Queensland Government
Department of
Agriculture and Fisheries

Our ref: CTS 07619/22
Your ref: A860355

27 May 2022

Mr Chris Whiting MP
Chair
State Development and Regional Industries Committee
sdric@parliament.qld.gov.au

Dear Mr Whiting

Thank you for your letter of 12 May 2022 regarding the assessment and management of the Queensland east coast Spanish Mackerel Fishery.

I would like to reiterate at the outset, that no changes have been made to recreational or commercial fishing rules for Spanish Mackerel at this time and none will be made until consultation with recreational and commercial fishers has been completed.

Stock Assessment

A stock assessment for the east coast Spanish Mackerel (refer **Attachment 1**) estimated the biomass to be between 14 per cent and 27 per cent of unfished levels, and most probably at around 17 per cent.

The stock assessment used a leading population model, known as stock synthesis, to assess the status of the fishery up to 2020. Stock Synthesis is one of the most widely used and tested stock assessment models in the world and is currently used by other Australian fisheries jurisdictions, including: the Commonwealth Scientific and Industrial Research Organisation (CSIRO); the South Australian Research and Development Institute (SARDI); the Australian Fisheries Management Authority (AFMA); and the Victorian Fisheries Authority (VFA).

The stock assessment used data on annual harvests taken by all fishing sectors, commercial catch rates of fish, age-length measures of fish, and biological parameters for fish growth, natural mortality and spawning activity.

The data used in the stock assessment included an additional four years of data (compared to the 2016 stock assessment) and comprised of approximately:

- 231 000 Queensland commercial logbook records

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- 7 000 New South Wales commercial logbook records
- 37 600 Queensland charter logbook records
- 70 100 recreationally and commercially caught Spanish Mackerel measured through routine biological monitoring and more than 1 400 boat ramp surveys
- 18 100 age data records.

Key assumptions used included:

- the Queensland east coast stock being reproductively isolated from other stocks in Australia
- the standardised catch rate index reflecting changes in abundance of legal sized Spanish mackerel
- the fishery was in an unfished state in 1911
- the ratio of fish that are female at birth is 50 per cent
- fish not changing sex during their life
- the first mature age of fish is after two years.

An independent review of the Spanish Mackerel stock assessment (refer **Attachment 2**) was conducted by Dr Neil Klaer, a former CSIRO fisheries scientist. The reviewer agreed the data was used appropriately in the assessment and that the assessment model itself was suitable. The reviewer questioned the model setting for lower resilience in the ability for Spanish Mackerel as a species to bounce back after high fishing pressure and was unable to support model predictions until this uncertainty was resolved. These reservations related to the value for the 'steepness parameter' or how resilient Spanish Mackerel are, they did not relate to the validity of the input data for the stock assessment.

Subsequent work conducted by the Department of Agriculture and Fisheries in response (refer **Attachment 3**) to Dr Klaer's review showed that his preference for a higher steepness value was not supported by model testing and that the stock assessment had used a more appropriate value.

The stock assessment and Dr Klaer's review were presented to the Sustainable Fisheries independent Expert Panel. In a communique (refer **Attachment 4**) from the meeting, the Expert Panel commented that the while Dr Klaer's comments were justified, the department's response was considered appropriate. Further, given the department's model is more precautionary than the reviewer's, the Panel considered that the most responsible way forward is to accept the stock assessment base case as the most credible scenario and to make management decisions accordingly.

This is further supported by an estimate in the recent stock assessment of Spanish Mackerel in the Torres Strait. The Torres Strait assessment estimated steepness at 0.47. DAF used a value of 0.45 for the east coast fishery, while Dr Klaer's preference was higher at 0.7.

The need for action is further supported by longstanding concerns about sustainability, with evidence of a 70 per cent reduction in the number of Spanish Mackerel spawning aggregations within two decades, a decline in historically important spawning aggregations from waters east of Cairns, a reduction in the size and frequency of spawning aggregations in the Lucinda region and a long-term decline in commercial catch rates.

Consultation on Management Action

Under Federal and Queensland Government harvest strategy guidelines, appropriate management action is required to rebuild fish stocks when the biomass falls below the limit reference point of 20 per cent biomass. Doing nothing is not an option and would go against the fundamental principles of the Queensland Sustainable Fisheries Strategy 2017–2027, the main objective of the Fisheries Act 1994 and the Queensland Government's responsibility to ensure our public fishery resources are managed in a responsible and sustainable manner.

If action is not taken, there is a real risk of further biomass decline and long-lasting and far more significant economic impacts for commercial fishers, recreational fishers, fish processors, café and restaurant owners and the broader community.

There are a range of management measures that could be used to rebuild the east coast Spanish Mackerel stock to sustainable levels (40 per cent of unfished biomass). Each management measure has a different impact and benefit. There are also numerous combinations and permutations of management measures that could be combined to form possible management action. These different combinations of management measures would also have different impacts and benefits.

The impacts and benefits vary between fishing sectors within the fishery (e.g., commercial fishers, recreational fishers, traditional fishers, fish and chip shop owners, tackle retailers and environmental organisations) and within fishing sectors (e.g., those with a greater reliance on or traditional use of the resource). Therefore, it was important to understand the preferences of stakeholders who have an interest in the fishery initially to inform possible management actions and subsequently a decision on final management action.

A discussion paper and survey (refer **Attachment 5**) were designed to elicit and better understand the preferences of stakeholders who have an interest in the fishery.

The survey sought to describe specific aspects and relationships of management measures and stakeholder groupings. It is acknowledged that the survey data collected is from individuals with vested interests and is therefore subjective. In designing the survey questions, it was acknowledged that there is no single correct answer, but some combinations would be more effective than others at achieving rebuilding. However, they were appropriate to be considered and were used in modelling predicted rebuilding timeframes for the fishery.

The discussion paper was released on 6 April 2022 and used a structured online survey to elicit stakeholder feedback on possible management measures to rebuild the Queensland east coast Spanish mackerel fishery to sustainable levels. The discussion paper was open to everybody to make a submission through the Department of Agriculture and Fisheries' engagement hub website (https://daf.engagementhub.com.au/spanish-mackerel-2022) and was widely communicated through a media release, social media and communication with fishing tackle associations and peak bodies representing both commercial and recreational fishers. Submissions could be made online or in writing.

Public consultation closed on 5 May 2022 and 1 470 submissions were received, including 1 437 responses to the online survey and 33 written submissions.

The majority of survey respondents were from recreational fishers (78 per cent), with submissions also received from commercial fishers (five per cent), charter fishing operators (four per cent), interested community members (seven per cent), seafood wholesales/marketers (one per cent), hospitality workers/owners (one per cent), fishing tackle retailers (one per cent), Traditional Owners/fishers (one per cent) and environmental, industry peak body and other non-government organisations (one per cent). Nearly 1 000 free-form written comments were also received through the survey.

At the request of the commercial fishing industry, the Department of Agriculture and Fisheries met with commercial Spanish mackerel fishers who are likely to be most affected by potential changes to management arrangements. Invitations were sent to 48 identified commercial fishers and charter fishing operators. Meetings were held in Townsville on 21 April 2022, Cairns on 26 April 2022 and Sunshine Coast on 3 May 2022, at which 33 commercial fishers attended. No charter fishing operators accepted the invitation and attended any of the meetings.

The Department of Agriculture and Fisheries also met with representatives of the recreational fishing sector and fishing tackle industry during the public consultation process.

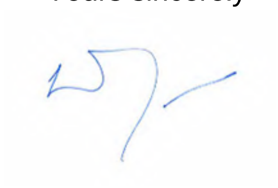
A further round of consultation will be undertaken on potential management action before a final decision is made by the Queensland Government later in 2022. This will provide a further opportunity for Queenslanders to have a say, including those who may not have taken up the opportunity as part of the initial round of consultation.

Transitional Measures

It is important to note that no changes have been made to recreational or commercial fishing rules for Spanish Mackerel at this point in time. Transitional arrangements cannot be determined until a final decision on management action has been made by government.

Thank you again for writing to me on this matter. If you would like any further information, please contact Mr Graeme Bolton, Deputy Director-General, Fisheries and Forestry on [redacted] or by email at [redacted].

Yours sincerely



Robert Gee
Director-General
Department of Agriculture and Fisheries

Attachment 1 – Spanish mackerel EC stock assessment report 2021
Attachment 2 – East coast Spanish mackerel stock assessment external review 2021
Attachment 3 – Spanish mackerel EC response to reviewer 2021
Attachment 4 – Sustainable Fisheries Strategy Expert Panel meeting Communique
Attachment 5 – EC Spanish Mackerel Fishery Discussion Paper

Stock assessment of Australian east coast Spanish mackerel (*Scomberomorus commerson*)

2021

Queensland Government

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Summary

Australian east coast Spanish mackerel (*Scomberomorus commerson*) are large offshore pelagic fish. They form a single genetic stock between Cape York Peninsula in north Queensland and Newcastle on the New South Wales mid-coast. In these waters the species has been recorded to live for up to 26 years, grow to over 30 kg in weight and mature between two and four years of age.

During springtime, east coast Spanish mackerel school to form one of the most notable and predictable spawning aggregations of fish on the Great Barrier Reef. The spawning aggregation occurs in waters north of Townsville, typically over a two lunar month period. Spanish mackerel can have strong reef fidelity during the spawning season.

Following the last stock assessment, in 2016, some stakeholders raised concerns about the perceived reduced size of the spawning aggregation and under catch of the Queensland commercial quota. This assessment updates the estimates of spawning stock biomass ratio (population indicator for female egg production relative to the start of the fishery in 1911). This is the seventh stock assessment on the east coast stock since 2000.

This stock assessment implemented an annual time-step, two-sex, age-structured population model within Stock Synthesis software. The model incorporated data from 1911 to 2020, including annual estimated commercial, charter and recreational harvest (including recreational released fish mortality), commercial standardised catch rates, fish age-length frequencies, and key long-term fishery information on fishing power changes and catch rates. The assessment was conducted at the whole stock level, including data from across jurisdictions and fishing sectors.

Over the last five years, 2016 to 2020, the total Spanish mackerel harvest by all fishing sectors averaged 515 tonnes (t) per year (Figure 1). This was approximately half the annual harvest compared to 1973–2004. The annual allocated Queensland commercial quota was initially set to 619 t in 2004–05, then revised to 578 t since 2016–17.

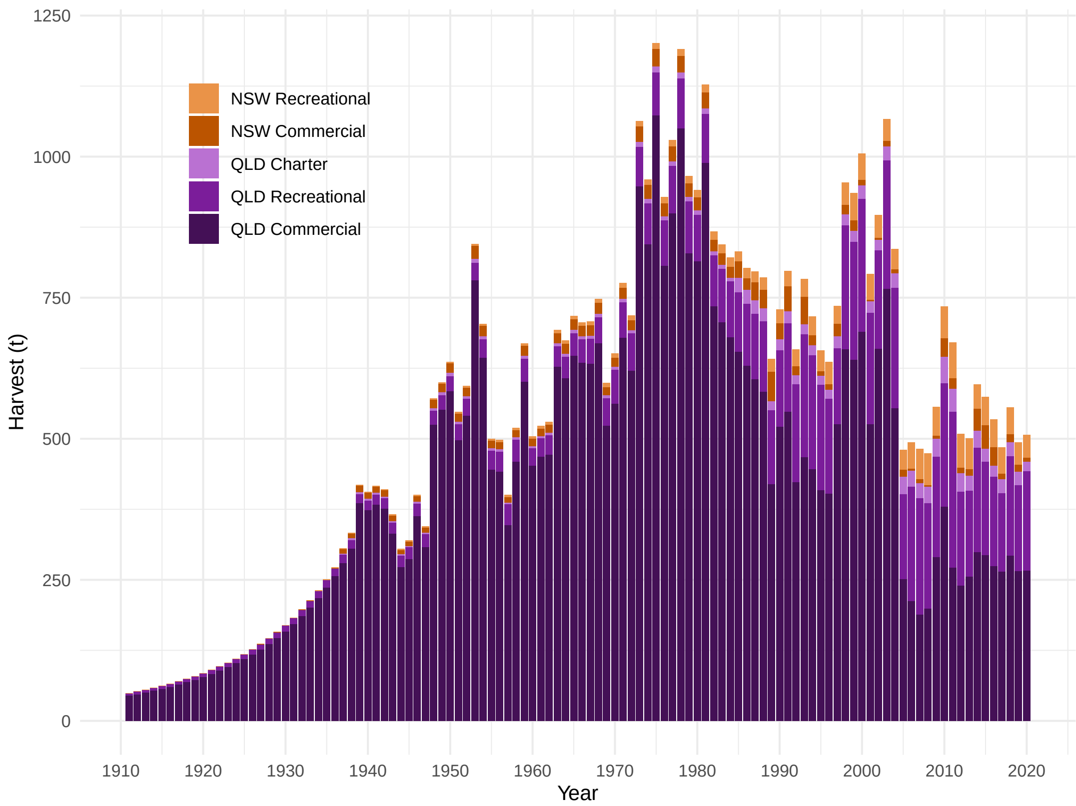

Figure 1: Annual estimated harvest from commercial, recreational and charter sectors between 1911 and 2020 for Spanish mackerel

Queensland commercial catch rates in 1989–2020 were standardised to estimate an index of legal-sized Spanish mackerel abundance through time (Figure 2). The catch rate index informed proportionally on the annual change in abundance of legal-sized fish relative to 1990. This was a primary assumption for the stock assessment. Catch rates were standardised through two-component statistical analyses (binomial generalized linear model for the probability of catching Spanish mackerel, multiplied by the linear mixed model for when catch rates were taken).

The catch rates were influenced by two main factors: annual increases in fishing power due to improved fishing gears and technologies, and the probability model showing fewer days when Spanish mackerel were caught. The selected base case results, in Figure 2, indicate 2016–2020 catch rates were 25–38% below what they were in 1990. The standardised commercial catch rates in 2017 and 2020 were record lows in Queensland.

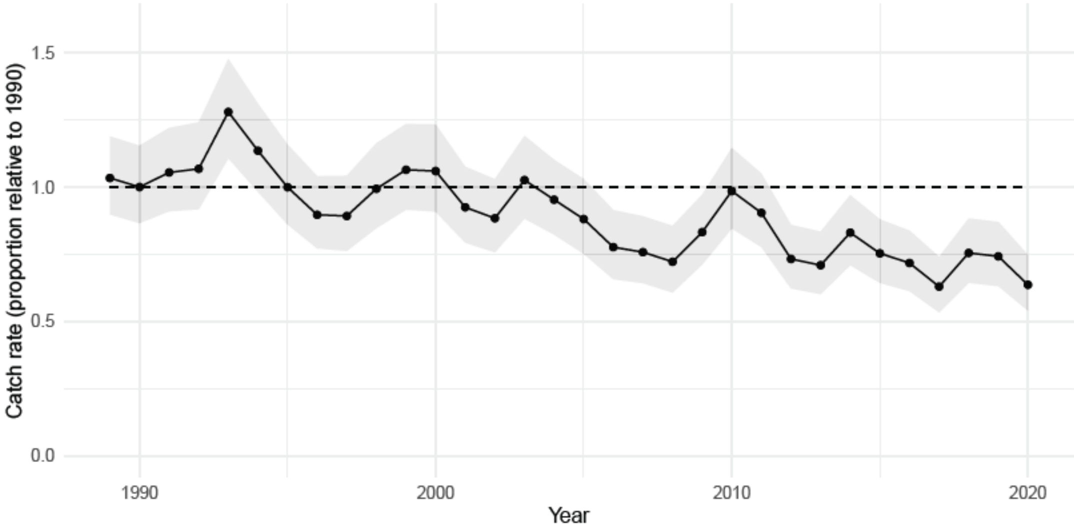

Figure 2: Annual standardised catch rates (95% confidence intervals) for Queensland commercial line-caught Spanish mackerel between the years of 1988 and 2020—dashed line indicates catch rate in 1990

Eight model scenarios were run, covering a range of assumptions. Spawning biomass ratios were relatively similar among all model runs (ranged between 14% and 27% of unfished spawning biomass in 2020), except one at 57%. The base case data and analysis, selected by the overseeing project team, recognised potential influences of annual changes in fishing power and hyperstability (aggregation effects of fish and fishers). The analysis suggested that spawning biomass had declined (Figure 3) as a result the high harvests during the 1970s, early 1980s and early 2000s (Figure 1). In 2020, base case analysis estimated spawning biomass at 17% (±4%) of the unfished biomass (Figure 3).

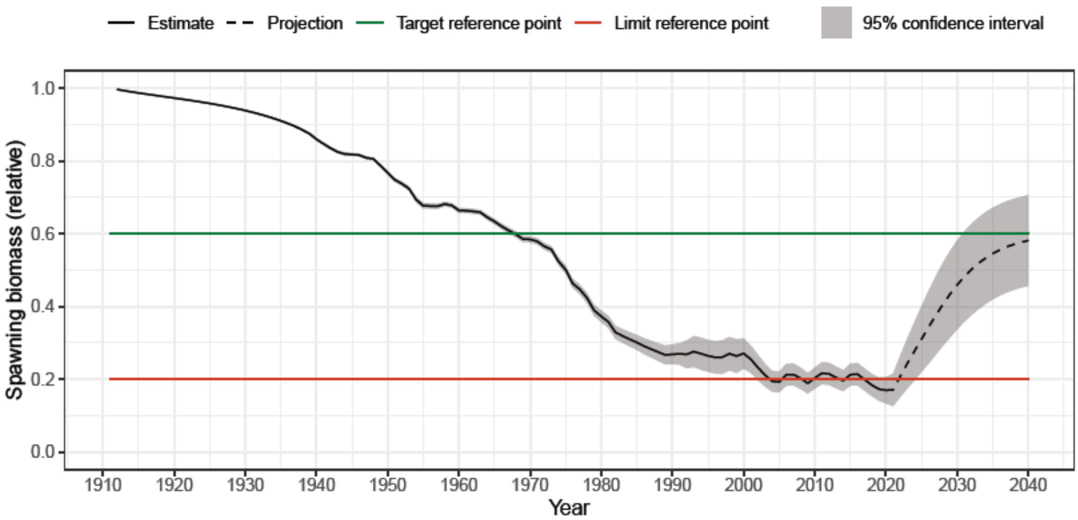

Figure 3: Estimated and predicted biomass trajectory relative to unfished for Spanish mackerel from 1911 to 2040

Estimates of recommended biological catch, including all waters, sectors and discard mortality, vary with datasets and model assumptions of fish natural mortality and spawning productivity (steepness resilience parameter). The draft harvest strategy policy for spawning biomass ratios below 20% recommends zero harvest.

There is presently substantial unfished Queensland commercial quota (267 t fished, 311 t unfished). The current Queensland total allowable commercial catch quota is 578 t. If this were to be largely utilised, together with current or increased charter, recreational and New South Wales commercial harvests, then the biomass of the Spanish mackerel population may further deplete.

Estimated reference points of annual harvest include all fishing sectors: commercial, charter and recreational across Queensland and New South Wales. They also include a discard morality component required in fishery management allocations. As part of this, potential harvest strategies need to consider risks from target fishing of spawning aggregations, potentially including time-area closures or bounds on localised fishing pressure. The report provides a number of recommendations to support future stock assessment and management procedures.

Table 1: Current and target indicators for the base case analysis

Parameter	**Estimate**
Current (2020) biomass (relative to unfished)	17%
Current (2020) harvest	507 t (90.5% QLD, 9.5% NSW)
Sustainable harvest at biomass target (60%)	557 t
Recommended biological catch (2021) to achieve target	0 t

Acknowledgements

The work was overseen by a project team committee that consisted of the authors and the following scientists, data specialists and managers: Carlie Heaven, Sue Helmke, Rachel Janes, Eddie Jebreen, Ashley Lawson, Susannah Leahy, Robyn Lovett, Chad Lunow, Tyson Martin, Anthony Roelofs, Darren Roy and Daniella Teixeira. The role of the committee was collaborative to share interpretation and decision making on data inputs, assessment methods and results.

In addition to their roles on the committee, we would like to thank Carlie Heaven and Ashley Lawson for assistance with the Queensland commercial harvest data and the acquisition of weather data from the Bureau of Meteorology; John Stewart for the provision of, and assistance with, the New South Wales commercial and recreational harvest data; Tyson Martin for the provision of, and assistance with, the Queensland boat ramp survey data; Jason McGilvray for the assistance with the biological age and length monitoring data; and Daniella Teixeira and Rachel Janes for the provision of, and assistance with, the Queensland recreational statewide survey data. We thank Robyn Lovett for providing constructive inputs throughout the project as an independent stock assessment scientist.

Sincere thanks to the stock assessment scientists outside of the project team who provided input on a range of technical and conceptual challenges. We thank Alex Campbell for providing assistance with modelling using the Stock Synthesis software, and Amanda Northrop and George Leigh for their valuable insights regarding modelling and tuning. We also thank James Thorson for his advice on implementing the steepness parameter estimates extracted from his meta-analysis (Thorson 2020).

The authors acknowledge the fishers and scientists who have contributed to past research on Spanish mackerel. We thank Sarah Buckley for her research into historical fishing information, which enabled the calculation of decadal catch rates and fishing power changes.

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

Glossary

ACN	Authority chain number
AFMA	Australian Fisheries Management Authority
age	Age within this report refers to age group unless otherwise stated
B	Biomass, total weight of a population or of a component of a population. This assessment refers to spawning biomass, measured by spawning egg production
B_{limit}, B_{20}	Biomass limit reference point, the point below which the risk to the population is regarded as unacceptable under the DAF Sustainable Fisheries Strategy
B_{MSY}	Biomass at maximum sustainable yield
B_{target}, B_{60}	Target biomass, the desired biomass of the population. The reference point refers to the target objective. For example the Queensland Sustainable Fisheries Strategy 60% biomass target and a proxy for biomass at maximum economic yield (MEY).
B_0	Mean equilibrium virgin unfished biomass, average biomass level if fishing had not occurred. Virgin state corresponds to the first year assessed in 1911.
Catch rate	Index of fish abundance, referred to as average (mean) catch rates standardised (adjusted) to a constant vessel and fishing power through time. All references to catch rates were standardised unless specified to be different.
Catchability, q	The ability to catch fish. More formally, it is defined as the probability of catching a fish with a single unit of standardised fishing effort. Catchability is the interaction of the fishing gear and a fish's behaviour, whereas fishing power is a property of the fishing effort, gear and practices.
CKMR	Close-kin mark-recapture
EC	East coast
F_{B60}, F_{btg}	Fishing mortality that achieves 60% spawning biomass
Fishery	This stock assessment evaluated Australian east coast Spanish mackerel. The assessment was conducted on the whole (genetic) stock across jurisdictions and included commercial, charter, recreational and research data from both New South Wales and Queensland. The fishery covers all fishing sectors: commercial, charter and recreational.
Fishing power	Measures 'a' or 'a group' of fishing operations' effectiveness in catching fish. More generally, fishing power refers to a measure of deviation in actual fishing effort from the standard unit of effort. For example, the standard unit of effort used to calculate catch rates may be scaled to an average fishing operation in 1990. The elements of fishing power and catchability have the potential to bias abundance indices derived from nominal catch rates. Therefore, methods of standardisation are required based on the data at hand.
Fishing year	1 July to 30 June. Also labelled as 'year' within. Fishing years were equal to financial years to group the seasonal and biological patterns of Spanish mackerel. Labelling used the second year in the financial year string. For example the financial year July 2019 to June 2020 was labelled as 2020 fishing year.
FL	Fork length
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
GBRMPA	The Great Barrier Reef Marine Park Authority
GLM	Generalised linear model
h	Beverton-Holt steepness parameter
ITQ	Individual transferable quota
JL	Jaw length
LMM	Linear mixed model
M	Natural mortality

MLS	Minimum legal size
MSY	Maximum sustainable yield, the maximum level at which the species can be routinely exploited without long-term depletion
NRIFS	The National Recreational and Indigenous Fishing Survey conducted by the Australian Department of Agriculture, Fisheries and Forestry
NSW	New South Wales
Overfished	A fish population with a biomass below the biomass limit reference point (B_{limit})
Overfishing	The condition where a population is experiencing too much fishing and the removal rate is unsustainable, that is, fishing mortality is higher than fishing mortality at maximum sustainable yield. F measured the level of fish harvested by different fishing sectors.
QLD	Queensland
R_0	Virgin recruitment
RAP	The Representative Areas Program
RBC	Recommended biological catch, the estimated total annual catch that can be taken by fishing, while achieving the management objectives for the fishery
Reference point	An indicator of the level of fishing, harvest or size of a fish population, used as a benchmark for interpreting the results of an assessment
REML	Restricted maximum likelihood (type of linear mixed model), statistical method used to standardise catch rates
RFish	Recreational fishing surveys conducted by Fisheries Queensland
SM	Fishery symbol used to access the commercial east coast Spanish mackerel fishery
SRFS	The Statewide Recreational Fishing Survey conducted by the Queensland Department of Agriculture and Fisheries
SS	Stock Synthesis
t	Tonnes
TACC	Total allowable commercial catch
TL	Total length
VMS	Vessel monitoring system
Vulnerability	Probability of fish to being exposed to fishing mortality. This varies for different sized/aged fish. This is generally a result of fish being present in the fishing area (fishery) and their susceptibility to being caught by the fishing gear.
WW	Whole weight

1 Introduction

Spanish mackerel, *Scomberomorus commerson*, are large pelagic fish. In Australian east coast waters, they are recognised as a high-quality eating and powerful sports fish, and are an important target species for all fishing sectors. Spanish mackerel are mainly caught from offshore reefs, shoals and bays, and sometimes from ocean beaches and headlands. Catches are primarily taken by line fishing techniques, with some harvest by the growing popularity in spear fishing. Net fishing for east coast Spanish mackerel is prohibited.

East coast Spanish mackerel have been observed to live up to 26 years and can weigh in excess of 30 kg. They reach sexual maturity above the minimum legal size limit of 75 cm between two and four years of age. East coast Spanish mackerel form a single genetic stock in ocean waters between Cape York Peninsula and northern New South Wales (Buckworth et al. 2007).

Movement patterns are varied and depend on spawning and feeding behaviours, water temperatures, and currents. Some fish can remain localised, whereas some fish move along the east coast (Buckworth et al. 2007). Spanish mackerel generally aggregate more in northern tropical waters during winter and spring for feeding and spawning, and some fish move to southern waters during summer and autumn to extend their feeding range. Seasonal and spatial patterns of fishing follow the predictable locations of schooling fish.

Tobin et al. (2013) and Tobin et al. (2014) characterised east coast Spanish mackerel as an obligate transient aggregator, meaning their spawning–schooling behaviour was generally restricted to specific reef locations. Fish acoustic-tag monitoring identified some fish as having strong reef fidelity during the spawning season (Tobin et al. 2014). This predictable schooling and aggregation behaviour signified that east coast Spanish mackerel were vulnerable to overexploitation.

Commercial fishing of Spanish mackerel commenced in 1911, with fishing operations targeting spawning aggregations on the Great Barrier Reef (Thurstan et al. 2016; Buckley et al. 2017). The reported commercial fleet increased in size from one operation in 1911 to twenty in 1936. This increased to 36 fishing operations in 1937 and to 115 by 1950. Between 1934 and 1947 estimated commercial landings per fishing operation ranged up to 540 Spanish mackerel (about 4 t) for a two day fishing trip, with at least 300 t of Spanish mackerel taken commercially in 1938 (Thurstan et al. 2016).

Since 1938 commercial harvests of Spanish mackerel steadily built to produce around 1000 t per year during the 1970s and reduced to around 500–700 t between 1998 and 2004 (Campbell et al. 2012). Prior to 2005 the fishery was less regulated (Table 1.1). Since 2005 commercial harvests decreased to around 300 t per year after the Queensland commercial quota system was implemented.

In Queensland waters, access to the commercial east coast Spanish mackerel fishery is restricted to holders of an 'SM' fishery symbol. This symbol is linked to individual quota holdings, established on 1 July 2004, and as of April 2021 there were 240 licensed operations (each 'SM' licence symbol identifies the primary line-fishing operation) (Department of Agriculture and Fisheries 2021).

Of these licences which includes the primary fishing vessel (mothership), about 200 were each permitted to use between 1 and 5 additional smaller boats called dories or dinghies. The total number of licensed fishing boats tallies around 600, including about 400 dories. Of the 240 licences, 187 held individual transferable quotas (ITQ) sharing the current annual 578.013 t total quota (Queensland total allowable commercial catch: TACC). In total 53 licences held no quota and were not permitted to harvest Spanish mackerel for commercial purposes.

The commercial fishing sector in New South Wales waters is small compared to Queensland. Spanish mackerel generally only school and feed in New South Wales waters during summer and autumn. Harvests of Spanish mackerel were first reported in 1937 at 8 t (Campbell et al. 2012; O'Neill et al. 2018). Annual harvests built steadily to 52 t in 1989. Harvests reduced to below 13 t per year between 2000 and 2009, returned back to 40 t in 2015, and has since dropped to 6 t in 2018 (Langstreth et al. 2018). Since the 1970s the number of commercial fishing operations harvesting Spanish mackerel from New South Wales waters was approximately 50 vessels per year.

Information on fishing efforts and harvests from the non-commercial fishing sectors varied in time and quality. Historical fishing by charter and recreational operations were not well known or frequently reported. In Queensland there were 322 active licensed charter operations in April 2021 (Department of Agriculture and Fisheries 2021), with many setup for offshore fishing. Measures of recreational fishing in Queensland have been surveyed periodically since 1997 suggesting 14 000–33 000 boat-days per year have been expended catching east coast Spanish mackerel (Higgs 2001; Henry et al. 2003; Higgs et al. 2007; McInnes 2008; Taylor et al. 2012; Webley et al. 2015; Teixeira et al. 2021).

For all fishery sectors, additional rules apply to limit fishing pressures such as the current 75 cm minimum total fish length for all kept Spanish mackerel and recreational in possession fish bag-limits (Table 1.1).

Table 1.1: History of east coast Spanish mackerel management in Queensland and New South Wales

Year	Management	Legislation
Queensland		
18 April 1957	Introduced a minimum legal size (MLS) of 18 inches (45.72 cm) for Spanish mackerel. This provision commenced on 1 January 1958	*Fisheries Act 1957*
16 Dec 1976	MLS amended to 45 cm for Spanish mackerel	*Fisheries Act 1976*
1 Jan 1988	Commercial logbook database began	
22 May 1990	Recreational fishers prohibited from selling any of their catch	
25 Jun 1993	MLS increased to 75 cm for Spanish mackerel and introduction of recreational in-possession limit of 10 fish	*Fishing Industry Organisation and Marketing Regulation 1991*
15 July 1994	Amendment to allow twice the in-possession limit for Spanish mackerel, as part of the reef fish provisions, if taken during an extended fishing charter (extended fishing charters occur over a continuous duration of 48 hours or more)	*Fishing Industry Organisation and Marketing Regulation 1991*
21 Feb 2003	Investment Warning for Spanish mackerel issued	

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Table 1.1 – *Continued from previous page*

Year	Management	Legislation
12 Sep 2003	Amendment to set a recreational in-possession limit of three fish. The amendments also introduced a total allowable catch of 619 520 units (1 unit equals 1 kg) and an individual transferable quota management system for the commercial sector. These amendments took effect on 1 July 2004.	*Fisheries Regulation 1995*
1 July 2004	The Great Barrier Reef Marine Park Authority (GBRMPA) revised the reef zonings and expanded the Representative Areas Program (RAP). The zoning process gave consideration for the importance of Spanish mackerel fishing and five key reefs remained open to fishing (Tobin et al. 2014).	*Great Barrier Reef Marine Park Zoning Plan 2003*
28 May 2019	Recreational boat limits set to two times the possession limit to a total of six Spanish mackerel per boat (these boat limits do not apply to charter fishers)	*Fisheries Declaration 2019*
	The total allowable commercial catch (TACC) stands at 578 013 kg following cancellation of units and the 2014 surrender of units bought by the former Australian Government Department of Environment, Water, Heritage and the Arts as part of the structural adjustment package for the Representative Area Program for the Great Barrier Reef introduced in July 2004.	
New South Wales		
1 Jul 1998	Bag limit of five introduced (comprised all of Spanish mackerel or all of spotted mackerel or partly of each)	*Fisheries And Oyster Farms Act 1935 – Regulation*
3 Sep 2007	The minimum legal length of Spanish mackerel of 75 cm total length was introduced in NSW	*Fisheries Management (General) Amendment (Prohibited Size Fish and Bag Limits) Regulation 2007 under the Fisheries Management Act 1994*

A number of stock assessments have evaluated fishing pressures on east coast Spanish mackerel (O'Neill et al. 2000; Hoyle 2002; Welch et al. 2002; Hoyle 2003; Campbell et al. 2012; O'Neill et al. 2018). For results up to the 2016 fishing year, estimated Spanish mackerel spawning population sizes were 30–50% of 1911 levels depending on the data analysed (O'Neill et al. 2018). This report also concluded that fishing pressure was too high to allow the population to increase in size, or to improve/increase catch rates. Recommendations were noted to reduce fishing pressure on Spanish mackerel to increase fish abundance, catch rates and protection of spawning aggregations.

Tobin et al. (2014) described the decline of historically important Spanish mackerel spawning aggregations from waters east of Cairns, as well as a reduction in the size and frequency of spawning aggregations in waters out from Lucinda. The data were further examined by Buckley et al. (2017), who concluded a significant reduction in the number of Spanish mackerel spawning aggregations and a long term decline in commercial catch-rates in the Lucinda region. Logbook data show about 40% of the Queensland commercial harvest was generally taken from the Lucinda region during the well-known September–November spawning season. Significant proportions of harvest were also taken recreationally and by charter operations from the broader Cairns–Townsville region.

In 2020 the Queensland Department of Agriculture and Fisheries commissioned an updated stock assessment for east coast Spanish mackerel. This stock assessment evaluates historical trends in data for the east coast of Australia, estimates spawning population biomass and predicts target harvest reference points for the stock. The report informs fishery management agencies and stakeholders on estimates of sustainable harvest that will build and maintain the fishery in the long term.

2 Methods

2.1 Data sources

Data sources included in this assessment (Table 2.1) were used to determine fish catch rates, age and length compositions, and annual harvests. Data sets were compiled by fishing year[1] (July–June) and all references to year should be assumed to be fishing year, unless stated otherwise. The assessment period began in 1911 up until and including 2020 based on available information.

Table 2.1: Data used in the Spanish mackerel stock assessment

Type	Year	Source
QLD commercial	1989–2020	Logbook data collected by Fisheries Queensland
	1937–1981	Historical Queensland Fish Board Data (O'Neill et al. 2018; Campbell et al. 2012)
QLD recreational	1997, 1999, 2002, 2005	RFish recreational fishing surveys conducted by Fisheries Queensland (Higgs 2001; Higgs et al. 2007; McInnes 2008)
	2011, 2014, 2020	Statewide Recreational Fishing Survey conducted by Fisheries Queensland (Taylor et al. 2012; Webley et al. 2015; Teixeira et al. 2021).
	2001	Recreational fishing surveys conducted by the Australian Department of Agriculture, Fisheries and Forestry (the National Recreational and Indigenous Fishing Survey, NRIFS) (Henry et al. 2003).
	2016–2020	Boat ramp survey, conducted by Fisheries Queensland
QLD charter	1997–2020	Logbook data collected by Fisheries Queensland
NSW commercial	1985–2020	Logbook data collected by New South Wales Department of Primary Industries, Fisheries
NSW recreational	2001, 2014, 2018	New South Wales survey using similar methodology to the NRIFS (West et al. 2015; Murphy et al. 2020)
Historical surveys	1941–2013	Historical fishing information (decadal catch rates and fishing power changes) collected by Buckley et al. (2017)
Biological data	2005–2020	Biological monitoring (age and length) undertaken by Fisheries Queensland
Lunar	1989–2020	Continuous daily luminous scale of 0 (new moon) to 1 (full moon) (O'Neill et al. 2014)
Wind	1989–2020	Weather data collected by Bureau of Meteorology

2.1.1 Regions

One degree latitude bands were used to stratify data for analyses, from 12° S (Lockhart, QLD) to 34° S (Port Stephens, NSW) (Figure 2.1). Region names are added to the map for reference. All report commentary refers to east coast fish and does not include adjacent Torres Strait or Gulf of Carpentaria fish stocks.

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

In general, approximately 90% of historical annual harvests of east coast Spanish mackerel were taken from Queensland waters compared to New South Wales, with approximately half of Queensland commercial harvest taken from the key spawning region of Lucinda (latitude band 19).

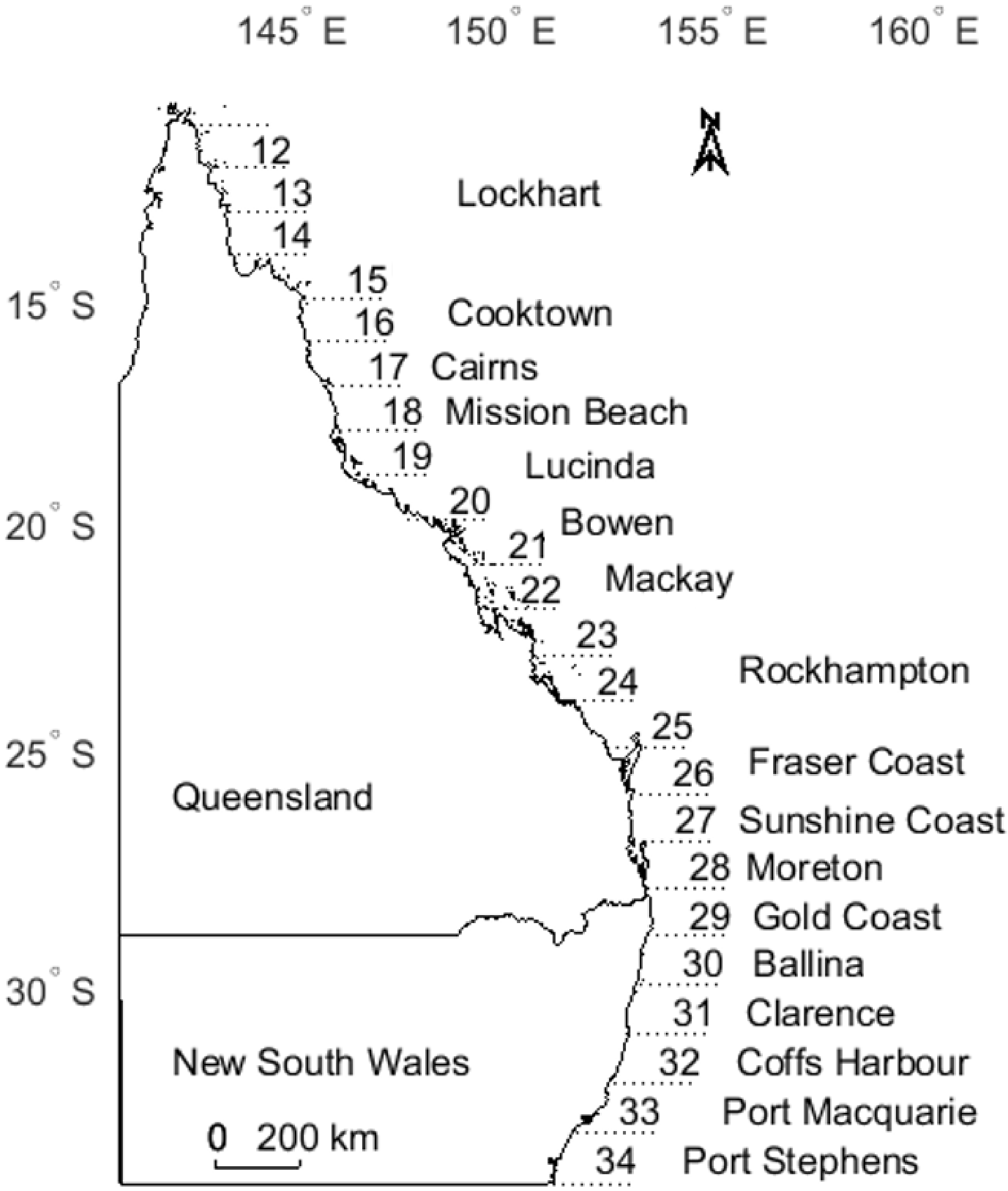

Figure 2.1: Spatial stratification for the catch rate standardisation analysis

2.1.2 Commercial

The Queensland Fish Board data documented monthly and annual commercial landings of Spanish mackerel for 45 years from 1937 to 1981. The harvest tonnages were originally published in annual reports of the various fish boards responsible for marketing and distributing fish in Queensland. The data were digitised in the early 2000s. No fishing effort data were available to complement the fish landings data. For the stock modelling, it was assumed the fish board tonnages of Spanish mackerel were relatively complete and taken from along Queensland's east coast (Campbell et al. 2012).

Between 1989 and 2020, Queensland commercial harvests of Spanish mackerel were recorded through the compulsory logbook system. The data consisted of the daily fish harvest (in kilograms) by species from each fishing operation. The spatial resolution of where fish were harvested was based on 30×30 minute latitudinal and longitudinal grids, which were grouped into one degree latitude bands.

Commercial harvest (in kilograms) of Spanish mackerel from New South Wales waters was recorded through compulsory logbook systems from 1985 to 2020. From 1985 to 2009 monthly harvests by species were reported per fishing operation. The procedure changed to daily reports in 2010. The spatial resolution of where fish were harvested was based on one degree latitude bands.

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 state and regional scales. See the references listed in Table 2.1 for more detail.

The statewide methods used telephone surveys of random households to estimate recreational fishing participation, catch and effort. Logbook records of fish catches and fishing effort were maintained by a sample of fishing households. Fishing data were demographically weighted to estimate total catches of fish and fishing effort by factors such as key species, seasons and coastal regions.

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

In 2001, 2014 and 2018 statewide surveys of recreational fishing were completed for New South Wales waters. The survey methods were equivalent to those used in Queensland.

Through boat ramp surveys, recreational data were collected by Fisheries Queensland in 18 different regions, extending from Aurukun to the Gold Coast. Fifteen of these regions were along the Queensland east coast, with Cooktown being the northern most region. 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). These data were used to inform recreational discarding behaviour.

2.1.4 Charter

Harvests of Spanish mackerel taken by Queensland charter vessels were recorded through the logbook system from 1997 to 2020. This provided the operator identifier, the date, the location fished, retained catch by species (recorded by weight) and the number of guests on the trip.

2.1.5 Historical

Commercial mean decadal relative catch rates from Thurstan et al. (2016), from 1941 to 2013, were evaluated in the stock assessment. Given the sample size of data and verification testing completed in separate published papers (including the previous stock assessment by O'Neill et al. (2018)), the dataset was incorporated at the decadal time-scale.

2.1.6 Age and length compositions

Fish age-length compositions of Spanish mackerel were sampled over a number of years by fishery monitoring and research programs. The details of sampling were documented by Sumpton et al. (2004), Tobin et al. (2004), Campbell et al. (2012) O'Neill et al. (2018), and Fisheries Queensland (2021).

The monitoring program has been conducted since 2000. In 2000–2002 sampling was focused solely on Spanish mackerel that were commercially fished in the Lucinda area during the spawning season in October/November (Sumpton et al. 2004). From 2005, sampling was increased to be temporally and spatially expansive covering both commercial and recreational harvests of Spanish mackerel in Queensland (Tobin et al. 2004; Campbell et al. 2012). Sampling of age data (otoliths collection) has been in operation since fishing year 2002 (Sumpton et al. 2004). Opportunistic collection of age data from New South Wales (2009–2020) has been included.

2.2 Harvest estimates

Commercial, charter and recreational harvest and data were analysed to reconstruct the history of harvest from 1911 (prior to which east coast Spanish mackerel harvest is presumed to be small) until the end of 2020. This section describes how these data were combined to create the history of Spanish mackerel harvest. All harvest is retained (landed) unless stated otherwise. Figure 2.2 shows a graphical overview of the methods used to reconstruct the harvest history for this assessment.

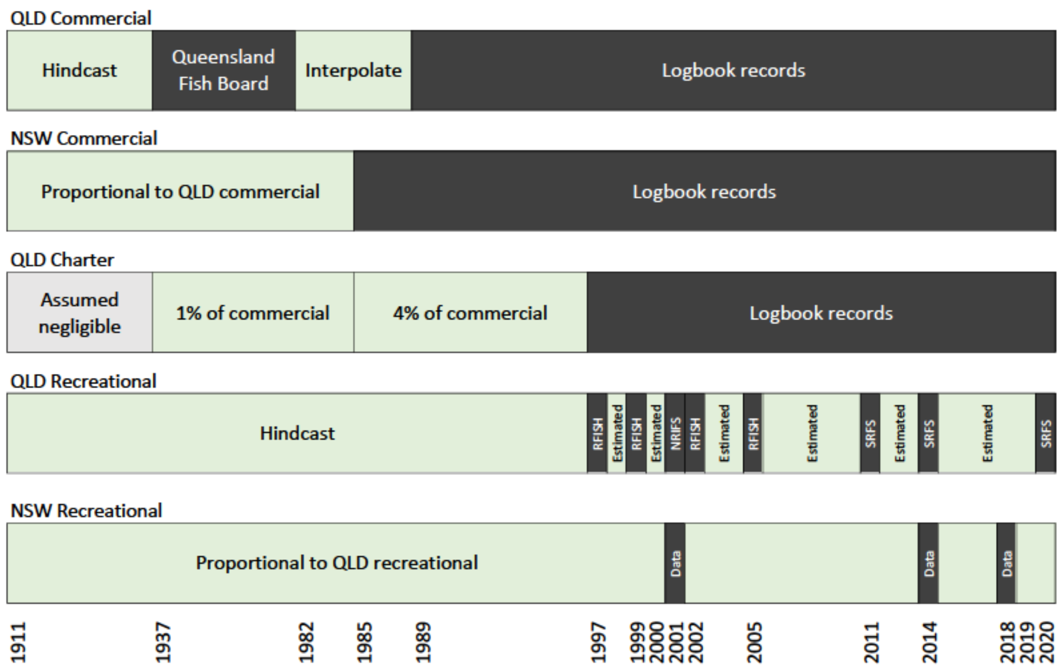

Figure 2.2: Overview of the methods used to estimate harvests

2.2.1 Commercial harvest

Queensland commercial sector harvest:

- equalled logbook values from 1989 through 2020.
- were linearly interpolated from 1982 to 1988, using coefficients based on the best fit of available harvests in each year 1973–1996 (from O'Neill et al. (2018) and Campbell et al. (2012)).
- equalled Queensland Fish Board records from 1937 to 1981.
- were hindcasted from 1911 to 1937. The preceding year's Queensland commercial harvest C_{t-1} starting from 1937, was calculated back in time to 1911 by reducing the annual tonnage by the power of 0.985 ($C_{t-1} = C_t^{0.985}$)(Campbell et al. 2012; O'Neill et al. 2018).

New South Wales commercial harvest:

- equalled New South Wales logbook values from 1985 to 2020.
- prior to 1985 was estimated based on the geometric mean of the proportion of New South Wales to Queensland commercial harvest between 1985 and 2009 (Campbell et al. 2012; O'Neill et al. 2018). For these years the proportion was 2.7%, showing the magnitude of commercial New South Wales harvests was small compared to those from Queensland waters.

2.2.2 Charter harvest

As per the previous assessment (O'Neill et al. 2018), Queensland charter sector harvest:

- estimates equalled Queensland charter logbook values from first records in 1997 through to 2020.
- estimates were assumed to be equivalent to 4% of the commercial take from 1985 until 1996.
- estimates were assumed to be equivalent to 1% of the commercial take from 1937 until 1984.
- was assumed to be negligible prior to 1937.

2.2.3 Recreational harvest

Queensland recreational catches (numbers of kept and released fish) of Spanish mackerel were estimated using data from eight statewide surveys (telephone-logbook surveys) (Table 2.1), and annual changes in fishing power, boat registrations and catch rates.

Estimates from the RFish surveys in 1997, 1999, 2002 and 2005 had higher participant drop out. This may bias the mean catch rates and fishing effort upwards and result in an overestimate of recreational fish catches. To account for this bias, a simple ratio method from Leigh et al. (2017) was applied to reduce RFish catch estimates to better align with the 2001, 2011, 2014 and 2020 surveys:

$$c_{2001}/(\frac{2}{3}c_{1999} + \frac{1}{3}c_{2002}). \tag{2.1}$$

The RFish catch adjustments were calculated at 0.340 for harvested and 0.256 for released Spanish mackerel. The assumption in this scaling was that the RFish estimates were overstated by the same fraction in all survey years in which the RFish methodology was employed.

Released survey estimates of Spanish mackerel were tallied into the recreational harvest. A 50% discard mortality rate was assumed on released fish. No research has quantified discard mortality rates of Spanish mackerel, but observations by scientists and fishers suggest that discard mortality is high. The decision to included discard mortality on released fish was based on information from the Department of Fisheries, Western Australia. Anecdotal evidence there suggested high post-discard mortality due to stress of capture (Western Australian Government 2016). A rate higher than 50% was not considered as the addition of spurious harvest may risk overestimating sustainable harvest. Survey released-fish estimates can be biased upwards due to the time lag and poor memory recall of fish numbers by anglers (Lyle 1999; Connelly et al. 2011).

All of the Queensland recreational surveys (other than the 2011 survey) had records of "unspecified mackerel". For each survey, the ratio of known Spanish mackerel to total identified mackerel (i.e. Spanish, grey, school, shark and spotted mackerel combined) was applied to the total number of unspecified mackerel, and these were added to the Spanish mackerel catch. This method was applied to kept and released fish separately. In the 1997 RFish survey all mackerel were unspecified, so a conservative ratio of 12% was applied, which was the minimum of all RFish unspecified mackerel ratios.

Estimates of kept and released fish were predicted for years with no survey information. This was required for the population modelling in order to estimate time-series trends of Spanish mackerel. The methods were based on Bessell-Browne et al. (2018) and Lovett et al. (2020), with the following calculations:

1. Catches prior to 1997 were hindcast from the mean of the known 1997, 1999, 2001 and 2002 survey estimates. Hindcasting was scaled proportional to:
    - the trend in boat registrations (effort pre-1991 $\sim$ Poisson GLM back in time based on 1991–2008 data),
    - fishing power scenario (years prior to 1951 were set equal to the 1951 fishing power estimate), and
    - catch rates (decadal pre-1989 and standardised annual rates post-1988).

   The proportional trend was relative to the scale = 1 in 1997.
2. Catches after 1997 were estimated by annual commercial catch rates multiplied by mean fishing effort. Mean effort was calculated from the known survey catches divided by their annual standardised catch rate.

Queensland recreational harvest:

- estimates for 1997, 1999, 2002, and 2005 were set to equal the values from the rescaled RFish estimates and the methods described above.
- estimates for 2001, 2011, 2014 and 2020 were set to equal the values calculated using the NRIFS (2001) and SRFS (2011, 2014 and 2020) surveys and the methods described above.
- were hindcasted from 1911 to 1997 using calculation 1, above.
- estimates for between survey years, 1998, 2001, 2003–2004, 2006–2010, 2012–2013 and 2015–2019, were calculated using calculation 2, above.

New South Wales recreational harvest:

- was equal to the Queensland recreational harvest rescaled by the ratio of New South Wales to Queensland recreational catch, over the years for which NSW data were available. This ratio was 0.23.

The harvest from the recreational surveys was reported in numbers of fish. These numbers were converted into total weight of fish, using the average fish weight. The average fish weight was calculated separately for kept and released fish. For kept fish between 2005 and 2020 the average fish weights were calculated each year using the monitoring length data. Prior to 2005, the average fish weight was defined as the average of all fish caught recreationally from 2005 to 2020 (without grouping by year). This average weight for all years is 7.80 kg.

For released fish, the boat ramp survey data showed that approximately 33% of reported Spanish mackerel were released between 2016 to 2020, and that only 2.3% of sampled fishers were at, or over, the bag limit. The statewide recreational fishing survey data indicated that 29% of caught Spanish mackerel were released, and 51% of those were released because they were "too small" (according to either fisher preference or MLS) and a further 6% were released for being below MLS. This suggests that fish were being released due to being undersized. Thus, the average weight of a released fish was defined as the weight of a fish 1 cm below the minimum legal size of 75 cm. This translates to 2.11 kg (for a 74 cm fish). This weight was considered to be a mid-point that accounts for undersize and oversize fish being released.

2.3 Abundance indices

Relative trends in legal-sized Spanish mackerel abundance were inferred from Queensland commercial logbook data. The logbook data provided commercial line catch rates (kg whole weight) of Spanish mackerel per fishing-operation day.

The catch rate index informed proportionally on the annual change in abundance of legal-sized Spanish mackerel. This was a primary assumption for the stock assessment. The assumption of proportionality was made only after catch rates were standardised for factors affecting fish catchability and fishing efficiency (Hilborn et al. 1992).

O'Neill et al. (2018) described why catch rates were standardised and the critical factors. This was to address the issues of hyperstability and missing fishing effort data (zero catches not reported, and no data on the number of locations, gears and hours fished per fishing operation day). The main factors considered to lessen these issues were:

- annual changes in fishing power to examine how increased fishing effort and improved gears and technologies affect catch rates.
- a probability model to overcome the non-reporting of zero catches. Walters (2003) suggested presence-absence data may aid in dealing with suspect hyperstability. This was applied in the previous stock assessment and the approach was endorsed at the time by the scientific advisory committee (Campbell et al. 2012; O'Neill et al. 2018).

From the initial logbook data, a series of filters were applied to obtain the Spanish mackerel data for catch rate standardisation. The filters used criteria relating to species, location, fishing method, fishing date and trip duration. The filtering process is detailed in Appendix A.4.

The catch rate information was analysed in relation to two components/models defining mean catch rates $E(c)$:

$$E(c) = p(c)E(c|c > 0), \tag{2.2}$$

where the first component ($p(c)$) measured the availability and capture of fish according to the probability and the second component ($E(c|c > 0)$) was for where a weight of fish was caught and retained (i.e. $c > 0$).

The models used to standardise catch rates of Spanish mackerel were completed using the software GenStat (VSN International 2020). The analyses used generalised linear (GLM) and linear mixed (LMM) models. The LMM used the 'REML' (restricted maximum likelihood) algorithm allowing for model terms that can contain both fixed and random effects. The variables modelled included effects of:

- fishing year ($year$),
- latitude band ($latband$),
- seasonal variables ($s1 - s6$),
- wind component variables ($windew, windns$),
- lunar phase variables ($lunar, lunar\_adv$),
- number of fishing operations ($nACN$), and
- fishing operations (ACN).

The analyses were defined based on:

1. A probability model (GLM for predicting $p(c)$) for catching Spanish mackerel by the commercial fleet.
2. A catch rate model (for harvests > 0; $E(c|c > 0)$) incorporating annual changes (offsets) in fishing power to examine how increased fishing effort and improved gear technologies affect catch rates. In analysis, the fishing power offset was a logarithm value.

The probability model, a binomial GLM with logit link function, was specified as:

$$\begin{aligned} log\left(\frac{p(c)}{1-p(c)}\right) =& year * latband + latband.s1 + latband.s2 + latband.s3 + latband.s4 + \\ & latband.nACN + windew + windew^2 + windns + windns^2 \end{aligned} \tag{2.3}$$

where the data were structured per month, using average monthly wind components, and the model was run for both additive and interaction effects between year and latband (the interaction form was noted in the above equation).

The catch rate LMM model, for when Spanish mackerel were caught, was specified as:

$$\begin{aligned} log(catch\_offset) =& year * latband + latband.s1 + latband.s2 + latband.s3 + latband.s4 + latband.s5 + latband.s6 + \\ & latband.lunar + latband.lunar\_adv + windew + windew^2 + windns + windns^2 + random(ACN) \end{aligned} \tag{2.4}$$

where the data were structure per fishing-operation day, $log(catch\_offset)$ was calculated as $log(catch) - log(fp)$, fp was the annual proportional fishing power to be log offset, and the ACN fishing operation factor was treated as random variable.

The annual proportional fishing powers were estimated per year and region in the previous stock assessment (Figure 14 in O'Neill et al. (2018), reproduced in Appendix A.7). No new data were available, and the 2015–2020 fishing powers were assumed equal and unchanged. Two fishing power offsets were considered: 1) based on the actual data provided by fishers (full fishing power), and 2) a square root estimate (about half fishing power effect).

The square root scenario recognised potential fishing power increases, but this was a constrained effect to account for possible overestimation. This was in consideration that each fishing gear effect, which was suggested by fishers, may not truly be independent full add-ons to fishing power. The fishing power data represented increased use in global positioning systems, colour depth sounders, down riggers and baiting technique (Appendix Table 14 and Figures 38–29 in O'Neill et al. (2018)).

In total four different annual indices of fish abundance for 1989–2020 were calculated from the Queensland commercial line data. The four results evaluated the effects of possible hyperstability (either no adjustment—i.e. constant probability of catching Spanish mackerel—or adjusted for $p(c)$) and increased fishing power offset (labelled 'half' for a reduced square root increase, or 'full' for a full increase as suggested by the data). Catch rates with half fishing power with probability adjustment (for hyperstability) were selected as a base case for the model and others were used in sensitivity analyses.

The prediction of standardised mean catch rates of Spanish mackerel was formed using GenStat's 'PREDICT' and 'VPREDICT' procedures for the GLM and LMM models respectively (VSN International 2020). Mean catch rates ($\text{log\_prediction}_{y,a}$) were predicted from the model terms fishing year (y) × latitude band area (a), keeping all other model terms constant. Logarithm predictions were biased corrected and back transformed:

$$c_{y,a} = \exp(\text{log\_prediction}_{y,a} + \frac{\sigma^2}{2} + \text{log\_offset}_{2020} \pm 1.96 \times \text{log\_prediction\_se}_{y,a}), \tag{2.5}$$

where $c_{y,a}$ is the catch rate for year y at latitude band area a, σ^2 was the residual model variance, $\text{log\_prediction\_se}_{y,a}$ was the prediction standard error, and the ± component is upper and lower 95% confidence intervals. The term log_offset_{2020} corresponded to the fishing power setting in year 2020 and the se label was the standard error.

Final predictions were normalised annually as proportions measured against the fishing year 1990. Ninety-five percent confidence intervals were calculated for all predictions.

The seasonality of Spanish mackerel catch rates was modelled using sinusoidal data to identify the time of year. In total six trigonometric covariates were considered, which together modelled an average seasonal pattern of catch rates (Marriott et al. 2014): $s_1 = \cos(2\pi d_y/T_y)$, $s_2 = \sin(2\pi d_y/T_y)$, $s_3 = \cos(4\pi d_y/T_y)$, $s_4 = \sin(4\pi d_y/T_y)$, $s_5 = \cos(6\pi d_y/T_y)$, $s_6 = \sin(6\pi d_y/T_y)$, where d_y was the cumulative day of the year and T_y was the total number of days in the year (365 or 366).

The wind direction and strength data were from representative coastal weather stations along Queensland east coast and spatially referenced to one-degree latitude bands. The recorded measures of wind speed (km hour^{-1}) and direction (degrees for where the wind blew from) were converted to daily components between 3 am and 3 pm. The north-south ($windns$) and east-west ($windew$) wind components were:

$$windns = \text{km hour}^{-1} \times \cos(\text{radians(degrees)}), \text{ and}$$

$$windew = \text{km hour}^{-1} \times \sin(\text{radians(degrees)}). \tag{2.6}$$

The wind components were used to standardise Spanish mackerel catch rates for different wind directions and strengths. The component functions considered the wind directions as degrees measured clockwise from true north such that:

- 0° or 0 radians = North,
- 90° or π/2 radians = East,
- 180° or π radians = South, and
- 270° or 3π/2 radians = West.

Two lunar variables estimated the variation in Spanish mackerel catch rates according to the moon phase (i.e. contrasting waxing and waning patterns of the moon phase). The lunar phase (luminance) was a calculated measure of the moon cycle with values ranging between 0 (new moon) and 1 (full moon) for each day of the year (Courtney et al. 2002; Begg et al. 2006; O'Neill et al. 2006). The luminance measure ($lunar$) followed a sinusoidal pattern and was copied and advanced 7 days ($\sim \frac{1}{4}$ lunar cycle) into a new variable ($lunar\_adv$) to quantify the cosine of the lunar data (O'Neill et al. 2006).

2.4 Biological information

2.4.1 Fork length and total length

All length measurements were provided in either fork length (FL), total length (TL) or jaw length (JL) and the population model was run using FL.

The following conversions by Mackie et al. (2003) and Fisheries Queensland (unpublished) were applied where necessary:

$$TL = 42.74 + (1.06 \times FL) \tag{2.7}$$

$$FL = (TL - 42.74)/1.06 \tag{2.8}$$

$$FL = 2193.05 - 2488.95 \times (0.99376283^{JL}) \tag{2.9}$$

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

2.4.2 Fecundity and maturity

Model inputs of fecundity and maturity of Spanish mackerel were taken from relationships determined by Sumpton et al. (2004):

$$\text{eggs} = 76539 \times \text{kilogram of fish.} \tag{2.10}$$

Maturity values in the model were length-based, following a logistic function with coefficients obtained from Mackie et al. (2005) and Begg et al. (2006):

$$mat = \frac{exp(-10.349 + 0.0128FL)}{1 + exp(-10.349 + 0.0128FL)}$$

where mat is maturity and FL is fork length (cm). The age-dependent maturity was calculated from length-dependent maturity within Stock Synthesis using age-length transition matrix (Methot et al. 2013). The first mature age was set as two years of age.

2.4.3 Weight and length

The weight-length relationship was taken from Mackie et al. (2003):

$$WW = 3.40 \times 10^{-9} \times FL^{3.12} \tag{2.11}$$

where WW is whole weight (kg) and FL is fork length (mm).

2.5 Population model

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

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

2.5.1 Model assumptions

The main assumptions underlying the model included:

- The Australian east coast stock is reproductively isolated.
- The standardised catch rate index inform proportionally on the annual change in abundance of legal-sized Spanish mackerel.
- The fishery began from an unfished state in 1911.
- The fraction of fish that are female at birth is 50% and fish do not change sex during their life.
- Growth occurs according to the von Bertalanffy growth curve.
- The weight and fecundity of Spanish mackerel are parametric functions of their size.
- The first mature age is at 2+ years, after which the proportion of mature fish depends on size.
- The proportion of fish vulnerable to fishing depends on their size, not age, fishing sector nor time.
- The instantaneous natural mortality rate does not depend on size, age, year or sex.
- Deterministic annual recruitment is a Beverton-Holt function of stock size.

2.5.2 Model parameters

A variety of parameters were included in the model, with some of these fixed at specified values and others estimated. No prior distributions were used for the estimated parameters, unless stated otherwise.

Table 2.2: Parameters fixed or estimated in the model

Parameter	Value	Prior / Reference
Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1911)	Estimated	No prior
Beverton-Holt stock recruitment steepness (h)	0.45	Thorson (2020)
Fork length at age 1 (FL_1) (male and female)	Estimated	No prior
Fork length at maximum age (FL_{inf}) (male and female)	Estimated	No prior
von Bertalanffy growth parameter (κ) (male and female)	Estimated	No prior
Coefficient of variation in length at age 1 (male and female)	Estimated	No prior
Coefficient of variation in length at maximum age (male and female)	Estimated	No prior
Natural mortality (NatM, M)	Estimated	Then et al. (2015)
Commercial selectivity inflection (cm)	Estimated	No prior
Commercial selectivity width (cm)	Estimated	No prior
Standard deviation of natural log recruitment (σ_R)	0.35	O'Neill et al. (2018)

Natural mortality (M) was estimated in the model, initially with a log-normal prior. This prior had a (natural scale) median value of 0.29 and standard deviation of 0.1. This prior was based on the meta-analytical approach from Then et al. (2015). The prior is defined as a log-normal distribution with a median value (corresponding to the mean in log-space) equal to $4.899 \times A_{max}^{-0.916}$ and logscale standard deviation equal to 0.1. While the oldest fish in the dataset provided was 26 years old, the maximum age was considered to be 22 years old (the second oldest fish) for the calculation of the prior. This placed the natural mortality at 0.29, which was in between the two scenarios considered in O'Neill et al. (2018) in which M was fixed to 0.25 and 0.33. Once model optimization became stable, M was attempted to be estimated without a prior.

Beverton-Holt stock recruitment steepness (h) was fixed at a value of 0.45, based on the meta-analysis of Thorson (2020). Table 4 of Thorson (2020) lists a steepness value of h=0.69 for the Scombridae family, however Figure 3 of the same paper indicates great variation in steepness at the genus level (*Scomberomorus*). The R package "*FishLife*" was used to extract the steepness value for the *Scomberomorus* genus (h=0.45) from the meta-analysis described in the paper. Different levels of h were tested as sensitivity analyses.

Standard deviation of natural log recruitment (σ_R) was fixed at 0.35, based on the recruitment variability estimated in the previous assessment (O'Neill et al. 2018). Recruitment deviations between 1989 and 2018 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, Francis weighting of age and length data within Stock Synthesis was completed (Francis 2011).

2.5.4 Sensitivity tests and scenarios

Several additional model runs were undertaken to determine sensitivity to fixed parameters, assumptions and model inputs (Table 2.3).

Four catch rate scenarios were explored (as described in Section 2.3): two which included a probability adjustment to prevent hyperstability and two which did not. These catch rate scenarios also affected the recreational harvest reconstruction.

Table 2.3: Scenarios tested to determine sensitivity to parameters, assumptions and model inputs

Scenario	Steepness	Natural mortality	Probability adjustment	Fishing power
1 (Base)	0.45	Estimated	Yes	Half
2	0.35	Estimated	Yes	Half
3	0.55	Estimated	Yes	Half
4	0.55	Estimated	No	Half
5	Estimated	0.33	No	Half
6	0.65	Estimated	No	Half
7	0.45	Estimated	Yes	Full
8	0.45	Estimated	No	Full

The values of steepness (h) that were explored in this assessment were chosen to align with range of estimated values in O'Neill et al. (2018).

In addition to the scenarios presented in Table 2.3, two additional scenarios were explored to address the issue of shark depredation using the base case catch rates and steepness fixed at 0.45 and 0.55. Full details of this scenario are presented in Appendix F.

2.5.5 Forward projections

Stock Synthesis's forecast sub-model was used to provide forward projections of biomass and future harvest targets, following a 20:60:60 harvest control rule. This rule (also known as a hockey stick rule), has a linear ramp in fishing mortality between 20% spawning biomass, where fishing mortality is set at zero, and 60% exploitable biomass, where fishing mortality is set at the equilibrium level that achieves 60% biomass (F_{B60}). Below 20% spawning biomass fishing mortality remains set at zero, and above 60% spawning biomass fishing mortality remains set at F_{B60} (Figure 2.3). This shifting rate of fishing mortality starts out small, which enables the stock to recover much more quickly and means that harvests are impacted for a shorter period. This assessment did not include a discount factor to account for uncertainty in recommended target estimates as the Fisheries Queensland Spanish Mackerel Fishery Working Group and fishery management will evaluate whether to apply discount factors to recommended biological catch.

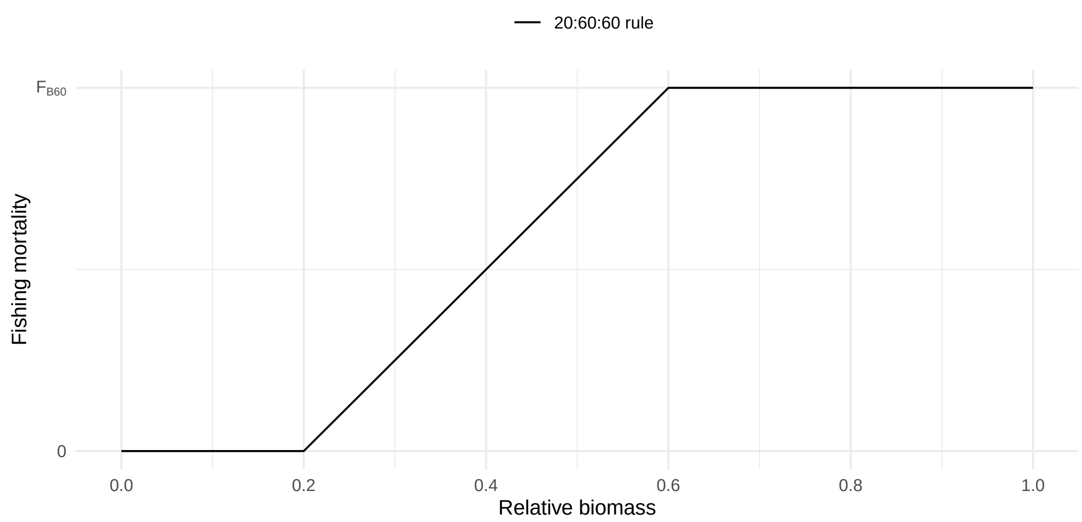

Figure 2.3: The 20:60:60 harvest control rule

3 Results

3.1 Model inputs

Figure 3.1 summarises the assembled data sets input to the model. Note that standardised catch rates and decadal catch rates were included as abundance indices in Stock Synthesis, and they were denoted as “Fleet” and “Survey”, respectively.

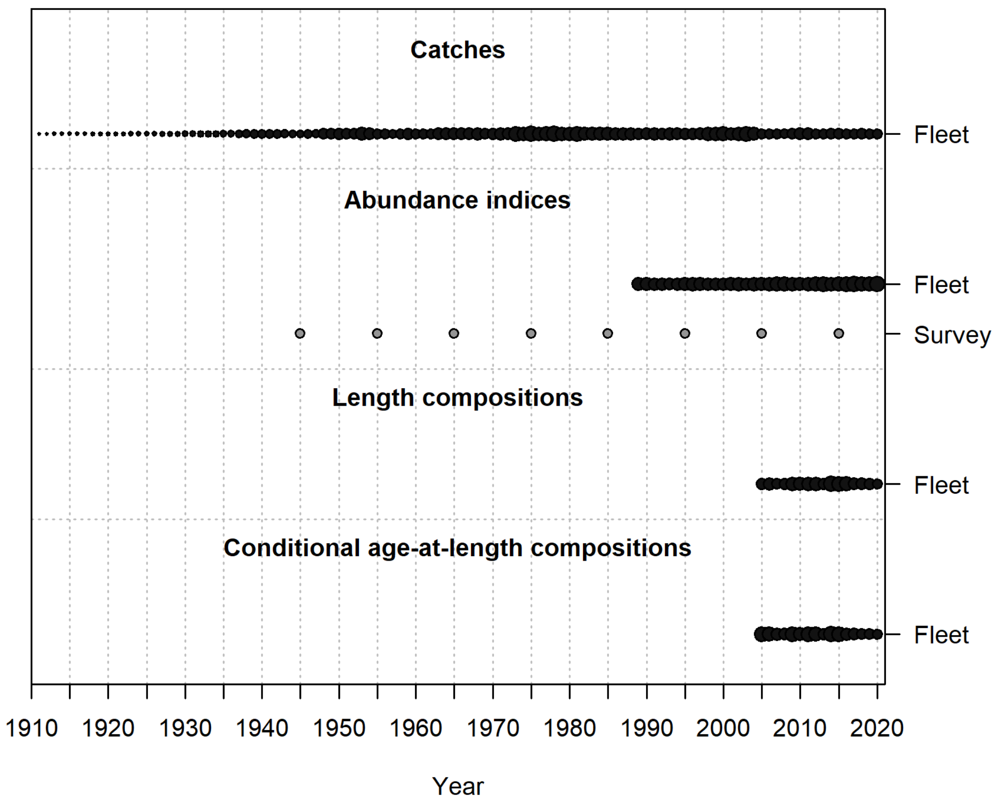

Figure 3.1: Data presence by year for each category of data type for east coast Spanish mackerel

3.1.1 Harvest estimates

Total combined harvest from commercial, recreational (including assumed discard mortality) and charter sectors in Queensland and New South Wales is shown in Figure 3.2. Harvest shares for each sector in years when recreational fishing surveys were conducted are shown in Table 3.1.

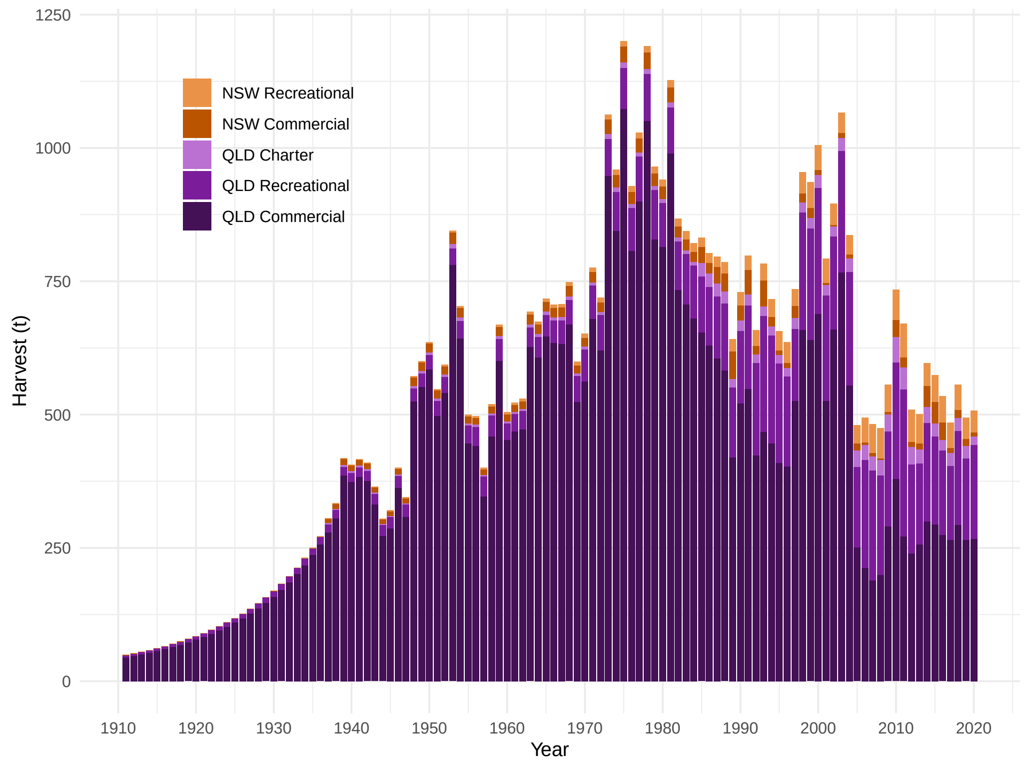

Figure 3.2: Annual estimated harvest from commercial, recreational and charter sectors between 1911 and 2020 for Spanish mackerel

Table 3.1: Harvest shares per sector (including "QLD discard mortality") expressed in kilograms with annual percentages

Sector	2001	2014	2020
QLD Commercial	525 945 (66.4%)	299 872 (50.3%)	266 565 (52.5%)
QLD Charter	20 207 (2.6%)	30 041 (5.0%)	16 650 (3.3%)
NSW Commercial	3 384 (0.4%)	39 703 (6.7%)	7495 (1.5%)
NSW Recreational	45 535 (5.7%)	42 522 (7.1%)	40 626 (8.0%)
QLD Recreational	189 577 (23.9%)	164 229 (27.5%)	166 272 (32.8%)
QLD discard mortality	7748 (1.0%)	20 037 (3.4%)	9778 (1.9%)

The harvest estimates peaked over the periods 1973–1981 and 1998–2004 with a mean harvest of 993 t. The majority of the total harvest was attributed to the commercial sector until early 2000s, before the commercial line harvest quota (total allowable commercial catch: TACC) was introduced in 2005. Since then, the estimated total harvest has reduced to around 500–600 t per year (except in 2010 and 2011).

In Queensland waters, annual commercial harvests of Spanish mackerel ranged around 400–780 t between the years 1989 and 2004. These harvests declined greatly to range around 200–380 t since the introduction of the TACC. Most commercially harvested fish were taken from offshore waters north of Bowen (North and Townsville regions in Figure 3.3). The TACC was considerably under filled for all years 2005–2020 (Figure 3.3).

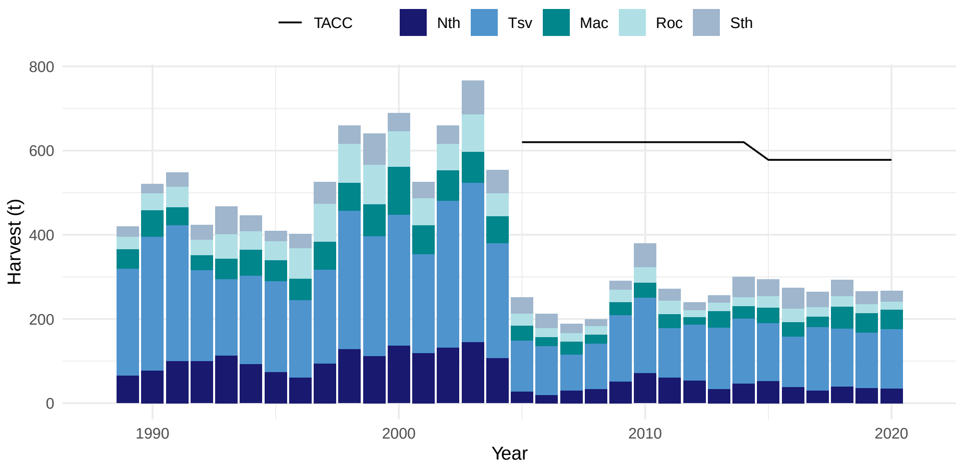

Figure 3.3: Total harvests of Spanish mackerel by fishing year as reported by commercial line fishing operations in Queensland waters—the graph coloured areas were: North (Nth) latitudes 12–17, Townsville (Tsv) latitudes 18–20, Mackay (Mac) latitudes 20–22, Rockhampton (Roc) latitudes 23–25 and South (Sth) latitudes 25–29

Figure 3.4 shows the Queensland recreational harvest reconstruction in more detail.

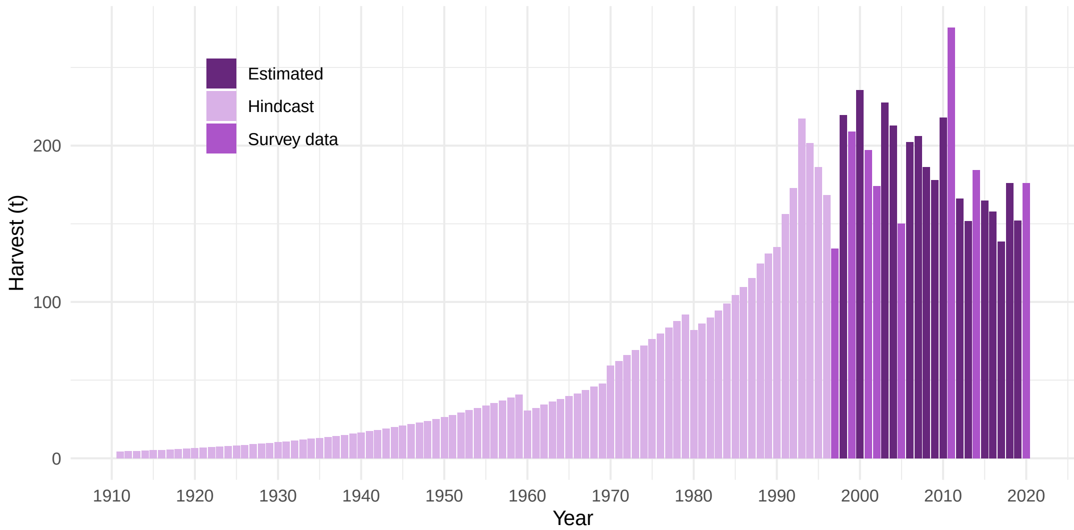

Figure 3.4: Annual estimated harvest from the recreational sector between 1911 and 2020 for Spanish mackerel

3.1.2 Standardised catch rates

The analyses described in Section 2.3 resulted in four catch rate scenarios (Figure 3.5). Model diagnostics were satisfactory (Tables C.1, C.2, Figures C.1 and C.2).

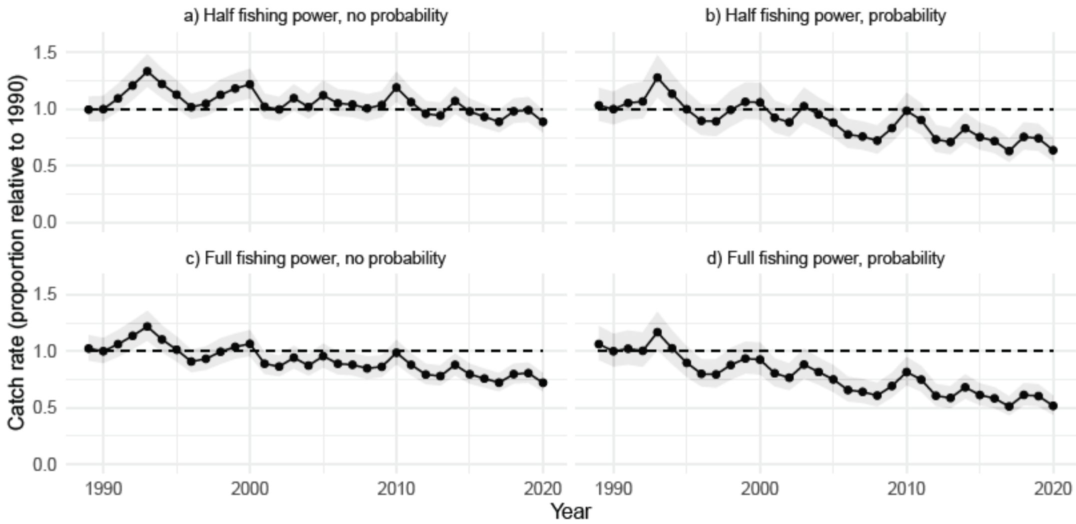

Figure 3.5: Annual standardised catch rates (95% confidence intervals) for Queensland commercial line-caught Spanish mackerel between the years of 1989 and 2020, for four scenarios

Figure 3.5b shows the base case that was selected. The base case assumed half fishing power and included the probability model (Figure C.3). Discussions within the project team agreed that half fishing power was considered appropriate to account for fishing power and that probability adjustment was important to account for the hyperstability nature of the fishery. This base case shows a mid-range scenario, as opposed to a more stable (Figure 3.5a) or declining outcome (Figure 3.5d). The base case scenario shows a downward trend over the whole time series, ending with a catch rate of about 60% of that at the start of the time series.

Scenarios 4–6 explored the effect of using the higher standardised catch rates (half fishing power without probability model) (Figure 3.5a). The trend in this optimistic catch rate is quite flat but still with an overall slightly downward trend. Standardised catch rates with full fishing power—with and without probability adjustment—was tested in Scenarios 7 and 8, respectively.

Figure 3.6 shows the historical decadal catch rates that were input into the model. Only one data point per decade was entered into the model.

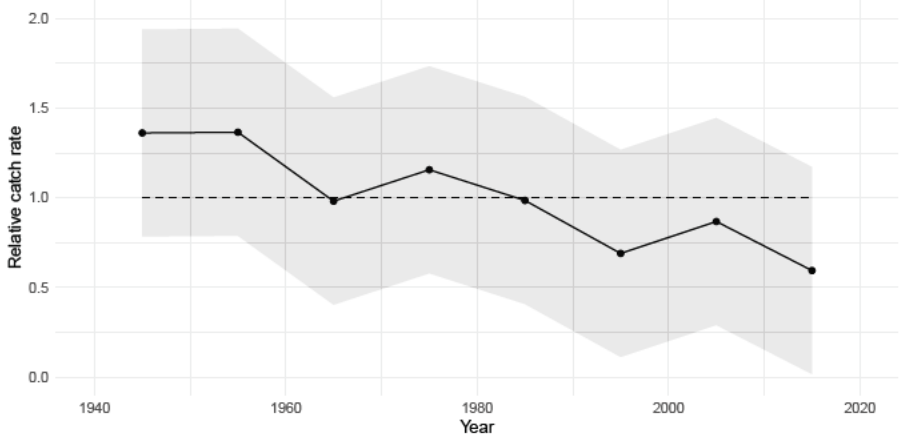

Figure 3.6: Historical decadal catch rates (relative to average) for commercial line-caught Spanish mackerel between the years of 1945 and 2015—shade indicates 95% confidence intervals

3.1.3 Age-at-length

The age data were input as conditional age-at-length in the population model (Figures A.1–A.2). Age composition of Spanish mackerel analysed by the monitoring team is provided in Appendix D.

3.1.4 Length composition

Fishery sex-based length compositions were input to the population model (Figures 3.7–3.9).

Figure 3.7: Annual length compositions of female Spanish mackerel for fish caught between 2005 and 2020 in Queensland in all sectors combined

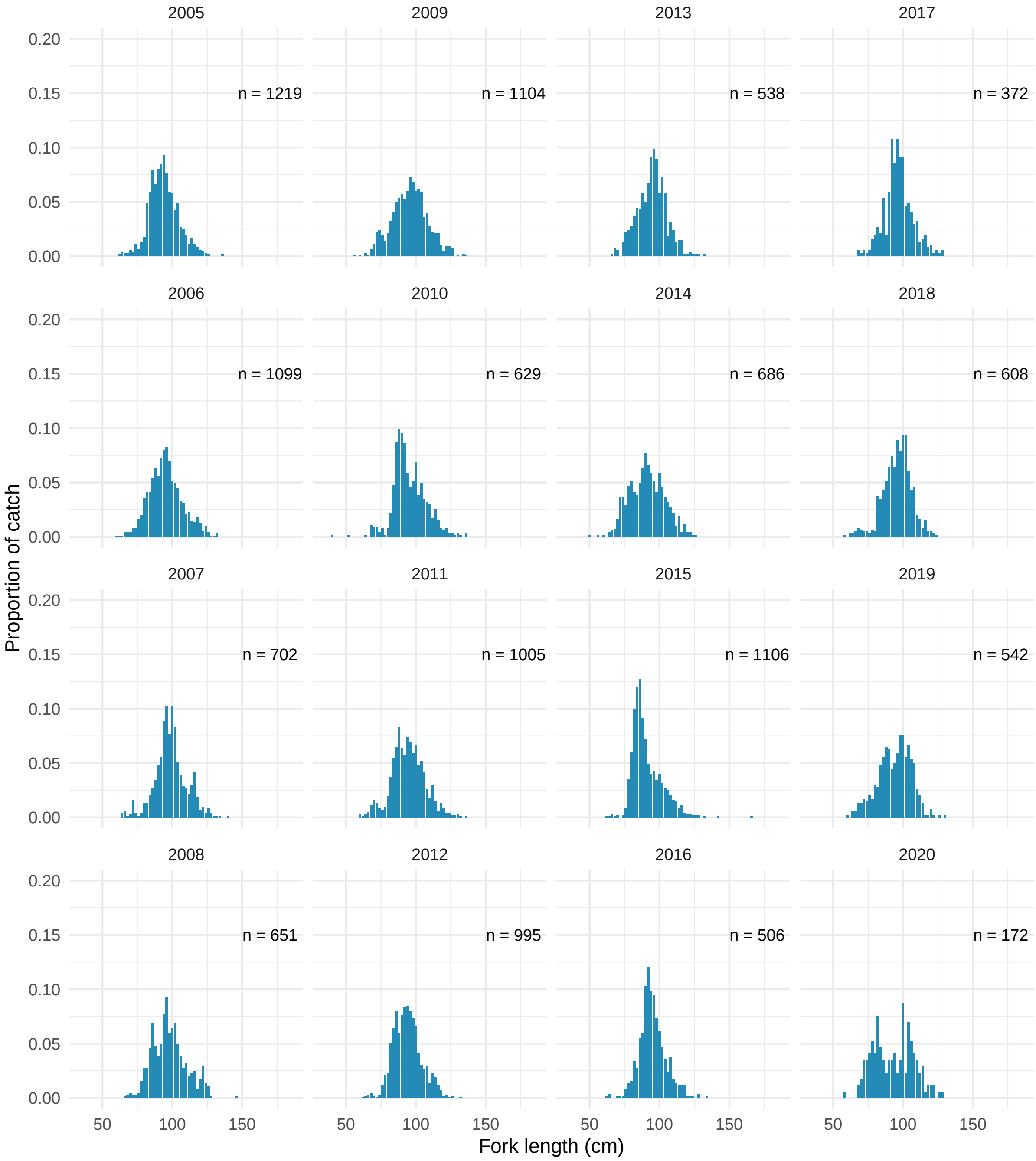

Figure 3.8: Annual length compositions of male Spanish mackerel for fish caught between 2005 and 2020 in Queensland in all sectors combined

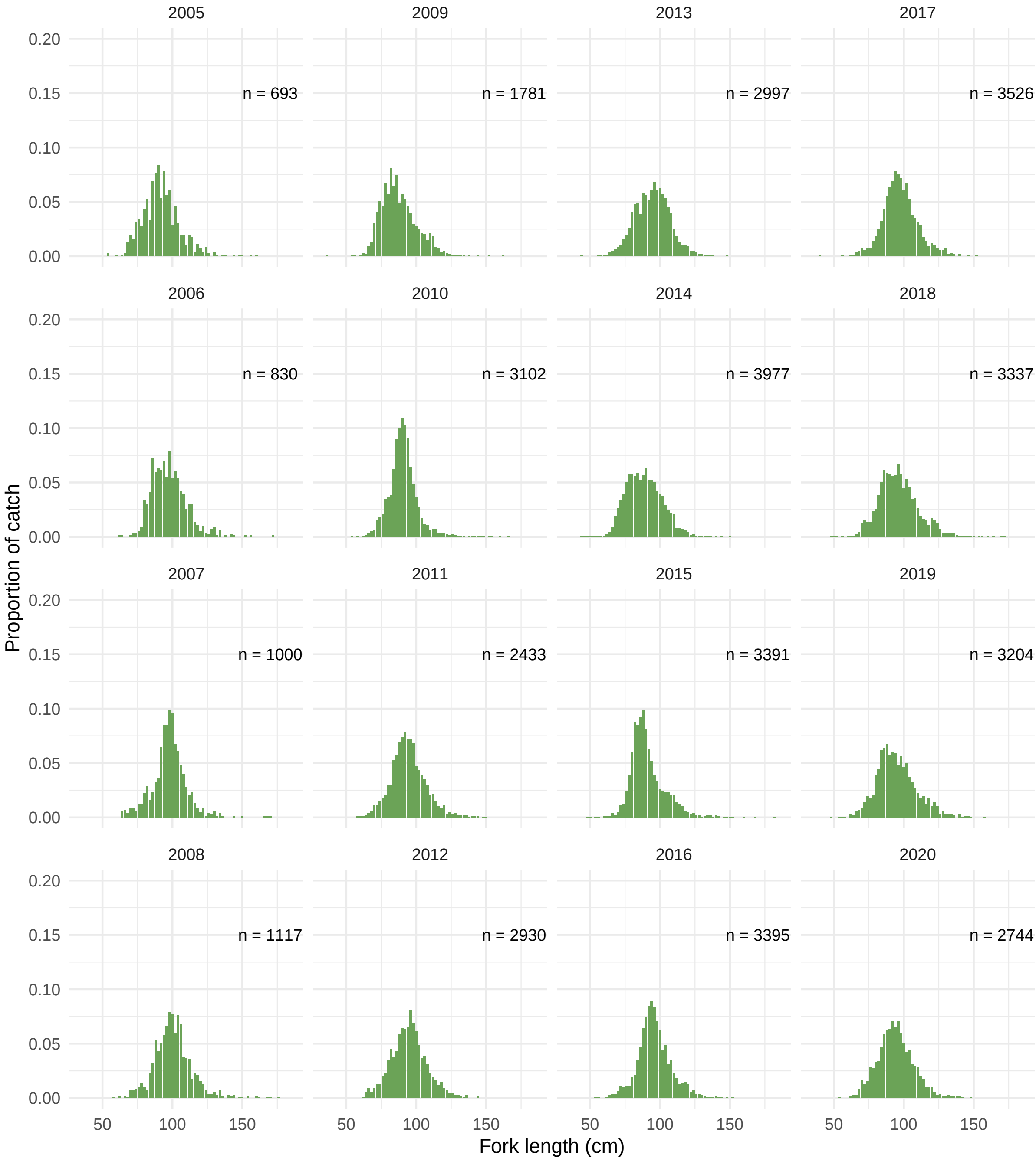

Figure 3.9: Annual length compositions of unknown-sex Spanish mackerel for fish caught between 2005 and 2020 in Queensland in all sectors combined

3.2 Model outputs

3.2.1 Model parameters

Parameters estimated for the base case population model is shown in Table 3.2. No prior was used for natural mortality once the model had stabilised.

Table 3.2: Summary of parameter estimates for Spanish mackerel from the base population model

Parameter	Estimate	Standard deviation
Natural mortality per year	0.27	0.01
Fork length at age 1 (FL_1) female (cm)	66.9	1.39
Fork length at maximum age (FL_{inf}) female (cm)	130.19	2.38
von Bertalanffy growth parameter (κ) female	0.29	0.03
Coefficient of variation in length at age 1 female	0.07	0.01
Coefficient of variation in length at maximum age female	0.07	0.01
Fork length at age 1 (FL_1) male (cm)	65.97	1.28
Fork length at maximum age (FL_{inf}) (cm) male	114.18	1.29
von Bertalanffy growth parameter (κ) male	0.35	0.03
Coefficient of variation in length at age 1 male	0.08	0.01
Coefficient of variation in length at maximum age male	0.04	0.003
Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1911)	13.3	0.05
Commercial selectivity inflection (cm)	81.28	0.9
Commercial selectivity width (cm)	11.46	1.34

3.2.2 Model fits

Good fits were achieved for all data sets including abundance indices, length compositions and conditional age-at-length (Appendices B.1).

3.2.3 Selectivity

Selectivity of Spanish mackerel in the east coast stock/fishery was estimated within the model. Estimated parameters suggest that 50% of Spanish mackerel are selected at 81 cm fork length, while 95% are selected at 93 cm (Table 3.2, Figure 3.10). These estimates suggest that Spanish mackerel are caught larger than the minimum legal size of 75 cm total length, which corresponds to approximately 67 cm fork length (Figure 3.10).

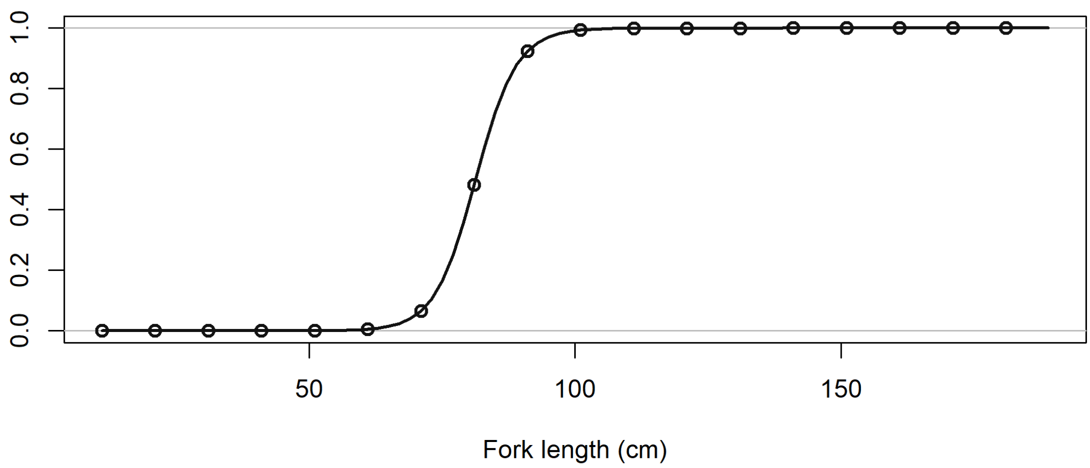

Figure 3.10: Model estimated length-based selectivity for Spanish mackerel in 2020

3.2.4 Growth curve

The von Bertalanffy growth curve, including coefficients of variation of old and young fish, was estimated within the model for both males and females (Table 3.2, Figure 3.11).

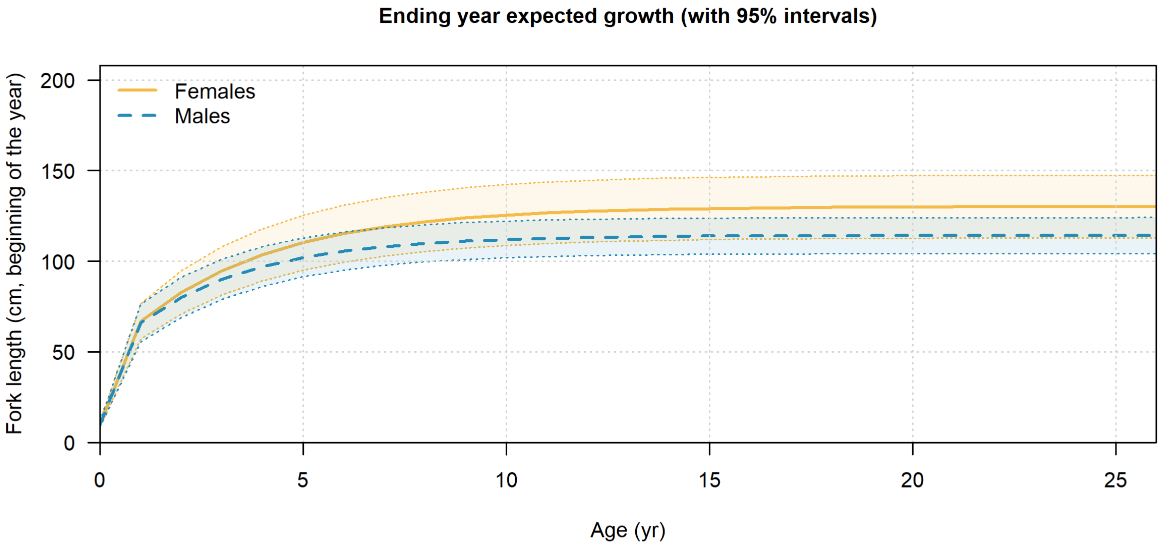

Figure 3.11: Model estimated growth curve for Spanish mackerel by sex in 2020

3.2.5 Biomass

The model predicted that the spawning stock biomass declined between the virgin state in 1911 to around 60% of unfished biomass in late 1960s. The spawning biomass sharply declined in 1970s and 1980s, reaching spawning biomass down below 30% of unfished biomass by 1990. Biomass level was relatively stable in 1990s at around 26% of unfished state, but further declined in early 2000s by 8–9%. The spawning biomass ratio has been around limit reference point B_{20} since 2005. In 2020, the stock level was estimated to be 17% unfished spawning biomass (Figure 3.12).

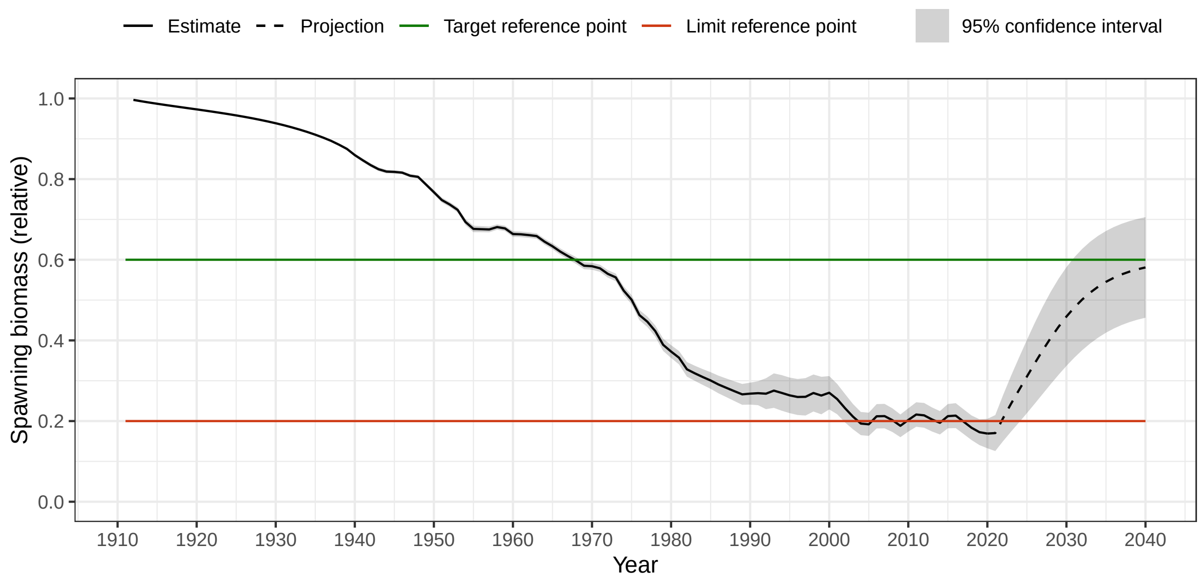

Figure 3.12: Predicted spawning biomass trajectory relative to virgin for Spanish mackerel, from 1911 to 2040

The relationship between the biomass estimate and fishing mortality are presented in a phase plot (Appendix B.2.1, Figure B.6).

The equilibrium yield curve informs on the productivity of the stock at different biomass levels (Figure 3.13).

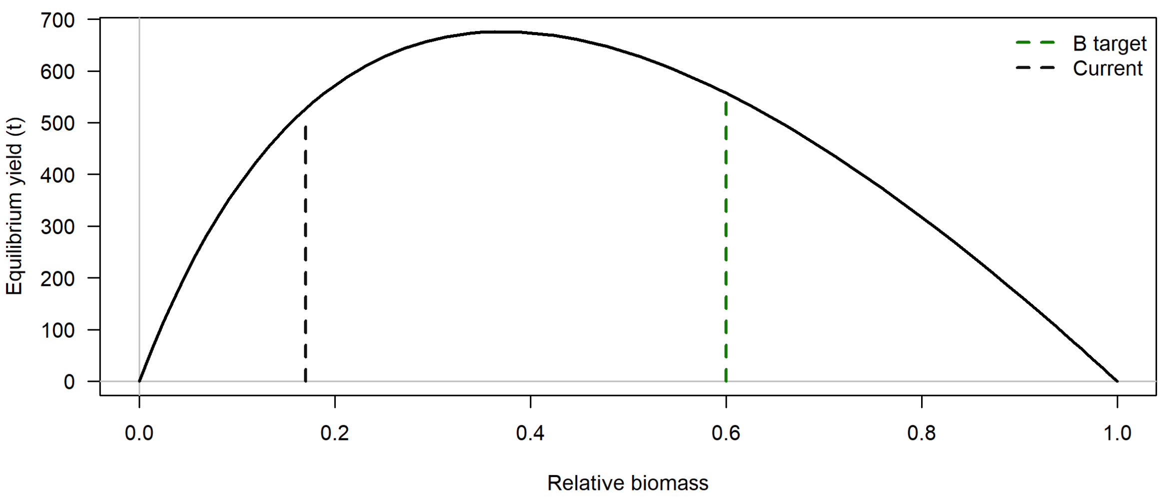

Figure 3.13: Equilibrium yield curve for Spanish mackerel

3.2.6 Harvest targets

Recommended biological catches (RBCs) to move the stocks to the desired level B_{60} are shown in Table 3.3. Note that RBCs are for all sectors and jurisdictions combined (including discard mortality).

Because the current biomass is less than B_{20}, the recommended limit is zero for the first year of rebuilding, rising to 283 t in 2030 and 515 t in 2040.

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

Year	RBCs (t)	Biomass ratio
2021	0	0.17
2022	4	0.21
2023	26	0.24
2024	53	0.28
2025	84	0.31
2026	120	0.34
2027	160	0.38
2028	201	0.41
2029	243	0.43
2030	283	0.46
2031	322	0.48
2032	357	0.5
2033	389	0.52
2034	417	0.53
2035	441	0.55
2036	462	0.56
2037	479	0.56
2038	493	0.57
2039	505	0.58
2040	515	0.58

3.2.7 Sensitivity

The eight scenarios presented in Section 2.5.4 all had parameters that were estimated cleanly (none hit their bounds), and final parameter gradients were small implying no convergence problems.

Table 3.4 shows the differences between model scenarios. Apart from scenario 6, spawning biomass ratio and sustainable harvest at B_{60} are relatively similar among different model runs, which indicate that the model results are, in general, not greatly sensitive to the parameter values that were fixed.

Table 3.4: Summary of the Spanish mackerel results from the base case and the sensitivity tests
Log-likelihood ($-\ln L$) values are not comparable as different Francis weighting was applied to individual scenario; biomass is presented as a ratio relative to an unfished state, and annual harvest values are in tonnes.

Scenario	h	M	Prob	FP	$-\ln L$	B_{2020}/B_0	Harvest at B_{60}
1	0.45	Est	Y	0.5	389.547	0.169	557
2	0.35	Est	Y	0.5	381.06	0.202	552
3	0.55	Est	Y	0.5	394.127	0.145	543
4	0.55	Est	N	0.5	349.142	0.205	543
5	Est	0.33	N	0.5	346.412	0.269	564
6	0.65	Est	N	0.5	370.121	0.574	759
7	0.45	Est	Y	1	370.851	0.144	564
8	0.45	Est	N	1	385.279	0.193	560

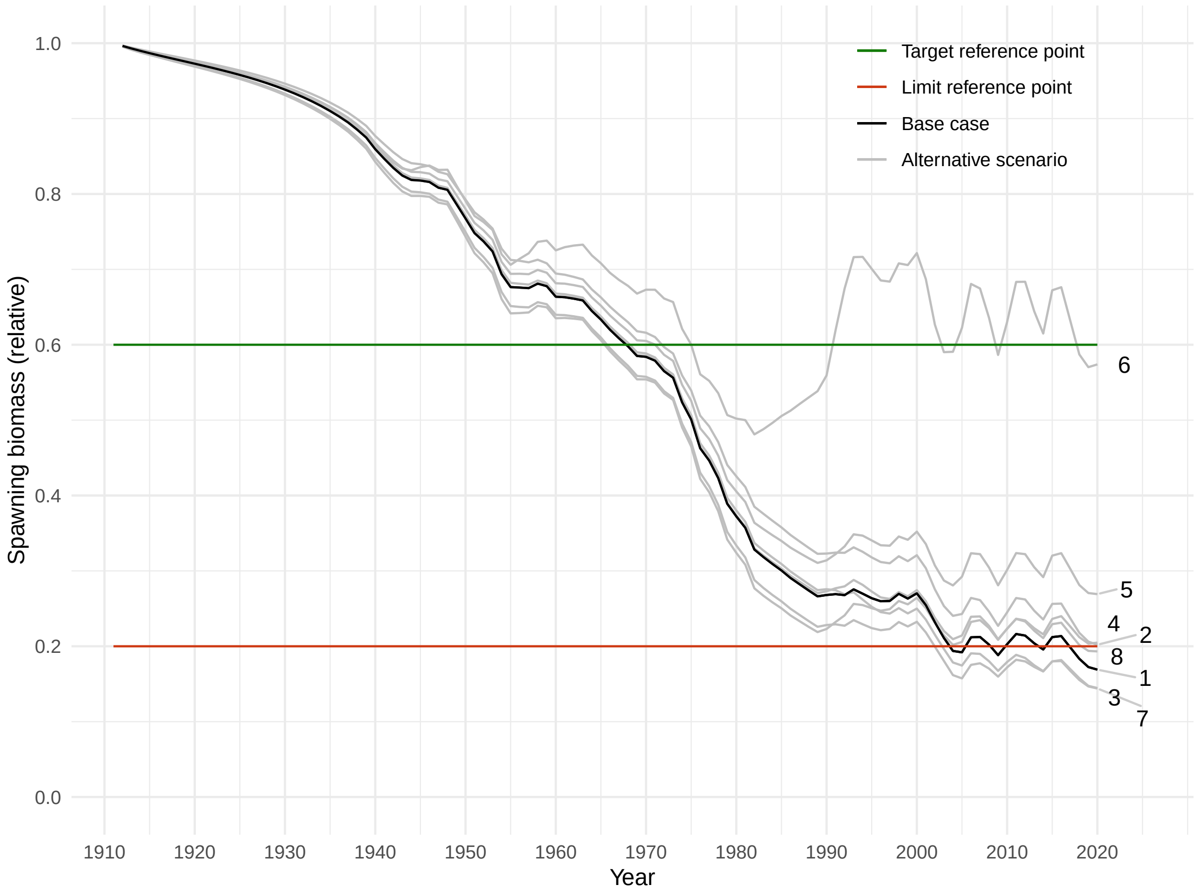

Figure 3.14: Predicted spawning biomass trajectory relative to virgin for Spanish mackerel, from 1911 to 2020 for all eight sensitivity tests—scenarios are summarised in Table 3.4

4 Discussion

4.1 Stock status

Results suggest there has been a long-term decline in the Spanish mackerel spawning population along the Australian east coast. The estimated large 1970s and early 2000s harvests (≥ 900 t) had strong depleting effects (see the slope of biomass decline during these years; Figure 3.12). The large harvests in 1998–2004 were just prior to new quota management. In these years there were on average an extra 24–69 commercial operations per year fishing, when the estimated Spanish mackerel spawning population size was around 30% in the base case. The drive to fish in the 1998–2004 years was a significant effect on the 2020 spawning biomass results. The results of the base case scenario suggest the spawning stock might be as low as 17% (±4%), which is below the limit reference point of 20%.

The numbers of spawning Spanish mackerel of the Lucinda region (latitude band 19) are believed to contribute substantially to the stock's overall reproduction level during the spawning months in spring (O'Neill et al. 2018; Buckley et al. 2017; Tobin et al. 2014). Levels of fish harvest remain significant in latitude 19, and the decreasing standardised catch rates suggest the Spanish mackerel spawning aggregation was reduced (Figure C.5). The low recruitment deviations, on new spawned fish, for 2014–2016 also contribute to the low spawning biomass result (Figure B.7)

4.2 Stock assessment uncertainties

Stock assessment scenario testing, using different data and model settings, can be effective to identify a range of possible results. Broader uncertainties can be found to identify best-case and worst-case solutions. Herein, the stock assessment model was run 8 times, with different settings of data inputs, model steepness and natural mortality (Table 2.3). This was to identify key assumptions, variations and uncertainties in the 2020 results. The key aspects that varied in analyses were four different time series of commercial catch rates, four settings of the reproductive rate steepness and different estimates of natural mortality.

For each model run the results for finding the parameter values that maximise the model fit to the data were presented (maximum likelihood solutions and asymptotic errors). From the range of results, two key states were noted:

- low spawning biomass ratios ranging 14–27% in 2020 (scenarios 1–5, 7 and 8; which were similar to the estimates in group 4 low spawning biomass results and settings (i.e. half fishing power with probability catch rate) in Figure 27 of O'Neill et al. (2018)), and
- high spawning biomass ratios 57% in 2020 (scenario 6; which was similar to the group 2 high spawning biomass results in Figure 27 of O'Neill et al. (2018)).

The highest 2020 spawning biomass result (B_{2020}/B_0) of 57% was associated with catch rates that were less standardised for fishing power and hyperstability considerations, matched with a resilient (high) reproductive rate steepness ($h = 0.65$), high natural mortality for reduced longevity (generally less than 10 years of age) and fishing mortality effect, and higher potential recruitment (virgin R_0) levels. Some of these aspects are questionable and for such a result to be likely, many schools of fish would be present to support harvests, catch rates, and a potential total fishery MSY of over 1000 t per year. However, the potential Queensland TACC of 578 t was only roughly half caught for many years since 2005.

In addition, there are a number of other aspects that might associate to the low biomass ratios:

- Spanish mackerel were aged to be longer lived up to 26 years. This was older than in the Gulf of Carpentaria and the Torres Strait, where both of these stocks of fish have been in decline towards limit reference points (O'Neill et al. 2021; Bessell-Browne et al. 2020).
- There has been a steady decline in catch rates of Spanish mackerel in stocks across northern Australia (O'Neill et al. 2021; Bessell-Browne et al. 2020).
- Recent environmental conditions might limit spawning success and survival rates or fish catchability, however no environmental data were readily available to test hypotheses (Section 4.3.1).
- Trends in catch rates generally suggested a lower resilient steepness parameter (h).

4.3 Unmodelled influences

There are a number of possible drivers of the Australian east coast Spanish mackerel population that have not been identified or fully understood. The following points should be taken into consideration when interpreting results. They give emphasis to ensure safe levels of harvest rates are enforced when fishing aggregations of Spanish mackerel.

4.3.1 Environmental influences

Little is known about the environmental drivers on stock size of Spanish mackerel. Particularly, we don't know the specific environmental conditions or cycles that affect Spanish mackerel survival, success of spawning to produce new young for the year, or the abundance of bait fish populations on which mackerel feed. Welch et al. (2014) indicated that spring sea surface temperature could potentially be a key environmental variable for Spanish mackerel, affecting recruitment by influencing the timing of spawning, egg production and larval survival, and potentially affecting growth and catchability. Long-term and ongoing declines in the primary productivity of waters off the east coast of Queensland (Richardson et al. 2020, FRDC Research Project Number 2019/013, in press) may be negatively impacting growth and survival of larval Spanish mackerel, or negatively impacting the abundance of bait fish on which juvenile and adult mackerel feed.

Declining trends in population size have been reported in Spanish mackerel stock in the Gulf of Carpentaria (Bessell-Browne et al. 2020) and other mackerel species in Queensland (Bessell-Browne et al. 2018; Lovett et al. 2019). Bessell-Browne et al. (2020) indicated that numerous warm water events in recent years might have influenced the recruitment and spawning location and timing of Spanish mackerel stock in northern Australia. The relationship between changing environmental conditions and Spanish mackerel recruitment and prey availability merits direct investigation, as these relationships have important implications for potential rates of recovery of the east coast Spanish mackerel stock. In particular, periods of elevated sea surface temperatures are predicted to become more severe and frequent with climate change (Cai et al. 2014; Wang et al. 2020), and are already implicated in significant environmental cascades, in which warmer conditions enhance water column stratification, limiting upwelling of nutrients and the primary productivity blooms on which higher organisms depend (Richardson et al. 2020).

In the Torres Strait, Spanish mackerel catch rates fell near 50% between 2009 and 2018 (O'Neill et al. 2021). Reductions in fish quota followed the downturn in catch rates. This may suggest an environmental influence on fish recruitment and/or survival. Levels of harvest alone could not explain the downturn, which has also been seen in other Spanish mackerel fisheries across northern Australia (Bessell-Browne et al. 2020).

4.3.2 Hyperstability

The predictable aggregation and movement of Spanish mackerel attract fishers in the same regions and seasons each year. When present, aggregated schools of Spanish mackerel on the surface ensures high catchability and makes them susceptible to overfishing. This behaviour also introduces the problem of hyperstability for stock assessments and management (Walters 2003; Campbell et al. 2012). This hyperstability means that catch rates can remain high, even when fish numbers in schools are decreasing (Walters 2003). Although corrections have been made when standardising catch rates through probability and fishing power adjustments, it is difficult to determine the full extent of its impact as seen in the variation in catch rate results when comparing different levels of adjustments (Figure 3.5).

4.4 Recommendations

4.4.1 Data

Early fish age monitoring data from the late 1970s and late 1990s were available from research projects by McPherson (1992) and McPherson (1993). However the sampling was spatially restricted to the spawning aggregation north of Townsville and not across the east coast. It is recommended that the methodology and suitability of these data be reviewed and standardised for consideration in the next assessment of this stock similar to methods used by AFMA Research Project Number: 2019/0831, in the Torres Strait.

The age-length data from 2000 to 2004 were also excluded as they were not representative of the entire east coast. It is recommended that these data be investigated and if possible, standardised for use in future assessments.

It is also recommended that the re-weighting/re-scaling of the age and length data is investigated for the next assessment. The regional stratification used to sample monitoring data is allocated proportionally to commercial catch. In practice, sampling can not always be stratified as intended, so data can be re-weighted to reflect this regional distribution. This assessment did not include re-weighting of monitoring data, however this should be considered in future assessments.

The quality of commercial data would be improved by accurate effort measures with fishing time and accurate location recorded for each commercial operation. More data should be collected regarding targeting species, zero catches and number of dories and hours fished each operation day. Electronic reporting systems and vessel monitoring system information may be valuable for achieving these objectives.

4.4.2 Monitoring and research

Continued annual monitoring of fish age and length structures, by fishing sector with spatial references, is required to support stock assessment and ensure accurate reference points for harvest strategies.

Information on trends in annual fish recruitment, from the fish age frequencies, improved our understanding of potential impacts of environmental variation on the population and would help to confirm the model predictions of poor recruitment in recent years.

Monitoring of the fished status of the Spanish mackerel spawning aggregation is important for determining the overall stock health. Fine scale details on fishing locations are required to understand potential localised fishing mortality, numbers of aggregations and densities of Spanish mackerel (O'Neill et al. 2018).

Shark depredation is increasingly being noted by many offshore line fishers in Queensland (Major 2020) yet its impact on Spanish mackerel harvests and catch rates are unknown. While a pilot depredation scenario was hypothesized and considered in Appendix F, more research is needed to quantify shark depredation affect on east coast Spanish mackerel fishery.

4.4.3 Management

The results of the assessment recommends that:

- action needs to be taken to rebuild the stock towards the Sustainable Fisheries Strategy biomass target of 60%.
- once the stock recovers to the target spawning biomass level, the annual sustainable harvest of Spanish mackerel be capped at the level for 60% spawning biomass for all fishing sectors and east coast waters combined (minus any discard mortality) (Table 3.3).

4.4.4 Assessment

Specific recommendations for a future Spanish mackerel assessment include:

- exploration of alternative recreational harvest reconstruction methods, such as the methodology developed by Holden et al. (2020),
- incorporating historical length and age data collected in late 1970s and 1990s in the model,
- review on monitoring data between 2000 and 2004 and re-examine their utility,
- investigation on the improvement of population modelling in Stock Synthesis for the steepness parameter and it's uncertainty, and consideration of age-based maturity.
- specific analysis on the spawning aggregation data.
- investigation on the effect of shark depredation rates.

Separate to the recommendations listed above, independent survey research is required to resolve stock assessment uncertainties on spawning biomass levels and the potential number of schools of fish to harvest. Suggested methods include extensive fish genetic tag-recapture or new close-kin mark-recapture (CKMR) research. CKMR has been applied to southern bluefin tuna, transforming its stock assessment and forming an ongoing key fishery independent index of fish abundance (Bravington et al. 2016; Davies et al. 2020). A successful and well executed CKMR study could provide estimates to verify levels of spawning biomass, natural mortality and potential fishery yields.

4.5 Conclusions

This assessment was commissioned to establish the status of Spanish mackerel on Australia's east coast and inform the *Sustainable Fisheries Strategy*. The most plausible scenarios suggested biomass is currently between 14 and 27% of unfished levels, and most likely at 17% and that the stock is in need of rebuilding. The results provide annual recommended biological catches (RBCs) using a 20:60:60 control rule. These RBCs aim to rebuild the spawning biomass towards the 60% level, consistent with the 2027 biomass targets set in the Queensland Government's *Sustainable Fisheries Strategy*. To achieve this, management procedures should review and consider options for input and output controls as noted by

Walters et al. (2004). This is to safe guard against excess fishing pressure and to mitigate effects on the breeding population leading to reduced production of fish eggs and recruitment.

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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: Sample size of fish measured and aged for input to the model for Spanish mackerel

Year	Length	Age
2005	3026	1366
2006	3028	1307
2007	2256	941
2008	2281	907
2009	3845	1341
2010	4465	1099
2011	4282	1443
2012	4968	1253
2013	4069	775
2014	5588	1520
2015	5723	1393
2016	4517	954
2017	4169	887
2018	4305	730
2019	3895	728
2020	3286	655

A.2 Conditional age-at-length

Conditional age-at-length composition data were input to the population model (Figures A.1–A.2).

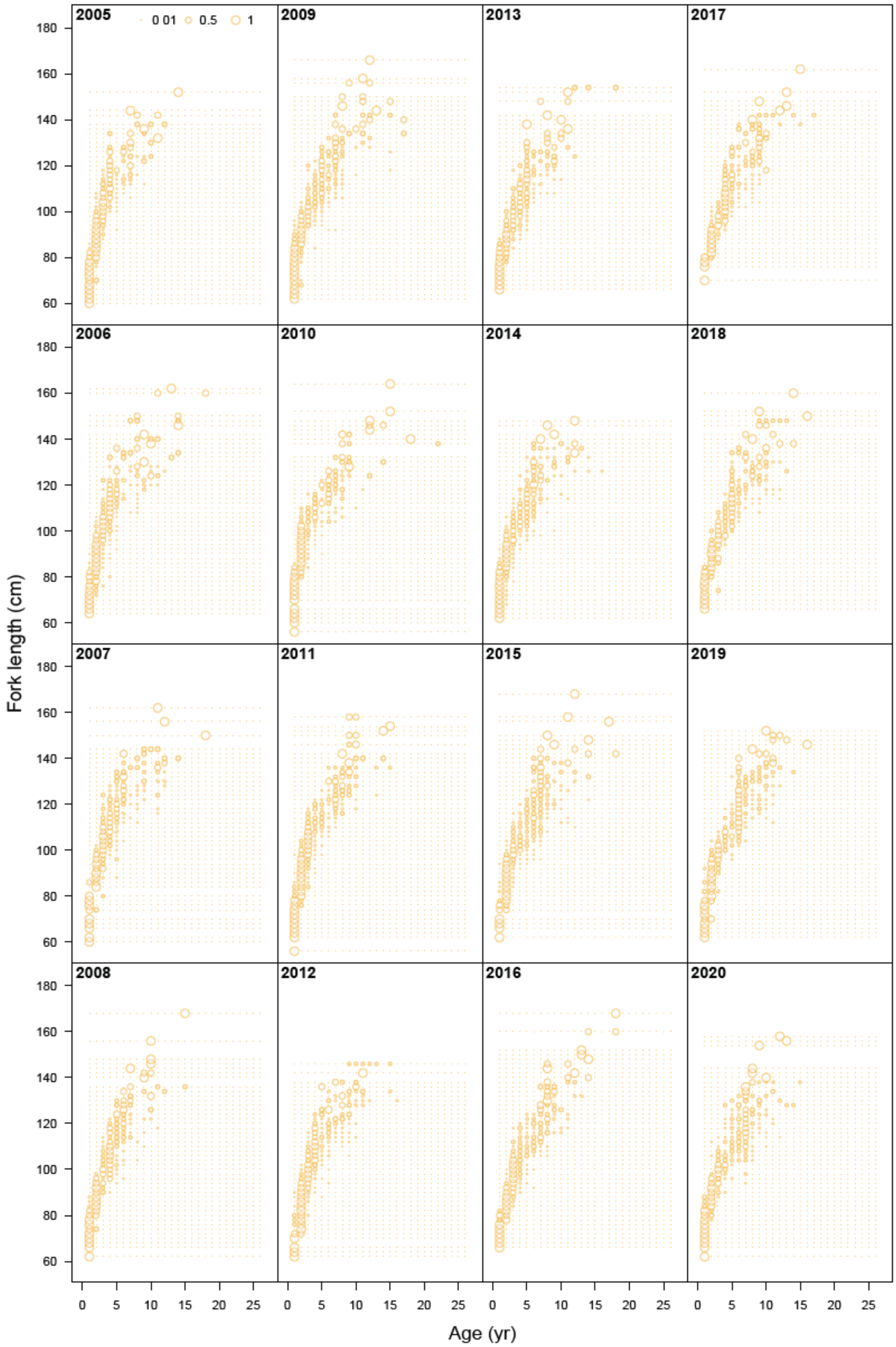


Figure A.1: Conditional age-at-length compositions of female Spanish mackerel between 2005 and 2020 —circle size is proportional to relative sample size in each bin across rows (i.e. for a given length bin)

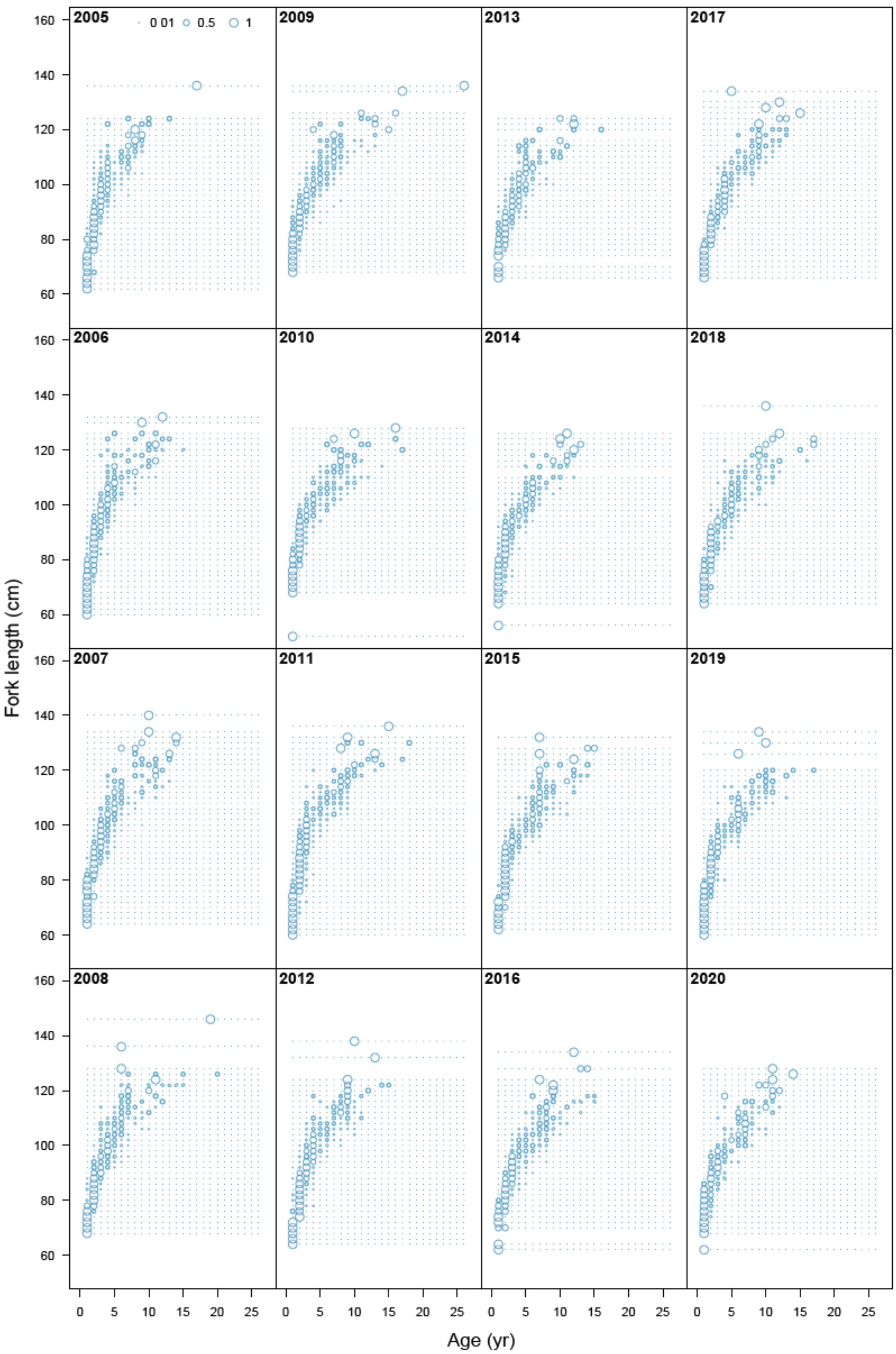


Figure A.2: Conditional age-at-length compositions of male Spanish mackerel between 2005 and 2020—circle size is proportional to relative sample size in each bin across rows (i.e. for a given length bin)

A.3 Biological data

A.3.1 Fecundity and maturity

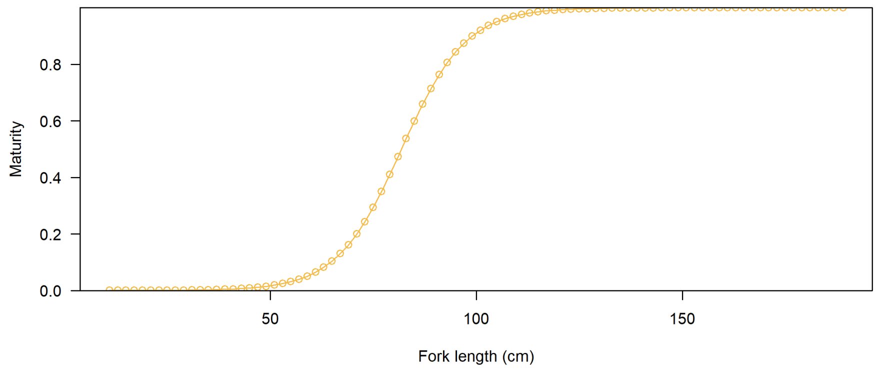


Figure A.3: Maturity at length for female Spanish mackerel

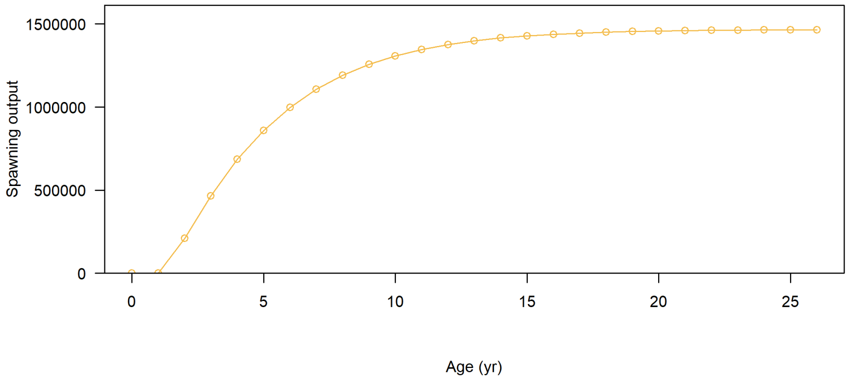


Figure A.4: Spawning output (maturity times fecundity) at age for Spanish mackerel

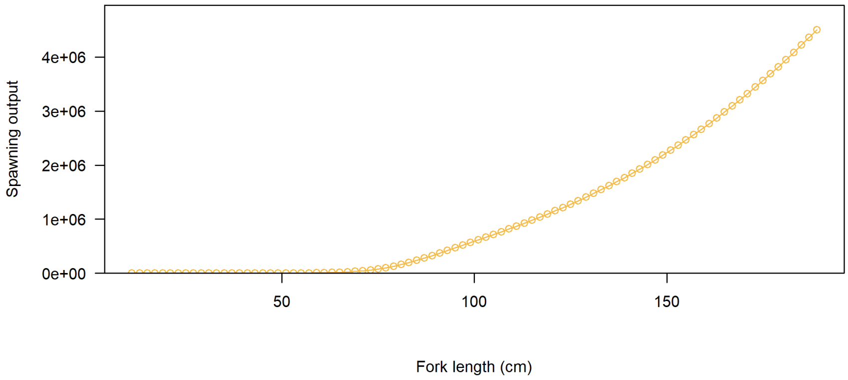


Figure A.5: Spawning output (maturity times fecundity) at length for Spanish mackerel

A.3.2 Weight and length

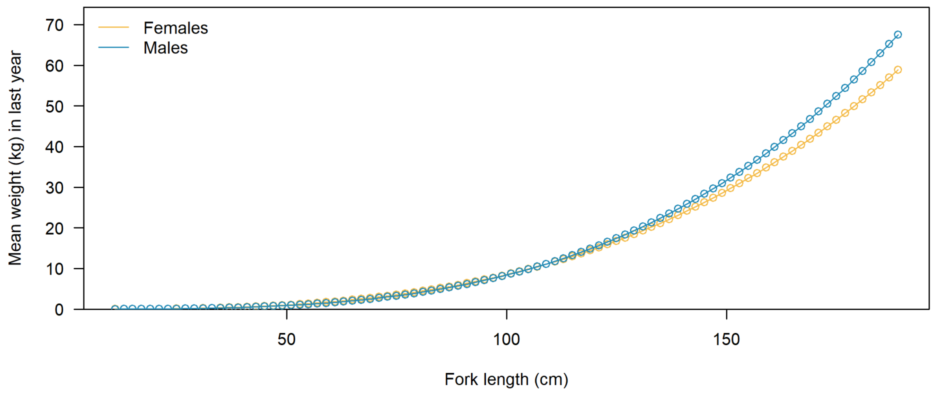


Figure A.6: Weight-length relationship for Spanish mackerel

A.3.3 Fishing power offsets

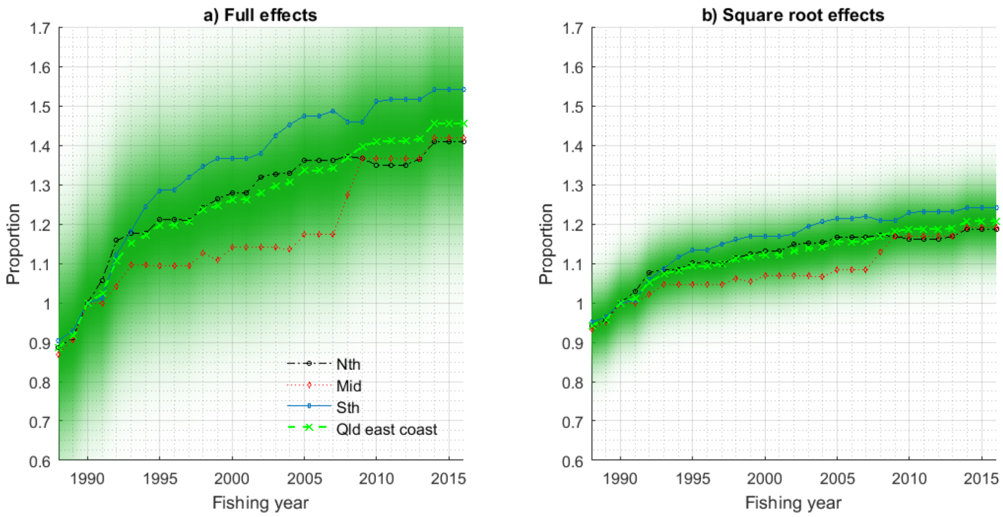


Figure A.7: The annual fishing power offsets that were estimated per year and region in the previous stock assessment (O'Neill et al. 2018)

A.4 Abundance indices

Commercial catch data were extracted from the Queensland logbook database. From the initial set of records, the catch rate data were defined through a series of filters.

For the probability model (first component of the standardisation model), the following filters were applied:

- Spanish mackerel (CAAB Code 37441007) catches per latitude band and day.
- Where multiple latitudes were recorded on a single day, the catch was summed over all records, and the location was set to mean of latitude derived and mean of longitude derived.
- Date between 1 July 1988 and 30 June 2020.

- Location was east coast (between 11.00° S and 28.50° S, ≥ 142.5° E).
- Location excluded records in the far north latitude band 11 (due to lack of available data).

For the catch rate model (second component of the standardisation model), the following filters were applied:

- Line fishers that had at least three years of catching Spanish mackerel.
- Line fishing methods included “Trolling”, “Handline”, and “Line fishing”.
- Where multiple locations were fished on a single day, the catch was summed over all records, and the location was set to mean of latitude and mean of longitude.
- Date between 1 July 1988 and 30 June 2020.
- Duration of the fishing trip was a single day.
- Location was east coast (between 11.00° S and 28.50° S, ≥ 142.5° E).
- Where kilograms of Spanish mackerel caught was greater than zero.

Appendix B Model outputs

B.1 Goodness of fit

B.1.1 Abundance indices

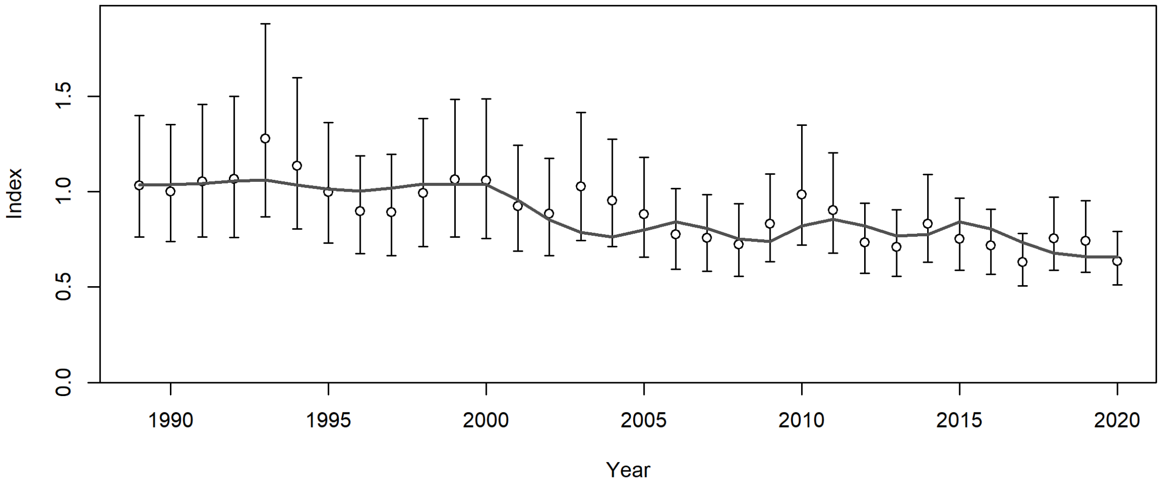


Figure B.1: Model predictions (grey line) to commercial catch rates for Spanish mackerel for base case scenario

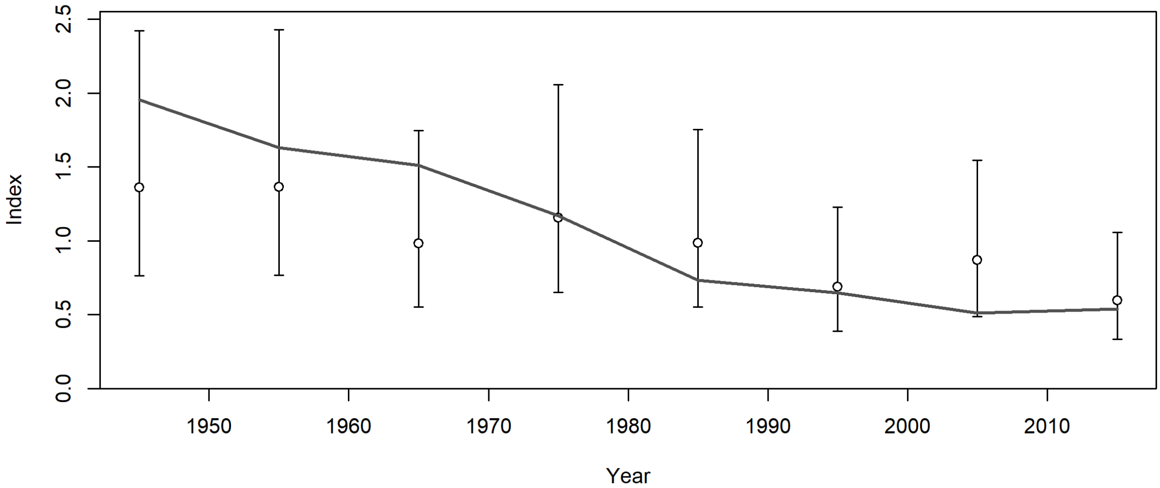


Figure B.2: Model predictions (grey line) to historical decadal catch rates for Spanish mackerel for the base case scenario

B.1.2 Length compositions

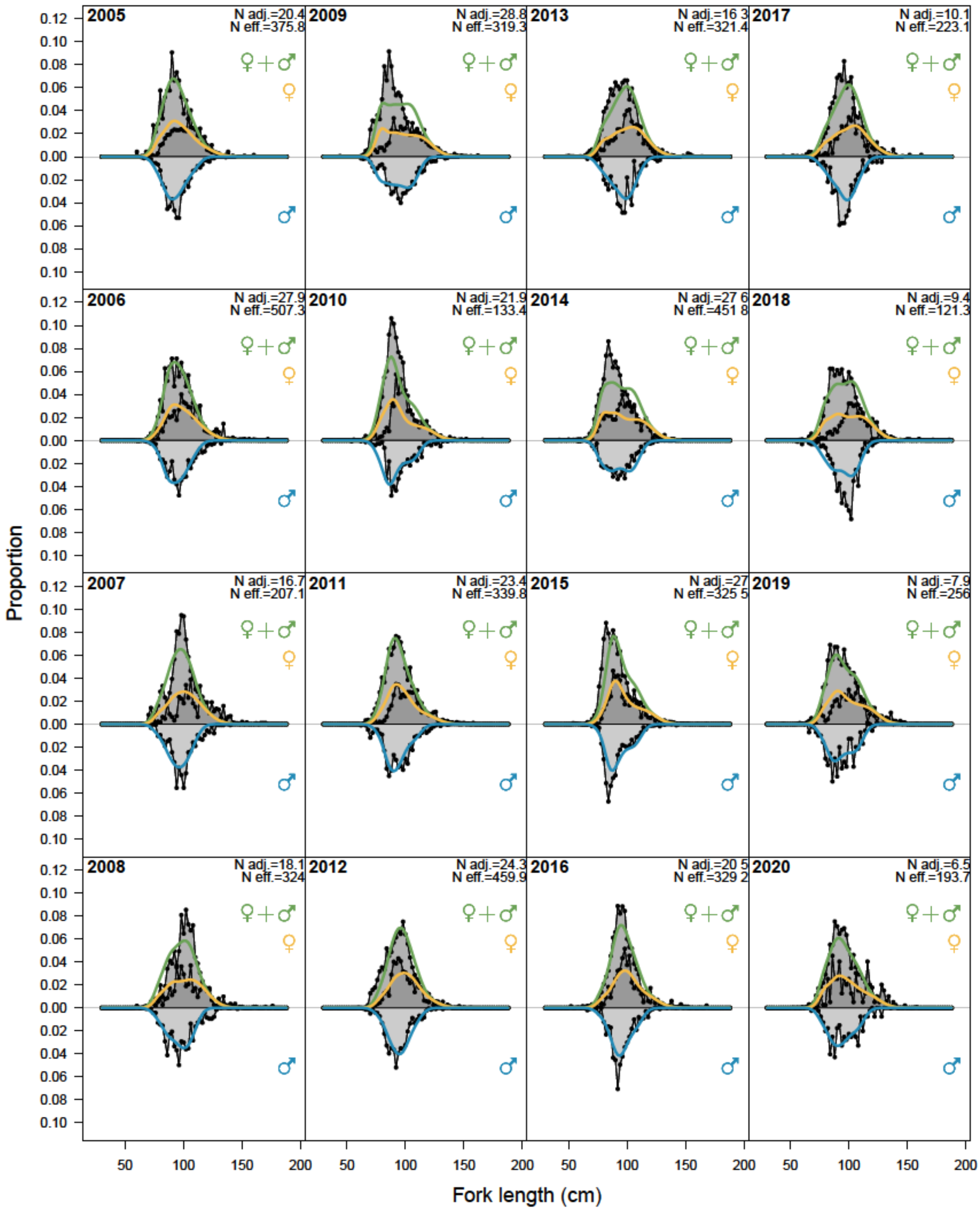


Figure B.3: Length structure for the commercial fleet for Spanish mackerel for each sex for the base case scenario

'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. Shaded areas are actual data and coloured lines indicate fitted values.

B.1.3 Conditional age-at-length compositions

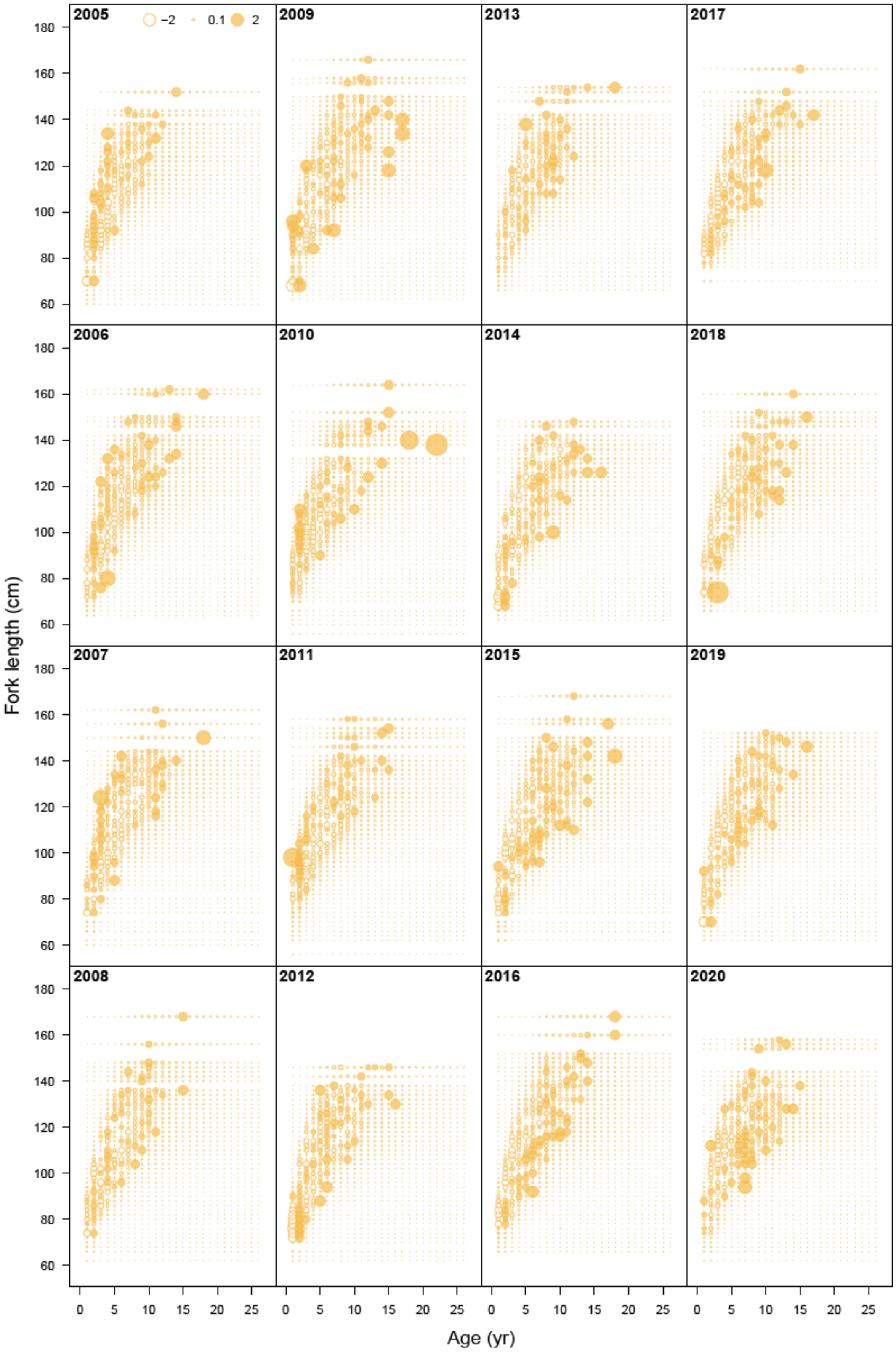


Figure B.4: Pearson residuals for age-at-length compositions for the commercial fleet for female Spanish mackerel for the base case scenario

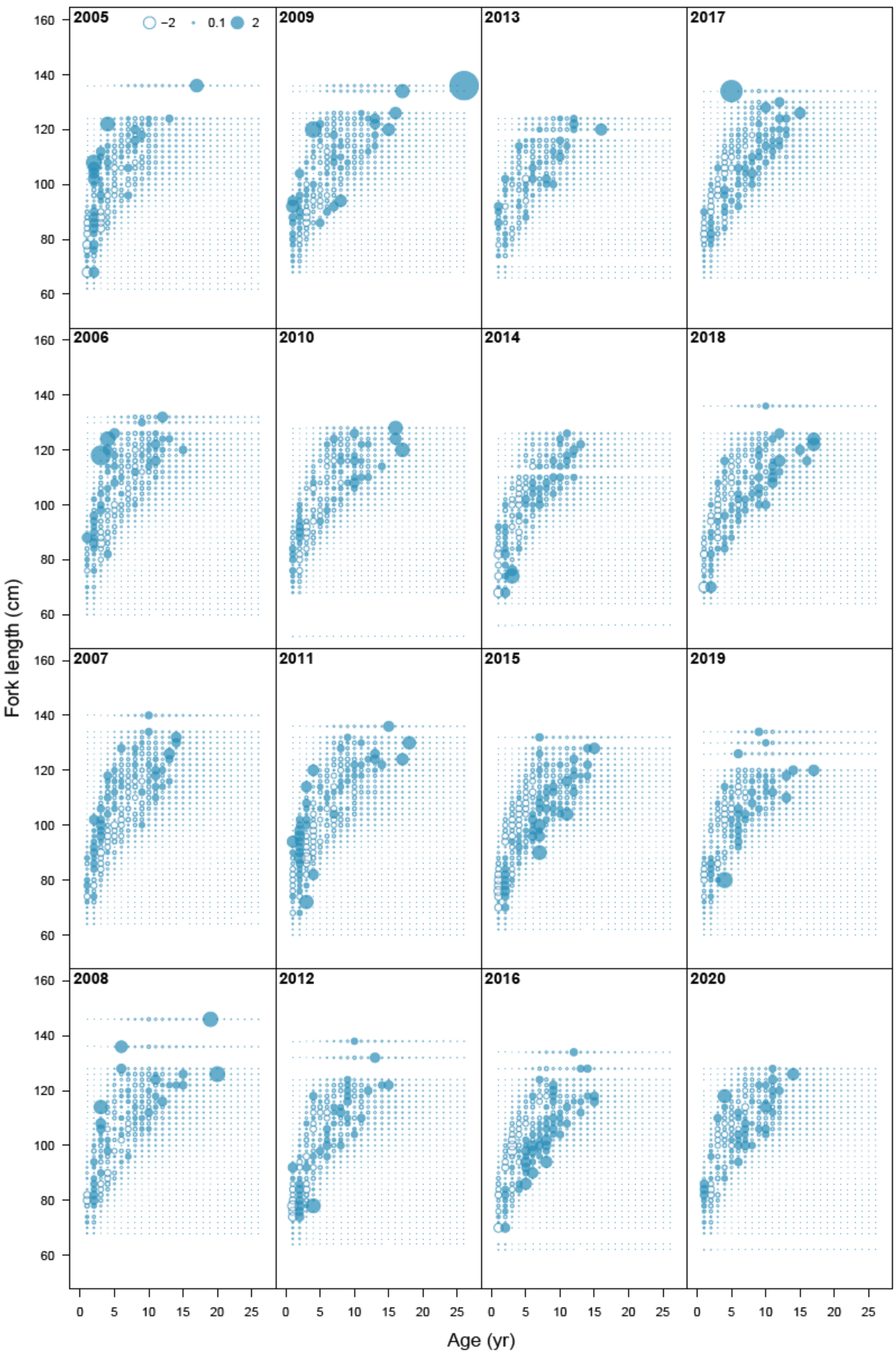


Figure B.5: Pearson residuals for age-at-length compositions for the commercial fleet for male Spanish mackerel for the base case scenario

B.2 Other outputs

B.2.1 Phase plot

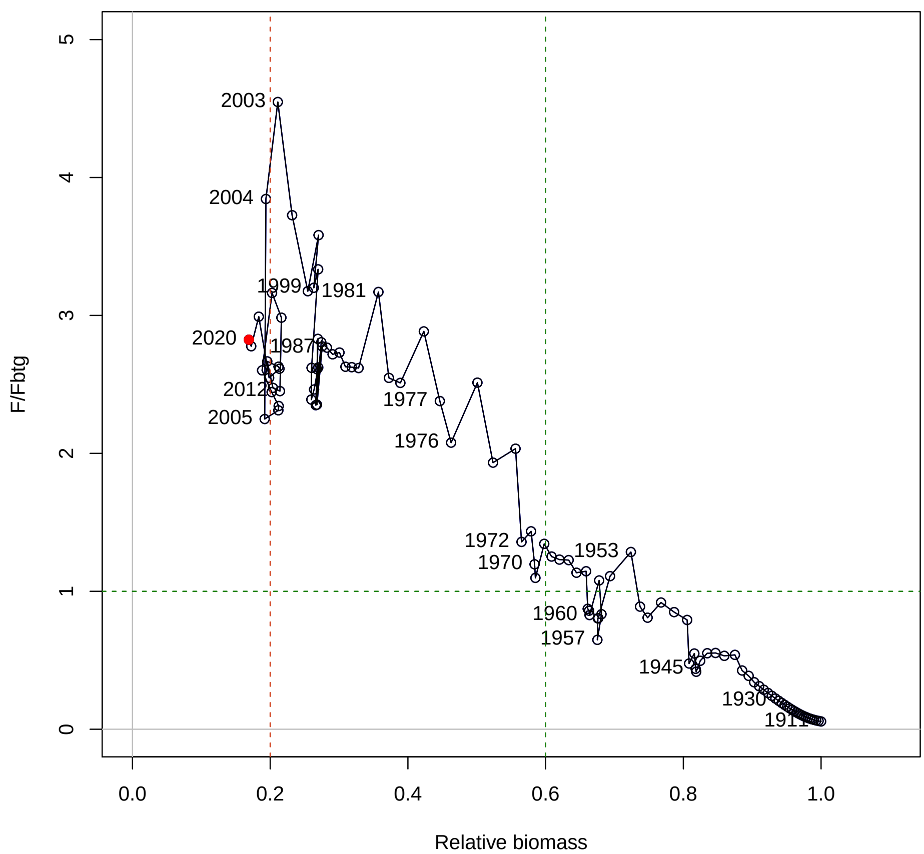


Figure B.6: Phase plot for Spanish mackerel for the base case scenario

The horizontal axis is the biomass ratio of Queensland Spanish mackerel relative to unfished and the vertical axis is the fishing mortality relative to the fishing mortality which would produce the *Sustainable Fisheries Strategy* biomass target of 60%. The red dashed vertical line is the limit reference point (20% relative biomass) and the green dashed vertical line is the target reference point (60% relative biomass).

B.2.2 Recruitment deviations

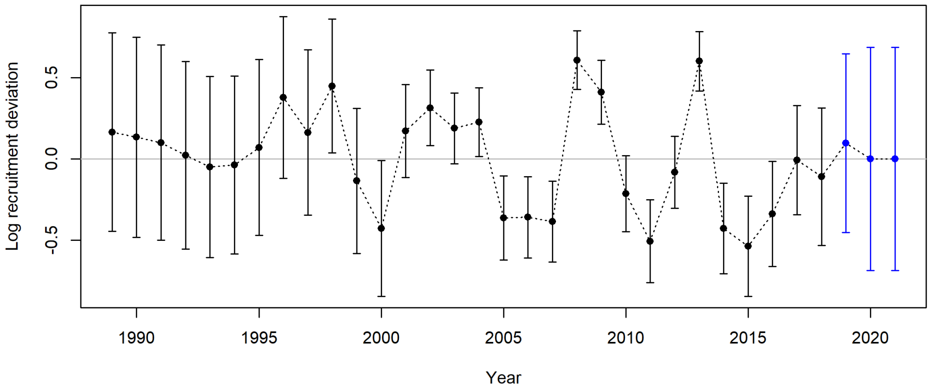


Figure B.7: Recruitment deviations with 95% confidence intervals for Spanish mackerel for the base case scenario

B.2.3 Harvest rate

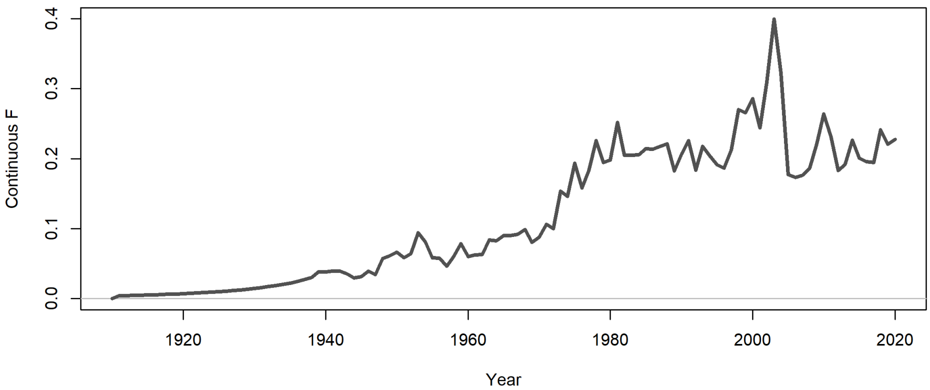


Figure B.8: Harvest rate for Spanish mackerel for the base case scenario

B.2.4 Likelihood profiles

Section 3.2.8 of Bessell-Browne et al. (2020) describes the importance and interpretation of likelihood profiles in stock assessments analysis.

The likelihood profile shows that two optima—one global and one local—exist within the appropriate range of virgin recruitment values. Depending on the initial values and priors used to configure the parameters, the model tended towards one of the two optima. Figure B.9 and Figure B.10 showed that, of the two optima, the lower virgin recruitment ($\ln(R_0) = 13.25$ for base case and $\ln(R_0) = 13.0$ for scenario 4) was more likely as the associated change in log likelihood was closer to zero.

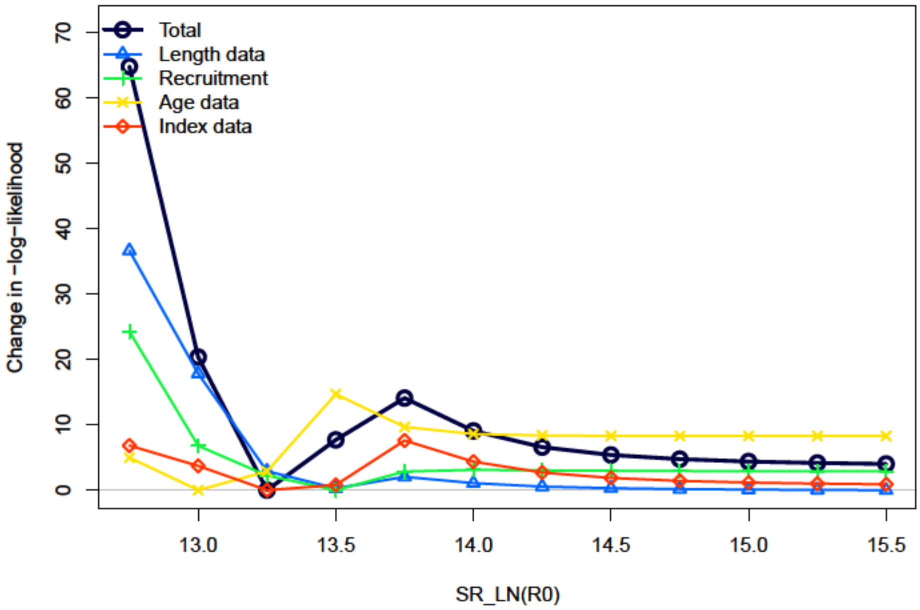


Figure B.9: Likelihood profile for SR_LN(R0) (virgin recruitment) for the base case scenario with steepness (h) fixed at 0.45

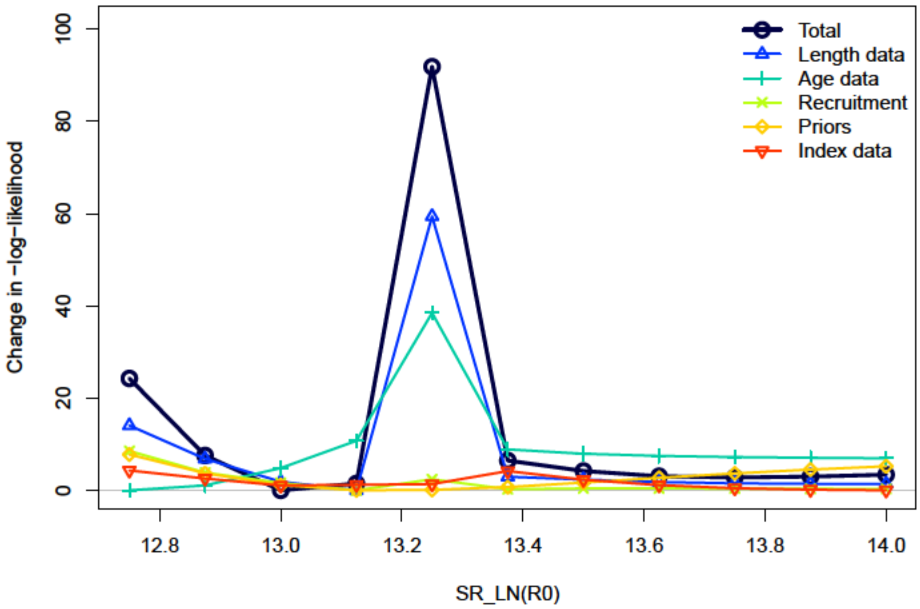


Figure B.10: Likelihood profile for SR_LN(R0) (virgin recruitment) for scenario 4 with steepness (h) fixed at 0.55

B.2.5 Spawning output vs recruitment

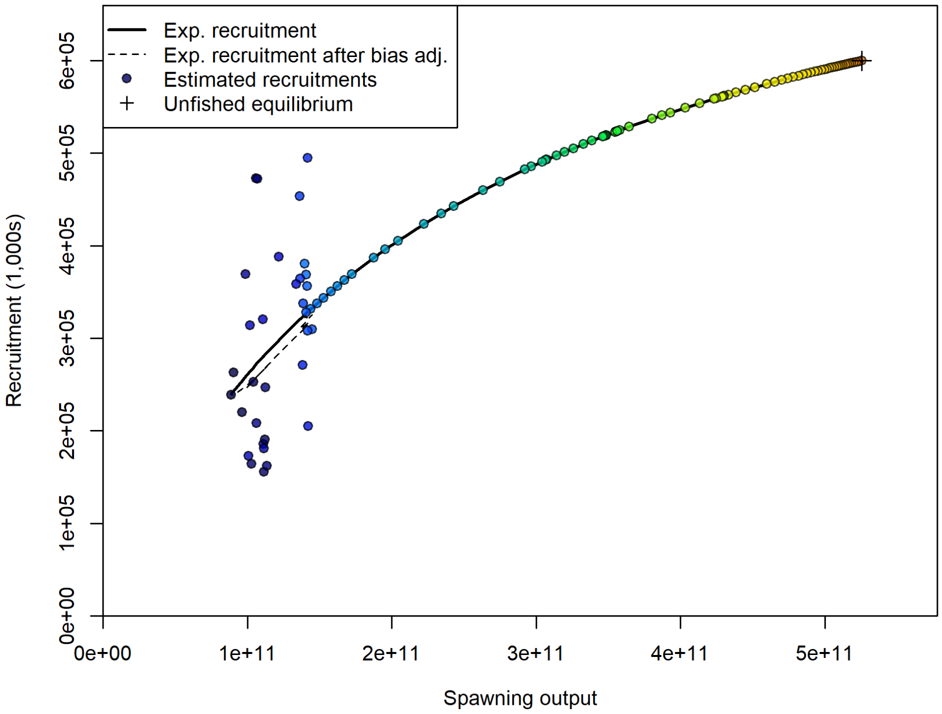


Figure B.11: Stock-recruit curve; point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years

Appendix C Additional catch rate outputs and diagnostic plots

Additional outputs from catch rate standardisation, including model summary statistics, diagnostic plots, predicted probability *p(c)* of commercially catching Spanish mackerel (overall and by latitude bands), and fishing power effect estimated from REML analysis are shown below to support discussion of the report.

Table C.1: Summary statistics for the binomial generalised linear model of Queensland commercial line fishing days

Regression analysis

Response variate:	ndaysS - when a Spanish mackerel was caught
Binomial totals:	Ndays - number of calendar days in a month
Distribution:	Binomial
Link function:	Logit
Fitted terms:	Constant + fishyear + latband + fishyear.latband + s1.latband + s2.latband + s3.latband + s4.latband + nACN.latband + windew + windns (FACTORIAL limit for expansion of formula = 2)
Submodels:	POL(windew; 2) POL(windns; 2)

Summary of analysis

Source	d.f.	deviance	mean deviance	deviance ratio	approx F pr.
Regression	595	64596.	108.565	46.77	<.001
Residual	5548	12877.	2.321		
Total	6143	77473.	12.612		

Percentage mean deviance accounted for 81.6
Percentage deviance accounted for 83.4
Adjusted r-squared statistic (based on deviance) 0.816
R-squared statistic (based on deviance) 0.834
Akaike information criterion cannot be estimated.
Schwarz Bayes information criterion cannot be estimated.

Wald tests for dropping terms

Term	Wald statistic	d.f.	F statistic	F pr.
fishyear.latband	1176.6	465	2.53	<0.001
latband.s1	466.3	16	29.15	<0.001
latband.s2	359.3	16	22.45	<0.001
latband.s3	108.1	16	6.75	<0.001
latband.s4	42.8	16	2.67	<0.001
latband.nACN	2563.5	16	160.22	<0.001
windns	45.6	1	45.57	<0.001
windns2	0.5	1	0.51	0.473
windew	4.2	1	4.17	0.041
windew2	0.1	1	0.09	0.764

Table C.2: Summary statistics for the linear mixed model of Queensland commercial line fishing days

REML variance components analysis

Fixed model:	Constant + fishyear + latband2* + fishyear.latband2 + latband2 s1 + latband2.s2 + latband2.s3 + latband2.s4 + latband2.s5 + latband2.s6 + latband2.lunar + latband2.lunar_adv + windew + windew2 + windns + windns2
Random model:	acn
Number of units:	191128

Full fishing power					Square-root fishing power (half fishing power)			
Estimated variance components					**Estimated variance components**			
Random term	component	s.e.			Random term	component	s.e.	
acn	0.3601	0.0193			acn	0.3607	0.0193	
Residual variance model					**Residual variance model**			
Term	Sigma2	s.e.			Term	Sigma2	s.e.	
Residual	0.837	0.0027			Residual	0.836	0.0027	
Deviance: -2*Log-Likelihood					**Deviance: -2*Log-Likelihood**			
Deviance	d.f.				Deviance	d.f.		
163330.79	190482				163264.46	190482		

Dropping individual terms from full fixed model (Full fishing power | Square-root fishing power)

Fixed term	Wald statistic	n.d.f.	F statistic	F pr	Wald statistic	n.d.f.	F statistic	F pr
fishyear.latband2	5251 97	465	11.29	<0.001	5106.46	465	10.98	<0.001
latband2 s1	2616 86	16	163.55	<0.001	2622.06	16	163.88	<0.001
latband2 s2	2033.09	16	127.07	<0.001	1987.14	16	124.2	<0.001
latband2 s3	178.75	16	11.17	<0.001	178.42	16	11.15	<0.001
latband2 s4	511.51	16	31.97	<0.001	516.54	16	32.28	<0.001
latband2 s5	477.82	16	29.86	<0.001	477	16	29.81	<0.001
latband2 s6	69.16	16	4.32	<0.001	67.4	16	4.21	<0.001
latband2.lunar	254.06	16	15.88	<0.001	254.68	16	15.92	<0.001
latband2.lunar adv	521.76	16	32.61	<0.001	522.38	16	32.65	<0.001
windew	6.87	1	6.87	0.009	6.64	1	6.64	0.01
windew2	28.71	1	28.71	<0.001	28.69	1	28.69	<0.001
windns	230.98	1	230 98	<0.001	230.64	1	230.64	<0.001
windns2	14.89	1	14.89	<0.001	14.81	1	14.81	<0.001

* latband2 grouped the most southern (lat11 and lat12) and northern latbands (lat28 and 29) together.

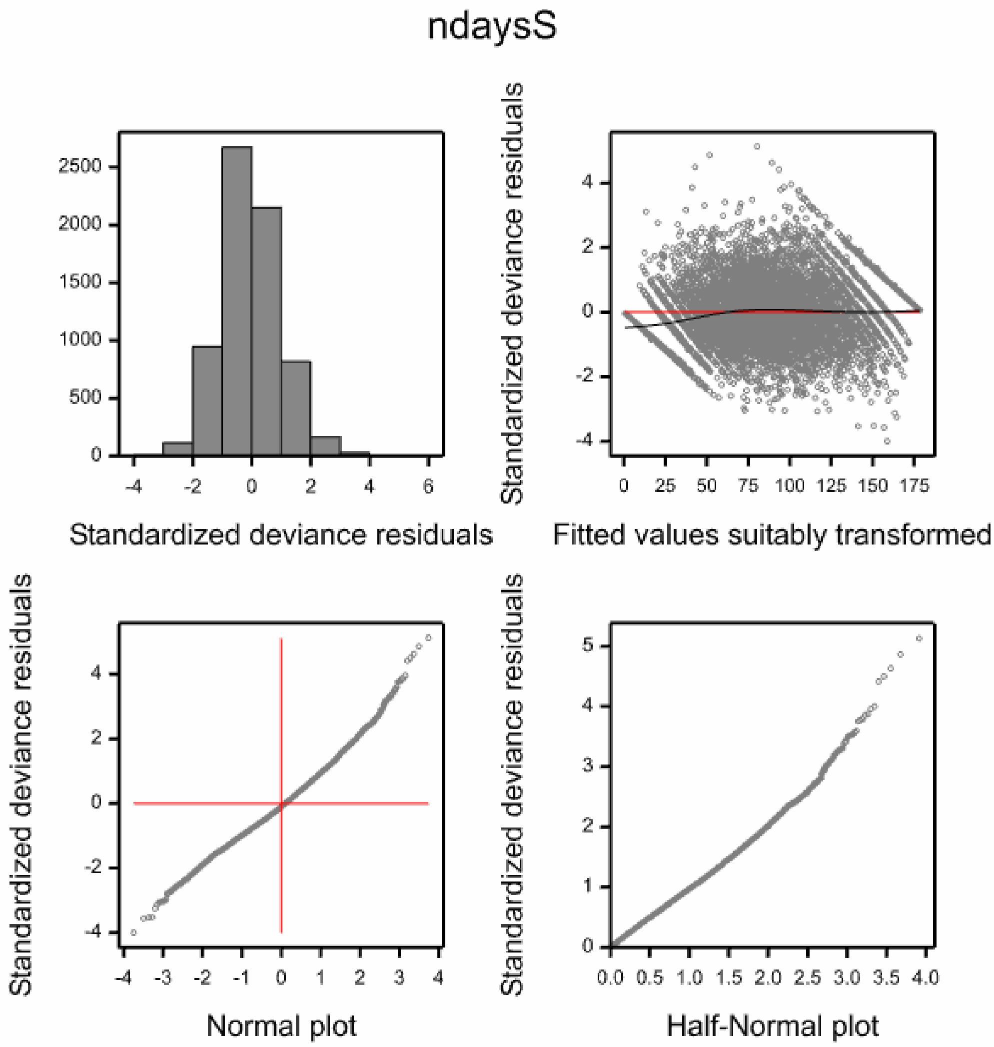


Figure C.1: Residual diagnostic plots for the binomial model analysis

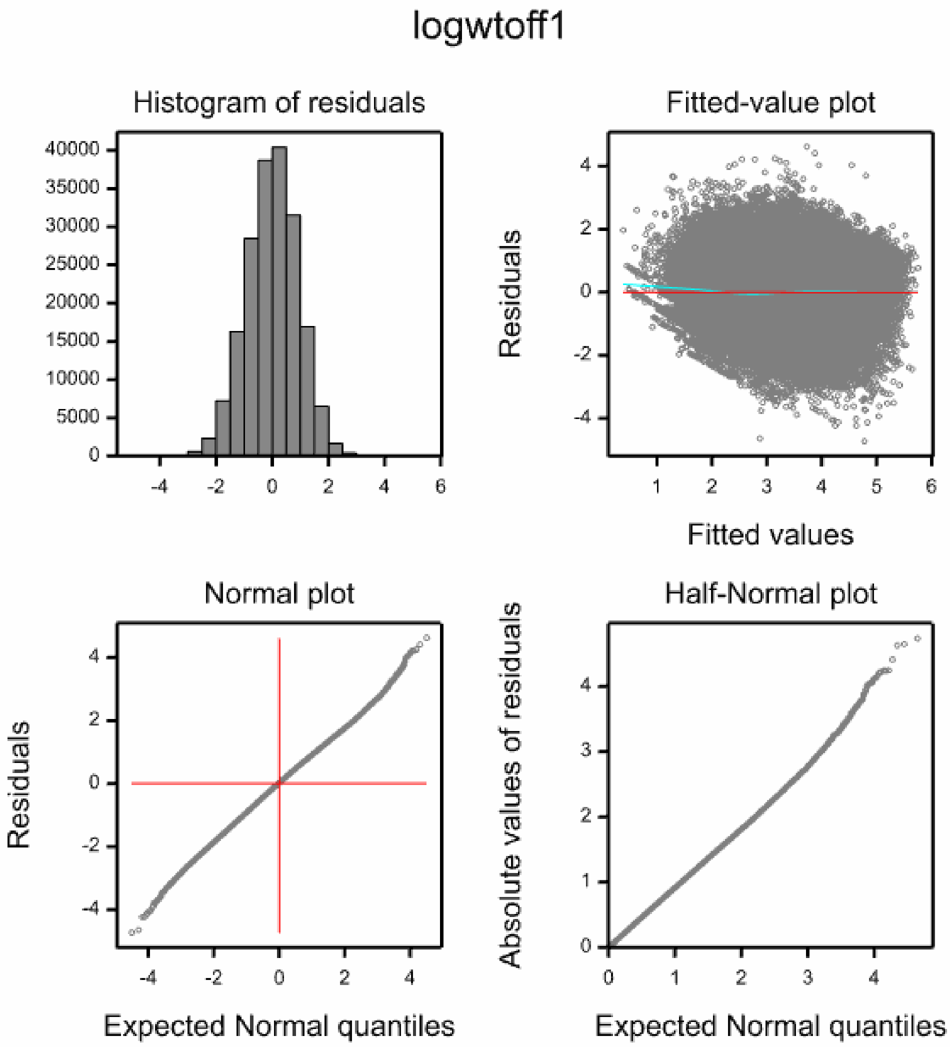


Figure C.2: Residual diagnostic plots for the linear mixed model assuming half fishing power increase (base case)

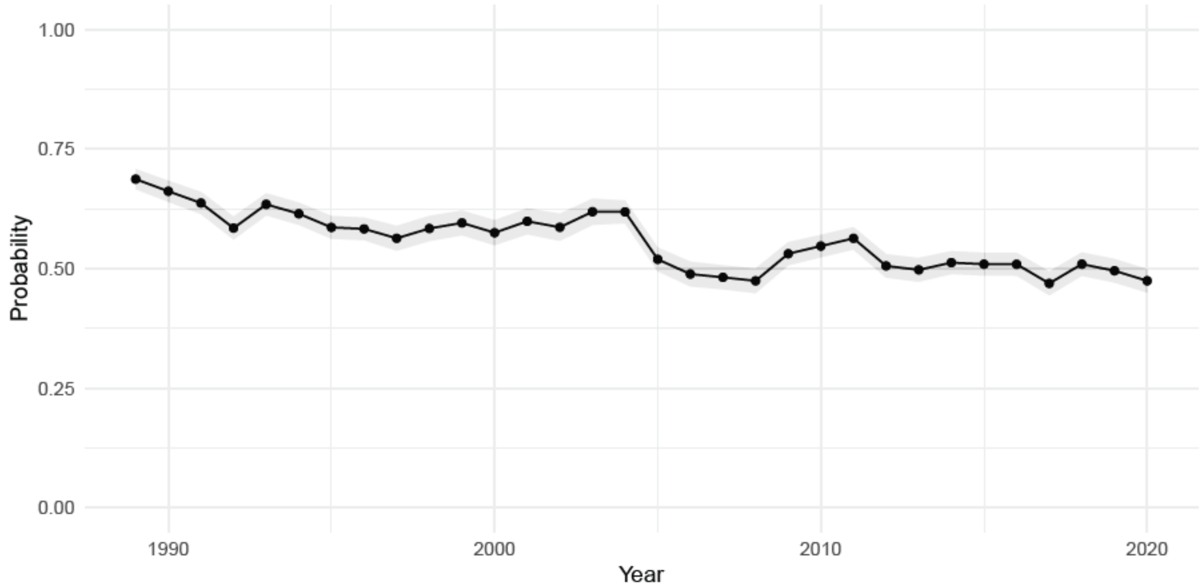


Figure C.3: Probability of commercially harvesting Spanish mackerel by fishing year—the error bars represent ± 2 standard errors on mean predictions

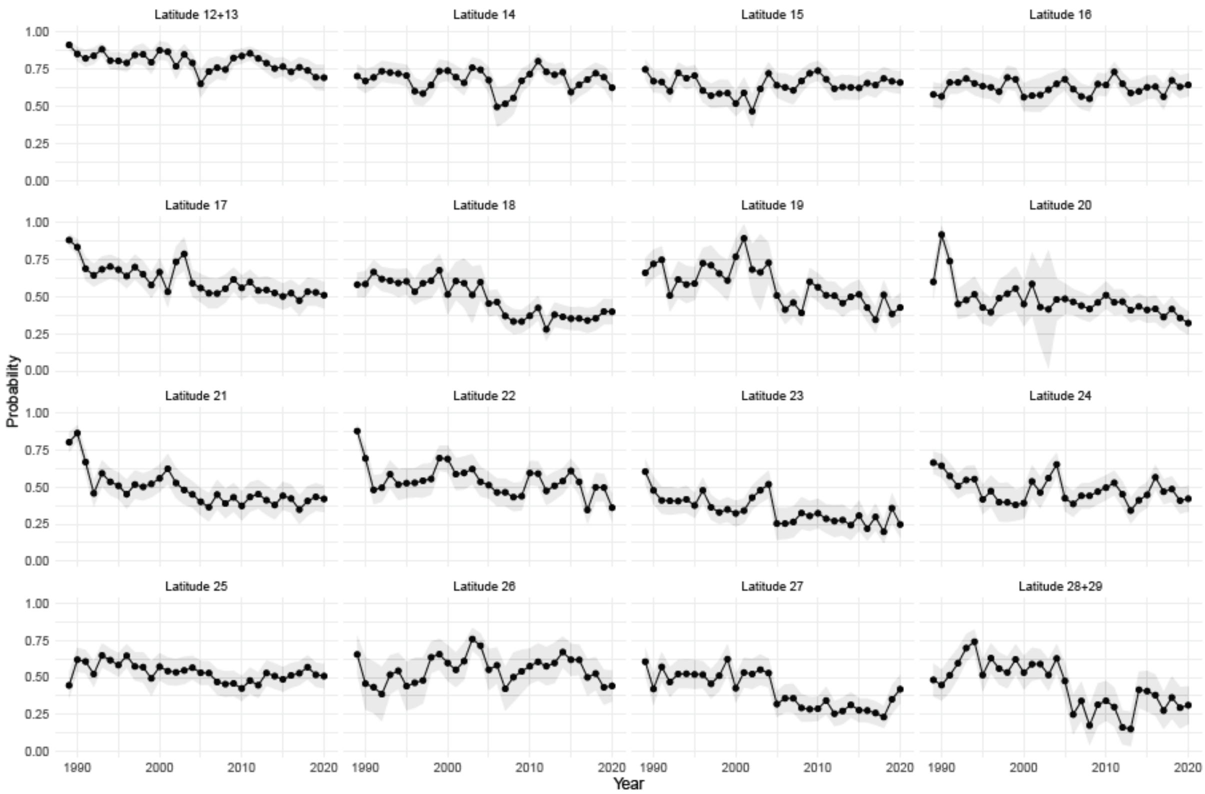


Figure C.4: Probability of commercially harvesting Spanish mackerel by latitude and fishing year—the error bars represent ± 2 standard errors on mean predictions

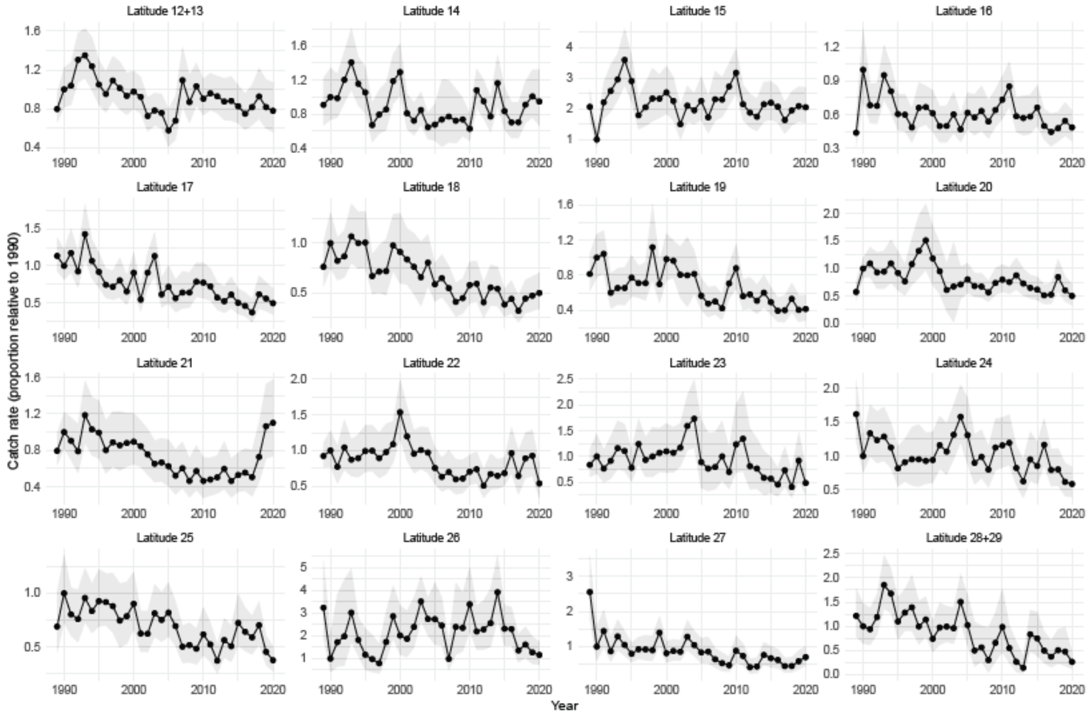


Figure C.5: Standardised mean catch rates of Spanish mackerel by latitude band and fishing year for the half fishing power with probability adjustment (with 95% confidence interval bands)—catch rates were scaled proportionally, with year 1990 = 1

Figure C.6 shows vessel-operation's mean catch efficiency for the base case model (half fishing power). The commercial sector's mean fishing power for Spanish mackerel was estimated to be about 27% higher in 2020 compared to 1989.

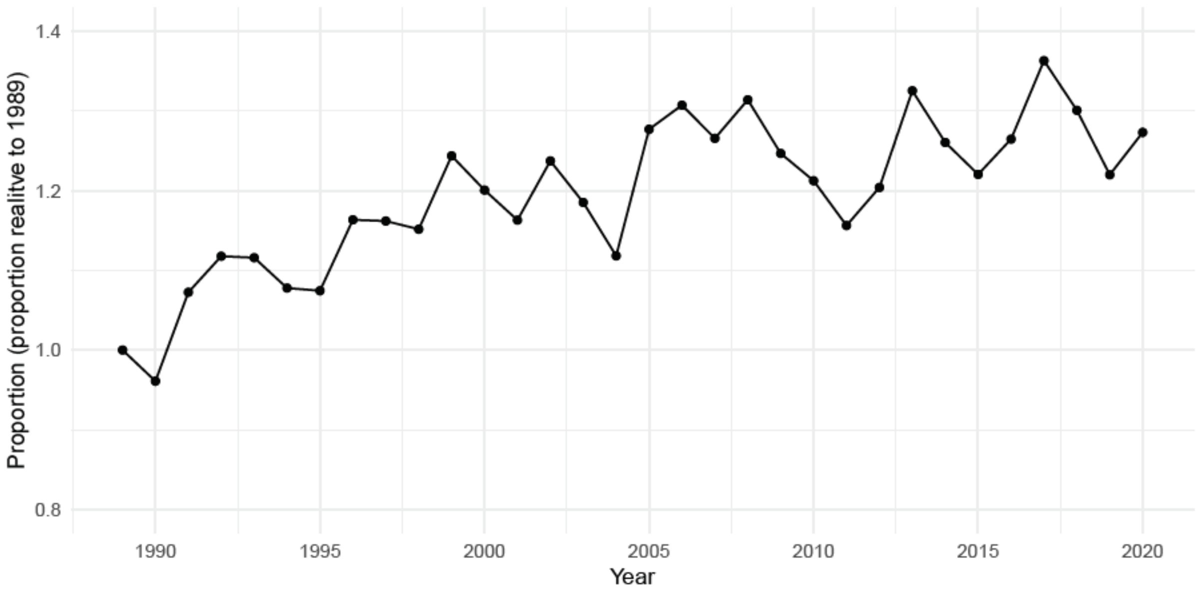


Figure C.6: Estimated Queensland commercial sector mean fishing power as calculated from the vessel-acn random-model parameters in REML

Appendix D Age compositions

Monitoring of annual fish age-length structures of Spanish mackerel, across east coast Queensland waters, has been continuous since 2005 (Figure D.1). The fish age data showed Spanish mackerel live up to 26 years of age. Most of the fish sampled were aged in the 1+ to 8+ cohort age-groups. Few older fish were present.

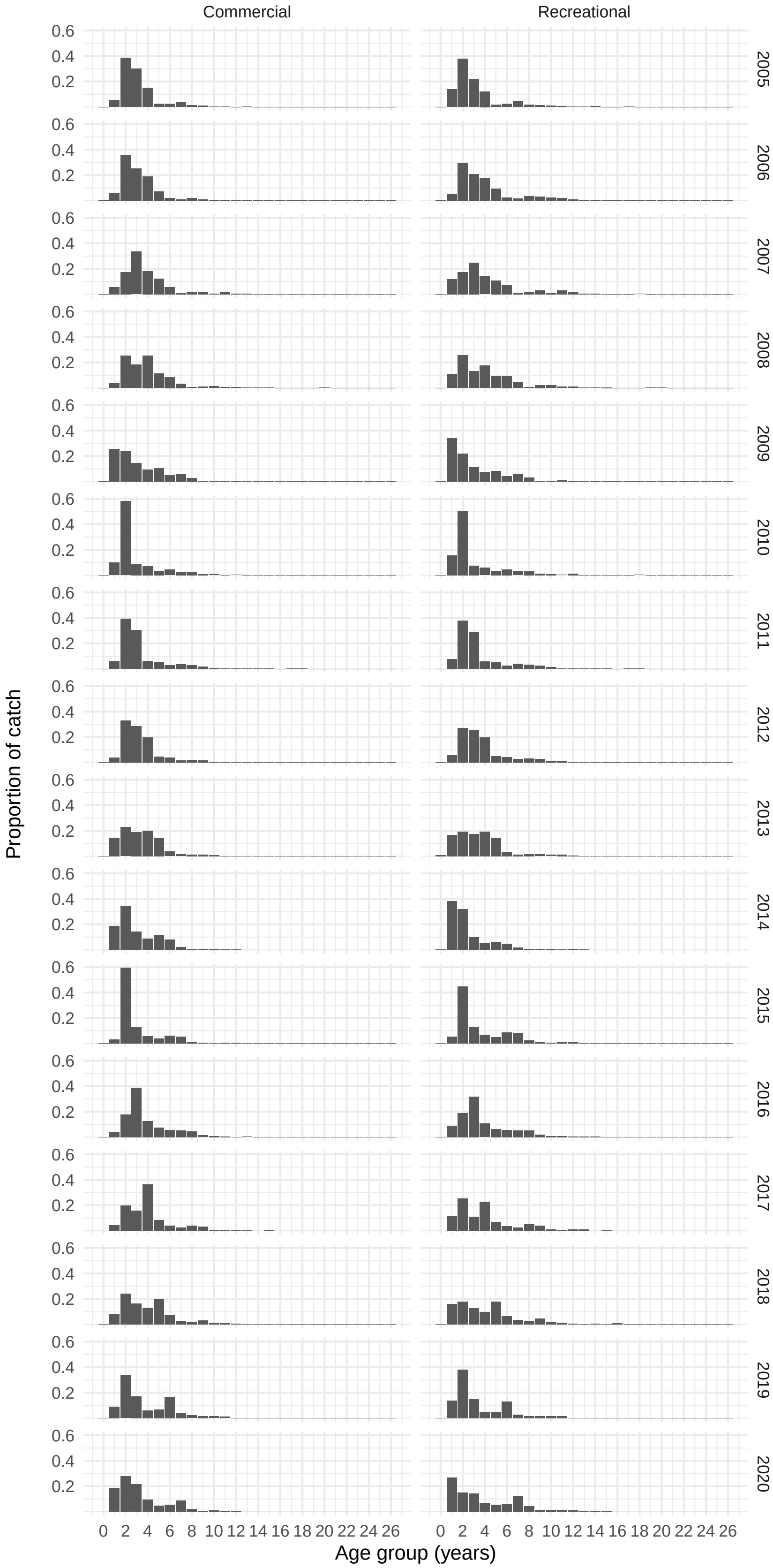


Figure D.1: Annual age compositions of Spanish mackerel for line-caught fish between 2005 and 2020

Zero-plus and one-plus year old Spanish mackerel were not fully vulnerable to fishing. Their frequency varied between years, but do indicate strengths of recruitment of young fish and their changed vulnerability from year to year. The data suggested pulses of recruitment resulting from spawning events in 2008 and 2013. This can be seen from the frequency of 1+ year old fish in 2009 flowing through to be 5+ year old fish in 2013 (Figure D.1). Similarly and more recently, 1+ year old fish in 2014 flowed through to be 3+ year old fish in 2016 (Figure D.1). The patterns of recruitment were evident in the data from both the commercial and recreational fishing sectors.

For each fishing sector and year, the declines in the age frequency of Spanish mackerel from 2+ years were modelled using a simple catch-curve (Figure D.2; log-linear Poisson model). The slope estimates were averaged over years to provide a rough measure of annual fish total mortality Z; smoothing out annual recruitment variation. The mean estimates were 0.40 year^{-1} and 0.48 year^{-1} from the recreational and commercial fishing data respectively (s.e. 0.019 and 0.027). On average, estimates of fish mortality from the commercial sector's data were higher, likely due to the difference in size and therefore age of fish targeted by each sector. The commercial estimate was near the limit reference point of 2 $\times$ natural mortality (M); assuming M = 0.27 year^{-1}); 1.5 $\times$ M was considered a sustainable target reference point for pelagic fish such as Spanish mackerel (Welch et al. 2002).

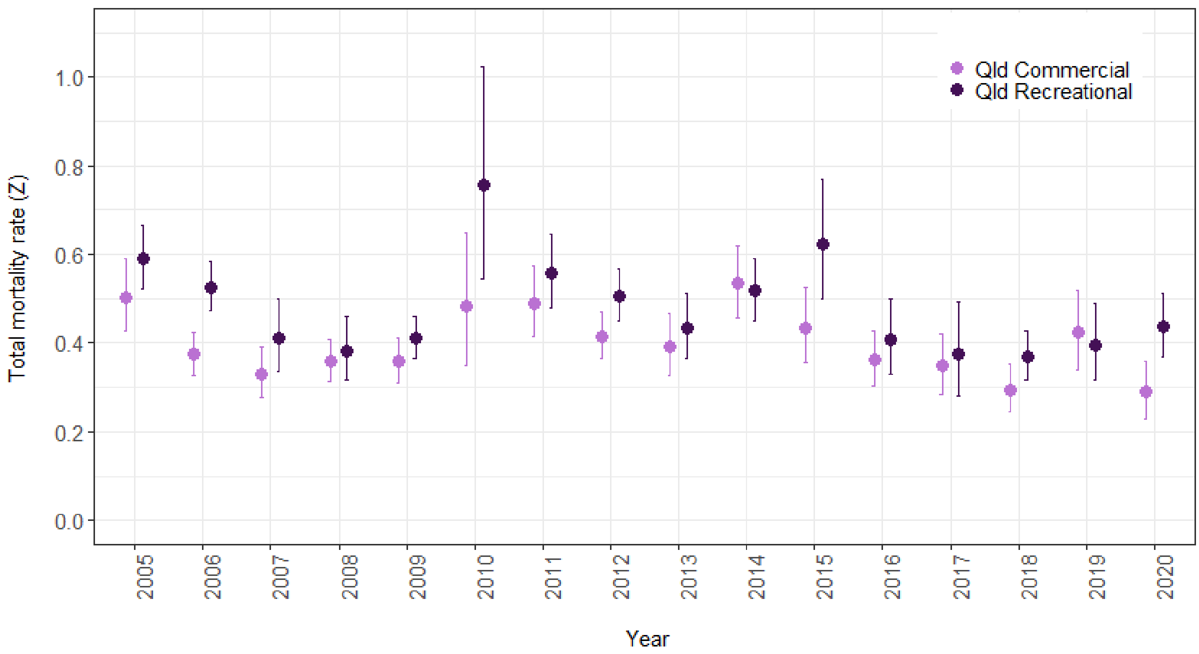


Figure D.2: Annual total mortality estimate (Z) of east coast Spanish mackerel for commercial and recreational sectors

Appendix E Results of sensitivity tests and scenarios

This chapter presents the outputs of the model and goodness-of-fit plots for scenarios 2 to 8.

E.1 Scenario 2

Scenario 2 was identical to the base case except steepness, h, was fixed at 0.35 instead of 0.45.

Table E.1: Stock Synthesis parameter estimates for the scenario 2 population model for Spanish mackerel

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
Natural mortality	0.33	3	0.01	0.5	0.29	0.01
Length at age 1 (FL_1) female	66.75	1	30	90	72	1.41
Length at maximum age (FL_{inf}) female	130.2	1	100	180	140	2.4
von Bertalanffy growth parameter (κ) female	0.29	1	0.1	0.4	0.22	0.03
Coefficient of variation in length at age 1 female	0.08	4	0.01	0.3	0.12	0.01
Coefficient of variation in length at maximum age female	0.07	4	0.01	0.2	0.14	0.01
Length at age 1 (FL_1) male	65.92	1	30	85	70	1.3
Length at maximum age (FL_{inf}) male	114.27	1	100	200	120	1.33
von Bertalanffy growth parameter (κ) male	0.34	1	0.1	0.45	0.21	0.03
Coefficient of variation in length at age 1 male	0.08	4	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age male	0.04	4	0.01	0.2	0.12	0
Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1911)	13.82	1	10	14.25	13.79	0.05
Commercial selectivity inflection (cm)	81.57	2	30	120	60	0.93
Commercial selectivity width (cm)	11.56	2	0	20	0.5	1.34

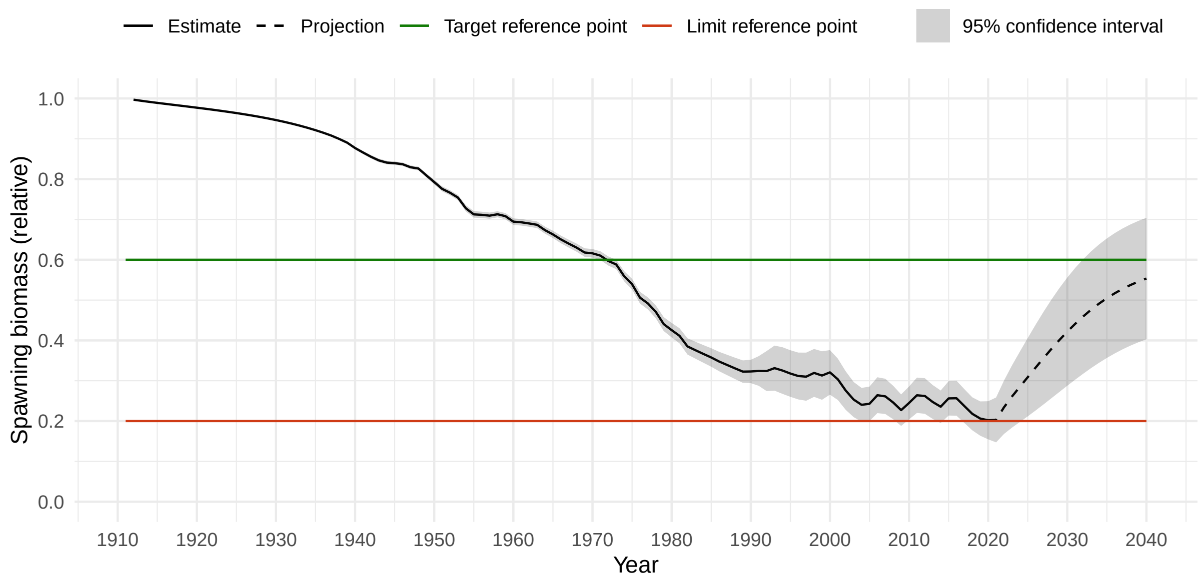


Figure E.1: Predicted spawning biomass trajectory relative to virgin for Spanish mackerel, from 1911 to 2040, for scenario 2

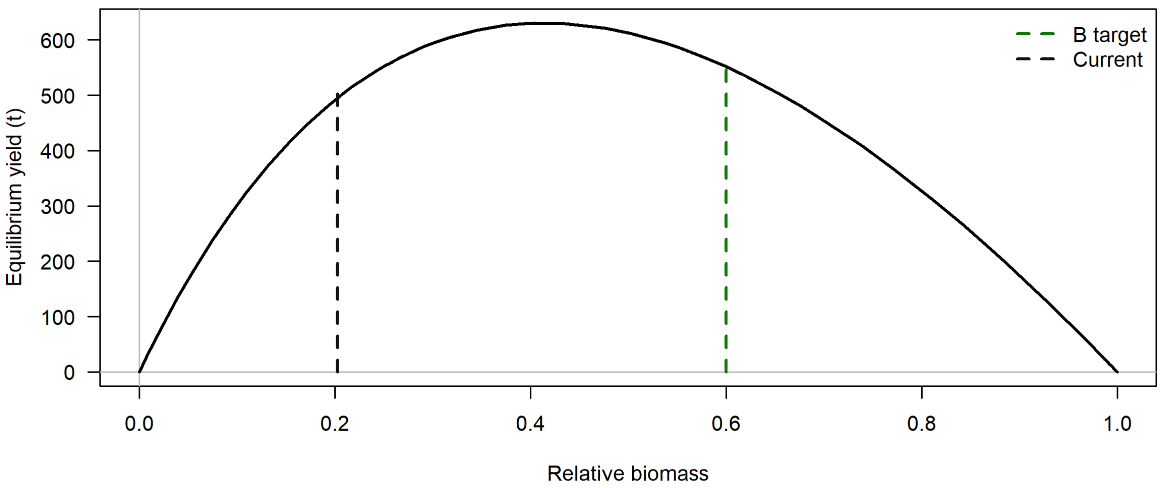


Figure E.2: Equilibrium yield curve for Spanish mackerel for scenario 2

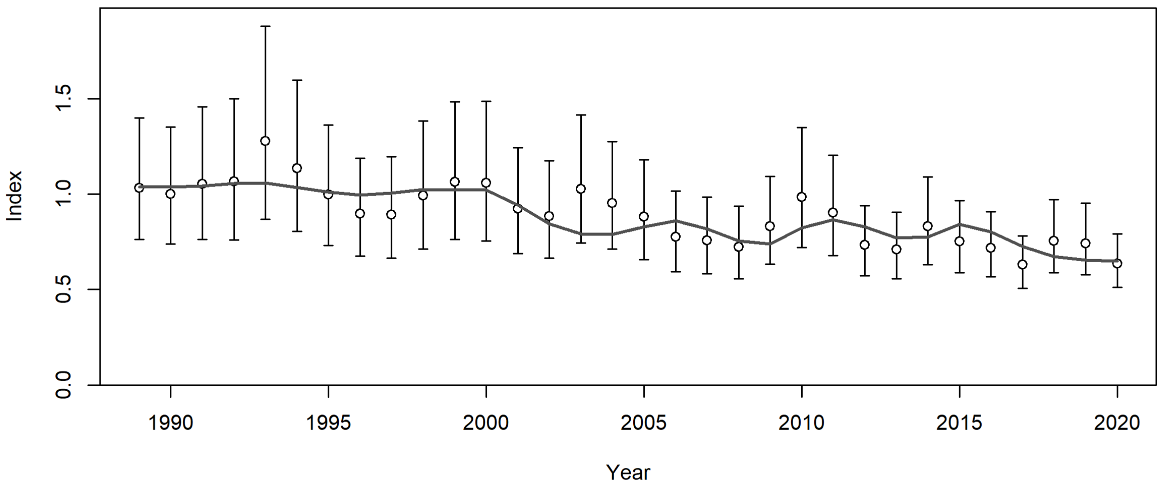


Figure E.3: Model predictions (grey line) to commercial catch rates for Spanish mackerel for scenario 2

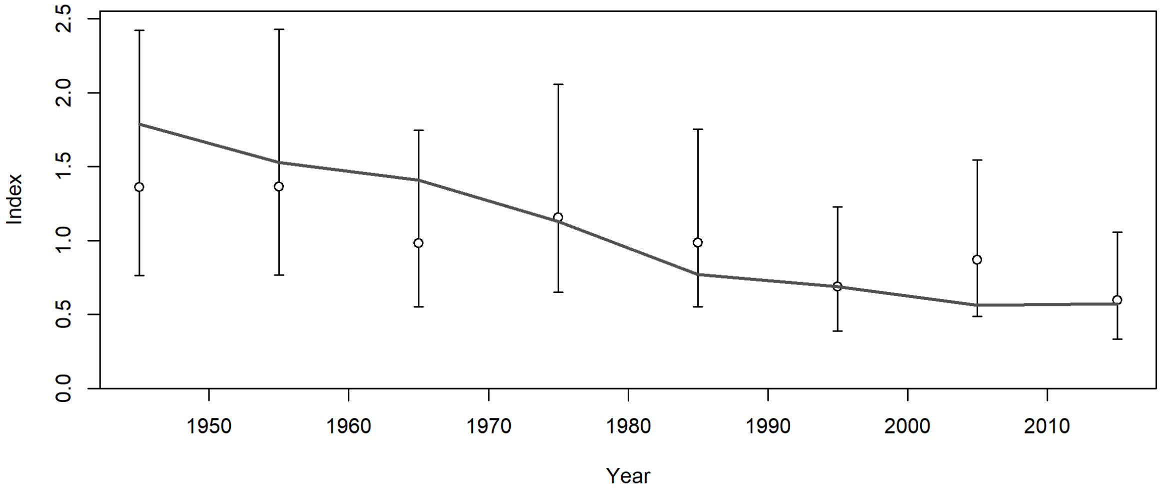


Figure E.4: Model predictions (grey line) to historical decadal catch rates for Spanish mackerel for scenario 2

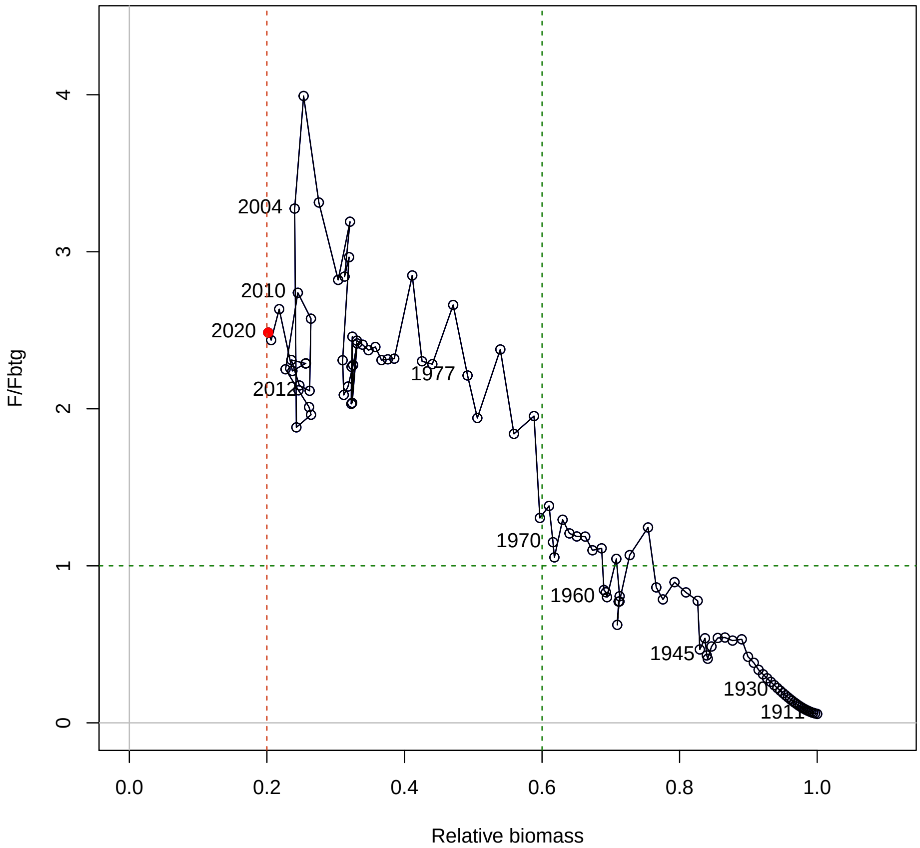


Figure E.5: Phase plot for Spanish mackerel for scenario 2

The horizontal axis is the biomass ratio of Queensland Spanish mackerel relative to unfished and the vertical axis is the fishing mortality relative to the fishing mortality which would produce the *Sustainable Fisheries Strategy* biomass target of 60%. The red dashed vertical line is the limit reference point (20% relative biomass) and the green dashed vertical line is the target reference point (60% relative biomass)

E.2 Scenario 3

Scenario 3 was identical to the base case except steepness, h, was fixed at 0.55 instead of 0.45.

Table E.2: Stock Synthesis parameter estimates for the scenario 3 population model for Spanish mackerel

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
Natural mortality	0.23	2	0.01	0.5	0.29	0.01
Length at age 1 (FL_1) female	67	3	30	90	72	1.38
Length at maximum age (FL_{inf}) female	130.16	3	100	180	140	2.38
von Bertalanffy growth parameter (κ) female	0.29	3	0.1	0.4	0.22	0.03
Coefficient of variation in length at age 1 female	0.07	5	0.01	0.3	0.12	0.01
Coefficient of variation in length at maximum age female	0.07	5	0.01	0.2	0.14	0.01
Length at age 1 (FL_1) male	65.99	3	30	85	70	1.27
Length at maximum age (FL_{inf}) male	114.08	3	100	200	120	1.27
von Bertalanffy growth parameter (κ) male	0.35	3	0.1	0.45	0.21	0.03
Coefficient of variation in length at age 1 male	0.08	5	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age male	0.04	5	0.01	0.2	0.12	0
Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1911)	12.93	1	12.5	13.25	12.97	0.04
Commercial selectivity inflection (cm)	81.03	4	30	120	60	0.88
Commercial selectivity width (cm)	11.36	4	0	20	0.5	1.35

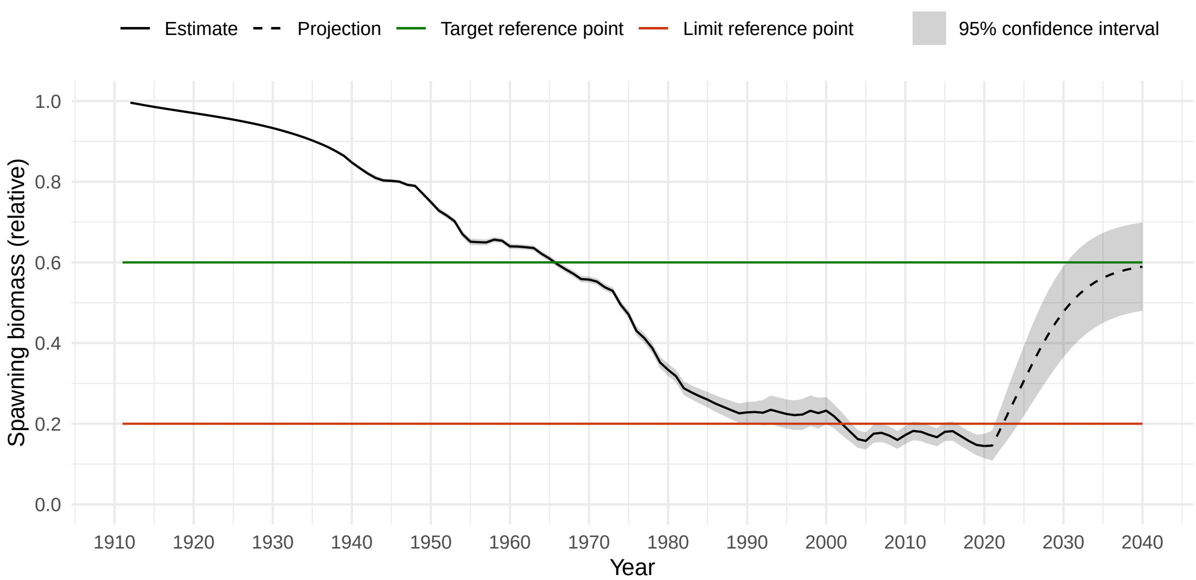


Figure E.6: Predicted spawning biomass trajectory relative to virgin for Spanish mackerel, from 1911 to 2040, for scenario 3

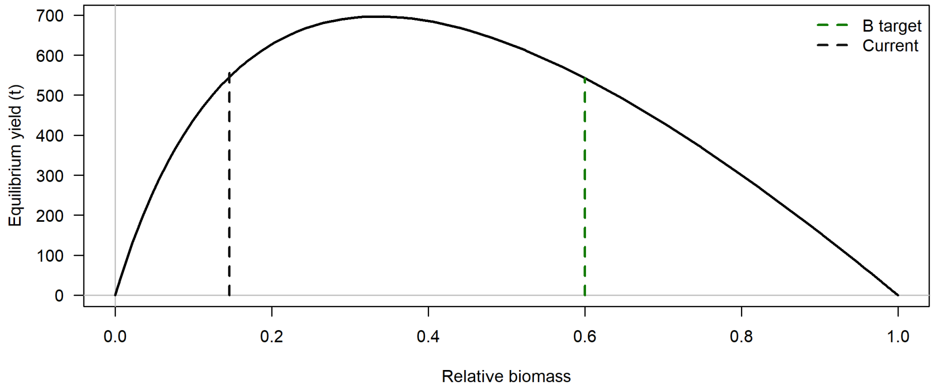


Figure E.7: Equilibrium yield curve for Spanish mackerel for scenario 3

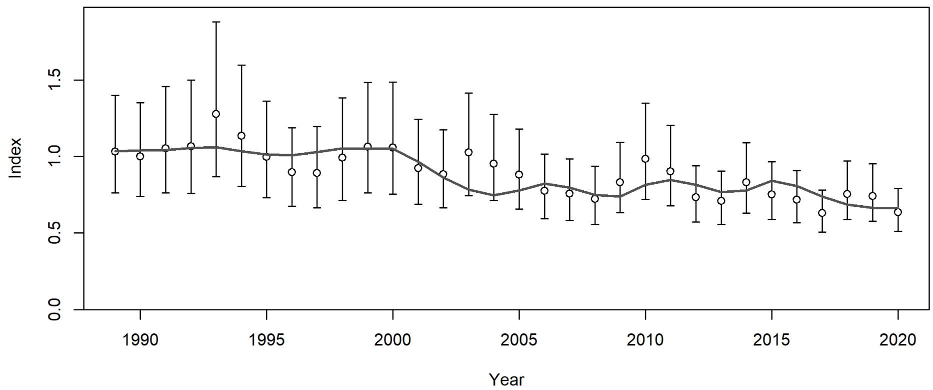


Figure E.8: Model predictions (grey line) to commercial catch rates for Spanish mackerel for scenario 3

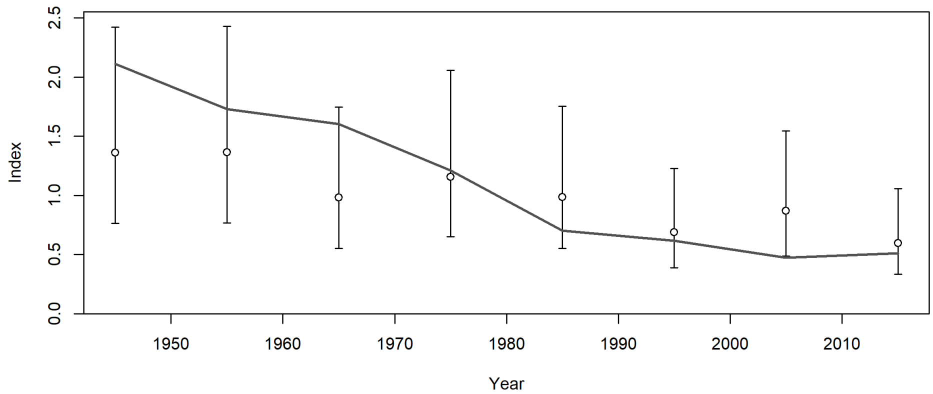


Figure E.9: Model predictions (grey line) to historical decadal catch rates for Spanish mackerel for scenario 3

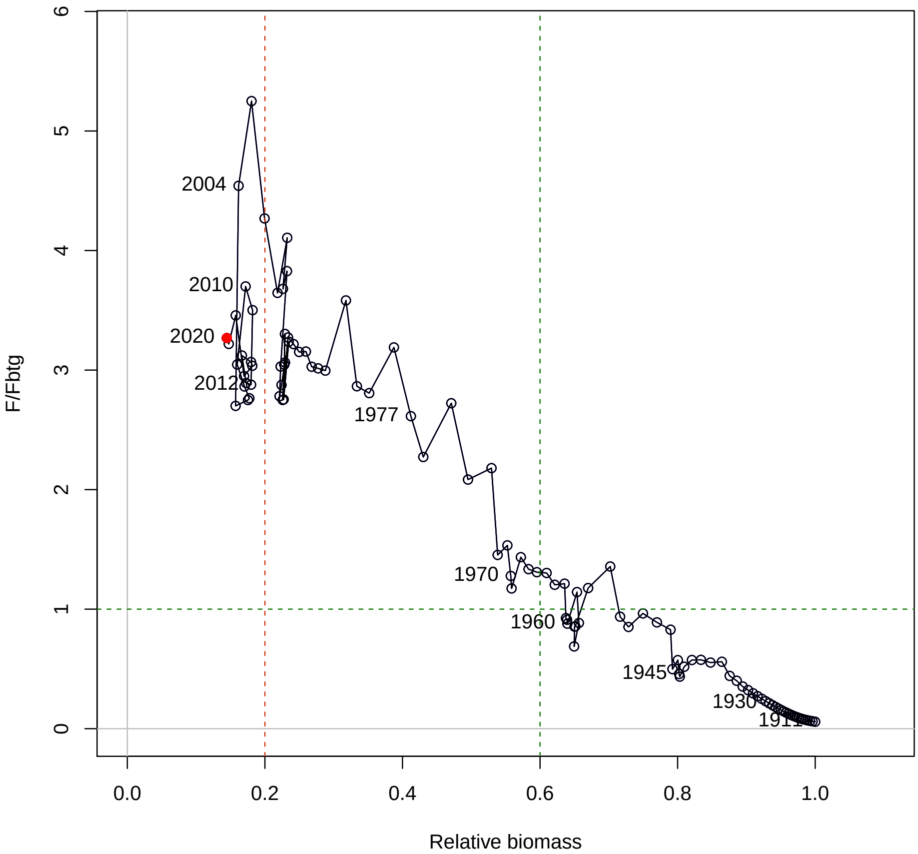


Figure E.10: Phase plot for Spanish mackerel for scenario 3

The horizontal axis is the biomass ratio of Queensland Spanish mackerel relative to unfished and the vertical axis is the fishing mortality relative to the fishing mortality which would produce the *Sustainable Fisheries Strategy* biomass target of 60%. The red dashed vertical line is the limit reference point (20% relative biomass) and the green dashed vertical line is the target reference point (60% relative biomass)

E.3 Scenario 4

Scenario 4 was identical to the base case except the catch rate modelling did not include a probability model (i.e. the higher catch rate scenario was used), and steepness, h, was fixed at 0.55.

Table E.3: Stock Synthesis parameter estimates for the scenario 4 population model for Spanish mackerel

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
Natural mortality	0.26	2	0.01	0.5	0.29	0.01
Length at age 1 (FL_1) female	67.21	3	30	90	72	1.43
Length at maximum age (FL_{inf}) female	130.7	3	100	180	140	2.51
von Bertalanffy growth parameter (κ) female	0.28	3	0.1	0.4	0.22	0.03
Coefficient of variation in length at age 1 female	0.07	5	0.01	0.3	0.12	0.01
Coefficient of variation in length at maximum age female	0.07	5	0.01	0.2	0.14	0.01
Length at age 1 (FL_1) male	66.14	3	30	85	70	1.33
Length at maximum age (FL_{inf}) male	114.34	3	100	200	120	1.37
von Bertalanffy growth parameter (κ) male	0.34	3	0.1	0.45	0.21	0.03
Coefficient of variation in length at age 1 male	0.08	5	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age male	0.04	5	0.01	0.2	0.12	0
Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1911)	13.04	1	10	14.2	13	0.04
Commercial selectivity inflection (cm)	81.41	4	30	120	60	0.9
Commercial selectivity width (cm)	11.65	4	0	20	0.5	1.37

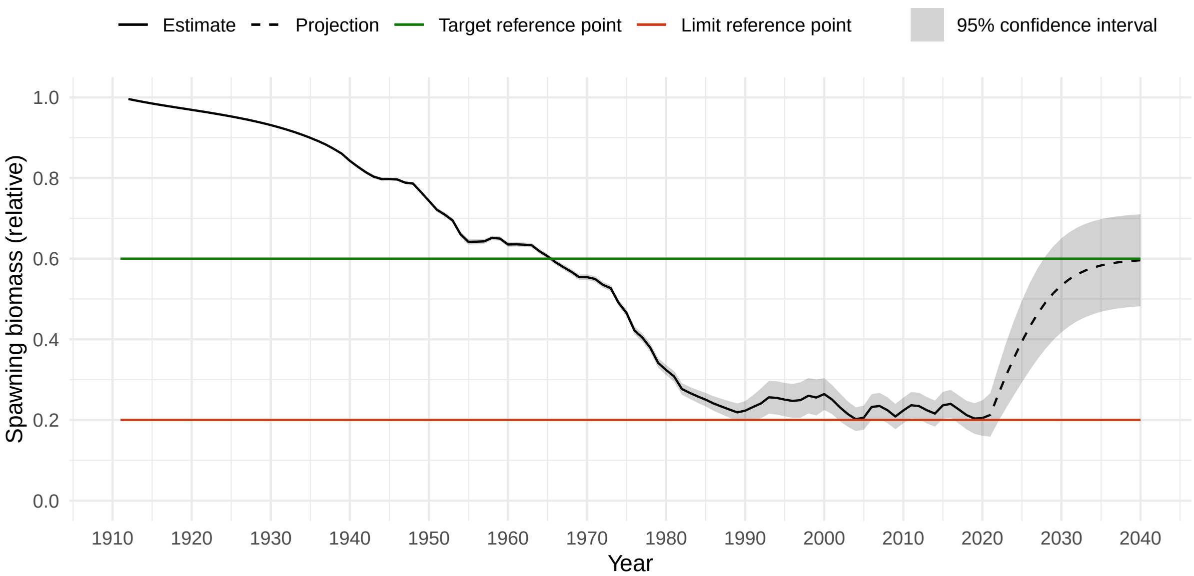


Figure E.11: Predicted spawning biomass trajectory relative to virgin for Spanish mackerel, from 1911 to 2040, for scenario 4

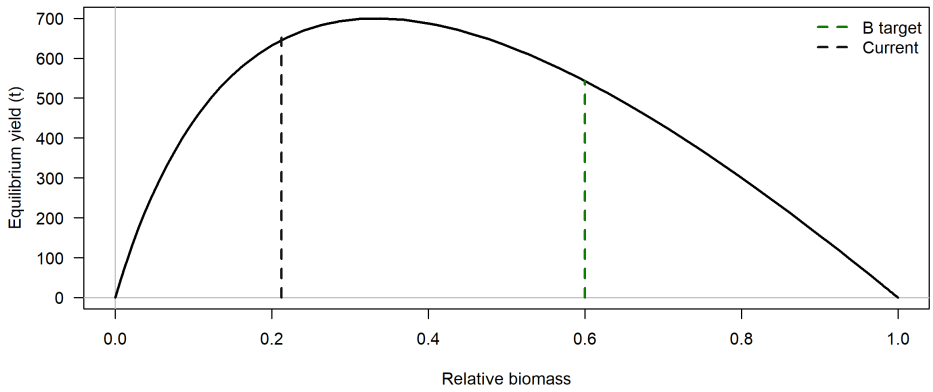


Figure E.12: Equilibrium yield curve for Spanish mackerel for scenario 4

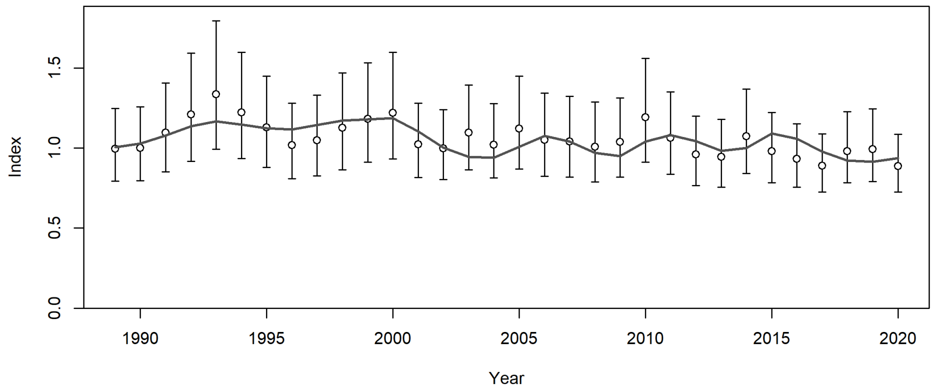


Figure E.13: Model predictions (grey line) to commercial catch rates for Spanish mackerel for scenario 4

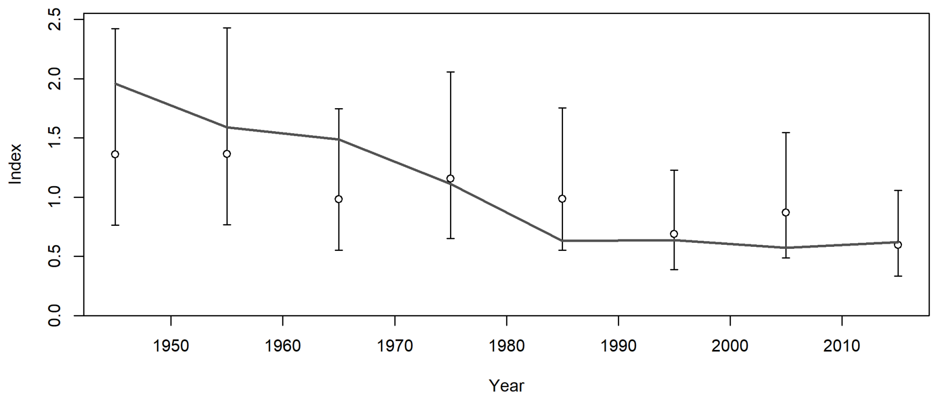


Figure E.14: Model predictions (grey line) to historical decadal catch rates for Spanish mackerel for scenario 4

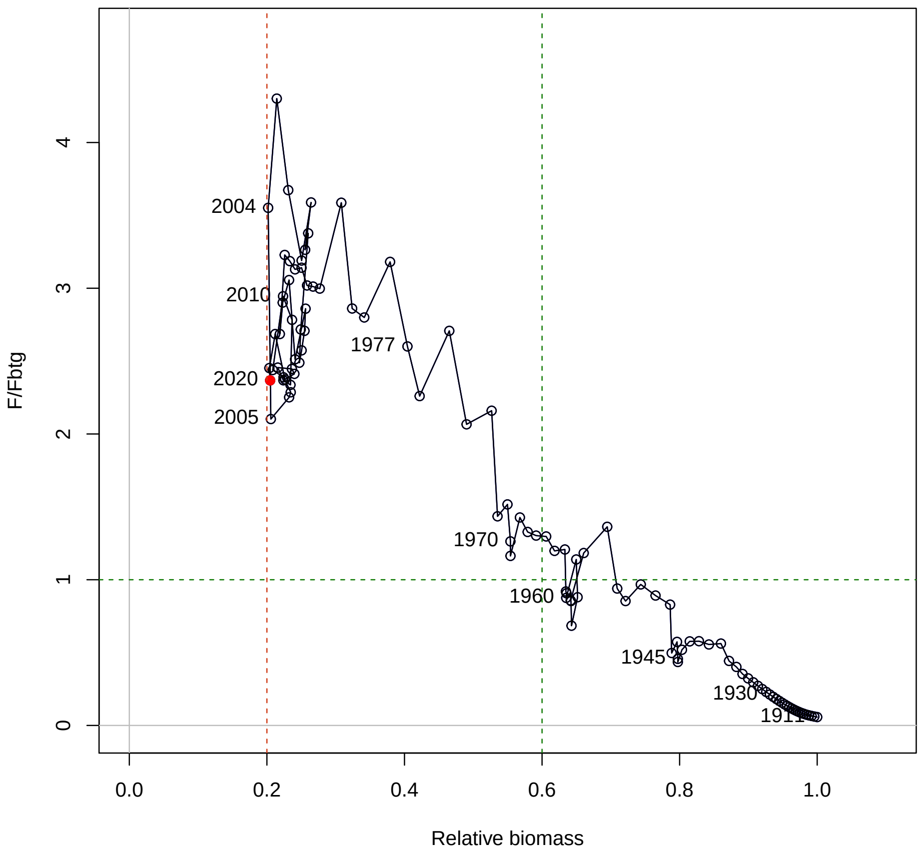


Figure E.15: Phase plot for Spanish mackerel for scenario 4

The horizontal axis is the biomass ratio of Queensland Spanish mackerel relative to unfished and the vertical axis is the fishing mortality relative to the fishing mortality which would produce the *Sustainable Fisheries Strategy* biomass target of 60%. The red dashed vertical line is the limit reference point (20% relative biomass) and the green dashed vertical line is the target reference point (60% relative biomass)

E.4 Scenario 5

Scenario 5 used the same input data as scenario 4, but estimating steepness h instead of fixing at 0.55. Natural mortality (M) was fixed at 0.33.

Table E.4: Stock Synthesis parameter estimates for the scenario 5 population model for Spanish mackerel

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
Length at age 1 (FL_1) female	66.86	3	30	90	72	1.46
Length at maximum age (FL_{inf}) female	130.39	3	100	180	140	2.48
von Bertalanffy growth parameter (κ) female	0.29	3	0.1	0.4	0.22	0.03
Coefficient of variation in length at age 1 female	0.07	5	0.01	0.3	0.12	0.01
Coefficient of variation in length at maximum age female	0.07	5	0.01	0.2	0.14	0.01
Length at age 1 (FL_1) male	66.06	3	30	85	70	1.34
Length at maximum age (FL_{inf}) male	114.42	3	100	200	120	1.38
von Bertalanffy growth parameter (κ) male	0.34	3	0.1	0.45	0.21	0.03
Coefficient of variation in length at age 1 male	0.08	5	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age male	0.04	5	0.01	0.2	0.12	0
Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1911)	13.66	1	10	15	13	0.07
Steepness (h) of Beverton-Holt function	0.39	2	0.2	1	0.55	0.02
Commercial selectivity inflection (cm)	81.61	4	30	120	60	0.92
Commercial selectivity width (cm)	11.65	4	0	20	0.5	1.36

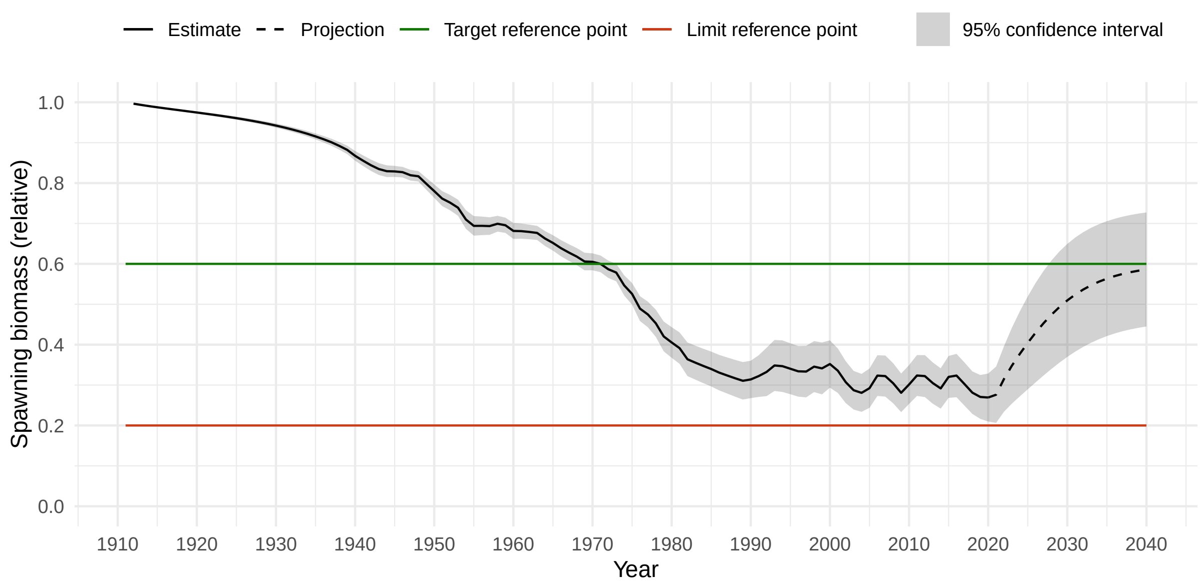


Figure E.16: Predicted spawning biomass trajectory relative to virgin for Spanish mackerel, from 1911 to 2040, for scenario 5

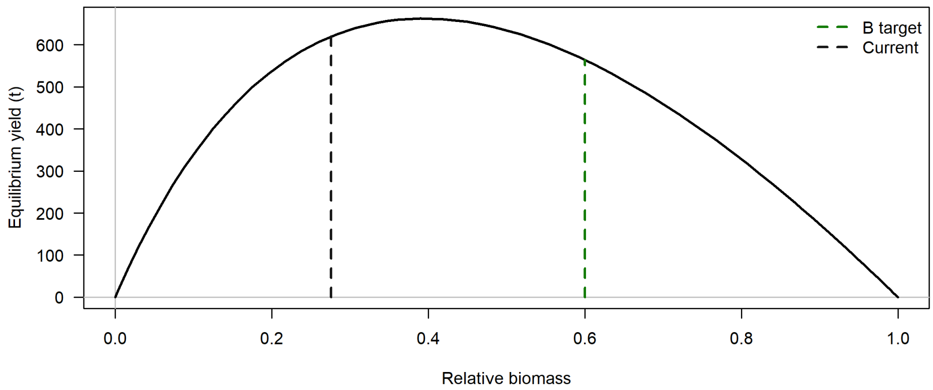


Figure E.17: Equilibrium yield curve for Spanish mackerel for scenario 5

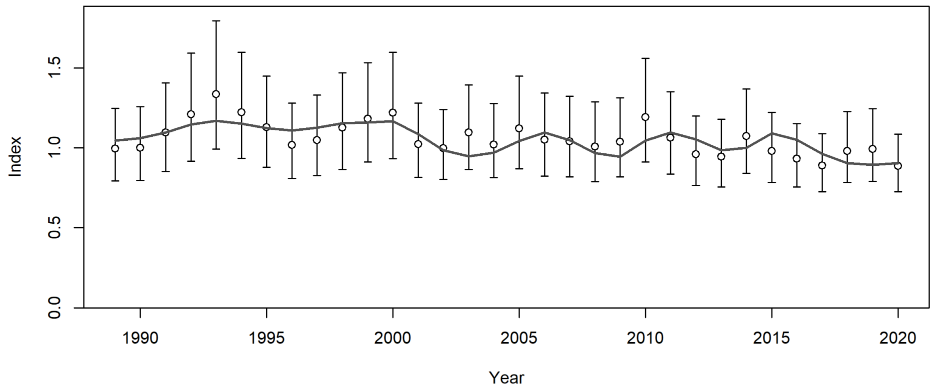


Figure E.18: Model predictions (grey line) to commercial catch rates for Spanish mackerel for scenario 5

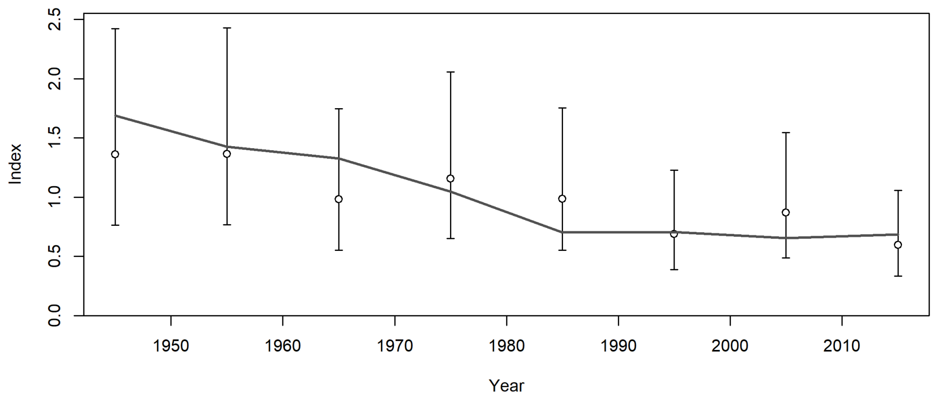


Figure E.19: Model predictions (grey line) to historical decadal catch rates for Spanish mackerel for scenario 5

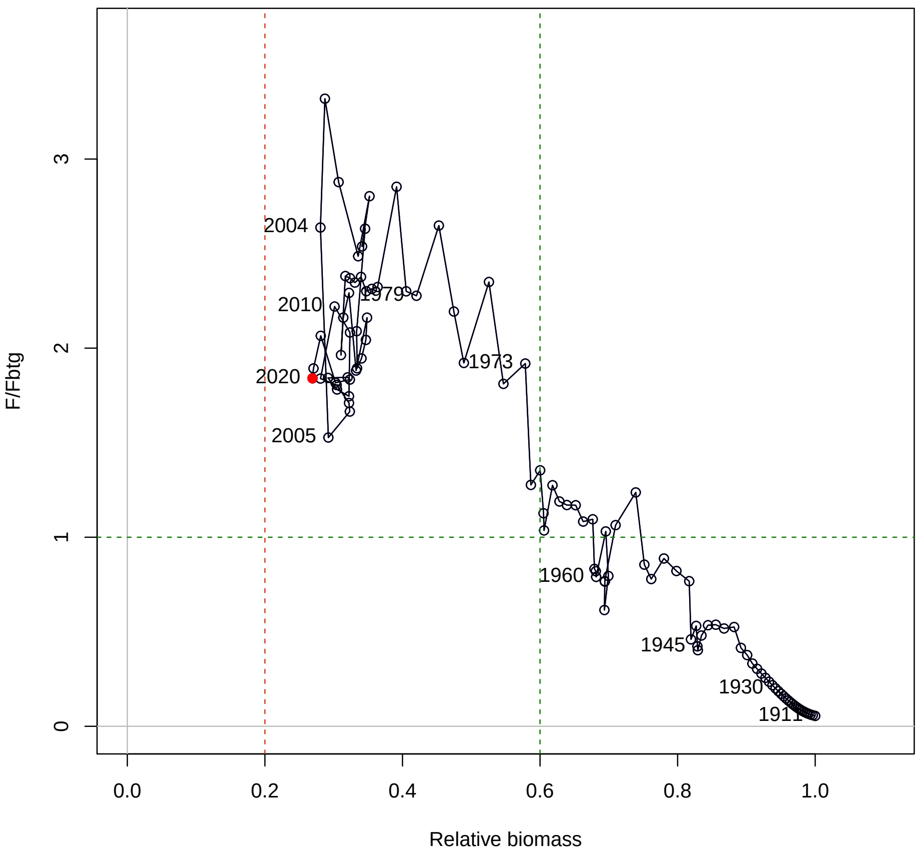


Figure E.20: Phase plot for Spanish mackerel for scenario 5

The horizontal axis is the biomass ratio of Queensland Spanish mackerel relative to unfished and the vertical axis is the fishing mortality relative to the fishing mortality which would produce the *Sustainable Fisheries Strategy* biomass target of 60%. The red dashed vertical line is the limit reference point (20% relative biomass) and the green dashed vertical line is the target reference point (60% relative biomass)

E.5 Scenario 6

Scenario 6 used the same input data as the base case except a probability adjustment was not included in the catch rate analysis, and steepness h was fixed at 0.65.

Table E.5: Stock Synthesis parameter estimates for the scenario 6 population model for Spanish mackerel

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
Natural mortality	0.37	3	0.01	0.5	0.29	0.02
Length at age 1 (FL_1) female	66.74	2	30	90	72	1.44
Length at maximum age (FL_{inf}) female	130.32	2	100	180	140	2.44
von Bertalanffy growth parameter (κ) female	0.29	2	0.1	0.4	0.22	0.03
Coefficient of variation in length at age 1 female	0.08	4	0.01	0.3	0.12	0.01
Coefficient of variation in length at maximum age female	0.07	4	0.01	0.2	0.14	0.01
Length at age 1 (FL_1) male	65.9	2	30	85	70	1.32
Length at maximum age (FL_{inf}) male	114.36	2	100	200	120	1.36
von Bertalanffy growth parameter (κ) male	0.34	2	0.1	0.45	0.21	0.03
Coefficient of variation in length at age 1 male	0.08	4	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age male	0.04	4	0.01	0.2	0.12	0
Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1911)	13.6	1	10	15	13	0.18
Commercial selectivity inflection (cm)	81.57	3	30	120	60	0.93
Commercial selectivity width (cm)	11.54	3	0	20	0.5	1.33

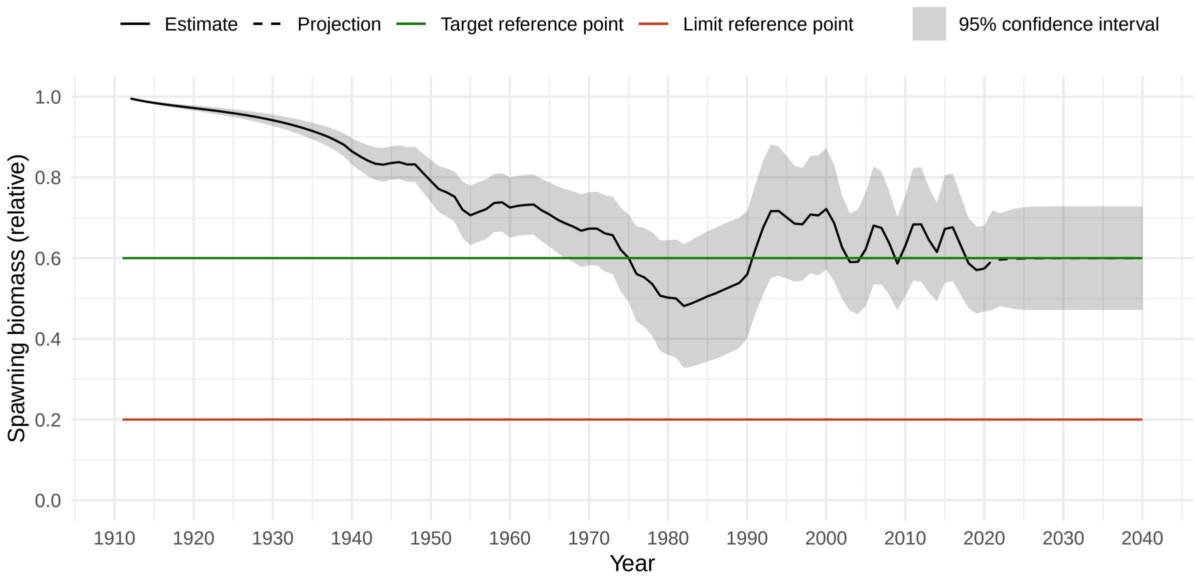


Figure E.21: Predicted spawning biomass trajectory relative to virgin for Spanish mackerel, from 1911 to 2040, for scenario 6

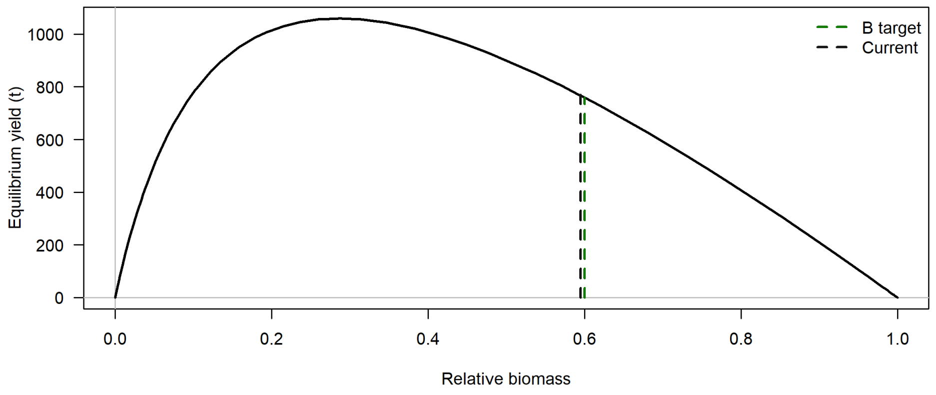


Figure E.22: Equilibrium yield curve for Spanish mackerel for scenario 6

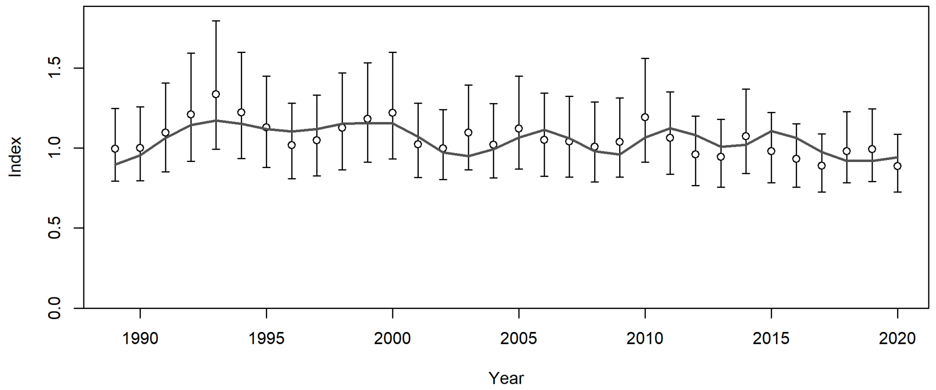


Figure E.23: Model predictions (grey line) to commercial catch rates for Spanish mackerel for scenario 6

Figure E.24: Model predictions (grey line) to historical decadal catch rates for Spanish mackerel for scenario 6

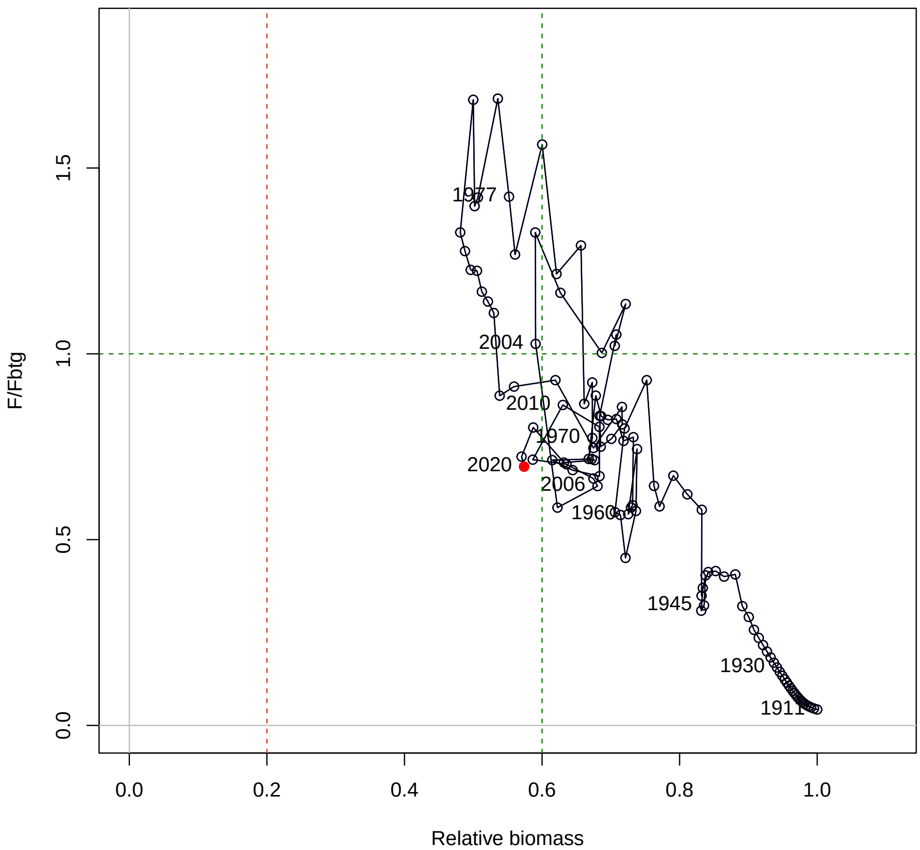


Figure E.25: Phase plot for Spanish mackerel for scenario 6
The horizontal axis is the biomass ratio of Queensland Spanish mackerel relative to unfished and the vertical axis is the fishing mortality relative to the fishing mortality which would produce the *Sustainable Fisheries Strategy* biomass target of 60%. The red dashed vertical line is the limit reference point (20% relative biomass) and the green dashed vertical line is the target reference point (60% relative biomass)

E.6 Scenario 7

Scenario 7 used the same input data as the base case except catch rates were calculated used full fishing power instead of half.

Table E.6: Stock Synthesis parameter estimates for the scenario 7 population model for Spanish mackerel

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
Natural mortality	0.26	3	0.01	0.5	0.29	0.01
Length at age 1 (FL_1) female	67.12	2	30	90	72	1.42
Length at maximum age (FL_{inf}) female	130.56	2	100	180	140	2.47
von Bertalanffy growth parameter (κ) female	0.28	2	0.1	0.4	0.22	0.03
Coefficient of variation in length at age 1 female	0.07	4	0.01	0.3	0.12	0.01
Coefficient of variation in length at maximum age female	0.07	4	0.01	0.2	0.14	0.01
Length at age 1 (FL_1) male	66.14	2	30	85	70	1.31
Length at maximum age (FL_{inf}) male	114.41	2	100	200	120	1.35
von Bertalanffy growth parameter (κ) male	0.34	2	0.1	0.45	0.21	0.03
Coefficient of variation in length at age 1 male	0.08	4	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age male	0.04	4	0.01	0.2	0.12	0
Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1911)	13.28	1	10	13.75	13.3	0.05
Commercial selectivity inflection (cm)	81.35	2	30	120	60	0.88
Commercial selectivity width (cm)	11.58	2	0	20	0.5	1.33

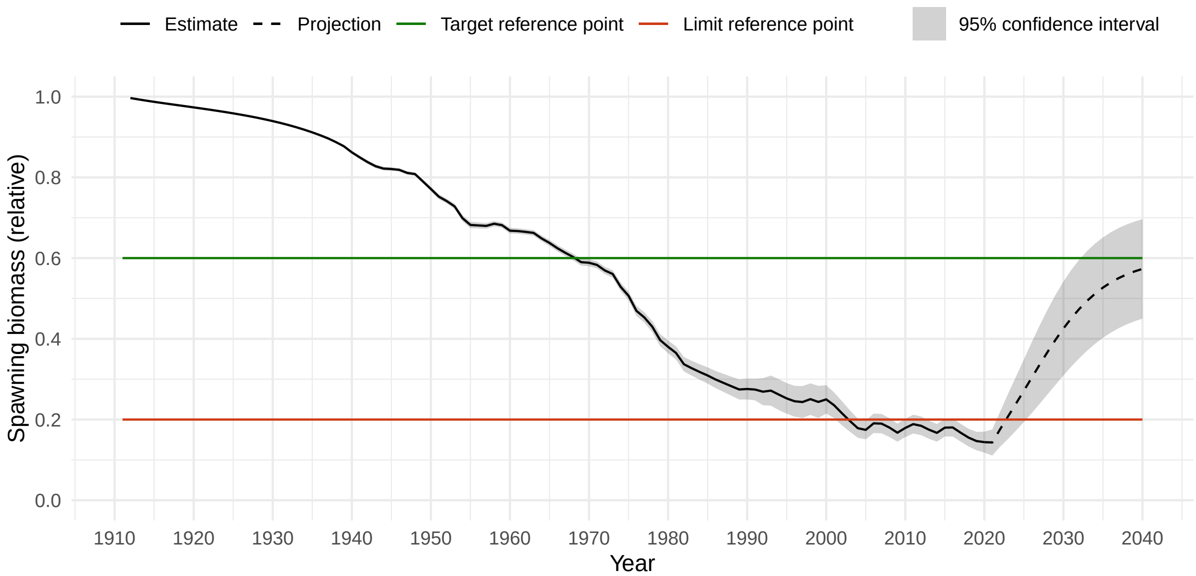


Figure E.26: Predicted spawning biomass trajectory relative to virgin for Spanish mackerel, from 1911 to 2040, for scenario 7

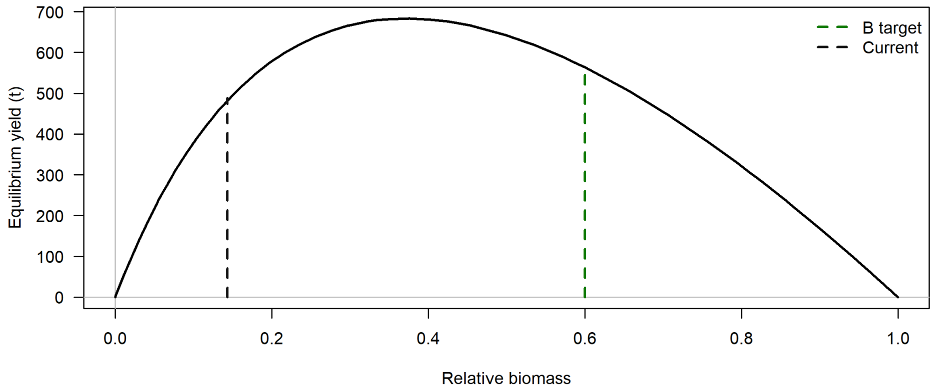


Figure E.27: Equilibrium yield curve for Spanish mackerel for scenario 7

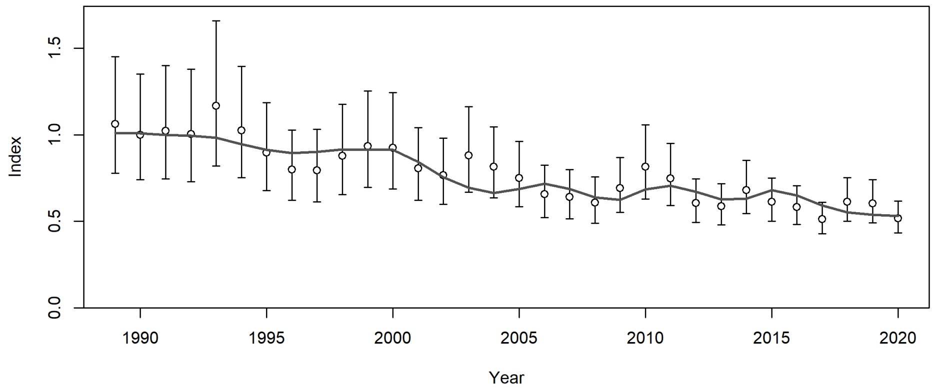


Figure E.28: Model predictions (grey line) to commercial catch rates for Spanish mackerel for scenario 7

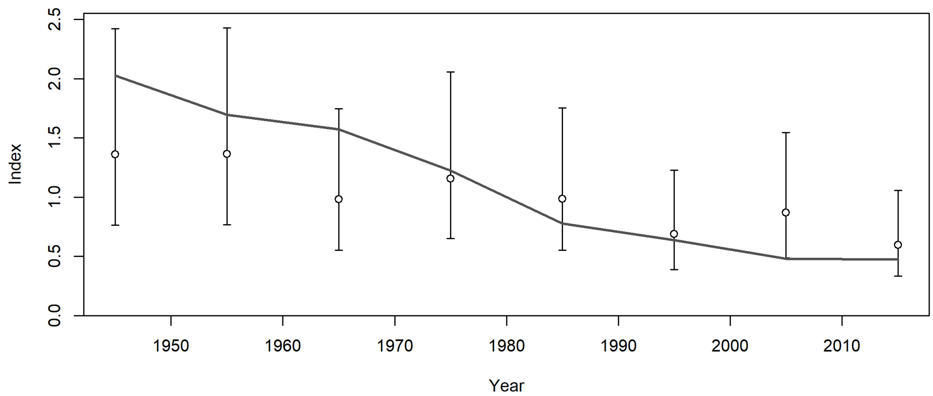


Figure E.29: Model predictions (grey line) to historical decadal catch rates for Spanish mackerel for scenario 7

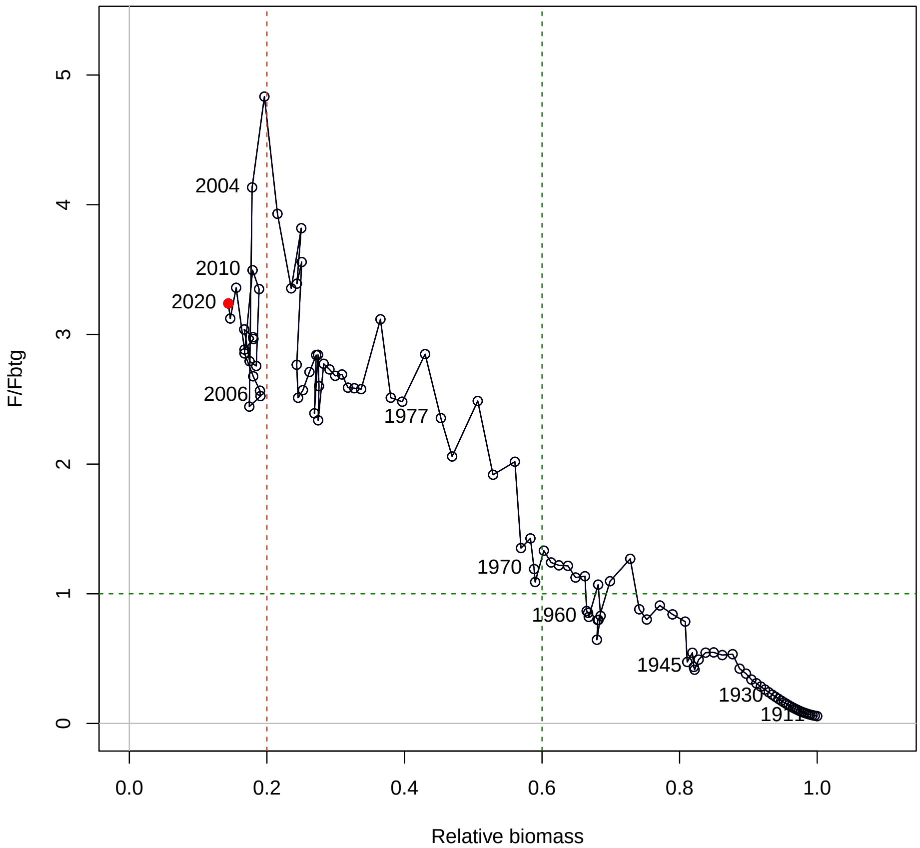


Figure E.30: Phase plot for Spanish mackerel for scenario 7

The horizontal axis is the biomass ratio of Queensland Spanish mackerel relative to unfished and the vertical axis is the fishing mortality relative to the fishing mortality which would produce the *Sustainable Fisheries Strategy* biomass target of 60%. The red dashed vertical line is the limit reference point (20% relative biomass) and the green dashed vertical line is the target reference point (60% relative biomass)

E.7 Scenario 8

Scenario 8 used the same input data as the base case except catch rates were calculated used full fishing power instead of half, and no probability adjustment was used.

Table E.7: Stock Synthesis parameter estimates for the scenario 8 population model for Spanish mackerel

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
Natural mortality	0.28	1	0.01	0.5	0.28	0.01
Length at age 1 (FL_1) female	67.01	2	30	90	67.01	1.38
Length at maximum age (FL_{inf}) female	130.38	2	100	180	130.38	2.38
von Bertalanffy growth parameter (κ) female	0.29	2	0.1	0.4	0.29	0.03
Coefficient of variation in length at age 1 female	0.07	4	0.01	0.3	0.07	0.01
Coefficient of variation in length at maximum age female	0.07	4	0.01	0.2	0.07	0.01
Length at age 1 (FL_1) male	66.05	2	30	85	66.05	1.28
Length at maximum age (FL_{inf}) male	114.28	2	100	200	114.28	1.3
von Bertalanffy growth parameter (κ) male	0.34	2	0.1	0.45	0.34	0.03
Coefficient of variation in length at age 1 male	0.08	4	0.01	0.3	0.08	0.01
Coefficient of variation in length at maximum age male	0.04	4	0.01	0.2	0.04	0
Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1911)	13.33	3	10	15	13.33	0.05
Commercial selectivity inflection (cm)	81.34	2	30	120	81.34	0.89
Commercial selectivity width (cm)	11.58	2	0	20	11.58	1.33

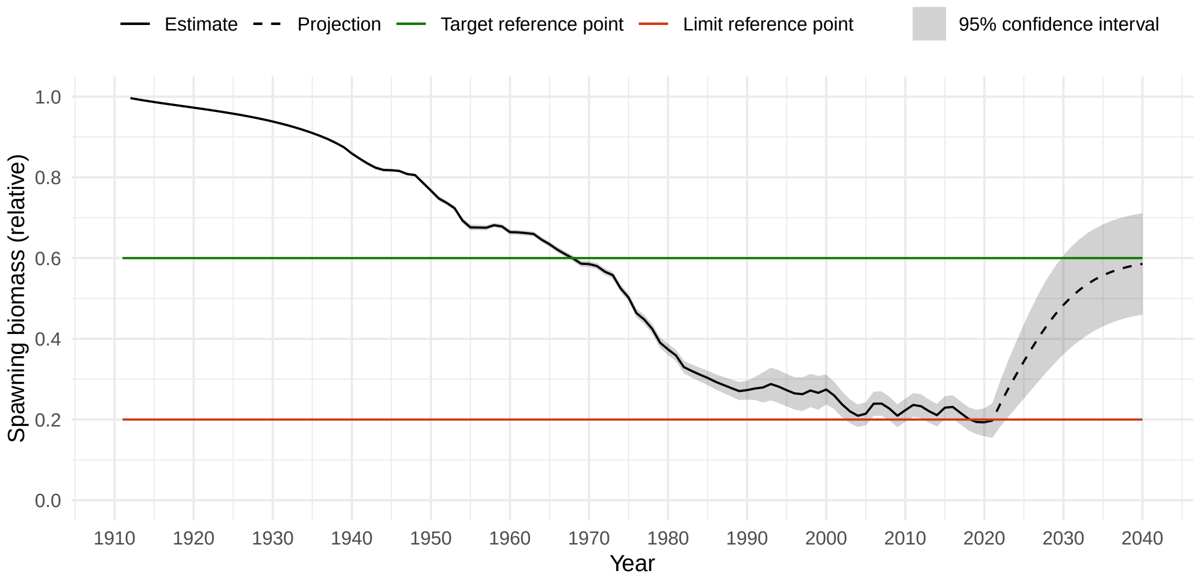


Figure E.31: Predicted spawning biomass trajectory relative to virgin for Spanish mackerel, from 1911 to 2040, for scenario 8

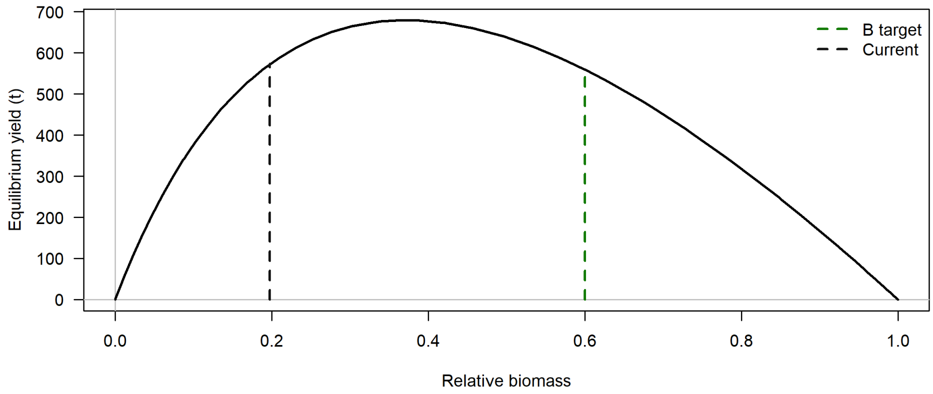


Figure E.32: Equilibrium yield curve for Spanish mackerel for scenario 8

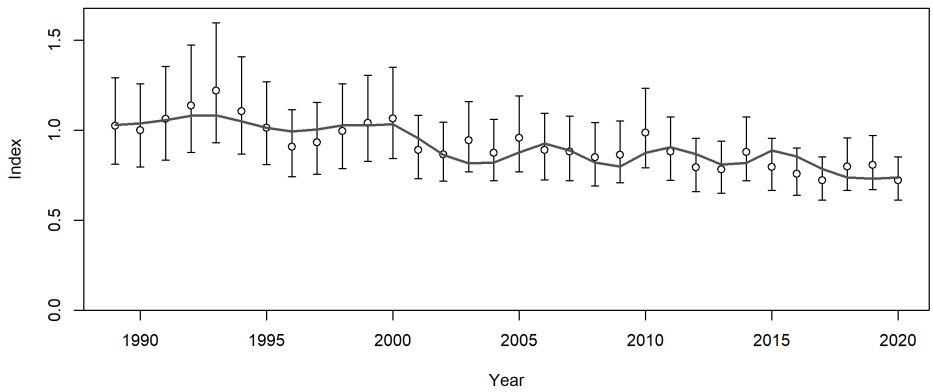


Figure E.33: Model predictions (grey line) to commercial catch rates for Spanish mackerel for scenario 8

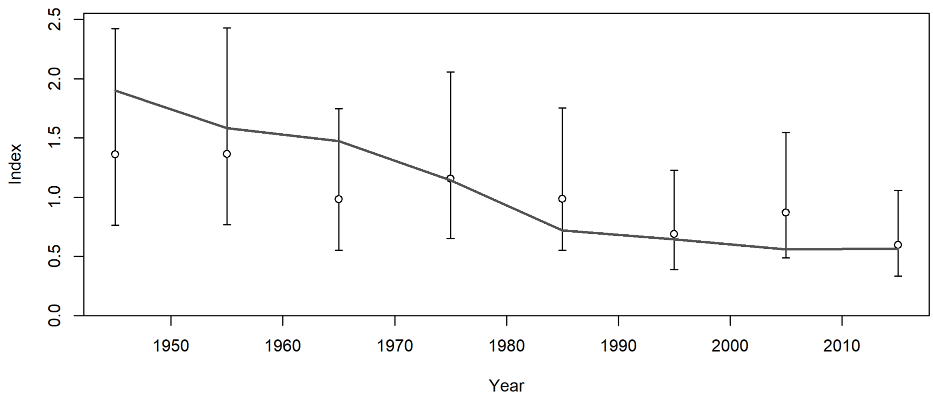


Figure E.34: Model predictions (grey line) to historical decadal catch rates for Spanish mackerel for scenario 8

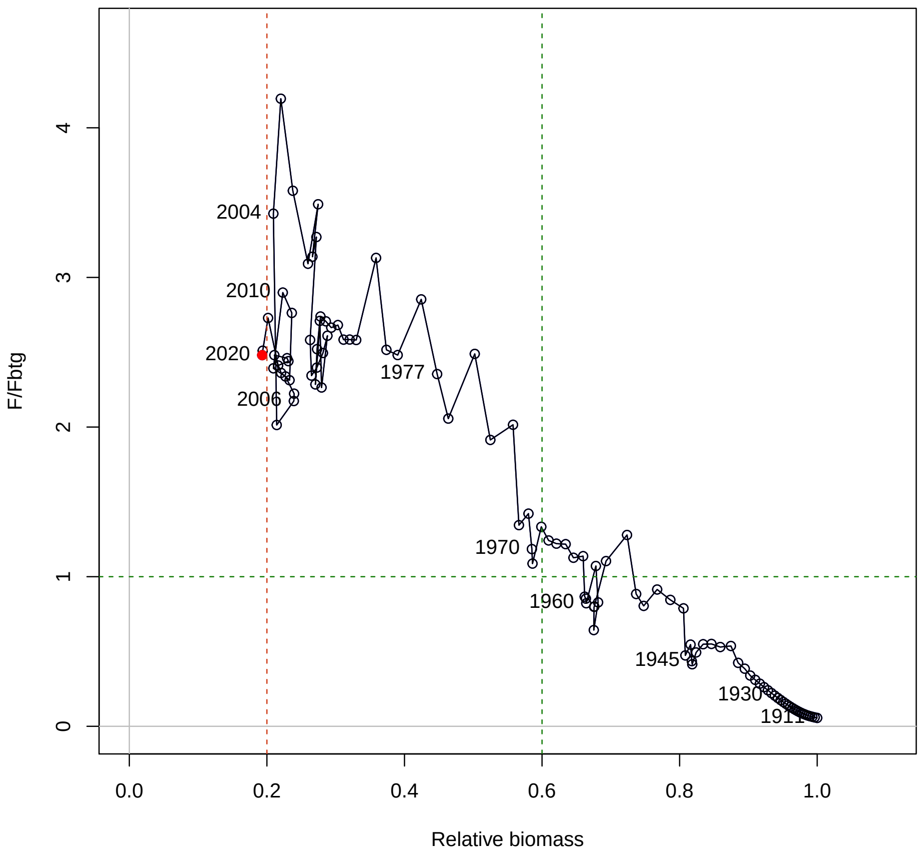


Figure E.35: Phase plot for Spanish mackerel for scenario 8

The horizontal axis is the biomass ratio of Queensland Spanish mackerel relative to unfished and the vertical axis is the fishing mortality relative to the fishing mortality which would produce the *Sustainable Fisheries Strategy* biomass target of 60%. The red dashed vertical line is the limit reference point (20% relative biomass) and the green dashed vertical line is the target reference point (60% relative biomass)

Appendix F Shark depredation

F.1 Background and methods

Depredation, when a shark preys on a fisher's catch before landing, is increasingly being described by many offshore line fishers in Queensland (Major 2020). Some offshore line fishers report shark depredation as increasing each year (pers. comm. Queensland rocky reef working group). To capture this phenomenon in stock assessment, a scenario was developed to hypothesise that the rate of depredation may have increased.

In these scenarios, shark depredation was assumed to increase from 2009, when fishery management introduced Queensland commercial quota for east coast shark harvest and the requirement to hold a commercial shark fishing 'S' symbol. Queensland commercial east coast shark catch decreased following the management changes in 2009 (Queensland annual total east coast shark quota was 600 t per financial year; mean annual shark harvest pre-quota, 2000–2009, was 1190 t; mean annual shark harvest, 2010–2020, was 338 t), and there was a belief among some fishers that these changes have directly resulted in higher numbers of shark and higher depredation rates.

In addition, to support the notion of increased shark depredation in offshore line fisheries, annual nominal levels of otter trawling have roughly halved since 2009, with a decline in bycatch discarding on which sharks may scavenge and feed (Wang et al. 2020; Hill et al. 2000). With less discarded trawl bycatch, one could speculate that sharks may alter their scavenging patterns as needed to rob more from offshore line fishing catches.

The change in shark depredation (decrease in landed Spanish mackerel harvest) since 2009 was hypothesised using the following equation:

$$d = (1 - r)^t \tag{F.1}$$

where d was the relative annual shark offset effect for reduced Spanish mackerel harvest since 2009, r was the hypothesised annual rate effect = 0.01842347, t was the cumulative years since 2009, and d was equal to 1 prior to 2009. The assumed reduction in Spanish mackerel catch due to shark depredation was 0.2 in 2020. The annual rate r was estimated to match $d = 1 - 0.2$ after 12 years in 2020.

The value of 0.2 related to the fraction of fish lost during the catching process (discard effects were accounted separately). This was a maximum value from Mitchell et al. (2018): "Gilman et al. (2008) conducted a large-scale study of depredation in 12 commercial pelagic longline fisheries from eight countries worldwide, with the highest rate of shark depredation (20%) recorded in the Australian fishery."

Lesser rates might be more realistic, but the high rate was used to assess a maximal effect in stock assessment. In the recent national Spanish mackerel research meeting (online in March 2021), Western Australian researchers measured smaller depredation effects around 3–5% and 8–10% varying with fishing grounds (pers. comm.); the WA research is ongoing. Shark depredation was not an issue in New South Wales waters (pers. comm.).

The shark depredation effect was applied two-fold: 1) in the combined log annual shark + log fishing power offset for non-zero catch rate analysis and standardisation, and 2) total annual harvests were inflated for lost fish by dividing harvest only estimates by the shark offset (Rabearisoa et al. 2018). The recreational harvest estimates were recalculated on the new catch rate results from step 1. These steps altered the data inputs into Stock Synthesis, to form the shark depredation scenario.

For the 2020 stock assessment results, interpretation and use, a 20% shark allocation is required in TACC allocation, unless mitigation measures are used to reduce the assumed effects. Overall, the shark analysis scenario aimed to provide an example test to compare different results against the base case stock assessment. In addition, a higher level of steepness parameter (h = 0.55) was tested to check the sensitivity of h on shark depredation effect adjustment.

F.2 Results

Standardised catch rate adjusted for shark depredation effect is given in Figure F.1. The summary of stock assessment results is provided in Table F.1, with full results in Section F.2.1 and F.2.2.

Notable points in results were:

- Standardised catch rates post 2009 were higher for the assumed 20% shark depredation adjustment (Figure F.1).
- Natural mortality and virgin recruitment (log($R0$) are similar, but slightly higher with shark depredation adjustment.
- Estimated spawning biomasses in 2020 were about 6% higher compared to assuming no shark effects, likely due to higher catch rate used as an index of abundance.

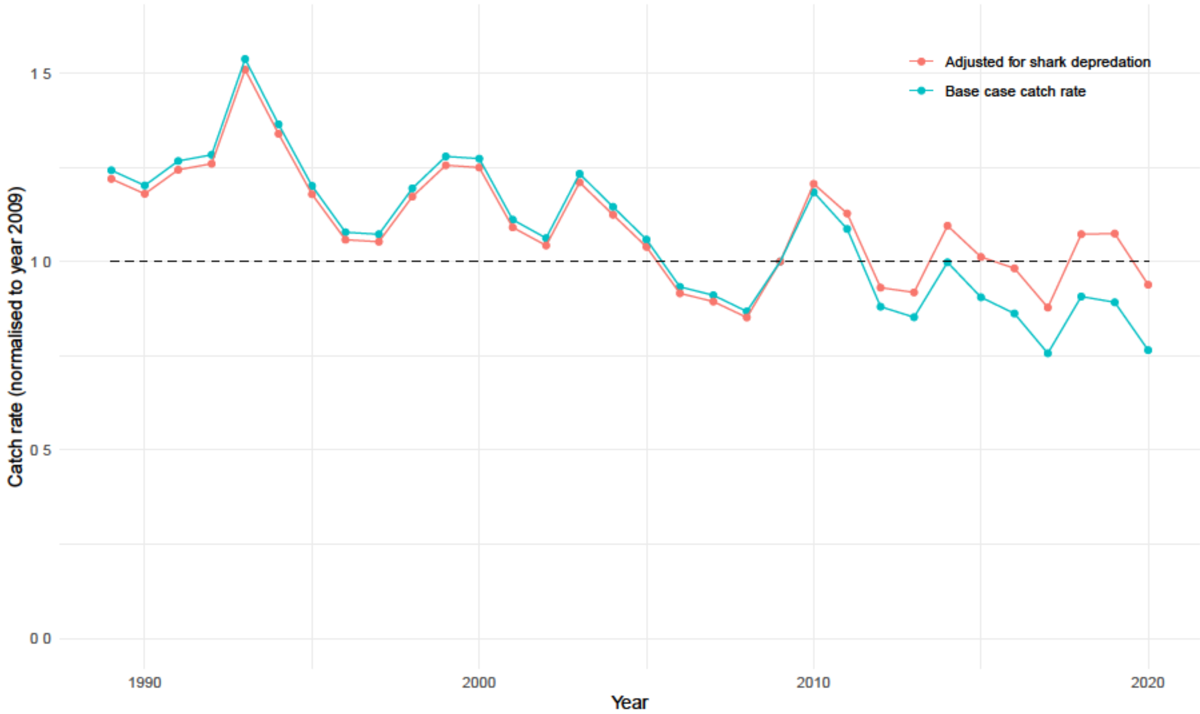


Figure F.1: Comparison of standardised catch rate with and without shark depredation effect, normalised to 2009.

Table F.1: Comparison of stock assessment results with and without shark depredation effect

parameters/indicators	Results for no depredation	Results adjusted for depredation
Scenario=1		
Steepness h (fixed)	0.45	0.45
Natural mortality M	0.27	0.28
log(R_0)	13.3	13.37
Spawning ratio B_{2020}/B_0	0.17	0.23
Sustainable harvest at B_{60}	557 t	573 t
Scenario=3		
Steepness h (fixed)	0.55	0.55
Natural mortality M	0.23	0.24
log(R_0)	12.93	12.99
Spawning ratio B_{2020}/B_0	0.14	0.20
Sustainable harvest at B_{60}	543 t	556 t

F.2.1 Steepness fixed at 0.45

Table F.2: Stock Synthesis parameter estimates for the shark depredation scenario population model where steepness was fixed at 0.45 for Spanish mackerel

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
Natural mortality	0.28	3	0.01	0.5	0.29	0.01
Length at age 1 (FL_1) female	66.82	1	30	90	72	1.4
Length at maximum age (FL_{inf}) female	130.21	1	100	180	140	2.39
von Bertalanffy growth parameter (κ) female	0.29	1	0.1	0.4	0.22	0.03
Coefficient of variation in length at age 1 female	0.07	4	0.01	0.3	0.12	0.01
Coefficient of variation in length at maximum age female	0.07	4	0.01	0.2	0.14	0.01
Length at age 1 (FL_1) male	65.93	1	30	85	70	1.28
Length at maximum age (FL_{inf}) male	114.23	1	100	200	120	1.3
von Bertalanffy growth parameter (κ) male	0.35	1	0.1	0.45	0.21	0.03
Coefficient of variation in length at age 1 male	0.08	4	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age male	0.04	4	0.01	0.2	0.12	0
Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1911)	13.37	1	10	13.75	13.3	0.05
Commercial selectivity inflection (cm)	81.44	2	30	120	60	0.91
Commercial selectivity width (cm)	11.52	2	0	20	0.5	1.35

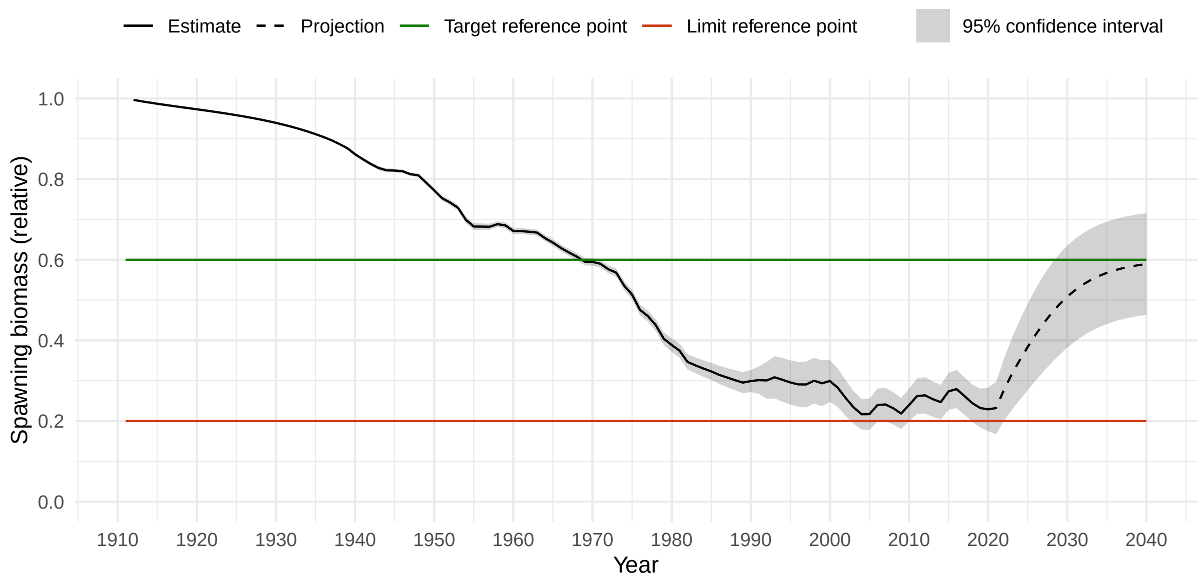


Figure F.2: Predicted spawning biomass trajectory relative to virgin for Spanish mackerel, from 1911 to 2040, for shark depredation scenario where steepness was fixed at 0.45

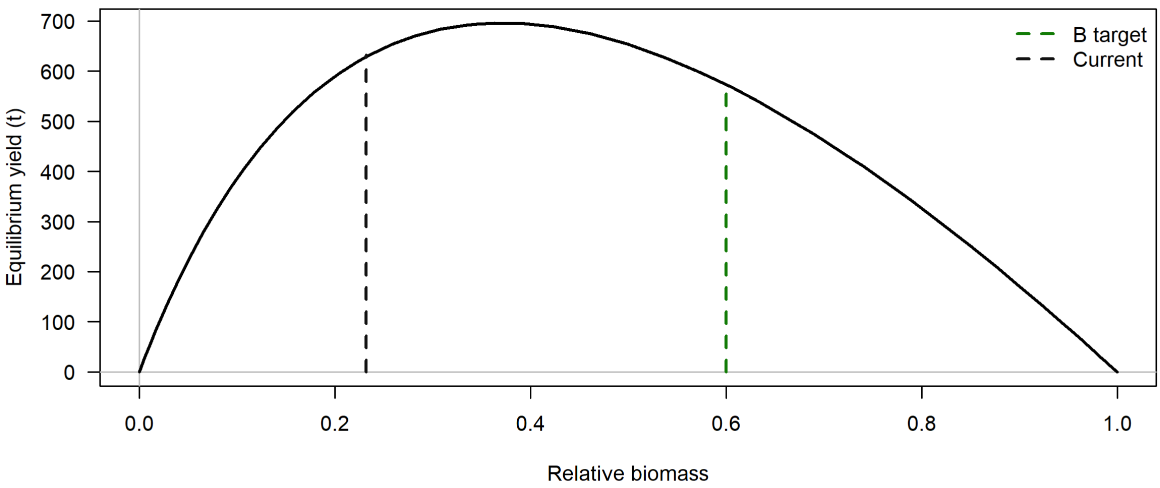


Figure F.3: Equilibrium yield curve for Spanish mackerel for shark depredation scenario where steepness was fixed at 0.45

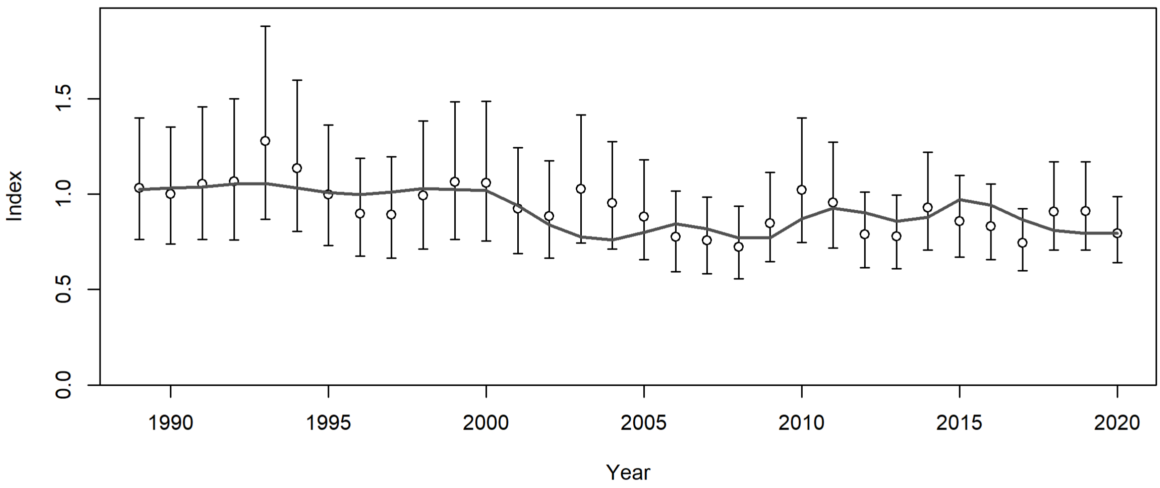


Figure F.4: Model predictions (grey line) to commercial catch rates for Spanish mackerel for shark depredation scenario where steepness was fixed at 0.45

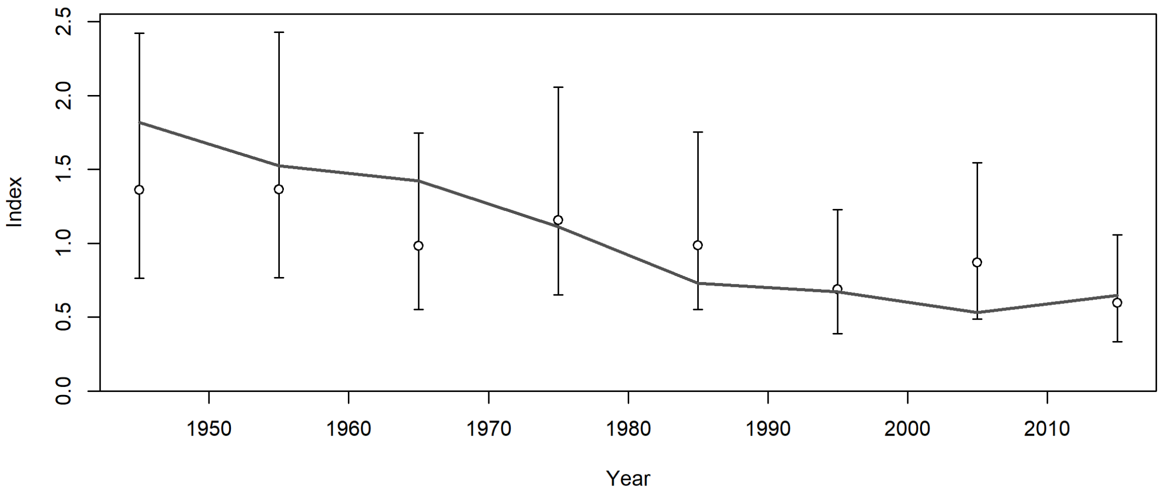


Figure F.5: Model predictions (grey line) to historical decadal catch rates for Spanish mackerel for shark depredation scenario where steepness was fixed at 0.45

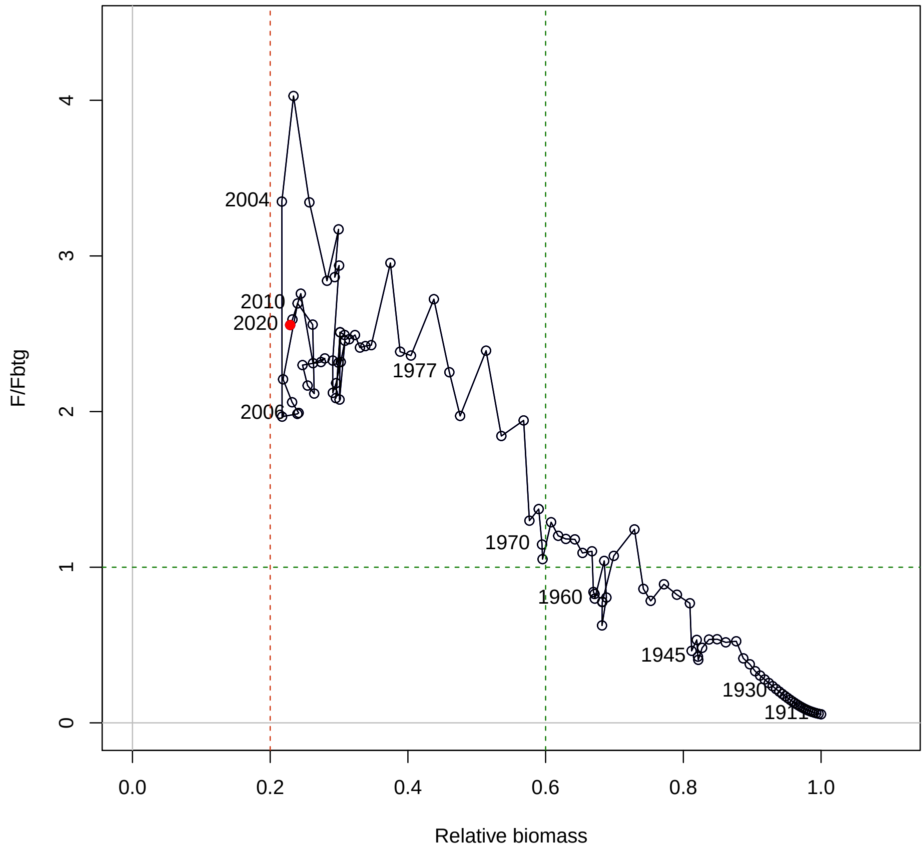


Figure F.6: Phase plot for Spanish mackerel for shark depredation scenario where steepness was fixed at 0.45

The horizontal axis is the biomass ratio of Queensland Spanish mackerel relative to unfished and the vertical axis is the fishing mortality relative to the fishing mortality which would produce the *Sustainable Fisheries Strategy* biomass target of 60%. The red dashed vertical line is the limit reference point (20% relative biomass) and the green dashed vertical line is the target reference point (60% relative biomass)

F.2.2 Steepness fixed at 0.55

Table F.3: Stock Synthesis parameter estimates for the shark depredation scenario population model for Spanish mackerel where steepness was fixed at 0.55

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
Natural mortality	0.24	3	0.01	0.5	0.29	0.01
Length at age 1 (FL_1) female	66.96	1	30	90	72	1.39
Length at maximum age (FL_{inf}) female	130.27	1	100	180	140	2.4
von Bertalanffy growth parameter (κ) female	0.29	1	0.1	0.4	0.22	0.03
Coefficient of variation in length at age 1 female	0.07	4	0.01	0.3	0.12	0.01
Coefficient of variation in length at maximum age female	0.07	4	0.01	0.2	0.14	0.01
Length at age 1 (FL_1) male	65.99	1	30	85	70	1.29
Length at maximum age (FL_{inf}) male	114.2	1	100	200	120	1.31
von Bertalanffy growth parameter (κ) male	0.35	1	0.1	0.45	0.21	0.03
Coefficient of variation in length at age 1 male	0.08	4	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age male	0.04	4	0.01	0.2	0.12	0
Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1911)	12.99	1	10	13.75	13.3	0.05
Commercial selectivity inflection (cm)	81.23	2	30	120	60	0.89
Commercial selectivity width (cm)	11.47	2	0	20	0.5	1.35

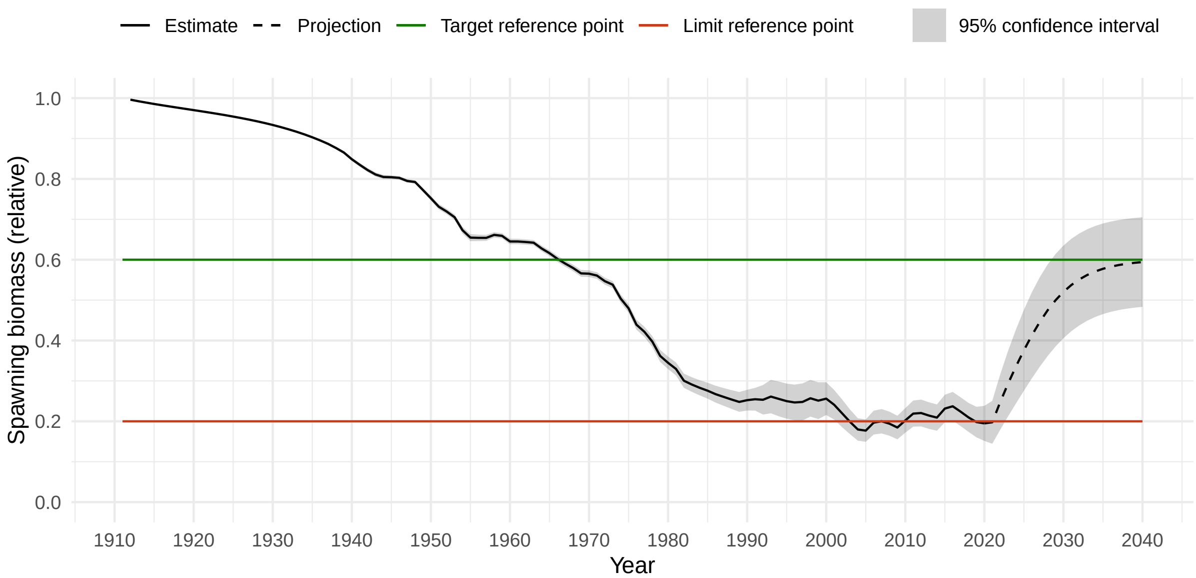


Figure F.7: Predicted spawning biomass trajectory relative to virgin for Spanish mackerel, from 1911 to 2040, for shark depredation scenario where steepness was fixed at 0.55

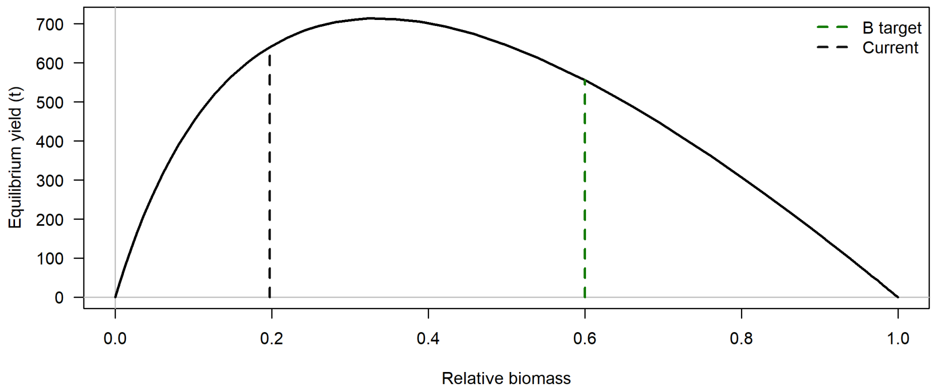


Figure F.8: Equilibrium yield curve for Spanish mackerel for shark depredation scenario where steepness was fixed at 0.55

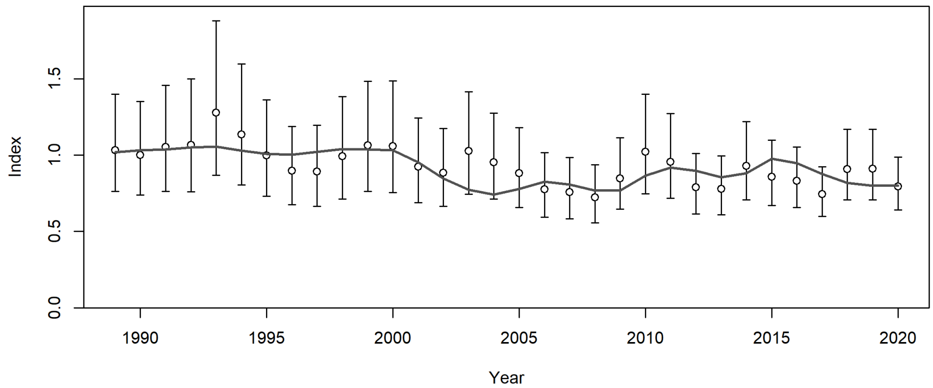


Figure F.9: Model predictions (grey line) to commercial catch rates for Spanish mackerel for shark depredation scenario where steepness was fixed at 0.55

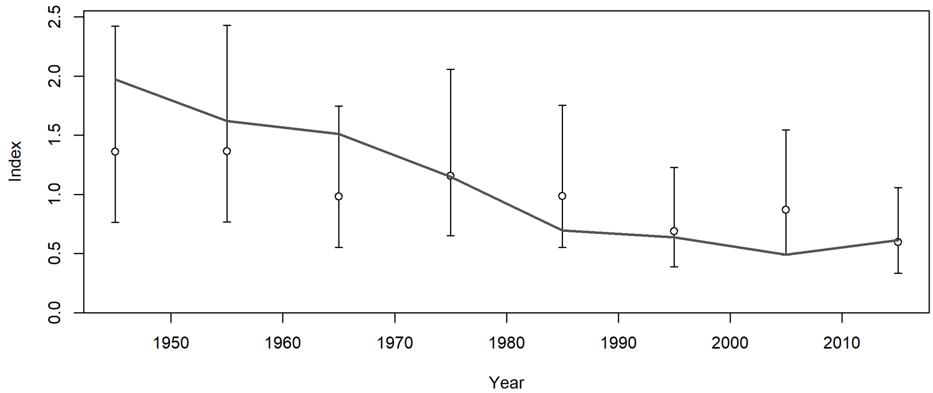


Figure F.10: Model predictions (grey line) to historical decadal catch rates for Spanish mackerel for shark depredation scenario where steepness was fixed at 0.55

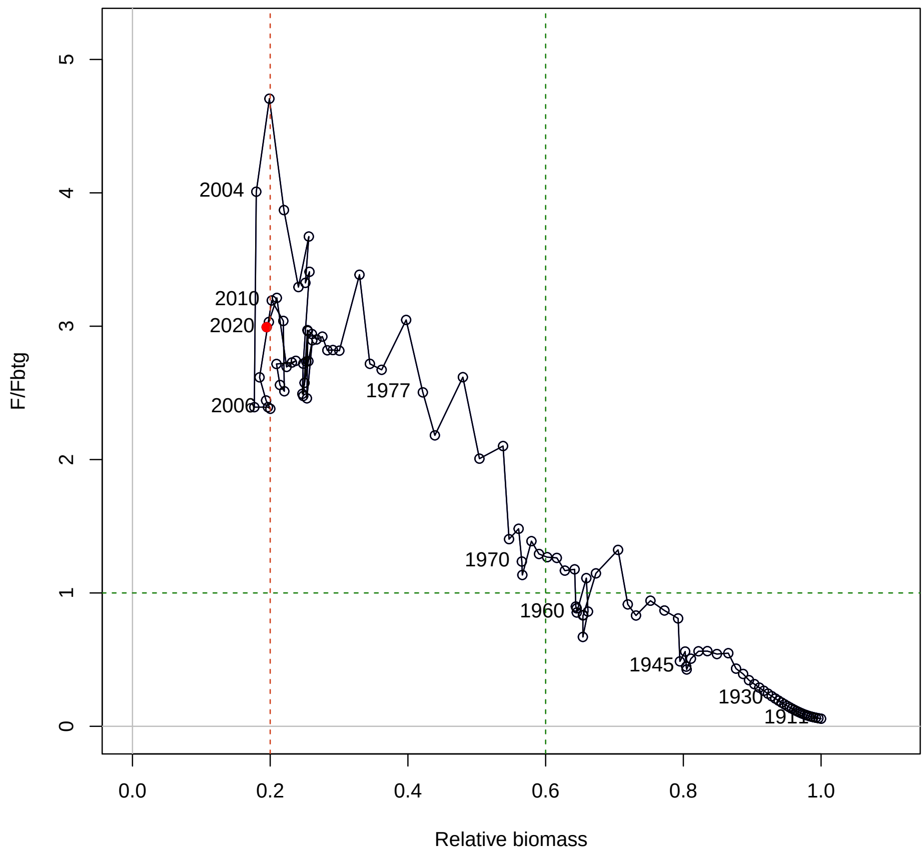


Figure F.11: Phase plot for Spanish mackerel for shark depredation scenario where steepness was fixed at 0.55

The horizontal axis is the biomass ratio of Queensland Spanish mackerel relative to unfished and the vertical axis is the fishing mortality relative to the fishing mortality which would produce the *Sustainable Fisheries Strategy* biomass target of 60%. The red dashed vertical line is the limit reference point (20% relative biomass) and the green dashed vertical line is the target reference point (60% relative biomass)

Independent review of the stock assessment of east coast Spanish mackerel (*Scomberomorus commerson*) in Queensland, Australia.

Prepared by

Neil Klaer

Prepared for

Queensland Department of Agriculture and Fisheries

Desk-top review
15 June – 6 July 2021

Contents

Executive Summary

This is a desktop review of the 2021 Australian east coast Spanish mackerel (*Scomberomorus commerson*) fishery stock assessment by the Department of Agriculture and Fisheries (DAF) Queensland carried out during the period June 15 to 6 July 2021.

Major uncertainties for the stock assessment relate to total catch (including discards), catchability change and hyperstability in fishery CPUE and the assumed level of stock-recruitment resilience or steepness for the stock. I examined stock assessment settings and diagnostics in detail and agree that the assessment has been competently constructed and is adequate given the available data. The assessment uses a base-case and sensitivity scenario approach which is adequate for management purposes but lacks detail for scientific examination of the stock assessment model. I have provided advice on further consideration of model uncertainty and improvements to model documentation for scientific purposes.

It has long been recognised that steepness is a highly influential but uncertain parameter for fisheries stock assessments. Spanish mackerel do not fit the profile of a species likely to allow robust steepness estimation. This assessment chose a Beverton-Holt stock recruitment steepness fixed at a value of 0.45 for the base-case, based on a new meta-analysis (Thorson 2020). That low central value for steepness for Spanish mackerel is, in my experience with many assessments, inconsistent with previous accepted fisheries stock assessment practice for most schooling pelagic bony fish species and comparable existing DAF Spanish mackerel assessments that seem to centre near a value of 0.6. It therefore requires a much-expanded justification within the current assessment document. It is difficult to recommend use of such a value for a stock assessment base-case without having an improved understanding of why the meta-analysis produced this low value for the genus Scomberomorus.

The assessment report included a fairly comprehensive section on recommendations separated as they apply to data, monitoring and research, management and the stock assessment. I agree with those recommendations and particularly encourage any efforts to make use of earlier composition data that may enable extension of recruitment deviation estimation to earlier years, and exploration of the development of fishery-independent abundance indices such as from close-kin genetic analysis.

I am unable to support the conclusions regarding future harvest levels for the east coast Spanish mackerel stock until reservations regarding the most appropriate central value for steepness for the base-case are resolved.

1 Review Activities

This is a desktop review of the 2021 Australian east coast Spanish mackerel (*Scomberomorus commerson*) fishery stock assessment by the Department of Agriculture and Fisheries (DAF) Queensland (Tanimoto et al. 2021). The review process was sent out by DAF for competitive tender, and I was contracted to do the review. Formal terms of reference for the review were included in the contract. I received the Spanish mackerel stock assessment report and associated model input files on 9 June in preparation for commencement of the review on 15 June. During the review, I requested some additional documents listed in the Annex. Having access to the model files greatly assisted the review as I could examine more detailed diagnostics not provided by the assessment report and run my own diagnostic code on the models. It was discovered that I had not received the correct model SS executable file or input files used by scenario 8 due to problems transferring executable files via email, and this was corrected on 25 June. It seems that this problem may be avoided in future through transfer of assessment files using a file-sharing system such as OneDrive rather than by email. I provided my thoughts (largely as they appear in this review) regarding the use of a steepness value for the base-case assessment from the Thorson (2020) study to the assessment authors on 28 June. I completed the review on 6 July and sent my draft report to Mai Tanimoto, Alise Fox and Sue Helmke. Comments were received on 14 July and my report was adjusted according to those, without modification to overall findings. I thank all who I have had contact with for this review which progressed efficiently and professionally.

2 Review of stock assessment of Spanish mackerel

2.1 Scope of works for the review

The Department of Agriculture and Fisheries (DAF) is seeking an independent review of the "Stock assessment of Australian East Coast Spanish Mackerel fishery". The review is not limited to, but should address the following points:

1. Provide comment model inputs and outputs and adequacy of these data to achieve the objectives of the assessment, including:
    a. Providing biomass ratio estimates in relation to the fishery reference points
    b. Assumptions used in the analysis of catch rates
    c. Assumptions used in the estimation of harvest sizes
    d. Confidence in model inputs and outputs
    e. Assumptions used in the stock synthesis models
    f. The adequacy of the population dynamic model used in the assessment
    g. Appropriate recommended biological catch / Total Allowable Catch.
2. Provide comment on the accuracy of key statements in the report summary and conclusion. How well are they supported by available data, analysis and literature?
3. Provide comment on recommendations for management and monitoring and inclusion of additional data in future assessments.
4. Any other outputs or graphical figures that the report could have provided.

2.2 Findings according to terms of reference

2.2.1 Provide comment model inputs and outputs and adequacy of these data in order to achieve the objectives of the assessment

2.2.1 a. Providing biomass ratio estimates in relation to the fishery reference points

For assessment purposes the east coast Spanish mackerel population is assumed to be a single reproductively isolated stock from Newcastle on the NSW coast to Cape York Peninsula in QLD. Predictable winter and spring feeding and spawning aggregations in northern tropical areas, movement of some fish to feed in southern waters during summer and autumn, and genetic studies support this assumption.

A time series of total spawning biomass (spawning output) is estimated for the stock as input to QDAF (2020) harvest control rules to reach future catch recommendations. The ratio of $B_{current}/B_0$ can be determined with more accuracy than absolute spawning biomass, and current management is based on a target for that ratio of 0.6 and a limit of 0.2 (QDAF 2020). Management currently relies on central values of these estimates from a selected base-case, and do not specifically take account of stock assessment uncertainty, except indirectly through selection of the target ratio and an uncertainty buffer. Uncertainty in stock assessment results is provided as asymptotic distributional ranges for the base-case, and via results from several sensitivity model scenarios.

2.2.1 b. Assumptions used in the analysis of catch rates

Queensland commercial line logbook data per fishing-operation day were used as input for catch rate standardisation for the commercial fishing fleet. O'Neill et al. (2018) describes issues that cause difficulty in interpreting catch rates from this fishery-dependent source that include: no consistent daily recording of each fishing operation's target species, vessels/skippers, gear, travel time, search time and efficiency, locations fished, active fishing time and zero catches. I could not find a summary background discussion in the assessment document of these features of the logbook data or methods that may have been employed to initially filter the data prior to analysis. A two-stage standardisation model was used. The first stage was a binomial GLM that predicted the probability of catching Spanish mackerel. The second stage was a LMM that predicted the annual catch magnitude for operations that had positive catches. Effects accounted for were year, latitude, season, wind, lunar phase, number of fishing operations and fishing power offset. This general form of standardisation is commonly applied in fisheries and seems appropriate. The assessment document did include a good summary of the standardisation procedure and main diagnostics produced.

The historical decadal catch rate from Thurstan et al. (2016) was not described in detail in the assessment document. However, it was stated that sample size and verification testing was done previously e.g. by O'Neill et al. (2018). This index (and associated fishing power estimates) does provide key input as the long-term abundance index for the assessment, beginning in 1941 and ending in 2013.

Accounting for change in fishing power is not commonly done with fishery-dependent abundance indices, but it is widely recognised as an important source of possible bias.

The work previously done to collect relevant information and to account for uncertainty in this assessment through application of differing fishing power scenarios seems to be a good approach to this difficult, important, and often ignored issue. In the absence of fishery-independent abundance indices, these efforts are particularly appropriate.

2.2.1 c. Assumptions used in the estimation of harvest sizes

The assessment document included an excellent figure (Figure 2.2) that summarises assumptions made to estimate harvest sizes from the various sources from 1911 to 2020. I recommend that such a figure be included in any assessment document where complicated catch history reconstruction has been carried out.

There are many assumptions that combine to enable the construction of a complete catch history. Major uncertainties include the mortality rate and size assumed for discarded fish for the recreational fishery, the relationship of recreational boat registrations to fishing effort for Spanish mackerel, the relative catch of commercial and recreational fishing effort, and hindcast or interpolated years of unknown catches for various fishery components.

Despite good efforts in historical catch reconstruction, the number of assumptions shows that historical harvest estimates for Spanish mackerel are uncertain and this uncertainty should be evident in assessment results. The scenarios examined did not include alternative catch history, although it may be that the influence of this is less important than the factors that were examined.

I agree that the current constructed catch history makes reasonable assumptions and is acceptable.

2.2.1 d. Confidence in model inputs and outputs

Confidence in model outputs derives from the correct use of an appropriate assessment model, while making full use of input data and estimating properties specific to the stock to allow total population estimation for management.

The current assessment has been developed using Stock Synthesis (SS) (Methot and Wetzel 2013) that has many advantages including use of input data of most types even if incomplete, verification via simulation of the basic dynamics and many assessment options, fitting of growth within the assessment, appropriate procedures for estimation of parameter uncertainty, wide use throughout the world with many previous applications, and automated methods for production and display of model diagnostics. There are also disadvantages of SS including a steep learning curve and potential risk of inappropriately using it and its many options, but I believe that the stock assessment team have undertaken appropriate formal SS training. I agree with the choice and appropriateness of the stock assessment framework and also acknowledge that there are perhaps equally capable alternatives available such as CASAL.

It has long been recognised that steepness is a highly influential but uncertain parameter for fisheries stock assessments. It has been generalised in the past that estimation of steepness within a stock assessment requires input data to support estimation of individual stock and recruitment points (informed by abundance or size/age composition data) that cover a wide range of stock size and potentially multiple fish-down and recovery periods (e.g. see Lee et al. 2012). Appropriate fixed values or prior distributions for steepness for most fish taxonomic groups have not been studied in detail, perhaps except for US Pacific coast rockfish. Until recently, many stock assessments have assumed that steepness is unknown and have used a default generic value, such as 0.75 for marine demersal fish stocks from Shertzer and Conn (2012). It has been common past practice to assume that schooling pelagic bony fish species have relatively high reproductive resilience, with many assessments of those assuming steepness of 0.7 or more, and not a small number at or near steepness 1.0 (e.g. Zhu 2012 for bigeye tuna).

Spanish mackerel do not fit the profile of a species likely to allow robust steepness estimation. It does not provide long contrasting periods at different stock sizes that are informed by sufficient data to estimate recruitment deviations during those periods. Even so, the previous east coast Spanish mackerel stock assessment (O'Neill et al. 2018) estimated steepness within an ensemble approach that used 227 different models to attempt to encompass stock assessment uncertainty. This resulted in a clustering of 177 plausible scenarios with average steepness values of 0.31, 0.46, 0.61, 0.65 and 0.83. It is difficult to determine from the assessment documentation what aggregated average steepness value applies to all of the 11 stocks chosen for MCMC analysis. They did say that "stock status results and harvest reference points were sensitive to the reproductive rate r. MCMC analyses explored this uncertainty, with estimates of r < 4 [i.e. steepness < 0.5] considered conservative."

The current assessment simply states "Beverton-Holt stock recruitment steepness (h) was fixed at a value of 0.45, based on the meta-analysis of Thorson (2020). Different levels of h were tested as sensitivity analyses." and "The values of steepness (h) that were explored in this assessment were chosen to align with range of estimated values in O'Neill et al. (2018)." It has been recognised by the authors that this required more explanation, which I was provided separately.

The Thorson (2020) meta-analysis (as the title states) provides a new way of predicting recruitment density dependence and intrinsic growth rate for all fishes worldwide. This is accomplished via an integration of two previous meta-analytic models:

1. An evolutionary model of life-history parameters (Thorson et al., 2017) fitted to field measurements of size, growth, mortality and maturity for thousands of species worldwide as compiled by FishBase (Froese, 1990);

2. A hierarchical model for stock-recruit parameters (Thorson et al., 2014) fitted to stock and recruitment measurements from the original RAM database (Myers, Bridson, & Barrowman, 1995).

This seems to be a fine approach, possibly alleviating our previous difficulty in choosing appropriate steepness values for many species. It also potentially displaces previous accepted practice for fisheries stock assessment scientists. I was curious whether this new approach had gained acceptance by groups that recommend best or good practice for fisheries stock assessment, but this method is so new that information on that is not yet available. From that viewpoint, I recommend a degree of caution at this stage. It is possible to seek values of steepness from this new study at whatever taxonomic level seems most appropriate, and there is no guidance yet available for that either. The authors noted that the resultant steepness value for family Scombridae was 0.69. However, it was also noted that a wide range of steepness values existed when results were examined by genus. The value for genus Scomberomorus was chosen for this assessment, with a value of 0.45. From my experience with many stock assessments, that low central value for steepness for Spanish mackerel is inconsistent with previous accepted practice, and comparable existing DAF Spanish mackerel assessments. As such, it requires a much-expanded justification within the current assessment document.

I have SS input files for accepted US base-case assessments for three species in the genus Scomberomorus. Some or all of these may have contributed recruitment series to the RAM Legacy database. These were SEDAR 28 2012 South Atlantic Spanish mackerel, SEDAR 38 2014 Gulf of Mexico king mackerel, and SEDAR 38 2014 South Atlantic king mackerel. These stock assessments used fixed steepness values of 0.8, 0.98 and 0.99 respectively, although those values are not used by subsequent steepness meta-analysis. I investigated how many Scomberomorus species assessments were in the RAM database and found six (4 US National Marine Fisheries Service king and Spanish mackerel, 2 Fisheries Agency of Japan Spanish mackerel), three of which may relate to those mentioned. I believe that follow-up work continuing from this is required to understand why the Thorson (2020) study produces a low steepness value for the genus Scomberomorus. It is difficult to recommend use of such a value for a stock assessment base-case without having that understanding.

2.2.1 e. Assumptions used in the stock synthesis models

The Spanish mackerel SS model is simply structured. It is annual, 1 spawning season, 1 fishing fleet, 1 survey, 1 area, 2 gender, 2 CPUE, with length/age/age-length compositions associated with the fishing fleet via simple length-based asymptotic selectivity and no modelling of discards (treated as additional catch). Model tuning included recruitment deviation bias adjustment and application of recommended multipliers for length and age composition data to adjust sample sizes. These general model features should all have been described in the assessment document under model assumptions. I examined model settings in comparison with others I have reference to and found none that were unusual except use of maturity option 6 which is less common, but simply allows maturity to be input by length as a vector.

R4SS output for the base-case revealed some notable aspects, but none of particular concern when compared to output of other accepted SS assessments. Fit to historical decadal catch rate shows a systematic pattern that would fail a runs test – 3 points fitted above observations 1945 to 1965, 4 points fitted below observations 1985 to 2015. This suggests some conflict in the model between early CPUE (the period of major stock biomass decline) and other model settings. Overall aggregated fits to composition data are relatively poor and residual plots show exceptionally large values at the tails of the distribution of the available data. However, it is recognised that the input data are relatively “noisy”.

2.2.1 f. Adequacy of the population dynamic model used in the assessment

For an assessment that used a base-case and uncertainty scenario approach, adequacy could be defined as whether the base-case provides a representative mid value among potential alternative models that adequately explore known major uncertainties. In addressing this, it would be useful if assessment documents provided a table that summarises those uncertainties and how the assessment has addressed them.

In Table 1 I present my own interpretation of a list of uncertainties for the current Spanish mackerel assessment and their associated questions. Most commonly for assessment documentation, such questions are converted to alternative scenarios that are examined more thoroughly via sensitivity analyses. The relative importance of uncertainties is often judged according to their influence on the stock assessment results.

Table 1 Dimensions of uncertainty and level potentially addressed via alternative model scenarios

Uncertainty	Degree addressed	Comments/questions
Total catch	No	A single best estimate for historical catches was used.
Fishery CPUE	No	Sensitivity to weighting applied in the assessment to recent and historical commercial CPUE series was not examined.
Fishing power change	Yes	Scenarios were constructed that gave different emphasis to fishing power change through time.
CPUE hyperstability	Partly	Scenarios were constructed that accounted for CPUE hyperstability or not, as a component of the commercial fishery CPUE standardisation.
Steepness	Yes	Sensitivity to different fixed steepness values around the base-case value was examined. Note reservations about the central base-case value chosen.
Natural mortality	Yes	Natural mortality was estimated for most scenarios.
Discards	Partly	Discarding was not modelled as part of the assessment, and data are probably insufficient to allow that. Assumptions about discards and discard mortality affect total catch for the recreational fishery and potentially catch and CPUE for the commercial fishery via effects such as shark depredation. Shark depredation was acknowledged and examined by additional sensitivity analyses.

Uncertainties in model implementation in this report are examined through the presentation of a base-case and 7 sensitivity model scenarios that examine alternative plausible values for steepness, natural mortality (fixed in one scenario), how CPUE interpretation included hyperstability and fishing power effects. Dimensions of uncertainty presented do cover apparent major ones, but a more comprehensive list can potentially be constructed. True sensitivity analysis that alters only one factor from the base-case for the purpose of stock assessment diagnosis was not included and could be considerably expanded through examination of lower and higher weights (potentially via Lambda adjustments) for the various data inputs and assumptions.

Hyperstability is a difficult problem to address for this fishery, and I think it has been recognised that the probability of zero catch approach used is perhaps the best approximate way to address it given the available data. Recommendations to collect additional data in future on aspects such as search effort and travel time may allow the problem to be further resolved via catch rate modelling, perhaps allowing extension of those results into the available historical data.

I agree with the authors that the sensitivity scenarios span a range of alternative model structures that are useful in conveying model uncertainty to fishery managers. My suggestions here apply to a wider range of sensitivity and other tests that could be examined and presented to allow improved scientific judgement of the behaviour and uncertainty of the assessment models.

Likelihood profiles provide useful insight to model behaviour, and it was good to see those included for R0 for the base-case and scenario 4. These indicate that those models achieved minimum values for the range of R0 examined, but that a probable implausible minimum also exists for extremely high R0 values. They also show that the different scenarios are greatly different in which model components (compositions, priors, indices) have the greatest influence on the minimum overall likelihood value.

I agree that sensible decisions have been made to choose among alternatives for the base-case, except my reservations regarding the central value for steepness already discussed. There is some potential interaction in accounting for hyperstability and fishing power, and I agree with the author’s decision to account for hyperstability and use the square root version of fishing power for the base-case.

The population dynamics model used for this assessment is adequate.

2.2.1 g. Appropriate recommended biological catch

Policy for the estimation of catch levels to achieve a target spawning biomass is outlined by QDAF (2020). Model results were projected forward following the 20:60:60 harvest control rule. Results show that this was done to 2040. This harvest control rule is consistent with the DAF Sustainable Fisheries Strategy. The document states that this assessment did not include a discount factor to account for uncertainty in recommended target estimates, but this decision was not explained in the document. I agree that the form of the harvest control rule and therefore projections follow from the policy and are appropriate. Methods used are therefore acceptable, but reservations remain regarding the base-case value for steepness used to make those projections.

2.2.2 Provide comment on the accuracy of key statements in the report summary and conclusion. How well are they supported by available data, analysis and literature?

For management purposes, the report adequately describes important aspects of the species biology, current assessment input data, model construction, and model results. I have discussed above some potential improvements in that regard, but mostly for scientific rather than management purposes. Uncertainty in the spawning biomass trajectory within the current base-case is presented, as well as the spawning biomass series for various sensitivity scenarios. Future harvest levels according to the harvest control rule for the base model as well as sensitivity scenarios were also provided. These are adequate to describe central values for future harvest recommendations and the uncertainty of those to some extent.

I am unable to support the conclusions regarding future harvest levels for the east coast Spanish mackerel stock until reservations regarding the most appropriate central value for steepness for the base-case are resolved.

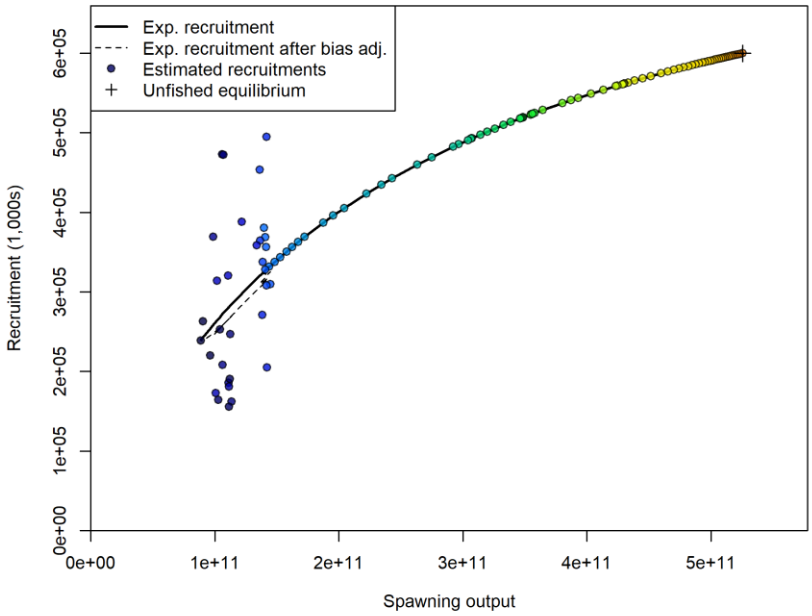
2.2.3 Provide comment on recommendations for management and monitoring and inclusion of additional data in future assessments

The assessment report included a fairly comprehensive section on recommendations separated as they apply to data, monitoring and research, management and the stock assessment. I agree with those recommendations. Any efforts to make use of earlier composition data that may enable extension of recruitment deviation estimation to earlier years is important for this assessment. I have included recommendations for additional exploration of model uncertainty in this report. It is a standard research recommendation to develop fishery-independent abundance indices for fisheries that do not have them. Whether this is possible is normally determined by the value and importance of the fishery. How this might be cost-effectively achieved for Spanish mackerel should be considered – e.g., close-kin genetic analysis as ready recommended by the authors. This is a significant problem for this fishery as it is reasonable to expect that catchability change and hyperstability of fishery-dependent abundance indices will be an on-going problem for future stock assessments.

2.2.4 Any other outputs or graphical figures that the report could have provided to aid fishery management processes

Outputs and graphical figures provided in the report were sufficient for fishery management purposes. However, they were not sufficient to allow scientific review of the stock assessment. As I was provided with model input files I was able to run my own diagnostics to support this review. I believe that it has become necessary to provide such files to scientific reviewers to allow a thorough examination of the assessment implementation.

The plot of fitted spawning output vs recruitment for at least the base-case is of key importance and should be included in a stock assessment document. For east coast Spanish mackerel this makes it noticeably clear that recruitment deviations are only estimated for a narrow range of spawning output values. While this is appropriate given available data, this plot emphasises that much of the stock history is minimally informed by data other than catches and potentially assumptions about life history such as steepness.



Where assessments are regularly made for the same species using the same modelling framework, an opportunity arises to provide an audit trail that comprehensively and transparently shows model changes since the last assessment – commonly called a bridging analysis. Such a bridging analysis involves examination of absolute spawning biomass and recruitment trends over time after the application of sequential changes to model source code version revision, structural assumptions, changes to fixed parameter values or priors, and the inclusion of recent data (source by source where possible – catch, index, age and length composition by fleet). This provides a continuum from the previous assessment to the current base-case. Such a process (or an improvement on it) could be considered in the future for any regular SS assessments by DAF. It is understood that a detailed bridging analysis may not be required if the absolute biomass and recruitment series have changed little from one assessment to the next, but experience says that this is rarely the case.

Although the previous stock assessment for east coast Spanish mackerel by O'Neill et al. (2018) did not use SS, there may still have been an opportunity to construct a bridging analysis by commencing with a model that attempted to replicate those results – at least for a selected representative case. Provision of such a bridging analysis gives confidence to interested groups (e.g. managers or industry) that there is consistency among stock assessments. It also highlights where differences have arisen from – either via changes in modelling approach, or new data.

The ensemble approach to stock assessment is one that has been increasingly recommended (e.g. see Thorson 2020). A common current approach as in the assessment here uses a base-case and additional scenarios that represent axes of uncertainty as in the current assessment. Integration of results over a range of models selected to represent structural and data uncertainty more comprehensively is potentially superior for obtaining values of interest to management and should be considered.

Inclusion of the overall likelihood values in the summary table of sensitivity analysis results (Table 3.4) is useful, although differences in model structure and tuning sometimes make those statistically incomparable. A separate table with likelihood components further broken down into components such as CPUE or composition fit often still allows much insight into model behaviour that is unobtainable otherwise.

Evidence for model convergence should be considered and can be based on jittering starting values for estimated parameters. An improvement on this is via MCMC or bootstrap runs, although the additional time required for such procedures is recognized.

As CPUE standardisation is a complex procedure that produces much output on fits to the data and diagnostics that should be examined, I believe that this might be best achieved by the production of a document separate to the stock assessment on that process. Such a document, if comprehensive, could be examined independently by statisticians for sign-off as procedures that can simply be updated for assessment purposes in the future, potentially without detailed re-examination as part of stock assessment reviews.

3 References

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An illustration using bigeye tuna (Thunnus obesus) in the eastern Pacific Ocean. Fisheries Research 119– 120: 89– 93. doi:10.1016/j.fishres.2011.12.008

Annex 1: Bibliography of materials provided for review

Tanimoto M, Fox AR, O'Neill MF, and Langstreth JC. 2021. Stock assessment of Australian east coast Spanish mackerel (Scomboromorus commerson). Queensland Department of Agriculture and Fisheries Report.

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Supplementary data files

SS starter, .ctl, .dat, and forecast files for the base-case model and 9 additional scenarios.

Authors' response to east coast Spanish mackerel assessment review

11 August 2021

We appreciate the time and effort the reviewer dedicated to examining the stock assessment of Australian east coast Spanish mackerel (2021). The reviewer's report, knowledge of Stock Synthesis software and insightful comments provided valuable information to the stock assessment.

We have incorporated several suggestions made by the reviewer. Those changes are highlighted within the stock assessment report.

A point-by-point response to the reviewer's comments follows:

Reviewers' Comments to the Authors

Reviewer: "I could not find a summary background discussion in the assessment document of these features of the logbook data or methods that may have been employed to initially filter the data prior to analysis." (p6, Section 2.2.1b)

Authors: The following description on data-filtering was added to page 11, Section 2.3 Abundance indices, and page 44, Appendix A Section A4 in the main report.

Section 2.3 Abundance indices

From the initial logbook data, a series of filters were applied to obtain the Spanish mackerel data for catch rate standardisation. The filters used criteria relating to species, location, fishing method, fishing date and trip duration. The filtering process was detailed in Appendix A Section A4.

Appendix A A4

Commercial catch data were extracted from the Queensland logbook database. From the initial set of records, the catch rate data was defined through a series of filters.

For the probability model (first component of the standardisation model), the following filters were applied:

- Spanish mackerel (CAAB Code= 37441007) catches per latitude band and day.
- Where multiple latitudes were recorded on a single day, the catch was summed over all records, and the location was set to mean of latitude derived and mean of longitude derived.
- Date between 1 July 1988 and 30 June 2020.
- Location was east coast (between 11.00° S and 28.50° S, >= 142.5 ° E)
- Location excluded records in the far north latitude band 11 (due to lack of available data).

For the catch rate model (second component of the standardisation model), the following filters were applied:

- Line fishers that had at least three years of catching Spanish mackerel.
- Line fishing methods included "Trolling", "Handline", and "Line fishing".
- Where multiple locations were fished on a single day, the catch was summed over all records, and the location was set to mean of latitude and mean of longitude.
- Date between 1 July 1988 and 30 June 2020.
- Duration of the fishing trip was a single day.

- Location was east coast (between 11.00° S and 28.50° S, >= 142.5 ° E).
- Where kilograms of Spanish mackerel caught was greater than zero.

Reviewer: "Despite good efforts in historical catch reconstruction, the number of assumptions shows that historical harvest estimates for Spanish mackerel are uncertain and this uncertainty should be evident in assessment results. The scenarios examined did not include alternative catch history, although it may be that the influence of this is less important than the factors that were examined." (p7, Section2.2.1d)

Authors: The authors agree that it would have been ideal to consider alternative harvest scenarios as part of the sensitivity analyses. We will endeavour to test alternative harvest scenarios again in the next assessment. We note different harvest scenarios were analysed by Campbell et al. (2012) and Welch et al. (2002), showing marginal variations in biomass ratios.

Reviewer: "Until recently, many stock assessments have assumed that steepness is unknown and have used a default generic value, such as 0.75 for marine demersal fish stocks from Shertzer and Conn (2012). It has been common past practice to assume that pelagic species have relatively high reproductive resilience, with many assessments of those assuming steepness of 0.7 or more, and not a small number at or near steepness 1.0 (e.g. Zhu 2012 for bigeye tuna)." (p8, Section 2.2.1d)

Authors: Steepness is an influential parameter and thus, if fixed, should be at a value or range of values that are justified by the stock's biological information and data. We do not believe that using a "generic default value" meets this standard and instead have opted to be informed by estimates of this parameter from stock assessments on the same species or species with similar biology.

Specifically, we have used the most comprehensive and up-to-date meta-analysis available – the FishLife analysis by Thorson (2020), which incorporates stock assessment information from the global RAM legacy database. We would like to emphasise the trade-off involved in obtaining information from this meta-analysis at the genus and family taxonomic levels.

We have chosen to be primarily informed by the genus level steepness values as these are more likely to be relevant biologically. However, we acknowledge that the higher sample size associated with the family level estimates is arguably preferable. The family level steepness value is higher (0.69) and therefore we further investigated scenarios with steepness at 0.7.

This resulted in mixed outcomes depending on setting for natural mortality and the model generally had poor fit to input data, issues with convergence (i.e. unable to find model results), and high recruitment residuals in early years (Table 1).

For scenarios estimating natural mortality, estimated values were less realistic given the age to which east coast Spanish mackerel are known to live. Fixing natural mortality with high steepness generally resulted in poor fit to the data. In particular, the scenario C (fixing M at 0.25) had poor weighting (over-weighting) to age and length composition data.

The overall finding was that the model did not fit well with high steepness given current input data and resulted in less plausible parameter estimates (e.g. very high natural mortality and low sized-based selectivity). Detailed results of additional scenarios are provided in Response Appendix 1 (located at the end of this document).

Table 1 Summary of the Spanish mackerel results from the base case and additional model runs Note: bold italic values indicate parameter estimated from the model; base case standardised catch rate was used for all additional runs; log-likelihood (-lnL) values are not comparable as different Francis weighting was applied to individual scenario; spawning biomass is presented as a ratio relative to an unfished state; and equilibrium annual harvest values are in tonnes.

Scenario	h	M	-lnL	B_{2020}/B_0	Harvest at B_{60}
1 (Base)	0.45	***0.27 (no prior)***	389.547	0.169	557
A	0.7	***0.39 (with prior)***	401.921	0.582	894
B	0.7	***0.18 (with prior)***	426.574	0.122	511
C	0.7	0.25	647.875	0.405	546
D	0.7	0.33	435.955	0.571	727
E	***0.49***	0.25	390.279	0.157	552

We would also like to draw attention to a characteristic of the assessment that may imply the specific value of steepness is less a source of uncertainty than it might at first appear. This is the “bi-modal” (two-valued) nature of the space of possible solutions. Additional sensitivity analysis runs indicate that it is possible for “high steepness” scenarios to result in “low biomass” (~ 20%) outcomes as well as “low steepness” scenarios to end up in “high biomass” (~ 60%) outcomes.

In general, the high biomass scenarios were considered less plausible than the low biomass scenarios because they are either associated with unrealistically high natural mortality, or very large early-year recruitment residuals, or convergence problems or some combination of these.

We also found that when natural mortality was fixed at 0.25 and steepness was estimated, consistent with scenarios in O'Neill et al. (2018), the final estimate for steepness was 0.49 (scenario E, Table 1). In general, scenario E results were similar to the base case model with the spawning biomass ratio B_{2020} at 16% (base case = 17%) and harvest at B_{60} was estimated at 552 tonnes (base case = 557 tonnes).

Based on the information above, we feel the base case results in the report remains a credible scenario.

Reducing uncertainty in future assessments might be more about understanding how much, if any, probability should be associated with the “higher mode” than about steepness setting per se. As well as gauging the realism in natural mortality and MSY values, one way to do this would be through an MCMC analysis in combination with a genuine steepness prior (as opposed to a fixed value).

Reviewer: “The current assessment simply states “Beverton-Holt stock recruitment steepness (h) was fixed at a value of 0.45, based on the meta-analysis of Thorson (2020). Different levels of h were tested as sensitivity analyses.” and “The values of steepness (h) that were explored in this assessment were chosen to align with range of estimated values in O’Neill et al. (2018).” It has been recognised by the authors that this required more explanation, which I was provided separately.” (p8, Section 2.2.1d)

Authors: We acknowledge that further explanation of the choices of base case steepness value was needed and the revised text reads as follows on Section 2.5.2 Model parameters:

“Beverton-Holt stock recruitment steepness (h) was fixed at a value of 0.45, based on the meta-analysis of Thorson (2020). Table 4 of Thorson (2020) lists a steepness value of h=0.69

for the Scombridae family, however Figure 3 of the same paper indicates great variation in steepness at the genus level (*Scomberomorus*). The R package "FishLife" was used to extract the steepness value for the *Scomberomorus* genus (h=0.45) from the meta-analysis described in the paper."

We have explored steepness extensively and concluded that the value used in this assessment is the most appropriate based on current evidence. Future work will refine our understanding of steepness for this stock. In the process of gaining this understanding we will consider how Thorson's meta-analysis has combined information from various sources.

Reviewer: "From my experience with many stock assessments, that low central value for steepness for Spanish mackerel is inconsistent with previous accepted practice, and comparable existing DAF Spanish mackerel assessments. As such, it requires a much-expanded justification within the current assessment document." (p9, Section 2.2.1d)

Authors: The first statement is persuasive and is implied in the "No BS guide to fisheries stock assessment.ppt" on capamresearch.org for an unknown stock recruitment relationship. However, scientific/peer opinion has varied in literature on appropriate upper settings on steepness (Myers et al, 1999), particularly when hyperstability might confound stock assessments. In addition, basing stock assessments on a sole high steepness value might not be risk adverse or contribute to further understanding. More capamresearch.org documentation and guidance is required around this parameter capturing assessment findings more broadly from Australia.

The Australian east coast Spanish mackerel assessment in 2012 (Campbell et al., 2012) used fixed steepness of 0.52 as a base case, which was based on the mode of the empirical prior distribution for the Scombridae family reported by Myers et al. (1999). The steepness estimated in the following stock assessment (O'Neill et al., 2018) ranged between 0.25 and 0.8 over 177 scenarios with median value of 0.41.

For the Torres Strait Spanish mackerel stock, the estimation of steepness in the assessment by O'Neill and Tobin (2016) estimated steepness which varied 0.35–0.59. The estimated steepness values for the most recent stock assessment by Buckworth et al. (2021) had a mean steepness of 0.4 over the six core stock assessment analyses.

It is difficult to give credence to a high sole steepness value. In general, Spanish mackerel data from the east coast, Torres Strait (Buckworth et al., 2021) and Gulf of Carpentaria (Bessell-Browne et al., 2020) cannot match well with the high steepness values noted from overseas on the review paragraph 2 on page 9.

Early publication on the reproductive rates for Scombridae species (mackerel and tuna species) suggested steepness with median h = 0.52, 20th percentile = 0.3 and 80th percentile = 0.72; (Table 1, Myers et al., 1999). Myers et al. (1999) concluded that h will vary with species, natural mortality and age-at-maturity, with the number of annual replacement spawners typically ranging 1–7 per spawner per year. Using Myers et al. (1999) biological generalisation, an expected steepness (h) for Spanish mackerel could range 0.4 to 0.87; noting this range is higher than the values summarised for Scombridae. This value could also vary between stocks or areas.

We believe the different levels of fixed steepness analysed in the report and herein were within the range estimated in existing DAF Spanish mackerel assessments. We acknowledge that more research is required for the selection of base case steepness value and the report has been amended in accordance with the feedback.

Reviewer: "I have SS input files for accepted US base-case assessments for three species in the genus Scomberomorus. Some or all of these may have contributed recruitment series to the RAM Legacy database. These were SEDAR 28 2012 South Atlantic Spanish mackerel, SEDAR 38 2014 Gulf of Mexico king mackerel, and SEDAR 38 2014 South Atlantic king mackerel. These stock assessments used fixed steepness values of 0.8, 0.98 and 0.99 respectively, although those values are not used by subsequent steepness meta-analysis." (p9, Section 2.2.1d)

Authors: We reviewed the three assessments and found that:

- SEDAR (2012) used steepness value fixed at 0.75 for South Atlantic Spanish mackerel,
- The base case model for Gulf of Mexico king mackerel estimated steepness at 0.79 with beta prior of 0.7 (sd = 0.11) (SEDAR, 2014a).
- The base case model for South Atlantic king mackerel estimated steepness at 0.5 with uniform prior (SEDAR, 2014b).

The review panel for the last two assessments recommended to fix steepness at 0.99. This explained why the input files, the reviewer had from these three assessments, had such a high value of 0.99. We also understand why these values were not used by subsequent steepness meta-analysis. The authors believe that there is scientific evidence that lower steepness values were estimated in these assessments prior to panel review, and this aligns with steepness values estimated by Thorson (2020) and our findings, as presented on the previous page.

Reviewer: "In addressing this, it would be useful if assessment documents provided a table that summarises those uncertainties and how the assessment has addressed them." (p10, Section 2.2.1f)

Authors: Authors appreciate reviewer's suggestion and will endeavour to consider in future stock assessment report.

Reviewer: "True sensitivity analysis that alters only one factor from the base-case for the purpose of stock assessment diagnosis was not included and could be considerably expanded through examination of lower and higher weights (potentially via Lambda adjustments) for the various data inputs and assumptions." (p10, Section2.2.1f).

Authors: This comparative approach and full sensitivities tests were completed by Campbell et al. (2012) and O'Neill et al. (2018). We concluded that our model runs can now be more selective and informative. For the next assessment, the project team will suggest sensitivity tests following a factor-by-factor design.

Reviewer: "The document states that this assessment did not include a discount factor to account for uncertainty in recommended target estimates, but this decision was not explained in the document." (p11, Section 2.2.1g)

Authors: Authors added the following sentence to the report in page 17, Section 2.5.5 Forward projection: "This assessment did not include a discount factor to account for uncertainty in recommended target estimates as the Fisheries Queensland Spanish Mackerel Fishery Working Group and fishery management will evaluate whether to apply discount factors to recommended biological catch."

Reviewer: “Any efforts to make use of earlier composition data that may enable extension of recruitment deviation estimation to earlier years is important for this assessment.” (p12, Section 2.2.3)

Authors: Authors note the importance of including earlier age and length composition data and will endeavour reviewing available data and standardise for consideration in the future assessment and this is listed as a recommendation in Stock Assessment Report Section 4.4.1.

Reviewer: “Integration of results over a range of models selected to represent structural and data uncertainty more comprehensively is potentially superior for obtaining values of interest to management and should be considered.” (p13, Section 2.2.4)

Authors: Authors agreed with the reviewer’s comments, and this has been our common approach.

Reviewer: “The plot of fitted spawning output vs recruitment for at least the base-case is of key importance and should be included in a stock assessment document.”

Authors: The plot of the base case model was added in the report, Appendix B, Section B.2.

Reviewer: “Although the previous stock assessment for east coast Spanish mackerel by O’Neill et al. (2018) did not use SS, there may still have been an opportunity to construct a bridging analysis by commencing with a model that attempted to replicate those results – at least for a selected representative case.” (p13, Section 2.2.4)

Authors: Authors consider this a useful exercise. This will be considered by the advisory project team. To note, a bridging analysis (comparing custom and Stock Synthesis models) is scheduled for upcoming Torres Strait Spanish mackerel stock assessment. Results will help inform the east coast stock assessment.

Reviewer: “Evidence for model convergence should be considered and can be based on jittering starting values for estimated parameters. An improvement on this is via MCMC or bootstrap runs, although the additional time required for such procedures is recognized.“ (p14, Section 2.2.4)

Authors: We have explored uncertainty in steepness values by exploring a range of fixed steepness values. We have also explored overall model convergence by applying different starting values for estimated parameters (using jitter function in Stock Synthesis). While we concluded that more plausible results were obtained with lower biomass outcome (i.e., reasonable M and R0 estimates, better performed recruitment deviation), jittering starting values revealed that the model could lead to two distinct solutions based on the allowed upper extent on M. We are not ruling out that there are alternative solutions under more sensitivity runs. MCMC might help report the broader uncertainties in the model. Expansion of model sensitivity runs, jittering and changing the number of parameters estimated may provide further evidence on model convergence and stock scenarios.

Reviewer: “A separate table with likelihood components further broken down into components such as CPUE or composition fit often still allows much insight into model behaviour that is unobtainable otherwise.” (p14, Section 2.2.4)

Authors: The table of negative log likelihoods broken down into components for eight scenarios are provided in Table 2 (details of each scenario are in Table 2.3 of the main report). Authors agree with reviewer’s suggestion and will endeavour to include this in the future stock assessment reports.

Table 2 Breakdown of negative log-likelihood for each scenario. Zero values indicate components that are not applicable to this assessment.

Scenario	1 (Base)	2	3	4	5	6	7	8
TOTAL	389.55	381.06	394.13	349.14	346.41	370.12	370.85	385.28
Catch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Equil_catch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Survey	-58.35	-60.35	-56.29	-66.80	-69.11	-66.86	-59.75	-70.53
Length_comp	77.78	77.33	76.66	78.18	78.10	79.88	80.43	81.36
Age_comp	379.19	372.61	382.99	347.47	347.06	364.52	360.02	384.10
Recruitment	-9.24	-8.91	-9.53	-10.67	-10.76	-11.16	-10.01	-9.83
InitEQ_Regime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Forecast_Recruitmen	0.04	0.05	0.03	0.02	0.04	0.02	0.03	0.04
Parm_priors	0.13	0.33	0.26	0.94	1.08	3.72	0.13	0.13
Parm_softbounds	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Parm_devs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crash_Pen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Reviewer: "As CPUE standardisation is a complex procedure that produces much output on fits to the data and diagnostics that should be examined, I believe that this might be best achieved by the production of a document separate to the stock assessment on that process." (p14, Section 2.2.4)

Authors: In general, this will be considered for future stock assessment reports.

Amendments made to the report:

1. A paragraph of data filtering process was added in page 11, Section 2.3 Abundance indices and detailed description was added in page 44, Appendix A Section A4.
2. Expanded description of the selection of base case steepness parameter was added in page 16, Section 2.5.2 Model parameters.
3. The plot of fitted spawning output vs recruitment was added in Appendix B Section B.2.
4. Justification of not applying discount factor was added in page 17, Section 2.5.5 Forward Projections.

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Bessell-Browne, P, MF O'Neill, and JC Langstreth (2020). Stock assessment of the Queensland Gulf of Carpentaria Spanish mackerel (*Scomberomorus commerson*) fishery 2019. Tech. rep. Brisbane: Queensland Department of Agriculture, Fisheries and Forestry.

Buckworth, R.C., O'Neill, M.F., Trappett, A.G., and Langstreth, J.C. (2021). Spanish mackerel stock assessment, with appraisal of environmental drivers. Torres Strait AFMA Project Number: RR2019/0831. Department of Agriculture and Fisheries, Queensland Government.

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Welch, D. J., S. D. Hoyle, N. A. Gribble, and G. McPherson (2002). Preliminary assessment of the Queensland east coast Spanish mackerel fishery. Tech. rep. Brisbane. Agency for Food, Fibre Sciences, and Queensland Fisheries Service. Department of Primary Industries.

Response Appendix 1

Scenario A - Result warning: natural mortality estimate was biologically very high, and the large early-year recruitment deviations were implausible.

Scenario A was identical to the base case except steepness, *h,* was fixed at 0.70 instead of 0.45 with upper bound of natural mortality was set as 0.5. Note that all outputs are standard Stock Synthesis outputs produced by R4SS package.

Table 3: Stock Synthesis parameter estimates for the scenario A population model for Spanish mackerel

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
Natural mortality	0.39	3	0.01	0.5	0.29	0.02
Length at age 1 (*FL1*) female	66.62	1	30	90	72	1.42
Length at maximum age (*FLinf*) female	130.14	1	100	180	140	2.40
von Bertalanffy growth parameter (κ) female	0.29	1	0.1	0.4	0.22	0.03
Coefficient of variation in length at age 1 female	0.08	4	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age female	0.07	4	0.01	0.2	0.14	0.01
Length at age 1 (*FL1*) male	65.73	1	30	85	70	1.30
Length at maximum age (*FLinf*) male	114.24	1	100	200	120	1.32
von Bertalanffy growth parameter (κ) male	0.35	1	0.1	0.45	0.21	0.03
Coefficient of variation in length at age 1 male	0.08	4	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age male	0.04	4	0.01	0.2	0.13	0.00
Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1911)	13.77	1	10	15	13.3	0.25
Commercial selectivity inflection (cm)	81.50	2	30	120	60	0.93
Commercial selectivity width (cm)	11.40	2	0	20	0.5	1.32

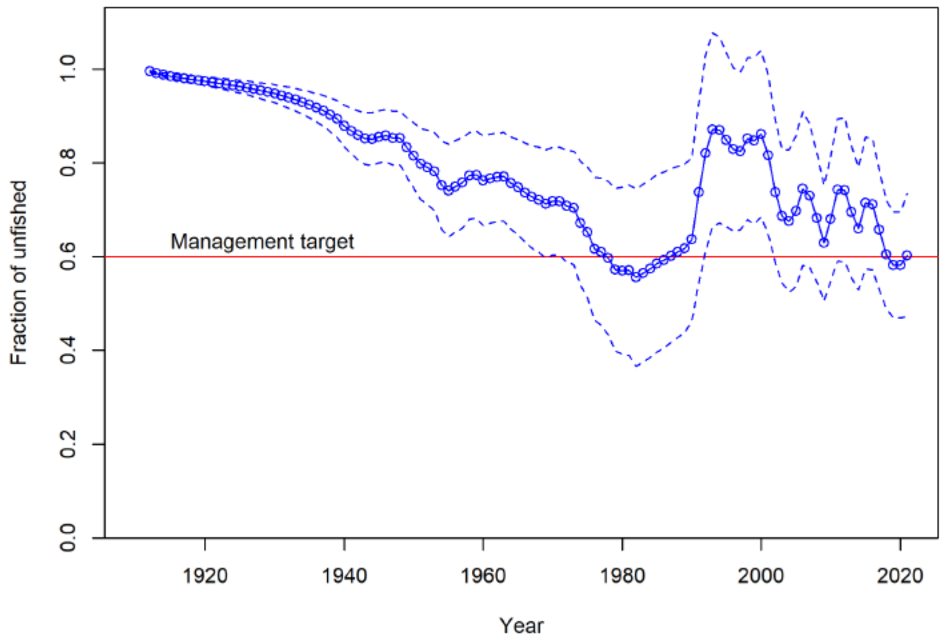

Figure 1: Predicted spawning biomass trajectory relative to virgin for Spanish mackerel, from 1911 to 2020, for scenario A

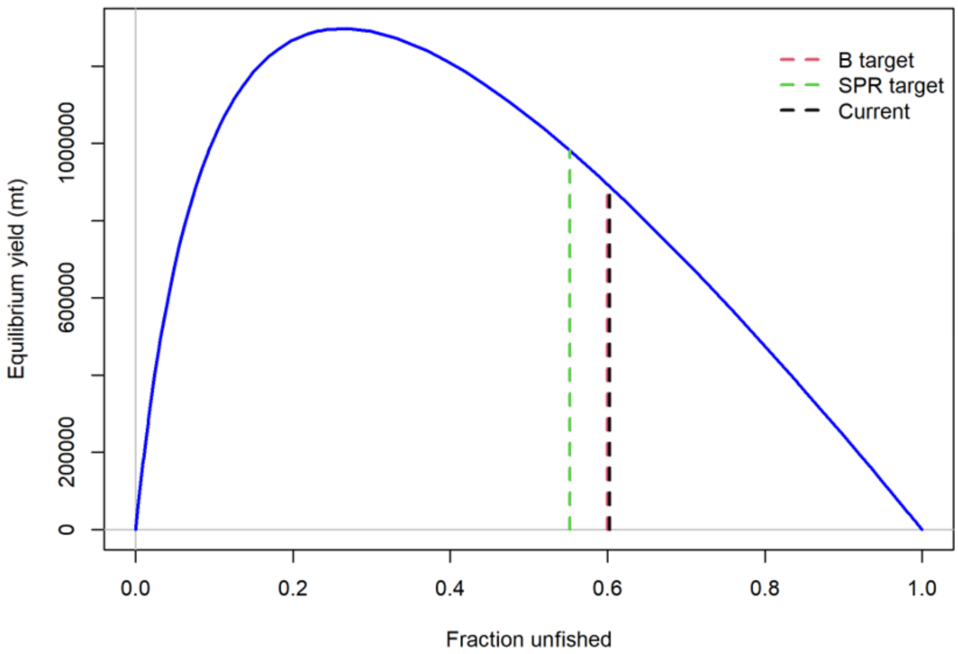

Figure 2: Equilibrium yield curve for Spanish mackerel for scenario A

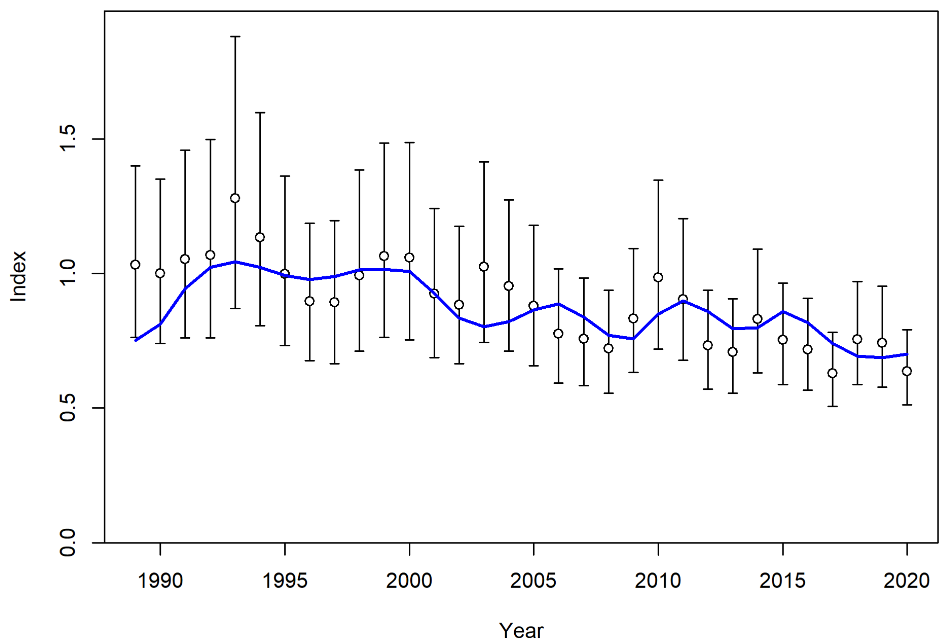

Figure 3: Model predictions (blue line) to commercial catch rates for Spanish mackerel for scenario A

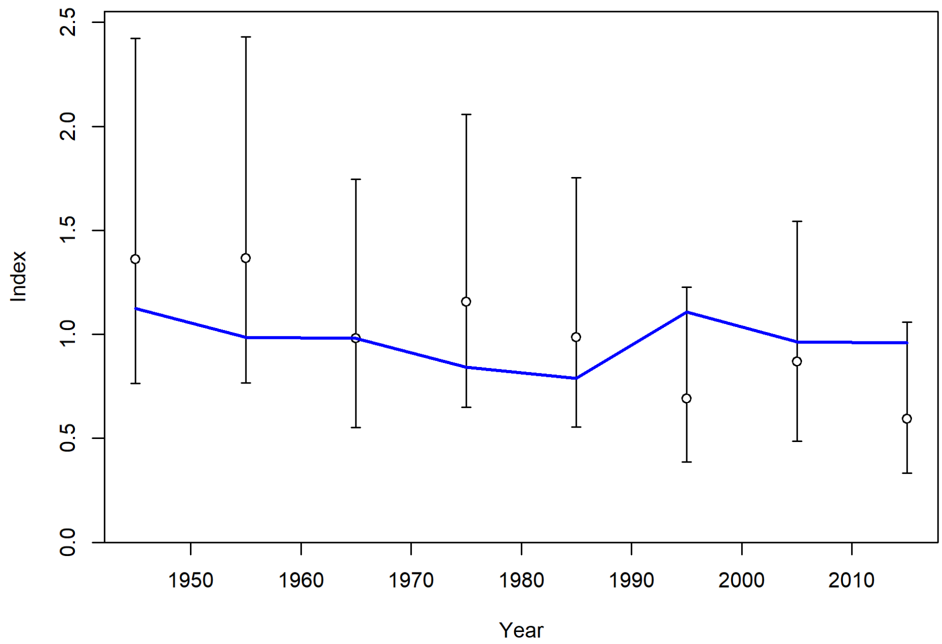

Figure 4: Model predictions (blue line) to historical decadal catch rates for Spanish mackerel for scenario A

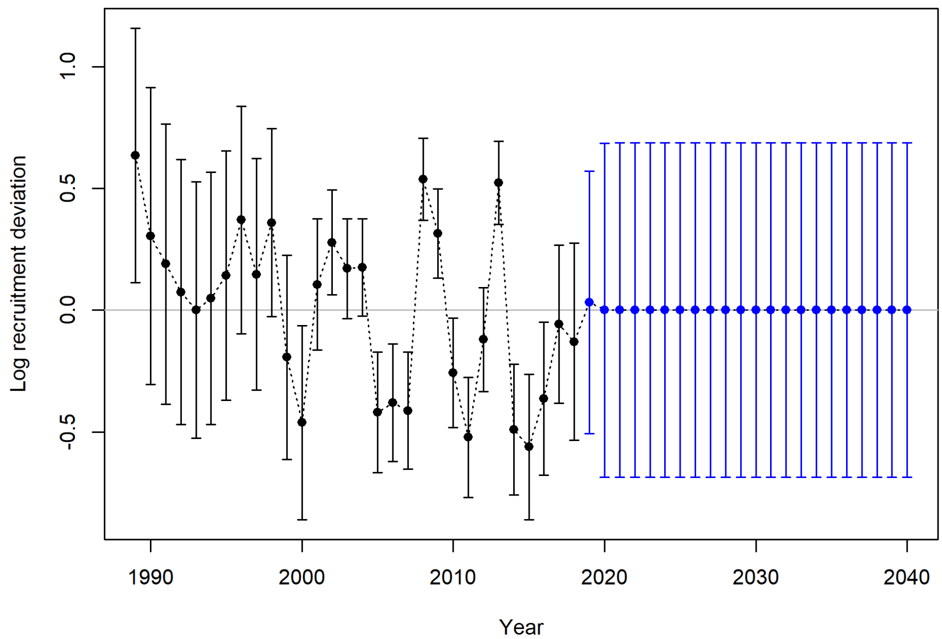

Figure 5 Recruitment deviations with 95% confidence intervals for Spanish mackerel for scenario A

Scenario B - Result warning: issue with model convergence (unable to find solution).

Scenario B was identical to the base case except steepness, *h,* was fixed at 0.70 instead of 0.45 with upper bound of natural mortality was set as 0.4. Note that this scenario had final gradient (0.00166) greater than threshold value of 0.0001, indicating the model had trouble finding solution.

Table 4: Stock Synthesis parameter estimates for the scenario B population model for Spanish mackerel

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
Natural mortality	0.18	2	0.01	0.4	0.25	0.01
Length at age 1 (*FL1*) female	67.60	1	30	90	72	1.33
Length at maximum age (*FLinf*) female	131.27	1	100	180	140	2.50
von Bertalanffy growth parameter (κ) female	0.28	1	0.1	0.4	0.22	0.02
Coefficient of variation in length at age 1 female	0.07	4	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age female	0.07	4	0.01	0.2	0.14	0.01
Length at age 1 (*FL1*) male	66.02	1	30	85	70	1.25
Length at maximum age (*FLinf*) male	114.03	1	100	200	120	1.26
von Bertalanffy growth parameter (κ) male	0.35	1	0.1	0.45	0.21	0.03
Coefficient of variation in length at age 1 male	0.08	4	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age male	0.04	4	0.01	0.2	0.13	0.00
Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1911)	12.55	1	10	15	12.00	0.04
Commercial selectivity inflection (cm)	81.07	3	30	120	81	0.85
Commercial selectivity width (cm)	11.49	3	0	20	11	1.35

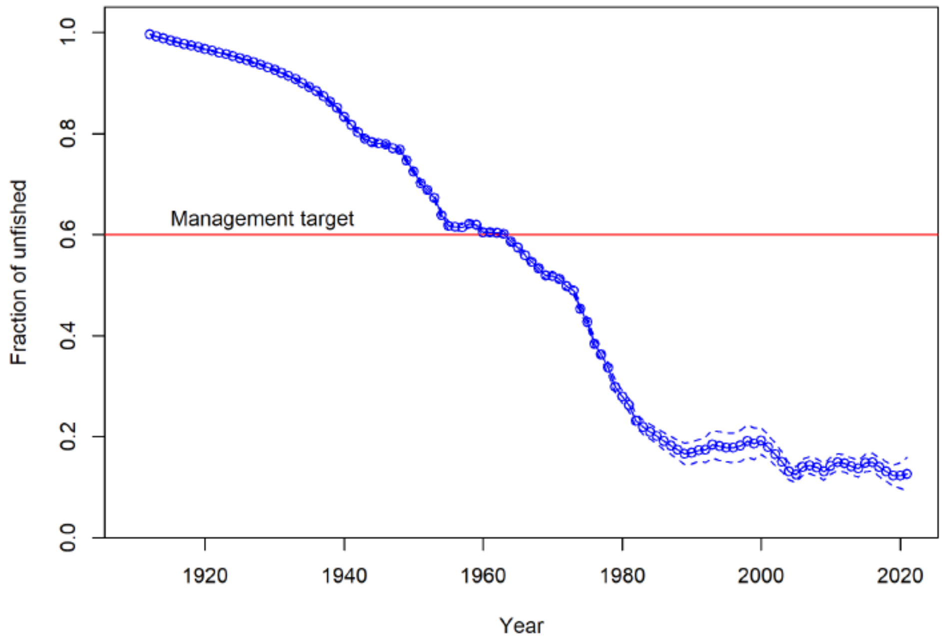

Figure 6: Predicted spawning biomass trajectory relative to virgin for Spanish mackerel, from 1911 to 2020, for scenario B

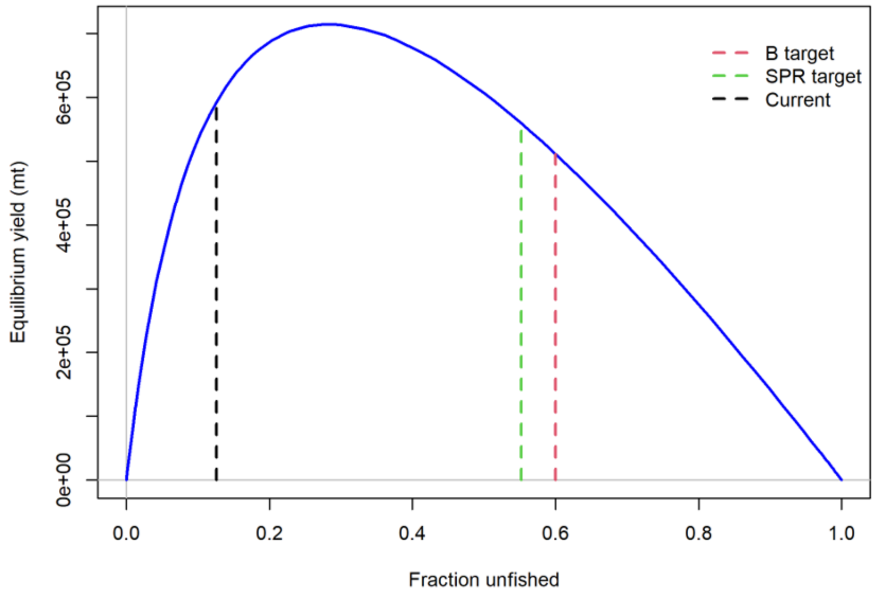

Figure 7: Equilibrium yield curve for Spanish mackerel for scenario B

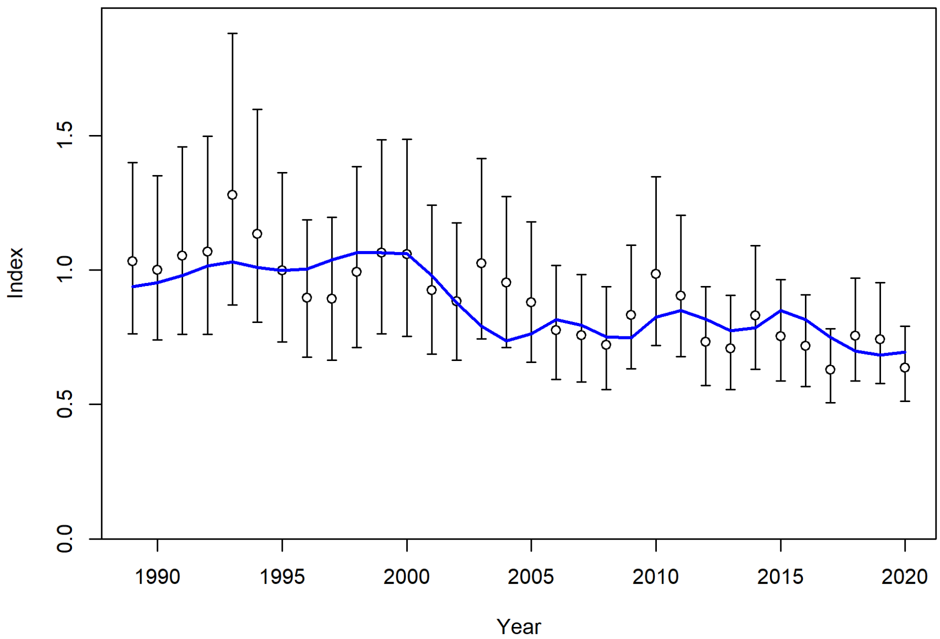

Figure 8: Model predictions (blue line) to commercial catch rates for Spanish mackerel for scenario B

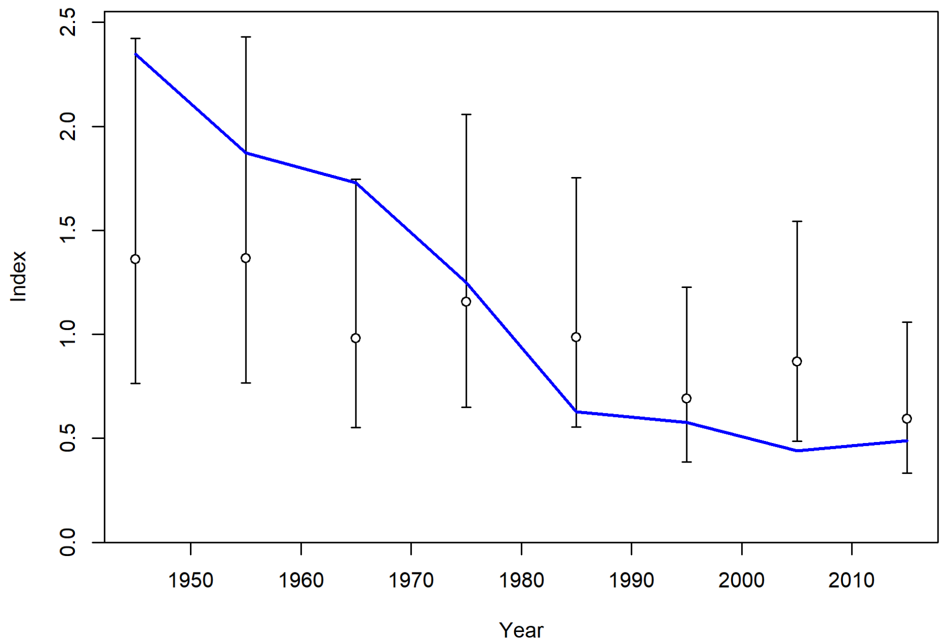

Figure 9: Model predictions (blue line) to historical decadal catch rates for Spanish mackerel for scenario B

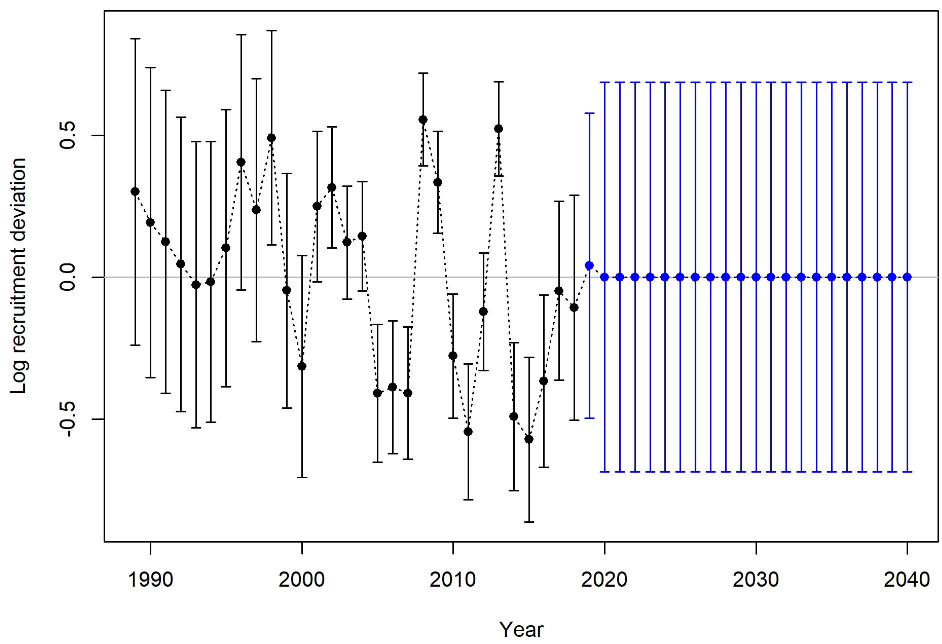

Figure 10 Recruitment deviations with 95% confidence intervals for Spanish mackerel for scenario B

Scenario C - Result warning: no optimal solution, poor fit to the index data, and the large early-year recruitment deviations were unlikely.

Scenario C used base case standardised catch rate and steepness (*h*) *and* natural mortality (*M*) were fixed at 0.7 and 0.25, respectively. This scenario had poor weighting to age and length composition data. Stock synthesis suggested further adjusting Francis weighting for length and age data by applying multiplier of 0.6691 and 0.7293, respectively. However, the model was unable to converge when these multipliers were applied to the model, indicating the model struggled to fit input data with current parameter settings.

Table 5: Stock Synthesis parameter estimates for the scenario C population model for Spanish mackerel

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
Length at age 1 (*FL1*) female	67.49	2	30	90	72	1.20
Length at maximum age (*FLinf*) female	131.51	2	100	180	140	2.24
von Bertalanffy growth parameter (κ) female	0.28	2	0.1	0.4	0.22	0.02
Coefficient of variation in length at age 1 female	0.07	4	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age female	0.07	4	0.01	0.2	0.14	0.00
Length at age 1 (*FL1*) male	65.91	2	30	85	70	1.09
Length at maximum age (*FLinf*) male	114.29	2	100	200	120	1.10
von Bertalanffy growth parameter (κ) male	0.35	2	0.1	0.45	0.21	0.02
Coefficient of variation in length at age 1 male	0.08	4	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age male	0.05	4	0.01	0.2	0.13	0.00
Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1911)	12.85	1	10	15	13.3	0.02
Commercial selectivity inflection (cm)	80.59	3	30	120	60	0.75
Commercial selectivity width (cm)	11.19	3	0	20	0.5	1.10

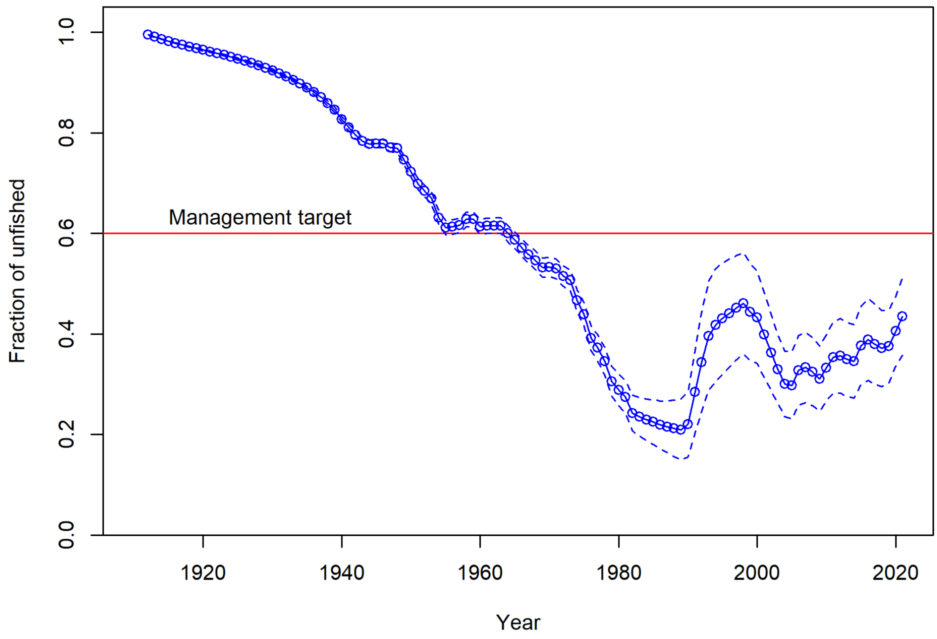

Figure 11: Predicted spawning biomass trajectory relative to virgin for Spanish mackerel, from 1911 to 2020, for scenario C

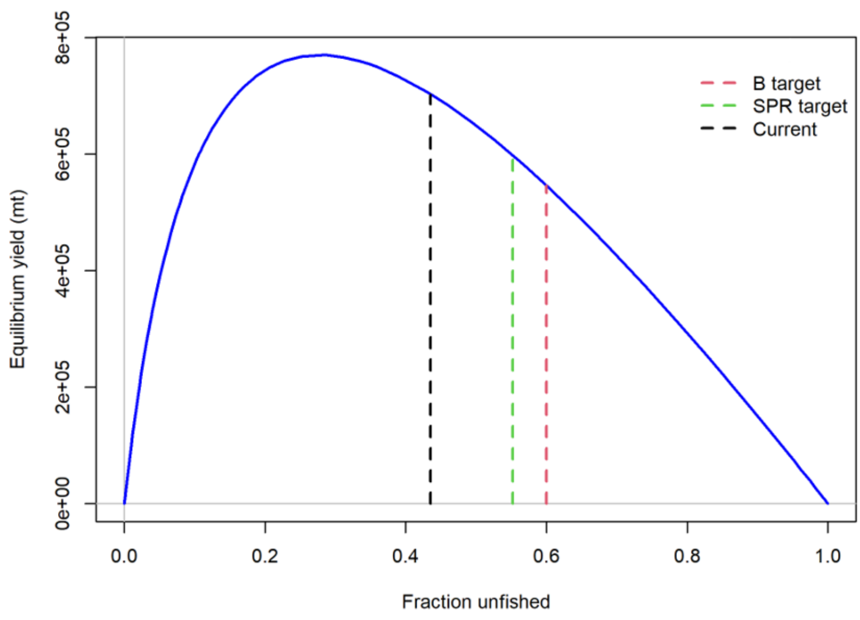

Figure 12: Equilibrium yield curve for Spanish mackerel for scenario C

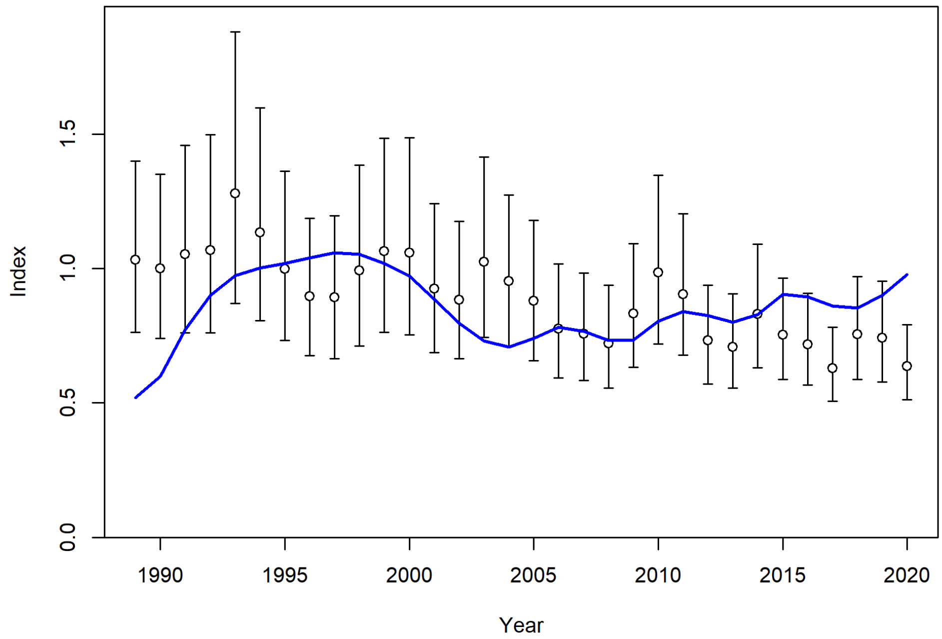

Figure 13: Model predictions (blue line) to commercial catch rates for Spanish mackerel for scenario C

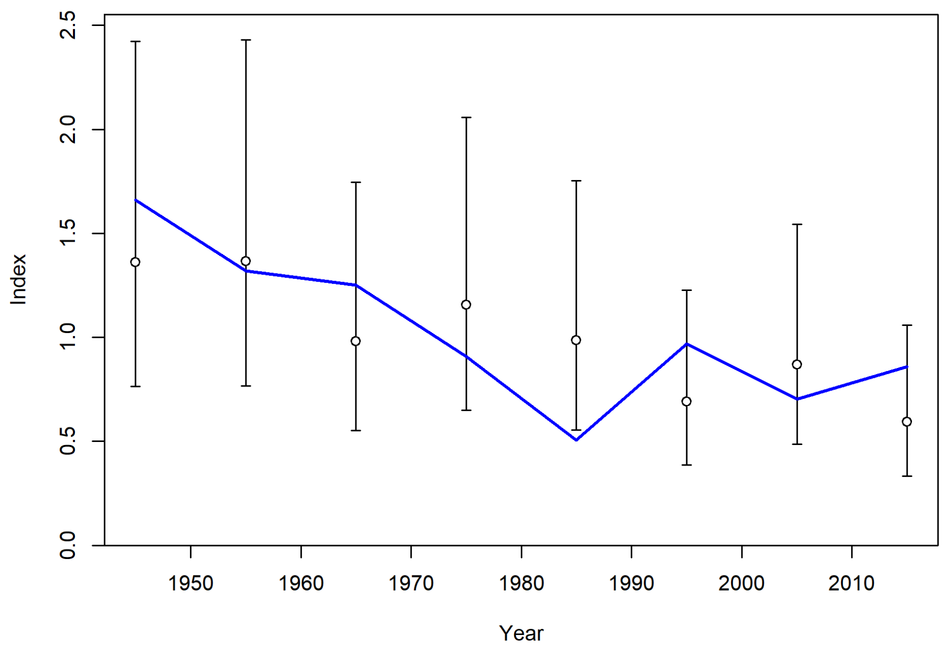

Figure 14: Model predictions (blue line) to historical decadal catch rates for Spanish mackerel for scenario C

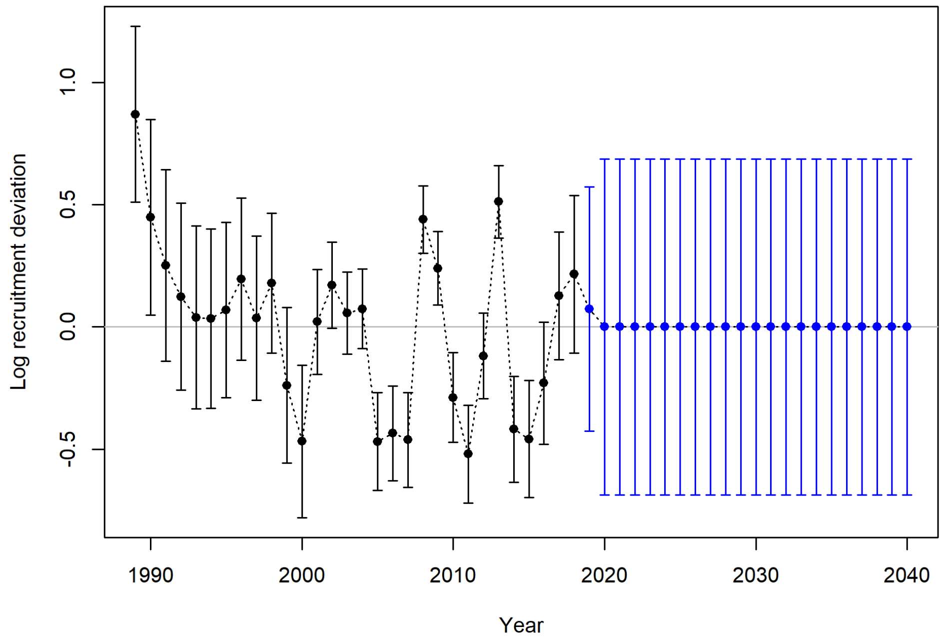

Figure 15 Recruitment deviations with 95% confidence intervals for Spanish mackerel for scenario C

Scenario D - Result warning: fixing two key parameters (h and M) was not ideal, poor fit to the index data, and the large early-year recruitment deviations were unlikely.

Scenario D used base case standardised catch rate and steepness (*h*) *and* natural mortality (*M*) were fixed at 0.7 and 0.33, respectively.

Table 6: Stock Synthesis parameter estimates for the scenario D population model for Spanish mackerel

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
Length at age 1 (*FL1*) female	66.84	1	30	90	72	1.42
Length at maximum age (*FLinf*) female	130.58	1	100	180	140	2.45
von Bertalanffy growth parameter (κ) female	0.29	1	0.1	0.4	0.22	0.03
Coefficient of variation in length at age 1 female	0.07	4	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age female	0.07	4	0.01	0.2	0.14	0.01
Length at age 1 (*FL1*) male	65.72	1	30	85	70	1.29
Length at maximum age (*FLinf*) male	114.26	1	100	200	120	1.29
von Bertalanffy growth parameter (κ) male	0.35	1	0.1	0.45	0.21	0.03
Coefficient of variation in length at age 1 male	0.08	4	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age male	0.05	4	0.01	0.2	0.13	0.00
Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1911)	13.39	1	10	15	13.3	0.06
Commercial selectivity inflection (cm)	80.55	2	30	120	81	0.82
Commercial selectivity width (cm)	10.94	2	0	20	11	1.26

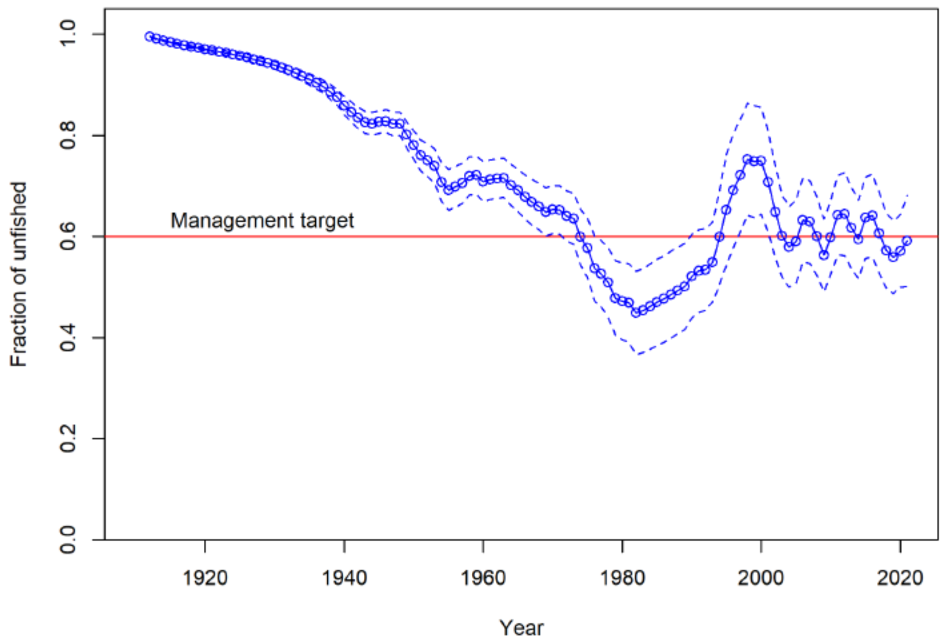

Figure 16: Predicted spawning biomass trajectory relative to virgin for Spanish mackerel, from 1911 to 2020, for scenario D

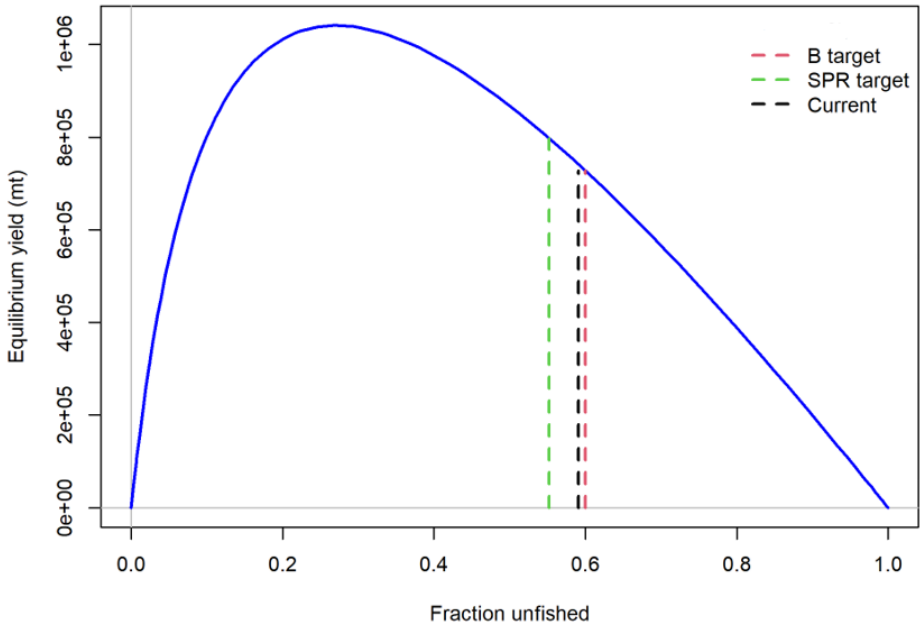

Figure 17: Equilibrium yield curve for Spanish mackerel for scenario D

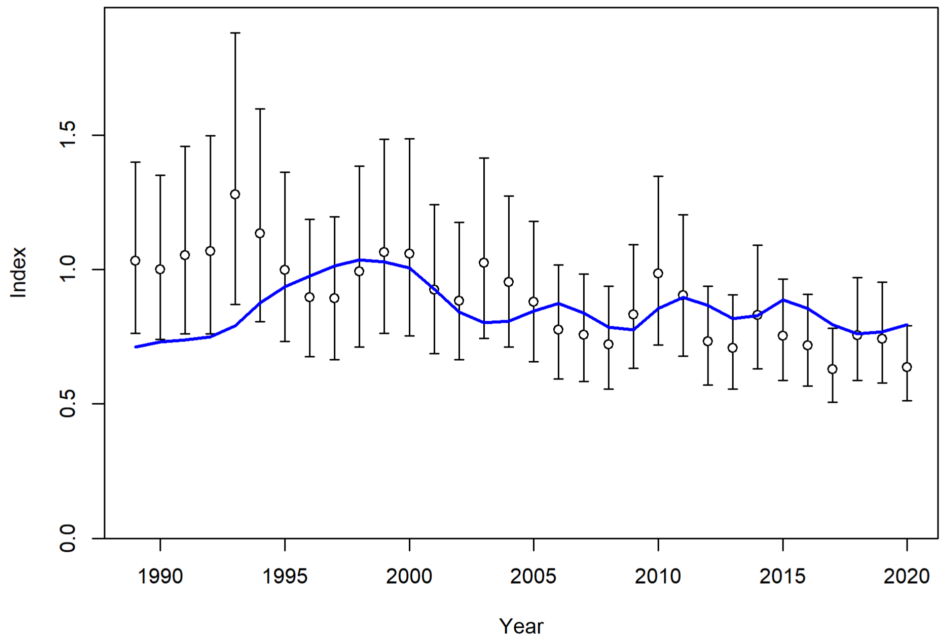

Figure 18: Model predictions (blue line) to commercial catch rates for Spanish mackerel for scenario D

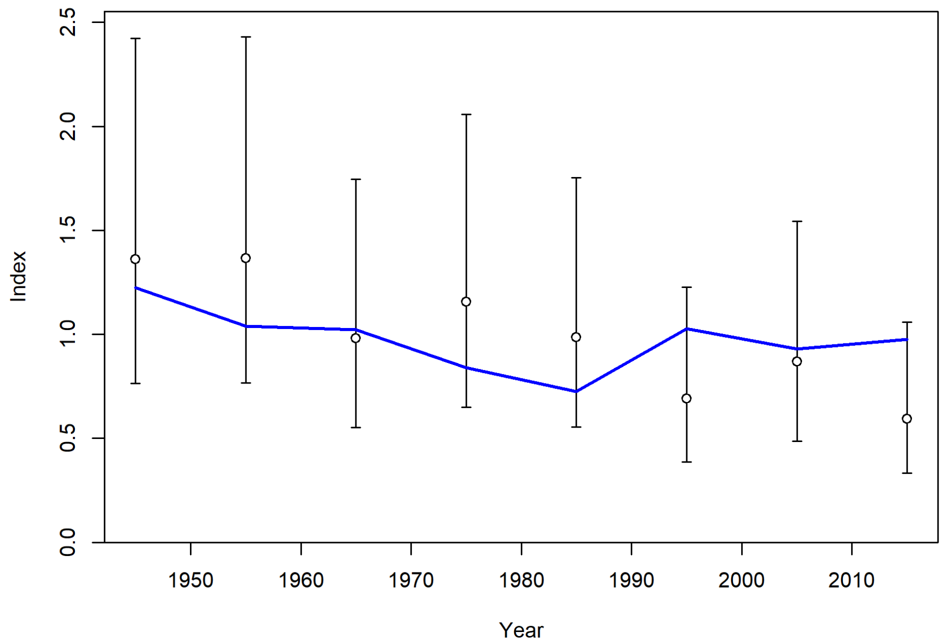

Figure 19: Model predictions (blue line) to historical decadal catch rates for Spanish mackerel for scenario D

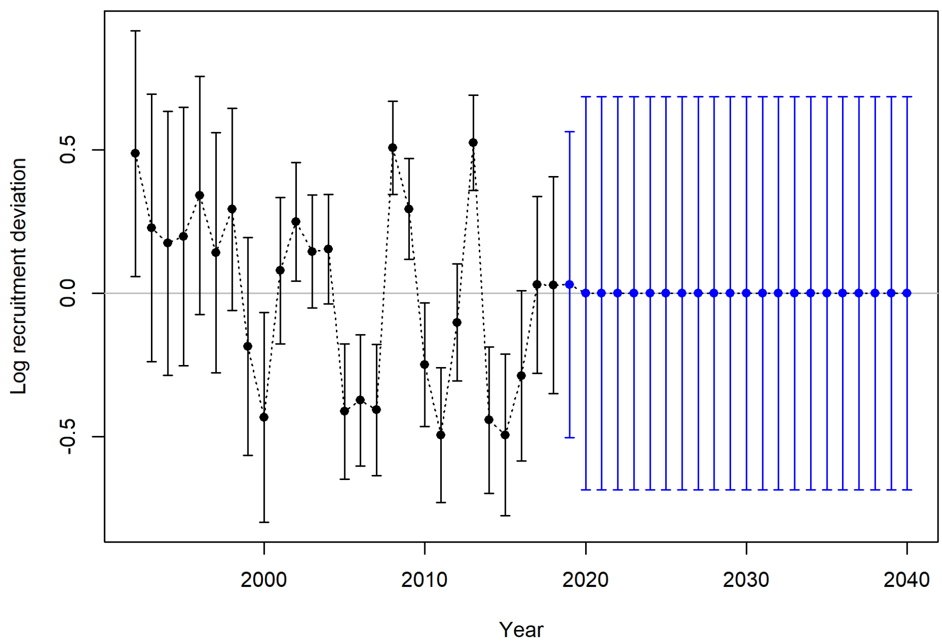

Figure 20 Recruitment deviations with 95% confidence intervals for Spanish mackerel for scenario D

Scenario E - No result warning: generally reasonable fits to the index data, the early-year recruitment deviations were not overly extreme, and model parameters appeared plausible.

Scenario E used standardised catch rate, natural mortality was fixed at 0.25 and steepness, *h,* was estimated in the model.

Table 7: Stock Synthesis parameter estimates for the scenario E population model for Spanish mackerel

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
Length at age 1 (*FL1*) female	66.90	1	30	90	72	1.40
Length at maximum age (*FLinf*) female	130.11	1	100	180	140	2.38
von Bertalanffy growth parameter (κ) female	0.29	1	0.1	0.4	0.22	0.03
Coefficient of variation in length at age 1 female	0.07	4	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age female	0.07	4	0.01	0.2	0.14	0.01
Length at age 1 (*FL1*) male	66.00	1	30	85	70	1.29
Length at maximum age (*FLinf*) male	114.17	1	100	200	120	1.31
von Bertalanffy growth parameter (κ) male	0.35	1	0.1	0.45	0.21	0.03
Coefficient of variation in length at age 1 male	0.08	4	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age male	0.04	4	0.01	0.2	0.13	0.00
Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1911)	13.14	1	10	16	13.5	0.05
Beverton-Holt steepness (*h*)	0.49	3	0.2	1	0.7	0.02
Commercial selectivity inflection (cm)	81.10	2	30	120	60	0.87
Commercial selectivity width (cm)	11.38	2	0	20	0.5	1.34

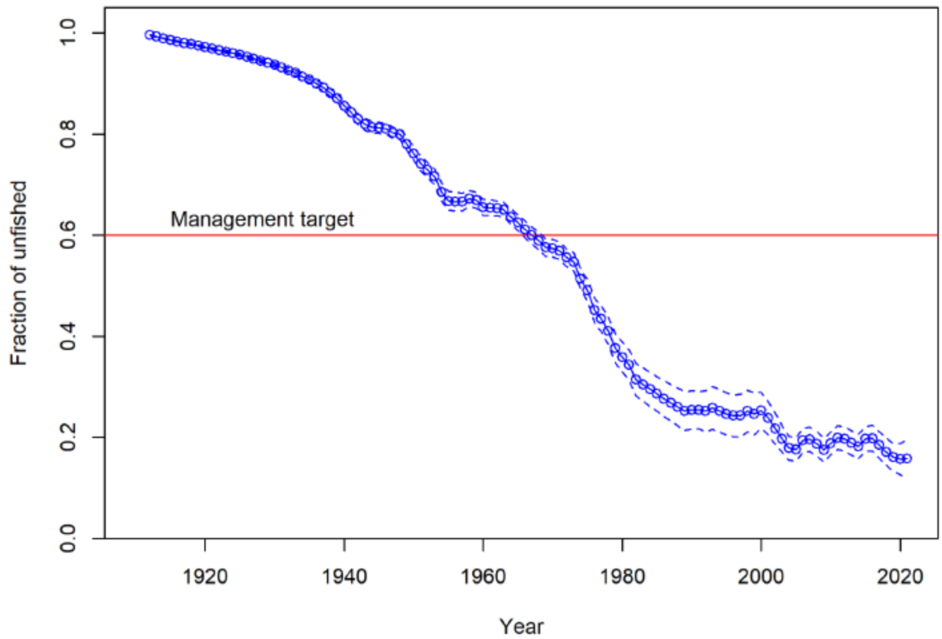

Figure 21: Predicted spawning biomass trajectory relative to virgin for Spanish mackerel, from 1911 to 2020, for scenario E

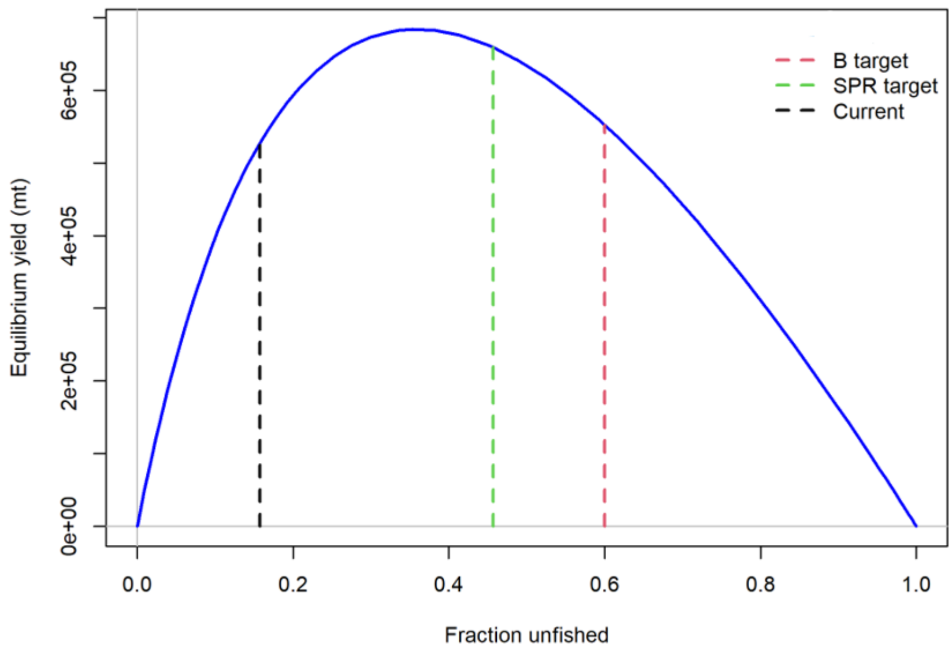

Figure 22: Equilibrium yield curve for Spanish mackerel for scenario E

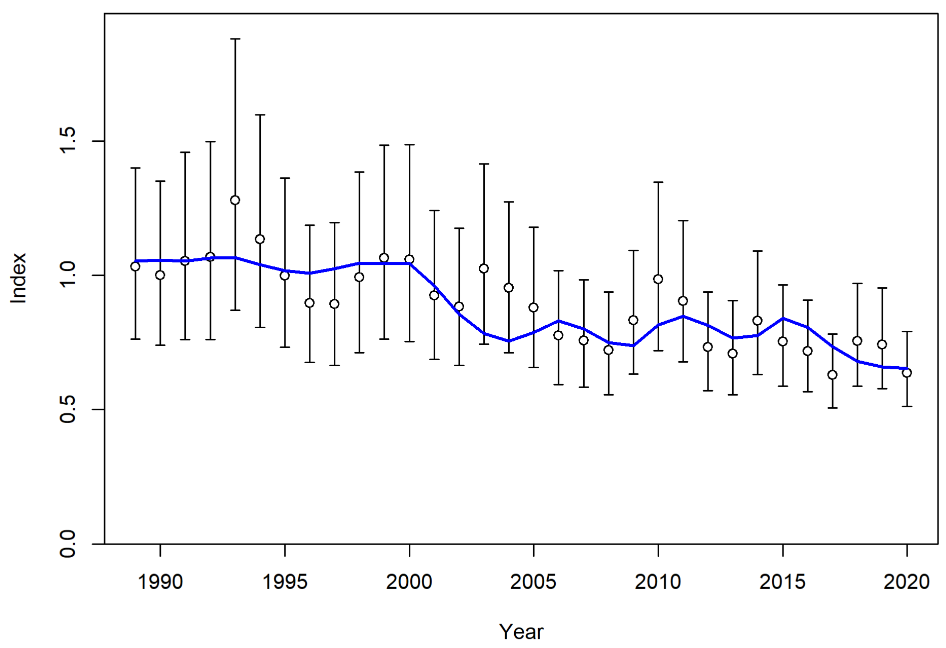

Figure 23: Model predictions (blue line) to commercial catch rates for Spanish mackerel for scenario E

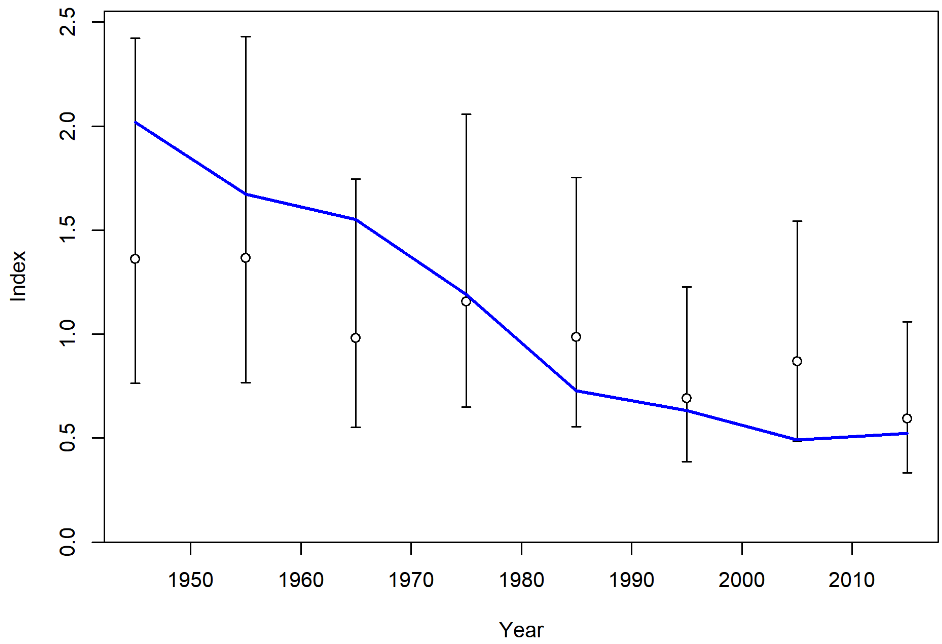

Figure 24: Model predictions (blue line) to historical decadal catch rates for Spanish mackerel for scenario E

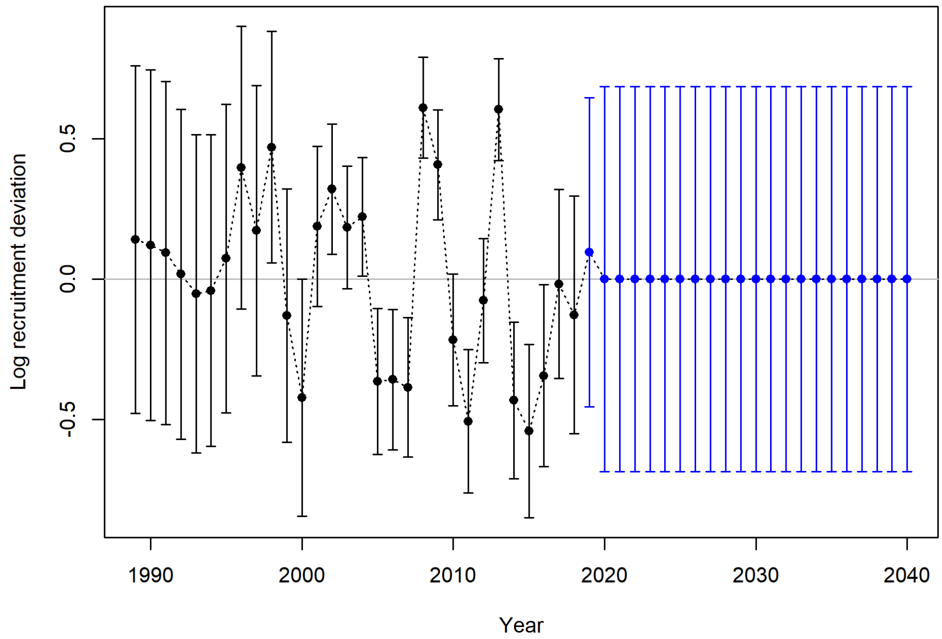

Figure 25 Recruitment deviations with 95% confidence intervals for Spanish mackerel for scenario E

Sustainable Fisheries Strategy
2017–2027

SUSTAINABLE FISHERIES EXPERT PANEL
Communique: 3 November 2021

Role of the panel: The Sustainable Fisheries Expert Panel was established to provide independent expert advice to the Minister responsible for fisheries and Fisheries Queensland on best practice fisheries management and implementation of the Sustainable Fisheries Strategy 2017-2027. Its advice does not represent Queensland Government policy.

A half-day meeting (Meeting 13) of the Sustainable Fisheries Scientific Expert Panel (the Panel) was held via videoconference on 3 November 2021.

Prior to the meeting, the Panel acknowledged the valuable contribution of Dr Michelle Heupel, who formally resigned from the Expert Panel on 20 September 2021 due to work commitments including a new post as co-Chair of a global committee directly relevant to her position as Director of the Integrated Marine Observing System. Fisheries Queensland emphasised the importance of Michelle's advice in relation to protected species that has positioned the department well in terms of the future, while acknowledging there is still much to do.

The purpose of the meeting was for Fisheries Queensland to provide the Panel with updates on the stock assessments and management options for Spanish mackerel, snapper, and pearl perch.

Fisheries Queensland provided an **update on the implementation of Sustainable Fisheries Strategy**. A number of operational issues with reporting have been raised by industry and the department is responding by investigating and modifying requirements were appropriate. The Panel expressed support of this flexible approach. Fisheries Queensland advised that a relatively small proportion of fishers affected by the recent allocation decisions are pursuing the internal and external review options. The stock assessment process is being reviewed to ensure consultation occurs in a more streamlined and consistent manner. The Panel supported ongoing efforts to ensure stock assessment results are more accessible to non-scientific readers. The post implementation review recommendations for vessel tracking are being implemented and a range of short- and long-term priorities is being developed. A digital strategy is being developed and a major investment will be required to modernise the department's existing IT systems in the context of the overall government digital strategy. This has implications for ensuring an effective interface with the new commercial fishing app. The Panel heard that part of the digital strategy will explore ways in which fisheries clients can extract the most value from data collected, noting that fisheries data are complex and difficult to interpret.

The Panel also heard that the overall consultation framework under the Sustainable Fisheries Strategy is a current focus, given a number of concerns that the working groups are not adequately representing fishers' views. Complementary models for additional consultation mechanisms are currently being considered. The panel noted the considerable challenges faced by the working groups in developing advice to underpin the implementation of measures to rebuild depleted fish stocks.

Fisheries Queensland provided an update on the East coast **Spanish mackerel** fishery stock assessment and in particular the outcome of the independent review, which queried particular values on which the model was based. The stock assessment team have devoted considerable time to investigating this concern and modelling additional scenarios. The Panel commented that the reviewer's comments were justified, but the department's response is considered defensible. Given that the Department's model is more precautionary than the reviewer's, the Panel considered that the most responsible way forward is to accept the stock assessment base case as the most credible scenario and make management decisions accordingly. The uncertainty regarding the model parameters of interest will be progressively resolved by future stock assessments. The Panel also heard that a bridging analysis between the type of model used in 2016 and the model used in 2021 is being undertaken for the Torres Strait and the results will be relevant to other parts of Queensland. The Panel suggested additional assumptions that might have contributed to the difference between the 2016 and 2021 assessments, which the stock assessment team will investigate further. Given the likely impact of the new assessment of management decisions, the Panel stressed the importance of plain English explanations of key differences between the assessments and justification for the use of the base case.

Fisheries Queensland outlined several **management options for Spanish mackerel** in response to the stock assessment. The Panel reiterated their previous advice that options that do not align with the Harvest strategy policy's minimum rebuilding timeframes should not be considered. Viable management options should be expected to produce detectable evidence of rebuilding, assuming rebuilding occurs as per modelled predictions. Potential issues were discussed including a possible effort shift to New South Wales, high grading, post-release mortality and the practical difficulties of maintaining an equitable approach to both constraining recreational and commercial catch. The Panel expressed caution about the presentation of potential social and economic impacts, which may be misleading if not presented in an appropriately nuanced manner. It was also noted that in a rebuilding scenario, ecological considerations in terms of the stock biomass need to be paramount: without a fishable biomass there can be no social and economic benefits.

The Panel noted that the latest **stock assessments for snapper and pearl perch** are yet to be published and are undergoing peer review. It is understood that no improvements are apparent in the stock biomass compared to previous assessments. Similar comments were raised as for the Spanish mackerel rebuilding strategy, in terms of advice that only options to that achieve improvement to the stock within the minimum rebuilding timelines should be considered.

Fisheries Queensland provided information on **management options for snapper and pearl perch** including modelled scenarios for rebuilding. The Panel recommended investigation of additional models to bridge the large gap between the rebuilding rate under a complete closure to fishing and the much slower (and inadvisable) rebuild under of less restrictive interventions – at rates that might not be detectable in subsequent stock assessments. Concerns similar to those held for Spanish mackerel were raised by Panel members in terms of effort shift and the management of recreational fishing take. Habitat modification to improve refuge habitat for sub-adults was discussed, While the Panel considered such an initiative useful, it noted that would not influence stock rebuilding in the short term and was not a substitute for more direct management action.

Fisheries Queensland also outlined measures being pursued to improve the presentation of stock assessment results to working groups and to the general public. This remains an ongoing area for improvement. The Panel reiterated that a Panel member will attend the upcoming working group meetings.

The Panel expressed appreciation for the significant efforts made by Fisheries Queensland to improve the data on which fisheries management decisions are made.

The Panel emphasised that a common problem is the effect of a rapidly growing human population, particularly in SEQ, on recreational take and rebuilding strategies. The Panel noted that measures such as habitat restoration and behavioural shifts by anglers may assist in the protection of fish stocks, but ultimately measures to constrain the recreational catch in high population areas must be considered. Possible mechanisms to achieve this, as well as practical issues with implementation were discussed. A cultural shift towards understanding that recreational fishing is a privilege rather than a right needs to occur. The Panel also firmly recommended that restocking should not be considered as a tool in serious fisheries management.

The next meeting will be scheduled for mid December to discuss development of harvest strategies for Gulf fisheries as well as an update on the process for Commonwealth Wildlife Trade Operation approvals for the coral and sea cucumber fisheries.

The members of the Sustainable Fisheries Expert Panel are: Associate Professor Ian Tibbetts (Chair), Dr Cathy Dichmont, Professor Ian Cartwright, Associate Professor Daryl McPhee, Professor Natalie Stoeckl, Dr Sean Pascoe, and Professor Bronwyn Gillanders.

Queensland east coast Spanish mackerel fishery

Consultation on management action

Discussion paper

Queensland Government

This publication has been compiled by Fisheries Queensland.

The Department of Agriculture and Fisheries proudly acknowledges all First Nations peoples (Aboriginal peoples and Torres Strait Islanders) and the Traditional Owners and Custodians of the country on which we live and work. We acknowledge their continuing connection to land, waters and culture and commit to ongoing reconciliation. We pay our respect to their Elders past, present and emerging.

Contents

Background

In 2021, Fisheries Queensland completed a stock assessment of Australian east coast Spanish mackerel using the most current biological data and commercial and recreational catch data. **This stock assessment estimated that the number of east coast Spanish mackerel (biomass) was between 14% and 27% of unfished levels, and most probably at around 17%** (see Figure 1).

The latest Status of Australian Fish Stocks Report for the fishery, published by the Fisheries Research and Development Corporation, has classified the east coast Spanish mackerel stock as ‘depleted’.

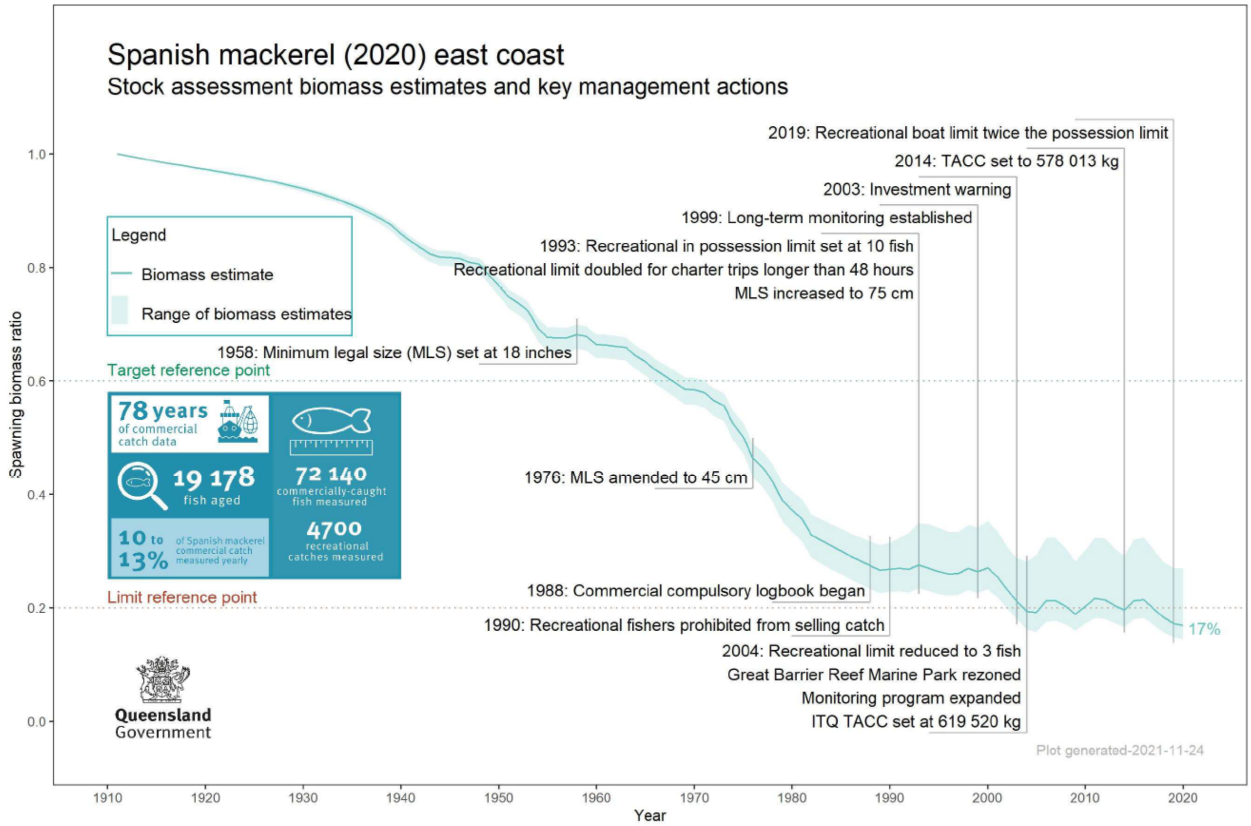

Figure 1: Chart of 2020 Australian east coast stock assessment biomass estimates and key management actions for Spanish mackerel

In line with best practice, Fisheries Queensland conducts independent reviews of stock assessments and other scientific reports on a regular basis.

An independent review of the Spanish mackerel stock assessment was conducted by a former Commonwealth Scientific and Industrial Research Organisation (CSIRO) fisheries scientist. The reviewer agreed the data was used appropriately in the assessment, that the assessment model itself was suitable and agreed with the stock assessment’s recommendations on data, monitoring and research and future management of the stock. However, the reviewer questioned the model setting for a lower resilience in the ability of Spanish mackerel to bounce back from high fishing pressure – referred to as ‘steepness’.

The department conducted further analysis of the stock assessment model based on the concerns raised. The analysis found a higher steepness value was not supported by model testing and that the stock assessment had used a more appropriate value. A higher value was also in contrast to findings from the most up-to-date and comprehensive examination of data from independent studies to determine overall trends of ‘steepness’.

The stock assessment, independent review and Fisheries Queensland's response to the independent review were presented to the independent Queensland Sustainable Fisheries Expert Panel. The Expert Panel commented that, while the reviewer's findings were justified, the department's response was considered appropriate. Further, **the Expert Panel considered that the most responsible way forward is to accept the estimated biomass of 17% as the most credible scenario and to make management decisions accordingly.**

The need for action is further supported by longstanding concerns about sustainability, with evidence of a 70% reduction in the number of Spanish mackerel spawning aggregations within two decades, a decline in historically important spawning aggregations from waters east of Cairns, a reduction in the size and frequency of spawning aggregations in the Lucinda region and a long-term decline in commercial catch rates.

Under Commonwealth and Queensland harvest strategy guidelines, immediate management action is required to rebuild fish stocks when the biomass falls below the limit reference point of 20% biomass.

Doing nothing is not an option and would go against the fundamental principles of the *Queensland Sustainable Fisheries Strategy: 2017–2027*, the main objective of the *Fisheries Act 1994* and the Queensland Government's responsibility to ensure our public fishery resources are managed in a responsible and sustainable manner.

The sustainable management of the Spanish mackerel fishery is also crucial in maintaining ongoing export (accreditation) approval under the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth).

This discussion paper is seeking feedback on possible management measures to rebuild the east coast Spanish mackerel stock to sustainable levels (40% of unfished biomass).

The stock assessment, the independent review of the assessment and the response to the review is available at https://era.daf.qld.gov.au/id/eprint/8226.

Information on the Expert Panel (including membership, terms of reference and meeting communiques) is available at www.daf.qld.gov.au/business-priorities/fisheries/sustainable/sustainable-fisheries-expert-panel.

Information on the Spanish mackerel fishery working group is also available at www.daf.qld.gov.au/business-priorities/fisheries/sustainable/fishery-working-groups/spanish-mackerel-fishery-working-group.

Have your say

No decisions have been made and none will be made until after consultation.

Fisheries Queensland is seeking feedback from commercial, recreational, charter and traditional fishers, environmental groups and other stakeholders on management measures presented in this discussion paper to rebuild the Queensland east coast Spanish mackerel fishery. Feedback on this discussion paper will be used to develop options for management action and a draft harvest strategy to rebuild this important fishery.

Different management measures will have different impacts on individual sectors within the fishery (e.g. commercial fishers, recreational fishers, traditional fishers, fish and chip shop owners, tackle retailers and environmental organisations). Therefore, it is important to understand the preferences of people who have an interest in the fishery so we can make a balanced decision on final management arrangements.

The fastest and easiest way to provide your feedback is to complete the online survey at:

daf.engagementhub.com.au/spanish-mackerel-2022

The survey questions are also available at the end of this document if you would prefer to print out the survey and post your submission to:

Spanish mackerel fishery discussion paper
Department of Agriculture and Fisheries
GPO Box 46
Brisbane Qld 4001

PLEASE NOTE: The survey questions are designed to seek your input – **they are not a voting tool**. Answers to these questions will be used to help develop options for management action and provide an insight into the preferences of all stakeholders.

Submissions close 5 pm, Thursday 5 May 2022.

For more information, email fisheriesmanagers@daf.qld.gov.au or call 13 25 23.

If you would like to receive updates on the Spanish mackerel consultation, email your details to fisheriesmanagers@daf.qld.gov.au.

About the fishery

The east coast Spanish mackerel commercial fishery is a line-only fishery that exclusively targets Spanish mackerel (*Scomberomorus commerson*) by trolling or towing lures and baited lines behind the vessel and near the surface of the water.

Spanish mackerel are also a highly popular target species for recreational and charter fishers. Recreational and charter fishers take Spanish mackerel by trolling or towing lures and baited lines behind boats, fishing from rocky headlands and beaches, or using spearguns around reefs and rocky outcrops.

Catch statistics

During September to November each year, Spanish mackerel school to form one of the most notable and predictable spawning aggregations of fish on the Great Barrier Reef. These spawning aggregations are primarily located in the Lucinda region in waters north of Townsville. Approximately 40% of the total Queensland commercial harvest is taken from this region each year during the spawning season.

Commercial harvest peaked at around 1000 tonnes per year during the 1970s, before declining to 700 tonnes per year in the 1990s and early 2000s. In 2004, there was a further decline following the rezoning of the Great Barrier Reef Marine Park and introduction of a total allowable commercial catch (TACC) of 619.5 tonnes. Commercial harvest has remained stable since this time at about 300 tonnes per year and approximately 50% of the TACC has been caught each year on average.

Recreational harvest has also remained relatively stable since 2004 at around 180 tonnes each year (including charter). However, charter harvest has steadily declined since 2009 and is at an all-time low, possibly, in part, reflecting the recent impacts of COVID-19. More than a quarter of recreationally caught Spanish mackerel are released.

The fishery also includes a traditional fishing sector, which remains the least understood of all sectors. However, it is assumed that this sector has comparatively low levels of effort, with fishing activities aligning closely with the recreational fishing sector.

The stock is also fished in northern New South Wales, where approximately 48 tonnes is harvested each year (9.5% of total harvest across Queensland and New South Wales).

There are strong concerns about the hyperstability of Spanish mackerel due to its aggregating behaviour. Other issues include latent effort in the fishery (fishing capacity such as licences and quota authorised for use, but not currently being used), the influence of environmental drivers on recruitment success and unquantified sources of fishing mortality such as depredation (typically by sharks) and post-release mortality.

CASE STUDY: What is hyperstability?

Hyperstability occurs when catch rates remain high even as fish populations decline. Fisheries that target fish spawning aggregations can exhibit hyperstability because these aggregations provide easy opportunities for fishers to target and catch large quantities of fish, resulting in an ‘illusion of plenty’.

A prime example of hyperstability is the North Atlantic cod fishery. With the improvement in fishing technology, catch rates skyrocketed in the 1960s to more than 800 000 tonnes per year, before dropping to zero by the early 1990s. North Atlantic Cod naturally gather in massive schools and as the population declined, the cod aggregated together in even larger numbers giving the impression the fishery was in great shape. This combined with fishers who had centuries of knowledge about when and where North Atlantic Cod would aggregate, led to the collapse of the species.

Reference: Hamilton, R.J., Almany, G.R., Stevens, D. et al. Hyperstability masks declines in bumphead parrotfish (*Bolbometopon muricatum*) populations. *Coral Reefs* 35, 751–763 (2016). https://doi.org/10.1007/s00338-016-1441-0.

Economic and social value

The east coast Spanish mackerel fishery is an iconic fishery in Queensland, supplying fresh local seafood to coastal communities, providing a valuable source of recreation for many Australians and maintaining the connection between traditional fishers and their sea country.

In 2018–19, the fishery's commercial sector contributed 66 full-time equivalent jobs and $6.7 million (including flow-on effects) to the economy, while recreational fishers were estimated to have spent approximately $6.8 million on Spanish mackerel fishing trips. The total value of commercially landed catch was estimated to be $3.4 million, with around 90% sold in Queensland and the remainder sold interstate. Beach prices for Spanish mackerel were estimated to be approximately $12.10/kg.

The average commercial Spanish mackerel fisher does not specialise in the fishery, earning around 72% of their revenue in other fisheries. The commercial sector is almost entirely comprised of part-time boats, except for a smaller group (20–25 boats) of dedicated Spanish mackerel fishers that primarily target spawning aggregations. These fishers earn more than 80% of their revenue in the fishery and are responsible for approximately 50% of the total commercial harvest.

More economic and social data for Queensland's fisheries is available at www.daf.qld.gov.au/business-priorities/fisheries/monitoring-research/data/economic-and-social-data.

Current management arrangements

Under the *Fisheries Act 1994*, the fishery is currently managed via a mixture of input controls, which limit the amount of fishing effort put into the fishery, and output controls, which directly limit the amount of fish harvested (see Table 1).

Of the known key reefs for Spanish mackerel spawning on Queensland's east coast, two are classified as no-take (green) zones within the Great Barrier Reef Marine Park. Green zones cover approximately 33% of the Great Barrier Reef Marine Park area. The two known reefs that are Spanish mackerel spawning reefs in green zones cover less than 1% of the Great Barrier Reef Marine Park area.

Table 1: Overview of current management arrangements for the east coast Spanish mackerel fishery

Sector	Input controls	Output controls
All	Gear restrictions	Minimum legal size
Commercial	• Limited entry • Vessel and tender restrictions	• Total allowable commercial catch • Individual transferable quota
Recreational (incl. charter)	Nil	• In-possession limits • Boat limits (primarily to address black-marketing of priority species)
Traditional	Limited to fishing for purposes of satisfying personal, domestic or non-commercial needs, carried out in accordance with the particular traditional laws and customs of the native title holders	

Objective of management action

Under the *Queensland Sustainable Fisheries Strategy: 2017–2027*, the minimum standard for all Queensland's fisheries is to achieve at least a maximum sustainable yield of 40% to 50% of unfished biomass. For stocks assessed to have a biomass below 20%, a timeframe for rebuilding back to sustainable levels with a reasonable level of certainty should be defined within a range of the minimum time, and twice the minimum time, taken to rebuild the stock in the absence of fishing.

For east coast Spanish mackerel, this equates to a rebuilding timeframe of between 7 and 14 years.

To achieve a rebuilding timeframe of 7 years, there would need to be a 100% reduction in harvest, meaning a total closure of the fishery. To achieve a rebuilding timeframe of 14 years, there would need to be at least a 35% reduction in the total harvest of east coast Spanish mackerel. The combination of management measures implemented would inform the overall reduction in harvest across all sectors and the rebuilding timeframe.

The benefits of adopting a shorter rebuilding timeframe of 7 years and a total closure include:

- maximum protection for the stock with the fastest rebuilding time and greatest chance of successful recovery
- management restrictions can be lifted sooner
- simpler to communicate and comply with
- easier to identify black-marketing.

However, there are potential risks associated with this approach, including:

- significant socio-economic impacts with flow-on effects for all stakeholders, including commercial and recreational fishers, charter operators, tackle store owners, seafood processors, tourism operators, etc.
- catch and effort data would no longer be available, meaning fishery-independent research and surveys will be required to monitor fishery performance and stock recovery
- lack of supply affecting future market access
- removal of supply of locally caught Spanish mackerel to Queenslanders on the east coast
- devaluation of commercial fishing endorsements and equipment
- increased risk of effort shift into other fisheries
- increased risk of black-marketing and non-compliance.

In comparison, the benefits of adopting a longer rebuilding timeframe of 14 years with a 35% reduction in harvest include:

- lower socio-economic impacts by allowing a moderate level of fishing to occur
- maintenance of local supply and market for Spanish mackerel, supporting fishing-related businesses (commercial fishers, seafood wholesalers, tourism operators, etc.)
- catch and effort data would still be collected to monitor fishery performance and stock recovery.

However, the potential risks of a longer rebuilding time and allowing moderate fishing to continue include:

- longer timeframes to rebuild the stock
- less protection for the stock and a lower chance of successful recovery
- export accreditation and other Commonwealth approvals may be affected
- greater risk that stronger measures might be required in the future, such as a full closure of the fishery.

The preference is to rebuild the stock to sustainable levels (40% of unfished biomass) allowing some targeted fishing, providing it can be achieved within an appropriate timeframe.

However, if this cannot be achieved or the stock continues to decline, the east coast Spanish mackerel fishery may have to be closed for a period of time, similar to snapper in South Australia.

CASE STUDY: Action to protect the future of snapper stocks in South Australia

Like Spanish mackerel, snapper (*Chrysophrys auratus*) is an iconic fish in Australia and a primary target species for commercial, recreational and charter boat fishing sectors in a range of jurisdictions, including South Australia, Victoria, Western Australia and Queensland. Similar to Spanish mackerel, snapper in South Australia aggregate and are targeted by fishers due to their strong schooling behaviour.

In South Australia, the decline of snapper stocks had been noted anecdotally by the recreational, commercial and charter sectors for several years. This was supported by science and stock assessments, with low numbers of juvenile snapper entering the fishery over a long period of time, combined with a decline in the overall biomass of the fishery and a reduction in commercial catch rates.

Since 2011, South Australia made incremental management changes in response to continued evidence of stock decline. Despite these incremental changes, snapper stocks continued to decline. In 2019, tough decisions were announced to secure the long-term future of the snapper fishery following consideration of the latest available science and feedback from all stakeholders.

Commencing 1 November 2019, the snapper fishery was closed (for all sectors) for the West Coast, Spencer Gulf and Gulf St Vincent regions until 31 January 2023.

In the South East Region, the stock has remained at sustainable levels and has been kept open, subject to strict new provisions that have evolved over time. These have included a seasonal closure, a total allowable commercial catch limit and quota management, a total allowable recreational catch limit, daily recreational bag and boat limits, mandatory recreational catch reporting, size limits, charter access through tags and regulated daily passenger limits, as well as encouraging good handling and release practices to maximise survival of released snapper.

Reference: Government of South Australia, Department of Primary Industries and Regions, <https://www.pir.sa.gov.au/fishing/snapper>.

Recent examinations of global fish stocks indicate that 'data-rich' stocks with formal model-based assessments of biomass and fishing mortality have a more positive outlook and, on average, have recovered to sustainable levels. There is evidence that more than 150 overfished stocks around the world have recovered within a 10-year period under effective fisheries management.

While the east coast Spanish mackerel stock is at risk of further decline, it is a 'data-rich' stock supported by a robust monitoring and assessment program. Spanish mackerel also has the right management framework in place (including recreational in-possession limits and a total allowable commercial catch) to take immediate and effective action.

Overall, this means the successful recovery of Spanish mackerel should be achievable in a reasonable timeframe if the management response is appropriate and timely.

Management measures

The following management measures can be used to reduce fishing pressure and allow the east coast Spanish mackerel stock to rebuild to sustainable levels.

In line with the principles of the *Queensland Sustainable Fisheries Strategy: 2017—2027*, any combination of management measures should aim to minimise impacts on fishing efficiency (prioritising output controls over input controls), address fishing pressure across all sectors equitably, maintain historical catch shares and mitigate unintended effects such as increased post-release mortality or effort shift into low-capacity fisheries.

All fishing sectors have a shared responsibility in the management of this stock. This means an equitable approach that reduces fishing pressure from all sectors is required for successful stock rebuilding. The proposed management of the Spanish mackerel fishery assumes a 60% commercial and 40% recreational (including charter) catch share arrangement, which reflects historical catch shares since the introduction of quota in 2004. Fisheries Queensland will consider the consultation feedback received and aim to maintain this catch share in determining appropriate combinations of management measures to rebuild the stock. Different combinations of management measures will have different impacts on, and rebuilding times for, the Spanish mackerel fishery.

Total allowable commercial catch

Quota units are used in commercial fisheries across Australia to manage the sustainability of fish stocks and improve catch rates and profitability by controlling competition and allowing fishers to plan their activities and minimise their operational costs. A quota unit is not a fixed weight of fish – it is a fixed percentage of fish.

Each commercial fisher is allocated a number of shares, or quota units, in a fishery, which can be bought, sold or leased. These quota units are a percentage of the total allowable commercial catch (TACC) for that fishery. The TACC is the total catch limit for the commercial sector in a fishery and does not include fish caught by recreational, charter or traditional fishers. The TACC can be lowered or raised in response to changes in a stock's biomass and is the most direct method to control commercial harvest levels.

The current TACC for east coast Spanish mackerel is 578 tonnes but, on average, only half has been used or landed each year since 2004. Consequently, any revision to the TACC will need to take this into consideration.

Table 2 presents the estimated effects of setting a revised TACC, which, in combination with other measures, could rebuild the stock within the required timeframes.

Table 2: Estimated effects of setting a revised total allowable commercial catch

Management measure		Estimated reduction in harvest	
		Commercial	Recreational
Set the total allowable commercial catch (TACC) to:	53 tonnes (9% of current TACC)	80%	N/A
	107 tonnes (18% of current TACC)	60%	N/A
	160 tonnes (28% of current TACC)	40%	N/A
	214 tonnes (37% of current TACC)	20%	N/A

Recreational in-possession and boat limits

Recreational in-possession limits are a direct control on recreational harvest and are used to:

- conserve species that are sought-after or easily caught
- ensure everyone has the opportunity for a good fishing experience
- reduce black-marketing
- promote responsible fishing.

In-possession limits do not apply on a per day basis, meaning that any fish caught previously but still in your possession (e.g. at home in the freezer), are included in the in-possession limit.

Boat limits are in effect for nine priority black-market species – mud crab, prawns, snapper, black jewfish, barramundi, Spanish mackerel, shark, tropical rock lobster and sea cucumber. For these species, no more than two times the in-possession limit for that species is permitted onboard a boat with two or more people on board at any time. For example, the current individual in-possession limit for Spanish mackerel is three, with a boat limit of six. Boat limits may help to reduce the overall recreational harvest; however, their primary purpose is to combat black-marketing by preventing commercial quantities being taken on a recreational fishing trip. Boat limits do not apply to licensed charter fishing trips.

Boat ramp and recreational survey data indicate that, of those recreational fishers who landed Spanish mackerel in Queensland, approximately 70% only landed one Spanish mackerel per trip. Consequently, any revision to the in-possession limit will need to take this into consideration.

Table 3 presents the estimated effects of setting a revised recreational in-possession and boat limits, which, in combination with other measures, could rebuild the stock within the required timeframes.

Table 3: Estimated effects of setting a revised recreational in-possession and boat limits

Management measure		Estimated reduction in harvest	
		Commercial	Recreational
Set the recreational in-possession limit and boat limit (currently 3 per person / 6 per boat) to:	1 per person (2 per boat)	N/A	9–18%
	1 per person (3 per boat)	N/A	7–13%
	1 per person (6 per boat)	N/A	6–12%
	2 per person (2 per boat)	N/A	8–16%
	2 per person (4 per boat)	N/A	2–4%

Minimum legal size limit

Minimum legal size limits prevent the take of fish below a certain size and are intended to protect juvenile fish, providing a greater opportunity for those fish to spawn at least once and contribute to recruitment. Minimum legal size limits can allow fish to grow to a greater size, with potential benefits for the value per fish for commercial fishers and the availability of 'trophy-sized' fish for recreational fishers.

Spanish mackerel typically reach sexual maturity at 90 cm total length, which is above the current minimum legal size of 75 cm. Increasing the minimum legal size to 90 cm could potentially allow a greater proportion of the stock to reproduce, leading to faster rebuilding of the stock.

However, it is important to note there are implications for increasing the minimum size limit for Spanish mackerel, including dangers associated with releasing large active fish and poor survival of fish that have been released due to predation by sharks or the stress of being captured. Previous research has suggested that increasing the minimum legal size for Spanish mackerel would have little benefit in improving egg production or the yield per fish.

It should also be noted that only a small proportion of Spanish mackerel caught by commercial and recreational fishers are in the 75 cm to 90 cm size range. Therefore, increasing the size limit would likely have limited effect on rebuilding the stock, even without considering the low survival of released fish.

Table 4 presents the estimated effects of setting a revised minimum size limit to better align with the size at which half the population is sexually mature (90 cm), which, in combination with other measures, could rebuild the stock within the required timeframes.

Table 4: Estimated effects of setting a revised minimum size limit

Management measure		Estimated reduction in harvest	
		Commercial	Recreational
Set the minimum legal size (currently 75 cm) to:	90 cm	4–7%	7–14%
	85 cm	1–2%	3–6%

Seasonal closures

Seasonal closures are used in Queensland and Commonwealth fisheries and by environmental regulatory authorities to prevent people from fishing at certain times of the year to protect species at vulnerable times in their life cycle – such as when fish are migrating in large numbers or in the lead up to, during or after spawning events. While they are not currently used in the Spanish mackerel fishery, closures may provide some protection to Spanish mackerel stocks and help rebuild the stock.

Spanish mackerel form large spawning aggregations in reefs off north Queensland each year between September and November. These aggregations contribute substantially to the stock's overall reproduction level during the spawning months and currently support up to 40% of the total commercial harvest. Spanish mackerel are also thought to aggregate throughout the year when feeding and migrating.

Seasonal closures can be an effective tool in reducing harvest and protecting vulnerable aggregations. Fishery-wide or regional closures may afford more protection than fine-scale area closures, especially for highly mobile species like Spanish mackerel.

Due to the seasonal movement patterns of Spanish mackerel up and down Queensland's east coast each year, seasonal closures could be applied separately in the northern and southern areas of the fishery. This would prove less restrictive than fishery-wide closures while offering a comparable level of protection.

Closures are not a direct control on harvest and may also result in the redistribution of fishing effort outside the closure period or to other fisheries. Longer closures may have significant impacts on market access and can disproportionately affect some fishers that have historically operated during the closure periods.

Table 5 presents the estimated effects of introducing seasonal closures, which, in combination with other measures, could rebuild stocks within the required timeframes.

Table 5: Estimated effects of introducing seasonal closures

Management measure		Estimated reduction in harvest	
		Commercial	Recreational
Introduce seasonal closures*	16 weeks all east coast OR 8 weeks each north & south	13–41%	13–26%
	12 weeks all east coast OR 6 weeks each north & south	9–30%	10–19%
	8 weeks all east coast OR 4 weeks each north & south	6–20%	6–13%
	4 weeks all east coast OR 2 weeks each north & south	3–10%	3–9%

* Estimated effects of seasonal closures assume that closure periods will include February, March, October and November

Fine-scale area closures

Fine-scale area closures (or regulated waters) prevent people from fishing in certain areas, including:

- where a population of endangered or threatened species is known to live
- where fish congregate in the lead up to, during or after spawning
- where fish may mass or get trapped near artificial barriers and be susceptible to overfishing
- to separate incompatible uses (e.g. spearfishing in a swimming area).

These can be highly effective for species that have limited movement or evidence of localised depletion, but are generally less effective for a highly mobile species like Spanish mackerel. However, there is evidence that Spanish mackerel return to the same reefs for spawning, meaning that they may benefit from area closures that protect key spawning reefs (noting that two of the key spawning reefs are already protected by Commonwealth and state marine park zoning).

The effects of fine-scale area closures are difficult to estimate for Spanish mackerel and further monitoring and research would be required to assess their effectiveness. This form of management can also be more complex (if they include multiple area or reef-based closures) and make compliance with regulations more challenging.

Better recreational fishing data

The Spanish mackerel stock assessment has one of largest datasets of all Queensland fisheries and includes more than:

- 231 000 Queensland commercial logbook records
- 7 000 New South Wales commercial logbook records
- 37 600 Queensland charter logbook records
- 70 100 recreationally and commercially caught Spanish mackerel measured through routine biological monitoring and more than 1 400 boat ramp surveys
- 18 100 age data records.

Understanding the catch and effort and participation rate of recreational fishers is an important part of sustainably managing and assessing Queensland's fisheries. The recreational fishing data used in the Spanish mackerel stock assessment is collected through statewide recreational fishing surveys and boat ramp surveys. These surveys have been extensively designed to provide statistical rigour in the results.

The latest statewide recreational fishing survey contacted more than 8500 households to determine recreational fishing participation rates, with more than 2100 households taking part in a 12-month logbook program to record fishing activity and expenditure. More than 2900 boat ramp surveys are conducted across the state each year to monitor changes in effort, catch rates, value of recreational fishing and fish lengths over time.

Notwithstanding this, many stakeholders have expressed a desire for better recreational catch data for Spanish mackerel. Improved monitoring and research is also a foundational reform of the *Queensland Sustainable Fisheries Strategy: 2017–2027* and includes several actions relating to improved data collection, additional monitoring of key biological stocks and the use of novel technologies such as apps.

Other jurisdictions such as Victoria and South Australia have introduced mandatory recreational catch reporting for at-risk or high-value species such as rock lobster and snapper. There are a range of ways that recreational catch can be reported in a timely and cost-effective way, such as using modern technology like smartphone apps.

Shark depredation

Recreational and commercial fishers in Queensland, and in other Australian jurisdictions, are anecdotally reporting increases in shark depredation. Shark depredation occurs when a hooked fish is partially or completely removed by a shark before the catch can be retrieved by the fisher. While the 2020 east coast Spanish mackerel stock assessment did investigate the potential effects of shark depredation on biomass, there is limited data on shark depredation. Shark depredation has been identified as a key research priority by Fisheries Queensland and there are a number of research projects currently underway.

Commercial fishing for shark and ray (including hammerhead shark) on Queensland's east coast is primarily managed through a TACC, as well as in-possession and maximum size limits for commercial fishers who do not hold a specific endorsement (the 'S' fishery symbol). Over the past five years, the Queensland east coast shark and ray fishery has landed, on average, less than 25% of the total TACC for shark, suggesting there may not be a strong market demand for shark (commonly called flake).

Next steps

Feedback from this first round of consultation will inform the development of options for management action and a draft harvest strategy for the fishery. Further consultation will be conducted before a preferred option is presented to the Queensland Government for a final decision.

Survey questions

Your say matters and we want to hear from you about which management measures you prefer. The questions with an asterisk (*) are mandatory.

Question 1. Tell us who you are:

Name:

Address:

Postcode*:

Email address:

Question 2. What sector of the Spanish mackerel fishery are you part of?*

- ☐ Commercial fisher
- ☐ Recreational fisher
- ☐ Charter fishing operator
- ☐ Traditional fisher / Traditional Owner
- ☐ Seafood wholesaler/marketer
- ☐ Hospitality (restaurant, café, fish and chip shop) owner/worker
- ☐ Fishing tackle retailer
- ☐ Environmental group, industry peak body or other non-government organisation
- ☐ Interested community member
- ☐ Other

Question 3. How many times per year do you go fishing for Spanish mackerel?

Question 4. How many Spanish mackerel on average do you catch each trip?

Question 5. Which rebuilding timeframes should be considered?*

- ☐ 7 years
- ☐ 9 years
- ☐ 11 years
- ☐ 14 years

Question 6. The total allowable commercial catch (TACC) should be set at:

- ☐ 53 tonnes
- ☐ 107 tonnes
- ☐ 160 tonnes
- ☐ 214 tonnes

Question 7. The recreational in-possession and boat limit should be set at:

- ☐ 1 per person, 2 per boat
- ☐ 1 per person, 3 per boat
- ☐ 1 per person, 6 per boat
- ☐ 2 per person, 2 per boat
- ☐ 2 per person, 4 per boat

Question 8. The minimum size limit for Spanish mackerel should be set at:

- ☐ 75cm
- ☐ 85cm
- ☐ 90cm

Question 9. Do you support a whole east coast seasonal closure?

- ☐ Yes
- ☐ No

Question 10. How long should a whole east coast seasonal closure be?

- ☐ 16 weeks
- ☐ 12 weeks
- ☐ 8 weeks
- ☐ 4 weeks

Question 11. Do you support a split north/south seasonal closure?

- ☐ Yes
- ☐ No

Question 12. How long should a split north/south seasonal closure be?

- ☐ 8 weeks each north and south
- ☐ 6 weeks each north and south
- ☐ 4 weeks each north and south
- ☐ 2 weeks each north and south

Question 13. Would you support different recreational and commercial seasonal closures?

- ☐ Yes
- ☐ No

Question 14. Which recreational combination would you prefer?

- ☐ Higher recreational in-possession limit and a longer recreational seasonal closure

  or

- ☐ Lower recreational in-possession limit and a shorter recreational seasonal closure

Question 15. Would you support better recreational catch reporting?

- ☐ Yes
- ☐ No

Question 16. Are there any other issues, opportunities or solutions that you would like to raise?