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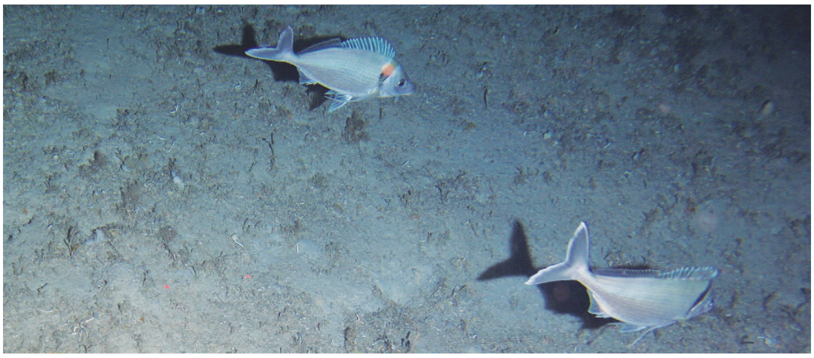
2017/0824 June 2020

Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2018 and 2019



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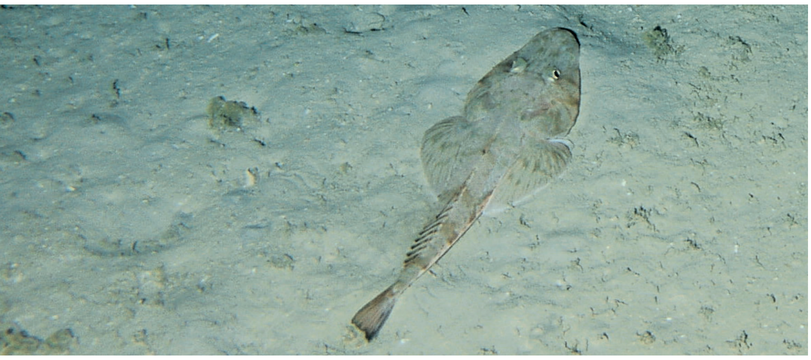

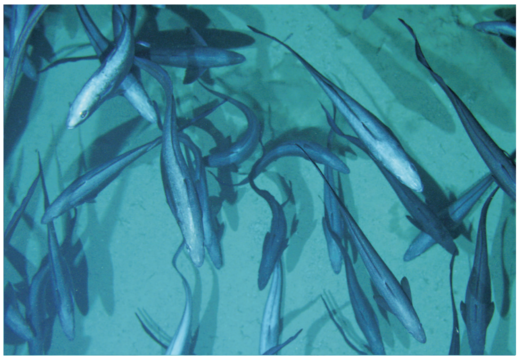

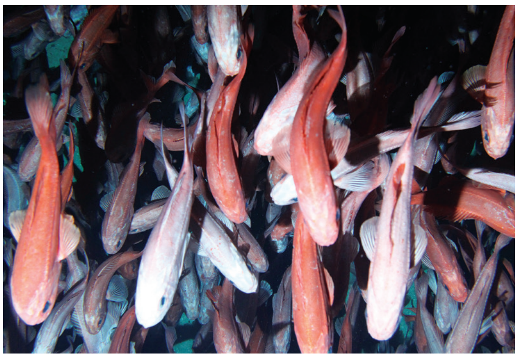

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Cover photographs

Front cover, jackass morwong, orange roughy, blue grenadier, and flathead.

Report structure

Part 1 of this report describes the Tier 1 assessments of 2019. Part 2 describes the Tier 3 and Tier 4 assessments, catch rate standardisations and other work contributing to the assessment and management of SESSF stocks in 2019.

Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2018 and 2019

Part 1: 2018

G.N. Tuck

June 2020
Report 2017/0824

Australian Fisheries Management Authority

Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2019

TABLE OF CONTENTS

1. Non-Technical Summary

Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2018 and 2019

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OBJECTIVES:

- Provide quantitative and qualitative species assessments in support of the four SESSFRAG assessment groups, including RBC calculations within the SESSF harvest strategy framework
- 2018: Provide Tier 1 assessments for Blue grenadier, Jackass morwong (east and west), School shark, and Silver warehou; Tier 3 assessment for Alfonsino; Tier 4 assessments for Blue eye trevalla and Deepwater shark (east and west); and Tier 5 for Smooth oreo.
- 2019: Provide Tier 1 assessments for Deepwater flathead, Tiger flathead, Western gemfish, and Gummy shark; and Tier 4 for Mirror Dory

Outcomes Achieved - 2019

The 2019 assessments of stock status of the key Southern and Eastern Scalefish and Shark fishery (SESSF) species are based on the methods presented in this report. Documented are the latest quantitative assessments for the SESSF quota species. Typical assessment results provide indications of current stock status, in addition to an application of the recently introduced Commonwealth fishery harvest control rules that determine a Recommended Biological Catch (RBC). These assessment outputs are a critical component of the management and Total Allowable Catch (TAC) setting process for these fisheries. The results from these studies are being used by SESSFRAG, industry and management to help manage the fishery in accordance with agreed sustainability objectives.

1.1 Slope, Shelf and Deepwater Species

School whiting

This chapter presents results of fixed catch projections for school whiting (*Sillago flindersi*) to provide information on possible projected stock status in light of increases in NSW catches in state waters in 2017 and 2018, compared to the anticipated NSW catch when setting the Commonwealth TAC following the 2017 school whiting stock assessment. Similar high catch levels are expected in NSW state waters for 2019 and possibly 2020 and 2021. This increase in catch resulted in the total catch exceeding the RBC in 2017 and 2018. A range of fixed catch two-year projections (2020-2021) were run to examine the effect of the increase in total reported catch for 2017 and 2018 and the expectation that the 2019 total catch would also exceed the RBC. This enabled the risk to the stock to be assessed from the increased catches expected from 2017-2019.

Updates to catch and CPUE alone resulted in a revision downwards to the 2018 stock status, from 47% in the last stock assessment to 36% in this analysis. These changes are due to revisions to the 2017 catch and to the revised CPUE series. Projecting forward to 2020, using preliminary 2018-2019 catches, takes the stock status to 35%, which is expected to recover to 44% at the start of 2022, if the RBC is caught in 2020 and 2021 and there is average recruitment from 2014 onwards.

Given the 2020 and 2021 catches may exceed the RBC, four fixed catch projections were examined, with total catches (including discards) ranging from 1,600-1,900 t. Projected stock status at the start of 2022 ranged from 34% to 39% under the fixed catch scenarios, compared to 44% if the RBC is caught in 2020 (1,165 t) and 2021 (1,357 t). Four low and four high recruitment scenarios were also investigated, with 2022 stock status ranging from 22% to 38% under the low recruitment scenarios and from 44% to 53% under the high recruitment scenarios.

Tiger flathead

The assessment of tiger flathead (*Neoplatycephalus richardsoni*) was updated to provide estimates of stock status in the SESSF at the start of 2020. The 2016 stock assessment has been updated with the inclusion of data to the end of 2018, comprising an additional three years of catch, discard, CPUE, length and age data and ageing error updates. An additional 2016 survey point is included from the Fishery Independent Survey (FIS) and FIS length frequencies have been included from the winter 2016 FIS and summer 2008, 2010 and 2012 FIS. A range of sensitivities were explored.

Changes to the last stock assessment include: using the FIS3 abundance indices; including summer FIS length frequencies; incorporation of conditional age-at-length data for 2008 from the FIS; and updating the tuning method and bias ramp estimation. This change in stock status is largely due to below average newly estimated recruitment events, particularly in 2013 but also in 2014, and a revision to the previously estimated 2012 recruitment event. The 2013 poor recruitment is supported both by the age and length data and by the recent index data, and the updated assessment fits all of these data sources well.

The 2020 spawning stock biomass is 33.67% of unexploited stock biomass (SSB_0) for the updated base case. The 2020 recommended biological catch (RBC) under the 20:35:40 harvest control rule for the updated base case is 2,334 t, and is below the long-term yield (assuming average recruitment in the future) of 2,986 t. The average RBC over the three-year period 2020-2022 is 2,563 t and over the five-year period 2020-2024, the average RBC is 2,648 t.

Bight redfish

The assessment for Bight Redfish (*Centroberyx gerradi*) in the GAB was updated from the last assessment in 2015. The base case has been updated by the inclusion of data up to the end of 2018-19, which entails an additional four years of catch, CPUE, length and age data and ageing error updates since the 2015 assessment, and incorporation of survey results from the 2017-18 from the GAB Fishery Independent Survey (GAB-FIS).

Results show poor fits to the CPUE and FIS abundance series, but reasonable fits to length and conditional age-at-length data. This assessment estimates that the projected 2020-21 spawning stock biomass will be 64% of virgin spawning stock biomass. The 2020-21 Recommended Biological Catch (RBC) under the 20:35:41 harvest control rule is 1,024 t. The average RBC over the three-year period 2020-21: 2022-23 is 963 t. The long-term RBC is 912 t.

Deepwater flathead

The assessment for deepwater flathead (*Neoplatycephalus conatus*) in the GAB was updated from the last assessment in 2016. The base case has been updated by the inclusion of data up to the end of 2018/19, which entails an additional 3 years of catch, CPUE, length and age data and ageing error updates since the 2016 assessment, and incorporation of survey results from the Fishery Independent Survey (GABFIS).

The base case assessment provides reasonably good fits to the catch rate data, length data and conditional age-at-length data, however, the fit to the two most recent GABFIS points is poor. The inclusion of new and updated data in the current assessment has led to some changes in the shape of the spawning biomass trajectory, but the depletion remains near the target of 43%. The assessment estimates that the projected 2020/21 spawning stock biomass will be 45% of virgin stock biomass (projected assuming 2018/19 catches in 2019/20). The 2020/21 Recommended Biological Catch (RBC) under the 20:35:43 harvest control rule is 1,253 t. The average RBC over the three-year period 2020/21 - 2022/23 is 1,238 t. The long-term RBC is 1,218 t.

Several sensitivities to the base case model structure were conducted. These included a model with Danish seine as a separate fleet and a model with interpolated GABFIS biomass indices where the FIS was not conducted in recent years. The former model, while showing promise as a future base case model, was unusually sensitive to the inclusion of the Danish seine fleet even though this fleet catches only a small proportion of the total GAB catch. If this fleet continues to operate in the GAB, then it is important that sufficient samples are collected. Only three years of Danish seine length frequency data and two years of age data are available. The interpolated GABFIS model was suggested to look at how influential the FIS data points are to the estimated biomass trajectories. Results conclude that the GABFIS can have a strong influence on the biomass predicted by the model. This result can contribute to discussions regarding the frequency of FIS surveys in both the GAB and SESSF.

KEYWORDS: fishery management, southern and eastern scalefish and shark fishery, stock assessment, trawl fishery, non-trawl fishery

2. Background

The Southern and Eastern Scalefish and Shark Fishery (SESSF) is a Commonwealth-managed, multi-species and multi-gear fishery that catches over 80 species of commercial value and is the main provider of fresh fish to the Sydney and Melbourne markets. Precursors of this fishery have been operating for more than 85 years. Catches are taken from both inshore and offshore waters, as well as offshore seamounts, and the fishery extends from Fraser Island in Queensland to south west Western Australia.

Management of the SESSF is based on a mixture of input and output controls, with over 20 commercial species or species groups currently under quota management. For the previous South East Fishery (SEF), there were 17 species or species groups managed using TACs. Five of these species had their own species assessment groups (SAGs) – orange roughy (ORAG), eastern gemfish (EGAG), blue grenadier (BGAG), blue warehou (BWAG), and redfish (RAG). The assessment groups comprise scientists, fishers, managers and (sometimes) conservation members, meeting several times in a year, and producing an annual stock assessment report based on quantitative species assessments. The previous Southern Shark Fishery (SSF), with its own assessment group (SharkRAG), harvested two main species (gummy and school shark), but with significant catches of saw shark and elephantfish.

In 2003, these assessment groups were restructured and their terms of reference redefined. Part of the rationale for the amalgamation of the previous separately managed fisheries was to move towards a more ecosystem-based system of fishery management (EBFM) for this suite of fisheries, which overlap in area and exploit a common set of species. The restructure of the assessment groups was undertaken to better reflect the ecological system on which the fishery rests. To that end, the assessment group structure now comprises:

- SESSFRAG (an umbrella assessment group for the whole SESSF)
- South East Resource Assessment Group (Slope, Shelf and Deep RAG)
- Shark Resource Assessment Group (Shark RAG)
- Great Australian Bight Resource Assessment Group (GAB RAG)

Each of the depth-related assessment groups is responsible for undertaking stock assessments for a suite of key species, and for reporting on the status of those species to SESSFRAG. The plan for the resource assessment groups (South East, GAB and Shark RAGs) is to focus on suites of species, rather than on each species in isolation. This approach has helped to identify common factors affecting these species (such as environmental conditions), as well as consideration of marketing and management factors on key indicators such as catch rates.

The quantitative assessments produced annually by the Resource Assessment Groups are a key component of the TAC setting process for the SESSF. For assessment purposes, stocks of the SESSF currently fall under a Tier system whereby those with better quality data and more robust assessments fall under Tier 1, while those with less reliable available information are in Tiers 3 and 4. To support the assessment work of the four Resource Assessment Groups, the aims of the work conducted in this report were to develop new assessments if necessary (under all Tier levels), and update and improve existing ones for priority species in the SESSF.

3. Need

A stock assessment that includes the most up-to-date information and considers a range of hypotheses about the resource dynamics and the associated fisheries is a key need for the management of a resource. In particular, the information contained in a stock assessment is critical for selecting harvest strategies and setting Total Allowable Catches.

4. Objectives

These Objectives include the SESSFRAG agreed changes to the assessment schedule:

- Provide quantitative and qualitative species assessments in support of the four SESSFRAG assessment groups, including RBC calculations within the SESSF harvest strategy framework
- 2018: Provide Tier 1 assessments for Blue grenadier, Jackass morwong (east and west), School shark, and Silver warehou; Tier 3 assessment for Alfonsino (removed); Tier 4 assessments for Blue eye trevalla (addition of T5 for seamounts) and Deepwater shark (east and west); and Tier 5 for Smooth oreo (removed).
- 2019: Provide Tier 1 assessments for Deepwater flathead, Tiger flathead, Western gemfish (moved to T4), Bight redfish (addition) and Gummy shark (delayed); and Tier 4 for Mirror Dory

5. School whiting (*Sillago flinders*) projections based on CPUE updates to 2018, estimated catch to 2019 and projected catch scenarios to 2021

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5.1 Executive Summary

This document presents results of fixed catch projections for school whiting (*Sillago flindersi*) to provide information on possible projected stock status in light of increases in NSW catches in state waters in 2017 and 2018, compared to the anticipated NSW catch when setting the Commonwealth TAC following the 2017 school whiting stock assessment. Similar high catch levels are expected in NSW state waters for 2019 and possibly 2020 and 2021 (Karina Hall, pers. comm.). This increase in catch resulted in the total catch exceeding the RBC in 2017 and 2018, with a high chance of this also occurring in 2019 given anticipated NSW and Commonwealth catches.

At the November 2019 SERAG meeting, participants requested a range of fixed catch two-year projections (2020-2021) be run to examine the effect of the increase in total reported catch for 2017 and 2018 and the expectation that the 2019 total catch would also exceed the RBC. This enables the risk to the stock to be assessed from the increased catches expected from 2017-2019, including scenarios where the RBC may continue to be exceeded for the years 2020-2021, for a range of projected catch values.

Updated data used from the 2017 assessment, including preliminary catch (combined Commonwealth and state catch) for 2017-2018, estimated 2019 catch and updated CPUE series to the end of 2018 were included in this analysis. Updates to age and length composition data were not available and were not included. These updates to catch and CPUE alone resulted in a revision downwards to the 2018 stock status, from 47% in the last stock assessment to 36% in this analysis. These changes are due to revisions to the 2017 catch and to the revised CPUE series, which has a downturn at the end of the time series. Projecting forward to 2020, using preliminary 2018-2019 catches, takes the stock status to 35%, which is expected to recover to 44% at the start of 2022, if the RBC is caught in 2020 and 2021 and there is average recruitment from 2014 onwards.

Given the 2020 and 2021 catches may exceed the RBC, four fixed catch projections were examined, with total catches (including discards) ranging from 1,600-1,900 t. Projected stock status at the start of 2022 ranged from 34% to 39% under the fixed catch scenarios, compared to 44% if the RBC is caught in 2020 (1,165 t) and 2021 (1,357 t).

Four low and four high recruitment scenarios were also investigated, with 2022 stock status ranging from 22% to 38% under the low recruitment scenarios and from 44% to 53% under the high recruitment scenarios.

5.2 Previous assessment and changes to data

5.2.1 *The fishery*

School whiting (*Sillago flindersi*) occur in the eastern regions of the SESSF and Bass Strait (zones 10, 20, 30, 60 and 91) and are commonly found on sandy substrates to depths of about 60m, and sometimes as deep as 150m. School whiting are benthic feeders and they mainly spawn during summer in the southern parts of their range, but with some evidence of spawning in the spring, winter and possibly all year round in the northern parts of their range. They grow rapidly, reach a maximum age of about nine years and become sexually mature at about two years of age.

In the SESSF, recruitment to the fishery occurs at around three years of age. Selectivity of 50% is only achieved for three-year-old fish for the Danish seine fishery and the otter trawl fishery. Except for the NSW Danish seine fleet, selectivity for two-year-olds is less than 20% and for one-year olds is less than 2%. The majority of the catch from 1947-1995 has been taken using Danish seine (mainly in zone 60 of the SESSF - Bass Strait) although the fraction of the catch taken by otter trawl has increased recently, and averaged more than 65% of the total catch from 1998-2010 and around 50% of the total catch since 2011. In contrast to the Danish seine catches, catches by otter trawl occur predominantly in SESSF zone 10, with most of this catch taken by state registered trawlers. Much of the school whiting caught by the Lakes Entrance Danish seine fleet since 1993 has been sent to an export market, although issues with quality of whiting caught in the summer months have reduced catches for the export market during this time.

Annual catches (landings and discards) of school whiting used in the 2017 assessment, with preliminary catch updates for 2017-2019 for the 2019 projections, are shown in Table 5.1 and also in Figure 5.1 (separated by fleet) and Figure 5.2 (separated by jurisdiction). Large catches of school whiting were first taken in the 1980s (Smith, 1994) and catches increased to over 2,000 t in 1986, 1990, 1991, 1993 and 1995. Catches have remained over 1,200 t since 1986, with the peaks in catches generally reducing since the 1990s. Catches between 2008 and 2016 have generally been between 1,200 and 1,500 t. However, there has been a recent increase in catches, especially in NSW state waters, with preliminary total catches between 1,750 and 2,000 t between 2017 and 2019.

Discard percentages are variable and appear market driven. From 1986-1996, more than 50% of the catch was taken by Commonwealth registered vessels, dropping to around 35% in the period 1997-2013 and then increasing back to around 50% between 2014 and 2016. Catches of school whiting taken by state registered vessels comprised more than 50% of the total catch for the period 1997-2013 and have varied between 40% and 50% between 2014 and 2016 (Figure 5.2). Since 2017, preliminary catches of school whiting taken by state registered vessels are in the range 60-70%.

The Commonwealth TAC for calendar years 2005 and 2006 was 1,500 t and in 2007 this was reduced to 750 t, maintained at 750 t in 2008 and increased to 1125 t in 2009. Since 2009 the Commonwealth TAC has varied between 600 and 1,000 t. The total landed catch (state and Commonwealth) averaged 1,350 t between 2004 and 2016, ranging between 1,200 t and just over 1,500 t. In the period 1994-2003, the total landed catch averaged over 1,700 t. Since 2017, the preliminary total landed catch increased to an average of 1,850 t, which is more than 200 t greater than the RBC (1,615 t) in the same period. The total state catch has averaged around 700 t in the period 2008-2016, and with an average of around 1,000 t in the decade 1998-2007 and in the period 2017-2019 (preliminary catches, Karina Hall, pers. comm.).

5.2.2 *Stock structure*

School whiting is assumed to be a single stock off the east coast of Australia and in Bass Strait, which is largely encompassed by the SESSF but does continue further north above Barrenjoey Point to Ballina. Stout whiting (*Silllago robusta*) is caught off northern New South Wales and the range of these two species overlaps between Ballina and Clarence River, with the northern limit for school whiting at Ballina. NSW catches of stout whiting and school whiting were split equally between the two whiting species in this region where they both occur.

Dixon *et al.* (1986, 1987) report a discontinuity in the relatedness between samples observed between Forster and Coffs Harbour, which may indicate some degree of separation between the fish from northern and southern NSW. However, the genetic techniques used in this work had little genetic variation and hence low power and this was combined with low sample sizes and possible non-representative sampling (A, Moore, pers. comm.). While this may indicate a possible location to split stocks genetically, it remains unconfirmed using modern techniques. This species would benefit greatly from a new study that uses modern molecular markers and representative sampling. Both the resolution of modern markers and the analysis techniques have increased dramatically the late 1980s. Modern markers and a new study would help to clarify the population structure in this species (A, Moore, pers. comm.).

5.2.3 *Previous assessment*

The most recent full quantitative stock assessment for school whiting using data up to 2016 was performed in 2017 (Day, 2017) using Stock Synthesis version SS-V3.30.08.03, (Methot et al 2017).

5.2.4 *Model structure for projected catch scenarios*

The same model structure and assumptions described in the 2017 assessment (Day, 2017) are used for the projected catch scenarios presented here. Changes include updating to the latest version of Stock Synthesis uses the current version of Stock Synthesis, SS-V3.30.14.05 (Methot et. al, 2018), using preliminary catches for 2017, 2018 and 2019 and updating the Danish seine and trawl CPUE series up to the end of 2018. All other data used (discard estimates, length composition data, conditional age-at-length data, ageing error matrix) in these projected catch scenarios are identical to those data used in the 2017 assessment.

5.2.5 *Landed catches*

The model uses a calendar year for all catch data. Landings data come from a number of sources. Early Victorian school whiting catches are available from 1947-1978 (Wankowski, 1983) and later Victorian state catches, from 1979-2006, were provided by Matt Koopman. Information enabling these Victorian state catches to be separated by fleet is not available, so it is assumed that 3% of these catches are from the otter trawl fleet and 97% are from Danish seine for the whole period. Matt Koopman supplied a catch history separated into state and Commonwealth catches for the period 1957-2006. None of these catches are separated by fleet.

The original data for the NSW component of this catch for the period from 1957-1992 is from Pease and Grinberg (1995). Corrections were made to these catches to remove the stout whiting component from the catch (Kevin Rowling, pers. comm.), with these corrections based on how far north the catch was landed along the NSW coast. Due to limited availability of catch data in the period 1957-1984, 66% of the NSW catches reported by Pease and Grinberg were assigned to school whiting in this period. These adjusted catches of school whiting were incorporated into the NSW state catch history initially provided by Matt Koopman.

The NSW state catch history from 1985 onwards was further revised in 2017 (Karina Hall, pers. comm.) to improve the estimates of school whiting catches, by excluding the best estimates of stout whiting catches in specific northern fishing zones in NSW state waters during this period. The proportion of whiting catch comprising stout whiting increases the further north the catch is taken. Best estimates of the NSW state catch data by fleet for 2017-2019 were included (Karina Hall, pers. comm.).

After all of these adjustments to the NSW catch total are completed, the total NSW state catch was then allocated in the ratio of 97% to the otter trawl fleet and 3% to the NSW Danish seine fleet from 1957-1994. From 1995 to 2009 all of the NSW state catch was assumed to be otter trawl. From 2010 to 2016, the Danish seine component of the NSW state catch is known and the remaining catch is assumed to be otter trawl. The NSW Danish seine catch from 2010 onwards is not publicly available. The Danish seine component of the NSW state catch from 2017-2019 was not available, so was estimated based on the average proportion of NSW Danish seine catch from 2011-2016.

Tasmanian state catches are available from 1995-2016 and all of this catch was assigned to the Victorian Danish seine fleet. Tasmanian state catches for the period 2017-2019 were assumed to be equal to the last known catch (2016). Victorian state catch in 2019 was assumed to be the same as the last known catch (2018). All Victorian state catch is assumed to be 97% Danish seine and 3% trawl.

Commonwealth catches from 1985-2016 are separated into otter trawl and Danish seine (assumed to be the “Victorian Danish seine” fleet). These data come from the Commonwealth logbook records. Updates to the Commonwealth catches were made for 2017 and 2018, using the fleet composition from logbook data and the catch totals from the Catch Disposal Records (CDRs). The 2019 CDR was estimated based on the monthly CDRs to the end of August, with the likely incomplete August records replaced with the July 2019 catch. This total was then scaled up to a full year based on the average proportion of the annual CDR caught to the end of August for the previous five years. This Commonwealth CDR total for 2019 was separated by fleet using the logbook proportion from January 2019 to mid-September 2019, assuming that this proportion is representative of the catch for the full year.

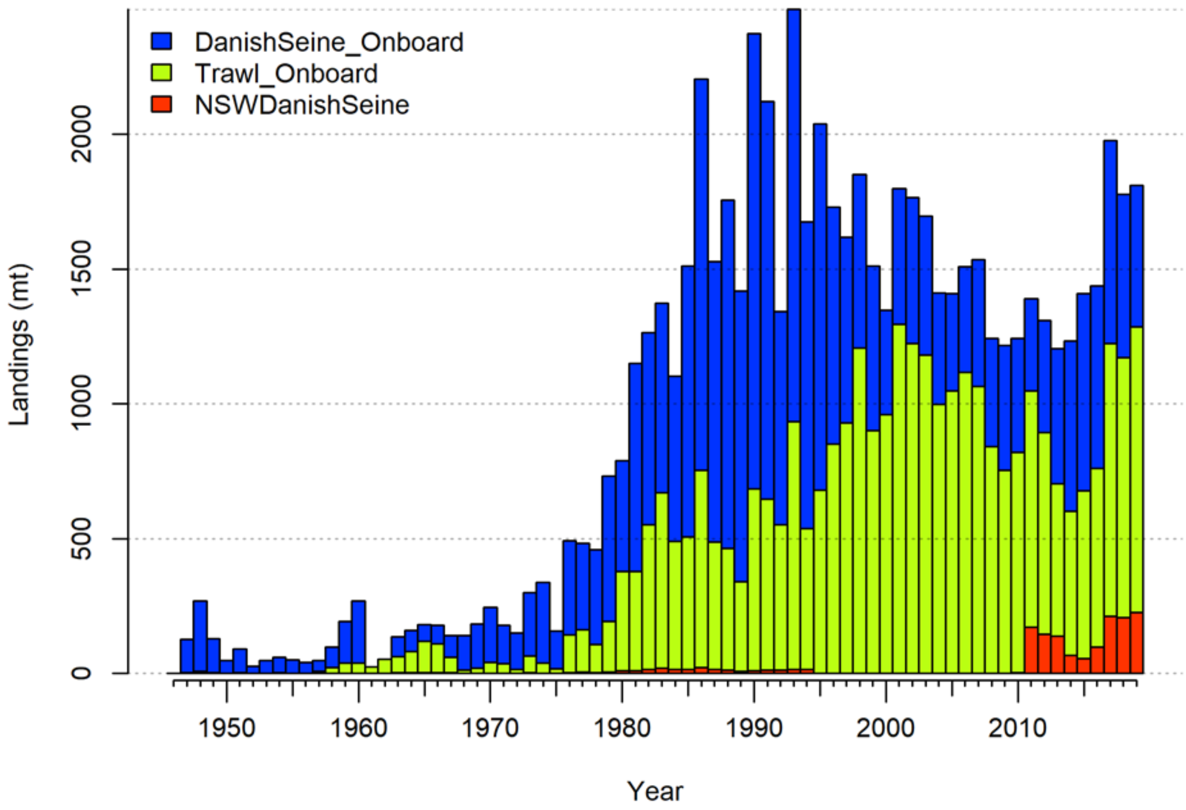

Figure 5.1. Total landed catch (tonnes) of school whiting by fleet (stacked) from 1947-2019. Recent NSW Danish seine catches are not publicly available.

Annual landed catches for the three fleets used in this assessment (Victorian Danish seine, otter trawl and NSW Danish seine) are shown in Figure 5.1 and Table 5.1, with recent NSW Danish seine catches redacted, and with only the total catches listed in Table 5.1 for the period 2010-2016 (catches by fleet are not listed for these years), to maintain confidentiality of NSW Danish seine catches. The same catch history separated into state and Commonwealth components is shown in Figure 5.1.

This catch history is slightly modified from the catch history presented at the September 2017 SERAG meeting (Day 2017). Issues were discovered in both the NSW state catch data and the Commonwealth catch data with catches misreported on both sides of the line at Barrenjoey Point, and corrections were made to these data sources where possible before the December 2017 SERAG meeting. In addition to these changes, the Commonwealth catch history between 2003 and 2007 was updated in the preliminary base case (Day 2017) using data provided by AFMA. Updates to the Victorian Inshore Trawl component of this catch were inconsistent in the AFMA database with the data used in 2009, which was compiled by Neil Klaer (SEF2 VIC catches). Discrepancies between the two data sources could not be resolved. As the data compiled by Neil Klaer was processed closer to the collection of the data, a decision was made to use this data source. The maximum difference in any one year between these two sources of data was 50 t in 2004, with a combined difference of 34 t over a five-year period, so the effect of this change was minor.

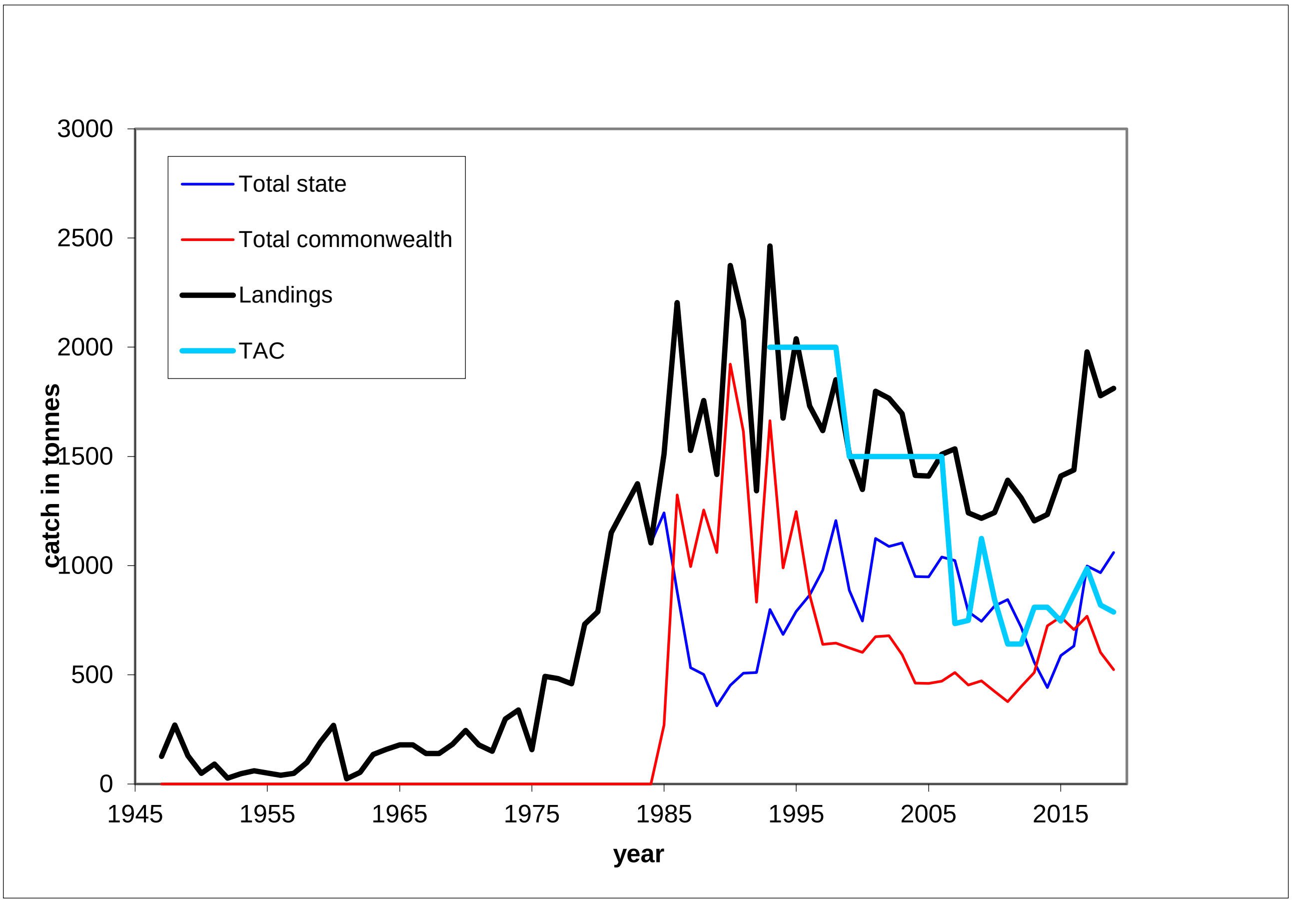

Figure 5.2. Total landed catch of school whiting in the SESSF from 1947-2019 (black line with circles), with preliminary catches 2019-2019, and this same catch separated into jurisdiction with state catches (blue) and Commonwealth catches (red). The Commonwealth TAC is shown from 1993-2019 (aqua). The Commonwealth catches were larger than the state catches in the periods 1987-1996 and 2014-2016. The state catches (blue) comprise the whole catch until 1985. The Commonwealth catch starts in 1985.

Table 5.1. Total retained catches (tonnes) of school whiting per fleet for calendar years from 1947-2009. Only the combined total for all fleets is shown for 2010-2016, with preliminary (*) combined totals for 2017-2019.

Year	Vic DS	Otter trawl	NSW DS	Total	Year	Vic DS	Otter trawl	NSW DS	Total
1947	122	4	0	126	1982	714	535	16	1264
1948	262	8	0	270	1983	705	650	19	1374
1949	125	4	0	129	1984	614	476	14	1104
1950	47	1	0	49	1985	1005	492	14	1511
1951	89	3	0	92	1986	1451	732	21	2205
1952	26	1	0	27	1987	1041	473	14	1528
1953	46	1	0	47	1988	1293	451	13	1756
1954	59	2	0	61	1989	1079	331	8	1418
1955	49	2	0	51	1990	1691	673	10	2375
1956	39	1	0	40	1991	1477	634	12	2123
1957	41	7	0	48	1992	791	540	12	1343
1958	76	22	1	98	1993	1529	919	16	2464
1959	154	38	1	193	1994	1138	521	16	1675
1960	230	37	1	268	1995	1359	680	0	2039
1961	0	23	1	24	1996	880	850	0	1731
1962	0	52	2	54	1997	688	931	0	1619
1963	73	61	2	136	1998	645	1207	0	1852
1964	78	79	2	159	1999	610	901	0	1511
1965	59	117	4	180	2000	388	961	0	1349
1966	69	107	3	179	2001	502	1296	0	1799
1967	81	57	2	140	2002	544	1223	0	1767
1968	128	12	0	140	2003	515	1180	0	1696
1969	164	18	0	183	2004	415	998	0	1413
1970	204	40	1	245	2005	362	1047	0	1410
1971	143	36	1	180	2006	393	1117	0	1510
1972	135	14	0	149	2007	469	1065	0	1534
1973	233	64	2	299	2008	400	842	0	1242
1974	301	37	1	338	2009	463	754	0	1216
1975	139	17	0	157	2010	424	816	4	1243
1976	351	138	4	493	2011	343	878	171	1391
1977	322	157	5	483	2012	416	748	147	1310
1978	352	104	3	459	2013	501	566	138	1205
1979	538	188	5	732	2014	632	534	68	1234
1980	412	367	11	789	2015	732	622	56	1410
1981	772	368	11	1151	2016	676	663	99	1438
					2017	676	663	99	1978*
					2018	676	663	99	1777*
					2019	676	663	99	1811*

The state catch is a significant proportion of the total catch for school whiting (Figure 5.2). From 1986-1996 the state catch averaged around 30% of the total catch, but from 1997-2013, the state catch increased and the Commonwealth catch decreased and as a result the state catch averaged around 60% of the total catch in this period. Between 2014 and 2016, the Commonwealth catch increased and the state catch decreased, with the Commonwealth catch averaging just over 50% in this period. Since 2017, preliminary catches of school whiting taken by state registered vessels are in the range 60-70% of the total catch of school whiting. The difference between catches in state and Commonwealth jurisdictions does not affect this assessment directly, but it does affect how catches are allocated to the different fleets, and it will have an impact on the allocation of the RBC.

The NSW trawl fleet averages around 85% of the total state catches in the period 1986-2019. The Commonwealth catch starts in 1985 and the Victorian Danish seine fleet comprises around 85% of the Commonwealth catch since 1986. The Commonwealth catch was less than the state catch in the period 1997-2013 and from 2017-2019.

The recent TAC history, which only applies to the Commonwealth component of the catch, is listed in Table 5.2.

Table 5.2. Total allowable catch (tonnes) from 1993 to 2019.

Year	TAC Agreed
1993	2000
1994	2000
1995	2000
1996	2000
1997	2000
1998	2000
1999	1500
2000	1500
2001	1500
2002	1500
2003	1500
2004	1500
2005	1500
2006	1500
2007	734
2008	750
2009	1125
2010	844
2011	641
2012	641
2013	809
2014	809
2015	747
2016	868
2017	986
2018	820
2019	788

5.2.6 *Catch rate indices*

Catch per unit effort (CPUE) data from the Commonwealth logbook database were standardised using general linear models (GLMs) to obtain relative abundance indices (Sporcic, 2019b; Table 5.3) from the period 1986-2018 for the Victorian Danish seine fleet and from 1995-2018 for the trawl fleet. These updated values, plus the new values for 2017 and 2018 were incorporated into the projected catch scenarios.

Table 5.3. Standardised CPUE indices and coefficient of variation (Sporcic, 2019a, 2019b) for the Victorian Danish seine fleet and the trawl fleet for school whiting. The coefficient of variation is initially set at a value equal to the root mean squared deviation from a *loess* fit (Sporcic, 2019a).

Year	Catch rate Vic DS	cv (DS)	Catch rate trawl	cv c.v. (TW)
1986	1.154	0.177		
1987	1.2784	0.177		
1988	1.6296	0.177		
1989	1.0813	0.177		
1990	1.67	0.177		
1991	1.4755	0.177		
1992	1.0682	0.177		
1993	1.5237	0.177		
1994	0.8915	0.177		
1995	1.1312	0.177	1.2149	0.178
1996	0.7436	0.177	1.3647	0.178
1997	0.5603	0.177	0.9456	0.178
1998	0.5409	0.177	0.9546	0.178
1999	0.6211	0.177	1.1572	0.178
2000	0.6445	0.177	1.1584	0.178
2001	0.8924	0.177	1.2701	0.178
2002	0.8724	0.177	1.0505	0.178
2003	0.9153	0.177	1.0011	0.178
2004	0.8344	0.177	0.774	0.178
2005	0.9307	0.177	1.0908	0.178
2006	0.8392	0.177	1.5043	0.178
2007	1.1119	0.177	1.4814	0.178
2008	1.1011	0.177	0.9496	0.178
2009	1.1872	0.177	0.8229	0.178
2010	1.0406	0.177	0.9888	0.178
2011	0.8333	0.177	0.8433	0.178
2012	0.8969	0.177	0.6211	0.178
2013	0.9184	0.177	0.5541	0.178
2014	1.0047	0.177	0.7539	0.178
2015	0.9564	0.177	0.6898	0.178
2016	0.9357	0.177	0.9264	0.178
2017	0.8688	0.177	1.0682	0.178
2018	0.8467	0.177	0.8143	0.178

The restrictions used in selecting data for analysis for Danish seine fleet were: (a) the catch rate had to be larger than zero, (b) catches in zone 60 only (c) catches in less than 100m depth and (d) effort is considered as catch per shot rather than as catch per hour, to allow for missing records of total time for each shot for data early in the fishery (Sporcic 2019b).

The restrictions used in selecting data for analysis for the trawl fleet seine were: (a) the catch rate had to be larger than zero, (b) catches in zones 10, 20 and 91 only (c) catches in less than 150m depth and (d) effort is considered as catch per hour. Catches recorded in zone 91 are apparently caught in state waters, but it appears there were issues with location recorded for some shots and these either represent shots which were actually in zone 10 or at least record school whiting caught by Commonwealth registered vessels in zone 91. In either case the catch rate data should be informative so records from zone 91 were included (Sporcic 2019b).

5.3 Alternative catch and recruitment scenarios

5.3.1 NSW catch increases

New South Wales introduced quota shares for a combined school whiting and stout whiting (*Sillago robusta*) TAC for operators in the Ocean Trawl sectors (north of the Barrenjoey line). The combined 2019 TAC was set at 1189 t. The NSW Southern Fish Trawl Fishery, which operates inside three nautical miles south of the Barrenjoey line, is not restricted by quota on school whiting. As a result, catches of school whiting in NSW state waters increased in 2017 and 2018 and are also expected to be high in 2019 (Karina Hall, pers. comm.), with the RBC expected to be exceeded in 2017, 2018 and 2019. The increase in NSW state catch from 2017 was not reported in 2018 (Castillo-Jordán et. al, 2018) as there appeared to be issues with the data reported from NSW in that year (Paul Burch, pers. comm.). However, this increase in NSW state catch, in both 2017 and 2018, was reported in 2019 (Burch et. al, 2019) and, as this meant the total catch in 2017 and 2018 was over the RBC in those years, a request was made by SERAG in November 2019 to consider some fixed catch projections.

SERAG requested a range of fixed catch two-year projections (2020-2021) be run to examine the effect of the increase in total catch reported for 2017 and 2018 and the expectation that the 2019 total catch would also exceed the RBC. This enables the risk to the stock to be assessed from the increased catches expected from 2017-2019, including scenarios where the RBC may continue to be exceeded for the years 2020-2021, for a range of projected catch values. This analysis was also run with low and high recruitment scenarios.

5.3.2 Update catch from 2017 to 2020 and update CPUE to 2018

Initial data updates to the 2017 base case model were performed in a stepwise manner, with four scenarios considered in this data update section.

1. 2017 base case (WHS2017BaseCase)
2. Translate from SS-V3.30.08.03 to SS-V3.30.14.05
3. Update catch to 2020 (WHS2019UpdateCatch)
4. Update CPUE to 2018, with updated catch retained (WHS2019CatchRBC)

Under each of these initial scenarios, projections are made under average recruitment, with future (projected) catches set to the RBC. The first two scenarios, based on the 2017 base case, project catches from 2018 onwards. The last two scenarios, which feature fixed catches until 2019, project catches from 2020 onwards.

The translation to SS-V3.30.14.05 (scenario 2) made minimal difference, so the results of this scenario are not shown here.

The values of the projected catches for scenarios 1, 3 and 4, and the subsequent (calculated) RBC, are listed in Table 5.4 for the period 2017-2023. These values are calculated from 2018 onwards, for the 2017 base case, and from 2020 onwards, for the scenario with updated catch and CPUE, with all calculated values shown in bold in Table 5.4. Similarly the calculated stock status at the beginning of each year from 2017-2023, assuming average recruitment, is shown in Table 5.5 and displayed in Figure 5.3, showing the relative stock status over the full time series from 1947-2040 and in Figure 5.4, showing the relative stock status from 2010-2023.

Table 5.4. Fixed catch projections (including discards) for 2017-2023 and the RBC calculated (shown in bold) after applying these projected catches (under average recruitment) for the 2017 base case, the updated catch and updated CPUE scenarios.

	Fix Catch		
Year	2017 Base case	Update Catch	Update CPUE
2017	1,438	2,146	2,151
2018	**1,605**	1,938	1,943
2019	**1,614**	1,983	1,988
2020	**1,622**	**1,352**	**1,165**
2021	**1,629**	**1,474**	**1,357**
2022	**1,633**	**1,532**	**1,433**
2023	**1,636**	**1,562**	**1,474**

Table 5.5. Projected stock status for 2017-2023 following application of fixed catch projections (including discards) for 2018-2020 after applying the projected catches and RBCs from Table 4 (from average recruitment) for the 2017 base case, the updated catch and updated CPUE scenarios.

	Depletion (%)		
Year	2017 Base case	Update Catch	Update CPUE
2017	44.7	44.0	39.8
2018	46.9	40.3	36.3
2019	47.2	39.3	35.5
2020	47.4	38.4	34.6
2021	47.6	42.8	40.6
2022	47.8	44.9	43.5
2023	47.8	45.9	44.8

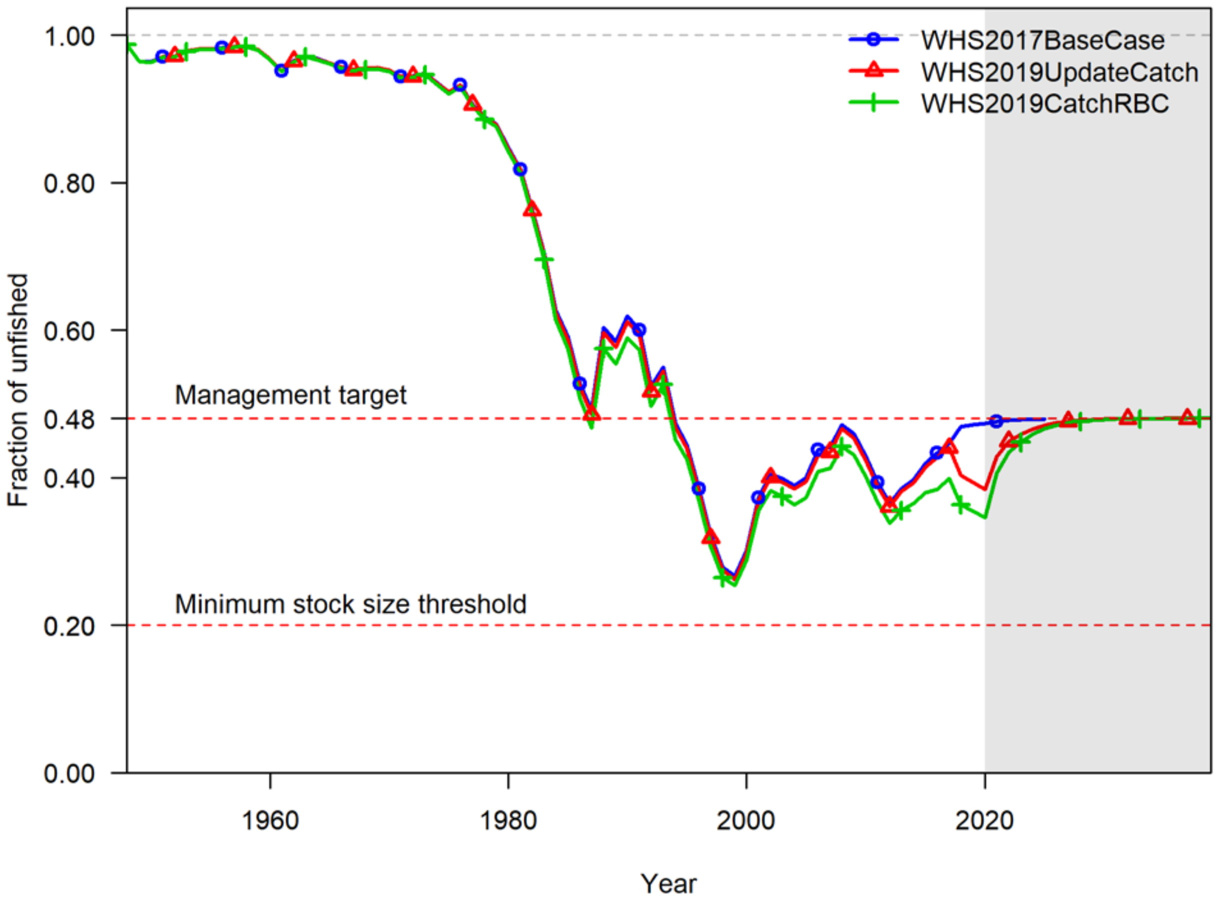

Figure 5.3. Relative spawning biomass (1947-2040) for the 2017 base case, the updated catch and updated CPUE (labelled here as WHS2019CatchRBC) scenarios (under average recruitment).

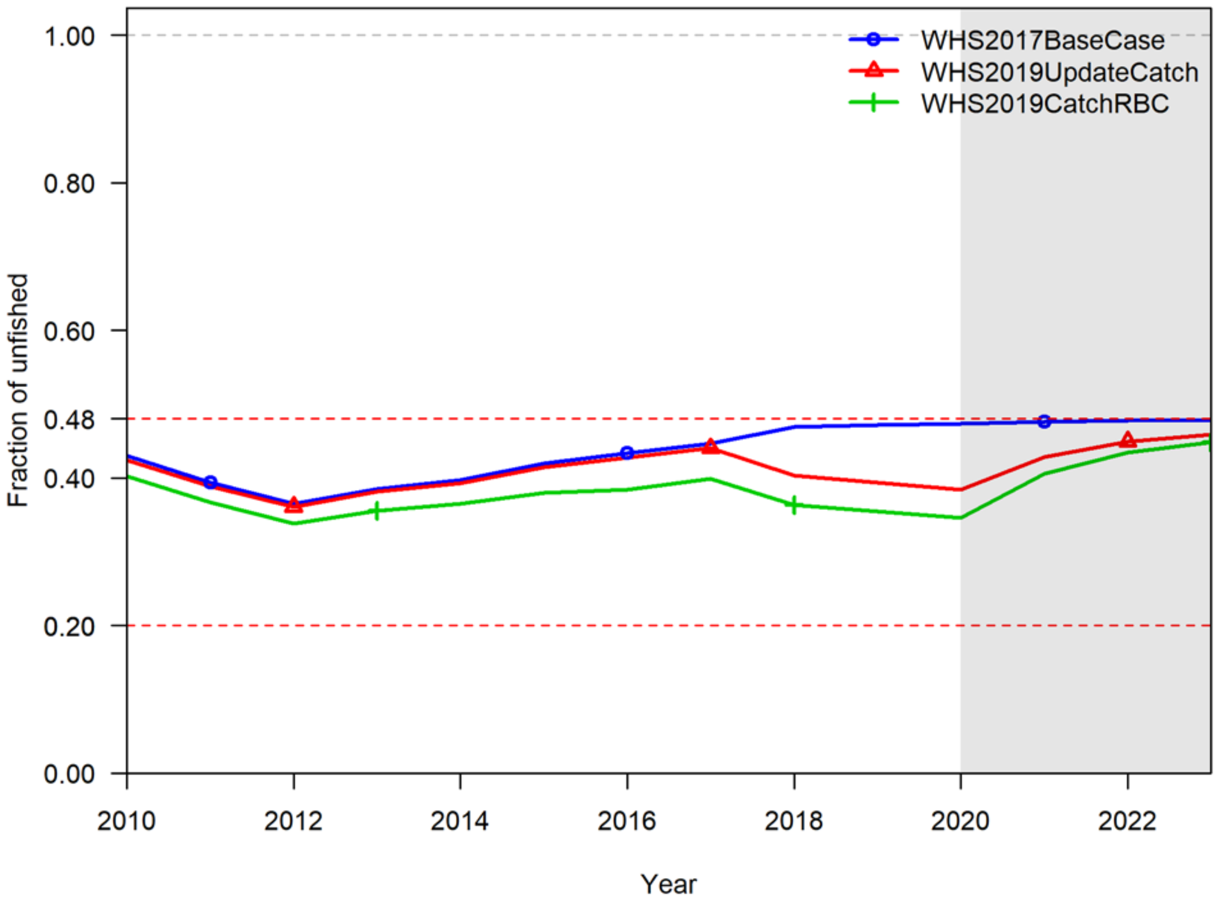

Figure 5.4. Relative spawning biomass (2010-2023) for the 2017 base case, the updated catch and updated CPUE scenarios (under average recruitment).

Recruitment deviations for the 2017 base case, the updated catch and updated CPUE scenarios are shown in Figure 5.5. This shows that recruitment is set to average recruitment from 2014 for all three scenarios. Note that the recent estimated recruitment events are revised downwards, and more so in 2013, with the addition of the updated CPUE. This revision to the recruitment is influenced by the updated CPUE, which shows a decline in the most recent data, with subsequent improvements to the fit to the updated CPUE.

Updating both the catch data and CPUE results in changes to predicted spawning biomass. The relative stock status in 2021 is 48% for scenario 1 (after applying the RBC, given the projected stock status) compared to 41% for scenario 3 (catch and CPUE updated). The relative stock status in 2022 is 48% for scenario 1 (after applying the RBC, given the projected stock status) compared to 44% for scenario 3 (catch and CPUE updated).

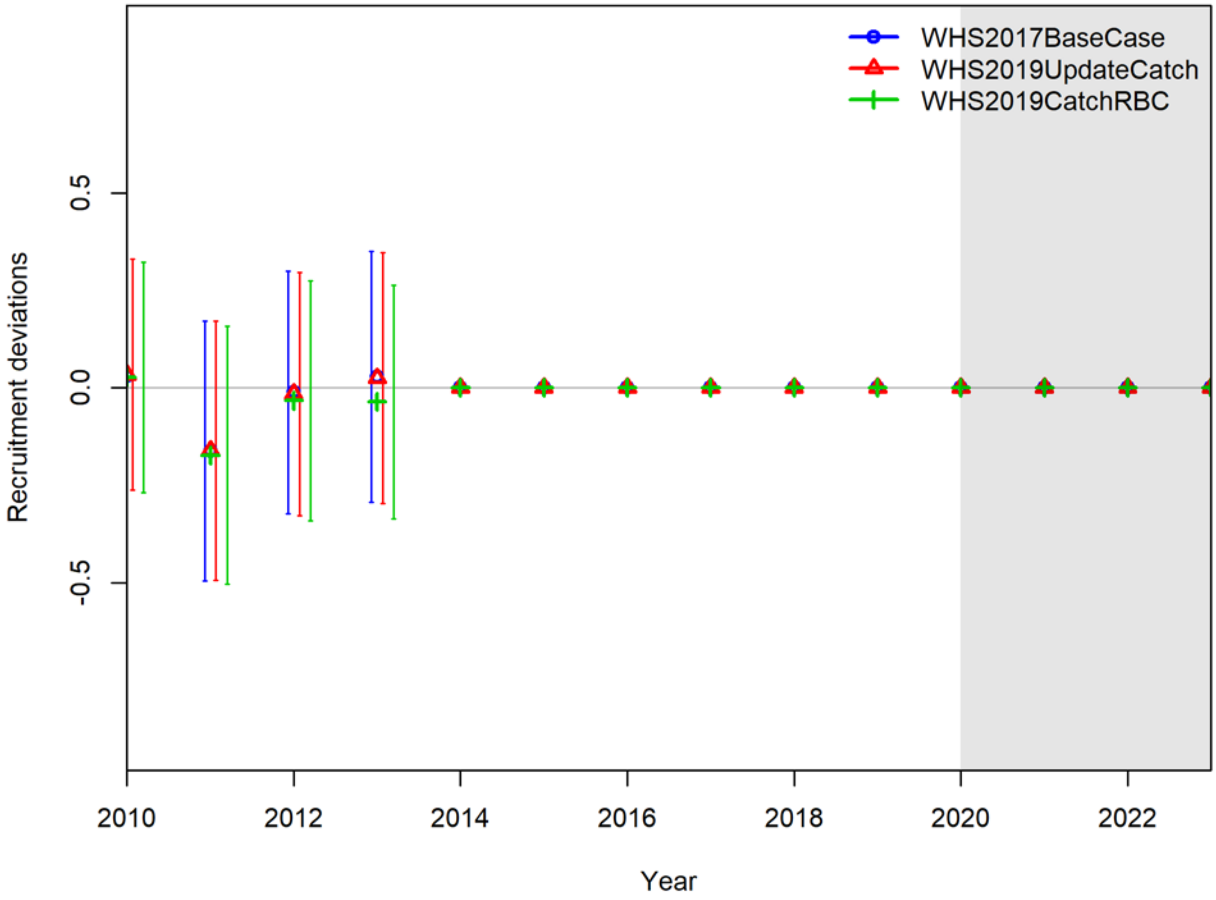

Figure 5.5. Recruitment deviations (2010-2023) for the 2017 base case, the updated catch and updated CPUE scenarios (showing average recruitment).

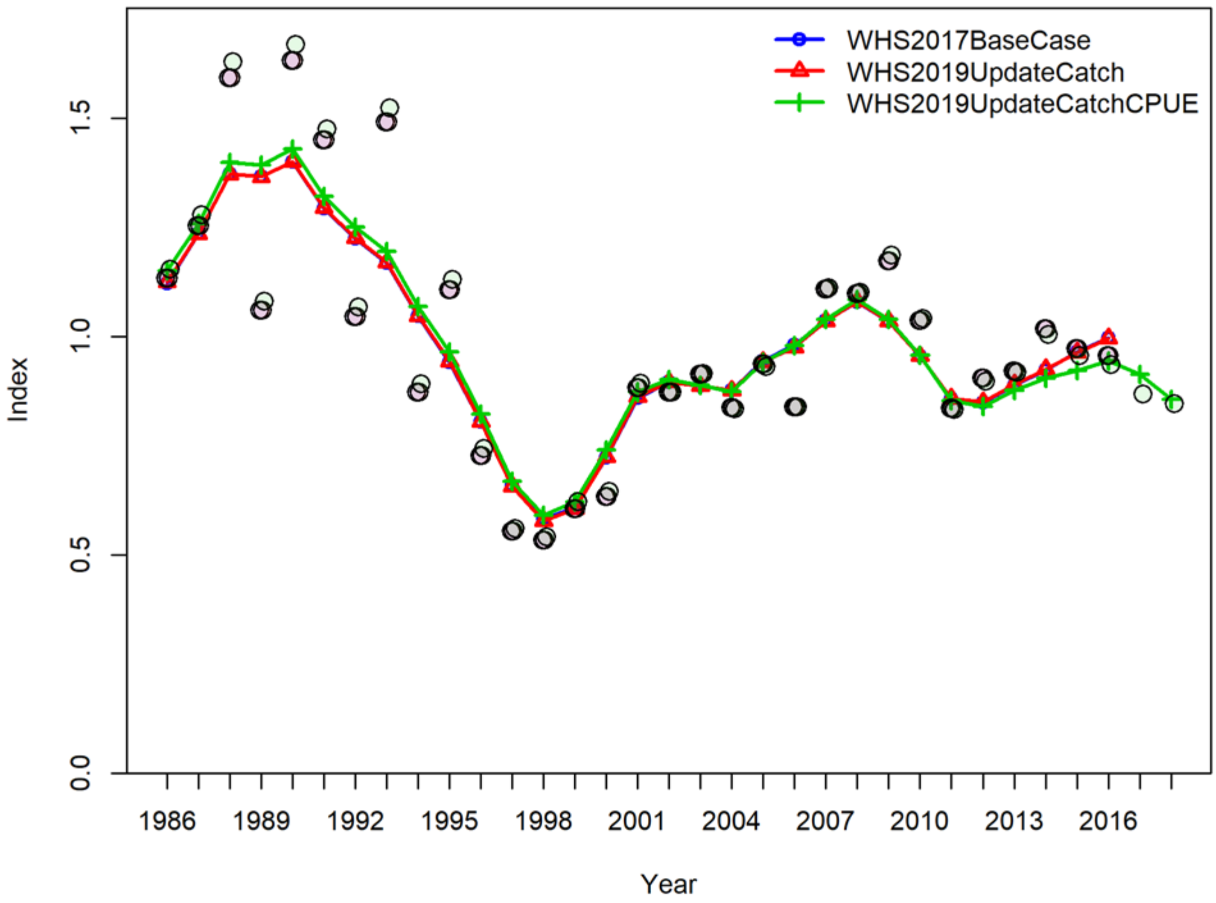

Figure 5.6. Fits to the Danish seine CPUE series for the 2017 base case, the updated catch and updated CPUE scenarios.

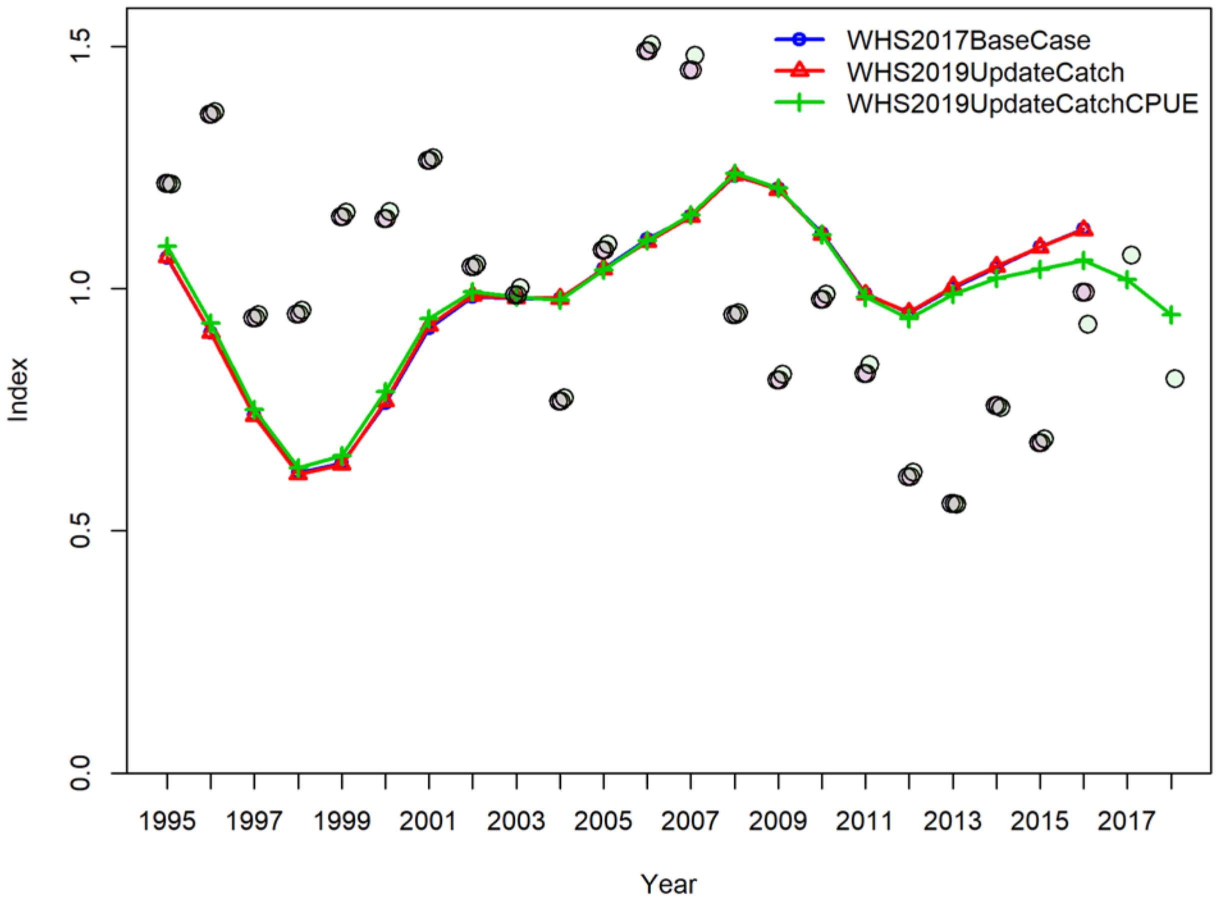

Figure 5.7. Fits to the trawl CPUE series for the 2017 base case, the updated catch and updated CPUE scenarios.

5.3.3 *Alternative fixed catch projections 2020-2021*

Following the initial data updates to the 2017 base case model a series of catch projections were run with fixed catches (including all catches and discards) for the years 2020 and 2021, with future projected catches from 2022 onwards set to the RBC (under average recruitment). These scenarios were compared to the 2017 base case with updated catch and CPUE from the previous section.

1. 2017 base case with updated catch and CPUE (WHS2019CatchRBC)
2. Fix total catches (including discards) in 2020 and 2021 to 1,600 t (WHS2019Catch1600)
3. Fix total catches (including discards) in 2020 and 2021 to 1,700 t (WHS2019Catch1700)
4. Fix total catches (including discards) in 2020 and 2021 to 1,800 t (WHS2019Catch1800)
5. Fix total catches (including discards) in 2020 and 2021 to 1,900 t (WHS2019Catch1900)

Under each of these scenarios, projections are still made under average recruitment, with future (projected) catches set to the RBC. The first scenario projects catch from 2020 onwards. The last four scenarios, which feature fixed catches until 2021, project catches from 2022 onwards.

The values of the projected catches for scenarios 1-5, and the subsequent (calculated) RBC, are listed in Table 5.6 for the period 2017-2023. These values are calculated from 2020 onwards, for the scenario with updated catch and CPUE, and 2022 onwards for all other scenarios, with all calculated values shown in bold in Table 5.4. Similarly the calculated stock status level at the beginning of each year from 2017-2022, assuming average recruitment, is shown in Table 5.7 and displayed in Figure 5.8, showing the relative stock status over the full time series from 1947-2040 and in Figure 5.9, showing the relative stock status from 2010-2023.

Table 5.6. Fixed catch projections (including discards) for 2017-2023 and the RBC calculated (shown in bold) after applying these projected catches (under average recruitment) for the updated catch and updated CPUE scenario, and the four fixed catch scenarios (1,600 – 1,900 t) under average recruitment.

	Fix Catch				
Year	Update catch & CPUE	1600	1700	1800	1900
2017	2,151	2,151	2,151	2,151	2,151
2018	1,943	1,943	1,943	1,943	1,943
2019	1,988	1,988	1,988	1,988	1,988
2020	**1,165**	1,600	1,700	1,800	1,900
2021	**1,357**	1,600	1,700	1,800	1,900
2022	**1,433**	**1,298**	**1,258**	**1,218**	**1,116**
2023	**1,474**	**1,402**	**1,380**	**1,358**	**1,351**

Table 5.7. Projected stock status for 2017-2023 following application of fixed catch projections (including discards) for 2018-2020 after applying these projected catches and RBCs from Table 6 (from average recruitment) for the updated catch and updated CPUE scenario, and the four fixed catch scenarios (1,600 – 1,900 t).

	Depletion (%)				
Year	Update catch & CPUE	1600	1700	1800	1900
2017	39.8	39.8	39.8	39.8	39.8
2018	36.3	36.3	36.3	36.3	36.3
2019	35.5	35.5	35.5	35.5	35.5
2020	34.6	34.6	34.6	34.6	34.6
2021	**40.6**	**36.9**	**36.0**	**35.2**	**34.4**
2022	**43.5**	**38.5**	**37.0**	**35.6**	**34.1**
2023	44.8	42.2	41.5	40.7	40.4

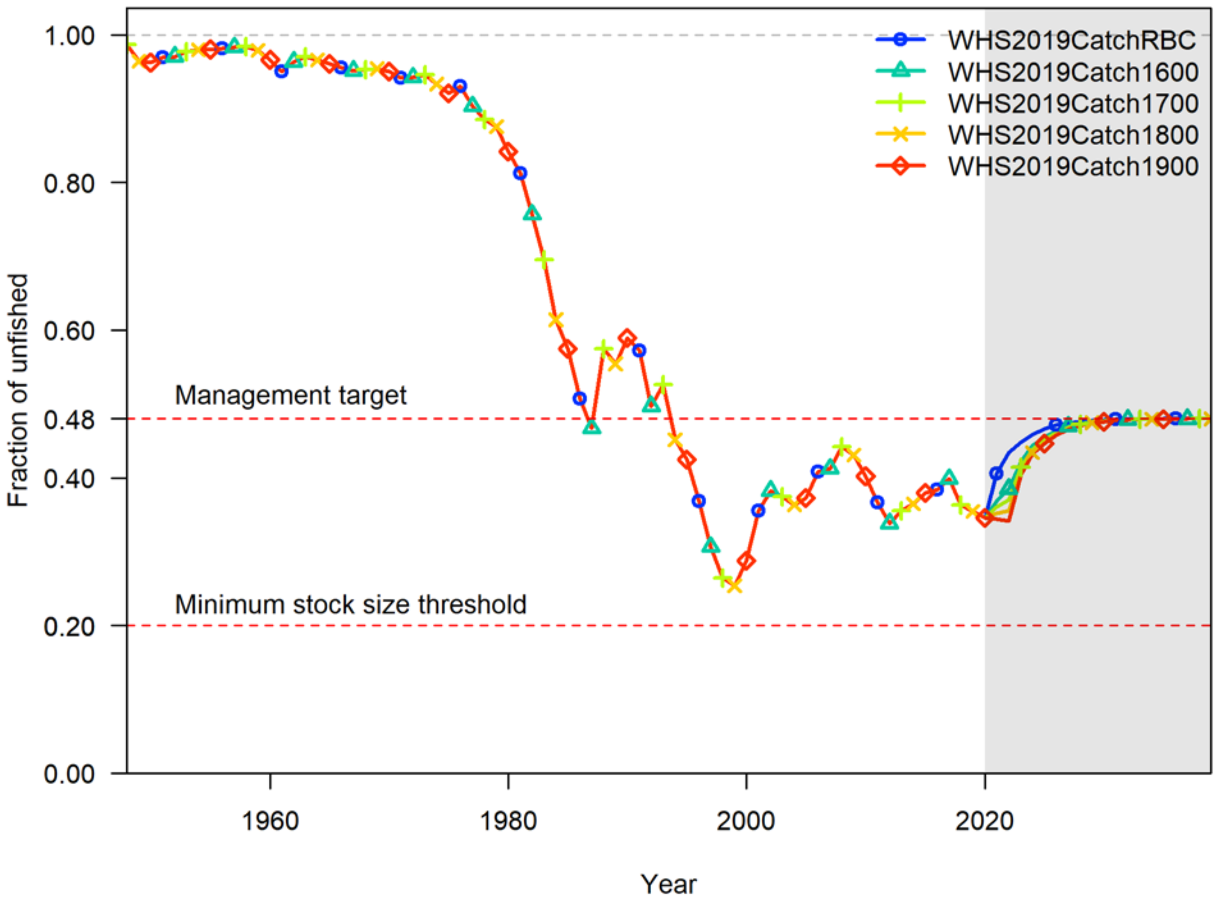

Figure 5.8. Relative spawning biomass (1947-2040) for the updated catch and updated CPUE scenario, and the four fixed catch scenarios (1,600 – 1,900 t) under average recruitment.

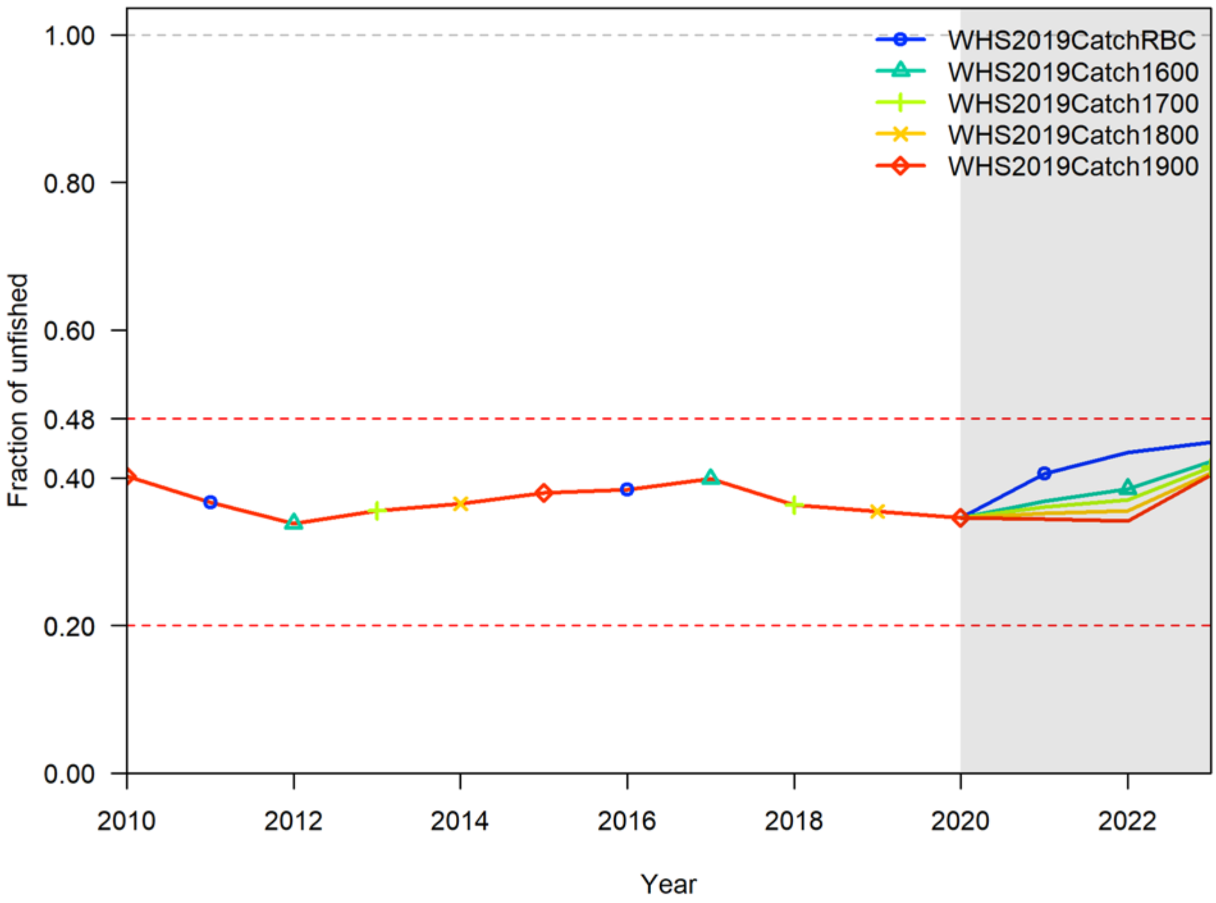

Figure 5.9. Relative spawning biomass (2010-2023) for the updated catch and updated CPUE scenario, and the four fixed catch scenarios (1,600 – 1,900 t) under average recruitment.

Recruitment deviations for the 2017 base case, the updated catch and updated CPUE scenarios are shown in Figure 5.10. This shows that recruitment is set to average recruitment from 2014 for all five scenarios.

Projecting under a range of fixed catch scenarios results in changes to predicted spawning biomass. The relative stock status in 2021 is 41% for scenario 1 (after applying the RBC, given the projected stock status) and ranges from 37% for scenario 2 (fixed catches of 1600 t) down to 34% for scenario 5 (fixed catches of 1900 t). The relative stock status in 2022 is 44% for scenario 1 (after applying the RBC, given the projected stock status) and ranges from 39% for scenario 2 (fixed catches of 1600 t) down to 34% for scenario 5 (fixed catches of 1900 t).

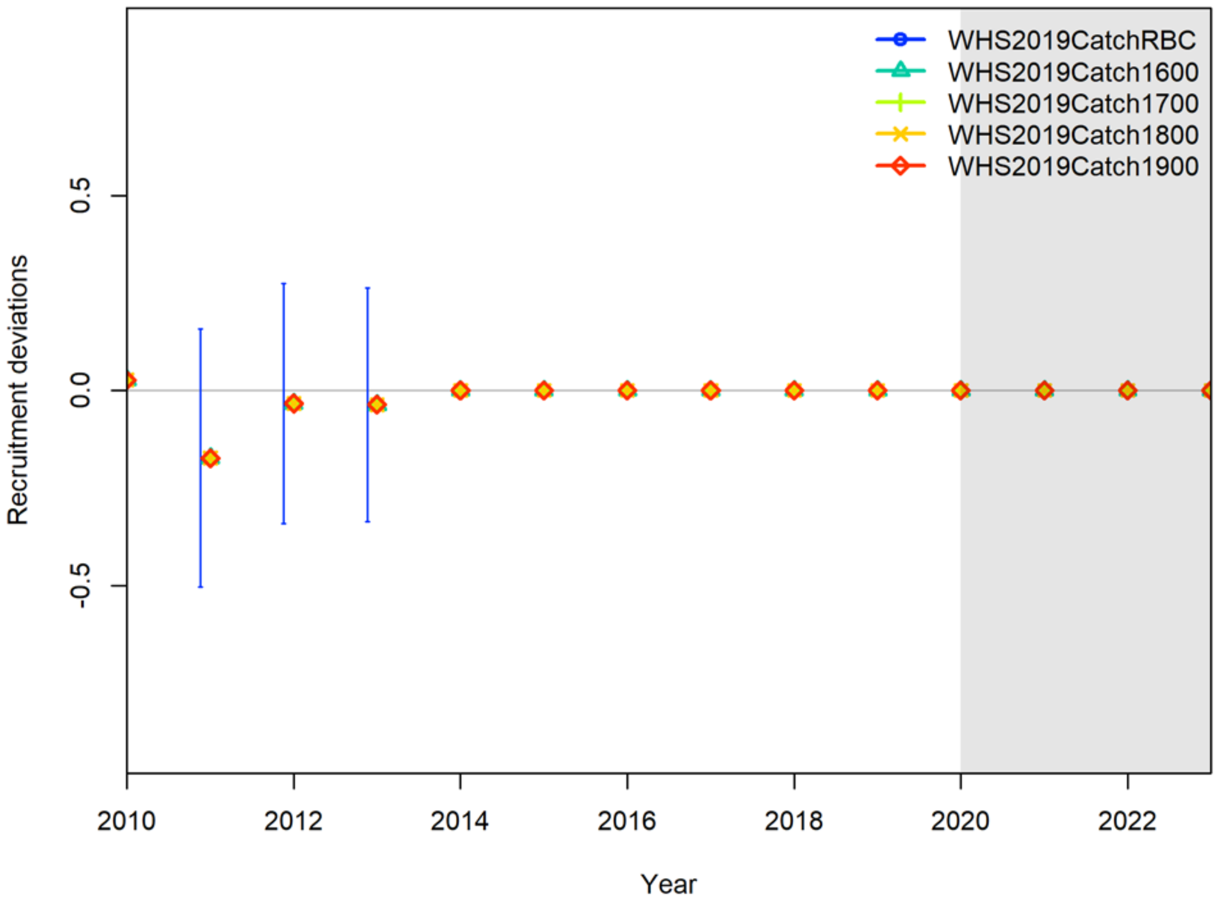

Figure 5.10. Recruitment deviations (2010-2023) for the updated catch and updated CPUE scenario, and the four fixed catch scenarios (1,600 – 1,900 t) under average recruitment.

5.3.4 *Alternative projections under low recruitment 2020-2021*

Following the initial catch projections with fixed catches (including all catches and discards) for the years 2020 and 2021, with future projected catches from 2022 onwards set to the RBC under average recruitment, a further set of low recruitment scenarios were run. These low recruitment scenarios involved fixing the recruitment deviations for the eight-year period from 2014-2021. The assumed low recruitment period stops in 2021 and recruitment is assumed to be average from 2022 onwards. This covers the period where recruitment is not estimated by the model and where standard projections involve average recruitment, taken directly from the stock recruitment curve. The recruitment deviations used were the 25th percentile of the recruitment deviations estimated between 1981 and 2013, a period where recruitment is considered to be well estimated. The value used for the 25th percentile (low recruitment) is -0.139.

As in the previous section, these low recruitment scenarios were compared to the 2017 base case with updated catch and CPUE from the previous section.

1. 2017 base case with updated catch and CPUE (WHS2019CatchRBC)
2. Projected catches calculated using the RBC for each year from 2020-2040, calculated assuming average recruitment will occur in all future projections, but with low recruitment actually fixed in the period 2014-2021 (WHS2019_SensLowRecruit1)

3. Projected catches calculated using the RBC for each year from 2020-2021 calculated from scenario 1 above (assuming average recruitment from 2014-2021) then project with the RBC assuming there will be average recruitment in all future projections (2022-2040), but with low recruitment actually fixed in the period 2014-2021 (WHS2019_SensLowRecruitRBC2019)
4. Fix total catches (including discards) in 2020 and 2021 to 1,600 t but with low recruitment fixed in the period 2014-2021 (WHS2019_SensLowRecruit1600)
5. Fix total catches (including discards) in 2020 and 2021 to 1,900 t but with low recruitment fixed in the period 2014-2021 (WHS2019_SensLowRecruit1900)

In scenarios 2-4, the effect of low recruitment from 2014 onwards modifies the stock status in 2020, and the difference in stock status between scenario 1 and these other scenarios is due to the poor recruitment assumed from 2014-2019. In scenario 2, the low stock status in 2020 is noticed, but average recruitment is expected in setting the RBC in future, including in 2020 and 2021, where in fact recruitment is fixed below average. In scenario 3, the low stock status is not noticed until 2022, as the RBC is set assuming average recruitment right through until 2022. In scenarios 4 and 5, catches are independently set (fixed) in 2020 and 2021 and the low stock status is not noticed until 2022.

In scenario 2, RBC calculations are all made under expected future average recruitment, with future (projected) catches set to the RBC, without knowledge that recruitment will be poor in 2020 and 2021. Cases 3, 4 and 5 have catches fixed up until 2021, so do not involve RBC calculations until 2022. In all scenarios, RBCs are calculated appropriately from 2022 onwards, both expecting and experiencing average recruitment. The first two scenarios projects catch from 2020 onwards. The last three scenarios, which feature fixed catches until 2021, project catches from 2022 onwards.

The values of the projected catches for scenarios 1-5, and the subsequent (calculated) RBC, are listed in Table 5.8 for the period 2017-2023. These values are calculated from 2020 onwards, for scenarios 1 and 2, and from 2022 onwards for scenarios 3, 4 and 5, with all calculated values shown in bold in Table 5.8. Similarly the calculated stock status level at the beginning of each year from 2017-2022, assuming average recruitment, is shown in Table 5.9 and displayed in Figure 5.11, showing the relative stock status over the full time series from 1947-2040 and in Figure 5.12, showing the relative stock status from 2010-2023.

Table 5.8. Fixed catch projections (including discards) for 2017-2023 and the RBC calculated (shown in bold) after applying these projected catches for the low recruitment scenarios. The column labelled 1 refers to scenario 2 -WHS2019_SensLowRecruit1.

		Fix Catch			
Year	Update catch & CPUE	1	RBC2019	1600	1900
2017	2,151	2,148	2,148	2,148	2,148
2018	1,943	1,949	1,949	1,949	1,949
2019	1,988	2,003	2,003	2,003	2,003
2020	**1,165**	**318**	1,165	1,600	1,900
2021	**1,357**	**1,205**	1,354	1,597	1,896
2022	**1,433**	**1,268**	**846**	**450**	**152**
2023	**1,474**	**1,352**	**1,303**	**1,287**	**1,258**

Table 5.9. Projected stock status for 2017-2023 following application of fixed catch projections (including discards) for 2020-2022 after applying these projected catches and RBCs from Table 8 (from low recruitment) for the updated catch and updated CPUE scenario, and for the low recruitment scenarios. The column labelled 1 refers to scenario 2 - WHS2019_SensLowRecruit1.

	Depletion (%)				
Year	Update catch & CPUE	1	RBC2019	1600	1900
2017	39.8	36.2	36.2	36.2	36.2
2018	36.3	30.2	30.2	30.2	30.2
2019	35.5	27.5	27.5	27.5	27.5
2020	34.6	24.9	24.9	24.9	24.9
2021	**40.6**	**36.4**	**29.2**	**25.6**	**23.3**
2022	**43.5**	**37.5**	**30.6**	**25.8**	**21.7**
2023	44.8	37.1	35.6	35.3	34.4

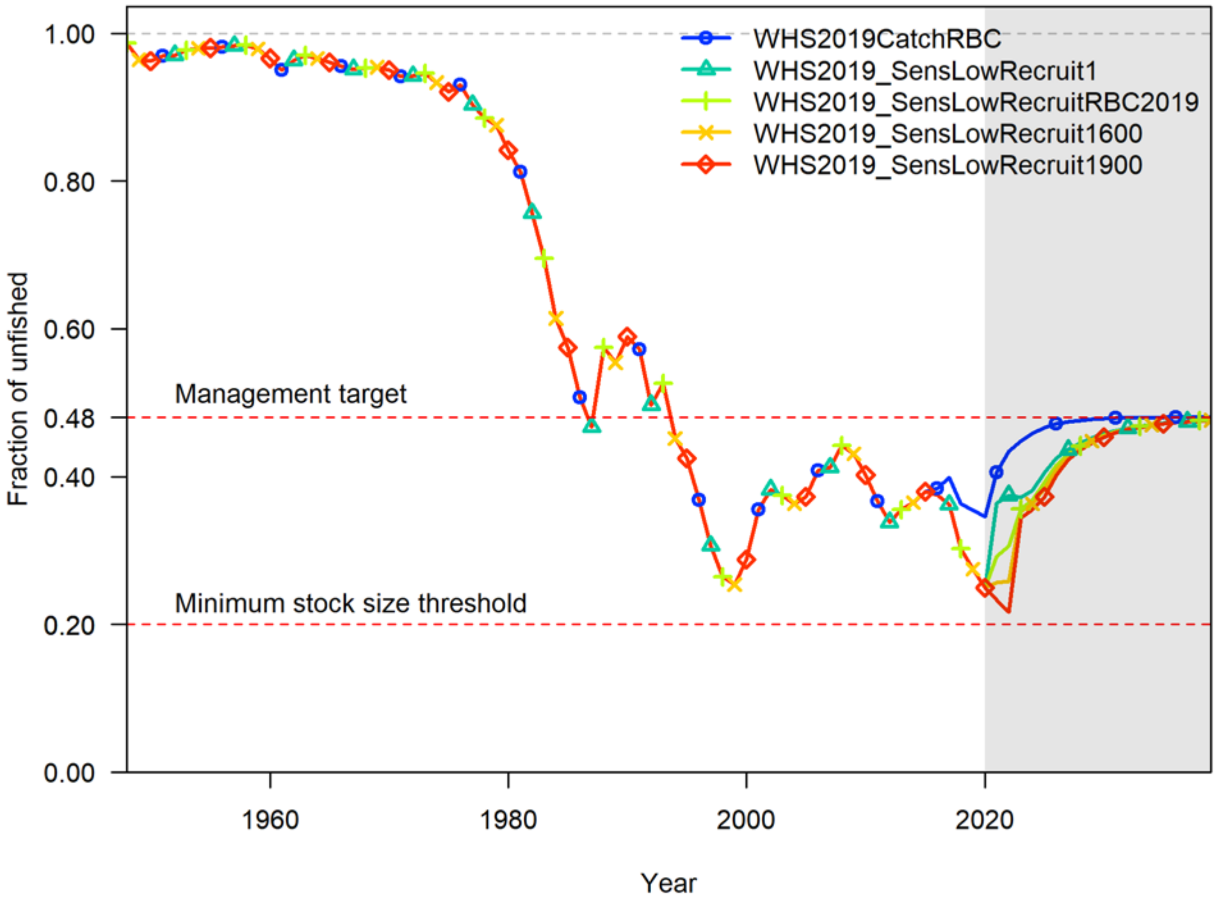

Figure 5.11. Relative spawning biomass (1947-2040) for the updated catch and updated CPUE scenario, and the four low recruitment scenarios.

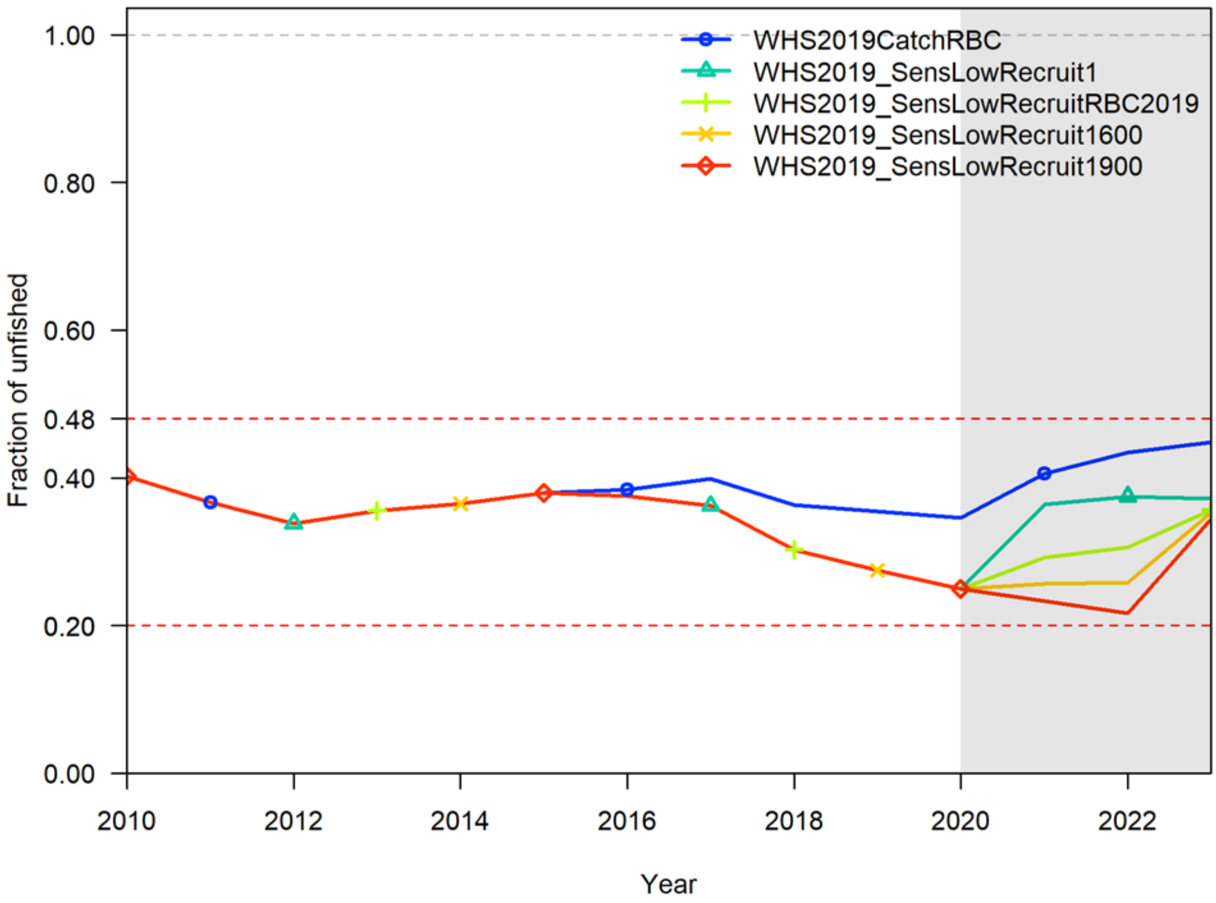

Figure 5.12. Relative spawning biomass (2010-2023) for the updated catch and updated CPUE scenario, and the four low recruitment scenarios.

Recruitment deviations for the 2017 base case, the updated catch and updated CPUE scenarios are shown in Figure 5.13. This shows that recruitment is set to average recruitment from 2014 for scenario 1 and below average from 2014-2021 for scenarios 2-5.

Projecting under low recruitment with a range of fixed catch scenarios results in changes to predicted spawning biomass. The relative stock status in 2021 is 41% for scenario 1 (after applying the RBC, given the projected stock status) and ranges from 36% for scenario 2 (fixed catches of 1600 t) down to 23% for scenario 5 (fixed catches of 1900 t). The relative stock status in 2022 is 44% for scenario 1 (after applying the RBC, given the projected stock status) and ranges from 38% for scenario 2 (fixed catches of 1600 t) down to 22% for scenario 5 (fixed catches of 1900 t).

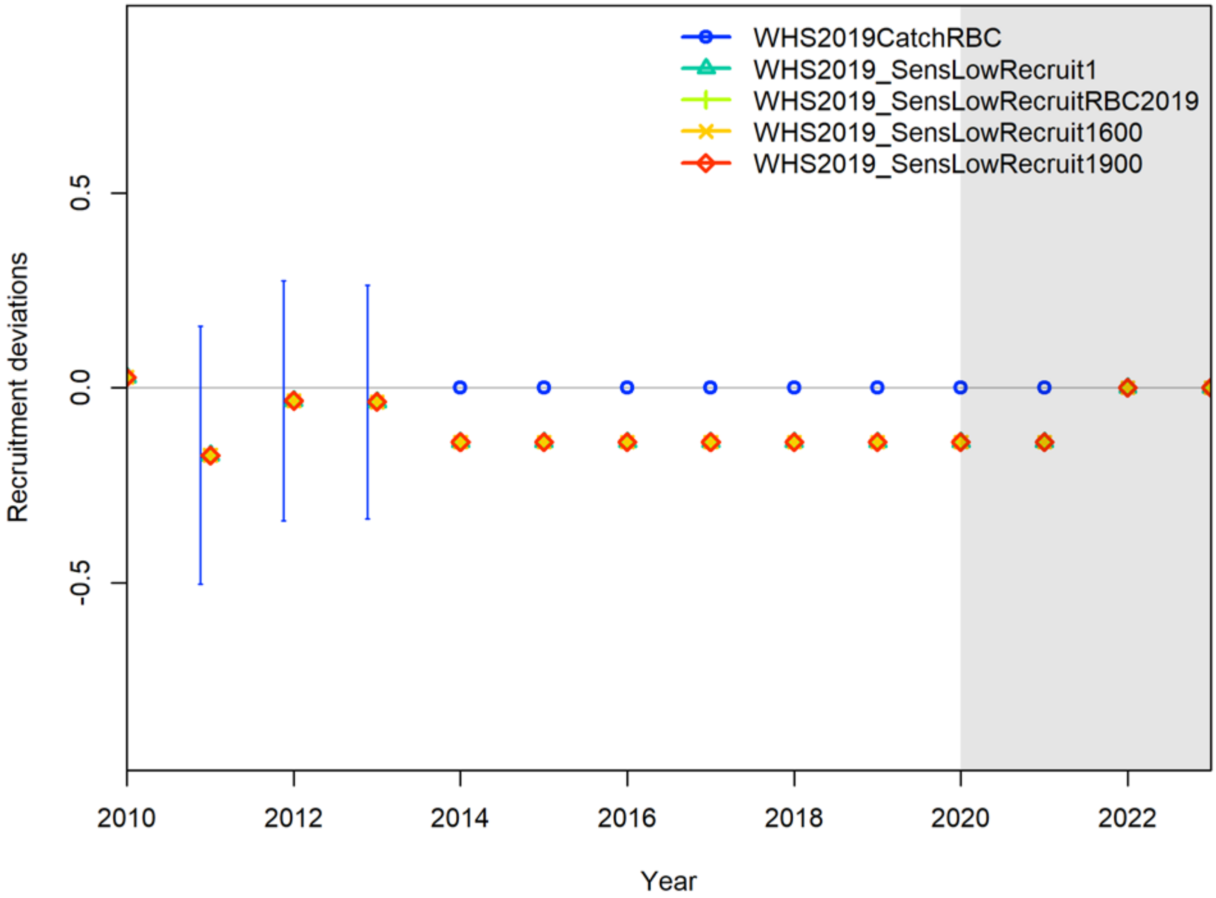

Figure 5.13. Recruitment deviations (2010-2023) for the updated catch and updated CPUE scenario, and the four low recruitment scenarios.

5.3.5 *Alternative projections under high-recruitment 2020-2021*

Following the initial catch projections with low recruitment scenarios, a further set of high recruitment scenarios were run. As with the low recruitment scenarios, the high recruitment scenarios involved fixing the recruitment deviations for the eight-year period from 2014-2021. The assumed high recruitment period stops in 2021 and recruitment is assumed to be average from 2022 onwards. This covers the period where recruitment is not estimated by the model and where standard projections involve average recruitment, taken directly from the stock recruitment curve. The recruitment deviations used were the 75th percentile of the recruitment deviations estimated between 1981 and 2013, a period where recruitment is considered to be well estimated. The value used for the 75th percentile (high recruitment) is 0.0954.

As in the previous section, these high recruitment scenarios were compared to the 2017 base case with updated catch and CPUE from the previous section.

1. 2017 base case with updated catch and CPUE (WHS2019CatchRBC)
2. Projected catches calculated using the RBC for each year from 2020 -2040, calculated assuming average recruitment will occur in all future projections, but with high recruitment actually fixed in the period 2014-2021 (WHS2019_SensHiRecruit1)

3. Projected catches calculated using the RBC for each year from 2020-2021 calculated from scenario 1 above (assuming average recruitment from 2014-2021) then project with the RBC assuming there will be average recruitment in all future projections (2022-2040), but with high recruitment actually fixed in the period 2014-2021 (WHS2019_SensHiRecruitRBC2019)
4. Fix total catches (including discards) in 2020 and 2021 to 1,600 t but with high recruitment fixed in the period 2014-2021 (WHS2019_SensHiRecruit1600)
5. Fix total catches (including discards) in 2020 and 2021 to 1,900 t but with high recruitment fixed in the period 2014-2021 (WHS2019_SensHiRecruit1900)

In scenarios 2-4, the effect of high recruitment from 2014 onwards modifies the stock status in 2020, and the difference in stock status between scenario 1 and these other scenarios is due to the good recruitment assumed from 2014-2019. In scenario 2, the high stock status in 2020 is noticed, but average recruitment is expected in setting the RBC in future, including in 2020 and 2021, where in fact recruitment is fixed above average. In scenario 3, the high stock status is not noticed until 2022, as the RBC is set assuming average recruitment right through until 2022. In scenarios 4 and 5, catches are independently set (fixed) in 2020 and 2021 and the high stock status is not noticed until 2022.

In scenario 2, RBC calculations are all made under expected future average recruitment, with future (projected) catches set to the RBC, without knowledge that recruitment will be good in 2020 and 2021. Scenarios 3, 4 and 5 have catches fixed up until 2021, so don't involve RBC calculations until 2022. In all scenarios, RBCs are calculated appropriately from 2022 onwards, both expecting and experiencing average recruitment. The first two scenarios projects catch from 2020 onwards. The last three scenarios, which feature fixed catches until 2021, project catches from 2022 onwards.

The values of the projected catches for scenarios 1-5, and the subsequent (calculated) RBC, are listed in Table 5.10 for the period 2017-2023. These values are calculated from 2020 onwards, for scenarios 1 and 2, and from 2022 onwards for scenarios 3 ,4 and 5, with all calculated values shown in bold in Table 5.10. Similarly the calculated stock status level at the beginning of each year from 2017-2022, assuming average recruitment, is shown in Table 5.11 and displayed in Figure 5.14, showing the relative stock status over the full time series from 1947-2040 and in Figure 5.15, showing the relative stock status from 2010-2023.

Table 5.10. Fixed catch projections (including discards) for 2017-2023 and the RBC calculated (shown in bold) after applying these projected catches for the high recruitment scenarios. The column labelled 1 refers to scenario 2 - WHS2019_SensHiRecruit1.

		Fix Catch			
Year	Update catch & CPUE	1	RBC2019	1600	1900
2017	2,151	2,153	2,153	2,153	2,153
2018	1,943	1,940	1,940	1,940	1,940
2019	1,988	1,981	1,981	1,981	1,981
2020	**1,165**	**1,431**	1,165	1,600	1,900
2021	**1,357**	**1,563**	1,358	1,601	1,902
2022	**1,433**	**1,599**	**1,695**	**1,560**	**1,437**
2023	**1,474**	**1,582**	**1,630**	**1,561**	**1,497**

Table 5.11. Projected stock status for 2017-2023 following application of fixed catch projections (including discards) for 2020-2022 after applying these projected catches and RBCs from Table 10 (from high recruitment) for the updated catch and updated CPUE scenario, and for the high recruitment scenarios. The column labelled 1 refers to scenario 2 - WHS2019_SensHiRecruit1.

	Depletion (%)				
Year	Update catch & CPUE	1	RBC2019	1600	1900
2017	39.8	42.6	42.6	42.6	42.6
2018	36.3	41.0	41.0	41.0	41.0
2019	35.5	41.7	41.7	41.7	41.7
2020	34.6	42.1	42.1	42.1	42.1
2021	**40.6**	**47.1**	**49.4**	**45.6**	**43.1**
2022	**43.5**	**49.8**	**53.3**	**48.3**	**43.8**
2023	44.8	51.4	53.2	50.7	48.4

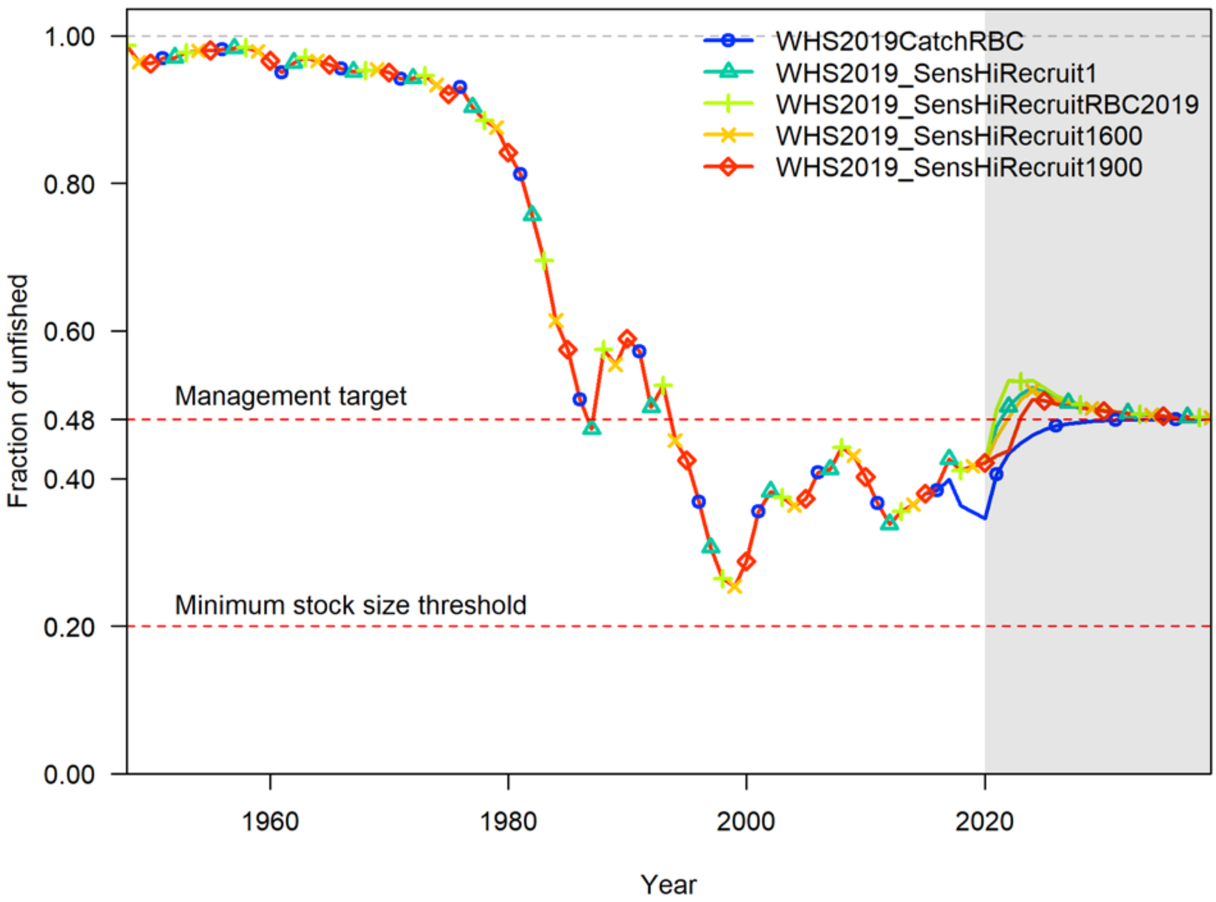

Figure 5.14. Relative spawning biomass (1947-2040) for the updated catch and updated CPUE scenario, and the four high recruitment scenarios.

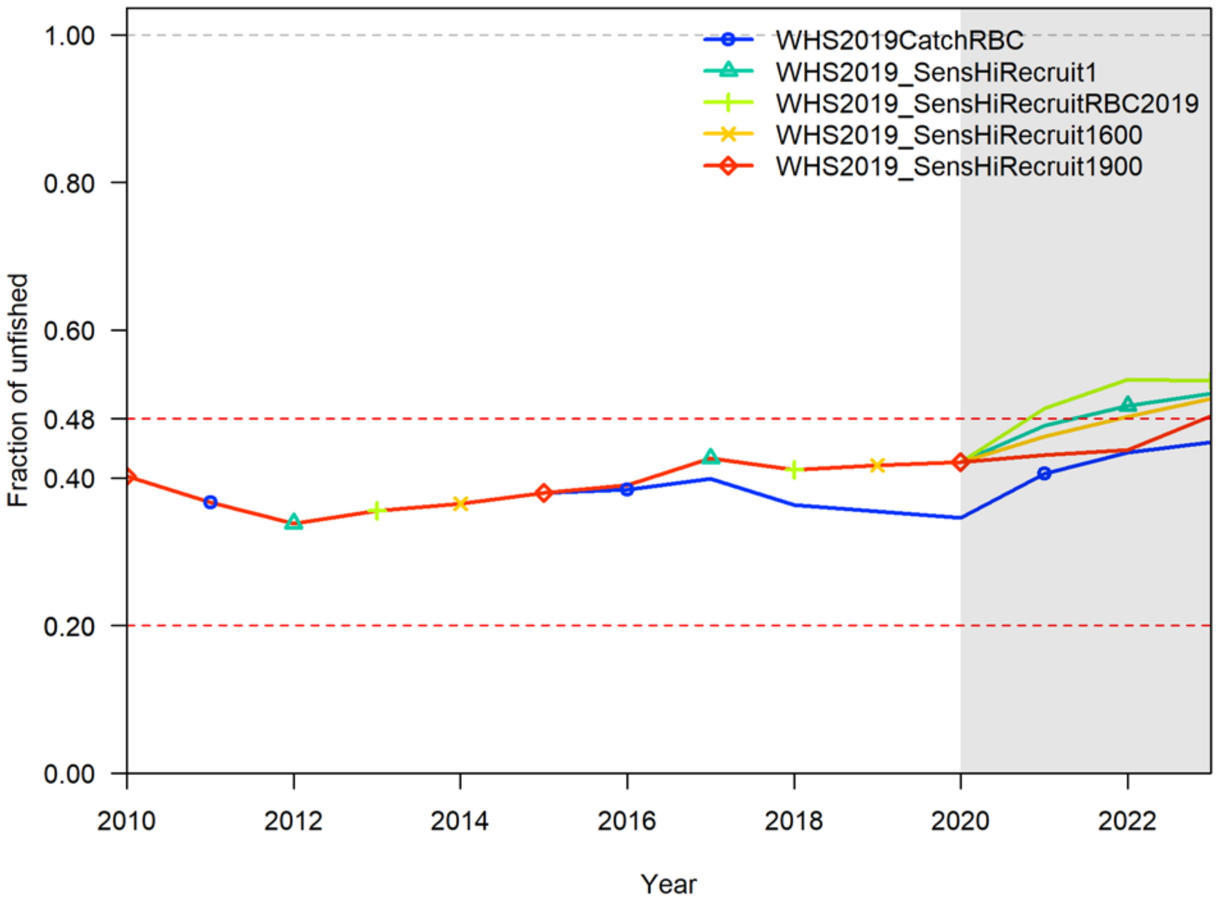

Figure 5.15. Relative spawning biomass (2010-2023) for the updated catch and updated CPUE scenario, and the four high recruitment scenarios.

Recruitment deviations for the 2017 base case, the updated catch and updated CPUE scenarios are shown in Figure 5.16. This shows that recruitment is set to average recruitment from 2014 for scenario 1 and above average from 2014-2021 for scenarios 2-5.

Projecting under high recruitment with a range of fixed catch scenarios results in changes to predicted spawning biomass. The relative stock status in 2021 is 41% for scenario 1 (after applying the RBC, given the projected stock status) and ranges from 49% for scenario 3 (2019 RBC) down to 43% for scenario 5 (fixed catches of 1900 t). The relative stock status in 2022 is 44% for scenario 1 (after applying the RBC, given the projected stock status) and ranges from 53% for scenario 2 (2019 RBC) down to 44% for scenario 5 (fixed catches of 1900 t).

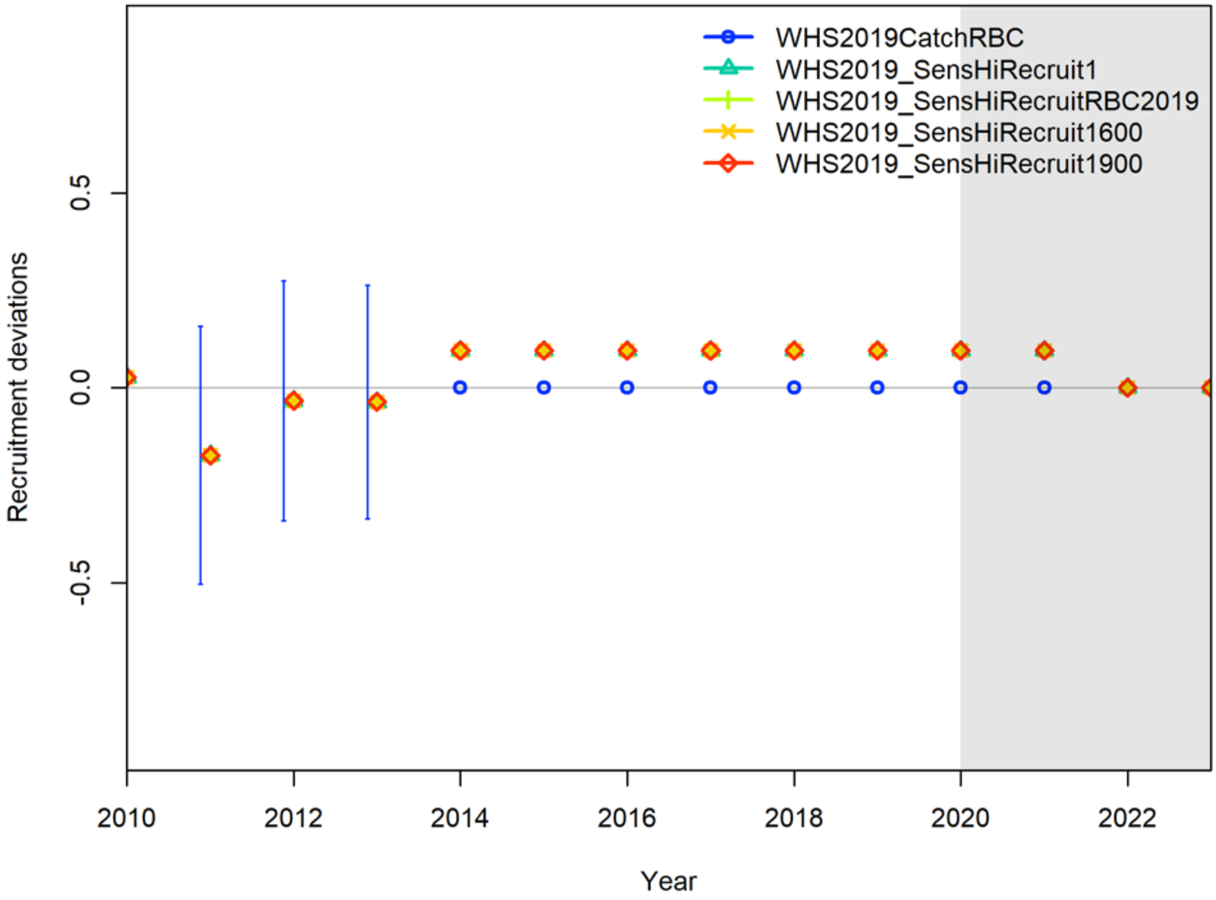

Figure 5.16. Recruitment deviations (2010-2023) for the updated catch and updated CPUE scenario, and the four low recruitment scenarios.

5.4 Acknowledgements

Age data was provided by Kyne Krusic-Golub (Fish Ageing Services), ISMP and AFMA logbook and CDR data were provided by John Garvey (AFMA). Mike Fuller, Roy Deng, Franzis Althaus, Paul Burch and Robin Thomson (CSIRO) pre-processed the data. Karina Hall (NSW DPI) provided NSW catch data and advice on school whiting fisheries in NSW state waters. Malcolm Haddon provided useful code for auto-balancing, Athol Whitten provided R code for organising plots. Geoff Tuck, Robin Thomson, Miriana Sporcic and Paul Burch are thanked for helpful discussions on this work.

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6. Tiger flathead (*Neoplatycephalus richardsoni*) stock assessment based on data up to 2018 – development of a preliminary base case

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6.1 Executive Summary

This document presents a suggested base case for an updated quantitative Tier 1 tiger flathead (*Neoplatycephalus richardsoni*) assessment for presentation at the first SERAG meeting in 2019. The last full assessment was presented in Day (2016). The preliminary base case has been updated by the inclusion of data up to the end of 2018, which entails an additional 3 years of catch, discard, CPUE, length and age data and ageing error updates since the 2016 assessment and incorporation of survey results from the Fishery Independent Survey (FIS) from 2016. This document describes the process used to develop a preliminary base case for tiger flathead through the sequential updating of recent data used by the stock assessment, using the stock assessment package Stock Synthesis (SS-V3.40.14).

Changes to the last stock assessment include: incorporation of conditional age-at-length data for 2008 from the FIS; improvement to the method of estimating the bias ramp and using an updated tuning method.

Results show reasonably good fits to the catch rate data, length data and conditional age-at-length data. This assessment estimates that the projected 2020 spawning stock biomass will be 34% of virgin stock biomass (projected assuming 2018 catches in 2019), compared to 43% at the start of 2017 from the 2016 assessment (Day 2016) and 50% at the start of 2014 from the 2013 assessment (Day and Klaer 2013). This change in stock status is largely due to below average newly estimated recruitment events, particularly in 2013 but also in 2014, and a revision to the previously estimated 2012 recruitment event. The 2013 poor recruitment is supported both by the age and length data and by the recent index data, and the updated assessment fits all of these data sources well.

6.2 Introduction

6.2.1 *Bridging from 2016 to 2019 assessments*

The previous full quantitative assessment for tiger flathead was conducted in 2016 (Day, 2016) using Stock Synthesis (version SS-V3.24Z, Methot and Wetzel, 2013, Methot, 2015). The 2019 assessment uses the current version of Stock Synthesis (version SS-V3.30.14.05, Methot, 2019), which includes some changes from SS_V3.24Z.

As a first step in the process of bridging to a new model, the model was translated from version SS-V3.24Z (Methot, 2015) to version SS-V3.30.14.05 (Methot et. al, 2019) using the same data and model structure used in the 2016 assessment. Once this translation was complete, improved features unavailable in SS-V3.24Z were incorporated into the SS-V3.30 assessment. These included allowing smaller lower bounds on minimum sample sizes and estimating a parameter that tunes the standard deviation to abundance indices. Following this step, the model was re-tuned using the most recent tuning protocols, thus allowing the examination of changes to both assessment practices and the tuning procedure on the previous model structure. These changes to software and tuning practices are likely to lead to changes to key model outputs, such as the estimates of depletion and the trajectory of spawning biomass. This initial bridging phase (Bridge 1) highlights changes that have occurred since 2016 simply through changes to software and assessment practices. The subsequent bridging exercise (Bridge 2) then sequentially updates the model with new data through to 2018.

The second part of the bridging analysis includes updating historical data (up to 2015), followed by including the data from 2016-2018 into the model. These additional data included new catch, discard, CPUE, FIS abundance indices, length composition data, conditional age-at-length data and an updated ageing error matrix. Additional SESSF FIS data were also included: 2016 FIS abundance index; 2016 FIS length frequencies; and 2008 FIS conditional age-at-length data. The last year of recruitment estimation was extended to 2015 (changed from 2012 in the 2016 assessment).

The use of updated software and the inclusion of additional data resulted in some differences in the fits to CPUE, conditional age-at-length data and length composition data. The usual process of bridging to a new model by adding new data piecewise and analysing which components of the data could be attributed to changes in the assessment outcome was conducted with the details outlined below.

6.2.2 *Update to Stock Synthesis SSV-3.30 and updated catch history (Bridge 1)*

The 2016 tiger flathead assessment (Flathead2015_3.24Z) was initially converted to the most recent version of the software, Stock Synthesis version SS-V3.30.14.05 (Flathead2015_3.30.14). Figure 6.1 shows that the differences in the assessment results from this step were minimal.

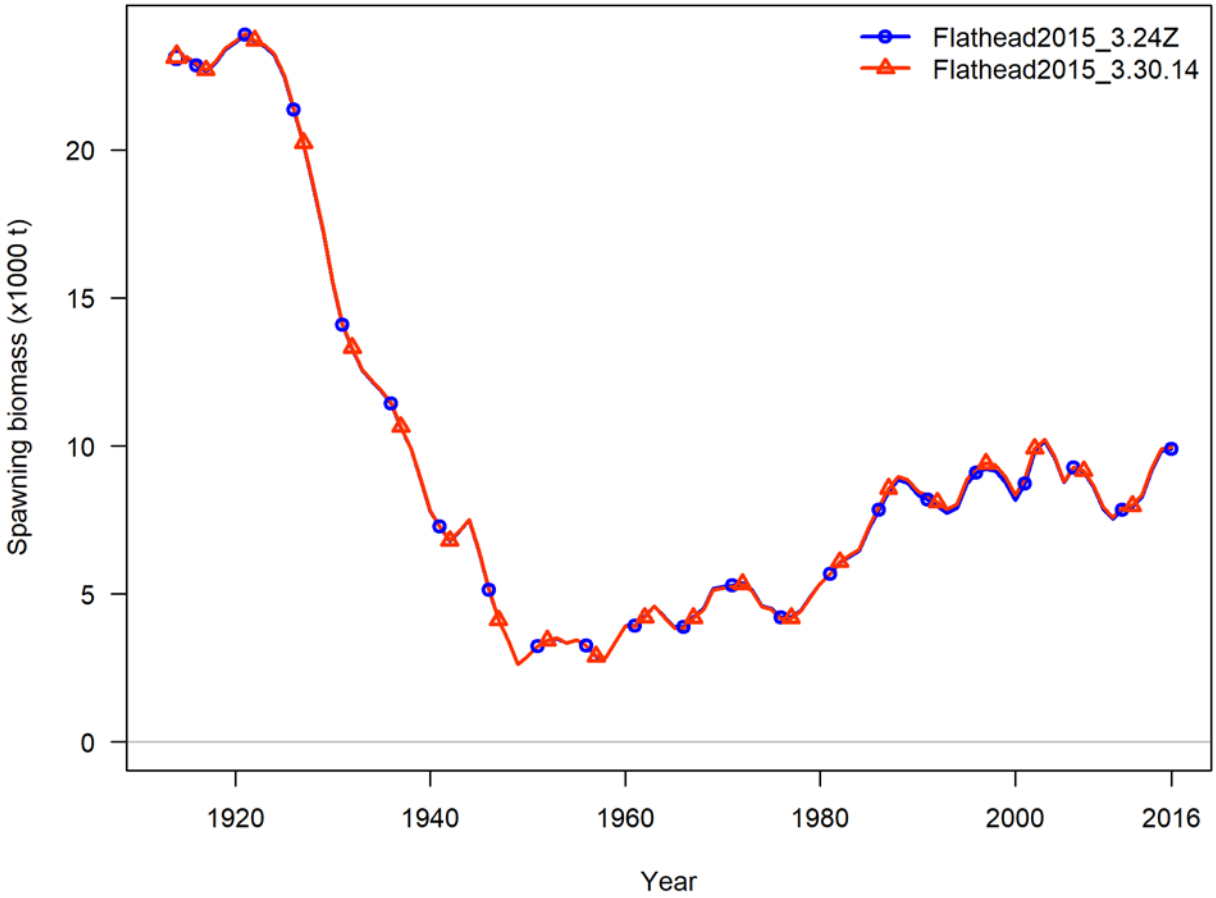

Figure 6.1. Comparison of the time-series of absolute spawning biomass from the 2016 assessment (Flathead2015_3.24Z – in blue) and a model converted to SS-V3.30 (Flathead2015_3.30.14 – in red).

New features available in the new version of Stock Synthesis, such as allowing smaller lower bounds on minimum sample sizes and estimating additional standard deviation to abundance indices were then incorporated (Flathead2015_3.30New), followed by retuning using the latest tuning protocol (Flathead2015_3.30Tuned). Details of the tuning procedure used are listed in Section 1.2.1. Revisions to the historical catches, between 2001 and 2015, including some corrections to allocations of catches between fleets and updates to recent state catches, and replacing the estimated 2016 catch with the actual 2016 catch, were then added to this tuned version of the 2016 model (Flathead2015_3.30ReviseCatch). This process demonstrates the outcomes that could theoretically have been achieved with the last assessment if we had the latest software, tuning protocols and corrected data available in 2016. This initial bridging step, Bridge 1, does not incorporate any data after 2015 or any structural changes to the assessment.

When these time series are plotted together (Figure 6.2 and Figure 6.3), there are minor changes due to incorporating new features in Stock Synthesis. The new tuning procedures result in an improved fit to the steam trawl index, largely through allowing more flexibility in early recruitment (prior to 1930) which alters the predicted biomass series, especially in the 1920s. The additional changes through catch revisions to 2015 are minimal.

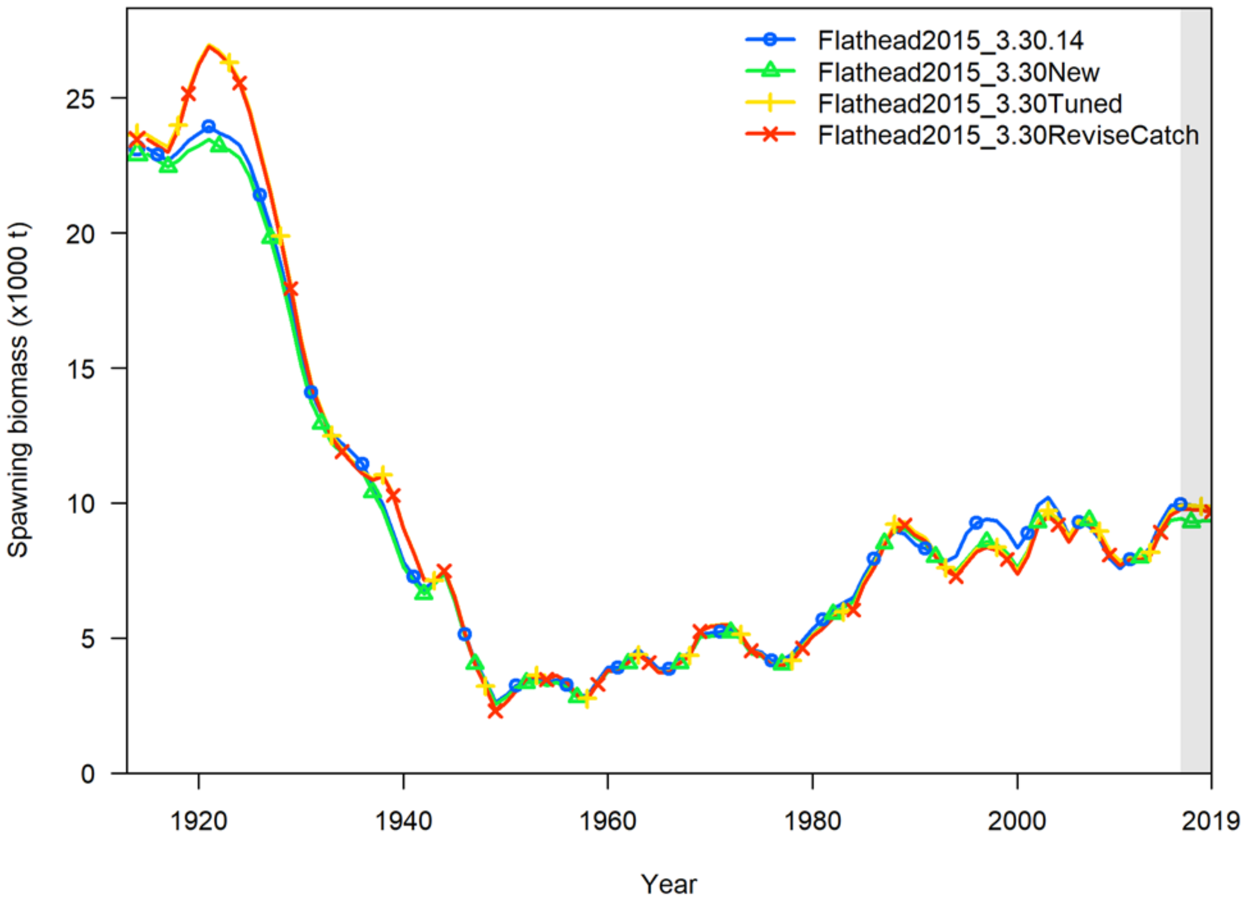

Figure 6.2. Comparison of the time-series of absolute spawning biomass from the 2016 assessment (Flathead2015_3.30.14 – in blue), incorporating new features (Flathead2015_3.30New – in green), retuning the model using the latest tuning protocols (Flathead2015_3.30Tuned – in yellow) and revising the historical catch to 2015 and the projected catch in 2016 (Flathead2015_3.30ReviseCatch – in red).

The results of Bridge 1 suggest that the stock was marginally more depleted in 2017 than the 2016 assessment indicated (43% of SSB_0), although the stock was still estimated to be above the target reference point of 40% of SSB_0. These changes are small enough to be well within the confidence bounds of the 2016 assessment results and the fits are generally improved through these revisions.

Fits to the abundance indices (Figure 6.4 to Figure 6.8) show changes through this process, mostly with small improvements to the fit during Bridge 1. However, the FIS indices show less noticeable change to fits (Figure 6.9 to Figure 6.10). The estimated recruitment series shows little change in broad trends during Bridge 1 (Figure 6.11), although there are several minor changes resulting from the new tuning procedures. In particular, the new tuning procedures allow for greater variation in recruitment prior to 1950, which in turn allows for better fits to the early CPUE data.

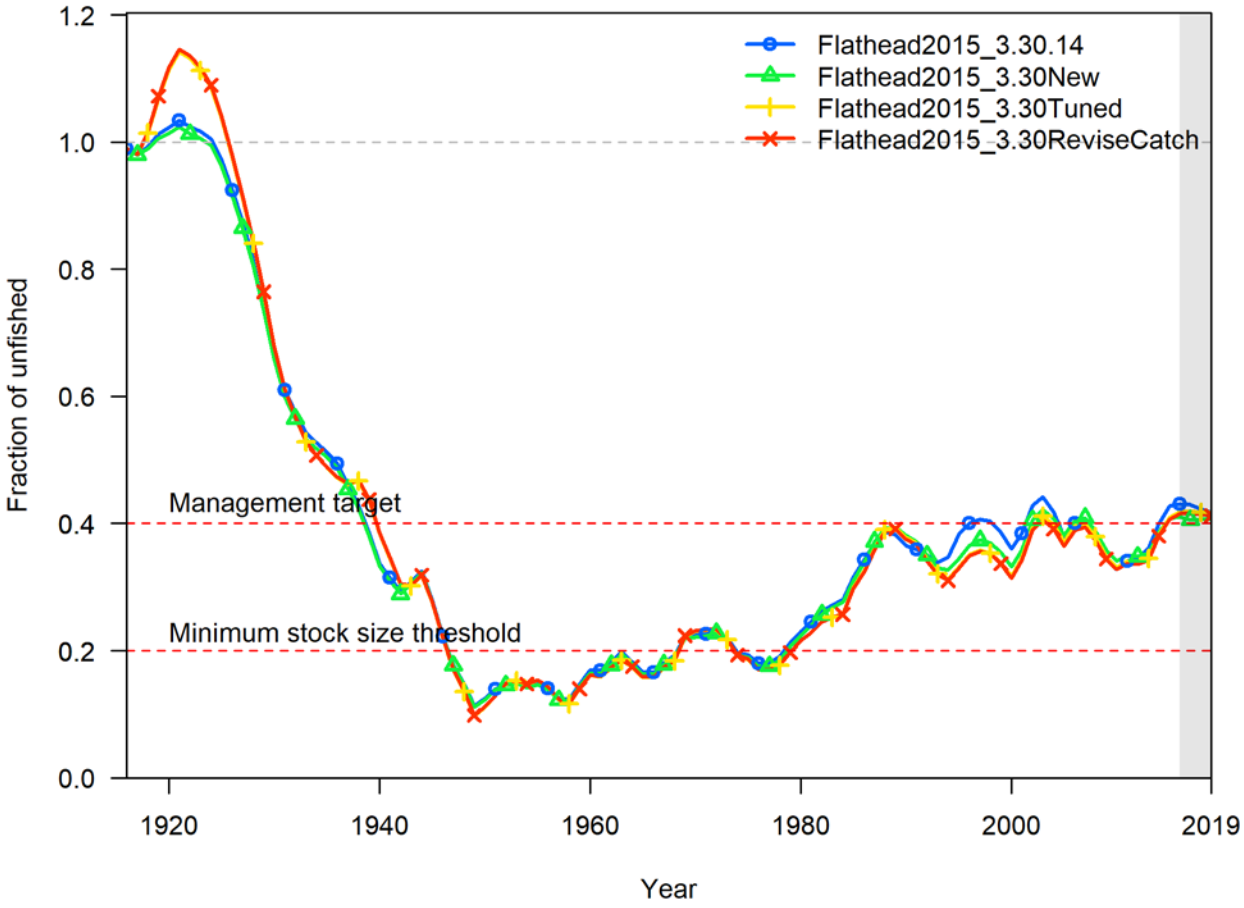

Figure 6.3. Comparison of the time-series of relative spawning biomass from the 2016 assessment (Flathead2015_3.30.14 – in blue), incorporating new features (Flathead2015_3.30New – in green), retuning the model using the latest tuning protocols (Flathead2015_3.30Tuned – in yellow) and revising the historical catch to 2015 and the projected catch in 2016 (Flathead2015_3.30ReviseCatch – in red). Note that the section shaded in grey indicates a few years of future projections, beyond the period covering data used in the assessment, which stops in 2015 in this case.

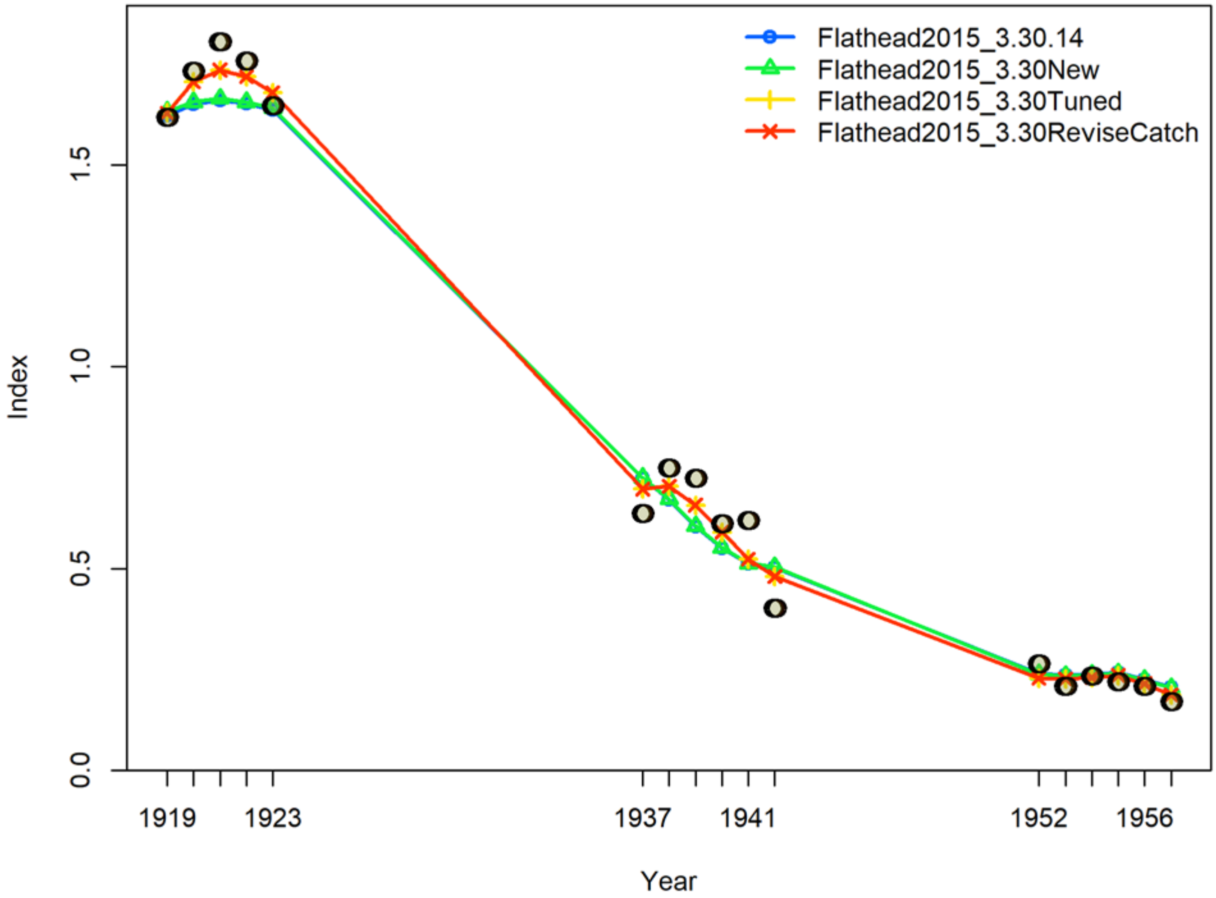

Figure 6.4. Comparison of the fit to the steam trawl CPUE index for the 2015 assessment (Flathead2015_3.30.14 – in blue), incorporating new features (Flathead2015_3.30New – in green), retuning the model using the latest tuning protocols (Flathead2015_3.30Tuned – in yellow) and revising the historical catch to 2015 and the projected catch in 2016 (Flathead2015_3.30ReviseCatch – in red).

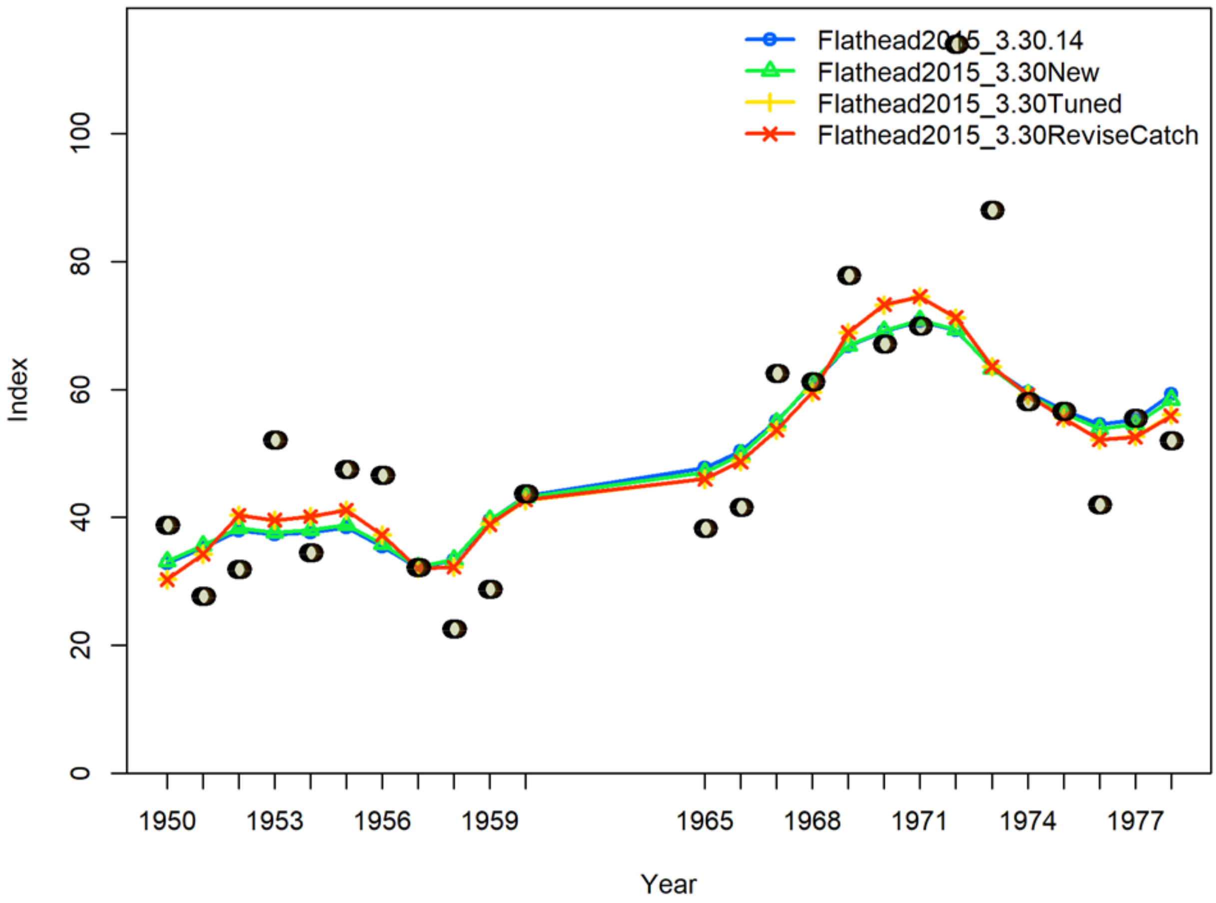

Figure 6.5. Comparison of the fit to the old Danish seine CPUE index for the 2015 assessment (Flathead2015_3.30.14 – in blue), incorporating new features (Flathead2015_3.30New – in green), retuning the model using the latest tuning protocols (Flathead2015_3.30Tuned – in yellow) and revising the historical catch to 2015 and the projected catch in 2016 (Flathead2015_3.30ReviseCatch – in red).

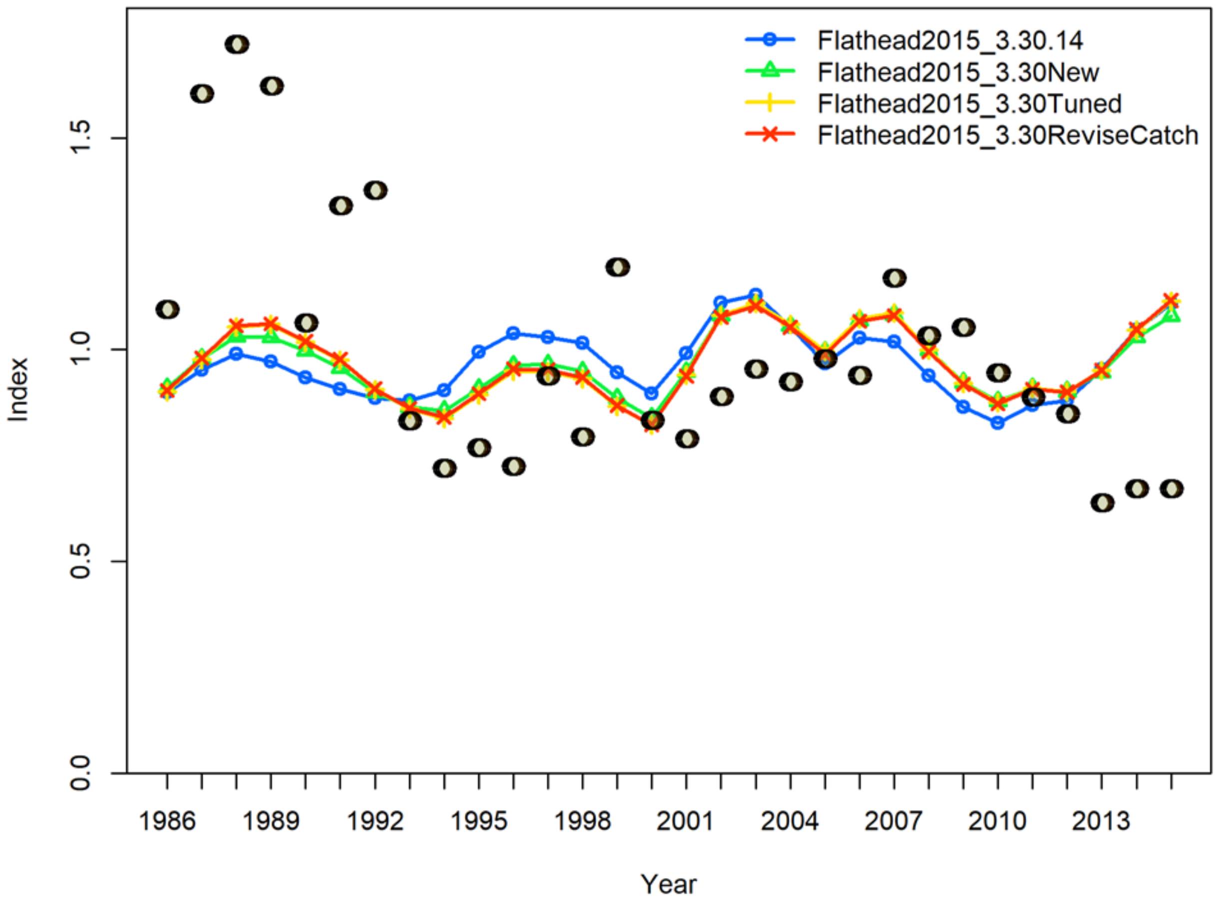

Figure 6.6. Comparison of the fit to the Danish seine CPUE index for the 2015 assessment (Flathead2015_3.30.14 – in blue), incorporating new features (Flathead2015_3.30New – in green), retuning the model using the latest tuning protocols (Flathead2015_3.30Tuned – in yellow) and revising the historical catch to 2015 and the projected catch in 2016 (Flathead2015_3.30ReviseCatch – in red).

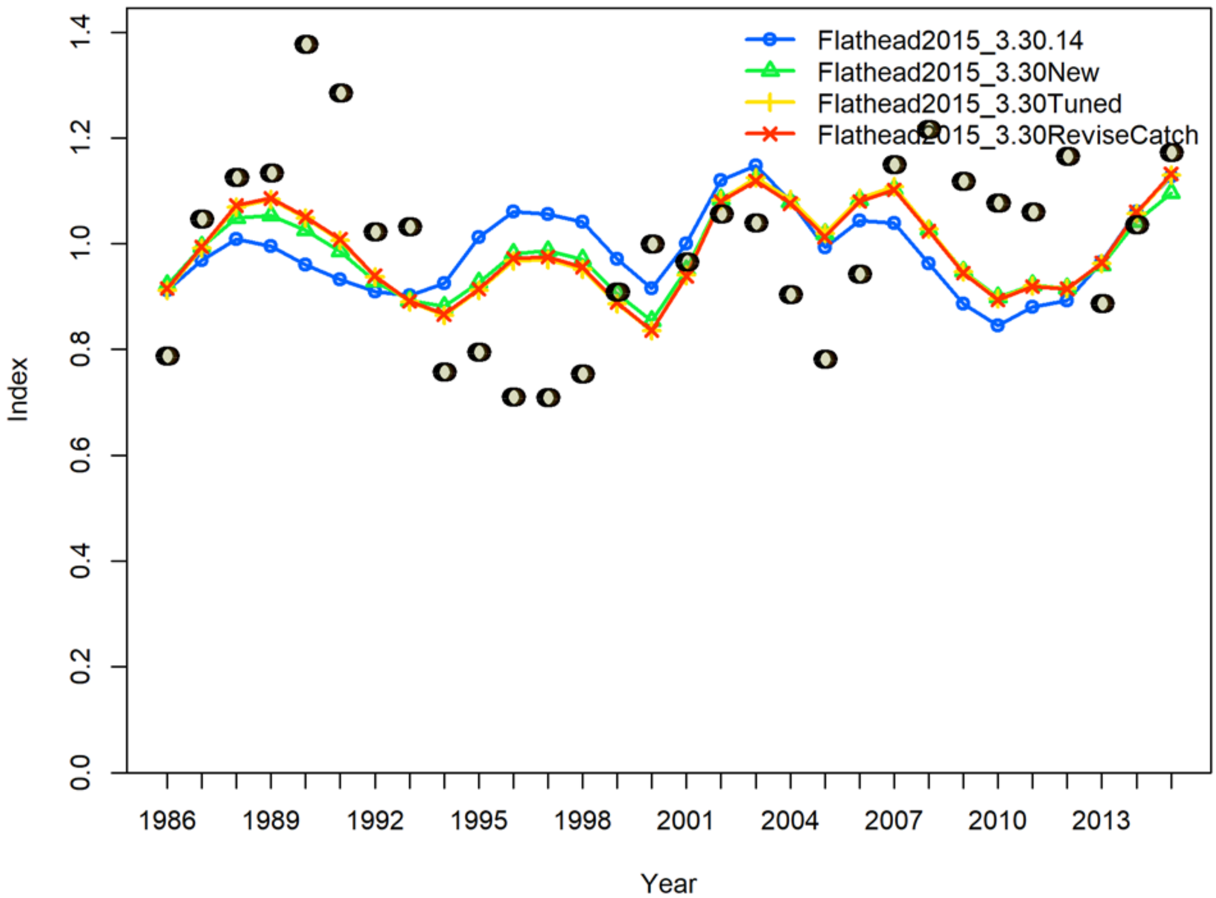

Figure 6.7. Comparison of the fit to the Eastern trawl CPUE index for the 2015 assessment (Flathead2015_3.30.14 – in blue), incorporating new features (Flathead2015_3.30New – in green), retuning the model using the latest tuning protocols (Flathead2015_3.30Tuned – in yellow) and revising the historical catch to 2015 and the projected catch in 2016 (Flathead2015_3.30ReviseCatch – in red).

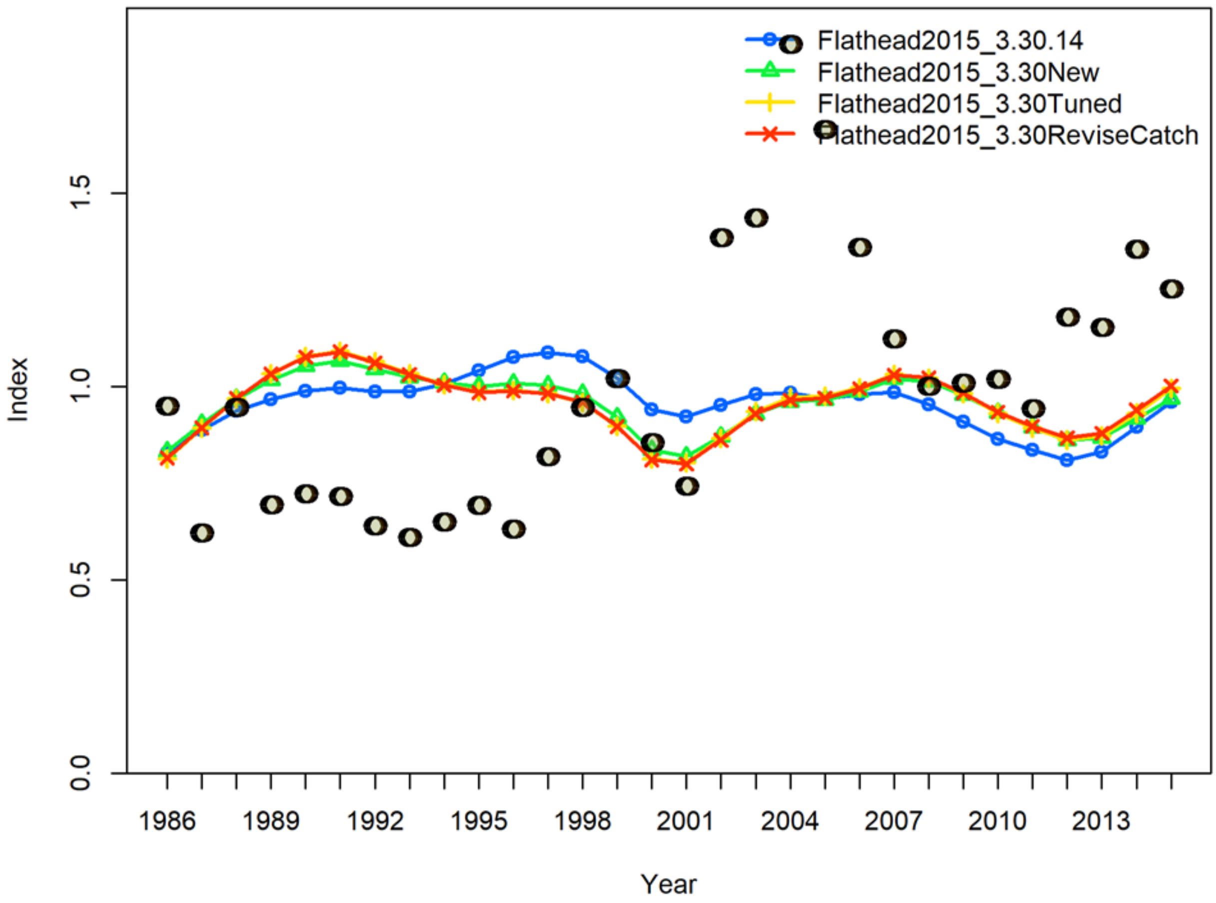

Figure 6.8. Comparison of the fit to the Tasmanian trawl CPUE index for the 2015 assessment (Flathead2015_3.30.14 – in blue), incorporating new features (Flathead2015_3.30New – in green), retuning the model using the latest tuning protocols (Flathead2015_3.30Tuned – in yellow) and revising the historical catch to 2015 and the projected catch in 2016 (Flathead2015_3.30ReviseCatch – in red).

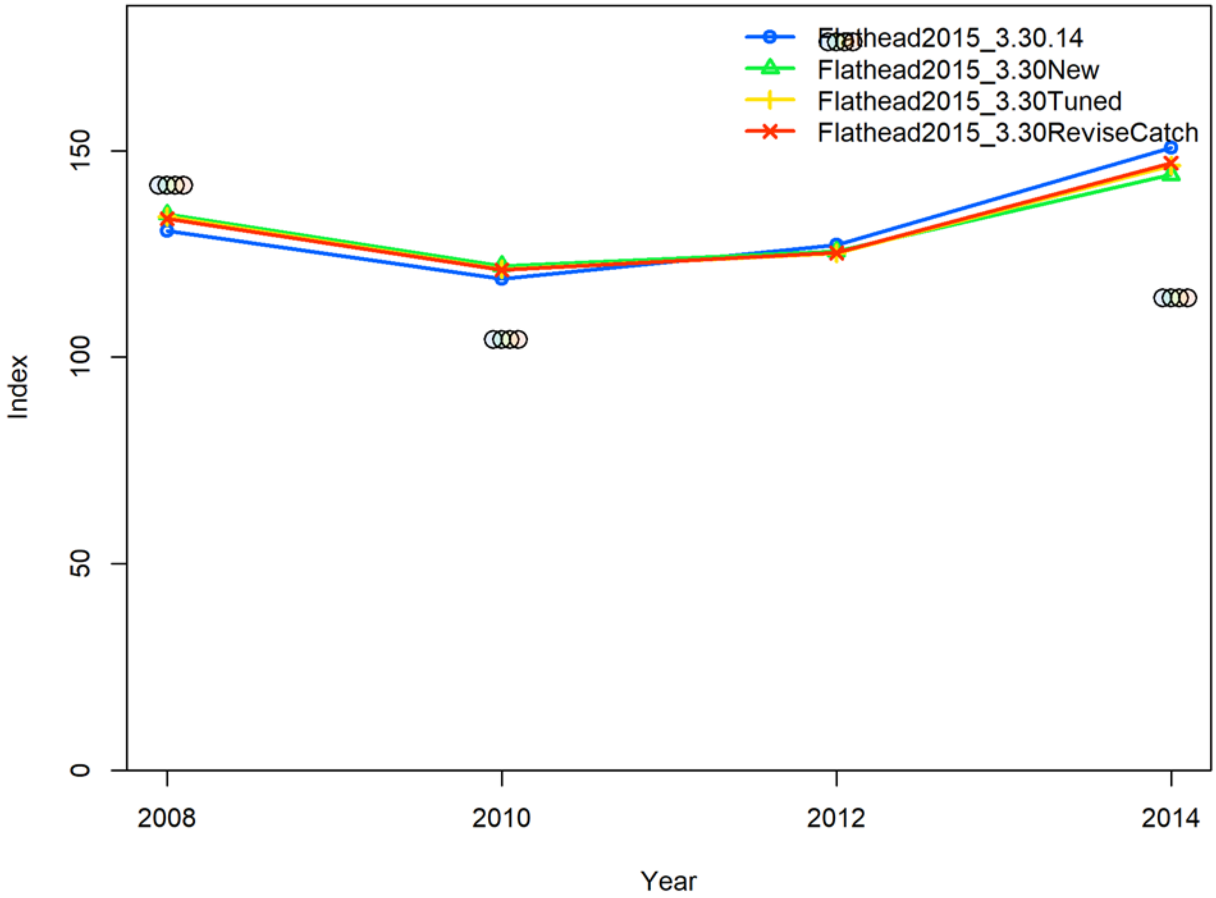

Figure 6.9. Comparison of the fit to the FIS_East (zones 10 and 20) abundance index for the 2015 assessment (Flathead2015_3.30.14 – in blue), incorporating new features (Flathead2015_3.30New – in green), retuning the model using the latest tuning protocols (Flathead2015_3.30Tuned – in yellow) and revising the historical catch to 2015 and the projected catch in 2016 (Flathead2015_3.30ReviseCatch – in red).

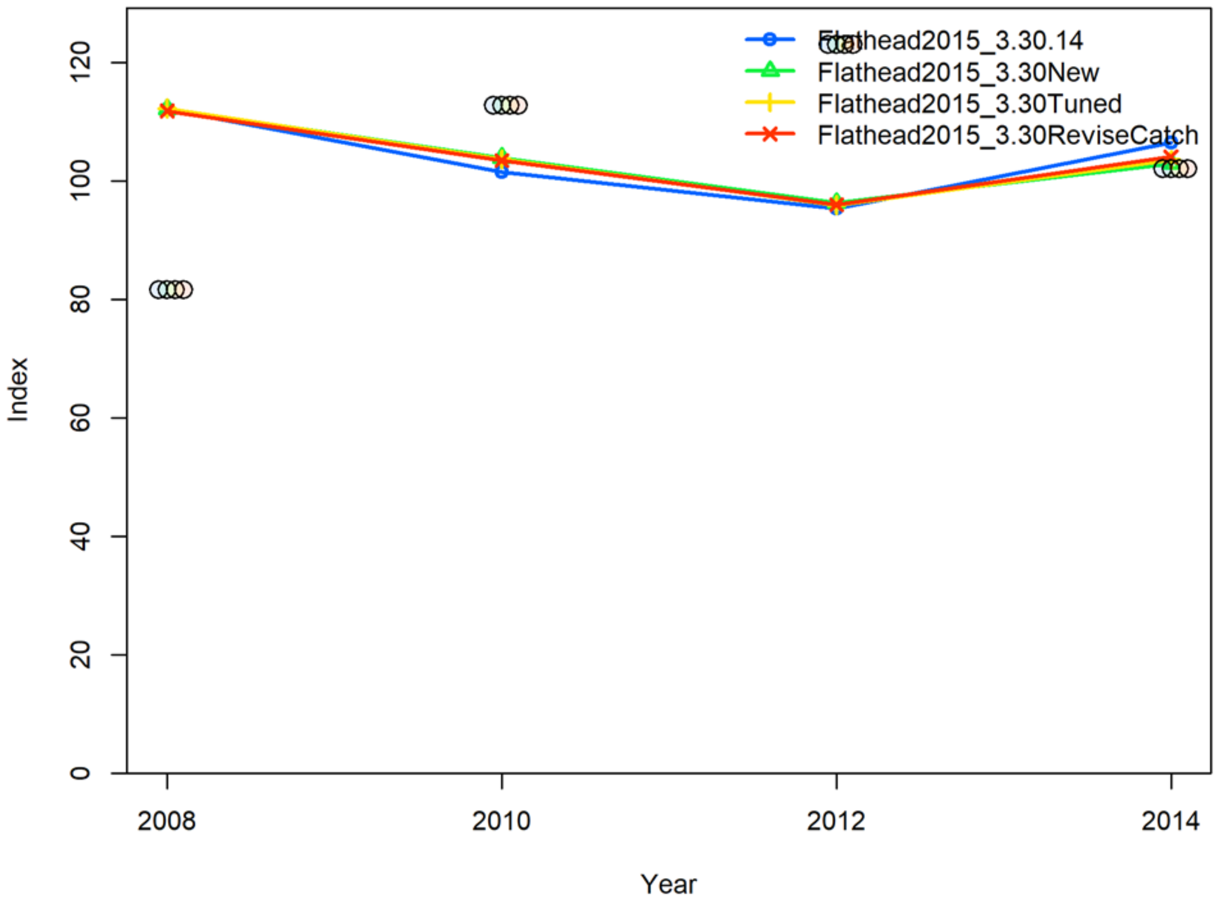

Figure 6.10. Comparison of the fit to the FIS_Tas (zone 30) abundance index for the 2015 assessment (Flathead2015_3.30.14 – in blue), incorporating new features (Flathead2015_3.30New – in green), retuning the model using the latest tuning protocols (Flathead2015_3.30Tuned – in yellow) and revising the historical catch to 2015 and the projected catch in 2016 (Flathead2015_3.30ReviseCatch – in red).

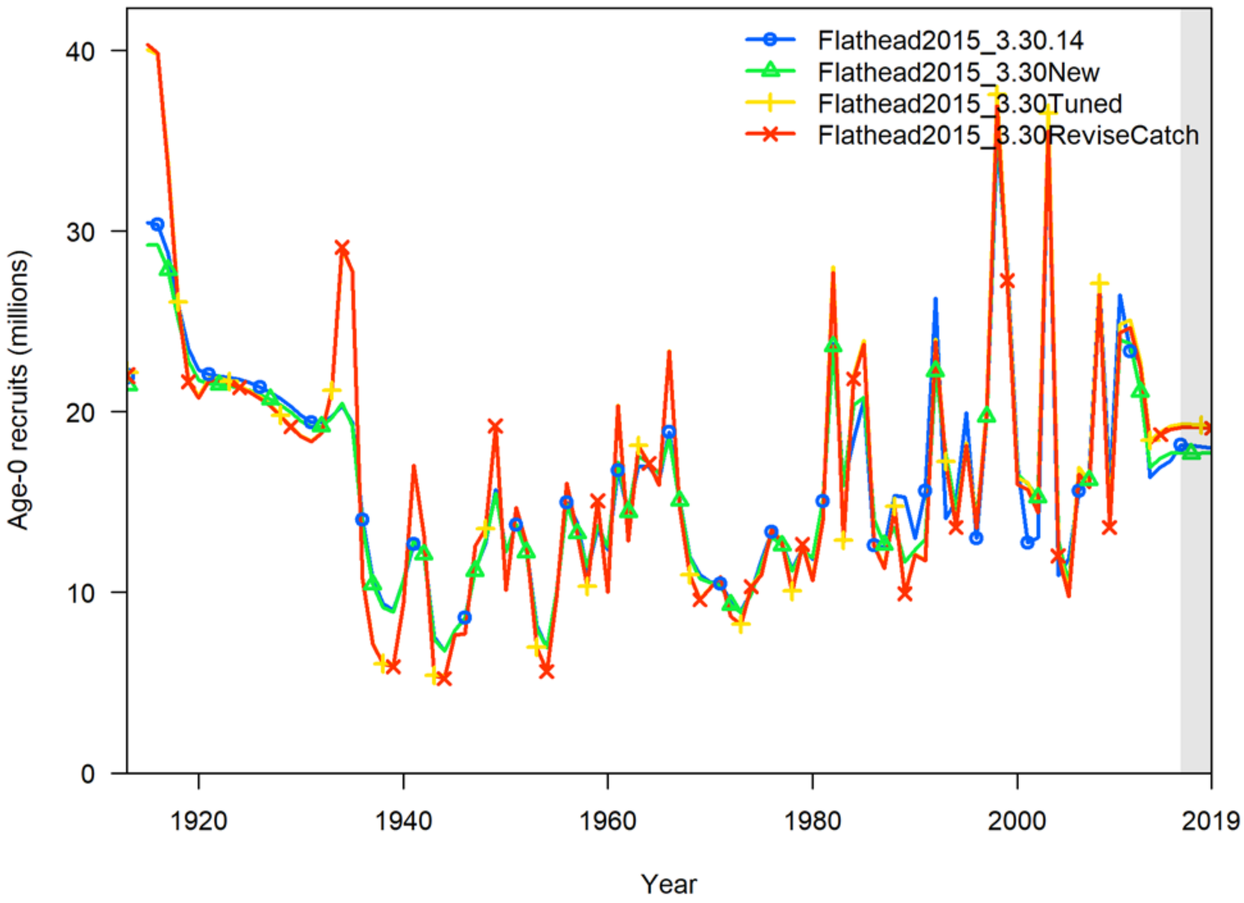

Figure 6.11. Comparison of the time series of recruitment from the 2015 assessment (Flathead2015_3.30.14 – in blue), incorporating new features (Flathead2015_3.30New – in green), retuning the model using the latest tuning protocols (Flathead2015_3.30Tuned – in yellow) and revising the historical catch to 2015 and the projected catch in 2016 (Flathead2015_3.30ReviseCatch – in red).

6.2.2.1 Tuning method

Iterative rescaling (reweighting) of input and output CVs or input and effective sample sizes is a repeatable method for ensuring that the expected variation of the different data streams is comparable to what is input (Pacific Fishery Management Council, 2018). Most of the indices (CPUE, surveys and composition data) used in fisheries underestimate their true variance by only reporting measurement or estimation error and not including process error.

In iterative reweighting, the effective annual sample sizes are tuned/adjusted so that the input sample size is equal to the effective sample size calculated by the model. In SS-V3.30 it is possible to estimate an additional standard deviation parameter to add to the input CVs for the abundance indices (CPUE).

1. Set the standard error for the log of relative abundance indices (CPUE or FIS) to the standard deviation of a loess curve fitted to the original data - which will provide a more realistic estimate to that obtained from the original statistical analysis. SSV-3.30 then allows an estimate to be made for an additional adjustment to the relative abundance variances appropriately.

An automated iterative tuning procedure was used for the remaining adjustments. For the recruitment bias adjustment ramps:

2. Adjust the maximum bias adjustment and the start and finish bias adjustment ramps as predicted by SSv3.30 at each step.

For the age and length composition data:

3. Multiply the stage-1 (initial) sample sizes for the conditional age-at-length data by the sample size multipliers using the approach of Punt (2017).
4. Similarly multiply the initial samples sizes by the sample size multipliers for the length composition data using the 'Francis method' (Francis, 2011).
5. Repeat steps 2 - 4, until all are converged and stable (with proposed changes < 1 – 2%).

This procedure constitutes current best practice for tuning assessments.

6.2.3 *Inclusion of new data: 2016-2018 (Bridge 2)*

Starting from the translated, retuned 2016 base case model with updated data to 2015 (previously referred to as "Flathead2015_3.30ReviseCatch" but simplified to "Flathead2015_3.30Updated" from here on), additional data from 2016-2018 were added sequentially to build a preliminary base case for the 2019 assessment:

1. Change final assessment year to 2018, add catch to 2018 (Flathead2019_addCatch2018).
2. Add CPUE to 2018 (from Sporcic (2019a, 2019b)) (Flathead2019_addCPUE2018), and the FIS abundance index for 2016 (Knuckey et al 2017) (Flathead2019_addFIS1_2016).
3. Add new discard fraction estimates from 1994 to 2018 (Flathead2019_addDiscards2018).
4. Add updated length frequency data to 2018 (Flathead2019_addLength2018).
5. Add updated age error matrix and conditional age-at-length data to 2018 and FIS conditional age-at-length data from 2008 (Flathead2019_addAge2018FIS).
6. Change the final year for which recruitments are estimated from 2012 to 2015 (Flathead2019_extendRec2015).
7. Retune using current tuning protocols, including Francis weighting on length-compositions and conditional age-at-length data (Flathead2019_Tuned).

Inclusion of the new data resulted in a series of changes to the estimates of recruitment and the time-series of absolute and relative spawning biomass (Figure 6.12 and Figure 6.13), with relatively small changes to these series as more data is added. Some changes are reversed from one step to the next, as additional data continues to be added (e.g. adding new catch data seems to have an effect that is largely cancelled out in the next step by updating the abundance indices). The most important change is extending the final year for which recruitment is estimated, resulting in a revision downwards of the 2012 recruitment (which was the last year of recruitment estimated in the 2016 assessment) and estimated below average recruitment for the newly estimated 2013 and 2014 recruitments (Figure 6.13), which in turn flows through to a reduction in the estimated stock biomass in 2019 (Figure 6.12). These below average recruitment events appear to be supported by the recent length and age data.

Fits to the early CPUE indices (Figure 6.14 and Figure 6.15) show little change as no new data is added in this period. Fits to the more recent CPUE (Figure 6.16 to Figure 6.18) show larger changes, especially in the last four years, 2015-2018, with extending the final year for which recruitment is estimated producing the largest change out of each of the steps shown. The largest improvement in fit is to the most recent four years of the CPUE time series for eastern trawl (Figure 6.17) with recruitment estimated to 2015. Changes in fits to the FIS indices are relatively minor (Figure 6.19 and Figure 6.20). Given the variability from point to point and the short time series, it would be hard to get better fits to the FIS series, especially given the species biology and the rest of the data included in the assessment. It appears that the fits to the much longer recent trawl CPUE indices are still much more influential. The fits to the historic CPUE indices are generally reasonable and the fit to the eastern trawl CPUE series matches the changes seen in the last six data points.

Inclusion of the new data had considerable impacts on the estimates of recruitment and the spawning biomass time series. With recruitment estimated up until 2015, this resulted in the 2012 recruitment (previously estimated in the 2016 assessment) to be revised down, compared to the 2016 assessment. Of the three new years of estimated recruitment (2013, 2014 and 2015), the first two are estimated to be below average, with 2013 having the lowest estimated recruitment deviation for over 50 years. The 2015 recruitment is estimated to be slightly above average, but this is the least informed estimate of these three new estimated recruitment events. These recruitment events appear to be supported by the recent length and age data and have resulted in an estimate of the depletion at the start of 2020 of 34% of unexploited stock biomass, SSB_0. While the most recent recruitments are well estimated, they should be treated with some caution as it is possible for future data to result in modifications to estimates of recent recruitment events, as occurred with the 2012 recruitment estimates from the 2015 assessment. Since 2005, various values have been used for the target and the breakpoint in the Tier 1 harvest control rule. In 2009, AFMA directed that the 20:35:40 (B_{lim}: B_{MSY}: F_{targ}) form of the harvest control rule be used for tiger flathead.

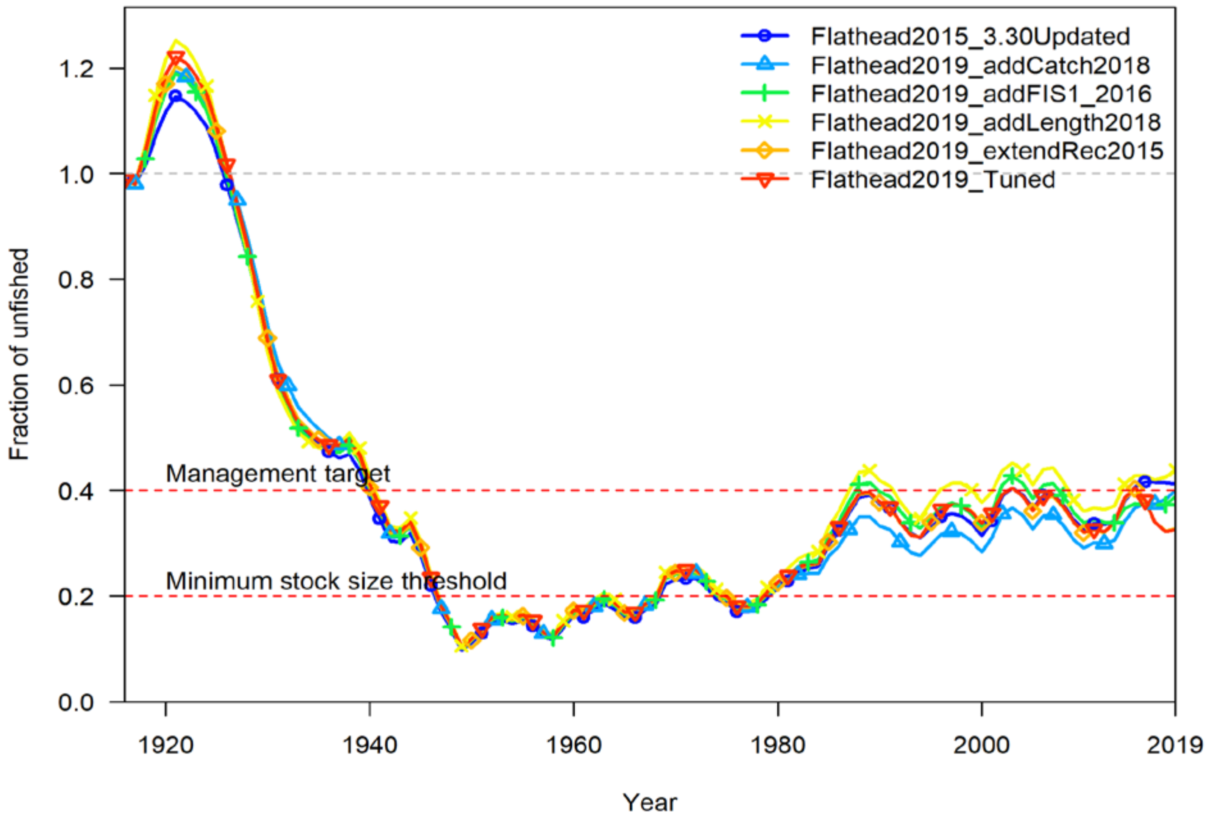

Figure 6.12. Comparison of the time series of relative spawning biomass for the updated 2016 assessment model converted to SS-V3.30.14 (Flathead2015_3.30Updated - blue) with various bridging models leading to a proposed 2019 base case model (Flathead2019_Tuned- red).

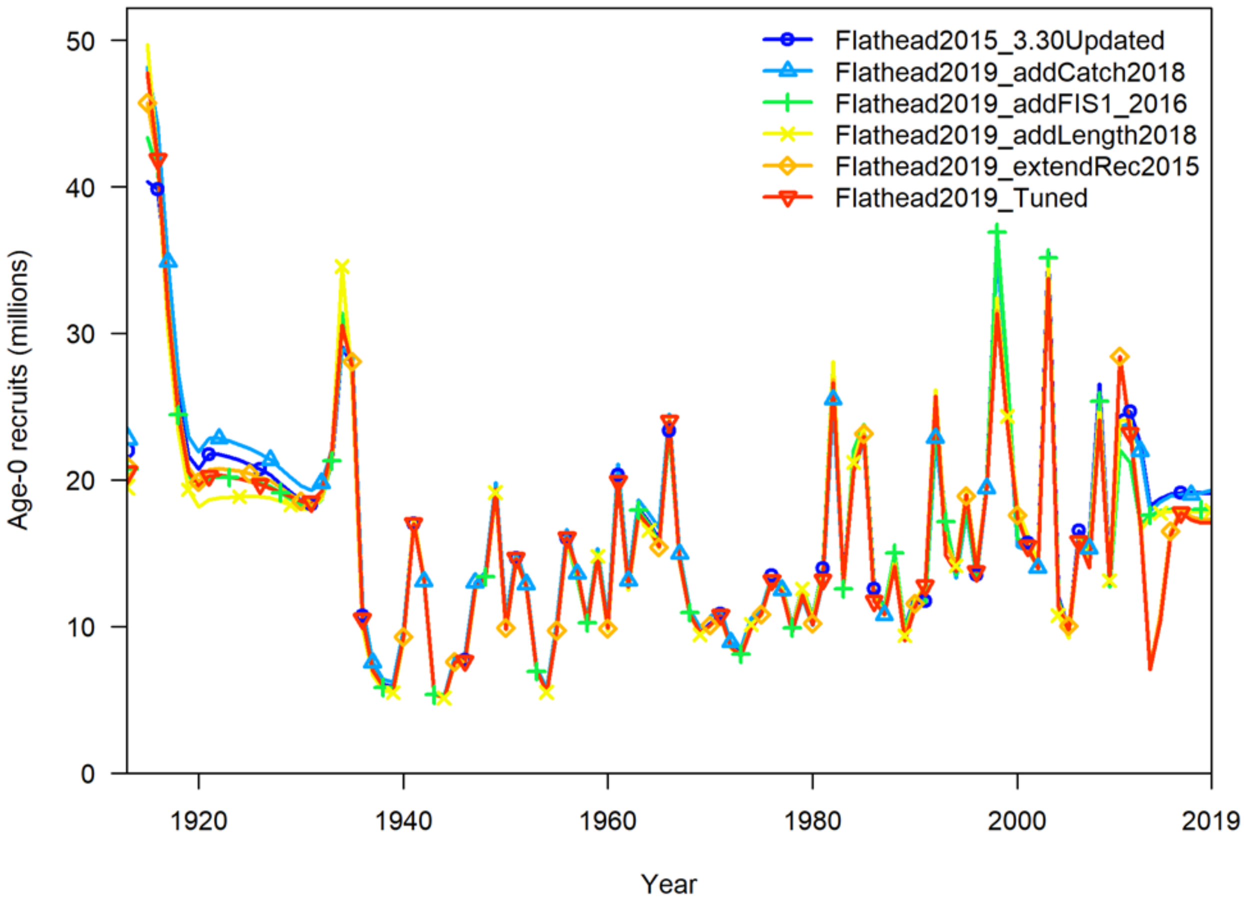

Figure 6.13. Comparison of the time series of recruitment from the updated 2016 assessment model converted to SS-V3.30.14 (Flathead2015_3.30Updated - blue) with various bridging models leading to a proposed 2019 base case model (Flathead2019_Tuned- red).

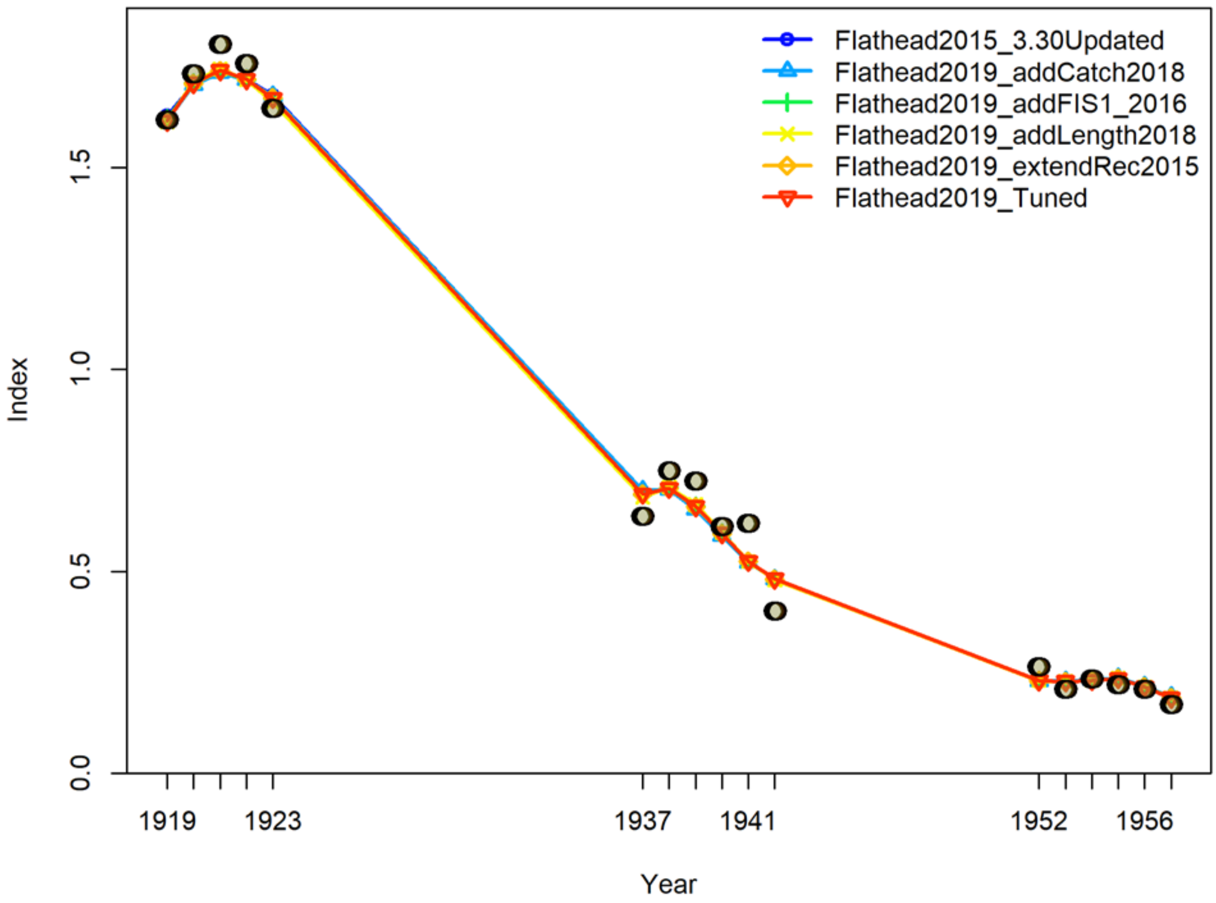

Figure 6.14. Comparison of the fit to the steam trawl CPUE index for the updated 2016 assessment model converted to SS-V3.30.14 (Flathead2015_3.30Updated - blue) with various bridging models leading to a proposed 2019 base case model (Flathead2019_Tuned- red).

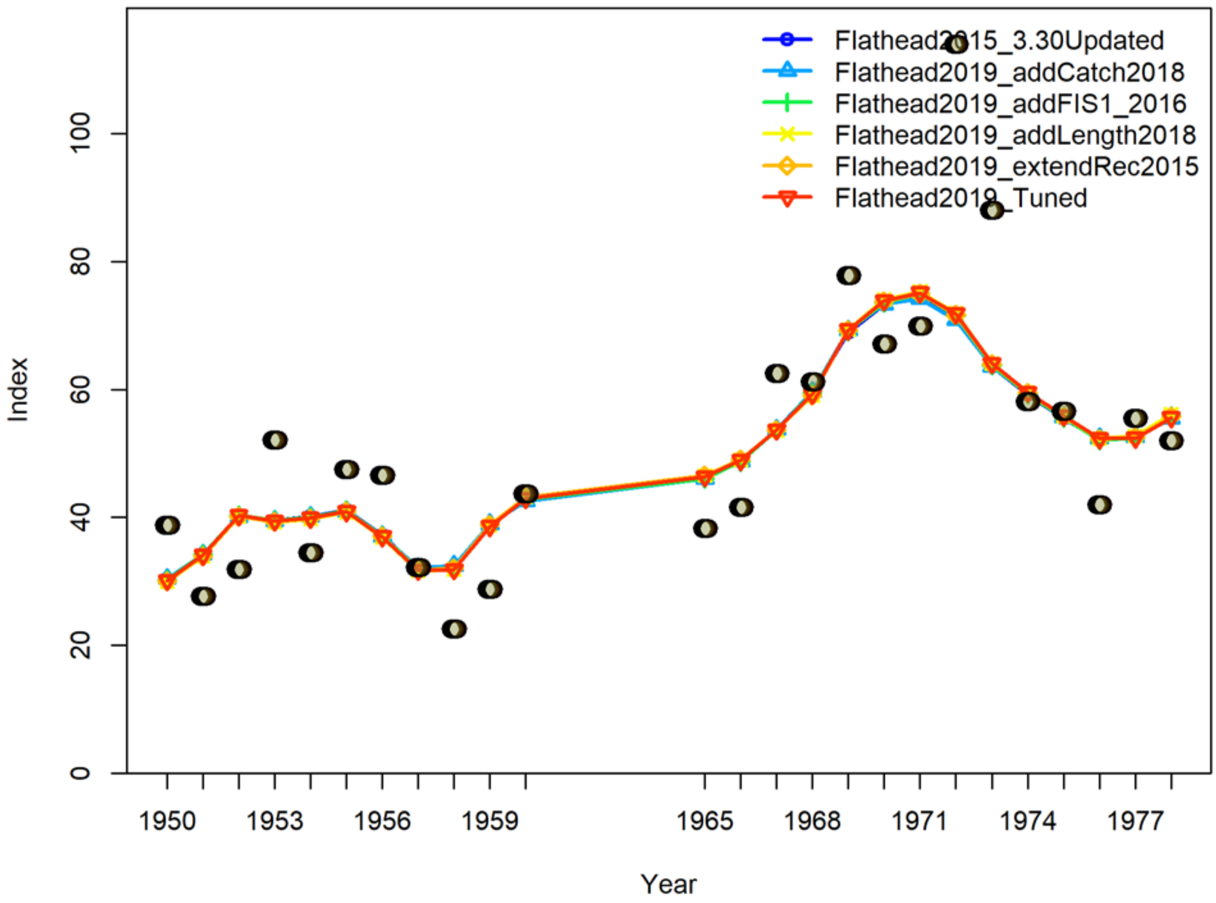

Figure 6.15. Comparison of the fit to the steam trawl CPUE index for the updated 2016 assessment model converted to SS-V3.30.14 (Flathead2015_3.30Updated - blue) with various bridging models leading to a proposed 2019 base case model (Flathead2019_Tuned- red).

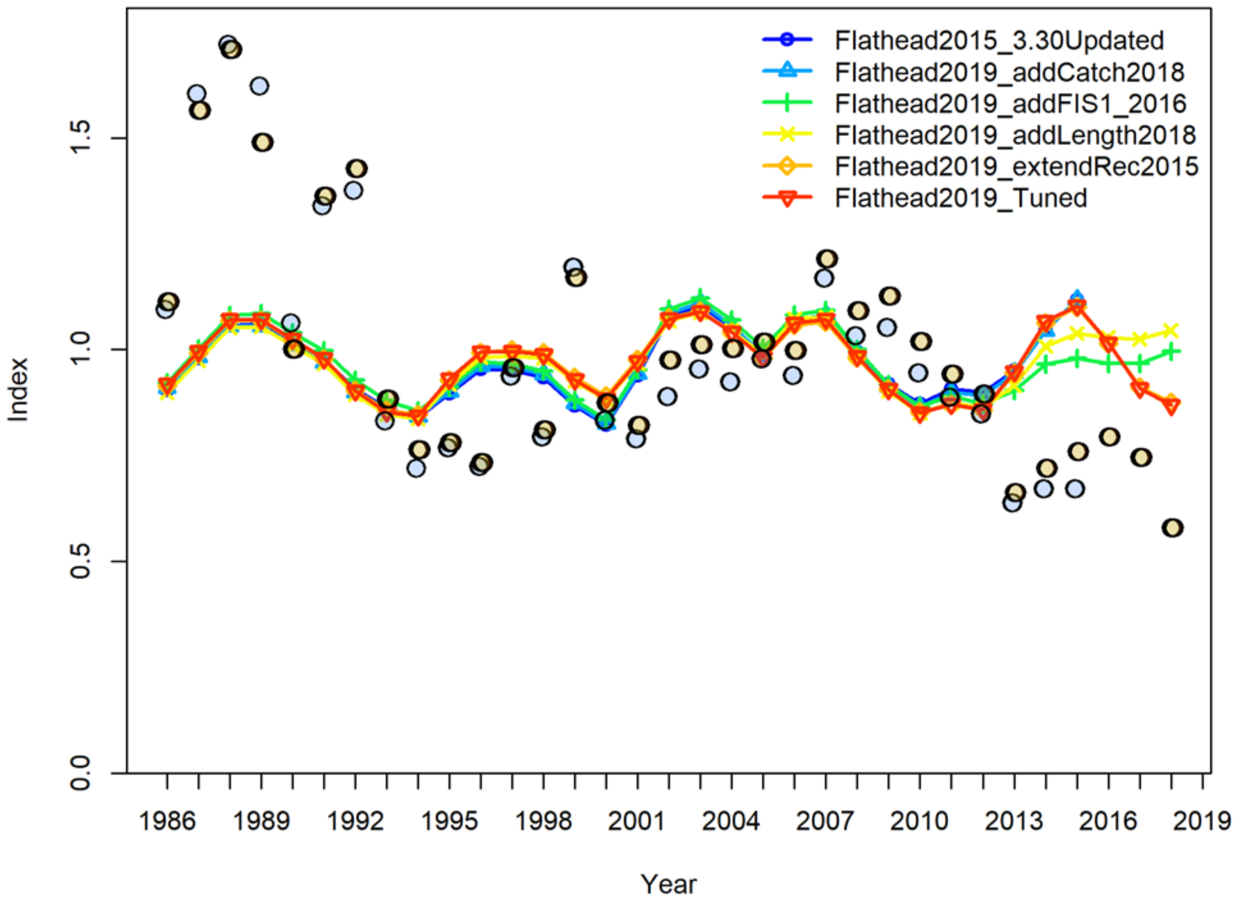

Figure 6.16. Comparison of the fit to the Danish seine CPUE index for the updated 2016 assessment model converted to SS-V3.30.14 (Flathead2015_3.30Updated - blue) with various bridging models leading to a proposed 2019 base case model (Flathead2019_Tuned- red).

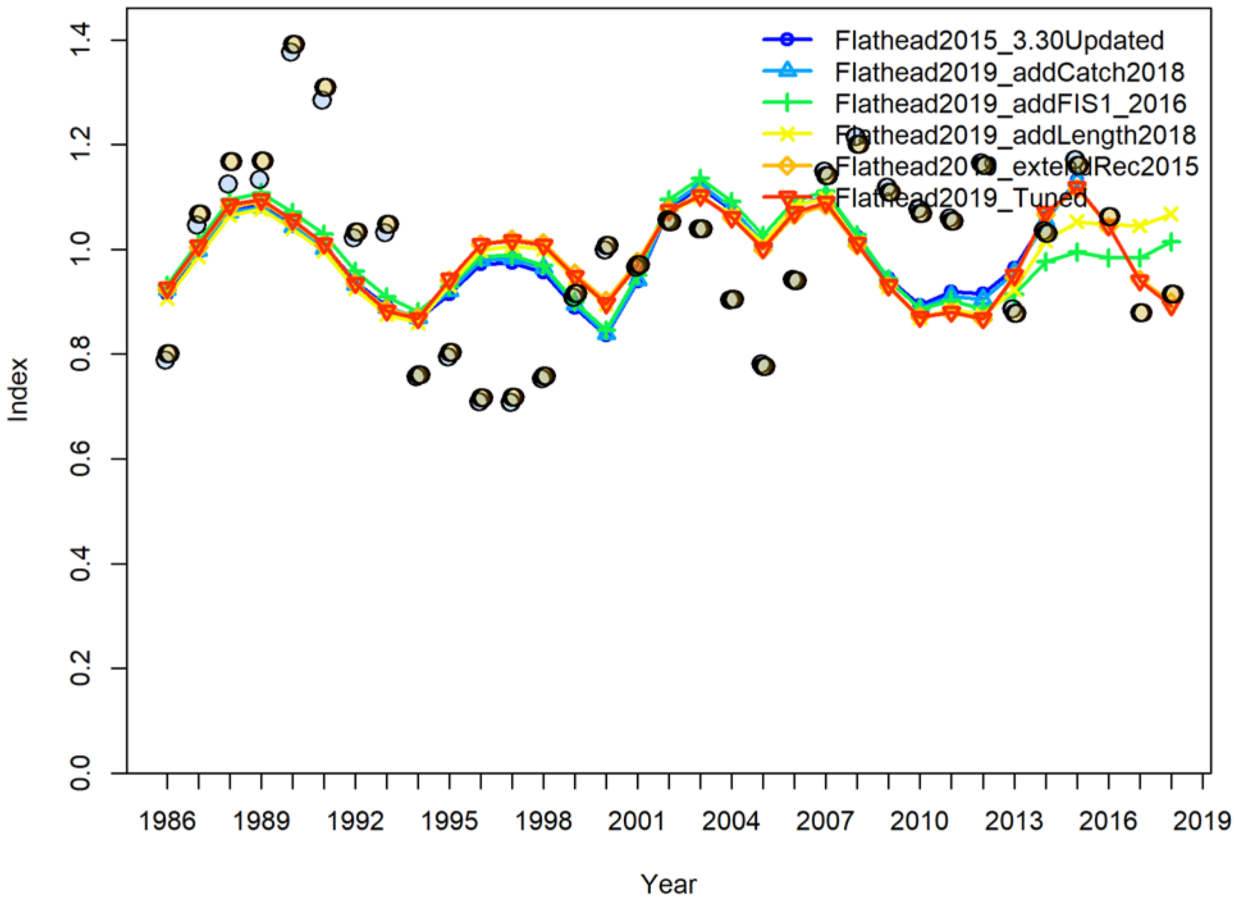

Figure 6.17. Comparison of the fit to the eastern trawl CPUE index for the updated 2016 assessment model converted to SS-V3.30.14 (Flathead2015_3.30Updated - blue) with various bridging models leading to a proposed 2019 base case model (Flathead2019_Tuned- red).

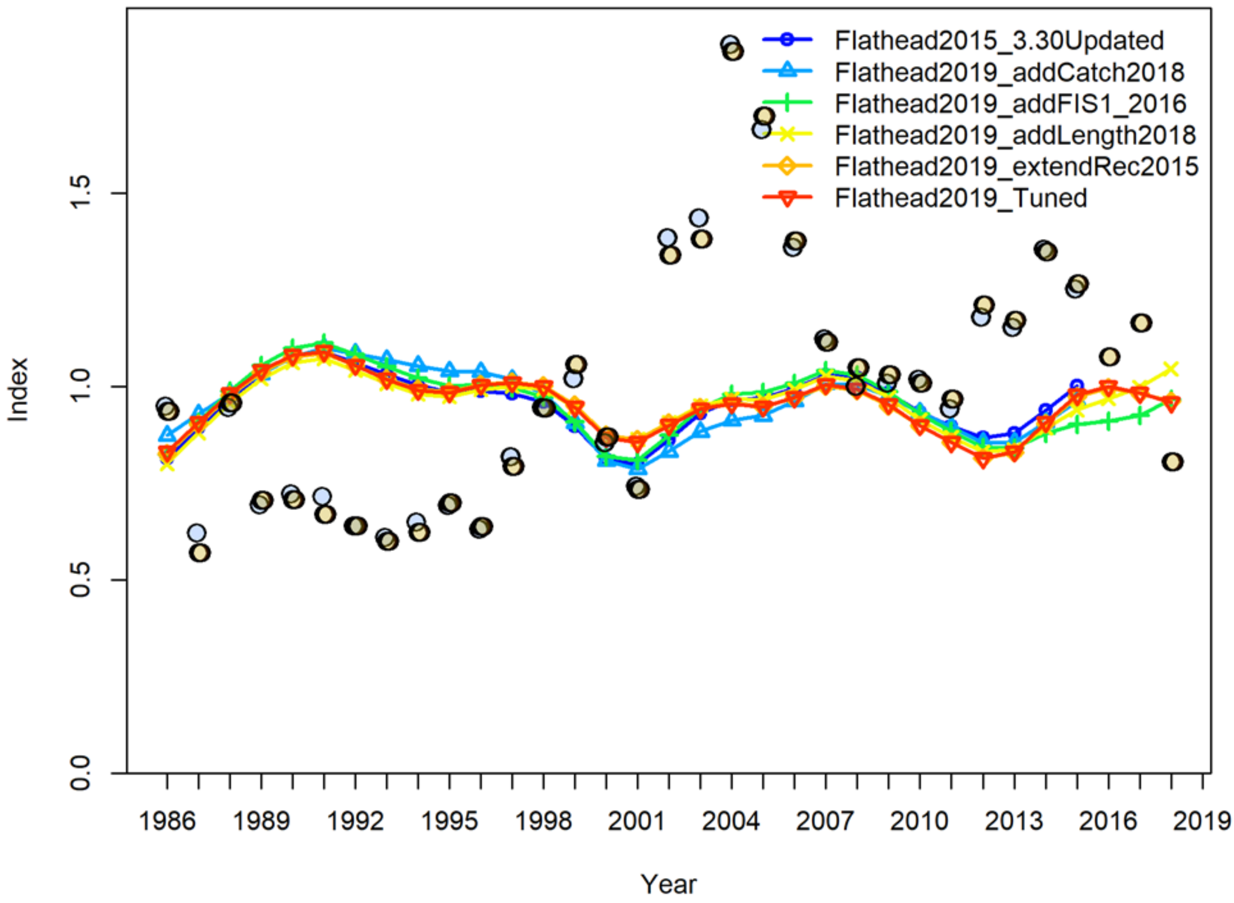

Figure 6.18. Comparison of the fit to the Tasmanian trawl CPUE index for the updated 2016 assessment model converted to SS-V3.30.14 (Flathead2015_3.30Updated - blue) with various bridging models leading to a proposed 2019 base case model (Flathead2019_Tuned- red).

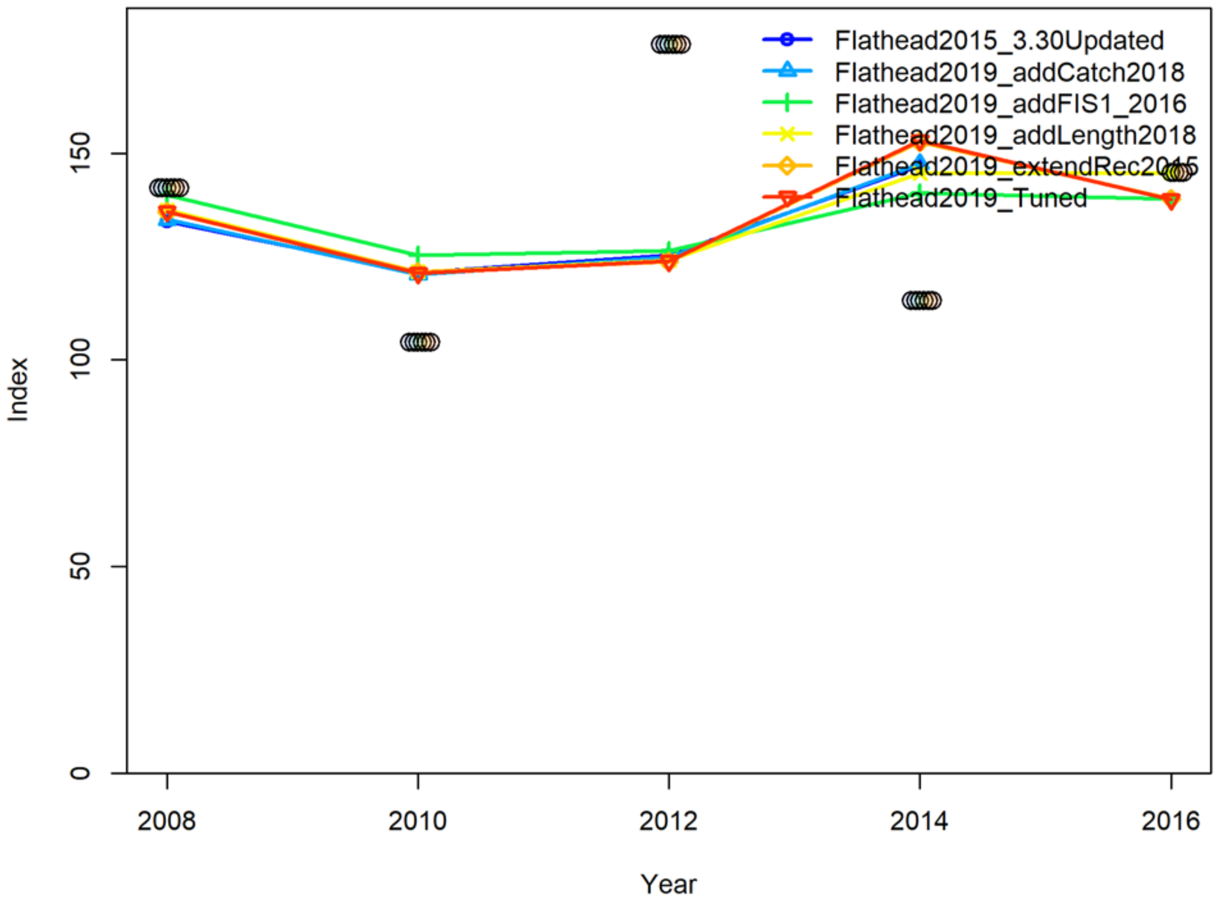

Figure 6.19. Comparison of the fit to the FIS_East (zones 10 and 20) abundance index for the updated 2016 assessment model converted to SS-V3.30.14 (Flathead2015_3.30Updated - blue) with various bridging models leading to a proposed 2019 base case model (Flathead2019_Tuned- red).

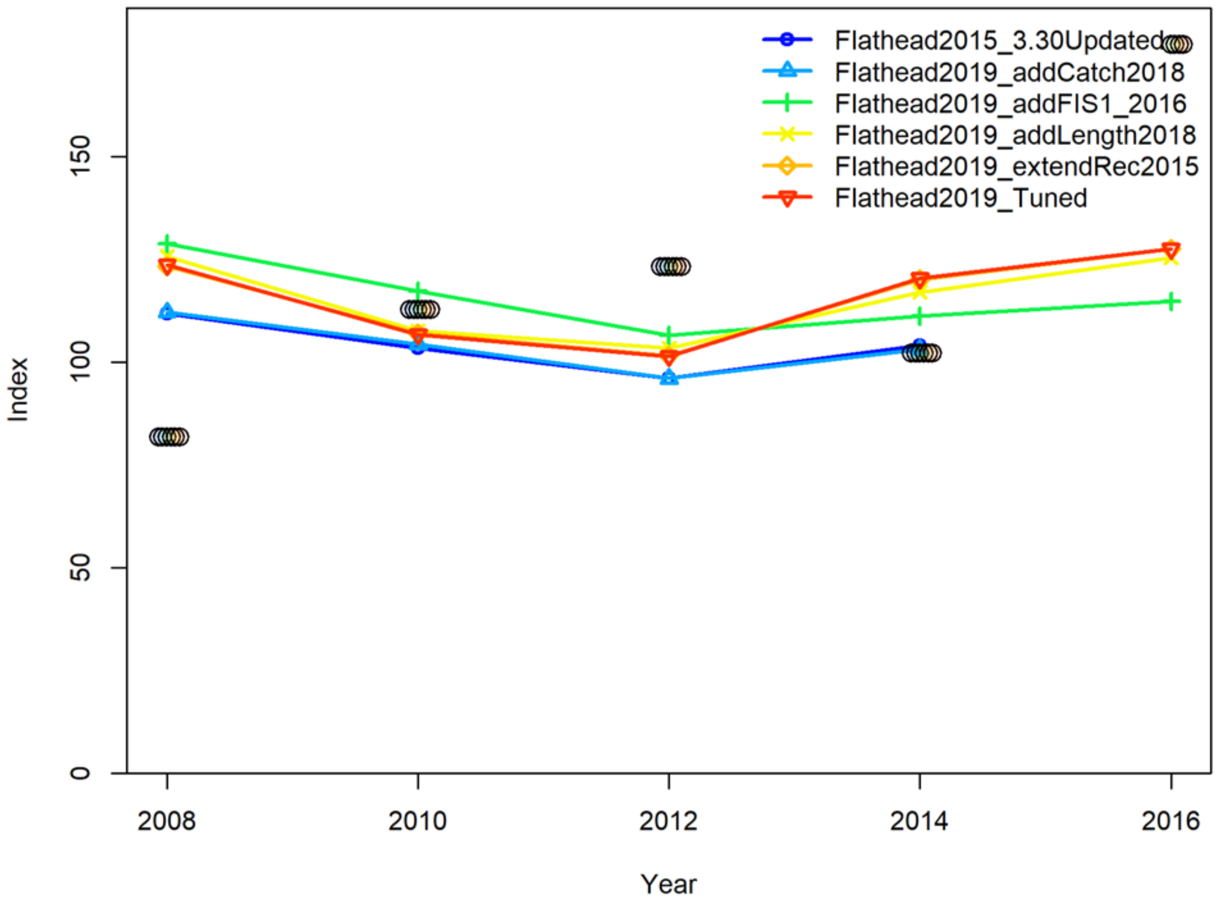

Figure 6.20. Comparison of the fit to the FIS_Tas (zone 30) abundance index for the updated 2016 assessment model converted to SS-V3.30.14 (Flathead2015_3.30Updated - blue) with various bridging models leading to a proposed 2019 base case model (Flathead2019_Tuned- red).

6.2.4 *Likelihood profiles*

As stated by Punt (2018), likelihood profiles are a standard component of the toolbox of applied statisticians. They are most often used to obtain a 95% confidence interval for a parameter of interest. Many stock assessments "fix" key parameters such as M and steepness based on *a priori* considerations. Likelihood profiles can be used to evaluate whether there is evidence in the data to support fixing a parameter at a chosen value. If the parameter is within the entire range of the 95% confidence interval, this provides no support in the data to change the fixed value. If the fixed value is outside the 95% confidence interval, it would be reasonable for a review panel to ask why the parameter was fixed and not estimated, and if the value is to be fixed, on what basis and why should what amounts to inconsistency with the data be ignored. Integrated stock assessments include multiple data sources (e.g., commonly catch-rates, length-compositions, and age-compositions) that may be in conflict, due for example to inconsistencies in sampling, but more commonly owing to incorrect assumptions (e.g., assuming that catch-rates are linearly related to abundance), i.e. model-misspecification. Likelihood profiles can be used as a diagnostic to identify these data conflicts (Punt, 2018).

Standard parameters to consider are natural mortality (M), steepness (h) and the logarithm of the unfished recruitment ($\ln R_0$).

For tiger flathead, the likelihood profile for natural mortality, *M*, a parameter fixed in the model, is shown in Figure 6.21 with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. This likelihood profile suggests that there is little information in the model that can be used to inform this parameter (fixed at 0.27 in the model). The index and length data (which suggest higher mortality) and the recruitment and discard data (which suggest lower mortality) are in conflict and the likelihood profile suggests higher values of mortality are preferred. However, this likelihood profile is essentially uninformative when the biological consequences of mortality values of 0.3, or greater, are considered.

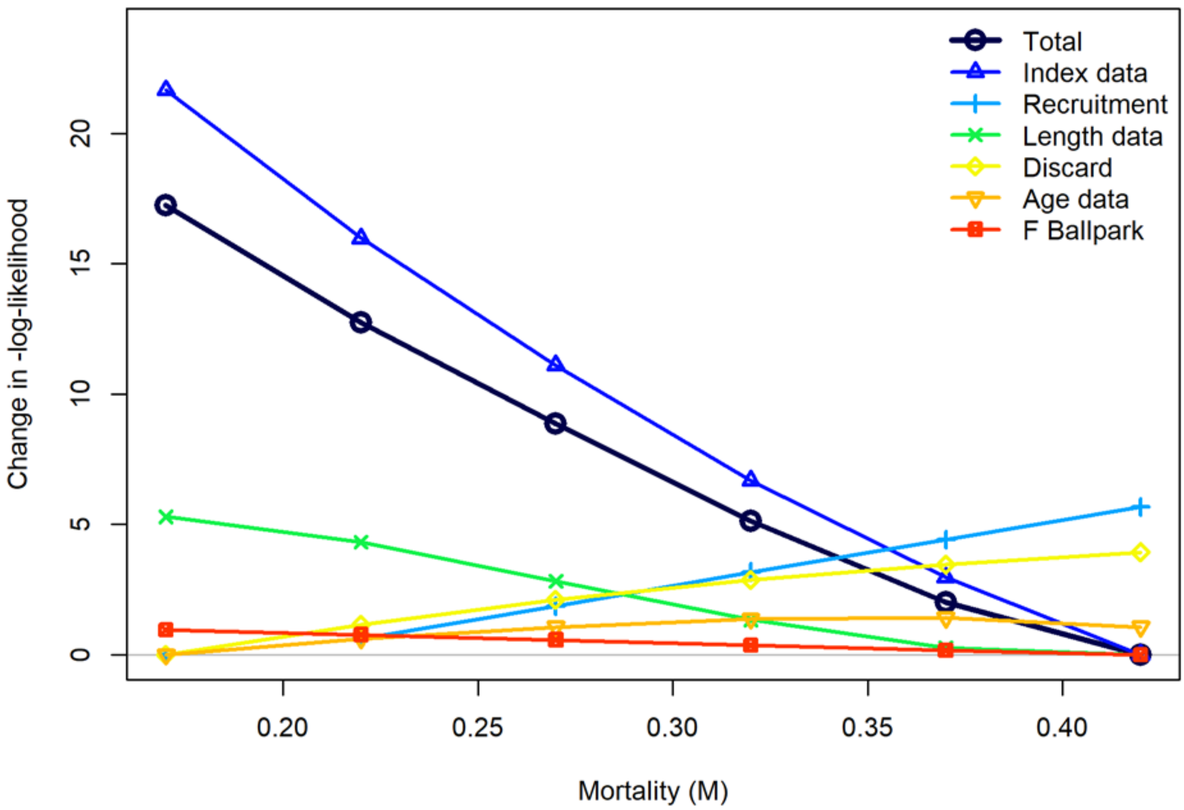

Figure 6.21. The likelihood profile for natural mortality, with *M* ranging from 0.17 to 0.42. The fixed value for *M* is 0.27yr^{-1}.

A likelihood profile for virgin spawning biomass (SSB_0) is shown in Figure 6.22 with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. SSB_0 is a derived parameter which is linked to the estimated parameter R_0, which is the average equilibrium recruitment and constructing this likelihood profile. To construct a likelihood profile on SSB_0 requires setting up an additional "fleet" with a single data point (in 1915) with very low standard error, essentially adding a "highly precise survey" of spawning biomass, setting the selectivity type to 30 (an index of *SSB*) and then allowing this spawning biomass value to vary between runs. This likelihood profile suggests a broad range of plausible values for SSB_0 ranging between around 15,000 and 29,000t with the most likely value at around 22,000t. The important data sources in providing information on SSB_0 are the index data and recruitment deviations. SSB_0 needs to be sufficiently high to enable the historical catches to be sustained, so this results in the recruitment component of the likelihood providing a lower bound on SSB_0 and the fits to the index data deteriorate with larger values of SSB_0. A likelihood profile for current spawning biomass and depletion would be useful additions to this analysis

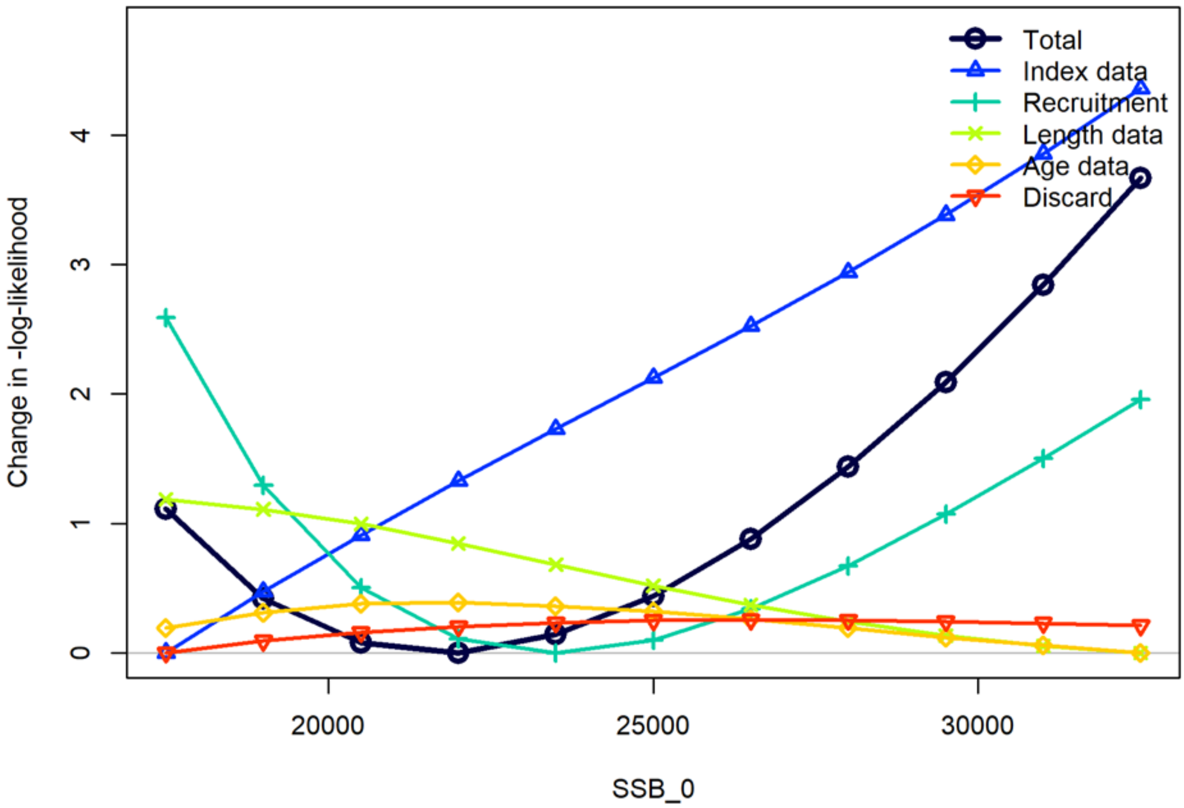

Figure 6.22. The likelihood profile for virgin spawning biomass, with SSB_0 ranging from 17,500 to 32,500t. The estimated value for SSB_0 is 21,715t.

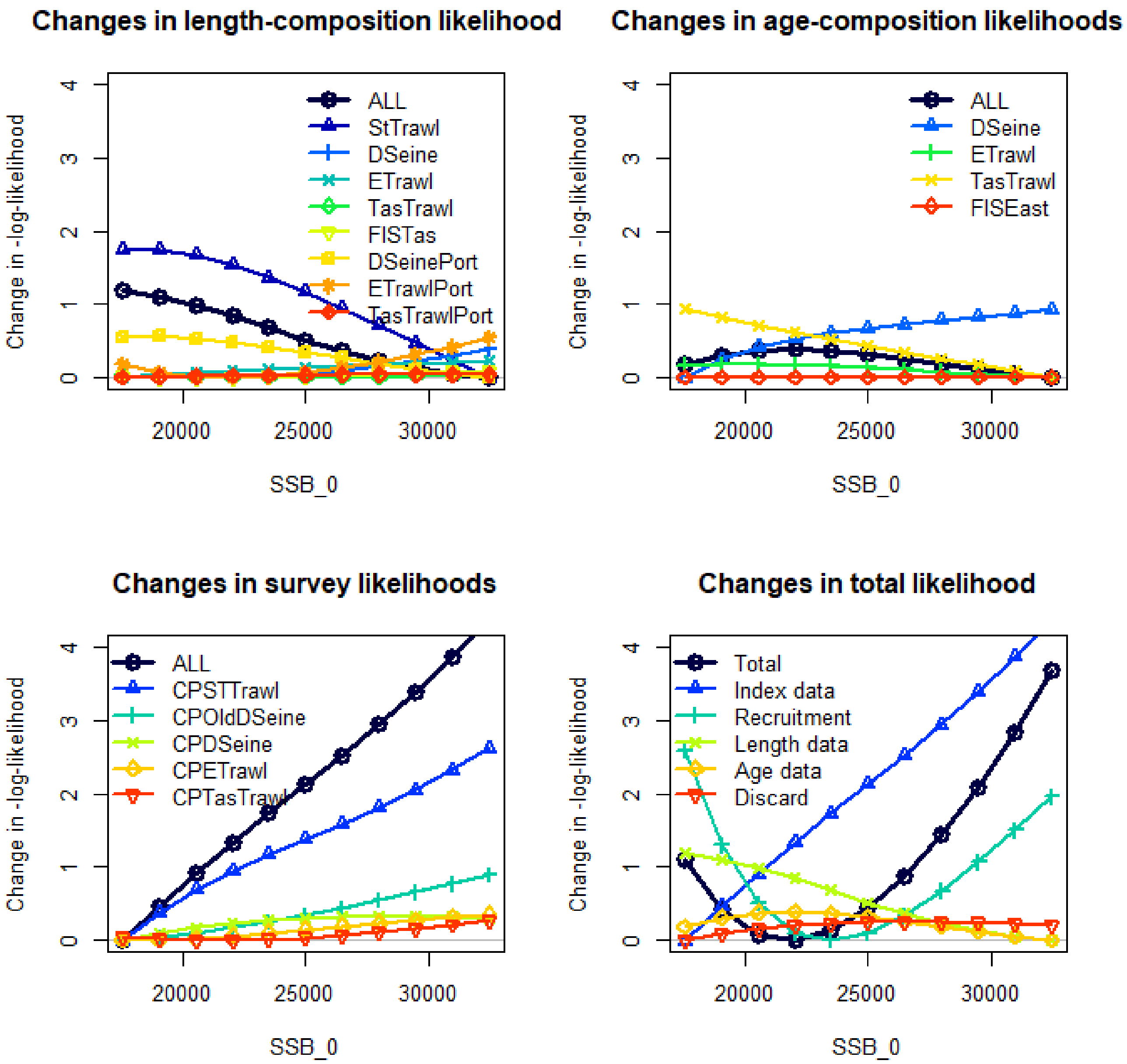

Figure 6.23. Piner plot for the likelihood profile for virgin spawning biomass, showing components of the change in likelihood for length, age and indices (CPUE) in addition to the changes in the total likelihood.

6.2.5 *Retrospectives*

A retrospective analysis was completed, starting from the most recent year of data, working backward in time and removing successive years of data from the assessment. This analysis can highlight potential problems and instability in an assessment, or some features that appear from the data.

A retrospective analysis for absolute spawning biomass is shown in Figure 6.24, with the data after 2017 removed initially (shown in light blue), then successive years of data removed back to 2013 (shown in red). The same analysis is plotted in terms of relative spawning biomass in Figure 6.25. In both cases the changes are minor with the largest change at the end of the retrospectives deleting all data after 2013 (orange, minor change) and 2014 (red, slightly larger change), at the end of both time series. These show a slight downward revision of the relative spawning biomass in the period 2010-

2015, as more years of additional data are added to the assessment. However, the effect is relatively small, and is only shown for these two retrospectives where a lot of data is removed.

When this retrospective analysis is applied to the recruitment time series (Figure 6.26), the more recent data results in a downward revision to the recruitment estimate in 2012. This recruitment is first estimated in the retrospective to 2015 (which corresponds to the data used in the 2016 assessment, shown in yellow), and this revision downwards is supported by data in 2016, 2017 and 2018. The first estimate of the 2013 recruitment is made in the 2016 retrospective (green) and is well below average. This estimate of 2013 recruitment is revised further downwards when data from 2017 and 2018 is added.

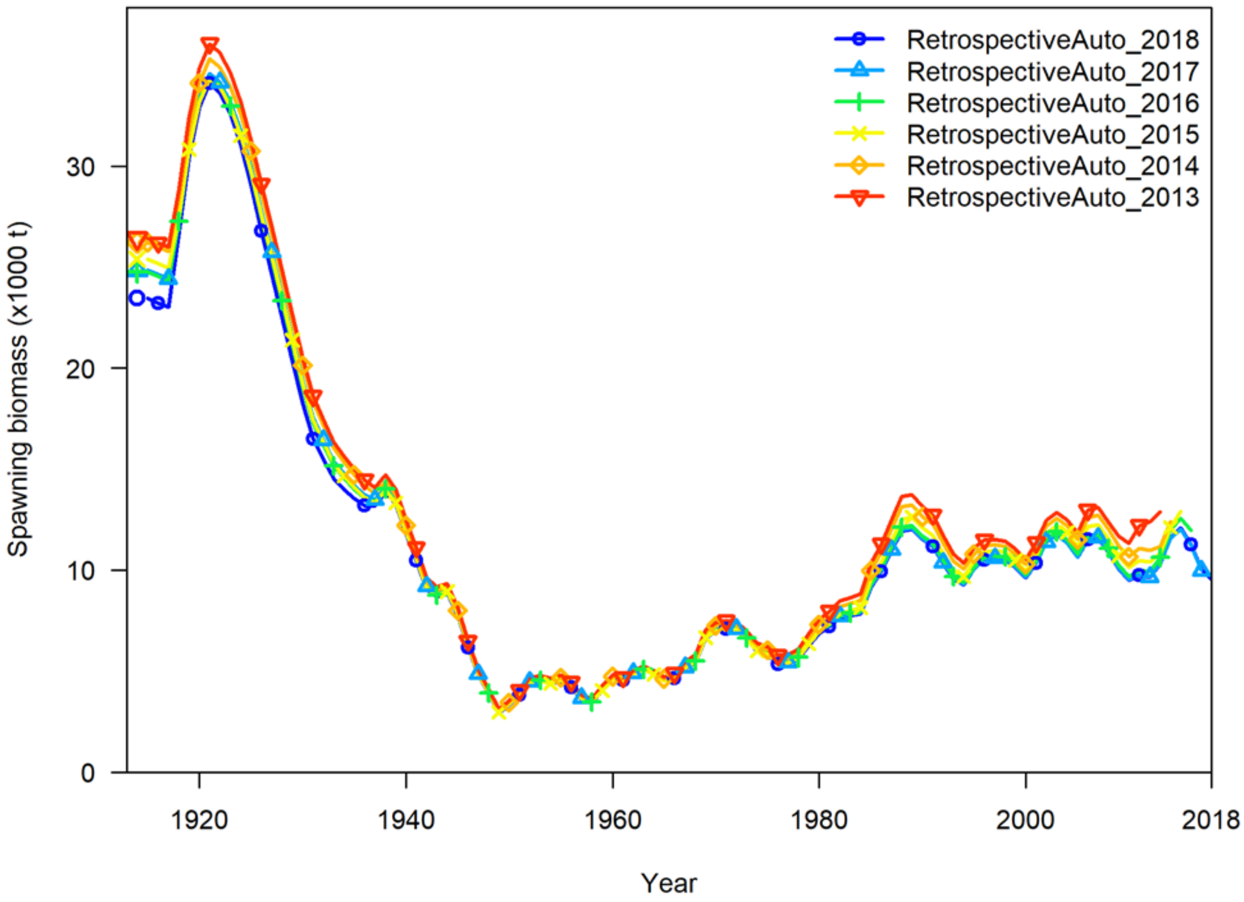

Figure 6.24. Retrospectives for absolute spawning biomass for tiger flathead, with data removed back to 2017 (light blue) and then successive years removed back to 2013 (red).

These retrospective analyses do not reveal any pathological patterns or apparent biases in the estimates at the end of the time series due to the addition of new data, which provides additional confidence in the stability of this assessment.

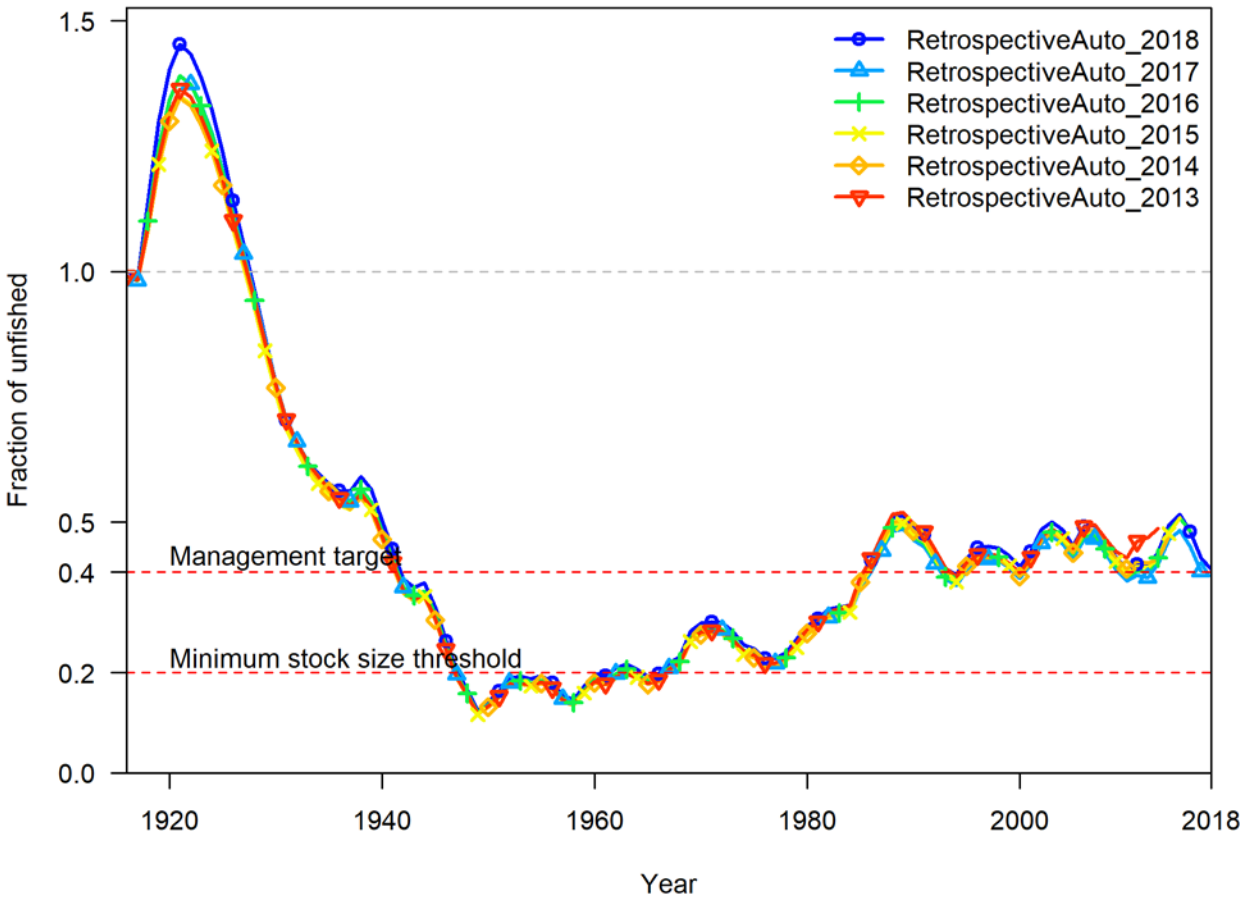

Figure 6.25. Retrospectives for relative spawning biomass for tiger flathead, with data removed back to 2017 (light blue) and then successive years removed back to 2013 (red).

6.2.6 *Future sensitivities*

Sensitivities to this potential base case have not yet been explored. In addition to the usual set of sensitivities (Day, 2016), (which includes sensitivities on mortality, maturity, fixing steepness and estimating mortality, σ_R and halving and doubling the weighting on length, age and CPUE data), there are some additional sensitivities that may be useful to explore. Two of these relate to the Fishery Independent Survey (FIS):

1. Incorporating all FIS3 abundance indices using reconditioned FIS abundance indices and adjusting for variations in catch rates within seasons (Sporcic et al 2019),
2. Incorporating Summer FIS length frequencies.

In addition, further sensitivities could be carried out on:

3. Excluding tiger flathead catches in the west (zones 40 and 50),
4. Using an alternative discard estimate series, reverting to a previously used method to calculate yearly discard rates.

Given the relatively small changes to the input data and the quantity of other data used in the assessment, it is unlikely that any of these additional sensitivities will produce results that are noticeably different to the base case.

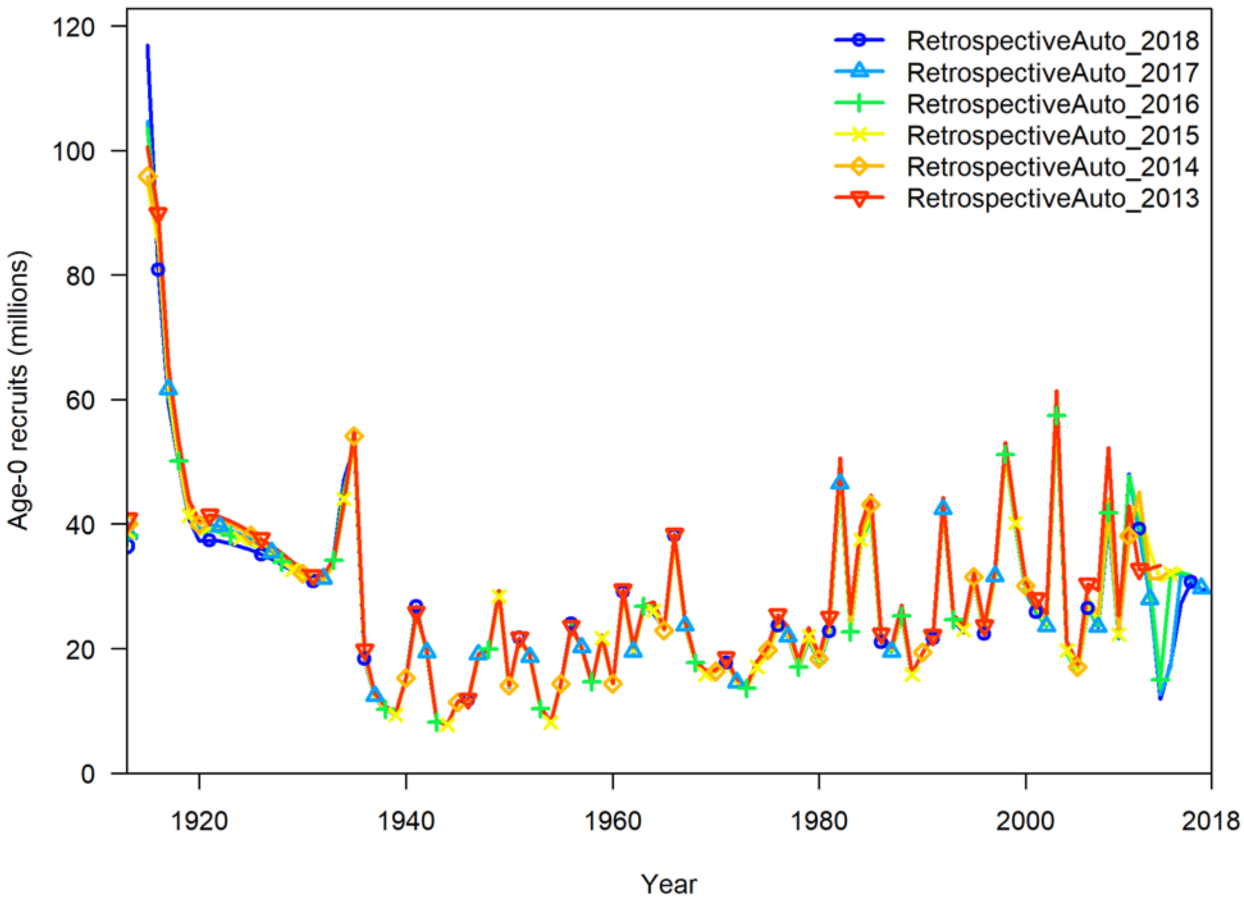

Figure 6.26. Retrospectives for recruitment for tiger flathead, with data removed back to 2017 (light blue) and then successive years removed back to 2013 (red).

For sensitivity 3 above, the western catches are already included in the assessment, as they are included in the CDRs, and allocated to the catches in the relevant eastern fleets in the same proportions as the eastern catches (from the logbook). To include these catches as a separate fleet would require a number of assumptions to be made (and agreed on by SERAG) and is unlikely to be a useful option given the absence of length frequency and age data from the west. Alternatively, this catch could be removed from the CDR in some fashion (requiring some scaling up of the western catch from the logbook to the CDRs and then removing the western portion from the CDR) but that would also require approval from SERAG.

6.3 Acknowledgements

Age data was provided by Kyne Krusic-Golub (Fish Ageing Services), ISMP and AFMA logbook and CDR data were provided by John Garvey (AFMA). Mike Fuller, Roy Deng, Franzis Althaus, Robin Thomson and Paul Burch (CSIRO) pre-processed the data. Geoff Tuck, Miriana Sporcic, Robin Thomson, Paul Burch, Malcolm Haddon (CSIRO), Claudio Castillo-Jordán (UW) and Ian Taylor (NOAA) are thanked for helpful discussions on this work. André Punt updated the ageing error matrix. Malcolm Haddon provided code for auto-tuning and Athol Whitten provided R code for organising plots.

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6.5 Appendix A

A.1 Preliminary base case diagnostics

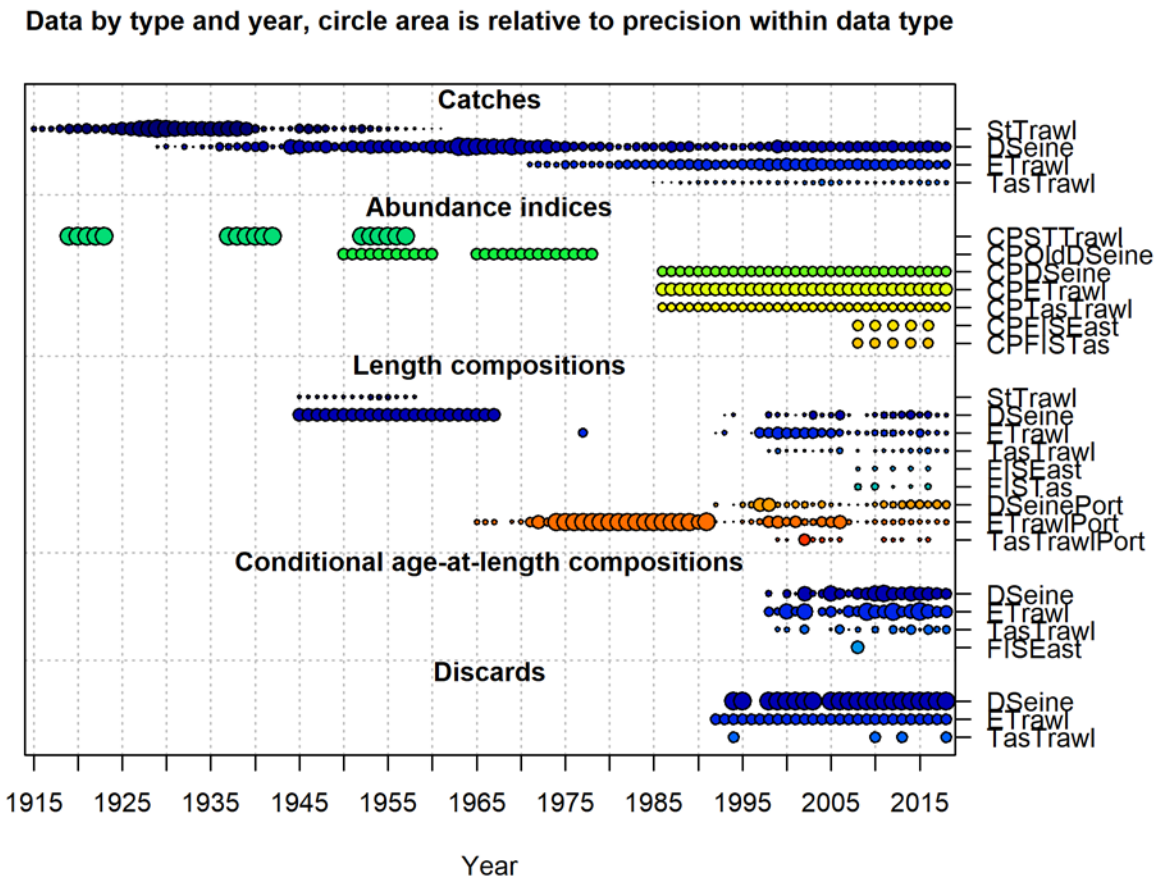

Figure A 6.1. Summary of data sources for tiger flathead stock assessment.

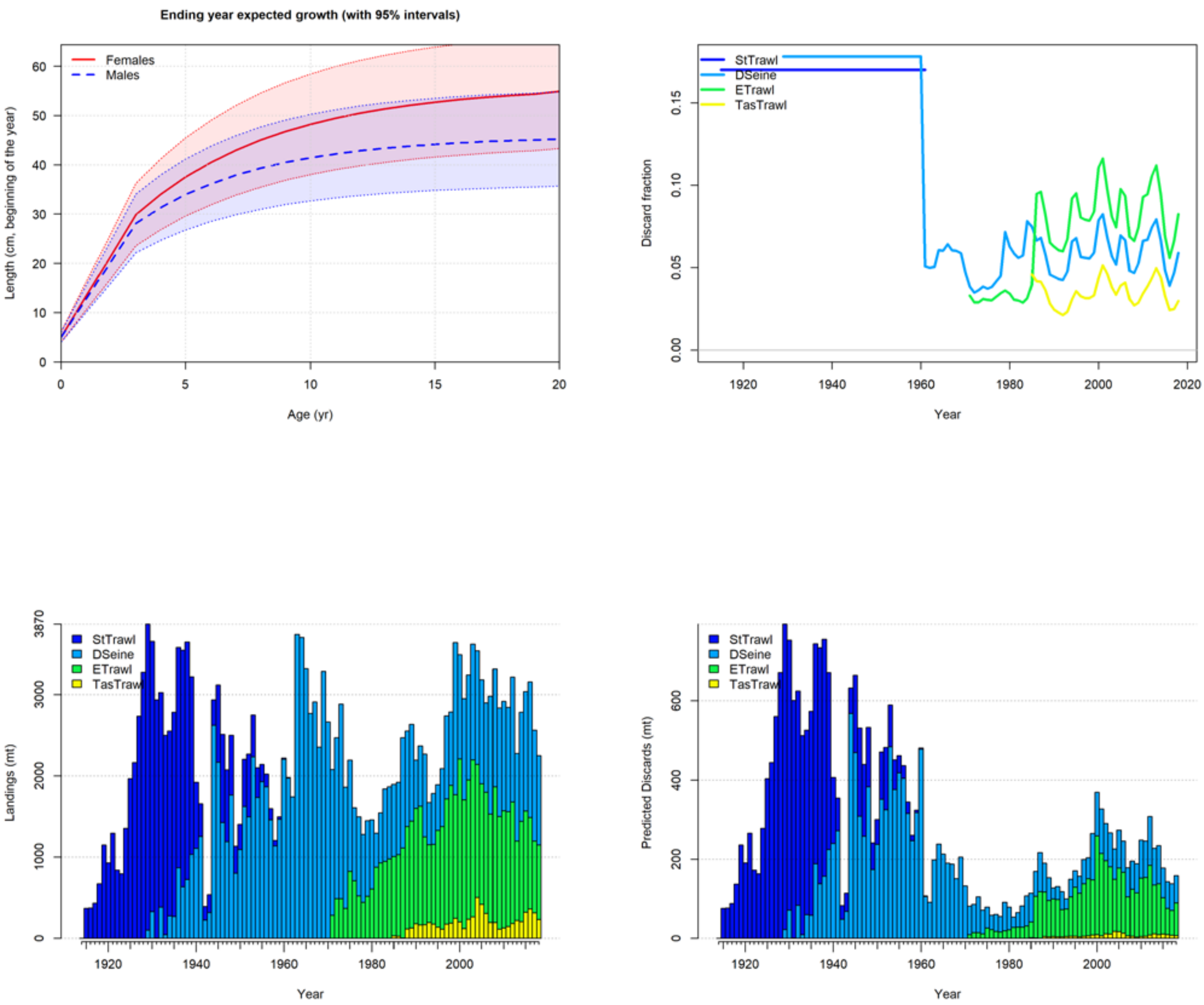

Figure A 6.2. Growth, discard fraction estimates, landings by fleet and predicted discards by fleet for tiger flathead.

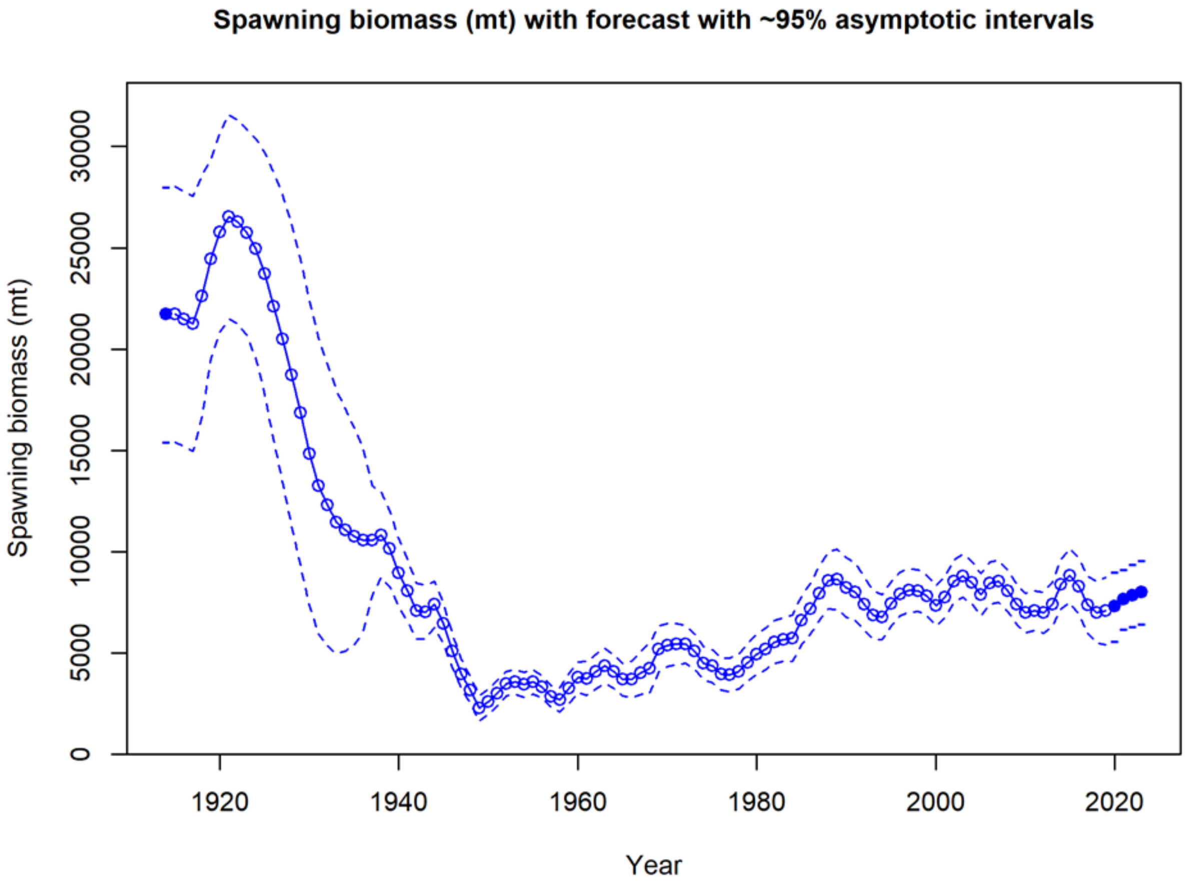

Figure A 6.3. Time series showing absolute spawning biomass with confidence intervals..

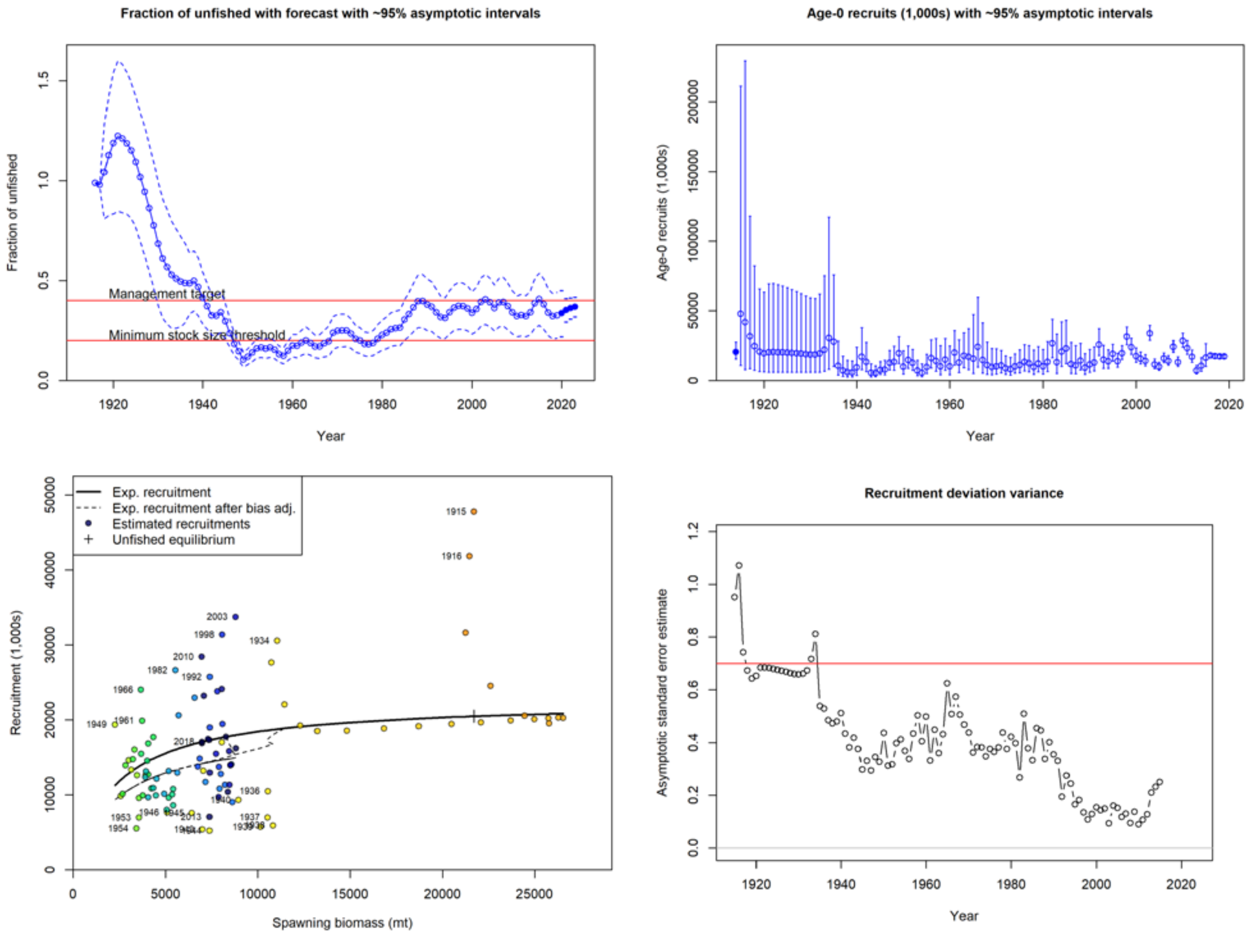

Figure A 6.4. Time series showing depletion of spawning biomass with confidence intervals, recruitment estimates with confidence intervals, stock recruitment curve and recruitment deviation variance check for tiger flathead.

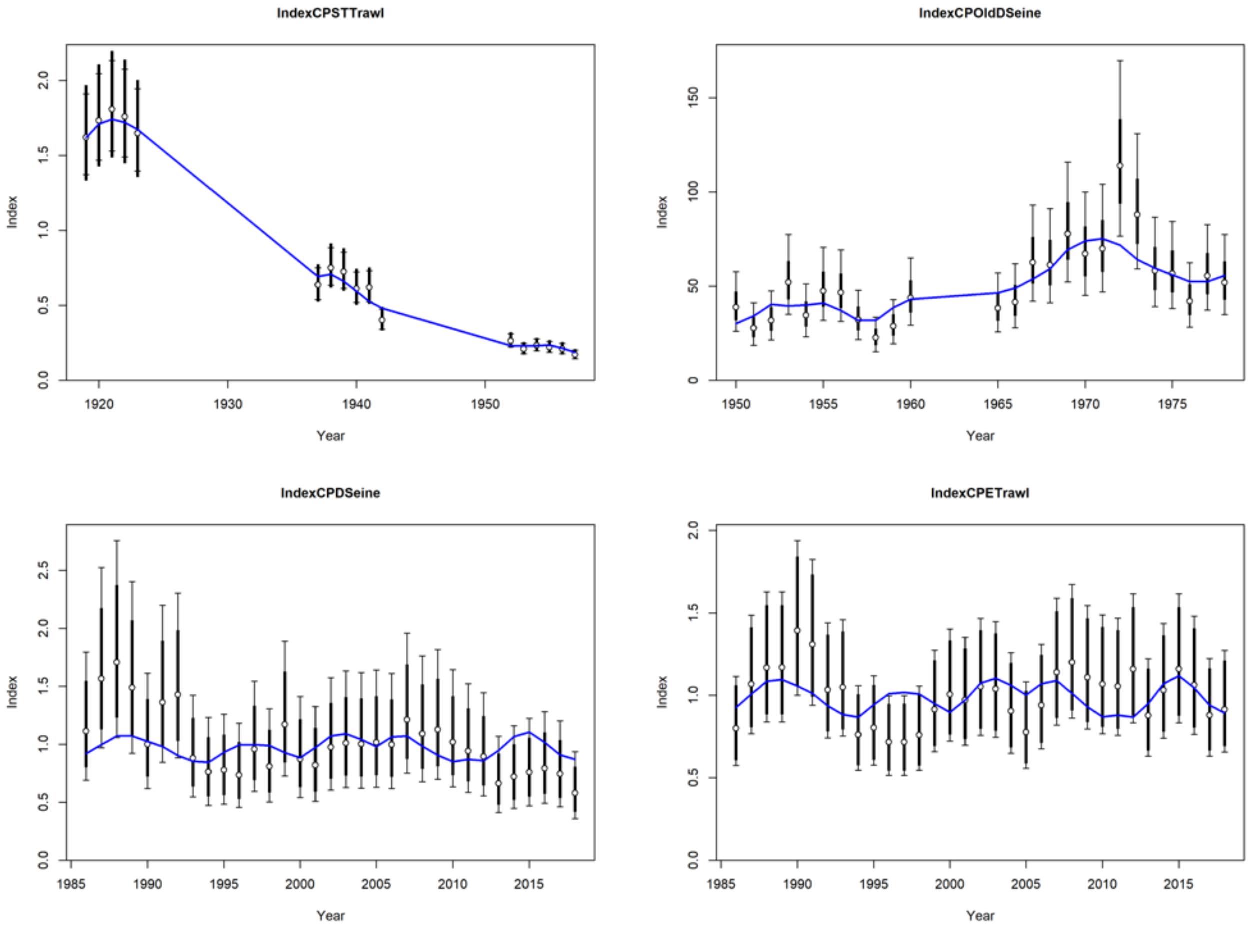

Figure A 6.5. Fits to CPUE by fleet for tiger flathead: steam trawl, old Danish seine, Danish seine, eastern trawl.

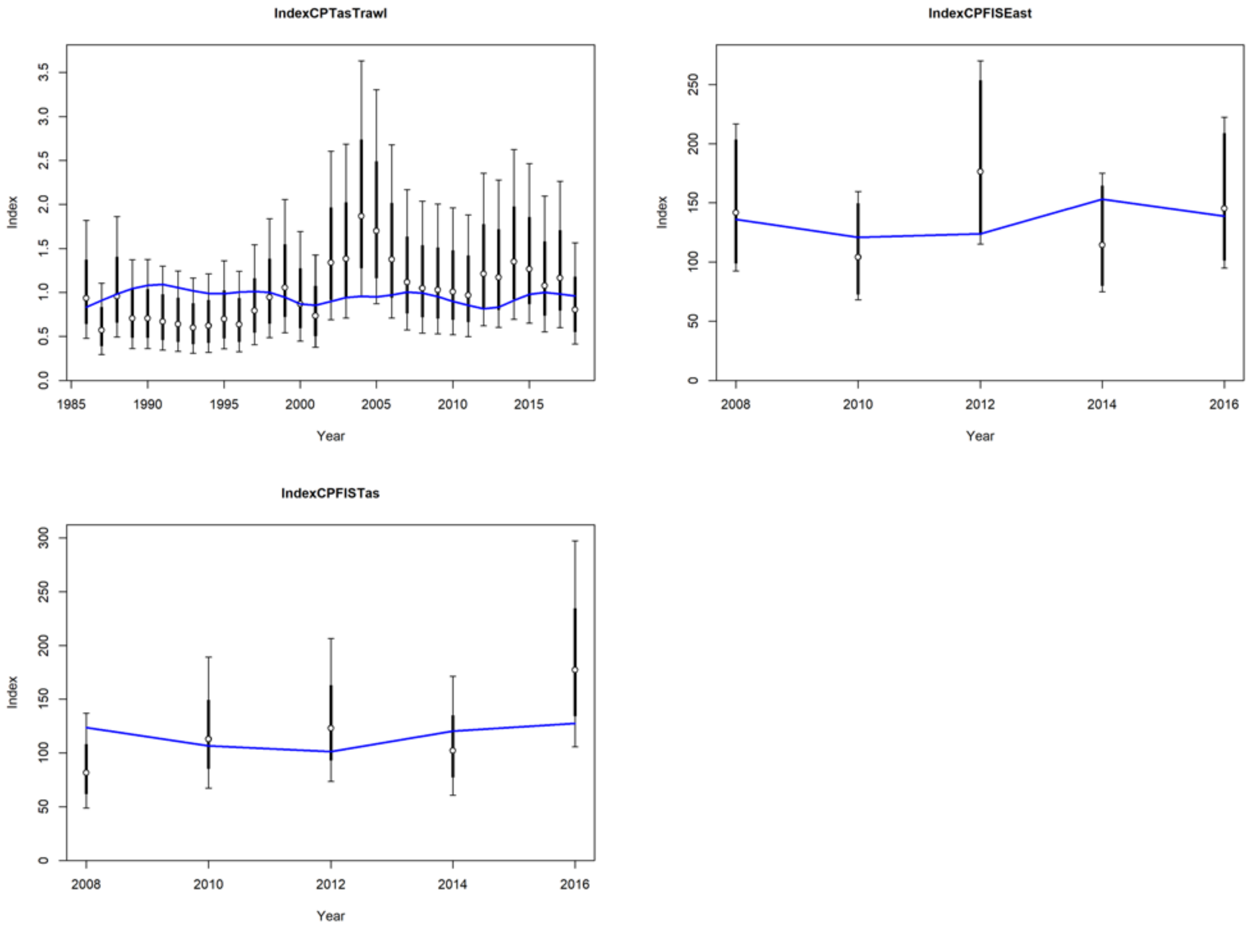

Figure A 6.6. Fits to CPUE by fleet for tiger flathead: Tasmanian trawl and the Fishery Independent Survey.

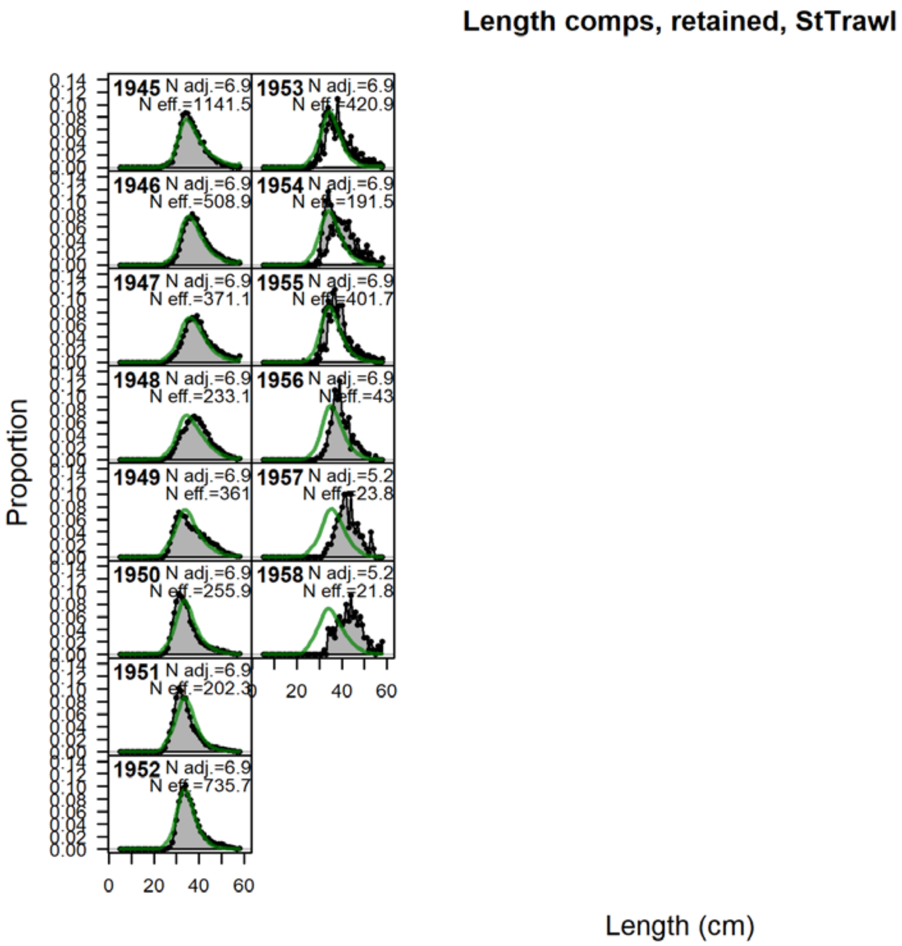

Figure A 6.7. Tiger flathead length composition fits: steam trawl retained.

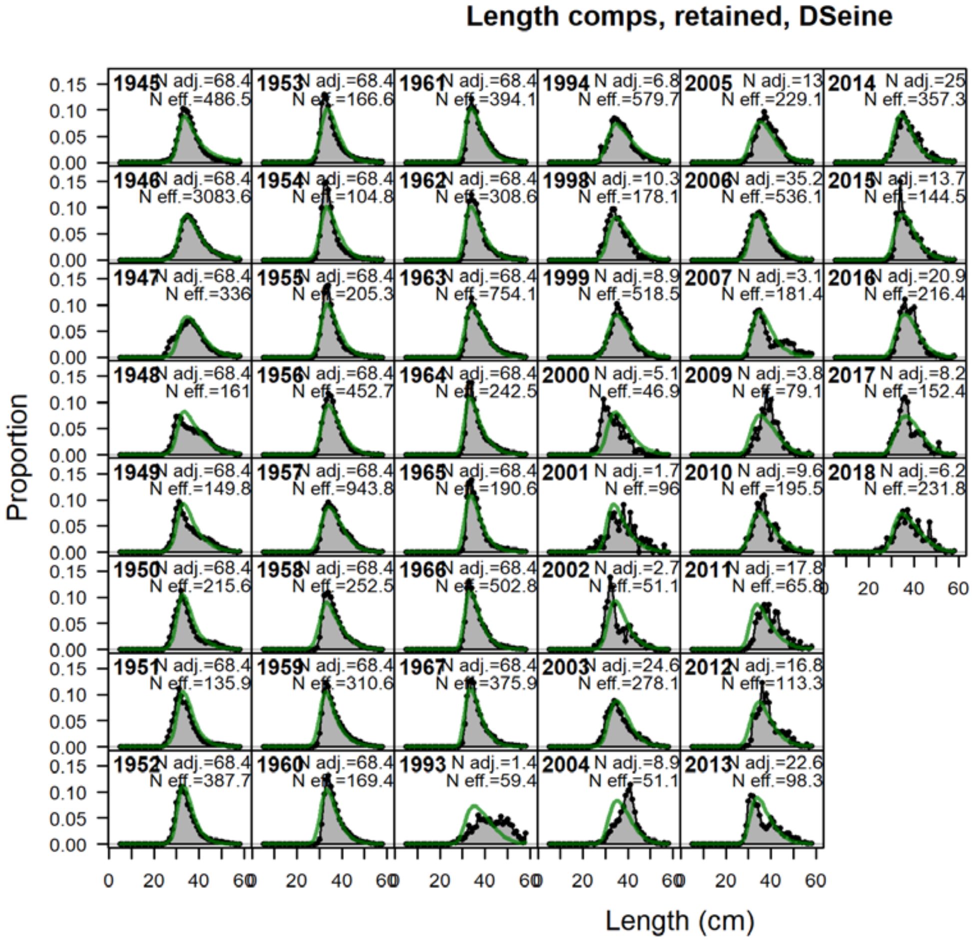

Figure A 6.8. Tiger flathead length composition fits: Danish seine retained.

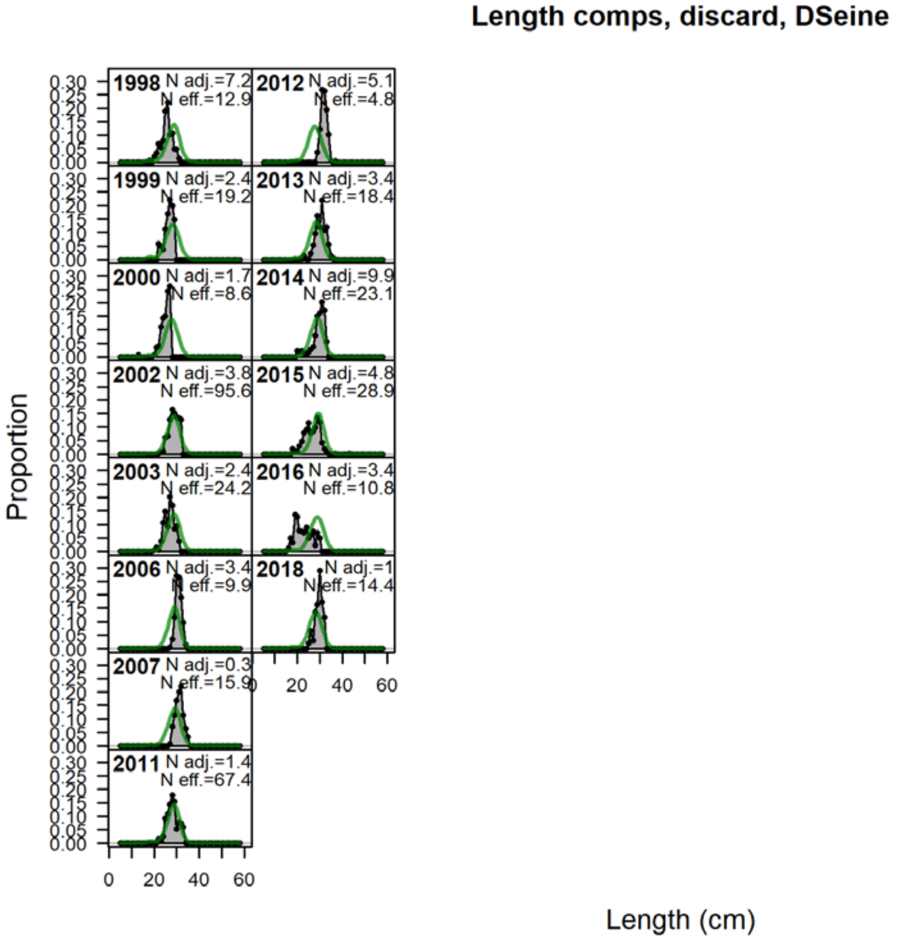

Figure A 6.9. Tiger flathead length composition fits: Danish seine discarded.

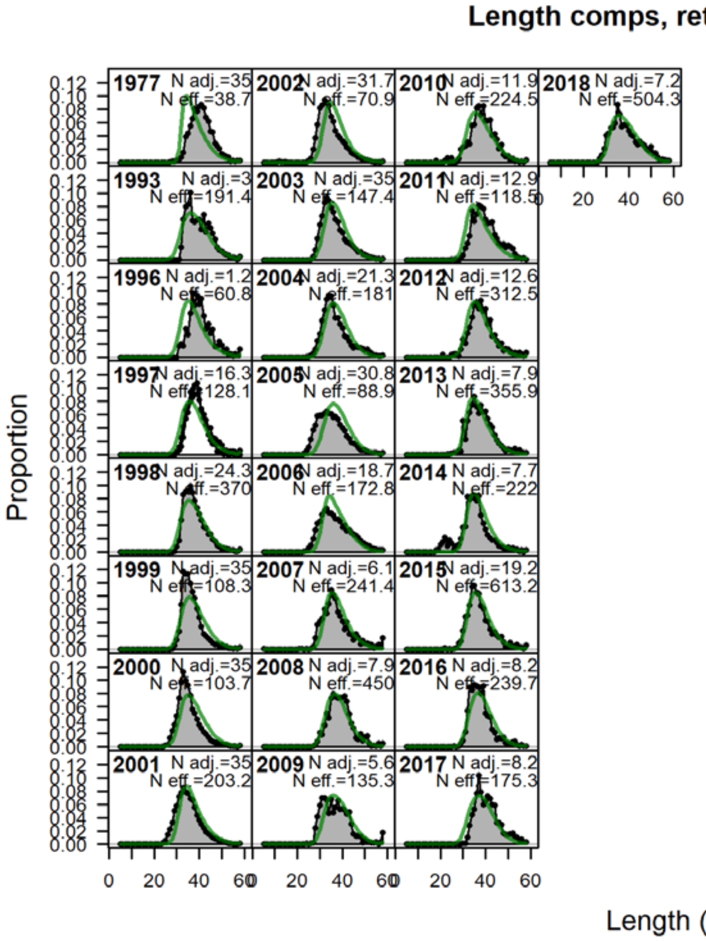

Figure A 6.10. Tiger flathead length composition fits: eastern trawl retained.

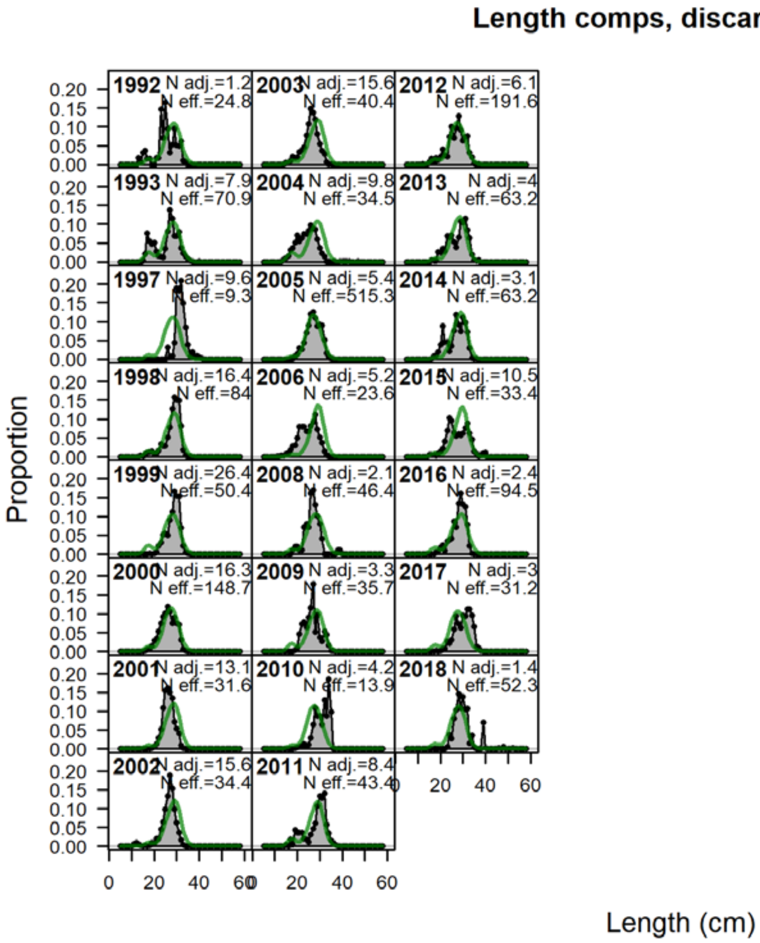

Figure A 6.11. Tiger flathead length composition fits: eastern trawl discarded.

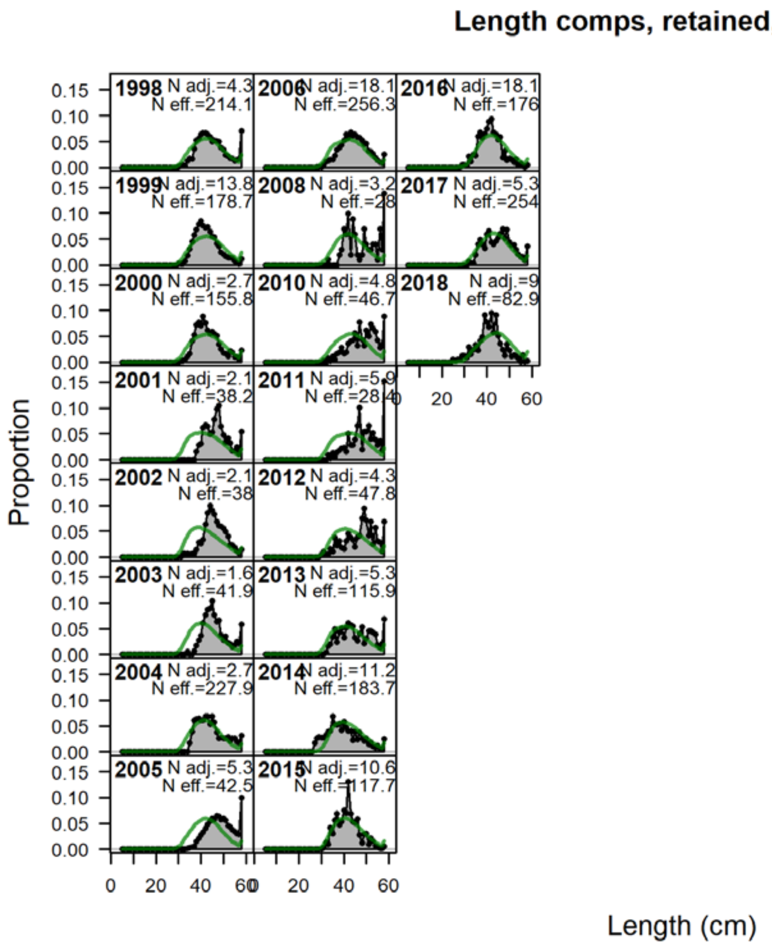

Figure A 6.12. Tiger flathead length composition fits: Tasmanian trawl retained.

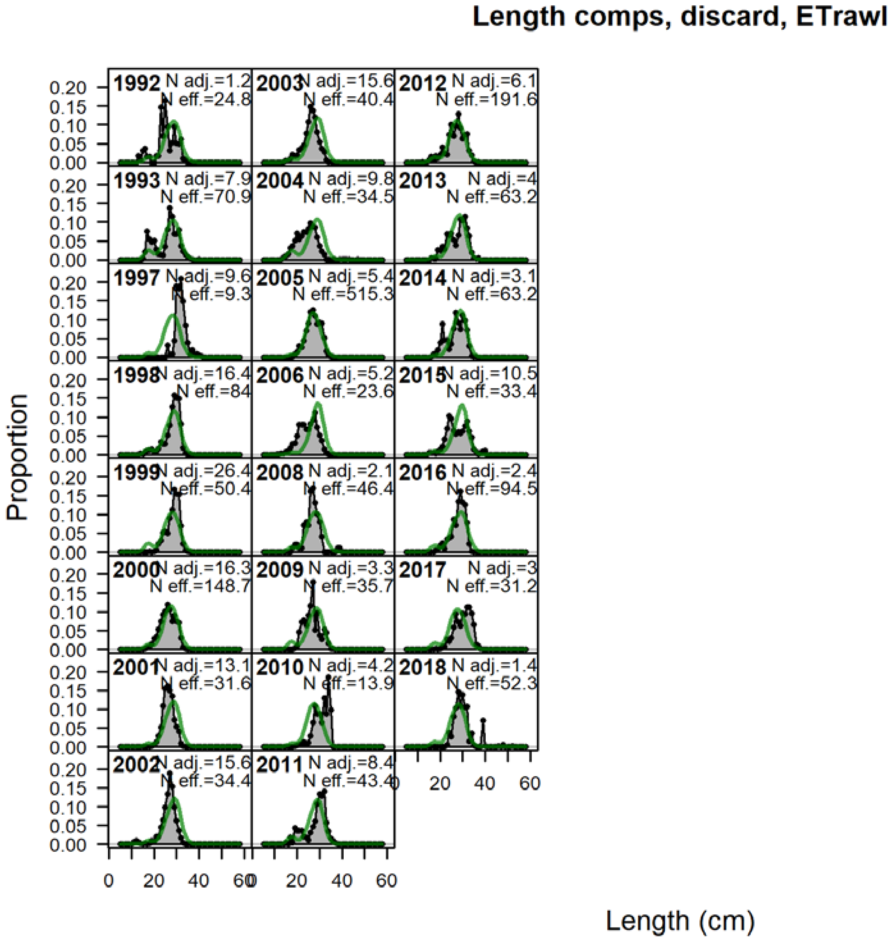

Figure A 6.13. Tiger flathead length composition fits: eastern trawl discarded.

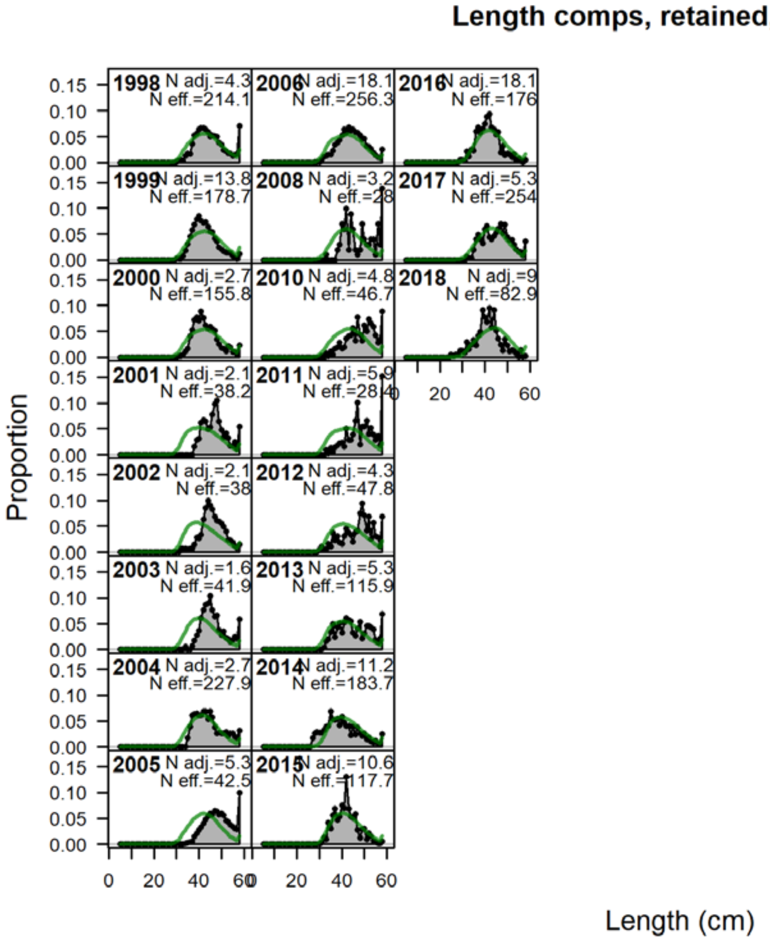

Figure A 6.14. Tiger flathead length composition fits: Tasmanian trawl retained.

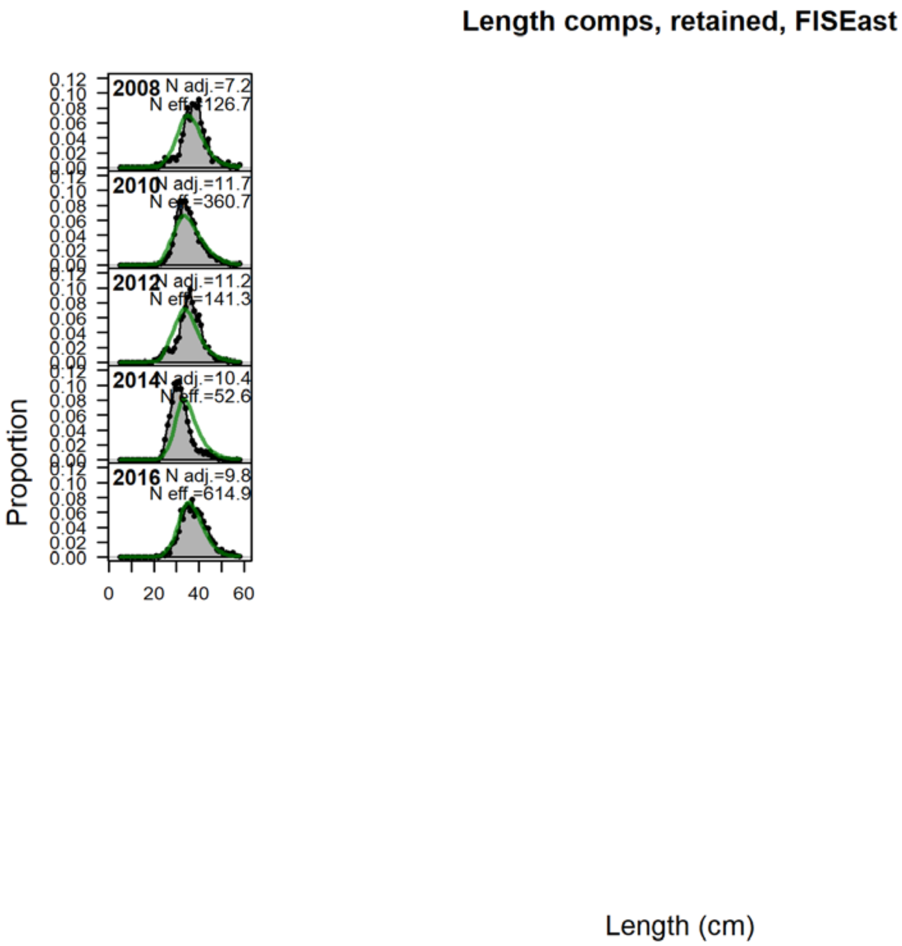

Figure A 6.15. Tiger flathead length composition fits: eastern FIS

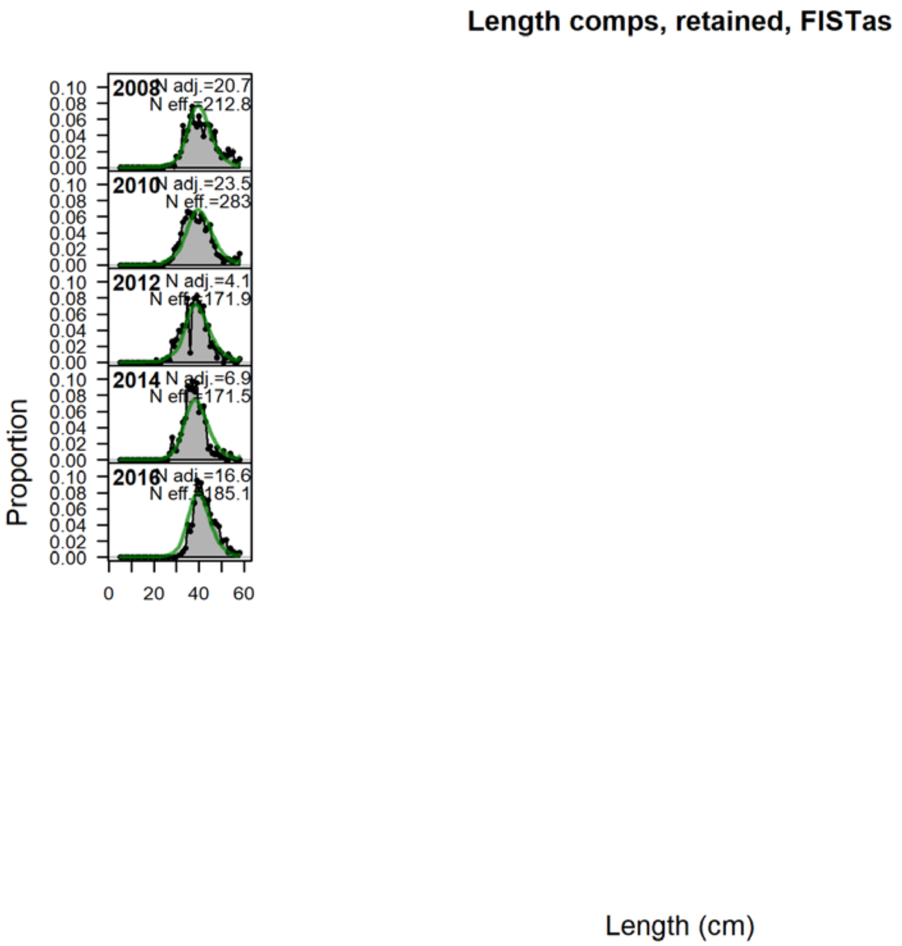

Figure A 6.16. Tiger flathead length composition fits: Tasmanian FIS.

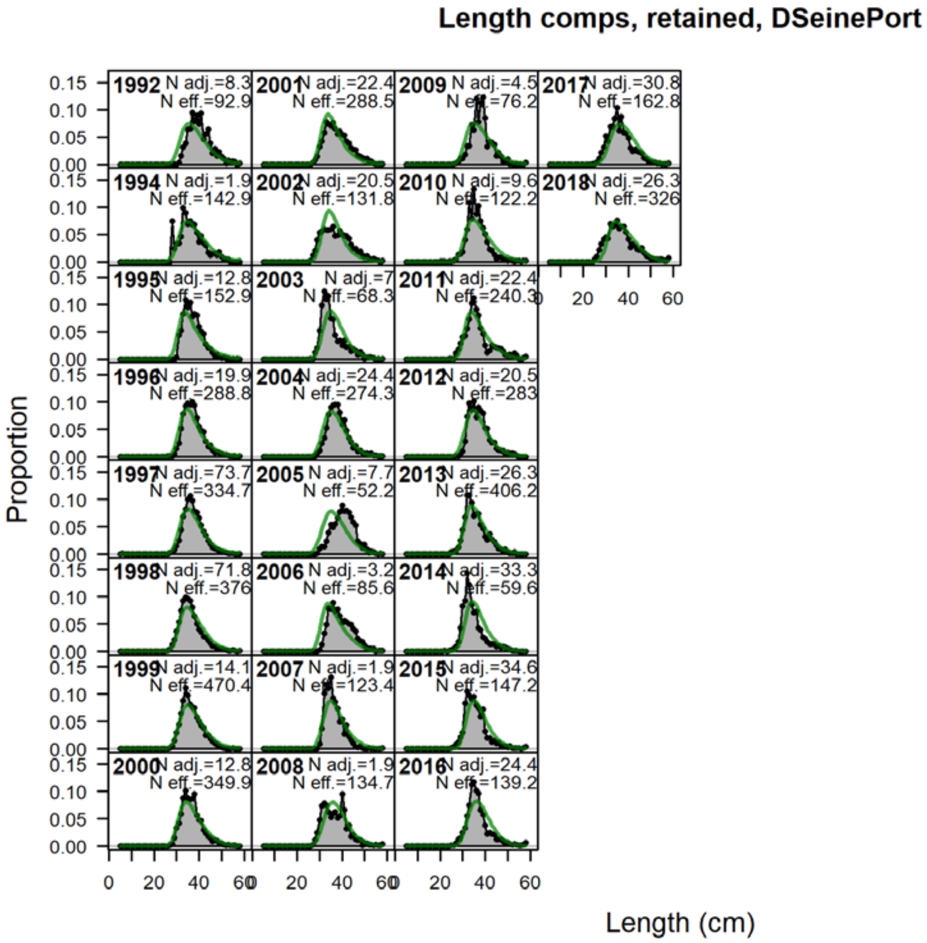

Figure A 6.17. Tiger flathead port length composition fits: Danish seine.

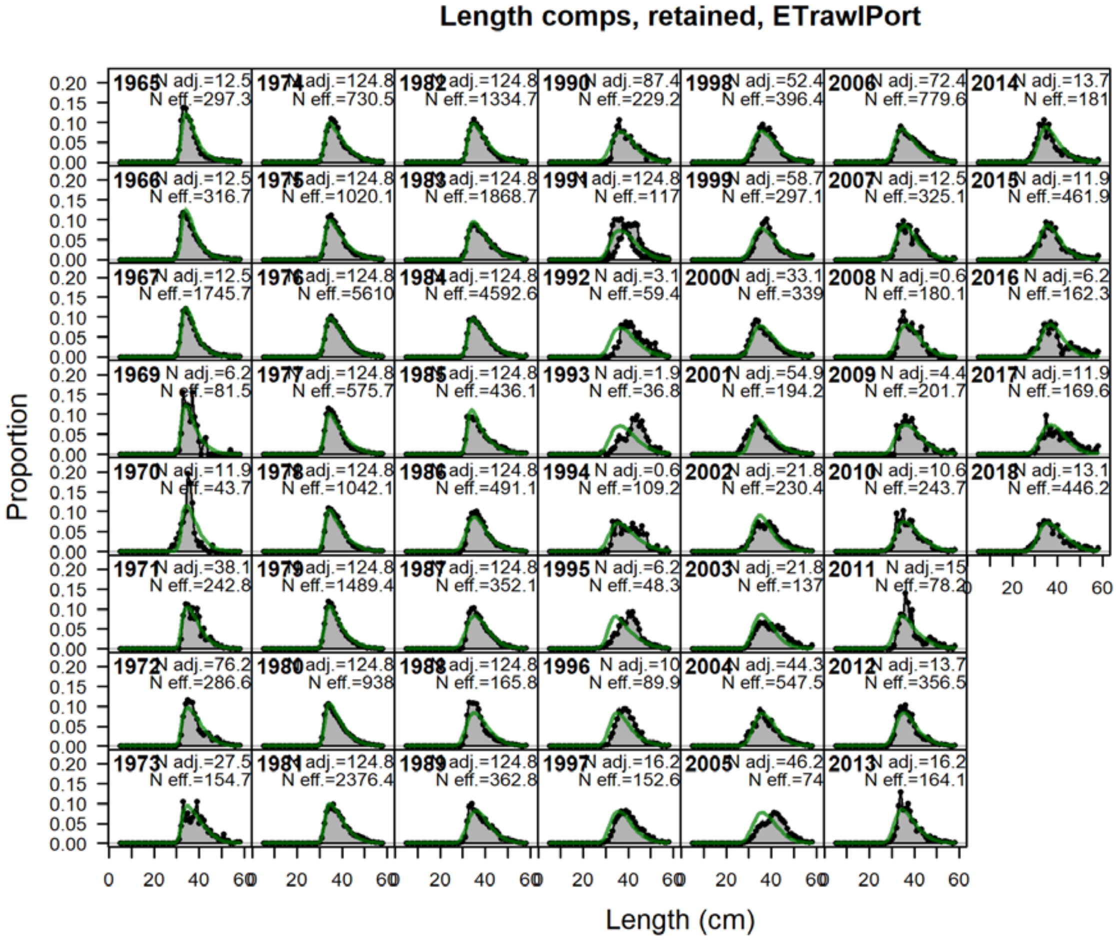

Figure A 6.18. Tiger flathead port length composition fits: eastern trawl.

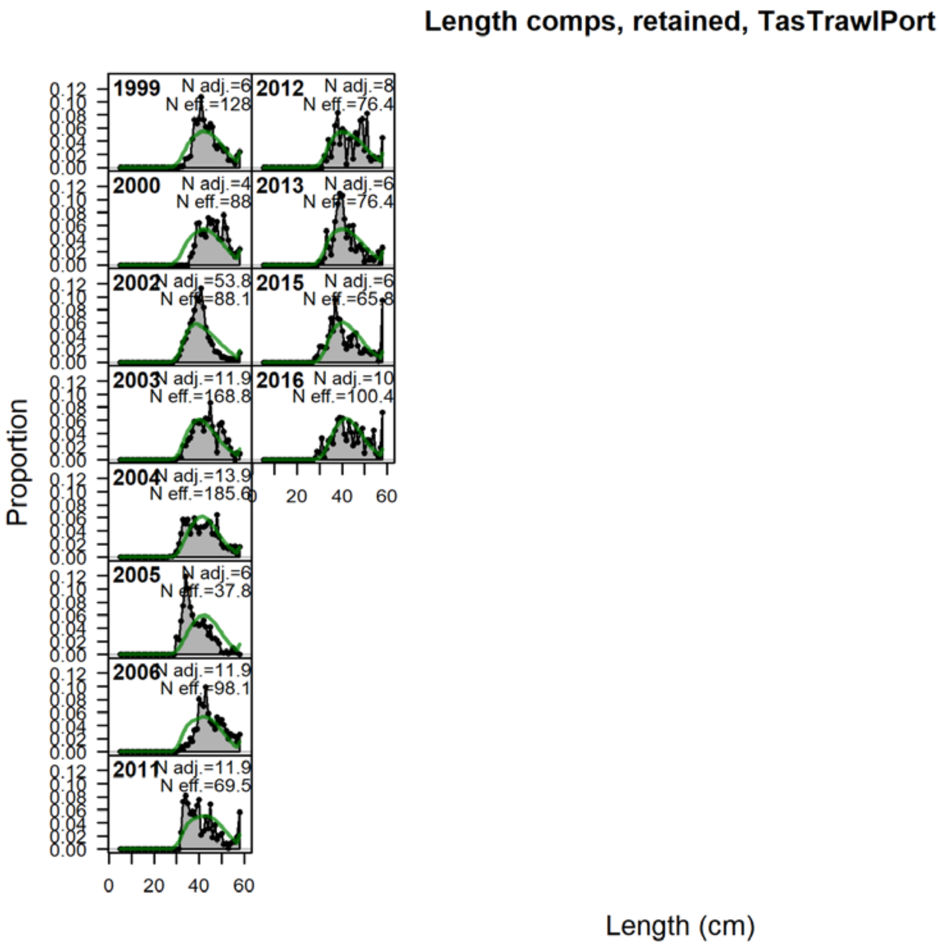

Figure A 6.19. Tiger flathead port length composition fits: Tasmanian trawl.

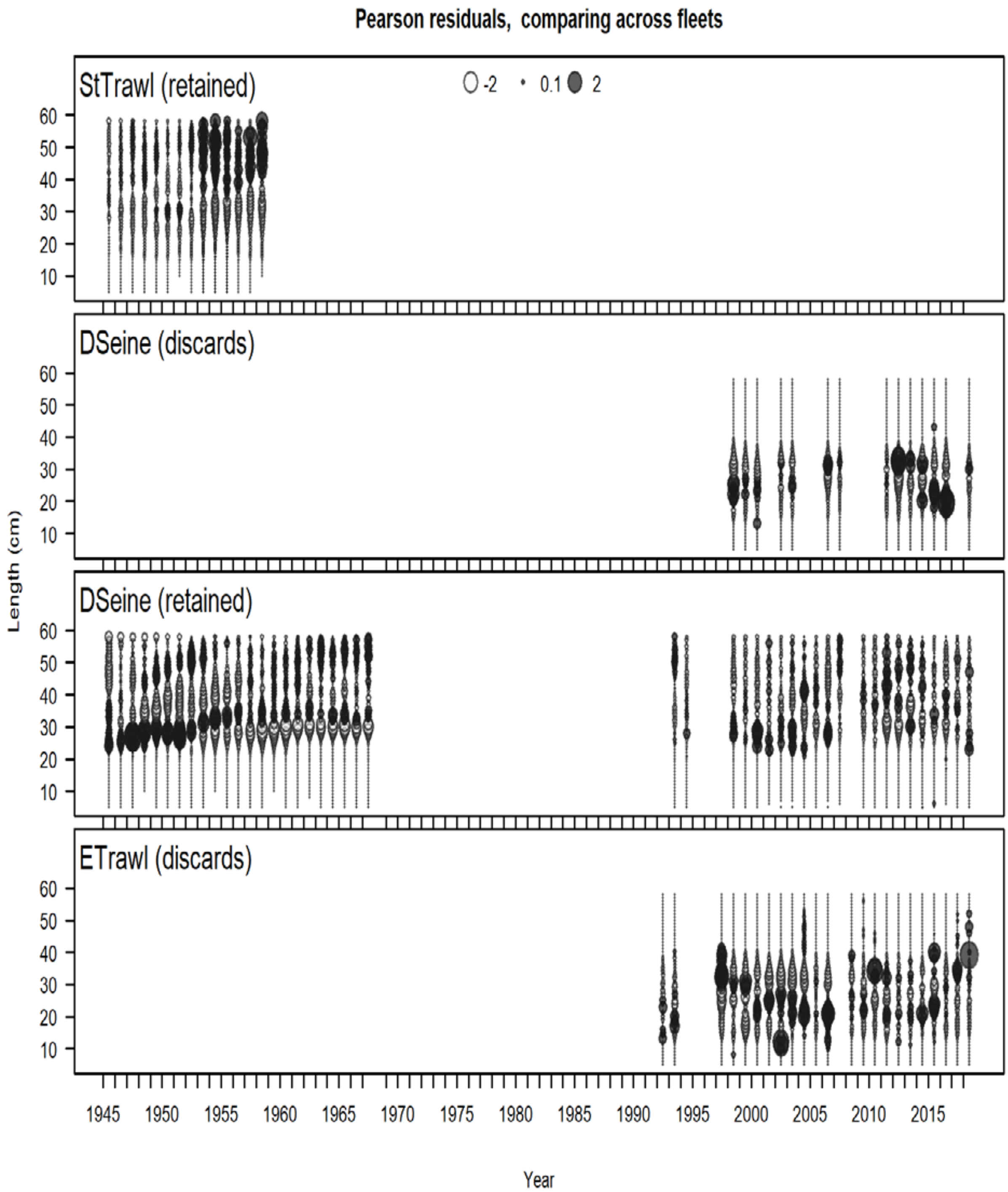

Figure A 6.20. Residuals from the annual length compositions (retained) for tiger flathead displayed by year and fleet.

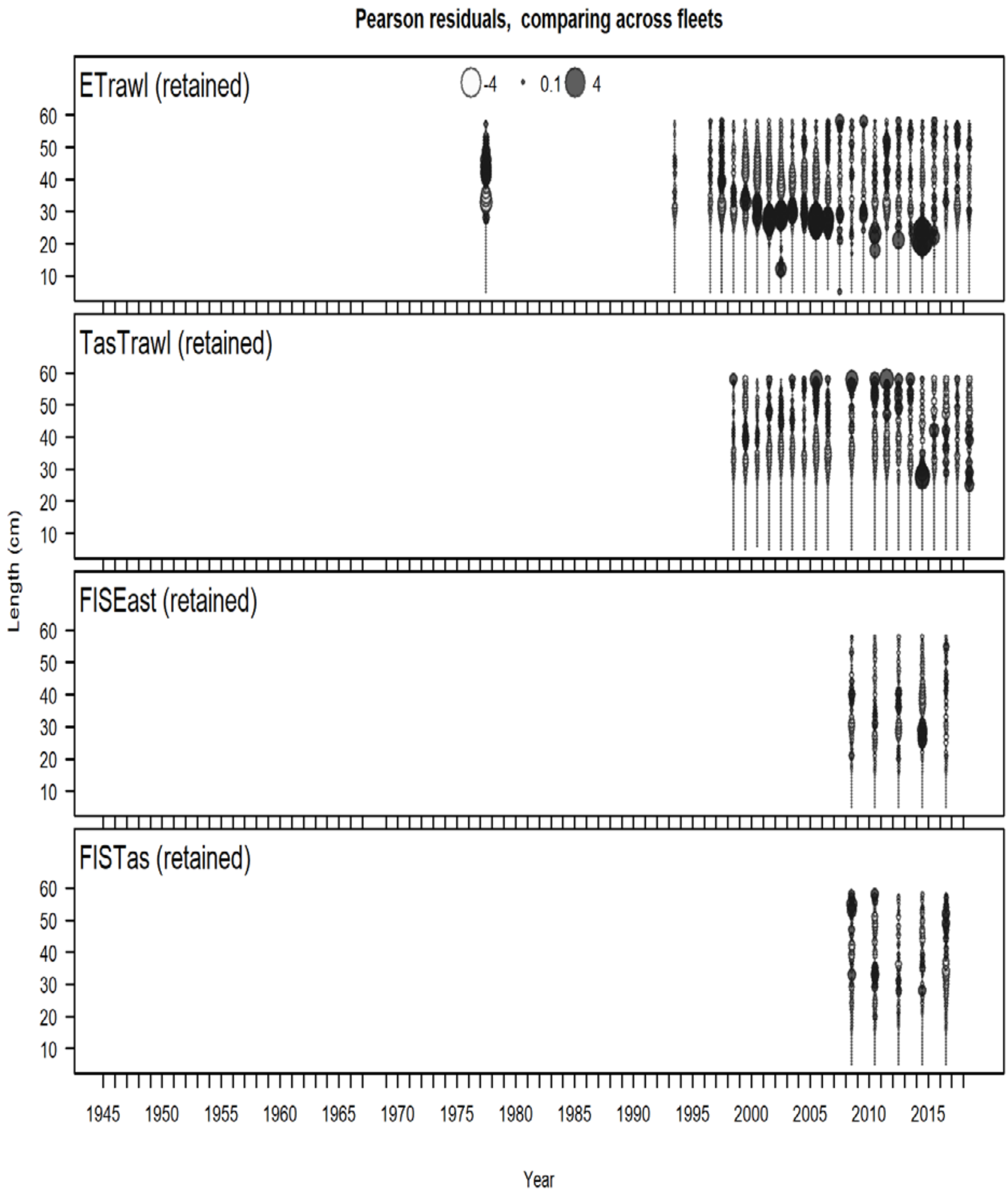

Figure A 6.21. Residuals from the annual length compositions (discarded) for tiger flathead displayed by year and fleet.

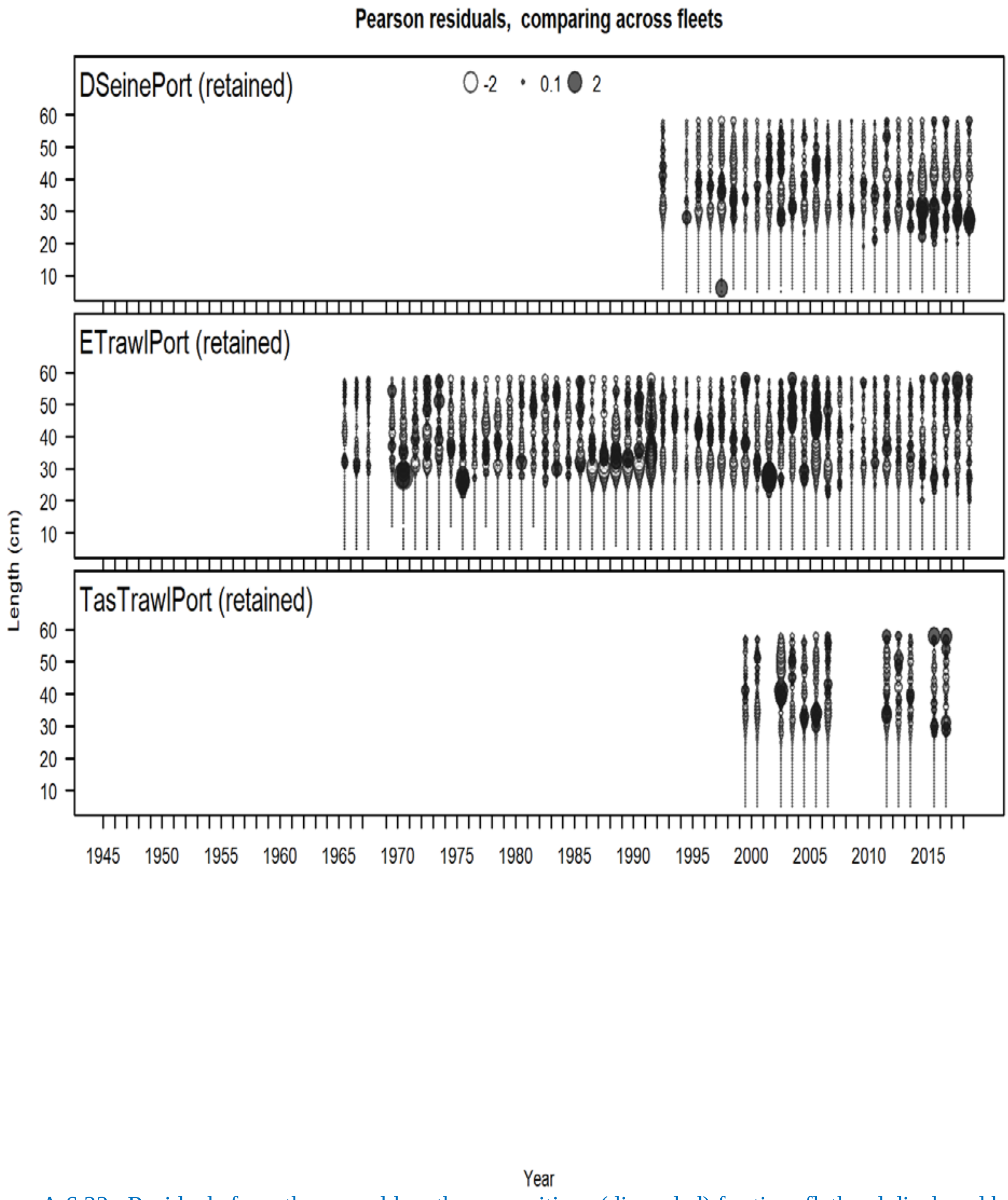

Figure A 6.22. Residuals from the annual length compositions (discarded) for tiger flathead displayed by year and fleet

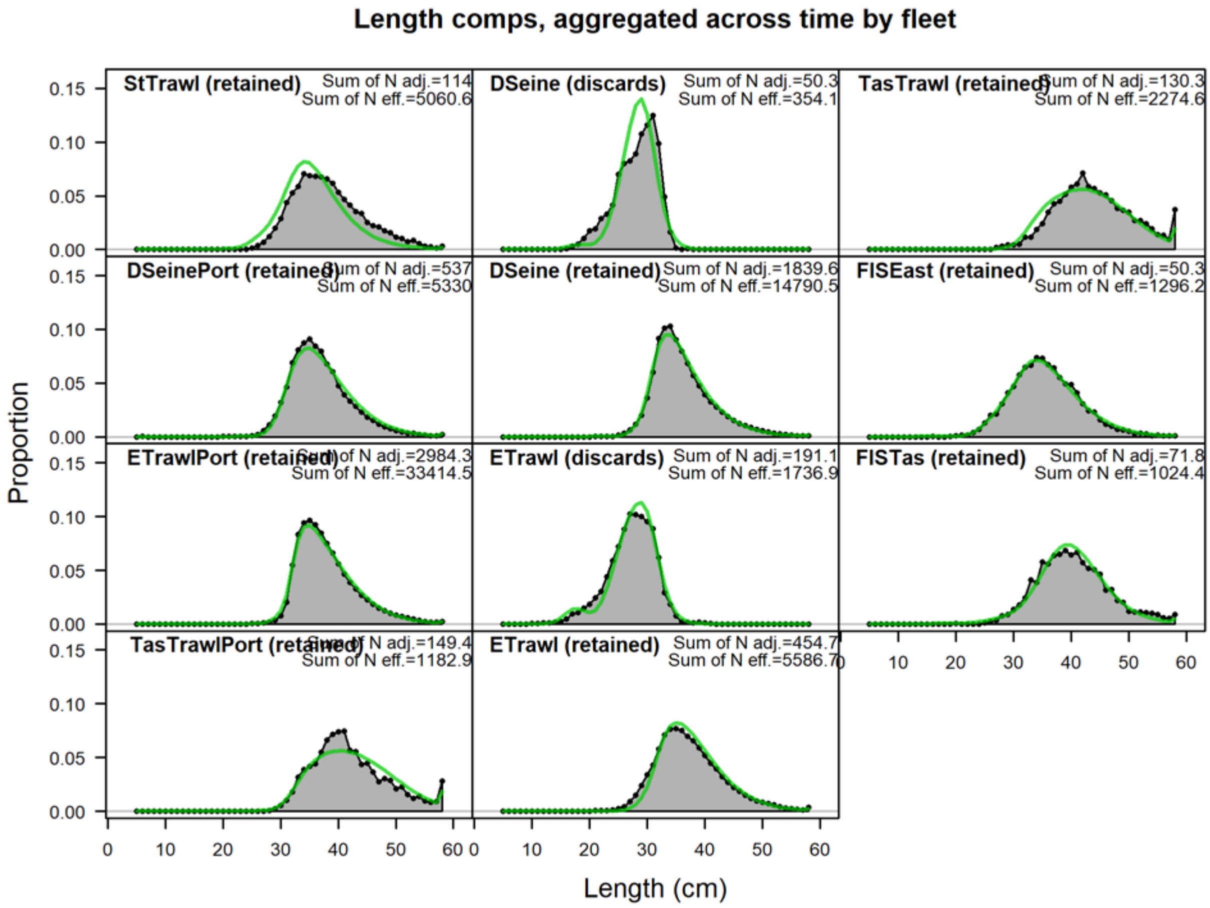

Figure A 6.23. Aggregated fits (over all years) to the length compositions for tiger flathead displayed by fleet.

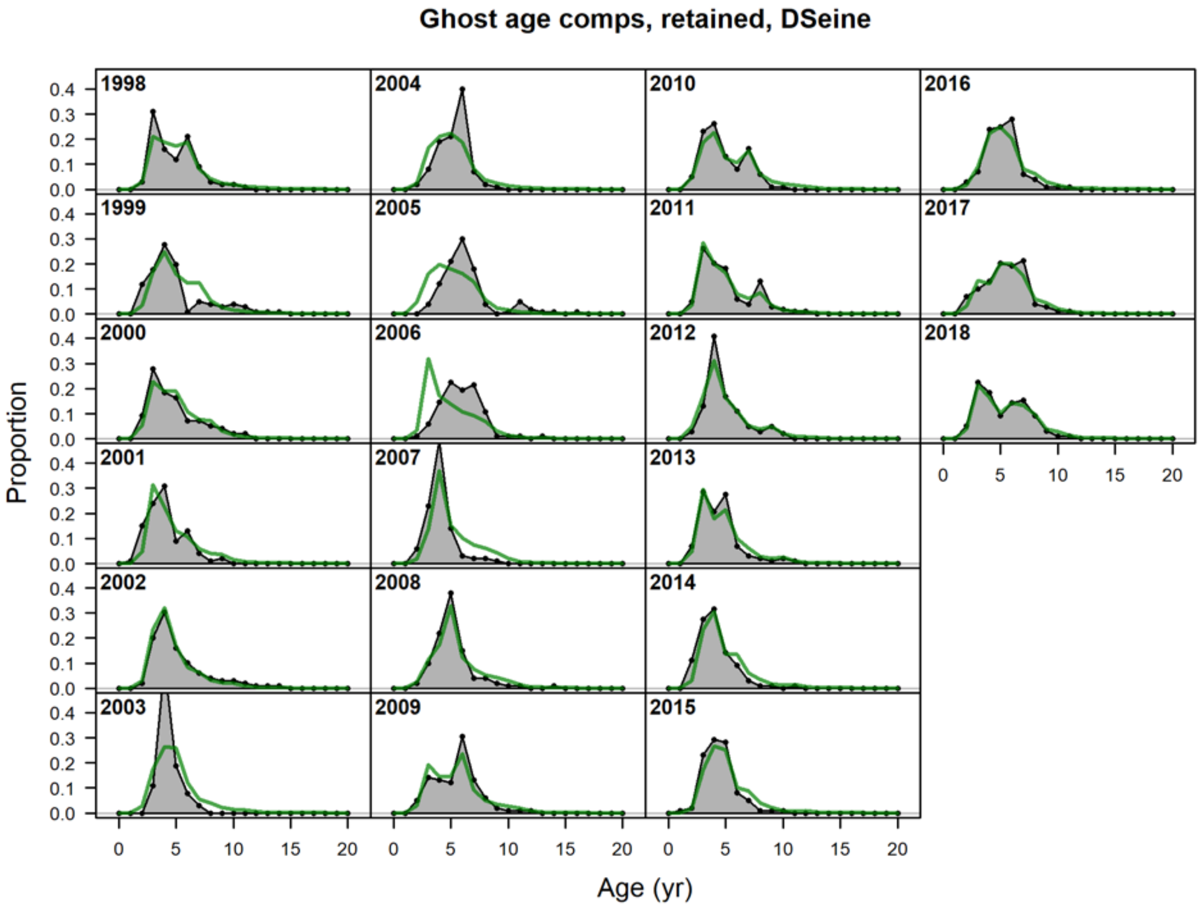

Figure A 6.24. Tiger flathead implied fits to age: Danish seine onboard retained.

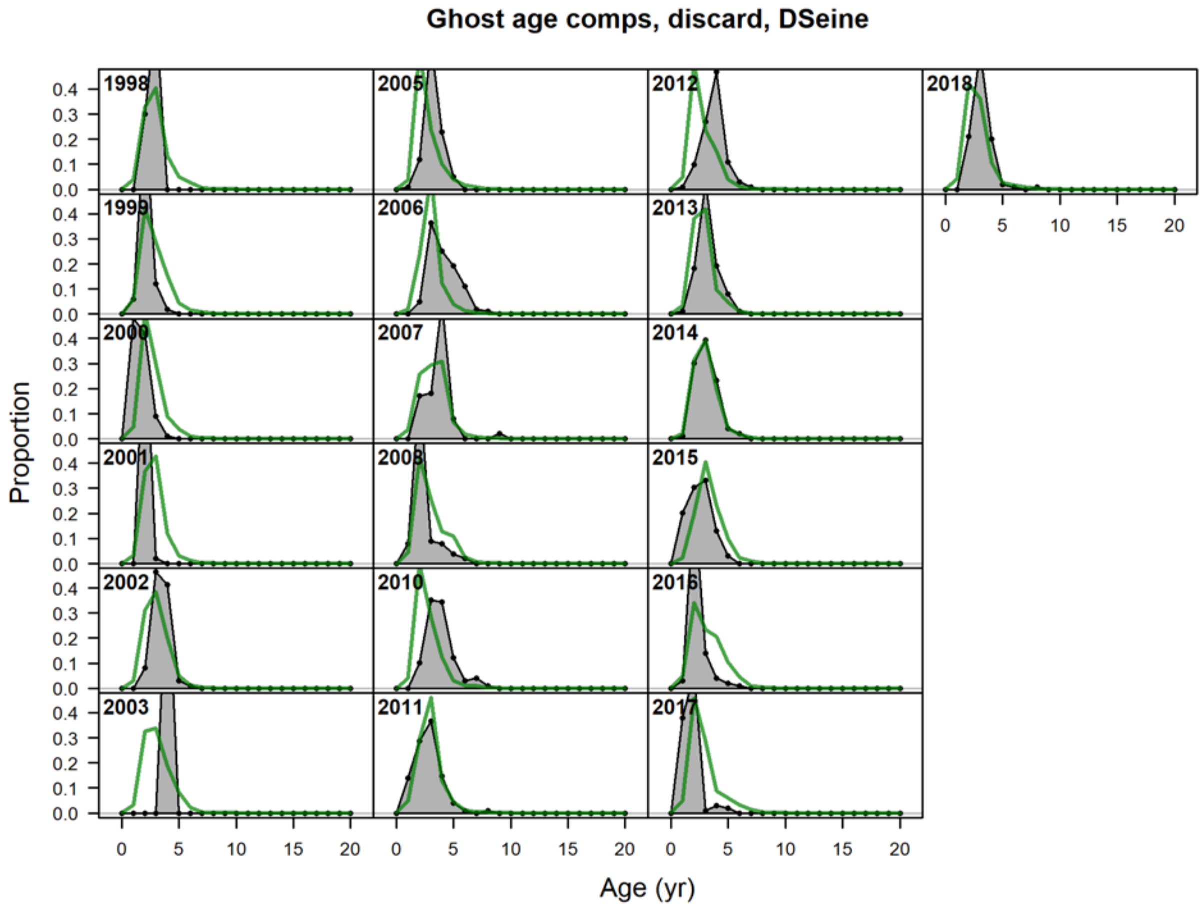

Figure A 6.25. Tiger flathead implied fits to age: Danish seine onboard discarded.

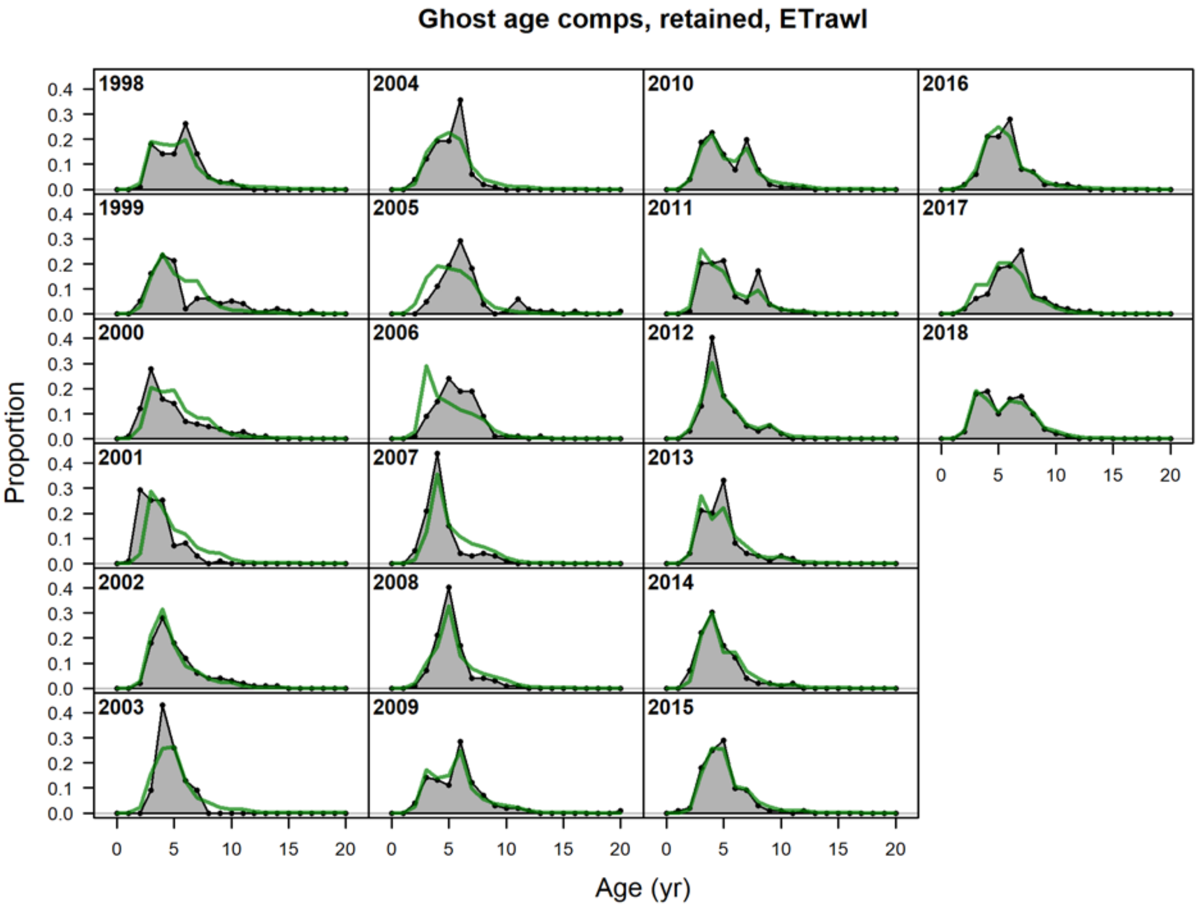

Figure A 6.26. Tiger flathead implied fits to age: Eastern trawl onboard retained.

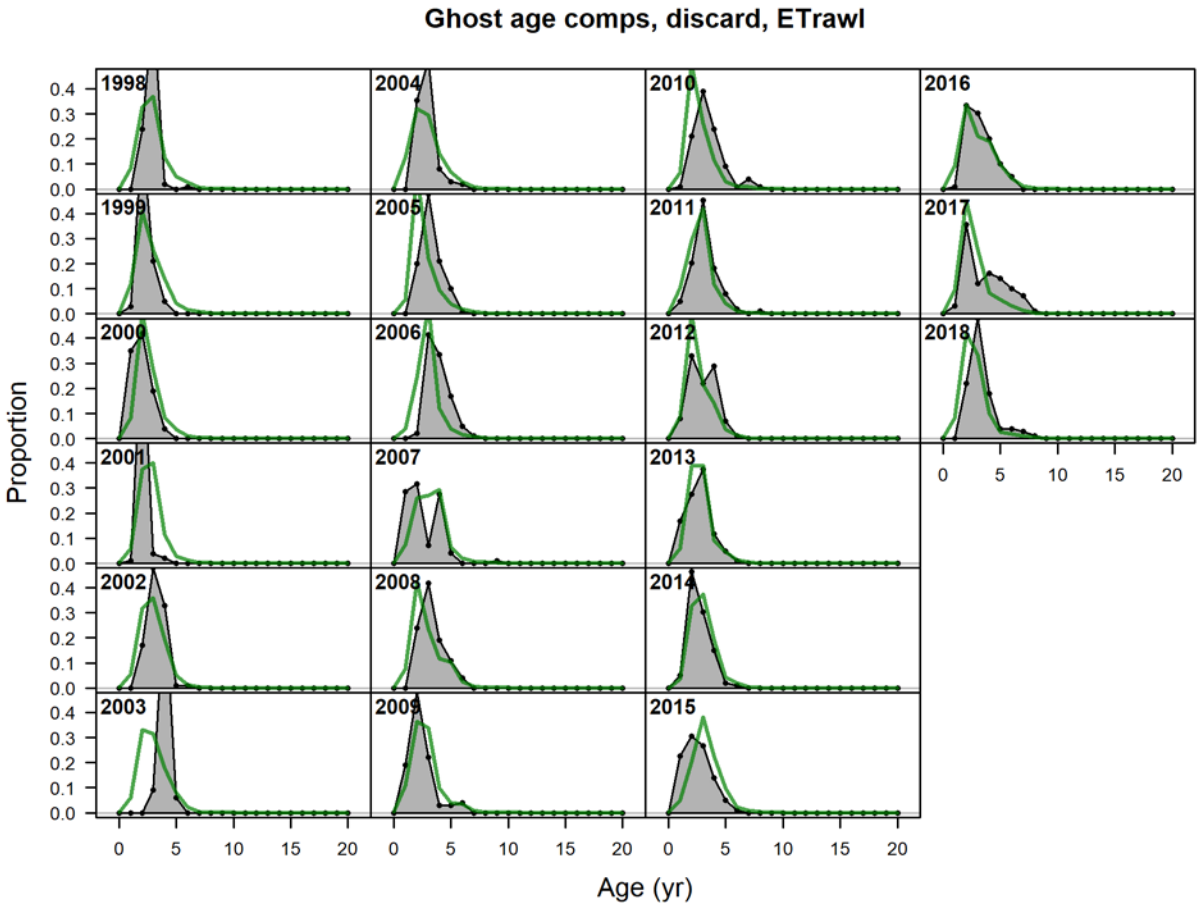

Figure A 6.27. Tiger flathead implied fits to age: Eastern trawl onboard discarded.

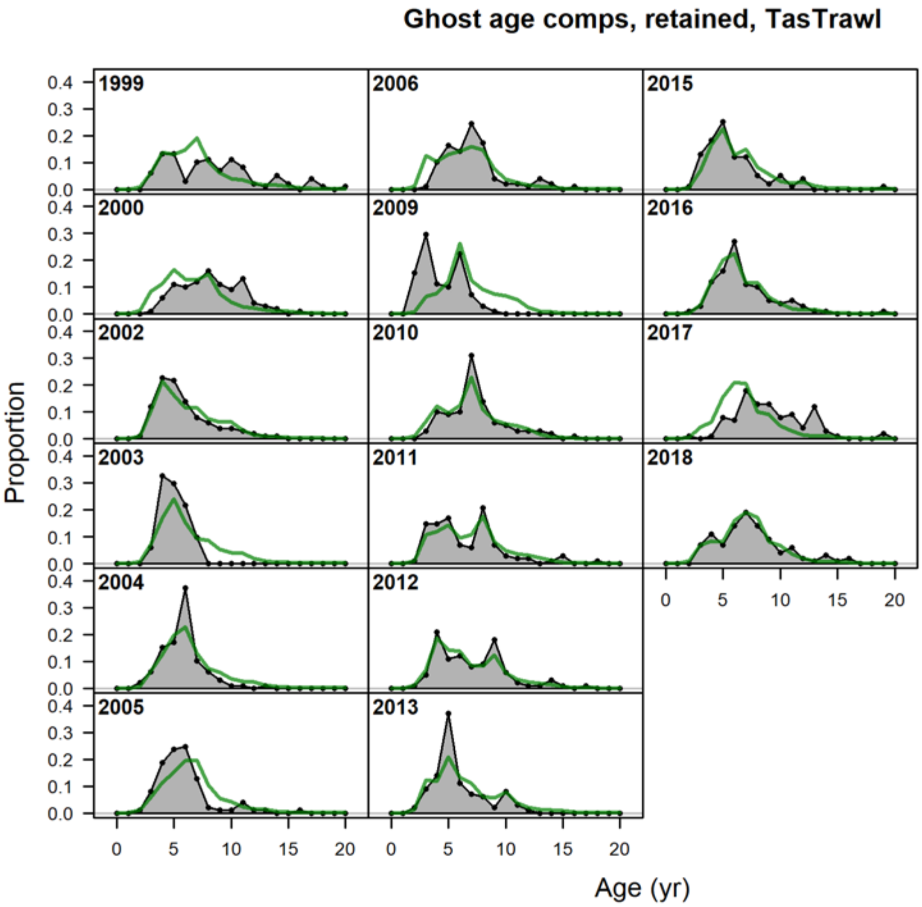

Figure A 6.28. Tiger flathead implied fits to age: Tasmanian trawl onboard retained.

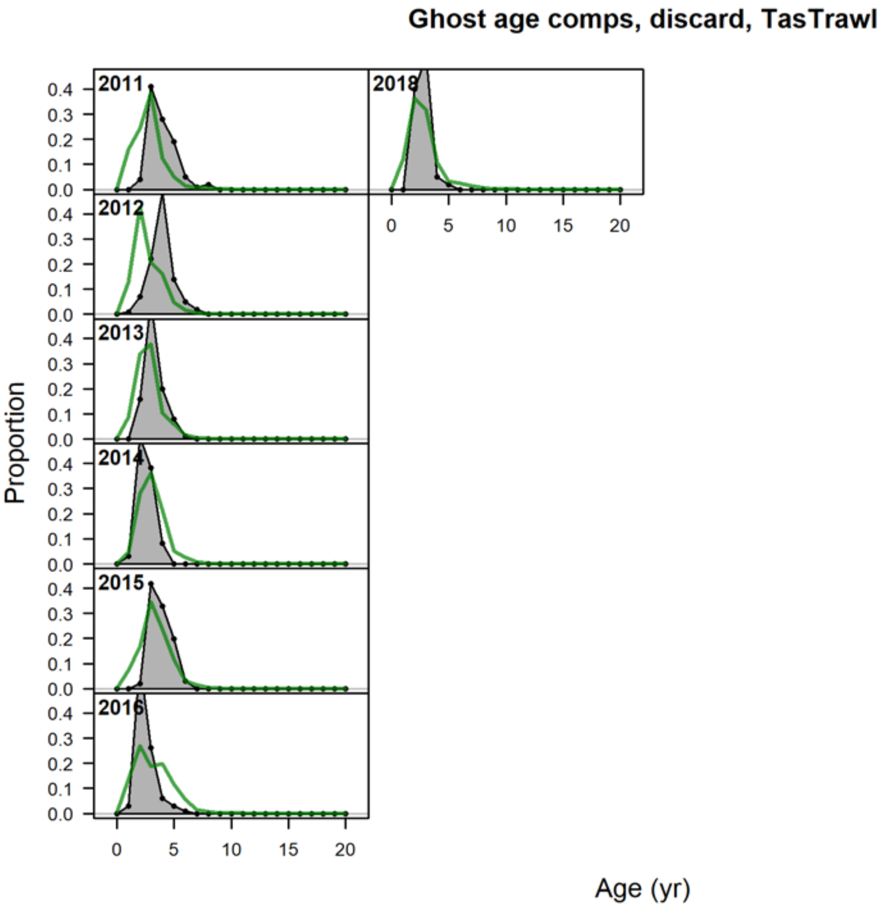

Figure A 6.29. Tiger flathead implied fits to age: Tasmanian trawl onboard discarded.

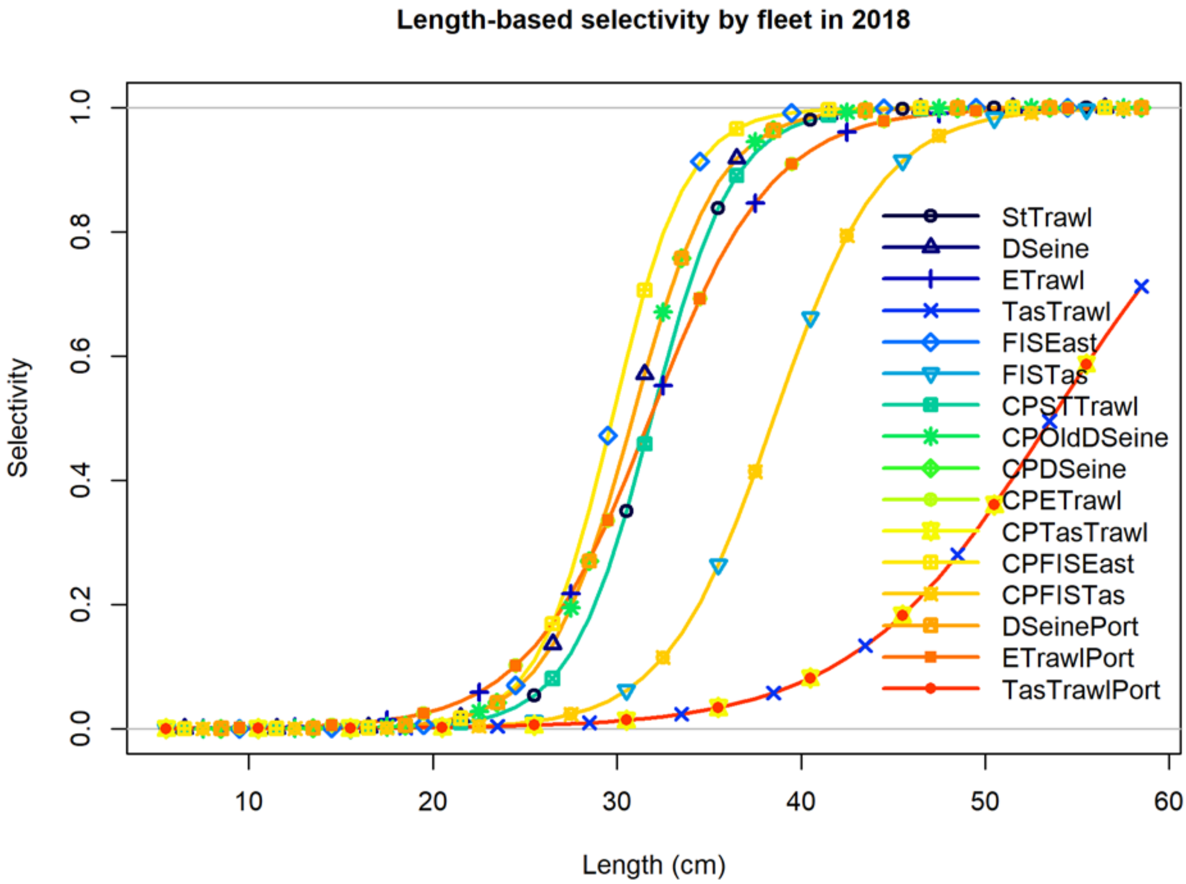

Figure A 6.30. Estimated selectivity curves for tiger flathead. There are only six different selectivity patterns listed here, with port and onboard fleets having the same selectivity and the "CP" fleets replicating the catch fleets. In some cases, the identical selectivity for three "fleets" are overwritten, as they actually represent only a single fleet.

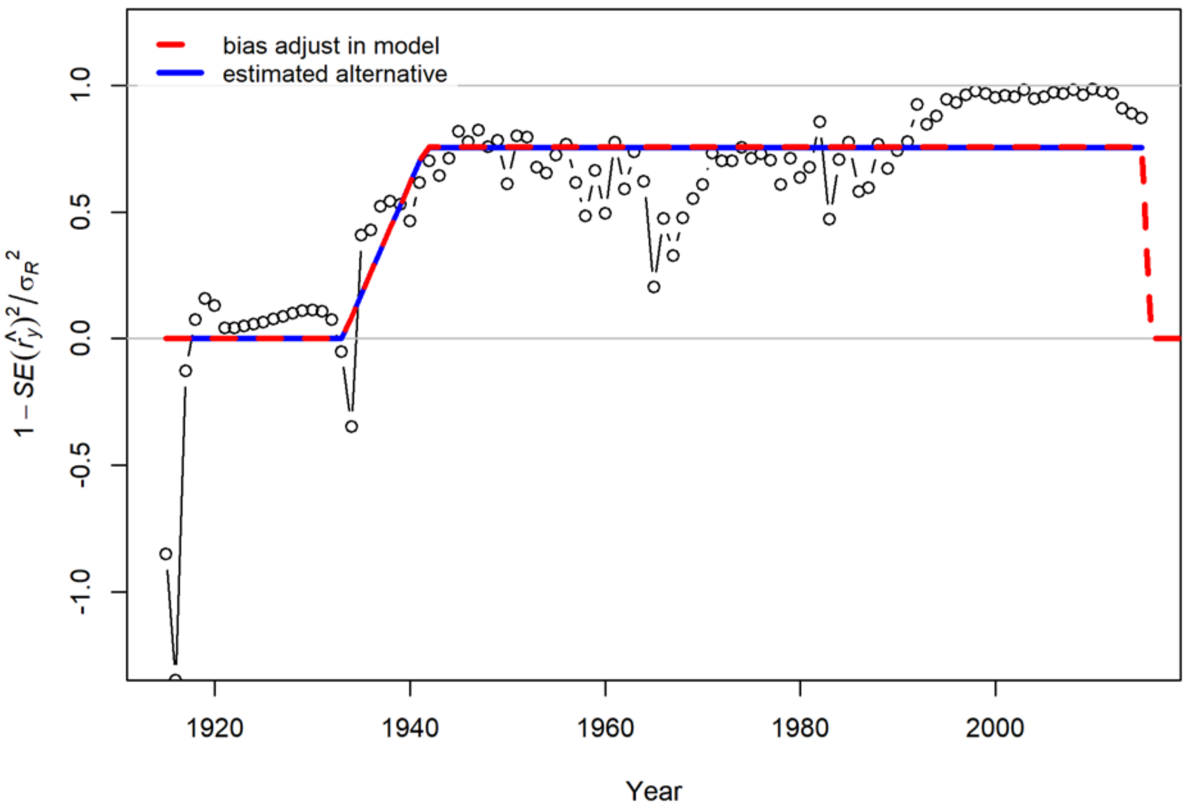

Figure A 6.31. Bias ramp adjustment for tiger flathead.

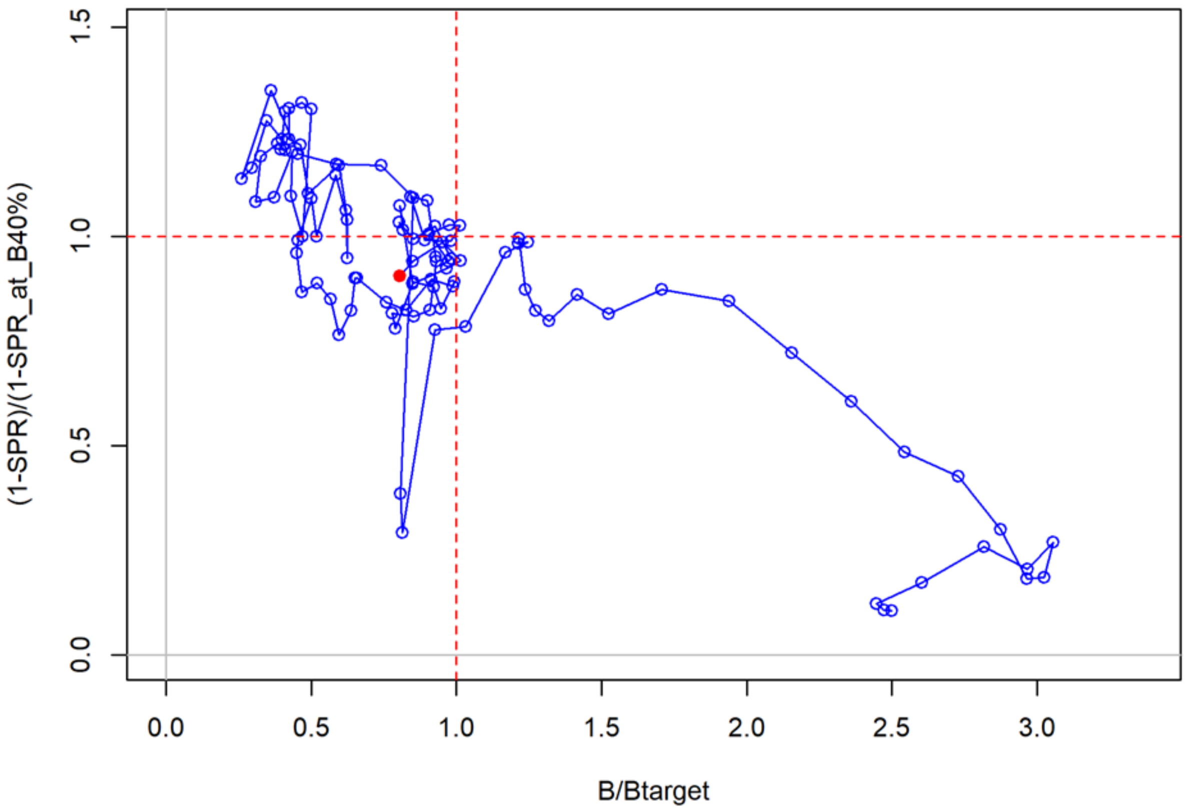

Figure A 6.32. Phase plot of biomass vs SPR ratio.

7. Tiger flathead (*Neoplatycephalus richardsoni)* stock assessment based on data up to 2018

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7.1 Executive Summary

This document updates the 2016 assessment of tiger flathead (*Neoplatycephalus richardsoni*) to provide estimates of stock status in the SESSF at the start of 2020. This assessment was performed using the stock assessment package Stock Synthesis (version SS-V3.30.14). The 2016 stock assessment has been updated with the inclusion of data up to the end of 2018, comprising an additional three years of catch, discard, CPUE, length and age data and ageing error updates. An additional 2016 survey point is included from the Fishery Independent Survey (FIS) and FIS length frequencies have been included from the winter 2016 FIS and summer 2008, 2010 and 2012 FIS. A range of sensitivities were explored.

The base case assessment estimates that current spawning stock biomass is 34% of unexploited stock biomass (SSB_0), compared to 42% in the 2016 assessment (Day, 2017) and 50% from the 2013 assessment (Day and Klaer, 2013). Under the agreed 20:35:40 harvest control rule, the 2020 recommended biological catch (RBC) is 2,334 t, and is below the long-term yield (assuming average recruitment in the future) of 2,986 t. The average RBC over the three-year period 2020-2022 is 2,563 t and over the five-year period 2020-2024, the average RBC is 2,648 t.

Exploration of model sensitivity showed a variation in spawning biomass from 27% to 41% of SSB_0, which occurred when natural mortality was fixed at values of 0.22 and 0.32 respectively. For the other standard sensitivities explored, the variation in spawning biomass was much narrower, ranging between 32% and 34%.

Changes to the last stock assessment include: using the FIS3 abundance indices; including summer FIS length frequencies; incorporation of conditional age-at-length data for 2008 from the FIS; and updating the tuning method and bias ramp estimation. This change in stock status is largely due to below average newly estimated recruitment events, particularly in 2013 but also in 2014, and a revision to the previously estimated 2012 recruitment event. The 2013 poor recruitment is supported both by the age and length data and by the recent index data, and the updated assessment fits all of these data sources well.

7.2 Introduction

7.2.1 *The fishery*

Tiger flathead have been caught commercially in the south eastern region of Australia since the development of the trawl fishery in 1915. They are endemic to Australian waters and are caught mainly on the continental shelf and upper slope waters from northern NSW to Tasmania and through Bass Strait. Historical records (e.g. Fairbridge, 1948; Allen, 1989; Klaer, 2005) show that steam trawlers caught tiger flathead from 1915 to about 1960. A Danish seine trawl fishery developed in the 1930s (Allen, 1989) and continues to the present day. Modern diesel trawling commenced in the 1970s.

7.2.2 *Previous assessments*

Prior to 2001, the previous quantitative assessment for tiger flathead was from the late 1980s (Allen, 1989). In that report, the assessment for tiger flathead was conducted based on catch and effort data using a surplus production model. The estimate of Maximum Sustainable Yield, MSY, for NSW and eastern Bass Strait was about 2,500 t.

Between 1989 and 2001, assessments of tiger flathead involved examination of trends in catches, catch rates, and in age and length data, but no quantitative assessments were undertaken. Assessments from 1993 to 2001 can be found in the annual reports of SEFAG (the South East Fishery Assessment Group). For example, the 1993 assessment noted that tiger flathead catches from south-east Tasmanian waters contained higher proportions of larger, older fish than those from eastern Bass Strait. This suggested that tiger flathead resources off Tasmania were either more lightly fished than those in the main fishing areas, or that there was a separate stock with different population characteristics off Tasmania.

During the period 2001-2004, data for tiger flathead were collated, summarized and presented at workshops (see Cui *et al*. (2004) for a detailed summary of these workshops and the analyses presented to them). These workshops led to revisions of the data series, analyses of the data, and to suggestions for revisions to the data sets and research priorities. The 2004 assessment (Cui *et al.*, 2004) used 89 years (1915–2003) of data to estimate the virgin spawning stock biomass and the 2004 spawning stock biomass relative to that in 1915 and provided, for the first time, a complete picture of the dynamics of the tiger flathead fishery.

A number of changes to both the input data and some model structural changes were made and presented in the assessments developed in 2005 (Punt 2005a, Punt 2005b). These assessments considered tiger flathead caught off eastern Tasmania in SEF zone 30 as either separate to, or part of the same stock in zones 10 (E NSW), 20 (E Bass Strait) and 60 (Bass Strait) combined. In the scenario where eastern Tasmanian flathead are part of the same stock, a separate fleet was constructed to account for catches made there. Modifications to estimates of historical catches from Klaer (2005) were incorporated into catch series used in the assessments. Length-frequency data for 1945-1967 and 1971-1984 were obtained, and uncertainty in discard rates was estimated using a bootstrap procedure.

Part of the intention for the 2006 assessment (Klaer, 2006a) was initially to duplicate as far as possible the assessment results from 2005 (Punt, 2005a, Punt 2005b) while implementing the assessment using the Stock Synthesis (SS2) framework. The same assumptions were made about stock structure, i.e. tiger flathead off eastern Tasmania may or may not be the same stock as those off NSW and Victoria. Steepness was treated as an estimable parameter and annual age frequencies were added directly into the model as samples independent to length frequencies. The 2006 Shelf RAG selected the model that treated Tasmanian trawl as a separate fleet fishing the same east coast stock as the most appropriate base case.

The 2009 assessment (Klaer, 2009) moved the model from Stock Synthesis version SS-V2.1.21 (June 2006) to Stock Synthesis version SS-V3.03 (May 2009). Major changes to previous assessments were the use of age-at-length data to estimate growth parameters, correction to discard estimation for steam trawl, allowing selectivity change in 1985 for diesel trawl and 1978 for Danish seine, and estimation of recruitment 3 years prior to the last year (2005) for the 2009 assessment that used data to the end of 2008.

The 2009 assessment was updated in 2010 (Klaer, 2010) using Stock Synthesis version SS-V3.11a, (Methot, 2010). For the 2010 assessment, changes were made to the treatment of discards prior to 1980, an additional growth parameter was estimated and the assumed value for natural mortality, M, was changed from 0.22 to 0.27.

The 2010 assessment was updated in 2013 (Day and Klaer, 2013) using Stock Synthesis version SS-V3.24f, (Methot, 2011). Results from three years of the winter Fishery Independent Survey (FIS) were included as an additional abundance index in the 2013 assessment, but no FIS length data were included.

The most recent full quantitative assessment for tiger flathead was performed in 2016 (Day, 2016) using Stock Synthesis version SS-V3.24Z, (Methot, 2015). This was the first ever use of SESSF FIS length data in a stock assessment, incorporating length data from four FIS surveys from 2008-2014.

7.2.3 *Modifications to the previous assessments*

This assessment uses the current version of Stock Synthesis, SS-V3.30.14.05 (Methot et. al, 2019). The number of growth parameters estimated and assumptions about mortality and early discarding rates in this assessment are identical to the 2016 assessment (Day, 2016). Three growth parameters are estimated (CV, K and $l_{\min}$), natural mortality is assumed to be 0.27 and the discarded catch for steam trawl and for Danish seine prior to 1960 is assumed to be 20% of the retained catch, which translates to a discard ratio (disc/[ret+disc]) of 17%.

An abundance index from the fishery independent survey (FIS) for the winter surveys for four years: 2008, 2010, 2012 and 2014 (Knuckey *et al.*, 2015) was included in the 2016 assessment and this index is retained in this assessment with one additional data point (2016). As the summer FIS was discontinued after 2012, the three data points from the summer FIS abundance index have not been included in this assessment or in any of the sensitivities. Additional FIS length frequency data was included in this assessment, including the 2016 winter FIS length frequency data and the summer FIS length frequency data from 2008, 2010 and 2012. In using the summer length frequencies, it is assumed that the winter and summer FIS surveys have the same selectivity and length frequencies from both seasons contribute to the selectivity estimates. While both surveys use the same gear, it is possible that different seasonal availability means this assumption may not be valid. With only three points in the summer abundance series and no prospect of additional points being added in future, this series is too short to include as a separate abundance index in the assessment. The same problem does not apply to the use of summer FIS length frequencies, as these three years of summer FIS lengths are combined with five years of winter FIS lengths to estimate selectivity.

Updates to data used in the previous assessment resulted from changes AFMA have made to their observer database (affecting data for all years) and changes, improvements and corrections in the processing of data and filtering of records (Thomson et al., 2019). However, some historical length frequency data used in the 2016 assessment are not present in the database. These length frequencies are included in the current assessment, by using data from the 2016 assessment for the following retained length frequencies:

1. Steam Trawl, Sydney Fish Market – 1953-1958
2. Eastern Trawl, Sydney Fish Market – 1965-1967

3. Danish seine, onboard – 1993-1994

In addition to this historical data, retained for this assessment, there appear to be some changes in the Tasmanian Trawl length frequencies in 2009 and 2010 which may warrant future investigation. Only one shot was recorded from each of the 2009 and 2010 onboard samples, so these length frequencies were excluded, as they were unlikely to be representative. Similarly, the 2009 port length frequency came from less than 100 fish so this length frequency was also excluded. These sample sizes are different to those produced by the 2013 automatic processing, so this may require further investigation.

Discard length frequencies from Danish seine in 1994 and 1995 and eastern trawl from 1994-1996 were excluded in previous assessments as these appear to have unrepresentative distributions. These discard length frequencies were also excluded from the current assessment.

Other substantial changes from the 2016 assessment include:

1. further modifications to the tuning procedures using latest agreed tuning protocols
2. inclusion of length frequency data from the fishery independent surveys from 2016 and summer length frequencies from 2008, 2010 and 2012.

When shots or trip were not known (Sydney Fish Market, Kapala or Blackburn data), the number of fish measured was divided by 10 and capped at 200. When the number of trips or shots was available, a cap of 120 trips and 200 shots was used to set an upper limit on the sample size, although the limit on trip numbers was never exceeded.

The Tier 1 discard estimates have been updated in 2019 to more closely match the discard calculations in Bergh et al. (2009). These estimates use ratios of total discards to (retained plus discard) catch on a per shot basis, rather than aggregated across a whole stratum, which are then weighted up according to Catch Disposal Records (CDR) landings within zone and season (N. Klaer, pers. comm.). These changes and other data updates produced some modifications to estimates of discards, especially for the Tasmanian trawl fleet where some very small values were excluded, with resulting higher estimates of discards for this fleet. To achieve reasonable levels of predicted discards, years with very low (<1%) discard rate data were excluded.

An updated estimate of the ageing error matrix constructed from the new ageing data was used (A Punt, pers. comm.). The only changes to age-at-length data were the addition of three years of new data from 2016 to 2018. Minor revisions were made to the catch history from 2001 onwards, with minor modifications to recent state catch history and some reallocation of catch between fleets due to misclassification of some vessels. Updates to the preliminary 2015 and assumed 2016 catches were made and new 2017 and 2018 catch data was included, with the 2019 catch data (required to calculate a 2020 RBC) assumed to be the same as the 2018 catch data.

Inclusion of the new data and tuning procedures resulted in changes to the estimates of recruitment and to the spawning biomass time series.

The usual process of bridging to a new model by adding new data piecewise and analysing which components of the data could be contributing to changes in the assessment outcome was conducted (Day, 2019).

7.3 Methods

7.3.1 *The data and model inputs*

7.3.1.1 Biological parameters

As male and female tiger flathead have different growth patterns (females are substantially larger), a two-sex model has been used.

The parameters of the von Bertalanffy growth equation are estimated by sex within the model-fitting procedure from age-at-length data. This approach accounts for the impact of gear selectivity on the age-at-length data collected from the fishery and the impact of ageing error. Three growth parameters are estimated for females (CV, K and l_{min}), with only one growth parameter fixed (l_{max} = 55.9), with this valued based on the estimate of l_{∞} obtained by Punt (2005a) by fitting von Bertalanffy growth curves to data from SESSF Zones 10 and 20 (NSW and eastern Bass Strait). An offset to K is estimated separately for males, with the other growth parameters using the same values as for female growth.

Estimates of the rate of natural mortality, M, reported in the literature vary from 0.21 to 0.46 yr^{-1}. This assessment uses a value of 0.27 yr^{-1} as the base case estimate of M as used in the previous assessment (Day, 2016) and as previously agreed to by SERAG. Sensitivity to this value is tested. The steepness of the stock-recruitment relationship, h, is estimated by the model, and for the base case is estimated to be 0.72.

Female tiger flathead become sexually mature at about three years of age, which corresponds to a length of about 30 cm (Klaer, 2010). Maturity is modelled as a logistic function, with 50% maturity fixed at 30 cm. Fecundity-at-length is assumed to be proportional to weight-at-length.

The parameters of the length-weight relationship are the same as those used in the previous assessment a=5.88 x 10^{-6}, b=3.31 (Day, 2016), with these parameters originally obtained by fitting von Bertalanffy growth curves to data from SESSF Zones 10 and 20, NSW and eastern Bass Strait (Punt, 2005a).

7.3.1.2 Fleets

The assessment data for tiger flathead have been separated into five ‘fleets’, which represent one or more gear, regional, or temporal differences in the fishery. Landings data from eastern Tasmania were separated from the catches from the other regions in the east, because the length compositions of catches from this area indicate that it lands larger fish.

1. Steam trawl – steam trawlers (1915 – 1961)
2. Danish seine – Danish seine from NSW, eastern Victoria and Bass Strait (1929 – 2018)
3. Eastern trawl – diesel otter trawlers from NSW, eastern Victoria and Bass Strait (1971 – 2018)
4. Tasmanian trawl – diesel otter trawlers from eastern Tasmania (1985 – 2018)
5. Fishery Independent Survey – (2008-2016)

7.3.1.3 Landed catches

A landed catch history for tiger flathead, separated into the four ‘fleets’, is available for all years from 1915 to 2018 (Table 7.1, Figure 7.1 and Figure 7.2). Landings from the FIS fleet were assumed to be zero, with the actual FIS catch included in the scaling up of logbook catches to landed catches.

Klaer (2005) describes the sources of information used to construct the historical landed catch record for each of the fleets to 1986. Quotas were introduced into the fishery in 1992, and from then onwards, records of landed catches as well as estimated catches from the logbook are available. The landings data give a more accurate measure of the landed catch than do the logbook data, but the logbook data contain more detail. For example, it is usually possible to separate logbook records, but not landing records, by fleet. The logbook catches for each fleet from 1992 onwards have been scaled up by the ratio of landed catches to logbook catches in each year (Thomson, 2002). Prior to 1992, the unscaled logbook catches are used.

In 2007 the quota year was changed from calendar year to the year extending from 1 May to 30 April, however the assessment is based on calendar years. All catches for recent years continue to be those made by calendar year, which may conflict with the fishing year TACs.

Small quantities of tiger flathead are caught in state waters. NSW and Victorian state catches have been added to the eastern trawl fleet, and Tasmanian state catches have been added to the Tasmanian fleet.

Non-trawl CDR are ignored in this assessment, as has been the case with previous tiger flathead assessments. These non-trawl catches have averaged 0.6 t per year between 2001-2010 and less than 2 t per year since 2011 so represent a very small proportion of the total catch. If these catches were to be included, they would need to be allocated to an existing fleet, with associated selectivity. It is not clear which fleet included in the assessment would most closely match the selectivity of this very small non-trawl catch.

In order to calculate the Recommended Biological Catch (RBC) for 2020, it is necessary to estimate the Commonwealth calendar year catch for 2019. The TAC (Table 7.2) was almost unchanged from 2018 to 2019 and the state catches are unknown for 2019. Hence, assuming that the same ratio of the TAC will be caught in 2019 as in 2018, with the same state catches as 2018, is equivalent to assuming that the catch in 2019 is identical to the 2018 catch. This gives estimated 2019 catches for the eastern fleet, the Tasmanian fleet, and the Danish seine fleet of 921 t, 268+ t and 1,107 t, respectively.

7.3.1.4 Species composition for the “tiger flathead” assessment

The Commonwealth quota basket for “tiger flathead” actually comprises six separate CAAB codes (Thomson and Day 2019a). Two CAAB codes have commonly been used for the majority of the catch, usually well over 99%: tiger flathead (37296001) and generic (undifferentiated) flathead (37296000). While the use of these two codes has changed since the introduction of e-logs, both codes are thought to largely contain tiger flathead (*Platycephalus richardsoni*). The remaining four CAAB codes consist of toothy flathead, southern sand flathead, bluespotted flathead and southern bluespotted flathead. Of these, southern sand flathead catches ranged between 10 t and 20 t from 1985-1989 and less than 10 t since 1990. Catches of southern bluespotted flathead were 5 t in 1995, 1 t in 2017 and less than 1 t in all other years. Catches of southern sand flathead and bluespotted flathead were less than 1 t in all years. The Commonwealth catch of these four species which are not tiger flathead usually comprises well less than 1% of the total Commonwealth catch. As such, the Commonwealth component of this catch is considered to be essentially tiger flathead catches.

State catches used in this assessment generally occur in shallower waters than Commonwealth and hence are more likely to contain sand flathead and bluespotted flathead. State catches from NSW, Victoria and Tasmania are report tiger flathead separately from other flathead species and only tiger flathead catches are requested by CSIRO.

Small quantities (less than 2% of the total CDR in all years from 1985-2018, and usually less than 1%) of tiger flathead are reported in logbook catches from zones 40 (western Tasmania) and 50 (western Bass Strait). It seems that some of these records could be deepwater flathead (Thomson and Day 2019b), potentially misreported in the logbooks as tiger flathead. These western logbook catches are included in the total catch (the CDR), but are allocated to fleets as if these catches were taken in the east. The relative proportion of the catch by fleet (Danish seine, eastern trawl, Tasmanian trawl) for each year can only be obtained from the logbook records. However, the total Commonwealth catch comes from the CDR totals, as this is considered to be more accurate than the logbook totals. Hence the annual proportions of catch by (eastern) fleet are applied to the annual CDR (which includes western catches), but actually assumes all of the catch comes from the eastern fleets. Given the western catch is relatively small, this is unlikely to have a large impact, and follows the precedent used to distribute this (western) catch used in tiger flathead assessments in recent years.

7.3.1.5 Updated landed catches 2001-2018

A slightly different catch history was used in both the preliminary base case presented to SERAG in October 2019 and the proposed base case presented to SERAG in December 2019, referred to here as the old base case, with differences in catches in the period 2001-2018.

Corrections to this catch history involved increasing the catch by an average of 76 t per year from 2001-2018, with the increases ranging from a minimum of 30 t in 2002 to a maximum of 128 t in 2008. The annual increases in catch were around 40 t to the Tasmanian trawl fleet and just under 20 t each for the Danish seine and eastern trawl fleets. These corrections were discovered late in the assessment process. All of the diagnostic plots, fits, discard estimates and RBC calculations presented here are for the updated base case with the corrected catch series. However, the likelihood profiles, retrospectives and sensitivities were calculated using the incorrect (lower) catch series from 2001-2018. The general principles and comparisons in these analyses with the lower catch series are not expected to show qualitative differences. The increase in annual catches from 2001-2018 averages 2.6% and ranges from 0.9% to 4.8%. Catches are unchanged for the period from 1915-2000.

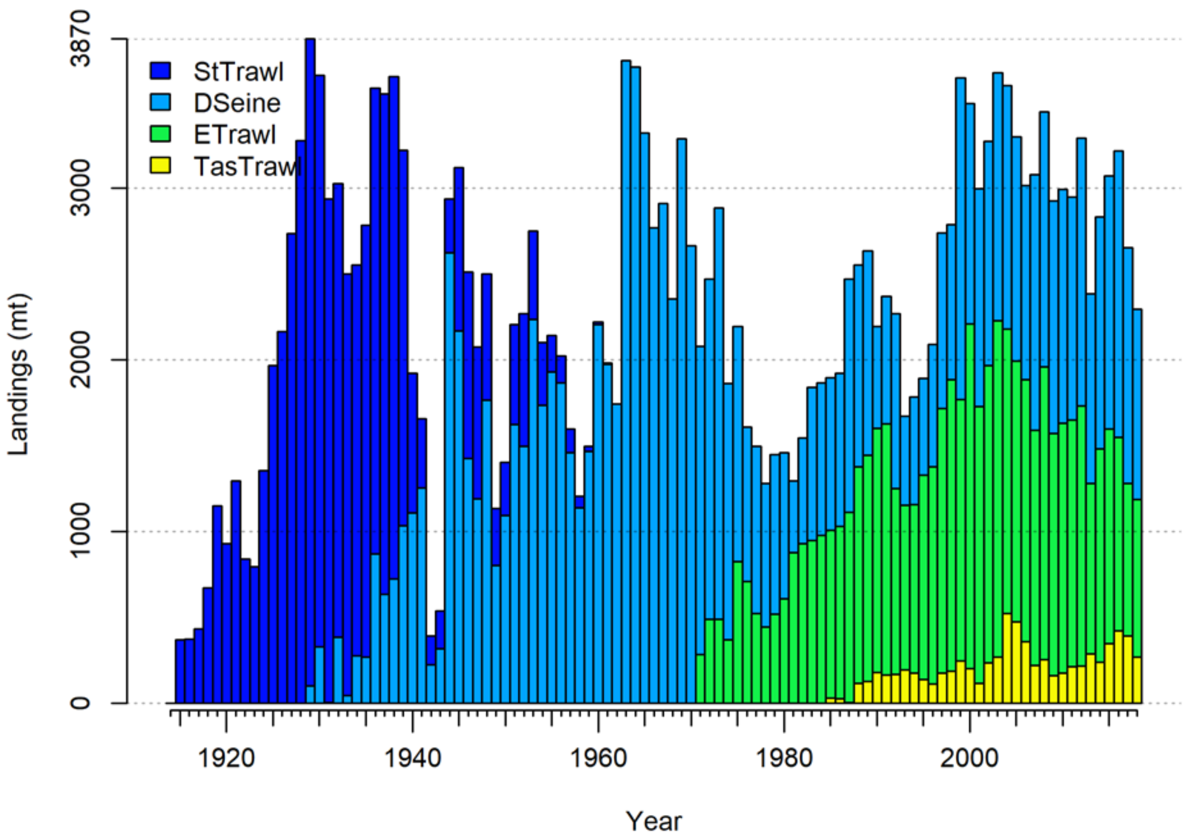

Figure 7.1. Total landed catch of tiger flathead by fleet (stacked) from 1915-2018.

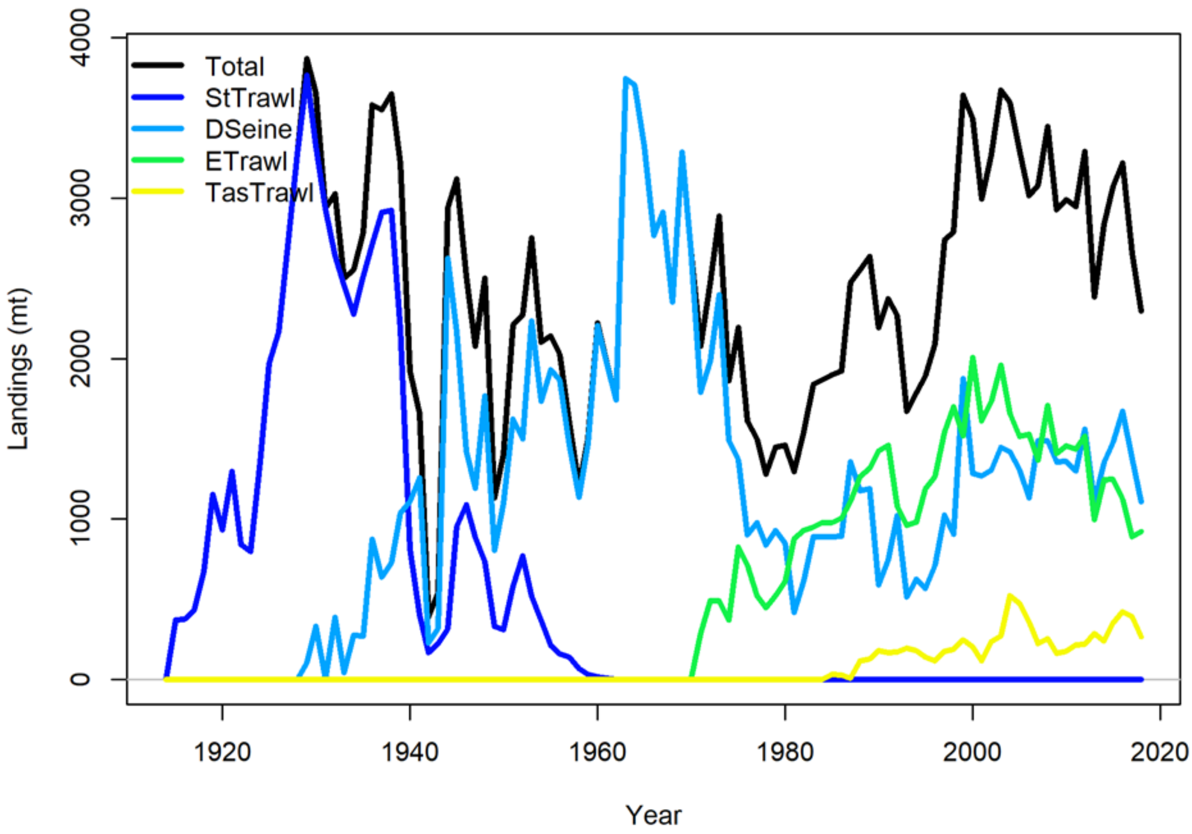

Figure 7.2. Total landed catch of tiger flathead by fleet from 1915-2018.

Table 7.1. Total retained catches (tonnes) of tiger flathead per fleet for calendar years from 1915-2019, with updated totals from the December SERAG meeting shown in bold.

Year	Fleet				Year	Fleet				Year	Fleet			
	St Trawl	D Seine	E Trawl	Tas Trawl		St Trawl	D Seine	E Trawl	Tas Trawl		St Trawl	D Seine	E Trawl	Tas Trawl
1915	371	0	0	0	1951	583	1,625	0	0	1987	0	1,358	1,109	6
1916	373	0	0	0	1952	769	1,499	0	0	1988	0	1,177	1,263	116
1917	432	0	0	0	1953	517	2,235	0	0	1989	0	1,189	1,318	128
1918	671	0	0	0	1954	366	1,737	0	0	1990	0	591	1,425	178
1919	1,151	0	0	0	1955	211	1,932	0	0	1991	0	746	1,461	166
1920	931	0	0	0	1956	157	1,868	0	0	1992	0	1,019	1,080	170
1921	1,297	0	0	0	1957	139	1,459	0	0	1993	0	516	962	194
1922	840	0	0	0	1958	68	1,138	0	0	1994	0	626	982	178
1923	796	0	0	0	1959	32	1,467	0	0	1995	0	564	1,189	139
1924	1,356	0	0	0	1960	15	2,206	0	0	1996	0	711	1,265	114
1925	1,969	0	0	0	1961	9	1,974	0	0	1997	0	1,023	1,542	175
1926	2,167	0	0	0	1962	0	1,742	0	0	1998	0	905	1,700	186
1927	2,735	0	0	0	1963	0	3,745	0	0	1999	0	1,873	1,520	248
1928	3,277	0	0	0	1964	0	3,707	0	0	2000	0	1,286	2,006	349
1929	3,768	102	0	0	1965	0	3,322	0	0	2001	0	**1,269**	**1,612**	**115**
1930	3,329	330	0	0	1966	0	2,769	0	0	2002	0	**1,305**	**1,731**	**236**
1931	2,932	4	0	0	1967	0	2,912	0	0	2003	0	**1,446**	**1,957**	**270**
1932	2,642	385	0	0	1968	0	2,355	0	0	2004	0	**1,418**	**1,658**	**522**
1933	2,456	44	0	0	1969	0	3,289	0	0	2005	0	**1,307**	**1,516**	**476**
1934	2,278	276	0	0	1970	0	2,667	0	0	2006	0	**1,132**	**1,526**	**359**
1935	2,514	270	0	0	1971	0	1,793	286	0	2007	0	**1,488**	**1,368**	**223**
1936	2,712	872	0	0	1972	0	1,981	491	0	2008	0	**1,487**	**1,705**	**255**
1937	2,912	637	0	0	1973	0	2,397	490	0	2009	0	**1,358**	**1,408**	**163**
1938	2,924	725	0	0	1974	0	1,493	369	0	2010	0	**1,359**	**1,458**	**175**
1939	2,185	1,035	0	0	1975	0	1,367	827	0	2011	0	**1,300**	**1,435**	**214**
1940	815	1,108	0	0	1976	0	900	712	0	2012	0	**1,560**	**1,516**	**217**
1941	403	1,255	0	0	1977	0	977	522	0	2013	0	**1,103**	**995**	**287**
1942	167	225	0	0	1978	0	836	446	0	2014	0	**1,352**	**1,244**	**239**
1943	223	317	0	0	1979	0	928	520	0	2015	0	**1,476**	**1,248**	**348**
1944	315	2,624	0	0	1980	0	851	609	0	2016	0	**1,671**	**1,126**	**422**
1945	953	2,168	0	0	1981	0	418	877	0	2017	0	**1,377**	**887**	**392**
1946	1,088	1,425	0	0	1982	0	615	930	0	2018	0	**1,107**	**921**	**268**
1947	884	1,193	0	0	1983	0	889	950	0	2019*	0	**1,107**	**921**	**268**
1948	735	1,767	0	0	1984	0	890	978	0					
1949	330	804	0	0	1985	0	890	978	30					
1950	310	1,095	0	0	1986	0	892	1,005	26					

*2019 catches are estimated

Table 7.2. Total allowable catch (t) from 1992 to 2019/20.

Year	TAC Agreed
1992	3000
1993	3000
1994	3500
1995	3500
1996	3500
1997	3500
1998	3500
1999	3500
2000	3500
2001	3500
2002	3500
2003	3500
2004	3500
2005	3150
2006	3000
2007	3015
2008/09	2850
2009/10	2850
2010/11	2750
2011/12	2750
2012/13	2750
2013/14	2750
2014/15	2878
2015/16	2860
2016/17	2882
2017/18	2712
2018/19	2507
2019/20	2468

7.3.1.6 Discard rates

Information on the discarding rate of tiger flathead was available from the PIRVic-run Integrated Scientific Monitoring Program (ISMP) for 1992-2006. From 2007 the ISMP was run by AFMA. The discard data are summarised in Table 7.3. Generally, discards of tiger flathead were in the order of 8% for Danish seine, 10% for eastern trawl and 1% for Tasmanian trawl.

There is limited information on discarding for the early steam trawl fleet (1915-61) and the early Danish seine fleet (1929-67). However, it is known that total discards for all species from steam trawl in the 1920s was in the order of 20% of the retained catch (Klaer, 2001). As there is no way to determine the species catch composition of the discards, Shelf RAG made the decision to apply this ratio to tiger flathead, which translates to a discard fraction of 17%. For the base case, all steam trawl (1915-1961) and early Danish seine (1929-1960) were assigned a constant discard fraction of 17% to apply equally to all selected fish (Figure 7.3). The discard fraction for Danish seine from 1961 to present was set using recent observed discard ratios since 1994. Recent observations were used to estimate discard fractions for the east coast and Tasmanian diesel trawl fleets.

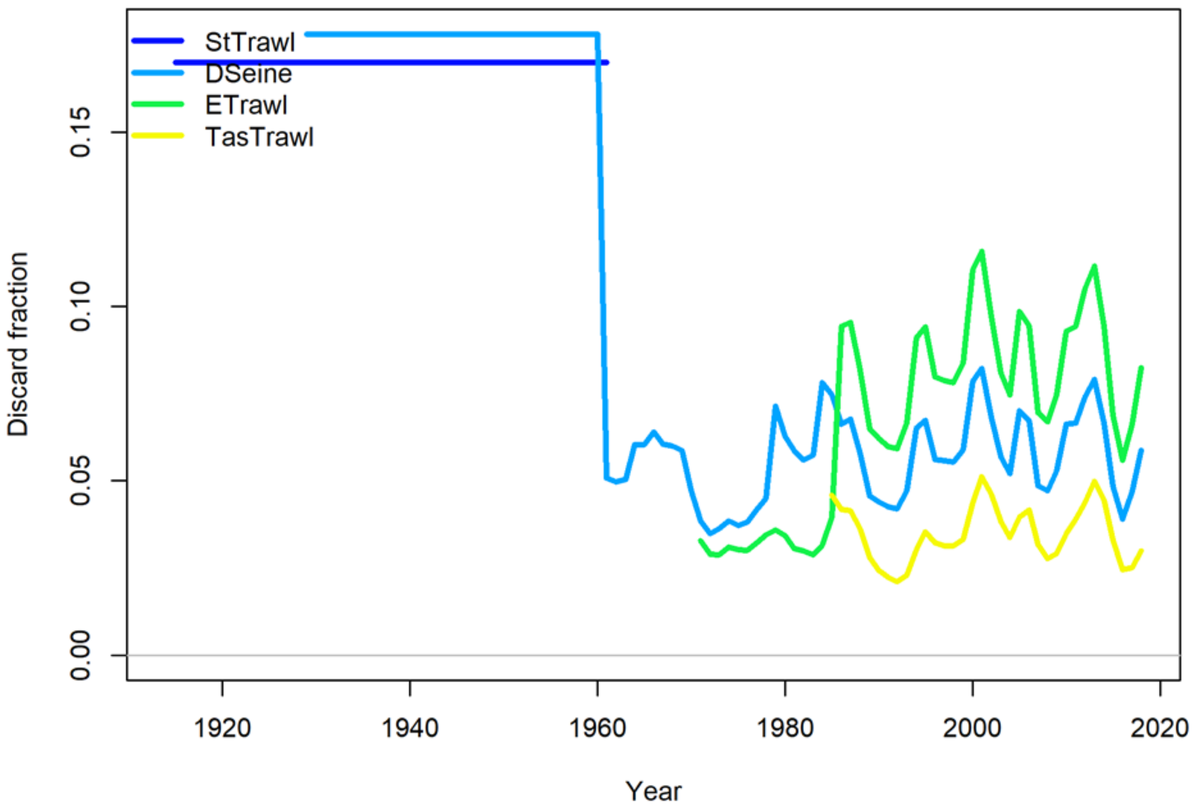

Figure 7.3. Model estimates of discard fractions per fleet.

Table 7.3. Proportion of catch discarded by fleet, with sample sizes.

Year	Fleet D Seine	n	E Trawl	n	Tas Trawl	n
1992			0.111655	11		
1993			0.071441	195		
1994	0.080965	79	0.091485	267	0.061636	18
1995	0.101318	44	0.108100	129		
1996			0.073031	240		
1997			0.044715	383		
1998	0.063355	23	0.100813	246		
1999	0.015514	34	0.111664	382		
2000	0.038976	27	0.088278	395		
2001	0.010290	41	0.052686	457		
2002	0.102959	30	0.058272	385		
2003	0.033118	113	0.060926	470		
2004		39	0.091059	387		
2005	0.064790	61	0.074755	461		
2006	0.034561	125	0.085904	369		
2007	0.036619	47	0.044946	106		
2008	0.043842	38	0.036190	214		
2009	0.114579	32	0.088945	200		
2010	0.140487	75	0.061709	171	0.029004	20
2011	0.267978	123	0.108886	140		
2012	0.066264	70	0.080755	118		
2013	0.126057	102	0.089382	128	0.012441	22
2014	0.156979	109	0.102284	112		
2015	0.036815	78	0.087488	204		
2016	0.039054	123	0.079863	111		
2017	0.065042	86	0.084152	157		
2018	0.032167	62	0.022506	120	0.013982	25

7.3.1.7 Catch rate indices

A standardised catch rate (CPUE) index is available for the historical steam trawl fleet for the years 1919-23, 1937-42, and 1952-57 (Klaer, 2006b; Table 7.4). An unstandardised catch rate index for early Danish seine has been used in tiger flathead assessments since Cui *et al.* (2004) (Table 7.5).

Catch and effort data from the SEF1 logbook database were standardised using GLMs to obtain indices of relative abundance (Sporcic 2019b; Table 7.6) from the period 1986-2018 for recent Danish seine, eastern and Tasmanian trawl fleets.

Abundance indices from the Fishery Independent Survey from 2008-2016 were also used, separated into zones 10 and 20, to match the eastern trawl fleet, and zone 30, to match the Tasmanian trawl fleet (Table 7.7). These abundance indices use the FIS3 abundance index (Sporcic et al., 2019) which reconditions the original FIS abundance index, as used in the 2016 assessment and all previous SESSF stock assessments which included FIS abundance indices, and accounts for within year variation in catch rates.

In this stock synthesis assessment, the coefficient of variation for the more recent abundance indices (CPUE from recent Danish seine, eastern and Tasmanian trawl fleets and both FIS3 abundance series) is initially set to a value equal to the root mean squared deviation from a loess fit (Sporcic, 2019a, 2019b) and additional variance is estimated for each abundance index to tune the input and output variances.

Table 7.4. Standardised catch rates for the steam trawl fleet (Klaer 2006b).

Year	Value	CV
1919	1.618	0.31
1920	1.732	0.31
1921	1.806	0.31
1922	1.758	0.31
1923	1.646	0.31
1937	0.635	0.31
1938	0.749	0.31
1939	0.723	0.31
1940	0.611	0.31
1941	0.618	0.31
1942	0.401	0.31
1952	0.262	0.31
1953	0.208	0.31
1954	0.232	0.31
1955	0.219	0.31
1956	0.208	0.31
1957	0.169	0.31

Table 7.5. Unstandardised catch rates for the early Danish seine fleet.

Year	Value	CV
1950	38.7	0.33
1951	27.6	0.33
1952	31.8	0.33
1953	52.0	0.33
1954	34.4	0.33
1955	47.4	0.33
1956	46.5	0.33
1957	32.1	0.33
1958	22.5	0.33
1959	28.7	0.33
1960	43.6	0.33
1965	38.2	0.33
1966	41.5	0.33
1967	62.5	0.33
1968	61.2	0.33
1969	77.8	0.33
1970	67.1	0.33
1971	69.9	0.33
1972	114.0	0.33
1973	88.0	0.33
1974	58.1	0.33
1975	56.6	0.33
1976	41.9	0.33
1977	55.5	0.33
1978	51.9	0.33

Table 7.6. Standardised catch rates for the Danish seine, eastern and Tasmanian diesel trawl fleets from 1986-2018. The coefficient of variation is initially set at a value equal to the root mean squared deviation from a loess fit (Sporcic, 2019a, Sporcic 2019b).

Year	Fleet					
	D Seine	CV	E Trawl	CV	Tas Trawl	CV
1986	1.1123	0.168	0.8007	0.143	0.9347	0.195
1987	1.5651	0.168	1.0671	0.143	0.5687	0.195
1988	1.7082	0.168	1.1680	0.143	0.9572	0.195
1989	1.4892	0.168	1.1685	0.143	0.7056	0.195
1990	0.9999	0.168	1.3918	0.143	0.7060	0.195
1991	1.3621	0.168	1.3097	0.143	0.6682	0.195
1992	1.4277	0.168	1.0334	0.143	0.6390	0.195
1993	0.8820	0.168	1.0476	0.143	0.5984	0.195
1994	0.7631	0.168	0.7605	0.143	0.6218	0.195
1995	0.7798	0.168	0.8031	0.143	0.6983	0.195
1996	0.7329	0.168	0.7158	0.143	0.6374	0.195
1997	0.9572	0.168	0.7171	0.143	0.7924	0.195
1998	0.8096	0.168	0.7581	0.143	0.9440	0.195
1999	1.1704	0.168	0.9150	0.143	1.0559	0.195
2000	0.8738	0.168	1.0067	0.143	0.8695	0.195
2001	0.8211	0.168	0.9701	0.143	0.7328	0.195
2002	0.9752	0.168	1.0530	0.143	1.3397	0.195
2003	1.0117	0.168	1.0389	0.143	1.3809	0.195
2004	1.0027	0.168	0.9040	0.143	1.8667	0.195
2005	1.0167	0.168	0.7764	0.143	1.6984	0.195
2006	0.9976	0.168	0.9400	0.143	1.3764	0.195
2007	1.2135	0.168	1.1402	0.143	1.1150	0.195
2008	1.0918	0.168	1.2005	0.143	1.0479	0.195
2009	1.1256	0.168	1.1085	0.143	1.0302	0.195
2010	1.0180	0.168	1.0686	0.143	1.0081	0.195
2011	0.9423	0.168	1.0539	0.143	0.9668	0.195
2012	0.8945	0.168	1.1600	0.143	1.2107	0.195
2013	0.6616	0.168	0.8776	0.143	1.1713	0.195
2014	0.7191	0.168	1.0301	0.143	1.3479	0.195
2015	0.7585	0.168	1.1597	0.143	1.2654	0.195
2016	0.7935	0.168	1.0627	0.143	1.0769	0.195
2017	0.7443	0.168	0.8791	0.143	1.1634	0.195
2018	0.5790	0.168	0.9138	0.143	0.8042	0.195

Table 7.7. FIS3 derived abundance indices for tiger flathead with corresponding coefficient of variation (cv) eastern trawl fleet (zones 10 and 20); and Tasmanian trawl fleet (zone 30). The coefficient of variation is initially set at a value equal to the root mean squared deviation from a loess fit (Sporcic, 2019a, Sporcic 2019b).

Year	FIS East Z 10, 20	CV	FIST Tas Z 30	CV
2008	11496.27	0.23	6019.18	0.07
2010	8585.84	0.23	7868.28	0.07
2012	16344.18	0.23	7808.31	0.07
2014	9574.55	0.23	9102.49	0.07
2016	8500.62	0.23	12961.75	0.07

7.3.1.8 Age composition data

An estimate of the standard deviation of age reading error was calculated by Andre Punt (pers. comm., 2019) from data supplied by Kyne Krusic-Golub of Fish Ageing Services (Table 7.8).

Age-at-length measurements, based on sectioned otoliths, provided by Fish Ageing Services, were available for the years 1998, 2000-2018 for the Danish seine fleet; 1998-2002, 2004-2018 for the eastern diesel trawl fleet; and 1999, 2000, 2002, 2005-2008, 2010 and 2012-2018 for the Tasmanian diesel trawl fleet (Table 7.9). Years for which the total number of fish aged was less than 10 were not used. No age information was available for the earlier fleets.

Table 7.8. Standard deviation of age reading error (A Punt pers. comm. 2019).

Age	sd
0.5	0.251046
1.5	0.274642
2.5	0.298508
3.5	0.322648
4.5	0.347064
5.5	0.371760
6.5	0.396738
7.5	0.422002
8.5	0.447555
9.5	0.473401
10.5	0.499543
11.5	0.525984
12.5	0.552728
13.5	0.579777
14.5	0.607137
15.5	0.634810
16.5	0.662799
17.5	0.691109
18.5	0.719743
19.5	0.748704
20.5	0.777997

7.3.1.9 Length composition data

Length composition information for the onboard retained components of catches is available for: the Danish seine fleet 1993-1994, 1998-2007 and 2009-2018; the eastern trawl fleet from 1977, 1993, 1996-2015; and the Tasmanian trawl fleet for 1998-2006, 2008, 2010-2018 along with the numbers of fish measured and numbers of shots in each year (Table 7.10). Length composition information from port data is available for: the steam trawl fleet from 1945-1958; the Danish seine fleet from 1945-1967, 1992 and 1994-2018; the eastern trawl fleet from 1965-1967, 1969-2018; and the Tasmanian trawl fleet for 1999-2000, 2002-2006, 2011-2013 and 2015-2016, along with the numbers of fish measured and numbers of trips in each year (Table 7.11 and Table 7.12). Length composition information from the ISMP for the discarded components of catches is available for: the Danish seine fleet 1998-2000, 2002-2003, 2006-2007, 2011-2016 and 2018; and the eastern trawl fleet from 1992-1993, 1997-2006 and 2008-2018; along with the numbers of fish measured and numbers of shots in each year (Table 7.13). In line with current standard practice in the SESSF, both port and onboard length frequencies are used when they are available.

Table 7.9. Number of age-length otolith samples included in the base case assessment by fleet 1998-2018.

Year	Fleet				
	D Seine	E Trawl	Tas Trawl	FIS East	Total
1998	101	212			313
1999		146	46		192
2000	192	544	56		792
2001	30	180			210
2002	558	588	149		1,295
2003	102				102
2004	174	152			326
2005	603	268	11		882
2006	312	64	141		517
2007	159	302	8		469
2008	363	229	66	48	706
2009	386	698			1,084
2010	617	423	88		1,128
2011	715	410			1,125
2012	468	696	131		1,295
2013	440	278	65		783
2014	583	451	162		1,196
2015	496	724	23		1,243
2016	487	456	180		1,123
2017	350	278	82		710
2018	299	353	134		786

Table 7.10. Number of onboard retained lengths and number of shots for length frequencies included in the base case assessment by fleet 1977-2018.

Year	Fleet	# fish		Fleet	# shots	
	D Seine	E Trawl	Tas Trawl	D Seine	E Trawl	Tas Trawl
1977		2,136			200	
1993	356	1,347		4	17	
1994	1,950			20		
1996		494			7	
1997		6,797			191	
1998	1,706	9,364	959	30	139	8
1999	1,765	18,771	3,066	26	259	26
2000	707	21,686	492	15	235	5
2001	238	21,952	383	3	213	4
2002	332	17,229	477	8	181	4
2003	4,158	18,187	399	72	201	3
2004	3,595	11,836	562	26	122	5
2005	5,353	18,745	1,692	38	176	10
2006	13,202	12,137	4,588	103	107	34
2007	1,593	1,243		9	35	
2008		1,482	101		45	6
2009	672	1,374		11	32	
2010	678	1,909	239	28	68	9
2011	1,303	1,881	334	52	74	11
2012	1,821	2,226	348	49	72	8
2013	2,479	1,880	410	66	45	10
2014	2,064	1,999	972	73	44	21
2015	1,925	4,393	741	40	110	20
2016	2,329	2,573	1,284	61	47	34
2017	960	1,803	683	24	47	10
2018	701	1,602	514	18	41	17

Table 7.11. Number of port retained lengths and number of trips used for length frequencies included in the base case assessment by fleet 1945-1991.

Year	Fleet	# fish		Fleet	# trips	
	St Trawl	D Seine	E Trawl	St Trawl	D Seine	E Trawl
1945	5,076	21,735		200	200	
1946	10,916	26,475		200	200	
1947	15,488	20,287		200	200	
1948	11,973	20,721		200	200	
1949	10,863	23,316		200	200	
1950	18,057	16,640		200	200	
1951	25,843	21,423		200	200	
1952	32,188	28,941		200	200	
1953	14,880	16,264		200	200	
1954	13,167	26,263		200	200	
1955	2,313	9,966		200	200	
1956	343	14,878		34	200	
1957	150	15,283		15	200	
1958	149	17,291		15	200	
1959		20,354			200	
1960		25,334			200	
1961		18,623			200	
1962		20,255			200	
1963		15,988			200	
1964		17,882			200	
1965		17,861	14,310		200	200
1966		19,101	23,222		200	200
1967		7,233	11,798		200	200
1969			96			10
1970			187			19
1971			610			61
1972			1,223			122
1973			435			44
1974			5,590			200
1975			11,684			200
1976			14,881			200
1977			18,017			200
1978			16,335			200
1979			12,189			200
1980			8,757			200
1981			6,184			200
1982			5,893			200
1983			5,140			200
1984			6,702			200
1985			2,633			200
1986			12,513			200
1987			8,154			200
1988			6,274			200
1989			3,999			200
1990			1,398			140
1991			4,040			200

Table 7.12. Number of port retained lengths and number of trips used for length frequencies included in the base case assessment by fleet 1992-2018.

Year	Fleet	# fish		Fleet	# trips	
	D Seine	E Trawl	Tas Trawl	D Seine	E Trawl	Tas Trawl
1992	1,442	873		13	5	
1993		502			3	
1994	292	156		3	1	
1995	1,566	1,418		20	10	
1996	3,760	2,520		31	16	
1997	11,857	5,106		115	26	
1998	11,346	11,302		112	84	
1999	5,079	12,747	519	22	94	3
2000	3,566	6,698	362	20	53	2
2001	5,690	11,087		35	88	
2002	3,569	6,208	5,201	32	35	27
2003	1,896	4,686	649	11	35	6
2004	4,280	10,247	1,520	38	71	7
2005	3,542	13,035	769	12	74	3
2006	1,375	13,029	1,323	5	116	6
2007	505	3,024		3	20	
2008	435	132		3	1	
2009	428	735	87	7	7	1
2010	751	2,107	64	15	17	1
2011	1,066	1,061	204	35	24	6
2012	884	771	188	32	22	4
2013	1,055	885	185	41	26	3
2014	1,691	1,288		52	22	
2015	2,401	1,099	232	54	19	3
2016	2,001	748	296	38	10	5
2017	2,481	1,265	92	48	19	1
2018	2,135	1,206	80	41	21	1

Table 7.13. Number of port retained lengths and number of trips used for length frequencies included in the base case assessment by fleet 1992-2018.

Year	Fleet	# fish	Fleet	# shots
	D Seine	E Trawl	D Seine	E Trawl
1992		131		7
1993		896		45
1997		139		55
1998	126	2,155	21	94
1999	104	3,988	7	151
2000	110	2,890	5	93
2002	235	2,834	11	89
2003	102	2,622	7	89
2004		3,098		56
2005		1,478		31
2006	119	2,116	10	30
2007	218		1	
2008		99		12
2009		376		19
2010		175		24
2011	132	546	4	48
2012	212	388	15	35
2013	125	477	10	23
2014	254	700	29	18
2015	175	1,504	14	60
2016	176	361	10	14
2017	57	599	1	17
2018	103	195	3	8

Table 7.14. Number of FIS length measurements and number of shots containing tiger flathead by fleet and year.

Year	FIS East	(Z 10,20)	FIST Tas	(Z 30)
	# fish	# shots	# fish	# shots
2008	2202	27	907	15
2010	3384	44	1281	17
2012	3722	42	287	3
2014	3403	39	588	5
2016	2491	37	894	12
Sum 2008	1750	20	363	3
Sum 2010	3042	31	591	9
Sum 2012	1675	29	810	14

7.3.1.10 Input data summary

The data used in this assessment is summarised in Figure 7.4, indicating which years the various data types were available.

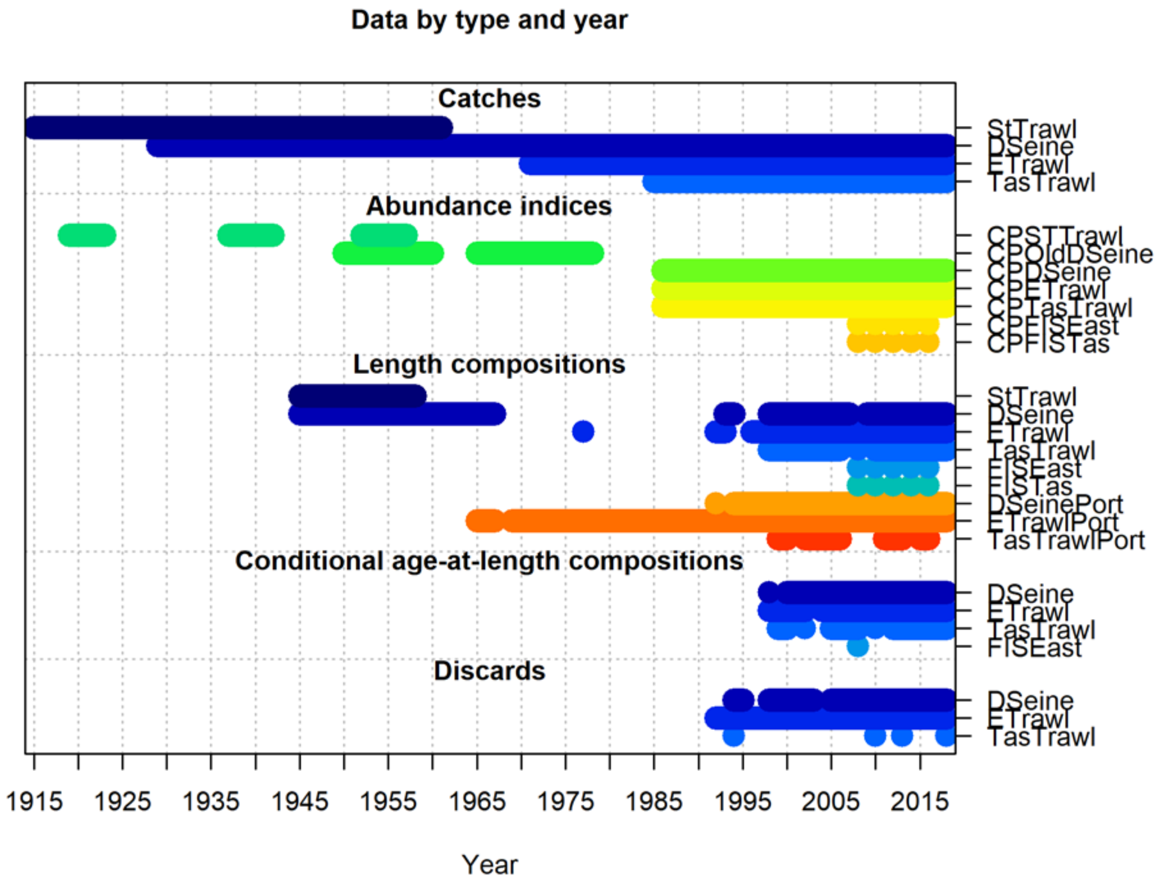

Figure 7.4. Summary of input data used for the tiger flathead assessment.

7.3.2 ***Stock assessment method***

7.3.2.1 Population dynamics model and parameter estimation

A two-sex stock assessment for tiger flathead was conducted using the software package Stock Synthesis version SS-V3.30.14.05, (Methot et. al, 2019). Stock Synthesis is a statistical age- and length-structured model which allows multiple fishing fleets and can be fitted simultaneously to the range of data available for tiger flathead. The population dynamics model, and the statistical approach used in the fitting of the model to the various types of data, are given fully in the SS technical description (Methot, 2005) and are not reproduced here. Some key features of the population dynamics model underlying Stock Synthesis which are pertinent to this assessment are discussed below.

a) Tiger flathead constitute a single stock within the area of the fishery, from zone 10 off Sydney, through zone 20 (eastern Bass Strait), zone 60 (Bass Strait) and zone 30 (eastern Tasmania). While alternative stock structures have been previously suggested, with the eastern Tasmanian stock potentially a separate stock (Cui et al. 2004, Punt 2005a, Klaer 2006a, Klaer 2009, Klaer 2010, Day and Klaer 2013, Day 2016), this single stock is the stock structure currently agreed by SERAG.

b) The stock is assumed to be unexploited at the start of 1915 when the steam trawl fishery commenced. Catches prior to this are thought to have been minimal.

c) The CVs of all abundance indices (including the FIS) were initially set to the root mean squared deviation from a loess fit to the fleet specific indices (Sporcic 2019a, Sporcic 2019b) and then tuned to match the model-estimated standard errors by estimating an additional variance parameter within Stock Synthesis.

d) Four fishing fleets are modelled.

e) Selectivity is assumed to vary among fleets, but the selectivity pattern for each separate fleet is modelled as length-specific, logistic and mostly time-invariant. The selectivity for Danish seine is allowed to change in 1978, and eastern diesel trawl in 1985. The two parameters of the selectivity function for each fleet are estimated within the assessment.

f) Retention is also defined as a logistic function of length, and the inflection and slope of this function are estimated for the three fleets where discard information is available (Danish seine, eastern trawl and Tasmanian trawl). Retention for the steam trawl fleet was implicitly assumed to be independent of length as no length frequency composition data is available on discards for this fleet.

g) The rate of natural mortality, M, is assumed to be constant with age, and also time-invariant. The value for M is fixed within the model at to 0.27 yr^{-1} as in the previous assessment (Day, 2016).

h) Recruitment to the stock is assumed to follow a Beverton-Holt type stock-recruitment relationship, parameterised by the average recruitment at unexploited spawning biomass, R_0, and the steepness parameter, h. Steepness is estimated within the model for the base case analysis. Deviations from the average recruitment at a given spawning biomass (recruitment residuals) are estimated for 1915 to 2015. Deviations are not estimated after 2015 because there are insufficient data to permit reliable estimation of recruitment residuals outside of this time period.

i) The value of the parameter determining the magnitude of the process error in annual recruitment, σ_R, is set equal to 0.7 in the base case. The magnitude of bias-correction depends on the precision of the estimate of recruitment and time-dependent bias-correction factors were estimated following the approach of Methot and Taylor (2011).

j) A plus-group is modelled at age twenty years.

k) Growth of tiger flathead is assumed to be time-invariant, that is there has been no change over time in the mean size-at-age, with the distribution of size-at-age determined from fitting the growth curve within the assessment using the age-at-length data. Differences in growth by gender are modelled.

l) The sample sizes for length and age frequencies were tuned for each fleet so that the input sample size was approximately equal to the effective sample size calculated by the model. Before this retuning of length frequency data was performed by fleet, any sample sizes with a sample size greater than 100 trips or 200 shots were individually down-weighted to a maximum sample size of 100 and 200 respectively. This is because the appropriate sample size for length frequency data is probably more closely related to the number of shots sampled, rather than the number of fish measured.

7.3.2.2 Relative data weighting

Iterative reweighting of input and output CVs or input and effective sample sizes is an imperfect but objective method for ensuring that the expected variation is comparable to the input (Pacific Fishery Management Council, 2018). This makes the model internally consistent, although some argue against this approach, particularly if it is believed that the input variance is well measured and potentially accurate. It is not necessarily good to down weight a data series just because the model does not fit it, if in fact, that series is reliably measured. On the other hand, most of the indices we deal with in fisheries underestimate the true variance by only reporting measurement and not process error.

Data series with a large number of individual measurements such as length or weight frequencies tend to overwhelm the combined likelihood value with poor fits to noisy data when fitting is highly partitioned by area, time or fishing method. These misfits to small samples mean that simple series such as a single CPUE might be almost completely ignored in the fitting process. This model behaviour is not optimal, because we know, for example, that the CPUE values are in fact derived from a very large number of observations.

Length compositions were initially weighted using trip and shot numbers, where available, instead of numbers of fish measured and by adopting the Francis weighting method (Francis 2011) for age and length composition data.

Shot or trip number is not available for all data, especially for some of the early length frequency data. In these cases, the number of trips was inferred from the number of fish measured using the average number of fish per trip for the relevant gear type for years where both data sources were available, or in some of the earlier years, dividing the number of fish by 10 and capping the resulting number at 200. The number of trips were also capped at 100 and the number of shots capped at 200. Samples with less than 100 fish measured per year were excluded.

These initial sample sizes, based on shots and trips, are then iteratively reweighted so that the input sample size is equal to the effective sample size calculated by the model using the Francis weighting method for length data and the Punt weighting method for conditional age-at-length data.

7.3.2.3 Tuning procedure

In iterative reweighting, the effective annual sample sizes are tuned/adjusted so that the input sample size is equal to the effective sample size calculated by the model. In SSv3.30 there is an automatic adjustment made to survey CVs (CPUE).

1. Set the standard error for the log of the relative abundance indices (CPUE, acoustic abundance survey, or FIS) to their estimated standard errors for each survey or for CPUE (and FIS values) to the root mean squared deviation of a loess curve fitted to the original data (which will provide a more realistic estimate to that obtained from the original statistical analysis). SSv3.30 then re-balances the relative abundance variances appropriately.
2. The initial value of the parameter determining the magnitude of the process error in annual recruitment, σ_R, is set to 0.7, reflecting the variation in recruitment for tiger flathead. The magnitude of bias-correction depends on the precision of the estimate of recruitment and time-dependent bias-correction factors were estimated following the approach of Methot and Taylor (2011).

An automated tuning procedure was used for the remaining adjustments. For the conditional age-at-length and length composition data:

3. Multiply the initial sample sizes for the conditional age-at-length data by the sample size multipliers using the approach of Punt (2017).
4. Similarly multiply the initial samples sizes by the sample size multipliers for the length composition data using the ‘Francis method’ (Francis, 2011).
5. Repeat steps 3 and 4, until all are converged and stable (proposed changes are < 1%).

This procedure may change in the future after further investigations but constitutes current best practice.

7.3.2.4 Calculating the RBC

The SESSF Harvest Strategy Framework (HSF) was developed during 2005 (Smith *et al*.2008) and has been used as a basis for providing advice on TACs in the SESSF quota management system from 2006 onwards. The HSF uses harvest control rules to determine a recommended biological catch (RBC) for each stock in the SESSF quota management system. Each stock is assigned to one of five Tier levels depending on the basis used for assessing stock status or exploitation level for that stock. Tiger flathead is classified as a Tier 1 stock as it has an agreed quantitative stock assessment.

The Tier 1 harvest control rule specifies a target and a limit biomass reference point, as well as a target fishing mortality rate. Since 2005 various values have been used for the target and the breakpoint in the rule. In 2009, AFMA directed that the 20:40:40 (B_{lim}: B_{MSY}: F_{targ}) form of the rule is used up to where fishing mortality reaches F_{48}. Once this point is reached, the fishing mortality is set at F_{48}. Day (2008) determined that for most SESSF stocks where the proxy values of B_{40} and B_{48} are used for B_{MSY} and B_{MEY} respectively, this form of the rule is equivalent to a 20:35:48 (B_{lim}: Inflection point: F_{targ}) strategy.

Previously, a preliminary economic analysis was used as a basis for using a 20:35:41 rule for tiger flathead (Klaer 2010). As steepness is an estimated parameter in the tiger flathead assessment, it is one of the few SESSF stocks where an MSY estimate may be taken from the base case stock assessment. SESSFRAG in 2010 determined that a tiger flathead RBC may be calculated using a rule that incorporates application of the default 1.2 multiplier to the MSY depletion level to determine a minimum value for an MEY depletion level. It was also agreed at SESSFRAG that if this level was below 40% of B_0, that the 40% level be used to generate an RBC to maintain the biological precaution implicit in the 40% level. As with the 2013 assessment, SERAG agreed that the default RBC for tiger flathead is calculated under the 20:35:40 strategy.

7.3.2.5 Sensitivity tests and alternative models

A number of tests were carried out to examine the sensitivity of the results of the model to some of the assumptions and data inputs:

1. M = 0.22 yr^{-1}.
2. M = 0.32 yr^{-1}.
3. 50% maturity at 27 cm.
4. 50% maturity at 33 cm.
5. σ_R set to 0.4.
6. σ_R set to 0.6.
7. σ_R set to 0.8.
8. First year of recruitment changed from 1915 to 1925.
9. Fix steepness (h) at 0.75 and estimate natural mortality (M).
10. Fix steepness (h) at 0.75 and fix natural mortality (M) at 0.27.

11. Fix steepness (h) at 0.65 and fix natural mortality (M) at 0.27.
12. Fix steepness (h) at 0.85 and fix natural mortality (M) at 0.27.
13. Double the weighting on the length composition data.
14. Halve the weighting on the length composition data.
15. Double the weighting on the age-at-length data.
16. Halve the weighting on the age-at-length data.
17. Double the weighting on the survey (CPUE) data.
18. Halve the weighting on the survey (CPUE) data.

The results of the sensitivity tests are summarized by the following quantities (Table 26):

1. SSB_0: the average unexploited female spawning biomass.
2. SSB_{2020}: the female spawning biomass at the start of 2020.
3. SSB_{2020}/SSB_0: the female spawning biomass depletion level at the start of 2020.
4. Steepness: the estimated steepness of the stock-recruitment relationship.
5. SSB_{MSY}/SSB_0: the female spawning biomass depletion level at maximum sustainable yield (MSY).
6. RBC_{2020}: the recommended biological catch (RBC) for 2020.
7. $\mathrm{RBC}_{2020\text{-}22}$: the mean RBC over the three years from 2020-2022.
8. $\mathrm{RBC}_{2020\text{-}23}$: the mean RBC over the five years from 2020-2023.
9. $\mathrm{RBC}_{\mathrm{longterm}}$: the longterm RBC.

The base case in this section refers only to the old base case. Hence, the RBC values were calculated for the old base case only. All sensitivities were calculated relative to the old base case, using the incorrect (lower) catch series from 2001-2018. The general principles and comparisons in these sensitivities to the old base case are not expected to show qualitative differences to similar sensitivities conducted with the updated base case.

It is possible that the eastern Tasmanian component of the stock could have different growth to the rest of the stock or could be assessed as a separate stock and these options could be explored in future assessments. The current assessment assumes a single stock and a single growth curve per sex for the whole stock, an assumption also made in previous assessments.

7.4 Results and discussion

7.4.1 The base case analysis

7.4.1.1 Parameter estimates

Figure 7.5 shows the estimated growth curve for female and male tiger flathead. All growth parameters are estimated by the model except for l_{max} (parameter values are listed in Table 7.15).

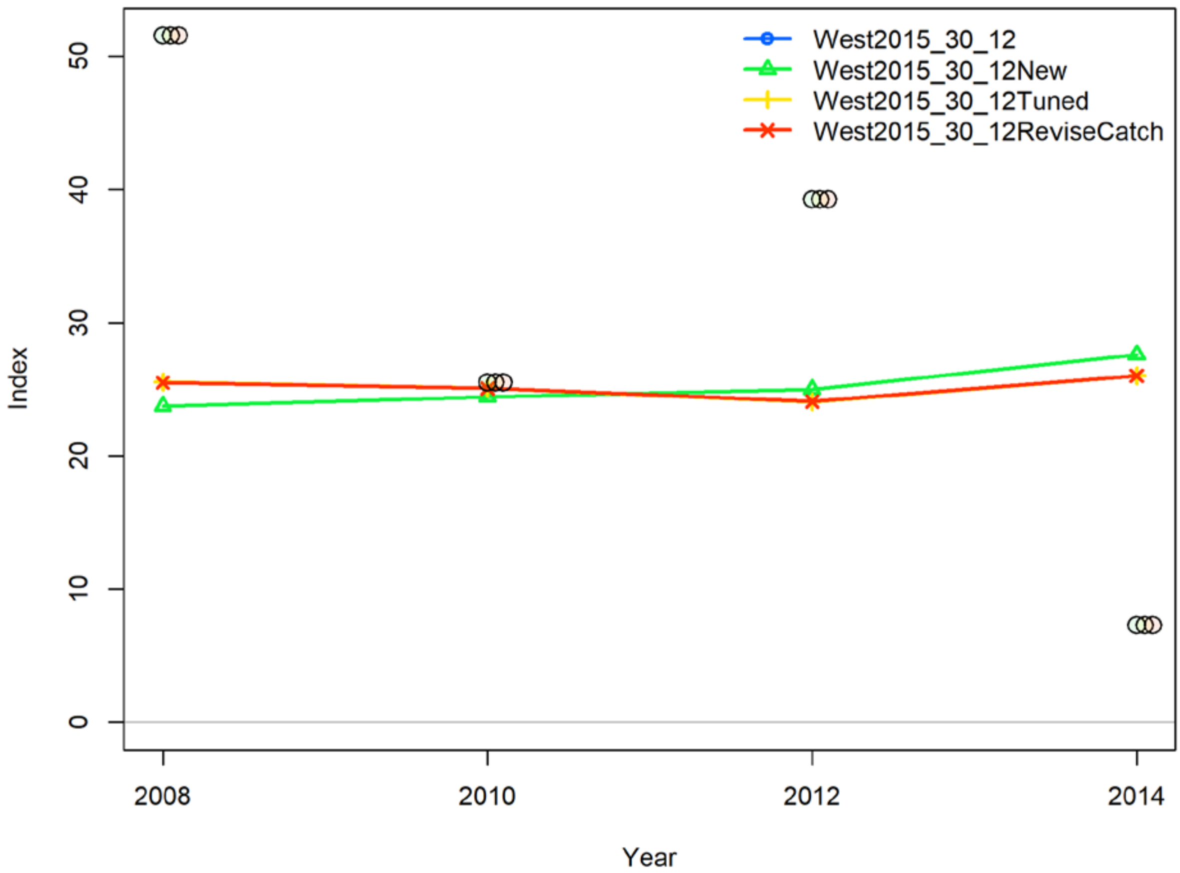

Figure 7.5. The model-estimated growth curves.

Table 7.15. Summary of parameters of the base case model.

Feature	Details	
Fleets	Steam trawl	Fixed discard rate of 17%
	Danish seine	Fixed discard rate of 17% to 1960, fitted
		Selectivity change in 1978 from early to
	East coast	Selectivity change in 1985 from early to
	Tasmanian	Diesel trawl in Zone 30
Natural	fixed	0.27
Steepness h	estimated	0.72
σ_R in	fixed	0.70
Recruitment	estimated	1915-2015, bias adjustment ramps 1933-1942
CV growth	estimated	0.108
Growth K	estimated	Female 0.172, Male 0.154
Growth l_{min}	estimated	Female age 2 29.89
Growth l_{max}	fixed	Female 55.9

Selectivity is assumed to be logistic for all fleets. The parameters that define the selectivity function are the length at 50% selection and the spread (the difference between length at 50% and length at 95% selection). Figure 7.6 shows the selectivity and retention functions for each of the commercial fleets. Figure 7.7 shows the selectivity for the two FIS fleets, FISEast (Zones 10 and 20) and FISTas (Zone 30). The difference in the selectivity patterns when the FIS fleet is split suggests different characteristics in the fish caught by the FIS in Zone 30 from fish caught by the FIS in zones 10 and 20, reflecting similar patterns seen in the commercial trawl data in these regions.

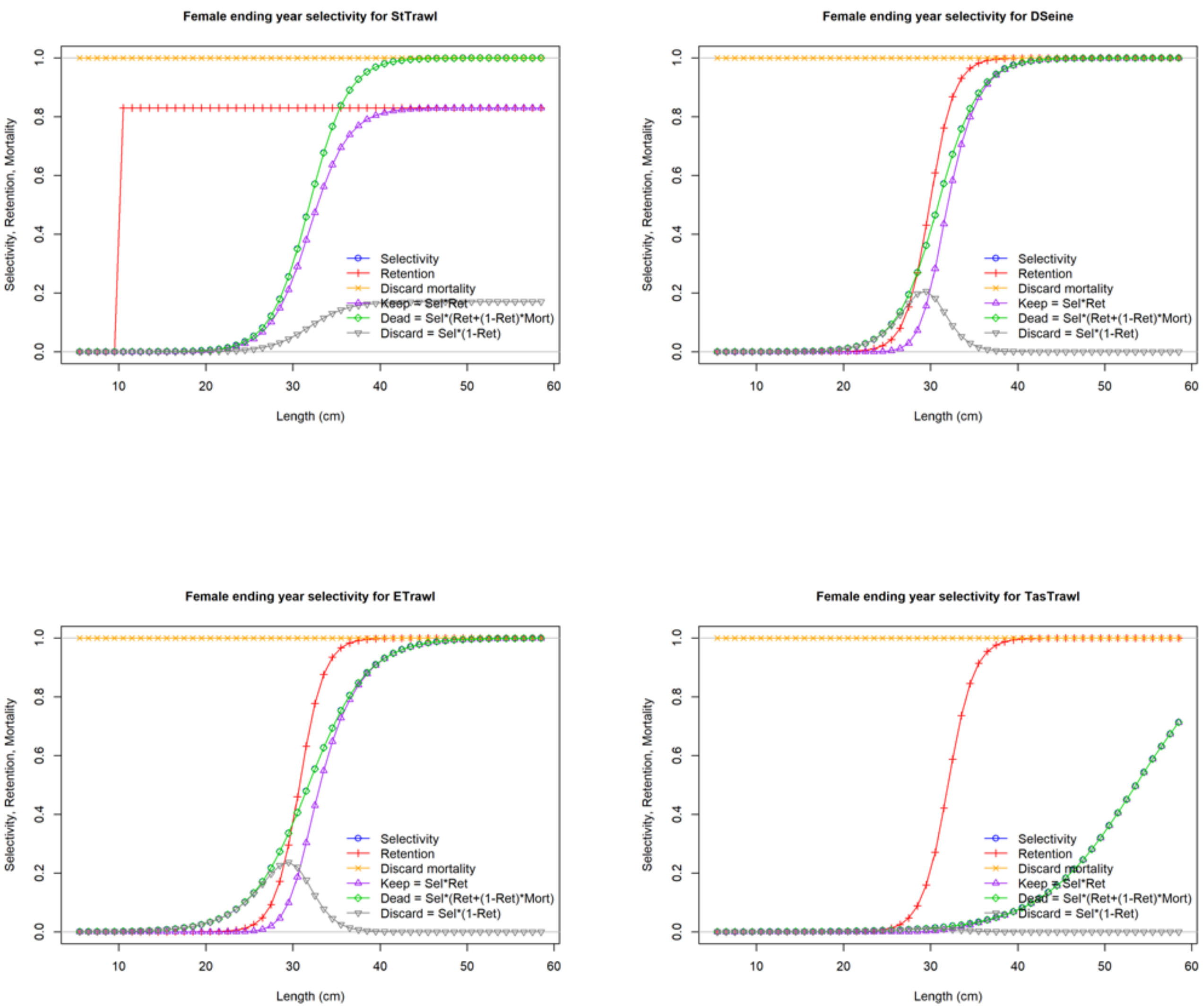

Figure 7.6. Selectivity (blue/green) and retention (red) functions for the four commercial fleets.

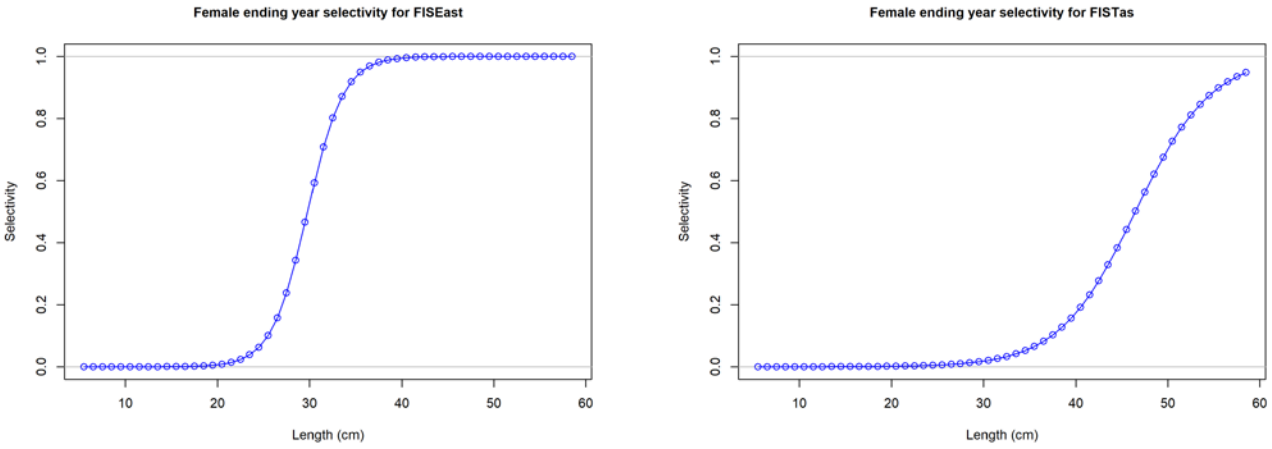

Figure 7.7. Selectivity for the eastern (left) and Tasmanian (right) FIS fleets when the FIS length frequencies are separated into zones.

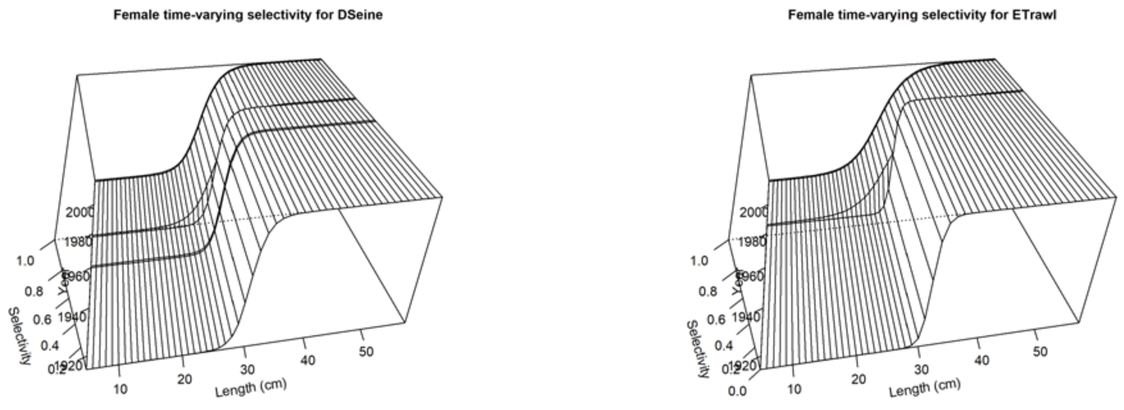

Figure 7.8. Time variation in selectivity for Danish seine and eastern diesel trawl.

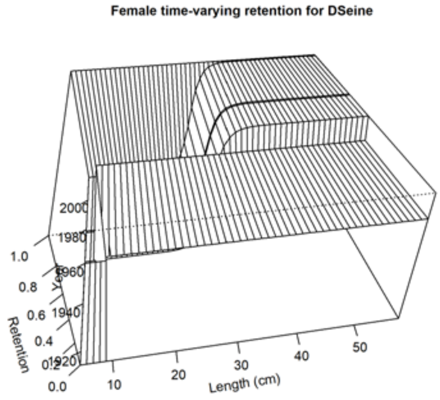

Figure 7.9. Time variation in retention for Danish seine.

7.4.1.2 Fits to the data

The fits to the catch rate indices (Figure 7.10) are variable in quality. The catch rate indices for the steam trawl fleet shows a considerable decline from 1915 to 1950, consistent with overexploitation during that time (see Fairbridge 1948, Klaer 2006b). The early Danish seine index from 1950 to 1978 was relatively flat or increasing over that period. Recent abundance indices from 1986 to present also show reasonably flat trends. The Tasmanian trawl fleet index is the worst fit for the recent indices, but the catch contribution by that fleet is also the smallest.

Inclusion of the new data and tuning procedures resulted in changes to the estimates of recruitment and to the spawning biomass time series. With increased flexibility to vary recruitment early in the time series, the fits to the steam trawl indices improved considerably and there were several modifications to estimated recruitment deviations, most noticeably a downward revision to the 2012 recruitment estimate. The estimated spawning biomass in the 1920s increased from around 1.05 times virgin biomass in the 2016 assessment to around 1.2 times the virgin biomass in the 2019 assessment, allowing a much better fit to the early steam trawl CPUE time series.

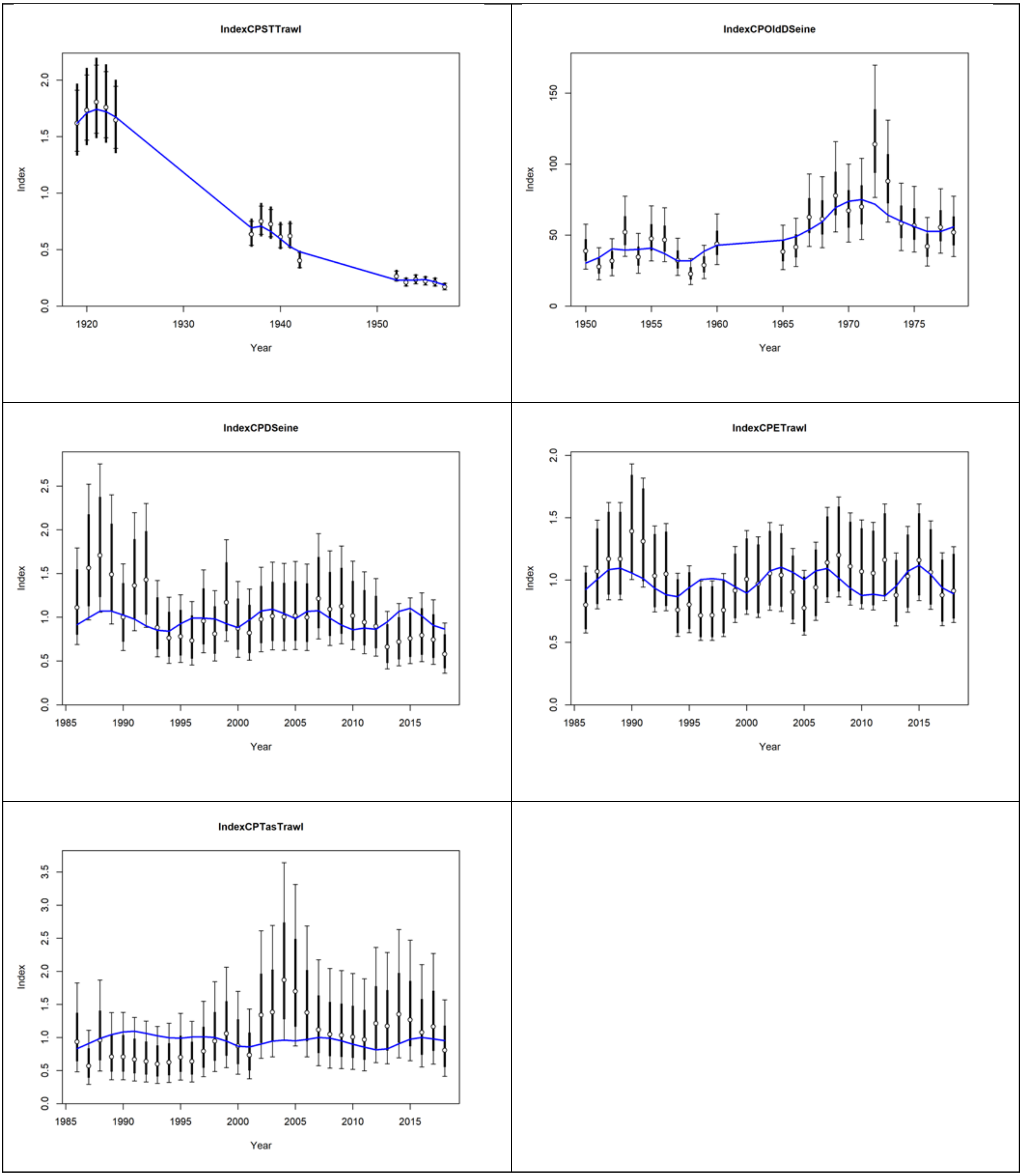

Figure 7.10. Observed (circles) and model-estimated (lines) catch rates vs year, with approximate 95% asymptotic intervals.

The fits to the FIS abundance indices separated into and eastern (zones 10 and 20) and Tasmanian (zone 30) fleets are shown in Figure 7.11. Variability between years and inconsistent patterns between the two regions makes it difficult to achieve any better fit to these data points, especially when three other indices are being fit simultaneously over the same time period.

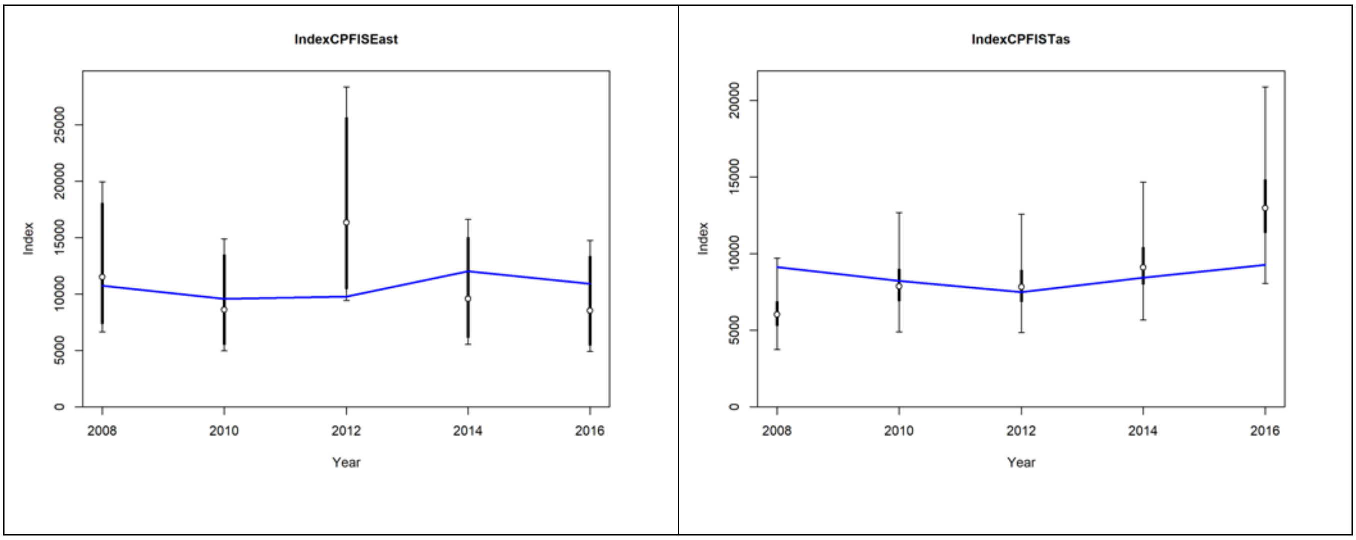

Figure 7.11. Observed (circles) and model-estimated (lines) catch rates vs year, with approximate 95% asymptotic intervals for the FIS abundance index separated into eastern (zones 10 and 20) and Tasmanian (zone 30) fleets.

The fits to the discard fractions (Figure 7.12) are reasonable given the variability in the data, with some very low data points (less than 2%) and others up to 20% for Danish seine and eastern trawl and up to 8% for Tasmanian trawl. The fits to the discard fractions for the eastern trawl and Danish seine fleets are considerably better than in the 2016 assessment, although this is helped by exclusion of some very small values (< 1%) from the Tasmanian trawl fleet. Including these low discard rates results in much lower overall predicted discard rates compared to the mean of the discard rates over all years with discard data for each fleet. Excluding these very small discard estimates has become standard practice in SESSF stock assessments in recent years.

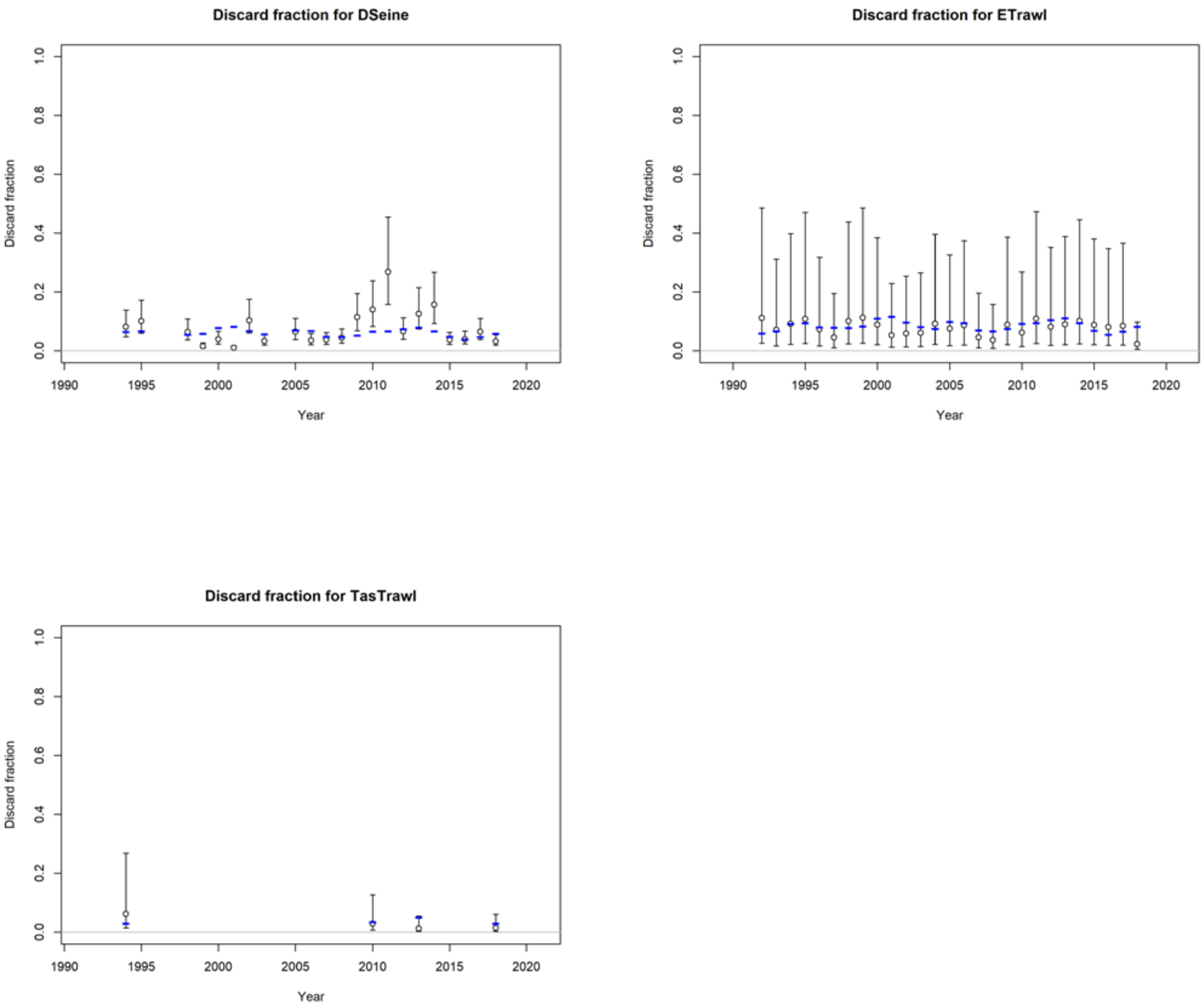

Figure 7.12. Observed (circles) and model-estimated (blue lines) discard estimates versus year, with approximate 95% asymptotic intervals.

The base case model is able to fit the aggregated retained and discarded length-frequency distributions very well (Figure 7.13 and Appendix A), with the exception of the Tasmanian trawl fleet, for which the actual sample sizes are relatively small. The fits to the historical steam trawl and early Danish seine fleets are better than those for the more recent data (except for steam trawl in 1957 and 1958). The number of fish measured for the historical data is generally very high, which leads to smoother observed distributions. The fits to the discarded length compositions are variable (Figure 7.13 and Appendix A). This is not surprising, as the observed discard length frequencies are quite variable from year to year, and actual sample sizes are small in comparison to the retained length frequencies.

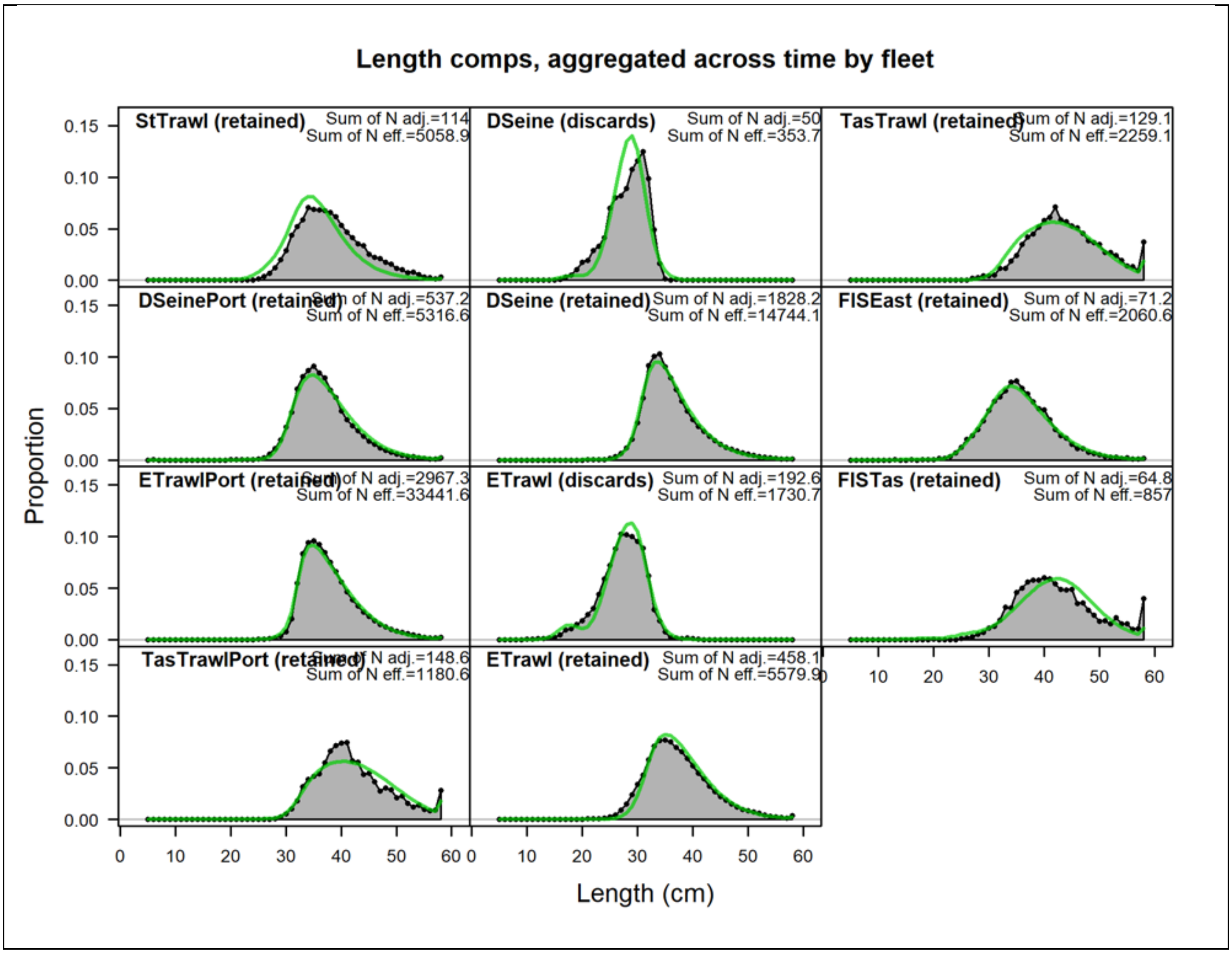

Figure 7.13. Fits to retained and discarded length compositions by fleet, separated by port and onboard samples, aggregated across all years. Observed data are grey and the fitted value is the green line.

The implied fits to the age composition data are shown in Appendix A. The age compositions were not fitted to directly, as age-at-length data were used. However, the model is capable of outputting the implied fits to these data for years where length frequency data are also available, even though they are not included directly in the assessment. The model fits the observed age data reasonably well for all three recent fleets for both retained and discarded age data.

Note that there are separate implied fits to age for the port and onboard data. There is only one set of age data, but this needs to be scaled up to length data (using an age-length key) to get implied fits to age, as the age data is not representative of the stock as a whole. This scaling up to length data can be done using either the onboard length data or the port length data – so it appears that there are two sets of age data.

The conditional age-at-length data is a little noisy between years, especially for the fleets with smaller catches. The mean age varies between 3 and 6 years for eastern trawl and Danish seine and between 6 and 11 years for the Tasmanian trawl fleet. This variability in the age-at-length data may be due to spatial or temporal variation in collection of age samples. The fits to conditional age-at-length are reasonable.

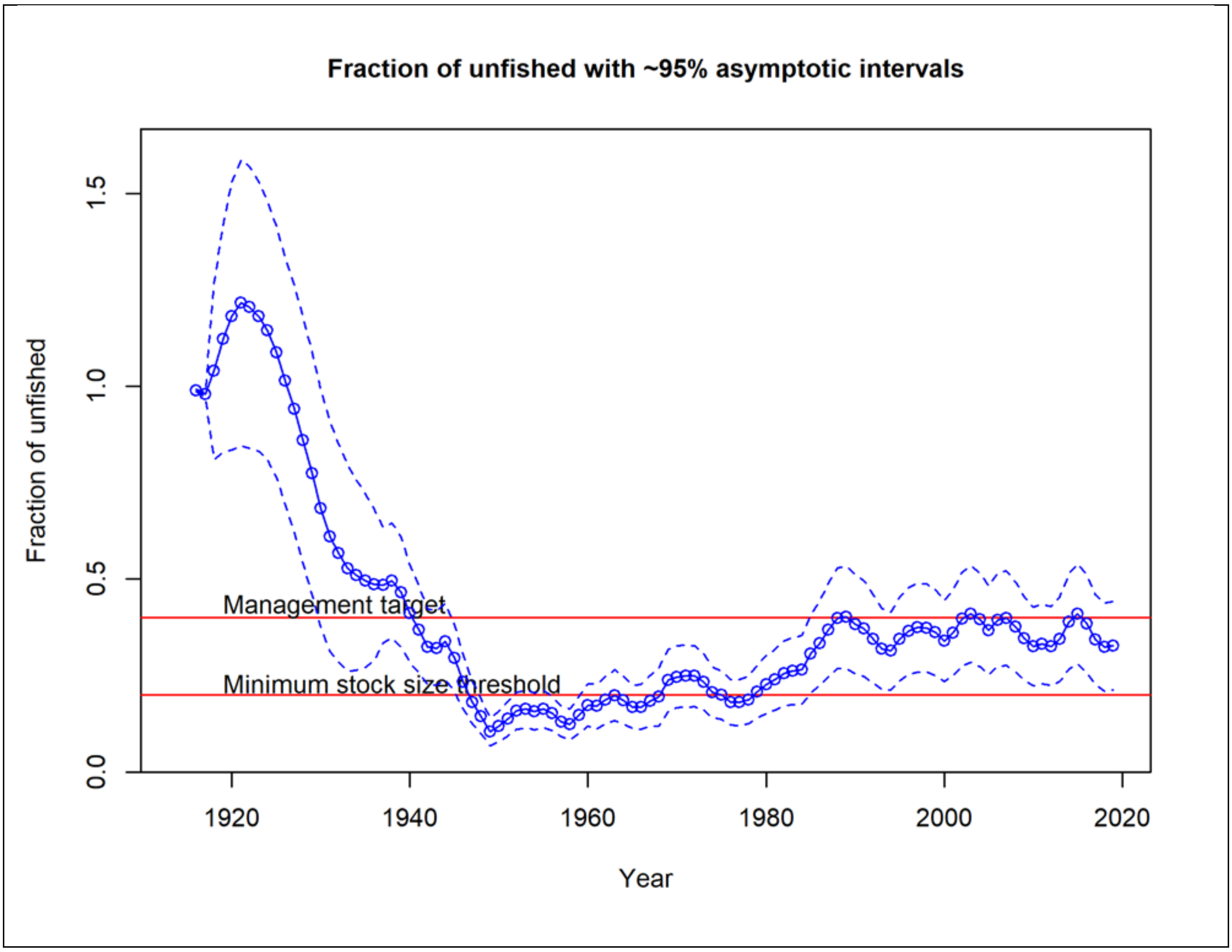

Figure 7.14. Time-trajectory of spawning biomass depletion (with approximate 95% asymptotic intervals) corresponding to the MPD estimates for the base case analysis for tiger flathead.

7.4.1.3 Assessment outcomes

Figure 7.14 shows the trajectory of spawning stock status. The stock declines substantially from the beginning of the fishery in 1915 to 1950, fluctuates near the minimum threshold of 20% SSB_0 during the 1950s, 1960s and 1970s, before an increase to near 40% SSB_0 by the 1990s. This increase in the 1980s was driven by a combination of favourable recruitments (Figure 7.16) and total landings of less than 2,000t in the late 1970s and early 1980s. The stock has fluctuated between 30% and 40% SSB_0 since around 1990 with a slight decrease in the last three years. The comparison to the base case from the 2016 assessment is shown in Figure 7.15.

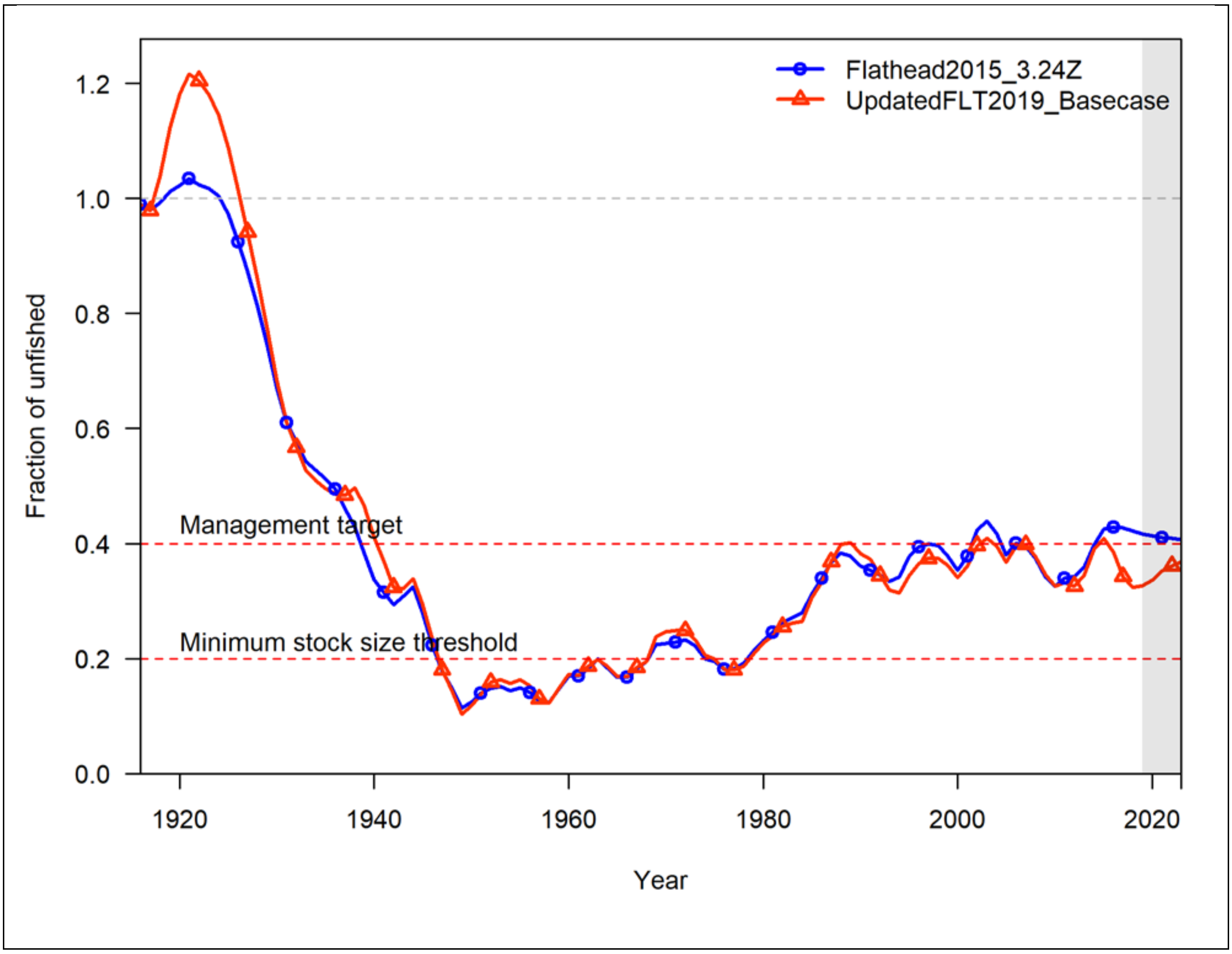

Figure 7.15. Time-trajectory of spawning biomass depletion corresponding to the MPD estimates for the base case analysis for the two base cases for the tiger flathead assessment in 2016 and in 2019.

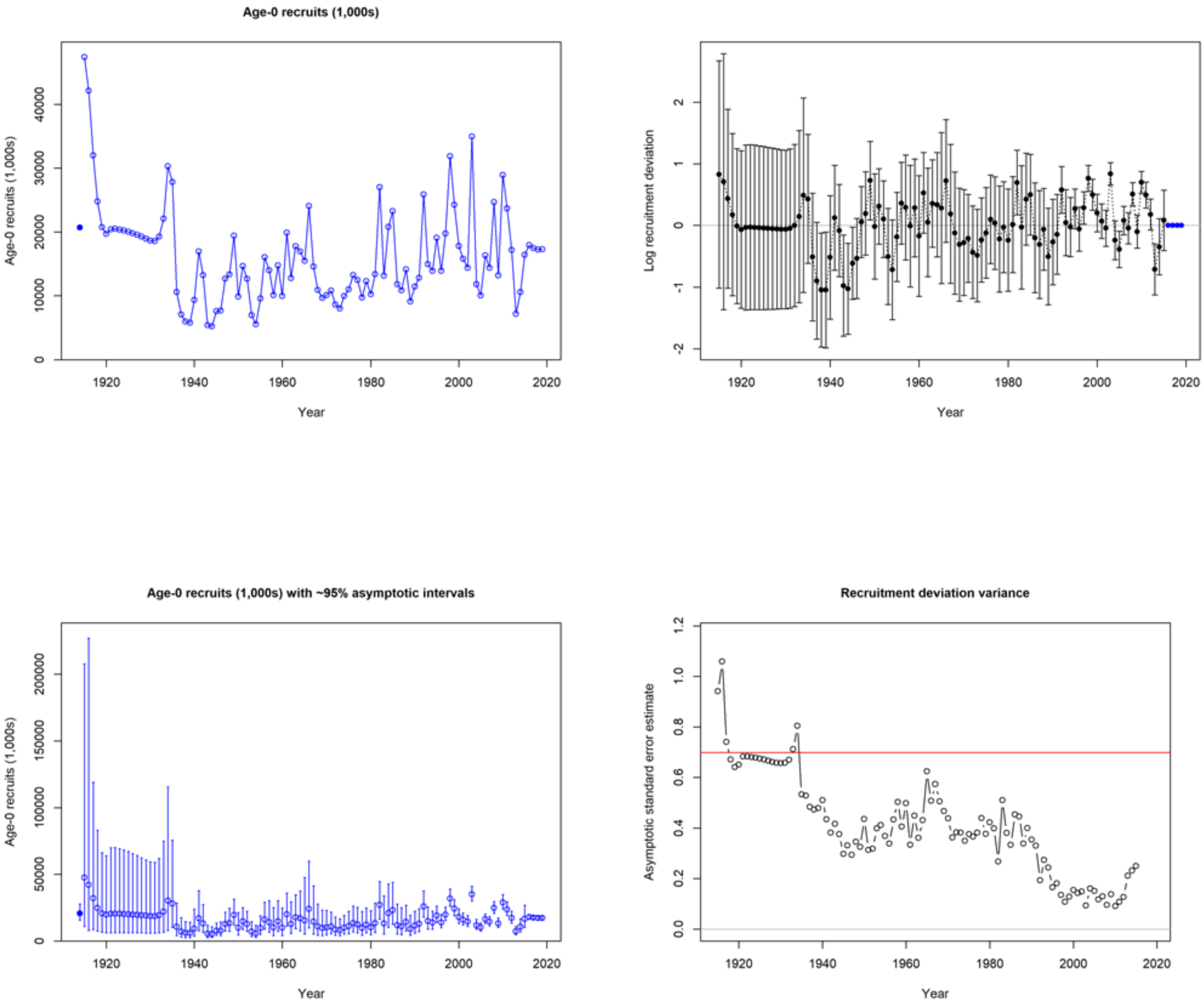

Figure 7.16. Recruitment estimation for the base case analysis. Top left: Time-trajectories of estimated recruitment numbers; top right: time trajectory of estimated recruitment deviations; bottom left: time-trajectories of estimated recruitment numbers with approximate 95% asymptotic intervals; bottom right: the standard errors of recruitment deviation estimates.

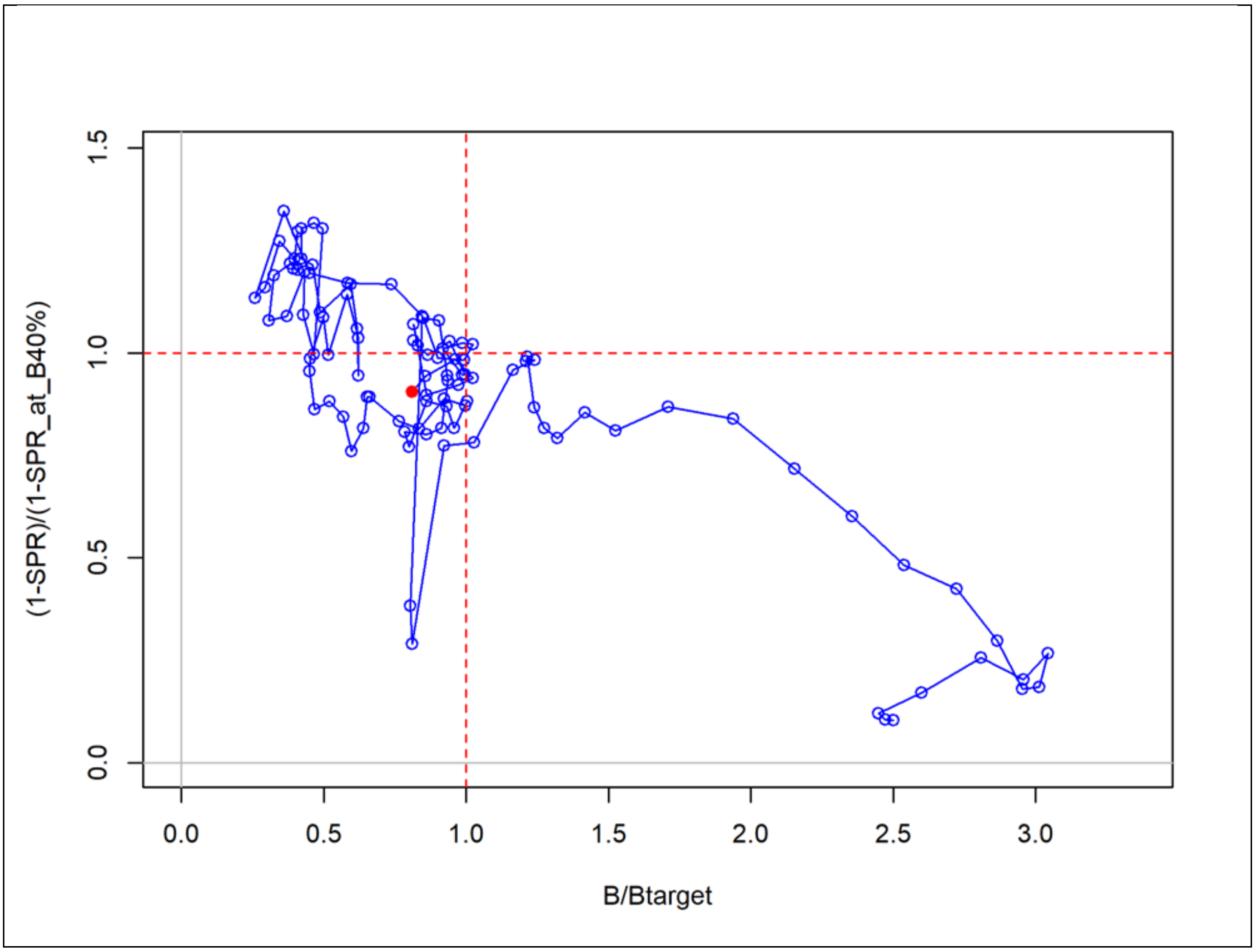

Figure 7.17. Kobe plot for the base case analysis, showing the trajectory of spawning biomass (relative to B0) plotted against (1-SPR) as a ratio of the target, which is a proxy for fishing mortality, essentially integrating fishing mortality across fleets in the fishery.

Figure 7.17 shows a Kobe plot for the base case analysis. This plot shows a time series of spawning biomass plotted against spawning potential ratio, which provides a measure of overall fishing mortality, and shows the stepwise movement in this space from the start of the fishery, in the bottom right corner, when there was low fishing mortality and high biomass to the present day (the red dot) where the biomass is just below the target (to the left of the vertical red dashed line) and the fishing mortality is below the target fishing level (below the horizontal red dashed line). This trajectory shows an increase in overall fishing mortality and a decrease in biomass from 1915 to about 1950, with movement from the bottom right corner to the top left corner, when the biomass was well below the target and the fishing mortality was above the target rate. The years 1942 and 1943 stand out in this trajectory when fishing effort dropped notably, with the biomass at around 75% of the target (or 30% of B_0). Apart from this short period of reduced fishing effort during World War II, fishing mortality stayed above the target rate until 1978, when fishing mortality reduced considerably, and stayed around or below the target until the late 1990s. This allowed the spawning biomass to recover to near the target (40% of B_0) in the late 1990s. Since the late 1990s, fishing mortality has increased again, with a slight drop in the last six years. This period has been supported by relatively strong recruitment over the last 20 years.

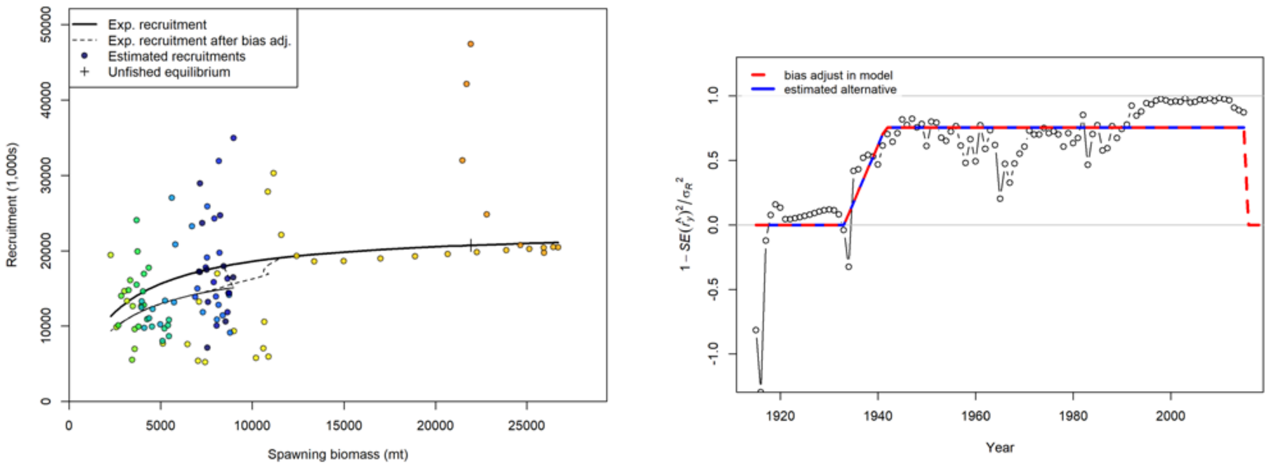

Figure 7.18. Recruitment estimation for the base case analysis. Left: the stock-recruit curve and estimated recruitments; right: bias adjustment.

The time-trajectories of recruitment and recruitment deviation are shown in Figure 7.16. Estimates of recruitments since about 1940 are generally variable, but periods of above and below average recruitment levels appear for periods of up to eight years. Long-term regular cycles are not evident however. Recruitment in the past 30 years is estimated to have been highly variable. The variability in estimated recent recruitment is likely to be a result of the model attempting to fit the increased quantity of data in recent years, particularly the age data.

The base case assessment estimates that current spawning stock biomass is 34% of unexploited stock biomass (SSB_0), compared to 42% from the 2016 assessment (Day, 2017) and 50% from the 2013 assessment (Day and Klaer, 2013). The 2020 recommended biological catch (RBC) under the 20:35:40 harvest control rule is 2,334 t (Table 7.16) and the long term yield (assuming average recruitment in the future) is 2,986 t (Table 7.26). Averaging the RBC over the three year period 2020-2022, the average RBC is 2,563 t (Table 7.26) and over the five year period 2020-2024, the average RBC is 2,648 t (Table 7.26). The RBCs for each individual year from 2020-2024 are listed in Table 16 for the base case.

Table 7.16. Yearly projected RBCs (tonnes) across all fleets under the 20:35:40 harvest control rules for the updated base case, assuming average recruitment from 2016.

RBCs Year	Base
2020	2,334
2021	2,648
2022	2,706
2023	2,755
2024	2,796

7.4.1.4 Discard estimates

Model estimates for discards for the period 2020-24 with the 20:35:40 Harvest Control Rule are listed in Table 7.17 for the base case, with a range of 164 to 183 t.

Table 7.17. Yearly projected discards (tonnes) across all fleets under the 20:35:40 harvest control rules with catches set to the calculated RBC for each year from 2020 to 2024 rules for the updated base case, assuming average recruitment from 2016.

Discards Year	Base
2020	164
2021	181
2022	181
2023	182
2024	183

7.4.2 *Likelihood profiles*

As stated by Punt (2018), likelihood profiles are a standard component of the toolbox of applied statisticians. They are most often used to obtain a 95% confidence interval for a parameter of interest. Many stock assessments “fix” key parameters such as mortality (M) and steepness (h) based on a priori considerations. Likelihood profiles can be used to evaluate whether there is evidence in the data to support fixing a parameter at a chosen value or indeed support for estimating that parameter. If the parameter is within the entire range of the 95% confidence interval (within 1.92 units of likelihood), this provides no support in the data to change the fixed value. If the fixed value is outside the 95% confidence interval, it would be reasonable for a review panel to ask why the parameter was fixed and not estimated, and if the value is to be fixed, on what basis and why should what amounts to inconsistency with the data be ignored. Integrated stock assessments include multiple data sources (e.g., commonly catch-rates, length-compositions, and age-compositions) that may be in conflict, due for example to inconsistencies in sampling, but more commonly owing to incorrect assumptions (e.g., assuming that catch-rates are linearly related to abundance), i.e. model-misspecification. Likelihood profiles can be used as a diagnostic to identify these data conflicts (Punt, 2018).

Initial likelihood profiles (for mortality and virgin biomass on the 2019 preliminary base case) were presented at the October 2019 SERAG meeting (Day 2019). These are repeated here for the 2019 old base case, using the incorrect (lower) catch series from 2001-2018, with additional likelihood profile on steepness, spawning biomass in 2018 and relative spawning biomass status (depletion). The comparisons in these analyses with the old base case are not expected to show qualitative differences to updated comparisons with the corrected catch series.

7.4.2.1 Natural mortality

For tiger flathead, the likelihood profile for natural mortality, M, a parameter fixed in the model, is shown in Figure 7.19 with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. This likelihood profile suggests that there is little information in the model that can be used to inform this parameter (fixed at 0.27 in the model). The index and length data (which both suggest higher mortality) and the recruitment and discard data (which both suggest lower mortality) are in conflict and the likelihood profile suggests higher values of mortality are preferred. However, this likelihood profile is essentially uninformative when the biological consequences of mortality values greater than 0.3 are considered on the expected maximum age for this species.

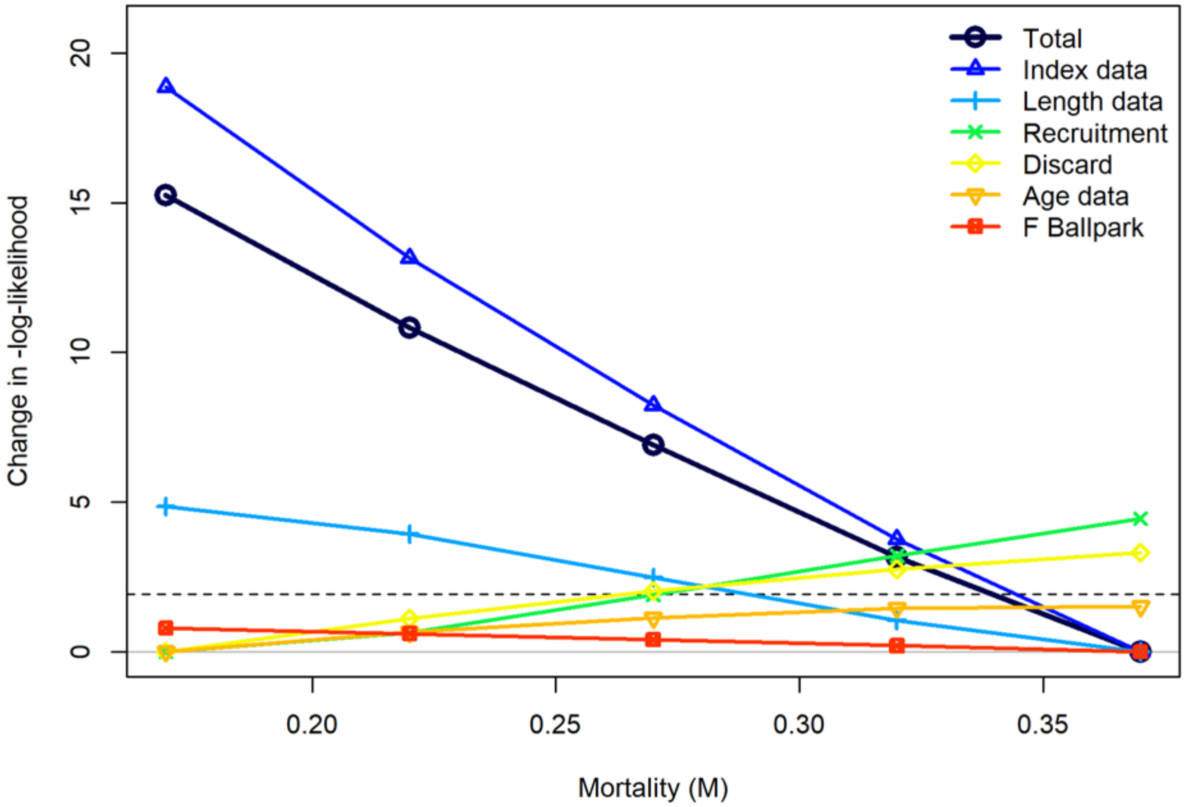

Figure 7.19. The likelihood profile for natural mortality, with *M* ranging from 0.17 to 0.37. The fixed value for *M* is 0.27yr^{-1}.

7.4.2.2 Steepness

A likelihood profile for steepness (*h*), a parameter estimated in the model, is shown in Figure 7.20 with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. This likelihood profile gives information on the components of the data which are most influential in estimating *h* and gives an indication of how precisely *h* can be estimated, and perhaps whether *h* should be estimated.

The likelihood profile in Figure 7.20 is relatively flat, with very little difference in likelihood values between 0.6 and 0.95. While the model can obtain an estimate for *h*, this profile would suggest that a wide range of values cannot be distinguished by the data. This suggest that *h* should not be estimated in the next tiger flathead stock assessment. Steepness is often impossible to estimate in stock assessment models. Being able to estimate steepness is more likely if recruitment has been estimated at both high biomass levels and, with a recovery, from low biomass levels. Despite this assessment having all of these features, it appears steepness is not estimated very precisely here, so it may be better to fix this value (*h*=0.75) in the next tiger flathead stock assessment.

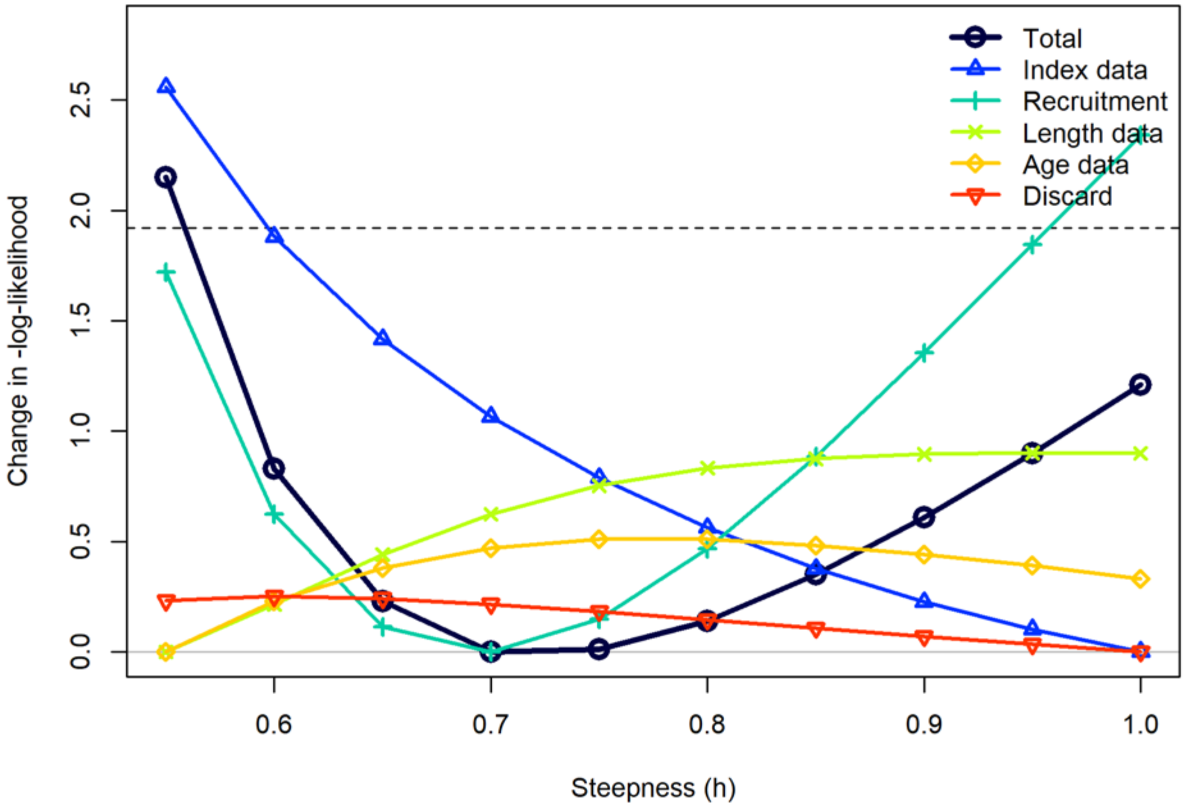

Figure 7.20. The likelihood profile for steepness, with *h* ranging from 0.55 to 1. The estimated value for *h* is 0.72.

The most important data sources in providing information on *h* are the index data and recruitment deviations (Figure 7.20). While neither data source is that influential, the index data support a higher value of steepness (a more productive stock) than the recruitment data (which support a less productive stock). The steam trawl CPUE data has the most influence on the index component of this likelihood (Figure 7.21).

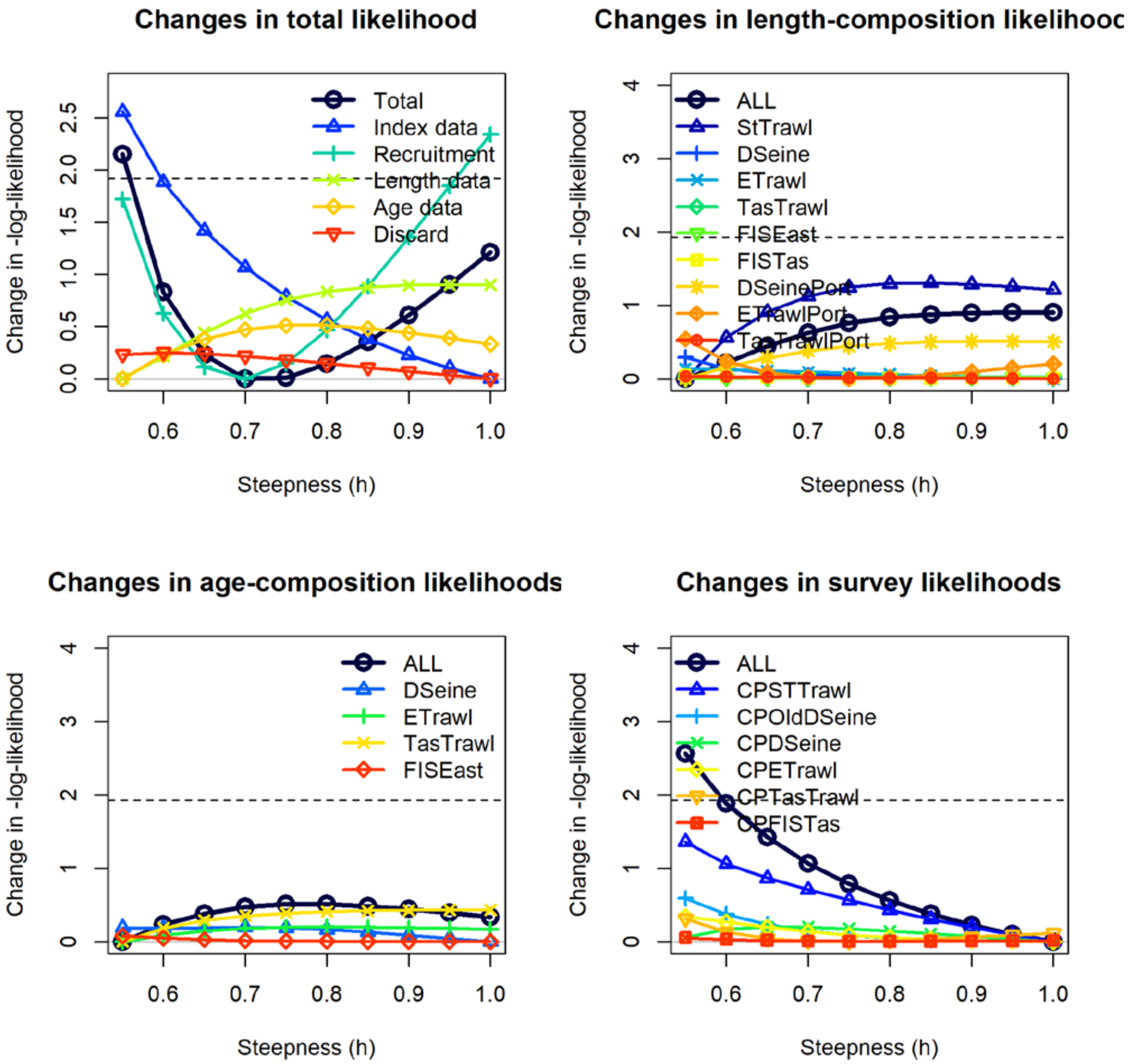

Figure 7.21. Piner plot for the likelihood profile for virgin spawning biomass, showing components of the change in likelihood for length, age and indices (CPUE) in addition to the changes in the total likelihood.

7.4.2.3 Virgin spawning biomass

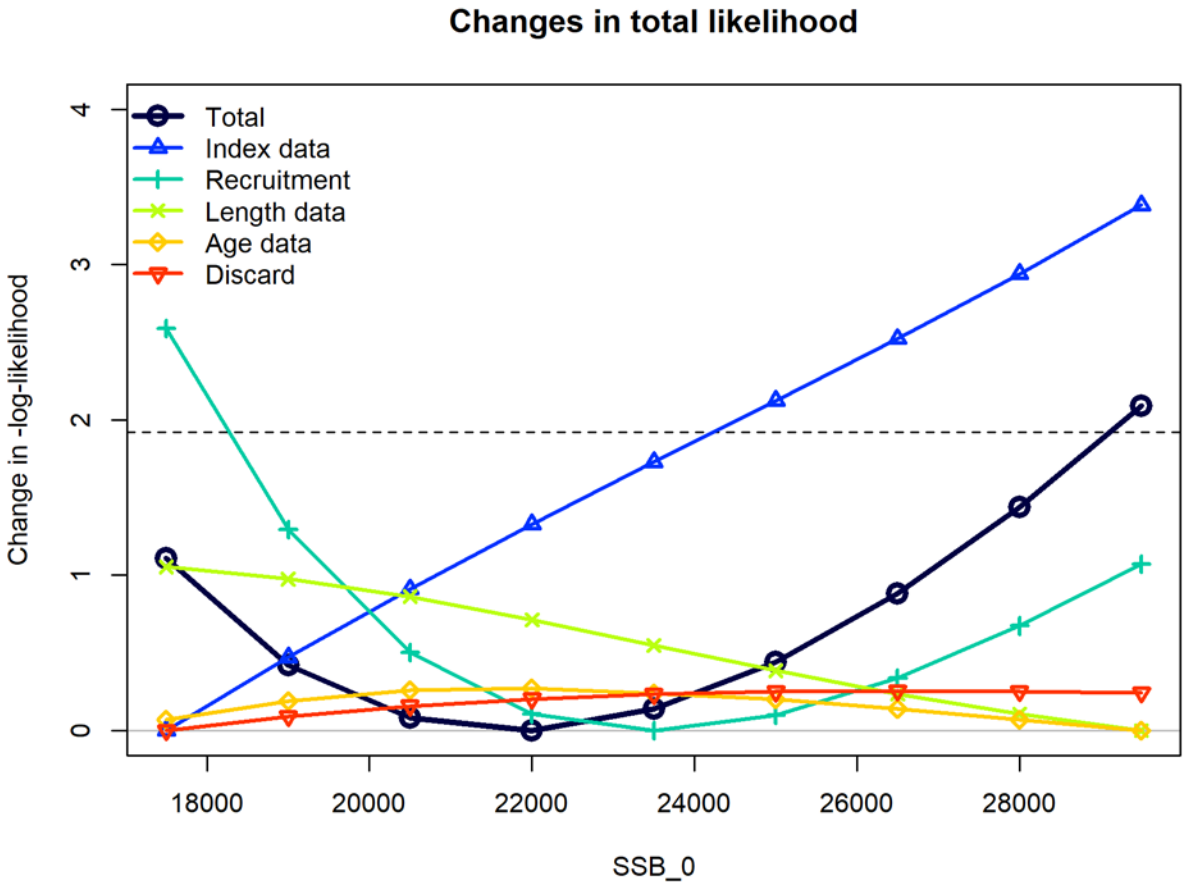

Figure 7.22. The likelihood profile for virgin spawning biomass, with SSB_0 ranging from 17,500 to 29,500t. The estimated value for SSB_0 is 21,737 t.

A likelihood profile for virgin spawning biomass (SSB_0) is shown in Figure 7.22 with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. SSB_0 is a derived parameter which is linked to the estimated parameter R_0, which is the average equilibrium recruitment. To construct a likelihood profile on SSB_0 requires setting up an additional "fleet" with a single data point (in 1915) with very low standard error, essentially adding a "highly precise survey" of spawning biomass, setting the selectivity type to 30 (an index of *SSB*) and then allowing this spawning biomass value to vary between runs. This likelihood profile suggests a broad range of plausible values for SSB_0 ranging between around 15,000 and 29,000t with the most likely value at around 22,000t.

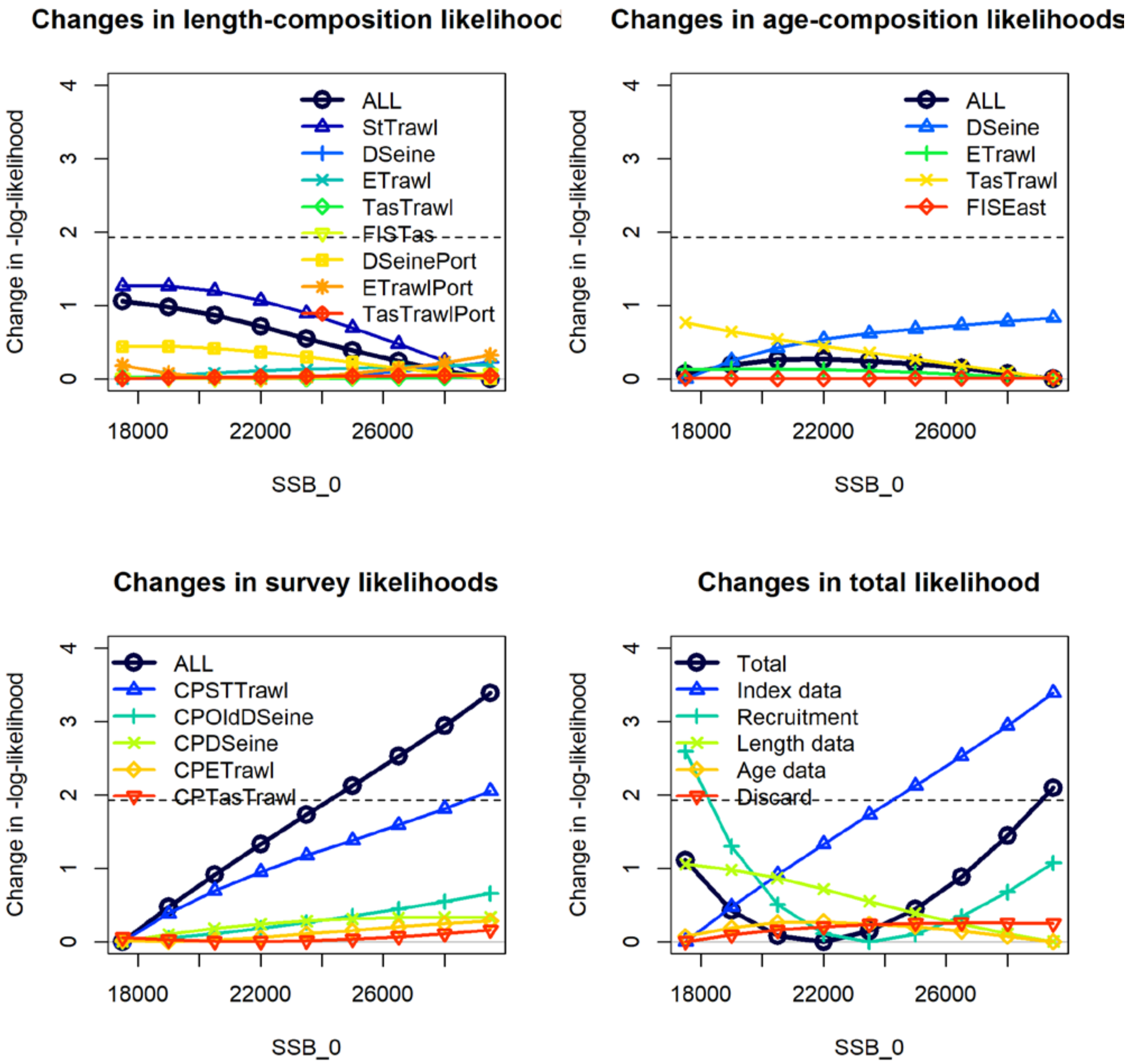

Figure 7.23. Piner plot for the likelihood profile for virgin spawning biomass, showing components of the change in likelihood for length, age and indices (CPUE) in addition to the changes in the total likelihood.

The important data sources in providing information on SSB_0 are the index data and recruitment deviations (Figure 7.22). SSB_0 needs to be sufficiently high to enable the historical catches to be sustained, so this results in the recruitment component of the likelihood providing a lower bound on SSB_0.The fits to the index data deteriorate with larger values of SSB_0. Not surprisingly, the steam trawl CPUE data has the most influence on the index component of this likelihood (Figure 7.23).

7.4.2.4 Current (2018) spawning biomass

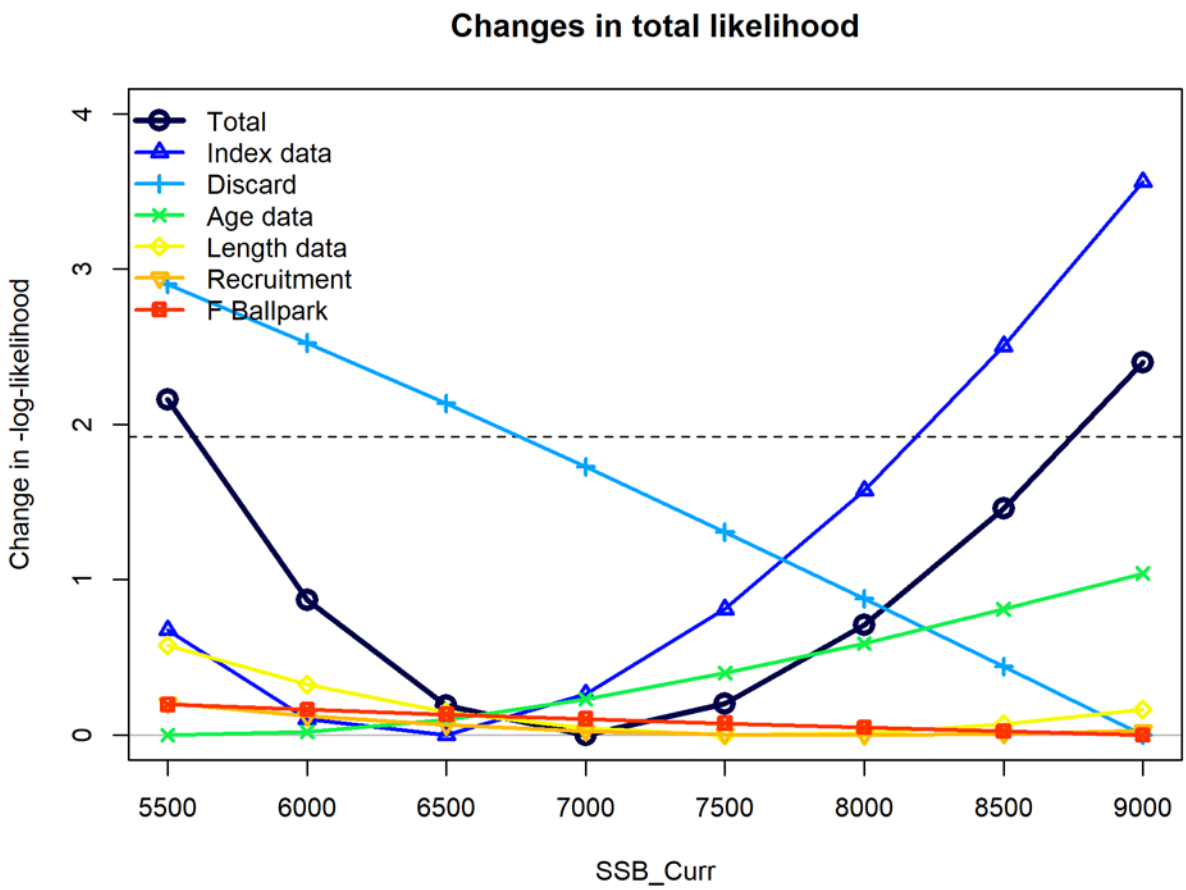

Figure 7.24. The likelihood profile for 2018 spawning biomass, ranging from about 5,500 to 8,750 t. The estimated value for 2018 spawning biomass is 6,970 t.

A likelihood profile for current spawning biomass (SSB_{2018}) is shown in Figure 7.24 with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. Like SSB_0, SSB_{2018} is a derived parameter which is linked to the estimated parameter R_0, which is the average equilibrium recruitment. To construct a likelihood profile on SSB_0 requires setting up an additional "fleet" with a single data point (in 2018) with very low standard error, essentially adding a "highly precise survey" of spawning biomass, setting the selectivity type to 30 (an index of *SSB*) and then allowing this spawning biomass value to vary between runs. This likelihood profile suggests a broad range of plausible values for SSB_{2018} ranging between around 5,500 and 8,750 t with the most likely value at around 7,000 t.

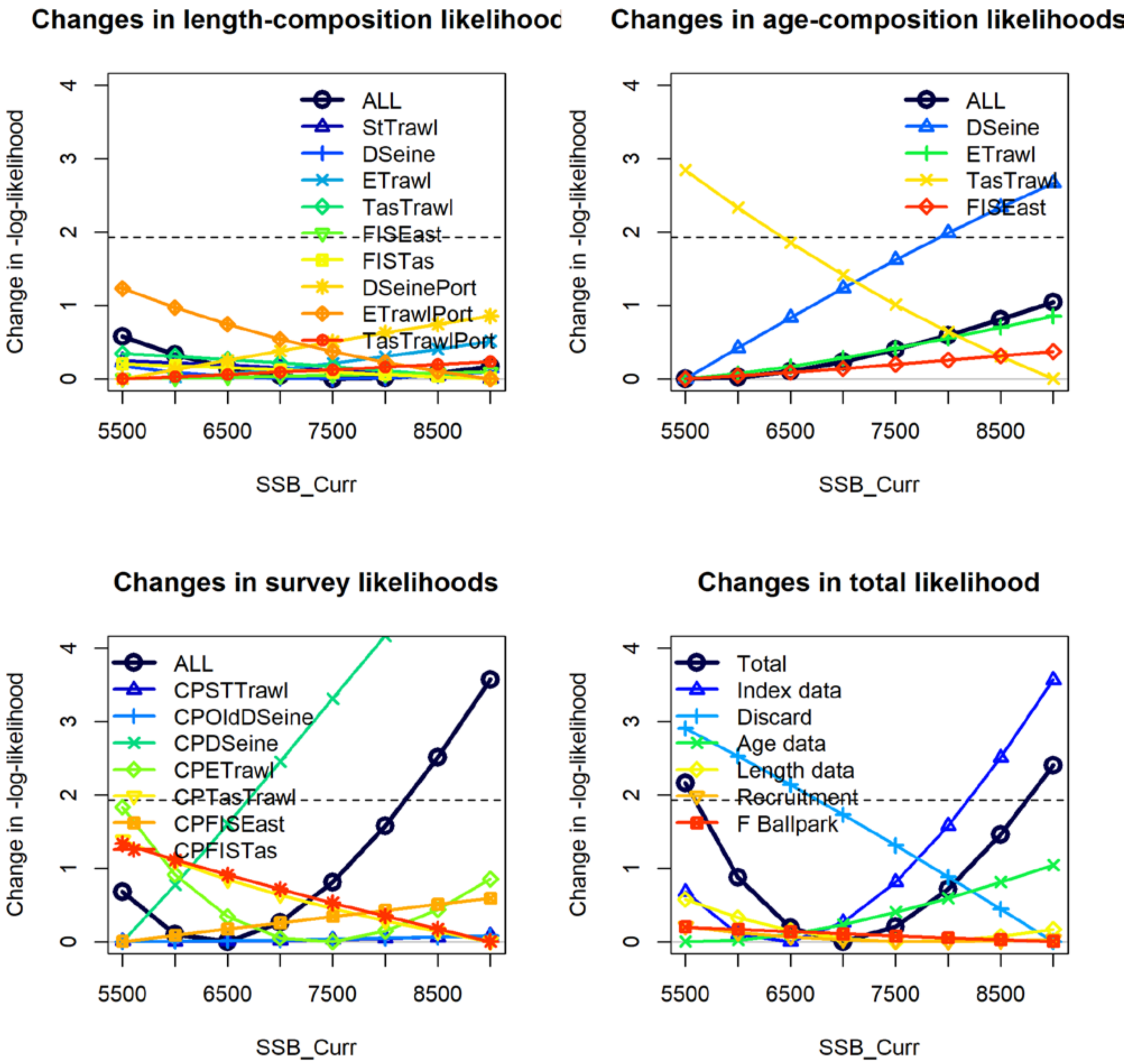

Figure 7.25. Piner plot for the likelihood profile for 2018 spawning biomass, showing components of the change in likelihood for length, age and indices (CPUE) in addition to the changes in the total likelihood.

The important data sources in providing information on *SSB*$_{2018}$ are the index data and discard data (Figure 7.24). Within the index data, the Danish seine data appears to be in conflict with the other indices, supporting a lower *SSB*$_{2018}$, while the Tasmanian indices (both CPUE and FIS) support a higher value of *SSB*$_{2018}$ (Figure 7.24). This same conflict between Danish seine and Tasmanian trawl data also appears in the age data (Figure 7.25).

7.4.2.5 Relative spawning biomass (depletion)

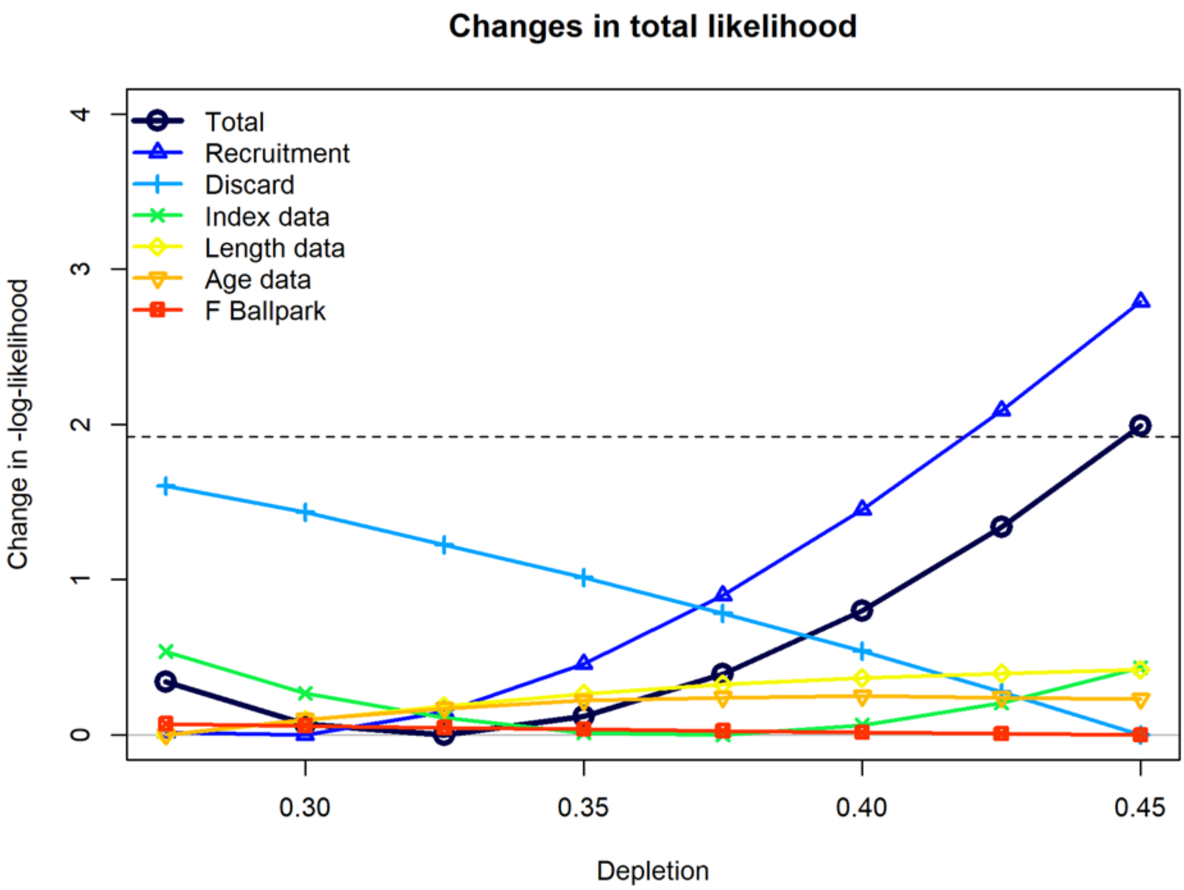

Figure 7.26. The likelihood profile for relative spawning stock biomass (depletion) in 2018, ranging from about 20% to 45%. The estimated value for depletion in 2018 is 32%.

A likelihood profile for current spawning biomass (SSB_{2018}) relative to SSB_0 is shown in Figure 7.26 with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. Like SSB_0 and SSB_{2018} is a derived parameter. To construct a likelihood profile on SSB_0 requires setting up an additional "fleet" with a value of 1.0 in 1915 and an additional data point at the end of the series (2018), specifying a depletion level with a very low standard error, essentially adding a "highly precise survey" of depletion, setting the selectivity type to 34 (an index of *SSB*) and then allowing this relative spawning biomass value to vary between runs. This likelihood profile suggests a broad range of plausible values for depletion in 2018 ranging between around 20% and 45%, with the most likely value at around 32%. The model did not converge for values of depletion below 27.5%, but the minimum of the likelihood profile appears to be above this value. Recruitment and discard data have the most influence.

Ideally this likelihood profile would be produced for depletion at the start of 2020, as with the depletion profile on current biomass (2020 rather than 2018). However, likelihood profiles can only be constructed on parameters that are associated with likelihood values (requiring actual data) and not projected values, so 2018 is the last year that a likelihood profile can be constructed, either for spawning biomass or depletion.

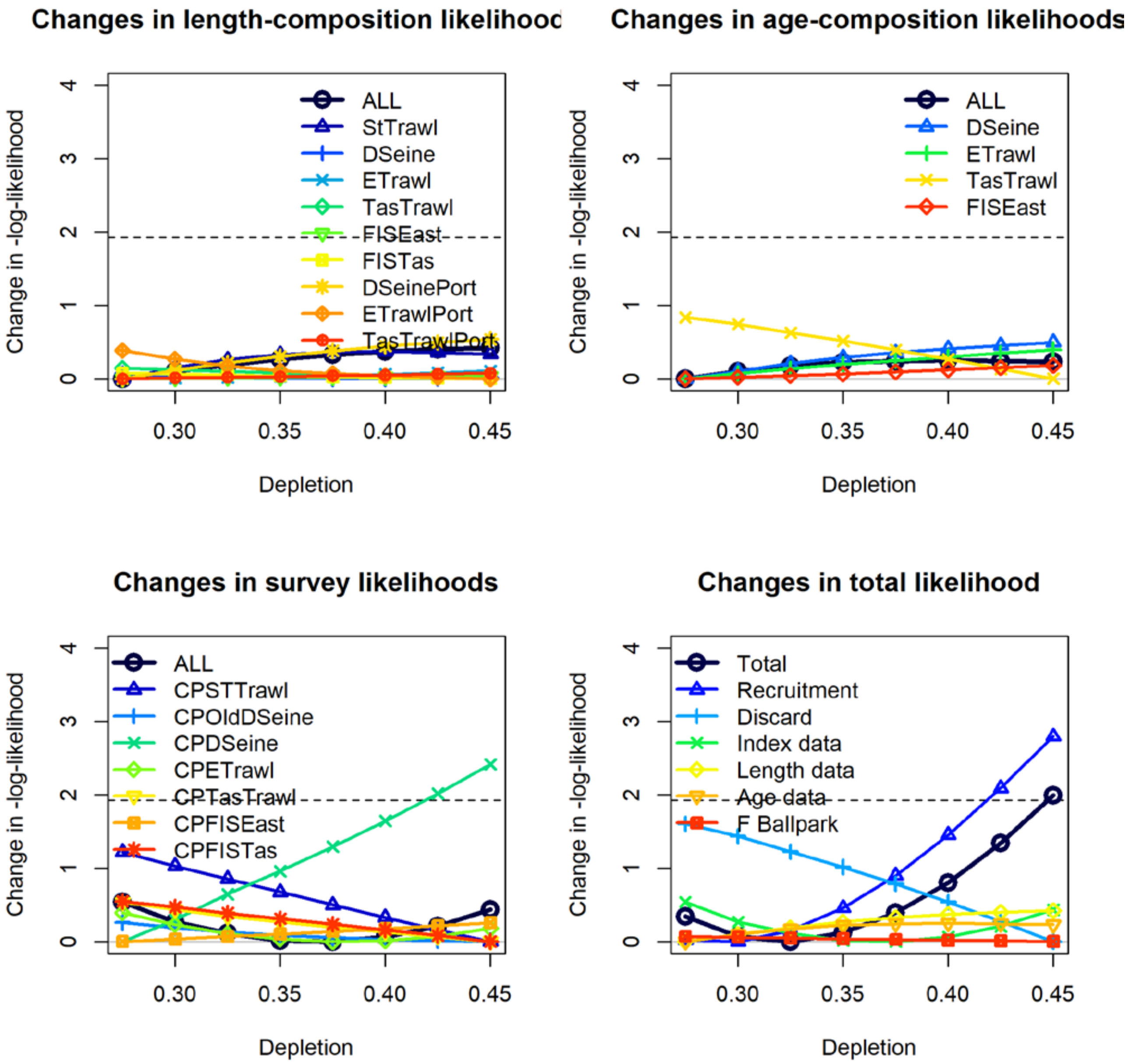

Figure 7.27. Piner plot for the likelihood profile for 2018 spawning biomass, showing components of the change in likelihood for length, age and indices (CPUE) in addition to the changes in the total likelihood.

The important data sources in providing information on relative spawning stock biomass are the recruitment and discard data (Figure 7.26). While not very influential, within the index data, the modern Danish seine and steam trawl indices appear to be in conflict with each other (Figure 7.27).

7.4.3 *Retrospectives*

Preliminary retrospective analyses were presented at the October 2019 SERAG meeting (Day 2019). These used an automated retrospective function in Stock Synthesis and r4ss. This automated procedure allows quick production of retrospective plots, but unfortunately has some problems where not all data is not correctly removed at each step of the process. These retrospective analyses were repeated manually, and the corrected plots are included here, albeit with the old base case, using the incorrect (lower) catch series from 2001-2018.

The comparisons in these retrospective analyses with the old base case are not expected to show qualitative differences to updated comparisons with the corrected catch series. Retrospective analyses involve working backward in time and removing successive years of data from the assessment, starting from the most recent year of data. This analysis can highlight potential problems and instability in an assessment, or some features that appear from the data. While the qualitative nature of the initial retrospective analysis (Day, 2019) has not changed, some quantitative features have been corrected.

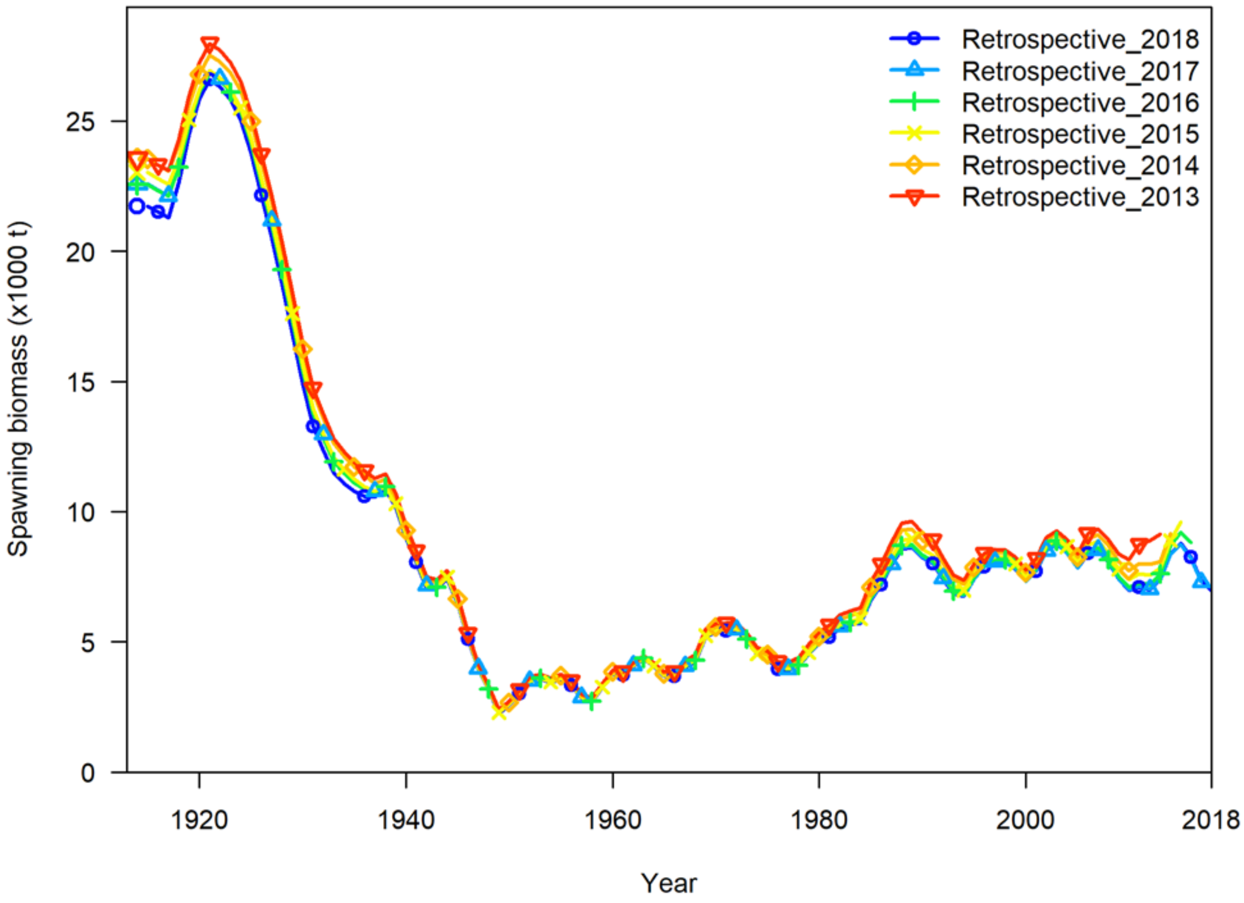

Figure 7.28. Retrospectives for absolute spawning biomass for tiger flathead, with data removed back to 2017 (light blue) and then successive years removed back to 2013 (red).

A retrospective analysis for absolute spawning biomass is shown in Figure 7.28, with the data after 2017 removed initially (shown in light blue), then successive years of data removed back to 2013 (shown in red). The same analysis is plotted in terms of relative spawning biomass in Figure 7.29. In both cases the changes are minor with the largest change at the end of the retrospectives deleting all data after 2013 (orange, minor change) and 2014 (red, slightly larger change), at the end of both time series. These show a slight downward revision of the relative spawning biomass in the period 2010-2015, as more years of additional data are added to the assessment. However, the effect is relatively small, and is only shown for these two retrospectives where a lot of data is removed.

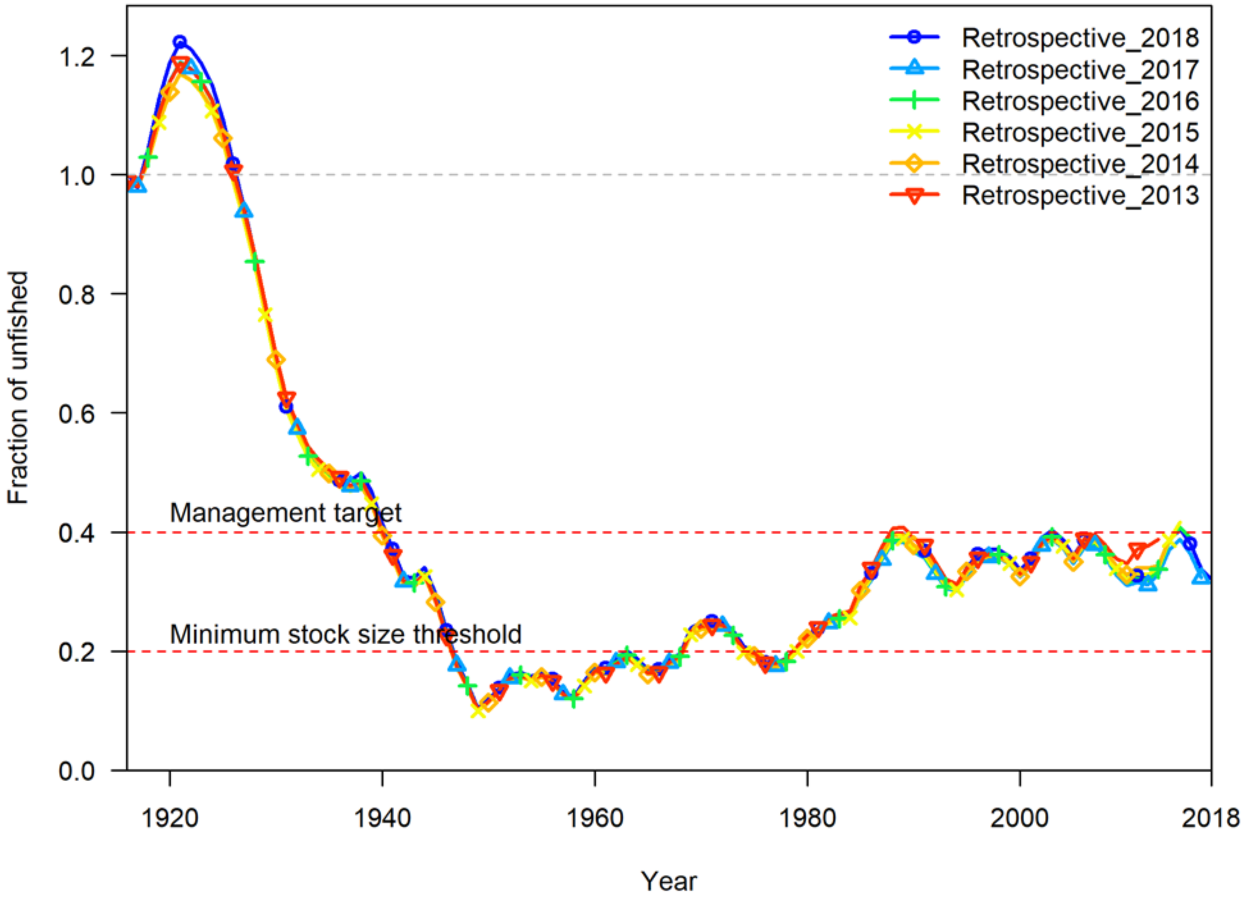

Figure 7.29. Retrospectives for relative spawning biomass for tiger flathead, with data removed back to 2017 (light blue) and then successive years removed back to 2013 (red).

When this retrospective analysis is applied to the recruitment time series (Figure 7.30), the more recent data results in a downward revision to the recruitment estimate in 2012. This recruitment is first estimated in the retrospective to 2015 (which corresponds to the data used in the 2016 assessment, shown in yellow), and this revision downwards is supported by data in 2016, 2017 and 2018. The first estimate of the 2013 recruitment is made in the 2016 retrospective (green) and is well below average. This estimate of 2013 recruitment is revised further downwards when data from 2017 and 2018 is added.

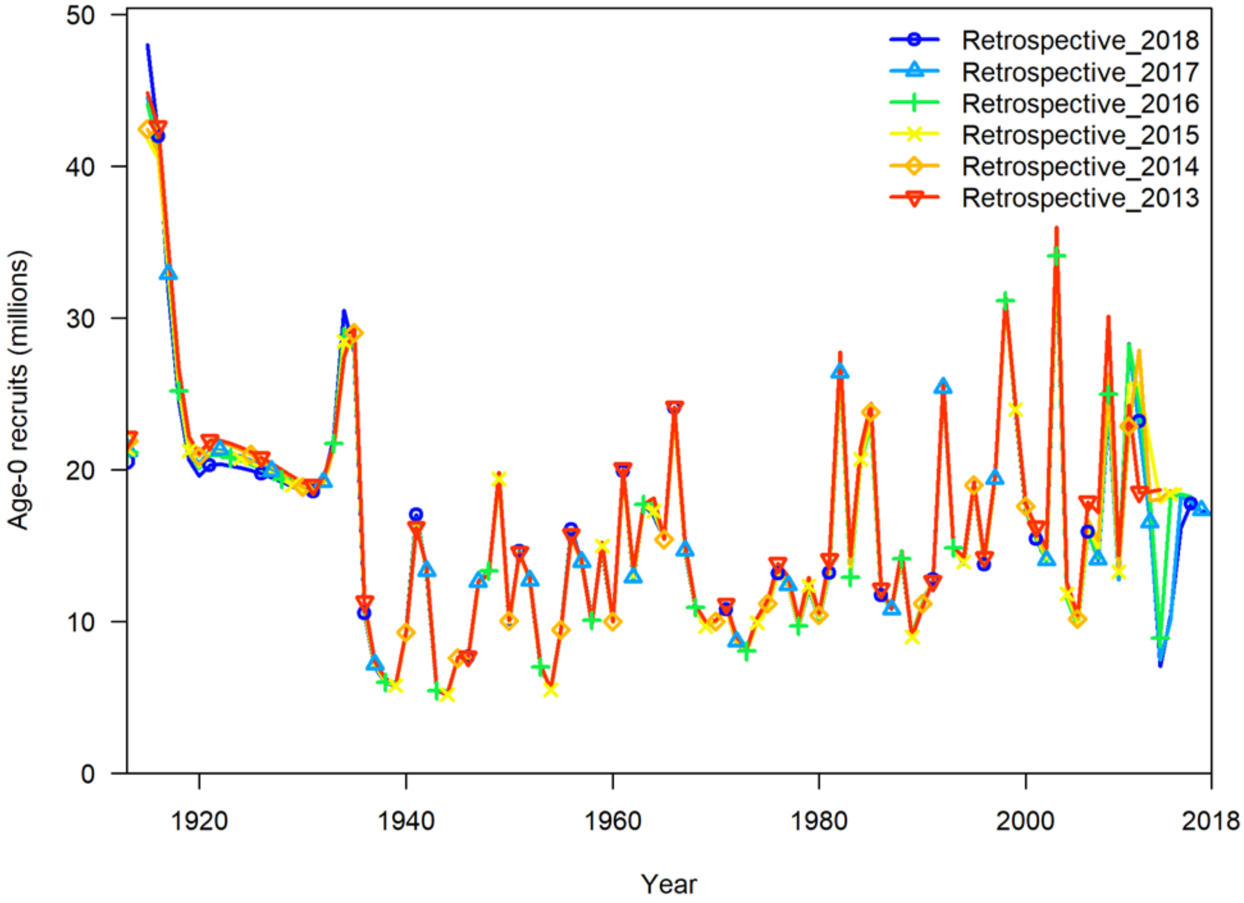

Figure 7.30. Retrospectives for relative spawning biomass for tiger flathead, with data removed back to 2017 (light blue) and then successive years removed back to 2013 (red).

An alternative presentation of the retrospective analysis applied to the recruitment time series is shown in a "squid plot" (Figure 7.31), which follows changes in the recruitment deviations for particular cohorts as the last five years of data is successively removed. Each coloured string corresponding to a cohort only includes a maximum of six points, one for the old base case and one for each retrospective. Each string can be followed from right to left as successive years of data are removed. The changes to the recruitment deviation estimate, as each year of data is removed, are measured by changes in the y-axis, with a negative value indicting a revision downwards and a positive value indicating a revision upwards, relative to the most recent estimate. For the cohorts born in years 2011-2015, the point on the far left of each string represents average recruitment, as this corresponds to a year when this cohort is not estimated for the 2013 retrospective, an analysis where recruitment is first estimated in 2010. Hence the corresponding y-values, for these left most points, represent the magnitude of the final recruitment deviation estimated in the old base case, with positive y-values corresponding to negative recruitment deviations (for the old base case using all data) and negative y-values corresponding to positive recruitment deviations. The variation along each string indicates how the recruitment deviation estimate changes as each year of successive data is added (moving to the right) or removed (moving to the left). Changes to estimates of deviations for the older birth years (e.g. 2005 and 2006) are smaller than more recent birth years, as there is little additional information on the size of these cohorts from data obtained in the period 2013-2018. These cohort birth years are largely flat and on the right-hand side of this "squid plot".

Examples of pathological patterns in a squid plot would include a one-sided plot where all the adjustments to recent recruitment events were in the same direction (e.g. all positive or all negative), indicating a trend that may warrant further exploration and may indicate some model mis-specification. There is no indication of this here.

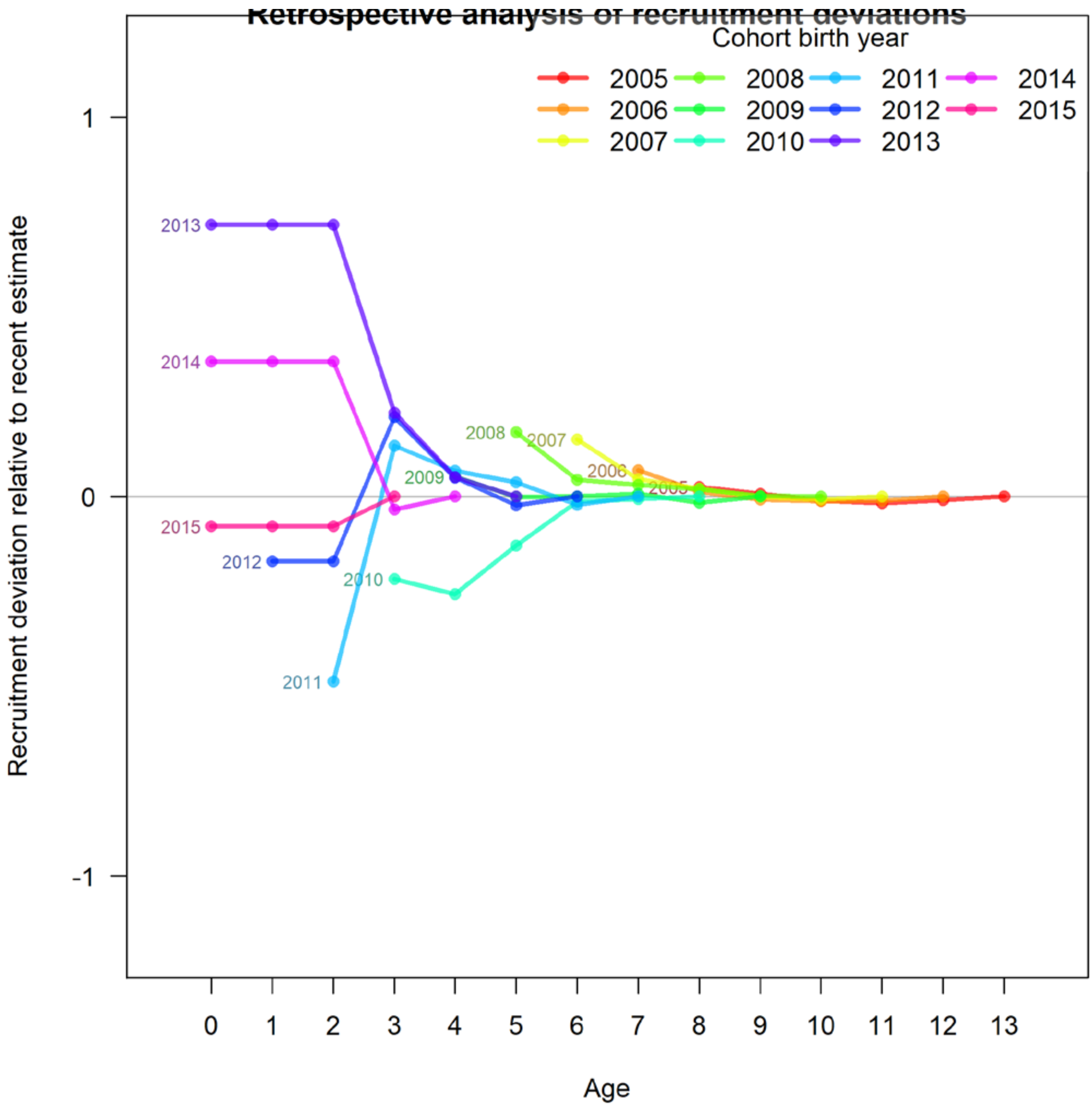

Figure 7.31. Retrospective analysis of recruitment deviations (squid plot) for tiger flathead, with data removed in successive years back to 2013.

These retrospective analyses do not reveal any pathological patterns or apparent biases in the estimates at the end of the time series due to the addition of new data, which provides additional confidence in the stability of this assessment.

7.4.4 *Alternative catch series and recruitment scenarios*

All alternative catch series analyses in this section were conducted before the catch series was updated from 2001-2018 (see Section 7.3.1.5), so is based on the incorrect (lower) catch series described earlier, which produced a depletion estimate of 33% at the start of 2020, compared to 34% with the revised catches. While the details may change marginally, the general principles and relative results are not expected to remain largely unchanged with the corrected catch series.

7.4.4.1 Alternative fixed catch projections 2020-2022

With the change in estimated stock status, from 42% (Day, 2017) in the 2016 assessment to 34% in the 2019 assessment, SERAG requested a range of fixed catch three-year projections be run to examine the effect of stepping down the RBC from the values calculated in 2016 (2866 t) to the new RBC values calculated in 2019 for the old base case (that used the incorrect (lower) catch series). This enables the risk to the stock to be assessed if the RBC was to be exceeded during the years 2020-2022. The relative stock status is compared between these scenarios for each year between 2020 and 2023.

The values of the projected catches for each of the four catch scenarios for the period 2020-22, and the subsequent (calculated) 2023 RBC, are listed in Table 7.18. Scenario 1 is the old base case, with the "projected catch" equal to the calculated RBC values (assuming the calculated RBC is caught each year). Scenario 4 shows the catch under the 2016 three-year multi-year RBC, fixed for the period 2020-2022. Scenarios 2 and 3 show fixed intermediate catch values equally spaced between the catch in scenarios 1 and 4.

Table 7.18. Fixed catch projections for 2020-2022 and the RBC calculated for 2023 for the 2019 old base case and after applying projected catches for the three fixed catch scenarios.

Average	Fix Catch			
catch from: Year	1 base case 2019 RBC	2 fixed	3 fixed	4 fixed 2016 RBC
2019	2,426	2,426	2,426	2,426
2020	2,254	**2,458**	**2,662**	**2,866**
2021	2,616	**2,699**	**2,782**	**2,866**
2022	2,675	**2,738**	**2,802**	**2,866**
2023	2,724	2,677	2,629	2,511

The calculated stock status level at the beginning of each year from 2019-2023, assuming average recruitment, is shown in Table 7.19 and displayed in Figure 7.32, showing the relative stock status from 2010-2023.

Table 7.19. Calculated stock status for the 2019 old base case and after applying projected catches for 2020-2022 (under average recruitment) for the three fixed catch scenarios.

	Depletion (%)			
	1	2	3	4
catch from:	base case	fixed	fixed	fixed
Year	2019 RBC			2016 RBC
2019	32.4	32.4	32.4	32.4
2020	33.4	33.4	33.4	33.4
2021	35.1	34.6	34.2	33.7
2022	36.0	35.4	34.8	34.1
2023	36.7	36.0	35.3	34.6

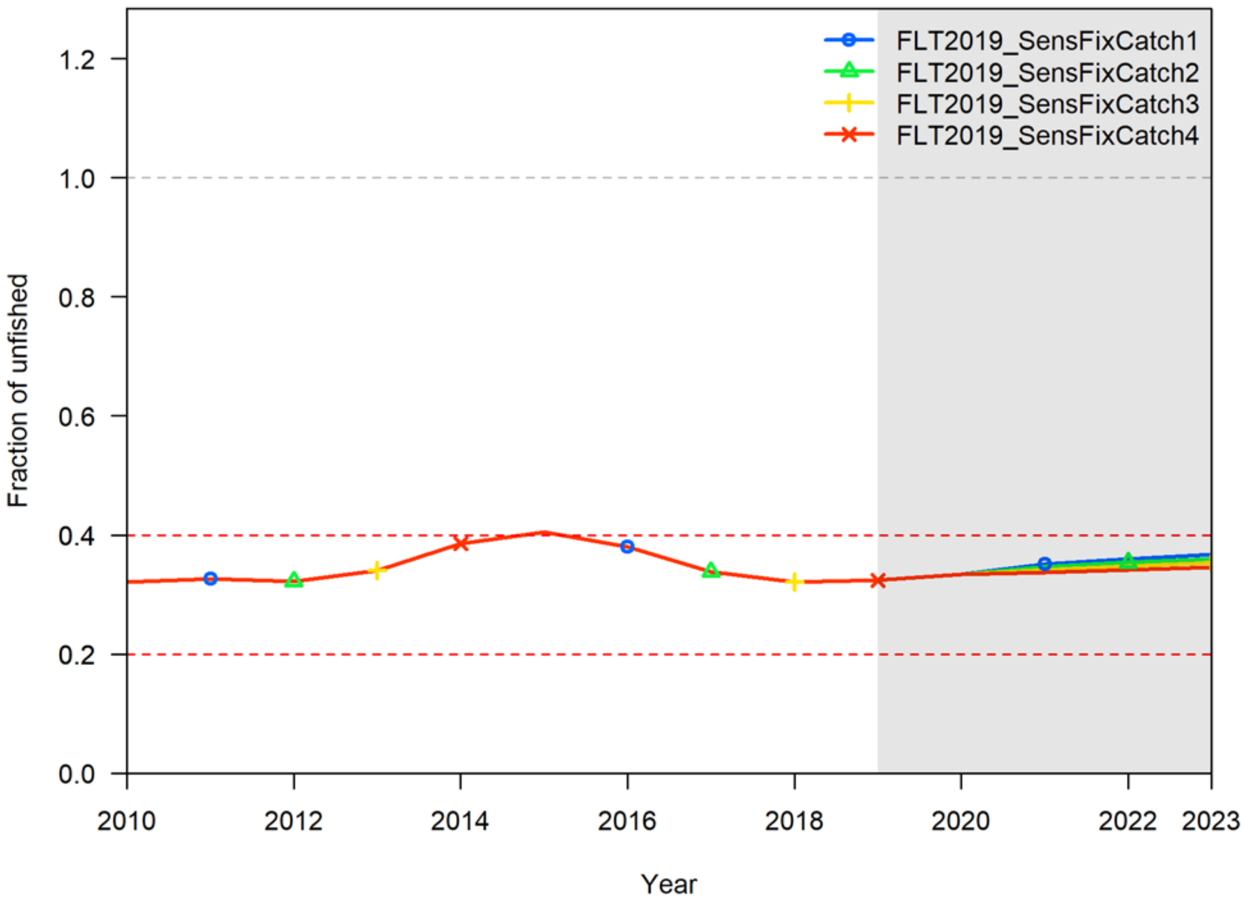

Figure 7.32. Relative spawning biomass (2010-2023) for the four fixed catch projections under average recruitment.

The 2023 stock status varies between 34.6% and 36.7% in these four scenarios.

7.4.4.2 Fixed catch projections 2020-2022 under a low recruitment scenario

Similar projections were also run for a low recruitment scenario, for the old base case, using the incorrect (lower) catch series, where recruitment deviations were fixed for the seven-year period from 2016-2022. This covers the period where recruitment is not estimated by the model and where standard projections involve average recruitment, taken directly from the stock recruitment curve. The recruitment deviations used were the 25th percentile of the recruitment deviations estimated between 1945 and 2015, a period where recruitment is considered to be well estimated. The value used for the 25th percentile (low recruitment) is -0.223.

The values of the projected catches for each of the four catch scenarios for the period 2020-22, run for the low recruitment scenario, and the subsequent (calculated) 2023 RBC (in bold), are listed in Table 7.20. Scenario 1 is the old base case, using the incorrect (lower) catch series, with the “projected catch” equal to the calculated RBC values (assuming the calculated RBC is caught each year). Scenario 2 is a mismatch where the RBC is calculated every year (expecting average recruitment into the future), but with poor recruitment every year during this projected period. Scenario 3 has the (retained) catches fixed by the RBC from the 2019 old base case, under poor recruitment. Scenario 4 has the (retained) catches fixed by the RBC from the 2016 three-year multi-year RBC for the period 2020-2022, under poor recruitment.

Table 7.20. Fixed catch projections for 2020-2022 and the RBC calculated for 2023 after applying these projected catches for the four fixed catch scenarios for the low recruitment scenario.

Low	Fix Catch			
	1	2	3	4
catch from:	base case	mismatch	fixed	fixed
Year	2019 RBC	RBC (low)	2019 RBC	2016 RBC
2019	2,426	2,405	2,426	2,426
2020	2,254	1,731	**2,254**	**2,866**
2021	2,616	1,963	**2,603**	**2,852**
2022	2,675	2,262	**2,651**	**2,839**
2023	2,724	2,523	1,817	1,403

The calculated stock status level at the beginning of each year from 2019-2023, assuming low recruitment for scenarios 2, 3 and 4, is shown in Table 7.21 and displayed in Figure 7.33, showing the relative stock status from 2010-2023.

Table 7.21. Calculated stock status following application of fixed catch projections for 2020-2022 (under low recruitment) for the four fixed catch scenarios under low recruitment.

Low	Depletion (%)			
	1	2	3	4
catch from:	base case	mismatch	fixed	fixed
Year	2019 RBC	RBC (low)	2019 RBC	2016 RBC
2019	32.4	31.4	31.4	31.4
2020	33.4	31.0	31.0	31.0
2021	35.1	32.2	30.9	29.6
2022	36.0	32.7	30.1	28.2
2023	36.7	32.5	29.2	27.0

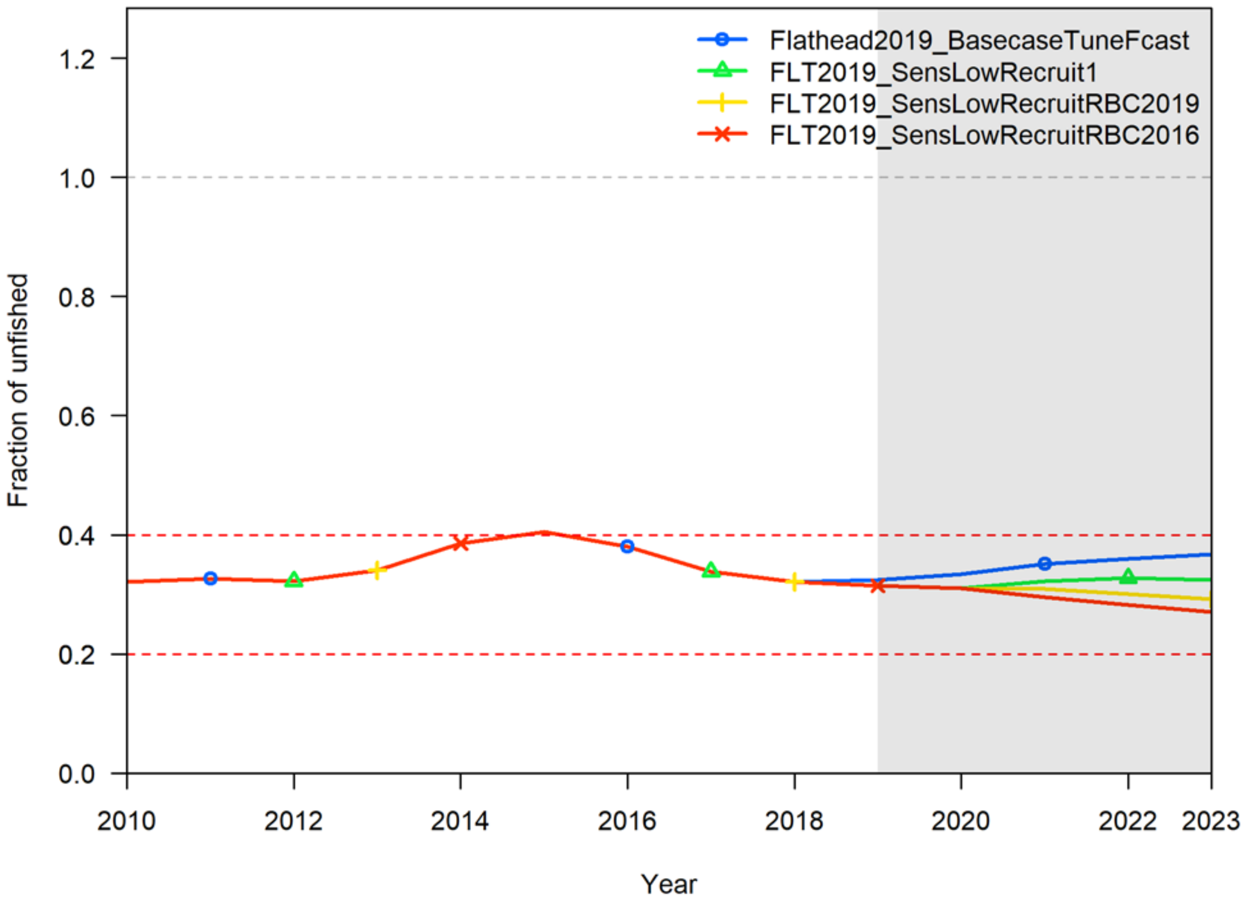

Figure 7.33. Relative spawning biomass (2010-2023) for the four fixed catch projections under low recruitment.

The results are shown in Figure 7.33, with the blue series (BasecaseTuneFcast) showing the projections applying the RBC calculated under average recruitment to dynamics under average recruitment (for the old base case, using the incorrect (lower) catch series). The other three series all show projections with the dynamics projected with poor recruitment from 2016 up until 2022, with a range of catch scenarios. The green series (SensLowRecruit1) shows the projections applying the RBC calculated with this low recruitment, where the calculation of each RBC point is made with the expectation that future recruitment will return to average. The yellow series (SensLowRecruit1RBC2019) shows the projections using the catch calculated under the RBC from the 2019 old base case (assuming average recruitment). The red series (SensLowRecruit1RBC2016) shows the projections using the catch calculated under the RBC from the 2016 assessment, continued on for an additional 3 years.

The 2023 stock status varies between 27.0% and 32.5% in these three low recruitment scenarios.

7.4.4.3 Fixed catch projections 2020-2022 under a high recruitment scenario

Similar projections were also run for a high recruitment scenario, for the old base case, using the incorrect (lower) catch series, where recruitment deviations were fixed for the seven-year period from 2016-2022. This covers the period where recruitment is not estimated by the model and where standard projections involve average recruitment, taken directly from the stock recruitment curve. The recruitment deviations used were the 75th percentiles of the recruitment deviations estimated between

1945 and 2015, a period where recruitment is considered to be well estimated. The value used for the 75th percentile (high recruitment) is 0.292.

The values of the projected catches for each of the four catch scenarios for the period 2020-22, run for the high recruitment scenario, and the subsequent (calculated) 2023 RBC (in bold), are listed in Table 7.22. Scenario 1 is the old base case, using the incorrect (lower) catch series, with the "projected catch" equal to the calculated RBC values (assuming the calculated RBC is caught each year). Scenario 2 is a mismatch where the RBC is calculated every year (expecting average recruitment into the future), but with good recruitment every year during this projected period. Scenario 3 has the (retained) catches fixed by the RBC from the 2019 old base case, under good recruitment. Scenario 4 has the (retained) catches fixed by the RBC from the 2016 three-year multi-year RBC for the period 2020-2022, under good recruitment.

Table 7.22. Fixed catch projections for 2020-2022 and the RBC calculated for 2023 after applying these projected catches for the four fixed catch scenarios.

High	Fix Catch			
	1	2	3	4
catch from:	base case	mismatch	fixed	fixed
Year	2019 RBC	RBC (high)	2019 RBC	2016 RBC
2019	2,426	2,459	2,426	2,426
2020	2,254	2,834	**2,255**	**2,867**
2021	2,616	3,057	**2,631**	**2,883**
2022	2,675	3,157	**2,704**	**2,898**
2023	2,724	3,168	3,377	3,232

The calculated stock status level at the beginning of each year from 2019-2023, assuming high recruitment for scenarios 2, 3 and 4, is shown in Table 7.23 and displayed in Figure 7.34, showing the relative stock status from 2010-2023.

Table 7.23. Calculated stock status following application of fixed catch projections for 2020-2022 (under average recruitment) for the four fixed catch scenarios.

High	Depletion (%)			
	1	2	3	4
catch from:	base case	mismatch	fixed	fixed
Year	2019 RBC	RBC (high)	2019 RBC	2016 RBC
2019	32.4	33.9	33.9	33.9
2020	33.4	37.4	37.5	37.5
2021	35.1	40.8	42.2	40.8
2022	36.0	43.8	46.1	44.2
2023	36.7	46.6	49.8	47.5

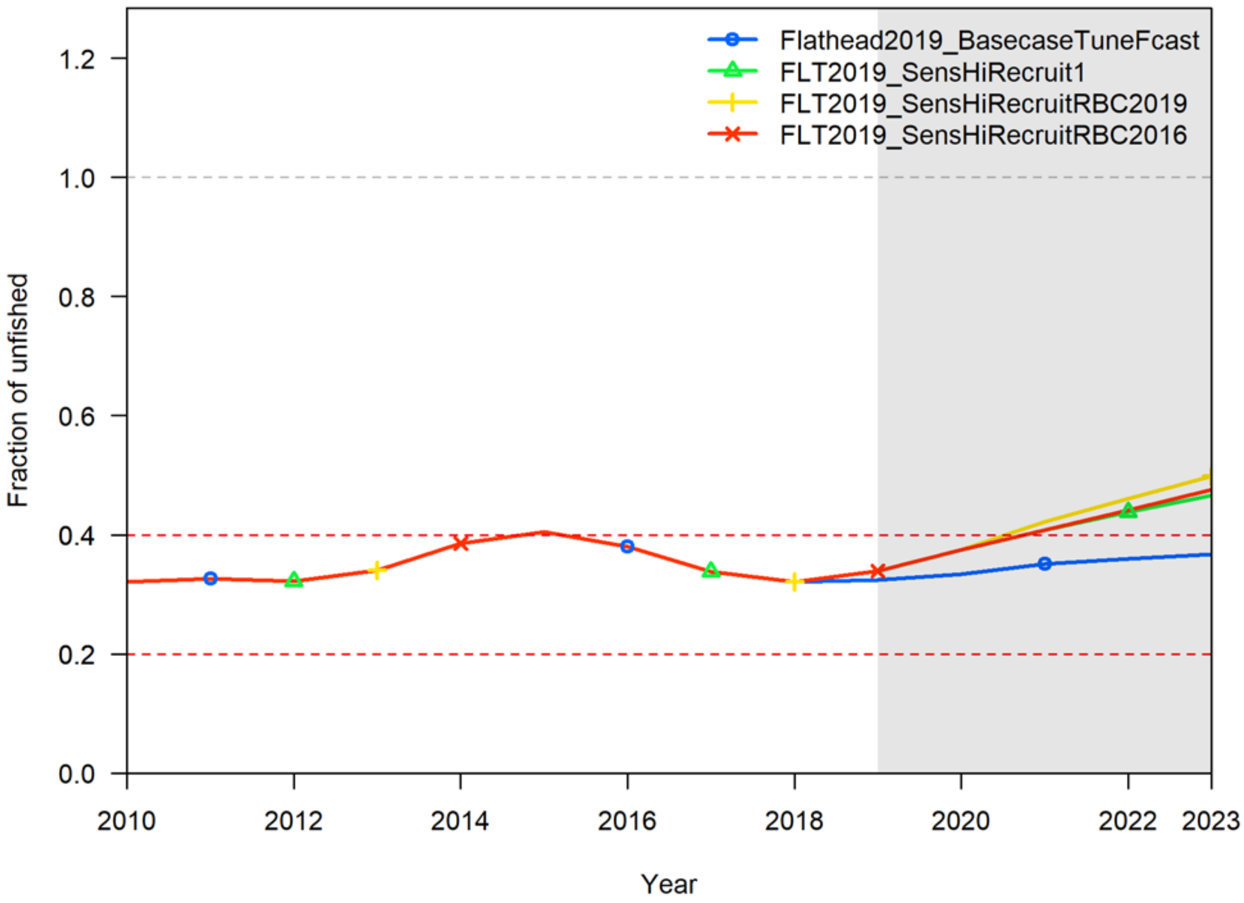

Figure 7.34. Relative spawning biomass (2010-2023) for the four fixed catch projections under high recruitment.

The results are shown in Figure 7.34, with the blue series (BasecaseTuneFcast) showing the projections applying the RBC calculated under average recruitment to dynamics under average recruitment (the old base case, using the incorrect (lower) catch series). The other three series all show projections with the dynamics projected with poor recruitment from 2016 up until 2022, with a range of catch scenarios. The green series (SensHiRecruit1) shows the projections applying the RBC calculated with this low recruitment, where the calculation of each RBC point is made with the expectation that future recruitment will return to average. The yellow series (SensHiRecruit1RBC2019) shows the projections using the catch calculated under the RBC from the 2019 old base case (assuming average recruitment). The red series (SensHiRecruit1RBC2016) shows the projections using the catch calculated under the RBC from the 2016 assessment, continued on for an additional 3 years.

The 2023 stock status varies between 46.6% and 49.8% in these three high recruitment scenarios.

Table 7.24. Fixed catch projections for 2020-2022 and the RBC calculated for 2023 after applying these projected catches for the four fixed catch scenarios.

	Fix Catch	
Year	2019 RBC	3 yr avg
2020	2,254	2,515
2021	2,616	2,515
2022	2,675	2,515
2023	2,724	2,729

The calculated stock status level at the beginning of each year from 2019-2023, assuming high recruitment for scenarios 2, 3 and 4, is shown in Table 7.23 and displayed in Figure 7.34, showing the relative stock status from 2010-2023.

Table 7.25. Calculated stock status following application of fixed catch projections for 2020-2022 (under average recruitment) for the four fixed catch scenarios.

	Depletion (%)	
Year	2019 RBC	3 yr avg
2020	33.4	33.4
2021	35.1	34.5
2022	36.0	35.7
2023	36.7	36.8

7.4.5 *Sensitivity tests and alternative models*

Results of the sensitivity tests are shown in Table 7.26. These sensitivities were conducted relative to the old base case, using the incorrect (lower) catch series (see Section 7.3.1.5). The results are very sensitive to the assumed value for natural mortality (M). Much of this variability is due to the estimated current depletion level, which can be as low as 27% SSB_0 when M is 0.22. For all other standard sensitivities, there is less variability in current depletion.

Unweighted likelihood components for the old base case and differences for the sensitivities reveal several points (Table 7.27). The overall likelihood is not improved for a smaller value of M, in contrast to the results from Day and Klaer (2013), but in line with the most recent assessment (Day, 2016) and earlier results in Klaer (2010). Steepness and M are highly correlated, and it is normally not possible to estimate both of these parameters. The base case is essentially uninformative about the value of M, which needs to be sourced independently of the stock assessment if steepness is estimated, but these results suggests that M should not be reduced.

In contrast to the 2016assessment, a few sensitivities show an overall improvement to the fit, notably when M is fixed at 0.22, for lower values of σ_R, outside the period where the bias ramp is estimated, and when M is estimated and h fixed. Note that likelihood profiles suggest that neither M nor h should be estimated in future assessments.

Exploration of model sensitivity showed a variation in spawning biomass from 27% to 41% of SSB_0 when natural mortality was fixed at values of 0.22 and 0.32 respectively. When recruitment is first estimated in 1925, to avoid possible spurious large estimates of recruitment early in the series, supported only by improved fits to the steam trawl CPUE, the spawning biomass was estimated to be 27% of SSB_0. When M is estimated and h fixed, the spawning biomass was estimated to be 41% of SSB_0. For all other sensitivities explored, the variation in spawning biomass was much narrower, ranging between 32% and 37%.

For the old base case (20:35:40 Harvest Control Rule with recruitment estimated to 2015), SSB_{MSY} is estimated to be 27% of SSB_0. If the standard MEY proxy multiplier of 1.2 is applied to this MSY estimate, the SSB_{MEY} estimate for the old base case is 32% of SSB_0. This proxy for SSB_{MEY} is rounded up to 40% of SSB_0 by agreement at SESSFRAG, with a 20:35:40 Harvest Control Rule used for tiger flathead.

7.4.6 *Future work*

7.4.6.1 Danish seine mesh size

The Danish seine fleet has made changes to the mesh size used for the flathead gear in recent years, with a transition to a slightly larger mesh size. While there is little evidence in the length frequency data to suggest a large change to selectivity as a result, it would be possible to use a time block with a transitional period and examine the resulting selectivity. The impact of such a change on both the selectivity and the spawning biomass could be explored in a future assessment. Given that the Danish seine length frequency distributions do not seem to have changed yet, it would be surprising if this produced very different results. It may be worth closely examining Danish seine length frequency data in future years to look for evidence of a change in size distribution for this fleet.

7.4.6.2 Tasmanian trawl growth parameters

In 2006, Shelf RAG selected the model that treated Tasmanian trawl as a separate fishing fleet fishing the same east coast stock as the most appropriate base case. It appears that growth may differ for the fish caught by the Tasmanian trawl and the Tasmanian FIS fleets, so the assumption for this model of the stock could be revisited in future. Options to consider include modelling the Tasmanian stock as a separate stock, estimating growth independently for the Tasmanian stock and excluding the Tasmanian data from the assessment.

7.4.6.3 Historical length frequencies

Some historical length frequencies from the 2013 assessment appear to have been lost due to changes to the database or the data processing. These distributions were included in this assessment, by using the same data used in 2013. This issue needs to be investigated to make sure the original data is not lost and that the most appropriate data is used in future assessments.

7.4.6.4 Steam trawl length frequencies

Length frequency data from the steam trawl fleet in the 1950s includes two sources of data which overlap for the period 1953-1955. Fits to the Sydney Fish Market data (1953-1958) are not as good as the fits to the Blackburn data (1945-1955), but there is some conflict between the data from these two sources. These data sources could potentially be treated differently to improve these fits to the steam trawl fleet.

7.4.6.5 Fix the value for steepness

Steepness is not estimated very precisely in this assessment, as demonstrated in the likelihood profile on steepness, with a wide range of values for steepness unable to be distinguished by the data. It is recommended that steepness is fixed at 0.75 in future tiger flathead stock assessments. This default value for steepness of 0.75 is a value chosen for many species where steepness is not known and cannot be estimated.

Table 7.26. Calculated stock status following application of fixed catch projections for 2020-2022 (under average recruitment) for the four fixed catch scenarios.

Case		SSB_0	SSB_{2020}	SSB_{2020}/SSB_0	Steepness	SSB_{MSY}/SSB_0	RBC_{2020}	$RBC_{2020\text{-}2}$	$RBC_{2020\text{-}4}$	$RBC_{longterm}$
0	base case 20:35:40 *M* 0.27	21,737	7,260	0.33	0.72	0.27	2,254	2,515	2,607	2,959
1	*M* 0.22	21,580	5,838	0.27	0.86	0.22				
2	*M* 0.32	22,991	9,332	0.41	0.61	0.31				
3	50% maturity at 27cm	22,900	7,861	0.34	0.70	0.28				
4	50% maturity at 33cm	20,156	6,467	0.32	0.75	0.25				
5	$\sigma_R = 0.4$	22,096	7,227	0.33	0.63	0.30				
6	$\sigma_R = 0.6$	22,102	7,227	0.33	0.68	0.28				
7	$\sigma_R = 0.8$	21,335	7,314	0.34	0.78	0.24				
8	first recruit est. in 1925	27,406	7,346	0.27	0.59	0.32				
9	estimate *M* (0.30), *h* 0.75	20,053	8,298	0.41	0.75	0.25				
10	fix *M* 0.27, fix *h* 0.75	21,081	7,244	0.34	0.75	0.26				
11	fix *M* 0.27, fix *h* 0.65	24,091	8,370	0.35	0.65	0.30				
12	fix *M* 0.27, fix *h* 0.85	19,201	7,159	0.37	0.85	0.21				
13	wt x 2 length comp	22,754	7,465	0.33	0.69	0.28				
14	wt x 0.5 length comp	21,051	7,123	0.34	0.75	0.26				
15	wt x 2 age comp	21,731	7,159	0.33	0.72	0.27				
16	wt x 0.5 age comp	21,729	7,368	0.34	0.73	0.27				
17	wt x 2 CPUE	19,707	6,934	0.35	0.79	0.24				
18	wt x 0.5 CPUE	22,916	7,911	0.35	0.69	0.28				

Table 7.27. Calculated stock status following application of fixed catch projections for 2020-2022 (under average recruitment) for the four fixed catch scenarios.

Case		Likelihood TOTAL	Survey	Discard	Length comp	Age comp	Recruitment	Parm_priors
0	base case 20:35:40 *M* 0.27	1621.52	-160.81	54.58	499.01	1231.62	-3.54	0.00
1	*M* 0.22	3.90	4.92	-0.93	1.45	-0.48	-1.27	0.00
2	*M* 0.32	-3.75	-4.47	0.73	-1.44	0.33	1.31	0.00
3	50% maturity at 27cm	-0.05	0.05	0.00	-0.02	0.00	-0.08	0.00
4	50% maturity at 33cm	0.06	-0.06	0.00	0.02	0.00	0.10	0.00
5	$\sigma_R = 0.4$	-5.58	10.15	-0.59	3.89	0.37	-19.39	0.00
6	$\sigma_R = 0.6$	-3.03	2.16	-0.14	0.80	-0.01	-5.83	0.00
7	$\sigma_R = 0.8$	3.50	-1.56	0.12	-0.60	0.05	5.49	0.00
8	first recruit est. in 1925	2.21	2.52	0.11	-0.24	0.08	-0.25	0.00
9	estimate *M* (0.30), *h* 0.75	-2.06	-3.14	0.38	-0.77	0.20	1.39	0.00
10	fix *M* 0.27, fix *h* 0.75	0.02	-0.14	-0.02	0.06	0.01	0.10	0.00
11	fix *M* 0.27, fix *h* 0.65	0.24	0.49	0.04	-0.25	-0.11	0.07	0.00
12	fix *M* 0.27, fix *h* 0.85	0.37	-0.55	-0.09	0.18	-0.01	0.84	0.00
13	wt x 2 length comp	5.23	6.22	4.29	-11.62	4.68	1.63	0.00
14	wt x 0.5 length comp	3.31	-2.80	-2.38	11.69	-1.98	-1.20	0.00
15	wt x 2 age comp	3.59	7.62	0.03	4.18	-8.46	0.17	0.00
16	wt x 0.5 age comp	3.09	-5.03	-0.29	-2.29	10.70	0.04	0.00
17	wt x 2 CPUE	8.69	-19.59	6.11	7.10	9.63	5.42	0.00
18	wt x 0.5 CPUE	6.67	22.67	-4.69	-3.25	-4.29	-3.74	0.00

7.5 Acknowledgements

Age data was provided by Kyne Krusic-Golub (Fish Ageing Services), ISMP and AFMA logbook and CDR data were provided by John Garvey (AFMA). Mike Fuller, Roy Deng, Franzis Althaus, Robin Thomson and Paul Burch (CSIRO) pre-processed the data. André Punt, Geoff Tuck, Miriana Sporcic, Robin Thomson, Paul Burch, Malcolm Haddon (CSIRO), Claudio Castillo-Jordán (UW), Ian Taylor, Jason Cope and Rick Methot (NOAA) are thanked for helpful discussions on this work. André Punt updated the ageing error matrix. Malcolm Haddon provided code for auto-tuning and Athol Whitten provided R code for organising plots. Geoff Liggins is thanked for identifying inconsistencies in catch data which resulted in late corrections to the catch data and an updated base case.

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7.7 Appendix A

A.1 Data source summary and fits to length composition data

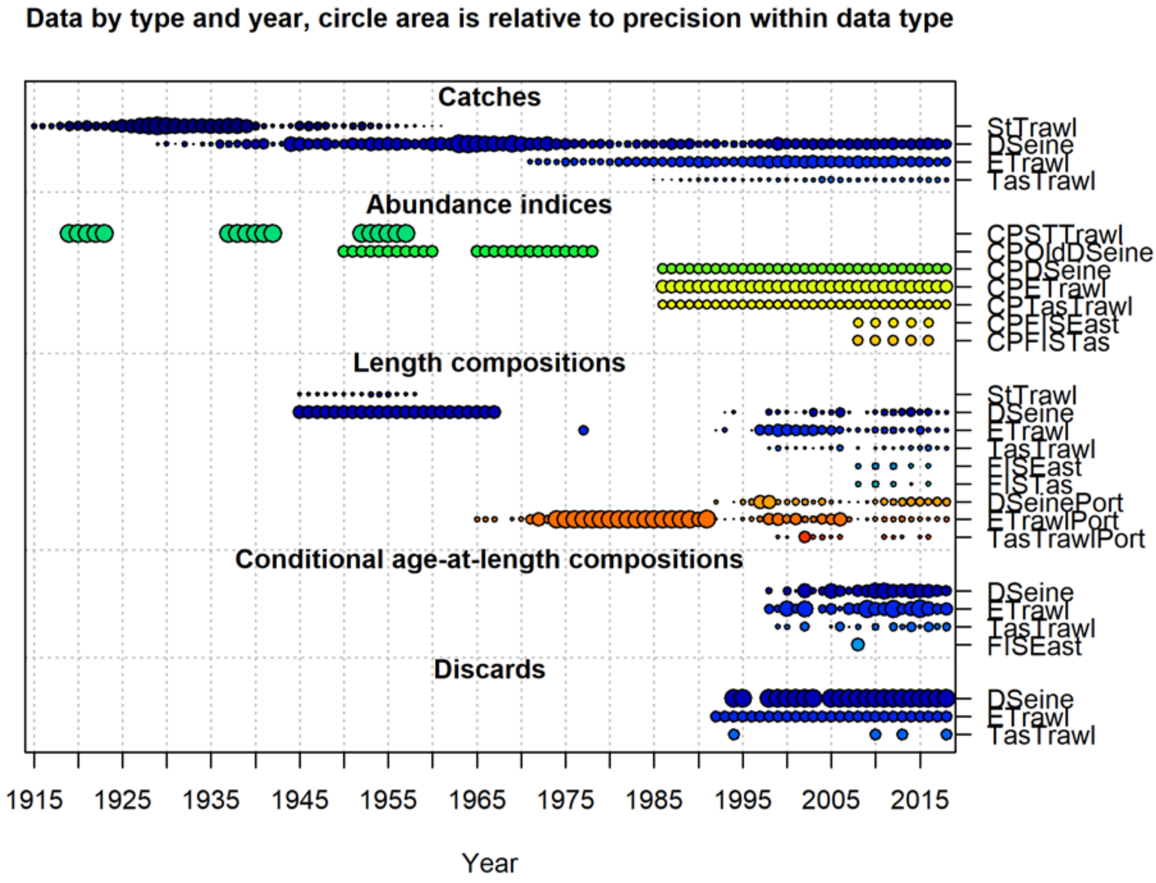

Figure A 7.1. Summary of data sources for tiger flathead stock assessment.

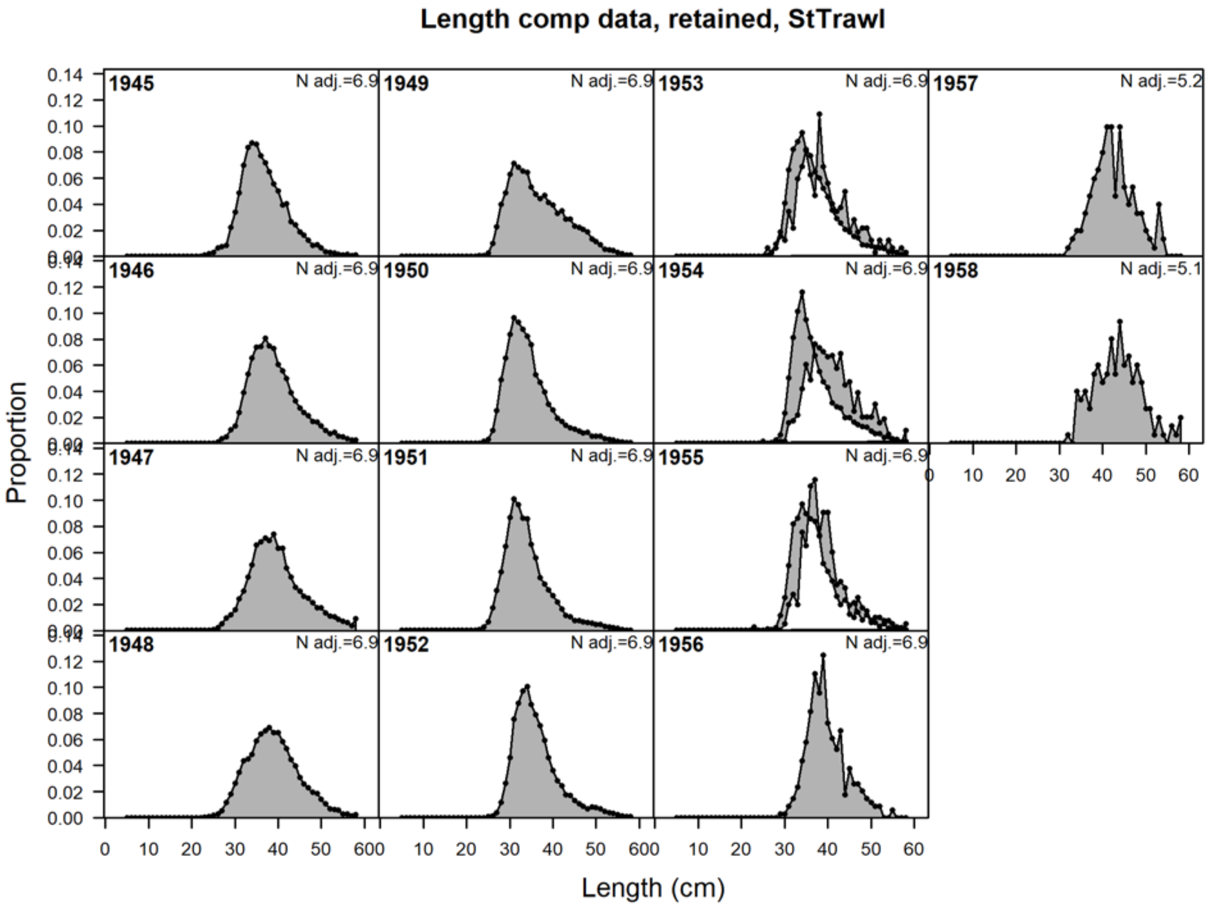

Figure A 7.2. Tiger flathead length composition fits: steam trawl retained.

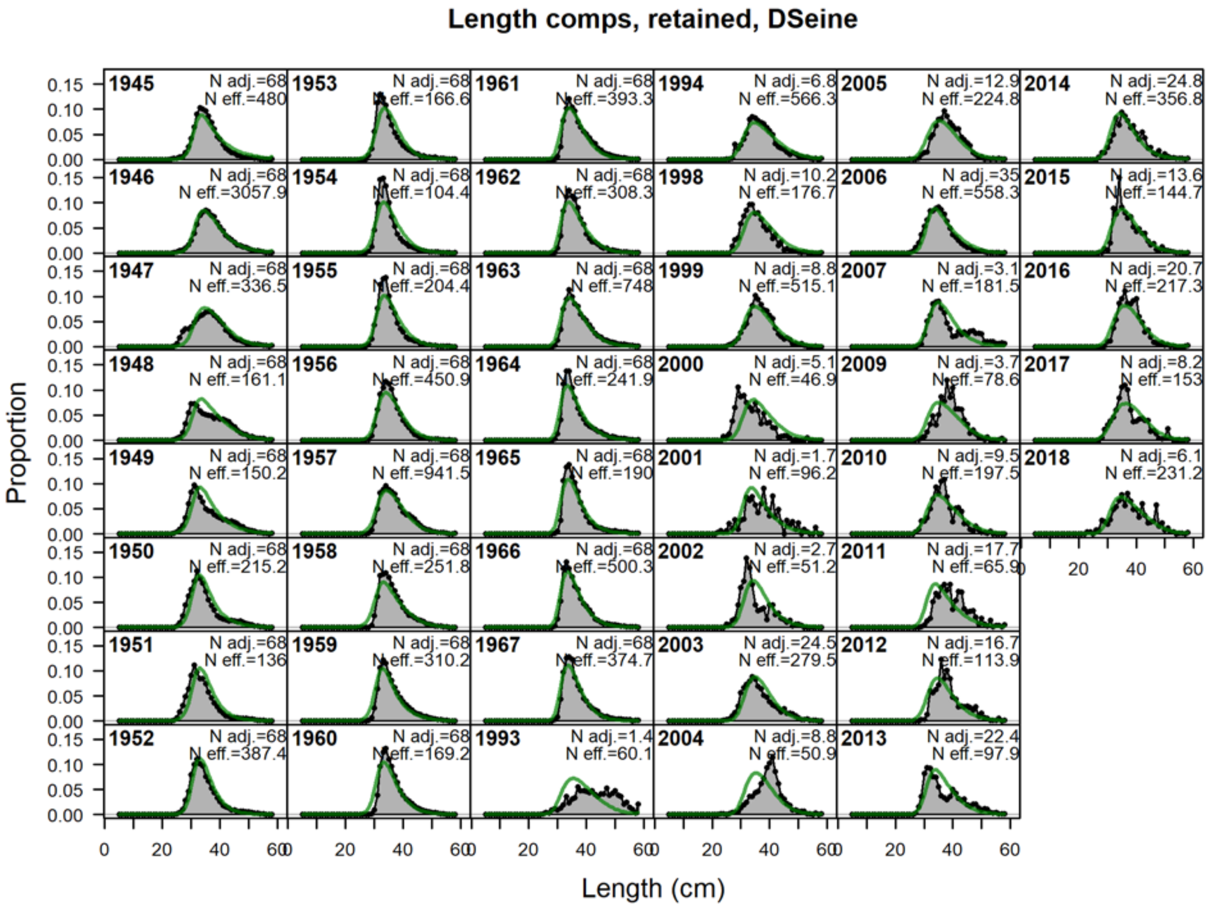

Figure A 7.3. Tiger flathead length composition fits: Danish seine retained onboard.

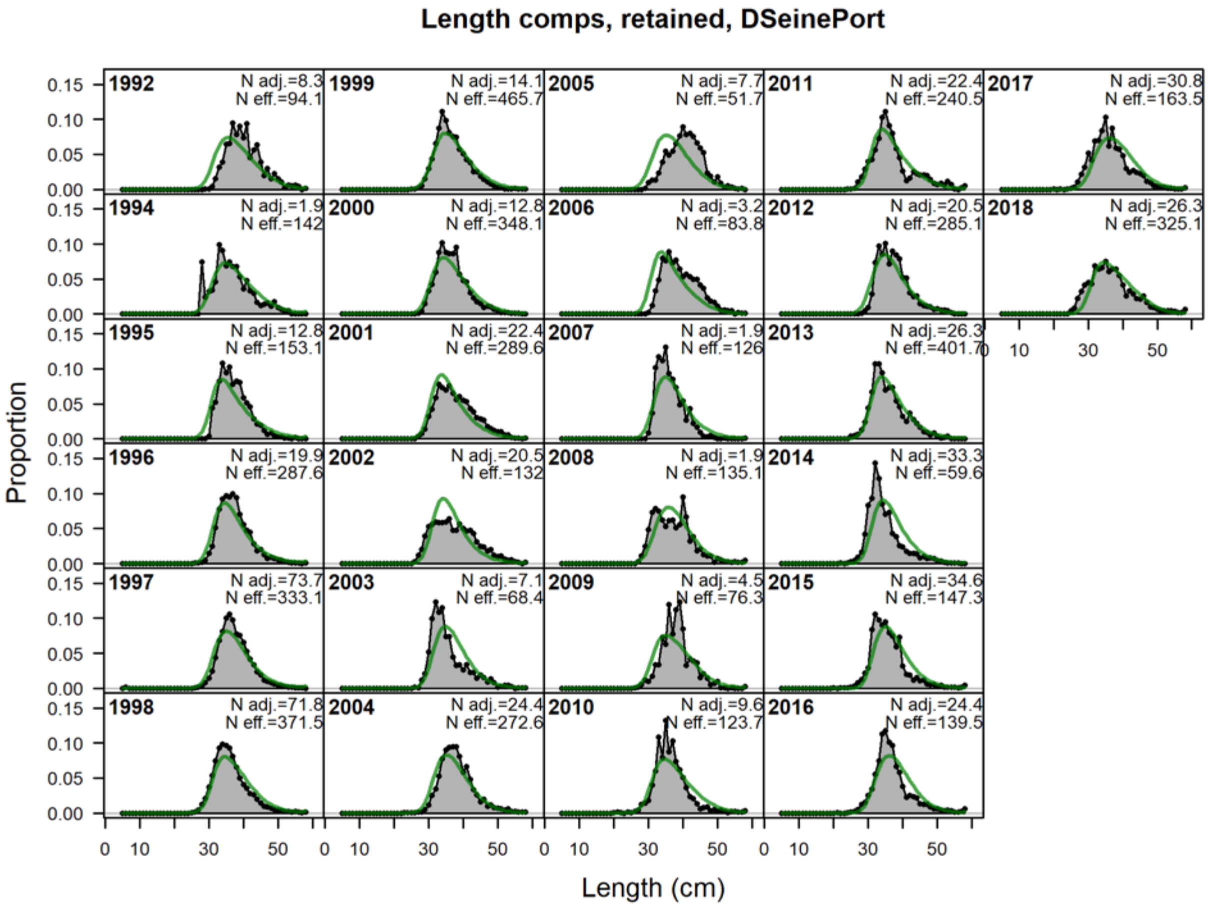

Figure A 7.4. Tiger flathead length composition fits: Danish seine retained port.

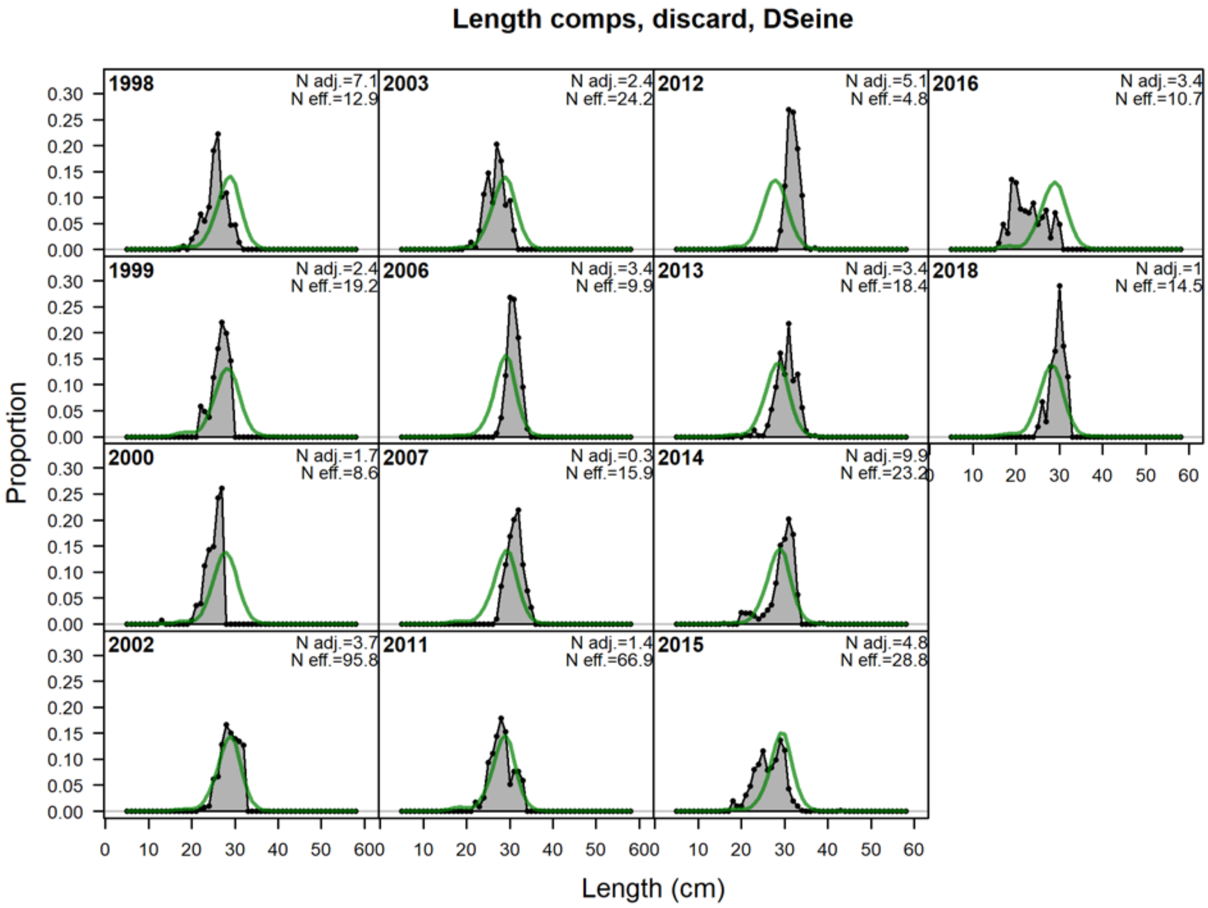

Figure A 7.5. Tiger flathead length composition fits: Danish seine discarded.

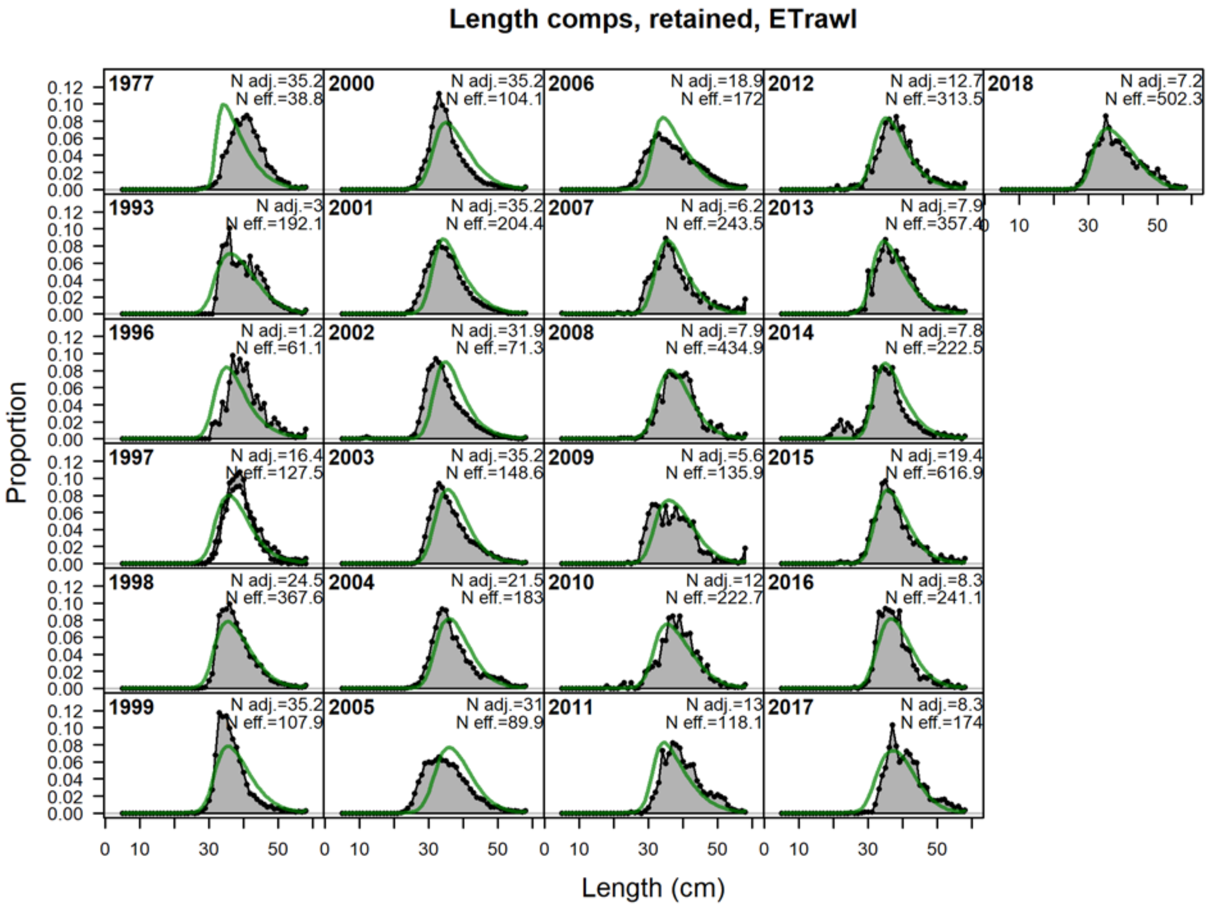

Figure A 7.6. Tiger flathead length composition fits: eastern trawl retained onboard.

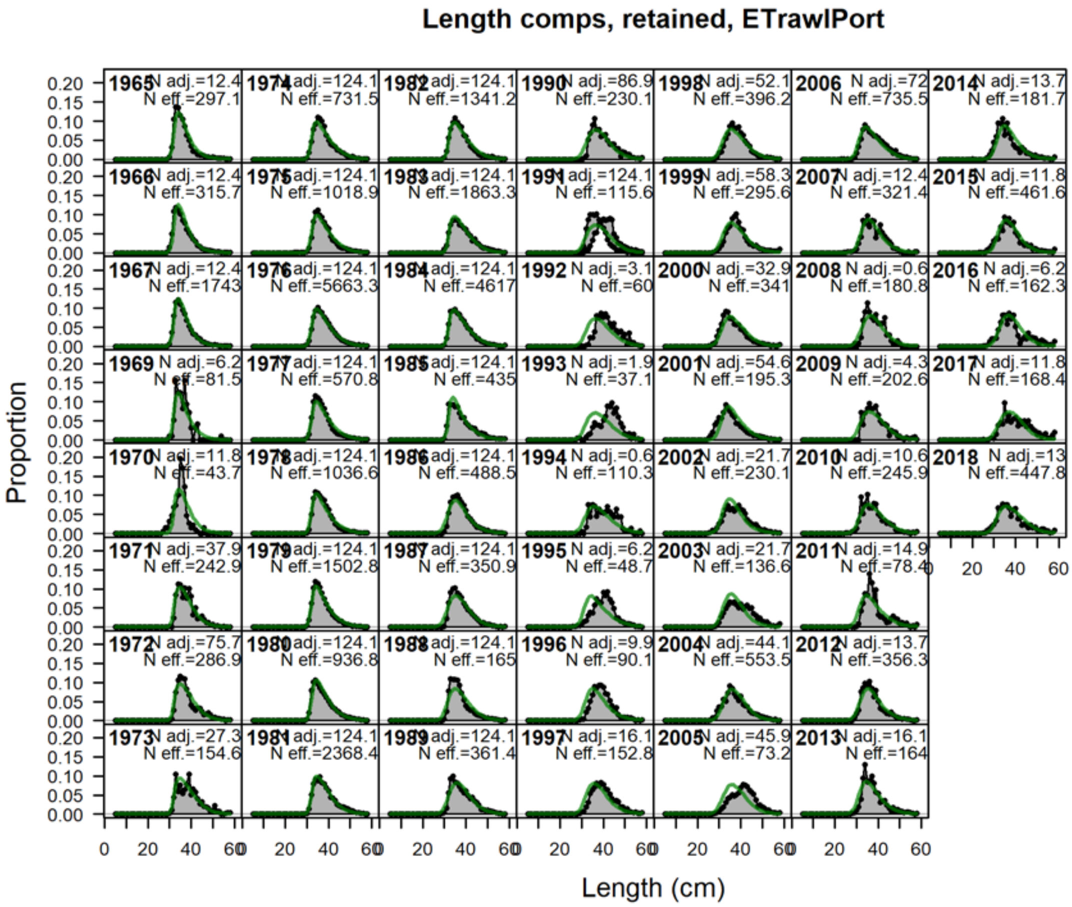

Figure A 7.7. Tiger flathead length composition fits: eastern trawl retained port.

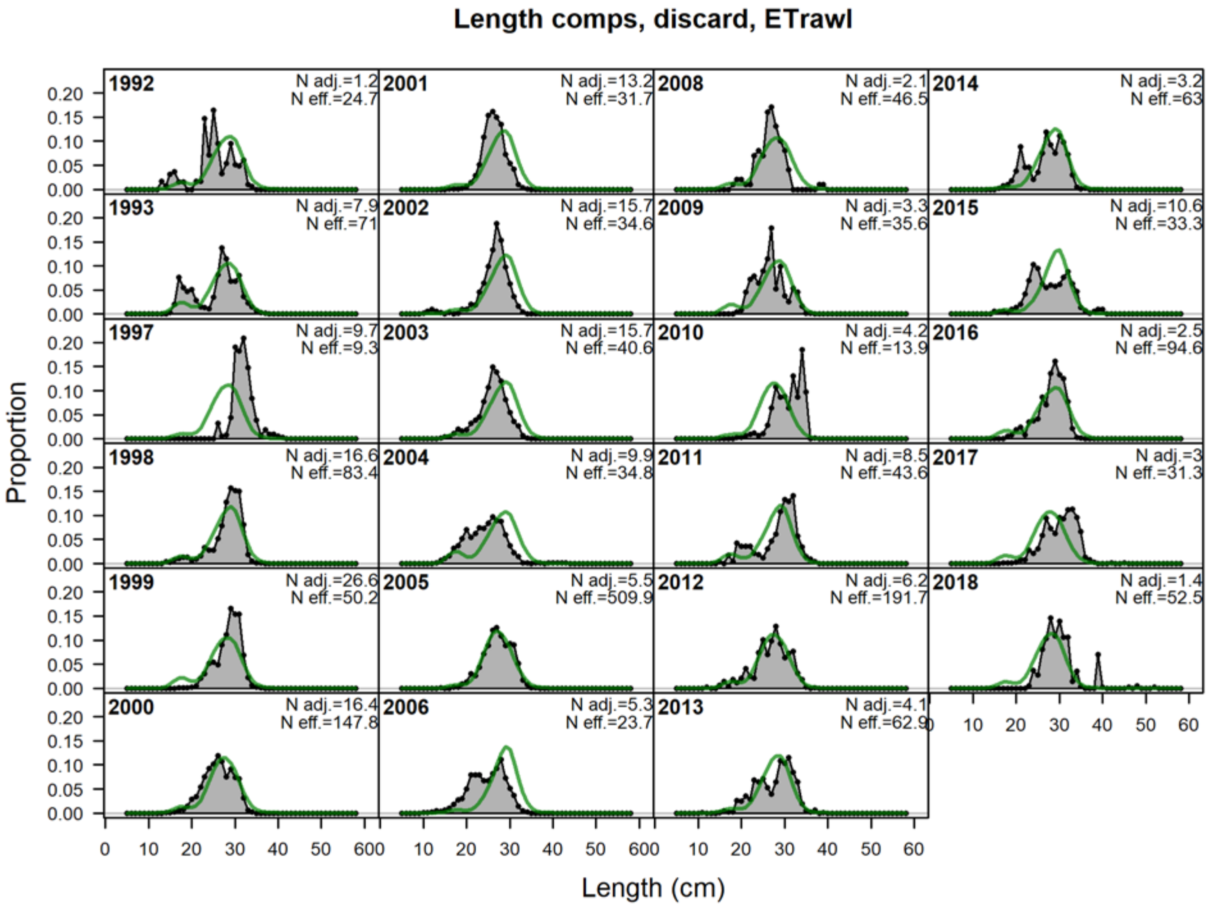

Figure A 7.8. Tiger flathead length composition fits: eastern trawl discarded.

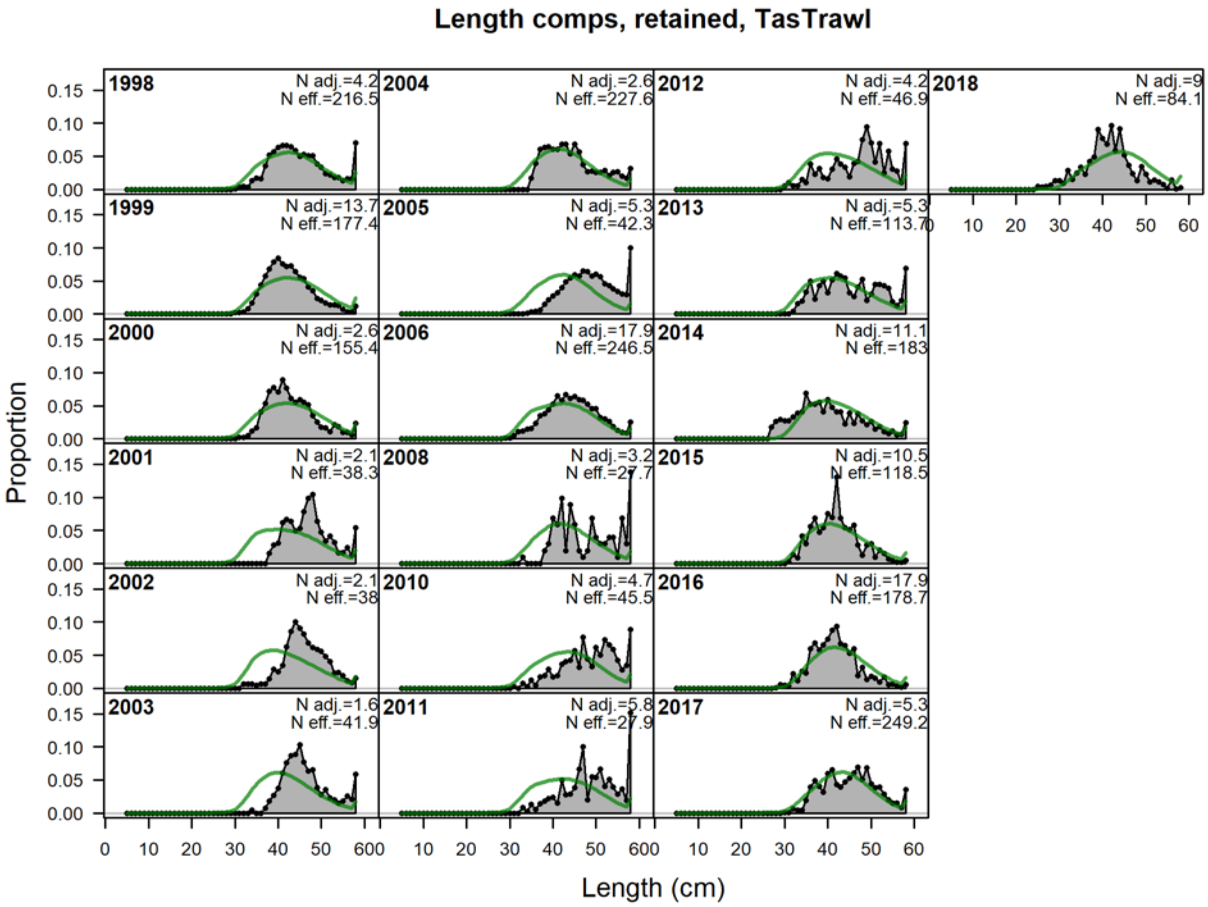

Figure A 7.9. Tiger flathead length composition fits: Tasmanian trawl retained onboard.

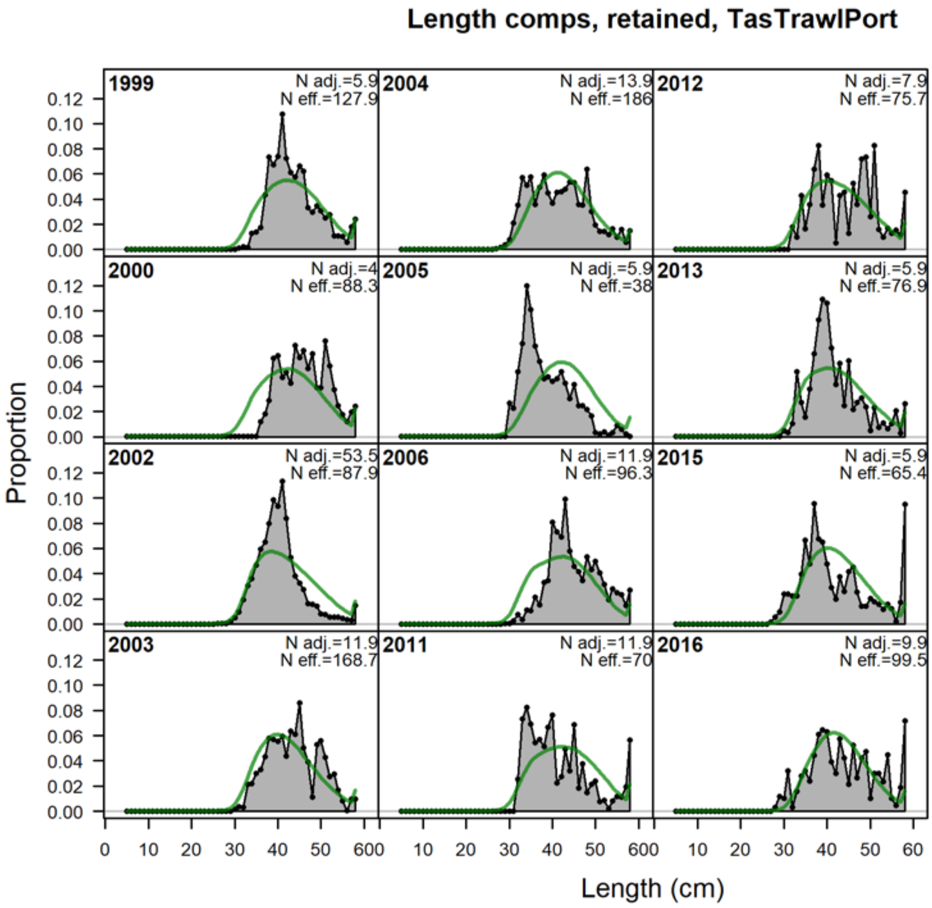

Figure A 7.10. Tiger flathead length composition fits: Tasmanian trawl retained port.

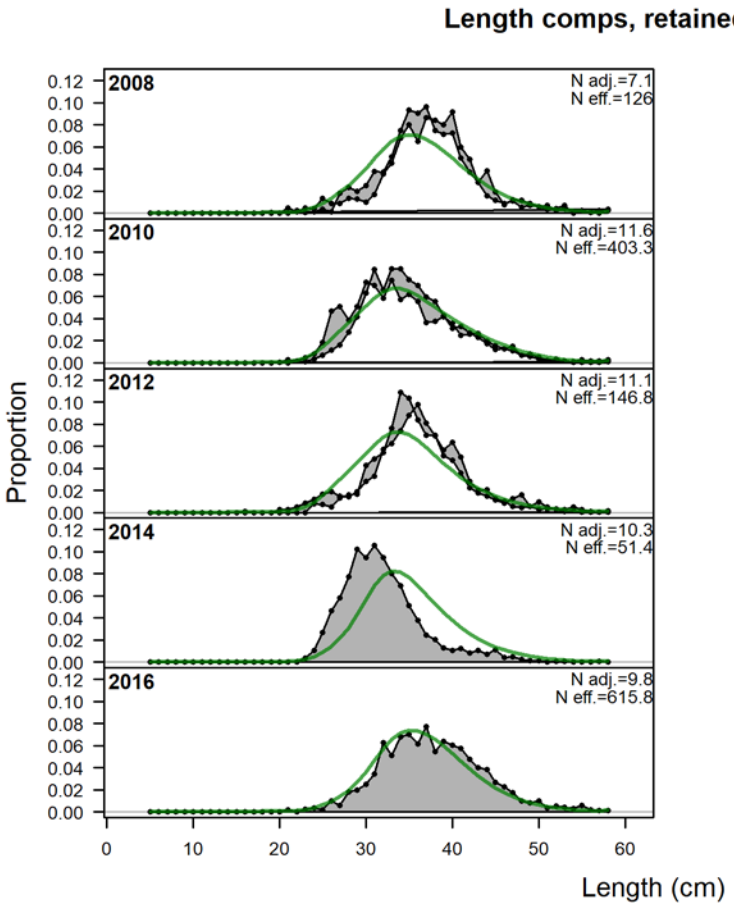

Figure A 7.11. Tiger flathead length composition fits: eastern FIS (zones 10 and 20).

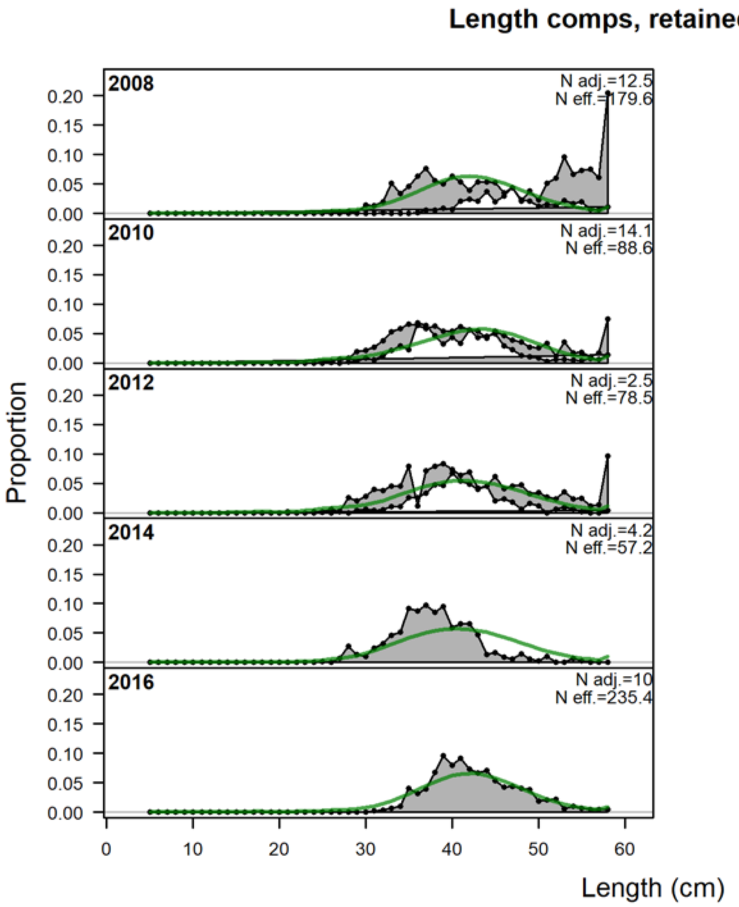

Figure A 7.12. Tiger flathead length composition fits: Tasmanian FIS (zone 30 only).

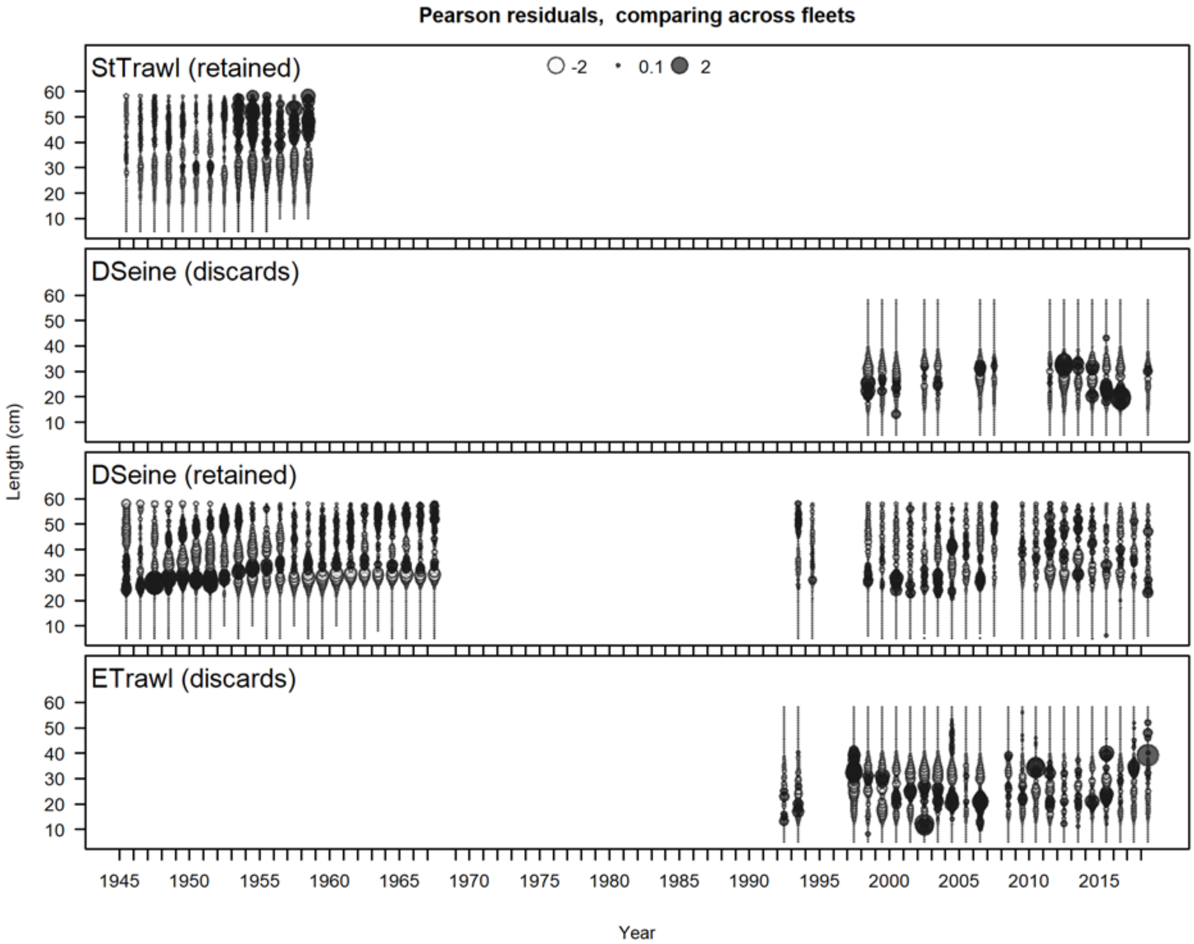

Figure A 7.13. Residuals from the annual length compositions for tiger flathead displayed by year and fleet: onboard fleets, retained and discarded.

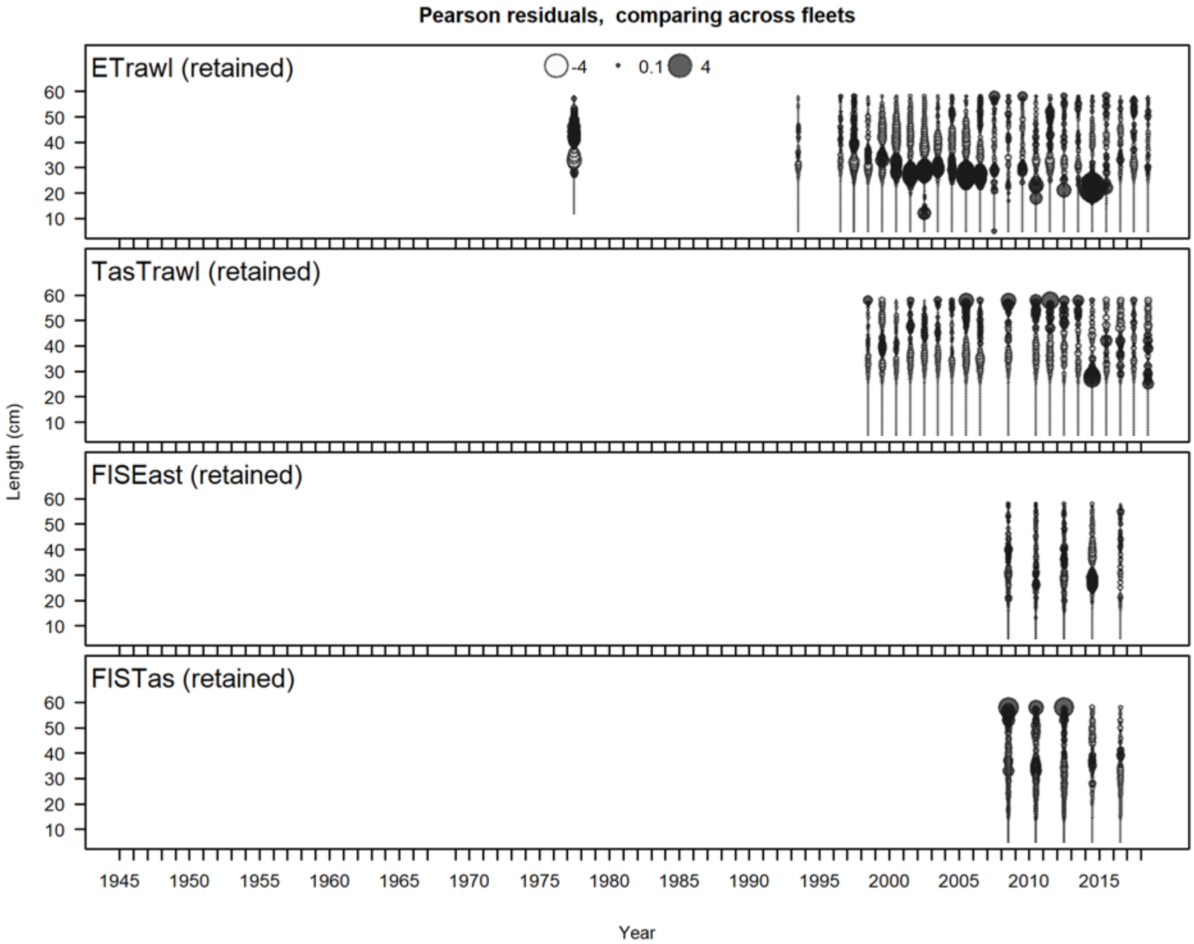

Figure A 7.14. Residuals from the annual length compositions for tiger flathead displayed by year and fleet: onboard fleets and FIS.

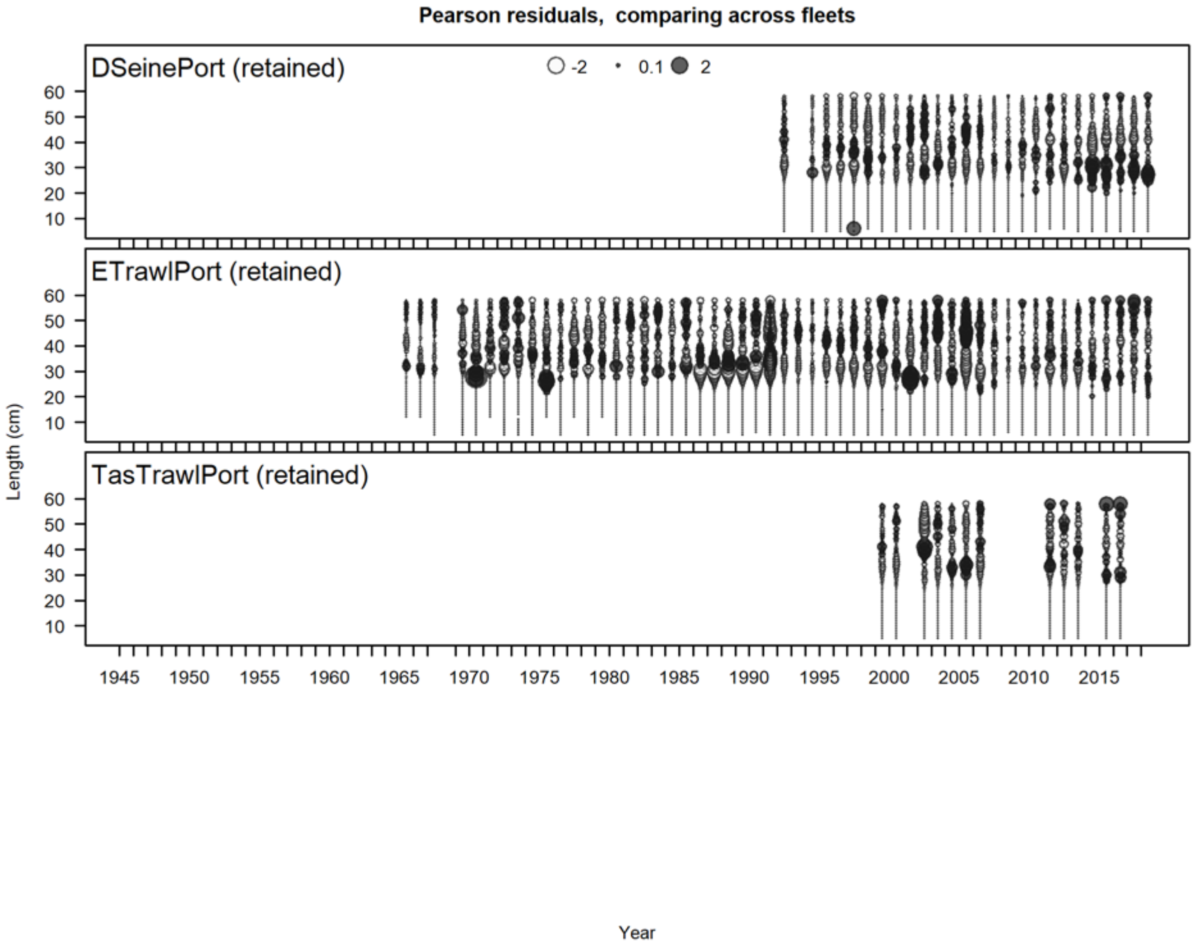

Figure A 7.15. Residuals from the annual length compositions for tiger flathead displayed by year and fleet: Port.

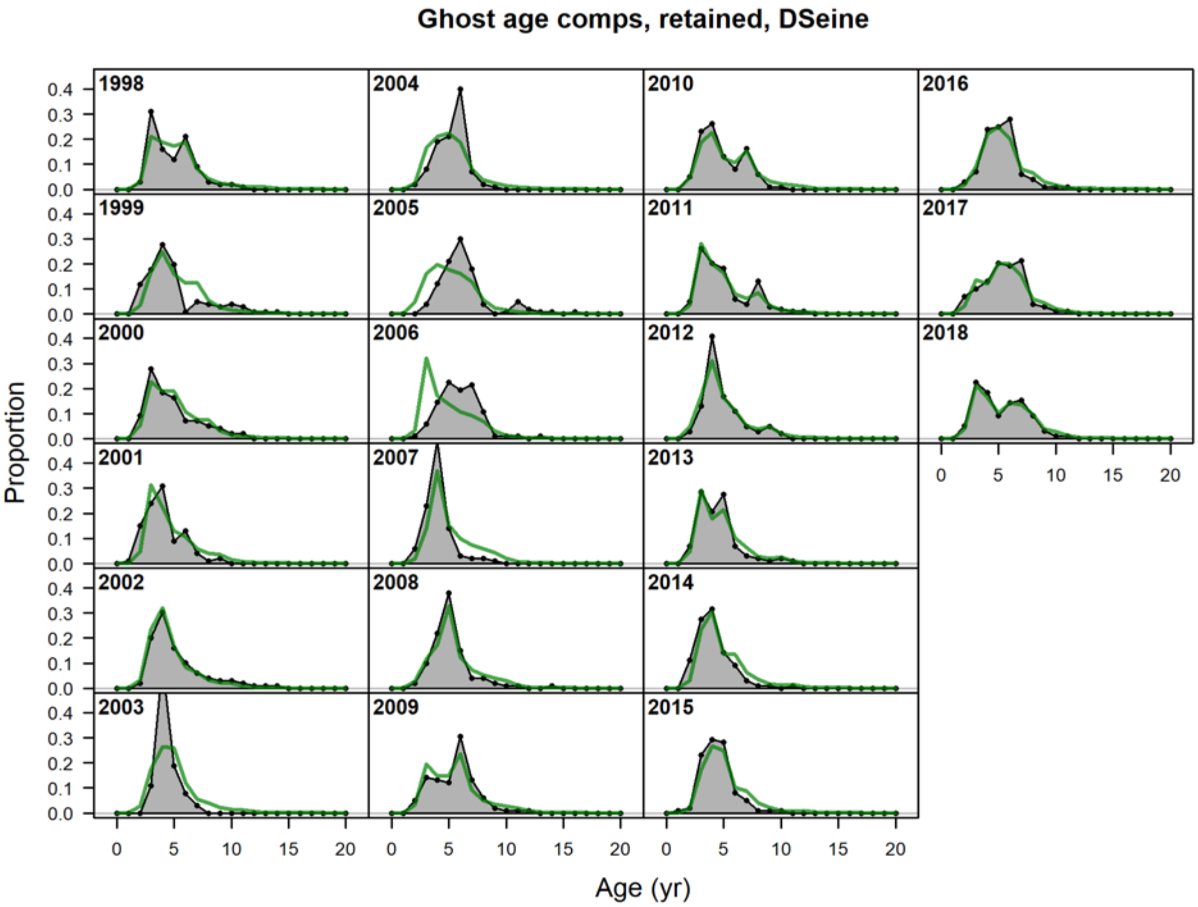

Figure A 7.16. Implied fits to age compositions for tiger flathead Danish seine (retained).

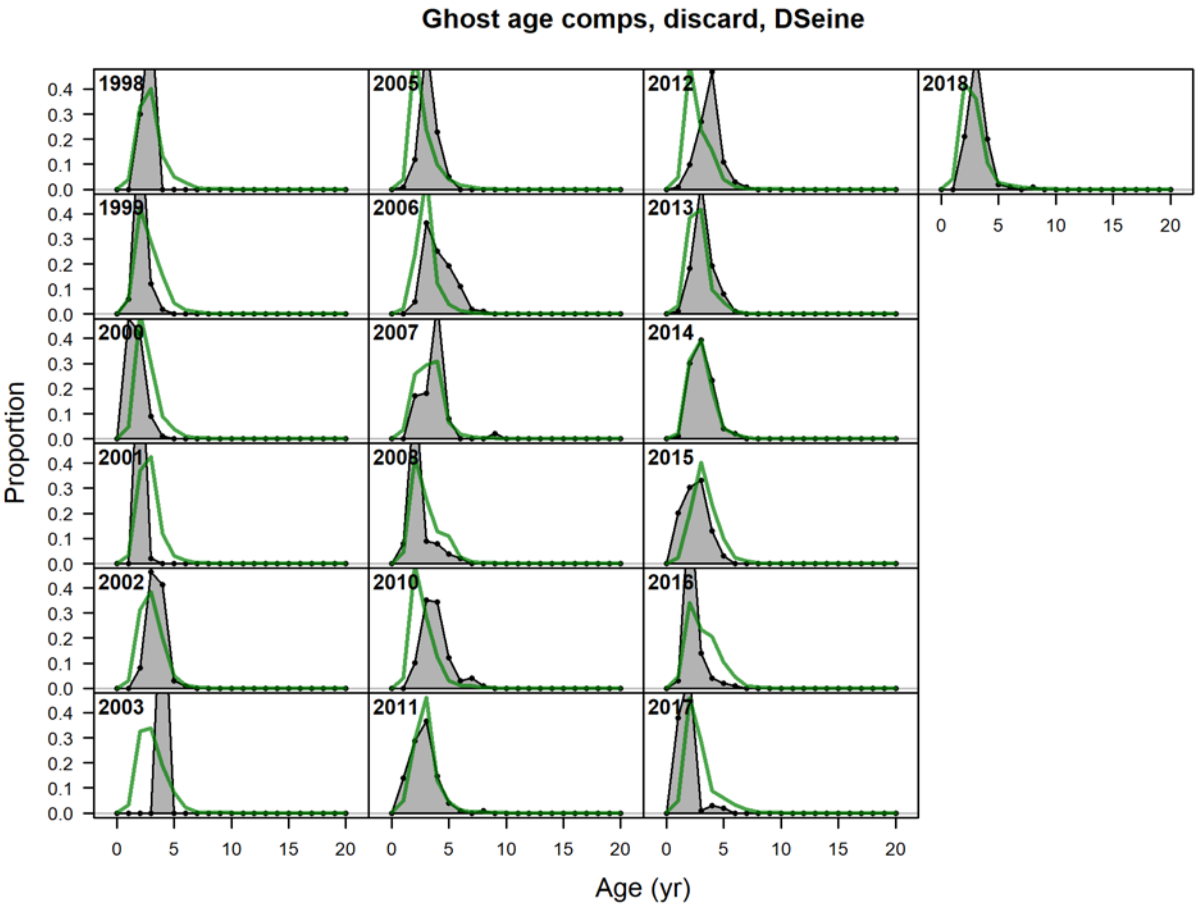

Figure A 7.17. Implied fits to age compositions for tiger flathead Danish seine (discarded).

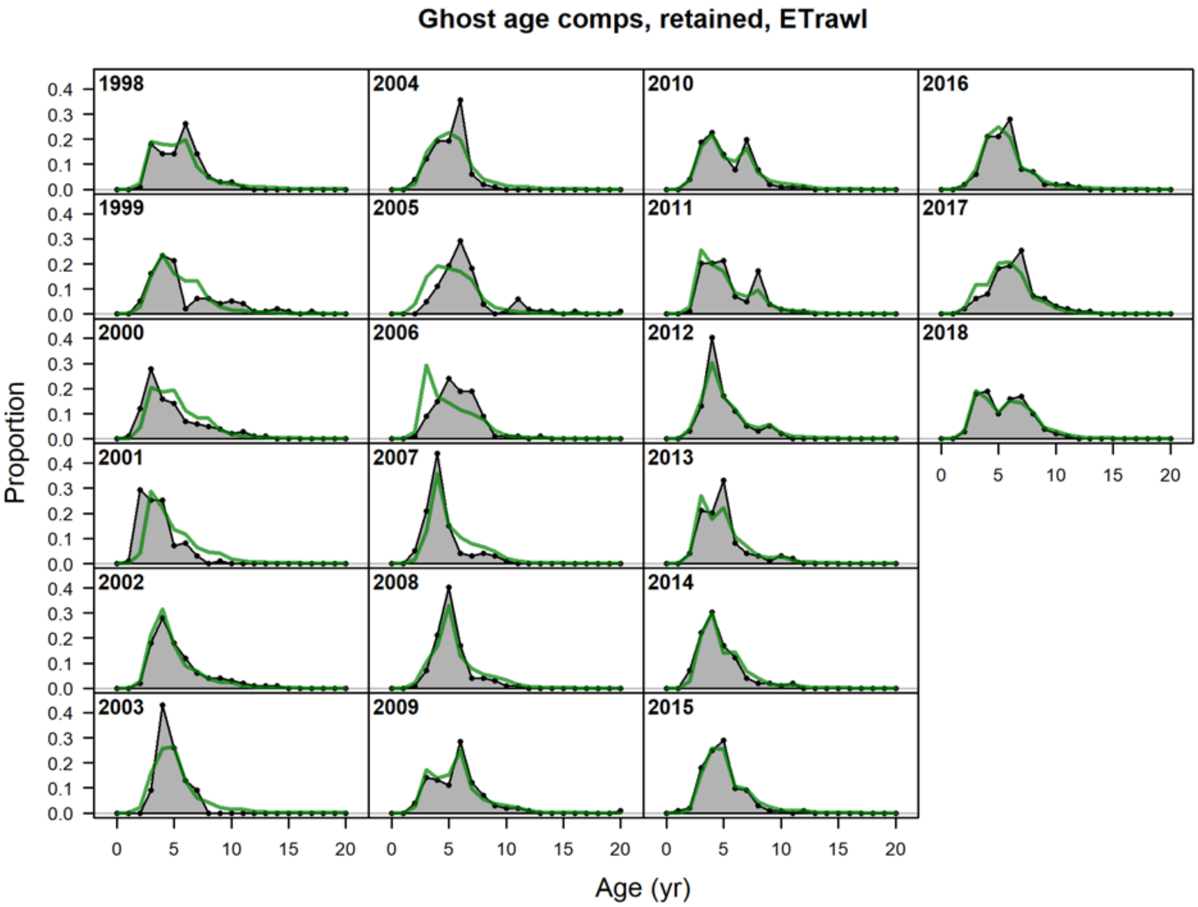

Figure A 7.18. Implied fits to age compositions for tiger flathead eastern trawl (retained).

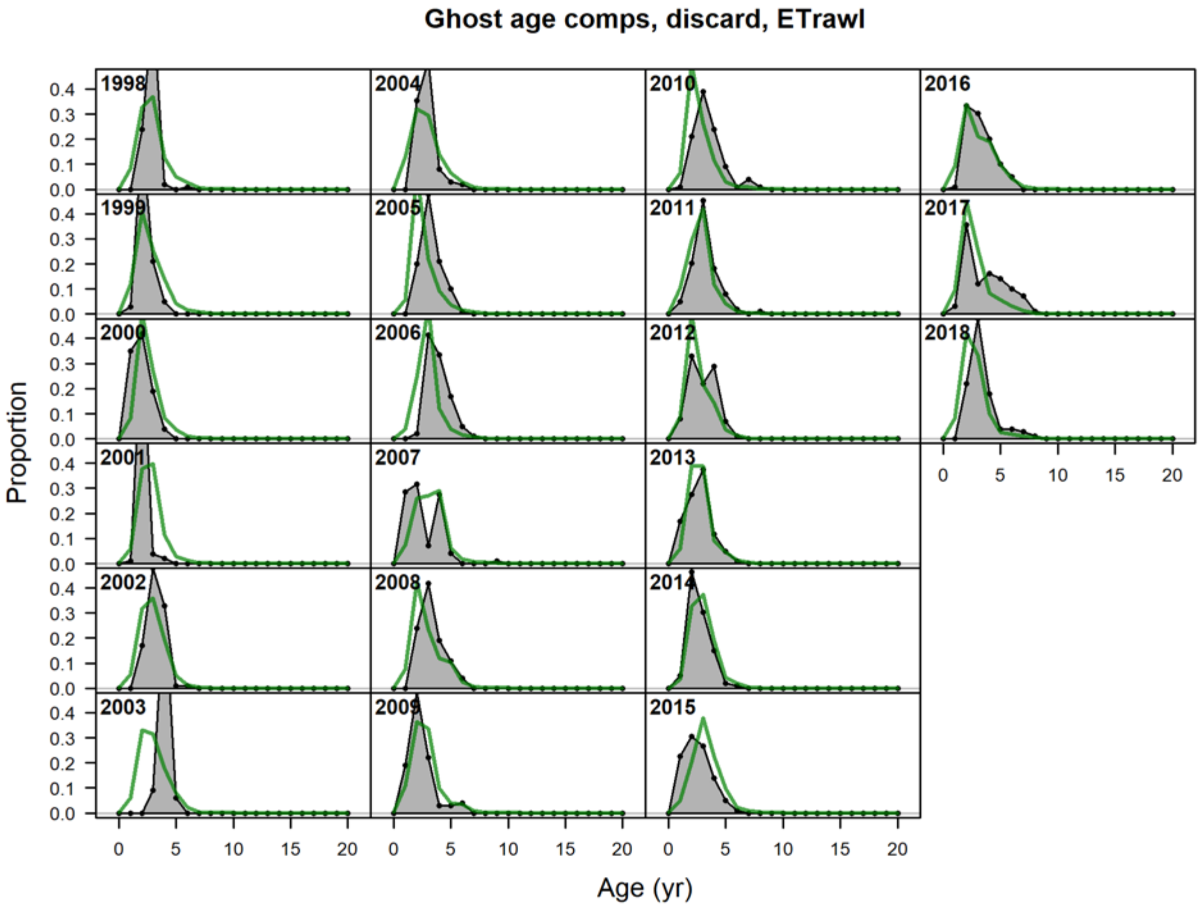

Figure A 7.19. Implied fits to age compositions for tiger flathead eastern trawl (discarded).

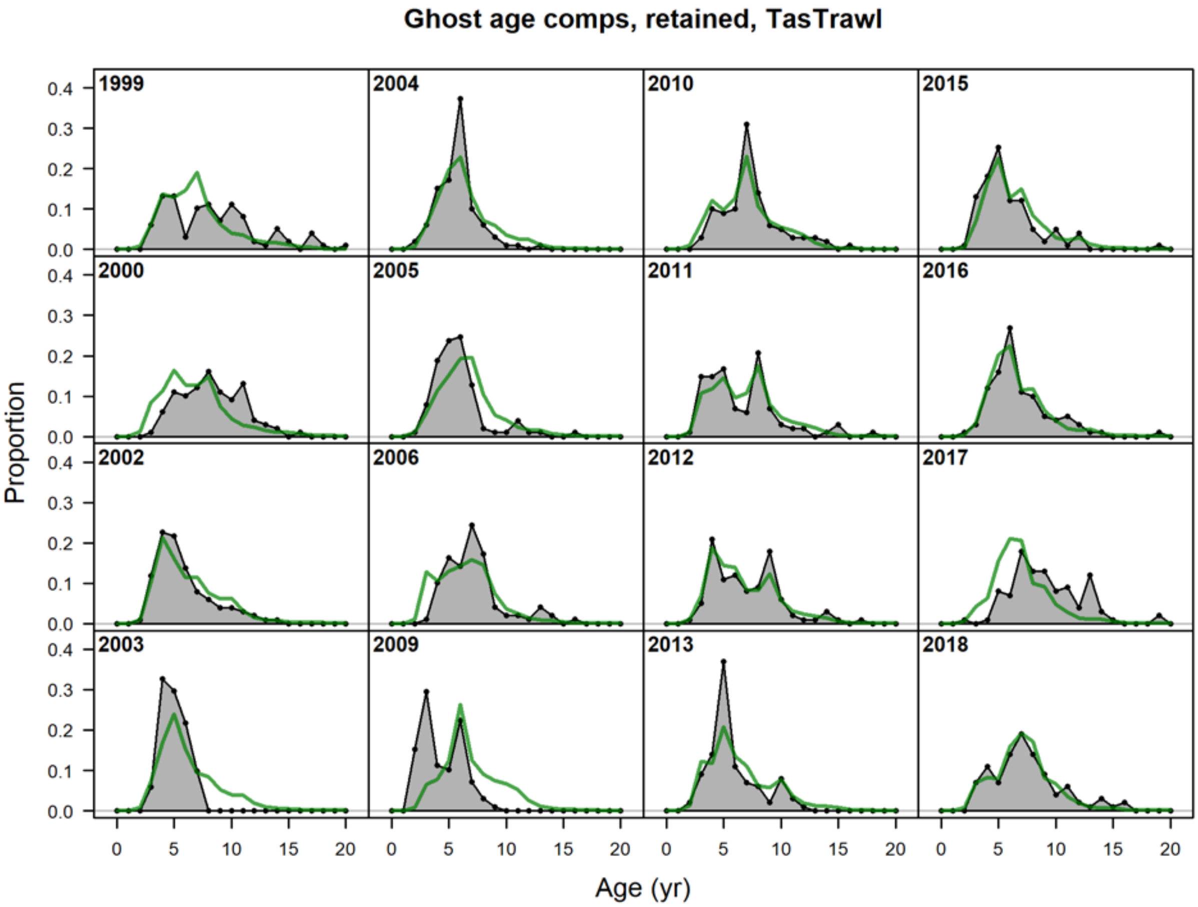

Figure A 7.20. Implied fits to age compositions for tiger flathead Tasmanian trawl (retained).

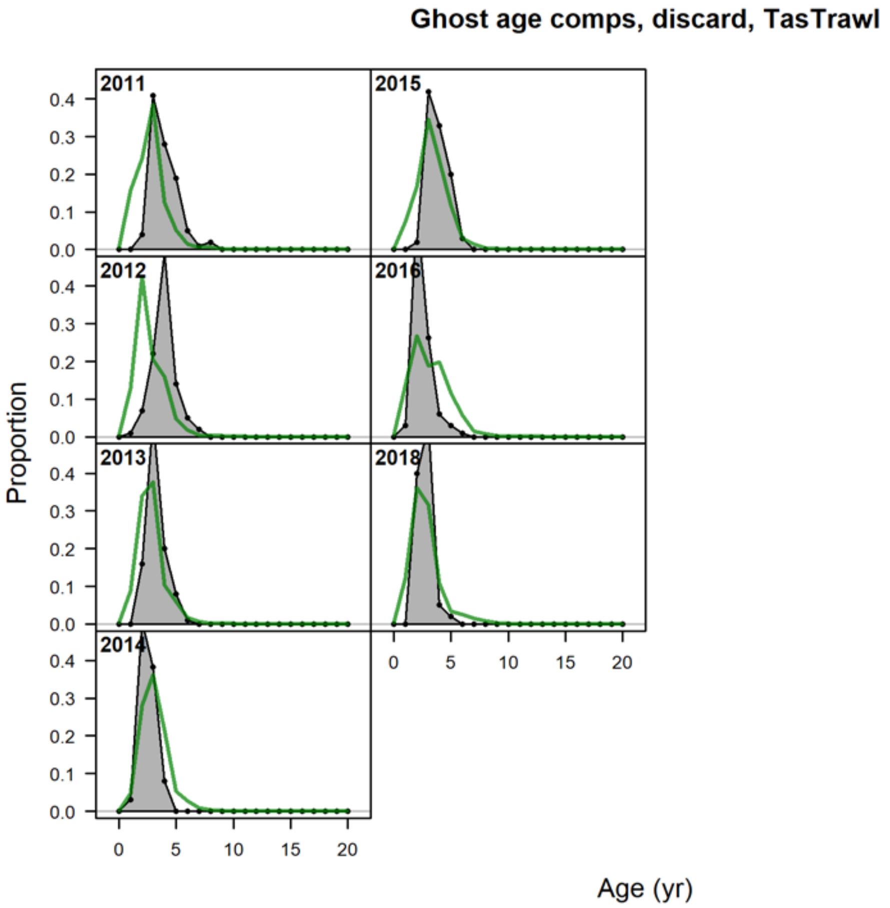

Figure A 7.21. Implied fits to age compositions for tiger flathead Tasmanian trawl (discarded).

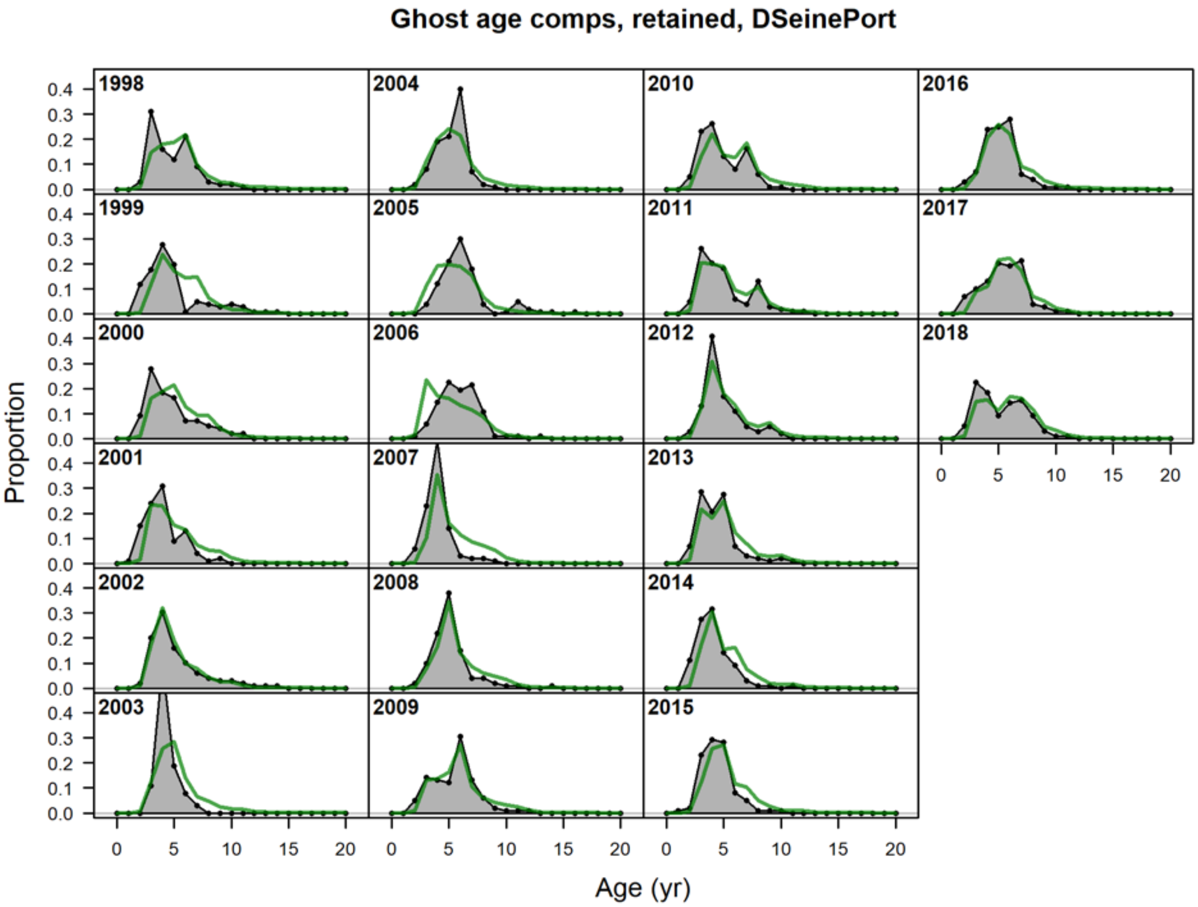

Figure A 7.22. Implied fits to age compositions for tiger flathead Danish seine port (retained).

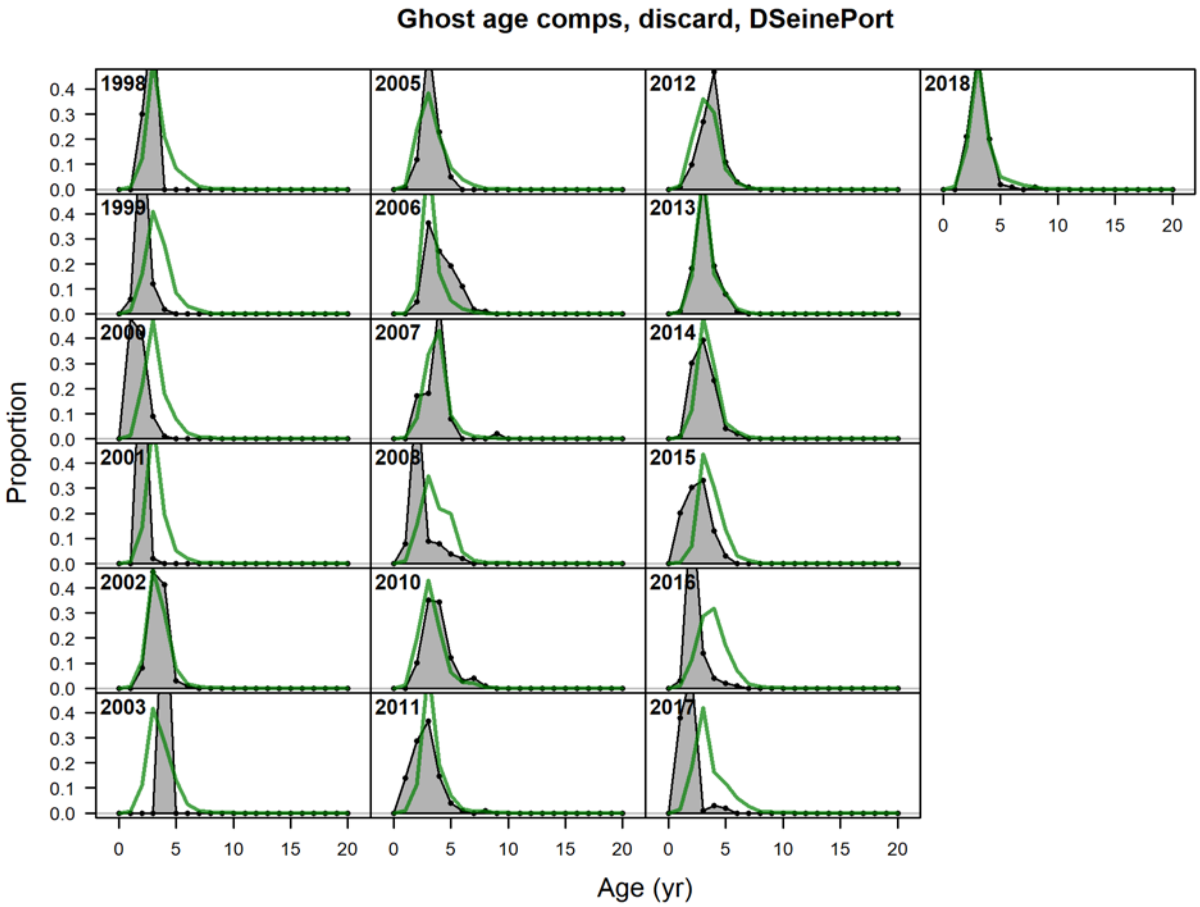

Figure A 7.23. Implied fits to age compositions for tiger flathead Danish seine port (discarded).

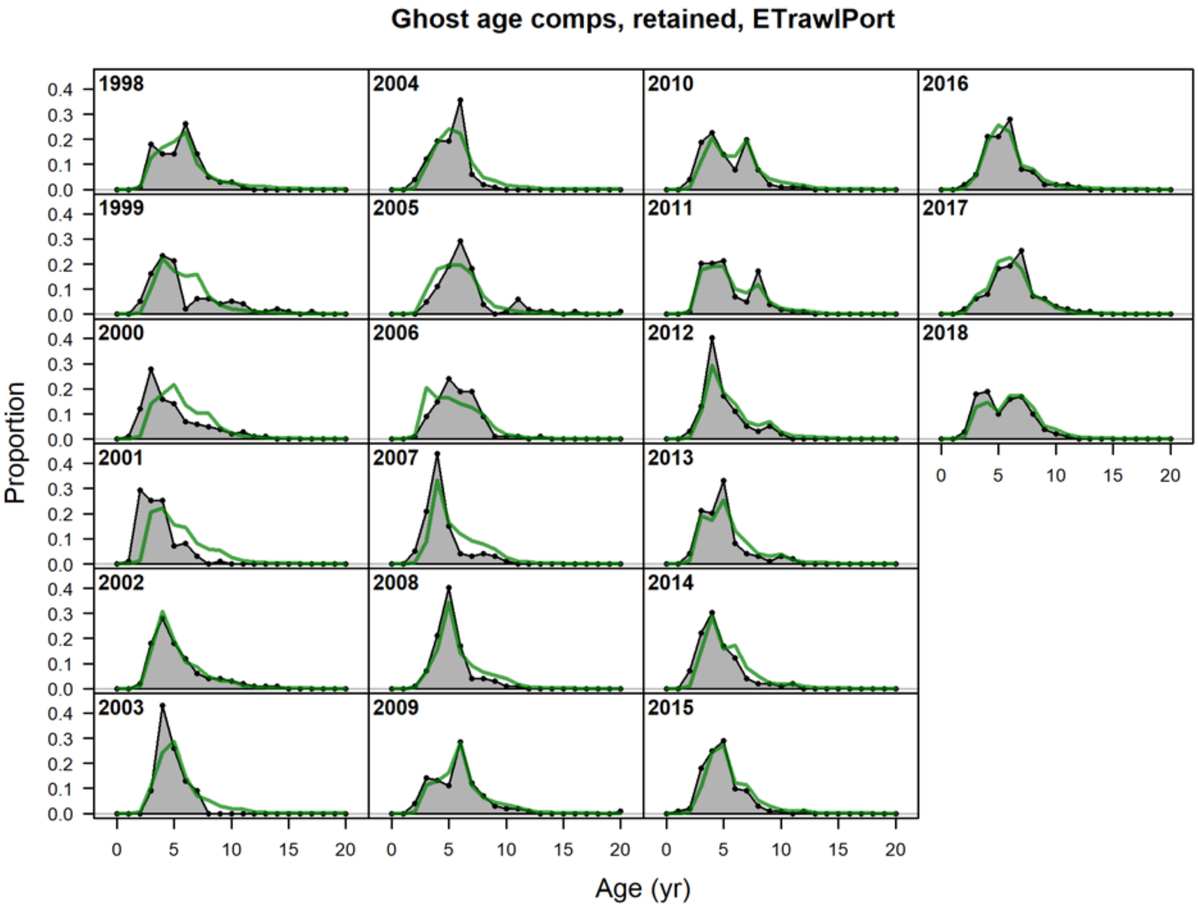

Figure A 7.24. Implied fits to age compositions for tiger flathead eastern trawl port (retained).

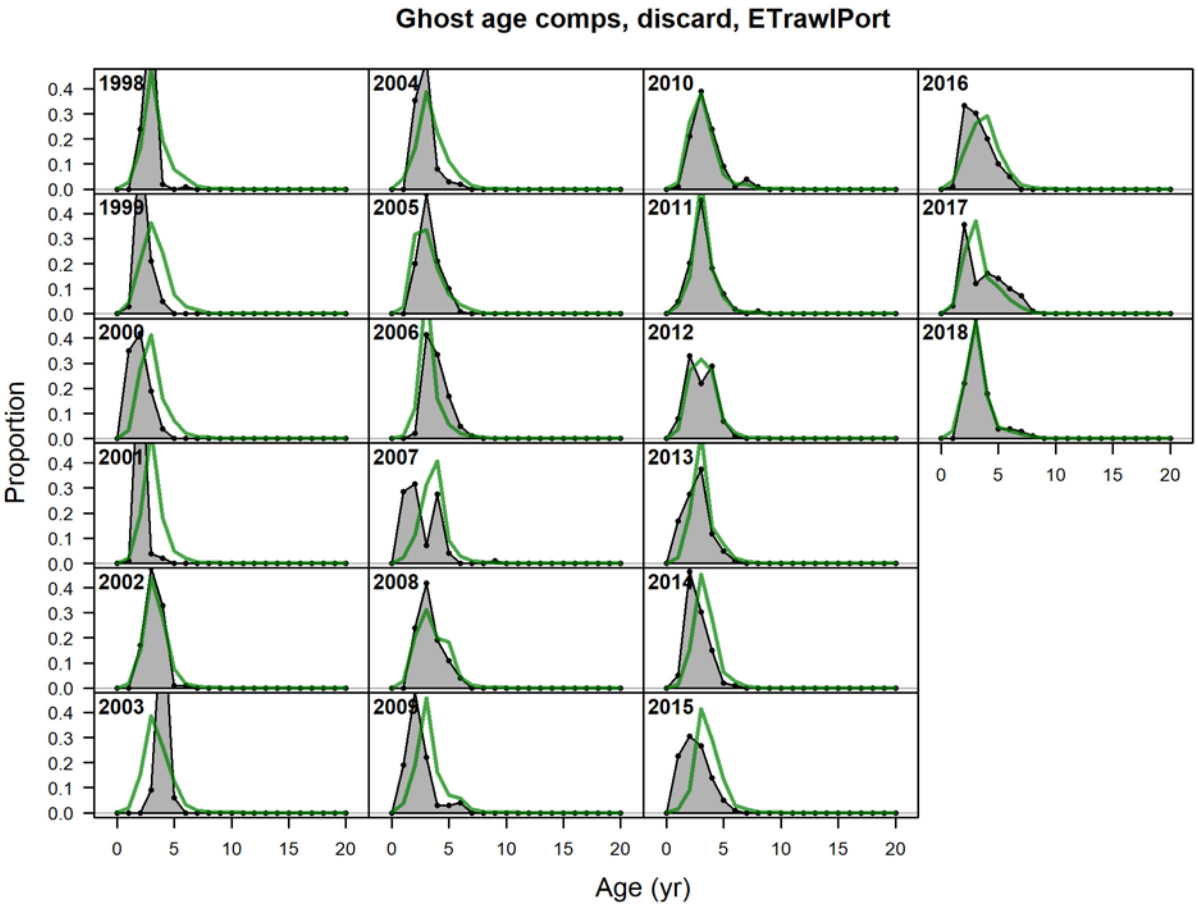

Figure A 7.25. Implied fits to age compositions for tiger flathead eastern trawl port (discarded).

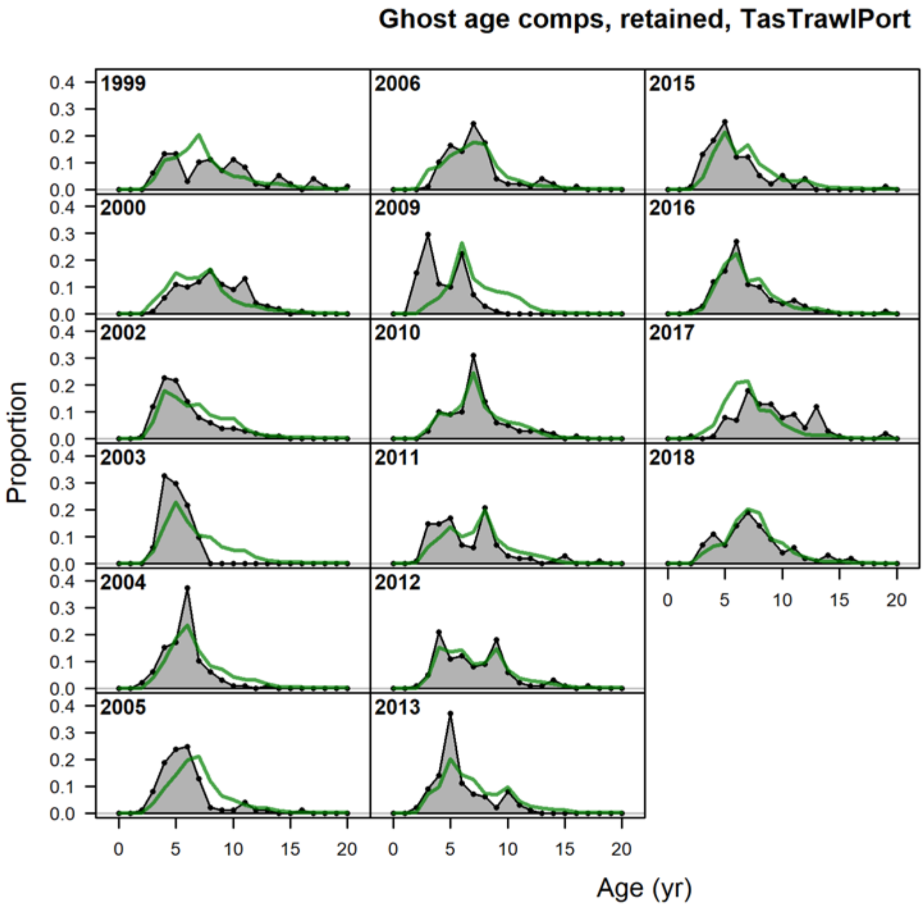

Figure A 7.26. Implied fits to age compositions for tiger flathead Tasmanian trawl port (retained).

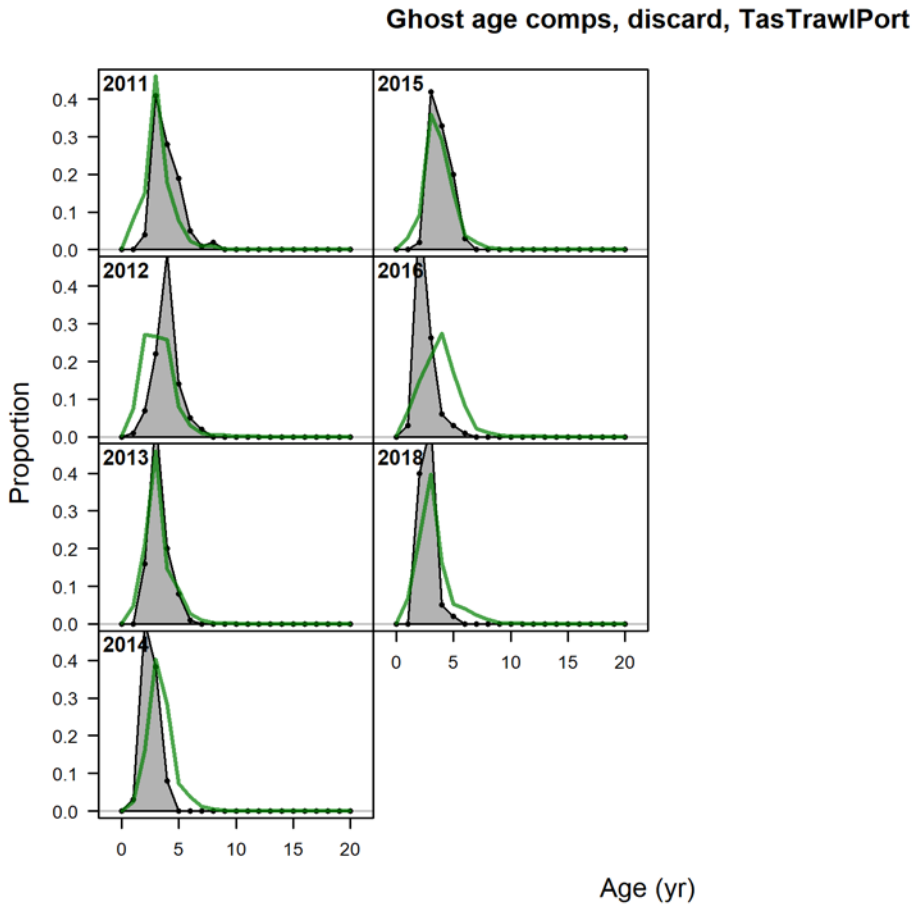

Figure A 7.27. Implied fits to age compositions for tiger flathead Tasmanian trawl port (discarded).

8. Updated catch series for tiger flathead (*Neoplatycephalus richardsoni*) stock assessment based on data up to 2018

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8.1 Executive Summary

This document explains the changes to the catch series between version 2 and version 3 of the 2019 tiger flathead (*Neoplatycephalus richardsoni*) assessment reports and the impacts of these changes on the spawning biomass series, the recruitment, the stock status and the calculated RBCs. The changes to the catch series are minor. This flows on to minor changes in the spawning biomass series and recruitment, with the 2020 spawning stock biomass changing from 33.67% of unexploited stock biomass (SSB_0) for the updated base case, compared to 33.40% for the old base case, with incorrect (lower) catch series from 2001-2018. The RBC calculations have also been updated.

The 2020 recommended biological catch (RBC) under the 20:35:40 harvest control rule for the updated base case is 2,334 t, and is below the long-term yield (assuming average recruitment in the future) of 2,986 t. The average RBC over the three-year period 2020-2022 is 2,563 t and over the five-year period 2020-2024, the average RBC is 2,648 t.

By comparison, the 2020 RBC is 2,254 t, with long term yield of 2,959t, for the old base case, with incorrect (lower) catch series from 2001-2018. For the old base case, the average RBC over the three-year period 2020-2022 is 2,515 t and over the five-year period 2020-2024, the average RBC is 2,607 t.

8.2 Introduction

8.2.1 *The incorrect catch series*

The tiger flathead stock assessment document presented to the SERAG meeting on December 3, 2019, (Day 2019a, Version 2 – 2 December 2019) included a catch series with errors in the period 2001-2018. The data processing is complex, involving the combination of state catches, which need to be allocated to fleets, and Commonwealth catches. Logbook catches are used to allocate Commonwealth catches to fleets, and these logbook values need to be scaled up to the values from the Catch Disposal Record (CDR) totals. In addition, decisions need to be made about non-trawl CDRs, state SEF2 catches and the agreed historical series of catches needs to be incorporated. The total annual catch summed over all fleets used in the assessment should be close to the total reported in the catch report (Burch et al., 2019). In this case, there are small differences between these totals due to inclusion of the non-trawl CDRs and exclusion of Victorian state SEF2 catches in Burch et al. (2019). The non-trawl CDR's are very small and typically excluded from the tiger flathead series, while the Victorian state SEF2 catches, which average 6.5 t per year over the period 2001-2012, have traditionally been included in the tiger flathead assessment.

However, the differences in these two catch series (Burch et al., 2019 and Day 2019a) were greater than could be explained from these two sources. Part of the error is due to incorrect allocation of CDRs caught in western Tasmania and western Bass Strait, which should have been allocated to the eastern fleets and the remaining error related to incorrect processing of catches from the Tasmanian trawl fleet. These errors were discovered following the December 2019 SERAG meeting (Geoff Liggins, pers. comm.).

Corrections to this catch history led to an increase in the catch by an average of 76 t per year from 2001-2018, with the increases ranging from a minimum of 30 t in 2002 to a maximum of 128 t in 2008. The annual increases in catch were around 40 t to the Tasmanian trawl fleet and just under 20 t each for the Danish seine and eastern trawl fleets. These corrections were discovered late in the assessment process, and there was only time to update the most important components of this document. All the diagnostic plots, fits, discard estimates and RBC calculations presented in Day (2019b, Version 3 – 19 December 2019) are for the updated base case with the corrected catch series. However, the likelihood profiles, retrospectives and sensitivities were calculated for the old base case, using the incorrect (lower) catch series from 2001-2018. The general principles and comparisons in these analyses with the lower catch series are not expected to show qualitative differences. The increase in annual catches from 2001-2018 averages 2.6% and ranges from 0.9% to 4.8%. Catches are unchanged for the period from 1915-2000.

Table 8.1. Total retained catches (tonnes) of tiger flathead per fleet for calendar years from 1915-2019, with updated totals since the December 2019 SERAG meeting shown in bold, (Day 2019b, Version 3 – 19 December 2019).

Year	Fleet				Year	Fleet				Year	Fleet			
	St Trawl	D Seine	E Trawl	Tas Trawl		St Trawl	D Seine	E Trawl	Tas Trawl		St Trawl	D Seine	E Trawl	Tas Trawl
1915	371	0	0	0	1951	583	1,625	0	0	1987	0	1,358	1,109	6
1916	373	0	0	0	1952	769	1,499	0	0	1988	0	1,177	1,263	116
1917	432	0	0	0	1953	517	2,235	0	0	1989	0	1,189	1,318	128
1918	671	0	0	0	1954	366	1,737	0	0	1990	0	591	1,425	178
1919	1,151	0	0	0	1955	211	1,932	0	0	1991	0	746	1,461	166
1920	931	0	0	0	1956	157	1,868	0	0	1992	0	1,019	1,080	170
1921	1,297	0	0	0	1957	139	1,459	0	0	1993	0	516	962	194
1922	840	0	0	0	1958	68	1,138	0	0	1994	0	626	982	178
1923	796	0	0	0	1959	32	1,467	0	0	1995	0	564	1,189	139
1924	1,356	0	0	0	1960	15	2,206	0	0	1996	0	711	1,265	114
1925	1,969	0	0	0	1961	9	1,974	0	0	1997	0	1,023	1,542	175
1926	2,167	0	0	0	1962	0	1,742	0	0	1998	0	905	1,700	186
1927	2,735	0	0	0	1963	0	3,745	0	0	1999	0	1,873	1,520	248
1928	3,277	0	0	0	1964	0	3,707	0	0	2000	0	1,286	2,006	349
1929	3,768	102	0	0	1965	0	3,322	0	0	2001	0	**1,269**	**1,612**	**115**
1930	3,329	330	0	0	1966	0	2,769	0	0	2002	0	**1,305**	**1,731**	**236**
1931	2,932	4	0	0	1967	0	2,912	0	0	2003	0	**1,446**	**1,957**	**270**
1932	2,642	385	0	0	1968	0	2,355	0	0	2004	0	**1,418**	**1,658**	**522**
1933	2,456	44	0	0	1969	0	3,289	0	0	2005	0	**1,307**	**1,516**	**476**
1934	2,278	276	0	0	1970	0	2,667	0	0	2006	0	**1,132**	**1,526**	**359**
1935	2,514	270	0	0	1971	0	1,793	286	0	2007	0	**1,488**	**1,368**	**223**
1936	2,712	872	0	0	1972	0	1,981	491	0	2008	0	**1,487**	**1,705**	**255**
1937	2,912	637	0	0	1973	0	2,397	490	0	2009	0	**1,358**	**1,408**	**163**
1938	2,924	725	0	0	1974	0	1,493	369	0	2010	0	**1,359**	**1,458**	**175**
1939	2,185	1,035	0	0	1975	0	1,367	827	0	2011	0	**1,300**	**1,435**	**214**
1940	815	1,108	0	0	1976	0	900	712	0	2012	0	**1,560**	**1,516**	**217**
1941	403	1,255	0	0	1977	0	977	522	0	2013	0	**1,103**	**995**	**287**
1942	167	225	0	0	1978	0	836	446	0	2014	0	**1,352**	**1,244**	**239**
1943	223	317	0	0	1979	0	928	520	0	2015	0	**1,476**	**1,248**	**348**
1944	315	2,624	0	0	1980	0	851	609	0	2016	0	**1,671**	**1,126**	**422**
1945	953	2,168	0	0	1981	0	418	877	0	2017	0	**1,377**	**887**	**392**
1946	1,088	1,425	0	0	1982	0	615	930	0	2018	0	**1,107**	**921**	**268**
1947	884	1,193	0	0	1983	0	889	950	0	2019*	0	**1,107**	**921**	**268**
1948	735	1,767	0	0	1984	0	890	978	0					
1949	330	804	0	0	1985	0	890	978	30					
1950	310	1,095	0	0	1986	0	892	1,005	26					

*2019 catches are estimated

Table 8.2. Incorrect total retained catches (tonnes) of tiger flathead per fleet for calendar years from 1915-2019, with incorrect values shown in the December 2019 SERAG meeting and used in Day (2019a, Version 2 – 2 December 2019) shown in bold.

Year	Fleet St Trawl	D Seine	E Trawl	Tas Trawl	Year	Fleet St Trawl	D Seine	E Trawl	Tas Trawl	Year	Fleet St Trawl	D Seine	E Trawl	Tas Trawl
1915	371	0	0	0	1951	583	1,625	0	0	1987	0	1,358	1,109	6
1916	373	0	0	0	1952	769	1,499	0	0	1988	0	1,177	1,263	116
1917	432	0	0	0	1953	517	2,235	0	0	1989	0	1,189	1,318	128
1918	671	0	0	0	1954	366	1,737	0	0	1990	0	591	1,425	178
1919	1,151	0	0	0	1955	211	1,932	0	0	1991	0	746	1,461	166
1920	931	0	0	0	1956	157	1,868	0	0	1992	0	1,019	1,080	170
1921	1,297	0	0	0	1957	139	1,459	0	0	1993	0	516	962	194
1922	840	0	0	0	1958	68	1,138	0	0	1994	0	626	982	178
1923	796	0	0	0	1959	32	1,467	0	0	1995	0	564	1,189	139
1924	1,356	0	0	0	1960	15	2,206	0	0	1996	0	711	1,265	114
1925	1,969	0	0	0	1961	9	1,974	0	0	1997	0	1,023	1,542	175
1926	2,167	0	0	0	1962	0	1,742	0	0	1998	0	905	1,700	186
1927	2,735	0	0	0	1963	0	3,745	0	0	1999	0	1,873	1,520	248
1928	3,277	0	0	0	1964	0	3,707	0	0	2000	0	1,286	2,006	349
1929	3,768	102	0	0	1965	0	3,322	0	0	2001	0	**1,246**	**1,585**	**121**
1930	3,329	330	0	0	1966	0	2,769	0	0	2002	0	**1,291**	**1,713**	**238**
1931	2,932	4	0	0	1967	0	2,912	0	0	2003	0	**1,425**	**1,931**	**266**
1932	2,642	385	0	0	1968	0	2,355	0	0	2004	0	**1,398**	**1,637**	**506**
1933	2,456	44	0	0	1969	0	3,289	0	0	2005	0	**1,279**	**1,489**	**417**
1934	2,278	276	0	0	1970	0	2,667	0	0	2006	0	**1,101**	**1,492**	**307**
1935	2,514	270	0	0	1971	0	1,793	286	0	2007	0	**1,451**	**1,337**	**194**
1936	2,712	872	0	0	1972	0	1,981	491	0	2008	0	**1,453**	**1,671**	**196**
1937	2,912	637	0	0	1973	0	2,397	490	0	2009	0	**1,336**	**1,388**	**113**
1938	2,924	725	0	0	1974	0	1,493	369	0	2010	0	**1,347**	**1,446**	**128**
1939	2,185	1,035	0	0	1975	0	1,367	827	0	2011	0	**1,282**	**1,418**	**145**
1940	815	1,108	0	0	1976	0	900	712	0	2012	0	**1,537**	**1,496**	**185**
1941	403	1,255	0	0	1977	0	977	522	0	2013	0	**1,078**	**977**	**221**
1942	167	225	0	0	1978	0	836	446	0	2014	0	**1,342**	**1,236**	**207**
1943	223	317	0	0	1979	0	928	520	0	2015	0	**1,470**	**1,244**	**324**
1944	315	2,624	0	0	1980	0	851	609	0	2016	0	**1,668**	**1,125**	**365**
1945	953	2,168	0	0	1981	0	418	877	0	2017	0	**1,368**	**882**	**315**
1946	1,088	1,425	0	0	1982	0	615	930	0	2018	0	**1,103**	**918**	**232**
1947	884	1,193	0	0	1983	0	889	950	0	2019 *	0	**1,103**	**918**	**232**
1948	735	1,767	0	0	1984	0	890	978	0					
1949	330	804	0	0	1985	0	890	978	30					
1950	310	1,095	0	0	1986	0	892	1,005	26					

*2019 catches are estimated

8.2.2 *Changes to the assessment outcome*

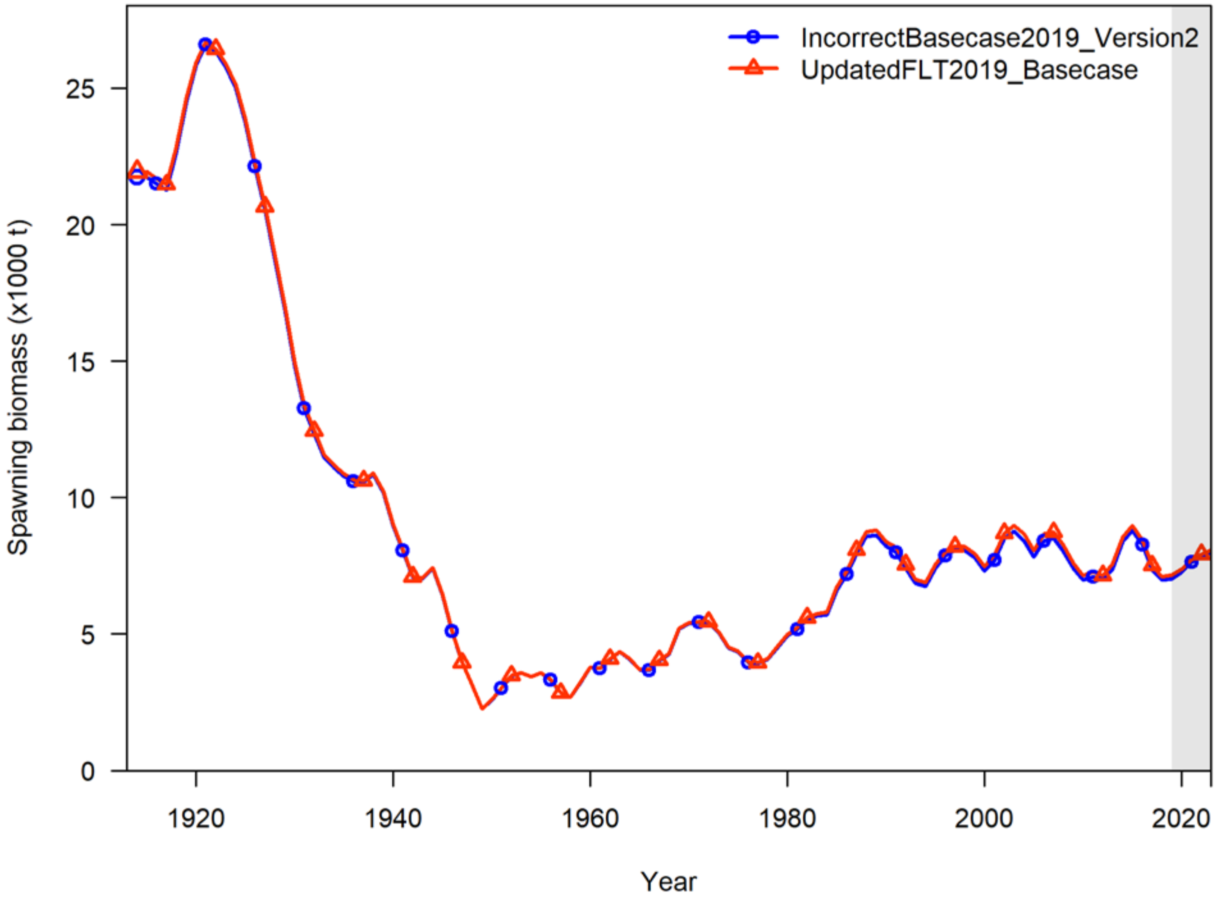

Figure 8.1. Comparison of the absolute spawning biomass from the old base case (version 2) and the updated base case (version 3).

The updated catch series was included in Day (2019b, Version 3 – 19 December 2019), with the resulting updated base case retuned and the RBC calculated. To explore the impact of this correction to the catch series, comparison plots were made showing the absolute spawning biomass time series (Figure 8.1), the relative spawning biomass time series (Figure 8.2) and the estimated recruitment time series (Figure 8.3). In all of these plots the changes in the outcomes were very small.

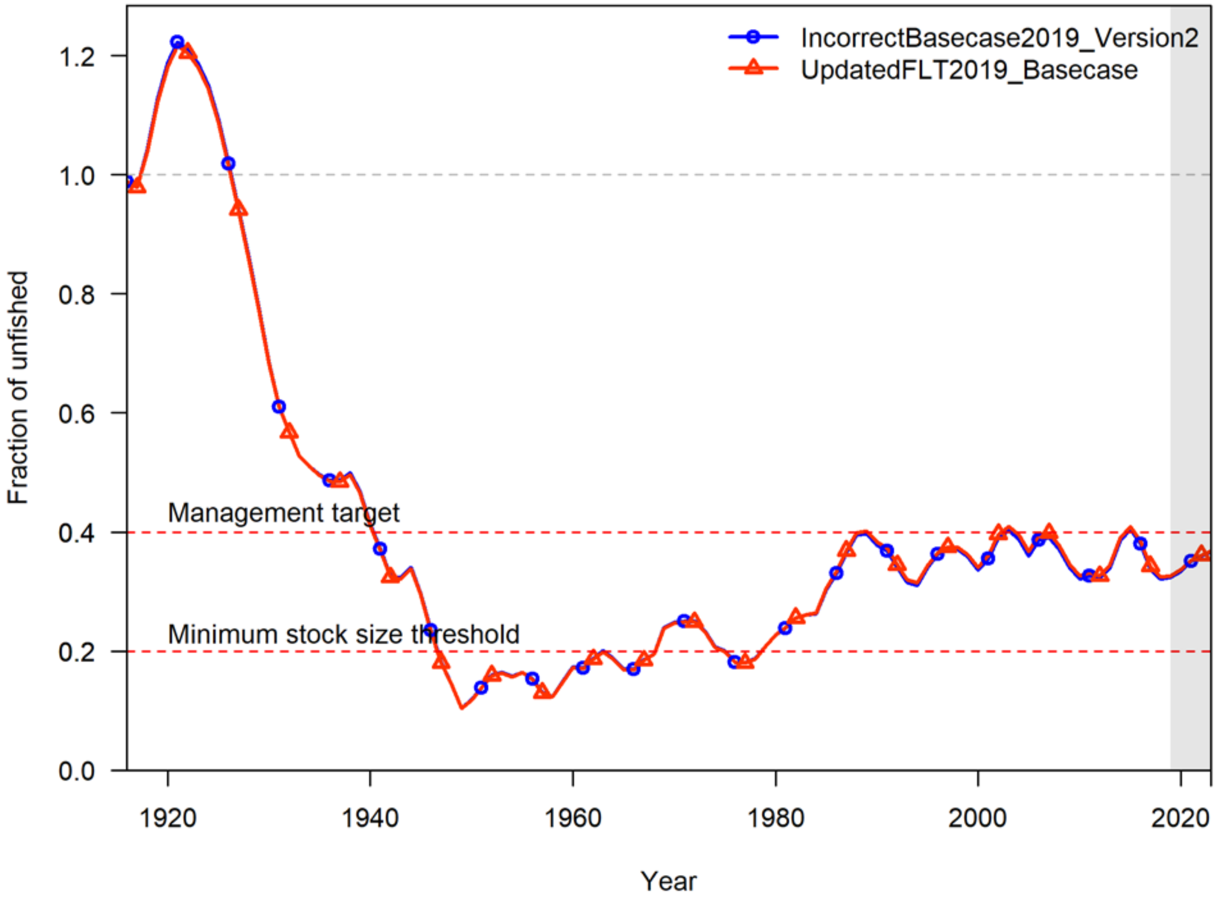

Figure 8.2. Comparison of the relative spawning biomass from the old base case (version 2) and the updated base case (version 3).

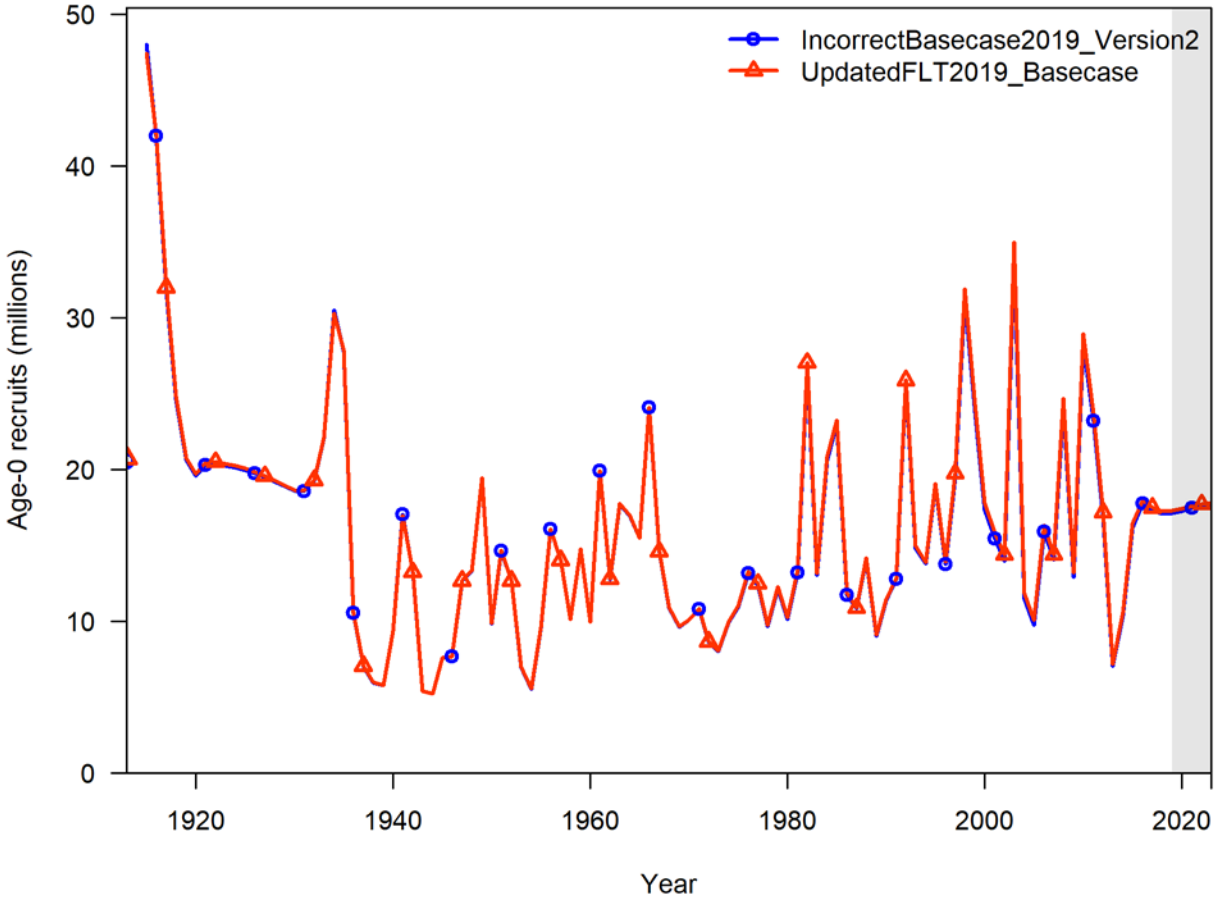

Figure 8.3. Comparison of the estimated recruitment time series from the old base case (version 2) and the updated base case (version 3).

The updated base case assessment estimates that current spawning stock biomass is 34% (33.67%) of unexploited stock biomass (SSB_0), compared to 33% (33.40%) calculated for the old base case, using the incorrect (lower) catch series from 2001-2018. While this appears to be a 1% change due to rounding when reporting this to the nearest whole percentage point, the actual change is only 0.27%.

The 2020 recommended biological catch (RBC) under the 20:35:40 harvest control rule for the updated base case is 2,334 t (Table 8.3) and the long term yield (assuming average recruitment in the future) is 2,986 t. Averaging the RBC over the three year period 2020-2022, the average RBC is 2,563 t and over the five year period 2020-2024, the average RBC is 2,648 t. The RBCs for each individual year from 2020-2024 are listed in Table 8.3 for the base case.

Table 8.3. Yearly projected RBCs (tonnes) across all fleets under the 20:35:40 harvest control rules for the updated base case (Day 2019b, Version 3 – 19 December 2019) assuming average recruitment from 2016.

RBCs Year	Base
2020	2,334
2021	2,648
2022	2,706
2023	2,755
2024	2,796

By comparison, the 2020 RBC is 2,254 t (Table 8.4), with long term yield of 2,959t, for the old base case, with incorrect (lower) catch series from 2001-2018. For the old base case, the average RBC over the three-year period 2020-2022 is 2,515 t and over the five-year period 2020-2024, the average RBC is 2,607 t. The RBCs for each individual year from 2020-2024 are listed in Table 8.4 for the old base case.

The RBC for the updated base case is 120 t larger in 2020, 32 t larger in 2021 and 31 t larger in 2022, compared to the values calculated for the old base case, using the incorrect (lower) catch series from 2001-2018 (Table 8.4).

Table 8.4. Yearly projected RBCs (tonnes) across all fleets under the 20:35:40 harvest control rules for the old base case, using the incorrect (lower) catch series from 2001-2018, (Day 2019a, Version 2 – 2 December 2019) assuming average recruitment from 2016.

RBCs Year	Base
2020	2,254
2021	2,616
2022	2,675
2023	2,724
2024	2,766

8.3 Acknowledgements

Geoff Tuck, Miriana Sporcic and Paul Burch (CSIRO) are thanked for helpful discussions on this work. Geoff Liggins is thanked for identifying inconsistencies in catch data which resulted in late corrections to the catch data and an updated base case.

8.4 References

Burch P, Althaus F and Thomson R 2019. Southern and Eastern Scalefish and Shark Fishery catches and discards for TAC purposes using data until 2018. Unpublished report to SERAG Meeting. 64 pp.

Day J 2019a. Tiger flathead (*Neoplatycephalus richardsoni*) stock assessment based on data up to 2018. Version 2 – 2 December 2019. Unpublished report to SERAG. 102 pp.

Day J 2019b. Tiger flathead (*Neoplatycephalus richardsoni*) stock assessment based on data up to 2018. Version 3 – 19 December 2019. Unpublished report to SERAG. 104 pp.

9. Draft Bight Redfish (*Centroberyx gerrardi*) stock assessment based on data to 2018-29: development of a preliminary base case

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9.1 Executive Summary

This document presents a suggested base case for an updated quantitative Tier 1 Bight Redfish (*Centroberyx gerradi*) assessment for presentation at the first GAB RAG meeting in 2019. The last full assessment was presented in Haddon (2015). The preliminary base case has been updated by the inclusion of data up to the end of financial year 2018-19, which entails an additional four years of catch, CPUE, length and/or age data and ageing error updates since the 2015 assessment and incorporation of survey results from the 2017-18 GAB Fishery Independent Survey (FIS). This document describes the process used to develop a preliminary base case for Bight Redfish through the sequential updating of recent data used by the stock assessment, using the stock assessment package Stock Synthesis (SS-V3.30.14).

Changes to the last stock assessment include: incorporation of conditional age-at-length data for 2005 from the GAB FIS; improvement to the method of estimating the bias ramp and using an updated tuning method.

Results show poor fits to the CPUE and FIS abundance series, but reasonable fits to length and conditional age-at-length data. This assessment estimates that the projected 2020-21 spawning stock biomass will be 70% of virgin stock biomass (projected assuming 2018-19 catches in 2019-2020), compared to 62% at the start of 2016-17 from the 2015 assessment (Haddon 2015) and 90% at the start of 2012-13 from the 2011 assessment (Klaer 2011). This change in stock status is mostly due to revisions to the estimates of recent large recruitment events towards the end of the time series, particularly in 1995, 1996 and 1999.

9.2 Introduction

9.2.1 *Bridging from 2014-15 to 2018-19 assessment*

The previous full quantitative assessment for Bight Redfish was conducted in 2015 (Haddon, 2015) using Stock Synthesis (version SS-V3.24U; Methot and Wetzel 2013, Methot 2015). The 2019 assessment uses the current version of Stock Synthesis (version SS-V3.30.14.05; Methot 2019), which includes some changes from SS_V3.24U.

As a first step in the process of bridging to a new model, the model was translated from version SS-V3.24U (Methot 2015) to version SS-V3.30.14.05 (Methot et. al. 2019) using the same data and model structure used in the 2015 assessment. Once this translation was complete, improved features unavailable in SS-V3.24U were incorporated into the SS-V3.30 assessment. These included allowing smaller lower bounds on minimum sample sizes and estimating a parameter that tunes the standard deviation to abundance indices. Following this step, the model was re-tuned using the most recent tuning protocols, thus allowing the examination of changes to both assessment practices and the tuning procedure on the previous model structure. These changes to software and tuning practices are likely to lead to changes to key model outputs, such as the estimates of depletion and the trajectory of spawning biomass. This initial bridging phase (Bridge 1) highlights changes that have occurred since 2015 simply through changes to software and assessment practices. The subsequent bridging exercise (Bridge 2) then sequentially updates the model with new data through to 2018.

The second part of the bridging analysis includes updating historical data (up to 2014-15), followed by including the data from financial years 2015-16 to 2018-19 into the model. These additional data included new catch, CPUE, FIS abundance indices, length composition data, conditional age-at-length data and an updated ageing error matrix. Additional FIS data were also included: 2017 GAB-FIS abundance index and 2017 GAB-FIS length frequencies. The last year of recruitment estimation was changed to 2003 (from 2005 in the 2015 assessment).

The use of updated software and the inclusion of additional data resulted in some differences in the fits to CPUE, conditional age-at-length data and length composition data. The usual process of bridging to a new model by adding new data piecewise and analysing which components of the data could be attributed to changes in the assessment outcome was conducted with the details outlined below.

9.2.2 *Update to Stock Synthesis SSV-3.30 and updated catch history (Bridge 1)*

The 2015 Bight Redfish assessment (BightRedfishV2015_3.24U) was initially converted to the most recent version of the software, Stock Synthesis version SS-V3.30.14.05 (BightRedfish2015_3.30.14). There are no discernible differences in the estimated annual spawning biomass between the two Stock Synthesis version updates (i.e., 3.24U and 3.30.14; Figure 9.1).

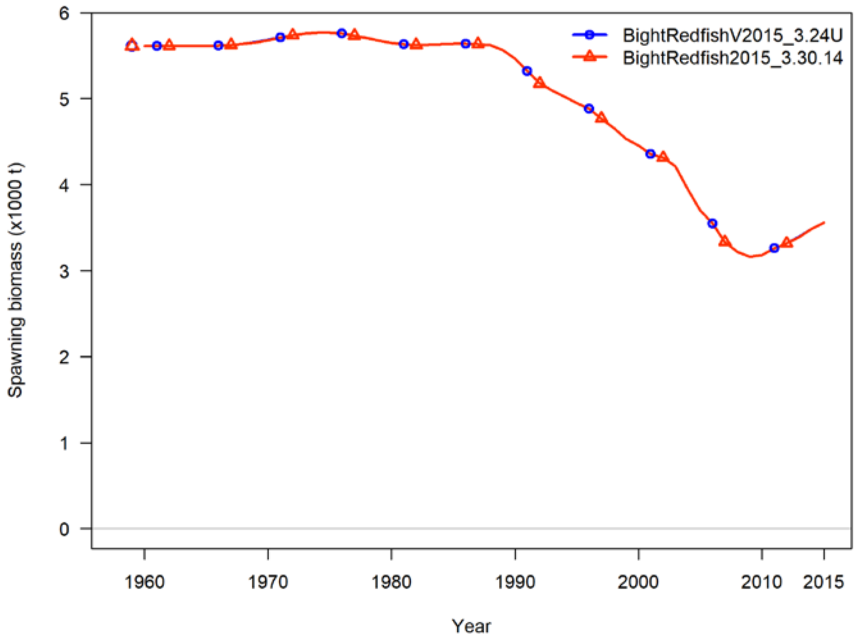

Figure 9.1. Comparison of the time-series of absolute spawning biomass from the 2015 assessment (BightRedfishV2015_3.24U – dark blue) and a model converted to SS-V3.30 (BightRedfish2015_3.30.14 – red).

New features available in the new version of Stock Synthesis, such as allowing smaller lower bounds on minimum sample sizes and estimating additional standard deviation to abundance indices were then incorporated (BightRedfish2015_3.30New), followed by retuning using the latest tuning protocol (BightRedfish_3.30Tuned). Details of the tuning procedure used are listed in Section 1.2.1. Revisions to the historical catches, which involved only updating the estimated 2014-15 catch with the actual 2014-15 catch, were then added to this tuned version of the 2015 model (BightRedfish2015_3.30ReviseCatch). This process demonstrates the outcomes that could theoretically have been achieved with the last assessment if we had the latest software, tuning protocols and corrected data available in 2015. This initial bridging step, Bridge 1, does not incorporate any data after 2014-15 or any structural changes to the assessment.

There was an overall increase in spawning biomass time series accounting for new features, tuning and revised catch (i.e., 2014-15 landed catch updated) (Figure 9.2, Figure 9.3).

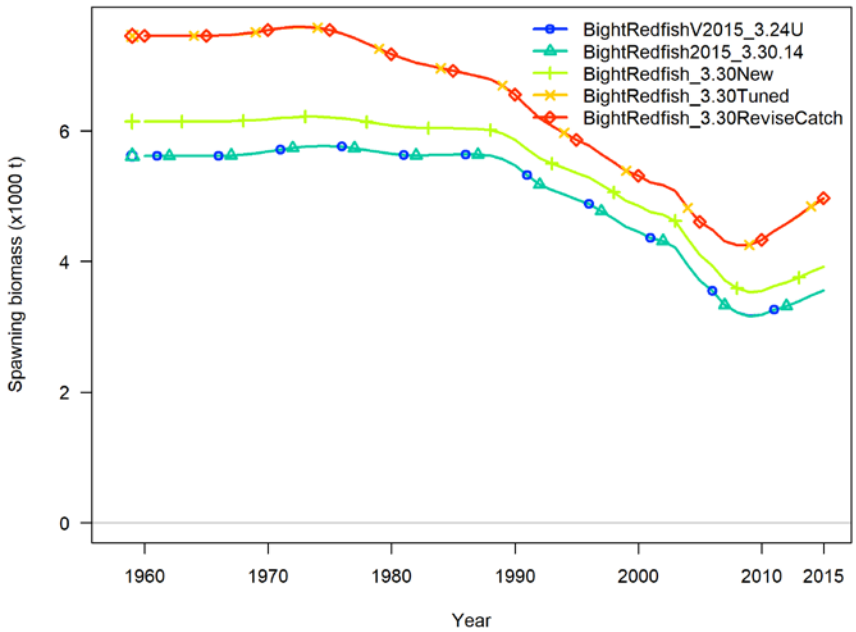

Figure 9.2. Comparison of the time-series of absolute spawning biomass from the 2015 assessment (BightRedfishV2015_3.30.14 – dark blue), a model converted to SS-V3.30 (BightRedfish2015_3.30.14 – light blue), incorporating new features (BightRedfish2015_3.30New – green), retuning the model using the latest tuning protocols (BightRedfish2015_3.30Tuned – yellow) and revising the historical catch to 2015 and the projected catch in 2016 (BightRedfish2015_3.30ReviseCatch – red).

The results of Bridge 1 suggest that the stock was marginally less depleted in 2015 than the previous assessment indicated (63% of SSB_0). These changes are small enough to be within the confidence bounds of the 2016 assessment results and the fits are generally improved through these revisions (Figure 9.3). Fits to the abundance indices (Figure 9.4 and Figure 9.5) show minor changes through this process. The estimated recruitment series shows little change in broad trends during Bridge 1 (Figure 9.6), although there are several minor changes resulting from the new tuning procedures. In particular, the new tuning procedures allow for greater variation in recruitment and higher base level recruitment (R_0) and increases to the peak recruitment events towards the end of the time series (1995, 1996 and 1999).

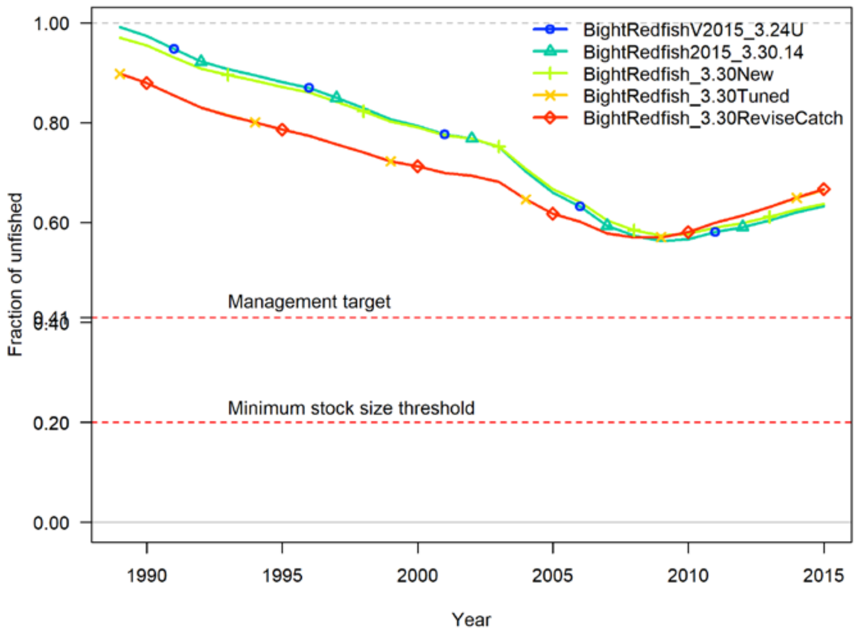

Figure 9.3. Comparison of the time-series of relative spawning biomass from the 2015 assessment (BightRedfishV2015_3.24U – dark blue), a model converted to SS-V3.30 (BightRedfish2015_3.30.14 – light blue), incorporating new features (BightRedfish2015_3.30New – green), retuning the model using the latest tuning protocols (BightRedfish2015_3.30Tuned – yellow) and revising the historical catch to 2015 and the projected catch in 2016 (BightRedfish2015_3.30ReviseCatch – red).

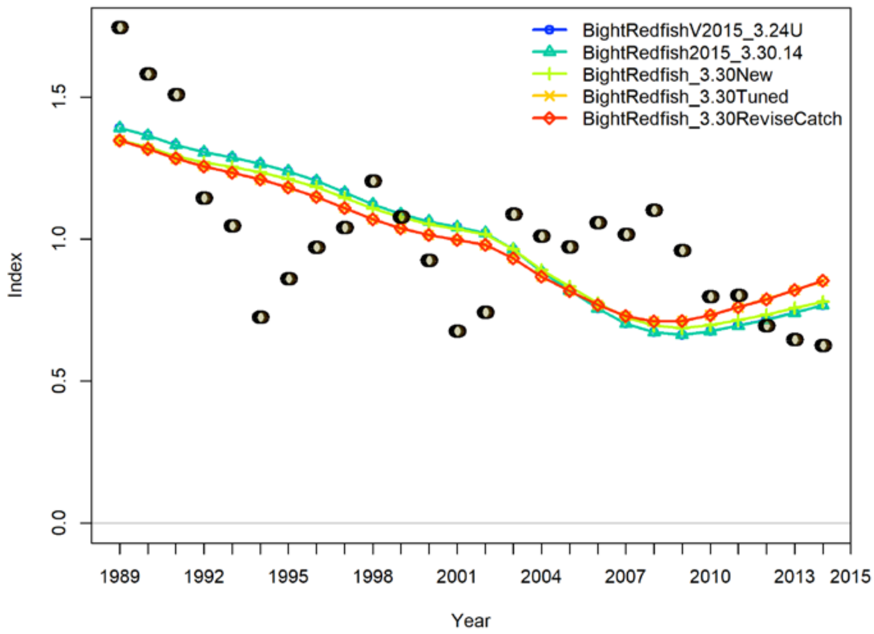

Figure 9.4. Comparison of the fit to the trawl CPUE index for the 2015 assessment (BightRedfishV2015_3.24U – dark blue), a model converted to SS-V3.30 (BightRedfish2015_3.30.14 – light blue), incorporating new features (BightRedfish2015_3.30New – green), retuning the model using the latest tuning protocols (BightRedfish2015_3.30Tuned – yellow) and revising the historical catch to 2014-15 (BightRedfish2015_3.30ReviseCatch – red).

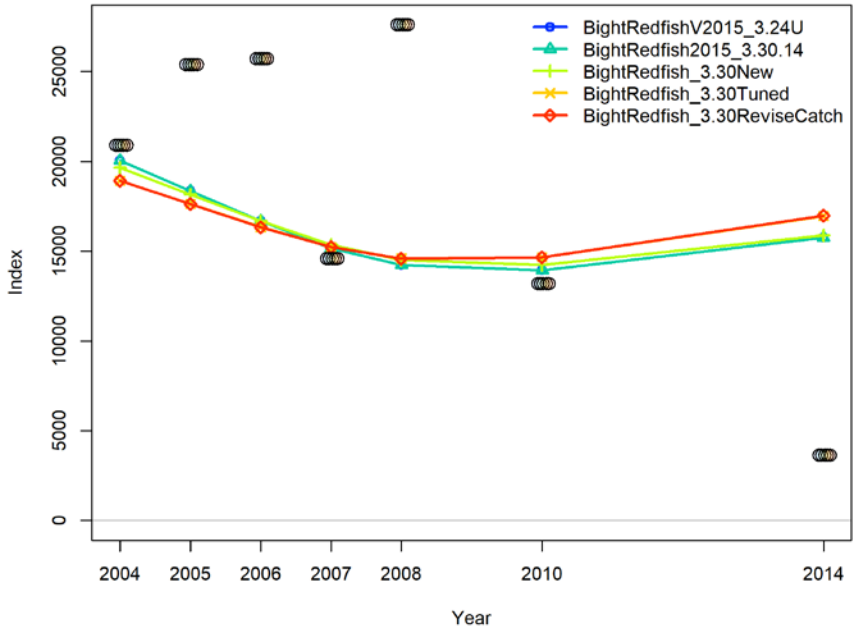

Figure 9.5. Comparison of the fit to the GAB-FIS abundance index for the 2015 assessment (BightRedfishV2015_3.24U – dark blue), a model converted to SS-V3.30 (BightRedfish2015_3.30.14 – light blue), incorporating new features (BightRedfish2015_3.30New – green), retuning the model using the latest tuning protocols (BightRedfish2015_3.30Tuned – yellow) and revising the historical catch to 2014-15 (BightRedfish2015_3.30ReviseCatch – red).

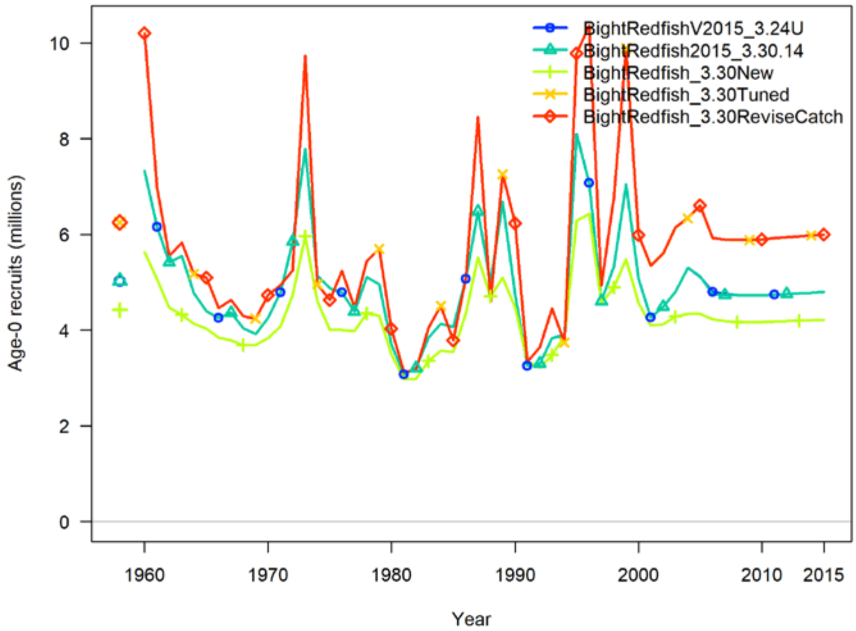

Figure 9.6. Comparison of the time series of recruitment from the 2015 assessment (BightRedfishV2015_3.24U – dark blue), a model converted to SS-V3.30 (BightRedfish2015_3.30.14 – light blue), incorporating new features (Flathead2015_3.30New – green), retuning the model using the latest tuning protocols (Flathead2015_3.30Tuned – yellow) and revising the historical catch to 2015 and the projected catch in 2016 (Flathead2015_3.30ReviseCatch – red).

9.2.2.1 Tuning method

Iterative rescaling (reweighting) of input and output CVs or input and effective sample sizes is a repeatable method for ensuring that the expected variation of the different data streams is comparable to what is input (Pacific Fishery Management Council, 2018). Most of the indices (CPUE, surveys and composition data) used in fisheries under-estimate their true variance by only reporting measurement or estimation error and not including process error.

In iterative reweighting, the effective annual sample sizes are tuned/adjusted so that the input sample size is equal to the effective sample size calculated by the model. In SS-V3.30 it is possible to estimate an additional standard deviation parameter to add to the input CVs for the abundance indices (CPUE).

1. Set the standard error for the log of relative abundance indices (CPUE or FIS) to the standard deviation of a loess curve fitted to the original data - which will provide a more realistic estimate to that obtained from the original statistical analysis. SSV-3.30 then allows an estimate to be made for an additional adjustment to the relative abundance variances appropriately.

An automated iterative tuning procedure was used for the remaining adjustments. For the recruitment bias adjustment ramps:

2. Adjust the maximum bias adjustment and the start and finish bias adjustment ramps as predicted by SSV3.30 at each step.

For the age and length composition data:

3. Multiply the stage-1 (initial) sample sizes for the conditional age-at-length data by the sample size multipliers using the approach of Punt (2017).
4. Similarly multiply the initial samples sizes by the sample size multipliers for the length composition data using the ‘Francis method’ (Francis, 2011).
5. Repeat steps 2 - 4, until all are converged and stable (with proposed changes < 1 – 2%).

This procedure constitutes current best practice for tuning assessments.

9.2.3 *Inclusion of new data: 2015-26 to 2018-19 (Bridge 2)*

Starting from the translated, retuned 2016 base case model with updated data to 2014-15 (previously referred to as “BightRedfish_3.30ReviseCatch” but simplified to “BightRedfish2015_3.30Updated” from here on), additional data from 2015-16 to 2018-19 were added sequentially to build a preliminary base case for the 2019 assessment:

1. Change final assessment year to 2018 and add catch to 2018 (BightRedfish2019_addCatch2018).
2. Add GAB-FIS abundance index for 2017 (Knuckey et al. 2018) (BightRedfish2019_addFIS2017) and CPUE to 2018 (from Sporcic 2019a; 2019b) (BightRedfish2019_addCPUE2018).
3. Add updated length frequency data to 2018 (BightRedfish2019_addLength2018).
4. Add updated age error matrix and conditional age-at-length data to 2018 and GAB-FIS conditional age-at-length data from 2008 (BightRedfish2019_addAge2018FIS).
5. Change the final year for which recruitments are estimated from 2005 to 2003 (BightRedfish2019_Rec2003).

6. Retune using current tuning protocols, including Francis weighting on length-compositions and conditional age-at-length data (BightRedfish2019_Tuned).

Inclusion of the new data resulted in a series of changes to estimated recruitment and the time-series of relative spawning biomass (Figure 9.7 and Figure 9.8). Changes to stock status are largest between 2005 to 2015. Adding each data source reduces the stock status slightly in this period, with a small increase at the final step (re-tuning the model).

Peaks in estimated recruitment are generally revised downwards between 1980 and 2000, as more data is added (Figure 9.9). By contrast, as more data is added, there is an increase to the 2003 estimated recruitment, with a slight decrease at the final step (re-tuning the model). Note that the last year of estimated recruitment is changed from 2005 to 2003 at the step when length is added, as it became apparent that too many recruitment years were estimated in earlier models.

Fits to both CPUE and GAB-FIS indices are largely unchanged with the addition of new data (Figure 9.9, Figure 9.10). In both series, estimated fits are poor. This is due to the biology and life span of this species, make it difficult to follow the short-term variability evident in the abundance series. This suggests that CPUE may be showing short term changes that do not just reflect changes in population abundance.

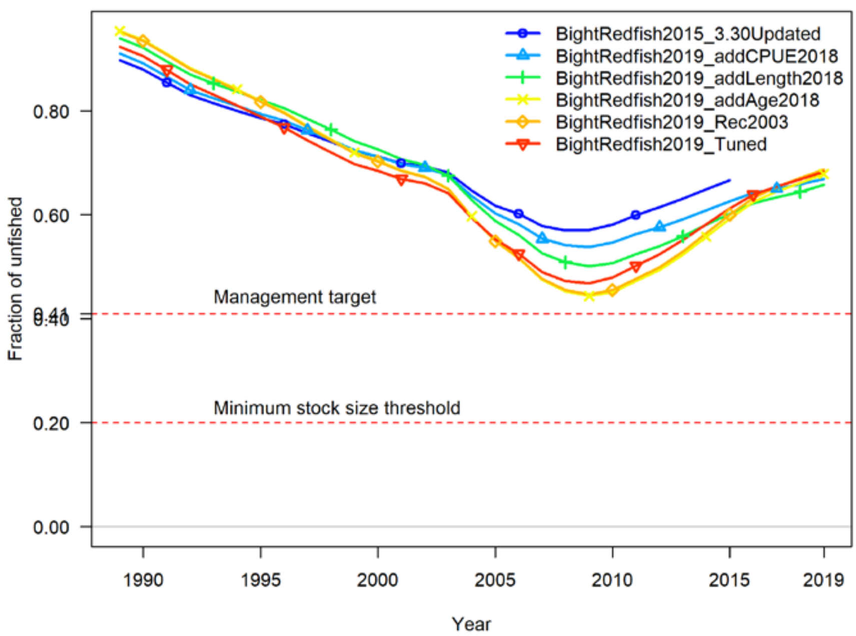

Figure 9.7. Comparison of the time series of relative spawning biomass for the updated 2015 assessment model converted to SS-V3.30.14 (BightRedfish2015_3.30Updated - blue) with various bridging models leading to a proposed 2019 base case model (BightRedfish2019_Tuned - red).

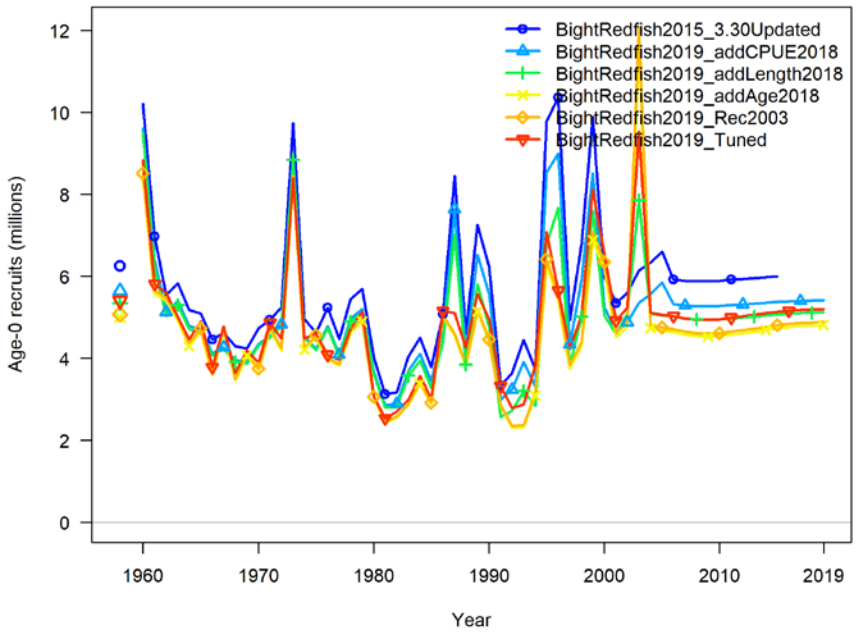

Figure 9.8. Comparison of the time series of recruitment from the updated 2015 assessment model converted to SS-V3.30.14 (BightRedfish2015_3.30Updated – dark blue) with various bridging models leading to a proposed 2019 base case model (BightRedfish2019_Tuned – red).

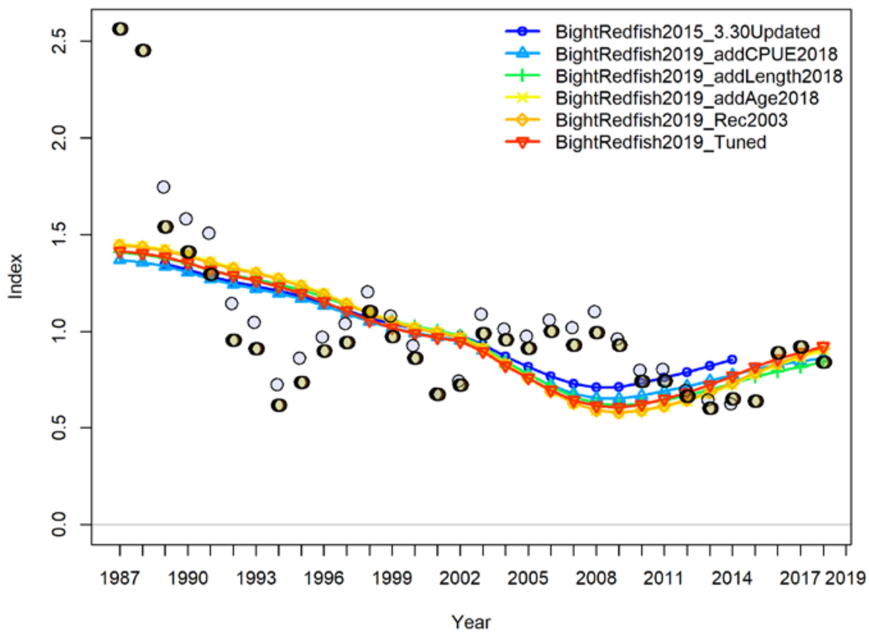

Figure 9.9. Comparison of the fit to the trawl CPUE index for the updated 2015 assessment model converted to SS-V3.30.14 (BightRedfish2015_3.30Updated – dark blue) with various bridging models leading to a proposed 2019 base case model (BightRedfish2019_Tuned – red).

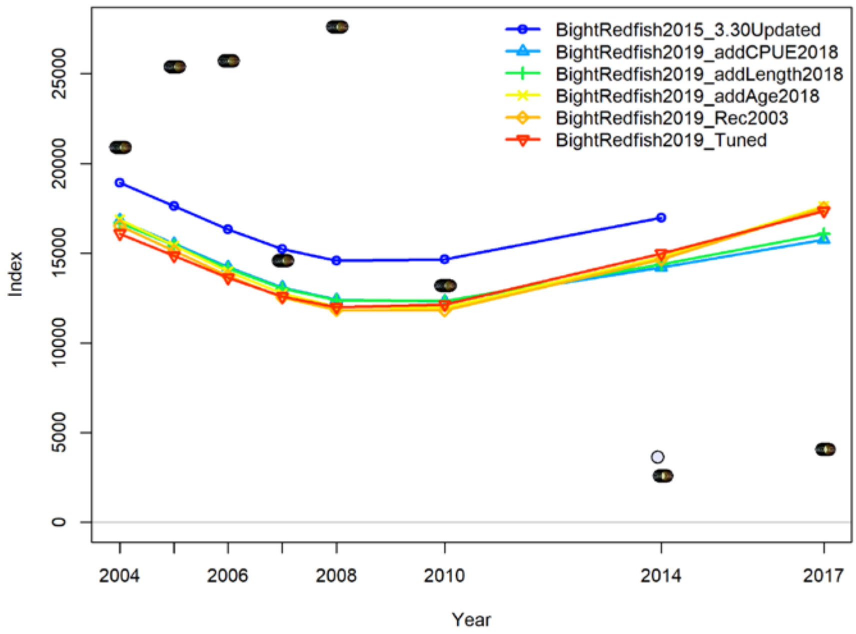

Figure 9.10. Comparison of the fit to the FIS abundance index for the updated 2015 assessment model converted to SS-V3.30.14 (BightRedfish2015_3.30Updated – dark blue) with various bridging models leading to a proposed 2019 base case model (BightRedfish2015_Tuned – red).

9.3 Assessment outcomes of the 2019 base case model

9.3.1 *Results*

Results show poor fits to the CPUE and GAB-FIS abundance series, but reasonable fits to length and conditional age-at-length data (Appendix A). Selected fixed and/or estimated parameters are tabulated in Table 9.1 and landed catch and standardized CPUE tabulated in Table 9.2.

This assessment estimates that the projected 2020-21 spawning stock biomass will be 70% of virgin stock biomass (projected assuming 2018-19 catches in 2019-2020), compared to 62% at the start of 2016-17 from the 2015 assessment (Haddon 2015) and 90% at the start of 2012-13 from the 2011 assessment (Klaer 2011). This change in stock status is mostly due to revisions to the estimates of recent large recruitment events towards the end of the time series, particularly in 1995, 1996 and 1999.

Table 9.1. Bight Redfish: Summary of selected parameters from the 2019 base case model. Years represent the first year of each financial year e.g., 2015 refers to 2015-16.

Description	Parameter	Combined Male/Female	Comment(s)
Years	y	1988-2018	
Recruitment Deviates	r	estimated 1980 - 2003	
Fleets		1 Trawl only	
Discards		none significant, not Fitted	
Age classes	a	0 – 64 years	
Sex ratio	p_s	0.5 (1:1)	
Natural mortality	M	estimated (0.1017) per year	
Steepness	h	0.75	
Recruitment variation	σ_r	0.7	
Female maturity		25 cm (TL)	
Growth	L_{max}	37.939 cm (TL)	fixed
	K	0.110936	fitted
	L_{min}	16.7648	fitted
	CV	0.131095	fitted
		Female	Male
Length-weight (based	f_1	0.0001 cm (TL)/gm	0.002
on standard length)	f_2	2.559	2.552

Table 9.2. Bight Redfish: Financial year values of catch and estimated standardized CPUE (Trawl) from 1988-89 to 2018-19. Catch is taken from logbook estimates until 2005-06. Subsequently, CDR catches are used to 2014-15 (Haddon, 2015) and catches from 2015-16 to 2018-19 from CDR landings database. Discards are assumed to be trivial. Standardized CPUE is from Sporcic (2019).

Season	Catch (t)	CPUE
1987-88		2.5623
1988-89	85.65	2.4517
1989-90	170.83	1.5382
1990-91	281.81	1.4084
1991-92	265.61	1.2932
1992-93	120.70	0.9523
1993-94	107.47	0.9084
1994-95	157.80	0.6177
1995-96	173.92	0.7349
1996-97	327.18	0.8966
1997-98	372.62	0.9406
1998-99	437.79	1.1019
1999-00	323.64	0.9718
2000-01	387.88	0.8591
2001-02	262.61	0.673
2002-03	424.67	0.7201
2003-04	946.48	0.9862
2004-05	937.46	0.954
2005-06	789.70	0.9101
2006-07	1023.91	0.9977
2007-08	808.02	0.9275
2008-09	681.89	0.9927
2009-10	469.70	0.9282
2010-11	297.60	0.7396
2011-12	341.48	0.742
2012-13	273.45	0.6629
2013-14	207.05	0.5994
2014-15	196.56	0.6496
2015-16	176.95	0.6367
2016-17	317.09	0.8866
2017-18	288.49	0.918
2018-19	214.50	0.8385

9.3.2 *Likelihood profiles*

As stated by Punt (2018), likelihood profiles are a standard component of the toolbox of applied statisticians. They are most often used to obtain a 95% confidence interval for a parameter of interest. Many stock assessments “fix” key parameters such as M and steepness based on *a priori* considerations. Likelihood profiles can be used to evaluate whether there is evidence in the data to support fixing a parameter at a chosen value. If the parameter is within the entire range of the 95% confidence interval, this provides no support in the data to change the fixed value. If the fixed value is outside the 95% confidence interval, it would be reasonable for a review panel to ask why the parameter was fixed and not estimated, and if the value is to be fixed, on what basis and why should what amounts to inconsistency with the data be ignored. Integrated stock assessments include multiple data sources (e.g., commonly catch-rates, length-compositions, and age-compositions) that may be in conflict, due for example to inconsistencies in sampling, but more commonly owing to incorrect assumptions (e.g., assuming that catch-rates are linearly related to abundance), i.e. model-misspecification. Likelihood profiles can be used as a diagnostic to identify these data conflicts (Punt, 2018).

Standard parameters to consider are natural mortality (M), steepness (h) and the logarithm of the unfished recruitment ($\ln R_0$).

9.3.2.1 Natural mortality (M)

For Bight Redfish, the likelihood profile for natural mortality, M, is shown in Figure 9.11 with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. This parameter is estimated in the model (M=0.1017 y^{-1}) and the likelihood profile suggests that it is well estimated. The index (suggest higher mortality) and length data (suggest lower mortality) show some conflict. The age data are most influential on the total likelihood, with similar minimum values. The confidence intervals on M are narrow ranging between approximately 0.093 and 0.11.

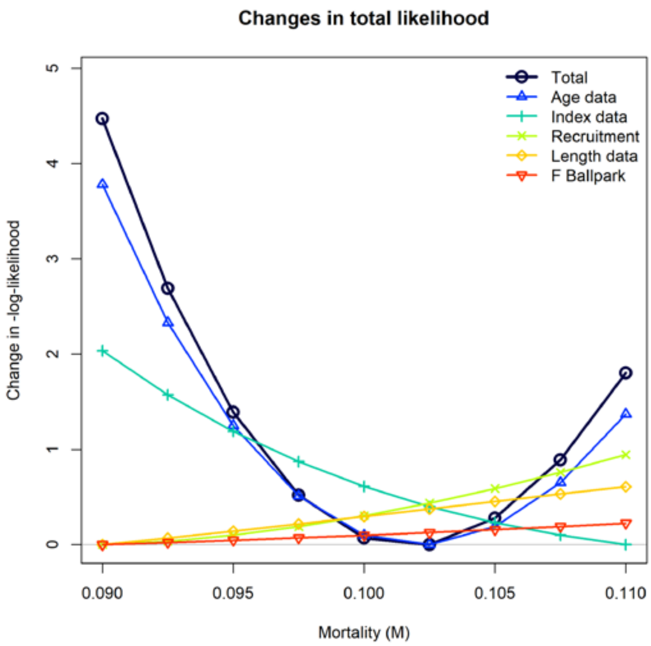

Figure 9.11. Bight Redfish: The likelihood profile for natural mortality (M), ranging from 0.09 to 0.11. The estimated value for M is 0.1017 yr^{-1}.

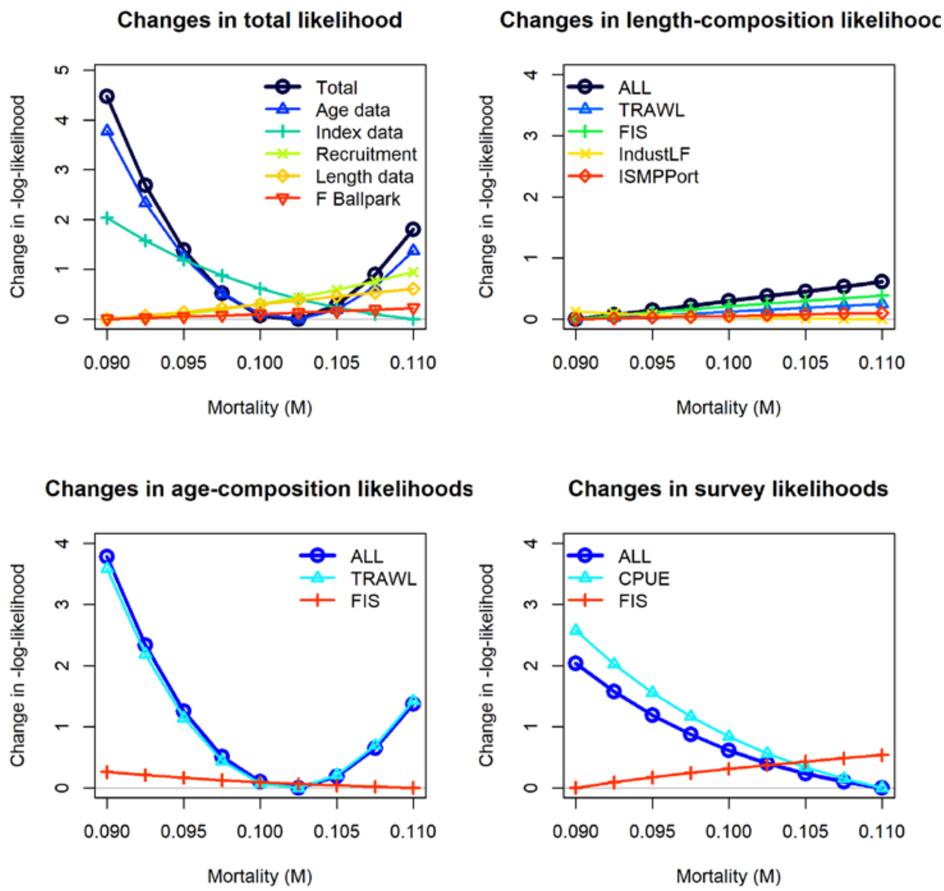

Figure 9.12. Bight Redfish: The likelihood profile for natural mortality (*M*), ranging from 0.09 to 0.11. The estimated value for *M* is 0.1017 yr^{-1}. Bight Redfish: Piner plot for the likelihood profile for natural mortality (*M*), showing components of the change in likelihood for length, age and indices (CPUE; GAB-FIS) in addition to the changes in the total likelihood.

9.3.2.2 Steepness (h)

A likelihood profile on steepness, *h*, shows the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours (Figure 9.13). This figure shows that steepness is not well defined as the 95% confidence limits are not crossed (log-likelihood of 1.92 on the y-axis) by the total likelihood within the range considered (*h* = 0.6 to 0.8). This is not surprising given the stock in the base case model has not been depleted to levels that would define steepness. It is therefore reasonable to fix steepness at 0.75.

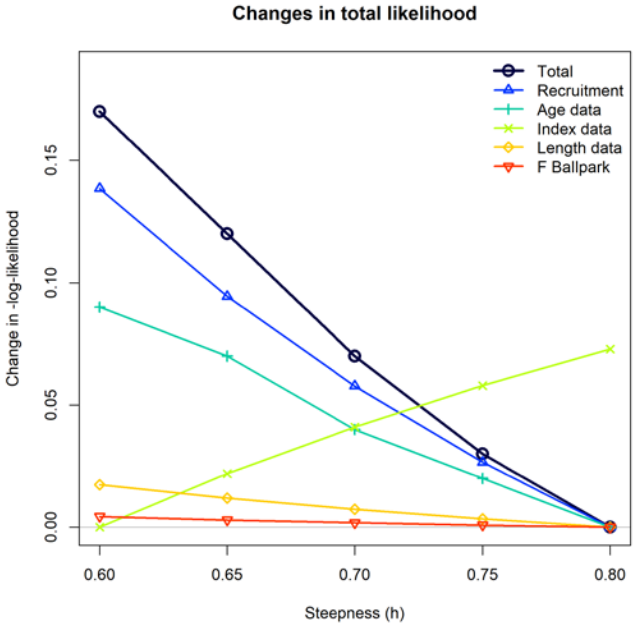

Figure 9.13. Bight Redfish: The likelihood profile for steepness (*h*), ranging from 0.6 to 0.8. The fixed value for *h* is 0.75.

9.3.2.3 Virgin spawning biomass (SSB_0)

A likelihood profile for virgin spawning biomass (SSB_0) is shown in Figure 9.14 and Figure 9.15 with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. SSB_0 is a derived parameter which is linked to the estimated parameters R_0, which is the average equilibrium recruitment and constructing this likelihood profile. To construct a likelihood profile on SSB_0 requires setting up an additional "fleet" with a single data point (in 1960) with very low standard error, essentially adding a "highly precise survey" of spawning biomass, setting the selectivity type to 30 (an index of *SSB*) and then allowing this spawning biomass value to vary between runs. This likelihood profile suggests a broad range of plausible values for SSB_0 ranging between around 6000 and 9500 t with the most likely value at around 7300 t. The important data sources in providing information on SSB_0 are the index data and age data (Trawl). SSB_0 needs to be sufficiently high to enable the historical catches to be sustained, so this results in the recruitment component of the likelihood providing a lower bound on SSB_0 and the fits to the age data deteriorate with larger values of SSB_0. A likelihood profile for depletion would be a useful addition to this analysis.

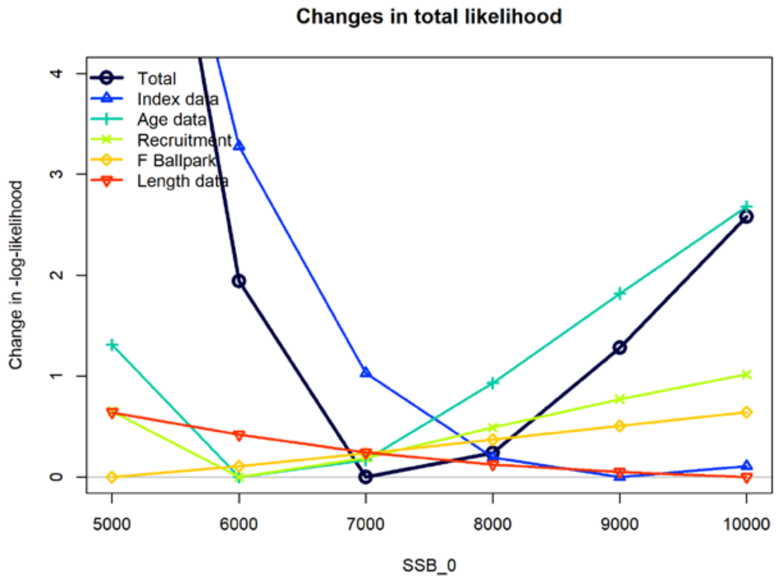

Figure 9.14. Bight Redfish: The likelihood profile for virgin spawning biomass, with *SSB₀* ranging from 2000 to 800 t. The estimated value for SSB_0 is 7295 t.

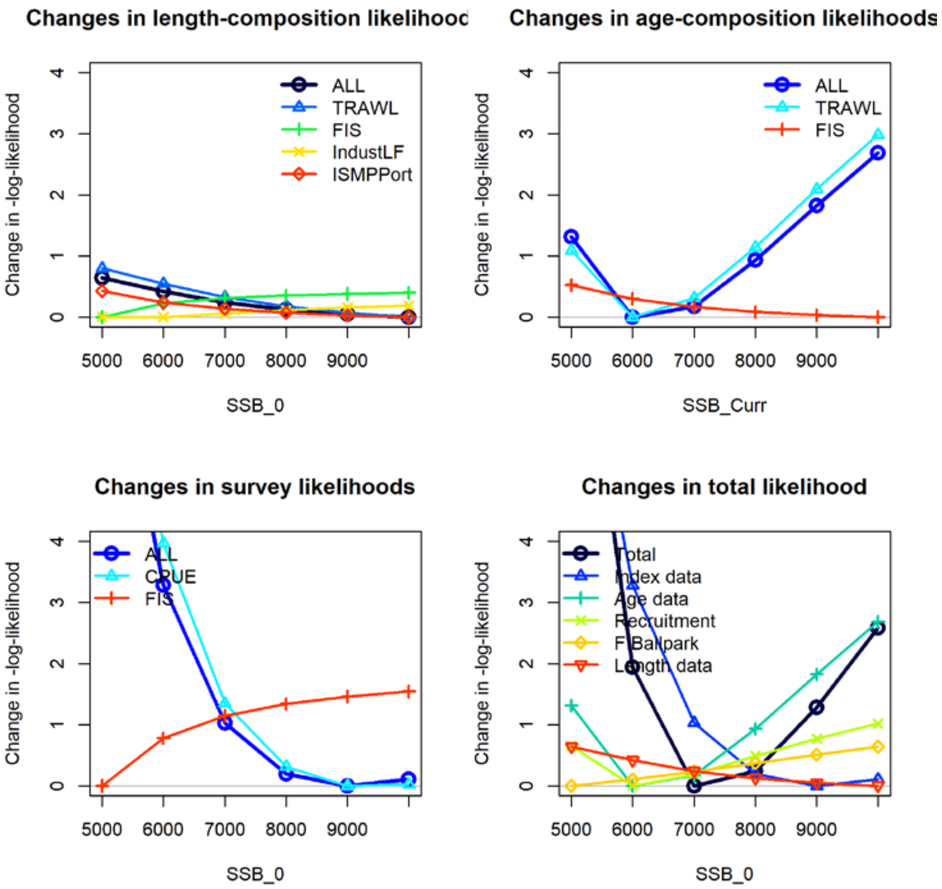

Figure 9.15. Bight Redfish: Piner plot for the likelihood profile for 2018 spawning biomass (SSB_Curr), showing components of the change in likelihood for length, age and indices (CPUE, GAB-FIS) in addition to the changes in the total likelihood.

9.3.2.4 Current (2018) spawning biomass (SSB_{2018})

A likelihood profile for current (2018) spawning biomass (SSB_{2018}), using the same techniques as for SSB_0, is shown in Figure 9.16 and Figure 9.17 with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours.

This likelihood profile suggests a broad range of plausible values for SSB_{2018} ranging between around 3500 and 7500 t with the most likely value at around 4900 t. The important data sources in providing information on SSB_{2018} are the index data and estimated recruitments. SSB_{2018} needs to be sufficiently high to enable the historical catches to be sustained, so this results in the recruitment component of the likelihood providing a higher bound on SSB_{2018} and the fits to the index data deteriorate with smaller values of SSB_{2018}. A likelihood profile for depletion would be a useful addition to this analysis.

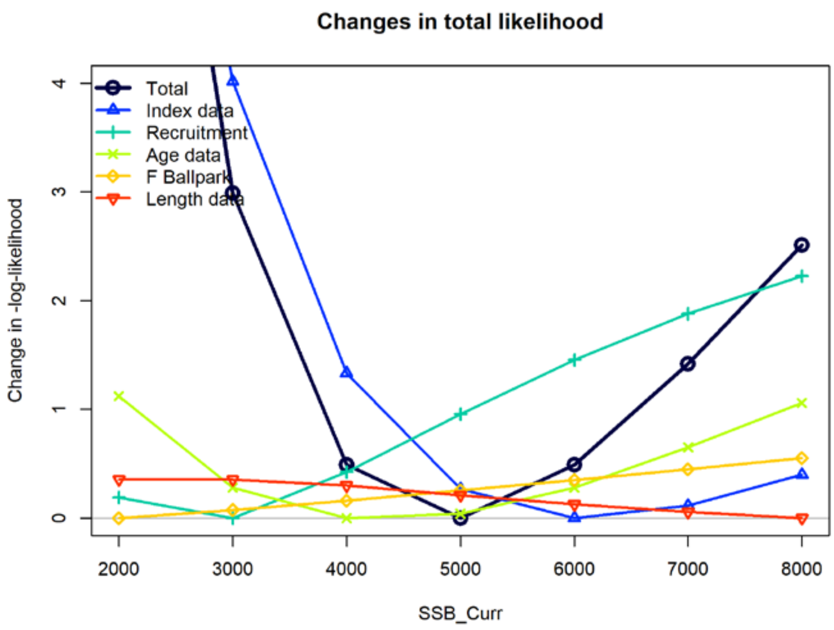

Figure 9.16. Bight Redfish: The likelihood profile for current (2018) spawning biomass, with SSB_{2018} ranging from 2000 to 800 t. The estimated value for SSB_{2018} is 4879 t.

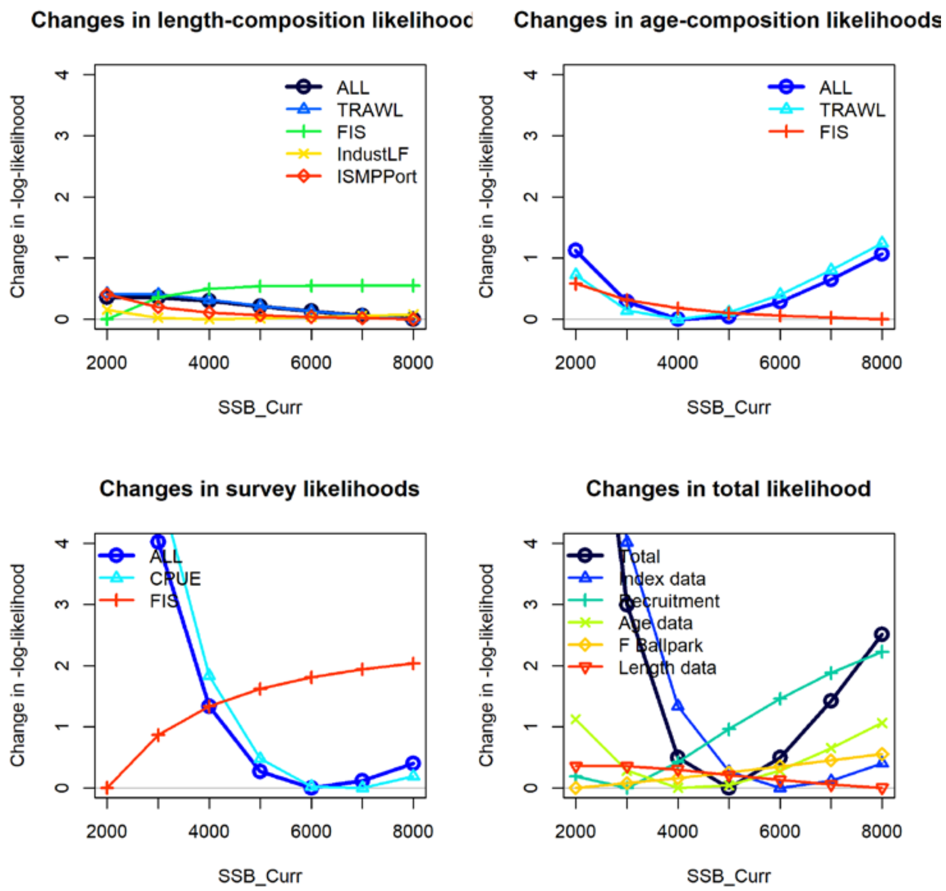

Figure 9.17. Bight Redfish: Piner plot for the likelihood profile for current (2018) spawning biomass (SSB_Curr), showing components of the change in likelihood for length, age and indices (CPUE, GAB-FIS) in addition to the changes in the total likelihood.

9.3.3 *Retrospectives*

A retrospective analysis was completed, starting from the most recent year of data, working backward in time and removing five successive years of data from the assessment. This analysis can highlight potential problems and instability in an assessment, or some features that appear from the data.

A retrospective analysis for absolute spawning biomass is shown in Figure 9.18, with the base case model in dark blue, and then successive years data removed back to 2013 (shown in red). The same analysis is plotted in terms of relative spawning biomass in Figure 9.19. In both cases the changes are minor with the largest change with the last retrospective in the series, which deletes all data from 2014 onwards (Retrospective_2013, red). This retrospective shifts the whole absolute spawning biomass series upwards. The relative series is mostly unchanged until 2005 (Figure 9.19). The most recent data results in lower estimates of relative biomass from 2005 onwards, with the largest change occurring with the addition of the 2014 data. This pattern in biomass spawning change is explained by the changes in recruitment in the 2013 retrospective analysis, with recruitment generally being revised downwards with the addition of the 2014 data (red to orange; Figure 9.20) from about the late 1980s onwards. The large spikes in recruitment at the end of the last two retrospective analyses (light and dark blue) may be revised when extra years of data are included in a future assessment.

These retrospective analyses do not reveal any pathological patterns or apparent biases in the estimates at the end of the time series due to the addition of new data, which provides additional confidence in the stability of this assessment.

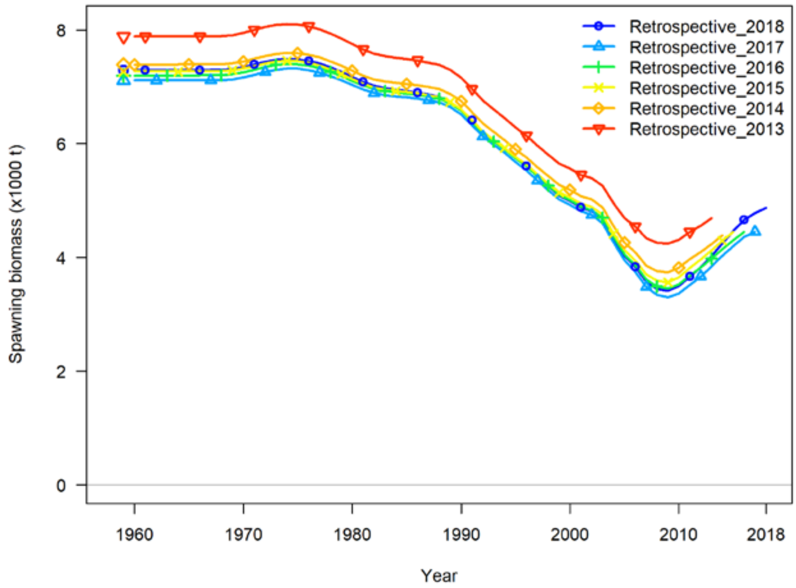

Figure 9.18. Bight Redfish: Retrospectives for absolute spawning biomass, with the most recent base case assessment shown (blue) and then successive years removed back to 2013 (red).

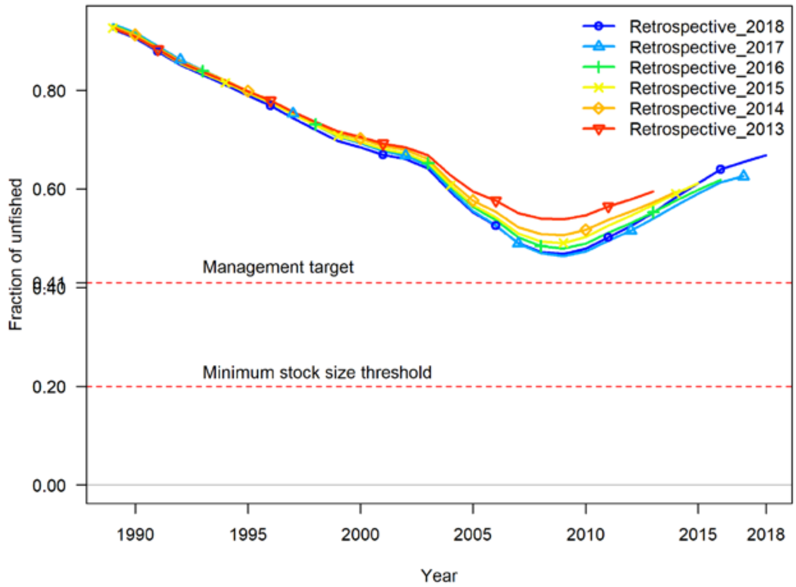

Figure 9.19. Bight Redfish: Retrospectives for relative spawning biomass, with the most recent base case assessment shown (blue) and then successive years removed back to 2013 (red).

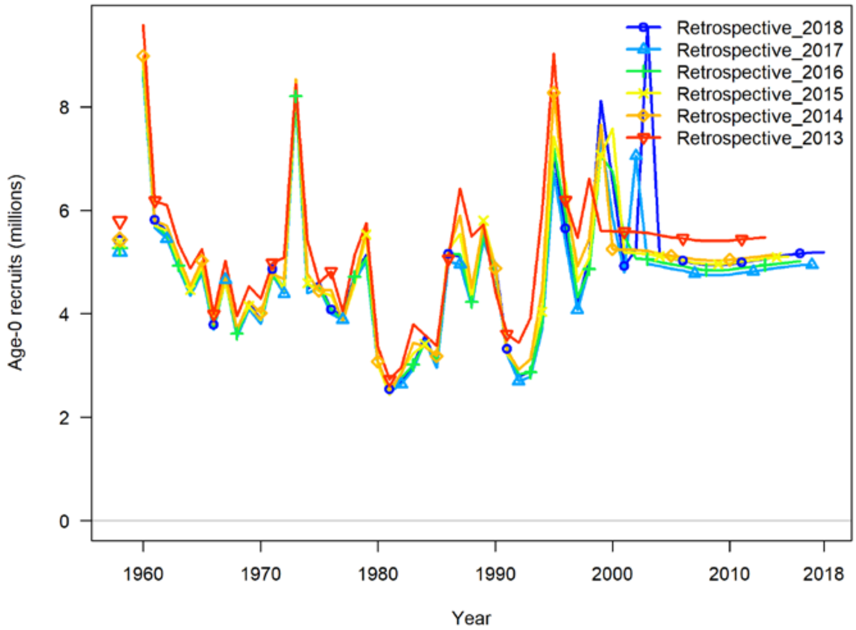

Figure 9.20. Bight Redfish: Retrospectives for recruitment, with the most recent base case assessment shown (blue) and then successive years removed back to 2013 (red).

9.3.4 *Future sensitivities*

Sensitivities to this potential base case have not yet been explored. In addition to the usual set of sensitivities (Haddon, 2015), (which includes sensitivities on mortality, maturity, fixing steepness and estimating mortality, σ_R and halving and doubling the weighting on length, age and CPUE data), there is an additional sensitivity that may be useful to explore:

1. Incorporating CPUE abundance indices to end FY 2019.

Given the relatively small changes to the input data and the quantity of other data used in the assessment, it is unlikely that this additional sensitivity will produce results that are noticeably different to the preliminary base case.

9.4 Acknowledgements

Age data was provided by Kyne Krusic-Golub (Fish Ageing Services), Integrated Scientific Monitoring Program (ISMP) and Commonwealth logbook and Catch Disposal Record (CDR) data were provided by John Garvey (AFMA). Thanks also goes to the CSIRO contributors: Mike Fuller, Roy Deng, Franzis Althaus and Robin Thomson for pre-processing the data. Geoff Tuck (CSIRO), Robin Thomson, Malcolm Haddon (CSIRO) and Ian Taylor (NOAA) are thanked for helpful discussions on this work. André Punt (CSIRO) updated the ageing error matrix. Malcolm Haddon provided code for auto-tuning and Athol Whitten provided R code for organising plots.

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9.6 Appendix A

A.1 Preliminary base case diagnostics

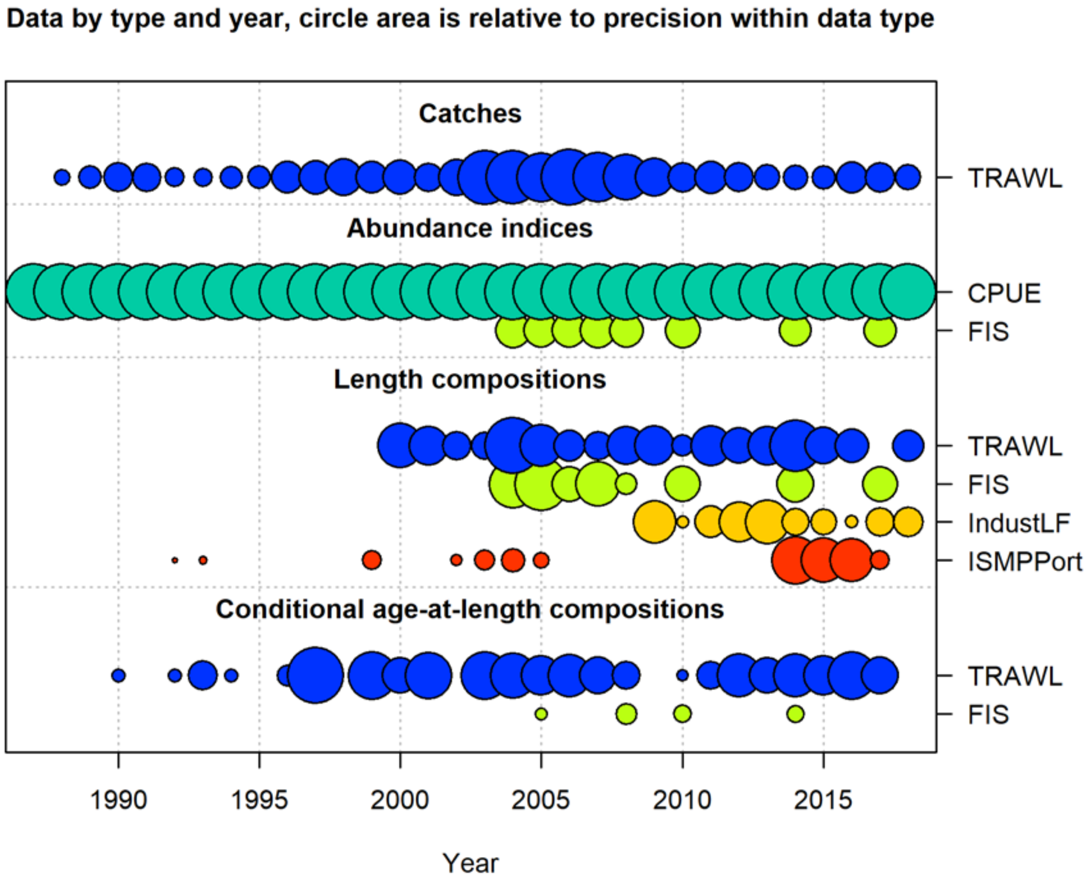
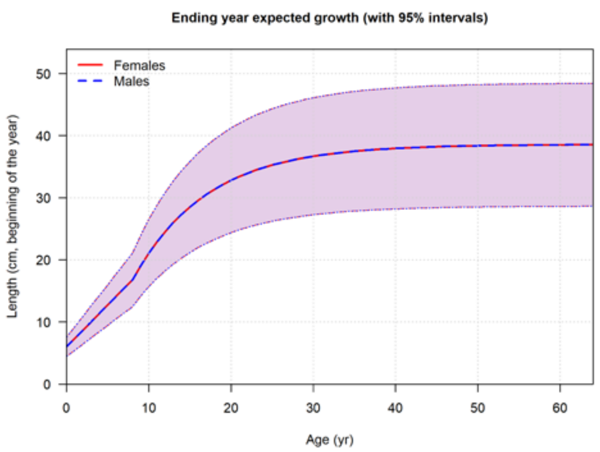


Figure A 9.1. Summary of data sources for Bight Redfish stock assessment.



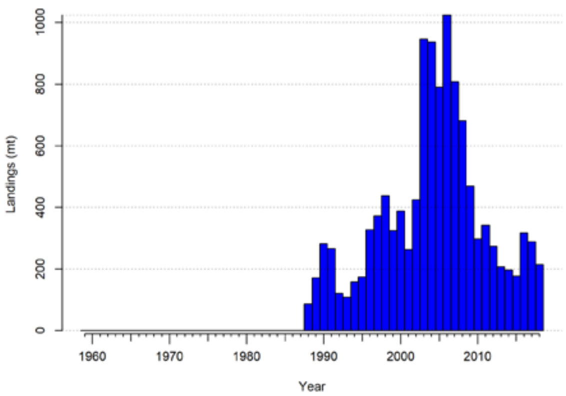


Figure A 9.2. Bight Redfish: Estimated growth curve and landings frequency distribution.

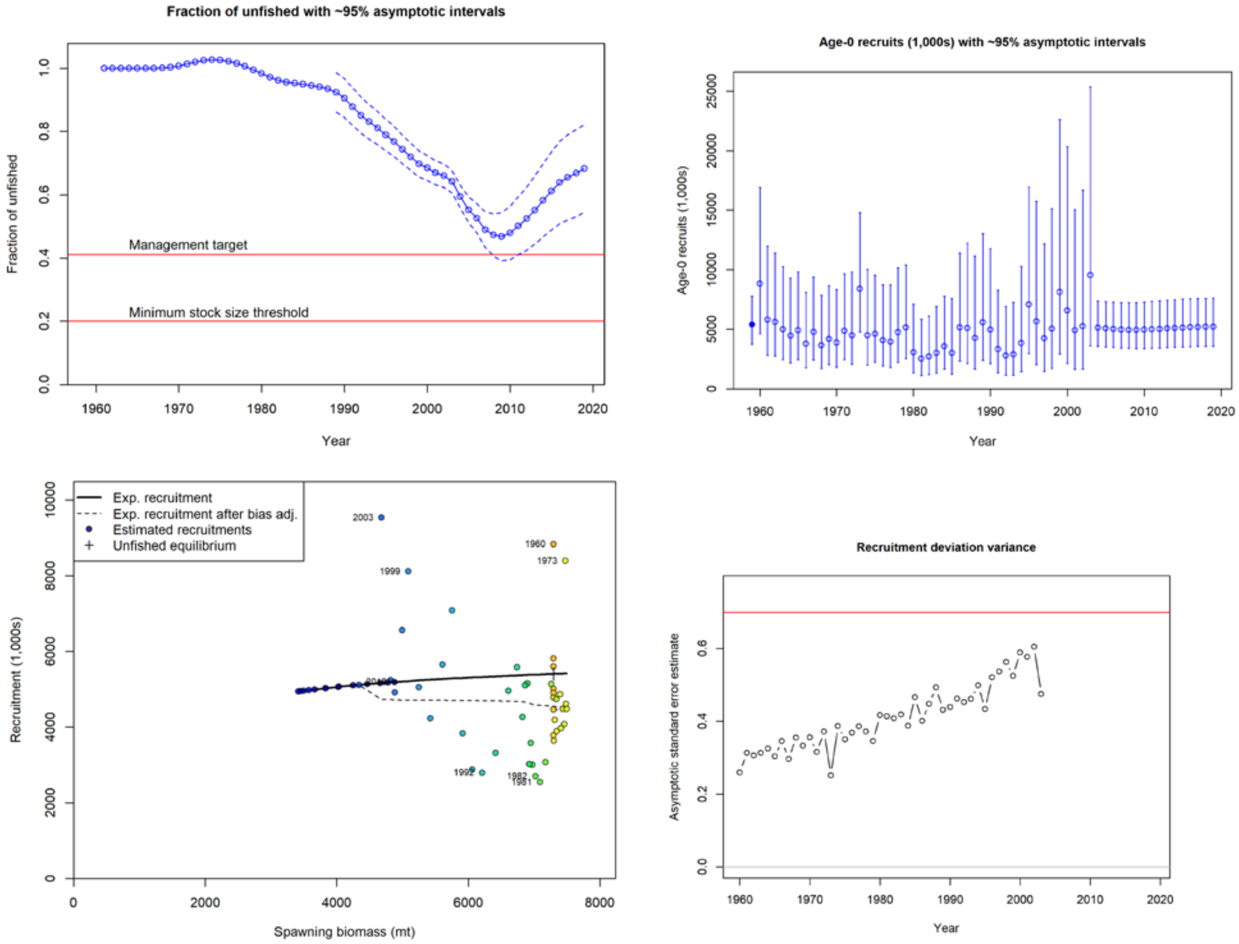


Figure A 9.3. Bight Redfish: Time series showing depletion of spawning biomass with confidence intervals (top left), recruitment estimates with confidence intervals (top right), stock recruitment curve (bottom left) and recruitment deviation variance check (bottom right).

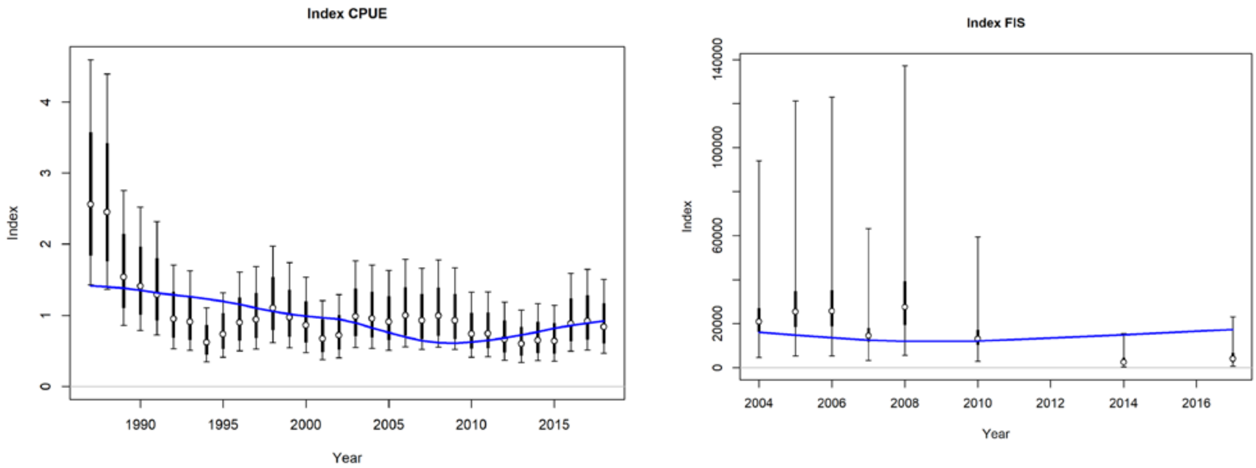


Figure A 9.4. Bight Redfish: Fits to CPUE and GAB Fishery Independent Survey (FIS).

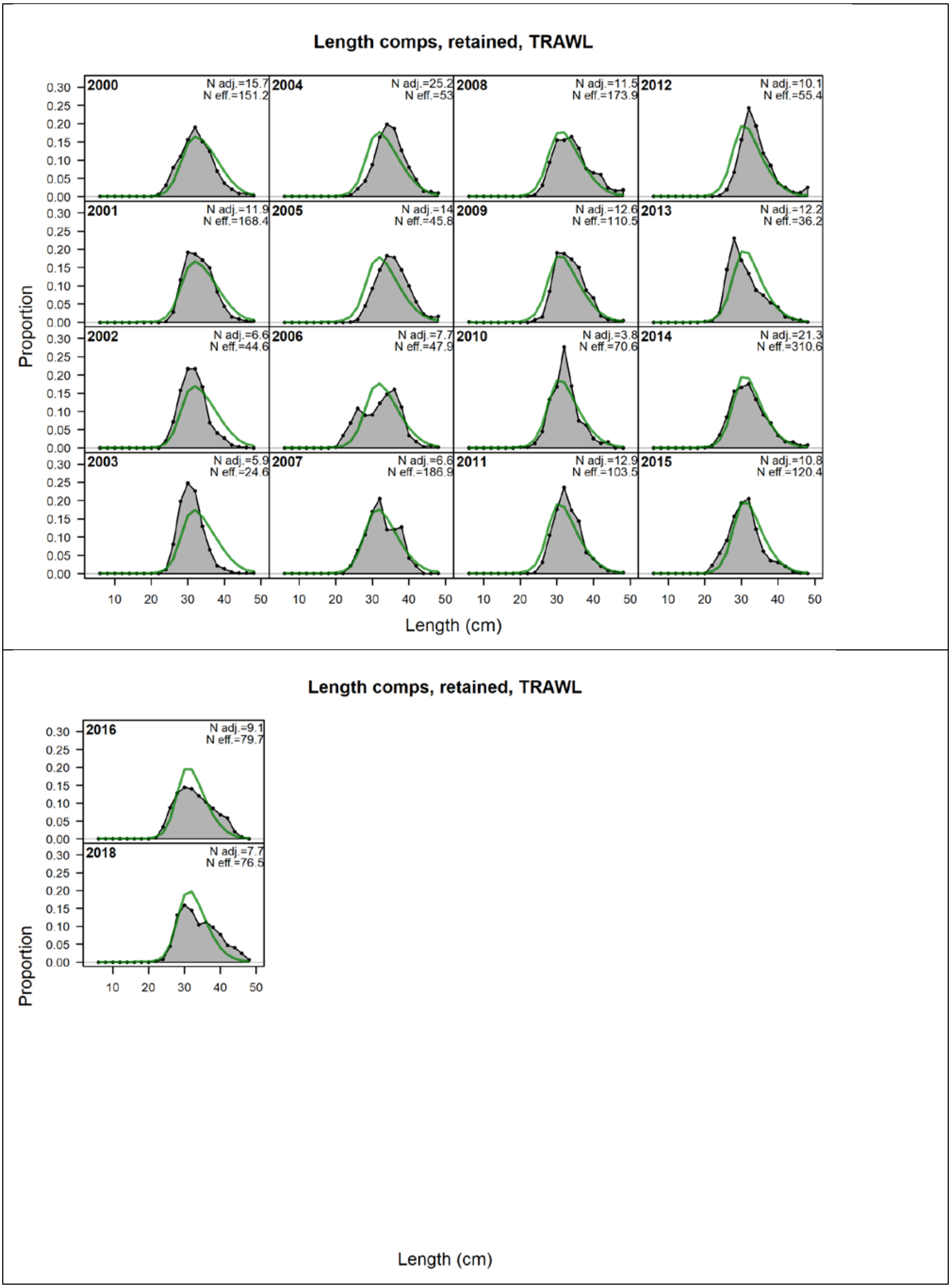


Figure A 9.5. Bight Redfish: Length composition fits - trawl retained.

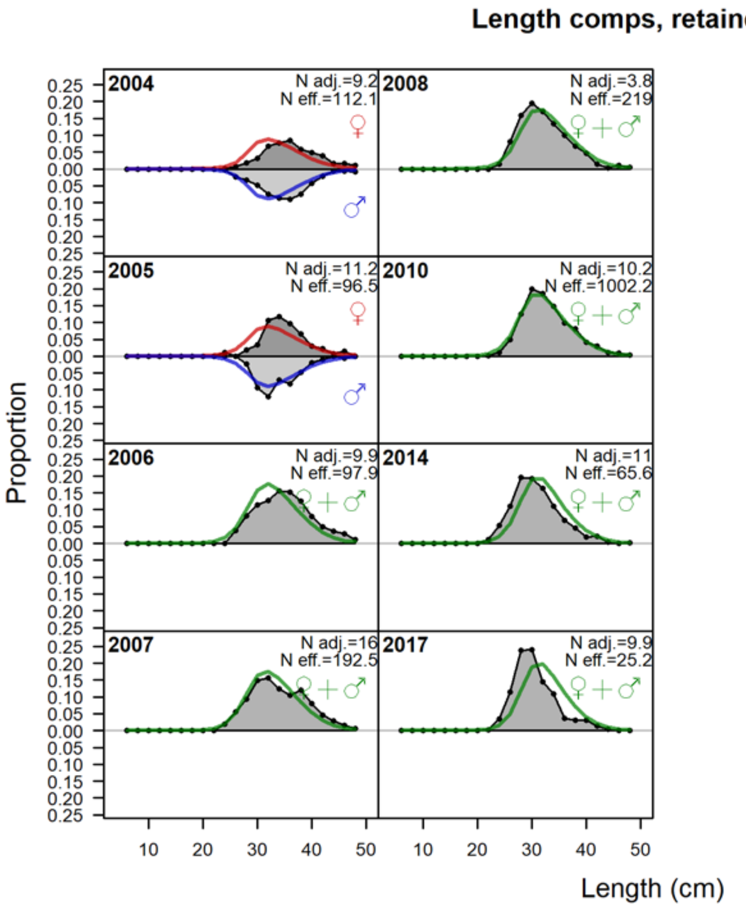


Figure A 9.6. Bight Redfish: Length composition fits - FIS retained.

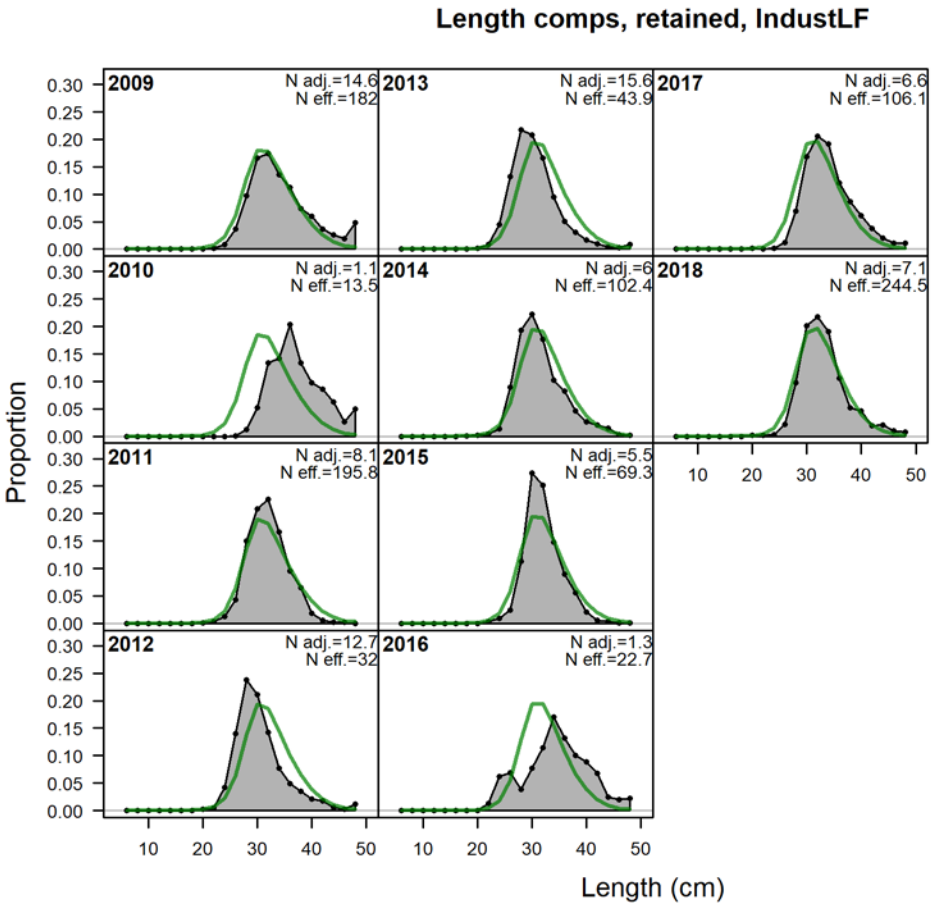


Figure A 9.7. Bight Redfish: Port length composition fits - Trawl.

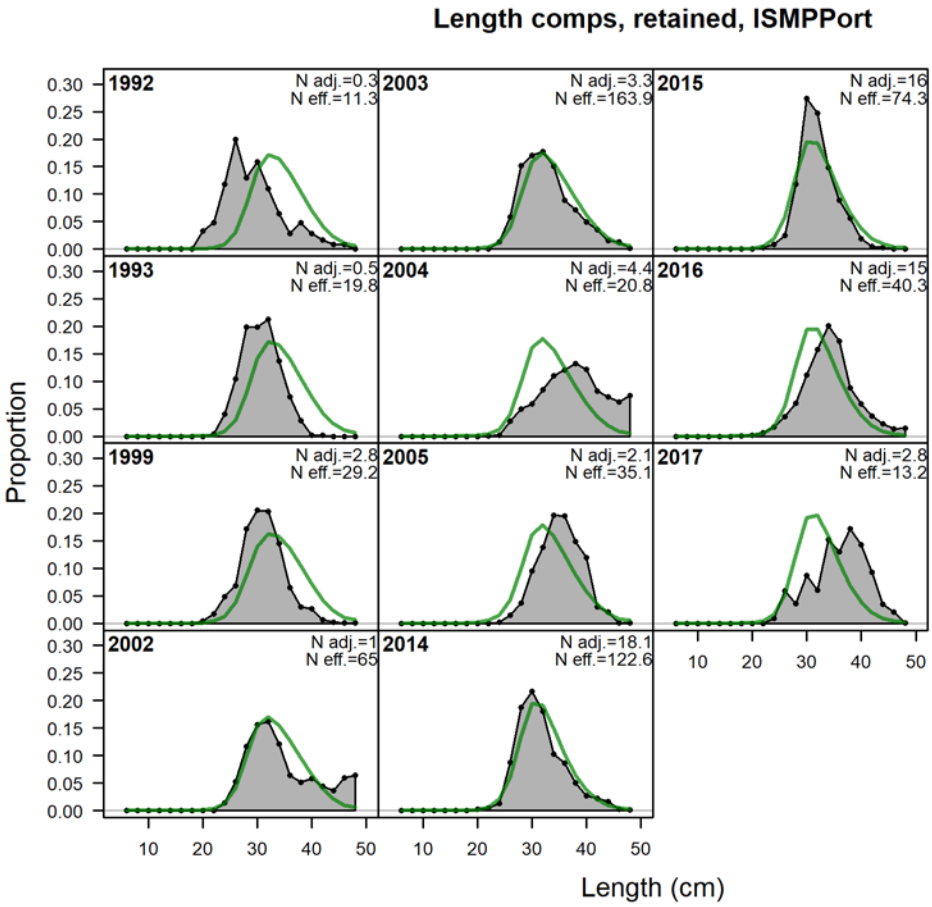


Figure A 9.8. Bight Redfish: Port length composition fits - ISMP Port.

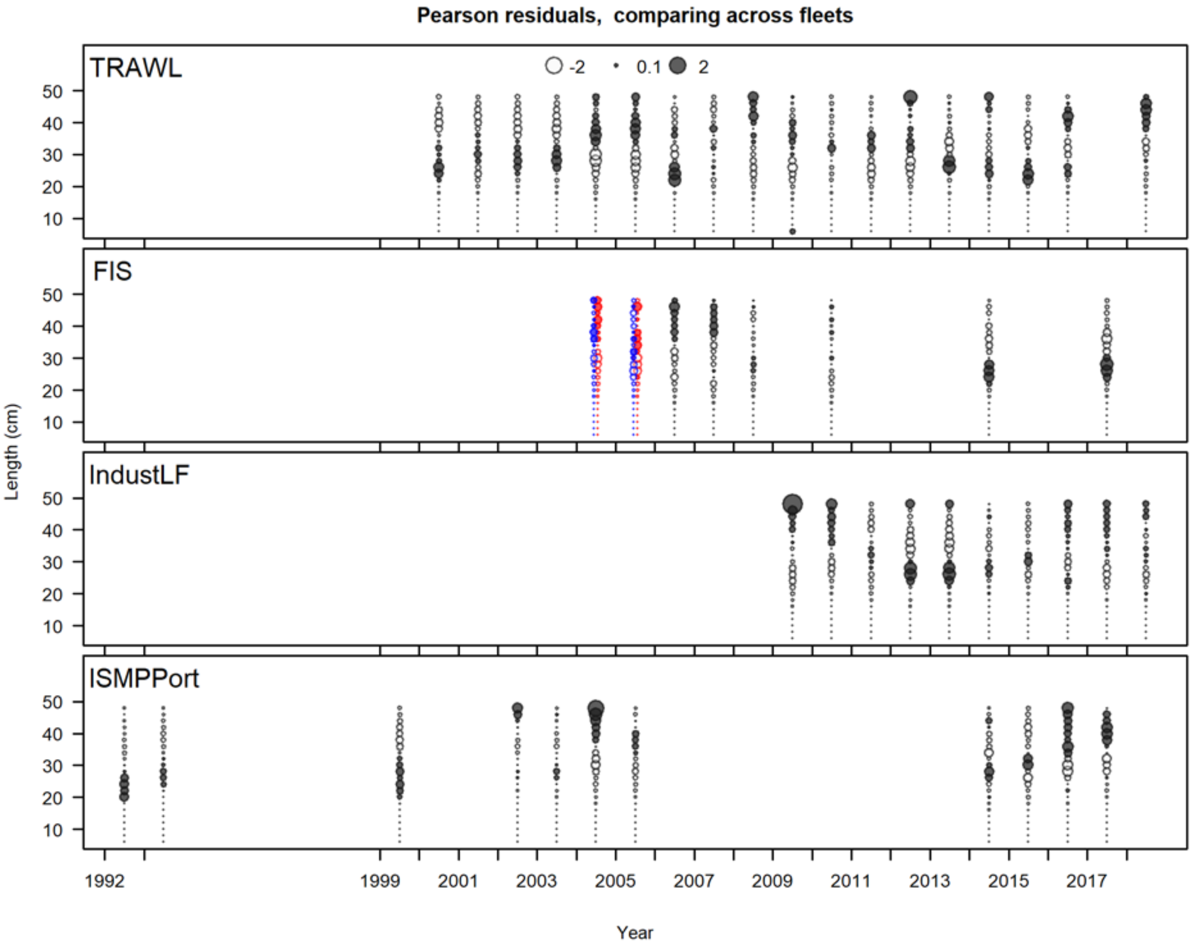


Figure A 9.9. Bight Redfish: Residuals from the annual length compositions (retained) displayed by year and fleet.

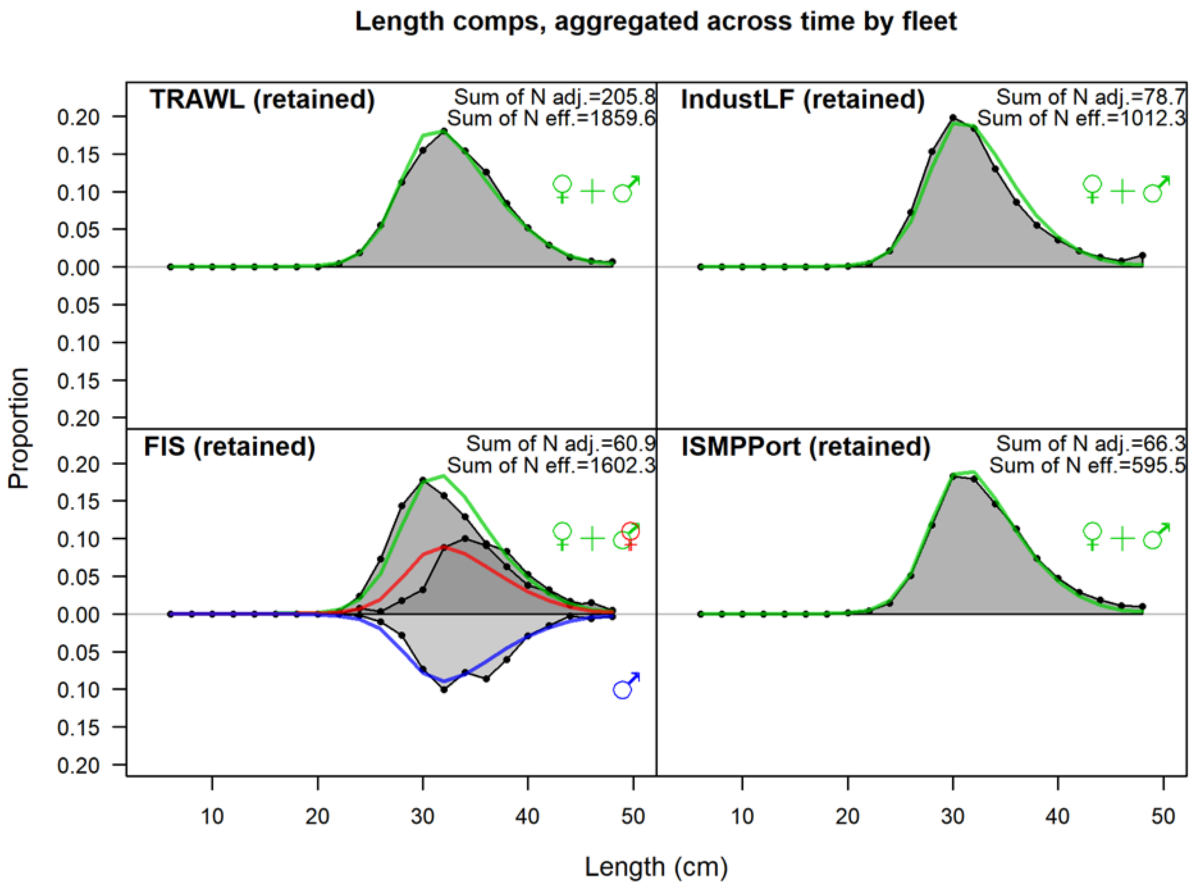
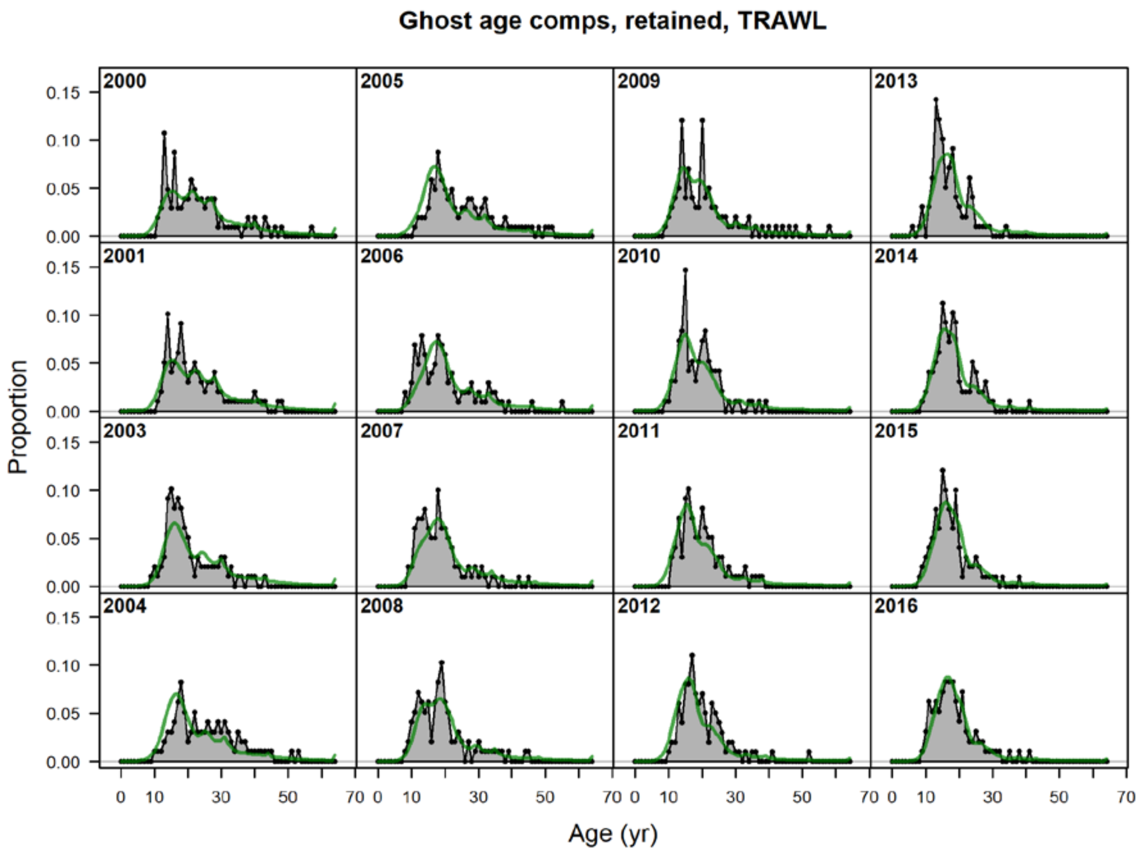


Figure A 9.10. Bight Redfish: Aggregated fits (across all years) to the length compositions displayed by fleet.



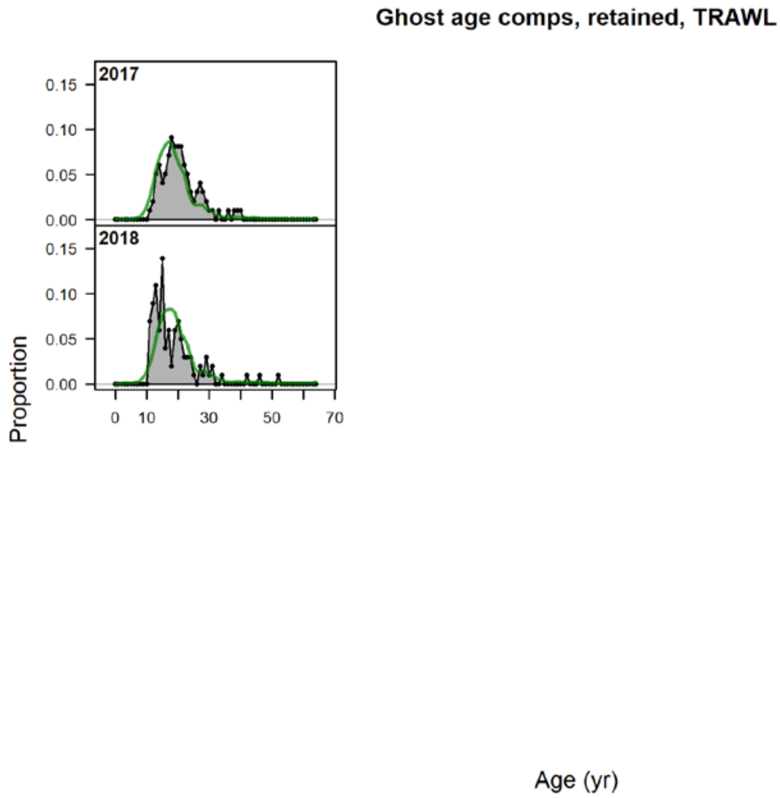


Figure A 9.11. Bight Redfish: Implied fits to age - Trawl onboard (retained).

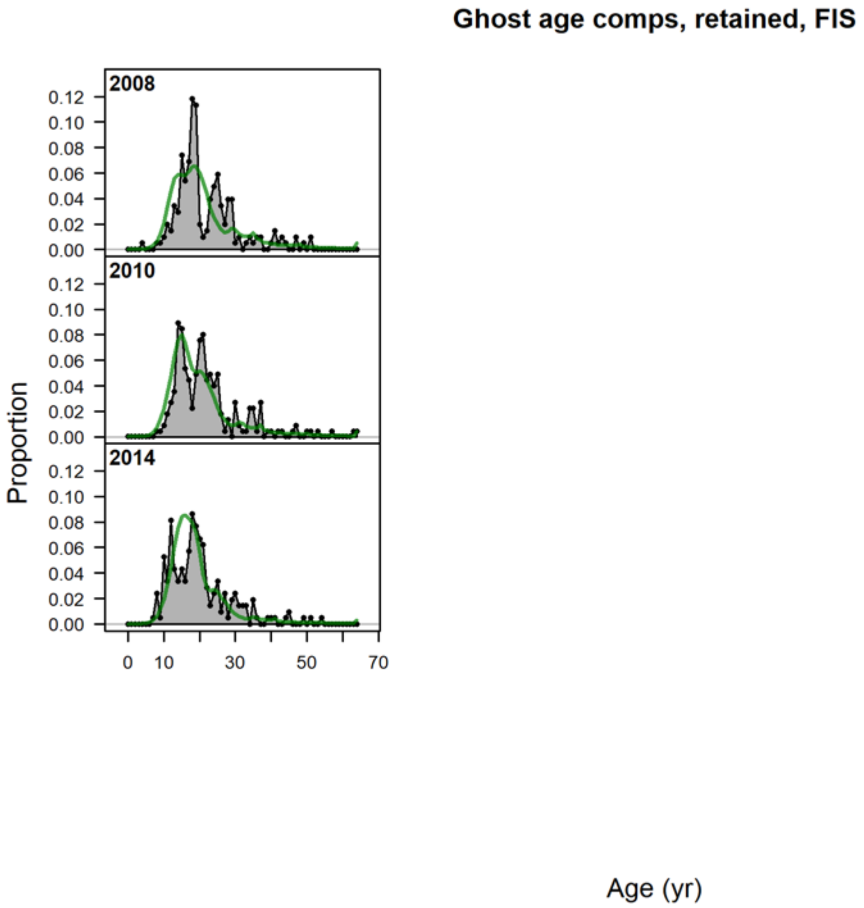


Figure A 9.12. Bight Redfish: Implied fits to age: GAB FIS (retained).

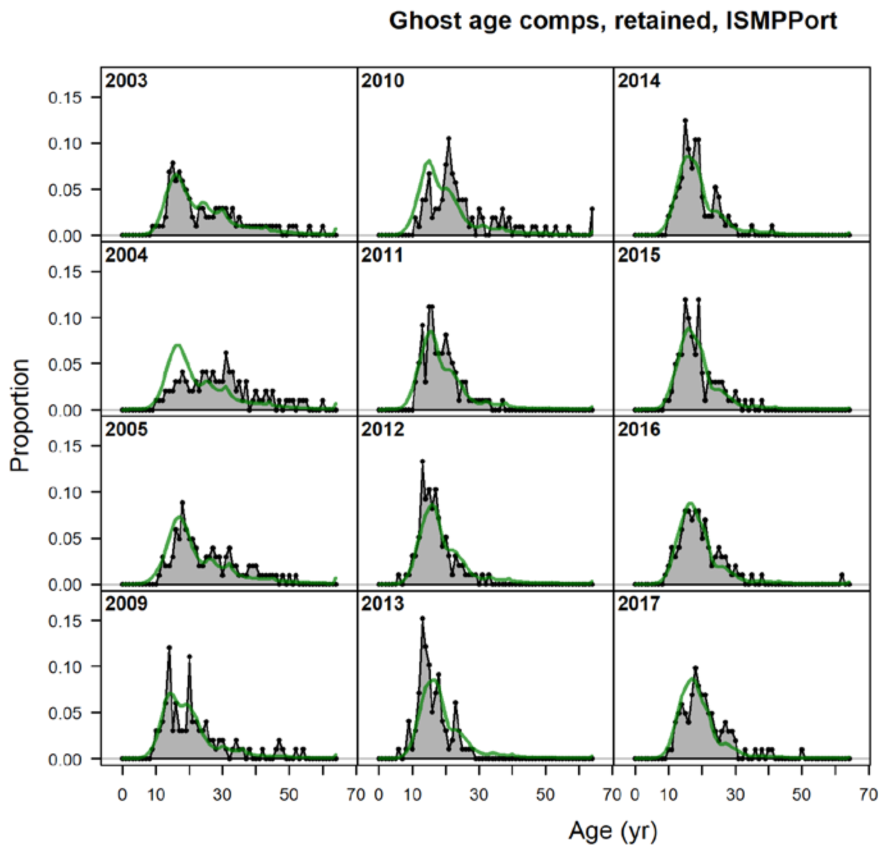


Figure A 9.13. Bight Redfish: Implied fits to age - ISMP Port.

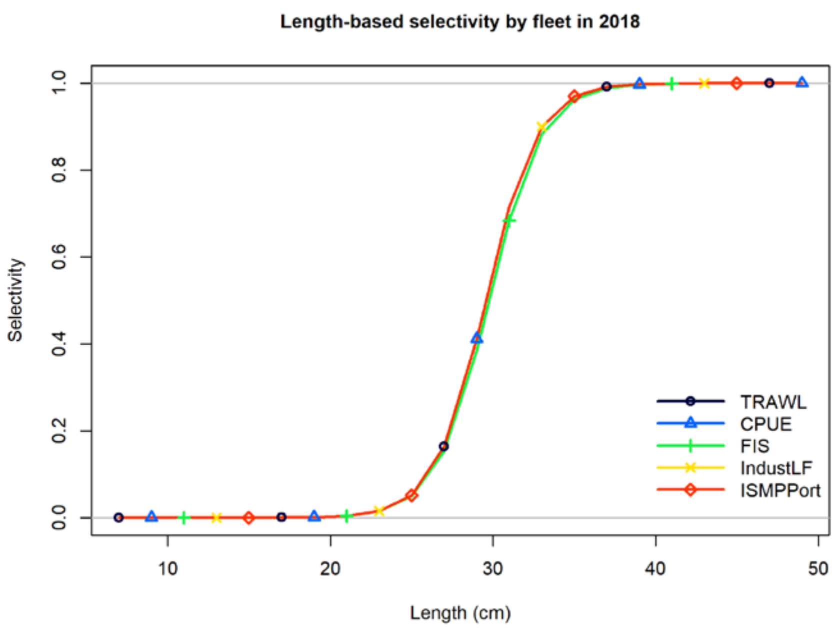


Figure A 9.14. Bight Redfish: Estimated selectivity curves. There are five different selectivity curves, all having the same selectivity.

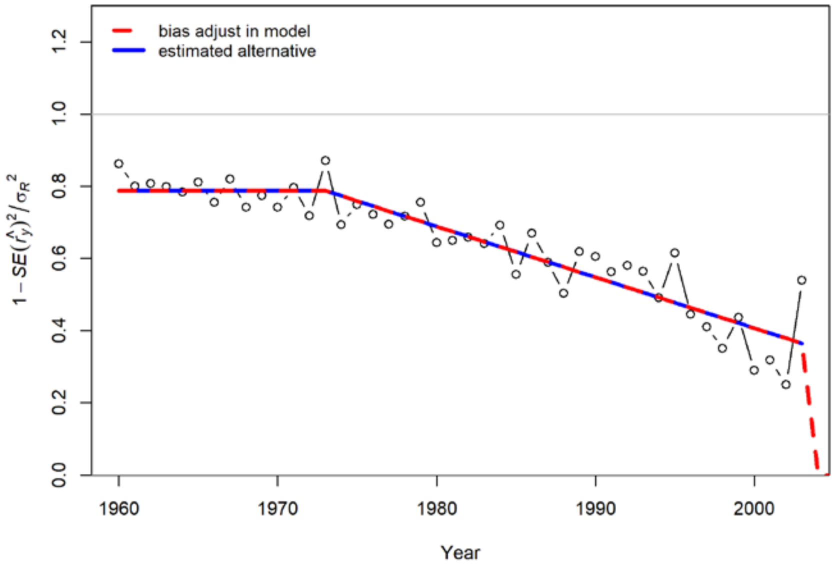


Figure A 9.15. Bight Redfish: Bias ramp adjustment.

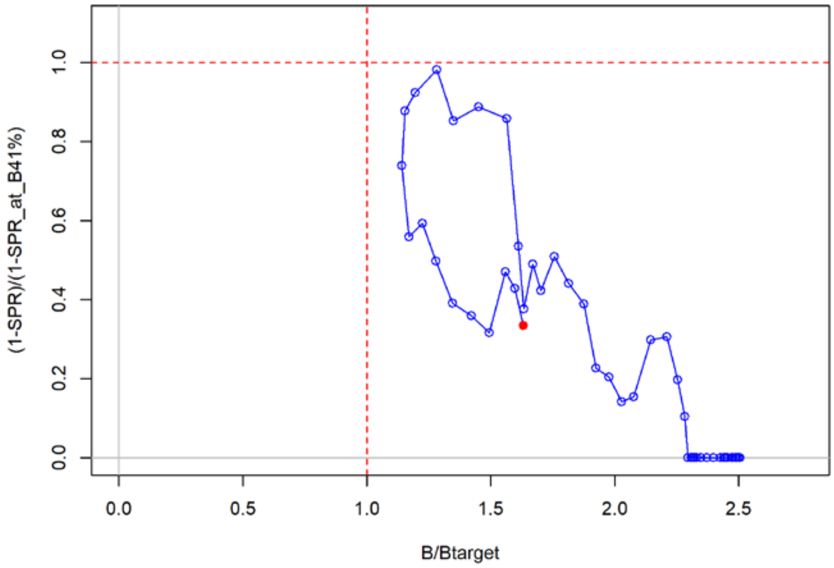


Figure A 9.16. Bight Redfish: Phase plot of biomass vs SPR ratio.

10. Bight Redfish (*Centroberyx gerrardi*) stock assessment based on data to 2018-19

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10.1 Executive Summary

This document presents the agreed base case for the Tier 1 Bight Redfish (*Centroberyx gerradi*) assessment for presentation at the second GABRAG meeting in December 2019. The last full assessment was presented in Haddon (2015). The base case has been updated by the inclusion of data up to the end of 2018-19, which entails an additional four years of catch, CPUE, length and age data and ageing error updates since the 2015 assessment, and incorporation of survey results from the 2017-18 from the GAB Fishery Independent Survey (GAB-FIS). The process used to develop a preliminary base case for Bight Redfish through the sequential updating of recent data and updating the stock assessment package Stock Synthesis (SS-V3.40.14) was presented in November 2019. This document provides further detail of the agreed base case, with RBC values and sensitivities to the base case model structure.

Exploration of the initial ageing error matrix highlighted issues relating to both the size of the data set and the influence of a small number of old fish on the results. An updated ageing error matrix resolved these issues and also reduced a spike in the last recruitment estimate (2003). This updated ageing error matrix was presented as a sensitivity in November 2019 and was accepted as the agreed base case.

As seen in November 2019, results show poor fits to the CPUE and FIS abundance series, but reasonable fits to length and conditional age-at-length data. This assessment estimates that the projected 2020-21 spawning stock biomass will be 64% of virgin spawning stock biomass (B_0), compared to 62% B_0 at the start of 2016-17 from the 2015 assessment (Haddon, 2015) and 90% B_0 at the start of 2012-13 from the 2011 assessment (Klaer, 2011). The 2020-21 Recommended Biological Catch (RBC) under the 20:35:41 harvest control rule is 1,024 t. The average RBC over the three-year period 2020-21: 2022-23 is 963 t. The long-term RBC is 912 t.

Eighteen sensitivities to the base case model structure were examined. The results are very sensitive to the assumed value for natural mortality (*M*) and quite sensitive to the exclusion of the CPUE index. However, both of these sensitivities result in considerably larger likelihoods, with deterioration in the fits to the age and survey data respectively.

10.2 Introduction

10.2.1 *The fishery*

The trawl fishery in the Great Australian Bight (GAB) primarily targets two species, Bight Redfish (*Centroberyx gerrardi*) and Deepwater Flathead (*Neoplatycephalus conatus*), and these have been fished sporadically in the GAB since the early 1900s (Kailola et al., 1993). The GAB trawl fishery (GABTF) was set up and managed as a developmental fishery in 1988, and since then a permanent fishery has been established with increasing catches of both species, although catches of Bight redfish have declined recently. Bight Redfish are endemic to southern Australia, occurring from off Lancelin in WA to Bass Strait in depths from 10 m to 500 m. Deepwater Flathead are also endemic to Australia and inhabit waters from NW Tasmania, west to north of Geraldton in WA in depths from 70 m to more than 490 m (Kailola et al., 1993; www.fishbase.org). The two species are often caught in the same trawl tows although Bight Redfish is most commonly taken in the east of the GAB.

10.2.2 *Previous assessments*

An initial stock assessment workshop for the GABTF held in 1992 focused on the status of Deepwater Flathead and Bight Redfish. Sources of information for the workshop included historical data, logbook catch data, observer data and biological information. With so few years of data available at that time, catch-per-unit-area (kg/km^2) was calculated for quarter-degree squares and then scaled to the total area in which the species had been recorded. The approximate exploitable biomass estimates for Deepwater Flathead and Bight Redfish obtained by this crude method were 32,000 t and 12,000 t respectively (Tilzey and Wise, 1999). Large uncertainties in the method prevented calculation of error bounds.

Wise and Tilzey (2000) produced the first attempt to assess the status of Bight Redfish using an age- and sex-structured stock assessment model. The virgin total biomass estimates for the base case model was 9,095t (4,924 – 13,266 t). In 2002 an updated assessment was carried out for Bight redfish and the unexploited biomass estimates for the base case model was then 9,563 t (8,368 – 10,759 t).

GABTF assessments in 2005 (Wise and Klaer, 2006; Klaer, 2006) used a custom-designed integrated assessment model developed using the AD Model Builder software (Fournier et al., 2012). A series of fishery-independent resource surveys was also commenced in 2005, providing a single annual biomass estimate for Bight Redfish and Deepwater Flathead (Knuckey et al., 2015), plus extra samples of length and age composition data. Initially, attempts were made to make absolute abundance estimates using classical swept area methods from the survey data. The unexploited biomass level estimated using this approach was 13,932 t and current depletion level was estimated at 75% for Bight Redfish.

The 2006 assessment (Klaer and Day, 2007) duplicated as far as possible the assessment results from 2005 using the Stock Synthesis (SS) framework. Although it was possible to replicate 2005 results reasonably well, there were a few differences in the model structure implemented in Stock Synthesis including calculation of recruitment residuals independently and allowing recruitment residuals to occur prior to the commencement of the fishery.

An attempt was made to incorporate as much previously unused data as possible into the 2007 assessment - particularly length-frequencies (Klaer, 2007). Age-frequencies were no longer used explicitly but conditional age-at-length distributions were obtained from age-length keys. In addition, the model used original age-at-length measurements to fit growth curves within the model, to better allow for the interaction between selectivity and the growth parameters. Depletion of Bight Redfish in 2007 was estimated at 82%, and the unexploited female spawning biomass was estimated at 18,685 t.

The model structure for the 2009 assessment for Bight redfish (Klaer, 2010) was similar to the 2007 assessment, but used a more recent version of Stock Synthesis. Differences were the use of the fishery independent survey as a relative abundance index, estimation of fewer growth parameters, estimation of the natural mortality rate, and adjustment of the relative weighting of abundance indices versus length and age composition information. The unexploited female biomass was estimated at 12,272 t and the depletion at 77%.

In 2011, the Bight Redfish assessment was updated using the latest version of Stock Synthesis (SS-V3.21d) and the most recent data on ISMP collected length and age composition as well as the standardized CPUE and FIS estimates of relative abundance (Klaer, 2012a,b). This led to an estimate of unfished female spawning biomass of 26,210 t and a spawning biomass depletion estimate of 90%.

In 2015, the Bight Redfish assessment was updated using version SS-V3.24U (Methot and Wetzel, 2013; Methot, 2015) and the most recent data on ISMP collected length and age composition as well as the standardized CPUE and FIS estimates of relative abundance (Haddon, 2014a,b; Sporcic, 2015). This led to an estimate of unfished female spawning biomass of 5,451 t and a spawning biomass depletion estimate of 63%.

10.2.3 *Modifications to the previous assessment*

A preliminary base case was developed and presented to GABRAG in November 2019. This was used to describe the changes made to the previous assessment by the sequential addition of the new data now available along with other minor modelling changes.

The latest version of Stock Synthesis was used (SS-V3.30.14.05; Methot et. al., 2018) and data updates were implemented. The usual process of bridging to a new model was conducted, by adding new data piecewise and analysing which components of the data contributed to changes in the assessment outcome (Sporcic et al., 2019).

10.3 Methods

10.3.1 *Data and model inputs*

10.3.1.1 Biological parameters

Male and female Bight redfish are assumed to have the same biological parameters except for the length-weight relationship.

Three of the four parameters relating to the von Bertalanffy growth equation are estimated within the model-fitting procedure from the observed age-at-length data. This approach attempts to account for the impact of gear selectivity on the age-at-length data collected from the fishery and any impacts of ageing error.

The rate of natural mortality per year, M, is estimated in the base case model, with the estimated value being close to 0.1. A likelihood profile was constructed, as the model outcomes are very sensitive to this parameter, where M is given a series of fixed values and all other parameters are re-fitted to determine the effect on the total likelihood and individual components of the likelihood.

Maturity is modelled as a logistic function, with 50% maturity at 25 cm. Fecundity-at-length is assumed to be proportional to weight-at-length.

The assessment data for Bight Redfish comes from a single trawl fleet; although there is now a Danish seine vessel operating and some pair-trawling occurring in the GAB, but only catching a very small quantity of Bight Redfish.

10.3.1.2 Fleets

The assessment data for Bight Redfish come from one fleet. However, the data from that fleet have been separated into four sub-fleets which allow for potential differences in selectivity/availability:

a) Trawl Onboard measurements

b) Trawl Port measurements

c) Trawl Industry collected measurements

d) Trawl GAB-FIS measurements

10.3.1.3 Landed catches

A landed catch history for Bight Redfish is available for the years from 1988-89 to 2018-19 (Figure 10.1; Table 10.1). Landed catches were derived from GAB logbook records for the years to 2005-06 and catch disposal records have been the source of total landings since then. All landings were aggregated by financial year.

In 2007 the quota year was changed from calendar year to the year extending from 1 May to 30 April. As the assessment is conducted according to financial year, the recent quota year change has resulted in closer alignment of the assessment and quota years. In the intervening year the quota year was extended to 16 months to allow for this change, which is one reason catches were elevated in the 2006-07 financial year (Table 10.1).

In order to calculate the Recommended Biological Catch (RBC) for 2020-21, it is necessary to estimate the financial year catch for 2019-20. TACs have been substantially under-caught in recent years and so the 2019-20 catch was assumed to be the same as the catch in 2018-19 (215 t).

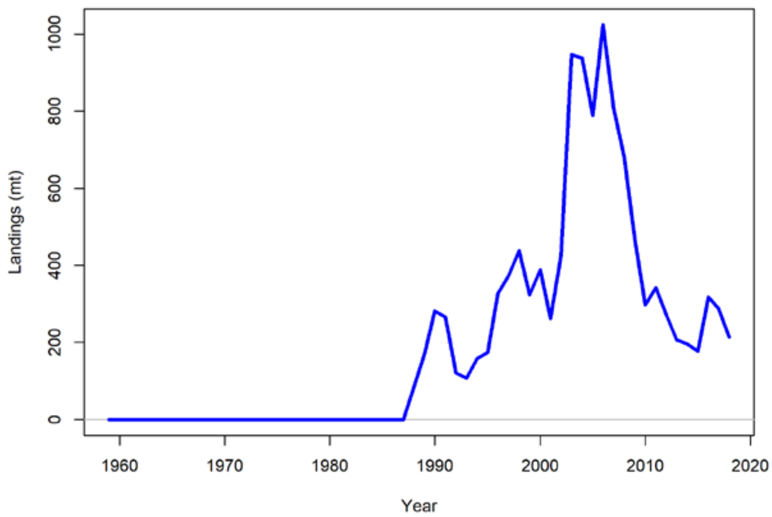

Figure 10.1. Total reported landed catch of Bight redfish from 1987-88 to 2018-19 (see Table 1).

10.3.1.4 CPUE indices

Data from the GAB fishery used in the CPUE analysis was based on depths between 0 – 1000 m, taken by Trawl. Also, analyses were restricted to vessels present for more than two years and which caught an average annual catch > 4 t, and for trawl shots more than one hour but less than 10 hours. Instead of five-degree zones across the GAB, 2.5-degree zones were employed to allow better resolution of location, based differences in CPUE. Also, a depth range of 50 – 300 m was used in the analysis. Catches in 1986-87 were relatively low and only taken by a single vessel and so were omitted from analysis (Sporcic, 2015, p209) and also omitted from the current CPUE analysis (Sporcic, 2019a,b). Annual standardized CPUE used in the stock assessment model are tabulated in Table 10.1.

Table 10.1. Financial year values of catch, standardized CPUE (Trawl) and GAB_FIS from 1988-89 to 2018-19. Catch is taken from logbook estimates until 2005-06. Subsequently, CDR catches are used to 2014-15 (Haddon, 2015) and catches from 2015-16 to 2018-19 from CDR landings database. Discards are assumed to be trivial. Standardized CPUE are from Sporcic (2019a,b). GAB-FIS abundance indices are from Knuckey et al. (2015) and Knuckey et al. (2018). ^: Interpolated GAB-FIS (blue bold; see sensitivity Section 3.3: Case 16).

Season	Catch (t)	CPUE	GAB-FIS	INTERPOLATED GAB-FIS^
1987-88		2.5623		
1988-89	85.65	2.4517		
1989-90	170.83	1.5382		
1990-91	281.81	1.4084		
1991-92	265.61	1.2932		
1992-93	120.70	0.9523		
1993-94	107.47	0.9084		
1994-95	157.80	0.6177		
1995-96	173.92	0.7349		
1996-97	327.18	0.8966		
1997-98	372.62	0.9406		
1998-99	437.79	1.1019		
1999-00	323.64	0.9718		
2000-01	387.88	0.8591		
2001-02	262.61	0.673		
2002-03	424.67	0.7201		
2003-04	946.48	0.9862		
2004-05	937.46	0.954	20887	20887
2005-06	789.70	0.9101	25380	25380
2006-07	1023.91	0.9977	25713	25713
2007-08	808.02	0.9275	14591	14591
2008-09	681.89	0.9927	27610	27610
2009-10	469.70	0.9282		
2010-11	297.60	0.7396	13189	13189
2011-12	341.48	0.742		**10535**
2012-13	273.45	0.6629		**7881**
2013-14	207.05	0.5994		**5227**
2014-15	196.56	0.6496	2573	2573
2015-16	176.95	0.6367		**3066**
2016-17	317.09	0.8866		**3560**
2017-18	288.49	0.918	4053	4053
2018-19	214.50	0.8385		

10.3.1.5 Age composition data

An estimate of the standard deviation of age reading error was calculated by Andre Punt (pers. comm., 2019) from data supplied by Kyne Krusic-Golub of Fish Ageing Services (Table 10.2).

Age-at-length measurements, based on sectioned otoliths, provided by Fish Ageing Services, were available for the years 1990, 1992-94, 1996-97, 1999-01, 2003-08, 2010-17 for otoliths collected onboard and from 2005, 2008, 2010, 2014 for otoliths collected at port (Table 10.3).

Table 10.2. Standard deviation (SD) of age reading error (A Punt pers. comm. 2019).

AGE	SD	AGE	SD
0.5	0.04417	32.5	1.41344
1.5	0.04417	33.5	1.45761
2.5	0.08834	34.5	1.50178
3.5	0.13251	35.5	1.54595
4.5	0.17668	36.5	1.59012
5.5	0.22085	37.5	1.63429
6.5	0.26502	38.5	1.67846
7.5	0.30919	39.5	1.72263
8.5	0.35336	40.5	1.7668
9.5	0.39753	41.5	1.81097
10.5	0.4417	42.5	1.85514
11.5	0.48587	43.5	1.89931
12.5	0.53004	44.5	1.94348
13.5	0.57421	45.5	1.98765
14.5	0.61838	46.5	2.03182
15.5	0.66255	47.5	2.07599
16.5	0.70672	48.5	2.12016
17.5	0.75089	49.5	2.16433
18.5	0.79506	50.5	2.2085
19.5	0.83923	51.5	2.25267
20.5	0.8834	52.5	2.29684
21.5	0.92757	53.5	2.34101
22.5	0.97174	54.5	2.38518
23.5	1.01591	55.5	2.42935
24.5	1.06008	56.5	2.47352
25.5	1.10425	57.5	2.51769
26.5	1.14842	58.5	2.56186
27.5	1.19259	59.5	2.60603
28.5	1.23676	60.5	2.6502
29.5	1.28093	61.5	2.69437
30.5	1.3251	62.5	2.73854
31.5	1.36927	63.5	2.78271
		64.5	2.82688

Table 10.3. Number of age-length otolith samples included in the base case assessment by sub-fleet 1990-2017.

YEAR	ONBOARD	PORT	TOTAL
1990	45		45
1992	46		46
1993	224		224
1994	47		47
1996	113		113
1997	822		822
1999	595		595
2000	330		330
2001	558		558
2003	601		601
2004	538		538
2005	413	101	514
2006	473		473
2007	355		355
2008	207	295	502
2010	34	223	257
2011	201		201
2012	488		488
2013	332		332
2014	490	203	693
2015	403		403
2016	594		594
2017	354		354

10.3.1.6 Length composition data

The number of shots or days of length frequency data for retained components of catches is available for sub-fleets: Onboard: 2000-16, 2018; GAB-FIS: 2009-18; and Industry (days): 1992-93, 1999, 2002-05, 2014-17 (Table 10.4). Also, the number of trips of length frequency data for retained components of catches is available from Port for 2004-08, 2010, 2014 and 2017 (Table 10.4).

Table 10.4. Number of shots (onboard and GAB-FIS), days (industry) and trips (port) for length frequencies included in the base case assessment by sub-fleet 1992-2018.

YEAR	ONBOARD	PORT	INDUSTRY	GAB-FIS	TOTAL
1992			1		1
1993			2		2
1999			11		11
2000	45				45
2001	34				34
2002	19		4		23
2003	17		13		30
2004	72	36	17		125
2005	40	44	8		92
2006	22	39			61
2007	19	63			82
2008	33	15			48
2009	36			167	203
2010	11	40		13	64
2011	37			93	130
2012	29			146	175
2013	35			179	214
2014	61	43	70	69	243
2015	31		62	63	156
2016	26		58	15	99
2017		39	11	76	126
2018	22			82	104

10.3.1.7 Input data summary

Different data sources are available for the Bight Redfish assessment including catch (landings), standardized commercial CPUE, an index of relative abundance from the Fishery Independent Survey (GAB-FIS), conditional age-at-length data from the Integrated Scientific Monitoring Program (ISMP) and from the GAB-FIS, and length composition data from the ISMP (keeping port sampling separate from the onboard sampling), from the GAB-FIS, and from onboard crew sampling (Figure 10.2).

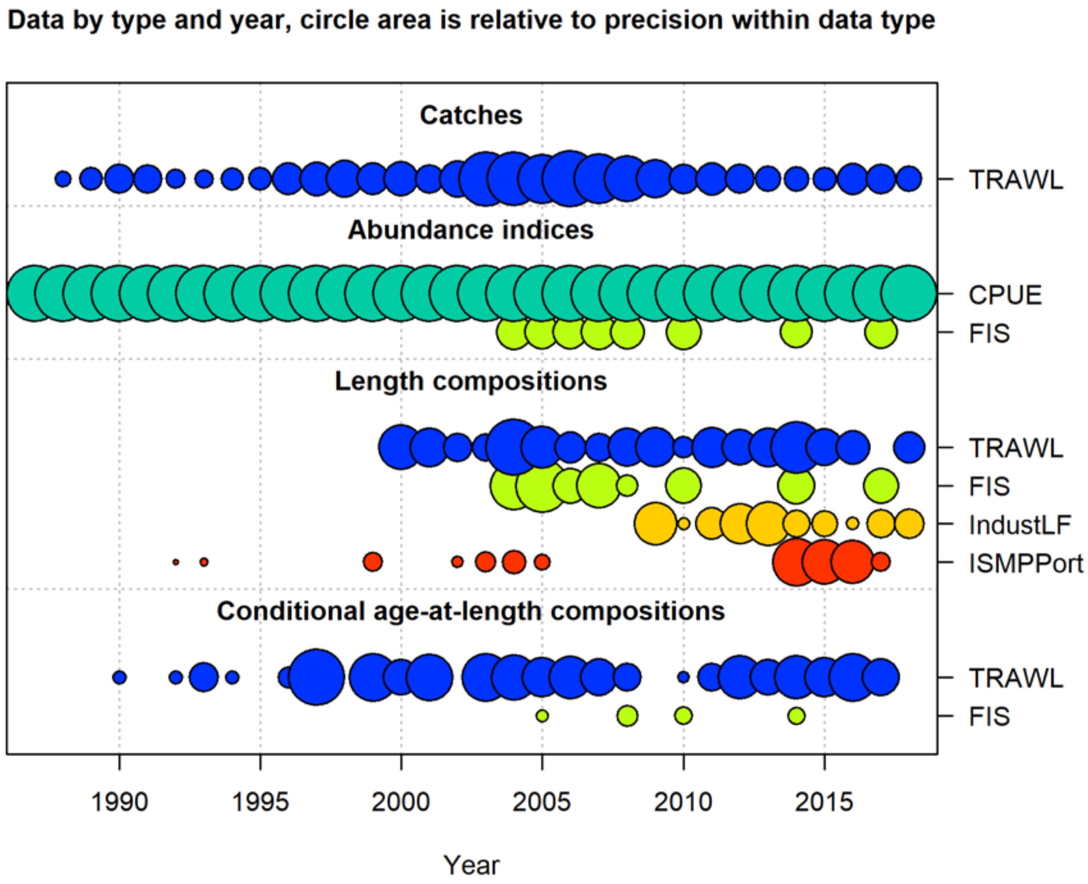

Figure 10.2. Data availability by type and year. The year axis denotes the start of the financial year, thus 1995 refers to 1995-96.

10.3.2 *Stock assessment method*

10.3.2.1 Population dynamics model and parameter estimation

A two-sex stock assessment for Bight Redfish was conducted using the software package Stock Synthesis version 3.30.14.05, (Methot et. al, 2019). Stock Synthesis is a statistical age- and length-structured model which allows multiple fishing fleets and can be fitted simultaneously to the range of data available for Bight Redfish. The population dynamics model, and the statistical approach used in the fitting of the model to the various types of data, are given fully in the Stock Synthesis technical description (Methot, 2005) and are not reproduced here. Some key features of the population dynamics model underlying Stock Synthesis which are pertinent to this assessment are discussed below.

a) Bight Redfish constitute a single stock within the area of the fishery.

b) The stock is assumed to be unexploited at the start of 1960 when the first recruitment deviations are estimated.

c) Catches used in this assessment are from 1988-89 (Haddon 2015) until 2018-19.

d) The CVs of all abundance indices (including the GAB-FIS) were initially set to the root mean squared deviation from a loess fit to the fleet specific indices (Sporcic, 2019a; Sporcic, 2019b) and then tuned to match the model-estimated standard errors by estimating an additional variance parameter within Stock Synthesis.

e) Four fishing sub-fleets are modelled.

f) Selectivity is assumed to vary among fleets, but the selectivity pattern for each separate sub-fleet is modelled as length-specific, logistic and time-invariant. The two parameters of the selectivity function for the trawl and GAB-FIS fleets are estimated within the assessment, with a common selectivity estimated (mirrored) for the industry, port and onboard trawl sub-fleets.

g) The rate of natural mortality, *M*, is assumed to be constant with age, and also time-invariant. The value for *M* is estimated within the model at 0.1017 yr^{-1}.

h) Recruitment to the stock is assumed to follow a Beverton-Holt type stock-recruitment relationship, parameterised by the average recruitment at unexploited spawning biomass, R_0, and the steepness parameter, *h*. Steepness is fixed at 0.75 for the base case analysis. Deviations from average recruitment at a given spawning biomass (recruitment residuals) are estimated from 1960 to 2003. Recruitment deviations are not estimated after 2003 because there are insufficient data to permit reliable estimation of recruitment residuals beyond 2003.

i) The value of the parameter determining the magnitude of the process error in annual recruitment, σ_R, is set equal to 0.7 in the base case. The magnitude of bias-correction depends on the precision of the estimate of recruitment and time-dependent bias-correction factors were estimated following the approach of Methot and Taylor (2011).

j) A plus-group is modelled at age sixty-four years.

k) Growth of Bight Redfish is assumed to be time-invariant, that is there has been no change over time in the mean size-at-age, with the distribution of size-at-age determined from fitting the growth curve within the assessment using the age-at-length data. Differences in growth by gender are modelled.

l) The sample sizes for length and age frequencies were tuned for each sub-fleet so that the input sample size was approximately equal to the effective sample size calculated by the model. Before this retuning of length frequency data was performed by sub-fleet, any sample sizes with a sample size greater than 100 trips or 200 shots were individually down-weighted to a maximum sample size of 100 and 200 respectively. This is because the appropriate sample size for length frequency data is probably more closely related to the number of shots sampled, rather than the number of fish measured.

10.3.2.2 Relative data weighting

Iterative reweighting of input and output CVs or input and effective sample sizes is an imperfect but objective method for ensuring that the expected variation is comparable to the input (Pacific Fishery Management Council, 2018). This makes the model internally consistent, although some argue against this approach, particularly if it is believed that the input variance is well measured and potentially accurate. It is not necessarily good to down weight a data series just because the model does not fit it, if in fact, that series is reliably measured. On the other hand, most of the indices we deal with in fisheries underestimate the true variance by only reporting measurement and not process error.

Data series with a large number of individual measurements such as length or weight frequencies tend to overwhelm the combined likelihood value with poor fits to noisy data when fitting is highly partitioned by area, time or fishing method. These misfits to small samples mean that simple series such as a single CPUE might be almost completely ignored in the fitting process. This model behaviour is not optimal, because we know, for example, that the CPUE values are in fact derived from a very large number of observations.

Length compositions were initially weighted using trip and shot numbers, where available, instead of numbers of fish measured and by adopting the Francis weighting method (Francis, 2011) for age and length composition data.

Shot or trip number is not available for all data, especially for some of the early length frequency data. In these cases, the number of trips was inferred from the number of fish measured using the average number of fish per trip for the relevant gear type for years where both data sources were available. Samples with less than 100 fish measured per year were excluded.

These initial sample sizes, based on shots and trips, are then iteratively reweighted so that the input sample size is equal to the effective sample size calculated by the model using the Francis weighting method for length data and the Punt weighting method for conditional age-at-length data.

10.3.2.3 Tuning procedure

In iterative reweighting, the effective annual sample sizes are tuned/adjusted so that the input sample size is equal to the effective sample size calculated by the model. In SS-V3.30 there is an automatic adjustment made to survey CVs (CPUE).

1. Set the standard error for the log of the relative abundance indices (CPUE, acoustic abundance survey, or GAB-FIS) to their estimated standard errors for each survey or for CPUE (and GAB-FIS values) to the root mean squared deviation of a *loess* curve fitted to the original data (which will provide a more realistic estimate to that obtained from the original statistical analysis). Stock Synthesis then re-balances the relative abundance variances appropriately.
2. The initial value of the parameter determining the magnitude of the process error in annual recruitment, σ_R, is set to 0.7, reflecting the variation in recruitment. The magnitude of bias-correction depends on the precision of the estimate of recruitment and time-dependent bias-correction factors were estimated following the approach of Methot and Taylor (2011).

An automated tuning procedure was used for the remaining adjustments. For the conditional age-at-length and length composition data:

3. Multiply the initial sample sizes for the conditional age-at-length data by the sample size multipliers using the approach of Punt (2017).
4. Similarly multiply the initial samples sizes by the sample size multipliers for the length composition data using the ‘Francis method’ (Francis, 2011).
5. Repeat steps 3 and 4, until all are converged and stable (proposed changes are < 1%).

This procedure may change in the future after further investigations but constitutes current best practice.

10.3.2.4 Calculating the RBC

The SESSF Harvest Strategy Framework (HSF) was developed during 2005 (Smith et al., 2008) and has been used as a basis for providing advice on TACs in the SESSF quota management system from

2006 onwards. The HSF uses harvest control rules to determine a recommended biological catch (RBC) for each stock in the SESSF quota management system. Each stock is assigned to one of five Tier levels depending on the basis used for assessing stock status or exploitation level for that stock. Bight Redfish is classified as a Tier 1 stock as it has an agreed quantitative stock assessment.

The Tier 1 harvest control rule specifies a target and a limit biomass reference point, as well as a target fishing mortality rate. Since 2005 various values have been used for the target and the breakpoint in the rule. In 2009, AFMA directed that the 20:40:40 (B_{lim}: B_{MSY}: F_{targ}) form of the rule is used up to where fishing mortality reaches F_{targ}. Once this point is reached, the fishing mortality is set at F_{targ}. Day (2009) determined that for most SESSF stocks where the proxy values of B_{40} and B_{48} are used for B_{MSY} and B_{MEY} respectively, this form of the rule is equivalent to a 20:35:48 (B_{lim}: Inflection point: F_{targ}) strategy. An economic analysis was used to determine B_{MEY} (Kompas et al., 2012) and as a result, the 20:35:41 rule was used for Bight Redfish.

10.3.2.5 Sensitivity tests and alternative models

A number of tests were carried out to examine the sensitivity of the results of the model to some of the assumptions and data inputs:

1. M = 0.125 yr^{-1}
2. M = 0.075 yr^{-1}
3. h = 0.85
4. h = 0.65
5. 50% maturity at 23 cm
6. 50% maturity at 27 cm
7. σ_R set to 0.6
8. σ_R set to 0.8
9. Double the weighting on the length composition data
10. Halve the weighting on the length composition data
11. Double the weighting on the age-at-length data
12. Halve the weighting on the age-at-length data
13. Double the weighting on the index (CPUE and GAB-FIS) data
14. Halve the weighting on the index (CPUE and GAB-FIS) data
15. Exclude the GAB-FIS series
16. Interpolate GAB-FIS values between 2010-14 and 2014-17
17. Exclude the CPUE series
18. Extend the recruitment deviations to 2005

The results of the sensitivity tests are summarized by the following quantities (Table 10.7):

1. SSB_0: the average unexploited female spawning biomass
2. SSB_{2020}: the female spawning biomass at the start of 2020-21

3. SSB_{2020}/SSB_0: the female spawning biomass depletion level at the start of 2020-21
4. RBC_{2020}: the recommended biological catch (RBC) for 2020-21
5. $RBC_{2020-22}$: the mean RBC over the three years from 2020-21 to 2022-23
6. $RBC_{2020-24}$: the mean RBC over the five years from 2020-21 to 2023-24
7. $RBC_{longterm}$: the longterm RBC

The RBC values were calculated for the agreed base case only.

10.4 Results and Discussion

10.4.1 *The base case analysis*

10.4.1.1 Parameter estimates

Figure 10.3 shows the estimated growth curve for Bight Redfish, where the same set of parameters are estimated for males and females combined (Table 10.5). All growth parameters are estimated by the model except for L_{max} (parameter values are listed in Table 10.5).

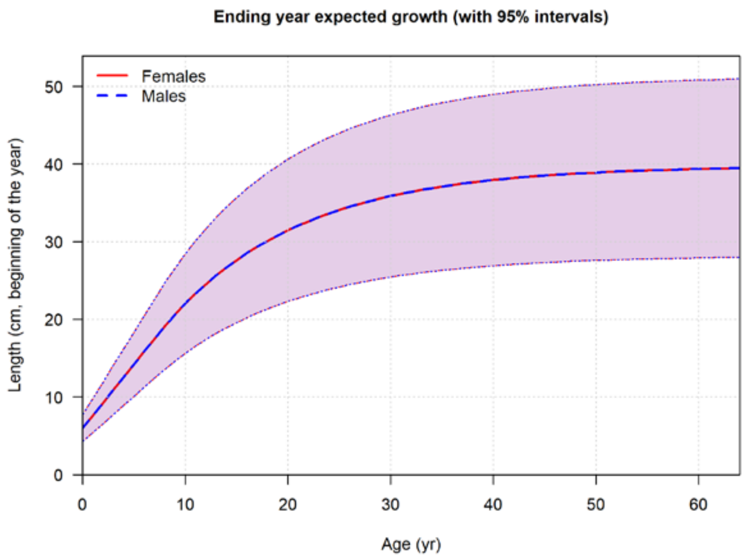

Figure 10.3. The model-estimated growth curves.

Selectivity is assumed to be logistic for all sub-fleets. The parameters that define the selectivity function are the length at 50% selection and the spread (the difference between length at 50% and length at 95% selection). The industry, port and onboard length frequency data all have the same (mirrored) selectivity (red; Figure 10.4) with very similar selectivity to the GAB-FIS fleet (green; Figure 10.4).

Table 10.5. Summary of selected parameters from the 2019 base case model. Years represent the first year of each financial year e.g., 2015 refers to 2015-16.

Description	Parameter	Combined Male/Female	Comment(s)
Years	y	1960-2018	
Recruitment Deviates	*r*	estimated 1960 - 2003	
Fleets		1 Trawl only	
Discards		none significant, not fitted	
Age classes	*a*	0 – 64 years	
Sex ratio	p_s	0.5 (1:1)	fixed
Natural mortality	*M*	0.1017 per year	estimated
Steepness	*h*	0.75	fixed
Recruitment variation	σ_r	0.7	
Female maturity		25 cm (TL)	fixed
Growth	L_{max}	37.939 cm (TL)	fixed
	K	0.110936	fitted
	L_{min}	16.7648	fitted
	CV	0.131095	fitted
		<u>Female</u>	<u>Male</u>
Length-weight (based	f_1	0.0001 cm (TL)/gm	0.002
on standard length)	f_2	2.559	2.552

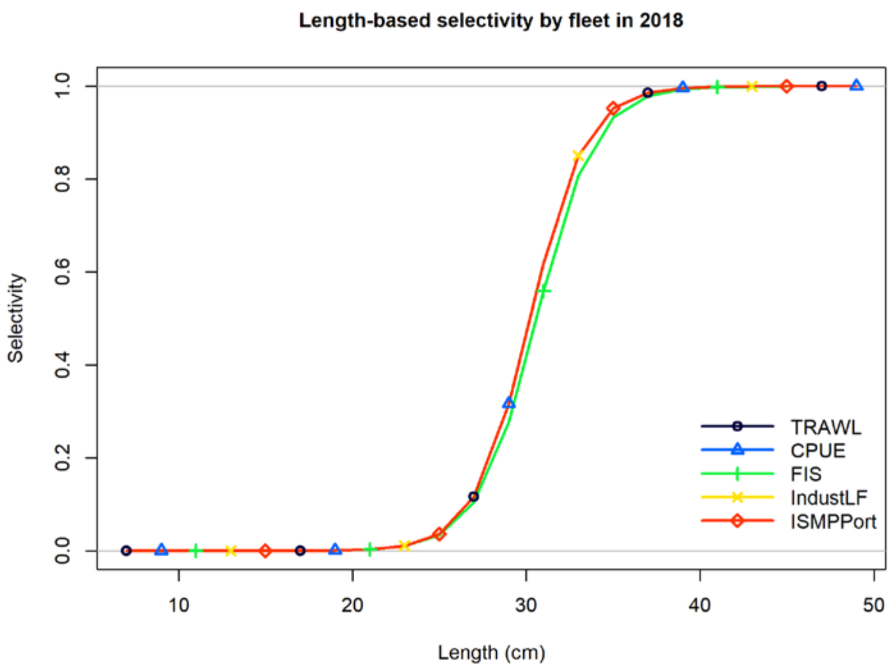

Figure 10.4. Selectivity functions by sub-fleet. The industry, port and onboard length frequency data all have the same (mirrored) selectivity (red), with very similar selectivity to the GAB-FIS sub-fleet (green).

10.4.1.2 Fits to the data

The fits to both the CPUE and GAB-FIS indices are poor (Figure 10.5). The model was not adequately able to fit the decline in the initial part of the CPUE series (i.e. 1987 to 1994). Given the longevity of this species, the modelled population dynamics are unable to reflect the more rapid changes observed in the CPUE series, both with the initial decline and later oscillations in the series. This may reflect environmentally driven availability.

The GAB-FIS estimates for 2014 and 2016 are considerably lower than the earlier GAB-FIS estimates (Figure 10.5). The fit to this series is a compromise between fitting the data up to 2010 and fitting the last two data points. As such, the influence of the last two points is to lower the overall fit to the series (which degrades the fit to the series up until 2010). As with the fits to the CPUE series, the modelled population dynamics cannot respond to the speed of the changes to the GAB-FIS indices.

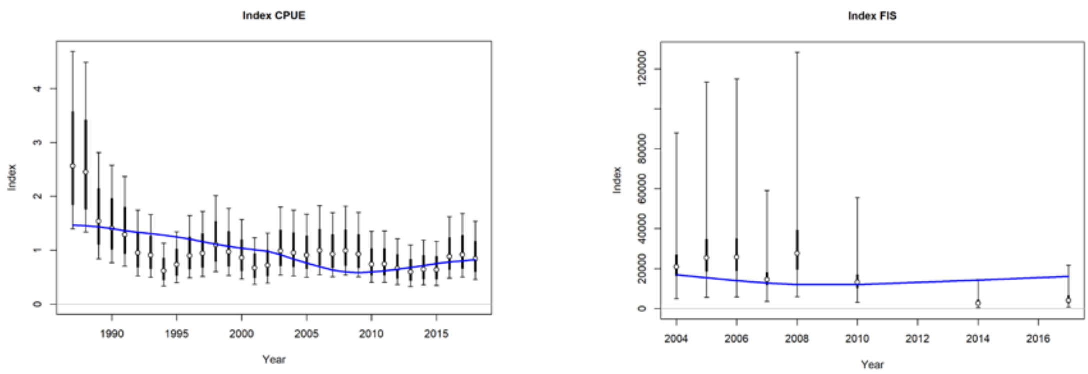

Figure 10.5. Annual Observed (circles) and model-estimated (lines) CPUE and GAB-FIS, with approximate 95% asymptotic intervals.

The base case model fitted the aggregated retained length-frequency distributions very well (Figure 10.6 and Appendix A)

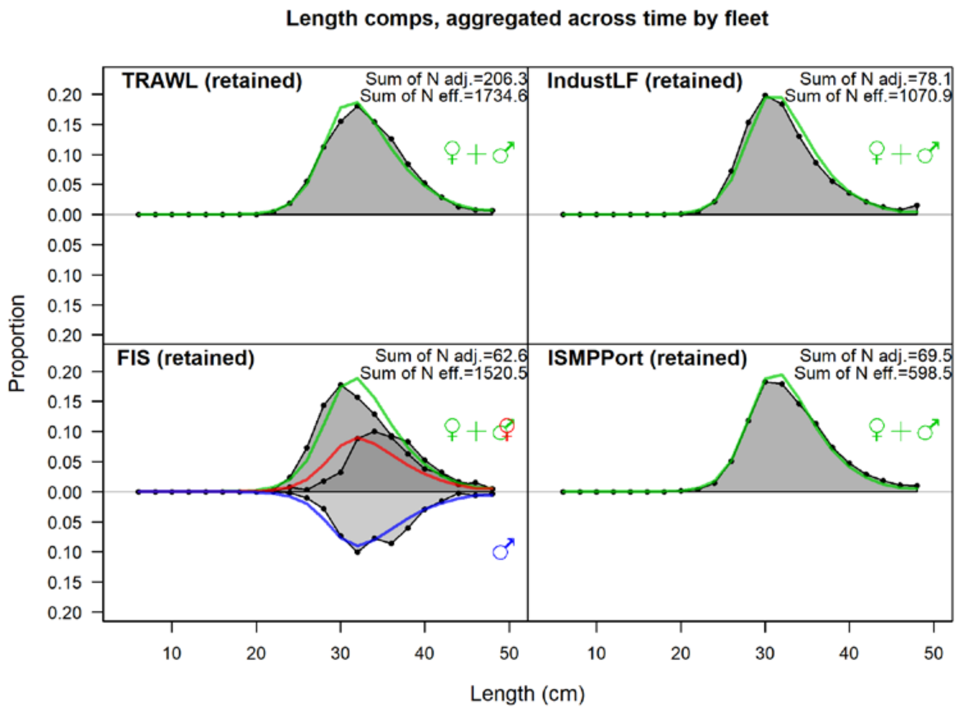

Figure 10.6. Fits to retained length compositions by fleet, separated by onboard, port and industry samples, aggregated across all years. Observed data are grey and the fitted values are shown in the green (male and female combined), red (female) and blue (male) lines.

The implied fits to the age composition data are shown in Appendix A. The age compositions were not fitted to directly, as conditional age-at-length data were used. However, the model is capable of producing implied fits to these data for years where length frequency data are also available, even though they are not included directly in the assessment. The model fits the observed age data reasonably well.

Note that there are separate implied fits to age for the port and onboard data. There is only one set of age data, but this needs to be scaled up to length data (using an age-length key) to get implied fits to age, as the age data is not representative of the stock as a whole. This scaling up to length data can be done using either the onboard length data or the port length data – so it appears that there are two sets of age data.

The conditional age-at-length data is a little noisy between years, especially for the fleets with smaller catches. The mean age seen in the conditional age-at-length data varies between about 20 and 30 years for both trawl and GAB-FIS. This variability in the age-at-length data may be due to spatial or temporal variation in collection of age samples. The fits to conditional age-at-length are reasonable.

10.4.1.3 Assessment outcomes

Figure 10.7 shows the trajectory of spawning stock status. The stock declines steadily from the beginning of the fishery in 1988 to 2004 followed by a sharper decline to 2009 due to the increase in annual catch (over 800 t) between 2003-07. The stock increases steadily between 2010-18. The comparison to the base case from the 2015 assessment is shown in Figure 10.8.

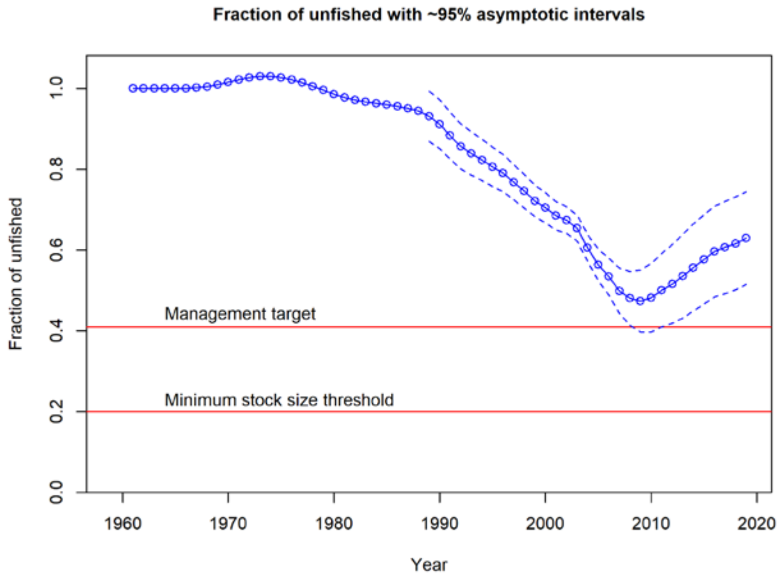

Figure 10.7. Time-trajectory of spawning biomass depletion (with approximate 95% asymptotic intervals) corresponding to the maximum posterior distribution (MPD) estimates for the base case analysis for Bight Redfish.

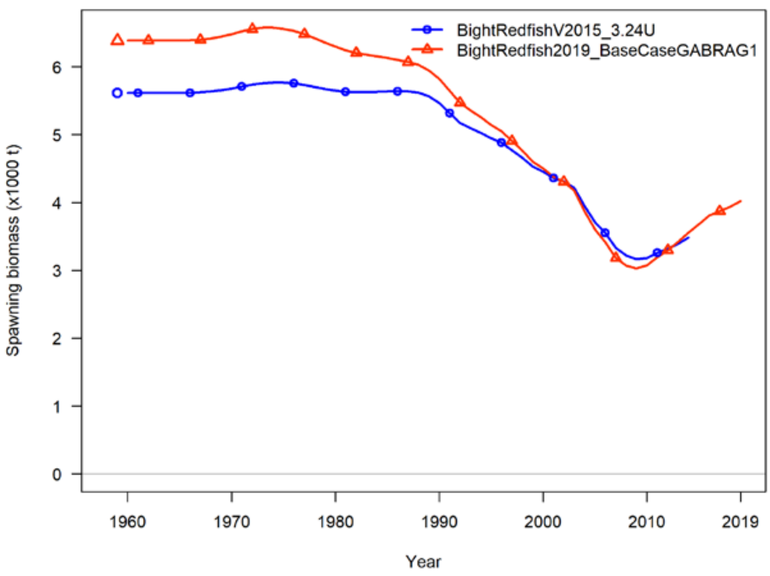

Figure 10.8. Time-trajectory of spawning biomass corresponding to the maximum posterior distribution (MPD) estimates for the base case analysis for the two base cases for the Bight Redfish assessment in 2015 and in 2019.

The time-trajectories of recruitment and recruitment deviation are shown in Figure 10.9. Estimates of recruitments since about 1980 are generally variable. Notably, seven out of the last ten recruitment deviations are above average.

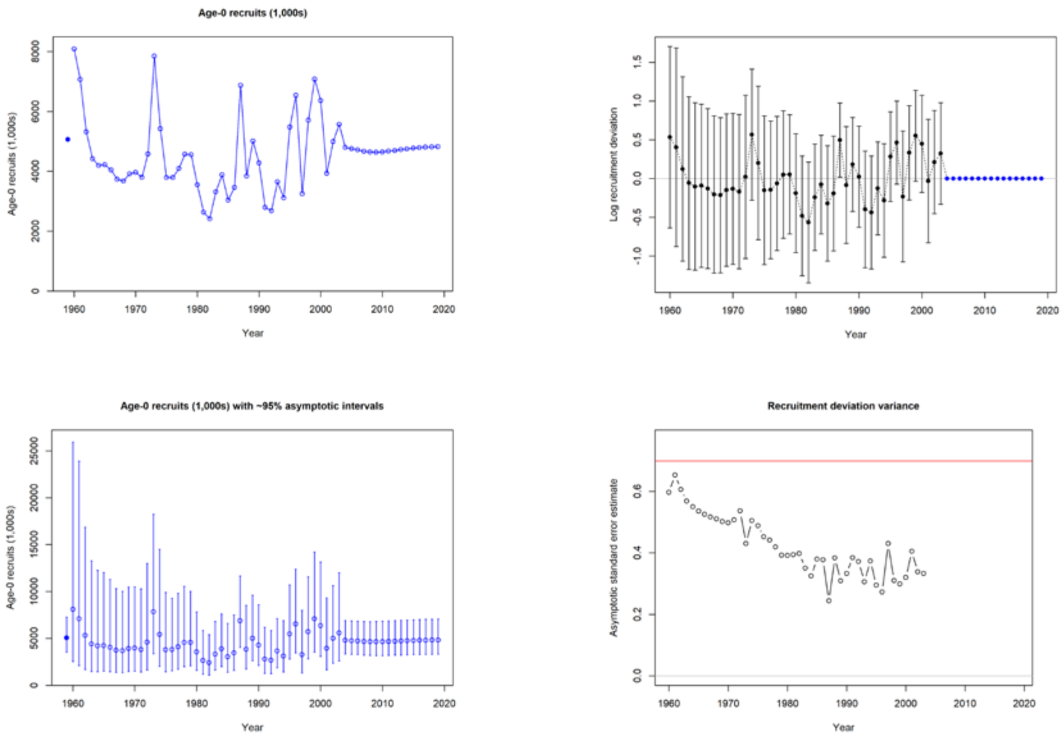

Figure 10.9. Recruitment estimation for the base case analysis. Top left: Time-trajectories of estimated recruitment numbers; Top right: time trajectory of estimated recruitment deviations; Bottom left: time-trajectories of estimated recruitment numbers with approximate 95% asymptotic intervals; Bottom right: the standard errors of recruitment deviation estimates.

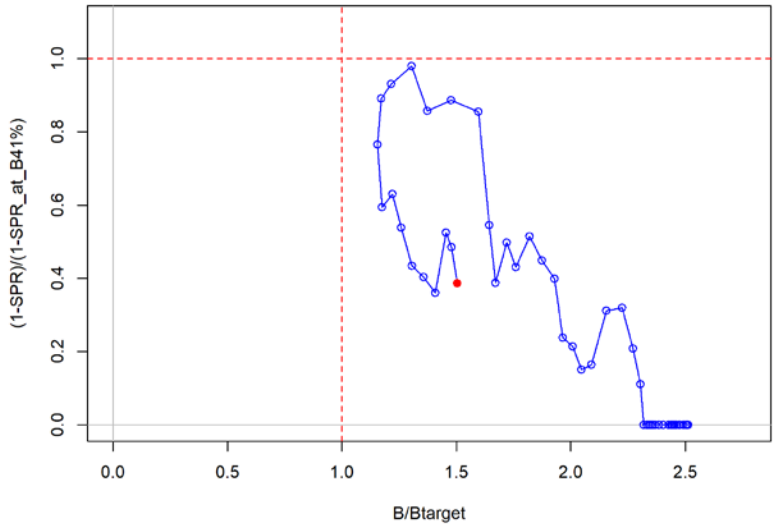

Figure 10.10. Kobe plot for the base case analysis, showing the trajectory of spawning biomass (relative to B_0) plotted against (1-SPR) as a ratio of the target, which is a proxy for fishing mortality, essentially integrating fishing mortality across fleets in the fishery.

Figure 10.10 shows a Kobe plot for the base case analysis. This plot shows a time series of spawning biomass plotted against spawning potential ratio, which provides a measure of overall fishing mortality, and shows the stepwise movement in this space from the start of the fishery, in the bottom right corner, when there was low fishing mortality and high biomass to the present day (the red dot) with biomass above the target (to right of the vertical red dashed line) and the fishing mortality below the target fishing level (below the horizontal red dashed line). This trajectory shows an increase in overall fishing mortality and a decrease in biomass up until about 2009, with a subsequent decrease in fishing mortality and increase in biomass since then.

Figure 10.11 shows the fit to the stock recruitment relationship, with outlying years identified and the fit to the bias ramp.

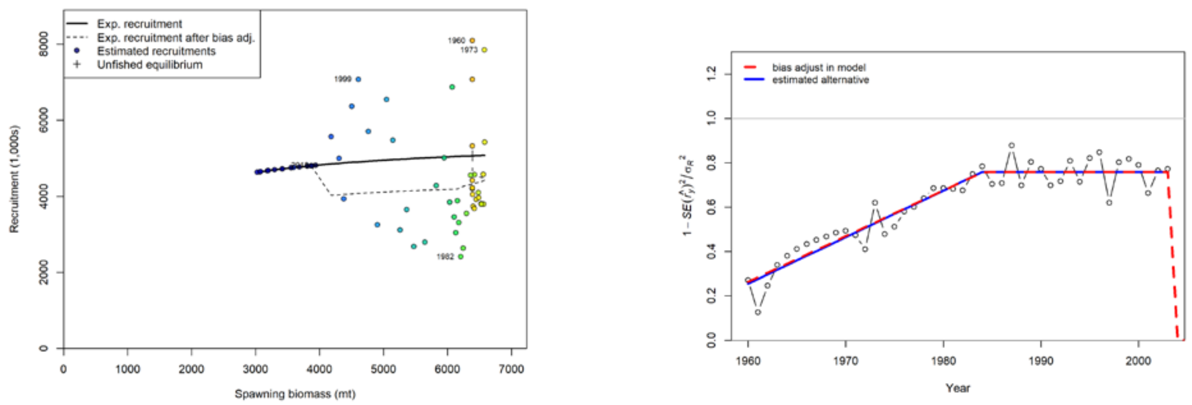

Figure 10.11. Recruitment estimation for the base case analysis. Left: the fitted stock-recruit curve and estimated recruitments; Right: bias adjustment.

The base case assessment estimates that current spawning stock biomass is 64% of unexploited stock biomass (SSB_0). The 2020 recommended biological catch (RBC) under the 20:35:41 harvest control rule is 1,024 t (Table 10.6) and the long term yield (assuming average recruitment in the future) is 607 t (Table 10.7). The average RBC over the three year period: 2020-2022 is 963 t (Table 10.7) and over the five year period 2020-2024, the average RBC is 912 t (Table 10.7). The RBCs for each individual year from 2020-24 are listed in Table 10.6 for the base case.

Table 10.6. Yearly projected RBCs (t) across all fleets under the 20:35:41 harvest control rules: assuming average recruitment from 2004.

YEAR	RBC (t)
2020	1024
2021	961
2022	905
2023	856
2024	813

10.4.2 *Likelihood profiles*

As stated by Punt (2018), likelihood profiles are a standard component of the toolbox of applied statisticians. They are most often used to obtain a 95% confidence interval for a parameter of interest. Many stock assessments "fix" key parameters such as *M* and steepness based on *a priori* considerations. Likelihood profiles can be used to evaluate whether there is evidence in the data to support fixing a parameter at a chosen value. If the parameter is within the entire range of the 95% confidence interval, this provides no support in the data to change the fixed value. If the fixed value is outside the 95% confidence interval, it would be reasonable for a review panel to ask why the parameter was fixed and not estimated, and if the value is to be fixed, on what basis and why should what amounts to inconsistency with the data be ignored. Integrated stock assessments include multiple data sources (e.g., commonly catch-rates, length-compositions, and age-compositions) that may be in conflict, due for example to inconsistencies in sampling, but more commonly owing to incorrect assumptions (e.g., assuming that catch-rates are linearly related to abundance), i.e. model-misspecification. Likelihood profiles can be used as a diagnostic to identify these data conflicts (Punt, 2018).

Standard parameters to consider are natural mortality (*M*), steepness (*h*), virgin spawning biomass (SSB_0), 2018 spawning biomass (SSB_{2018}) and spawning stock biomass relative to SSB_0 (depletion).

10.4.2.1 Natural mortality (M)

For Bight Redfish, the likelihood profile for natural mortality, *M*, is shown in Figure 10.12 and Figure 10.13 with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. This parameter is estimated in the model (M=0.1017 y^{-1}) and the likelihood profile suggests that it is well estimated. The index data (suggest higher mortality) and length data (suggest lower mortality) show some conflict. The age data are most influential on the total likelihood, with similar minimum values to the total likelihood. The confidence intervals on *M* are narrow ranging between approximately 0.093 and 0.11.

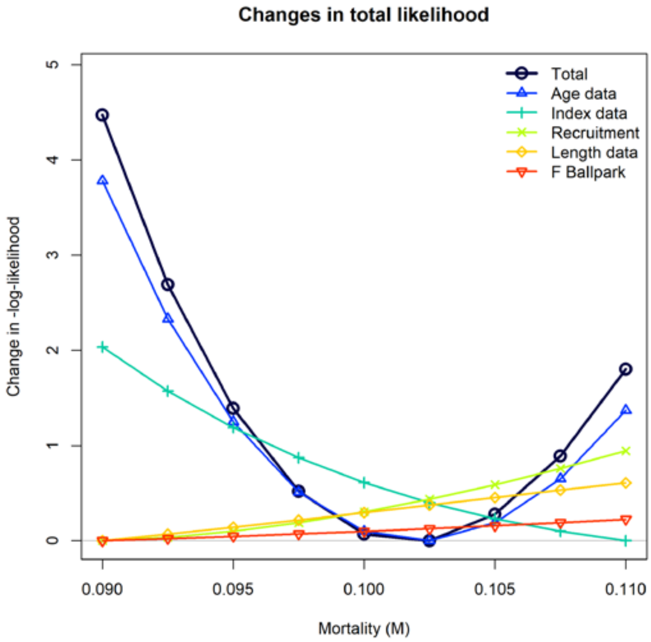

Figure 10.12. The likelihood profile for natural mortality (*M*), ranging from 0.09 to 0.11 yr^{-1}. The estimated value for *M* is 0.1017 yr^{-1}.

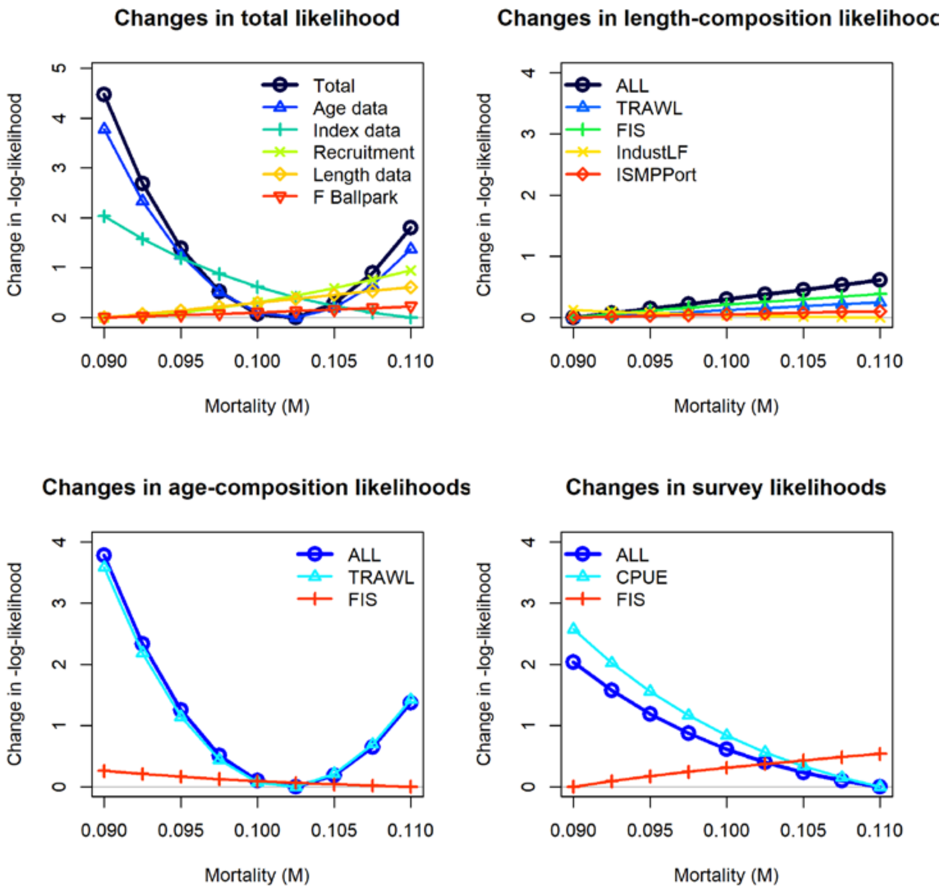

Figure 10.13. Piner plot for the likelihood profile for natural mortality (*M*), showing components of the change in likelihood for length, age and indices (CPUE; GAB-FIS) in addition to the changes in the total likelihood.

10.4.2.2 Steepness (h)

A likelihood profile on steepness, *h*, shows the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours (Figure 10.14). This figure shows that steepness cannot be well estimated, as the 95% confidence limits are not crossed (log-likelihood of 1.92 on the y-axis) by the total likelihood within the range considered (*h* = 0.6 to 0.8). This is not surprising given the stock in the base case model has not been depleted to levels that would enable steepness to be estimated. It is therefore reasonable to fix steepness at 0.75.

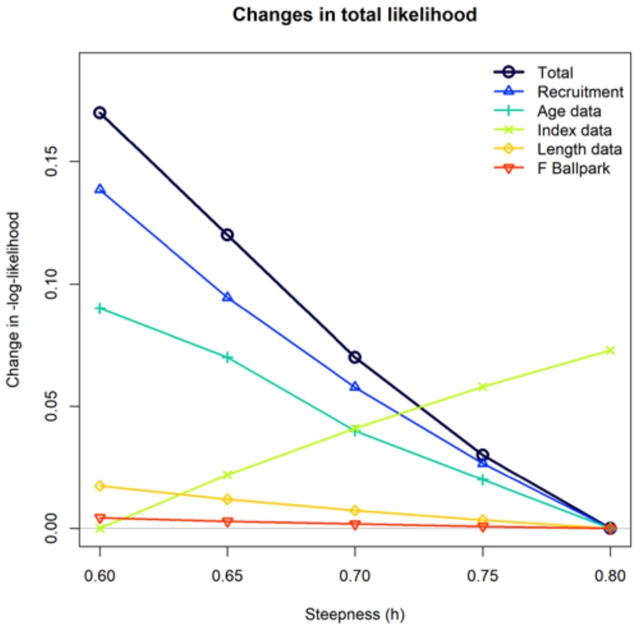

Figure 10.14. The likelihood profile for steepness (*h*), ranging from 0.6 to 0.8. The fixed value for *h* is 0.75.

10.4.2.3 Virgin spawning biomass (SSB_0)

A likelihood profile for virgin spawning biomass (SSB_0) is shown in Figure 10.15 and Figure 10.16 with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. SSB_0 is a derived parameter which is linked to the estimated parameters R_0, which is the average equilibrium recruitment and constructing this likelihood profile. To construct a likelihood profile on SSB_0 requires setting up an additional "fleet" with a single data point (in 1960) with very low standard error, essentially adding a "highly precise survey" of spawning biomass, setting the selectivity type to 30 (an index of *SSB*) and then allowing this spawning biomass value to vary between runs. The likelihood profile suggests a broad range of plausible values for SSB_0 ranging between around 6,000 and 9,500 t with the most likely value at around 7,300 t. The important data sources in providing information on SSB_0 are the index data and age data (Trawl). SSB_0 needs to be sufficiently high to enable the historical catches to be sustained, so this results in the recruitment component of the likelihood providing an upper bound on SSB_0 and the fits to the age data deteriorate with smaller values of SSB_0.

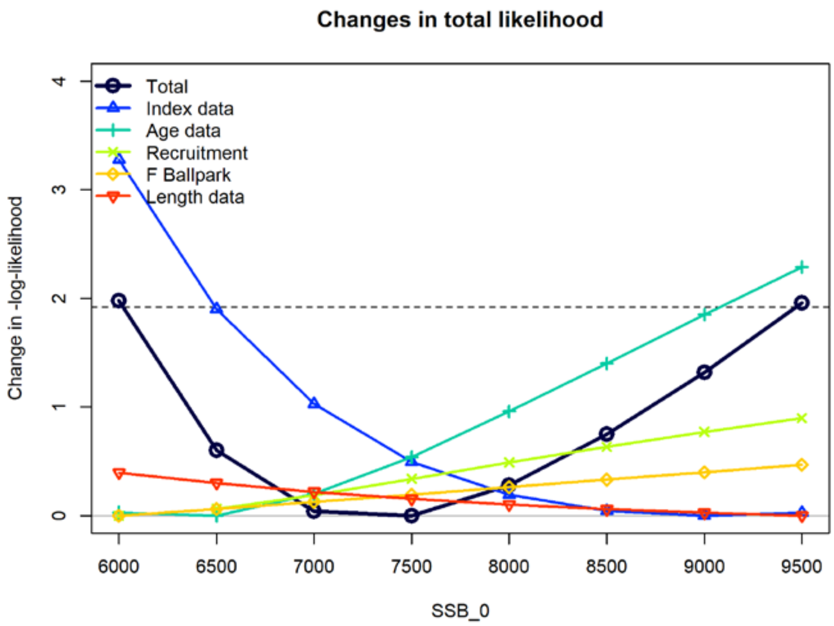

Figure 10.15. The likelihood profile for virgin spawning biomass, with SSB_0 ranging from 2,000 to 800 t. The estimated value for SSB_0 is 7,295 t.

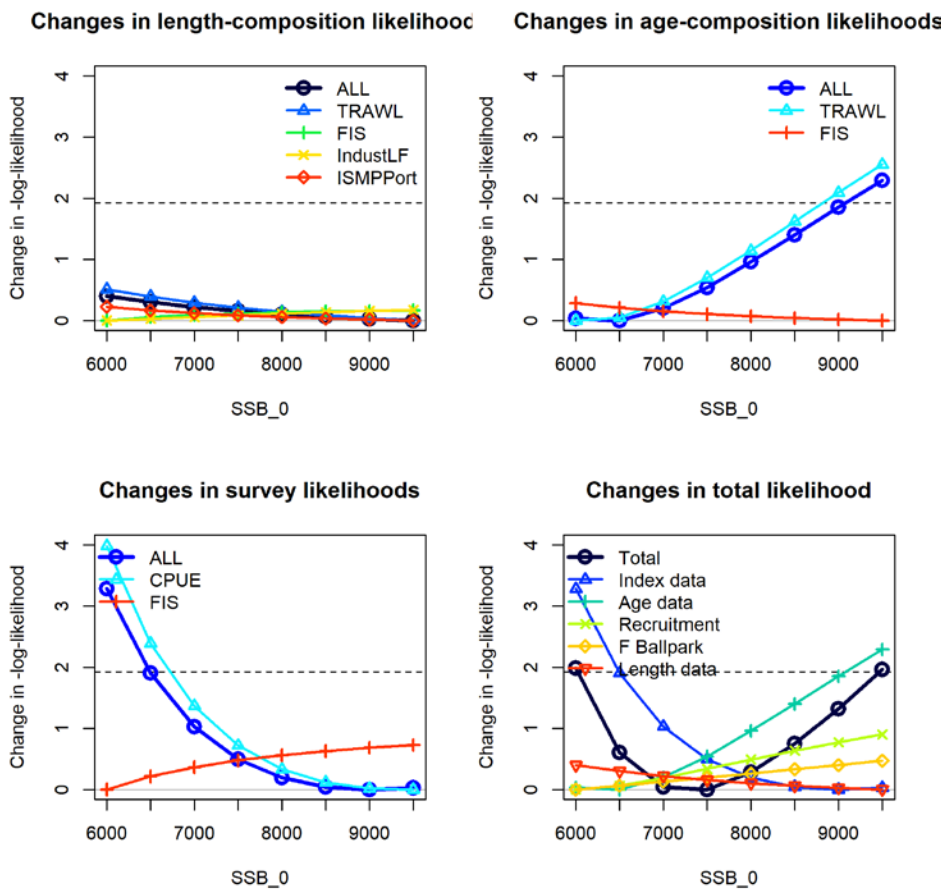

Figure 10.16. Piner plot for the likelihood profile for 2018 spawning biomass (SSB_0), showing components of the change in likelihood for length, age and indices (CPUE, GAB-FIS) in addition to the changes in the total likelihood.

10.4.2.4 Current (2018) spawning biomass (SSB_{2018})

A likelihood profile for current (2018) spawning biomass (SSB_{2018}), using the same techniques as for SSB_0, is shown in Figure 10.17 and Figure 10.18 with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours.

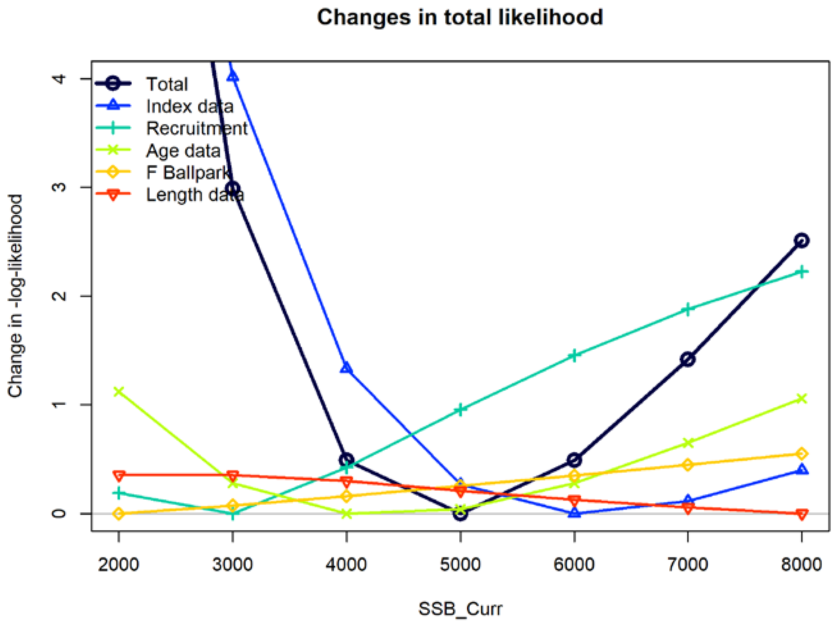

Figure 10.17. The likelihood profile for current (2018) spawning biomass, with SSB_{2018} ranging from 3,500 to 7,500 t. The estimated value for SSB_{2018} is 4,879 t.

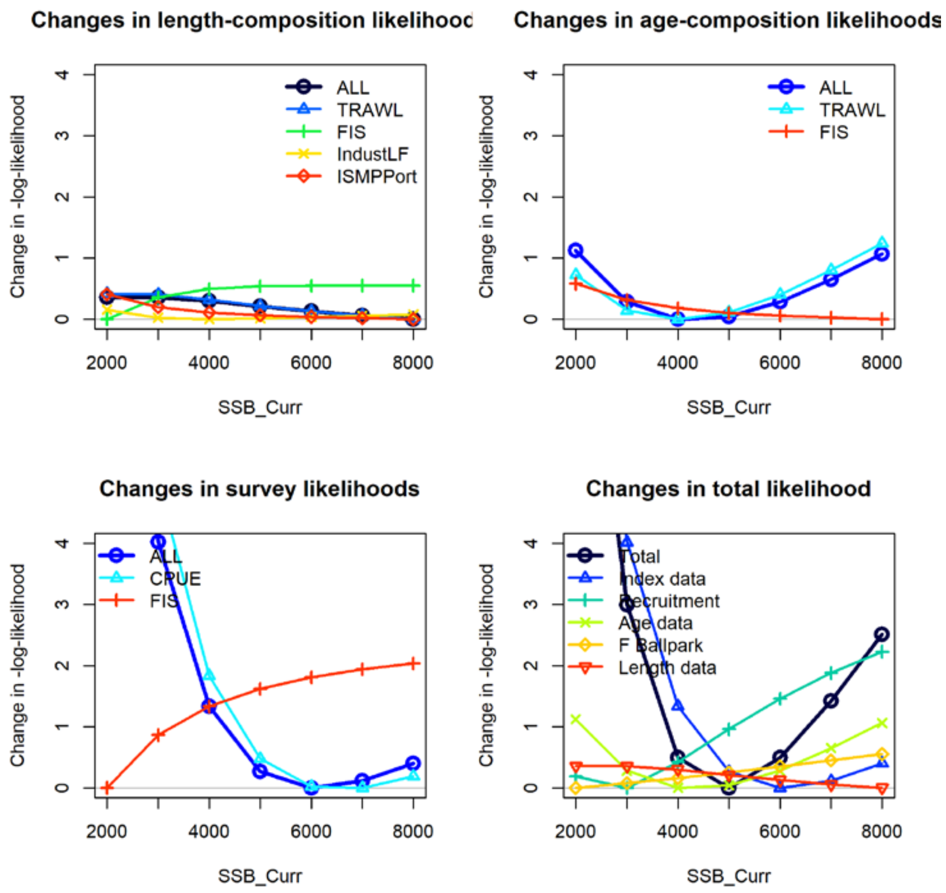

Figure 10.18. Piner plot for the likelihood profile for current (2018) spawning biomass (*SSB*$_{2018}$), showing components of the change in likelihood for length, age and indices (CPUE, GAB-FIS) in addition to the changes in the total likelihood.

10.4.2.5 Relative Spawning Stock Biomass (Depletion)

A likelihood profile for current (2018) spawning stock biomass relative to SSB_0 (depletion) is shown in Figure 10.19 and Figure 10.20 with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. Note that depletion here is calculated for an earlier year (2018-19), so it does not require the projected catch in 2019-20. As such, the depletion implied from this likelihood profile is different to the estimated value reported above for the projected 2020-21 spawning stock biomass (70% of SSB_0).

This likelihood profile suggests a broad range of plausible values for depletion ranging between around 0.55 and 0.82 with the most likely value at around 0.65. The important data sources in providing information on depletion are the index data and estimated recruitments.

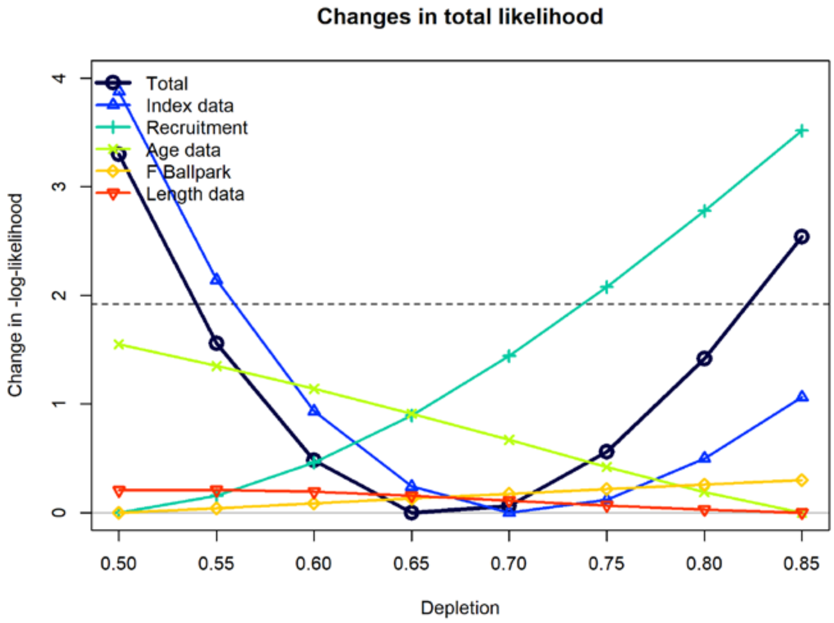

Figure 10.19. The likelihood profile for relative spawning stock biomass (depletion) in 2018, which suggests an optimal value of about 0.65 in 2018.

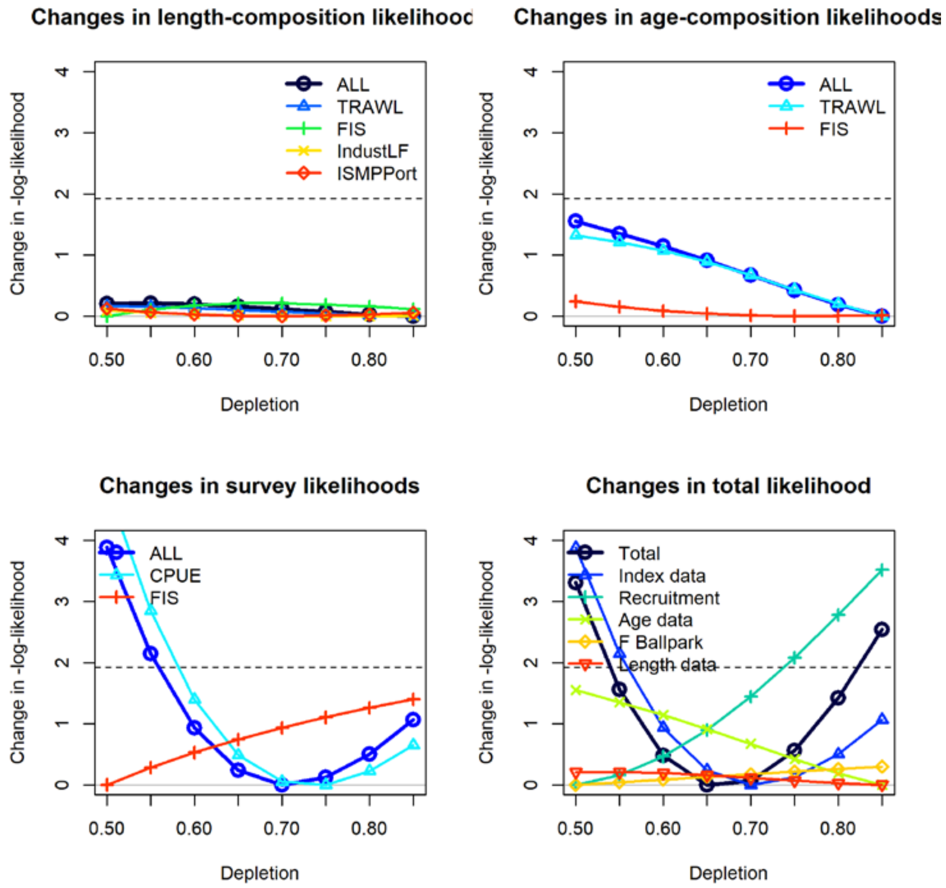

Figure 10.20. Piner plot for the likelihood profile for relative spawning stock biomass (depletion) in 2018-19, showing components of the change in likelihood for length, age and indices (CPUE, GAB-FIS) in addition to the changes in the total likelihood.

10.4.3 *Sensitivies*

Results of the sensitivity tests are shown in Table 10.7. The results are very sensitive to the assumed value for natural mortality (*M*). Much of this variability is due to the estimated current depletion level, which can be as low as 39% SSB_0 when *M* is 0.075. In addition, the results were quite sensitive when the CPUE index is excluded (i.e., using GAB-FIS as the only abundance index). It was somewhat sensitive to extending recruitment deviation estimates for an additional two years (i.e., up until 2005). However, this sensitivity produces unrealistically high recruitments in the last two years with little age and length data to inform them. Therefore, this sensitivity is unlikely to be considered as an acceptable alternative model. For all other standard sensitivities, there is limited variability in current depletion, ranging between 58% and 68% SSB_0. Adding additional interpolated FIS abundance indices made very little difference, to the estimates of spawning biomass or to the fits to the abundance indices.

Unweighted likelihood components for the base case and differences for the sensitivities largely show small (insignificant) changes in likelihood (Table 10.8). Sensitivities based on changes to *M* and excluding CPUE show considerably larger likelihoods (worse fits to: age in cases 1 and 2; survey in case 17).

Table 10.7. Summary of results for the base case and sensitivity tests. Recommended biological catches (RBCs) are only shown for agreed base case model (Case 0). Base case: 20:35:41; *M* 0.1017, *h* 0.75, 50% maturity 25 cm.

Case	Description	SSB_0	SSB_{2020}	SSB_{2020}/SSB_0	RBC_{2020}	$RBC_{2020\text{-}22}$	$RBC_{2020\text{-}24}$	$RBC_{longterm}$
0	Base case	6,387	4,093	0.64	1,024	963	912	607
1	*M* 0.125	8,854	6,909	0.78				
2	*M* 0.075	4,674	1,805	0.39				
3	*h* 0.85	6,369	4,160	0.65				
4	*h* 0.65	6,412	4,011	0.63				
5	50% maturity at 23 cm	6,939	4,598	0.66				
6	50% maturity at 27 cm	5,765	3,547	0.62				
7	$\sigma_R = 0.6$	6,016	3,850	0.64				
8	$\sigma_R = 0.8$	6,839	4,364	0.64				
9	wt x 2 length comp	6,398	4,058	0.63				
10	wt x 0.5 length comp	6,365	4,099	0.64				
11	wt x 2 age comp	5,886	3,566	0.61				
12	wt x 0.5 age comp	6,945	4,588	0.66				
13	wt x 2 index	7,023	4,792	0.68				
14	wt x 0.5 index	5,801	3,368	0.58				
15	no FIS	6,502	4,264	0.66				
16	Interpolate FIS	6,314	3,988	0.63				
17	No CPUE	4,910	2,196	0.45				
18	RecDev 2005	6,701	4,670	0.70				

Table 10.8. Summary of likelihood components for the base case and sensitivity tests. Likelihood components are unweighted, and cases 1-18 are shown as differences from the base case. A negative value indicates a better fit, a positive value a worse fit.

Case	Description	Likelihood					
		TOTAL	Survey	Discard	Length comp	Age comp	Recruitment
0	Base case	1409.02	-19.29	0.00	41.21	1392.65	-5.94
1	*M* 0.125	10.12	-2.22	0.00	0.79	9.71	1.57
2	*M* 0.075	25.06	9.82	0.00	-0.81	15.62	0.62
3	*h* 0.85	-0.18	-0.01	0.00	-0.01	-0.13	-0.02
4	*h* 0.65	0.23	0.02	0.00	0.02	0.18	0.02
5	50% maturity at 23 cm	-0.03	-0.01	0.00	0.00	-0.02	0.00
6	50% maturity at 27 cm	0.02	0.01	0.00	0.00	0.02	0.00
7	σ_R = 0.6	-2.26	0.26	0.00	0.01	0.93	-3.43
8	σ_R = 0.8	2.03	-0.25	0.00	-0.01	-0.83	3.09
9	wt x 2 length comp	0.33	0.25	0.00	-0.72	0.80	-0.01
10	wt x 0.5 length comp	0.14	-0.12	0.00	0.54	-0.28	0.01
11	wt x 2 age comp	0.85	1.99	0.00	0.38	-2.16	0.70
12	wt x 0.5 age comp	1.17	-1.46	0.00	-0.49	3.90	-0.86
13	wt x 2 index	0.70	-1.73	0.00	0.17	2.05	0.14
14	wt x 0.5 index	0.77	2.66	0.00	-0.17	-1.40	-0.25
15	no FIS	-2.37	-2.66	0.00	0.06	0.09	0.13
16	Interpolate FIS	2.09	2.26	0.00	-0.04	-0.05	-0.08
17	No CPUE	17.35	20.44	0.00	-0.48	-2.10	-0.34
18	RecDev 2005	-1.90	-0.26	0.00	-0.12	-2.00	0.48

10.4.4 *Future work*

We attempted to incorporate two additional sensitivities (i) CPUE up to end of FY 2019 (i.e., adding two additional months) and (ii) 2018 conditional age at length data. Apparent issues with data quality and checking prevented these sensitivities being completed and presented in this report.

10.5 Acknowledgements

Age data was provided by Kyne Krusic-Golub (Fish Ageing Services), Integrated Scientific Monitoring Program (ISMP) and Commonwealth logbook and Catch Disposal Record (CDR) data were provided by John Garvey (AFMA). Thanks also goes to the CSIRO contributors: Mike Fuller, Roy Deng, Franzis Althaus and Robin Thomson for pre-processing the data. Geoff Tuck (CSIRO), Robin Thomson, Malcolm Haddon (CSIRO) and Ian Taylor (NOAA) are thanked for helpful discussions on this work. André Punt (CSIRO) updated the ageing error matrix. Malcolm Haddon provided code for auto-tuning and Athol Whitten provided R code for organising plots. Geoff Tuck is also thanked for review of this work.

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10.7 Appendix A

A.1 Base case diagnostics

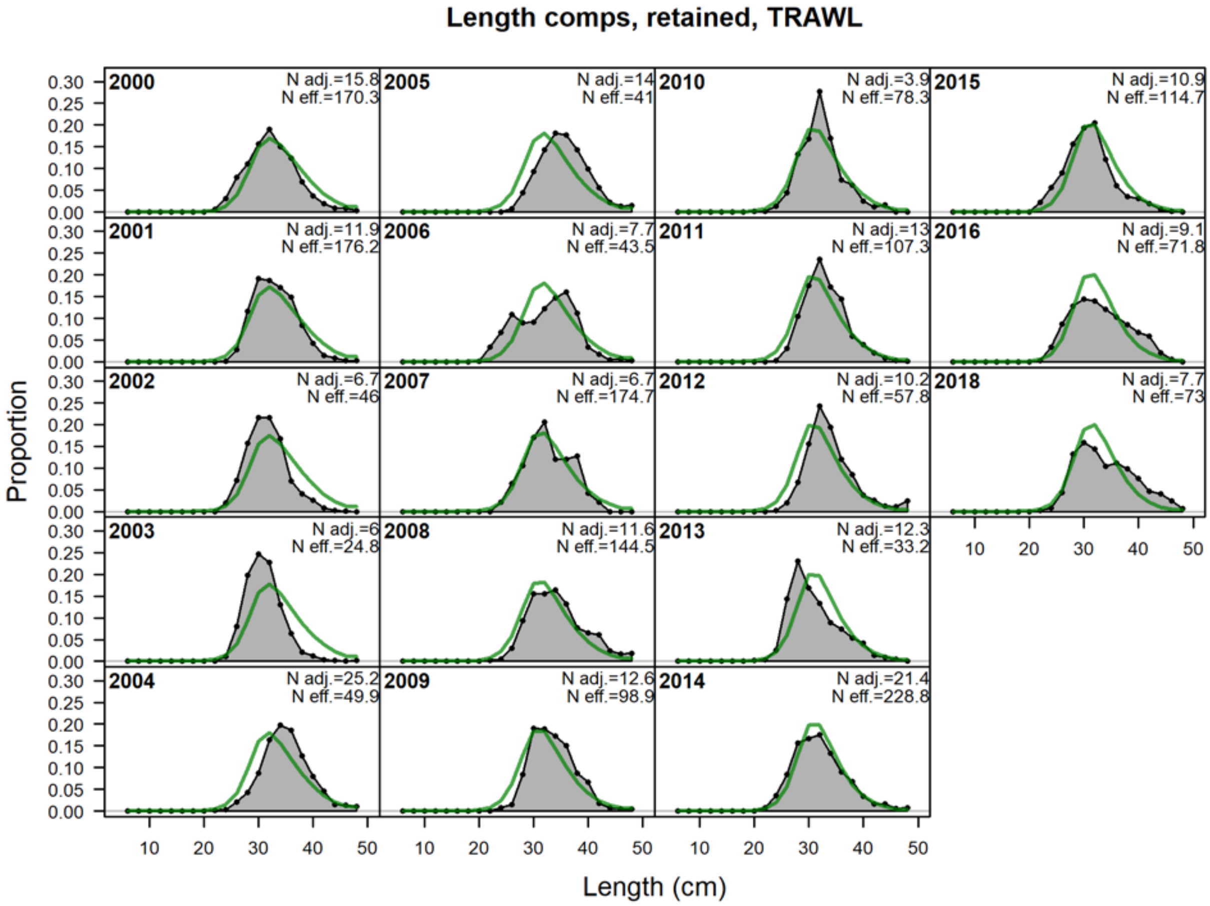

Figure A 10.1. Length composition fits - trawl retained.

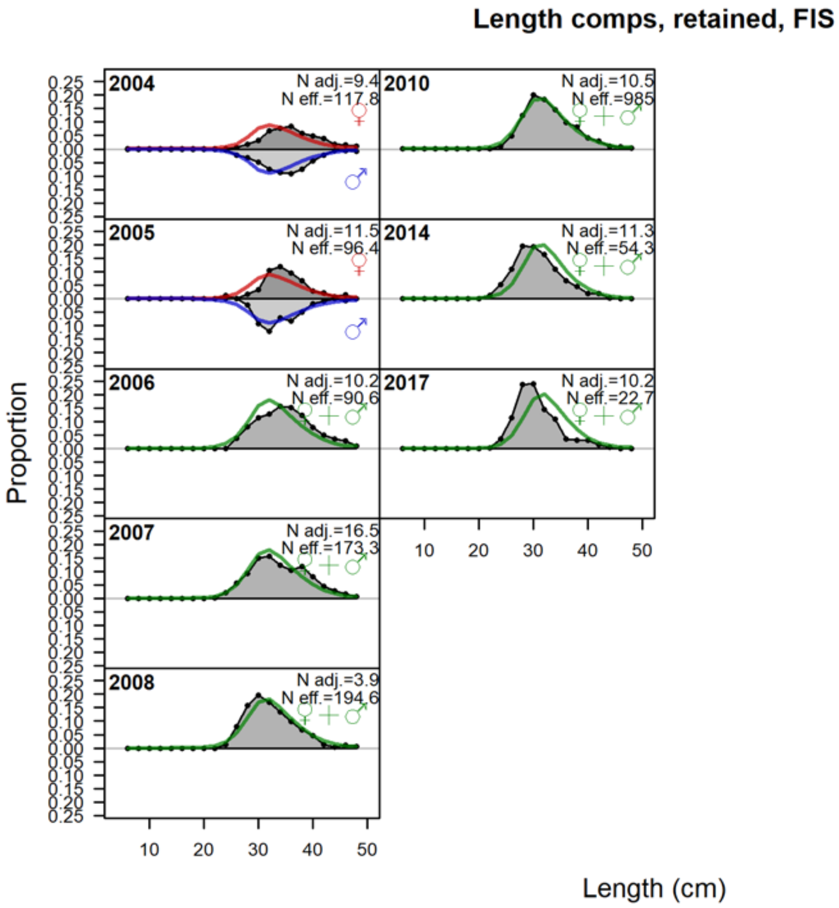

Figure A 10.2. Length composition fits - FIS retained.

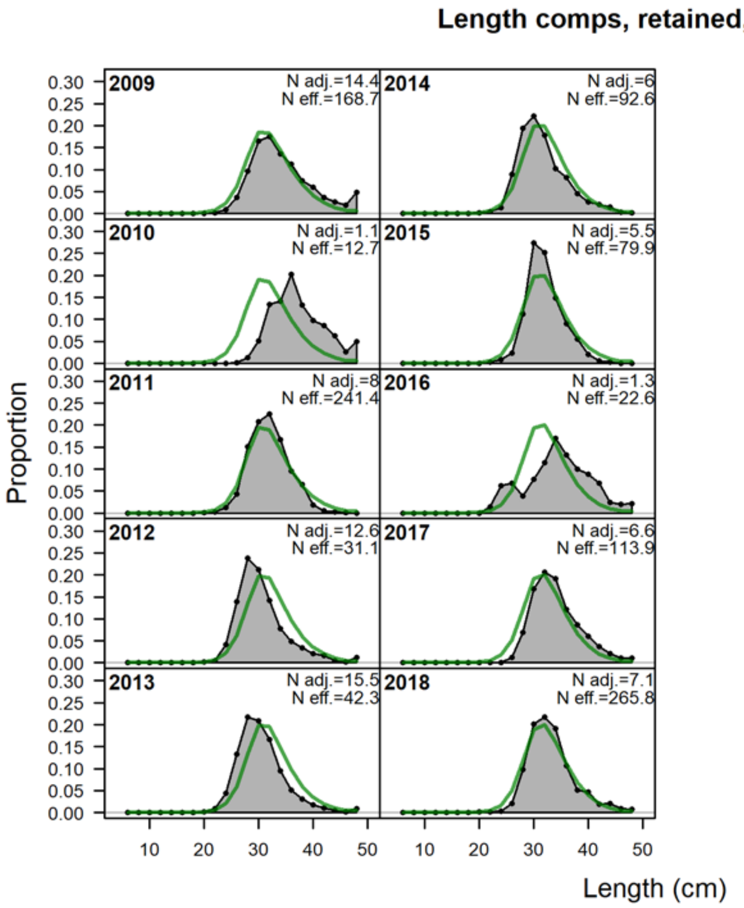

Figure A 10.3. Length composition fits - Industry.

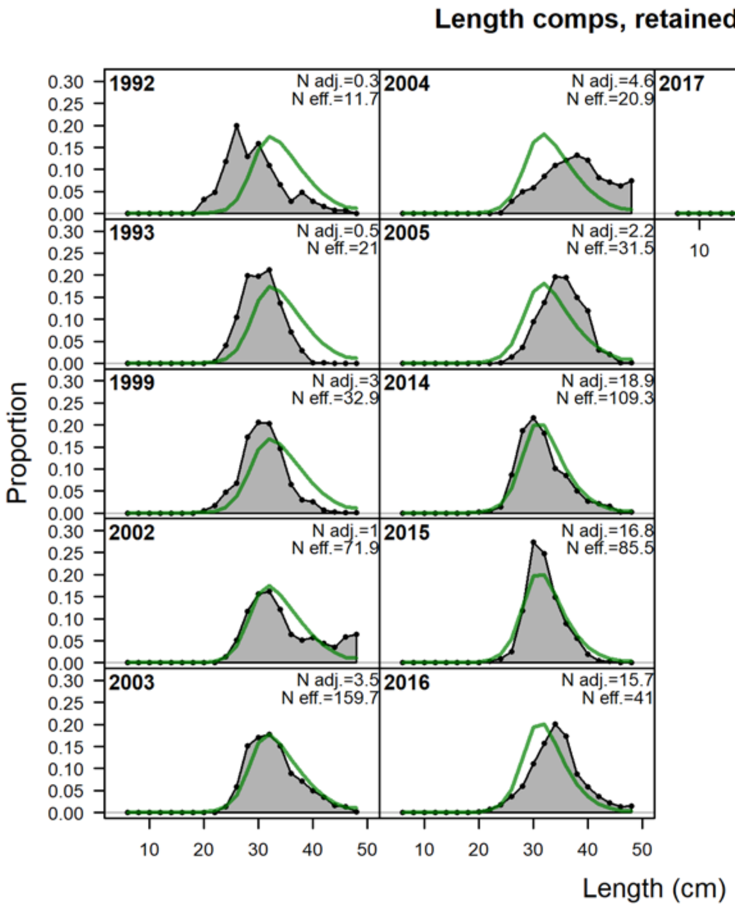

Figure A 10.4. Port length composition fits – ISMP.

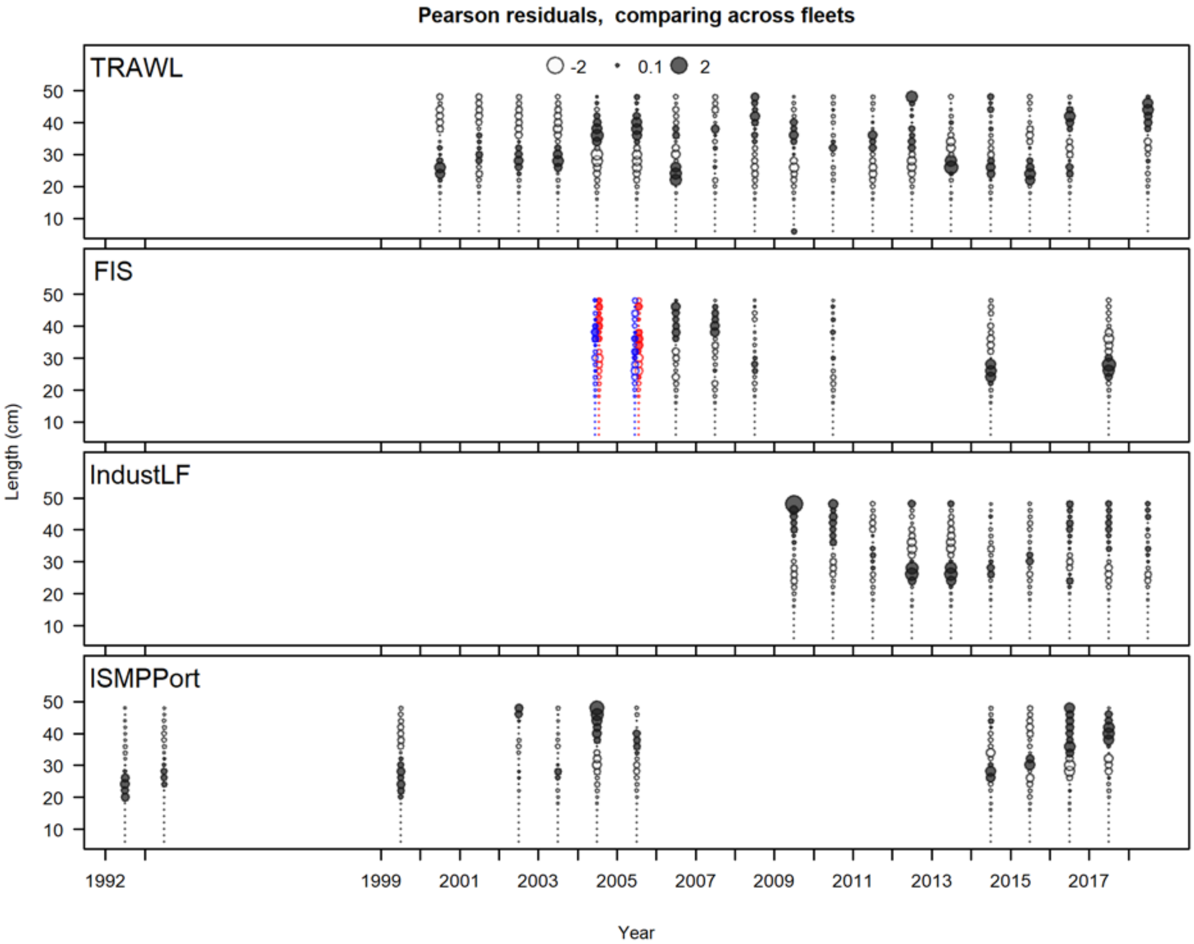

Figure A 10.5. Residuals from the annual length compositions (retained) displayed by year and sub-fleet.

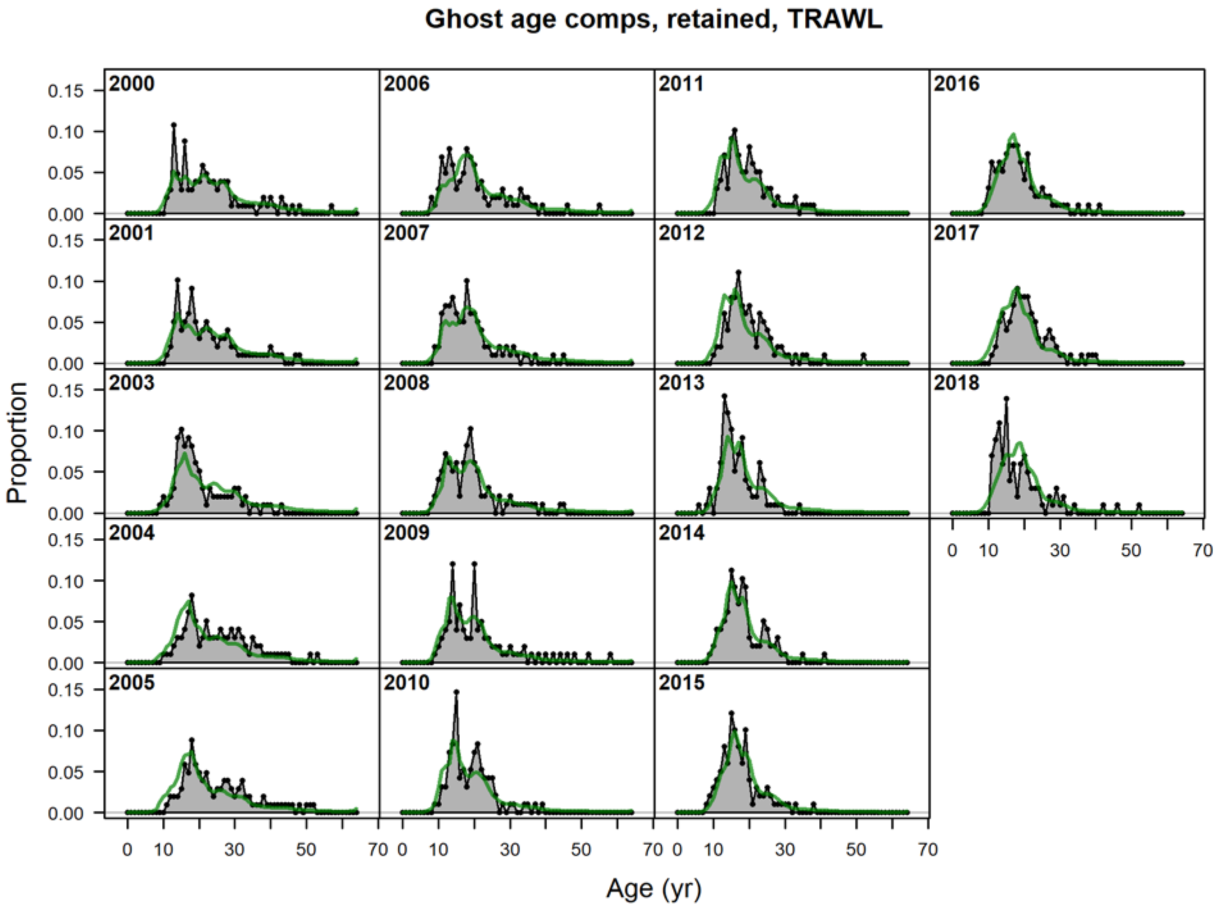

Figure A 10.6. Implied fits to age - Trawl onboard (retained).

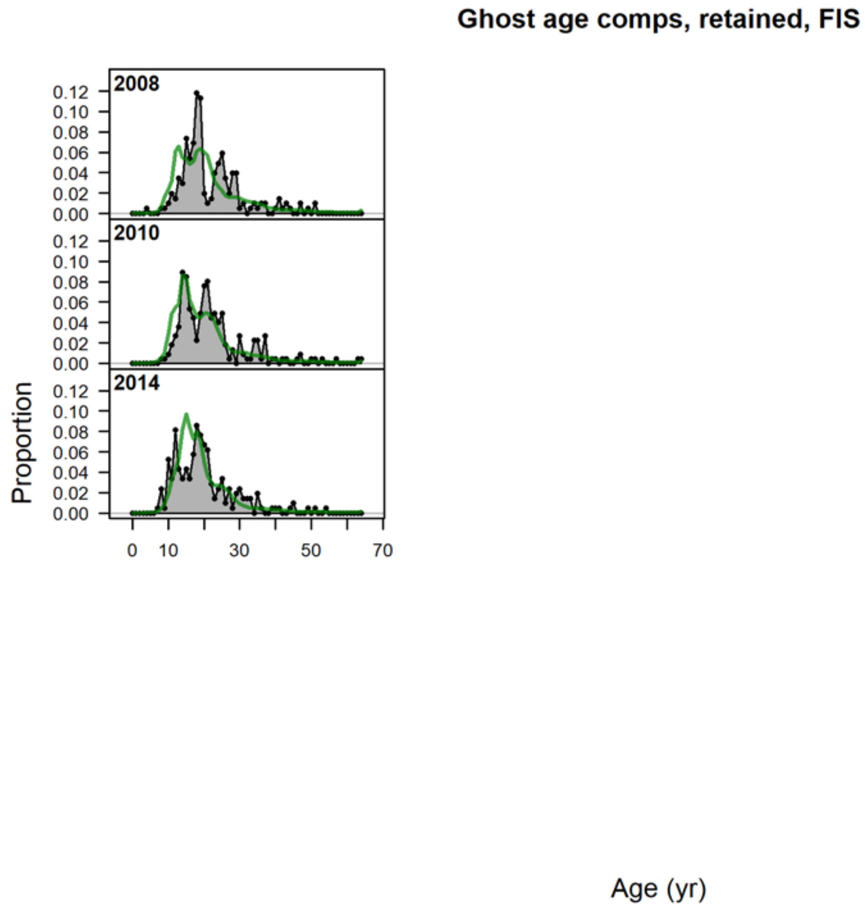

Figure A 10.7. Implied fits to age: GAB-FIS (retained).

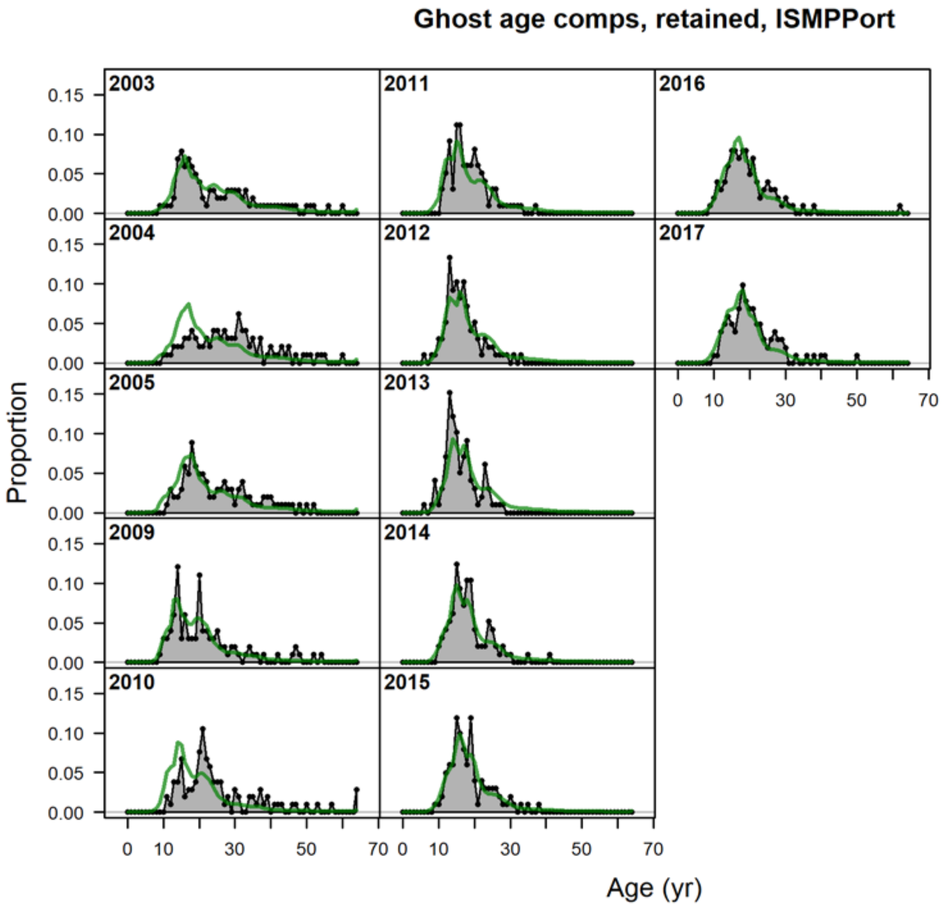

Figure A 10.8. Implied fits to age - ISMP Port.

11. Deepwater flathead (*Neoplatycephalus conatus*) stock assessment based on data up to 2018/19 – development of a preliminary base case

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11.1 Executive Summary

This document presents a suggested base case for an updated quantitative Tier 1 deepwater flathead (*Neoplatycephalus conatus*) assessment for presentation at the first GABRAG meeting in November 2019. The last full assessment was presented in Haddon (2016). The preliminary base case has been updated by the inclusion of data up to the end of 2018/19, which entails an additional 3 years of catch, CPUE, length and age data and ageing error updates since the 2016 assessment, and incorporation of survey results from the Fishery Independent Survey (GABFIS). This document describes the process used to develop a preliminary base case for deepwater flathead through the sequential updating of recent data used by the stock assessment, using the stock assessment package Stock Synthesis (SS-V3.40.14).

Results show reasonably good fits to the catch rate data, length data and conditional age-at-length data. This assessment estimates that the projected 2020/21 spawning stock biomass will be 45% of virgin stock biomass (projected assuming 2018/19 catches in 2019/20), compared to 45% at the start of 2016/17 from the 2016 assessment (Haddon 2016). The inclusion of new and updated data in the current assessment has led to some changes in the shape of the spawning biomass trajectory, but the depletion remains near the target of 43%. While the updated assessment generally fits all the data sources well, the fit to the two most recent GABFIS points is poor.

A sensitivity was conducted by including the Danish seine catches as a separate fleet. While the trajectory of biomass changed (generally a larger biomass through the 1990s and early 2000s), the final year depletion was similar to the preliminary base case model. The Danish seine fleet has not previously been included because of a lack of length and age samples. If this fleet continues to operate in the GAB, then it is important that sufficient samples are collected. At the moment, only three years of length frequency data and two years of age data are available.

11.2 Introduction

11.2.1 *Bridging from 2016 to 2019 assessments*

The previous full quantitative assessment for deepwater flathead was conducted in 2016 (Haddon, 2016) using Stock Synthesis (version SS-V3.24Z, Methot and Wetzel, 2013, Methot, 2015). The 2019 assessment uses the current version of Stock Synthesis (version SS-V3.30.14.05, Methot, 2019), which includes some changes from SS_V3.24Z.

As a first step in the process of bridging to a new model, the model was translated from version SS-V3.24Z (Methot, 2015) to version SS-V3.30.14.05 (Methot et al., 2019) using the same data and model structure used in the 2016 assessment. Once this translation was complete, improved features unavailable in SS-V3.24Z were incorporated into the SS-V3.30 assessment. These included allowing smaller lower bounds on minimum sample sizes and estimating a parameter that tunes the standard deviation to abundance indices. Following this step, the model was re-tuned using the most recent tuning protocols, thus allowing the examination of changes to both assessment practices and the tuning procedure on the previous model structure. These changes to software and tuning practices are likely to lead to changes to key model outputs, such as the estimates of depletion and the trajectory of spawning biomass. This initial bridging phase (Bridge 1) highlights changes that have occurred since 2016 simply through changes to software and assessment practices. The subsequent bridging exercise (Bridge 2) then sequentially updates the model with new data through to 2018/19.

The second part of the bridging analysis includes updating historical data (up to 2015/16), followed by including the data from 2016/17 - 2018/19 into the model. These additional data included new catch, CPUE, FIS abundance indices, length composition data, conditional age-at-length data and an updated ageing error matrix. Additional GAB FIS data were also included: 2017/18 FIS abundance index; FIS length frequencies and FIS conditional age-at-length data (Knuckey et al., 2018). The last year of recruitment estimation was extended to 2013 (changed from 2011 in Haddon (2016)).

The use of updated software and the inclusion of additional data resulted in some differences in the fits to CPUE, conditional age-at-length data and length composition data. The usual process of bridging to a new model by adding new data piecewise and analysing which components of the data could be attributed to changes in the assessment outcome was conducted, with the details outlined below.

11.2.2 *Update to Stock Synthesis SSV-3.30 (Bridge 1)*

The 2016 deepwater flathead assessment (FLD2016_SS3_24z) was initially converted to the most recent version of the software, Stock Synthesis version SS-V3.30.14.05 (V3_30). Figure 11.1 shows that the differences in the assessment results from this step were minimal.

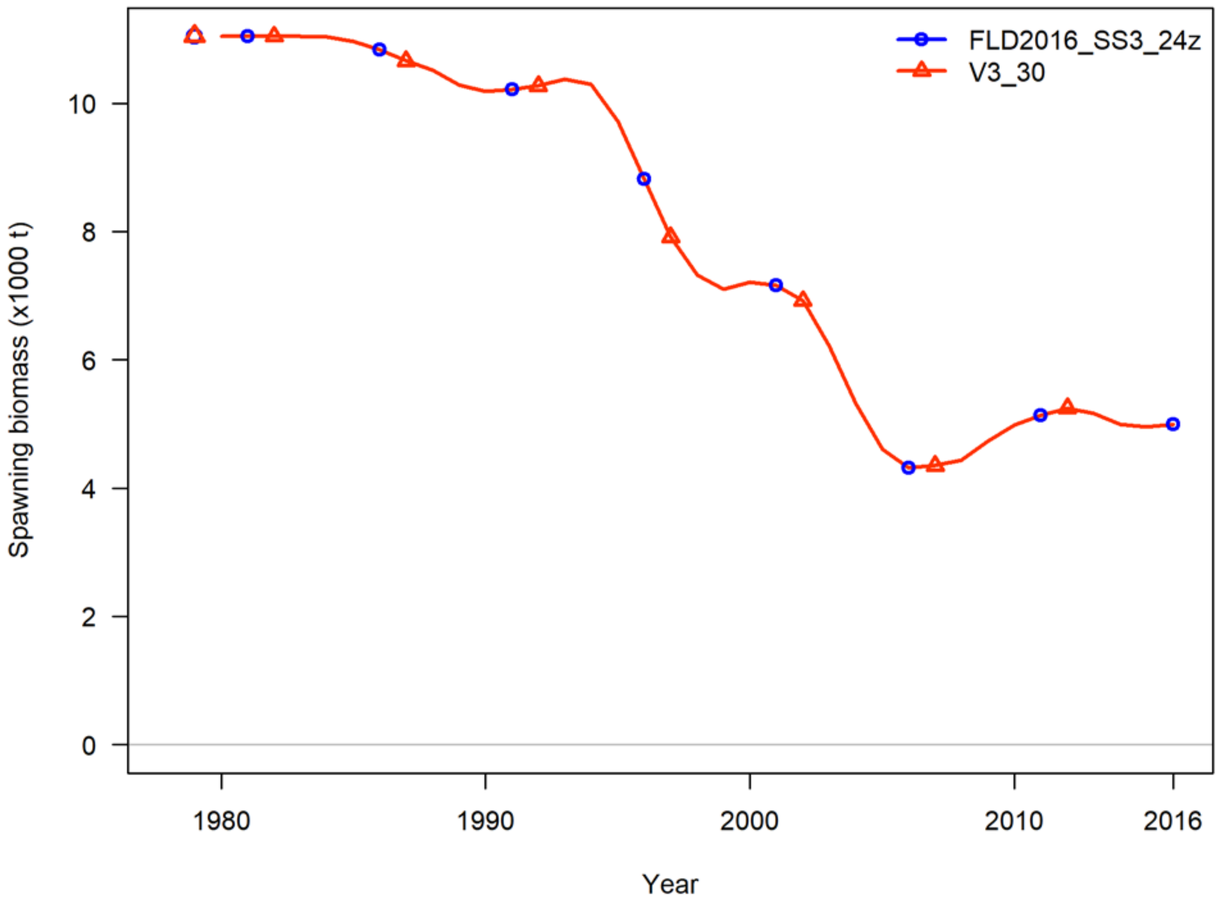

Figure 11.1. Comparison of the time-series of absolute spawning biomass from the 2016 assessment (FLD2016_SS3_24z – in blue) and a model converted to SS-V3.30 (V3_30 – in red).

New features available in the new version of Stock Synthesis, such as allowing smaller lower bounds on minimum sample sizes and estimating additional standard deviation to abundance indices were then incorporated (IndexSE), followed by retuning using the latest tuning protocol (FLD2016_Updated). Details of the tuning procedure used are listed in Section 1.2.1. This process demonstrates the outcomes that could theoretically have been achieved with the last assessment if we had the latest software, tuning protocols and corrected data available in 2016. This initial bridging step, Bridge 1, does not incorporate any data after 2015 or any structural changes to the assessment.

When these time series are plotted together (Figure 11.2 and Figure 11.3), there are minor changes due to incorporating new features in Stock Synthesis. The new tuning procedures result in an increase in the biomass series, largely through allowing more flexibility in recruitment. There is little change to the time-series of relative biomass (Figure 11.3).

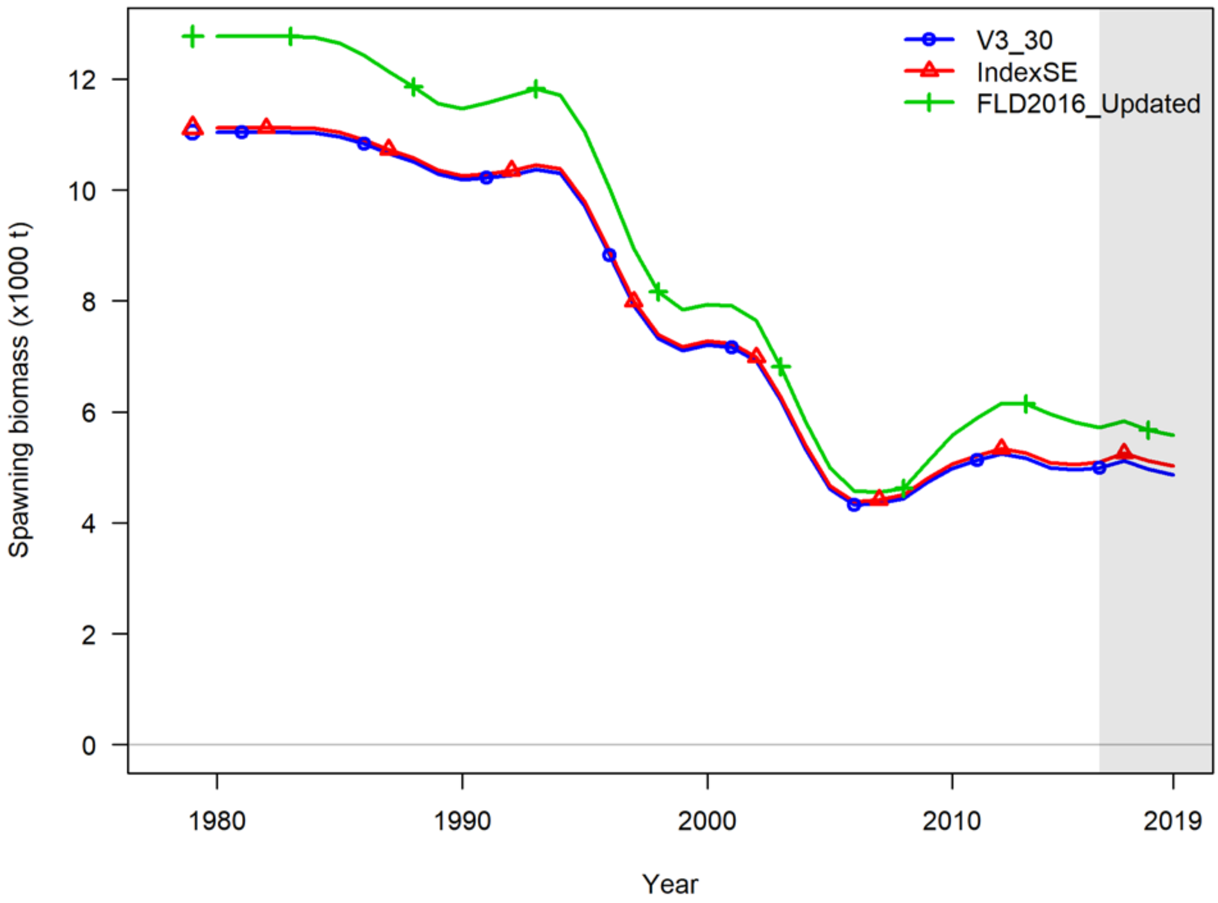

Figure 11.2. Comparison of the time-series of absolute spawning biomass from the 2016 assessment (V3_30 – in blue), incorporating new features (IndexSE – in red), and retuning the model using the latest tuning protocols (FLD2016_Updated – in green).

The results of Bridge 1 suggest that the stock depletion in 2017 based upon tuning and method updates is very similar to the 2016 assessment (Haddon, 2016), and above the target reference point of 43% of SSB_0. These changes are small enough to be well within the confidence bounds of the 2016 assessment results and the fits are generally improved through these revisions.

Fits to the abundance indices (Figure 11.4 and Figure 11.5) show changes through this process, mostly with small improvements to the fit during Bridge 1. The estimated recruitment series shows little change in broad trends during Bridge 1 (Figure 11.6), although there are changes resulting from the new tuning procedures. In particular, the new tuning procedures allow for greater variation in recruitment (from $\sigma_r = 0.5$ to 0.7).

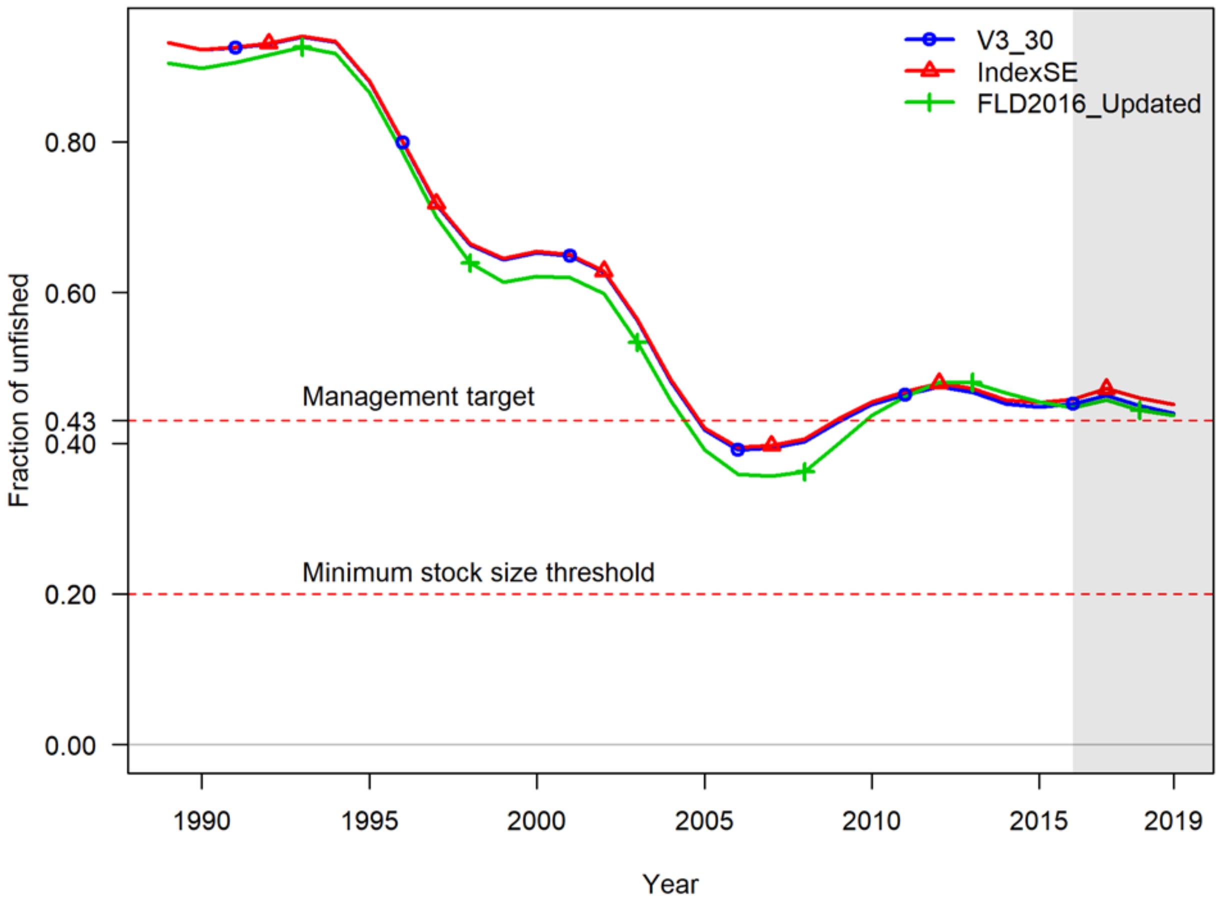

Figure 11.3. Comparison of the time-series of relative spawning biomass from the 2016 assessment (V3_30 – in blue), incorporating new features (IndexSE – in red), and retuning the model using the latest tuning protocols (FLD2016_Updated – in green). Note that the section shaded in grey indicates a few years of future projections, beyond the period covering data used in the assessment, which stops in 2015 in this case.

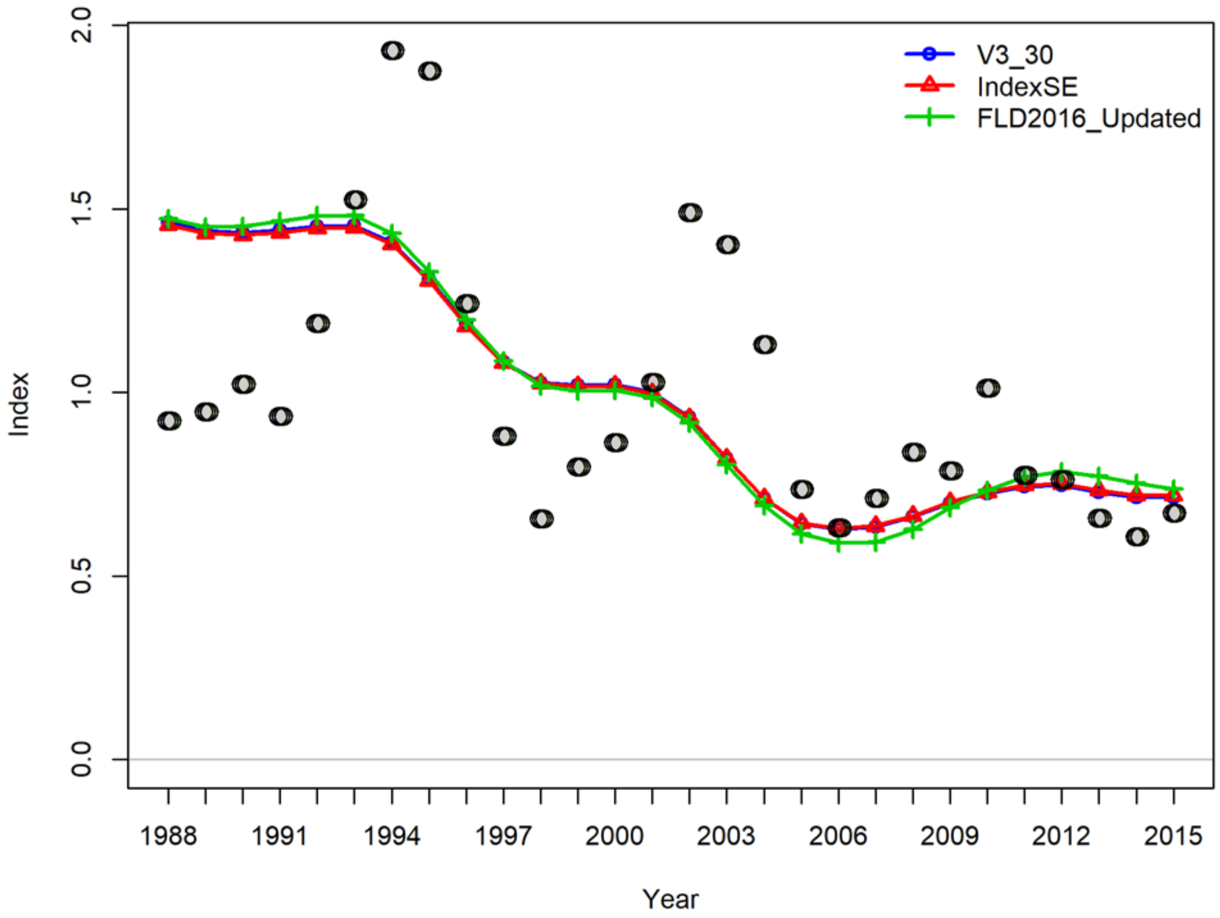

Figure 11.4. Comparison of the fit to the trawl CPUE index for the 2016 assessment (V3_30 – in blue), incorporating new features (IndexSE – in red), and retuning the model using the latest tuning protocols (FLD2016_Updated – in green).

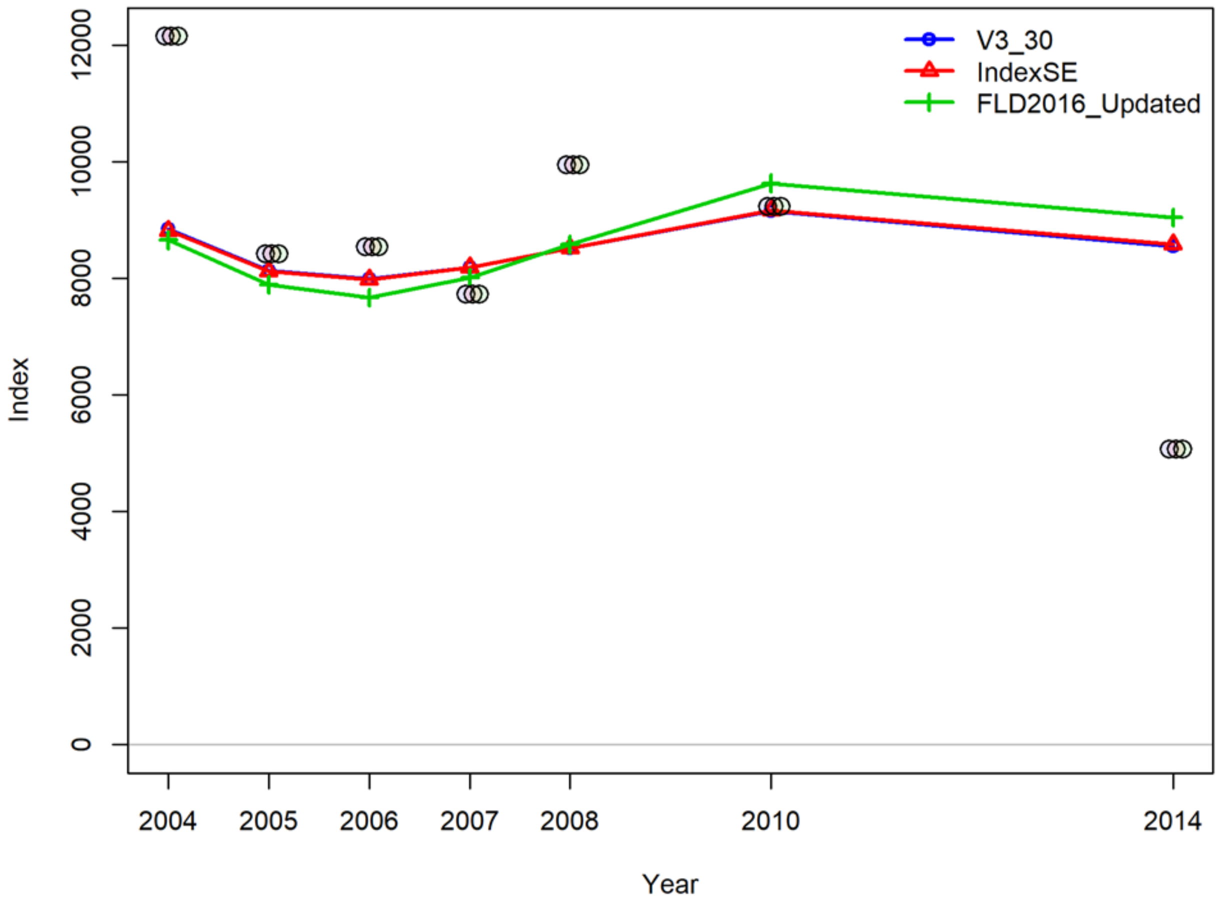

Figure 11.5. Comparison of the fit to the FIS abundance index for the 2016 assessment (V3_30 – in blue), incorporating new features (IndexSE – in red), and retuning the model using the latest tuning protocols (FLD2016_Updated – in green).

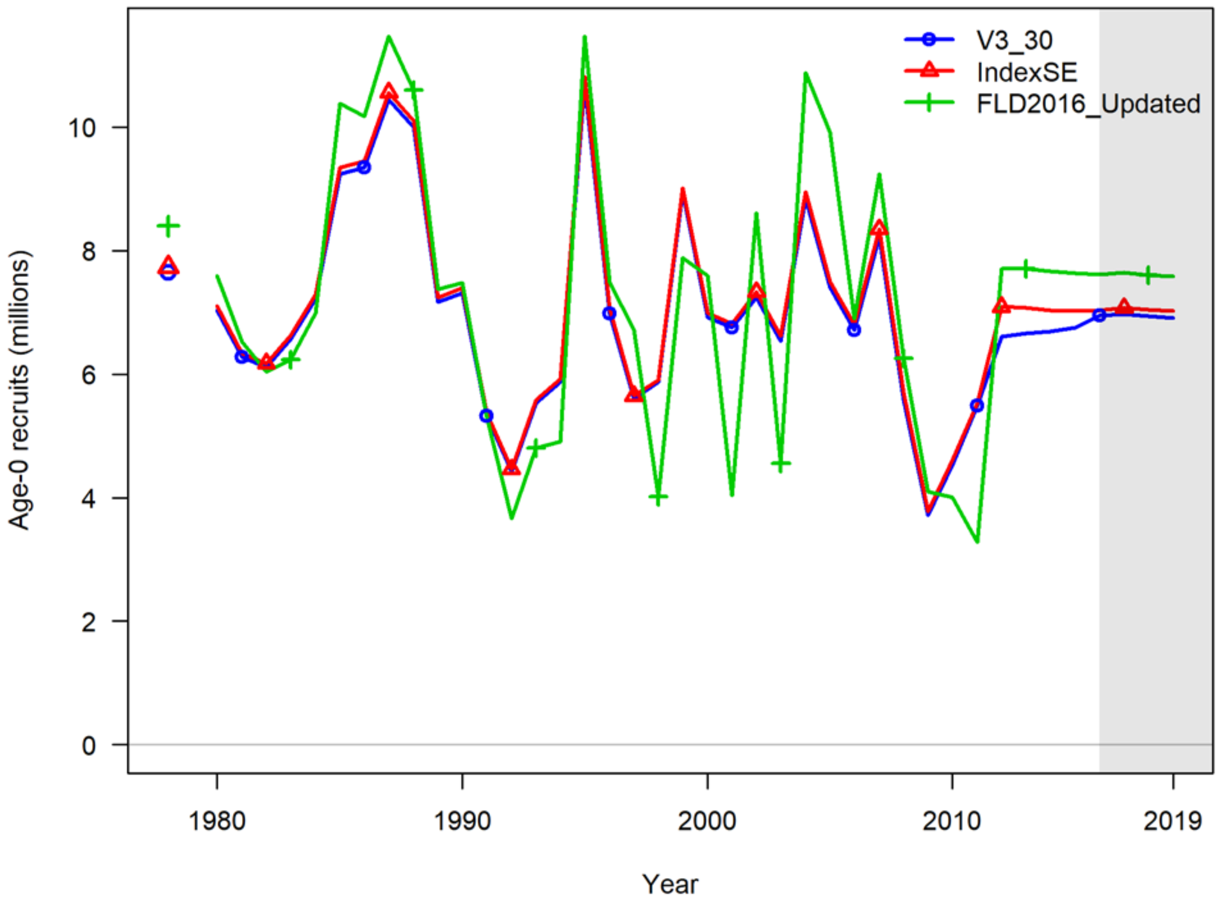

Figure 11.6. Comparison of the time series of recruitment from the 2016 assessment (V3_30 – in blue), incorporating new features (IndexSE – in red), and retuning the model using the latest tuning protocols (FLD2016_Updated – in green).

11.2.3 *Tuning methods*

Iterative rescaling (reweighting) of input and output CVs or input and effective sample sizes is a repeatable method for ensuring that the expected variation of the different data streams is comparable to what is input (Pacific Fishery Management Council, 2018). Most of the indices (CPUE, surveys and composition data) used in fisheries underestimate their true variance by only reporting measurement or estimation error and not including process error.

In iterative reweighting, the effective annual sample sizes are tuned/adjusted so that the input sample size is equal to the effective sample size calculated by the model. In SS-V3.30 it is possible to estimate an additional standard deviation parameter to add to the input CVs for the abundance indices (CPUE).

1. Set the standard error for the log of relative abundance indices (CPUE or FIS) to the standard deviation of a loess curve fitted to the original data - which will provide a more realistic estimate to that obtained from the original statistical analysis. SSV-3.30 then allows an estimate to be made for an additional adjustment to the relative abundance variances appropriately.

An automated iterative tuning procedure was used for the remaining adjustments. For the recruitment bias adjustment ramps:

2. Adjust the maximum bias adjustment and the start and finish bias adjustment ramps as predicted by SSv3.30 at each step.

For the age and length composition data:

3. Multiply the stage-1 (initial) sample sizes for the conditional age-at-length data by the sample size multipliers using the approach of Punt (2017).
4. Similarly multiply the initial samples sizes by the sample size multipliers for the length composition data using the 'Francis method' (Francis, 2011).
5. Repeat steps 2 - 4, until all are converged and stable (with proposed changes < 1 – 2%).

This procedure constitutes current best practice for tuning assessments.

11.2.4 *Inclusion of new data: 2016/17-2018/19 (Bridge 2)*

Starting from the translated, retuned 2016 base case model with updated data to 2015 (previously referred to as "FLD2016_Updated"), additional data from 2016-2018 were added sequentially to build a preliminary base case for the 2019 assessment:

1. Change final assessment year to 2018, add catch to 2018/19 (FLD2019_addCatch).
2. Add CPUE to 2018/19 (from Sporcic (2019)) (FLD2019_addCPUE), and the FIS abundance index for 2017/18 (FLD2019_addFIS).
3. Add updated length frequency data to 2018/19 (FLD2019_addLto2018).
4. Add updated age error matrix and conditional age-at-length data to 2018/19 (FLD2019_addAto2018).
5. Change the final year for which recruitments are estimated from 2011 to 2013 (FLD2019_extendRec2013).
6. Retune using current tuning protocols, including Francis weighting on length-compositions and conditional age-at-length data (FLD2019_Tuned).

All data sources, except the catch rate data, were through until 30 June 2019. Updating of the catch rate series will occur prior to the next RAG meeting. Inclusion of the new data resulted in a series of changes to the estimates of recruitment and the time-series of absolute and relative spawning biomass (Figure 11.7 to Figure 11.9). The inclusion of updated catch, CPUE and FIS data makes little difference to the time series of abundance. The most important changes are the inclusion of updated and new length data, extending the final year for which recruitment is estimated and re-tuning (red). The changes due to the length data are likely due to the standardisation of the length frequency processing methods which has returned to that used in Klaer (2013) and is used for all other Tier 1 assessments that use Stock Synthesis. While including the new age data led to a reduction in spawning biomass through the mid-2000s (as was seen in Klaer 2013), re-tuning under current best practice reversed this trend and returned the biomass to levels that cycle around the target (Figure 11.7; FLD2019_Tuned). Extending the recruitment to 2014 led to poor estimates of final year (2014) recruitment (not shown) and so the final year was chosen to be 2013 (FLD2019_extendRec2013). After tuning, this led to above average recruitment in 2013 and the biomass increasing towards the target in 2018/19 (FLD2019_Tuned). In general, the final tuned model led to higher estimates of recruitment across most years, due to the flexibility allowed through recruitment variability (a larger σ_r as determined by current best practice; Figure 11.9). As is common, while the most recent recruitment (2013) is well estimated, it should be treated with some caution as it is possible for future data to result in modifications to estimates of recent recruitment events.

Fits to the trawl CPUE (Figure 11.10) are improved through each step until the final tuning of the model (FLD2019_Tuned). The improvement to the CPUE fit is likely due to the flexibility allowed through recruitment variability again, and the tuning method that emphasises fits to the index data. The fit to the GABFIS is also reasonable, given the difficulty the model will likely have in fitting to the most recent two data points (Figure 11.11).

A comparison of the last three assessments shows that while the magnitude of biomass changed from Klaer (2013) to Haddon (2016), the current assessment shows a similar initial biomass and trend to Klaer (2013) (Figure 11.12). The relative biomass trend for the current assessment follows Klaer (2013) until the early 2000s before following a similar trend to Haddon (2016) since. All three assessments show a similar depletion of around 0.4 in 2012/13.

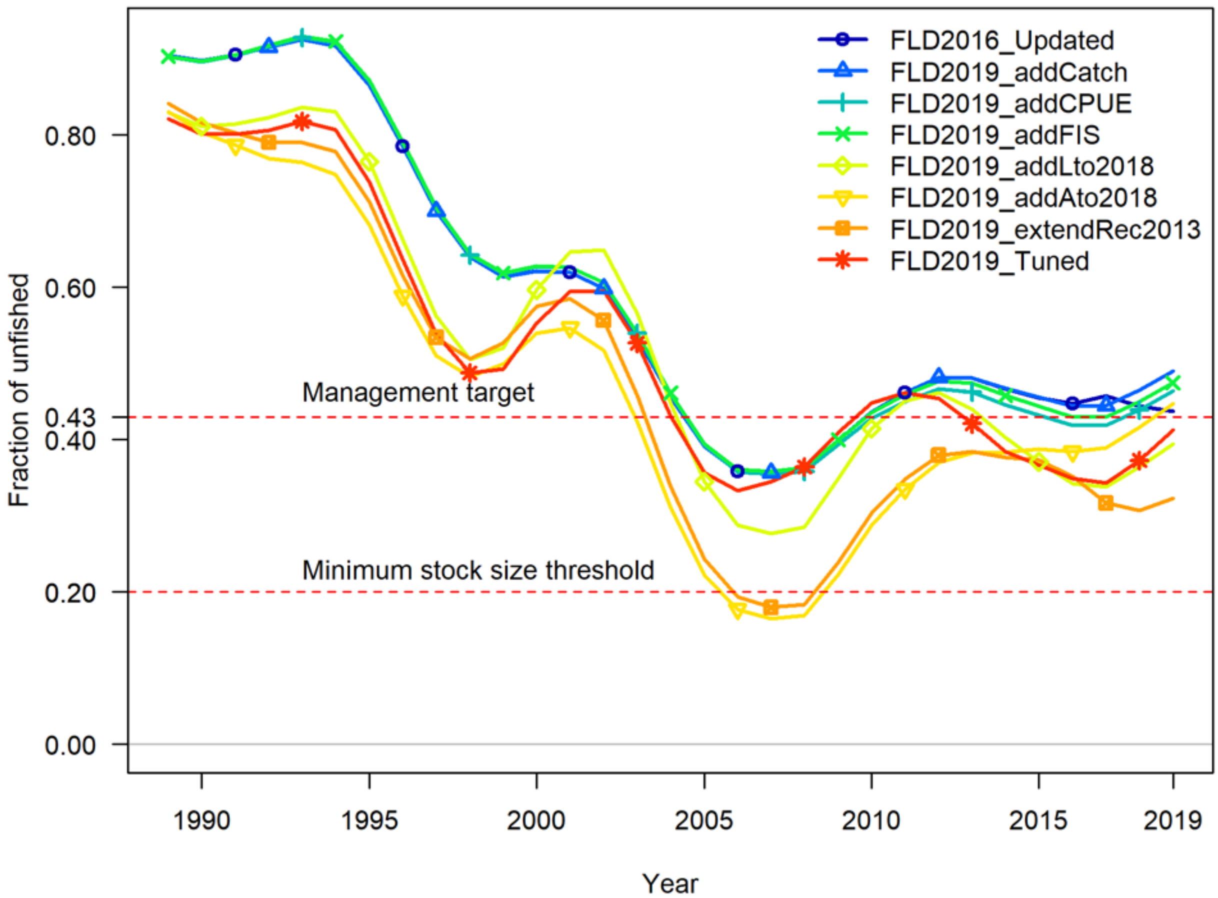

Figure 11.7. Comparison of the time series of relative spawning biomass for the updated 2016 assessment model converted to SS-V3.30.14 (FLD2016_Updated - blue) with various bridging models leading to a proposed 2019 base case model (FLD2019_Tuned - red).

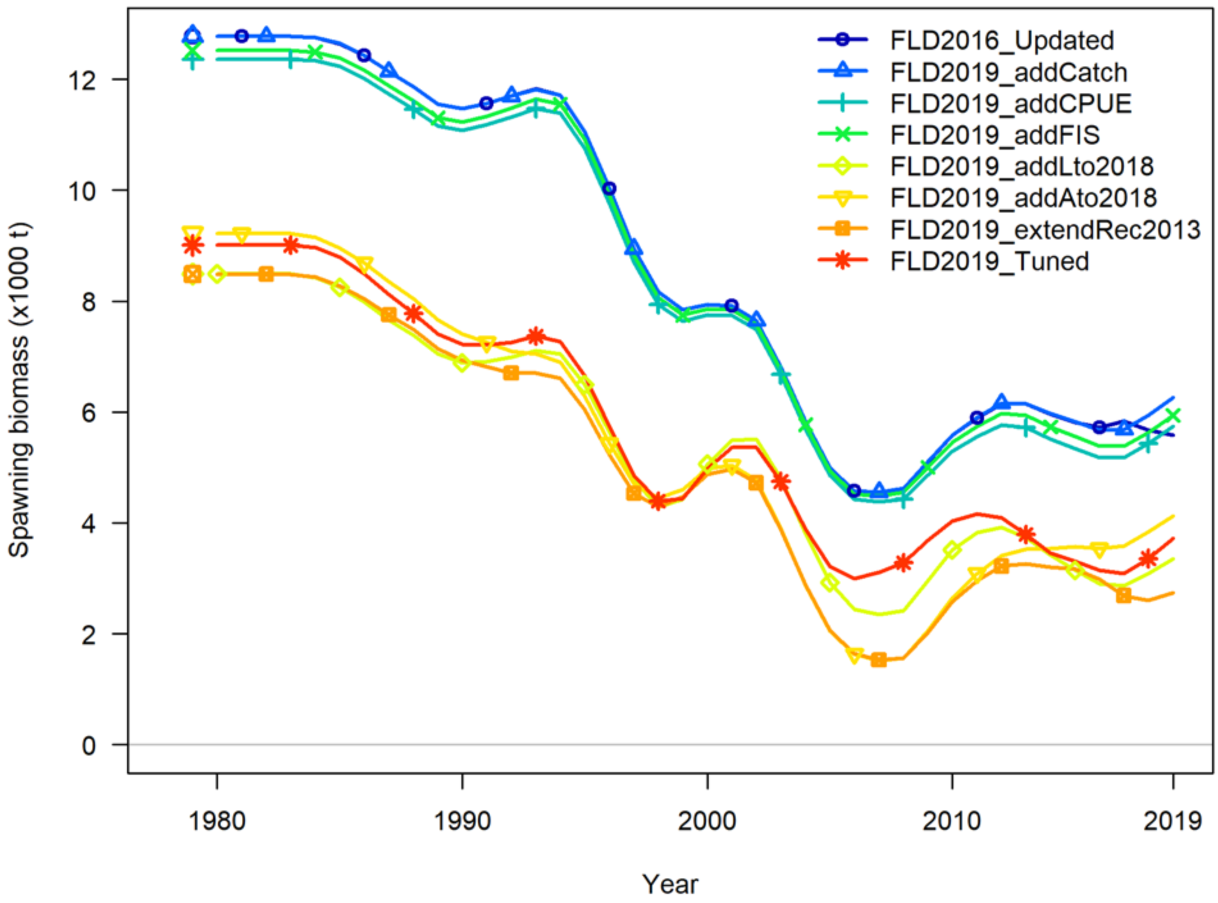

Figure 11.8. Comparison of the time series of spawning biomass for the updated 2016 assessment model converted to SS-V3.30.14 (FLD2016_Updated - blue) with various bridging models leading to a proposed 2019 base case model (FLD2019_Tuned - red).

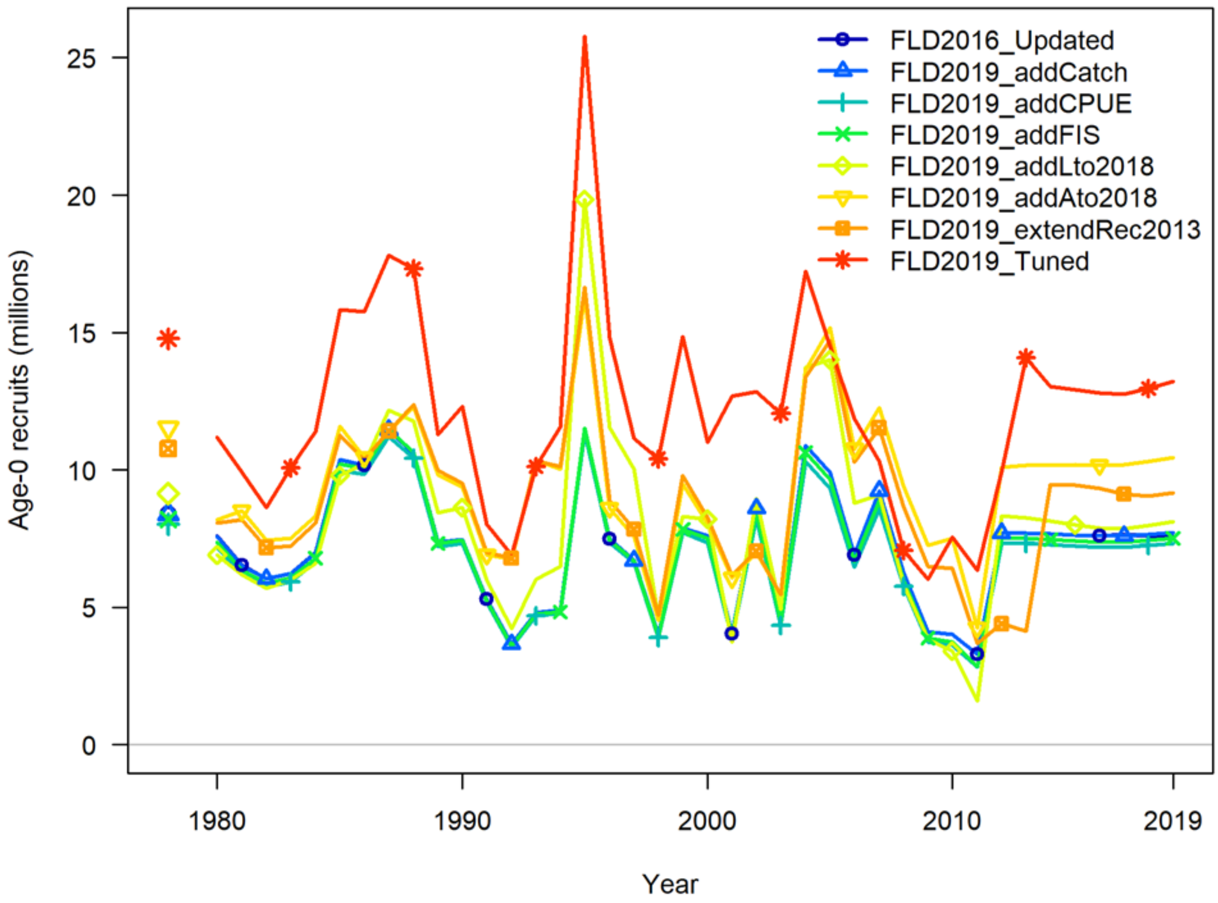

Figure 11.9. Comparison of the time series of recruitment from the updated 2016 assessment model converted to SS-V3.30.14 (FLD2016_Updated - blue) with various bridging models leading to a proposed 2019 base case model (FLD2019_Tuned - red).

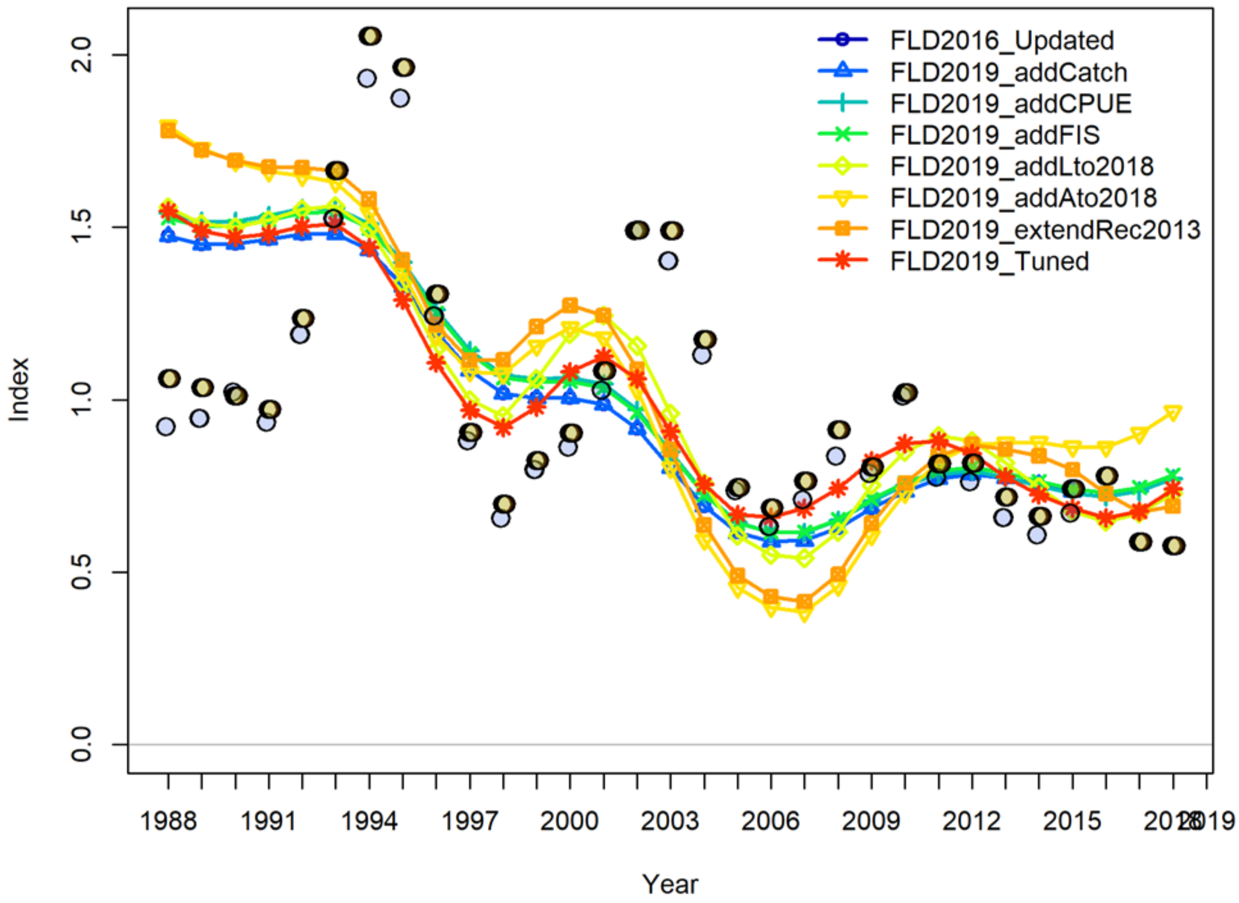

Figure 11.10. Comparison of the fit to the trawl CPUE index for the updated 2016 assessment model converted to SS-V3.30.14 (FLD2016_Updated - blue) with various bridging models leading to a proposed 2019 base case model (FLD2019_Tuned - red).

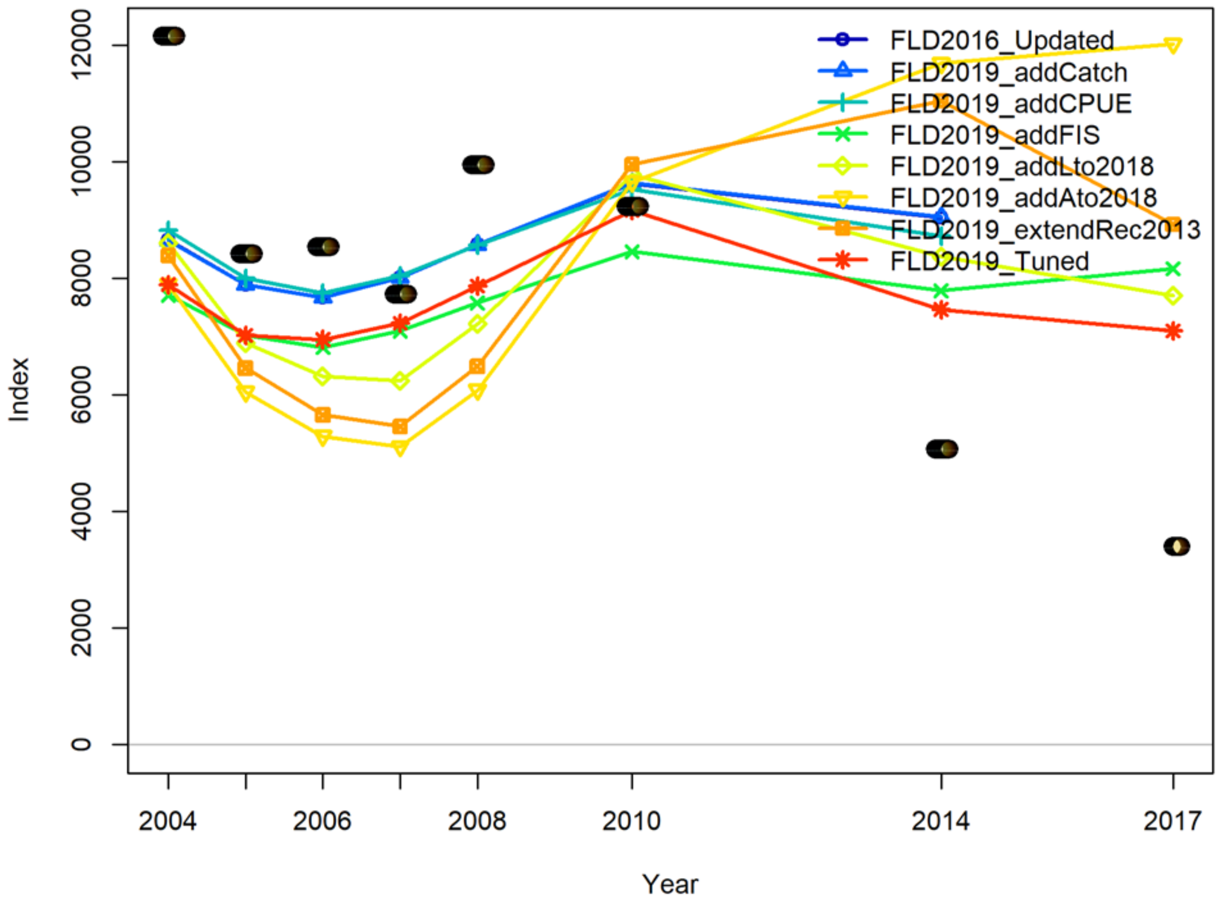

Figure 11.11. Comparison of the fit to the FIS abundance index for the updated 2016 assessment model converted to SS-V3.30.14 (FLD2016_Updated - blue) with various bridging models leading to a proposed 2019 base case model (FLD2019_Tuned - red).

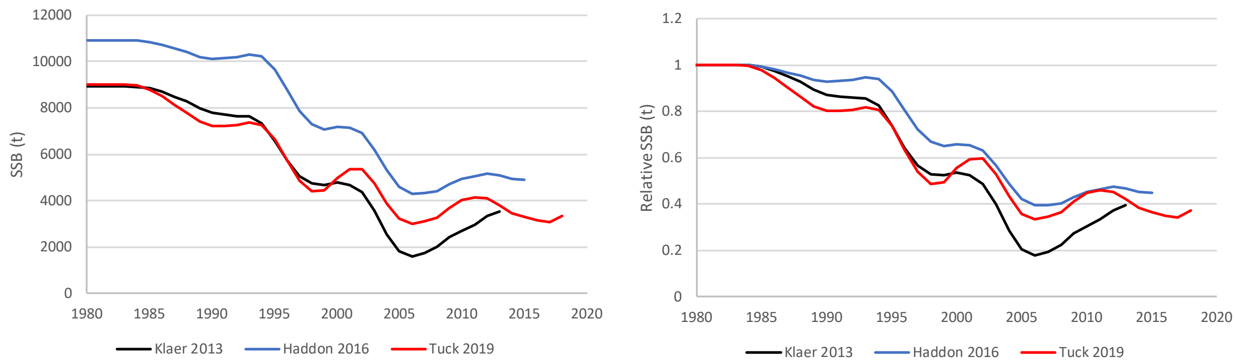

Figure 11.12. Comparison of the estimated spawning biomass (left) trajectories and relative biomass (right) trajectories for each of the last three assessments.

11.2.5 *The 2019 base case assessment model*

11.2.5.1 Model structure

Male and female Deepwater Flathead are assumed to have the same biological parameters except for their growth and the length-weight relationship (Table 11.1). Three of the four parameters relating to the von Bertalanffy growth equation are estimated within the model-fitting procedure from the observed age-at-length data; all male growth parameters are fitted as offsets to the female parameters. Fitting growth within the assessment model attempts to account for the impact of gear selectivity on the age-at-length data collected from the fishery and any impacts of ageing error.

The rate of natural mortality per year, *M*, is estimated in the base-case model, with the estimated value being close to 0.263 yr^{-1}; the model outcomes are sensitive to this parameter and a likelihood profile, where *M* is given a series of fixed values and all other parameters are re-fitted to determine the effect on the total likelihood and other model outputs was conducted. Maturity is modelled as a logistic function, with 50% maturity at about 40 cm. Fecundity-at-length is assumed to be proportional to weight-at-length.

The assessment data for Deepwater Flathead comes from a single trawl fleet; although there is now a Danish seine vessel operating in the fishery. For the base case model, Danish seine catches are added into the trawl time series to fully account for removals. A sensitivity to the inclusion of a Danish Seine fleet is also provided. The updated catch and catch rate data are in Table 11.2.

11.2.5.2 Results

Results show reasonably good fits to the catch rate data, length data and conditional age-at-length data (Appendix A). This assessment estimates that the projected 2020/21 spawning stock biomass will be 45% of virgin stock biomass (projected assuming 2018/19 catches in 2019/20; Figure 11.13), compared to 45% at the start of 2016/17 from the 2016 assessment (Haddon, 2016). The inclusion of new and updated data in the current assessment has led to changes in the shape of the spawning biomass trajectory (Figure 11.12), but the depletion remains near the target of 43%. The base case assessment estimated the unexploited female spawning biomass, *SSBo*, to be 9,008t. While the updated assessment generally fits all the data sources well, the fit to the two most recent GABFIS points is poor. Some further exploration of data sources (GABIA and Port length data) is recommended either this year or prior to the next assessment.

Table 11.1. Summary of selected parameters from the 2019 base case model for Deepwater Flathead. Sources: (1) Analyses of biological samples collected during the 2004 GAB reproductive study (Brown and Sivakumaran, 2007), (2) length and age samples collected between 2000-2003 and (3) length samples collected during the 2001 FRDC project. Years represent the first year of each financial year i.e. 2015 = 2015/2016 (adapted from Haddon, 2016).

Description	Source	Parameter	Combined Male/Female	
Years		y	1988-2018	
Recruitment Deviates		r	estimated 1980 - 2013	
Fleets			1 trawl only	
Discards			none significant, not fitted	
Age classes		a	0 – 29 years	
Sex ratio		p_s	0.5 (1:1)	
Natural mortality		M	estimated (0.263) per year	
Steepness		h	0.75	
Recruitment variation		σ_r	0.7	
Female maturity	1		40 cm (TL)	
Growth	2	L_{max}	65.0258 cm (TL)	fitted
		K	fitted	fitted
		L_{min}	fitted	fitted
		CV	Fitted (M & F assumed equal)	
			Female	Male
Length-weight (based	3	f_1	0.002 cm (TL)/gm	0.002
on standard length)		f_2	3.332	3.339

Table 11.2. Financial year values and estimates of catch and the standardized trawl CPUE for Deepwater Flathead in the GAB from 1988/1989 – 2018/2019. Catch is taken from logbook estimates until 2005/06 (Klaer, 2013; Haddon, 2016). Subsequently CDR catches are used. Discards are assumed to be trivial. Danish seine catches are added into the trawl catch for the base case assessment. Standardized CPUE is from Sporcic (2019).

Season	Catch (t)	CPUE
88/89	312.5	1.0601
89/90	394.7	1.0343
90/91	420.2	1.0106
91/92	608.1	0.9717
92/93	508.2	1.2351
93/94	585.1	1.6637
94/95	1254.8	2.0538
95/96	1551.6	1.9618
96/97	1459.3	1.3052
97/98	1010.4	0.9045
98/99	680.7	0.6969
99/00	545.0	0.8223
00/01	776.9	0.9019
01/02	963.6	1.082
02/03	1866.0	1.492
03/04	2482.1	1.4886
04/05	2264.1	1.1745
05/06	1545.6	0.7455
06/07	1029.9	0.6848
07/08	1025.4	0.7631
08/09	799.7	0.9111
09/10	851.3	0.8043
10/11	968.0	1.0191
11/12	973.4	0.8144
12/13	1027.8	0.8161
13/14	886.6	0.7165
14/15	567.1	0.6606
15/16	616.1	0.7405
16/17	732.0	0.7792
17/18	538.2	0.5878
18/19	517.7	0.5753

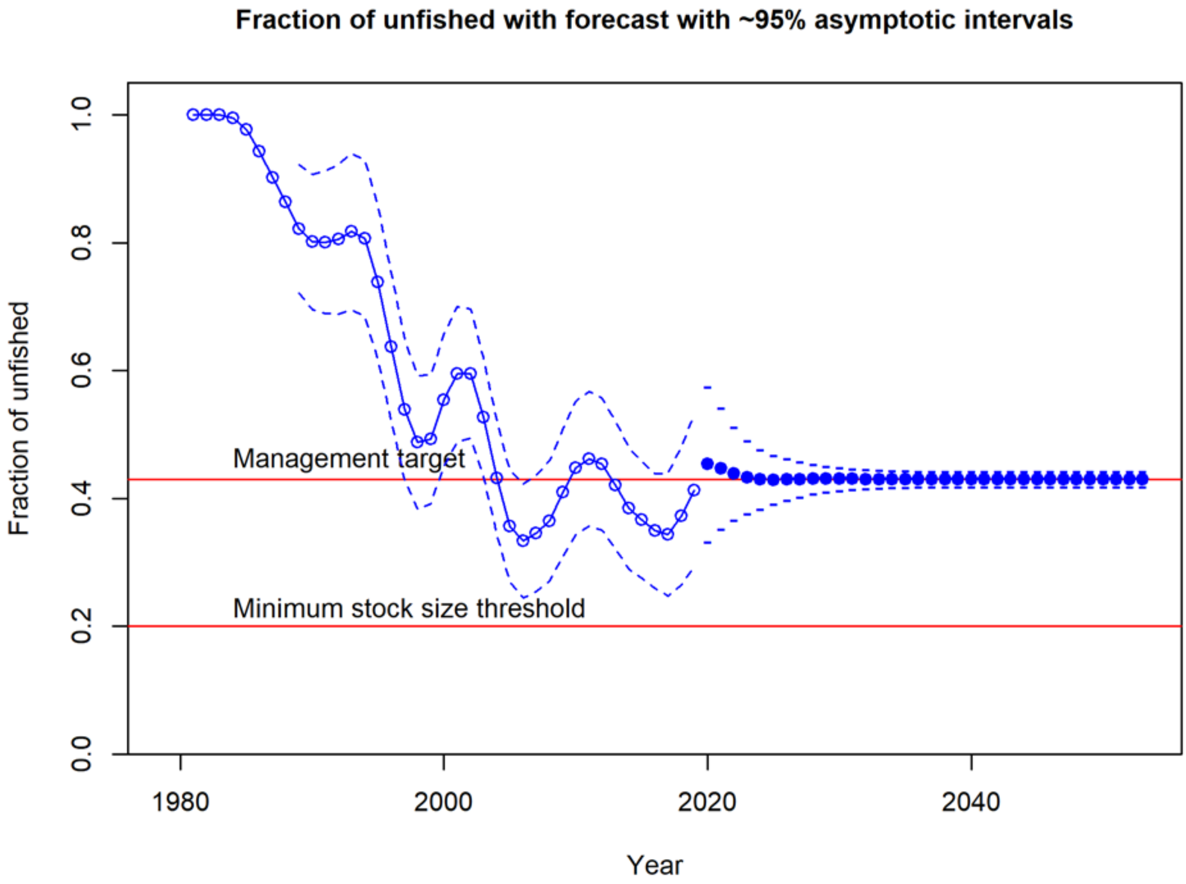

Figure 11.13. The projected relative spawning biomass trajectory for the deepwater flathead base case assessment.

11.2.6 *Likelihood profiles*

As stated by Punt (2018), likelihood profiles are a standard component of the toolbox of applied statisticians. They are most often used to obtain a 95% confidence interval for a parameter of interest. Many stock assessments "fix" key parameters such as *M* and steepness based on *a priori* considerations. Likelihood profiles can be used to evaluate whether there is evidence in the data to support fixing a parameter at a chosen value. If the parameter is within the entire range of the 95% confidence interval, this provides no support in the data to change the fixed value. If the fixed value is outside the 95% confidence interval, it would be reasonable for a review panel to ask why the parameter was fixed and not estimated, and if the value is to be fixed, on what basis and why should what amounts to inconsistency with the data be ignored. Integrated stock assessments include multiple data sources (e.g., commonly catch-rates, length-compositions, and age-compositions) that may be in conflict, due for example to inconsistencies in sampling, but more commonly owing to incorrect assumptions (e.g., assuming that catch-rates are linearly related to abundance), i.e. model-misspecification. Likelihood profiles can be used as a diagnostic to identify these data conflicts (Punt, 2018).

Standard parameters to consider are natural mortality (*M*), steepness (*h*) and the logarithm of the unfished recruitment (lnR_0).

For deepwater flathead, the likelihood profile for natural mortality, *M*, is shown in Figure 11.14 with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. This parameter is estimated in the model (M=0.263 yr^{-1}) and the likelihood profile suggests that it is reasonably well defined. The index and length data (suggest higher mortality) and the age data (suggest lower mortality) are somewhat in conflict. However, the confidence intervals on natural mortality are reasonably well defined between 0.225 and 0.3.

A likelihood profile on steepness, *h*, is shown in Figure 11.15 with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. This figure shows that steepness is not well defined as the 95% confidence limits are not crossed (log-likelihood of 1.92 on the y-axis) by the total likelihood within the range considered (h = 0.6 to 0.8). This is not surprising given the stock in the base case model has not been depleted to levels that would define steepness. It is therefore justified to fix steepness at 0.75.

A likelihood profile for virgin spawning biomass (SSB_0) is shown in Figure 11.16, with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. This likelihood profile suggests a range of plausible values for SSB_0 ranging between around 8,000 and 11,000t with the most likely value at around 9,000t. The components of the likelihood relating to length and recruitment suggest larger values of SSB_0 whereas the age and index data want lower values of SSB_0 (Figure 11.16 and Figure 11.17). Similarly, a likelihood profile on current biomass (2018/19) suggests a broad range of plausible values, from approximately 2,000t to over 5,000t (Figure 11.18). The Piner plot implies that the length data generally wants larger values of current biomass, however the index data and trawl ages want lower values (Figure 11.19).

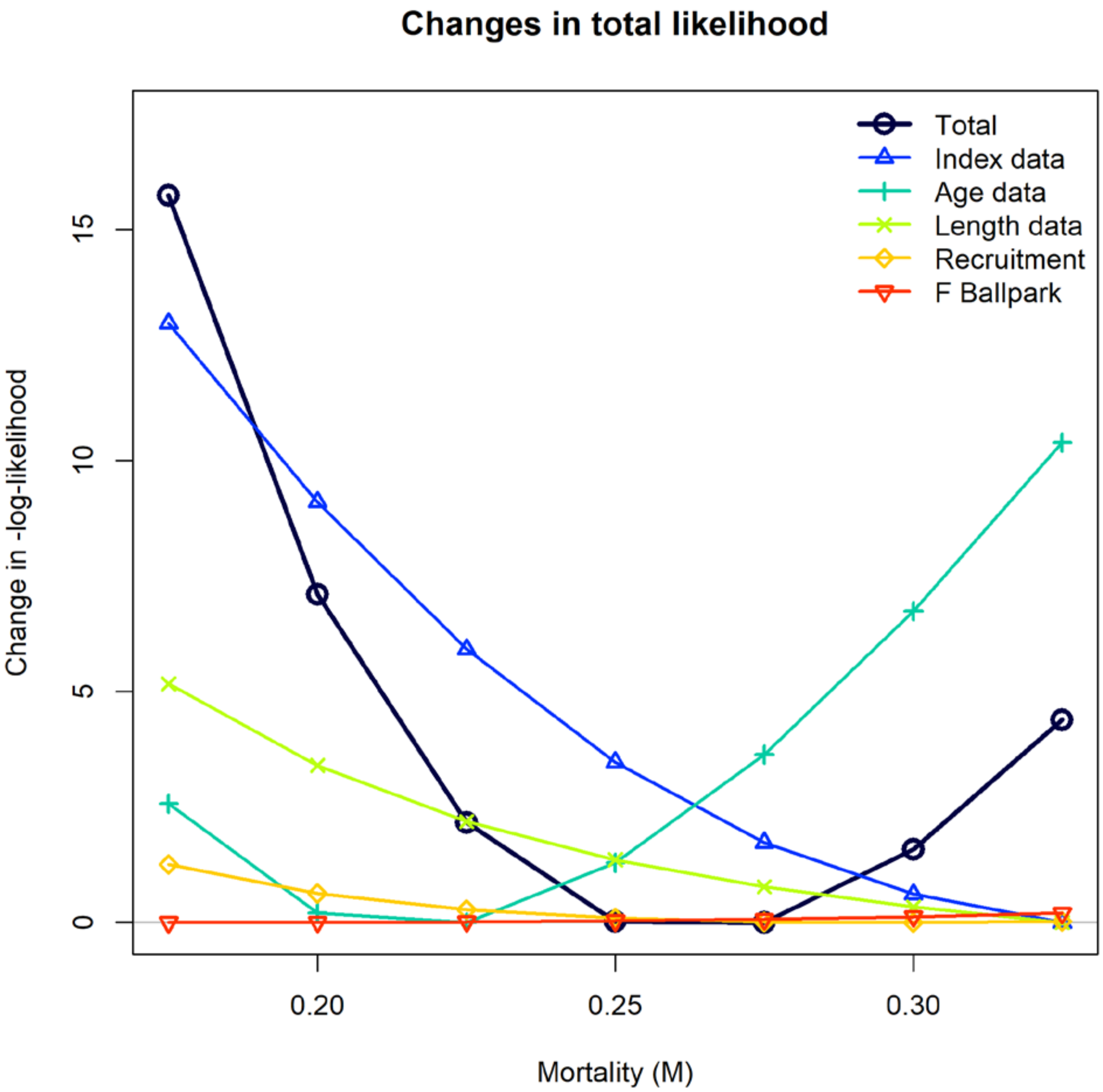

Figure 11.14. The likelihood profile for natural mortality, with *M* ranging from 0.175 to 0.325. The estimated value for *M* is 0.263yr^{-1}.

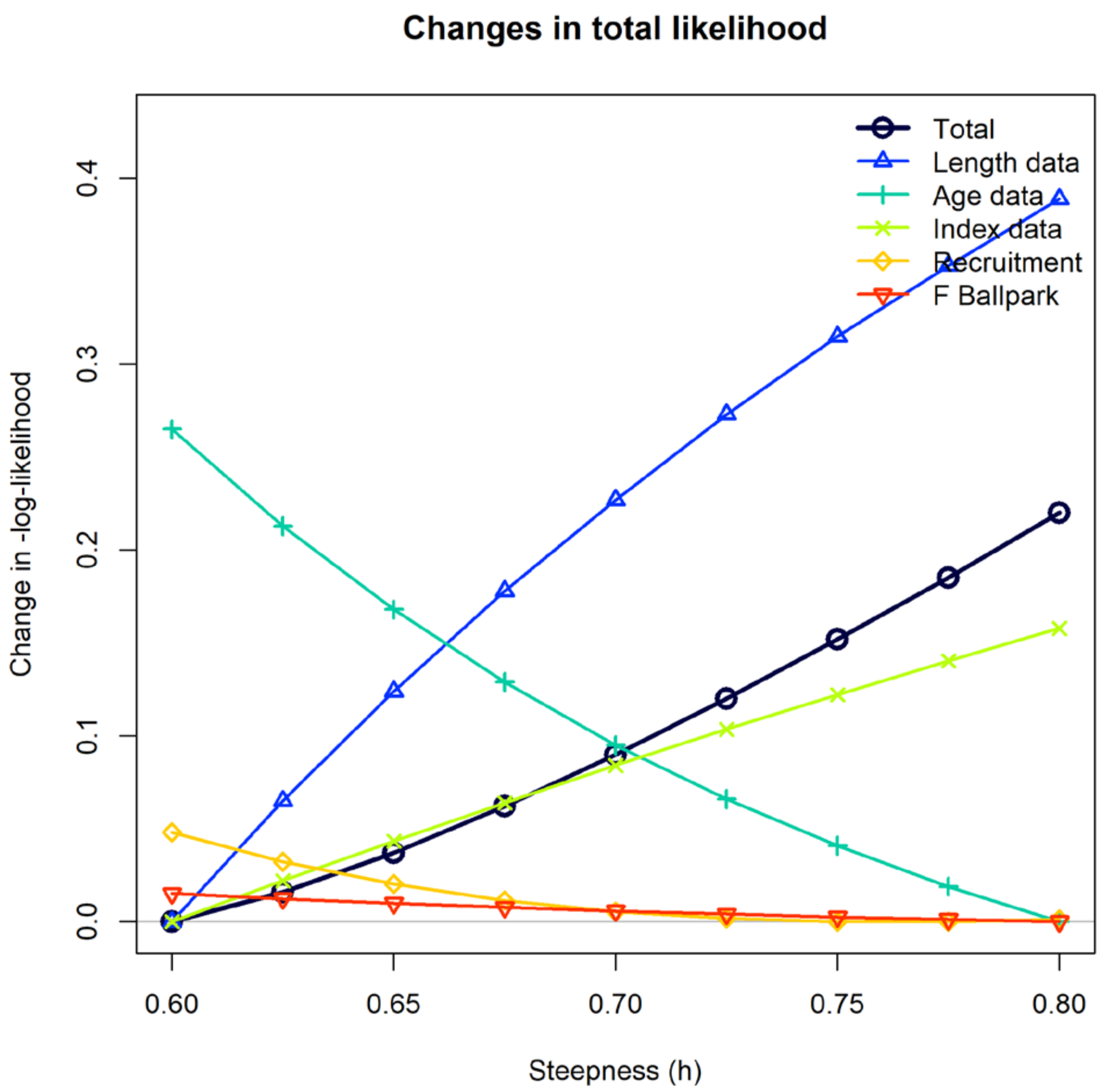

Figure 11.15. The likelihood profile for steepness, *h*, ranging from 0.6 to 0.8. The fixed value for steepness is 0.75.

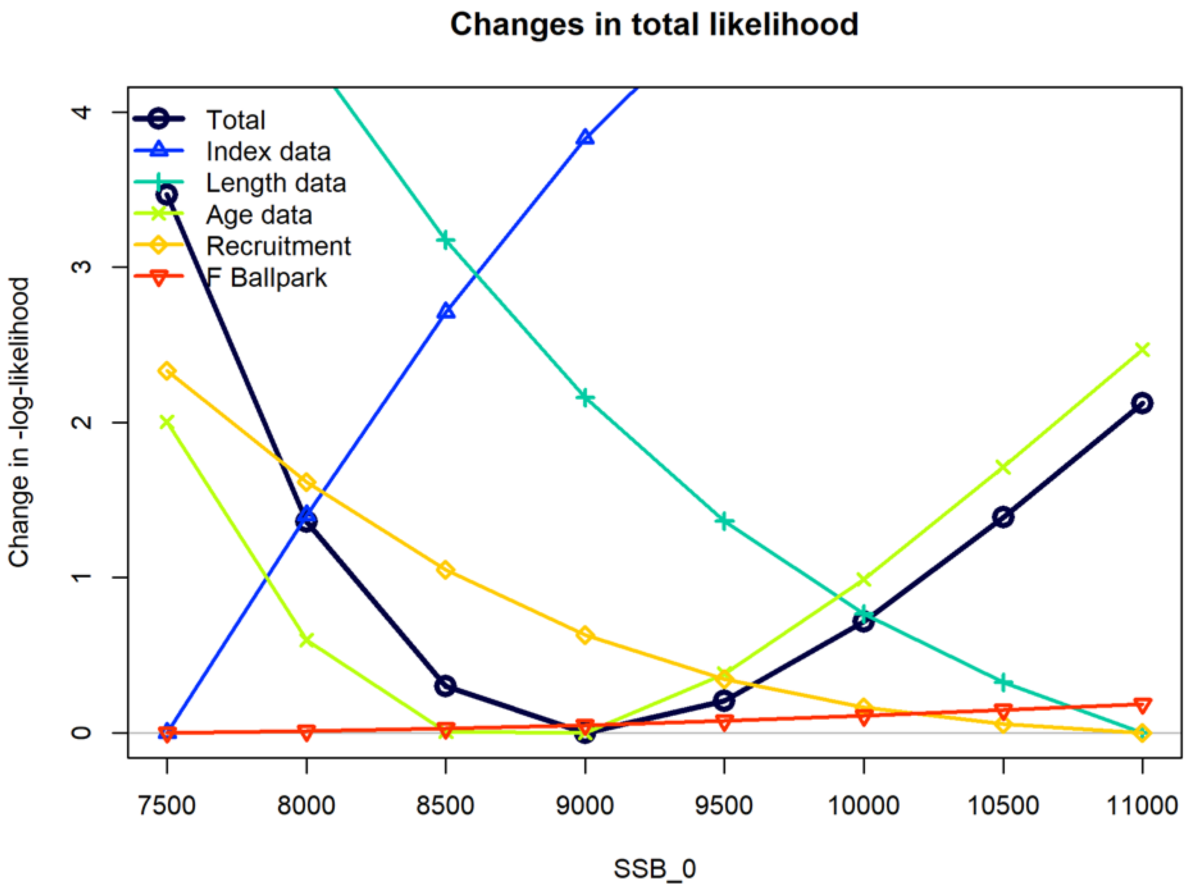

Figure 11.16. The likelihood profile for virgin spawning biomass, with *SSB_0* ranging from 7,500 to 11,000t. The estimated value for *SSB_0* is 9,000t.

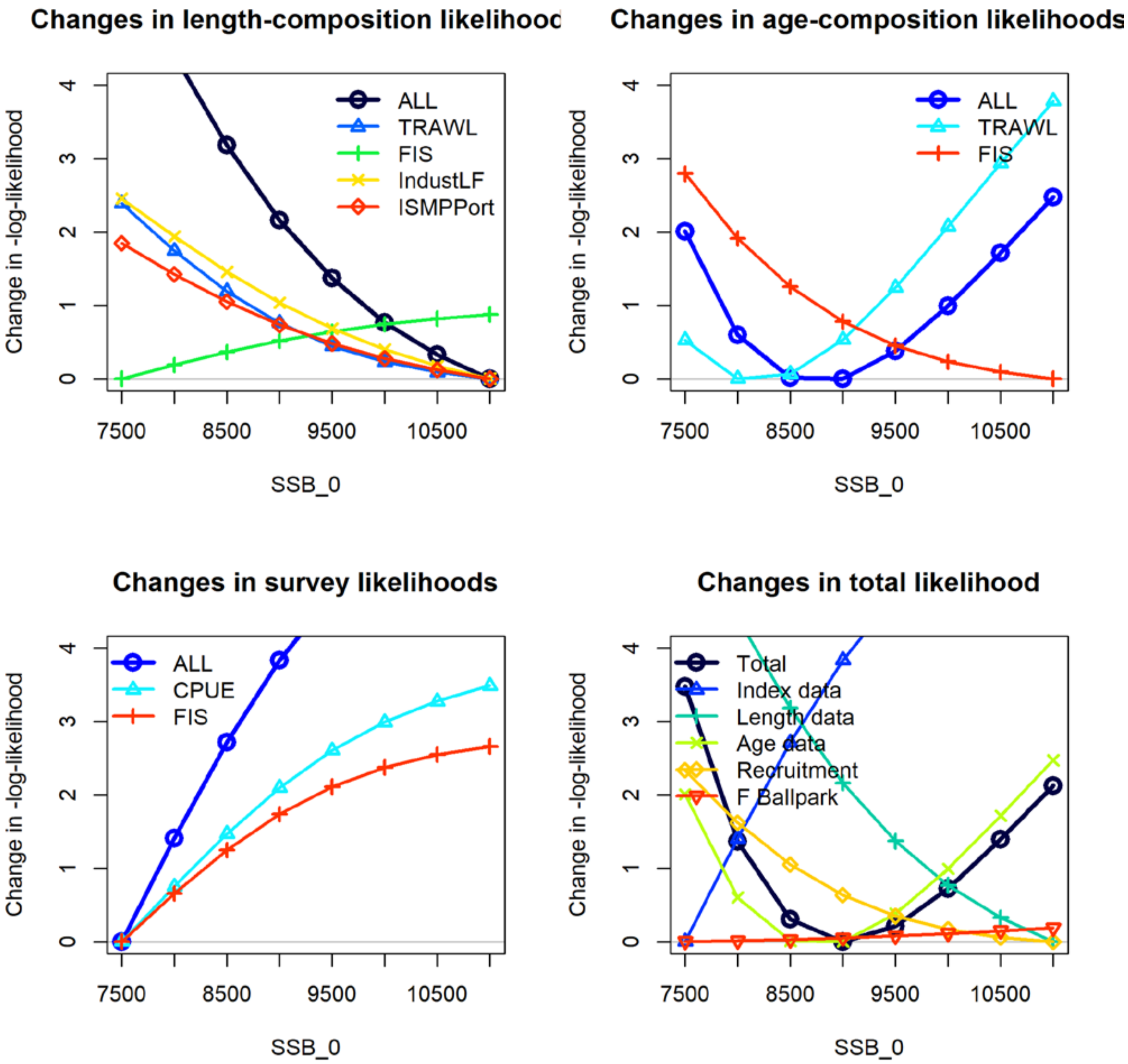

Figure 11.17. Piner plot for the likelihood profile for virgin spawning biomass, showing components of the change in likelihood for length, age and indices (CPUE) in addition to the changes in the total likelihood.

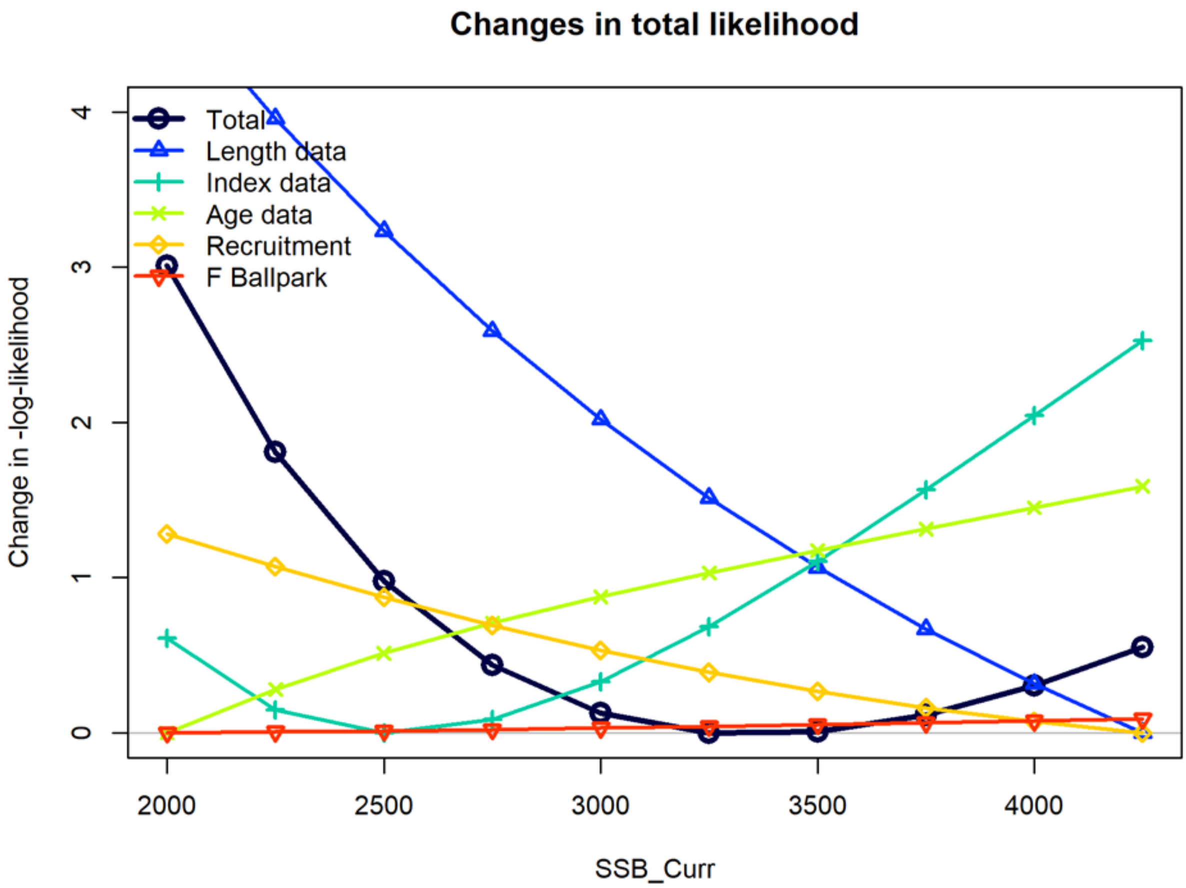

Figure 11.18. The likelihood profile for current spawning biomass.

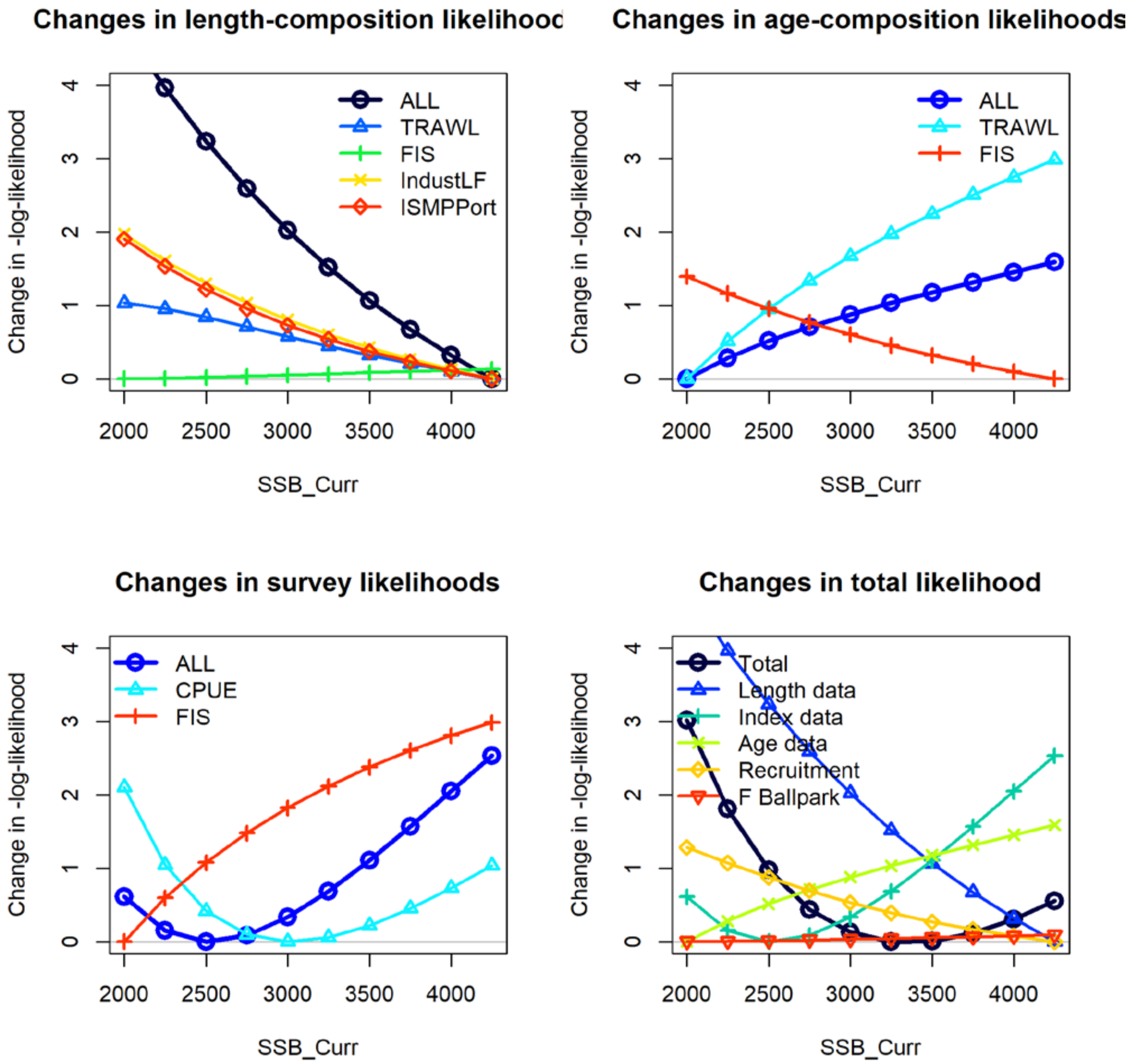

Figure 11.19. Piner plot for the likelihood profile for current spawning biomass, showing components of the change in likelihood for length, age and indices (CPUE) in addition to the changes in the total likelihood.

11.2.7 *Retrospectives*

A retrospective analysis was completed, starting from the most recent year of data, working backward in time and removing five successive years of data from the assessment. This analysis can highlight potential problems and instability in an assessment, or some features that appear from the data.

A retrospective analysis for absolute spawning biomass is shown in Figure 11.20, with the base case model in dark blue, and then successive years data removed back to 2013 (shown in red). The same analysis is plotted in terms of relative spawning biomass in Figure 11.21. There is some evidence of over-optimistic estimation of spawning biomass in the last year of the SSB trajectory, however this is not true of the base-case trajectory relative to the trajectory with the 2018/19 data removed (RetrospectiveAuto_2018 compared to RetrospectiveAuto_2017).

When this retrospective analysis is applied to the recruitment time series (Figure 11.22), the recruitments show an increasing trend in magnitude, except for the base-case assessment (RetrospectiveAuto_2018 compared to RetrospectiveAuto_2017). The recruitments from 2008 to 2012 are generally estimated to be stable as more data are added.

As stated, while there is some evidence of optimism in the final year of the biomass trajectory, the retrospective analyses do not reveal any pathological patterns or apparent biases in the estimates which provides additional confidence in the stability of this assessment.

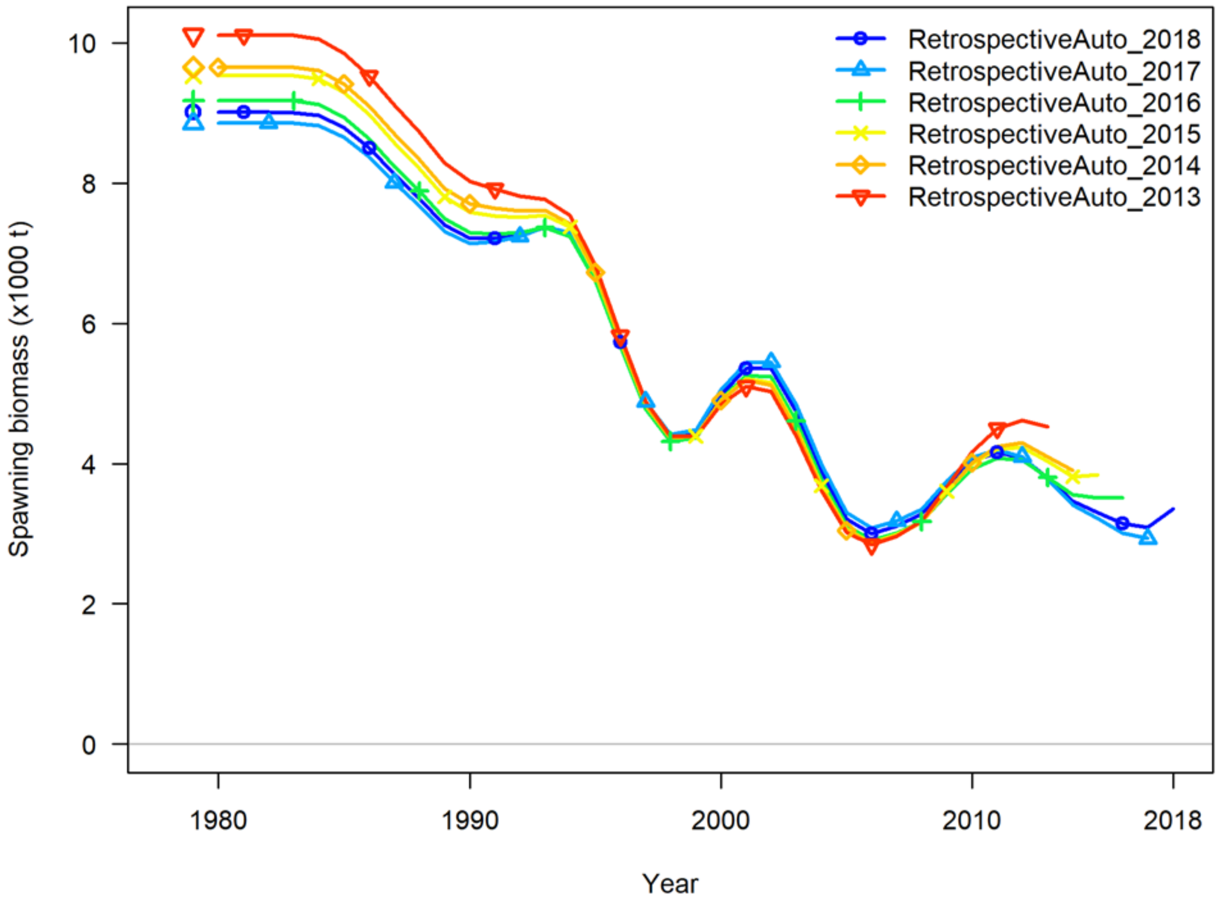

Figure 11.20. Retrospectives for absolute spawning biomass for deepwater flathead, with the most recent base case assessment shown (blue) and then successive years removed back to 2013 (red).

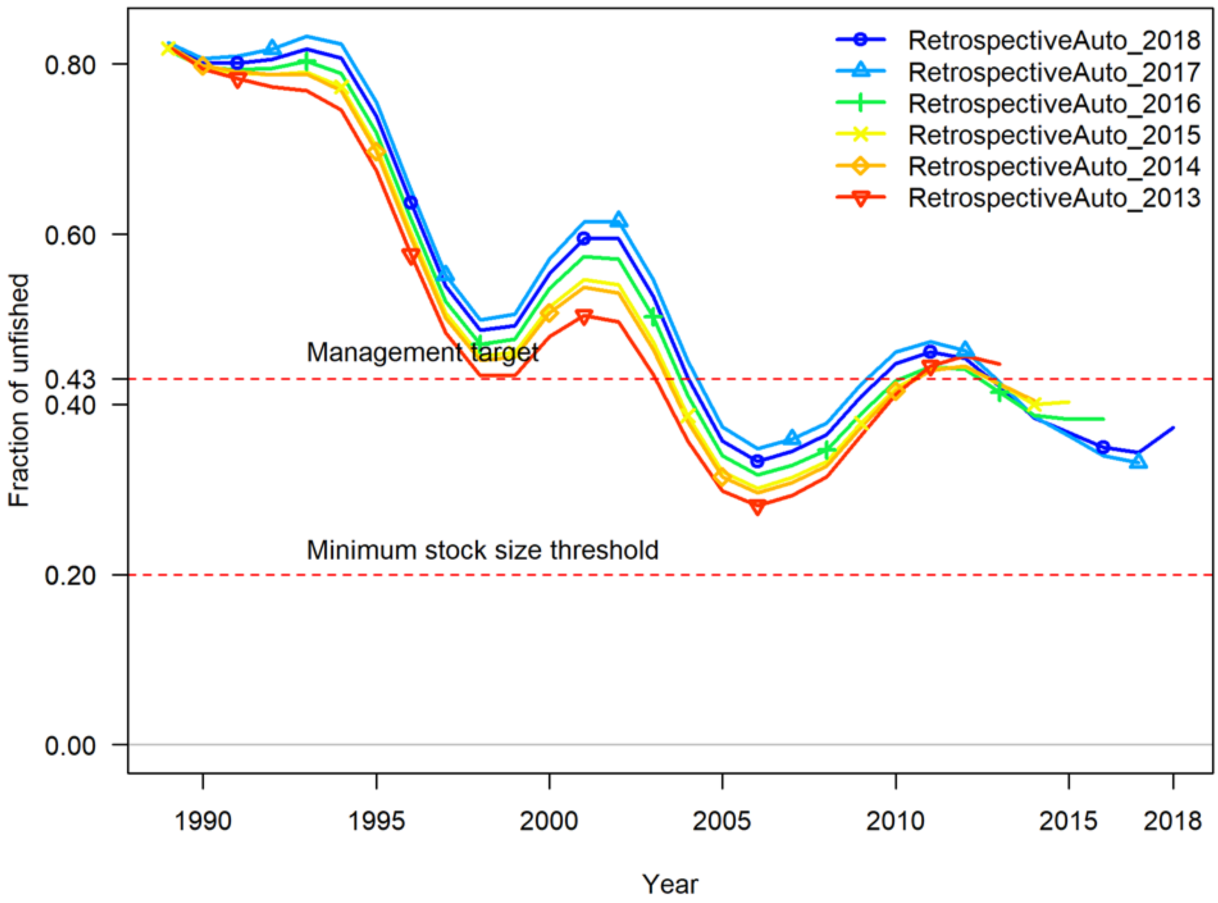

Figure 11.21. Retrospectives for relative spawning biomass for deepwater flathead, with the most recent base case assessment shown (blue) and then successive years removed back to 2013 (red).

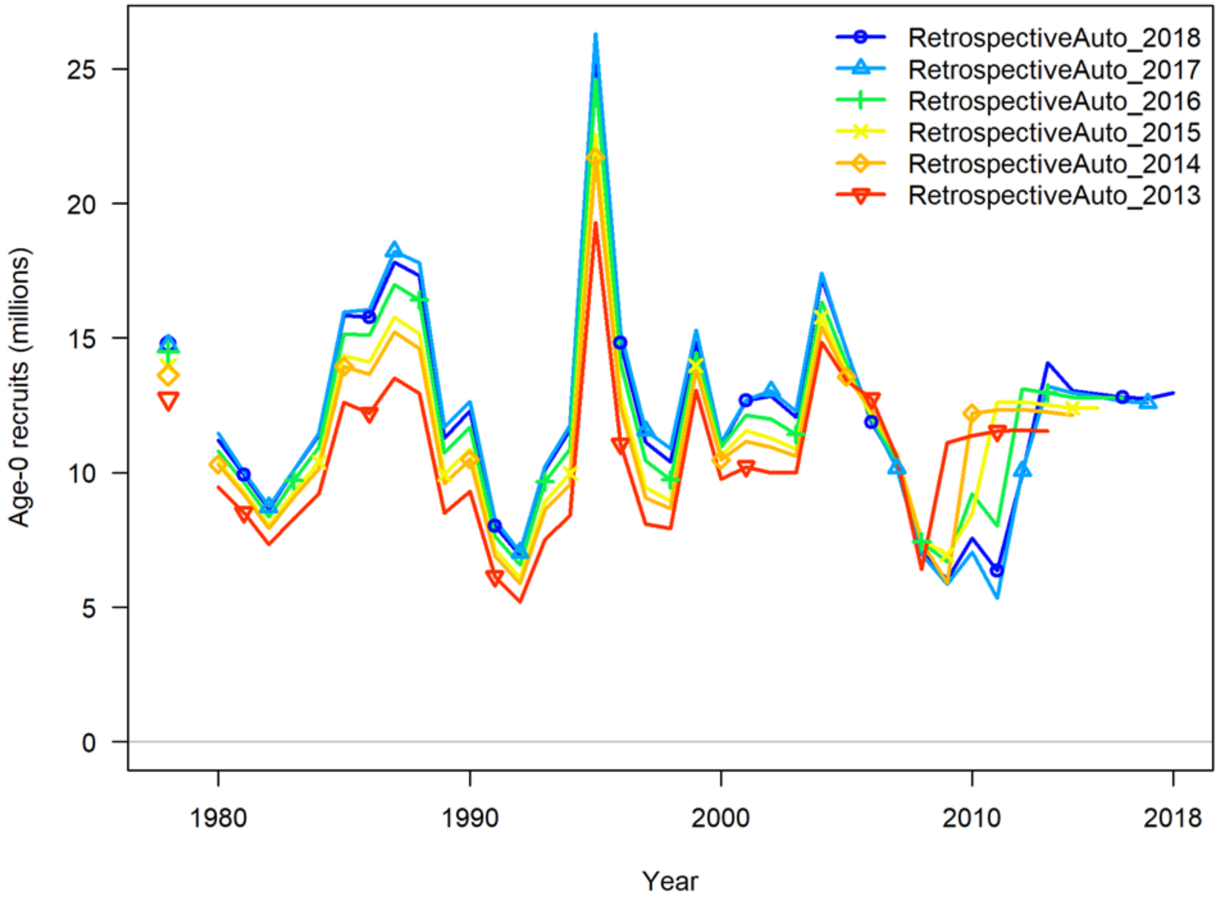

Figure 11.22. Retrospectives for recruitment for deepwater flathead, with the most recent base case assessment shown (blue) and then successive years removed back to 2013 (red).

11.2.8 *Sensitivities*

Sensitivities to the potential base case have not yet been explored. In addition to the usual set of sensitivities (which includes sensitivities on mortality, maturity, fixing steepness and estimating mortality, σ_R and halving and doubling the weighting on length, age and CPUE data), there are some additional sensitivities that may be useful to explore.

11.2.8.1 Inclusion of the Danish Seine fleet

A Danish seine vessel has been operating since 2010. In the base case model, catch from this fleet was added into the trawl fleet catch to account for total removals. Ideally, these catches would constitute part of a separate Danish seine (DS) fleet. However, in the past this fleet has not been included in the model structure due to a paucity of additional information (on lengths and ages for example, nor is there an index of abundance from this fleet). As a sensitivity, this fleet was included. This entailed separating out DS catches from trawl, using the proportion of each fleet's logbook catch apportioned to the CDR landings (Table 11.3). There were also two years of age-at-length data (2016 and 2017) and lengths from years 2012, 2016 and 2017 available. A separate selectivity function was estimated.

Results from this model showed an increase in the magnitude of spawning biomass across the mid-years of the time-series, but has a similar final year depletion level to the base case model (Figure

11.23). The increase in biomass can be seen through increased recruitments (Figure 11.24 and Figure 11.25). Fits to the index data (Figure 11.26) and lengths (Figure 11.27) are generally good.

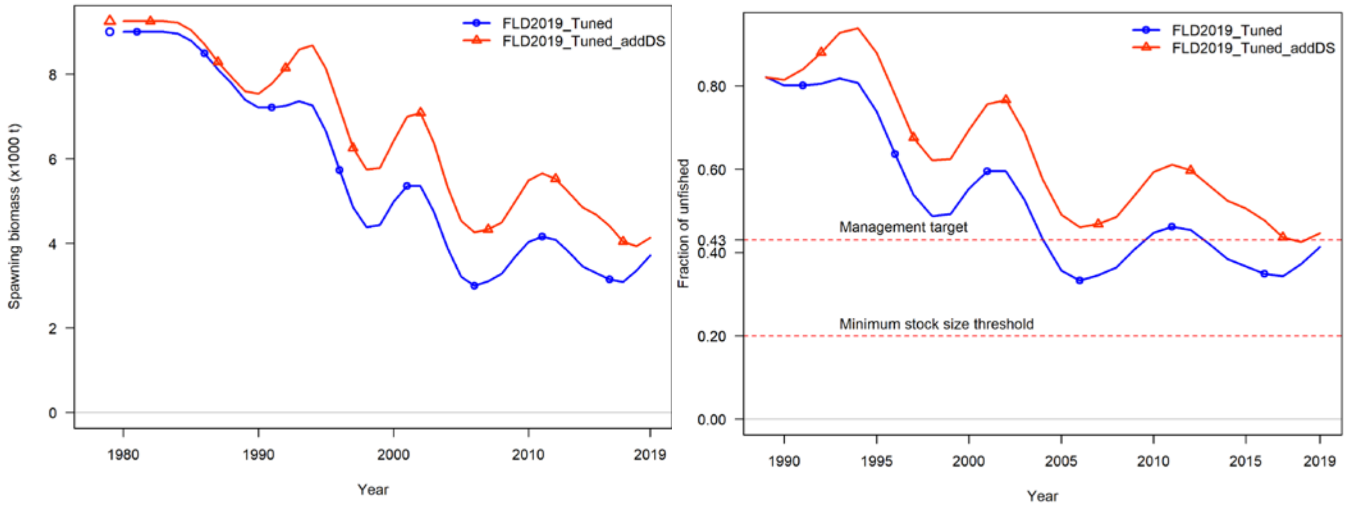

Figure 11.23. A comparison of the magnitude and relative spawning biomass trajectories for the base case model (FLD2019_Tuned; blue) and the sensitivity with Danish seine included (FLD2019_Tuned_addDS; red) for deepwater flathead.

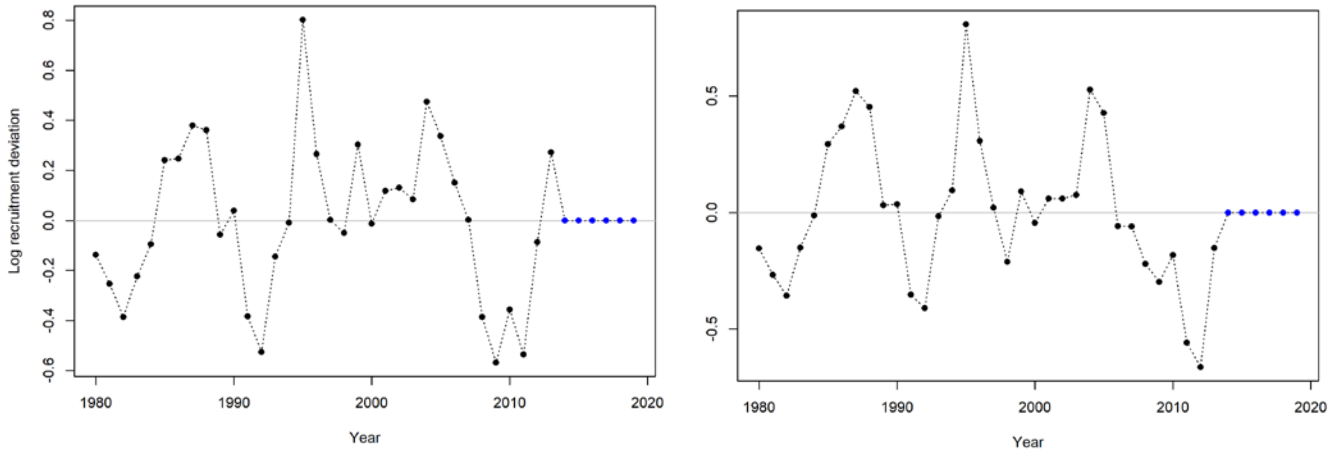

Figure 11.24. A comparison of the magnitude and relative spawning biomass trajectories for the base case model (FLD2019_Tuned; blue) and the sensitivity with Danish seine included (FLD2019_Tuned_addDS; red) for deepwater flathead.

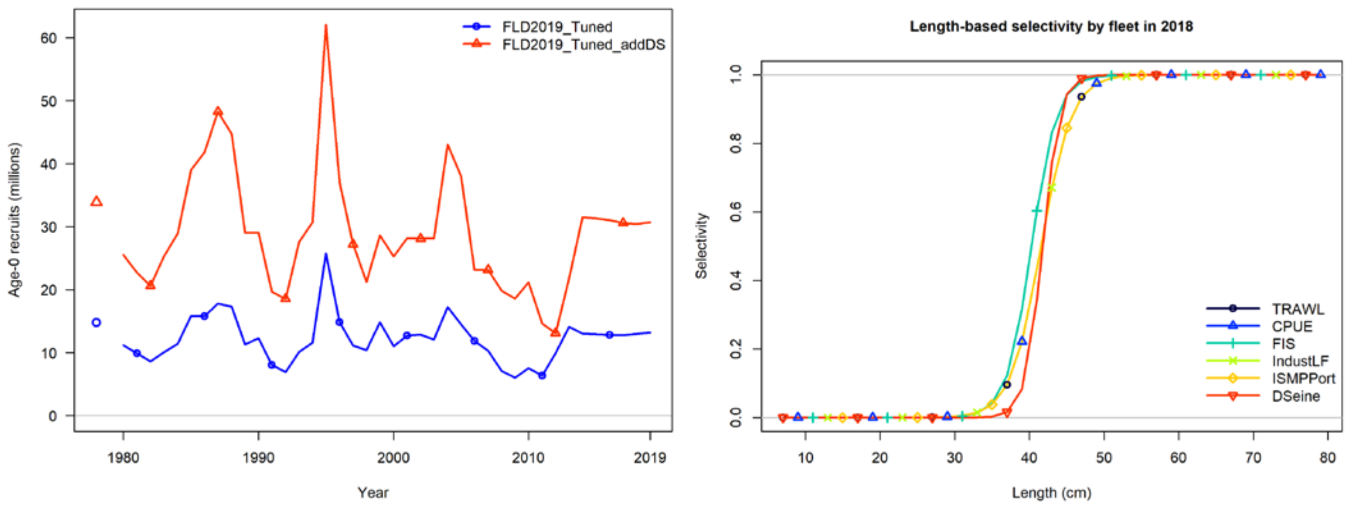

Figure 11.25. A comparison of the recruitment trajectories for the base case model (FLD2019_Tuned; blue) and the sensitivity with Danish seine included (FLD2019_Tuned_addDS; red) and estimated selectivity for each fleet for deepwater flathead.

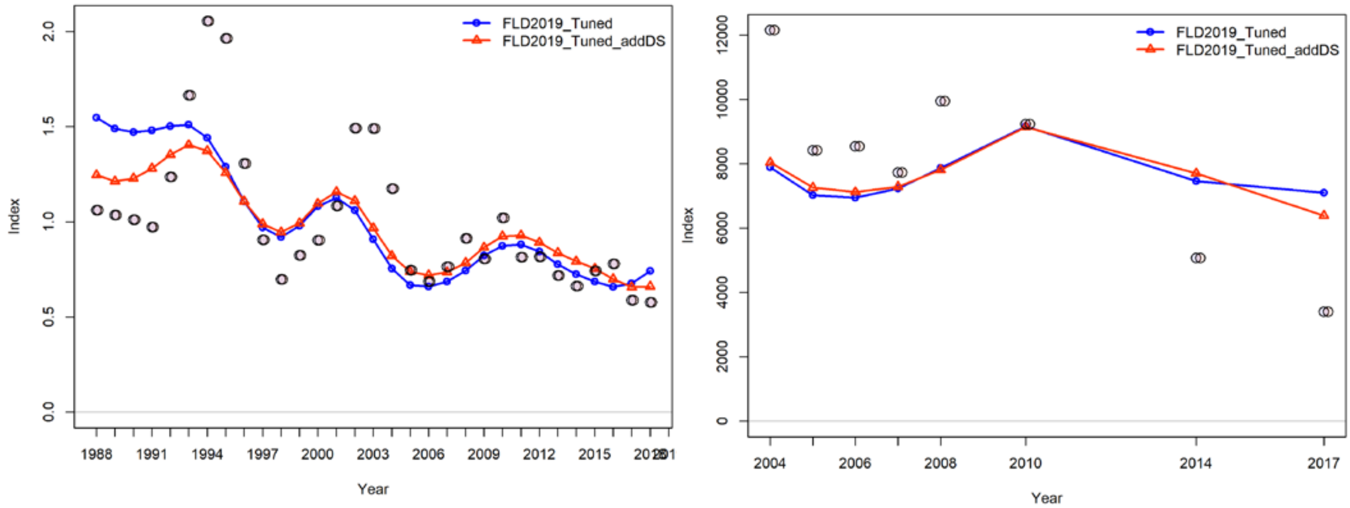

Figure 11.26. A comparison of fit to cpue and the FIS for the base case model (FLD2019_Tuned; blue) and the sensitivity with Danish seine included (FLD2019_Tuned_addDS; red) for deepwater flathead.

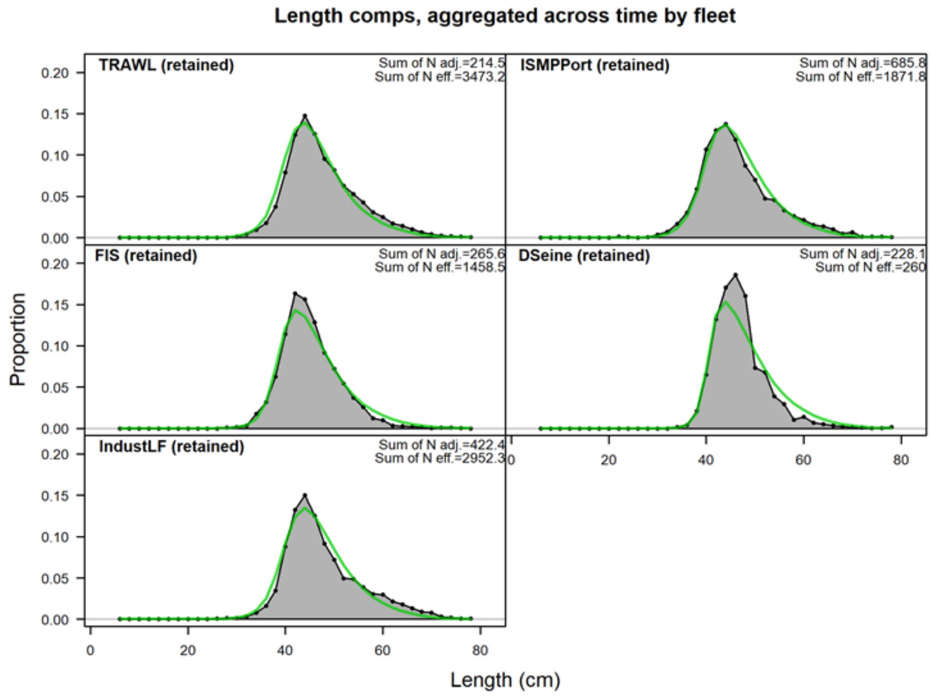

Figure 11.27. Aggregated fits (over all years) to the length compositions for deepwater flathead displayed by fleet for the Danish seine sensitivity.

Table 11.3. Financial year estimates of trawl (TW), Danish seine (DS) and Zone 50 (Z50; logbook) catch for Deepwater Flathead in the GAB from 1988/1989 – 2018/2019. * Note that 2017/18 catches for Z50 were used as an estimate of catches in 2018/19.

Season	TW	DS	Z50
88/89	312.5		0.6
89/90	394.7		1.6
90/91	420.2		0.1
91/92	608.1		
92/93	508.2		0.4
93/94	585.1		0.4
94/95	1254.8		12.2
95/96	1551.6		8.2
96/97	1459.3		20.1
97/98	1010.4		11.1
98/99	680.7		5.5
99/00	545.0		14.7
00/01	776.9		32.8
01/02	963.6		16.9
02/03	1866.0		22.6
03/04	2482.1		23.7
04/05	2264.1		41.7
05/06	1545.6		52.7
06/07	1029.9		31.6
07/08	1025.4		32.6
08/09	799.7		26.1
09/10	851.3		15.6
10/11	962.6	5.5	28.7
11/12	828.3	145.1	35.5
12/13	920.1	107.7	30.8
13/14	788.4	98.2	32.5
14/15	505.3	61.8	24.9
15/16	507.9	108.3	19.9
16/17	631.2	100.8	46.6
17/18	459.6	78.6	35.4
18/19	416.5	101.5	35.4*

11.2.8.2 Including Zone 50 catches

An additional sensitivity considered the addition of catches (logbook) of deepwater flathead from Zone 50 (Z50) to the GAB catch series (Table 11.3). There was little difference to the time-series of spawning biomass or relative spawning biomass under this scenario (Figure 11.28).

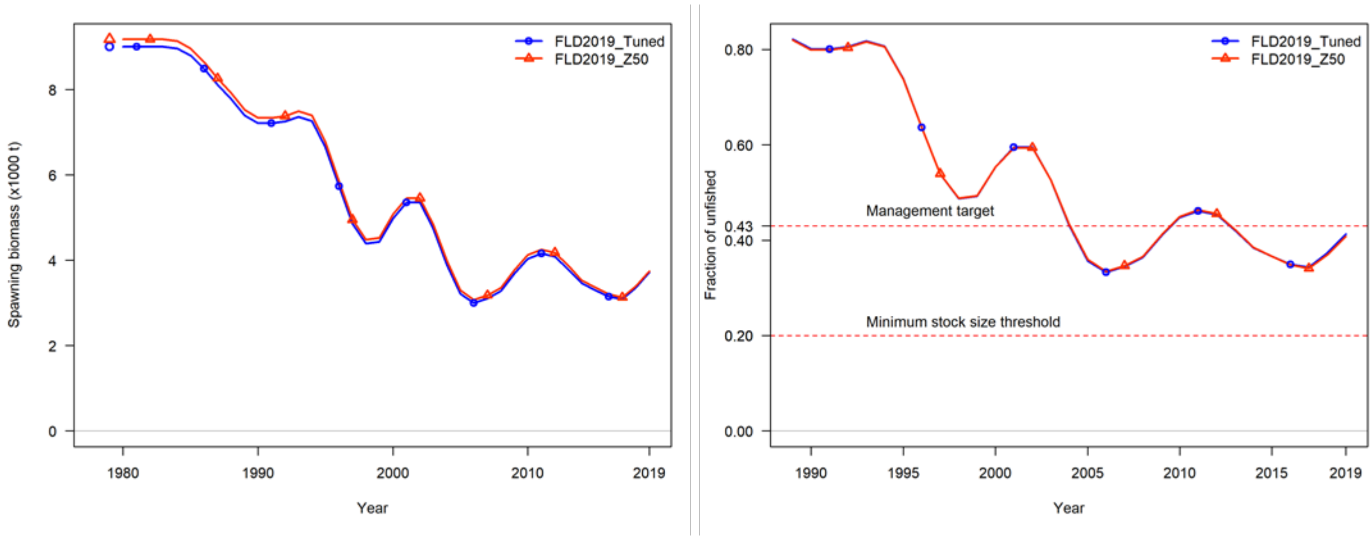

Figure 11.28. A comparison of the magnitude and relative spawning biomass trajectories for the base case model (FLD2019_Tuned; blue) and the sensitivity with Zone 50 catches added to the GAB catches (FLD2019_Z50; red) for deepwater flathead.

11.3 Acknowledgments

Age data was provided by Kyne Krusic-Golub (Fish Ageing Services), ISMP and AFMA logbook and CDR data were provided by John Garvey (AFMA). Mike Fuller, Roy Deng, Franzis Althaus and Robin Thomson (CSIRO) pre-processed the data. Miriana Sporcic, Robin Thomson, Malcolm Haddon (CSIRO), Claudio Castillo-Jordán (UW) and Ian Taylor (NOAA) are thanked for helpful discussions on this work. André Punt updated the ageing error matrix. Malcolm Haddon provided code for auto-tuning and Athol Whitten provided R code for organising plots.

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11.5 Appendix A

A.1 Preliminary base case diagnostics

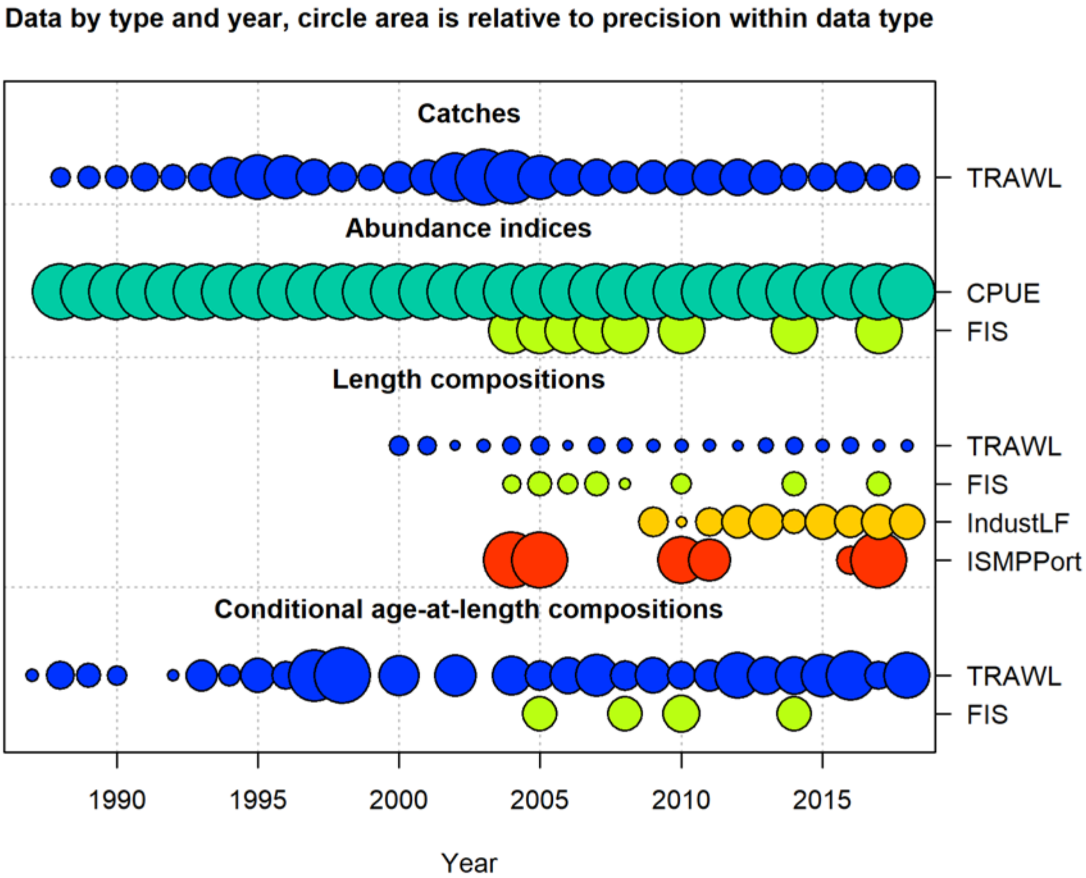

Figure A 11.1. Summary of data sources for deepwater flathead stock assessment.

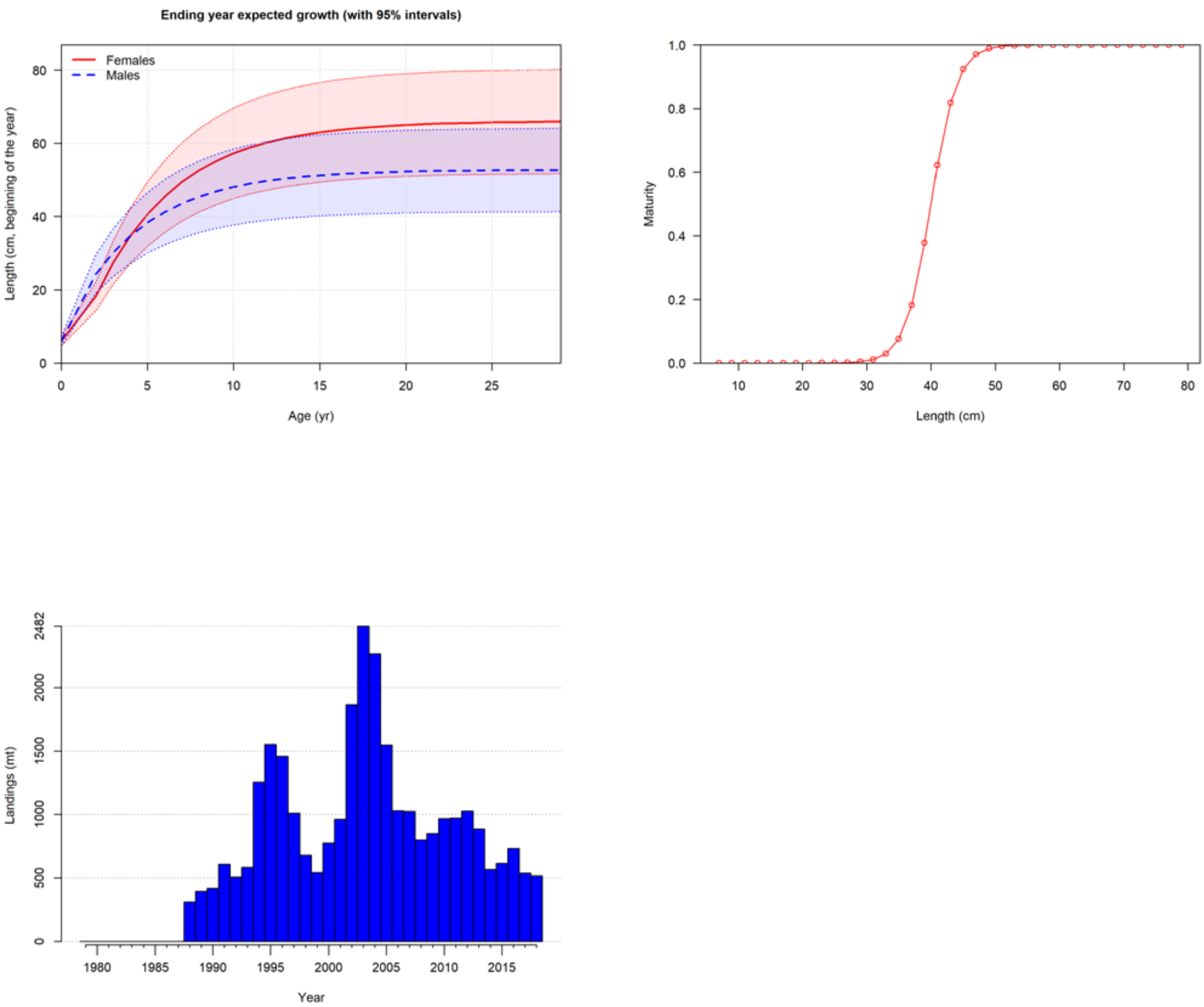

Figure A 11.2. Growth, maturity and landings by fleet for deepwater flathead.

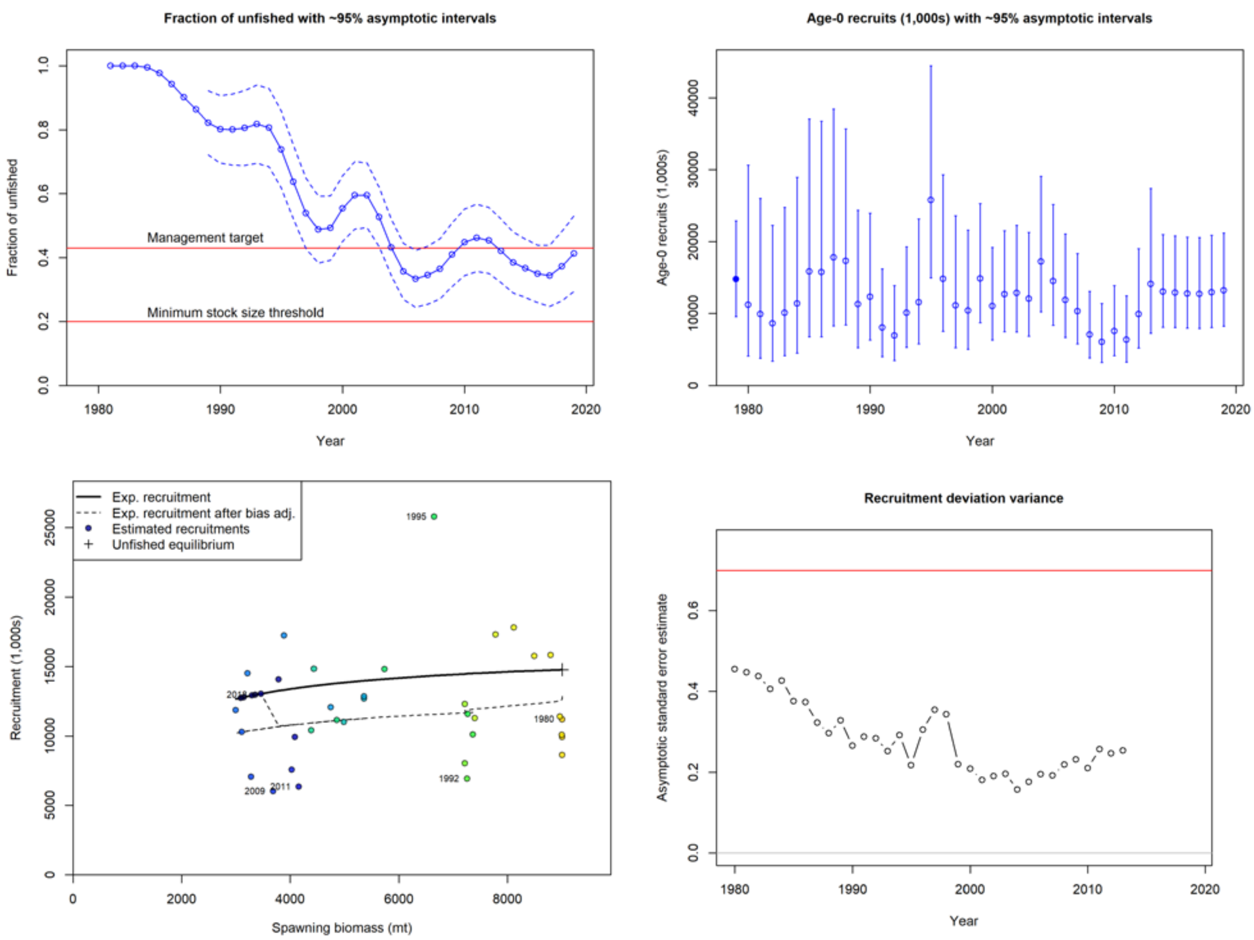

Figure A 11.3. Time series showing depletion of spawning biomass with confidence intervals, recruitment estimates with confidence intervals, stock recruitment curve and recruitment deviation variance check for deepwater flathead.

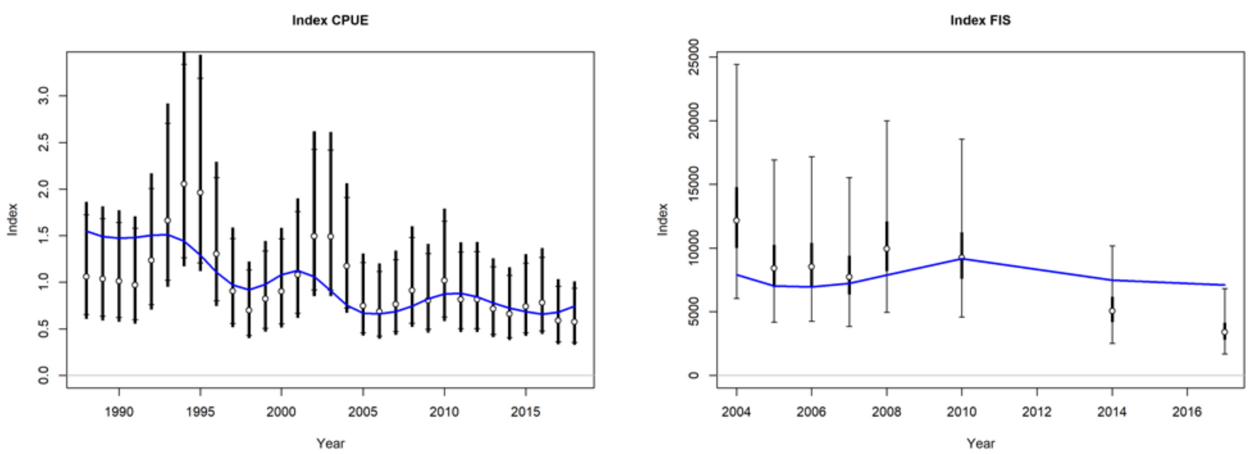

Figure A 11.4. Fits to CPUE and GABFIS for deepwater flathead.

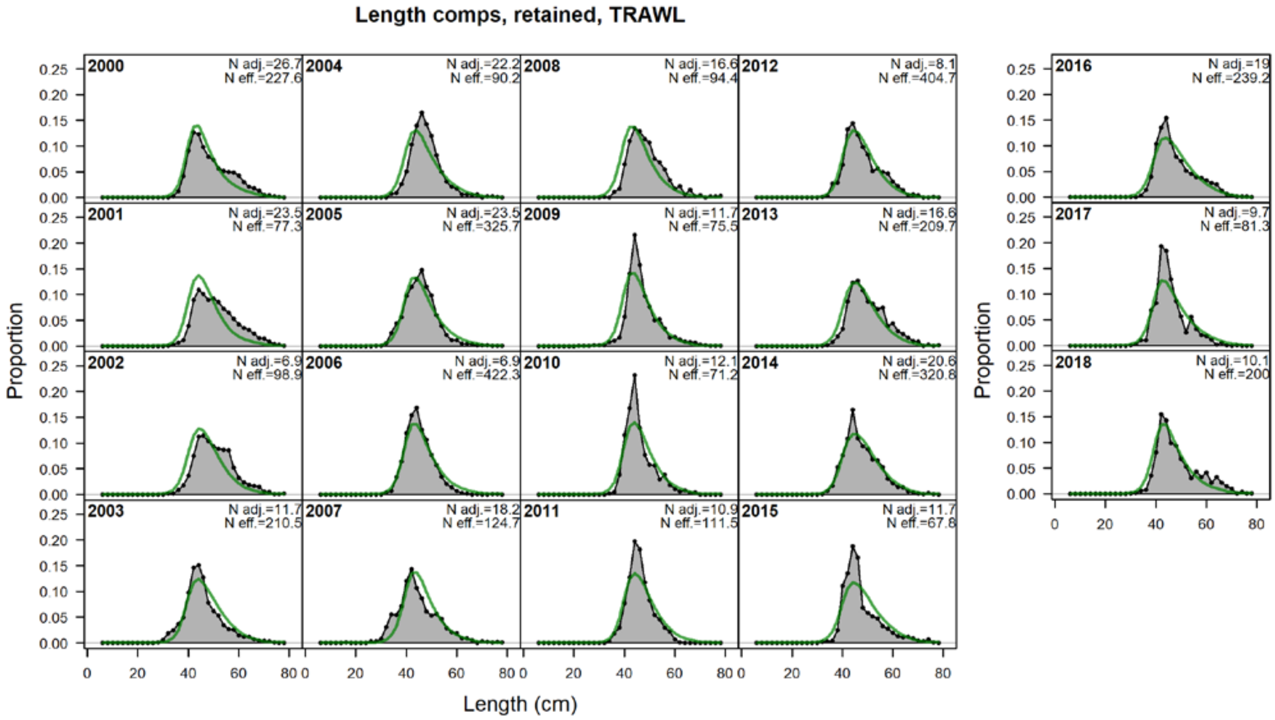

Figure A 11.5. Deepwater flathead length composition fits: retained trawl onboard.

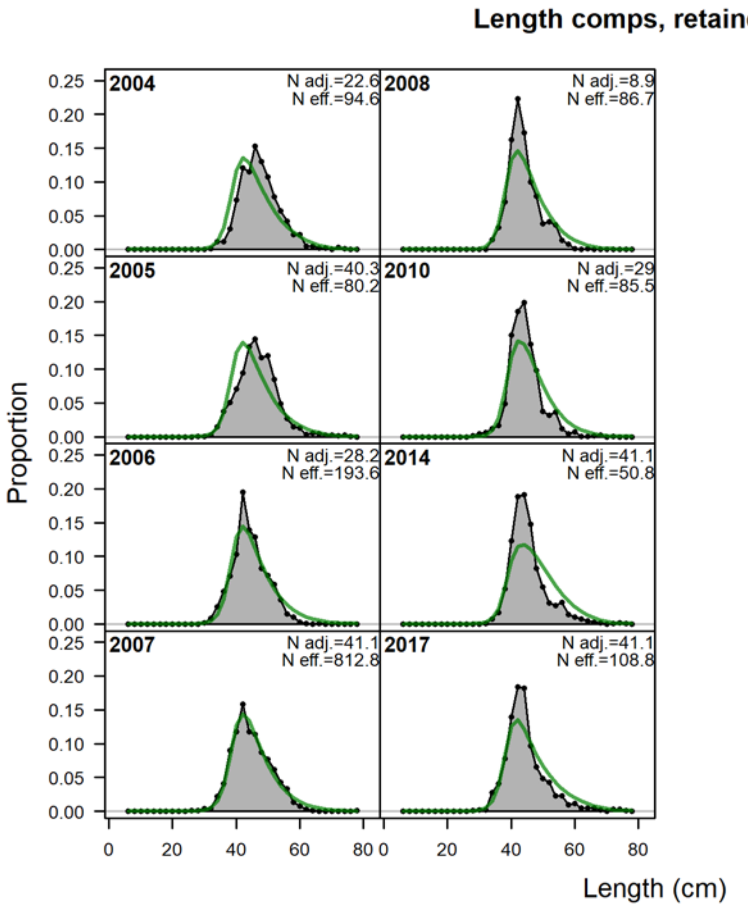

Figure A 11.6. Deepwater flathead length composition fits: FIS retained.

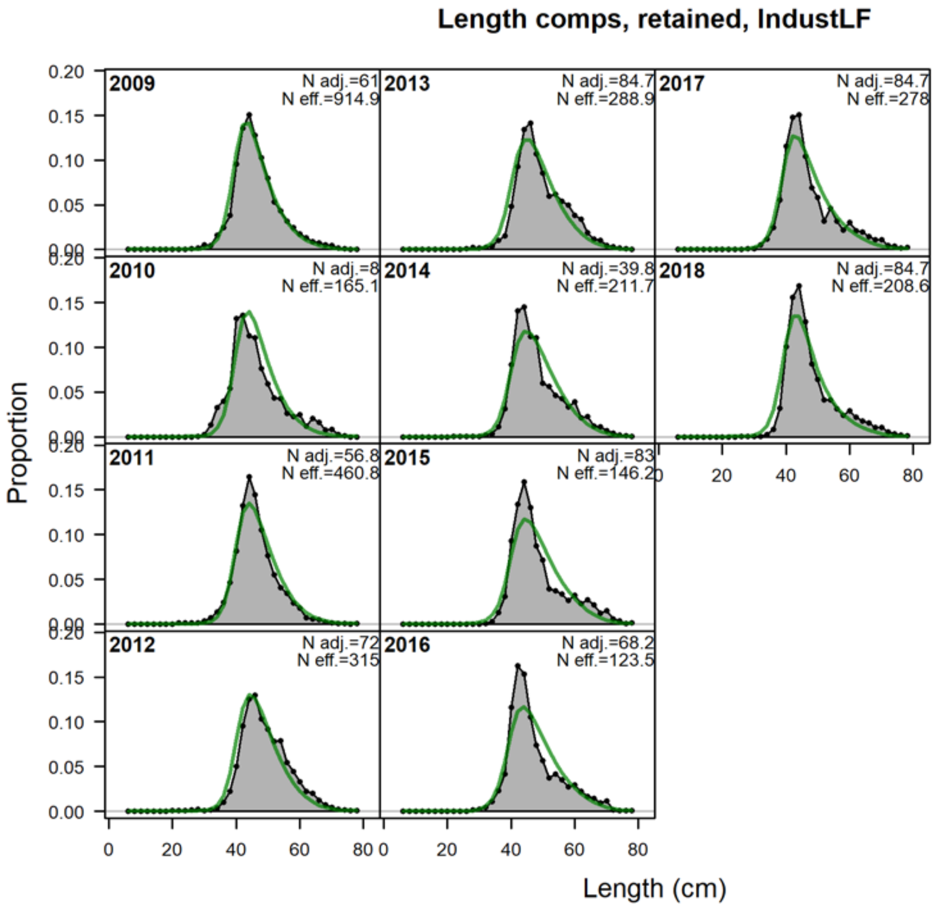

Figure A 11.7. Deepwater flathead length composition fits: Industry lengths.

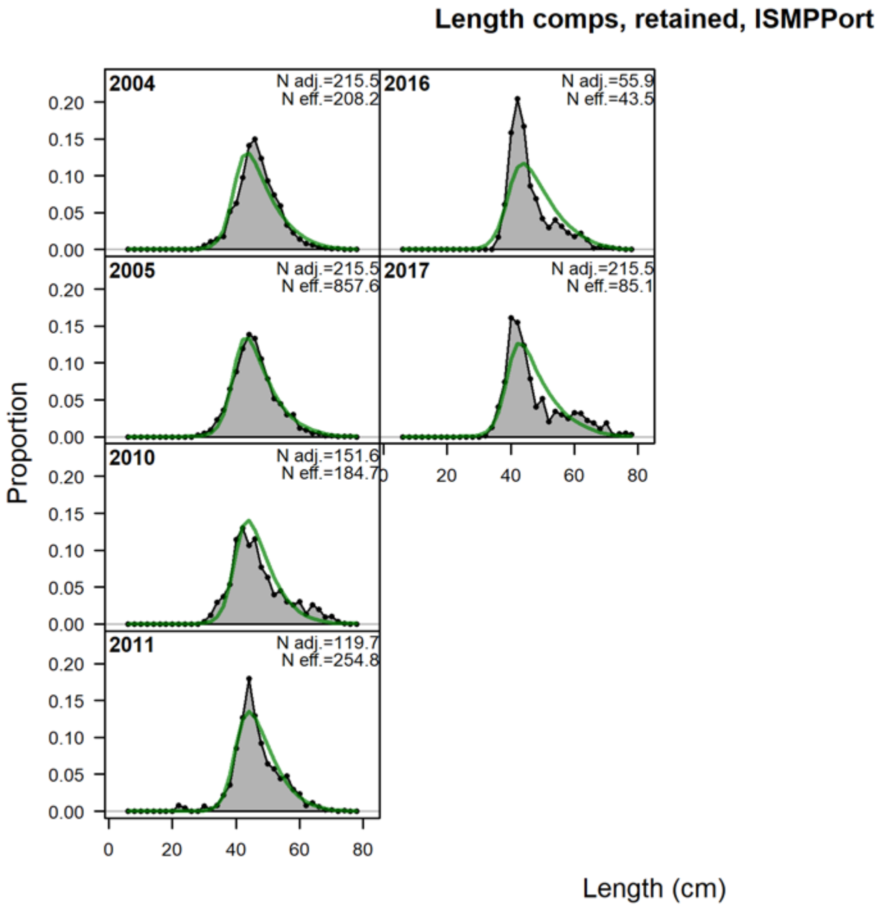

Figure A 11.8. Deepwater flathead length composition fits: Port.

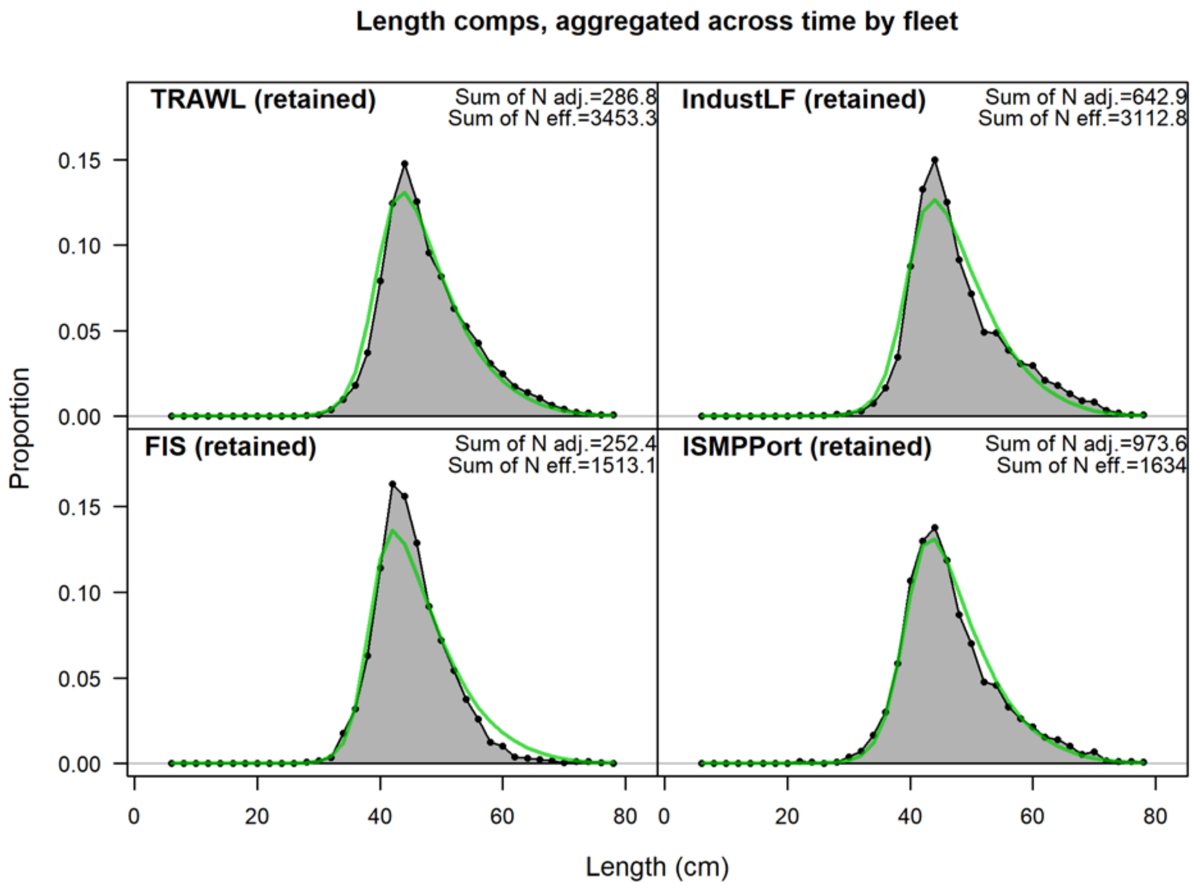

Figure A 11.9. Aggregated fits (over all years) to the length compositions for deepwater flathead displayed by fleet.

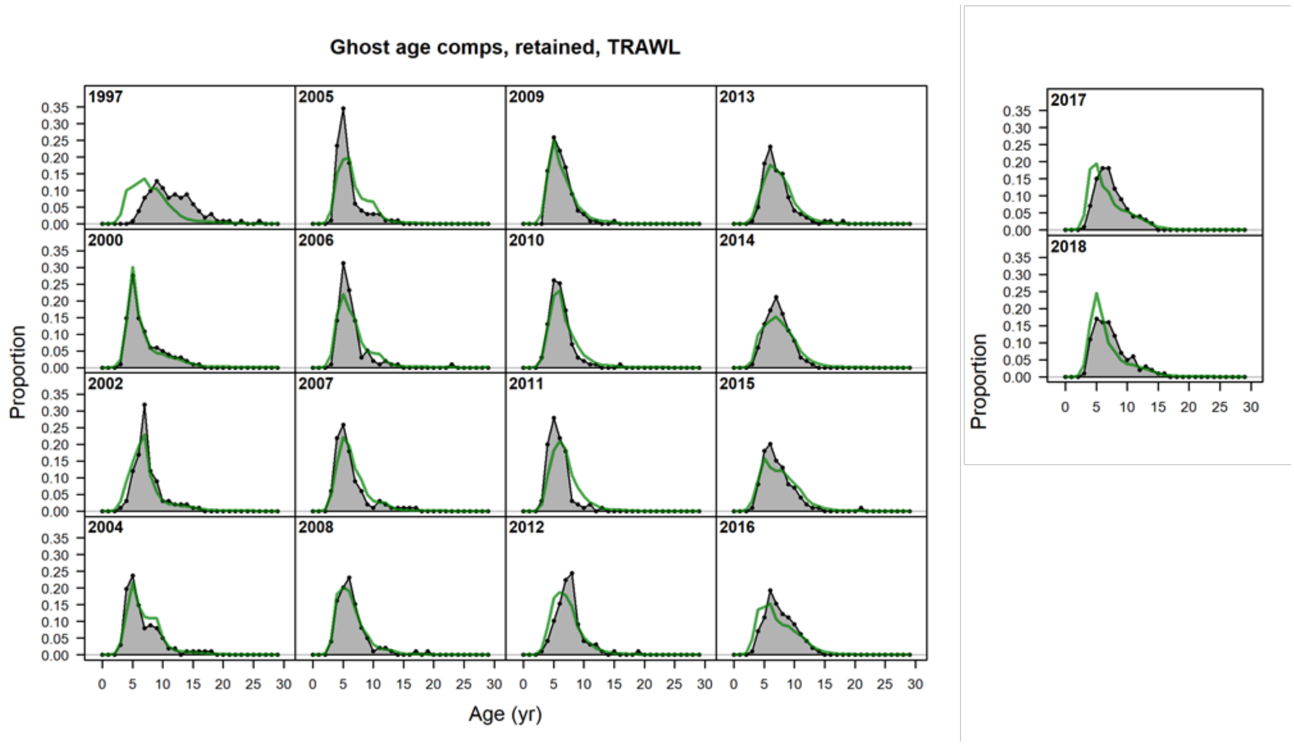

Figure A 11.10. Deepwater flathead implied fits to age: Trawl onboard retained.

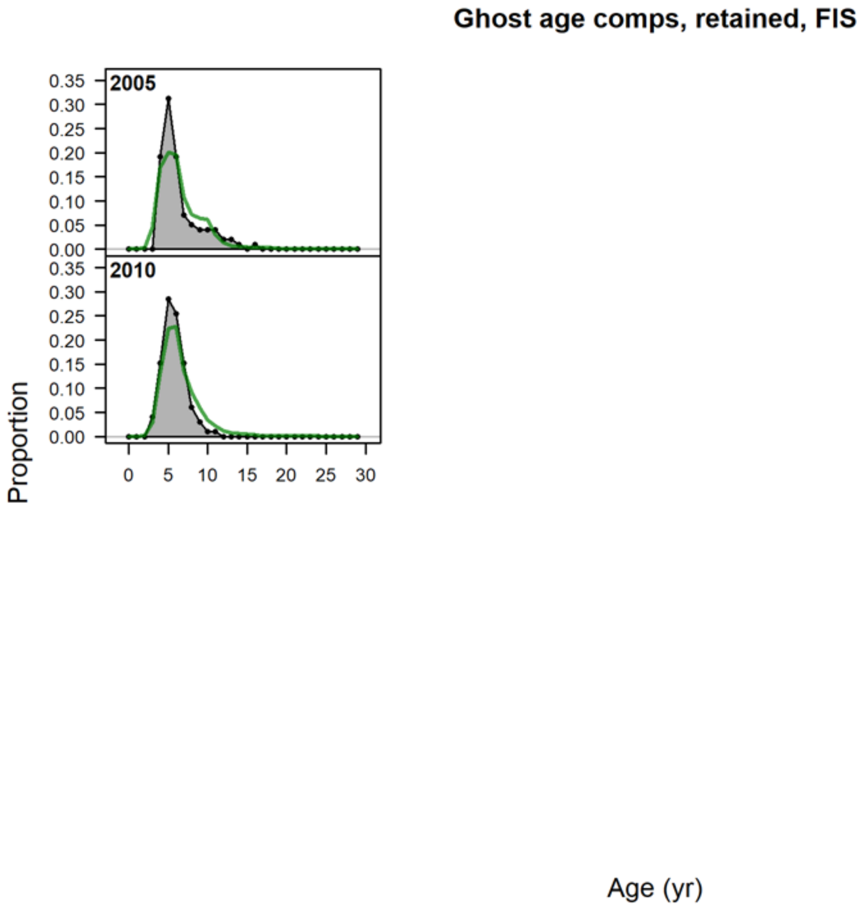

Figure A 11.11. Deepwater flathead implied fits to age: FIS

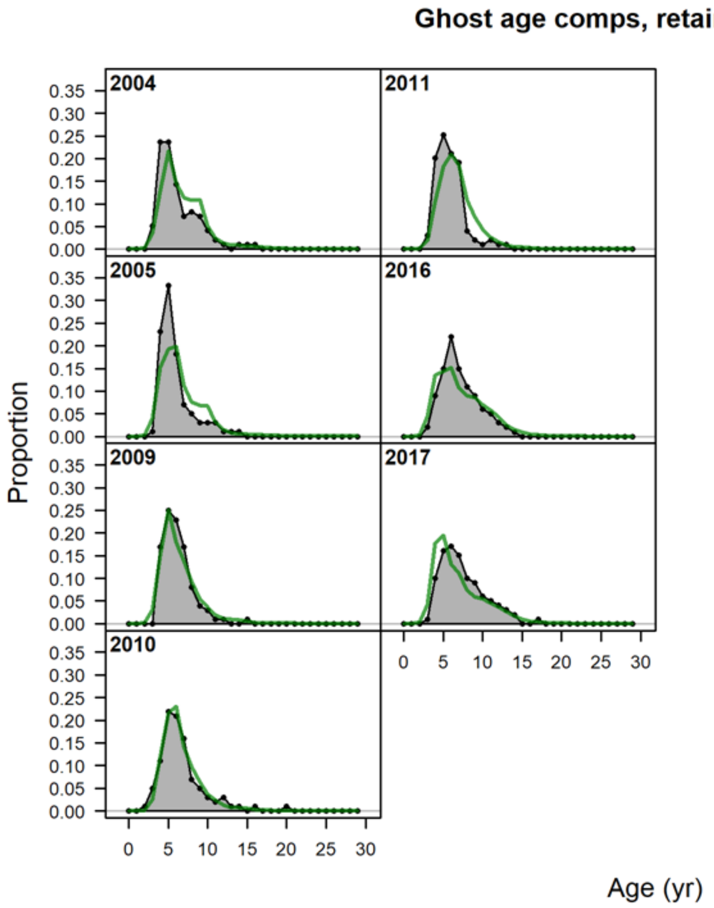

Figure A 11.12. Deepwater flathead implied fits to age: Port.

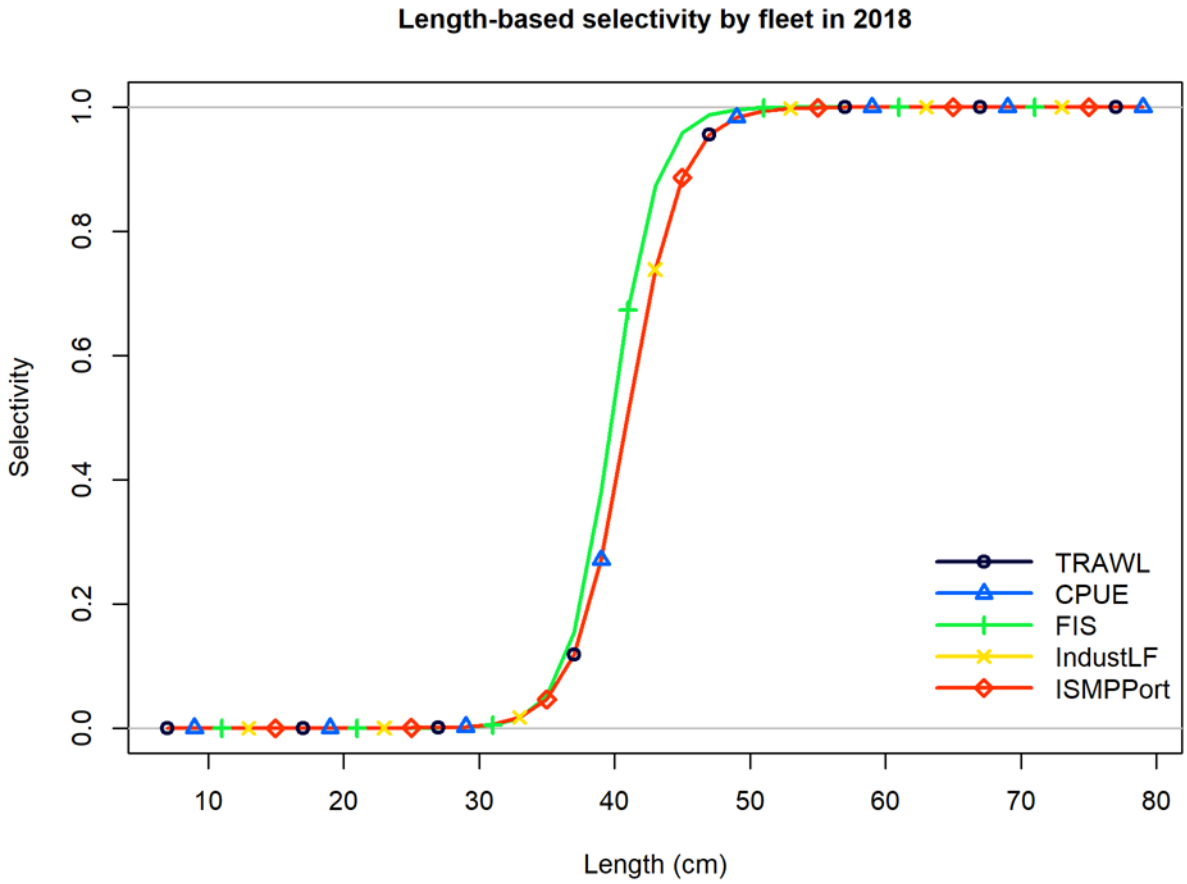

Figure A 11.13. Estimated selectivity curves for deepwater flathead. There are only two different selectivity patterns listed here, with Industry, port and onboard fleets having the same selectivity, but the FIS fleet having a separate estimated selectivity.

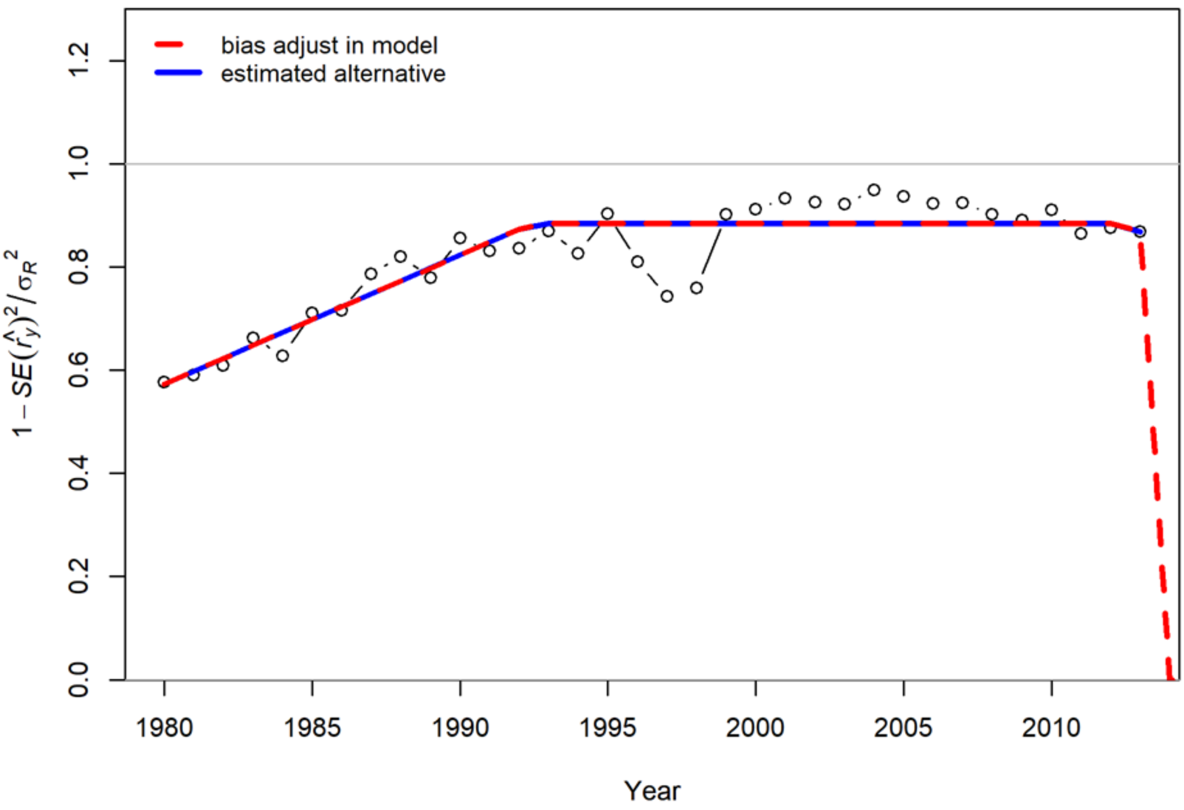

Figure A 11.14. Bias ramp adjustment for deepwater flathead.

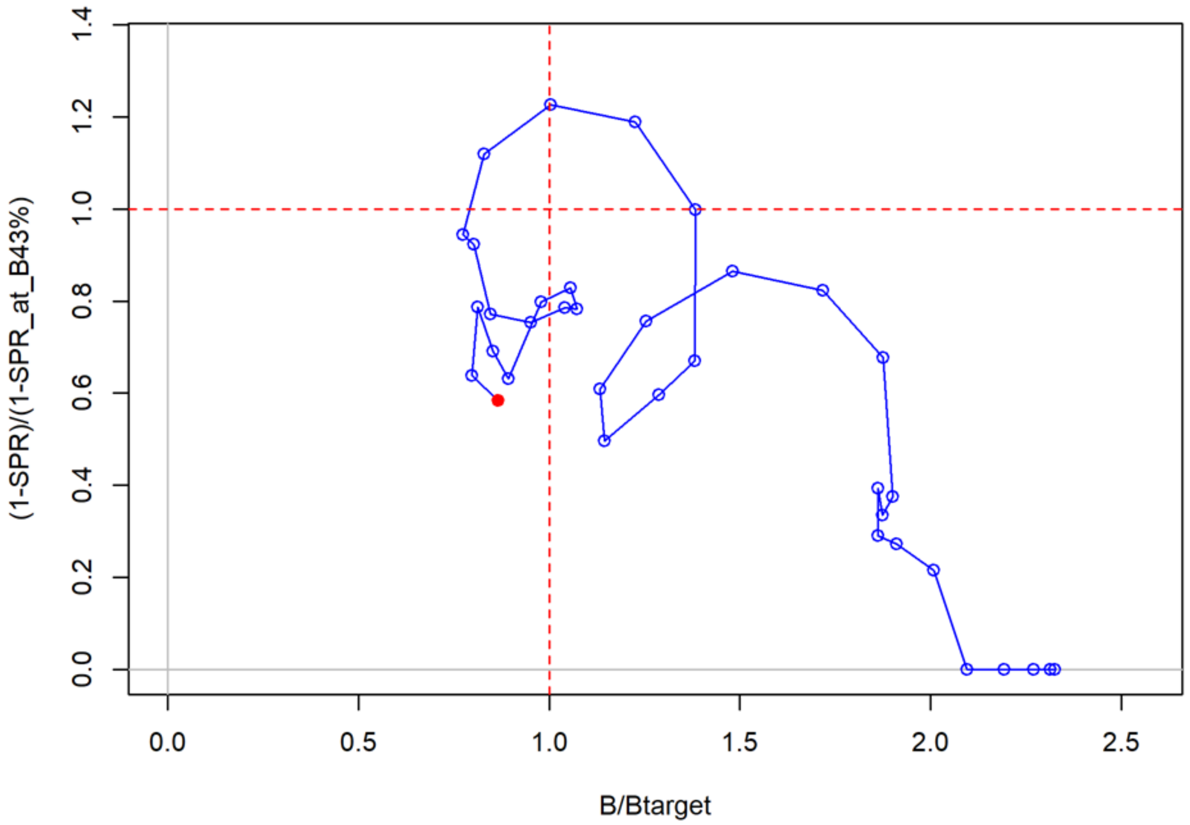

Figure A 11.15. Phase plot of biomass vs SPR ratio.

12. Deepwater flathead (*Neoplatycephalus conatus*) stock assessment based on data up to 2018/19

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12.1 Executive Summary

This document presents the agreed base case for the Tier 1 deepwater flathead (*Neoplatycephalus conatus*) assessment for presentation at GABRAG in December 2019. The last full assessment was presented in Haddon (2016). The base case has been updated by the inclusion of data up to the end of 2018/19, which entails an additional 3 years of catch, CPUE, length and age data and ageing error updates since the 2016 assessment, and incorporation of survey results from the Fishery Independent Survey (GABFIS). The process used to develop a preliminary base case for deepwater flathead through the sequential updating of recent data and updating the stock assessment package Stock Synthesis (SS-V3.40.14) was presented in November 2019. This document provides further detail of the agreed base case, with RBC values and sensitivities to the base case model structure.

As seen in November 2019, the base case provides reasonably good fits to the catch rate data, length data and conditional age-at-length data, however, the fit to the two most recent GABFIS points is poor. The inclusion of new and updated data in the current assessment has led to some changes in the shape of the spawning biomass trajectory, but the depletion remains near the target of 43%. The assessment estimates that the projected 2020/21 spawning stock biomass will be 45% of virgin stock biomass (projected assuming 2018/19 catches in 2019/20), compared to 45% at the start of 2016/17 from the 2016 assessment (Haddon, 2016). The 2020/21 Recommended Biological Catch (RBC) under the 20:35:43 harvest control rule is 1,253 t. The average RBC over the three-year period 2020/21 - 2022/23 is 1,238 t. The long-term RBC is 1,218 t.

A number of sensitivities to the base case model structure were conducted. These included a model with Danish seine as a separate fleet (presented in November 2019) and a model with interpolated GABFIS biomass indices where the FIS was not conducted in recent years. The former model, while showing promise as a future base case model, was unusually sensitive to the inclusion of the Danish seine fleet even though this fleet catches only a small proportion of the total GAB catch. If this fleet continues to operate in the GAB, then it is important that sufficient samples are collected. At the moment, only three years of Danish seine length frequency data and two years of age data are available. The interpolated GABFIS model was suggested to look at how influential the FIS data points are to the estimated biomass trajectories. Results conclude that the GABFIS can have a strong influence on the biomass predicted by the model. This result can contribute to discussions regarding the frequency of FIS surveys in both the GAB and SESSF.

12.2 Introduction

12.2.1 *The fishery*

The trawl fishery in the GAB primarily targets two species, Bight redfish (*Centroberyx gerrardi*) and deepwater flathead (*Neoplatycephalus conatus*), and these have been fished sporadically in the Great Australian Bight (GAB) since the early 1900s (Kailola et al., 1993). The GAB trawl fishery (GABTF) was set up and managed as a developmental fishery in 1988, and since then a permanent fishery has been established with increasing catches of both species, although catches of Bight Redfish have declined recently. Deepwater flathead are endemic to Australia and inhabit waters from NW Tasmania, west to north of Geraldton in WA in depths from 70m to more than 510m (Kailola et al., 1993; Gomon et al., 2008; www.fishbase.org). Bight Redfish are also endemic to southern Australia, occurring from off Lancelin in WA to Bass Strait in depths from 10m to 500m. The two species are often caught in the same trawl tows although Bight redfish is most commonly taken in the east of the GAB. This document focusses on the stock assessment for deepwater flathead.

12.2.2 *Previous assessments*

An initial stock assessment workshop for the GABTF held in 1992 focused on the status of deepwater Flathead and Bight Redfish. Sources of information for the workshop included historical data, logbook catch data, observer data and biological information. With so few years of data available at that time catch-per-unit-area (kg/km^2) was calculated for quarter-degree squares and then scaled to the total area in which the species had been recorded. The approximate exploitable biomass estimates for deepwater flathead and Bight Redfish obtained by this relatively informal method were 32,000t and 12,000t respectively (Tilzey and Wise 1999). Error bounds on these estimates could not be calculated.

Wise and Tilzey (2000) summarised the data for the GABTF focusing on deepwater flathead and Bight Redfish, the two principle commercial species in shelf waters. They produced the first attempt to assess the status of these deepwater flathead and Bight Redfish populations using age- and sex-structured stock assessment models. The virgin total biomass estimates for the deepwater flathead base case model were 53,760t (95% confidence interval is 2,488-105,032t). In 2002 an updated assessment was carried out including data up to 2001. The unexploited biomass estimates for the deepwater flathead base case model was then 12,876t (95%CI=11,928-13,824).

GABTF assessments in 2005 (Wise and Klaer, 2006; Klaer, 2007) used a custom-designed integrated assessment model developed using the AD Model Builder software (Fournier *et al*., 2012). A series of fishery-independent resource surveys was also commenced in 2005, providing a single annual biomass estimate for Bight Redfish and deepwater flathead (Knuckey *et al*., 2015), plus extra samples of length and age composition data. Initially, attempts were made to make absolute abundance estimates using classical swept area methods from the survey data. The unexploited biomass levels estimated for the base case models from the assessment models were 20,418t and 13,932t for deepwater flathead and Bight Redfish, respectively. The absolute biomass estimate from the survey at that time was consistent with other fishery data for deepwater flathead, but was much greater than the biomass modelled without the survey for Bight redfish. Survey estimates are now treated as indices of relative abundance separate from that obtained from the standardized commercial catch-per-unit-effort data.

The 2006 assessment (Klaer and Day, 2007) duplicated as far as possible the assessment results from 2005 using the Stock Synthesis (SS) framework. Although it was possible to replicate 2005 results reasonably well, there were a few differences in the model structure implemented in Stock Synthesis most importantly the calculation of recruitment residuals independently and allowing recruitment residuals to occur prior to the commencement of the fishery.

An attempt was made to incorporate as much previously unused data as possible into the 2007 assessment - particularly length-frequencies (Klaer, 2007). Age-frequencies were no longer used explicitly but conditional age-at-length distributions were obtained from age-length keys. In addition, the model used original age-at-length measurements to fit growth curves within the model, to better allow for the interaction between selectivity and the growth parameters. The depletion of deepwater flathead in 2007 was estimated at 56%, and the unexploited female spawning biomass was estimated at 8,836t (Klaer, 2007).

The 2010 assessment (Klaer 2011a, b) included all available port and on-board collected length data combined. Following agreement by the RAG, the 2010 assessment included the FIS as a relative index for the first time. Unexploited female spawning biomass, SSB_0, was estimated as 10,366t and current depletion at 62% of SSB_0. The long-term RBC estimate was 1,137t. This assessment indicated that the stock had been more depleted than previously predicted in 2005/06, being down near the 20% B_0 limit. Previous assessments had all indicated a stock in fish-down, but always above the target biomass.

The 2012 deepwater flathead assessment (Klaer 2013a, b) estimated an unexploited spawning stock biomass of 8,921t and a depletion at that time of 39% of SSB_0. The 2013/14 recommended biological catch (RBC) under the 20:35:43 harvest control rule was 979t and the long-term yield (assuming average recruitment in the future) was 1,051 t. An assessment was conducted in 2013 using data to the end of 2012/2013 (Klaer, 2014a, b). This estimated the unexploited spawning stock biomass of 9,320t and a depletion at the start of 2014/2015 of 45% of SSB_0. The 2014/15 RBC under the 20:35:43 harvest control rule was 1,146t and the long-term yield (assuming average recruitment in the future) was 1,105 t.

The previous deepwater flathead assessment was conducted in 2016 using data to the end of 2015/16 (Haddon, 2016). For the first time the ISMP data was divided into the on-board and Port based samples, the length and age composition data from the FIS was used, and the industry collected length composition data were also included. The base-case assessment estimated that the female spawning stock biomass at the start of 2016/2017 was 45.0% of unexploited female spawning stock biomass (SSB_0). The 2017/2018 recommended biological catch (RBC) under the agreed 20:35:43 harvest control rule was 1,155 t and the long-term yield (assuming average recruitment in the future) was 1,093 t. The unexploited female spawning biomass in 2016/2017 was estimated as 11,046 t.

Table 12.1. A summary of stock assessment outcomes for deepwater flathead. B_0 is the unfished female spawning biomass. The yield is the RBC for the following year with the long term estimated sustainable yield (LTY) in brackets for some years (prior to 2009 these are MSY estimates). The 1999 biomass estimate is of exploitable biomass while the rest reflect female spawning biomass.

Year	Authors	B_0 (t)	Depletion	RBC (LTY) (t)
1999	Tilzey and Wise (1999)	~32,000	-	
2000	Wise and Tilzey (2000)	53,760		
2002	Wise and Tilzey	12,876		
2005	Wise and Klaer (2006)	20,418	>79%	(670)
2006	Klaer and Day (2007)	10,084	50	1,070
2007	Klaer (2007)	8,841	56	1,524
2010	Klaer (2011b)	10,366	62	1,463 (1,137)
2012	Klaer (2013b)	8,921	39	979 (1,051)
2013	Klaer (2013b)	9,320	45	1,146 (1,105)
2016	Haddon (2016)	11,046	45	1,155 (1,093)
2019	Tuck et al. (2019b)	9,008	45	1,253 (1,218)

12.3 Methods

12.3.1 *Modifications to the previous assessment*

An initial base case quantitative Tier 1 deepwater flathead assessment was developed and presented to the GABRAB on the 21st November 2019 (Tuck et al., 2019); this was used to describe the changes from the previous assessment by the sequential addition of the new data now available (known as a bridging analysis) along with other structural changes. The last full assessment was presented in Haddon (2016).

The preliminary base case was updated by the inclusion of data up to the end of 2018/19, which entails an additional 3 years of catch, CPUE, length and age data and ageing error updates since the 2016 assessment, and incorporation of survey results from the Fishery Independent Survey (GABFIS) and using the stock assessment package Stock Synthesis (SS3-V3.30.14.05). It was agreed by members of GABRAG (November 2019) that the preliminary base case should be taken as the base case for RBC recommendations at the December GABRAG meeting. This document provides further details of the base case model, RBC recommendations and sensitivities.

12.3.2 *Model structure*

A two-sex stock assessment for deepwater flathead was implemented using the software package Stock Synthesis (SS; Methot and Wetzel, 2013). SS is a statistical age- and length-structured model that can be used to fit the various data streams now available for deepwater flathead, simultaneously. The population dynamics model, and the statistical approach used in the fitting of the model to the various types of data, are described in the SS operating manual (Methot, 2015) and technical description (Methot and Wetzel, 2013) and are not reproduced here.

A single stock of deepwater flathead was assumed to occur across the GAB. The stock was assumed to have been unexploited prior to 1988/1989. The selectivity pattern for the trawl fleet was modelled as not changing through time. The two parameters of the logistic selectivity function were estimated within the assessment. Now that FIS length and age composition data are included as data streams, a separate logistic selectivity was able to be estimated for the FIS.

Male and female deepwater flathead are assumed to have the same biological parameters except for their growth and the length-weight relationship (Table 12.2). Three of the four parameters relating to the von Bertalanffy growth equation are estimated within the model-fitting procedure from the observed age-at-length data; all male growth parameters are fitted as offsets to the female parameters. Fitting growth within the assessment model attempts to account for the impact of gear selectivity on the age-at-length data collected from the fishery and any impacts of ageing error.

The rate of natural mortality, M, was assumed to be constant with age, and also constant through time. The natural mortality rate is estimated in the base-case model, with the estimated value being close to 0.263 yr^{-1}. Maturity is modelled as a logistic function, with 50% maturity at 40 cm. Fecundity-at-length is assumed to be proportional to weight-at-length. Recruitment was assumed to follow a Beverton-Holt type stock-recruitment relationship, parameterised by the average recruitment at unexploited spawning biomass, R_0, and the steepness parameter, h. Steepness for the base-case analysis was assumed to be 0.75. Deviations from the average recruitment at a given spawning biomass (recruitment deviations) were estimated from 1980/1981 to 2013/2014. The value of the parameter determining the magnitude of the potential variation in annual recruitment, σ_R (SigmaR) was set equal to 0.7, as is standard practice. Age 29 is treated as a plus group into which all animals predicted to survive to ages greater than 29 are accumulated.

Table 12.2. Summary of selected parameters from the 2019 base case model for deepwater flathead. Sources: (1) Analyses of biological samples collected during the 2004 GAB reproductive study (Brown and Sivakumaran, 2007), (2) length and age samples collected between 2000-2003 and (3) length samples collected during the 2001 FRDC project. Years represent the first year of each financial year i.e. 2015 = 2015/2016 (adapted from Haddon, 2016).

Description	Source	Parameter	Combined Male/Female	
Years		y	1988-2018	
Recruitment Deviates		r	estimated 1980 - 2013	
Fleets			1 trawl only	
Discards			none significant, not fitted	
Age classes		a	0 – 29 years	
Sex ratio		p_s	0.5 (1:1)	
Natural mortality		M	estimated (0.263) per year	
Steepness		h	0.75	
Recruitment variation		σ_r	0.7	
Female maturity	1		40 cm (TL)	
Growth	2	L_{max}	65.0258 cm (TL)	fitted
		K	fitted	fitted
		L_{min}	fitted	fitted
		CV	Fitted (M & F assumed equal)	
			Female	Male
Length-weight (based	3	f_1	0.002 cm (TL)/gm	0.002
on standard length)		f_2	3.332	3.339

12.3.3 *Available data*

An array of different data sources are available for the deepwater flathead assessment including catch, standardized commercial CPUE, an index of relative abundance from the GAB Fishery Independent

Survey (FIS), age composition data from the Integrated Scientific Monitoring Program (ISMP) and from the FIS, and length composition data from four sources: the ISMP (keeping port sampling separate from the on-board sampling), from the FIS, and from on-board crew sampling (Figure 12.1). Age-at-length composition data for the fleet designated Trawl and the FIS were calculated from the available length compositions and conditional age-at-length data (age-length keys). Implied age compositions do not comprise additional data and are not included in the fitting of the model but are shown for information.

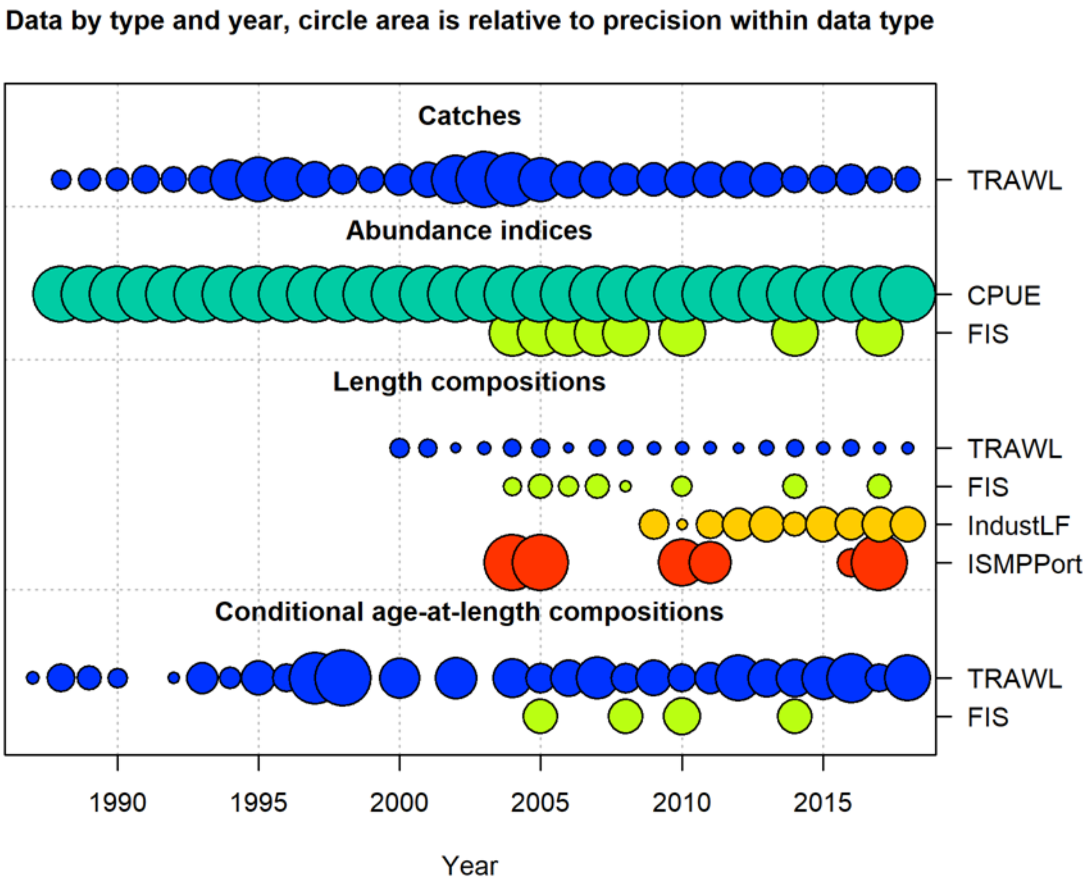

Figure 12.1. Summary of data sources for the 2019 base case deepwater flathead stock assessment.

The assessment data, other than catches, for deepwater flathead comes from a single trawl fleet; although there is a Danish seine vessel operating in the fishery. For the base case model, Danish seine catches are added into the trawl time series to fully account for removals. A sensitivity to the inclusion of a Danish Seine fleet is also provided. A landed catch history for deepwater flathead is available for the years from 1988/1989 to 2018/19. Landed catches were derived from GAB logbook records for the years to 2005 and catch disposal records have been the source of total landings since then. All landings were aggregated by financial year. In all figures, where single years are illustrated these represent the first year of the financial year. The 2018/19 catch value was used for the 2019/20 catch for projections and calculation of the 2020/21 RBC.

Catch rates from the trawl fishery were updated according to Sporcic (2019). The updated catch and catch rate data are in Table 12.3.

Table 12.3. Financial year values and estimates of catch and the standardized trawl CPUE for deepwater flathead in the GAB from 1988/1989 – 2018/2019. Catch is taken from logbook estimates until 2005/06 (Klaer, 2013; Haddon, 2016). Subsequently CDR catches are used. Discards are assumed to be negligible. Danish seine catches are added into the trawl catch for the base case assessment. Standardized CPUE is from Sporcic (2019).

Season	Catch (t)	CPUE
88/89	312.5	1.0601
89/90	394.7	1.0343
90/91	420.2	1.0106
91/92	608.1	0.9717
92/93	508.2	1.2351
93/94	585.1	1.6637
94/95	1254.8	2.0538
95/96	1551.6	1.9618
96/97	1459.3	1.3052
97/98	1010.4	0.9045
98/99	680.7	0.6969
99/00	545.0	0.8223
00/01	776.9	0.9019
01/02	963.6	1.082
02/03	1866.0	1.492
03/04	2482.1	1.4886
04/05	2264.1	1.1745
05/06	1545.6	0.7455
06/07	1029.9	0.6848
07/08	1025.4	0.7631
08/09	799.7	0.9111
09/10	851.3	0.8043
10/11	968.0	1.0191
11/12	973.4	0.8144
12/13	1027.8	0.8161
13/14	886.6	0.7165
14/15	567.1	0.6606
15/16	616.1	0.7405
16/17	732.0	0.7792
17/18	538.2	0.5878
18/19	517.7	0.5753

12.3.3.1 Fishery independent survey abundance estimates

There are now eight estimates of relative abundance from the trawl Fishery Independent Survey (Knuckey et al., 2018). The CV estimates for the abundance estimates are initially set at 0.10, but in the process of balancing the output variability with that input, these values are expanded (Table 12.4).

Table 12.4. FIS relative abundance estimates for deepwater flathead, with each survey estimate's coefficient of variation (taken from Knuckey *et al*., 2018).

Year	2004/05	2005/06	2006/07	2007/08	2008/09	2010/11	2014/15	2017/18
Estimate	12,152	8,415	8,540	7,725	9,942	9,227	5,065	3,396
CV (original)	0.05	0.06	0.05	0.06	0.05	0.05	0.09	0.06

12.3.3.2 Age composition data

An estimate of the standard deviation of age reading error was calculated by Andre Punt (pers. comm., 2019) from data supplied by Kyne Krusic-Golub of Fish Ageing Services (Table 12.5).

Age data exist from the ISMP sampling program and the GABFIS. Ages from the trawl ISMP program exist from 1987/88 to 2018/19, and for the FIS from 2005/06, 2008/09, 2010/11, and 2014/15 (Table 12.6). Age compositions (a combination of the age data and lengths for a particular year) are illustrated in the Appendix. These implied ages are not fit in the model, as the model uses the age-at-length data.

Table 12.5. The estimated standard deviation of normal variation (age-reading error) around age-estimates for the different age classes of deepwater flathead for two readers (1) and (2).

Age	StDev (1)	StDev (2)	Age	StDev (1).	StDev (2)	Age	StDev (1).	StDev (2)
0	0.217633	0.224181	10	0.566769	0.534678	20	1.04301	0.709502
1	0.217633	0.224181	11	0.609909	0.558339	21	1.09652	0.721021
2	0.253167	0.269406	12	0.653988	0.580356	22	1.1512	0.73174
3	0.289475	0.311491	13	0.699027	0.600845	23	1.20707	0.741715
4	0.326574	0.350653	14	0.745048	0.619911	24	1.26416	0.750997
5	0.364481	0.387095	15	0.792071	0.637652	25	1.32249	0.759634
6	0.403214	0.421006	16	0.840119	0.654161	26	1.38209	0.767671
7	0.442791	0.452562	17	0.889213	0.669524	27	1.44299	0.775151
8	0.48323	0.481926	18	0.939376	0.68382	28	1.44299	0.775151
9	0.524549	0.509251	19	0.990633	0.697123	29	1.44299	0.775151

Table 12.6. Number of age-length otolith samples included in the base case assessment by fleet.

Year	ISMP	FIS
1987	61	
1988	290	
1989	214	
1990	146	
1991		
1992	50	
1993	358	
1994	178	
1995	430	
1996	287	
1997	972	
1998	1162	
1999		
2000	599	
2001		
2002	639	
2003		
2004	563	
2005	326	229
2006	484	
2007	650	
2008	328	225
2009	465	
2010	290	262
2011	367	
2012	787	
2013	528	
2014	519	224
2015	666	
2016	877	
2017	293	
2018	774	

12.3.3.3 Length composition data

Length data exist from ISMP sampling (onboard and port), the GABFIS and industry sampling programs (Table 12.7). As is standard practice, the ISMP onboard and port length samples are separately fit in the model. A single selectivity is estimated as a function of length using length data from the ISMP and the industry sampling program. The GABFIS has a separate selectivity using the FIS lengths alone. The length compositions for each source are illustrated in the Appendix.

There had to be at least 100 measured fish for a retained and/or discard onboard and port length-composition data to be included in the assessment. For onboard samples, numbers of shots were used as the sampling unit (i.e. the stage-1 weights; Francis (2011)), with a cap of 200. For port samples, numbers of trips were used as the sampling unit, with a cap of 100. For industry samples, numbers of days of sampling were used as the sampling unit, with a cap of 200. The number of fish measured is not used as the sample size because the appropriate sample size for length-composition data is probably more closely related to the number of shots (onboard), trips (port) or days (industry) sampled, rather than the number of fish measured.

Table 12.7. Number of onboard retained lengths and number of shots, days or trips for length frequencies included in the base case assessment by fleet.

Year	Trawl Onboard		FIS		Industry Sampling		Port	
	Shots	Fish	Shots	Fish	Days	Fish	Trips	Fish
2000	66	6885						
2001	58	6402						
2002	17	2273						
2003	29	3124						
2004	55	3060	28	1131			27	3009
2005	58	3547	50	1738			27	2823
2006	17	980	35	937				
2007	45	1575	51	2399				
2008	41	1470	11	1332				
2009	29	1827			144	11760		
2010	30	837	36	959	19	1637	19	1637
2011	27	1352			134	10795	15	1006
2012	20	1372			170	10448		
2013	41	1721			200	10499		
2014	51	2614	51	1337	94	4826		
2015	29	1209			196	16092		
2016	47	2274			161	12826	7	1164
2017	24	1171	51	1052	200	25258	27	2378
2018	25	1009			200	24756		

12.3.4 *Tuning procedure*

In iterative reweighting, the effective annual sample sizes are tuned/adjusted so that the input sample size is equal to the effective sample size calculated by the model. In SSv3.30 there is an automatic adjustment made to survey CVs (CPUE).

1. Set the standard error for the log of the relative abundance indices (CPUE, acoustic abundance survey, or FIS) to their estimated standard errors for each survey or for CPUE (and FIS values) to the root mean squared deviation of a loess curve fitted to the original data (which will provide a more realistic estimate to that obtained from the original statistical analysis). SSv3.30 then re-balances the relative abundance variances appropriately.
2. The initial value of the parameter determining the magnitude of the process error in annual recruitment, σ_R, is set to 0.7, reflecting the variation in recruitment. The magnitude of bias-correction depends on the precision of the estimate of recruitment and time-dependent bias-correction factors were estimated following the approach of Methot and Taylor (2011).

An automated tuning procedure was used for the remaining adjustments. For the conditional age-at-length and length composition data:

3. Multiply the initial sample sizes for the conditional age-at-length data by the sample size multipliers using the approach of Punt (2017).

4. Similarly multiply the initial samples sizes by the sample size multipliers for the length composition data using the ‘Francis method’ (Francis, 2011).
5. Repeat steps 3 and 4, until all are converged and stable (proposed changes are < 1%).

This procedure may change in the future after further investigations but constitutes current best practice.

12.3.5 *Calculating the RBC*

The Tier 1 harvest control rule specifies a target and a limit biomass reference point, as well as a target fishing mortality rate. Since 2005 various values have been used for the target and the breakpoint in the rule. In 2009, AFMA directed that the 20:40:40 (B_{lim}: B_{MSY}: F_{targ}) form of the rule is used up to where fishing mortality reaches F_{48}, the default economic target of B_{MEY}. Once this point is reached, the fishing mortality is set at F_{48}. Day (2009) determined that for most SESSF stocks where the proxy values of B_{40} and B_{48} are used for B_{MSY} and B_{MEY} respectively, this form of the rule is equivalent to a 20:35:48 (B_{lim}: Inflection point: F_{targ}) strategy. For deepwater flathead the B_{MEY} value is 43% of B_0, as reported in Kompas et al. (2011), and therefore a 20:35:43 harvest control rule is used.

12.3.6 *Sensitivity tests and alternative models*

12.3.6.1 Standard sensitivities

A number of tests were carried out to examine the sensitivity of the results of the model to some of the assumptions and data inputs:

1. $M = 0.28$ yr^{-1}.
2. $M = 0.24$ yr^{-1}.
3. Fix steepness (h) at 0.85.
4. Fix steepness (h) at 0.65.
5. σ_R set to 0.8.
6. σ_R set to 0.6.
7. Double the weighting on the length composition data.
8. Halve the weighting on the length composition data.
9. Double the weighting on the age-at-length data.
10. Halve the weighting on the age-at-length data.
11. Double the weighting on the survey (CPUE) data.
12. Halve the weighting on the survey (CPUE) data.
13. Interpolated FIS abundance values (tuned).
14. Include Danish seine (tuned).

The results of the sensitivity tests are summarized by the following quantities:

1. SSB_0: the average unexploited female spawning biomass.
2. SSB_{2020}: the female spawning biomass at the start of 2020.

3. SSB_{2020}/SSB_0: the female spawning biomass depletion level at the start of 2020.
4. RBC_{2020}: the recommended biological catch (RBC) for 2020.
5. $RBC_{2020\text{-}22}$: the mean RBC over the three years from 2020-2022.
6. $RBC_{longterm}$: the longterm RBC.

The RBC values were calculated for the agreed base case only.

12.3.6.2 Interpolated FIS abundance values

To consider the potential influence of GABFIS abundance indices on model outcomes, GABRAG members suggested filling in years where there was no GABFIS by linearly interpolating the GABFIS points surrounding the missing years (from 2010). This results in the abundance indices shown in Figure 12.2.

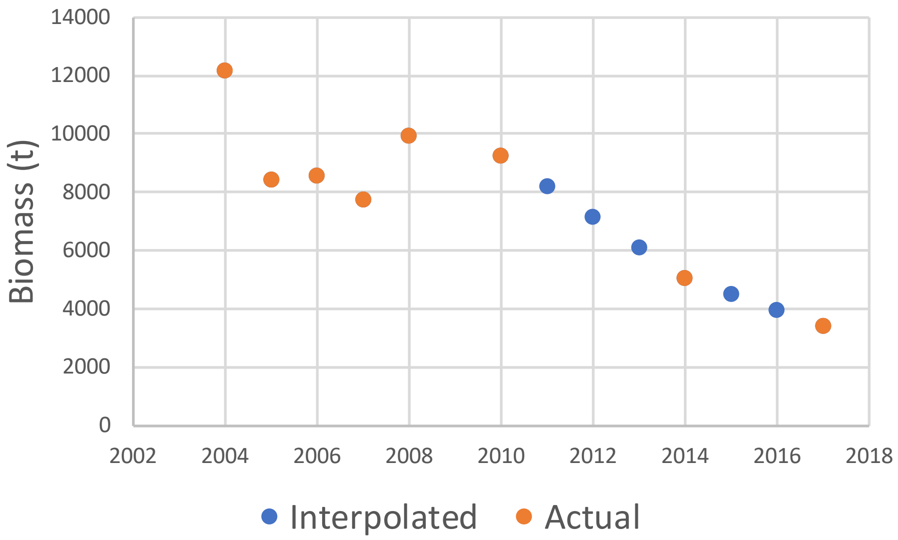

Figure 12.2. The GABFIS abundance values (orange) with linearly interpolated values from 2010 (blue).

12.3.6.3 Danish seine

The inclusion of a separate Danish seine (DS) fleet as an alternative to the base case model structure was considered at the November GABRAG meeting (Tuck et al., 2019). Diagnostics of this model will not be repeated here. However, standard sensitivity metrics are provided for this model. In past assessments, the DS fleet has not been included in the model structure due to a paucity of additional information (on lengths and ages for example, nor is there an index of abundance from this fleet). For this sensitivity, DS catches were separated from trawl, using the proportion of each fleet's logbook catch apportioned to the CDR landings (Table 3 of Tuck et al., 2019). There were also two years of age-at-length data (2016 and 2017) and lengths from years 2012, 2016 and 2017 available. A separate selectivity function was estimated. Results from this model showed an increase in the magnitude of spawning biomass across the mid-years of the time-series, but has a similar final year depletion level to the base case model.

12.3.6.4 Zone 50

An additional sensitivity provided in November 2019 considered the addition of catches (logbook) of deepwater flathead from Zone 50 (Z50) to the GAB catch series. There was little difference to the time-series of spawning biomass or relative spawning biomass under this scenario and so it is not considered further here.

12.4 Results

12.4.1 The base case

12.4.1.1 Parameter estimates

Figure 12.3 shows the estimated growth curve for female and male deepwater flathead.

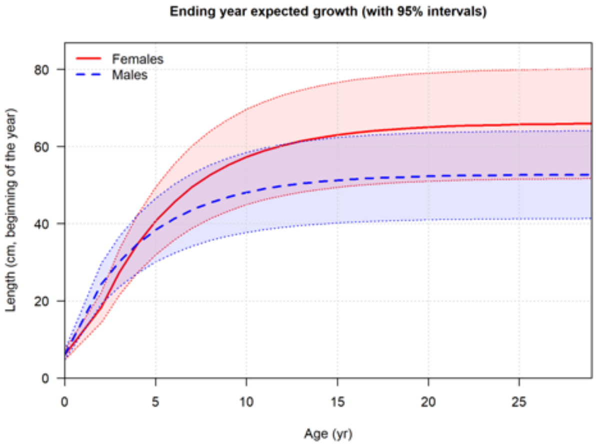

Figure 12.3. The model estimated growth curves for the base case deepwater flathead assessment.

Selectivity is assumed to be logistic for the trawl and FIS fleets. The parameters that define the selectivity function are the length at 50% selection and the spread (the difference between length at 50% and length at 95% selection).

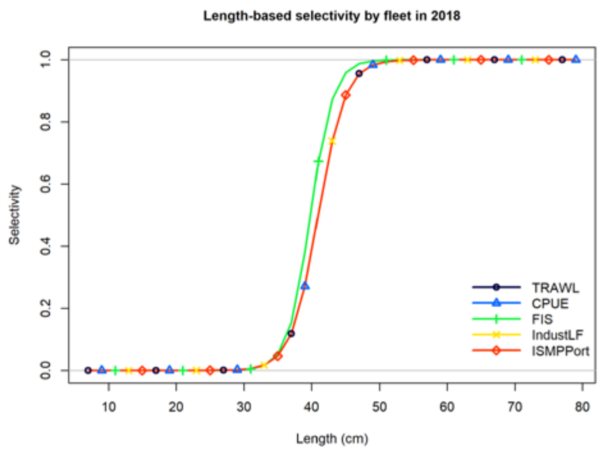

Figure 12.4. Estimated selectivity curves for deepwater flathead. There are only two different selectivity patterns listed here, with Industry, port and onboard fleets having the same selectivity, but the FIS fleet having a separate estimated selectivity.

12.4.1.2 *Fits to the data*

Results show reasonably good fits to the catch rate data (since 2005), length data and conditional age-at-length data. The fits to the FIS abundance indices show a fairly poor fit to the final two years, which may also have influenced the under-fit to the initial 5 years of FIS indices (Figure 12.5).

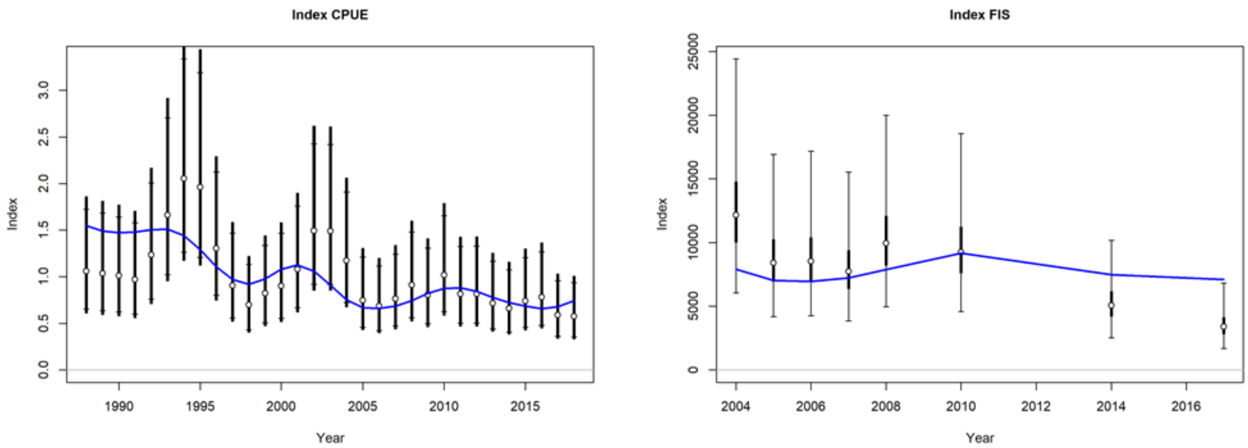

Figure 12.5. Fits to CPUE and GABFIS for deepwater flathead.

The base-case model is able to fit the aggregated retained length-frequency distributions very well (Figure 12.6). The annual length and age composition fits are shown in Appendix A. The age compositions were not fitted to directly, as age-at-length data were used. However, the model is capable of outputting the implied fits to these data for years where length frequency data are also available, even though they are not included directly in the assessment. The model fits the observed age data reasonably well. Note that there are separate implied fits to age for the port and onboard data. There is only one set of age data, but this needs to be scaled up to length data (using an age-length key) to get implied fits to age. This scaling up to length data can be done using either the onboard length data or the port length data, so it appears that there are two sets of age data.

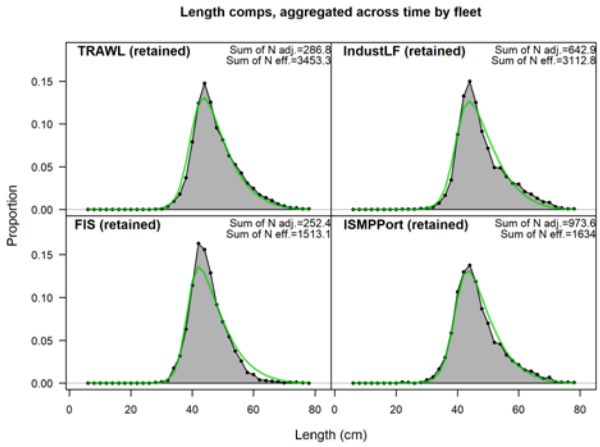

Figure 12.6. Aggregated fits (over all years) to the length compositions for deepwater flathead displayed by fleet.

12.4.1.3 Assessment outcomes

This assessment estimates that the projected 2020/21 spawning stock biomass will be 45% of virgin stock biomass (projected assuming 2018/19 catches in 2019/20; Figure 12.7), compared to 45% at the start of 2016/17 from the 2016 assessment (Haddon, 2016). The inclusion of new and updated data in the current assessment has led to changes in the shape of the spawning biomass trajectory, but the depletion remains near the target of 43%. The base case assessment estimated the unexploited female spawning biomass, *SSBo*, to be 9,008t. Recruitments show a fluctuating pattern, with a recent period of poor recruitment from 2008 to 2011. However, the 2012 and 2013 estimated recruitments are closer to average (Figure 12.8).

Figure 12.9 shows a Kobe plot for the base case analysis. This plot shows a time series of spawning biomass plotted against spawning potential ratio, which provides a measure of overall fishing mortality, and shows the stepwise movement in this space from the start of the fishery, in the bottom right corner, when there was low fishing mortality and high biomass, to the present day (the red dot) where the biomass is just below the target (to the left of the vertical red dashed line) and the fishing mortality is below the target fishing level (below the horizontal red dashed line).

The 2020 recommended biological catch (RBC) under the 20:35:43 harvest control rule is 1,253 t and the long-term yield (assuming average recruitment in the future) is 1,218 t. Averaging the RBC over the three-year period 2020/21 – 2022/23, the average RBC is 1,238 t (Table 12.8).

Table 12.8. Yearly projected RBCs (tonnes) under the 20:35:43 harvest control rule.

RBCs Year	Base
2020	1,253
2021	1,238
2022	1,224
2023	1,214
2024	1,211

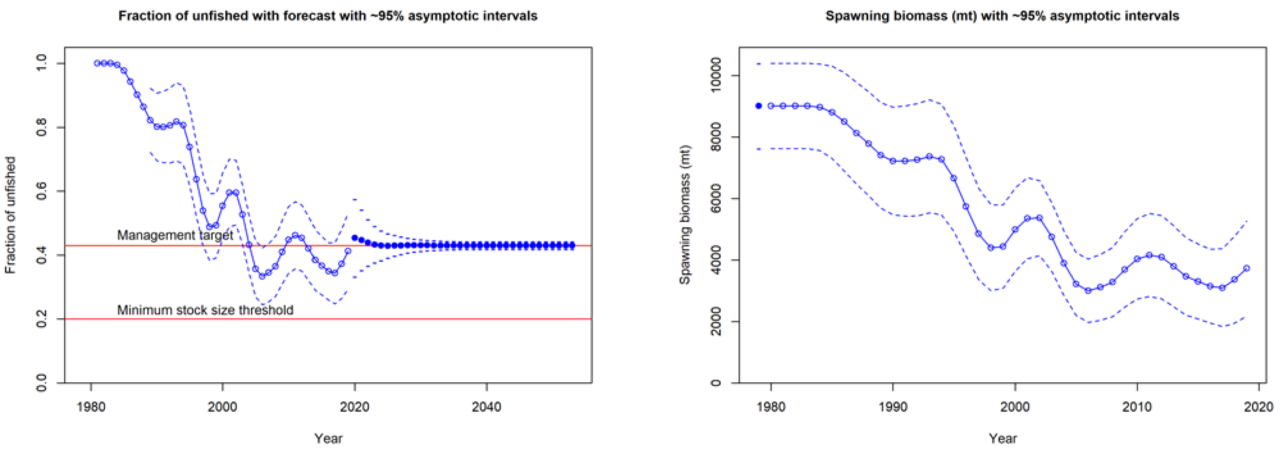

Figure 12.7. The projected relative spawning biomass trajectory (left) and magnitude of spawning biomass (right) for the deepwater flathead base case assessment.

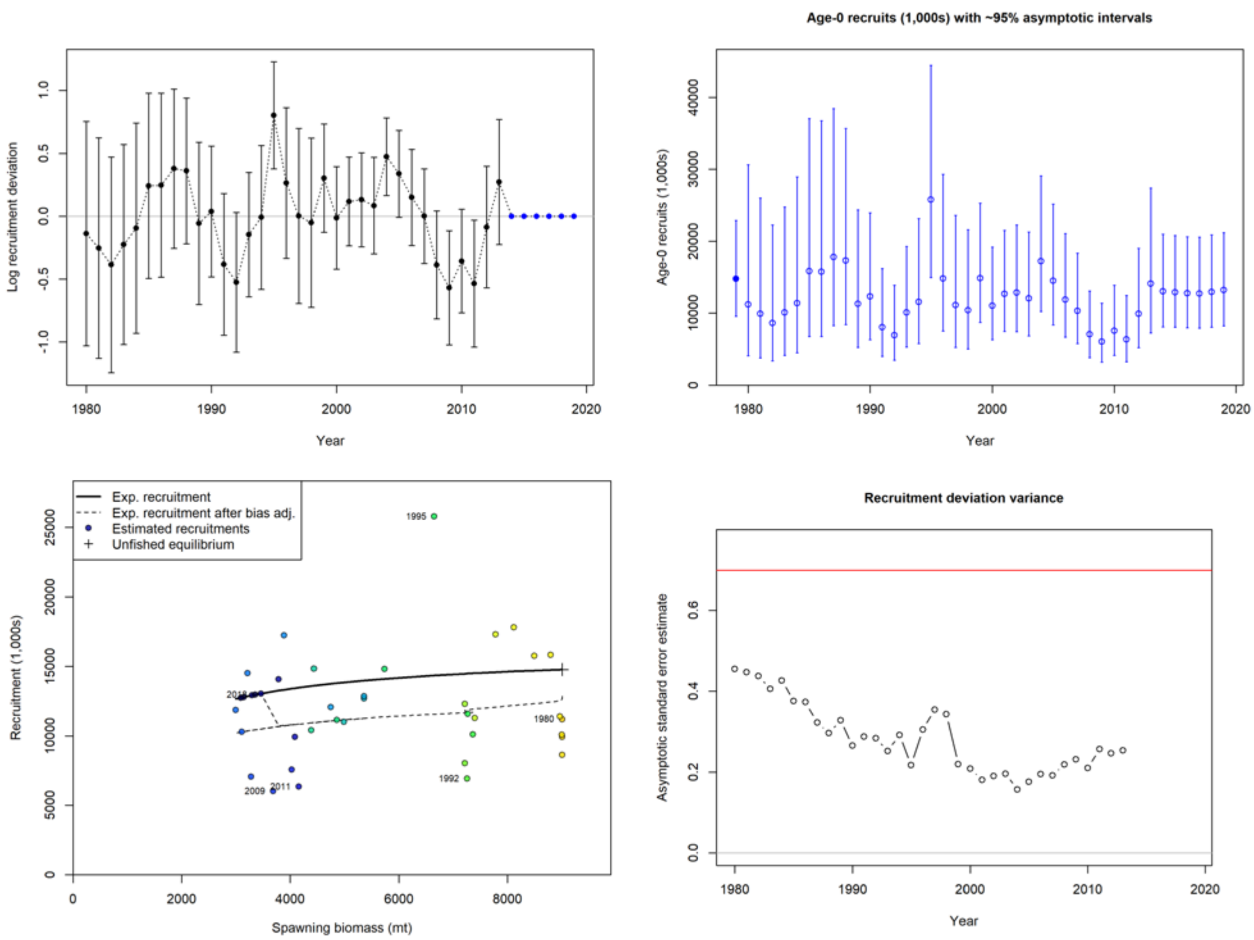

Figure 12.8. Recruitment deviations and estimates with confidence intervals (top), stock recruitment curve and recruitment deviation variance check (bottom) for deepwater flathead.

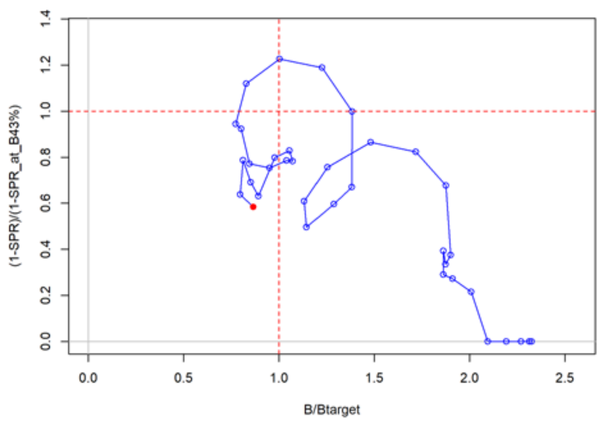

Figure 12.9. Phase plot of biomass vs SPR ratio.

12.4.2 *Likelihood profiles*

As stated by Punt (2018), likelihood profiles are a standard component of the toolbox of applied statisticians. They are most often used to obtain a 95% confidence interval for a parameter of interest. Many stock assessments "fix" key parameters such as *M* and steepness based on *a priori* considerations. Likelihood profiles can be used to evaluate whether there is evidence in the data to support fixing a parameter at a chosen value. If the parameter is within the entire range of the 95% confidence interval, this provides no support in the data to change the fixed value. If the fixed value is outside the 95% confidence interval, it would be reasonable for a review panel to ask why the parameter was fixed and not estimated, and if the value is to be fixed, on what basis and why should what amounts to inconsistency with the data be ignored. Integrated stock assessments include multiple data sources (e.g., commonly catch-rates, length-compositions, and age-compositions) that may be in conflict, due for example to inconsistencies in sampling, but more commonly owing to incorrect assumptions (e.g., assuming that catch-rates are linearly related to abundance), i.e. model-misspecification. Likelihood profiles can be used as a diagnostic to identify these data conflicts (Punt, 2018).

Likelihood profiles for key parameters of interest (such as natural mortality (*M*), steepness (*h*) and virgin spawning biomass) were provided in Tuck et al. (2019) for the agreed base case. These, and the retrospective analyses, are not repeated here. However, a likelihood profile for 2018 depletion was not available for the November GABRAG meeting and is shown in Figure 12.3, with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. The index data suggest a lower value of depletion, whereas the length data suggest a higher value. However, the confidence intervals of 2018 depletion are reasonably broad, being between 0.28 and 0.5 of virgin biomass.

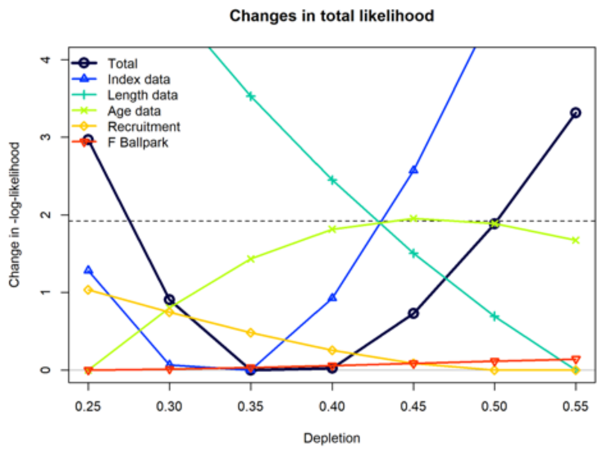

Figure 12.10. The likelihood profile for 2018 depletion.

12.4.3 *Sensitivity tests and alternative models*

12.4.3.1 Standard sensitivities

Results of the sensitivities to the potential base case are listed in Table 12.9. The usual set of sensitivities are provided (which includes sensitivities on mortality, steepness, σ_R and halving and doubling the weighting on length, age and index data) and the sensitivities to the inclusion of Danish seine and the interpolated FIS abundance values. Results are not overly sensitive to varying key parameters, with depletion estimates ranging between 41% and 53% of virgin biomass, but with most around 45%.

Unweighted likelihood components for the base case and differences for the sensitivities are shown in Table 12.8. This table tends to show that for most alternatives, the fit to the data is degraded by moving away from base case model values or weighting schemes.

12.4.3.2 Interpolated FIS abundance values

Including interpolated values since 2010 for the GABFIS for years in which there was no FIS led to a slight decline in the recent spawning biomass series. This is not too surprising, as the model is attempting to fit to a greater number of GABFIS points that show a declining relative abundance trend (Figure 12.11). While the fit to the recent GABFIS abundance may have improved, the fit to the earlier GABFIS abundance points has degraded. These results show that annual FIS points can have a strong influence on results, but it needs to be recognised that the imputed signal (from the linearly interpolated points) provided a strong and consistent signal of a declining relative biomass trend which may not have eventuated in reality given uncertainties associated with FIS surveys.

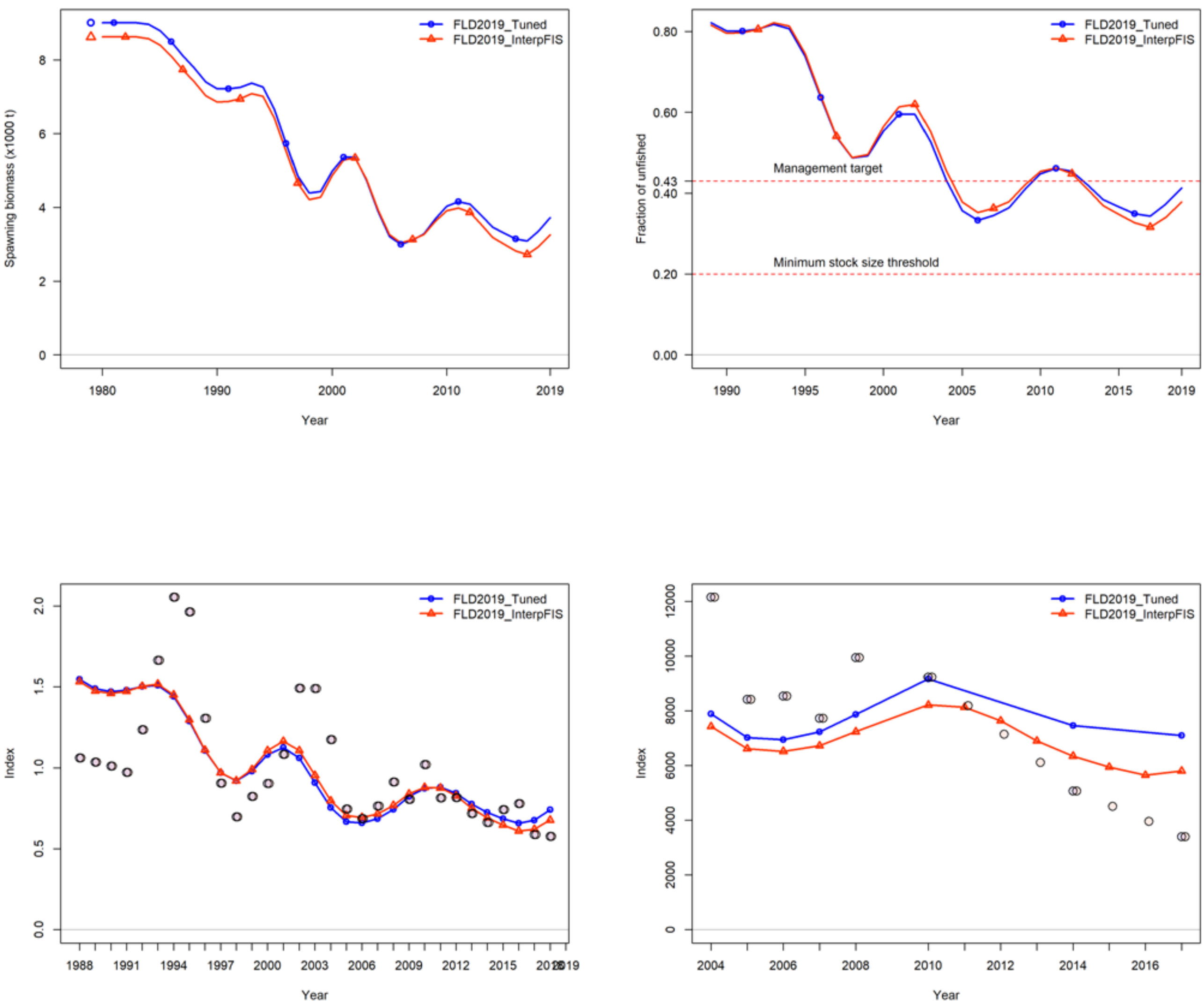

Figure 12.11. The magnitude of spawning biomass trajectory and relative spawning biomass (top), and fits to the catch rate data and FIS (bottom) for the deepwater flathead base case assessment (FLD2019_Tuned) and the sensitivity that includes interpolated FIS abundance values (FLD2019_InterpFIS).

Table 12.9. Summary of results for the base-case and sensitivity tests. Recommended biological catches (RBCs) are only shown for the base case.

Case		Likelihood TOTAL	Survey	Length comp	Age comp	Recruitment
0	base case (*M* 0.26, *h* 0.75)	544.81	-31.99	131.25	452.12	-6.63
1	*M* 0.28	0.42	-1.05	-0.37	1.85	-0.04
2	*M* 0.24	0.81	1.85	0.61	-1.73	0.11
3	*h* 0.85	0.14	0.07	0.14	-0.07	0.01
4	*h* 0.65	-0.11	-0.08	-0.19	0.13	0.02
5	$\sigma_R = 0.8$	3.53	0.38	0.12	-0.03	3.06
6	$\sigma_R = 0.6$	-3.60	-0.03	-0.11	-0.05	-3.41
7	wt x 2 length comp	5.35	1.94	-11.11	14.49	-0.01
8	wt x 0.5 length comp	2.48	-0.81	8.91	-5.82	0.21
9	wt x 2 age comp	4.49	7.61	8.62	-11.45	-0.27
10	wt x 0.5 age comp	6.87	-6.98	-9.40	22.31	0.89
11	wt x 2 index	4.41	-10.27	1.69	10.86	2.12
12	wt x 0.5 index	2.38	9.13	-1.13	-5.03	-0.59
13	interp FIS	-17.37	-7.13	-3.62	-7.08	0.46
14	include Danish seine	267.23	-6.15	0.55	272.10	0.60

Table 12.10. Summary of likelihood components for the base-case and sensitivity tests. Likelihood components are unweighted, and cases 1-14 are shown as differences from the base case. A negative value indicates a better fit, a positive value a worse fit.

Case		Likelihood TOTAL	Survey	Length comp	Age comp	Recruitment
0	base case (*M* 0.26, *h* 0.75)	544.81	-31.99	131.25	452.12	-6.63
1	*M* 0.28	0.42	-1.05	-0.37	1.85	-0.04
2	*M* 0.24	0.81	1.85	0.61	-1.73	0.11
3	*h* 0.85	0.14	0.07	0.14	-0.07	0.01
4	*h* 0.65	-0.11	-0.08	-0.19	0.13	0.02
5	$\sigma_R = 0.8$	3.53	0.38	0.12	-0.03	3.06
6	$\sigma_R = 0.6$	-3.60	-0.03	-0.11	-0.05	-3.41
7	wt x 2 length comp	5.35	1.94	-11.11	14.49	-0.01
8	wt x 0.5 length comp	2.48	-0.81	8.91	-5.82	0.21
9	wt x 2 age comp	4.49	7.61	8.62	-11.45	-0.27
10	wt x 0.5 age comp	6.87	-6.98	-9.40	22.31	0.89
11	wt x 2 index	4.41	-10.27	1.69	10.86	2.12
12	wt x 0.5 index	2.38	9.13	-1.13	-5.03	-0.59
13	interp FIS	-17.37	-7.13	-3.62	-7.08	0.46
14	include Danish seine	267.23	-6.15	0.55	272.10	0.60

12.5 Acknowledgments

Age data was provided by Kyne Krusic-Golub (Fish Ageing Services), ISMP and AFMA logbook and CDR data were provided by John Garvey (AFMA). Mike Fuller, Roy Deng, Franzis Althaus and Robin Thomson (CSIRO) pre-processed the data. Miriana Sporcic, Robin Thomson, Malcolm Haddon (CSIRO), Claudio Castillo-Jordán (UW) and Ian Taylor (NOAA) are thanked for helpful discussions on this work. André Punt updated the ageing error matrix. Malcolm Haddon provided code for auto-tuning and Athol Whitten provided R code for organising plots.

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12.7 Appendix A

A.1 Base case diagnostics

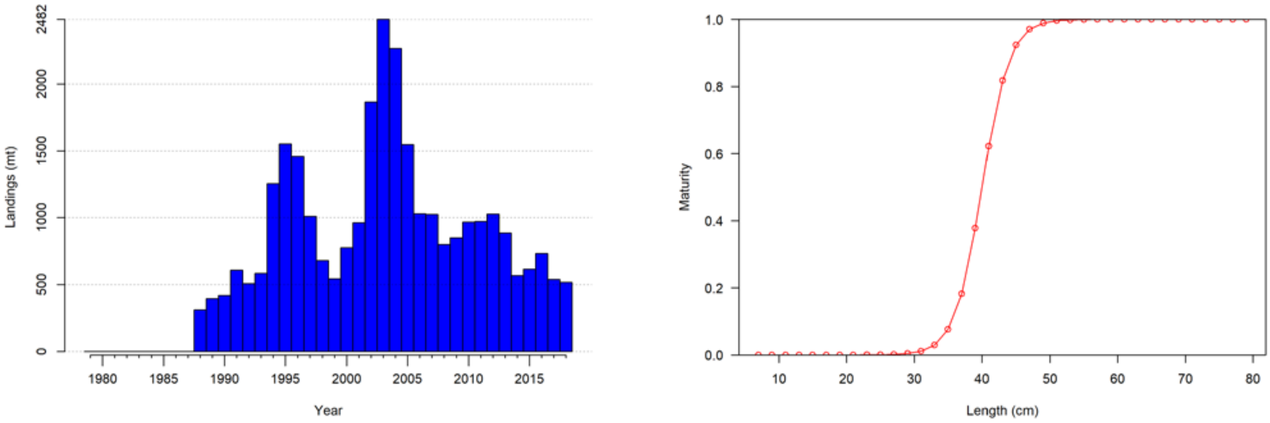

Figure A 12.1. Maturity and landings for deepwater flathead.

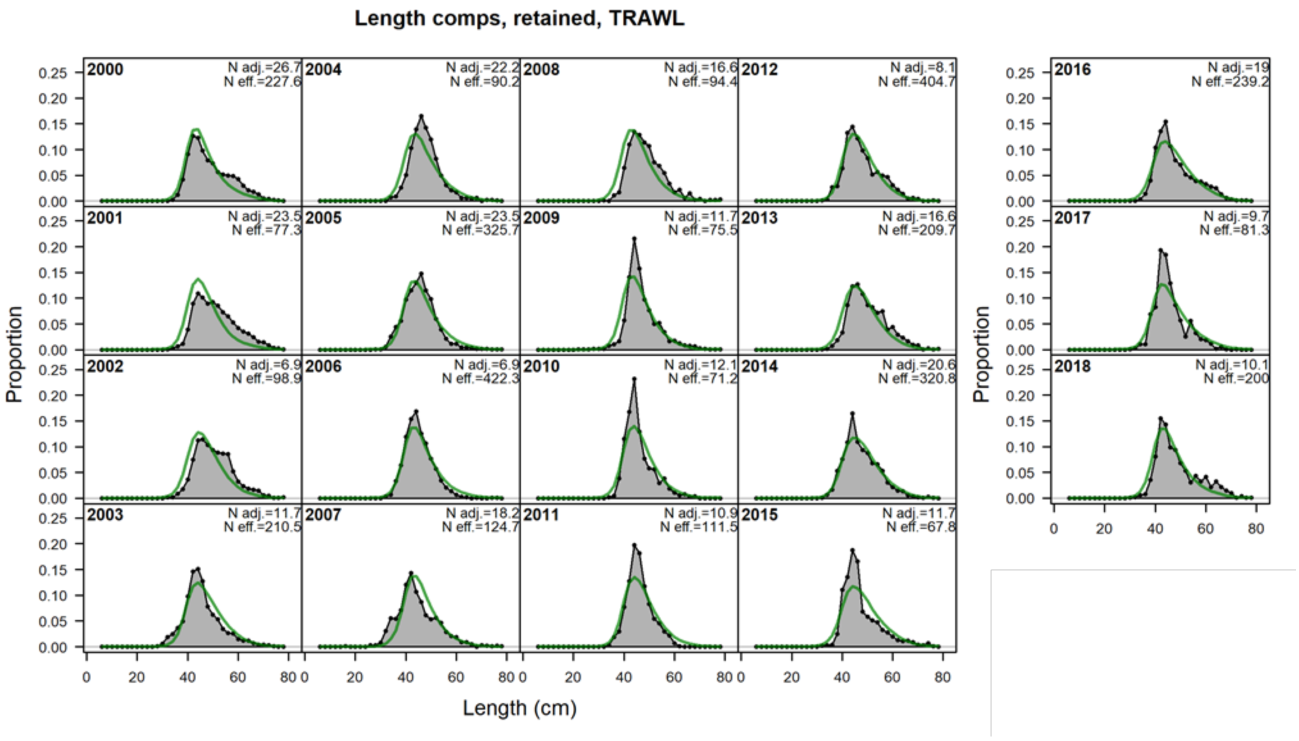

Figure A 12.2. Deepwater flathead length composition fits: retained trawl onboard.

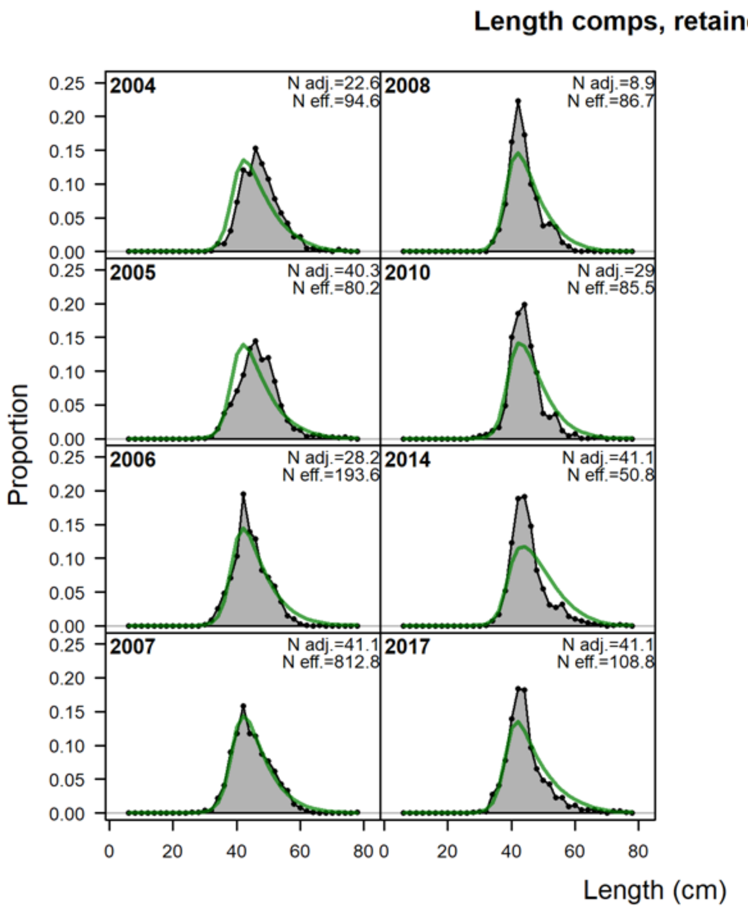

Figure A 12.3. Deepwater flathead length composition fits: FIS retained.

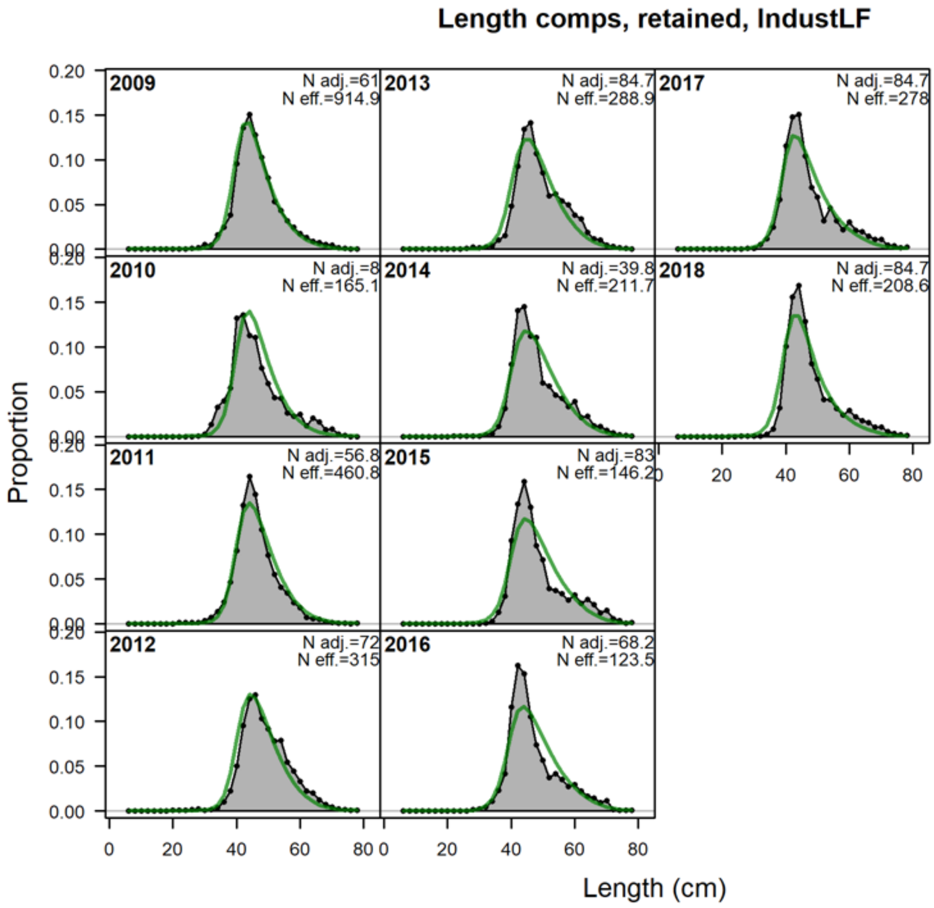

Figure A 12.4. Deepwater flathead length composition fits: Industry lengths.

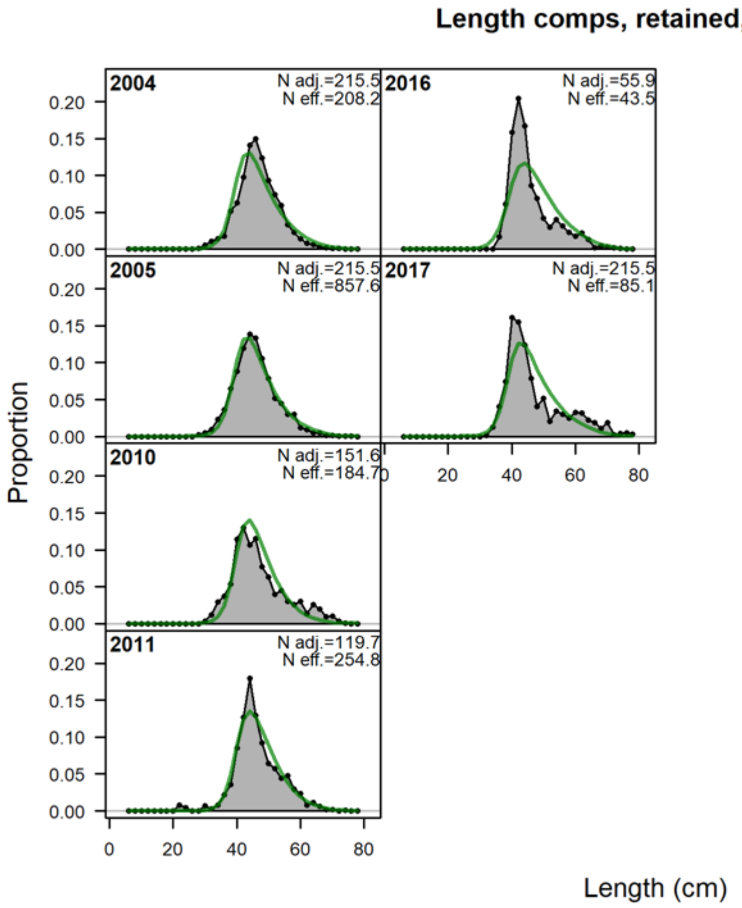

Figure A 12.5. Deepwater flathead length composition fits: Port.

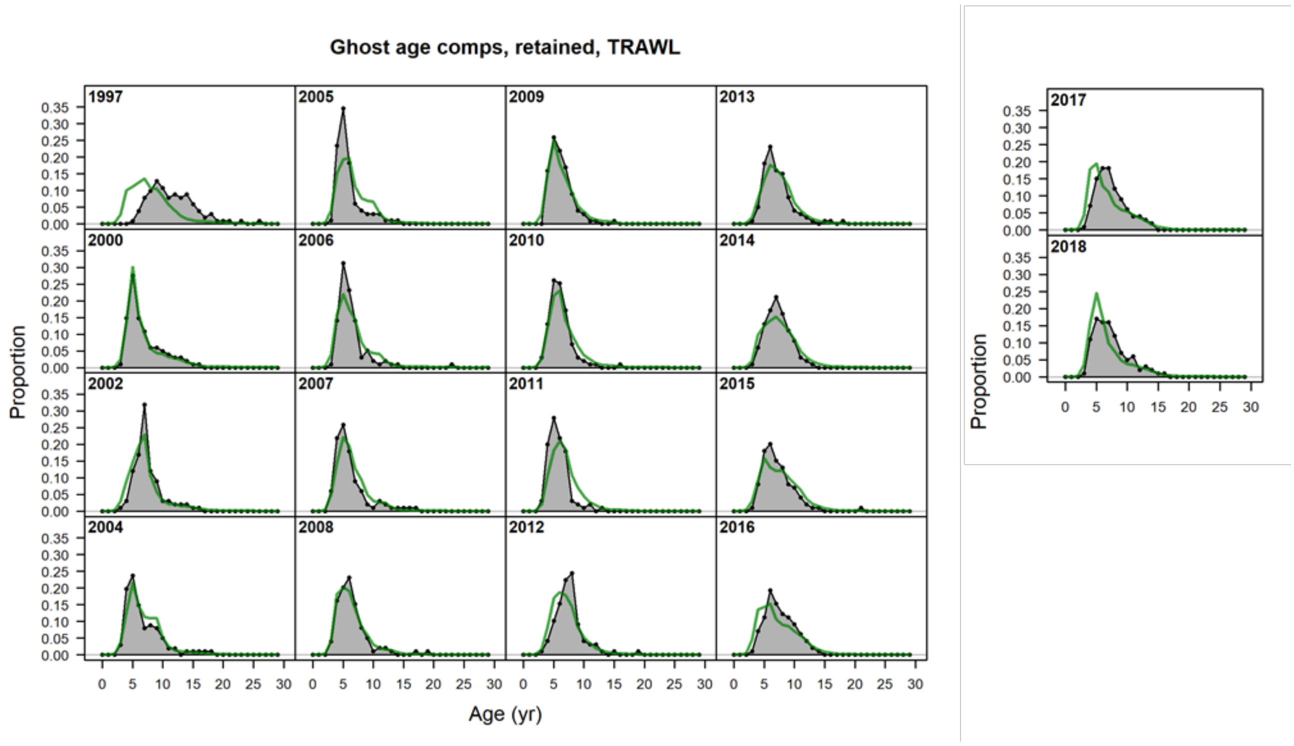

Figure A 12.6. Deepwater flathead implied fits to age: Trawl onboard retained.

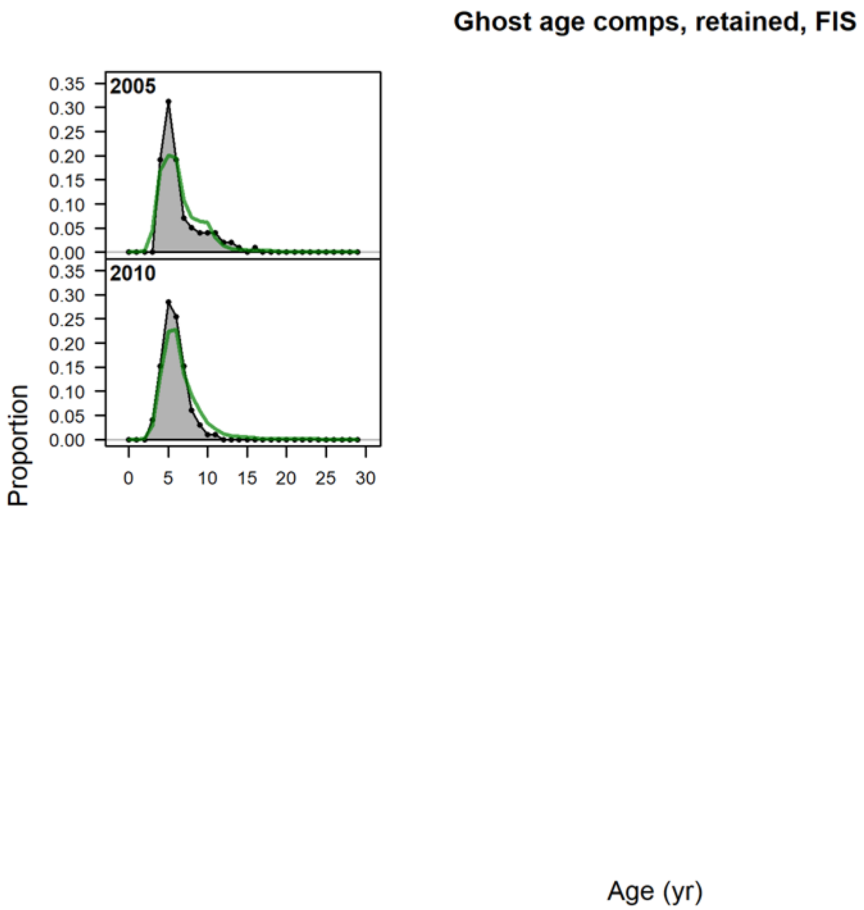

Figure A 12.7. Deepwater flathead implied fits to age: FIS

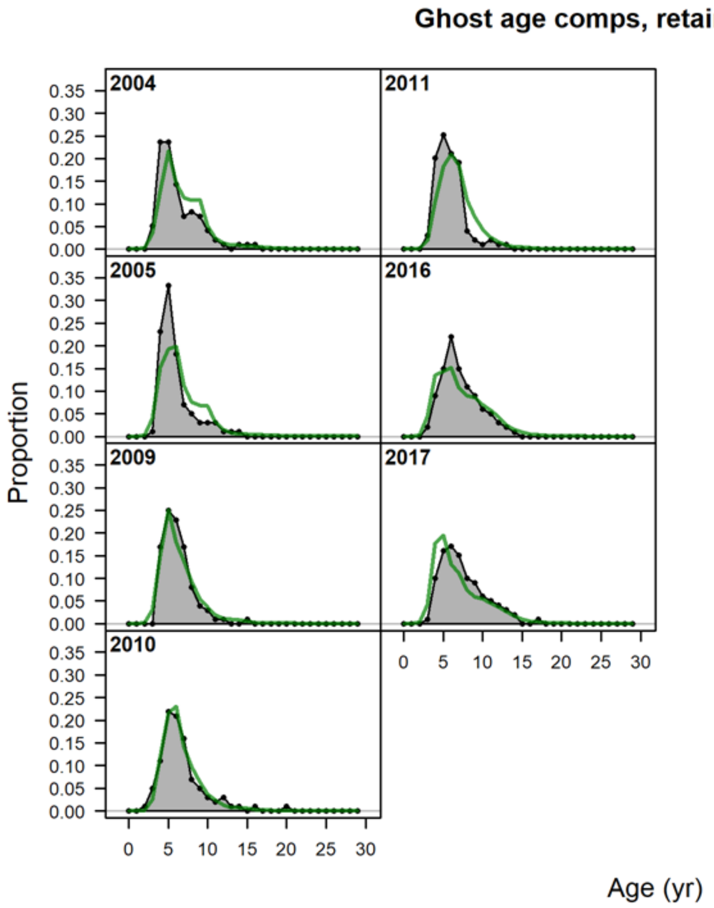

Figure A 12.8. Deepwater flathead implied fits to age: Port.

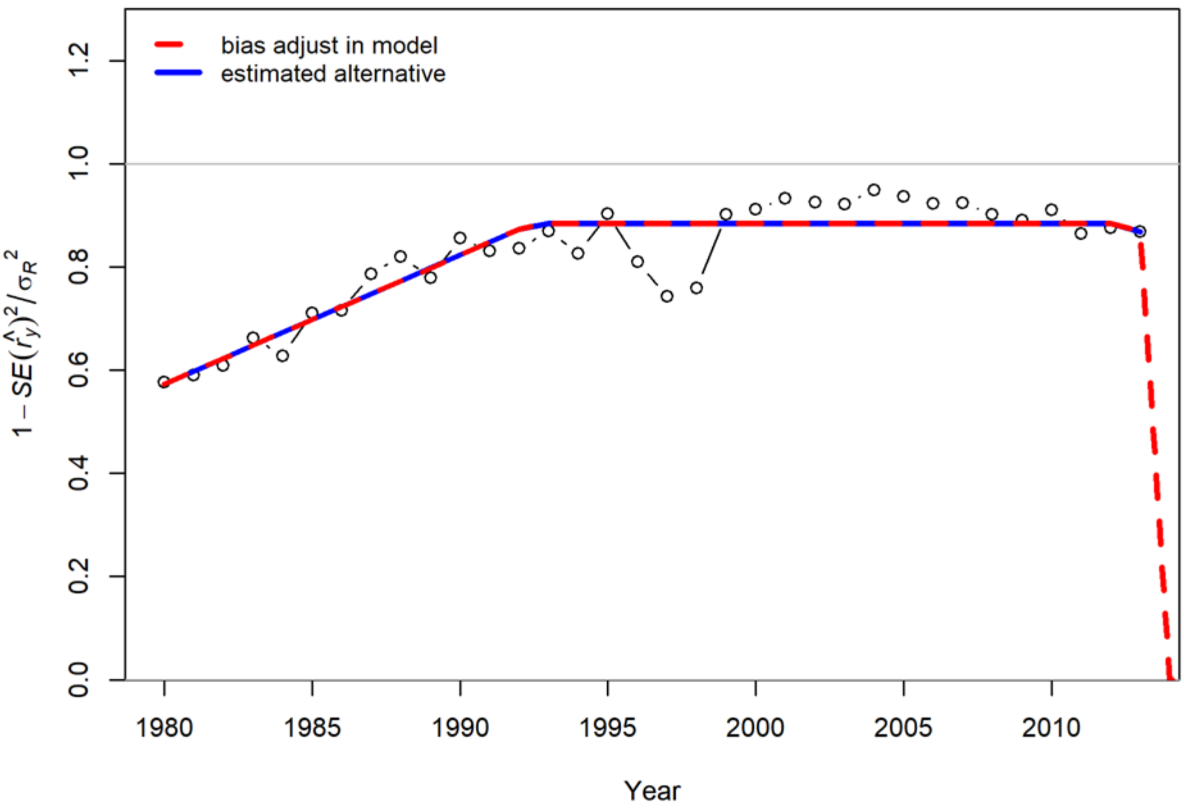

Figure A 12.9. Bias ramp adjustment for deepwater flathead.

13. Benefits

The results of this project have had a direct bearing on the management of the Southern and Eastern Scalefish and Shark Fishery. Direct benefits to the commercial fishing industry in the SESSF have arisen from improvements to, or the development of, assessments under the various Tier Rules of the Commonwealth Harvest Strategy Policy for selected quota and non-quota species. Information from the stock assessments has fed directly into the TAC setting process for SESSF quota species. As specific and agreed harvest strategies are being developed for SESSF species (a process required by and agreed to under EPBC approval for the fishery), improvements in the assessments developed under this project have had direct and immediate impacts on quota levels or other fishery management measures (in the case of non-quota species).

Participation by the project's staff on the SESSF Resource Assessment Groups has enabled the production of critical assessment reports and clear communication of the reports' results to a wide audience (including managers, industry). Project staff's scientific advice on quantitative and qualitative matters is also clearly valued.

The stock assessments presented in this report have provided managers and industry greater confidence when making key commercial and sustainability decisions for species in the SESSF. These assessments have provided the most up-to-date information, in terms of data and methods, to facilitate the management of the Southern and Eastern Scalefish and Shark Fishery.

14. Conclusion

- Provide quantitative and qualitative species assessments in support of the four SESSFRAG assessment groups, including RBC calculations within the SESSF harvest strategy framework.

The 2019 assessment of the stock status of key Southern and Eastern Scalefish and Shark fishery species is based on the methods presented in this report. Documented are the latest quantitative assessments (Tier 1) for key quota species (deepwater flathead, tiger flathead and Bight redfish), a projection update for school whiting, as well as cpue standardisations for shelf, slope, deepwater and shark species and Tier 4 analyses. Typical assessment outputs provided indications of current stock status and an application of the Commonwealth Harvest Strategy framework. This framework is based on a set of assessment methods and associated harvest control rules, with the decision to apply a particular combination dependent on the type and quality of information available to determine stock status (Tiers 1 to 5).

The assessment outputs from this project are a critical component of the management and TAC setting process for these fisheries. The results from these studies are being used by SESSFRAG, industry and management to help manage the fishery in accordance with agreed sustainability objectives.

Stock status and Recommended Biological Catch (RBC) conclusions (Tier 1):

Fixed catch projections for school whiting were conducted to provide information on possible projected stock status in light of increases in NSW catches in state waters in 2017 and 2018. Projecting forward to 2020, using preliminary 2018-2019 catches, takes the stock status to 35%, which is expected to recover to 44% at the start of 2022, if the RBC is caught in 2020 and 2021 and there is average recruitment from 2014 onwards. Given the 2020 and 2021 catches may exceed the RBC, four fixed catch projections were examined, with total catches (including discards) ranging from 1,600-1,900 t. Projected stock status at the start of 2022 ranged from 34% to 39% under the fixed catch scenarios, compared to 44% if the RBC is caught in 2020 (1,165 t) and 2021 (1,357 t). Four low and four high recruitment scenarios were also investigated, with 2022 stock status ranging from 22% to 38% under the low recruitment scenarios and from 44% to 53% under the high recruitment scenarios.

The assessment of tiger flathead was updated to provide estimates of stock status in the SESSF at the start of 2020. The 2020 spawning stock biomass is 33.67% of unexploited stock biomass (SSB_0) for the updated base case. The 2020 Recommended Biological Catch under the 20:35:40 harvest control rule for the updated base case is 2,334 t, and is below the long-term yield (assuming average recruitment in the future) of 2,986 t. The average RBC over the three-year period 2020-2022 is 2,563 t and over the five-year period 2020-2024, the average RBC is 2,648 t.

The assessment for Bight Redfish in the GAB was updated from the last assessment in 2015. The assessment estimates that the projected 2020-21 spawning stock biomass will be 64% of virgin spawning stock biomass. The 2020-21 Recommended Biological Catch under the 20:35:41 harvest control rule is 1,024 t. The average RBC over the three-year period 2020-21: 2022-23 is 963 t. The long-term RBC is 912 t.

The assessment for deepwater flathead (Neoplatycephalus conatus) in the GAB was updated from the last assessment in 2016. The inclusion of new and updated data in the current assessment has led to some changes in the shape of the spawning biomass trajectory, but the depletion remains near the target of 43%. The assessment estimates that the projected 2020/21 spawning stock biomass will be 45% of virgin stock biomass (projected assuming 2018/19 catches in 2019/20). The 2020/21 Recommended Biological Catch (RBC) under the 20:35:43 harvest control rule is 1,253 t. The average RBC over the three-year period 2020/21 - 2022/23 is 1,238 t. The long-term RBC is 1,218 t.

15. Appendix: Intellectual Property

No intellectual property has arisen from the project that is likely to lead to significant commercial benefits, patents or licenses.

16. Appendix: Project Staff

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