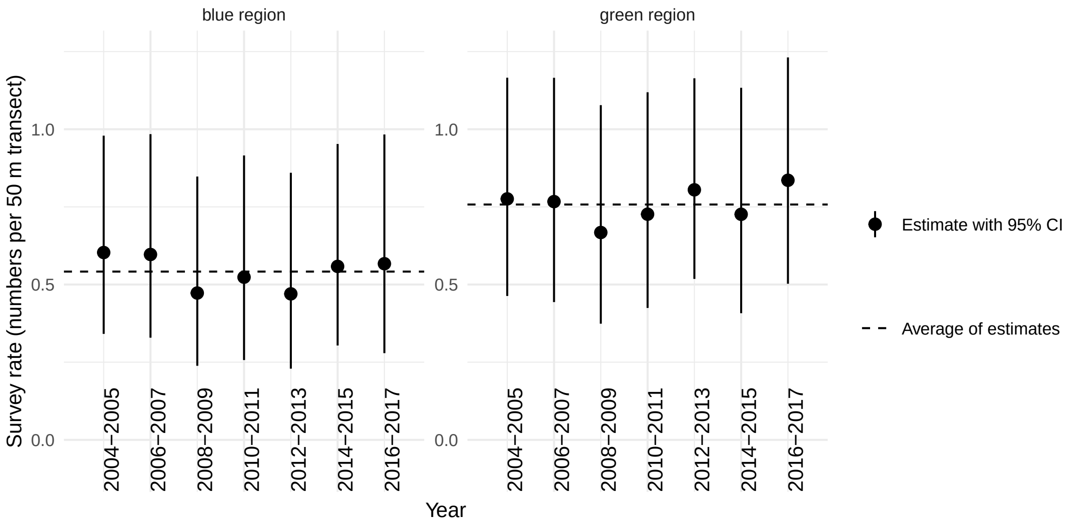

Figure 3.4: Underwater visual survey standardised index in blue regions (open after the introduction of the Representative Areas Program) and green regions (closed after the introduction of the Representative Areas Program) during two-year periods between 2004 and 2017

3.1.4 Age composition

Fishery age-composition data were input to the population model, as part of age-at-length compositions, for the blue region (Figure 3.5) and the green region (Figure 3.6). The data were right-skewed for most years in both regions.

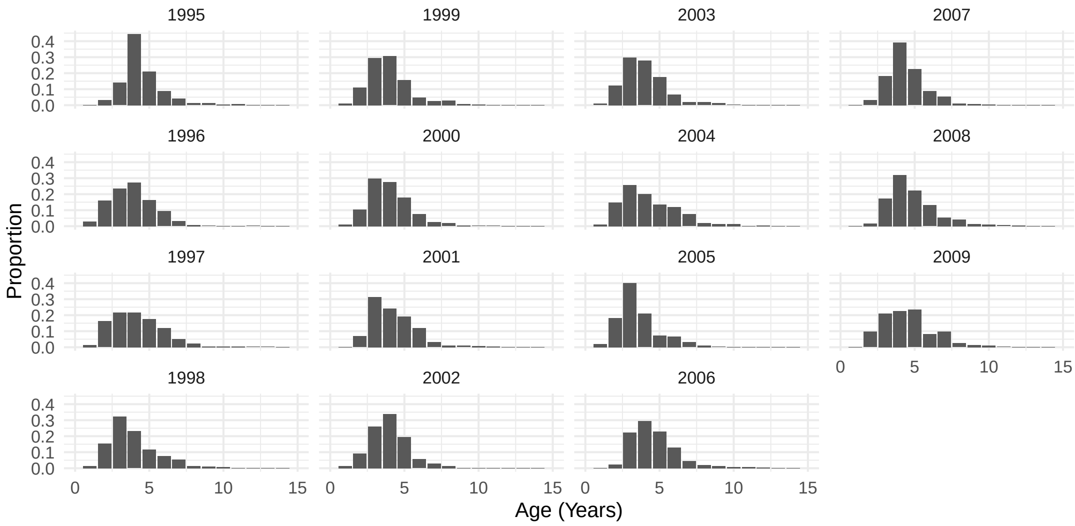

Figure 3.5: Annual age compositions of common coral trout for line-caught fish between 1995 and 2009 in the blue region

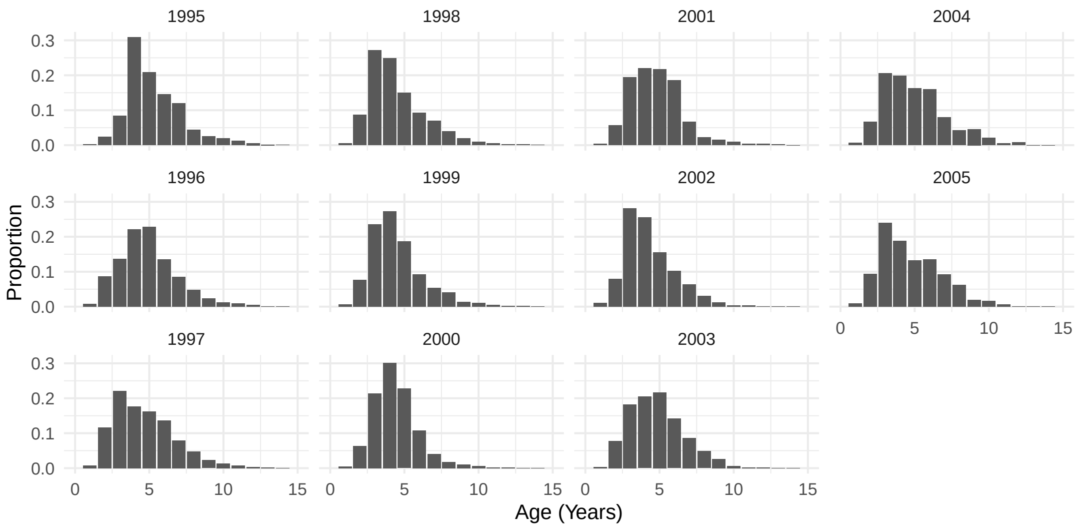

Figure 3.6: Annual age compositions of common coral trout for line-caught fish between 1995 and 2009 in the green region

3.1.5 Length composition

Fishery length compositions were input to the population model for the blue region (Figure 3.7) and the green region (Figure 3.8). Generally, the length distributions were right-skewed in the blue region, but symmetric in the green region. The median values approximately the same for both regions from 1995–2003.

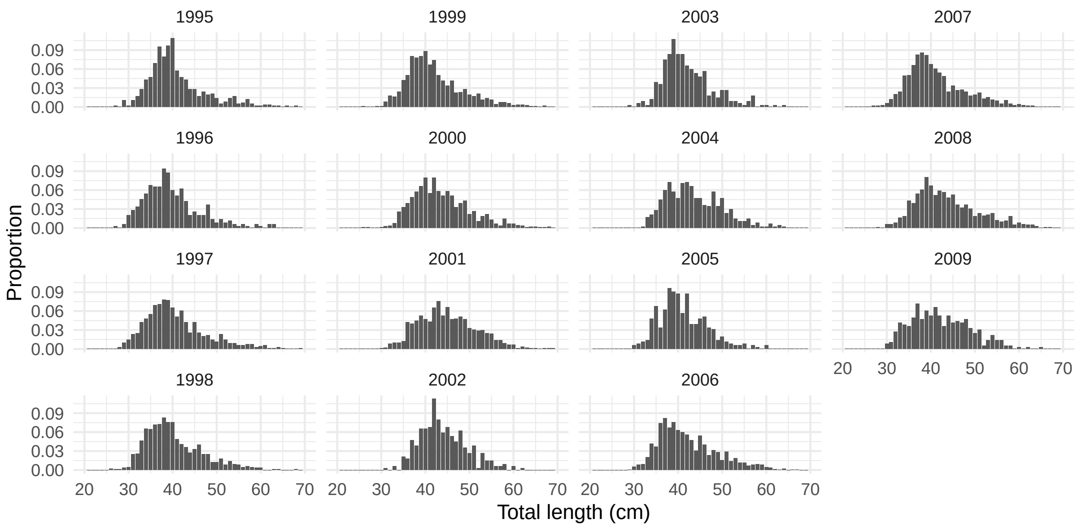

Figure 3.7: Annual length compositions of common coral trout for line-caught fish between 1995 and 2009 in the blue region

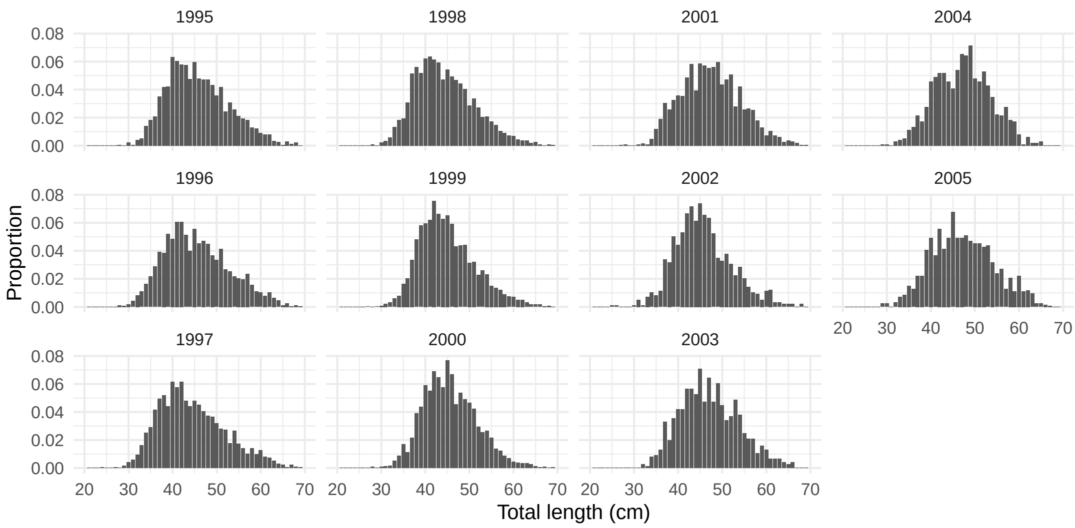

Figure 3.8: Annual length compositions of common coral trout for line-caught fish between 1995 and 2005 in the green region

Survey length compositions were input to the population model for the blue region (Figure 3.9) and the green region (Figure 3.10). Note the smaller sample sizes for these underwater surveys compared to the line-caught data (Table A.1. Appendix A). These sample sizes are input to the model and form a starting point for data set weighting.

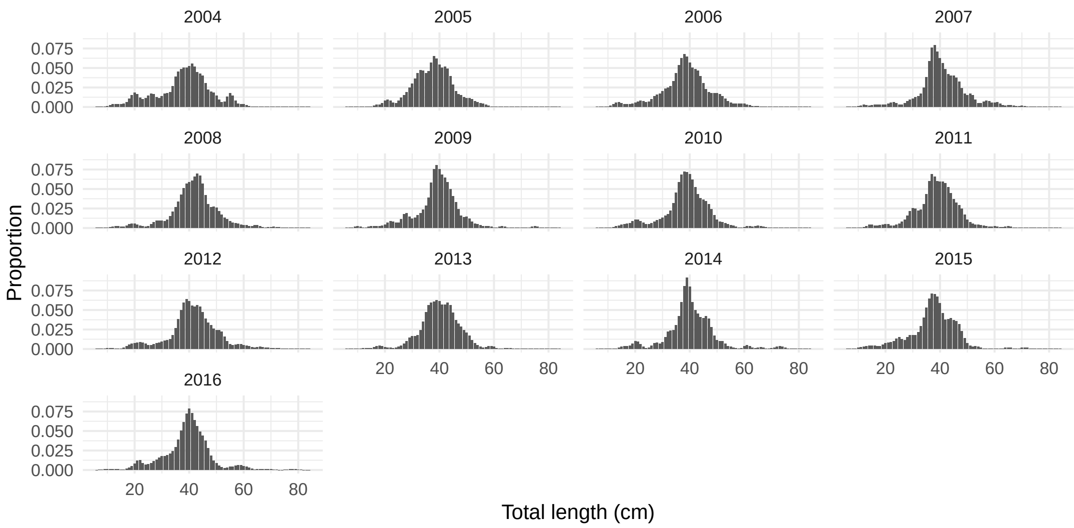

Figure 3.9: Annual length compositions of common coral trout for fish sighted in the underwater visual survey between 2004 and 2016 in the blue region. Raw compositions have been smoothed by a kernel with a bandwidth of 1.5.

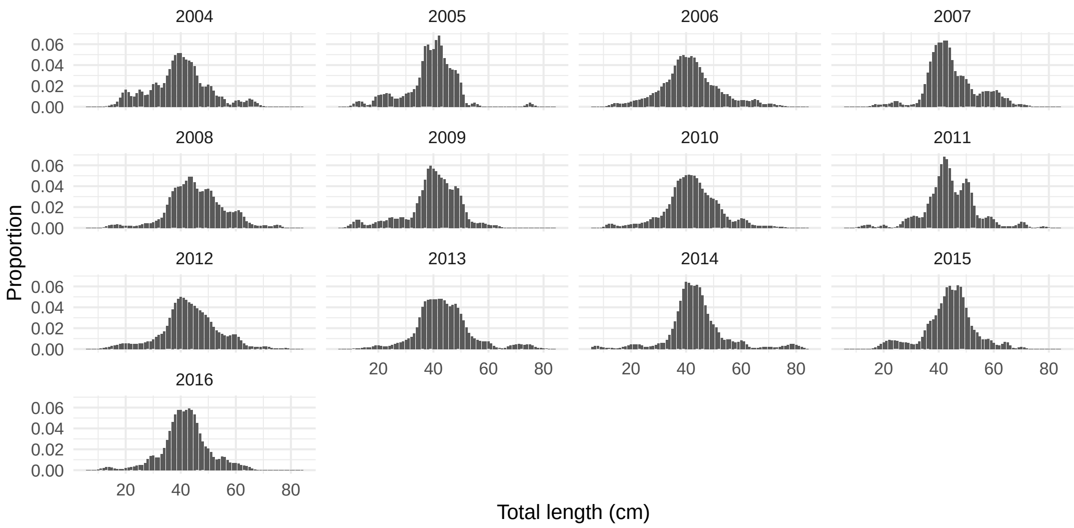

Figure 3.10: Annual length compositions of common coral trout for fish sighted in the underwater visual survey between 2004 and 2016 in the green region. Raw compositions have been smoothed by a kernel with a bandwidth of 1.5.

3.1.6 Other model inputs

Conditional age-at-length composition data and fixed biological relationships are provided in Appendix A, Sections A.2 and A.3.

3.2 Model outputs

3.2.1 Model parameters

Several parameters were estimated within the base case model (Table 3.1). The full list of estimated parameters for the base and sensitivity runs is given in Appendix B, Table B.2.

Table 3.1: Summary of parameter estimates from the base population model

Parameter	Estimate	Standard deviation	Explanation
M	0.38	0.04	Natural mortality
TL_1	14.80	1.21	Total length at age 1
TL_{18}	73.69	2.14	Total length at age 18
κ	0.13	0.03	von Bertalanffy growth rate
ϕ	-0.62	0.33	Proportion of recruitment going to the green region (logit scale)

Two additional model runs were undertaken to determine the sensitivity of the model to parameterisation assumptions (Appendix B). The base case model involved an estimation of natural mortality, whereas the "low" sensitivity test fixed this parameter at $M = 0.2$ (Table B.3). The "high" sensitivity test involved the use of asymptotic selectivity on the survey fleets (Table B.4).

In addition, the sensitivity of the model to the assumption that steepness was explored through a likelihood profile (Appendix B, Section B.3.3).

3.2.2 Model fits

Model fit diagnostics are detailed in Appendix B, Section B.2. Good fits were achieved for all data sets, including abundance indices, conditional age-at-length compositions and length compositions.

3.2.3 Selectivity

The selectivity of common coral trout was estimated within the model (Table B.2, Figure 3.11).

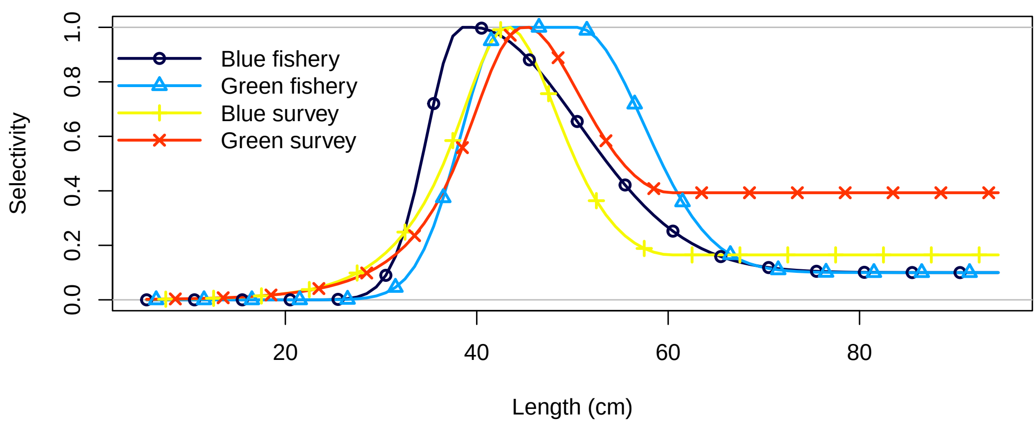

Figure 3.11: Model estimated length-based selectivity by fleet in 2019

3.2.4 Growth curve

The von Bertalanffy growth curve, including coefficients of variation of old and young fish, was estimated within the model (Table B.2, Figure 3.12).

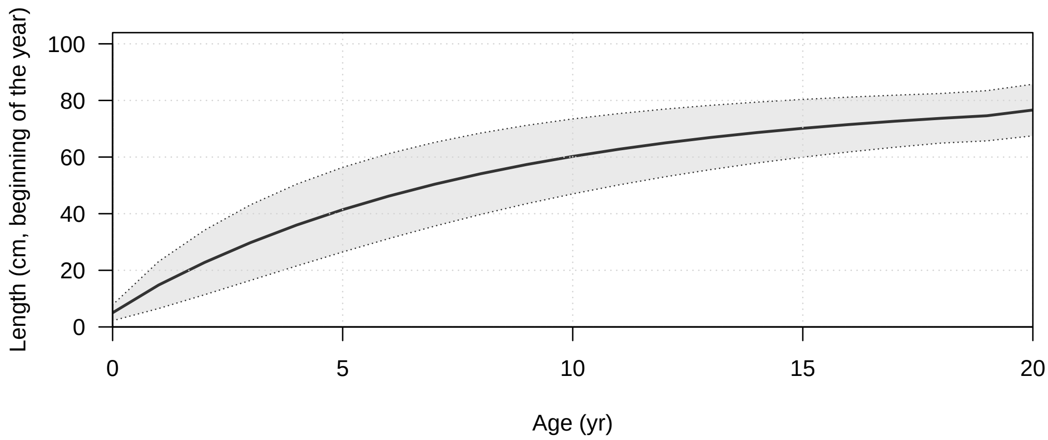

Figure 3.12: Model estimated growth of coral trout (95% confidence intervals)

3.2.5 Biomass

The base case model predicted spawning stock biomass declined between 1953 and 2011 to 51% unfished biomass. In 2020, the stock level was estimated to be 59% unfished total biomass (Figure 3.13). The wide confidence is partly due to the attempt to estimate natural mortality. They are likely more realistic than they would be if natural mortality had been fixed.

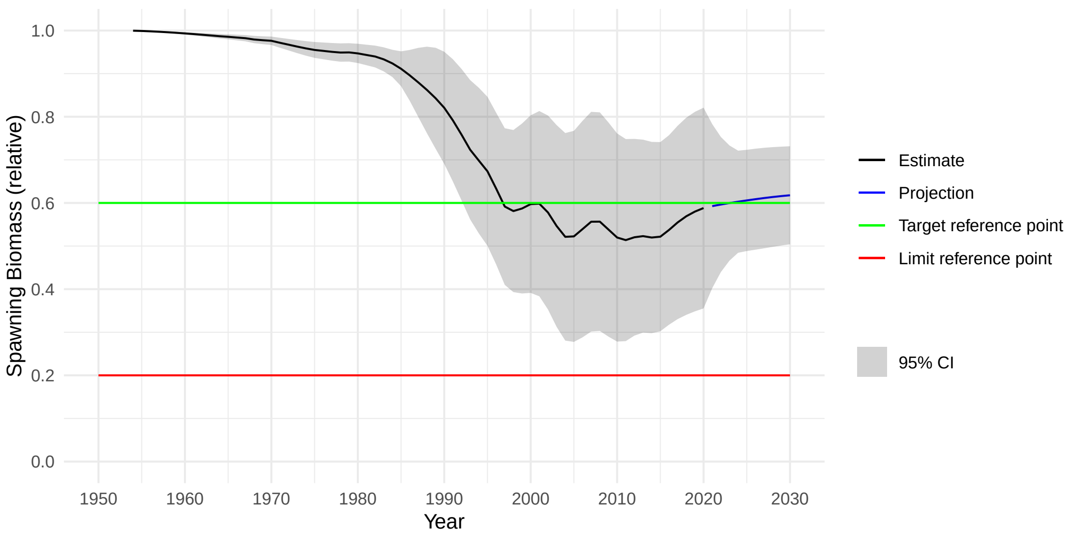

Figure 3.13: Predicted spawning biomass trajectory relative to virgin, from 1953 to 2030. Refer to Section 2.5.5 for a description of the projection phase (2021–2030)

The equilibrium yield informs on the productivity of the stock at different biomass levels (Figure 3.14). It is important to note that estimates of maximum sustainable harvest (MSH) should be interpreted with caution, for two reasons. Firstly, steepness was fixed within the model, yet it is a key driver of productivity. Secondly, due to the large fraction of the fishery closed to fishing (equilibrium quantities are based on post RAP conditions), the maximum yield must be taken at very high fishing mortality in the blue region, and the optimizer in Stock Synthesis struggled to achieve convergence. Whole-stock maximum yield is theoretically unobtainable with a sufficient fraction of the fishery closed, and the current assessment is near this impossibility boundary. This theoretical limitation can be seen in two aspects of the yield plot:

the relative biomass at which maximum yield is slightly to the right of the apex of the curve, and yields below 10% relative biomass are not possible.

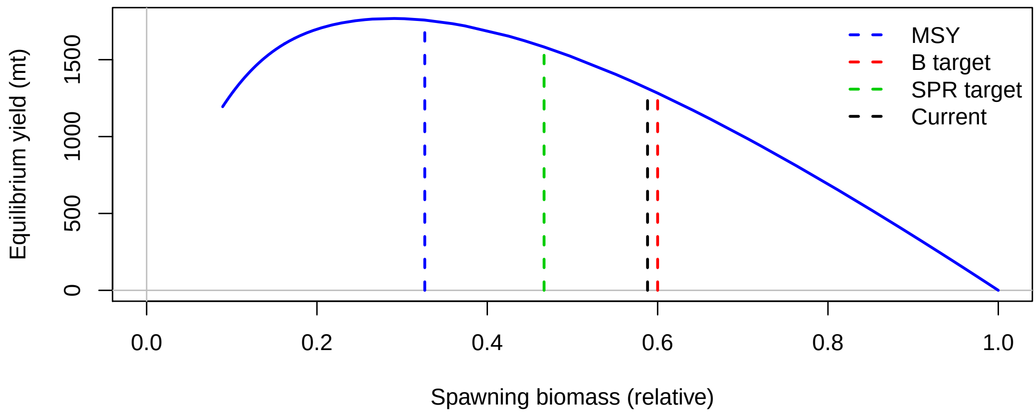

Figure 3.14: Equilibrium yield curve. The blue dashed line represents the equilibrium MSY harvest and depletion, while the grey line is the current and the green line is the 60% target harvest and depletion.

3.2.6 Harvest targets

Harvest targets have been calculated to maintain spawning biomass at the 60% target reference point for the base model, and two sensitivity test models, resulting in recommended biological harvests (RBHs) of 1034 t (base), 420 t (low), and 1258 t (high). These RBHs are the first in a schedule of projected recommended harvests for the Harvest Strategy 2017–2027, using the 20:60:60 harvest control rule with a 0.87 buffer. The schedule is presented here for the base case Table 3.2, and in Appendix B for sensitivity runs (Table B.6).

Table 3.2: Estimated total harvests and depletion levels of common coral trout to rebuild and maintain the stock at the target reference point of 60% unfished spawning biomass, following a 20:60:60 control rule with 0.87 buffer

Year	Harvest (t)	Depletion
2020	1034	0.59
2021	1044	0.59
2022	1058	0.60
2023	1074	0.60
2024	1081	0.60
2025	1087	0.61
2026	1091	0.61
2027	1095	0.61

4 Discussion

4.1 Stock status

Results from this assessment suggest the coral trout population on the Queensland east coast experienced some decline in the period 1950–1985, followed by a steeper decline through 2004. Population levels stabilised in the period from 2005–2015, followed by some recovery in the period 2016–2019. The current (2020) population level is around 59% of unfished spawning biomass.

The results also suggest that catch levels during the 1990s and early 2000s were higher than would be consistent with a 60% target reference point. Management reforms enacted in 2004 (whether the Representative Area Program rezoning or the influence of the total allowable commercial catch administered through individual transferable quotas or both) appear to have reduced fishing mortality to near target levels.

4.2 Performance of the population model

The base population model fits all data sets well. However, many different methods of aggregating the commercial catch rate data and the underwater visual survey data were investigated before settling on the analyses presented here. Earlier analyses led to relatively poorer model fit, particularly when the analyses aggregated in a way that preserved the longer time series data available in both cases (since 1988 for commercial catch rates and 1997 for UVS). The implicit assumption that these time periods contain signals that are not representative of the coral trout population needs to be further investigated and the current outputs interpreted accordingly.

Other model limitations of note include:

- the productivity parameter "steepness" (h) was fixed, and a likelihood profile confirmed the data are not sufficiently informative to estimate it;
- regional variation in biological characteristics has not been taken into account;
- hermaphroditism was briefly explored but did not produce sensible results, and the current assessment assumes a reproductive mechanism (males and females in fixed 50% proportion from birth) that does not reflect known biology of common coral trout;
- dome-shape selectivity is probably necessary, but the extent of the dome (i.e. how low selectivity becomes as lengths approach their maximum) is unclear;
- mirrored selectivity between the green and blue regions (both for the fishery and the survey) led to poorer fits and implausibly high natural mortality, yet it is a sensible null hypothesis, and the poor fit remains unexplained;
- the extent of discarding in the commercial sector remains largely unknown, and the limited data that were available to support an estimate may not be reliable;
- the fraction of harvest that is common coral trout in the commercial sector is based on a very small sample that may not be representative.

The hermaphroditism issue merits further discussion. By assuming a fixed sex ratio in modelling a species which exhibits sequential hermaphroditism, we may be misrepresenting the interaction between total mortality at age and fertilized egg production. This could result in underestimation of the productivity of the species (more likely if the hermaphroditism is socially controlled) or overestimation (more likely if hermaphroditism is environmentally influenced). Investigating this further should be a priority.

These limitations suggest a cautious interpretation of the current model outputs is needed, and further work will improve model performance.

4.3 Environmental influences

Since 2014, there have been two mass coral bleaching events, one tropical cyclone that severely impacted the GBR, and two crown-of-thorns outbreaks on the GBR (Australian Institute of Marine Science 2018). These events have reduced coral cover, which in turn reduced habitat and prey availability for coral trout (Tobin et al. 2010; Pratchett, Hoey, and Wilson 2014; Rogers, Blanchard, and Mumby 2017). Loss of coral reef habitat extent and complexity has been found to result in reductions in fisheries productivity of approximately 35% (Rogers, Blanchard, and Mumby 2017). Bleaching events can also influence coral trout growth rates and spawning output (Hughes 2010; Johnson and Welch 2010; Pratchett, Hoey, and Wilson 2014).

It is anticipated that increases in sea surface temperature (SST) will affect recruitment, by impacting the timing and duration of spawning events, along with increasing larval growth rates (Welch et al. 2010). In a review of the potential environmental variables impacting common coral trout, SST and nutrient changes were ranked as high risks to common coral trout, while upwelling and wind/current changes were ranked as medium risks (Welch et al. 2010). More specifically, SST over 28 °C negatively impacts the development of early life stages (Pratchett, Hoey, and Wilson 2014). While common coral trout in southern areas may be able to spawn at different times when water is cooler, this may be more difficult in northern regions.

Tropical cyclones may also affect the catchability of the fish. Catch rate declines are correlated with anomalous wave heights resulting from cyclone activity (Callaghan 2011a; Callaghan 2011b; Leigh et al. 2014; Courtney et al. 2015). These declines are most likely not associated with declines in stock size, as UVS data do not show the same pattern; instead, catch rates come back strongly one or two years after the cyclone. Further research is needed to explain these correlations.

There is evidence to suggest that climate change will cause cyclones to increase in intensity (Walsh et al. 2016) and bleaching events will become more extensive and more severe (Hughes et al. 2017).

None of these environmental factors have been modelled in this assessment, as the mechanisms that connect them to common coral trout abundance are not well understood and require further investigation. This is a major limitation of this model if these variables are changing systematically over time.

Outcomes from an FRDC project on "Effects of climate change and habitat degradation on coral trout" may be of value in addressing some of these unknowns.

4.4 Recommendations

4.4.1 Data

Data utility would be improved by accurate effort measures with fishing time and accurate location recorded for each commercial operation. Particularly useful would be the identification of commercial harvest to the species level. More frequent measures of recreational harvest and effort, as well as better species identification, would also benefit future assessments. More data should be collected regarding the number of discards, and the size composition of discarded fish from the commercial fishery. Electronic reporting systems may be valuable for achieving these objectives.

4.4.2 Monitoring

The discontinuation of the Fisheries Queensland reef line monitoring surveys at the end of 2009 led to greater uncertainty in model outputs. It is recommended that the newly restarted biological monitoring program continues on an annual basis and that the data it provides is included in the next assessment as soon as possible. Ensuring there is an adequate representation of males and females in the data is important and may enable hermaphroditism to be correctly modelled next time.

The underwater visual survey data from AIMS was particularly valuable, and it is recommended that the program continues in its current form.

4.4.3 Management

Management action in the early 2000s appears to have put stock levels on a sustainable track. The Sustainable Fisheries Strategy is a sensible way to maintain this as it is underpinned by a harvest control rule. This can buffer against model uncertainty and should remain responsive as modelling and data improve.

4.4.4 Assessment

Limitations with the performance of the current model have been discussed in this document. Specific recommendations for a future assessment are as follows:

- Selectivity be mirrored between green and blue regions, or the reason for this not being appropriate be understood and modelled appropriately
- The extent of selectivity domes be thoroughly sensitivity tested
- The appropriateness of a two-region model that is not spatially contiguous and covers such a broad area be reconsidered
- Hermaphroditism is modelled
- Abundance indices are restandardised with a view to including longer time series in the model, and thorough sensitivity testing is conducted
- An exploration is made of time-varying fraction of recruitment going to each region
- The assessment incorporates newly available age and length composition data from the restarted biological monitoring program
- The assessment investigates how data from the FRDC project on environmental influences (2018-034) be incorporated, if available

4.5 Conclusions

This assessment has informed the status of the common coral trout population on the east coast of Queensland. It suggests that current harvest levels are in line with the target reference point under the Sustainable Fisheries Strategy, with a small amount of rebuilding required to buffer against uncertainty. The results provide recommended biological harvests using a 20:60:60 control rule. Some limitations of the assessment have been noted and recommendations made.

References

Australian Institute of Marine Science (2018). *Long-term Reef Monitoring Program - Annual Summary Report on coral reef condition for 2017/18*. Tech. rep. Author.

Bergenius, M. A. J, G. Begg, and B. D. Mapstone (2006). "The use of otolith morphology to indicate the stock structure of common coral trout (Plectropomus leopardus) on the Great Barrier Reef, Australia". In: *Fishery Bulletin* 104, pp. 498–511.

Bergenius, M. A. J et al. (2005). "The use of otolith chemistry to determine stock structure of three epinepheline serranid coral reef fishes on the Great Barrier Reef, Australia". In: *Fisheries Research* 72, pp. 253–270.

Brooks, Mollie E. et al. (2017). "glmmTMB Balances Speed and Flexibility Among Packages for Zero-inflated Generalized Linear Mixed Modeling". In: *The R Journal* 9.2, pp. 378–400. URL: https://journal.r-project.org/archive/2017/RJ-2017-066/index.html.

Brown, Ian W. et al. (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.

Callaghan, Jeff (Sept. 2011a). *Case Study: Tropical Cyclone Justin, March 1997*. Tech. rep. Green Cross Australia. URL: http://hardenup.org/umbraco/customContent/media/595_Bundaberg-Cairns_Cyclone_Justin_1997.pdf (visited on 07/14/2015).

— (Sept. 2011b). *Tropical Cyclone Larry, 2006*. Tech. rep. Green Cross Australia. URL: http://hardenup.org/umbraco/customContent/media/2155_Innisfail_Cyclone_Larry_2006.pdf (visited on 07/01/2015).

Campbell, Alexander B. et al. (2019). *Stock assessment of the Queensland east coast common coral trout (Plectropomus leopardus) fishery*. Tech. rep. Queensland Department of Agriculture and Fisheries.

Courtney, Anthony J. et al. (Dec. 2015). *Physical oceanographic influences on Queensland reef fish and scallops*. Tech. rep. Final Report FRDC project no. 2013/020. Canberra: Fisheries Research and Development Corporation. URL: http://frdc.com.au/research/final-reports/Pages/2013-020-DLD.aspx (visited on 05/04/2016).

Department of Agriculture and Water Resources (Dec. 2018). *Guidelines for the Implementation of the Commonwealth Fisheries Harvest Strategy Policy*. Tech. rep. June. CC BY 4.0. Canberra.

Emslie, M. J. and A. J. Cheal (2018). *Visual census of reef fish*. Tech. rep. Australian Institute of Marine Science, Townsville, Australia.

Ferreira, Beatrice P. (Mar. 1995). "Reproduction of the common coral trout Plectropomus leopardus (Serranidae: Epinephelinae) from the central and northern Great Barrier Reef, Australia". In: *Bulletin of Marine Science* 56.2, pp. 653–669.

Fisheries Queensland (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. Unpublished report.

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

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.

Halliday, Ian and Julie Robins (2007). *Environmental Flows for Sub-tropical Estuaries: Understanding the Freshwater Needs of Estuaries for Sustainable Fisheries Production and Assessing the Impacts of Water Regulation*. Tech. rep. Brisbane: Department of Primary Industries and Fisheries. URL: http://frdc.com.au/research/Documents/Final_reports/2001-022-DLD.PDF (visited on 11/10/2016).

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

Harrison, Hugo B. et al. (June 2012). "Larval export from marine reserves and the recruitment benefit for fish and fisheries". In: *Current Biology* 22.11, pp. 1023–1028. URL: http://dx.doi.org/10.1016/j.cub.2012.04.008.

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).

Higgs, Jim (1999). *RFISH Technical Report No. 2: Results from the 1997 Diary Round*. Tech. rep. Brisbane: Queensland Department of Primary Industries.

— (2001). *Recreational Catch Estimates for Queensland Residents. RFISH Technical Report No. 3*. Tech. rep. Brisbane: Queensland Department of Primary Industries.

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.

Hoenig, John M. (1983). "Empirical use of longevity data to estimate mortality rates". In: *Fishery Bulletin* 81.4, pp. 898–903. URL: http://fishbull.noaa.gov/81-4/hoenig.pdf (visited on 07/27/2016).

Hughes, T. P. (2010). *Marine and Tropical Sciences Research Facility, Milestone Report for program 2.5i.3*. Report to the Australian Government Department of the Envrionment, Water, Heritage and the Arts. Australia: James Cook University.

Hughes, Terry P. et al. (2017). "Global warming and recurrent mass bleaching of corals". In: *Nature* 543, p. 373. DOI: 10.1038/nature21707. URL: https://doi.org/10.1038/nature21707.

Jensen, AL (1997). "Origin of relation between K and Linf and synthesis of relations among life history parameters". In: *Canadian Journal of Fisheries and Aquatic Sciences* 54, 987–989.

Johnson, J. E. and D. Welch (2010). "Marine fisheries management in a changing climate: a review of vulnerability and future options." In: *Reviews in Fisheries Science* 18, pp. 106–124.

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.

Leigh, G. M. et al. (2014). *Stock assessment of the Queensland east coast common coral trout (Plectropomus leopardus) fishery*. Monograph. URL: http://era.daf.qld.gov.au/4547/ (visited on 06/30/2015).

Mapstone, Bruce D. et al. (2004). *The Effects of Line Fishing on the Great Barrier Reef and Evaluations of Alternative Potential Management Strategies. Report of FRDC project 97/124.* Tech. rep. Townsville: CRC Reef Research Centre.

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

Methot, Richard D., Chantel R. Wetzel, and Ian G. Taylor (2019). *Stock Synthesis User Manual Version 3.30.13*. Tech. rep. Seattle, WA: National Oceanic and Atmospheric Administration, U.S. Dept. Commer., p. 215.

Northrop, Amanada et al. (2018). *Monitoring requirements for common coral trout*. Tech. rep. Brisbane: Queensland Department of Agriculture and Fisheries.

Pratchett, M. S., A. S. Hoey, and S. K. Wilson (2014). "Reef degradation and the loss of critical ecosystem goods and services provided by coral reef fishes". In: *Current Opinion in Environmental Sustainability* 7, pp. 37–43. DOI: 10.1016/j.cosust.2013.11.022.

Pratchett, M. S. et al. (2010). "Effects of climate change on reproduction, larval development, and adult health of coral trout (*Plectropomus* spp.)" In: *Final Rep to Fish Res Dev Corp Proj 2010/554, FRDC, James Cook University, Australia*.

Punt, AE (2018). *On the use of likelihood profiles in fisheries stock assessment*. Tech. rep. Technical paper for SESSF RAG, August 2018.

Queensland Department of Agriculture and Fisheries (2020). *Reef line fishery harvests strategy 2020-2025*. Tech. rep. Brisbane: Author.

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

Rogers, Alice, Julia L. Blanchard, and Peter J. Mumby (2017). "Fisheries productivity under progressive coral reef degradation". en. In: *Journal of Applied Ecology*, DOI: 10.1111/1365–2664.13051. ISSN: 1365-2664. DOI: 10.1111/1365-2664.13051. URL: http://onlinelibrary.wiley.com/doi/10.1111/1365-2664.13051/abstract (visited on 01/15/2018).

Samoilys, Melita A. (1997). "Periodicity of spawning aggregations of coral trout Plectropomus leopardus (Pisces: Serranidae) on the northern Great Barrier Reef". In: *Marine Ecology Progress Series* 160, pp. 149–159. URL: http://dx.doi.org/10.3354/meps160149http://eprints.jcu.edu.au/27784/.

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).

Thébaud, Olivier et al. (2014). "Micro-economic drivers of profitability in an ITQ-managed fishery: An analysis of the Queensland Coral Reef Fin-Fish Fishery". In: *Marine Policy* 43, pp. 200–207.

Then, Amy Y. et al. (Jan. 2015). "Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species". en. In: *ICES Journal of Marine Science* 72.1, pp. 82–92. ISSN: 1054-3139. DOI: 10.1093/icesjms/fsu136. URL: https://academic.oup.com/icesjms/article/72/1/82/2804320 (visited on 01/30/2018).

Tobin, Andrew J. et al. (2010). *Adapting to Change: Minimising Uncertainty About the Effects of Rapidly-changing Environmental Conditions on the Queensland Coral Reef Fin Fish Fishery*. Tech. rep. Townsville: James Cook University, Fishing & Fisheries Research Centre.

van Herwerden, Lynne et al. (2006). "Contrasting patterns of genetic structure in two species of the coral trout Plectropomus (Serranidae) from east and west Australia: introgressive hybridisation or ancestral polymorphisms". In: *Molecular Phylogenetics and Evolution* 41, pp. 420–435.

van Herwerden, Lynne et al. (July 2009). "Complex patterns of population structure and recruitment of *Plectropomus leopardus* (Pisces: Epinephelidae) in the Indo-West Pacific: Implications for fisheries management". In: *Marine Biology* 156.8, pp. 1595–1607. URL: http://dx.doi.org/10.1007/s00227-009-1195-0.

Walsh, Kevin J.E. et al. (Jan. 2016). "Tropical cyclones and climate change". en. In: *Wiley Interdisciplinary Reviews: Climate Change* 7.1, pp. 65–89. ISSN: 1757-7799. DOI: 10.1002/wcc.371. URL: http://onlinelibrary.wiley.com/doi/10.1002/wcc.371/abstract (visited on 01/17/2018).

Welch, D. J. et al. (2010). *Implications of climate change on fisheries resources of northern Australia. Part 1: Vulnerability assessment and adaptation options*. FRDC Project 2010/565. Australia: James Cook University.

A Appendix A - Model inputs

A.1 Age and length sample sizes

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

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

Year	Blue fishery (length)	Green fishery (length)	Blue survey (length)	Green survey (length)	Blue fishery (age)	Green fishery (age)
1995	577	3291			577	3291
1996	353	2634			353	2634
1997	690	2904			690	2904
1998	883	3569			883	3569
1999	1251	3515			1251	3515
2000	1095	2787			1095	2787
2001	876	1925			876	1925
2002	338	975			338	975
2003	335	762			335	762
2004	468	980	210	235	468	980
2005	354	1257	134	87	354	1257
2006	1561		504	865	1561	
2007	2544		255	265	2544	
2008	811		331	473	811	
2009	363		161	138	363	
2010			293	553		
2011			132	208		
2012			304	631		
2013			286	522		
2014			134	363		
2015			179	154		
2016			318	507		

A.2 Conditional age-at-length

Conditional age-at-length composition data were input to the population model for the blue region (Figure A.1) and the green region (Figure A.2).

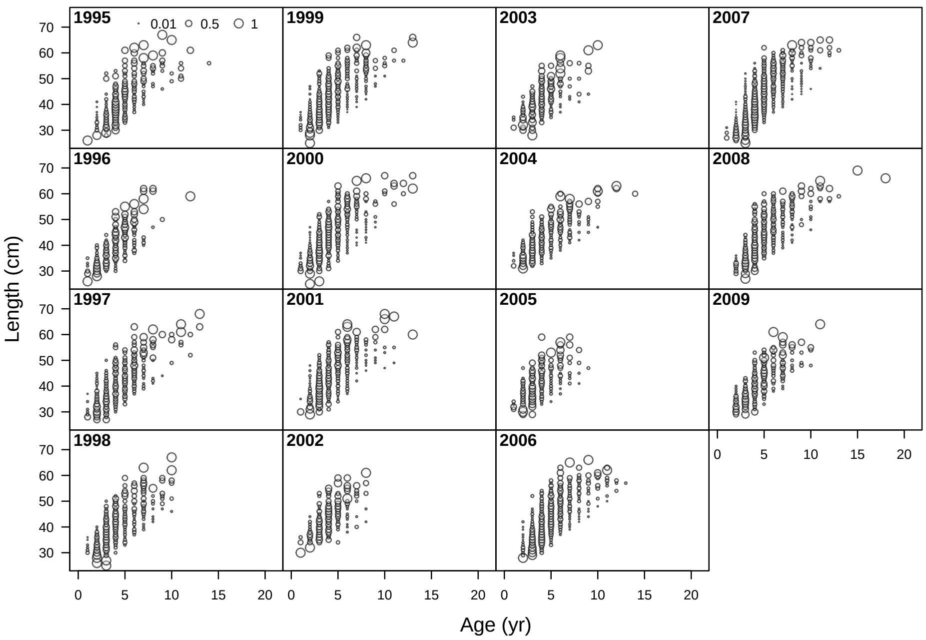

Figure A.1: Conditional age-at-length compositions for line caught fish between 1995 and 2009 in the blue region. Circle size is proportional to relative sample size in each bin across rows (i.e. for a given length bin)

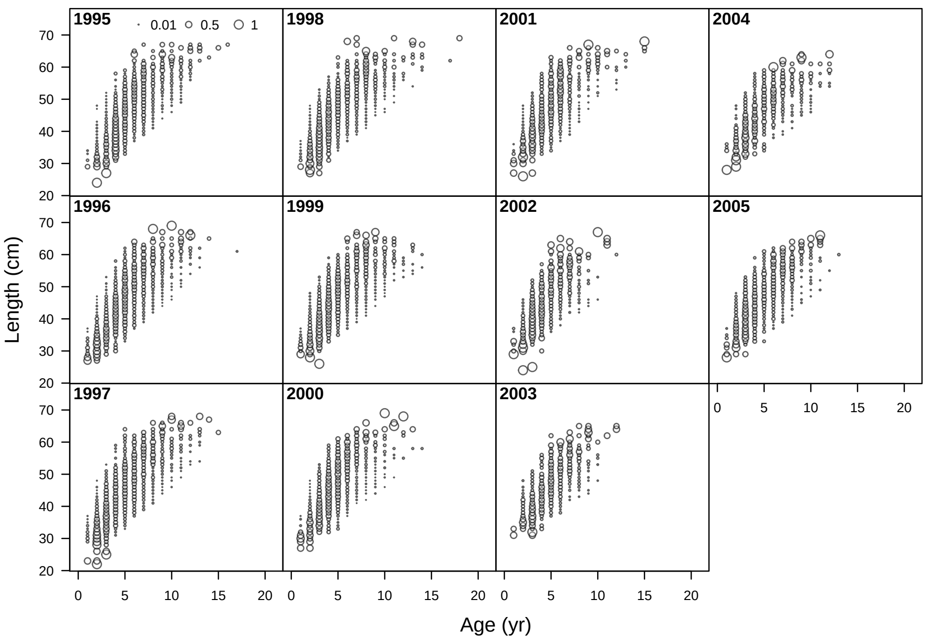

Figure A.2: Conditional age-at-length compositions of coral trout for line caught fish between 1995 and 2005 in the green region. Circle size is proportional to relative sample size in each bin across rows (i.e. for a given length bin)

A.3 Biological data

A.3.1 Fecundity and maturity

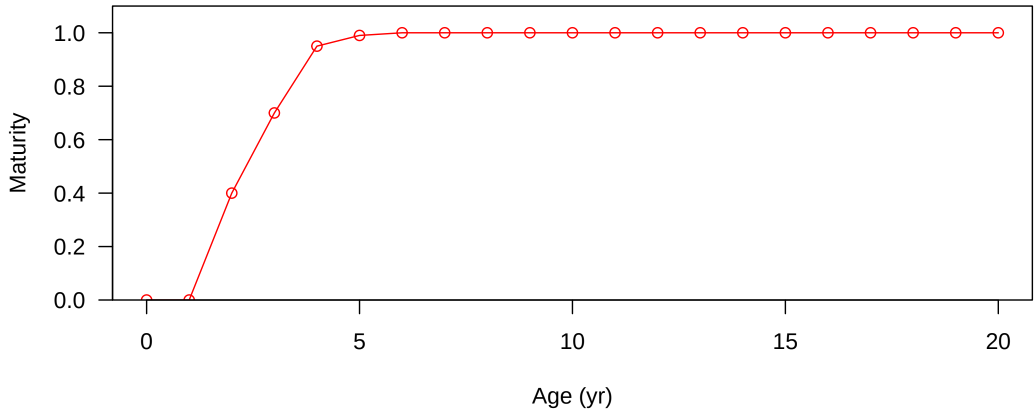

Figure A.3: Maturity at age

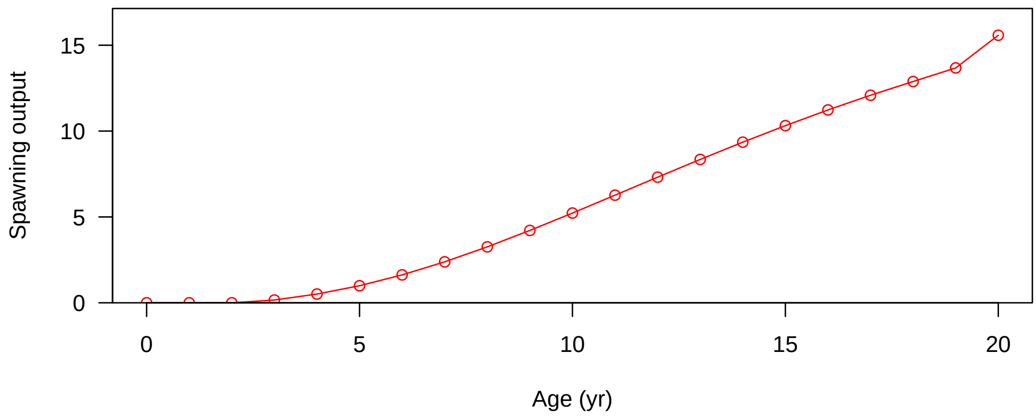

Figure A.4: Spawning output (maturity times fecundity) at age

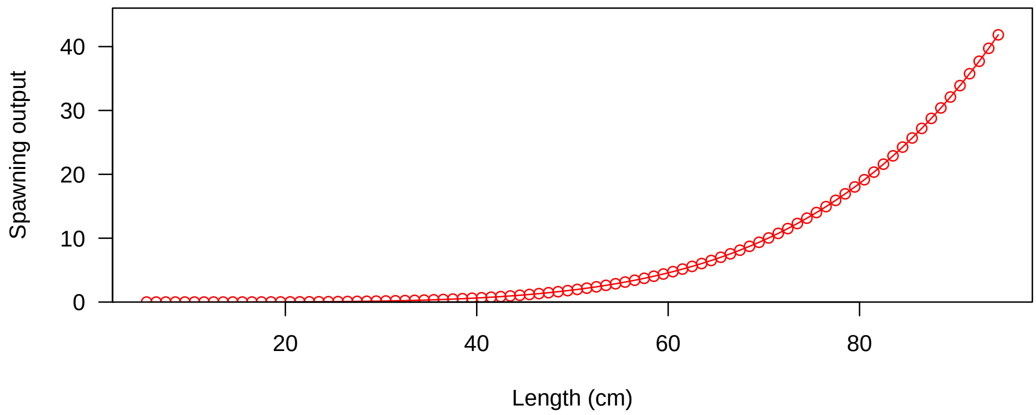

Figure A.5: Spawning output (maturity times fecundity) at length

A.3.2 Weight and length

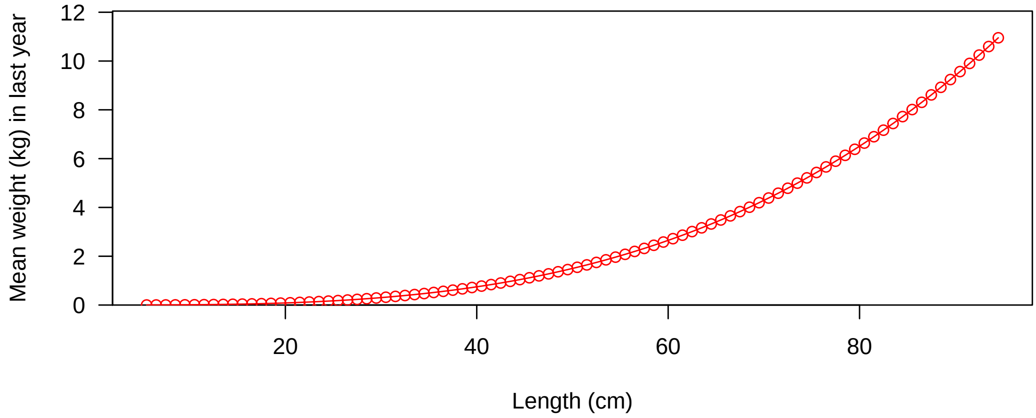

Figure A.6: Weight-length relationship

B Appendix B - Model outputs

B.1 Parameter estimates

Model parameters were estimated by Stock Synthesis, and parameter labels follow a Stock Synthesis specific naming convention (Table B.1). Parameters were estimated for the base case (Table B.2), fixed-M sensitivity (Table B.3) and asymptotic selectivity sensitivity (Table B.4). In addition, recruitment deviations were estimated between 1982 and 2019.

Table B.1: Parameter label explanation

Stock Synthesis Parameter Label	Explanation
NatM	Natural mortality (M)
L_at_Amin	Total length at Age 1 (TL1)
L_at_Amax	Total length at Age 18 (TL18)
VonBert_K	von Bertalanffy growth parameter (kappa)
CV_young	Coefficient of variation in total length at Age 1
CV_old	Coefficient of variation in total length at Age 18
RecrDist_area_2	Proportion of recruitment going to the green region (phi; logit scale)
SR_LN(R0)	logarithm of the number of recruits in 1953
Q_extraSD_FISHERY_BLUE	Extra standard deviation in catchability for the blue fishery
Q_extraSD_SURVEY_BLUE	Extra standard deviation in catchability for the blue survey
Q_extraSD_SURVEY_GREEN	Extra standard deviation in catchability for the green survey
SizeSel_P1_FISHERY_BLUE	Blue fishery selectivity, pattern 23, parameter p1 – peak: beginning size for the plateau (cm)
SizeSel_P2_FISHERY_BLUE	Blue fishery selectivity, pattern 23, parameter p2 - top: width of plateau, as logistic between peak and maximum length (cm)
SizeSel_P3_FISHERY_BLUE	Blue fishery selectivity, pattern 23, parameter p3 - ascending width: parameter value is ln(width; cm)
SizeSel_P4_FISHERY_BLUE	Blue fishery selectivity, pattern 23, parameter p4 - descending width: parameter value is ln(width; cm)
SizeSel_P5_FISHERY_BLUE	Blue fishery selectivity, pattern 23, parameter p5 - initial:selectivity at first bin, as logistic between 0 and 1
Retain_L_infl_FISHERY_BLUE	Blue fishery retention, asymptotic, parameter p1 - ascending inflection (cm)
SizeSel_P1_FISHERY_GREEN	Green fishery selectivity, pattern 23, parameter p1 – peak: beginning size for the plateau (cm)
SizeSel_P2_FISHERY_GREEN	Green fishery selectivity, pattern 23, parameter p2 - top: width of plateau, as logistic between peak and maximum length (cm)
SizeSel_P3_FISHERY_GREEN	Green fishery selectivity, pattern 23, parameter p3 - ascending width: parameter value is ln(width; cm)
SizeSel_P4_FISHERY_GREEN	Green fishery selectivity, pattern 23, parameter p4 - descending width: parameter value is ln(width; cm)
SizeSel_P5_FISHERY_GREEN	Green fishery selectivity, pattern 23, parameter p5 - initial:selectivity at first bin, as logistic between 0 and 1
Retain_L_infl_FISHERY_GREEN	Green fishery retention, asymptotic, parameter p1 - ascending inflection (cm)
SizeSpline_GradLo_SURVEY_BLUE	Blue survey selectivity, pattern 27 (spline), parameter p2 - gradient at the first node
SizeSpline_Val_1_SURVEY_BLUE	Blue survey selectivity, pattern 27 (spline), parameter p8 - selectivity at the first node
SizeSpline_Val_2_SURVEY_BLUE	Blue survey selectivity, pattern 27 (spline), parameter p9 - selectivity at the second node
SizeSpline_Val_4_SURVEY_BLUE	Blue survey selectivity, pattern 27 (spline), parameter p11 - selectivity at the fourth node
SizeSpline_GradLo_SURVEY_GREEN	Green survey selectivity, pattern 27 (spline), parameter p2 - gradient at the first node
SizeSpline_Val_1_SURVEY_GREEN	Green survey selectivity, pattern 27 (spline), parameter p8 - selectivity at the first node
SizeSpline_Val_2_SURVEY_GREEN	Green survey selectivity, pattern 27 (spline), parameter p9 - selectivity at the second node
SizeSpline_Val_4_SURVEY_GREEN	Green survey selectivity, pattern 27 (spline), parameter p11 - selectivity at the fourth node

Table B.2: Stock synthesis parameter estimates for the base population model

Stock Synthesis Parameter Label	Estimate	Phase	Min	Max	Initial value	Standard deviation
NatM	0.38	9	0.01	0.99	0.3	0.04
L_at_Amin	14.8	2	-10	45	10	1.21
L_at_Amax	73.69	3	50	90	70	2.14
VonBert_K	0.13	2	0.01	0.3	0.14	0.02
CV_young	0.29	4	0.05	0.5	0.2	0.02
CV_old	0.06	7	0	1.5	0.1	0.01
RecrDist_area_2	-0.62	4	-5	5	0	0.33
SR_LN(R0)	10.2	1	3	31	10	0.33
Q_extraSD_FISHERY_BLUE	0.04	6	-0.2	0.5	0.1	0.02
Q_extraSD_SURVEY_BLUE	0.02	6	-0.2	0.5	0.1	0.02
Q_extraSD_SURVEY_GREEN	0.03	6	-0.2	0.5	0.1	0.02
SizeSel_P1_FISHERY_BLUE	38.43	5	30	50	40	0.85
SizeSel_P2_FISHERY_BLUE	-5.84	5	-6	3	-1	4.66
SizeSel_P3_FISHERY_BLUE	3.26	5	-4	12	3	0.24
SizeSel_P4_FISHERY_BLUE	5.51	5	-3	6	5	0.32
SizeSel_P5_FISHERY_BLUE	-13.83	5	-15	5	-12	23.93
Retain_L_infl_FISHERY_BLUE	38.2	4	20	70	38	1.33
SizeSel_P1_FISHERY_GREEN	42.97	5	30	50	40	0.97
SizeSel_P2_FISHERY_GREEN	-1.9	5	-5	3	-1	0.52
SizeSel_P3_FISHERY_GREEN	3.75	5	-4	12	3	0.19
SizeSel_P4_FISHERY_GREEN	4.6	5	-3	6	5	0.5
SizeSel_P5_FISHERY_GREEN	-13.92	5	-15	5	-12	21.88
Retain_L_infl_FISHERY_GREEN	41.16	4	20	70	38	1.47
SizeSpline_GradLo_SURVEY_BLUE	0.19	3	0	1	0.1	0.03
SizeSpline_Val_1_SURVEY_BLUE	-5.25	2	-9	7	-5	0.26
SizeSpline_Val_2_SURVEY_BLUE	-1.71	2	-9	7	-3	0.1
SizeSpline_Val_4_SURVEY_BLUE	-2.79	2	-9	7	0	0.32
SizeSpline_GradLo_SURVEY_GREEN	0.17	3	0	1	0.1	0.03
SizeSpline_Val_1_SURVEY_GREEN	-5.13	2	-9	7	-5	0.27
SizeSpline_Val_2_SURVEY_GREEN	-1.85	2	-9	7	-3	0.09
SizeSpline_Val_4_SURVEY_GREEN	-1.84	2	-9	7	0	0.22

Table B.3: Stock synthesis parameter estimates for the low sensitivity (M=0.2) population model

Stock Synthesis Parameter Label	Estimate	Phase	Min	Max	Initial value	Standard deviation
L_at_Amin	14.87	2	-10	45	10	1.37
L_at_Amax	68.7	3	50	90	70	1.34
VonBert_K	0.18	2	0.01	0.3	0.14	0.02
CV_young	0.28	4	0.05	0.5	0.2	0.02
CV_old	0.07	7	0	1.5	0.1	0.01
RecrDist_area_2	-0.87	4	-5	5	0	0.27
SR_LN(R0)	9.02	1	3	31	10	0.1
Q_extraSD_FISHERY_BLUE	0.05	6	-0.2	0.5	0.1	0.02
Q_extraSD_SURVEY_BLUE	0.01	6	-0.2	0.5	0.1	0.02
Q_extraSD_SURVEY_GREEN	0.04	6	-0.2	0.5	0.1	0.02
SizeSel_P1_FISHERY_BLUE	37.5	5	30	50	40	0.77
SizeSel_P2_FISHERY_BLUE	-5.86	5	-6	3	-1	4.16
SizeSel_P3_FISHERY_BLUE	3.18	5	-4	12	3	0.25
SizeSel_P4_FISHERY_BLUE	4.96	5	-3	6	5	0.23
SizeSel_P5_FISHERY_BLUE	-13.36	5	-15	5	-12	30.27
Retain_L_infl_FISHERY_BLUE	38.92	4	20	70	38	1.39
SizeSel_P1_FISHERY_GREEN	41.46	5	30	50	40	0.93
SizeSel_P2_FISHERY_GREEN	-2.2	5	-5	3	-1	0.53
SizeSel_P3_FISHERY_GREEN	3.62	5	-4	12	3	0.22
SizeSel_P4_FISHERY_GREEN	4.46	5	-3	6	5	0.36
SizeSel_P5_FISHERY_GREEN	-12.71	5	-15	5	-12	30.79
Retain_L_infl_FISHERY_GREEN	42.24	4	20	70	38	1.46
SizeSpline_GradLo_SURVEY_BLUE	0.17	3	0	1	0.1	0.03
SizeSpline_Val_1_SURVEY_BLUE	-4.52	2	-9	7	-5	0.22
SizeSpline_Val_2_SURVEY_BLUE	-1.54	2	-9	7	-3	0.09
SizeSpline_Val_4_SURVEY_BLUE	-3.7	2	-9	7	0	0.25
SizeSpline_GradLo_SURVEY_GREEN	0.15	3	0	1	0.1	0.03
SizeSpline_Val_1_SURVEY_GREEN	-4.35	2	-9	7	-5	0.22
SizeSpline_Val_2_SURVEY_GREEN	-1.69	2	-9	7	-3	0.09
SizeSpline_Val_4_SURVEY_GREEN	-2.67	2	-9	7	0	0.17

Table B.4: Stock synthesis parameter estimates for the high sensitivity (asymptotic survey selectivity) population model

Stock Synthesis Parameter Label	Estimate	Phase	Min	Max	Initial value	Standard deviation
NatM	0.57	9	0.01	0.99	0.3	0.05
L_at_Amin	15.45	2	-10	45	10	0.98
L_at_Amax	74.68	3	50	90	70	3.57
VonBert_K	0.09	2	0.01	0.3	0.14	0.02
CV_young	0.28	4	0.05	0.5	0.2	0.02
CV_old	0.08	7	0	1.5	0.1	0.03
SR_LN(R0)	11.1	1	3	31	10	0.42
Q_extraSD_FISHERY_BLUE	0.03	6	-0.2	0.5	0.1	0.02
Q_extraSD_SURVEY_BLUE	0.02	6	-0.2	0.5	0.1	0.01
Q_extraSD_SURVEY_GREEN	0.04	6	-0.2	0.5	0.1	0.02
SizeSel_P1_FISHERY_BLUE	39.8	5	30	50	40	0.83
SizeSel_P2_FISHERY_BLUE	-0.78	5	-6	3	-1	0.45
SizeSel_P3_FISHERY_BLUE	3.39	5	-4	12	3	0.2
SizeSel_P4_FISHERY_BLUE	3.93	5	-3	6	5	1.64
SizeSel_P5_FISHERY_BLUE	-14.36	5	-15	5	-12	15.33
Retain_L_infl_FISHERY_BLUE	38.41	4	20	70	38	1.24
SizeSel_P1_FISHERY_GREEN	46.44	5	30	50	40	1.08
SizeSel_P2_FISHERY_GREEN	-1.01	5	-5	3	-1	0.49
SizeSel_P3_FISHERY_GREEN	4.08	5	-4	12	3	0.15
SizeSel_P4_FISHERY_GREEN	3.56	5	-3	6	5	1.48
SizeSel_P5_FISHERY_GREEN	-14.66	5	-15	5	-12	9.21
Retain_L_infl_FISHERY_GREEN	40.49	4	20	70	38	1.48
Size_inflection_SURVEY_BLUE	38.21	5	20	50	35	0.76
Size95width_SURVEY_BLUE	10.92	5	1	12	5	0.59
Size_inflection_SURVEY_GREEN	40.82	5	20	50	35	1
Size95width_SURVEY_GREEN	11.89	5	1	12	5	0.63

Likelihood components for the three model runs are given in Table B.5.

Table B.5: Likelihood components for the base model and sensitivity tests.

Indicator	Base	Low	High
Total NLL	108.551	135.034	148.223
Survey NLL	-65.3277	-63.9204	-65.4682
Length NLL	121.829	135.345	153.357
Age NLL	82.0679	89.5889	86.0193

B.2 Goodness of fit

B.2.1 Abundance indices

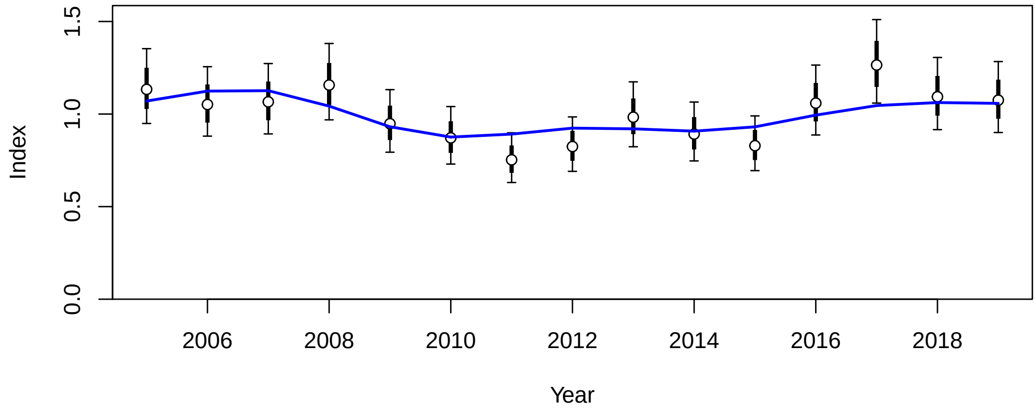

Figure B.1: Model predictions (blue line) to standardised catch rates (points). Thick black bars represent the standard error input into the model, while the thin error bars represent additional error estimated by the model

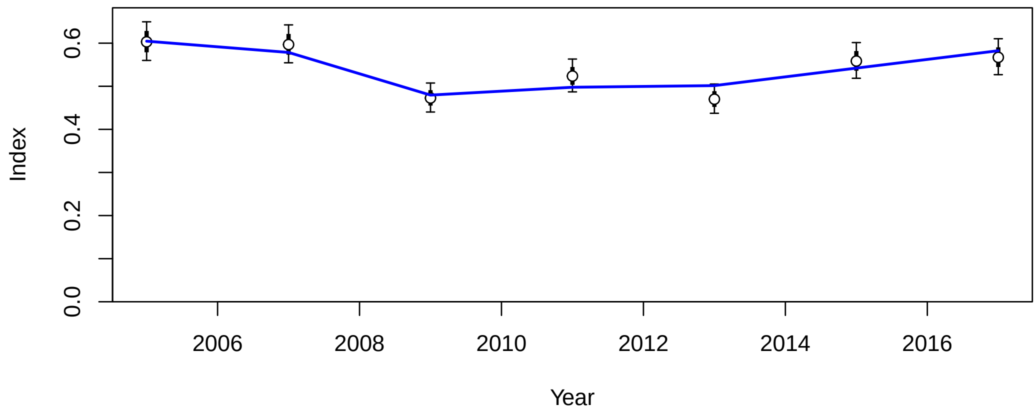

Figure B.2: Model predictions (blue line) to underwater survey rate for the blue region (points). Thick black bars represent the standard error input into the model, while the thin error bars represent additional error estimated by the model

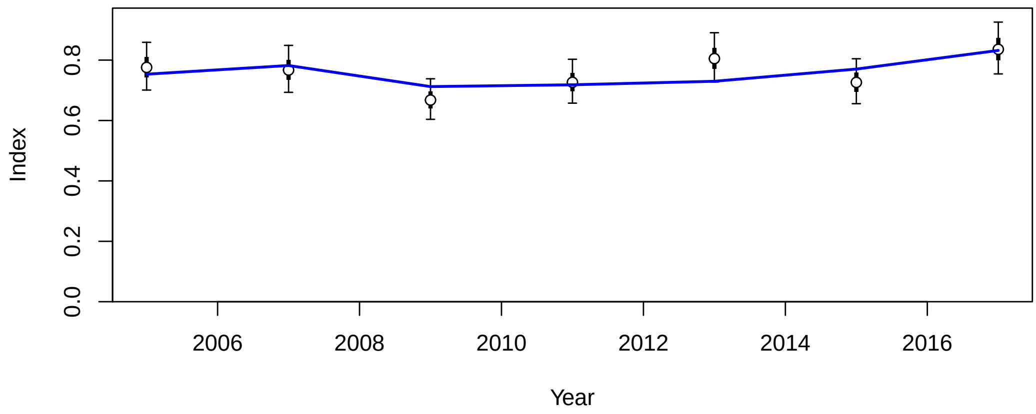

Figure B.3: Model predictions (blue line) to underwater survey rate for the green region (points). Thick black bars represent the standard error input into the model, while the thin error bars represent additional error estimated by the model

B.2.2 Length compositions

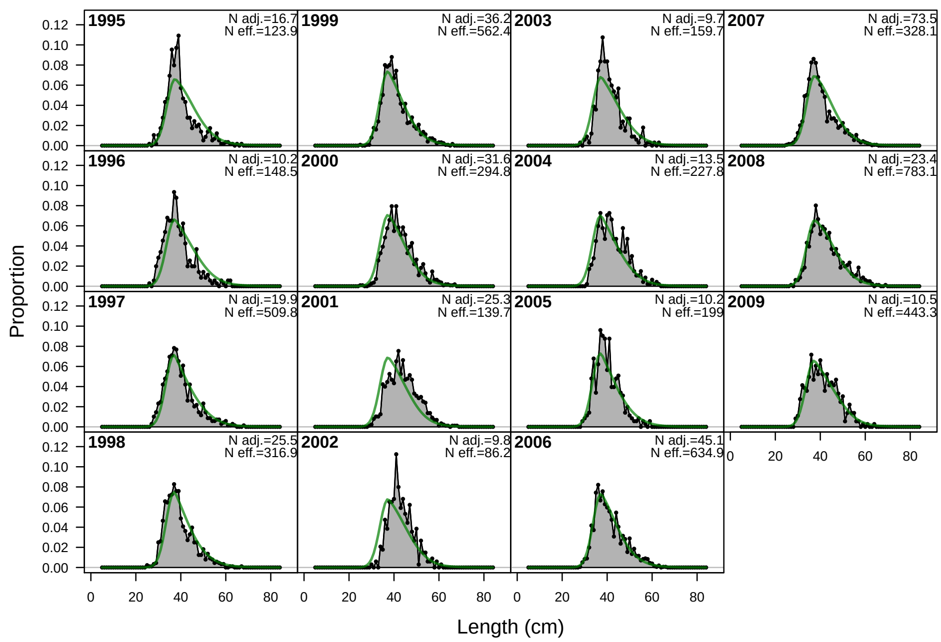

Figure B.4: Fits to length structures for the blue fishery fleet. 'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Iannelli tuning method

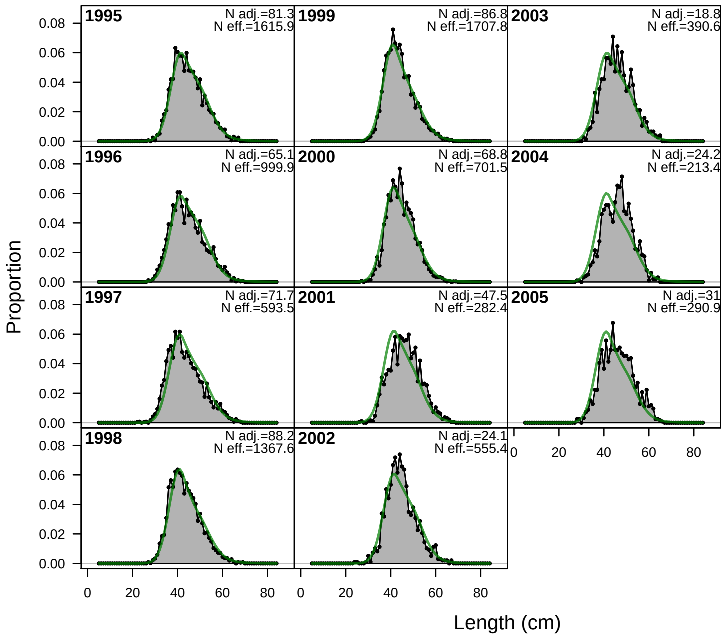

Figure B.5: Fits to length structures for the green fishery fleet. 'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Iannelli tuning method

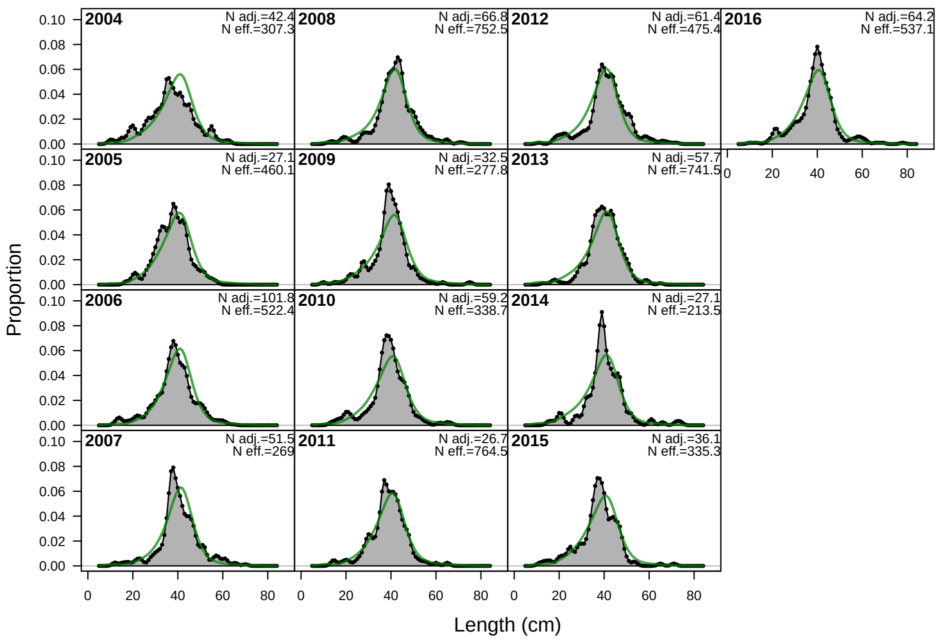

Figure B.6: Fits to length structures for the blue survey fleet. 'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Iannelli tuning method

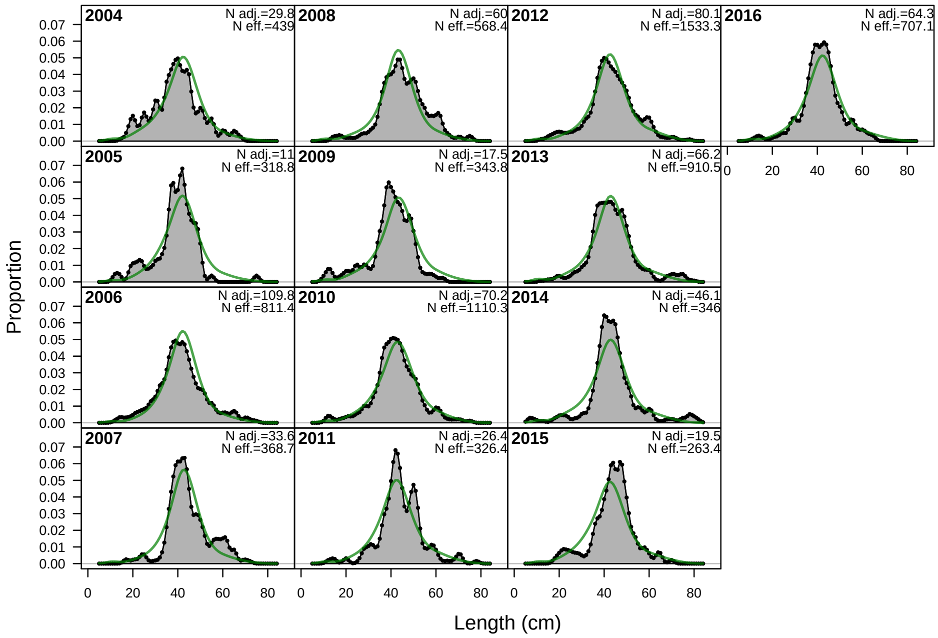

Figure B.7: Fits to length structures for the green survey fleet. 'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method

B.2.3 Conditional age-at-length compositions

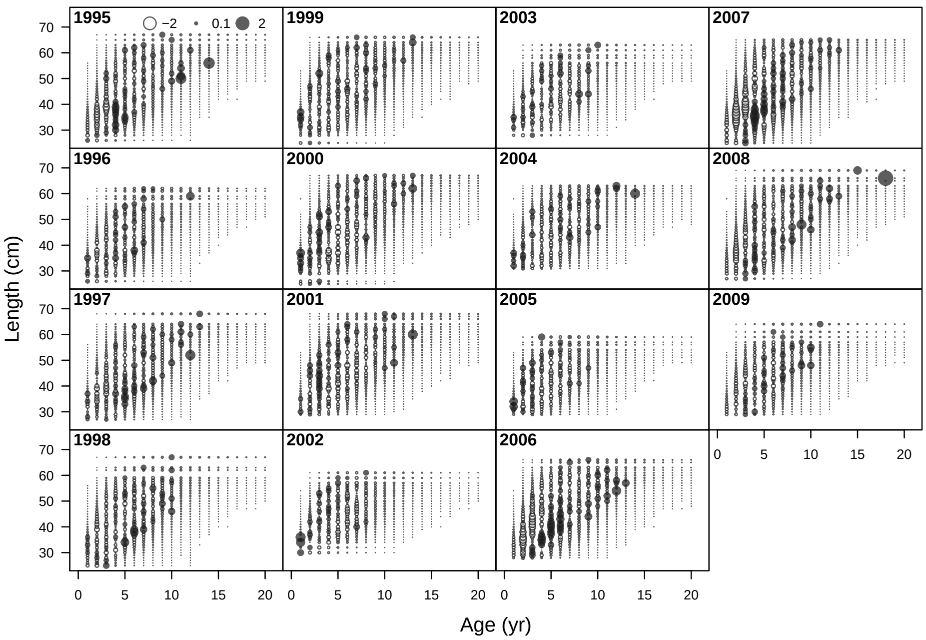

Figure B.8: Pearson residuals for age-at-length compositions for the blue fishery

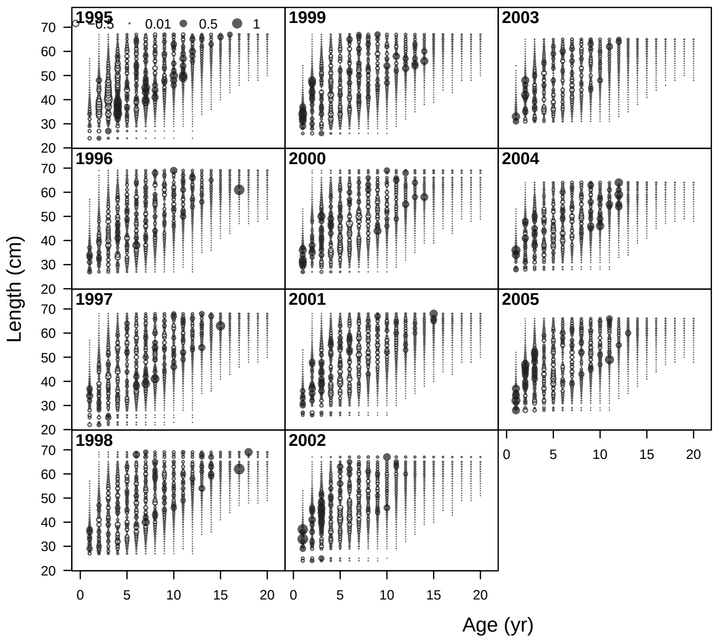

Figure B.9: Pearson residuals for age-at-length compositions for the green fishery

B.2.4 Discard fraction

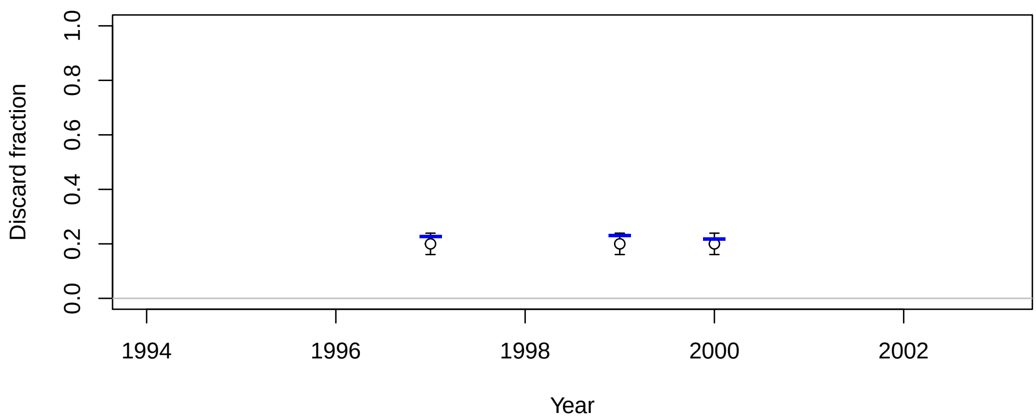

Figure B.10: Fit to discard fraction for the blue fishery

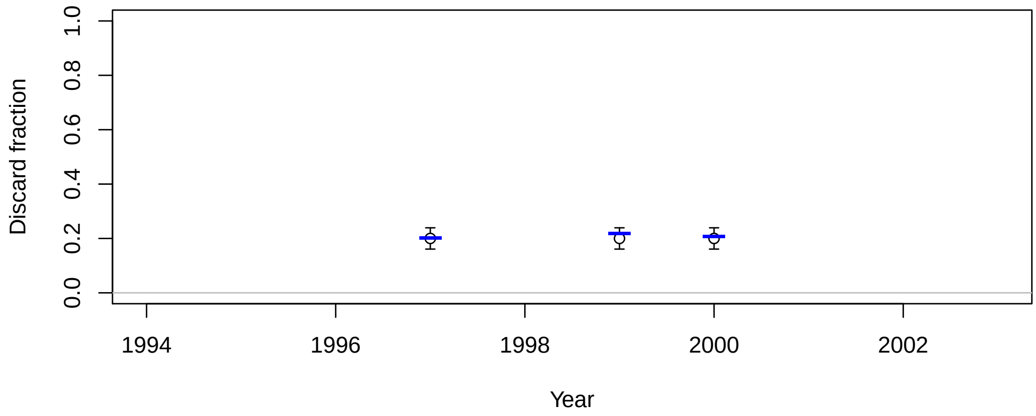

Figure B.11: Fit to discard fraction for the green fishery

B.3 Other outputs

B.3.1 Phase plot

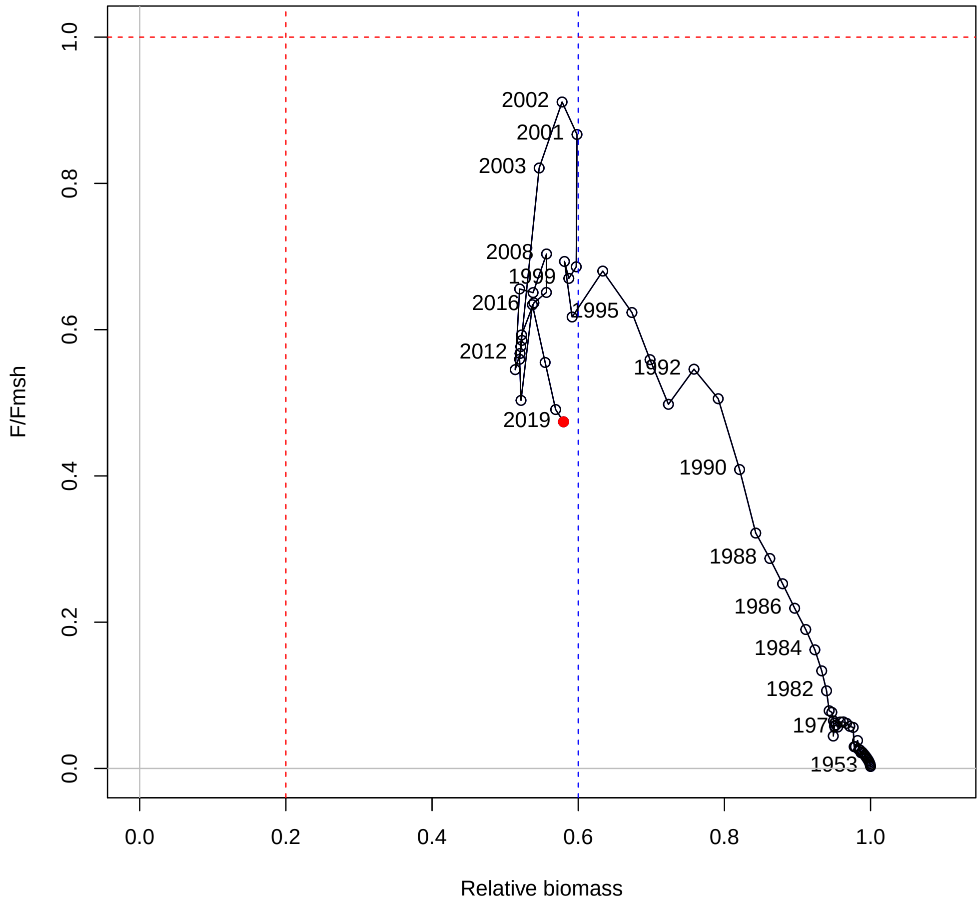

Figure B.12: Phase plot. The horizontal axis is the biomass ratio relative to unfished, and the vertical axis is the fishing mortality relative to fishing mortality at maximum sustainble harvest. The red dashed vertical line is the limit reference point (20% relative biomass), and the blue dashed vertical line is the target reference point (60% relative biomass)

B.3.2 Sensitivity harvest targets

Table B.6: Estimated total harvests and depletion levels of common coral trout to rebuild or maintain the stock at the target reference point of 60% unfished spawning biomass, following a 20:60:60 control rule with 0.87 buffer. Values are given for two sensitivity tests: 'low' (M=0.2), and 'high' (asymptotic survey selectivity)

Year	Harvest low (t)	Depletion low	Harvest high (t)	Depletion high
2020	420	0.46	1258	0.61
2021	461	0.48	1242	0.61
2022	499	0.49	1242	0.61
2023	536	0.51	1248	0.61
2024	571	0.52	1253	0.61
2025	604	0.53	1256	0.61
2026	634	0.54	1258	0.62
2027	660	0.55	1260	0.62

B.3.3 Likelihood profile

Likelihood profiles can be used to determine whether parameters have been fixed at appropriate values. Integrated stock assessments use numerous data sources which may be in conflict with each other, but likelihood profiles provide a tool to determine these conflicts (Punt 2018). A likelihood profile was calculated to explore the assumption on steepness (h=0.5).

In this case, the overall likelihood (combining likelihood contributions from all data sources) does not have an optimum value for steepness: the likelihood continues to improve as steepness approaches its theoretical maximum (Figure B.13). This confirms that there is insufficient information in the data to constrain this parameter, and that there is not some other value that is possible. This run was conducted with natural mortality fixed at its optimum value from the base case (M=0.38).

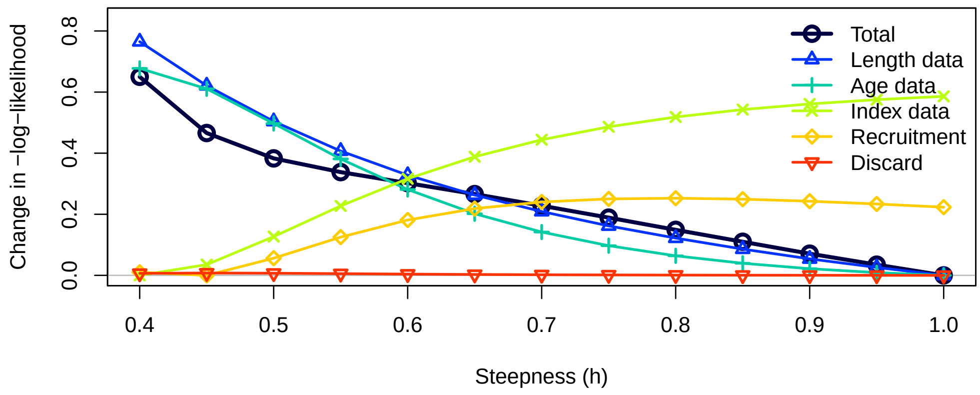

Figure B.13: Likelihood profile for steepness (h), ranging from 0.4 to 1.0

B.3.4 Mortality due to discarding

Based on the estimated selectivity and retention curves, and the input discard mortality rate (0.25), the model makes predictions of total dead and total retained biomass, from which the quantity dying due to discarding can be calculated (Figure B.14). This prediction is informed in part by the estimated discard fraction from Observer program data, with the goodness of fit provided in Appendix B, Section B.2.4.

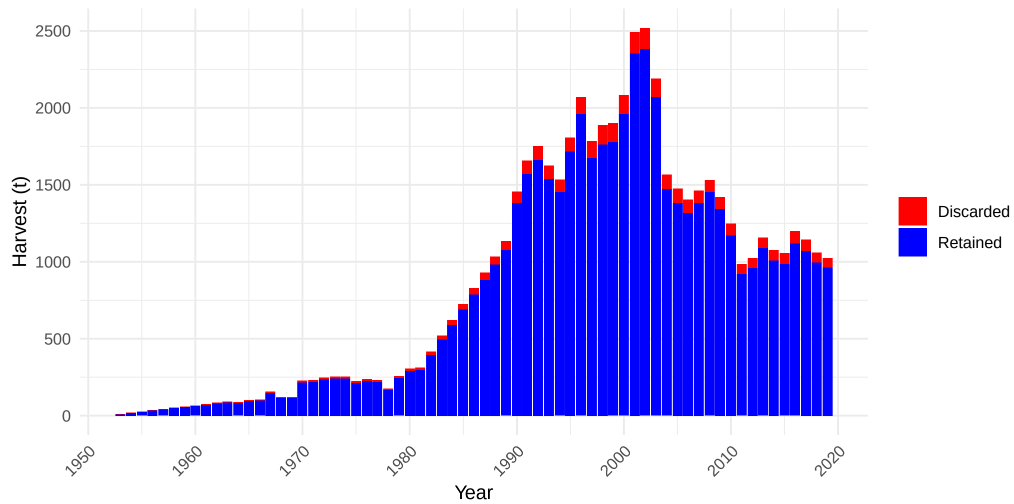

Figure B.14: Estimated total dead biomass, categorised by whether it was retained or discarded, from 1953 to 2019