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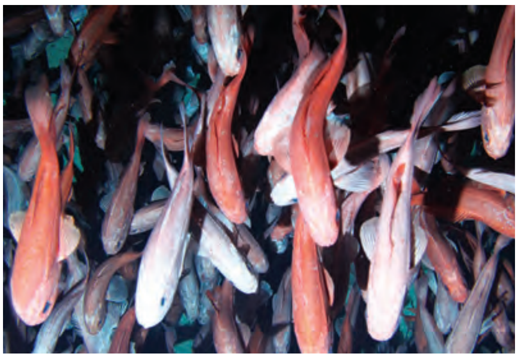
2019/0800 May 2022

Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2020 and 2021

PART
1

2021



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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 2021. Part 2 describes the Tier 4 and Tier 5 assessments, catch rate standardisations and other work contributing to the assessment and management of SESSF stocks in 2021.

Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2020 and 2021

Part 1: 2021

G.N. Tuck
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Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2021

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1. Non-Technical Summary

Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2020 and 2021

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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
- 2020: Provide Tier 1 assessments for Gummy Shark, Eastern Redfish and School Whiting; Tier 4 assessments for John Dory, Mirror Dory, Ocean Perch, OreoBasket, Ribaldo, Royal Red Prawn, Sawshark and Silver Trevally; and Tier 5 for Blue-eye Trevalla
- 2021: Provide Tier 1 assessments for Eastern Orange Roughy, Blue Grenadier, Eastern Jackass Morwong and Silver Warehou; Tier 4 for Mirror Dory and Tier 5 for E/W Deepwater Shark

Outcomes Achieved - 2021

The 2021 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 South East RAG Species

Blue Grenadier

This chapter updates the agreed base case for a Tier 1 assessment of Blue Grenadier (*Macruronus novaezelandiae*). The last full assessment was conducted in 2018. The 2018 assessment was updated by the inclusion of data up to the end of 2020, which entails an additional three years of catch, discard, CPUE, length and age data and ageing error updates. The agreed base case now includes estimation of both female and male natural mortality, and no longer includes the FIS survey results.

Results of the base case show reasonably good fits to the length-composition data, conditional age at length, egg and acoustic surveys and discard mass. As has been noted in previous Blue Grenadier assessments, the fit to the standardized non-spawning catch-rate index is generally poor; the model is unable to fit to the high early catch rates and over-estimates catch rates during the early 2000s. More recent catch rates fit reasonably well, including the recent marked increase in catch rate in 2019 and 2020.

The estimated time series of recruitment under the base-case parameter set shows the typical episodic nature of Blue Grenadier recruitment, with strong year-classes in 1979, the mid-1980s, 1994, and 2003, with very little recruitment between these years. However, recent recruitments are more stable, as was first observed in the 2018 assessment. The trajectories of spawning biomass show increases and decreases in spawning biomass as strong cohorts move into and out of the spawning population. For the base case model, the estimated virgin female spawning biomass (SSB_0) is 37,445 tonnes and the projected 2022 spawning stock biomass will be 155% of SSB_0 (projected assuming 2020 catches in 2021). The 2022 recommended biological catch (RBC) under the 20:35:48 harvest control rule is 23,777 t, with 245 t estimated discards (23,532 t retained). The long-term RBC is 7,100 t, with 183 t discards.

Eastern Jackass Morwong

This chapter updates the 2018 Tier 1 assessment of eastern Jackass Morwong (*Nemadactylus macropterus*) to provide estimates of stock status in the SESSF at the start of 2022. The 2018 stock assessment has been updated with the inclusion of data up to the end of 2020, comprising an additional three years of catch, discard, CPUE, length and age data and ageing error updates, including revisions to historical catch series, length frequencies and discard rates. A range of sensitivities were explored.

The base-case assessment estimates that the projected 2022 spawning stock biomass will be 15% of unexploited spawning stock biomass (SSB_0), with recruitment from 2016 onwards projected using a low recruitment scenario, using the average of the ten most recently estimated recruitment deviations, from 2006-2015. Under the agreed 20:35:48 harvest control rule, the 2022 recommended biological catch (RBC) is 0 t, with the long-term yield (assuming low recruitment in the future) of 91 t. The average RBC over the three-year period 2022-2024 is 0 t and over the five-year period 2022-2026, the average RBC is 1 t. If recruitment from 2016 onwards is assumed to be average, the projected 2022 spawning stock biomass would be 22% of SSB_0.

The updated assessment produces markedly different results from the 2018 assessment, under both the average and the low recruitment scenarios. This is due to downward revisions to the 13 of most recent 15 years of recruitment estimates from the 2018 assessment (for the period 1998-2012), poor recruitment estimates for the three new years of recruitment estimated in the 2021 assessment (for the years 2013-2015), a continuing decline in recent catches, a continuing decline in the recent CPUE indices and an improved fit to the most recent CPUE data points, partly due to the implementation of a low recruitment scenario.

Eastern Orange Roughy

This chapter updates the 2017 eastern zone Orange Roughy (*Hoplostethus atlanticus*) stock assessment to include revised modelling assumptions and new data for 2020. The objective of the 2021 assessment is to account for the uncertainty in M by estimating it within the assessment using an informative prior developed from New Zealand Orange Roughy assessments.

The 2021 base-case assessment updates the 2017 assessment with recent catch, relative estimates of female spawning biomass from the 2019 acoustic towed surveys at St Helens Hill and St Patricks Head, and new age composition data from the 2019 acoustic survey. Two major changes were made to the previous assessment: natural mortality is now estimated within the assessment and the plus-group are increased from 80 to 120 years.

The median estimate of unfished female spawning biomass from the MCMC analysis was 38,924 t, slightly lower than the MPD estimate of 40,479 t. The current 2022 female spawning biomass is estimated to be 11,644 t from the MCMC and 13,126 t from the MPD. Relative spawning biomass in 2022 is estimated at 30% of unfished levels from the MCMC and 32.4% of unfished levels from the MPD. Natural mortality was successfully estimated within the assessment. The median estimate of natural mortality from the MCMC analysis is M=0.0393 yr^{-1}, which is slightly higher than the MPD estimate of M=0.0386 yr^{-1}. The recommended biological catch (RBC) for 2022 from the MCMC analysis is 681 t, lower than the MPD estimate for 2022 of 944 t. The average RBC over the next three years (2022-2024) is 737 t from the MCMC analysis and 1,025 t from the MPD. There is a high level of uncertainty in the estimated RBC, with the 75% and 95% credible intervals from the MCMC analysis for the 2022 RBC being 287–1,316 t and 119–1,645 t respectively.

Further MCMC analysis was undertaken to evaluate scenarios of fixed catch projections of 550, 650, 737, 850 and 950 t yr^{-1} and a catch scenario proposed by industry of 1,166 t in 2022, 1,055 t in 2023 and 950 t yr^{-1} thereafter. The projections show that female spawning biomass is estimated to increase under all the fixed catch scenarios considered with the probability of the stock being below the limit reference point of 20% unfished spawning biomass in both 2024 and 2031 being less than 0.5%. Under the lowest constant catch scenario of 550 t yr^{-1}, stock status is estimated to be 0.317 and 0.348 in 2024 and 2031 respectively. Under the highest constant catch scenario of 950 t yr^{-1}, stock status is estimated to be 0.312 and 0.323 in 2024 and 2031 respectively. Under the industry proposed scenario stock status estimated to be 0.309 and 0.321 in 2024 and 2031 respectively. When the SESSF harvest control rule is used to set RBCs, the stock status is estimated to be 0.316 and 0.330 in 2024 and 2031 respectively.

School Whiting

This chapter presents School Whiting (*Sillago flindersi*) RBC projections from the 2020 stock assessment using a modified target MEY reference proxy of 40% instead of 48%. The 2020 School Whiting stock assessment estimates that current spawning stock biomass (at the beginning of 2021) is 41% of unexploited spawning stock biomass (SSB_0). Under the agreed 20:35:48 harvest control rule, the 2021 recommended biological catch (RBC) is 2,140 t. The RBC averaged over the three-year period of 2021-2023 is 2,237 t.

If the default (proxy) target reference point (48%) used in the SESSF harvest control rule, and specifically as used by AFMA for School Whiting, is reduced to 40%, a modified 20:35:40 harvest control rule can be applied. This lower target allows the stock to be fished to a lower target biomass (40% of unfished spawning stock biomass (SSB_0)). Under a revised 40% target, the 2021 recommended biological catch (RBC) would be 2,753 t. The RBC, calculated under a 20:35:40 harvest control rule, averaged over the three-year period of 2021-2023 is 2,730 t.

Silver Warehou

This chapter presents a quantitative Tier 1 assessment of Silver Warehou (*Seriolella punctata*) to provide stock status estimates at the start of 2022 and describes the base case. The 2018 base case has been updated with the inclusion of data up to the end of 2020, which entails an additional three years of catch, discard, CPUE, length and age data, along with ageing error updates, revisions to historical catch series, length frequencies and discard rates.

The assessment estimates that the projected 2022 stock status will be 29% of unfished spawning stock biomass (SSB_0) , projected assuming 2020 catches in 2021, with recruitment from 2016 onwards assumed to be below average, fixed at the average of 2011-2015 levels. The assessment suggests that stock status was as low as 21% of SSB_0 in 2016. Under the 20:35:48 harvest control rule, the 2022 recommended biological catch (RBC) is 587 t, while the long-term yield (assuming continuation of low recruitment) is 591 t. The average RBC over the three-year period 2022-2024 is 581 t.

This assessment has seen a continuation of below average recruitment noted in the last three assessments with the last 12 years of estimated recruitment all below average. This continuation of below average recruitment resulted in the base case for this assessment moving to low recruitments projected forward from 2016. This change reduced the severity of retrospective patterns observed in previous assessments.

Tiger Flathead

This chapter presents results of fixed catch projections for Tiger Flathead (*Neoplatycephalus richardsoni*) to provide information on possible projected stock status in light of changes to both catches and CPUE following the 2019 Tiger Flathead stock assessment.

Updated data used from the 2019 assessment, including preliminary catch (combined Commonwealth and state catch) for 2019-2020, estimated 2021 catch and updated CPUE series to the end of 2020 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 2020 stock status, from 34% in the last stock assessment to 32% in this analysis. These changes are due to revisions to the catches (2017-2021) and to the revised CPUE series, which has a downturn at the end of the time series (2019-2020) for the Danish seine CPUE. The eastern trawl and Tasmanian trawl CPUE series do not show the same downturn at the end of the CPUE series as Danish seine, with both trawl CPUE relatively flat in the period 2019-2020. Projecting forward to 2022 takes the stock status to 35% at the start of 2022, and this is expected to recover to 37% at the start of 2025, assuming that the RBC is caught in 2023 and 2024 and there is average recruitment from 2017 onwards. Changes to the projected stock status when the 2019 base case is updated are a consistent 1% reduction in stock status in the period 2020-2025, assuming the RBC is caught each year.

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 water species)
- Shark Resource Assessment Group (shark species)
- Great Australian Bight Resource Assessment Group (GAB species)

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 4 and 5. 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 a description of the SESSFRAG agreed changes to the assessment schedule and may differ from the objectives in the original contract:

- Provide quantitative and qualitative species assessments in support of the four SESSFRAG assessment groups, including RBC calculations within the SESSF harvest strategy framework

- 2020: Provide Tier 1 assessments for Gummy Shark, Eastern Redfish and School Whiting; Tier 4 assessments for John Dory, Mirror Dory, Ocean Perch, OreoBasket, Ribaldo, Royal Red Prawn, Sawshark and Silver Trevally; and Tier 5 for Blue-eye Trevalla

- 2021: Provide Tier 1 assessments for Eastern Orange Roughy, Blue Grenadier, Eastern Jackass Morwong and Silver Warehou; Tier 4 for Mirror Dory and Tier 5 for E/W Deepwater Shark

5. Blue grenadier (*Macruronus novaezelandiae*) stock assessment based on data up to 2020 – development of a preliminary base case

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5.1 Executive Summary

This document presents the preliminary base case for an updated quantitative Tier 1 assessment of Blue Grenadier (*Macruronus novaezelandiae*) for presentation at the SERAG2 meeting in October 2021. The last full assessment was conducted during 2018 (Castillo-Jordán and Tuck, 2018b). The preliminary base case has been updated with the inclusion of data up to the end of 2020, which entails an additional 3 years of catch, discard, CPUE, length and age data and ageing error updates since the 2018 assessment. This document describes the process used to develop a preliminary base case for Blue Grenadier through the sequential updating of recent data in the stock assessment, using the stock assessment package Stock Synthesis (SS-V3.30, Methot and Wetzel (2013)).

This document describes the standard Bridge 1, which updates the assessment to the most recent version of Stock Synthesis, ensures correct settings are used and updates the historical catch series, and Bridge 2, which sequentially incorporates updated data through to 2020. The base case specifications agreed by the SERAG in 2018 were maintained into the preliminary base case presented here. The main differences between the model of 2018 and 2021 are: replacing the variable length bins with 2 cm length bins (standard method across SESSF Tier 1 assessments) and using the latest methods for assigning final weights to the various data sources.

Results of the preliminary base case show reasonably good fits to the length-composition data, conditional age at length, egg survey, discards and acoustic survey. As has been noted in previous Blue Grenadier assessments, the fit to the standardized non-spawning catch-rate index is generally poor; the model is unable to fit to the high early catch rates and over-estimates catch rates during the early 2000s. More recent catch rates fit reasonably well, including the recent marked increase in catch rate in 2019 and 2020.

The estimated time series of recruitment under the base-case parameter set shows the typical episodic nature of Blue Grenadier recruitment, with strong year-classes in 1979, the mid-1980s, 1994, and 2003, with very little recruitment between these years. However, the recent recruitments are more stable, as was first observed in the 2018 assessment. The trajectories of spawning biomass show increases and decreases in spawning biomass as strong cohorts move into and out of the spawning population.

The estimated virgin female spawning biomass (B_0) is 40,759 t tonnes and the projected 2022 spawning stock biomass will be 126% of virgin female spawning biomass (projected assuming 2020 catches in 2021), compared to 122% for 2019 in the 2018 assessment.

Further development and sensitivity testing should include the addition of the FIS lengths and estimating selectivity for the FIS fleet (rather than mirroring to the selectivity of the non-spawning fleet) and estimating male natural mortality.

5.2 Introduction

5.2.1 *2021 Blue Grenadier assessment base case.*

The 2021 preliminary base case assessment of Blue Grenadier uses an age- and size-structured model implemented in the generalized stock assessment software package, Stock Synthesis (SS) (Version 3.30.17.00, Methot et al. (2021)). The methods utilised in SS are based on the integrated analysis paradigm. SS can allow for multiple seasons, areas and fleets, but most applications are based on a single season and area. Recruitment is governed by a stochastic Beverton-Holt stock-recruitment relationship, parameterized in terms of the steepness of the stock-recruitment function (h), the expected average recruitment in an unfished population (R_0), and the degree of variability about the stock-recruitment relationship (σ_r). SS allows the user to choose among a large number of age- and length-specific selectivity patterns. The values for the parameters of SS are estimated by fitting to data on catches, catch-rates, discard mass, discard and retained catch length-frequencies, and conditional age-at-length data. The population dynamics model and the statistical approach used in fitting the model to the various data types are given in the SS technical documentation (Methot, 2005).

Model data have been updated by the inclusion of data up to the 2020 calendar year (length-composition and conditional age-at-length data; age reading-error matrices, standardized catch rate series; landings and discard catch weight) and information from acoustic surveys of spawning biomass (series from 2003-2010, pertaining to total spawning biomass), with an assumption of 2-times turnover on the spawning ground (Russell and Smith, 2006; Punt et al. 2015). The base-case egg survey estimates of female (only) spawning biomass for 1994 and 1995 are included, as are the FIS survey estimates for the non-spawning fishery. The model fits directly to length-composition data (by sex where possible) and conditional age-at-length data by fleet. Retained length-composition data from port and onboard samples are separated.

The first bridging exercise (Bridge 1) highlights changes that have occurred since 2018 simply through changes to software and assessment practices. The subsequent bridging exercise (Bridge 2) then sequentially updates the assessment model with new data through to 2020.

The base–case model includes the following key features:

a) Blue grenadier consists of a single stock within the area of the fishery.

b) The model accounts for males and females separately (growth, natural mortality, age at first breeding).

c) The population was at its unfished biomass with the corresponding equilibrium (unfished) age-structure at the start of 1960.

d) The rate of natural mortality, M, is assumed to be constant with age, and also time-invariant. The value for female M is estimated within the assessment. Following previous assessments, male M is assumed be 20% greater than that of females.

e) 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 for the base-case analysis is set to 0.75. Deviations from the average recruitment at a given spawning biomass (recruitment residuals) are estimated for 1974 to 2017. Deviations are not estimated before 1974 or after 2017 because there are insufficient data to permit reliable estimation of recruitment residuals outside of this time period.

f) The population plus-group is modelled at age 20 years. The maximum age for age observations is 20 years.

g) Growth is assumed to follow a von Bertalanffy type length-at-age relationship, with the parameters of the growth function being estimated separately for females and males inside the assessment model. Growth is also assumed to vary through time and to be cohort (year class) specific. Evidence for time-varying and cohort specific growth in Blue Grenadier has been accumulating over several decades (see Punt and Smith 2001; Whitten et al., 2013). The 2021 base-case model treats conditional age-at-length information as data (i.e. to incorporate error), and predicts the expected length-at-age for each year. This is achieved by estimating the parameters of a von Bertalanffy growth function where the expected annual growth increment is based on the von Bertalanffy growth function but with a growth rate parameter that is determined by an expected value and a cohort-specific deviation. Cohort-specific deviations from average growth are estimated in the base case model for year classes 1978 to 2017.

h) Two fleets are included in the model – the spawning sub-fishery that operates during winter (June–August inclusive) off western Tasmania (zone 40), and the non-spawning sub-fishery that operates during other times of the year and in other areas throughout the year.

i) Each selectivity pattern was assumed to be length-specific, logistic and time-invariant for the spawning fleet and dome-shaped for the non-spawning fleet. The parameters of the selectivity function for each fleet were estimated within the assessment.

j) The inclusion of the FIS is considered for the non-spawning area, and the selectivity mirrors the corresponding non-spawning fleet (Fleet 2).

k) The CVs of the CPUE indices were initially set at a value equal to the standard error from a loess fit (0.252; Sporcic, 2021), before being re-tuned to the model-estimated standard errors within SS. The acoustic estimates were tuned through the estimation of an extra variance component that is added to the model input standard errors. This is done within SS.

l) Discard tonnage was estimated through the assignment of a retention function for the non-spawning fleet. This was defined as a logistic function of length, and the inflection and slope of this function were estimated where discard information was available. In addition, the discard length data from 1993, 1995 and 1996 were removed for the 2018 base case as recommended by SERAG (September, 2018) due to the existence of unusually large fish in the length distribution which is likely to be misreporting.

m) Retained and discarded onboard length sample sizes were capped at 200 and a minimum of 100 fish measured was required for length-composition data to be included in the assessment. For port samples, numbers of trips were used as the sampling unit, with a cap of 100. 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) or trips (port) sampled, rather than the number of fish measured.

The values assumed for fixed parameters of the preliminary base case model are shown in Table 5.1.

Table 5.1. Parameter values assumed for some of the non-estimated parameters of the base-case model

Parameter	Description	Value
M_f	Natural mortality for females	Estimated
M_m	Natural mortality for males	1.2* M_f
h	"steepness" of the Beverton-Holt stock-recruit curve	0.75
x	age observation plus group	20 years
μ	fraction of mature population that spawn each year	0.84
a_f	Female allometric length-weight equations	0.01502 g^{-1}.cm
b_f	Female allometric length-weight equations	2.728
a_m	Male allometric length-weight equations	0.0168 g^{-1}.cm
b_m	Male allometric length-weight equations	2.680
l_m	Female length at 50% maturity	63.7cm
l_s	Parameter defining the slope of the maturity ogive	-0.261

5.3 The fishery

Blue Grenadier are found from New South Wales around southern Australia to Western Australia, including the coast of Tasmania. Blue Grenadier is a moderately long-lived species with a maximum age of about 25 years. Age at maturity is approximately 4 years for males and 5 years for females (length-at-50% maturity for females is 57 cm and 64 cm respectively) based upon 32,000 Blue Grenadier sampled between February 1999 and October 2001 (Russell and Smith, 2006). There is also evidence that availability to the gear on the spawning ground differs by sex, with a higher proportion of small males being caught than females. This is most likely due to the arrival of males on the spawning ground at a smaller size (and younger age) than females. This was also noted by Russell and Smith (2006) who state that "young males entered the fishery one year earlier than females" and is consistent with information for Hoki from New Zealand (Annala et al., 2003). Large fish arrive earlier in the spawning season than small fish. Spawning occurs predominantly off western Tasmania in winter (the peak spawning period based upon mean GSIs calculated by month was estimated to be between June and August according to Russell and Smith (2006)). There is some evidence that a high proportion of fish remain spawning in September. Variations in spawning period noted by Gunn et al. (1989) may occur due to inter-annual differences in the development of coastal current patterns around Tasmania. Adults disperse following the spawning season and while fish are found throughout the south east region during the non-spawning season, their range is not well defined. Spawning fish have been caught off the east coast of Australia, and larvae from a likely eastern spawning area have been described by Bruce et al. (2001). Blue Grenadier are caught by demersal trawling. There are two defined fleets: the spawning (Zone 40, months June, July and August) and non-spawning fisheries (all other months and zones).

5.4 Bridging methodology

The previous full quantitative assessment for Blue Grenadier was performed in 2018 (Castillo-Jordán and Tuck, 2018) using Stock Synthesis (version SS-V3.30.12.00, Methot et al. (2018)). The 2021 assessment uses the current version of Stock Synthesis (version SS-V3.30.17.00, Methot et al. (2021)).

As a first step in the process of bridging to a new model, the data used in the 2018 assessment was used in the new software (SS-V3.30.17.00). Once this translation was complete, improved features unavailable in SS-V3.12.00 were incorporated into the SS-V3.30.17 assessment. The catch series was then updated to include any amended estimates for the historical period from 1998 to 2017 since the 2018 assessment. Following this step, the model was re-tuned using the most recent tuning protocols (Pacific Fishery Management Council, 2018), 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 may 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 2018 simply through changes to software and assessment practices.

The subsequent bridging exercise (Bridge 2) then sequentially updates the model with new data through to 2020. These additional data included new catch, discard estimates, CPUE, length composition data, conditional age-at-length data and an updated ageing error matrix. The last year of recruitment estimation and cohort dependent growth was extended to 2017 (from 2014 in Castillo-Jordán and Tuck (2018b)). The final step is to re-tune the model.

5.5 Bridge 1

The 2018 Blue Grenadier assessment (labelled 'GRE_2018_30_12_00') was converted to the most recent version of the software, Stock Synthesis version SS-V3.30.17.00 (labelled 'GRE_2018_30_17_00'). This resulted in no changes to the stock status estimates throughout the timeseries (Figure 5.1). There were no discernible changes that resulted from alteration of settings. Likewise, updating catches to 2017 also resulted in no discernible changes (labelled 'Updated_catch' and includes the previous changes (Figure 5.1)). The assessment was then tuned using the latest tuning protocol (labelled 'Tuned'). 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 2018. This initial bridging step, Bridge 1, does not incorporate any data after 2017 or any structural changes to the assessment. Re-tuning led to a reduction in the initial estimate of virgin biomass (Figure 5.1). Sensitivity to this parameter has been noted in previous assessments (Figure 5.2; Castillo-Jordán and Tuck, 2018a).

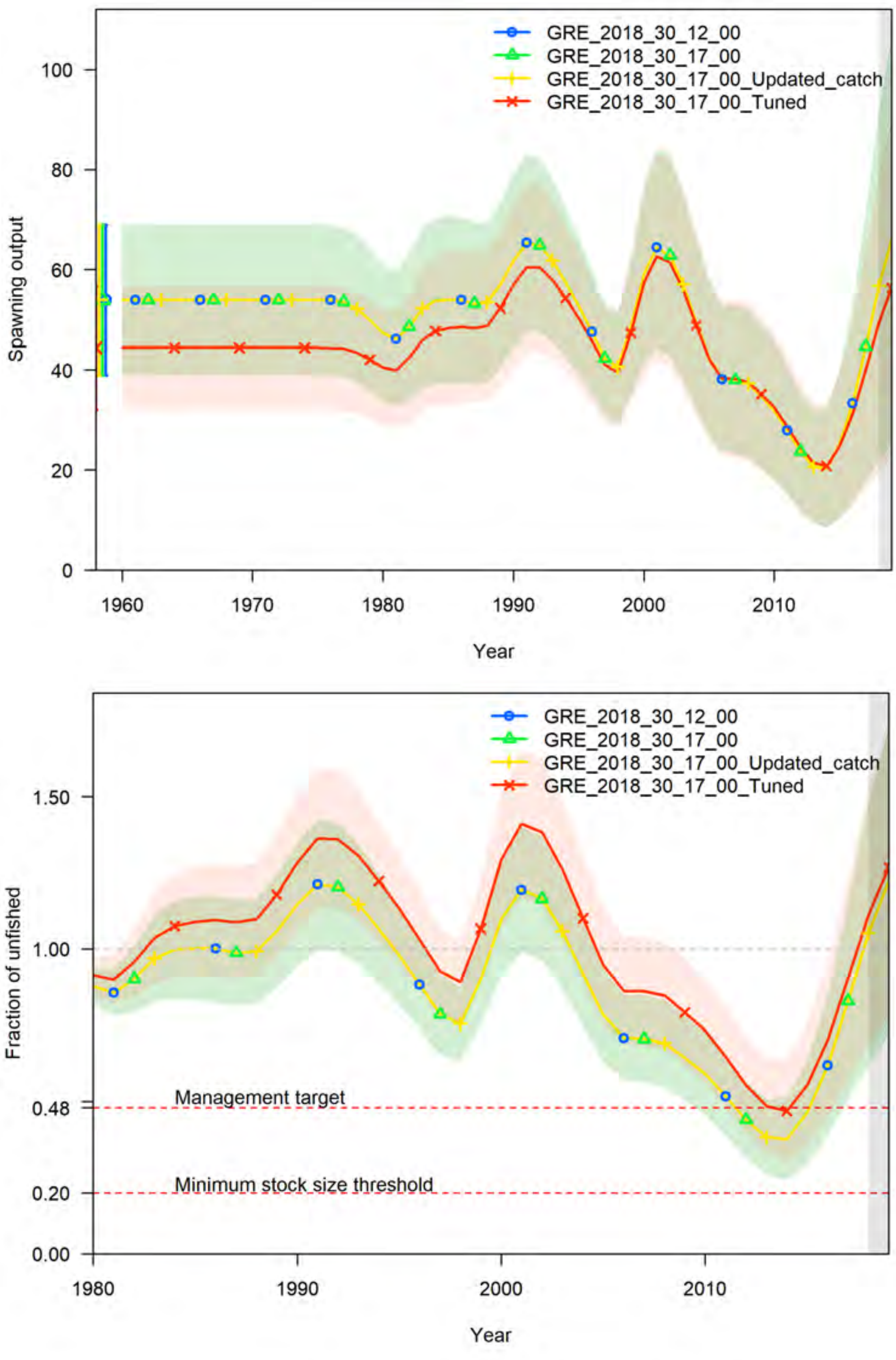


Figure 5.1. Comparison of the spawning (top) and relative (bottom) biomass time series for the 2018 assessment (SS3-30.12), a model converted to SS-V3.30.17, with updated settings and catches (Updated_catch) and then re-tuned (Tuned).

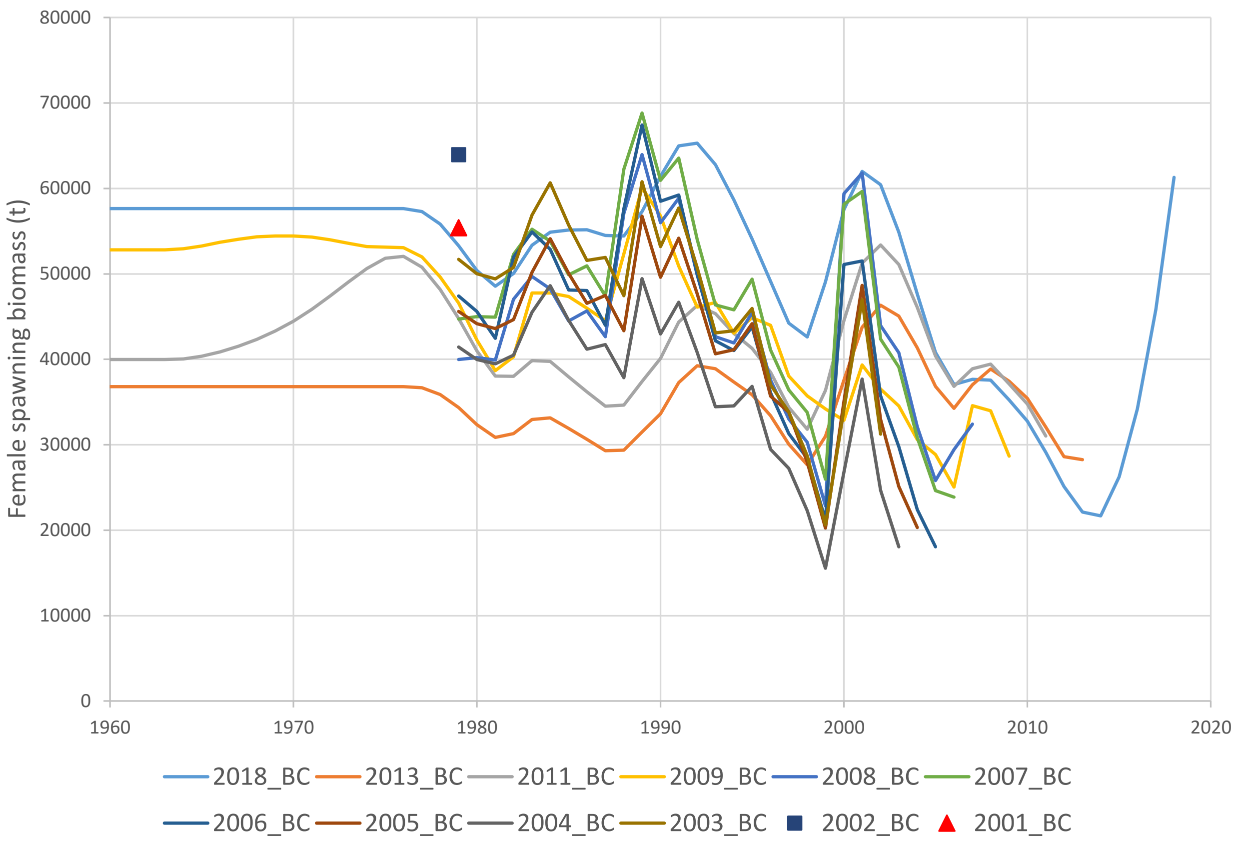


Figure 5.2. A retrospective of assessment outputs of female spawning biomass from each stock assessment from 2001 to 2018. Note that for 2001 and 2002 only values of biomass at 1979 were available (from Castillo-Jordán and Tuck, 2018a).

5.6 Bridge 2

5.6.1 Inclusion of new data

The data inputs to the assessment comes from multiple sources, including: length and conditional age-at-length data, updated standardized CPUE series (Sporcic, 2021), the annual total mass landed, discard mass, and age-reading error.

Starting from the converted 2018 base case model (labelled GRE_2018_Updated) additional and updated data to 2020 were added sequentially to develop a preliminary base case for the 2021 assessment, these steps included:

1. Change final assessment year to 2020, add catch to 2020 (addCatch2020).
2. Add CPUE to 2020 (from Sporcic (2021)) (addCPUE2020).
3. Add updated discard estimates to 2020 (add_Discards2020).
4. Update length frequency data, including both port and onboard length frequencies (addLengths2020). Conditional-age-at-length were also updated at this step due to changing the length bins used in the assessment.
5. Add updated age error matrix (addAgeErr2020).

6. Change the final year for which recruitments are estimated from 2014 to 2017 (extendRec2017).
7. Change the final year for which cohort dependent growth is estimated from 2014 to 2017 (extendCGD2017).
8. Retune using latest tuning protocols, including Francis weighting on length-compositions and conditional age-at-length data (Tuned_3).

5.6.2 *Results – base case*

Inclusion of the new data resulted in a series of changes to the outputs of the model. The addition of updated catch data and catch rate data made minimal difference to the estimated spawning biomass (Figure 5.3). The addition of updated discard estimates markedly reduced initial and final estimates of spawning biomass (Figure 5.3). There were minimal changes resulting from the addition of length and age data (Figure 5.3). Extending recruitment deviations and cohort dependent growth led to an increase in initial and final biomass due to the greater freedom to fit to recent input data (e.g. the catch rate series, Figure 5.3). Tuning resulted in downward revisions to the biomass series, with initial biomass similar to the updated 2018 assessment (Figure 5.3).

The sequential addition of data resulted in various changes to the recruitment estimates (Figure 5.4). The addition of further recruitment years (to 2017; GRE_2021_extendRec2017) has led to a marked increase in the magnitude of recent recruitment (between 2014 -2017) over the assumed values from the recruitment curve (Figure 5.4). Final tuning also increased the estimates of recruitment from the early years of the fishery (late 1970s and mid 1980s, Figure 5.4).

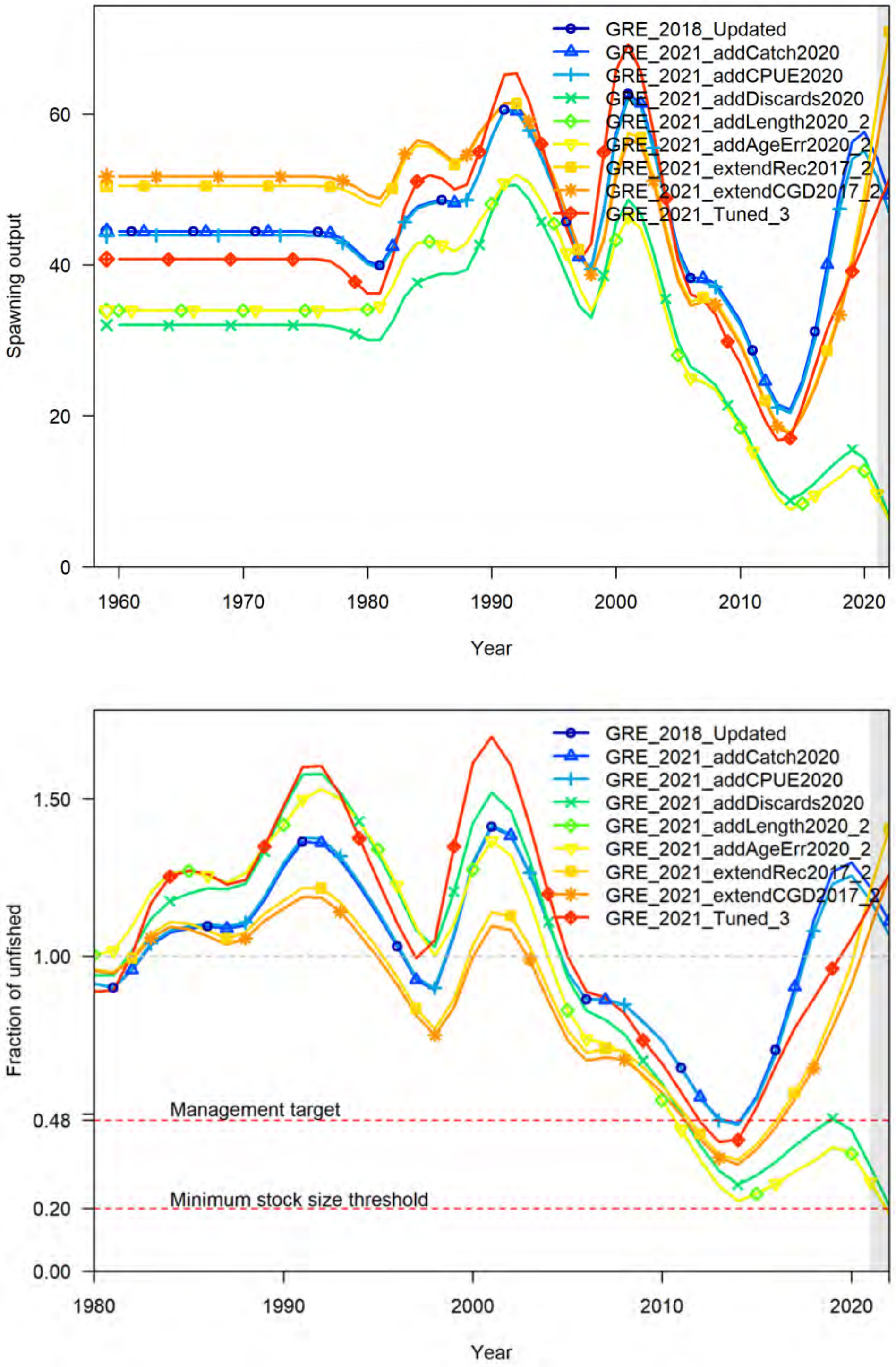
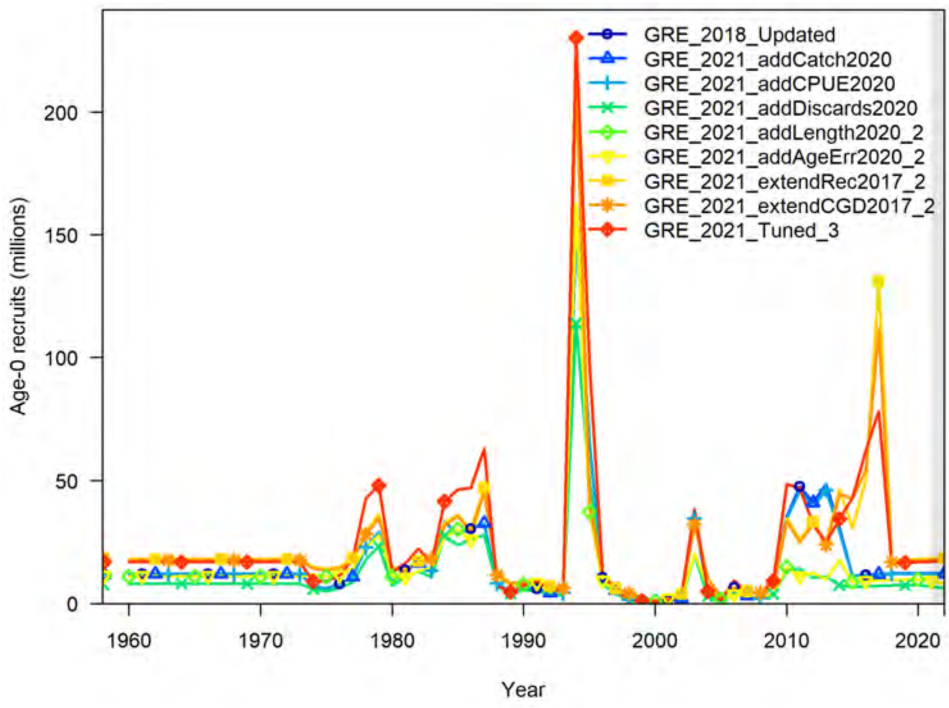


Figure 5.3. Comparison of the absolute (top) and relative (bottom) spawning biomass for the updated 2018 assessment converted to SS-V3.30.17 (GRE_2018_Updated – dark blue) with various bridging models leading to the 2021 base case (GRE_2021_Tuned_3 - red)



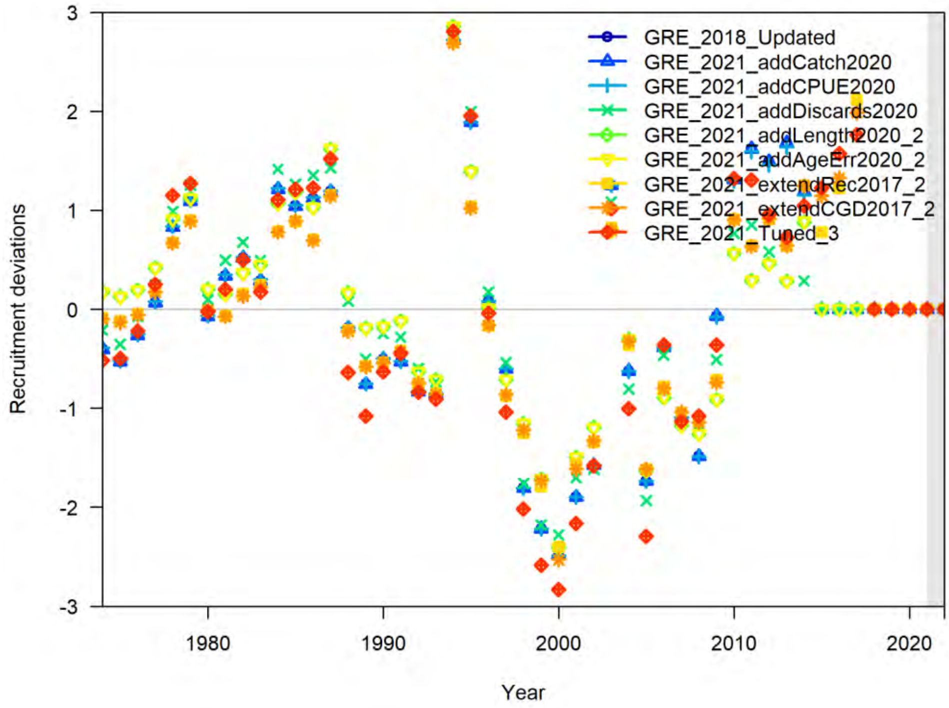


Figure 5.4. Comparison of the estimated recruitment (top) and deviations (bottom) for the updated 2018 assessment model converted to SS-V3.30.17 (GRE_2018_Updated – dark blue) with various bridging steps leading to the 2021 base case (GRE_2021_Tuned_3 - red)

The impacts of inclusion of new data on fits to the non-spawning fishery CPUE series are illustrated in Figure 5.5. As has been noted before, the fits to CPUE are generally poor until the mid-2000s. The addition of new data and extending recruitment estimation to 2017 has allowed a reasonable fit to the recent marked increase in CPUE since 2018.

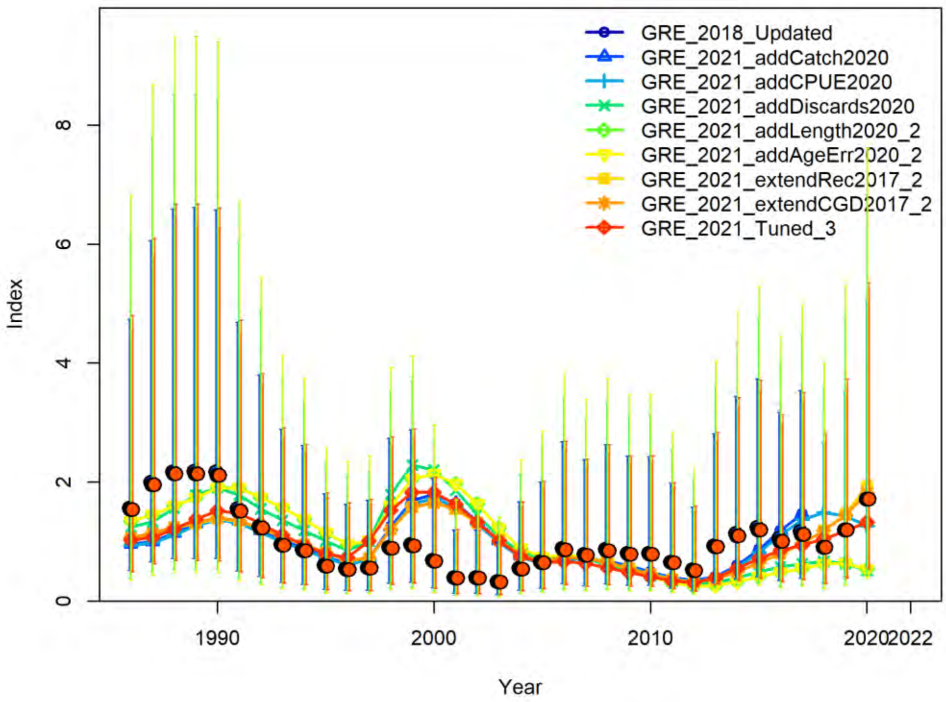


Figure 5.5. Comparison of the fit to the non-spawning fishery CPUE index for the updated 2018 assessment model converted to SS-V3.30.17 (GRE_2018_Updated – dark blue) with various bridging models leading to the 2021 preliminary base case (GRE_2021_Tuned_3 - red)

5.6.3 *Fits to data – base case*

Estimated outputs and fits to the data of the preliminary base case are presented in Figure 5.6–Figure 5.13. Fits are comparable to those in the previous assessment (see Castillo- Jordán and Tuck (2018b)). Fits to the acoustic and FIS surveys are reasonable, although there is little variation in the estimated values and the fit is relatively flat while passing through the confidence intervals. The fit to discard mass is reasonable, although there is some under-fitting from 2015-17. Fits to the length composition data are good across the retained and discard lengths, and for port and onboard lengths. Note the saw-tooth port lengths which may be due to in-port rounding of measurements. This will be further investigated.

5.6.4 *Assessment outcomes -base case*

The estimated virgin female biomass is 40,759 tonnes (compared to 53,909 tonnes in 2018 and 36,815 tonnes in the 2013 assessments). Initial biomass is known to be sensitive in this model and often has varied betweem 35,000 tonnes and 60,000 tonnes. Castillo- Jordán and Tuck (2018a) showed that there is uncertainty regarding the initial biomass from the likelihood profile for $\ln R_0$ (Figure 5.15). A likelhood profile on initial biomass (amongst others) will be conducted for SERAG3 in 2021 to further investigate this sensitivity.

The projected 2022 spawning stock biomass will be 126% of virgin female spawning biomass (projected assuming 2020 catches in 2021), compared to 122% for 2019 in the 2018 assessment, and 94% for 2014 in the 2013 assessment.

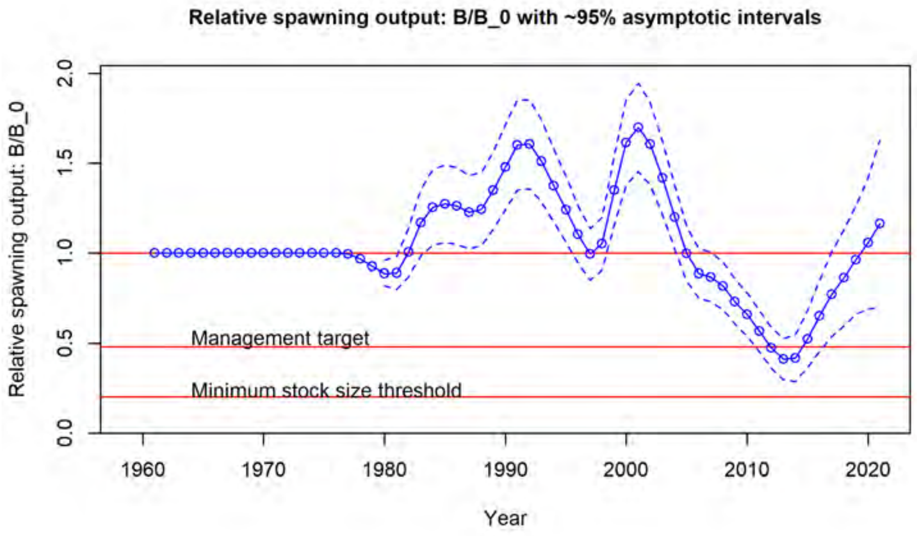


Figure 5.6. The estimated time-series of relative spawning biomass for the 2021 preliminary base case assessment

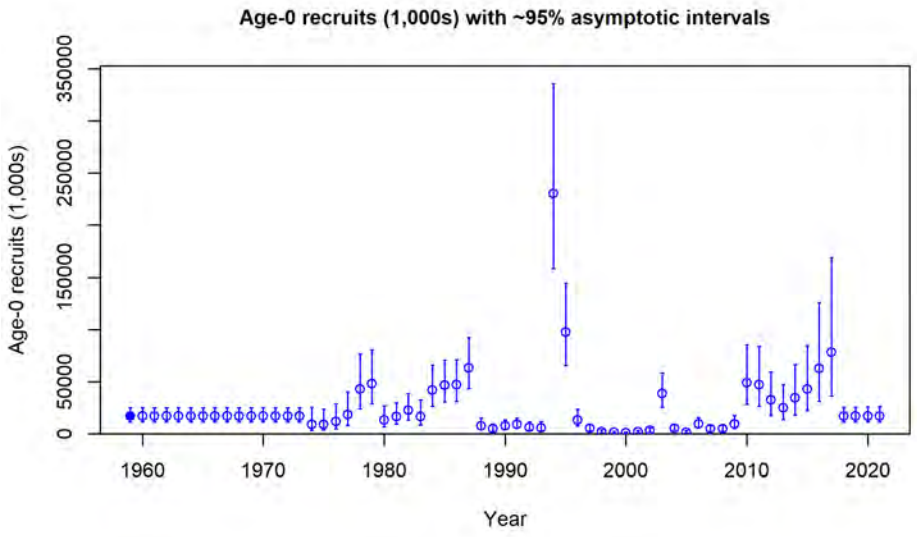


Figure 5.7. The estimated time-series of recruitment for the 2021 preliminary base case assessment

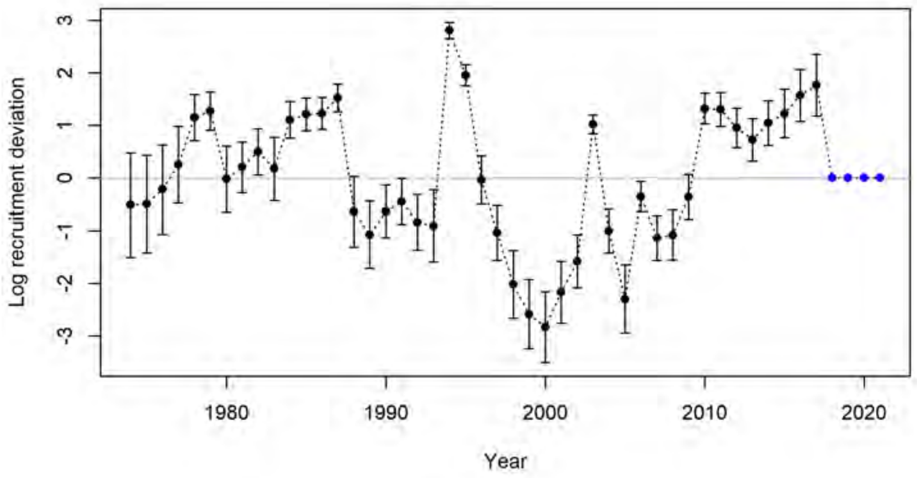


Figure 5.8. The estimated time-series of recruitment deviations for the 2021 preliminary base case assessment

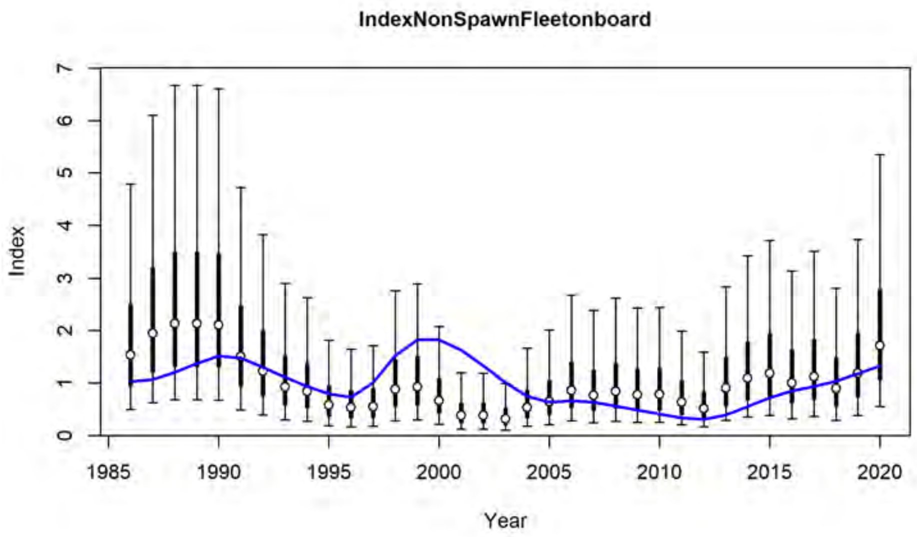


Figure 5.9. Fits to the non-spawning fishery CPUE for the 2021 preliminary base case assessment

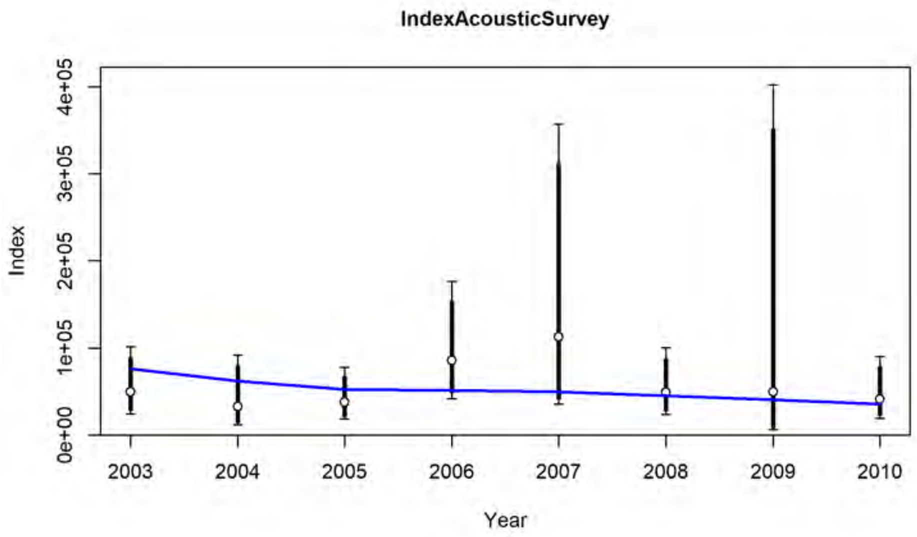


Figure 5.10. Fits to the acoustic survey for the 2021 preliminary base case assessment

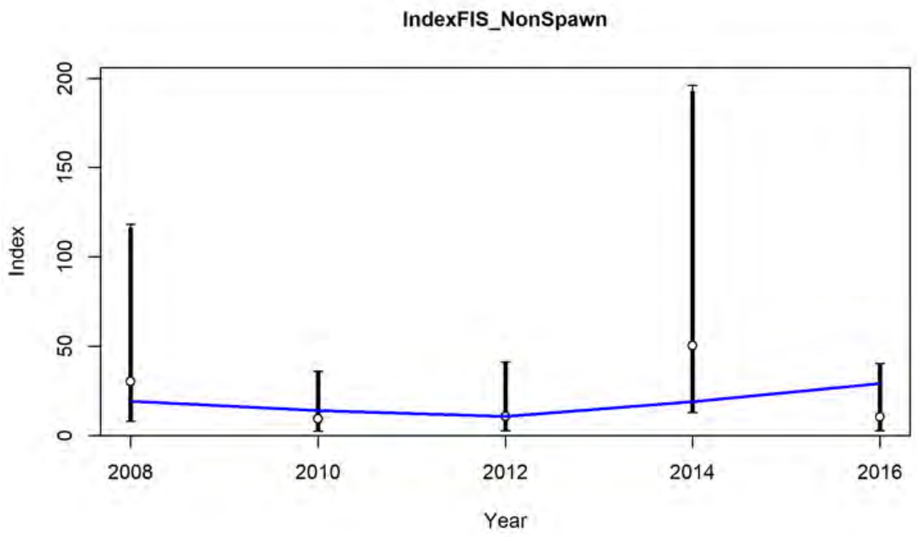


Figure 5.11. Fits to the FIS winter non-spawning survey for the 2021 preliminary base case assessment

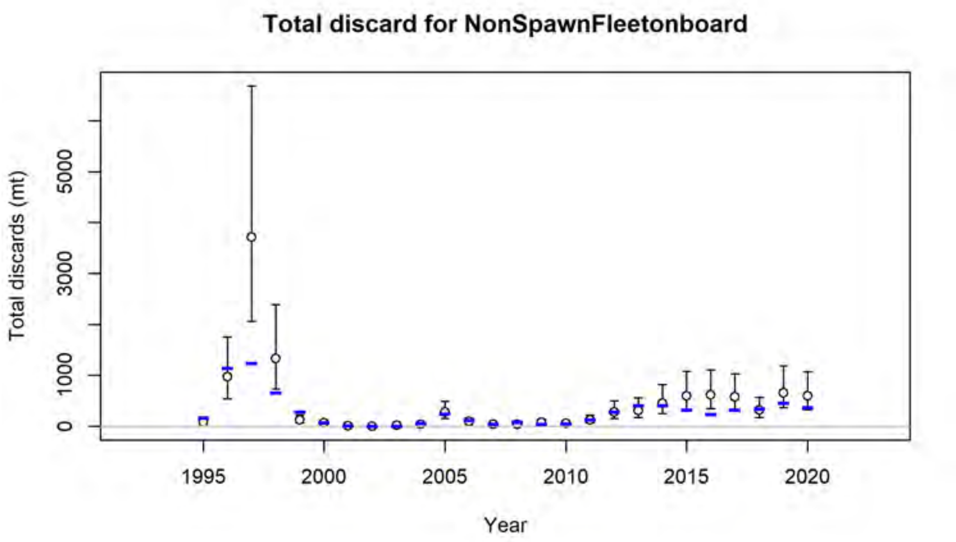


Figure 5.12. Fits to the non-spawning fishery discards for the 2021 preliminary base case assessment

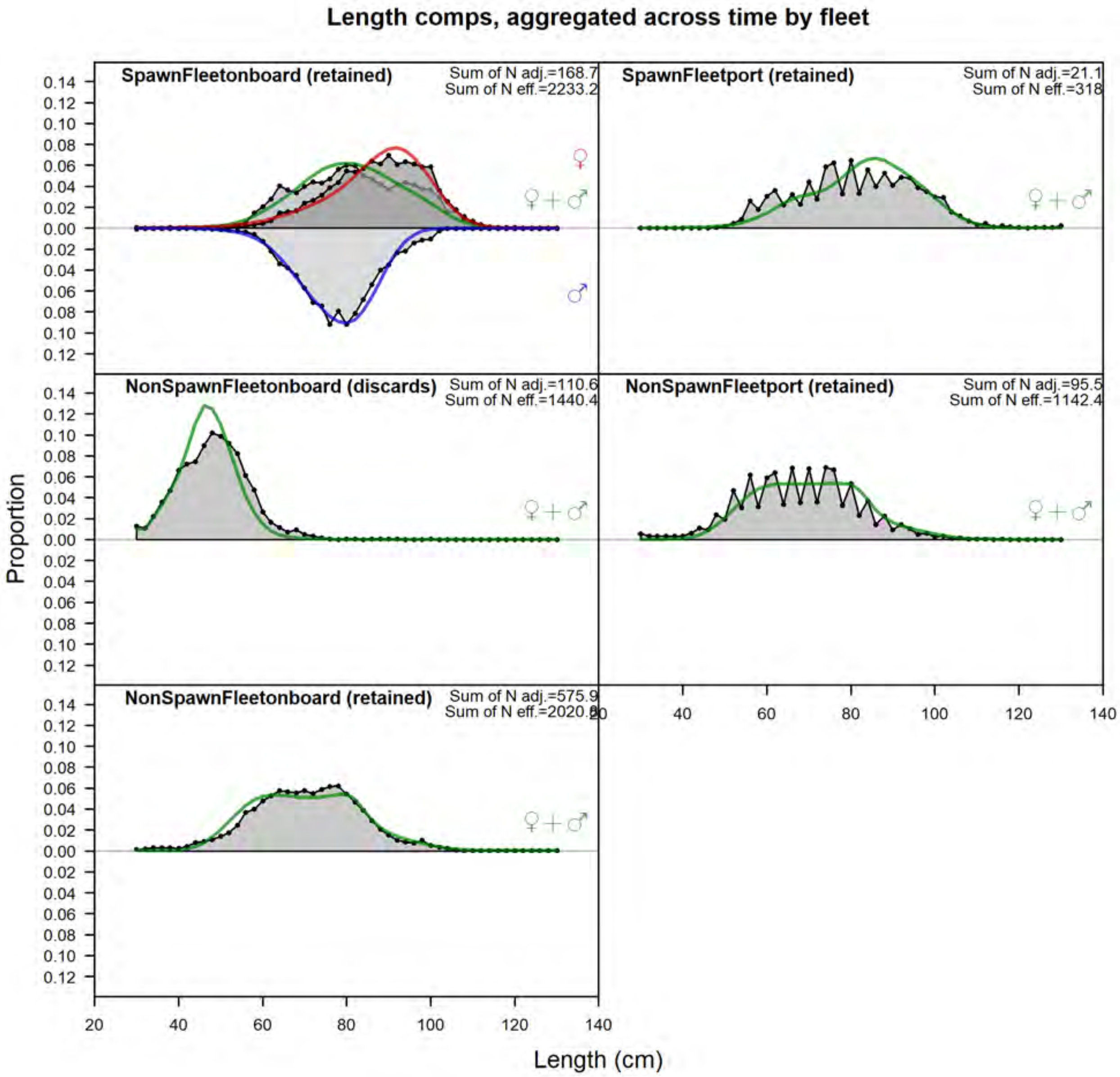


Figure 5.13. Fits to the aggregated length data for the 2021 preliminary base case assessment

5.7 Acknowledgements

Age data were provided by Kyne Krusic-Golub (Fish Ageing Services), ISMP and AFMA logbook and CDR data were provided by John Garvey (AFMA). Mike Fuller, Paul Burch, Robin Thomson, Roy Deng, Franzis Althaus, Toni Cannard and Caroline Sutton (CSIRO) pre-processed the data. Miriana Sporcic provided standardised CPUE. Malcolm Haddon provided useful code for auto-balancing, Athol Whitten provided useful R code for organising plots. Paul Burch provided an updated ageing error matrix. Jemery Day, Andre Punt, Robin Thomson and Paul Burch (CSIRO) provided valuable review and discussion of this work. Ian Taylor, Chantel Wetzel, Kathryn Doering and Kelli Johnson (NOAA) are thanked for helpful reccomendations and fixes in relation to the the r4ss package. The r4ss package maintained by Ian Taylor (https://github.com/r4ss/r4ss) was critical for producing multiple diagnostic plots, and tuning models.

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5.9 Appendix

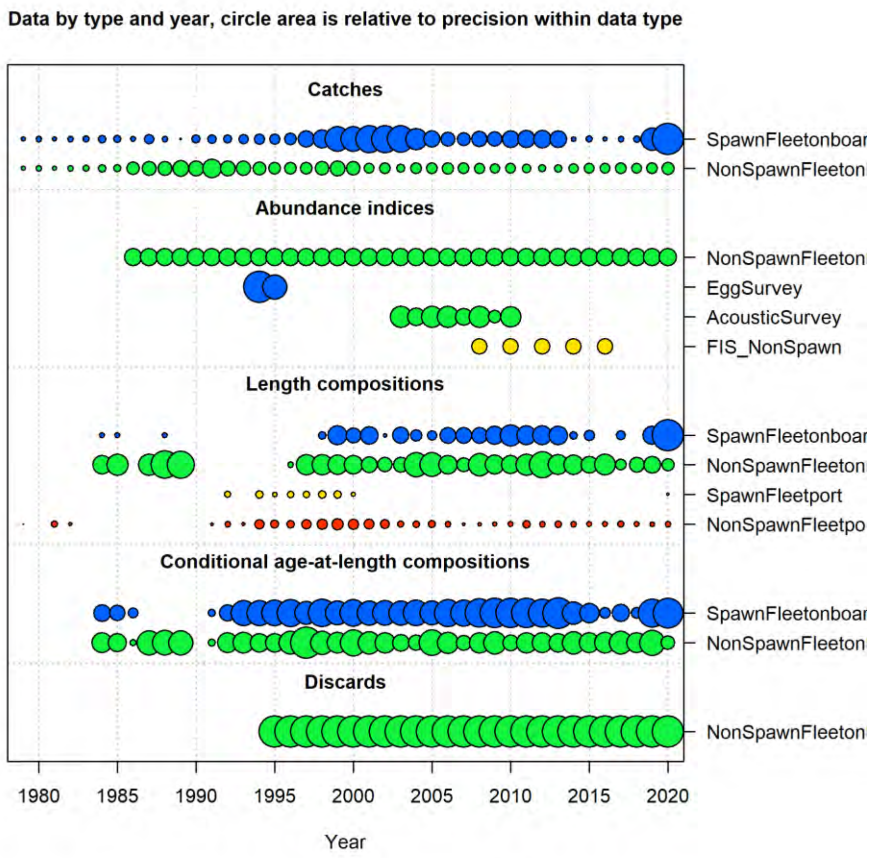


Figure 5.14. Summary of Blue Grenadier data sources

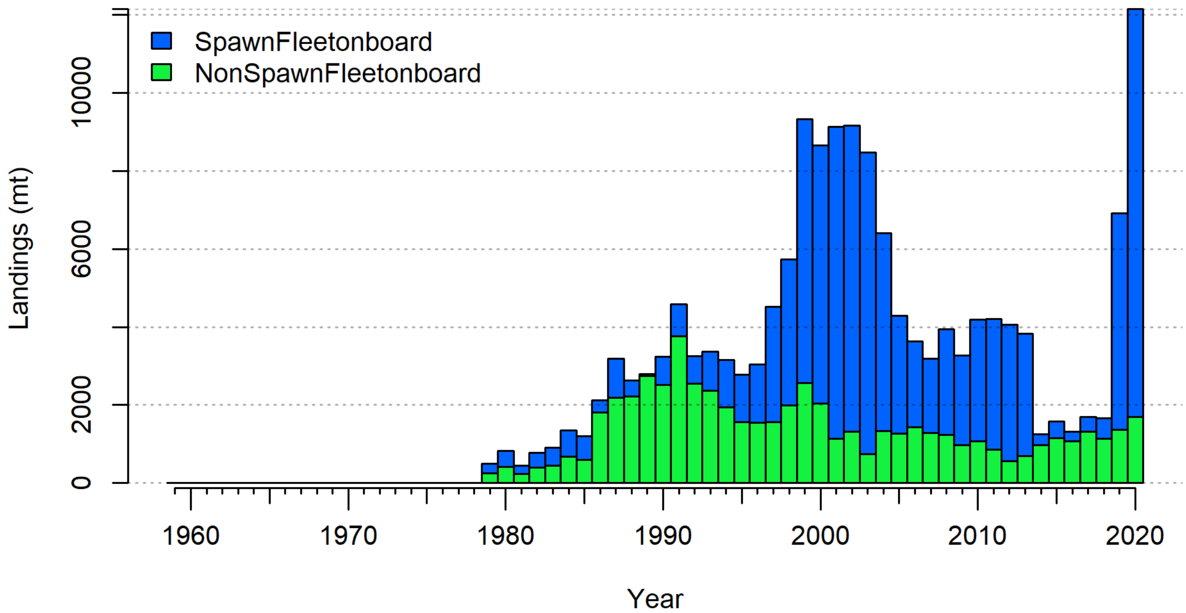


Figure 5.15. Summary of catch by fleet

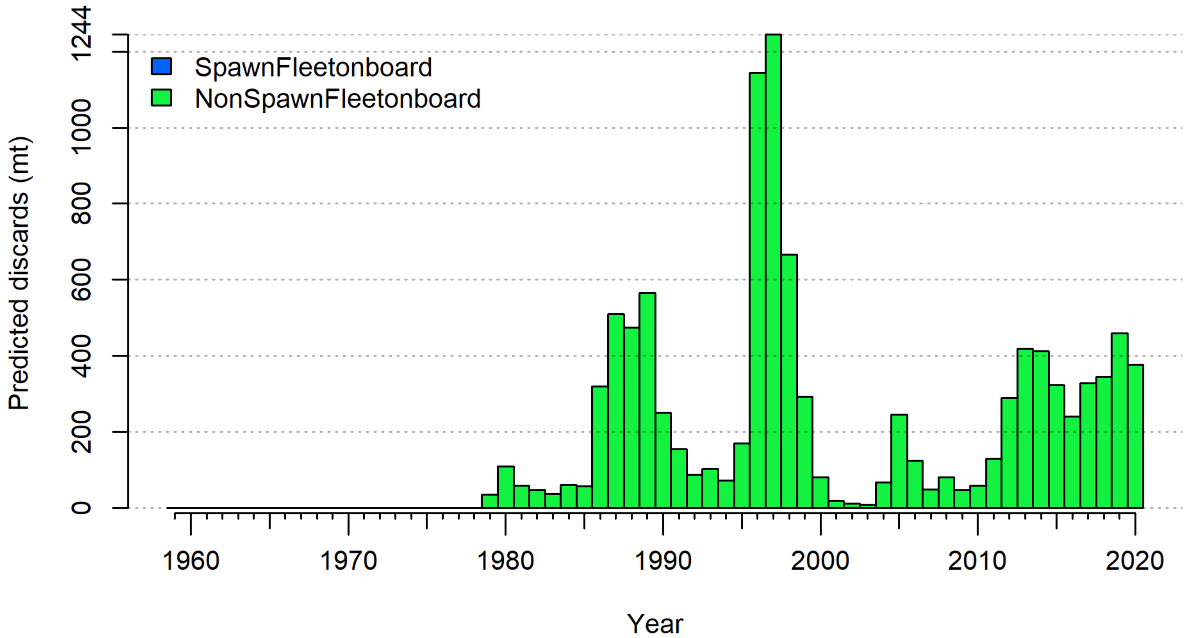


Figure 5.16. Summary of total discards by fleet

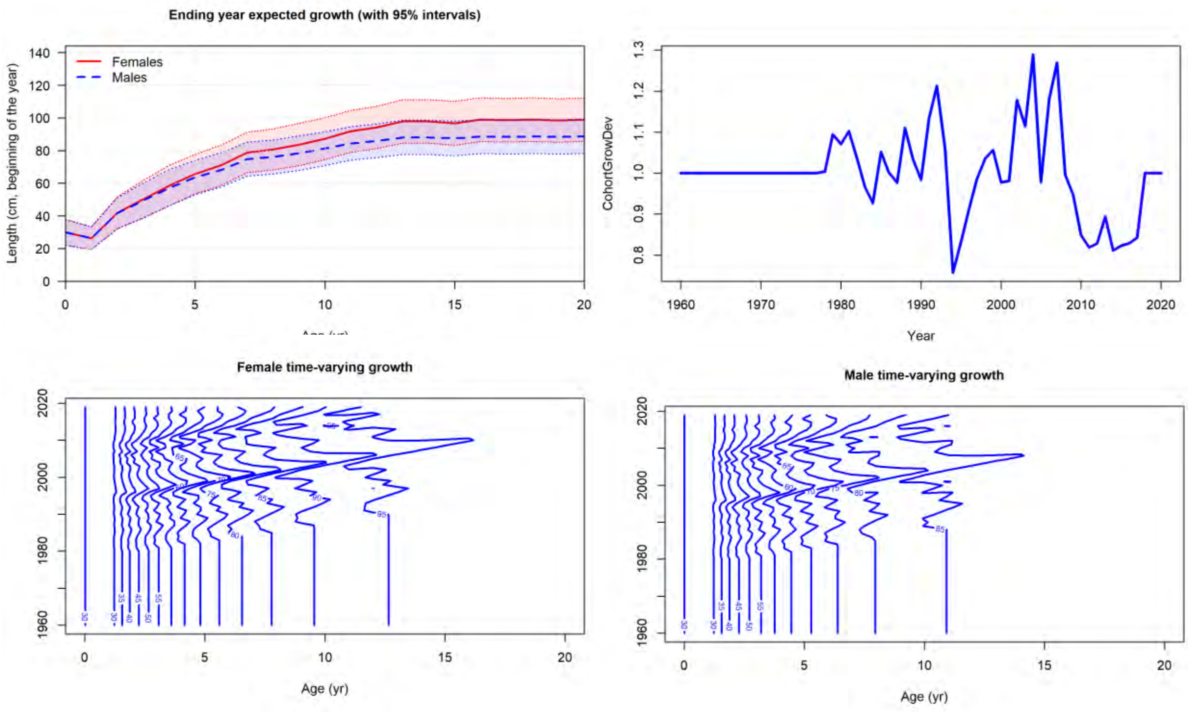


Figure 5.17. Estimated growth for Blue Grenadier

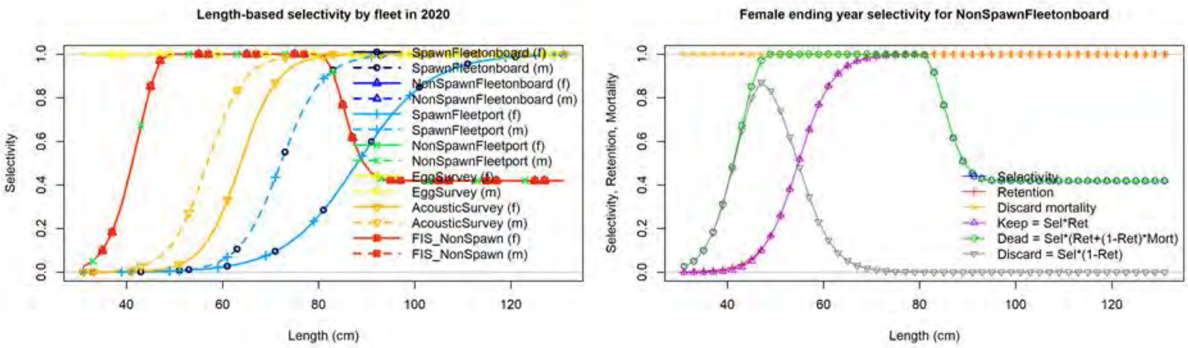


Figure 5.18. Estimated selectivity and retention by fleet for the base case

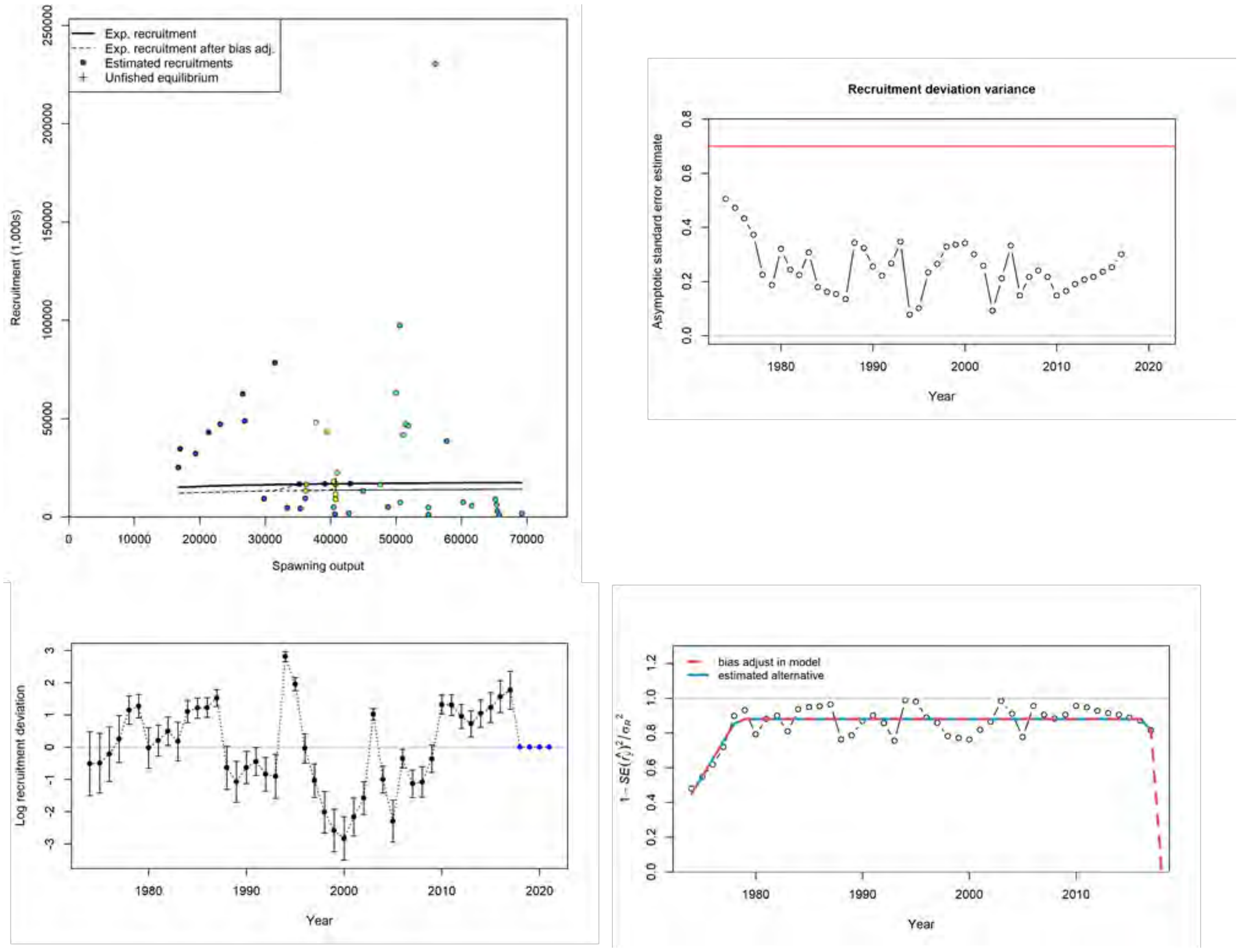


Figure 5.19. Time series showing the stock recruitment curve, recruitment deviations and recruitment deviation variance check for blue grenadier.

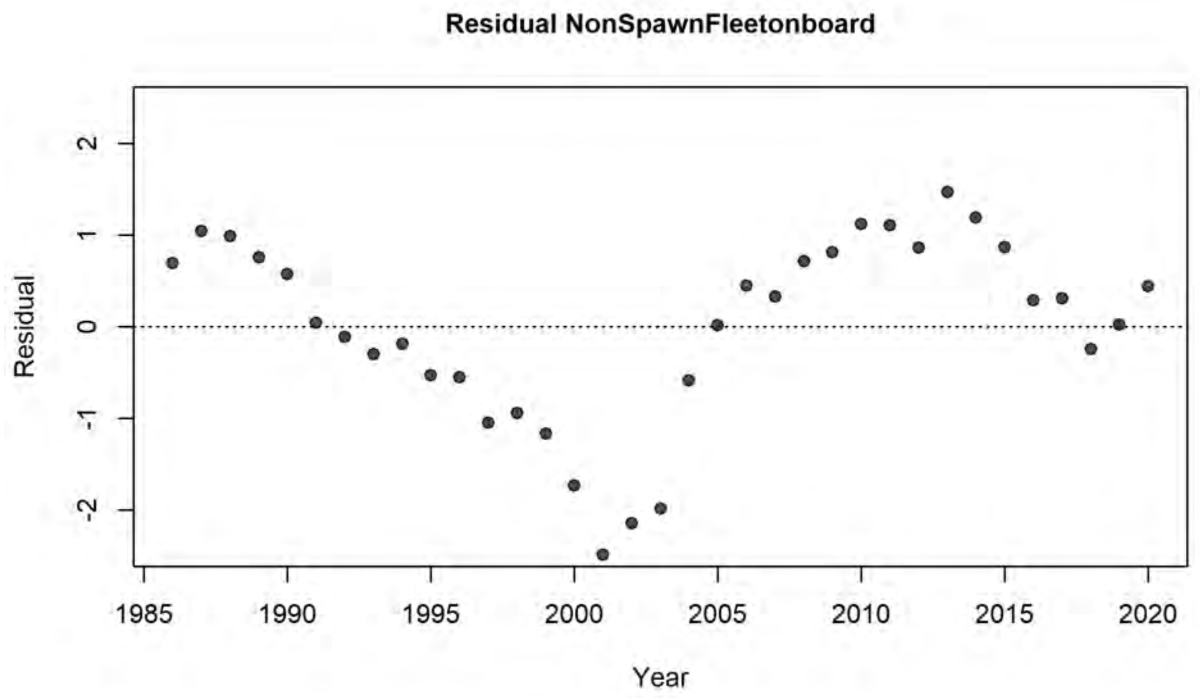


Figure 5.20. Residuals for fits to CPUE.

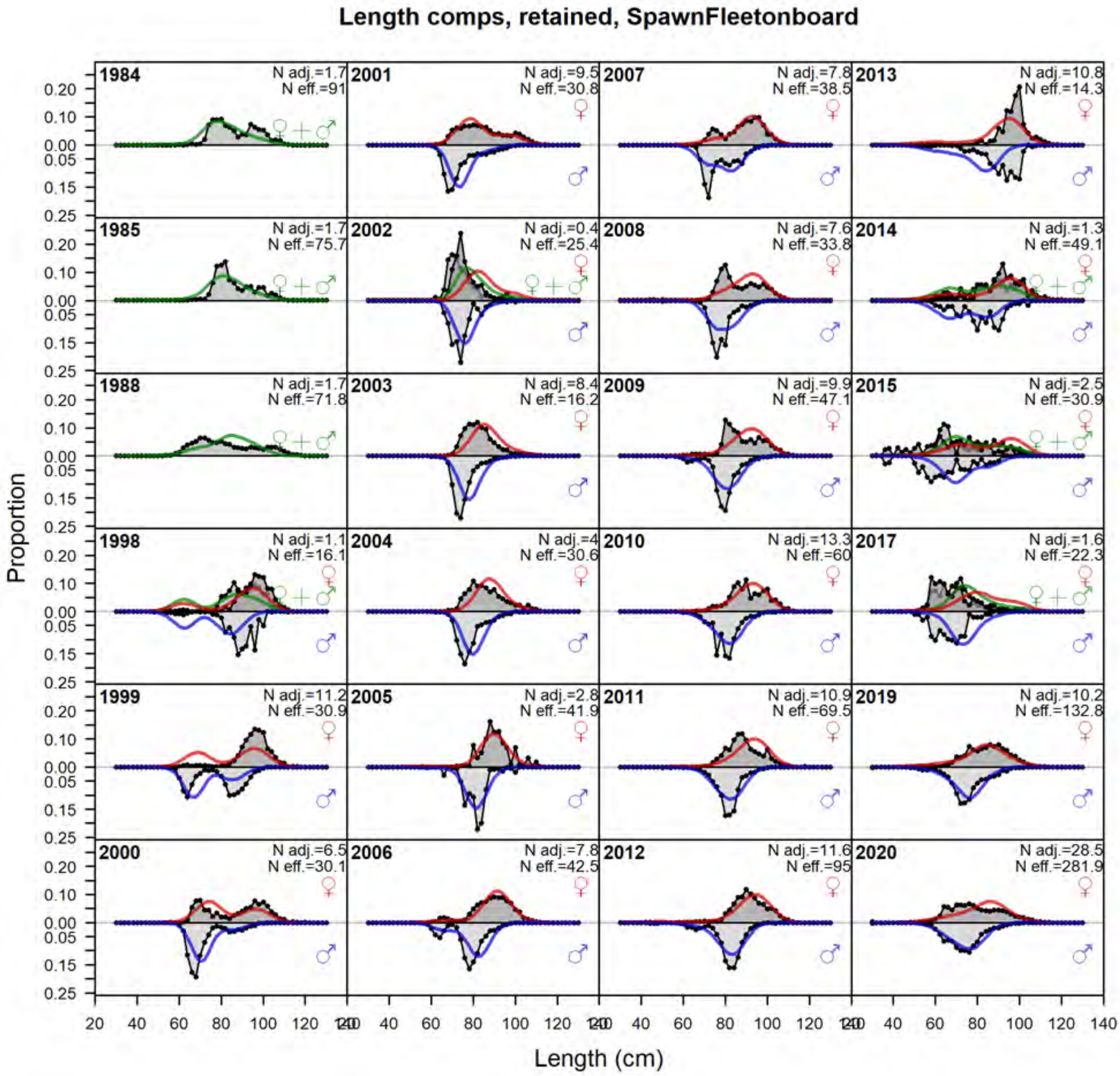


Figure 5.21. Length composition fits: onboard spawning fleet retained.

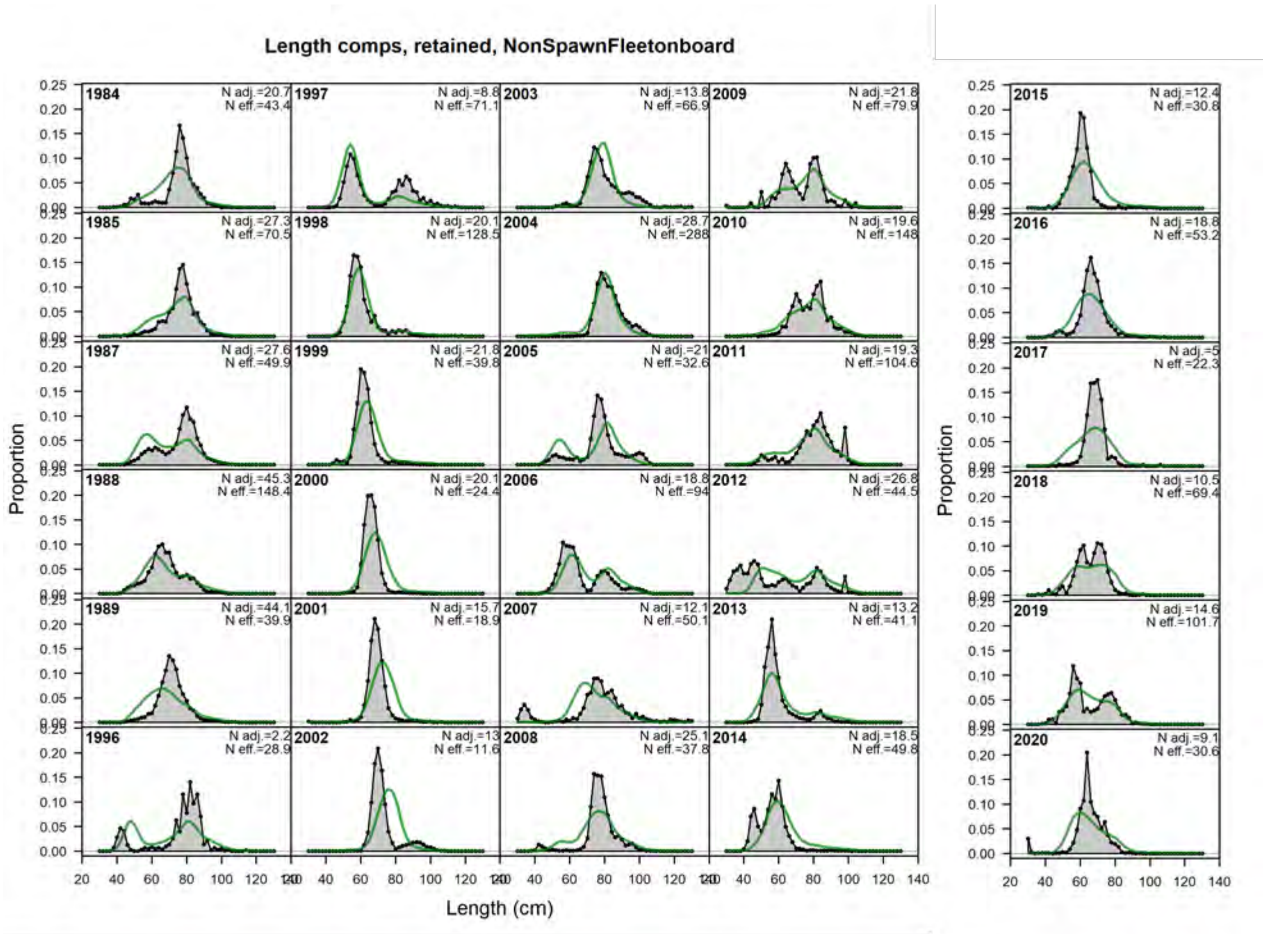


Figure 5.22. Length composition fits: onboard non-spawning fleet retained.

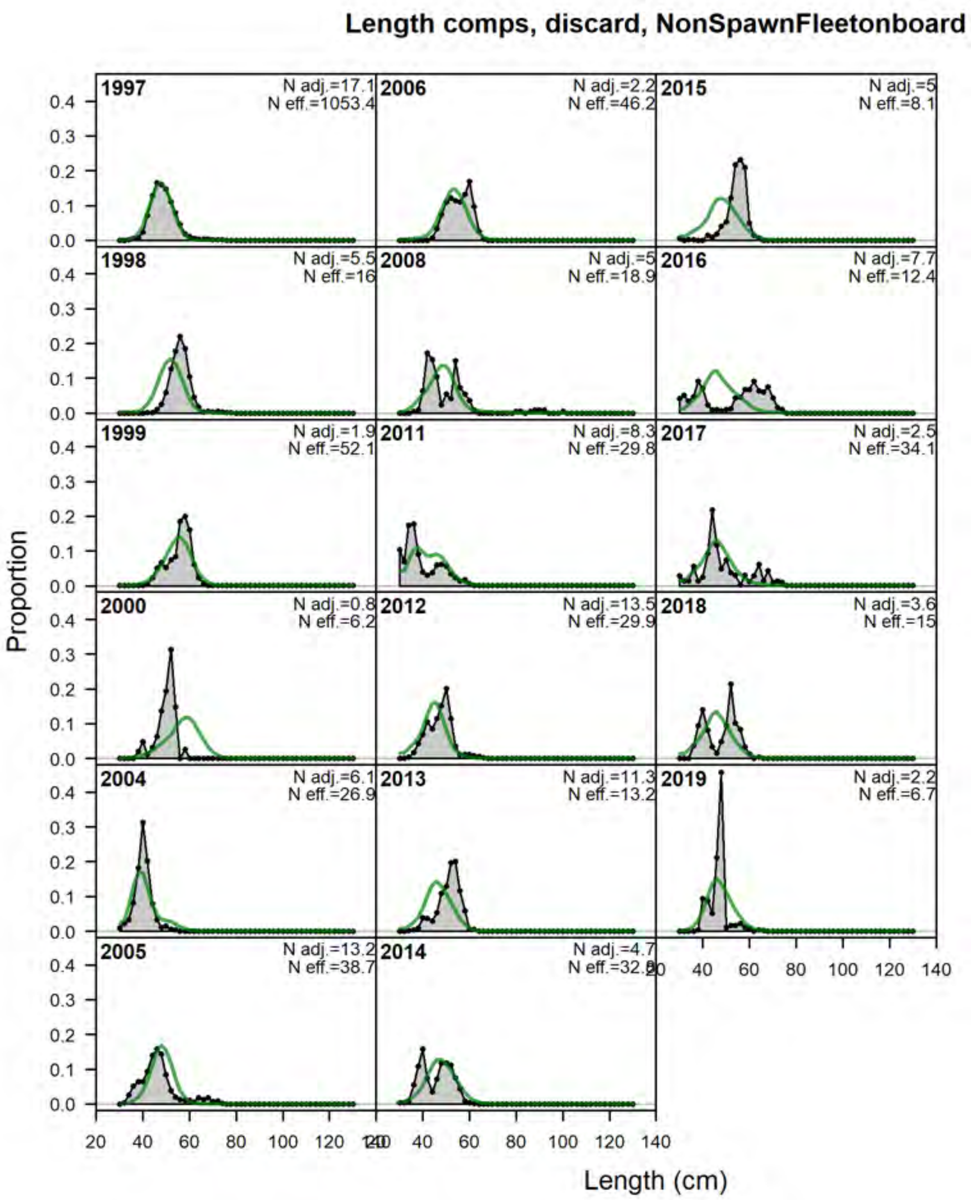


Figure 5.23. Length composition fits: onboard non-spawning fleet discard.

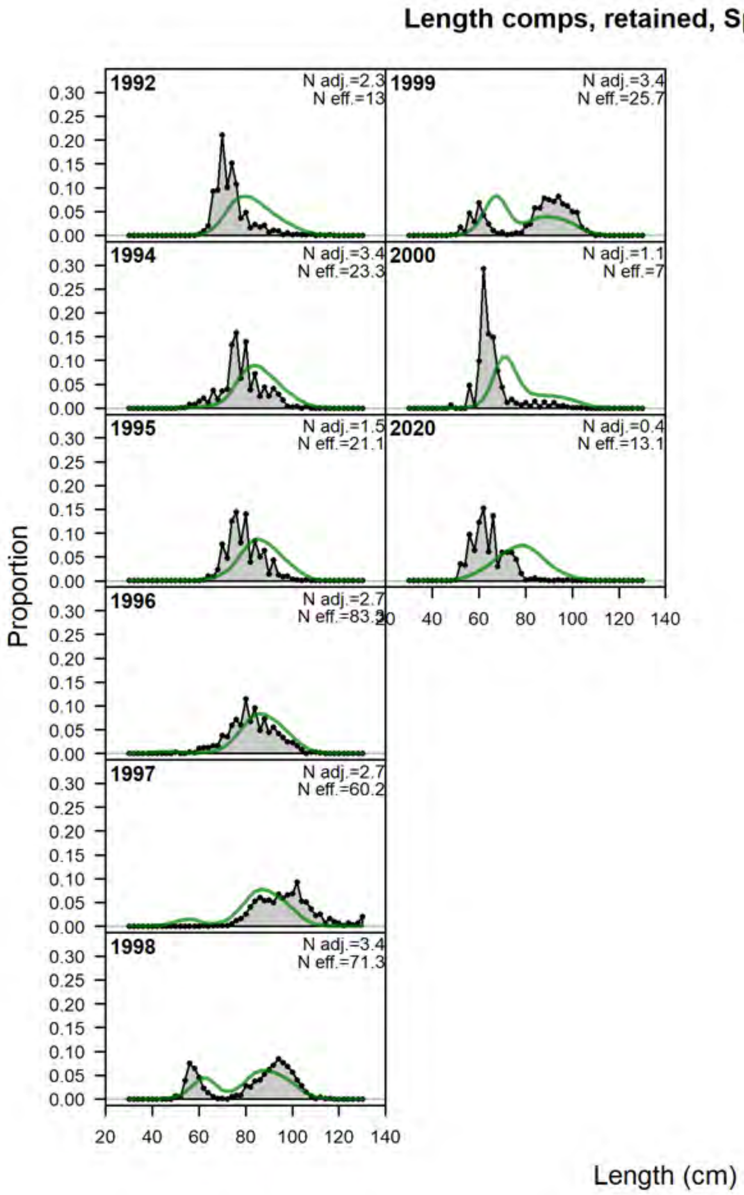


Figure 5.24. Length composition fits: port spawning fleet retained.

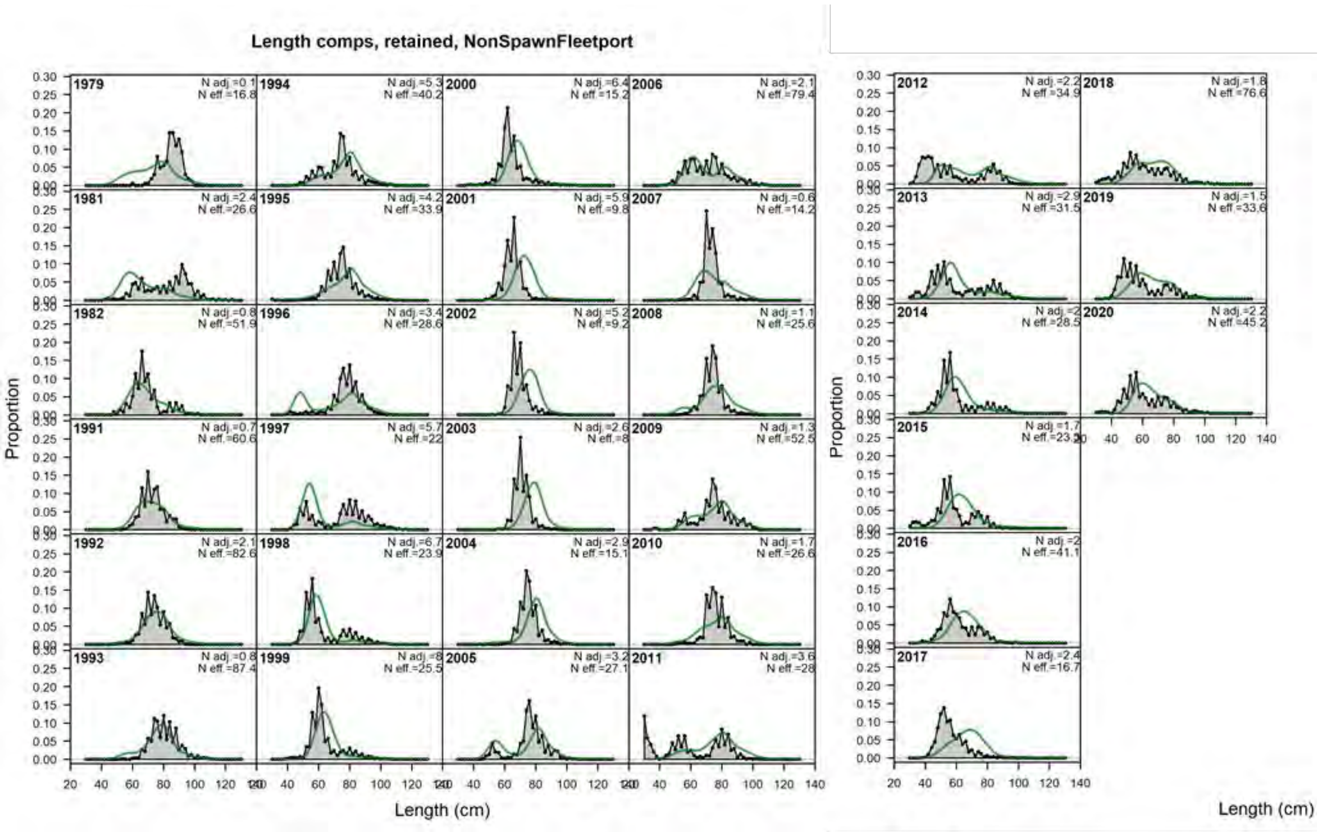


Figure 5.25. Length composition fits: port non-spawning fleet retained.

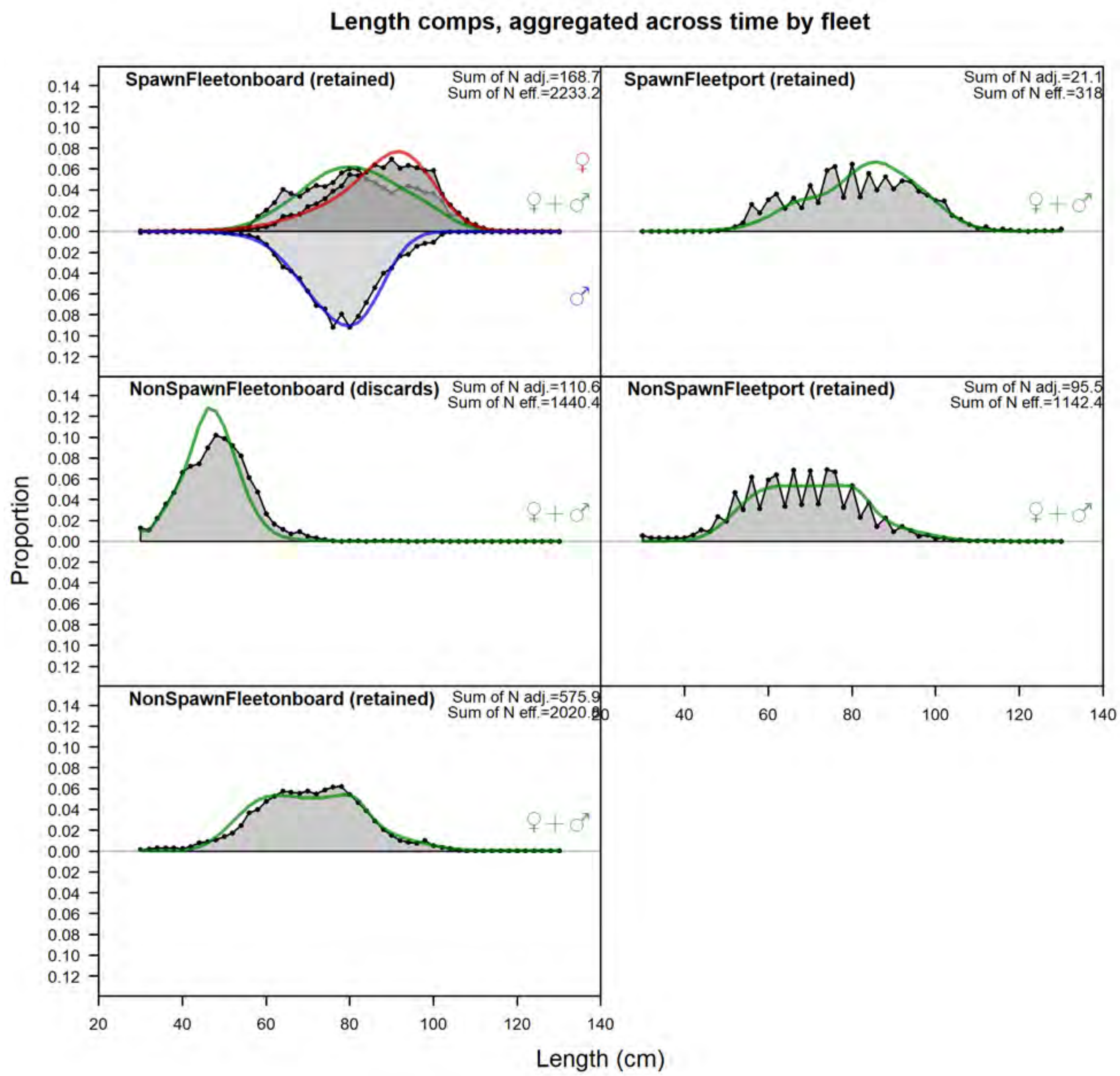


Figure 5.26. Length composition fits aggregated across years.

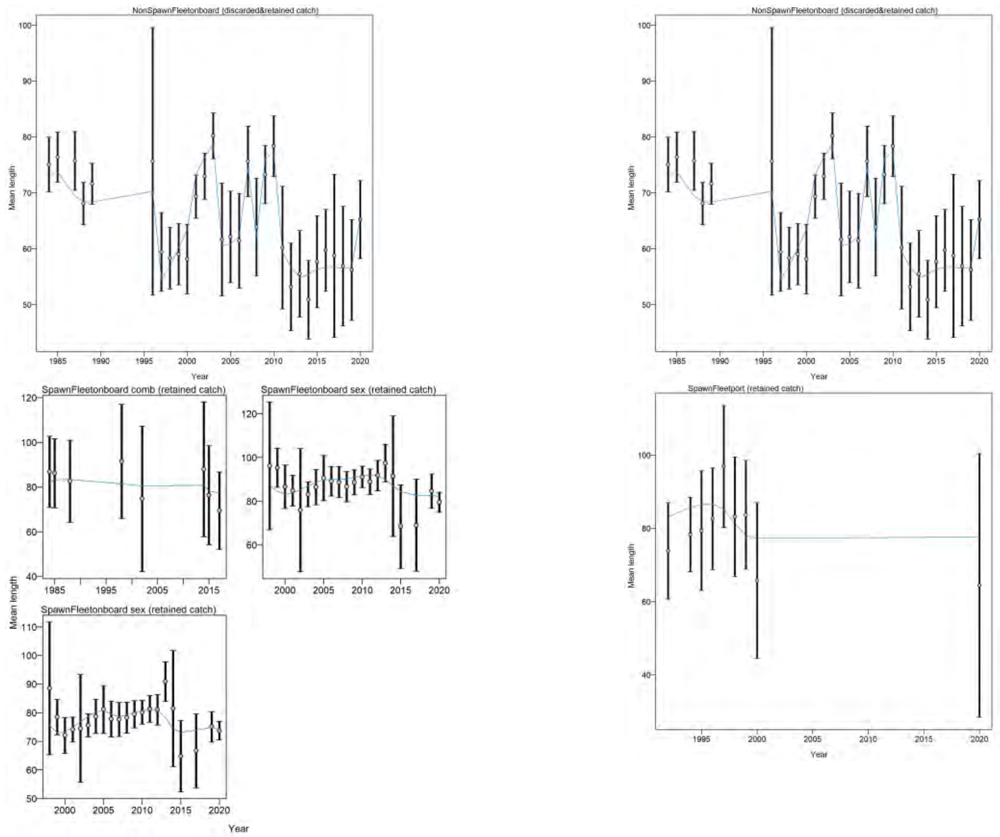


Figure 5.27. Length composition fit diagnostics from tuning. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data.

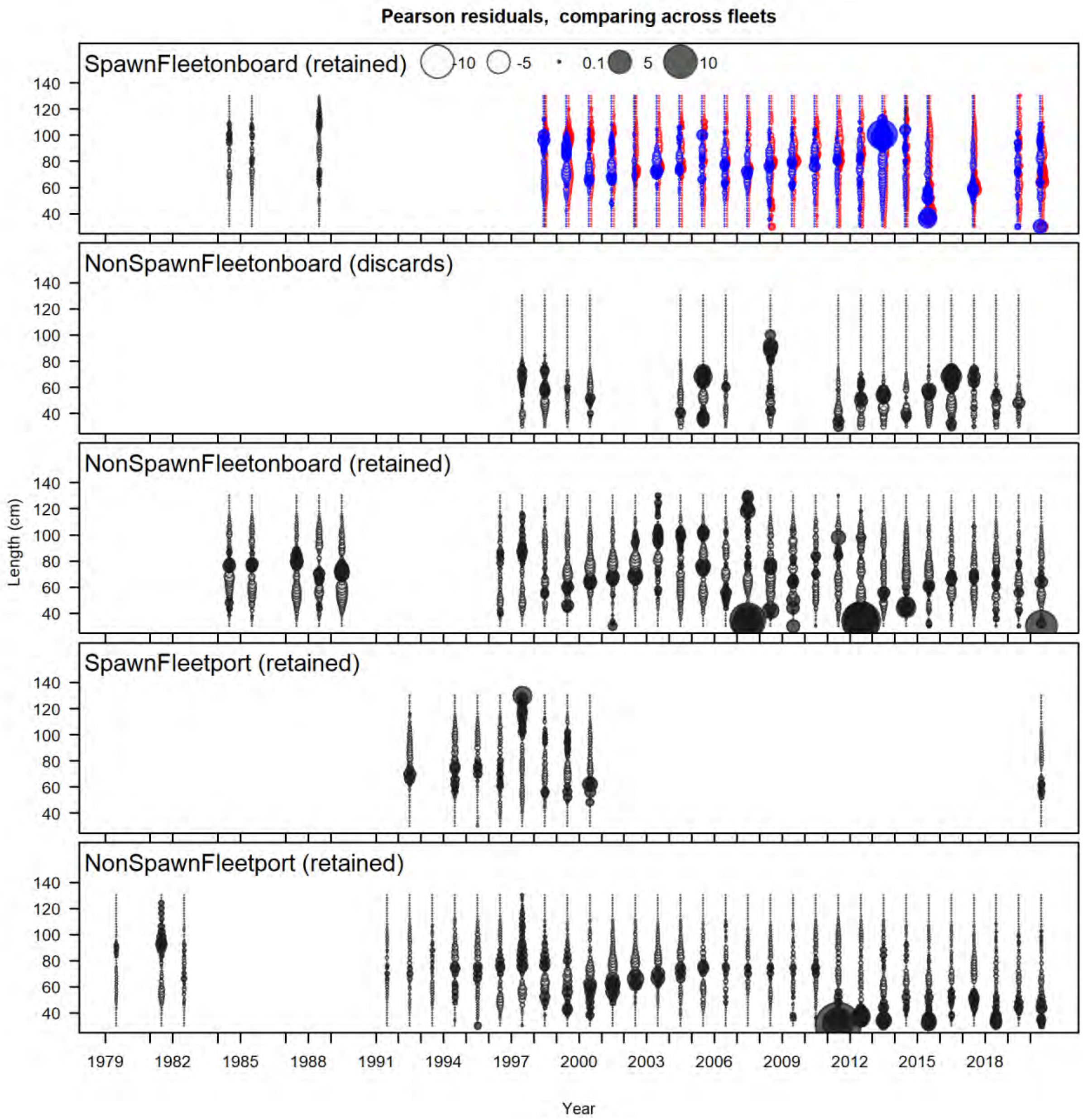
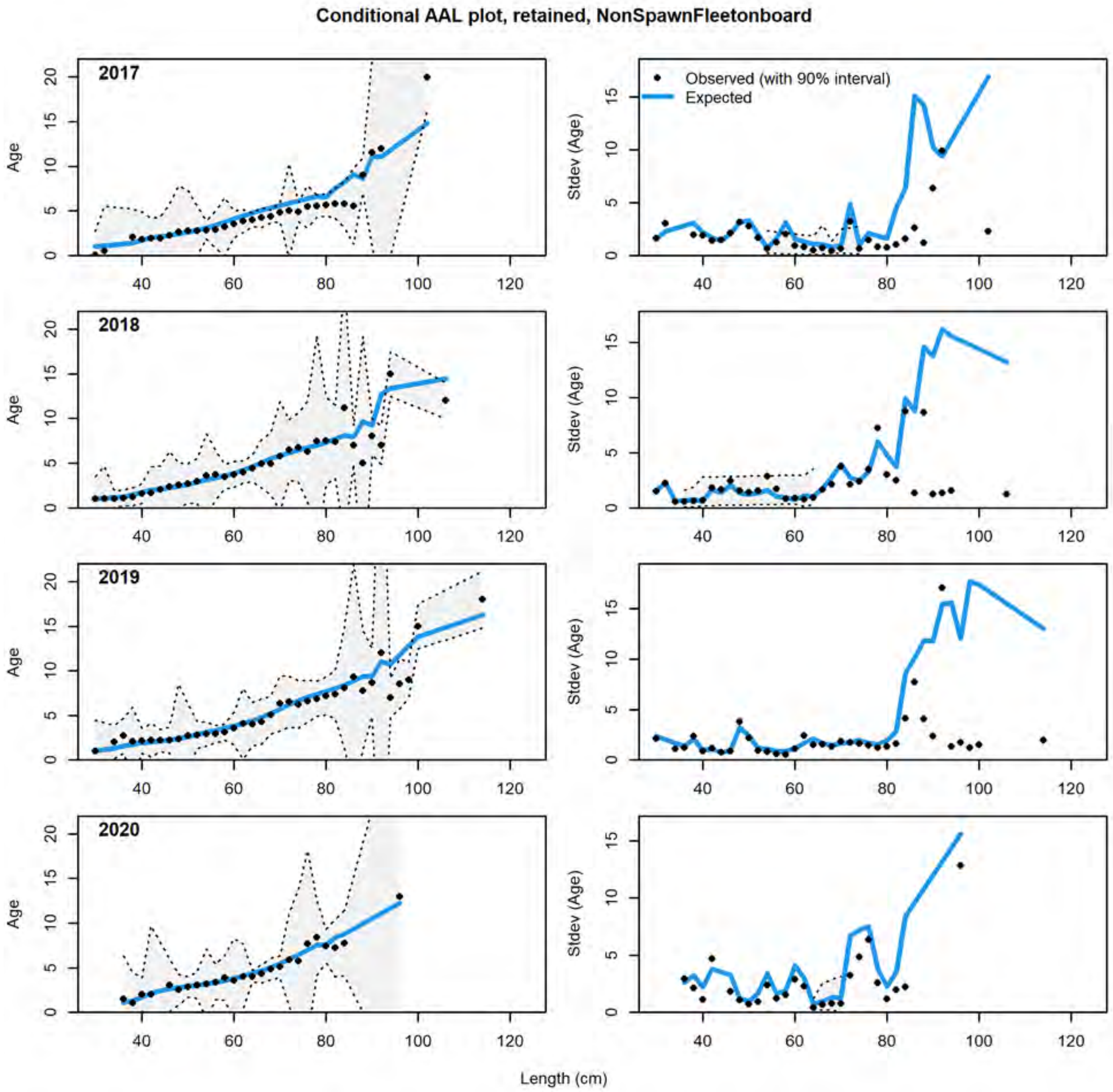
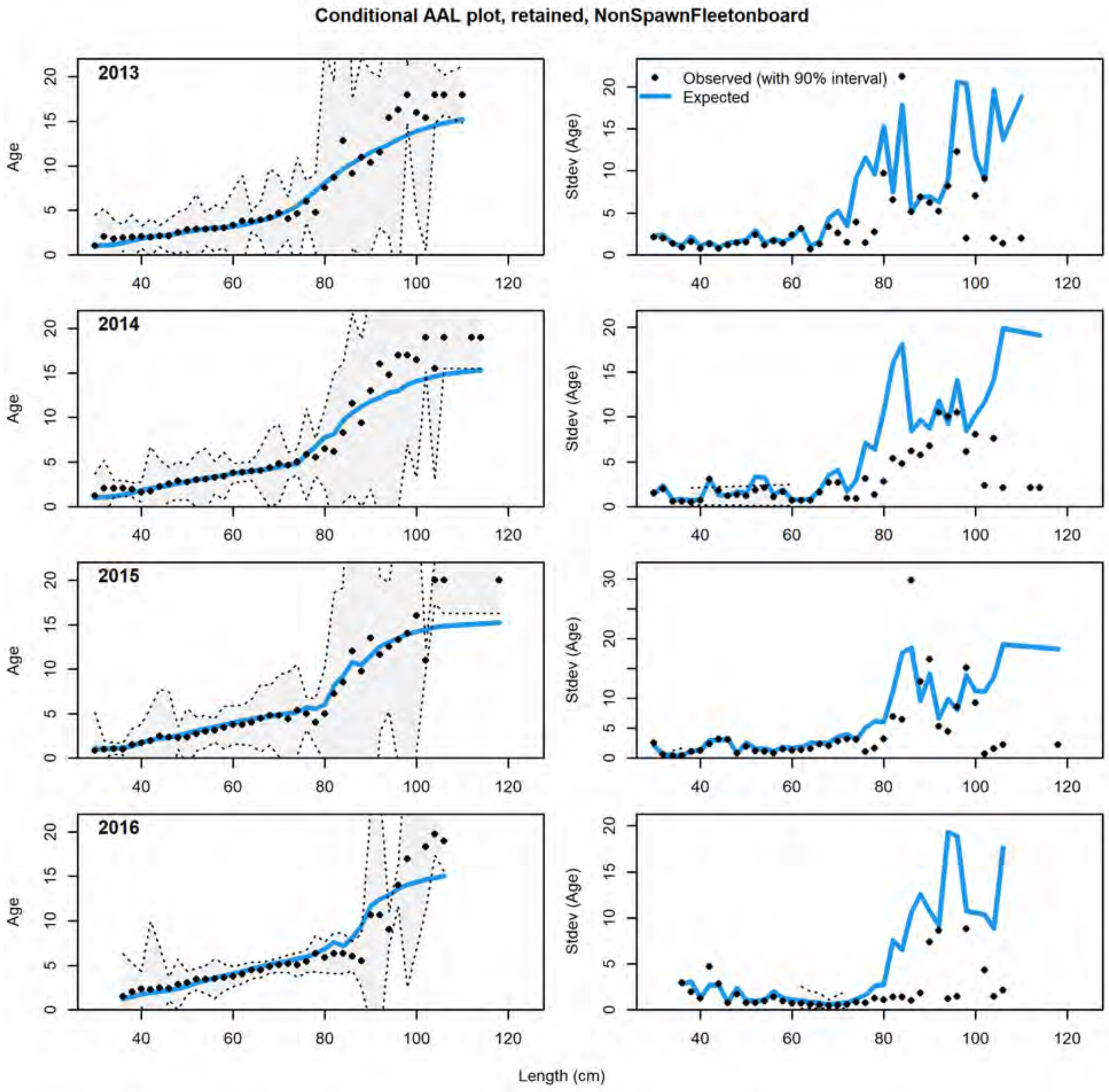


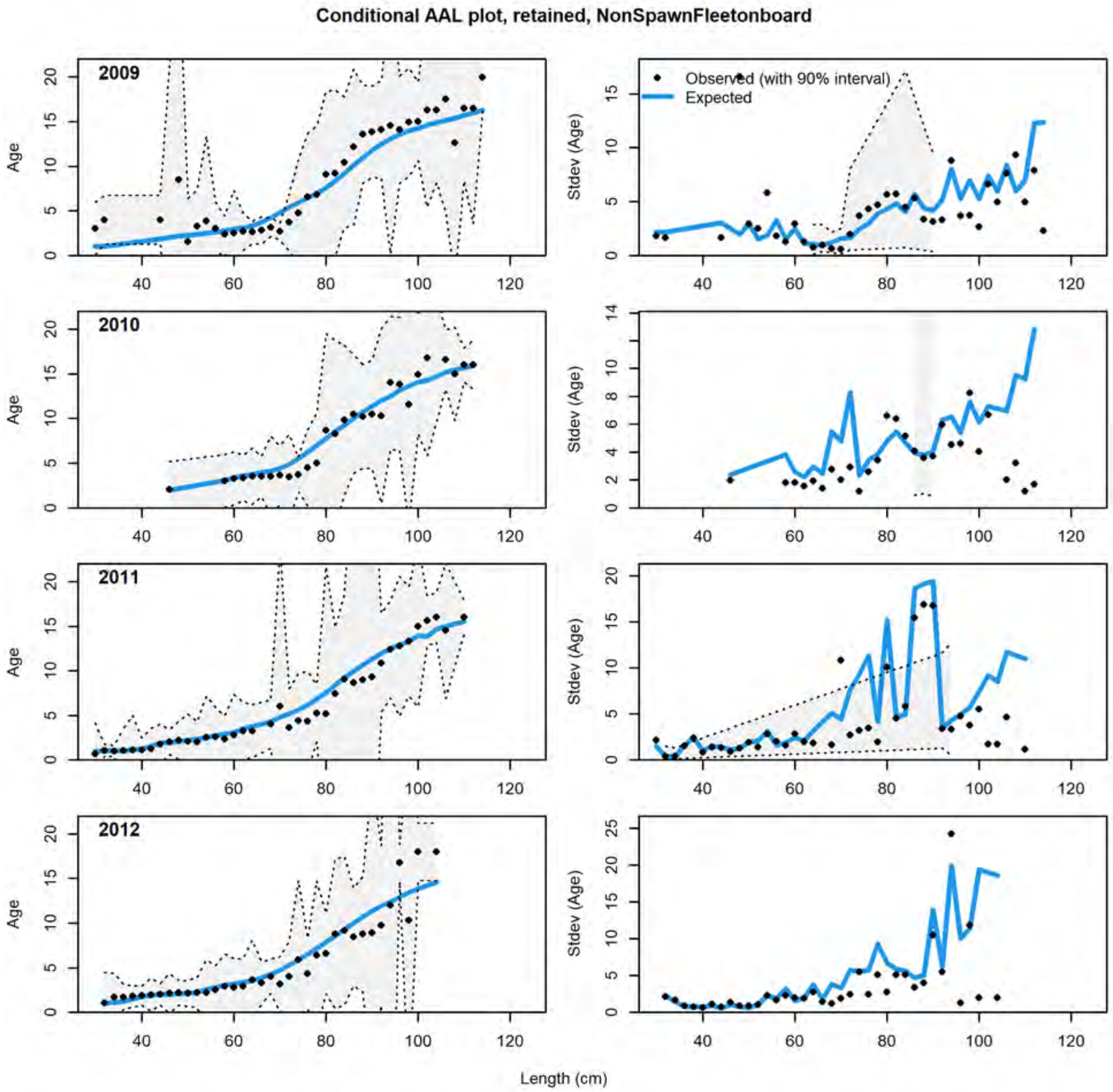
Figure 5.28. Residuals from the annual length compositions for base case.



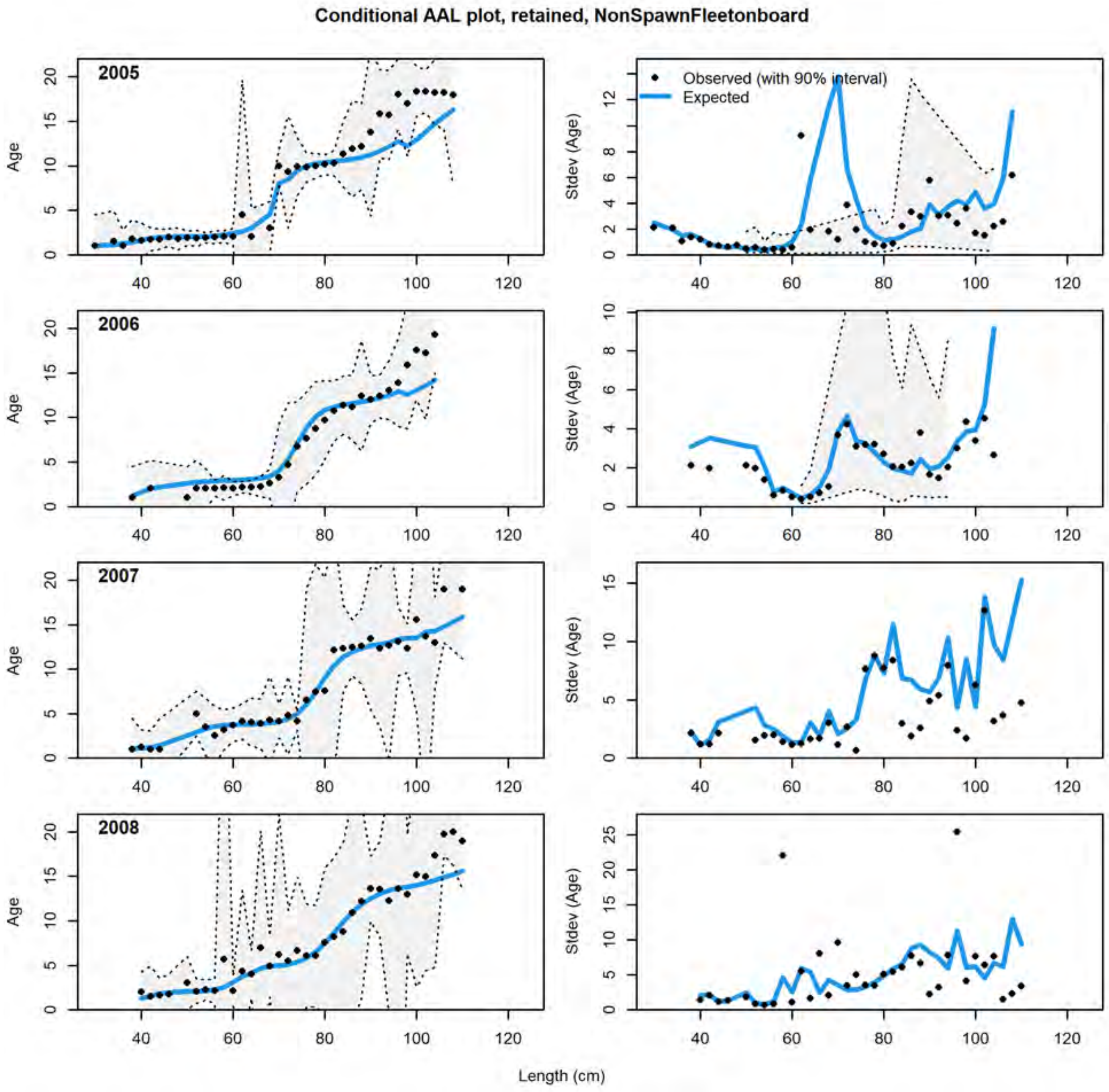
Conditional AAL plot, retained, NonSpawnFleetonboard
2017
2018
2019
2020
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)



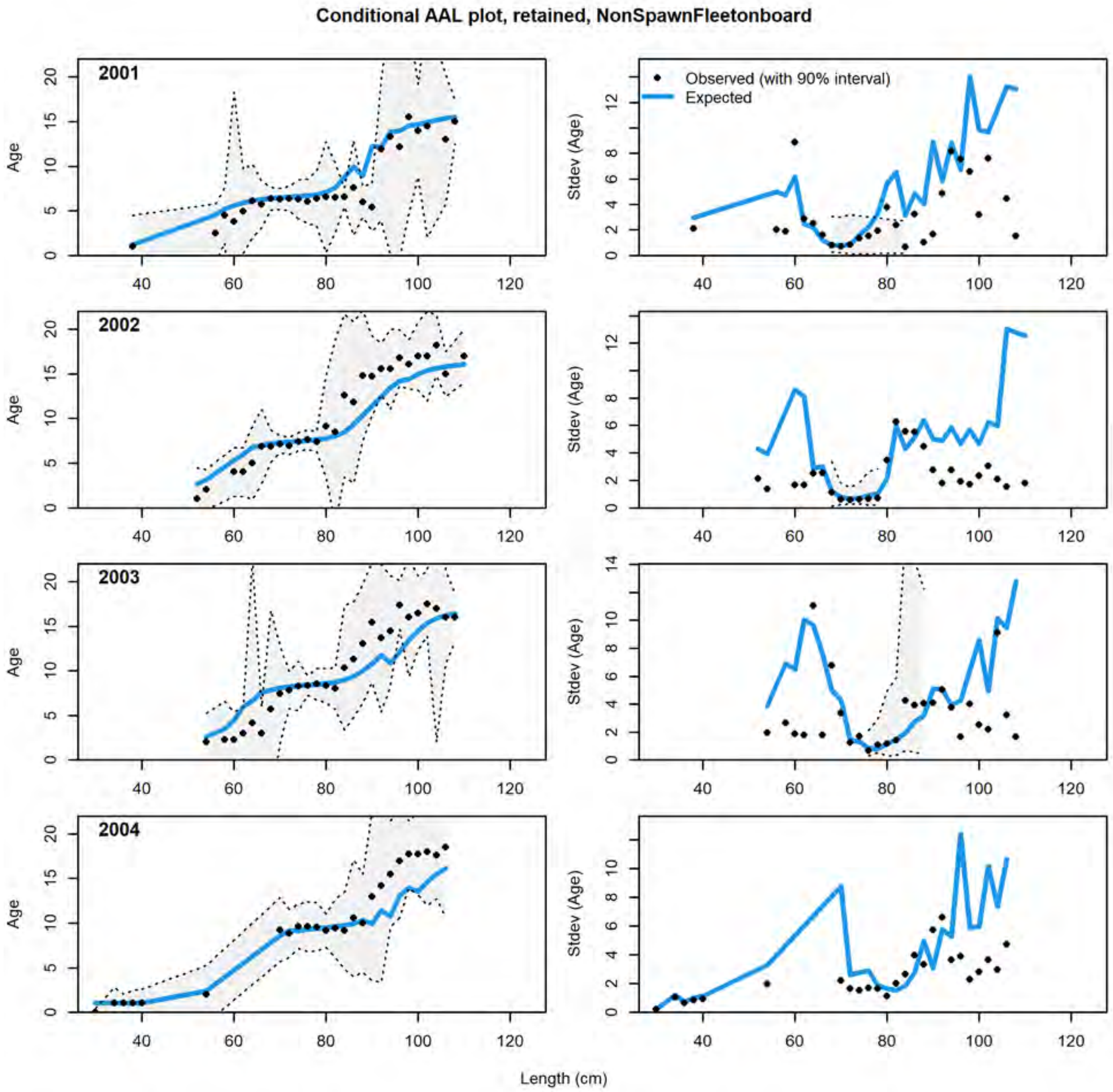
Conditional AAL plot, retained, NonSpawnFleetonboard
2013
2014
2015
2016
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)



Conditional AAL plot, retained, NonSpawnFleetonboard
2009
2010
2011
2012
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)



Conditional AAL plot, retained, NonSpawnFleetonboard
2005
2006
2007
2008
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)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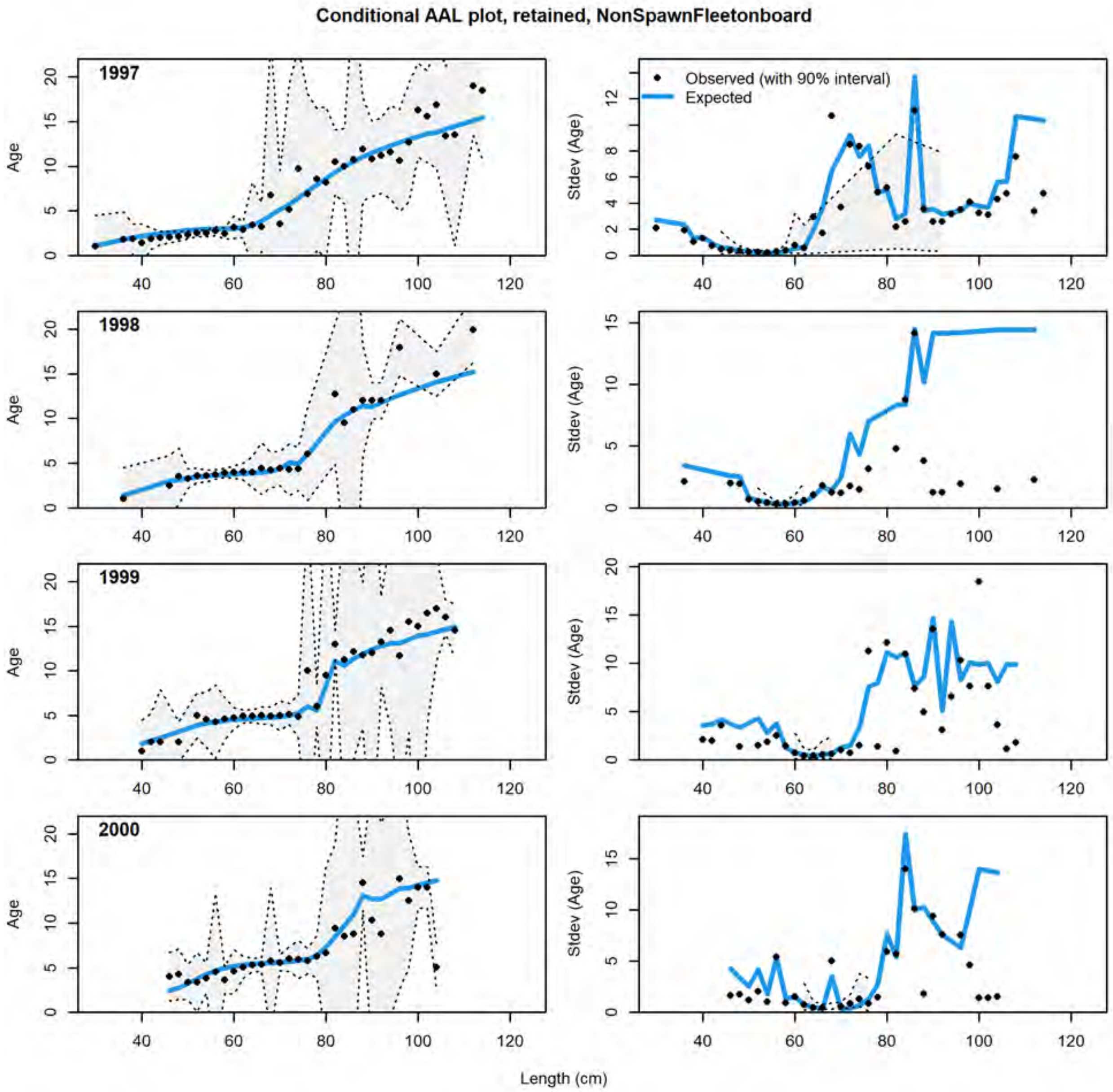
2001
2002
2003
2004
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)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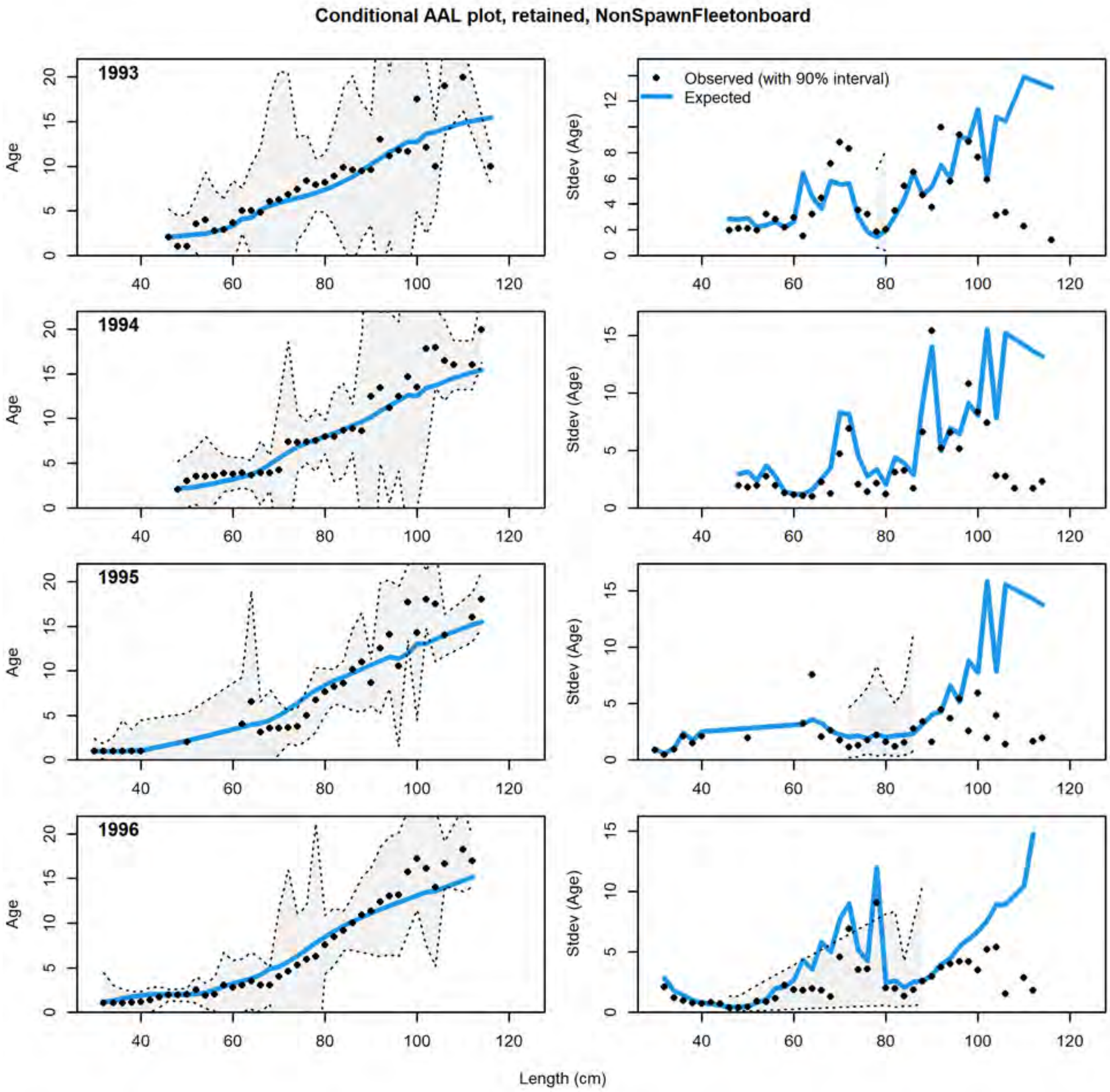
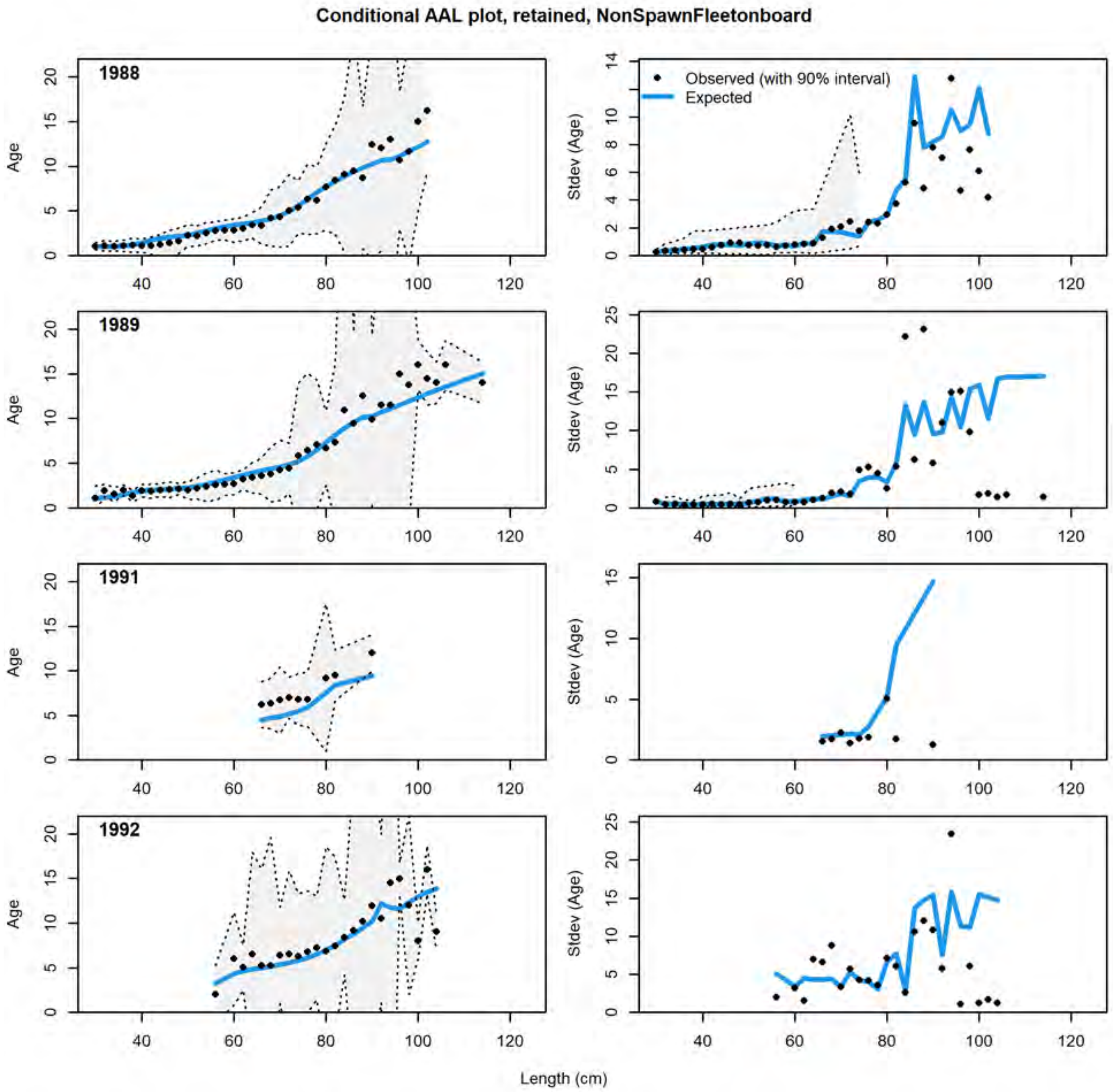
1997
1998
1999
2000
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)


Conditional AAL plot, retained, NonSpawnFleetonboard
1993
1994
1995
1996
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)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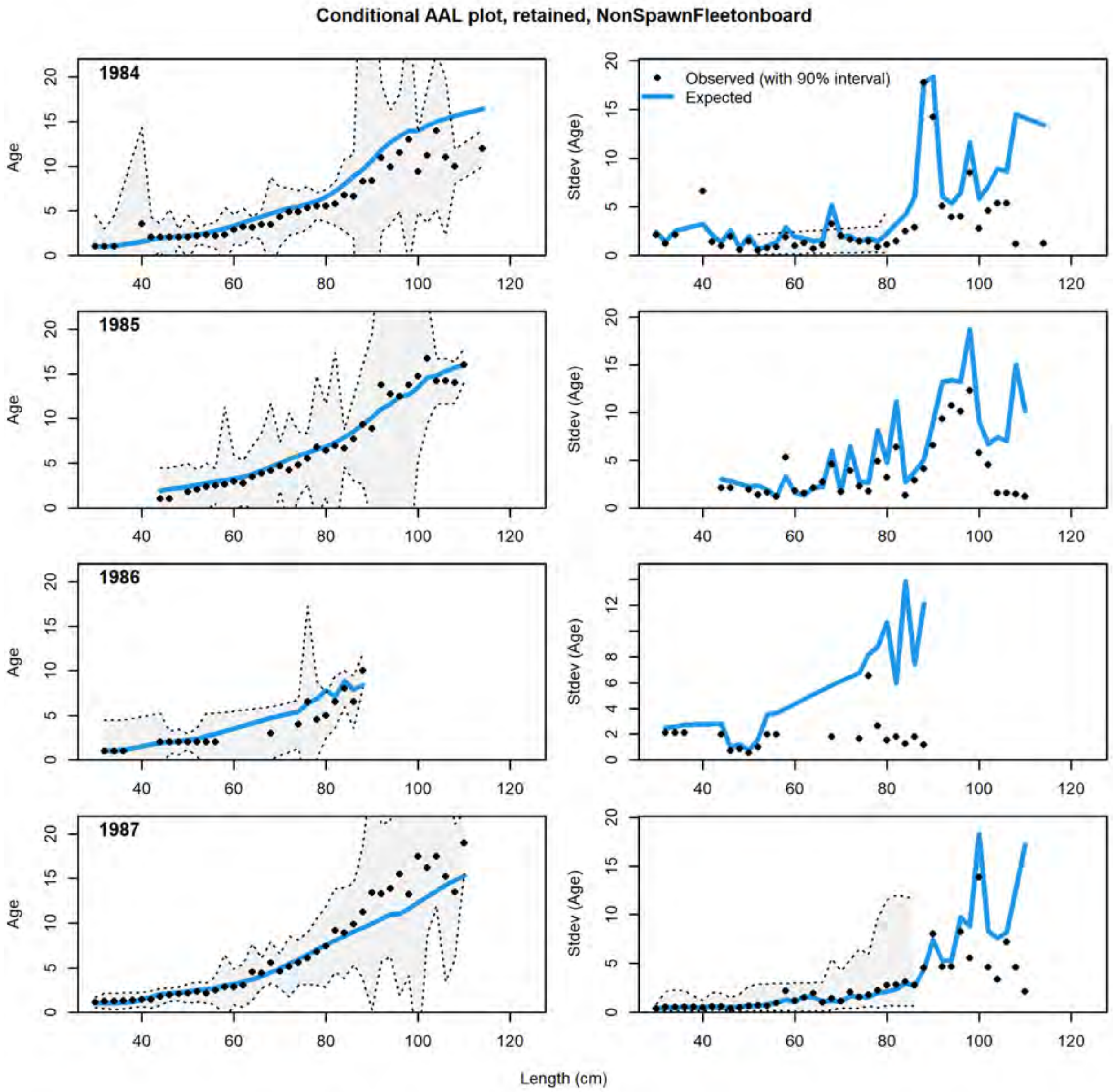
1988
1989
1991
1992
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)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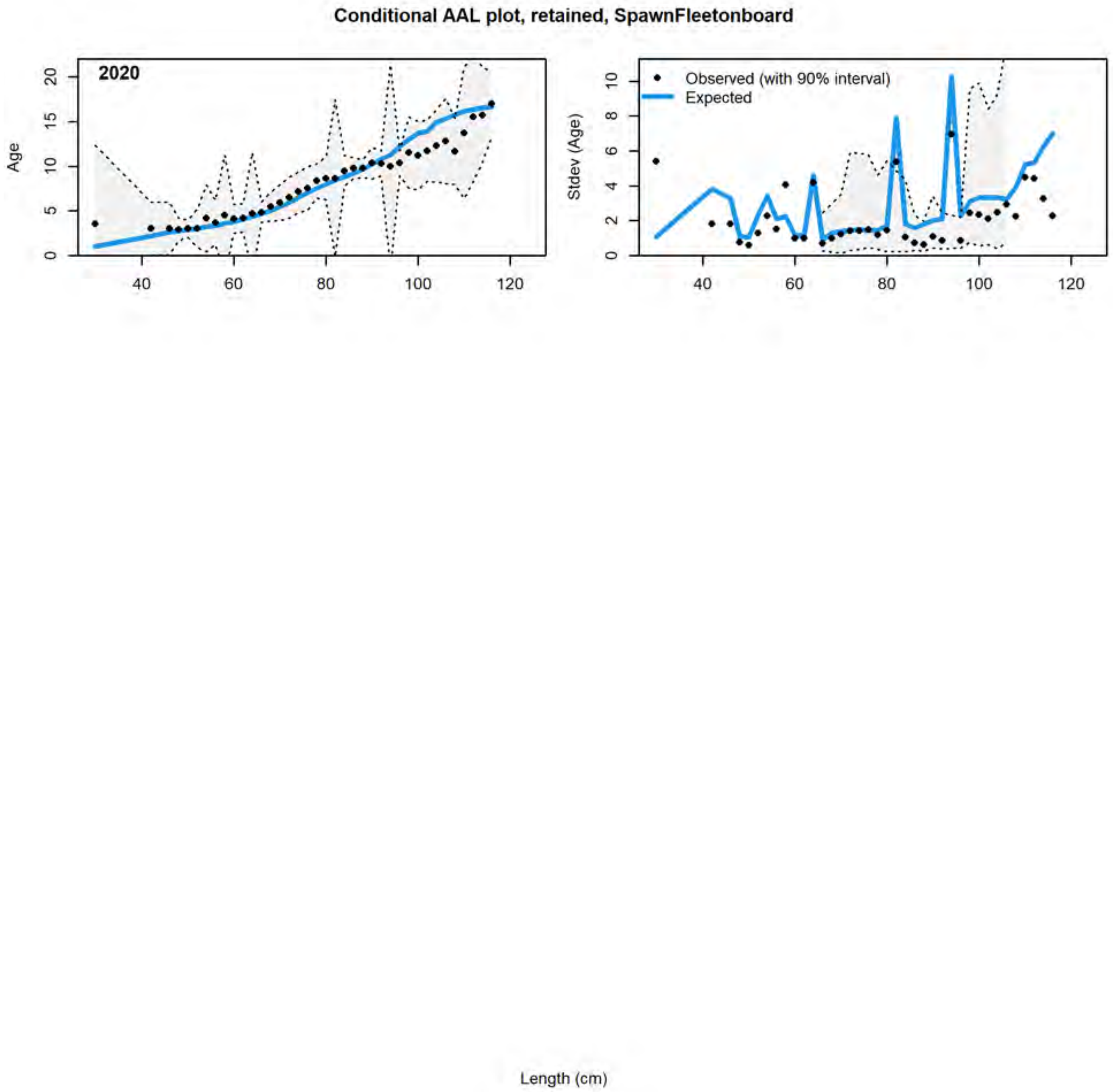
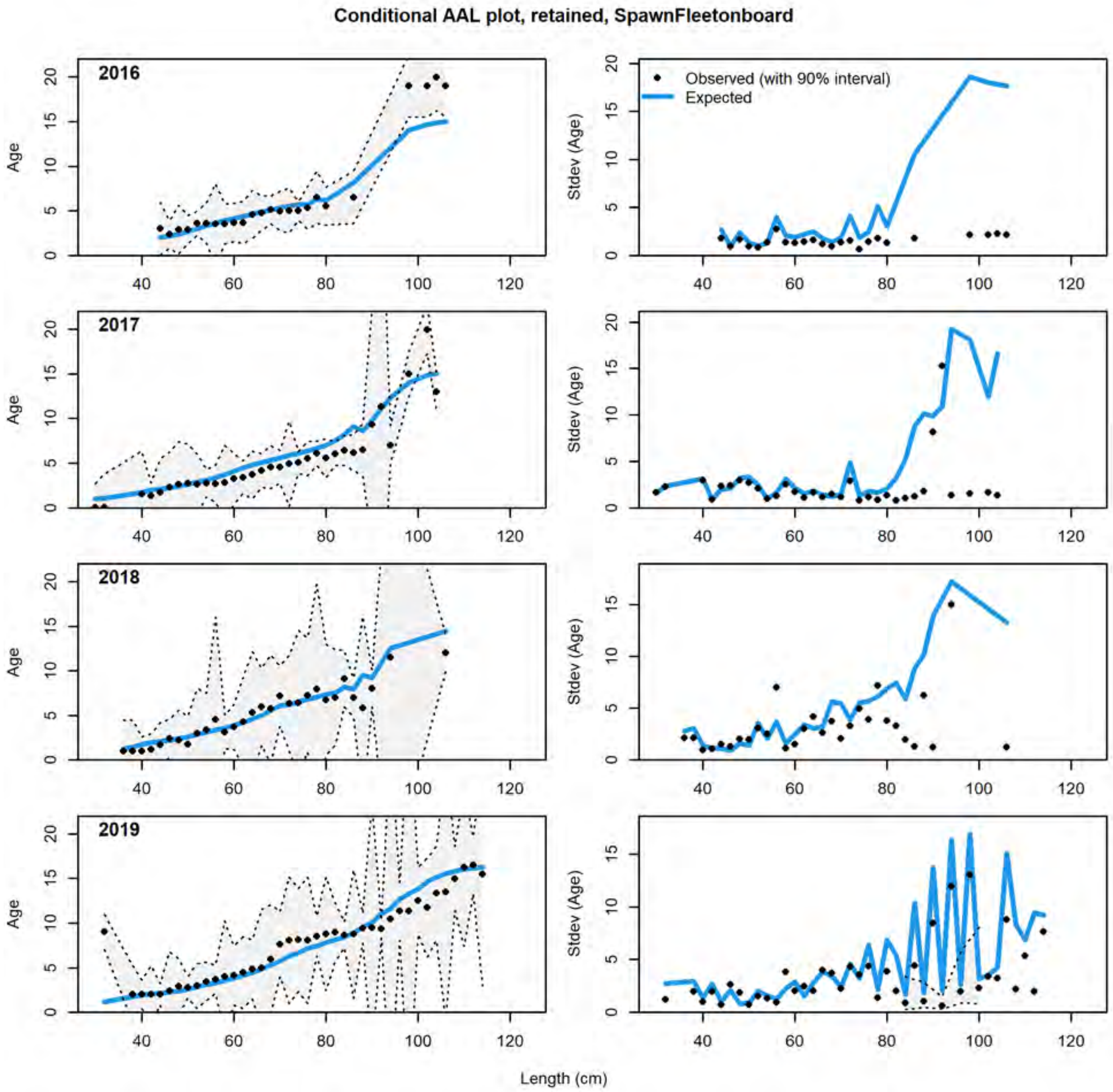
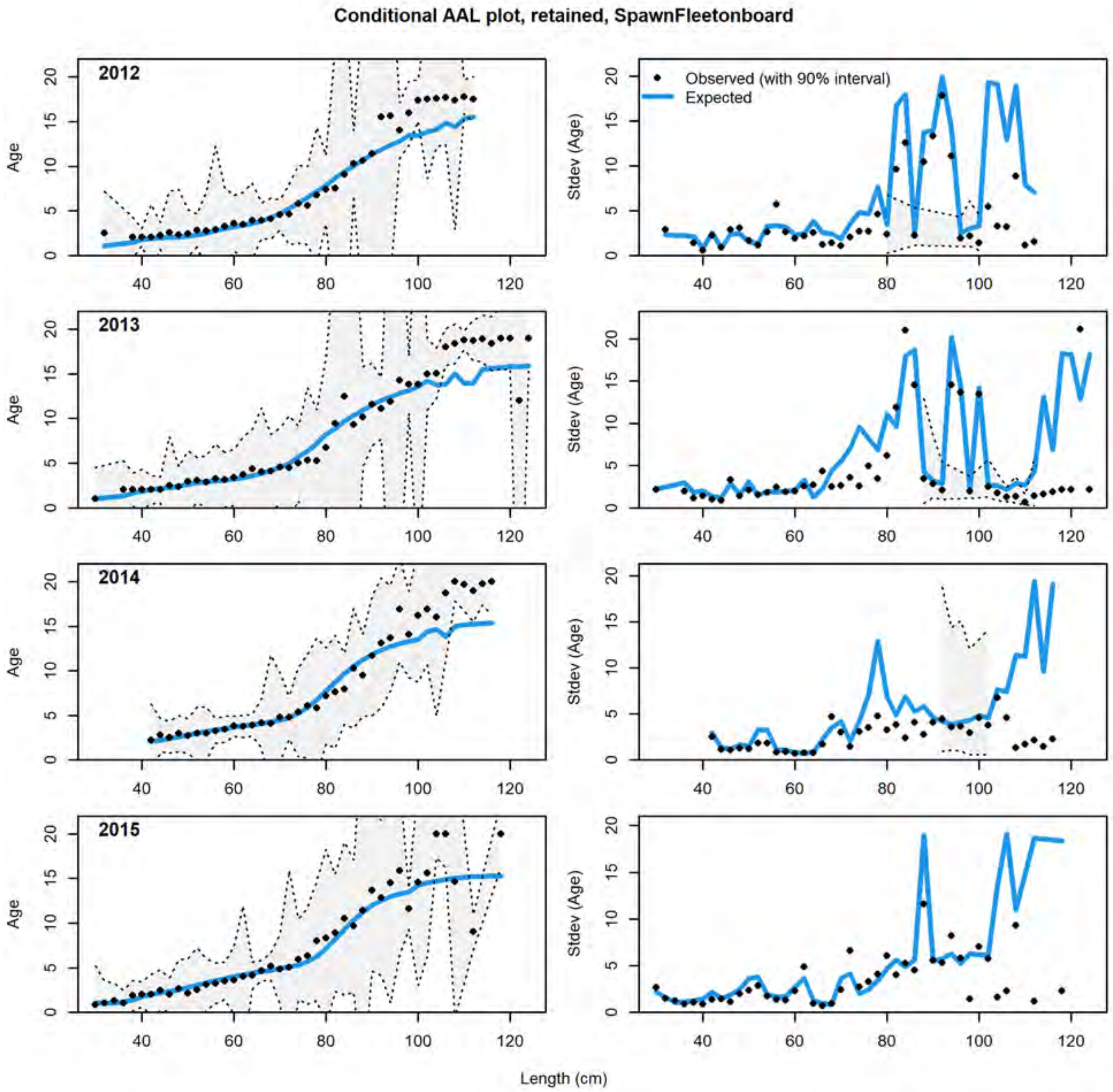
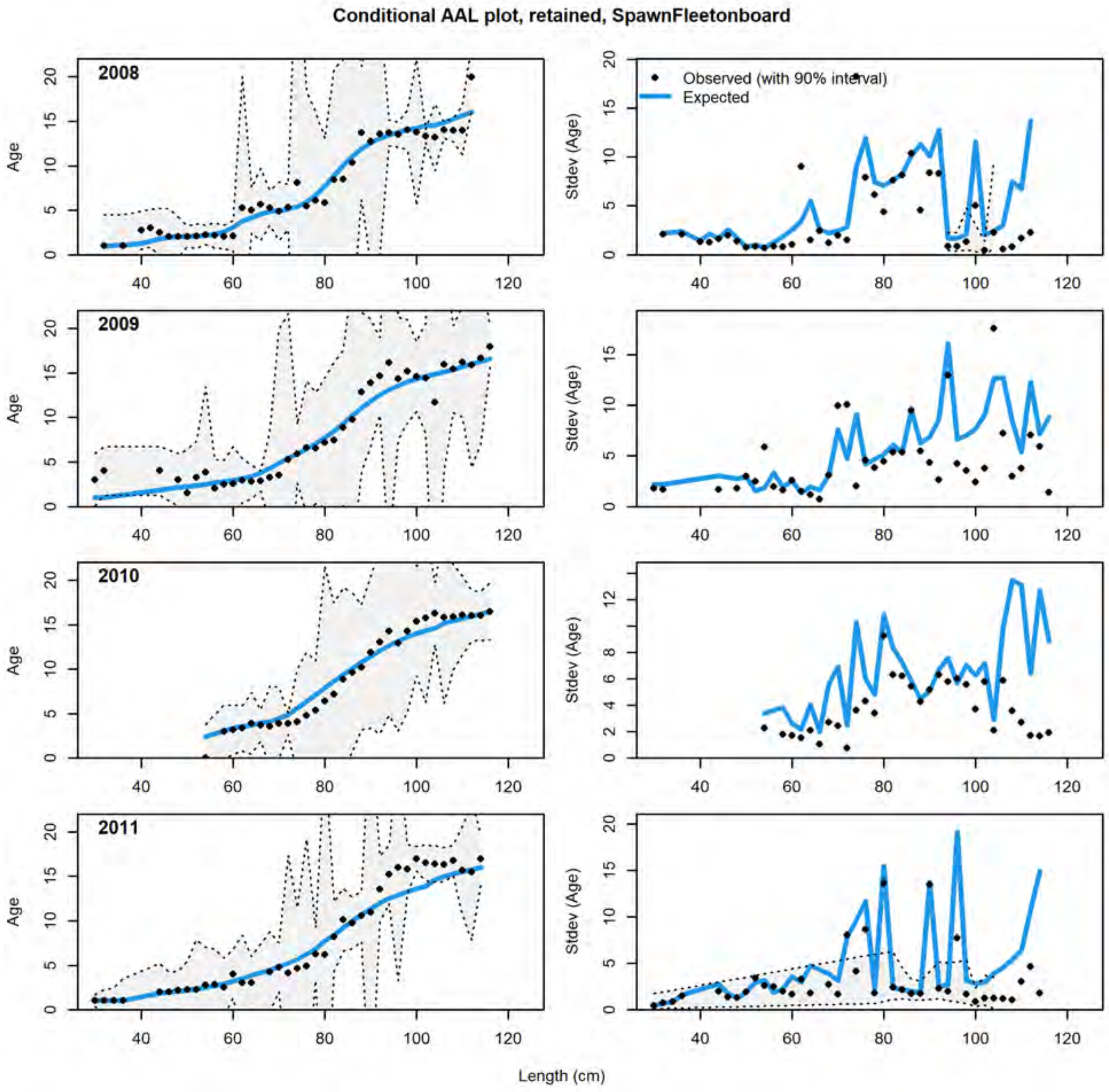
1984
1985
1986
1987
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)

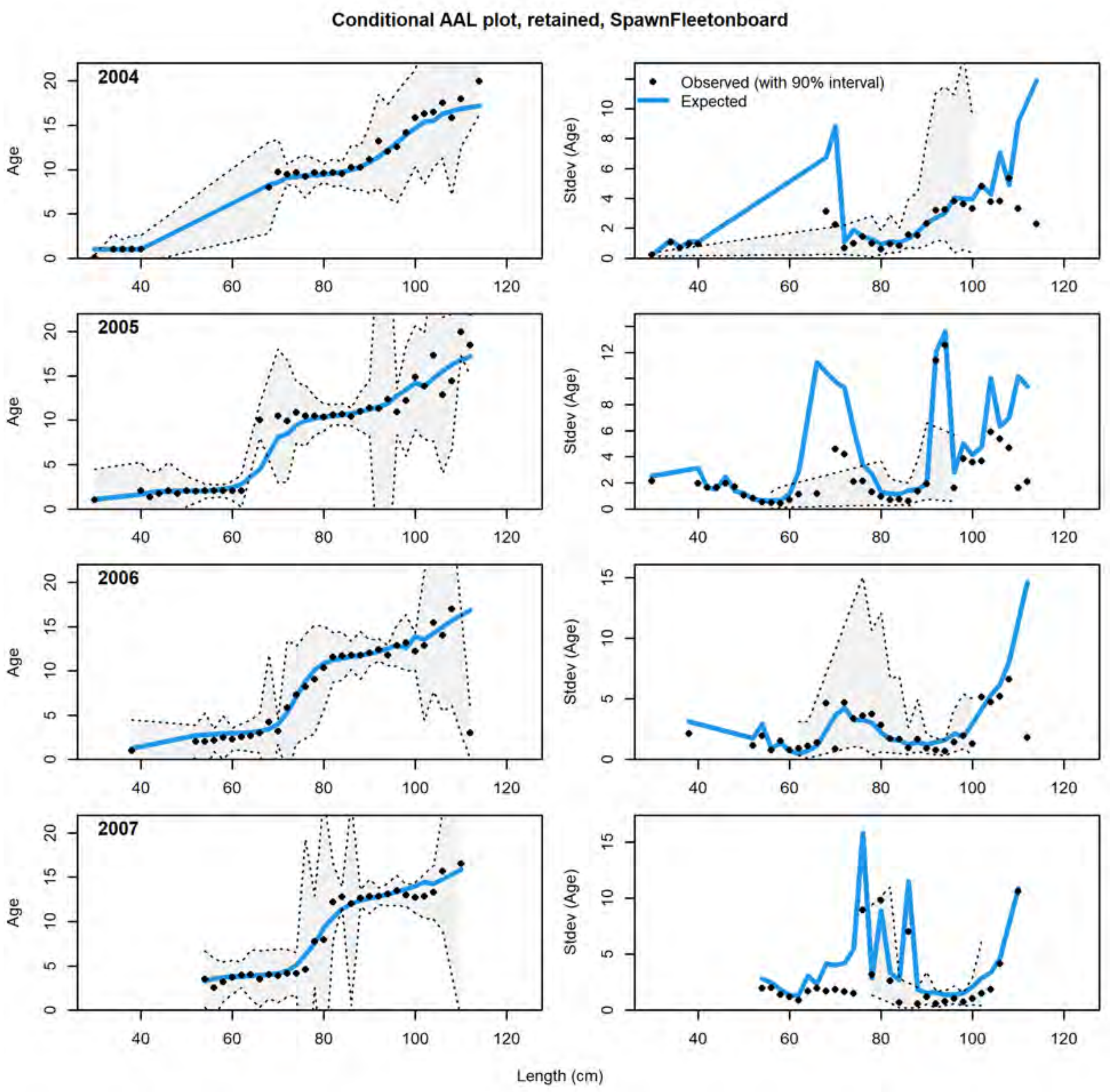

Conditional AAL plot, retained, SpawnFleetonboard
2020
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)

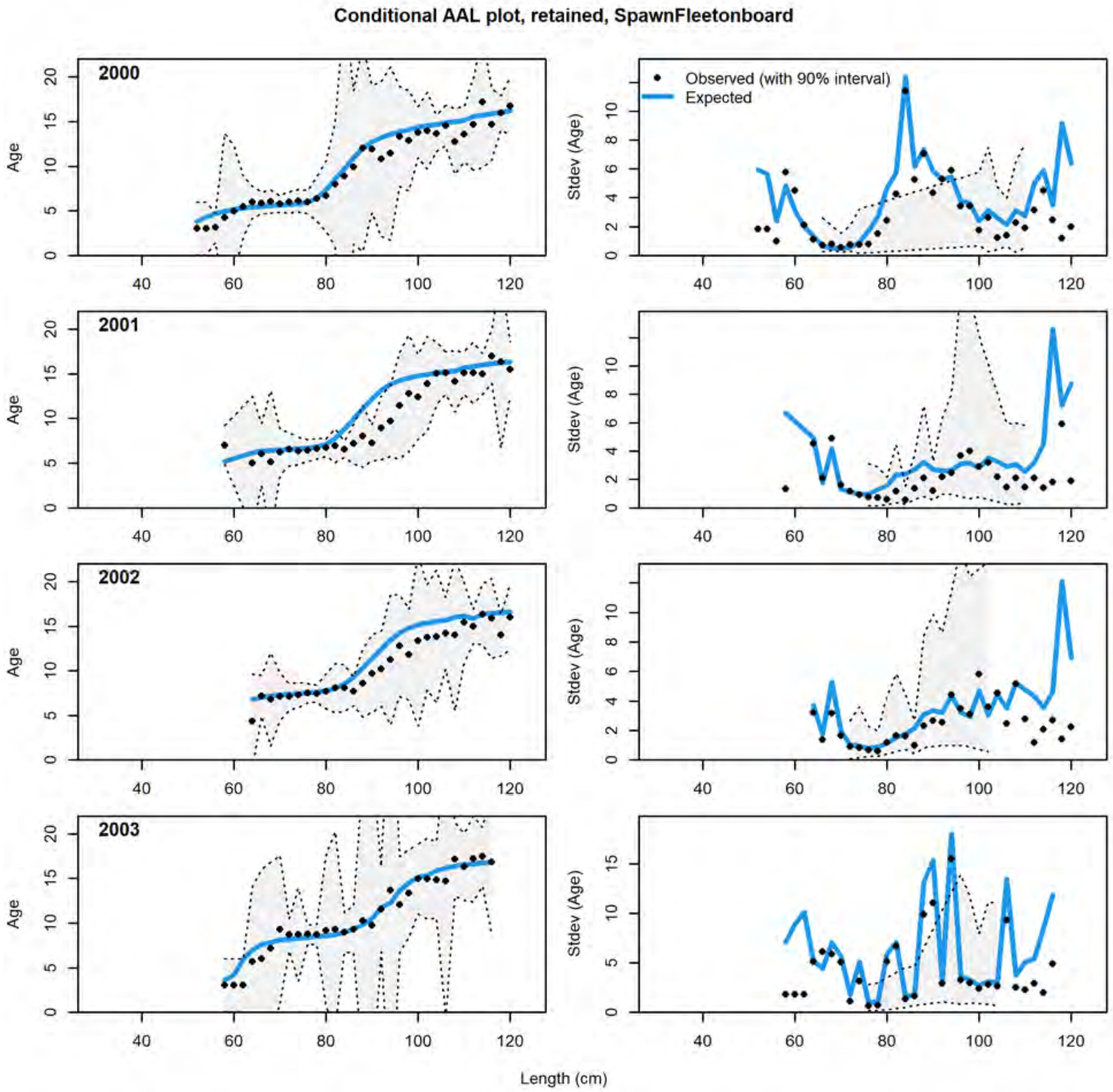

Conditional AAL plot, retained, SpawnFleetonboard
2016
2017
2018
2019
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)
0
5
10
15
20
40
60
80
100
120

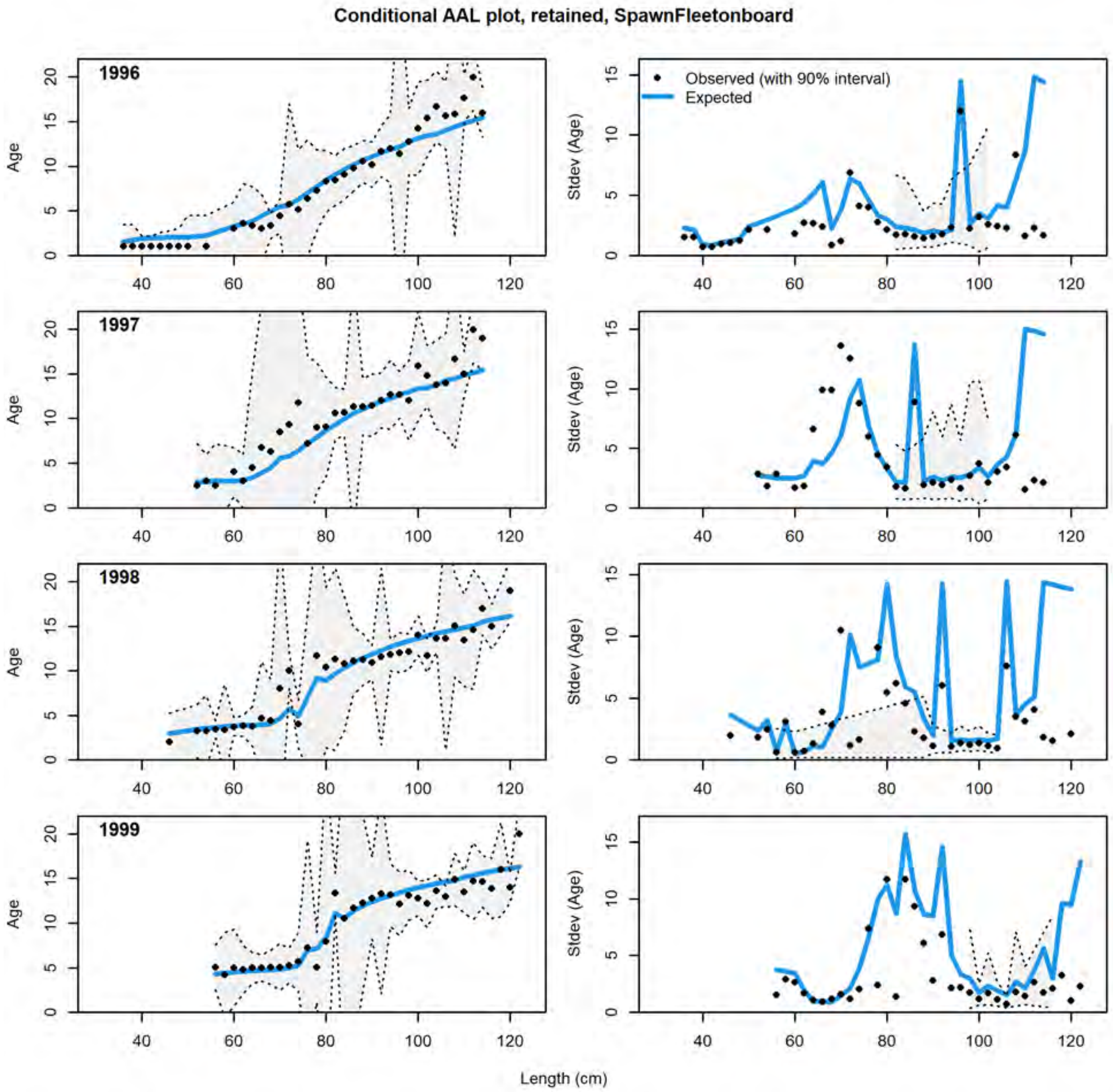

Conditional AAL plot, retained, SpawnFleetonboard
2012
2013
2014
2015
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)



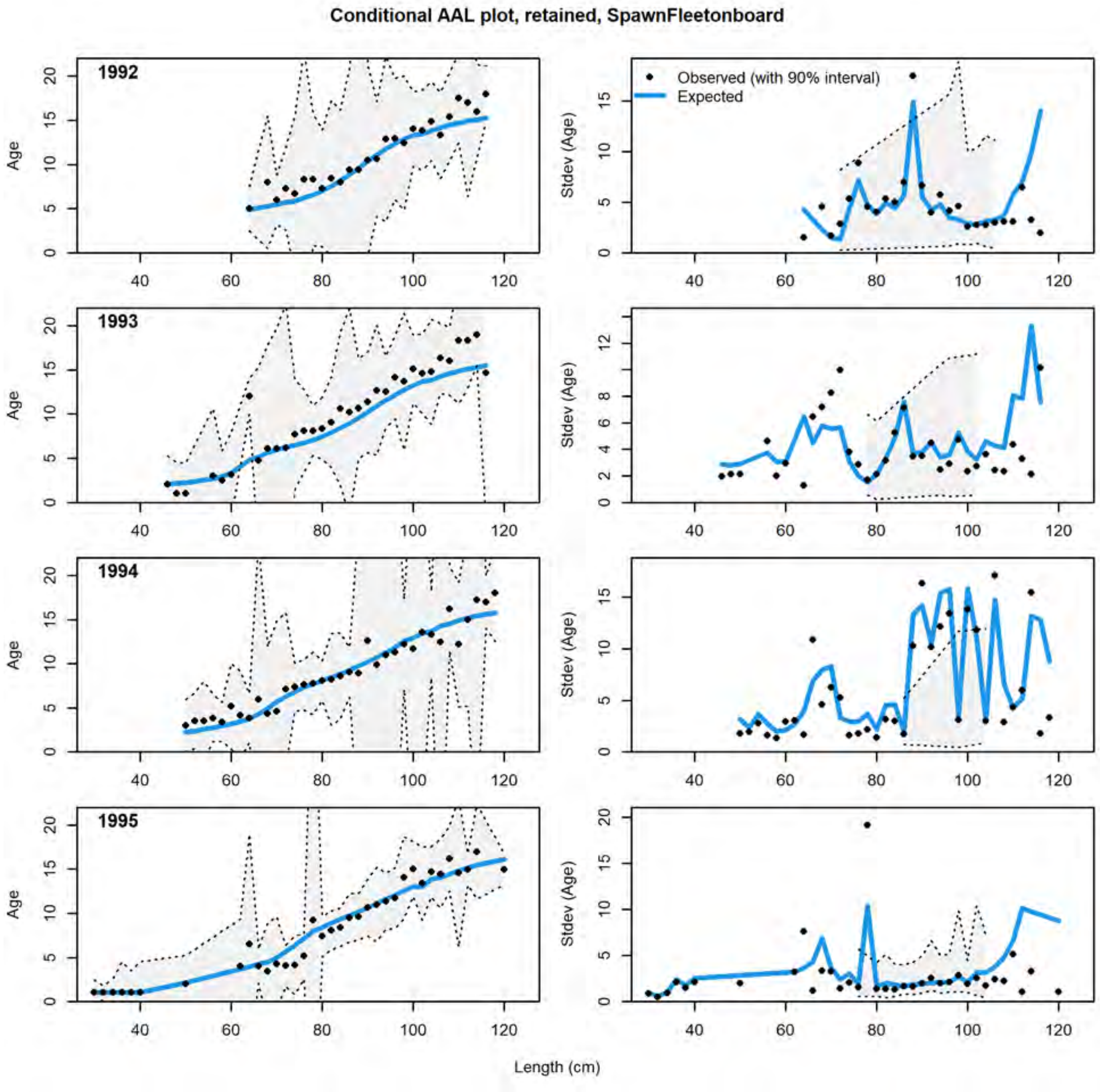
Conditional AAL plot, retained, SpawnFleetonboard
2008
2009
2010
2011
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)


Conditional AAL plot, retained, SpawnFleetonboard
2004
2005
2006
2007
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)


Conditional AAL plot, retained, SpawnFleetonboard
2000
2001
2002
2003
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)



Conditional AAL plot, retained, SpawnFleetonboard
1996
1997
1998
1999
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)


Conditional AAL plot, retained, SpawnFleetonboard
1992
1993
1994
1995
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)

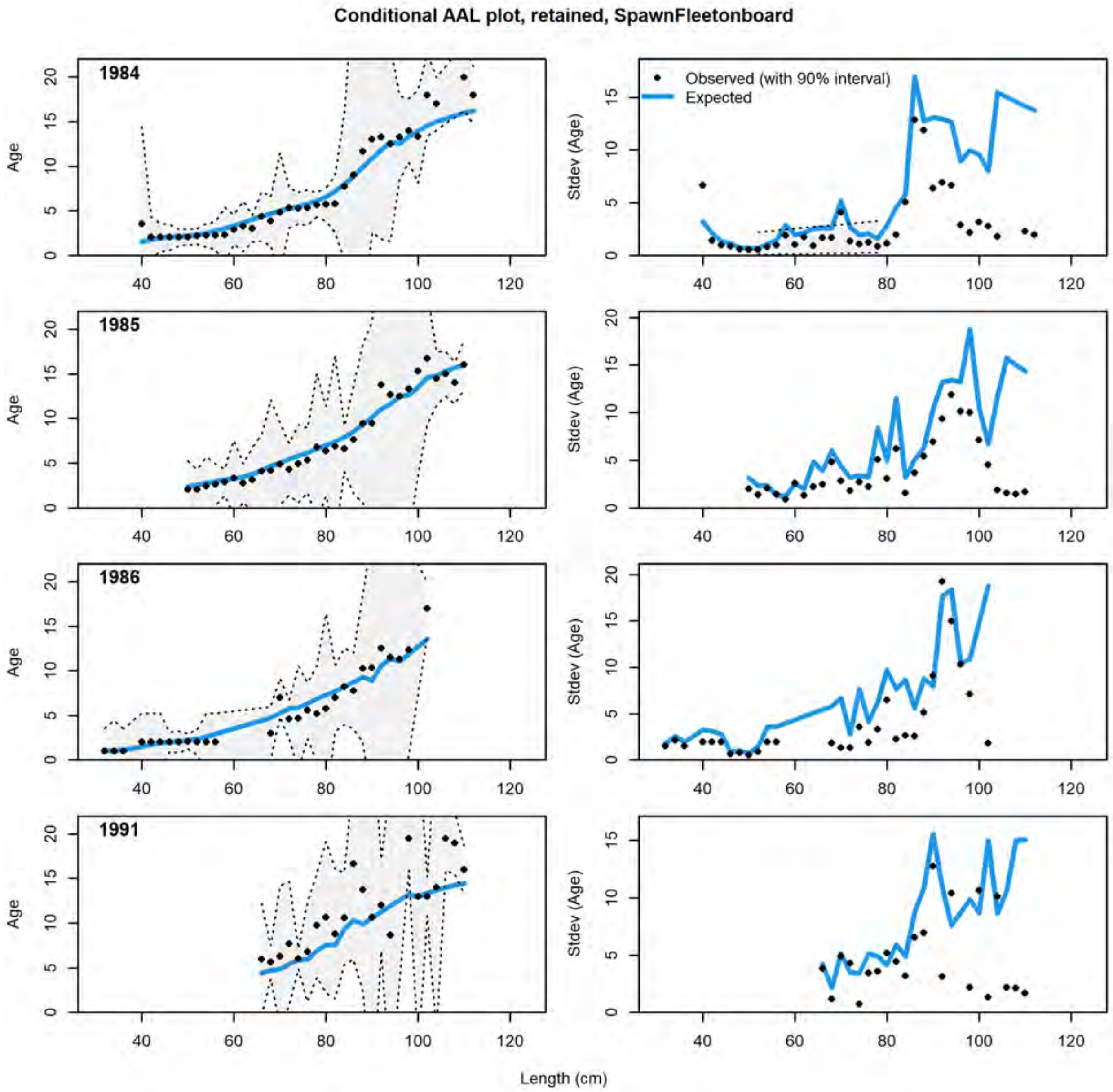
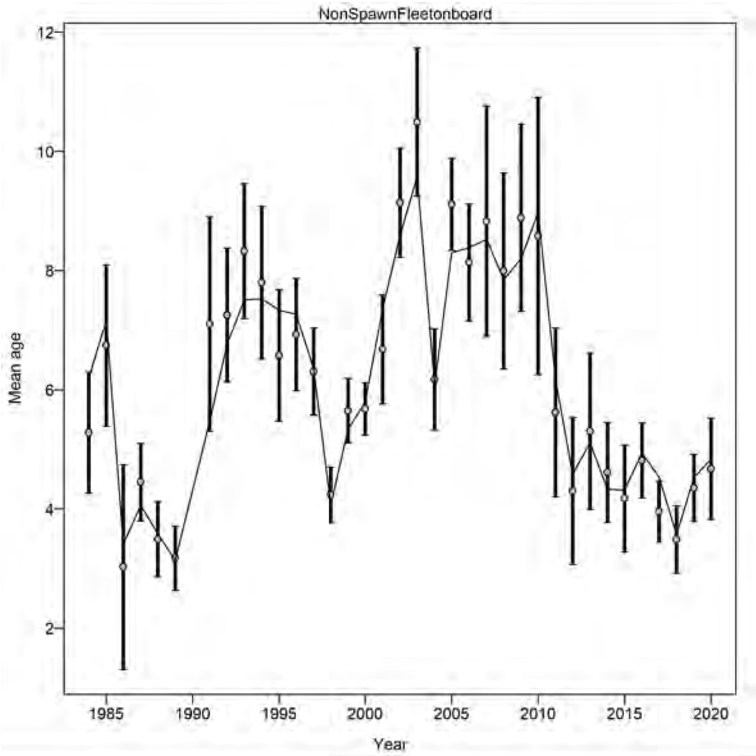


Figure 5.29. Fits to conditional age at length data.



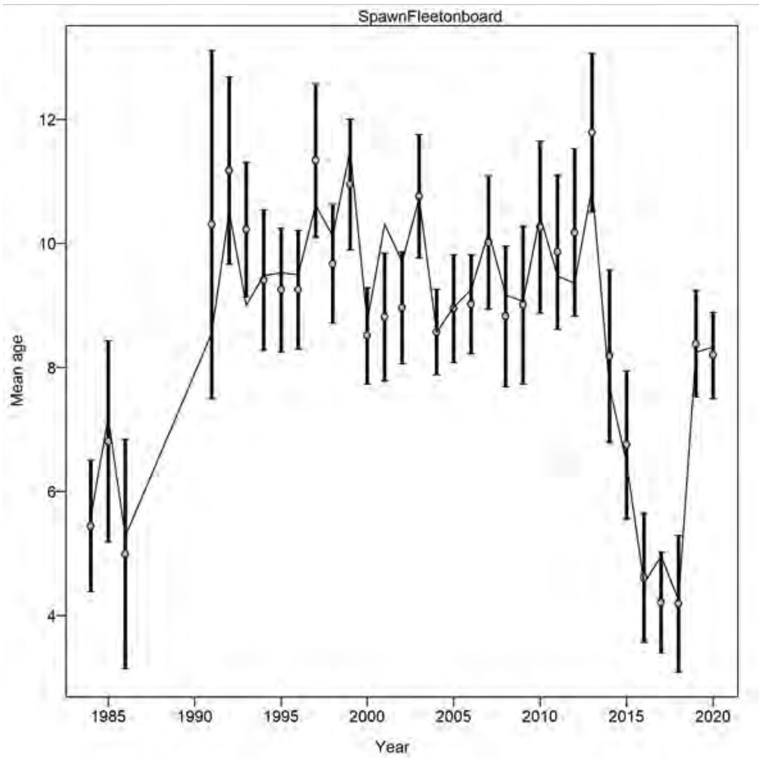
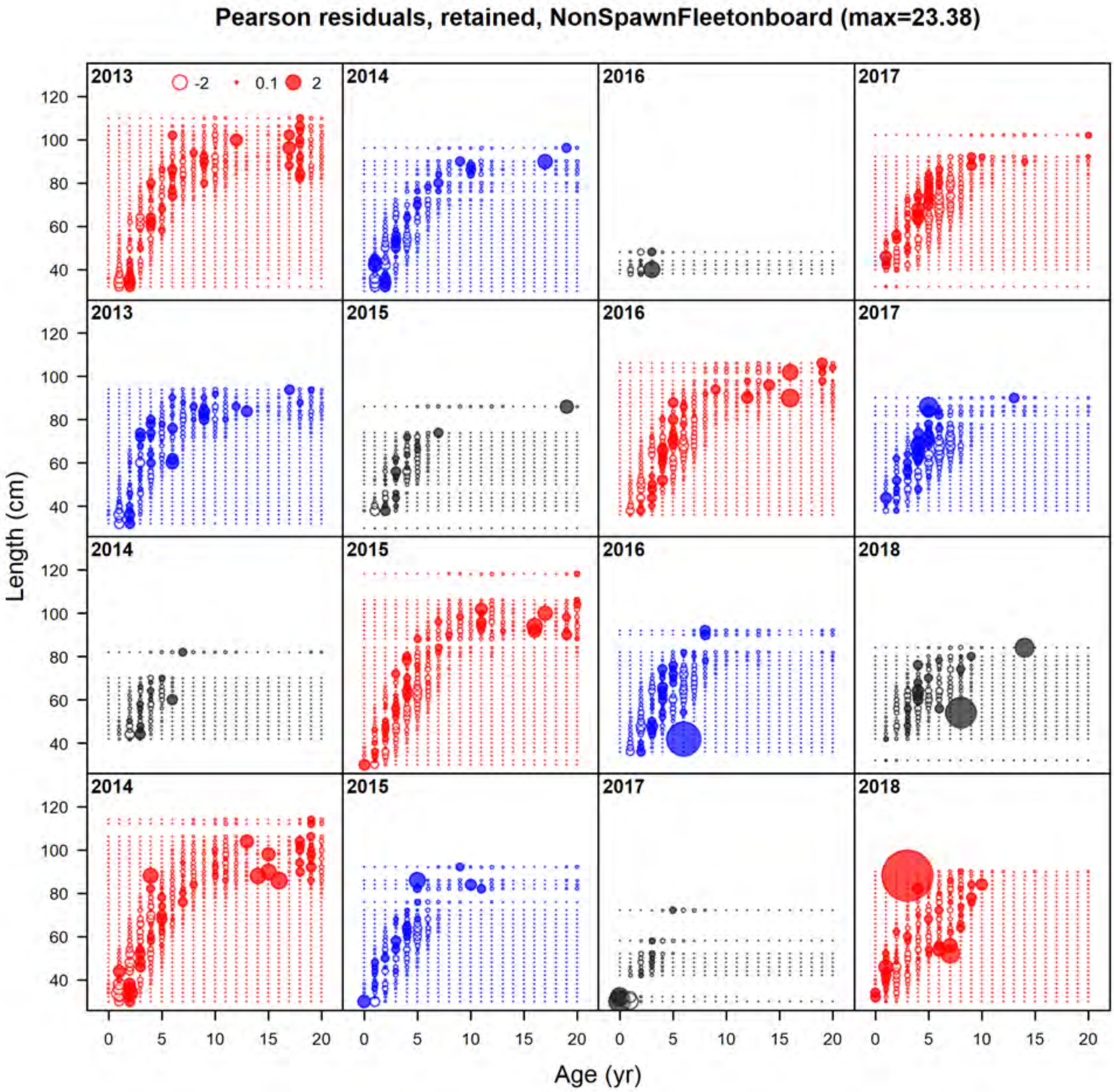
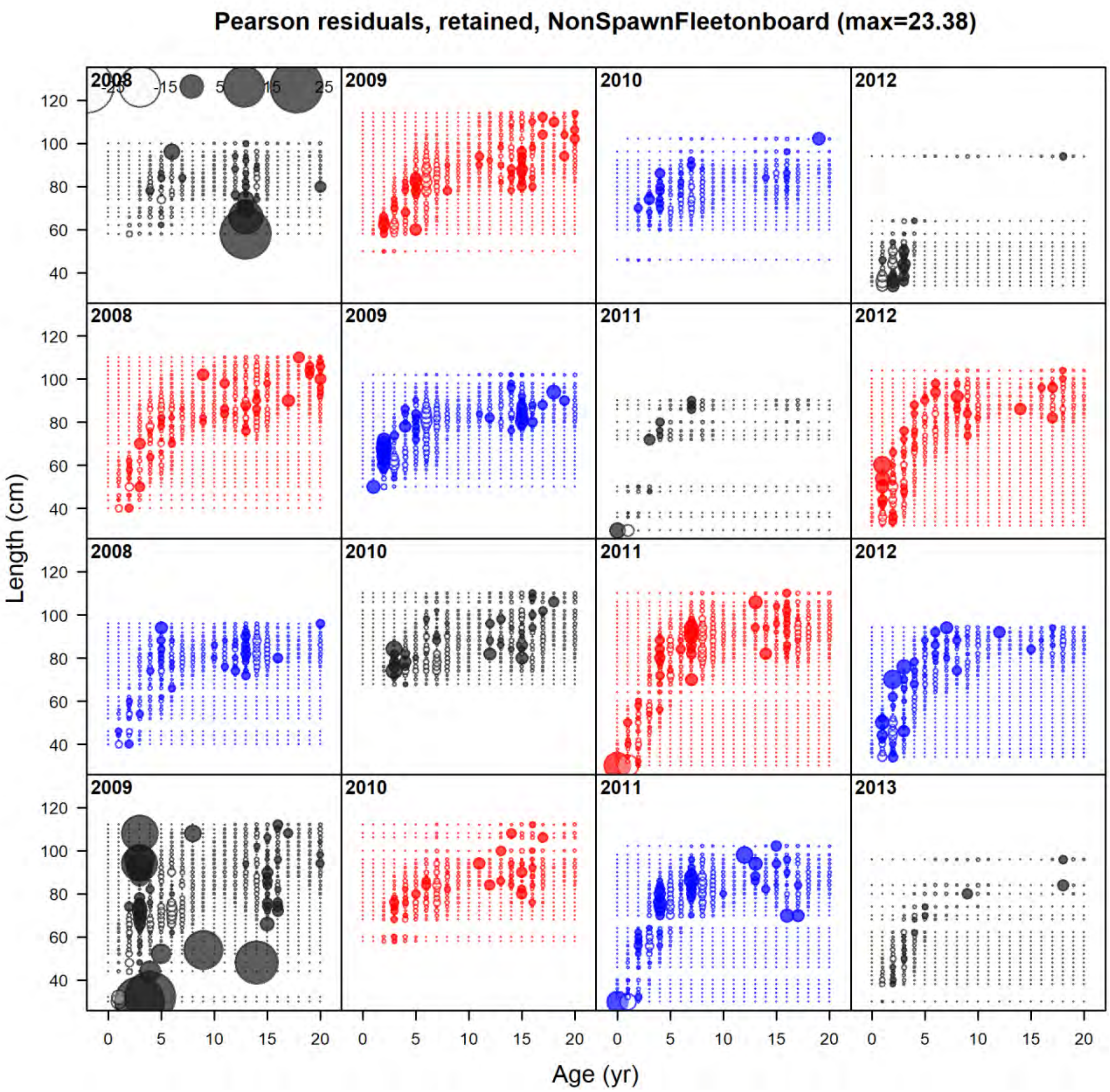
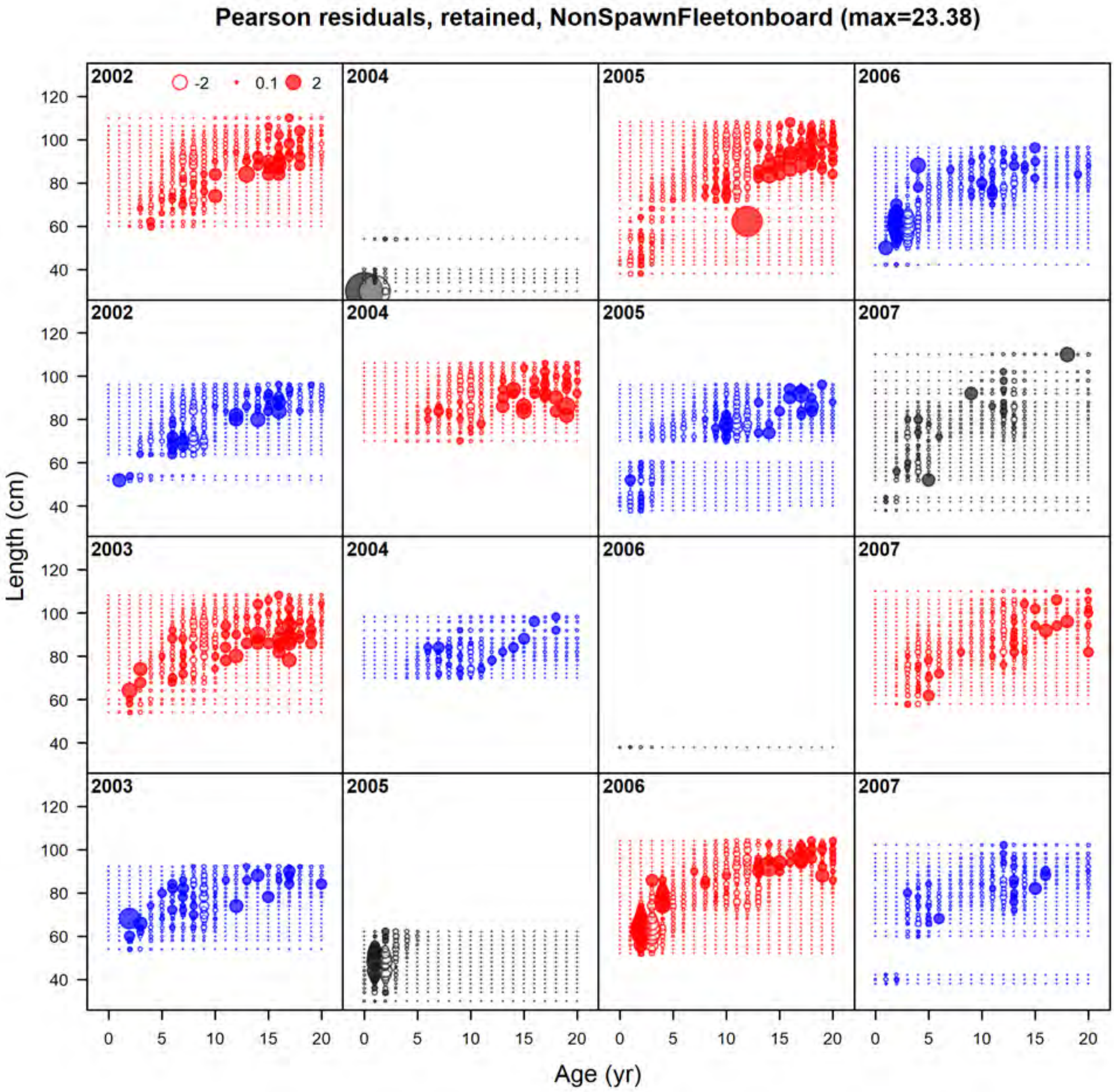
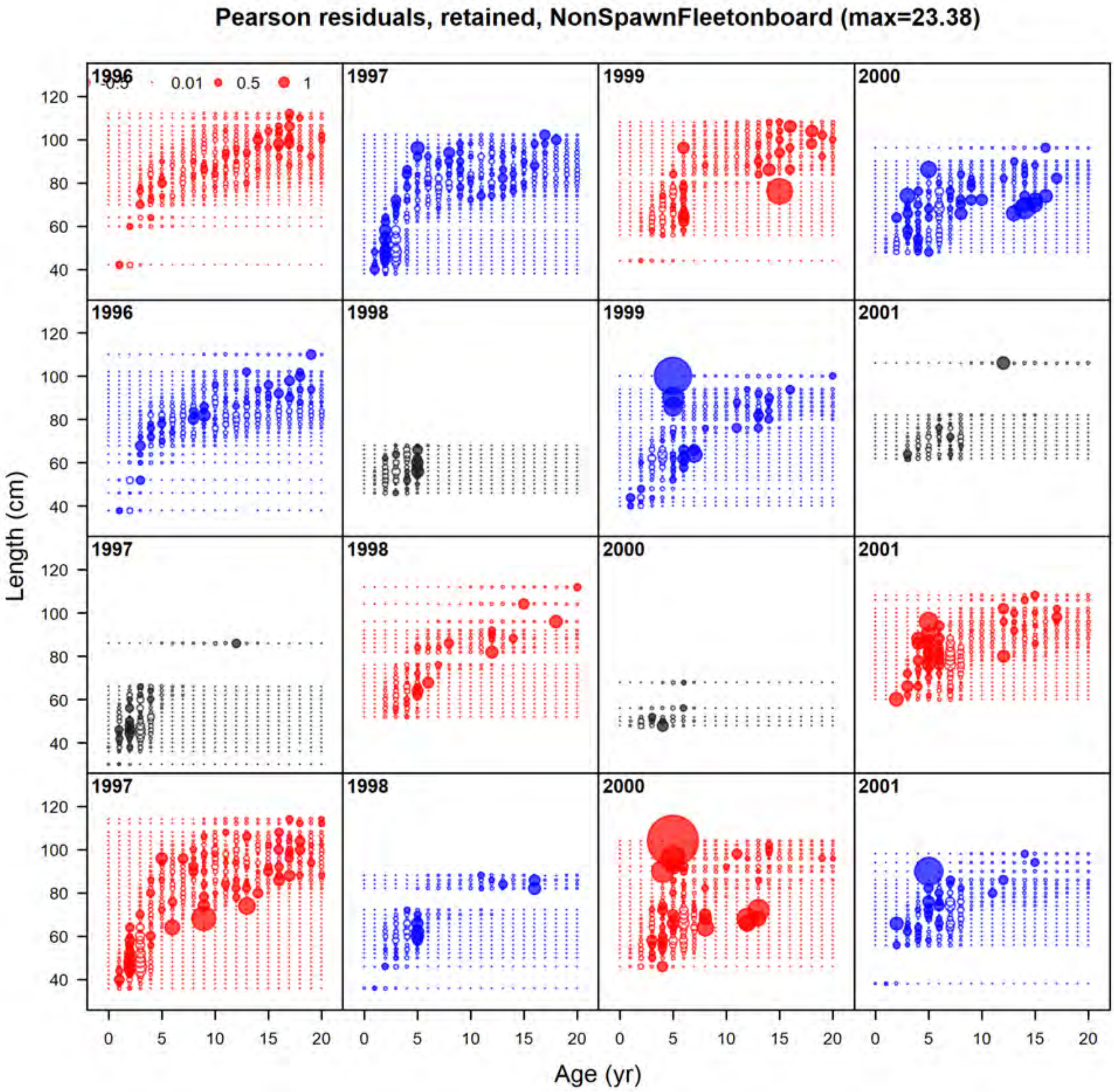


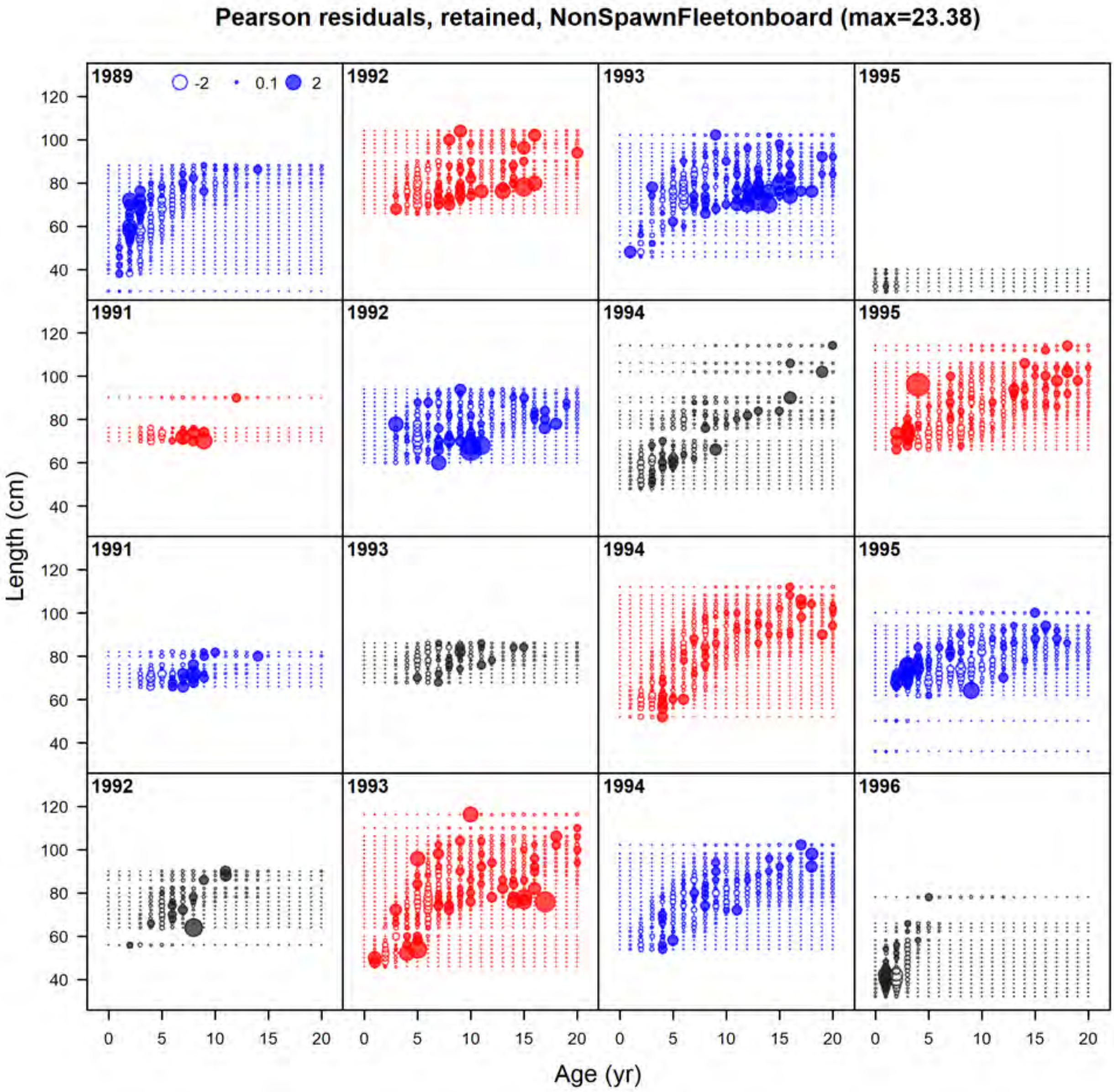
Figure 5.30. Data weighting of conditional age at length data for the onboard non spawning and spawning fleets.


Pearson residuals, retained, NonSpawnFleetonboard (max=23.38)
2013
-2
0.1
2
2014
2016
2017
2013
2015
2016
2017
2014
2015
2016
2018
2014
2015
2017
2018
Length (cm)
Age (yr)

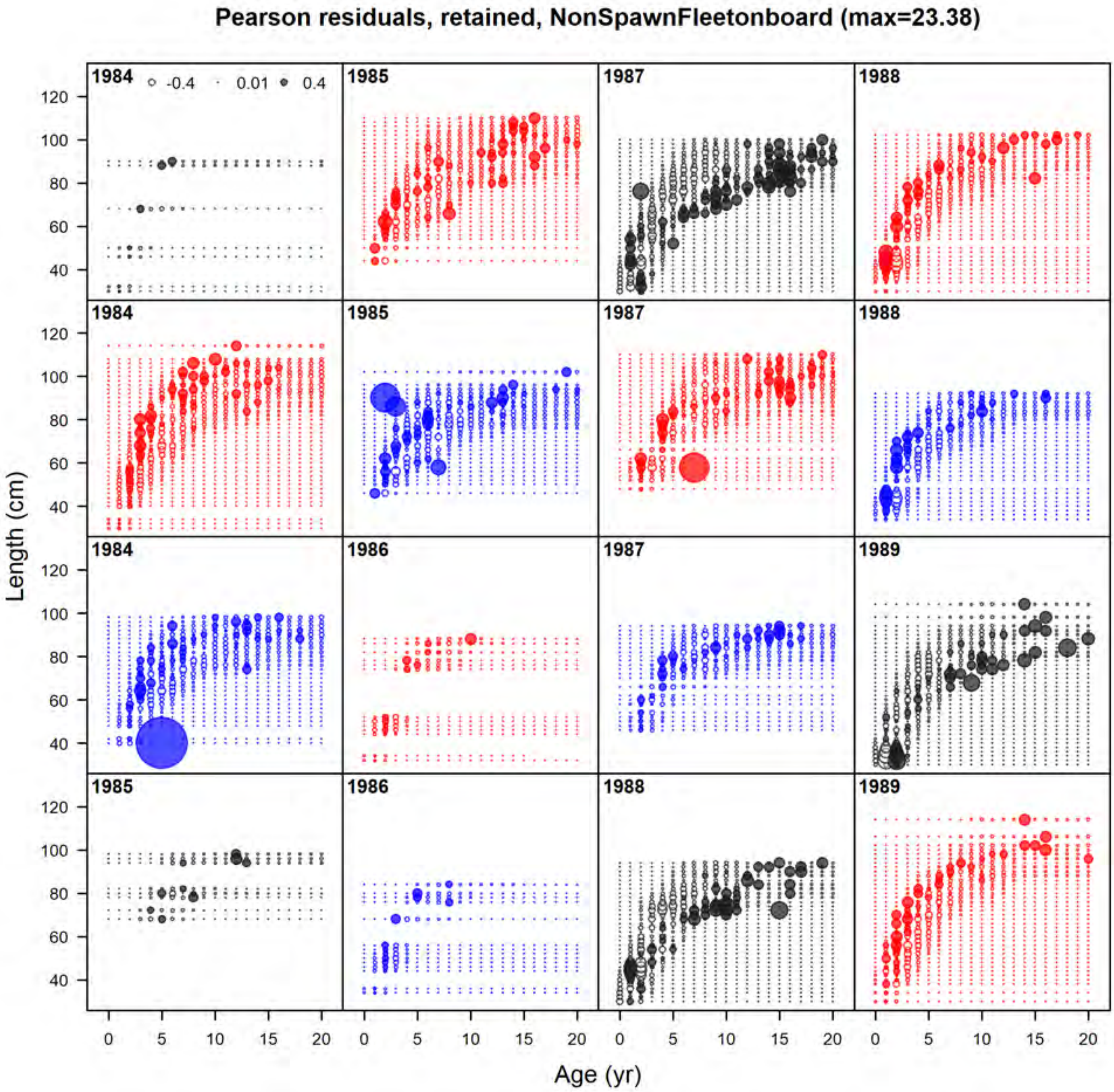

Pearson residuals, retained, NonSpawnFleetonboard (max=23.38)
-25
-15
5
15
25
2008
2009
2010
2012
2008
2009
2011
2012
2008
2010
2011
2012
2009
2010
2011
2013
Length (cm)
Age (yr)
120
100
80
60
40
0
5
10
15
20

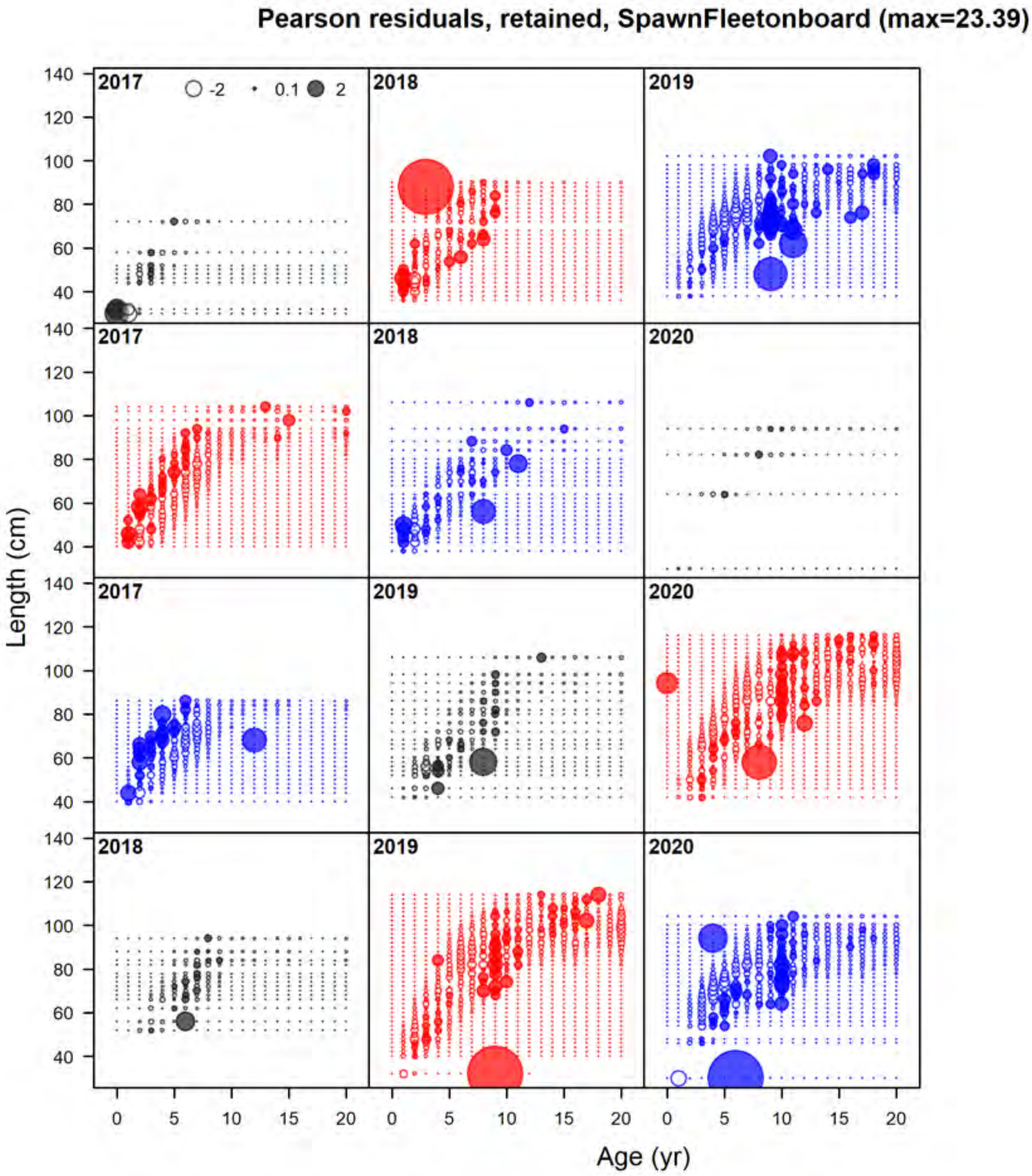

Pearson residuals, retained, NonSpawnFleetonboard (max=23.38)
-2
0.1
2
2002
2004
2005
2006
2002
2004
2005
2007
2003
2004
2006
2007
2003
2005
2006
2007
Length (cm)
Age (yr)

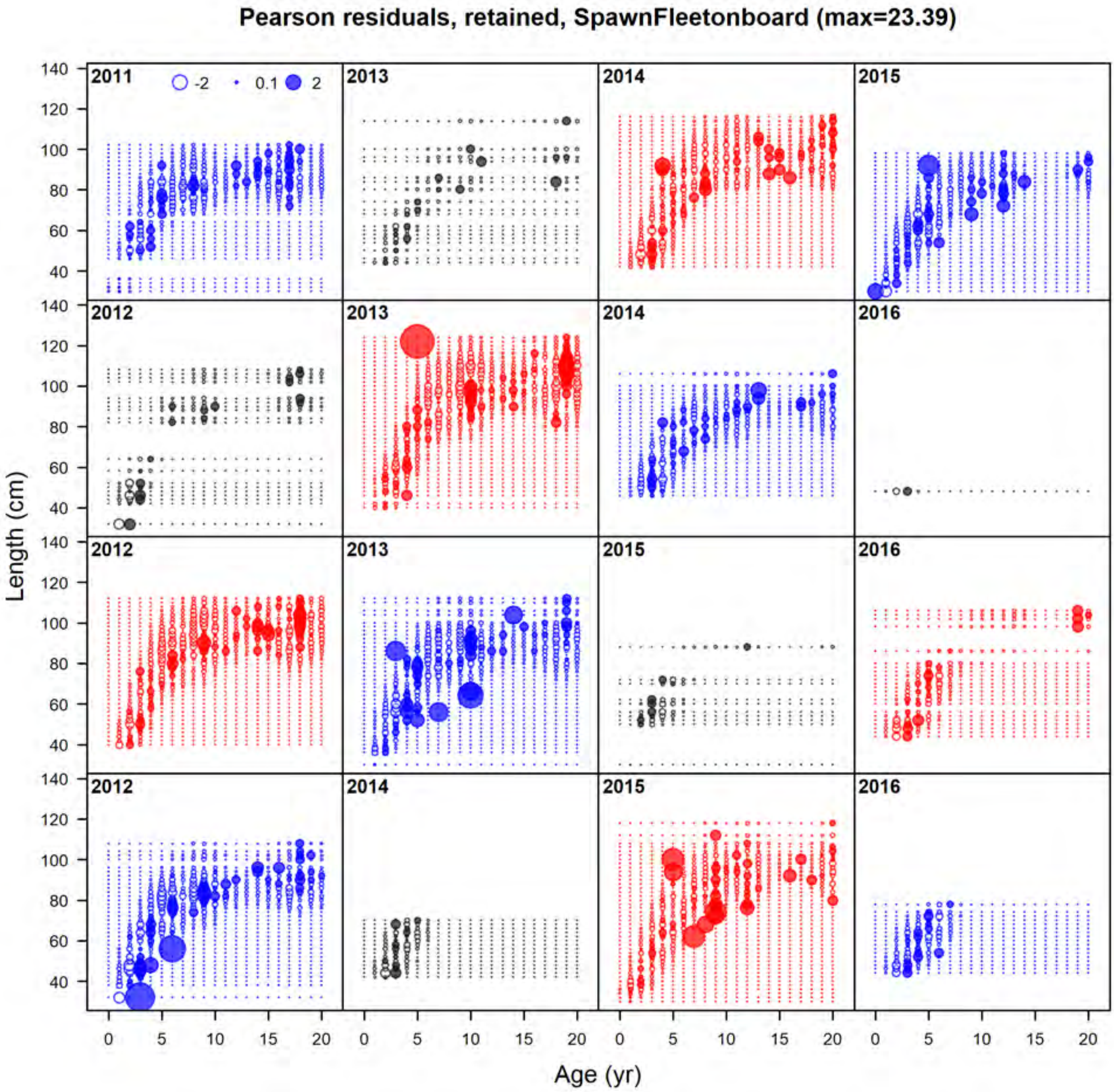

Pearson residuals, retained, NonSpawnFleetonboard (max=23.38)
-0.5
0.01
0.5
1
1996
1997
1999
2000
1996
1998
1999
2001
1997
1998
2000
2001
1997
1998
2000
2001
Length (cm)
Age (yr)



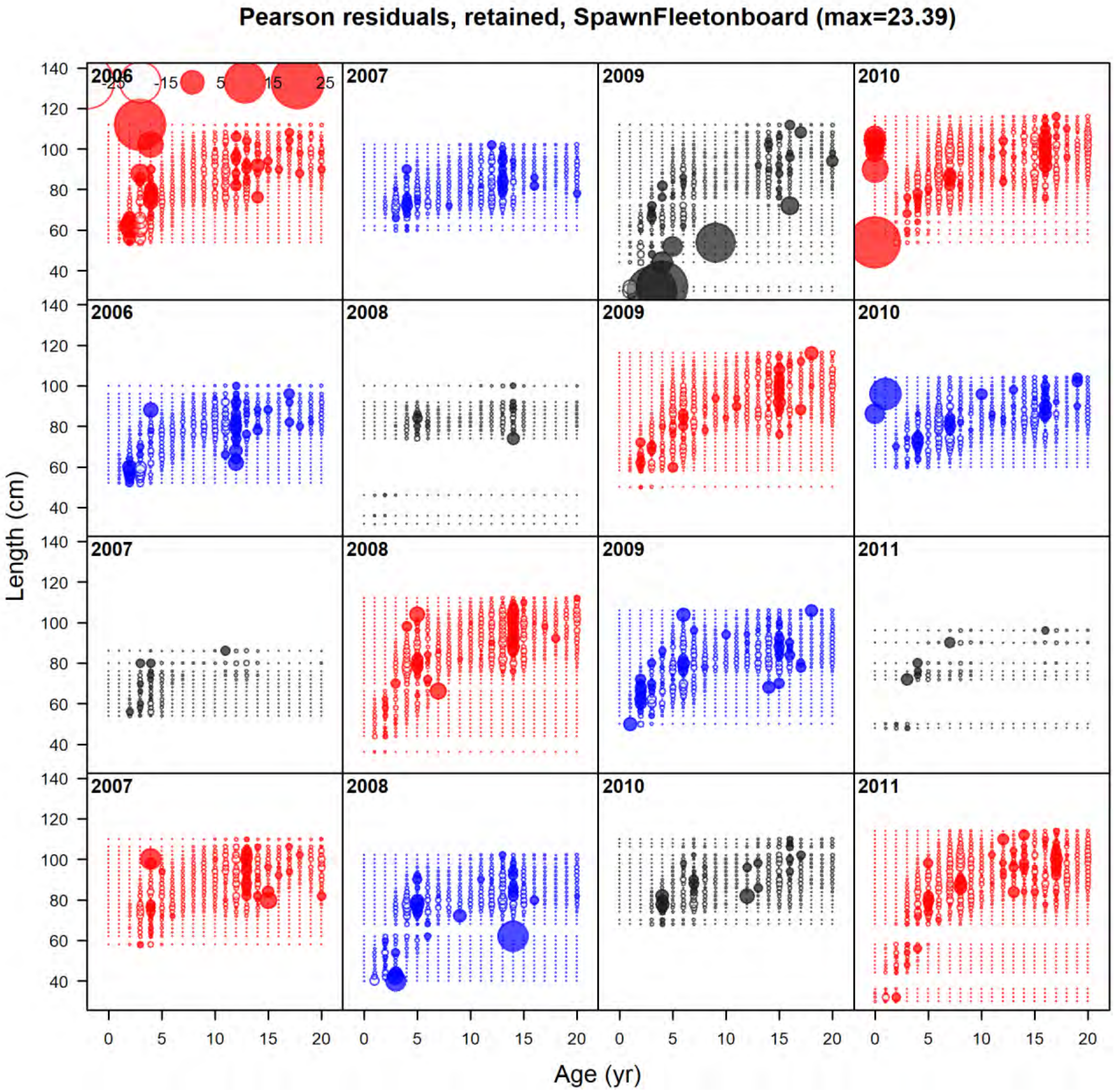
Pearson residuals, retained, NonSpawnFleetonboard (max=23.38)
1989
-2
0.1
2
1992
1993
1995
1991
1992
1994
1995
1991
1993
1994
1995
1992
1993
1994
1996
Length (cm)
Age (yr)

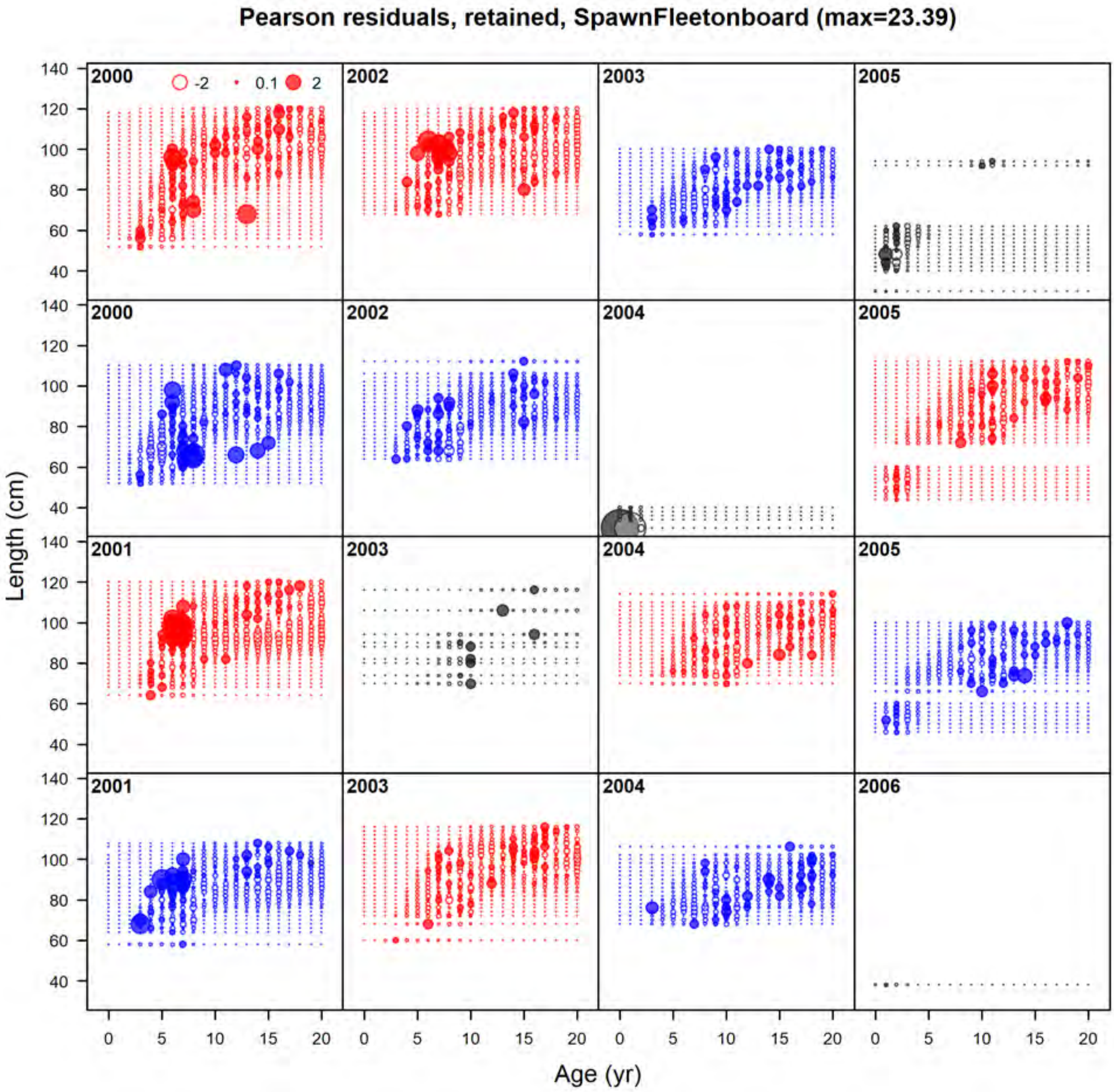

Pearson residuals, retained, NonSpawnFleetonboard (max=23.38)
1984
-0.4
0.01
0.4
1985
1986
1987
1988
1989
Length (cm)
Age (yr)

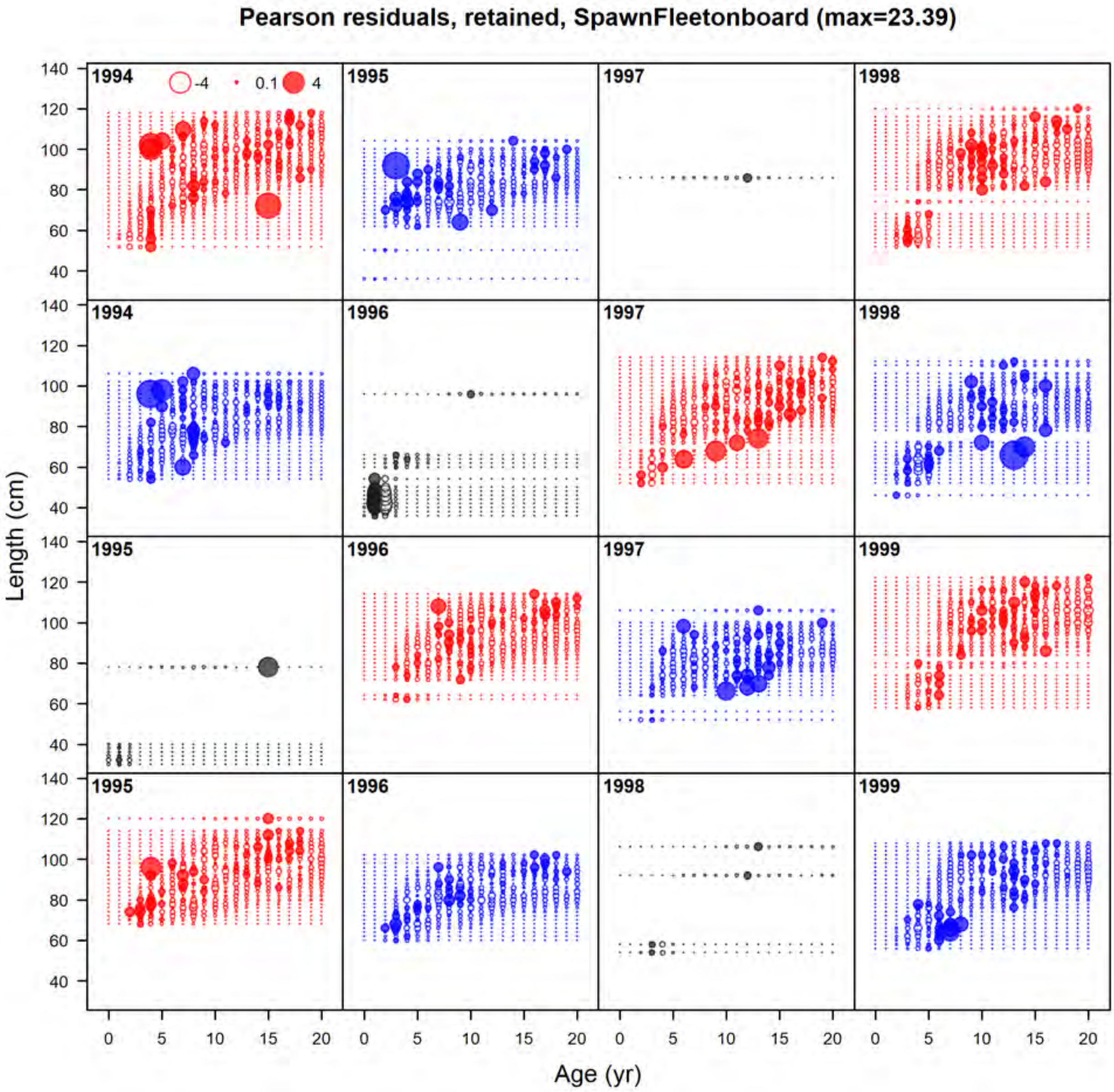

Pearson residuals, retained, SpawnFleetonboard (max=23.39)
2017
-2
0.1
2
2018
2019
2017
2018
2020
2017
2019
2020
2018
2019
2020
Length (cm)
Age (yr)

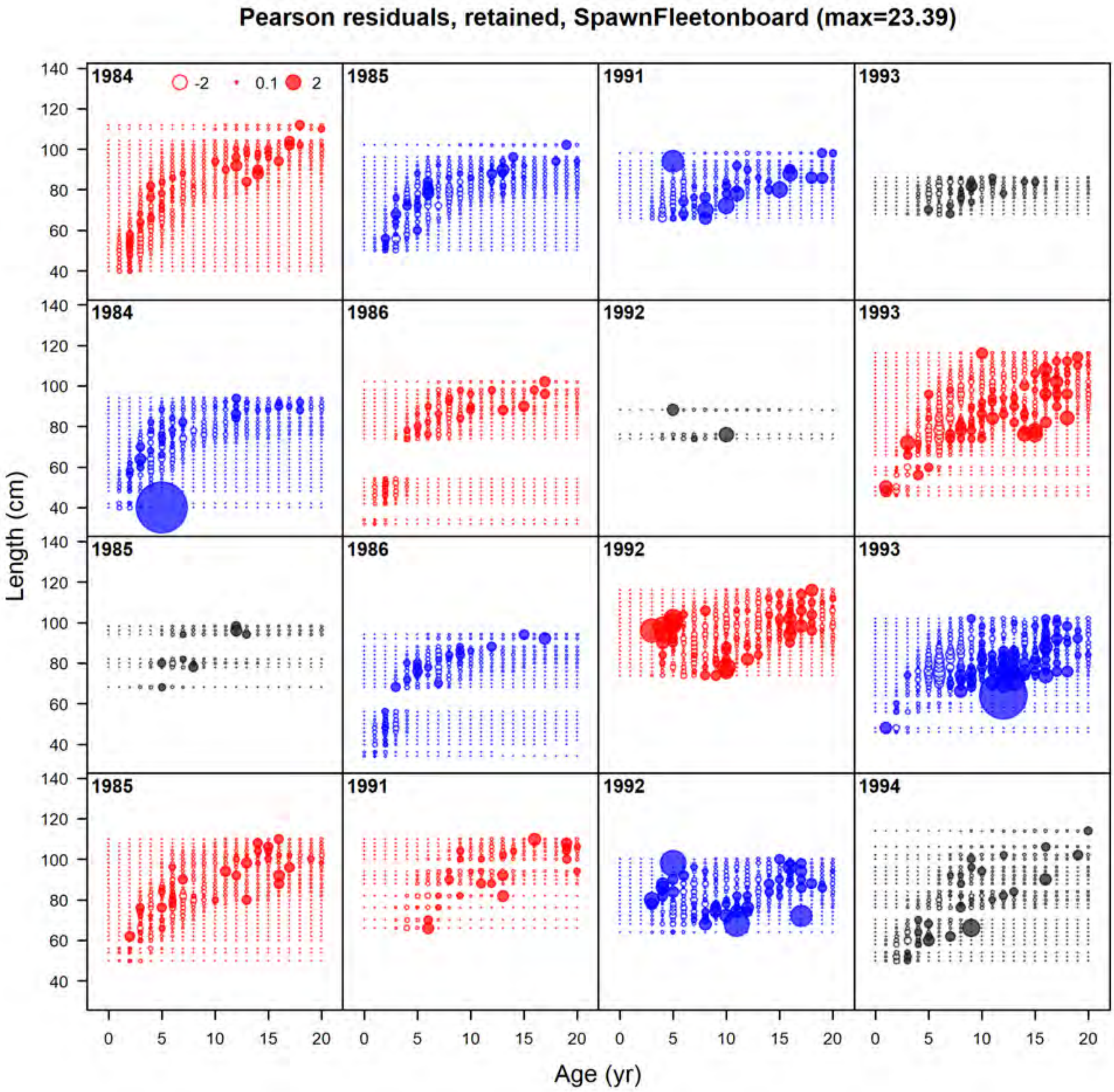


Pearson residuals, retained, SpawnFleetonboard (max=23.39)
-2
0.1
2
2011
2013
2014
2015
2012
2013
2014
2016
2012
2013
2015
2016
2012
2014
2015
2016
Length (cm)
Age (yr)


Pearson residuals, retained, SpawnFleetonboard (max=23.39)
2006
-25
-15
5
15
25
2007
2009
2010
2006
2008
2009
2010
2007
2008
2009
2011
2007
2008
2010
2011
Length (cm)
Age (yr)


Pearson residuals, retained, SpawnFleetonboard (max=23.39)
-2
0.1
2
2000
2002
2003
2005
2000
2002
2004
2005
2001
2003
2004
2005
2001
2003
2004
2006
Length (cm)
Age (yr)


Pearson residuals, retained, SpawnFleetonboard (max=23.39)
-4
0.1
4
1994
1995
1997
1998
1994
1996
1997
1998
1995
1996
1997
1999
1995
1996
1998
1999
Length (cm)
Age (yr)


Pearson residuals, retained, SpawnFleetonboard (max=23.39)
-2
0.1
2
1984
1985
1991
1993
1984
1986
1992
1993
1985
1986
1992
1993
1985
1991
1992
1994
Length (cm)
Age (yr)

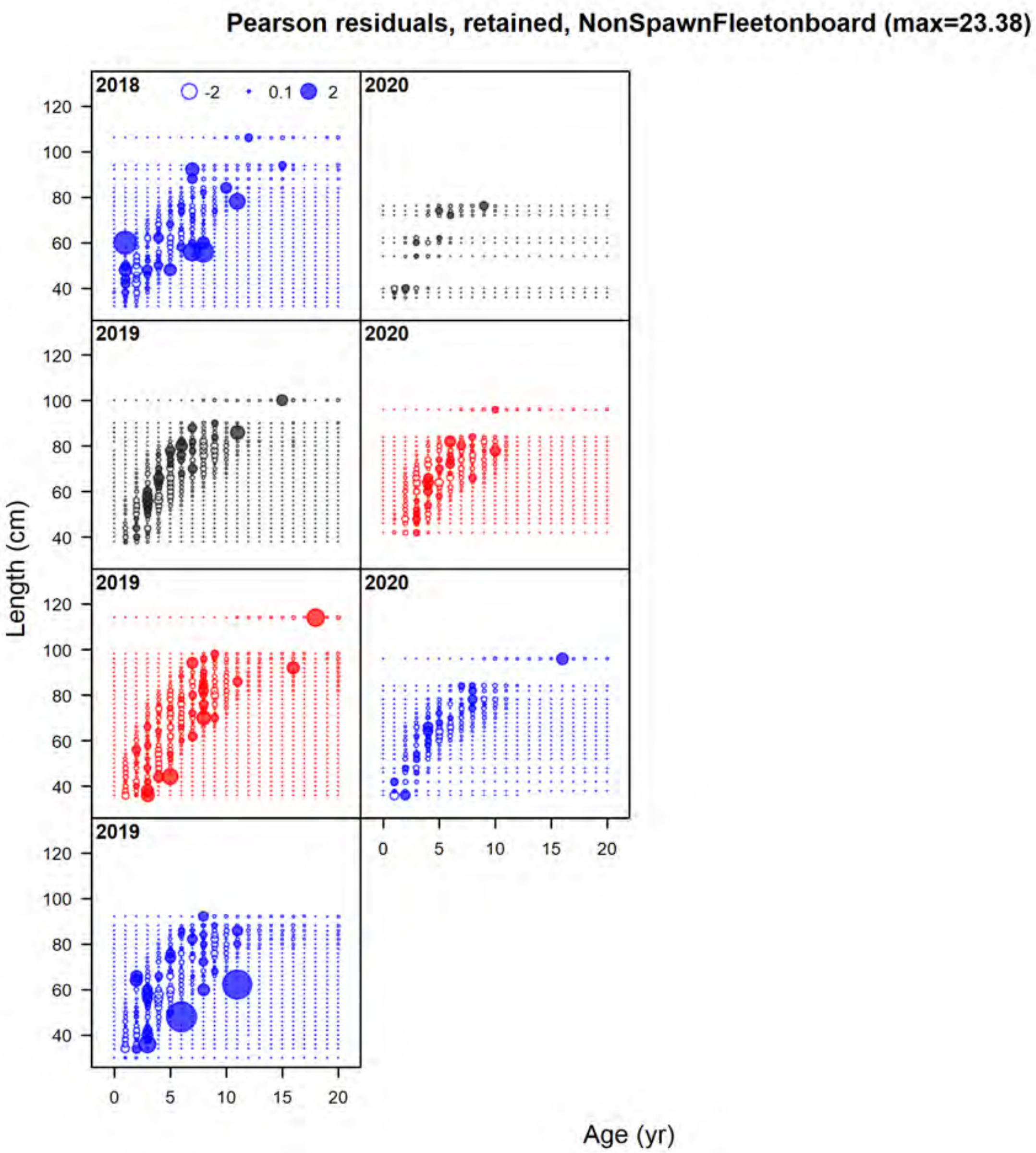


Figure 5.31. Pearson residuals of conditional age at length data.

6. Blue Grenadier (*Macruronus novaezelandiae*) stock assessment based on data up to 2020

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6.1 Executive Summary

This document presents the agreed base case for an updated quantitative Tier 1 assessment of Blue Grenadier (*Macruronus novaezelandiae*) for presentation at the SERAG3 meeting in 2021. The last full assessment was conducted in 2018 (Castillo-Jordán and Tuck, 2018b). The preliminary base case was presented at SERAG2 (October 2021; Tuck and Bessell-Browne, 2021) and the 2018 assessment was updated by the inclusion of data up to the end of 2020, which entails an additional three years of catch, discard, CPUE, length and age data and ageing error updates. The development of, and results from, the preliminary base case for Blue Grenadier through the sequential updating of recent data in the stock assessment, using the stock assessment package Stock Synthesis (SS-V3.30, Methot and Wetzel (2013)) is described in Tuck and Bessell-Browne (2021) and is not repeated here. This document describes the agreed base case from SERAG2 which differs from the preliminary base case through the inclusion of estimation of both female and male natural mortality, and no longer including the FIS survey results.

Results of the base case show reasonably good fits to the length-composition data, conditional age at length, egg and acoustic surveys and discard mass. As has been noted in previous Blue Grenadier assessments, the fit to the standardized non-spawning catch-rate index is generally poor; the model is unable to fit to the high early catch rates and over-estimates catch rates during the early 2000s. More recent catch rates fit reasonably well, including the recent marked increase in catch rate in 2019 and 2020.

The estimated time series of recruitment under the base-case parameter set shows the typical episodic nature of Blue Grenadier recruitment, with strong year-classes in 1979, the mid-1980s, 1994, and 2003, with very little recruitment between these years. However, recent recruitments are more stable, as was first observed in the 2018 assessment. The trajectories of spawning biomass show increases and decreases in spawning biomass as strong cohorts move into and out of the spawning population.

For the base case model, the estimated virgin female spawning biomass (SSB_0) is 37,445 tonnes and the projected 2022 spawning stock biomass will be 155% of SSB_0 (projected assuming 2020 catches in 2021), compared to 122% for 2019 in the 2018 assessment. The 2022 recommended biological catch (RBC) under the 20:35:48 harvest control rule is 23,777 t, with 245 t estimated discards (23,532 t retained). The long-term RBC is 7,100 t, with 183 t discards.

6.2 Introduction

An integrated analysis model, implemented in the generalized stock assessment software package, Stock Synthesis (SS) (Methot and Wetzel, 2013), was applied to the stock of Blue Grenadier in the Southern and Eastern Scalefish and Shark Fishery (SESSF), with data updated by the inclusion of data up to the end of the 2020 calendar year (length-composition and conditional age-at-length data; age reading-error matrices, standardized catch rate series; landings and discard catch weight) and information from acoustic surveys of spawning biomass (series from 2003-2010, pertaining to total spawning biomass), with an assumption of 2-times turnover on the spawning ground (Russell and Smith, 2006; Punt et al., 2015). The base-case egg survey estimates of female (only) spawning biomass for 1994 and 1995 are included. The model fits directly to length-composition data (by sex where possible) and conditional age-at-length data by fleet. Retained length-composition data from port and onboard samples are fit separately with a common selectivity curve by fleet.

The assessment model presented in 2011 (Tuck and Whitten, 2011; Tuck, 2011) was the first for Blue Grenadier to be implemented using Stock Synthesis (SS). The 2013 assessment updated this assessment using SS-V3.22a (Tuck, 2013), and the last full assessment was in 2018 (Castillo-Jordán and Tuck, 2018b), using 3.30.12.00-safe. The preliminary base case presented to SERAG in October 2021 (Tuck and Bessell-Browne, 2021) illustrated the changes that have occurred since 2018 through changes to software, assessment practices and new data (bridging). The bridging analysis are not repeated here.

The use of SS allows for multiple fishing fleets and can fit simultaneously to several data sources and types of information. The population dynamics model, and the statistical approach used in the fitting of the model to the various types of data, is outlined fully in the SS user manual (Methot et al., 2021) and is not reproduced here. This document updates the assessment presented in 2018 and the preliminary assessment presented at SERAG in October 2021 (Tuck and Bessell-Browne, 2021).

6.3 The fishery

Blue Grenadier are found from New South Wales around southern Australia to Western Australia, including the coast of Tasmania. Blue Grenadier is a moderately long-lived species with a maximum age of about 25 years. Age at maturity is approximately four years for males and five years for females (length-at-50% maturity for females is 57 cm and 64 cm respectively) based upon 32,000 Blue Grenadier sampled between February 1999 and October 2001 (Russell and Smith, 2006). There is also evidence that availability to the gear on the spawning ground differs by sex, with a higher proportion of small males being caught than females. This is most likely due to the arrival of males on the spawning ground at a smaller size (and younger age) than females. This was also noted by Russell and Smith (2006) who state that "young males entered the fishery one year earlier than females" and is consistent with information for Hoki from New Zealand (Annala et al., 2003). Large fish arrive earlier in the spawning season than small fish. Spawning occurs predominantly off western Tasmania in winter (the peak spawning period based upon mean gonadosomatic index (GSI) calculated by month was estimated to be between June and August according to Russell and Smith (2006)). There is some evidence that a high proportion of fish remain spawning in September. Variations in spawning period noted by Gunn et al. (1989) may occur due to inter-annual differences in the development of coastal current patterns around Tasmania. Adults disperse following the spawning season and while fish are found throughout the south east region during the non-spawning season, their range is not well defined. Spawning fish have been caught off the east coast of Australia, and larvae from a likely eastern spawning area have been described by Bruce et al. (2001). Blue Grenadier are caught by demersal trawling. There are two defined fleets: the spawning (SESSF Zone 40, months June, July and August) and non-spawning fisheries (all other months and zones).

6.4 Data

The assessment has been updated since the previous assessment (Castillo-Jordán and Tuck, 2018) by including recent length-composition and conditional age-at-length data from the spawning and non-spawning fisheries; updated standardized CPUE series (Sporcic, 2021), the total mass landed and discarded, and updated age-reading error matrices. Acoustic estimates of spawning biomass (2003-2010) and estimates of the female spawning biomass in 1994 and 1995 from egg surveys (Bulman et al., 1999) are included (Figure 6.1). The agreed base case no longer includes the FIS abundance estimates from the non-spawning area, as SERAG2 did not believe the series (FIS1-3) was indexing either the spawning or non-spawning biomass; extremely large inter- annual fluctuations in survey biomass are evident. Data were formulated by calendar year (i.e. 1 Jan to 31 Dec), as in previous models.

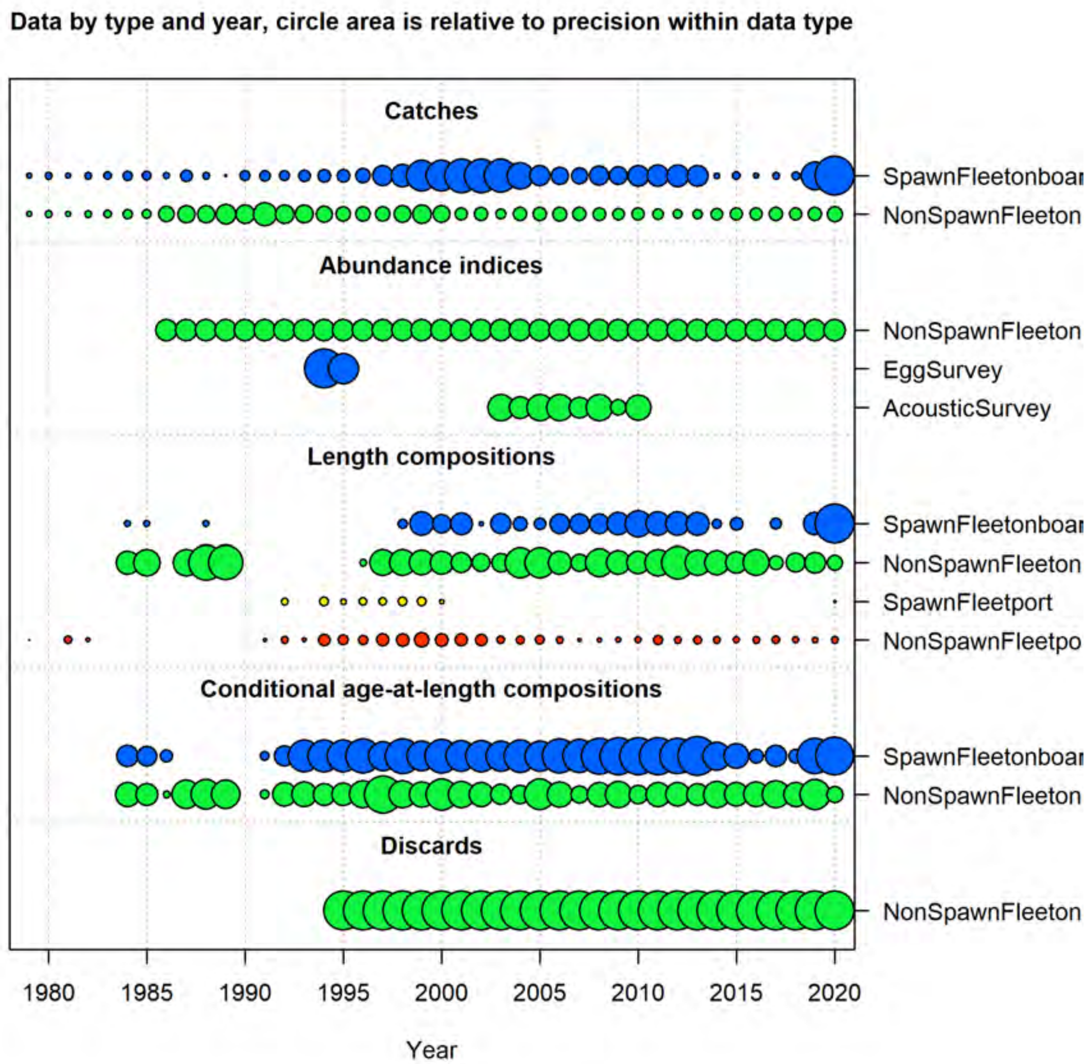

Figure 6.1. A summary of the input data for the base case Blue Grenadier assessment.

6.4.1 *Catch data*

6.4.1.1 Landings

The landings from the logbook data were used to apportion catches to the spawning and non-spawning fisheries (Table 6.1). The logbook landings have been adjusted upwards to match the CDR totals to take account of differences between logbook and landings data (multiple of 1.4 for the non-spawning fishery, based on 40% conversion from headed and gutted to whole, since 1986 and up to and including 1997 (reliable CDR data were available from 1998); 1.2 for the spawning fishery from 1986 up to and including 1996 (when factory vessels entered the spawning fishery) (D. Smith, pers. comm.). As stated by Thomson and He (2001), the factor is lower for the spawning fleet than the non-spawning fleet because some fish in the spawning fishery, landed headed and gutted, were recorded as being landed whole. These factors were chosen by the Blue Grenadier Assessment Group (BGAG) (Chesson and Staples (1995), as cited by Punt (1998)). The adjusted logbook catches were then scaled up to the SEF2 data (CDR). As historical CDR data were only available from 1992, the average scaling factor from 1992 to 1996 (1.07) was used to scale the data for years between 1986 and 1991. Note that in years 2008 to 2013 logbook data were greater than landings from the CDR. In these cases, the tonnage from the CDR was used as the total catch (AFMA, pers. comm. 2011). Table 6.2 lists the annual catches used in the assessment and the annual TAC (Figure 6.2). The annual logbook catches by sub-fishery and the adjustments made to determine the catches used in the assessment are shown in Table 6.1. No state catches are included and are assumed negligible or included in the historical values.

6.4.1.2 Discards

Discard rates were estimated from onboard data which gives the weight of the retained and discarded component of those shots that were monitored (Thomson and Klaer, 2011, Burch et al 2018). The discard rates are then scaled up to discard mass. The discard values from 1995 to 2002 are based on estimates calculated from ISMP data by MAFRI and reported in He et al. (1999) and Tuck, Smith and Talman (2004). The MAFRI estimates of discards were made accounting for differences in sampling and discard rates according to the ISMP zones. As agreed by Slope RAG (2011), since 2003 discard rates are estimated using the methods described in Thomson and Klaer (2011). Tier 1 stock assessments implemented in Stock Synthesis estimate discards within the assessment by fitting to discard proportions or mass calculated by fleet. Discard proportions are estimated for a population (stock) by fleet, year, zone and season (usually a quarter) and then scaled to landed (CDR) catch to obtain estimates by population, fleet and year (Klaer 2018). The discard proportion is estimated as the sum of the discarded catch divided by the sum of discarded catch and the landed catch (Klaer 2018; Method 1). The previous assessment used Method 2, where the discard proportion was estimated as the average of the proportion discarded in each shot (Klaer 2018). However, Method 2 does not scale the mean discard proportion by shot weight and it is therefore sensitive to the discarding practices from shots with small catches and, as such, may not be representative of the overall fishery. At its August 2020 Data Meeting SESSFRAG endorsed the use of Method 1 to estimate discard proportions for Tier 1 assessments from 2020 onwards. The discard rates calculated for and input to Tier 1 stock assessments are used to fit retention selectivity curves, so individual year values are not greatly influential on model estimated discard rates. Information in support of the historical values was not able to be obtained and further exploration of the methods and data used to estimate these values should be encouraged. The discard data are provided in Table 6.2. The discard data were assumed to have standard error (on the log-scale) of 0.3. As with previous assessments, only discards from the non-spawning fishery are considered.

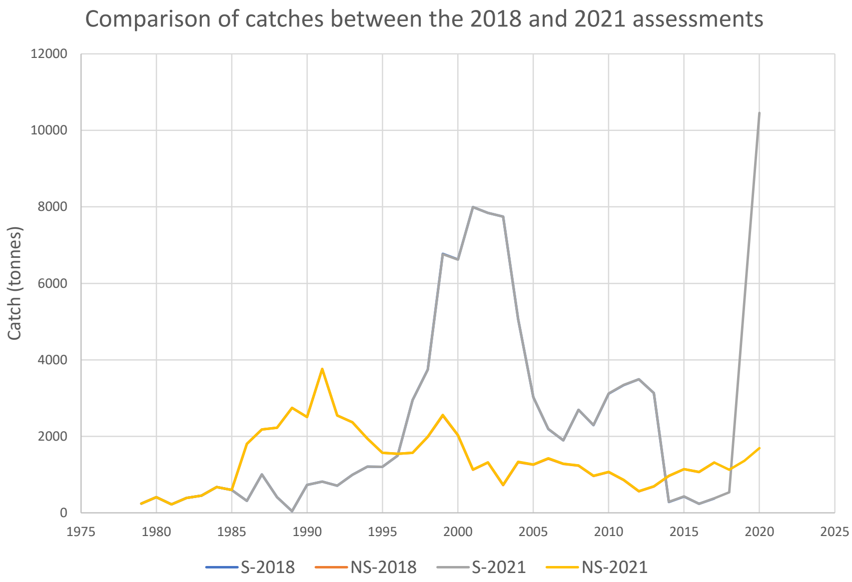

Figure 6.2. A comparison of total annual catches from the 2018 base case assessment and the updated catch used in the 2021 assessment for the spawning (S) and non-spawning (NS) fisheries.

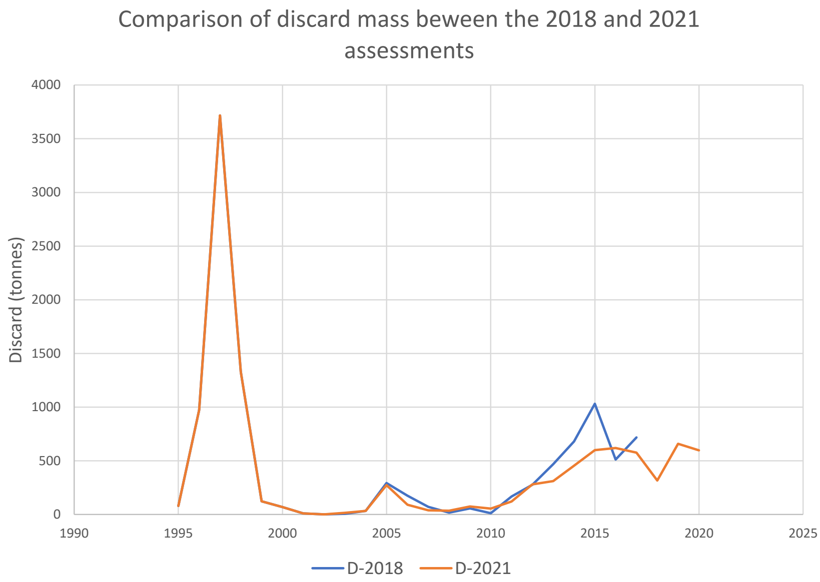

Figure 6.3. A comparison of total annual estimated discard mass from the 2018 base case assessment and the updated catch used in the 2021 assessment for the non-spawning fishery.

Table 6.1. Logbook and CDR landings for the spawning and non-spawning sub-fisheries by calendar year and adjustments made to account for logbooks being less than landings and incorrect reporting process code. Shaded CDR are historical landings values. [1] average of CDR/logbook ratio from 1992 to 1996.

Year	Logbook		CDR	H&G Multiplier		Adjusted Logbook			CDR / logbook	Catch for assessment	
	Spawning	Non-		Spawnin	Non-	Spawning	Non-	Total		Spawning	Non-
1979	245	245		1	1	245	245	490	1.00	245	245
1980	410	410		1	1	410	410	820	1.00	410	410
1981	225	225		1	1	225	225	450	1.00	225	225
1982	390	390		1	1	390	390	780	1.00	390	390
1983	450	450		1	1	450	450	900	1.00	450	450
1984	675	675		1	1	675	675	1350	1.00	675	675
1985	600	600		1	1	600	600	1200	1.00	600	600
1986	246	1204		1.2	1.4	295	1685	1981	1.07	317	1806
1987	782	1455		1.2	1.4	939	2036	2975	1.07	1006	2183
1988	319	1485		1.2	1.4	383	2079	2461	1.07	410	2228
1989	36	1829		1.2	1.4	43	2560	2604	1.07	46	2745
1990	570	1671		1.2	1.4	684	2340	3023	1.07	733	2508
1991	637	2508		1.2	1.4	764	3511	4275	1.07[1]	819	3764
1992	509	1565	3259	1.2	1.4	610	2191	2802	1.16	710	2549
1993	812	1659	3362	1.2	1.4	975	2323	3298	1.02	994	2368
1994	974	1338	3151	1.2	1.4	1169	1873	3042	1.04	1211	1940
1995	911	1017	2775	1.2	1.4	1093	1424	2517	1.10	1205	1570
1996	1200	1061	3040	1.2	1.4	1439	1485	2925	1.04	1496	1544
1997	2623	997	4516	1	1.4	2623	1396	4019	1.12	2947	1569
1998	2739	1459	5733	1	1	2739	1459	4198	1.37	3740	1993
1999	5460	2068	9324	1	1	5460	2068	7528	1.24	6762	2562
2000	5735	1761	8655	1	1	5735	1761	7496	1.15	6622	2033
2001	7309	1034	9128	1	1	7309	1034	8343	1.09	7997	1131
2002	6825	1151	9165	1	1	6825	1151	7976	1.15	7843	1322
2003	7239	687	8480	1	1	7239	687	7926	1.07	7746	735
2004	4647	1225	6401	1	1	4647	1225	5872	1.09	5066	1336
2005	2880	1204	4293	1	1	2880	1204	4085	1.05	3027	1266
2006	2058	1339	3625	1	1	2058	1339	3397	1.07	2196	1429
2007	1815	1232	3184	1	1	1815	1232	3048	1.04	1896	1287
2008	2838	1307	3938	1	1	2838	1307	4145	0.95	2696	1242

2009	2723	1151	3269	1	1	2723	1151	3874	0.84	2298	971
2010	3384	1162	4195	1	1	3384	1162	4545	0.92	3123	1072
2011	3554	917	4207	1	1	3554	917	4471	0.94	3345	863
2012	3838	624	4063	1	1	3838	624	4461	0.91	3495	568
2013	3443	764	3828	1	1	3443	764	4207	0.91	3133	695
2014	279	935	1258	1	1	279	935	1215	1.04	289	969
2015	401	1061	1578	1	1	401	1061	1462	1.08	433	1146
2016	217	978	1311	1	1	217	978	1195	1.10	238	1073
2017	362	1261	1698	1	1	362	1261	1623	1.05	379	1319
2018	508	1067	1665	1	1	508	1067	1575	1.06	537	1128
2019	5799	1424	6914	1	1	5799	1424	7224	0.96	5551	1363
2020	9146	1482	12151	1	1	9146	1482	10628	1.14	10457	1694

Table 6.2. Landed and discarded catches for the spawning and non-spawning sub-fisheries by calendar year. These estimates have been scaled up to the landings data. Standardised CPUE (Sporcic, 2021) for the non-spawning sub-fisheries by calendar year are shown, along with the TAC. [1] a voluntary industry reduction to 4,200 t was implemented in 2005. [2] This was a 16 month TAC. [3] From 2008/09, the TACs cover the fishing year 1 May to 30 April. In the table below, 2008 refers to 2008/09. * This is an estimate of retained catch equal to the 2020 catch.

Year	Spawning (t)	Non-spawning (t)	Discards (t)	TAC	CPUE
1979	245	245			
1980	410	410			
1981	225	225			
1982	390	390			
1983	450	450			
1984	675	675			
1985	600	600			
1986	317	1806			1.5312
1987	1006	2183			1.9494
1988	410	2228			2.1329
1989	46	2745			2.1313
1990	733	2508			2.1103
1991	819	3764			1.5098
1992	710	2549			1.2214
1993	994	2368			0.9287
1994	1211	1940		10000	0.8412
1995	1205	1570	80	10000	0.5802
1996	1496	1544	975	10000	0.5262
1997	2947	1569	3716	10000	0.5464
1998	3740	1993	1329	10000	0.8818
1999	6762	2562	123	10000	0.9257
2000	6622	2033	69	10000	0.6643
2001	7997	1131	10	10000	0.3828
2002	7843	1322	2	10000	0.3794
2003	7746	735	16	9000	0.3171
2004	5066	1336	35	7000	0.5326
2005	3027	1266	275	5000[1]	0.6428
2006	2196	1429	91	3730	0.8564
2007	1896	1287	40	4113[2]	0.7622
2008	2696	1242	36	4368[3]	0.8386
2009	2298	971	76	4700	0.7778
2010	3123	1072	56	4700	0.7805
2011	3345	863	123	4700	0.637
2012	3495	568	281	5208	0.508
2013	3133	695	311	5208	0.9059
2014	289	969	455	6800	1.092
2015	433	1146	601	8796	1.1867
2016	238	1073	619	8810	1
2017	379	1319	576	8765	1.1183
2018	537	1128	317	8810	0.899
2019	5551	1363	659	12183	1.1917
2020	10457	1694	598	12183	1.7107
2021	10457*	1694*			

6.4.2 *Catch rates*

Sporcic (2021) provides the updated standardised catch rate series for the non-spawning fishery of Blue Grenadier (Table 6.2; Figure 6.4). The catch rate generally follows the fluctuations of stock size driven by large, but sporadic, recruitments. The standard deviation of log-CPUE is assumed to be 0.252 (value equal to the standard error from a loess fit), but an extra variance component is estimated for the CPUE index during the tuning process.

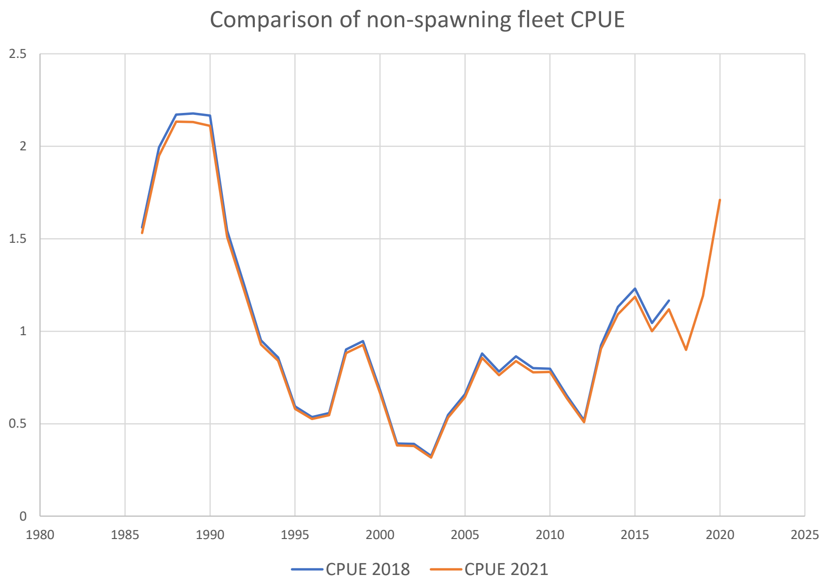

Figure 6.4. A comparison of the annual standardised catch rates series for Blue Grenadier between the 2018 and 2021 assessments.

6.4.3 *Length-composition and age data*

Length and age data are included in the assessment as length-composition data and conditional age-at-length data by fleet and sex (the latter if available). Onboard and port length-compositions, when available, are used separately. Separating port and onboard lengths first occurred in the 2018 assessment. Prior to 2018, only port samples had been used to create the length-compositions. Plots of the observed length and age data are shown in later figures, with the corresponding model predicted values.

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. 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) or trips (port) sampled, rather than the number of fish measured (Table 6.3; Table 6.4).

Table 6.3. The years for which length data were available for the sub-fleets (spawning onboard = 1; spawning port = 3; non-spawning onboard = 2; non-spawning port = 4), sex (0 = no gender specified; female =1; male =2), partition (part: discard = 1; retained = 2). N is the number of shots (onboard) or trips (port). Red length data were excluded due to low sample sizes. [1] the average number of fish from years 1984 and 1988. [2] these years of discard lengths were removed due to spurious numbers of large fish.

Year	Nfish	Fleet	Sex	Part	N
1984	1046	1	0	2	12
1985	1090[1]	1	0	2	12
1988	1133	1	0	2	12
1998	812	1	0	2	10
1998	1037	1	1	2	8
1998	469	1	2	2	8
1999	4147	1	1	2	79
1999	5929	1	2	2	79
2000	2672	1	1	2	48
2000	2956	1	2	2	46
2001	3620	1	1	2	67
2001	4256	1	2	2	67
2002	262	1	0	2	2
2002	444	1	1	2	3
2002	450	1	2	2	3
2003	2700	1	1	2	59
2003	2853	1	2	2	59
2004	1307	1	1	2	28
2004	1370	1	2	2	28
2005	198	1	1	2	20
2005	141	1	2	2	20
2006	3184	1	1	2	56
2006	3081	1	2	2	55
2007	2957	1	1	2	54
2007	1897	1	2	2	55
2008	3073	1	1	2	53
2008	2177	1	2	2	54
2009	3868	1	1	2	73
2009	3374	1	2	2	70
2010	2488	1	1	2	98
2010	1453	1	2	2	94
2011	4207	1	1	2	79
2011	3266	1	2	2	77
2012	3939	1	1	2	77
2012	3060	1	2	2	82
2013	1	1	0	2	1
2013	4443	1	1	2	76
2013	3892	1	2	2	76
2014	592	1	0	2	7
2014	229	1	1	2	9
2014	179	1	2	2	9
2015	715	1	0	2	11

2015	723	1	1	2	18
2015	862	1	2	2	18
2017	777	1	0	2	12
2017	131	1	1	2	11
2017	193	1	2	2	11
2018	10	1	0	2	1
2019	57	1	0	2	19
2019	3389	1	1	2	72
2019	4324	1	2	2	72
2020	8	1	0	2	6
2020	6776	1	1	2	204
2020	8774	1	2	2	201

Year	Nfish	Fleet	Sex	Part	N
1984	1935	2	0	2	75
1985	1829	2	0	2	99
1987	4063	2	0	2	100
1988	6660	2	0	2	164
1989	2424	2	0	2	160
1996	829	2	0	2	8
1997	3367	2	0	2	32
1998	8290	2	0	2	73
1999	8768	2	0	2	79
2000	9362	2	0	2	73
2001	6309	2	0	2	57
2002	5329	2	0	2	47
2003	2754	2	0	2	50
2004	7586	2	0	2	104
2005	5754	2	0	2	76
2006	6549	2	0	2	68
2007	1109	2	0	2	44
2008	2624	2	0	2	91
2009	2100	2	0	2	79
2010	2562	2	0	2	71
2011	1755	2	0	2	70
2012	3087	2	0	2	97
2013	1841	2	0	2	48
2014	2631	2	0	2	67
2015	1555	2	0	2	45
2016	3960	2	0	2	68
2017	1236	2	0	2	18
2018	1585	2	0	2	38
2019	2579	2	0	2	53
2020	1261	2	0	2	33

Year	Nfish	Fleet	Sex	Part	N
1992[2]	159	2	0	1	3
1993[2]	1532	2	0	1	12
1994[2]	2366	2	0	1	27
1995[2]	6651	2	0	1	61
1996[2]	5999	2	0	1	50
1997	6967	2	0	1	62
1998	2212	2	0	1	20
1999	940	2	0	1	7
2000	132	2	0	1	3
2003	11	2	0	1	6
2004	1078	2	0	1	22
2005	5299	2	0	1	48
2006	1225	2	0	1	8
2007	16	2	0	1	2
2008	219	2	0	1	18
2009	97	2	0	1	6
2010	16	2	0	1	2
2011	792	2	0	1	30
2012	1327	2	0	1	49
2013	1455	2	0	1	41
2014	873	2	0	1	17
2015	500	2	0	1	18
2016	1360	2	0	1	28
2017	531	2	0	1	9
2018	682	2	0	1	13
2019	151	2	0	1	8
2020	32	2	0	1	5
1992	774	3	0	2	6
1994	1038	3	0	2	9
1995	465	3	0	2	4
1996	927	3	0	2	7
1997	851	3	0	2	7
1998	1648	3	0	2	9
1999	1079	3	0	2	9
2000	360	3	0	2	3
2014	82	3	0	2	1
2016	74	3	0	2	1
2020	100	3	0	2	1

Year	Nfish	Fleet	Sex	Part	N
1979	164	4	0	2	2
1980	40	4	0	2	1
1981	1425	4	0	2	36
1982	478	4	0	2	12
1991	927	4	0	2	10
1992	3832	4	0	2	31
1993	1810	4	0	2	12
1994	8624	4	0	2	79
1995	7055	4	0	2	62
1996	5505	4	0	2	51
1997	11844	4	0	2	85
1998	16234	4	0	2	100
1999	13898	4	0	2	119
2000	13728	4	0	2	95
2001	12000	4	0	2	88
2002	9416	4	0	2	77
2003	5037	4	0	2	38
2004	4440	4	0	2	43
2005	6310	4	0	2	48
2006	3019	4	0	2	31
2007	979	4	0	2	9
2008	1955	4	0	2	16
2009	1080	4	0	2	19
2010	833	4	0	2	26
2011	1925	4	0	2	54
2012	1331	4	0	2	33
2013	1744	4	0	2	43
2014	1611	4	0	2	30
2015	2048	4	0	2	25
2016	1887	4	0	2	29
2017	2061	4	0	2	35
2018	1943	4	0	2	27
2019	1222	4	0	2	22
2020	1864	4	0	2	32

Table 6.4. Number of age-length otolith samples by fleet included in the base case assessment.

Year	Spawn	Non-spawn
1984	512	735
1985	432	603
1986	174	71
1987		1027
1988		1092
1989		1031
1990		
1991	93	100
1992	481	706
1993	1122	772
1994	1130	623
1995	1154	637
1996	1296	932
1997	932	1697
1998	1334	948
1999	992	802
2000	1247	1224
2001	1062	891
2002	1077	751
2003	1035	514
2004	1187	435
2005	1016	1185
2006	1313	816
2007	1205	396
2008	1437	753
2009	1545	907
2010	1530	451
2011	1515	763
2012	1391	715
2013	1655	621
2014	884	887
2015	696	723
2016	221	773
2017	537	928
2018	221	733
2019	1406	1119
2020	1579	344

6.4.4 *Acoustic survey estimates*

Estimates of spawning biomass for 2003-2010 are provided in Ryan and Kloser (2012). There are no acoustic estimates since 2010. Table 6.5 shows the estimates of spawning biomass with their corresponding CV's used in the assessment. Sampling CVs less than 0.3 were increased to 0.3 to account for process error. Low sampling CVs (of 0.19 for example) were considered too low for an acoustic survey and a minimum of 0.3 should be used to reflect the total uncertainty (D. Smith, pers comm., Tuck et al., 2004; Slope RAG 2011). Of 22 acoustic CVs used for Hoki in New Zealand, none are lower than 0.3 (Francis, 2009). It is assumed that the spawning ground experiences a turnover rate of two (i.e. for the model applied here, the spawning biomass estimates are doubled) (Russell and Smith, 2006; Punt et al., 2015). The acoustic survey selectivity is matched to the maturity ogive, as it is assumed the acoustic survey observes mature fish on the spawning ground.

Table 6.5. The estimated biomass (tonnes) of Blue Grenadier on the spawning grounds in years 2003 to 2010 (Ryan and Kloser, 2012).

	2003	2004	2005	2006	2007	2008	2009	2010
Biomass (t)	24,690	16,295	18,852	42,882	56,330	24,450	24,787	20,622
CV for assessment model	0.30	0.46	0.30	0.30	0.52	0.30	1	0.33
Sampling CV	0.16	0.46	0.14	0.14	0.52	0.22	1	0.33

6.4.5 *Egg survey estimates*

Egg survey estimates of female spawning biomass are available for 1994 and 1995 (Bulman et al., 1999). The egg-estimates (CV) for 1994 and 1995 respectively are: 57,772 (0.18) and 41,409 (0.29) tonnes. For the analysis considered here, the base-case egg estimates were used.

6.4.6 *Biological parameters and stock structure assumptions*

The assessment assumes that the proportion of females that spawn in each year is 0.84 and a length at 50% maturity of 63.7 cm for females (Russel and Smith, 2006). The female maturity ogive is shown in Figure 6.4.

The length weight-relationship for males and females was estimated from spawning fishery data over years 1999 to 2008 (Figure 6.5). Natural mortality for females and males is estimated when fitting the model.

Francis (2009) reviews the values of steepness used in New Zealand Hoki assessments, where a value of h=0.9 had been used since 1994. This value of steepness was derived from work of Punt et al. (1994) using 45 stocks of Gadiform species (0.9 is the median). Following an analysis of the profile likelihood, the effect of steepness on the 2007 assessment and additional information of Myers et al. (1999; 2002) beyond that used by Punt et al. (1994), Francis (2009) concludes that steepness should be reduced to h=0.75. This value of steepness has been assumed in all Blue Grenadier assessments since 2011 and in this assessment.

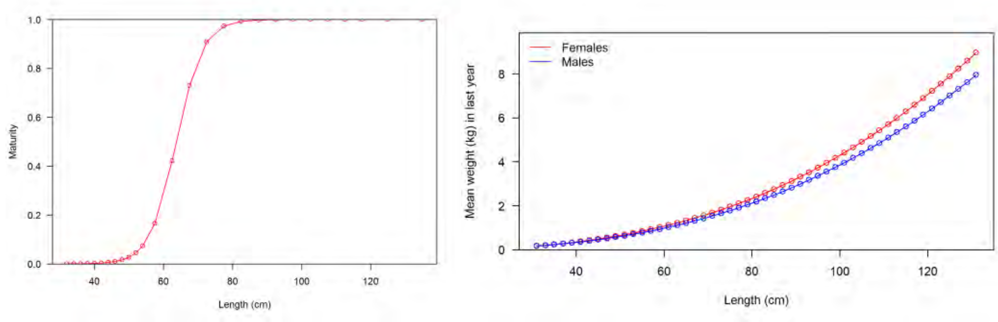

Figure 6.5. The maturity ogive by length for female Blue Grenadier (parameters from Russell and Smith (2006)) and the length-weight relationship for males and females.

6.4.7 *Age-reading error*

Updated standard deviations for aging error by reader (A and B) have been estimated, producing the age-reading error matrix of Table 6.6 (A. Punt and P. Burch, pers. comm.). Reader A applied to years 1991-93 and 2007-20, and reader B to years 1984-90 and 1994-2006.

Table 6.6. The standard deviation of age reading error for readers A and B.

	St Dev	
Age	A	B
0	0.198	0.281
1	0.198	0.281
2	0.258	0.299
3	0.305	0.318
4	0.341	0.338
5	0.369	0.359
6	0.391	0.383
7	0.407	0.408
8	0.420	0.435
9	0.430	0.464
10	0.438	0.495
11	0.444	0.529
12	0.448	0.565
13	0.452	0.604
14	0.455	0.646
15	0.457	0.691
16	0.459	0.740
17	0.460	0.792
18	0.461	0.848
19	0.462	0.908
20	0.462	0.974

6.5 Analytical Approach

6.5.1 Model structure and parameters

The 2021 base case assessment of Blue Grenadier uses an age- and size-structured model implemented in the generalized stock assessment software package, Stock Synthesis (SS) (Version 3.30.17.00, Methot et al. (2021)). The methods utilised in SS are based on the integrated analysis paradigm. SS can allow for multiple seasons, areas and fleets, but most applications are based on a single season and area. Recruitment is governed by a stochastic Beverton-Holt stock-recruitment relationship, parameterized in terms of the steepness of the stock-recruitment function (h), the expected average recruitment in an unfished population (R_0), and the degree of variability about the stock-recruitment relationship (σ_r). SS allows the user to choose among a large number of age- and length-specific selectivity patterns. The values for the parameters of SS are estimated by fitting to data on catches, catch-rates, discard mass, discard and retained catch length-frequencies, and conditional age-at-length data. The population dynamics model and the statistical approach used in fitting the model to the various data types are given in the SS technical documentation.

Model data have been updated by the inclusion of data up to the 2020 calendar year (length-composition and conditional age-at-length data; age reading-error matrices, standardized catch rate series; landings and discard catch weight) and information from acoustic surveys of spawning biomass (series from 2003-2010, pertaining to total spawning biomass), with an assumption of two-times turnover on the spawning ground (Russell and Smith, 2006; Punt et al. 2015). The base-case egg survey estimates of female (only) spawning biomass for 1994 and 1995 are included. The model fits directly to length-composition data (by sex where possible) and conditional age-at-length data by fleet. Retained length-composition data from port and onboard samples are separated.

The base–case model includes the following key features:

a) Blue grenadier consists of a single stock within the area of the fishery.

b) The model accounts for males and females separately (growth, natural mortality, age at first breeding).

c) The population was at its unfished biomass with the corresponding equilibrium (unfished) age-structure at the start of 1960.

d) The rate of natural mortality, M, is assumed to be constant with age, and also time-invariant. The value for female and male M is estimated within the assessment.

e) 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 for the base-case analysis is set to 0.75. Deviations from the average recruitment at a given spawning biomass (recruitment residuals) are estimated for 1974 to 2017. Deviations are not estimated before 1974 or after 2017 because there are insufficient data to permit reliable estimation of recruitment residuals outside of this time period.

f) The population plus-group is modelled at age 20 years. The maximum age for age observations is 20 years.

g) Growth is assumed to follow a von Bertalanffy type length-at-age relationship, with the parameters of the growth function being estimated separately for females and males inside the assessment model. Growth is also assumed to vary through time and to be cohort (year class) specific. Evidence for time-varying and cohort specific growth in Blue Grenadier has been accumulating over several decades (see Whitten et al., 2013). The 2021 base-case model treats conditional age-at-length information as data (i.e. to incorporate error), and predicts the expected length-at-age for each year. This is achieved by estimating the parameters of a von Bertalanffy growth function where the expected annual growth increment is based on the von Bertalanffy growth function but with a growth rate parameter that is determined by an expected value and a cohort-specific deviation. Cohort-specific deviations from average growth are estimated in the base case model for year classes 1978 to 2017.

h) Two fleets are included in the model – the spawning fishery that operates during winter (June – August inclusive) off western Tasmania (zone 40), and the non-spawning sub-fishery that operates during other times of the year and in other areas throughout the year. GAB catches are not included.

i) Each selectivity pattern was assumed to be length-specific, logistic and time-invariant for the spawning fleet and dome-shaped for the non-spawning fleet. The parameters of the selectivity function for each fleet were estimated within the assessment.

j) The CVs of the CPUE indices were initially set at a value equal to the standard error from a loess fit (0.252; Sporcic, 2021), before being re-tuned to the model-estimated standard errors within SS. The acoustic estimates were tuned through the estimation of an extra variance component that is added to the model input standard errors. This is done within SS.

k) Discard tonnage was estimated through the assignment of a retention function for the non-spawning fleet. This was defined as a logistic function of length, and the inflection and slope of this function were estimated where discard information was available. In addition, the discard length data from prior to 1996 were removed as recommended by SERAG (September, 2018) due to the existence of unusually large fish in the length distribution which is likely to be misreporting.

l) Retained and discarded onboard length sample sizes were capped at 200 and a minimum of 100 fish measured was required for length-composition data to be included in the assessment. For port samples, numbers of trips were used as the sampling unit, with a cap of 100. 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) or trips (port) sampled, rather than the number of fish measured.

The values assumed for fixed parameters of the preliminary base case model are shown in Table 6.7.

Table 6.7. Parameter values assumed for some of the non-estimated parameters of the base-case model

Parameter	Description	Value
M_f	Natural mortality for females	Estimated
M_m	Natural mortality for males	Estimated
h	"steepness" of the Beverton-Holt stock-recruit curve	0.75
x	age observation plus group	20 years
μ	fraction of mature population that spawn each year	0.84
a_f	Female allometric length-weight equations	0.01502 g^{-1} cm
b_f	Female allometric length-weight equations	2.728
a_m	Male allometric length-weight equations	0.0168 g^{-1} cm
b_m	Male allometric length-weight equations	2.680
l_m	Female length at 50% maturity	63.7 cm
l_s	Parameter defining the slope of the maturity ogive	-0.261

6.5.2 *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) 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. SS-V3.30 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 SS-V3.30 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.

6.5.3 *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 for fishing years 2006–2020. 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 a Tier level depending on the basis used for assessing stock status or exploitation level for that stock. Blue Grenadier is assessed 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. 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) has determined that for most SESSF stocks where the proxy values of B_{40} and B_{48} are used for B_{MSY} and B_{MEY} this form of the rule is equivalent to a 20:35:48 strategy.

This document reports RBCs calculated under the 20:35:48 strategy.

6.5.4 *Sensitivity tests*

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

1. h = 0.85, 0.65 (0.75 in the base case)
2. M_{fem} = 0.21, 0.25 (0.23 in the base case)
3. Double and halve the weighting on the length composition data.
4. Double and halve the weighting on the age-at-length data.
5. Double and halve the weighting on the index (survey) data.
6. σ_r = 0.6, 0.8 (0.7 in the base case)

The results of the sensitivity tests are summarized by the following quantities:

1. SB_0 the average equilibrium female spawning biomass.
2. SB_{2022} the female spawning biomass at the start of 2022.
3. SB_{2022}/SB_0 the depletion level at the start of 2022, i.e. the 2022 spawning biomass expressed as a fraction of the unexploited spawning biomass.
4. *2022 RBC* - the 2022 RBC, calculated using the 20:35:48 harvest rule (presented for the agreed base case only).
5. *Long-term RBC* - the long-term RBC calculated using the 20:35:48 harvest rule (presented for the agreed base case only).

6.6 Results

6.6.1 The base-case analysis

6.6.1.1 Transition from the 2018 base case to the 2021 base case

The development of a preliminary base case, and a bridging analysis from the 2018 assessment (Castillo-Jordán and Tuck, 2018b), was presented at the October 2021 SERAG 2 meeting (Tuck and Bessell-Browne, 2021), including updating the version of Stock Synthesis and sequentially updating data. This bridging analysis is not repeated in this report.

6.6.1.2 Paramater estimates

Figure 6.6 shows how the expected mean length-at-age values change over time for the base case model. The ridges reflect the impact of the estimated cohort dependent growth with some cohorts growing faster or slower than average. This figure also shows the expected mean length-at-age values for the end-year of the model. The impact of slower than average growth is visible by the decrease in expected size of say 10 year old fish in 2005, corresponding to the larger than average recruitment in 1994. Natural mortality for females was estimated to be $M_f = 0.23$ and males was $M_m = 0.24$.

The selectivity for the spawning and non-spawning fisheries and the retention function for the non-spawning fishery are shown in Figure 6.7. Selectivity is assumed to be time-invariant, sex-specific and logistic for the spawning fleet and dome-shaped for the non-spawning fleet.

The estimate of the parameter that defines the initial numbers (and biomass), ln(R_0), is 9.89 for the base case.

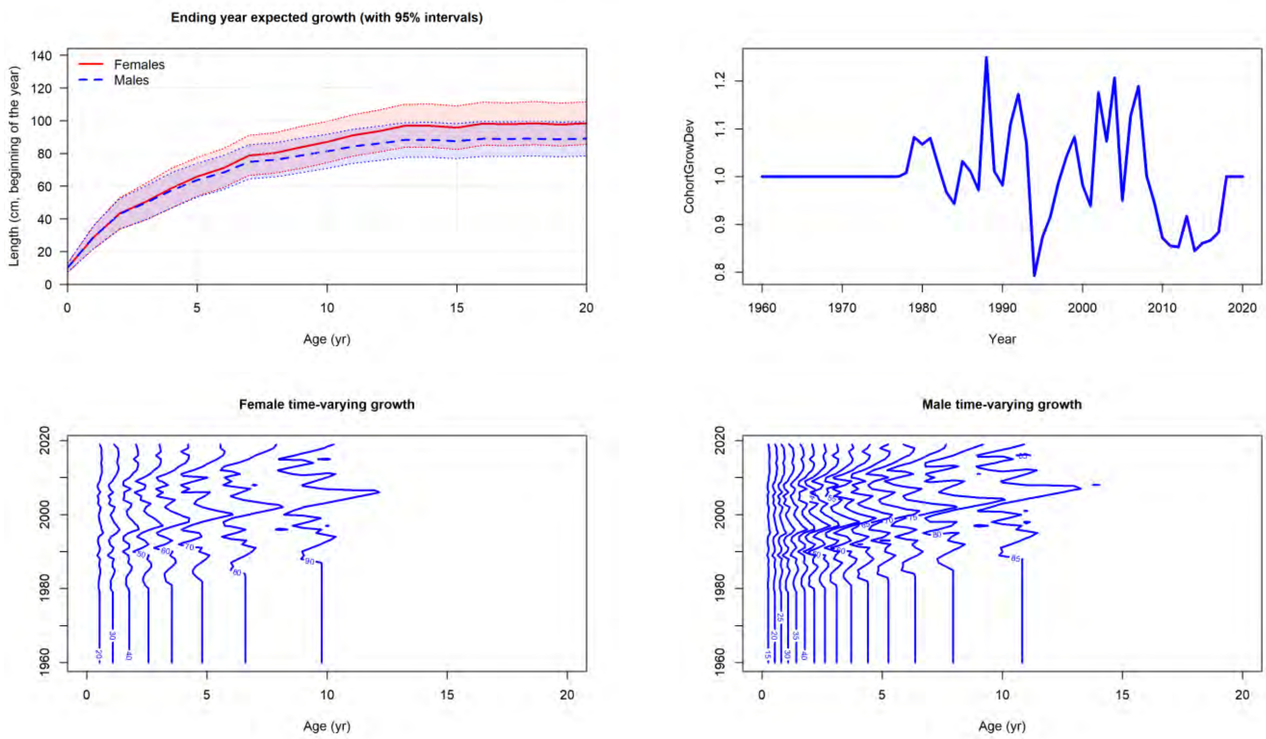

Figure 6.6. The estimate growth curve, with cohort dependent growth for Blue Grenadier.

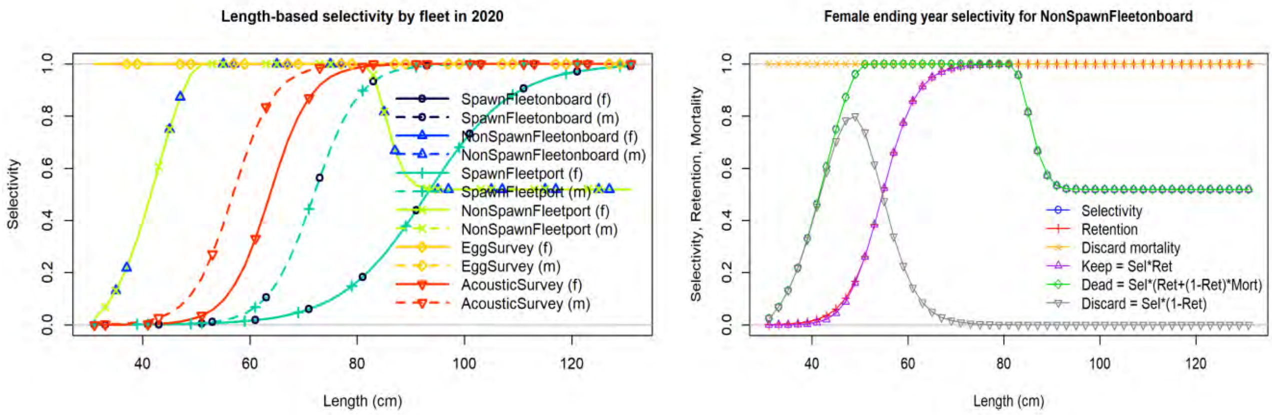

Figure 6.7. Estimated selectivity for the spawning and non-spawning fleets, port and onboard samples and for males (m) and females (f) and the estimated retention function for the non-spawning fleet.

6.6.1.3 Fits to the data

Figure 6.8 shows the model fit to the non-spawning catch rate series. The model fits intersect most of the 95% confidence intervals for the data, indicating that adjustments to the CVs for the indices performed as expected. As has been seen in all previous assessment models for Blue Grenadier, the model is not able to fit the rise in catch rate following the large recruitment of the mid-1990s. More recent increases in catch rate are estimated well. The fit to the discard mass is able to replicate the increase in discarding through the late 1990s, mid-2000s and since 2012, however the magnitude is under-estimated (as has been the case with previous assessments). In the past, alternative models that time-blocked discarding, re-weighted discard CVs and included a discard fleet have all been unsuccessful in improving the fit to the discard and CPUE data. Further consideration should be given to the GLM model structure used in the standardisation of CPUE. Fits to the biomass estimates from the acoustic surveys and egg surveys were reasonable. The predicted biomass trajectory intersects all 95% confidence intervals.

The base-case model fits to the aggregated retained and discarded length-frequency distributions well (Figure 6.9). Note that a single selectivity is estimated for the combined port and onboard fleets. The saw-tooth port lengths which occurs when lengths measured in dorsal standard length (DSL), with values across all length bins, are converted to standard (STD) length, resulting in some length bins with lower estimates and higher estimates in neighbouring bins in the new length composition. Length composition fits by year and fleet are in the Appendix.

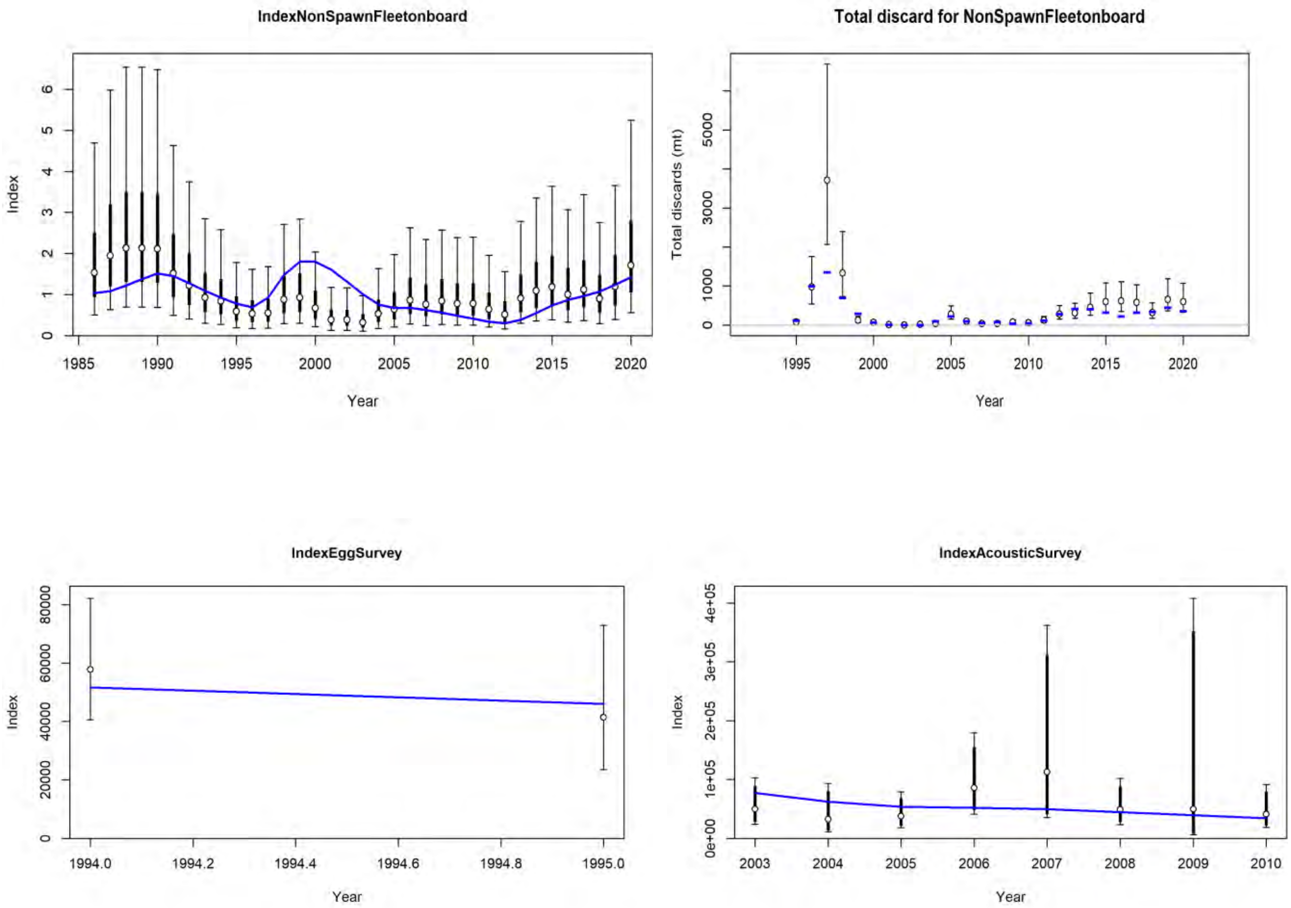

Figure 6.8. Fits to the non-spawning CPUE index, discard mass, egg survey and acoustic survey.

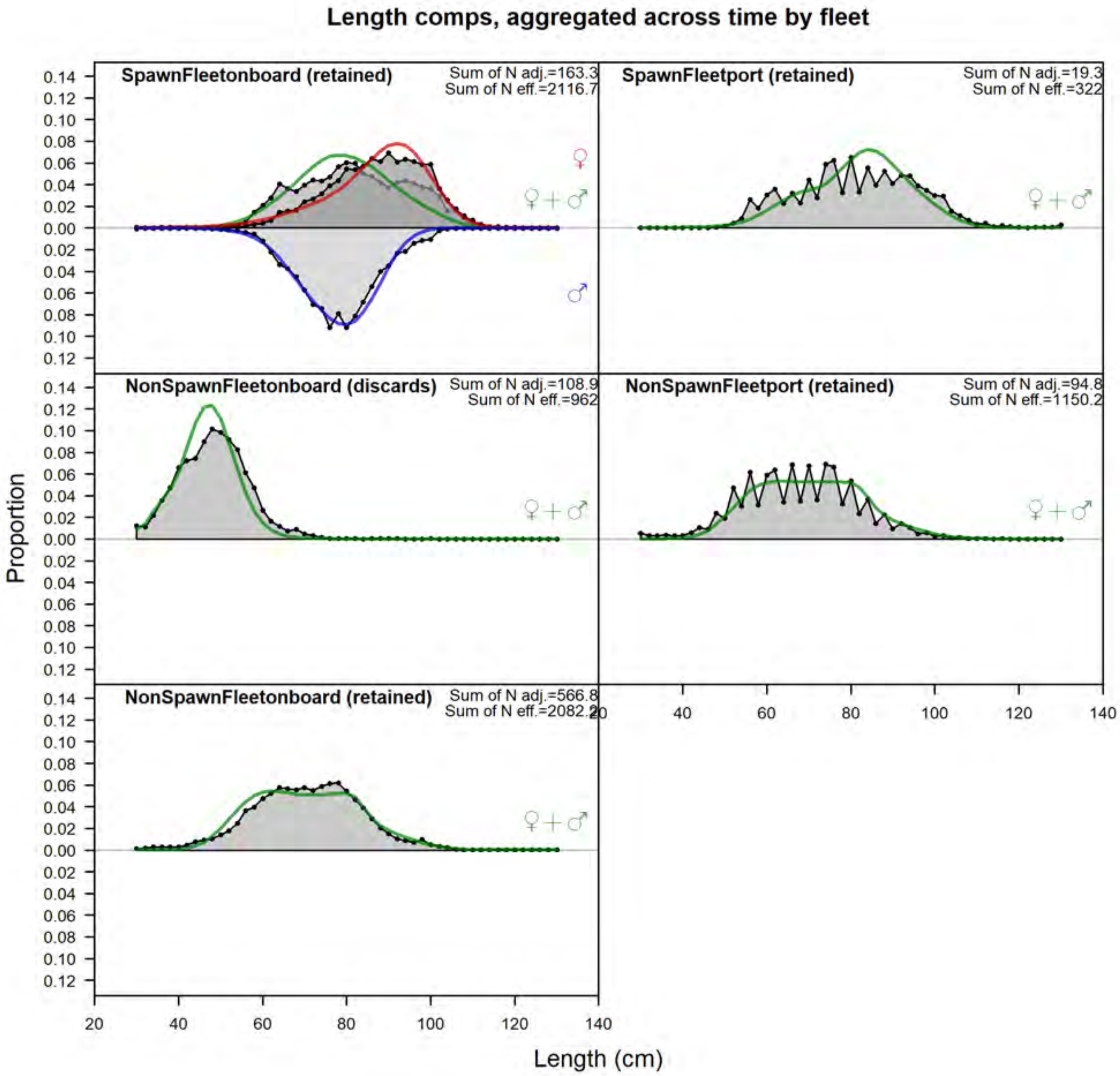

Figure 6.9. Length composition fits aggregated across years.

6.6.1.4 Assessment outcomes – base case

The estimated time series of recruitment under the base-case parameter set shows the typical episodic nature of Blue Grenadier recruitment, with strong year-classes in 1979, the mid-1980s, 1994, 2003, and from 2010 to 2017 (Figure 6.10). The trajectories of spawning biomass and spawning biomass relative to the un-exploited level are shown in Figure 6.10. This shows the increases and decreases in spawning biomass as the strong cohorts move into and out of the spawning population. Spawning biomass has varied considerably, with biomass below the target in 2013 and 2014, but nearly double virgin biomass in 1991, 2001 and 2021. Figure 6.11 shows various recruitment diagnostics and the annual recruitment deviations for the base case model. The figure showing recruitment deviations illustrates the historical episodic nature of recruitment, but also that the last eight estimates of recruitment are well above average. The Kobe plot in Figure 6.12 shows that the stock is well above virgin biomass levels, but also that there is considerable uncertainty regarding both relative fishing mortality and stock status.

The estimated virgin female biomass is 37,445 t (compared to 53,909 t in 2018 and 36,815 t in the 2013 assessments). Initial biomass is known to be sensitive in this model and often has varied betweem 35,000 t and 60,000 t (Figure 6.13; Castillo- Jordán and Tuck, 2018a). A likelihood profile on initial biomass illustrates this uncertainty (Section 5.2).

For the base case model, the projected 2022 spawning stock biomass will be 155% of virgin female spawning biomass (projected assuming 2020 catches in 2021), compared to 122% for 2019 in the 2018 assessment, and 94% for 2014 in the 2013 assessment. The 2022 recommended biological catch (RBC) under the 20:35:48 harvest control rule is 23,777 t, with 245 t estimated discards (23,532 t retained). The long-term RBC is 7,100 t, with 183 t discards (Table 6.8).

Table 6.8. The estimated RBC (tonnes), retained portion of the RBC, estimated discards and relative stock status for Blue Grenadier under the base case model. The retained catch up to 2020 is the actual tonnage (and 2021 catches are projected assuming 2020 catches in 2021), and the RBC is the sum of retained and estimated discards. The grey shading for year 2022 is used for stock status and RBC determination.

Year	RBC	Retained	Discard	Status
2017	2026	1698	328	0.87
2018	2010	1665	345	0.98
2019	7370	6914	456	1.09
2020	12,513	12,151	362	1.23
2021	12,341	12,151	190	1.41
2022	23,777	23,532	245	1.55
2023	21,605	21,391	214	1.47
2024	18,712	18,504	207	1.31
2025	15,848	15,643	205	1.14
2026	13,480	13,277	203	0.97
2027	11,684	11,482	201	0.84
2028	10,380	10,181	199	0.74
2029	9,458	9,262	196	0.66
2030	8,816	8,623	194	0.61
2031	8,370	8,178	191	0.58
2032	8,055	7,866	189	0.55
2033	7,827	7,640	188	0.54
2034	7,658	7,472	187	0.52
2035	7,529	7,343	186	0.51
2036	7,429	7,244	185	0.51
2037	7,351	7,166	184	0.50
2038	7,289	7,105	184	0.50
2039	7,241	7,058	184	0.49
2040	7,204	7,020	183	0.49
2041	7,174	6,991	183	0.49
2042	7,151	6,968	183	0.49
2043	7,133	6,950	183	0.48
2044	7,118	6,936	183	0.48
2045	7,107	6,925	183	0.48

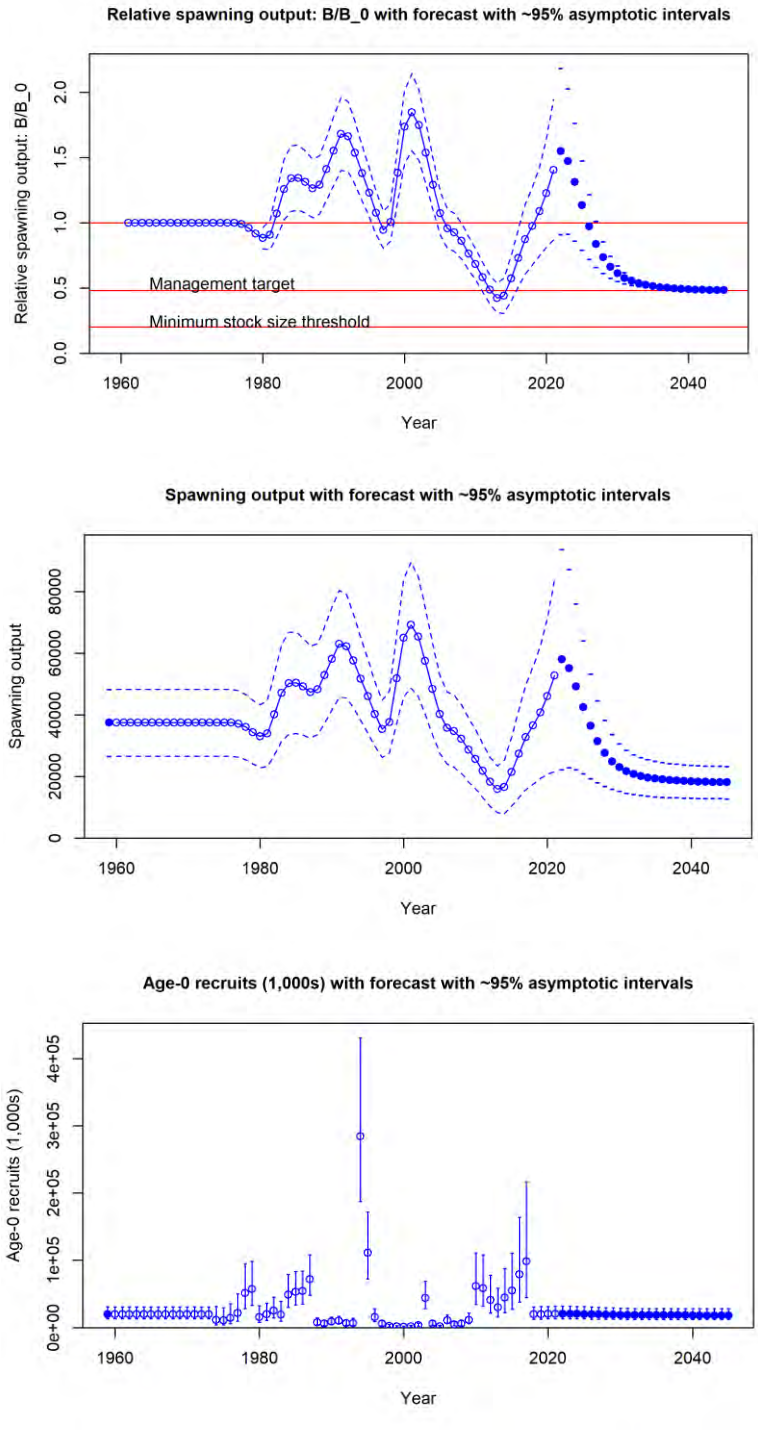

Figure 6.10. The estimated time-series of relative spawning biomass and annual recruitment for the 2021 base case assessment for Blue Grenadier.

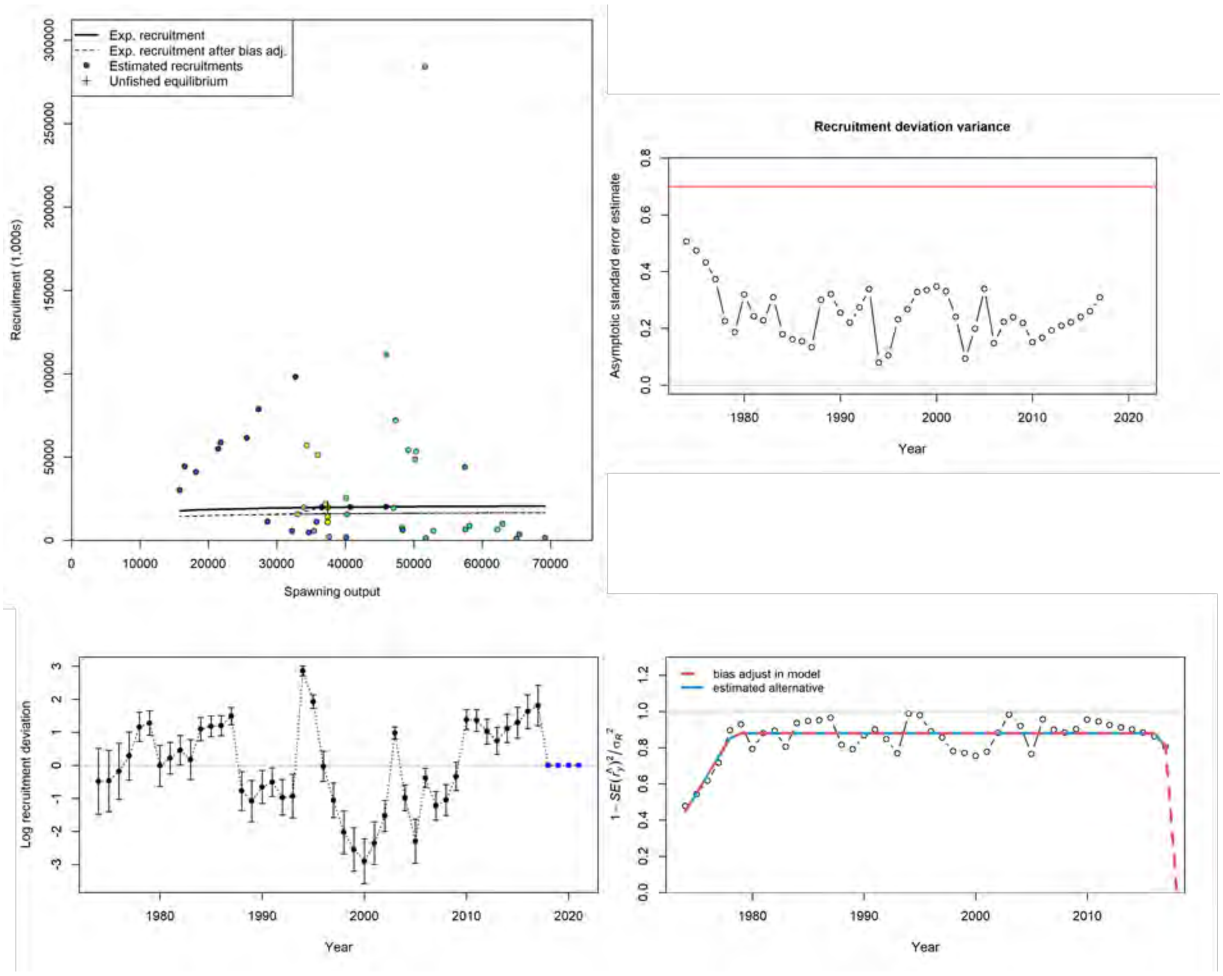

Figure 6.11. Time series showing the stock recruitment curve, recruitment deviations, recruitment deviation variance check and bias ramp for Blue Grenadier.

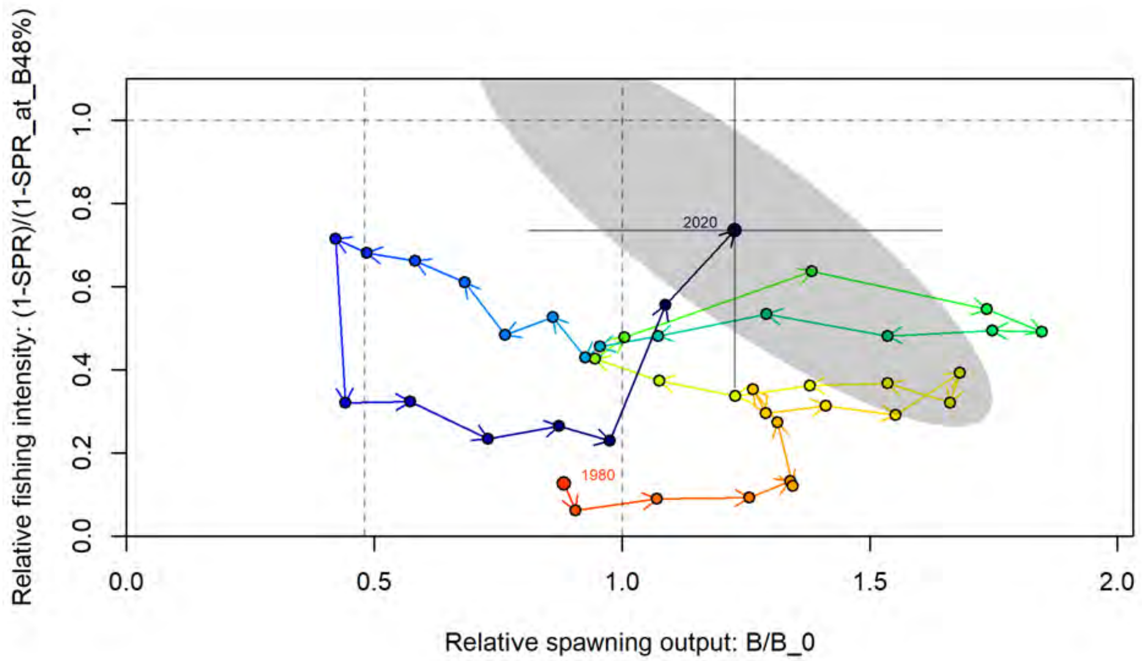

Figure 6.12. Kobe plot showing relative fishing mortality (y-axis) versus relative spawning biomass (x-axis).

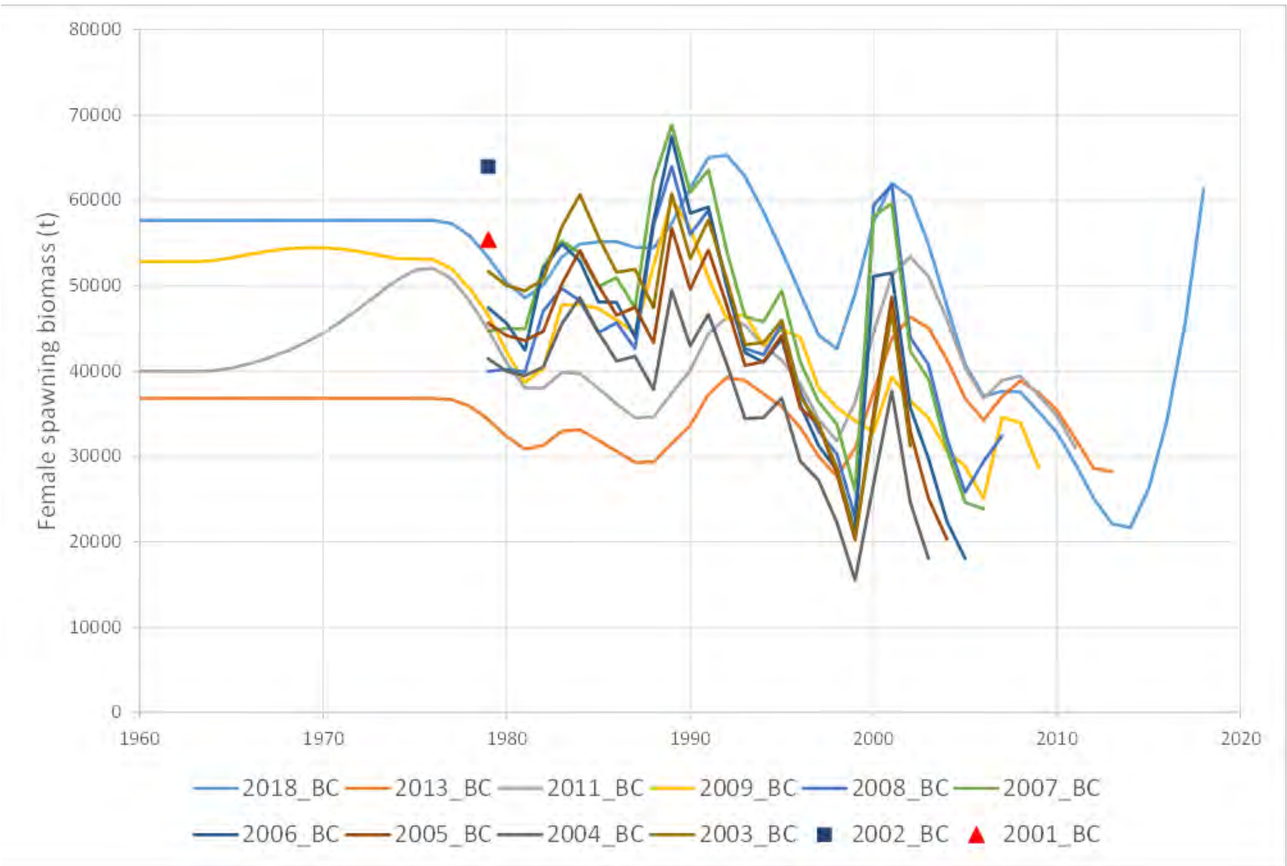

Figure 6.13. A retrospective of assessment outputs of female spawning biomass from each stock assessment from 2001 to 2018. Note that for 2001 and 2002 only values of biomass in 1979 were available (from Castillo-Jordán and Tuck, 2018a).

6.6.2 ***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 female natural mortality (M_f), virgin spawning biomass and stock status are provided in Figure 6.14-Figure 6.16.

For Blue Grenadier, the likelihood profile for female natural mortality, M_f, is shown in Figure 6.14, 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=0.23 yr^{-1}) and the likelihood profile suggests that it is reasonably well estimated, with a likely range between 0.21 and 0.26 yr^{-1}. The index and age data (suggest higher mortality) and the length data (suggest lower mortality) are in conflict. The non-spawning CPUE and to a lesser extent the egg survey data are driving the preference towards higher estimates of M_f, while there is little information in the Acoustic Survey data. All length data inputs are suggesting lower estimates of M_f, however, this is mostly driven by the spawning fleet onboard data. There is conflict in age data between the fleets, with the spawning fleet age data suggesting higher estimates of M_f are preferable, while the non-spawning fleet age data suggests lower estimates.

A likelihood profile for virgin spawning biomass (SSB_0) is shown in Figure 6.15, with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. This likelihood profile suggests a range of plausible values for SSB_0 ranging between around 27,000 and 52,000 t with the most likely value at around 37,000 t. The components of the likelihood relating to the surveys suggest larger values of SSB_0 whereas the age data want lower values of SSB_0. Similarly, a likelihood profile on stock status (2020) suggests a broad range of plausible values, from approximately 0.8 to 1.7 (Figure 6.16). The index and age data suggest higher relative biomass whereas the length data suggest lower relative biomass.

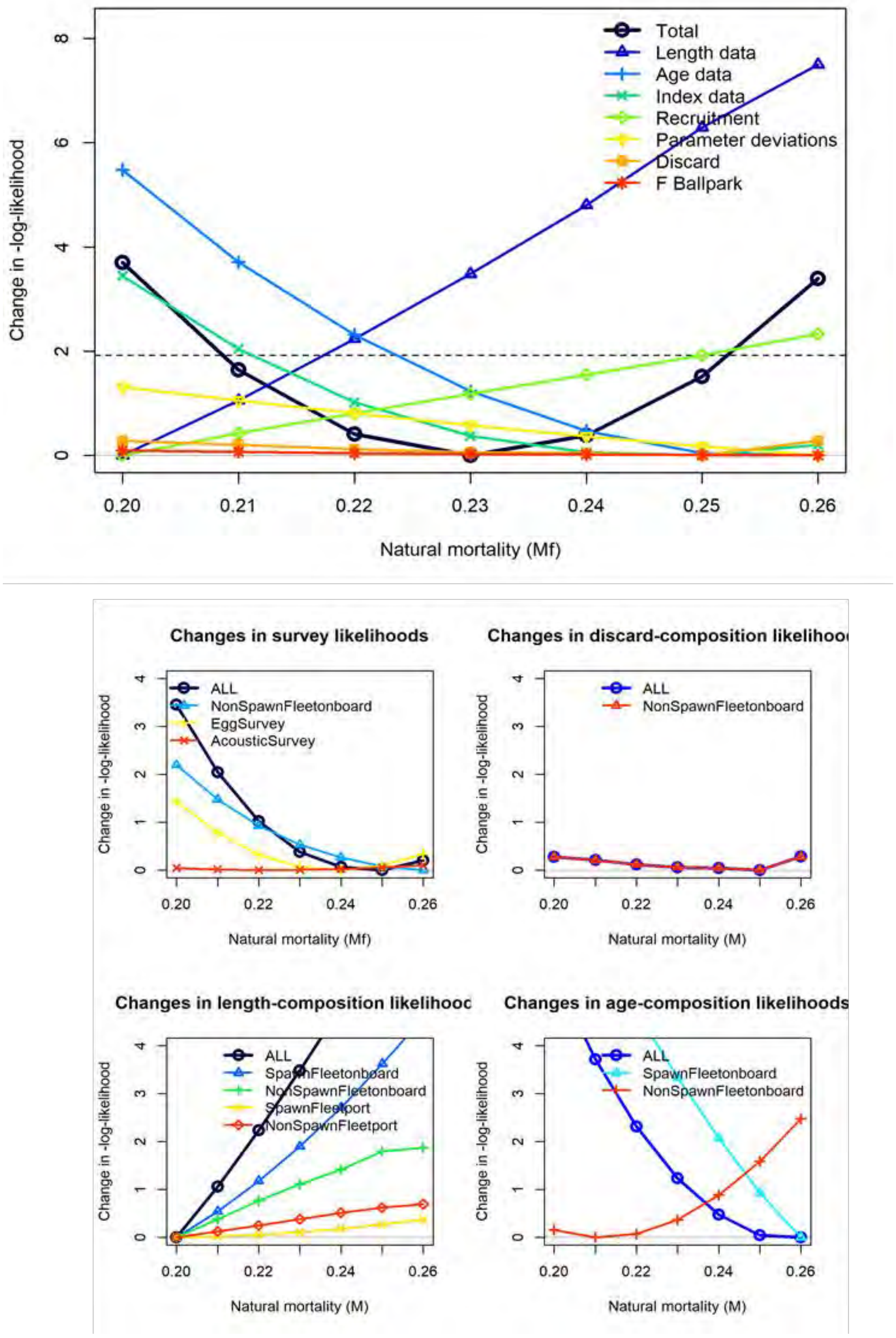

Figure 6.14. The likelihood profile (top) for female natural mortality, with 95% CIs for M_f ranging from 0.21 to 0.26. The estimated value for M is 0.23 yr^{-1}. Piner plot (bottom) for the likelihood profile showing components of the change in likelihood for index, discard, length and age in addition to the changes in the total likelihood.

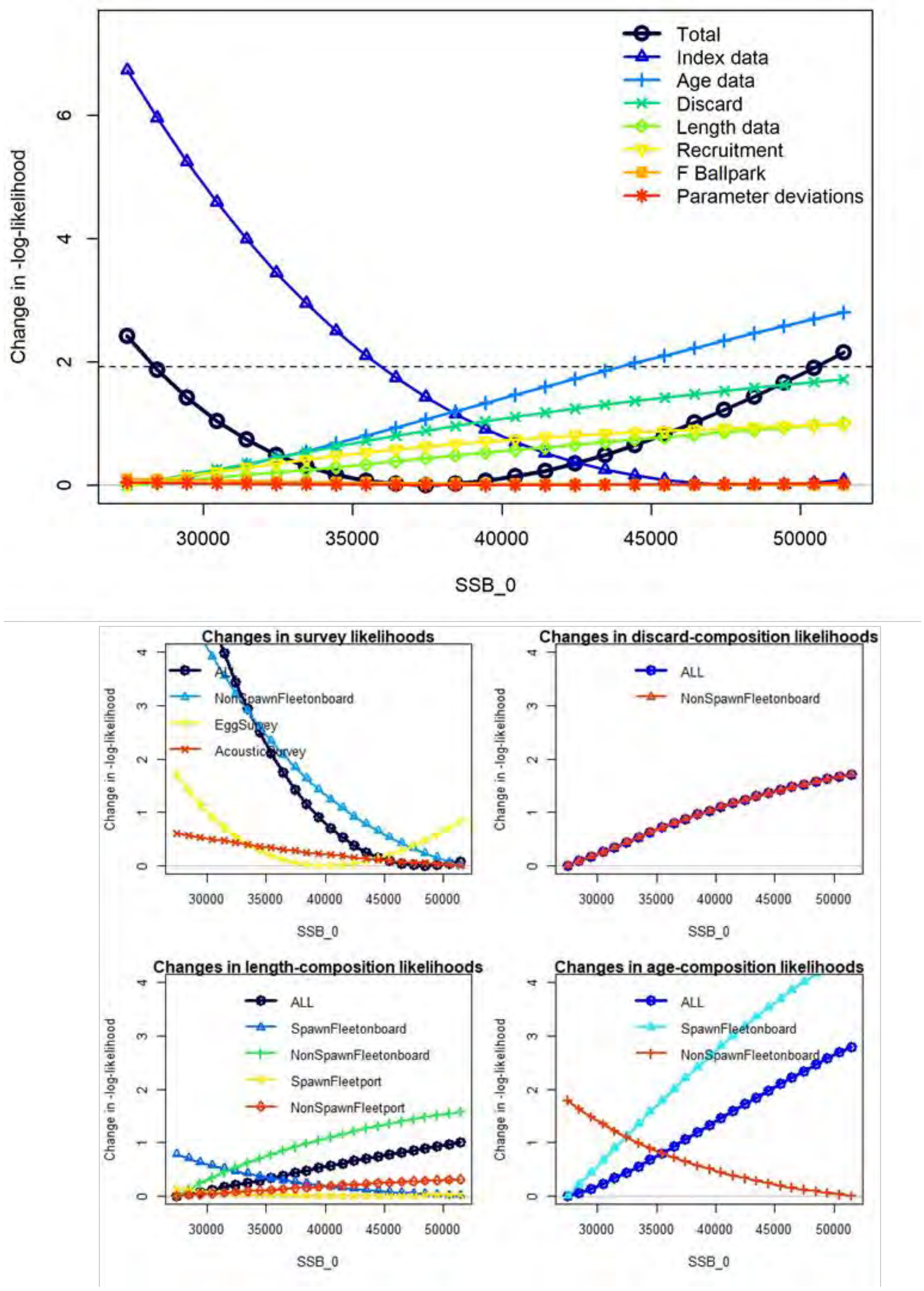

Figure 6.15. The likelihood profile (top) for virgin spawning biomass, with 95% CIs ranging from 27,000 t to 52,000 t. The estimated value is 37,000 t. Piner plot (bottom) for the likelihood profile showing components of the change in likelihood for index, discard, length and age in addition to the changes in the total likelihood.

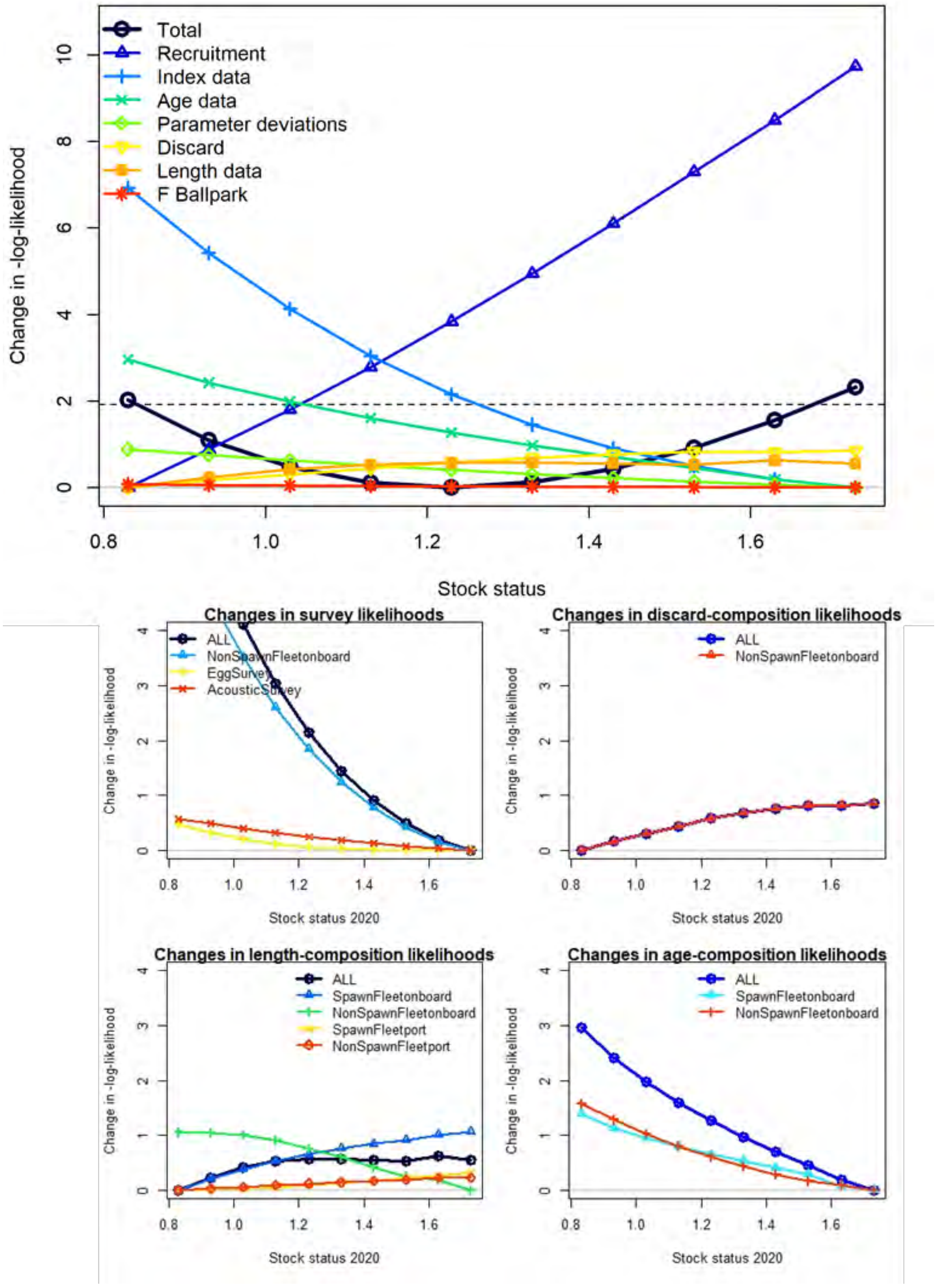

Figure 6.16. The likelihood profile (top) for 2020 stock status, with 95% CIs ranging from 0.8 to 1.7. The estimated value is 1.25. Piner plot (bottom) for the likelihood profile showing components of the change in likelihood for index, discard, length and age in addition to the changes in the total likelihood.

6.6.3 *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 (Cadrin and Vaughan, 1997; Mohn, 1999). The severity of retrospective patterns can be quantified using a statistic called Mohn's rho, which is defined as the average of the relative differences between an estimate from an assessment with a truncated time series and an estimate of the same quantity from an assessment using the full time series (Hurtado-Ferro et al., 2015). Mohn's rho values are calculated for a range of effects, including SSB, recruitment, *F* and stock status. As a general rule, values of Mohn’s rho higher than 0.20 or lower than −0.15 are cause for concern in an assessment (Hurtado-Ferro et al., 2015). The retrospective analysis for relative and absolute spawning biomass, fit to non-spawning catch rate, and recruitment is shown in Figure 6.17, with the base case model in dark blue, and then successive years data removed back to 2015 (shown in red).

There is some evidence of over-optimistic estimation of the spawning biomass in the last year of the SSB trajectory in each case, which is also supported by Mohn’s Rho being 0.26 for biomass, -0.49 for recruitment, -0.1 for *F* and 0.26 for stock status. Of these, estimates for biomass, recruitment and stock status are higher or lower than threshold values and indicate retrospective patterns of concern, suggesting some misspecification within this assessment.

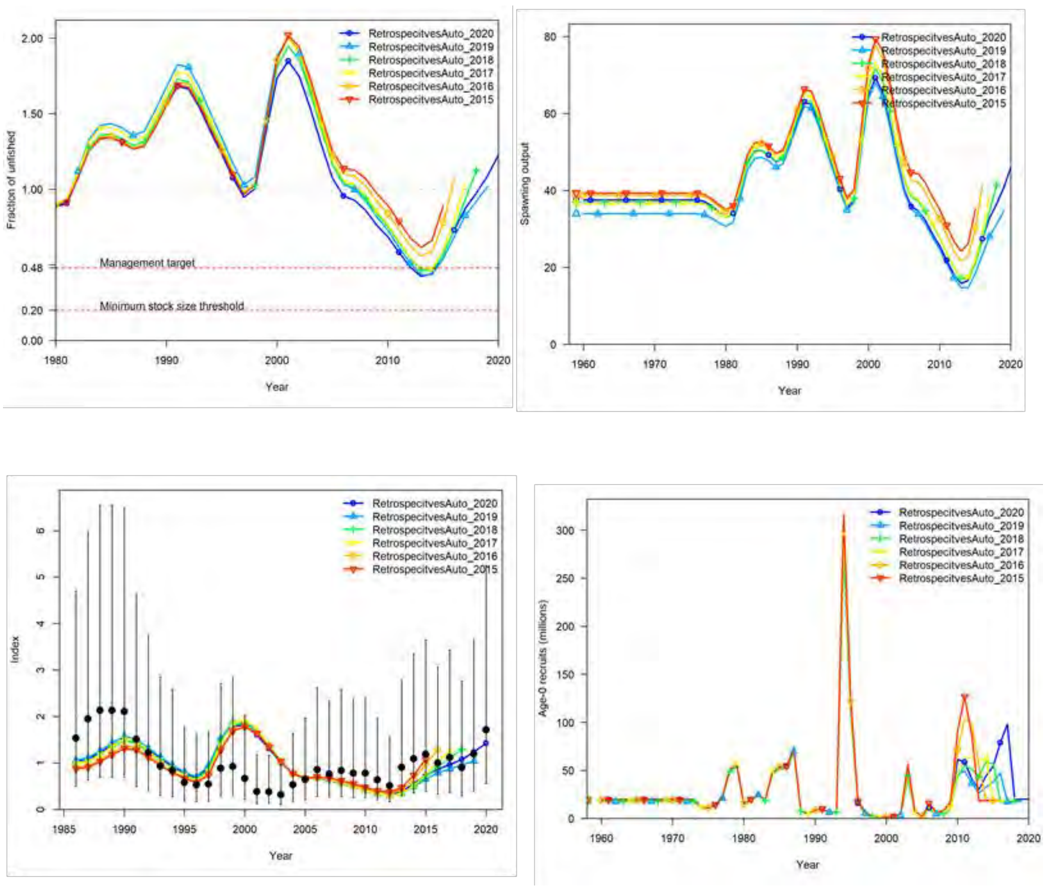

Figure 6.17. Retrospectives for relative and absolute spawning biomass, CPUE and recruitment for Blue Grenadier, with the most recent base case assessment shown (blue) and then successive years removed back to 2015 (red).

6.6.4 *Jitter analysis*

Jitter analysis is a technique used to test the optimality, robustness and stability of the maximum likelihood estimate obtained for a particular model. This involves randomly changing the starting values used for all estimated parameters and re-running the model, to test what alternative solutions may be found by the optimisation algorithm from different initial locations, which is sometimes referred to as sensitivity to initial conditions. Two diagnostics are of interest with a jitter analysis, initially a check on whether a better "optimal solution" may be found, with a higher likelihood value, and also to see how frequently the optimal solution is found. As all estimated parameters are randomly modified, or "jittered," simultaneously, this can sometimes result in a model either failing to converge or finding a local maximum in a different (suboptimal) part of the multi-dimensional parameter space. A jitter analysis was conducted with 25 replications, modifying initial values by 0.1.

For the base case eight of the 25 jitter replicates found the same optimum solution, with a likelihood of 1922.81. The remaining 17 replicates found worse 'optimal' solutions with 16 replicated with a likelihood of 1923.24 and the last with a likelihood of 1930.00.

6.6.5 *Sensitivities*

Results of the sensitivities to the potential base case are listed in Table 6.9. The usual set of sensitivities are provided (which includes sensitivities on natural mortality, steepness, σ_R and halving and doubling the weighting on length, age and index data). Relative spawning biomass varies between 1.35 and 2.12 of virgin biomass, but with most sensitivities near 1.6.

Unweighted likelihood components for the base case and differences for the sensitivities are shown in Table 6.10. 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.

Table 6.9. Summary of results for the base case model BC and sensitivity tests. RBC 2022-24 is the average 3-year RBC. RBC 2022-26 is the average 5-year RBC. Note that only the base case is tuned.

Model	SB0	SB_Curr	CurrDepl	2022 RBC	RBC 2022-2024	RBC 2022-2026	RBC Long-term
Base Case Model (M_f=0.23, M_m=0.24, h=0.75)	37,445	57,991	1.55	23,777	21,365	18,684	7,100
M_f = 0.21	36,245	48,939	1.35				
M_f = 0.25	38,442	65,679	1.71				
h = 0.65	39,149	69,311	1.77				
h = 0.85	38,350	66,991	1.75				
σ_R= 0.6	34,745	48,002	1.38				
σ_R = 0.8	42,079	84,083	2.00				
Double weight on Index data	43,313	91,726	2.12				
Half weight on Index data	32,439	44,700	1.38				
Double weight on Length data	38,551	72,653	1.88				
Half weight on Length data	39,971	70,952	1.78				
Double weight on Age data	35,639	61,653	1.73				
Half weight on Age data	41,872	69,796	1.67				

Table 6.10. Summary of likelihood components for the base-case BC and sensitivity tests. Likelihood components are unweighted, and sensitivities from the BC are shown as differences from the base case. A negative value indicates a better fit, a positive value a worse fit.

Model	TOTAL	Survey	Discard	Length comp	Age comp	Recruitment
Base Case Model (M_f=0.23, M_m=0.24, h=0.75)	1922.81	-6.73	25.55	308.00	1505.08	66.61
$M_f = 0.21$	0.97	0.86	-0.01	-1.16	1.53	-0.57
$M_f = 0.25$	0.87	-0.53	0.03	1.61	-0.56	0.59
$h = 0.65$	1.44	0.32	7.91	-9.84	0.27	2.40
$h = 0.85$	-0.34	0.72	7.45	-9.89	0.00	0.91
$\sigma_R = 0.6$	21.41	0.74	2.62	1.14	4.79	12.35
$\sigma_R = 0.8$	-7.65	-3.02	-2.10	9.81	-5.15	-6.98
Double weight on Index data	8.51	-5.54	2.25	8.83	0.14	2.95
Half weight on Index data	1.49	4.43	6.24	-9.52	-0.28	0.09
Double weight on Length data	14.04	0.10	24.20	-41.84	23.55	4.76
Half weight on Length data	18.63	-1.07	-9.22	50.88	-18.75	-0.57
Double weight on Age data	12.46	0.80	2.32	27.02	-29.93	10.35
Half weight on Age data	11.58	-0.29	6.61	-24.43	38.63	-7.34

6.7 Discussion

The estimated virgin female biomass is 37,445 t (compared to 53,909 t in 2018 and 36,815 t in the 2013 assessments). Initial biomass is known to be sensitive in this model and often has varied between 35,000 t and 60,000 t. The likelihood profiles reinforce that initial biomass is uncertain, as is the estimate of current stock status. However, all model sensitivities showed current relative biomass being well above the target and likely to be above initial biomass levels. There continues to be strong estimates of recent recruitment (eight years above average) which is a good sign for the fishery. As with all assessments, recent estimates of recruitment are generally less well estimated (as there are less data to inform those estimates) and so some caution should be taken with regard to the estimated recent recruitments. In addition, reducing the broad estimates of relative current biomass would be beneficial, and additional acoustic estimates of spawning biomass will likely assist in this regard. As has been observed in previous assessments of Blue Grenadier, the fit to the non-spawning fishery catch rate, especially in the early years, is poor. Further refinement of the model should consider alternative GLM models for CPUE standardisation, or potential changes to model structure to account for the poor fit. The assessment shows retrospetive patterns of concern for biomass, *F* and stock status estimates. These results suggest that there could be some misspecification in the assessment with a time varying factor that may not be accounted for in the assessment. Further investigation of these patterns in future assessments is warranted.

Assessment outcome:

The projected 2022 spawning stock biomass will be 155% of virgin female spawning biomass (projected assuming 2020 catches in 2021), compared to 122% for 2019 in the 2018 assessment, and 94% for 2014 in the 2013 assessment.

For the base case model, the 2022 recommended biological catch (RBC) under the 20:35:48 harvest control rule is 23,777 t, with 245 t estimated discards (23,532 t retained). The long-term RBC is 7,100 t, with 183 t discards.

6.8 Acknowledgements

Age data were provided by Kyne Krusic-Golub (Fish Ageing Services), ISMP and AFMA logbook and CDR data were provided by John Garvey (AFMA). Mike Fuller, Paul Burch, Robin Thomson, Roy Deng, Franzis Althaus, Toni Cannard and Caroline Sutton (CSIRO) pre-processed the data. Miriana Sporcic provided standardised CPUE. Malcolm Haddon provided useful code for auto-balancing, Athol Whitten provided useful R code for organising plots. Paul Burch provided an updated ageing error matrix. Jemery Day, Andre Punt, Robin Thomson and Paul Burch (CSIRO) provided valuable review and discussion of this work. Ian Taylor, Chantel Wetzel, Kathryn Doering and Kelli Johnson (NOAA) are thanked for helpful reccomendations and fixes in relation to the the r4ss package. The r4ss package maintained by Ian Taylor (https://github.com/r4ss/r4ss) was critical for producing multiple diagnostic plots, and tuning models.

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Tuck, G.N. 2013. Stock assessment of blue grenadier *Macruronus novaezelandiae* based on data up to 2012. Technical report to the Slope Resource Assessment Group 6-8 November 2013. Hobart Tasmania.

Tuck, G.N. and Bessell-Browne, P. (2021) Blue grenadier (*Macruronus novaezelandiae*) stock assessment based on data up to 2020 – development of a preliminary base case. Technical paper presented to the SERAG, 20-21 October 2021, Hobart, Australia.

Tuck, G.N., Smith, D.C and Talman, S. 2004. Updated stock assessment for blue grenadier *Macruronus novaezelandiae* in the South East Fishery: August 2004. Report to the Slope Fishery Assessment Group, August 2004.

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6.10 Appendix

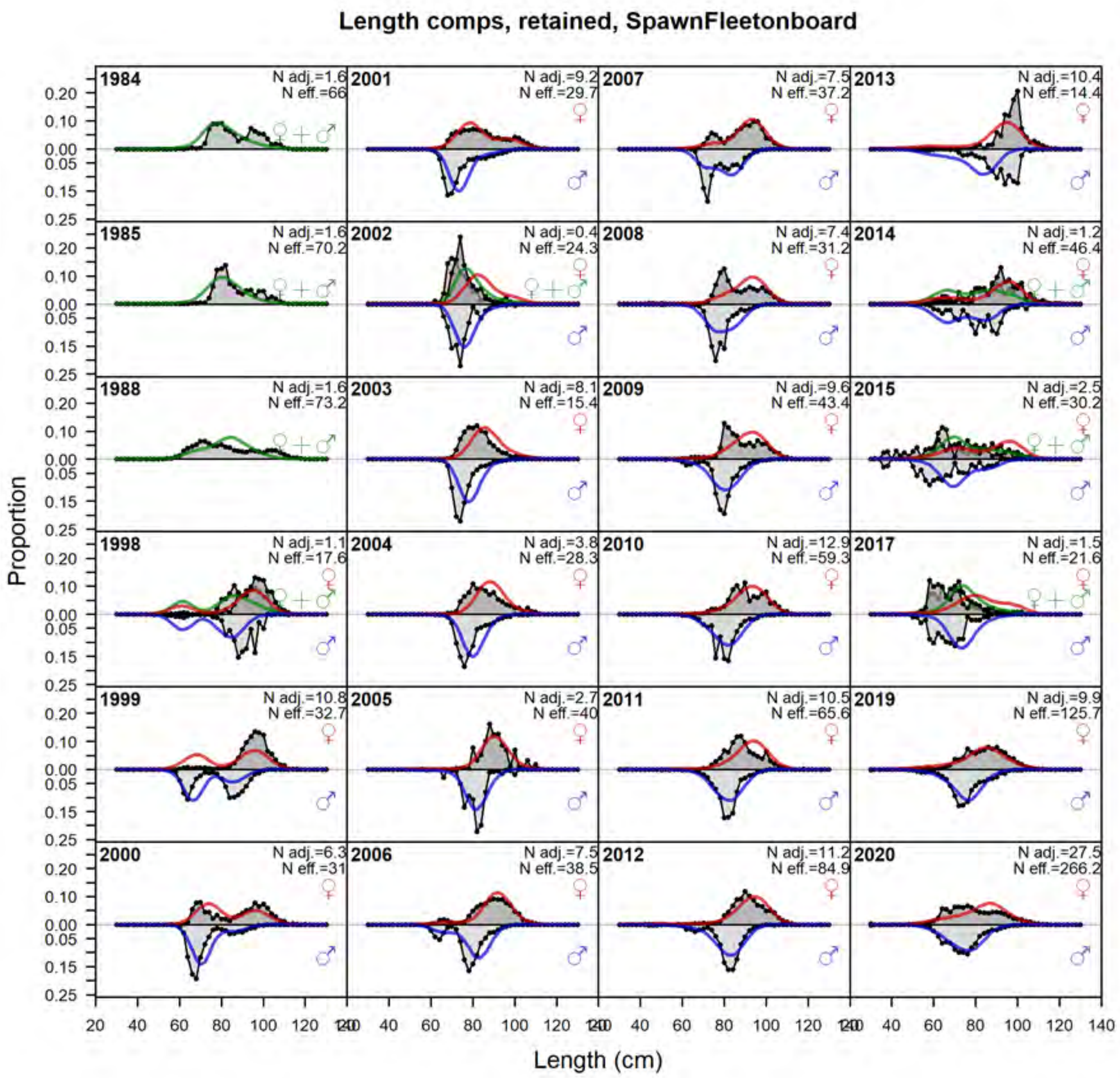


Figure 6.18. Length composition fits: onboard spawning fleet retained.

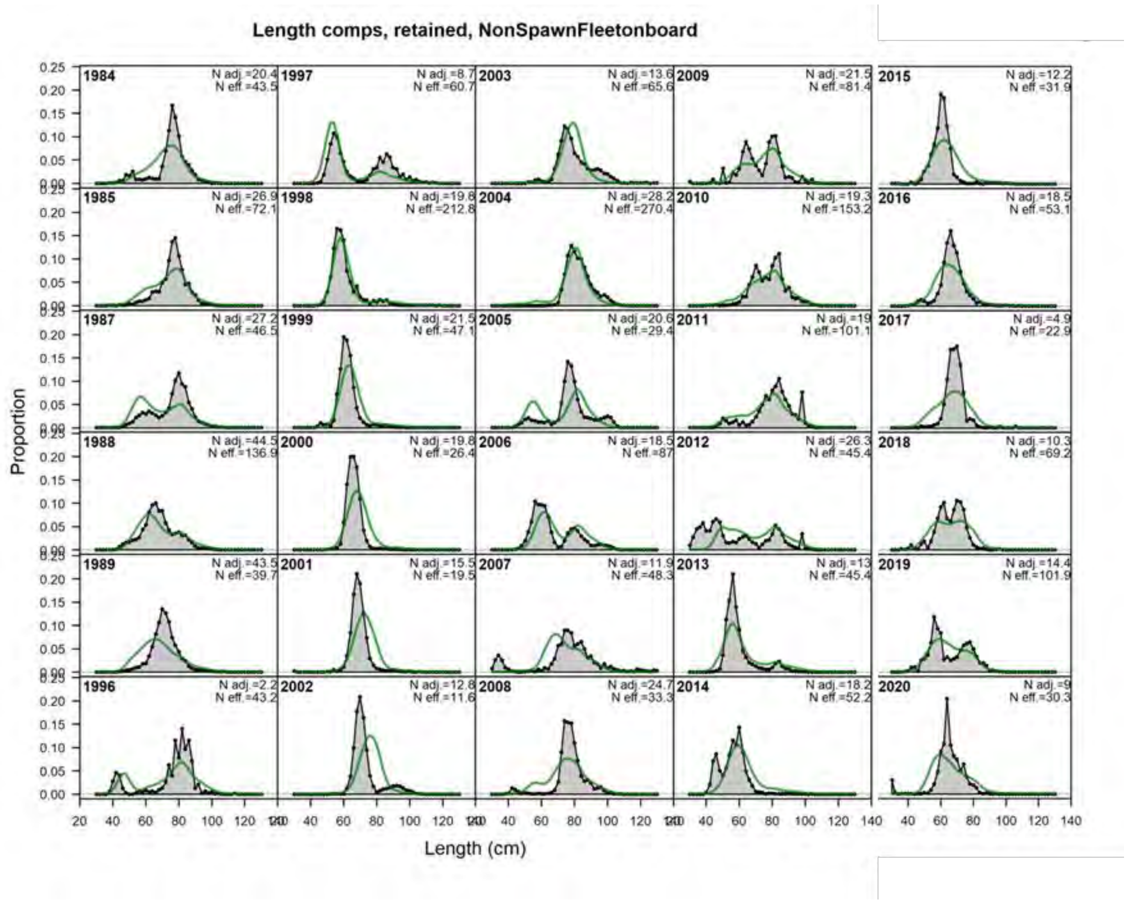


Figure 6.19. Length composition fits: onboard non-spawning fleet retained.

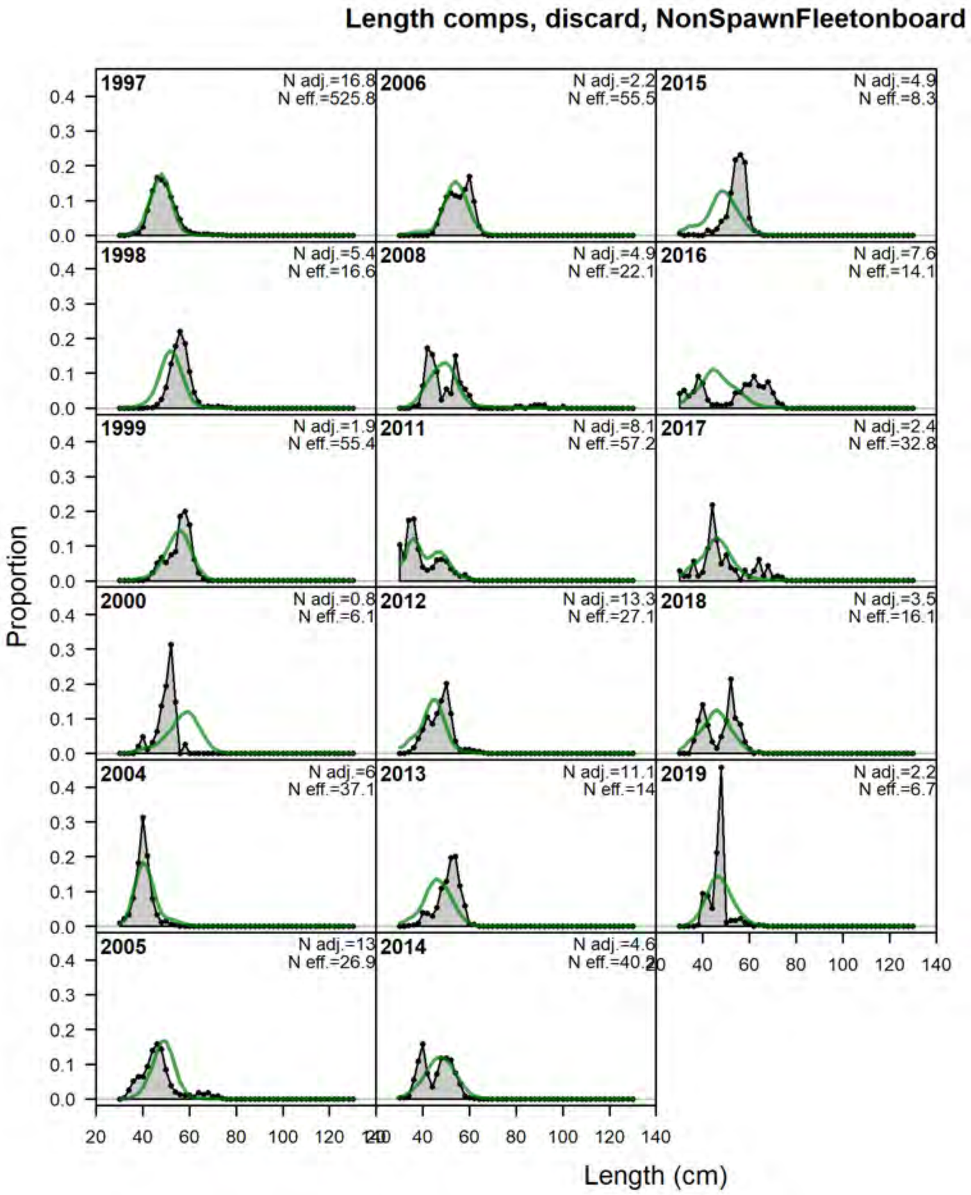


Figure 6.20. Length composition fits: onboard non-spawning fleet discard.

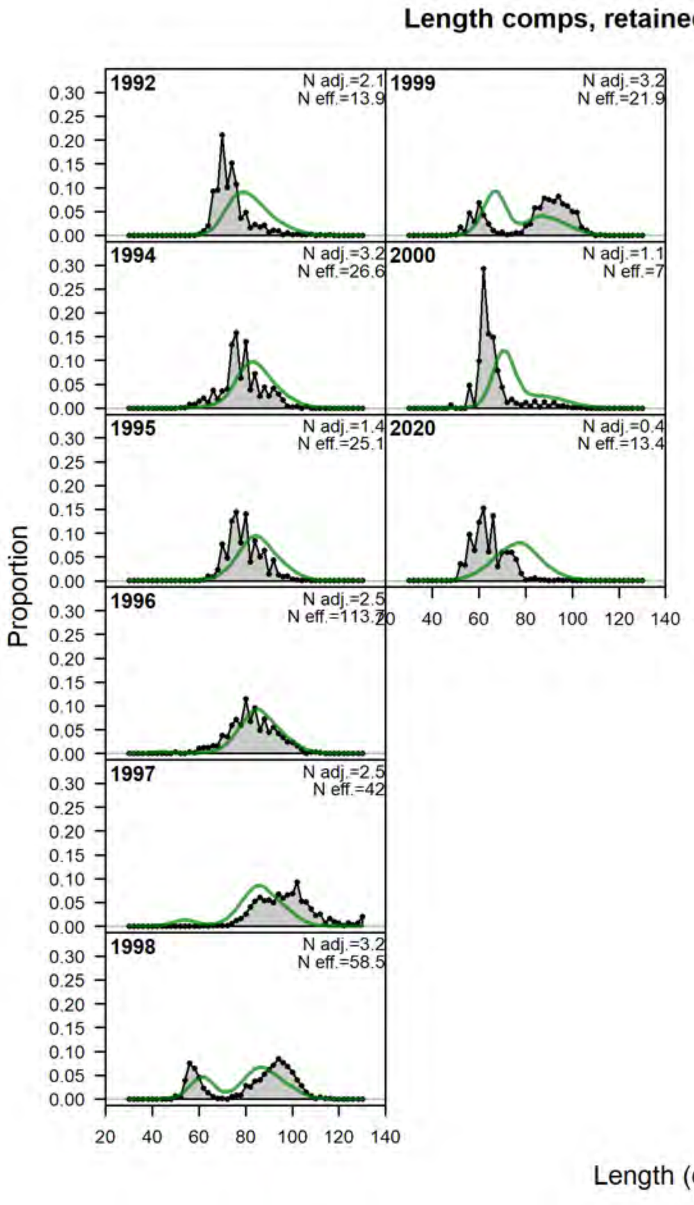


Figure 6.21. Length composition fits: port spawning fleet retained.

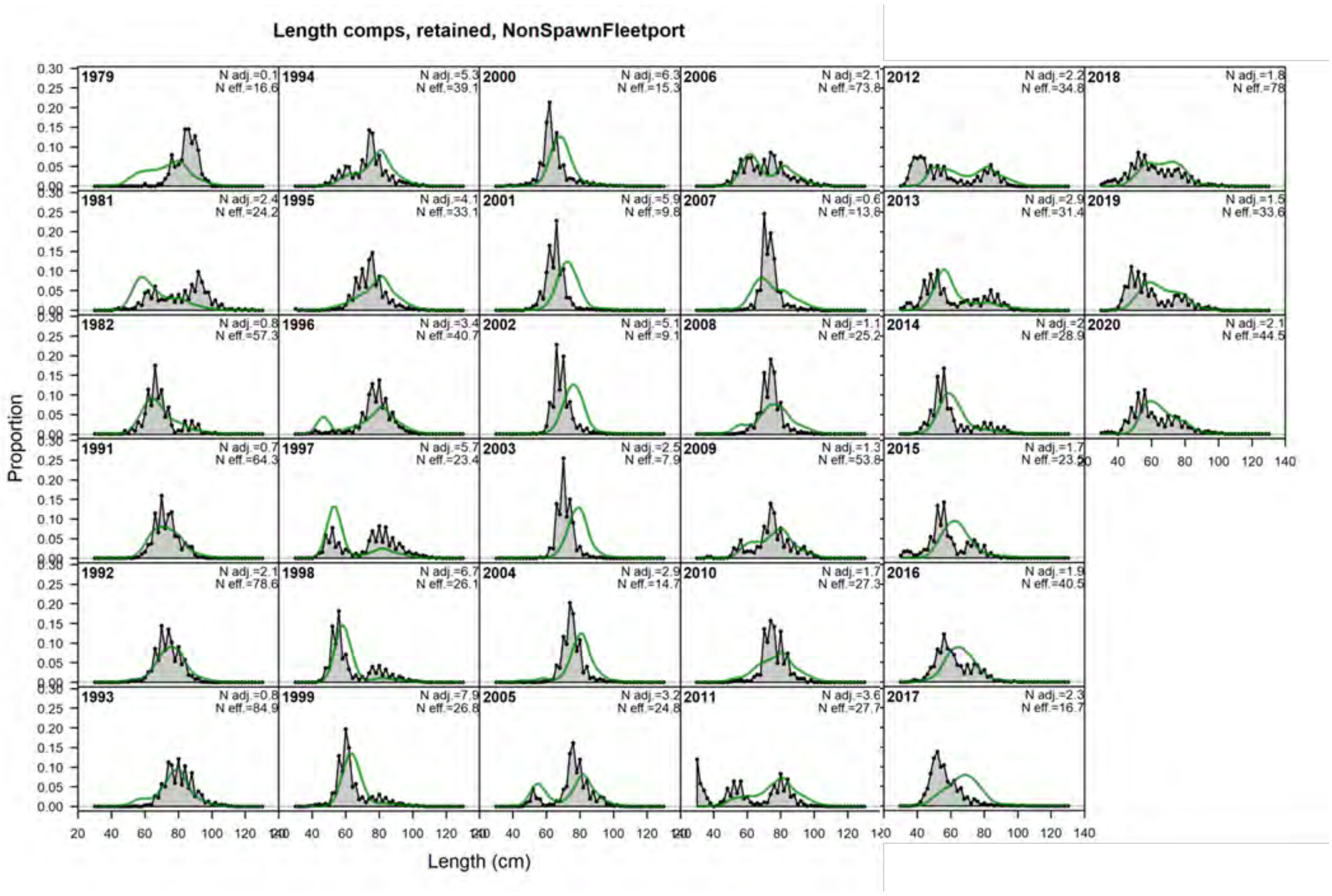


Figure 6.22. Length composition fits: port non-spawning fleet retained.

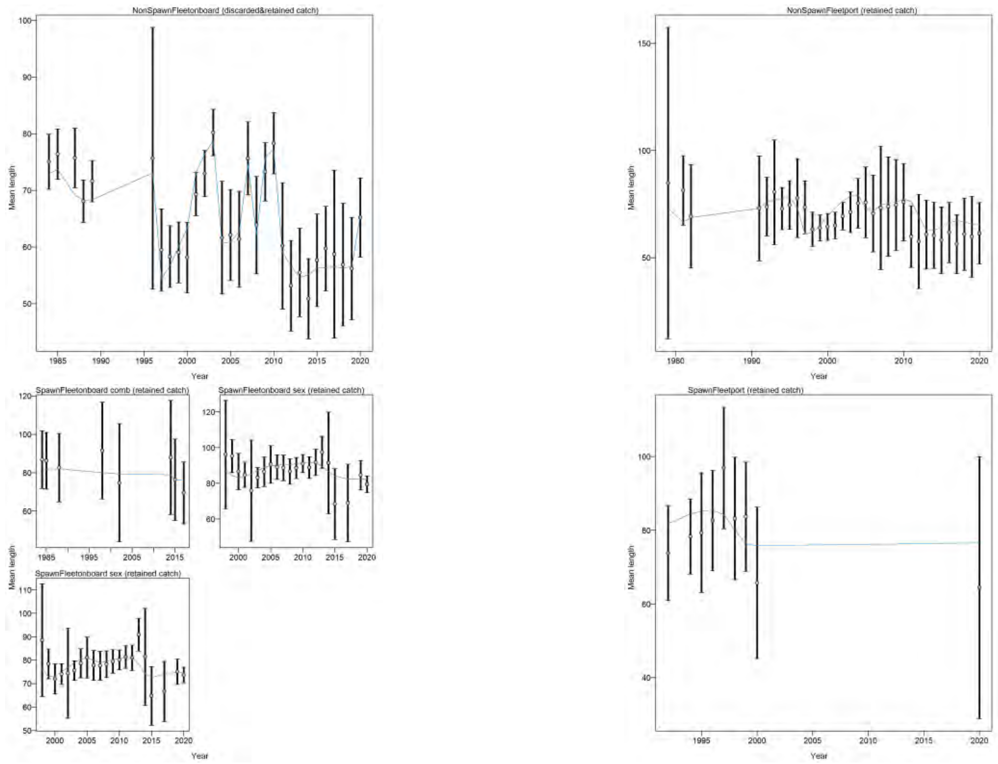


Figure 6.23. Length composition fit diagnostics from tuning. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data.

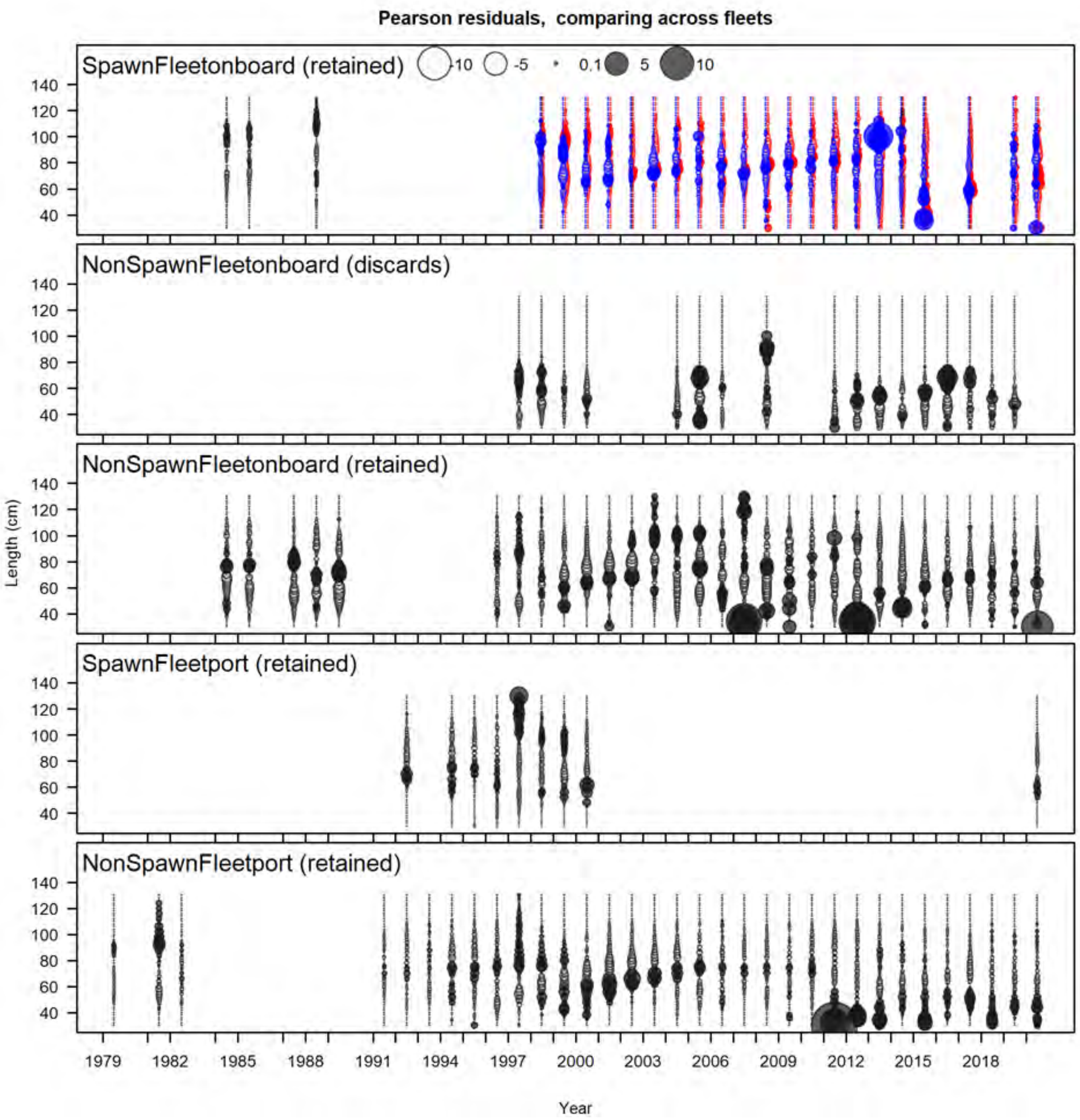


Figure 6.24. Residuals from the annual length compositions for base case

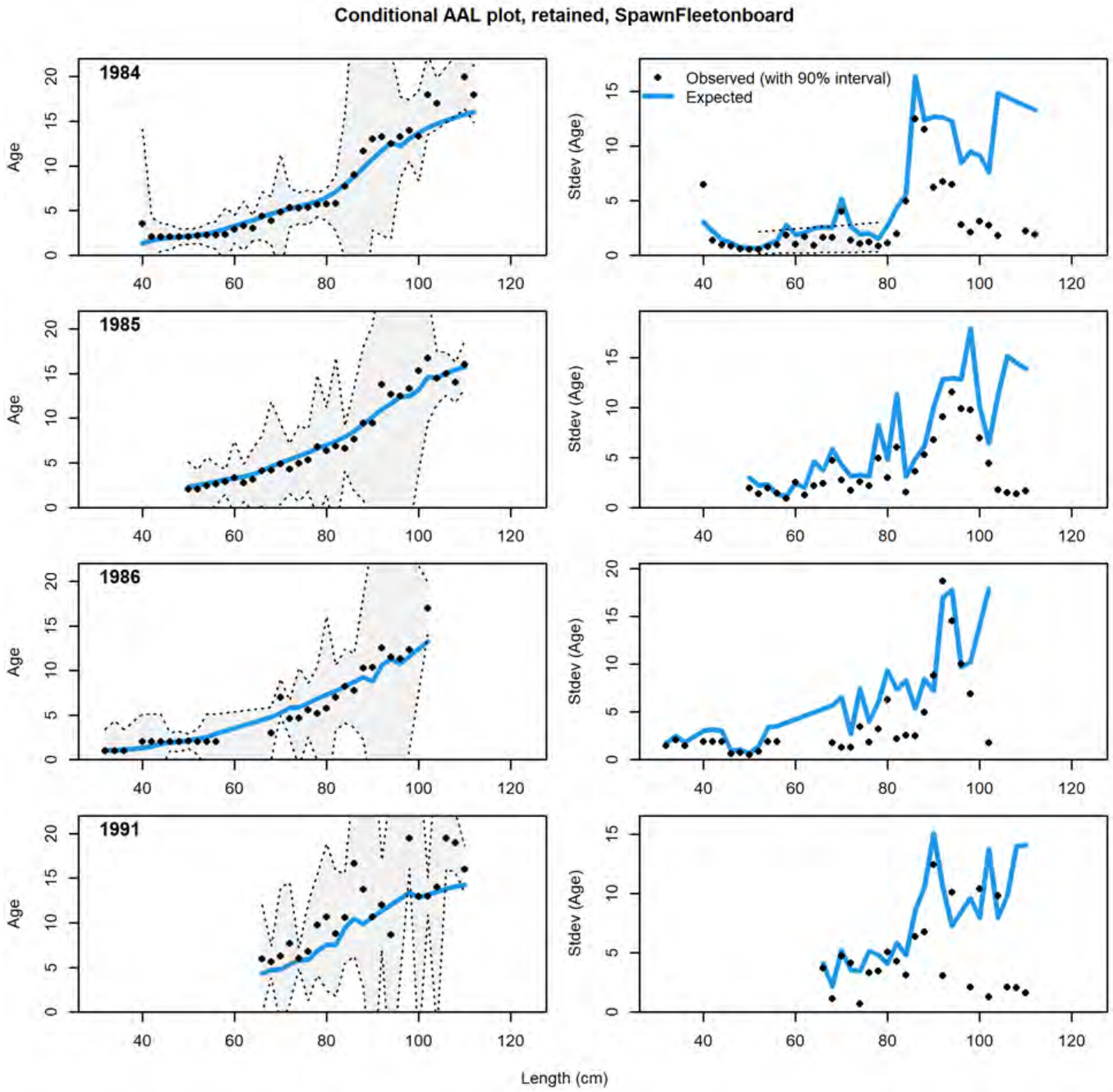
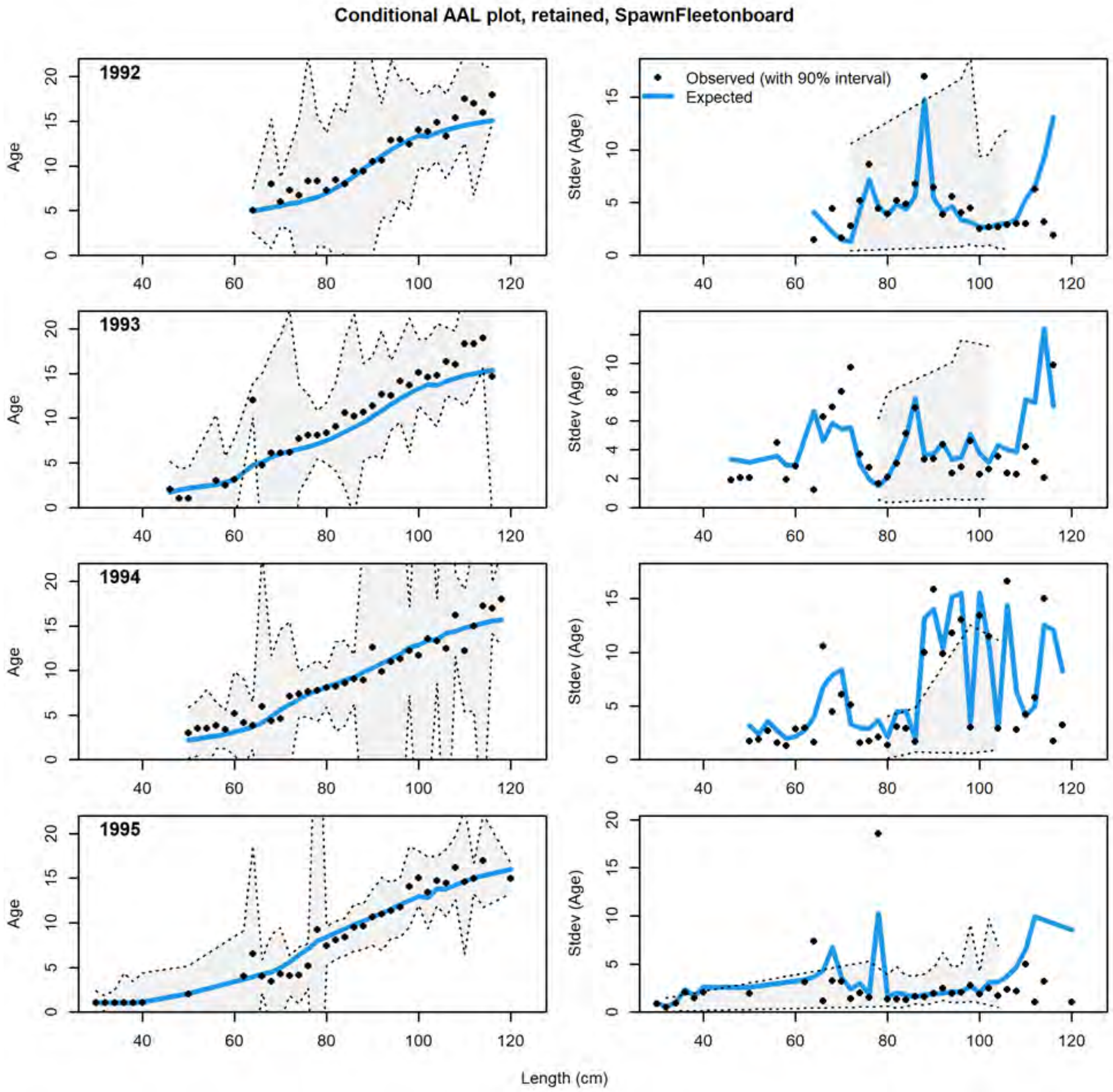
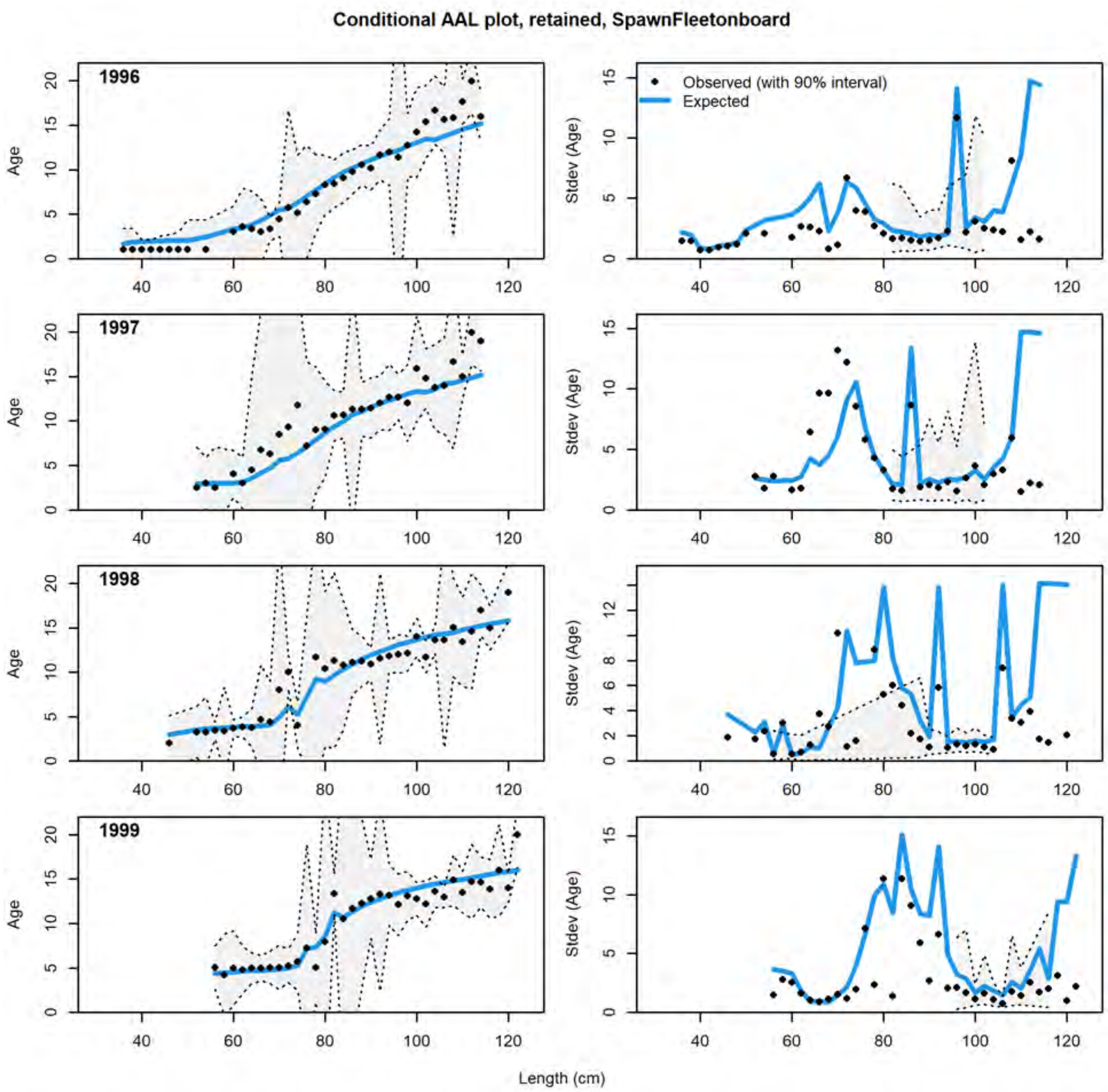
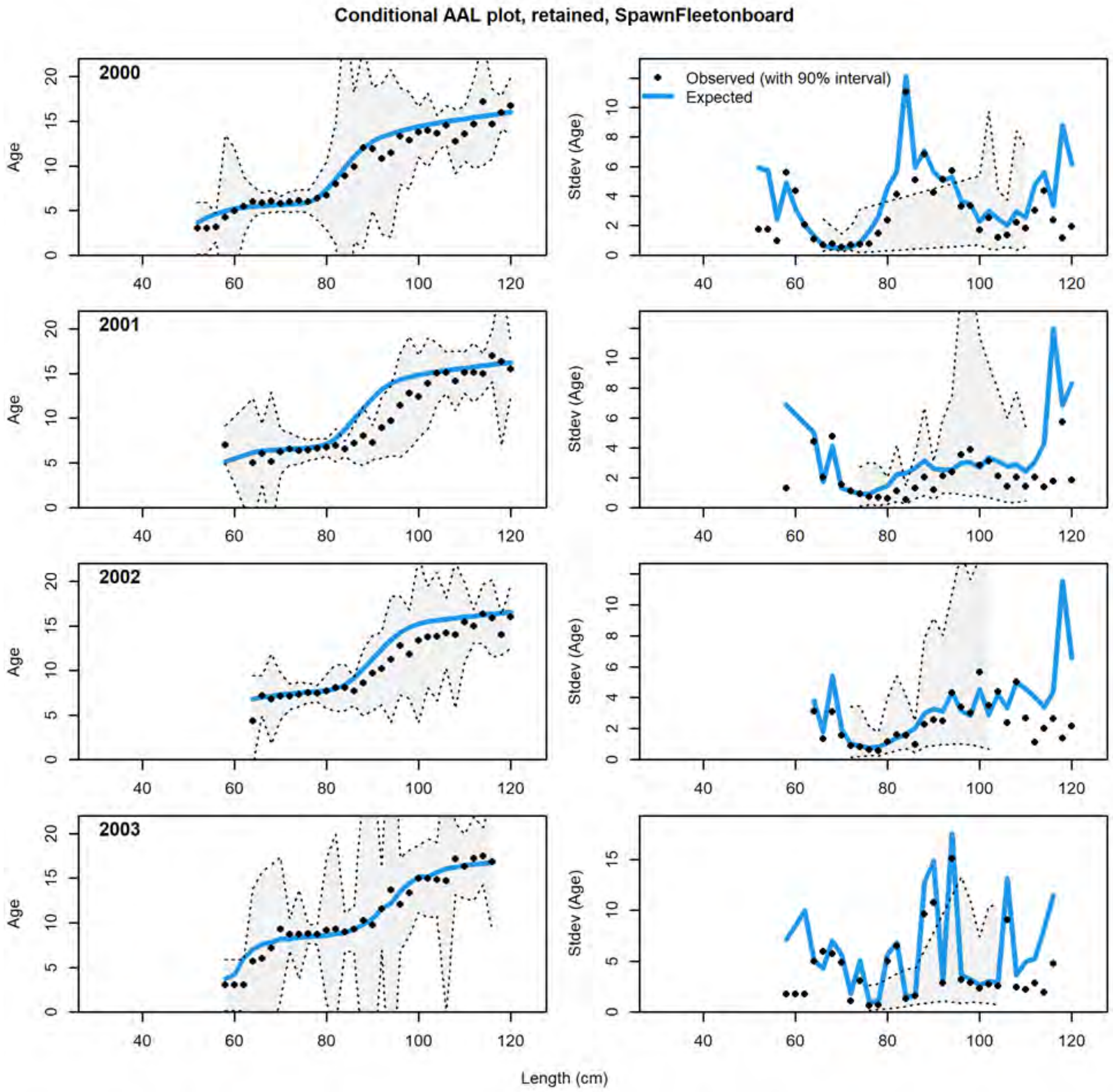
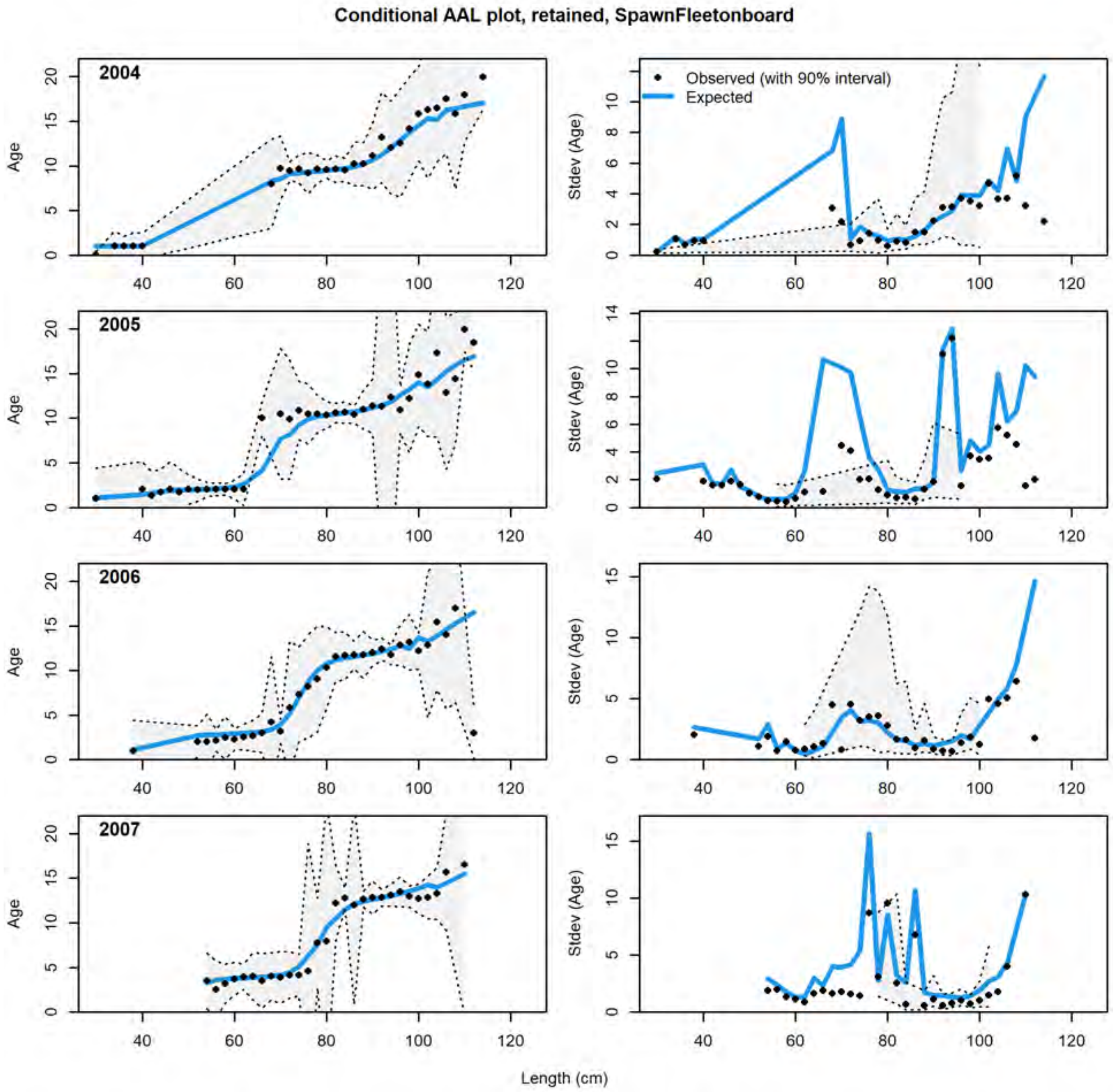


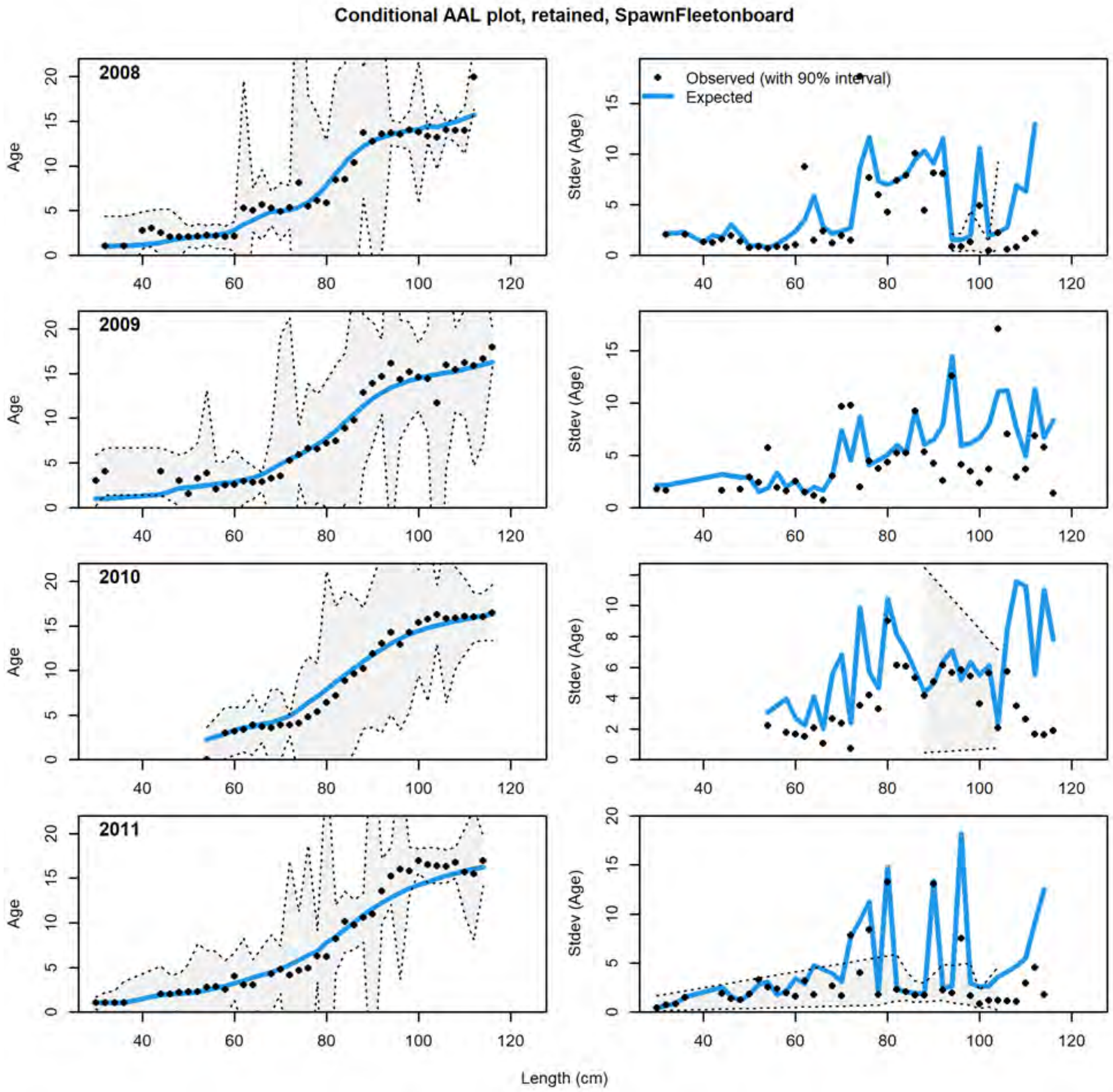
Figure 6.25. Fits to conditional age at length data.


Conditional AAL plot, retained, SpawnFleetonboard
1992
1993
1994
1995
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)


Conditional AAL plot, retained, SpawnFleetonboard
1996
1997
1998
1999
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)


Conditional AAL plot, retained, SpawnFleetonboard
2000
2001
2002
2003
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)


Conditional AAL plot, retained, SpawnFleetonboard
2004
2005
2006
2007
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)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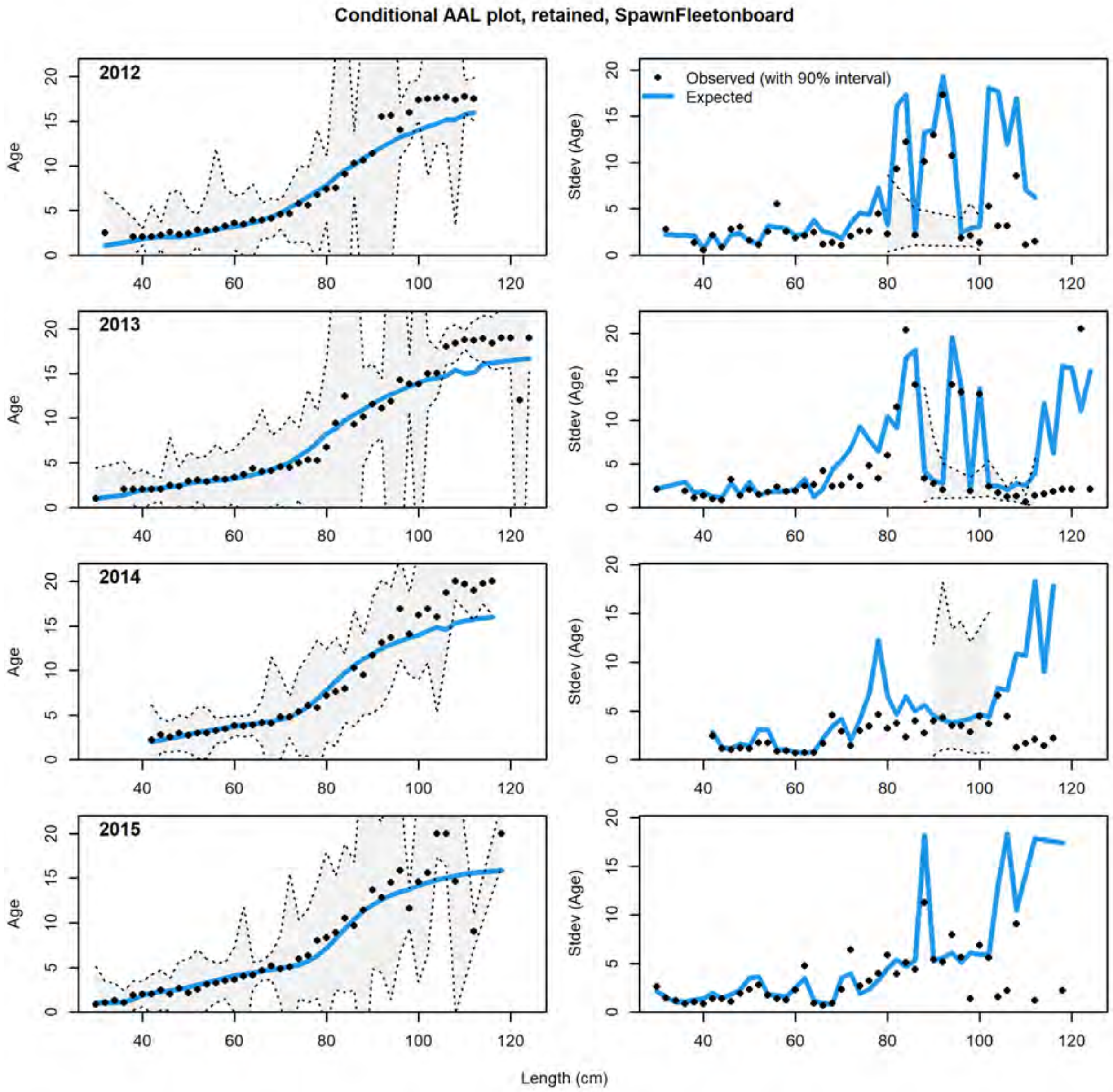
2008
2009
2010
2011
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)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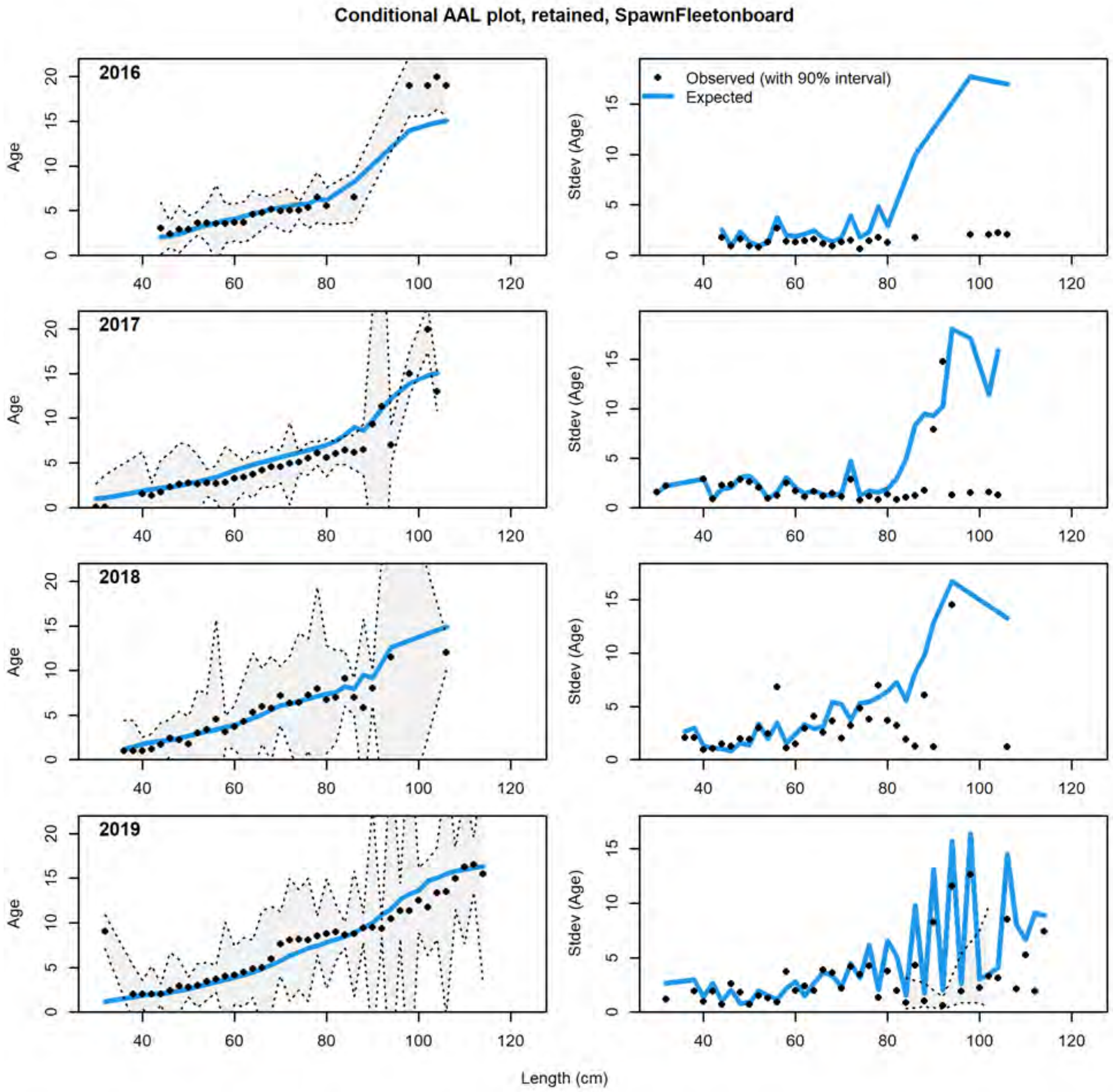
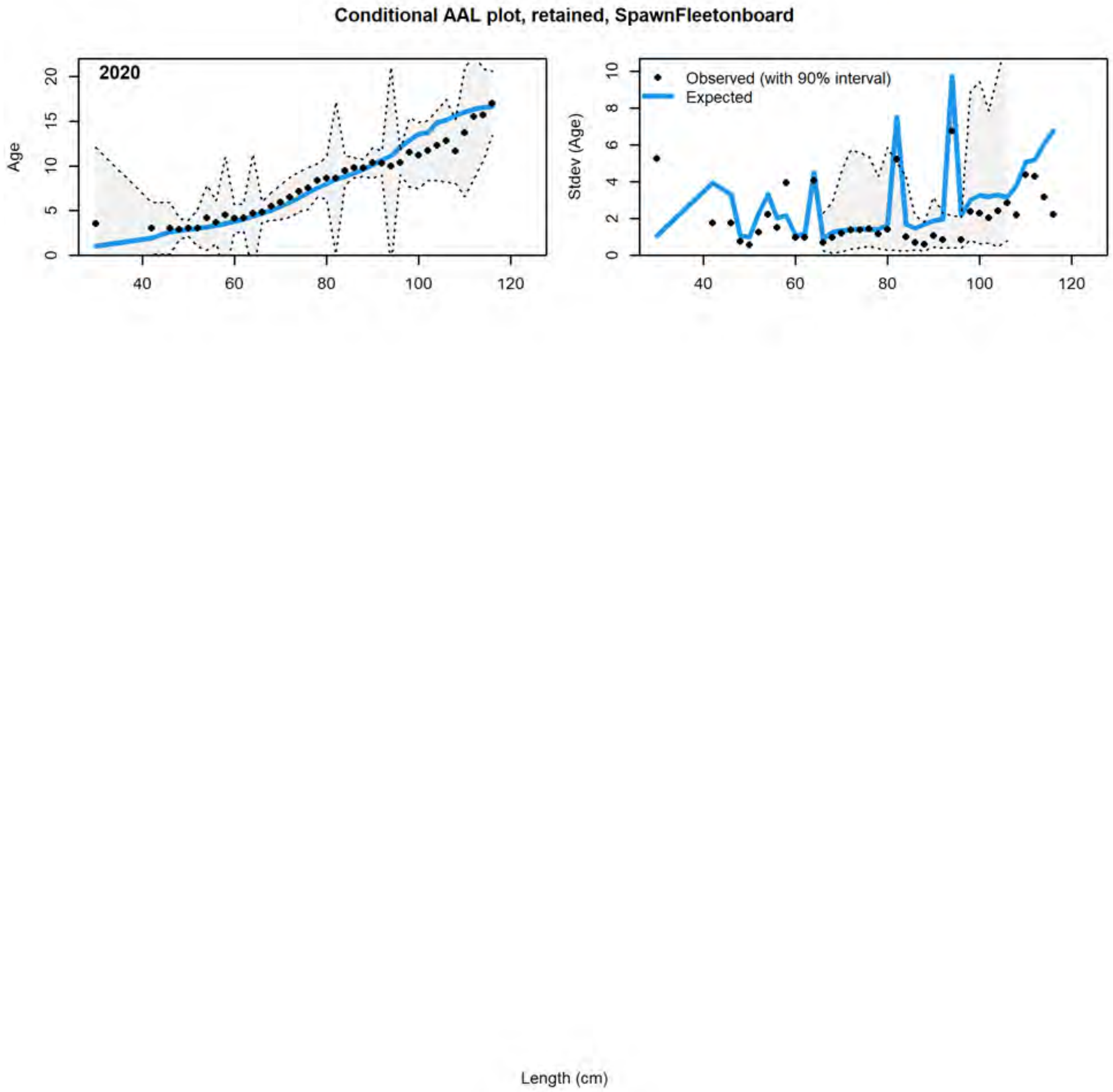
2012
2013
2014
2015
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)



Conditional AAL plot, retained, SpawnFleetonboard
2016
2017
2018
2019
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)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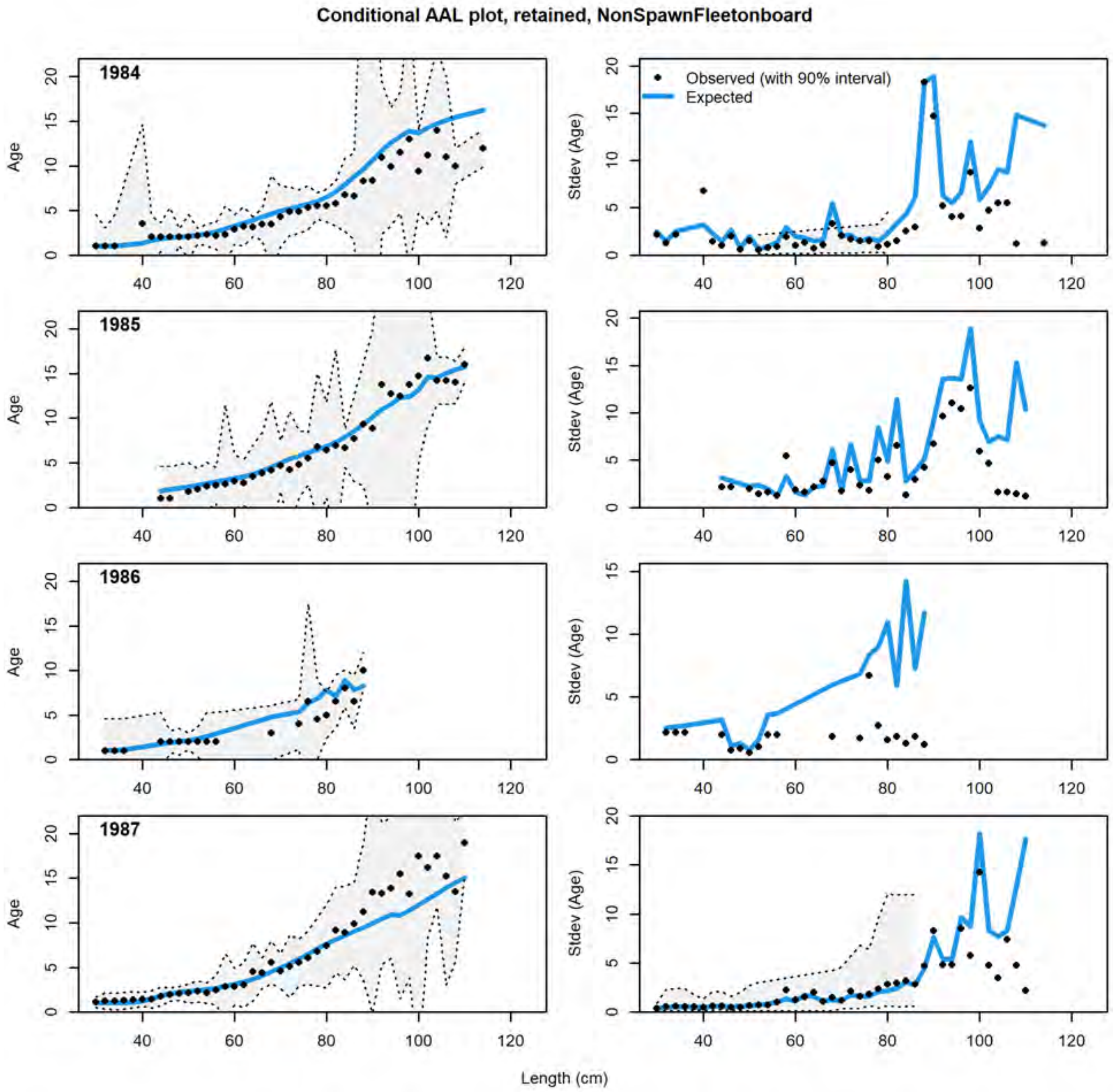
2020
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)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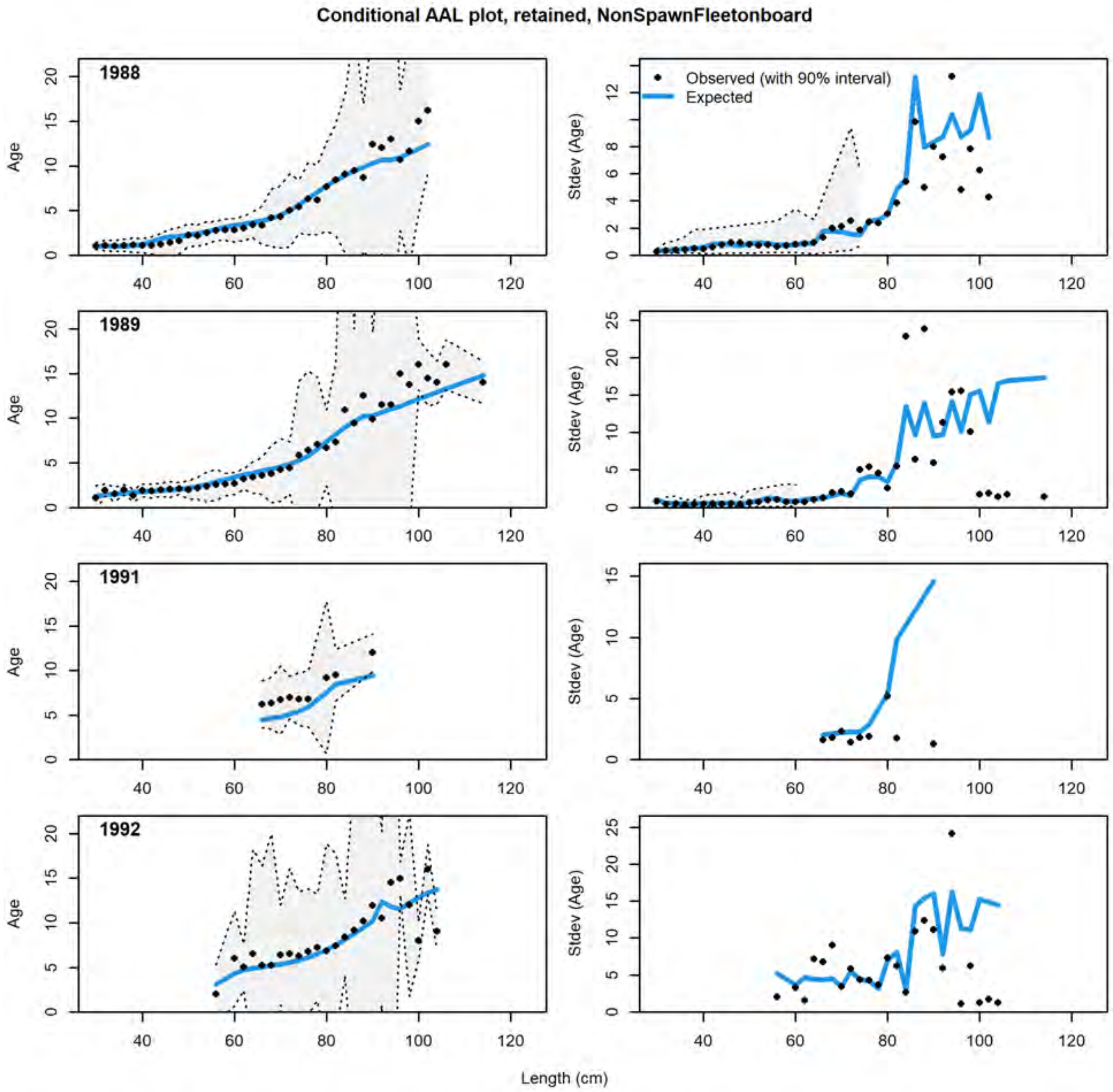
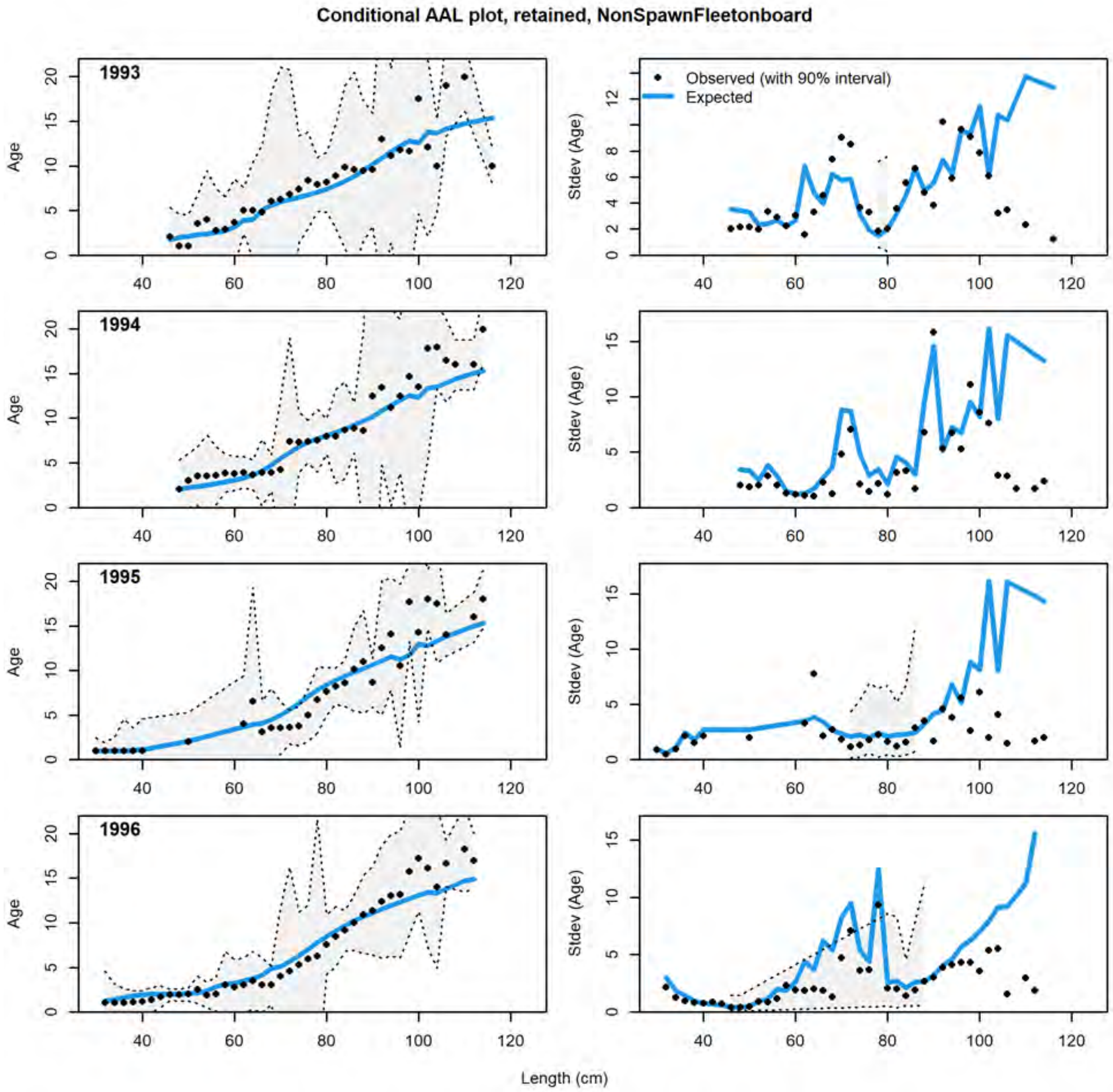
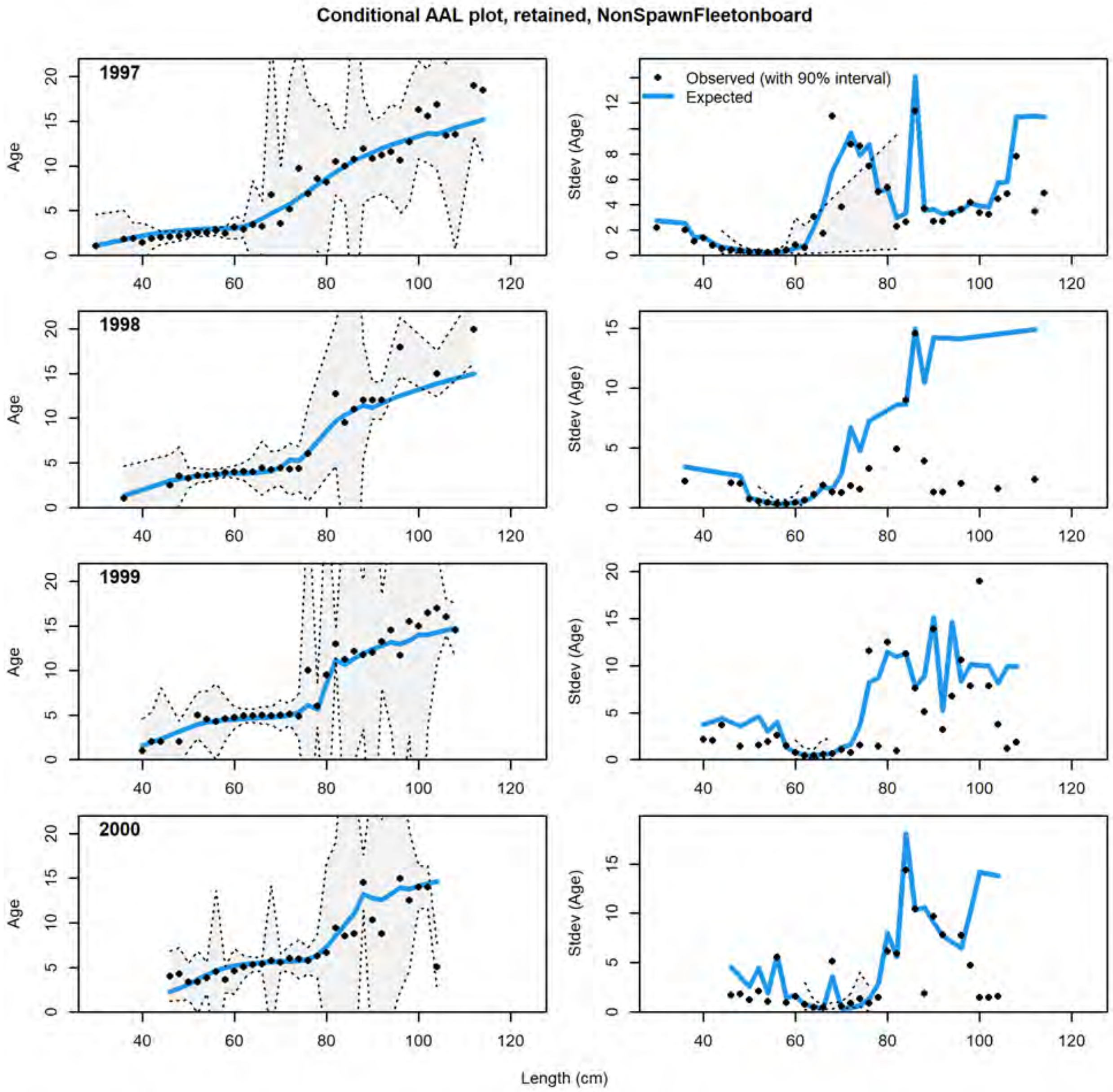
1984
1985
1986
1987
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)



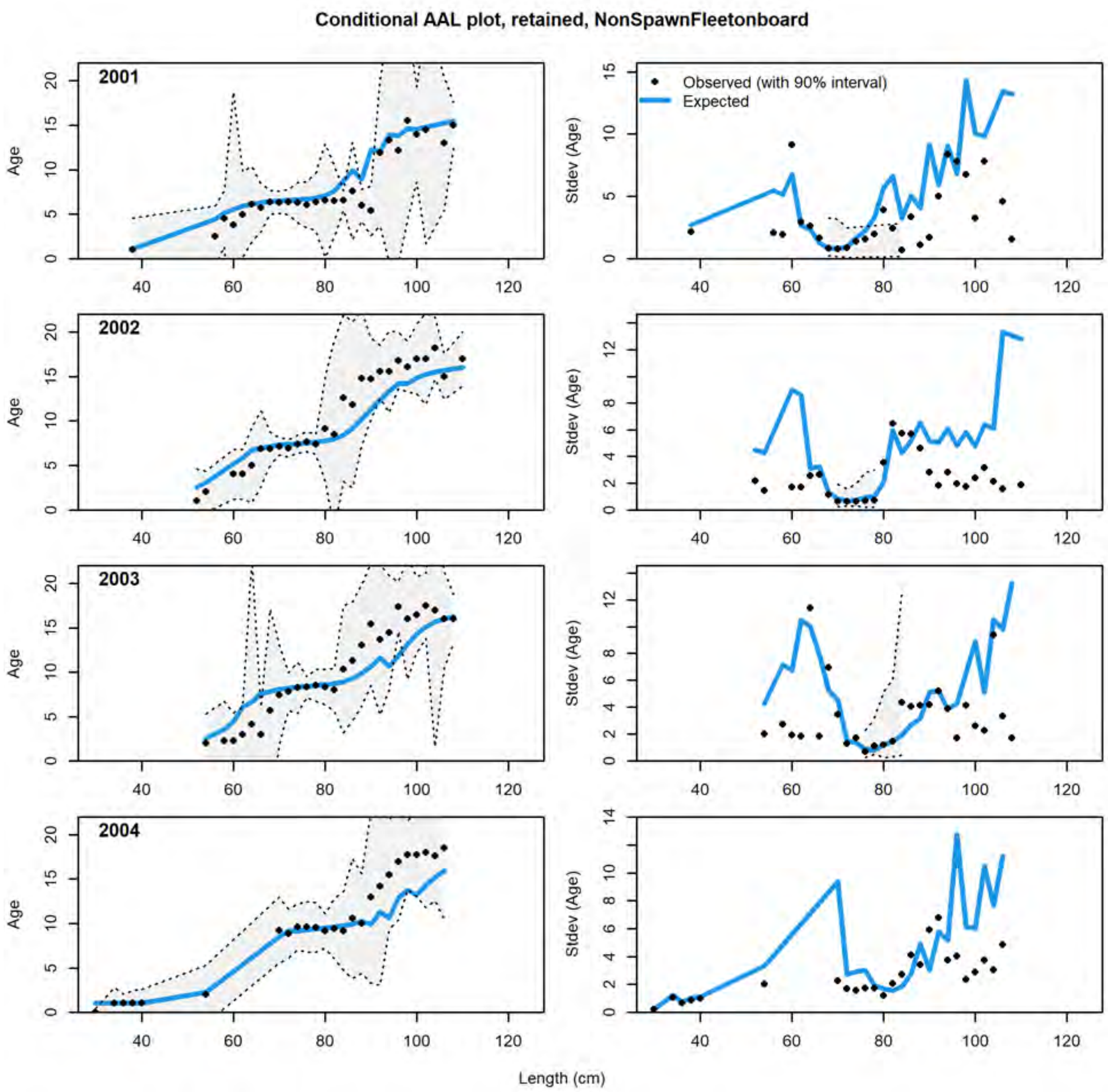
Conditional AAL plot, retained, NonSpawnFleetonboard
1988
1989
1991
1992
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)



Conditional AAL plot, retained, NonSpawnFleetonboard
1993
1994
1995
1996
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)



Conditional AAL plot, retained, NonSpawnFleetonboard
1997
1998
1999
2000
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)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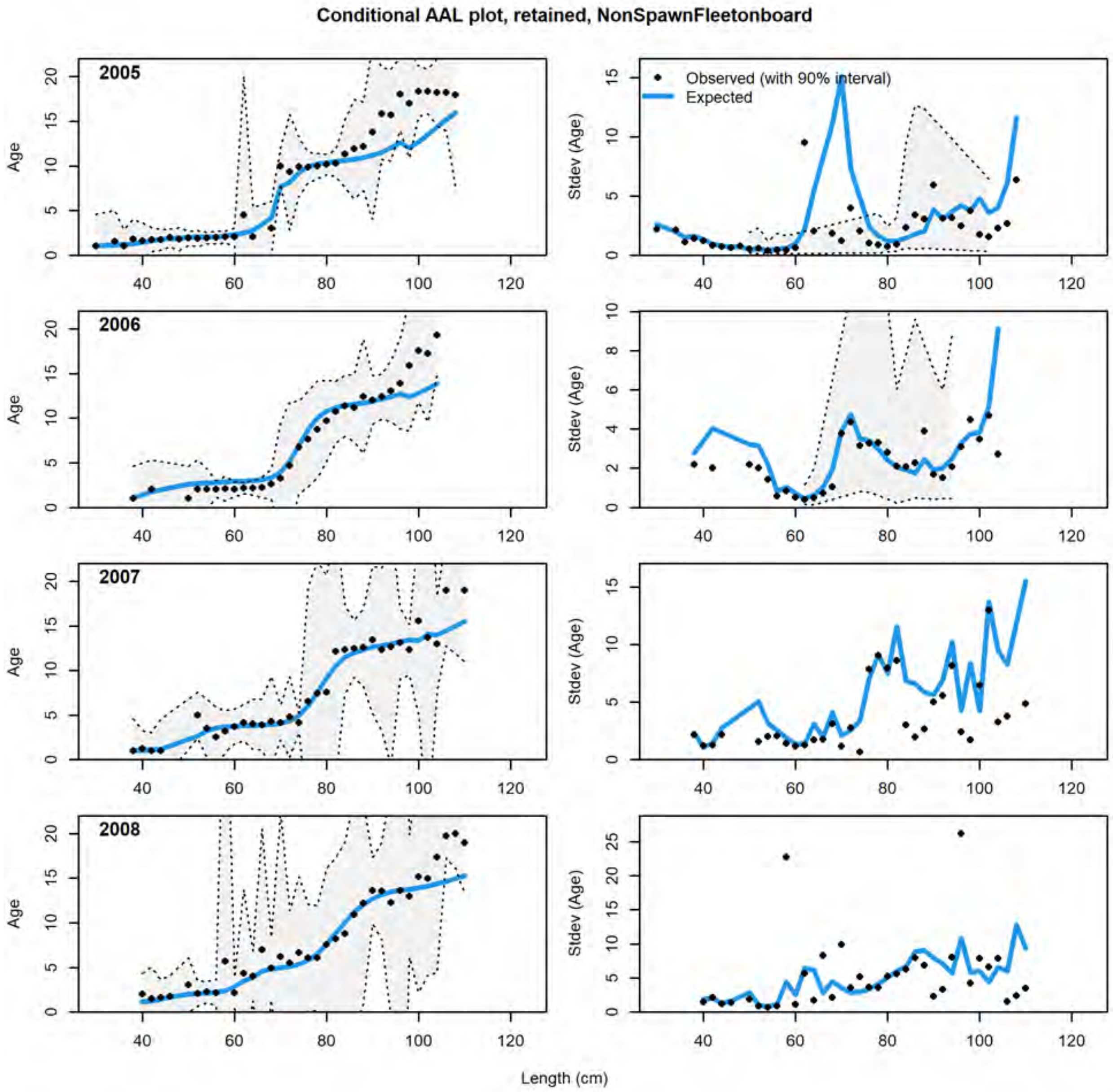
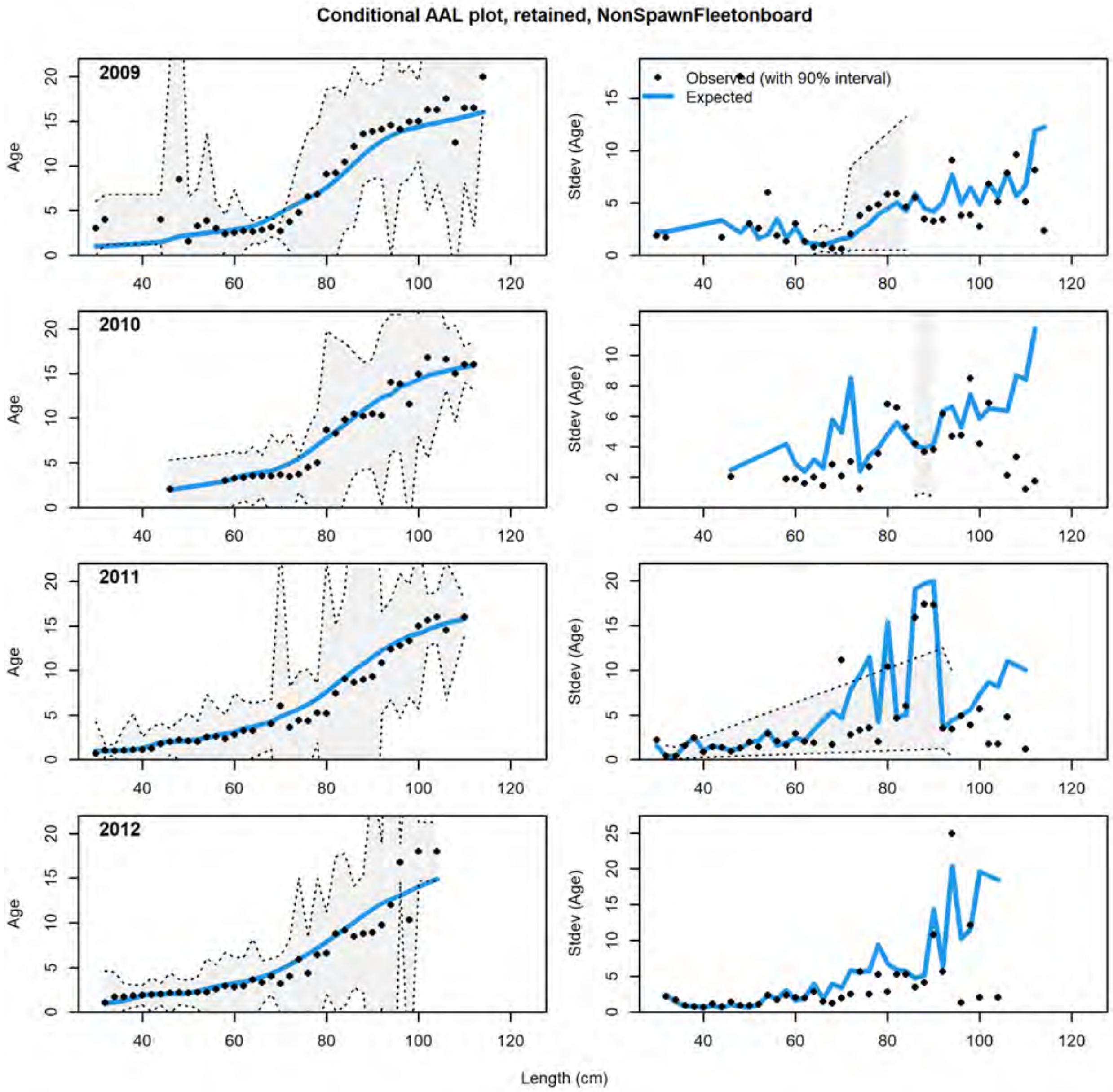
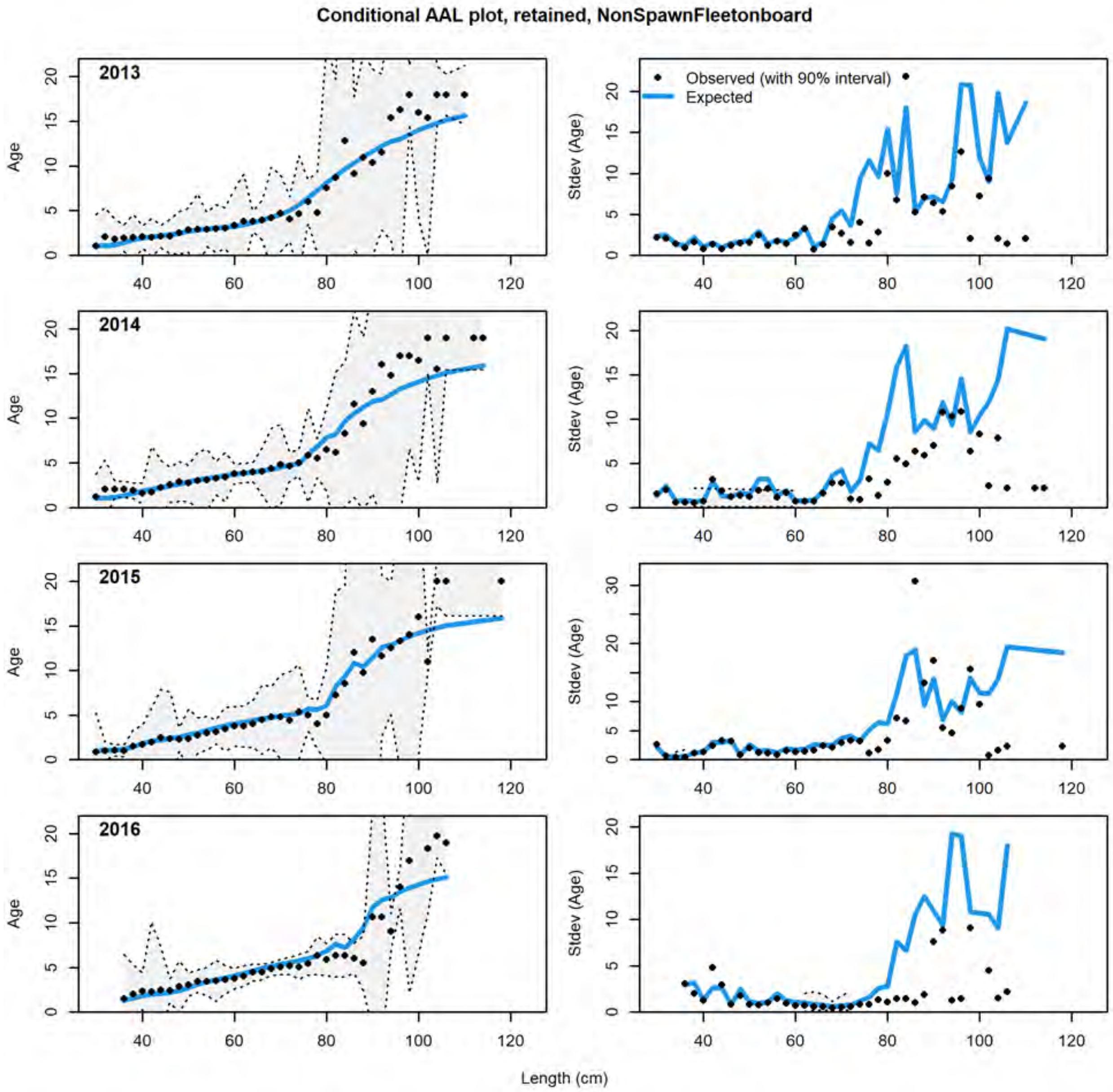
2001
2002
2003
2004
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)

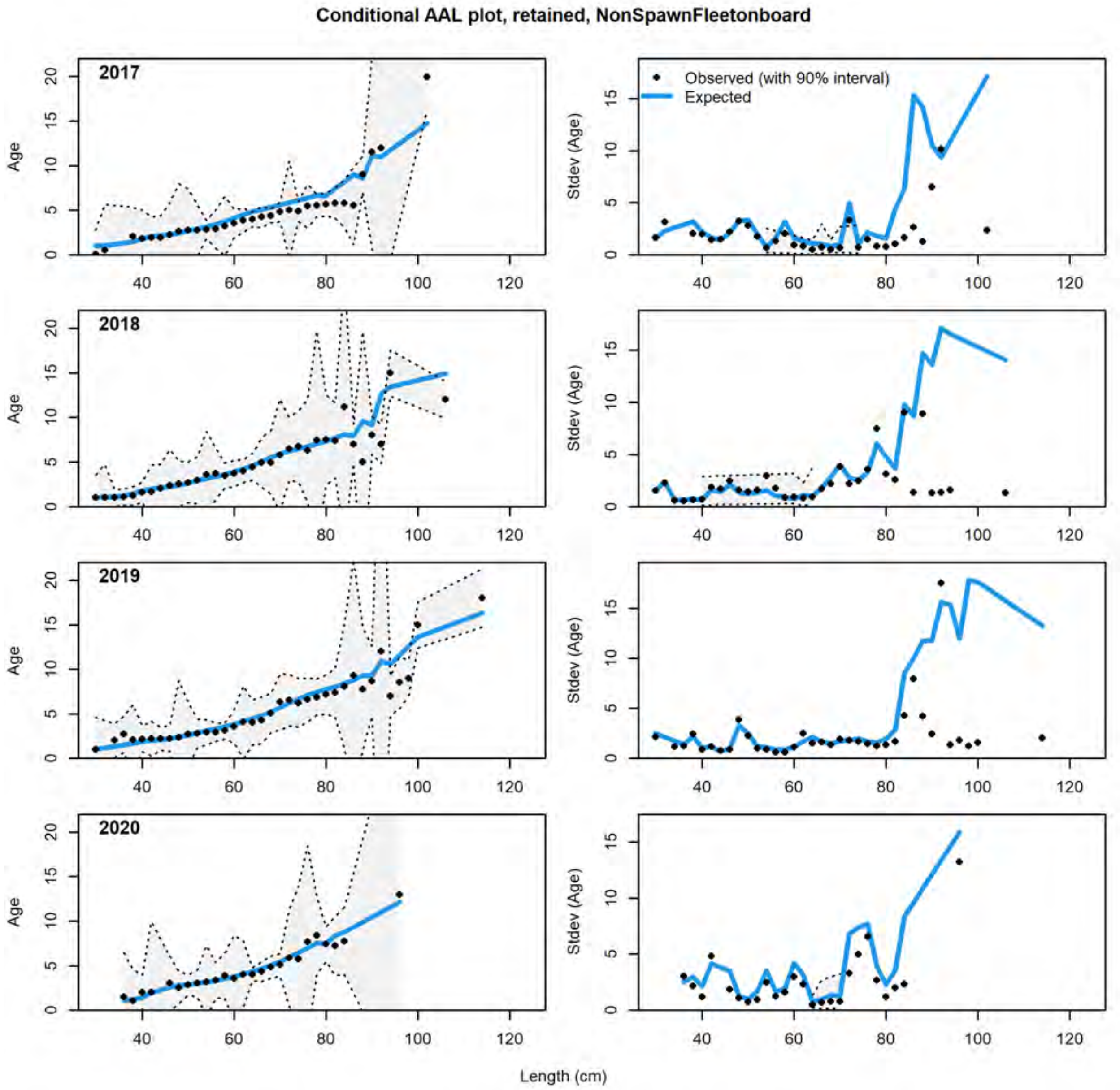

Conditional AAL plot, retained, NonSpawnFleetonboard
2005
2006
2007
2008
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)



Conditional AAL plot, retained, NonSpawnFleetonboard
2009
2010
2011
2012
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)



Conditional AAL plot, retained, NonSpawnFleetonboard
2013
2014
2015
2016
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)


Conditional AAL plot, retained, NonSpawnFleetonboard
2017
2018
2019
2020
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)

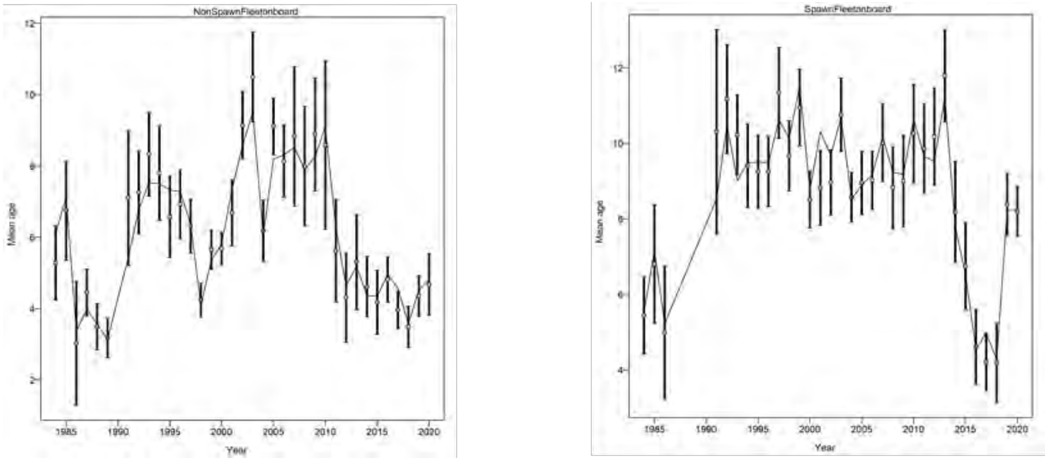


Figure 6.26. Data weighting of conditional age at length data for the onboard non spawning and spawning fleets

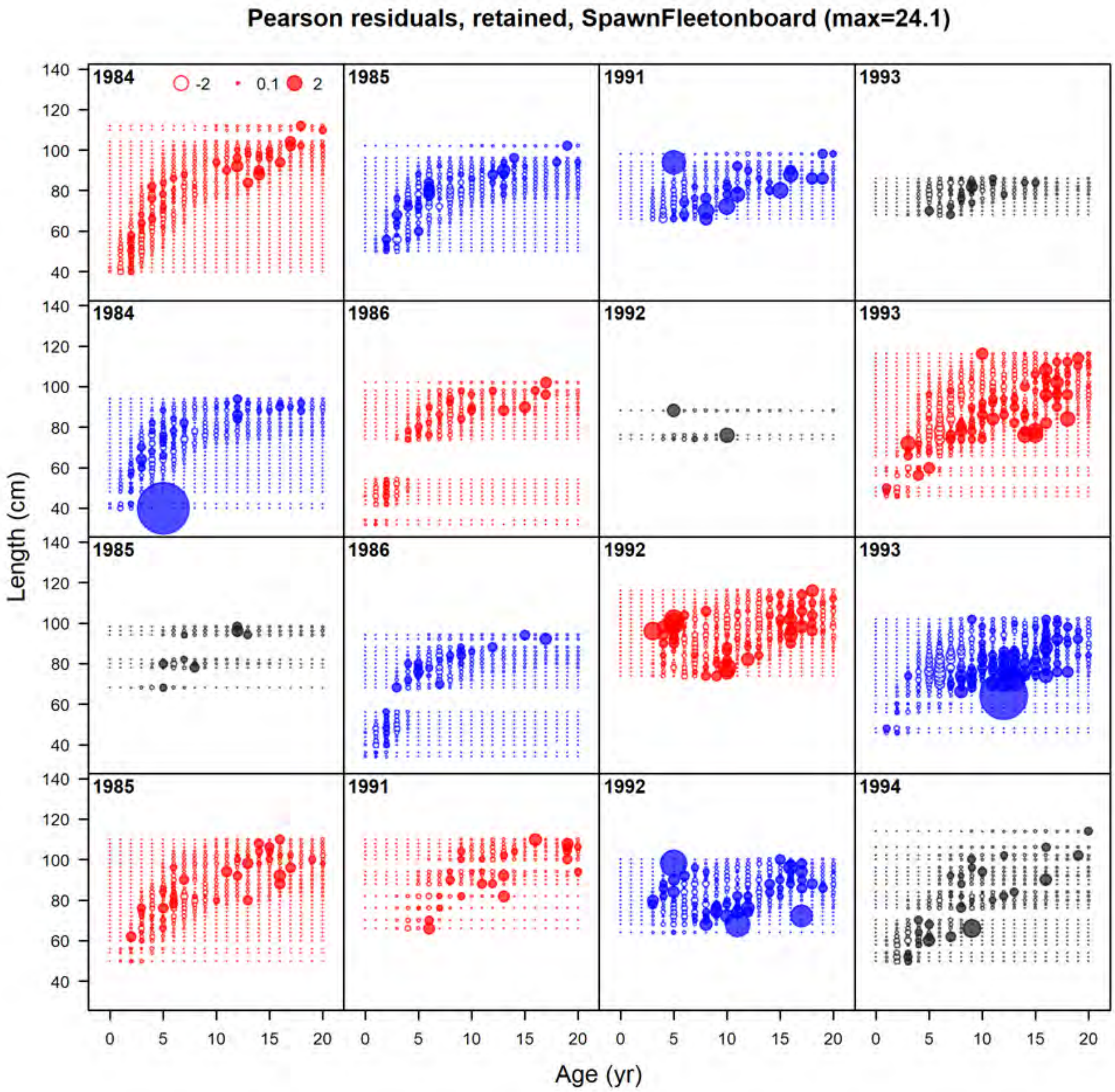
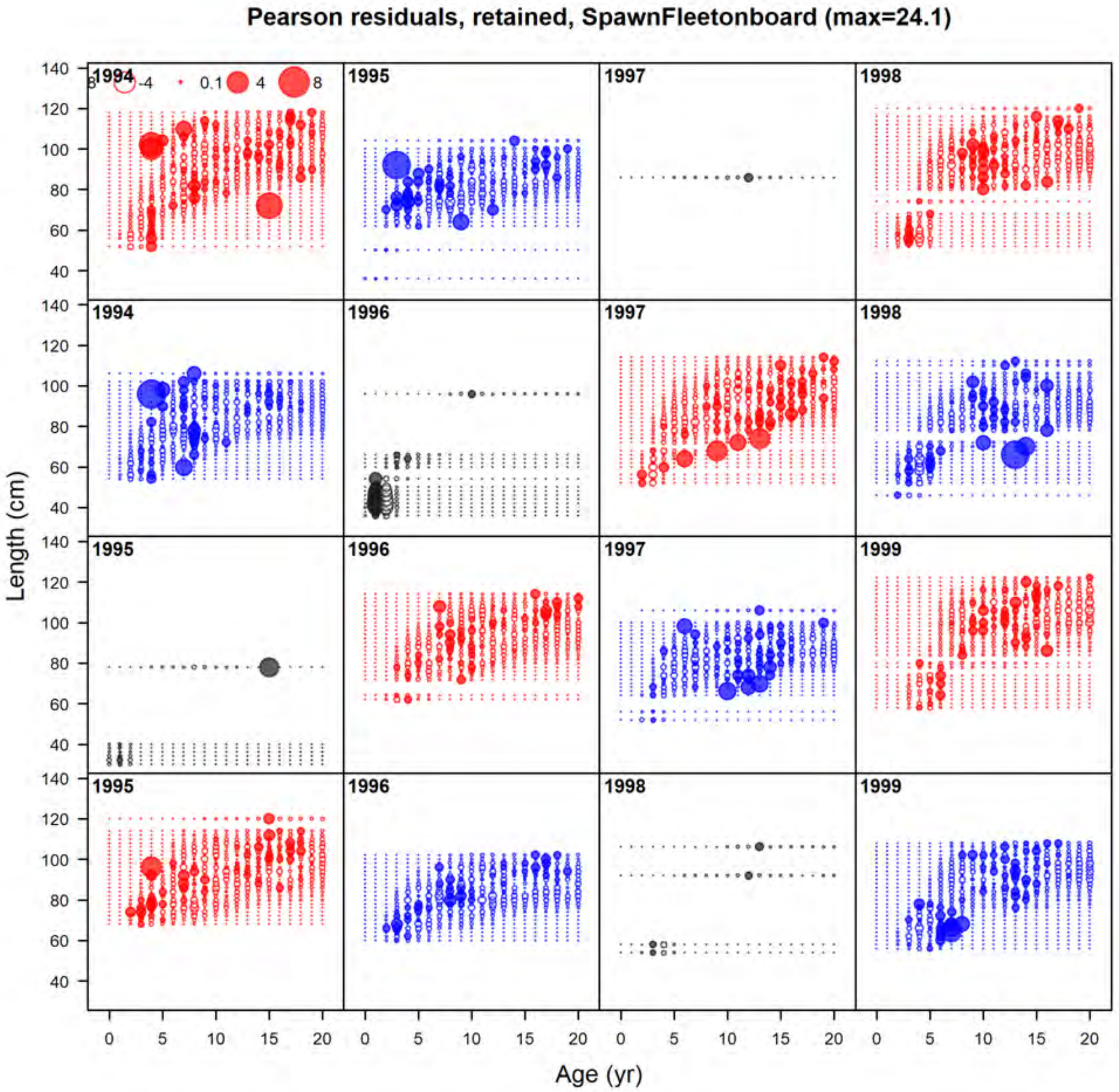
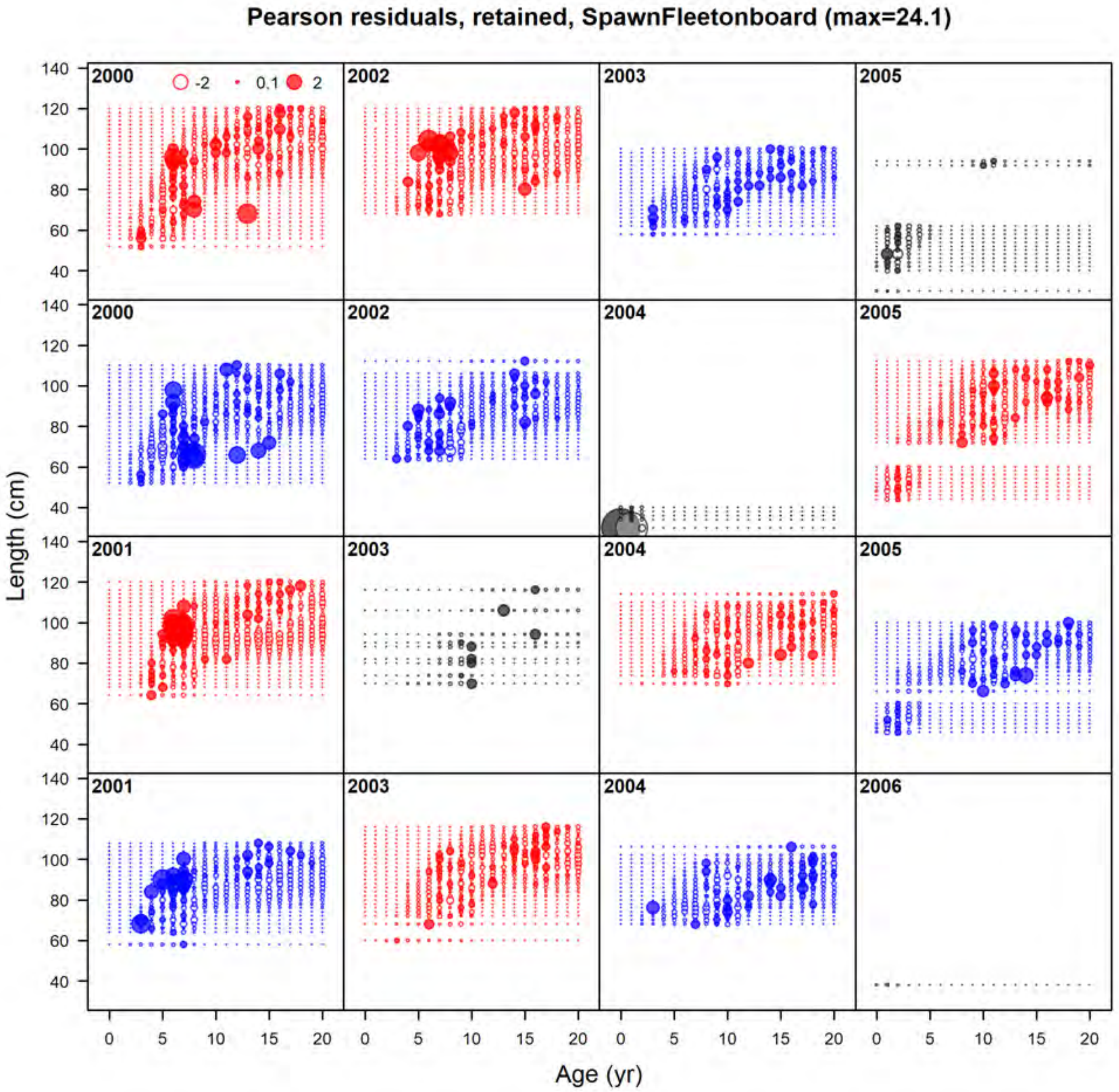
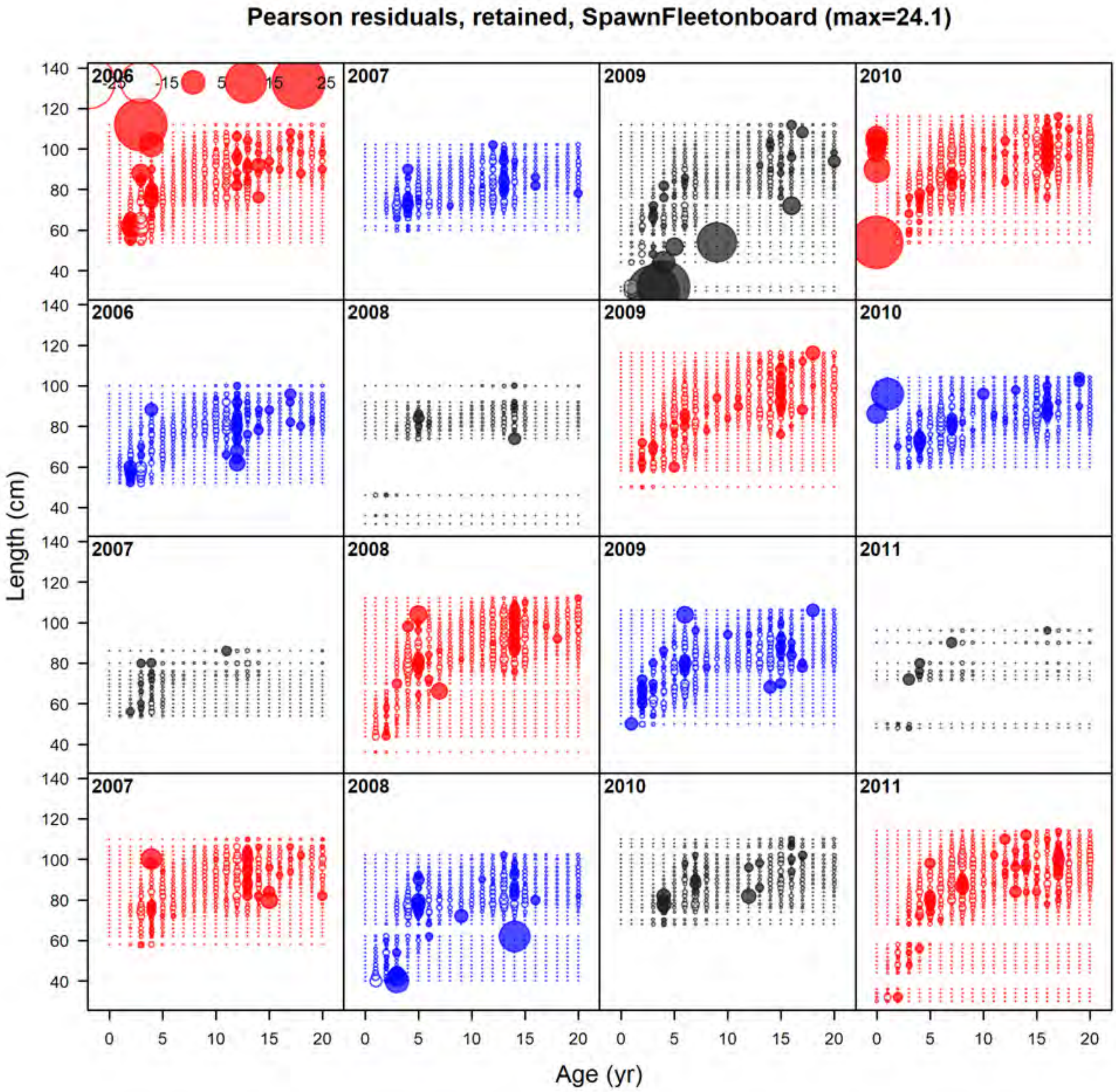
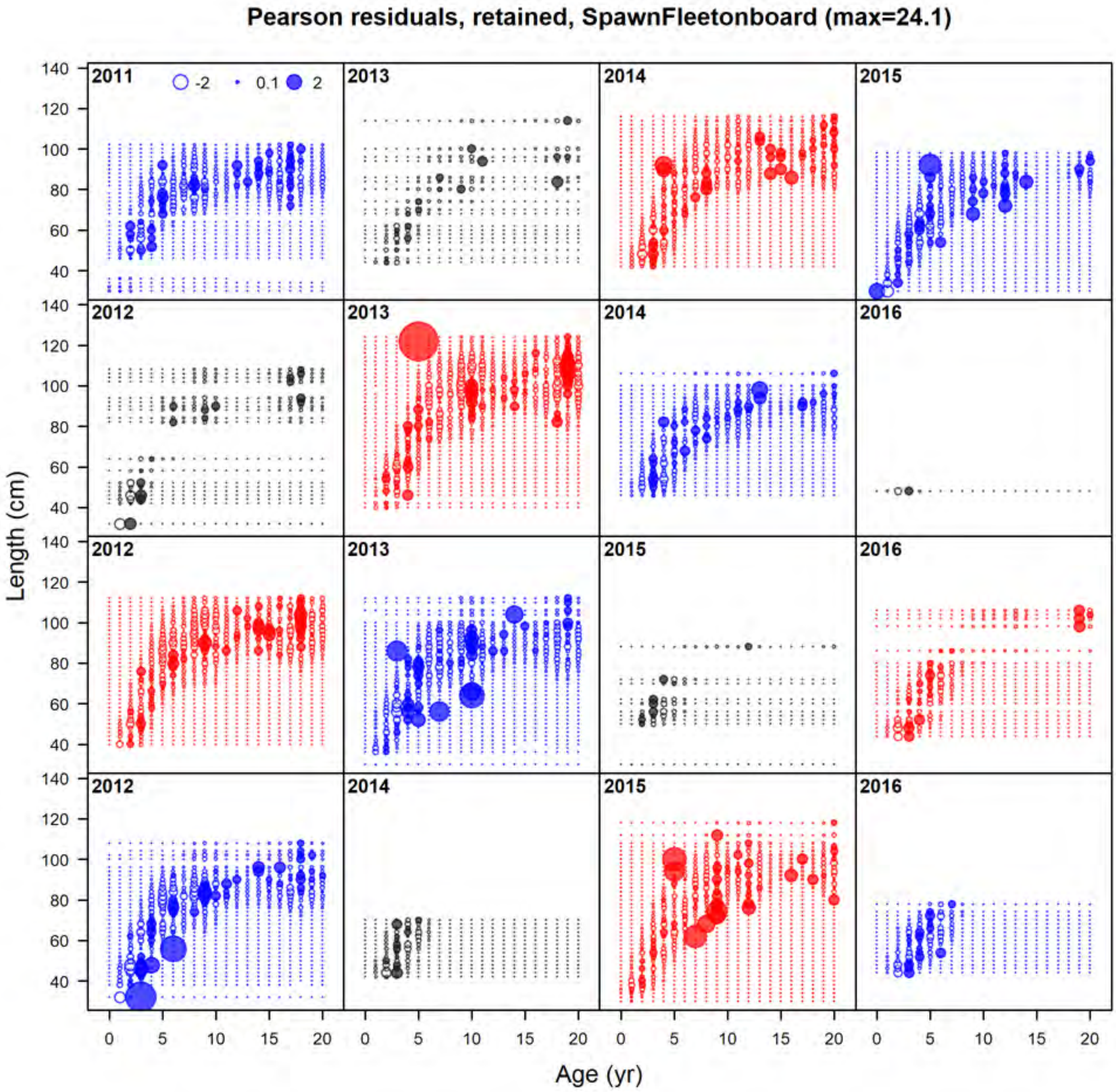


Figure 6.27. Pearson residuals of conditional age at length data.


Pearson residuals, retained, SpawnFleetonboard (max=24.1)
-4
0.1
4
8
1994
1995
1997
1998
1994
1996
1997
1998
1995
1996
1997
1999
1995
1996
1998
1999
Length (cm)
Age (yr)


Pearson residuals, retained, SpawnFleetonboard (max=24.1)
2000
-2
0.1
2
2002
2003
2005
2000
2002
2004
2005
2001
2003
2004
2005
2001
2003
2004
2006
Length (cm)
Age (yr)


Pearson residuals, retained, SpawnFleetonboard (max=24.1)
-25
-15
5
15
25
2006
2007
2009
2010
2006
2008
2009
2010
2007
2008
2009
2011
2007
2008
2010
2011
Length (cm)
Age (yr)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-2
0.1
2
2011
2013
2014
2015
2012
2013
2014
2016
2012
2013
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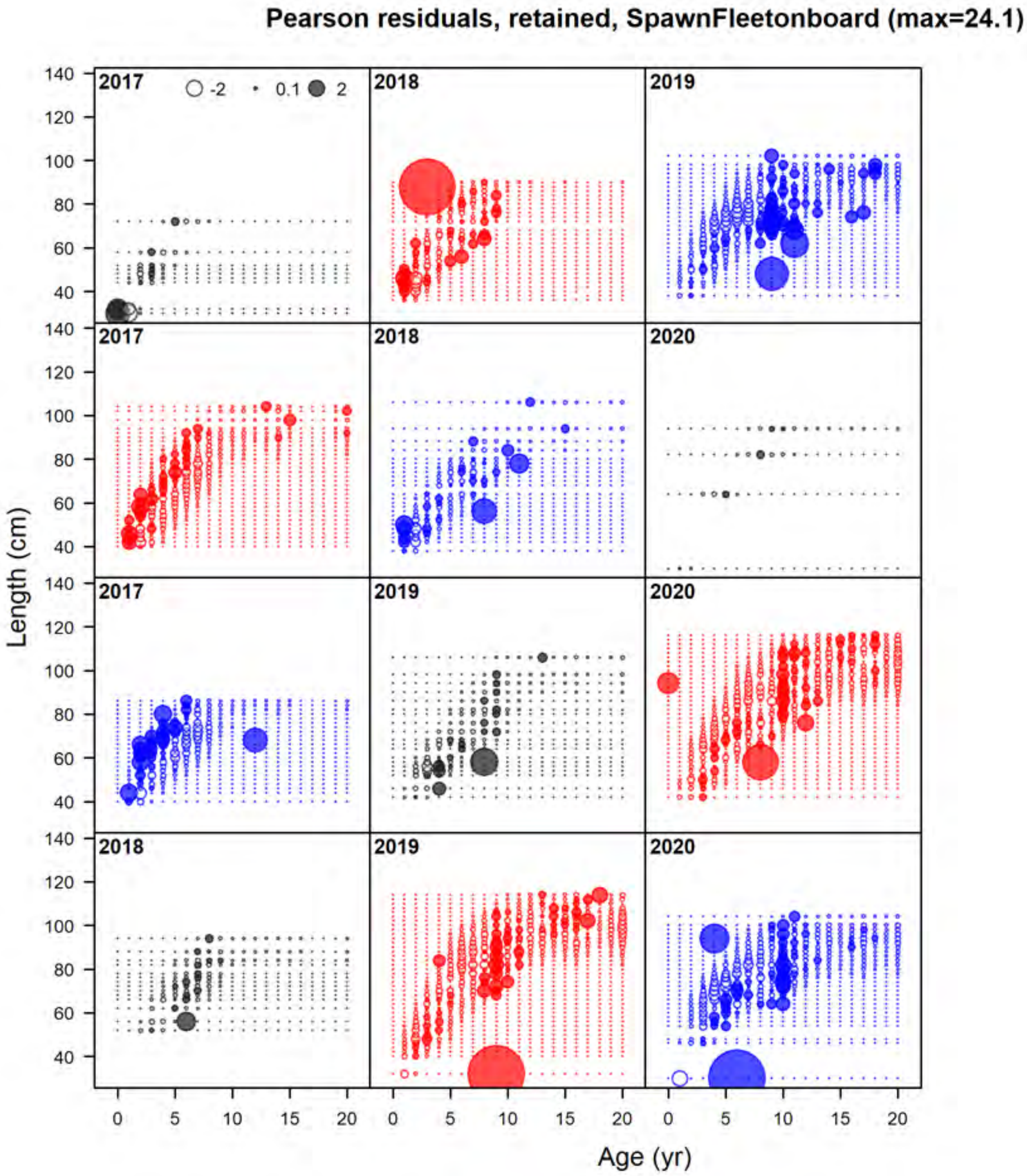
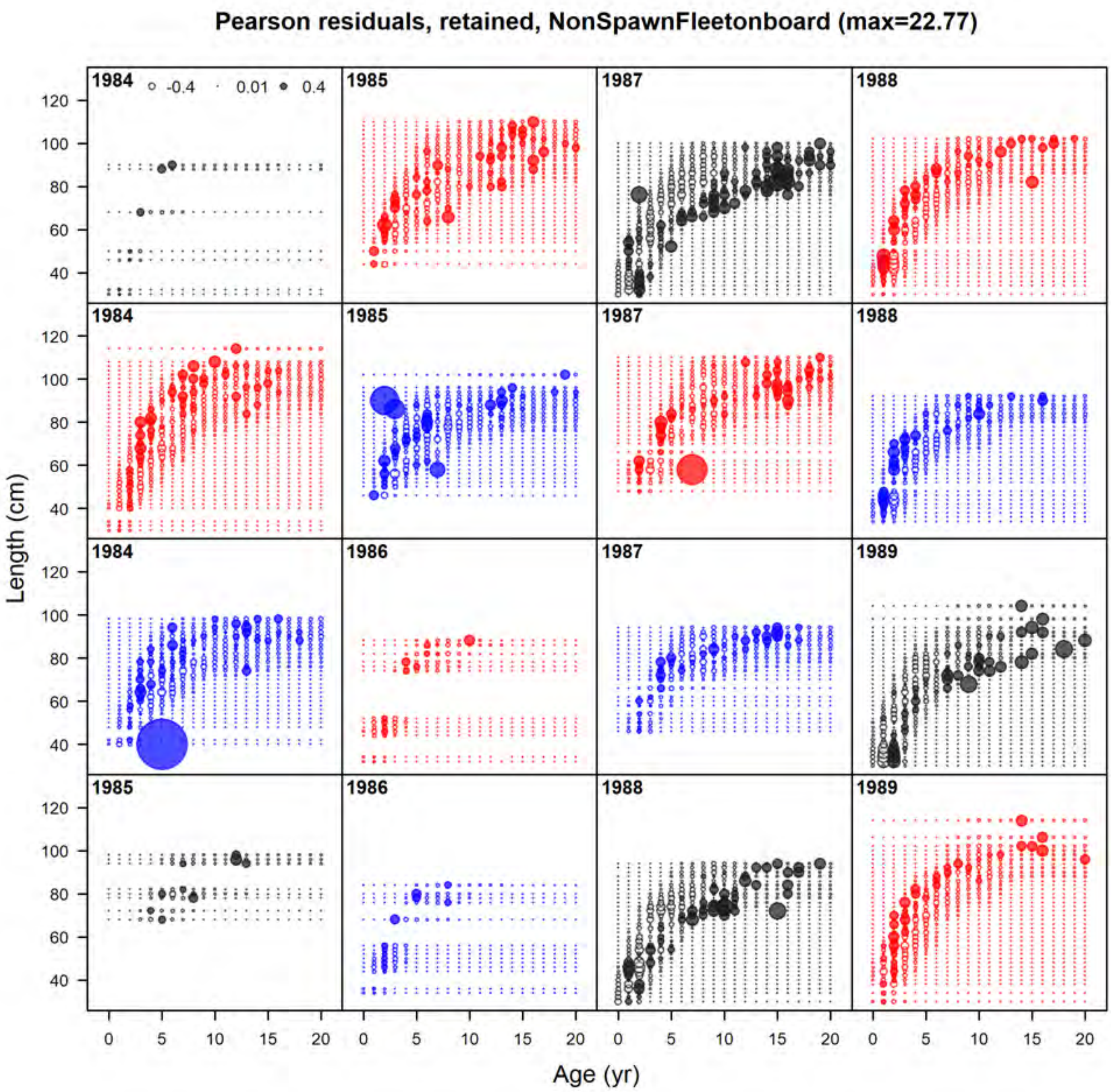
2016
2012
2014
2015
2016
Length (cm)
Age (yr)


Pearson residuals, retained, SpawnFleetonboard (max=24.1)
-2
0.1
2
2017
2018
2019
2017
2018
2020
2017
2019
2020
2018
2019
2020
Length (cm)
Age (yr)
140
120
100
80
60
40
0
5
10
15
20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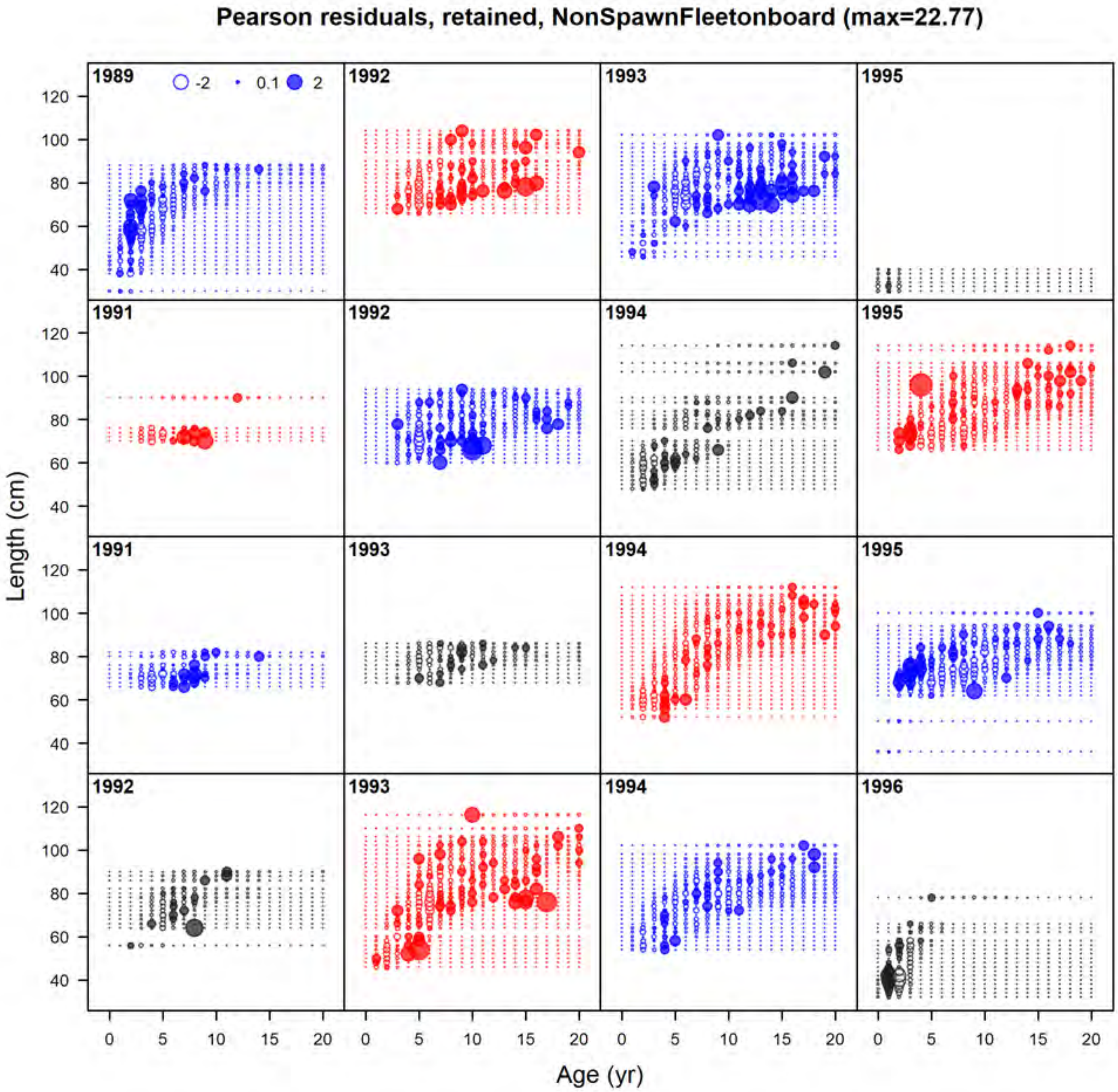
1984
-0.4
0.01
0.4
1985
1987
1988
1984
1985
1987
1988
1984
1986
1987
1989
1985
1986
1988
1989
Length (cm)
Age (yr)


Pearson residuals, retained, NonSpawnFleetonboard (max=22.77)
1989
-2
0.1
2
1992
1993
1995
1991
1992
1994
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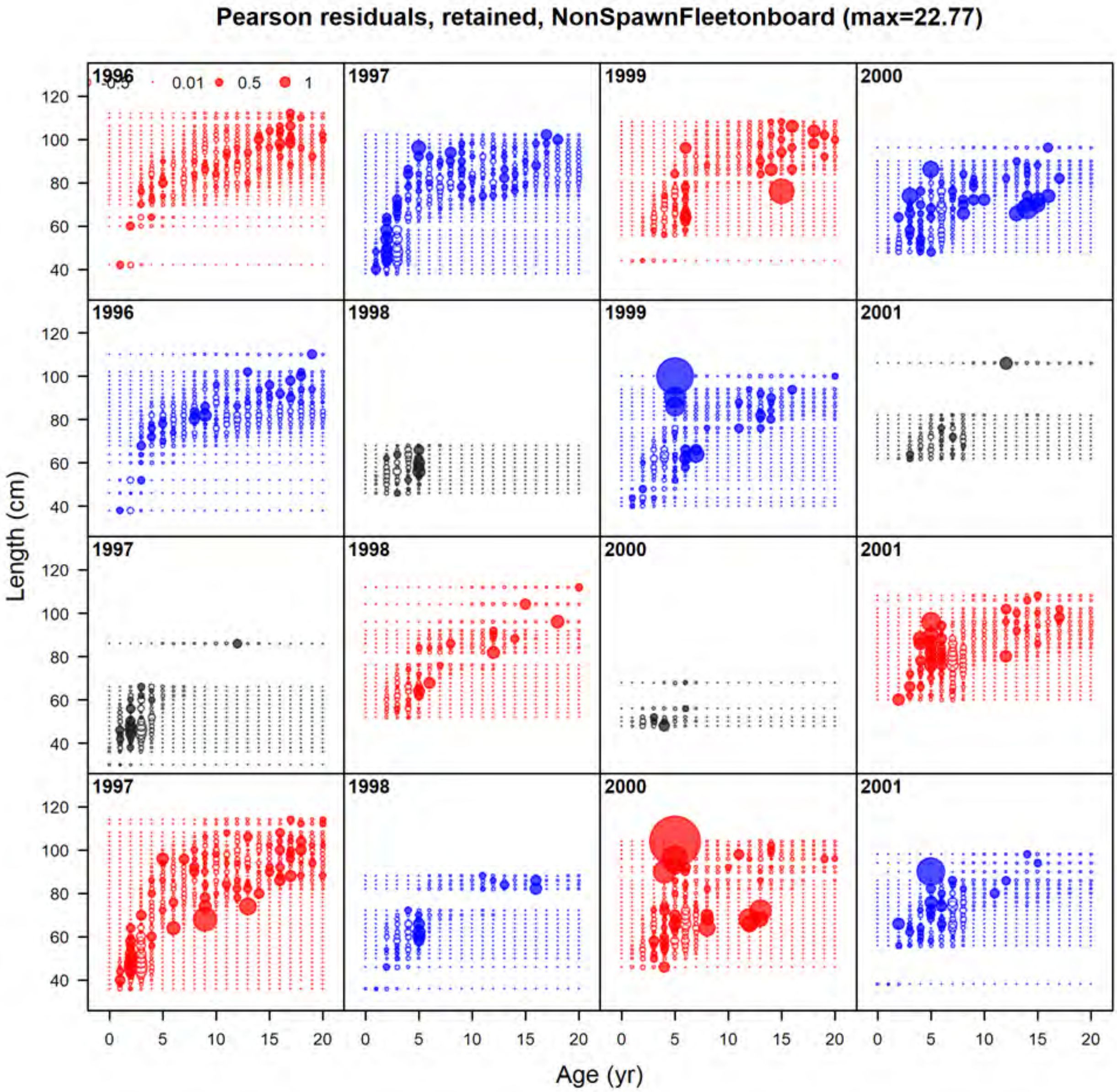
1996
Length (cm)
Age (yr)



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-0.5
0.01
0.5
1
1996
1997
1999
2000
1996
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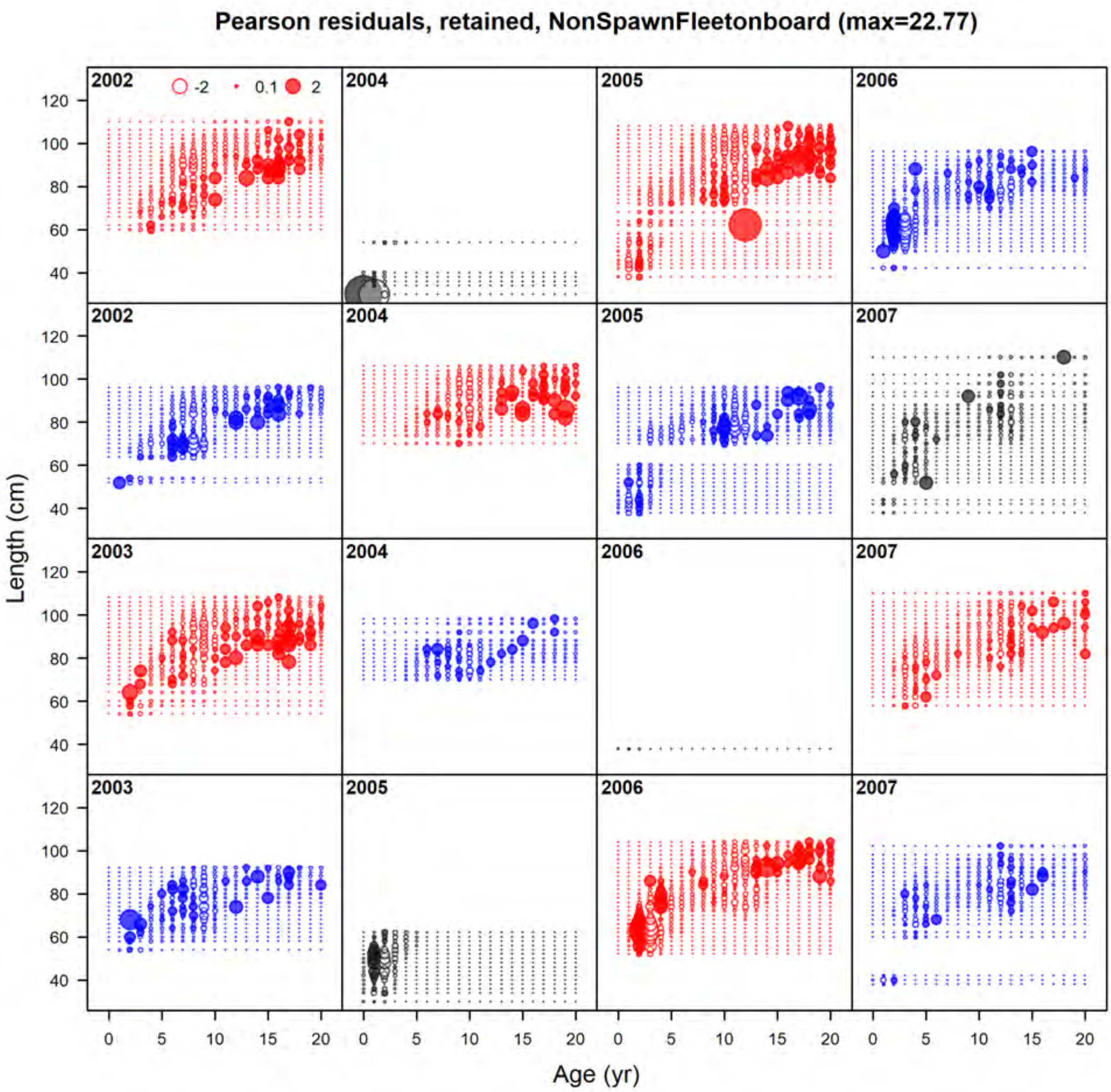
1998
2000
2001
Length (cm)
Age (yr)


Pearson residuals, retained, NonSpawnFleetonboard (max=22.77)
2002
-2
0.1
2
2004
2005
2006
2002
2004
2005
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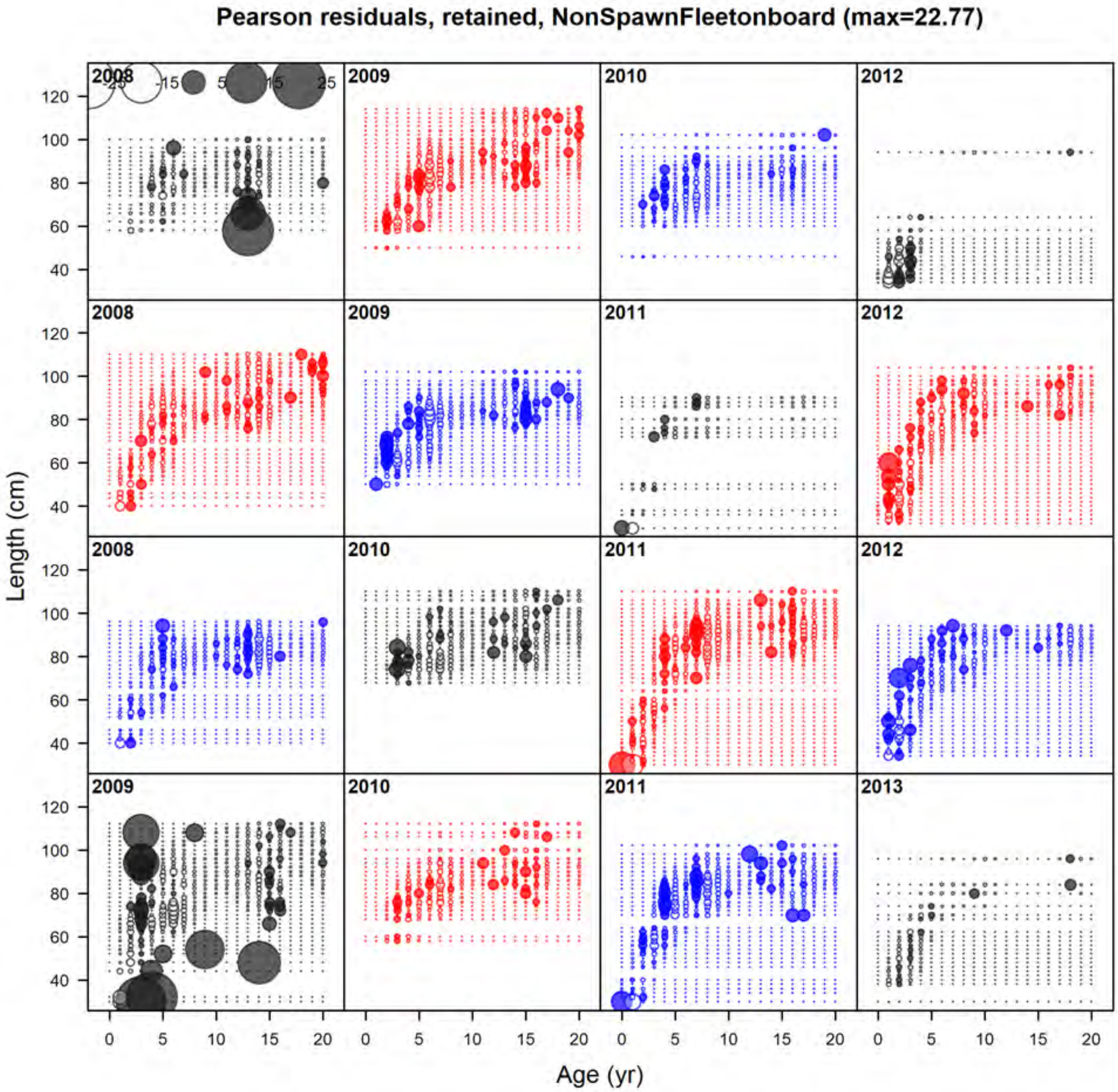
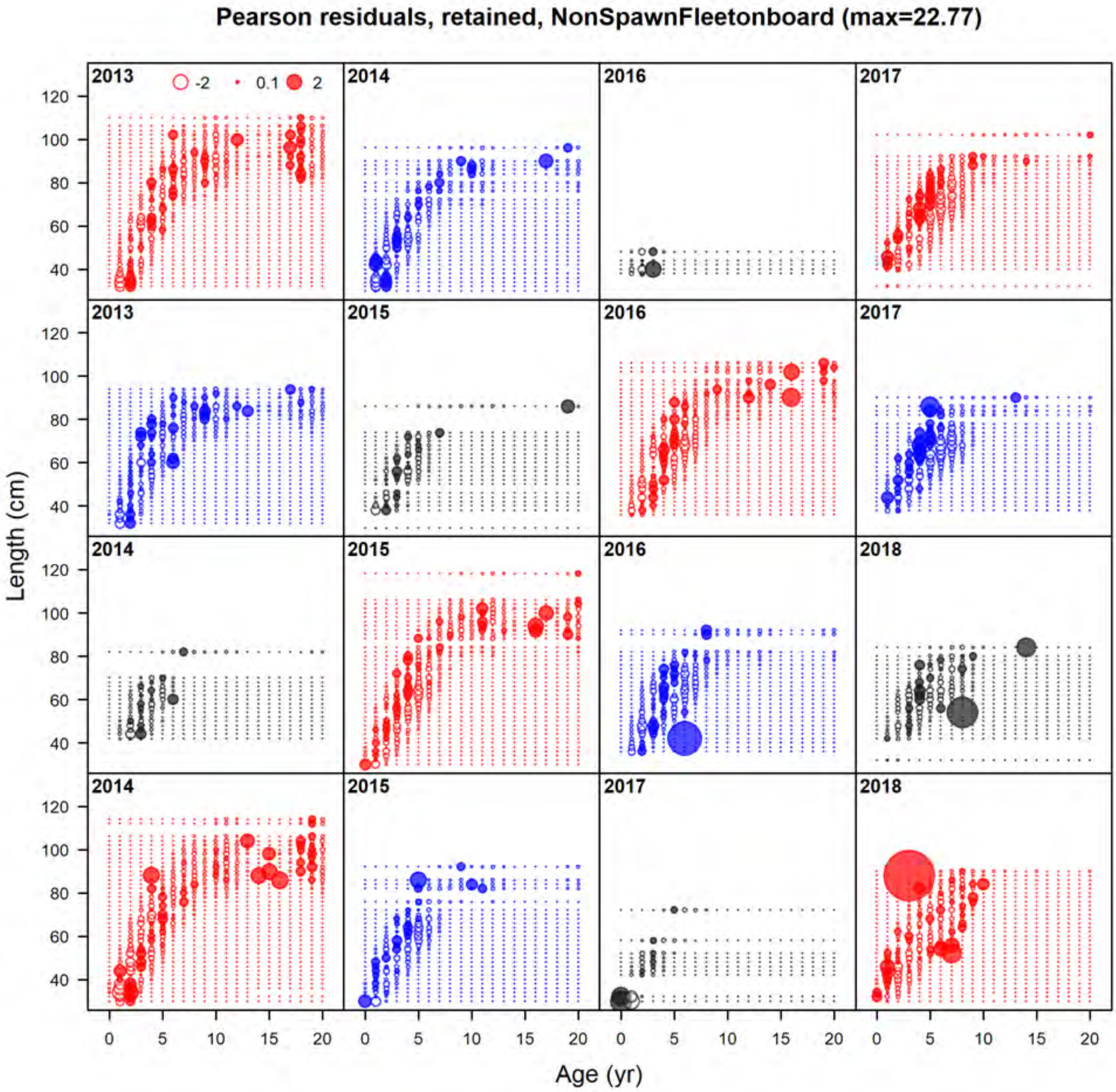
2003
2005
2006
2007
Length (cm)
Age (yr)


Pearson residuals, retained, NonSpawnFleetonboard (max=22.77)
-25
-15
5
15
25
2008
2009
2010
2012
2008
2009
2011
2012
2008
2010
2011
2012
2009
2010
2011
2013
Length (cm)
Age (yr)



Pearson residuals, retained, NonSpawnFleetonboard (max=22.77)
2013
-2
0.1
2
2014
2016
2017
2013
2015
2016
2017
2014
2015
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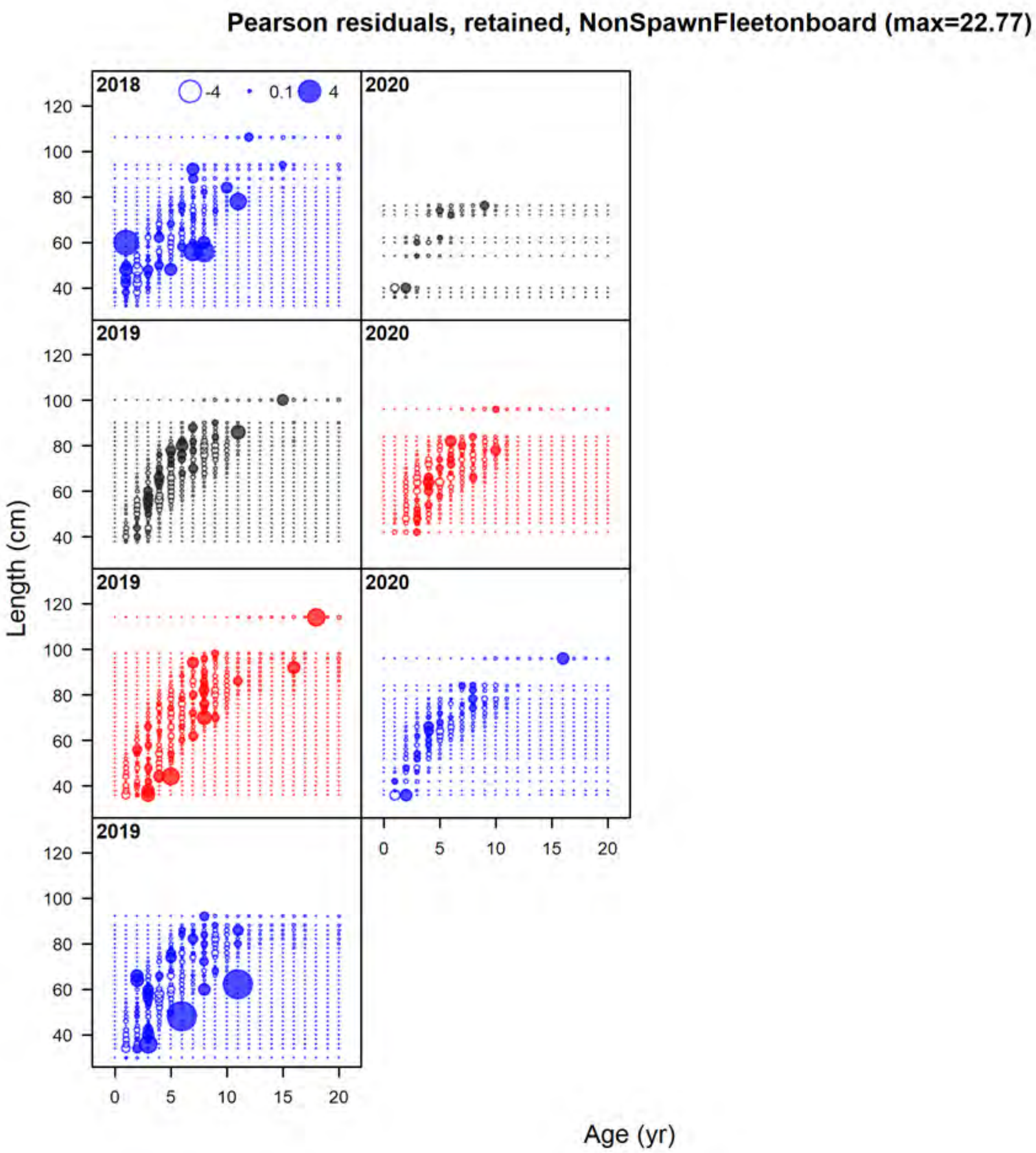
2014
2015
2017
2018
Length (cm)
Age (yr)


Pearson residuals, retained, NonSpawnFleetonboard (max=22.77)
2018
-4
0.1
4
2020
2019
2020
2019
2020
2019
Length (cm)
Age (yr)
120
100
80
60
40
0
5
10
15
20

7. Eastern Jackass Morwong (*Nemadactylus macropterus*) stock assessment based on data up to 2020 – development of a preliminary base case

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7.1 Executive Summary

This document presents a suggested base case for an updated quantitative Tier 1 assessment of eastern Jackass Morwong (*Nemadactylus macropterus*) for presentation at the October SERAG meeting in 2021. The last full assessment was presented in Day and Castillo-Jordán (2018). The preliminary base case has been updated by the inclusion of data up to the end of 2020, which entails an additional three years of catch, discard, CPUE, length-composition and conditional age-at length data and updates to the ageing error matrices since the 2018 assessment. This document describes the process used to develop a preliminary base case for Jackass Morwong through the sequential updating of recent data to the stock assessment, using the stock assessment package Stock Synthesis (SS-V3.30.17).

Results show good fits to the abundance data (CPUE and FIS), especially the CPUE data for the most recent years for the active CPUE fleets (eastern and Tasmanian trawl), where the additional CPUE data points have continued to decline for both fleets. The fits to the length composition and conditional age-at-length data are good. This assessment estimates that the projected 2022 spawning stock biomass will be 22% of virgin stock biomass (projected assuming 2020 catches in 2021), which is considerably lower than the estimated stock status of 35% at the start of 2019 obtained from the last assessment (Day and Castillo-Jordán, 2018). Recent recruitment estimates (2007-2012) have been revised downwards with the inclusion of new data, with the three additional newly estimated recruitment deviations (2013-2015) all below average.

With this updated assessment, the last 12 estimated recruitment deviations are now all below average, indicating a continuing decline in productivity for this stock, which may require a review of the productivity shift previously adopted for this assessment.

7.2 Introduction

7.2.1 *Eastern Jackass Morwong assessment base case in 2021*

The 2021 preliminary base case assessment of eastern Jackass Morwong uses an age- and size-structured model implemented in the generalized stock assessment software package, Stock Synthesis (SS-V3.30.12.00, Methot et al. (2021)). The methods utilised in Stock Synthesis are based on the integrated analysis paradigm. Stock Synthesis can allow for multiple seasons, areas and fleets, but most applications are based on a single season and area. Recruitment is governed by a stochastic Beverton-Holt stock-recruitment relationship, parameterized in terms of the steepness of the stock-recruitment function (h), the expected average recruitment in an unfished population (R_0), and the degree of variability about the stock-recruitment relationship (σ_r). Stock Synthesis allows the user to choose among a large number of age- and length-specific selectivity patterns. The values for the parameters of Stock Synthesis are estimated by fitting to data on catches, catch-rates, discard rates, discard and retained catch length-frequencies, and conditional age-at-length data. The population dynamics model and the statistical approach used in fitting the model to the various data types are given in the Stock Synthesis technical documentation (Methot, 2005).

The base case model includes the following key features:

A single region, single stock model is considered with three currently active fleets: a trawl fleet in the east operating in SESSF zones 10 and 20 in NSW and Vic (eastern trawl); a Danish seine fleet operating in zones 10, 20 and 30 (Danish seine); and a trawl fleet operating off eastern Tasmania in zone 30 (Tasmanian trawl). Selectivity is modelled separately for each fleet, with all selectivity patterns assumed to be length-specific and logistic. The parameters of the selectivity function for each fleet were estimated within the assessment.

The model does not account for males and females separately and fits one growth curve across both sexes.

The initial and final years are 1915 and 2020.

The CVs of the CPUE indices are initially set at a value equal to the standard error from a loess fit (0.143 (eastern trawl), 0.367 (Tasmanian trawl); Sporcic (2021)), before being re-tuned to the model-estimated standard errors within Stock Synthesis.

Discard weight (t) is estimated through a retention function. This is defined as a logistic function of length, and the inflection and slope of this function are estimated where discard information was available.

The rate of natural mortality, M, is assumed to be time- and age-invariant. The value for M is assumed to be 0.15 y^{-1}.

Recruitment to the stock is assumed to follow a Beverton-Holt 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 is fixed at 0.7.

The initial value of the parameter determining the magnitude of the process error in annual recruitment, σ_r, is set to 0.7.

The population plus-group is modelled at age 30 years.

Growth is assumed to follow a von Bertalanffy length-at-age relationship, with the parameters of the growth function estimated together for females and males inside the assessment model.

Retained and discarded onboard length sample sizes, based on numbers of trips sampled, are capped at 200 trips, with a requirement that greater than 100 individual fish are sampled each year, if length data for that year is to be included in the model. For port samples, the number of trips is used as the sampling unit, with a cap of 100 trips (which was not reached). The number of shots or trips is used as the sample size because the appropriate sample size for length frequency data is probably more closely related to the number of shots (onboard) or trips (port) sampled, rather than the number of fish measured per year.

The values assumed for selected fixed parameters of the base case models are shown in Table 7.1.

Table 7.1. Parameter values assumed for selected fixed parameters in the base-case model.

Parameter	Description	Value
M	Natural mortality	0.15
h	steepness' of the Beverton-Holt stock-recruit curve	0.7
x	age observation plus group	30 years
a	allometric length-weight equations	0.000017 g^{-1} cm
b	allometric length-weight equations	3.031
l_m	Female length at 50% maturity	24.5 cm

7.3 Bridging analysis

7.3.1 Bridging from 2018 to 2021 assessments

The previous full quantitative assessment for eastern Jackass Morwong was conducted during 2018 (Day and Castillo-Jordán, 2018) using Stock Synthesis (SS-V3.30.12.00, Methot et al., 2018). The 2021 assessment uses the current version of Stock Synthesis (SS-V3.30.17.00, Methot et al., 2021), which has relatively minor changes from SS-V3.30.12.

As a first step in the process of bridging to a new model, the model was translated from version SS-V3.30.12 (Methot et al., 2018) to version SS-V3.30.17 (Methot et.al., 2021) using the same data and model structure used in the 2018 assessment. Once this translation was complete, minor changes to the implementation of the productivity shift and improved features unavailable in SS-V3.30.12 were incorporated into the SS-V3.30.17 assessment. Following this step, the model was re-tuned using the most recent tuning protocols (Pacific Fishery Management Council, 2018), 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 stock status and the trajectory of spawning biomass. This initial bridging phase (Bridge 1) highlights changes that have occurred since 2018 simply through changes to software and assessment practices. The subsequent bridging exercise (Bridge 2) then sequentially updates the model with new data through to 2020.

The second part of the bridging analysis includes updating historical data (up to 2017), followed by including the data from 2018-2020 into the model. These additional data included new catch, discard, CPUE, length composition data, conditional age-at-length data, and an updated ageing error matrix. The last year of recruitment estimation was extended to 2015 (from 2012 in the 2018 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.

7.4 Bridge 1: Update to Stock Synthesis version and update catch history

The 2018 eastern Jackass Morwong assessment (MOW2018BaseCase_3.30.12) was initially translated to the most recent version of the software, Stock Synthesis version SS-V3.30.17 (MOW2018BaseCase_3.30.17). Figure 7.1 shows that the differences in the assessment results from this step were minimal.

New features available in the new version of Stock Synthesis were incorporated, including changes to the implementation of the 1988 productivity shift (MOW2018_3.30.17_New), followed by updating the catch history up to 2017, incorporating revisions to the catch history in the period 1986-2017 and replacing the estimated 2018 catch with the actual 2018 catch, (MOW2018_3.30.17_ReviseCatch), and finally retuning using the latest tuning protocols (MOW2018_3.30.17_Retuned). 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 2018. This initial bridging step, Bridge 1, does not incorporate any data after 2017 or any structural changes to the assessment, other than the changes to the implementation of the 1988 productivity shift.

When these time series are plotted together, there are virtually no changes in the translation to SS-V3.30.17, but considerable changes when the new features were added, largely due to differences in implementation of the 1988 productivity shift, followed by further minor changes when updating the catch history and the model was retuned using current model tuning protocols (Figure 7.2 and Figure 7.3).

The results of Bridge 1 suggest that there was essentially no change, from around 1980 to the end of the time series, in both the absolute abundance estimates and the relative stock status, relative to the new B_0 associated with the 1988 productivity shift.

Fits to the abundance indices (Figure 7.4 to Figure 7.8) show very limited changes to the fits through this process during Bridge 1, although the fits to the earliest steam trawl CPUE are improved at step “New” (Figure 7.6). The FIS indices show virtually no change to fits during Bridge 1 (Figure 7.9 to Figure 7.10). The estimated recruitment series (absolute number of recruits) shows very little change in broad trends during Bridge 1, although the initial recruitment estimate (R_0) increases slightly at step “New” from the start of the time series through until 1940, well before the productivity shift is incorporated (Figure 7.11). The recruitment deviations are slightly modified, mostly due to changes at step “New” (Figure 7.12), but the changes are so small that this is hard to see in absolute numbers of recruits.

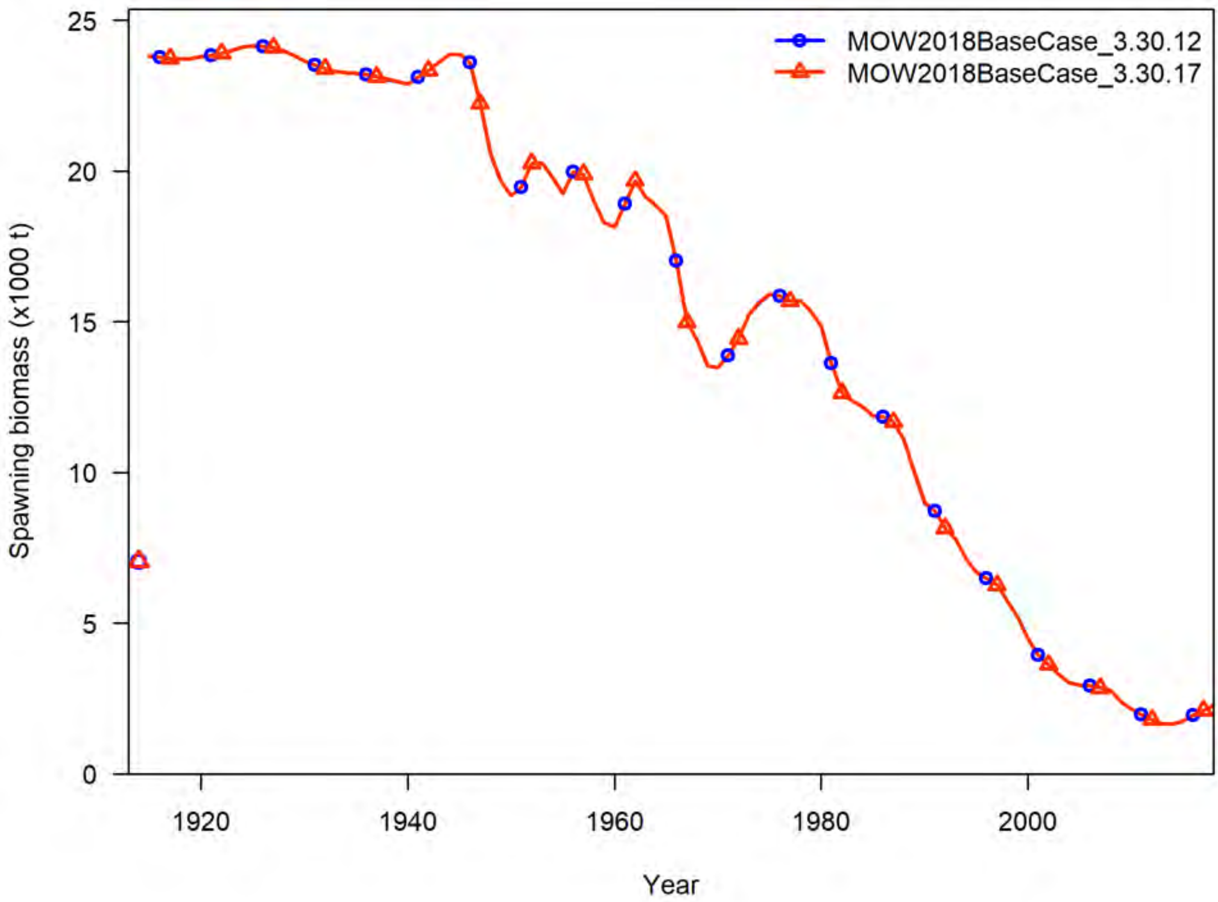

Figure 7.1. Comparison of the time-series of absolute spawning biomass from the 2018 assessment (MOW2018BaseCase_3.30.12 – in blue), and a model with the same data converted to SS-V3.30.17 (MOW2018BaseCase_3.30.17– in red).

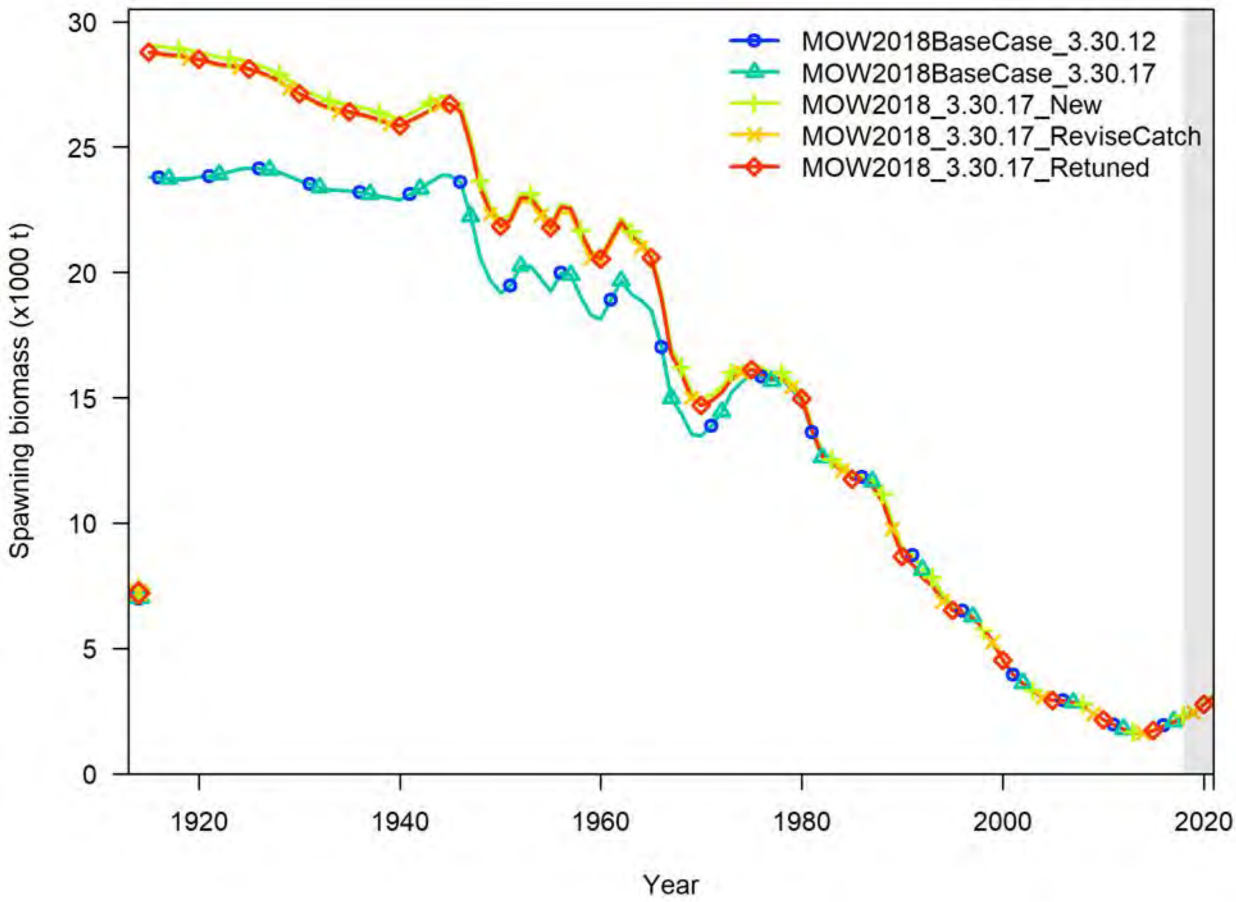

Figure 7.2. Comparison of the time-series of absolute spawning biomass from the 2018 assessment (MOW2018BaseCase_3.30.12 – in royal blue), converting to SS-V3.30.17 (MOW2018BaseCase_3.30.17 – in light blue), incorporating new features (MOW2018_3.30.17_New – in green), revising the historical catch to 2017 and the projected catch in 2018 (MOW2018_3.30.17_ReviseCatch – in orange) retuning the model using the latest tuning protocols (MOW2018_3.30.17_Retuned – in red). The changes shown are largely due to changes in the implementation of the 1988 productivity shift in the updated version of Stock Synthesis.

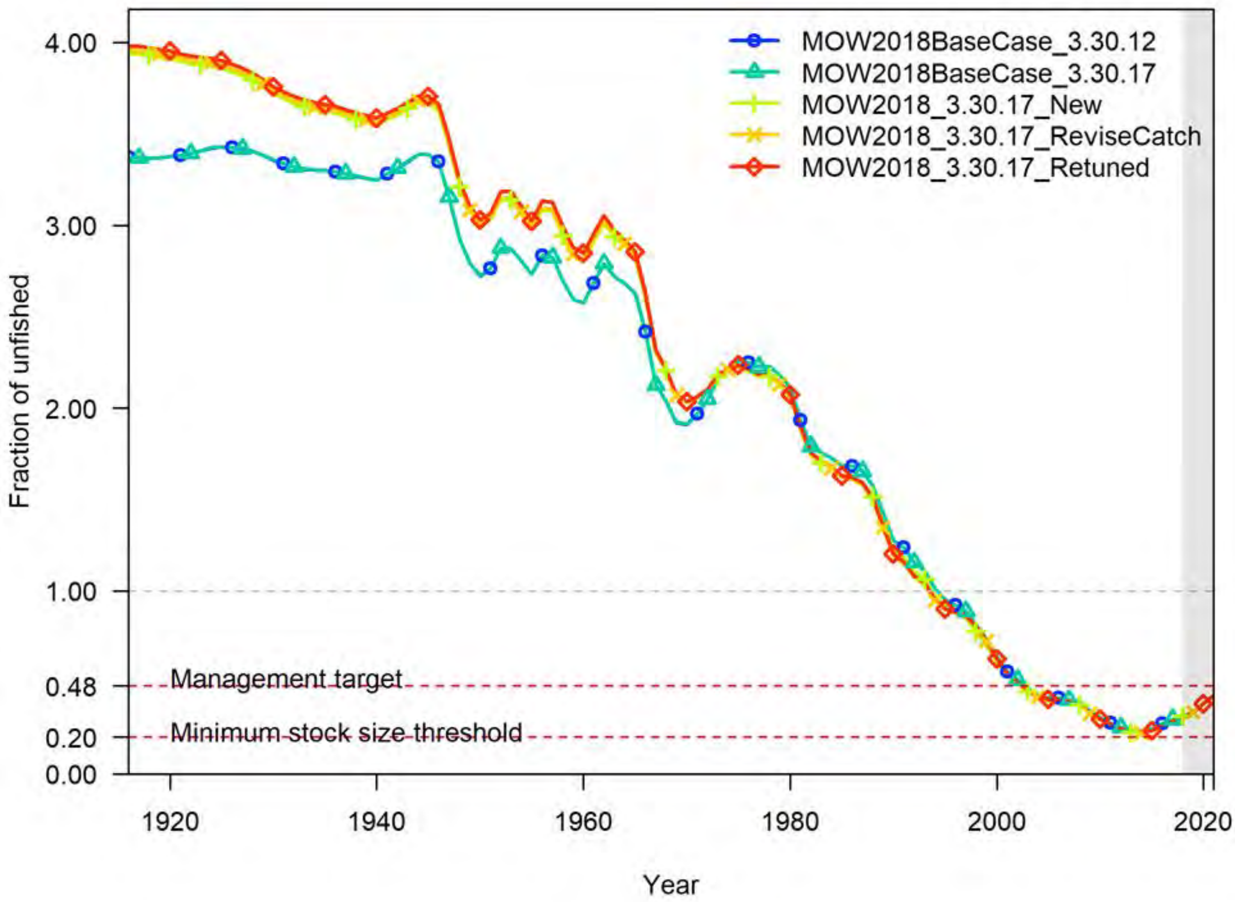

Figure 7.3. Comparison of the time-series of relative spawning biomass from the 2018 assessment (MOW2018BaseCase_3.30.12 – in royal blue), converting to SS-V3.30.17 (MOW2018BaseCase_3.30.17 – in light blue), incorporating new features (MOW2018_3.30.17_New – in green), revising the historical catch to 2017 and the projected catch in 2018 (MOW2018_3.30.17_ReviseCatch – in orange) retuning the model using the latest tuning protocols (MOW2018_3.30.17_Retuned – in red).

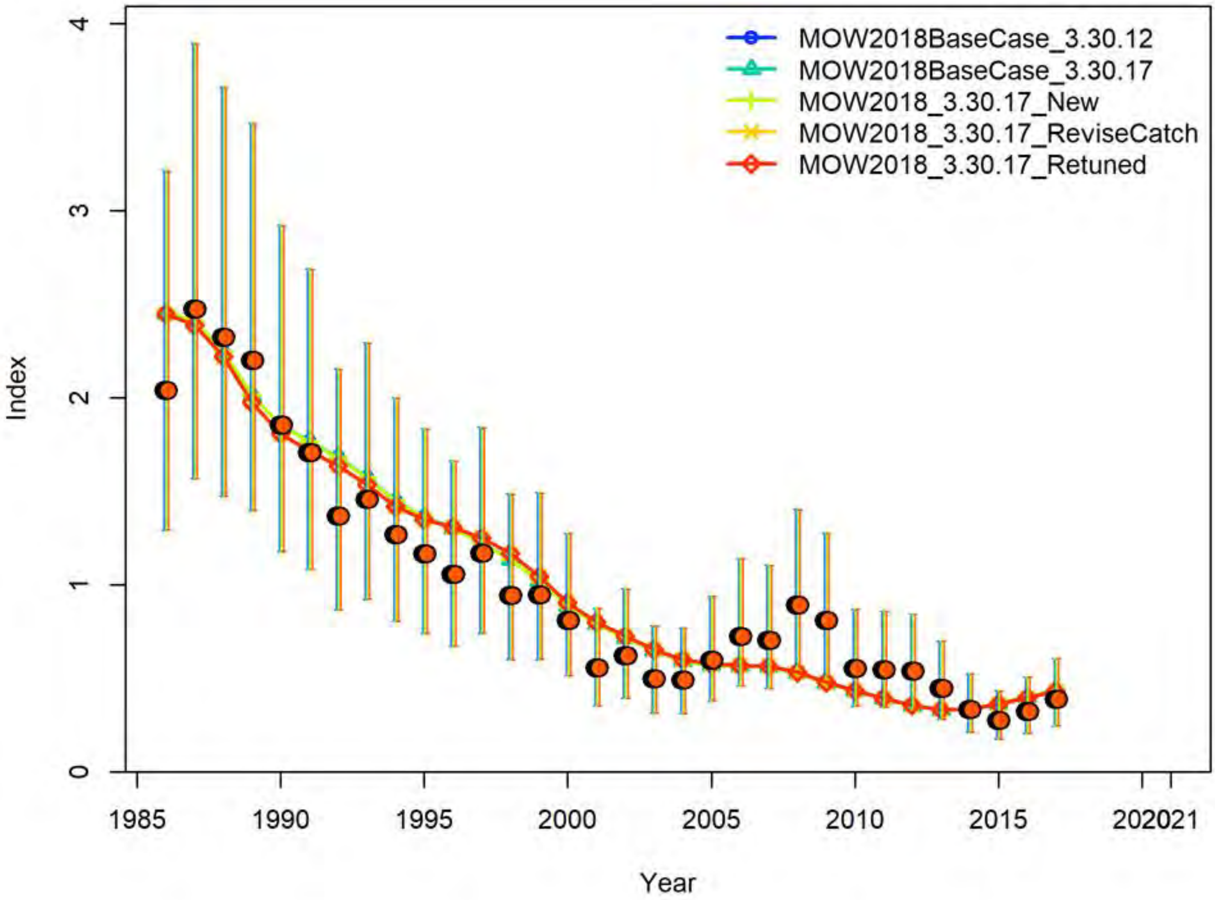

Figure 7.4. Comparison of the fit to the Eastern trawl CPUE index for the 2018 assessment (MOW2018BaseCase_3.30.12 – in royal blue), converting to SS-V3.30.17 (MOW2018BaseCase_3.30.17 – in light blue), incorporating new features (MOW2018_3.30.17_New – in green), revising the historical catch to 2017 and the projected catch in 2018 (MOW2018_3.30.17_ReviseCatch – in orange) retuning the model using the latest tuning protocols (MOW2018_3.30.17_Retuned – in red).

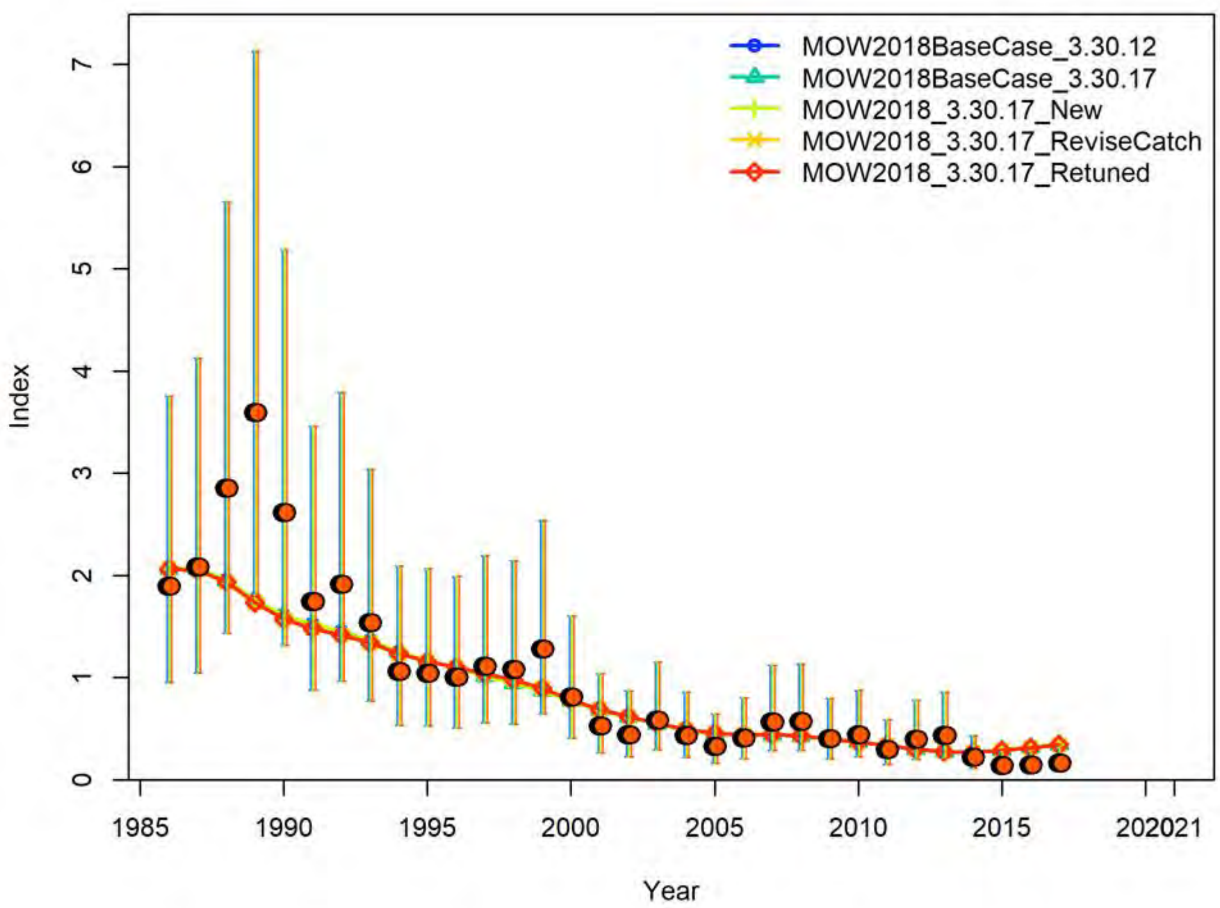

Figure 7.5. Comparison of the fit to the Tasmanian trawl CPUE index for the 2018 assessment (MOW2018BaseCase_3.30.12 – in royal blue), converting to SS-V3.30.17 (MOW2018BaseCase_3.30.17 – in light blue), incorporating new features (MOW2018_3.30.17_New – in green), revising the historical catch to 2017 and the projected catch in 2018 (MOW2018_3.30.17_ReviseCatch – in orange) retuning the model using the latest tuning protocols (MOW2018_3.30.17_Retuned – in red).

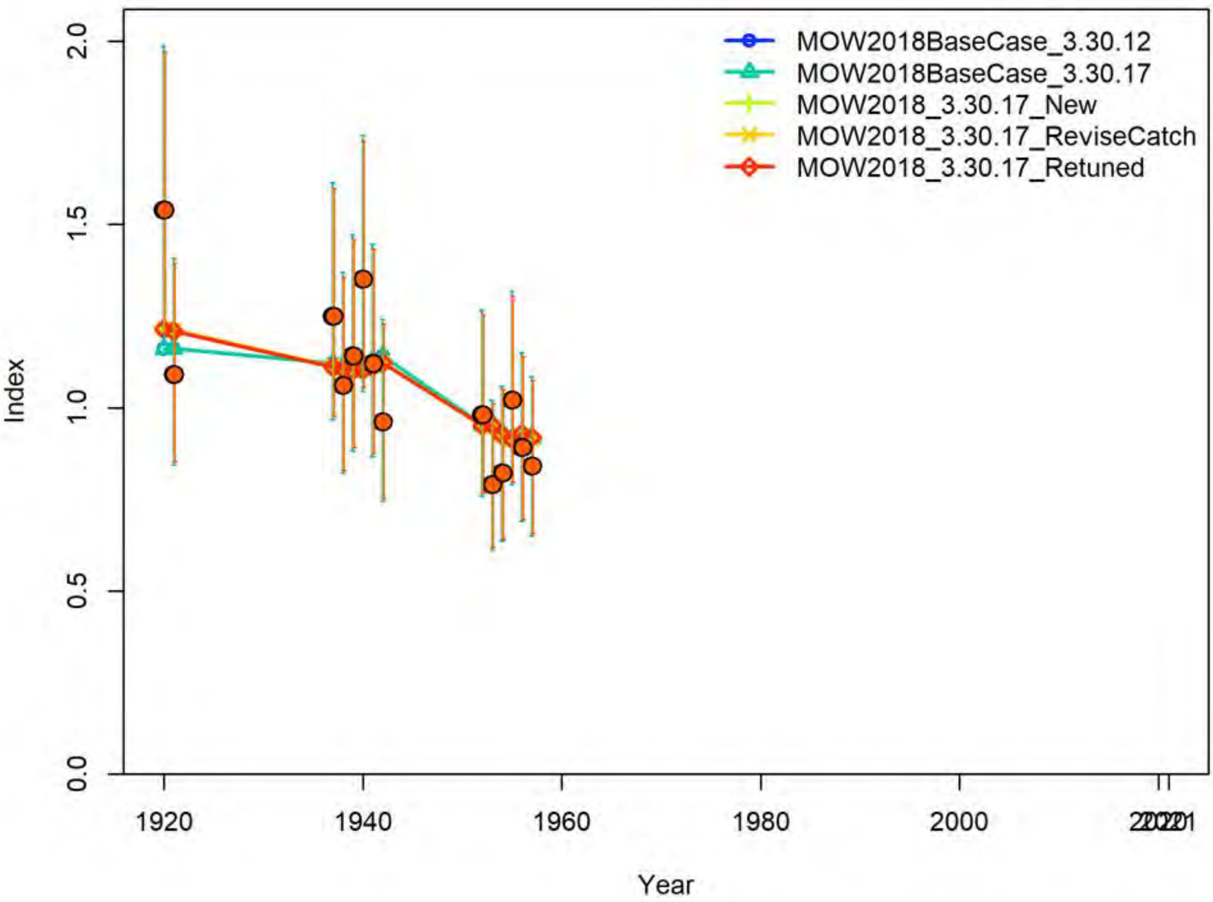

Figure 7.6. Comparison of the fit to the Steam trawl CPUE index for the 2018 assessment (MOW2018BaseCase_3.30.12 – in royal blue), converting to SS-V3.30.17 (MOW2018BaseCase_3.30.17 – in light blue), incorporating new features (MOW2018_3.30.17_New – in green), revising the historical catch to 2017 and the projected catch in 2018 (MOW2018_3.30.17_ReviseCatch – in orange) retuning the model using the latest tuning protocols (MOW2018_3.30.17_Retuned – in red).

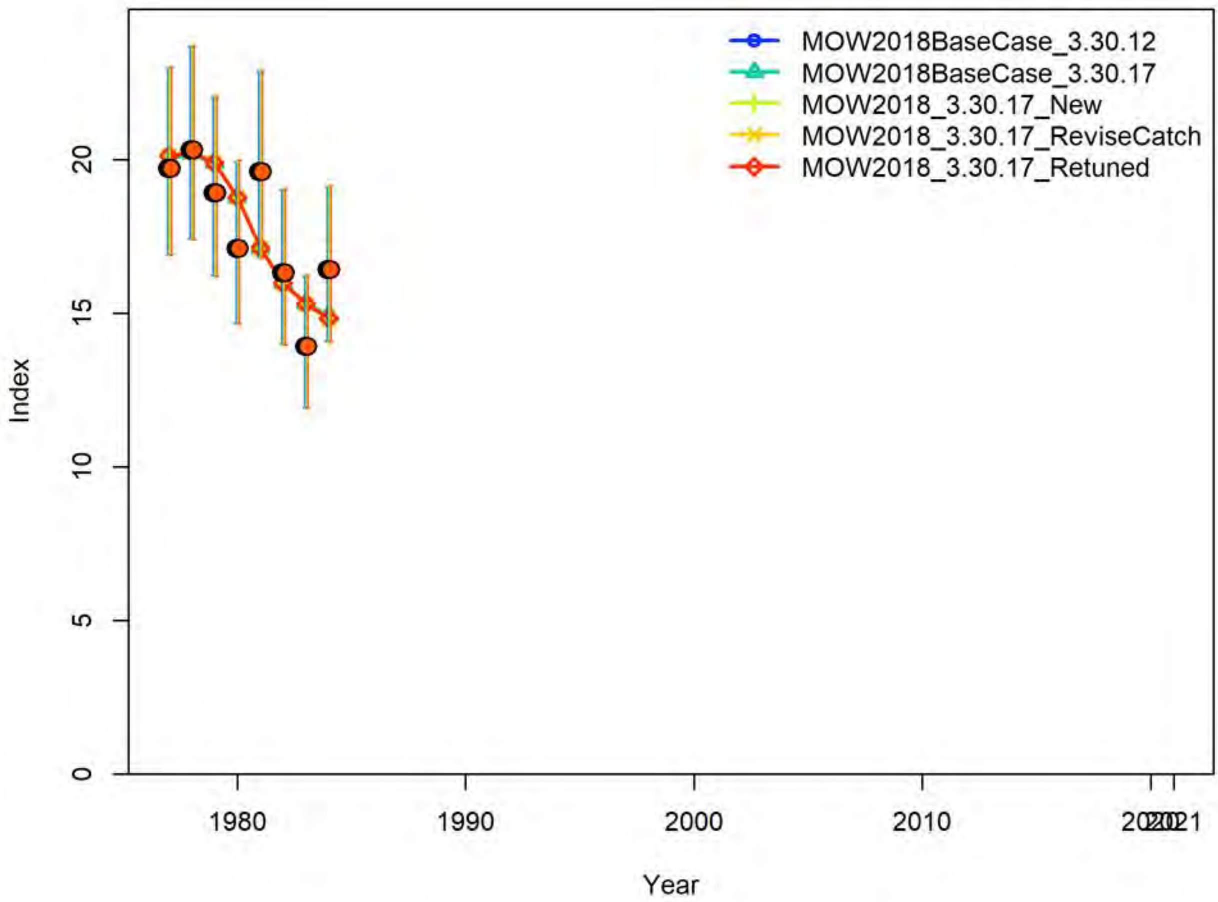

Figure 7.7. Comparison of the fit to the mixed CPUE index for the 2018 assessment (MOW2018BaseCase_3.30.12 – in royal blue), converting to SS-V3.30.17 (MOW2018BaseCase_3.30.17 – in light blue), incorporating new features (MOW2018_3.30.17_New – in green), revising the historical catch to 2017 and the projected catch in 2018 (MOW2018_3.30.17_ReviseCatch – in orange) retuning the model using the latest tuning protocols (MOW2018_3.30.17_Retuned – in red).

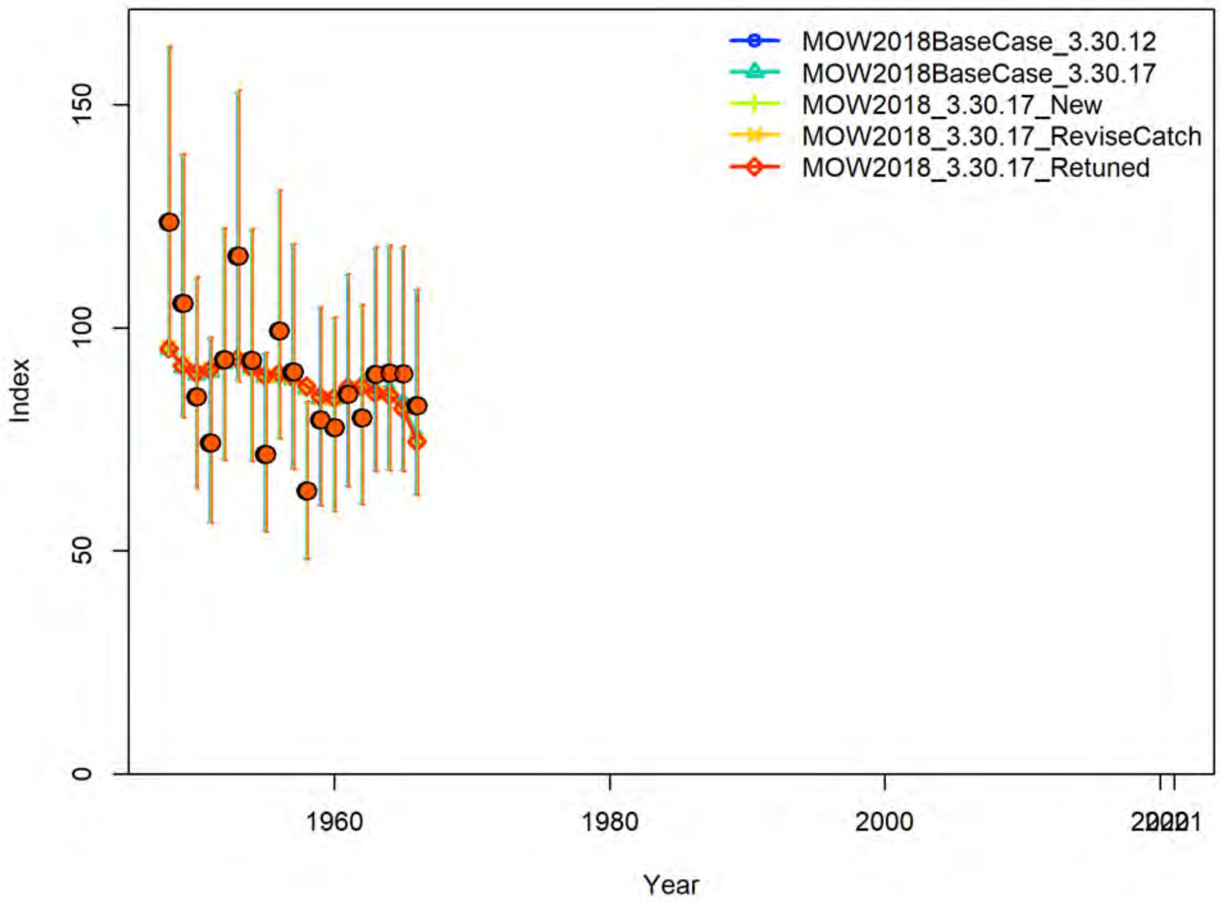

Figure 7.8. Comparison of the fit to the Smith CPUE index for the 2018 assessment (MOW2018BaseCase_3.30.12 – in royal blue), converting to SS-V3.30.17 (MOW2018BaseCase_3.30.17 – in light blue), incorporating new features (MOW2018_3.30.17_New – in green), revising the historical catch to 2017 and the projected catch in 2018 (MOW2018_3.30.17_ReviseCatch – in orange) retuning the model using the latest tuning protocols (MOW2018_3.30.17_Retuned – in red).

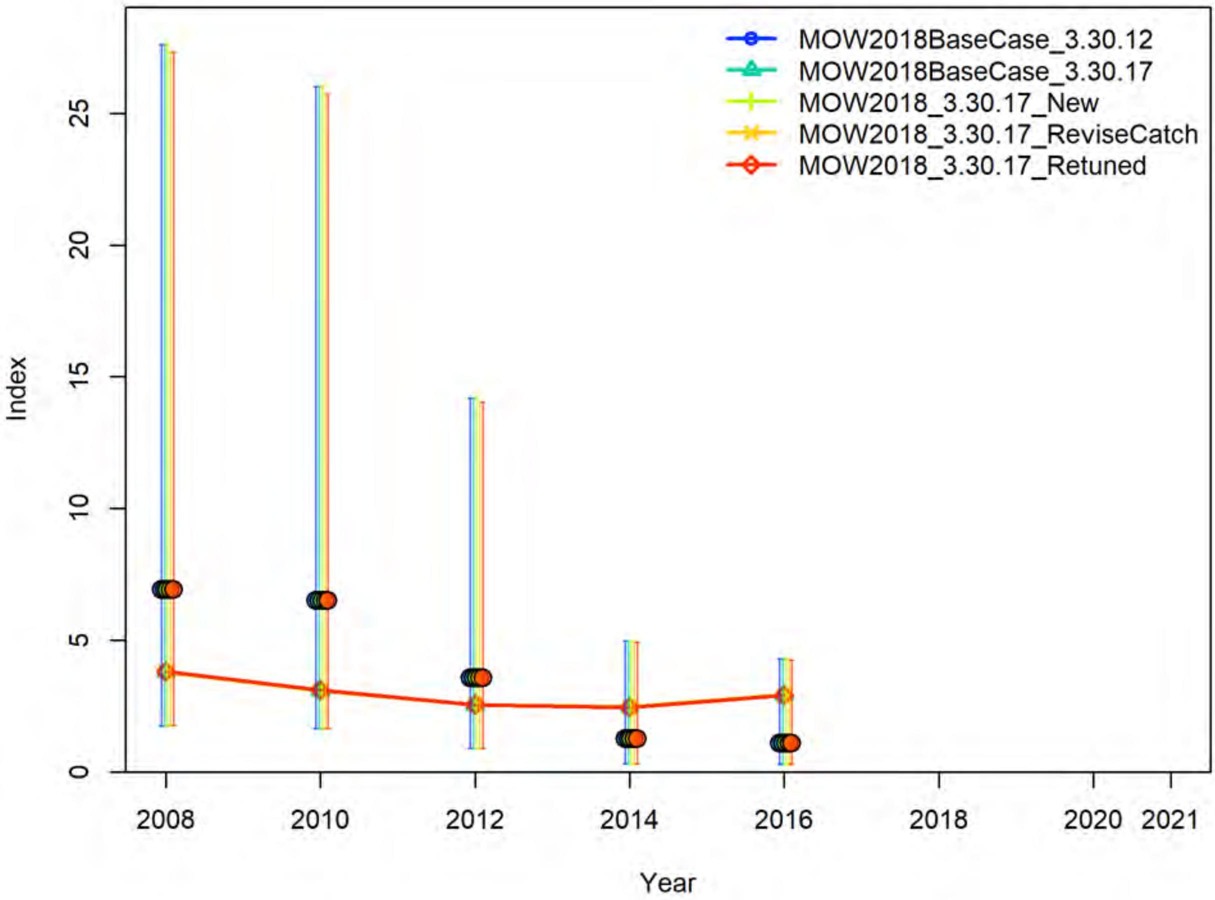

Figure 7.9. Comparison of the fit to the FIS_East (zones 10 and 20) abundance index for the 2018 assessment (MOW2018BaseCase_3.30.12 – in royal blue), converting to SS-V3.30.17 (MOW2018BaseCase_3.30.17 – in light blue), incorporating new features (MOW2018_3.30.17_New – in green), revising the historical catch to 2017 and the projected catch in 2018 (MOW2018_3.30.17_ReviseCatch – in orange) retuning the model using the latest tuning protocols (MOW2018_3.30.17_Retuned – in red).

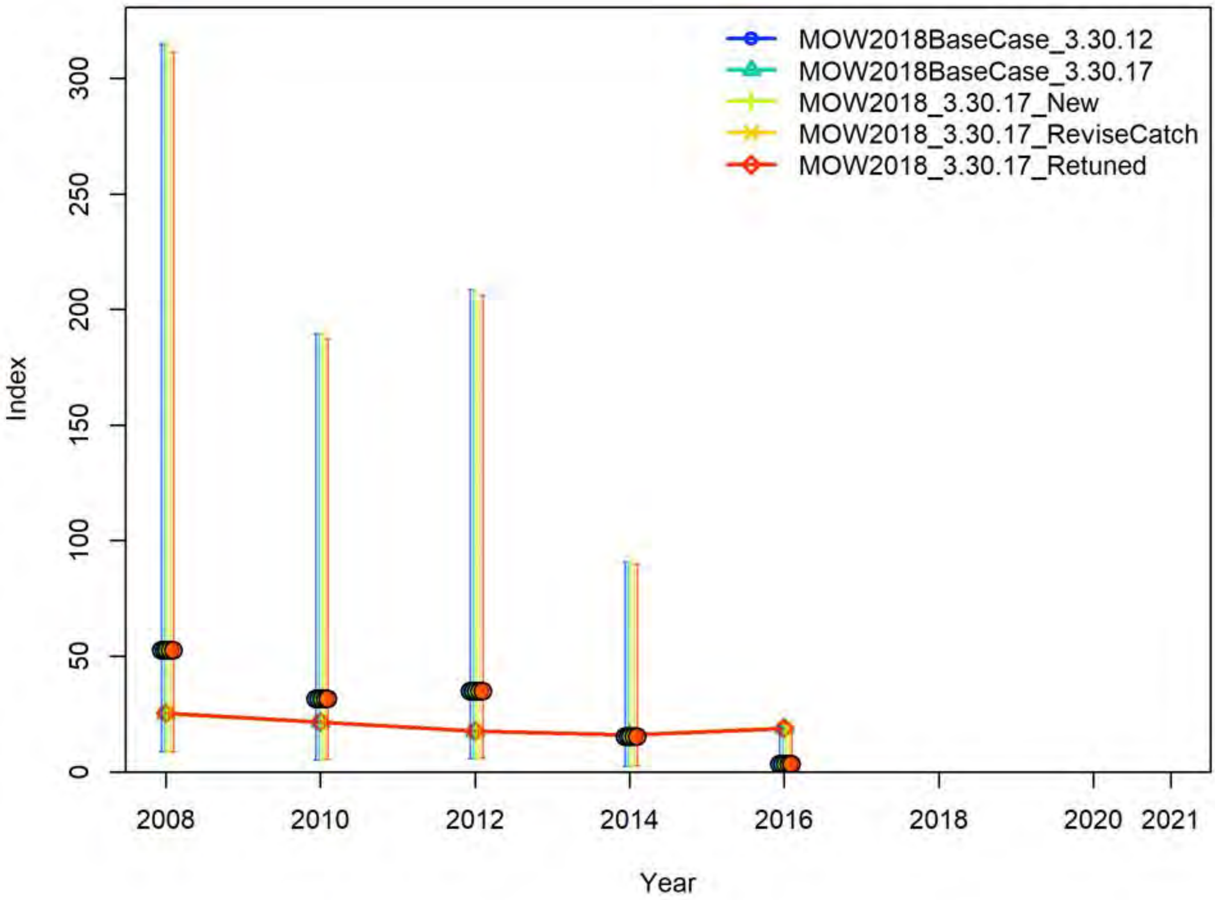

Figure 7.10. Comparison of the fit to the FIS_Tas (zone 30) abundance index for the 2018 assessment (MOW2018BaseCase_3.30.12 – in royal blue), converting to SS-V3.30.17 (MOW2018BaseCase_3.30.17 – in light blue), incorporating new features (MOW2018_3.30.17_New – in green), revising the historical catch to 2017 and the projected catch in 2018 (MOW2018_3.30.17_ReviseCatch – in orange) retuning the model using the latest tuning protocols (MOW2018_3.30.17_Retuned – in red).

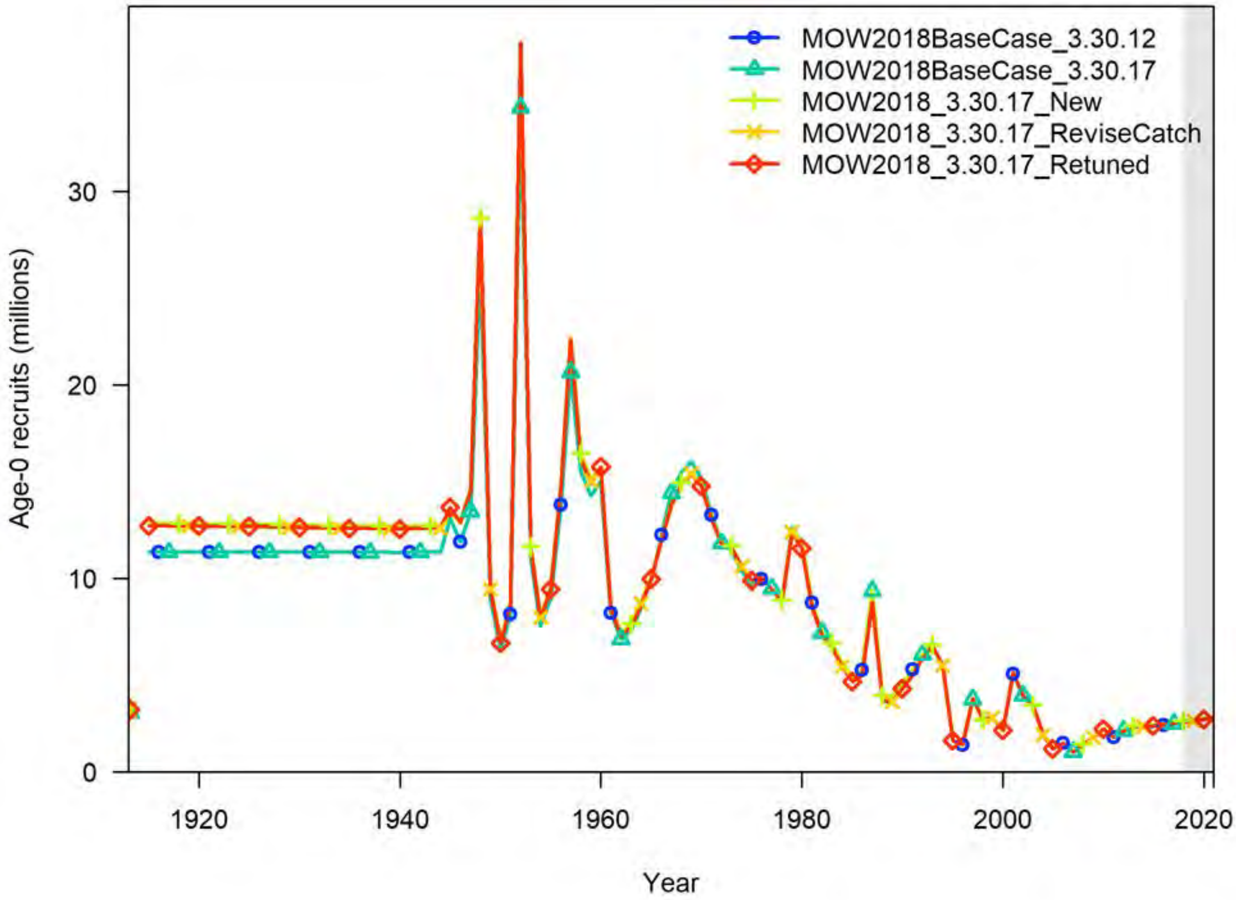

Figure 7.11. Comparison of the time series of absolute recruitment from the 2018 assessment (MOW2018BaseCase_3.30.12 – in royal blue), converting to SS-V3.30.17 (MOW2018BaseCase_3.30.17 – in light blue), incorporating new features (MOW2018_3.30.17_New – in green), revising the historical catch to 2017 and the projected catch in 2018 (MOW2018_3.30.17_ReviseCatch – in orange) retuning the model using the latest tuning protocols (MOW2018_3.30.17_Retuned – in red).

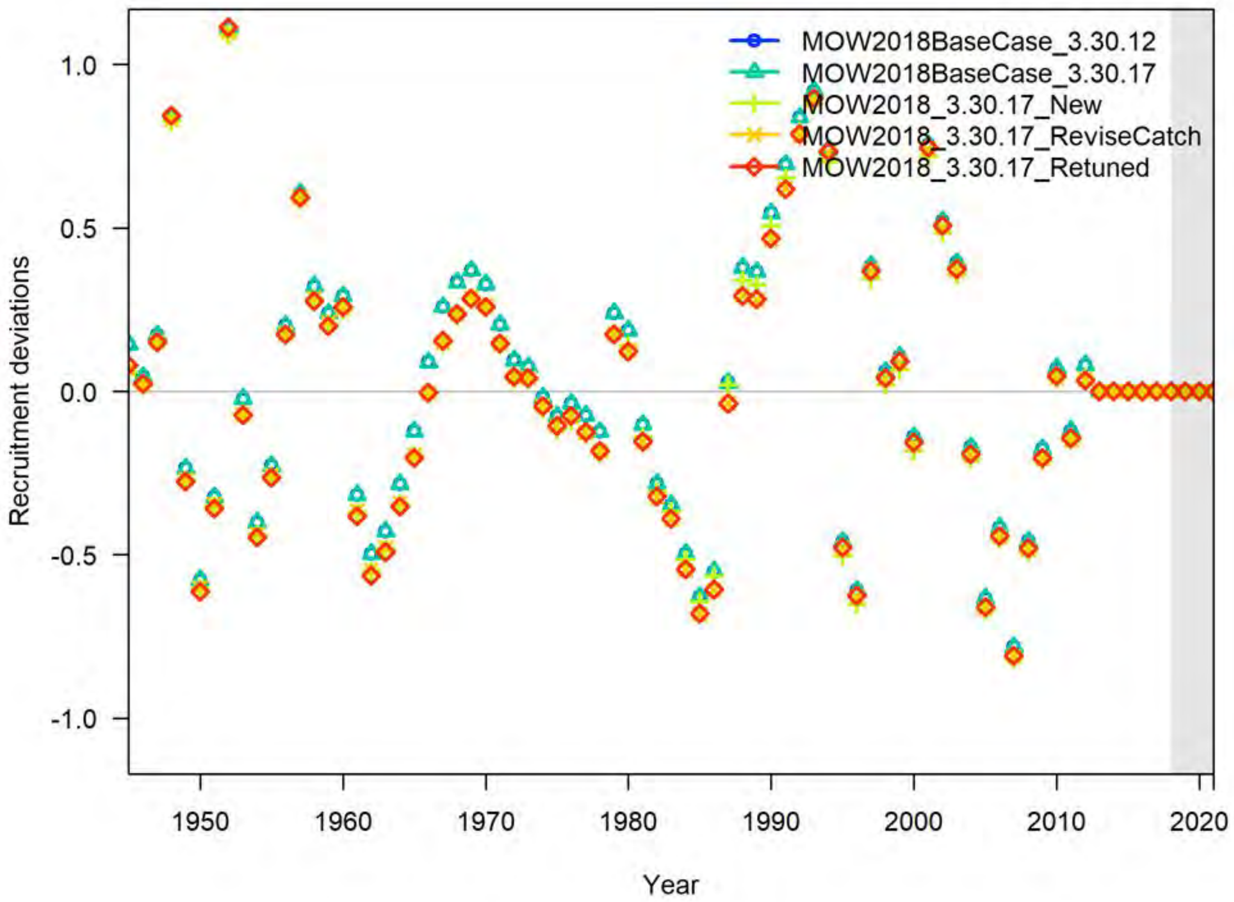

Figure 7.12. Comparison of the time series of estimated recruitment deviations from the 2018 assessment (MOW2018BaseCase_3.30.12 – in royal blue), converting to SS-V3.30.17 (MOW2018BaseCase_3.30.17 – in light blue), incorporating new features (MOW2018_3.30.17_New – in green), revising the historical catch to 2017 and the projected catch in 2018 (MOW2018_3.30.17_ReviseCatch – in orange) retuning the model using the latest tuning protocols (MOW2018_3.30.17_Retuned – in red).

7.4.1 *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). The tuning steps undertaken are detailed below:

1. Set the standard error for the log of relative abundance indices (CPUE or FIS) to their estimated standard errors 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 SSV-3.30 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.

7.5 Bridge 2: Inclusion of new data (2018-2020)

Starting from the final step of Bridge 1, the retuned 2018 base case model with updated data to 2017 (MOW2018_3.30.17_Retuned), additional data from 2018-2020 were added sequentially to build a preliminary base case for the 2021 assessment:

1. Change final assessment year to 2020, add catch to 2020 (MOW2021_addCatch2020).
2. Add CPUE to 2020 (from Sporcic (2021)), (MOW2021_addCPUE2020).
3. Add new discard fraction estimates from 1993 to 2020 (MOW2021_addDiscards2020).
4. Add updated length frequency data to 2020 (MOW2021_addLength2020).
5. Add updated age error matrix and conditional age-at-length data to 2020 (MOW2021_addAge2020).
6. Change the final year for which recruitments are estimated from 2012 to 2015 (MOW2021_extendRec2015).
7. Retune using current tuning protocols, including Francis weighting on length-compositions and Punt weighting on conditional age-at-length data (MOW2021_Tuned).
8. Update the FIS abundance indices to FIS2 abundance indices (Sporcic et al., 2019), add FIS length composition data for the two FIS fleets (East FIS and Tas FIS), estimate selectivity for these two fleets and retune (MOW20201_FIS_Tuned). This final step is recommended as the preliminary 2021 base case.

Inclusion of the new data resulted in a series of changes to the estimates of recruitment and hence to the time-series of both absolute and relative spawning biomass (Figure 7.13 and Figure 7.14), with relatively large changes in spawning biomass time-series in the period from 1915 through to around 1990, then fairly consistent estimates from all bridging steps from 1990 through to around 2015, followed by some divergence from 2015-2021. For the early years of the spawning biomass series, updating the CPUE resulted in an increase to spawning biomass, a pattern largely reversed by adding new discard data, with minor changes from the next few bridging steps and then a decline when recruitment is extended to 2015. For the most recent years of the spawning biomass series, from 2015 to 2021, there was a revision of spawning biomass downwards at the step when the CPUE data was updated, with minor adjustments to this part of the series in the following bridging steps. Note that the 1915 stock status shown in Figure 7.14 is plotted relative to the 1988 equilibrium spawning biomass, post productivity shift, rather than relative to the 1915 unfished equilibrium spawning biomass. Equilibrium spawning biomass in 1988 is shown in Figure 7.13 as individual plotted points for each bridging step, with values ranging between 5,000 and 8000 t, shown just next to the y-axis in 1915 (Figure 7.13, bottom left corner).

Changes to the recruitment series are shown in Figure 7.15. These relative changes are easier to see in the changes to the recruitment deviations (Figure 7.16). The revisions to recruitment typically occur over a number of bridging steps, and are especially noticeable in the years 2008-2012, the last five years of estimated recruitment deviations from the 2018 assessment. All of the revisions from 2008-2012 result in reduced estimated recruitment. When three additional recruitment deviations are estimated through until 2015, the three new estimates are all well below average, with 2013 and 2014 featuring the lowest estimated recruitment deviations in the whole series, with the last 12 estimated recruitment deviations being below average. This appears consistent with a continued decline in productivity in recent years, with some evidence to suggest that this decline began around 1980 and has continued steadily since then, allowing for the fact that a step reduction in productivity is modelled in 1988 in Figure 7.16.

Fits to the CPUE indices (Figure 7.17 to Figure 7.21) and the FIS abundance index (Figure 7.22 and Figure 7.23) generally feature relatively minor changes as data are added, with the most significant change in the early years due to updating the discard data for the eastern trawl and Tasmanian trawl fleets (Figure 7.17 and Figure 7.18), and in extending recruitment estimates to 2015 in the final years for eastern trawl Figure 7.17) and to a lesser extent for Tasmanian trawl (Figure 7.18). The changes resulting from extending recruitment estimates, also result in better fits to the last few years of CPUE data for both the eastern trawl and Tasmanian trawl CPUE series (Figure 7.17 and Figure 7.18).

There are minimal changes to the historical CPUE series which have no new data. The fits to the FIS abundance index (Figure 7.22 and Figure 7.23) are not very good. Given the variability from point to point, it would be hard to get good fits to these series, and to fit the species biology and the rest of the data in the assessment. However, both FIS series suggest there is a larger decline in biomass from 2008-2016 than the model estimates. If the model could fit the FIS abundance data better, it would produce even lower stock status estimates. It appears that the fits to the much longer recent trawl CPUE indices are much more influential. The fits to the historic CPUE indices are reasonable. The fit to the eastern trawl CPUE series from the 2018 assessment, matched the slight increase seen in the last two CPUE data points (2017 and 2018) in the 2018 assessment. The additional CPUE data points (2018-2020) are all lower than the CPUE in 2017 for eastern trawl, and the 2021 assessment fits this decline in CPUE from 2017-2020.

7.5.1 *Results from Bridge 2 from the 2018 assessment*

Inclusion of three years of new data in the 2018 assessment (Day and Castillo-Jordán, 2018) resulted in relatively small changes to estimates of recruitment and the spawning biomass time series, with the time series of spawning biomass showing a minimum stock biomass level in 2013 and 2014 of around 23% but with an apparent recovery since then, with stronger recruitment and low fishing pressure up until 2017. Recruitment was only able to be estimated for one additional year at that time, despite using three more years of additional data, with upward revisions to the recruitment estimates from 2010 and 2011 and slightly higher than average recruitment estimated for 2012. The 2018 assessment stated that “these latest recruitment estimates may be further revised with the inclusion of additional data in future assessments, with new data that may help inform these recruitment estimates”, and indeed these latest recruitment estimates were all revised down in the new 2021 proposed base case.

The 2015 assessment (Tuck et al., 2015) estimated the stock status at the start of 2016 to be 36%. The 2018 base case has an estimate of stock status at the start of 2019 of 35% of unexploited stock biomass, SSB_0, (projected assuming 2017 catches in 2018) with the equilibrium female spawning biomass in 1988 (post productivity shift) estimated at 3,523 t (reduced from 3,977 t from the 2015 assessment) and in 2019 the female spawning biomass is projected to be 1,237 t (reduced from the 2019 projected value of 1,560 t from the 2015 assessment).

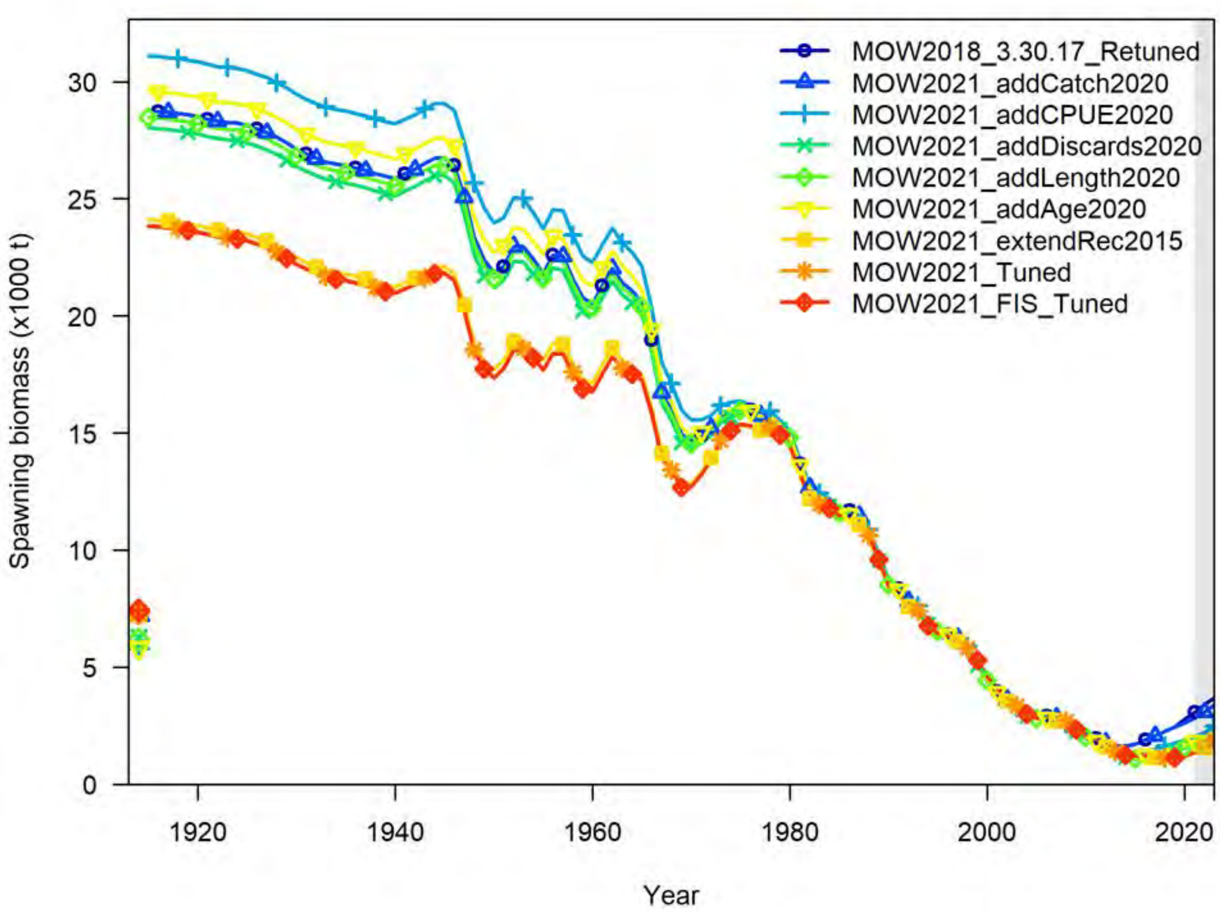

Figure 7.13. Comparison of the time series of absolute spawning biomass for the updated 2018 assessment model converted to SS-V3.30.17 (MOW2018_3.30.17_Retuned – dark blue) with various bridging models leading to a proposed 2018 base case model (MOW2021_FIS_Tuned - red).

7.5.2 *Results from Bridge 2 from the 2021 assessment*

While the inclusion of three years of new data in the 2021 assessment may superficially appear to result in relatively minor changes to the spawning biomass and recruitment time series, these changes require careful scrutiny. Due to the productivity shift resulting in a very large initial stock status in 1915, relative to the 1988 equilibrium spawning biomass (three to five times higher), apparently small changes to the spawning biomass after 2010 shown in Figure 7.13 and Figure 7.14 actually result in substantial changes, relative to the target and limit reference points (B_{48} and B_{20}). For the preliminary base case for 2021, the spawning biomass is now estimated to be below the limit reference point (B_{20}) for the period 2013-2021, with a minimum stock status of 15% in 2018 and 2019, 17% in 2016, 19% in 2021 and at the start of 2022 the projected stock status is 21%, assuming average recruitment has occurred since 2016. This is a change to the model estimated stock status of around 35% in the period between 2016 and 2019 which was produced from the 2018 and 2015 stock assessments. If this stock status is compared to the pre-productivity shift biomass, the minimum stock status would be 4.8% in both 2018 and 2019 with a 2022 stock status of 6.7%, and with all values of stock status below 20% since the year 2000.

Similarly, there are considerable revisions downwards to recent recruitment deviations (Figure 7.16), starting with the addition of updated discard data and continuing as more steps are undertaken in Bridge 2. These downwards revisions of recent recruitment deviations apply especially for the period 2007-2012, which are the last 6 years of estimated recruitment deviations from the 2018 assessment. Noticeably the three new years with recruitment deviations estimated, 2013-2015 are all well below average, with estimates for the 2013 and 2014 recruitment deviations resulting in the largest negative recruitment deviations in the whole recruitment deviation time series. Given this run of 12 years of below average recruitments, even with a 1988 productivity shift already implemented, considerable caution is required when interpreting results of models projecting forwards applying average recruitment since 2016, as these projections may be misleading, if recruitment has not returned to average since 2016.

The 2021 preliminary base case estimates the stock status at the start of 2022 (projected assuming 2020 catches in 2021) to be 22%. The 2021 preliminary base case estimates stock status at the start of 2019 to be 15% (compared to projected values of 35% and 39% respectively from the 2018 and 2015 assessments for 2019). The equilibrium female spawning biomass in 1988 (post productivity shift) is estimated to be 3,715 t (compared to 3,523 t from the 2018 assessment and 3,977 t from the 2015 assessment) and in 2022 the female spawning biomass is estimated to be 801 t (compared to projections in 2022 of 1,366 t from the 2018 assessment and 1,667 t from the 2015 assessment).

The changes to the predicted stock status between the 2021 preliminary base case and the 2018 and 2015 assessment appear to be largely driven by recent CPUE data for both the eastern trawl and Tasmanian trawl fleets. Extending recruitment estimates to 2015 allowed improvements to the fit to the three new CPUE data points (2018-2020) for the eastern trawl fleet (Figure 7.17), overriding the apparent increase in eastern trawl CPUE at the end of this previous CPUE series (2015-2017) from the 2018 assessment, an increase which the model appeared to fit to in 2018. Similarly, the additional three CPUE points for the Tasmanian trawl series result in an adjustment (compared to the 2018 assessment) to the biomass projections in 2015-2017 (Figure 7.18), which was the end of the series from the 2018 assessment. The slightly optimistic model estimates for 2015-2017 (fitted series higher than the CPUE data points) from the 2018 assessment have been revised down in 2021, as the model has additional CPUE points (2018-2020) which do not support or allow this increase in biomass to be fitted at the end of the series. There is clearly no strong signal in the length and age data, indicating good recent recruitment, which would prevent the model fitting the recent CPUE data for both the eastern and Tasmanian trawl fleets. Of course, the most recent estimates of recruitment may be revised in subsequent stock assessments, as additional data becomes available to further inform these recruitment estimates.

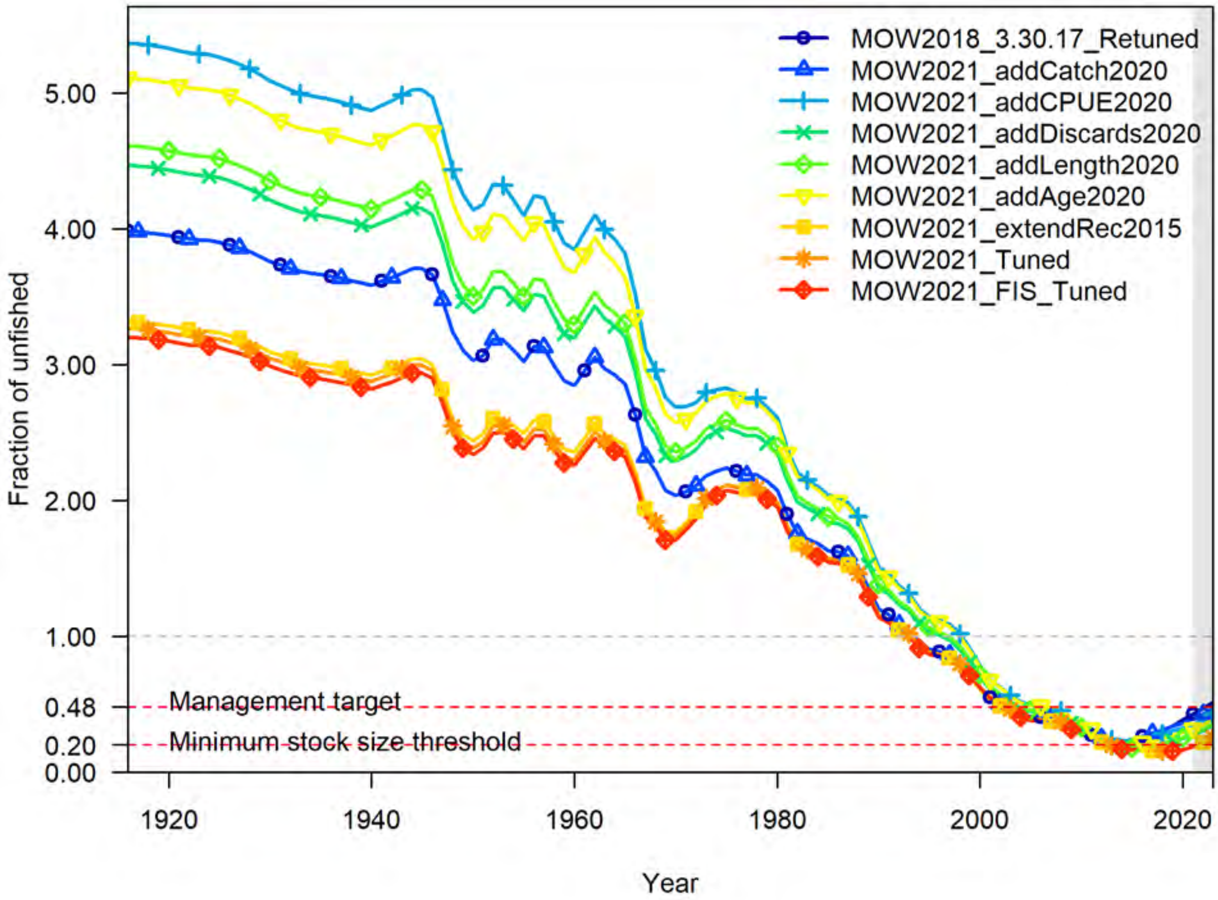

Figure 7.14. Comparison of the time series of relative spawning biomass for the updated 2018 assessment model converted to SS-V3.30.17 (MOW2018_3.30.17_Retuned – dark blue) with various bridging models leading to a proposed 2018 base case model (MOW2021_Tuned - red).

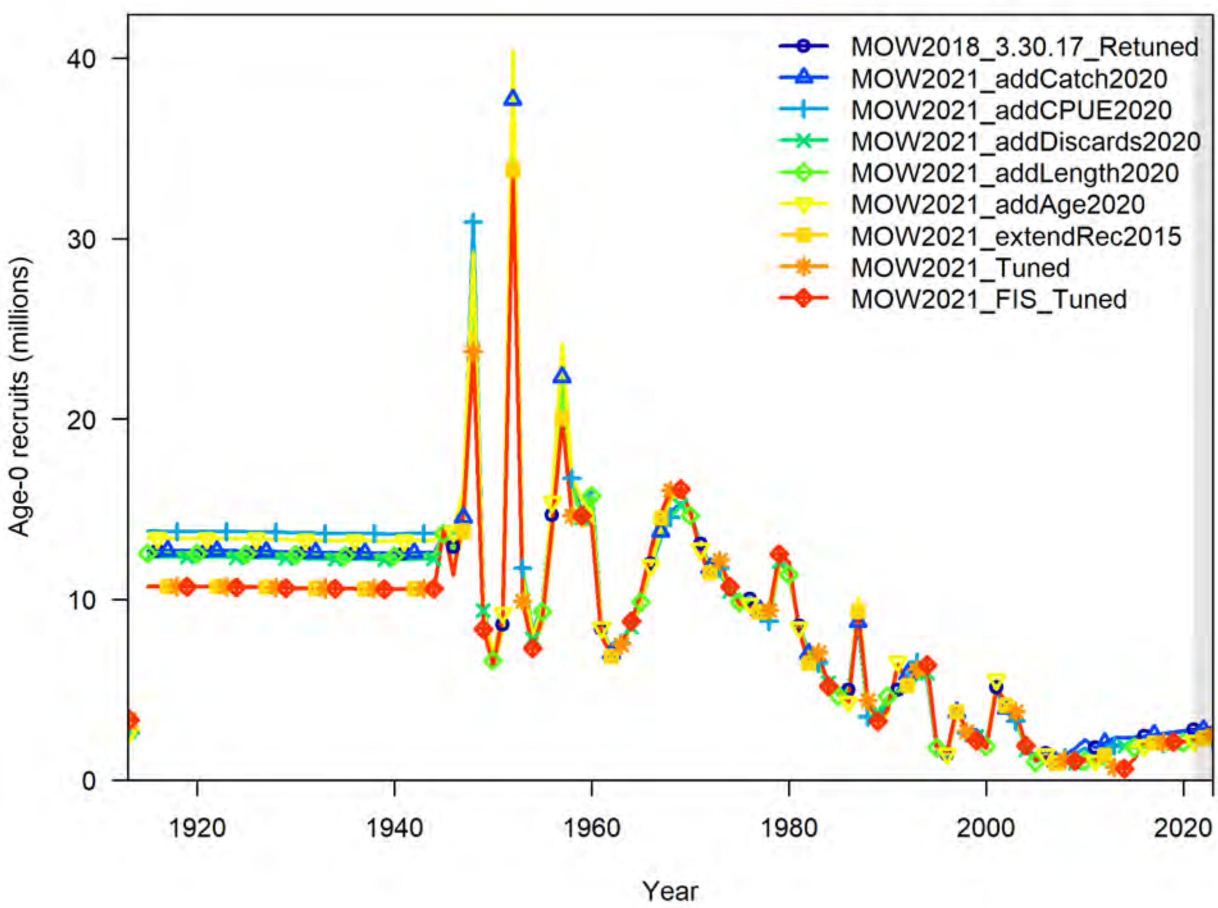

Figure 7.15. Comparison of the time series of absolute recruitment from the updated 2018 assessment model converted to SS-V3.30.17 (MOW2018_3.30.17_Retuned – dark blue) with various bridging models leading to a proposed 2018 base case model (MOW2021_Tuned - red).

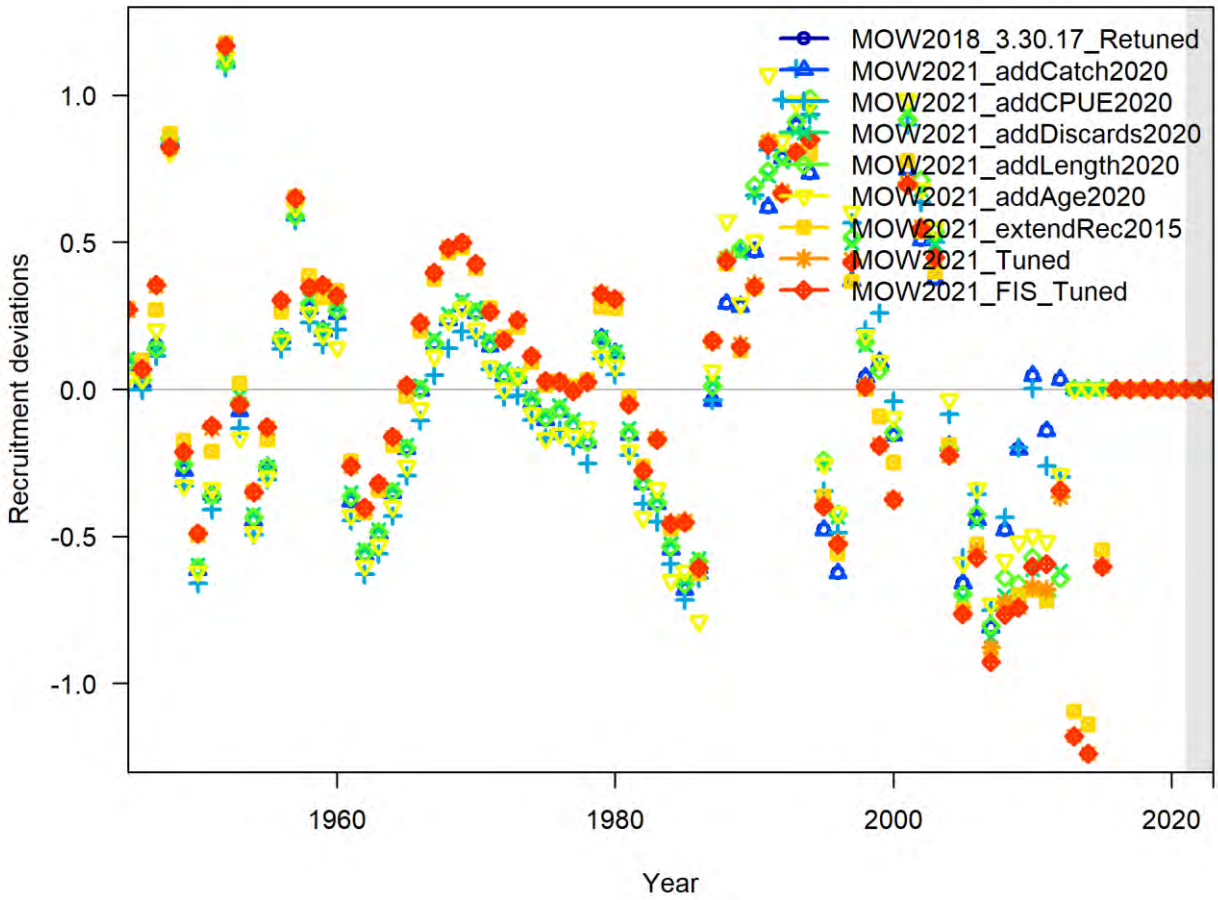

Figure 7.16. Comparison of the time series of estimated recruitment deviations from the updated 2018 assessment model converted to SS-V3.30.17 (MOW2018_3.30.17_Retuned – dark blue) with various bridging models leading to a proposed 2018 base case model (MOW2021_Tuned - red).

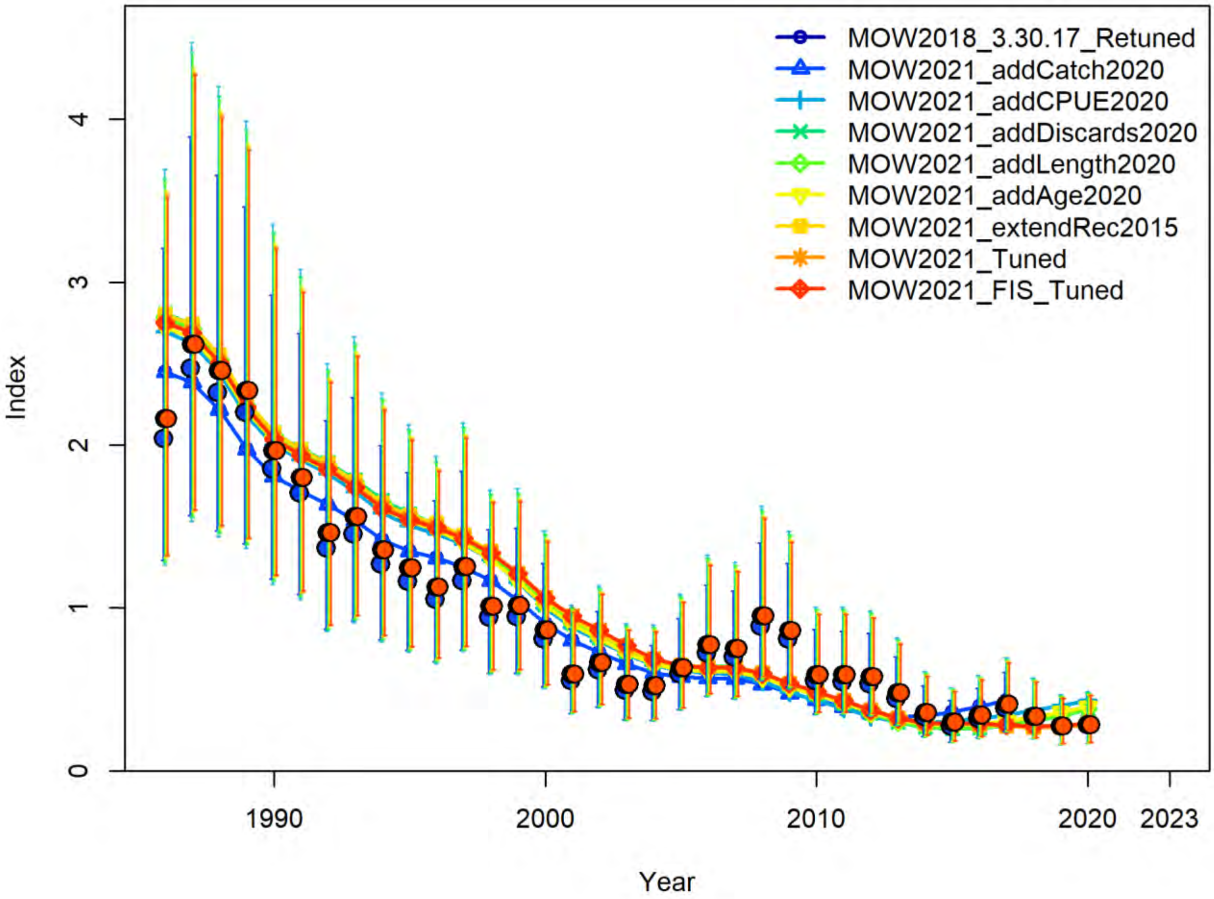

Figure 7.17. Comparison of the fit to the eastern trawl CPUE index for the updated 2018 assessment model converted to SS-V3.30.17 (MOW2018_3.30.17_Retuned – dark blue) with various bridging models leading to a proposed 2018 base case model (MOW2021_Tuned - red).

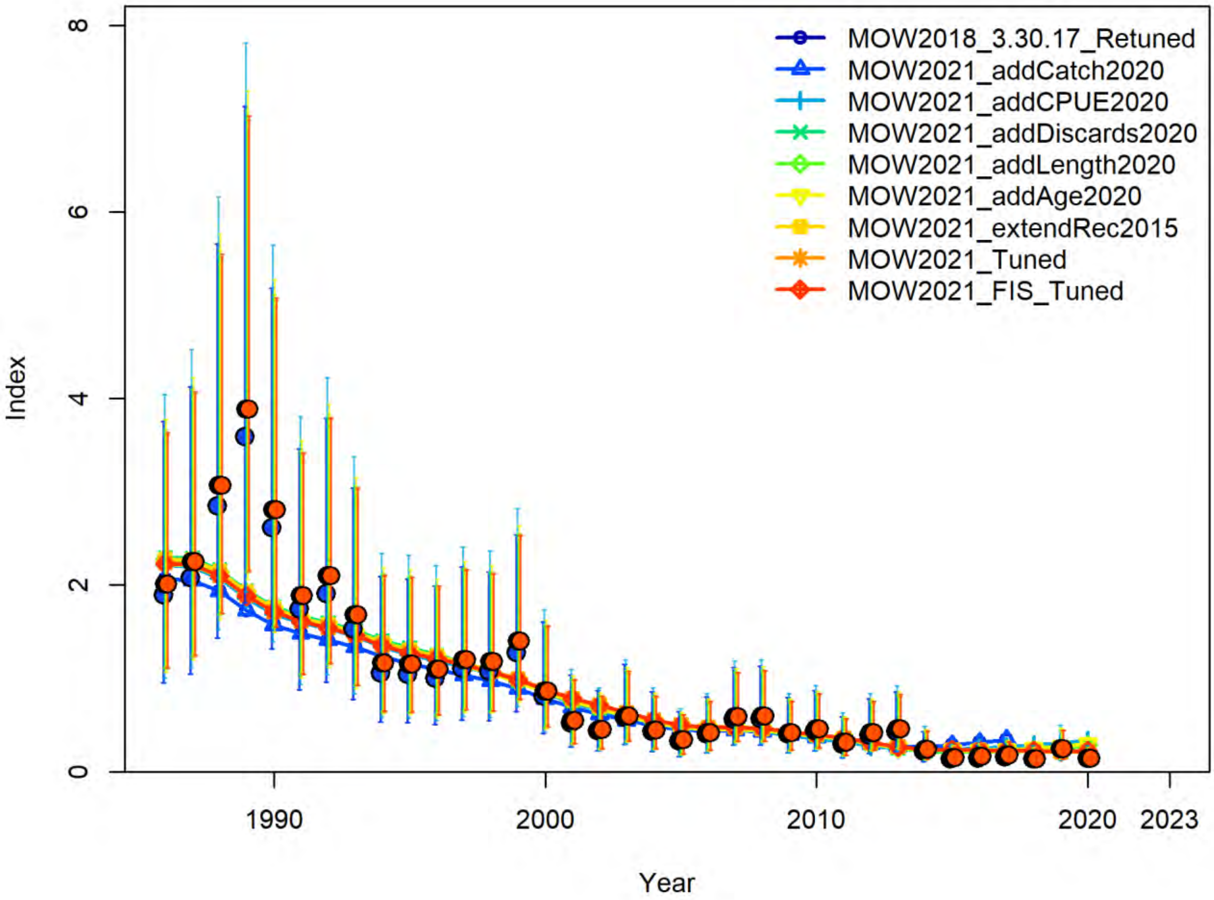

Figure 7.18. Comparison of the fit to the Tasmanian trawl CPUE index for the updated 2018 assessment model converted to SS-V3.30.17 (MOW2018_3.30.17_Retuned – dark blue) with various bridging models leading to a proposed 2018 base case model (MOW2021_Tuned - red).

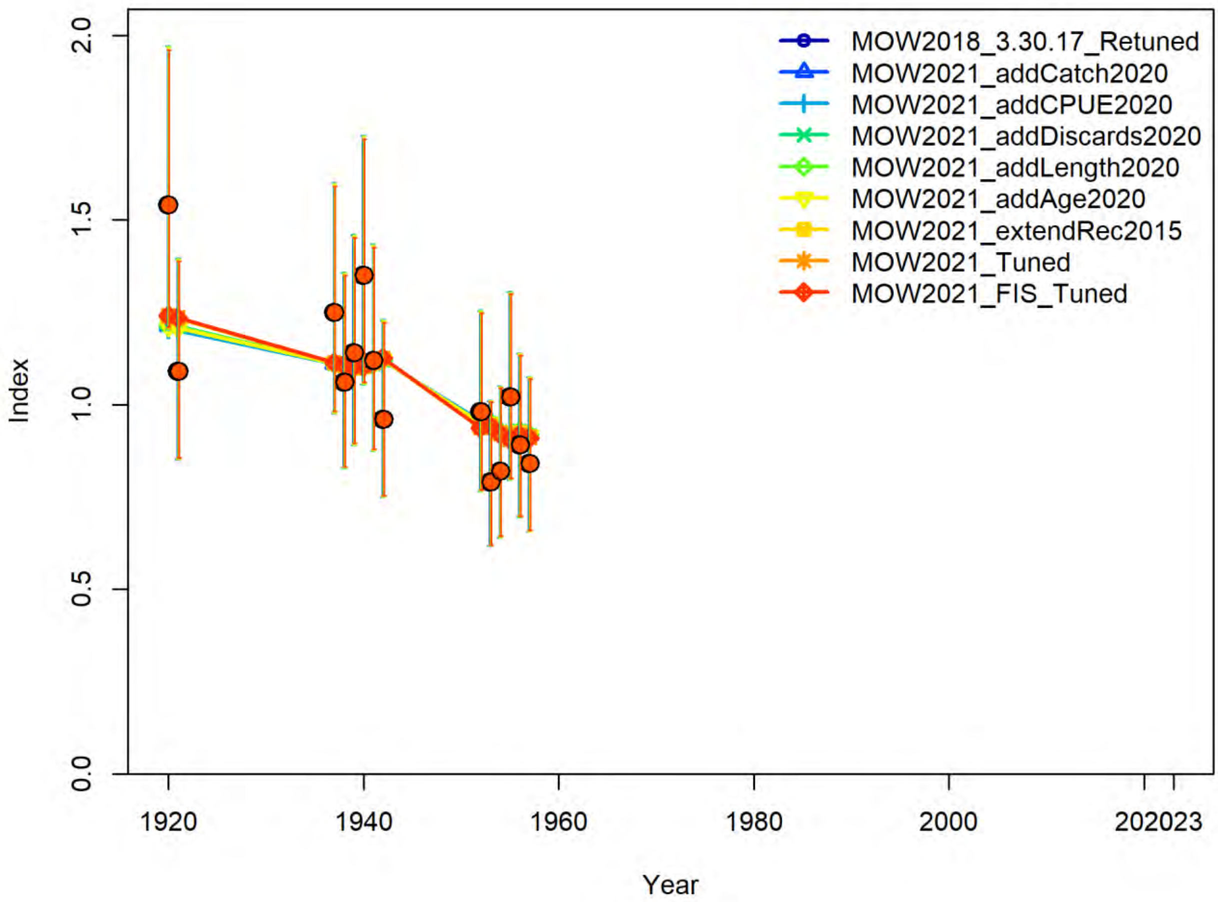

Figure 7.19. Comparison of the fit to the steam trawl CPUE index for the updated 2018 assessment model converted to SS-V3.30.17 (MOW2018_3.30.17_Retuned – dark blue) with various bridging models leading to a proposed 2018 base case model (MOW2021_Tuned - red).

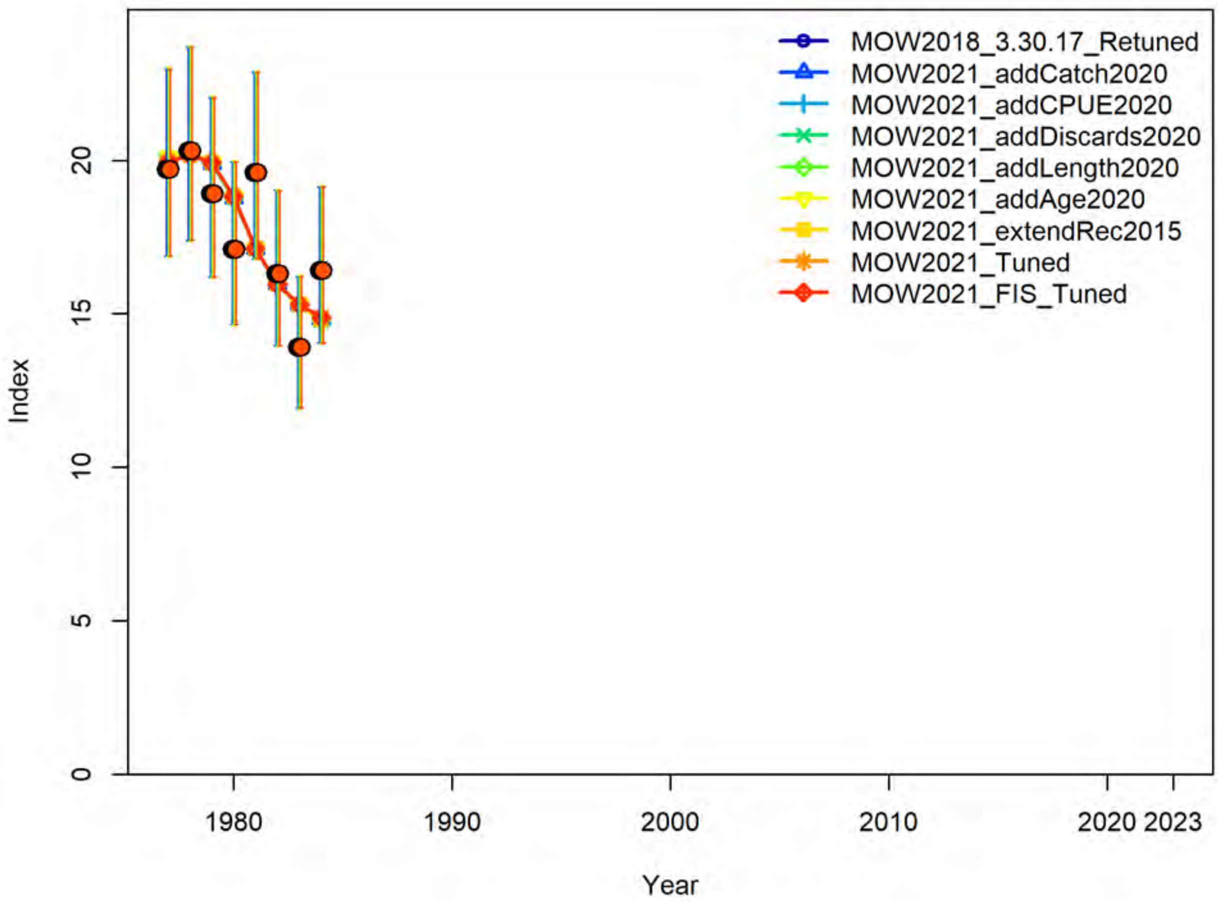

Figure 7.20. Comparison of the fit to the mixed CPUE index for the updated 2018 assessment model converted to SS-V3.30.17 (MOW2018_3.30.17_Retuned – dark blue) with various bridging models leading to a proposed 2018 base case model (MOW2021_Tuned - red).

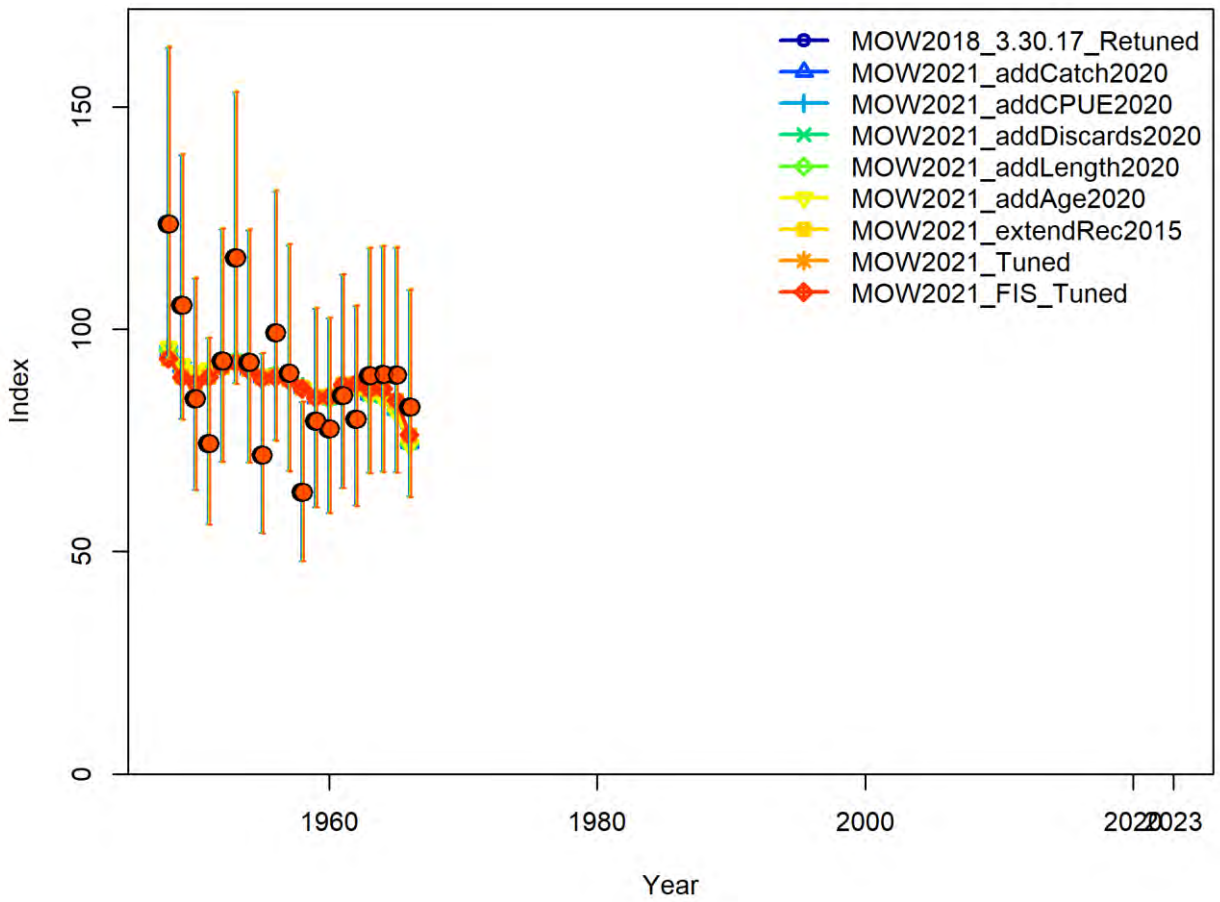

Figure 7.21. Comparison of the fit to the Smith CPUE index for the updated 2018 assessment model converted to SS-V3.30.17 (MOW2018_3.30.17_Retuned – dark blue) with various bridging models leading to a proposed 2018 base case model (MOW2021_Tuned - red).

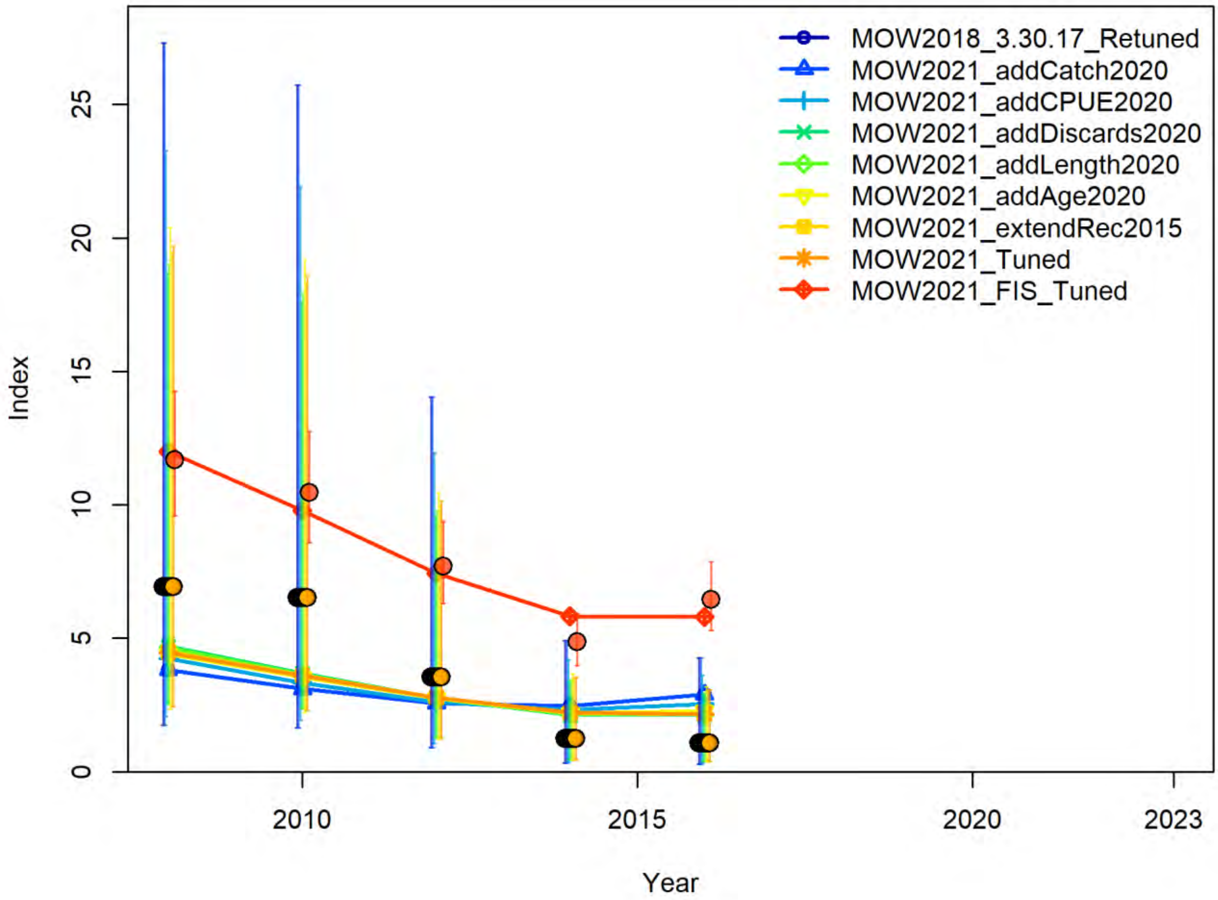

Figure 7.22. Comparison of the fit to the FIS east (Zones 10 and 20) index for the updated 2018 assessment model converted to SS-V3.30.17 (MOW2018_3.30.17_Retuned – dark blue) with various bridging models leading to a proposed 2018 base case model (MOW2021_Tuned - red).

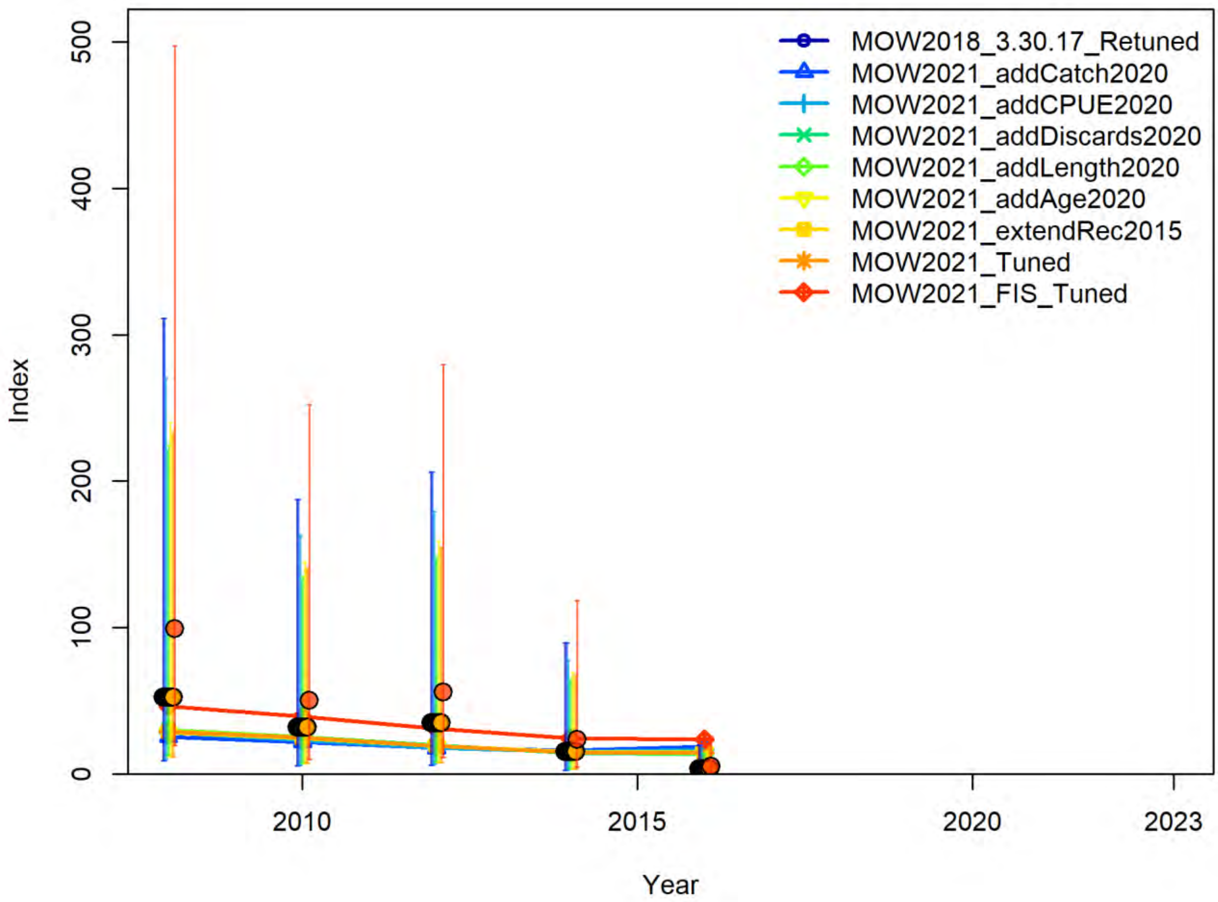

Figure 7.23. Comparison of the fit to the FIS Tas (Zone 30) index for the updated 2018 assessment model converted to SS-V3.30.17 (MOW2018_3.30.17_Retuned – dark blue) with various bridging models leading to a proposed 2018 base case model (MOW2021_Tuned - red).

7.6 Dynamic B_0

It is possible to calculate dynamic B_0 (Bessell-Browne et al., 2022) by projecting the population forward from its initial state without applying fishing mortality, assuming that the deviations in recruitment about the stock-recruitment relationship are not influenced by fishing pressure and are only influenced by non-fishing related factors, such as environmental drivers. These annual deviations are therefore assumed to be the same in both the fished and unfished cases. This explicitly assumes that fishing affects the numbers-at-age, but not the deviations in biological parameters about their expected values for any particular year. Dynamic B_0 is another way to account for the changing productivity of a stock without having to specify a specific year to implement a productivity shift, as is done in the current assessment. It also allows for trends in productivity to occur through time, rather than assuming a step function where there is a disconnect between two different productivity states.

Dynamic B_0 for Jackass Morwong is initially the same as static B_0 between 1915 and 1945 as recruitment deviations are not estimated over this period (Figure 7.24, top panel). Between 1946 and 1988 dynamic B_0 is higher than static B_0, before dropping sharply for the remainder of the timeseries (Figure 7.24, top panel). Note that in the assessment model a productivity shift is implemented in 1988, altering the estimated value of B_0.

Estimated relative stock status varies considerably between the base case model with a productivity shift using static B_0 compared to that estimated using dynamic B_0 (Figure 7.24, bottom panel). Under dynamic B_0 the relative stock status falls below the target reference point (B_{48}) initially in the late 1960s, then recovers to values just above B_{48} in the early 1970s, then in 1981 falls below B_{48} and stays below B_{48} until the end of the time series. Relative to the limit reference point (B_{20}), the relative stock status under dynamic B_0 drops below the B_{20} from 2013-2015, and then increases to above (B_{20}) at the end of the time series (2020 in this case). This series is in stark contrast to the relative depletion series estimated using the productivity shift, where stock status is not estimated to fall below the target reference point until 2003, then falling below the limit reference point in 2013, the same year as estimated using dynamic B_0 (Figure 7.24, lower plot). Stock status using the productivity shift is then estimated to stay below the limit reference point until 2022, when it is projected to recover to a value greater than B_{20}, seven years after the population was estimated to recover to a value greater than B_{20} under dynamic B_0 (Figure 7.24).

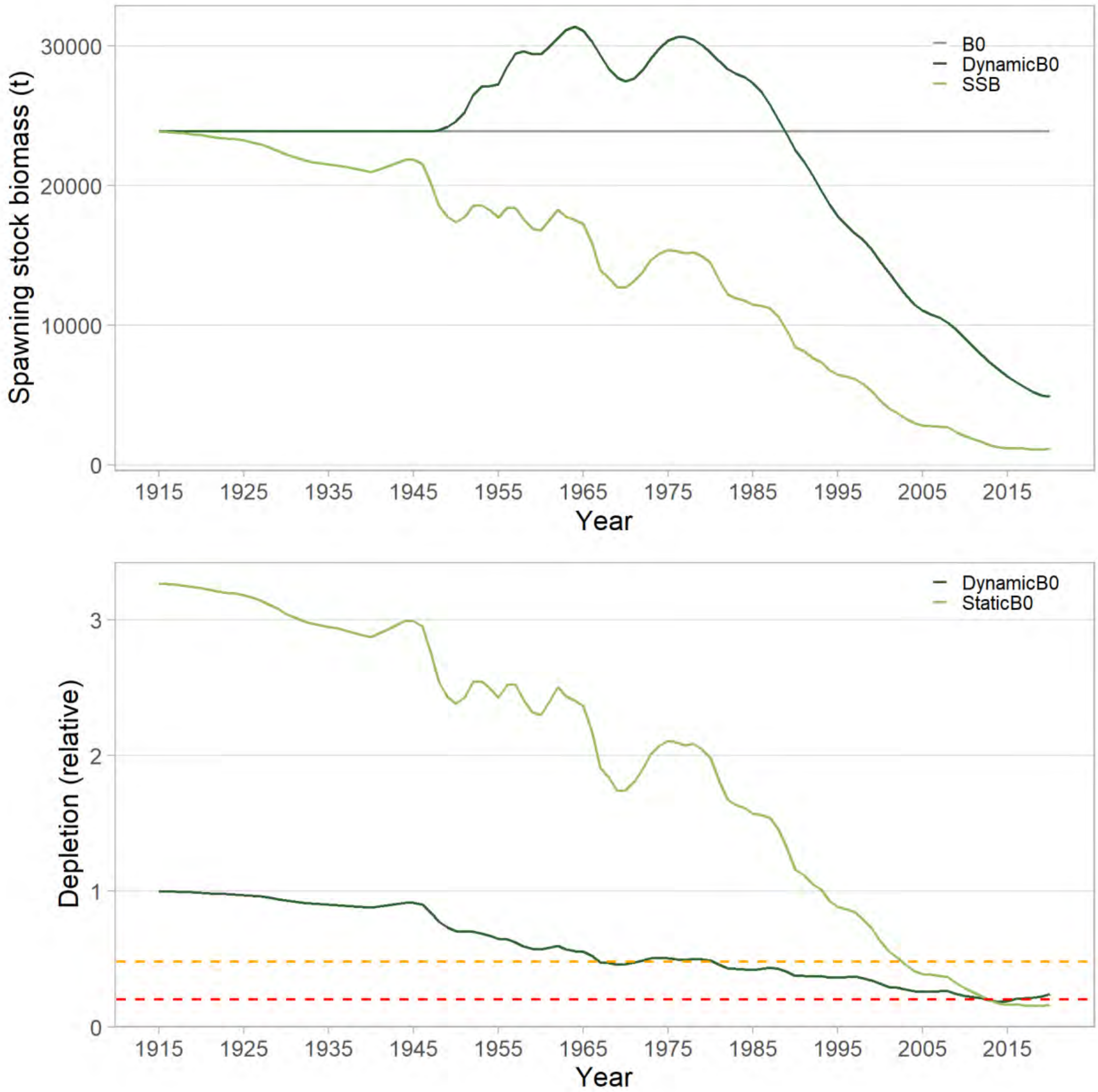

Figure 7.24. Dynamic B_0 for Jackass Morwong: spawning stock biomass (top) showing the trajectory of "dynamic B_0" (dark green) and the preliminary base case model predicted spawning stock biomass (light green), and; stock status (bottom) showing the trajectory of relative stock status, with a productivity shift implemented as a step function in 1988, under static B_0 (light green) and under dynamic B_0 (dark green). The orange dashed line is the target reference point (B_{48}) and the red dashed line is the limit reference point (B_{20}).

7.7 Future work and unresolved issues

There are still some unresolved issues relating to allocation of recent state catches for the period 2014-2020 between eastern and western fleets, especially for Tasmanian and Victorian state catches, but these catches are relatively small compared to other catches in the same period, and any future revisions are unlikely to have a noticeable influence on the assessment outcomes. Some of these catches are currently masked, with assumptions made about this catch data, due to concerns about use of confidential data and the five-boat rule. Ideally, appropriate use of the actual data will be negotiated for future assessments, ensuring that the confidentiality requirements of the data owners are respected. It would be good to resolve these issues to ensure the best possible data is available for use in the future stock assessments.

There are also some unresolved issues relating to NSW state catches in the period 1986-1999. In 2007, an attempt was made to account for double counting (i.e. recording catches in both state and Commonwealth logbooks) catches reported to NSW state in the period 1986-2009 (Kevin Rowling, pers comm. 2021, Sally Wayte, pers. comm. 2021). While the details are not fully documented in the relevant stock assessment reports, and alternative catch series could be constructed for this period using different assumptions to account for double counting, it appears that the changes to these potential catch series would be relatively small. Larger revisions to the catch history back to 1986 incorporated in Bridge 2 in 2021 had very little impact on both the spawning biomass time series and the recruitment estimates (Figure 7.13 and Figure 7.14), so it is likely such revisions would have no material impact on the assessment results.

There appear to be convergence issues with the updated ageing error matrix, relating to potential outliers in the data. This requires further investigation.

Any results from this assessment should be treated with some caution given the recent data quality available for this assessment and the quality of the eastern trawl CPUE data. Sporcic (2021) state that "The structural adjustment altered the effect of the vessel factor on the standardised result. However, log(CPUE) has also changed in character from 2014-2020, with spikes of low catch rates arising" and "Annual standardized CPUE has been below the long-term average since about 2000 with apparent periodicity. Both the recorded catch (36.6 t) and number of records (956) in 2020 were the lowest in the series."

Note that the preliminary base case model fit to the FIS abundance indices are generally poor (Figure 7.22 and Figure 7.23), although these are considerably improved for the Eastern FIS series in the final step of Bridge 2, when the FIS2 series is used, with additional CVs on these abundance series estimated within the model at 0.37 and 0.59 respectively for the MOW2021_Tuned step of the bridging (slightly smaller than the values estimated in the 2018 assessment), and then 0.003 and 0.62 respectively, for the MOW2021_FIS_Tuned step of the bridging. The additional CV estimated to the eastern trawl CPUE index was 0.11, with a negative value estimated for all other CPUE indices, indicating the initial CV values were too broad for these other fleets.

7.8 Acknowledgements

Age data were provided by Kyne Krusic-Golub (Fish Ageing Services), ISMP and AFMA logbook and CDR data were provided by John Garvey (AFMA). Mike Fuller, Paul Burch, Robin Thomson, Roy Deng, Franzis Althaus, Toni Cannard and Caroline Sutton (CSIRO) were all involved in pre-processing the data. Malcolm Haddon provided useful code for auto-tuning, Athol Whitten provided useful R code for organising plots. André Punt, Paul Burch and Sandra Curin-Osorio provided an updated ageing error matrix. André Punt, Geoff Tuck, Miriana Sporcic, Sandra Curin-Osorio, Paul Burch, Robin Thomson and Brett Stacy and are thanked for helpful discussions on this work. Ian Taylor, Richard Methot and Chantel Wetzel (NOAA Fisheries) are thanked for all the Stock Synthesis support and advice. The r4ss package maintained by Ian Taylor (https://github.com/r4ss/r4ss) was critical for producing multiple diagnostic plots, and tuning models. Geoffrey Liggins contributed to useful discussions on the catch history.

7.9 References

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7.10 Appendix A

7.10.1 *Preliminary base case diagnostics*

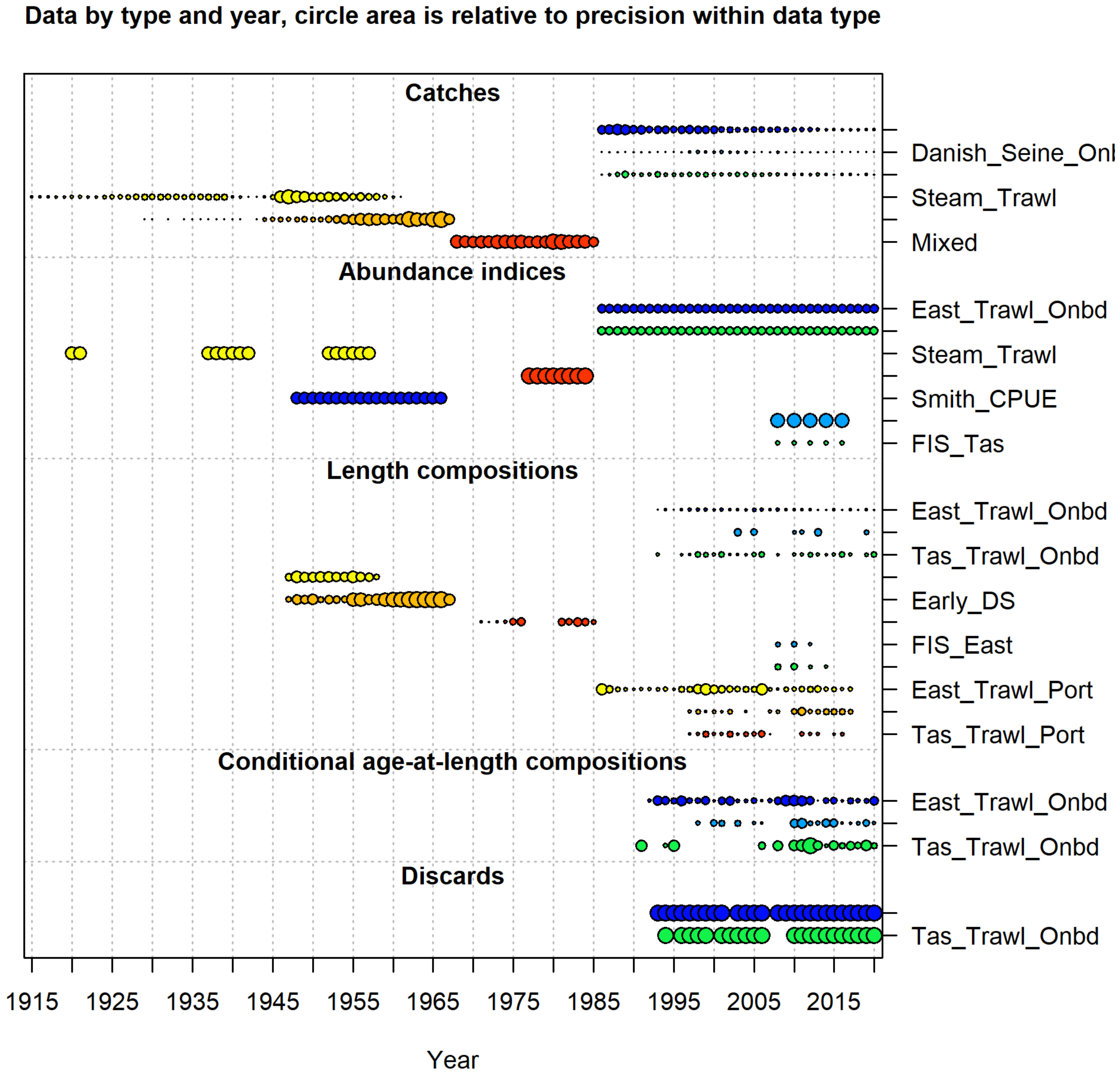


Figure A 7.1. Summary of data sources for eastern Jackass Morwong stock assessment.

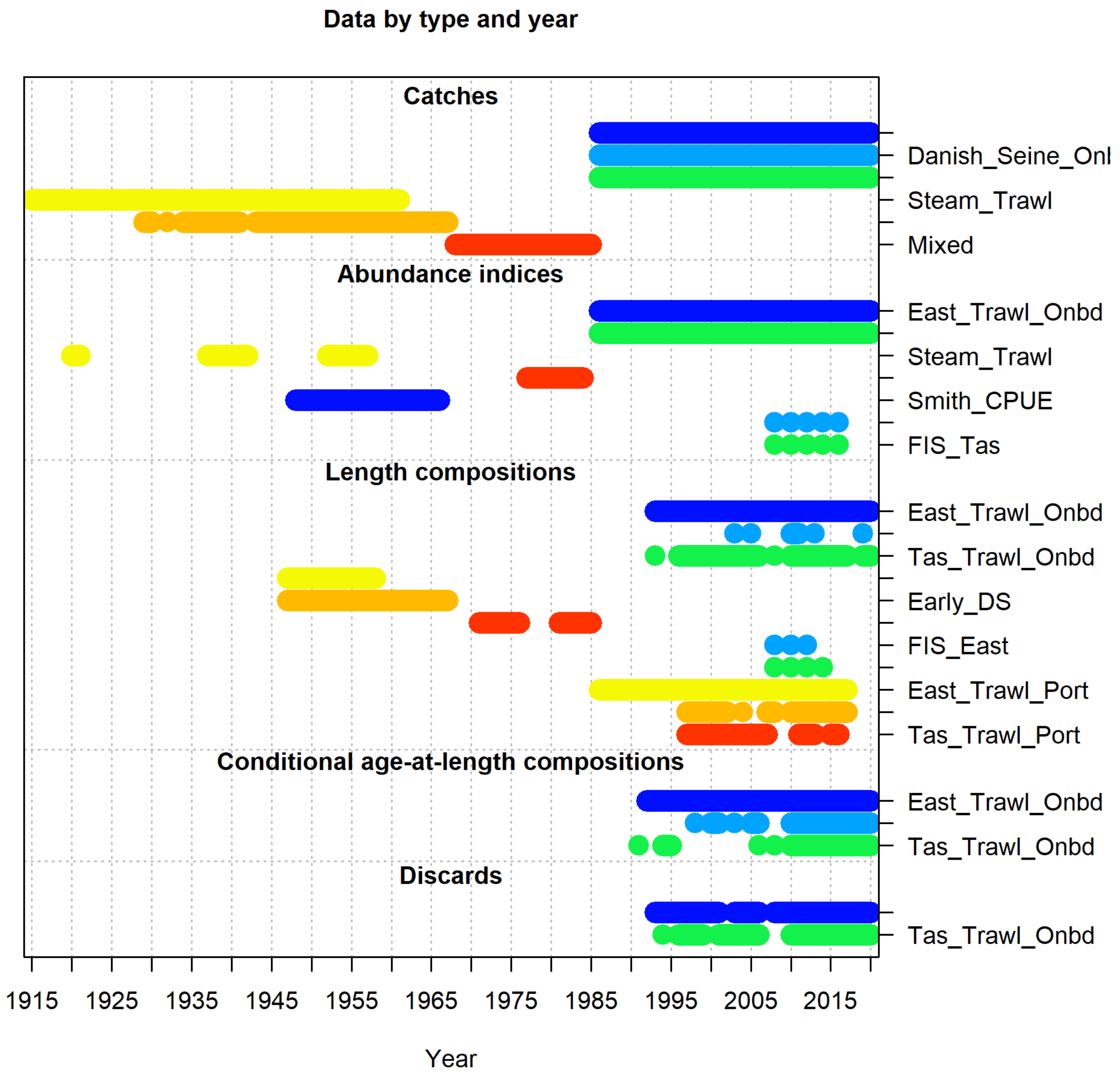


Figure A 7.2. Summary of data sources for eastern Jackass Morwong stock assessment.

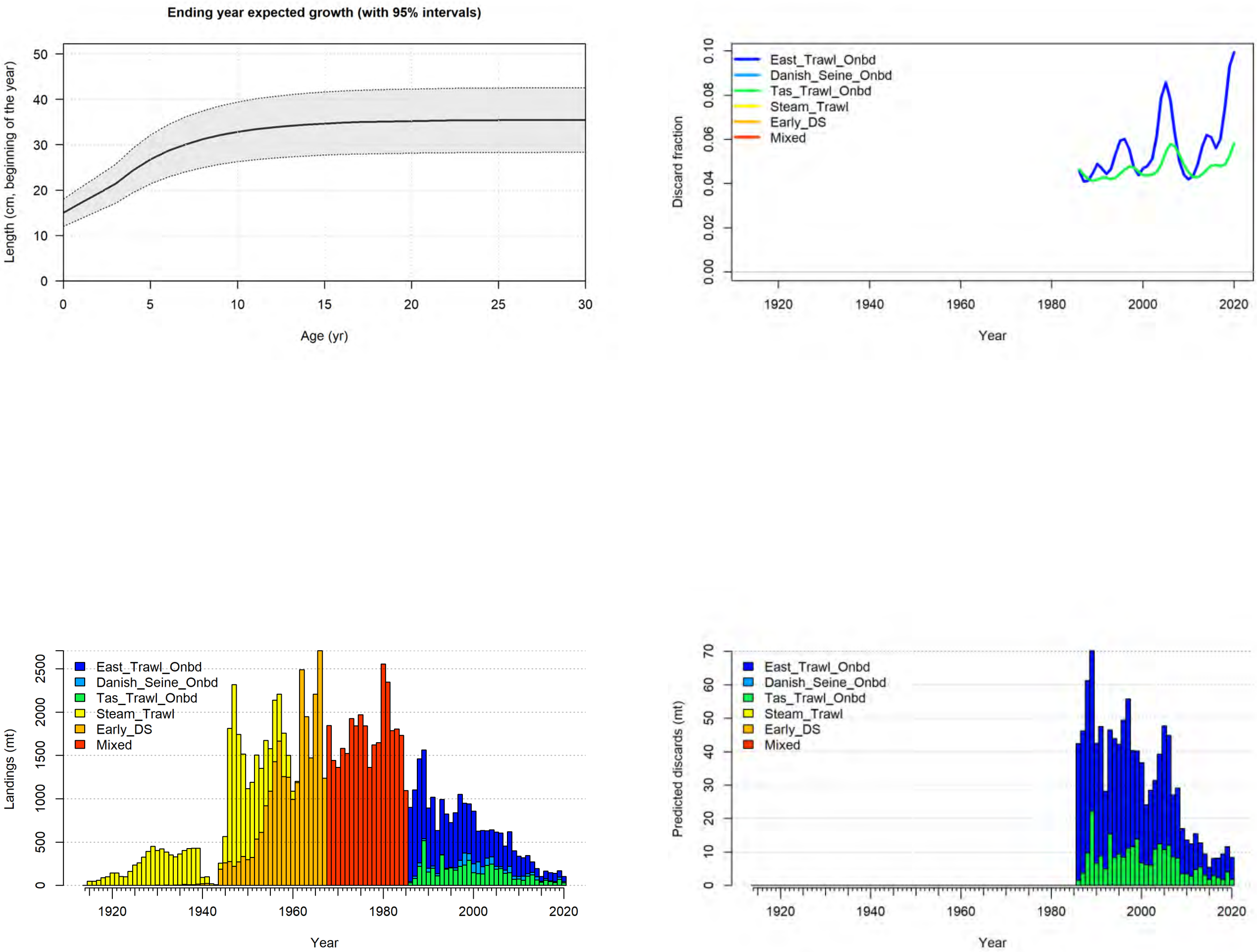


Figure A 7.3. Growth, discard fraction estimates, landings by fleet and predicted discards by fleet for eastern Jackass Morwong.

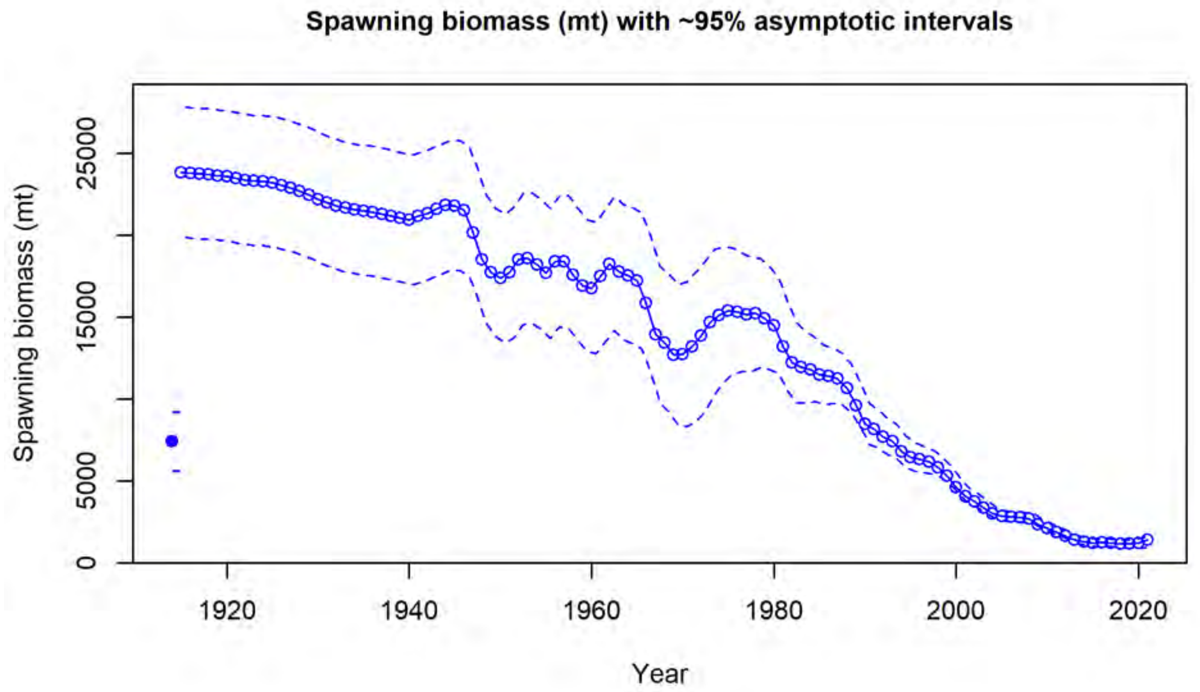


Figure A 7.4. Time series showing absolute spawning biomass with confidence intervals.

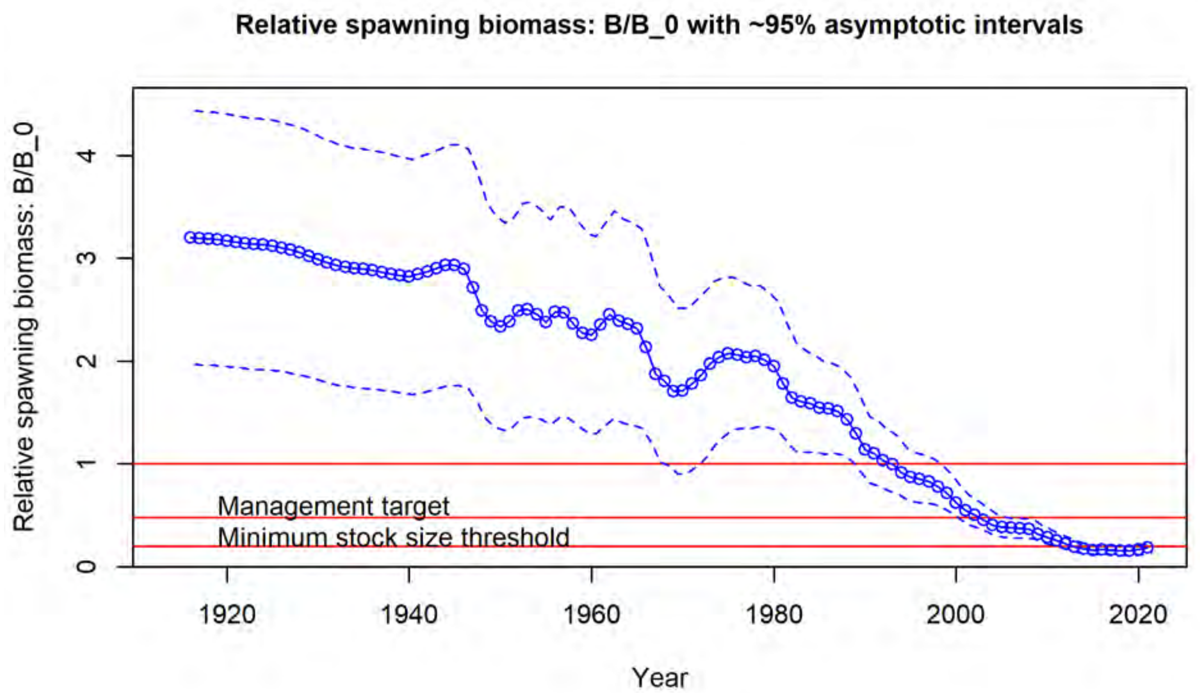


Figure A 7.5. Time series showing relative spawning biomass with confidence intervals.

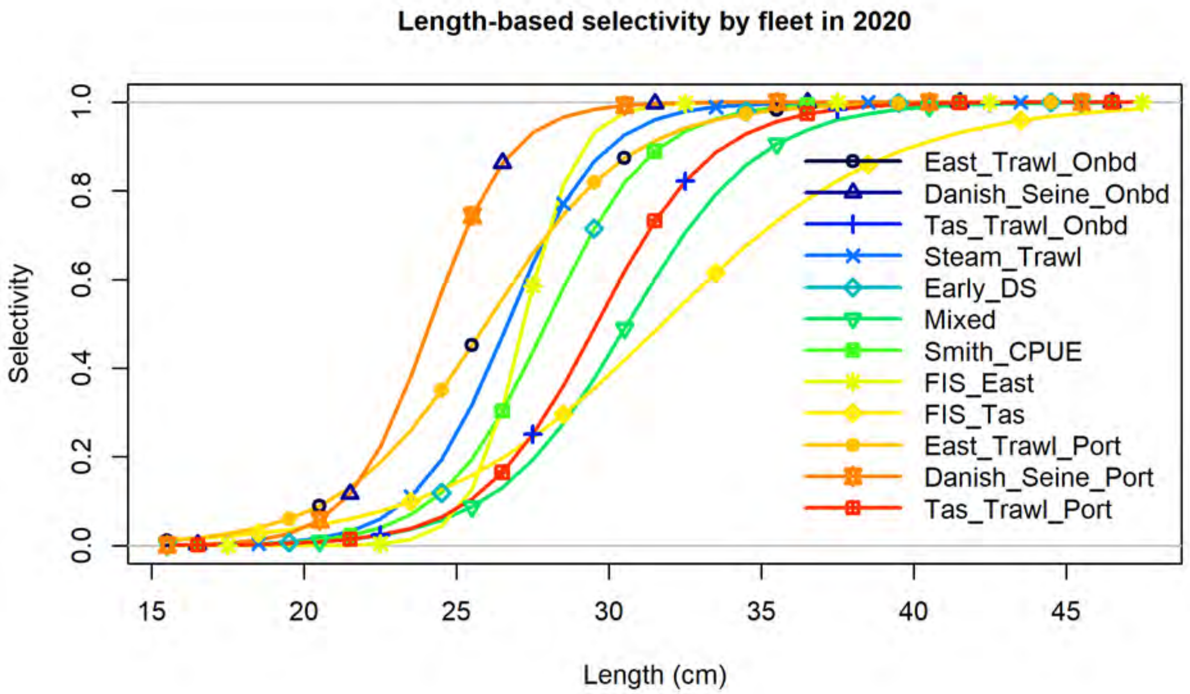


Figure A 7.6. Estimated selectivity and retention curves for eastern Jackass Morwong by fleet.

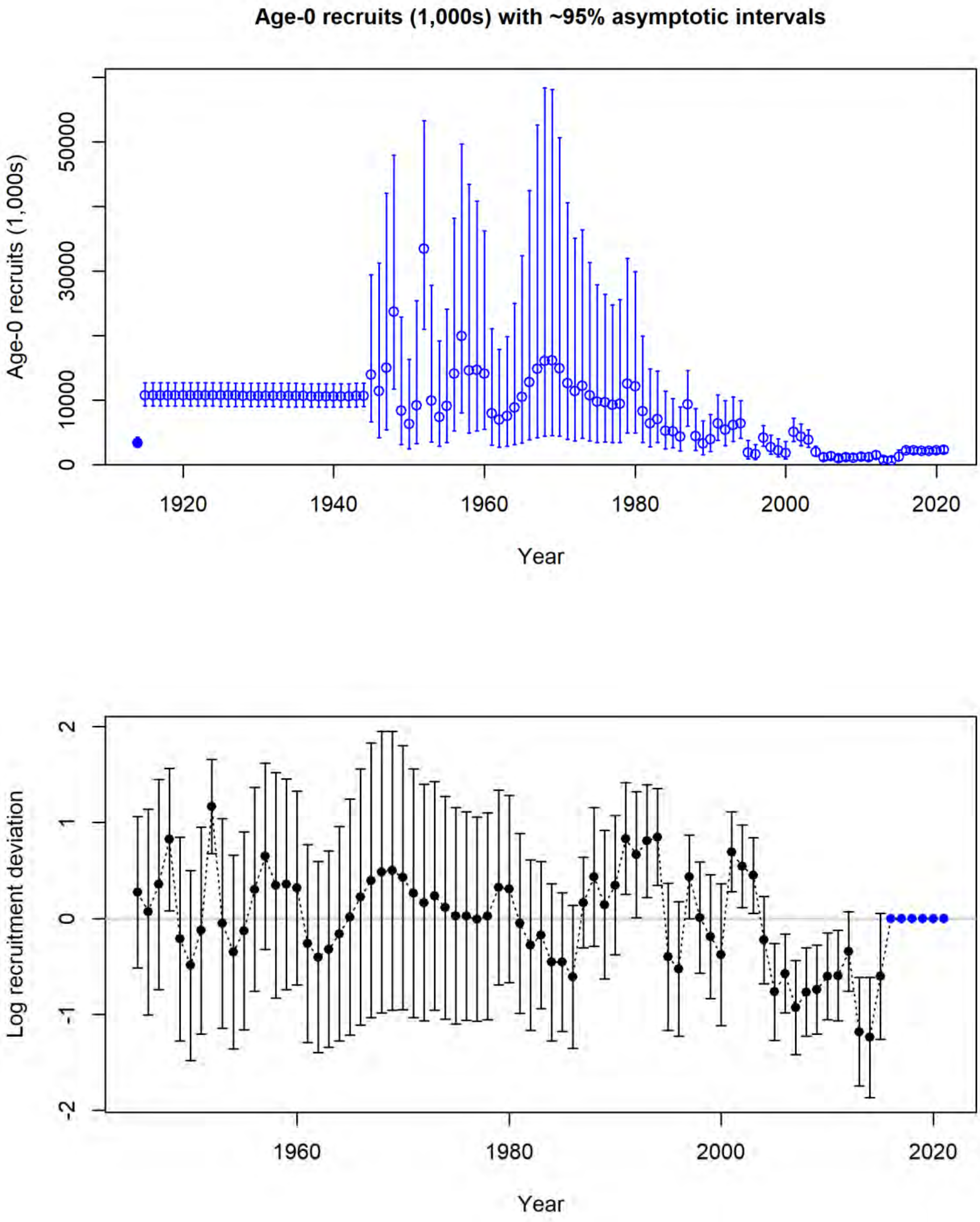


Figure A 7.7. Time series showing absolute recruitment estimates with confidence intervals (top) and recruitment deviations with confidence intervals (bottom) for Jackass Morwong.

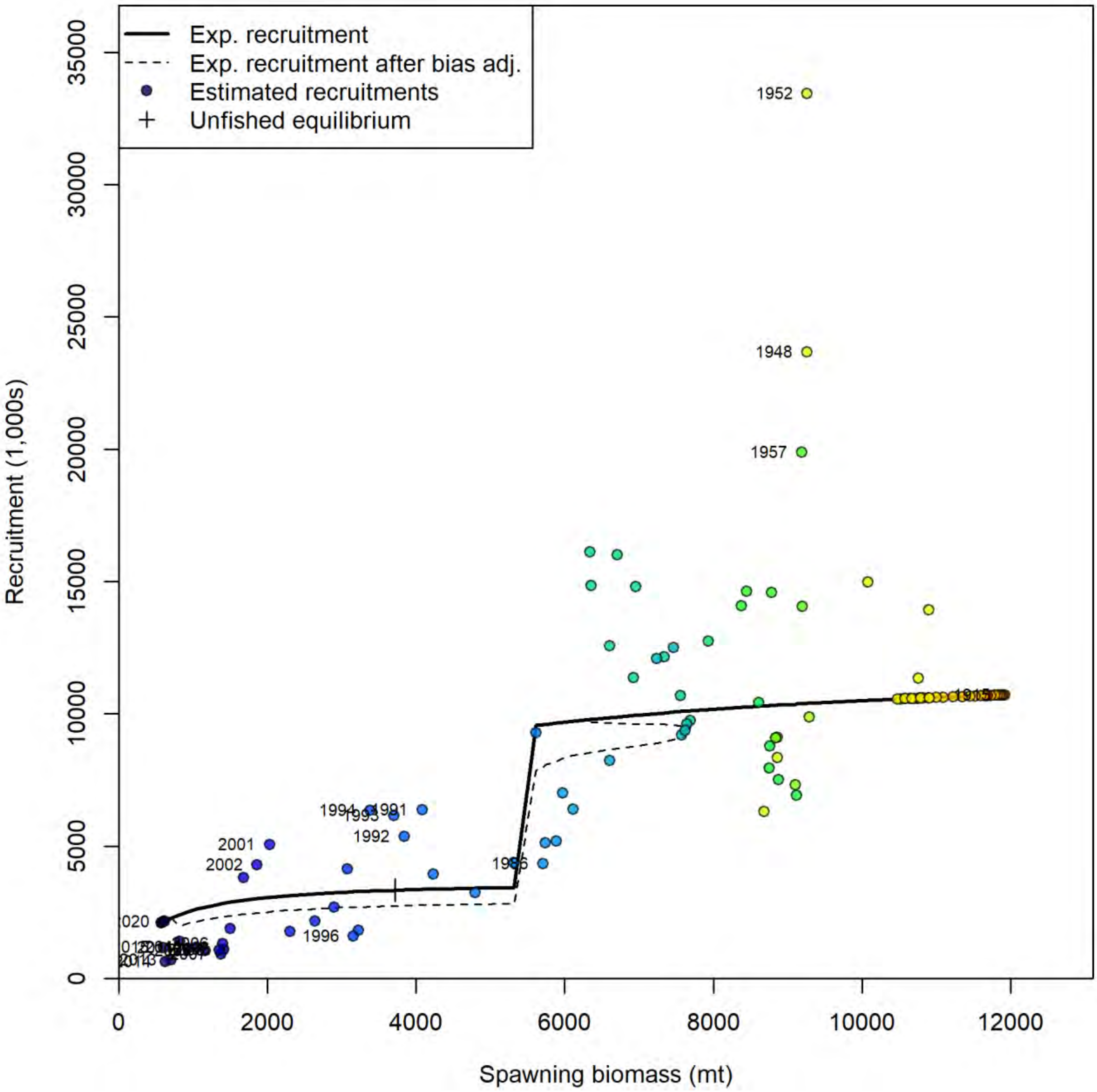


Figure A 7.8. Time series showing stock recruitment curve for Jackass Morwong.

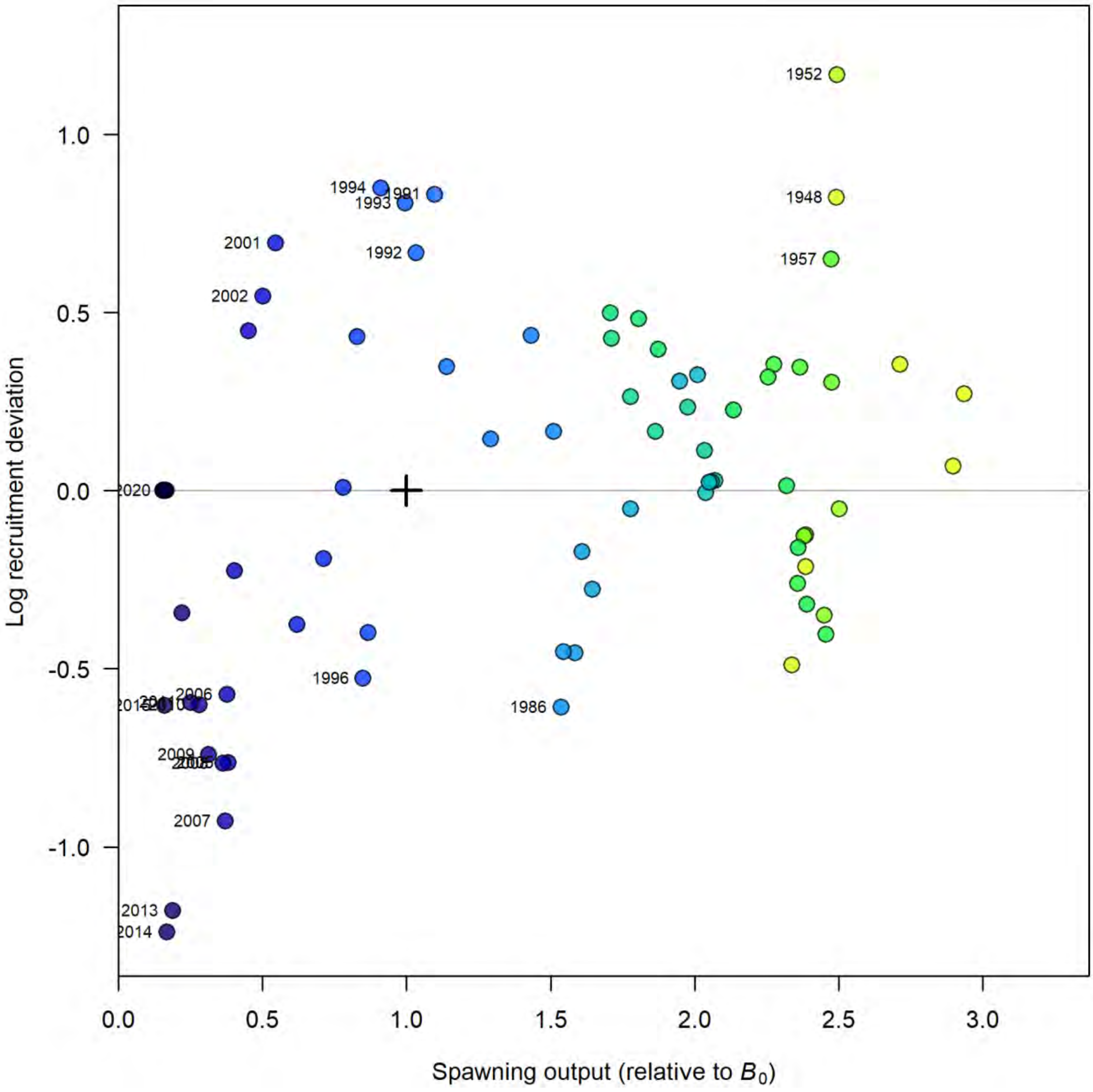
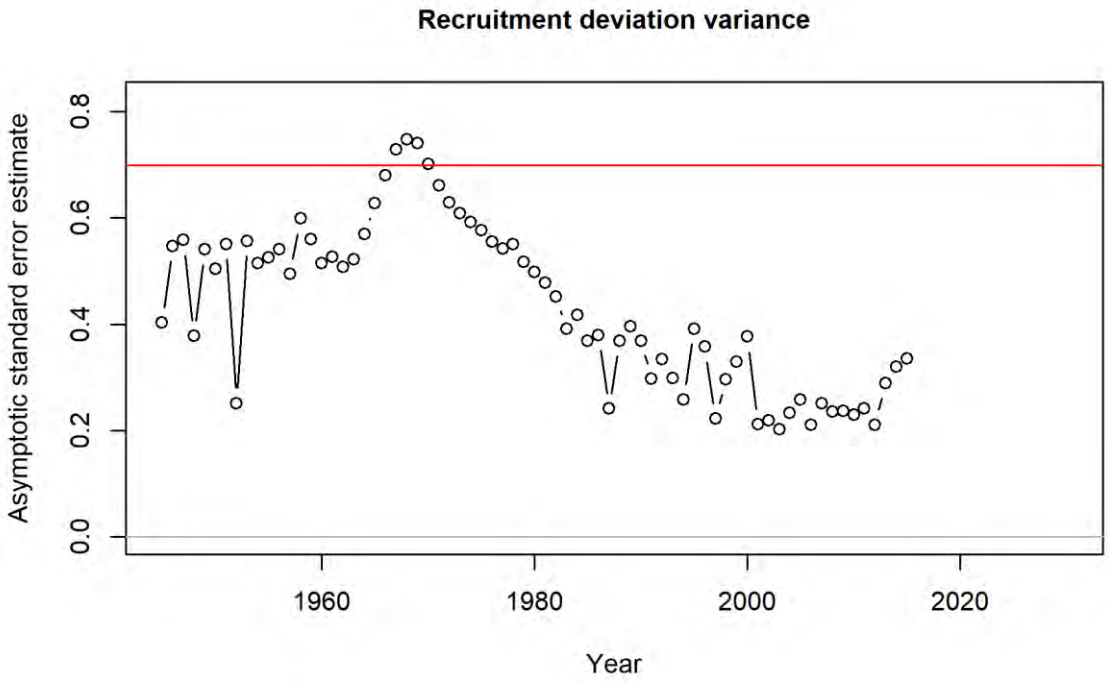


Figure A 7.9. Time series showing stock recruitment deviations for Jackass Morwong.



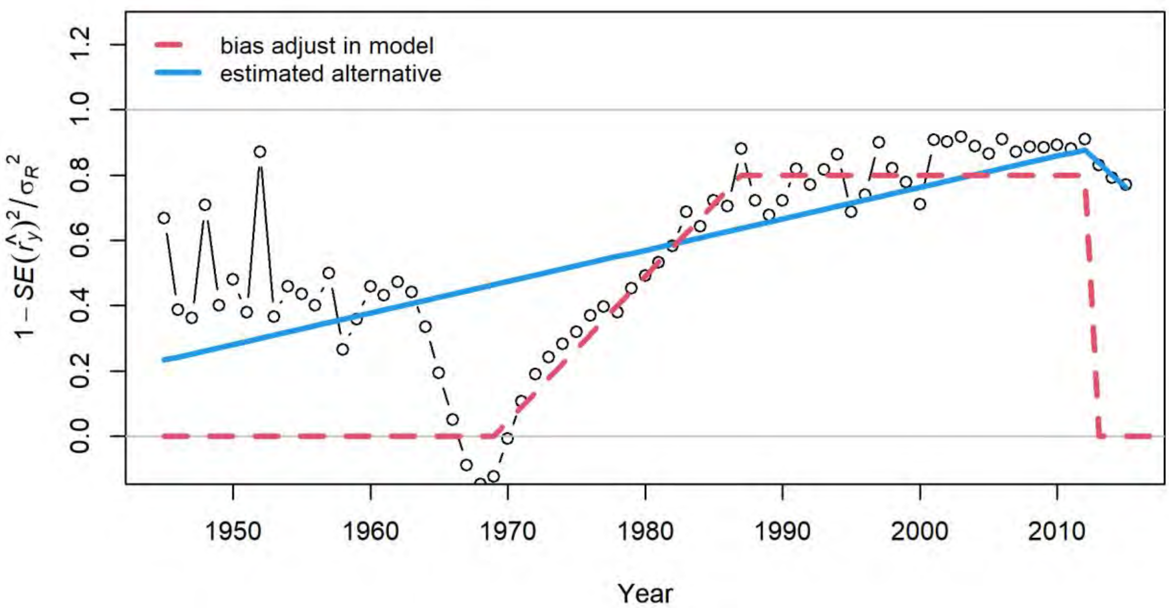


Figure A 7.10. Recruitment deviation variance check and bias ramp adjustment for Jackass Morwong.

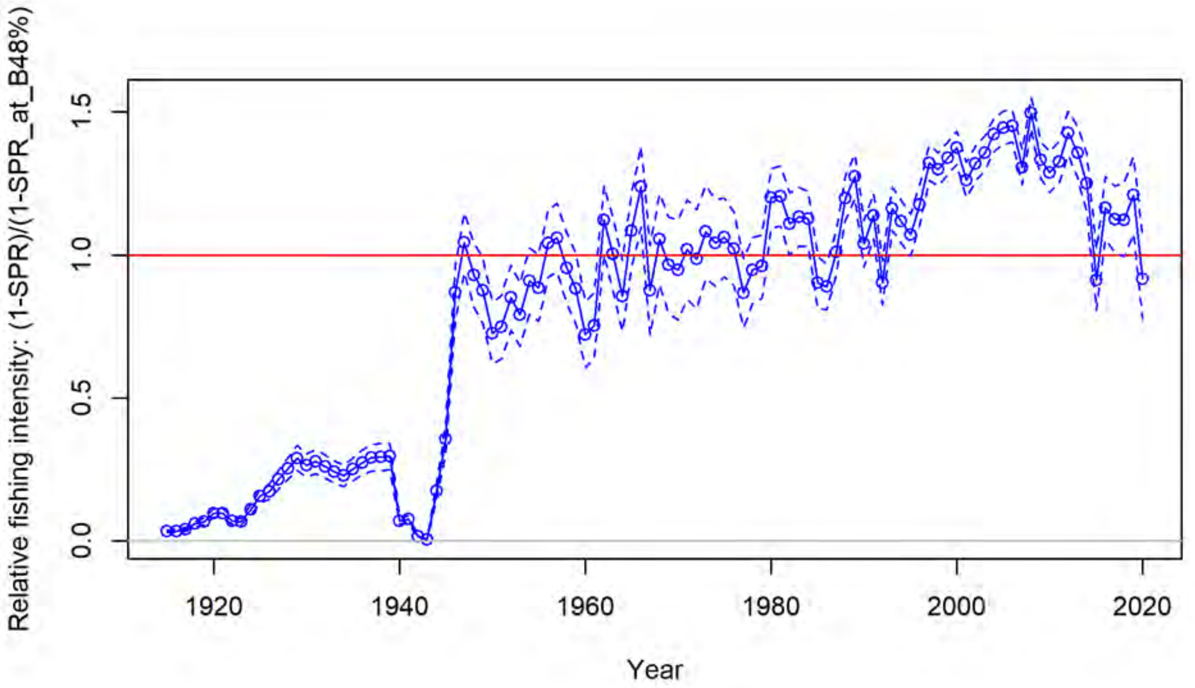


Figure A 7.11. Time series of SPR ratio for Jackass Morwong.

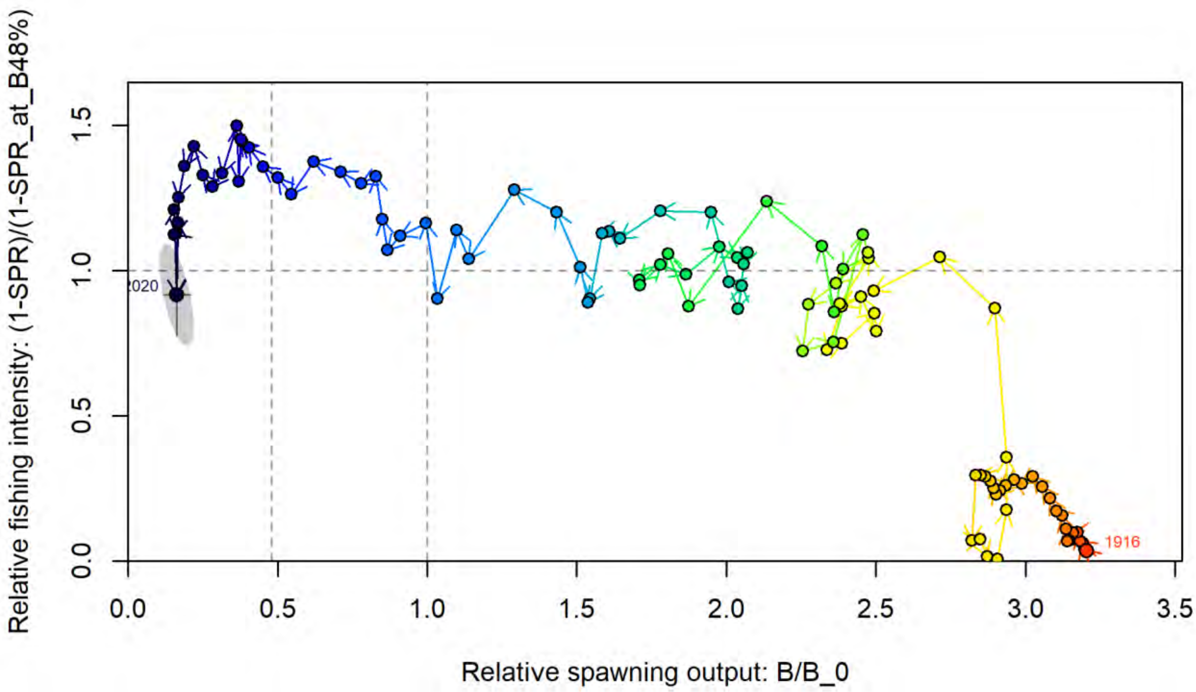


Figure A 7.12. Phase plot of biomass vs SPR ratio for Jackass Morwong.

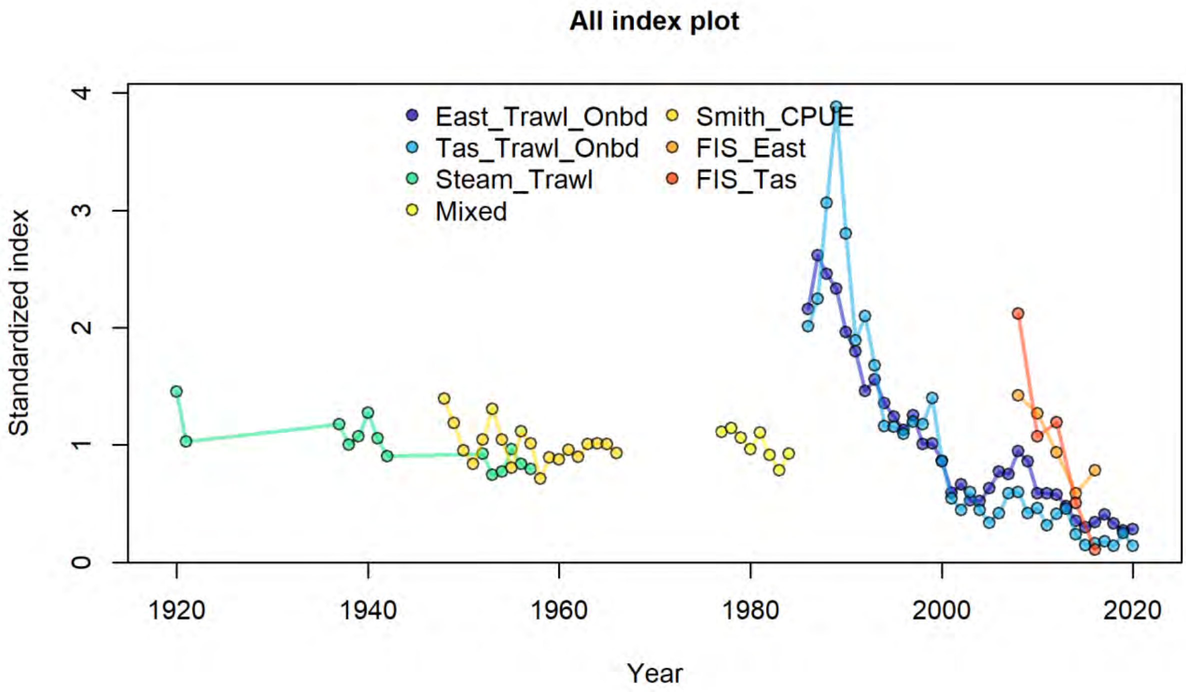


Figure A 7.13. Time series showing all CPUE and FIS abundance series for Jackass Morwong.

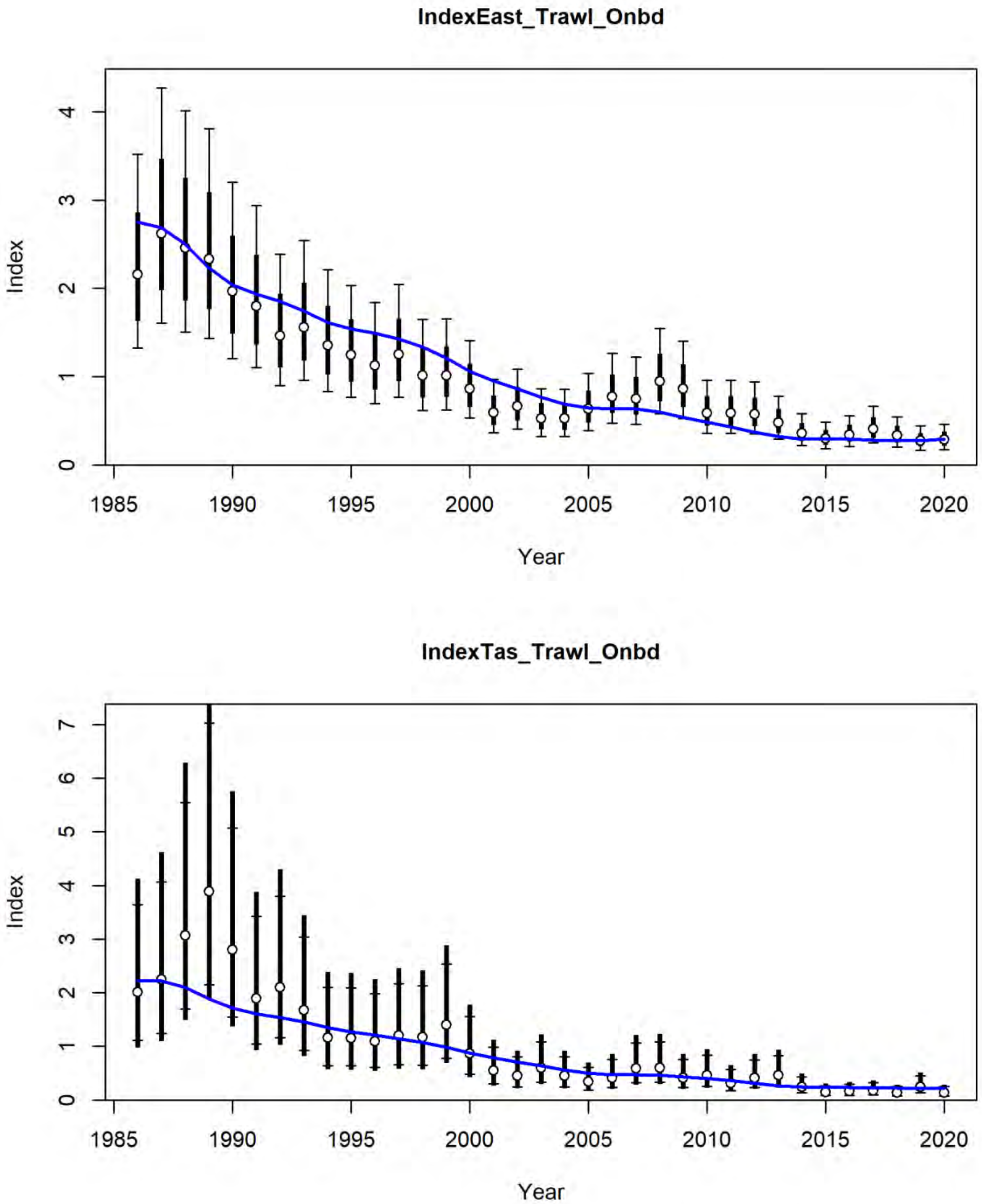
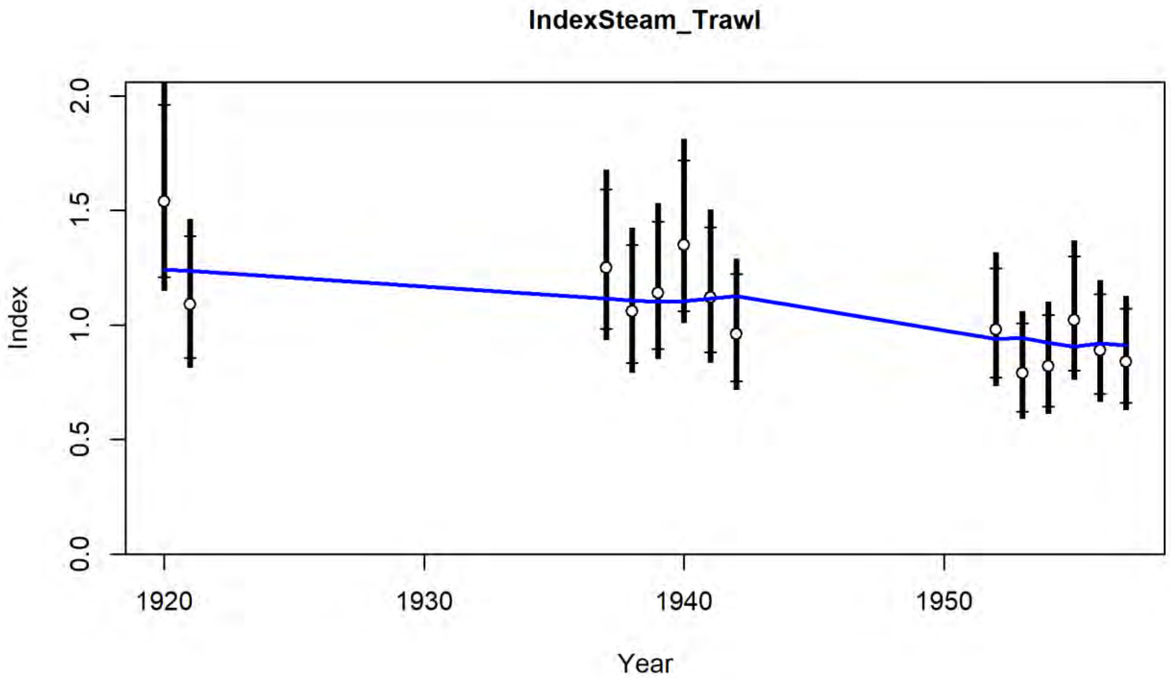


Figure A 7.14. Fits to CPUE by fleet for eastern Jackass Morwong: eastern trawl (top) and Tasmanian trawl (bottom).



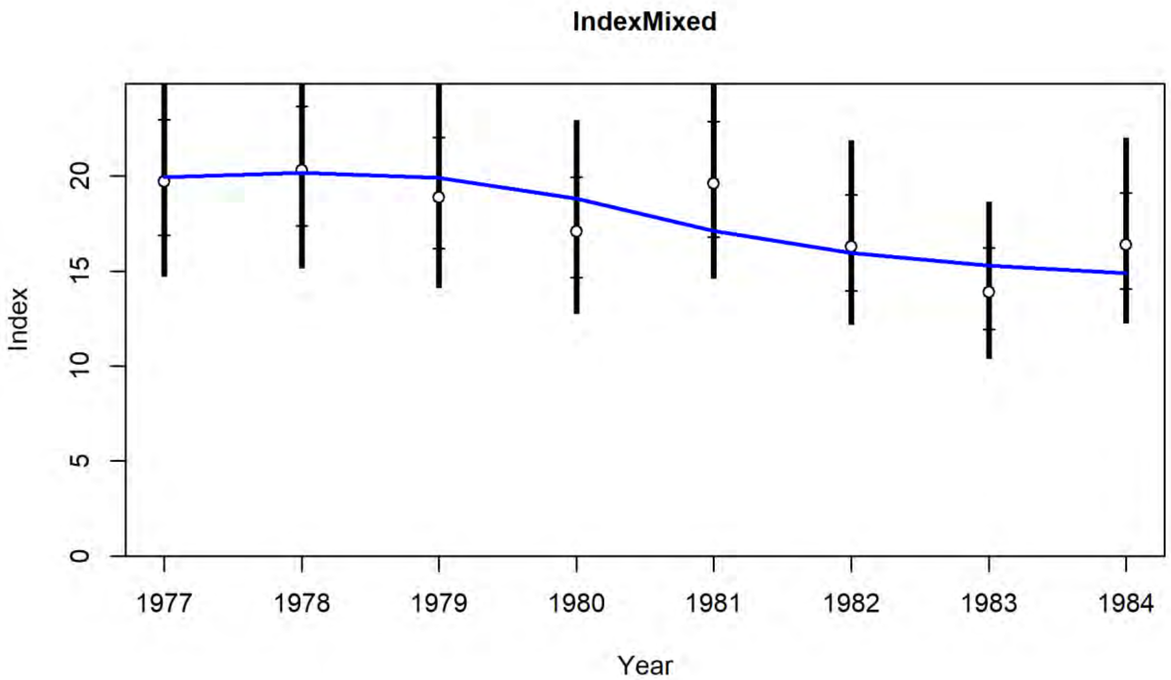


Figure A 7.15. Fits to CPUE by fleet for eastern Jackass Morwong: steam trawl (top) and mixed (bottom).

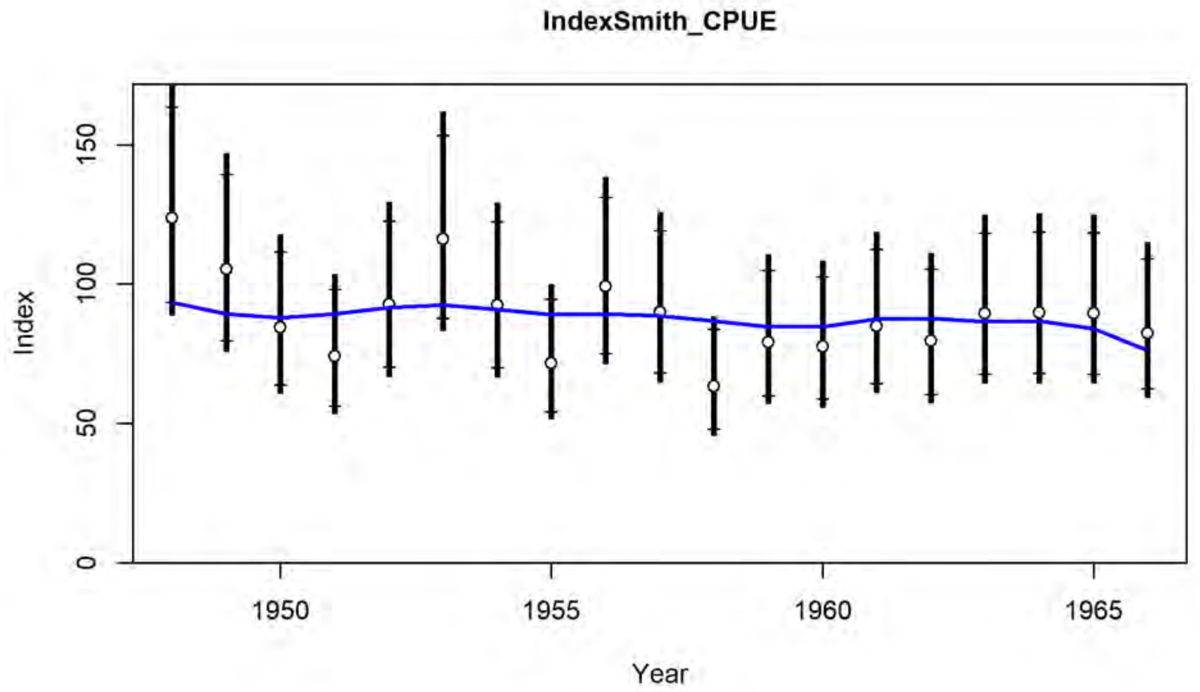
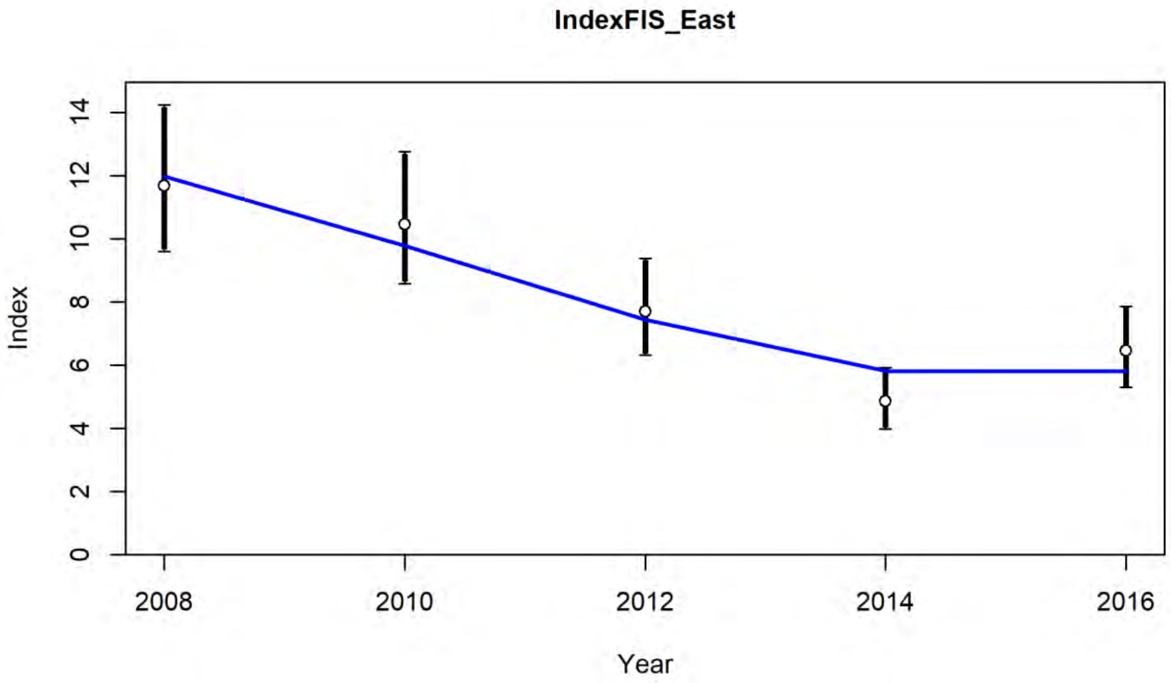


Figure A 7.16. Fits to CPUE by fleet for eastern Jackass Morwong: Smith CPUE.



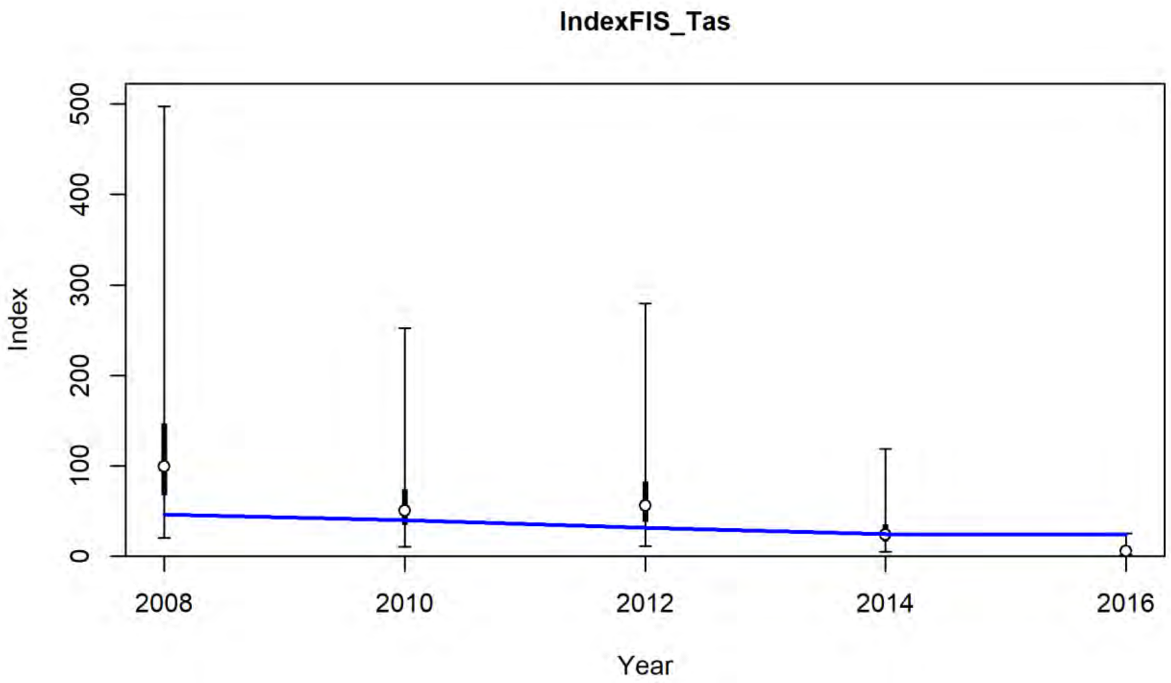
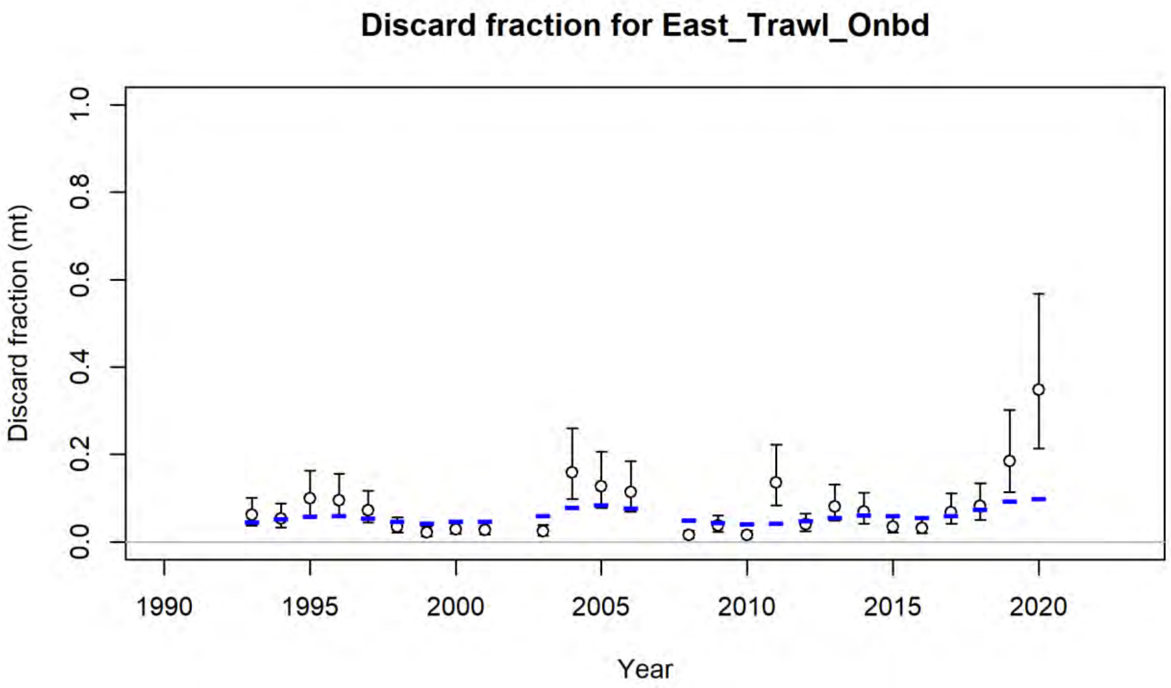


Figure A 7.17. Fits to FIS by fleet for eastern Jackass Morwong: eastern trawl (top) and Tasmanian trawl (bottom).



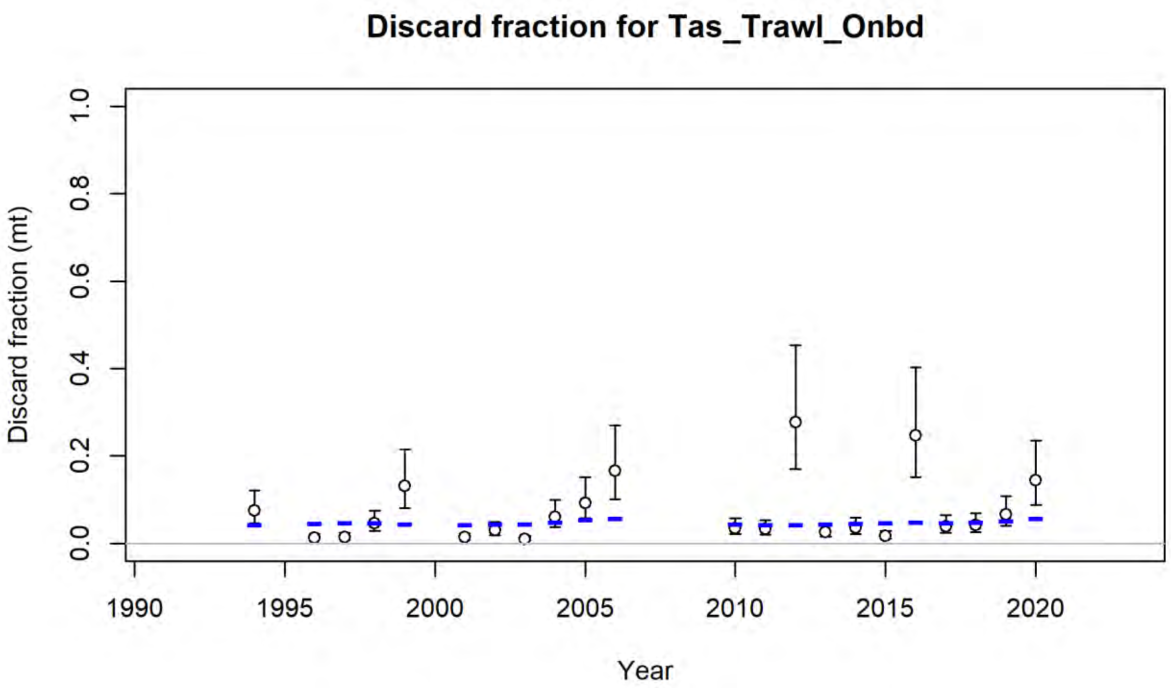


Figure A 7.18. Fits to discard rates for eastern trawl (top) and Tasmanian trawl (bottom) for eastern Jackass Morwong.

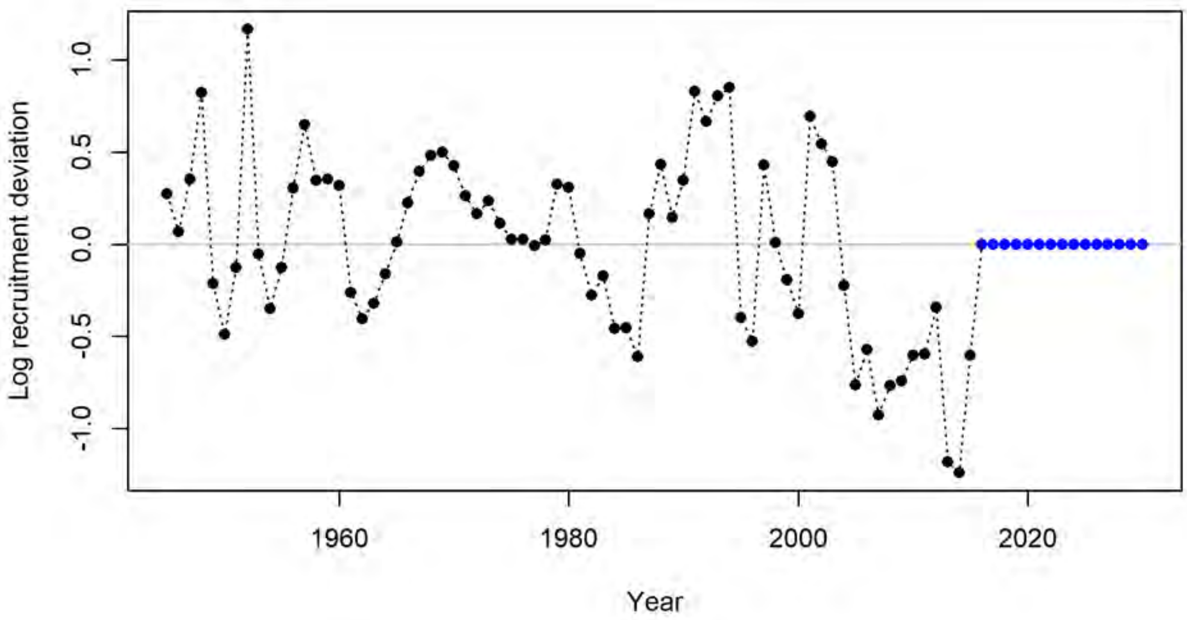


Figure A 7.19. Recruitment deviations for eastern Jackass Morwong.

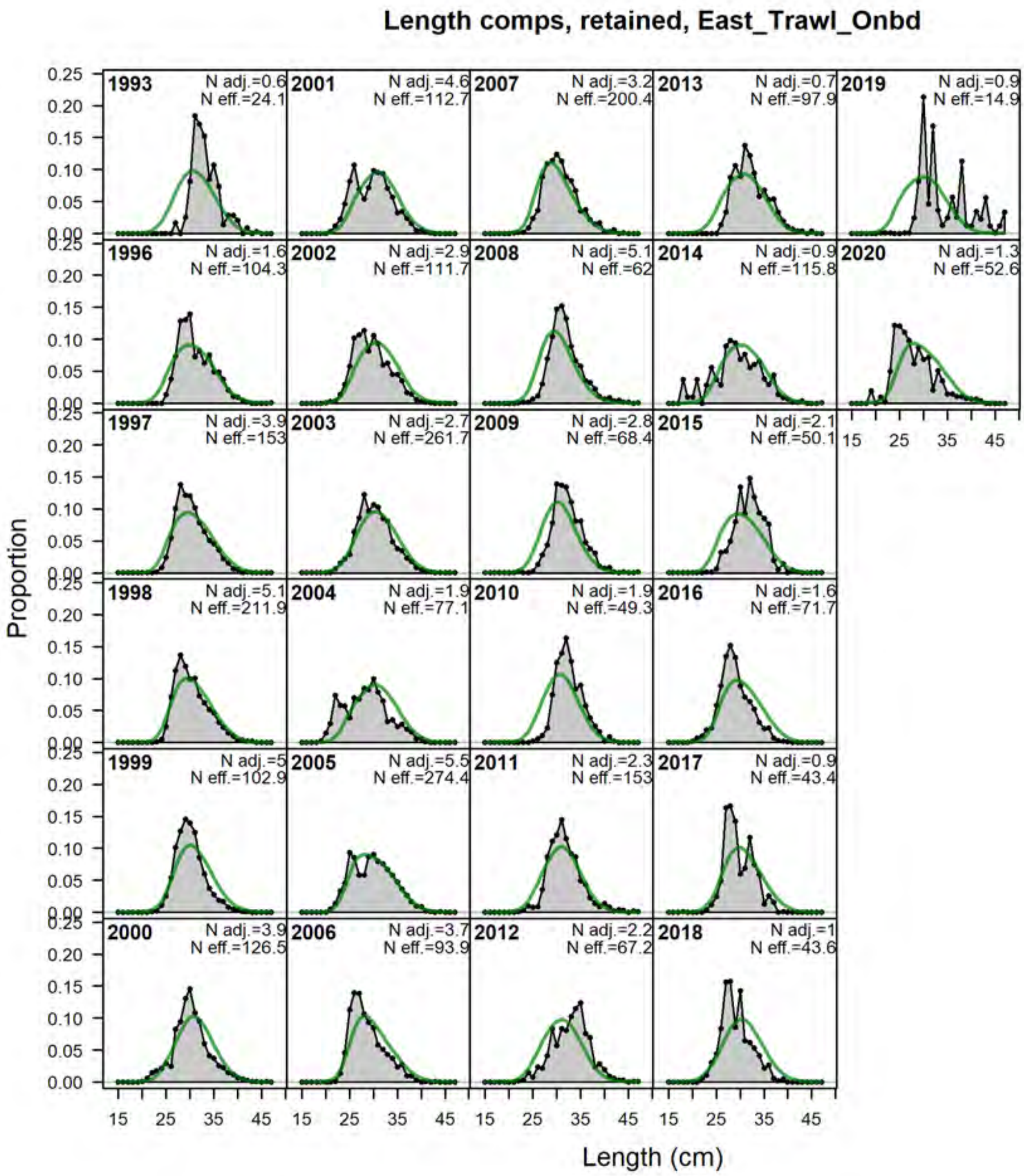


Figure A 7.20. Eastern Jackass Morwong length composition fits: eastern trawl onboard retained.

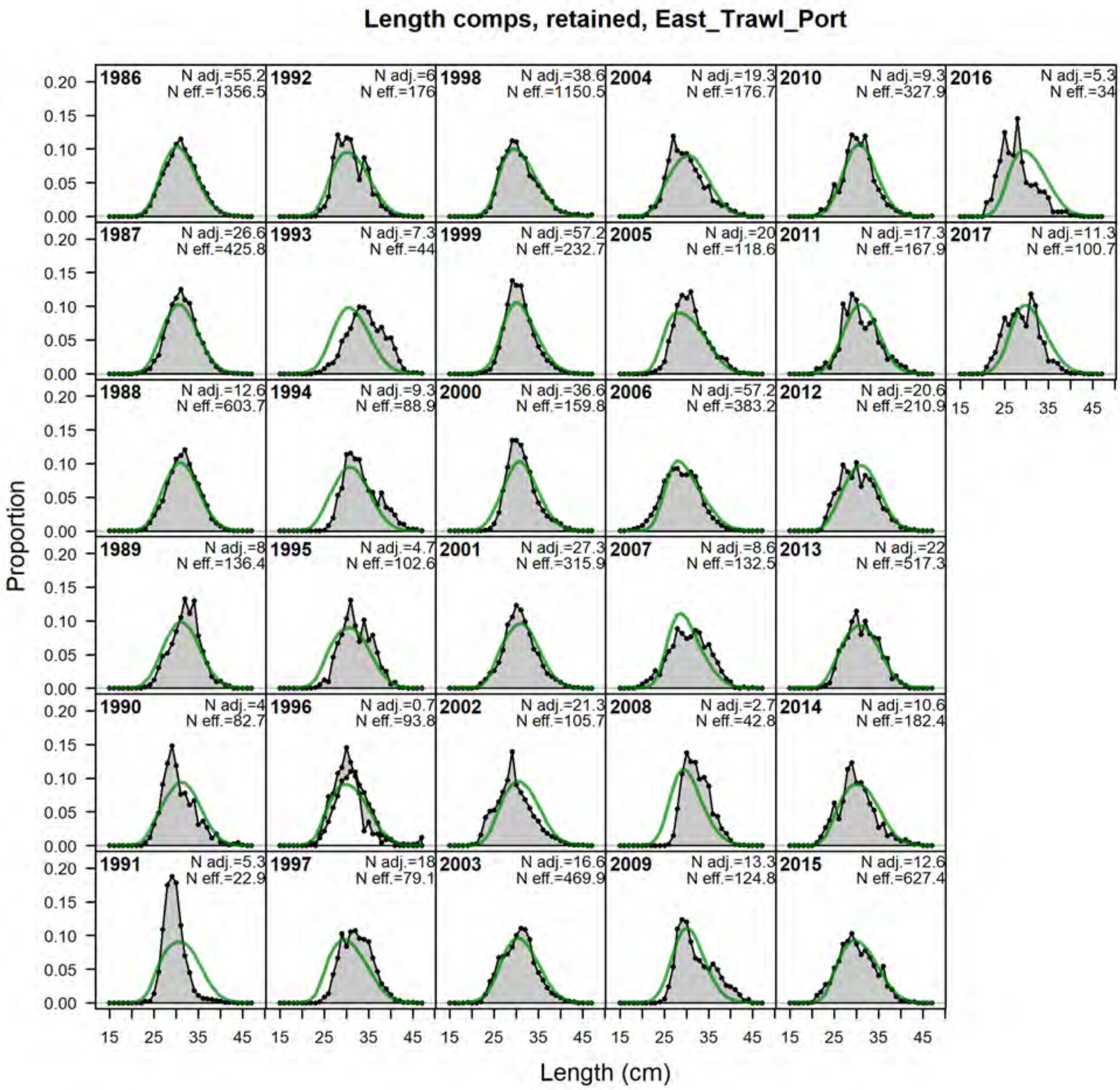


Figure A 7.21. Eastern Jackass Morwong length composition fits: eastern trawl port retained.

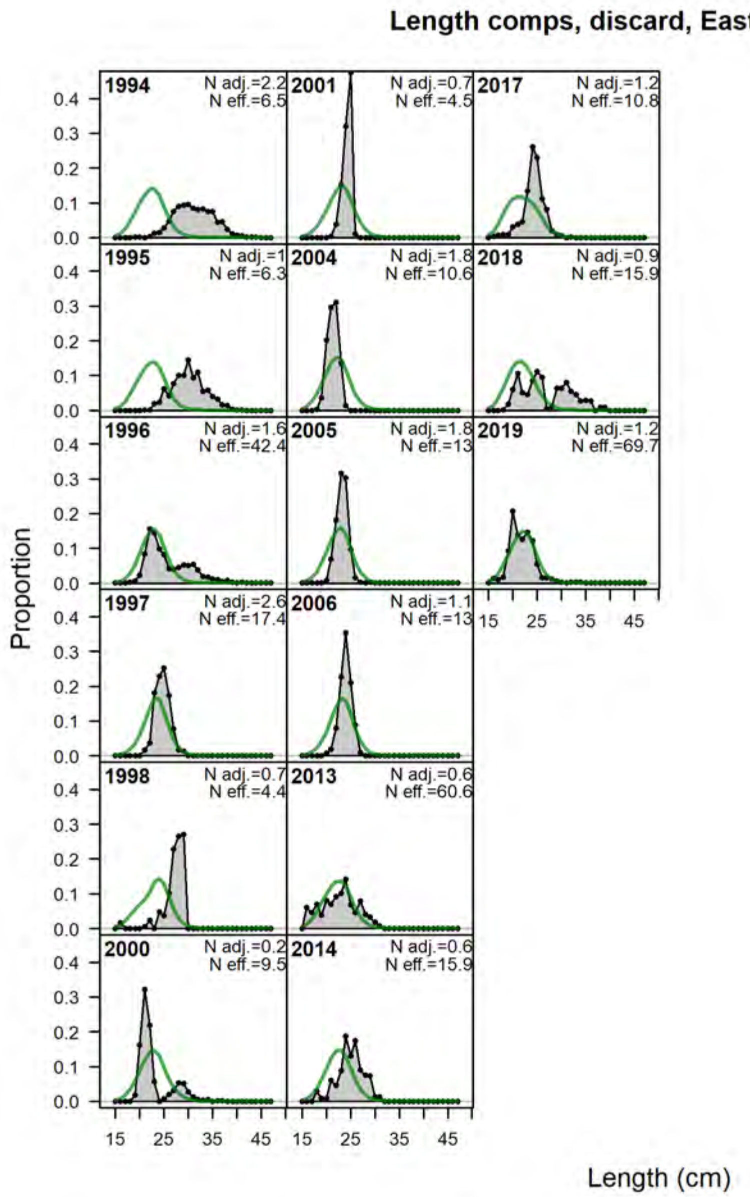


Figure A 7.22. Eastern Jackass Morwong length composition fits: eastern trawl discarded.

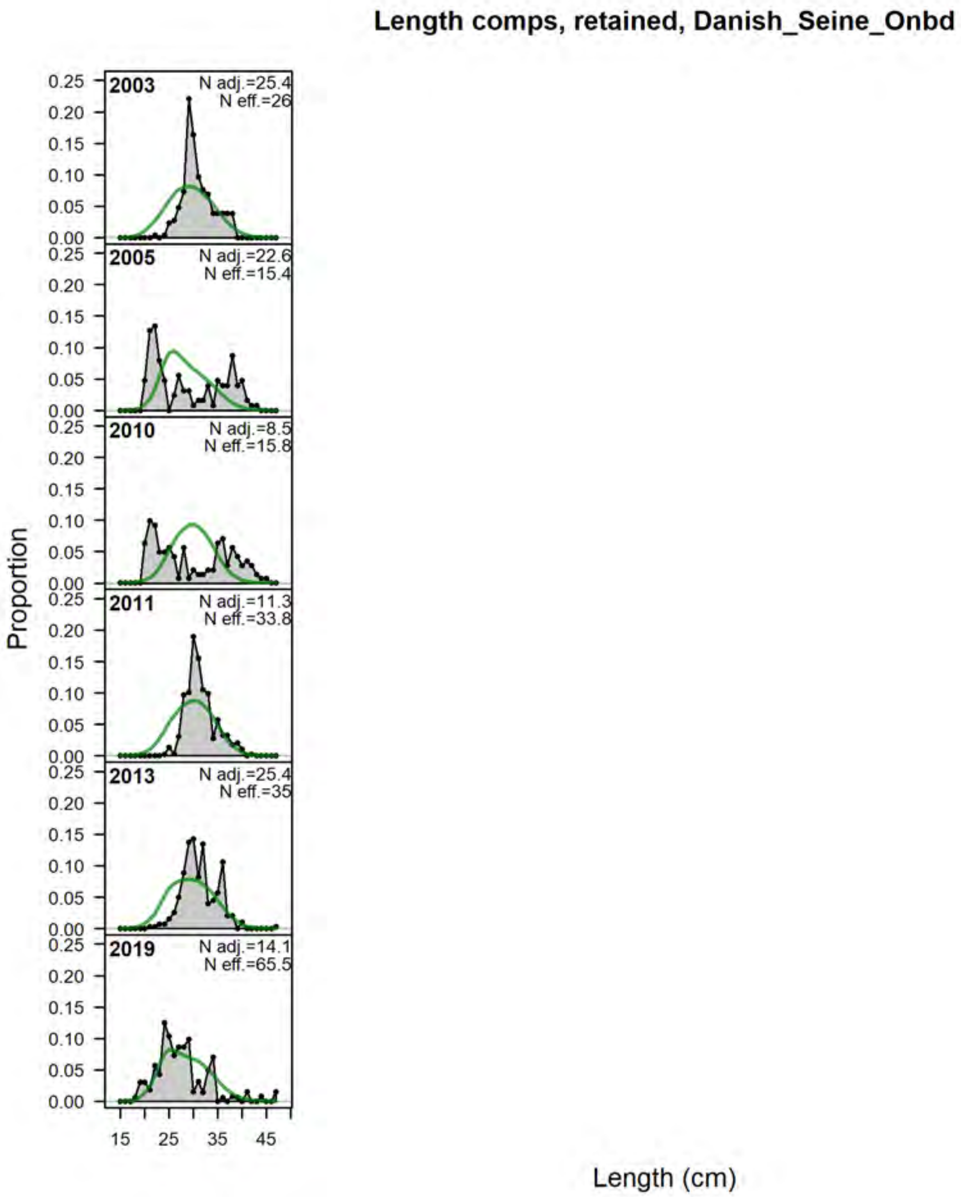


Figure A 7.23. Eastern Jackass Morwong length composition fits: Danish seine onboard retained.

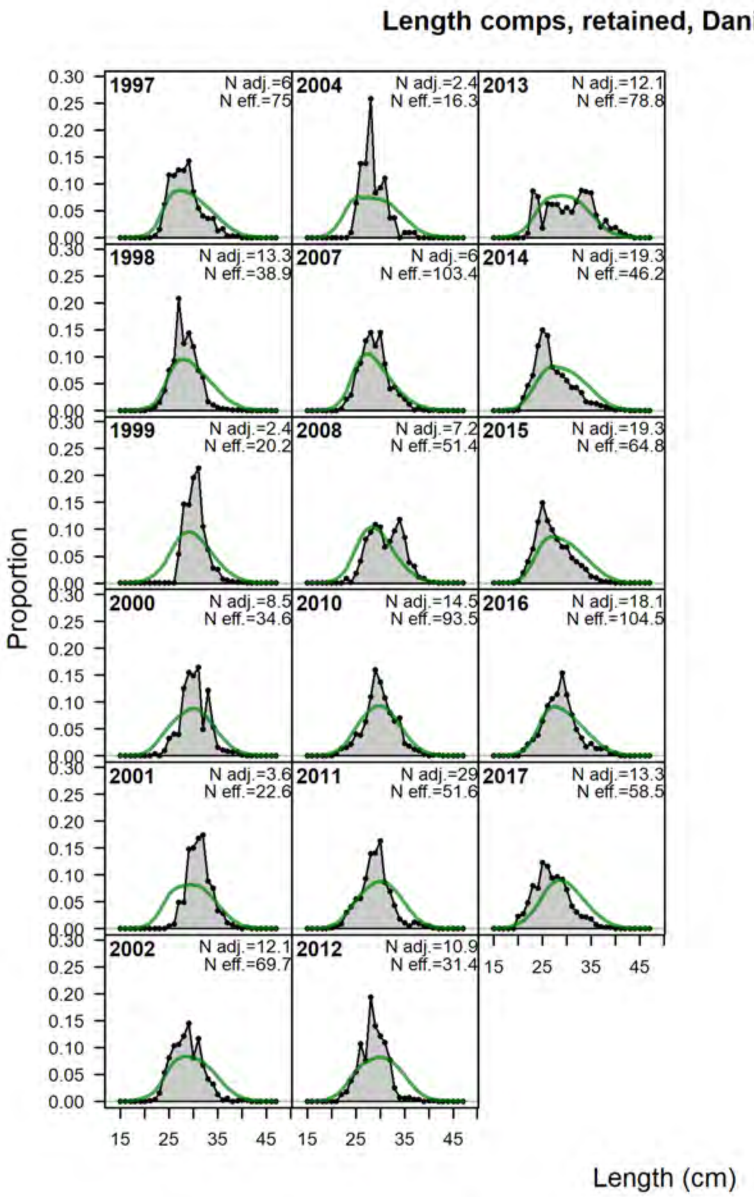


Figure A 7.24. Eastern Jackass Morwong length composition fits: Danish seine port retained.

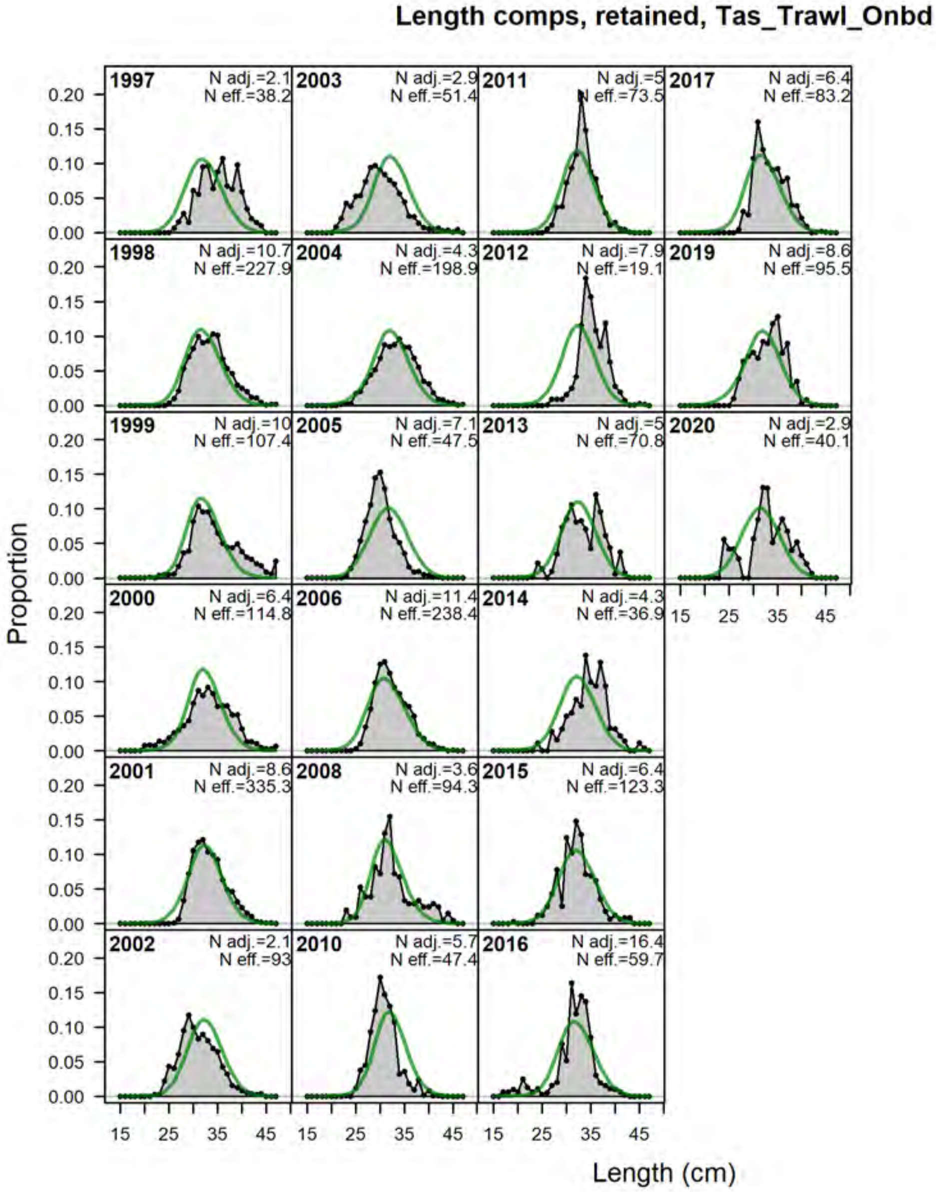


Figure A 7.25. Eastern Jackass Morwong length composition fits: Tasmanian trawl onboard retained.

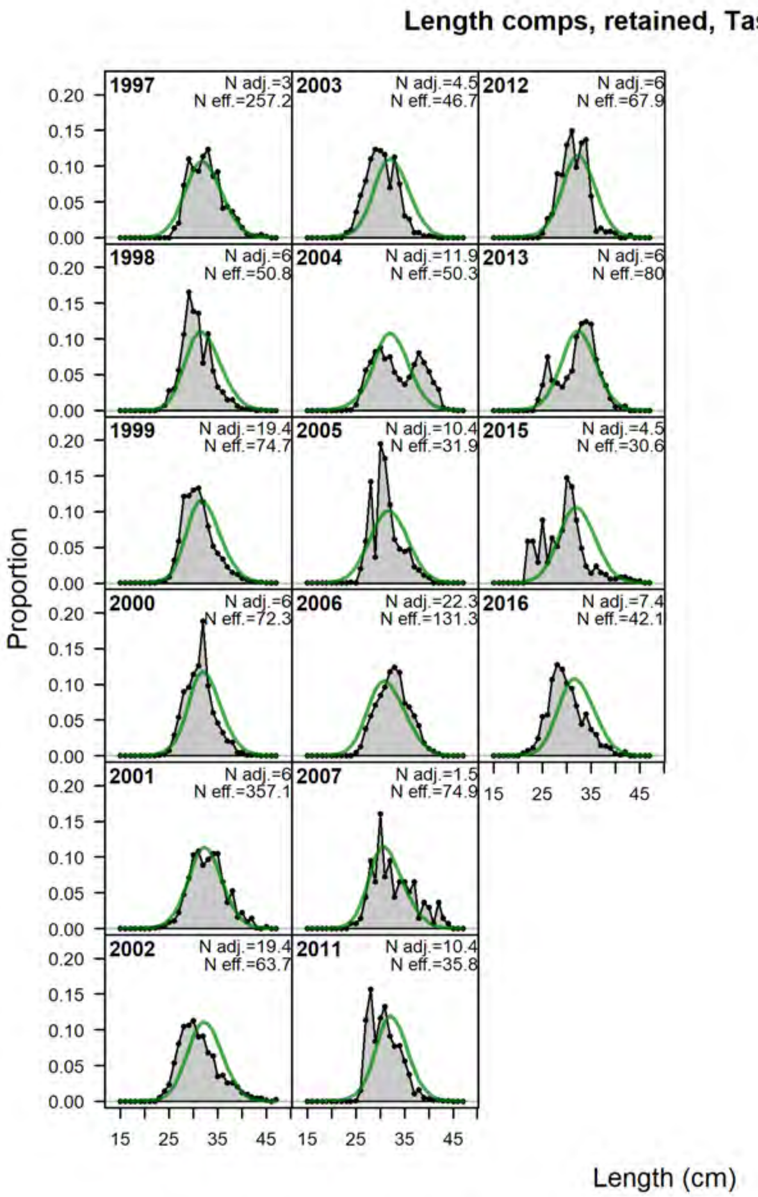


Figure A 7.26. Eastern Jackass Morwong length composition fits: Tasmanian trawl port retained.

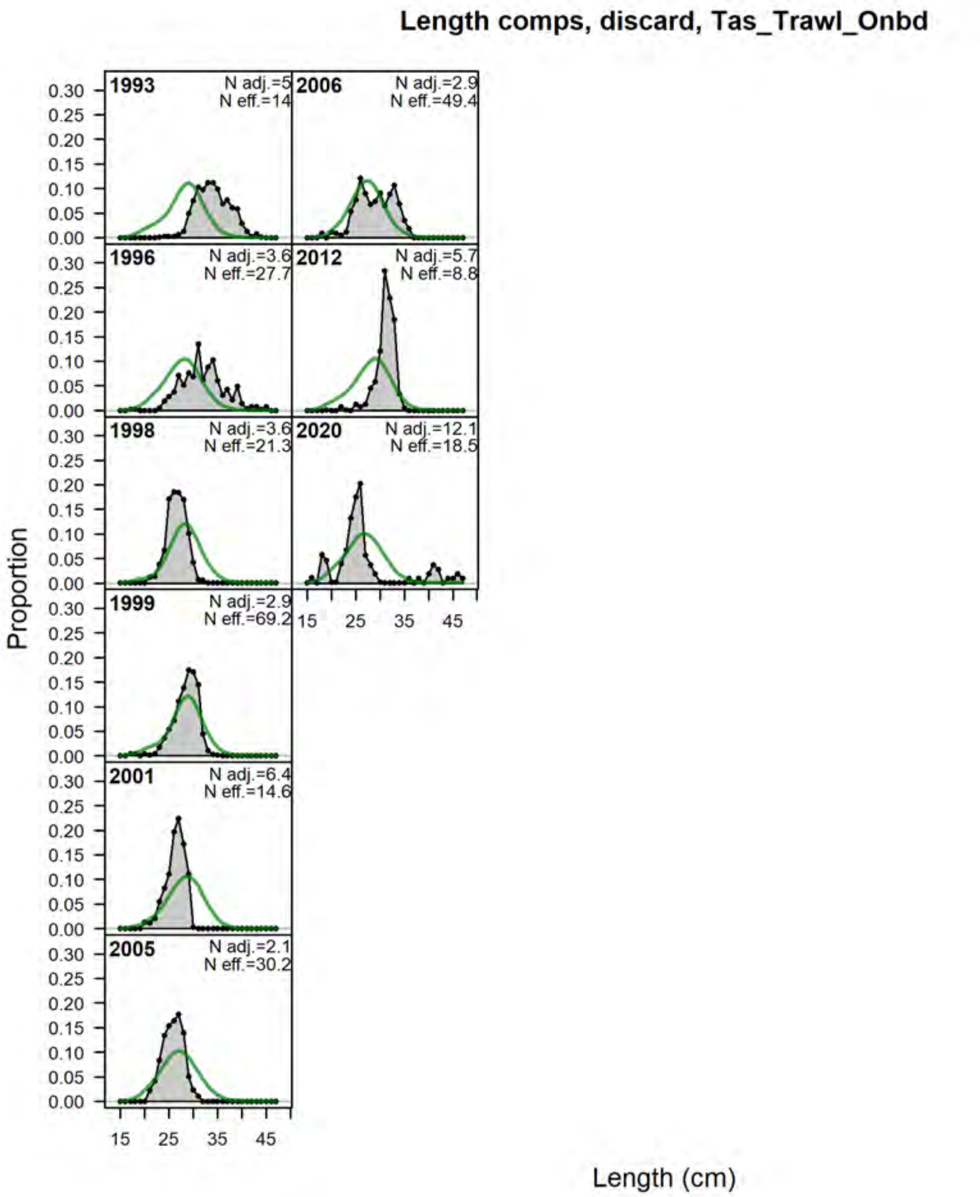


Figure A 7.27. Eastern Jackass Morwong length composition fits: Tasmanian trawl discarded.

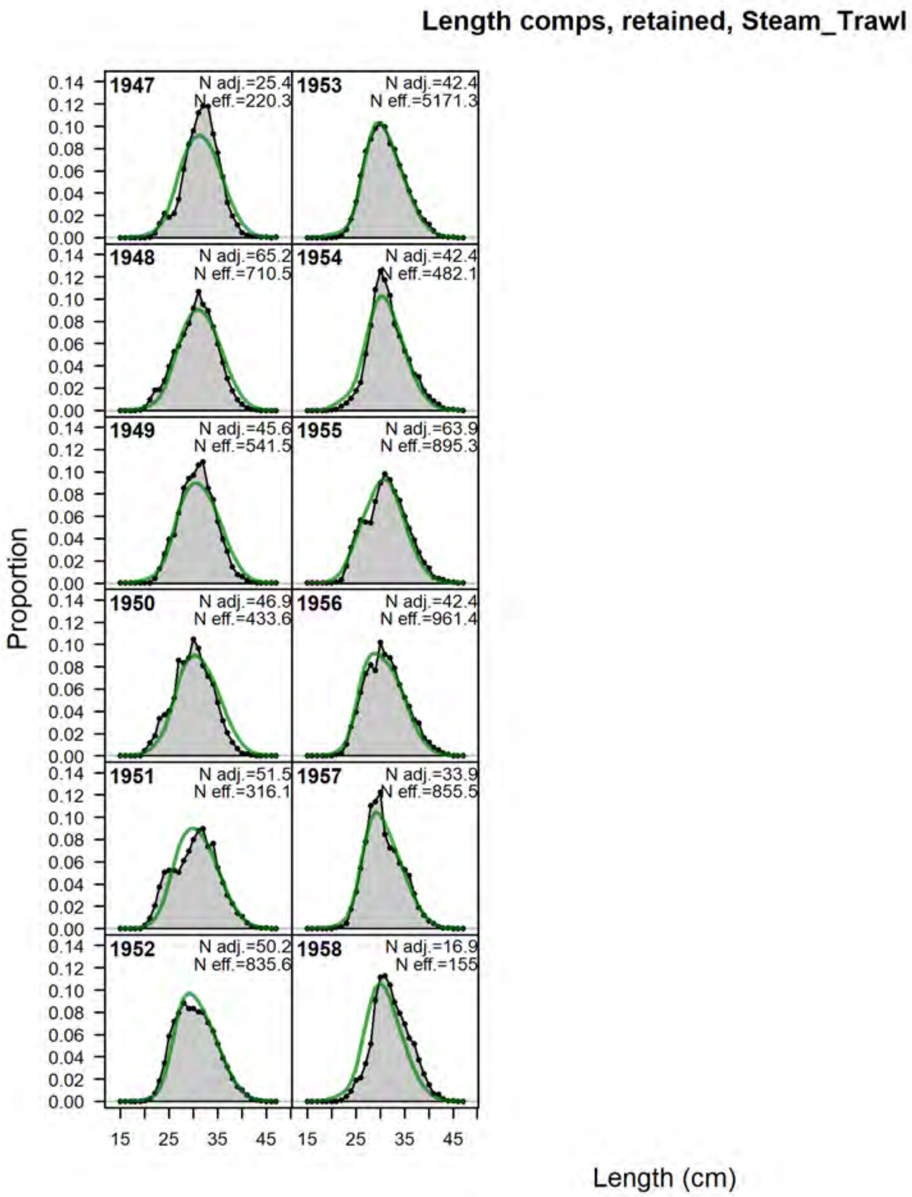


Figure A 7.28. Eastern Jackass Morwong length composition fits: steam trawl retained.

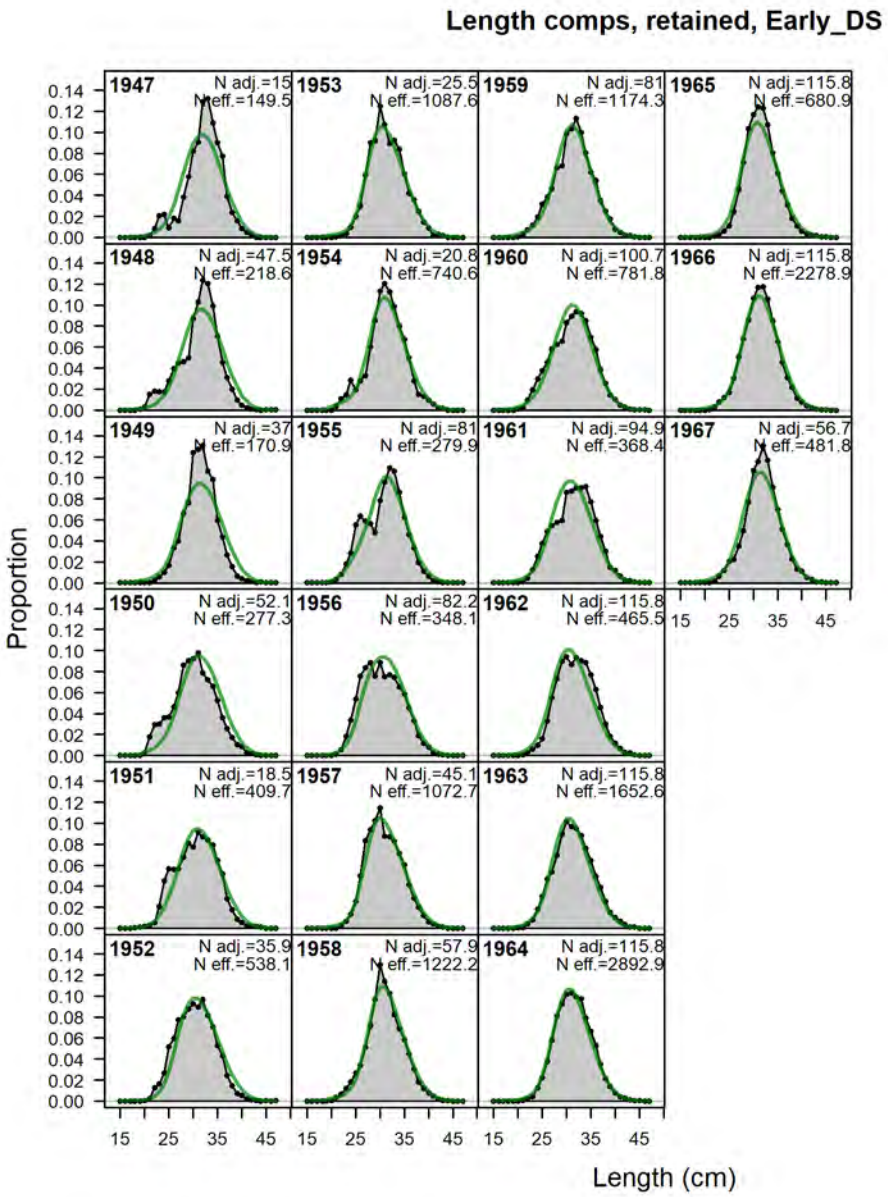


Figure A 7.29. Eastern Jackass Morwong length composition fits: early Danish seine retained.

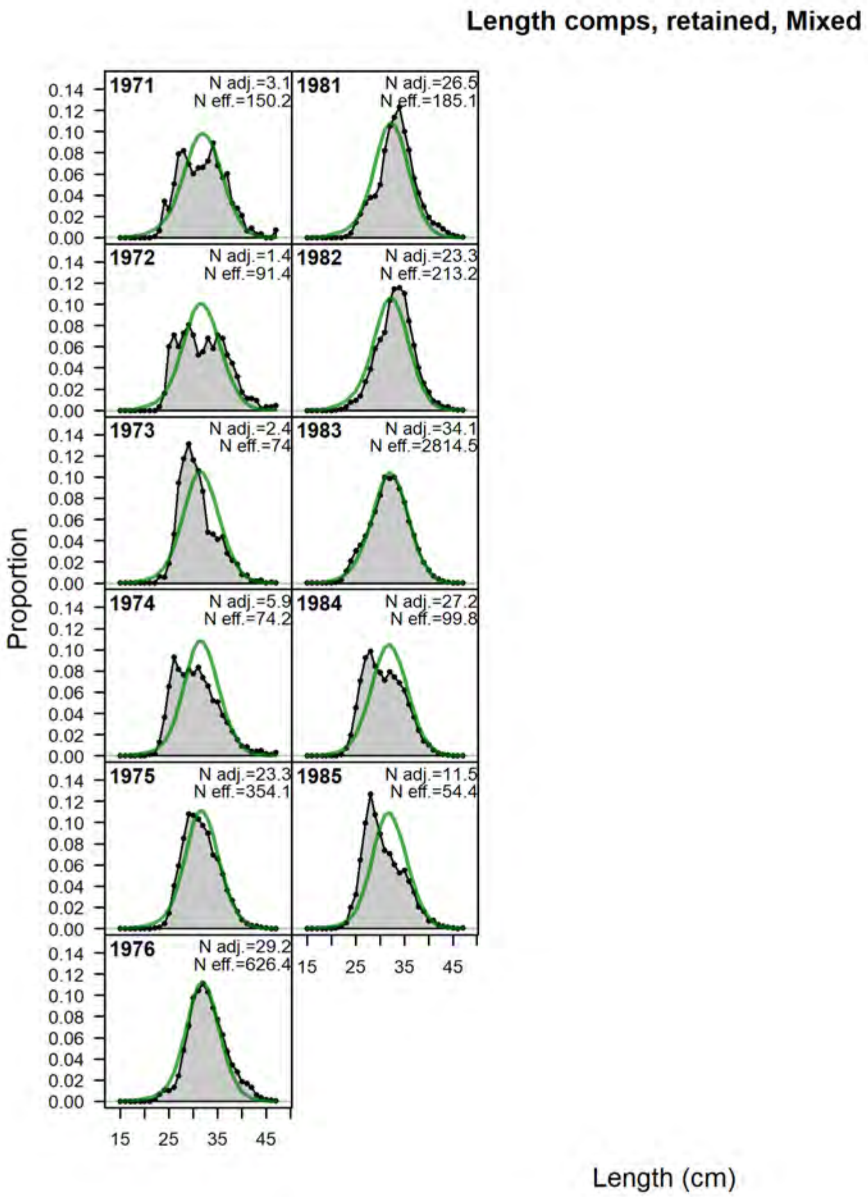


Figure A 7.30. Eastern Jackass Morwong length composition fits: mixed retained.

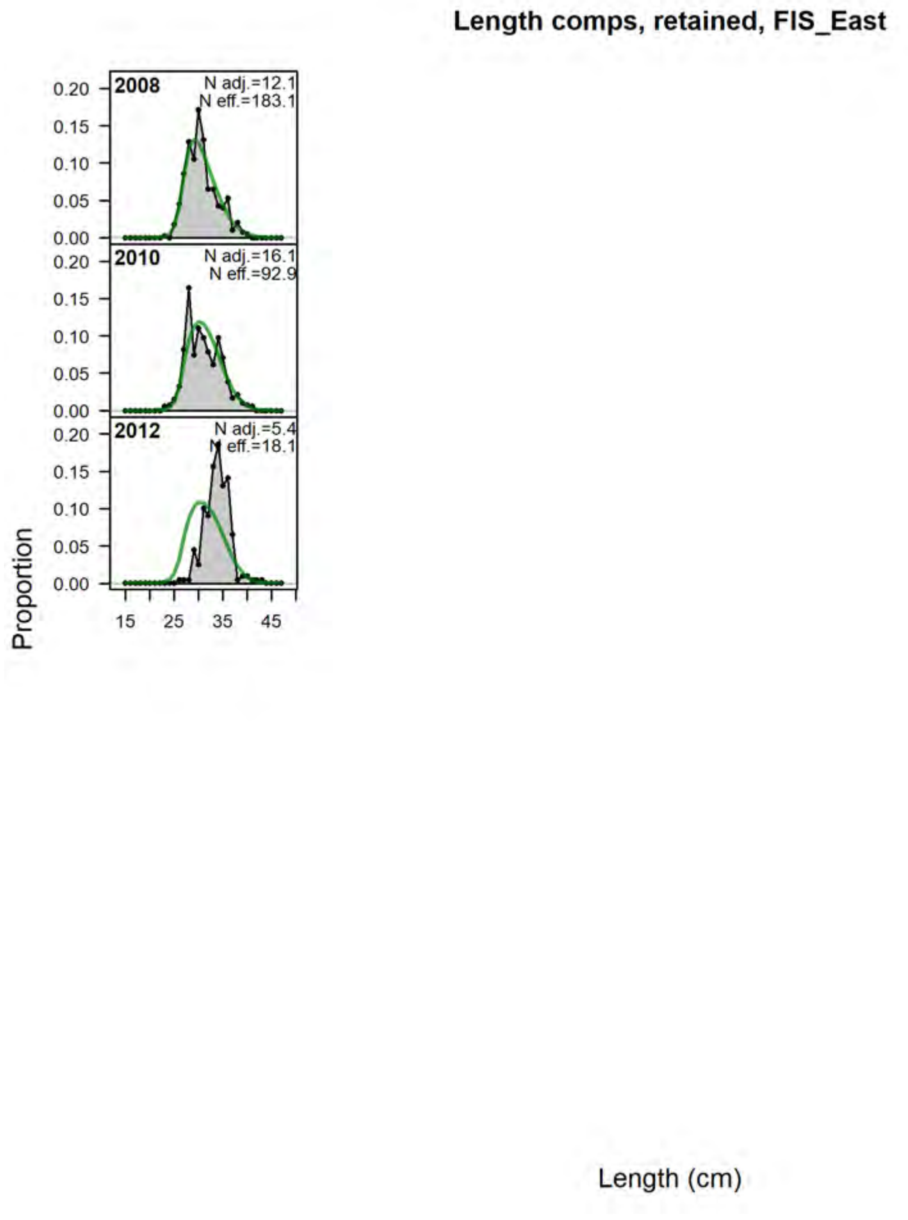


Figure A 7.31. Eastern Jackass Morwong length composition fits: FIS eastern trawl retained.

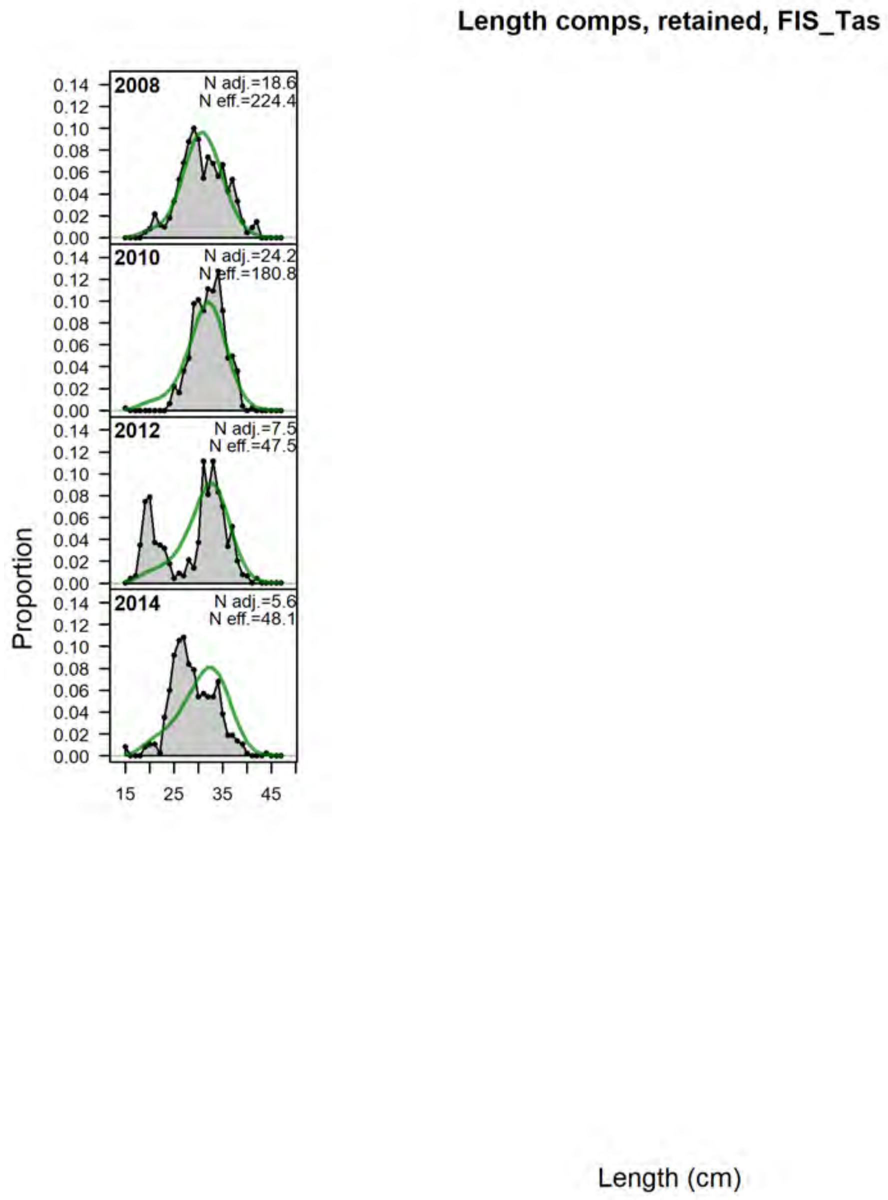


Figure A 7.32. Eastern Jackass Morwong length composition fits: FIS Tasmanian trawl retained.

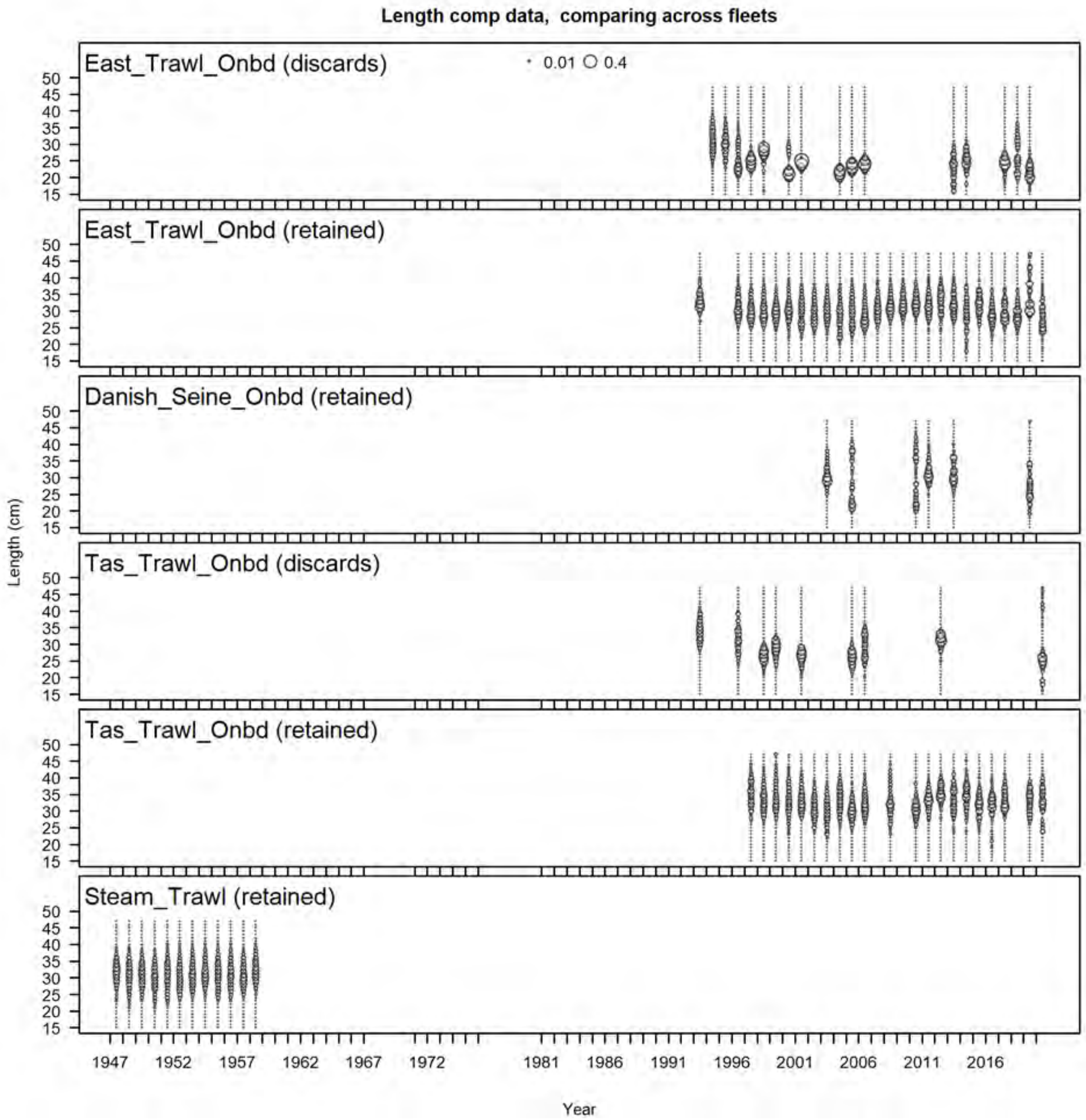


Figure A 7.33. Residuals from the annual length compositions (retained and discarded) for eastern Jackass Morwong displayed by year for trawl and Danish seine fleets.

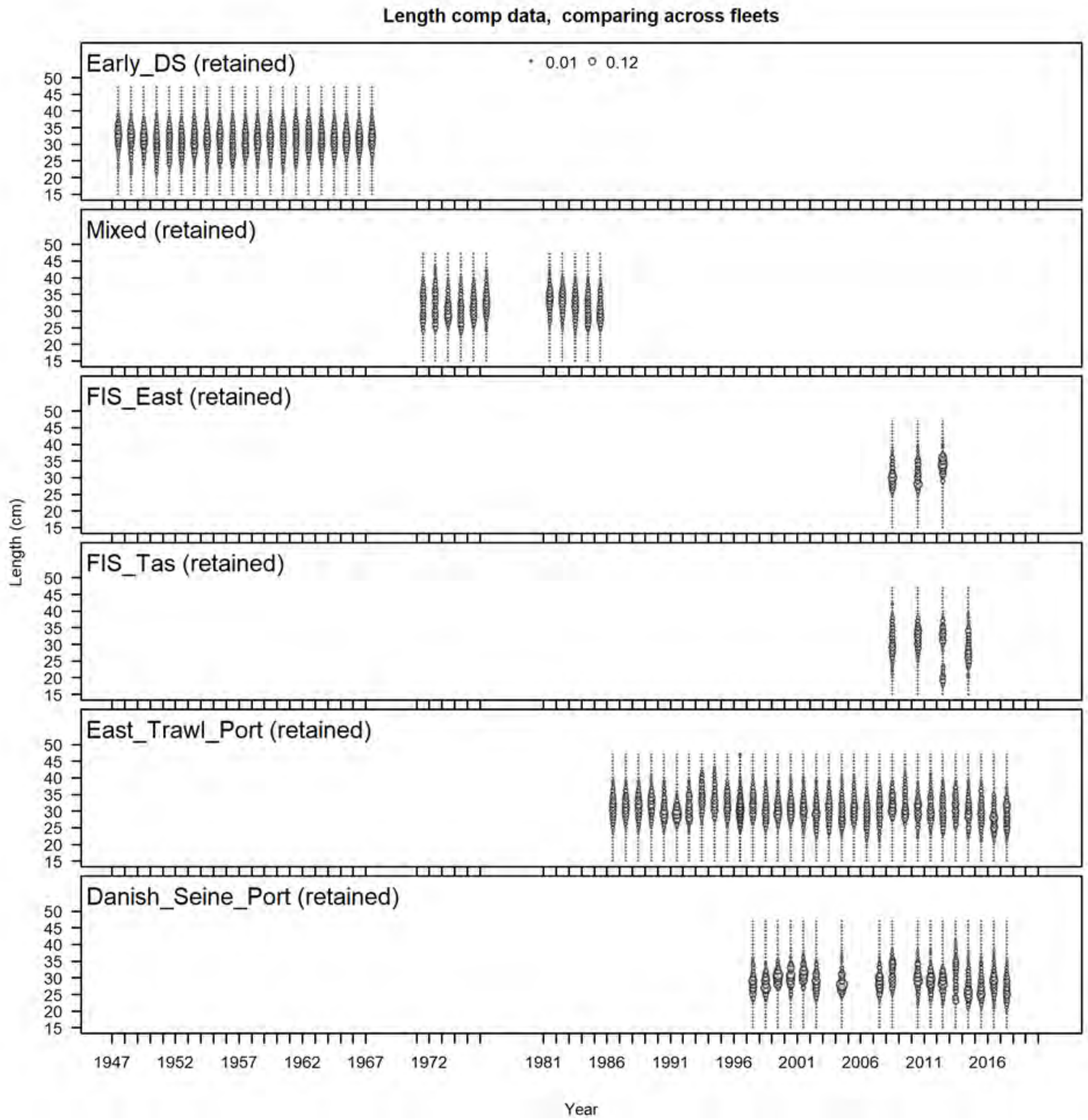


Figure A 7.34. Residuals from the annual length compositions (retained) for eastern Jackass Morwong displayed by year for trawl and Danish seine fleets.

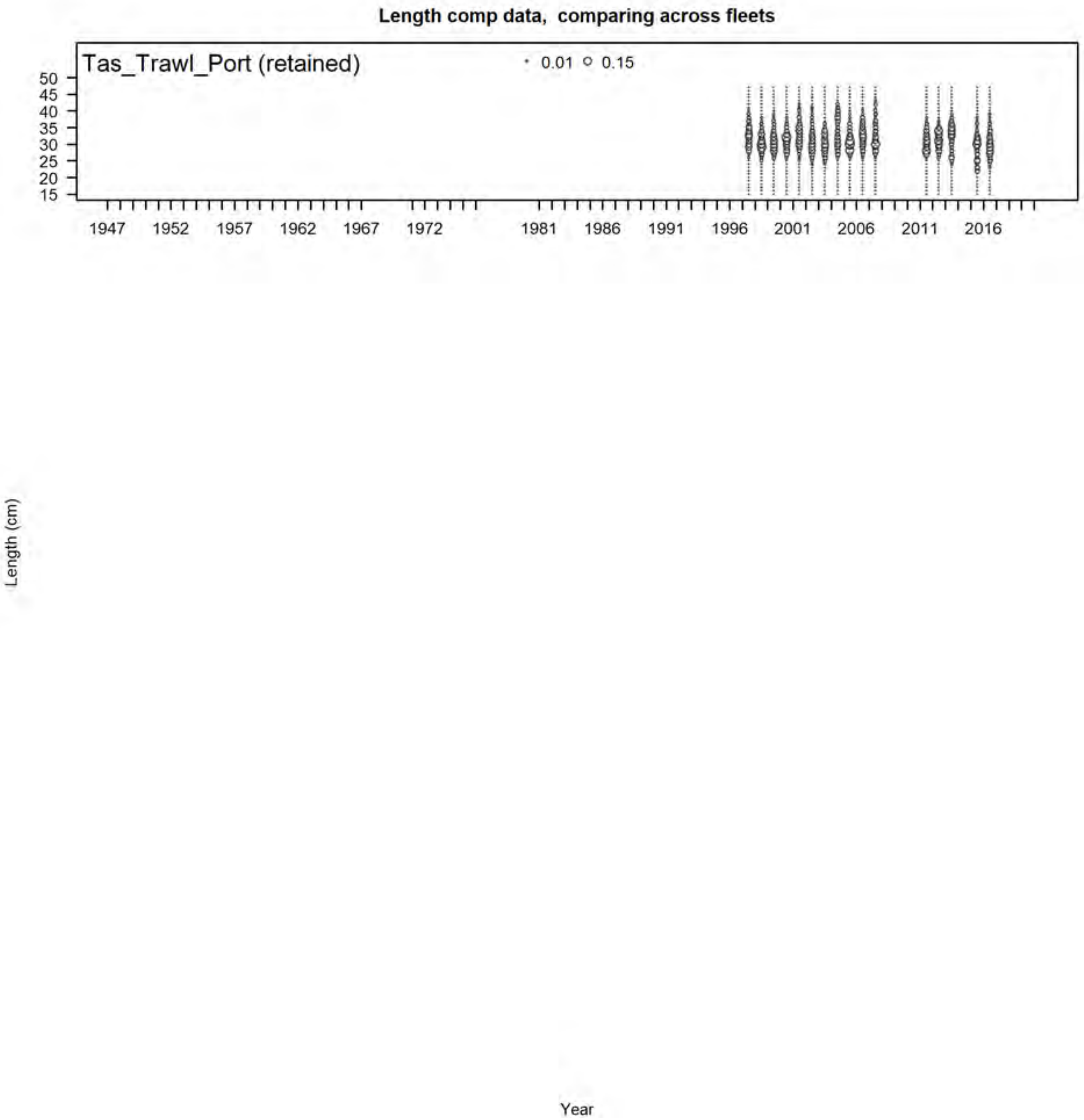


Figure A 7.35. Residuals from the annual length compositions (retained) for eastern Jackass Morwong displayed by year for trawl fleets.

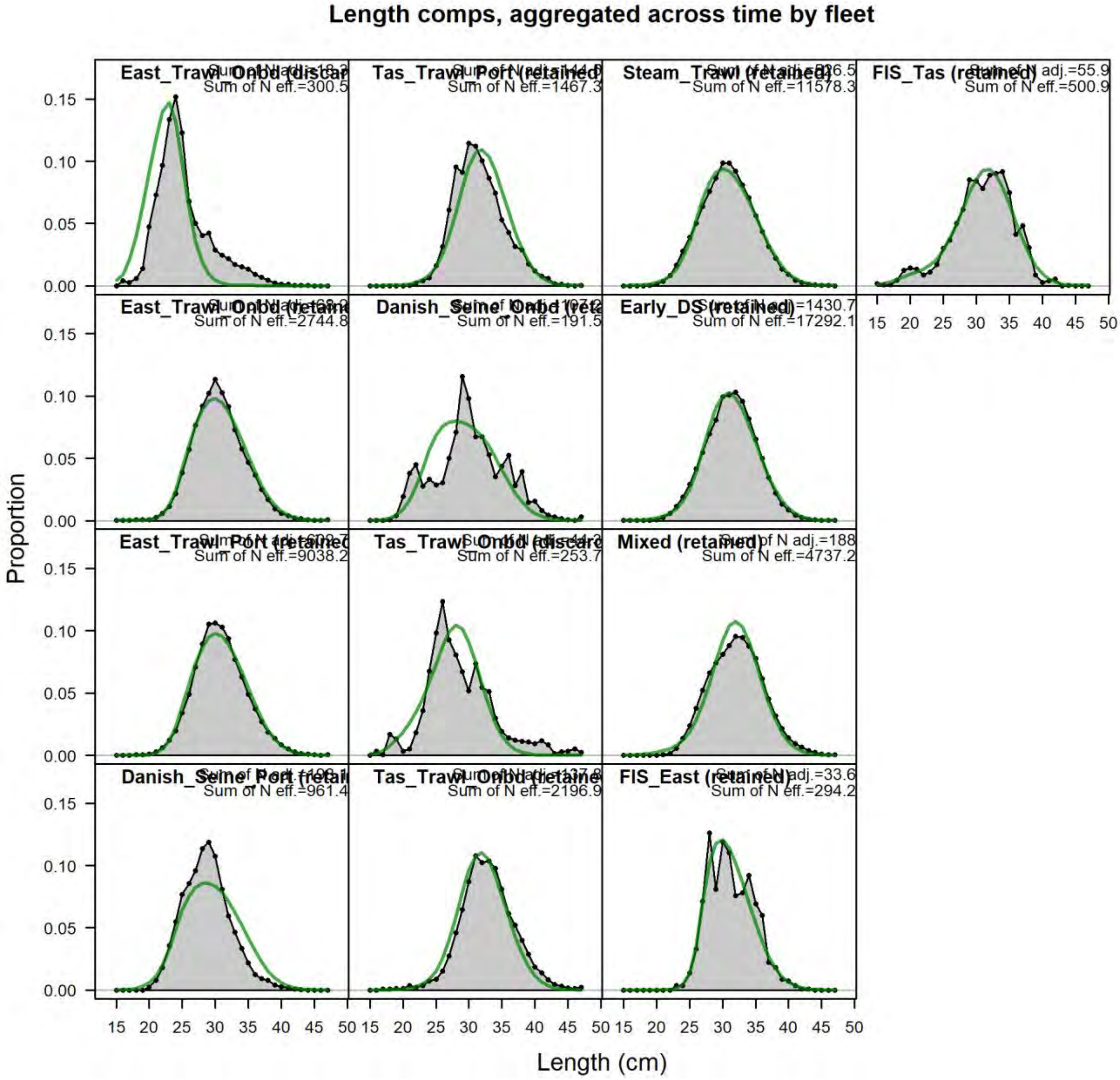


Figure A 7.36. Aggregated fits (over all years) to the length compositions for eastern Jackass Morwong displayed by fleet.

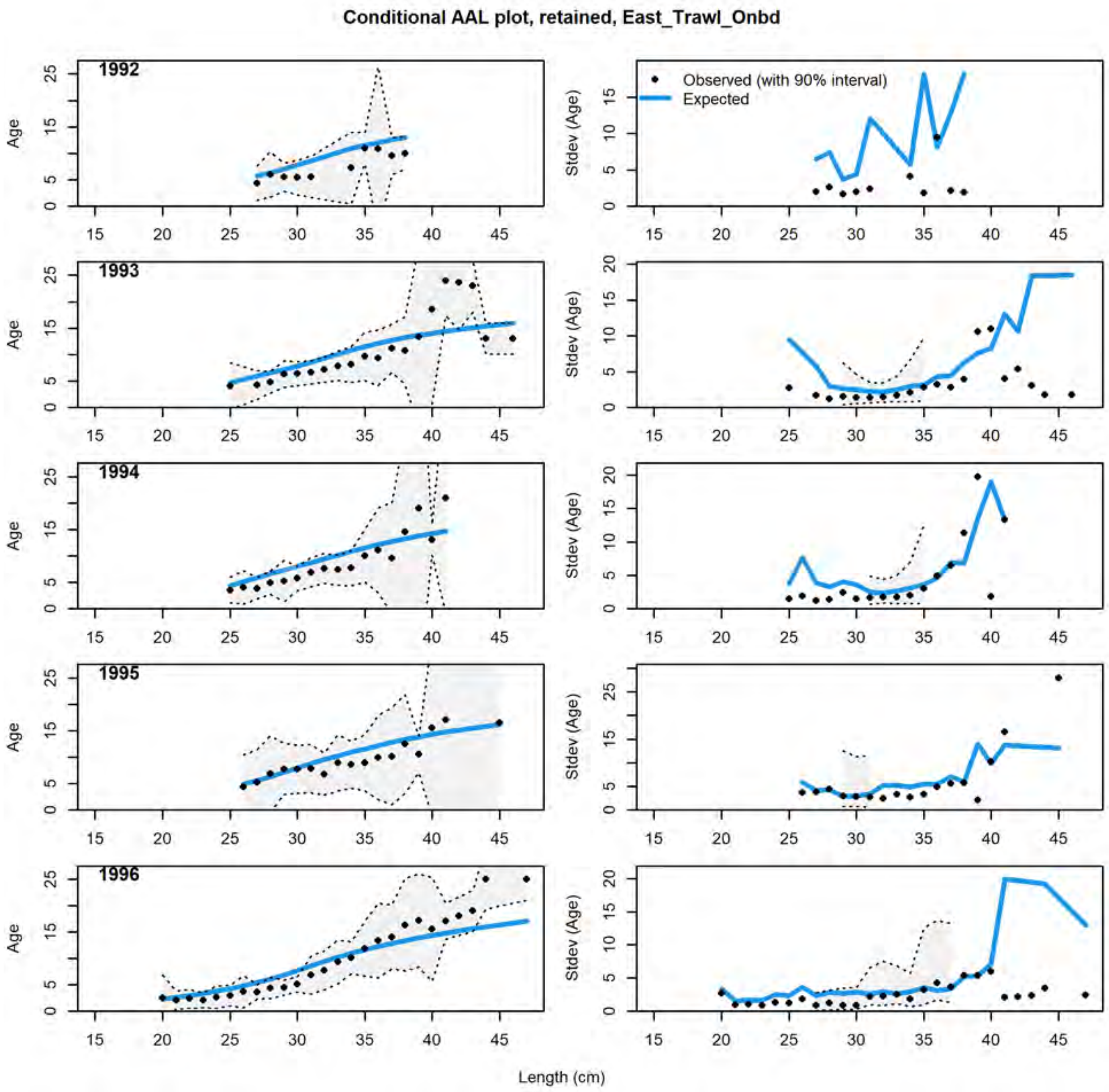


Figure A 7.37. Eastern Jackass Morwong conditional age-at-length fits: eastern trawl part 1.

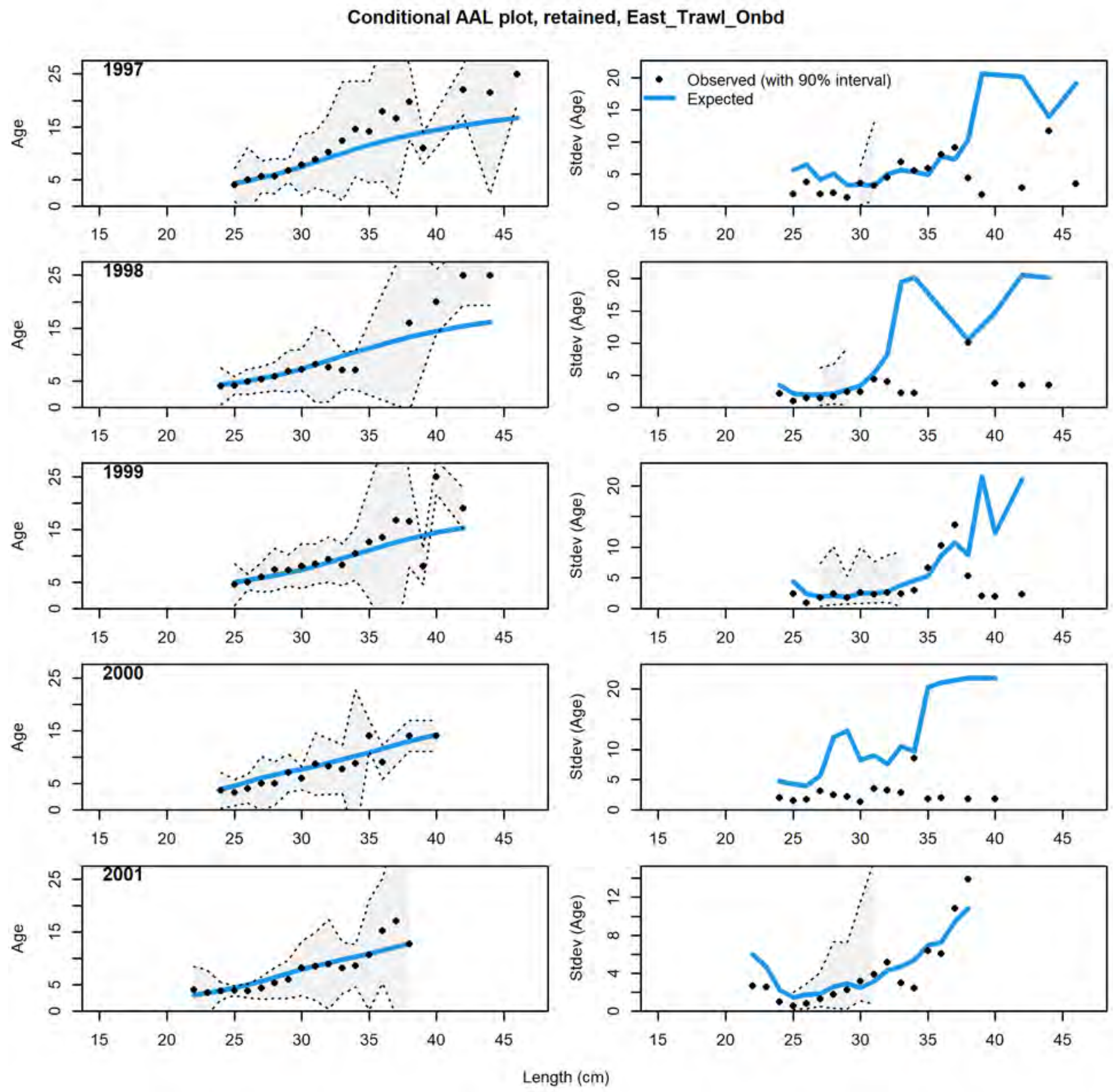


Figure A 7.38. Eastern Jackass Morwong conditional age-at-length fits: eastern trawl part 2.

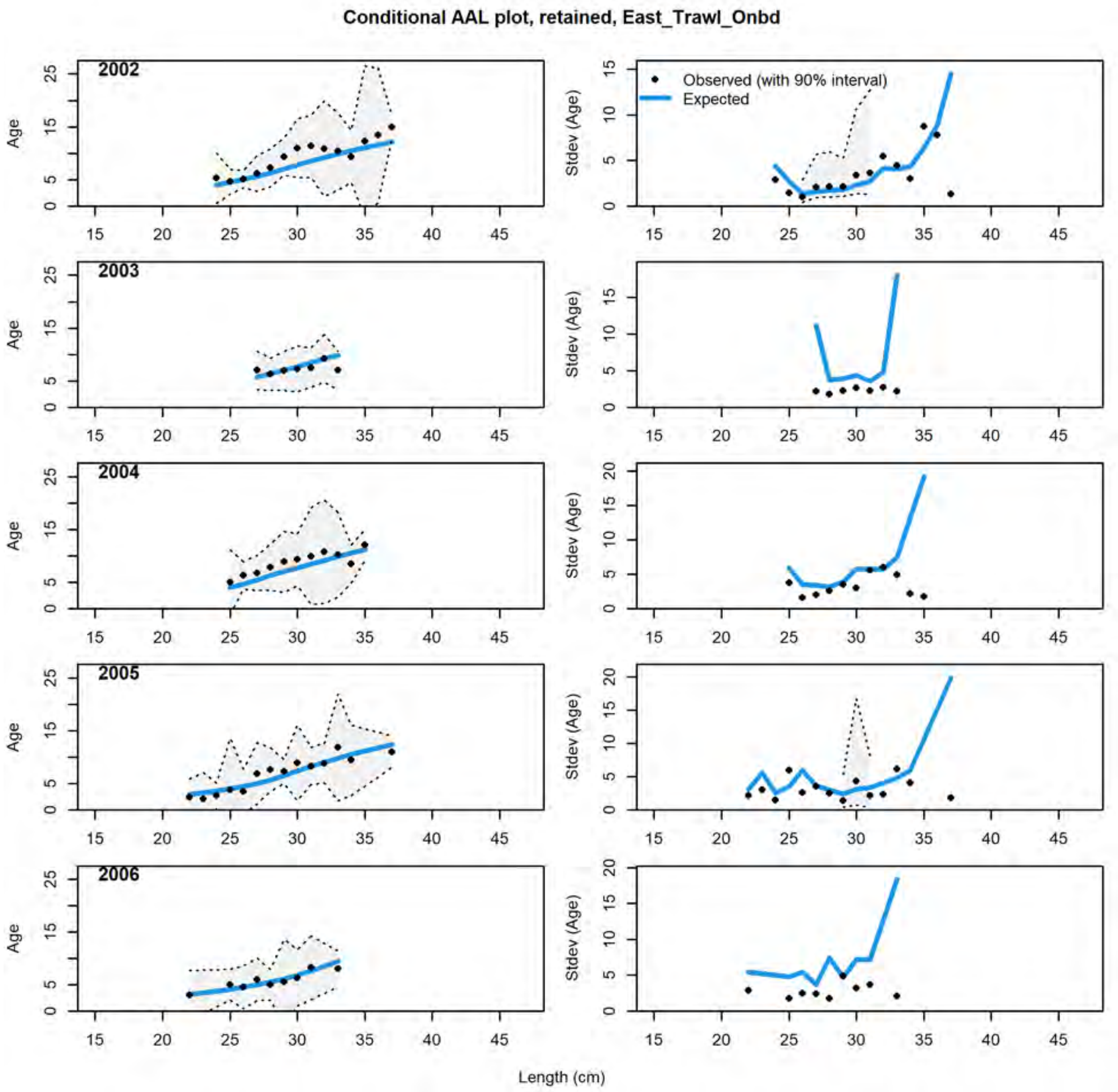


Figure A 7.39. Eastern Jackass Morwong conditional age-at-length fits: eastern trawl part 3.

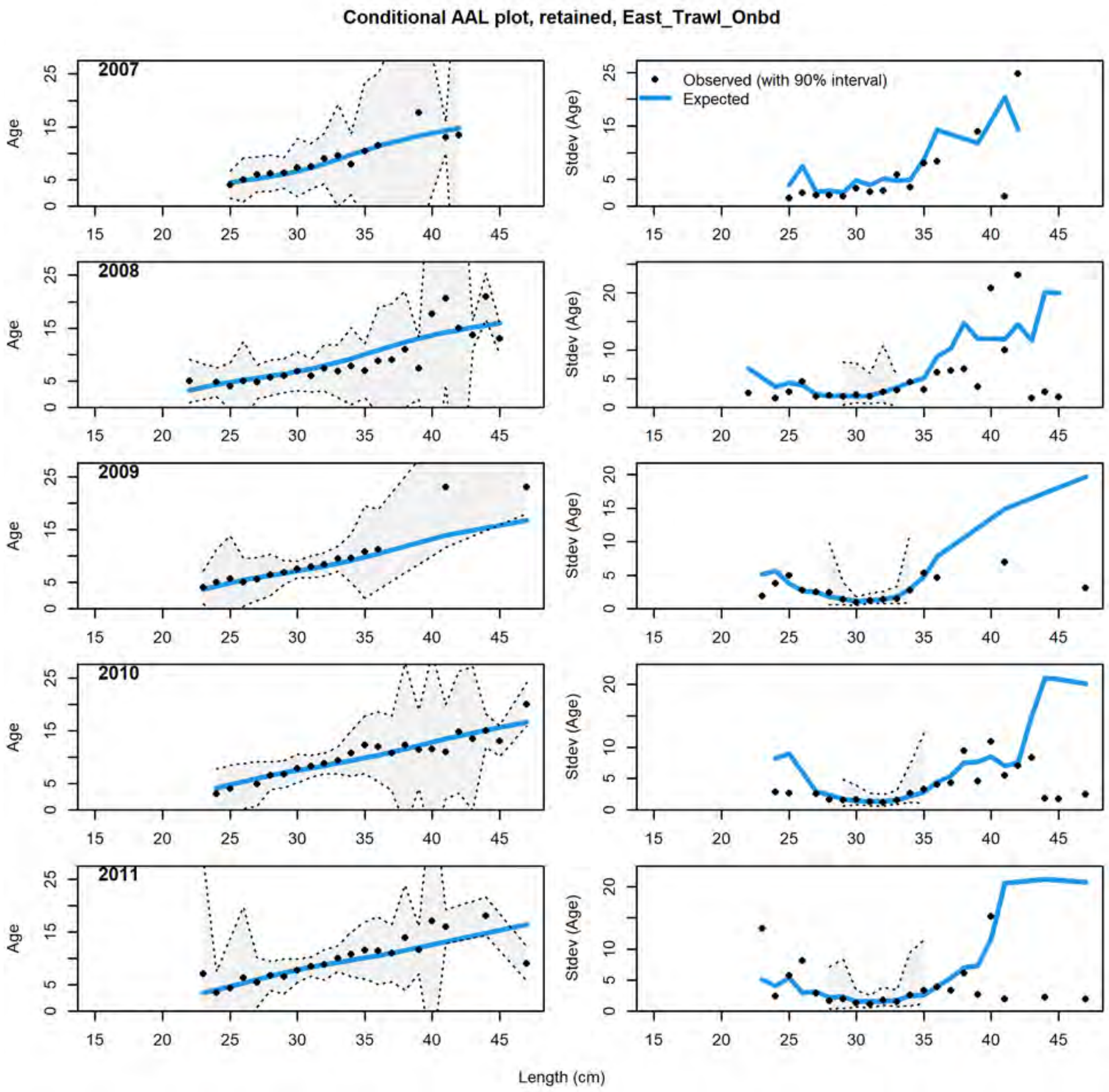


Figure A 7.40. Eastern Jackass Morwong conditional age-at-length fits: eastern trawl part 4.

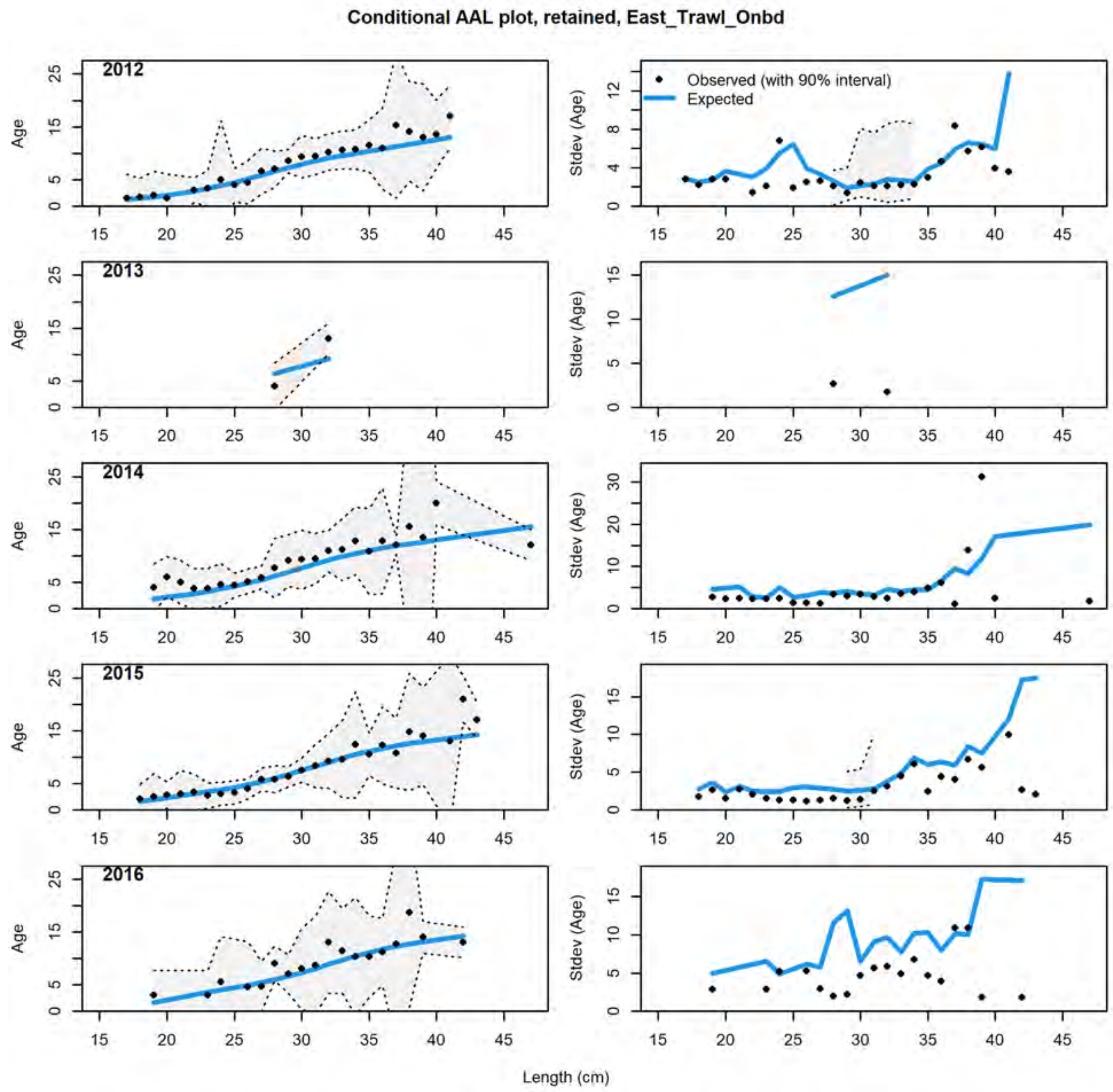


Figure A 7.41. Eastern Jackass Morwong conditional age-at-length fits: eastern trawl part 5.

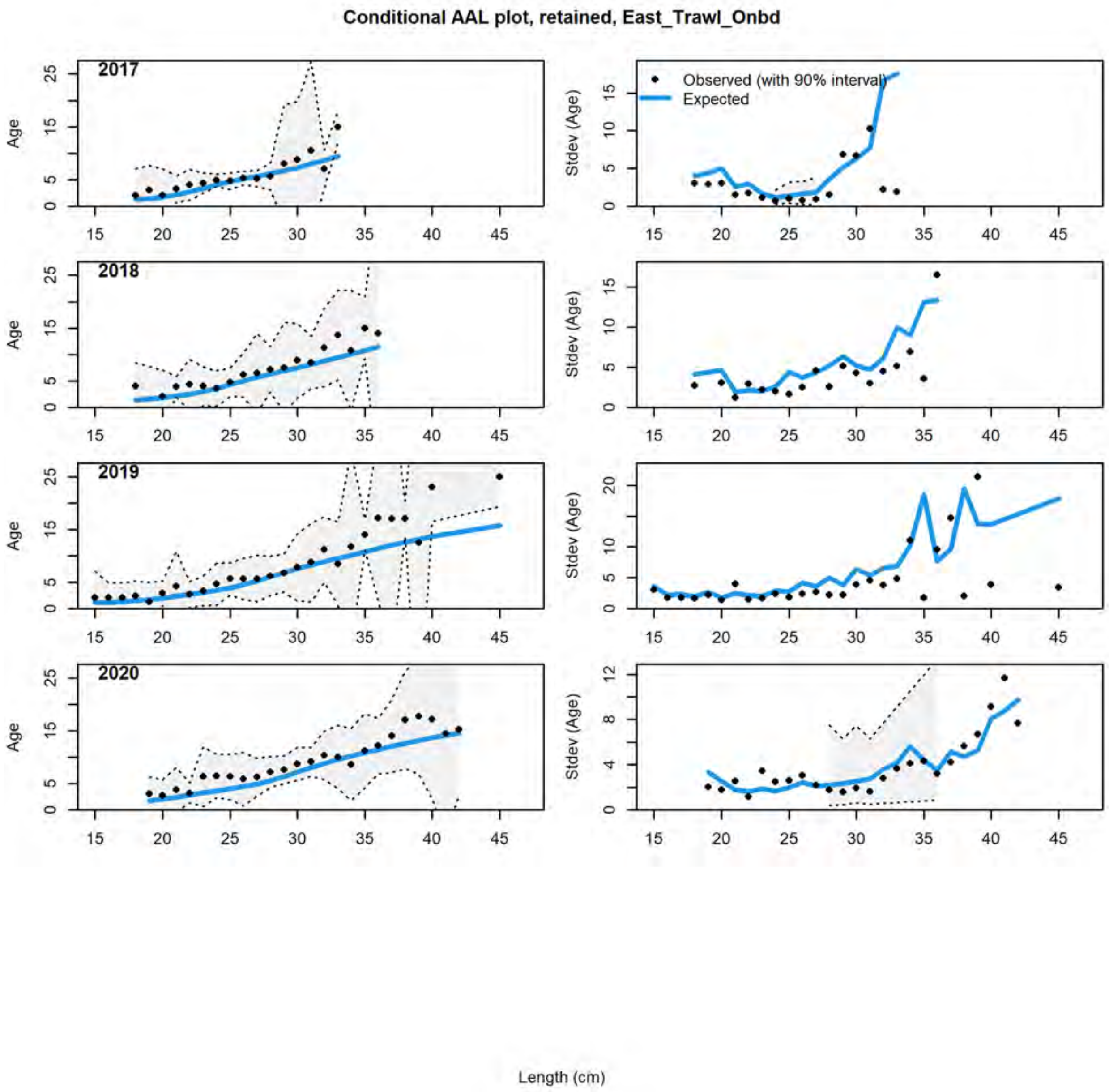


Figure A 7.42. Eastern Jackass Morwong conditional age-at-length fits: eastern trawl part 6.

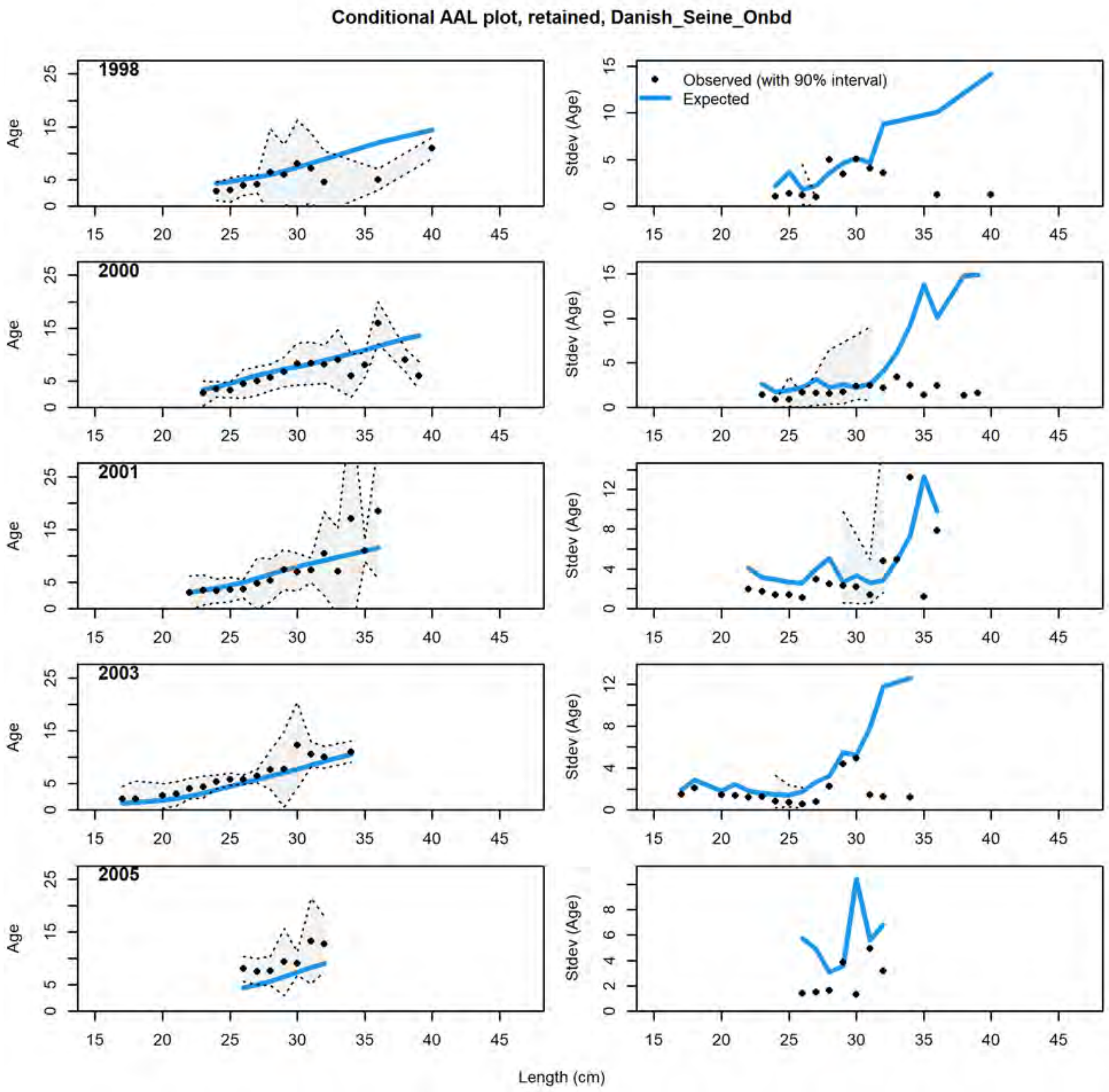


Figure A 7.43. Eastern Jackass Morwong conditional age-at-length fits: Danish seine part 1.

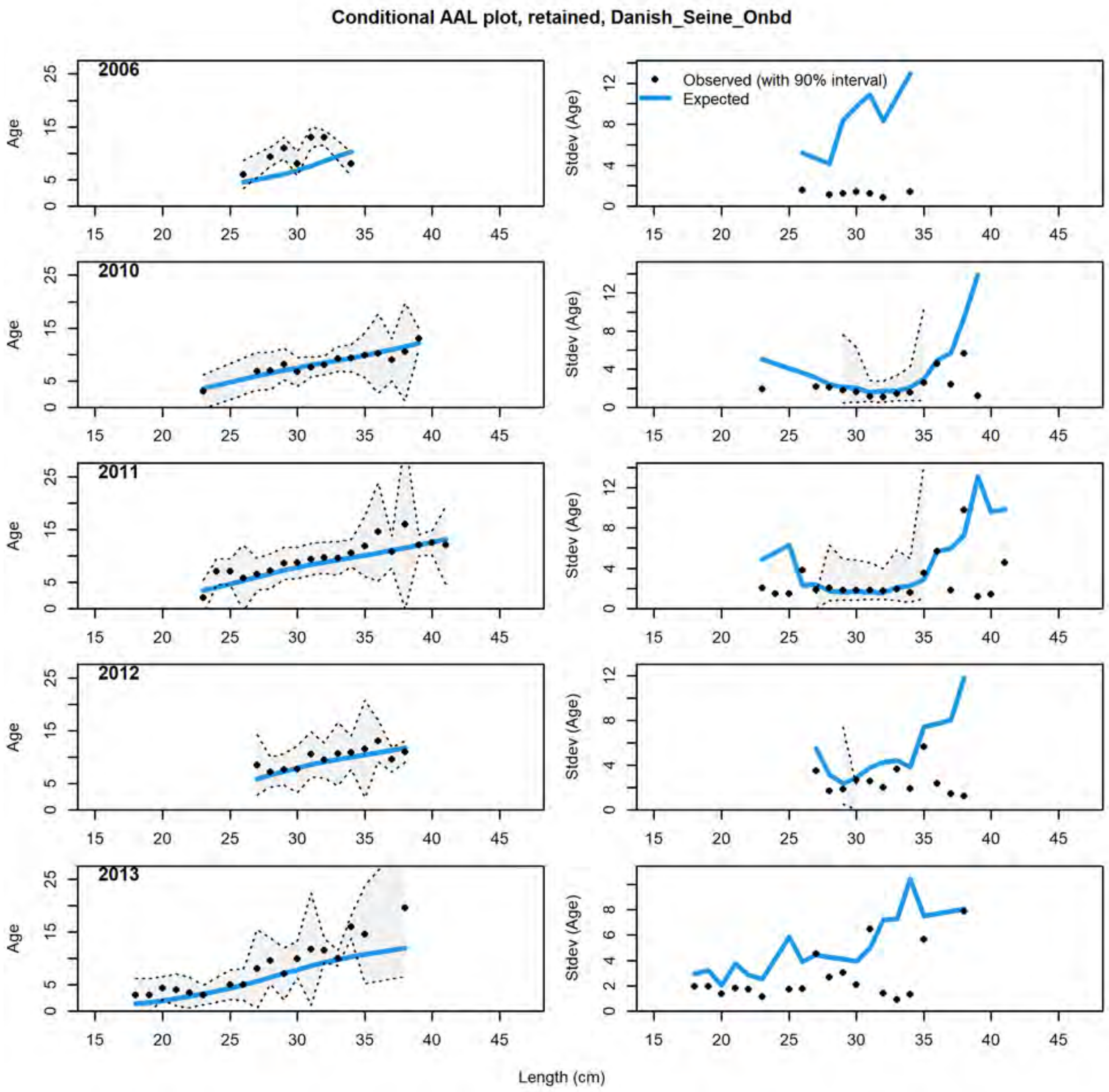


Figure A 7.44. Eastern Jackass Morwong conditional age-at-length fits: Danish seine part 2.

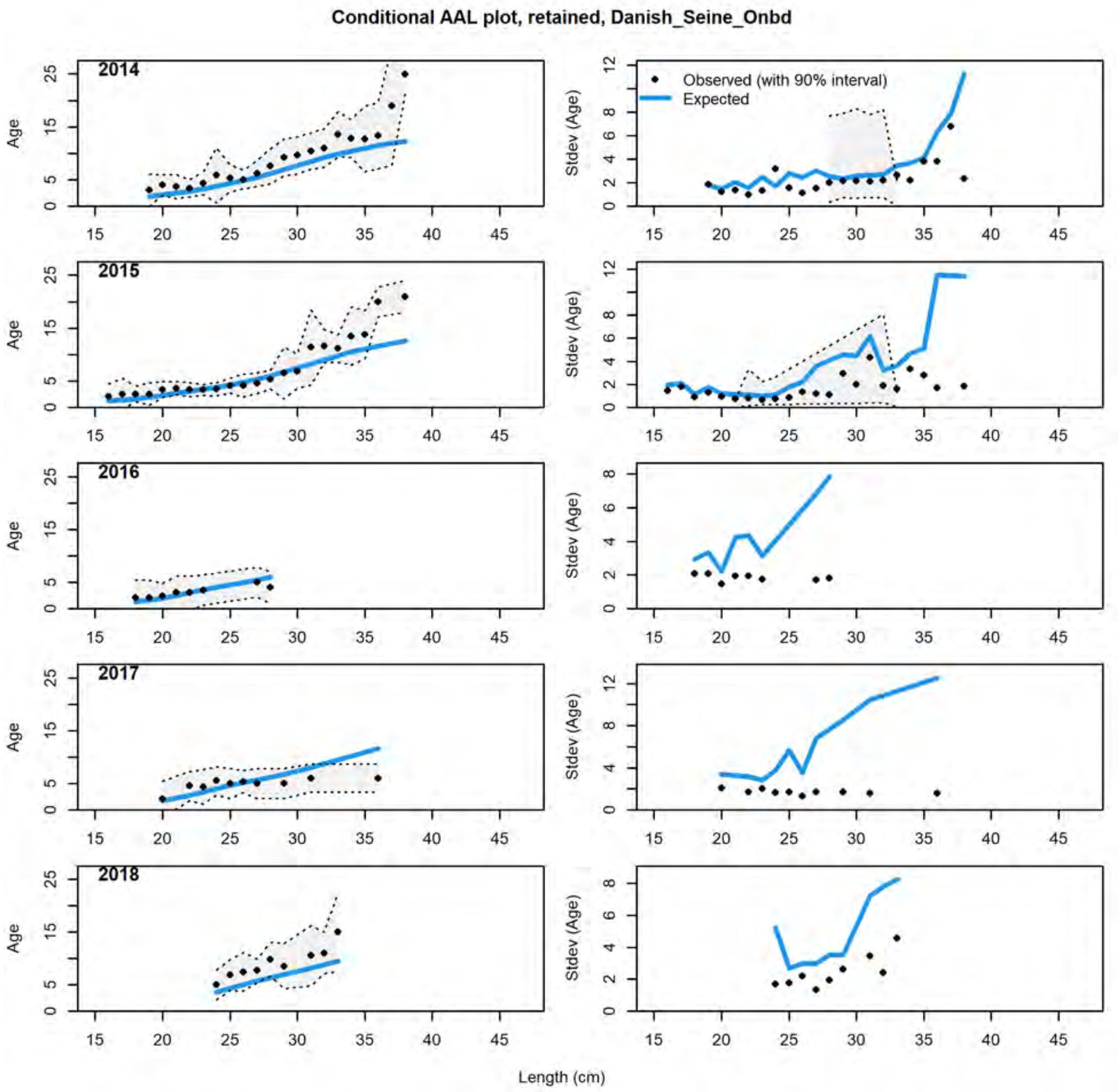


Figure A 7.45. Eastern Jackass Morwong conditional age-at-length fits: Danish seine part 3.

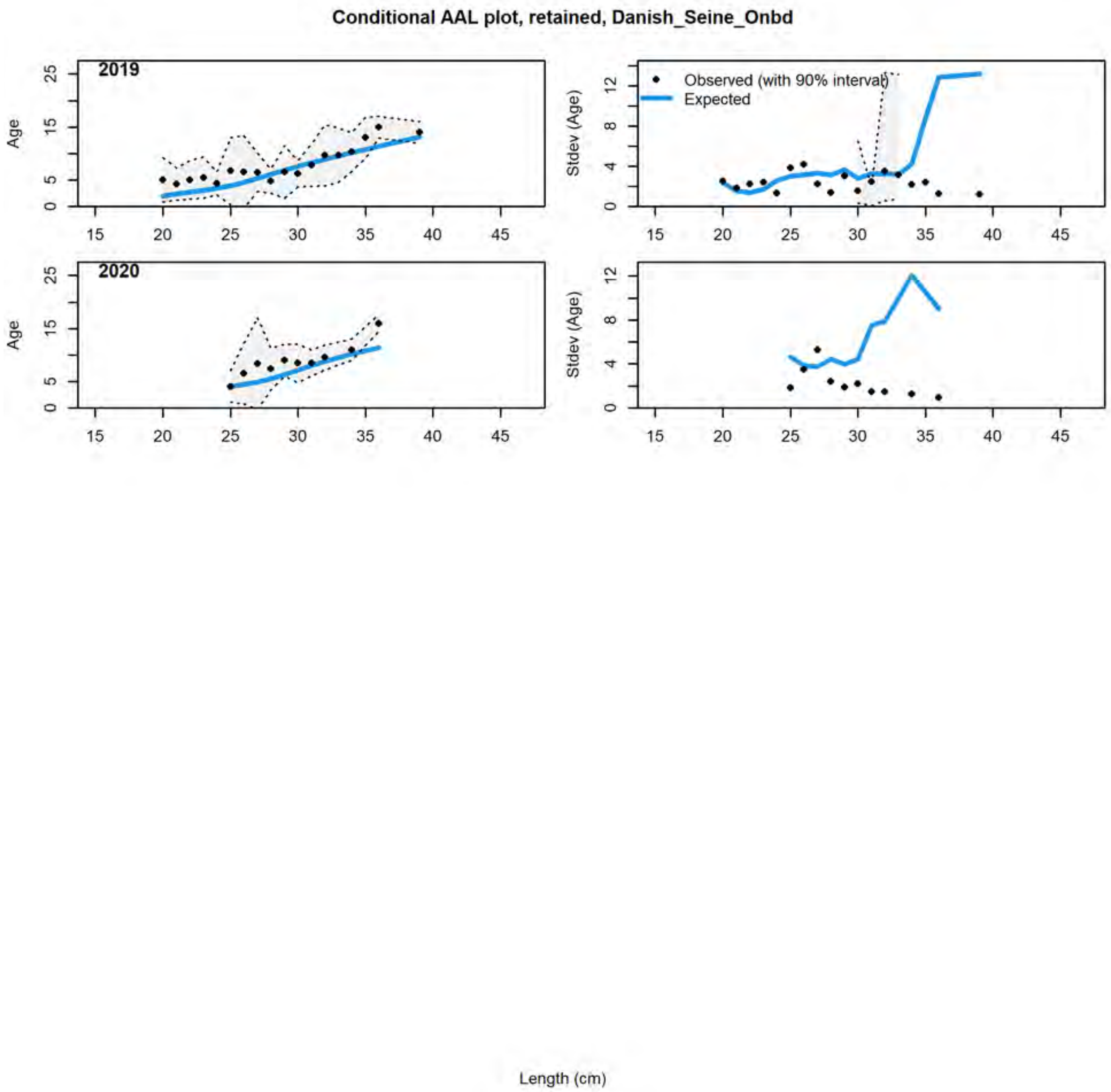


Figure A 7.46. Eastern Jackass Morwong conditional age-at-length fits: Danish seine part 4.

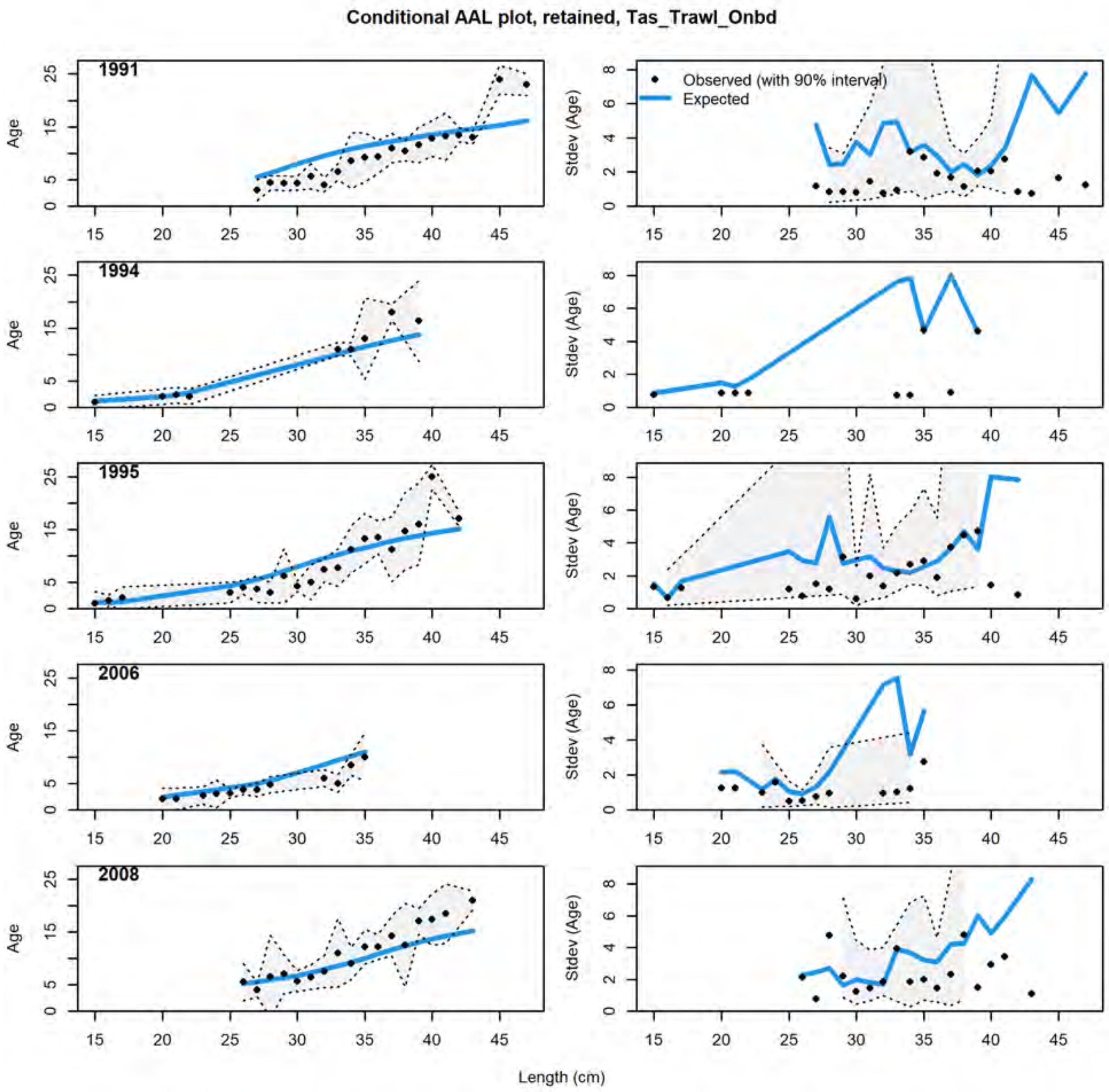


Figure A 7.47. Eastern Jackass Morwong conditional age-at-length fits: Tasmanian trawl part 1.

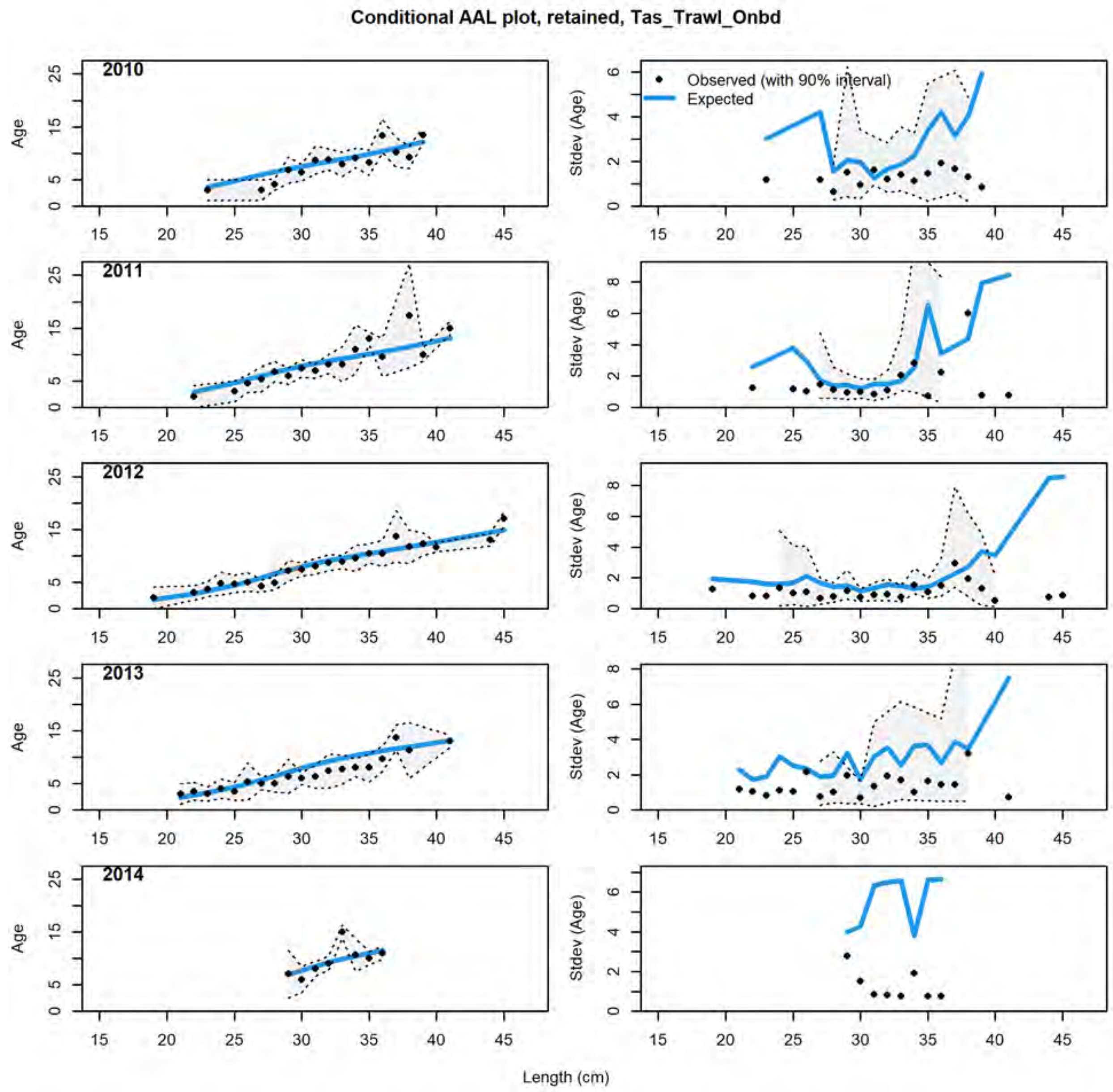


Figure A 7.48. Eastern Jackass Morwong conditional age-at-length fits: Tasmanian trawl part 2.

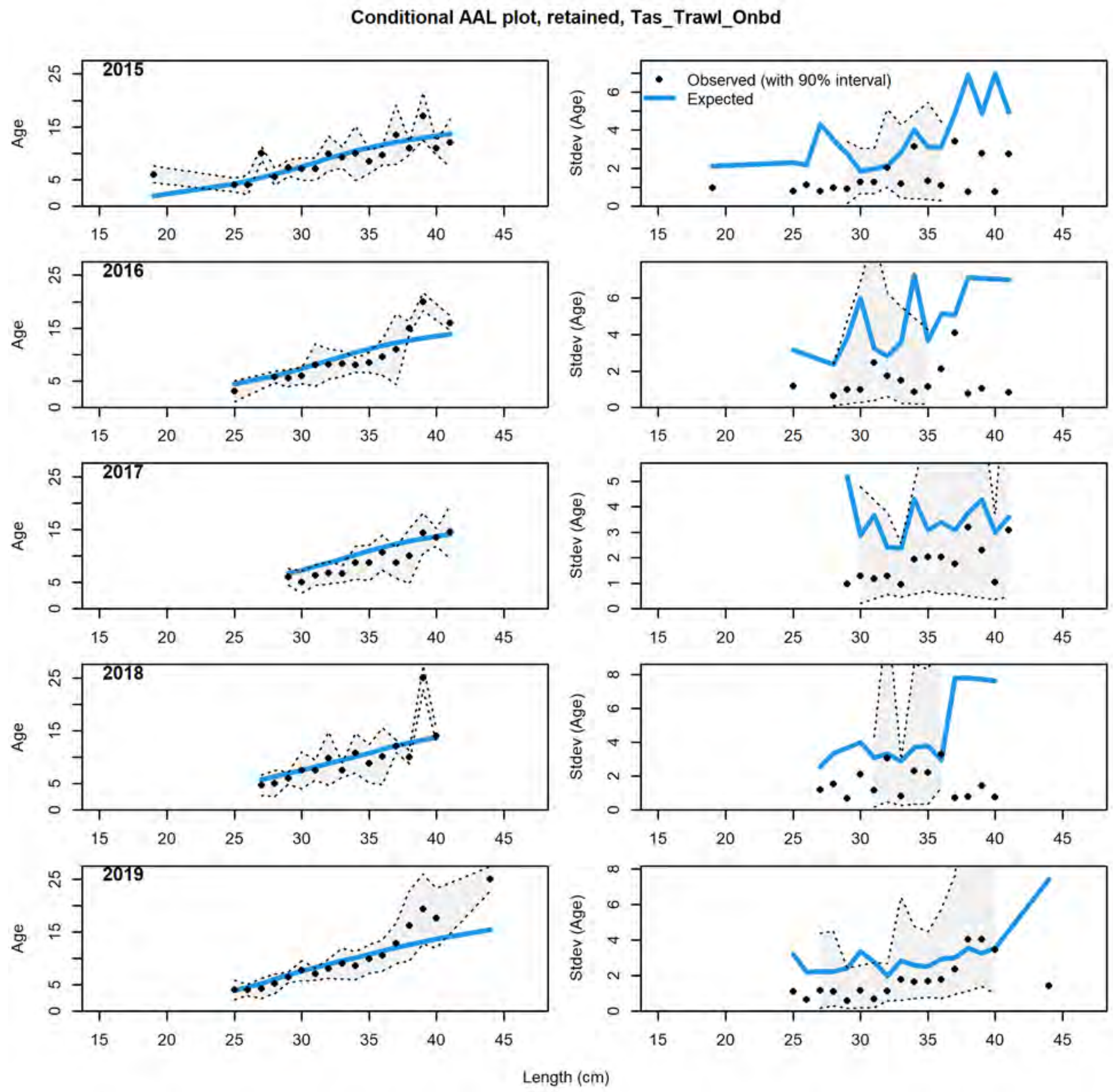


Figure A 7.49. Eastern Jackass Morwong conditional age-at-length fits: Tasmanian trawl part 3.

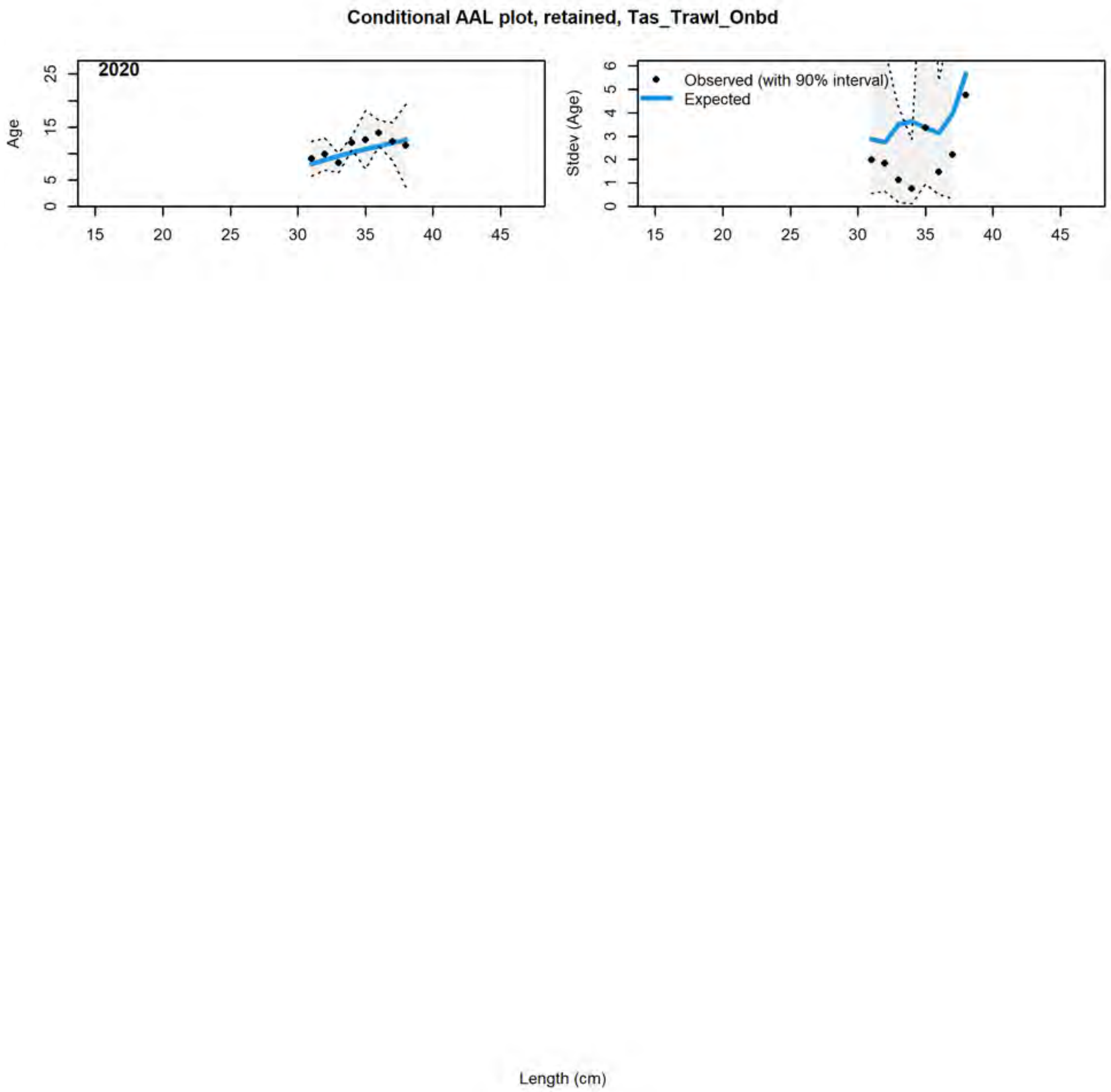


Figure A 7.50. Eastern Jackass Morwong conditional age-at-length fits: Tasmanian trawl part 4.

8. Eastern Jackass Morwong (*Nemadactylus macropterus*) stock assessment based on data up to 2020

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8.1 Executive Summary

This document updates the 2018 Tier 1 assessment of eastern Jackass Morwong (*Nemadactylus macropterus*) to provide estimates of stock status in the SESSF at the start of 2022 and describes the base case assessment and some of the issues encountered during development. This assessment was performed using the stock assessment package Stock Synthesis (version V3.30.17). The 2018 stock assessment has been updated with the inclusion of data up to the end of 2020, comprising an additional three years of catch, discard, CPUE, length and age data and ageing error updates, including revisions to historical catch series, length frequencies and discard rates. A range of sensitivities were explored.

The base-case assessment estimates that the projected 2022 spawning stock biomass will be 15% of unexploited spawning stock biomass (SSB_0), with recruitment from 2016 onwards projected using a low recruitment scenario, using the average of the ten most recently estimated recruitment deviations, from 2006-2015. Under the agreed 20:35:48 harvest control rule, the 2022 recommended biological catch (RBC) is 0 t, with the long-term yield (assuming low recruitment in the future) of 91 t. The average RBC over the three-year period 2022-2024 is 0 t and over the five-year period 2022-2026, the average RBC is 1 t. If recruitment from 2016 onwards is assumed to be average, the projected 2022 spawning stock biomass would be 22% of SSB_0.

Exploration of model sensitivity showed variation in spawning biomass across all sensitivities ranging from 7% to 24% of SSB_0 with greatest sensitivity to natural mortality. Excluding this sensitivity to natural mortality, the other sensitivities showed a much narrower range, from 13% to 17% of SSB_0.

The updated assessment produces markedly different results from the 2018 assessment, under both the average and the low recruitment scenarios. This is due to downward revisions to the 13 of most recent 15 years of recruitment estimates from the 2018 assessment (for the period 1998-2012), poor recruitment estimates for the three new years of recruitment estimated in the 2021 assessment (for the years 2013-2015), a continuing decline in recent catches, a continuing decline in the recent CPUE indices and an improved fit (compared to the 2018 assessment) to the most recent CPUE data points, partly due to the implementation of a low recruitment scenario. As in the 2018 assessment, results show good fits to the CPUE data, poor fits to the FIS2 abundance data for the Tasmanian trawl fleet and good fits to the length composition and conditional age-at-length data. In contrast to the 2018 assessment, the 2021 assessment features improved fits to the FIS2 abundance data for the eastern trawl fleet.

Given the recent series of 12 years of below average recruitment, low recruitment projections are expected to produce much more realistic predictions in the near future. Incorporating low recruitment into the base case, marginally improves the retrospective patterns, which indicate significant change

to quantities estimated by the model through the addition of recent data, with possible model misspecification and/or recent temporal changes to recruitment and/or biological parameters. Incorporating low recruitment projections complicates the technical calculations of sensitivities, likelihood profiles and retrospectives, but this approach is likely to give much more realistic results and avoid an overly optimistic short-term outlook, which typically gets revised downwards when the next assessment is conducted.

Likelihood profiles indicate there is some conflict within and between data sources contributing to the likelihood components. As with the retrospectives, this could indicate some model misspecification, possibly related to unaccounted spatial and or temporal variation. Likelihood profiles also indicate information on the uncertainty in estimates of stock status in 2020 and provide information on the data sources which are most influential in informing the estimation of some parameters and some derived quantities. Results from likelihood profiles could be used to help guide future data collection which could increase the quality and quantity of data which is most informative for future stock assessment models. For Jackass Morwong, it appears the estimates of discard proportions are quite informative, and increased focus on collecting this data could potentially improve future assessments.

8.2 Introduction

8.2.1 *The fishery*

Jackass Morwong (*Nemadactylus macropterus*) have been landed in southern Australia since the inception of the steam trawl fishery off New South Wales in the early twentieth century (Fay 2004), with the initial fishery concentrating in the east (SESSF Zones 10, 20 and 30). Jackass Morwong were not favoured during the initial years of this fishery, when the main target species was Tiger Flathead (*Neoplatycephalus richardsoni*). Declines in Tiger Flathead catches, and improved market acceptance, led to increased targeting of Jackass Morwong during the 1930s and later years of the steam trawl fishery (Klaer, 2001). Annual estimates of landings of Jackass Morwong from the steam trawl fishery in the east between 1915 and 1957 reached a peak of about 2,000 t during the late 1940s (Day and Bessell-Browne, 2021).

The fishery expanded greatly during the 1950s, with Danish seine vessels becoming the main vessels in the fishery. Landings of Jackass Morwong in NSW and eastern Victoria increased following WWII, and, at their peak in the 1960s, annual landings were of the order of 2,500 t. The fishery shifted southwards during this time, with the majority of the landed catches coming from eastern Victoria. Landings of Jackass Morwong then dropped to around 1,000 t by the mid-1980s (Table 8.2 and Table 8.3), with landings in eastern Tasmania becoming an increasing proportion of catches. By the mid-1980s, the majority of Jackass Morwong was being landed by modern otter trawlers; with small landings by Danish seine vessels in eastern Victoria and eastern Bass Strait (Smith and Wayte, 2002). Catches were not recorded in the west (SESSF zones 40 and 50) until 1986.

Since the introduction of management measures into the South East Fishery in 1985, the recorded catch of Jackass Morwong (combining catches from the east and the west) has ranged between 1,648 t in 1989 (1,563 t in the east and 85 t in the west) down to 112 t in 2015 (103 t in the east and 9 t in the west). Annual landings of Jackass Morwong in the east have declined steadily since 1968, averaging 1,650 t from 1968-1989, then dropping to average 900 t during the 1990s, declining to average 600 t from 2000-2009, then declining further to average 300 t from 2010-2014 and finally averaging less than 150 t per year since 2015 (Table 8.2 and Table 8.3). The catch in 2020 is the second lowest combined total since World War II (114 t, with 103 t in the east and 11 t in the west) and the equal lowest catch for the east since World War II (103 t in both 2015 and 2020) (Table 8.2 and Table 8.3).

The catches appear to have been constrained by the total allowable catch (TAC) in the periods 2002-2005 and 2008-2011. In 1992, an initial TAC was set at 1,500 t (Smith and Wayte, 2002), with this single TAC set to cover catches in both the east and the west. The agreed TAC was reduced to 1,200 t in 2000, to 960 t in 2003, briefly increased to 1,200 t in 2006, then further decreased to 878 t in 2007. Since 2008 the TAC has fluctuated between 450-600 t. These changes to the TAC have been in response to stock assessments showing the stock to be at declining levels. The TAC was set at 450 t from 2009-2011 as a bycatch TAC i.e. the amount of unavoidable bycatch of Jackass Morwong that could be expected from fishing for other species. Klaer and Smith (2008) calculated that in 2006, 59% of Jackass Morwong trawl catch was caught as bycatch (mainly from flathead fishing). From the logbook data in 2006, the Jackass Morwong trawl catch was 763 t. Thus 59% of this, or 450 t, would be bycatch that is unavoidable, assuming catches of species that have Jackass Morwong as a bycatch stayed the same as 2006 levels (Wayte, 2011).

Catches of Jackass Morwong in the west have been recorded since 1986 (153 t) with less than 100 t of catch taken annually in the west from 1987-1999, then catch totals exceeding 100 t in the period 2000-2008 (with a peak of 322 t in 2001). All catches in the west have been less than 100 t since 2009, with the exception of 101 t caught in 2011, with only four years where the catches exceed 50 t in this period (2009, 2011, 2017 and 2018) and catches as low as 10 t in 2015 and 13 t in 2020. While the western catches were not included in stock assessments conducted before 2007, the TAC has always been set for the combined eastern and western stocks. Since 2007, the recommended biological catches (RBC) used to determine the TAC (for the combined stock) is simply the sum of the RBC for the eastern stock and the RBC for the western stock. The eastern and western stocks have been managed under a single TAC, so an RBC of zero for the eastern stock in 2008 and 2009, (combined with a non-zero RBC from the western stock) still allowed a non-zero TAC to be set for the combined stock in those years, and allowed some of that TAC to be taken in the eastern part of the stock.

Jackass Morwong is also caught in small quantities in state waters off NSW and Tasmania, and by the non-trawl sector of the fishery, although these landings are not large. These non-trawl catches are relatively small, compared to catches from the trawl sector, averaging 17 t per year from 1985-1994 and less than 1 t per year since 1995. In the 2021 assessment, these non-trawl catches have been included in the catch totals, with the non-trawl catch allocated to the eastern trawl and Tasmanian trawl fleet in the same proportion as the records of the trawl catch disposal record (CDR) catches allocated to these two fleets. Previous Jackass Morwong assessments excluded CDR totals from vessels in the non-trawl sector. State catches have been added to the Commonwealth catches, with NSW state catches included in the eastern trawl fleet, Victorian state catches split equally between the eastern and western trawl fleets and Tasmanian state catches split equally between the Tasmanian and western trawl fleets. The small quantity of state catch from Victoria and Tasmania allocated to the western trawl fleet was not included in the western trawl fleet catch totals in the 2018 assessment report (Day and Castillo-Jordán, 2018b), but is included in the western trawl catch totals here (Table 8.3).

The assessment data for the eastern stock of Jackass Morwong have been separated into six ‘fleets’, which represent one or more gear, regional, or temporal differences in the fishery. In the east, 50% recruitment to the fishery occurs between three and seven years of age, depending on gear type, compared to around eight years in the west.

8.2.2 *Stock Structure*

Genetic studies conducted by the CSIRO have found no evidence of separate stocks of Jackass Morwong in Australian waters. New Zealand and Australian stocks are however, distinct (Elliott et al., 1992). Analysis of otolith microstructure (Proctor et al., 1992) found differences between Jackass Morwong from southern Tasmania and those off NSW and Victoria, but it is unclear if such differences indicate separate stocks. Differences among Jackass Morwong in the western and eastern zones have been suggested (D.C. Smith, MAFRI, pers. comm. 2004; I. Knuckey, Fishwell, pers. comm. 2004), and it is assumed for the purposes of this assessment that there are separate stocks of Jackass Morwong in the eastern and western zones (Wayte, 2011). Bessell-Browne et al., (2021) reviewed stock structure for three SESSF species and report that "Jackass Morwong are not genetically different between the two regions and there is no current evidence supporting differences in otolith microchemistry. Mixing of Jackass Morwong is unknown although differences in recruitment between regions suggests some separation of populations along with differences in length and age distributions. While there has been limited research at the appropriate spatial scale to determine splits in stock structure, the differences in recruitment patterns between the two regions were considered adequate to justify conducting separate assessments to the east and west."

8.2.3 *Previous assessments*

Smith (1989) analysed catch and effort data for the Eden fishery (1971-72 to 1983-84), finding a significant decline in catch-per-unit-effort (CPUE) to 1980. Lyle (1989) analysed logbook data for Tasmania and western Bass Strait from 1976-84. No trends were apparent in these data.

The biomass of Jackass Morwong in the eastern zone was estimated to be about 10,000 t in the mid-1980s (Smith, 1989), using a combination of trawl surveys and VPA. Age-structured modelling of the NSW component of the fishery indicated that Maximum Sustainable Yield (MSY) is approached with a fishing mortality (F) between 0.2 and 0.3 yr^{-1}, and that the fishery was at optimum levels in the mid-1980s (Smith, 1989).

At the 1993 meeting of SEFSAG, the recent age data (from the Central Ageing Facility, CAF) and length data were presented together with new age and length data from southeastern Tasmania. Estimates of total mortality from catch curve analyses were similar to previous estimates in the early 1980s. Length and age data from southeastern Tasmania were characterised by a greater proportion of larger and older fish. Preliminary ageing data from sectioned otoliths were tabled at SEFAG in 1994 which suggested that Jackass Morwong were longer lived (35 years) than previously thought (20 years). Subsequent ageing has resulted in a maximum age records of 46 years for a male and 43 years for a female (K Krusic-Golub, pers. comm., 2020).

Smith (1994) reported a range of maximum sustainable yield estimates with annual "sustainable catches" for Jackass Morwong at levels ranging from 1,150 – 3,800 t and also suggested that "the most urgent need is to fully define the stock structure in the SEF". Smith (1994) also reported estimates of maximum spawning stock biomass ranging from 40,000 t to 78,000 t.

In 1995, catch and unstandardised effort by major area in the fishery were derived from logbook records for the period 1986-94. Whereas the 1994 assessment stated that catch rates had remained relatively stable for the previous 4 years, GLM-standardized trawl catch rates exhibited a slow decline from 1987. Indeed, Smith and Wayte (2002) note that the mean unstandardised catch rate of Jackass Morwong has continued to decline, and, since 1996, has triggered AFMA's catch rate performance criterion.

An assessment in 1997 was based on the collation and analysis of catch and effort data, combined with new biological information on growth rates of Jackass Morwong. Information on length frequencies and the retained and discarded catch of Jackass Morwong was obtained from SMP data and the FRDC report by Liggins (1996). Further length-frequency data were available from NSW and Tasmanian state projects. Catch curve analysis on fish between 5 and 26 years old produced an estimate for total mortality of 0.18 yr^{-1}. This was considerably lower than previous estimates of 0.6 to 0.77 yr^{-1} and was a direct result of the "new" maximum age. It is also lower than the values obtained by applying the 1993/94 age-length key (0.3 yr^{-1}) to length composition data. Using a value for M of 0.09 yr^{-1}, a fishing mortality (F) of 0.09 yr^{-1} was estimated.

Klaer (2006) used a stock reduction analysis (SRA) method to model the population of Jackass Morwong off NSW using catch history data from 1915-61. This analysis led to a point estimate of unexploited total recruited biomass, which is larger than spawning biomass, of 29,400 t, with a 1961 stock status of 70%.

The first formal quantitative assessment of Jackass Morwong was conducted by Fay (2004) based on data to 2002, using Coleraine, an integrated stock assessment software package. It used a generalised age-structured modelling approach to assess the status and trends of the Jackass Morwong trawl fishery in the eastern zones, using data from the period 1915-2002. The 2004 assessment indicated that the spawning biomass of Jackass Morwong was between 25–45% of the 1915 unexploited biomass. The base-case model estimated the current spawning biomass was 37% of the unexploited biomass. The model could not adequately reconcile changes in catch rates in the late 1980s with catches during this same period.

The 2004 assessment was updated in 2006 using Coleraine with additional data that had become available since the previous assessment (Fay, 2006). Two recent (1986-2005) catch rate series were explored in the 2006 assessment. ShelfRAG originally chose to use a catch rate standardisation that was restricted to vessels which caught Jackass Morwong for at least 5 years and had a median annual catch of at least 5 t. Only shots in which at least 30 kg of Jackass Morwong were caught were included. The new standardized catch rate time series, which was chosen to be consistent with other SESSF assessments, also endeavoured to select targeted shots by selecting shots with ≥1 kg of Jackass Morwong from vessels that had reported catches of Jackass Morwong for three or more years and whose median annual catch was greater than 2 t.

Base-case estimates of stock status in 2006 when the model was fit to the ≥1 kg catch rate series indicated that the stock was at a low level, around 15% of the unexploited equilibrium state. This led to RBCs in 2007 of zero under all Tier 1 and Tier 2 harvest control rules (HCRs). If the model was fitted to the new age and length data but used the ≥30 kg catch rate index, estimates of current stock status were more optimistic, with stock status in 2006 estimated to be 35% of the unexploited state. This assessment also recommended "accounting for the western areas of the SESSF" in future assessments.

The results of the 2006 assessment were clearly sensitive to the catch and effort data used to calculate a catch rate index that is representative of changes in biomass. As the estimated population trend is primarily driven by this catch rate index, the choice of data included is key to estimates of stock status for this population. For the 2004 assessment, it was considered that a greater than 30 kg cut-off for catch and effort data was reasonable for Jackass Morwong. However, the increasing trend in the number of shots catching small amounts of Jackass Morwong from those vessels targeting the species (Day 2006) suggests that this might not be the case. The analysis by Day showed that the increase in small shots is not due to a change in reporting practices. In 2006, ShelfRAG decided to use the ≥ 1 kg catch rate as input to the base-case, as this was the more precautionary approach, no evidence against using this series was presented, and it is consistent with the approach used for other SESSF assessments.

The 2007 base-case assessment (Wayte and Fay, 2007) for the eastern stock estimated that the 2008 spawning stock biomass was 19% of unexploited stock biomass. This assessment was largely driven by the recent catch rate indices, which indicated a 70% decline in the stock over the last 20 years. The age and length data when fitted in the absence of the catch rate indices did not indicate the same magnitude of decline. In order to fit the catch rate indices, the model estimated that recruitments were largely below average in the last 25 years, although there was some evidence for an above average recruitment in 2003. Stock status across all sensitivities varied between 11% and 28%.

A preliminary assessment for the western stock in 2007 indicated that the stock had declined in recent years as fishing pressure has increased, but spawning stock biomass was 63%, still considerably higher than the target level. The long-term RBCs estimated for the western stock were comparable with the 2007 catch levels. The single RBC calculated for Jackass Morwong (combining the east (0 t) and west (297 t) stocks) was 297 t (using the 20:40:48 control rule), with this RBC coming entirely from the western part of the stock. The TAC was set allowing for unavoidable bycatch of Jackass Morwong in the east.

The 2008 base-case assessment for the eastern stock (Wayte and Fay, 2009) estimated that the 2009 spawning stock biomass was 19% of unexploited stock biomass. The 2007 assessment had estimated good recruitments for both 2003 and 2004. However, the limited amount of 2007 data used in the 2008 assessment did not support the high 2004 recruitment estimate. Several data types were not available for 2007, and, for the data that were available, sample sizes were lower than in previous years. The 2008 CPUE indices indicated that the stock abundance was unchanged from the previous year.

The 2008 base-case assessment for the western stock (Wayte and Fay, 2009), was still considered to be preliminary, due to limited data, and estimated that the 2009 spawning stock biomass was 68% of unexploited stock biomass. The single RBC calculated for Jackass Morwong (combining the east (0 t) and west (381 t) stocks) was 381 t (using the 20:35:48 control rule), with this RBC coming entirely from the western part of the stock.

The 2009 assessment (Wayte, 2010) estimated recruitment deviations up to four years before the end of the data instead of two years as in previous assessments. This change was made because it was recognised that fish spawned two and three years before the end of the data will not be well-represented in the data, and this problem had been compounded in the years leading up to the 2009 assessment by poor data collection. The eastern trawl CPUE index showed a slight increase, and the 2003 recruitment continued to be estimated as above average – leading to a slight recovery in the current status of the stock to above the limit reference level (24%). Catch rates had declined in recent years, despite lower catches than in the past. To reconcile this information the 2009 base-case assessment estimated recruitments to have been consistently below average since the early 1980s. The 2009 assessment examined two other possible reasons for this decline: that recruitment is more closely related to stock size than previously assumed (i.e. steepness is lower); or that a regime shift has occurred. Both these models led to a better fit to the data than the base-case, but neither were accepted as a new base-case. The best estimate of lower steepness was considered to be unrealistically low for a Perciforme species such as Jackass Morwong (Myers et al 1999). The regime shift model gave a more optimistic picture of current stock status than the other models, because it revised down the estimate of unfished equilibrium spawning stock biomass, but the estimate of sustainable long-term catch was also greatly reduced. It was considered that more evidence for the existence of a regime shift was required before this model was considered plausible.

The 2009 base-case assessment for the western stock (Wayte, 2010), was considered to be increasingly uncertain, with no recent length frequency data (for 2007 and 2008), and estimated that the 2010 spawning stock biomass was 70% of unexploited spawning stock biomass. The single RBC calculated for Jackass Morwong (combining the east (143 t) and west (367 t) stocks) increased to 510 t, with this RBC coming from both the eastern and western part of the stock.

The 2010 base-case assessment for the eastern stock (Wayte, 2010) estimated that current spawning stock biomass was 26% of unexploited stock biomass. Concern was expressed that catches in the east had remained above the eastern component of the (combined) RBC. The western stock assessment continued to be considered as increasingly uncertain, with no recent length frequency data (for 2007-2009). Catches of Jackass Morwong in the Great Australian Bight (GAB) were found to be at a similar level to western Jackass Morwong catches, but it is not known whether the GAB Jackass Morwong form a separate stock and these GAB catches were not included in the western Jackass Morwong assessment.

In 2010 the RAG decided to include both port and onboard retained length frequency data (for both historic and current years) in future assessments, whereas previously only port data had been used. The 2010 assessment was run with this change in length frequency data (as well as any other changes to the data up to 2009), and very little change to the assessment result was seen.

The 2010 base-case assessment for the western stock (Wayte, 2010), continued to be considered increasingly uncertain, with no recent length frequency data (for 2007-2009), and estimated that the current spawning stock biomass was 70% of unexploited stock biomass. The single RBC calculated for Jackass Morwong (combining the east (228 t) and west (329 t) stocks) increased to 557 t, with this RBC coming from both the eastern and western part of the stock.

At the ShelfRAG meeting on October 3-4, 2011, an alternative base-case assuming that eastern Jackass Morwong has undergone a shift to lower recruitment was presented and accepted and was used as the base-case for the eastern assessment (Wayte, 2011). The justification for this switch is well described in Wayte (2011), including MSE testing implications of assuming (or not) the recruitment shift. The western assessment used the same assumptions as in previous years (no recruitment shift).

The 2011 base-case assessment for the eastern stock (Wayte, 2011) accepted that there was a productivity shift for the eastern stock of Jackass Morwong and estimated that current spawning stock biomass was 35% of 1988 equilibrium stock biomass.

The 2011 base-case assessment for the western stock (Wayte, 2011), continued to be considered increasingly uncertain, with no recent length frequency data (for 2007-2010), and estimated that the current spawning stock biomass was 67% of unexploited stock biomass. The single RBC calculated for Jackass Morwong (combining the east (358 t) and west (282 t) stocks) increased to 640 t, with this RBC coming from both the eastern and western part of the stock.

The 2015 base-case assessment for the eastern stock (Tuck et al., 2015a) estimated that current spawning stock biomass (i.e. to the beginning of 2016) was 37% of 1988 equilibrium stock biomass. The western stock assessment (Tuck et al., 2015b) continued to be considered as increasingly uncertain, with no length frequency data for 2007-2010, limited age data, low samples size for length compositions, very low catches and conflict between the length and catch rate data. In this assessment, growth parameters were not estimated, and instead were fixed at the values estimated from the eastern assessment. The current spawning stock biomass (i.e. to the beginning of 2016) was estimated to be 69% of unexploited stock biomass. The single RBC calculated for Jackass Morwong (combining the east (314 t) and west (249 t) stocks) increased to 563 t, with this RBC coming from both the eastern and western part of the stock.

The 2018 base-case assessment for the eastern stock (Day and Castillo-Jordán, 2018a) estimated that current spawning stock biomass (i.e. to the beginning of 2019) was 35% of 1988 equilibrium stock biomass. The western stock assessment (Day and Castillo-Jordán, 2018b) continued to be considered as increasingly uncertain, with poor fits to the CPUE index (and concerns about whether this index was tracking abundance), unrepresentative sampling and generally poor data quality and quantity, limited age data, low samples size for length compositions, very low catches, conflict between fits to the length and age data and the fits to the catch rate data. In this assessment, growth parameters were not estimated, and instead were fixed at the values estimated from the eastern assessment and retrospective patterns that warranted further attention. The current spawning stock biomass (i.e. to the beginning of 2019) was estimated to be 68% of unexploited stock biomass. The single RBC calculated for Jackass Morwong (combining the east (261 t) and west (235 t) stocks) increased to 496 t, with this RBC coming from both the eastern and western part of the stock.

8.2.4 *Modifications to the previous assessments*

The 2021 assessment uses Stock Synthesis version SS-V3.30.17.00, (Methot et al., 2021), updated from version SS-V3.30.12 (Methot et al., 2021) that was used in the 2018 assessment. New catch, discard, length and conditional age at-length data is available from the three-year period from 2018-2020. In addition to these new and updated data, there are updated standardised CPUE series for the eastern (Zones 10 and 20) and Tasmanian (Zone 30) trawl fleets, each with three additional data points and updated estimates for the ageing error matrix.

8.2.4.1 Data-related notes

1. Length-frequency data are included separately for onboard and port data by fleet. Port and onboard fleets share a single selectivity pattern.
2. Length frequency data are weighted by shot or trip numbers rather than numbers of fish measured. A cap of 100 trips and 200 shots was used to set an upper limit on the sample size.
3. There are five CPUE time series, with the oldest dating back to 1920 (steam trawl) and the most recent time series derived from logbook data for otter trawl, separated into Eastern trawl (SESSF Zones 10 and 20) and Tasmanian trawl (SESSF Zone 30).
4. State catches have been added to catches from the appropriate fleets.
5. The ageing error matrix has been updated.
6. Catch, discard, length-composition, age-at-length, and catch rate data have been added for the period 2018-2020. The historical catch series (from 1986-2017) was also revised to incorporate changes in the catch database.

8.2.4.2 Model-related notes

1. Growth is assumed to follow a von Bertalanffy type length-at-age relationship, with all four growth parameters estimated separately, based primarily on the age-at-length data from fish that were measured and aged from extracted otoliths.

2. Natural mortality, *M*, is fixed (0.15) in the model.
3. Recruitment residuals are estimated from 1945-2015, with the last recruitment event estimated five years before the most recent available data.
4. An updated tuning procedure is used to balance the weighting of each of the data sources that contribute to the overall likelihood function, using the method of Francis (2011) for weighting length data and the method of Punt (2017) for weighting age data. The CPUE series is balanced within Stock Synthesis, by estimating additional variance to each CPUE series, and improvements have been incorporated in the treatment of recruitment variance (σ_R) and the recruitment bias ramp adjustment.
5. Discard rates for Tier 1 assessments are required by fishing fleet. This means that the discard estimates for TAC purposes used for Tier 3 and 4 assessments which are provided in the discard report (Deng et al., 2021) cannot be used in Tier 1 assessments. The discards from Deng et al. (2021) are produced using a set of rules to determine, for the entire quota fishery, whether sufficient data are available to make an annual fishery wide discard estimate. The discard rates calculated for and input to Tier 1 stock assessments are used to fit retention selectivity curves, so individual year values are not greatly influential on model estimated discard rates.
6. The Tier 1 discard estimates have been updated in 2021 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 CDR landings within zone and season (N. Klaer, pers. comm.).

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 by Day and Bessell-Browne (2021).

8.3 Methods

8.3.1 *The data and model inputs*

The 2021 base case assessment of Jackass Morwong uses an age- and size-structured model implemented in the generalized stock assessment software package, Stock Synthesis (Version 3.30.17.00, Methot et al. (2021)). The methods utilised in Stock Synthesis are based on the integrated analysis paradigm. Stock Synthesis can allow for multiple seasons, areas and fleets, but most applications are based on a single season and area. Recruitment is governed by a stochastic Beverton-Holt stock-recruitment relationship, parameterised in terms of the steepness of the stock-recruitment function (h), the expected average recruitment in an unfished population (R_0), and the degree of variability about the stock-recruitment relationship (σ_R). Stock Synthesis allows the user to choose among a large number of age- and length-specific selectivity patterns. The values for the parameters of Stock Synthesis are estimated by fitting to data on catches, catch-rates, discard rates, discard and retained catch length-frequencies, and conditional age-at-length data. The population dynamics model and the statistical approach used in fitting the model to the various data types are given in the SS technical documentation (Methot, 2005).

The base case model includes the following key features:

A single region, single stock model is considered with six fleets. Selectivity is modelled separately for each fleet, with selectivity patterns assumed to be length-specific and logistic. The parameters of the selectivity function for each fleet were estimated within the assessment.

The model does not account for males and females separately and fits one growth curve across both sexes.

The initial and final years are 1915 and 2020.

8.3.1.1 Biological parameters

A single-sex model (i.e. both sexes combined) was used, which assumes growth and other biological parameters do not vary between males and females in the population.

Age-at-length data was used as an input, and all four parameters of the von Bertalanffy growth equation were estimated within the model fitting procedure. This is more appropriate than pre-specifying these values because it accounts for the impact of gear selectivity on the age-at-length data collected from the fishery and the impact of ageing error.

As in the 2018 assessment, M was fixed in the model at 0.15, and assumed to be time invariant and independent of age. The base-case value for the steepness of the Beverton-Holt stock-recruitment relationship, h, is fixed at 0.7.

Growth is assumed to follow a von Bertalanffy length-at-age relationship, with the parameters of the growth function estimated together for females and males inside the assessment model.

Jackass Morwong become sexually mature at a length of about 24.5 cm, when the fish are around four years of age. Maturity is modelled as a logistic function, with 50% maturity at 24.5 cm fixed in the assessment. Fecundity-at-length is assumed to be proportional to weight-at-length. The parameters of the length-weight relationship are obtained from Smith and Robertson (1995) (a=1.7 × 10^{-5}, b=3.031).

8.3.1.2 Fleets

The assessment data for the eastern stock of Jackass Morwong have been separated into six '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 (Wayte, 2011). The six fleets are:

1. Eastern trawl – otter trawlers from NSW, eastern Victoria and Bass Strait (1986–2020)
2. Danish seine – Danish seine from NSW, eastern Victoria and Bass Strait (1986–2020)
3. Tasmanian trawl – otter trawlers from eastern Tasmania (1986–2020)
4. Steam trawl – steam trawlers (1915–1961)
5. Early Danish seine – Danish seine (1929–1967). These landings may include a small amount of motor trawl catches.
6. Mixed – mixed Danish seine and diesel trawl catch (1968–1985).

8.3.1.3 Landed catches

The model uses a calendar year for all catch data. Annual landed catches by fleet used in this assessment are shown in Figure 8.1, Figure 8.2 and listed in Table 8.1, Table 8.2 and Table 8.3, which also includes the catches for the western trawl fleet, used only in the western Jackass Morwong assessment which has not been updated since 2018 (Day and Castillo-Jordán, 2018b).

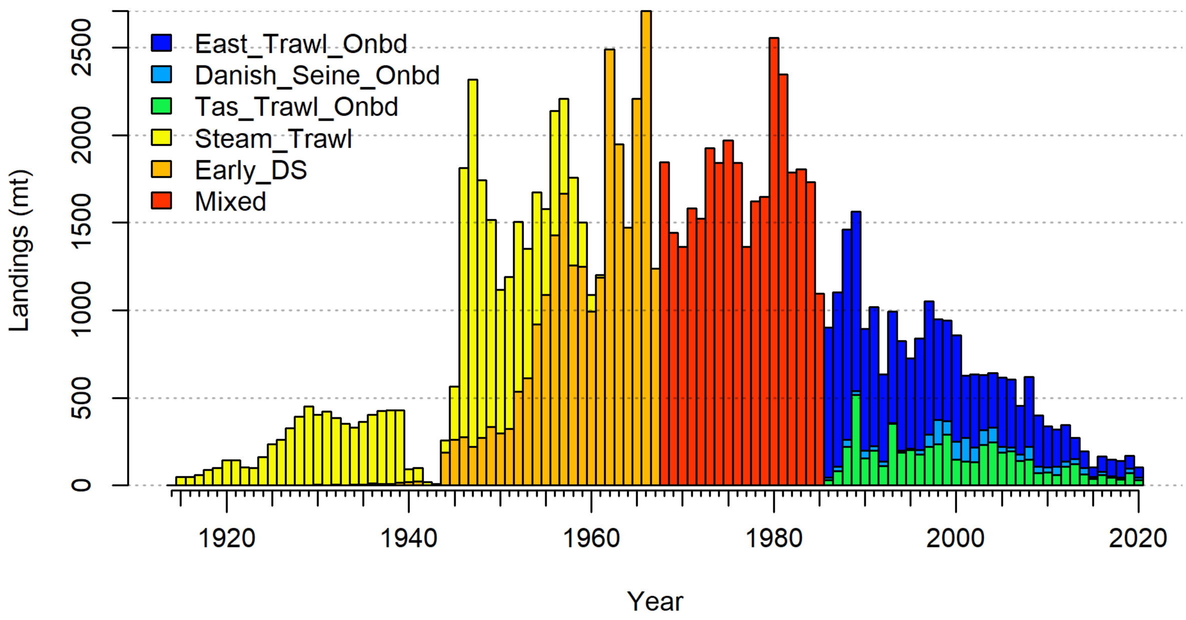


Figure 8.1. Total landed catch (tonnes) of eastern Jackass Morwong by fleet (stacked) from 1915-2020.

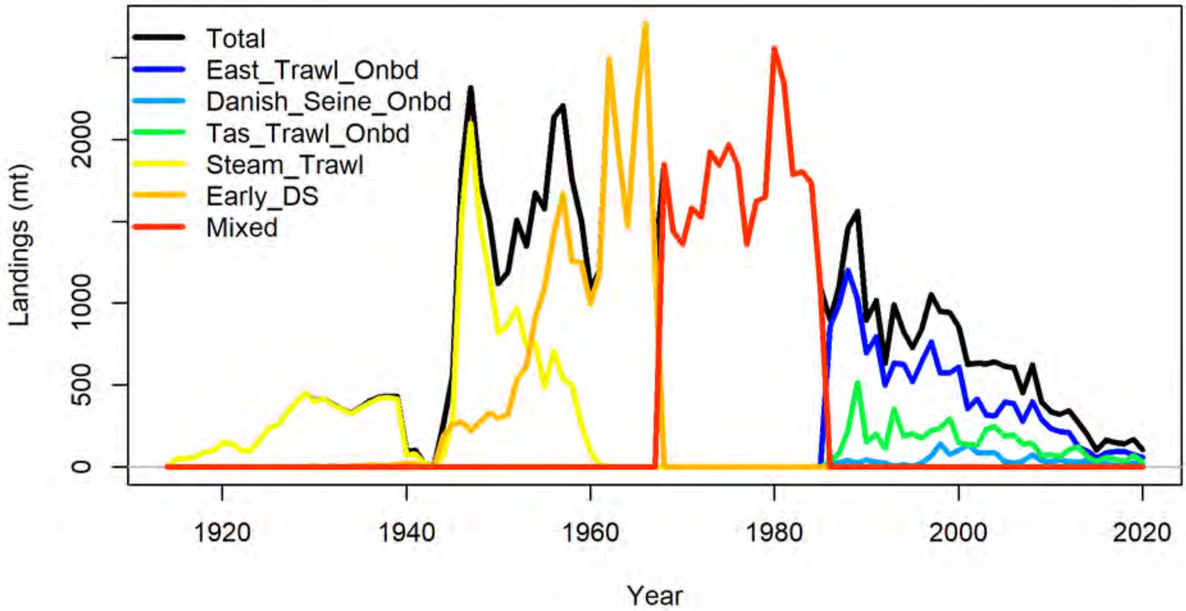


Figure 8.2. Total landed catch of eastern Jackass Morwong by fleet from 1915-2020.

Table 8.1. Total retained catches (tonnes) of eastern Jackass Morwong by steam trawlers and early Danish seine vessels, 1915–1967.

Year	Steam trawl trawl	Early Danish seine	Year	Steam trawl trawl	Early Danish seine
1915	49		1942	20	0
1916	50		1943	2	5
1917	58		1944	67	189
1918	89		1945	305	260
1919	99		1946	1538	275
1920	145		1947	2096	221
1921	143		1948	1472	273
1922	102		1949	1182	334
1923	98		1950	819	299
1924	162		1951	867	322
1925	235		1952	971	535
1926	259		1953	740	612
1927	327		1954	754	920
1928	391		1955	489	1088
1929	449	1	1956	709	1430
1930	398	4	1957	540	1668
1931	420	0	1958	501	1257
1932	380	5	1959	253	1249
1933	352	0	1960	95	993
1934	326	4	1961	16	1185
1935	361	3	1962		2489
1936	390	12	1963		1950
1937	419	8	1964		1472
1938	421	9	1965		2210
1939	413	17	1966		2709
1940	74	18	1967		1237
1941	79	21			

Klaer (2006) used a compilation of catch data from historical steam trawlers (Klaer and Tilzey, 1996) to recreate a catch history for Jackass Morwong for this sector of the fishery from 1915 to 1961 (Table 8.1). Estimates of total annual landings of Jackass Morwong from the eastern zones by Danish seine vessels during 1929-67 (Table 8.1), and the mixed fleet during 1968-85 (Table 8.2) were compiled from Klaer (2006) and Allen (1989).

The landings for the 'early Danish seine' fleet may include some catches from small motor trawlers which began to appear in the fishery in about 1954 (Blackburn, 1978), but it is believed that these catches are small in comparison to the Danish seine catches (N. Klaer, pers. comm., 2012).

The 'mixed' fleet consisted primarily of Danish seine vessels until the mid-1970s when the first modern otter diesel trawlers entered the fishery (Klaer, 2006), but no separation of landings by gear type is available for this period. For the purposes of this assessment, therefore, landings during 1968-85 were treated as coming from one fleet with a single selectivity pattern.

Table 8.2. Total retained catches (tonnes) of eastern Jackass Morwong by the mixed fleet of Danish seine and diesel trawlers, 1968 – 1985.

Year	mixed
1968	1846
1969	1442
1970	1362
1971	1582
1972	1525
1973	1925
1974	1843
1975	1969
1976	1841
1977	1361
1978	1624
1979	1649
1980	2556
1981	2347
1982	1789
1983	1806
1984	1733
1985	1096

The landings for the more recent years (eastern trawl, Danish seine, Tasmanian trawl and western trawl) (Table 8.3) are extracted from the SESSF logbook database, CDRs and state catches. Quotas were introduced into the fishery in 1992 (Table 8.8), and from then onwards, both CDRs and estimated catches from the logbook are available. The CDRs give a more accurate measure of the landed catch than the logbook data, but the logbook data contain detail on the relative catch by gear type. It is usually possible to separate logbook records by fleet, but CDRs cannot be separated 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. 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. The total catch for the 2008 calendar year was 708 t which was larger than the actual 2008-09 TAC of 641 t. In 2008, catches were high in January-April. These months are part of the 2007-08 quota year.

Small totals of Jackass Morwong are caught in state waters. In previous assessments, NSW trawl and trap catches were added to the eastern trawl fleet, Tasmanian state catches were added to the Tasmanian trawl fleet, and the small quantities of Victorian state catches were excluded as they were thought to be "negligible and questionable" (S. Wayte, pers. comm., 2012). Victorian state catches have now been included in catch totals in this assessment, added to the eastern trawl fleet from 2000 onwards and added to the western trawl fleet from 1994 onwards. In this assessment, NSW state catches (both trap and trawl) are still included in the catch for the eastern trawl fleet. Data processing changes resulted in the Victorian and Tasmanian state catches being split into eastern and western components for the 2021 assessment, with the assumption that these catches should be allocated equally between the appropriate eastern fleets (eastern trawl fleet for the Victorian catch and Tasmanian trawl fleet for the Tasmanian state catch) and the western fleet (western trawl fleet).

Table 8.3. Total retained catches (tonnes) from 1986–2020 of Jackass Morwong (east and west) for: the eastern trawl fleet (Commonwealth catches in SESSF zones 10 and 20 plus NSW state catches and eastern Victorian state catches); the Tasmanian trawl fleet (Commonwealth catches in eastern Tasmania plus eastern Tasmanian state catches); the Danish seine fleet in Bass Strait/eastern Victoria and NSW (with discards added into the catch totals for this fleet); the total for these three eastern fleets; the western trawl fleet (Commonwealth catches in western Tasmania and western Victorian and western Tasmanian state catches included – the 2018 assessment excluded estimated western trawl state catches);total Commonwealth catches (excluding discards); total state catches (excluding discards) and the TAC (combined eastern and western stocks) from 1992–2021.

Year	eastern trawl	Danish seine	Tas trawl	Total (eastern)	western trawl	Commonwealth (east + west) (no discards)	state (east + west) (no discards)	TAC
1986	858	13	31	902	153	813	88	
1987	993	26	82	1101	60	1014	85	
1988	1201	39	221	1462	67	1372	86	
1989	1024	23	516	1563	85	1521	41	
1990	697	44	153	894	83	855	36	
1991	793	28	198	1018	47	977	39	
1992	500	23	112	635	72	586	47	1500
1993	635	5	351	991	27	939	53	1500
1994	626	10	188	824	27	745	78	1500
1995	519	5	203	727	99	657	69	1500
1996	640	25	175	840	50	742	92	1500
1997	763	67	221	1051	70	931	95	1500
1998	577	139	234	950	73	811	72	1500
1999	576	74	292	941	97	844	55	1500
2000	610	101	147	858	139	745	60	1200
2001	356	136	135	627	326	494	69	1185
2002	416	84	133	633	294	560	37	950
2003	315	85	230	629	204	544	33	960
2004	313	84	245	642	223	539	40	960
2005	395	32	187	614	239	569	40	960
2006	389	22	196	606	222	560	43	1200
2007	279	35	141	454	144	427	12	878
2008	401	75	146	621	124	581	9	560
2009	292	38	69	400	80	376	7	450
2010	233	31	72	336	49	321	5	450
2011	215	44	61	320	101	307	3	450
2012	210	29	107	346	42	326	8	568
2013	119	31	120	270	43	250	5	568
2014	96	35	64	195	14	167	4	568
2015	56	11	37	103	10	91	7	598
2016	87	19	58	164	31	145	7	474
2017	93	9	45	147	90	128	14	513
2018	95	12	33	141	54	129	5	505
2019	74	23	72	169	31	146	9	469
2020	60	14	29	103	13	86	8	468
2021								463

Ideally, the Victorian and Tasmanian state catches would be split in a proportion that better reflects the catch by region (perhaps in a future assessment), as around 95% of the Tasmanian state catch is thought to be taken from eastern Tasmania, east of longitude 147° East (F. Seaborn, pers. comm., 2021). Given Tasmanian state catches have only averaged 5.5 t per year since 1995 (and only 2 t per year since 2008), and Victorian state catches have averaged 0.1 t per year since 1994, the effects of changing the allocation of the catch east and west of longitude 147° East are likely to be minimal.

Since the 2018 assessment, the catch history has been revised from 1986 onwards to incorporate several minor changes to the catch history. These include revisions to the filtering of records and allocations of catches to fleets from the Commonwealth logbook records in the period 1986-2020. Non-trawl CDRs were also incorporated into the catch history for the period 1985-2020, allocated to the eastern and Tasmanian trawl fleets in the same proportion as the logbook catches from those fleets for each year with non-trawl CDR data. Catches from the Danish seine fleet include estimates of discards (as retention is not estimated for this fleet), so revisions to the discard rate estimates in this period resulted in revisions to the Danish seine catch history from 1986-2017. Victorian state catches were added to the catch history for the period 1994-2015 (Althaus et al., 2021), with average catches of 0.1 t in that period, with half of these annual catch totals allocated to the eastern trawl fleet and half to the western trawl fleet (which is not used in this eastern Jackass Morwong assessment). Victorian state catches from 1986-1993 were not incorporated in this catch history as they were considered to be “negligible and questionable” (S. Wayte, pers. comm, 2012). Tasmanian state catches were added from 1995-2020 (Althaus et al., 2021), again with half of these annual catch totals allocated to the Tasmanian trawl fleet and half to the western trawl fleet. The allocation of Victorian and Tasmanian state catches to eastern and western fleets could be reviewed in future assessments, either to match the allocation from earlier assessments, or to match a better estimate of the split of the catches east and west of longitude 147° East, but the effects on the assessment results from any changes to these proportions would be minor given the size of these catches.

NSW state catch records from 1986-1999 were determined by Kevin Rowling and Sally Wayte (Wayte, 2012) to address issues relating to potential double counting of catches recorded NSW state and Commonwealth waters in that period, and these catches have not been modified. NSW state catch records from 2000-2020 were obtained from Althaus et al. (2021). Catches from the NSW trap fishery were added to the eastern trawl fleet for the period 1986-2006 (S. Wayte, pers. comm.).

In order to calculate the RBC for 2022, it is necessary to estimate the catch for 2021. Without any other information, the 2021 catch is assumed to be identical to the 2020 catch. The recent TAC history, which applies to the combined eastern and western stocks, is also listed in Table 8.3, alongside the total catches (Commonwealth plus state) of the western stock of Jackass Morwong. The percentage of the total catch taken in the west is quite variable, averaging around 20% since 2000, but ranging from 7% (in 2014) to 38% in 2017. Total catches (excluding discards) are listed separated into catches by Commonwealth and by state (with catches from all states combined) in Table 8.3. The percentage of the total catch since 1986 which is caught by state registered vessels averages 6%, declining to an average of 5% since 2001.

8.3.1.4 Discard rates

Information on the discard proportions of Jackass Morwong by fleet is available from the ISMP for 1994-2021, for the eastern and Tasmanian trawl fleets. This program was run by PIRVic from 1992-2006 and by AFMA from 2007 onwards. These data are summarised in Table 8.4. Discard rates were estimated from onboard data which gives the weight of the retained and discarded component of those shots that were monitored (Deng et al., 2021). Discard proportions vary amongst years and have been as high as 28% in 2012 for the Tasmanian Trawl and 35% in 2020 for the eastern trawl.

Table 8.4. Discard proportions for eastern trawl and Tasmanian trawl fleets from 1993 to 2021 with sample sizes for each data point. Entries in grey indicate data that are not used either due to small sample size (less than 10 samples) or because the value is too close to zero (less than 0.01).

Year	eastern trawl	n	Tas trawl	n
1992	1.0000	1		
1993	0.0622	167	0.0068	34
1994	0.0536	291	0.0744	25
1995	0.0998	123		
1996	0.0951	235	0.0134	30
1997	0.0720	414	0.0146	21
1998	0.0347	208	0.0463	53
1999	0.0219	238	0.1318	79
2000	0.0294	220	0.0030	32
2001	0.0272	295	0.0139	44
2002	0.0032	233	0.0302	12
2003	0.0241	242	0.0105	15
2004	0.1593	220	0.0608	30
2005	0.1263	338	0.0930	29
2006	0.1133	246	0.1656	82
2007	0.0002	75		
2008	0.0162	174	0.0000	8
2009	0.0370	89	0.0062	9
2010	0.0160	88	0.0352	24
2011	0.1364	81	0.0331	36
2012	0.0397	56	0.2780	45
2013	0.0803	54	0.0252	34
2014	0.0689	53	0.0359	23
2015	0.0350	57	0.0176	48
2016	0.0323	40	0.2471	49
2017	0.0681	64	0.0393	36
2018	0.0825	63	0.0423	15
2019	0.1850	92	0.0663	60
2020	0.3481	32	0.1440	39

Discard practices can be variable between years for reasons that are difficult to model, such as changes in market demands or issues with quota availability, with some years having very low discard rates and others having considerable discard rates. Without a mechanism to explain these years of very low discarding, discarding practices are assumed to be constant through time. Including those years with very low discard rates forces the model to fit very low discard rates to all years, due to the low absolute variation associated with low discard rates, even those years when discarding is known to be higher, and underestimates discarding over all years. As a result, years with very low discard proportions (less than 1%) are excluded as inputs to stock synthesis (the greyed figures in the proportion columns in

Table 8.4) giving more believable estimates of discarding in general. Note that any annual discard estimate coming from a sample size of less than 10 is also excluded as it is unlikely to be representative of typical discarding practices.

Observations were then used to estimate discard rates, for each fleet (Figure 8.3) and hence discarded catches for each fleet (Figure 8.4, Figure 8.5), with estimated discard rates between 4% and 9% for the eastern trawl fleet and between 4% and 6% for the Tasmanian trawl fleets.

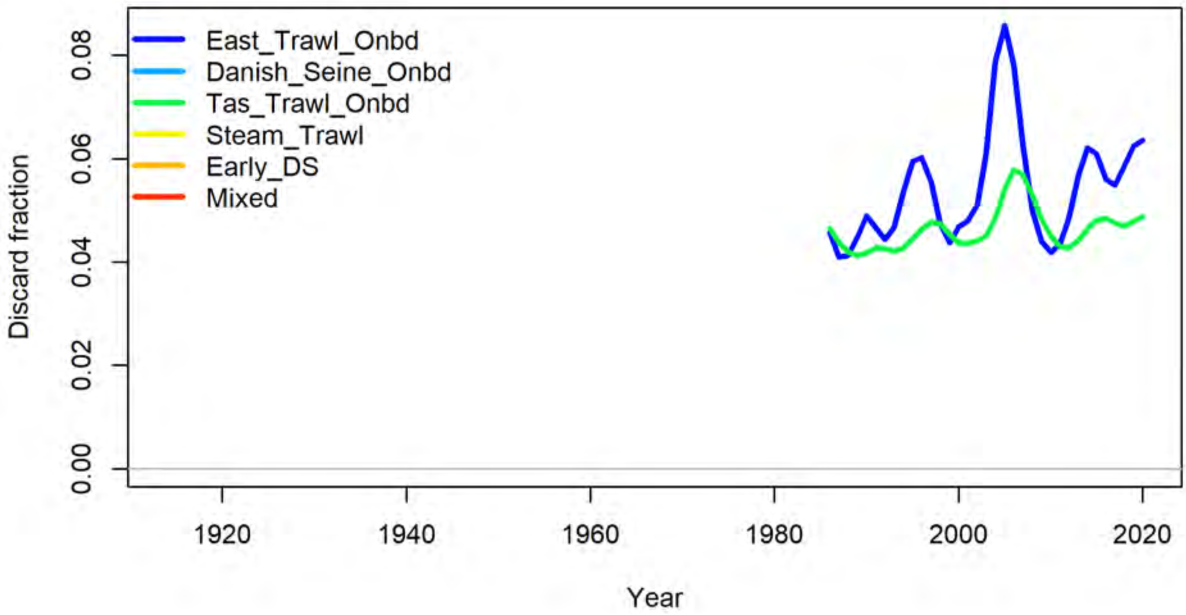


Figure 8.3. Model estimates of discard fractions by fleet, eastern trawl (blue) and Tasmanian trawl (green).

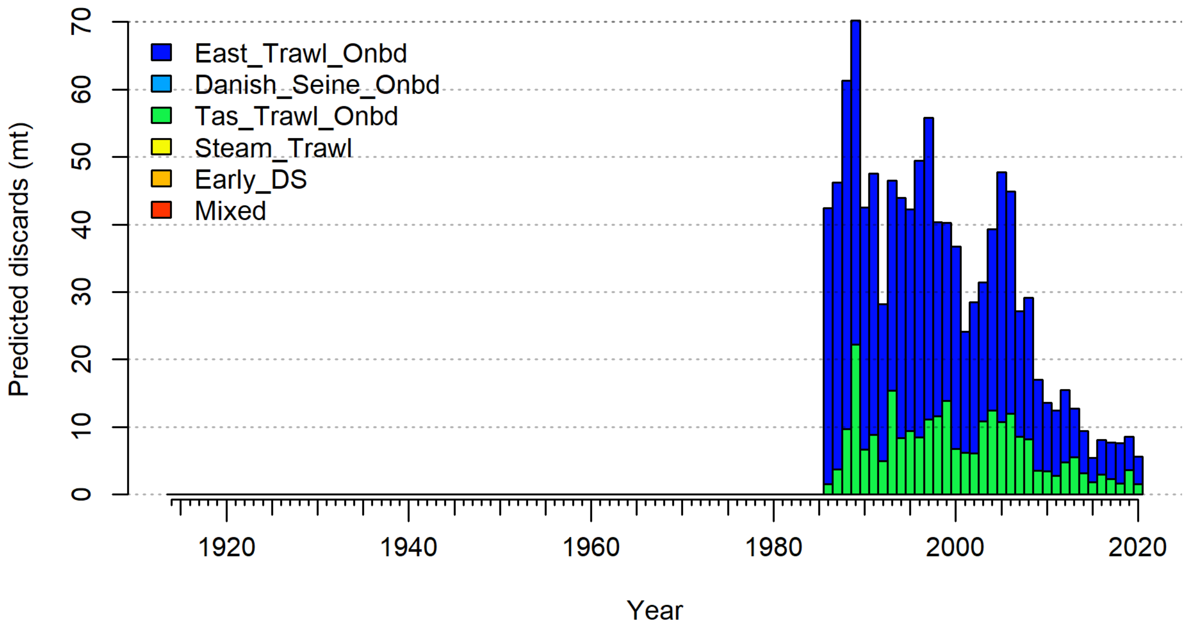


Figure 8.4. Estimated discards (tonnes, stacked) of eastern Jackass Morwong in the SESSF from 1986-2020, eastern trawl (blue) and Tasmanian trawl (green).

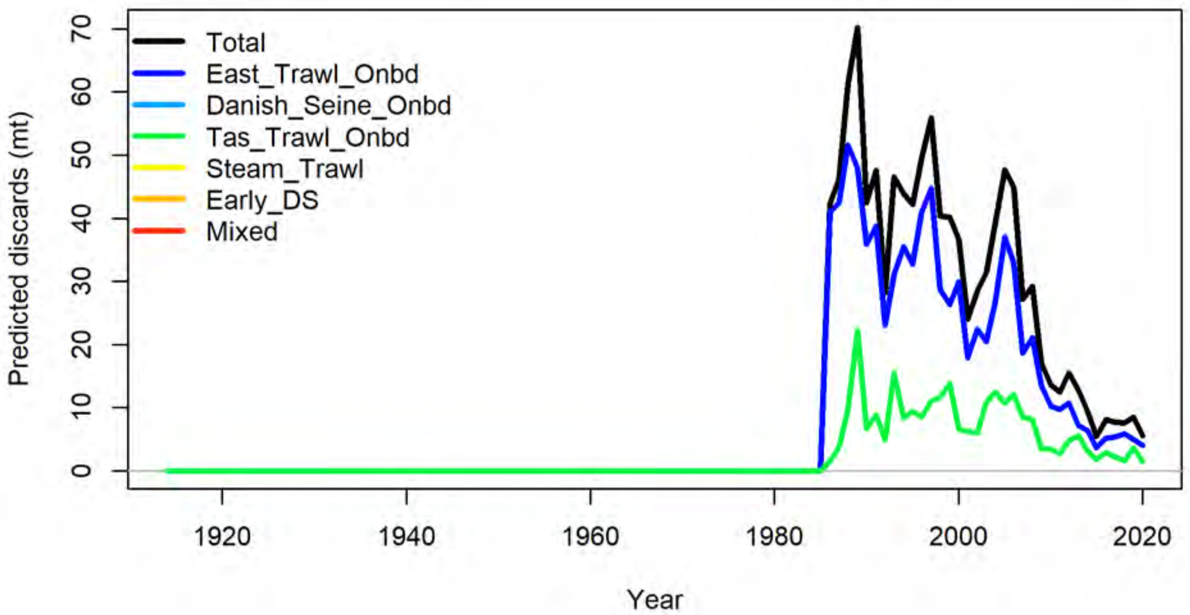


Figure 8.5. Estimated discards (tonnes) of eastern Jackass Morwong in the SESSF from 1986-2020, eastern trawl (blue) and Tasmanian trawl (green). combined total (black).

8.3.1.5 Catch rate and FIS abundance indices

A standardised catch rate (CPUE) index is available for the historical steam trawl fleet for the years 1920-21, 1937-42, and 1952-57 (Klaer, 2006; Table 8.5). Smith (1989) presented a standardised catch rate index for Jackass Morwong for 1948-66 Table 8.6). This index standardises for gear type during a period of overlap between the steam trawl fishery and the onset of Danish seine vessels. Smith (1989) also provided a standardised CPUE index for all vessels for the period 1977-84 (Table 8.7). This index corresponds to the mixed fleet.

Catch and effort data from the SEF1 logbook database were standardised using GLMs to obtain indices of relative abundance (Sporcic 2021a; Table 8.5) from the period 1986-2020 for the eastern and Tasmanian trawl fleets. In the stock synthesis assessment, the coefficient of variation is initially set at a value equal to the root mean squared deviation from a loess fit (Sporcic, 2021b) and additional variance is estimated for this CPUE index to tune the input and output variances.

Table 8.5. Standardised catch rate indices and coefficient of variation Standardised catch rates for the steam trawl fleet.

Year	Catch rate	cv
1920	1.54	0.15
1921	1.09	0.15
1937	1.25	0.15
1938	1.06	0.15
1939	1.14	0.15
1940	1.35	0.15
1941	1.12	0.15
1942	0.96	0.15
1952	0.98	0.15
1953	0.79	0.15
1954	0.82	0.15
1955	1.02	0.15
1956	0.89	0.15
1957	0.84	0.15

Table 8.6. Standardised catch rate indices and coefficient of variation calculated by Smith (1989) for the overlap years of the early Danish seine fleet and the steam trawl fleet.

Year	Catch rate	cv
1948	123.7	0.17
1949	105.4	0.17
1950	84.4	0.17
1951	74.2	0.17
1952	92.8	0.17
1953	116.1	0.17
1954	92.6	0.17
1955	71.6	0.17
1956	99.2	0.17
1957	90.1	0.17
1958	63.3	0.17
1959	79.3	0.17
1960	77.6	0.17
1961	85.0	0.17
1962	79.7	0.17
1963	89.5	0.17
1964	89.8	0.17
1965	89.6	0.17
1966	82.4	0.17

Table 8.7. Standardised catch rate indices and coefficient of variation calculated by Smith (1989) for the overlap years of the steam trawl fleet and the early Danish seine fleet.

Year	Catch rate	cv
1977	19.7	0.15
1978	20.3	0.15
1979	18.9	0.15
1980	17.1	0.15
1981	19.6	0.15
1982	16.3	0.15
1983	13.9	0.15
1984	16.4	0.15

Table 8.8. Standardised catch rate indices and coefficient of variation (Sporcic, 2021a) for eastern and Tasmanian trawl fleets fleet for eastern Jackass Morwong and the FIS2 abundance indices (Sporcic et al, 2019). The coefficient of variation is initially set at a value equal to the root mean squared deviation from a loess fit (Sporcic, 2021b).

Year	eastern trawl		Tas trawl		eastern FIS		TAS FIS	
	Catch rate	cv	Catch rate	cv	Catch rate	cv	Catch rate	cv
1986	2.159	0.143	2.009	0.367				
1987	2.618	0.143	2.248	0.367				
1988	2.457	0.143	3.064	0.367				
1989	2.334	0.143	3.884	0.367				
1990	1.963	0.143	2.805	0.367				
1991	1.800	0.143	1.889	0.367				
1992	1.461	0.143	2.097	0.367				
1993	1.558	0.143	1.679	0.367				
1994	1.356	0.143	1.163	0.367				
1995	1.244	0.143	1.153	0.367				
1996	1.128	0.143	1.097	0.367				
1997	1.251	0.143	1.197	0.367				
1998	1.009	0.143	1.176	0.367				
1999	1.013	0.143	1.401	0.367				
2000	0.863	0.143	0.862	0.367				
2001	0.594	0.143	0.545	0.367				
2002	0.664	0.143	0.447	0.367				
2003	0.528	0.143	0.596	0.367				
2004	0.523	0.143	0.446	0.367				
2005	0.633	0.143	0.338	0.367				
2006	0.774	0.143	0.416	0.367				
2007	0.749	0.143	0.588	0.367				
2008	0.948	0.143	0.597	0.367	11.695	0.098	98.878	0.200
2009	0.860	0.143	0.415	0.367				
2010	0.587	0.143	0.459	0.367	10.471	0.098	50.073	0.200
2011	0.587	0.143	0.314	0.367				
2012	0.574	0.143	0.415	0.367	7.695	0.098	55.575	0.200
2013	0.477	0.143	0.456	0.367				
2014	0.355	0.143	0.240	0.367	4.854	0.098	23.518	0.200
2015	0.298	0.143	0.147	0.367				
2016	0.342	0.143	0.161	0.367	6.452	0.098	4.989	0.200
2017	0.406	0.143	0.176	0.367				
2018	0.333	0.143	0.138	0.367				
2019	0.272	0.143	0.247	0.367				
2020	0.283	0.143	0.139	0.367				

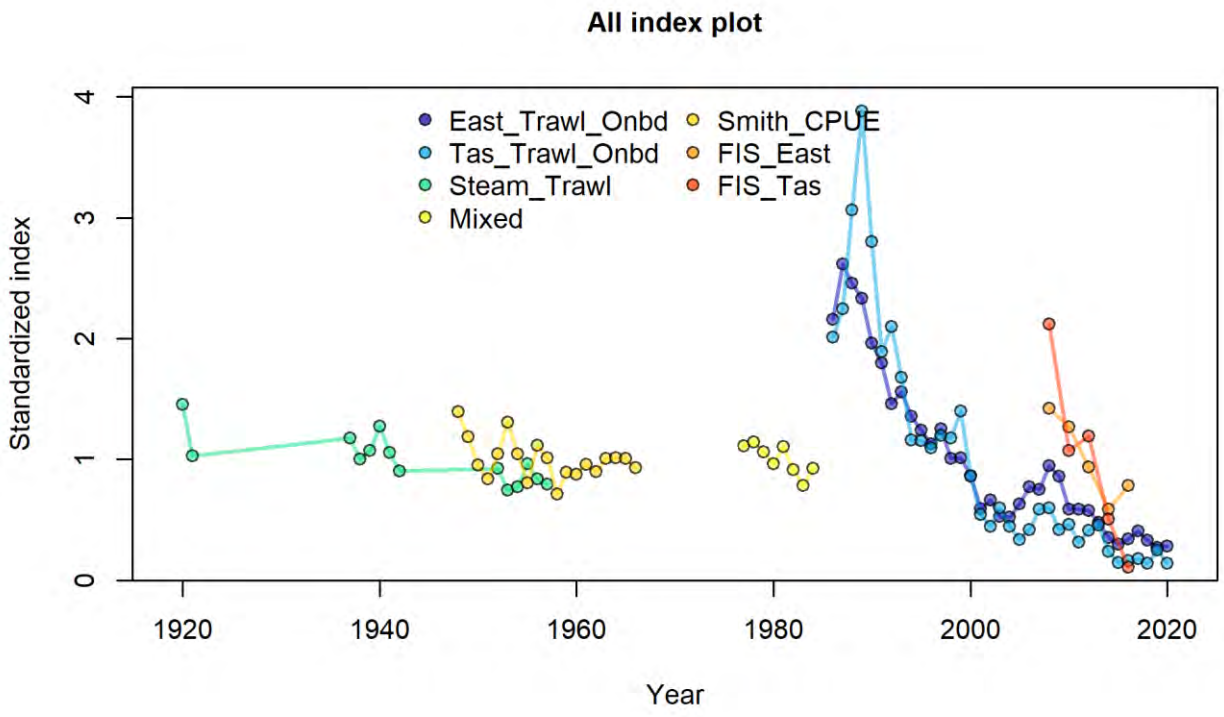


Figure 8.6. All seven CPUE and abundance series plotted on a normalised scale (mean of each series equals 1), enabling comparison of trends between time series.

The restrictions used in selecting data for analysis for eastern trawl fleet were: (a) vessels had to have been in the fishery for three or more years, (b) the catch rate had to be larger than zero, (c) catches in SESSF zone 10 and 20 only and (d) catches in between 70 and 300 m depth.

The restrictions used in selecting data for analysis for Tasmanian trawl fleet were: (a) vessels had to have been in the fishery for three or more years, (b) the catch rate had to be larger than zero, (c) catches in SESSF zone 30 only and (d) catches in between 70 and 300 m depth.

Abundance indices for eastern Jackass Morwong for the FIS2 surveys (Sporcic et al, 2019) conducted between 2008 and 2016 are provided in Table 8.8. The FIS2 indices are updated from the FIS1 indices used in the 2018 assessment and are conditioned on more appropriate logbook data from a period after the SESSF structural adjustment in 2007. FIS1 abundance values are reported for all years for Jackass Morwong for the whole fishery (east and west, Knuckey et al., 2015, Knuckey et al., 2017), but are separated into zones reflecting the fleets used in Tier 1 assessments in 2016 for both FIS1 and FIS2 series in Sporcic et al. (2019). The FIS2 abundance series for eastern and Tasmanian Jackass Morwong (Sporcic et al., 2019) are listed in Table 8.8. As with the CPUE indices (Sporcic, 2021b), the coefficient of variation is initially set at a value equal to the root mean squared deviation from a loess fit (Sporcic et al, 2019) and additional variance is estimated for this abundance index to tune the input and output variances.

All seven CPUE and abundance indices are plotted on the same normalised scale for easy comparison in Figure 8.6.

8.3.1.6 Length composition data

Port and onboard length composition data are both used separately, with the gear selectivity estimated jointly from both port and onboard data, as is the standard practice in the SESSF stock assessments. For onboard data, the number of shots is considered to be more representative of the information content in the length frequencies than the number of fish measured. For port data, the number of shots is not available, but the number of trips can be used instead. In the 2021 assessment, the initial sample size associated with each length frequency in the assessment is the number of shots or trips.

Length composition data for the discarded component of the catch is available from 1993-2020 for the eastern trawl, Tasmanian trawl and Danish seine fleets (Table 8.9), although discard length composition data is not used for the Danish seine fleet, due to sporadic data availability and highly variable discard rate estimates for this fleet. Length composition data for the retained component of the catch is available from 1947-1967 for the steam trawl and early Danish seine fleets (Blackburn, 1978) and from 1971-1985 for the mixed fleet (Table 8.10). Length composition data for the retained component of the onboard catch is available for a range of years from 1996-2020 for the three current fleets, eastern trawl, Tasmanian trawl and Danish seine, with two extra years of data outside this range (1993 for eastern trawl, and a small (unusable) sample in 1994 for Danish seine). Length composition data for the FIS fleets is available for every second year from 2008-2016, separated into FIS fleets to match the eastern trawl and Tasmanian trawl fleets (Table 8.11), although the samples in 2016 are too small to be used in the assessment for either FIS fleet, and also too small in 2014 for the eastern trawl FIS fleet.

Length composition data for the retained component of the port measured catch is available for a range of years from 1996-2020 for the three current fleets, eastern trawl, Tasmanian trawl and Danish seine. This data includes some revisions to the port collected length composition data for the years 1996-2016 and three years of new port collected length composition data (2018-2020). Unfortunately, this updated port collected length composition data was accidentally excluded from the base case, so the port length composition collected data used in the 2021 base case (Table 8.12) is identical to that used in the 2018 assessment. The numbers of shots and fish measured by year for the new and revised port length data (1996-2020) is listed in Table 8.13, and this data was included in a sensitivity to the base case, after the base case runs were completed, to examine the impact of failing to include these data in the assessment. Fortunately, this impact was minimal.

Port length composition data is also available for earlier years, from 1986-1990 for eastern trawl, from the Sydney Fish Market, and from 1991-1995 for eastern trawl, with again a small unusable port sample in 1992 for the Danish seine fleet (Table 8.12 and Table 8.13) and for this historical data, there were no revisions to the port length composition data, so the numbers of shots and numbers of fish measured per year listed in Table 8.12 and Table 8.13 is identical for the period 1986-1995.

Length data were excluded for years with less than 100 individual fish measured, as this was considered to be unrepresentative (with excluded data listed in grey in Table 8.9, Table 8.11, Table 8.12 and Table 8.13). Sample sizes for retained length frequencies, including both the number of individuals measured and number of trips (inferred numbers of trips listed in blue) are listed in in Table 8.10, Table 8.11, Table 8.12 and Table 8.13 for each fleet and year for the period 1947-2020 and for discarded length frequencies in Table 8.9 for the period 1993-2020. For years and gear types where the number of trips is not available (i.e. for fish measured in the Sydney Fish Market (1971-1990) or from Blackburn data (1947-1967)), the number of trips is inferred from the number of fish measured per trip for years where this data is available for each gear type.

Table 8.9. Number of onboard discarded lengths and number of shots for length frequencies included in the base case assessment by fleet 1993-2020. Entries in grey indicate data that are not used due to small sample size (either less than 100 fish measured or Danish seine discards, which are not used due to high variability in Danish seine discard rates).

year	fleet eastern trawl # fish	(discard) Tas trawl # fish	DS # fish	eastern trawl # shots	Tas trawl # shots	DS # shots
1993	72	745	79	6	7	2
1994	1516		262	18		13
1995	778			8		
1996	564	488		13	5	
1997	342	10		21	2	
1998	152	427		6	5	
1999	57	588		5	4	
2000	276		34	2		1
2001	118	419	6	6	9	1
2002						
2003	10		131	2		6
2004	374	84	363	15	1	11
2005	692	431		15	3	
2006	458	227		9	4	
2007	1			1		
2008	10			3		
2009						
2010	10	24		1	1	
2011	63	58		5	3	
2012	9	512		1	8	
2013	200	84	197	5	7	13
2014	179		221	5		4
2015	46	42		8	5	
2016	37	9	5	4	3	2
2017	542	66		10	2	
2018	169			7		
2019	151	82	131	10	6	10
2020	68	169	5	4	17	1

Table 8.10. Number of port (Sydney Fish Market (SFM)) and onboard (Blackburn) retained lengths and implied number of shots or trips for length frequencies included in the base case assessment by fleet 1947-1985. The number of shots or trips in this table (in blue) is inferred from numbers of fish measured

year	fleet steam trawl (Blackburn) # fish	(retained) early DS (Blackburn) # fish	mixed (SFM) # fish	steam trawl (Blackburn) # shots	early DS (Blackburn) # shots	mixed (SFM) # trips
1947	4836	1590		39	13	
1948	13960	5070		100	41	
1949	8577	3882		70	32	
1950	8823	5511		72	45	
1951	9721	1933		79	16	
1952	9456	3779		77	31	
1953	7956	2749		65	22	
1954	8033	2231		65	18	
1955	12010	8627		98	70	
1956	7997	8769		65	71	
1957	6351	4826		52	39	
1958	3243	6205		26	50	
1959		8569			70	
1960		10660			87	
1961		10038			82	
1962		15498			100	
1963		17887			100	
1964		24744			100	
1965		16586			100	
1966		19328			100	
1967		5980			49	
1971			1127			9
1972			631			4
1973			1080			7
1974			3614			17
1975			5388			67
1976			7971			84
1981			8684			76
1982			7911			67
1983			13608			98
1984			11552			78
1985			4825			33

Table 8.11. Number of lengths and number of shots for FIS length frequencies included in the base case assessment by fleet 2008-2016. Entries in grey indicate data that are not used due to small sample size (less than 100 fish measured).

year	FIS fleet Eastern trawl # fish	Tas trawl # fish	Eastern trawl # shots	Tas trawl # shots
2008	347	251	9	10
2010	388	426	12	13
2012	166	439	4	4
2014	67	368	2	3
2016	3	31	1	1

Table 8.12. Number of port and onboard retained lengths and number of shots or trips for length frequencies included in the base case assessment by fleet 1986-2020. The number of trips from early NSW data (SFM, 1986-1990, in blue) is inferred from numbers of fish measured. Entries in grey indicate data that are not used due to small sample size (less than 100 fish measured) or due to accidental omission (port samples from 2018-2020).

year	fleet east onbd # fish	(retained) east port # fish	Tas onbd # fish	Tas port # fish	DS onbd # fish	DS port # fish	east onbd # shots	east port # trips	Tas onbd # shots	Tas port # trips	DS onbd # shots	DS port # trips
1986		13441						83				
1987		4900						40				
1988		3649						19				
1989		1786						12				
1990		901						6				
1991		1181						8				
1992		1355				51		9				1
1993	147	2359					5	11				
1994		1124			3			14			2	
1995		667						7				
1996	864	233/ 2990		87		33	13	1 / 26		1		1
1997	3099	3190	257	282		340	32	27	3	2		5
1998	3416	8060	1514	835		1088	42	58	15	4		11
1999	3596	12659	1509	2384		295	41	86	14	13		2
2000	1969	7974	934	762	24	374	32	55	9	4	1	7
2001	3183	5603	1881	664		315	38	41	12	4		3
2002	2172	5757	647	2116		487	24	32	3	13		10
2003	1540	4066	691	424	142	61	22	25	4	3	9	1
2004	609	3544	1042	1248		108	16	29	6	8		2
2005	3381	5747	1621	1391	120	78	45	30	10	7	8	1
2006	1950	13123	1961	2757	60		30	86	16	15	6	
2007	1008	2029		137	30	753	26	13		1	1	5
2008	2241	651	207		15	635	42	4	5		1	6
2009	915	1644		80	50		23	20		1	1	
2010	603	1436	268	89	141	428	16	14	8	1	3	12
2011	611	758	292	263	153	512	19	26	7	7	4	24
2012	690	1116	630	141		216	18	31	11	4		9
2013	207	1008	347	214	163	288	6	33	7	4	9	10
2014	370	931	159		57	800	7	16	6		1	16
2015	495	1445	202	154		902	17	19	9	3		16
2016	687	600	295	240	5	810	13	8	23	5	2	15
2017	337	1029	486	55		530	7	17	9	1		11
2018	268	1100	76	87		860	8	18	7	1		19
2019	170	732	429	103	144	676	7	12	12	2	5	13
2020	242	1426	136	319		369	11	25	4	4		8

Table 8.13. Number of port and onboard retained lengths and number of shots or trips for length frequencies which should have been included in the base case assessment by fleet 1986-2020. The number of trips from early NSW data (SFM, 1986-1990, in blue) is inferred from numbers of fish measured. Entries in grey indicate data that are not used due to small sample size (less than 100 fish measured).

year	fleet east onbd # fish	(retained) east port # fish	Tas onbd # fish	Tas port # fish	DS onbd # fish	DS port # fish	east onbd # shots	east port # trips	Tas onbd # shots	Tas port # trips	DS onbd # shots	DS port # trips
1986		13441						83				
1987		4900						40				
1988		3649						19				
1989		1786						12				
1990		901						6				
1991		1181						8				
1992		1355				51		9				1
1993	147	2359					5	11				
1994		1124			3			14			2	
1995		667						7				
1996	864	233 / 2990		87		33	13	1 / 20		1		1
1997	3099	3190	257	282		340	32	23	3	2		4
1998	3416	8060	1514	835		1088	42	51	15	4		9
1999	3596	12659	1509	2384		295	41	73	14	13		2
2000	1969	7974	934	762	24	374	32	52	9	4	1	4
2001	3183	5603	1881	664		315	38	41	12	4		3
2002	2172	5757	647	2116		487	24	32	3	13		9
2003	1540	4066	691	424	142	61	22	21	4	3	9	1
2004	609	3544	1042	1316		108	16	28	6	9		2
2005	3381	5747	1621	1391	120	78	45	30	10	7	8	1
2006	1950	13604	1961	2757	60		30	84	16	15	6	
2007	1008	1530		464	30	753	26	11		4	1	5
2008	2241	651	207		15	635	42	4	5		1	6
2009	915	2119		80	50	12	23	42		1	1	1
2010	603	1867	268	122	141	622	16	40	8	3	3	22
2011	611	1125	292	351	153	731	19	37	7	9	4	28
2012	690	1423	630	188		291	18	35	11	5		10
2013	207	1209	347	247	163	383	6	30	7	5	9	9
2014	370	931	159		57	800	7	15	6		1	14
2015	495	1597	202	176		1043	17	20	9	3		14
2016	687	617	295	240	5	810	13	8	23	5	2	14
2017	337	1029	486	55		530	7	17	9	1		11
2018	268	1100	76	87		860	8	18	7	1		19
2019	170	732	429	103	144	676	7	12	12	2	5	13
2020	242	1426	136	319		369	11	25	4	4		8

8.3.1.7 Age composition data

An estimate of the standard deviation of age-reading error was calculated by André Punt (pers. comm., 2021) using data supplied by Kyne Krusic-Golub and a variant of the method of Richards *et al*. (1992) (Table 8.14). This age data, with multiple reads of individual otoliths, which was used to estimate the ageing error had some obvious discrepancies. One record featured an otolith aged as either six or zero years old, but this otolith was unreadable on the second read, and should not have been recorded as age zero (J. Barrow, pers. Comm., 2021). To ensure convergence of the ageing error estimation, other records with large variation between the first and second read were excluded. These records and the convergence of the ageing error estimate should be examined more carefully when the ageing error is next updated. Age-at-length measurements, provided by Kyne Krusic-Golub of Fish Ageing Services Pty Ltd, are available from 1992-2020 for the eastern trawl fleet, from 1991-2020 for the Tasmanian trawl fleet and from 1998-2020 for the Danish seine fleet (Table 8.15).

Table 8.14. Standard deviation of age reading error (A Punt pers. comm. 2021).

Age	**sd**
0.5	0.146691
1.5	0.146691
2.5	0.22875
3.5	0.279308
4.5	0.316403
5.5	0.349419
6.5	0.382902
7.5	0.418765
8.5	0.45756
9.5	0.499182
10.5	0.543257
11.5	0.589336
12.5	0.636991
13.5	0.685851
14.5	0.735615
15.5	0.786048
16.5	0.836969
17.5	0.888242
18.5	0.939769
19.5	0.991477
20.5	1.04331
21.5	1.09524
22.5	1.14723
23.5	1.19926
24.5	1.25132
25.5	1.30341
26.5	1.35551
27.5	1.40762
28.5	1.45973
29.5	1.51185
30.5	1.56398

Table 8.15. Number of age-length otolith samples included in the base case assessment by fleet 1991-2020.

Year	Fleet Eastern trawl	Danish seine	Tasmanian trawl
1991			99
1992	55		
1993	412		
1994	330		19
1995	200		96
1996	507		
1997	169		
1998	166	52	
1999	314		
2000	43	118	
2001	301	92	
2002	379		
2003	72	95	
2004	83		
2005	164	25	
2006	30	10	49
2007	117		
2008	262		77
2009	554		
2010	558	183	86
2011	482	224	108
2012	337	63	206
2013	2	46	71
2014	174	151	12
2015	244	153	72
2016	46	11	34
2017	203	16	62
2018	96	34	42
2019	131	105	91
2020	369	26	36

8.3.1.8 Input data summary

The data used in this assessment is summarised in Figure 8.7 and Figure 8.8, indicating which years the various data types were available.

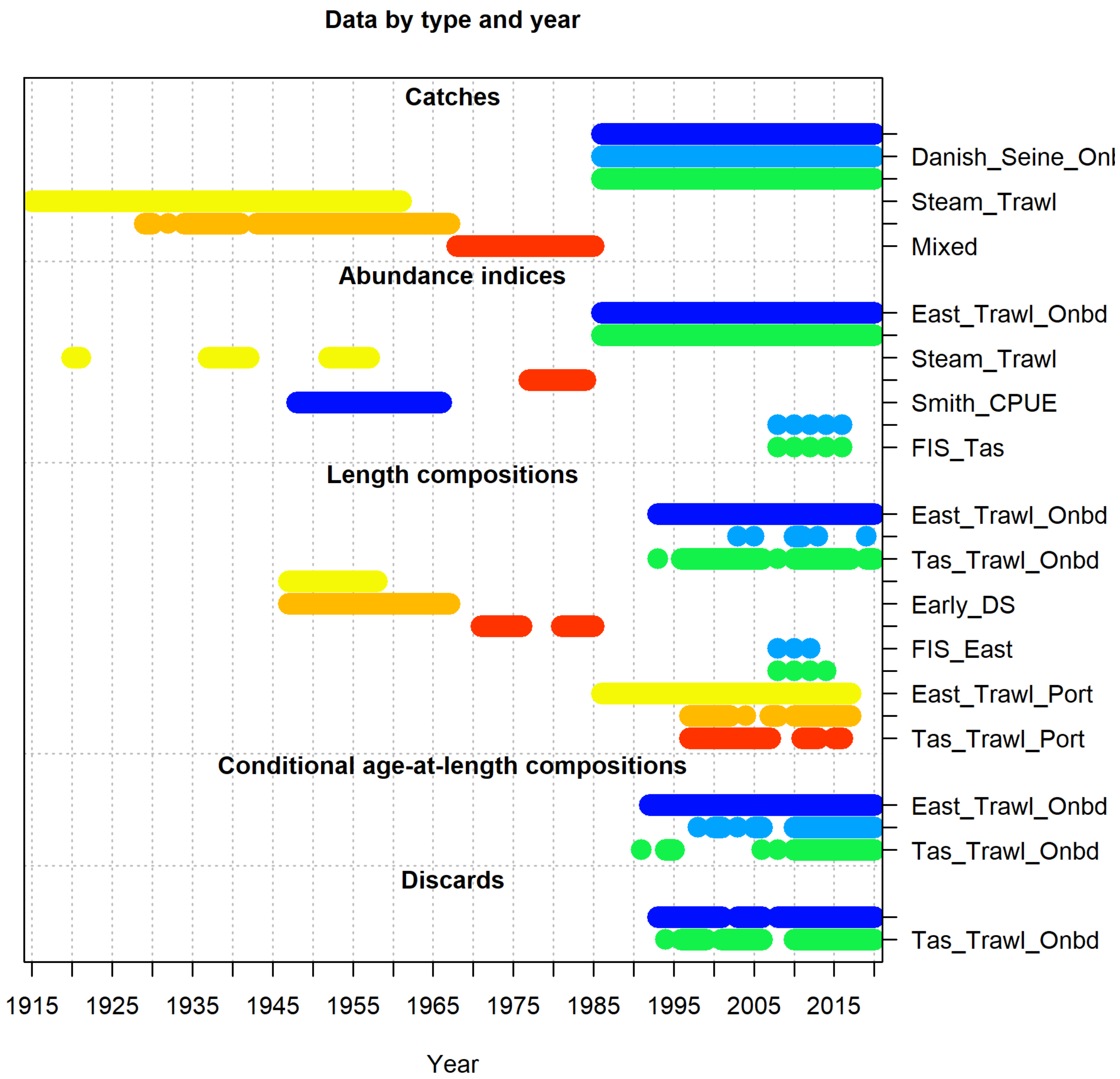


Figure 8.7. Summary of input data used for the eastern Jackass Morwong assessment base case (which accidentally excluded the port length composition data from 2018-2020).

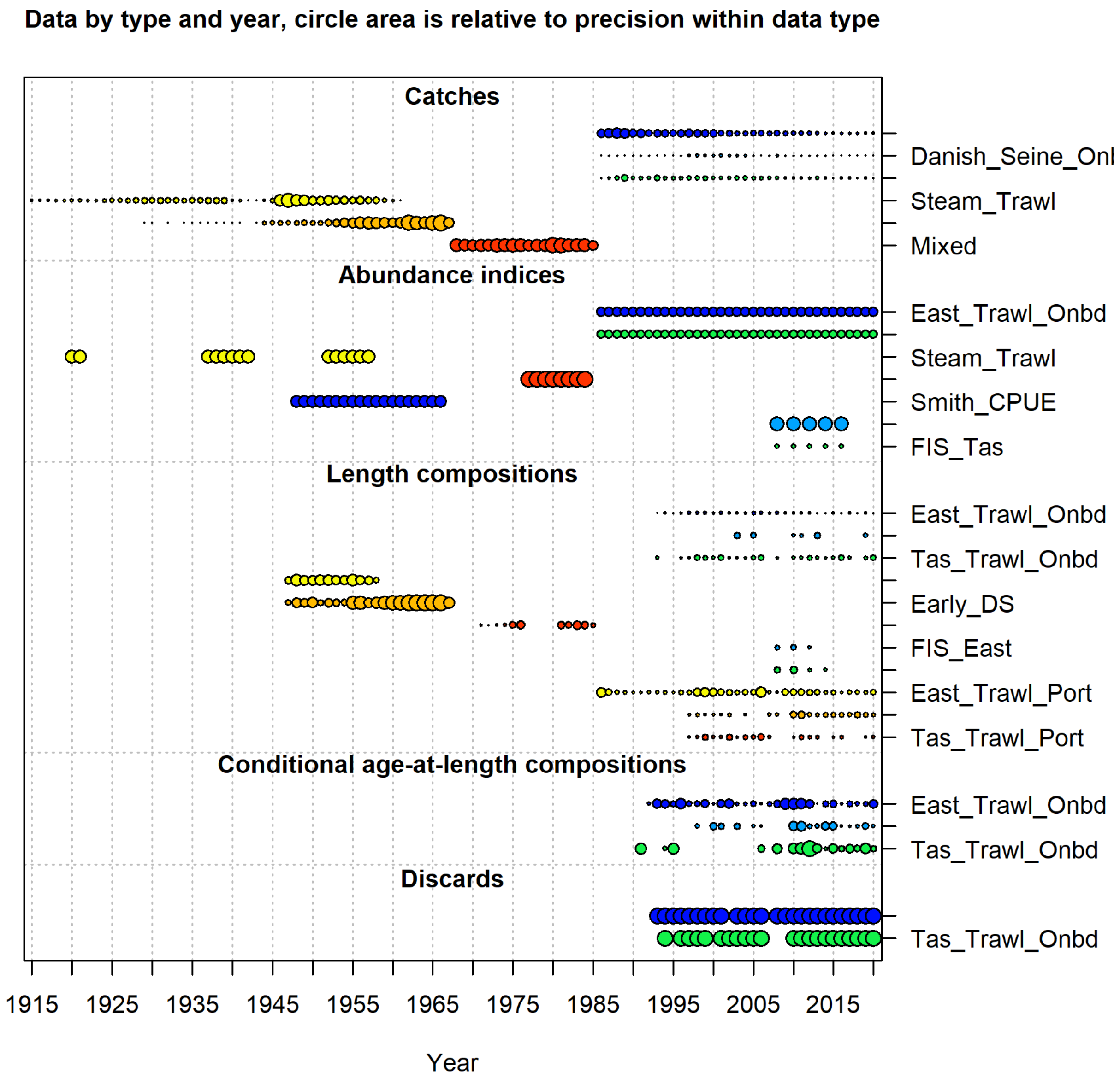


Figure 8.8. Summary of input data used for the eastern Jackass Morwong assessment, including the port length composition data from 2018-2020, which should have been included in the base case.

8.3.2 *Stock assessment method*

8.3.2.1 Population dynamics model and parameter estimation

A single-sex stock assessment for eastern Jackass Morwong was conducted using the software package Stock Synthesis (version SS-V3.30.17.00, Methot *et al*. 2021, Methot and Wetzel, 2013). Stock Synthesis is a statistical age- and length-structured model which can allow for multiple fishing fleets and can be fitted simultaneously to the types of information available for Jackass Morwong. 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 technical documentation and (Methot, 2005), and are not reproduced here.

A single stock of Jackass Morwong was assumed for the eastern assessment, with an assumption of two productivity regimes, with different stock-recruitment relationships: the first from 1915 when the steam trawl fishery commenced, and the second, lower productivity regime, from 1988 when productivity and recruitment became lower (Wayte, 2011; Wayte, 2013). Catches from western Tasmania and western Victoria were assumed to come from a separate stock and are therefore not considered in the eastern assessment.

Some key features of the base-case model are:

a) Jackass Morwong constitute a single stock within the area of the fishery (SESSF Zones 10, 20 and 30).

b) The population was at its unfished biomass with the corresponding equilibrium (unfished) age-structure at the start of 1915.

c) The CVs of the CPUE indices for the eastern and Tasmanian trawl fleets and the FIS abundance indices were initially set to the root mean squared deviation from a loess fit to the fleet specific indices (Sporcic, 2021b) and then tuned to match the model-estimated standard errors by estimating an additional variance parameter within Stock Synthesis.

d) Six fishing fleets are modelled.

e) Selectivity was assumed to vary among fleets, but the selectivity pattern for each fleet was modelled as length-specific, logistic and time-invariant. The two parameters of the selectivity function for each fleet were estimated within the assessment.

f) Retention was also defined as a logistic function of length, and the inflection and slope of this function were estimated for the two fleets where discard information was available (eastern trawl and Tasmanian trawl).

g) The rate of natural mortality, M, is assumed to be constant with age, and also time-invariant. The value for M was fixed (0.15) within the model in this assessment.

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 for the base-case analysis is set to 0.7. Deviations from the average recruitment at a given spawning biomass (recruitment residuals) are estimated for 1945 to 2015. Deviations are not estimated prior to 1945 or 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 thirty years.

k) Growth of Jackass Morwong is assumed to be time-invariant, meaning there is no change over time in mean size-at-age, with the distribution of size-at-age being estimated along with the remaining growth parameters within the assessment. No differences in growth related to sex are modelled, because the stock is modelled as a single-sex model.

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 downweighted to a maximum sample size of 100 and 200 respectively.

8.3.2.2 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 apparently 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 and the approach of Punt (2017) for conditional age-at-length 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. 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 (2011) weighting method for length data and the Punt (2017) weighting method for conditional age-at-length data.

8.3.2.3 Iterative reweighting 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). The iterative reweighting method is outlined below:

1. Set the standard error for 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). SS-V3.30 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 Jackass Morwong. 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 (Pacific Fishery Management Council, 2018).

8.3.2.4 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 a Tier level depending on the basis used for assessing stock status or exploitation level for that stock. Jackass Morwong 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. This document reports RBCs calculated under the 20:35:48 strategy.

8.3.2.5 The base case model

SERAG accepted the model structure of the preliminary base case assessment for eastern Jackass Morwong presented in October 2021 (Day and Bessell-Browne, 2021), with the stipulation that the base case assumed recruitment from 2016 onwards had fixed recruitment deviations equal to the mean of the estimated recruitment deviations from 2006-2015 (-0.754).

Estimates of recruitment for Jackass Morwong have been below average since the early 2000s, with this potentially a consequence of directional environmental change. If this below average recruitment trend continues into the future, assuming a return to average recruitment would result in overly optimistic biomass and stock status estimates. Due to these concerns the base case for this assessment incorporates low, rather than average, recruitment projected into the future. The more usual "average recruitment" scenario, with recruitment deviations set to zero from 2016 onwards, is included as a sensitivity.

8.3.2.6 Retrospective analyses

A retrospective analysis Mohn (1999) has been undertaken to identify whether below average recruitment and declining stock size would have been identified by previous assessments using the same assumptions, data and tuning as this assessment.

The retrospective analysis was undertaken using the following procedure:

1. One year of data was removed sequentially from the 2021 base case assessment;
2. Time dependent model parameters (e.g. last year of recruitment) were changed to be one year earlier;
3. The model was run to determine stock status estimates when less data is available;
4. Steps 1–3 were repeated for five years, removing one year of data at each step.

Trends in spawning biomass and estimated recruitment are then examined to help understand how reliable the most recent few years of estimated recruitments and spawning biomass are in the current assessment. Mohn's rho values are then calculated to quantitatively determine the severity of the retrospective pattern (Hurtado-Ferro et al., 2015).

8.3.2.7 Likelihood profiles

Likelihood profiles are a standard component of the toolbox of applied statisticians and are most often used to obtain a 95% confidence interval for a parameter of interest (Punt, 2018). Many stock assessments "fix" key parameters such as natural mortality 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 range of the 95% confidence interval of the total likelihood profile, this provides no support from the data to change the fixed value. If the fixed value is outside the 95% confidence interval, and there is evidence that the data holds information about this parameter, 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 should 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 to inconsistencies in sampling, but more commonly owing to incorrect assumptions or model misspecification (e.g., assuming that catch-rates are linearly related to abundance). Likelihood profiles can be used as a diagnostic to identify these data conflicts (Punt, 2018).

Likelihood profiles were constructed for the base case with low recruitment for mortality, steepness, unexploited spawning biomass, 2020 spawning biomass and 2020 stock status.

8.3.2.8 Jitter analysis

Jitter analysis is a technique used to test the optimality, robustness and stability of the maximum likelihood estimate obtained for a particular model. This involves randomly changing the starting values used for all estimated parameters and re-running the model, to test what alternative solutions may be found by the optimisation algorithm from different initial locations, which is sometimes referred to as sensitivity to initial conditions. Two diagnostics are of interest with a jitter analysis, initially a check on whether a better "optimal solution" may be found, with a higher likelihood value, and also to see how frequently the optimal solution is found. As all estimated parameters are randomly modified, or "jittered", simultaneously, this can sometimes result in a model either failing to converge or finding a local maximum in a different (suboptimal) part of the multi-dimensional parameter space. A jitter analysis was conducted with 25 replications, modifying initial values by 0.1.

8.3.2.9 Sensitivity tests and alternative models

The following sensitivity tests were used to examine the sensitivity of the results to model assumptions and data inputs:

1. $M = 0.1$ yr^{-1}.
2. $M = 0.2$ yr^{-1}.
3. $h = 0.6$.
4. $h = 0.8$.
5. 50% maturity at 22 cm.
6. σ_R set to 0.65.
7. σ_R set to 0.75.
8. Double the weighting on the length composition data.
9. Halve the weighting on the length composition data.
10. Double the weighting on the age-at-length data.
11. Reduce the weighting on the age-at-length data.
12. Double the weighting on the survey (CPUE) data.
13. Halve the weighting on the survey (CPUE) data.
14. Rerun the model without a productivity shift in 1988.
15. Assume average recruitment from 2016 onwards (recruitment deviations fixed at zero).

The results of the sensitivity tests are summarized by the following quantities (Table 8.23):

1. SSB_0: the average unexploited female spawning biomass.
2. SSB_{2022}: the female spawning biomass at the start of 2022.
3. SSB_{2022}/SSB_0: the female stock status level at the start of 2022.
4. RBC_{2022}: the recommended biological catch (RBC) for 2022.
5. $\text{RBC}_{2022\text{-}24}$: the mean RBC over the three years from 2022-2024.
6. $\text{RBC}_{2022\text{-}26}$: the mean RBC over the five years from 2022-2026.
7. $\text{RBC}_{\text{longterm}}$: the longterm RBC.

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

8.4 Results and discussion

8.4.1 The base-case analysis

8.4.1.1 Transition from 2018 base case to 2021 base case

The development of a preliminary base case, and a bridging analysis from the 2018 assessment (Day and Castillo-Jordán, 2018a), was presented at the October 2021 SERAG 2 meeting (Day and Bessell-Browne, 2021), including updating the version of Stock Synthesis and sequentially updating data. This bridging analysis is not repeated in this report.

8.4.1.2 Parameter estimates

Figure 8.9 shows the estimated growth curve for Jackass Morwong. All growth parameters are estimated by the model (parameter values are listed in Table 8.16).

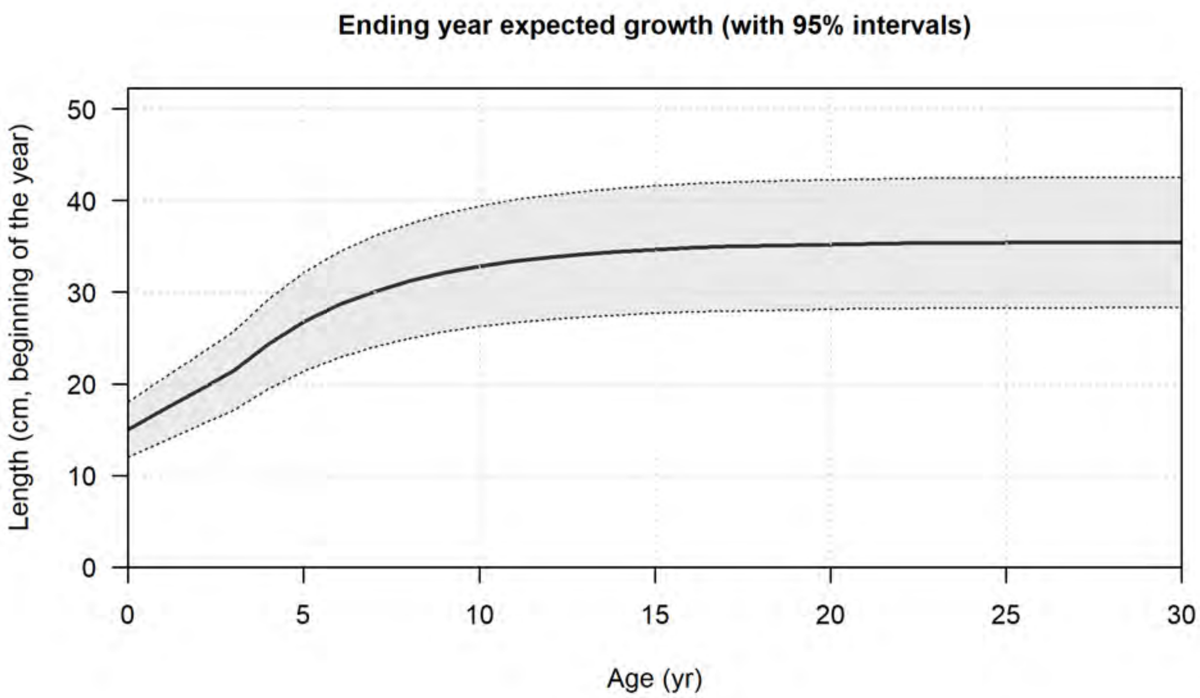


Figure 8.9. Fixed growth curve for eastern Jackass Morwong, using parameters estimated from the eastern morwong stock assessment.

Table 8.16. Summary of parameters of the base case model.

Feature	Details	
Natural mortality *M*	fixed	0.15
Steepness *h*	fixed	0.7
σ_R	fixed	0.7
Recruitment devs	estimated	1945-2015, bias adjustment ramps 1969-86 and 2012-13
CV growth	estimated	0.102
Growth *K*	estimated	0.239
Growth l_{min} (cm)	estimated	21.4
Growth l_{max} (cm)	estimated	35.2

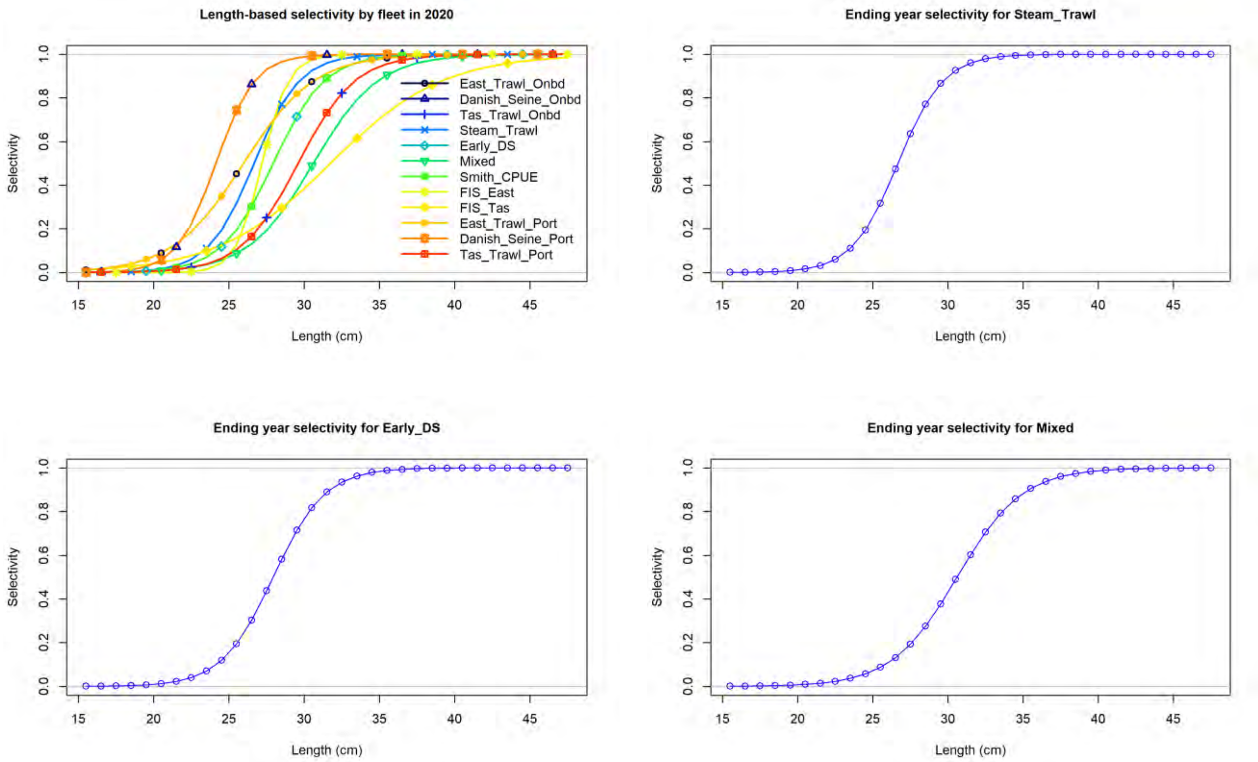


Figure 8.10. Selectivity for all six fleets (top left: note that the port fleets are mirrored to the selectivity of other fleets) and selectivity functions for the three historical fleets (steam trawl (top right); early Danish seine (bottom left); mixed (bottom right)).

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). The estimates of these parameters for the current fleets are as follows: for the eastern trawl fleet are 26.0 cm and 6.92 cm; for the Danish seine fleet are 24.1 cm and 3.81 cm; and for the Tasmanian trawl are 29.6 cm and 5.61 cm. For the FIS fleets the parameters are as follows: for the eastern trawl fleet are 27.2 cm and 2.59 cm; and for the Tasmanian trawl are 31.7 cm and 11.0 cm. For the historical fleets the parameters are as follows: for the steam trawl fleet are 26.7 cm and 4.47 cm;

for the early Danish seine fleet are 27.9 cm and 5.04 cm; and for the mixed fleet are 30.6 cm and 6.39 cm. All of these values are similar to the values for the selectivity parameters estimated in the 2018 assessment. Figure 8.10 and Figure 8.11 show the selectivity and retention functions for each fleet with selectivity estimated. The estimate of the parameter that defines the initial numbers (and biomass), $ln(R_0)$, is 8.11 for the base case.

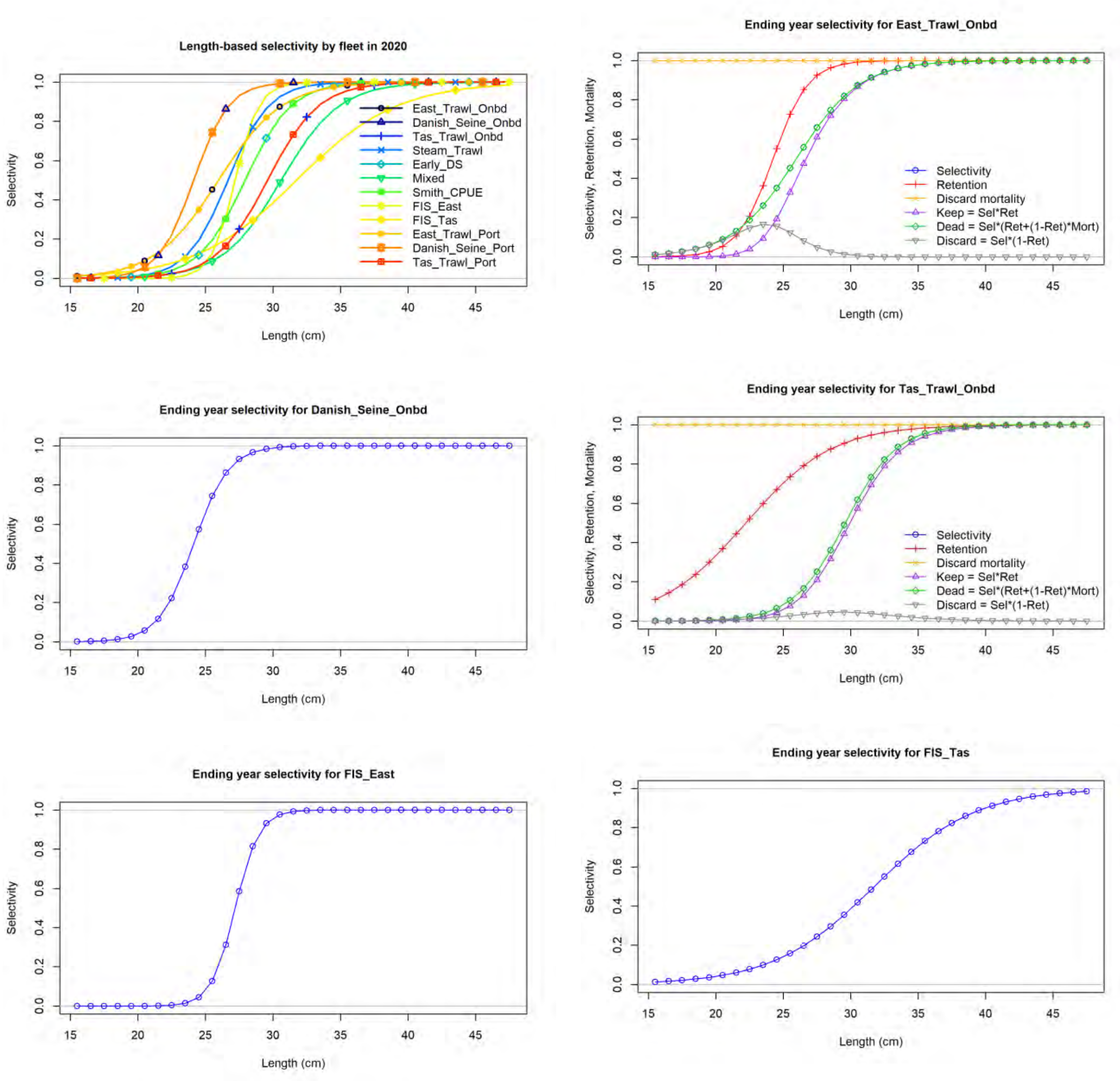


Figure 8.11. Selectivity for all six fleets (top left: note that port fleets are mirrored to the selectivity of other fleets) and selectivity (blue/green) and retention (red) functions for the three current fleets (eastern trawl (top right); Danish seine (middle left); Tasmanian trawl (middle right)) and for the two FIS fleets (eastern trawl FIS fleet (bottom left); Tasmanian trawl FIS fleet (bottom right)).

8.4.1.3 Fits to the data

The fits to the steam trawl fleet catch rate indices are good (Figure 8.12), with the series suggesting some decline in biomass apparent by the 1950s. The Smith indices (Figure 8.13) suggest abundance is generally relatively constant, with the model estimating a decline in abundance in the early 1980s. These fits to the historical abundance indices are largely unchanged from the fits from the 2018 assessment. The fits to the recent catch rate series from the trawl fleets are remarkably good (Figure 8.14), with the model generally matching the decline in these series, albeit struggling to fit the hump at the start of the Tasmanian trawl series, and a smaller hump from 2003-2008 for the eastern trawl series. The fits to both of these series suggest a steady decline in abundance from 1986-2015, with a flattening of the abundance from 2015-2020, albeit at very low levels. While the point estimates of the abundance indices from the FIS2 for eastern Jackass Morwong have generally declined since 2008, the model, which also fits to a number of other data sources, produces a declining abundance trajectory over this period (Figure 8.15), fitting the eastern trawl FIS2 abundance series very well, but being unable to fit the steeper decline seen in the FIS2 abundance series for the Tasmanian trawl fleet.

In general, the fits to abundance series are very similar to the fits in the 2018 assessment, with the exception to improved fits to the most recent years, and no longer any suggestion of an increase in spawning biomass at the end of the time series.

The fits to the historical abundance indices generally estimate negative additional variance, indicating that the variance supplied is sufficient for reasonable fits. This parameter is negative for the Tasmanian trawl fleet and close to zero for the eastern trawl FIS2 abundance index (well balanced) but is positive for the eastern trawl fleet and the Tasmanian trawl FIS2 abundance index, suggesting the model requires more variance than the initial values from the loess fit to achieve an acceptable fit.

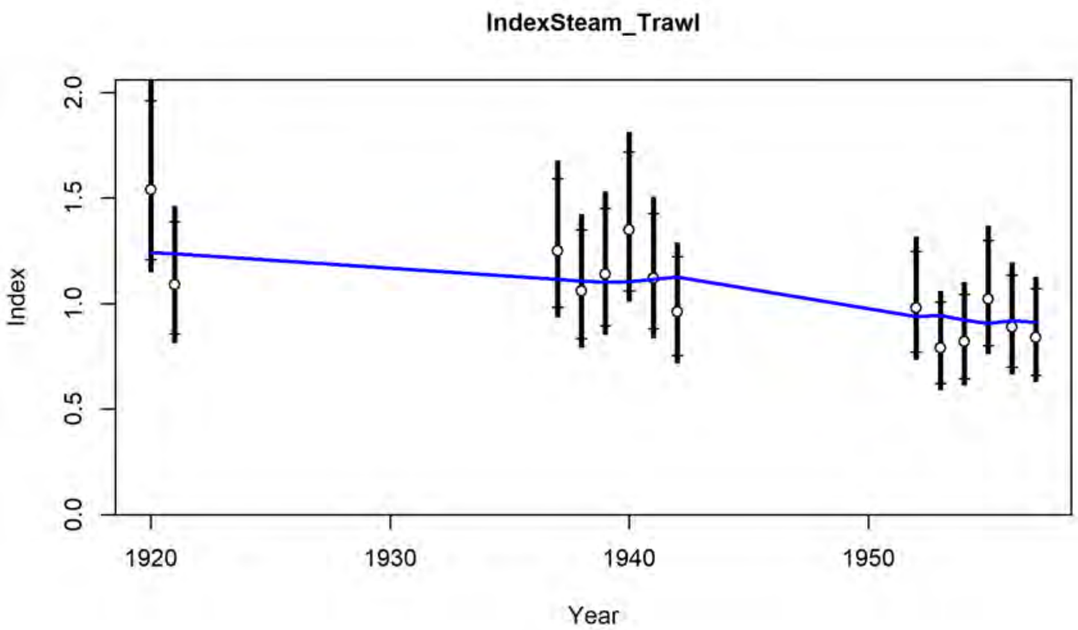
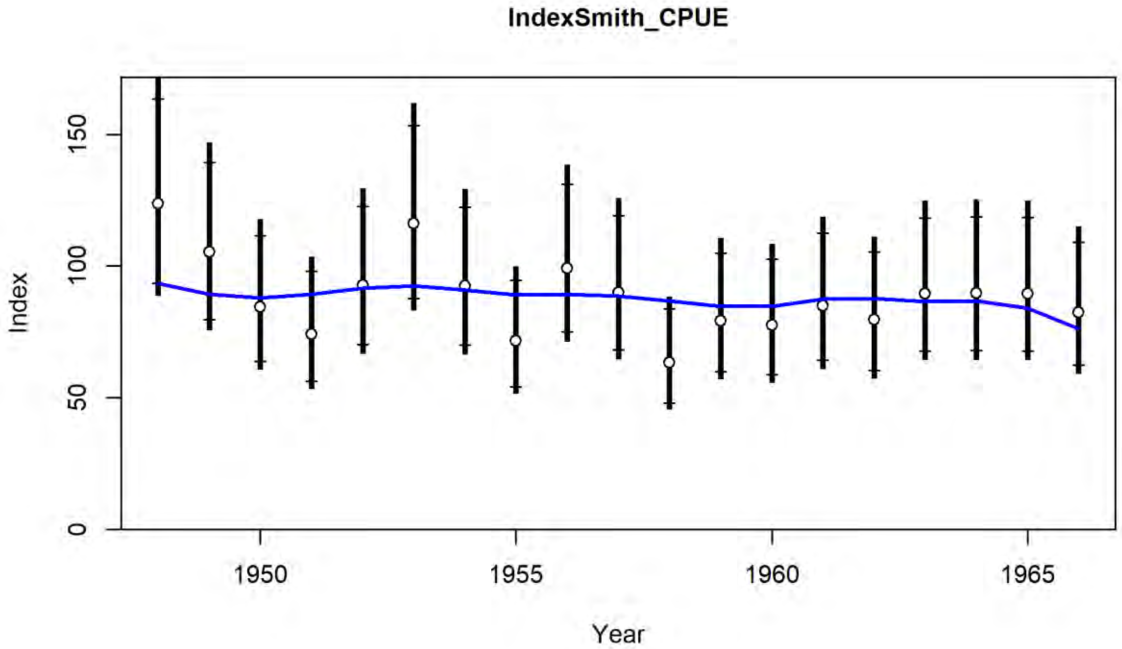


Figure 8.12. Observed (circles) and model-estimated (blue line) catch rates vs year, with approximate 95% asymptotic intervals for steam trawl fleet. The thin lines with capped ends should match the thick lines for a balanced model. This index is balanced by estimating an additional variance parameter within Stock Synthesis, which in this case is negative, suggesting the model fits well with less variance than the initial values from the loess fit.



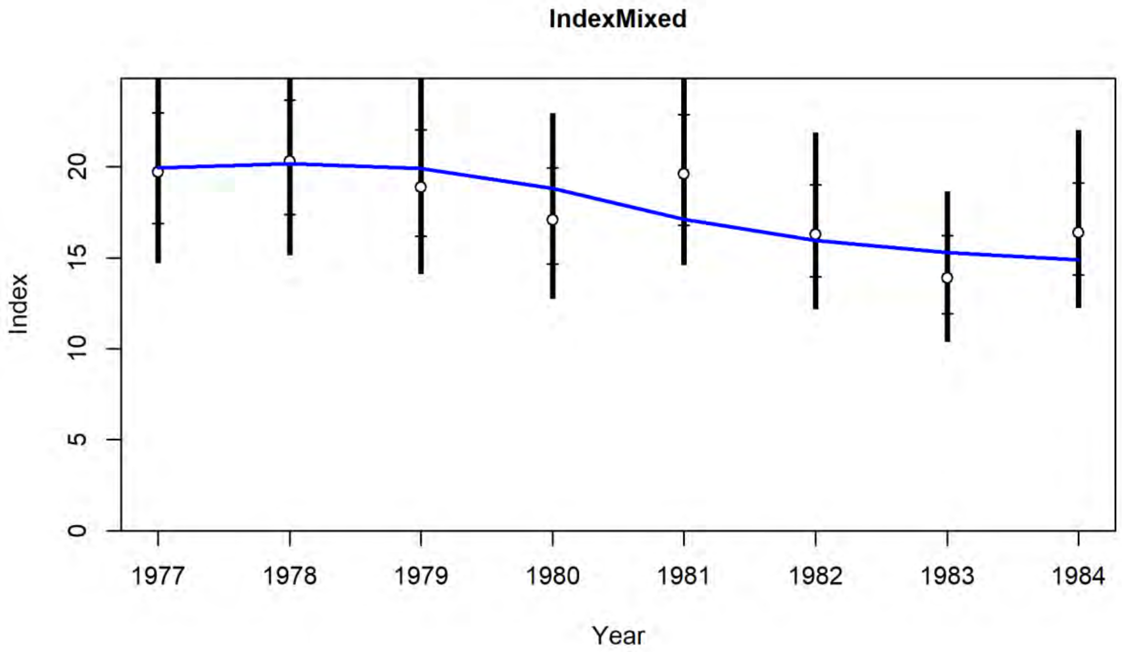


Figure 8.13. Observed (circles) and model-estimated (blue line) catch rates vs year, with approximate 95% asymptotic intervals for the Smith CPUE indices for the overlap between steam trawl and Danish seine (top) and the later mixed fleet (bottom). The thin lines with capped ends should match the thick lines for a balanced model. These indices are balanced by estimating an additional variance parameter within Stock Synthesis, which in these cases are both negative, suggesting the models fit well with less variance than the initial values from the loess fit.

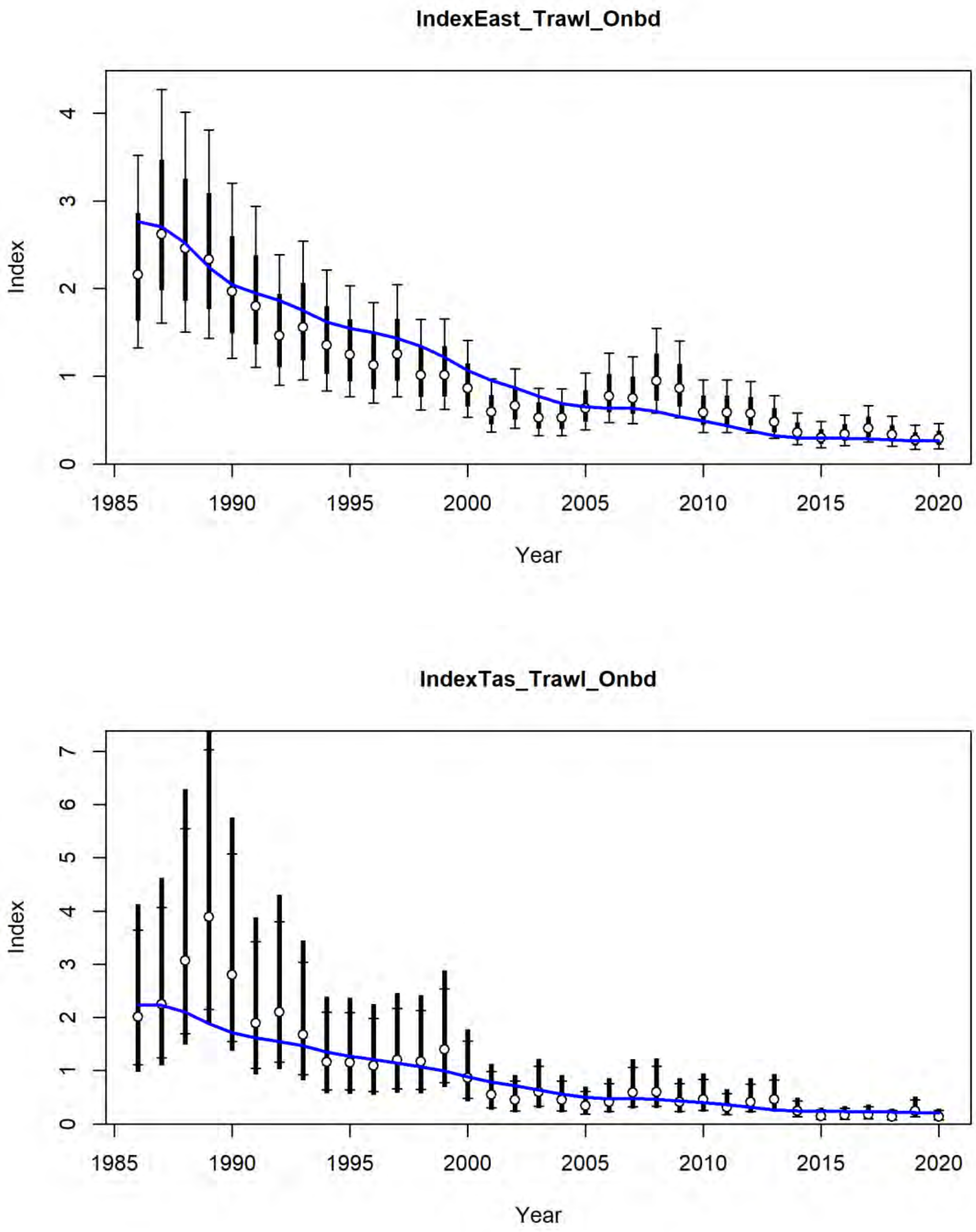
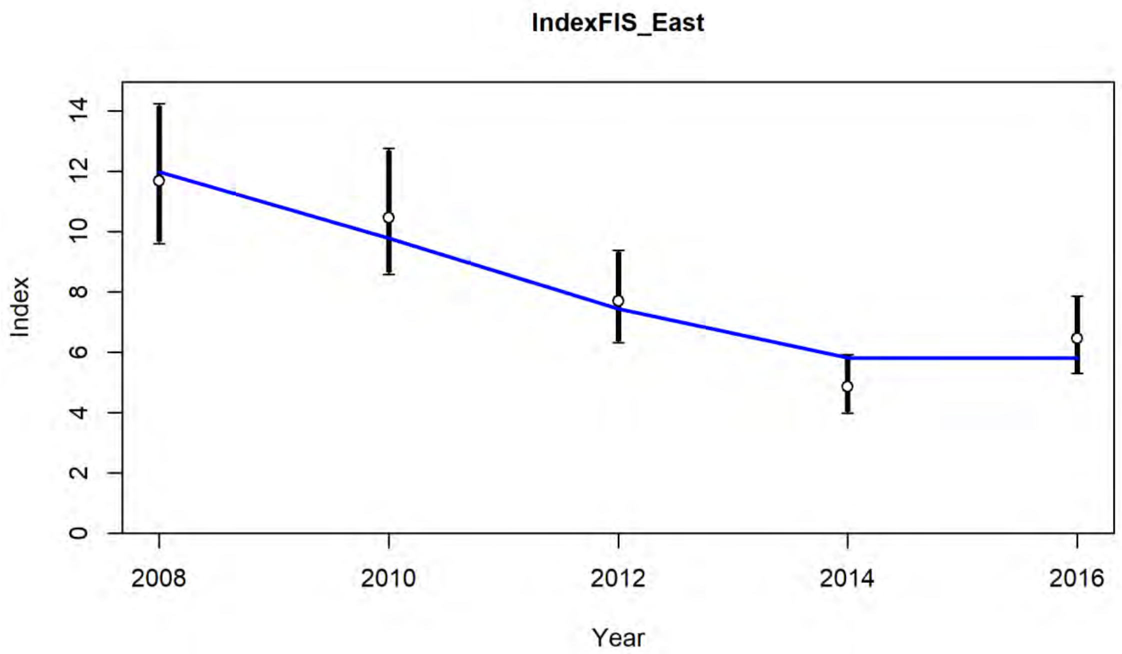


Figure 8.14. Observed (circles) and model-estimated (blue line) catch rates vs year, with approximate 95% asymptotic intervals for the eastern trawl fleet (top) and the Tasmanian trawl fleet (bottom). The thin lines with capped ends should match the thick lines for a balanced model. These indices are balanced by estimating an additional variance parameter within Stock Synthesis, which for eastern trawl is positive, suggesting the model requires more variance than the initial values from the loess fit to achieve a good fit. For the Tasmanian trawl fleet, the additional variance estimated is negative, suggesting the model fits well with less variance than the initial values from the loess fit.



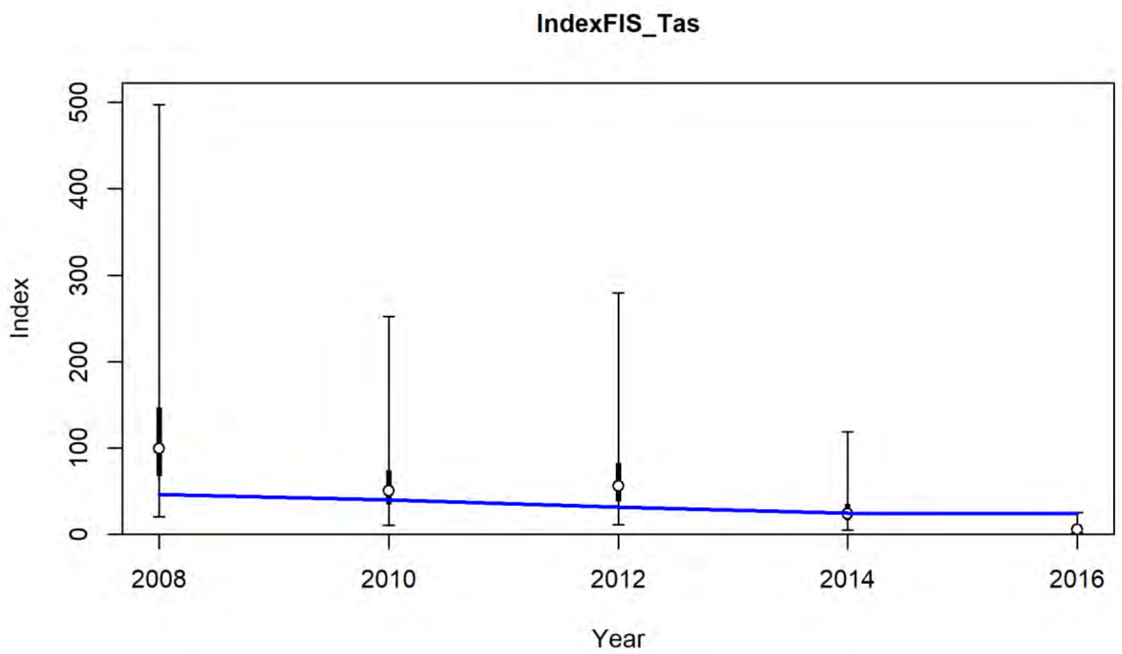


Figure 8.15 Observed (circles) and model-estimated (blue line) catch rates vs year, with approximate 95% asymptotic intervals for the eastern FIS fleet (top) and the Tasmanian FIS fleet (bottom). The thin lines with capped ends should match the thick lines for a balanced model. These indices are balanced by estimating an additional variance parameter within Stock Synthesis, which in the Tasmanian trawl case is positive, suggesting the model requires more variance than the initial values from the loess fit to achieve a good fit.

The total standard error, comprising the input standard error (Table 8.5, Table 8.6, Table 8.7 and Table 8.8) plus the additional standard error estimated within Stock Synthesis, gives some measure of how well each CPUE series is fit.

This total standard error is lowest for the mixed fleet with 0.079, followed by the steam trawl fleet mixed fleet with 0.12, the mixed fleet with 0.14, the eastern trawl FIS fleet with 0.17, the eastern trawl fleet with 0.25, the Tasmanian trawl fleet with 0.30 and the Tasmanian trawl FIS fleet with 0.72. It is generally easier to fit shorter time series, and conflicting signals between multiple CPUE series also adds to the difficulty of fitting to CPUE.

Overall, the fits to all CPUE series are remarkably good, except for the eastern trawl CPUE, as shown by the patterns in residual plots in Figure 8.16. The residual patterns are markedly different between the two longest time series from the eastern and Tasmanian trawl CPUE series, which both cover 25 years. The residual pattern for the Tasmanian trawl series looks well balanced, in contrast to the residual pattern for the eastern trawl series over the same time period. The eastern trawl CPUE residuals indicate some potential problems, with an initial long run where the fitted values are below the data points (1990-2006), followed by another long run with the fitted values above the data points (2007-2020). While this residual pattern indicates a possible problem with this fit to the eastern trawl CPUE, the model is simultaneously balancing the fits to the Tasmanian trawl CPUE series, with associated good residual patterns for this series, so this appears to be the best overall result that can be achieved to fit both series simultaneously.

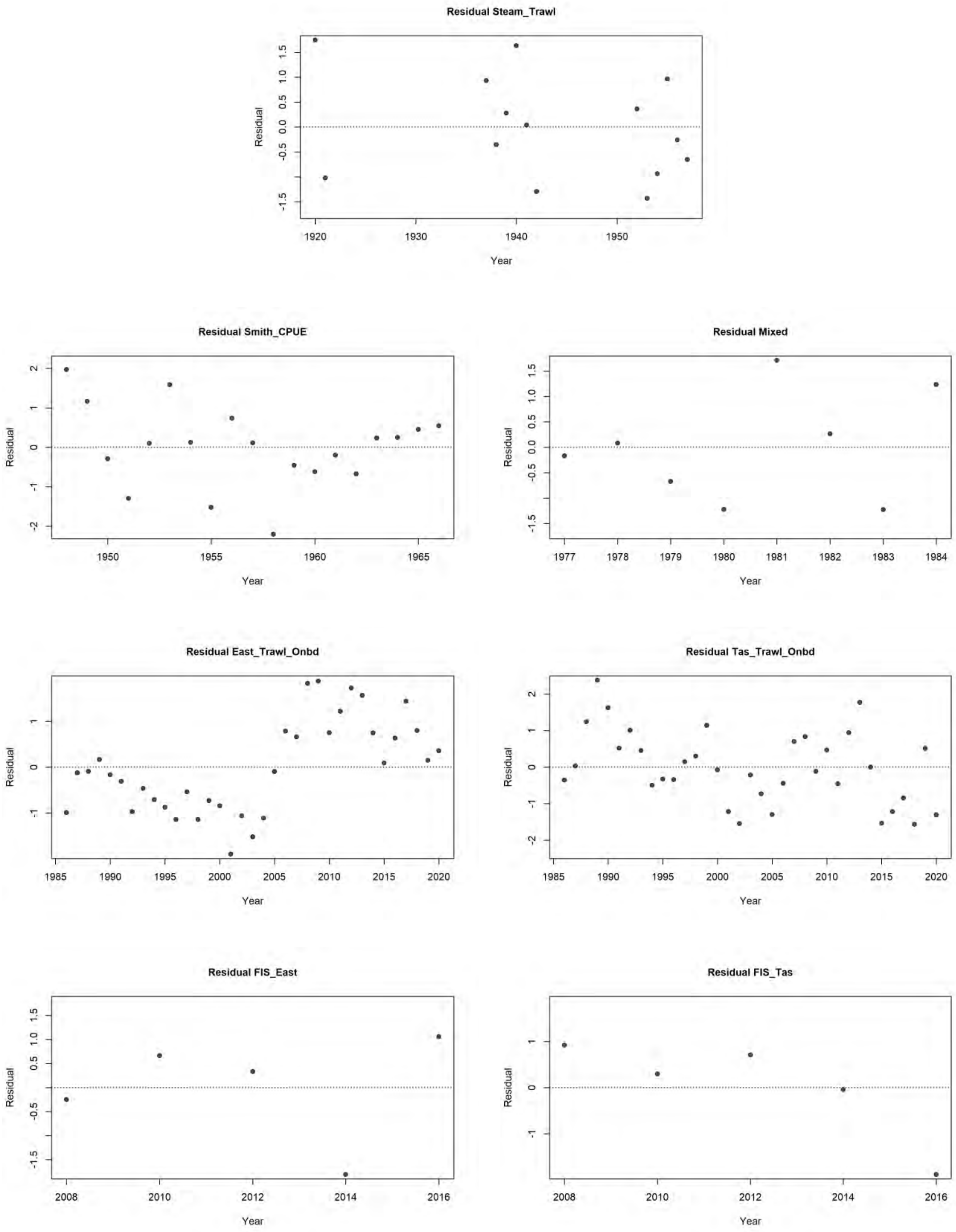
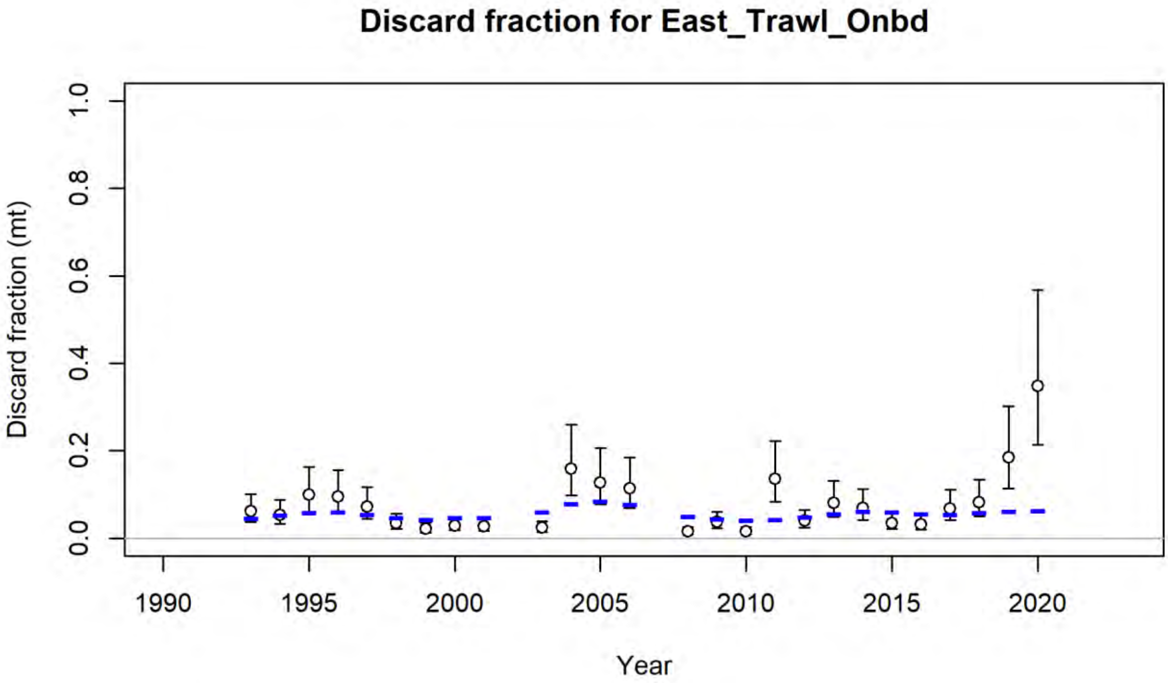


Figure 8.16. Residual patterns for fits to the seven CPUE series: steam trawl (top); Smith CPUE (second row, left); mixed fleet (second row, right); eastern trawl (third row, left); Tasmanian trawl (third row, right); FIS eastern trawl (bottom row, left); FIS Tasmanian trawl (bottom row, right).

The fits to the discard rate data for the current trawl fleets (Figure 8.17) are reasonable given the variability in the data. The discard proportion series has been revised since 2018, so the fits are quite different to those from the 2015 assessment, with estimated discarding rates less than 10% for both fleets. The discard rate for the eastern trawl fleet has increased in 2019 and 2020 to the highest rates on record. These discarding rates in the eastern trawl fleet warrant close attention in future years. To achieve predicted discard rates which have a better match to the overall discard rates, two years of very low (<1%) discard rate data (Table 8.4) were excluded from the eastern trawl fleet (2002 and 2007) and one additional year of discard rate data was excluded because the number of samples to estimate the discard rate was less than 10 (1992). Four years of very low (<1%) discard rate data were also excluded from the Tasmanian trawl fleet (1993, 2000, 2008 and 2009). If these very low discard rates are included in the model, the fitted discard rates match these very low rates well but give very poor fits to all other years with discard rates >1%. 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. Fits to the age and length composition data for discarded catches are shown in Appendix A.

The base-case model fits the aggregated retained and discarded length-frequency distributions very well (Figure 8.18 and Appendix A), with the exception of the retained length frequencies from Danish seine onboard. Note that a single selectivity is estimated for the combined port and onboard fleet in this case and, with the variation in data apparent between these different sources, the fits to both the port and onboard data require some compromise. The aggregated fits to the historical length frequency measurements are excellent (Figure 8.18).



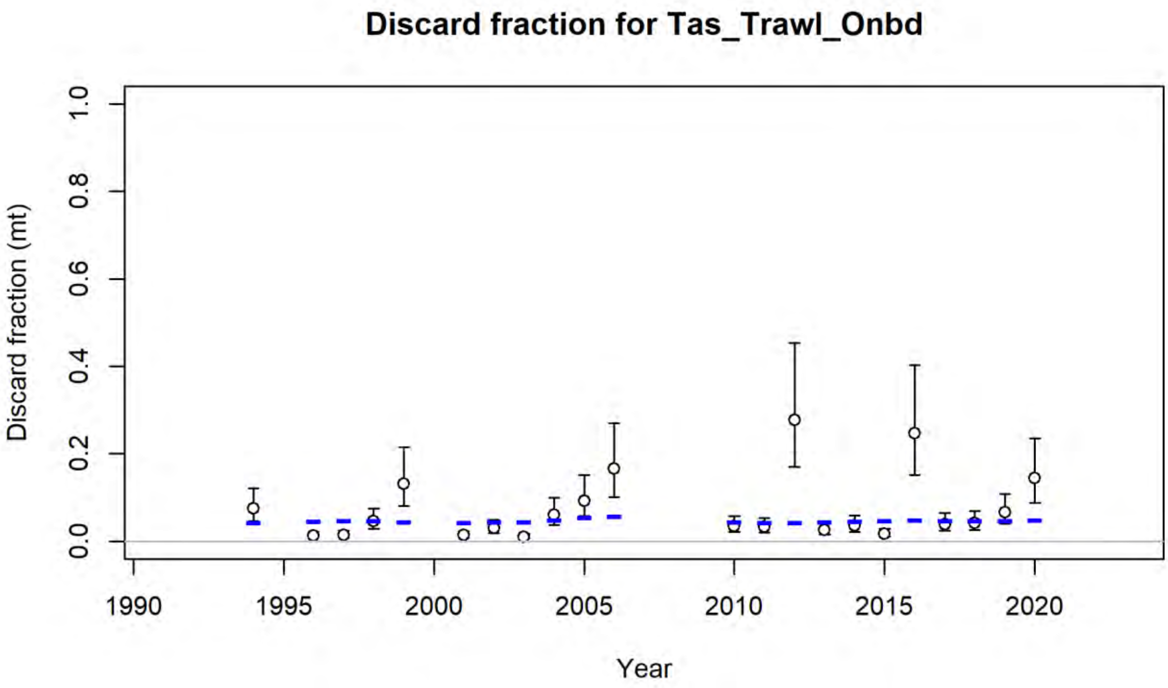


Figure 8.17. Observed (circles) and model-estimated (blue lines) discard estimates versus year for the eastern trawl fleet (top) and the Tasmanian trawl fleet (bottom), with approximate 95% asymptotic intervals.

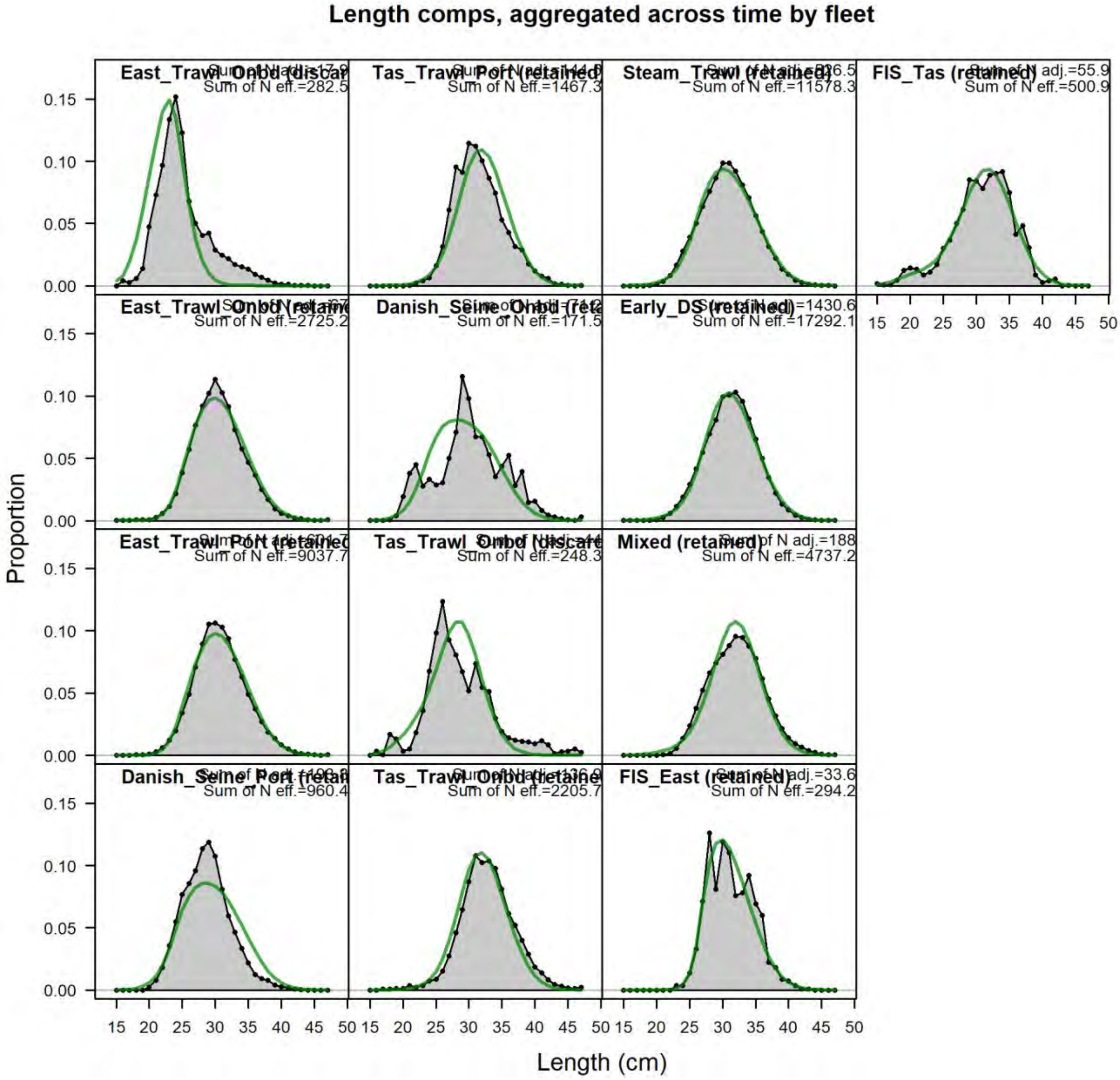


Figure 8.18. Fits to retained and discarded length compositions by fleet, separated by port and onboard samples, aggregated across all years. Observed data are grey and the fitted value is the green line.

The conditional age-at-length data is a little noisy between years, especially for the fleets with smaller catches. The mean age varies between seven and 11 years for eastern trawl, three and ten years for Danish seine, and four and 11 years for Tasmanian trawl. This variability in the age-at-length data is likely to be due to spatial or temporal variation in collection of age samples. The fits to conditional age-at-length are reasonable. Residuals for these fits and mean age for each year, aggregated across length bins, are shown in Appendix A.

The contributions to the total negative log likelihood by fleet and data source is shown in Table 8.17. This gives an indication of the contribution to the total negative log likelihood from different data components. These likelihood components decrease as the fit improves yet increase as the number of data points used for this fit increases, so a direct comparison is not always useful. The eastern trawl and Tasmanian trawl CPUE series have the same number of data points, so in this case, the lower values (negative, but larger in absolute magnitude, in this case) for the eastern trawl CPUE indicates a better fit than the Tasmanian trawl CPUE. Similarly, the fit to the Eastern trawl FIS abundance series is better than the fit to the Tasmanian trawl FIS abundance series, and the comparison is meaningful as they both have five data points. Comparing pairs from the other CPUE series is more nuanced and is only meaningful if the likelihood is smaller (more negative) from a series with a smaller number of CPUE data points. In this case, no conclusions can be drawn from the fits to the steam trawl CPUE, the mixed fleet CPUE and the Smith CPUE. For the length data, the only relevant comparison is between the two FIS fleets, as they each have the same number of years of data, and in this case the fits to the eastern trawl FIS lengths are better than those for the Tasmanian trawl FIS lengths.

Table 8.17. Negative log likelihood contributions by fleet and data source.

Likelihood component	Discard	Length	Age	CPUE
Fleet				
Eastern trawl (onboard)	59.5	25.3	181.3	-31.0
Eastern trawl (port)		39.7		
Danish seine (onboard)		32.8	130.2	
Danish seine (port)		33.7		
Tasmanian trawl (onboard)	116.8	57.4	301.9	-24.6
Tasmanian trawl (port)		22.7		
Steam trawl		15.7		-22.3
Early Danish seine		34.5		
Mixed		11.9		-16.3
Smith CPUE				-27.5
Eastern trawl FIS2		3.6		-9.0
Tasmanian trawl FIS2		7.9		1.5

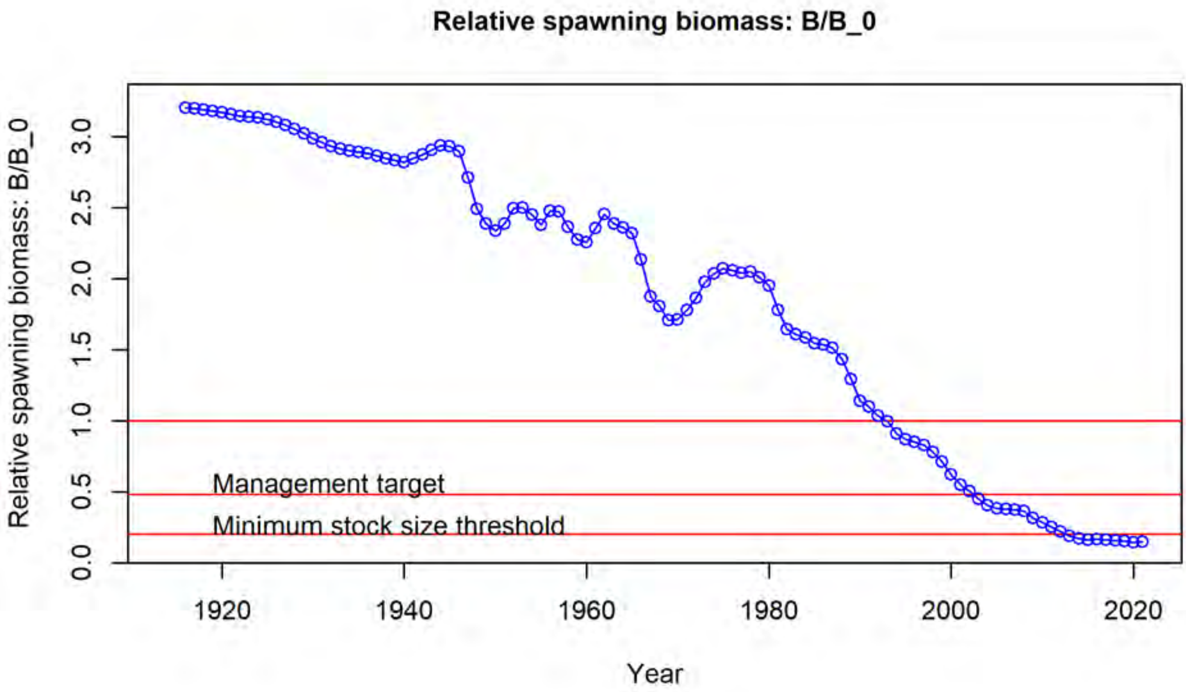


Figure 8.19. Time-trajectory of spawning biomass stock status corresponding to the MPD estimates for the base case analysis for eastern Jackass Morwong. Approximate 95% asymptotic intervals cannot be produced for the low recruitment scenario used in the base case.

8.4.1.4 Assessment outcomes (2021)

The current spawning stock biomass (Figure 8.19) is estimated to be 15% of unfished spawning stock biomass (i.e. spawning stock biomass at the start of 2022 relative to 1988 equilibrium spawning stock biomass), apparently with limited uncertainty, (the 95% asymptotic intervals cannot be calculated for the low recruitment base case to confirm this). The updated assessment estimates that the stock status first fell below B_{20} in 2013 and has remained below B_{20} ever since. In comparison, the last full assessment in 2018 (Day and Castillo-Jordán, 2018a) estimated the 2016 spawning biomass to be 35% of the 1988 equilibrium spawning stock biomass, with an expectation of continued recovery through to 2019. The current assessment estimates that the stock has a gradual decline for the first 30 years of the fishery, in contrast to the 2018 assessment results which estimated a much flatter trajectory in the same time period. The stock biomass then follows a variable trajectory through until the mid-1970s, followed by a steady decline through to 2020. In 1993, the stock first falls below the 1988 equilibrium spawning stock biomass, in 2003, the stock was estimated to first fall below the adjusted target reference point, B_{48}, relative to the 1988 equilibrium biomass, and in 2013 it first falls below the limit reference point, B_{20}, and has remained below B_{20} ever since.

In the 2018 stock assessment, seven of the last nine estimated recruitment events were below average (Figure 8.20 and Figure 8.21), with the other two only just above average (2010 and 2012). These recruitment deviations have been revised and all nine of these recruitment events, in addition to the three additional newly estimated recruitment events (2013-2015), are all estimated below average (the most recent 12 recruitments estimated to be below average), even with the productivity shift model implemented, as first accepted in the 2011 stock assessment model (Figure 8.21).

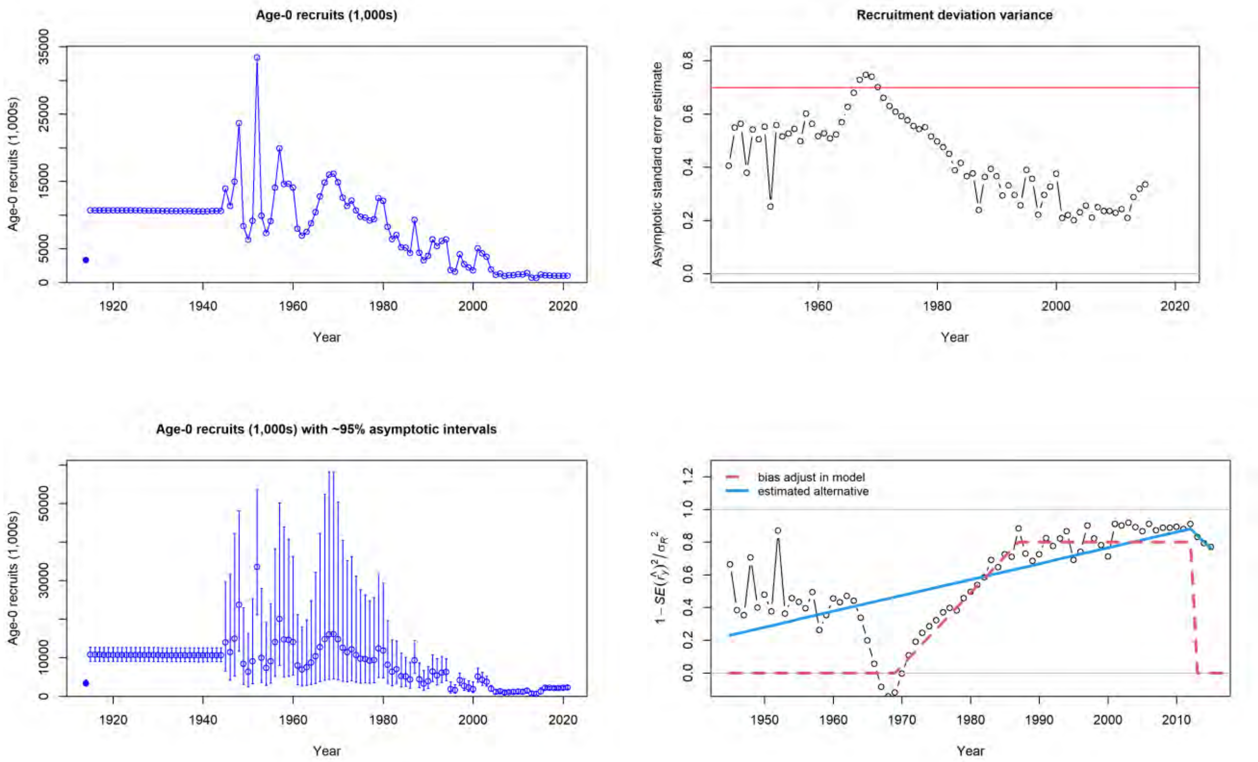
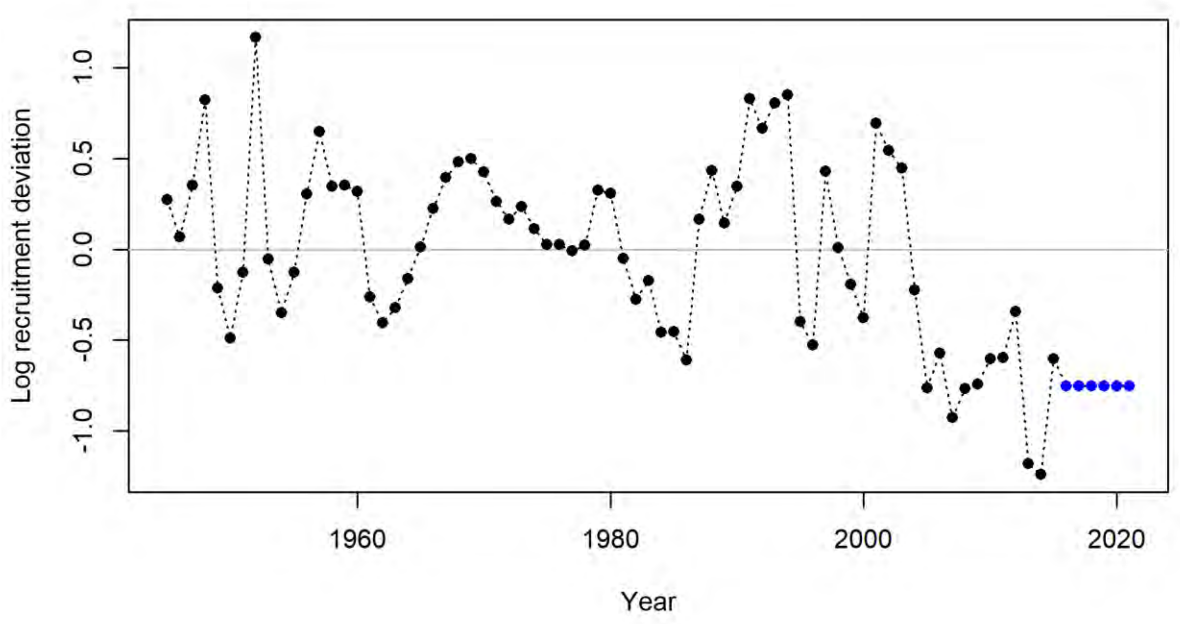


Figure 8.20. Recruitment estimation for the base case analysis. Top left: Time-trajectories of estimated recruitment numbers for the low recruitment base case; top right: the standard errors of recruitment deviation estimates; bottom left: time-trajectories of estimated recruitment numbers with approximate 95% asymptotic intervals for the modified base case, with average recruitment from 2016 onwards; bottom right: bias adjustment.

As the base case requires recruitment deviations to be fixed from 2016 onwards, it is not possible to calculate a hessian and estimate asymptotic uncertainty for this model. As a result, figures in this report requiring estimates of uncertainty are based on the modified base case, where recruitment from 2016 onwards is assumed to be average, allowing uncertainty estimates to be calculated for all parameters. This gives an indication of the type of uncertainty which may be expected from the low recruitment base case, although this modified base case is a different model, and values of the estimated parameters may vary slightly from the base case, with greater differences expected in the model outputs towards the end of the time series, from 2016 onwards. This is illustrated clearly in Figure 8.21, where the top plot (base case without uncertainty) has the recruitment deviations fixed below average from 2016 onwards and the bottom plot (modified base case, with uncertainty) has the recruitment deviations fixed at zero (equivalent to average recruitment) from 2016 onwards. The effect of these assumptions on absolute recruitment can also be seen in the left column plots in Figure 8.20.



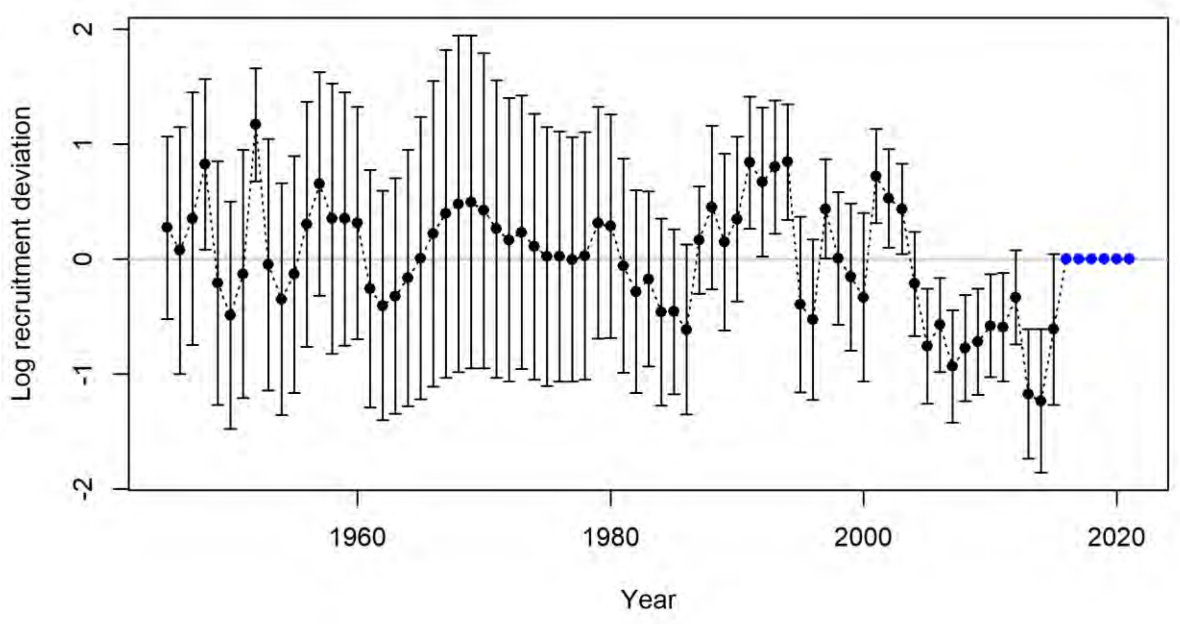


Figure 8.21. Time trajectory of estimated recruitment deviations for the base case, low recruitment from 2016 onwards (top) and of estimated recruitment deviations for the modified base case, average recruitment from 2016 onwards, with 95% confidence intervals.

The time-trajectories of estimated recruitment and estimated recruitment deviations are shown in Figure 8.20 and Figure 8.21. Estimates of recruitments appear to be correlated in the 1960s and 1970s, where there is limited information to inform these estimates and recruitment deviations are more variable since the 1980s and after the productivity shift (Figure 8.21). Recruitment is variable from 1986-2003 with recruitment deviations estimated both above and below zero. This is followed by a period of 12 years of below average estimated recruitment between 2004 and 2015, when the mean estimated recruitment deviation is -0.7, and a period of below average recruitment from 2006 to 2012 when the mean estimated recruitment deviation is -0.26. For the low recruitment base case, recruitment deviations from 2016 onwards are fixed at the mean recruitment deviation for the ten-year period 2006-2015, giving a fixed low future recruitment deviation of -0.75396 used in the base case (with low recruitments). These fixed low recruitments from 2016 onwards affect the projections beyond 2022, but also affect the biomass trajectory from 2016-2022, as these modelled recruitment events from the below average recruitment from 2016 onwards begin to flow into the spawning stock biomass prior to 2022, as these recruits reach maturity.

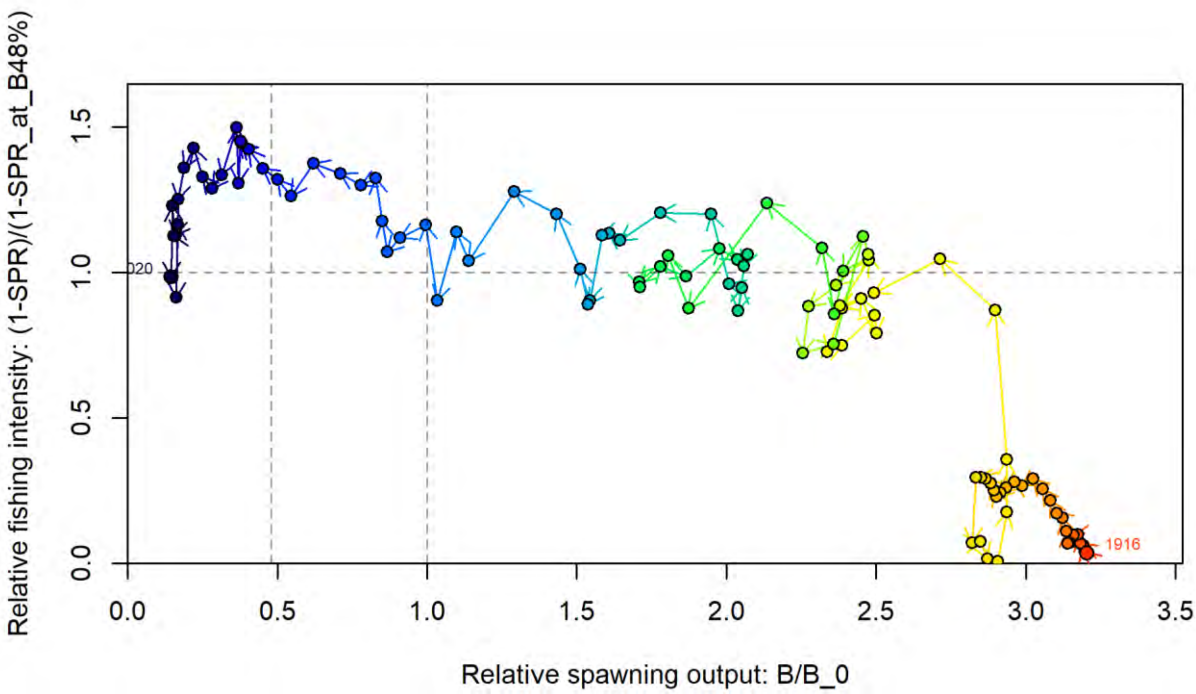


Figure 8.22. Kobe plot for the base case, showing the trajectory of spawning biomass (relative to B_0) plotted against 1-SPR, which is a proxy for fishing mortality, essentially integrating fishing mortality across fleets in the fishery. The horizontal line indicates the target fishing intensity that should theoretically result in the population reaching B_{48}.

Figure 8.22 shows a Kobe plot for the base case. 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 2020 (the red dot) where the biomass is below the limit reference point (less than 0.2 on the x-axis) and the fishing mortality is below the target fishing level (below the horizontal dashed line, the "target fishing value" which will achieve B_{48}). The fishing mortality has been below the target fishing mortality for only three of the last 30 years, in 1992, just before the biomass fell below the 1988 equilibrium unfished biomass, and again in 2015 and 2020. Fishing mortality first exceeded the target fishing mortality just before 1950, and varied above and below this mortality up until 1992, when there was a series of 23 consecutive years fishing above the target fishing mortality. In contrast, the Kobe plot from the 2018 assessment indicated that indicates the fishing mortality for the eastern stock of Jackass Morwong has been below the target fishing level for the last four years, following a period of around 20 years when the fishing mortality was above this target.

The spawning potential ratio is also plotted against year (Figure 8.23), which shows the time series above and below the target fishing mortality more clearly. Figure 8.23 indicates that the fishing mortality was at the historically highest levels in the period from 1997-2012, with only a slight reduction in fishing intensity in the most recent seven years and has been above the "target fishing mortality" for 27 out of the last 30 years.

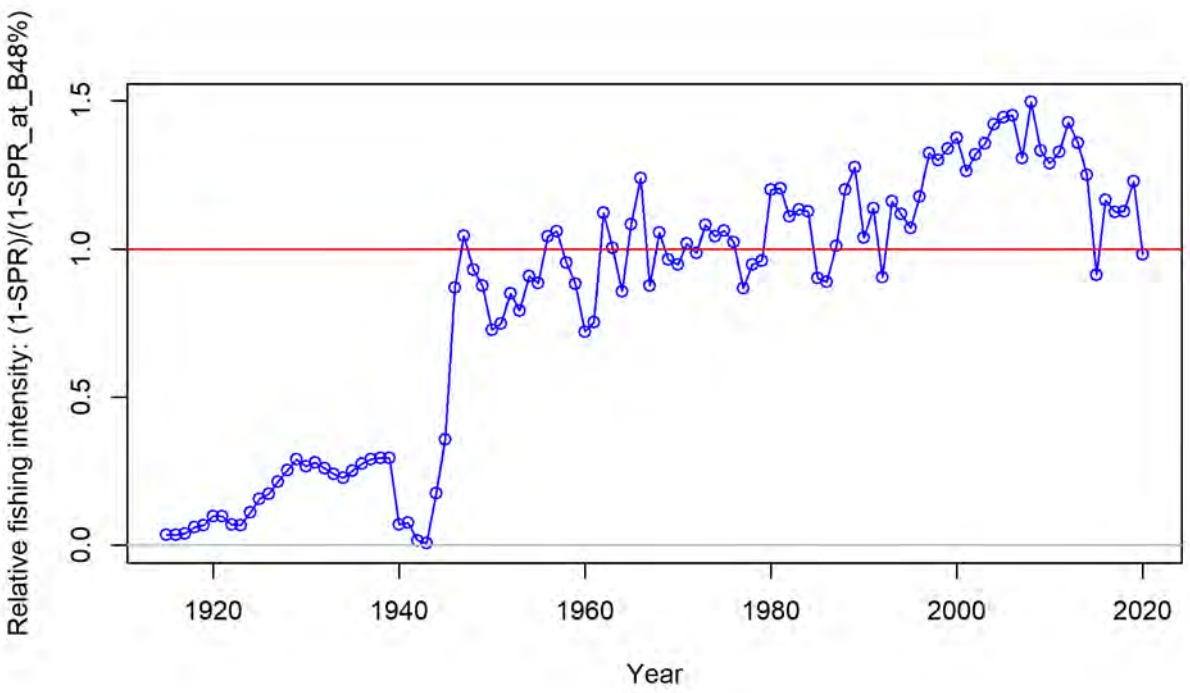


Figure 8.23. Time series of 1-SPR ratio, a proxy for fishing mortality, integrating fishing mortality across fleets in the fishery. The horizontal red line indicates the target fishing intensity that should theoretically result in the population reaching B_{48}.

The time-trajectories of recruitment and recruitment deviation are shown in Figure 8.20 and Figure 8.21. The model now has two stock-recruitment relationships, before and after 1988 (Figure 8.24). While the productivity shift (from 1988) which is incorporated into this model improves the residuals for the recruitment estimates from 1988 onwards, there appears to be considerable serial correlation and some patterns that may require further exploration (see the concentration of below average residuals for the years 2004-2015 in the bottom left hand corner of the right panel of Figure 8.24). It seems clear that a sudden step change in productivity in 1988 is not the best explanation for the recruitment patterns observed here, and there may have been further changes to the productivity since 1988. The first seven years after the recruitment shift (1988-1994) show recruitment that is well above average (Figure 8.21), followed by six years with variable recruitment (1995-2000), another three years with well above average recruitment (2001-2003), followed by 12 years of below average recruitment (2004-2015).

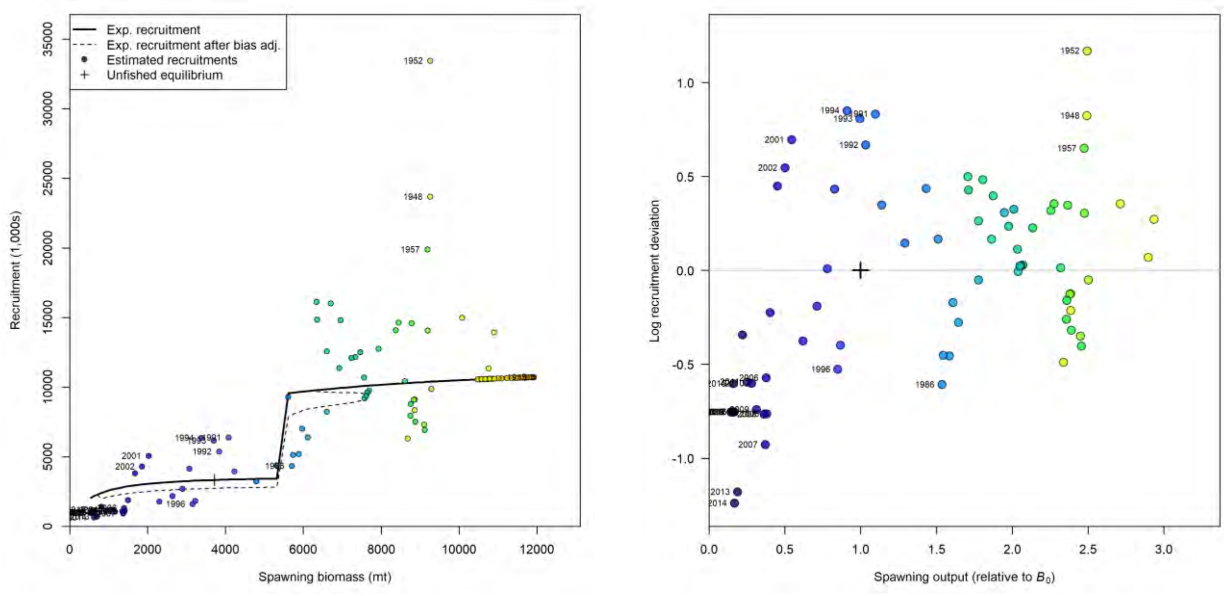


Figure 8.24. Recruitment estimation for the base case analysis. Left: the stock-recruit curve and estimated recruitments; right: log recruitment deviations from the stock recruitment curve.

8.4.1.5 *Historical assessment outcomes*

Table 8.18. Estimated stock status for the year the RBC was calculated (one year after each assessment was conducted) listed by assessment year and primary assessment author for eastern and western stocks of Jackass Morwong for assessments conducted between 2004 and 2021.

	stock status (%)		
Assessment year	east	west	Comments
2004 (Fay)	25-45		assessment was preliminary and uncertain (Coleraine)
2006 (Fay)	15		overfished in east - partly due to new CPUE series, which included previously excluded “small shots” (< 30kg) (SS)
2007 (Wayte)	19	63	still overfished in the east, not overfished in the west
2008 (Wayte)	19	68	still overfished in the east, not overfished in the west
2009 (Wayte)	24	70	no longer overfished in the east
2010 (Wayte)	26	70	gradual recovery continues
2011 (Wayte)	35	67	productivity shift accepted (aiding "recovery" in east) - new target and limit reference points applied in east
2015 (Tuck)	37	69	stable?
2018 (Day)	35	68	still stable?
2021 (prelim)	22		average recruitment assumed from 2016 onwards
2021 (base case)	15		overfished in east, low recruitment assumed from 2016 onwards

Table 8.18 summarises the estimated stock status for the year following each assessment (the year for which the RBC is calculated), for assessments conducted between 2004 and 2021, indicating stock status in the east and the west, with comments on notable changes to the assessment. All assessments from 2006 onwards were conducted in Stock Synthesis. The 2021 results include the preliminary base case which incorporates average recruitment from 2016 onwards (also sensitivity 15) and the adopted

base case with low recruitment assumed from 2016 onwards. Assessments were not conducted for the western stock prior to 2007. A western stock assessment was not conducted in 2021 due to limited data, poor data quality, concerns about the adequacy of the CPUE series to index the stock abundance and repeated concerns about the inability of previous western stock assessments to fit to the CPUE series. The initial western stock assessments were considered "preliminary" and then later classified as "increasingly uncertain" with concerns expressed about limited sampling effort, unrepresentative sampling, conflict between different data sources (highlighting potential unrepresentative sampling), very low catches and problematic retrospective patterns.

Comparison of base case results for the 2015, 2018 and 2021 assessments are show for absolute biomass (Figure 8.25), relative biomass or stock status (Figure 8.26 and Figure 8.27) and recruitment (Figure 8.28 and Figure 8.29).

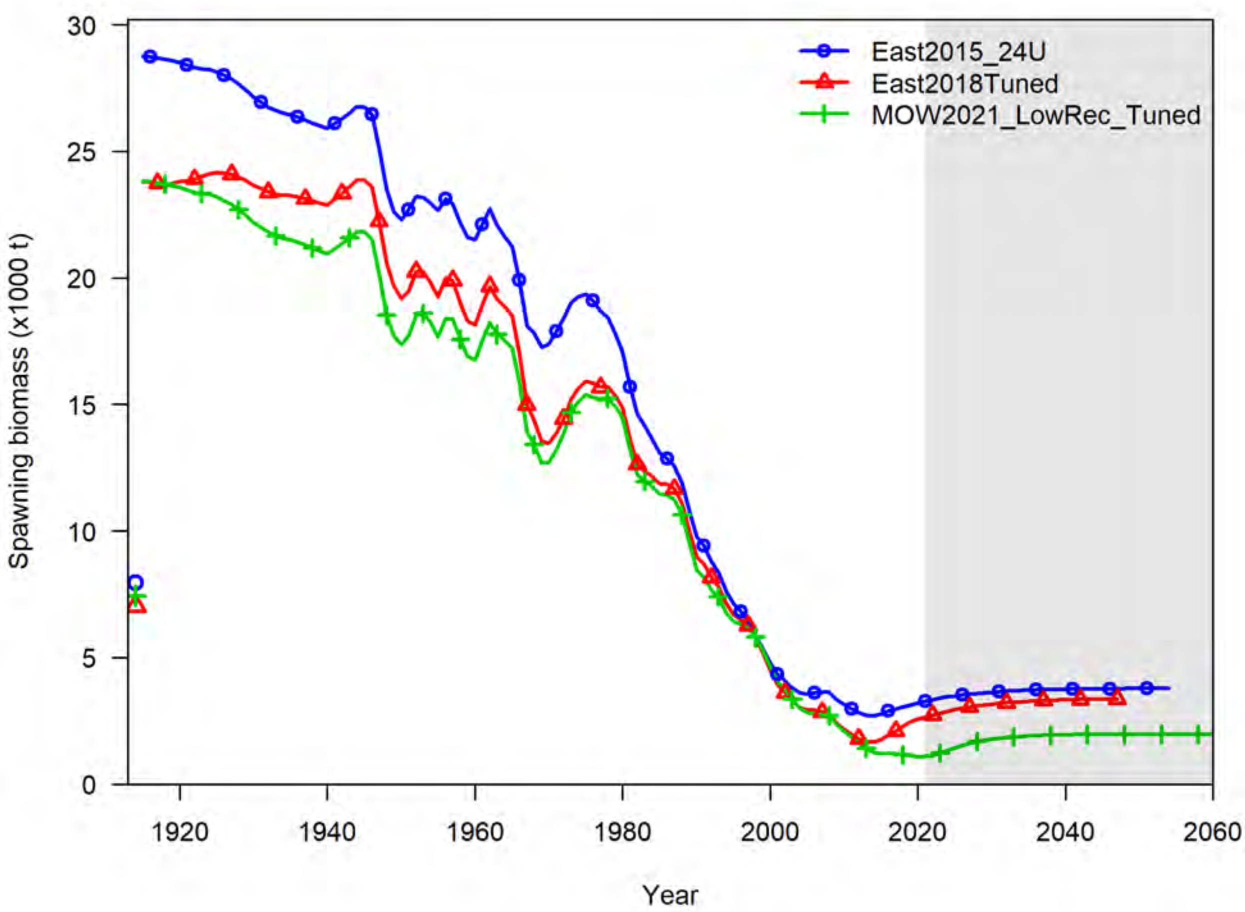


Figure 8.25. Comparison of estimated absolute spawning stock biomass times series for the last three eastern Jackass Morwong stock assessments: 2015 base case (blue); 2018 base case (red); and 2018 base case (green).

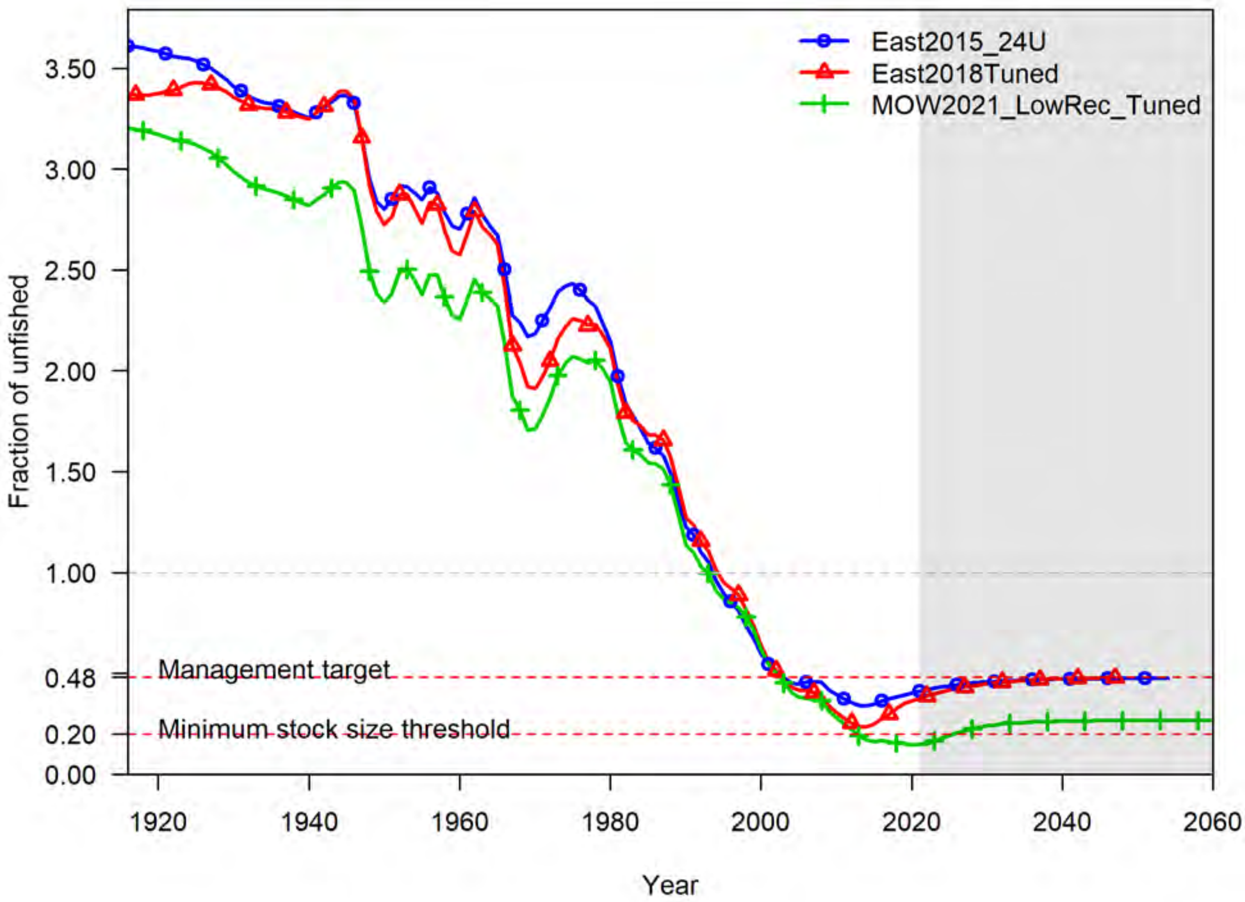


Figure 8.26. Comparison of estimated relative biomass (stock status) times series for the last three eastern Jackass Morwong stock assessments: 2015 base case (blue); 2018 base case (red); and 2018 base case (green).

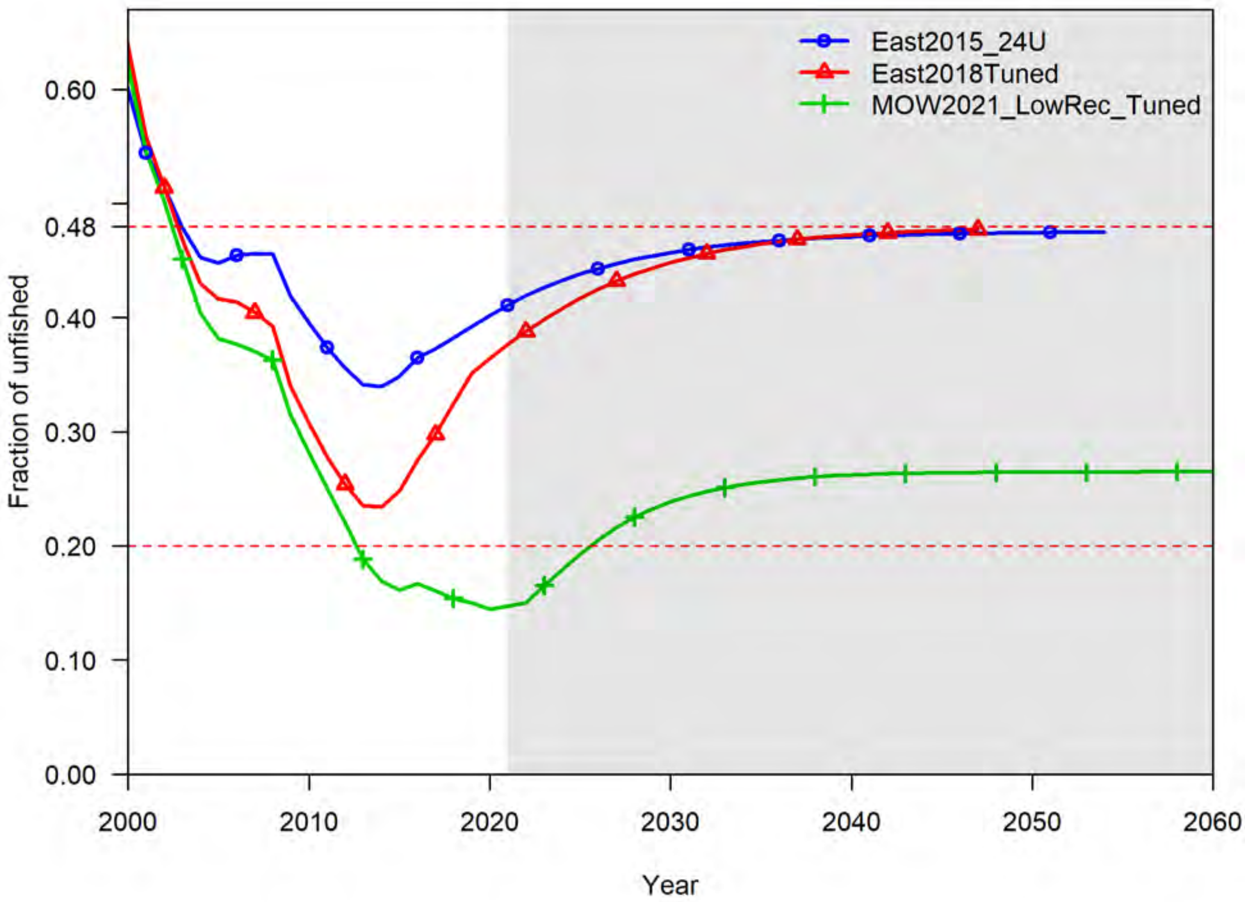


Figure 8.27. Comparison of estimated relative biomass (stock status) times series for the last three eastern Jackass Morwong stock assessments from 2000 onwards: 2015 base case (blue); 2018 base case (red); and 2018 base case (green).

Figure 8.27 highlights the revisions to the estimates of stock status as more data became available to successive assessments, especially in the period from 2010 to 2020, and also indicates that the projected catches for the low recruitment 2021 base case (using the SESSSF Harvest Control Rule, which assumes average future recruitment) do not allow the stock to recover to the target reference point (SSB_{48}) in the projection period.

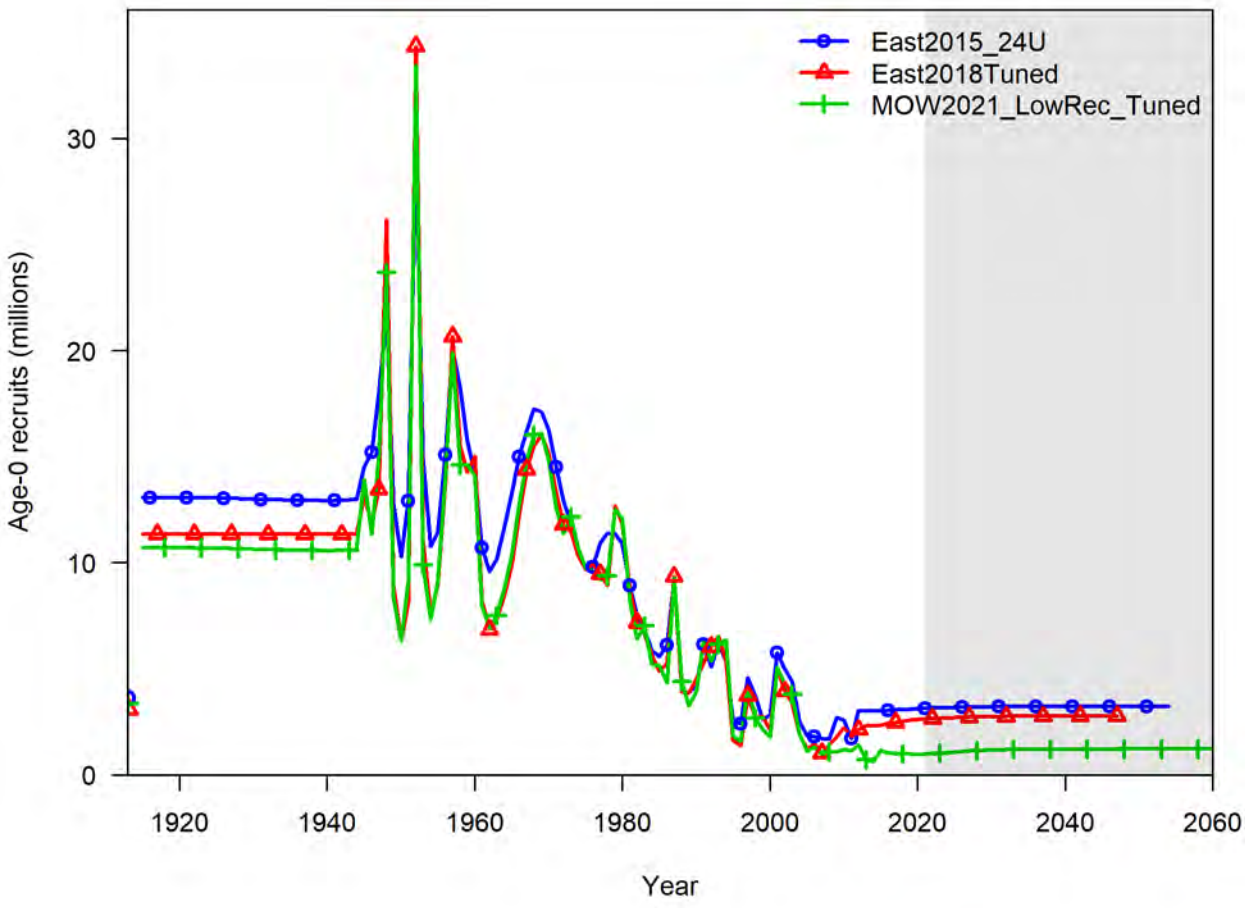


Figure 8.28. Comparison of estimated absolute recruitment times series for the last three eastern Jackass Morwong stock assessments: 2015 base case (blue); 2018 base case (red); and 2018 base case (green).

Figure 8.28 and Figure 8.29 highlight the fixed low recruitment from 2016 onwards for the 2021 assessment. The downwards revision of recent deviations in the 2021 assessment is also clear in Figure 8.28, with the recruitment deviations from 2021 (green crosses) often revised downwards towards the end of the time series. Compared to the 2018 assessment (Figure 8.28, red triangles), 13 of the last 15 estimated recruitment deviations (1998-2012) have been revised downwards in the 2021 assessment compared to the 2018 assessment, with an average downward revision of recruitment deviations of -0.27 compared to an upwards revision of 0.04 for the two exceptions.

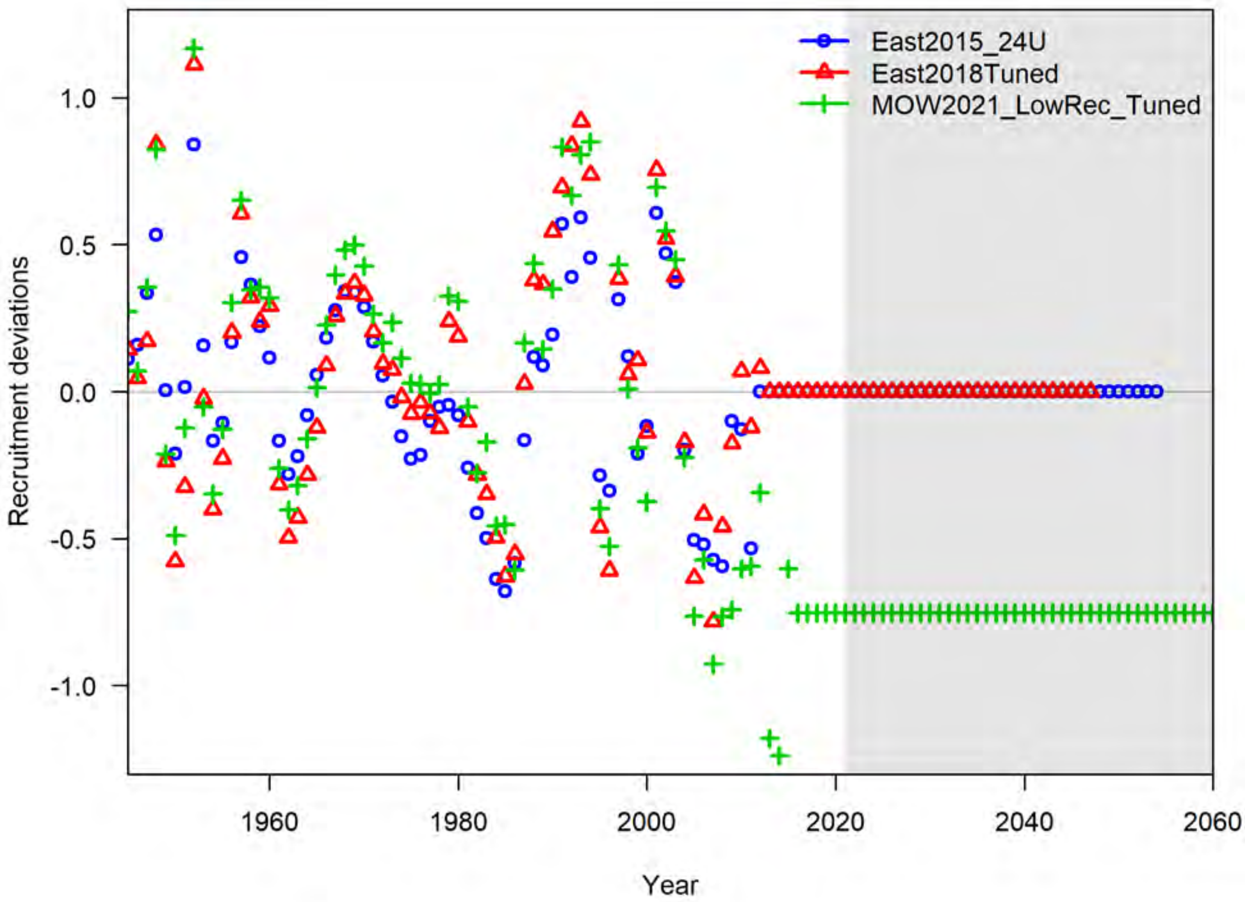


Figure 8.29. Comparison of estimated recruitment deviations for the last three eastern Jackass Morwong stock assessments: 2015 base case (blue); 2018 base case (red); and 2018 base case (green).

8.4.2 *Application of the HCR*

An estimate of the catch for the 2021 calendar year is needed to run the model forward to calculate the 2022 spawning biomass and estimated stock status. We assume the same catch by fleet in 2021 as was caught in 2020, which was a total catch of 103 t, comprising 60 t from the eastern trawl fleet, 14 t from the Danish seine fleet and 19 t from the Tasmanian trawl fleet.

The base-case assessment estimates that current spawning stock biomass is 15% of unexploited stock biomass (SSB_0). The 2022 recommended biological catch (RBC) under the 20:35:48 harvest control rule is 0 t (Table 8.19) and the long-term yield (assuming low recruitment from 2016 onwards) is 91 t (Table 8.23). Averaging the RBC over the three-year period 2019-2021, the average RBC is 0 t and over the five-year period 2019-2023, the average RBC is 1 t (Table 8.23). The RBCs for each individual year from 2022-2026 are listed in Table 8.19 for the base case, with low recruitment assumed from 2016 onwards.

Table 8.19. Yearly projected RBCs (tonnes) across all fleets under the 20:35:48 harvest control rules all assuming low recruitment from 2016 for the agreed base.

Year	RBC
2022	0
2023	0
2024	0
2025	0
2026	6

8.4.3 *Discard estimates*

Model estimates for discards for the period 2022-26 with the 20:35:48 harvest control rule, assuming that the catch is equal to the RBC from 2022-2026, are listed in Table 8.20 for the base case, with a range of 0.0 to 0.2 t for these projected years. Historical values are also listed back to 2017 for estimated discard mass. Table 8.20 also lists the stock status from 2017-2026 (estimated and projected stock status (assuming that the RBC is caught for projections).

Table 8.20. Yearly estimated (bold) and projected (grey) values for (i) stock status (%) and (ii) discards (tonnes) across all fleets under the 20:35:48 harvest control rule, with catches set to the calculated RBC for each projected year from 2022 to 2026 for the low recruitment base case, and with catches in 2021 assumed to be the same values as the catches from 2020.

Year	Stock status (%)	Discards (t)
2017	**16.1**	**7.7**
2018	**15.4**	**7.6**
2019	**15.0**	**8.6**
2020	**14.4**	**5.6**
2021	14.7	5.5
2022	15.0	0.0
2023	16.5	0.0
2024	17.9	0.0
2025	19.3	0.0
2026	20.5	0.2

8.4.4 *Fixed catch, low recruitment projections*

Estimates of recruitment deviations for Jackass Morwong have been below average since the early 2000s (Figure 8.21), which is possibly a consequence of directional environmental change. If below average recruitment continues into the future, producing model projections which assume average recruitment from 2016 onwards would result in overly optimistic estimates of biomass and stock status. Due to these concerns, the base case for this assessment incorporates low, rather than average, fixed recruitment deviations from 2016 onwards. The projected value for low recruitments is based on the average recruitment deviations between 2004 and 2015 (producing an average recruitment deviation value of= -0.754). A range of fixed annual catches for a series of constant catch projection scenarios, with total retained catch set at 0 t, 50 t, 100 t and 150 t, were projected through to 2060 with this low recruitment level to explore biomass trajectories. The fixed historical recruitment deviation time series used for low projections is the same as that shown in Figure 8.21.

As the low recruitment scenario markedly reduces stock productivity, the population is no longer able to recover to unfished levels in the absence of fishing, or indeed even to recover to B_{48}, as is apparent from the 0 t catch projection scenario, under which the population only recovers near to 40% of SSB_0 (Figure 8.30, blue line). When various fixed catches are projected (0 t, 50 t, 100 t, 150 t and the RBC obtained from applying the HCR), the equilibrium stock status declines accordingly (32% for 50 t, 21% for 100 t, 0 % for 150 t and 26.5 % for the RBC, Table 8.21). The RBC is applied using the standard SESSF Harvest Control Rule, which assumes that all future recruitment will be average. When the RBC is calculated, the assumed low recruitment from 2016 to the year before the RBC is set is properly accounted for, but the (expected) low recruitment in the future is not considered, as the current RBC calculation, which is built in to Stock Synthesis, does not allow for anything other than average recruitment in the future. It appears that catches of around 100 t only just allows the stock to recover to B_{20} and catches above 100 t result in a continued decline in stock size (Figure 8.30).

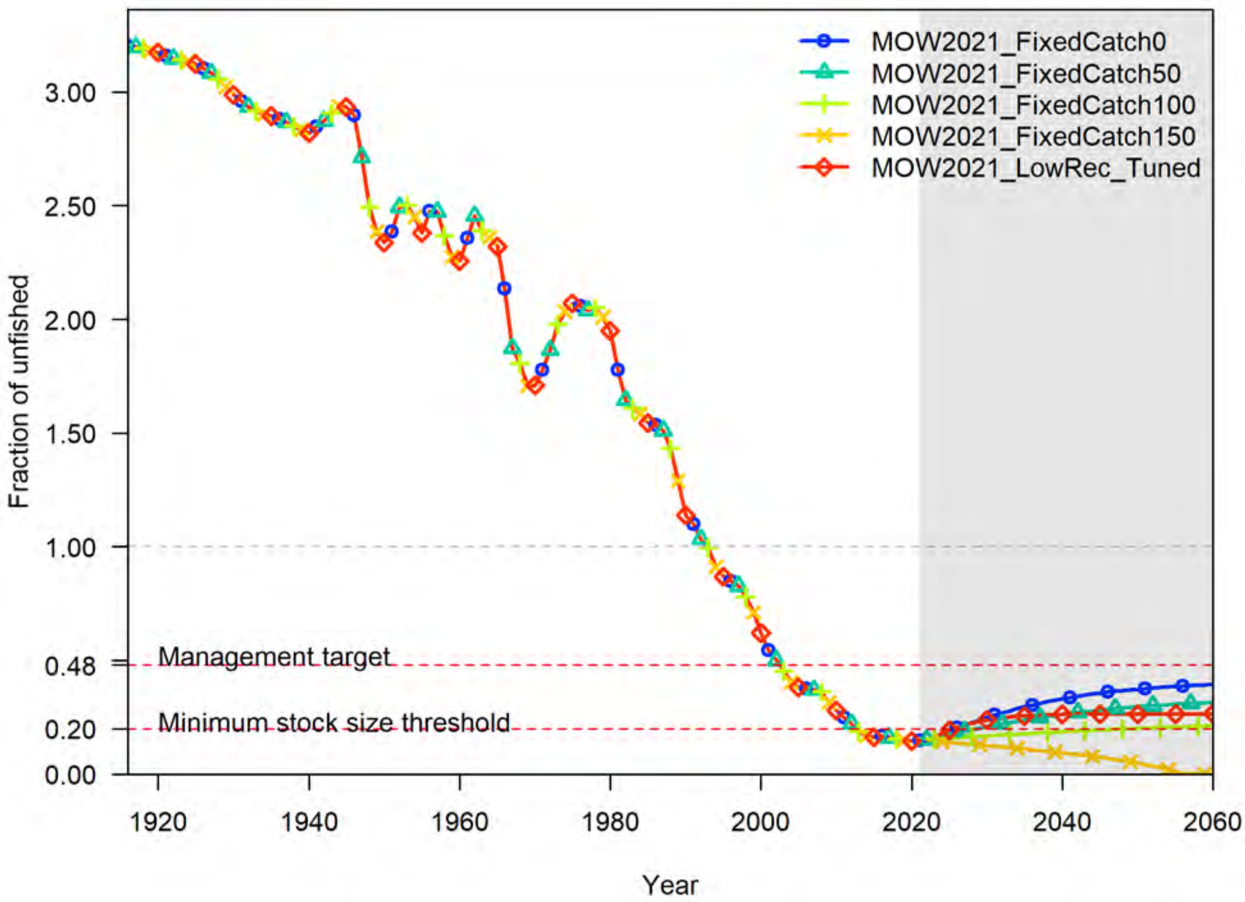


Figure 8.30. Stock status time-series for the RBC calculated by the SESSF harvest control rule (red), and four alternative constant catch scenarios 0 t, 50 t, 100 t, 150 t. All scenarios assume low recruitment for the entire forecast period.

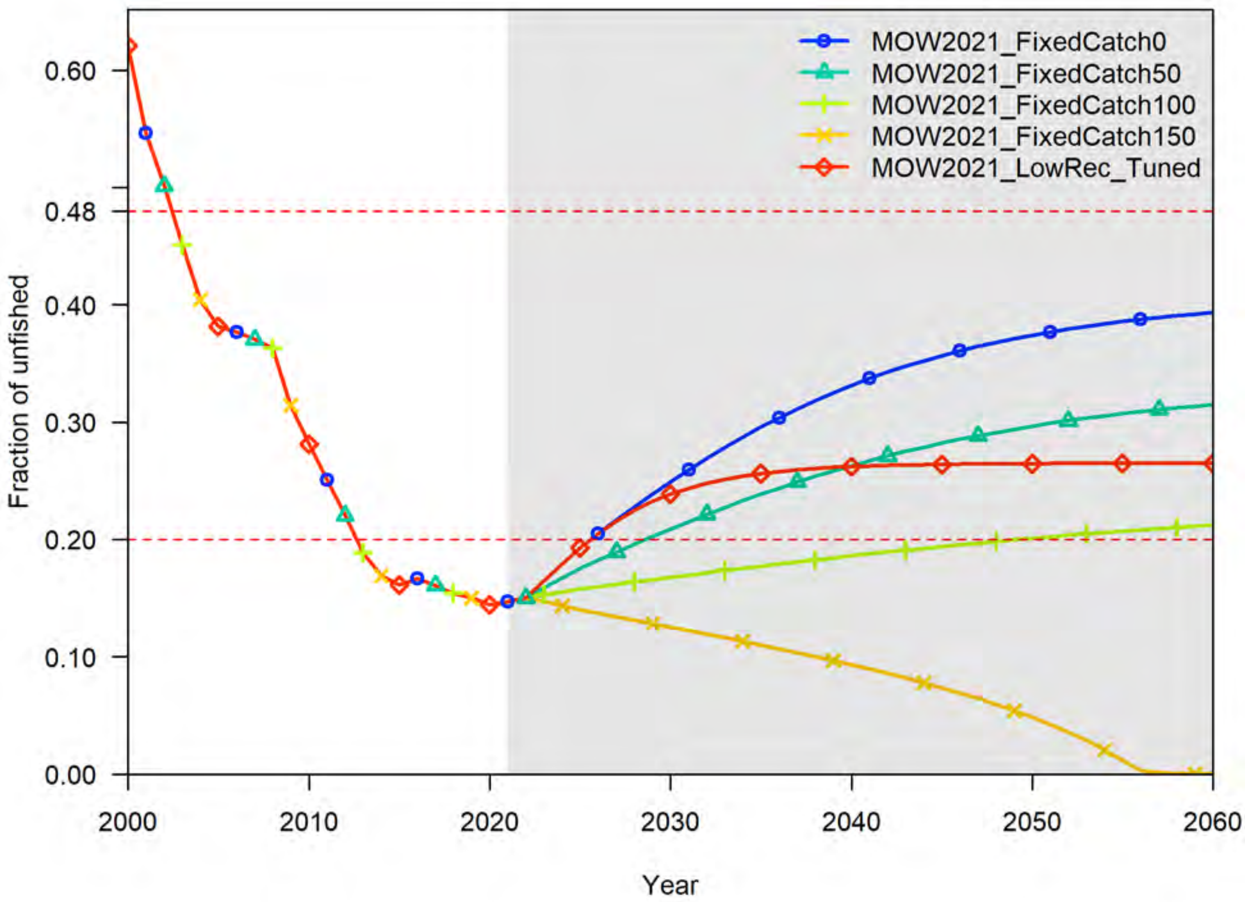


Figure 8.31. Stock status time-series (2000-2060) for the RBC calculated by the SESSF harvest control rule (red), and four alternative constant catch scenarios 0 t, 50 t, 100 t, 150 t. All scenarios assume low recruitment for the entire forecast period.

Table 8.21 provides stock status, retained catches and estimated discards for the low recruitment scenarios with zero catch (0 t), 50 t, 100 t and 150 t catches and applying the standard SESSF harvest control rule (HCR).

Table 8.21. Stock status (SS, %), retained catch (RET, t) and estimated discards (DIS, t) corresponding to the low recruitment, fixed catch projection scenarios with the zero catch (0 t), 50 t constant catch, 100 t constant catch, 150 t constant catch and applying the HCR.

Catch	0 t			50 t			100 t			150 t			HCR		
Year	SS	RET	DIS	SS	RET	DIS	SS	RET	DIS	SS	RET	DIS	SS	RET	DIS
2022	15.0	0.0	0.0	15.0	50.0	2.6	15.0	100.0	5.2	15.0	150.0	7.9	15.0	0.0	0.0
2023	16.5	0.0	0.0	15.9	50.0	2.5	15.3	100.0	5.1	14.7	150.0	8.0	16.5	0.0	0.0
2024	17.9	0.0	0.0	16.7	50.0	2.4	15.5	100.0	5.1	14.4	150.0	8.1	17.9	0.0	0.0
2025	19.3	0.0	0.0	17.5	50.0	2.3	15.8	100.0	5.0	14.0	150.0	8.2	19.3	0.0	0.0
2026	20.5	0.0	0.0	18.2	50.0	2.3	16.0	100.0	5.0	13.7	150.0	8.3	20.5	5.5	0.2
2027	21.7	0.0	0.0	18.9	50.0	2.2	16.2	100.0	5.0	13.4	150.0	8.4	21.6	18.6	0.7
2028	22.8	0.0	0.0	19.6	50.0	2.2	16.4	100.0	4.9	13.1	150.0	8.5	22.5	30.4	1.2
2029	23.9	0.0	0.0	20.3	50.0	2.2	16.6	100.0	4.9	12.8	150.0	8.6	23.3	40.7	1.6
2030	24.9	0.0	0.0	20.9	50.0	2.2	16.8	100.0	4.9	12.5	150.0	8.7	23.9	49.5	1.9
2031	25.9	0.0	0.0	21.5	50.0	2.1	17.0	100.0	4.9	12.2	150.0	8.8	24.4	57.1	2.2
2032	26.9	0.0	0.0	22.1	50.0	2.1	17.2	100.0	4.8	11.9	150.0	8.9	24.8	63.5	2.4
2033	27.9	0.0	0.0	22.7	50.0	2.1	17.4	100.0	4.8	11.6	150.0	9.0	25.1	68.8	2.6
2034	28.7	0.0	0.0	23.3	50.0	2.1	17.5	100.0	4.8	11.3	150.0	9.1	25.4	73.2	2.8
2035	29.6	0.0	0.0	23.8	50.0	2.0	17.7	100.0	4.8	11.0	150.0	9.2	25.6	76.8	2.9
2036	30.4	0.0	0.0	24.4	50.0	2.0	17.9	100.0	4.7	10.7	150.0	9.3	25.8	79.7	3.0
2037	31.1	0.0	0.0	24.9	50.0	2.0	18.1	100.0	4.7	10.4	150.0	9.5	25.9	82.0	3.1
2038	31.8	0.0	0.0	25.4	50.0	2.0	18.3	100.0	4.7	10.0	150.0	9.6	26.1	83.9	3.2
2039	32.5	0.0	0.0	25.8	50.0	2.0	18.4	100.0	4.7	9.7	150.0	9.8	26.1	85.5	3.3
2040	33.1	0.0	0.0	26.3	50.0	1.9	18.6	100.0	4.7	9.3	150.0	10.0	26.2	86.7	3.3
2041	33.7	0.0	0.0	26.7	50.0	1.9	18.8	100.0	4.6	9.0	150.0	10.1	26.3	87.6	3.3
2042	34.3	0.0	0.0	27.1	50.0	1.9	18.9	100.0	4.6	8.6	150.0	10.3	26.3	88.4	3.4
2043	34.8	0.0	0.0	27.5	50.0	1.9	19.1	100.0	4.6	8.2	150.0	10.6	26.3	89.0	3.4
2044	35.2	0.0	0.0	27.9	50.0	1.9	19.2	100.0	4.6	7.8	150.0	10.8	26.4	89.5	3.4
2045	35.7	0.0	0.0	28.2	50.0	1.9	19.4	100.0	4.6	7.4	150.0	11.1	26.4	89.8	3.4
2046	36.1	0.0	0.0	28.5	50.0	1.9	19.5	100.0	4.6	6.9	150.0	11.4	26.4	90.1	3.4
2047	36.5	0.0	0.0	28.8	50.0	1.9	19.7	100.0	4.5	6.4	150.0	11.8	26.4	90.4	3.4
2048	36.8	0.0	0.0	29.1	50.0	1.8	19.8	100.0	4.5	5.9	150.0	12.3	26.4	90.6	3.4
2049	37.1	0.0	0.0	29.4	50.0	1.8	20.0	100.0	4.5	5.4	150.0	12.9	26.5	90.7	3.4
2050	37.4	0.0	0.0	29.7	50.0	1.8	20.1	100.0	4.5	4.8	150.0	13.6	26.5	90.8	3.5
2051	37.7	0.0	0.0	29.9	50.0	1.8	20.2	100.0	4.5	4.2	150.0	14.6	26.5	90.9	3.5
2052	37.9	0.0	0.0	30.1	50.0	1.8	20.4	100.0	4.5	3.6	150.0	16.1	26.5	91.0	3.5
2053	38.2	0.0	0.0	30.3	50.0	1.8	20.5	100.0	4.5	2.8	150.0	18.4	26.5	91.1	3.5
2054	38.4	0.0	0.0	30.5	50.0	1.8	20.6	100.0	4.4	2.0	150.0	23.2	26.5	91.1	3.5
2055	38.6	0.0	0.0	30.7	50.0	1.8	20.7	100.0	4.4	1.2	137.8	34.2	26.5	91.1	3.5
2056	38.8	0.0	0.0	30.9	50.0	1.8	20.8	100.0	4.4	0.3	54.3	17.7	26.5	91.2	3.5
2057	38.9	0.0	0.0	31.1	50.0	1.8	20.9	100.0	4.4	0.1	34.6	8.3	26.5	91.2	3.5
2058	39.1	0.0	0.0	31.2	50.0	1.8	21.0	100.0	4.4	0.0	12.6	2.1	26.5	91.2	3.5
2059	39.2	0.0	0.0	31.4	50.0	1.8	21.1	100.0	4.4	0.0	-2.7	0.4	26.5	91.2	3.5
2060	39.3	0.0	0.0	31.5	50.0	1.8	21.2	100.0	4.4	0.1	5.7	0.2	26.5	91.2	3.5

8.4.5 *Retrospective analysis*

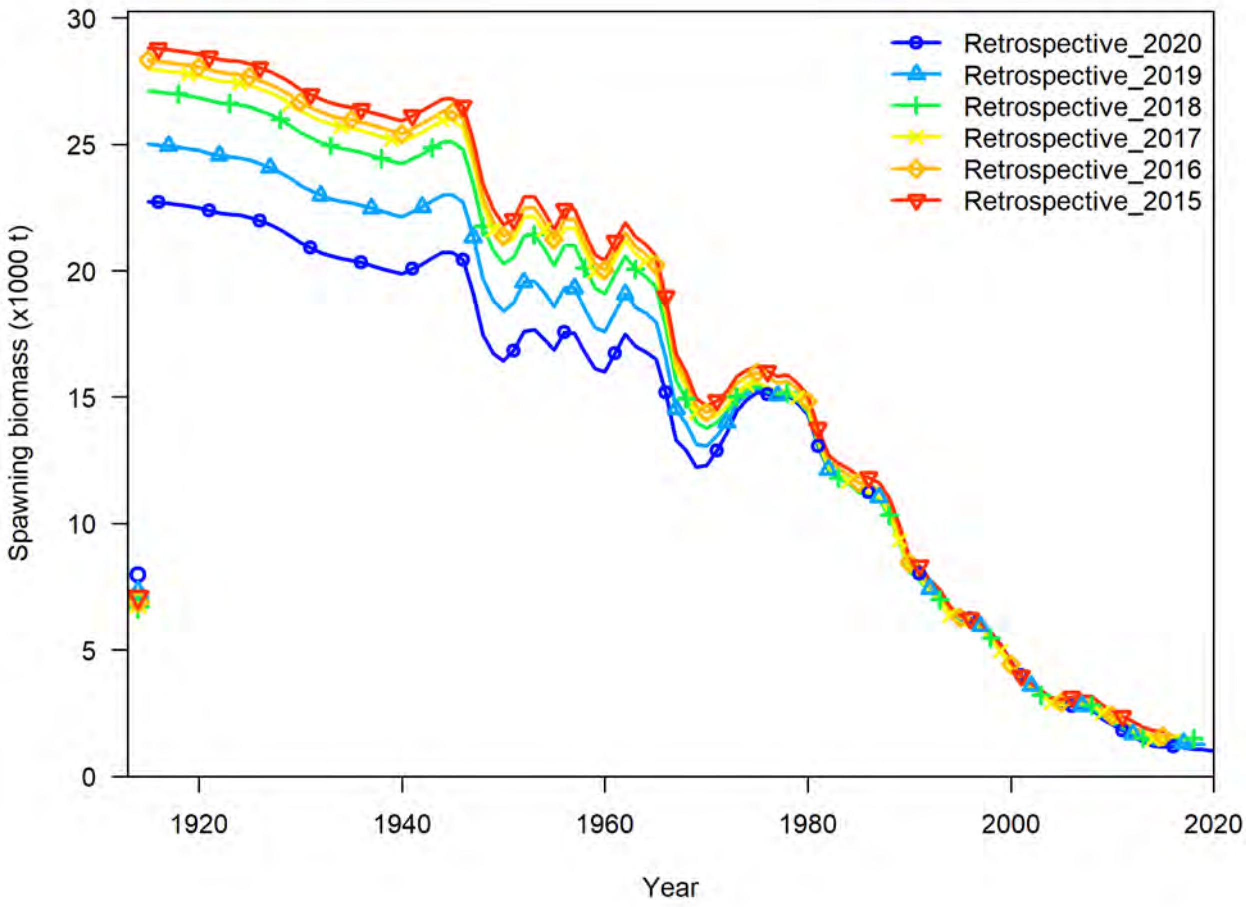


Figure 8.32. Retrospectives for absolute spawning biomass for Jackass Morwong, with data included to 2020 (blue) and then successive years removed back to 2015 (red).

A retrospective analysis for absolute spawning biomass is shown in Figure 8.32, with the data after 2019 removed initially (shown in light blue), then successive years of data removed back to 2015 (shown in red). The same analysis is plotted in terms of relative spawning biomass in Figure 8.33. In both cases the changes are largest for the first two years of data removal, with a slightly larger initial spawning stock biomass estimated as each successive year of data is removed, but with apparently small differences in recent years (Figure 8.32). This change becomes clearer when plotted as relative stock status (Figure 8.33), normalised to the 1988 equilibrium spawning biomass, in which case the 1915 equilibrium biomass, is revised substantially when the first two years of data is removed, with minimal changes as further years of data are removed. This suggests that the most recent two years of data have been most influential in revising the initial stock status downward (translated into 1988 equilibrium spawning stock biomass). The changes in the most recent years are hard to distinguish in Figure 8.33, given the scale of the 1915 spawning stock biomass and stock status, so the same retrospective trajectories, showing the last 20 years only, is presented in Figure 8.34.

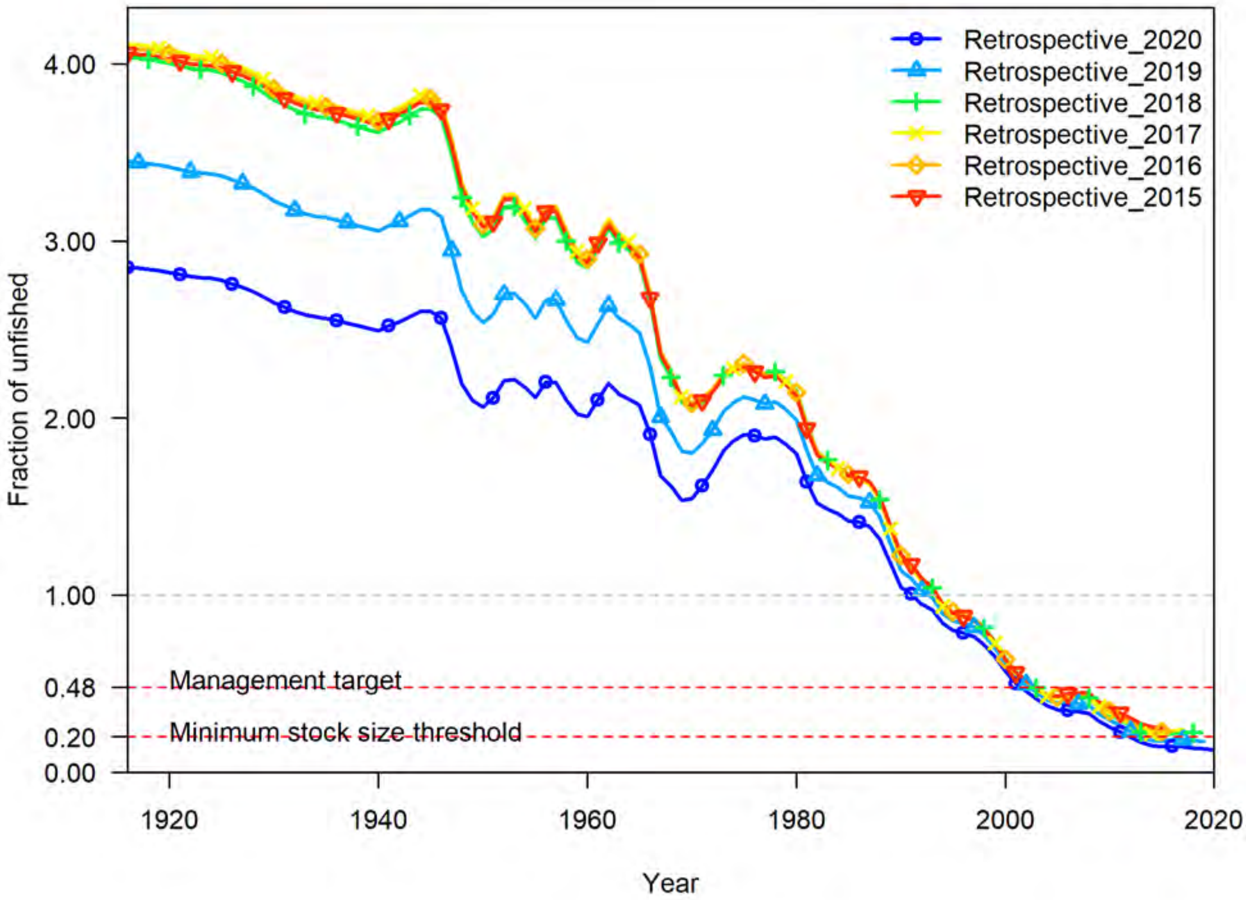


Figure 8.33. Retrospectives for relative stock status for Jackass Morwong, with data included to 2020 (blue) and then successive years removed back to 2015 (red).

When this retrospective analysis is applied to the absolute recruitment time series (Figure 8.35), the most significant changes appear to predominantly affect the initial equilibrium recruitment level, R_0, with again the largest changes seen when the data from 2020 and 2019 are removed.

However, there are some more subtle changes that can be drawn out when examining the plot showing recruitment residuals (Figure 8.36), rather than absolute recruitment, which indicates a gradual change in the estimates of the recent recruitment events (over a period of around 20 years), with a clear pattern where the most recent residuals are continually revised down as more data is used to estimate them, with larger downward revisions to the most recent estimates of recruitment deviations. This suggests that the inclusion of the most recent years of data included in this assessment supports successively more pessimistic estimates of recent recruitment.

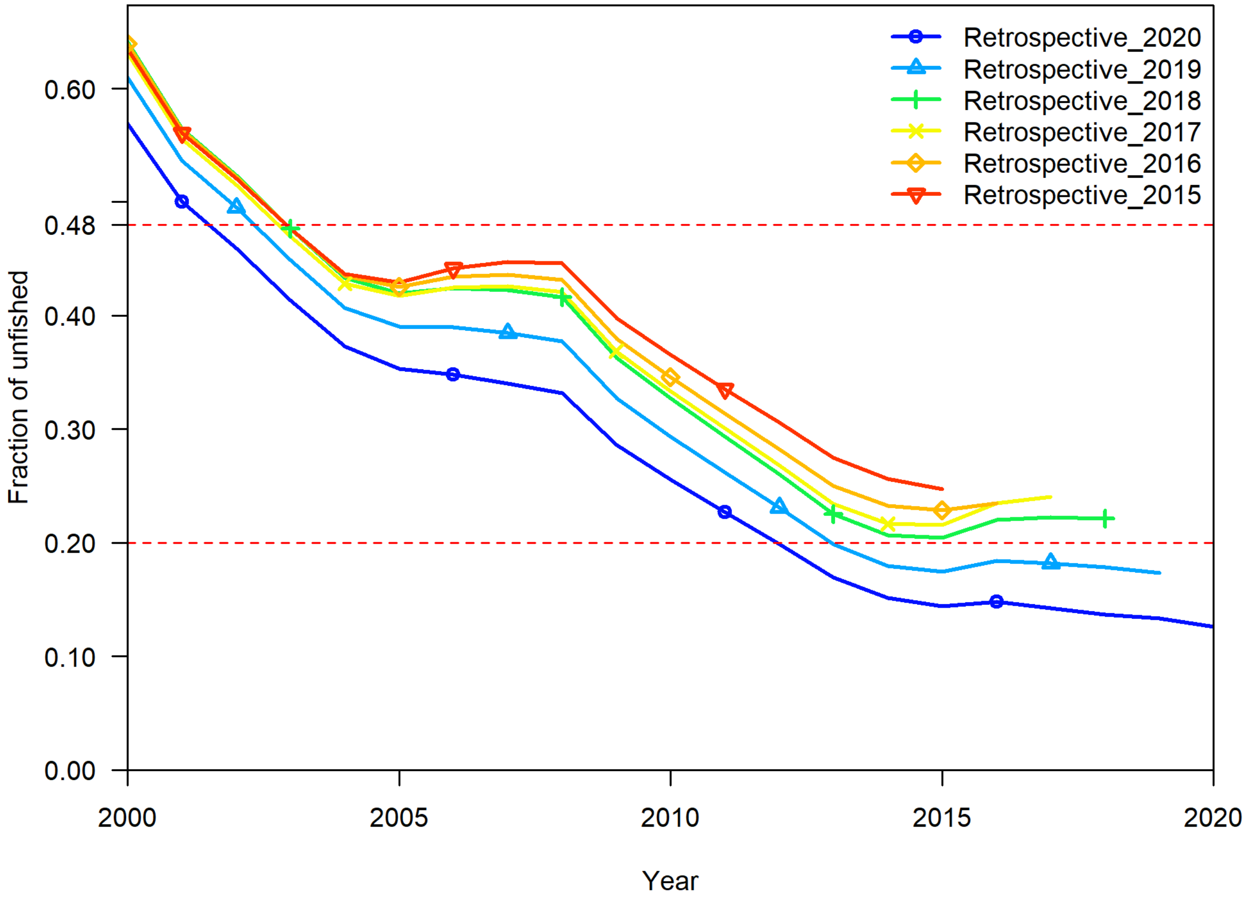


Figure 8.34. Retrospectives for relative stock status for Jackass Morwong, with data included to 2020 (blue) and then successive years removed back to 2015 (red) – plotted from 2000-2020.

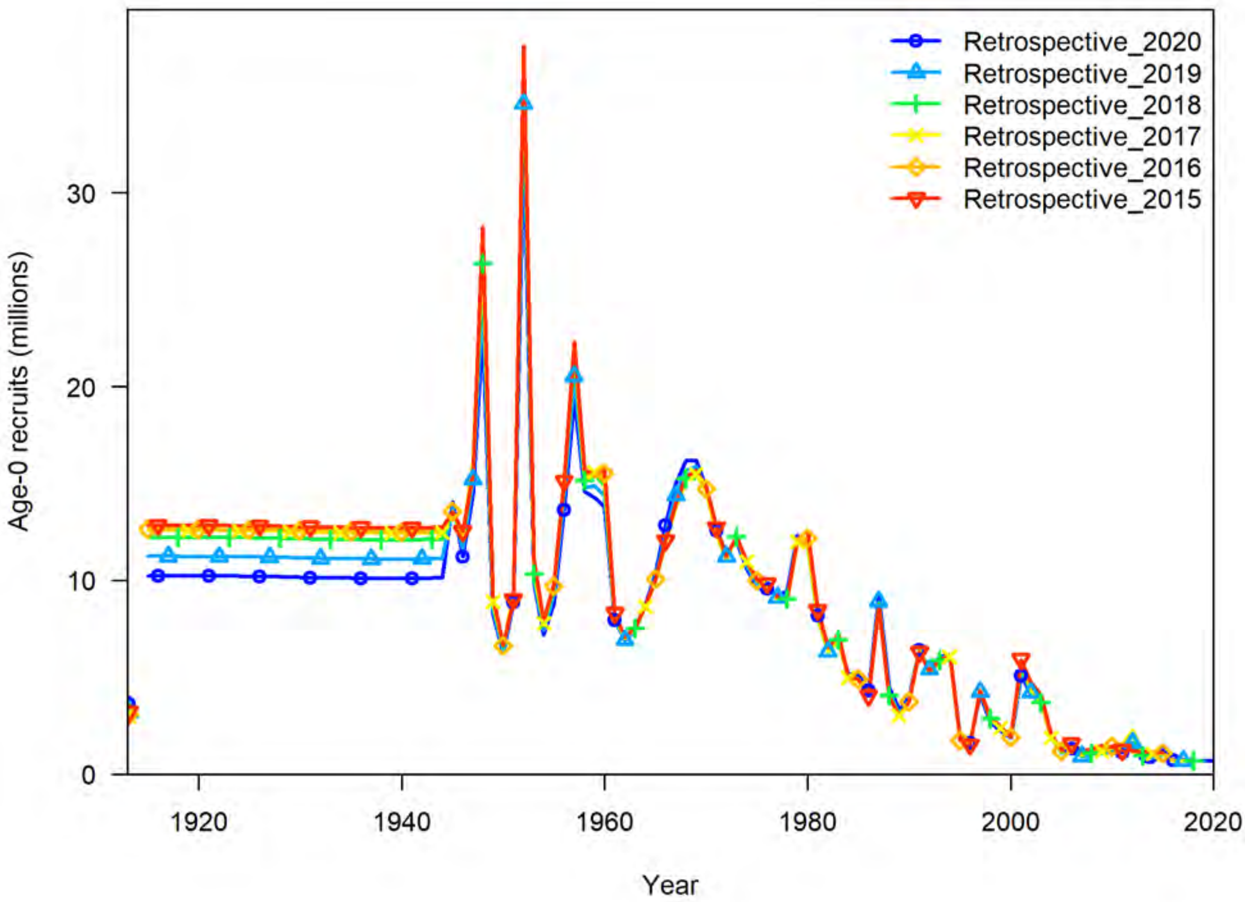


Figure 8.35. Retrospectives for absolute recruitment for Jackass Morwong, with data included to 2020 (blue) and then successive years removed back to 2015 (red).

An alternative presentation of the retrospective analysis applied to the recruitment time series is shown in a "squid plot" shown here for retrospectives with average recruitment from 2016 onwards (Figure 8.37) and low recruitment from 2016 onwards (Figure 8.38). Under average recruitment, the squid pot is very unbalanced, indicating that the revisions to recent recruitment deviations are consistently in the same direction, in this case clearly showing that revisions to the recruitment deviations are all in the same direction (downwards) as more data is considered, indicating a pattern that is not being adequately modelled, potentially model misspecification or temporal changes to parameters (e.g. time varying unidirectional biological changes that could potentially be environmentally driven) that are not considered or allowed for in the assumptions of this model. This pattern is partially alleviated with low recruitment projections, for the last five cohorts (fish spawned in the years 2011-2015), where the initial estimate of cohort strength is now compared to the expected low recruitment, rather than to the (rather unlikely) average recruitment.

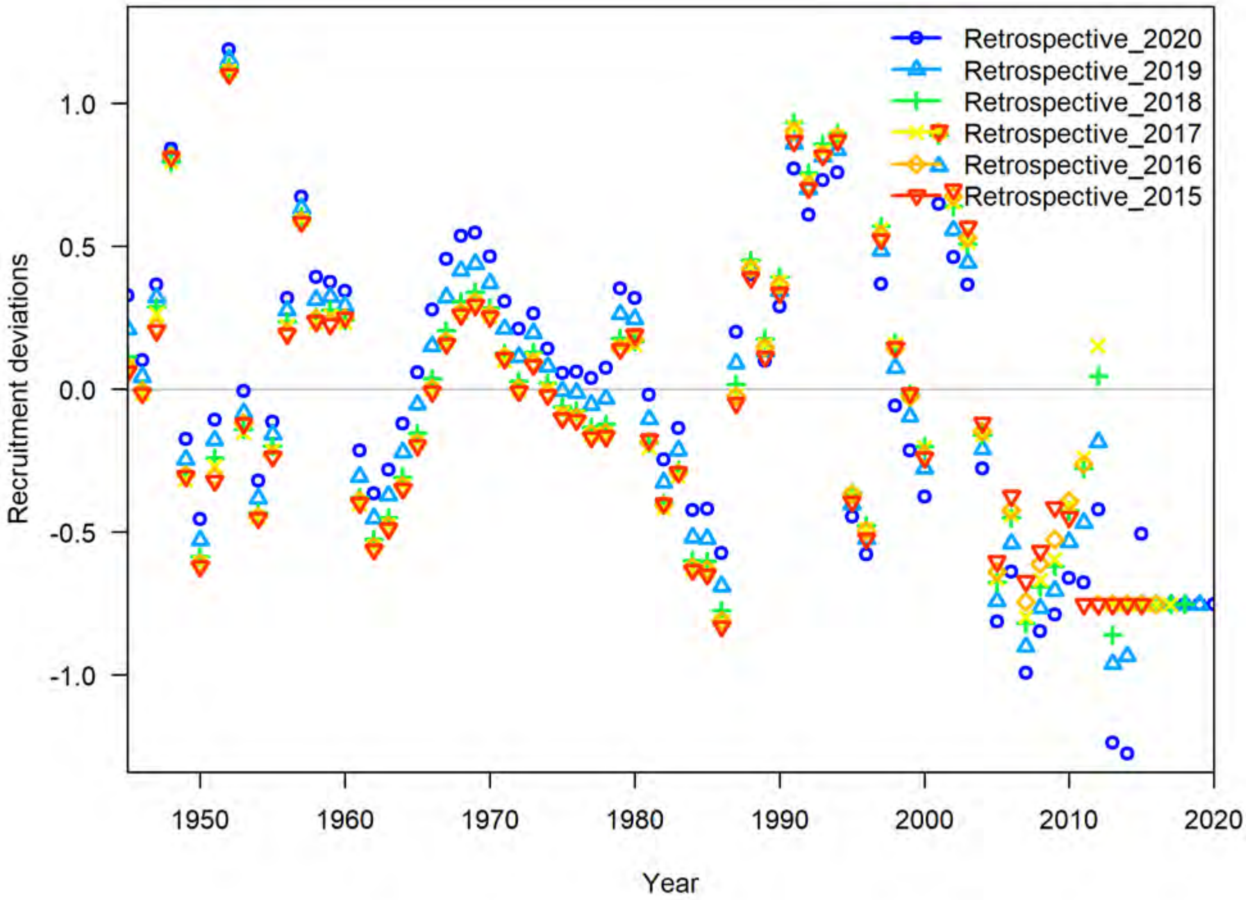


Figure 8.36. Retrospectives for recruitment deviations for Jackass Morwong, with data included to 2020 (blue) and then successive years removed back to 2015 (red).

Squid plots follow 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 base case model using data up to 2020 and then one more point one for each of the five different retrospectives. Each string can be followed from right to left as successive years of data are removed. The changes to the estimates of recruitment deviation, 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. Large changes on the y-axis indicate large revisions, and if all the changes have the same sign (positive or negative) this indicates a series of changes in the same direction, so indicating some bias rather than somewhat random revisions. In this case, most of the change (vertically, in the y-axis) is in the first two points (as you move from right to left on each string), indicating that most recent two years of data is having the largest influence on these revisions.

For cohorts spawned in years 2011-2015, the point on the far left of each string represents average recruitment, as this corresponds to a year when the recruitment deviation for this cohort cannot be estimated. Hence the corresponding y-values, for these left most points for cohorts spawned in 2011-2015, represent the magnitude of the final recruitment deviation estimated in the base case with positive y-values corresponding to negative recruitment deviations 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 (although still largest when the 2020 and 2019 data is removed), as there is less additional information on the size of these cohorts from data obtained in the period 2015-2018, although these recruitments are still generally revised downwards, albeit by smaller amounts by data in the years 2015-2018.

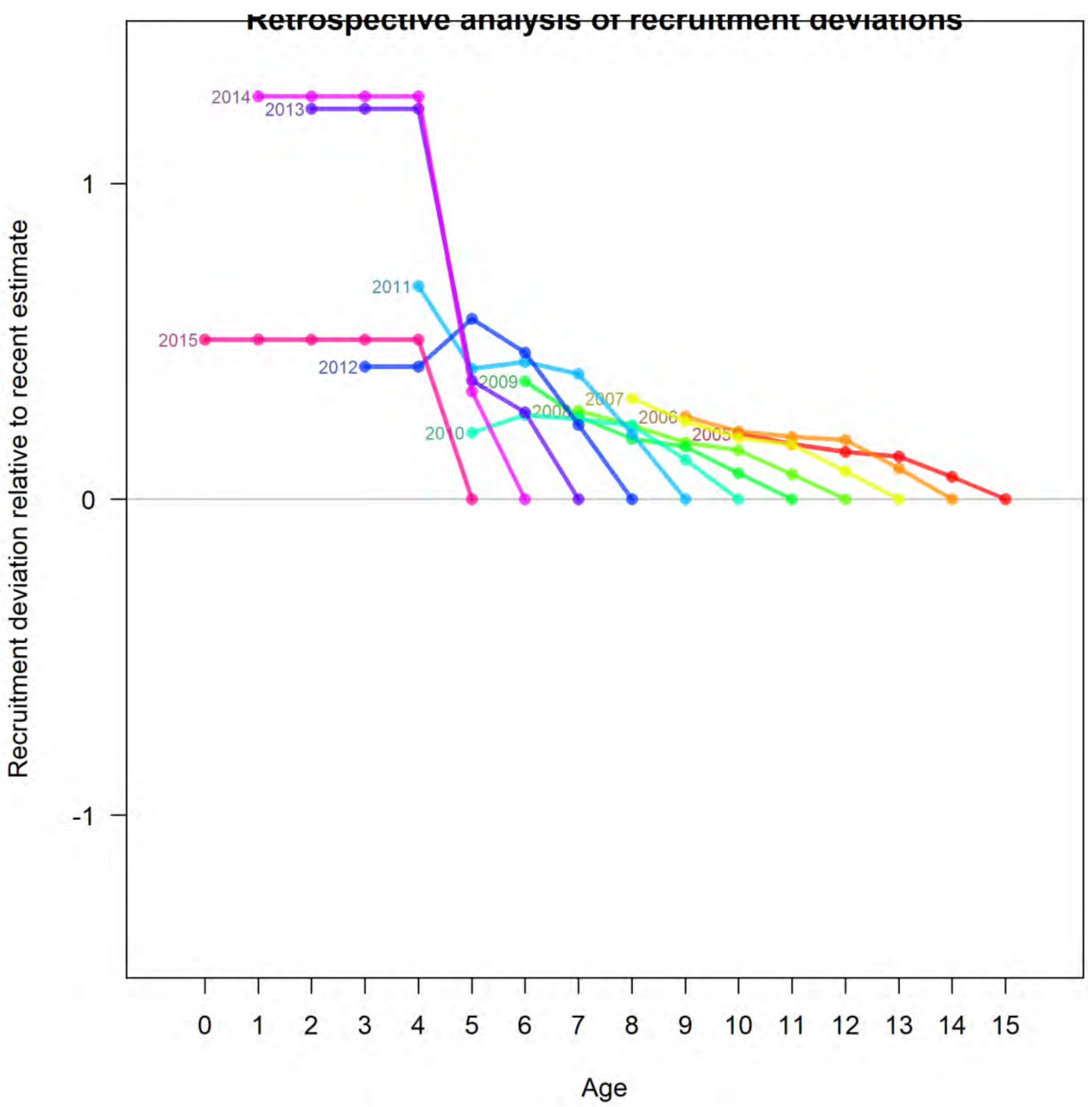


Figure 8.37. Retrospective analysis of recruitment deviations (squid plot) for Jackass Morwong with average recruitment and data removed in successive years back to 2015.

There are only three revisions of recruitment deviations upwards in this whole series (Figure 8.37, movements downwards on the y-axis) and these are all minor revisions. The 2010 cohort is revised upwards from the 2015 data and the 2011 and 2012 cohorts are revised upwards when data from 2016 is added, but all three cohorts have their recruitment revised downwards later as subsequent years of data are added.

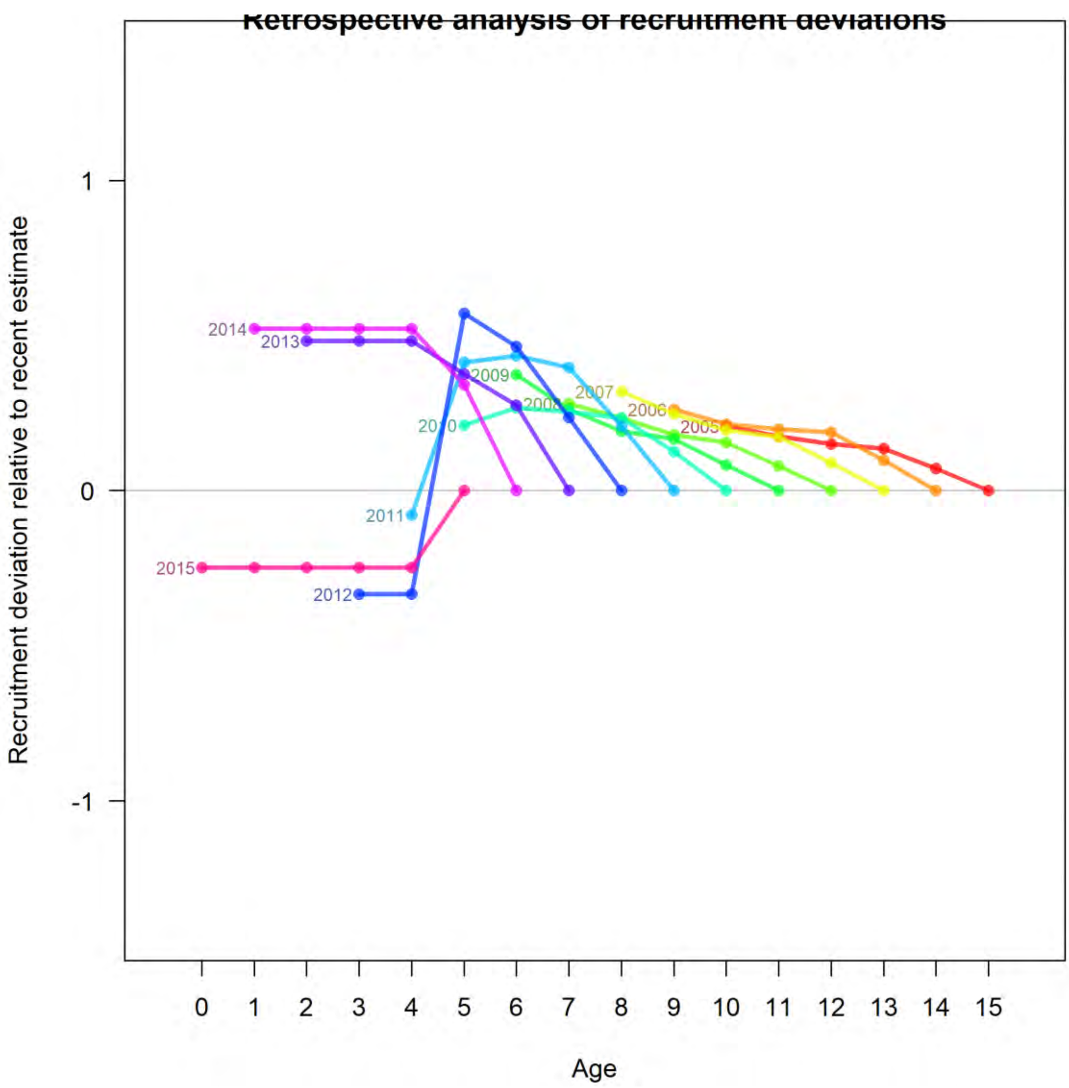


Figure 8.38. Retrospective analysis of recruitment deviations (squid plot) for Jackass Morwong with low recruitment and data removed in successive years back to 2015.

In the most recent School Whiting assessment report, Day et al (2020) state "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 misspecification." The one-sided squid plots shown here are a classic example of just such a pathological pattern.

Fits to the eastern and Tasmanian trawl CPUE series, (Figure 8.39 and Figure 8.40) for these retrospective analyses show a clear pattern, especially when plotted on a log scale, where an optimistic increase at the end of the time series get successively revised downwards as additional years of data are added, and the model "expected" increase in the subsequent new CPUE data points is not realised.

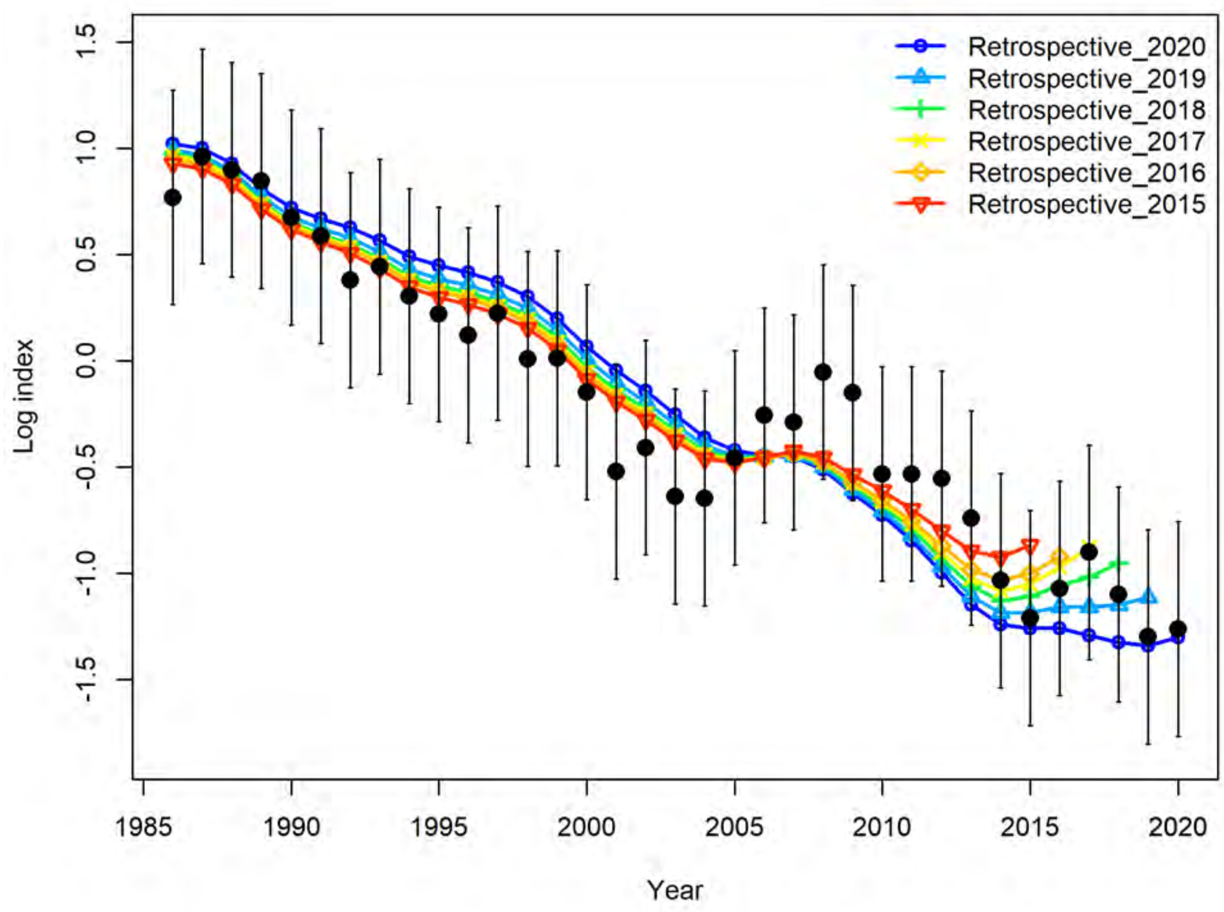


Figure 8.39. Retrospective fits to the log of the for the eastern trawl CPUE fits for Jackass Morwong, for the base case with low recruitment and data removed in successive years back to 2015.

The severity of retrospective patterns can be quantified using Mohn's rho, a statistic which is defined as the average of the relative differences between an estimate obtained from an assessment with a truncated time series and an estimate of the same quantity from an assessment using the full time series (Hurtado-Ferro et al., 2015). Mohn's rho values are calculated for a range of quantities, including spawning stock biomass, recruitment, fishing mortality and stock status. As a general rule of thumb, values of Mohn’s rho higher than 0.20 or lower than -0.15 are cause for concern in an assessment (Hurtado-Ferro et al., 2015).

A retrospective analysis was conducted for the base case with the assumption of average recruitment, with only the squid plot (Figure 8.37) shown for this analysis, and also for the base case with low recruitment (Figure 8.32-Figure 8.36, Figure 8.38-Figure 8.40). The values of Mohn’s rho, for both the low and average recruitment scenarios, are listed in Table 8.22, and this indicates retrospective patterns in the assessment under average recruitment for spawning stock biomass, fishing mortality and stock status. The statistics all improve under the assumption of low recruitment from 2016 onwards, compared to the average recruitment scenario, as the values are all smaller in absolute value, with Mohn’s rho for recruitment, -0.051, now indicating that the retrospective pattern for recruitment is even less of a concern under low recruitment. However, there are still issues with retrospective patterns for spawning stock biomass, fishing mortality and stock status.

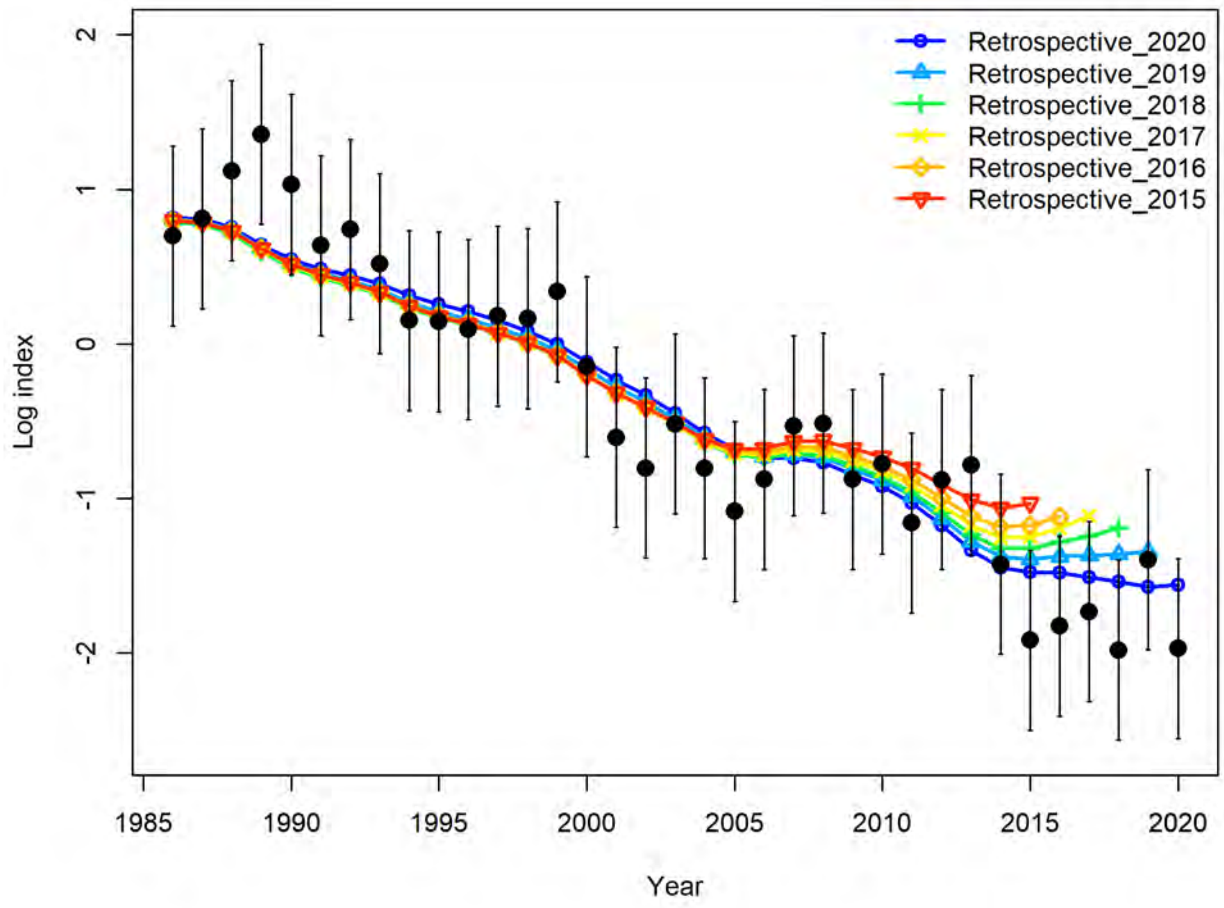


Figure 8.40. Retrospective fits to the log of the for the Tasmanian trawl CPUE fits for Jackass Morwong, for the base case with low recruitment and data removed in successive years back to 2015.

Table 8.22. Mohn's rho values for the average recruitment and low recruitment retrospectives.

	Average recruitment	Low recruitment
SSB	0.501	0.378
Recruitment	0.165	-0.051
F	-0.364	-0.256
Stock status	-0.723	0.582

8.4.6 *Likelihood profiles*

8.4.6.1 Natural mortality

For Jackass Morwong the likelihood profile for natural mortality, *M*, a parameter fixed in the base case at 0.15 yr^{-1}, is shown in Figure 8.41 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 *M* could vary between around 0.22 to 0.36 yr^{-1} with this range higher than the fixed value in the model.

The index data support higher values for *M*, driven entirely by the eastern trawl fleet CPUE (Figure 8.42). The length data support lower values for *M*, driven largely by the length data from the mixed fleet. The eastern trawl fleet discard data give some support to lower values of *M*. Overall, the age data gives very limited support to lower *M* values, but there is conflict within this data source, with the Tasmanian trawl age data supporting higher values for *M* and the eastern trawl age data supporting lower values for *M*.

Overall, there is conflicting data, within and between data sources, to inform the estimation of *M*. The apparent support in the data for higher values of *M* appears biologically unreasonable, given individuals are known to live to over 40 years of age.

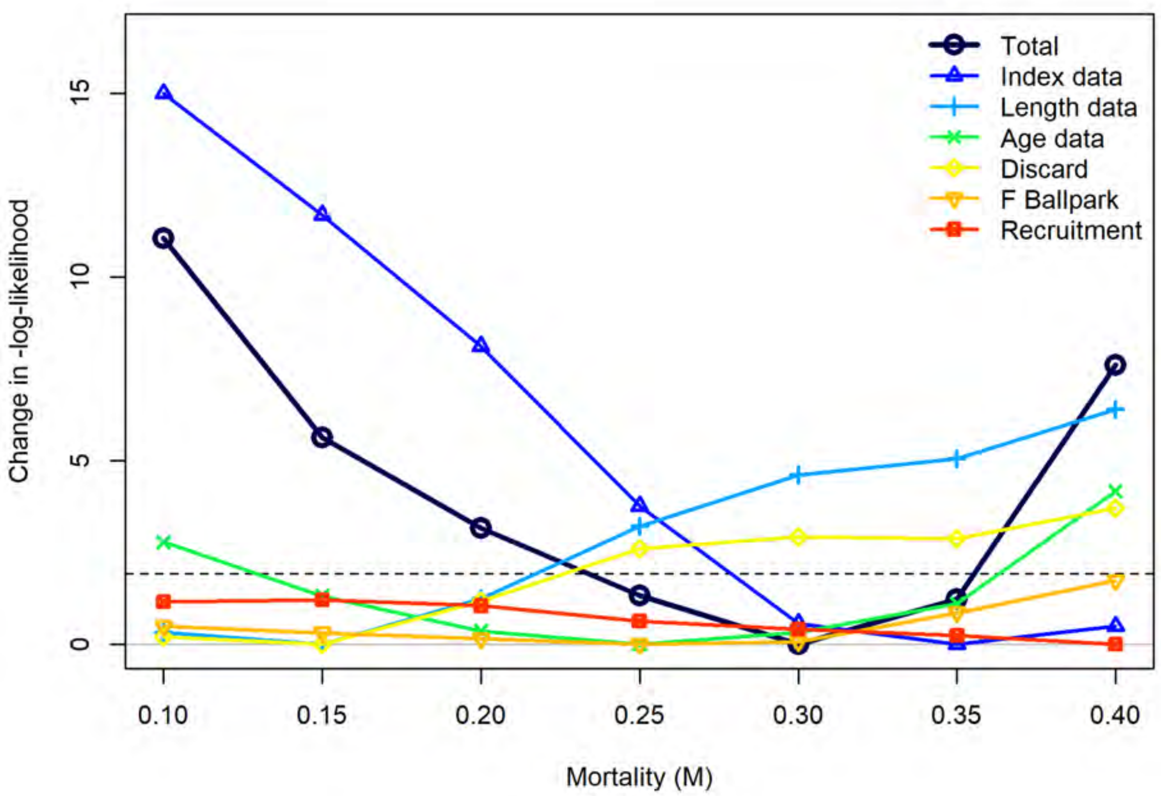


Figure 8.41. The likelihood profile for natural mortality for the base case with low recruitment, with *M* ranging from 0.1 to 0.4. *M* is fixed in the base case at 0.15 yr^{-1}.

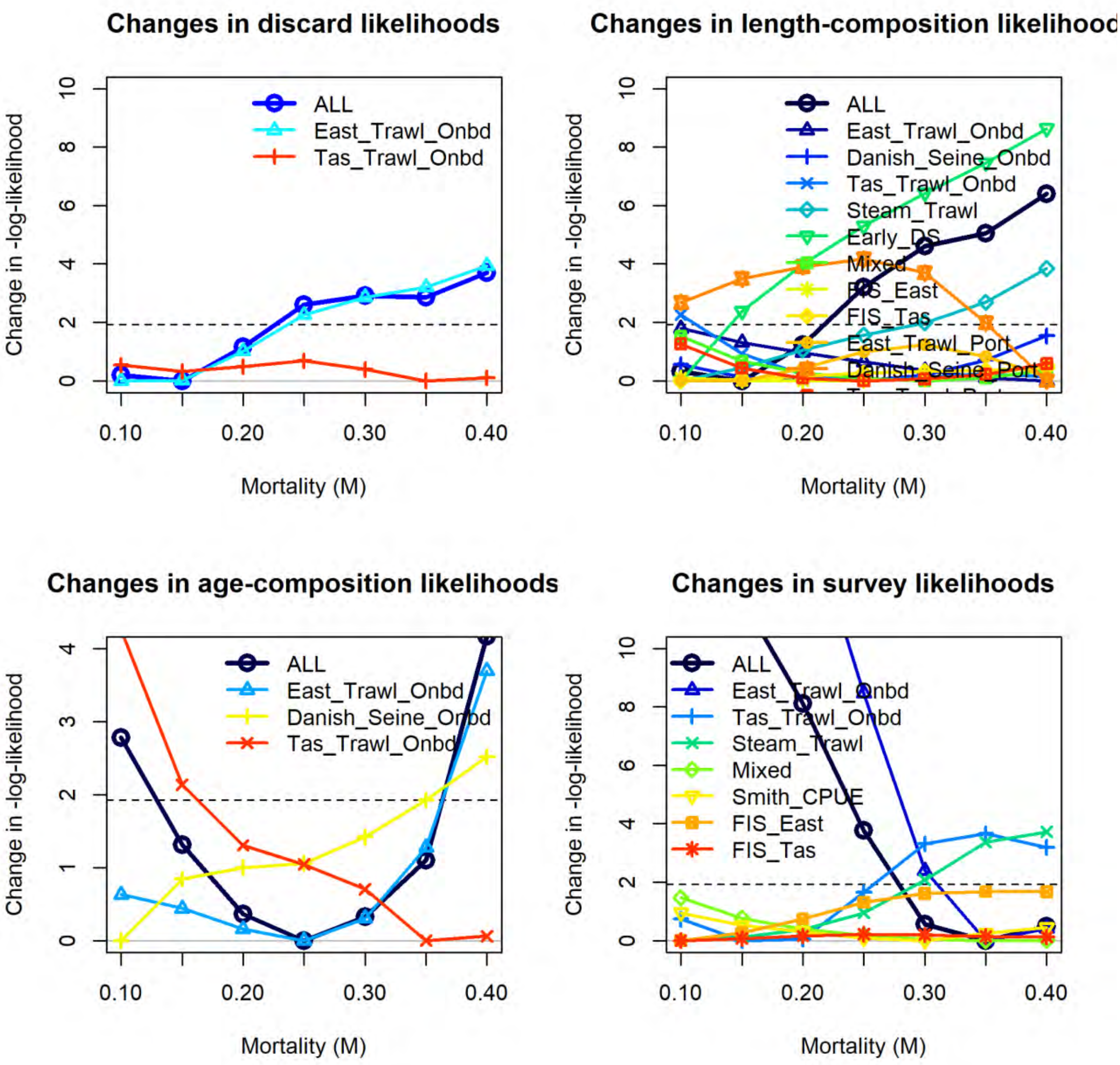


Figure 8.42. Piner plot for the likelihood profile for natural mortality for the base case with low recruitment, showing components of the change in likelihood for discard rate estimates, length, age, and surveys (CPUE) by fleet.

8.4.6.2 Steepness

For Jackass Morwong the likelihood profile for steepness, h, a parameter fixed in the base case at 0.7, is shown in Figure 8.43 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 indeed whether h should be estimated.

This likelihood profile in Figure 8.43 is uninformative as it is relatively flat, with very little difference in likelihood values between 0.3 and 0.8, with the only real information suggesting that a value of 0.9 is too high. This suggests that there is insufficient information contained in the data used in this model to inform a value for *h*, so this parameter should be fixed in this model. It is common that *h* is unable to be estimated in stock assessment models. There appears to be no benefit in repeating a likelihood profile on *h* for future stock assessments for Jackass Morwong, nor in attempting to estimate this parameter, at least in the foreseeable future.

Of the limited information in the model that can be used to inform steepness, the most influential data sources in providing information on *h* are the discard data and recruitment (Figure 8.43). While neither data source is that influential, the discard data (mostly through the eastern trawl fleet, Figure 8.44) support a higher value of *h* (a more productive stock) than the recruitment (which takes the form of a penalised log likelihood on deviations from the Beverton-Holt stock recruitment relationship) which supports a lower values *h*. Other components of the likelihood appear to have little to inform the value of *h*.

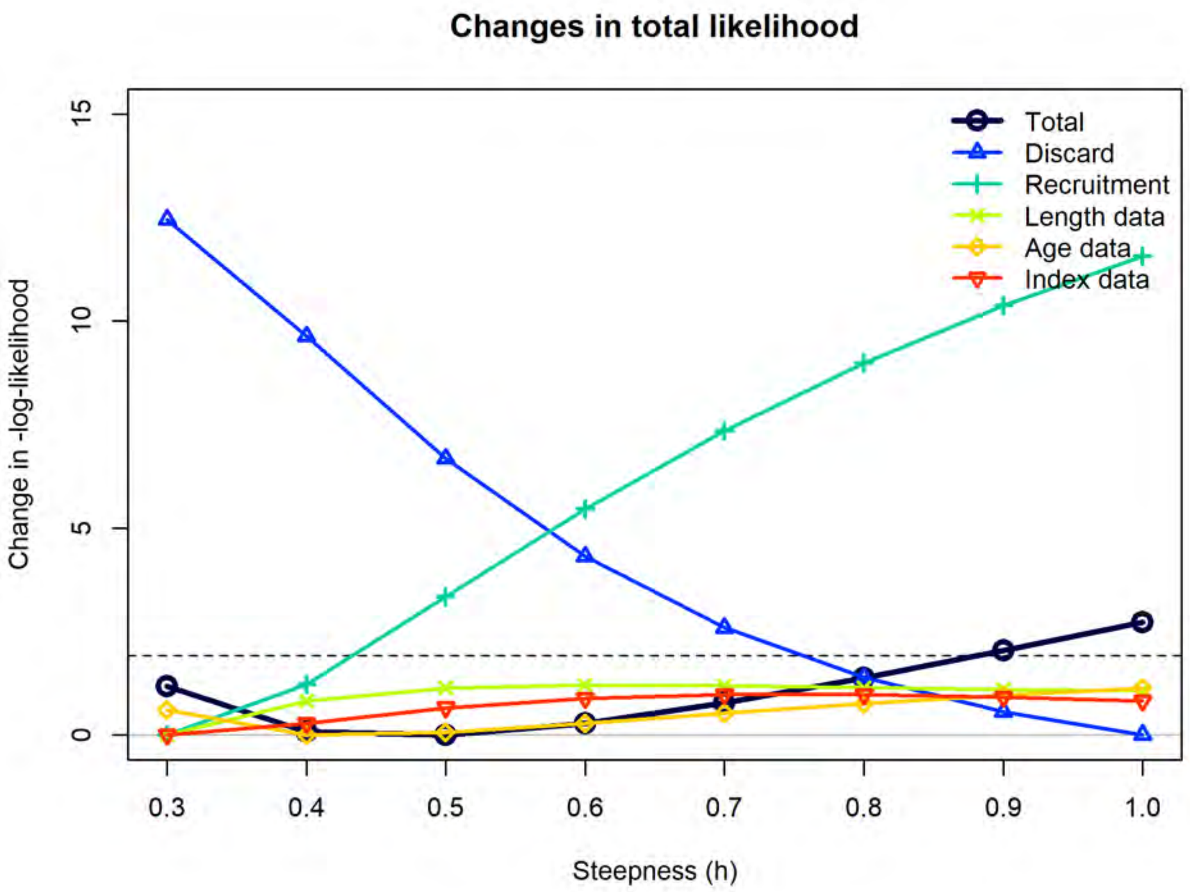


Figure 8.43. The likelihood profile for steepness for the base case with low recruitment, with *h* ranging from 0.3 to 1.0. *h* is fixed in the base case at 0.7.

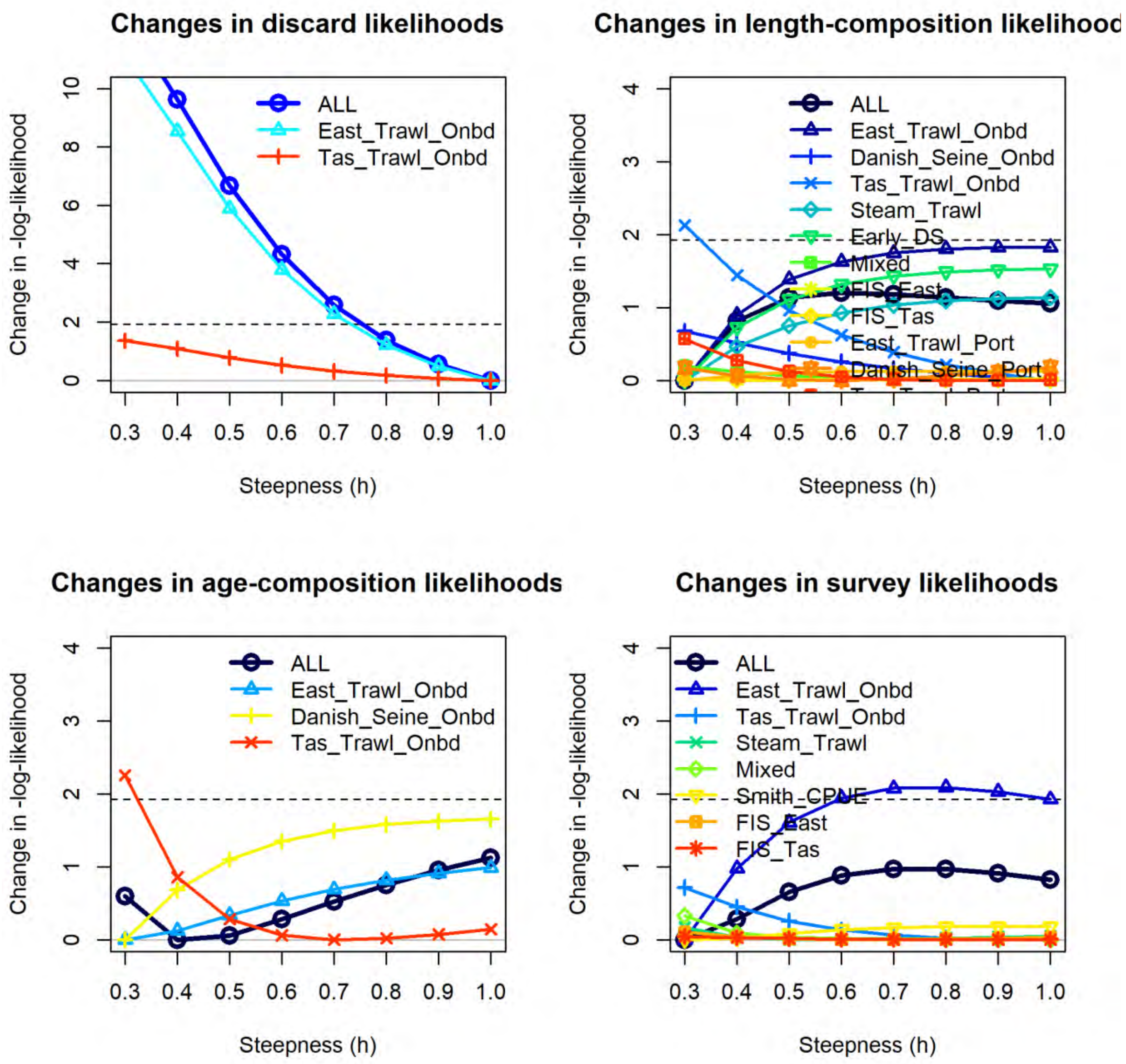


Figure 8.44. Piner plot for the likelihood profile for steepness for the base case with low recruitment, showing components of the change in likelihood for discard rate estimates, length, age, and surveys (CPUE) by fleet.

8.4.6.3 Unexploited spawning biomass

A likelihood profile for unexploited spawning stock biomass (SSB_0) is shown in Figure 8.45 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 19,000 t and 27,000 t with the most likely value at around 23,000 t. The asymptotic approximations, which makes some strong assumptions, suggest a symmetric distribution of plausible values ranging between 20,000 t and 28,000 t, and a most likely value at around 24,000 t.

The important data sources in providing information on SSB_0 are the recruitment (penalised log-likelihood) and the discard data (Figure 8.45). The recruitment supports a higher value for SSB_0, and the discard data support a lower value for SSB_0, driven entirely by discard rates from through the eastern trawl fleet (Figure 8.46). Recruitment essentially provides a lower bound on SSB_0 while the discard data provide an upper bound. SSB_0 is estimated with considerable uncertainty.

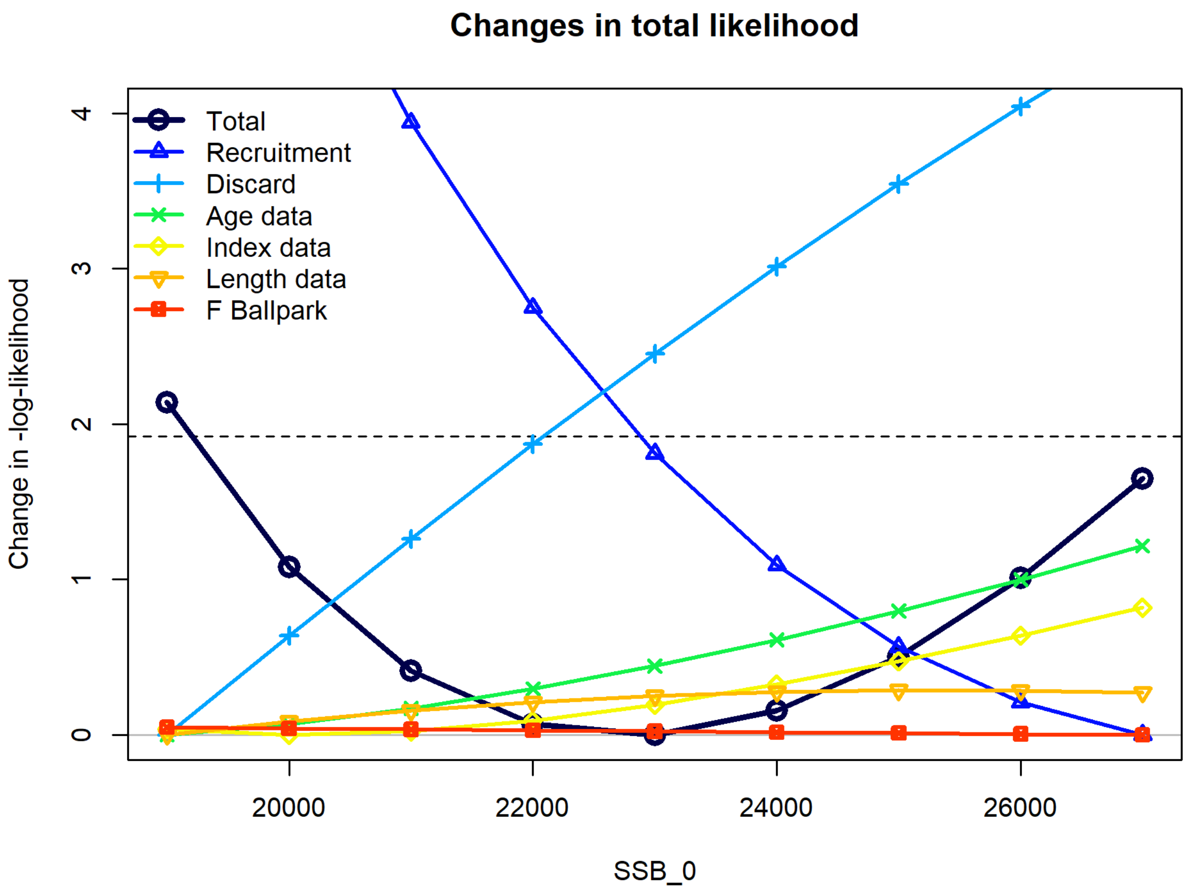


Figure 8.45. The likelihood profile for unexploited spawning stock biomass for the base case with low recruitment, with unexploited spawning stock biomass ranging from 19,000 t to 27,000 t. The base case estimate for SSB_0 is 23,841 t.

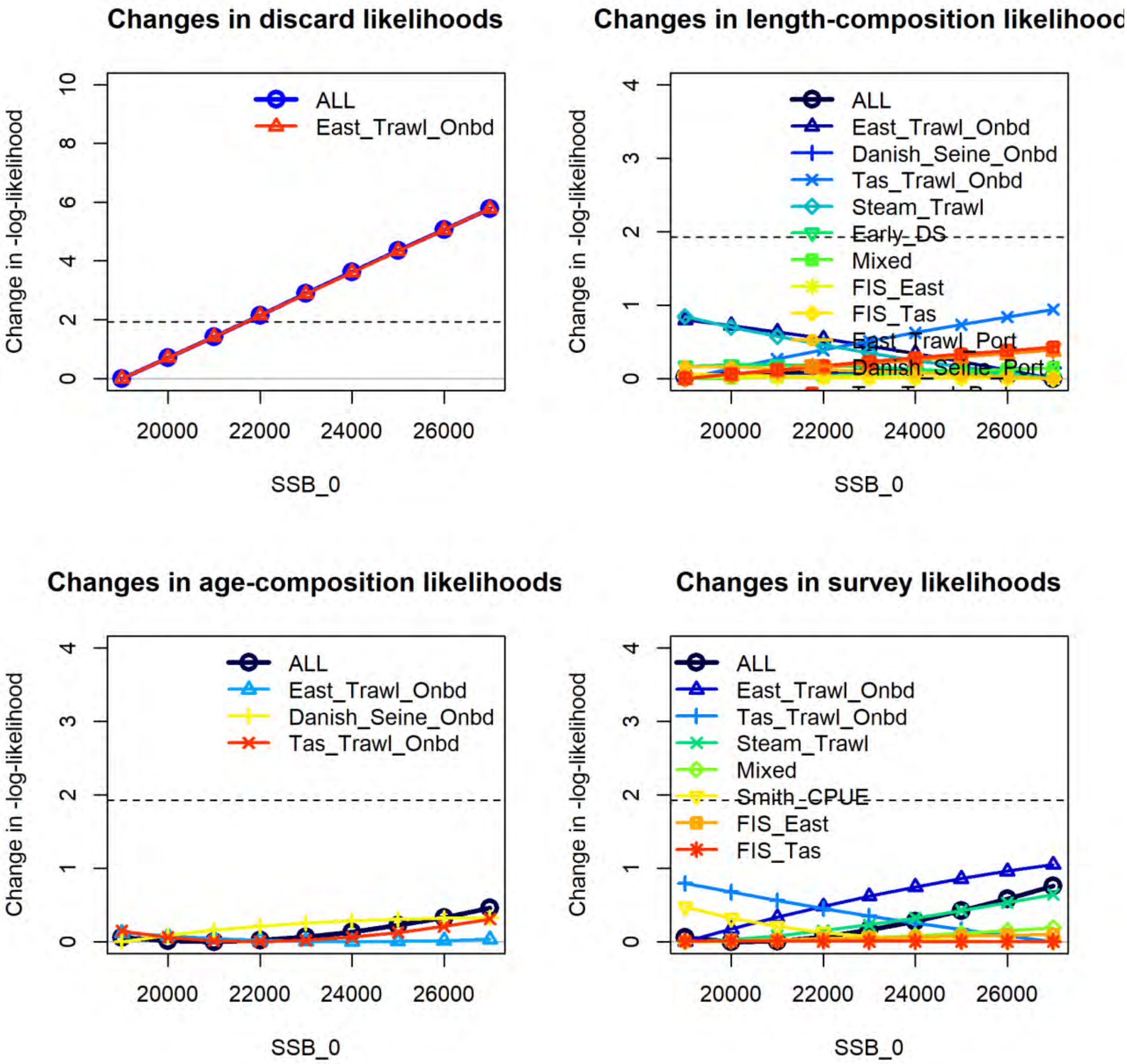


Figure 8.46. Piner plot for the likelihood profile for unexploited spawning stock biomass for the base case with low recruitment, showing components of the change in likelihood for discard rate estimates, length, age, and surveys (CPUE) by fleet.

8.4.6.4 2020 spawning biomass

A likelihood profile for current spawning biomass (SSB_{2020}) is shown in Figure 8.47 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_{2020} 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_{2020} requires setting up an additional “fleet” with a single data point (in 2020) 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_{2020} ranging between around 900 t and 1,650 t with the most likely value at around 1,200 t. In contrast, the asymptotics, which make some strong assumptions, suggest an estimate of 1, 075 t with apparently tight confidence intervals, although technically these cannot be calculated for the base case with low recruitment.

The important data sources in providing information on SSB_{2020} are the index and discard data (Figure 8.47). The index data support a higher value for SSB_{2020}, mainly through data from the eastern trawl fleet, although the Tasmanian trawl fleet apparently supports a lower value for SSB_{2020}, (Figure 8.48), while the discard data support a lower value for SSB_{2020}, entirely through the eastern trawl fleet discard data (Figure 8.48). The index data essentially provides a lower bound on SSB_{2020} while the discard data provide an upper bound. While having a smaller influence the recruitment data support a higher value of SSB_{2020} and the age data support a lower value (Figure 8.47). SSB_{2020} is estimated with considerable uncertainty, but it is clearly an order of magnitude lower than SSB_0. It is notable that there is considerable conflict both between and within likelihood components, which may suggest that there may be issues with unrepresentative data or potential model misspecification, possibly due to unaccounted for spatial or temporal effects.

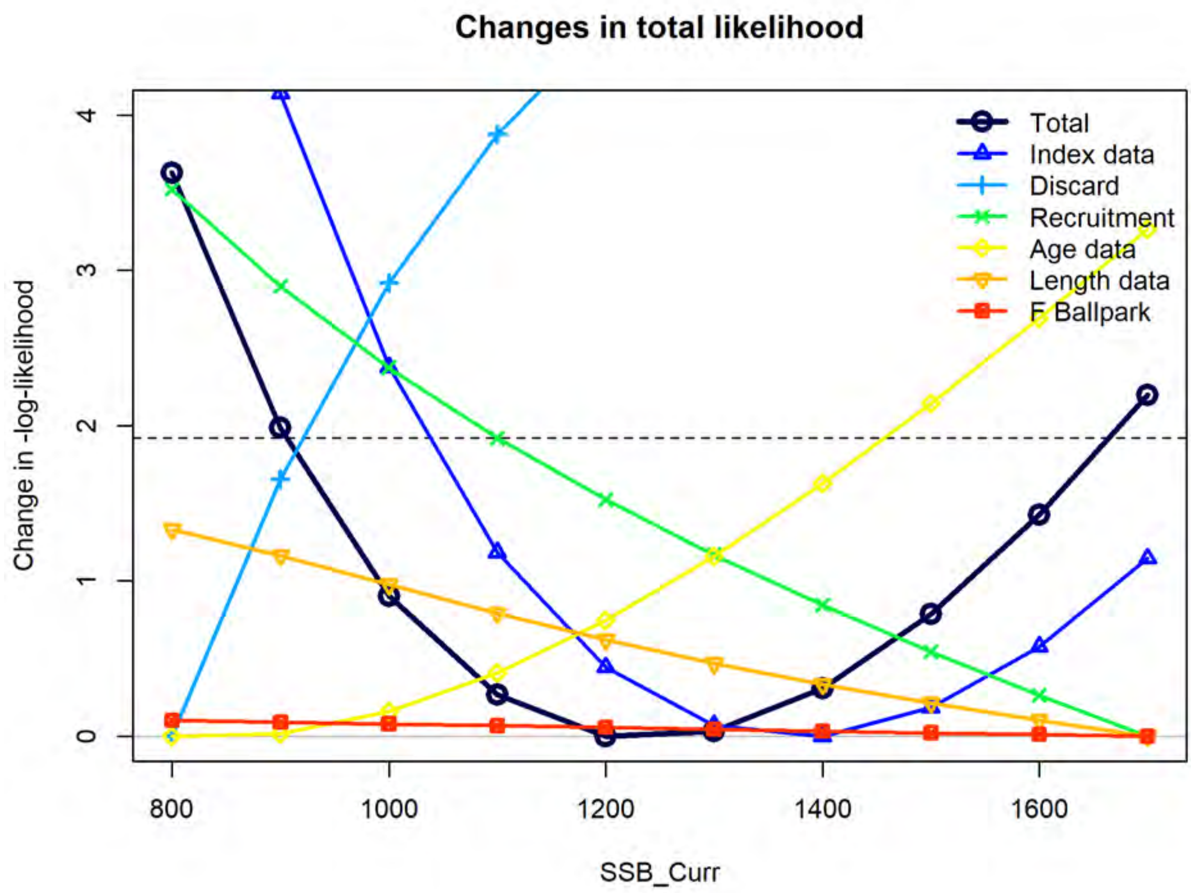


Figure 8.47. The likelihood profile for 2020 spawning stock biomass for the base case with low recruitment, with 2020 spawning stock biomass ranging from 800 t to 1,700 t. The base case estimate for SSB_{0020} is 1,115 t.

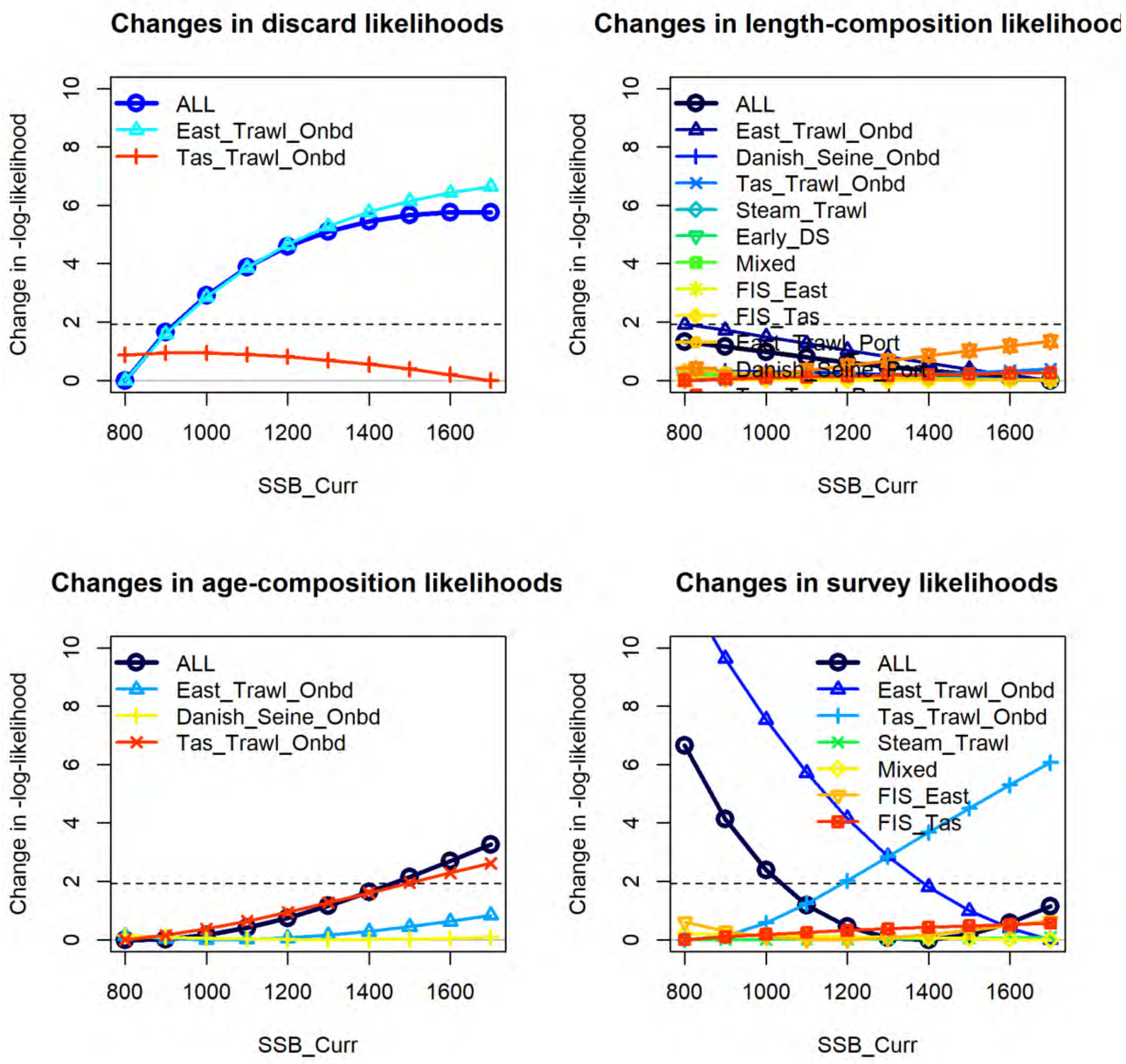


Figure 8.48. Piner plot for the likelihood profile for 2020 spawning stock biomass for the base case with low recruitment, showing components of the change in likelihood for discard rate estimates, length, age, and surveys (CPUE) by fleet.

8.4.6.5 2020 stock status

A likelihood profile for 2020 stock status is shown in Figure 8.49 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_{2020}, 2020 stock status is a derived parameter. To construct a likelihood profile on 2020 stock status requires setting up an additional “fleet” with a value of 1.01 in 1989 and an additional data point where the stock status (relative to the 1988 productivity shift) is close to one, which is seen in the base case in 1989, specifying this stock status with a very low standard error, essentially adding a “highly precise survey” of stock status, 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 range of plausible values for stock status in 2020 ranging between around 11% and 20%, with the most likely value at around 15%. Discard, recruitment and index have the most influence (Figure 8.49).

Ideally this likelihood profile would be produced for stock status at the start of 2022, as with the likelihood profile on current biomass (2022 rather than 2020). However, likelihood profiles can only be constructed on parameters that are associated with likelihood values (requiring actual data) and not projected values, so 2020 is the last year that a likelihood profile can be constructed, either for spawning biomass or stock status.

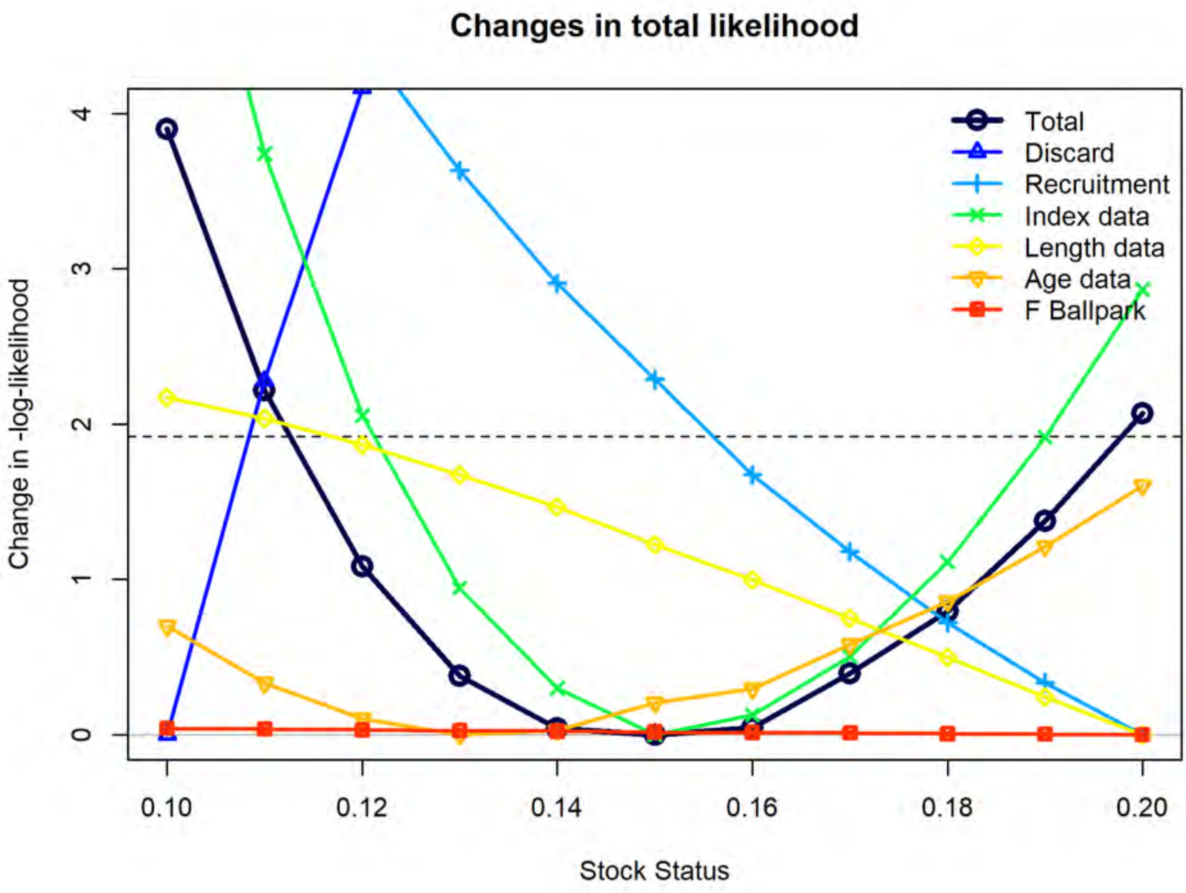


Figure 8.49. The likelihood profile for 2020 stock status for the base case with low recruitment, with 2020 stock status ranging from 10% to 20%. The base case estimate for 2020 stock status is 14%.

The important data sources in providing information on stock status are the discard, recruitment and index data (Figure 8.49). As with current spawning biomass, both the recruitment and index data support a higher value for relative spawning stock biomass, mainly through data from the eastern trawl fleet, although once again, in contrast, the Tasmanian trawl fleet apparently supports a lower value for stock status (Figure 8.50), while the discard data support a lower value for stock status, based entirely on the eastern the trawl fleet discard rates (Figure 8.50). The recruitment and index data essentially provide a lower bound on relative spawning stock biomass while the discard data provide an upper bound. Relative spawning stock biomass is estimated with considerable uncertainty. However, there is strong evidence to suggest that the stock status was below 20% in 2020. As with the likelihood profile on SSB_{2020}, there is considerable conflict both between and within likelihood components, which again supports the hypothesis that there may be issues with unrepresentative data or potential model misspecification, possibly due to unaccounted for spatial or temporal effects. Temporal changes in fishing, targeting practices or biological changes such as changes in recruitment or natural mortality in recent years, could potentially explain the problems fitting the data, and producing a coherent consistent explanation of model outputs, given the assumptions being used in the model. Incorporating such modelling changes ought to be justified by some clear evidence of these changes, and this may require additional data that is not currently available.

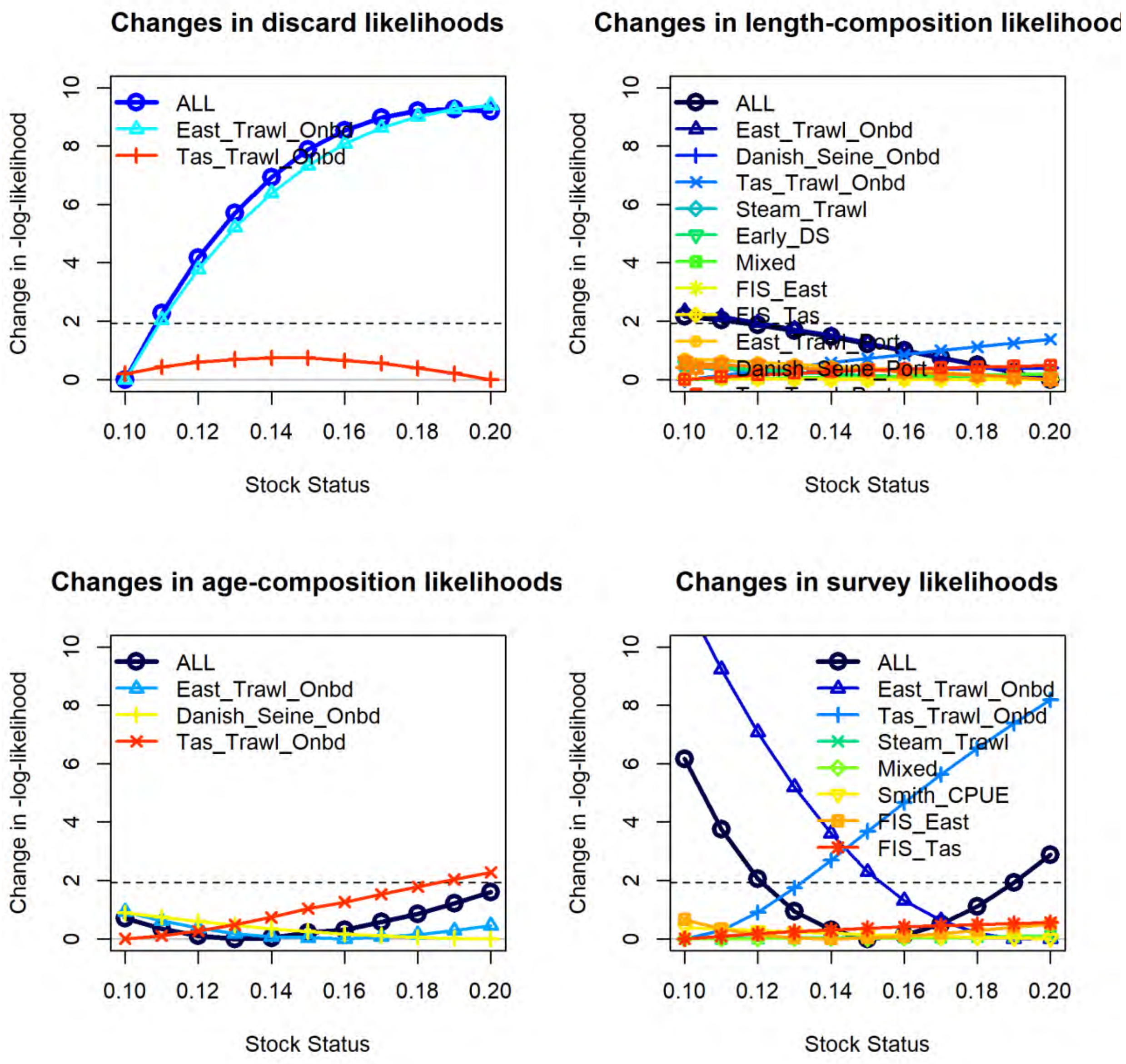


Figure 8.50. Piner plot for the likelihood profile for 2020 stock status for the base case with low recruitment, showing components of the change in likelihood for discard rate estimates, length, age, and surveys (CPUE) by fleet.

8.4.7 *Jitter analyses*

For the base case, 23 of the 25 jitter replicates found the same optimal solution, with negative log likelihood of 943.449. The remaining two replicates found different (worse) “optimal” solutions, with negative log likelihood values of 968 and 993. This result gives confidence that the solutions found with the chosen parameter starting values for the base case are the optimal solutions.

8.4.8 *Sensitivity tests and alternative models*

Results of the sensitivity tests are shown in Table 8.23. This table indicates that stock status is not overly sensitive to changes in parameters or weightings, with the exception for changes to natural mortality.

This assessment is also insensitive to the weighting placed on the age compositions, with no change to the stock status by doubling or halving the weight on age data. However, it has some sensitivity to changing weightings on length and CPUE data. In both cases, increasing the weighting on length and CPUE data results in higher stock status estimates (16% in both cases). The decreased weight on CPUE data leads to lower stock status estimates than the base case (14%), with no change in stock status by decreasing the weighting on the length data. These patterns when changing the weighting on length and CPUE data suggest that there is no conflict in the information provided from these two data sources. Despite these changes in stock status, the changes in likelihood values with changes to the weighting of different data sources, are relatively small (Table 8.24). This likelihood table also suggests that there is often conflict between the discard likelihood and other components, with the likelihood change to the discard component generally being relatively large (in absolute terms) and in the opposite direction to changes in weighting in either the length, age or survey data.

There are two additional “average recruitment” sensitivities listed in Table 8.23 and Table 8.24. The first shows the results from a model with no productivity shift implemented, with average recruitment from 2016 onwards (sensitivity 14) and the second keeps the 1988 productivity shift in place and simply fixes recruitment to average from 2016 onwards (sensitivity 15). The “no productivity shift” sensitivity has very different behaviour to the base case (Figure 8.51-Figure 8.54), and it appears to be purely coincidental that the 2022 stock status (14%) is very similar to the base case. The sensitivity with average recruitment from 2016 onwards results in a higher 2022 stock status (22%), due to the relative increase in contribution to spawning stock biomass as the higher recruitment from 2016 enters the spawning stock biomass. This sensitivity results in a lower negative log likelihood, through improvements to the fit to the discard data and, to a lesser extent, improvements to the fits to the age data, but with poorer fits to the length data. However, the sensitivity tables do not indicate the improvements to the poor retrospective patterns, illustrated in Table 8.22, when the low recruitment scenario is compared to the average recruitment scenario.

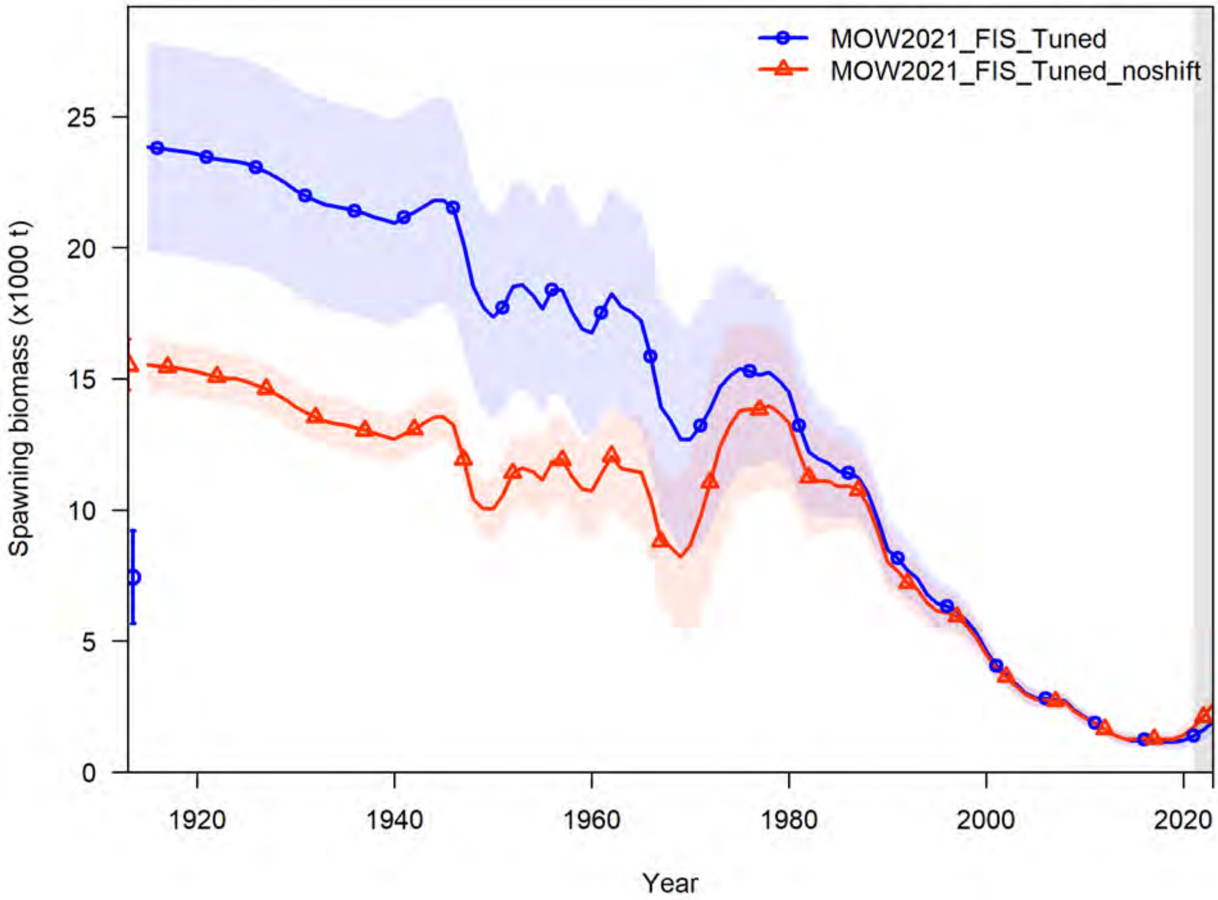


Figure 8.51. Comparison of the absolute biomass series for the no productivity shift model (red, with average recruitment from 2016 onwards) and the average recruitment base case (blue, a single productivity shift in 1988).

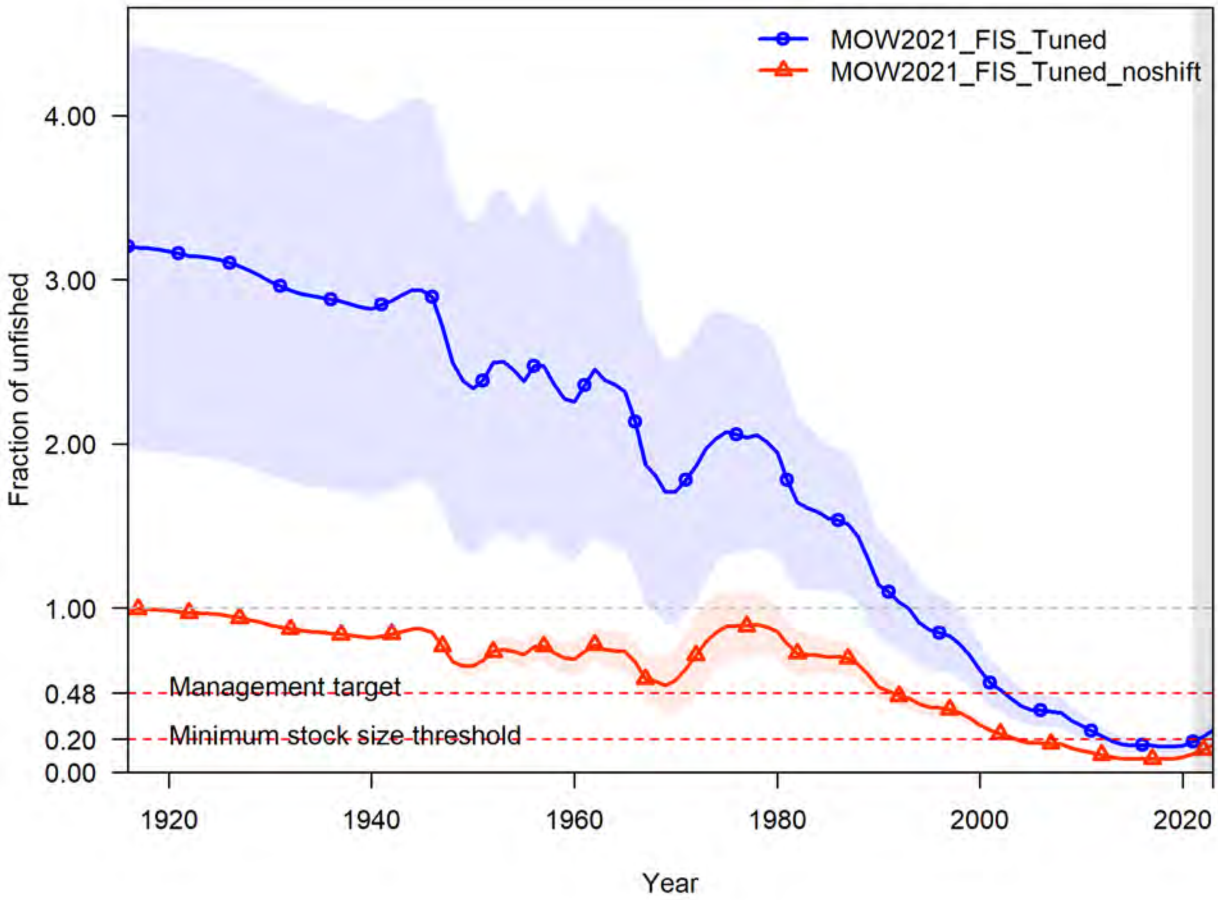


Figure 8.52. Comparison of the relative biomass series for the no productivity shift model (red, with average recruitment from 2016 onwards) and the average recruitment base case (blue, a single productivity shift in 1988).

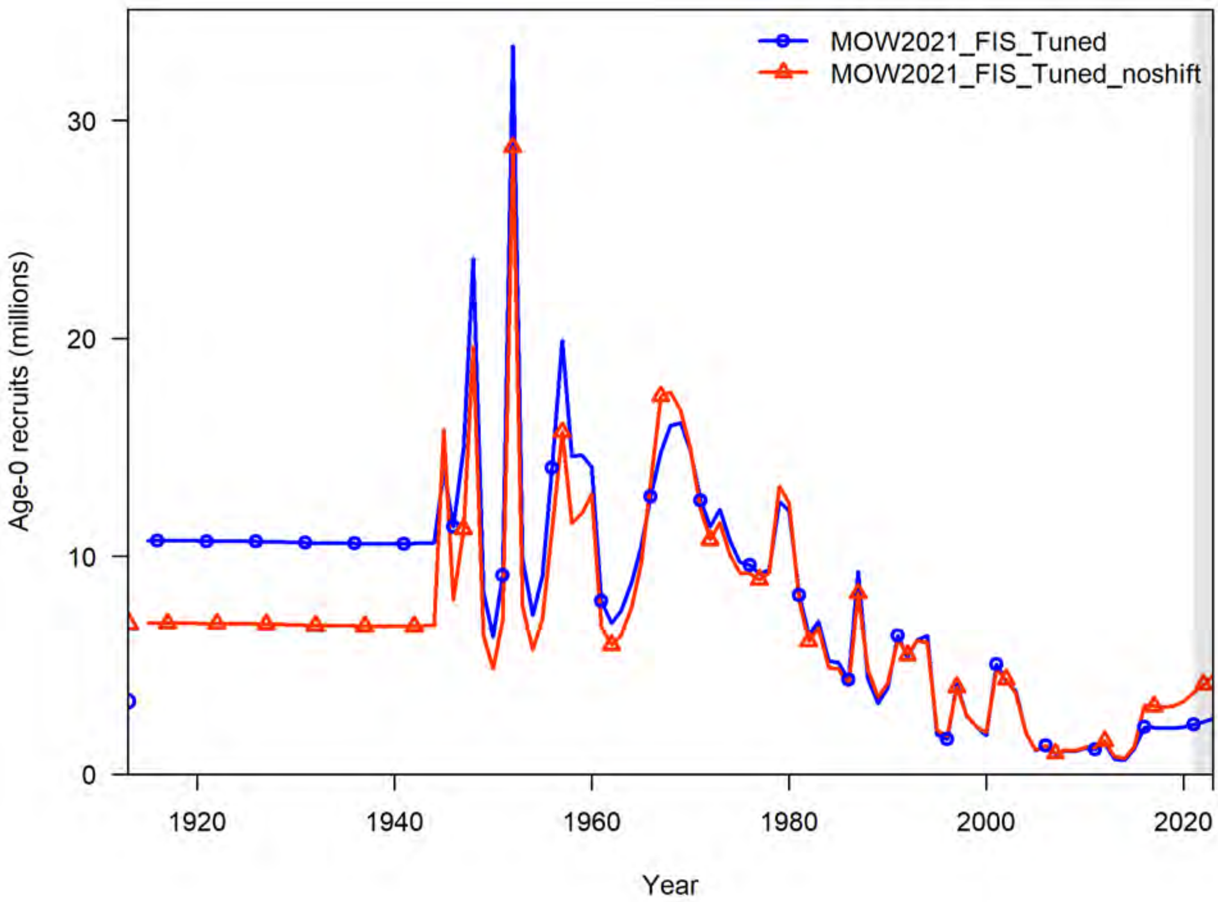


Figure 8.53. Comparison of the absolute recruitment series for the no productivity shift model (red, with average recruitment from 2016 onwards) and the average recruitment base case (blue, a single productivity shift in 1988).

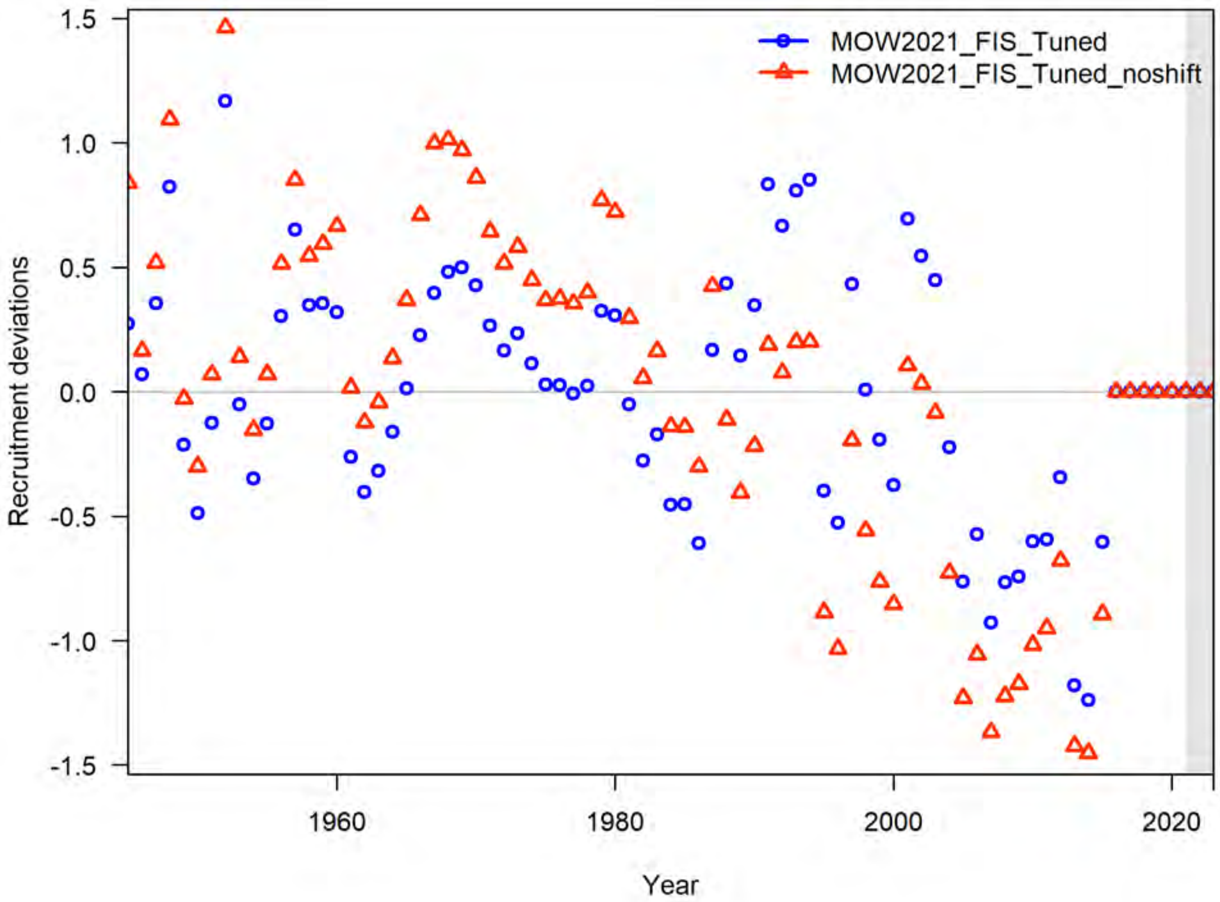


Figure 8.54. Comparison of the recruitment deviations for the no productivity shift model (red, with average recruitment from 2016 onwards) and the average recruitment base case (blue, a single productivity shift in 1988).

Table 8.23. Summary of results for the base-case and sensitivity tests. Recommended biological catches (RBCs) are only shown for agreed base case model.

Case		SSB_0	SSB_{2022}	SSB_{2022}/SSB_0	RBC_{2022}	$RBC_{2022-24}$	$RBC_{2022-26}$	$RBC_{longterm}$
0	base case (*M* 0.15, *h* 0.7, 50% mat 24.5)	7,429	1,115	0.15	0	0	1	91
1	*M* 0.1	11,834	830	0.07				
2	*M* 0.2	6,526	1,568	0.24				
3	*h* 0.6	8,118	1,052	0.13				
4	*h* 0.8	6,910	1,165	0.17				
5	50% maturity at 22cm	7,800	1,251	0.16				
6	$\sigma_R = 0.6$	6,912	1,126	0.16				
7	$\sigma_R = 0.8$	8,016	1,107	0.14				
8	wt x 2 length comp	7,112	1,132	0.16				
9	wt x 0.5 length comp	7,585	1,100	0.15				
10	wt x 2 age comp	7,271	1,099	0.15				
11	wt x 0.5 age comp	7,393	1,121	0.15				
12	wt x 2 CPUE	7,285	1,162	0.16				
13	wt x 0.5 CPUE	7,273	1,012	0.14				
14	no productivity shift (avg recruitment)	15,534	2,105	0.14				
15	average recruitment from 2016 onwards	7,429	1,603	0.22				

Table 8.24. Summary of likelihood components for the base-case and sensitivity tests. Likelihood components are unweighted, and cases 1-15 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	Discard	Length comp	Age comp	Recruitment
0	base case (M 0.15, h 0.7, 50% mat 24.5)	980.45	-129.20	176.34	285.13	613.38	8.31
1	M 0.1	7.61	3.41	3.23	0.37	0.72	-0.31
2	M 0.2	-3.71	-3.73	0.72	1.01	-1.36	-0.19
3	h 0.6	1.57	-0.02	4.43	0.12	-1.10	-1.87
4	h 0.8	-1.35	-0.27	-2.04	-0.55	0.06	1.43
5	50% maturity at 22cm	-0.24	-0.10	0.51	-0.26	-0.46	0.06
6	$\sigma_R = 0.6$	2.70	-0.08	2.66	0.81	-0.44	-0.26
7	$\sigma_R = 0.8$	-1.88	-0.16	-0.87	-1.02	-0.43	0.59
8	wt x 2 length comp	3.35	4.61	9.78	-14.28	1.13	2.07
9	wt x 0.5 length comp	7.15	-1.90	-7.49	17.65	0.19	-1.27
10	wt x 2 age comp	3.81	2.80	8.96	0.53	-8.72	0.21
11	wt x 0.5 age comp	2.84	-2.30	-6.11	0.45	10.86	-0.05
12	wt x 2 CPUE	5.57	-10.65	6.43	4.45	4.67	0.61
13	wt x 0.5 CPUE	1.90	9.25	-2.40	-3.18	-2.11	0.35
14	no productivity shift (avg recruitment)	-6.12	3.48	-24.20	35.53	-36.87	15.91
15	average recruitment from 2016 onwards	-12.09	0.25	-20.42	15.58	-7.49	0.00

8.4.9 Omissions to the base case: port length composition data and right hand side of bias adjustment

Two minor issues were discovered in the development of the 2021 base case after the initial stock assessment and analysis was already complete, with two minor steps in the bridging from the 2018 assessment overlooked.

1. The port collected length composition data was not updated from the 2018 assessment, so the 2021 base case does not include: (i) the revisions to these data from 1986-2016; and (ii) the new port collected length composition data for 2018-2020.
2. The bias adjustment was not updated from the 2018 assessment, an update to the right-hand side of the bias adjustment was overlooked in developing the base case. Instead of switching to a bias adjustment of zero in 2016, to match the additional three years of estimated recruitment deviations, the base case switched to zero in 2013, using the same bias adjustment as used in the 2018 assessment.

The bias adjustment used for Jackass Morwong is somewhat unusual, in that it ignores the apparent information on recruitment in the period from the 1940s to the 1960s, so as not to overestimate the precision from the 1960s to the 1980s, where there is no length composition data and hence limited information on recruitment in this period. Hence this bias adjustment diverges slightly from the recommended approach of Methot and Taylor (2011), in the left-hand ramp of this bias adjustment (Figure 8.55). This is consistent with the approach used in the previous Jackass Morwong assessments in 2018. When applied to the data in the 2015 assessment, applying the approach of Methot and Taylor (2011) resulted in a bias adjustment, with no bias adjustment prior to 1969, and the form of this bias adjustment was maintained for consistency in both the 2018 and 2021 assessments. However, the right-hand side of this bias adjustment should have been modified in the 2021 base case.

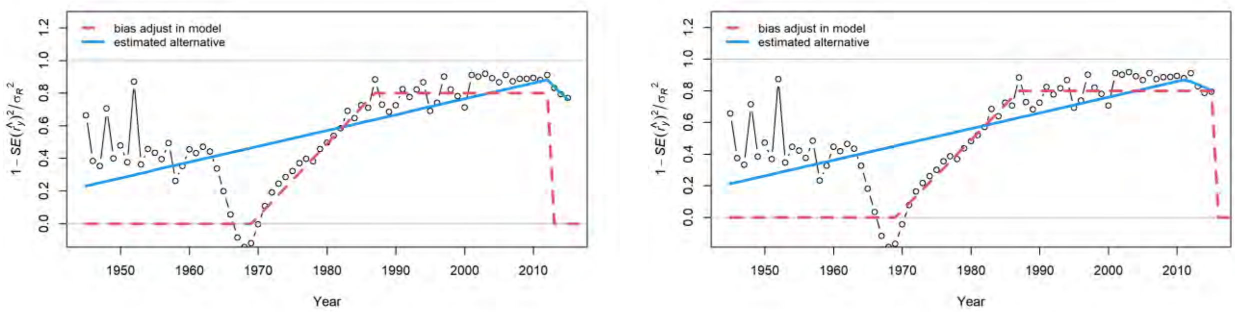


Figure 8.55. Bias adjustment used in the 2021 base case (left), with no bias adjustment from 2013 onwards and bias adjustment that should have been used in the 2021 base case (right), with no bias adjustment from 2016 onwards.

To explore the effect of updating these two data sources, these were first addressed independently, with the base case (MOW2021_LowRec_Tuned) modified to address only one issue at a time (MOW2021_LowRec_Tuned_bias_2 and MOW2021_LowRec_Tuned_port_2), followed by addressing both issues simultaneously (MOW2021_LowRec_Tuned_Updated), with all models iteratively reweighted. Changes to stock status were relatively minor (Figure 8.56 and Figure 8.57), with most of the change due to the updates to the port collected length composition data, and not due to the changes due to the bias ramp adjustment, with slightly higher stock status in 2022 (16%).

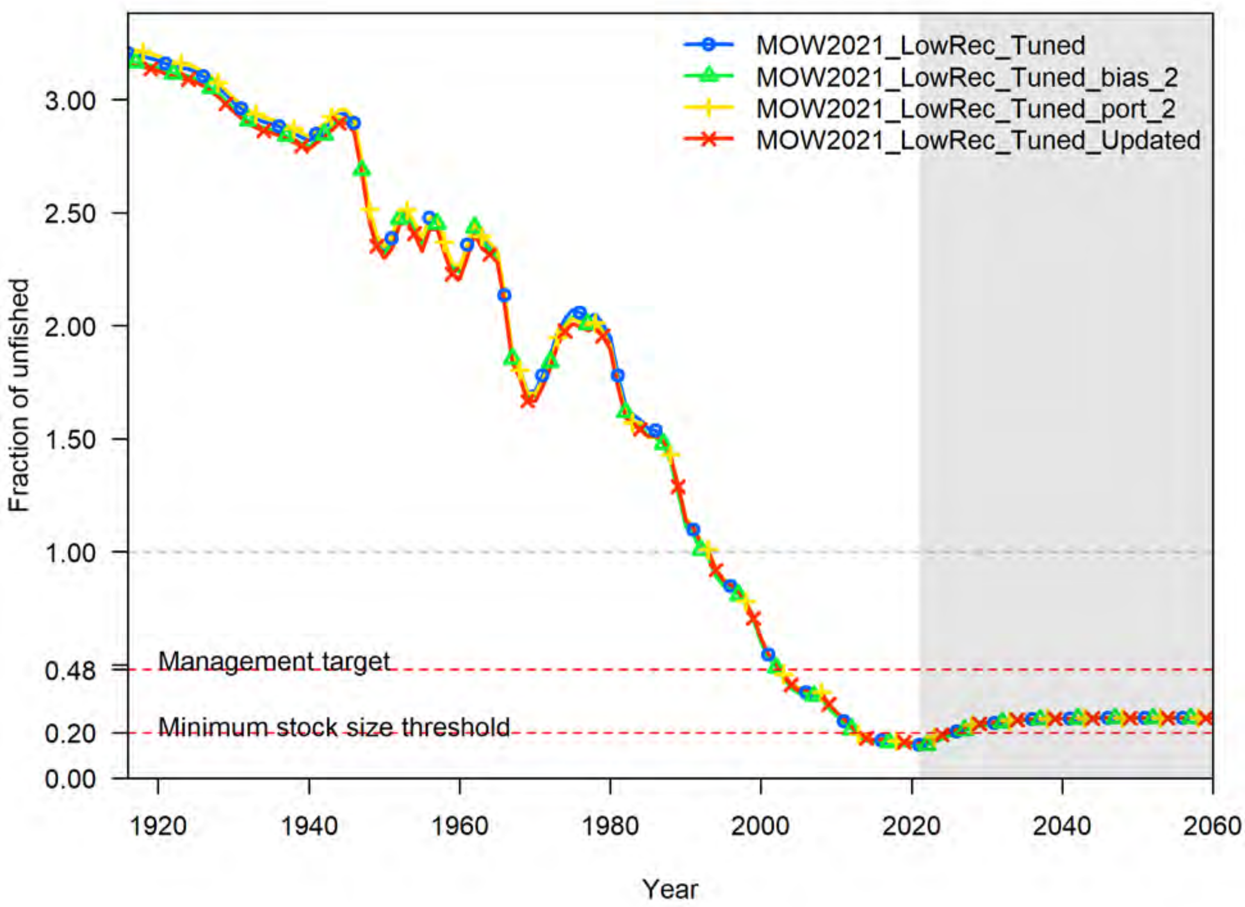


Figure 8.56. Comparison of the stock status time series for the 2021 base case (blue, MOW2021_LowRec_Tuned), the base case with the updated bias adjustment (green, MOW2021_LowRec_Tuned_bias_2), the base case with the updated port length composition data (yellow, MOW2021_LowRec_Tuned_port_2), and the base case with the both the updated bias adjustment and the updated port length composition data (red, MOW2021_LowRec_Tuned_Updated).

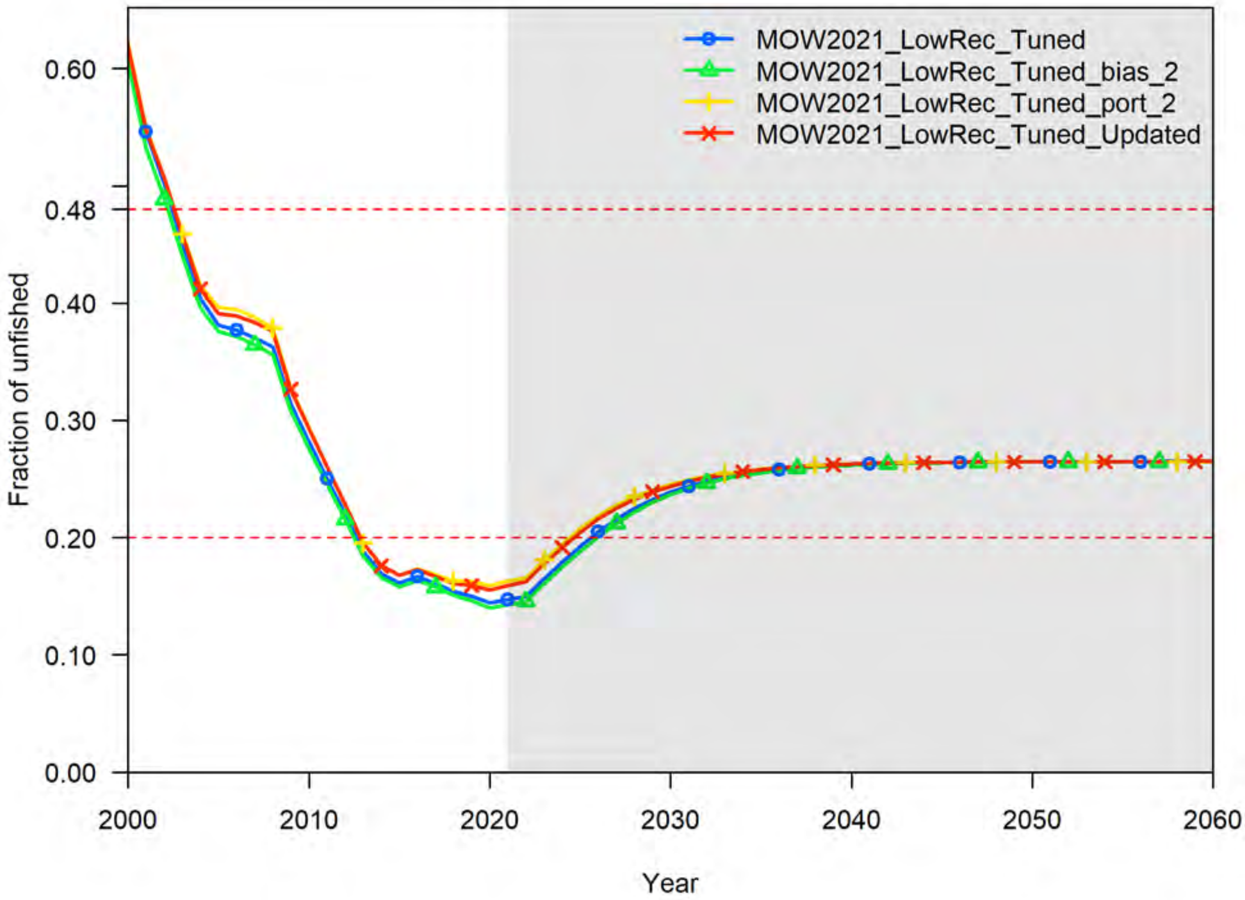


Figure 8.57. Comparison of the stock status time series (2000-2060 only) for the 2021 base case (blue, MOW2021_LowRec_Tuned), the base case with the updated bias adjustment (green, MOW2021_LowRec_Tuned_bias_2), the base case with the updated port length composition data (yellow, MOW2021_LowRec_Tuned_port_2), and the base case with the both the updated bias adjustment and the updated port length composition data (red, MOW2021_LowRec_Tuned_Updated).

The changes to the absolute recruitment time series were minimal (Figure 8.58) with the largest changes to the estimated recruitment deviations in the period 2013-2015 (Figure 8.59), with contributions from both the adjustment to the bias ramp and the additional port collected length composition data. As a result of these changes, the average recruitment deviation for the last 10 years of estimated recruitment should be revised from -0.754 to -0.706.

While the changes to the estimated stock status in 2022 and the average recruitment deviation used for low recruitment projections resulting from these updates would both lead to a slightly more optimistic projected "recovery" of Jackass Morwong in the next few years, there would be no change to the likely classification of overfished in 2022, and the pathway and projected time to recovery would be qualitatively similar to the results from the base case, if the updated base case was to be used. The stock status is projected to "recover" to 20% in 2025 for the updated base case, albeit with future low recruitment using the recruitment deviation of -0.754. The base case is projected to "recover" to 20% one year later (2026) than this updated base case. Given the uncertainties in the assumed projected recruitment, and the uncertainties in the estimates of stock status, the change between the results from the base case and the updated base case are small, compared to the known margins of uncertainty in the model output.

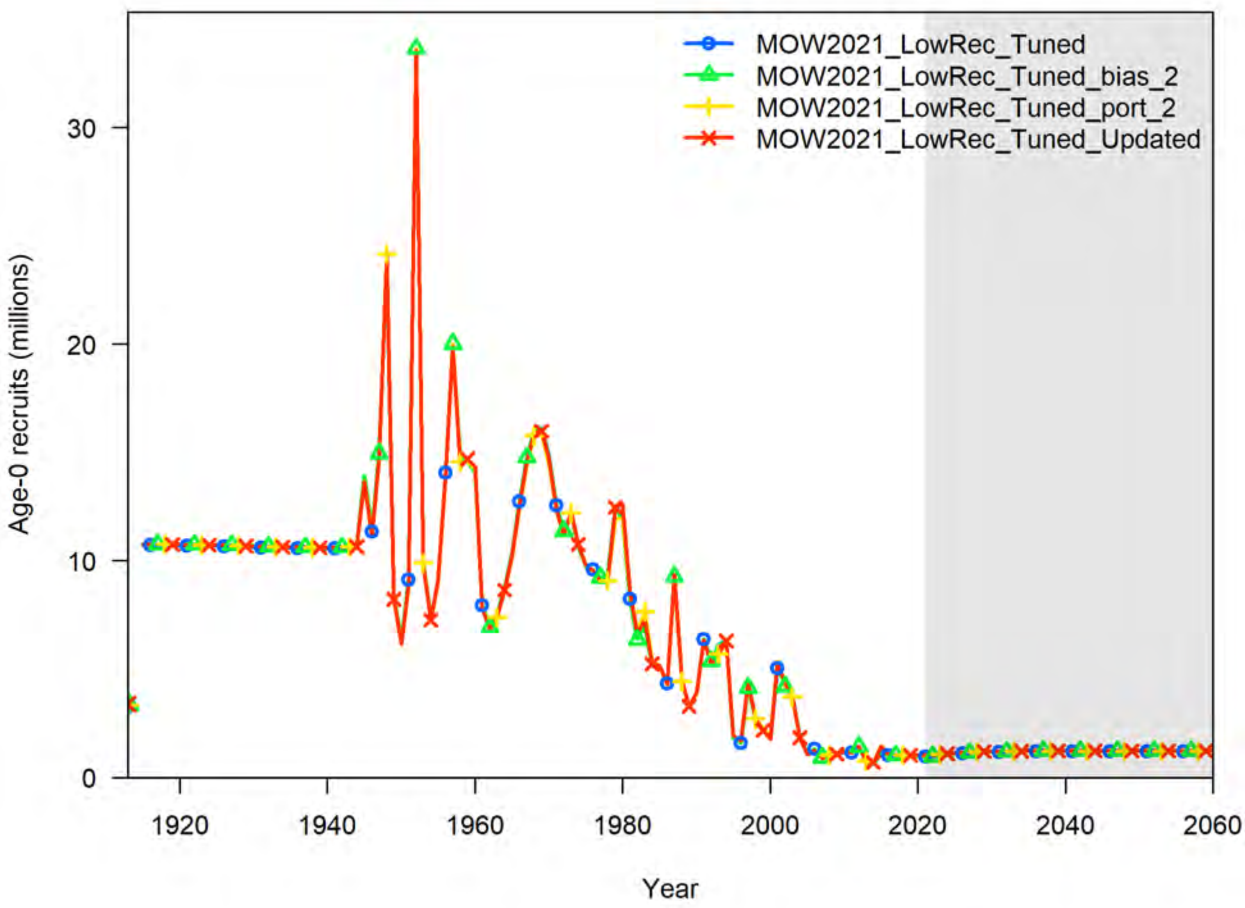


Figure 8.58. Comparison of absolute recruitment for the 2021 base case (blue, MOW2021_LowRec_Tuned), the base case with the updated bias adjustment (green, MOW2021_LowRec_Tuned_bias_2), the base case with the updated port length composition data (yellow, MOW2021_LowRec_Tuned_port_2), and the base case with the both the updated bias adjustment and the updated port length composition data (red, MOW2021_LowRec_Tuned_Updated).

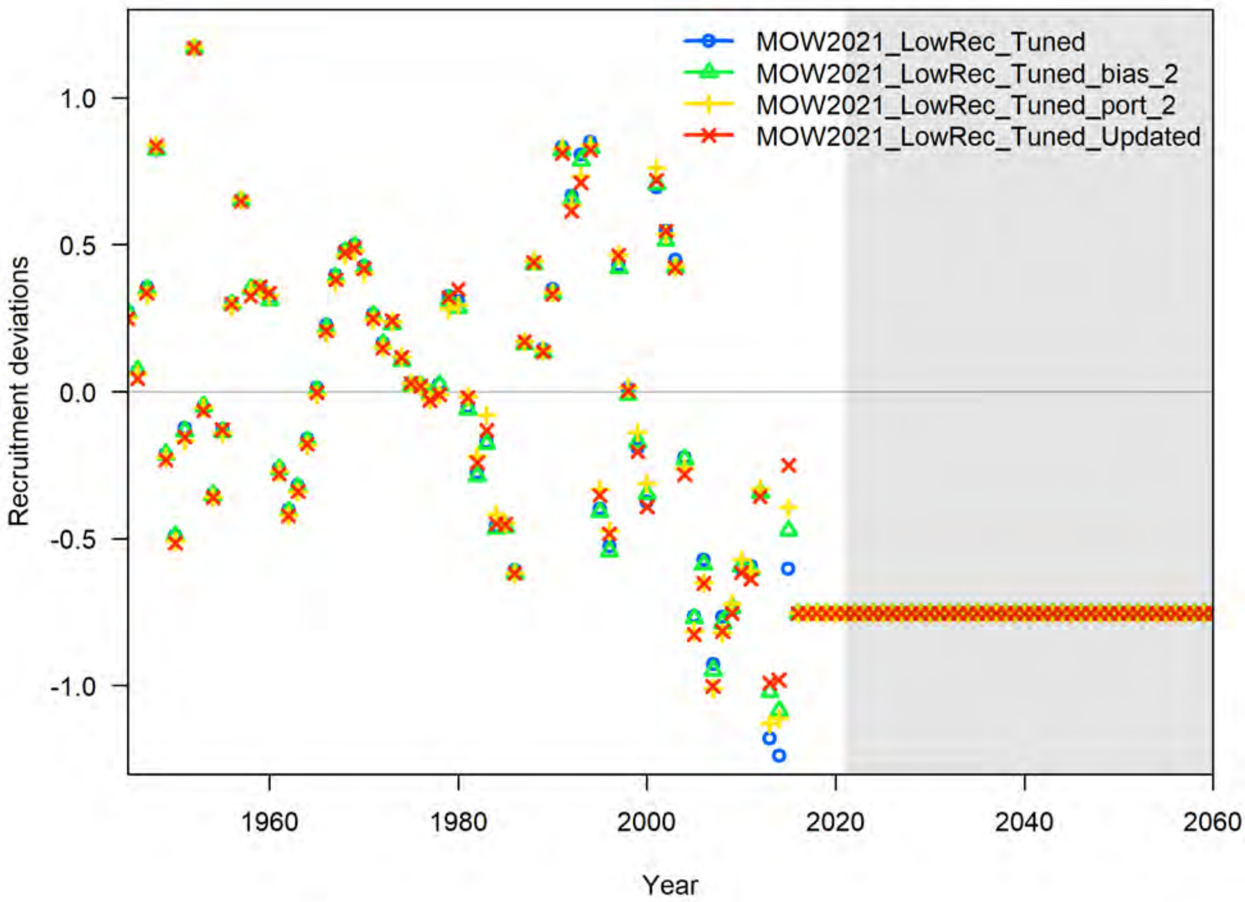


Figure 8.59. Comparison of the recruitment deviations for the 2021 base case (blue, MOW2021_LowRec_Tuned), the base case with the updated bias adjustment (green, MOW2021_LowRec_Tuned_bias_2), the base case with the updated port length composition data (yellow, MOW2021_LowRec_Tuned_port_2), and the base case with the both the updated bias adjustment and the updated port length composition data (red, MOW2021_LowRec_Tuned_Updated).

8.4.10 *Dynamic B_0*

It is possible to calculate dynamic B_0 (Bessell-Browne et al., 2022) by projecting the population forward from its initial state without applying fishing mortality, assuming that the deviations in recruitment about the stock-recruitment relationship are not influenced by fishing pressure and are only influenced by non-fishing related factors, such as environmental drivers. These annual deviations are therefore assumed to be the same in both the fished and unfished cases. This explicitly assumes that fishing affects the numbers-at-age, but not the deviations in biological parameters about their expected values for any particular year. Dynamic B_0 is another way to account for the changing productivity of a stock without having to specify a specific year to implement a productivity shift, as is done in the current assessment. It also allows for trends in productivity to occur through time, rather than assuming a step function where there is a disconnect between two different productivity states. This analysis was conducted on the preliminary base case, with the assumption of average recruitment from 2016 onwards.

Dynamic B_0 for Jackass Morwong is initially the same as static B_0 between 1915 and 1945 as recruitment deviations are not estimated over this period (Figure 8.60, top panel). Between 1946 and 1988 dynamic B_0 is higher than static B_0, before dropping sharply for the remainder of the timeseries (Figure 8.60, top panel). Note that in the assessment model a productivity shift is implemented in 1988, altering the estimated value of B_0.

Estimated relative stock status varies considerably between the base case model with a productivity shift using static B_0 compared to that estimated using dynamic B_0 (Figure 8.60, bottom panel). Under dynamic B_0 the relative stock status falls below the target reference point (B_{48}) initially in the late 1960s, then recovers to values just above B_{48} in the early 1970s, then in 1981 falls below B_{48} and stays below B_{48} until the end of the time series. Relative to the limit reference point (B_{20}), the relative stock status under dynamic B_0 drops below the B_{20} from 2013-2015, and then increases to above (B_{20}) at the end of the time series (2020 in this case). This series is in stark contrast to the relative stock status series estimated using the productivity shift, where stock status is not estimated to fall below the target reference point until 2003, then falling below the limit reference point in 2013, the same year as estimated using dynamic B_0 (Figure 8.60, lower plot). Stock status using the productivity shift is then estimated to stay below the limit reference point until 2022, when it is projected to recover to a value greater than B_{20}, seven years after the population was estimated to recover to a value greater than B_{20} under dynamic B_0 (Figure 8.60).

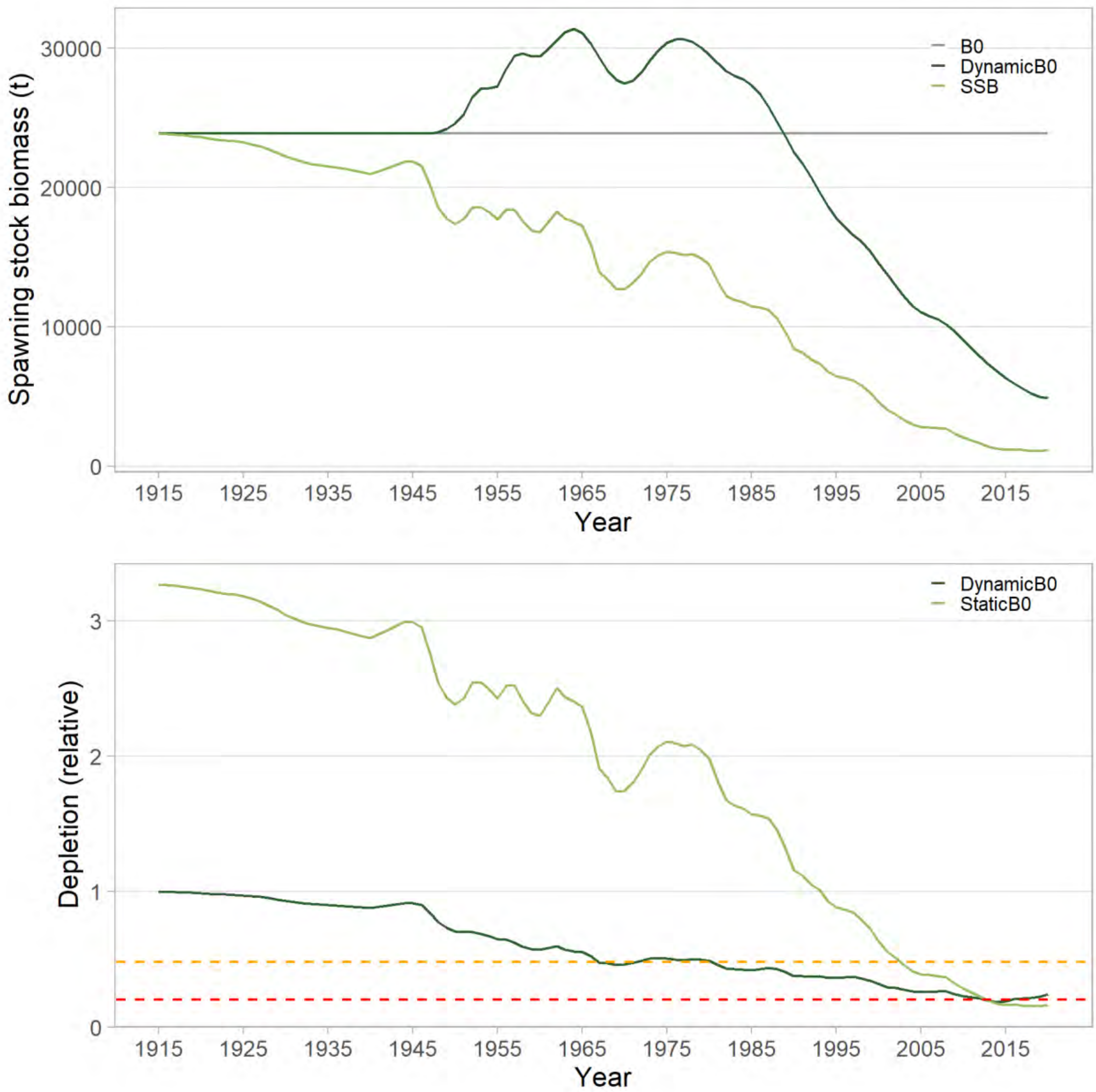


Figure 8.60. Dynamic B_0 for Jackass Morwong: spawning stock biomass (top) showing the trajectory of "dynamic B_0" (dark green) and the preliminary base case model predicted spawning stock biomass (light green), and; stock status (bottom) showing the trajectory of relative stock status, with a productivity shift implemented as a step function in 1988, under static B_0 (light green) and under dynamic B_0 (dark green). The orange dashed line is the target reference point (B_{48}) and the red dashed line is the limit reference point (B_{20}).

8.4.11 *MCMC analysis*

8.4.11.1 MCMC analysis

Markov chain Monte Carlo (MCMC) methods can be used for approximating the posterior distribution for parameters of interest in a Bayesian framework (Gelman et al. 2003). This enables estimation of the probability distribution of quantities such as stock status. An MCMC simulation should be run long enough so that the model converges, in the sense that the parameter vectors are random independent samples from the posterior (i.e. the distribution of draws is close enough to the target posterior distribution $p(\theta \mid y)$ (Gelman et al, 2003)).

As MCMC analysis requires estimation of all parameters, making use of the variance associated with parameter estimation, including variance in estimates of future recruitment deviations, it is not possible to run an MCMC analysis on the low recruitment scenario, in which recruitment from 2016 onwards is fixed. An alternative model was set up to attempt to mimic the appropriate behaviour, by imposing an additional productivity shift in 2016, but essentially fixing the value of the new “2016 equilibrium biomass” and tuning this value in an attempt to match the spawning biomass trajectory for the base case and the “double recruitment shift MCMC model”. While the results are not perfect, this may give an indication of the range of uncertainty in estimates of stock status in the period of most interest, 2010-2026. The reasons for running an MCMC analysis was to estimate the probability that the stock status is below SSB_{20} in the period 2010-2026, and this double recruitment shift MCMC model seemed to be a reasonable approximation for these purposes (Figure 8.61 and Figure 8.62).

MCMC simulations were run for 24 million cycles, with every 10,000th iteration saved. This gave 2,400 samples from the posterior distribution. The first 400 samples were omitted from the chain, which resulted in 2,000 posterior samples. The total run time was three days using a standard scientific personal computer.

Model convergence was assessed using the following statistics: (i) the extent of batch auto-correlation (examined using trace plots), as high autocorrelations indicate slow mixing and slow convergence, (ii) whether the posterior distribution was approximately multivariate normal (we examined the plot of the posterior distribution), and whether the distribution of the chain is stationary, as judged by the p-value computed from the Geweke statistic (which should be close to ±1.96) and (iii) whether the Heidelberger and Welch test is passed or not (Heidelberger and Welch 1983, Gelman et al. 2003). The R package, coda (Plummer et al., 2006) and r4ss (Taylor et al., 2014), were used to produce the plots and statistics.

8.4.11.2 MCMC results for low recruitment scenario

Diagnostic statistics and plots show that the MCMC run appears to have converged sufficiently, with 93% of the parameters passing the Geweke test, indicating no significant differences in the median values between the first and last parts of the chain, only one parameter having an autocorrelation greater than 0.4, and only one parameter failed (Q_extraSD_East_Trawl_Onbd.1) the Heidelberger and Welch test.

The median of the posterior distribution (MPD) from the MCMC simulations from the double recruitment shift MCMC model is close to the maximum likelihood estimate (MLE) for the low recruitment base case, for 1988 equilibrium biomass and spawning stock biomass from 2022-2026 (Table 8.25) and for stock status from 2022-2026 (Table 8.26), noting that the two models are not identical. The MLE estimates are outside of the 95% credibility intervals, in all cases, but the width of the credibility interval is indicative of the likely confidence bounds on the MLE estimate from the base case, at least for the 2022 stock status.

The spawning stock biomass time series (top panels) and stock status time series (bottom panels) are shown in Figure 8.61, with the left panels showing these series for the period 1915-2060, and the right panels expanded to show the details in the period 2010-2026, with the MLE from the base case shown in red and the MPD estimate from the double recruitment shift MCMC model shown in black with 50% credibility intervals (shaded) and 95% credibility intervals (dotted lines).

The absolute recruitment time series (top panels) and recruitment deviation time series (bottom panels) are shown in Figure 8.62, with the left panels showing these series for the period 1915-2060, and the right panels expanded to show the details in the period 2010-2026, with the MLE from the base case shown in red and the MPD estimate from the double recruitment shift MCMC model shown in black with 50% credibility intervals (shaded) and 95% credibility intervals (dotted lines).

Table 8.25. Spawning stock biomass from the MLE for the base case (low recruitment) and for the MPD with 95% credibility intervals for the double recruitment shift MCMC model.

	MLE	MPD	95% credible intervals	
Year	SSB		low	high
1988	7964.83	8200.55	8132	8264
2022	1308.98	1205.66	1192	1218
2023	1433.01	1300.13	1288	1311
2024	1523.31	1370.90	1359	1381
2025	1585.96	1421.98	1411	1432
2026	1640.69	1463.99	1453	1474

Table 8.26. Stock status from the MLE for the base case (low recruitment) and for the MPD with 95% credibility intervals for the double recruitment shift MCMC model.

	MLE	MPD	95% credible intervals	
Year	stock status		low	high
2022	16.4	14.7	14.5	14.8
2023	18.0	15.9	15.7	16
2024	19.1	16.7	16.6	16.9
2025	19.9	17.3	17.3	17.5
2026	20.6	17.9	17.8	17.9

While this MCMC analysis is indicative only, as it applies to a model which is different to the base case, this analysis gives an indication on the likely confidence intervals that should apply to the MLE estimates. If that assumptions holds, the probability of the stock status reaching B_{20} by 2024 is likely to be less than 5%, but will be close to 50% by 2025, and over 95% by 2026, assuming the catch is zero (no bycatch) for the next four years.

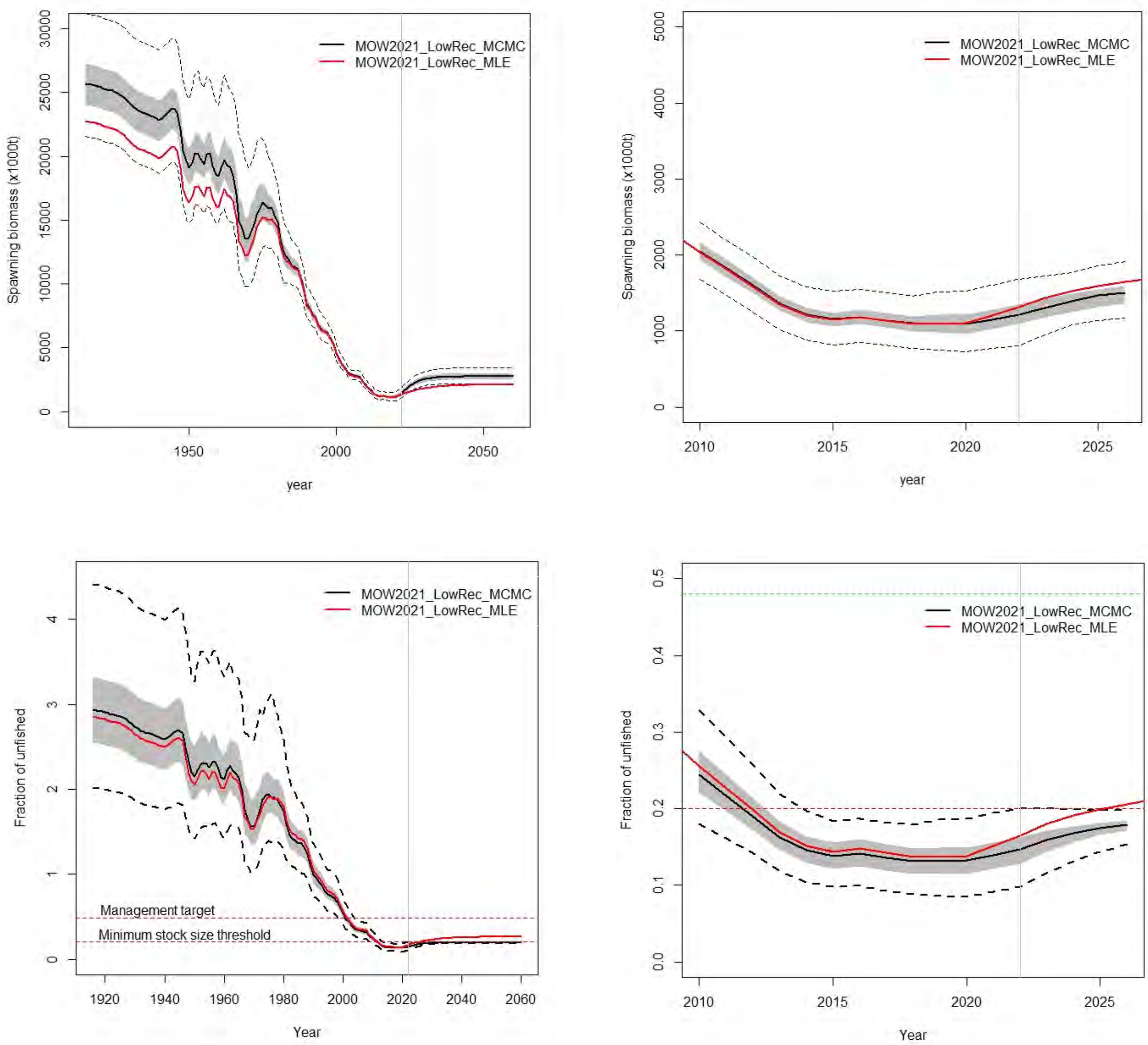


Figure 8.61. Absolute spawning biomass (top) and stock status (bottom) for the maximum likelihood estimate (MLE, red line) from the low recruitment base case and the median of the posterior distribution (MPD, black line) for the double recruitment shift MCMC model, with 50% (grey shaded area) and 95% credible intervals (dashed lines). The right panels focus on the time series from 2010-2016.

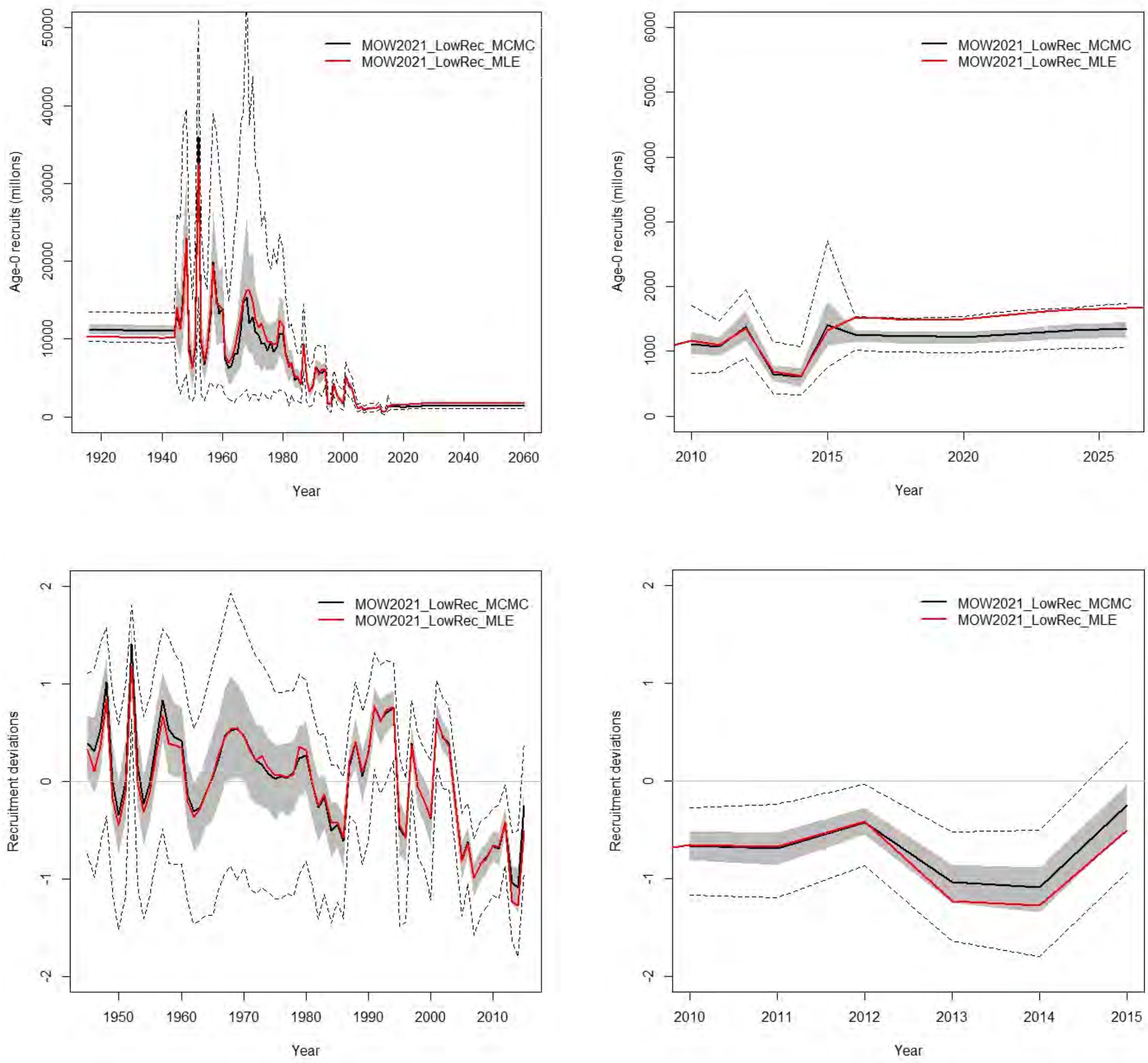


Figure 8.62. Absolute recruitment estimates (top) and recruitment deviations (bottom) for the maximum likelihood estimate (MLE, red line) from the low recruitment base case and the median of the posterior distribution (MPD, black line) for the double recruitment shift MCMC model, with 50% (grey shaded area) and 95% credible intervals (dashed lines). The right panels focus on the time series from 2010-2016.

Table 8.27. Summary statistics for parameters from the MCMC analysis.

Label	autocor	Geweke	N_{eff}/N	Heidel-Welsch
L_at_Amin_Fem_GP_1	-0.021	-2.416	995	Passed
L_at_Amax_Fem_GP_1	0.036	-2.775	995	Passed
VonBert_K_Fem_GP_1	-0.021	2.647	995	Passed
CV_young_Fem_GP_1	0.011	3.000	911	Passed
SR_LN.R0.	0.012	-0.875	995	Passed
SR_LN.R0._BLK2add_1914	0.001	1.207	995	Passed
Q_extraSD_East_Trawl_Onbd.1.	0.034	-1.901	797	Failed
Q_extraSD_Tas_Trawl_Onbd.3.	0.039	-0.379	995	Passed
Q_extraSD_Steam_Trawl.4.	-0.026	-0.807	995	Passed
Q_extraSD_Mixed.6.	0.228	0.330	626	Passed
Q_extraSD_Smith_CPUE.7.	0.005	-0.963	995	Passed
Q_extraSD_FIS_East.8.	0.381	-0.292	389	Passed
Q_extraSD_FIS_Tas.9.	-0.012	0.905	995	Passed
Size_inflection_East_Trawl_Onbd.1.	-0.012	-1.404	995	Passed
Size_95.width_East_Trawl_Onbd.1.	-0.007	-1.479	995	Passed
Retain_L_infl_East_Trawl_Onbd.1.	0.017	-0.623	995	Passed
Retain_L_width_East_Trawl_Onbd.1.	0.023	0.274	995	Passed
Size_inflection_Danish_Seine_Onbd.2.	-0.005	-0.471	995	Passed
Size_95.width_Danish_Seine_Onbd.2.	-0.054	0.126	995	Passed
Size_inflection_Tas_Trawl_Onbd.3.	0.012	0.009	995	Passed
Size_95.width_Tas_Trawl_Onbd.3.	0.033	-0.197	995	Passed
Retain_L_infl_Tas_Trawl_Onbd.3.	0.099	-1.906	816	Passed
Retain_L_width_Tas_Trawl_Onbd.3.	0.095	2.023	822	Passed
Size_inflection_Steam_Trawl.4.	-0.001	-0.857	995	Passed
Size_95.width_Steam_Trawl.4.	0.016	0.185	995	Passed
Size_inflection_Early_DS.5.	0.033	-1.869	995	Passed
Size_95.width_Early_DS.5.	-0.018	-1.462	995	Passed
Size_inflection_Mixed.6.	0.007	-0.270	995	Passed
Size_95. Width_Mixed.6.	-0.018	0.010	995	Passed
Size_inflection_FIS_East.8.	**0.492**	3.000	253	No test
Size_95.width_FIS_East.8.	0.354	-0.606	360	Passed
Size_inflection_FIS_Tas.9.	-0.003	-0.598	995	Passed
Size_95.width_FIS_Tas.9.	-0.016	1.563	995	Passed

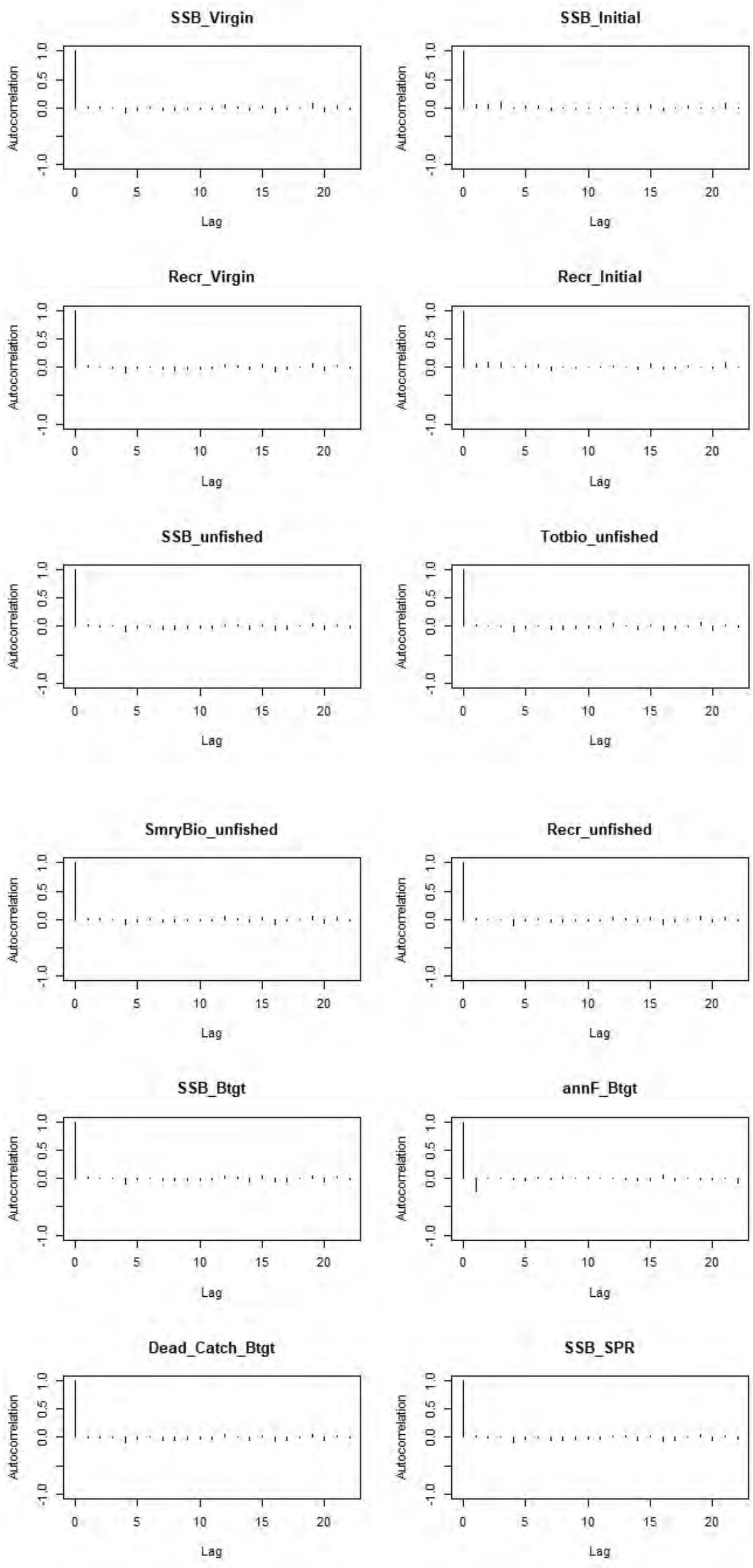


Figure 8.63. Autocorrelation plots for the double recruitment shift MCMC model.

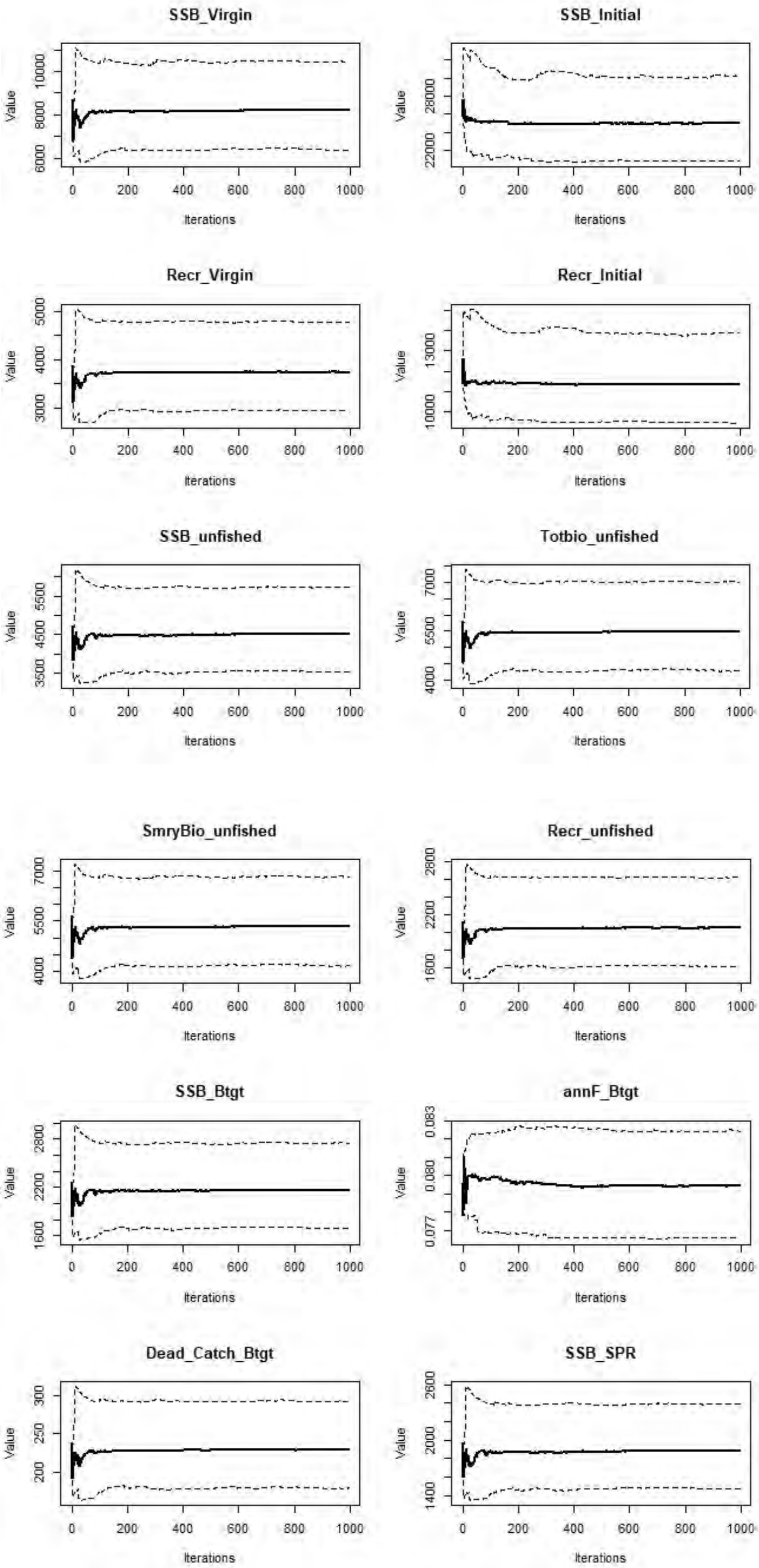


Figure 8.64. Trace plots (part 1): iterations vs sampled values for the double recruitment shift MCMC model.

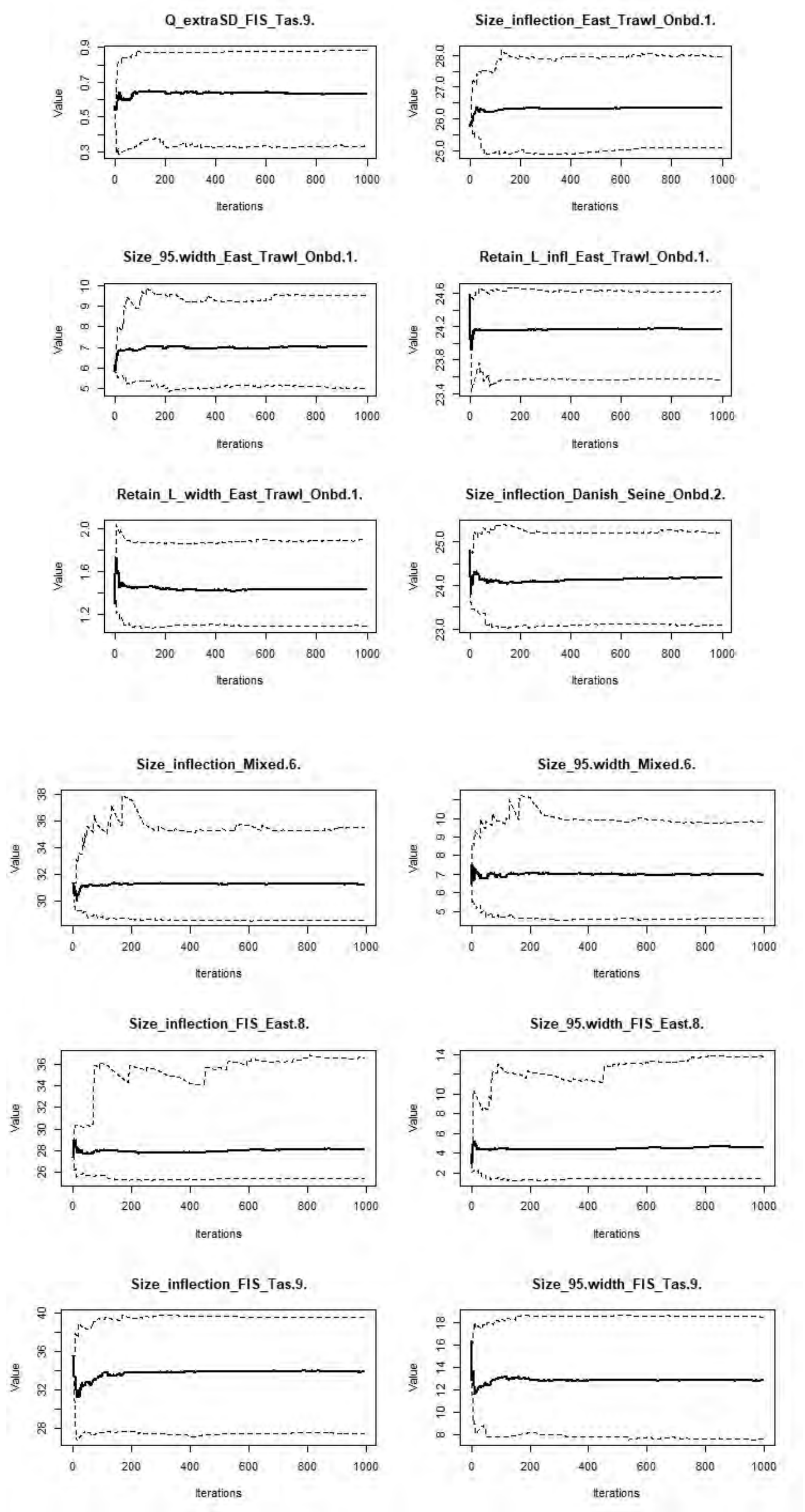


Figure 8.65. Trace plots (part2): iterations vs sampled values for the double recruitment shift MCMC model.

8.4.12 *Future work and potential issues with this assessment and data*

There are still some unresolved issues relating to allocation of recent state catches for the period 2014-2020 between eastern and western fleets (noting that the western fleet is used only for the western Jackass Morwong assessment), especially for Tasmanian and Victorian state catches, but these catches are relatively small compared to other catches in the same period, and any future revisions are unlikely to have a noticeable influence on the assessment outcomes. Some of these catches are currently masked, with assumptions made about this catch data, due to concerns about use of confidential data and the five-boat rule. Ideally, appropriate use of the actual data will be negotiated for future assessments, ensuring that the confidentiality requirements of the data owners are respected. It would be good to resolve these issues to ensure the best possible data is available for use in the future stock assessments.

There are also some unresolved issues relating to NSW state catches in the period 1986-1999. In 2007, an attempt was made to account for double counting (i.e. recording catches in both state and Commonwealth logbooks) catches reported to NSW state in the period 1986-2009 (Kevin Rowling, pers comm. 2021, Sally Wayte, pers. comm. 2021). While the details are not fully documented in the relevant stock assessment reports, and alternative catch series could be constructed for this period using different assumptions to account for double counting, it appears that the changes to these potential catch series would be relatively small. Larger revisions to the catch history back to 1986 incorporated in Bridge 2 in 2021 (Day and Bessell-Browne, 2021) had very little impact on both the spawning biomass time series and the recruitment estimates, so it is likely such revisions would have no material impact on the assessment results.

There appear to be convergence issues with the updated ageing error matrix, relating to potential outliers in the data. This requires further investigation.

Any results from this assessment should be treated with some caution given the recent data quality available for this assessment and the quality of the eastern trawl CPUE data. Sporcic (2021) states that “The structural adjustment altered the effect of the vessel factor on the standardised result. However, log(CPUE) has also changed in character from 2014-2020, with spikes of low catch rates arising” and “Annual standardized CPUE has been below the long-term average since about 2000 with apparent periodicity. Both the recorded catch (36.6 t) and number of records (956) in 2020 were the lowest in the series.”

8.5 Acknowledgements

Age data were provided by Kyne Krusic-Golub (Fish Ageing Services), ISMP and AFMA logbook and CDR data were provided by John Garvey (AFMA). Mike Fuller, Paul Burch, Robin Thomson, Roy Deng, Franzis Althaus, Toni Cannard and Caroline Sutton (CSIRO) were all involved in pre-processing the data. Malcolm Haddon provided useful code for auto-tuning, Athol Whitten provided useful R code for organising plots. André Punt and Paul Burch helped provide an updated ageing error matrix. André Punt, Geoff Tuck, Miriana Sporcic, Paul Burch, Robin Thomson and Brett Stacy and are thanked for helpful discussions on this work. Ian Taylor, Richard Methot and Chantel Wetzel and Kathryn Doering (NOAA Fisheries) are thanked for support and advice using Stock Synthesis. The r4ss package maintained by Ian Taylor (https://github.com/r4ss/r4ss) was critical for producing multiple diagnostic plots, and tuning models. Thanks to Ian Taylor for his patient advice on using this package and for answering numerous technical questions on Stock Synthesis over a number of years. Geoffrey Liggins contributed to useful discussions on the catch history.

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8.7 Appendix A

8.7.1 Fits to length composition, implied fits to age composition and diagnostics for fits to conditional age-at-length data

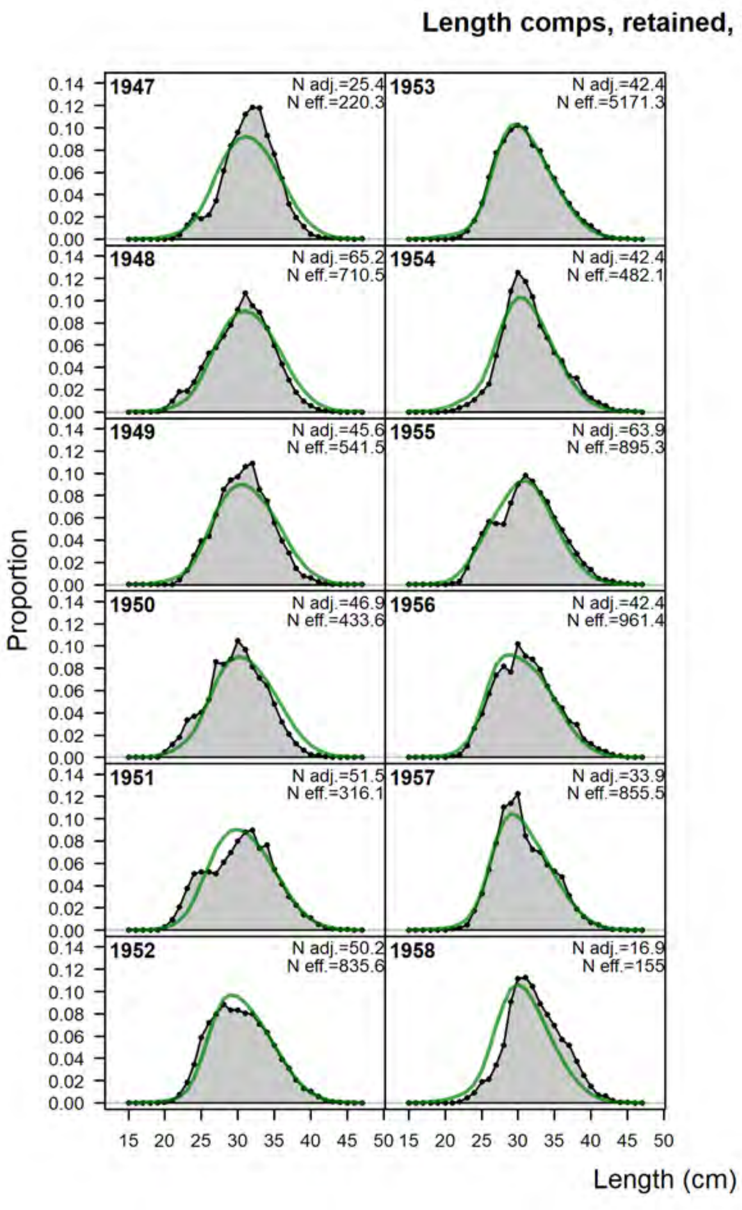


Figure A 8.1. Eastern Jackass Morwong length composition fits: steam trawl fleet retained.

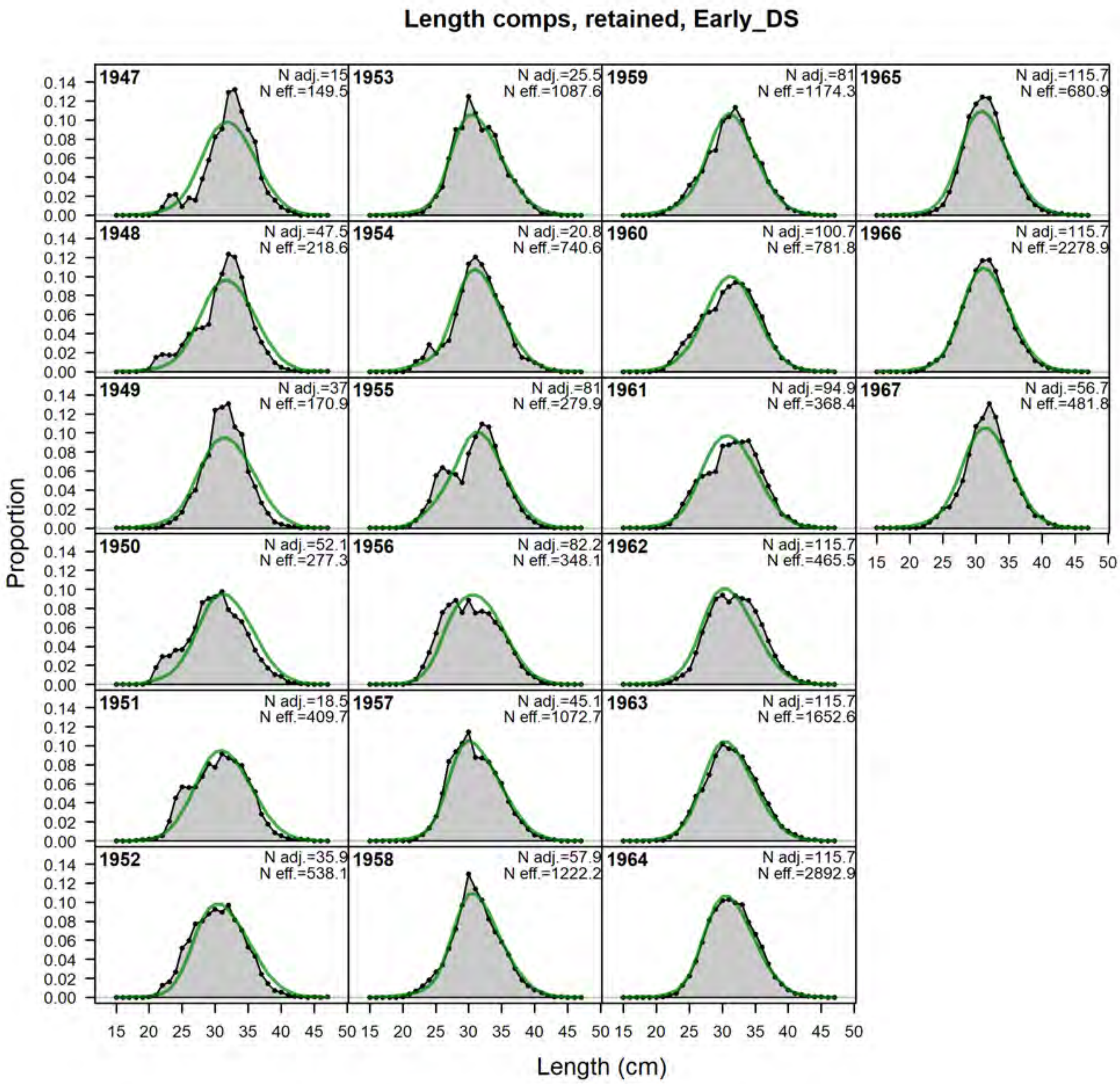


Figure A 8.2. Eastern Jackass Morwong length composition fits: early Danish seine fleet retained.

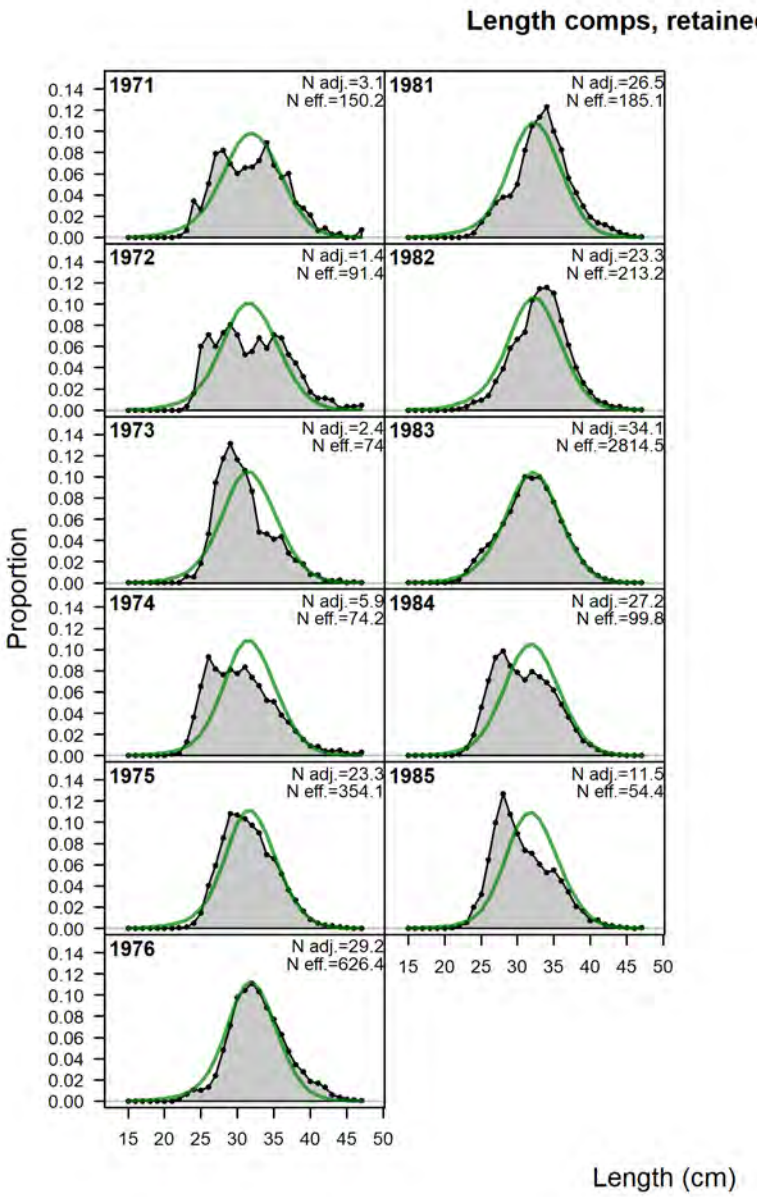


Figure A 8.3. Eastern Jackass Morwong length composition fits: mixed fleet retained.

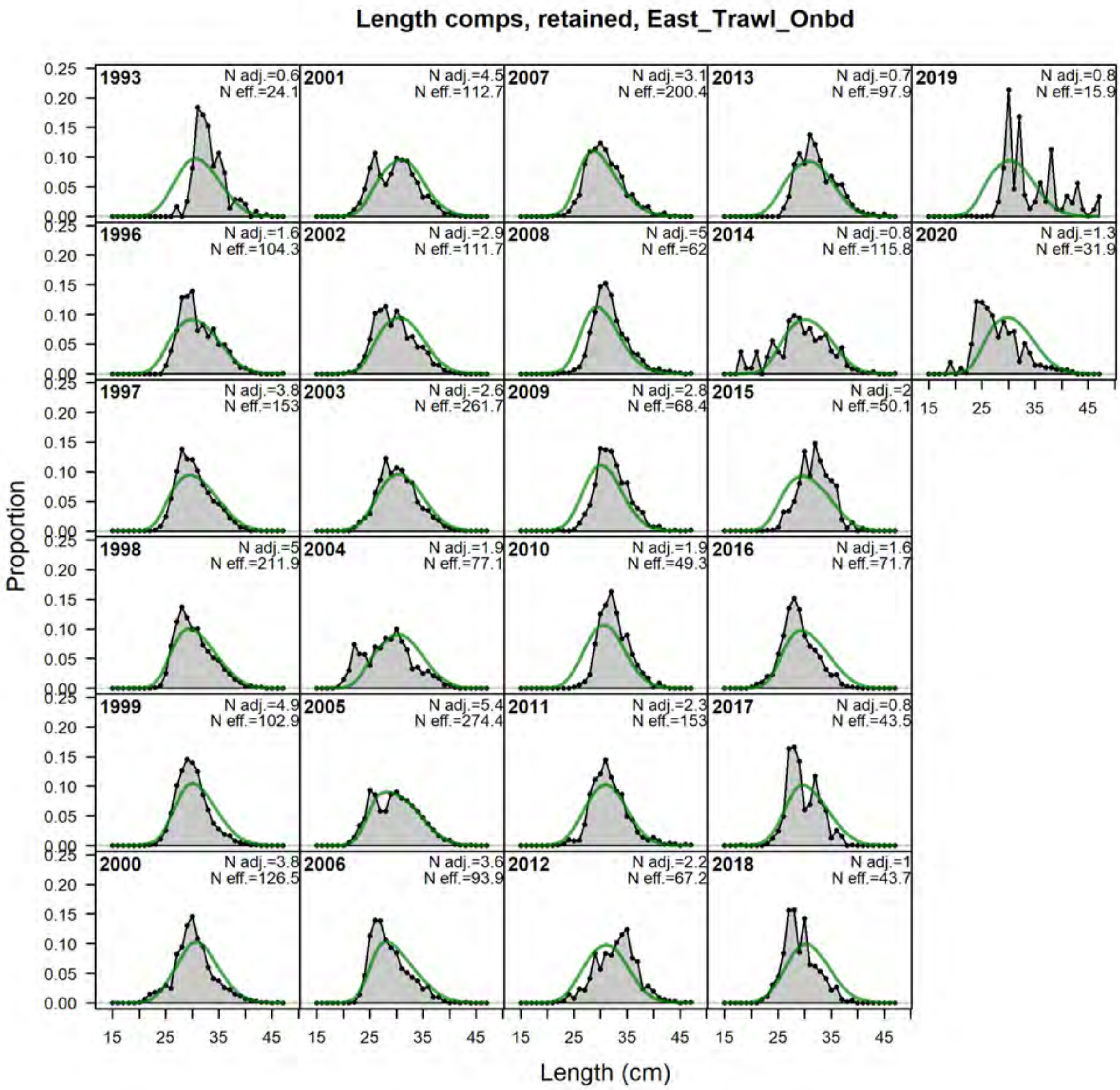


Figure A 8.4. Eastern Jackass Morwong length composition fits: eastern trawl fleet onboard retained.

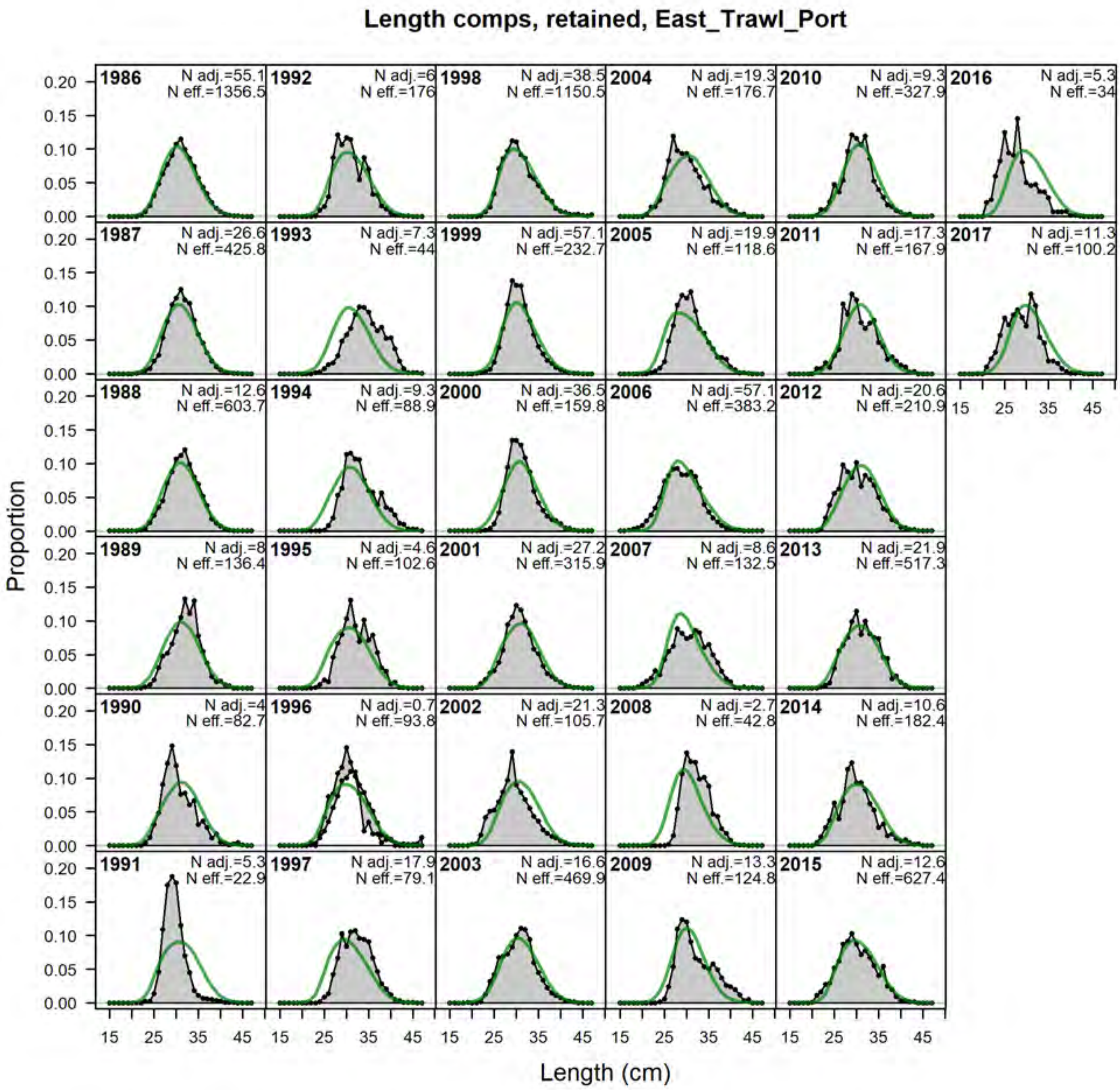


Figure A 8.5. Eastern Jackass Morwong length composition fits: eastern trawl fleet port retained.

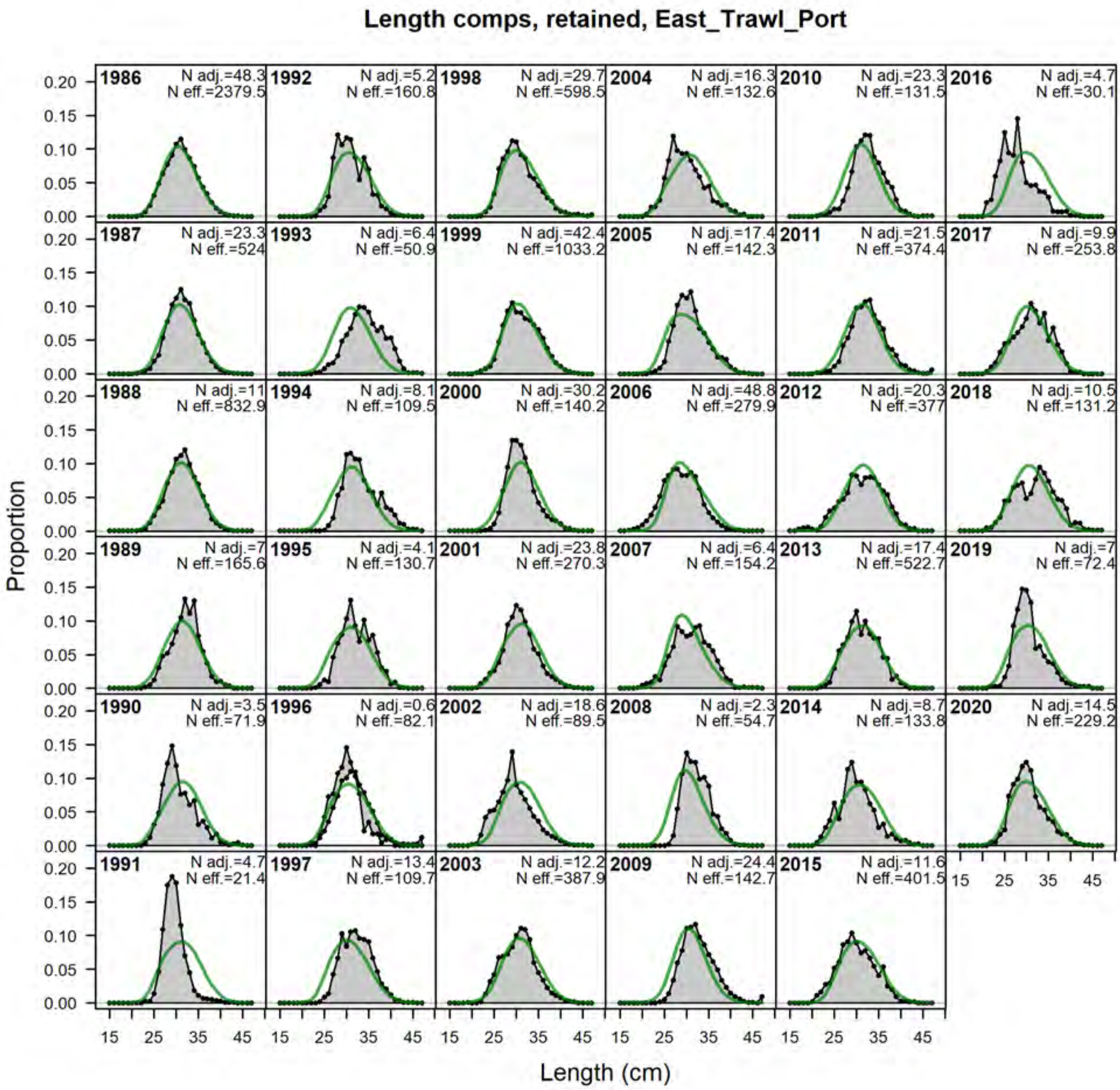


Figure A 8.6. Eastern Jackass Morwong length composition fits for the "updated base case" with revised port length composition data: eastern trawl fleet port retained.

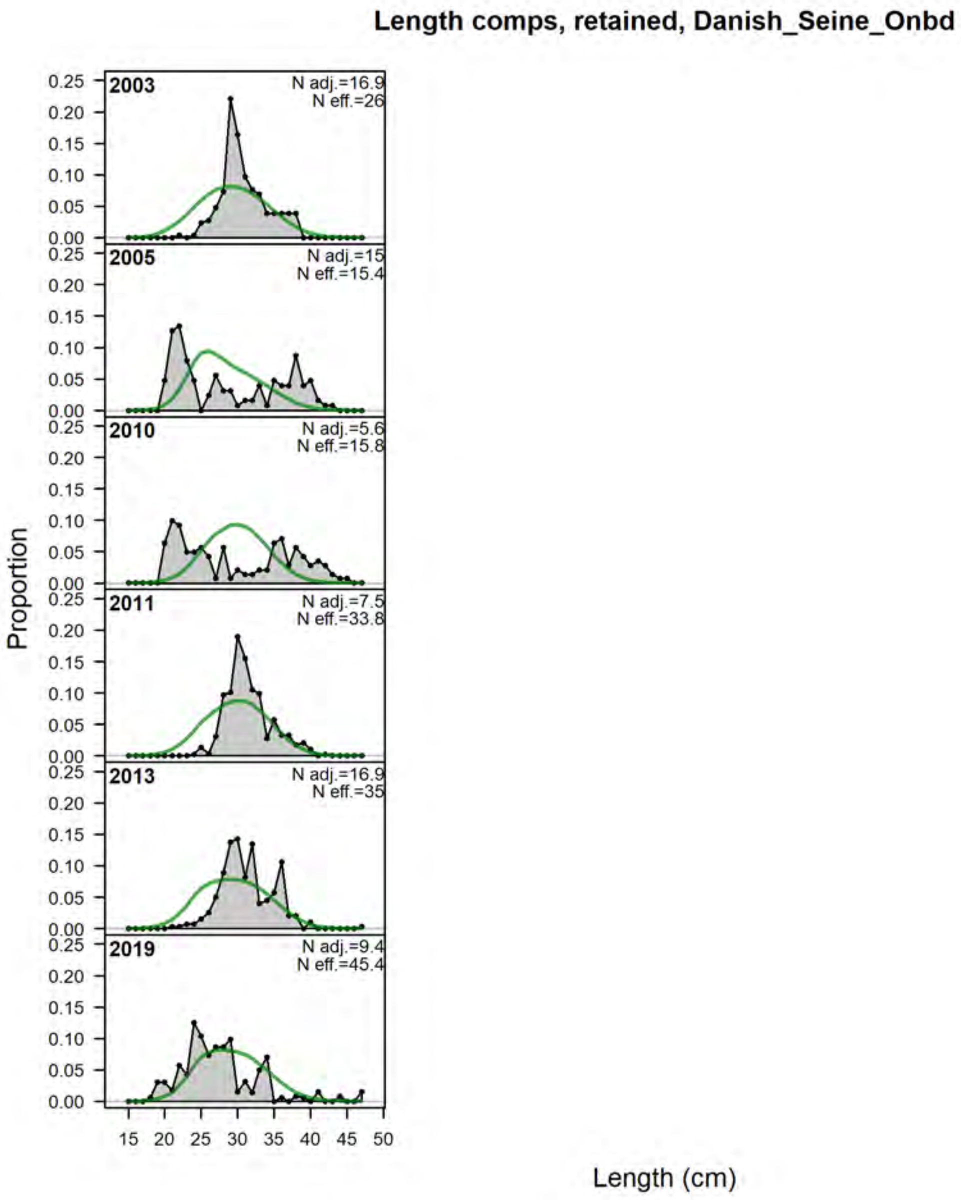


Figure A 8.7. Eastern Jackass Morwong length composition fits: Danish seine fleet onboard retained.

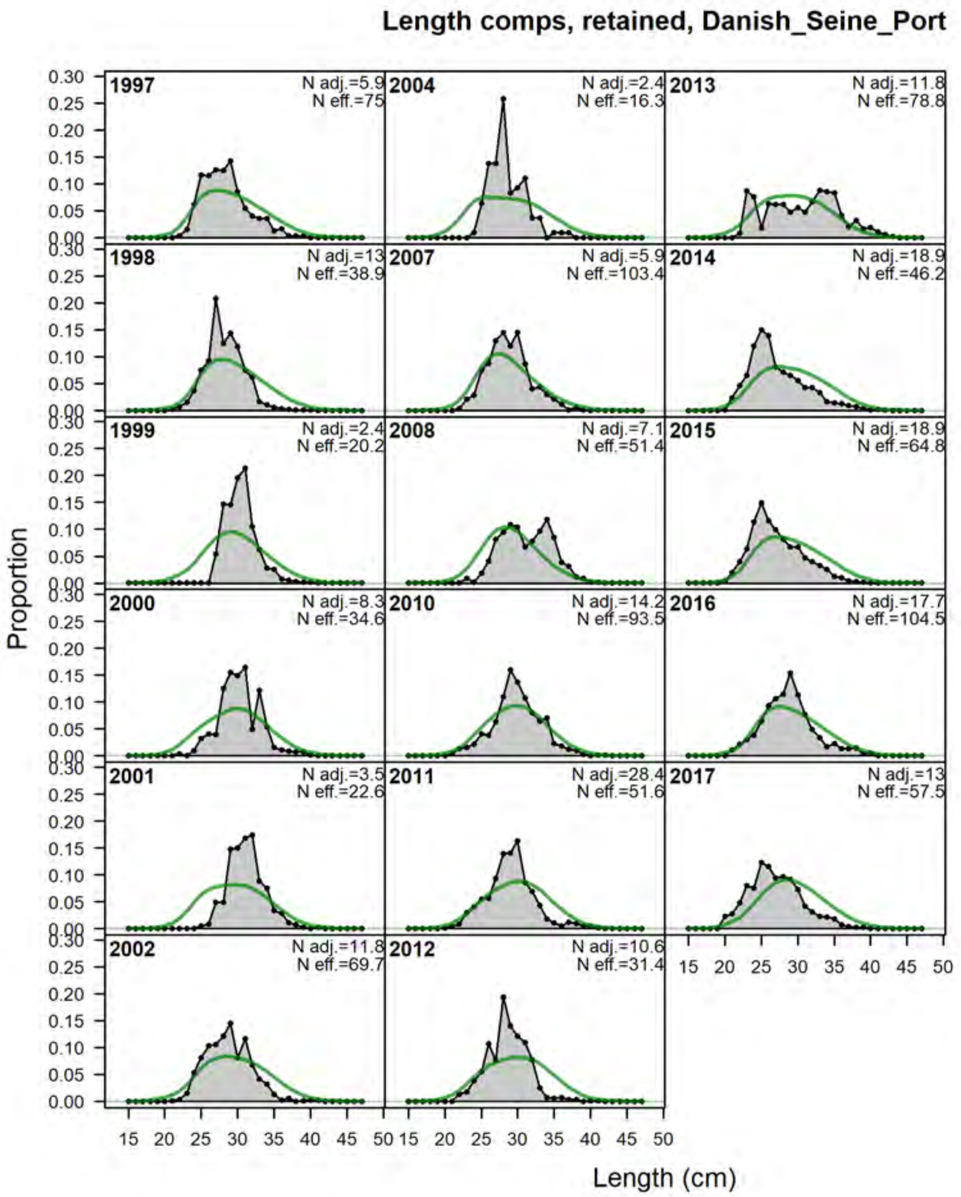


Figure A 8.8. Eastern Jackass Morwong length composition fits: Danish seine fleet port retained.

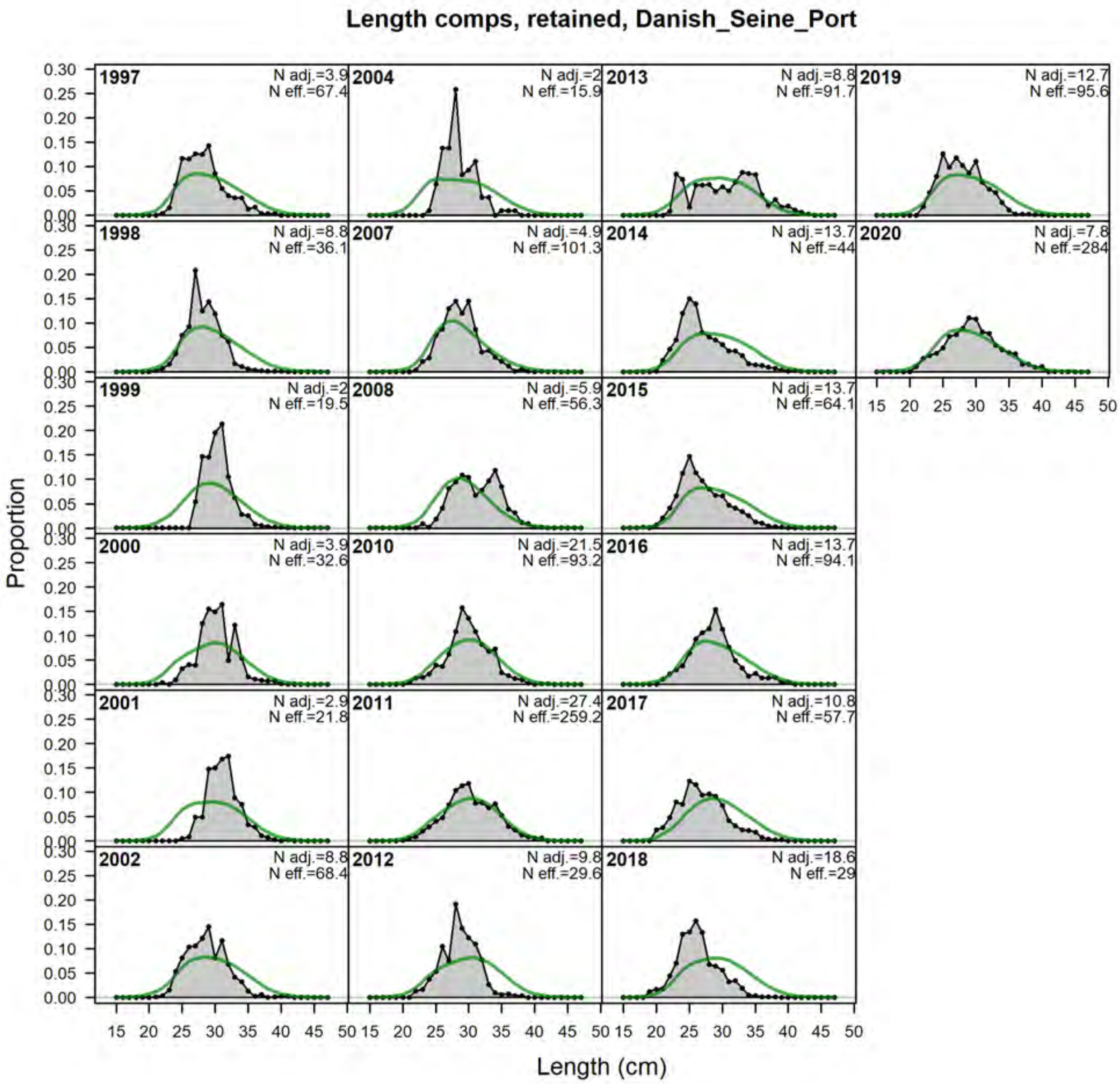


Figure A 8.9. Eastern Jackass Morwong length composition fits for the "updated base case" with revised port length composition data: Danish seine fleet port retained.

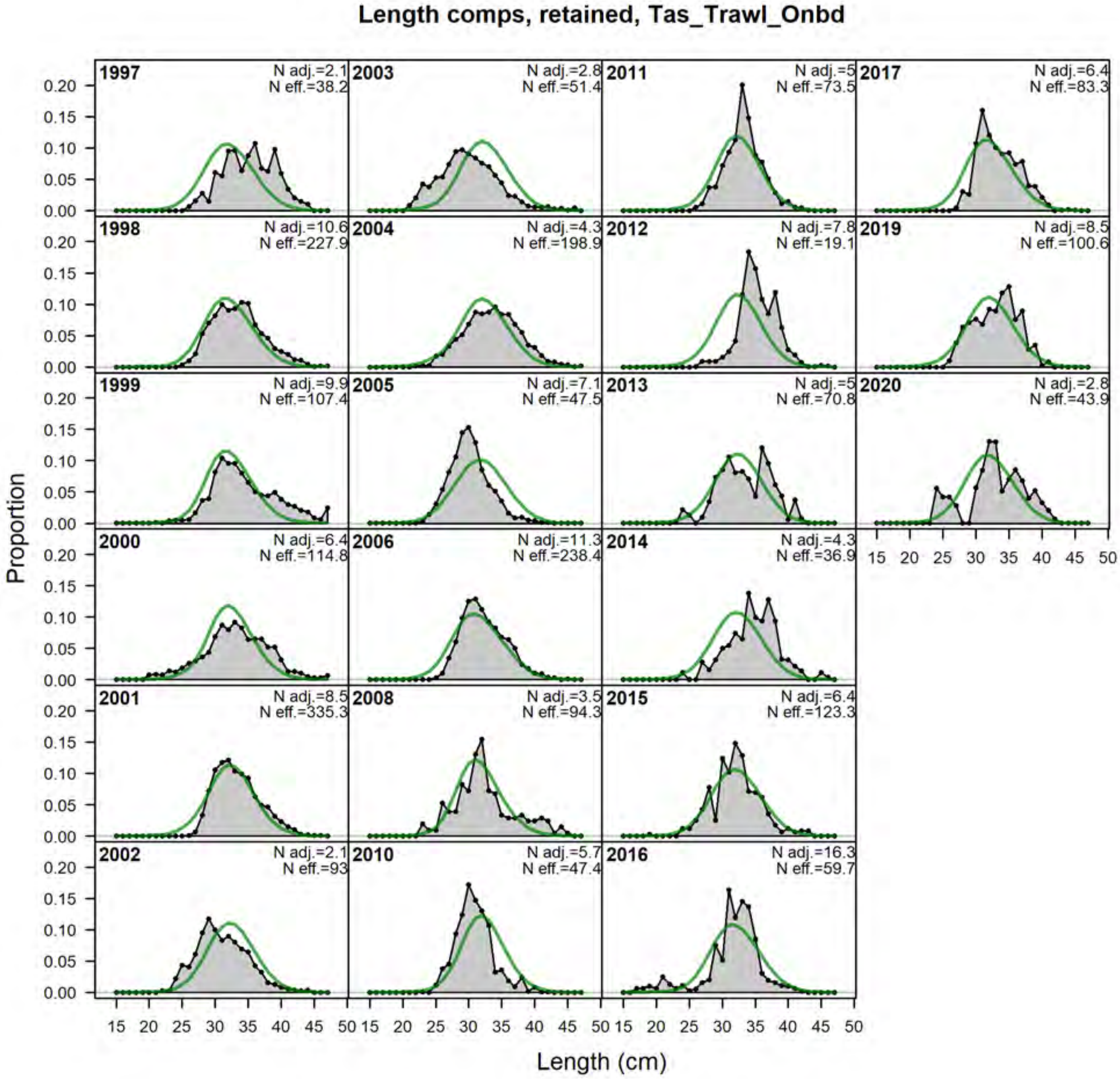


Figure A 8.10. Eastern Jackass Morwong length composition fits: Tasmanian trawl fleet onboard retained.

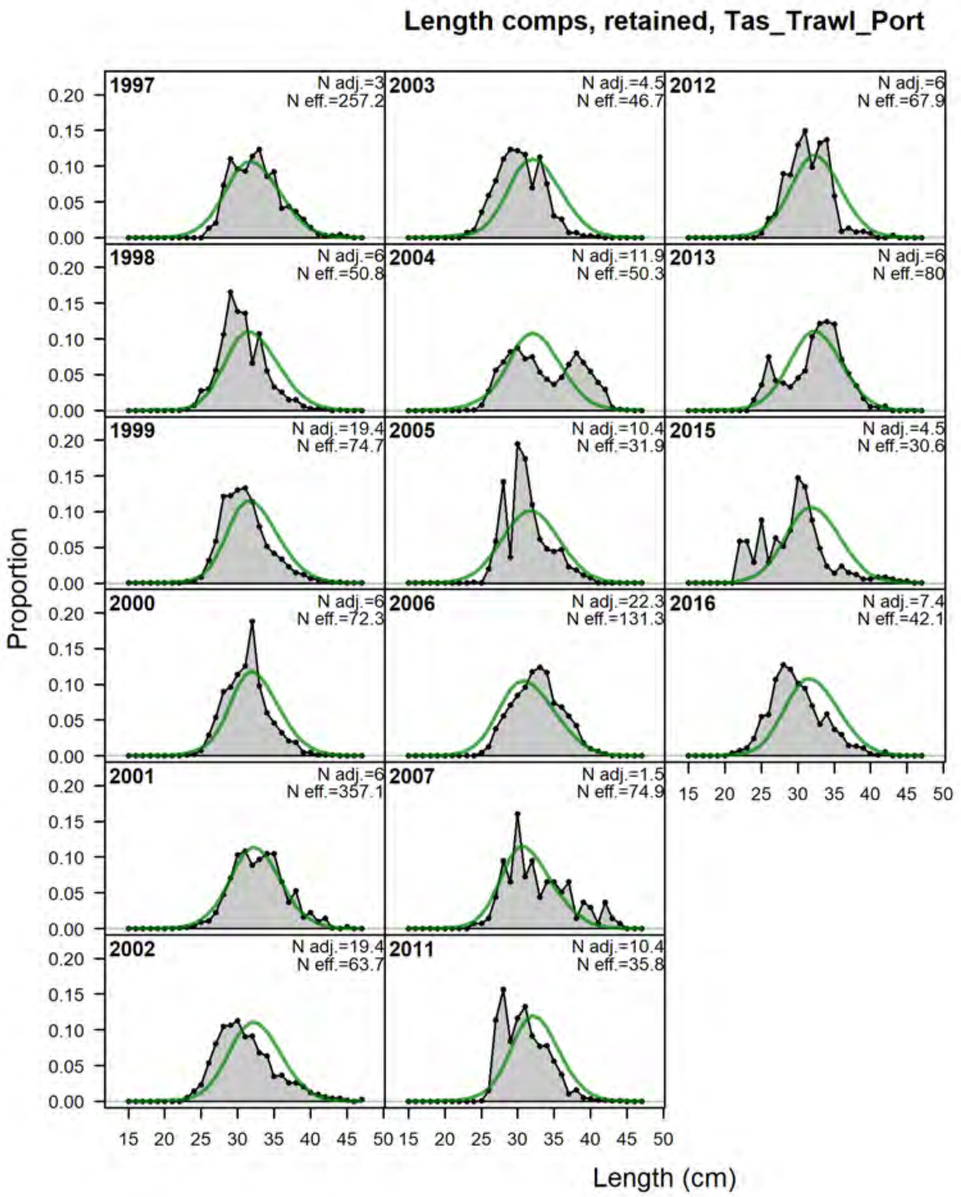


Figure A 8.11. Eastern Jackass Morwong length composition fits: Tasmanian trawl fleet port retained.

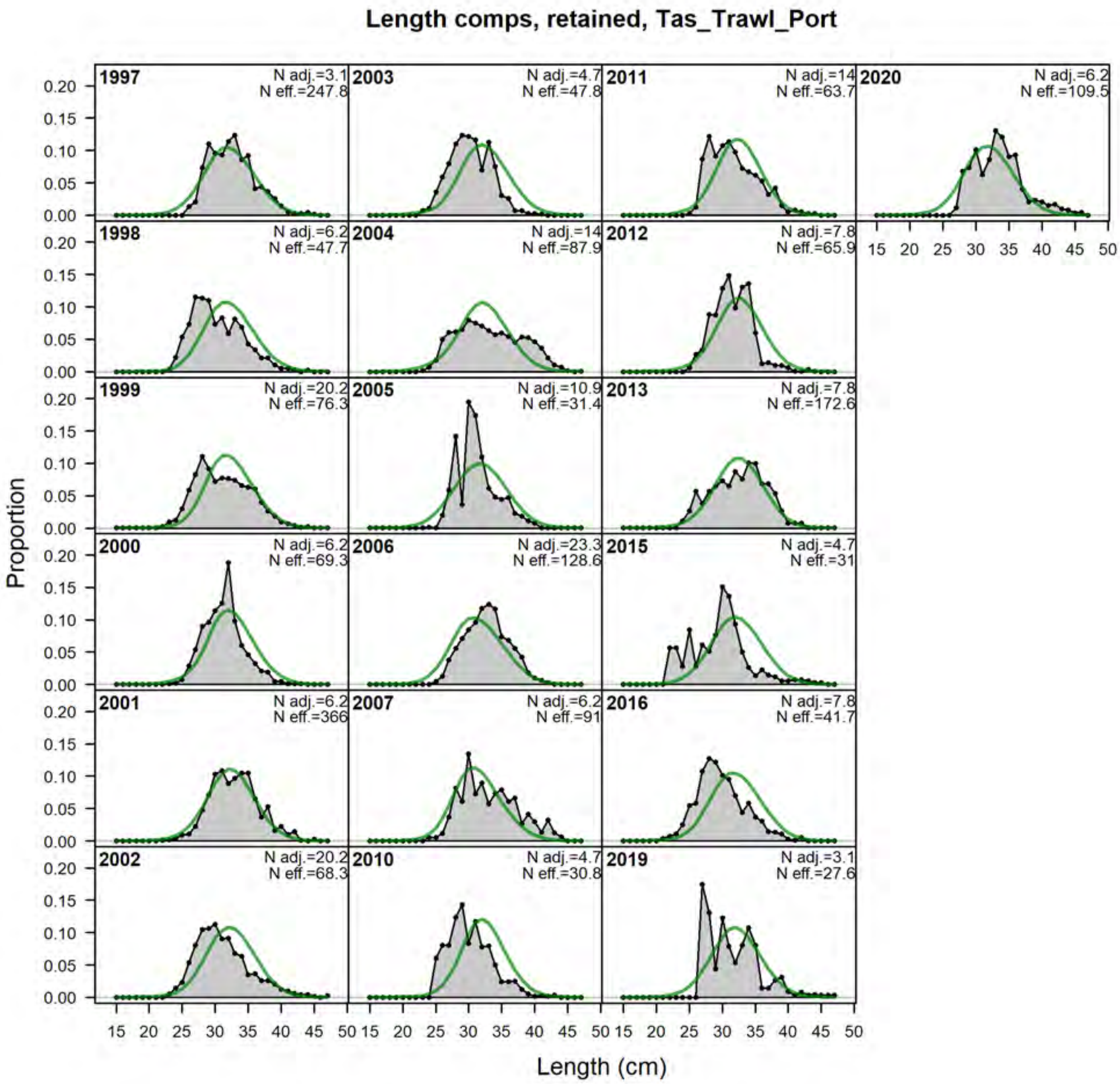


Figure A 8.12. Eastern Jackass Morwong length composition fits for the "updated base case" with revised port length composition data: Tasmanian trawl fleet port retained.

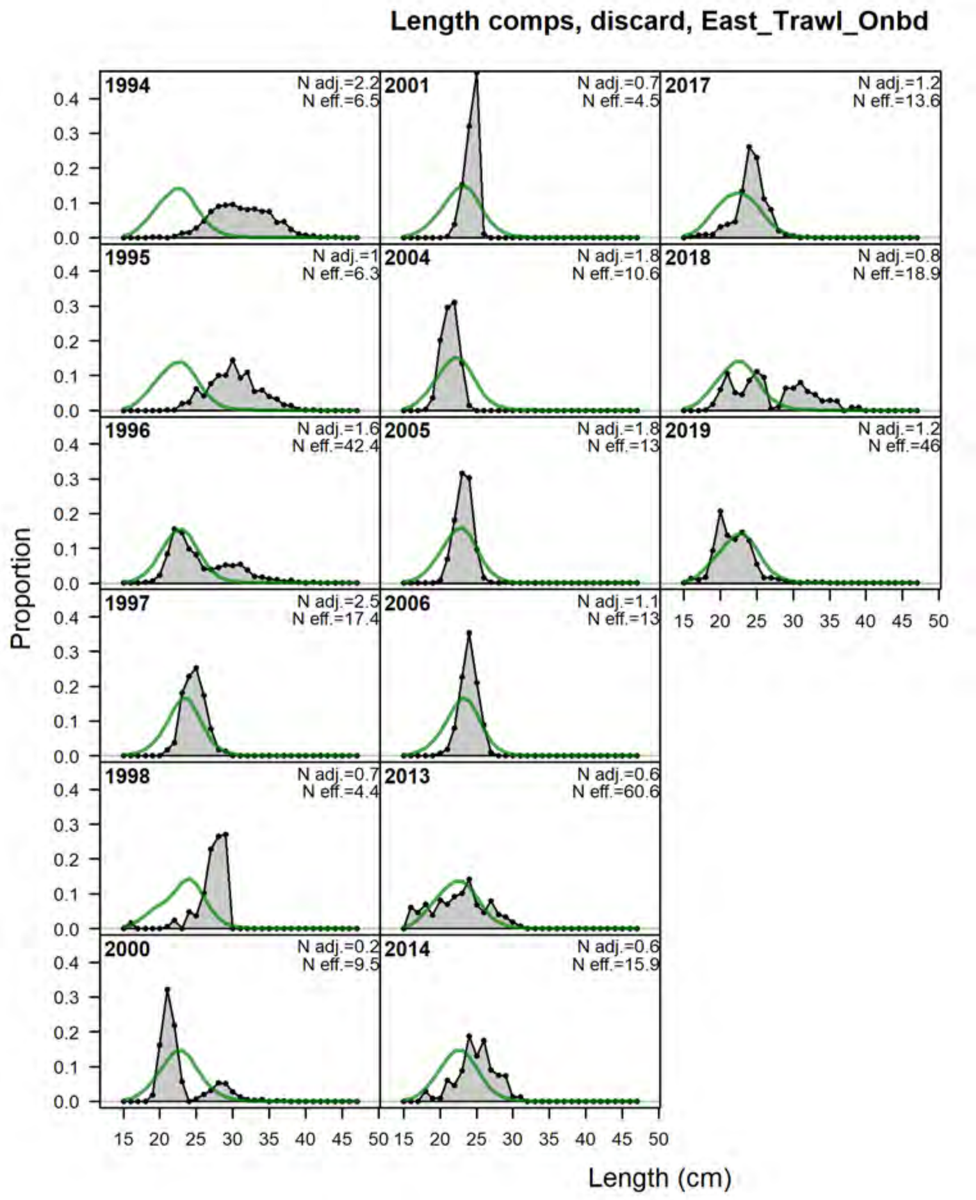


Figure A 8.13. Eastern Jackass Morwong length composition fits: eastern trawl discarded.

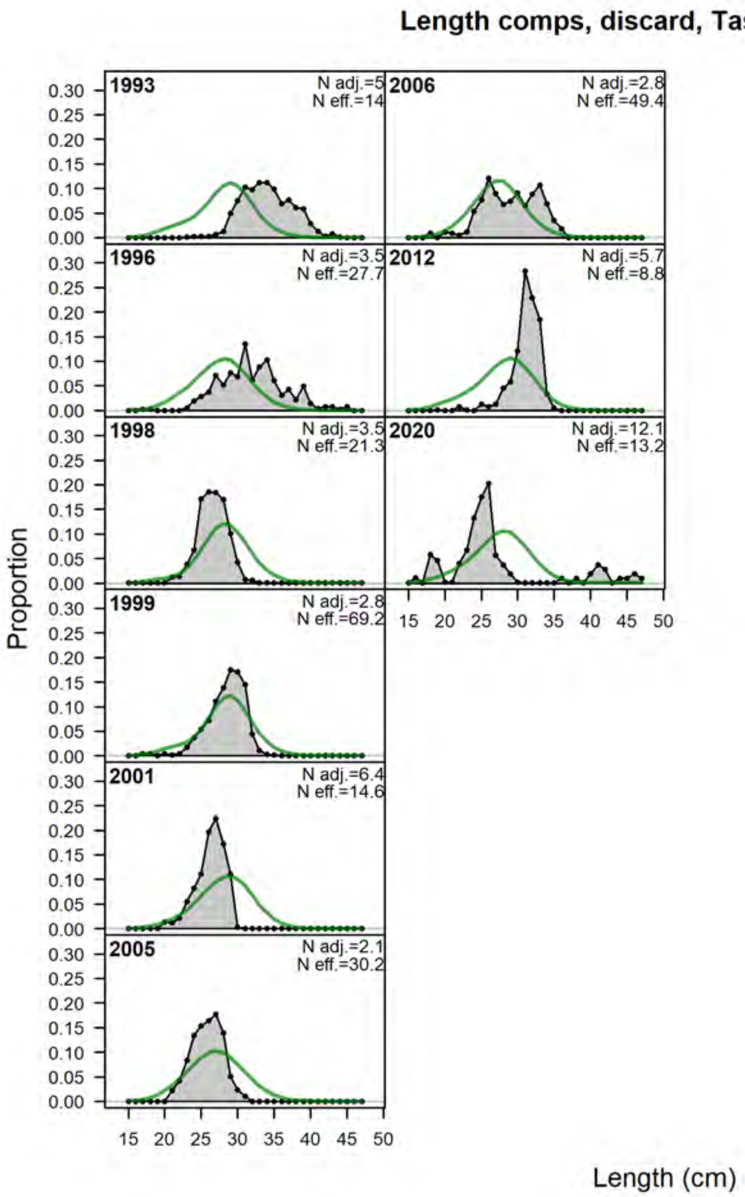


Figure A 8.14. Eastern Jackass Morwong length composition fits: Tasmanian trawl discarded.

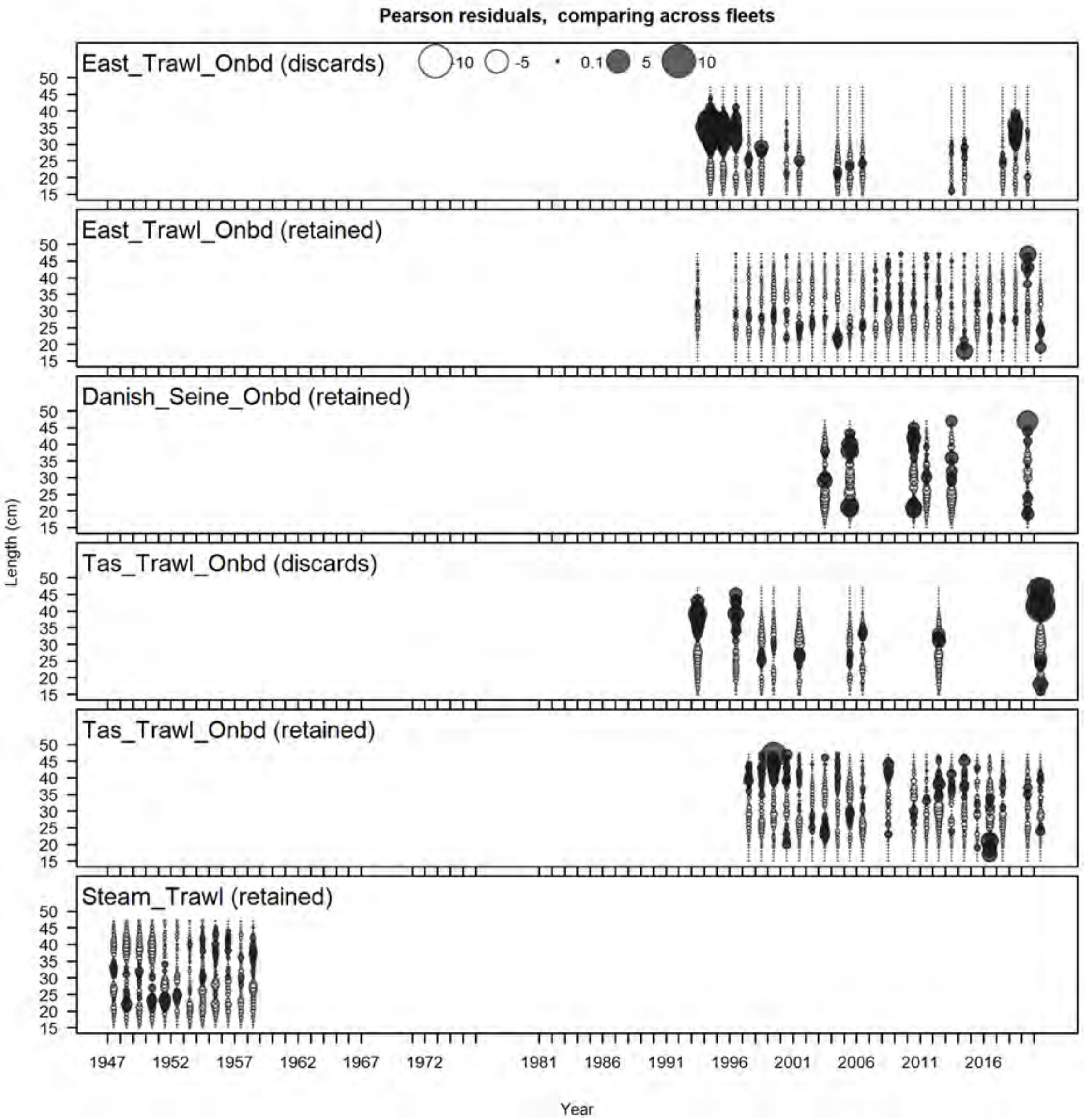


Figure A 8.15. Residuals from the annual length composition data for eastern Jackass Morwong (onboard) displayed by year and fleet for eastern and Tasmanian trawl fleets (retained and discarded), Danish seine and steam trawl fleets (retained).

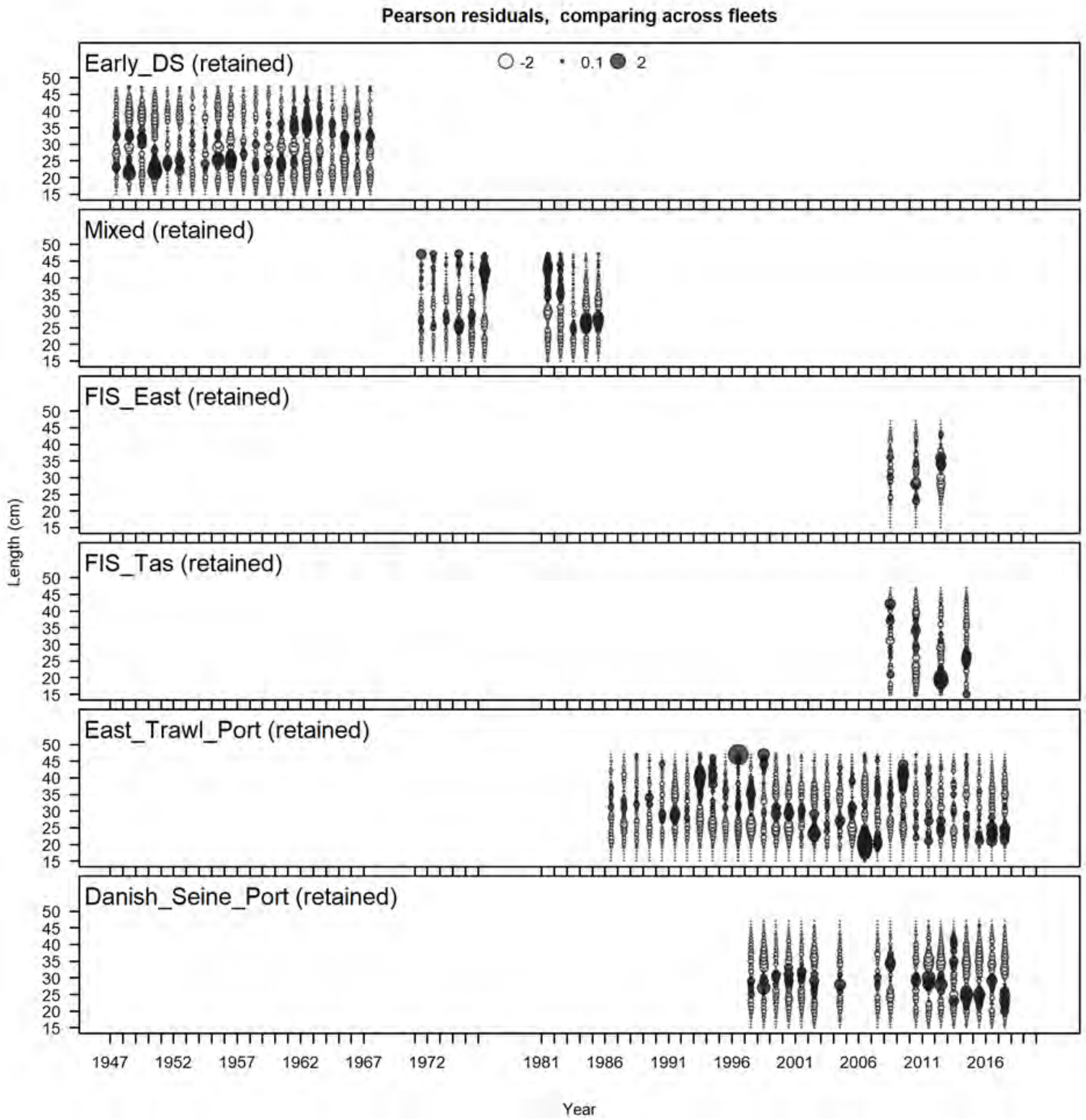


Figure A 8.16. Residuals from the annual length composition data for eastern Jackass Morwong displayed by year and fleet for the early Danish seine and mixed fleets (retained onboard), eastern trawl FIS and Tasmanian trawl FIS fleets and the eastern trawl and Danish seine fleets (retained port).

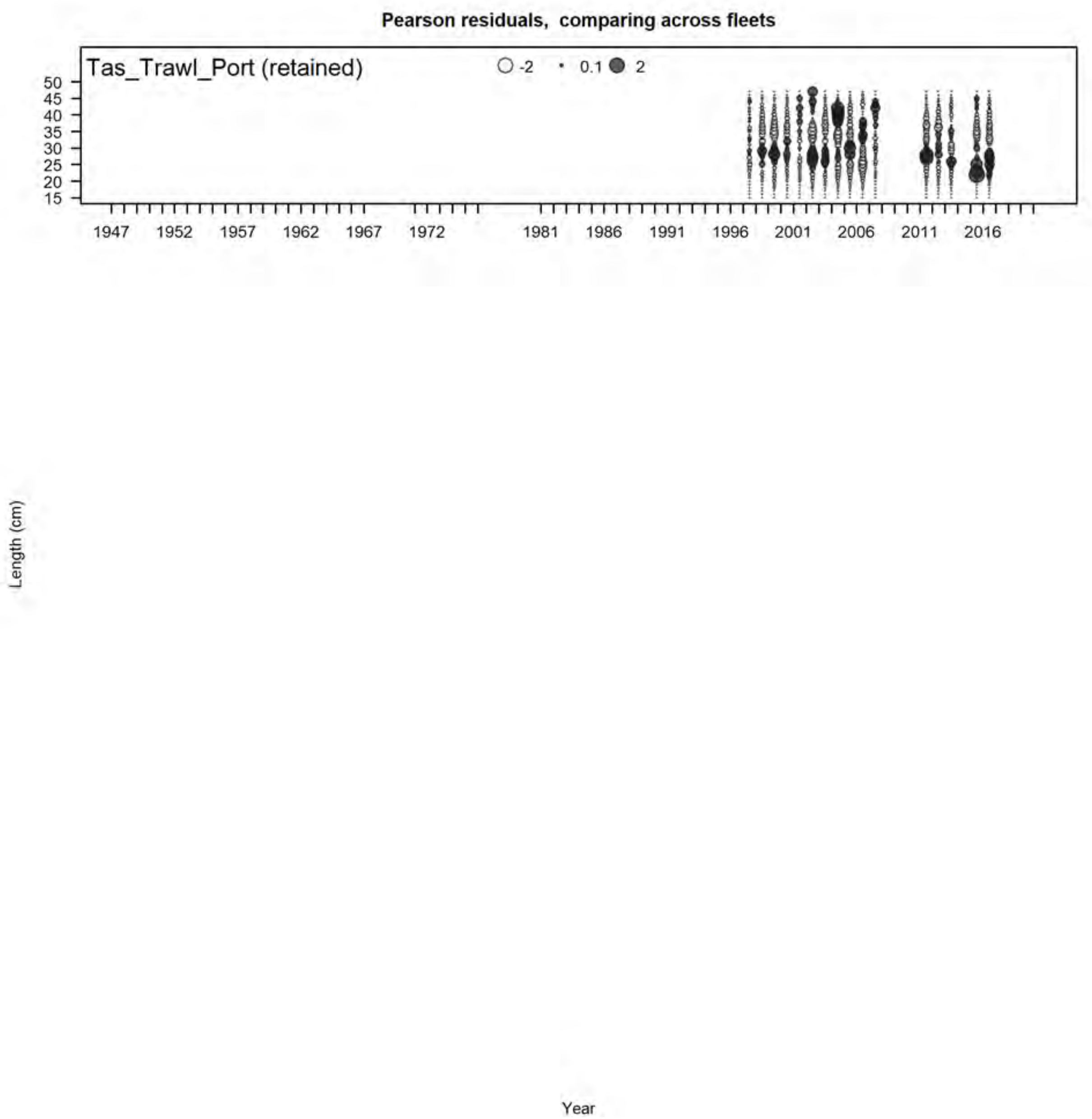


Figure A 8.17. Residuals from the annual length composition data for eastern Jackass Morwong displayed by year and fleet Tasmanian trawl fleet (retained port).

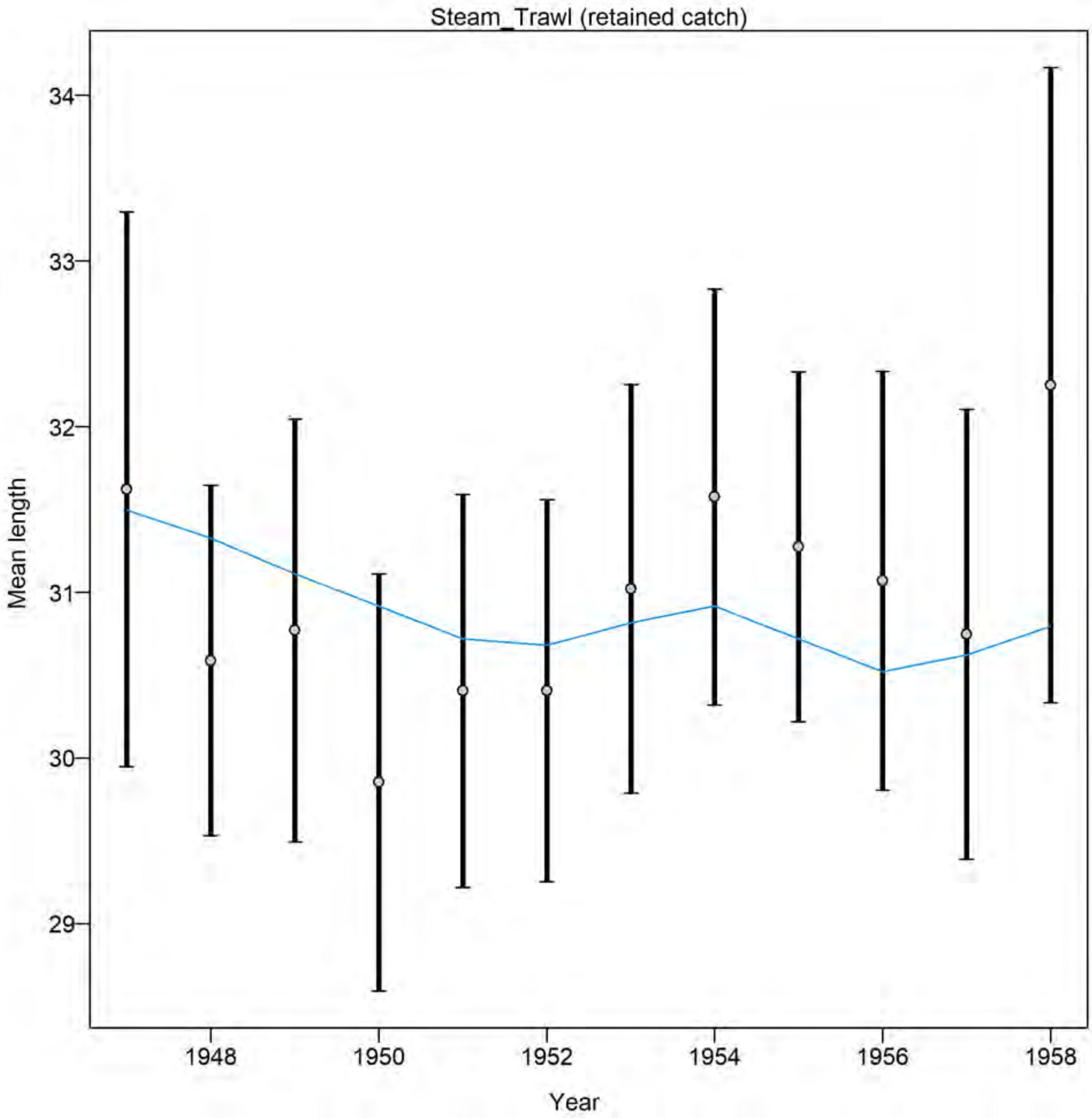
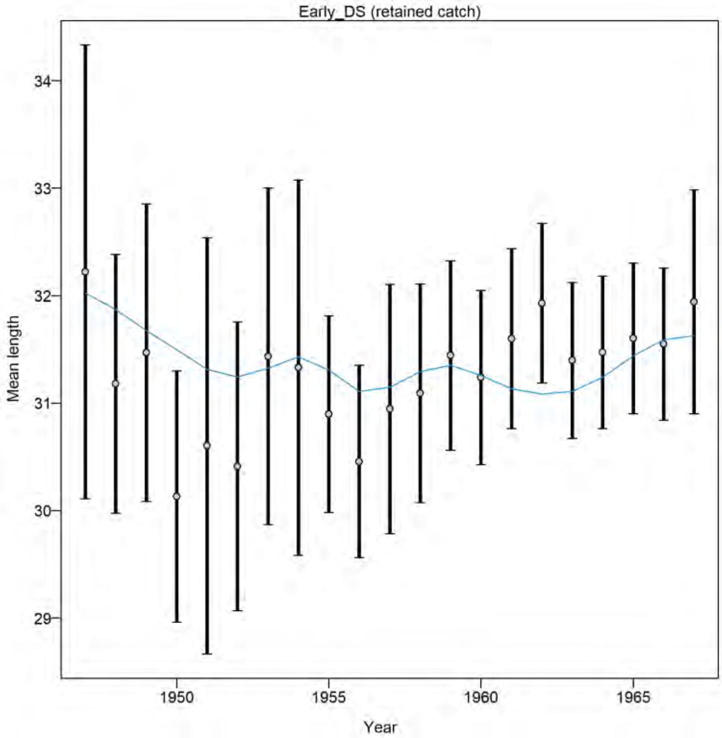


Figure A 8.18. Mean length for eastern Jackass Morwong from steam trawl with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced.



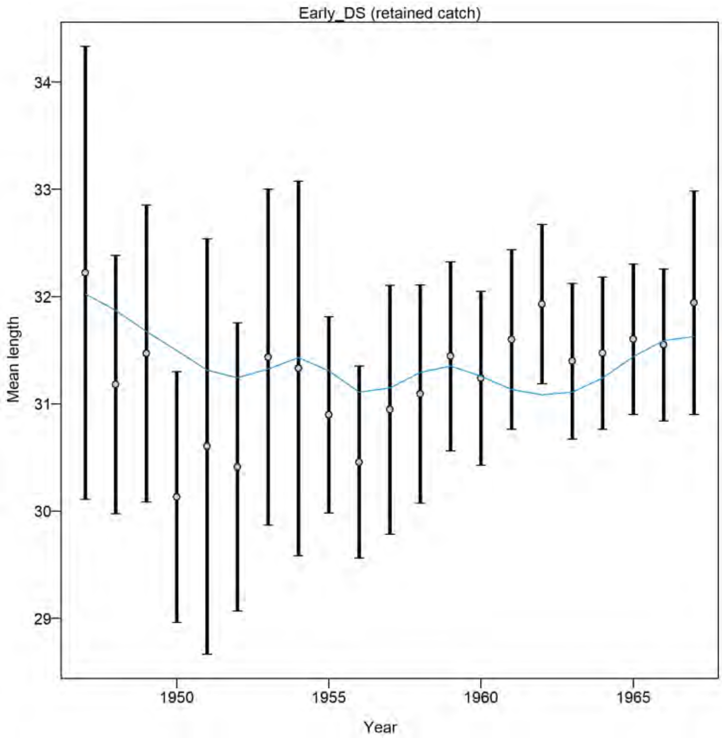
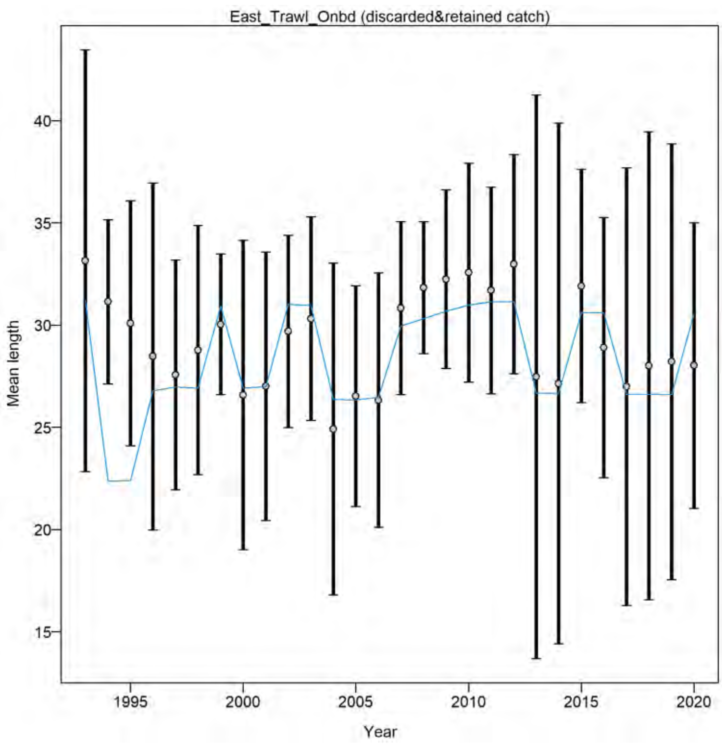


Figure A 8.19. Mean length for eastern Jackass Morwong from early Danish seine (top) and the mixed fleet (bottom) with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced.



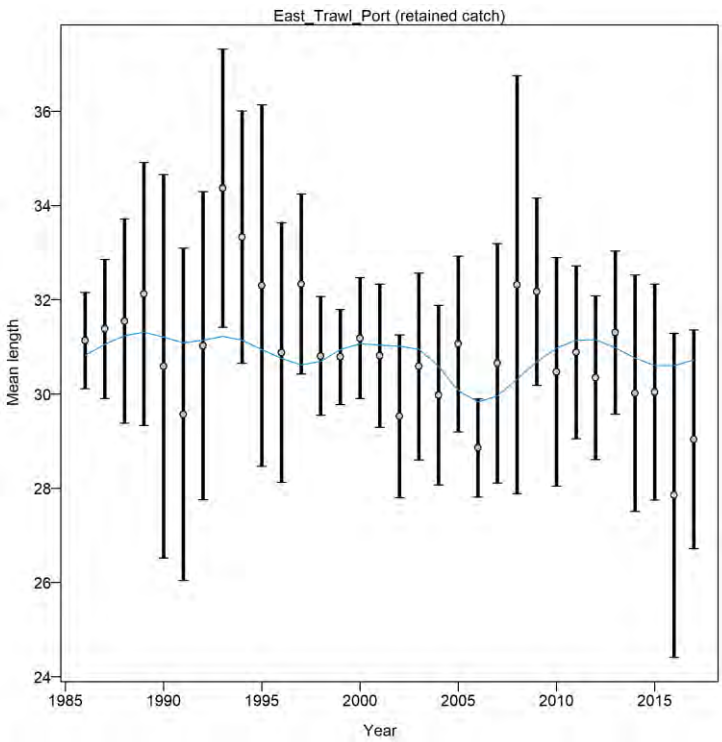


Figure A 8.20. Mean length for eastern Jackass Morwong from the eastern trawl fleet: onboard (top) and port (bottom) with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced.

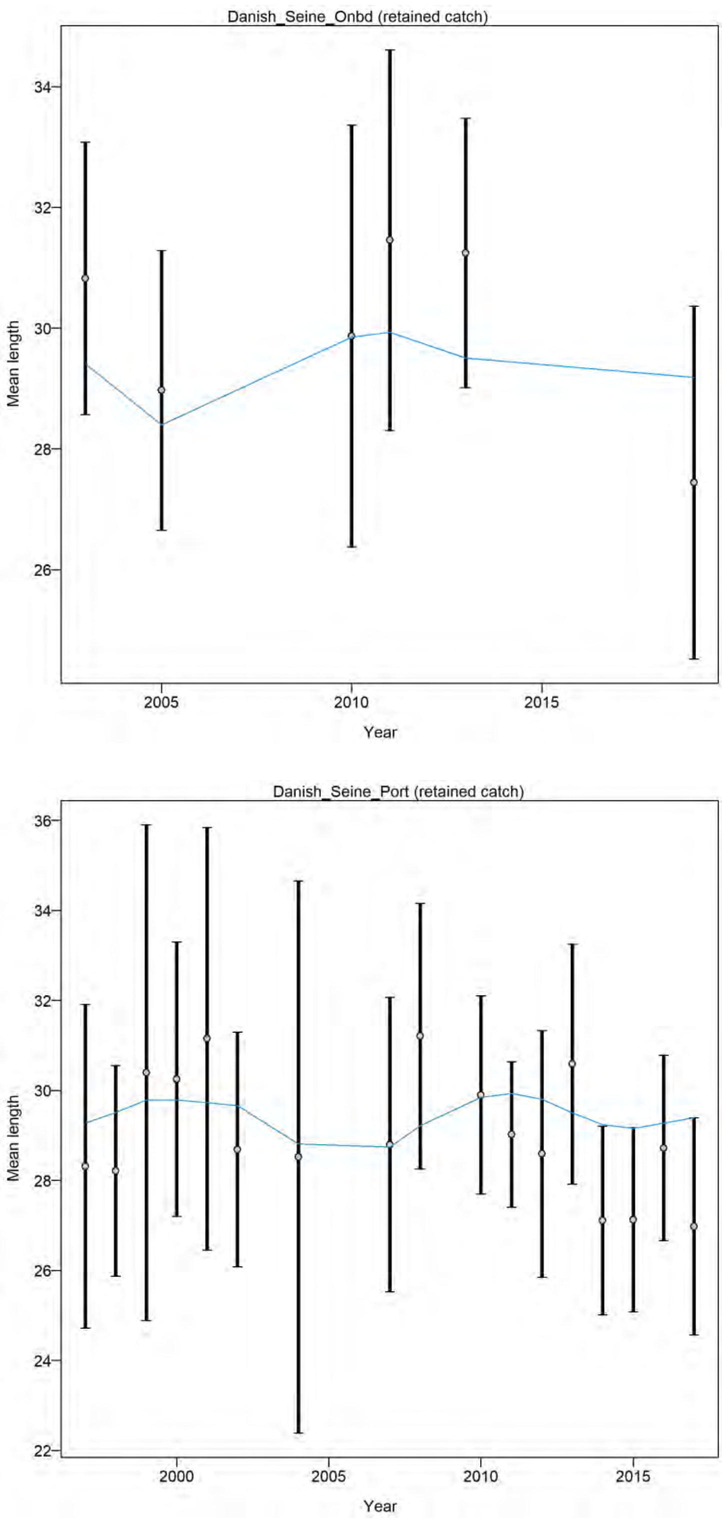
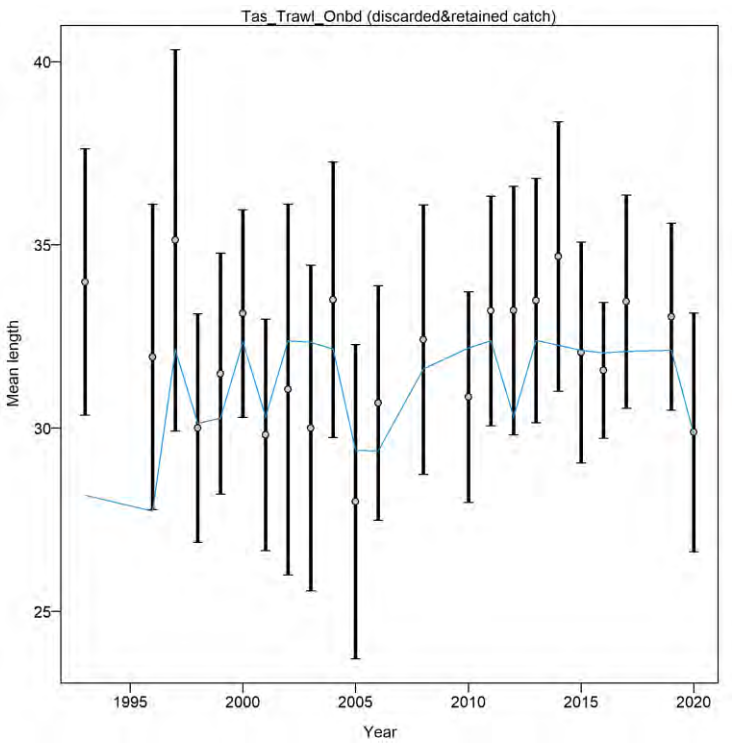


Figure A 8.21. Mean length for eastern Jackass Morwong from the Danish seine fleet: onboard (top) and port (bottom) with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced.



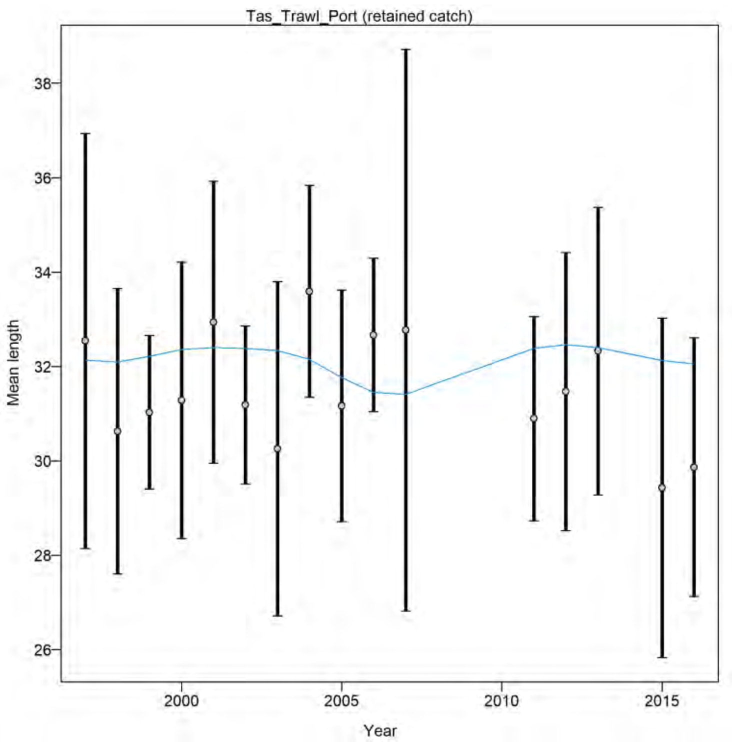


Figure A 8.22. Mean length for eastern Jackass Morwong from the Tasmanian trawl fleet: onboard (top) and port (bottom) with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced.

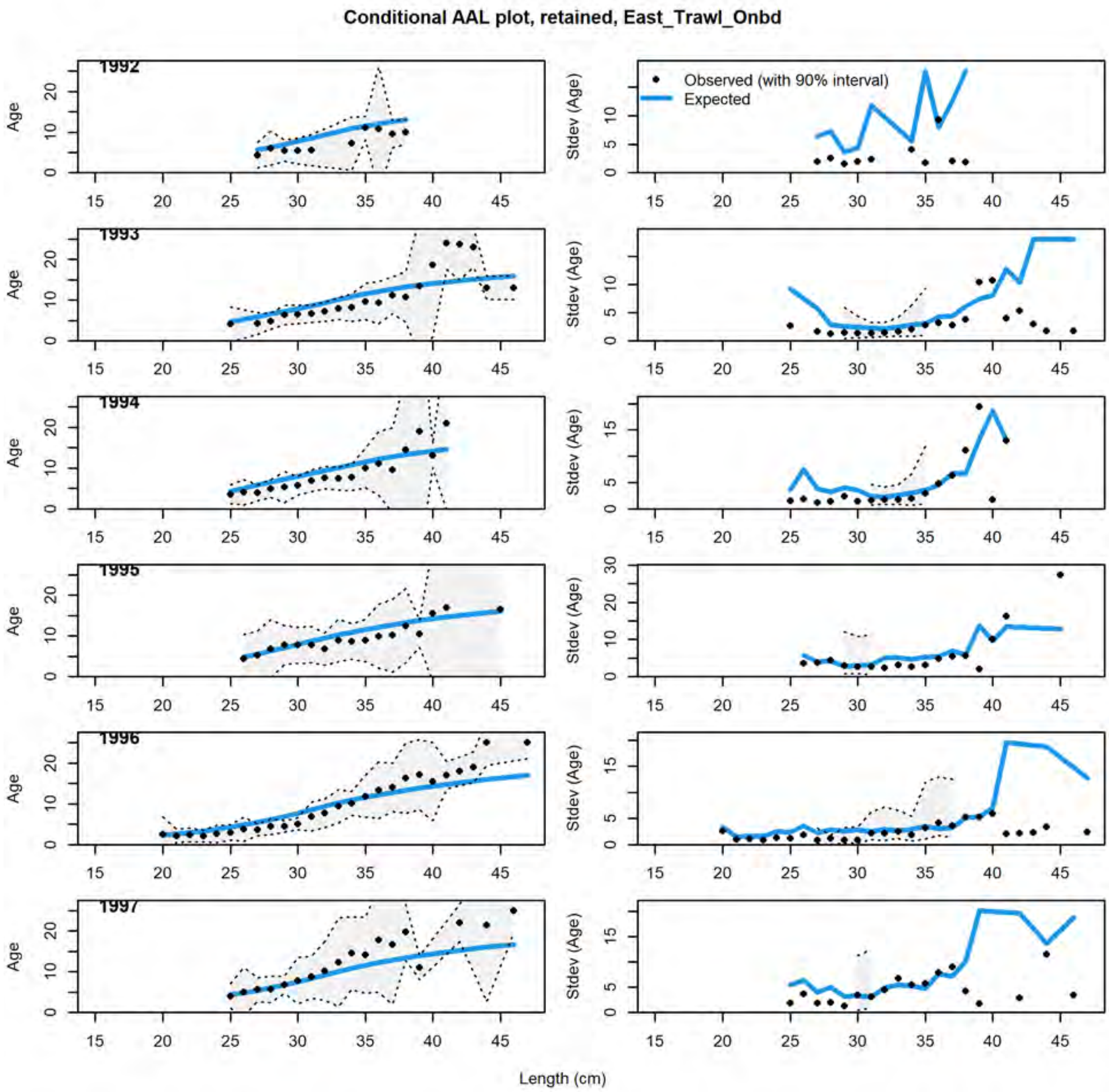


Figure A 8.23. Fits to conditional age-at-length data for eastern Jackass Morwong eastern trawl onboard (retained 1/5).

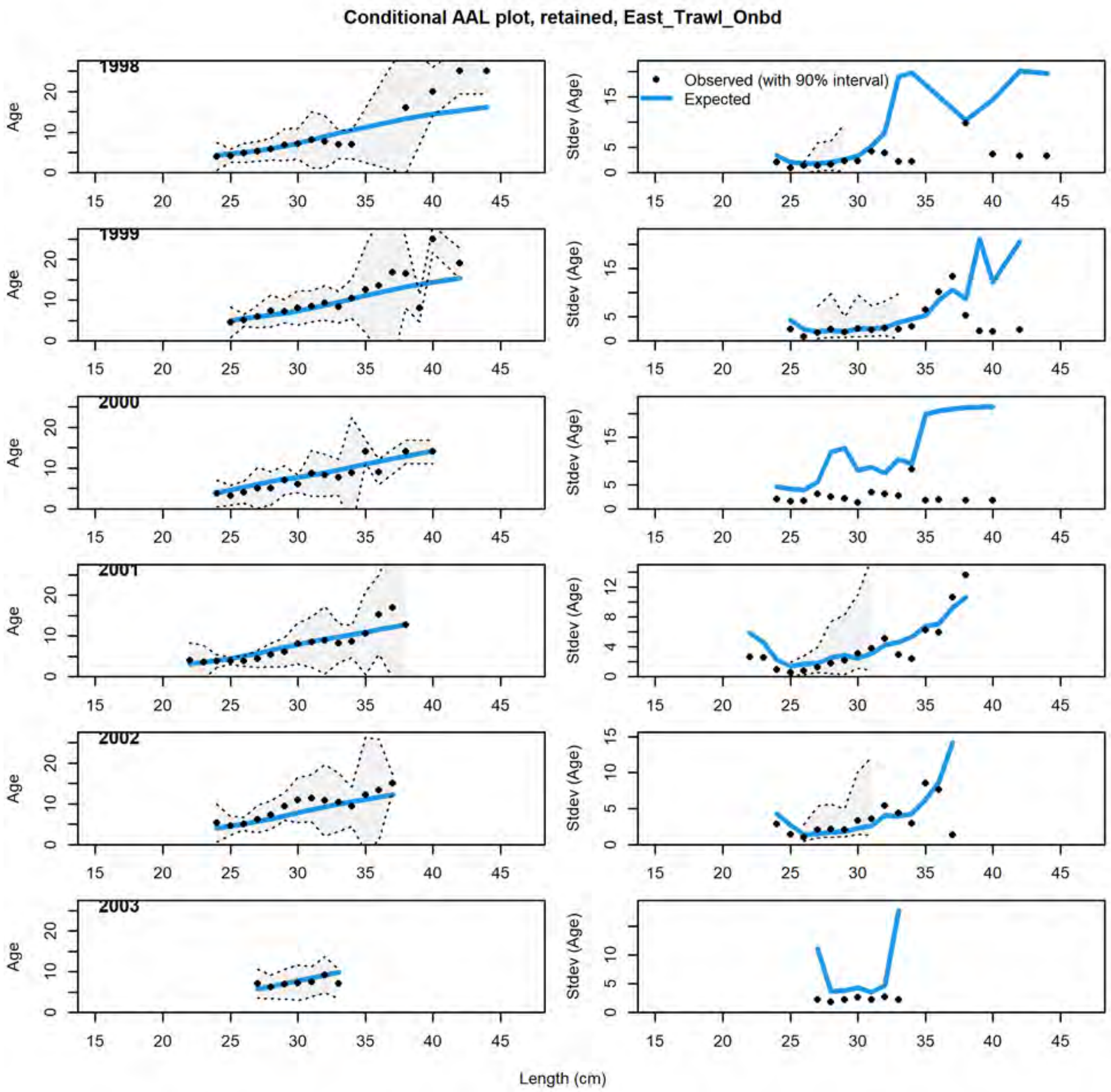


Figure A 8.24. Fits to conditional age-at-length data for eastern Jackass Morwong eastern trawl onboard (retained 2/5).

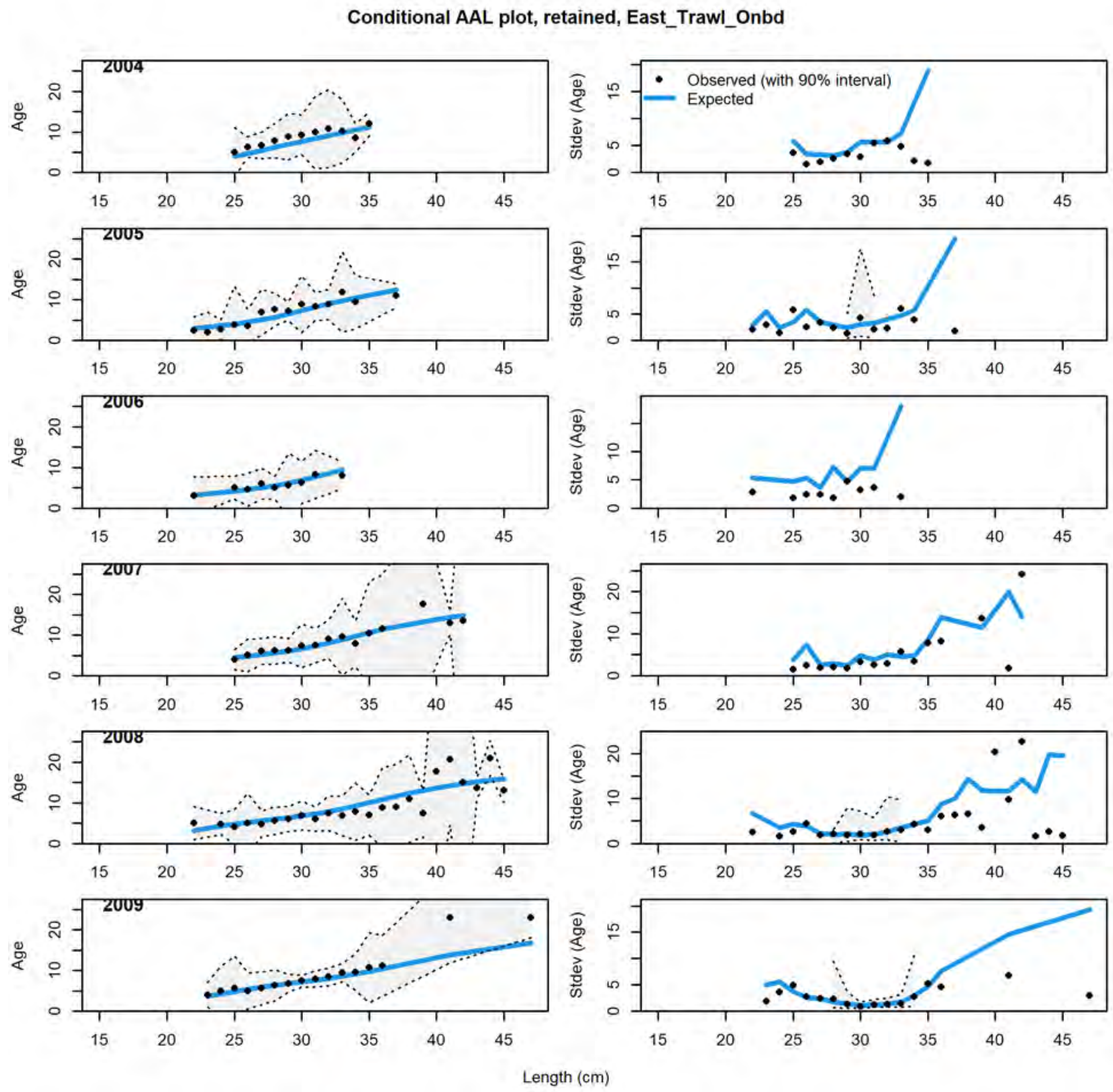


Figure A 8.25. Fits to conditional age-at-length data for eastern Jackass Morwong eastern trawl onboard (retained 3/5).

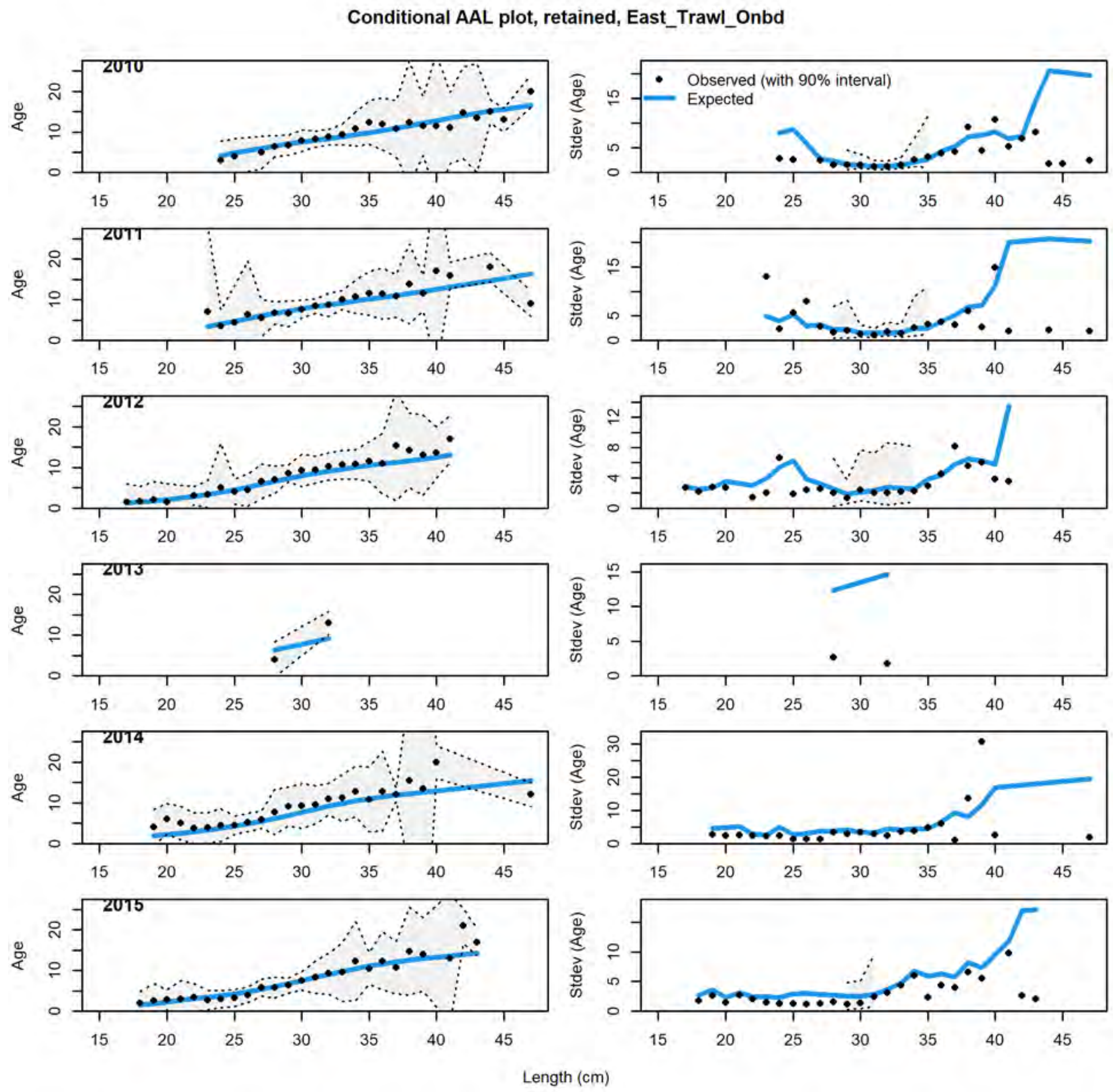


Figure A 8.26. Fits to conditional age-at-length data for eastern Jackass Morwong eastern trawl onboard (retained 4/5).

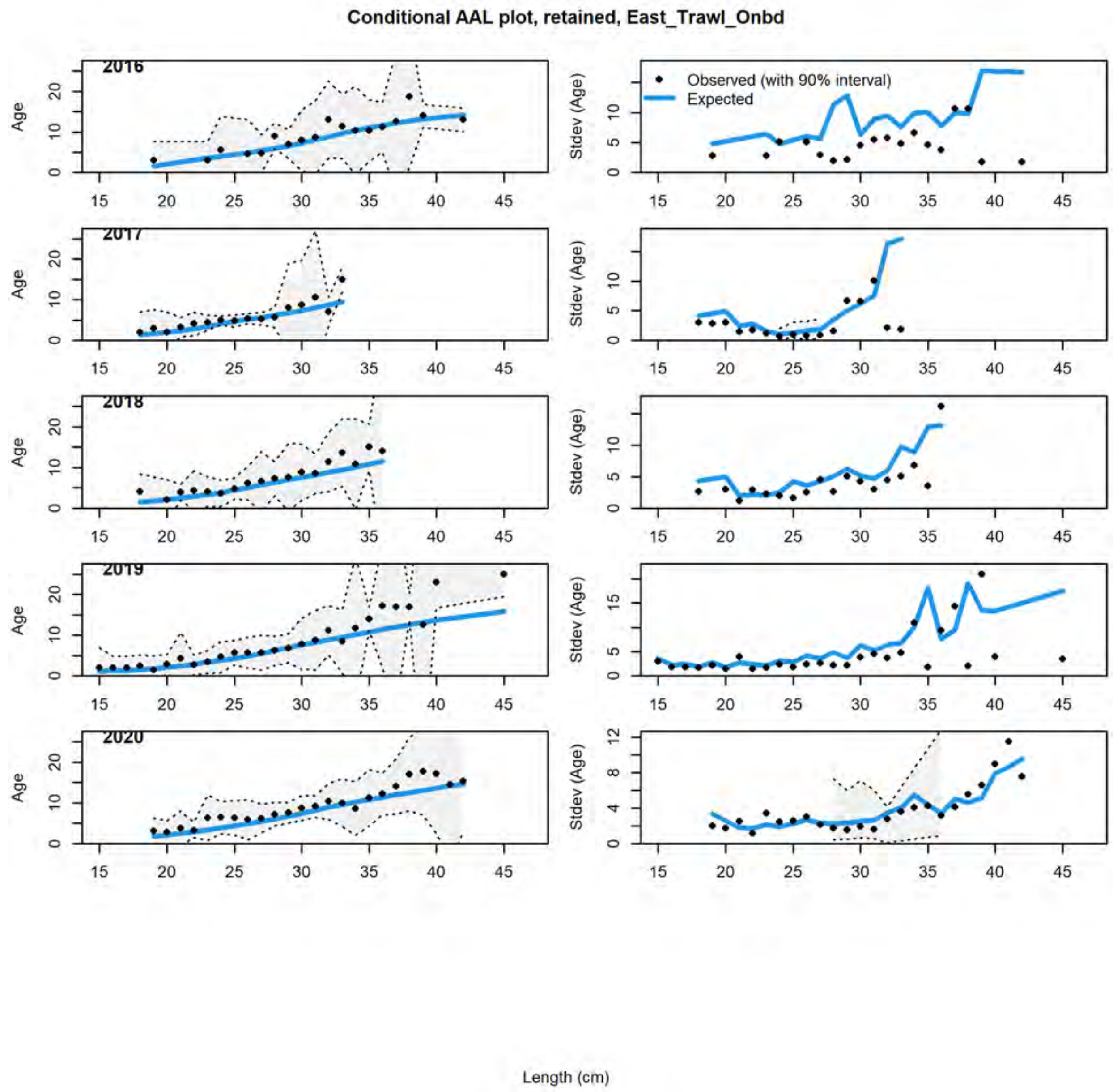


Figure A 8.27. Fits to conditional age-at-length data for eastern Jackass Morwong eastern trawl onboard (retained 5/5).

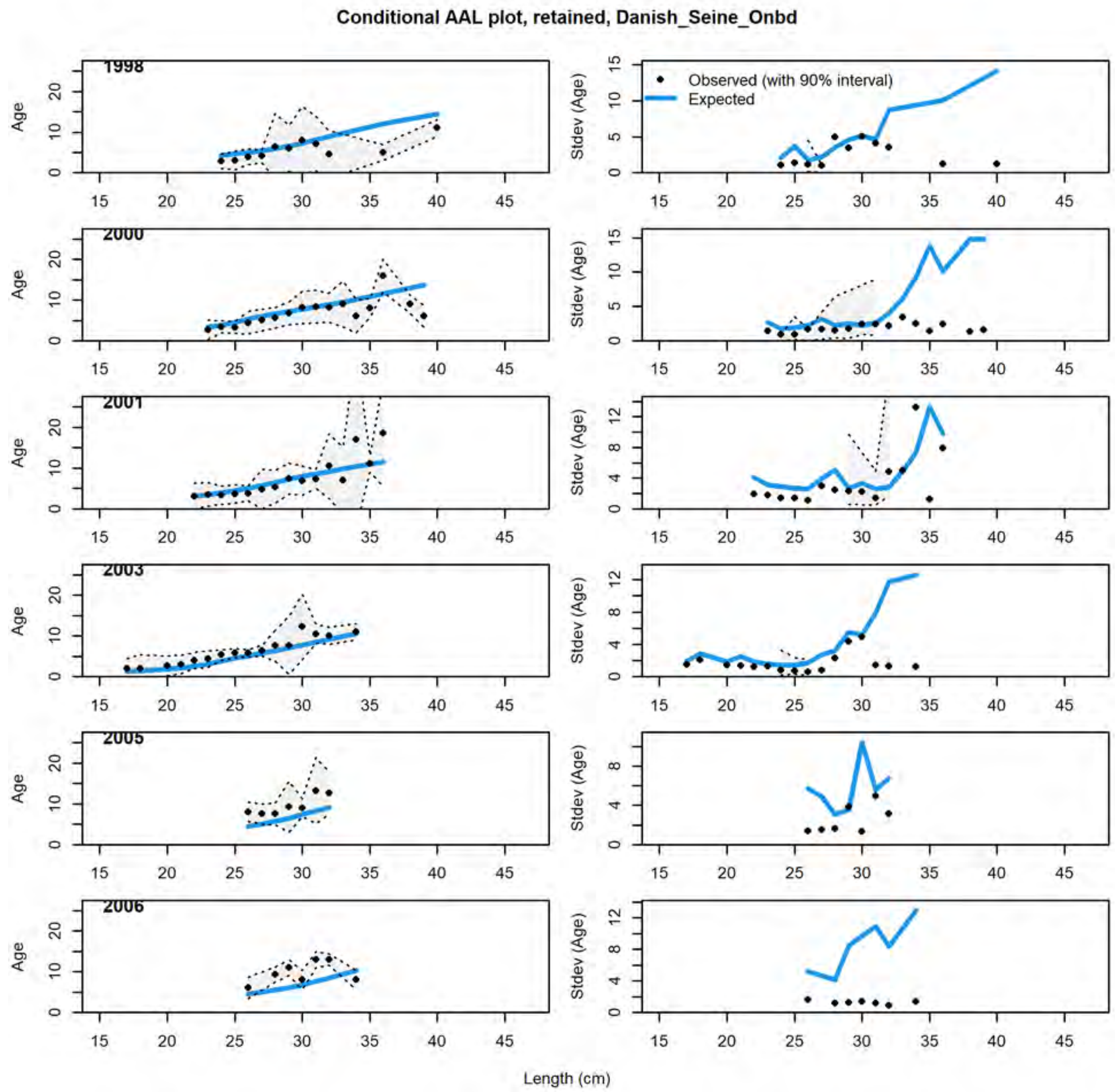


Figure A 8.28. Fits to conditional age-at-length data for eastern Jackass Morwong Danish seine onboard (retained 1/3).

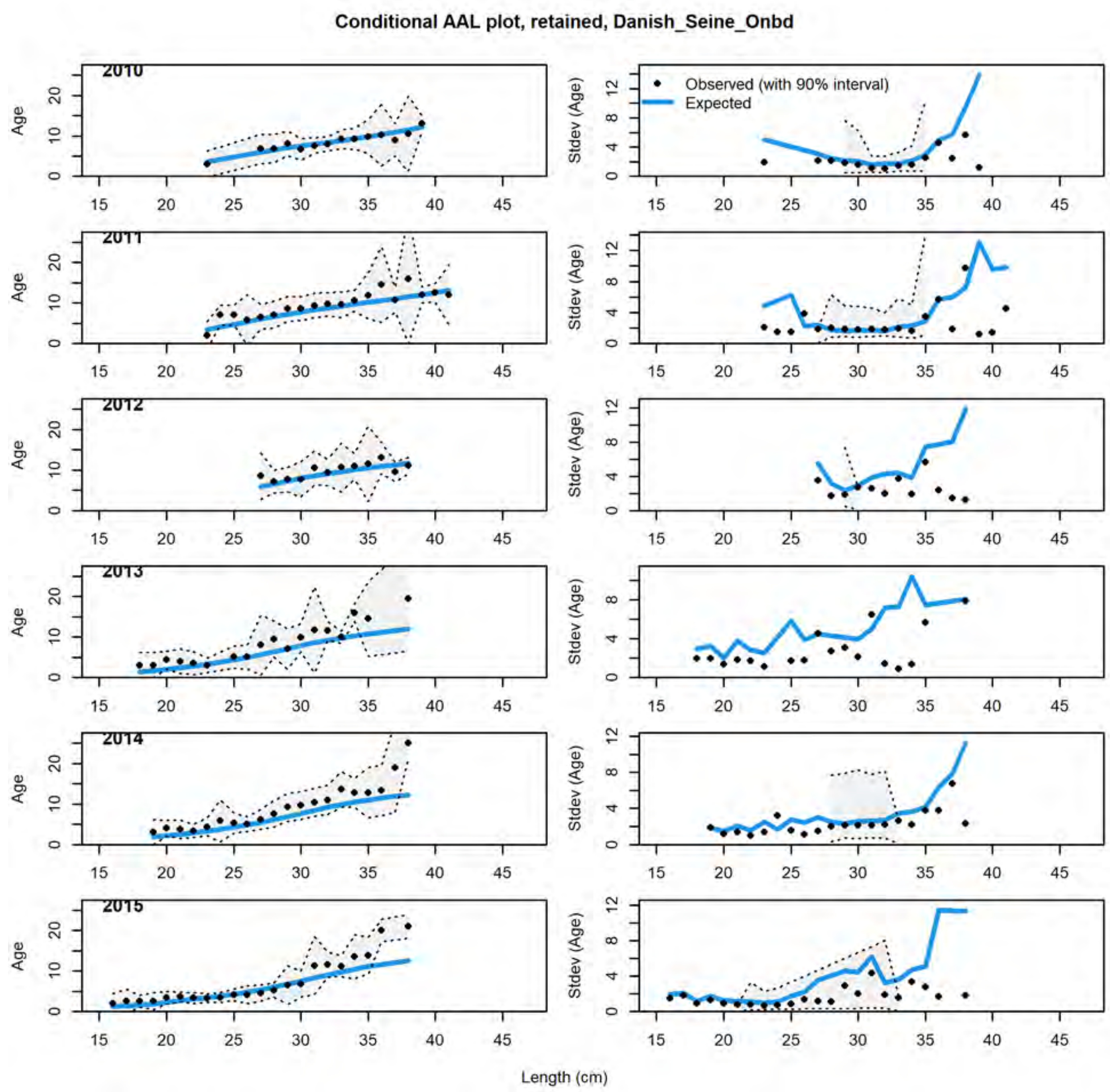


Figure A 8.29. Fits to conditional age-at-length data for eastern Jackass Morwong Danish seine onboard (retained 2/3).

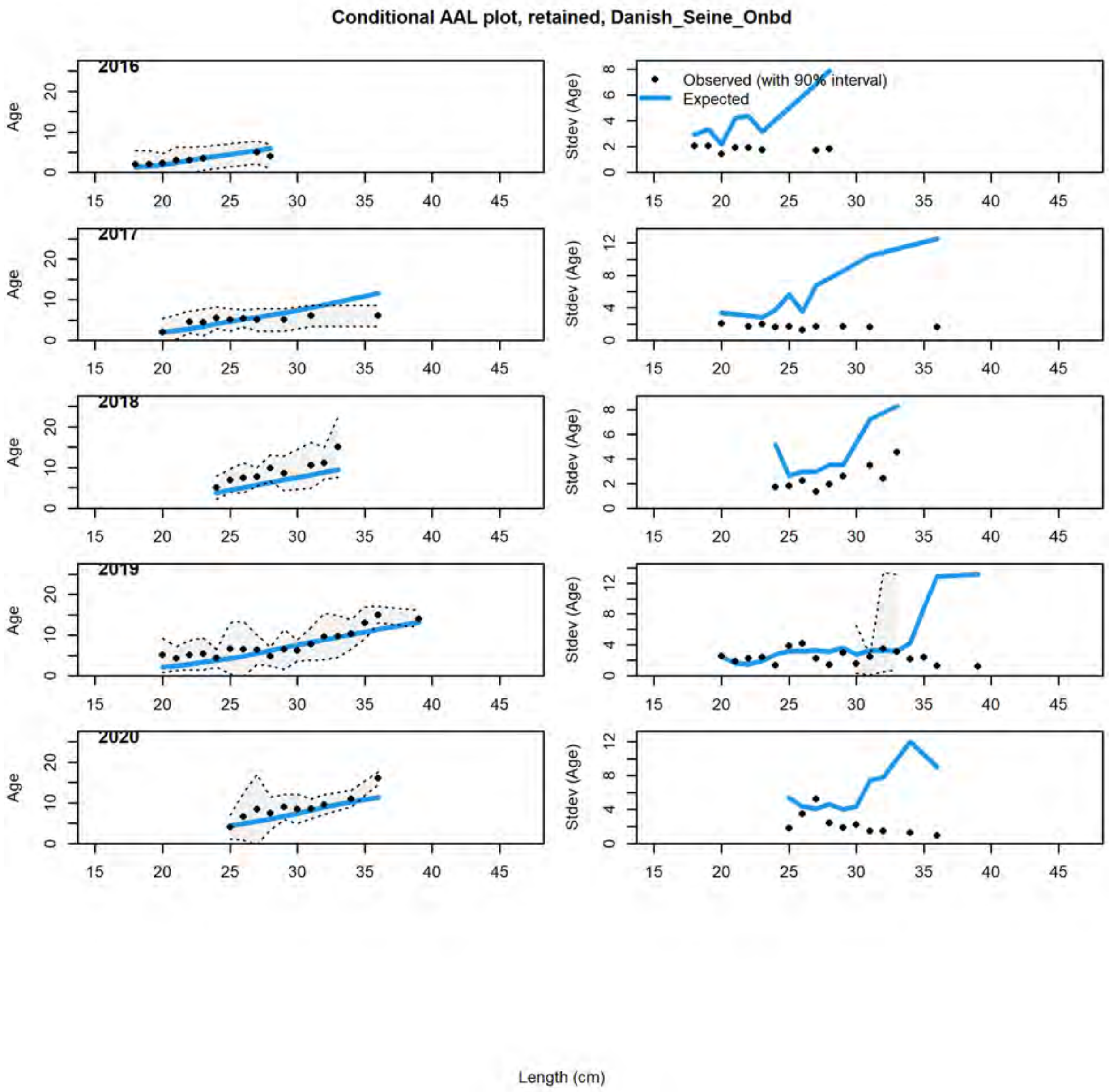


Figure A 8.30. Fits to conditional age-at-length data for eastern Jackass Morwong Danish seine onboard (retained 3/3).

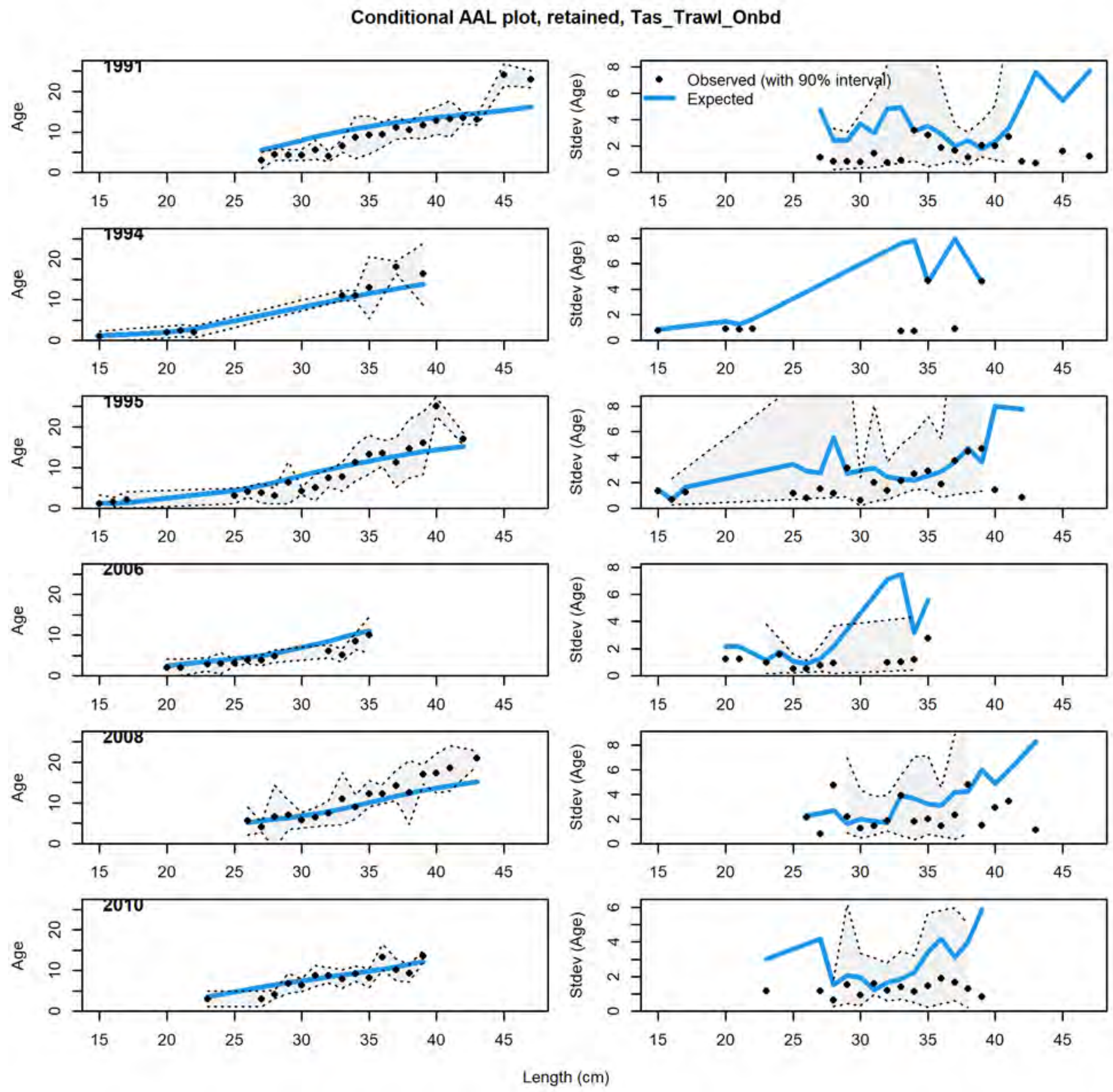


Figure A 8.31. Fits to conditional age-at-length data for eastern Jackass Morwong Tasmanian trawl onboard (retained 1/3).

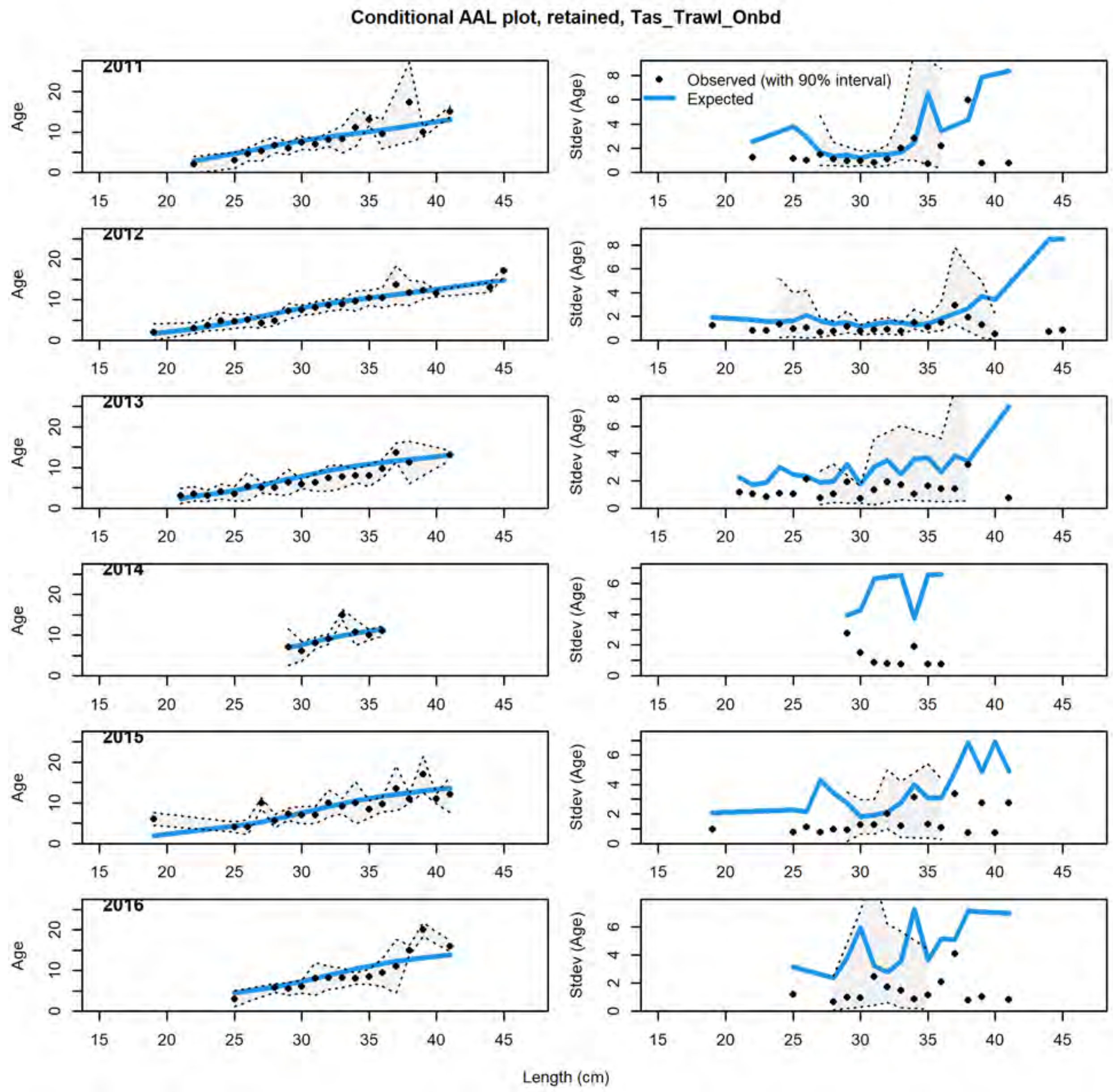


Figure A 8.32. Fits to conditional age-at-length data for eastern Jackass Morwong Tasmanian trawl onboard (retained 2/3).

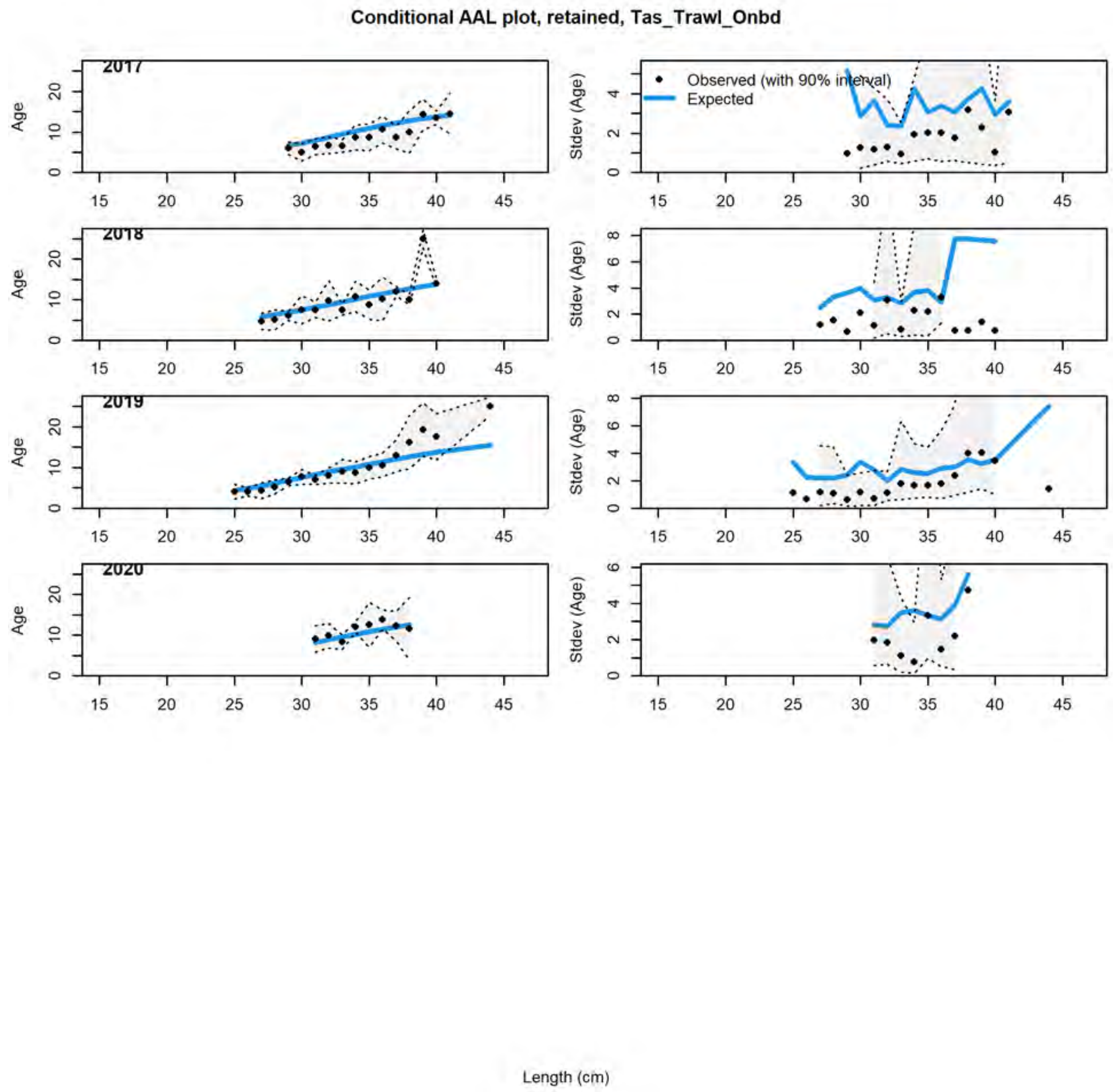


Figure A 8.33. Fits to conditional age-at-length data for eastern Jackass Morwong Tasmanian trawl onboard (retained 3/3).

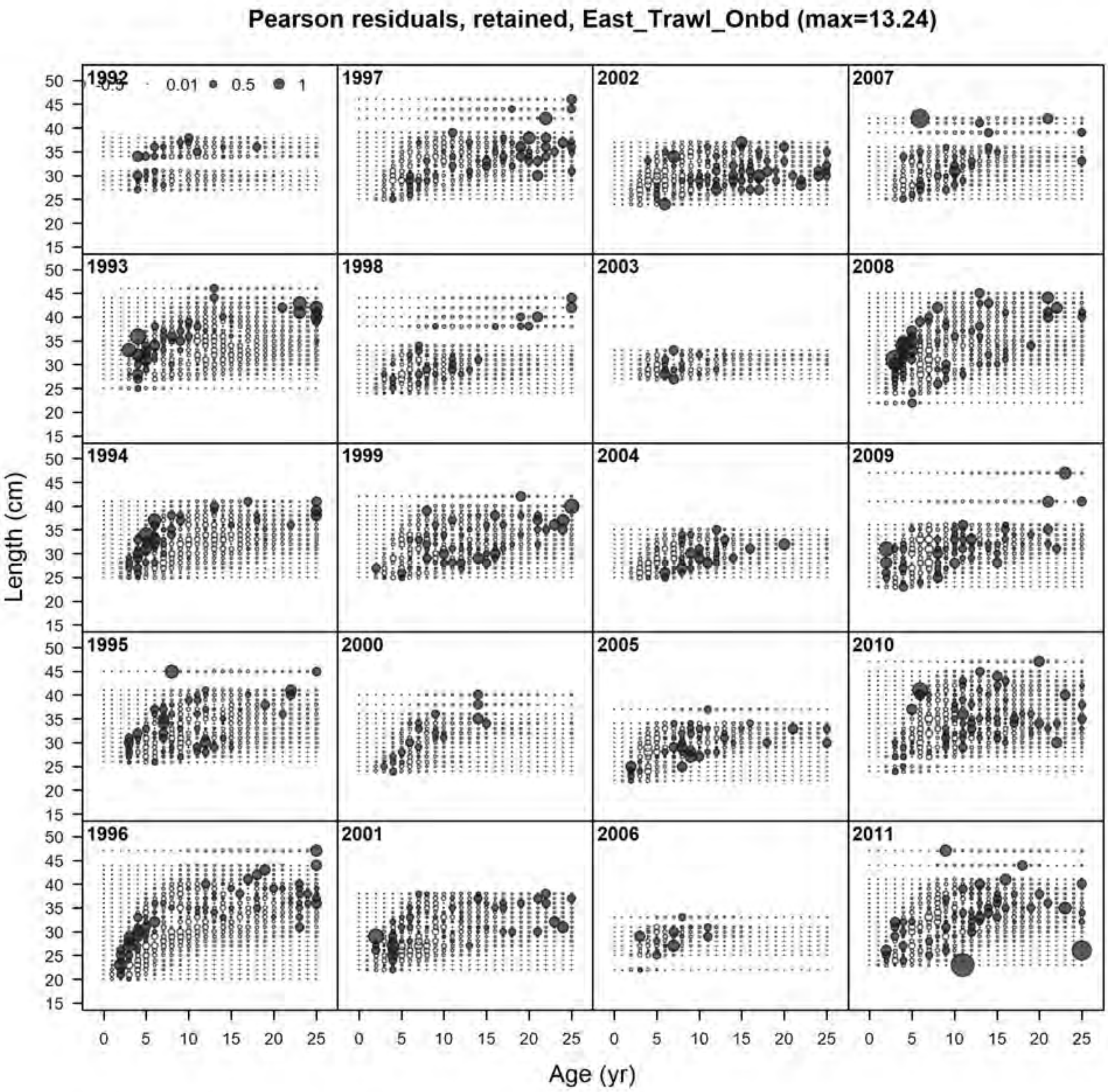


Figure A 8.34. Residuals from the fits to conditional age-at-length for eastern trawl (1/2). This plot gives some indication of the variability in the age samples from year to year.

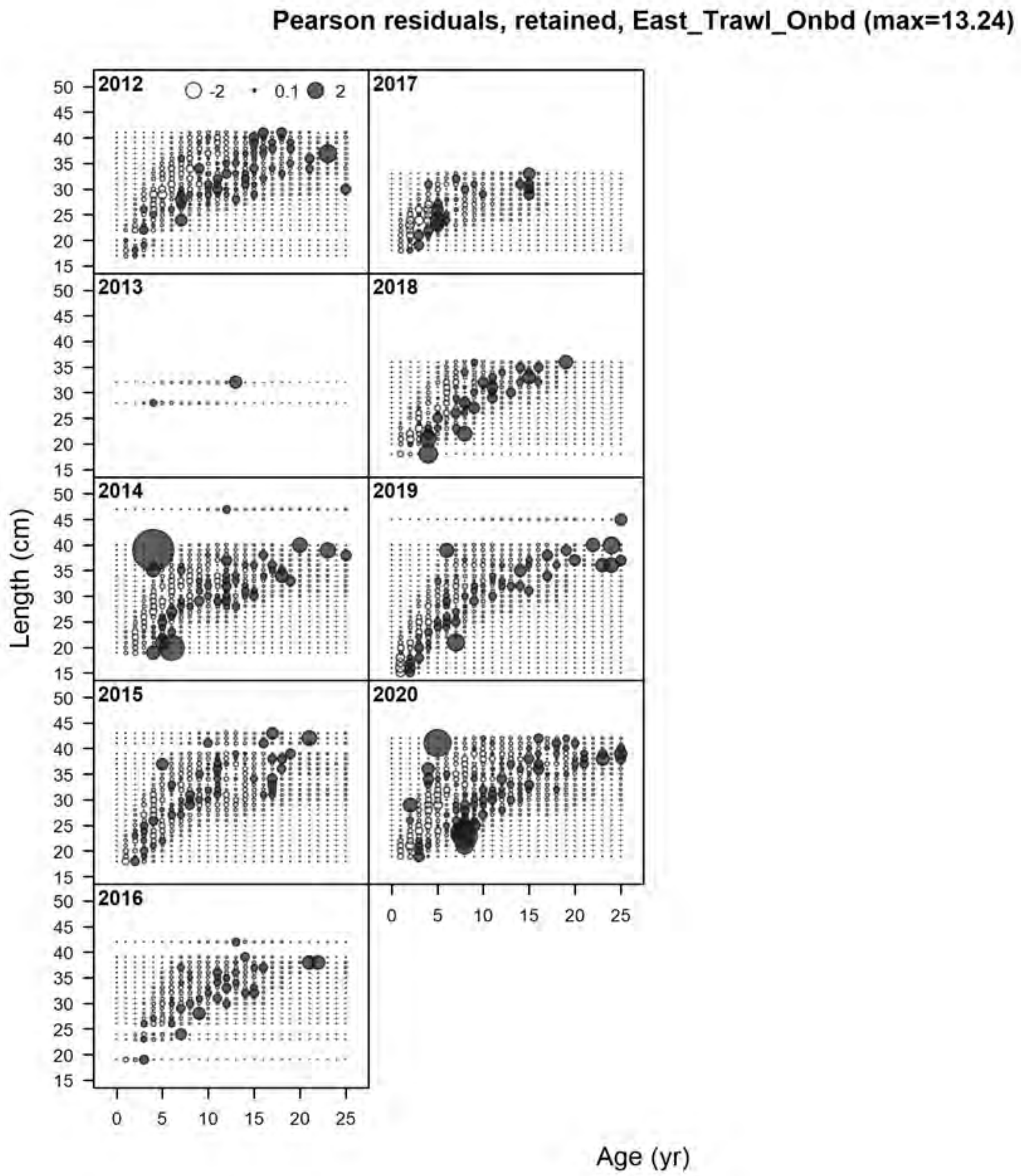


Figure A 8.35. Residuals from the fits to conditional age-at-length for eastern trawl (2/2). This plot gives some indication of the variability in the age samples from year to year.

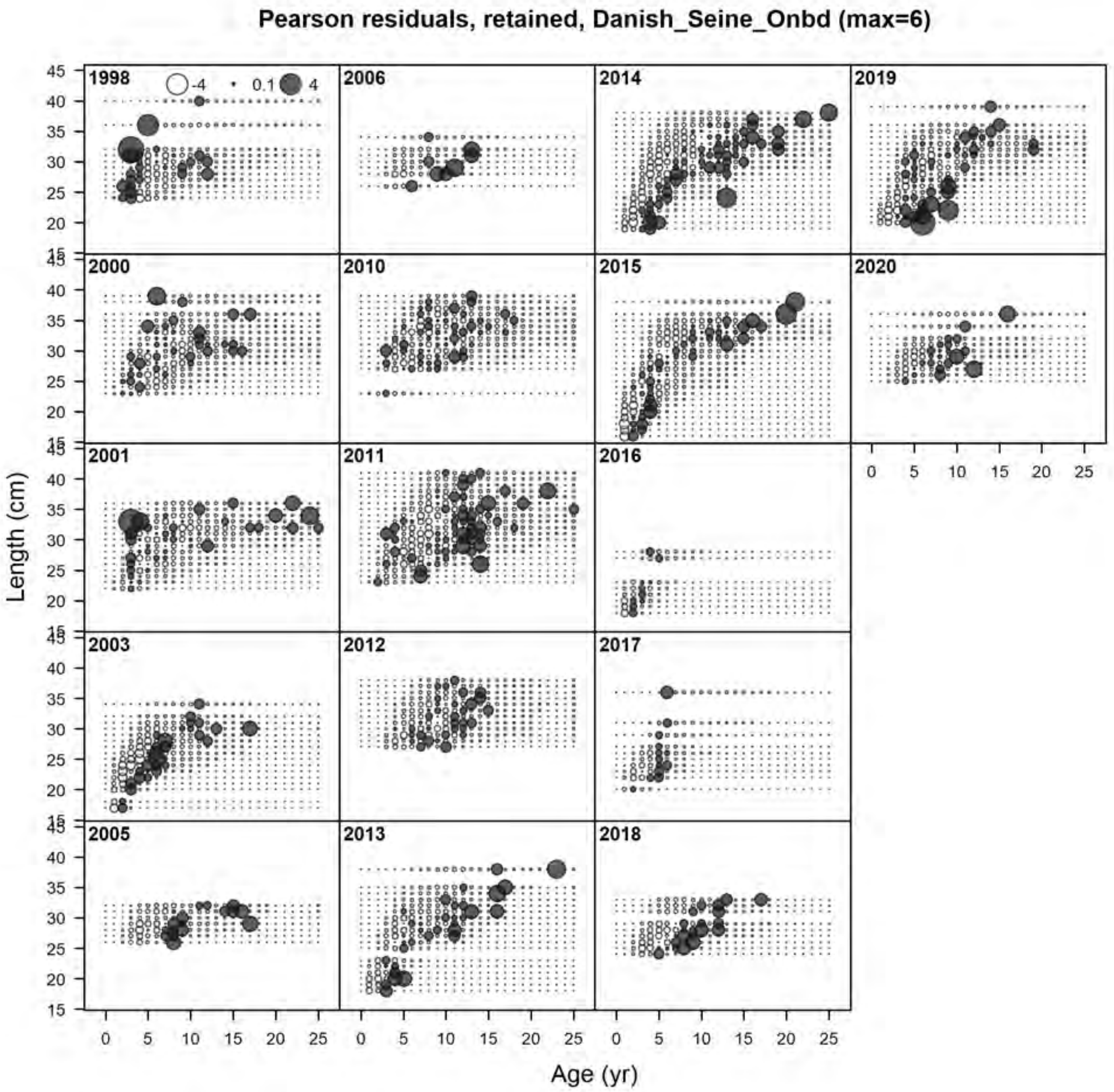


Figure A 8.36. Residuals from the fits to conditional age-at-length for Danish seine. This plot gives some indication of the variability in the age samples from year to year.

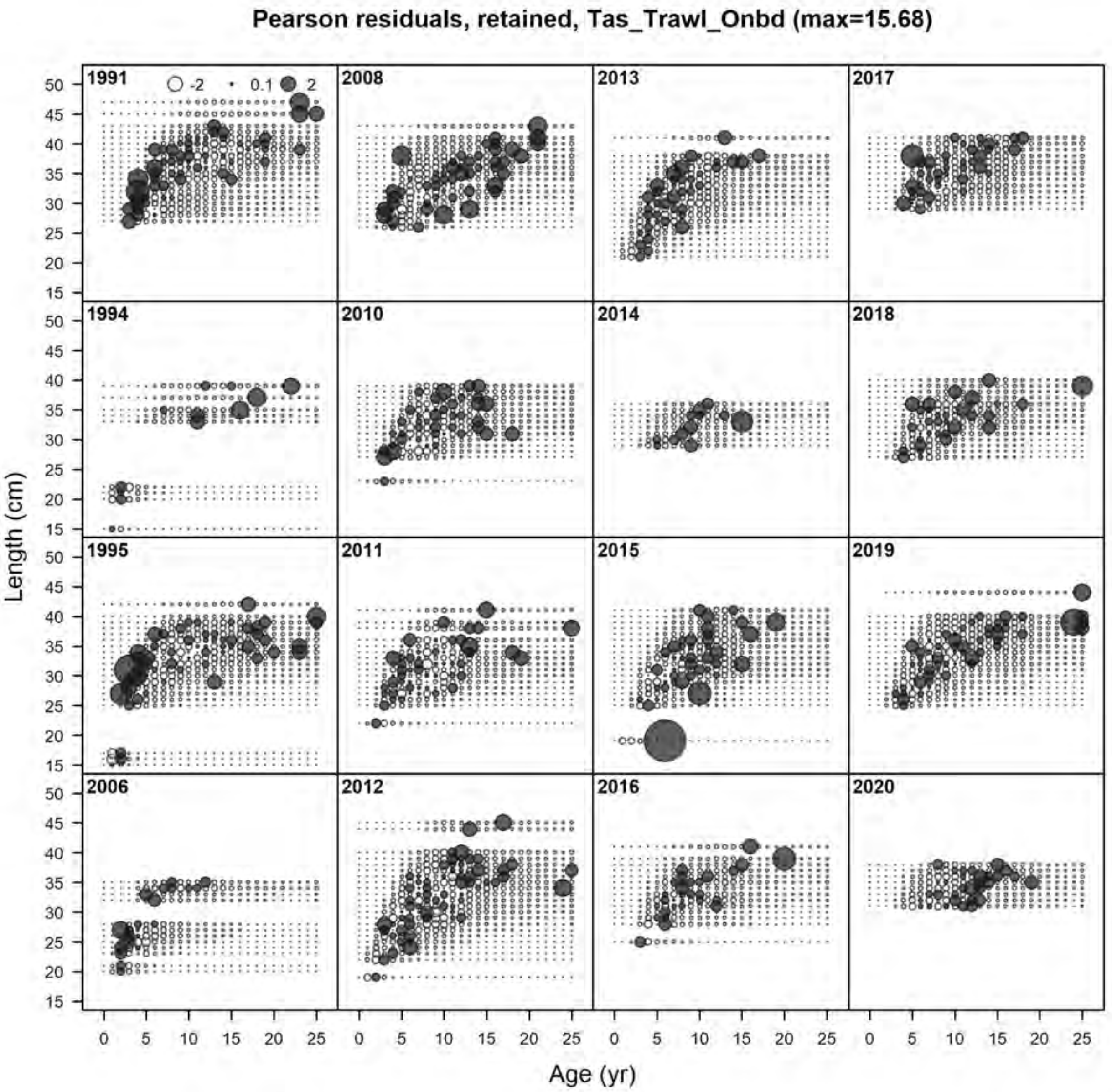


Figure A 8.37. Residuals from the fits to conditional age-at-length for Tasmanian trawl. This plot gives some indication of the variability in the age samples from year to year.

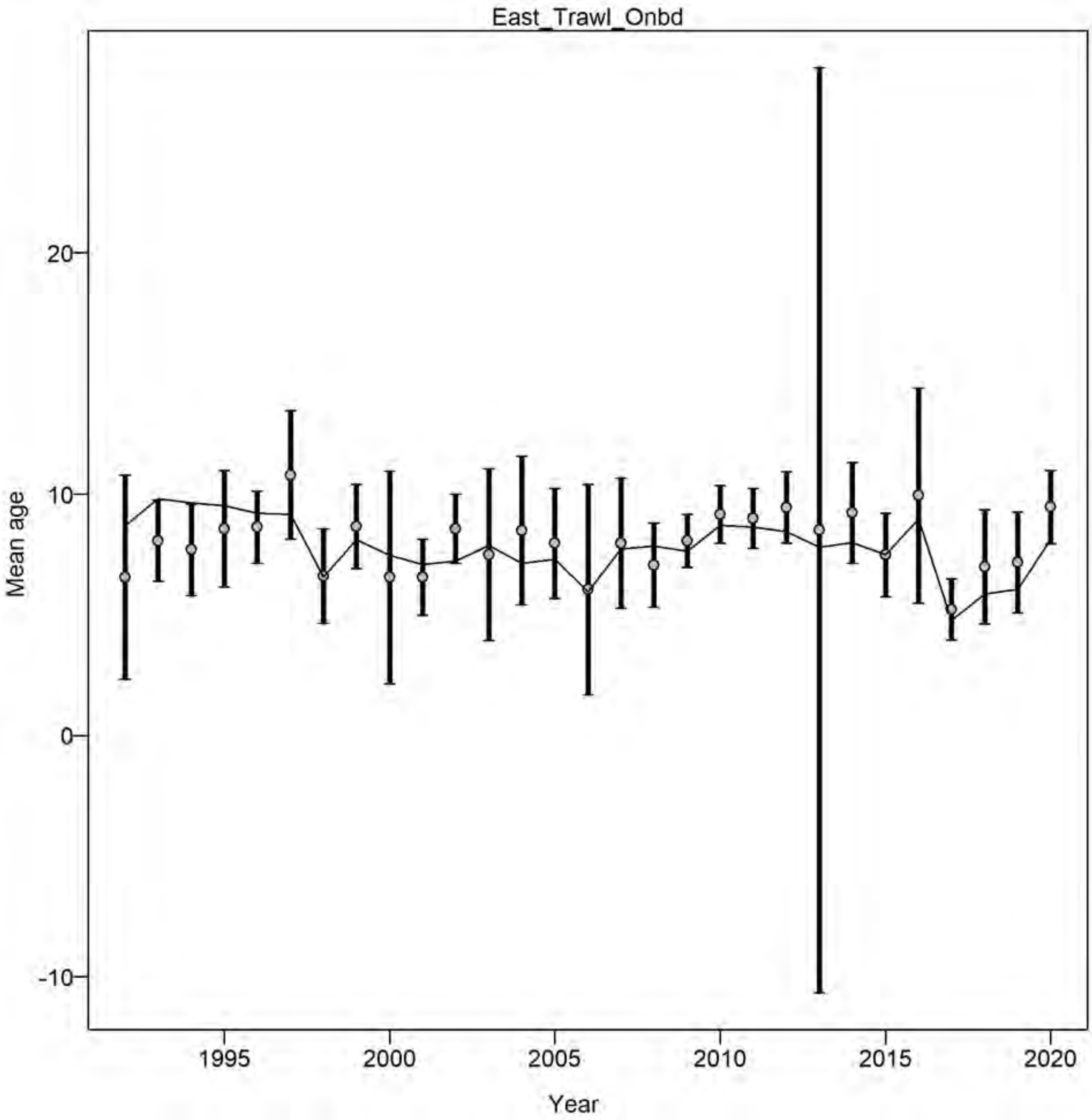


Figure A 8.38. Mean age (aggregated across length bins) for eastern Jackass Morwong from eastern trawl with 95% confidence intervals based on current samples sizes. Punt data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced. Yearly variation in the data is shown in changes in mean age, which can be large over a short period.

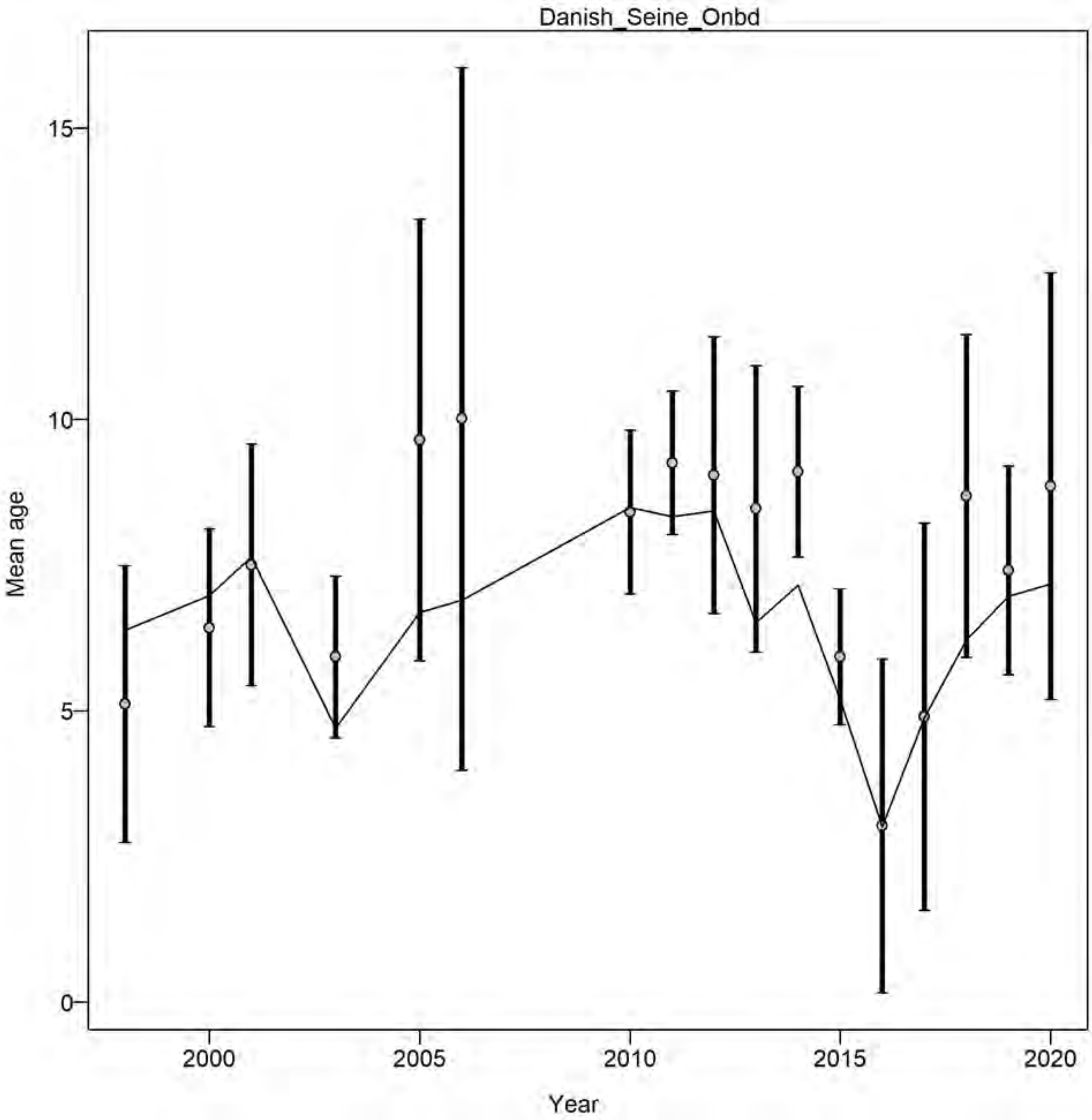


Figure A 8.39. Mean age (aggregated across length bins) for eastern Jackass Morwong from Daish seine with 95% confidence intervals based on current samples sizes. Punt data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced. Yearly variation in the data is shown in changes in mean age, which can be large over a short period.

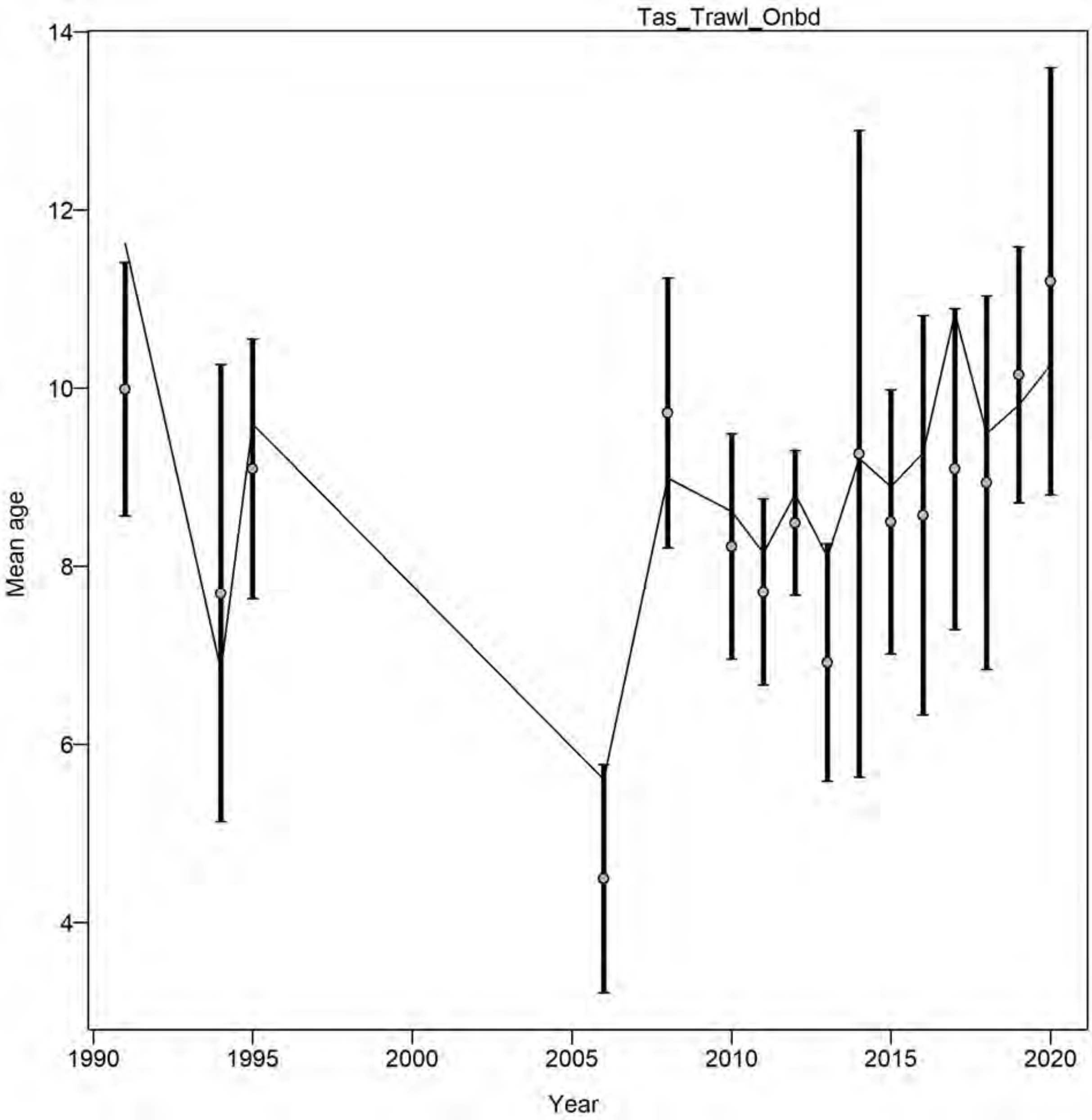


Figure A 8.40. Mean age (aggregated across length bins) for eastern Jackass Morwong from Tasmanian trawl with 95% confidence intervals based on current samples sizes. Punt data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced. Yearly variation in the data is shown in changes in mean age, which can be large over a short period.

9. Eastern zone Orange Roughy (*Hoplostethus atlanticus*) stock assessment based on data up to 2020 – development of a preliminary base-case

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9.1 Executive Summary

The 2017 eastern zone Orange Roughy assessment (Haddon 2017) and subsequent cross-catch risk assessment (Tuck et al. 2018) identified that the model is extremely sensitive to the assumed value of natural mortality (M). At its March 2021 Chairs Meeting, the Southern and Eastern Scalefish and Shark Fishery Resource Assessment Group (SESSFRAG) recommended that the eastern Orange Roughy 2021 stock assessment attempt to estimate M using an informative prior, with the fall back approach being the construction of a decision table with alternate states of nature and management actions, using agreed values of M and h.

A draft version of this report was presented to the Orange Rough Steering Committee (ORSC) in August 2021 to seek advice on:

1. The bridging of the 2017 assessment to include updated data to develop a preliminary base-case assessment with fixed natural mortality of M=0.04 yr^{-1} and
2. Consideration of likelihood profiles on M and h to propose parameters for a decision table with alternate states of nature and management actions.

The bridging of the 2017 assessment to produce a preliminary base-case assessment with fixed M=0.04 yr^{-1} was supported by the ORSC with the following additional recommendations:

- There are currently 80 age-classes in the assessment, with the maximum age-class treated as a plus group that comprises 5-9% of individuals in age sample collected in the 1990s. This may result in bias when M is estimated and increasing the number of age-classes in the assessment to 100 and 120 should be explored.
- Include as a sensitivity an analysis that removes the 1992 egg survey.
- Correct the retrospective analysis. The retrospective analysis in the draft report did not reduce the number of estimated recruitment deviations when the number of years of data was reduced.
- Plot the age-specific maturity and selectivity on the same figure to identify the magnitude of the difference between maturity and selectivity.

This document presents four candidate preliminary base-cases for an updated quantitative Tier 1 assessment of the eastern zone stock of Orange Roughy (*Hoplostethus atlanticus*) for consideration by SERAG. The first preliminary base-case uses a fixed natural mortality of M=0.04 yr^{-1} (from the base-case of the 2017 assessment). The purpose of the preliminary base-case with fixed natural mortality is to form a bridge between the base-case from the 2017 assessment with the addition of new data and

modelling assumptions and the 2021 model. Starting from the preliminary base-case assessment with fixed natural mortality of M=0.04 yr^{-1} the remaining candidate base-case assessments estimate natural mortality using an informative prior for M developed from a meta-analysis of the results of assessments for four stocks of Orange Roughy in New Zealand. The difference between the three preliminary base-cases that estimate natural mortality is the age of the plus-group in the 80 years (the same as the previous assessment), 100 years, and 120 years being included.

The preliminary base-case with fixed natural mortality of M=0.04 yr^{-1} updated the 2017 assessment to correct some minor errors in the assessment input files, to use current methods and software and include new data up to the end of 2020. Model fits to the acoustic biomass indices are reasonable, while fits to the 1992 age data and the male age data in general are relatively poor. Fits to the female age data were somewhat better than the fits to the male age data. However, there is considerable uncertainty associated with the age data in the assessment. Compared with the 2017 assessment, the 2021 preliminary base-case assessment with fixed natural mortality of M=0.04 yr^{-1} provides very similar, although slightly lower estimates of the 2017 female spawning biomass (12,700 t compared with 14,100 t) and the 2021 relative spawning biomass (0.31 compared with 0.33). This appears to be driven by the most recent 20 years of recruitment being slightly lower than those estimated in the 2017 assessment. This reduction in estimated recruitment appears to be primarily driven by the 2019 age data. A retrospective analysis shows slight reductions in estimated productivity for the eastern zone Orange Roughy stock with the successive additions of new acoustic survey and age data over the last decade.

The likelihood profile for natural mortality that was undertaken for the 2021 preliminary base-case assessment with a plus-group at 80 years shows that the negative log-likelihood is minimised at around M=0.032 yr^{-1} with 95% confidence intervals for M of ~0.0255 yr^{-1} – ~0.042 yr^{-1}. The likelihood profile for h was uninformative.

A log-normal prior for natural mortality was deveopled from a sample of 5,000 natural mortality estimates from the combined posterior for New Zealand Orange Roughy supplied by Patrick Cordue (ISL). This prior was used to estimate M within the eastern zone assessment using the same parameters and data as the preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1}. Additional models with higher plus groups (100 years and 120 years) were also evaluated. All models that estimated M converged and provided similar estimates of selectivity and catchability for the acoustic surveys, suggesting that we successfully estimated natural mortality within the assessment.

The estimated natural mortality, and hence the estimated productivity of the stock was sensitive to the number of age-classes in the model. Increasing the plus-group from the original 80 years used in previous assessments, to 100 years and 120 years resulted in the estimated natural mortality increasing from M=0.0344 yr^{-1} for the model with a plus-group at 80 years to M=0.0373 yr^{-1} and M=0.0386 yr^{-1} for the models with plus-groups at 100 years and 120 years, respectively. The models that estimated M gave very similar estimates of unfished female spawning biomass at around 41,000 t and 2021 female spawning biomass between 12,000 t and 13,000 t. Increasing the number of age-classes from 80 resulted in 2021 female relative spawning biomass increasing from ~0.29 to 0.31 and 0.32 for models with plus-groups at 100 years and 120 years respectively. The estimates of absolute recruitment differed among the models, with the models estimating higher values of natural mortality also having higher estimates of average absolute recruitment.

The models with higher plus groups had slightly better fits to the age data and no discernible change in the fits to the acoustic biomass indices, suggesting that the number of age-classes in the assessment should be increased. There was little difference in the fits to the age data between the models with higher plus groups.

We recommend that SERAG adopt either the model with a plus-group at either 100 years or 120 years as the agreed base-case for the 2021 eastern zone Orange Roughy assessment. Given the differences in the natural mortality estimates between the models with a plus-group at 100 years and 120 years and the uncertainty associated with those estimates, SERAG may wish to make use of a decision table with alternate states of nature and management actions (a cross-catch-risk assessment). If a decision table is requested we recommend using quantiles from the posterior of natural mortality from the agreed base-case assessment to categorize the states of nature as they are likely to better represent the uncertainty in natural mortality than a likelihood profile.

9.2 Background

9.2.1 Proposed approach for 2021 assessment

In 2020, following a request from the Australian Fisheries Management Authority (AFMA), the South East Resource Assessment Group (SERAG) discussed the uncertainty surrounding the estimate of natural mortality (M) used in the most recent stock assessment of eastern zone Orange Roughy and how to accommodate the uncertainty in M within the 2021 assessment. At its November 2020 meeting, SERAG requested CSIRO develop a robust process for estimating M for the 2021 eastern zone Orange Roughy stock assessment for review. CSIRO proposed estimating M within the assessment using an updated version of the informative prior for M of Cordue (2014). SERAG supported the proposed process but also wanted to make sure that there was a viable alternative available should the proposal to estimate M fail.

The Orange Roughy steering committee (ORSC) comprising Daniel Corrie, Dan Hogan, Mike Steer, Geoff Tuck, Paul Burch, André Punt, Andrew Penney and Matt Dunn (NIWA) was established to provide inter-sessional review of the work. Prior to the August 2021 meeting of the ORSC Kevin Stokes joined the ORSC and Dan Hogan was replaced by Simon Boag as the industry representative.

To address the potential failure of estimating natural mortality it was proposed to use a decision table with alternate states of nature and management actions (e.g. Tuck et al. 2018;). The work plan, developed in consultation with the ORSC, was:

1. Undertake a bridging analysis to update the 2017 assessment with the most recent data on catch, age and survey index of abundance.
2. Calculate likelihood profiles for M (noting the likelihood profile for M will be wider than the distribution for M estimated by the assessment, which is constrained by an informative prior) and steepness (h) to provide the ORSC with information to choose values of M and h for the decision table.
3. Review the Pacific Fishery Management Council terms of reference and identify a potential approach for identifying the values for M and h that correspond to a 90% confidence bound for the proposed cross-catch risk assessment.
4. Develop a process for constructing an informative a prior for natural mortality.

Following review by the ORSC to discuss the updated assessment, likelihood profiles and proposed parameters for the cost-catch risk assessment the assessment would proceed using the agreed data and methodology.

9.2.2 *Review by SESSFRAG March 2021*

The Southern and Eastern Scalefish and Shark Fishery Resource Assessment Group (SESSFRAG) reviewed the above proposal at its March 2021 Chairs Meeting. The key points and recommendation from the minutes of the SESSFRAG meeting are reproduced below, with some additional clarification provided in brackets.

- *Several meeting attendees raised concerns with using a decision table to select values of M, with their view being that this is a more risky approach than using a model or likelihood profiles [the proposed approach is not planning to use a decision table to select M].*
- *Concerns were also raised regarding previous decisions relating to the selection of M, with the value determined through a likelihood profile, not being used in the assessment; and instead opting for an 'assumed' value, determined through a comparison of Australian and New Zealand orange roughy stocks. It was noted that this occurred due to procedural issues, resulting from an alternate base case not being provided with sufficient time prior to the RAG meeting; and the level of impact of the value of M (determined through likelihood profile) on the assessment.*
- *It was emphasised that the process for selecting M needs to be clearly identified, to ensure that the value of M is selected based on the best available science.*

The RAG recommended that the eastern Orange Roughy 2021 stock assessment proceeds using the agreed data, to attempt to estimate M with an informative prior, with the fall back approach being the construction of a decision table with alternate states of nature and management actions, using the agreed values of M and h; with a progress update to be provided to the SESSFRAG Data Meeting (August 2021).

9.2.3 *Advice from Orange Roughy Steering Committee August 2021*

The ORSC met via video conference on Friday 13 August 2021 to review a draft of this report that included an updated preliminary base-case with fixed natural mortality of M=0.04 yr^{-1}, likelihood profiles on M and h and proposed parameters for a decision table with alternate states of nature and management actions (Burch and Curin-Osorio 2021).

The bridging of the 2017 assessment to produce a preliminary base-case assessment with fixed natural mortality of M=0.04 yr^{-1} was supported by the ORSC with the following recommendations:

1. There are currently 80 age-classes in the assessment, with the maximum age-class treated as a plus group that comprises 5-9% of individuals in age samples for earliest years with age data. This may result in bias when M is estimated and increasing the number of age-classes in the assessment to 100 and 120 should be explored.
2. Undertake a sensitivity removing the 1992 egg survey.
3. Correct the retrospective analysis to estimate fewer years of recruitment deviations (year classes) when sequentially removing data from the assessment in each year. The retrospective analysis in the draft report did not reduce the number of estimates of recruitment deviations, which is incorrect.

4. Age-specific maturity and selectivity should be plotted in the same figure to identify the magnitude of the difference between maturity and selectivity.

The ORSC discussed the process of estimating *M* using an informative prior and supported the approach of using an updated prior for *M* that uses the most recent available assessments for New Zealand Orange Roughy assessments for ORH 2A+2B+3A, ORH 3A (NWCR), ORH 3B (ESCR), ORH (Puysegur). The prior has been updated by Patrick Cordue as part of the submission for the extension of Marine Stewardship Council certification for New Zealand Orange Roughy in the ORH 3B region but is not yet publicly available. The ORSC noted the following:

- The prior of Cordue (2014) is relatively uninformative between plausible values of natural mortality for Orange Roughy (M=0.03yr^{-1} - M=0.045yr^{-1}).
- The Cordue prior assumes the data and model assumptions of the New Zealand Orange Roughy assessments are correct. Any bias in the New Zealand Orange Roughy assessments would likely be reflected in the prior.
- There was a discussion of how the relative weighting of the biomass indices and the age data in the assessment could potentially influence the estimation of *M*. Francis weighting gives more weight to the biomass indices, that suggest a lower *M*, and less weight to the age data that suggest a higher *M*. Francis weighting is the current best practice utilised across all SESSF stock assessments. The ORSC did not suggest that the 2021 assessment move away from this practice.

The ORSC discussed the construction of a decision table to be used to provide advice for setting eastern zone Orange Roughy TACs should the process to estimate *M* with an informative prior fail. The ORSC noted that it was important to develop a consistent approach for constructing decision tables to reduce the potential for confusion and that ideally a decision table would have a small number of states of nature and management actions. They also noted that a decision table should contain the mean or the median of the parameter of interest and be bounded by an even amount to each side. The ORSC recommended that:

- The decision table with five values of *M* taken from the 5%, 12.5%, 50%, 87.5% and 95% quantiles (90% and 75% bounds) from the likelihood profile on *M* and that a small number of sensible catch scenarios be chosen to reduce the complexity of the table.
- There was no information in the likelihood profile to inform the steepness of the stock recruitment relationship (*h*). The decision table for eastern zone Orange Roughy should be based on a fixed value of h=0.75 for all scenarios. The impact of varying *h* should be explored as a sensitivity to the base-case assessment. The cross-catch risk assessment of Tuck et al. (2018) used a fixed value of steepness (h=0.75) with two potential values of *M* and three catch series.

The advice from the Orange Roughy Steering Committee was presented to the August 2021 SESSFRAG Data Meeting and it agreed the process recommended by the ORSC for undertaking the eastern Orange Roughy Tier 1 stock assessment and decision table be adopted.

9.2.4 *Presentation to SERAG October 2021*

The presentation to the October 2021 meeting of SERAG included criteria for selecting the number of age-classess in the assessment and some additional figures that were not included in the 14th of October version of this report. The criteria to select the number of age-classes were determined based on discussions with André Punt (CSIRO and University of Washington) and Matt Dunn (NIWA). The plus group (number of age-classes) should be chosen so that:

1. The proportion of individuals in the plus group is small and
2. The number of age-classes with no individuals is small.

The optimal model is then selected based on inspection of the fits to the age and index data. To assist SERAG in selecting a base-case some additional figures have been added to the report (Figures 9.28 – 9.39).

9.3 Methods

The 2021 stock assessment for Eastern Zone Orange Roughy (*Hoplostethus atlanticus*, Collett 1889) uses an integrated stock assessment model implemented using Stock Synthesis 3.30.17 (Methot and Wetzel 2013). As in the preivous two assessments, it assumes a stock structure that combines the Eastern Zone (primarily St Helens Hill and St Patricks Head) and Pedra Branca from the Southern Zone (Figure 9.1). New data included since the previous stock assessment (Haddon 2017) are recent catches, relative estimates of female spawning biomass from the 2019 acoustic towed surveys at St Helens Hill and St Patricks Head, and new age composition data from the 2019 acoustic survey. In addition, other changes were made to the assessment, viz to estimate additional recruitment residuals and to use a revised ageing error matrix.

A small number of changes and corrections were made to the data used in the 2017 assessment, these were:

- Catches for 2015 and 2016 were updated from 460.4t and 360t respectively to 457.3t in 2015 and 384.5t in 2016.
- The model used to estimate ageing error for 2017 assessment had not fully converged.
- The priors and intial values for the two acoustic surveys and the fixed value of the egg survey were rounded to two decimal places in the Stock Synthesis input files of the 2014 and the 2017 assessments. The update increased the number of decimal places to nine.
- The fixed value of the standard deviation of recruitment (σ_R) was reported as 0.58 in Haddon (2017). However, σ_R was set to 0.7 in the assessment model.

The preliminary base-case assessment model with fixed natural mortality of M=0.04 yr^{-1} was developed by adding each of these model changes and data streams sequentially to the previous final base-case assessment model (Haddon 2017) to identify the effect of each new source of information using a formal bridging analysis. Data weighting (tuning) was then applied, and likelihood profiles for M and h were produced.

In addition to the preliminary base-case assessment model with fixed M, three candidate preliminary base-case assessments were developed that involved estimating M using an informative prior developed from the most recent available assessments for New Zealand Orange Roughy stock assessments for ORH 2A+2B+3A, ORH 3A (NWCR), ORH 3B (ESCR), ORH (Puysegur) and ORH 7A. The preliminary base-case assessments that estimate M differed in the number of age-classes in the model, with scenarios of 80 (the default from previous assessments), 100 and 120.
Data and assumptions used are described in more detail below.

9.3.1 *Stock Structure Hypothesis*

We use the stock structure assumption and historical catches that were agreed at a workshop held in Hobart in May 2014 and used in the 2014 and 2017 stock assessments (Upston et al. 2015, Haddon 2017). The stock structure assumes the Eastern Zone (primarily St Helens Hill and St Patricks Head) and Pedra Branca from the Southern Zone are combined because they are part of a single stock. Details of the reasoning behind this decision are provided in Upston et al (2015) and will be added to the final assessment report.

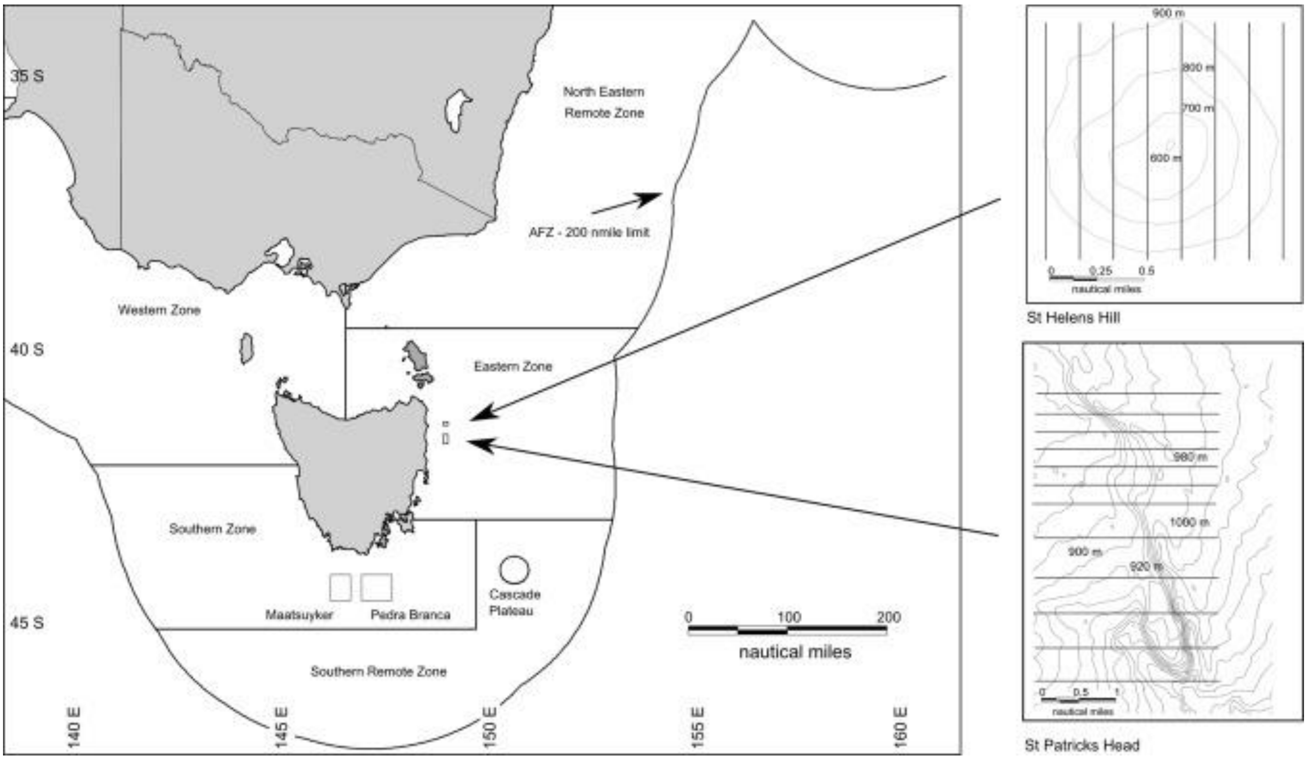


Figure 9.1. Map of Australian Orange Roughy management zones and areas.

9.3.2 *Biological Parameters*

No changes have been made to the fixed biological parameters used in the 2017 assessment. However, the fixed value for recruitment variability (σ_R) is now correctly reported as 0.7 (see Table 9.1 for a summary of the fixed and estimated parameters).

Male and female Orange Roughy are assumed to have the same biological parameters except for their length-weight relationship. In the absence of representative length data, none of the four parameters relating to the Von Bertalanffy growth equation are estimated within the model-fitting procedure. Maturity is modelled as a logistic function of length, with 50% maturity at 35.8 cm. The assumption is made that the maturity would approximately match fishery selectivity as estimated on the spawning aggregations (which are assumed to consist of mature animals). Fecundity-at-length is assumed to be directly proportional to weight-at-length, which is important for the estimation of the Spawning Potential Ratio, which can act as a proxy for fishing mortality; a requirement for the determination of stock status.

Table 9.1. The pre-specified model parameters used in the 2021 preliminary base-case assessments. * A fixed value of natural mortality of M=0.04yr^{-1} is used to develop the preliminary base-case assessment with fixed M. However, M is also estimated within the assessment using the informative prior, as described below. † Models with 80, 100 and 120 age-classes were evaluated.

Fixed parameters	Values		Source
Recruitment steepness, h	0.75		Annala (1994) cited in CSIRO & TDPIF (1996)
Recruitment variability , σ_R	0.7		
*Rate of natural mortality, M	0.04 yr^{-1}		Stokes (2009)
Maturity logistic inflection	35.8 cm		Upston et al (2015)
Maturity logistic slope	-1.3 cm^{-1}		Smith et al. (1995)
Von Bertalanffy K	0.06 yr^{-1}		Smith et al. (1995)
Length at 1 year Female	8.66 cm		
Length at 70 years Female	38.6 cm		
Length-weight scale, a	3.51×10^{-5}	Female	Lyle et al. (1991)
	3.83×10^{-5}	Male	
Length-weight power, b	2.97, 2.942	Female Male	Lyle et al. (1991)
†Plus-group age (years)	80, 100, 120		
Length at age CV for age 1	0.07		Estimated from data
Length at age CV for age 70	0.07		Expected offset from young
q egg survey catchability	0.9		Bell et al. (1992), Koslow et.al (1995), Wayte (2007)

9.3.3 *Data*

The data sources included in the eastern zone Orange Roughy assessment are catch (including discards), three indices of abundance (the egg survey estimate treated as an estimate of absolute abundance, and the two acoustic biomass estimates treated as relative abundance indices) and age composition data from the acoustic surveys and on-board sampling. A summary of the time periods of the data for the 2021 assessment is provided in Figure 9.2.

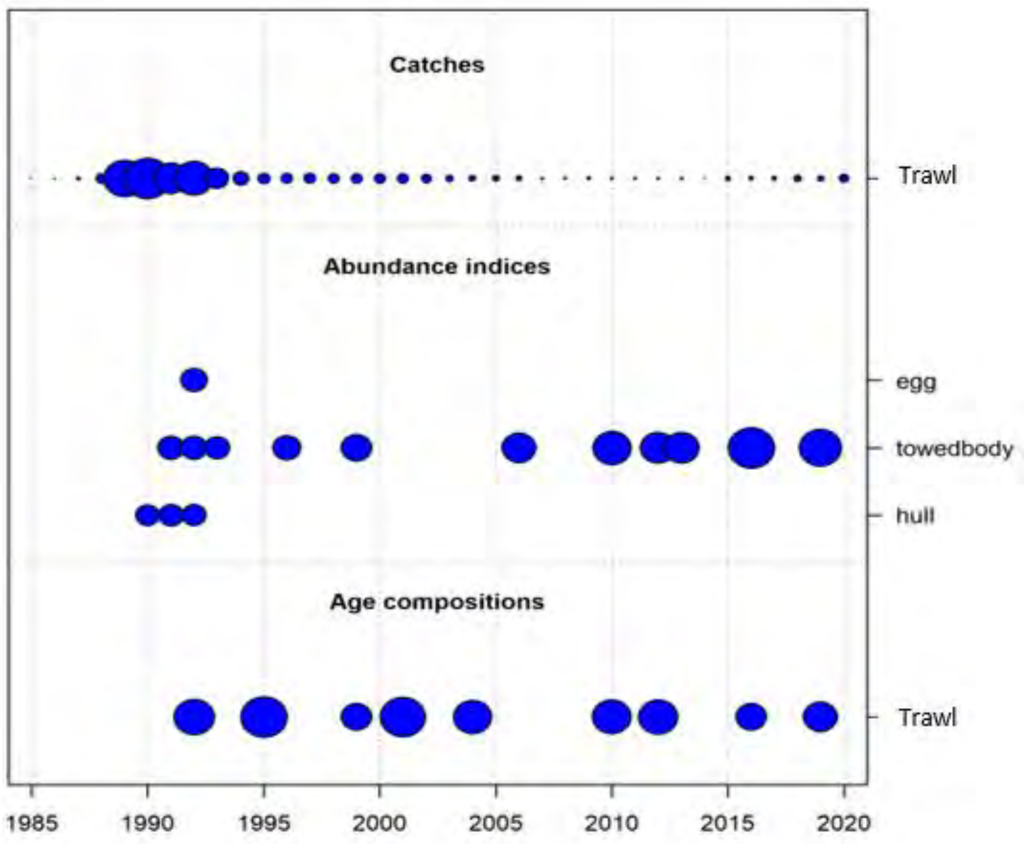


Figure 9.2. Data availability for the eastern zone Orange Roughy assessment by type and year.

9.3.3.1 Catch

The assessment uses the agreed catch history series from the 2014 assessment (Upston et al 2015) and updates the landed catches for 2015 – 2020 using logbook and catch disposal records (Figure 9.3, Table 9.2). Discarded catches were estimated for the period 2015 – 2020 from discard weight observations obtained by onboard observers using the method of Bergh et al (2009) as implemented in Deng et al (2020). Discarded catch estimates prior to 2015 have been incorporated in the agreed catch history.

The agreed catch history adjusted the reported catches as a result of estimates of burst bags and other initially unreported catches; Wayte (2007) provides details about how the catches from 1989 – 1994 were adjusted. The justification for these adjustments to the catch history leading to the "agreed" catch history are also given in CSIRO & TDPIF (1996) and descriptions of earlier stock assessments (for the years 1995, 1996 and 1997 – see Bax 1997, Bax 2000a and 2000b).

The quota year was changed in 2007 from calendar year to the year extending from 1 May to 30 April. The assessment, however, continues to be conducted according to the calendar year as most catches occurred prior to 2007.

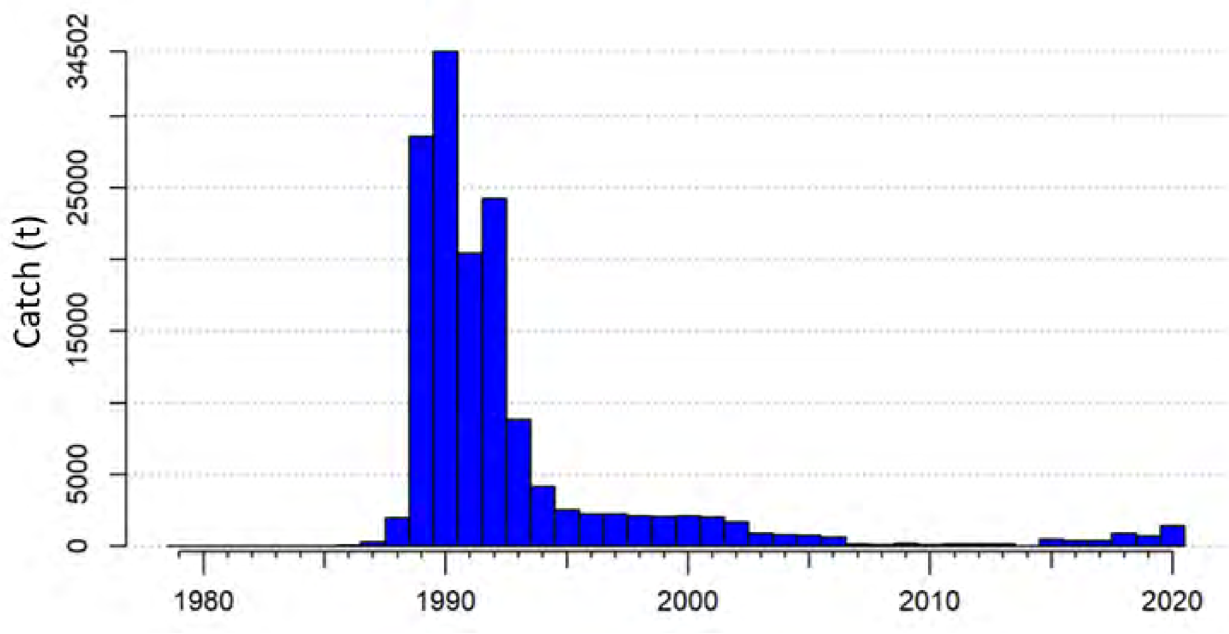


Figure 9.3. Catch, including discards, of the eastern zone Orange Roughy assessment. Catches for 1989 – 1994 incorporate adjustments for the proportion lost due to lost gear and burst bags/ burst panels, other losses, and misreporting (CSIRO & TDPIF 1996; Wayte 2007).

Table 9.2. Agreed catches, in tonnes, of eastern zone Orange Roughy, where the eastern zone stock includes Pedra Branca (PB) from the Southern Zone. The starred years 1989 – 1994 denote catches that incorporate adjustments for the proportion lost due to lost gear and burst bags/ burst panels, other losses, and misreporting (CSIRO & TDPIF 1996; Wayte 2007). * Total removals for 2021 were assumed to be the same as 2020.

Year	East	Pedra	South (Exc Pedra)	Discards	Total Removals
1985	6	0	58		6.0
1986	33	27	604		60.0
1987	310	0	353		310.0
1988	1949	0	469		1949.0
1989*	26236	2339	8547		28575.0
1990*	23200	11302	24128		34502.0
1991*	12159	8277	6149		20436.0
1992*	15119	9146	6908		24265.0
1993*	5151	3647	1839		8798.0
1994*	1869	2271	2557		4140.0
1995	1959	585	1572		2544.0
1996	1998	233	569		2231.0
1997	2063	187	267		2250.0
1998	1968	119	131		2087.0
1999	1952	100	74		2052.0
2000	1996	113	198		2109.0
2001	1823	204	153		2027.0
2002	1584	90	77		1674.0
2003	772	105	105		877.0
2004	767	30	50		797.0
2005	754	18	81		772.0
2006	614	1	4		615.0
2007	113	16	6		129.0
2008	98	0	0		98.0
2009	193	0	10		193.0
2010	113	0	18		113.0
2011	160	2	15		162.0
2012	163	0	22		163.0
2013	150	0	8		150.0
2014	20	0	20		20.0
2015	422	29	5	7	457.3
2016	352	29	19	3	384.5
2017	302	56	18	6	364.0
2018	862	45	8	3	909.5
2019	619	75	17	1	695.1
2020	1320	60	19	18	1397.5
2021					1397.5*

9.3.3.2 Age Data

The age data were received from Fish Ageing Services (FAS). Several corrections have been made to the ageing data since the 2017 assessment (Josh Barrow pers. com.). The number of age samples that were provided by FAS in 2017 and the number that were provided in 2021 are shown in Table 9.3. Differences were mostly minor, except for 1995 where additional samples that had been mislabeled as being from 1996 were added. Age data were also collected in 1987. However, previous assessments have excluded these data due to concerns that large fish were preferentially selected so that sampling was not representative (Malcolm Haddon pers. com.).

Table 9.3. Number of female and male age samples provided for the 2017 and 2021 assessments. Note the 2017 assessment and the 2021 preliminary base-case assessment with fixed natural mortality of M=0.04 yr^{-1} only updated the age data for 2016 and 2019 with age data from years prior taken from Upston et al. (2015).

	Female samples			Male samples		
Year	2017	2021	Difference	2017	2021	Difference
1992	410	410	0	596	596	0
1995	538	610	72	699	757	58
1999	435	435	0	394	394	0
2001	652	652	0	641	641	0
2004	414	414	0	504	504	0
2010	693	693	0	251	251	0
2012	426	426	0	545	545	0
2016	338	338	0	247	247	0
2019	-	418	-		309	-

The age data for the 2017 assessment treated ages from St Helens Hill and St Patricks Head in 2012 and 2016 as simple random samples of the population and added these ages to those from earlier years in the 2014 assessment. The 2021 preliminary base-case assessments that used 80 age-classes also treated the 2019 age samples from St Helens Hill and St Patricks Head as simple random samples of the population and added them to the ages used in the 2017 assessment. Samples collected prior to 2012 were combined and weighted based on either the relative abundance implied by the acoustic estimates or the relative catch (Wayte, 2007).

We reviewed the methods used for weighting of age compositions in the 2007, 2011 and 2014 assessments (Wayte 2007, Upston and Wayte 2011, Upston et al 2015). While the weighting of age samples by relative abundance implied by the acoustic estimates or the relative catch at St Helens Hill and St Patricks Head was investigated, age compositions in both locations were similar in all years where both locations were sampled except for 1999. Subsequently, the age composition data was unweighted with the exception of 1999 where a weighting of 1.08 was applied to the age composition data from St Patricks Head (see Table 6.5 from Upston et al 2015). The weighting on the 1999 age composition was based on the acoustic survey estimating that around 85% of the population was at St Patricks Head and took into account that sample sizes at St Patricks Head were larger in this year (Wayte 2007).

It was necessary to recalcualte age frequencies using raw age data supplied by FAS in 2021 and historical data held by CSIRO for the two scenarios that increased the number of age-classes in the model to 100 and 120 to investigate potential bias in the estimation of natural mortality. Age frequencies were unweighted except for 1999 where a weighting of 1.08 was applied to the age composition data from St Patricks Head, consistent with previous assessments. The data provided by

Fish Ageing Services for 1999 did not have any samples identified as being collected from St Patricks Head, with all samples recorded as “Eastern Zone” or “St Helens Hill”. A spreadsheet with raw data from 1999 was found and used to calculate age frequencies for scenarios with maximum model ages of 100 and 120. The number of ages for St Patricks Head matches those in earlier assessments. However, there were 10 additional ages for St Helens Hill compared with those from earlier assessments (Wayte 2007). Information in the spreadsheet could potentially be used to correct the location of capture for the 1999 age data in the FAS database.

It is recommended that the age data and the relative weighting of age samples collected from St Helens Hill and St Patricks Head should be reviewed prior to the next eastern zone Orange Roughy assessment.

9.3.3.3 Ageing error

An estimates of the standard deviations of age reading error by age were calculated from multiple readings of otoliths supplied by Josh Barrow (Fish Ageing Services) using the method of Punt et al. (2008) and is provided in Table 9.4. The estimates were updated from those used in the 2017 assessment to include the new ageing data from 2019 and recent corrections to the Fish Ageing Services database. Ageing uncertainty from the 2021 data was higher than in the 2017 assessment, but quite similar to the 2014 assessment (Upston et al. 2015). Upon investigation it was identified that the model used to estimate ageing error for eastern zone Orange Roughy in 2017 had not fully converged, which likely underestimated the uncertainty within the assessment to some degree.

Ageing error was also estimated using the approach described above for scenarios that increased the number of age-classes in the model to 100 and 120. The ageing error for the 100 age-class scenario did not achieve full convergence (max gradient = 0.024), so the ageing error for the scenario with 120 age-classes that did converge (max gradient < 0.001) was used for scenarios with both 100 and 120 age-classes. Estimates of ageing error for scenarios with 100 and 120 age-classes are provided in the Table A 9.1.

Table 9.4. The estimated standard deviation of normal variation (age-reading error) around age-estimates for the 80 age-classes of eastern zone Orange Roughy preliminary base-case assessment.

Age	StDev	Age	StDev	Age	StDev	Age	StDev
0	<0.001	21	1.5838	42	3.2233	63	4.8391
1	<0.001	22	1.6624	43	3.3008	64	4.9155
2	0.0797	23	1.7410	44	3.3782	65	4.9918
3	0.1594	24	1.8195	45	3.4556	66	5.0680
4	0.2390	25	1.8979	46	3.5329	67	5.1442
5	0.3185	26	1.9763	47	3.6102	68	5.2204
6	0.3980	27	2.0547	48	3.6874	69	5.2965
7	0.4775	28	2.1330	49	3.7645	70	5.3725
8	0.5568	29	2.2112	50	3.8416	71	5.4485
9	0.6362	30	2.2894	51	3.9187	72	5.5244
10	0.7154	31	2.3675	52	3.9957	73	5.6003
11	0.7946	32	2.4456	53	4.0726	74	5.6761
12	0.8738	33	2.5236	54	4.1495	75	5.7519
13	0.9529	34	2.6016	55	4.2264	76	5.8276
14	1.0320	35	2.6795	56	4.3031	77	5.9033
15	1.1110	36	2.7573	57	4.3799	78	5.9789
16	1.1899	37	2.8351	58	4.4565	79	6.0545
17	1.2688	38	2.9129	59	4.5332	80	6.1300
18	1.3476	39	2.9906	60	4.6097		
19	1.4264	40	3.0682	61	4.6862		
20	1.5051	41	3.1458	62	4.7627		

9.3.3.4 Biomass indices

There are now eleven estimates of relative abundance for the St Helens Hill and St Patricks Head area from the towed body acoustic surveys (Table 9.5). The acoustic survey data and methodology was reviewed thoroughly by Upston et al (2015). We added the biomass estimate from the most recent survey in 2019 (which found that mean female spawning biomass on the St Helens Hill and St Patricks Head area had increased to 36,900 t; Kloser and Sutton 2020) to the estimates used in the 2017 assessment.

Informative priors for the catchability coefficients (q) for the acoustic towed and hull biomass estimates were developed for the 2015 assessment using the methods of Cordue (presentation to the Australian Orange Roughy workshop, 15 - 16 May 2014; Cordue 2014) and modified for Australian eastern Orange Roughy (Upston et al. 2015). The details of the method used to develop the priors, including the distributions for each of the independent components, and the combined overall distribution for the acoustic q prior, are given in the Appendix.

In both the 2014 and 2017 assessments, the priors and intial values for the two acoustic surveys and the fixed value of the egg survey were rounded to two decimal places in the Stock Synthesis input. The 2021 preliminary base-case increases the number of decimal places to nine.

Table 9.5. The three abundance indices used in the eastern zone Orange Roughy assessment. Values up to 2012 were sourced from Upston et al (2015). The original 2013 towed acoustic survey value was increased by 18% as a result of a recalibration of the equipment (Kloser, pers. comm), and the 2016 estimate is from Kloser et al, (2016). DEPS is the daily egg production survey. The DEPS estimate is treated as an absolute abundance estimate while the others are treated as relative abundance indices and the method used to determine the priors is described in the Appendix.

Method	Year	Biomass (t)	CV	Catchability (*q*)
Hull				N(Ln(0.95), 0.92)
Hull	1990	120,239	0.63	
Hull	1991	71,213	0.58	
Hull	1992	48,985	0.59	
Towed				N(Ln(0.95), 0.3)
Towed	1991	59,481	0.49	
Towed	1992	56,106	0.50	
Towed	1993	22,811	0.53	
Towed	1996	20,372	0.45	
Towed	1999	25,838	0.39	
Towed	2006	17,541	0.31	
Towed	2010	24,000	0.25	
Towed	2012	13,605	0.29	
Towed	2013	14,368*	0.29	
Towed	2016	24,037	0.17	
Towed	2019	36,907	0.20	
DEPS	1992	15,922	0.50	0.9 (fixed)

9.3.4 *Tuning – Data Weighting*

Iterative rescaling (reweighting) of input and output CVs or input and effective sample sizes is a repeatable way to ensure that the expected variation of the different data streams is comparable to what is input (Pacific Fishery Management Council, 2020). 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. An automated iterative tuning procedure was used to adjust the recruitment bias ramp and the weighting on the age composition data.

For the recruitment bias adjustment ramps:

1. Adjust the maximum bias adjustment and the start and finish bias adjustment ramps as predicted by r4ss at each step.

For the age composition data:

2. Multiply the initial samples sizes by the sample size multipliers for the age composition data using the `Francis method' (Francis, 2011).

3. Repeat steps 1 - 2, until all are converged and stable (with proposed changes < 1%). This procedure constitutes current best practice for tuning assessments.

9.3.5 *Preliminary base-case assessment with fixed M*

The preliminary base-case assessment with a fixed natural mortality of M=0.04 yr^{-1} was developed by including data up to the end of 2020, which revised the catch series for 2015 - 2020 and added estimate of acoustic biomass and age composition data from the 2019 survey. Ageing error was also updated and additional recruitment deviations were estimated (1905-1986 compared to 1905-1983 in the 2017 assessment). The model was tuned as described above. Sensitivities to the weighting of the age data will be explored as part of the assessment.

9.3.6 *Likelihood profiles*

Likelihood profiles are a standard component of the toolbox of applied statisticians (Punt 2018). They are most often used to obtain 95% confidence intervals. Many stock assessments "fix" key parameters such as *M* and *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. 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 natural mortality (*M*) and steepness of the stock recruitment relationship (*h*) were conducted using the preliminary base-case assessment. Confidence intervals were constructed using a Chi squared distribution with one degree of freedom. The 2.5% and 97.5% quantiles of the likelihood profile of *M* and *h* (a 95% confidence interval) were therefore obtained at 1.92 log-likelihood units from the minimum, while the 5% and 95% quantiles (a 90% confidence interval) are obtained at 1.35 log-likelihood units from the minimum.

9.3.7 *Decision table with alternate state of nature and management action*

Decision tables illustrate the consequences of uncertainty to management decisions by using alternative models versus management actions. A decision table (also known as a cross-catch-risk assessment) was constructed for eastern zone Orange Roughy to explore the impacts of uncertainty in natural mortality (Tuck et al. 2018). At the March 2021 SESSFRAG Chairs Meeting it was agreed that a decision table should be constructed for eastern zone Orange Roughy should the estimation of *M* with an informative prior fail.

The specification of a decision table to be used to provide advice for setting eastern zone Orange Roughy TACs should the process to estimate *M* with an informative prior fail was discussed at the ORSC video conference in August 2021. The ORSC noted that it was important to develop a consistent approach for constructing decision tables to reduce the potential for confusion and that ideally a decision table would have a small number of states of nature and management actions. They also noted that a decision table should contain the mean or the median of the parameter of interest and be bounded by an even amount to each side. The ORSC recommended that:

- The decision table with five values of *M* taken from the 5%, 12.5%, 50%, 87.5% and 95% quantiles (90% and 75% bounds) from the likelihood profile on *M* and that a small number of sensible catch scenarios be chosen to reduce the complexity of the table.
- There was no information in the likelihood profile to inform the steepness of the stock recruitment relationship (*h*). The decision table for eastern zone Orange Roughy should use a fixed value of *h*=0.75 for all scenarios in the decision table. The impact of varying *h* should be explored as a sensitivity to the base-case assessment. The cross-catch risk assessment of Tuck et al. (2018) used a fixed value of steepness (*h*=0.75) with two potential values of *M* and three catch series.

We propose that the catch scenarios for decision table, should it be required, use the recommended biological catches (RBCs) from models that use the 12.5%, 50% and 87.5% quantiles of *M*. This will restrict the decision table to 15 scenarios.

Should SERAG accept a base-case assessment where *M* is estimated, there will still be uncertainty in the estimated natural mortality and SERAG may wish to utilise a decision table to assist in setting an RBC for eastern zone Orange Roughy. If this is the case we recommend that values of *M* be taken from the 5%, 12.5%, 50%, 87.5% and 95% quantiles of the posterior for *M* within the assessment.

9.3.8 *Prior for natural mortality*

Cordue (2014) developed a combined posterior for Orange Roughy natural mortality using the results from the New Zealand Orange Roughy stock assessments for ORH 2A+2B+3A, ORH 3A (NWCR), ORH 3B (ESCR), and ORH 7A. CSIRO proposed to use an updated version of the combined posterior for Orange Roughy natural mortality to develop a prior for *M* to use in the Australian eastern zone stock assessment to estimate *M*. The posterior for New Zealand Orange Roughy stocks has recently been updated by Patrick Cordue as part of the submission for the extension of Marine Stewardship Council certification for New Zealand Orange Roughy but is not yet publicly available. The updated posterior uses the most recent available assessments for New Zealand Orange Roughy stock assessments for ORH 2A+2B+3A, ORH 3A (NWCR), ORH 3B (ESCR), ORH (Puysegur) and ORH 7A.

We received permission from George Clement (Deepwater Group) to access to the updated combined posterior for New Zealand Orange Roughy *M* and a sample of 5,000 *M* estimates from the updated combined posterior distribution was provided by Patrick Cordue (ISL). To obtain a functional form of the prior for *M* that could be used in Stock Synthesis, we fitted Gamma, Beta, log-normal and Normal distributions to the combined posterior for New Zealand Orange Roughy using the MASS package in R (Venables and Ripley 2002). The distribution to use for the prior for *M* was selected by visual comparison of the fitted distributiuons.

9.3.9 *Preliminary base-case assessment with M estimated*

The preliminary base-case assessment with a fixed natural mortality of *M*=0.04 yr^{-1} was used as the starting point for models that estimate natural mortality with an informative prior on *M*.

The preliminary base-case assessment with a fixed natural mortality of *M*=0.04 yr^{-1} uses 80 age-classes in the assessment, with the oldest age-class being a plus group that aggregates individuals aged 80 or above. This structure has been used for at least the last three previous assessments (Upston and Wayte

2011, Upston et al 2015, Haddon 2017). The plus group comprises 5-9% of individuals from early age samples collected in 1992 and 1995. The ORSC was concerned that having a large proportion of the individuals in the plus group may impact the assessment when *M* is estimated and recommended scenarios with 100 and 120 age-classes be explored.

For the models with 100 and 120 age-classes, age frequencies were calculated using raw age data supplied by FAS in 2021 for all years except 1999. Previous assessments have reweighted the age 1999 data based on the location of capture (either St Helens Hill or St Patricks Head). The 1999 data provided by Fish Ageing Services did not have any samples identified as being collected from St Patricks Head, so the historical data held by CSIRO were used to calculate age frequencies for this year. To evaluate the potential impact of revising the age data in the assessment, an additional sensitivity with 80 age-classes using the revised age data was undertaken.

For the three scenarios that estimate *M* using the revised ageing data (with 80, 100 and 120 age-classes), a short MCMC analysis was undertaken to evaluate the posterior for *M*. A single chain was run for each scenario for total of 1,200,000 interations, with the first 200,000 iterations being discarded (the burn-in). For the remaining 1,000,000 iterations, every 20,000th iteration was saved, providing a sample of 250 values of the posterior.

Criteria to select the number of age-classes were determined based on discussions with André Punt (CSIRO and University of Washington) and Matt Dunn (NIWA). The plus group should be chosen so that

1. The proportion of individuals in the plus group is small and
2. The number of age-classes with no individuals is small.

The base-case is then selected based on inspection of the fits to the age and index data of the two models.

9.3.10 *Sensitivies*

The sensitivity of the assessment to the number of age-classes in the model was investigated by fitting models with 120 age-classes in the population and both 80 and 100 age-classes in the data (i.e. forming a plus-group when fitting the data at ages 80 and 100). In addition to the sensitivities investigating the number of age-classes in the model, a sensitivity removing the egg survey was undertaken for the model with fixed natural mortality of M=0.04 yr^{-1} and the scenarios that estimate *M* using the revised ageing data (with 80, 100 and 120 age-classes). Additional sensitivity analysis will be undertaken on the selected base-case for the final assessment report.

9.4 Results

9.4.1 *Bridge step 1: software and model assumptions*

The following adjustments were made to the 2017 base-case assessment:

0. **BC_2017**: The 2017 base-case assessment (Haddon 2017).
1. **BC_2017_SS33017**: Update to Stock Synthesis version 3.30.17.
2. **BC_2017_nopriors**: Remove the prior on the steepness of the stock recruitment relationship (steepness is not estimated within the assessment).
3. **BC_2017_survey_precision**: Increase the precision of the informative priors for the catchability of the two acoustic surveys and the egg survey from two decimal places to nine.
4. **BC_2017_updated:** Tune using the current tuning methodology.

There were minimal differences in the estimated biomass and recruitment from updating of the assessment software from Stock Synthesis version SS3.30.07 used for the 2017 assessment to the most recent version SS3.30.17 (Figure 9.4).

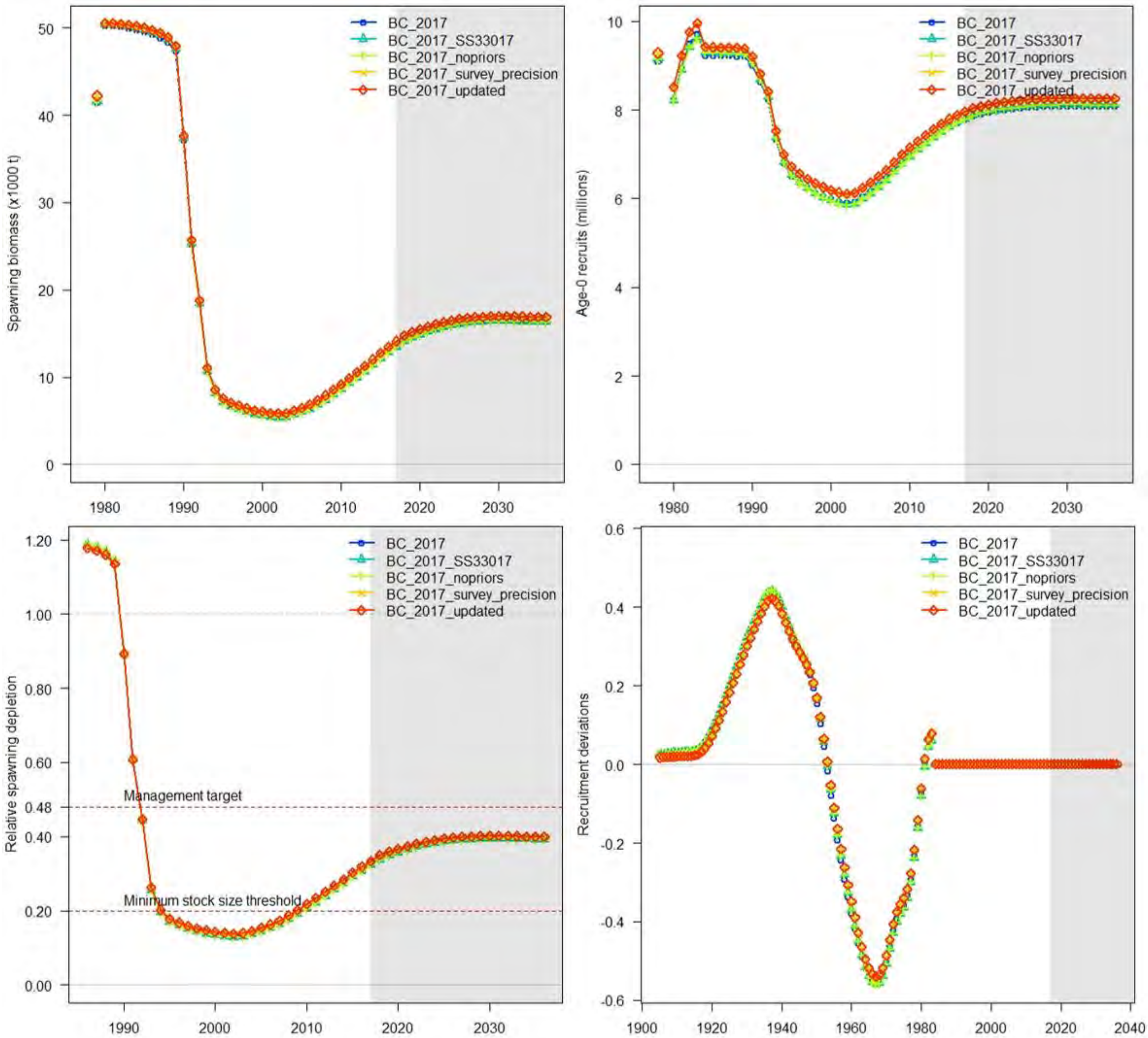


Figure 9.4. Comparison of absolute (top left) and relative (bottom left) spawning biomass, absolute recruitment (top right) and recruitment deviations (bottom right) from the four bridging models that update the software and model assumptions.

9.4.2 *Bridge step 2: new data*

Starting from the updated 2017 base-case model, additional data to 2020 were added sequentially to develop the preliminary base-case for the 2021 assessment:

0. **BC_2017_updated:** Model #4 from Bridge step 1.
1. **BC_2021_addCatch2020:** Update catches 2015 & 2016 and add 2017 – 2020.
2. **BC_2021_addBio2019:** Add biomass estimate for 2019.
3. **BC_2021_addAge2019:** Add age composition for 2019.
4. **BC_2021_addAgeErr2019:** Modify the ageing error matrix.
5. **BC_2021_extendRec:** Extend the estimated recruitment deviates to 1986.

6. **BC_2021_no_Q_prior:** Re-tuned, however, the priors on acoustic survey q's were not enabled.
7. **BC_2021_fixed_M:** Correct the omission of the priors on the acoustic survey q's and re-tune to provide the preliminary base-case assessment with fixed M (BC_2021_fixed_M).

Adding the catches to 2020 and the 2019 acoustic biomass estimate did not materially change the estimated biomass, recruitment, and the fits to the indices (Figure 9.5-Figure 9.7). The addition of the 2019 age composition data resulted in slightly lower estimates of recruitment at the start of the model (1900-1920) and a slightly lower spawning biomass and relative spawning biomass. Addition of the 2019 ageing error matrix, extending the estimated recruitment to 1986 and re-tuning led to slight reductions in number of recruits entering the fishery in the mid-1980s, but otherwise no differences.

After the August 2021 SESSFRAG Data Meeting it was identified that the preliminary base-case assessment presented to the Orange Roughy Steering Committee and SESSRAG did not have priors on the acoustic survey *q*'s model. This was corrected and there was no material difference in the results (Figure 9.5-Figure 9.7, Table 9.6). The new preliminary base-case model with a fixed natural mortality of *M*=0.04 yr^{-1} is "BC_2021_fixed_M".

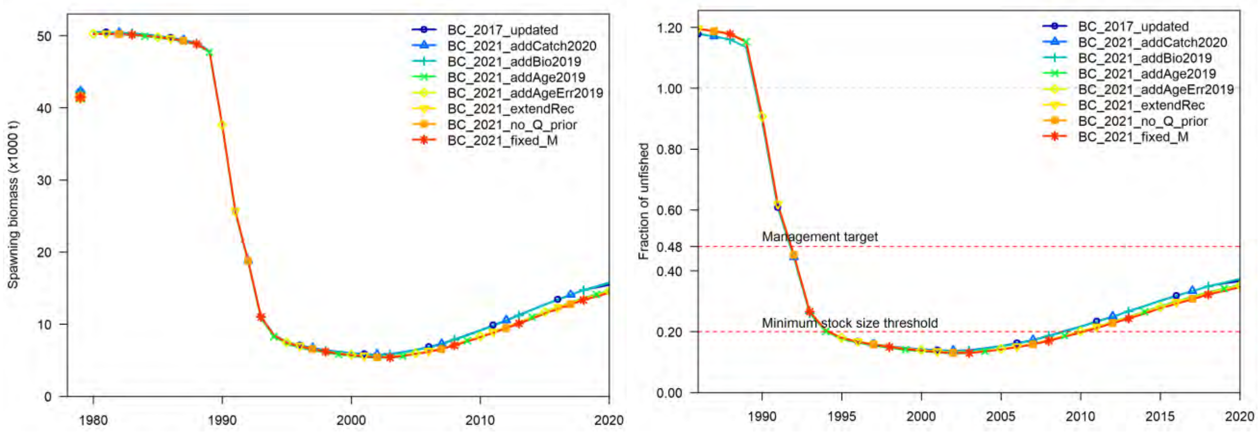


Figure 9.5. Comparison of the time-series of absolute (left) and relative (right) spawning biomass for the updated 2017 assessment model with bridging models that add new data sources leading to the 2021 preliminary base-case model with a fixed natural mortality of *M*=0.04 yr^{-1}.

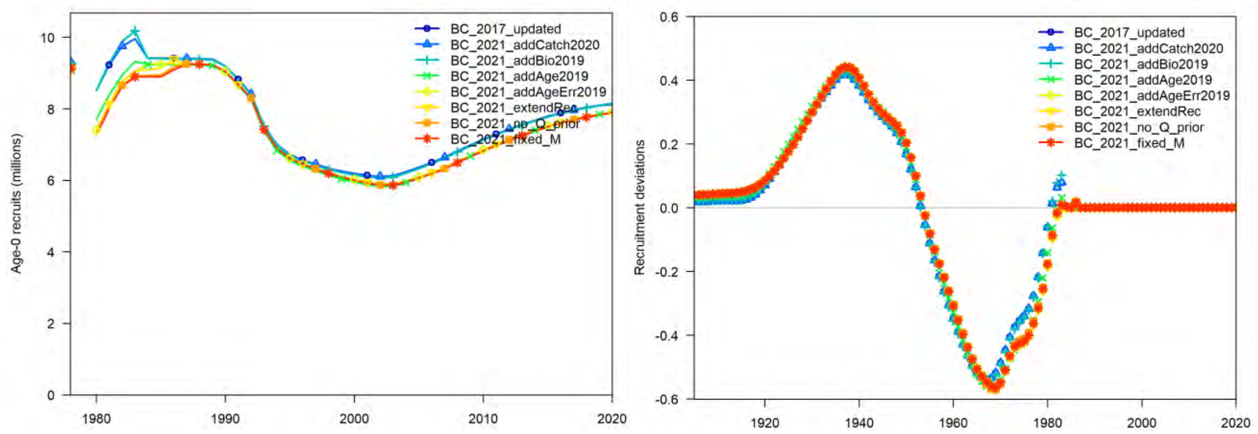


Figure 9.6. Comparison of the time-series of absolute recruitment (left) and recruitment deviations (right) for the updated 2017 assessment model with bridging models that add new data sources leading to the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1}.

Table 9.6. Summary of estimated catchability parameters and derived quantities for the 2017 assessment and with bridging models that add new data sources leading to the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1} (Fixed M 2021). Normal priors are defined by N (mean, standard deviation). The priors on the acoustic survey catchability are Normal on log(q). Survey q's are presented as exp(ln(q)), no bias correction is applied.

Model	SSB (unfished)	SSB 2017	SSB 2021	SSB Status 2017	SSB Status 2021	Towed survey q	Hull survey q
Haddon 2017	41,636	13,476	-	0.324	-	0.956	1.635
Updated 2017	42,211	14,111	-	0.334	-	0.886	1.582
addCatch 2020	42,211	14,102	16,102	0.334	0.381	0.886	1.582
addBio 2019	42,149	14,053	16,059	0.333	0.381	0.924	1.594
addAge 2019	41,370	13,011	14,963	0.314	0.362	0.956	1.572
addAgeErr 2019	41,459	12,951	14,894	0.312	0.359	0.925	1.528
extendRec	41,464	12,938	14,879	0.312	0.359	0.925	1.529
No q prior 2021	41,507	12,769	14,700	0.308	0.354	0.936	1.531
Fixed M 2021 (BC_2021_fixed_M)	**41,480**	**12,737**	**14,663**	**0.307**	**0.354**	**0.938**	**1.442**

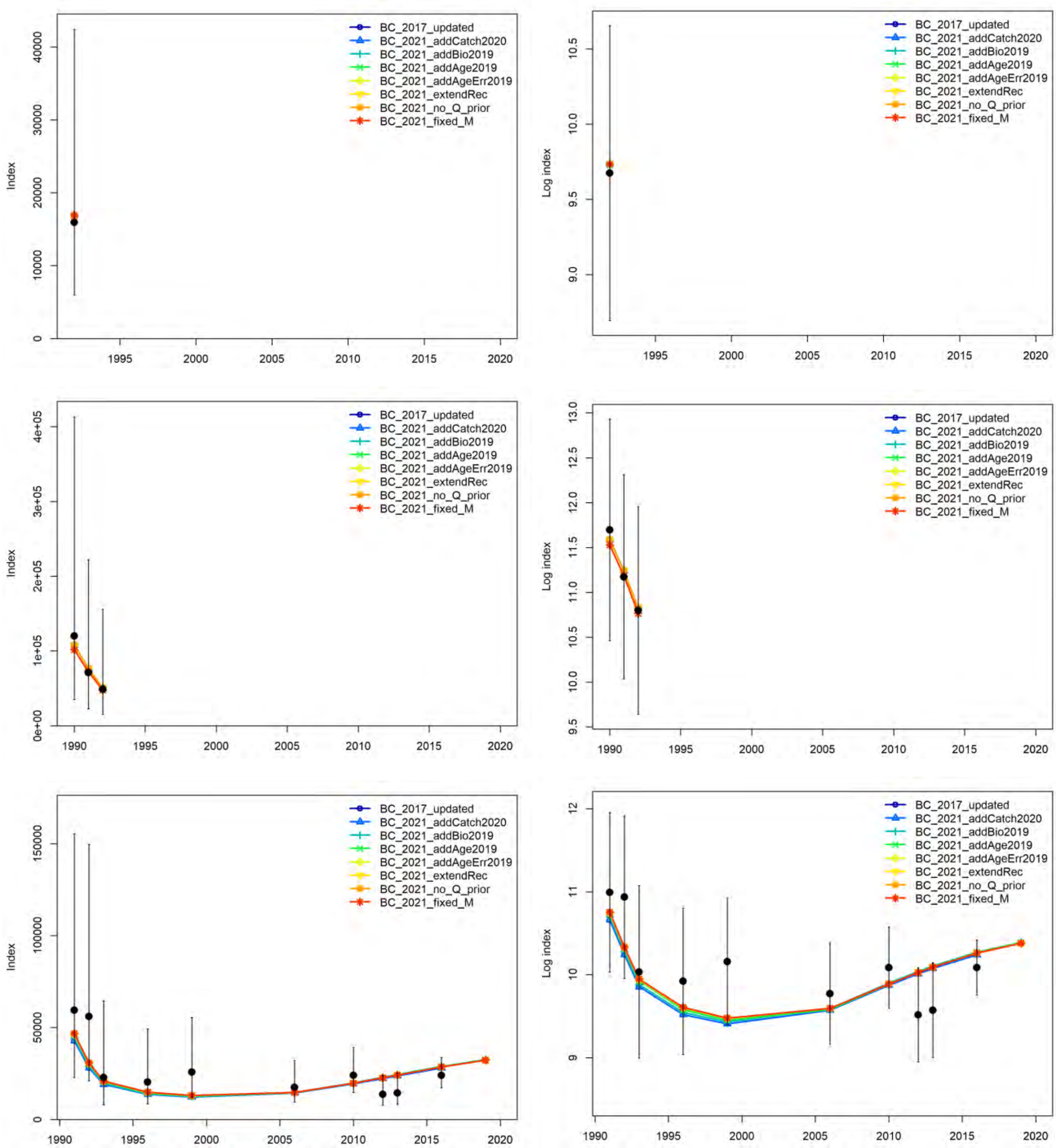


Figure 9.7. Comparison of the fits to the biomass indices (left) and log indices (right) for the egg (top), hull (middle) and towed (bottom) surveys for the updated 2017 assessment model with selected bridging models that sequentially add new data sources leading to the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1}. Towed acoustic survey biomass estimate for 2019 is not plotted (see Figure 9.11 for estimate).

9.4.2.1 Sensitivities

We undertook a sensitivity to estimate an additional recruitment deviation (for 1987) In addition to the two bridging steps were undertaken above. The recruitment deviation estimated for 1987 was above the mean (Figure 9.8). Recruitment strengths that estimated from very few observations are often revised downwards in subsequent assessments once more observations become available. It is standard practice to remove the most recent estimated recruitment if it is substantially above the mean and we have retained the model with recruitment estimated to 1986 as the preliminary base-case (Figure 9.8).

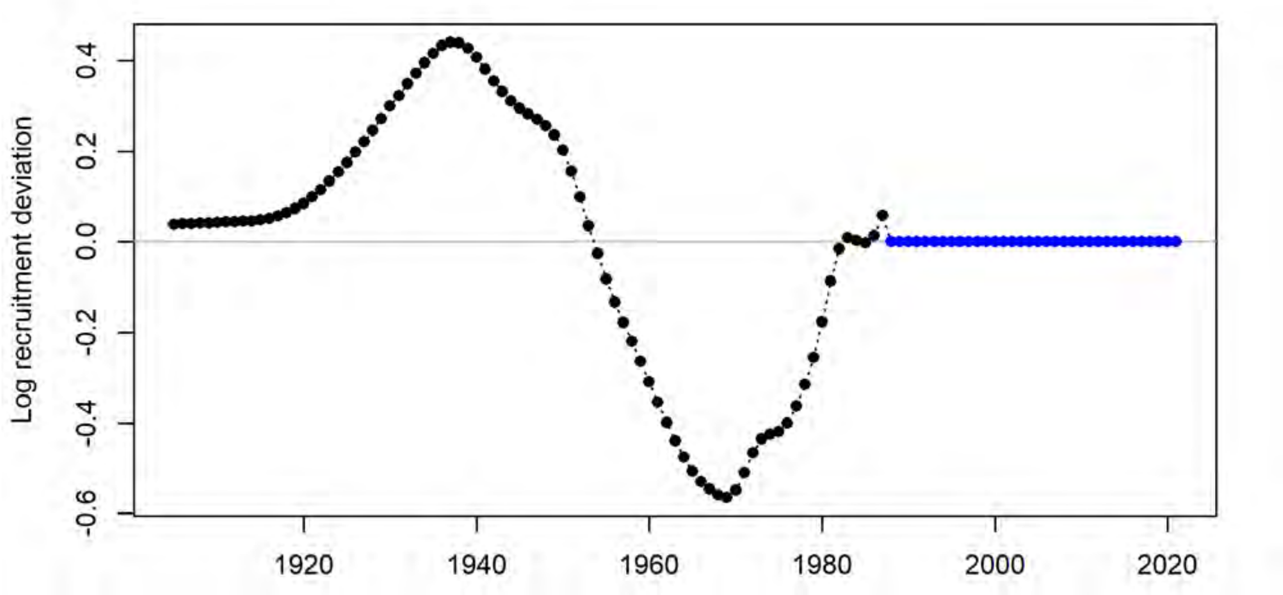


Figure 9.8. Recruitment deviations (log scale) from a sensitivity to 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1} that estimates an additional recruitment deviation for 1987.

9.4.3 *Preliminary base-case model with fixed M*

The preliminary base-case model converged with final gradient <$1e^{-4}$ and a positive definite Hessian. A jitter analysis was undertaken varying the starting parameter values by up to 10%. This determined that there was less than $1e^{-4}$ variability among the likelihood components and parameter estimates from the assessments undertaken with different starting values. Estimated spawning biomass in 2021 is 35% of unfished levels (Figure 9.9). Forward projecting the model 200 years into the future using the SESSF 20:35:48 harvest control rule showed that the stock reaches the target reference point (TRP) of 48% of unfished spawning biomass around 2130. Unfished spawning biomass is estimated to be above 40% by 2050 and above 45% by 2078 (Figure A 9.4).

Fits to the age composition data were poor for both sexes for the 1992 composition and for males in most years (Figure 9.10). Fits to the index data are good (Figure 9.11). There is a strong trend in recruitment over time, with recruitment estimated to be above average prior to 1950 and below average afterwards (Figure 9.12, Figure 9.13). The trend in recruitment is similar to that from the 2017 assessment. The estimated selectivity pattern is slightly different to the maturity ogive (Figure 9.14) The slope of the age-specific selectivity function was near its bound in both the 2021 and 2017 models (Table 9.7), and this was also the case for the 2017 base-case (Haddon 2017).

Estimated parameters were similar to those from the updated 2017 assessment (Table 9.7). Mean recruitment was slightly lower in the 2021 model, while catchability of the towed acoustic survey slightly higher and catchability of the hull survey slightly lower.

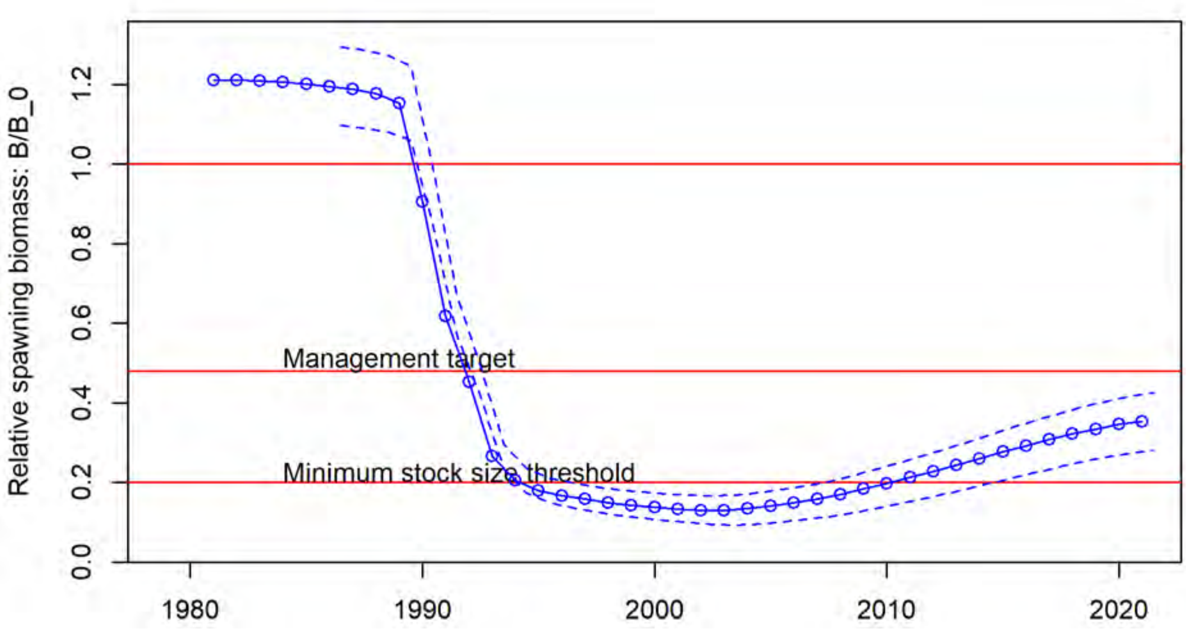


Figure 9.9. The estimated time-series of relative spawning biomass with asymptotic 95% confidence intervals for the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1}.

Table 9.7. The estimated parameters for the 2021 preliminary base-case assessment and the 2017 base-case assessment with updated software and model assumptions (BC_2017_updated). Normal priors are defined by N (mean, standard deviation). The priors on the acoustic survey catchability are Normal on log(q). Survey q's are presented as exp(ln(q)), no bias correction is applied.

Estimated parameters	Pars	2021 estimate	2017 estimate	Prior	Prior Type / Source
Unexploited recruitment; ln(R_0)	1	9.1194	9.1369		Uninformative
Recruitment deviations 1905-86[1]	82				Uninformative
Selectivity logistic inflection	1	34.961	35.214		Uninformative
Selectivity logistic width	1	1.003	1.002		Uninformative
q Acoustic towed catchability	1	0.9380	0.8857	N(Ln(0.95), 0.3)	Upston et. al. (2015)
q Hull catchability	1	1.4420	1.5824	N(Ln(0.95), 0.92)	Upston et. al. (2015)

[1] The 2017 assessment estimated recruitment deviations from 1905 – 1983 (a total of 79 parameters)

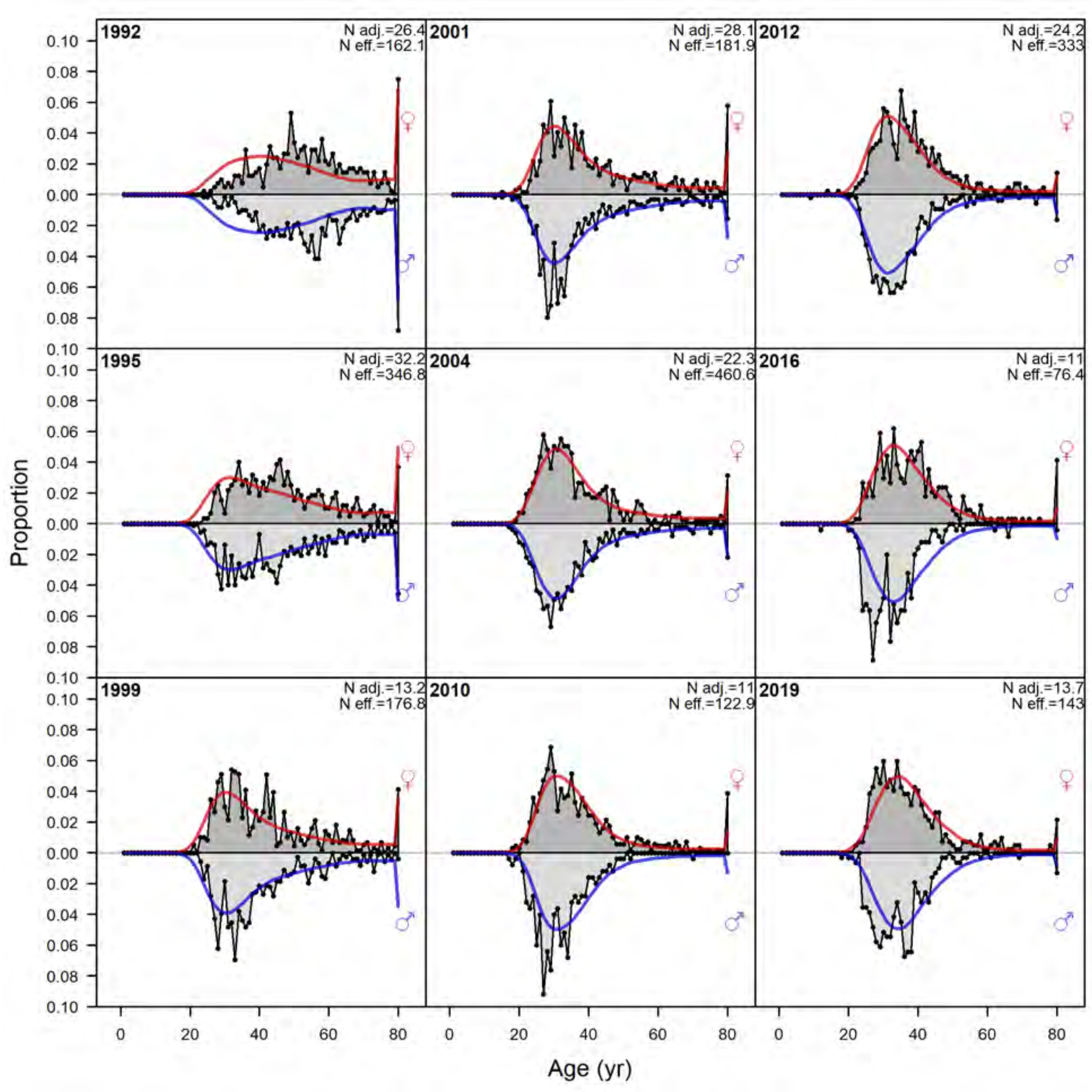


Figure 9.10. Fits to the age composition data for the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1}.

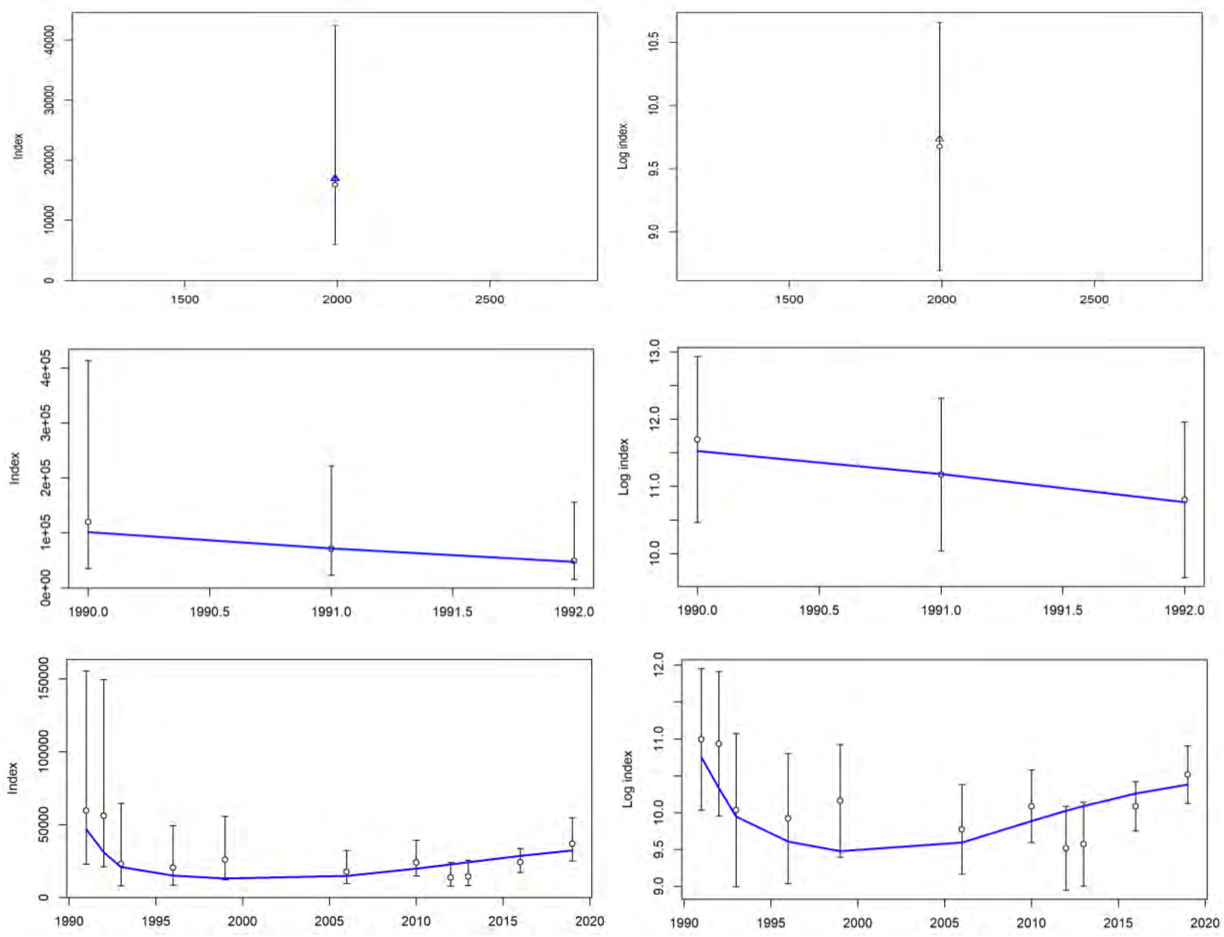


Figure 9.11. Fits to the biomass indices (left) and log indices (right) for the egg (top), hull (middle) and towed (bottom) surveys for the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1}.

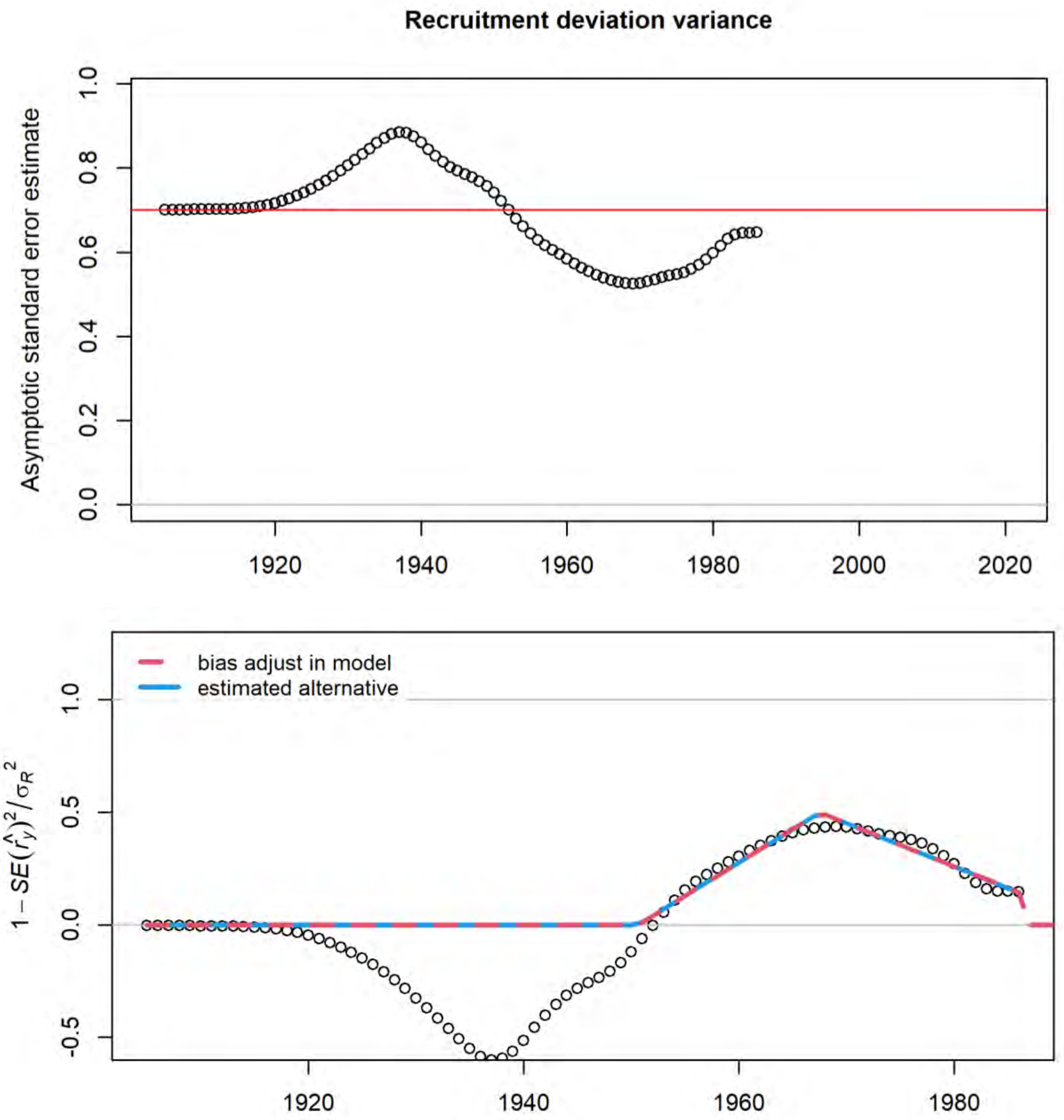


Figure 9.12. Recruitment deviation variance check and bias ramp adjustment for the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1}.

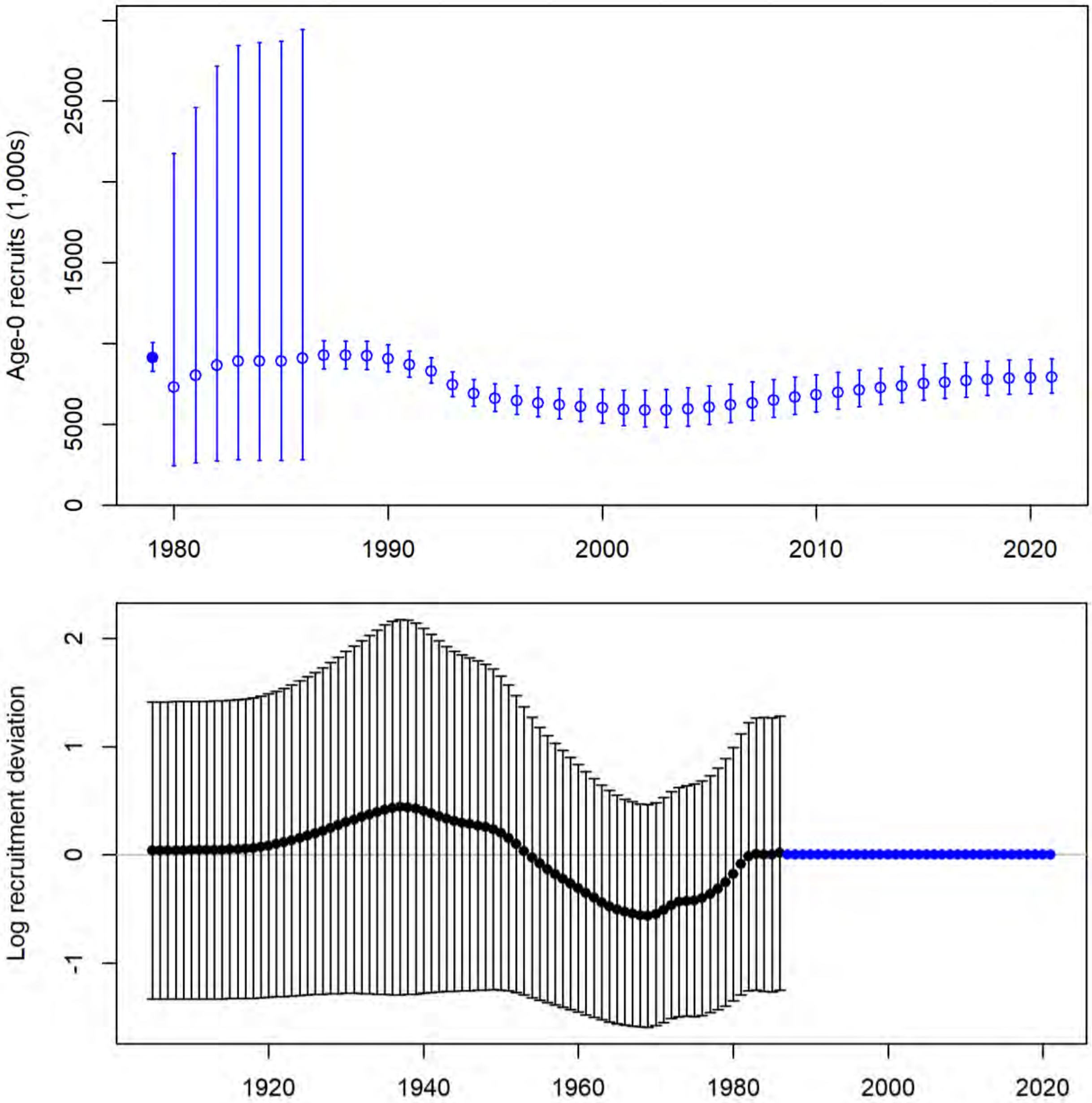


Figure 9.13. Time series of absolute recruitment estimates with confidence intervals (top) and recruitment deviations with confidence intervals (bottom) for the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1}. The projections beyond 2021 ignores variation in recruitment about the stock-recruitment relationship.

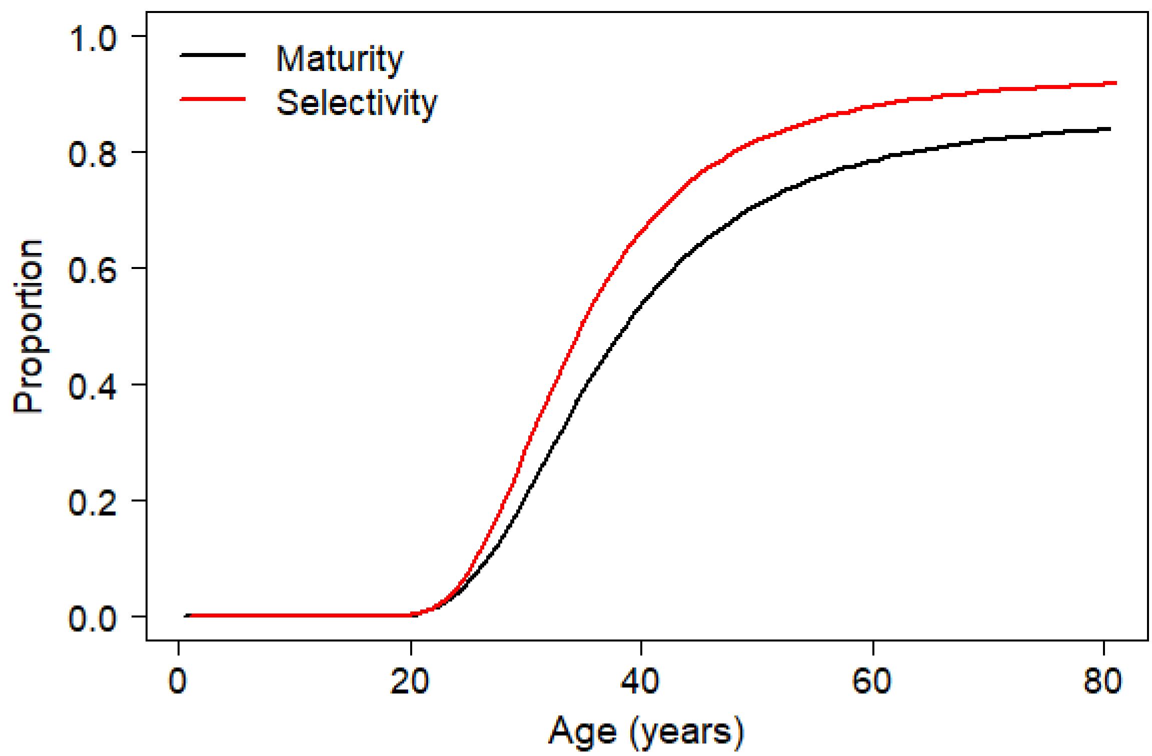


Figure 9.14. Estimated selectivity and fixed maturity ogives for the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1}.

9.4.4 *Retrospective analysis*

A retrospective analysis was undertaken to identify how the assessment outcomes may have changed as new data have been added to the assessment. We undertook assessments after removing four, seven and ten years of data from the preliminary base case model. While the trends in the four assessments were the same, the above average recruitment estimated prior to the commencement of the fishery declined by around a third and recent recruitment declined slightly as data were progressively added to the assessment (Figure 9.15). The decline in recruitment is observed as slightly lower absolute and relative spawning biomass estimates in each successive assessment.

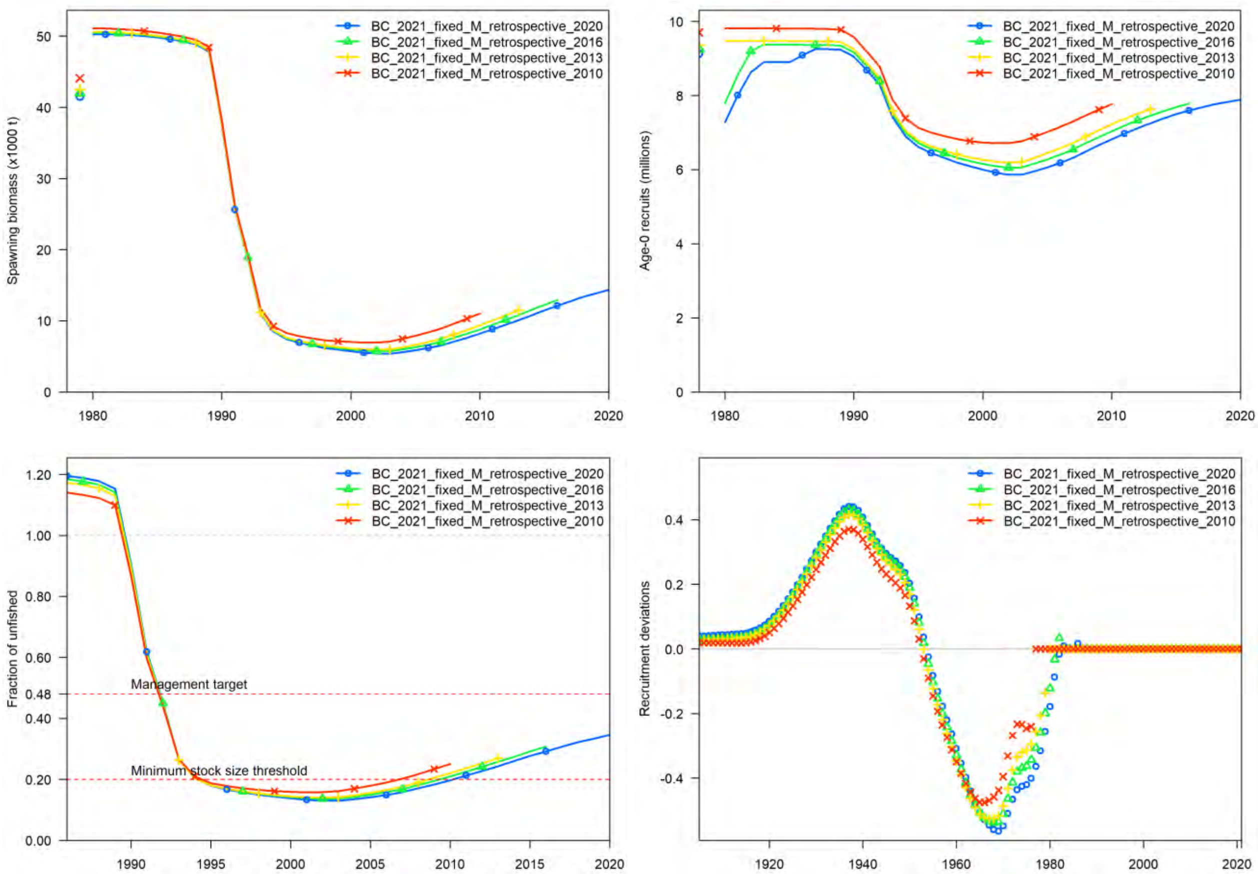


Figure 9.15. Retrospective analysis showing the absolute (top left) and relative (bottom left) spawning biomass, absolute recruitment (top right) and recruitment deviations (bottom right) from assessments that were undertaken after removing four, seven and ten years of data from the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1}.

9.4.5 ***Likelihood profiles***

The likelihood profile for natural mortality shows that the negative log-likelihood for M is minimised at 0.032 yr^{-1} (Figure 9.16, Table 9.8) with 95% confidence intervals for M of ~0.0255 yr^{-1} – ~0.042 yr^{-1}. This is the same as the maximum likelihood estimate of M=0.032 yr^{-1} that was obtained from the likelihood profile for M undertaken in the 2017 assessment (Haddon 2017). The age data prefer a higher value of natural mortality (M=0.038 yr^{-1}), while the biomass indices from the surveys prefer a lower value of natural mortality (M=0.023 yr^{-1}). This is the same pattern that was observed in the 2017 assessment.

The likelihood profile for the steepness of the stock recruitment relationship, *h,* provides essentially no information about this parameter in the assessment (Figure 9.17).

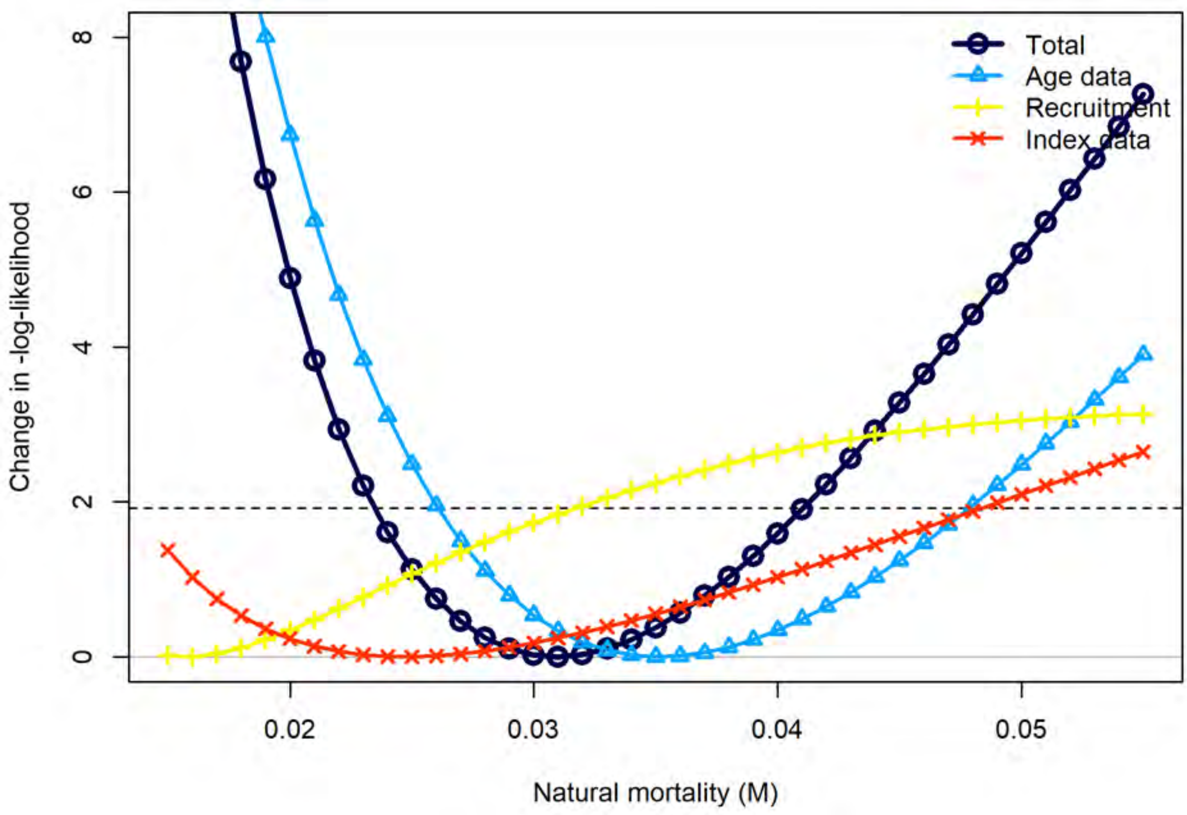


Figure 9.16. Likelihood profile for natural mortality. The fixed value of natural mortality in the 2021 preliminary base-case model is M=0.04 yr^{-1}.

Table 9.8. Changes in log-likelihood for the likelihood function (Total) and the contributions from the age composition data (Age), estimated recruitment (Recruit) and biomass indices (Index) for a likelihood profile on natural mortality. Minimum values for each component (Total, Age, Recruitment and Index) are shown in bold. The fixed value of natural mortality in the 2021 preliminary base-case model is M=0.04 yr^{-1}.

M	Total	Age	Recruitment	Index
0.015	19.0037	17.1762	0.2613	0.7072
0.016	15.8418	14.8027	0.1113	0.4958
0.017	13.1531	12.7411	0.0290	0.3338
0.018	10.8623	10.9442	**0.0000**	0.2121
0.019	8.9088	9.3742	0.0131	0.1234
0.020	7.2431	7.9997	0.0595	0.0621
0.021	5.8250	6.7949	0.1321	0.0234
0.022	4.6212	5.7384	0.2248	0.0037
0.023	3.6040	4.8118	0.3314	**0.0000**
0.024	2.7509	3.9999	0.4443	0.0104
0.025	2.0433	3.2923	0.5636	0.0326
0.026	1.4647	2.6791	0.6918	0.0642
0.027	1.0003	2.1506	0.8285	0.1037
0.028	0.6374	1.6978	0.9723	0.1497
0.029	0.3649	1.3128	1.1220	0.2012
0.030	0.1733	0.9889	1.2765	0.2574
0.031	0.0541	0.7200	1.4350	0.3175
0.032	**0.0000**	0.5008	1.5964	0.3809
0.033	0.0045	0.3266	1.7602	0.4470
0.034	0.0620	0.1933	1.9257	0.5154
0.035	0.1673	0.0971	2.0924	0.5856
0.036	0.3160	0.0347	2.2598	0.6573
0.037	0.5040	0.0033	2.4276	0.7301
0.038	0.7279	**0.0000**	2.5954	0.8039
0.039	0.9845	0.0226	2.7630	0.8783
0.040	1.2708	0.0688	2.9300	0.9532
0.041	1.5843	0.1367	3.0965	1.0284
0.042	1.9227	0.2245	3.2621	1.1036
0.043	2.2840	0.3305	3.4268	1.1788
0.044	2.6661	0.4533	3.5905	1.2539
0.045	3.0676	0.5916	3.7532	1.3287

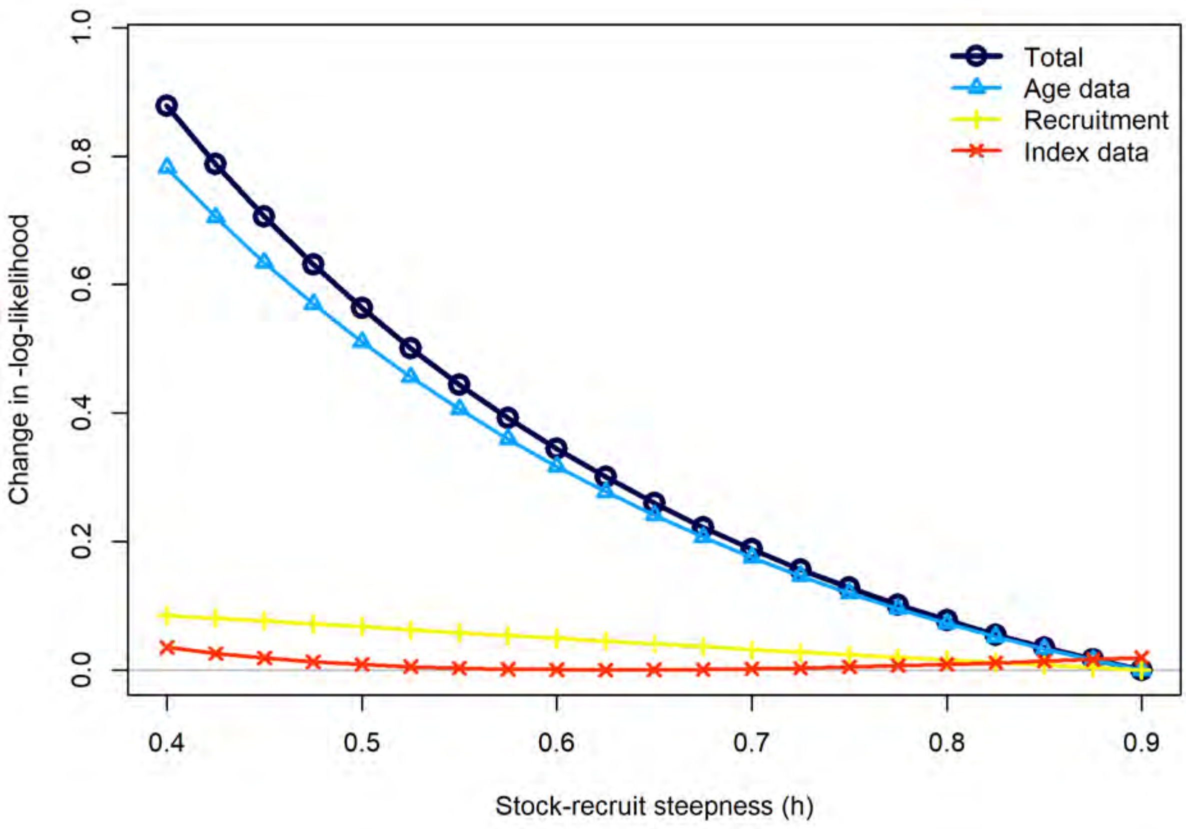


Figure 9.17. Likelihood profile for steepness of the stock recruitment relationship. The fixed value of steepness used in the 2021 preliminary base-case assessments is h=0.75.

9.4.6 *Decision table with alternate states of nature and management*

A likelihood profile for natural mortality from the preliminary base-case model with 80 age-classes shows the preferred value of natural mortality is M=0.032 yr^{-1} (Figure 9.16, Table 9.8) with 95% confidence intervals for M of ~0.0255 yr^{-1} – ~0.0420 yr^{-1}. Increasing the number of age-classes in the model to 100 and 120 lead to an increase in the preferred value of natural mortality obtained from likelihood profiles to ~M=0.038 yr^{-1} for both models (Figure A 9.8), which is consistent with the models that estimate M with plus-groups at 100 years and 120 years respectively (Table 9.10).

The difference in the estimated natural mortality when the plus-group in the model is increased highlights the sensitivity of the assessment to the number of age-classes in the model and the need to consider this when selecting a base-case assessment.

9.4.7 *Prior for natural mortality*

The four functional forms fitted to the combined posterior for New Zealand Orange Roughy natural mortality provided very similar curves (Figure 9.18, Table 9.9). The Gamma, Beta and log-normal models all slightly under-estimated natural mortality between M=0.029 yr^{-1} and M=0.033 yr^{-1} and slightly over-estimated natural mortality between M=0.034 yr^{-1} and M=0.038 yr^{-1} but otherwise fitted the posterior well. The fit of the Normal model was slightly poorer, being shifted slightly to the right. We selected the log-normal model to use as the prior for M because of the slightly better fit to the left-hand side of the posterior distribution for New Zealand Orange Roughy natural mortality.

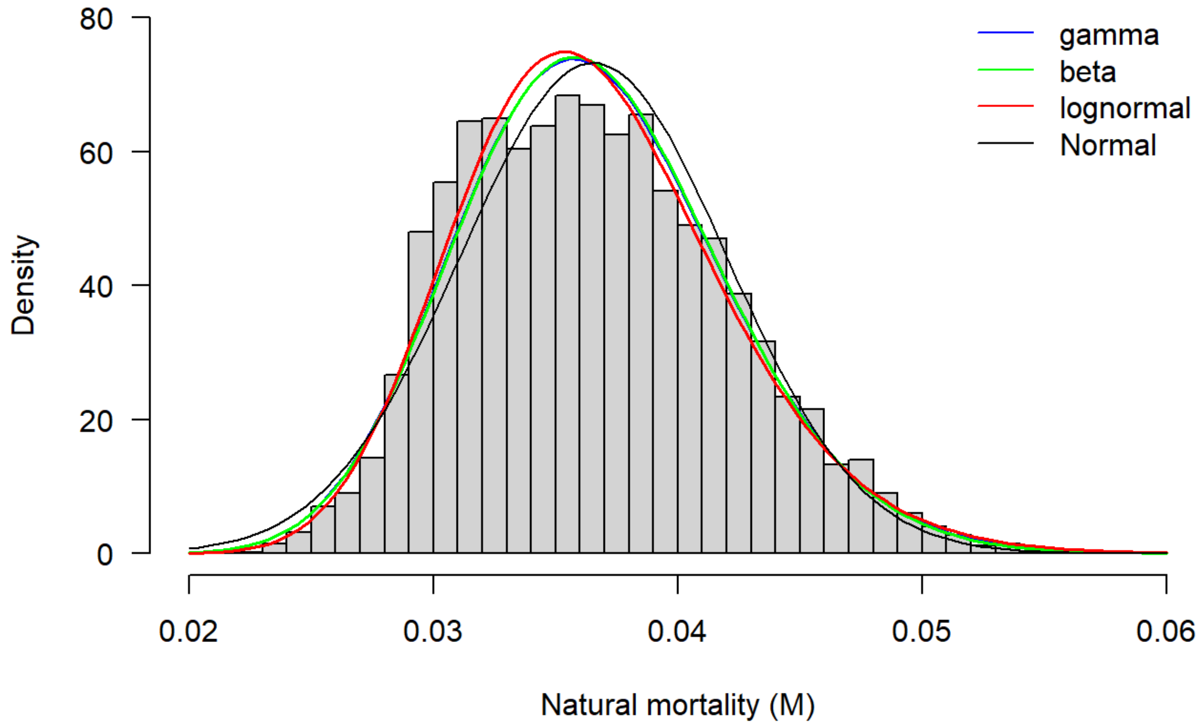


Figure 9.18. Combined posterior for New Zealand Orange Roughy stock assessments with fitted Gamma, Beta, log-normal and Normal distributions. Distribution supplied by Patrick Cordue (ISL).

Table 9.9. Estimated median, mean and standard deviation for the combined posterior of New Zealand Orange Roughy natural mortality in 2014 and 2021 (Cordue 2014, Cordue 2021) and Gamma, Beta and log-normal distributions fitted to the 2021 combined posterior.

Distribution	Median	Mean	Standard Deviation
Cordue 2014	0.03650	0.03734	0.00531
Cordue 2021	0.03617	0.03654	0.00545
Gamma	0.03627	0.03654	0.00545
Beta	0.03628	0.03654	0.00542
Log-normal	0.03614	0.03654	0.00547

9.4.8 *2021 preliminary base-case models that estimate M*

We estimated natural mortality within the assessment using a log-normal prior obtained from the combined posterior for New Zealand Orange Roughy stock assessments (Figure 9.18, Table 9.9). Age compositions were developed using the revised age data to investigate the impact of increasing the number of age-classes to 100 and 120.

Starting from the updated 2021 base-case model with fixed natural mortality, three candidate preliminary base-cases for the 2021 assessment were investigated:

0. **BC_2021_fixed_M:** Model #7 from Bridge step 2 that has a fixed natural mortality of M=0.04 yr^{-1}.

1. **BC_2021_est_M_80_original_ages:** Estimate natural mortality using the log-normal prior (Figure 9.18) with 80 age-classes using the original age data.
2. **BC_2021_est_M_80_ages:** Estimate natural mortality using the log-normal prior (Figure 9.18) with 80 age-classes using the revised age data.
3. **BC_2021_est_M_100_ages:** Estimate natural mortality using the log-normal prior (Figure 9.18) with 100 age-classes using the revised age data.
4. **BC_2021_est_M_120_ages:** Estimate natural mortality using the log-normal prior (Figure 9.18) with 120 age-classes using the revised age data.

Estimating *M* within the assessment using the original age data and 80 age-classes (model #1) resulted in a natural mortality estimate of M=0.0342 yr^{-1} (Table 9.10). Using the revised age data led to a slightly higher estimate of M=0.0344 yr^{-1}, while increasing the number of age-classes to 100 and 120 resulted in higher natural mortality estimates of M=0.0373 yr^{-1} and M=0.0386 yr^{-1} respectively. These estimates of *M* are consistent with the preferred value of *M* obtained from likelihood profiles of ~M=0.038 yr^{-1} for both models (Figure A 9.8). Uncertainty in the estimated natural mortality is represented by 250 samples of the posterior for *M* for the three models using the revised age data (Figure 9.39 9.22, Table 9.13).

All four models that estimated *M* gave very similar estimates of unfished female spawning biomass at ~41,000 t and the 2021 female spawning biomass between 12,000 t and 13,000 t (Figure 9.19, Table 9.10). Increasing the number of age-classes in the model resulted in relative spawning biomass increasing from ~0.29 of virgin for models with a plus-group at 80 years to 0.31 and 0.32 for models with 100 and 120 age-classes respectively. The estimates of absolute recruitment differed among the models, with the models with higher plus-groups estimating higher values of natural mortality also estimating higher absolute recruitment, while trends in recruitment and recruitment deviations were similar among models (Figure 9.20).

Estimating *M* resulted in an increase in the estimated catchability of the towed acoustic survey from q=0.938 for the model with fixed natural mortality of M=0.04 yr^{-1} to around q=1.1 for the four models estimating *M* (Table 9.10). This is observed in slight differences in the fits to the towed acoustic index (Figure 9.20).

Fits to the age data for the model with a plus-group at 80 years that estimated *M* were almost identical to those for the model with a fixed natural mortality of M=0.04 yr^{-1} (Figure 9.10 and Figure A 9.10). Both models under-estimated the proportion of younger age-classes in 1992 and 1995 and over-estimated the proportion of individuals in the plus group in 1999, while under-estimating the proportion of individuals in the plus group in most years after 2000. Increasing the number of age-classes to 100 provides better fits to the plus group after 2000, but still over-estimates the proportion of younger age-classes in 1992 and 1995 and over-estimates the proportion of individuals in the plus group before 2000 (Figure A 9.19). The fits to the age data for the model with a plus-group at 120 years is very similar to those for the model with a plus-group at 100 years (Figure A 9.28). All models show that the average age of males in the population is over-estimated compared with the data (Figure A 9.10 - Figure A 9.11, Figure A 9.19 - Figure A 9.20, Figure A 9.28 - Figure A 9.29).

Additional model diagnostic plots for the models that use the revised age data and estimate *M* with 80, 100 and 120 age-classes are provided in the appendix (Figure A 9.9 – Figure A 9.32).

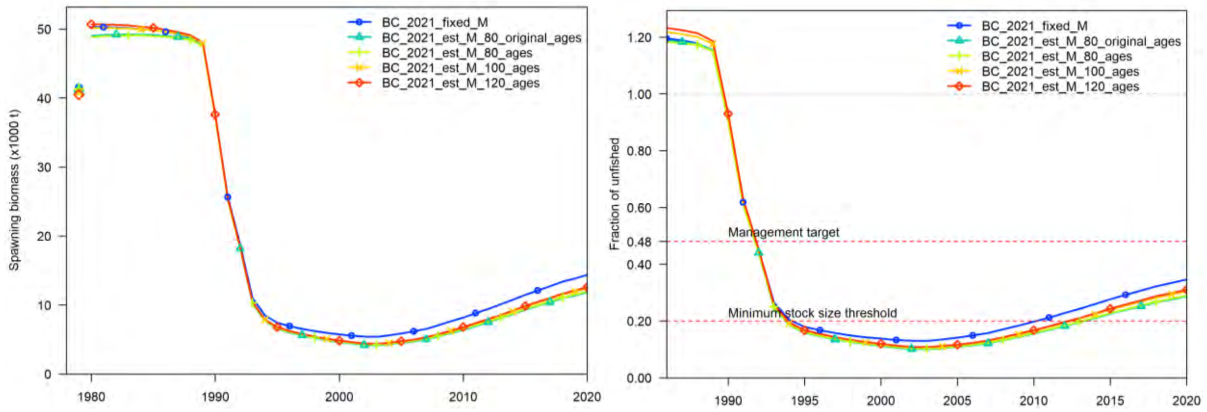


Figure 9.19. Comparison of the time-series of absolute (left) and relative (right) spawning biomass for the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1} and candidate preliminary base-case models with plus-groups of 80, 100 and 120 years.

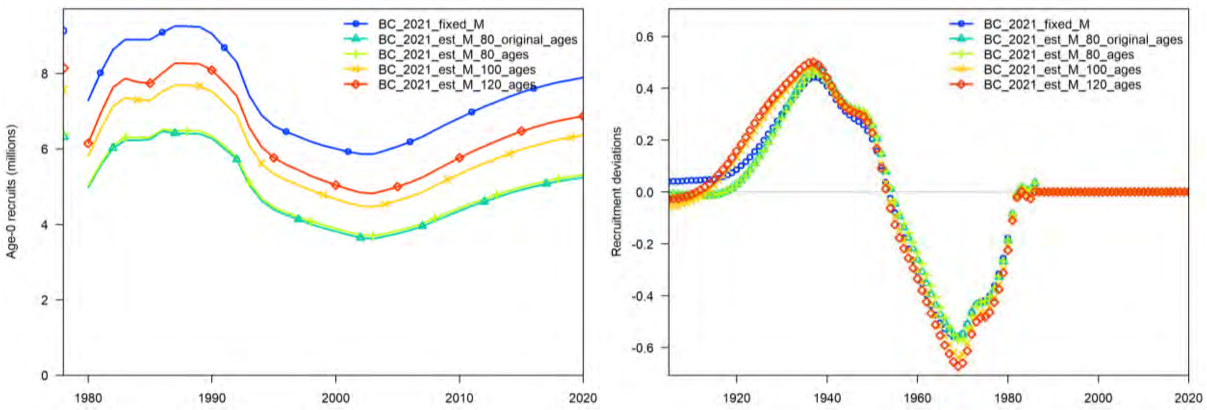


Figure 9.20. Comparison of the time-series of absolute recruitment (left) and recruitment deviations (right) for the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1} and candidate 2021 preliminary base-case models with plus-groups of 80, 100 and 120 years where M is estimated with a log-normal prior.

Table 9.10. Summary of estimated natural mortality, catchability parameters and derived quantities for the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1}* and candidate preliminary base-case models with plus-groups of 80, 100 and 120 years. Normal priors are defined by N (mean, standard deviation). The priors on the acoustic survey catchability are Normal on log(q). Survey q's are presented as exp(ln(q)), no bias correction is applied.

Model	SSB (unfished)	SSB 2021	SSB Status 2021	Towed survey q	Hull survey q	*M*
Fixed *M* 2021	41,480	14,663	0.354	0.9380	1.4420	0.04*
Estimate *M* 80 original ages	41,281	12,101	0.293	1.1260	1.4882	0.0342
Estimate *M* 80 ages	41,320	12,220	0.296	1.1070	1.4816	0.0344
Estimate *M* 100 ages	40,736	12,707	0.312	1.0982	1.4853	0.0373
Estimate *M* 120 ages	40,479	12,869	0.318	1.1028	1.4903	0.0386

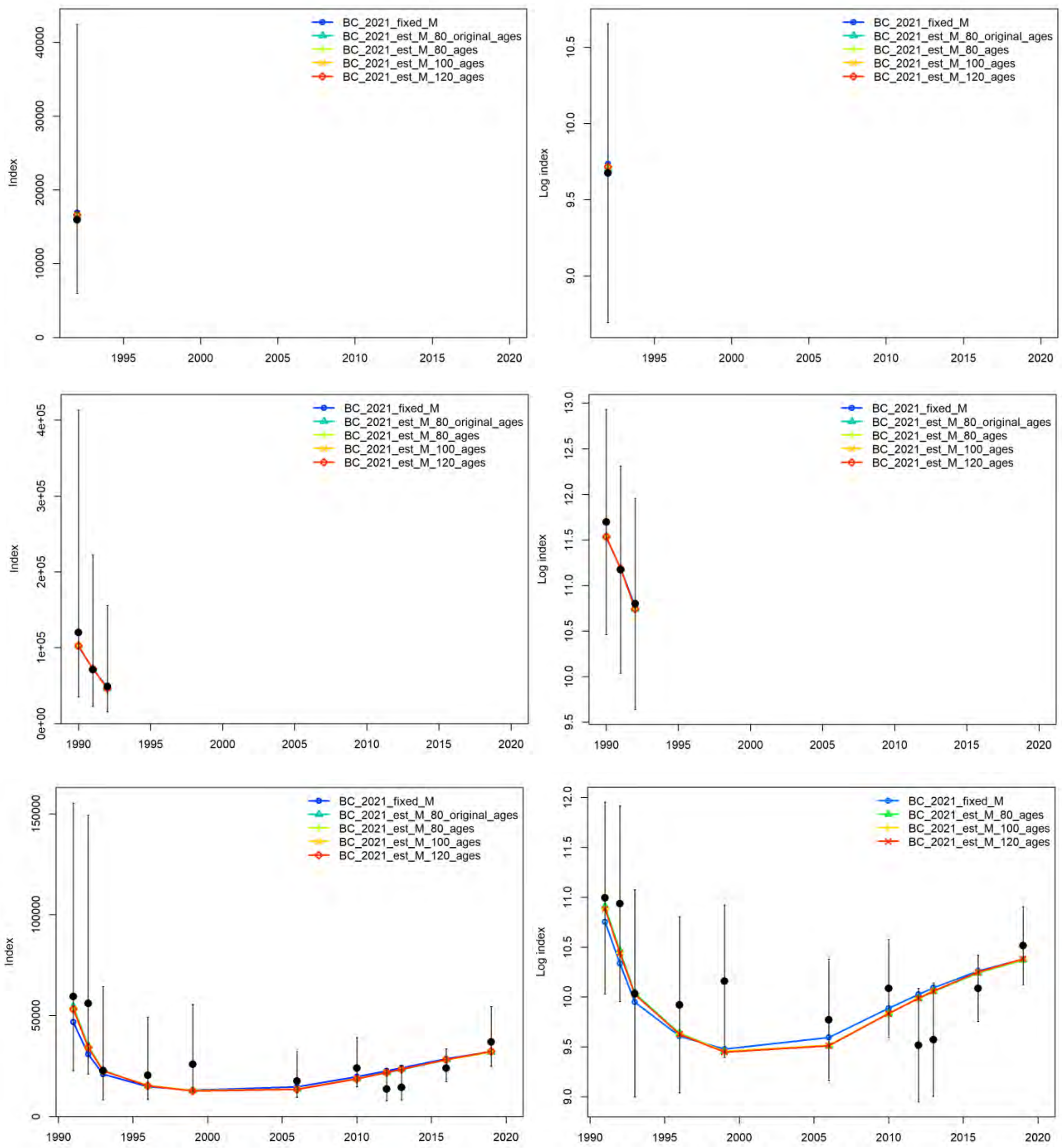


Figure 9.21. Comparison of the fits to the biomass indices (left) and log indices (right) for the egg (top), hull (middle) and towed (bottom) surveys for the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1} and candidate 2021 preliminary base-case models with plus-groups at 80, 100 and 120 years where M is estimated with a log-normal prior.

Table 9.11. The estimated parameters for the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1}* and candidate 2021 preliminary base-case models with plus groups at 80, 100 and 120 years where M is estimated with a log-normal prior. Normal priors are defined by N (mean, standard deviation). The priors on the acoustic survey catchability are Normal on log(q). Survey q's are presented as exp(ln(q)), no bias correction is applied.

Model	ln(R0)	Selectivity inflection	Selectivity width	Towed survey q	Hull survey q	M
Fixed M 2021	9.1194	34.961	1.003	0.9380	1.4420	0.04*
Estimate M 80 original ages	8.7526	34.956	1.003	1.1260	1.4882	0.0342
Estimate M 80 ages	8.7639	34.929	1.003	1.1070	1.4816	0.0344
Estimate M 100 ages	8.9322	35.033	1.002	1.0982	1.4853	0.0373
Estimate M 120 ages	9.0046	35.086	1.002	1.1028	1.4903	0.0386

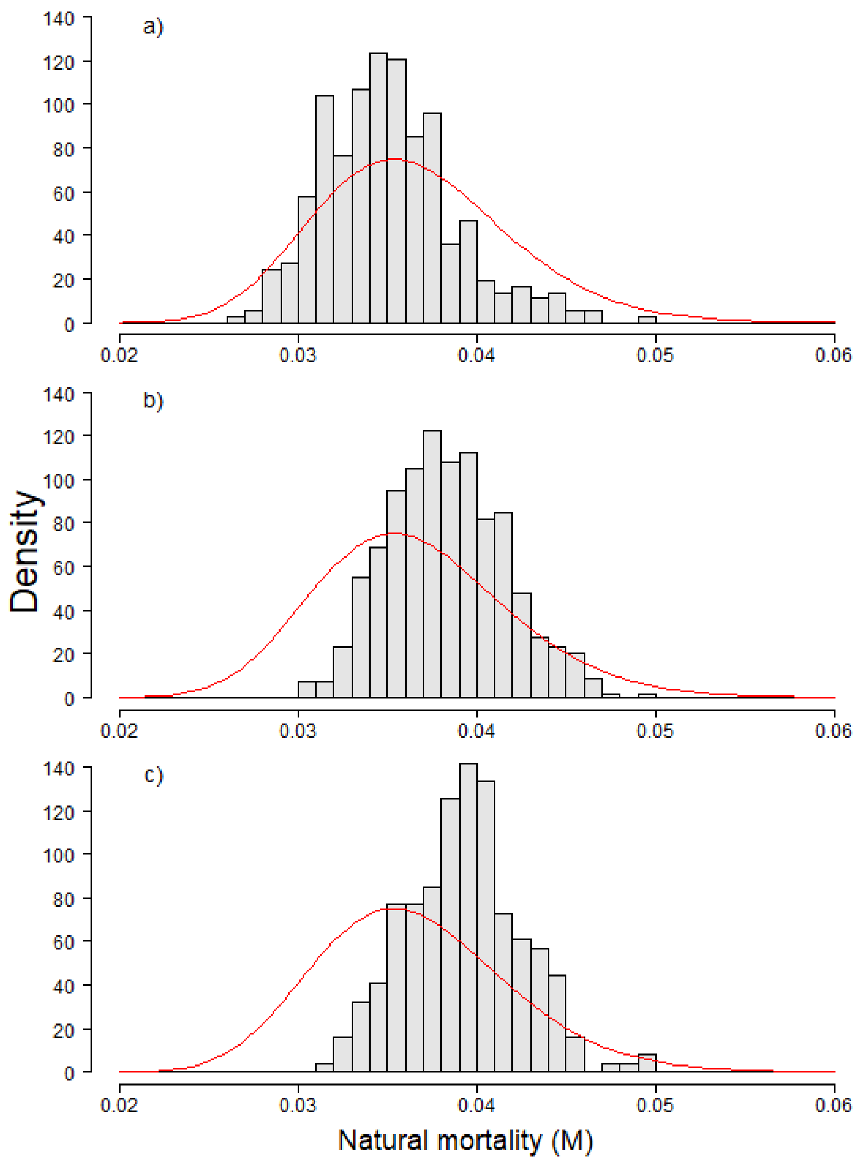


Figure 9.22. Histograms of natural mortality estimates from posteriors of candidate 2021 preliminary base-case models with plus-groups at 80 (a), 100 (b) and 120 (c) years. The red line represents the log-normal prior used to estimate M within the models.

Table 9.12. The estimate of natural mortality (*M*) and median, lower and upper 95% quantiles from the posterior for *M* for candidate 2021 preliminary base-case models with plus groups at 80, 100 and 120 years where *M* is estimated with a log-normal prior.

Model	Estimate	Median	Lower	Upper
Estimate *M* 80 ages	0.0344	0.0349	0.0286	0.0442
Estimate *M* 100 ages	0.0373	0.0382	0.0326	0.0454
Estimate *M* 120 ages	0.0386	0.0393	0.0331	0.0452

9.4.9 *Sensitivities*

The sensitivity of the assessment to the number of age-classes in the model shows an increase in the estimated absolute recruitment when the number of age-classes in the data is increased from 80 to 100, while there is little change in absolute recruitment when increasing the number of age-classes from 100 to 120 (Figure 9.23, Table 9.13). This suggets the model with a plus-group at 80 years is not representing the age composition data appropriately and either the model with a plus-group at 100 years or 120 years should be adopted as the base-case.

Table 9.13. Estimates of unfished and 2021 female spawning biomass, 2021 relative spawning biomass (SSB Status), acoustic survey catchabilities and natural mortality for the 2021 preliminary base-case model with a plus group at 80 years and models with a population plus group at 120 years and data plus groups at 80, 100 and 120 years.

Model	SSB (unfished)	SSB 2021	SSB Status 2021	Towed survey *q*	Hull survey *q*	*M*
80_pop_ages_80_data_ages	41,320	12,220	0.296	1.107	1.482	0.0344
120_pop_ages_80_data_ages	41,090	12,799	0.311	1.074	1.477	0.0366
120_pop_ages_100_data_ages	40,733	12,950	0.318	1.084	1.484	0.0381
120_pop_ages_120_data_ages	40,479	12,869	0.318	1.103	1.490	0.0386

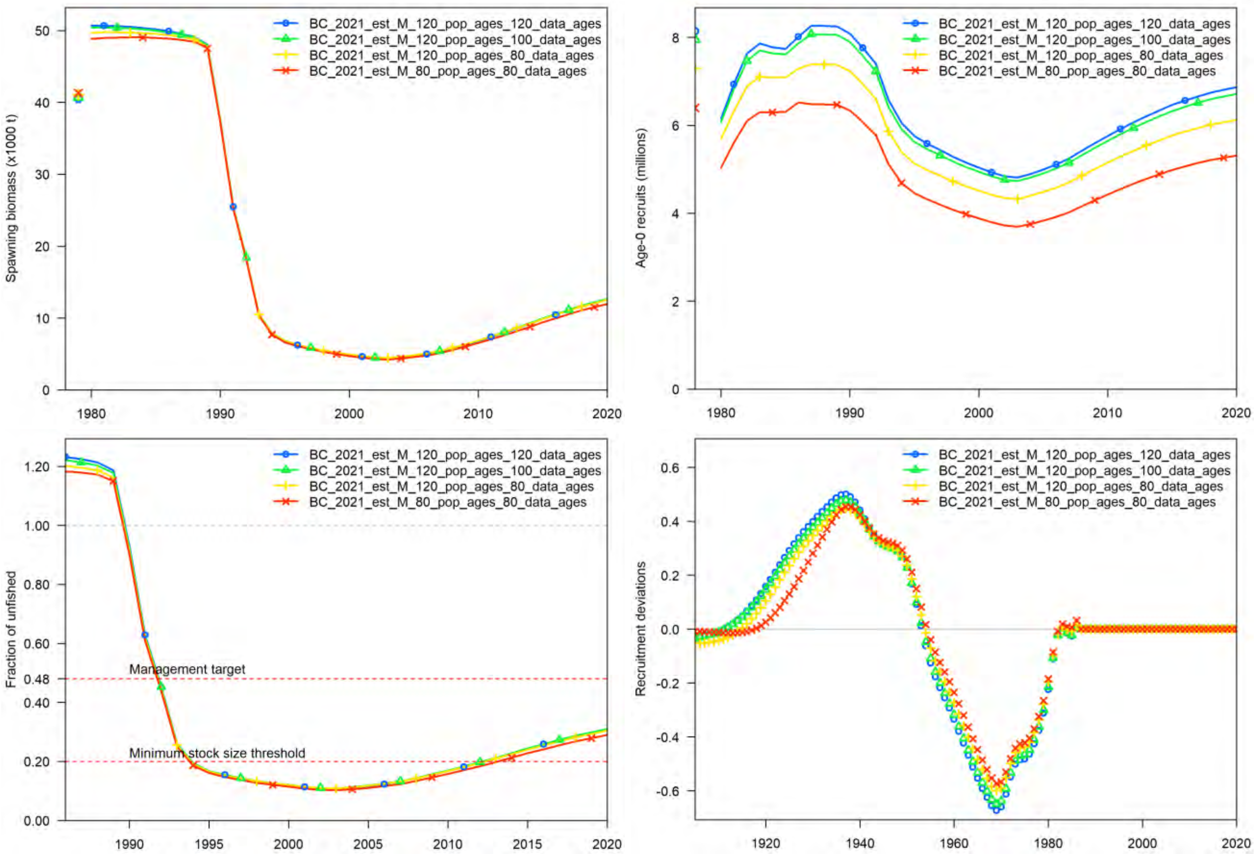


Figure 9.23. Comparison of absolute (top left) and relative (bottom left) spawning biomass, absolute recruitment (top right) and recruitment deviations (bottom right) from the 2021 preliminary base-case model with a plus group at 80 years and models with a population plus group at 120 years and data plus groups at 80, 100 and 120 years.

The three candidate 2021 preliminary base-case models with plus groups of 80, 100 and 120 years where *M* is estimated were insensitive to the removal of the index from the 1992 egg survey (Figure 9.24).

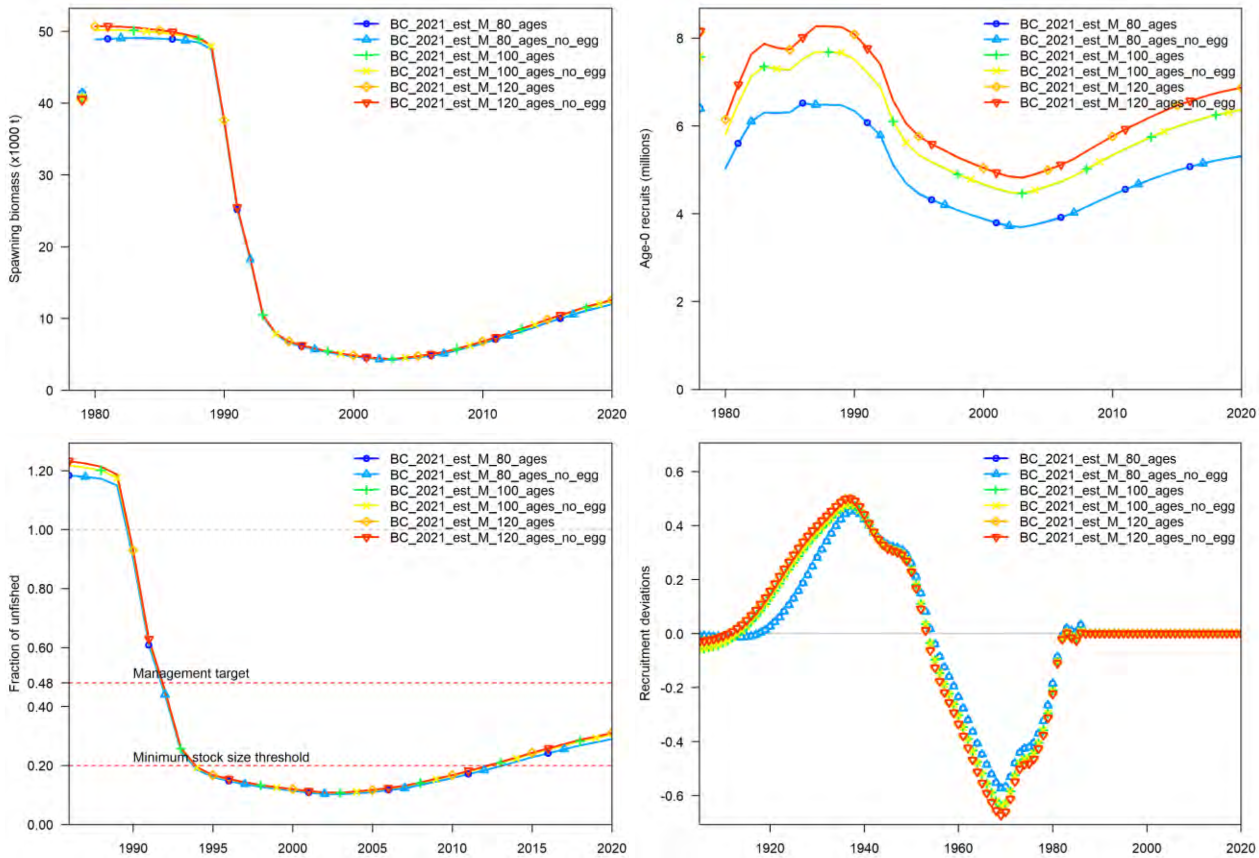


Figure 9.24. Comparison of absolute (top left) and relative (bottom left) spawning biomass, absolute recruitment (top right) and recruitment deviations (bottom right) from the three candidate 2021 preliminary base-case models with plus groups at 80, 100 and 120 years where *M* is estimated and sensitivities to those models with the 1992 egg survey removed.

9.4.10 *Retrospectives*

For the three candidate 2021 preliminary base-case models with plus groups of 80, 100 and 120 years where *M* is estimated retrospective analyses show the estimated productivty of the eastern zone Orange Roughy stock has declined slightly with the collection of additional data over the last decade (Figure 9.24-Figure 9.26). The estimated decline is greatest between 2010 and 2013, with more gradual declines from 2013 onwards.

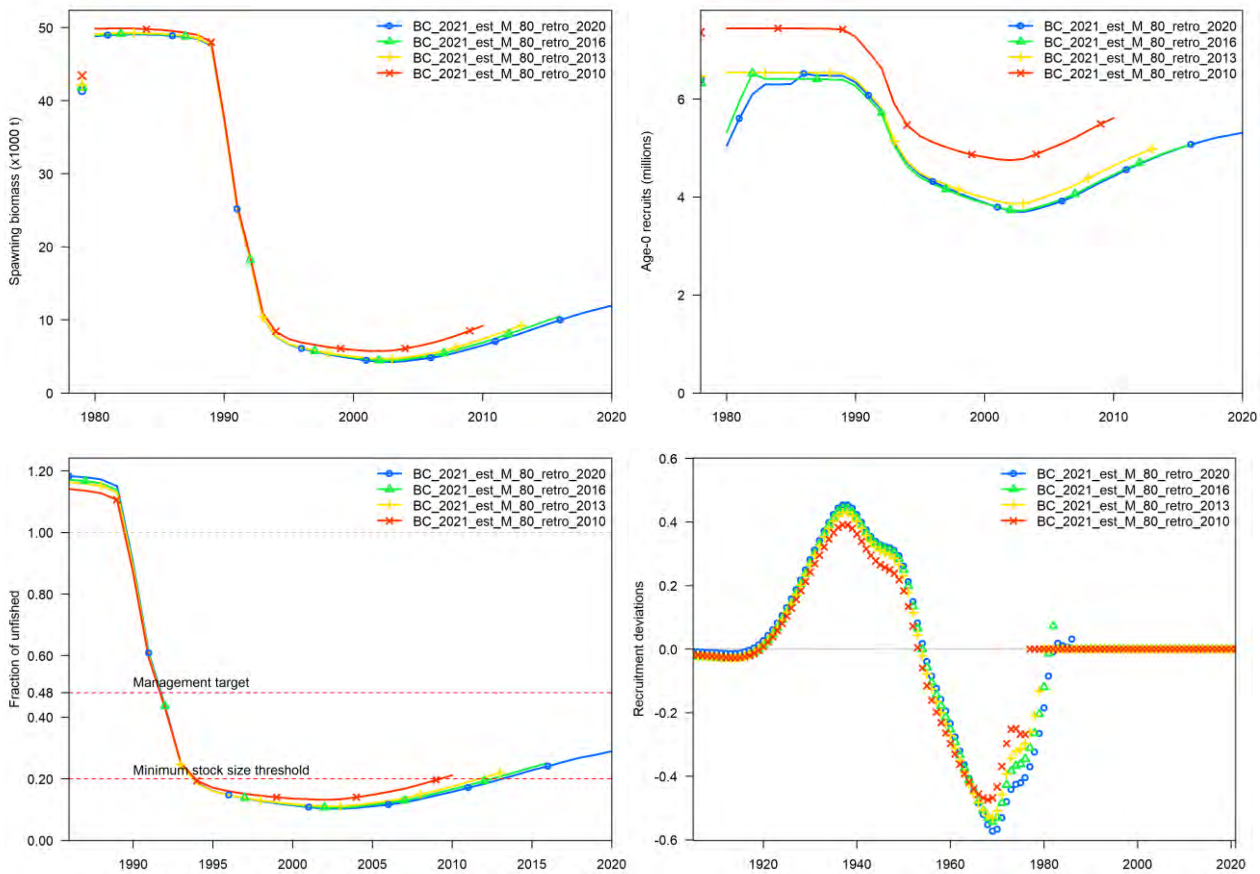


Figure 9.25. Retrospective analysis showing the absolute (top left) and relative (bottom left) spawning biomass, absolute recruitment (top right) and recruitment deviations (bottom right) from assessments that were undertaken after removing four, seven and ten years of data from the candidate 2021 preliminary base-case model with a plus group at 80 years where *M* is estimated.

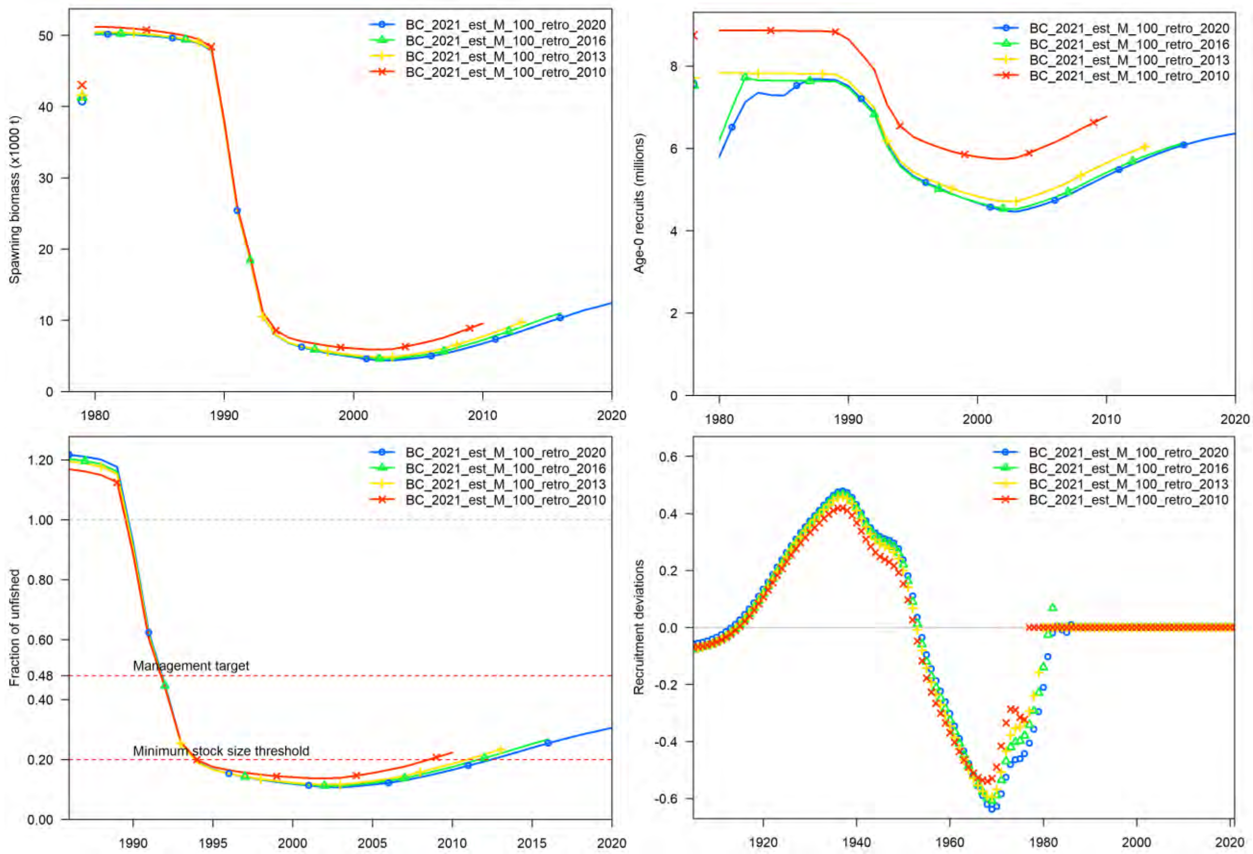


Figure 9.26. Retrospective analysis showing the absolute (top left) and relative (bottom left) spawning biomass, absolute recruitment (top right) and recruitment deviations (bottom right) from assessments that were undertaken after removing four, seven and ten years of data from the candidate 2021 preliminary base-case model with a plus group at 100 years where *M* is estimated.

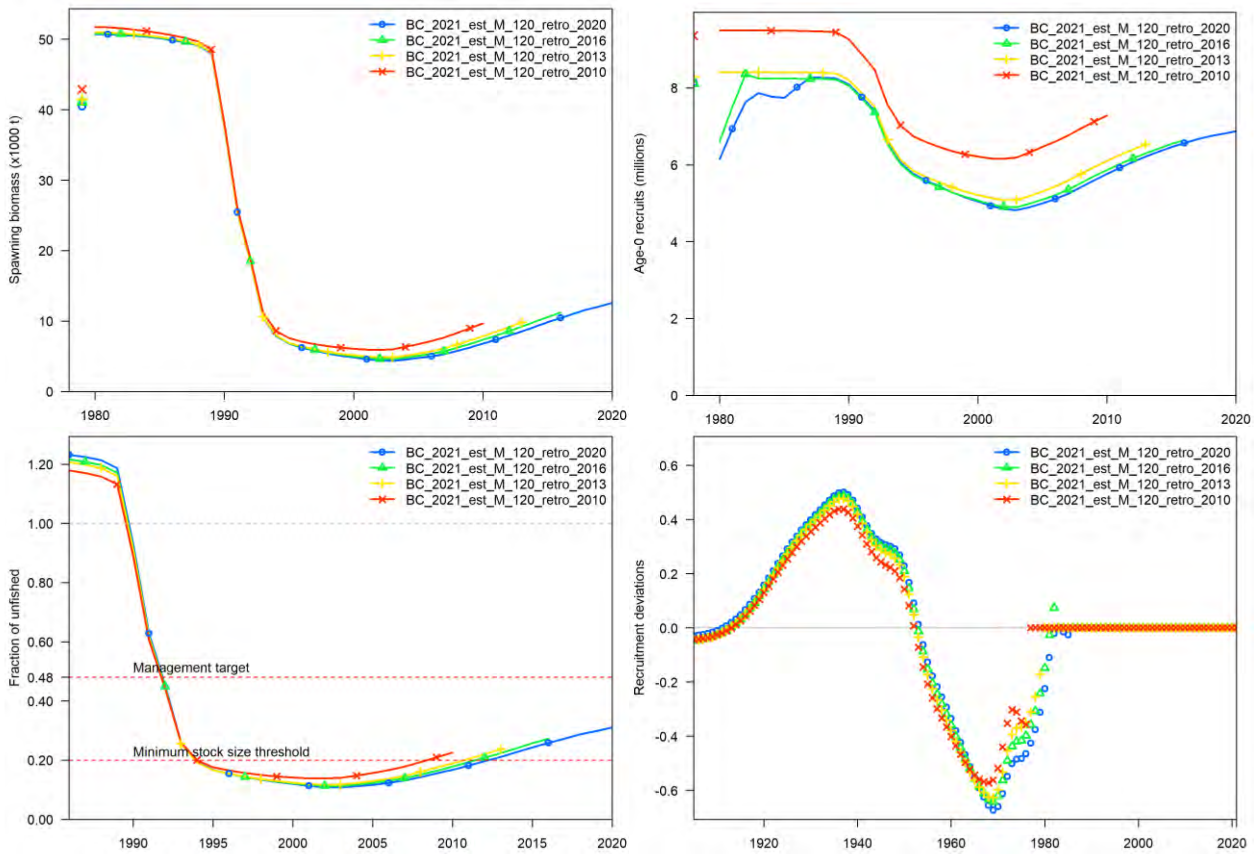


Figure 9.27. Retrospective analysis showing the absolute (top left) and relative (bottom left) spawning biomass, absolute recruitment (top right) and recruitment deviations (bottom right) from assessments that were undertaken after removing four, seven and ten years of data from the candidate 2021 preliminary base-case model with a plus group at 120 years where *M* is estimated.

9.4.11 *Proposed candidate base-case assessments*

Two candidate base-case assessments that estimated *M* were presented to SERAG for consideration, the model with a plus group at 100 years and the model with a plus group at 120 years. To assist SERAG in selecting a base-case for the 2021 assessment residuals for the index fits were provided (Figure 9.28) and the fits of both models to each year of age data and the age residuals were shown on the same figure (Figure 9.29-Figure 9.38).

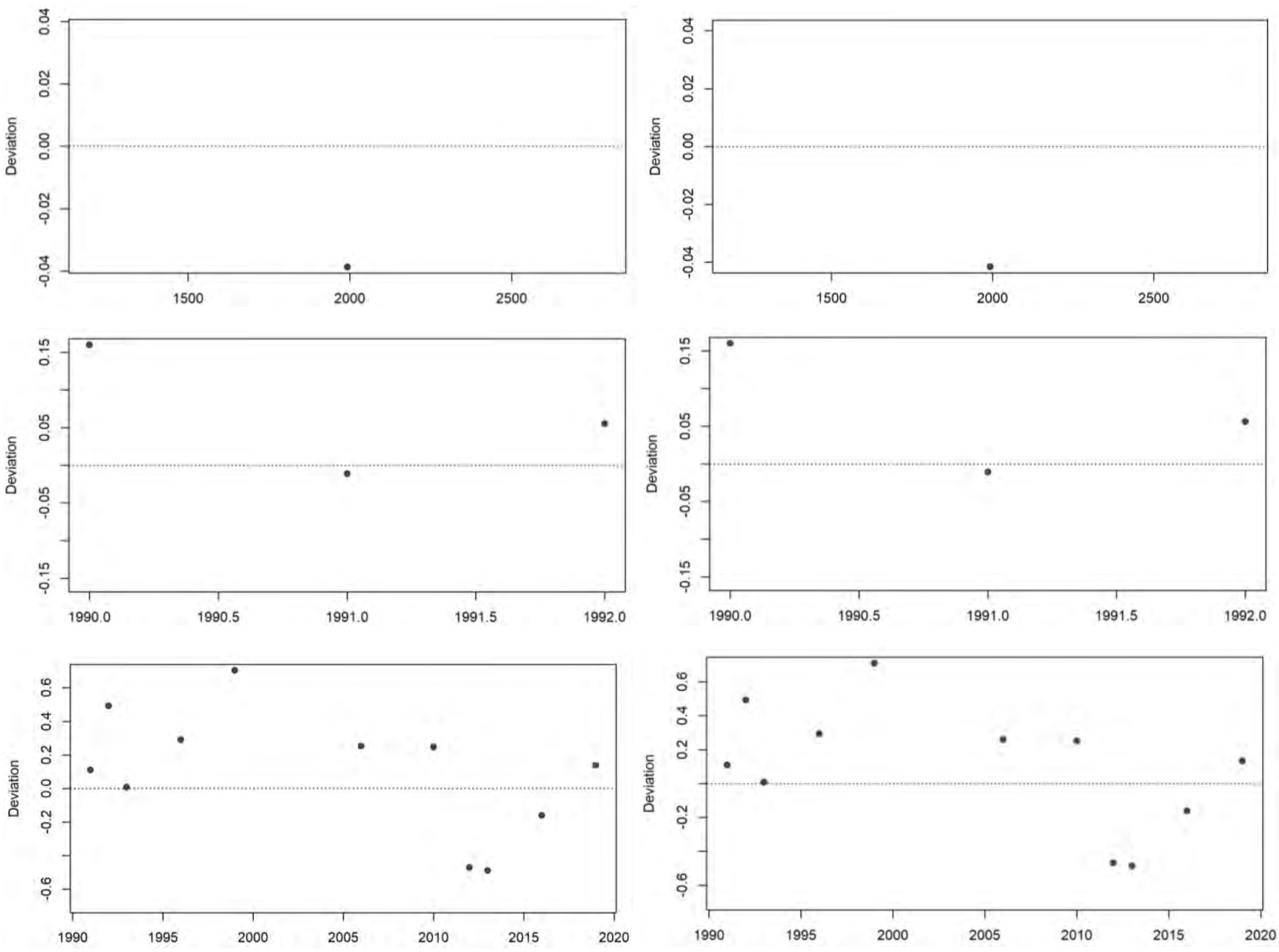


Figure 9.28. Residuals from fits to the egg survey (top), hull survey (middle) and vessel survey (bottom) indices for the 2021 preliminary base-case models with plus groups at 100 (left) and 120 years (right).

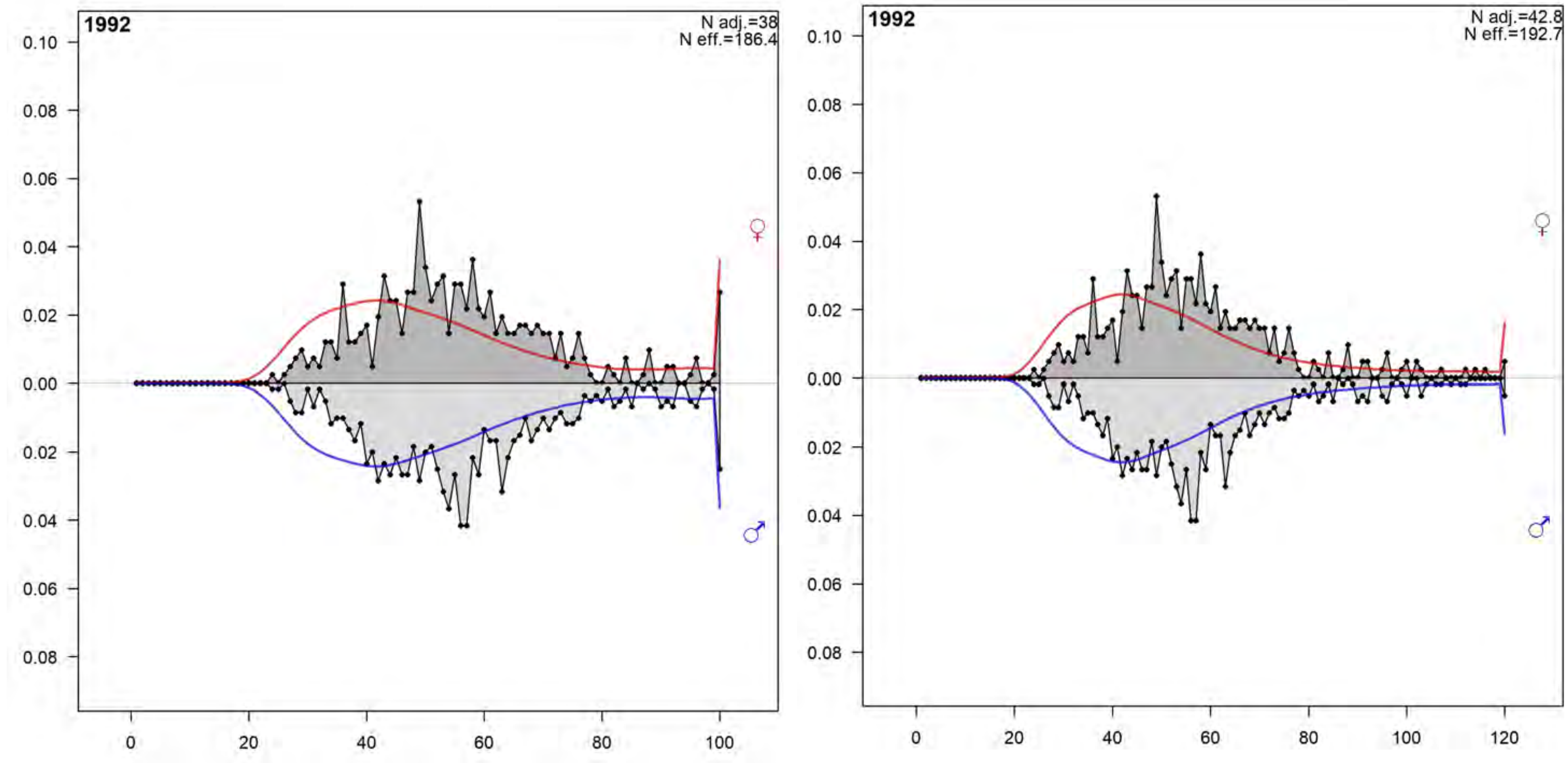
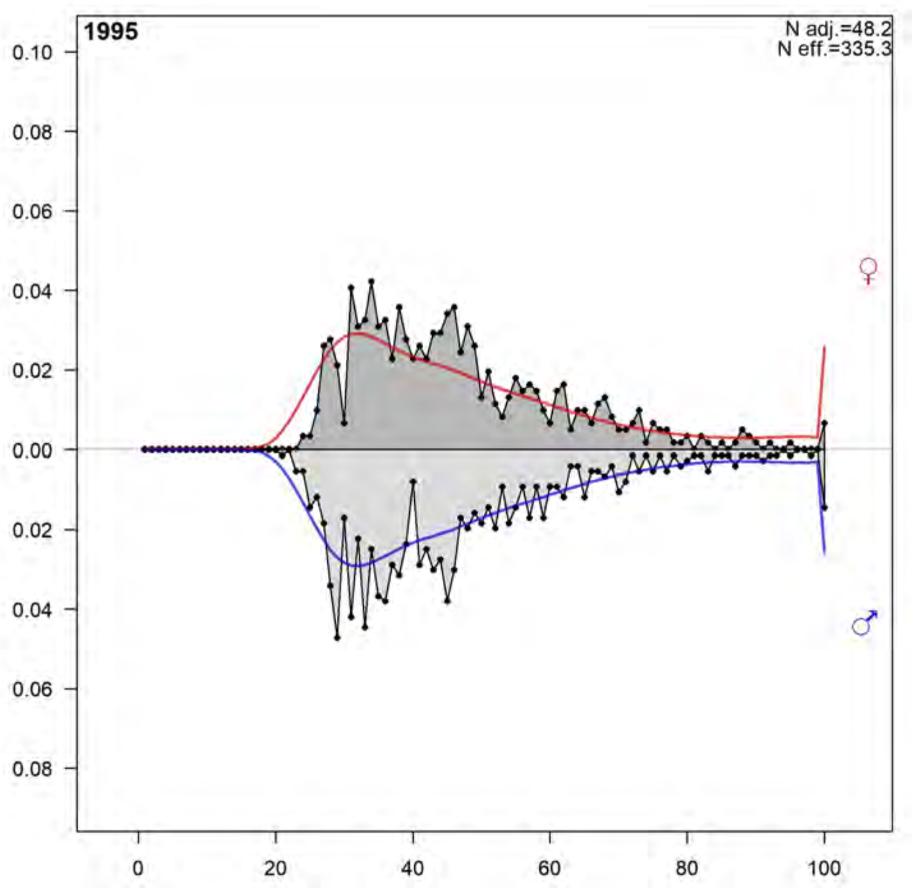


Figure 9.29. Fits to the 1992 age data for the 2021 preliminary base-case models that estimates *M* with a plus group at 100 years (left) and a plus group at 120 years (right).



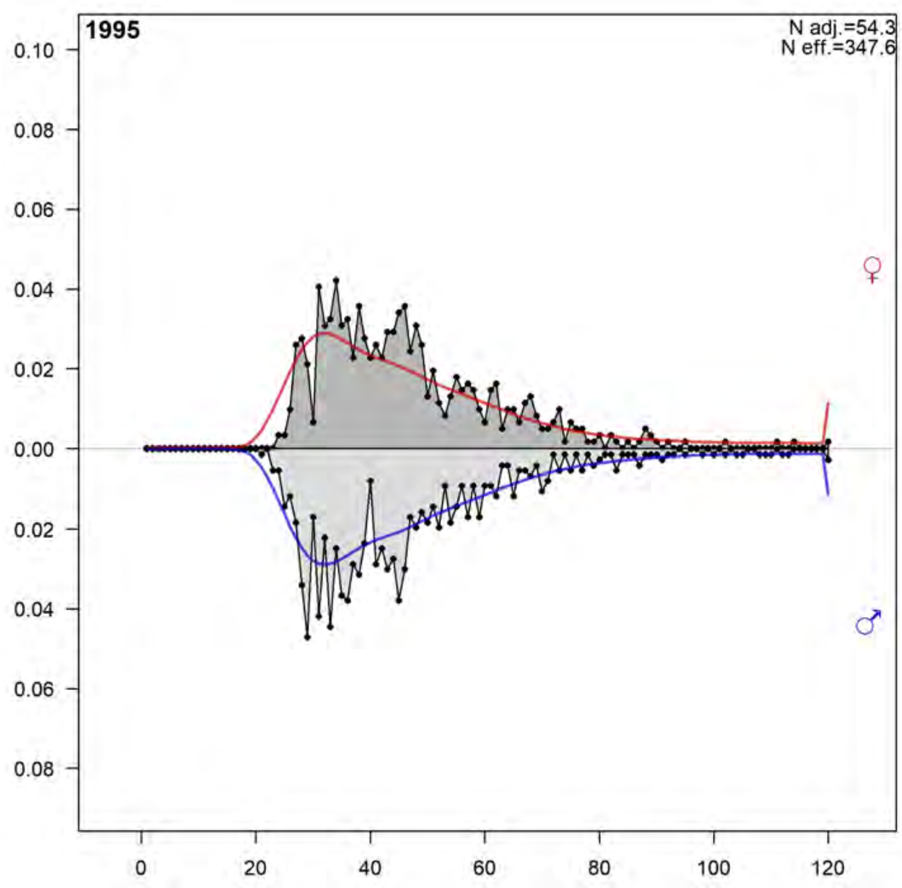


Figure 9.30. Fits to the 1995 age data for the 2021 preliminary base-case models that estimates *M* with a plus group at 100 years (left) and a plus group at 120 years (right).

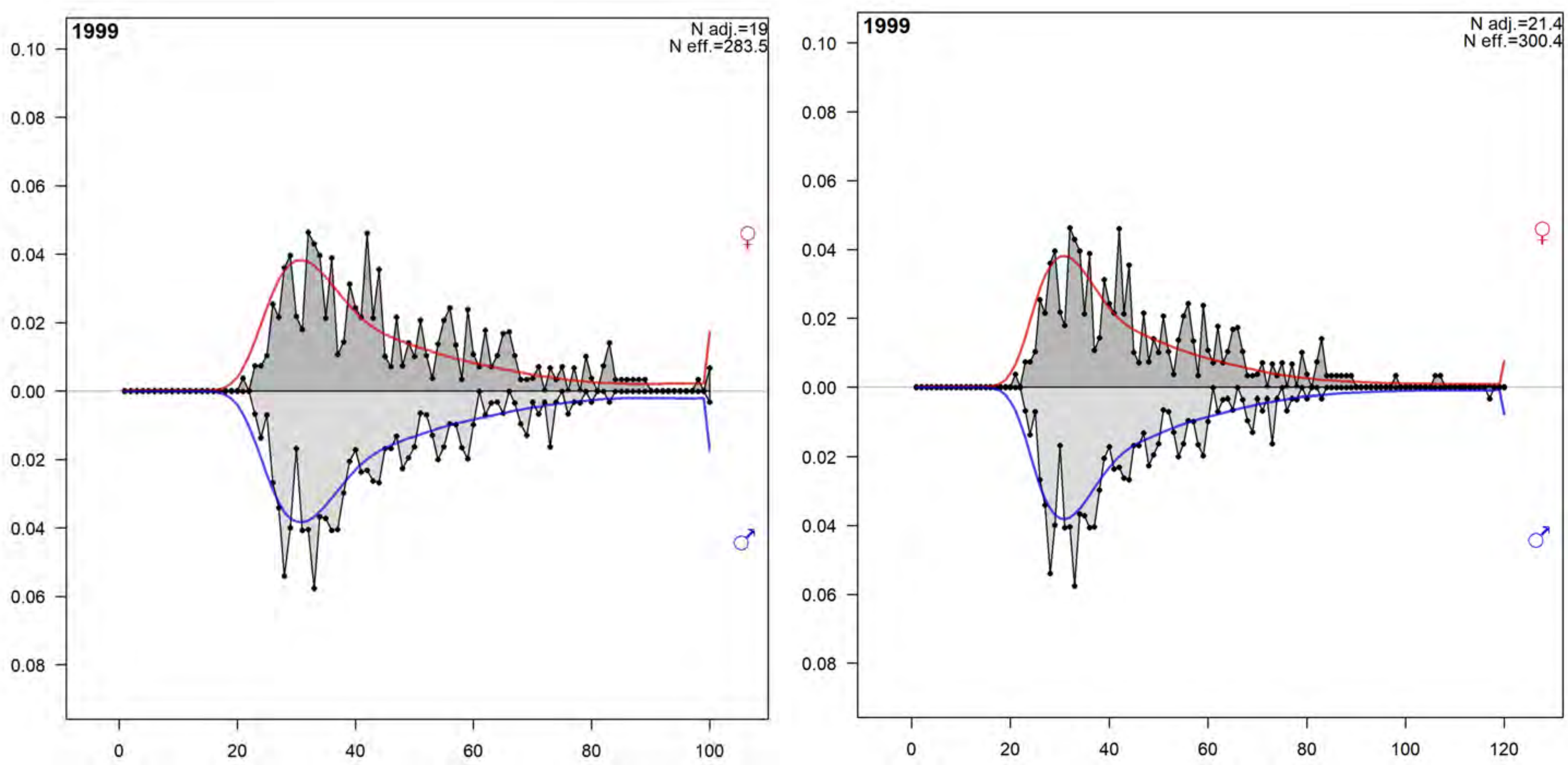
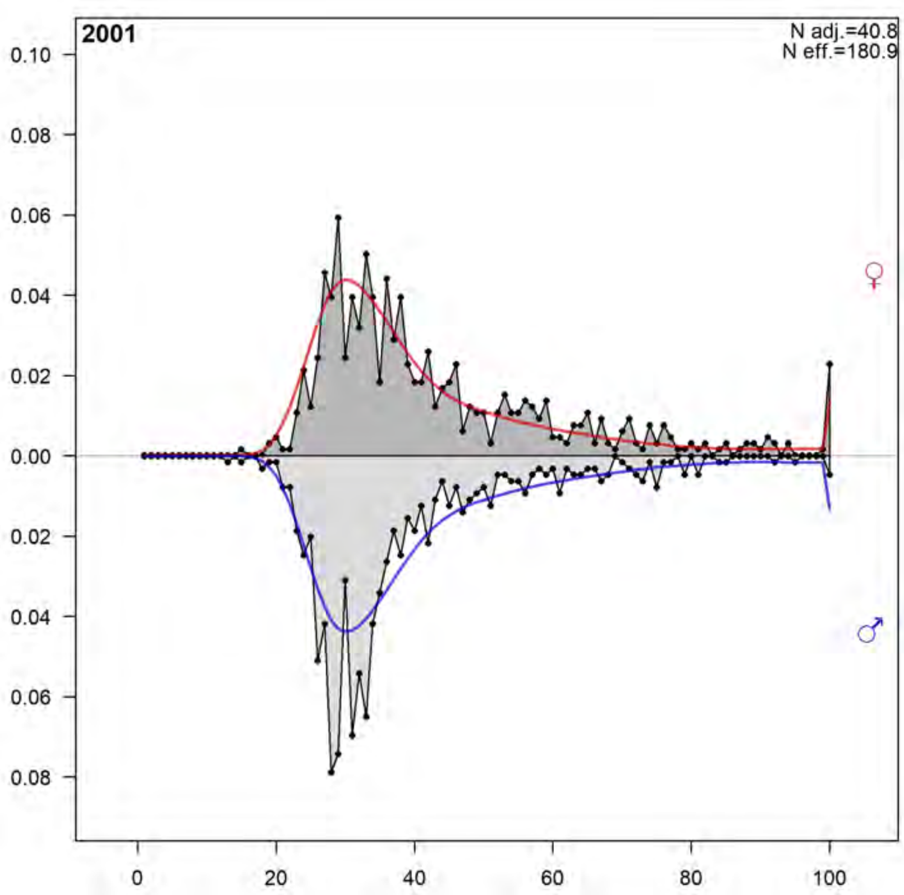


Figure 9.31. Fits to the 1999 age data for the 2021 preliminary base-case models that estimates *M* with a plus group at 100 years (left) and a plus group at 120 years (right).



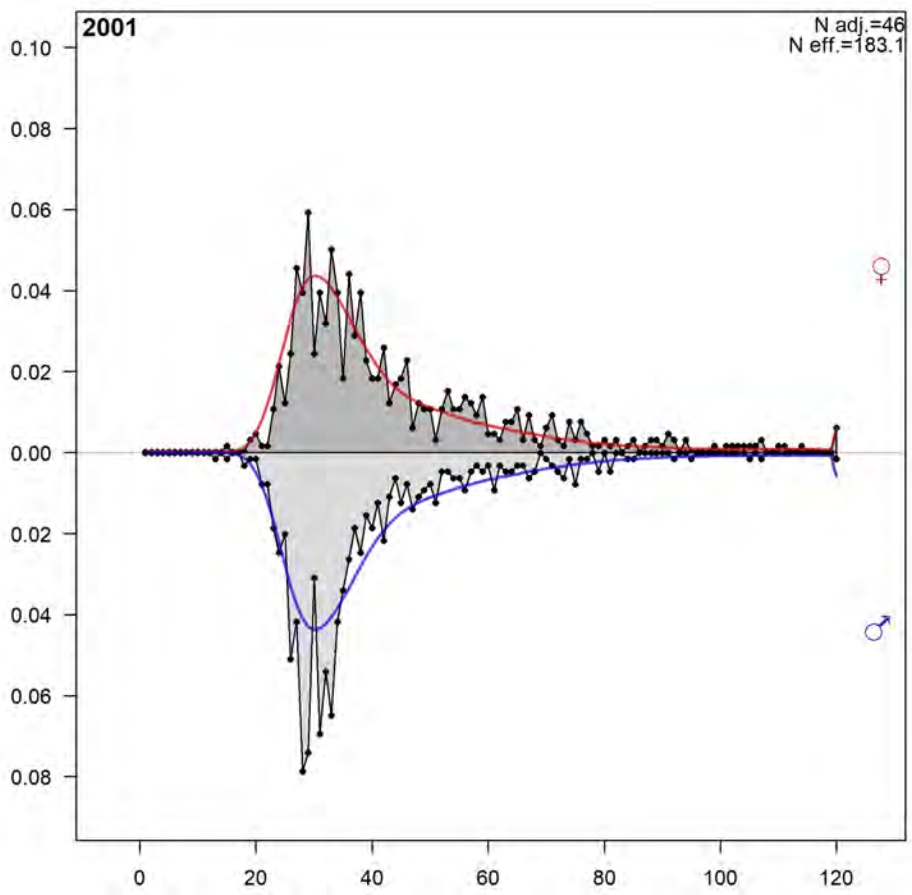


Figure 9.32. Fits to the 2001 age data for the 2021 preliminary base-case models that estimates *M* with a plus group at 100 years (left) and a plus group at 120 years (right).

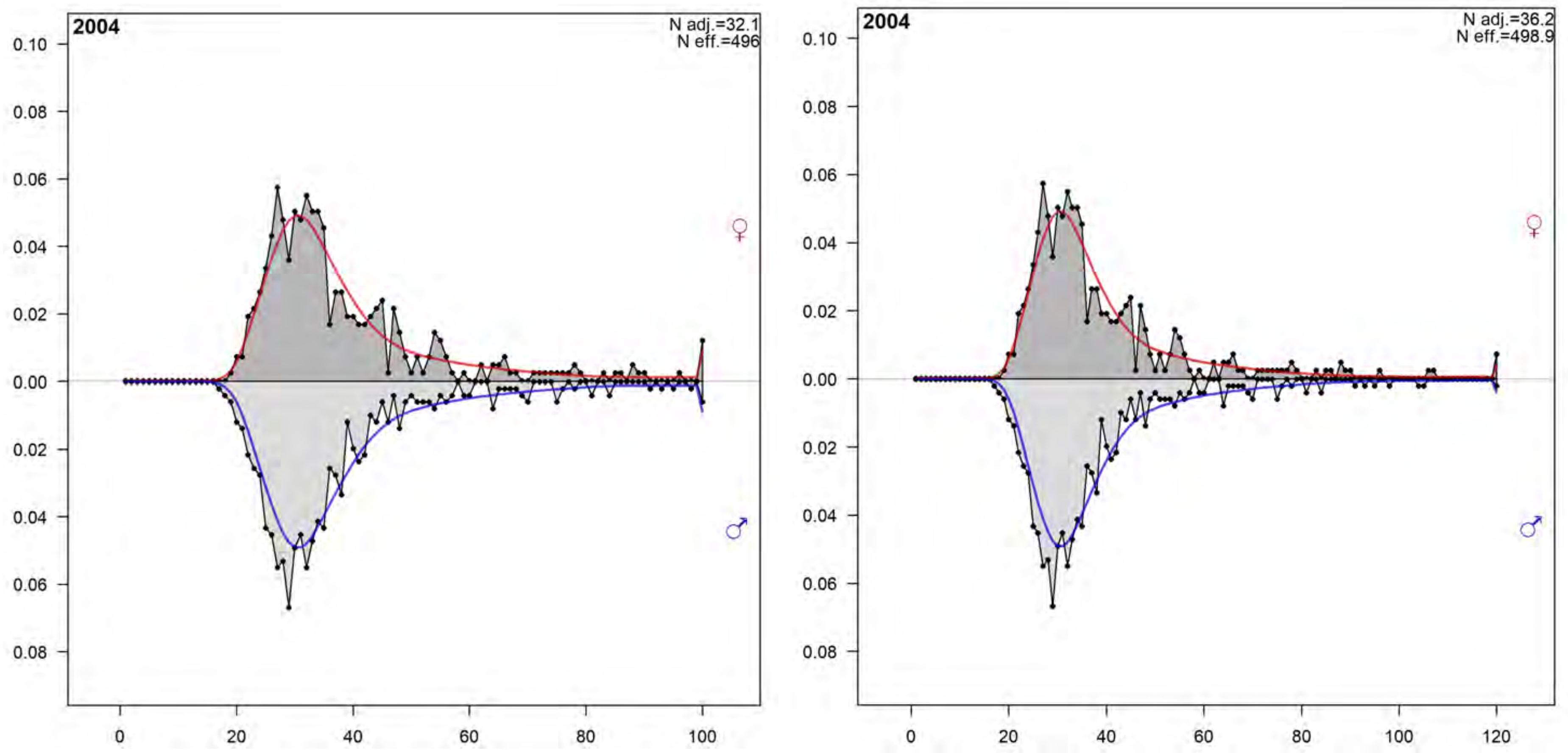


Figure 9.33. Fits to the 2004 age data for the 2021 preliminary base-case models that estimates *M* with a plus group at 100 years (left) and a plus group at 120 years (right).

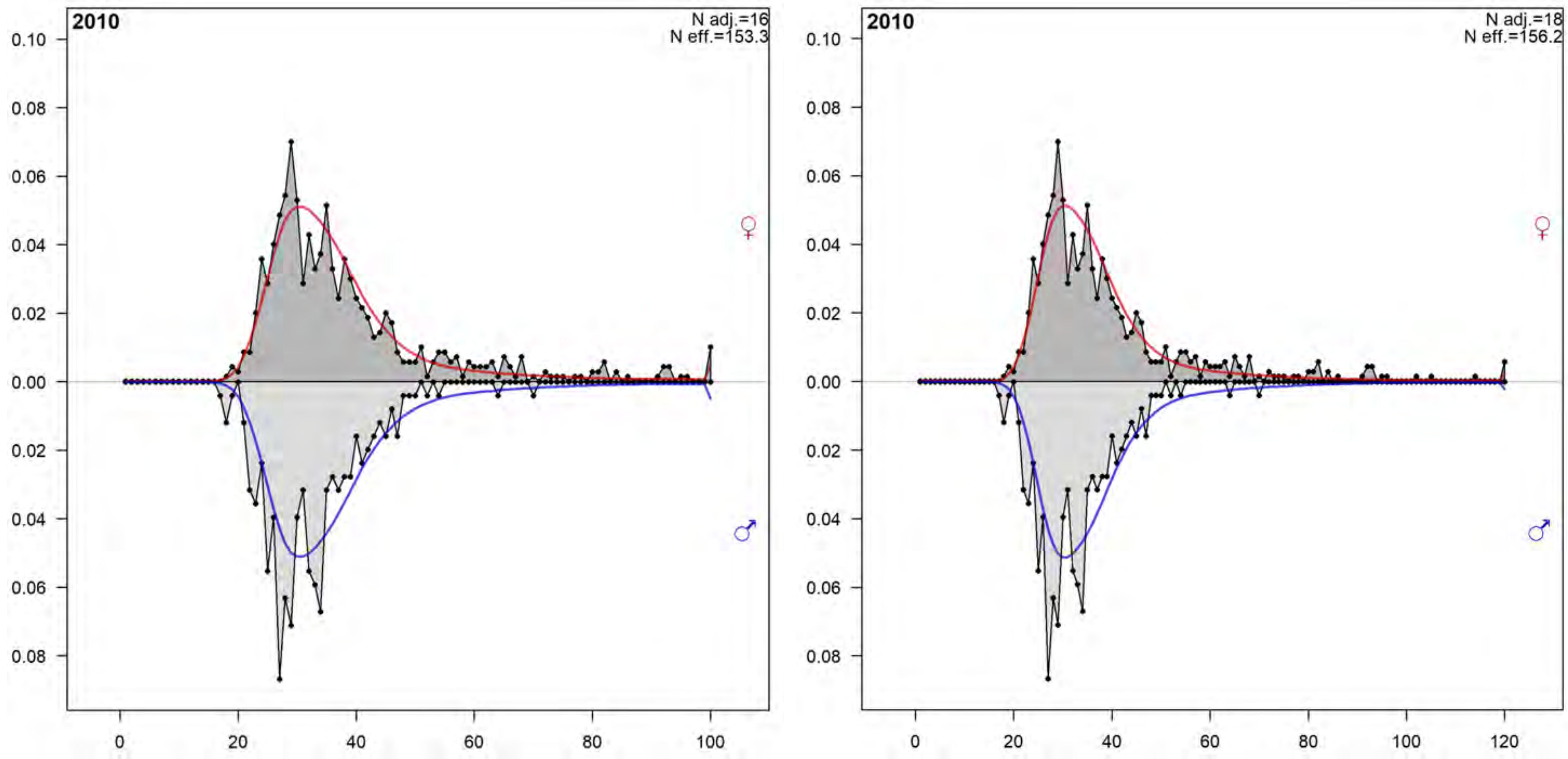


Figure 9.34. Fits to the 2010 age data for the 2021 preliminary base-case models that estimates *M* with a plus group at 100 years (left) and a plus group at 120 years (right).

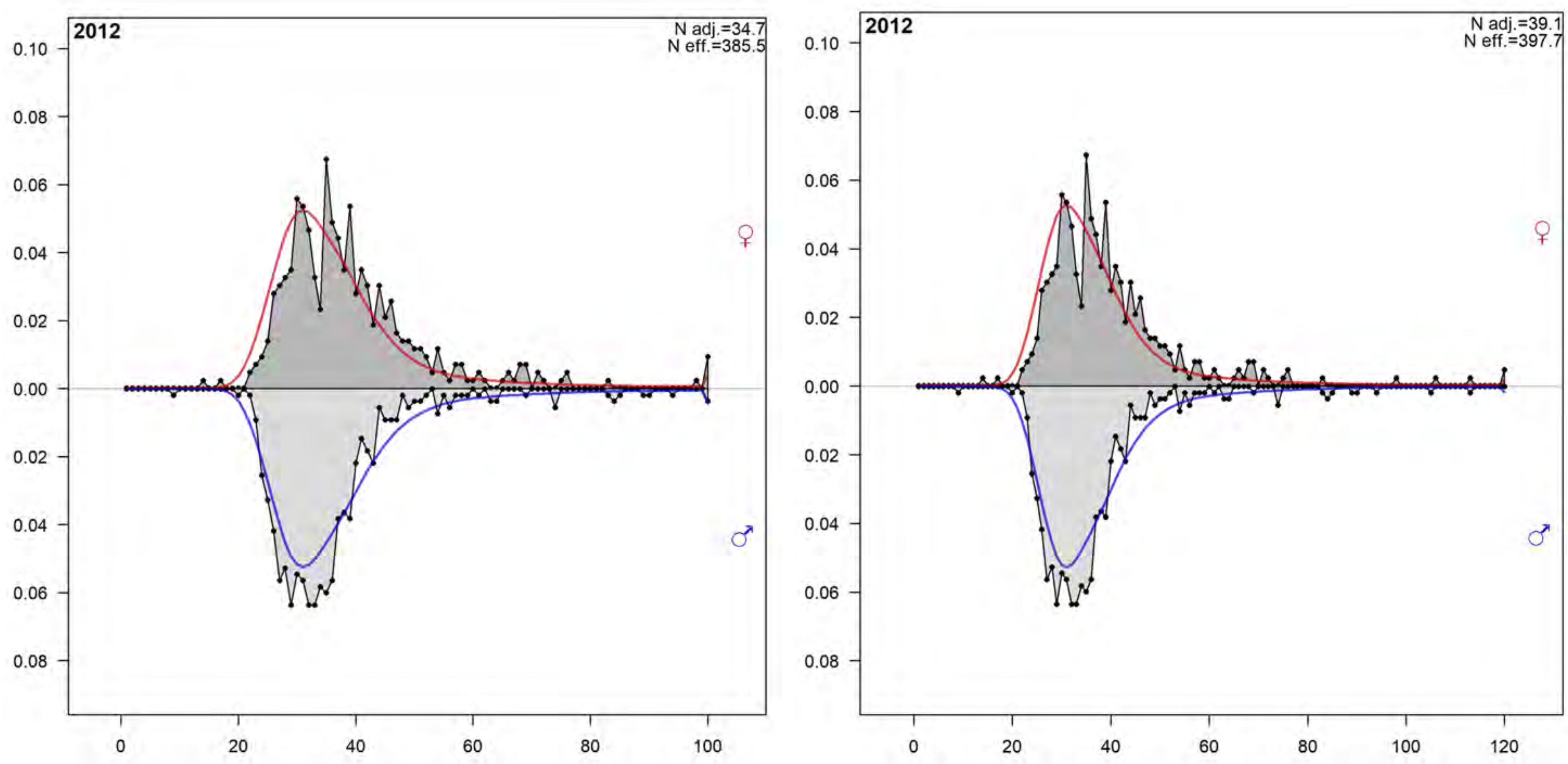


Figure 9.35. Fits to the 2012 age data for the 2021 preliminary base-case models that estimates *M* with a plus group at 100 years (left) and a plus group at 120 years (right).

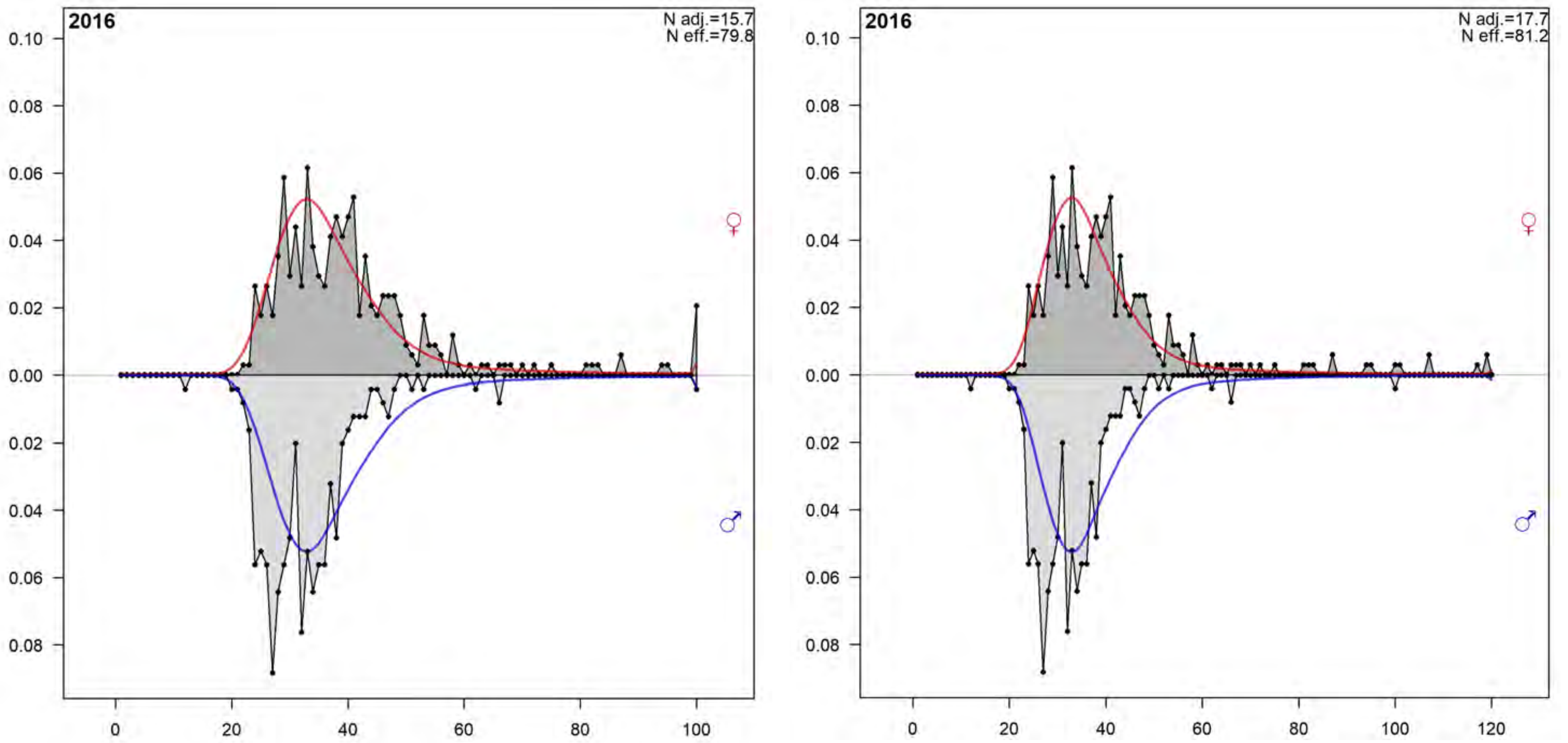


Figure 9.36. Fits to the 2016 age data for the 2021 preliminary base-case models that estimates *M* with a plus group at 100 years (left) and a plus group at 120 years (right).

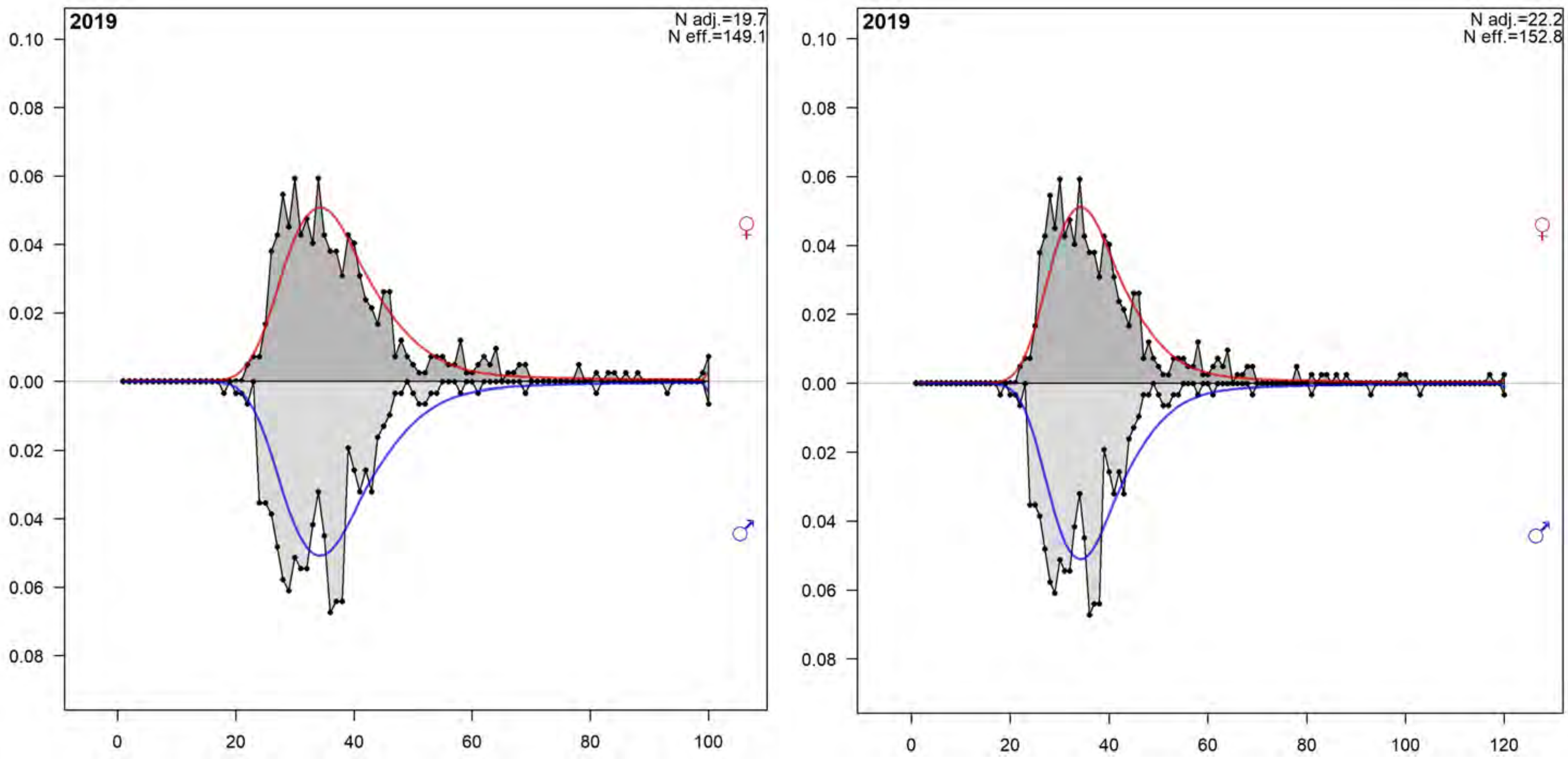


Figure 9.37. Fits to the 2019 age data for the 2021 preliminary base-case models that estimates *M* with a plus group at 100 years (left) and a plus group at 120 years (right).

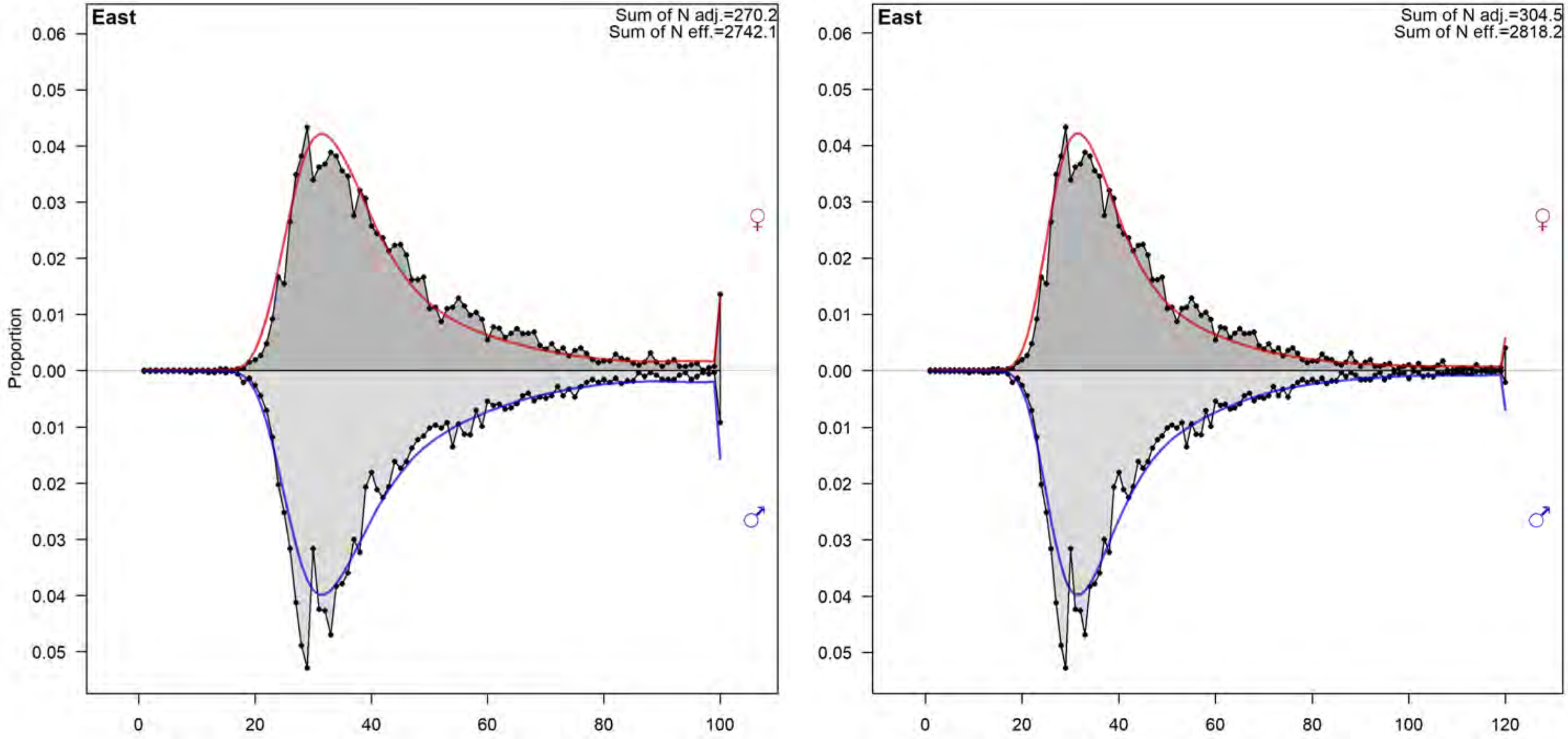


Figure 9.38. Fits to the combined age data (all years) for the 2021 preliminary base-case models that estimates *M* with a plus group at 100 years (left) and a plus group at 120 years (right).

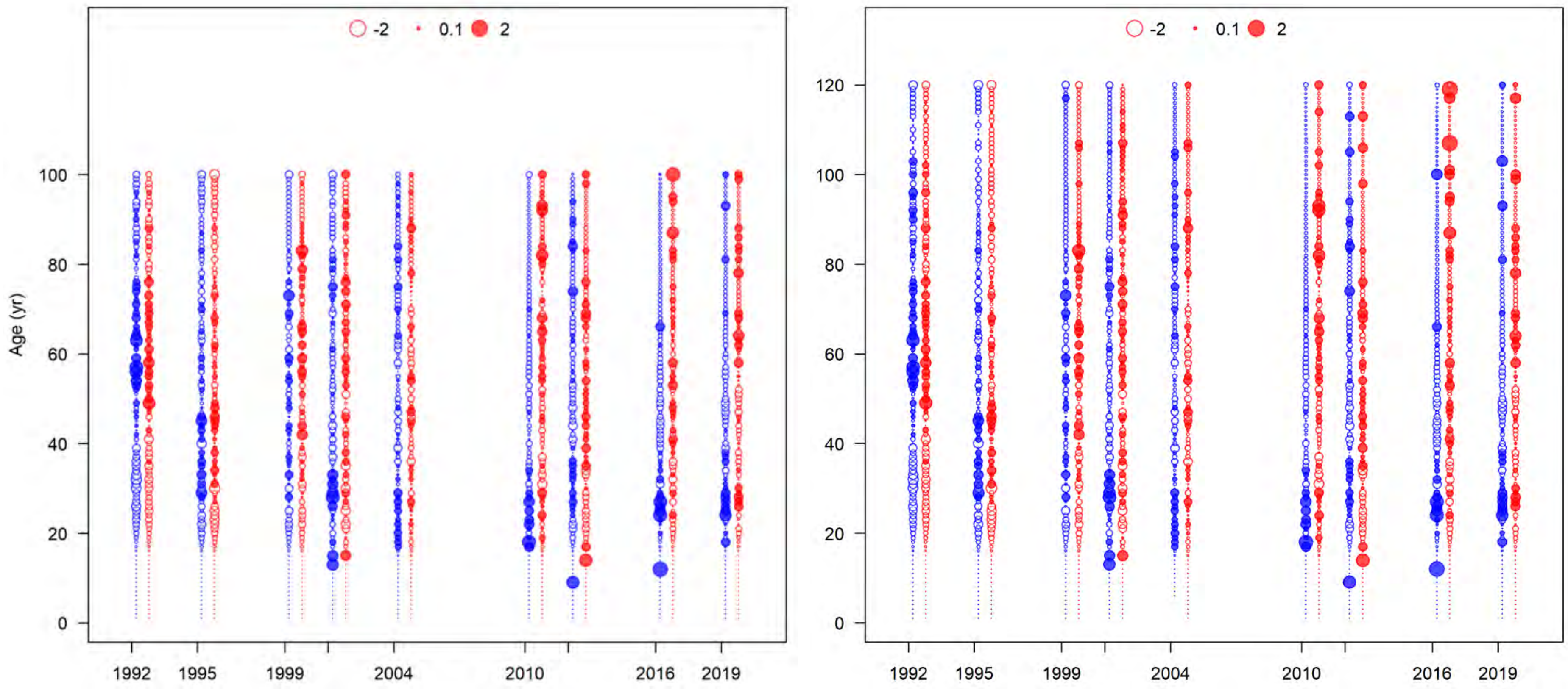


Figure 9.39. Pearson residuals for age data for the 2021 preliminary base-case models that estimates *M* with a plus group at 100 years (left) and a plus group at 120 years (right). Residuals for males are represented by blue circles and residuals for females by red circles.

9.5 Discussion

The primary objective of the 2021 eastern zone Orange Roughy stock assessment was to account for the uncertainty in natural mortality. We proposed to do this by estimating natural mortality within the assessment using an informative prior developed from New Zealand Orange Roughy assessments. We were able to successfully estimate natural mortality within the assessment and recommend that SERAG adopt one of the models that estimates *M* as the agreed base-case assessment. The estimate of *M*, and hence the estimated productivity of the stock was sensitive to the plus-group in the model (the age at which all animals are assumed to have the same weight and fecundity). Increasing the number of age-classes from the 80 used in previous assessments to 100 and 120 resulted in slightly better fits to the age data and no discernable change in the fits to the acoustic biomass indices, suggesting that the number of age-classes in the assessment should be increased. There was little difference in the fits to the age data between the models with 100 and 120 age-classes so it is difficult to recommend a model to take forward as the agreed base-case assessment. Both models are very similar however, the main difference being the model with 120 age-classes estimates a slightly higher natural mortality (M=0.0386 yr^{-1} compared with M=0.0373 yr^{-1} for the model with 100 age-classes). Given the differences in the natural mortality estimates between the models with 100 and 120 age-classes and the uncertainty associated with those estimates, SERAG may wish to make use of a decision table with alternate states of nature and management actions (a cross-catch-risk assessment). If a decision table is requested we recommend contstructing the decision table using quantiles from the posterior of natural mortality from the agreed base-case assessment as they are likely to better represent the uncertainty in natural mortality than a likelihood profile.

The 2021 eastern zone Orange Roughy stock assessment has focused on exploring the estimation natural mortality within the assessment using an informative prior developed from New Zealand Orange Roughy stocks. There are several other uncertainties associated with the eastern zone Orange Roughy assessment that should be investigated in future assessments. These are:

1. Review the method of developing catchability priors for the acoustic surveys and update the prior for the towed body survey.
2. Work with Fish Ageing Services to review the age data and the relative weighting of age samples collected from St Helens Hill and St Patricks Head.
3. Maturity appears to be mis-specified in the assessment, as it should be the same as selectivity. Investigate whether there is sufficient data to estimate maturity within the assessment (as is done for some New Zealand Orange Roughy stocks). If there are insufficient data to estimate maturity within the assessment then update the fixed values of the maturity parameters if recent data is available.
4. The selectivity of the trawl fleet and the acoustic surveys is the same. Investigate whether it is possible to separate them.
5. The stock structure hypothesis for Australian Orange Roughy should be further investigated. Exploratory fishing for Orange Roughy is currently being undertaken on non-spawning components of the Orange Roughy populations in the western and Albany and Esperance (GAB) zones. If the stock structure hypothesis for eastern zone Orange Roughy is incorrect there is the risk that the population being fished in the eastern zone is subject to additional fishing of the non-spawning component.

9.6 Acknowledgements

Age data was provided by Josh Barrow (Fish Ageing Services), acoustic biomass estimates were provided by Rudy Kloser (CSIRO), ISMP and AFMA logbook and CDR data were provided by John Garvey (AFMA). Franzis Althaus, Toni Cannard, Roy Deng, Mike Fuller, Caroline Sutton and Robin Thomson (CSIRO) pre-processed the data. George Clements (Deepwater Group Ltd) and Patrick Cordue (ISL) provided the combined posterior for New Zealand Orange Roughy natural mortality that was used to develop the prior for estimating natural mortality. Pia Bessell-Browne, Jemery Day, Malcolm Haddon, André Punt and Judy Upston provided guidance in the development of the assessment. The developers of Stock Synthesis, Richard Methot Jr., Chantel Wetzel, Ian Taylor, Kathryn Doering, and Kelli F. Johnson are thanked for making the software available. The r4ss package maintained by Ian Taylor (https://github.com/r4ss/r4ss) was used for creating plots of model outputs and diagnostics. The Orange Roughy Steering Committee comprising Daniel Corrie, Mike Steer, Geoff Tuck, André Punt, Andrew Penney, Matt Dunn, Kevin Stokes and Simon Boag provided advice on a preliminary version of this report.

This document was internally reviewed by Professor André Punt and Dr Geoff Tuck.

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9.8 Appendix A

9.8.1 Acoustic biomass priors

The acoutic priors were developed using the methods of Cordue (presentation to the Australian Orange Roughy workshop, 15 – 16 May 2014; Cordue 2014) for the New Zealand orange roughy assessments and modified for the Australian Eastern orange roughy situation using the available acoustic data for the hull and towed body surveys undertaken between 1990 and 2013 and expert judgement from the informal orange roughy acoustics working group in Hobart that included Judy Upston, Tim Ryan, Rudy Kloser and André Punt. The methods below are reproduced from Upston et al (2015):

Determine the sampling distribution, mean and CV associated with each of three components that we considered for the acoustic priors:

1. Uncertainty in acoustic target strength (TS), i.e. the ratio of true target strength to assumed target strength – lognormal distribution centred at 1 with CV=0.15 (after Cordue presentation 2014):
   a) calculate the mean and standard deviation of two independent mean estimates of acoustic TS, -52.0 and -51.1 dB (ignores sampling variability), and assume TS ~ N(-51.6, sd=0.64),
   b) convert TS from log scale to linear scale via $\log_e(10^{ts/10})$ where ts is random normal TS, to get $\log_e(10^{ts/10})$ ~ N(-11.88, 0.1476),
   c) calculate mean and standard deviation of lognormal distribution centred on 1 (including bias correction);
2. Percentage of the spawning stock on the Eastern grounds that acoustics is "seeing" – historically the assessment has assumed 100% and the current assessment assumes "most" (Beta distribution centred on 95%) but allows for the possibility that some spawning stock do not migrate to the Eastern grounds in some years (e.g. an estimated 10% of spawning fish from the South did not migrate to the East in 1992; Bell et al. 1992). Thus a Beta(95, 5) distribution, centred on 95% and with reasonably high values of α and β for an approximately normal shape, was chosen for this prior component. The distribution shape, with less probability mass towards the left-hand tail of the distribution (less probability of only 90% or fewer spawning fish migrating to the spawning grounds and being observed), seemed appropriate based on expert judgement. However, other Beta distributions could also have been used (e.g. Beta(950, 50));
3. Random error component capturing other uncertainty (e.g. estimated density of fish in an area; species ID issues; sampling variability in target strength since (i) is an average of the mean estimates). The random error has a lognormal distribution centred on 1, with a nominal "low" CV for towed body surveys, and a wider CV for the hull surveys, given the uncertainty with species ID and other issues (Kloser and Ryan et al. 2001).

The next step was to combine the independent component distributions to get an overall distribution. The CVs associated with each of the three components (and hence the overall prior) were determined by data and expert judgement – in combining the three components and setting a prior on acoustic catchability (*q* scalar) we essentially have made a statement about how well the acoustic towed or hull series is thought to provide an absolute estimate of biomass of the spawning roughy for the stock East and South (Pedra Branca). i.e. the stock we are assessing.

We have assumed on average a constant percentage of fish migrating to the eastern grounds and spawning each year. The priors will undoubtedly be further developed as more information becomes available, thus the random error component (lognormal with CV=0.25 for the towed body and 0.8 for the hull) was explicitly included to accommodate this.

Distributions for each of the independent components, and the combined overall distribution for the acoustic *q* prior are shown in Figure A 9.1 to Figure A 9.3.

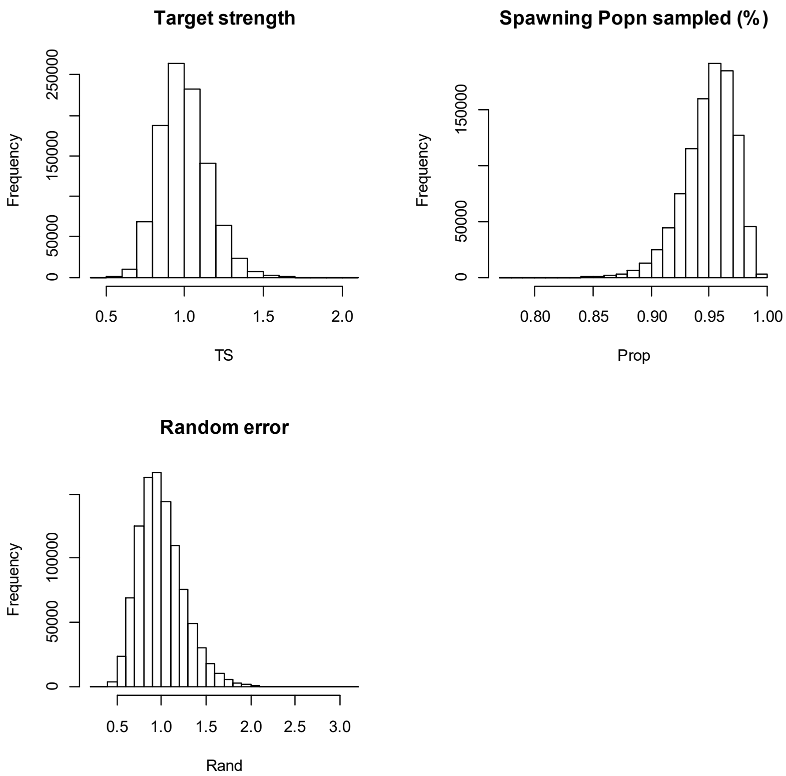


Figure A 9.1. Prior component distributions for target strength, spawning population sampled, and random error for acoustics towed (reproduced from Upston et al. 2015).

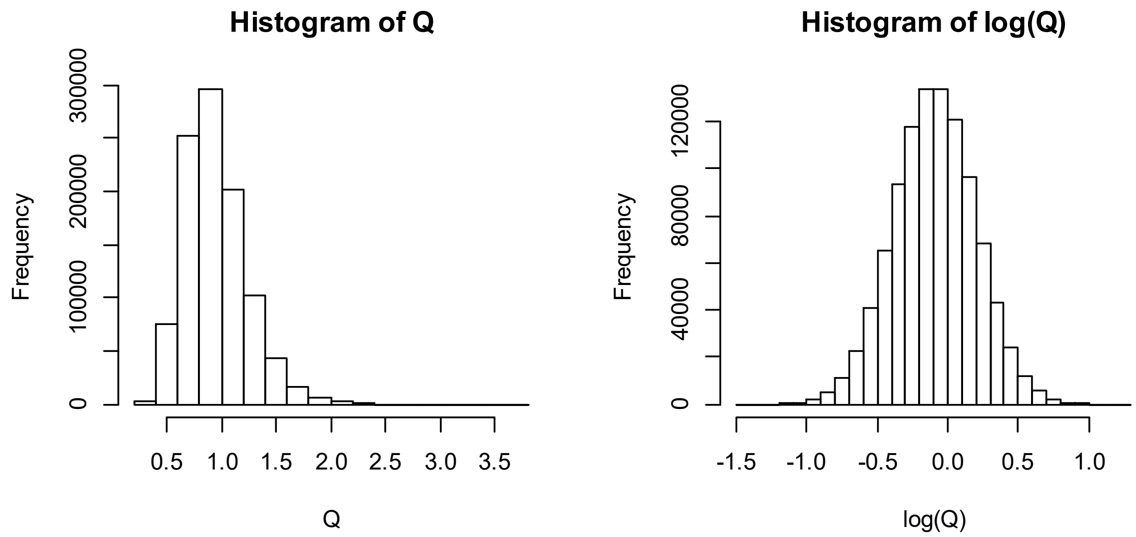


Figure A 9.2. Priors for q and $\ln(q)$ for acoustics towed (reproduced from Upston et al. 2015).

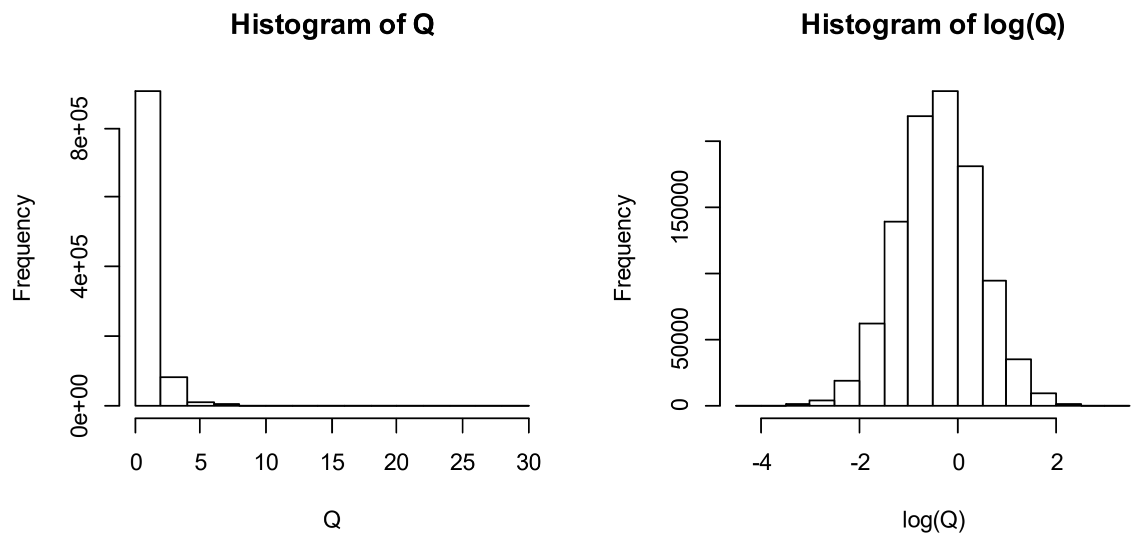


Figure A 9.3. Priors for q and $\ln(q)$ hull. The random error component is greater than that for towed body (reproduced from Upston et al. 2015).

9.8.2 *Additional ageing error estimates*

Table A 9.1. The estimated standard deviations of normal variation (StDev; age-reading error) around age-estimates for the different age-classes of eastern zone Orange Roughy for maximum model ages of 80, 100 and 120. * Ageing error for the 100 age-class scenario did not achieve full convergence (max gradient = 0.024), so estimates for the 120 age-class scenario were used.

Age	StDev 80	StDev 100*	StDev 120	Age	StDev 80	StDev 100*	StDev 120	Age	StDev 100*	StDev 120
0	<0.001	<0.001	<0.001	41	3.1458	3.1558	3.1529	81	6.327	6.200
1	<0.001	<0.001	<0.001	42	3.2233	3.2349	3.2304	82	6.406	6.275
2	0.0797	0.0787	0.0801	43	3.3008	3.3140	3.3078	83	6.486	6.350
3	0.1594	0.1574	0.1602	44	3.3782	3.3931	3.3851	84	6.565	6.425
4	0.2390	0.2362	0.2402	45	3.4556	3.4722	3.4624	85	6.645	6.499
5	0.3185	0.3149	0.3202	46	3.5329	3.5513	3.5396	86	6.724	6.574
6	0.3980	0.3936	0.4000	47	3.6102	3.6305	3.6167	87	6.804	6.648
7	0.4775	0.4724	0.4798	48	3.6874	3.7096	3.6937	88	6.883	6.723
8	0.5568	0.5512	0.5596	49	3.7645	3.7888	3.7707	89	6.963	6.797
9	0.6362	0.6299	0.6392	50	3.8416	3.8680	3.8477	90	7.042	6.872
10	0.7154	0.7087	0.7188	51	3.9187	3.9471	3.9245	91	7.122	6.946
11	0.7946	0.7875	0.7983	52	3.9957	4.0263	4.0013	92	7.202	7.020
12	0.8738	0.8663	0.8778	53	4.0726	4.1055	4.0781	93	7.281	7.094
13	0.9529	0.9451	0.9572	54	4.1495	4.1847	4.1547	94	7.361	7.168
14	1.0320	1.0240	1.0365	55	4.2264	4.2639	4.2313	95	7.440	7.242
15	1.1110	1.1028	1.1158	56	4.3031	4.3431	4.3079	96	7.520	7.316
16	1.1899	1.1817	1.1950	57	4.3799	4.4224	4.3843	97	7.600	7.390
17	1.2688	1.2605	1.2741	58	4.4565	4.5016	4.4607	98	7.679	7.464
18	1.3476	1.3394	1.3532	59	4.5332	4.5809	4.5371	99	7.759	7.538
19	1.4264	1.4182	1.4321	60	4.6097	4.6601	4.6134	100	7.838	7.612
20	1.5051	1.4971	1.5111	61	4.686	4.739	4.690	101	-	7.685
21	1.5838	1.5760	1.5899	62	4.763	4.819	4.766	102	-	7.759
22	1.6624	1.6549	1.6687	63	4.839	4.898	4.842	103	-	7.832
23	1.7410	1.7338	1.7474	64	4.915	4.977	4.918	104	-	7.906
24	1.8195	1.8127	1.8261	65	4.992	5.057	4.994	105	-	7.979
25	1.8979	1.8917	1.9047	66	5.068	5.136	5.070	106	-	8.053
26	1.9763	1.9706	1.9832	67	5.144	5.215	5.145	107	-	8.126
27	2.0547	2.0495	2.0616	68	5.220	5.295	5.221	108	-	8.199
28	2.1330	2.1285	2.1400	69	5.296	5.374	5.297	109	-	8.272
29	2.2112	2.2075	2.2183	70	5.373	5.453	5.373	110	-	8.345
30	2.2894	2.2864	2.2966	71	5.448	5.533	5.448	111	-	8.418
31	2.3675	2.3654	2.3748	72	5.524	5.612	5.524	112	-	8.491
32	2.4456	2.4444	2.4529	73	5.600	5.691	5.599	113	-	8.564
33	2.5236	2.5234	2.5309	74	5.676	5.771	5.674	114	-	8.637
34	2.6016	2.6024	2.6089	75	5.752	5.850	5.750	115	-	8.710
35	2.6795	2.6815	2.6868	76	5.828	5.930	5.825	116	-	8.783
36	2.7573	2.7605	2.7647	77	5.903	6.009	5.900	117	-	8.855
37	2.8351	2.8395	2.8425	78	5.979	6.088	5.975	118	-	8.928
38	2.9129	2.9186	2.9202	79	6.055	6.168	6.050	119	-	9.000
39	2.9906	2.9977	2.9978	80	6.130	6.247	6.125	120	-	9.073
40	3.0682	3.0767	3.0754							

9.8.3 *Additional diagnostics preliminary base-case with fixed M*

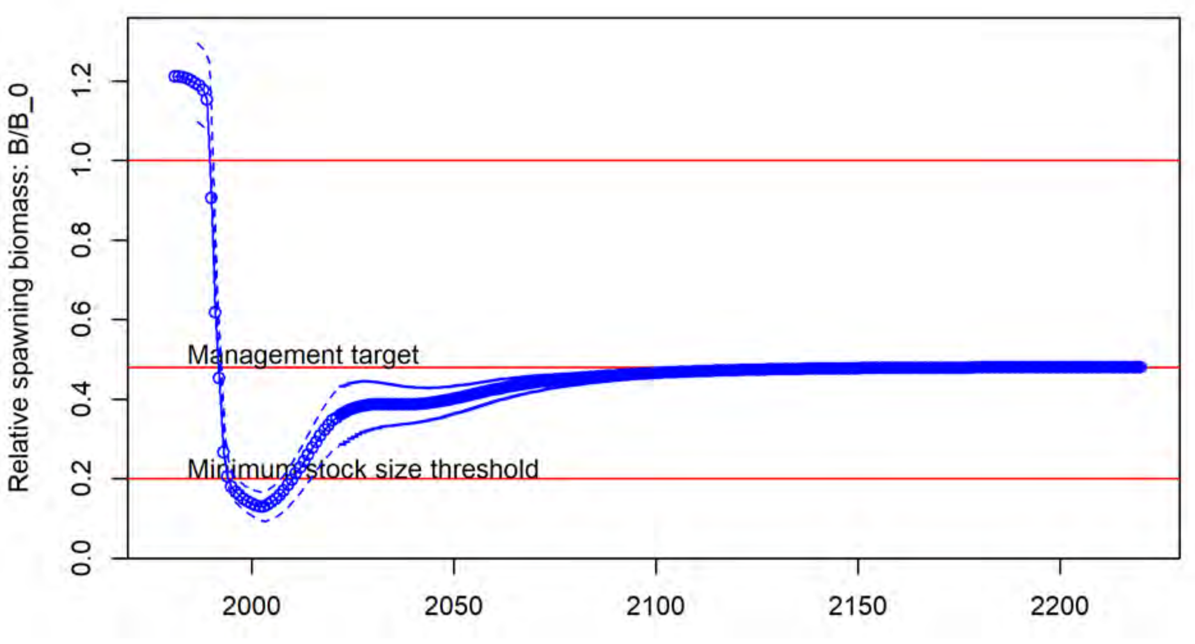


Figure A 9.4. The estimated time-series of relative spawning biomass for the 2021 preliminary base-case model with fixed *M* forecast 200 years into the future with catches set using the SESSF 20:35:48 harvest control rule.

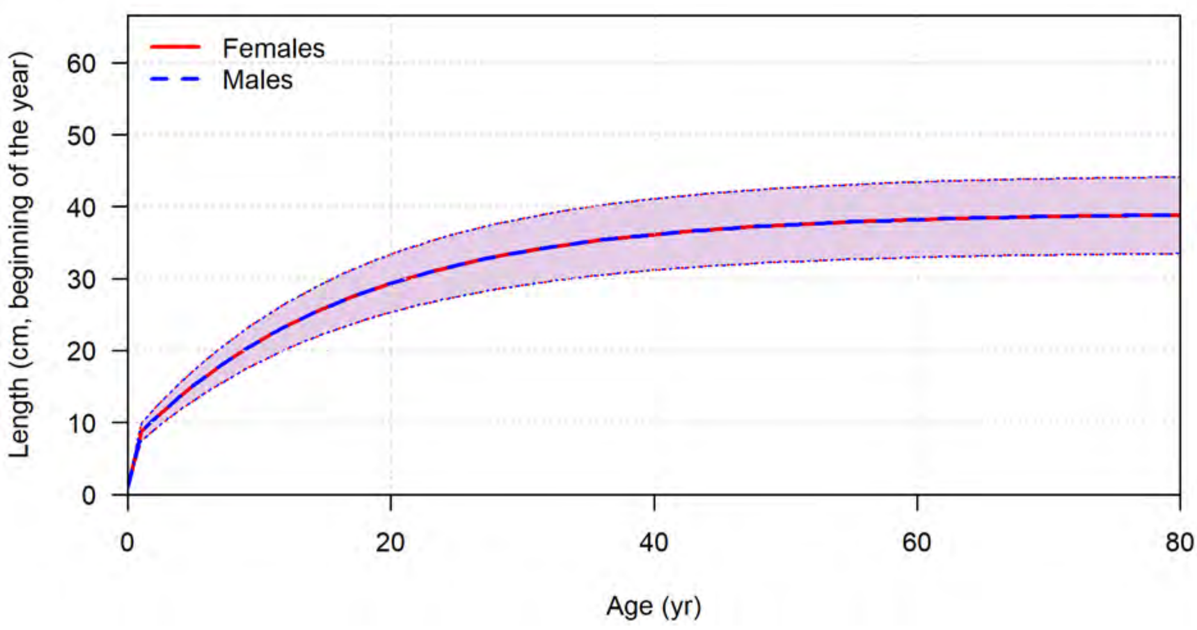


Figure A 9.5. Growth for the 2021 preliminary base-case model.

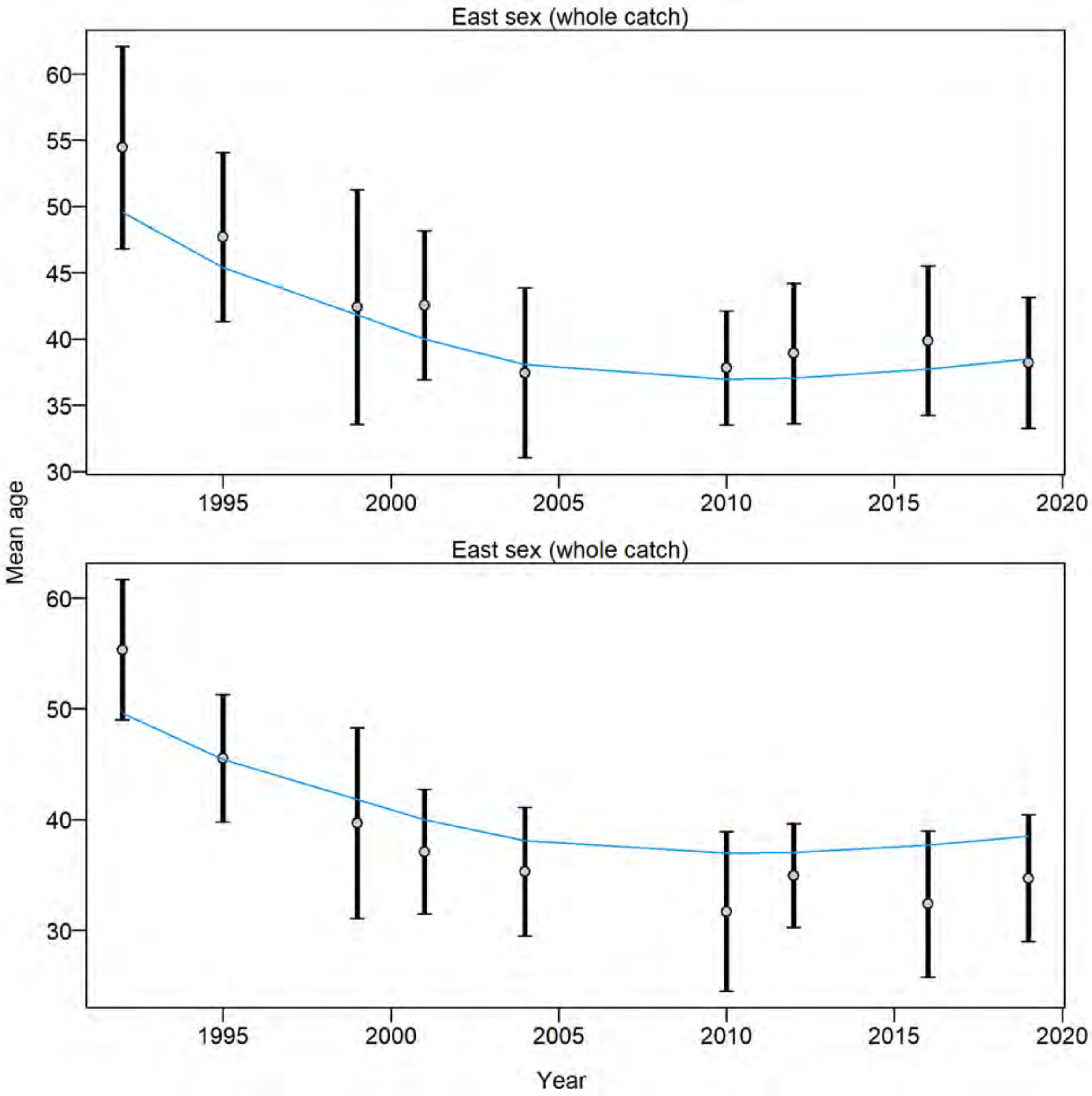


Figure A 9.6. Mean age for male and female samples with 95% confidence intervals based on current samples sizes for the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1}. Suggested multiplier for Francis data weighting method TA1.8 of age data with 95% interval is 0.9991 (0.6902-1.8461).

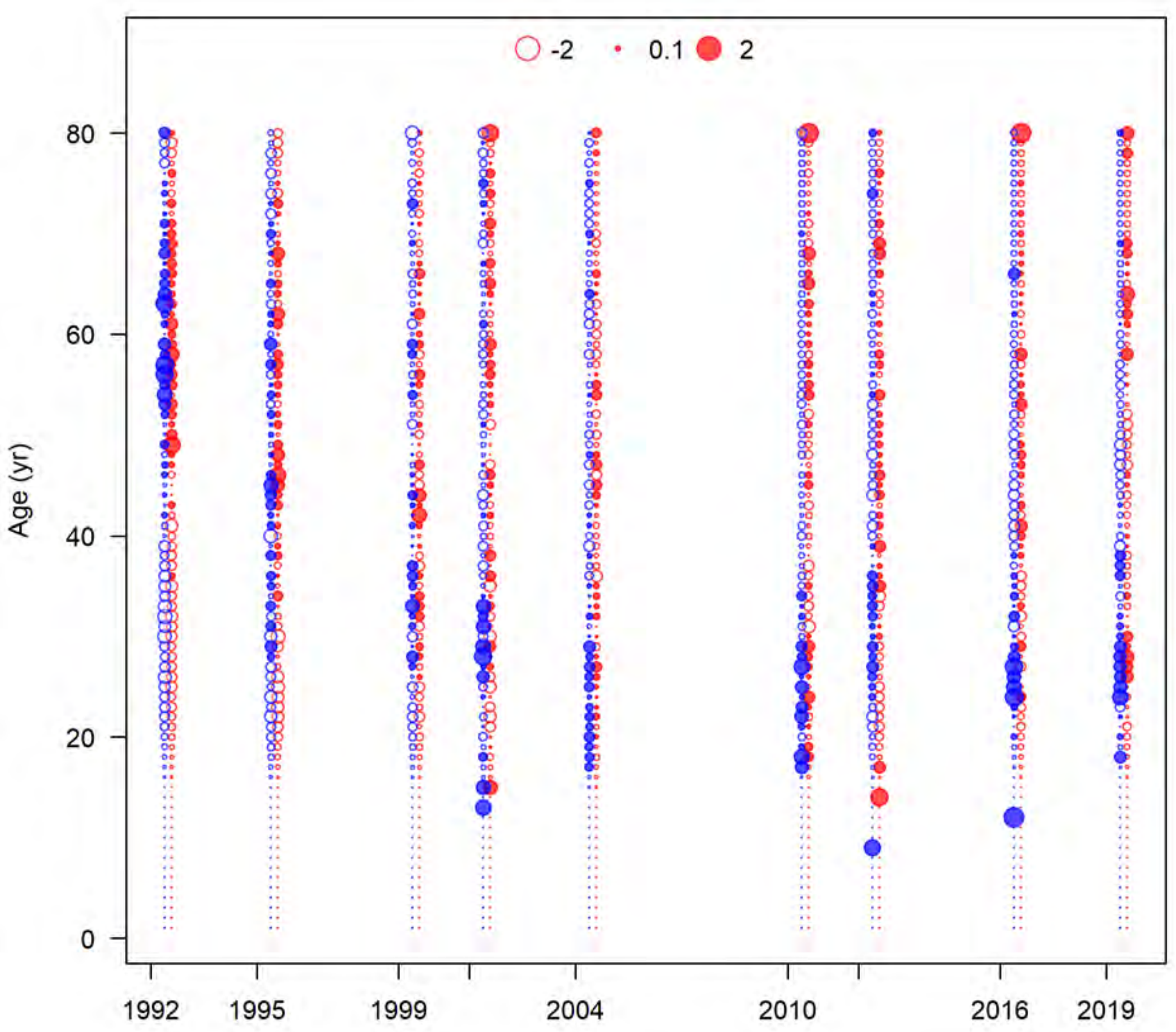


Figure A 9.7. Pearson residuals from the age composition data for the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1}.

9.8.4 *Additional diagnostics for candidate base-cases with M estimated*

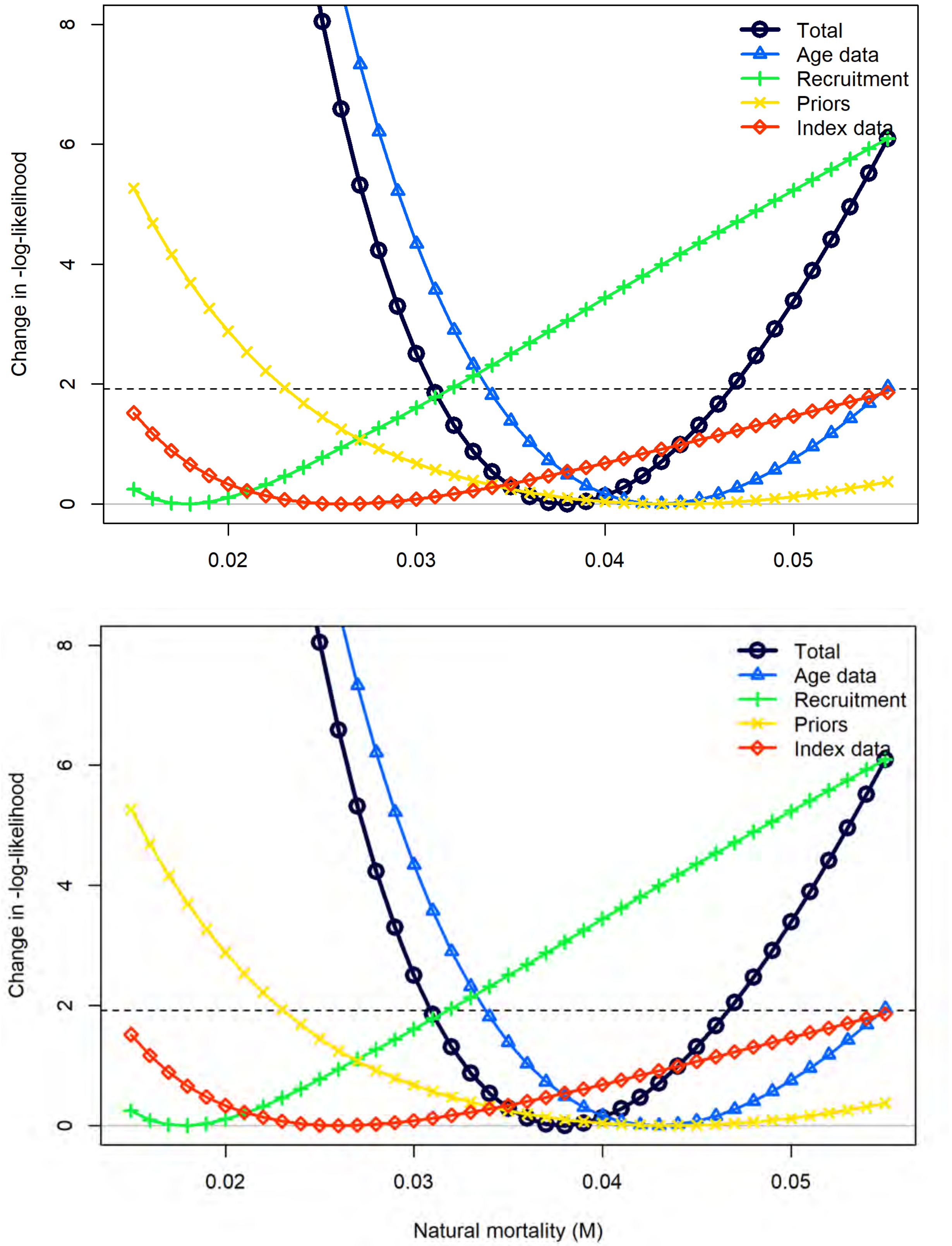


Figure A 9.8. Likelihood profiles for natural mortality for models with plus-groups of 100 (top) and 120 (bottom). When *M* was estimated, the model with a plus-group at 100 estimated natural mortality at *M*=0.0373 yr^{-1} and the model with a plus-group at 120 estimated natural mortality at *M*=0.0386 yr^{-1}.

9.8.5 Diagnostics for model with 80 age-classes and M estimated

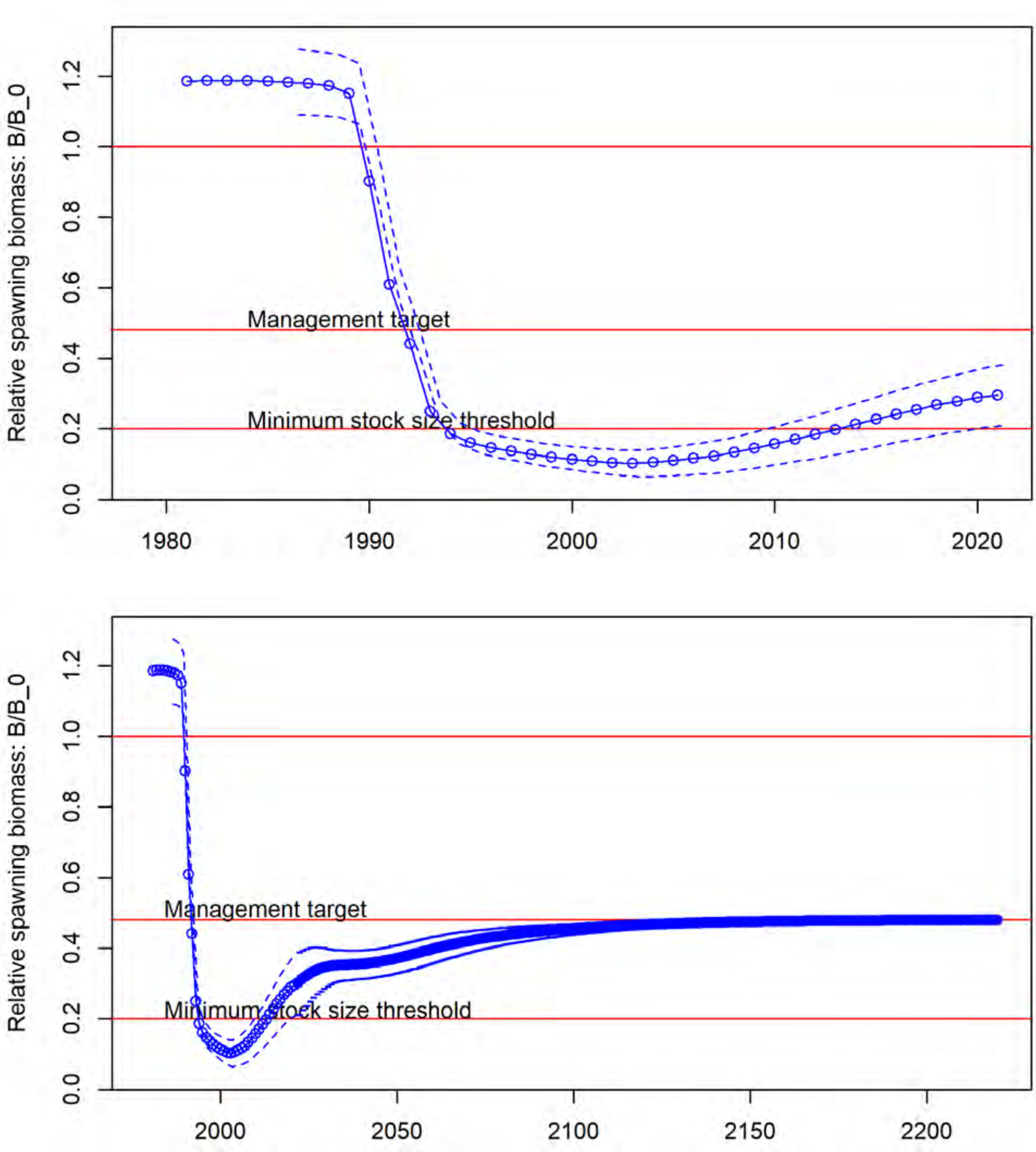


Figure A 9.9. The estimated time-series of relative spawning biomass with asymptotic 95% confidence intervals (top) and forecast 200 years into the future with catches set using the SESSF 20:35:48 harvest control rule (bottom) for the 2021 preliminary base-case model with a plus-group at 80 years and *M* estimated.

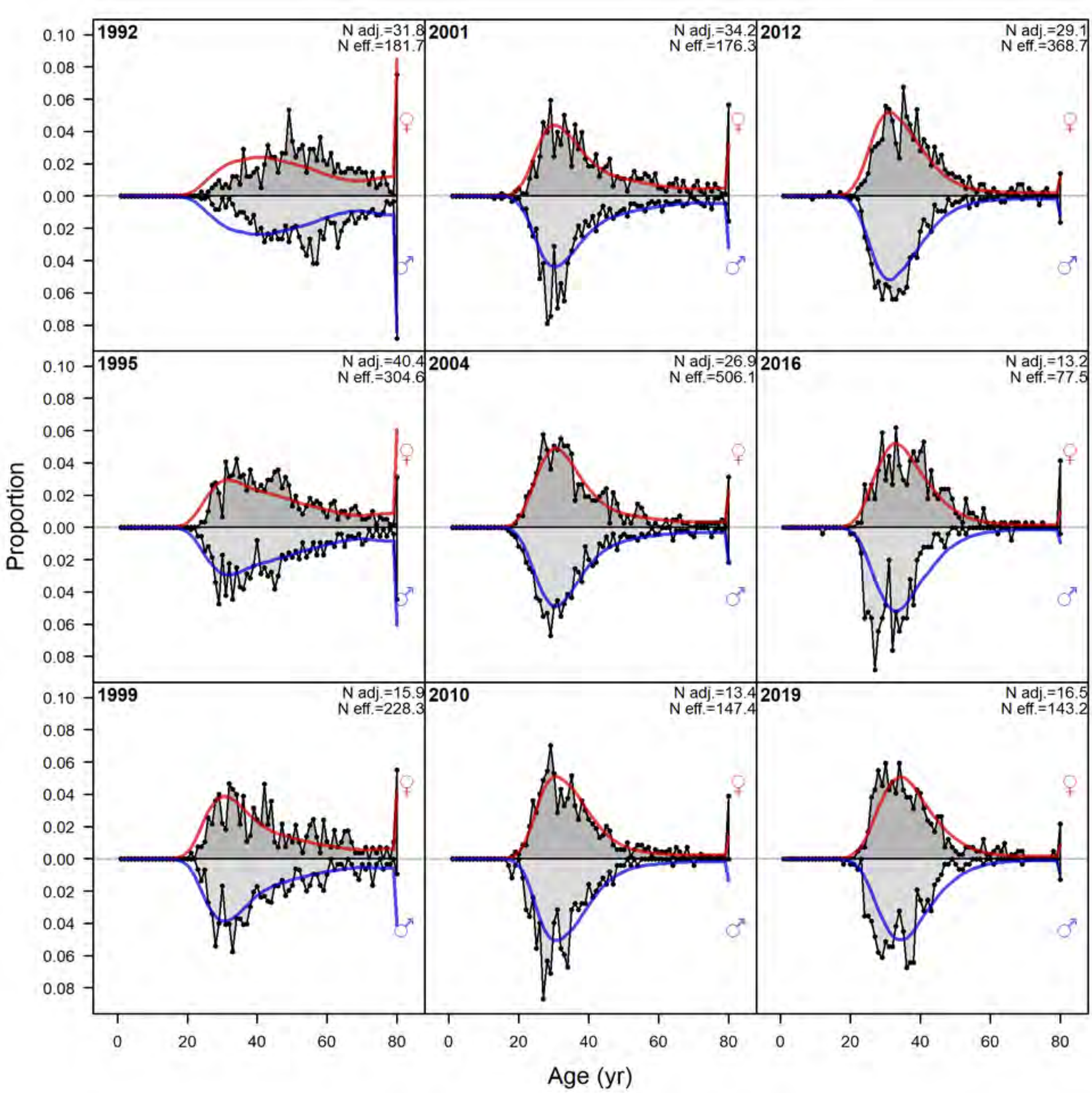


Figure A 9.10. Fits to the age composition data for the 2021 preliminary base-case model with a plus-group at 80 years and *M* estimated.

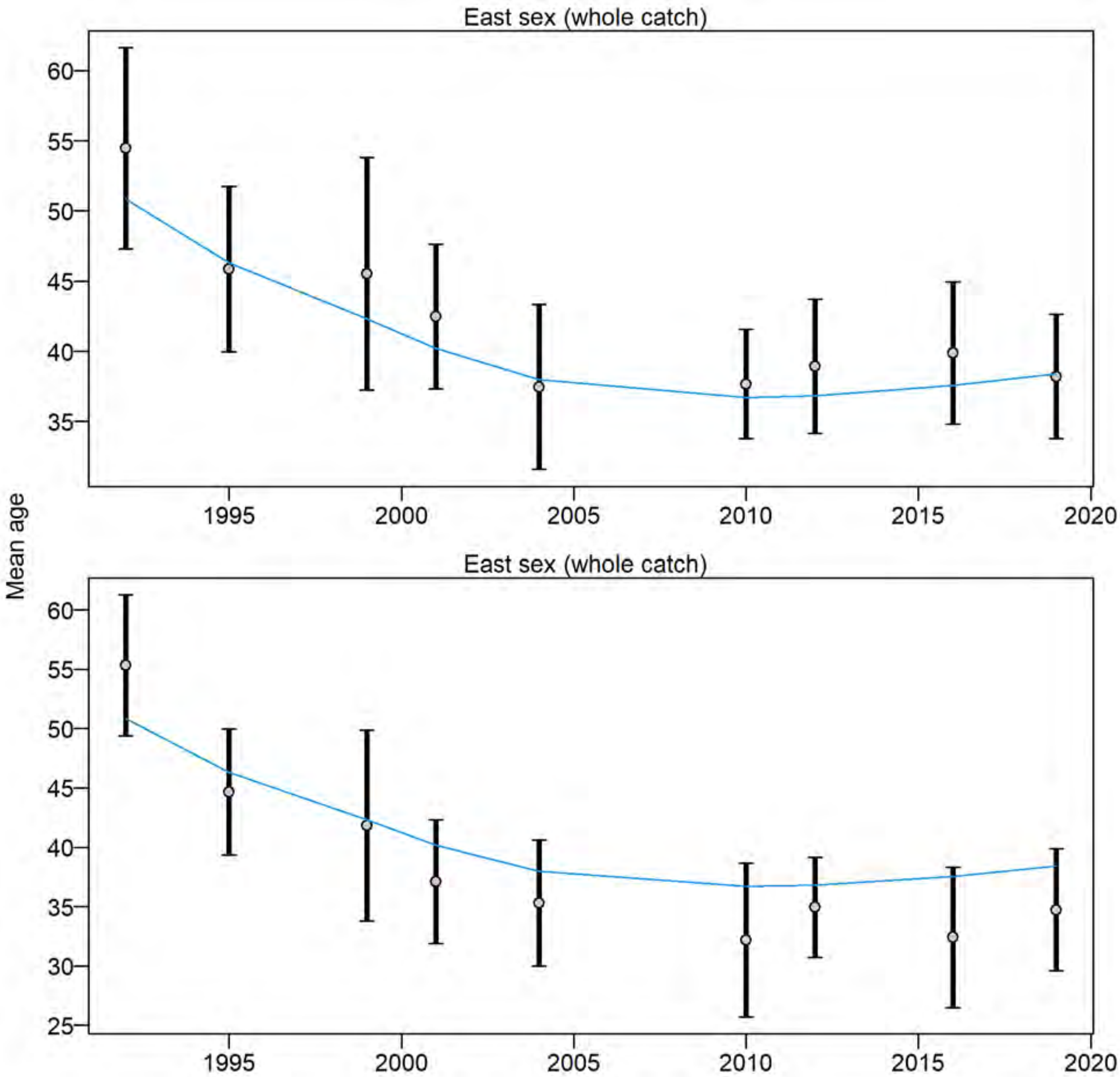


Figure A 9.11. Mean age for male and female samples with 95% confidence intervals based on current samples sizes for the 2021 preliminary base-case model with a plus-group at 80 years and *M* estimated. Suggested multiplier for Francis data weighting method TA1.8 of age data with 95% interval is 1.0002 (0.7479-1.8131).

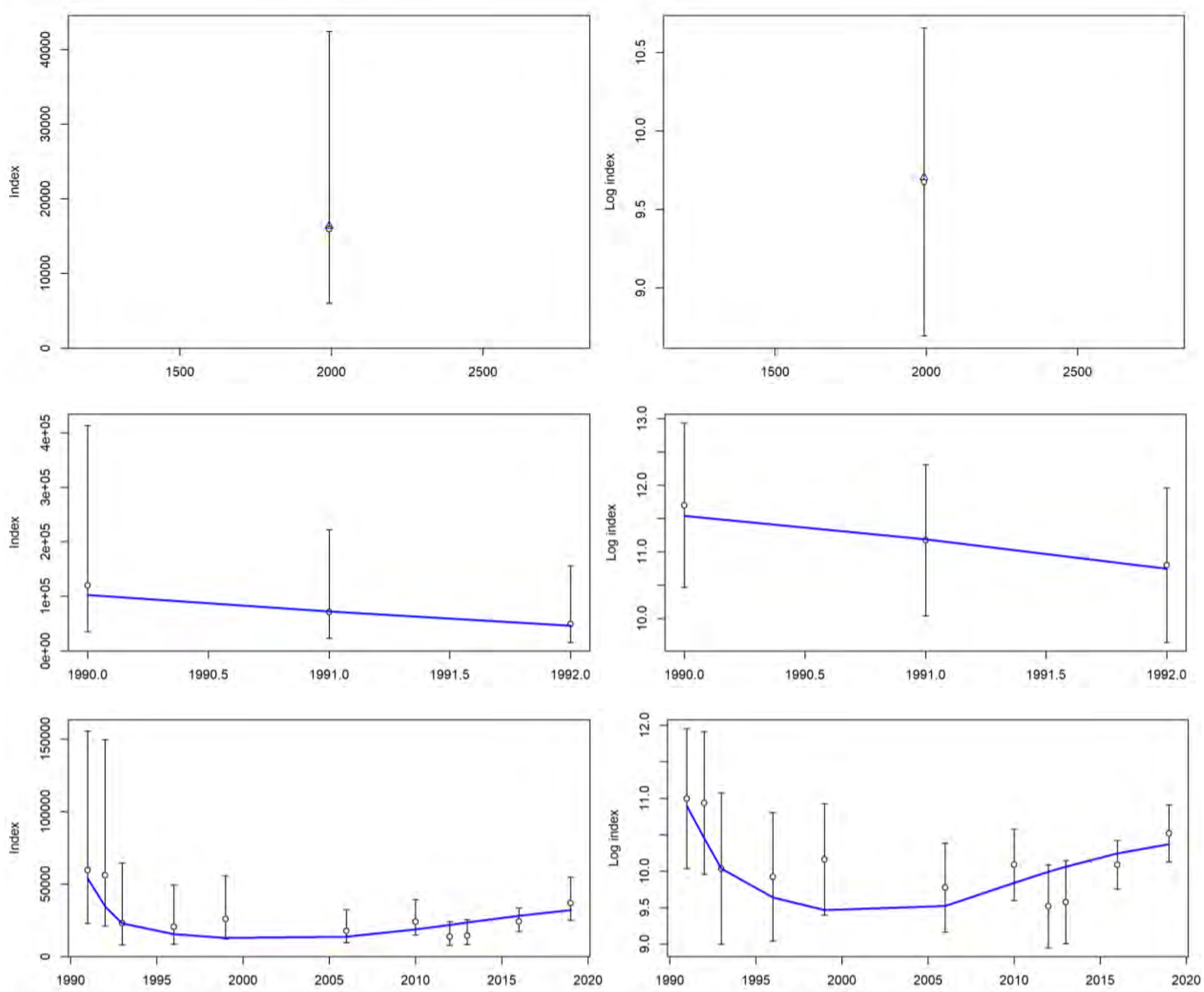


Figure A 9.12. Fits to the biomass indices (left) and log indices (right) for the egg (top), hull (middle) and towed (bottom) surveys for the 2021 preliminary base-case model with a plus-group at 80 years and *M* estimated.

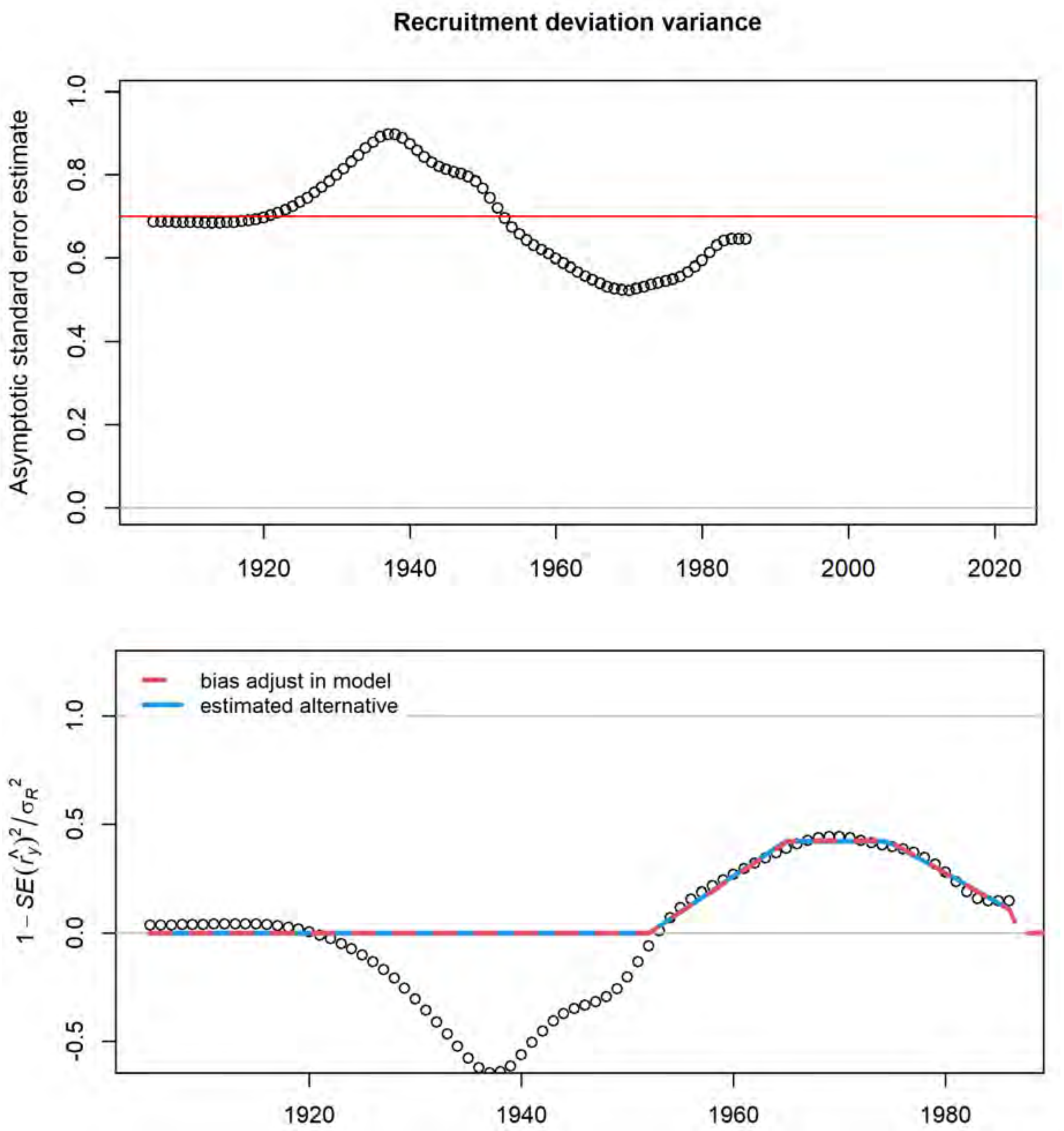


Figure A 9.13. Recruitment deviation variance check (top) and bias ramp adjustment (bottom) for the 2021 preliminary base-case model with a plus-group at 80 years and *M* estimated.

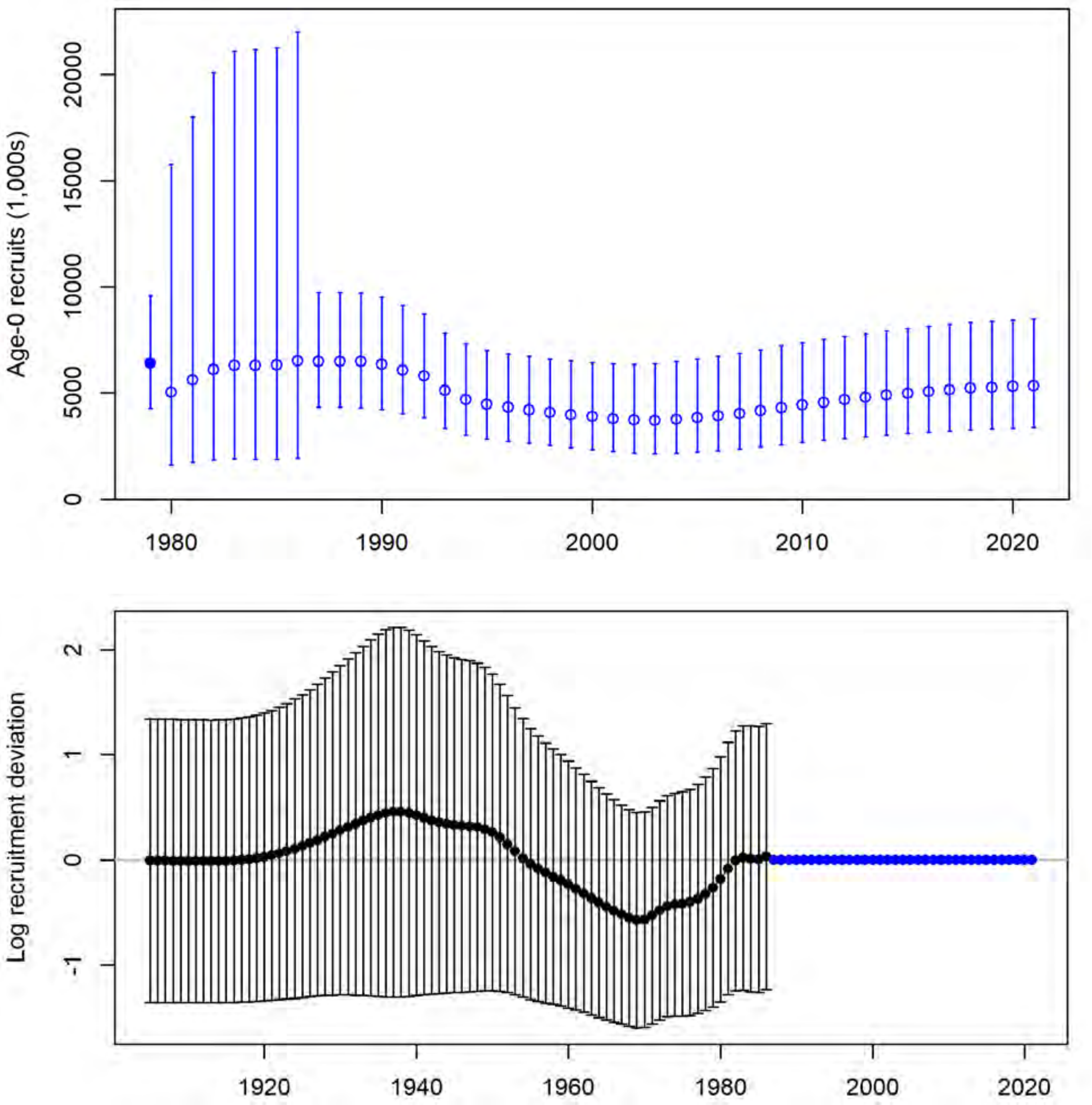


Figure A 9.14. Time series showing absolute recruitment estimates with confidence intervals (top) and recruitment deviations with confidence intervals (bottom) for the 2021 preliminary base-case model with a plus-group at 80 years and *M* estimated.

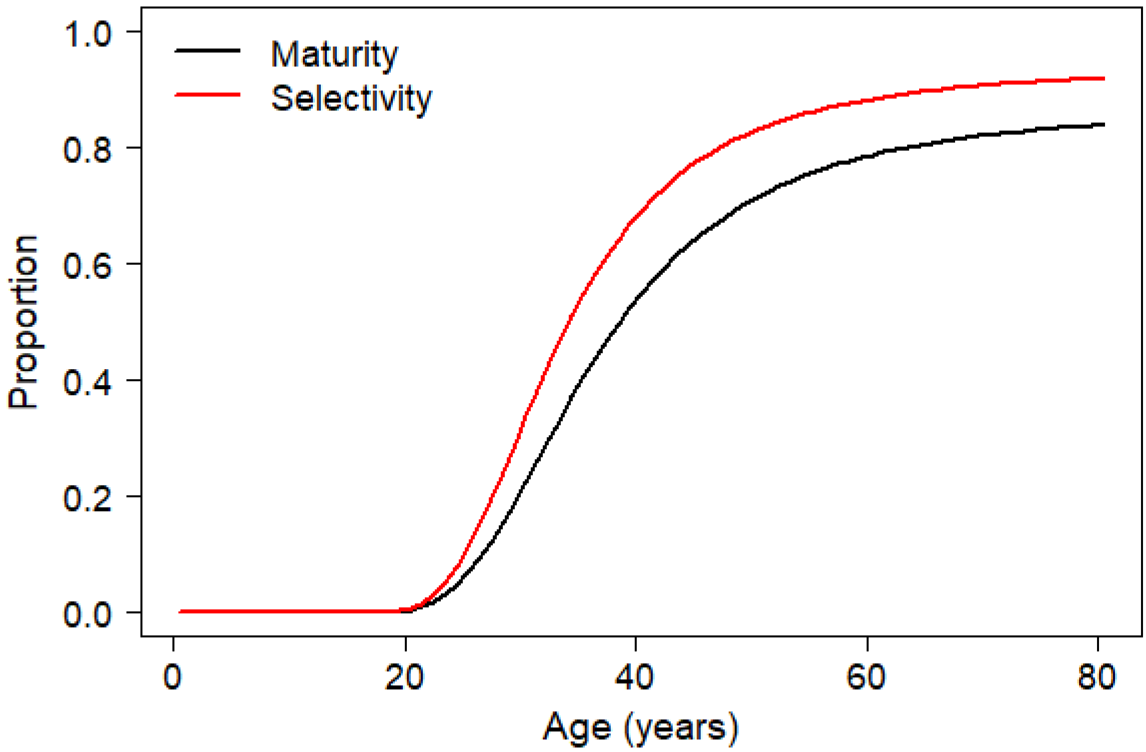


Figure A 9.15. Estimated selectivity and fixed maturity for the 2021 preliminary base-case model with a plus-group at 80 years and *M* estimated.

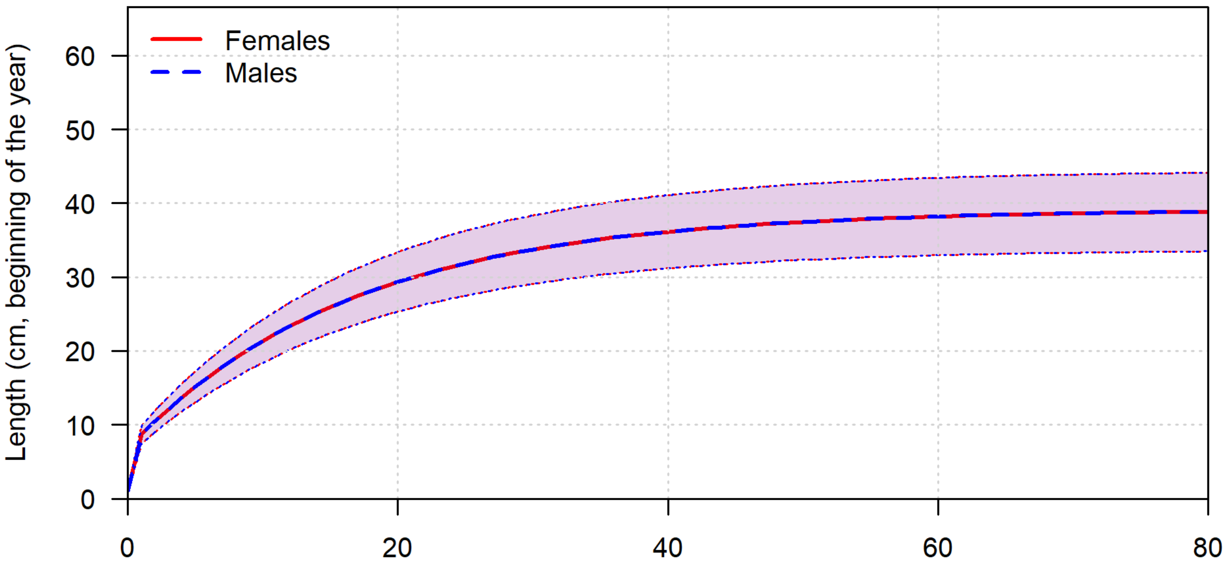


Figure A 9.16. Growth for the 2021 preliminary base-case model with 80 age-classes and *M* estimated.

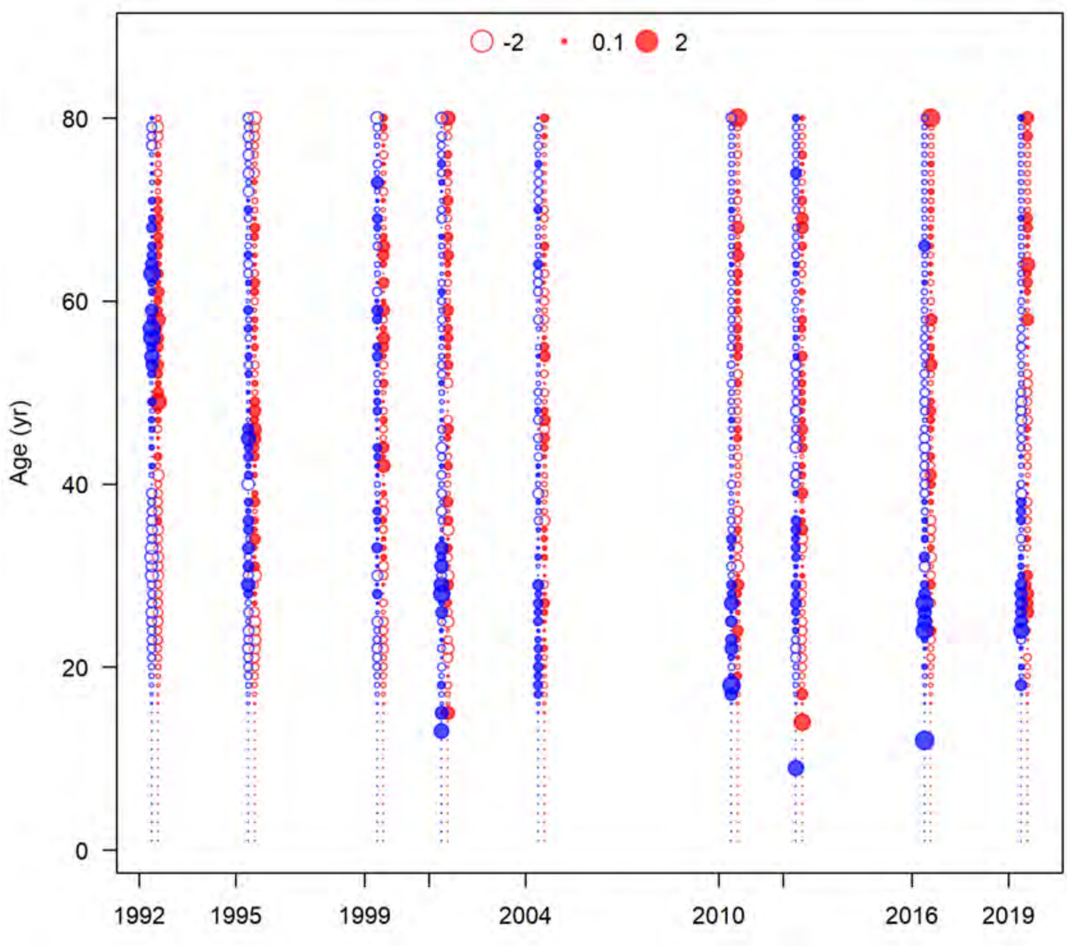


Figure A 9.17. Pearson residuals from the age composition for the 2021 preliminary base-case model with a plus-group at 80 years and *M* estimated.

9.8.6 *Diagnostics for model with 100 age-classes and M estimated*

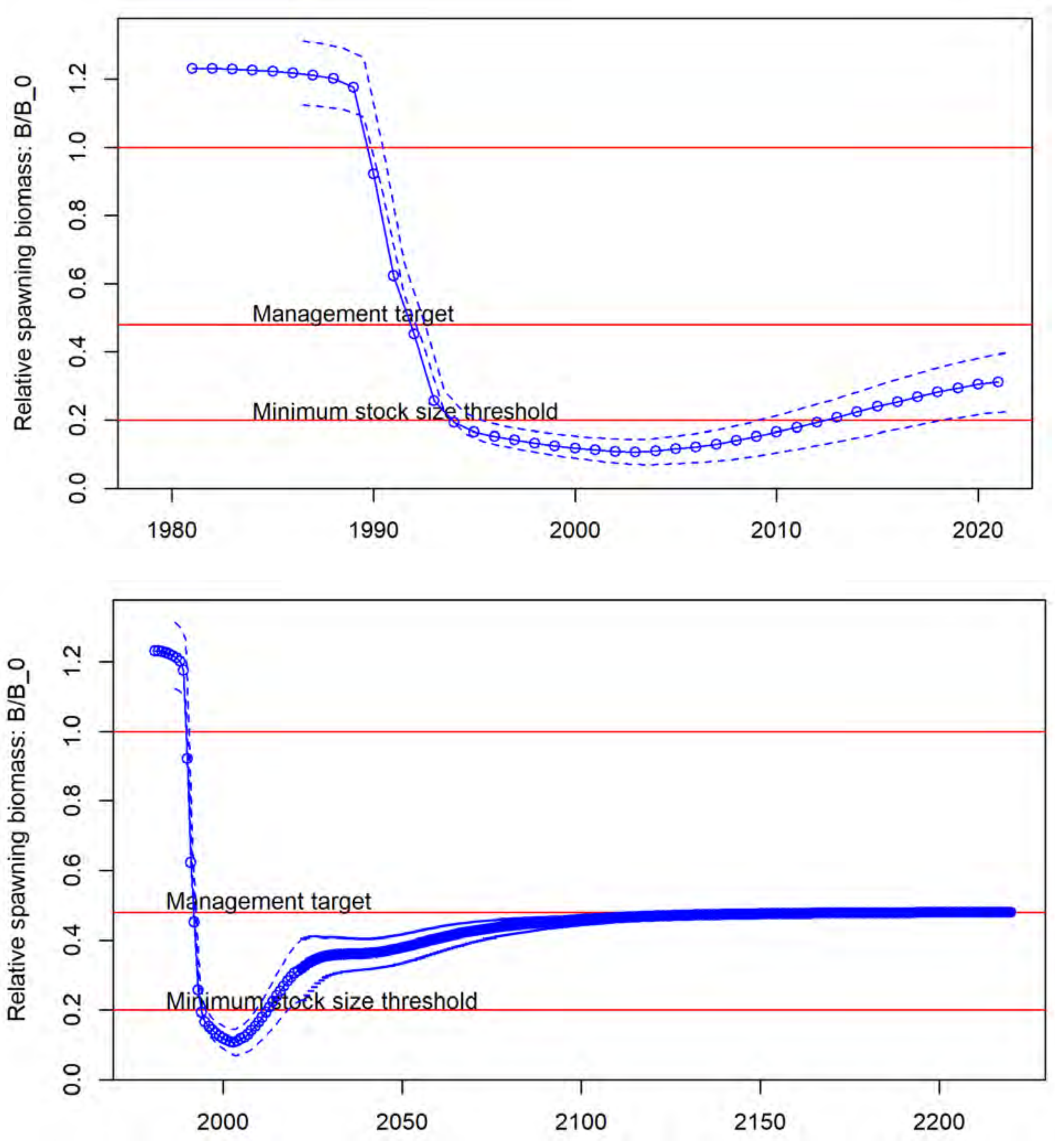


Figure A 9.18. The estimated time-series of relative spawning biomass with asymptotic 95% confidence intervals (top) and forecast 200 years into the future with catches set using the SESSF 20:35:48 harvest control rule (bottom) for the 2021 preliminary base-case model with a plus-group at 100 years and *M* estimated.

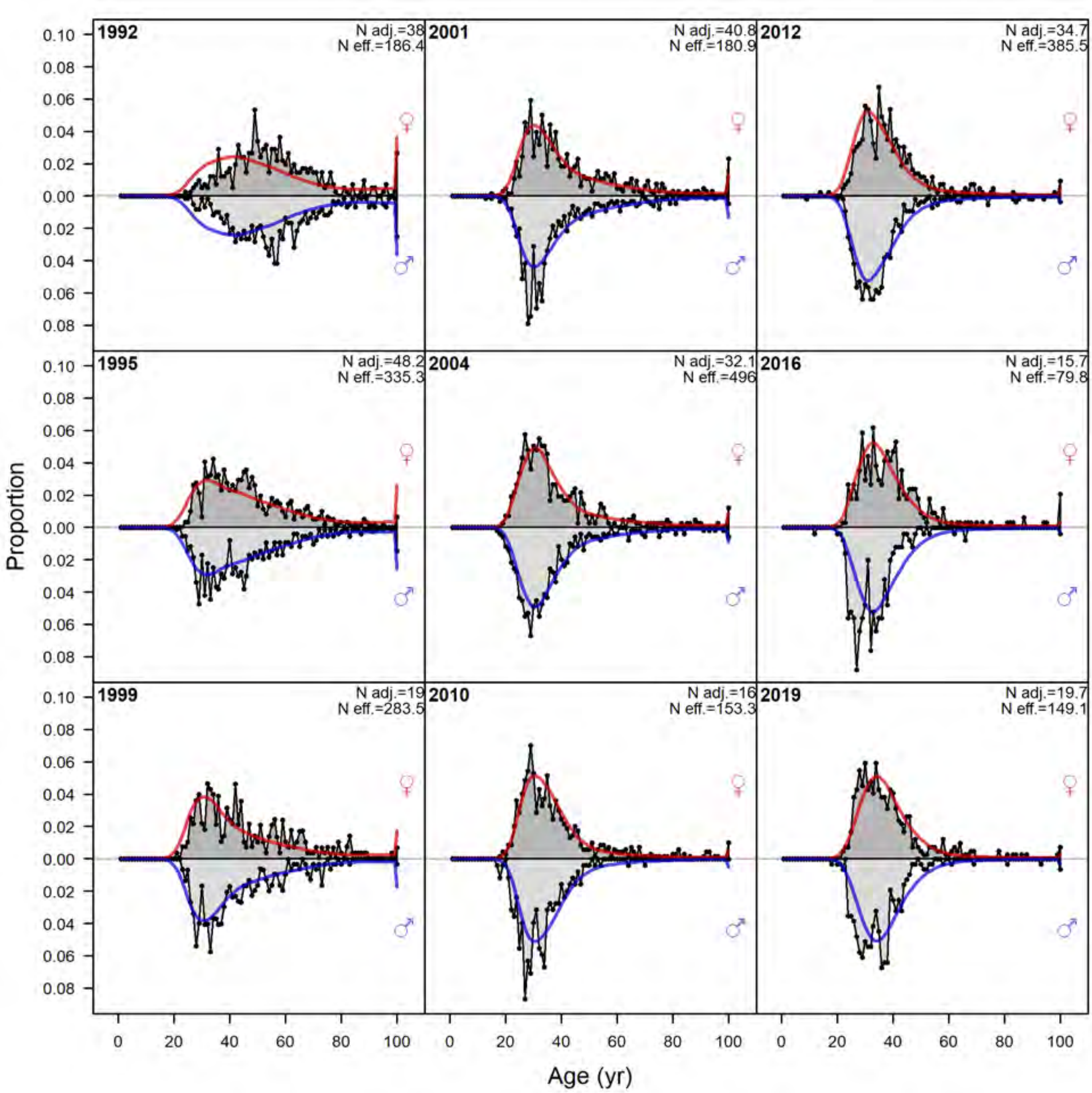


Figure A 9.19. Fits to the age composition data for the 2021 preliminary base-case model with a plus-group at 100 years and *M* estimated.

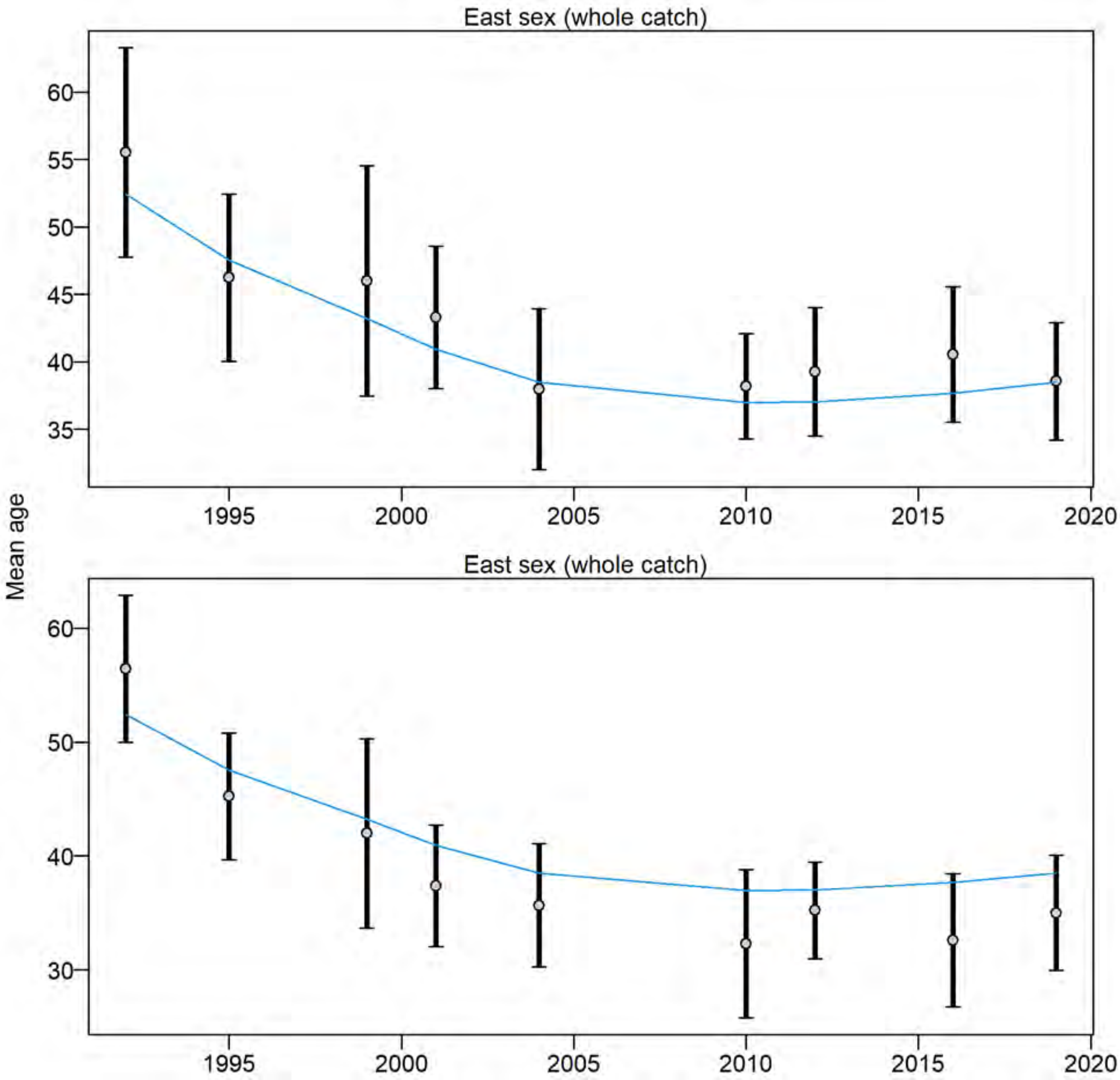


Figure A 9.20. Mean age for male and female samples with 95% confidence intervals based on current samples sizes for the 2021 preliminary base-case model with a plus-group at 100 years and *M* estimated. Suggested multiplier for Francis data weighting method TA1.8 of age data with 95% interval is 1.0014 (0.7852-1.7022).

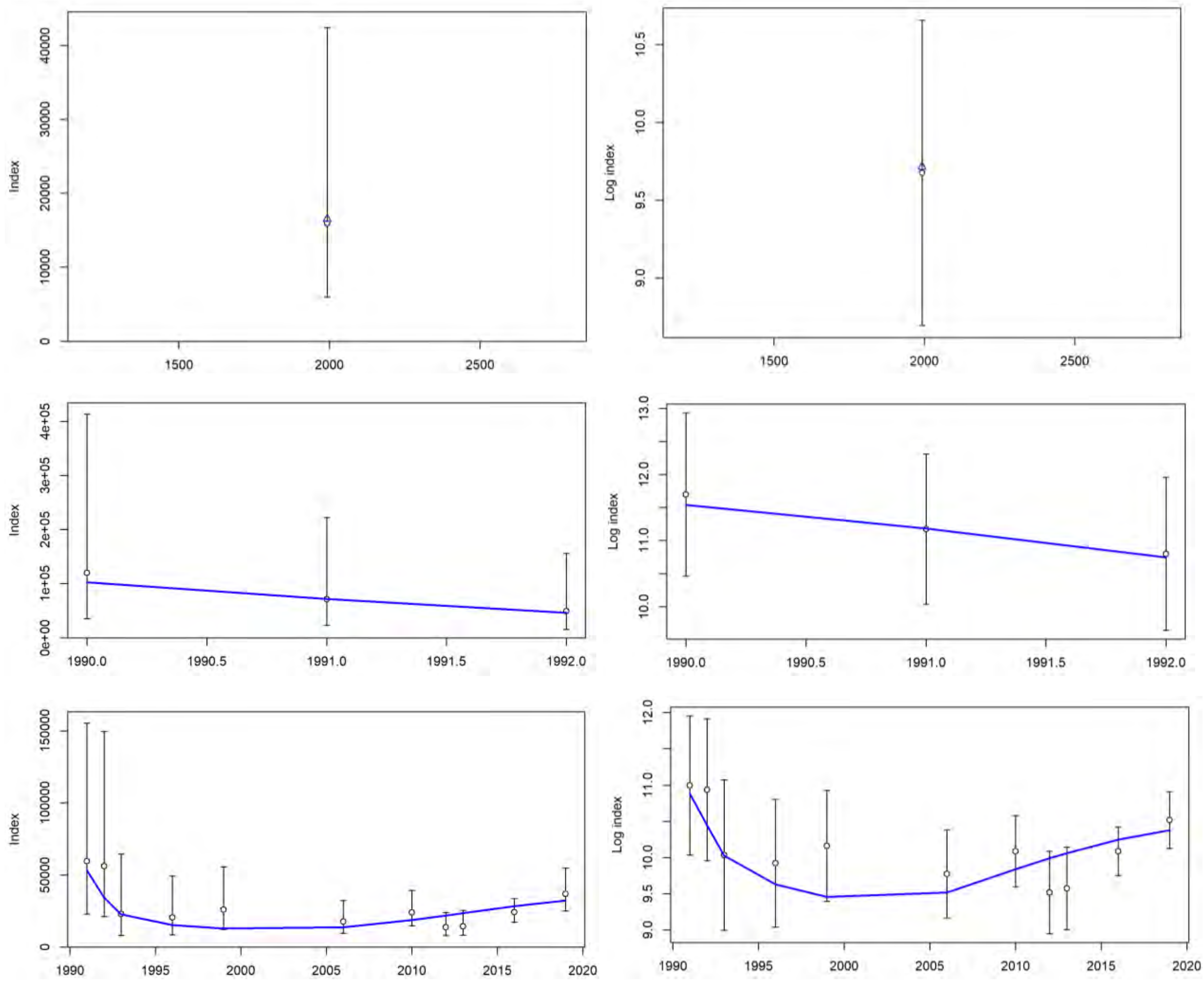


Figure A 9.21. Fits to the biomass indices (left) and log indices (right) for the egg (top), hull (middle) and towed (bottom) surveys for the 2021 preliminary base-case model with a plus-group at 100 years and *M* estimated.

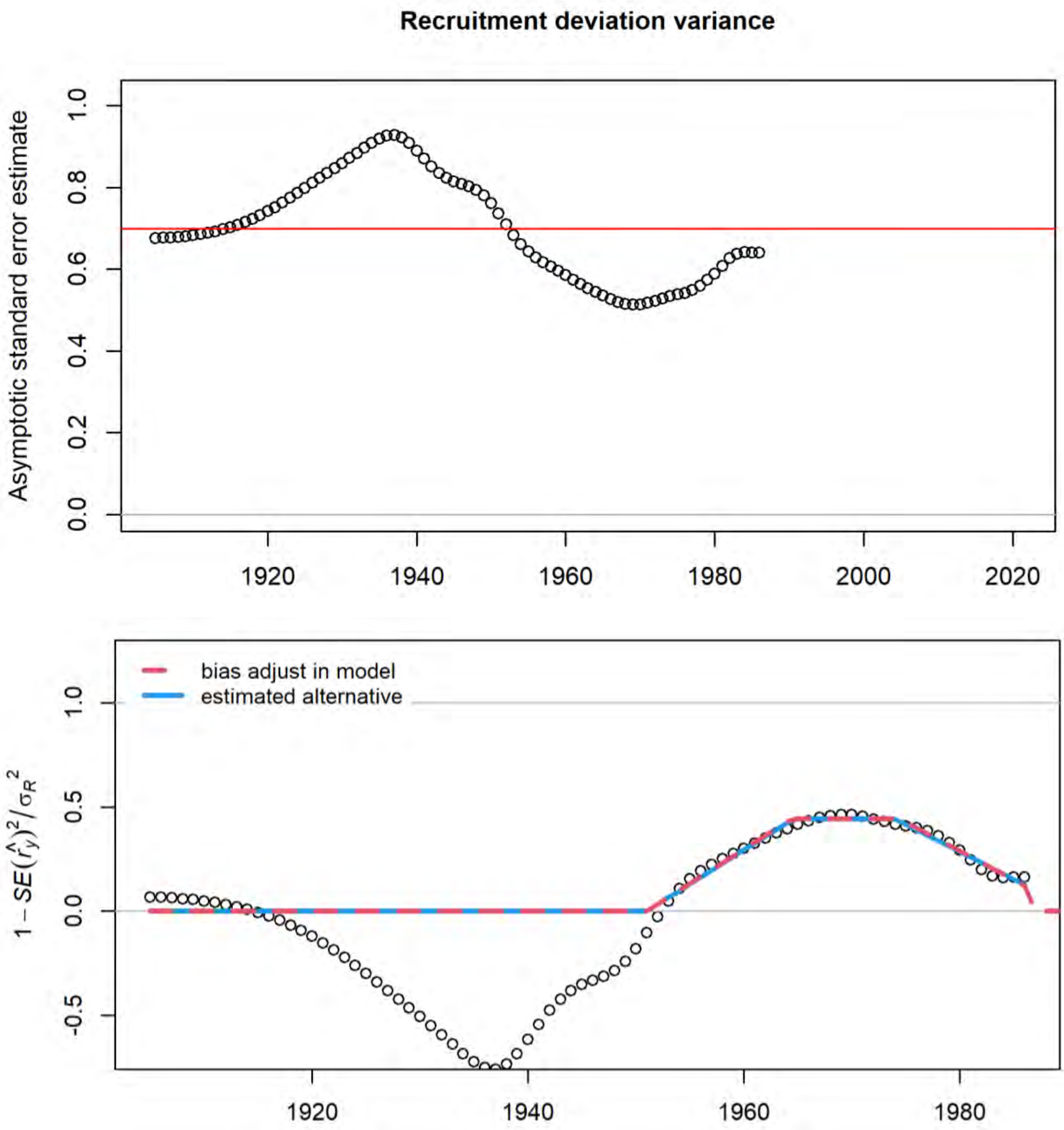
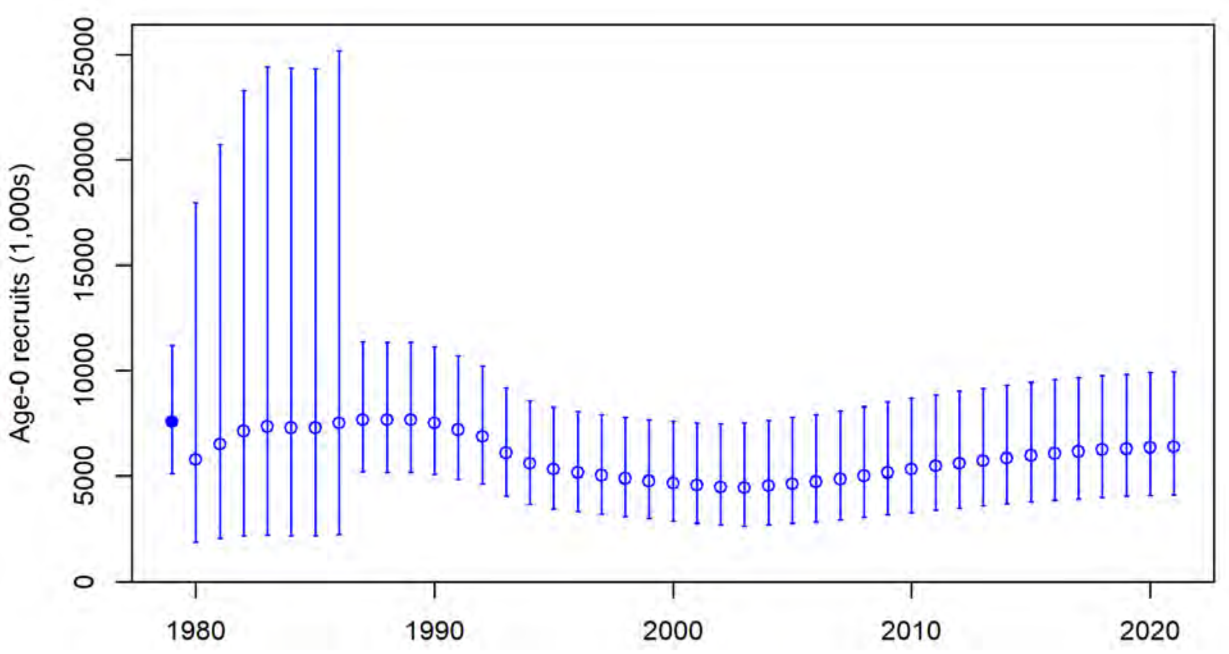


Figure A 9.22. Recruitment deviation variance check and bias ramp adjustment for the 2021 preliminary base-case model with a plus-group at 100 years and *M* estimated.



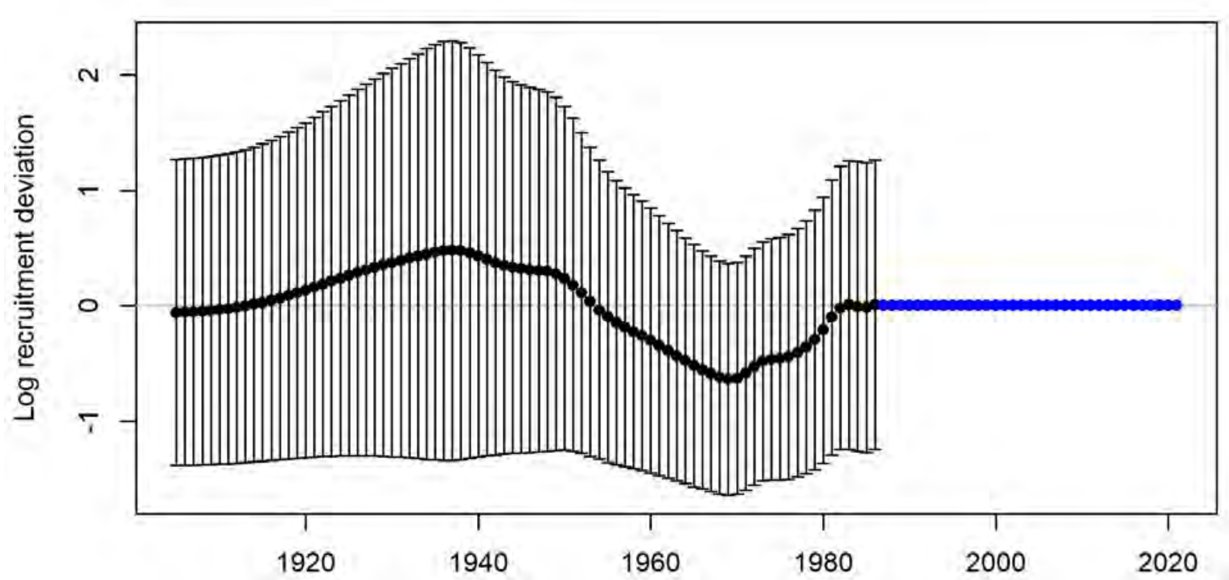


Figure A 9.23. Time series showing absolute recruitment estimates with confidence intervals (top) and recruitment deviations with confidence intervals (bottom) for the 2021 preliminary base-case model with a plus-group at 100 years and *M* estimated.

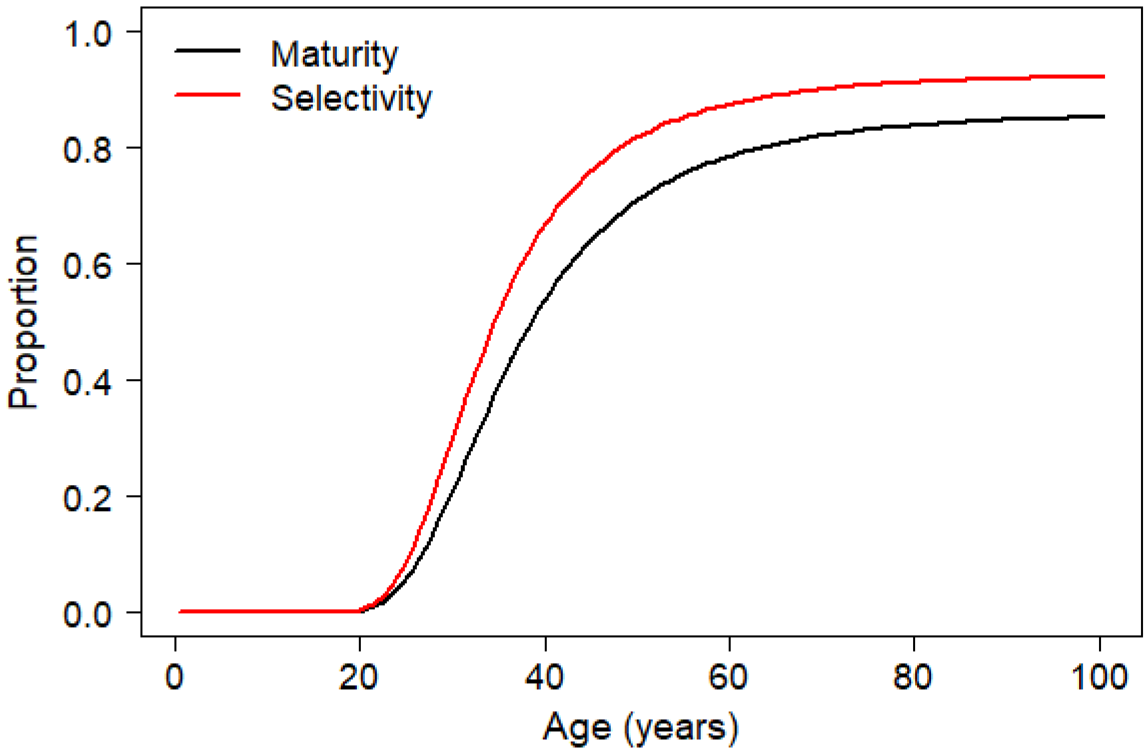


Figure A 9.24. Estimated selectivity and fixed maturity for the 2021 preliminary base-case model with a plus-group at 100 years and *M* estimated. Note maturity and selectivity are not independent above age 80.

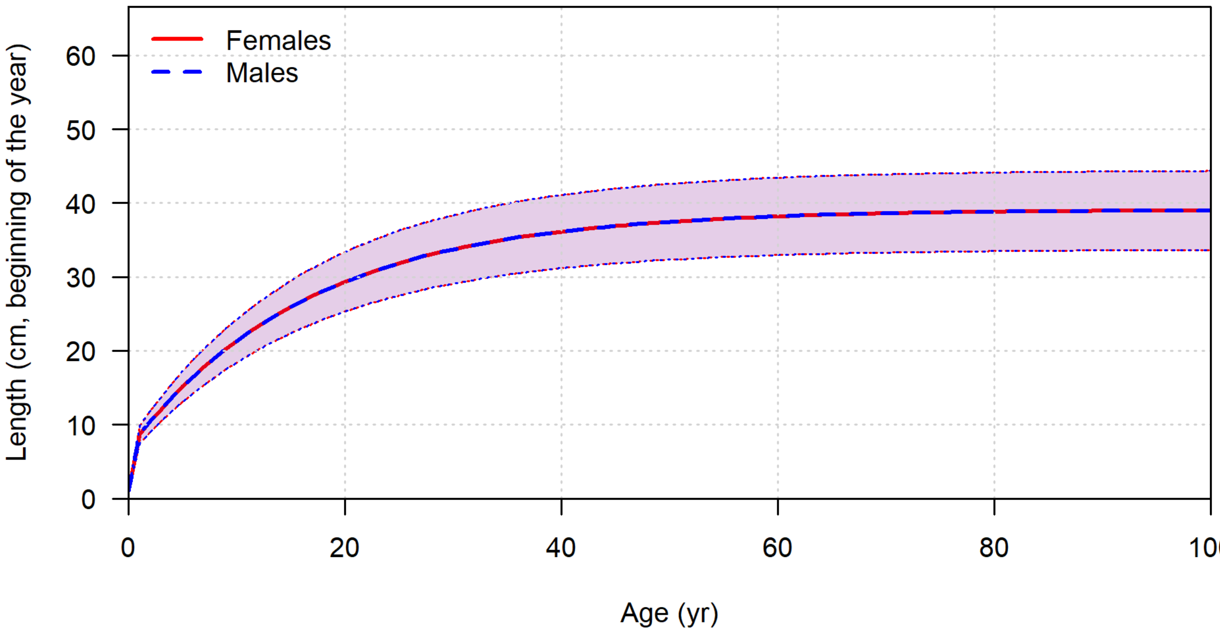


Figure A 9.25. Growth for the 2021 preliminary base-case model with a plus-group at 100 years.

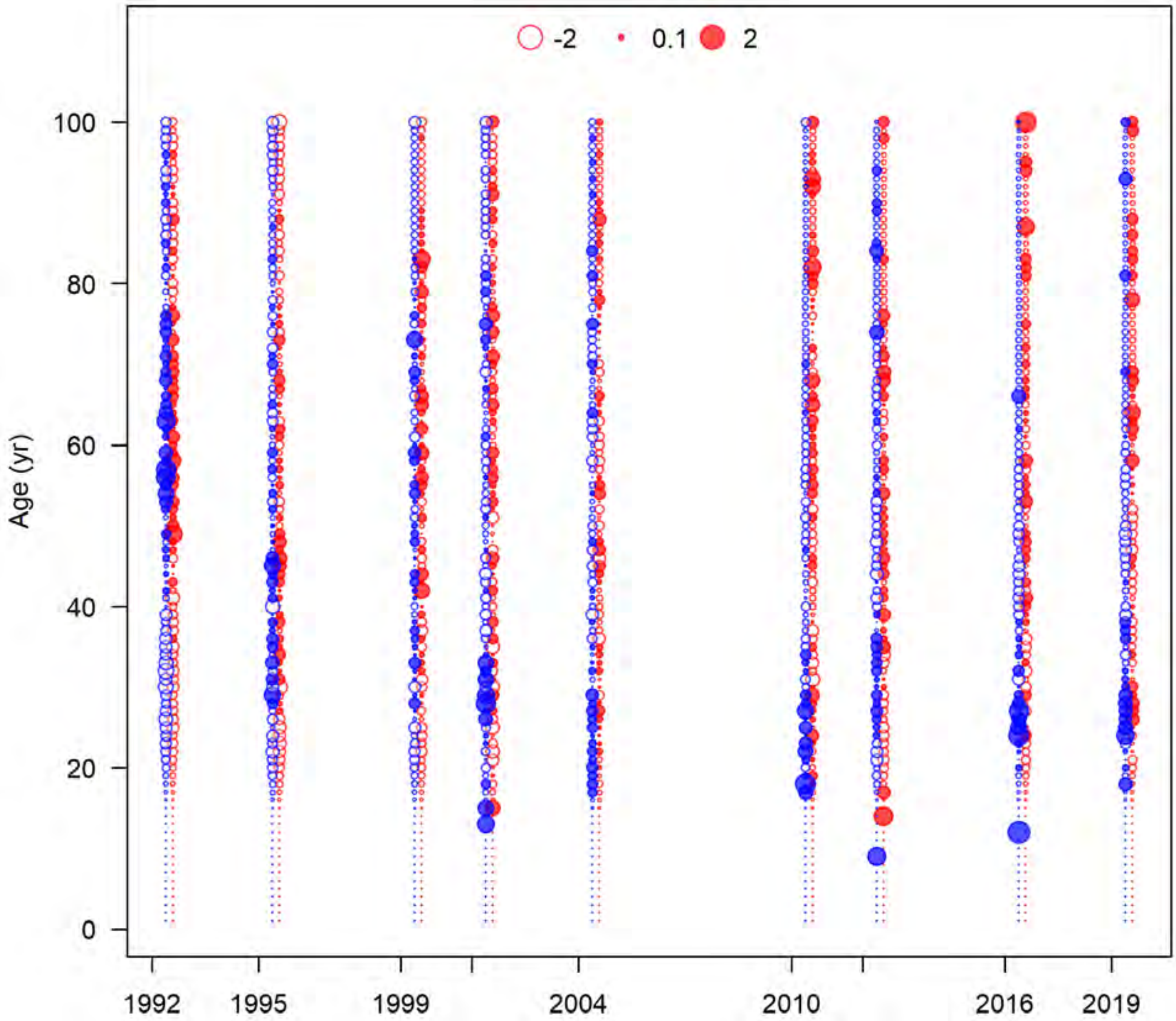
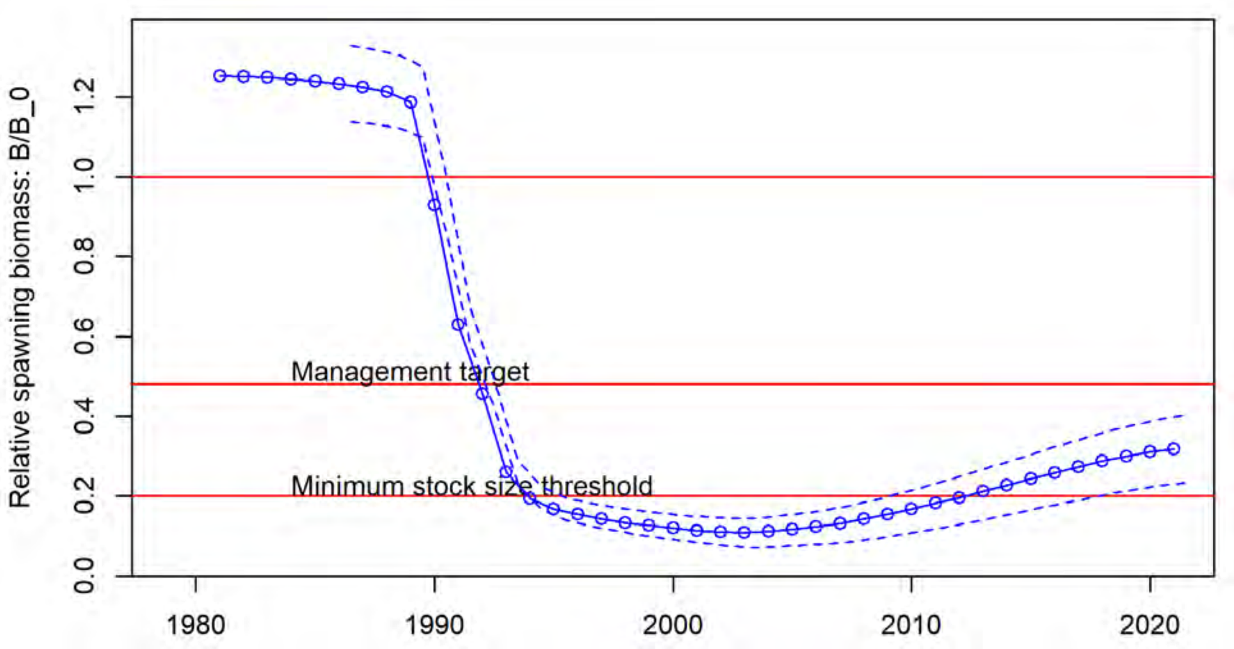


Figure A 9.26. Pearson residuals from the age composition data for the 2021 preliminary base-case model with a plus-group at 100 years and *M* estimated.

9.8.7 ***Diagnostics for model with 120 age-classes and M estimated***



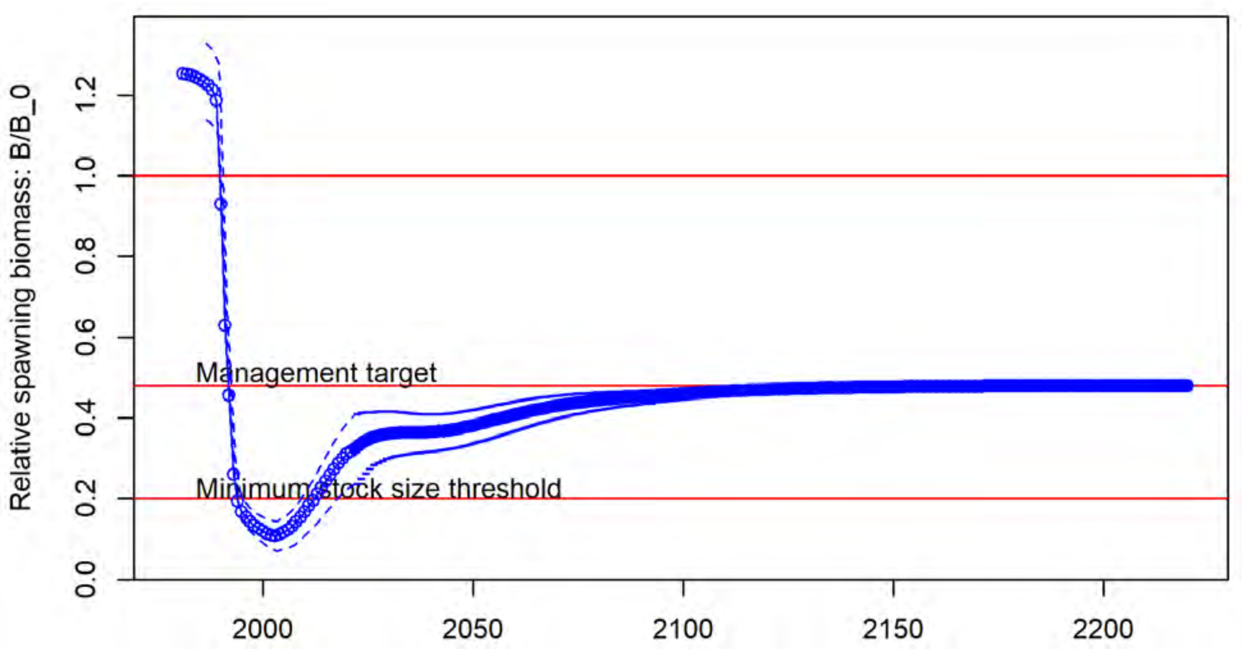


Figure A 9.27. The estimated time-series of relative spawning biomass with asymptotic 95% confidence intervals (top) and forecast 200 years into the future with catches set using the SESSF 20:35:48 harvest control rule (bottom) for the 2021 preliminary base-case model with a plus-group at 120 years and *M* estimated.

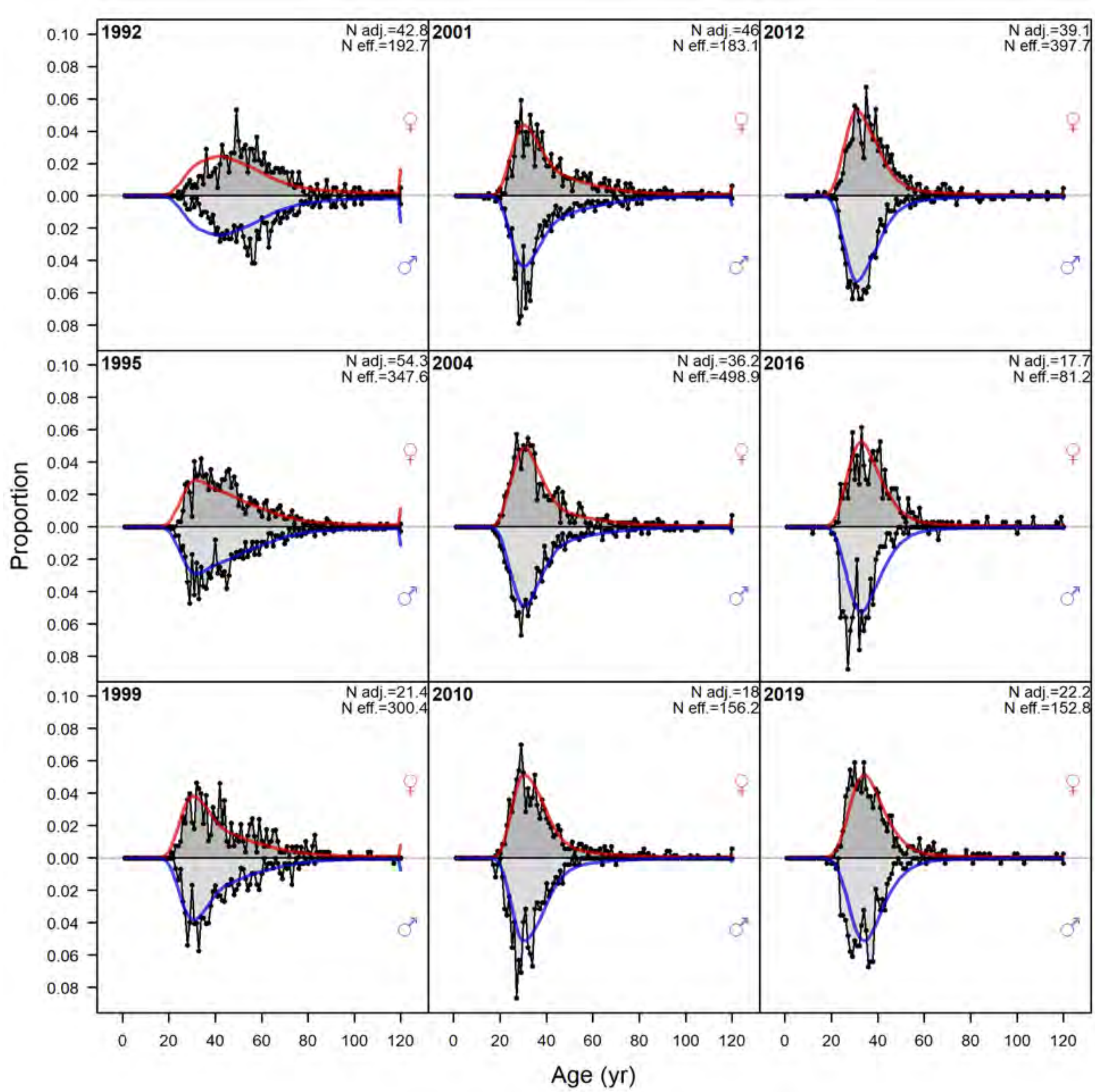


Figure A 9.28. Fits to the age composition data for the 2021 preliminary base-case model with a plus-group at 120 years and *M* estimated.

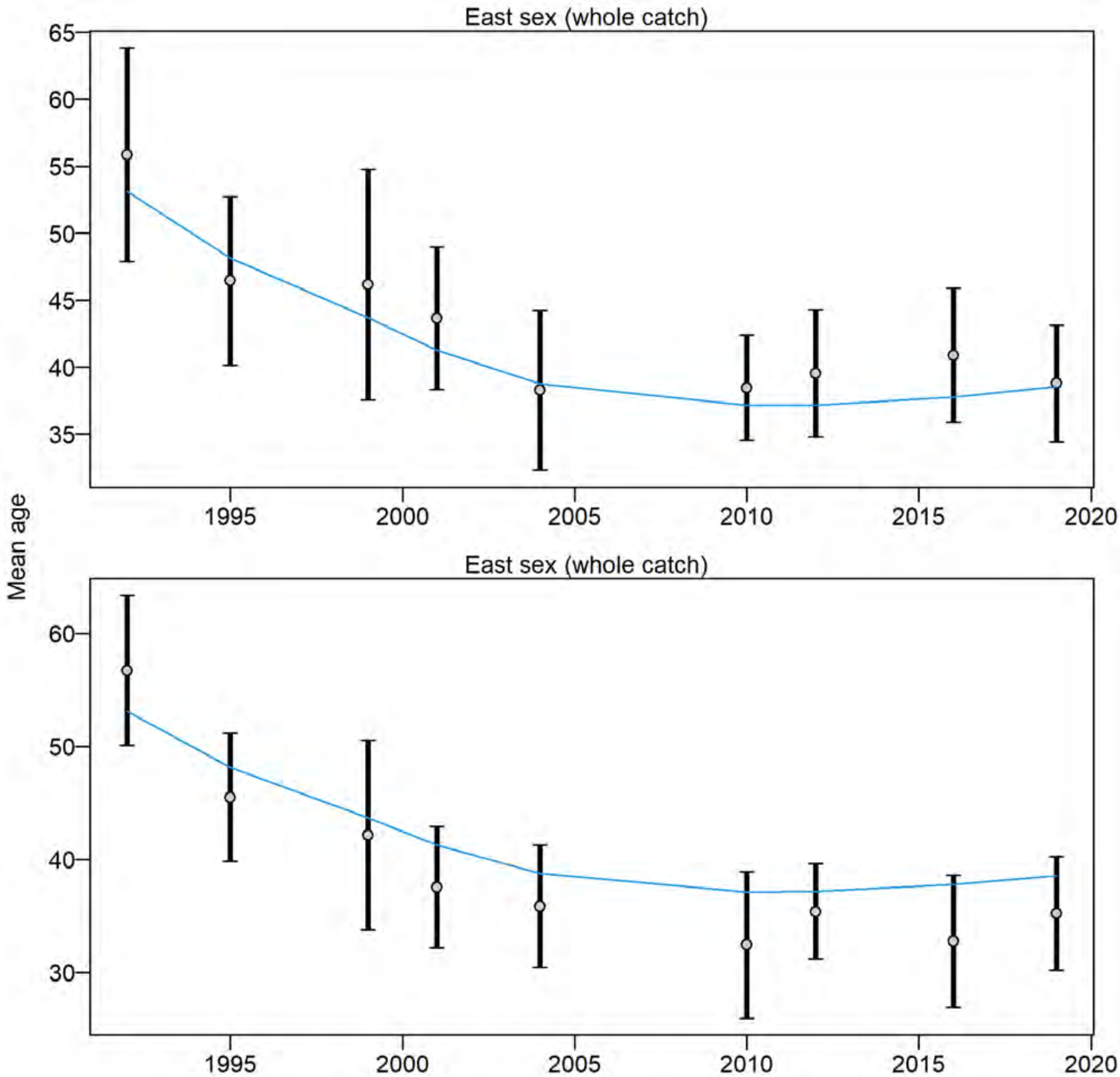


Figure A 9.29. Mean age for male and female samples with 95% confidence intervals based on current samples sizes for the 2021 preliminary base-case model with a plus-group at 120 years and *M* estimated. Suggested multiplier for Francis data weighting method TA1.8 of age data with 95% interval is 1.0022 (0.7615-1.7396).

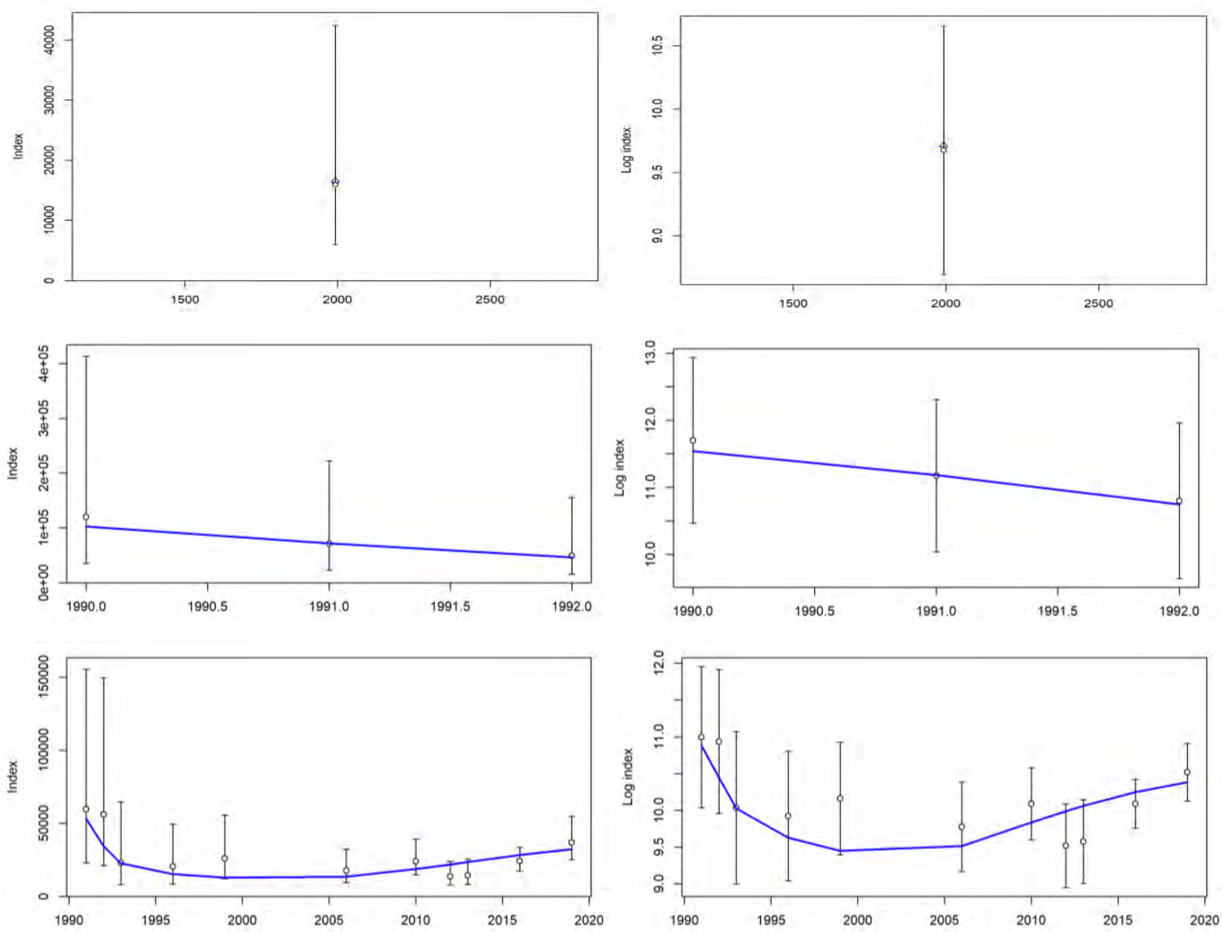


Figure A 9.30. Fits to the biomass indices (left) and log indices (right) for the egg (top), hull (middle) and towed (bottom) surveys for the 2021 preliminary base-case model with a plus-group at 120 years and *M* estimated.

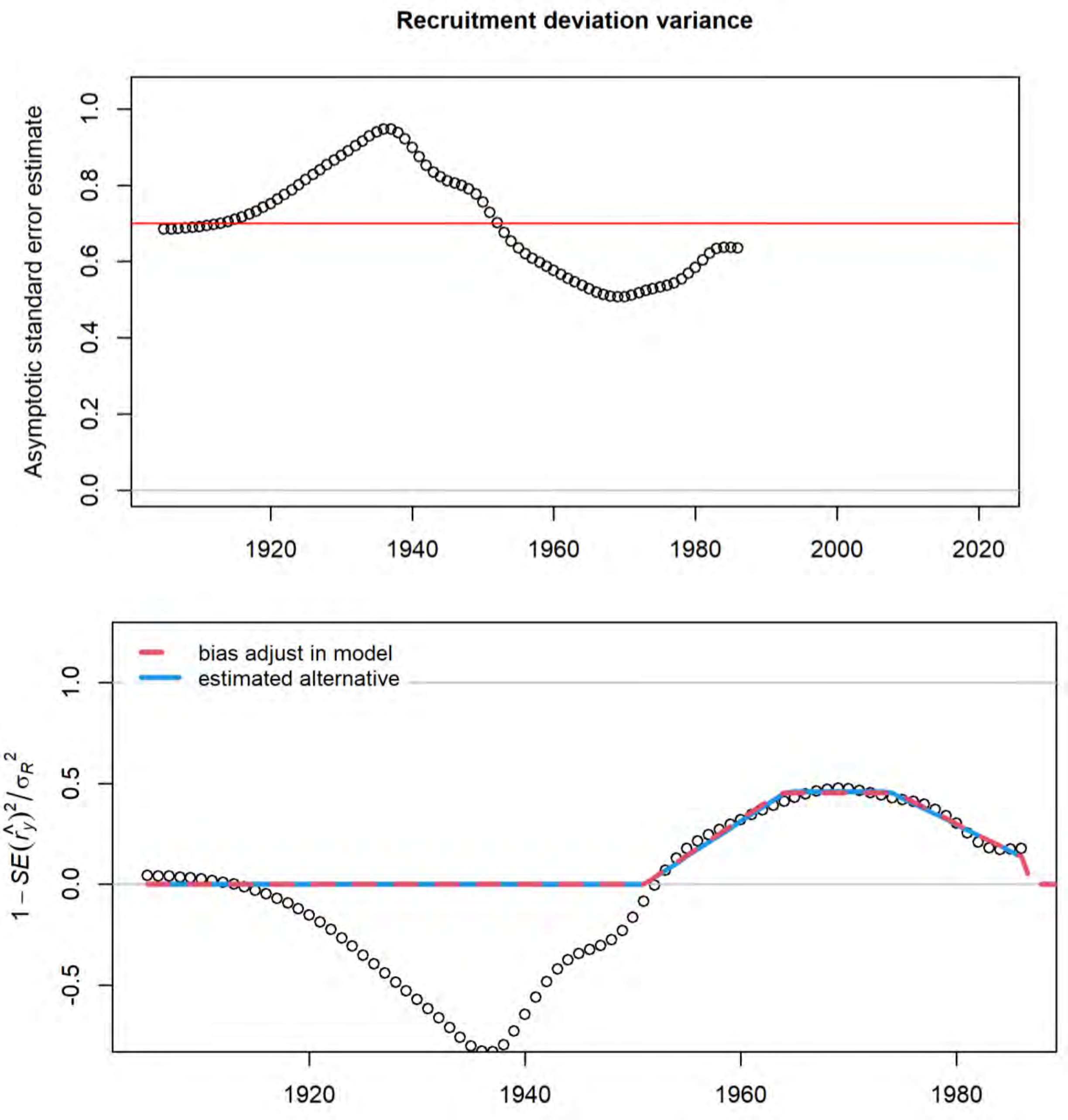


Figure A 9.31. Recruitment deviation variance check and bias ramp adjustment for the 2021 preliminary base-case model with a plus-group at 120 years and *M* estimated.

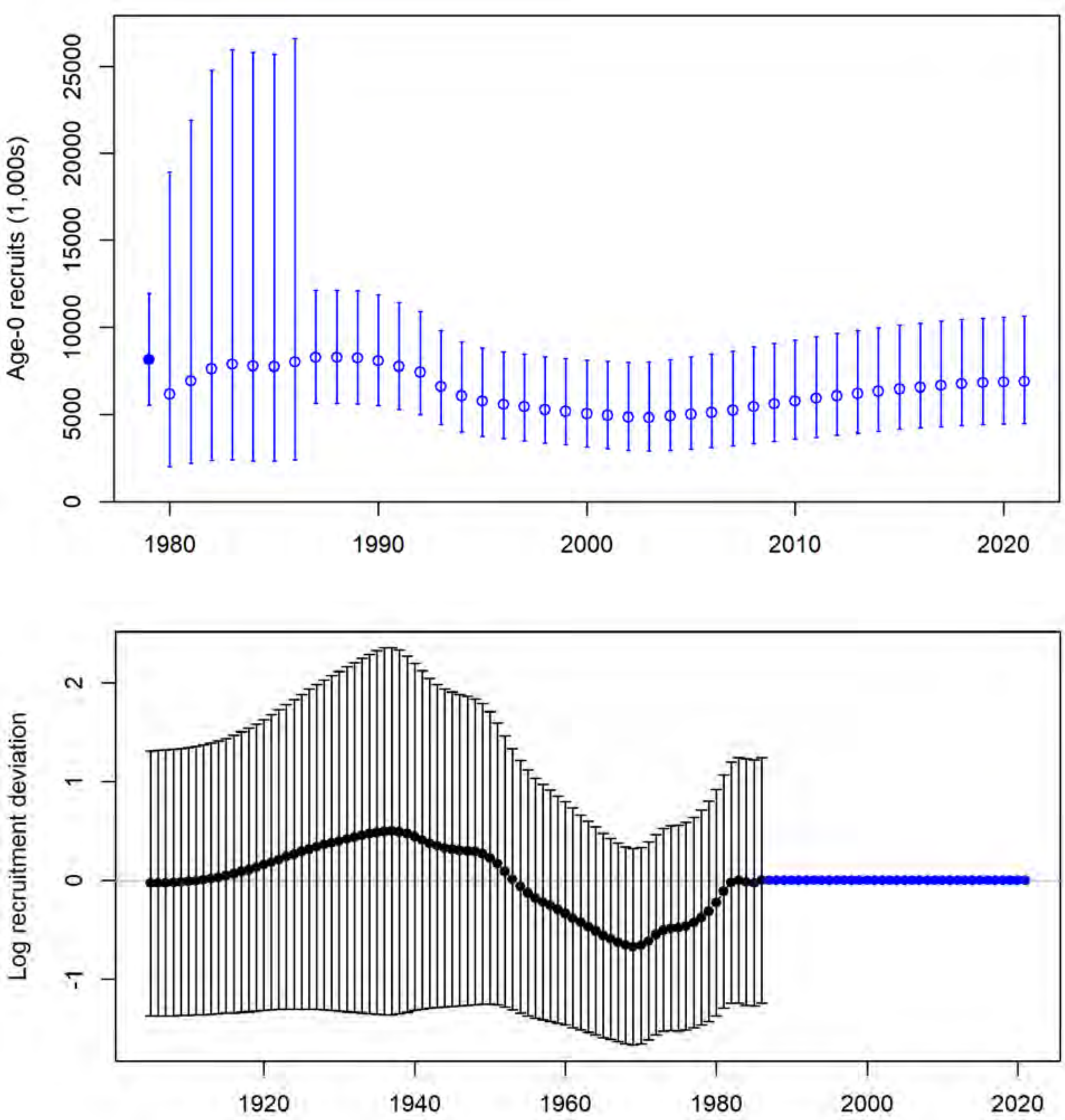


Figure A 9.32. Time series showing absolute recruitment estimates with confidence intervals (top) and recruitment deviations with confidence intervals (bottom) for the 2021 preliminary base-case model with a plus-group at 120 years and *M* estimated.

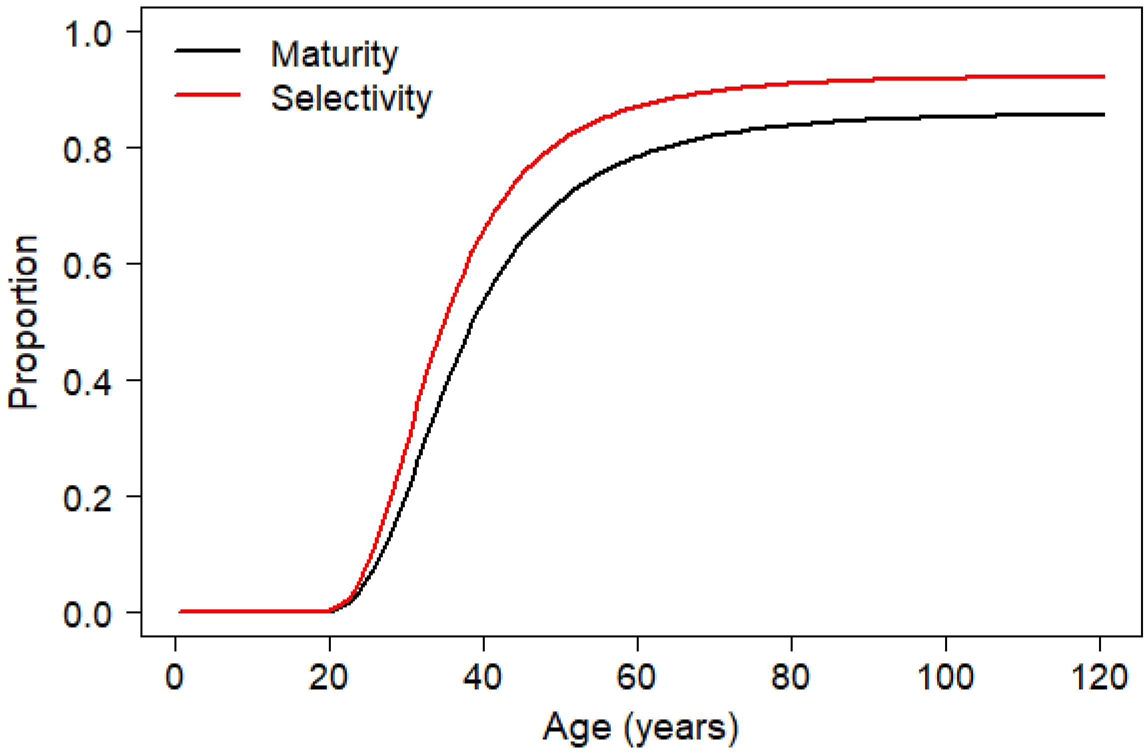


Figure A 9.33. Estimated selectivity and fixed maturity for the 2021 preliminary base-case model with a plus-group at 120 years and *M* estimated. Note maturity and selectivity are not independent above age 80.

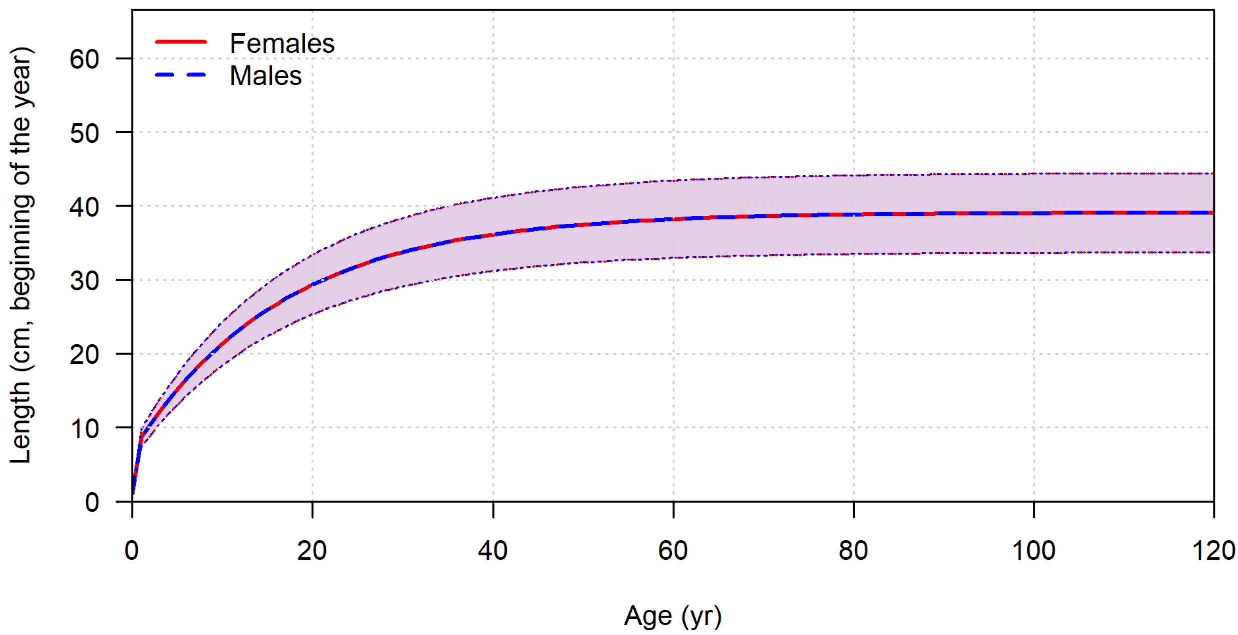


Figure A 9.34. Growth for the 2021 preliminary base-case model with a plus-group at 120 years.

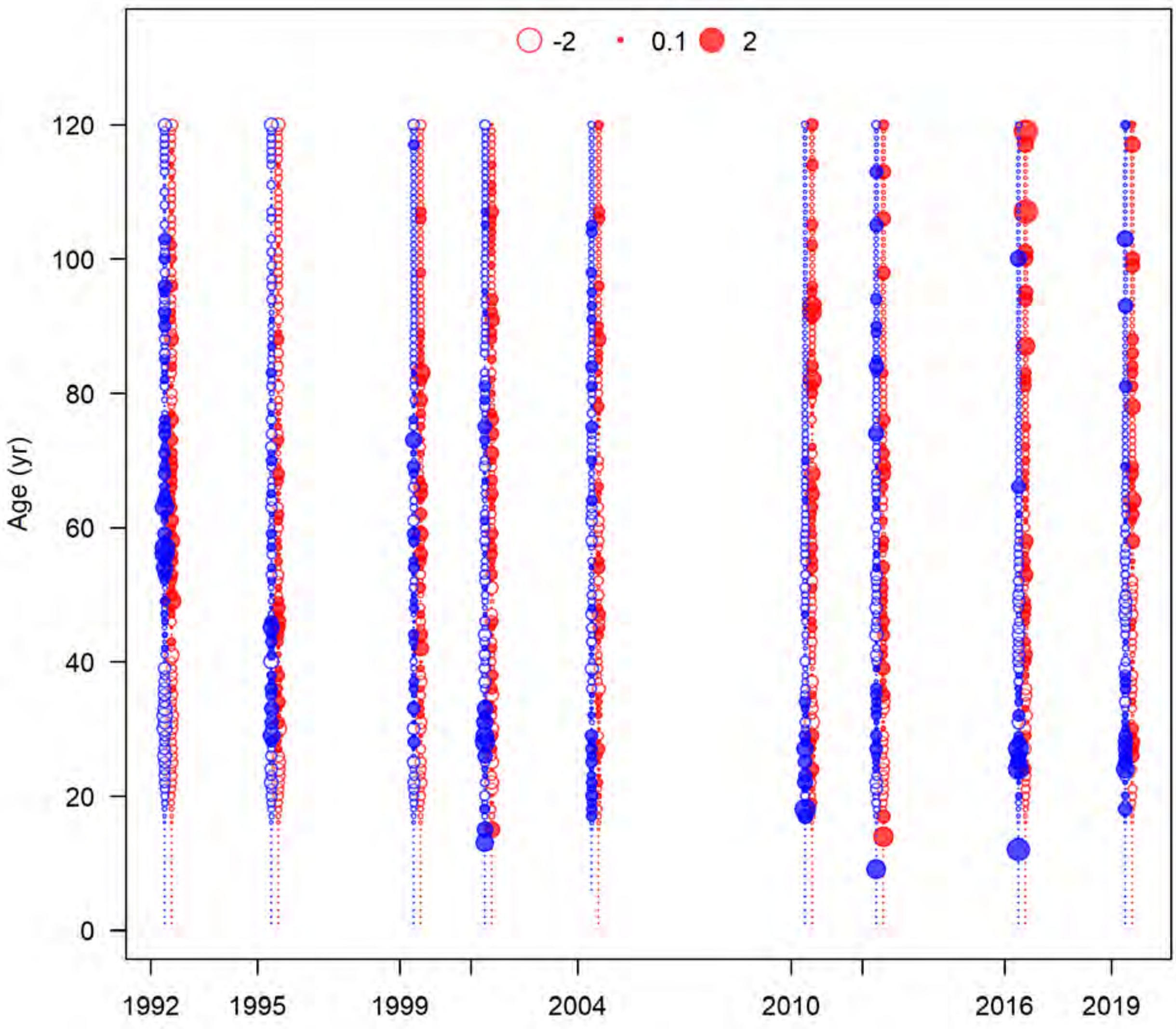


Figure A 9.35. Pearson residuals from the age composition data for the 2021 preliminary base-case model with a plus-group at 120 years and *M* estimated.

10. Eastern zone Orange Roughy (*Hoplostethus atlanticus*) stock assessment based on data up to 2020

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10.1 Executive Summary

This document was revised after the November SERAG meeting to include scenarios of fixed catch projections that were presented to SERAG, a catch scenario proposed by industry, a summary of the advice from the November SERAG meeting, the inclusion of appendices to assist in the preparation of the AFMA species summaries and the ABARES fishery status reports and the correction of a mistake in the reporting of the prior used for estimating annual recruitment deviations.

This document updates the 2017 eastern zone Orange Roughy stock assessment to include revised modelling assumptions and new data for 2020 using Stock Synthesis version 3.30.17. The 2017 eastern zone Orange Roughy assessment (Haddon 2017) and subsequent cross-catch risk assessment (Tuck et al. 2018) identified that the model is extremely sensitive to the assumed value of natural mortality (M). The objective of the 2021 assessment was to account for the uncertainty in M by estimating it within the assessment using an informative prior developed from New Zealand Orange Roughy assessments.

To provide inter-sessional review of the work the South East Resource Assessment Group (SERAG) established the Orange Roughy Steering Committee (ORSC) comprising Daniel Corrie, Mike Steer, Geoff Tuck, Paul Burch, André Punt, Andrew Penney, Matt Dunn (NIWA), Kevin Stokes and Simon Boag. The details of the development of the preliminary base-case assessment and its review by the ORSC, SESSFRAG and SERAG are described at the end of the Introduction to this report.

The 2021 base-case assessment updates the 2017 assessment with recent catch, relative estimates of female spawning biomass from the 2019 acoustic towed surveys at St Helens Hill and St Patricks Head, and new age composition data from the 2019 acoustic survey. Two major changes were made to the previous assessment, natural mortality is now estimated within the assessment and the plus group is increased from 80 to 120 years.

An initial Markov Chain Monte Carlo (MCMC) analysis identified that the estimated status is higher from the maximum posterior density (MPD) point estimate than that from MCMC's and this difference has an impact on the estimated Recommended Biological Catch (RBC). In addition uncertainty from the posterior of the width parameter of the logistic selectivity function was much higher than the asymptotic confidence intervals from the MDP. As SERAG does not have a formal procedure to choose between RBCs obtained from MPD and MCMC when both are available AFMA decided to convene the ORSC prior to the November 2021 SERAG meeting to review the MCMC analysis.

The ORSC evaluated the MCMC analysis and determined that the diagnostics suggested that the MCMC had converged and that the level of variability in the width parameter of the logistic selectivity was not extreme. The ORSC noted that while it was unusual that the median of the MCMC analysis did not correspond with the MPD, similar situations have occurred for Orange Roughy in New Zealand.

The ORSC advised that

1. The current MCMC analysis that estimates the width parameter of the logistic selectivity function should be retained,
2. The MCMC analysis should be used to provide advice in setting RBCs, not the MPD, and
3. Uncertainty in future stock status should be quantified using several constant catch projections.

The median estimate of unfished female spawning biomass from the MCMC analysis was 38,924 t, slightly lower than the MPD estimate of 40,479 t. The current 2022 female spawning biomass is estimated to be 11,644 t from the MCMC and 13,126 t from the MPD. Relative spawning biomass in 2022 is estimated at 30.0% of unfished levels from the MCMC and 32.4% of unfished levels from the MPD. Natural mortality was successfully estimated within the assessment. The median estimate of natural mortality from the MCMC analysis is M=0.0393 yr^{-1} , which is slightly higher than the MPD estimate of M=0.0386 yr^{-1}.

The recommended biological catch (RBC) for 2022 from the MCMC analysis is 681 t, lower than the MPD estimate for 2022 of 944 t. The average RBC over the next three years (2022-2024) is 737 t from the MCMC analysis and 1,025 t from the MPD. There is a high level of uncertainty in the estimated RBC, with the 75% and 95% credible intervals from the MCMC analysis for the 2022 RBC being 287 – 1,316 t and 119 – 1,645 t respectively.

In addition to the estimated RBC from the SESSF harvest control rule, further MCMC analysis was undertaken to evaluate scenarios of fixed catch projections of 550, 650, 737, 850 and 950 t yr^{-1} and a catch scenario proposed by industry of 1,166 t in 2022, 1,055 t in 2023 and 950 t yr^{-1} thereafter. The projections show that female spawning biomass is estimated to increase under all the fixed catch scenarios considered with the probability of the stock being below the limit reference point of 20% unfished spawning biomass in both 2024 and 2031 being less than 0.5%. Under the lowest constant catch scenario of 550 t yr^{-1}, stock status is estimated to be 0.317 and 0.348 in 2024 and 2031 respectively. Under the highest constant catch scenario of 950 t yr^{-1}, stock status is estimated to be 0.312 and 0.323 in 2024 and 2031 respectively. Under the industry proposed scenario stock status estimated to be 0.309 and 0.321 in 2024 and 2031 respectively. When the SESSF harvest control rule is used to set RBCs, the stock status is estimated to be 0.316 and 0.330 in 2024 and 2031 respectively.

10.2 Introduction

10.2.1 *Biology*

Orange Roughy (*Hoplostethus atlanticus*) are a long lived bentho-pelagic that inhabit deep waters 700–1300 m on the slope of the continental shelf and on seamounts. They feed on bentho- and mesopelagics, including prawns, fish and squid. Orange Roughy are long lived with maximum ages in excess of 150 years having been recorded. They reach a maximum length of 35–45 cm when they mature at around age 30. They form both spawning and non-spawning aggregations on seamounts where they are targeted by demersal trawling.

The stock structure of Orange Roughy in Australian waters remains uncertain. The 2021 eastern zone base-case assessment assumes the “combined” stock hypothesis of Wayte (2007), i.e., that the Eastern

Zone (primarily St Helens Hill and St Patricks Head) and Pedra Branca from the Southern Zone form a single stock. Further details of Orange Roughy stock structure are provided below.

10.2.2 *Previous Assessments*

Early stock assessments of the eastern stock of Orange Roughy (Bax, 2000) used stock reduction analysis (Kimura et al., 1984) to generate plausible estimates of unfished biomass and current biomass and then considered the outcome of projecting the modelled stock forward under different catch scenarios. In the early 2000s stock assessments that used relatively simple age-structured stock assessment models that were fitted using maximum likelihood methods and Bayesian approaches were developed (e.g., Wayte and Bax 2002). From 2006, fully integrated stock assessments using the Stock Synthesis software were conducted in 2006, 2007 and 2011, though their structure remained relatively simple (Wayte 2006, 2007, Upston and Wayte 2011).

In May 2014, prior to the 2014 eastern zone Orange Roughy assessment, a workshop was held in Hobart with the objectives of resolving the issue of differing biomass estimates from the acoustic optical surveys and the stock assessment and provide advice on appropriate reference points for eastern zone Orange Roughy (AFMA 2014). The 2014 assessment was then undertaken with informative priors developed for the acoustic biomass surveys based on the methods discussed during the workshop (Upston et al. 2015).

The 2017 eastern zone Orange Roughy assessment (Haddon 2017) and subsequent cross-catch risk assessment (Tuck et al. 2018) identified that the assessment results are extremely sensitive to the assumed value of natural mortality (M).

10.2.3 *Approach for the 2021 Assessment*

In 2020, following a request from the Australian Fisheries Management Authority (AFMA), the South East Resource Assessment Group (SERAG) discussed the uncertainty surrounding the estimate of M used in the most recent stock assessment of eastern zone Orange Roughy and how to accommodate the uncertainty in M within the 2021 assessment. At its November 2020 meeting, SERAG requested CSIRO develop a robust process for estimating M for the 2021 eastern zone Orange Roughy stock assessment for review. CSIRO proposed estimating M within the assessment using an informative prior developed using an updated version of the combined posterior for M for New Zealand Orange Roughy stock assessments (Cordue 2014). SERAG supported the proposed process but also wanted to ensure that there was a viable alternative available should the proposal to estimate M fail.

The Orange Roughy Steering Committee (ORSC) comprising Daniel Corrie, Dan Hogan, Mike Steer, Geoff Tuck, Paul Burch, André Punt, Andrew Penney and Matt Dunn (NIWA) was established to provide inter-sessional review of the work. Prior to the August 2021 meeting of the ORSC Kevin Stokes joined the ORSC and Dan Hogan was replaced by Simon Boag as the industry representative.

To address the potential failure of estimating M it was proposed to use a decision table with alternate states of nature and management actions (e.g. Tuck et al. 2018). The work plan, developed in consultation with the ORSC, was:

1. Undertake a bridging analysis to update the 2017 assessment with the most recent data on catch, age and survey index of abundance.
2. Calculate likelihood profiles for M (noting the likelihood profile for M will be wider than the distribution for M estimated by the assessment, which is constrained by an informative prior) and

steepness (*h*) to provide the ORSC with information to choose values of *M* and *h* for the decision table.

3. Review the Pacific Fishery Management Council terms of reference and identify a potential approach for identifying the values for *M* and *h* that correspond to a 90% confidence bound for the proposed cross-catch risk assessment.
4. Develop a process for constructing an informative a prior for *M*.

Following review by the ORSC to discuss the updated assessment, likelihood profiles and proposed parameters for the cost-catch risk assessment the assessment would proceed using the agreed data and methodology.

10.2.3.1 Review by SESSFRAG March 2021

The Southern and Eastern Scalefish and Shark Fishery Resource Assessment Group (SESSFRAG) reviewed the above proposal at its March 2021 Chairs Meeting. The key points and recommendation from the minutes of the SESSFRAG meeting are reproduced below, with some additional clarification provided in brackets.

- *Several meeting attendees raised concerns with using a decision table to select values of M, with their view being that this is a more risky approach than using a model or likelihood profiles [the proposed approach is not planning to use a decision table to select M].*
- *Concerns were also raised regarding previous decisions relating to the selection of M, with the value determined through a likelihood profile, not being used in the assessment; and instead opting for an 'assumed' value, determined through a comparison of Australian and New Zealand orange roughy stocks. It was noted that this occurred due to procedural issues, resulting from an alternate base case not being provided with sufficient time prior to the RAG meeting; and the level of impact of the value of M (determined through likelihood profile) on the assessment.*
- *It was emphasised that the process for selecting M needs to be clearly identified, to ensure that the value of M is selected based on the best available science.*

SESSFRAG recommended that the eastern zone Orange Roughy 2021 stock assessment proceeds using the agreed data, to attempt to estimate *M* using an informative prior, with the fall back approach being the construction of a decision table with alternate states of nature and management actions, using the agreed values of *M* and *h*; with a progress update to be provided to the SESSFRAG Data Meeting (August 2021).

10.2.3.2 Advice from Orange Roughy Steering Committee August 2021

The ORSC met via video conference on Friday 13 August 2021 to review a draft of the preliminary base-case assessment report (Burch and Curin-Osorio 2021) that included an updated preliminary base-case model with fixed natural mortality of M=0.04 yr^{-1}, likelihood profiles for *M* and *h* and proposed parameters for a decision table with alternate states of nature and management actions.

During the development of the preliminary base-case with fixed *M*, a small number of changes and corrections were made to the data used in the 2017 assessment, these were:

- Catches for 2015 and 2016 were updated from 460.4 t and 360 t respectively to 457.3 t in 2015 and 384.5 t in 2016.

- The model used to estimate ageing error for 2017 assessment had not fully converged so the ageing error matrix was updated.
- The priors and intial values for the two acoustic surveys and the fixed value of the egg survey were rounded to two decimal places in the Stock Synthesis input files of the 2014 and the 2017 assessments. The update increased the number of decimal places to nine.
- The fixed value of the standard deviation of recruitment (σ_R) was reported as 0.58 in Haddon (2017). However, σ_R was set to 0.7 in the assessment model.

The preliminary base-case assessment model with fixed *M* of 0.04 yr^{-1} was developed by adding each of these model changes and data streams sequentially to the previous final base-case assessment model (Haddon 2017) to identify the effect of each new source of information using a formal bridging analysis. Data weighting (tuning) was then applied, and likelihood profiles for *M* and *h* were produced.

The bridging of the 2017 assessment to produce a preliminary base-case assessment with fixed *M* of 0.04 yr^{-1} was supported by the ORSC with the following recommendations:

1. There are currently 80 age-classes in the assessment, with the maximum age-class treated as a plus group that comprises 5-9% of individuals in age samples for earliest years with age data. This may result in bias when *M* is estimated and increasing the number of age-classes in the assessment to 100 and 120 should be explored.
2. Undertake a sensitivity removing the 1992 egg survey.
3. Correct the retrospective analysis to estimate fewer years of recruitment deviations (year classes) when sequentially removing data from the assessment in each year. The retrospective analysis in the draft report did not reduce the number of estimated recruitment deviations, which is incorrect.
4. Age-specific maturity and selectivity should be plotted in the same figure to identify the magnitude of the difference between maturity and selectivity.

The ORSC discussed the process of estimating *M* using an informative prior and supported the approach of using an updated prior for *M* that uses the most recent available assessments for New Zealand Orange Roughy assessments for ORH 2A+2B+3A, ORH 3A (NWCR), ORH 3B (ESCR), ORH (Puysegur). The prior has been updated by Patrick Cordue as part of the submission for the extension of Marine Stewardship Council certification for New Zealand Orange Roughy in the ORH 3B region but is not yet publicly available. The ORSC noted the following:

- The prior of Cordue (2014) is relatively uninformative between plausible values of *M* for Orange Roughy (M=0.03 yr^{-1} - M=0.045 yr^{-1}).
- The Cordue prior assumes the data and model assumptions of the New Zealand Orange Roughy assessments are correct. Any bias in the New Zealand Orange Roughy assessments would likely be reflected in the prior.
- There was a discussion of how the relative weighting of the biomass indices and the age data in the assessment could potentially influence the estimation of *M*. Francis weighting gives more weight to the biomass indices, that suggest a lower *M*, and less weight to the age data that suggest a higher *M*. Francis weighting is the current best practice utilised across all SESSF stock assessments. The ORSC did not suggest that the 2021 assessment move away from this practice.

The ORSC discussed the construction of a decision table to be used to provide advice for setting eastern zone Orange Roughy TACs should the process to estimate *M* with an informative prior fail. The ORSC noted that it was important to develop a consistent approach for constructing decision tables to reduce the potential for confusion and that ideally a decision table would have a small number of states of nature and management actions. They also noted that a decision table should contain the mean or the median of the parameter of interest and be bounded by an even amount to each side. The ORSC recommended that;

- The decision table with five values of *M* taken from the 5%, 12.5%, 50%, 87.5% and 95% quantiles (90% and 75% bounds) from the likelihood profile on *M* and that a small number of sensible catch scenarios be chosen to reduce the complexity of the table.
- There was no information in the likelihood profile to inform the estimation of steepness of the stock recruitment relationship (*h*). The decision table for eastern zone Orange Roughy should be based on a fixed value of *h*=0.75 for all scenarios. The impact of varying *h* should be explored as a sensitivity to the base-case assessment. The cross-catch risk assessment of Tuck et al. (2018) used a fixed value of steepness (*h*=0.75) with two potential values of *M* and three catch series.

The advice from the ORSC was presented to the August 2021 SESSFRAG Data Meeting and it agreed the process recommended by the ORSC for undertaking the eastern Orange Roughy Tier 1 stock assessment and decision table be adopted.

10.2.3.3 Preliminary base-case assessment

Four candidate preliminary base-case assessments were presented to SERAG in October 2021. These were the model with fixed *M* of 0.04 yr^{-1} that was presented to the ORSC and three models that estimated *M* using an informative prior based on New Zealand Orange Roughy assessments with plus groups at 80 (the default from previous assessments), 100 and 120 years.

Criteria to select the number of age-classes were determined based on discussions with André Punt (CSIRO and University of Washington) and Matt Dunn (NIWA). The plus group (number of age-classes) should be chosen so that:

1. The proportion of individuals in the plus group is small and
2. The number of age-classes with no individuals in them is small.

SERAG was then asked to select the base-case assessment based on the ability of the model to estimate *M* and inspection of the fits to the age and index data.

The posteriors for *M* from the three candidate preliminary base-case assessments that estimated *M* showed that *M* was being well estimated, with the range of plausible values for Orange Roughy of *M*=0.03 yr^{-1} - *M*=0.045 yr^{-1} (Figure A 10.1). The fits to biomass indices and the age data for the three candidate preliminary base-case assessments that estimated *M* were very similar to those of the model with fixed natural mortality of *M*=0.04 yr^{-1} and SERAG endorsed the estimation of natural mortality within the assessment.

The models with plus groups at 100 and 120 years had slightly better fits to the age data and there was no discernible change in the fits to the acoustic biomass indices, suggesting that the number of age-classes in the assessment should be increased above 80. Distinguishing between the models with plus groups at 100 and 120 years was challenging however, because there was little difference in the fits to the age data between the two models and both models had a small proportion of individuals in the plus group and a small number of age-classes with no individuals, at least for the early age samples. As there was no evidence to reject the model with the higher plus group, SERAG decided to choose the model with a plus group at 120 years as the base-case for the 2021 assessment.

SERAG decided that a decision table with alternate states of nature and management actions would not be required to limit the amount of work required and scenarios presented. The uncertainty in model outputs will be appropriately characterized using a Bayesian posterior based on MCMC sampling, with model sensitivities undertaken using fixed natural mortality values chosen as the 12.5% and 85% quantiles from the posterior of *M*.

10.2.3.4 Advice from Orange Roughy Steering Committee November 2021

In the preparation of the final assessment report it was identified that the estimated status is higher from the maximum posterior density (MPD) point estimate than that from MCMC's and this difference is enough to have an impact on the estimated Recommended Biological Catch (RBC). In addition uncertainty from the posterior of the width parameter of the logistic selectivity function was much higher than the asymptotic confidence intervals from the MDP (Figure 10.15). As SERAG does not have a formal procedure to choose between RBCs obtained from MPD and MCMC when both are available AFMA decided to convene the ORSC prior to the November 2021 SERAG meeting to review the MCMC analysis.

The ORSC evaluated the MCMC analysis and determined that the diagnostics suggested that the MCMC had converged (although the results needed to be checked because it appeared the burn-in may have been included) and that the level of variability in the width parameter of the logistic selectivity was not so extreme as to suggeset that parameter should be fixed in the model. The ORSC noted that while it was unusual that the median of the MCMC analysis did not correspond with the MPD, although similar situations have occurred for Orange Roughy in New Zealand.

The ORSC advised that

1. The current MCMC analysis that estimates the width parameter of the logistic selectivity function should be retained,
2. The MCMC analysis should be used to provide advice in setting RBCs, not the MPD, and
3. Uncertainty in future stock status should be quantified using several constant catch projections.

10.2.3.5 Advice from SERAG November 2021

The final assessment was presented to the November 2021 SERAG meeting. The wide range of credible intervals for future RBCs was discussed and Patrick Cordue noted that much of this variability was due to stock status being below the 35% break point of the SESSF harvest control rule. SERAG agreed with the recommendation from the ORSC to use the MCMC analysis for providing management advice and asked that the estimated RBCs from the SESSF harvest control rule be provided to SEMAC along with the fixed catch projections scenarios.

10.2.3.6 Request from SEMAC February 2022

At the February 2022 SEMAC meeting a catch scenario of 1,166 t in 2022, 1,055 t in 2023 and 950 t yr^{-1} thereafter was proposed by industry. Estimates spawning biomass and stock status in 2024 and 2031 from this scenario have been added to Table 10.11.

10.3 Methods

10.3.1 *Model Structure*

The 2021 stock assessment for Eastern Zone Orange Roughy (*Hoplostethus atlanticus*, Collett 1889) uses an integrated stock assessment model implemented using Stock Synthesis 3.30.17 (Methot and Wetzel 2013). As in the previous two assessments, it assumes a stock structure that combines the Eastern Zone (primarily St Helens Hill and St Patricks Head) and Pedra Branca from the Southern Zone (Table 10.1, Figure 10.1). New data included since the previous stock assessment (Haddon 2017) are recent catches, relative estimates of female spawning biomass from the 2019 acoustic towed surveys at St Helens Hill and St Patricks Head, and new age-composition data from the 2019 acoustic survey. Additional recruitment residuals were also estimated. Two major changes were made to structure of the assessment from previous assessments they are;

1. the assessment uses a plus group at 120 years (an increase from a plus group at 80 years that was used previously), which also required the ageing error matrix to be re-estimated for 120 ages and,
2. *M* is estimated within the assessment using a log-normal prior developed from the most recent available assessments for New Zealand Orange Roughy stock assessments for ORH 2A+2B+3A, ORH 3A (NWCR), ORH 3B (ESCR), ORH (Puysegur) and ORH 7A. Previous assessments have assumed a fixed value of M=0.04 yr^{-1}.

The process of updating the model from the 2017 base-case to the 2021 base-case model, including increasing the number of age classess within the model and the estimation of *M* within the assessment is described in preliminary base-case report (Chapter 9). The data and assumptions used in the 2021 base-case assessment are described in more detail below.

10.3.1.1 Stock Structure

Five stock structure hypotheses have been used in past assessments of Eastern Zone Orange Roughy (Table 10.1). Model scenarios corresponding to these stock structure hypotheses were tested and reported on in the 2006 preliminary eastern zone assessment (Wayte 2006) and results of these scenarios did not differ greatly from each other. The 2021 eastern zone base-case assessment assumed the “combined” stock hypothesis of Wayte (2007), i.e., that the Eastern Zone (primarily St Helens Hill and St Patricks Head) and Pedra Branca from the Southern Zone form a single stock.

The reasoning behind the “combined” stock structure hypothesis is reproduced below from Wayte (2007).

> *Early analysis of otolith shape data by the Central Ageing Facility indicated that Orange Roughy caught in the spawning aggregation at St. Helens in the winter were not distinguishable from those caught in the Southern Zone for the rest of the year, but were different from those caught in the Eastern Zone outside the time of the spawning aggregation, and were different from those caught in the Southern Zone in winter. This implied that spawning Eastern Zone Orange Roughy and Southern Zone non-spawning Orange Roughy may comprise a common stock, which is distinct from an eastern non-spawning and southern winter caught ‘stock’. A subsequent analysis was less clear and reviewers have questioned the statistical approach used.*
>
> *Observations from fishers and processors suggested that Orange Roughy schools from Maatsuyker are part of a west coast Tasmania ‘stock’, while the Pedra Branca schools are part of the combined stock. Fishers’ observed little interchange of pelagic Orange Roughy schools*

between Pedra Branca and Maatsuyker, while processors suggested that fish from the two areas are morphologically distinct. Maatsuyker is on the western slope of the seabed continuation of Tasmania, while Pedra Branca is on the east.

Overall this evidence and earlier studies of stock structure based on parasites, genetics and otolith microchemistry have been inconclusive on whether Orange Roughy around Tasmania comprise one or several stocks. Only one substantial winter spawning aggregation (St Patricks and St Helens Hill) has been found and only one large consistent summer aggregation has been fished (Southern Zone main Maatsuyker and Pedra Banca). Low levels of spawning have been detected elsewhere and an analysis of catch data shows elevated winter catches in the Far Western Zone. The hypothesis that includes all Orange Roughy in the SEF (with the exception of the Cascade Plateau) as one stock is included on the recommendation of the 2002 review of the stock assessment.

Table 10.1. Stock structure hypotheses for Eastern, Southern and Western zone Orange Roughy. Reproduced from Wayte (2007).

Stock hypothesis	Description	Catch data required
East	All Orange Roughy in Eastern Zone, spawning and non-spawning	Total Eastern Zone catch (all months)
2002 Combined	Eastern Zone spawning Orange Roughy and Pedra Branca non-spawning Orange Roughy	Eastern Zone winter catch (June - August) and Pedra Branca non-winter catch (all months except June - August)
Combined[2]	All Eastern Zone and Pedra Branca Orange Roughy	Total Eastern Zone catch (all months) and Pedra Branca catches (all months)
East + South	All Orange Roughy in Eastern and Southern zones	Total Eastern Zone catch and total Southern Zone catch (all months)
East + South + West	All Orange Roughy in Eastern, Southern and Western zones	Total Eastern Zone catch and total Southern Zone catch and total Western Zone catch (all months)

[2] Used as the base-case stock hypothesis for the eastern zone Orange Roughy assessment since Wayte (2007).

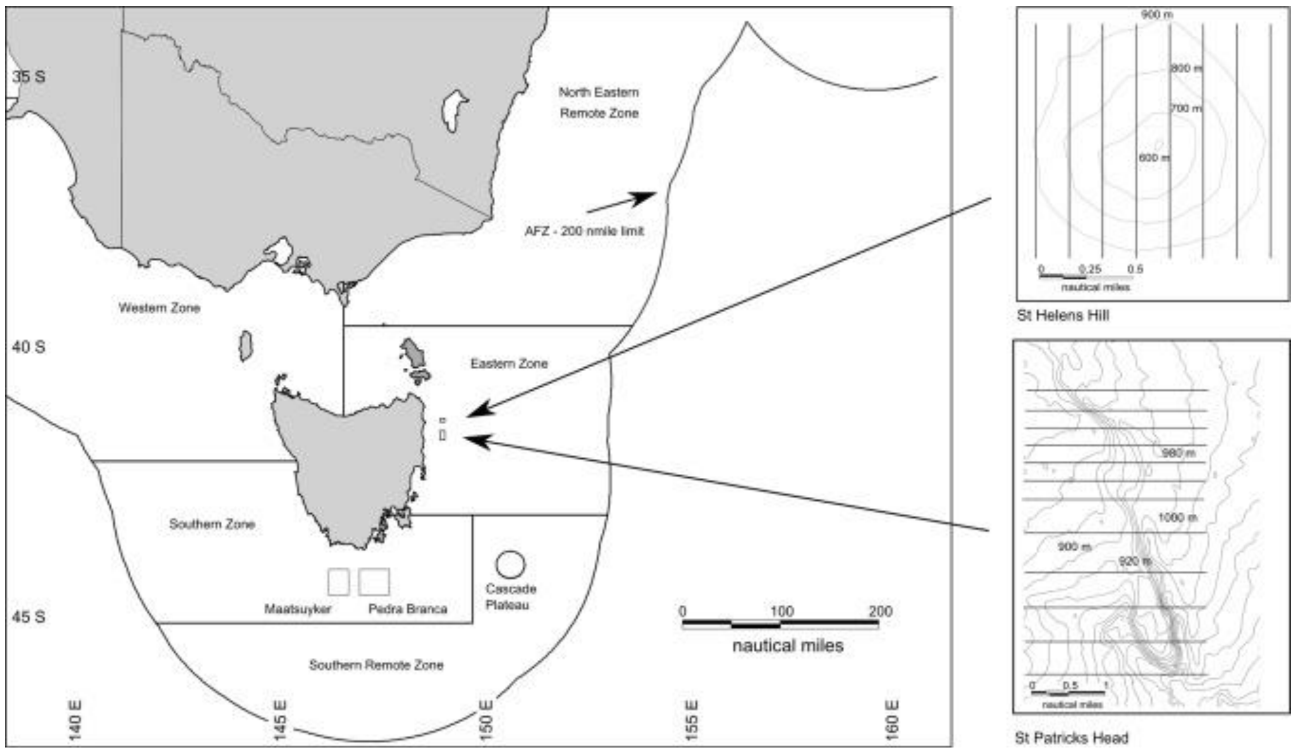


Figure 10.1. Map of Australian Orange Roughy management zones and areas.

10.3.1.2 Biological Parameters

No changes have been made to the pre-specified biological parameters used in the 2017 assessment. However, the fixed value for recruitment variability (σ_R) is now correctly reported as 0.7 (see Table 10.2 for a summary of the fixed and estimated parameters).

Male and female Orange Roughy are assumed to have the same biological parameters except for their length-weight relationship. In the absence of representative length data, none of the four parameters relating to the Von Bertalanffy growth equation are estimated within the model-fitting process. Maturity is modelled as a logistic function of length, with 50% maturity at 35.8 cm. The assumption is made that the maturity would approximately match fishery selectivity as estimated on the spawning aggregations (which are assumed to consist of mature animals). Fecundity-at-length is assumed to be directly proportional to weight-at-length, which is important for the estimation of the Spawning Potential Ratio, which can act as a proxy for fishing mortality; a requirement for the determination of stock status.

The length-weight relationship of spawning fish caught during AOS surveys at St Helens Hill and St Patrick Hill over the last decade is different than that assumed in the base-case assessment, with fish now being around 10% heavier (Kloser and Sutton 2020). This may indicate a change in the condition of spawning fish off the east coast of Tasmania. Prior to the next eastern zone Orange Roughy stock assessment, it is recommended that the length-weight relationship and other pre-specified biological parameters be re-estimated with recent data to evaluate whether they may have changed, with any changes to be incorporated into the next assessment.

Table 10.2. The pre-specified model parameters used in the 2021 base-case assessment.

Fixed parameters	Values		Source
Recruitment steepness, *h*	0.75		Annala (1994) cited in CSIRO & TDPIF (1996)
Recruitment variability ,σ_R	0.7		
Maturity logistic inflection	35.8 cm		Upston et al (2015)
Maturity logistic slope	-1.3 cm^{-1}		Smith et al. (1995)
Von Bertalanffy *K*	0.06 yr^{-1}		Smith et al. (1995)
Length at 1 year Female	8.66 cm		
Length at 70 years Female	38.6 cm		
Length-weight scale, *a*	3.51×10^{-5}	Female	Lyle et al. (1991)
	3.83×10^{-5}	Male	
Length-weight power, *b*	2.97, 2.942	Female Male	Lyle et al. (1991)
Plus-group age (years)	120		
Length at age CV for age 1	0.07		Estimated from data
Length at age CV for age 70	0		Expected offset from young
q egg survey catchability	0.9		Bell et al. (1992), Koslow et.al (1995), Wayte (2007)

10.3.2 *Data*

The data sources included in the eastern zone Orange Roughy assessment are catch (including discards), three indices of abundance (the egg survey estimate treated as an estimate of absolute abundance, and the two sets of acoustic biomass estimates treated as relative abundance indices) and age-composition data from the acoustic surveys and on-board sampling. A summary of the time periods of the data for the 2021 assessment is provided in Figure 10.2.

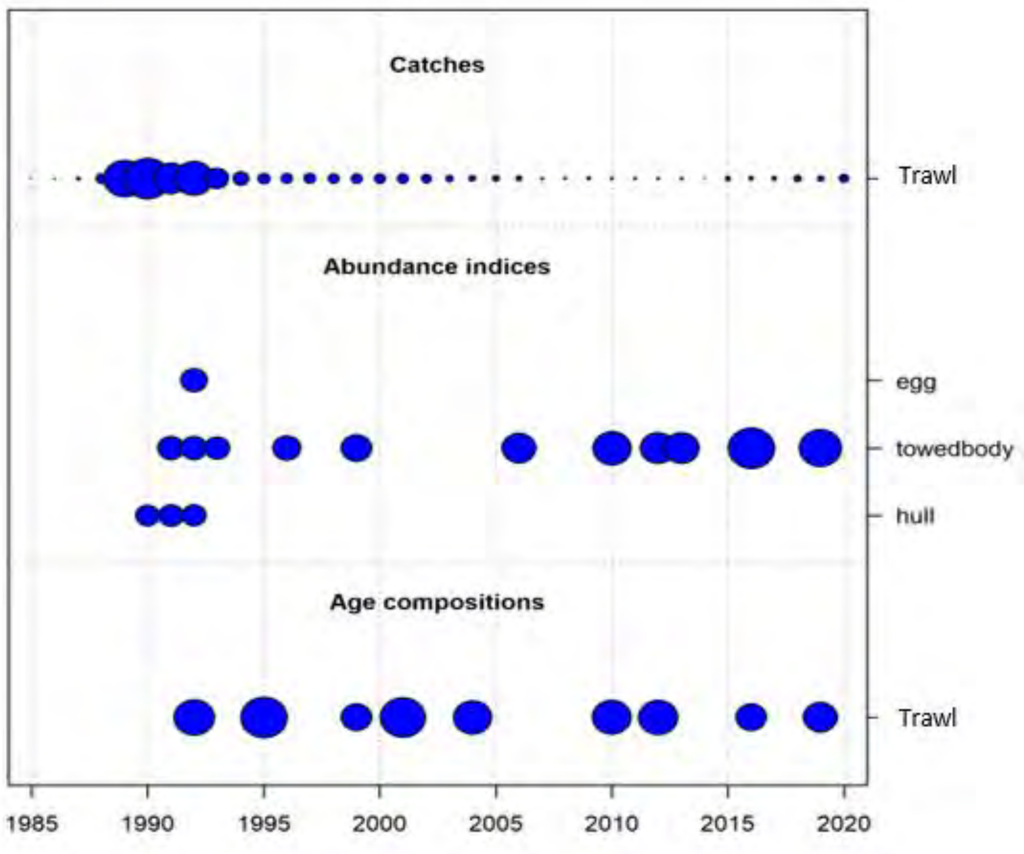


Figure 10.2. Data availability for the eastern zone Orange Roughy assessment by type and year.

10.3.2.1 Catch

The assessment uses the agreed catch history series from the 2014 assessment (Upston et al 2015, originally compiled by Wayte 2007) and updates the landed catches for 2015-2020 using logbook and catch disposal records (CDRs; Figure 10.3, Table 10.3). The agreed catch history adjusted the reported catches as a result of estimates of burst bags and other initially unreported catches. Wayte (2007) provides details about how the catches from 1989-1994 were adjusted for the five stock structure hypotheses. The “combined” stock hypothesis uses all catches from the Eastern Zone and catches from Pedra Branca in the Southern Zone (Table 10.1).

The agreed catch history that is used in the base-case assessment for the early years of the fishery is reproduced below from Wayte (2007).

The Eastern Zone catches have been adjusted for under-reporting in 1992, mis-reporting in 1993, and general losses in 1989-1994. It is believed that reported catches in 1992 were 55% of actual catches, so catches in this year were increased accordingly. In 1993, Eastern Zone catches were misreported as Southern zone catches. To estimate the level of this misreporting, reported Southern Zone winter (June–August) catches for each of the years 1989-1992 and 1994 were calculated as the proportion of total reported Eastern and Southern zone catches in those years. The total Southern and Eastern zone catch in 1993 was multiplied by the mean of these proportions to estimate actual Southern Zone winter catch. Reported 1993 Southern Zone catch above this estimate was assumed to have been caught in the Eastern Zone. These calculations resulted in 2,665 t being transferred from the Southern Zone catch total to the Eastern Zone catch total in 1993.

Other adjustments were made for burst bags, lost gear and burst panels. It was assumed, based on discussions with operators, that 30% of the total fish caught were lost in 1989 and 1990, 20% lost in 1991, and 10% lost in 1992, 1993 and 1994. The reported catches were increased accordingly. A catch series with half the value of these proportions lost was also calculated (based on different industry participants views). Assessments undertaken in 2006 using this alternative catch series gave very similar results to the other catch series (Wayte 2006).

Orange Roughy stock structure hypotheses and historical catches were reviewed at a workshop between AFMA, CSIRO, industry representatives and New Zealand scientists, held in Hobart in May 2014 (AFMA 2014). The workshop concluded that it is unlikely to be able to improve on the previously agreed catch time series but may still be worth examining the assessment implications of different catch histories on stock assessments.

The quota year was changed in 2007 from calendar year to the year extending from 1 May to 30 April. The assessment, however, continues to be conducted according to the calendar year as most catches occurred prior to 2007.

Discarded catches were estimated for the period 2015-2020 from discard weight observations obtained by onboard observers using the method of Bergh et al (2009) as implemented in Deng et al. (2021). Discarded catch estimates prior to 2015 have been incorporated in the agreed catch history under the assumption that discarding occuring randomly with respect to length and age.

Total removals for 2021 are assumed to be the same as the 2020 removals. Sensitivities are undertaken using estimated total removals for 2021 (obtained from AFMA on 25 October 2021) and the agreed 2021 TAC of 1569.4 t.

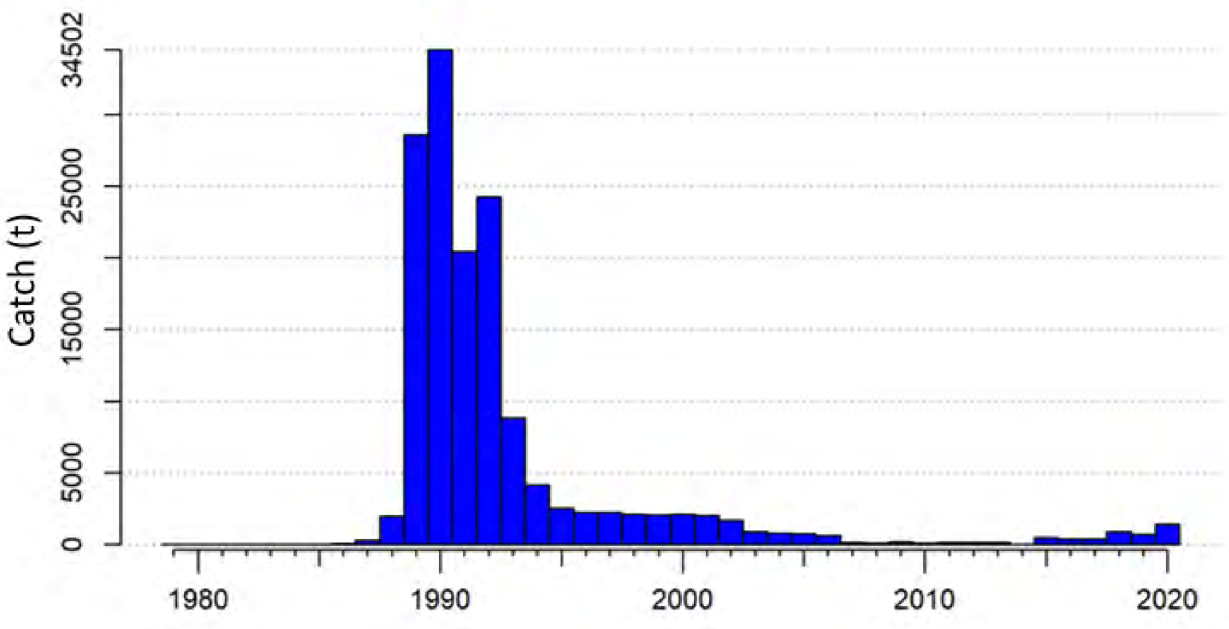


Figure 10.3. Catch, including discards, for the eastern zone Orange Roughy assessment. Catches for 1989–1994 incorporate adjustments for the proportion lost due to lost gear and burst bags/burst panels, other losses, and misreporting (Wayte 2007).

Table 10.3. Agreed catches, in tonnes, of eastern zone Orange Roughy, where the eastern zone stock includes Pedra Branca (PB) from the Southern Zone. *The catches for the years 1989–1994 incorporate adjustments for the proportion lost due to lost gear and burst bags/ burst panels, other losses, and misreporting (Wayte 2007). †Total removals for 2021 in the base-case assessment are assumed to be the same as the 2020 removals.

Year	East	Pedra	South (Exc Pedra)	Discards	Total Removals
1985	6	0	58		6.0
1986	33	27	604		60.0
1987	310	0	353		310.0
1988	1,949	0	469		1,949.0
1989*	26,236	2,339	8,547		28,575.0
1990*	23,200	11,302	24,128		34,502.0
1991*	12,159	8,277	6,149		20,436.0
1992*	15,119	9,146	6,908		24,265.0
1993*	5,151	3,647	1,839		8,798.0
1994*	1,869	2,271	2,557		4,140.0
1995	1,959	585	1,572		2,544.0
1996	1,998	233	569		2,231.0
1997	2,063	187	267		2,250.0
1998	1,968	119	131		2,087.0
1999	1,952	100	74		2,052.0
2000	1,996	113	198		2,109.0
2001	1,823	204	153		2,027.0
2002	1,584	90	77		1,674.0
2003	772	105	105		877.0
2004	767	30	50		797.0
2005	754	18	81		772.0
2006	614	1	4		615.0
2007	113	16	6		129.0
2008	98	0	0		98.0
2009	193	0	10		193.0
2010	113	0	18		113.0
2011	160	2	15		162.0
2012	163	0	22		163.0
2013	150	0	8		150.0
2014	20	0	20		20.0
2015	422	29	5	7	457.3
2016	352	29	19	3	384.5
2017	302	56	18	6	364.0
2018	862	45	8	3	909.5
2019	619	75	17	1	695.1
2020	1,320	60	19	18	1,397.5
2021					1,397.5†

10.3.2.2 Age Data

The age data were received from Fish Ageing Services (FAS). Several corrections have been made to the ageing data since the 2017 assessment (Josh Barrow pers. com.). The number of age samples that were provided by FAS in 2017 and the number that were provided in 2021 are shown in Table 10.4. Differences were mostly minor, except for 1995 where additional samples that had been mislabeled as being from 1996 were added. Age data were also collected in 1987. However, previous assessments have excluded these data due to concerns that large fish were preferentially selected so that sampling was not representative (Malcolm Haddon pers. com.).

Table 10.4. Number of female and male age samples used for the 2017 and 2021 base-case models.

	Female samples			Male samples		
Year	2017	2021	Difference	2017	2021	Difference
1992	410	410	0	596	596	0
1995	538	610	72	699	757	58
1999	435	282	-153	394	298	-96
2001	652	652	0	641	641	0
2004	414	414	0	504	504	0
2010	693	693	0	251	251	0
2012	426	426	0	545	545	0
2016	338	338	0	247	247	0
2019	-	418	-		309	-

The age data for the 2017 assessment treated ages from St Helens Hill and St Patricks Head in 2012 and 2016 as simple random samples of the population and added these ages to those from earlier years in the 2014 assessment. The 2021 preliminary base-case assessments that used 80 age-classes also treated the 2019 age samples from St Helens Hill and St Patricks Head as simple random samples of the population and added them to the ages used in the 2017 assessment. Samples collected prior to 2012 were combined and weighted based on either the relative abundance implied by the acoustic estimates or the relative catch (Wayte, 2007).

We reviewed the methods used for weighting of age compositions in the 2007, 2011 and 2014 assessments (Wayte 2007, Upston and Wayte 2011, Upston et al 2015). While the weighting of age samples by relative abundance implied by the acoustic estimates or the relative catch at St Helens Hill and St Patricks Head was investigated, age compositions in both locations were similar in all years where both locations were sampled except for 1999. Subsequently, the age composition data was unweighted with the exception of 1999 where a weighting of 1.08 was applied to the age composition data from St Patricks Head (see Table 6.5 from Upston et al 2015). The weighting on the 1999 age composition was based on the acoustic survey estimating that around 85% of the population was at St Patricks Head and took into account that sample sizes at St Patricks Head were larger in this year (Wayte 2007).

It was necessary to recalcualte age frequencies using raw age data supplied by FAS in 2021 and historical data held by CSIRO due to increasing the number of age-classes in the model to 120 (and the 100 ages tested in the preliminary base-case). Age frequencies were unweighted except for 1999 where a weighting of 1.08 was applied to the age composition data from St Patricks Head, consistent with previous assessments. The data provided by Fish Ageing Services for 1999 did not have any samples identified as being collected from St Patricks Head, with all samples recorded as “Eastern Zone” or “St Helens Hill”. A spreadsheet with raw data from 1999 was found and used to calculate age frequencies for scenarios with a plus group at 120 years. The number of ages for St Patricks Head matched those in earlier assessments. However, there were 10 additional ages for St Helens Hill compared with those from earlier assessments (Wayte 2007). Information in the spreadsheet could potentially be used to correct the location of capture for the 1999 age data in the FAS database.

It is recommended that the age data and the relative weighting of age samples collected from St Helens Hill and St Patricks Head should be reviewed prior to the next eastern zone Orange Roughy assessment.

10.3.2.3 Ageing error

An estimates of the standard deviations of age reading error by age were calculated from multiple readings of otoliths supplied by Josh Barrow (Fish Ageing Services) using the method of Punt et al. (2008) and are provided in Table 10.5. The estimates were updated from those used in the 2017 assessment to include the new ageing data from 2019, recent corrections to the Fish Ageing Services database and a plus group at 120 years (Table 10.5).

The model converged (maximum gradient <0.001). However, it was sensitive to the starting values of the parameters. It is recommended that ageing error for Orange Roughy be investigated further before the next assessment.

Table 10.5. The estimated standard deviation of normal variation (age-reading error) around age-estimates for 120 age-classes in the 2021 base-case model.

Age	StDev	Age	StDev	Age	StDev	Age	StDev
0	<0.001	31	2.3748	62	4.766	93	7.094
1	<0.001	32	2.4529	63	4.842	94	7.168
2	0.0801	33	2.5309	64	4.918	95	7.242
3	0.1602	34	2.6089	65	4.994	96	7.316
4	0.2402	35	2.6868	66	5.070	97	7.390
5	0.3202	36	2.7647	67	5.145	98	7.464
6	0.4000	37	2.8425	68	5.221	99	7.538
7	0.4798	38	2.9202	69	5.297	100	7.612
8	0.5596	39	2.9978	70	5.373	101	7.685
9	0.6392	40	3.0754	71	5.448	102	7.759
10	0.7188	41	3.1529	72	5.524	103	7.832
11	0.7983	42	3.2304	73	5.599	104	7.906
12	0.8778	43	3.3078	74	5.674	105	7.979
13	0.9572	44	3.3851	75	5.750	106	8.053
14	1.0365	45	3.4624	76	5.825	107	8.126
15	1.1158	46	3.5396	77	5.900	108	8.199
16	1.1950	47	3.6167	78	5.975	109	8.272
17	1.2741	48	3.6937	79	6.050	110	8.345
18	1.3532	49	3.7707	80	6.125	111	8.418
19	1.4321	50	3.8477	81	6.200	112	8.491
20	1.5111	51	3.9245	82	6.275	113	8.564
21	1.5899	52	4.0013	83	6.350	114	8.637
22	1.6687	53	4.0781	84	6.425	115	8.710
23	1.7474	54	4.1547	85	6.499	116	8.783
24	1.8261	55	4.2313	86	6.574	117	8.855
25	1.9047	56	4.3079	87	6.648	118	8.928
26	1.9832	57	4.3843	88	6.723	119	9.000
27	2.0616	58	4.4607	89	6.797	120	9.073
28	2.1400	59	4.5371	90	6.872		
29	2.2183	60	4.6134	91	6.946		
30	2.2966	61	4.690	92	7.020		

10.3.2.4 Biomass indices and acoustic survey priors

There are now eleven estimates of relative abundance for the St Helens Hill and St Patricks Head area from the towed body acoustic surveys (Table 10.6). The acoustic survey data and methodology was reviewed thoroughly by Upston et al (2015). We added the biomass estimate from the most recent survey in 2019 (which found that mean female spawning biomass on the St Helens Hill and St Patricks Head area had increased to 36,900 t; Kloser and Sutton 2020) to the estimates used in the 2017 assessment.

Table 10.6. The three abundance indices used in the eastern zone Orange Roughy assessment. Values up to 2012 were sourced from Upston et al (2015). The original 2013 towed acoustic survey value was increased by 18% as a result of a recalibration of the equipment (Kloser, pers. comm), and the 2016 estimate is from Kloser et al, (2016). DEPS is the daily egg production survey. The DEPS estimate is treated as an absolute abundance estimate while the others are treated as relative abundance indices and the method used to determine the priors is described below.

Method	Year	Biomass (t)	CV	Catchability (*q*)
Hull				N(Ln(0.95), 0.92)
Hull	1990	120,239	0.63	
Hull	1991	71,213	0.58	
Hull	1992	48,985	0.59	
Towed				N(Ln(0.95), 0.3)
Towed	1991	59,481	0.49	
Towed	1992	56,106	0.50	
Towed	1993	22,811	0.53	
Towed	1996	20,372	0.45	
Towed	1999	25,838	0.39	
Towed	2006	17,541	0.31	
Towed	2010	24,000	0.25	
Towed	2012	13,605	0.29	
Towed	2013	14,368*	0.29	
Towed	2016	24,037	0.17	
Towed	2019	36,907	0.20	
DEPS	1992	15,922	0.50	0.9 (fixed)

The informative priors for the catchability coefficients (*q*) for the acoustic towed and hull biomass estimates were developed using the methods of Cordue (presentation to the Australian Orange Roughy workshop, 15–16 May 2014; Cordue 2014) for the New Zealand Orange Roughy assessments and modified for the Australian Eastern Orange Roughy situation using the available acoustic data for the hull and towed body surveys undertaken between 1990 and 2013 and expert judgement from the informal Orange Roughy acoustics working group in Hobart that included Judy Upston, Tim Ryan, Rudy Kloser and André Punt. The methods below are reproduced from Upston et al (2015):

Determine the sampling distribution, mean and CV associated with each of three components that we considered for the acoustic priors:

(i) uncertainty in acoustic target strength (TS), i.e. the ratio of true target strength to assumed target strength – lognormal distribution centred at 1 with CV=0.15 (after Cordue presentation 2014):

a) calculate the mean and standard deviation of two independent mean estimates of acoustic TS, -52.0 and -51.1 dB (ignores sampling variability), and assume TS ~ N(-51.6, sd=0.64),

b) convert TS from log scale to linear scale via $\log_e(10^{ts/10})$ where ts is random normal TS, to get $\log_e(10^{ts/10}) \sim N(-11.88, 0.1476)$,

c) calculate mean and standard deviation of lognormal distribution centred on 1 (including bias correction);

(ii) percentage of the spawning stock on the Eastern grounds that acoustics is "seeing" – historically the assessment has assumed 100% and the current assessment assumes "most" (Beta distribution centred on 95%) but allows for the possibility that some spawning stock do not migrate to the Eastern grounds in some years (e.g. an estimated 10% of spawning fish from the South did not migrate to the East in 1992; Bell et al. 1992). Thus a Beta(95, 5) distribution, centred on 95% and with reasonably high values of α and β for an approximately normal shape, was chosen for this prior component. The distribution shape, with less probability mass towards the left-hand tail of the distribution (less probability of only 90% or fewer spawning fish migrating to the spawning grounds and being observed), seemed appropriate based on expert judgement. However, other Beta distributions could also have been used (e.g. Beta(950, 50));

(iii) random error component capturing other uncertainty (e.g. estimated density of fish in an area; species ID issues; sampling variability in target strength since (i) is an average of the mean estimates). The random error has a lognormal distribution centred on 1, with a nominal "low" CV for towed body surveys, and a wider CV for the hull surveys, given the uncertainty with species ID and other issues (Kloser and Ryan et al. 2001).

The next step was to combine the independent component distributions to obtain an overall distribution. The CVs associated with each of the three components (and hence the overall prior) were determined by data and expert judgement – in combining the three components and setting a prior on acoustic catchability (*q* scalar) we essentially have made a statement about how well the acoustic towed or hull series is thought to provide an absolute estimate of biomass of the spawning Orange Roughy stock in the East and South (Pedra Branca), i.e. the stock we are assessing.

We have assumed on average a constant percentage of fish migrating to the eastern grounds and spawning each year. The priors will undoubtedly be further developed as more information becomes available, thus the random error component (lognormal with CV of 0.25 for the towed body and 0.8 for the hull) was explicitly included to accommodate this.

Distributions for each of the independent components, and the combined overall distribution for the acoustic *q* prior are shown in Figure 10.4–Figure 10.6.

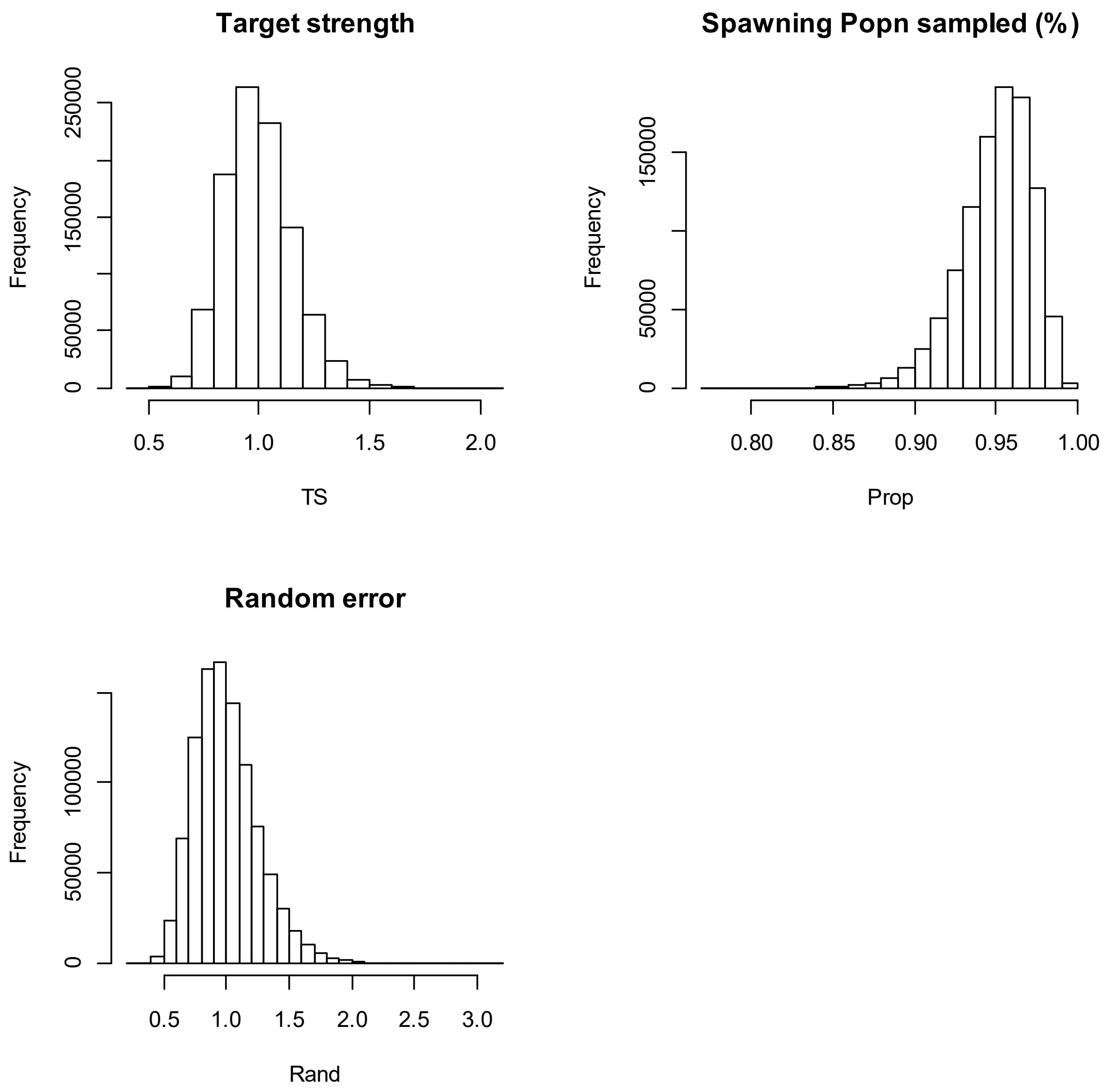


Figure 10.4. Prior component distributions for target strength, spawning population sampled, and random error for acoustics towed (reproduced from Upston et al. 2015).

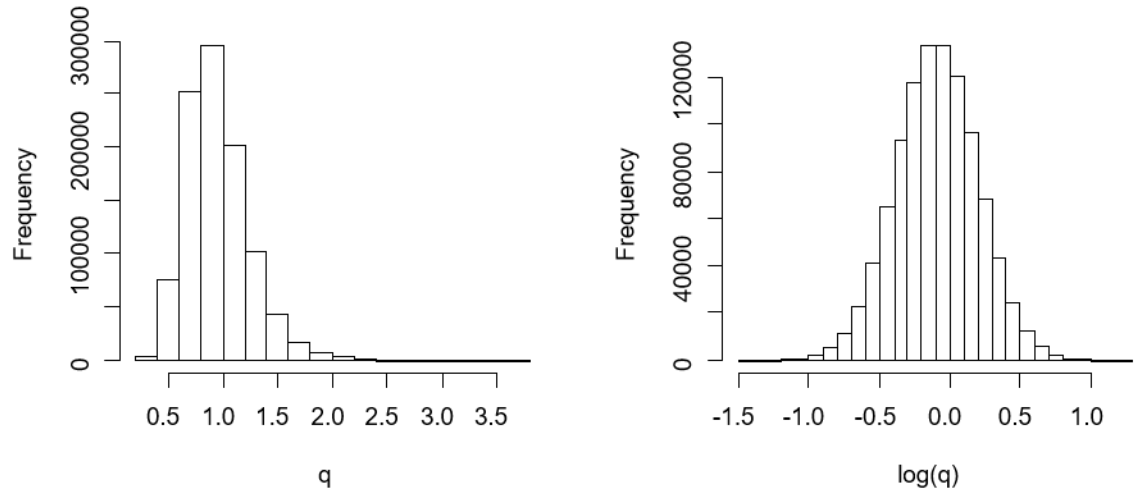


Figure 10.5. Histograms of data used to create priors for *q* and ln(*q*) for acoustics towed (reproduced from Upston et al. 2015).

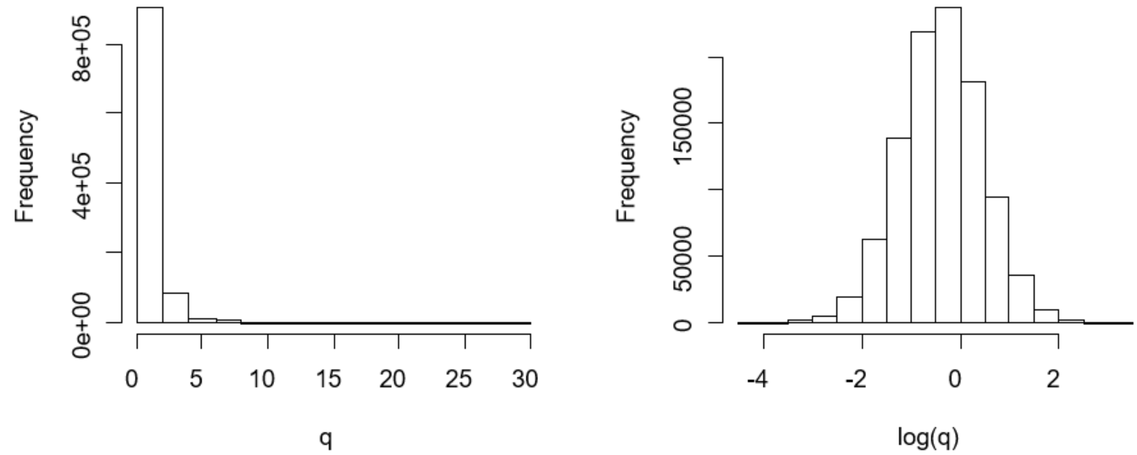


Figure 10.6. Histograms of data used to create priors for *q* and log(*q*) hull. The random error component is greater than that for towed body (reproduced from Upston et al. 2015).

The prior for the towed body acoustic surveys has not been updated since the 2015 assessment. Before the next eastern zone Orange Roughy assessment the methods for constructing the acoustic survey *q* priors should be reviewed and the prior for the towed body survey should be updated to include information obtained after 2014.

10.3.2.5 Prior for natural mortality

Cordue (2014) developed a combined posterior for Orange Roughy *M* using the results from the New Zealand Orange Roughy stock assessments for ORH 2A+2B+3A, ORH 3A (NWCR), ORH 3B

(ESCR), and ORH 7A. CSIRO proposed to use an updated version of the combined posterior for Orange Roughy *M* to develop a prior to use in the Australian eastern zone stock assessment to estimate *M*. The posterior for New Zealand Orange Roughy stocks was recently been updated by Patrick Cordue to use the most recent available assessments for New Zealand Orange Roughy stock assessments (ORH 2A+2B+3A, ORH 3A (NWCR), ORH 3B (ESCR), ORH (Puysegur) and ORH 7A) as part of the submission for the extension of Marine Stewardship Council certification for New Zealand Orange Roughy but was not publicly available at this assessment was being undertaken.

We received permission from George Clement (Deepwater Group) to access to the updated combined posterior for New Zealand Orange Roughy *M*, and a sample of 5,000 *M* estimates from the updated combined posterior distribution was provided by Patrick Cordue (ISL). To obtain a functional form of the prior for *M* that could be used in Stock Synthesis, we fitted a log-normal distribution to the combined posterior for New Zealand Orange Roughy using the MASS package in R (Venables and Ripley 2002). Other distributions were evaluated in the preliminary base-case report (Burch and Curin Osorio 2021) and found to be very similar and the log-normal model was selected to use as the prior for *M* because of the slightly better fit to the left-hand side of the posterior distribution for New Zealand Orange Roughy *M*.

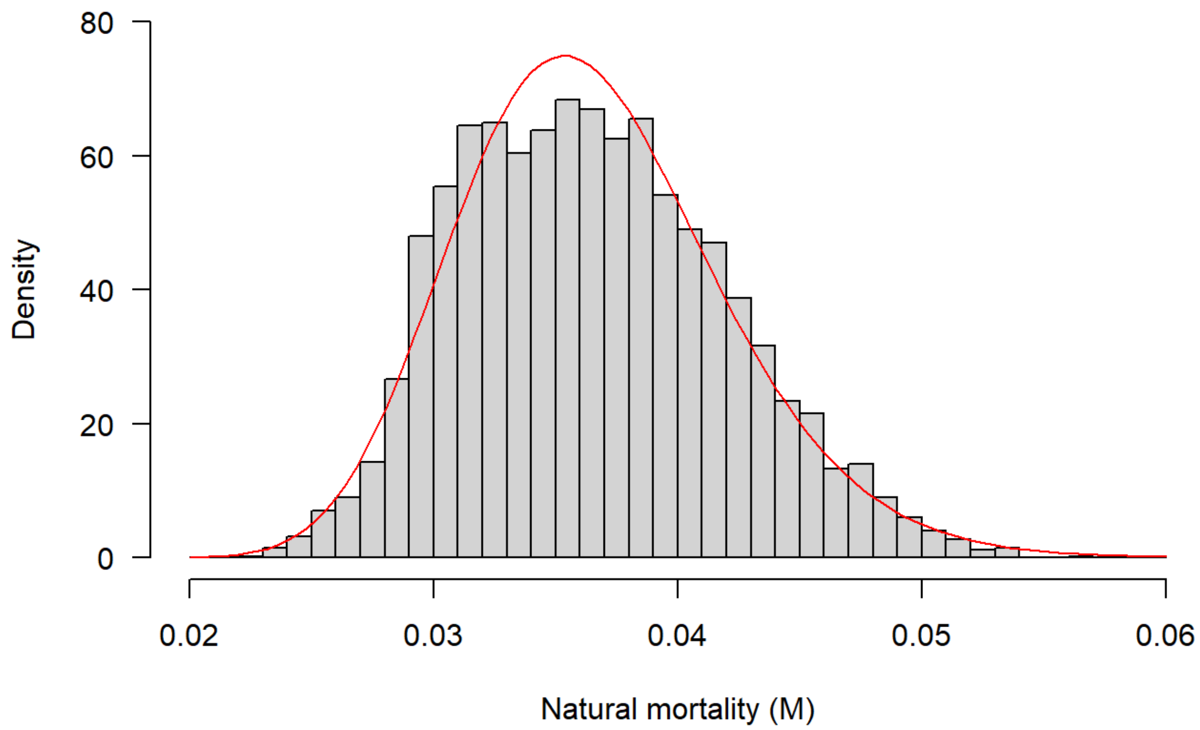


Figure 10.7. Combined posterior of *M* for New Zealand Orange Roughy stock assessments with fitted log-normal distribution. Distribution supplied by Patrick Cordue (ISL).

10.3.3 *2021 base-case assessment*

10.3.3.1 Fitting procedure

Assessment was undertaken using Stock Synthesis 3.30.17 (Methot and Wetzel 2013). Convergence was assessed be checking the final grandient was < $1e^{-4}$ (the default in Stock Synthesis) and the Hessian is positive definite. Estimates from the maximum posterior density (MPD) are presented along with median and uncertainty estimates from the MCMC analysis that is described below.

A jitter analysis that involved varying the starting values of the estimated parameters by up to 10% and re-running the assessment 100 times. Of these runs none failed to achieve convergence to the minimum of the objective function. Model outputs were summarised and plotted using R and the R package r4ss (Taylor et al. 2014). A summary of the estimated parameters and their priors is provided in Table 10.7.

Table 10.7. Summary of the estimated parameters for the 2021 base-case assessment, their priors and source. Normal priors are defined by N (mean, standard deviation). The priors on acoustic survey catchability are Normal on log(q). Survey q's are presented as exp(ln(q)), i.e. with no bias correction is applied.

Estimated parameters	Parameters	Prior	Prior Type / Source
Unexploited recruitment; ln(R_0)	1		Uninformative
Recruitment deviations 1905-1986	82		Uninformative
Selectivity logistic	2		Uninformative
q Acoustic towed catchability	1	N(Ln(0.95), 0.3)	Upston et. al. (2015)
q Hull catchability	1	N(Ln(0.95), 0.92)	Upston et. al. (2015)
Natural mortality *(M)*	1	Log-normal(-3.32, 0.148)	Cordue (ISL)

10.3.3.2 MCMC analysis

Markov chain Monte Carlo (MCMC) is a method for sampling parameter vectors from a posterior distribution in the Bayesian framework (Gelman et al. 2003). The MCMC simulation should be run long enough so that the algorithm converges in the sense that the parameter vectors are random independent samples from the posterior (i.e. the distribution of draws is close enough to the target posterior distribution $p(\theta|y)$; Gelman et al. 2003).

At its October 2021 meeting SERAG requested that that Bayesian posteriors based on MCMC be created for the eastern zone Orange Roughy assessment to permit comparison of the posteriors for *M* and the catchability of the acoustic surveys with their priors and to select 'low' and 'high' scenarios for *M* in the sensitivity analysis. Initial MCMC analysis identified that the width parameter from the age-based logistic selectivity of both the trawl fleet and the two acoustic surveys may have been mis-specified (Figure 10.15). An additional MCMC analyses was undertaken with the width parameter from the logistic selectivity fixed at its MPD estimate of 1.00198, however, this had minimal impact on the median stock status and RBCs from the MCMC analysis. The ORSC determined that the posterior of the width parameters from the logistic selectivity was not of concern and that the original MCMC analysis was used for the base-case assessment.

The MCMC was run for total of 2.5 million iterations with the first 500,000 iterations discarded (the burn-in). For the remaining 2 million iterations, every 1,000th iteration was saved, providing a sample of 2,000 values of the posteriors. To assess inter-chain variability three chains were run, with the parameters and derived quantaties from the first chain compared with their MPD estimates.

MCMC convergence was assessed using the statistics:

(i) The extent of batch auto-correlation (examined using trace plots), high autocorrelations indicate slow mixing and slow convergence,

(ii) Whether the posterior distribution was approximately multivariate normal (we examined the plot of the posterior distribution), and whether the distribution of the chain is stationary, as judged by the p-value computed from the Geweke statistic (which should within the range ±1.96) and

(iii) Whether the Heidelberger and Welch test is passed or not (Heidelberger and Welch 1981, 1983, Gelman et al. 2003).

The R package, coda (Plummer et al., 2006) and r4ss (Taylor et al., 2014), were used to produce the plots and statistics.

10.3.3.3 Tuning – Data Weighting

Iterative rescaling (reweighting) of input and output CVs or input and effective sample sizes is a repeatable way to ensure that the expected variation of the different data streams is comparable to what is input (Pacific Fishery Management Council, 2020). Most of the data sources (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. An automated iterative tuning procedure was used to adjust the recruitment bias ramp and the weighting on the age composition data.

For the recruitment bias adjustment ramps:

1. Adjust the maximum bias adjustment and the start and finish bias adjustment ramps as predicted by r4ss at each step.

For the age composition data:

2. Multiply the initial samples sizes by the sample size multipliers for the age-composition data using the `Francis method' (Francis, 2011).
3. Repeat steps 1 - 2, until all are converged and stable (with proposed changes < 1%). This procedure constitutes current best practice for tuning assessments.

10.3.3.4 Calculating the Recommended Biological Catch

The SESSF Tier 1 harvest control rule specifies a target and a limit biomass reference point, as well as a target fishing mortality rate to determine a recommended biological catch (RBC) for each stock in the SESSF quota management system (Smith et al., 2008). Since 2005 various values have been used for the target and the breakpoint in the rule. In 2009, AFMA directed that the 20:35:48 (B_{lim}: B_{break}: F_{targ}) form of the rule is used, assuming a F_{targ} of F_{48}, the default economic target for B_{MEY} in the SESSF.

This 20:35:48 rule is used for the 2021 eastern zone Orange Roughy assessment with the long-term RBC and the time for the stock to reach the target reference point estimated by projecting the asseessment forward in time using mean recruitment (subject to the stock recruitment relatonship) and catches from the SESSF harvest control rule.

10.3.4 *Sensitivities*

10.3.4.1 Likelihood Profiles

Likelihood profiles are a standard component of the toolbox of applied statisticians (Punt 2018). They are most often used to obtain 95% confidence intervals. Many stock assessments "fix" key parameters such as *M* and *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. 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 steepness of the stock recruitment relationship (*h*), female spawning biomass in 1980 (SSB_{1980}) and current stock status (SSB_{2021}/SSB_0) and *M* were conducted using the base-case assessment. Confidence intervals were constructed using a Chi squared distribution with one degree of freedom. The 2.5% and 97.5% quantiles of the likelihood profiles (a 95% confidence interval) were therefore obtained at 1.92 log-likelihood units from the minimum.

10.3.4.2 Retrospective analysis

A retrospective analysis was undertaken to identify how the assessment outcomes may have changed as new data have been added to the assessment. We undertook assessments after removing four, seven and ten years of data from the base-case model.

The severity of retrospective patterns can be quantified using a statistic called Mohn's rho, which is defined as the average of the relative differences between an estimate from an assessment with a truncated time series and an estimate of the same quantity from an assessment using the full time series (Hurtado-Ferro et al. 2015). Mohn's rho values are calculated for a range of effects, including SSB, recruitment, *F* and stock status. As a general rule of thumb values of Mohn's rho higher than 0.20 or lower than −0.15 are cause for concern in an assessment (Hurtado-Ferro et al. 2015). Mohn's rho statistic was estimated from the retrospective analysis using the R package r4ss (Taylor et al. 2014).

10.3.4.3 Sensitivity analyses

The sensitivity of the base-case model to values of some fixed parameters, data weighting, the natural mortality estimate and the catch in 2021 are explored. The following sensitivities are undertaken:

- Low (*h*=0.6) and high (*h*=0.9) steepness of the Beverton-Holt stock recruitment relationship.
- Low (σ_R = 0.6) and high (σ_R = 0.8) recruitment variability.
- Set natural mortality at the 12.5% (low) and 87.5% (high) quantiles from the posterior of *M*.
- Halve and double the weights on the age data in the likelihood.
- Removing the 1992 egg survey.
- Use the estimated catch for 2021 of 1,350 t provided by AFMA.
- Use the 2021 TAC of 1,569.4 t, that includes undercatch from the 2020 season.

10.3.4.4 Fixed Catch Projections

The ORSC requested fixed catch projections be developed in consultation with AFMA to be presented to the November 2021 SERAG meeting. An MCMC analysis was undertaken projecting the 2021 base-case model to 2031 with constant catches of 550, 650, 737, 850 and 950 t per annum. Stock status and the probability of being below the limit reference point were calculated in 2024 and 2031.

Each scenario was was run for a total of 2.5 million MCMC iterations with the first 750,000 iterations discarded (the burn-in). For the remaining 1.75 million iterations, every 1,000th iteration was saved, providing a sample of 1,750 values of the posteriors. Each scenario was started from a different random number seed, leading to median estimates of spawning biomass and stock status in 2021 that were slightly different among the different scenarios. These differences were minimal (<0.7%). To check the robustness of the results, the scenarios were re-run with longer MCMC chains (5 million iterations) after the November 2021 SERAG meeting. Estimates of stock status and the probability of being below the limit reference point in 2024 and 2031 from the longer chains were within 1% of those provided in Table 10.11.

At the February 2022 SEMAC meeting a catch scenario of 1,166 t in 2022, 1,055 t in 2023 and 950 t yr^{-1} thereafter was proposed by industry. Estimates spawning biomass and stock status in 2024 and 2031 from this scenario have been added to Table 10.11.

10.4 Results

10.4.1 *2021 base-case assessment model*

10.4.1.1 Parameter estimates and derived quantities

The base-case model (MPD estimate) converged with final gradient $<1e^{-4}$ and a positive definite Hessian. The jitter analysis found that there was less than $1e^{-4}$ variability among the likelihood components and parameter estimates from the assessments undertaken with different starting values, suggesting the base-case model is insensitive to the initial values of parameters.

The MCMC analysis converged after increasing the burn-in to exclude an additional 250,000 samples from the posterior (Figure A 10.3-Figure A 10.9, Table A 10.1). With the exception of the width of the selectivity function and one recruitment deviation, all parameters passed the standard diagnostic tests (Table A 10.1, Figure A 10.9). Estimates of parameters and derived quantities from the MPD were in most cases different from the posterior medians from the MCMC analysis (Figure 10.10, Figure 10.11, Figure 10.13–Figure 10.15, Table 10.8). This difference was discussed by the ORSC and while it is unsual that the MPD estimate and the posterior median from MCMC analysis differ it does occur from time to time and has occurred for some assessment models used for Orange Roughy in New Zealand.

The ORSC was not unduely concerned about the level of variability in the posterior of the width parameter of the logistic selectivity, and it was believed that it was not so extreme as to suggeset that parameter should be fixed in the model. As a sensitivity the MCMC analysis was re-run with the selectivity width parameter fixed at its MPD estimate. This did not change the difference between the parameter estimates from the MPD and the MCMC (Figure A 10.11, Figure A 10.12).

There was some correlation among the estimated parameters with M and the catchability (q) of the towed acoustic survey was highly correlated with mean unfished recruitment (R_0), which is not uncommon as these parameters are directly related to the productivity of the stock (Figure A 10.10).

The two parameters from the logistic selectivity function were also correlated, which again is not uncommon.

The median estimate of unfished female spawning biomass from the MCMC analysis was 38,924 t, which is slightly lower than the MPD estimate of 40,479 t (Figure 10.8, Table 10.8). The current 2022 female spawning biomass is estimated to be 11,644 t from the MCMC and 13,126 t from the MPD. Relative spawning biomass in 2022 is estimated at 30.0% of unfished levels from the MCMC and 32.4% of unfished levels from the MPD (Figure 10.8).

The estimated selectivity pattern is slightly different to the maturity ogive (Figure 10.9) and the width of the selectivity function was near its lower bound in both the 2021 and 2017 assessments. The fixed growth curve is shown in Appendix A (Figure A 10.2). There is a strong trend in recruitment over time, with recruitment estimated to be above average prior to 1950 and below average afterwards (Figure 10.10). This trend in recruitment is similar to that from the 2017 assessment.

The median estimate of M from the MCMC analysis is 0.0393 yr^{-1} slightly higher than the MPD estimate of 0.0386 yr^{-1} (Table 10.8). The median estimates of catchability for the towed and hull acoustic surveys from the MCMC analysis are 1.189 and 1.521 respectively, which are higher than the MPD estimates of 1.103 and 1.49 respectively (Table 10.8). These estimates are all higher than the 2017 assessment and imply is was an increase in estimated of the q for the towed survey compared with the previous assessment with a fixed M of 0.04 yr^{-1}. While a catchability greater than 1 means the model is inferring that the biomass is greater than the survey estimate. However, both catchability estimates well within range of the priors for acoustic survey catchability (Figure 10.14).

The recommended biological catch (RBC) for 2022 from the MCMC analysis is 681 t, lower than the MPD estimate for 2022 of 944 t (Table 10.8). The average RBC over the next three years (2022-2024) is 737 t from the MCMC analysis and 1,025 t from the MPD. There is a high level of uncertainty in the estimated RBC with the 75% and 95% credible intervals from the MCMC analysis for the 2022 RBC being 287–1,316 t and 119–1,645 t respectively.

Table 10.8. The estimated parameters and derived quantities for the 2021 base-case model. The estimate along with 95% asymptotic confidence intervals (2.5%, 97.5%) and coefficient of variation from the MPD is shown along with the Median, 95% (2.5%, 97.5%) and 75% (12.5%, 87.5%) credible intervals from 1,750 samples of the posterior from the MCMC analysis.

	MPD				**MCMC**					
Quantity	**Estimate**	**2.5%**	**97.5%**	**CV**	**Median**	**2.5%**	**12.5%**	**87.5%**	**97.5%**	**CV**
M	**0.0386**	0.0324	0.0448	0.0820	**0.0393**	0.0337	0.0358	0.0432	0.0461	0.0812
$ln(R_0)$	**9.005**	8.616	9.394	0.022	**9.006**	8.639	8.782	9.253	9.441	0.023
towed q	**1.103**	0.782	1.556	1.794	**1.189**	0.833	0.962	1.456	1.687	1.043
hull q	**1.490**	0.785	2.830	0.820	**1.521**	0.813	1.050	2.230	2.888	0.778
Selectivity inflection	**35.086**	34.591	35.582	0.007	**35.169**	34.600	34.836	35.563	35.902	0.009
Selectivity width	**1.002**	0.873	1.131	0.066	**1.446**	1.019	1.101	2.070	2.516	0.268
SSB_0	**40,479**	37,039	43,919	0.043	**38,924**	33,578	35,771	41,779	44,185	0.069
SSB_{2022}	**13,126**	8,939	17,313	0.163	**11,644**	8,332	9,475	14,285	16,779	0.185
SSB_{2023}	**13,466**	9,466	17,465	0.152	**11,892**	8,687	9,792	14,453	16,861	0.175
SSB_{2024}	**13,753**	9,953	17,553	0.141	**12,107**	8,996	10,094	14,555	16,857	0.166
SSB_{2025}	**13,989**	10,394	17,584	0.131	**12,263**	9,271	10,355	14,625	16,832	0.158
SSB_{2022}/SSB_0	**0.324**	0.237	0.411	0.137	**0.300**	0.228	0.254	0.356	0.401	0.148
SSB_{2023}/SSB_0	**0.333**	0.251	0.414	0.125	**0.307**	0.237	0.263	0.359	0.403	0.138
SSB_{2024}/SSB_0	**0.340**	0.264	0.416	0.114	**0.313**	0.246	0.271	0.362	0.404	0.128
SSB_{2025}/SSB_0	**0.346**	0.275	0.416	0.104	**0.318**	0.254	0.278	0.363	0.403	0.119
RBC_{2022}	**944**	0	2,003	0.572	**681**	119	287	1,316	1,645	0.566
RBC_{2023}	**1,029**	0	2,076	0.519	**740**	168	345	1,332	1,648	0.514
RBC_{2024}	**1,102**	81	2,124	0.473	**789**	215	395	1,338	1,648	0.470
RBC_{2025}	**1,163**	177	2,149	0.433	**830**	260	441	1,339	1,644	0.433
Average RBC (2022-2024)	**1,025**				**737**					

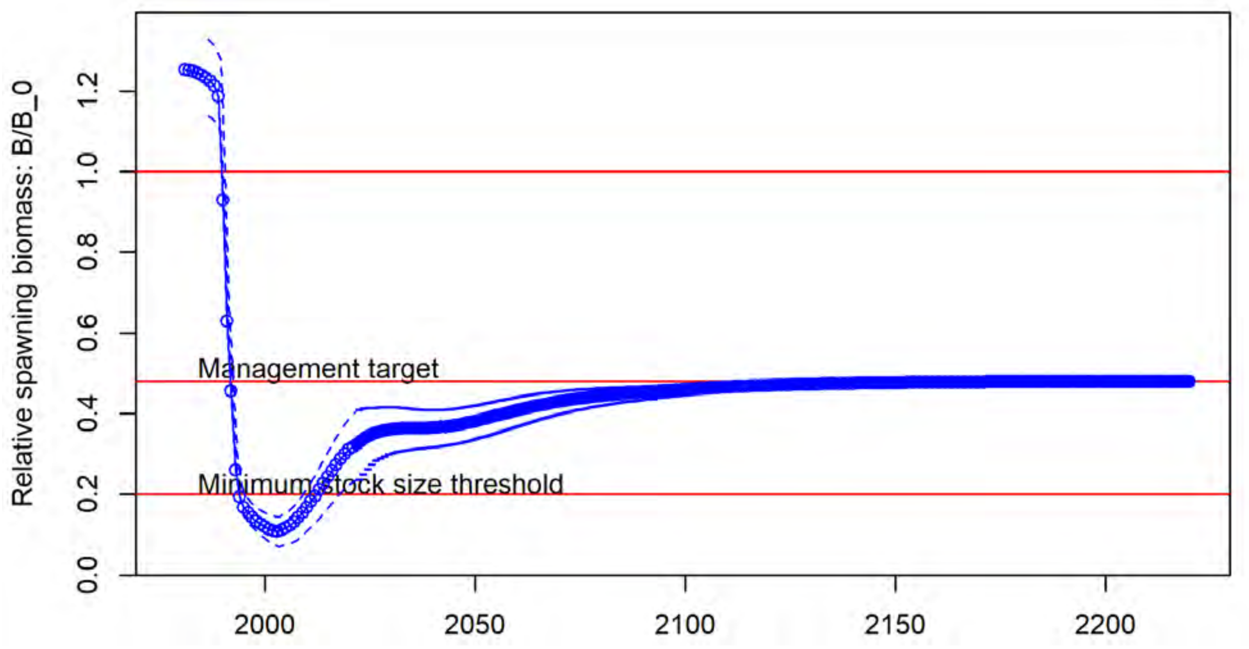


Figure 10.8. The MPD (point estimate) time-series of relative spawning biomass forecast 200 years into the future with catches set using the SESSF 20:35:48 harvest control rule for the 2021 base-case model. The dashed line indicates approximate 95% confidence intervals.

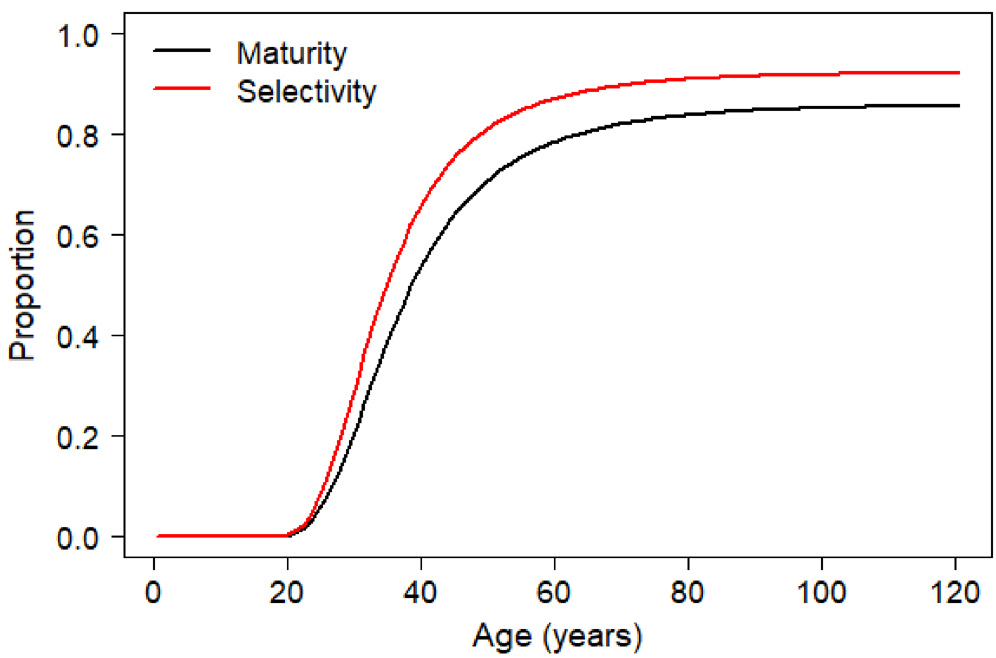


Figure 10.9. The estimated selectivity curve and prespecified maturity ogive for the 2021 base-case model.

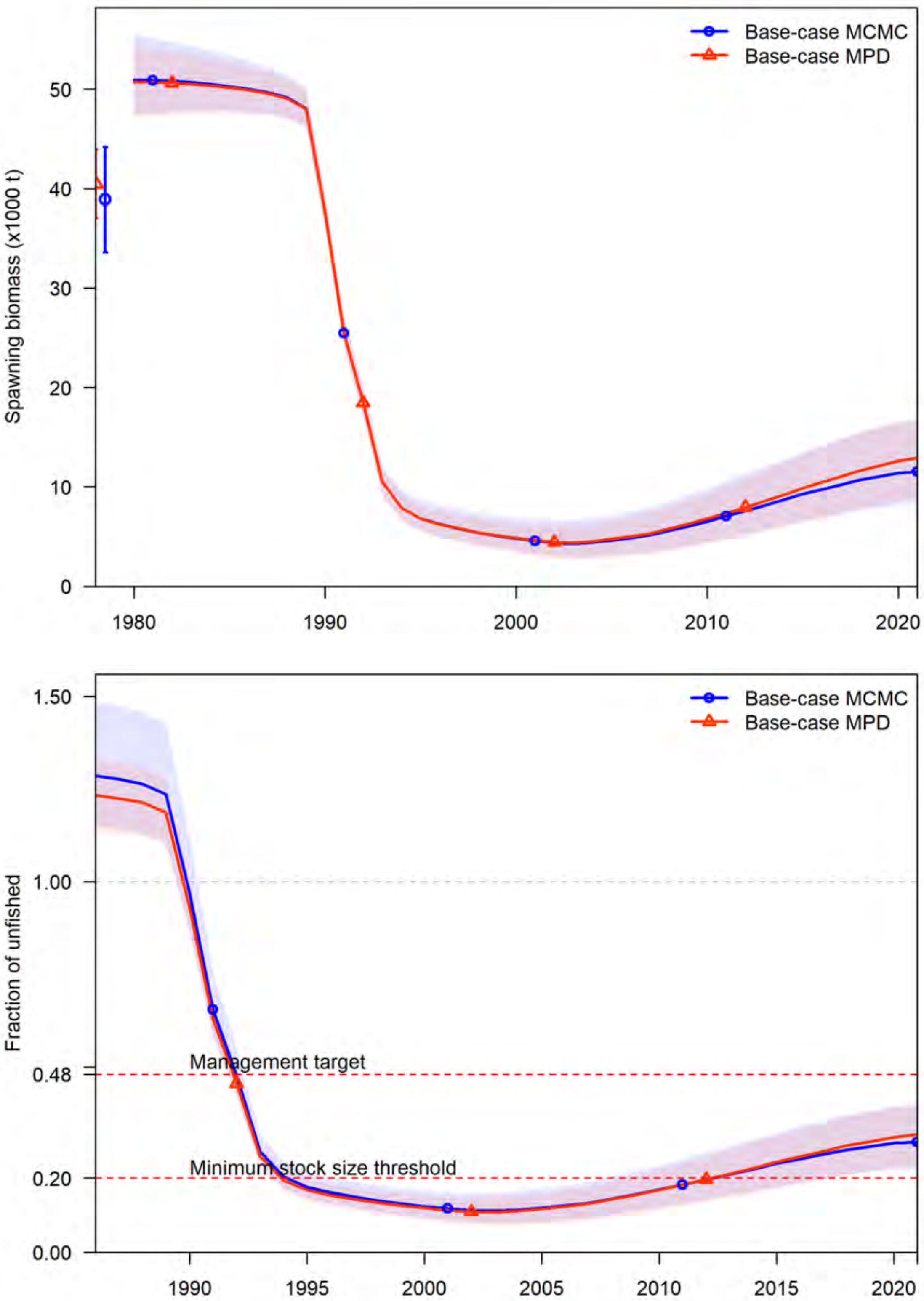


Figure 10.10. Comparison of time-series of absolute (top) and relative (bottom) spawning biomass (with ~95% intervals) for the 2021 base-case model. The red line and shading represent the point estimate and uncertainty from the MPD while the blue line and shading represents the median and uncertainty from 1,750 samples of the posterior from the MCMC.

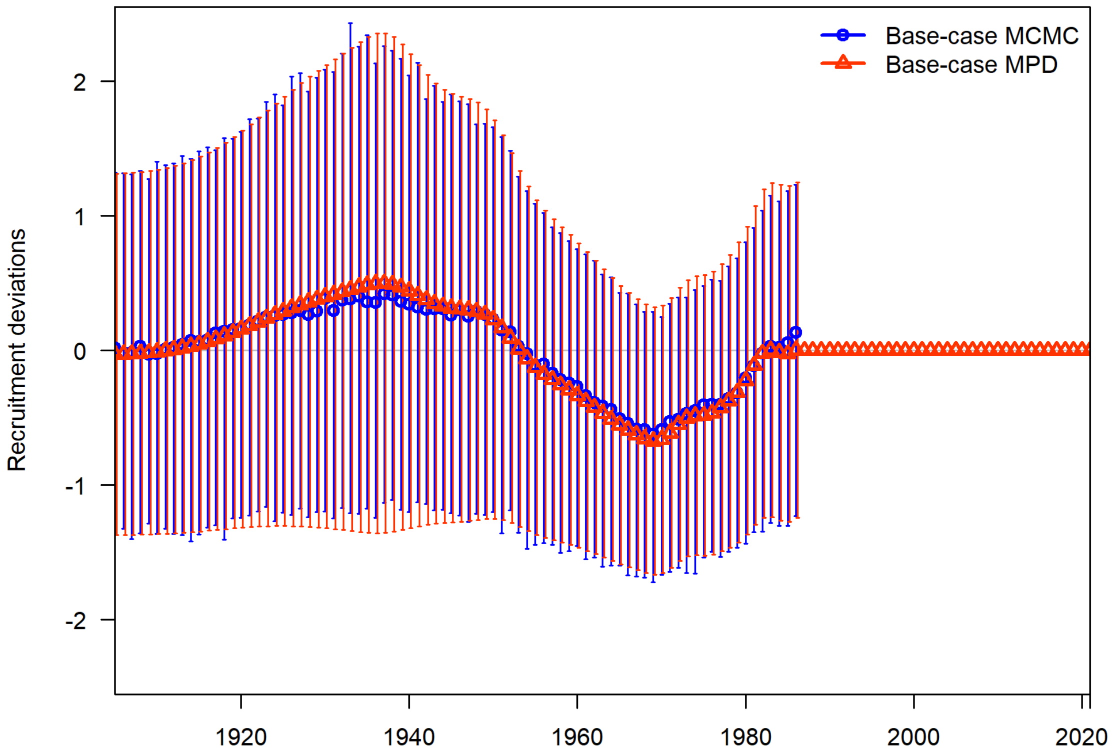


Figure 10.11. Comparison of time-series of recruitment deviations with ~95% intervals for the 2021 base-case model. The red line and shading represent the point estimate and uncertainty from the MPD while the blue line and shading represents the median and uncertainty from 1,750 samples of the posterior from the MCMC.

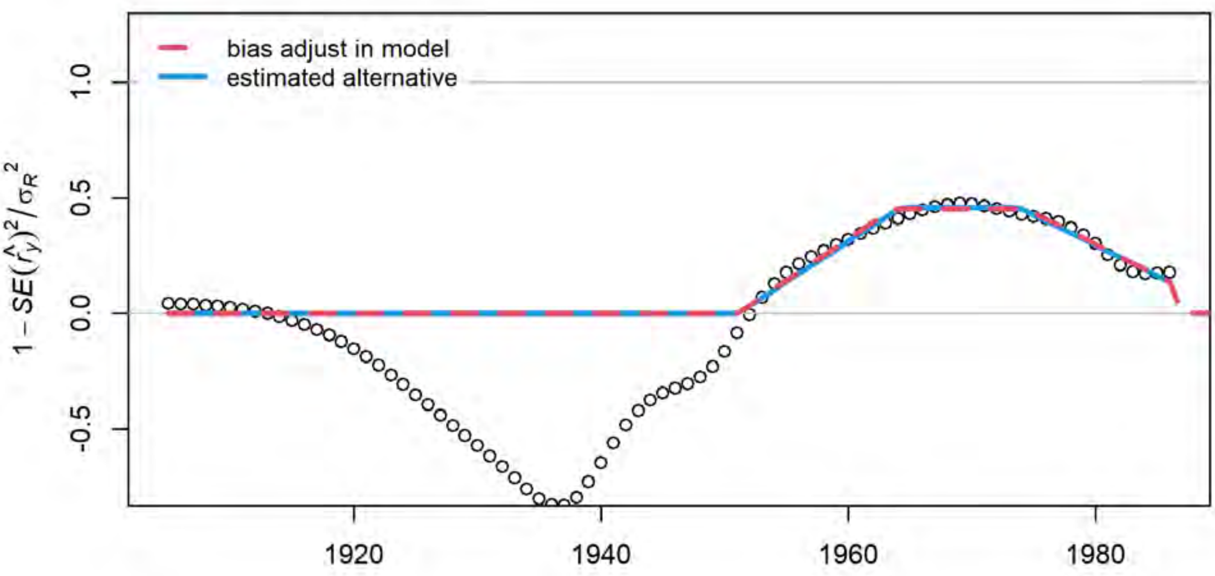


Figure 10.12. Bias ramp adjustment for the 2021 base-case model.

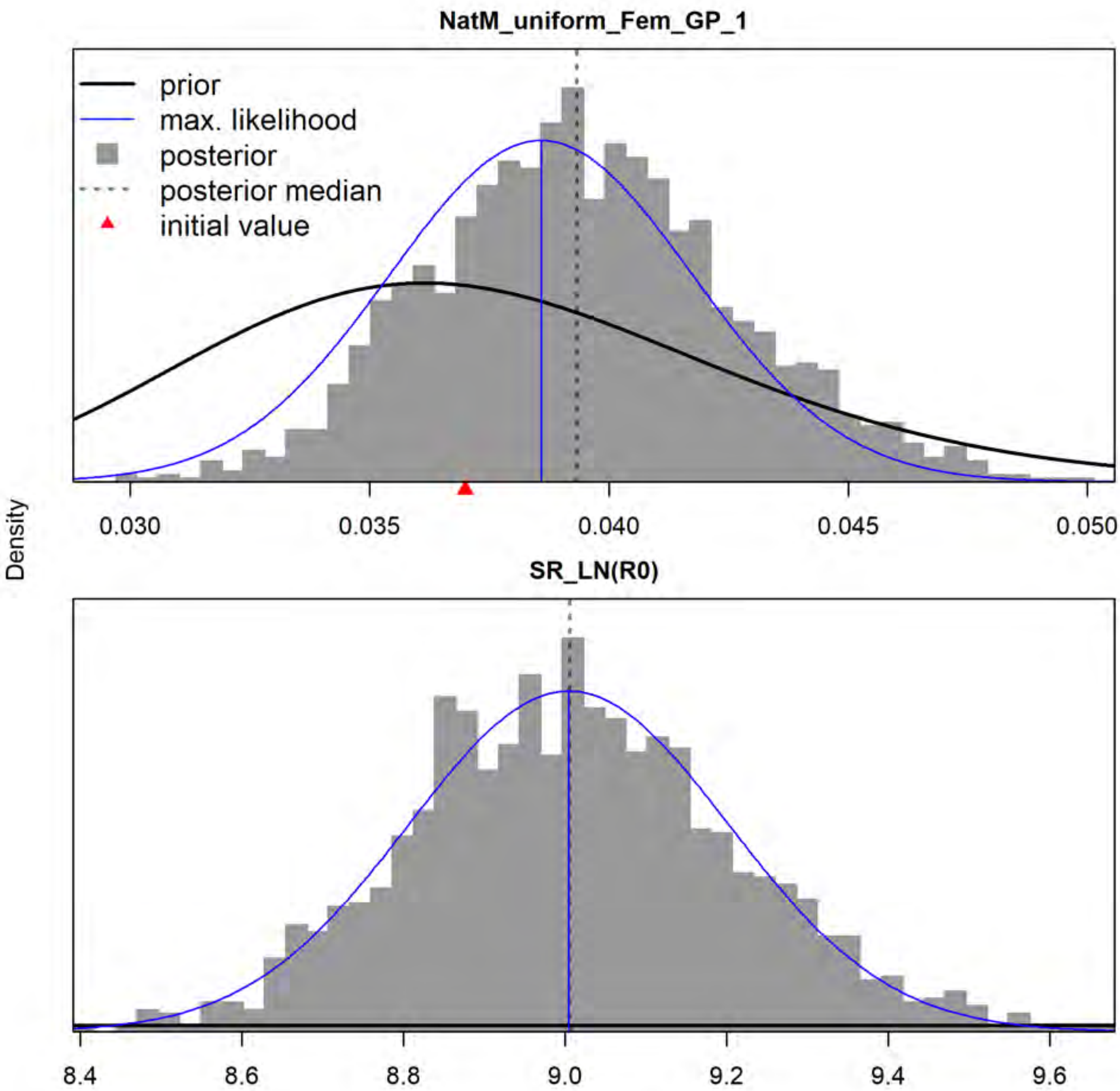


Figure 10.13. Histograms of the posterior of natural mortality (top) and the log of unfished mean recruitment (bottom) for the 2021 base-case model. The histogram comprises 1,750 samples from the posterior, the blue vertical and curved lines are the MPD estimate and asymptotic uncertainty and the black line is the prior.

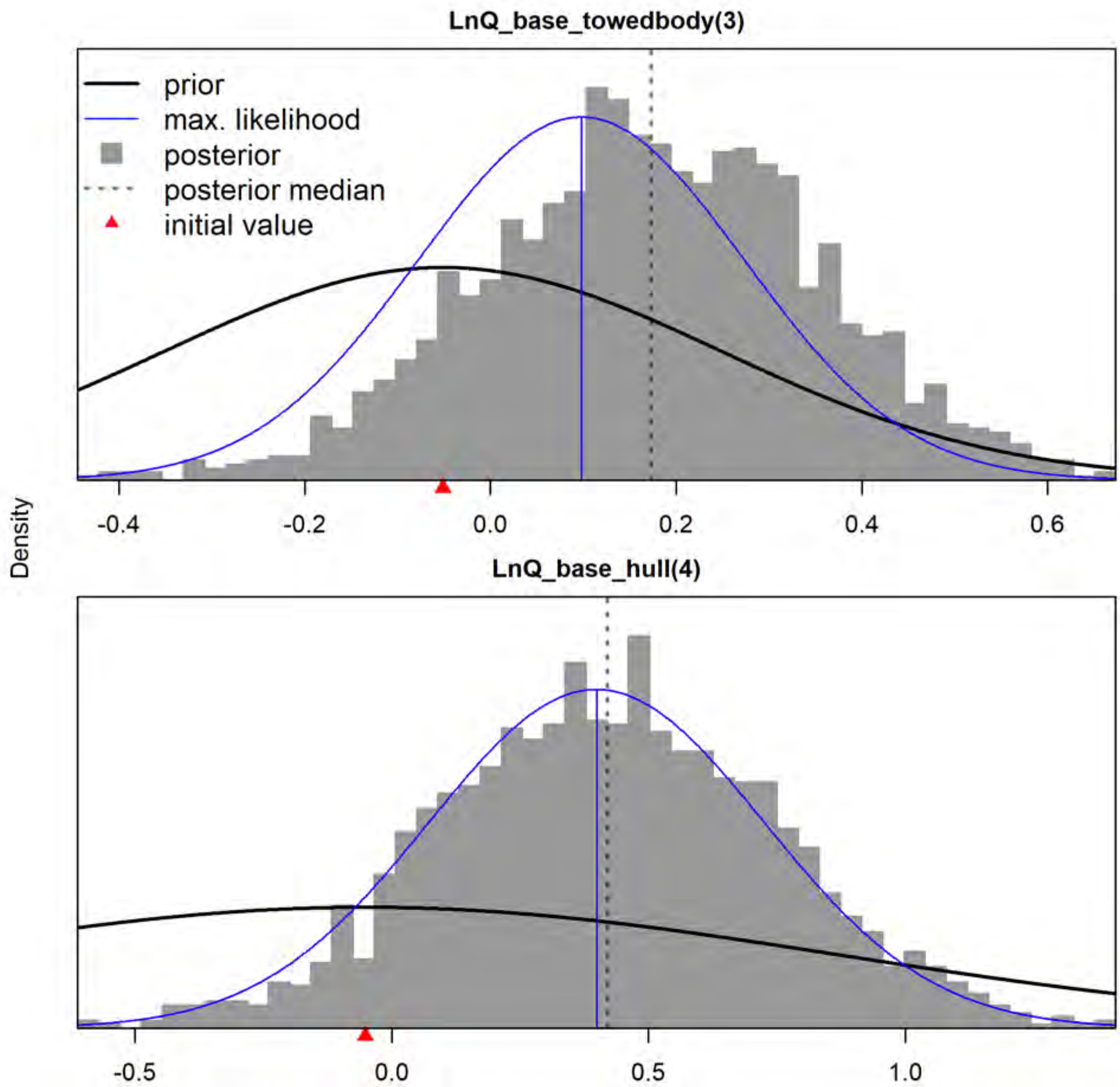


Figure 10.14. Histograms of the posterior of log catchability from the towed (top) and hull (bottom) acoustic surveys from the 2021 base-case model. The histogram comprises 1,750 samples from the posterior, the blue vertical and curved lines are the MPD estimate and asymptotic uncertainty and the black line is the prior. Note the acoustic catchability parameters are presented here as log(q), while they are presented as exp(log(q)) elsewhere in this report.

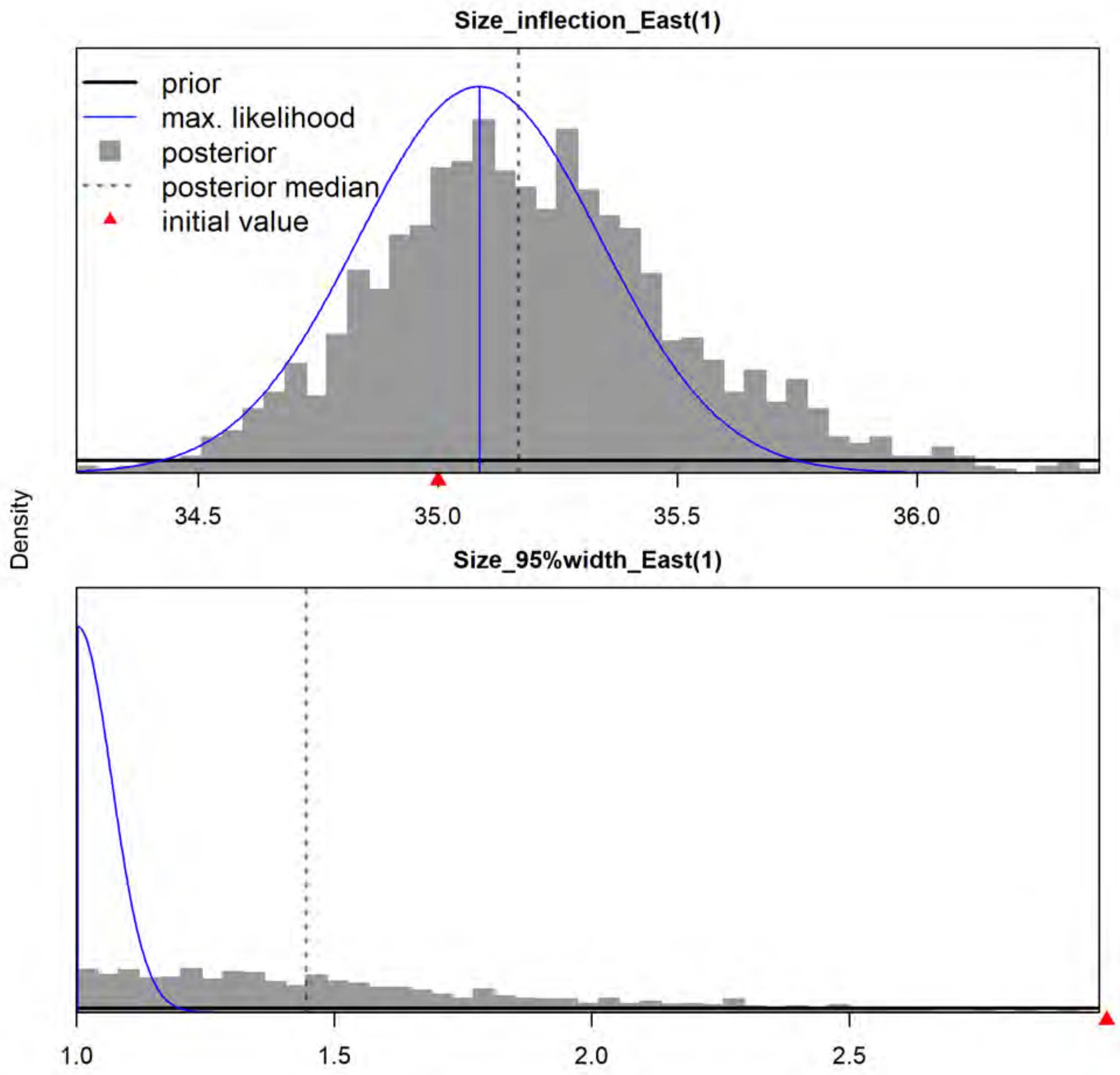


Figure 10.15. Histograms of the posterior of the inflection (top) and width (bottom) parameters of the length-based selectivity logistic selectivity for the 2021 base-case model. The histogram comprises 1,750 samples from the posterior, the blue vertical and curved lines are the MPD estimate and asymptotic uncertainty and the black line is the prior.

10.4.1.2 Fits to the data and diagnostics

Fits to the index data are reasonably good (Figure 10.16–Figure 10.19) and similar to those from the 2017 assessment. Residual plots of the fits to the index data show the model under-estimates the biomass from the towed body surveys before 2010 (Figure 10.19). However, the model estimates of survey-selected biomass are well within the confidence intervals of the survey biomass estimates.

The fits to the mean age by year show male ages are slightly over-estimated while female ages are slightly underestimated (Figure 10.20). The model under-estimates the proportion of younger age-classes in 1992 and 1995 and over-estimates the proportion of individuals in the plus group in 1999, while under-estimating the proportion of individuals in the plus group in most years after 2000 (Figure 10.21-Figure 10.25). There is no trend in the residuals of the fits to the age data (Figure 10.26).

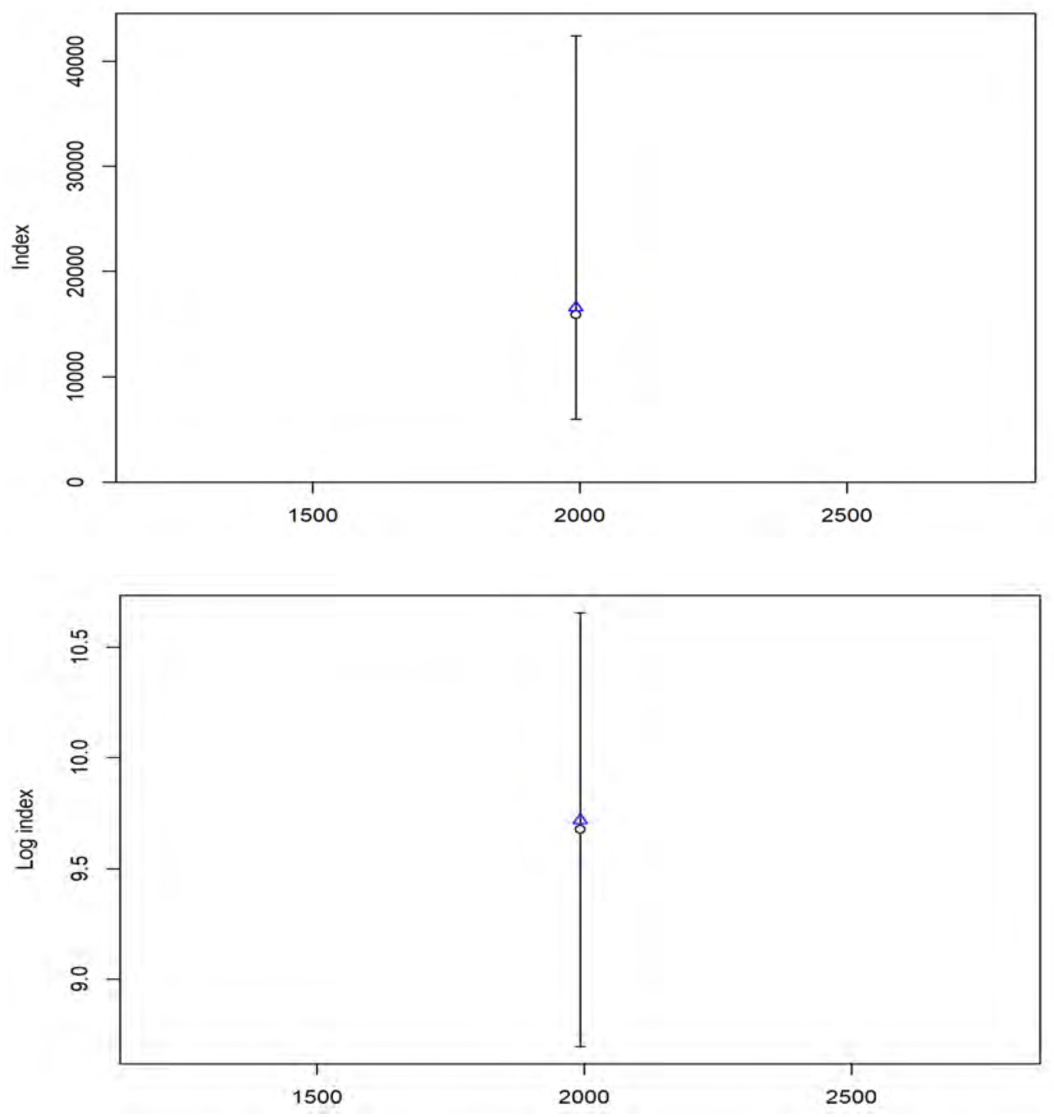


Figure 10.16. Fits to the biomass index (top) and log index (bottom) for the 1992 egg survey for the base-case model.

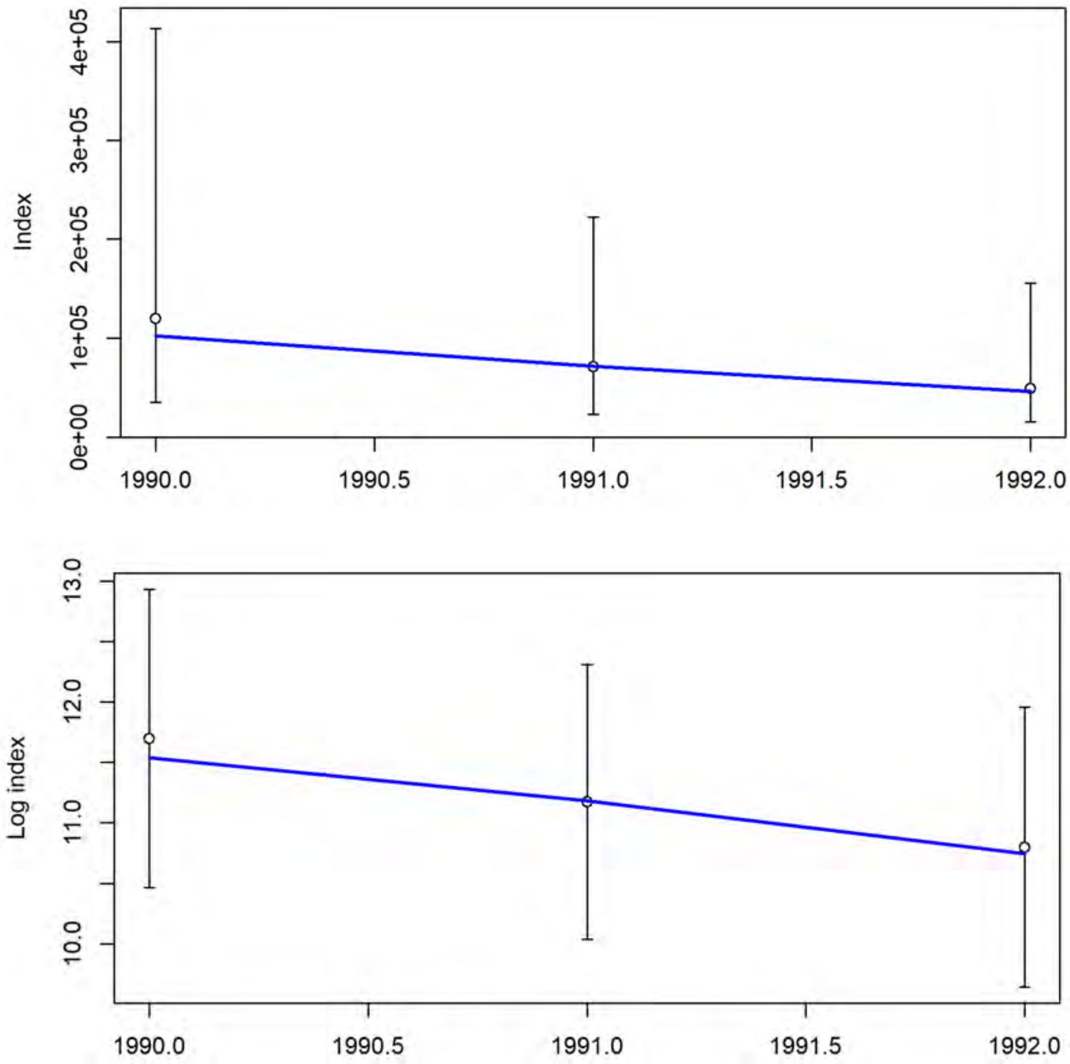
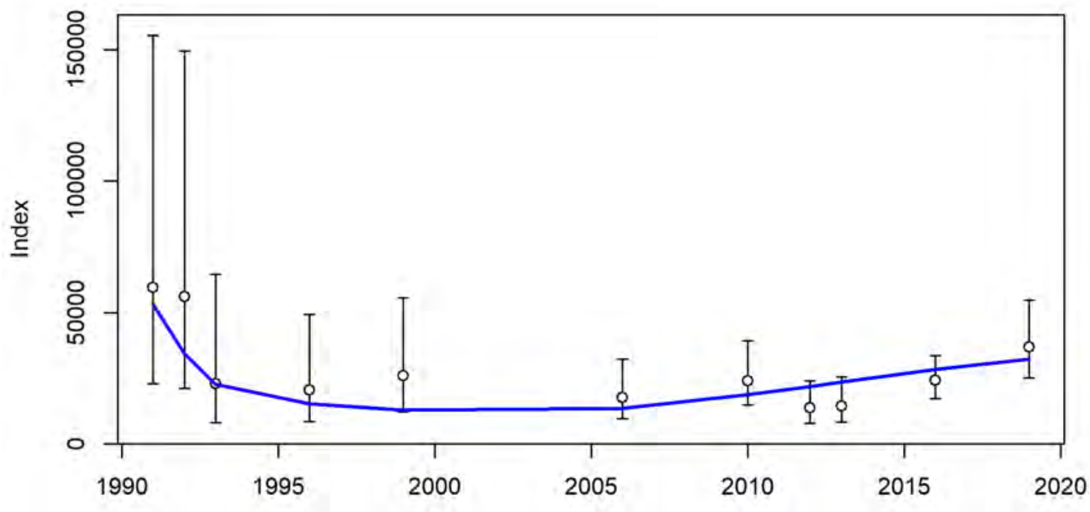


Figure 10.17. Fits to the biomass indices (top) and log indices (bottom) for the hull surveys for the 2021 base-case model.



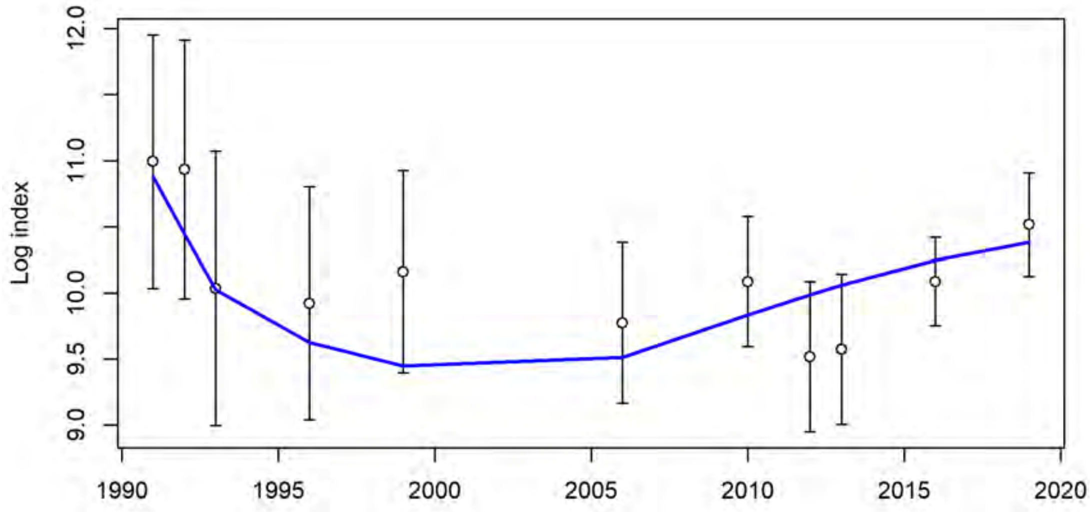


Figure 10.18. Fits to the biomass indices (top) and log indices (bottom) for the towed surveys for the 2021 base-case model.

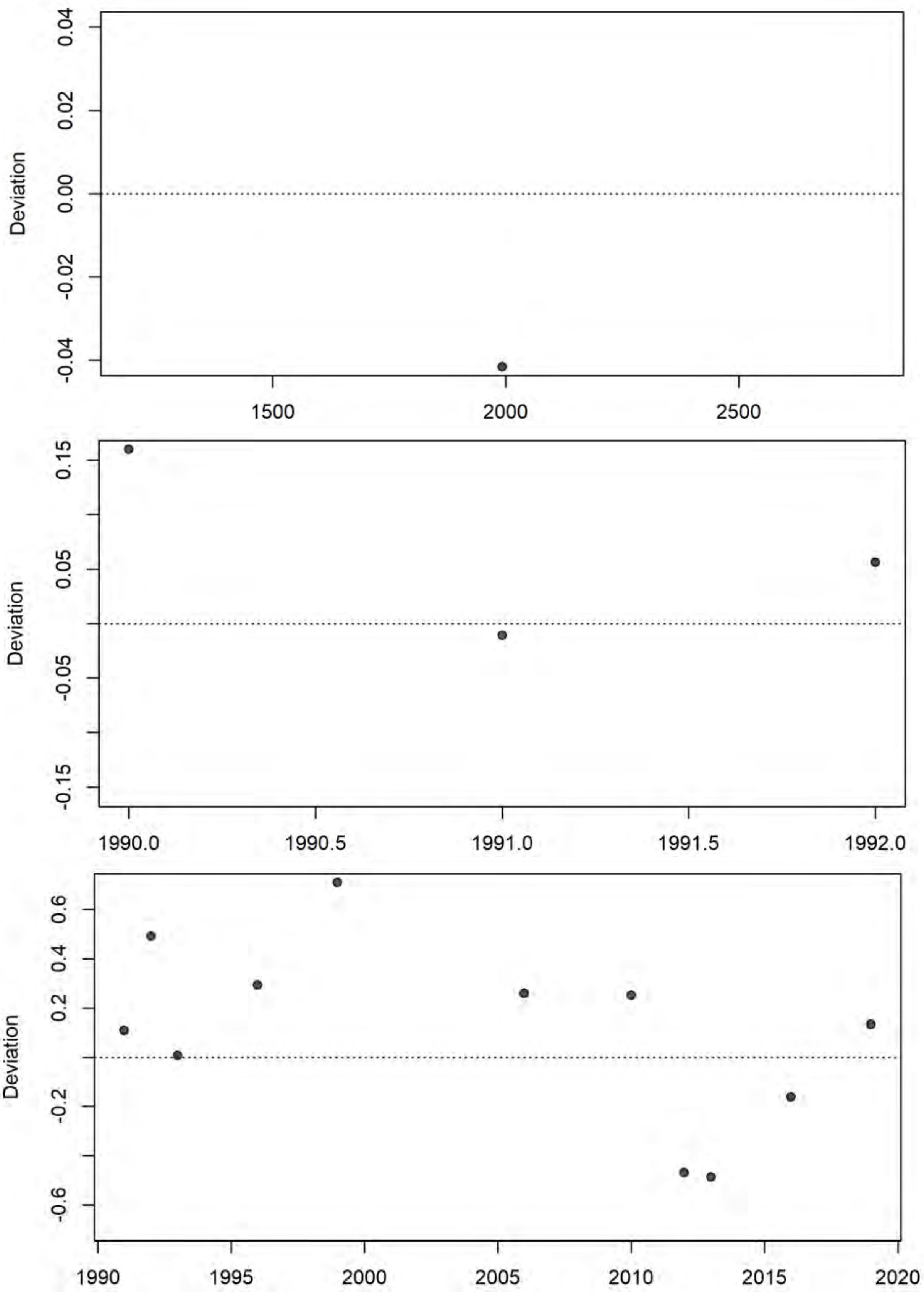


Figure 10.19. Standardized residuals from fits to the egg survey (top), hull survey (middle) and towed survey (bottom) indices for the 2021 base-case model.

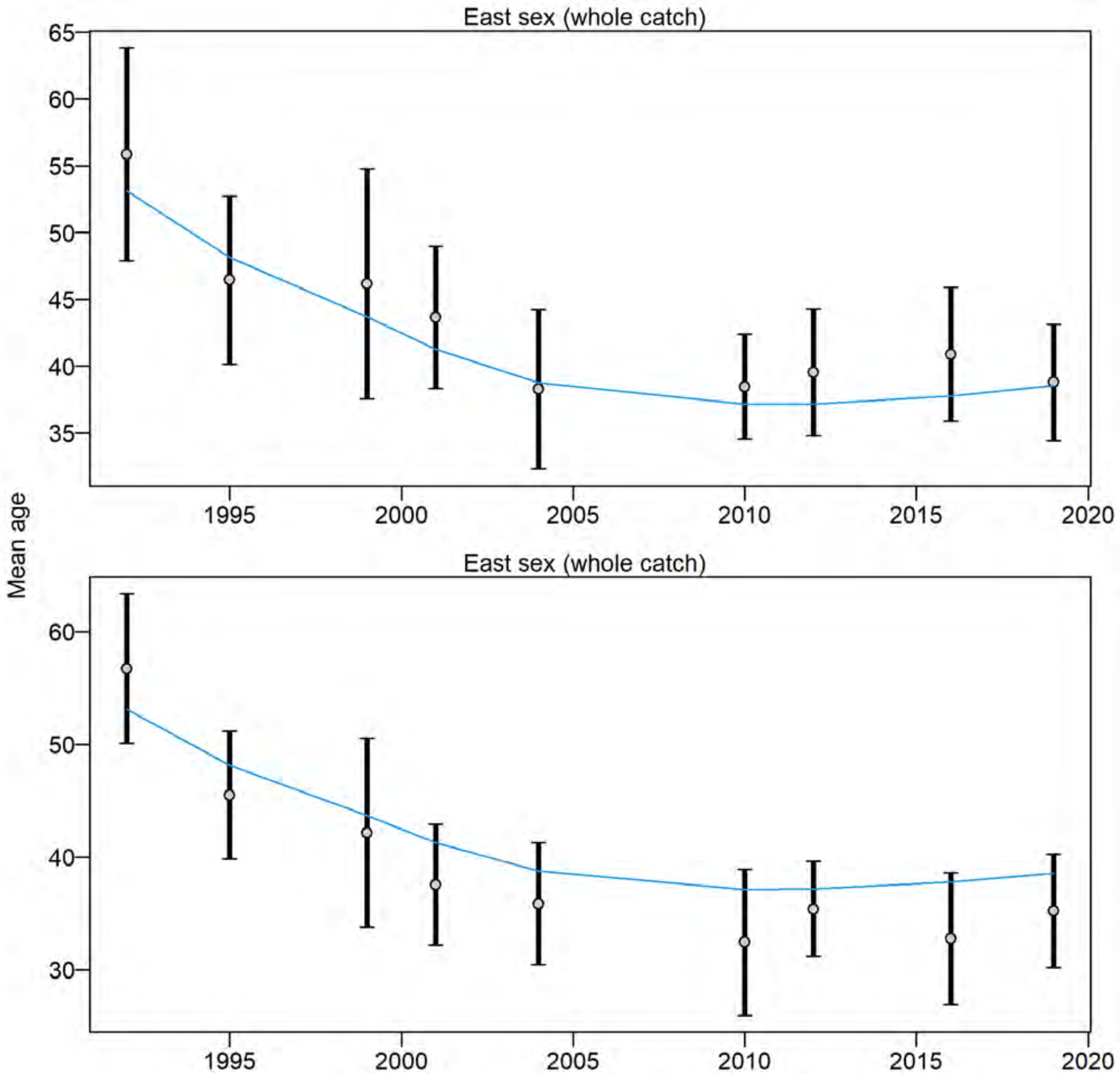


Figure 10.20. Mean age for male and female samples with 95% confidence intervals based on current sample sizes for the 2021 base-case model. The suggested multiplier for Francis data weighting method TA1.8 of age data with 95% interval is 1.0022 (0.7615-1.7396).

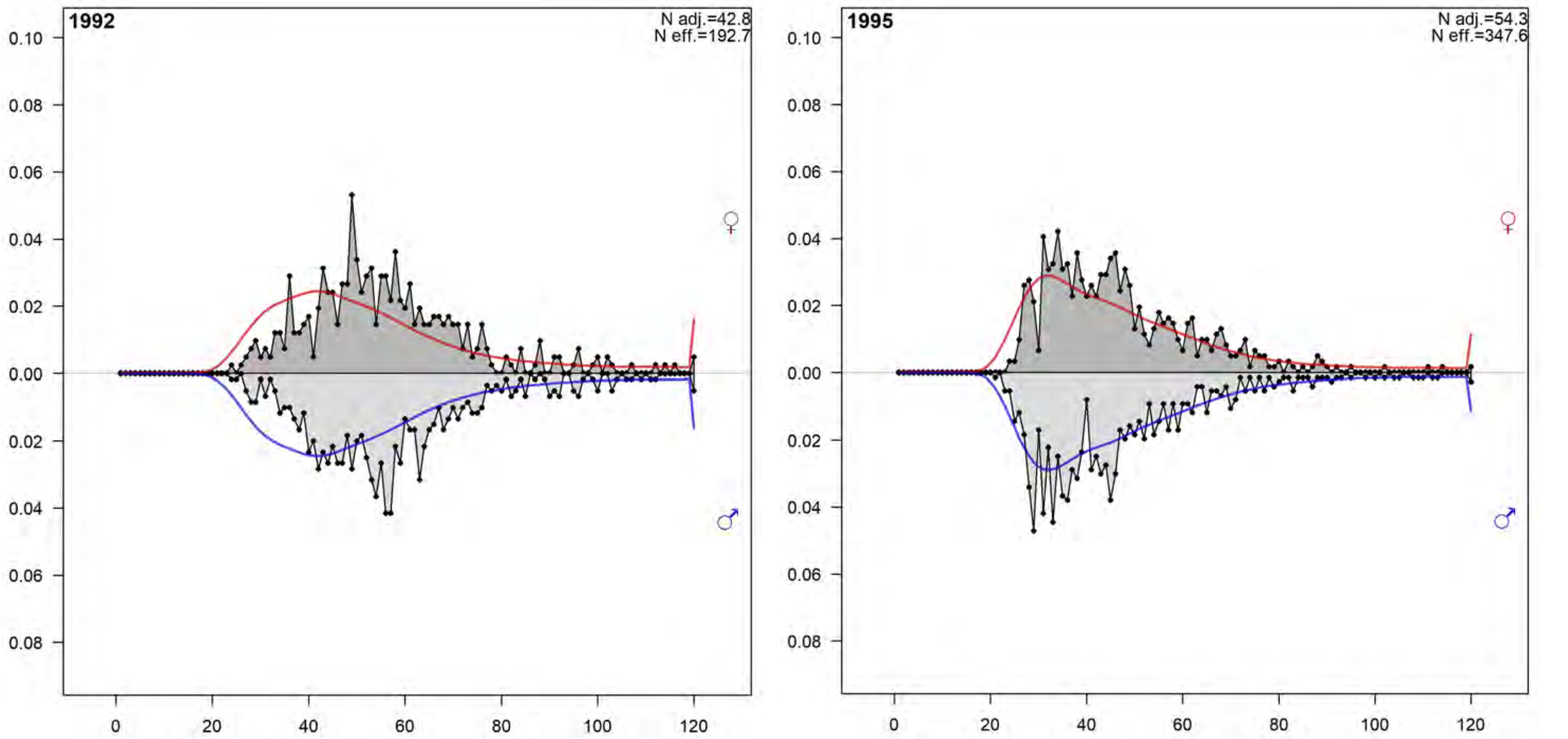


Figure 10.21. Fits to the 1992 and 1995 age data for the 2021 base-case model.

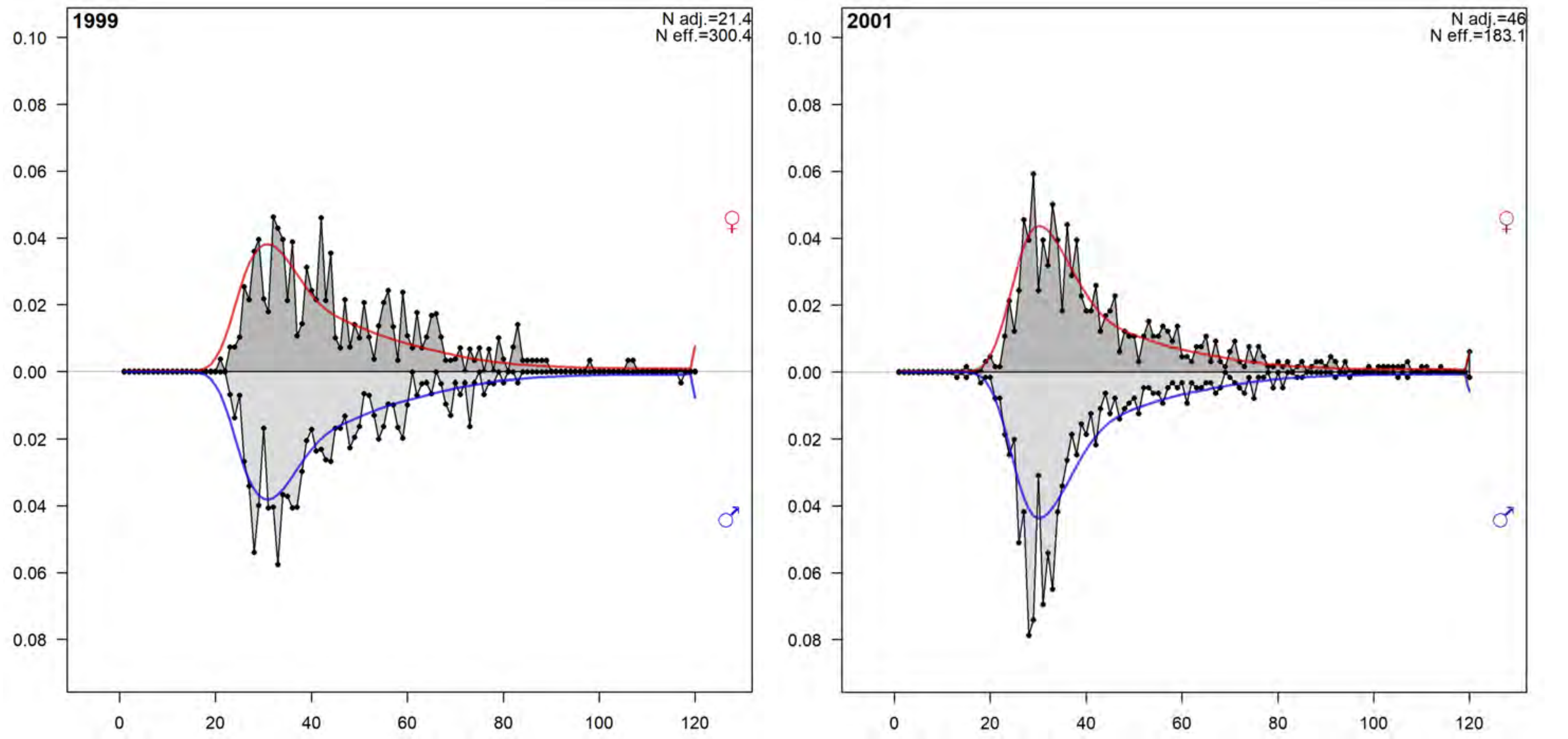


Figure 10.22. Fits to the 1999 and 2001 age data for the 2021 base-case model.

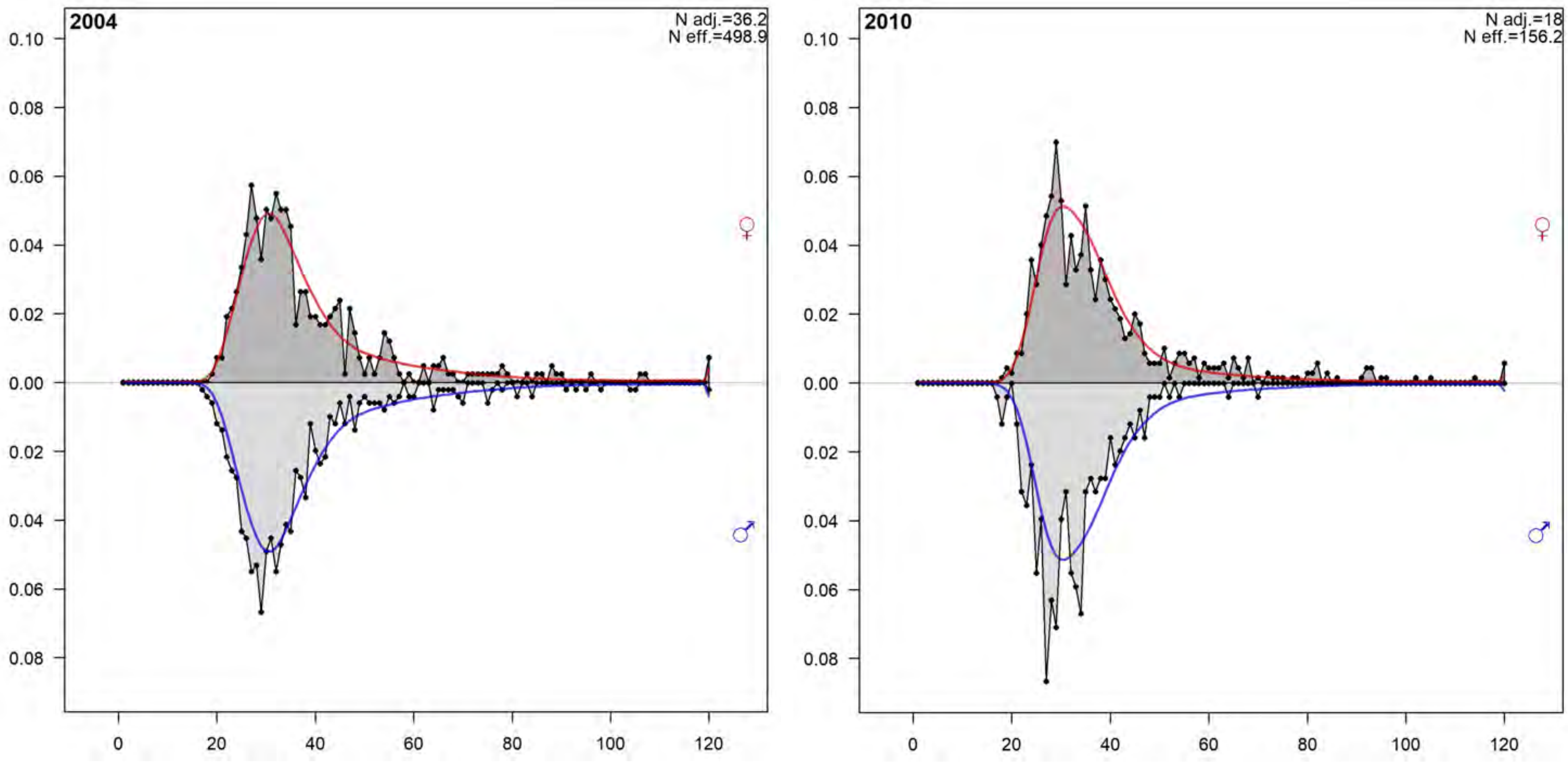


Figure 10.23. Fits to the 2004 and 2010 age data for the 2021 base-case model.

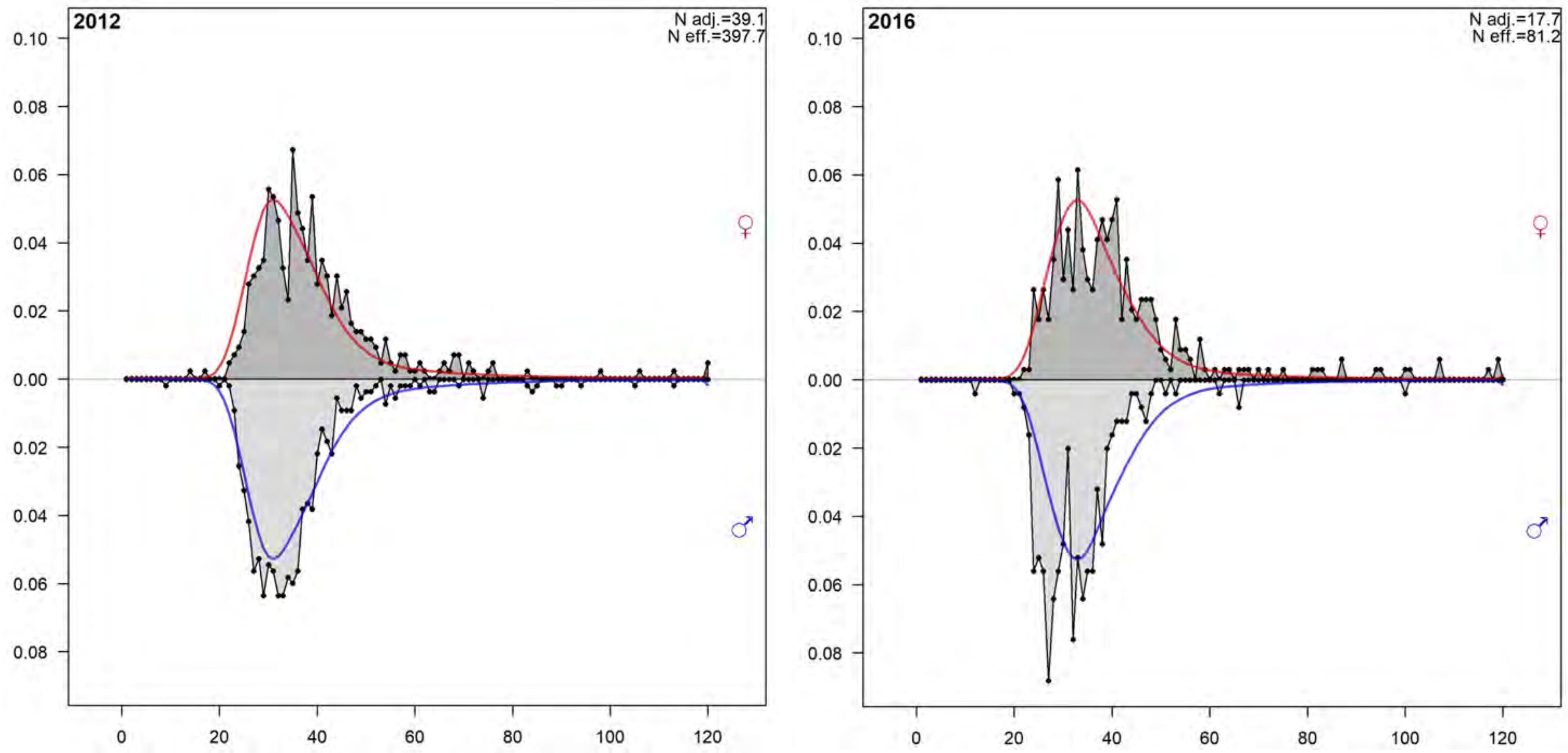


Figure 10.24. Fits to the 2012 and 2016 age data for the 2021 base-case model.

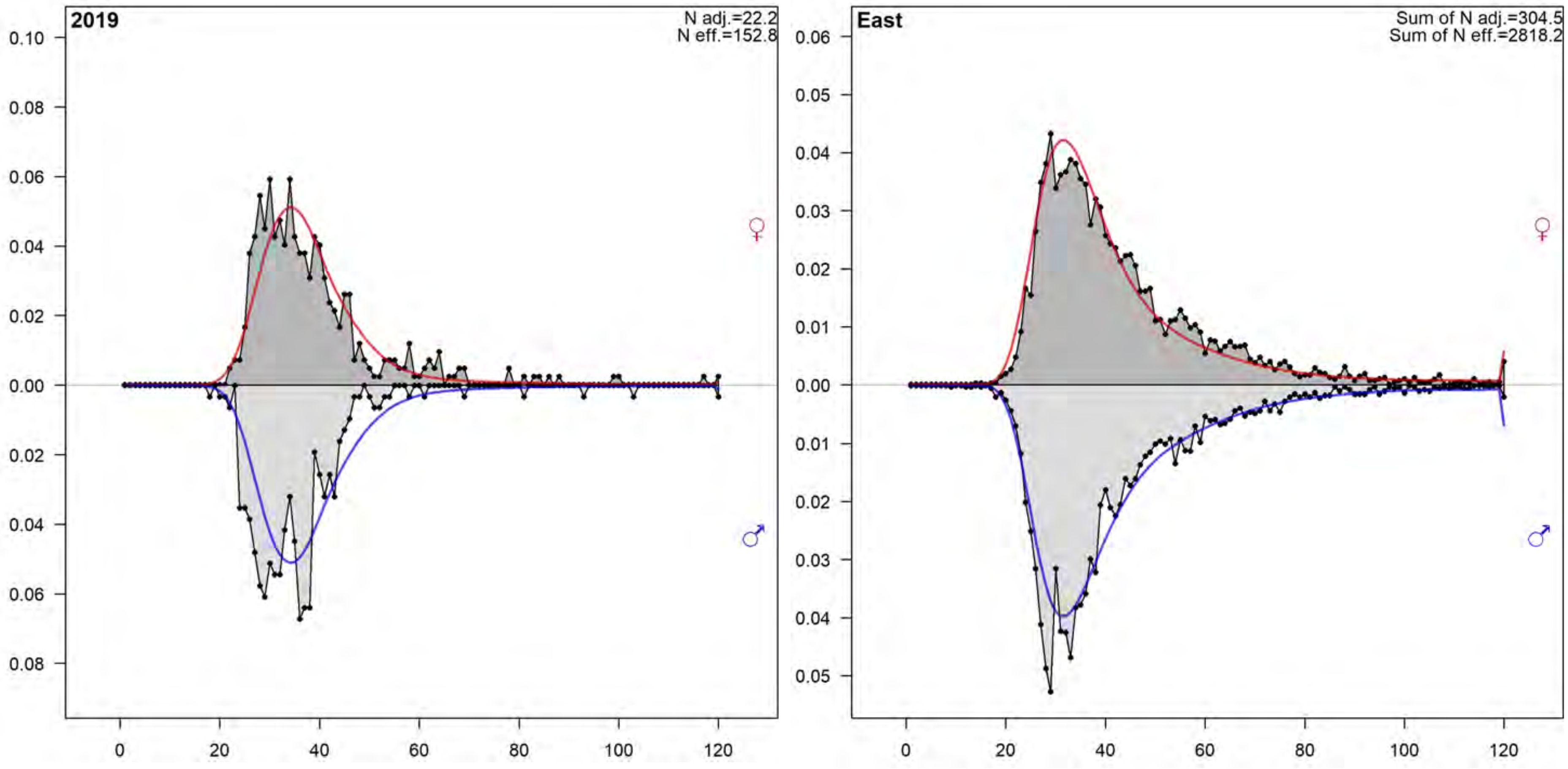


Figure 10.25. Fits to the 2019 age data and the age data combined for all years for the 2021 base-case model.

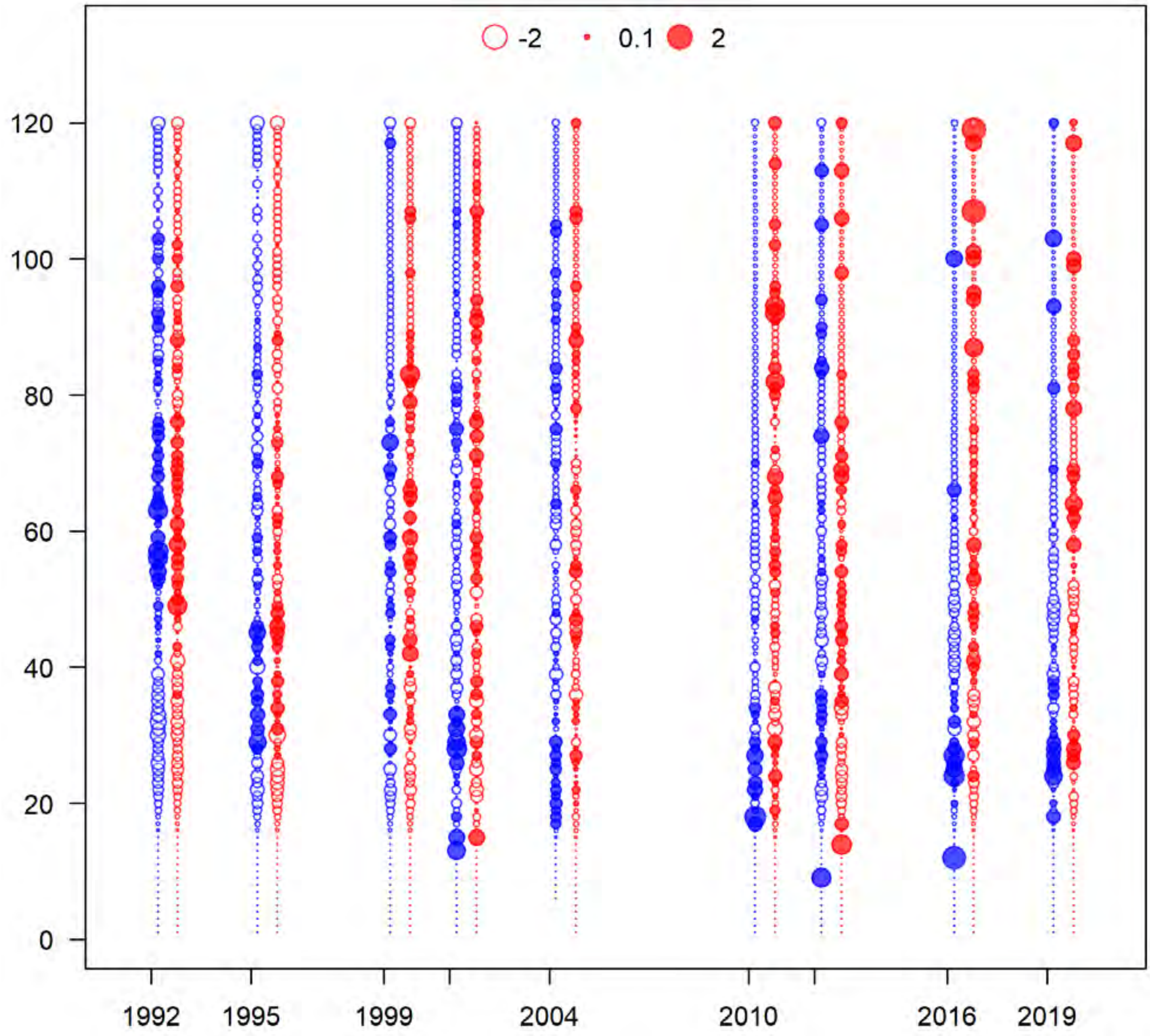


Figure 10.26. Pearson residuals for age data for the 2021 base-case model. Residuals for males are represented by blue circles and residuals for females by red circles. Filled circles represent positive residuals and unfilled circles represent negative residuals.

10.4.2 *Additional calculations to the base-case (sensitivities etc)*

10.4.2.1 Likelihood profiles

The likelihood profile for the steepness of the stock recruitment relationship, *h,* provides essentially no information about this parameter in the assessment (Figure 10.27). The likelihood profiles on SSB_{1980} and current stock status suggests female spawning biomass immediately prior to the beginning of the fishery was between 47,000 t and 55,000 t, and current stock status is between 24% and 40% of unfished levels (Figure 10.28 and Figure 10.29). Note that the assessment estimates the female spawning biomass in 1980 to be around 20% higher than its unfished equilibrium. The likelihood for *M* shows that *M* is likely between 0.031 yr^{-1} and 0.046 yr^{-1} (Figure 10.30).

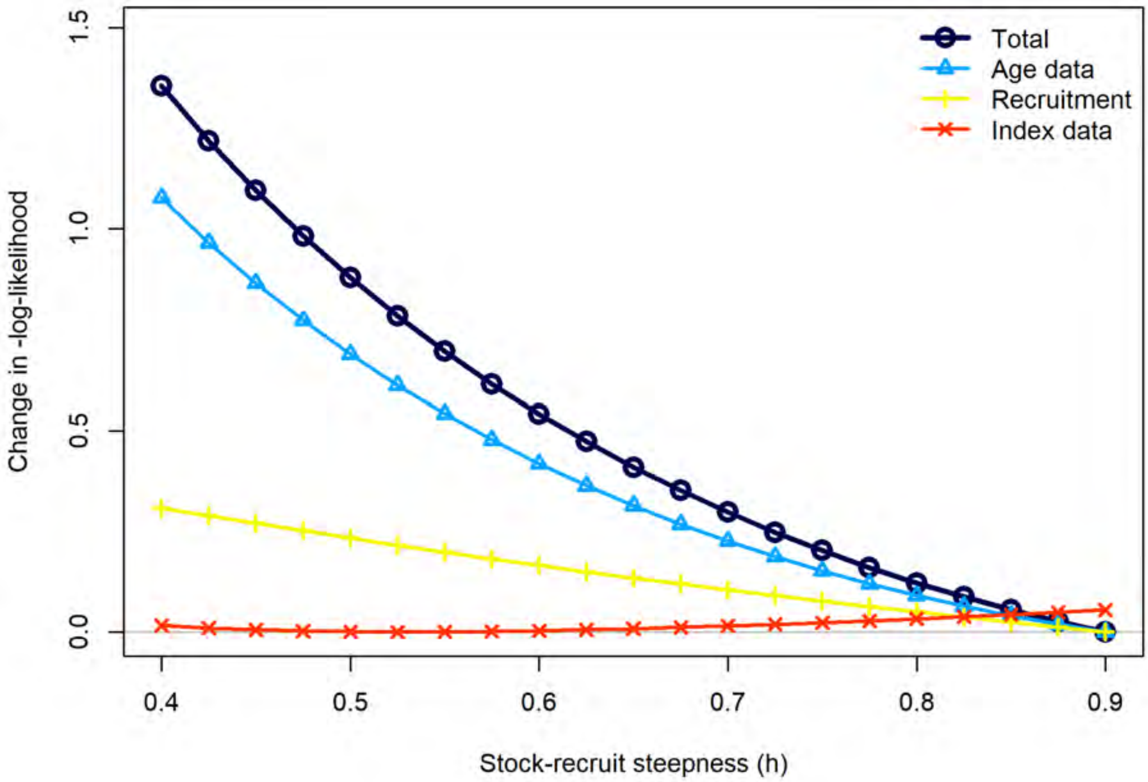


Figure 10.27. Likelihood profile for steepness of the stock recruitment relationship. The fixed value of steepness used in the 2021 base-case assessment is *h*=0.75.

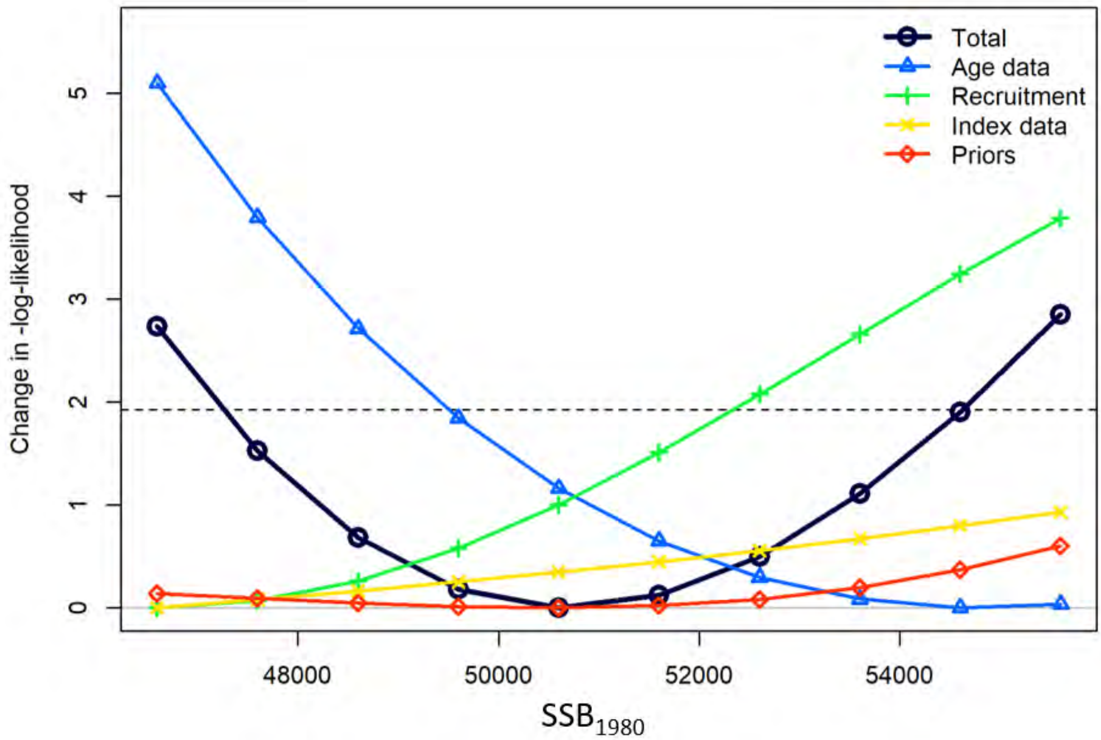


Figure 10.28. Likelihood profile for unfished female spawning biomass immediately prior to the beginning of the fishery (SSB_{1980}) for the 2021 base-case model. The MPD estimate of SSB_{1980} is 50,685 t. Note the estimate of female spawning biomass in 1980 is above the unfished equilibrium.

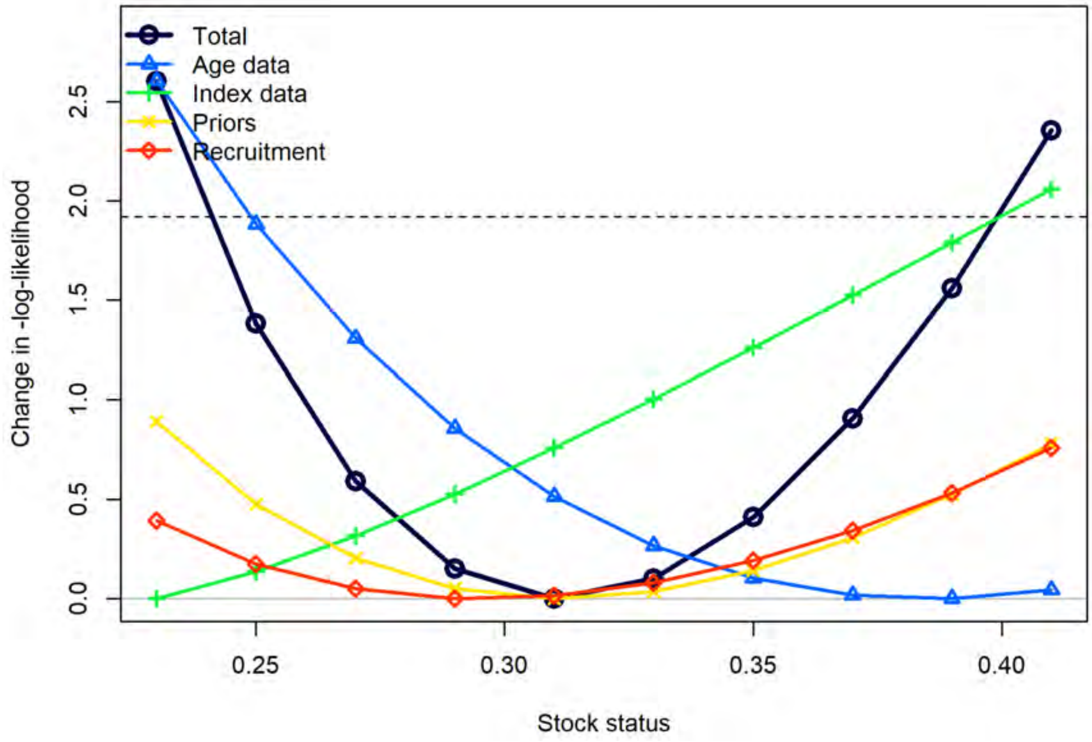


Figure 10.29. Likelihood profile for stock status in 2020 (SSB_{2020}/SSB_0) for the 2021 base-case model. The MPD estimate of 2020 stock status is 0.312.

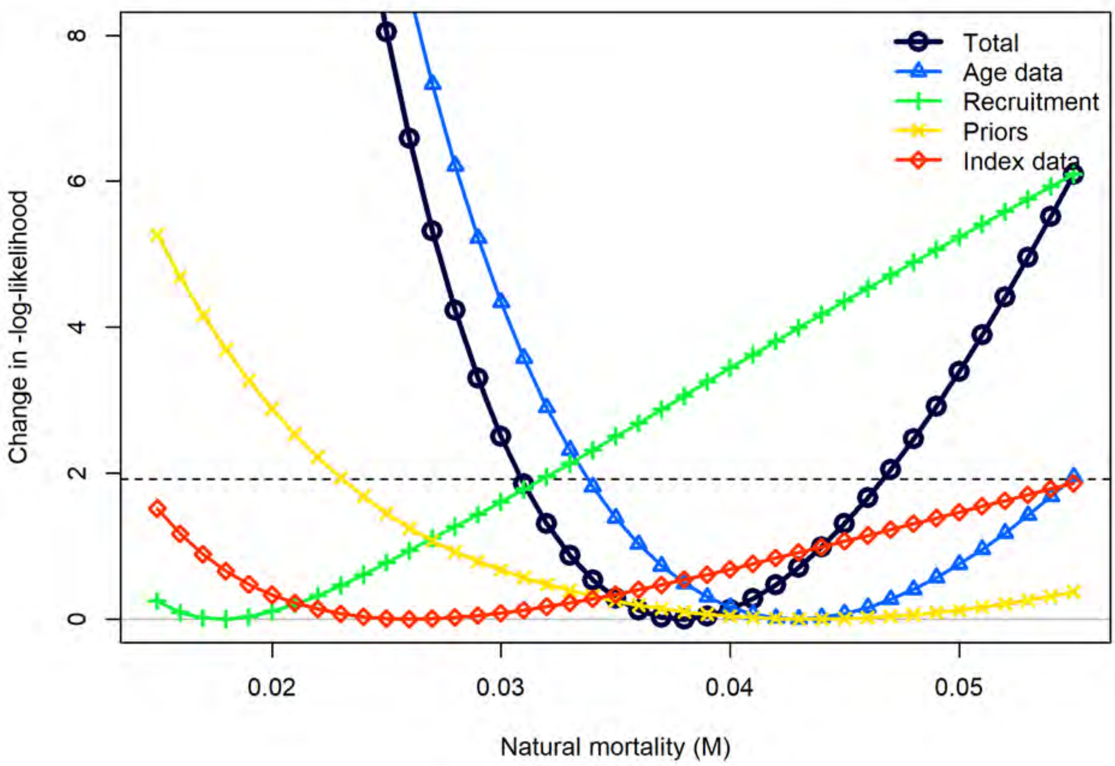


Figure 10.30. Likelihood profile for natural mortality for the 2021 base-case model. The MPD estimate of natural mortality is M=0.0386 yr^{-1}.

10.4.2.2 Retrospective analysis

While the trends in the retrospective assessments were the same, the above average absolute recruitment estimated prior to the commencement of the fishery declined by around a third and recent recruitment declined slightly as data were progressively added to the assessment (Figure 10.31 and Figure 10.32). The decline in recruitment is observed as slightly lower absolute and relative spawning biomass estimates in each successive assessment. This shows that the estimated productivity of the eastern zone Orange Roughy stock has declined slightly with the collection of additional data over the last decade. The estimated decline is greatest between 2010 and 2013, with more gradual declines from 2013 onwards.

Table 10.9. Estimated Mohn’s Rho statistics for the retrospective analysis 2021 base-case model. Values above 0.2 or below -0.15 suggest the retrospective pattern is cause for concern in an assessment (Hurtado-Ferro et al. 2015).

Quantity	Mohn's Rho
Spawning Biomass	0.5974
Recruitment	0.2911
Stock Status	0.4757
Fishing mortality (*F*)	-0.4459

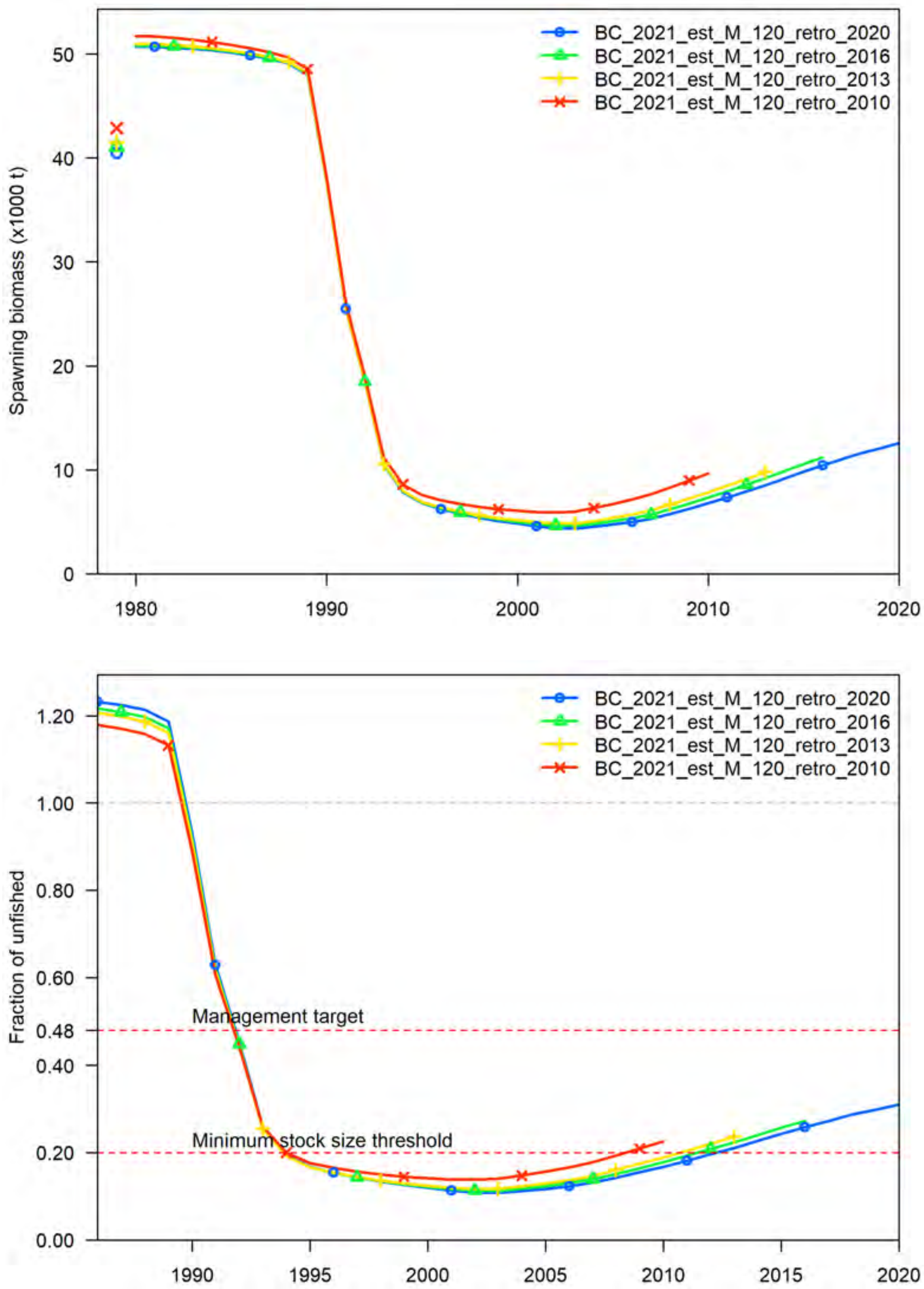


Figure 10.31. Retrospective analysis showing the absolute (top) and relative (bottom) spawning biomass from assessments that were undertaken after removing four, seven and ten years of data from the 2021 base-case model.

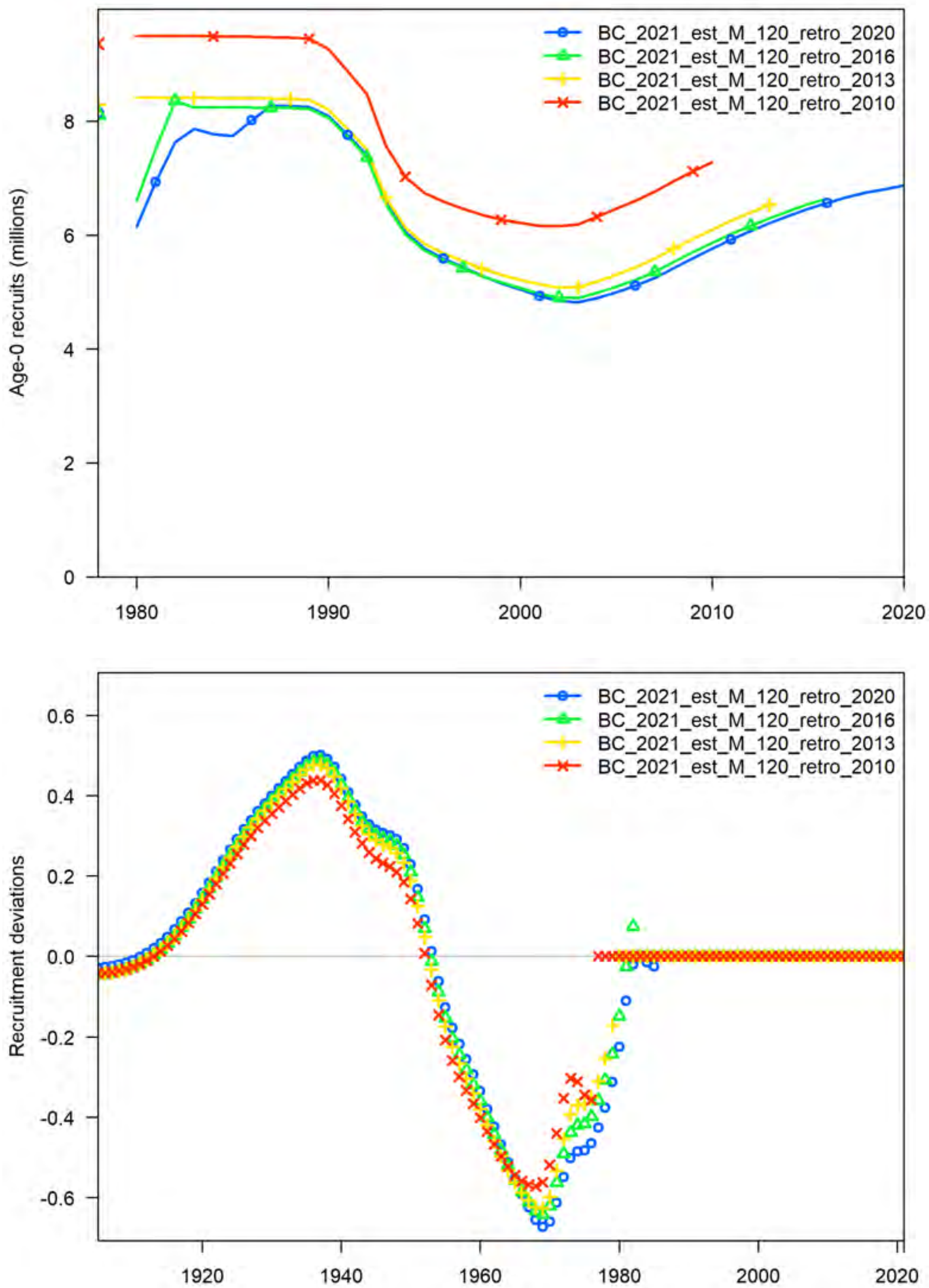


Figure 10.32. Retrospective analysis showing the absolute recruitment (top) and recruitment deviations (bottom) from assessments that were undertaken after removing four, seven and ten years of data from the 2021 base-case model.

10.4.2.3 Sensitivities

Sensitivities to the 2021 base-case are provided in Table 10.10. All sensitivites provide very similar estimates of unfished and current female spawning biomass. The greatest change in current stock status (SSB_0/SSB_{2022}) is between the low and high natural mortality scenarios that estimate current status to be 29.7% and 37.0% respectively.

Table 10.10. Sensitivities to the 2021 base-case model. NLL and ΔNLL represent the negative log-likelihood and change in negative log-likelihood compared with the base-case.

Scenario	NLL	ΔNLL	SSB_0	SSB_{2022}	SSB_0/SSB_{2022}
2021 base-case	83.72	0	40,479	13,126	0.3243
Low steepness ($h=0.6$)	84.06	0.3	40,363	12,783	0.3167
High steepness ($h=0.9$)	83.72	0.0	40,479	13,126	0.3243
Low recruitment variability ($s_R=0.6$)	85.97	2.2	41,236	13,893	0.3369
High recruitment variability ($s_R=0.8$)	82.05	-1.7	39,987	12,586	0.3148
Low natural mortality (M=0.0358)	84.14	0.4	40,612	12,067	0.2971
High natural mortality (M=0.0432)	83.97	0.2	40,606	15,029	0.3701
Halve the weighting on the age data	39.91	-43.8	42,225	13,740	0.3254
Double the weighting on the age data	166.27	82.5	38,660	12,298	0.3181
Remove the 1992 egg survey	84.41	0.7	40,485	13,135	0.3244
Use the estimated catch of 1,350t for 2021	83.72	0	40,479	13,138	0.3246
Use the 2021 TAC of 1,569t for 2021	83.72	0	40,479	13,083	0.3232

10.4.2.4 Fixed Catch Projections

The projections show that female spawning biomass is estimated to increase under all the fixed catch scenarios considered, with the probability of the stock being below the limit reference point of 20% unfished spawning biomass in both 2024 and 2031 being <0.5% (Table 10.11). Under the lowest constant catch scenario of 550 t yr^{-1}, stock status estimated to be 0.317 and 0.348 in 2024 and 2031 respectively. Under the highest constant catch scenario of 950 t yr^{-1}, stock status estimated to be 0.312 and 0.323 in 2024 and 2031 respectively. Under the industry proposed scenario stock status estimated to be 0.309 and 0.321 in 2024 and 2031 respectively. When the SESSF harvest control rule is used to RBCs stock status estimated to be 0.316 and 0.330 in 2024 and 2031 respectively.

Table 10.11. Estimated female spawning stock biomass (SSB), stock status (Status) relative to unfished and the probability of being below the limit reference point (Prob < LRP) in 2024 and 2031 for catches from the SESSF harvest control rule (HCR) and fixed catch scenarios of 550, 650, 737, 850 and 950 t and an industry proposal of 1,166 t in 2022, 1,055 t in 2023 and 950 t yr^{-1} thereafter.

Catch Scenario	SSB 2024	SSB 2031	Status 2024	Status 2031	Prob < LRP 2024	Prob < LRP 2031
HCR	12,269	12,831	0.3162	0.3295	<0.001	<0.001
550 t	12,378	13,609	0.3165	0.3481	<0.001	<0.001
650 t	12,325	13,364	0.3152	0.3419	<0.001	<0.001
737 t	12,279	13,149	0.3139	0.3363	<0.001	<0.001
850 t	12,215	12,887	0.3129	0.3294	0.001	0.001
950 t	12,123	12,583	0.3115	0.3230	0.003	0.002
Industry	12,041	12,504	0.3093	0.3208	0.004	0.002

10.5 Discussion

The primary objective of the 2021 eastern zone Orange Roughy stock assessment was to account for the uncertainty in *M*. We proposed to do this by estimating *M* within the assessment using an informative prior developed from New Zealand Orange Roughy assessments. We were able to successfully estimate *M* within the assessment and SERAG chose to adopt the model that estimates *M* with a plus group at 120 years as the agreed base-case assessment.

The estimated parameters and derived quantities from the MPD of the assessment were sufficiently different from the MCMC analysis to have an impact on the estimated RBC. The ORSC provided clear advice that RBCs from the MCMC analysis were preferable to those from the MPD because the MCMC analysis better acounts for uncertainty within the data and parameter space.

There is a clear retrospective pattern in the assessment that shows the estimated productivity of the stock has declined as more data had been collected over the last decade. While the magnitude of the decine has slowed since 2013, the presence of the retrospecitive pattern should be considered by SERAG when providing management advice. Future assessments should investigate the potential misspecification in the assessment driving this pattern.

The 2021 eastern zone Orange Roughy stock assessment has focused on exploring the estimation *M* within the assessment using an informative prior developed from New Zealand Orange Roughy stocks. There are several other uncertainties associated with the eastern zone Orange Roughy assessment that should be investigated in future assessments. These are;

1. Review the method for developing catchability priors for the acoustic surveys and update the prior for the towed body survey.
2. Work with Fish Ageing Services to review the age data and the relative weighting of age samples collected from St Helens Hill and St Patricks Head.
3. The model that is used to estimate age reading error is sensitive to the starting values of the model parameters.
4. Maturity appears to be mis-specified in the assessment, as it should be the same as selectivity. Investigate whether there is sufficient data to estimate maturity within the assessment (as is done for some New Zealand Orange Roughy stocks). If there are insufficient data to estimate maturity within the assessment then update the fixed values of the maturity parameters if recent data is available.
5. The selectivity of the trawl fleet and the acoustic surveys is the same and poorly estimated. Investigate whether it is possible to separate them.
6. Kloser and Sutton (2020) have observed that length-weight relationship measured during acoustic surveys over the last decade has been consistently higher than length-weight relationship from Lyle et al. (1991). This may indicate a change in the condition of Orange Roughy since the early period of the fishery.
7. The stock structure hypothesis for Australian Orange Roughy should be further investigated. Exploratory fishing for Orange Roughy is currently being undertaken on non-spawning components of the Orange Roughy populations in the western and Albany and Esperance (GAB) zones. If the stock structure hypothesis for eastern zone Orange Roughy is incorrect there is the risk that the population being fished in the eastern zone is subject to additional fishing of the non-spawning component. An example of the potential stock structure investigations is provided for New Zealand Orange Roughy by Dunn and Devine (2010).

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This document was internally reviewed by Professor André Punt and Dr Geoff Tuck.

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Wayte, S.E. (2007) Eastern Zone Orange roughy. pp 429 – 447 in Tuck, G.N. (ed) (2007) Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2006-2007. Volume 1: 2006. Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 570 p.

10.8 Appendix A – Additional tables and figures

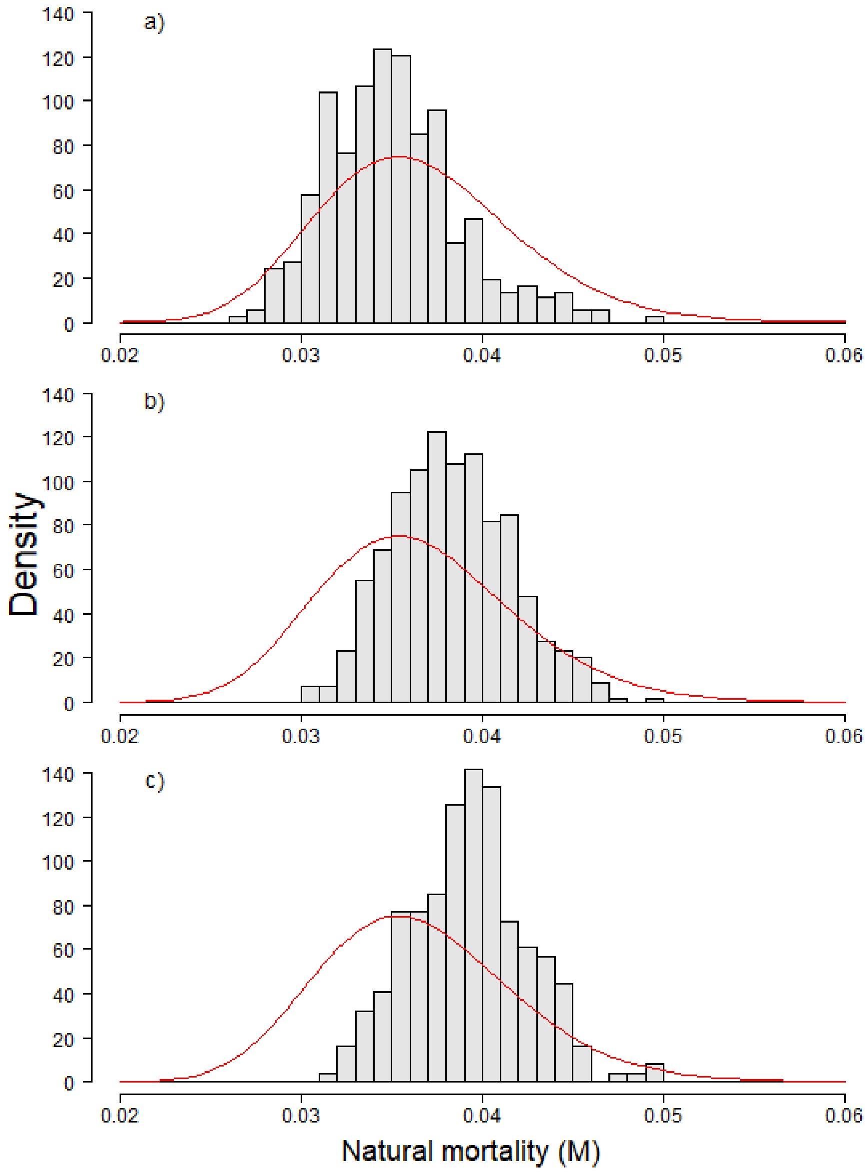

Figure A 10.1. Histograms of natural mortality estimates from posteriors of candidate 2021 preliminary base-case models with plus-groups at 80 (a), 100 (b) and 120 (c) years. The red line represents the log-normal prior used to estimate *M* within the models. Reproduced from the preliminary base-case assessment (Burch and Curin Osorio 2021).

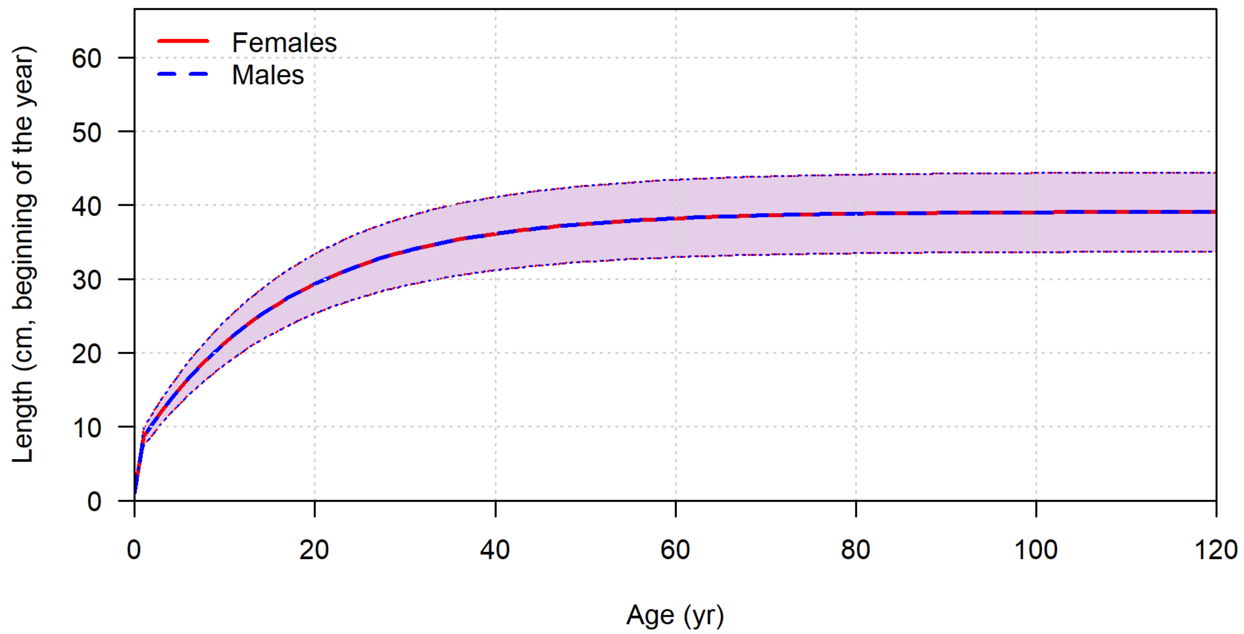

Figure A 10.2. Prespecified growth for the 2021 base-case model.

Table A 10.1. MCMC diagnostics from 1,750 samples of the posteriors for the estimated parameters (excluding the recruitment deviations) of the 2021 base-case model. Diagnostics are the autocorrelation, the Geweke statistic, the effective sample size (N_{eff}/N) and the Heidelberger-Welch convergence diagnostic.

Parameter	Autocorrelation	Geweke	N_{eff}/N	Heidel-Welsch
M	0.007	-0.733	1750	Passed
$ln(R_0)$	0.080	-1.780	1168	Passed
towed *q*	0.080	0.950	1181	Passed
hull *q*	0.020	1.244	1750	Passed
Selectivity inflection	0.335	0.614	186	Passed
Selectivity width	0.905	3.000	87	No test

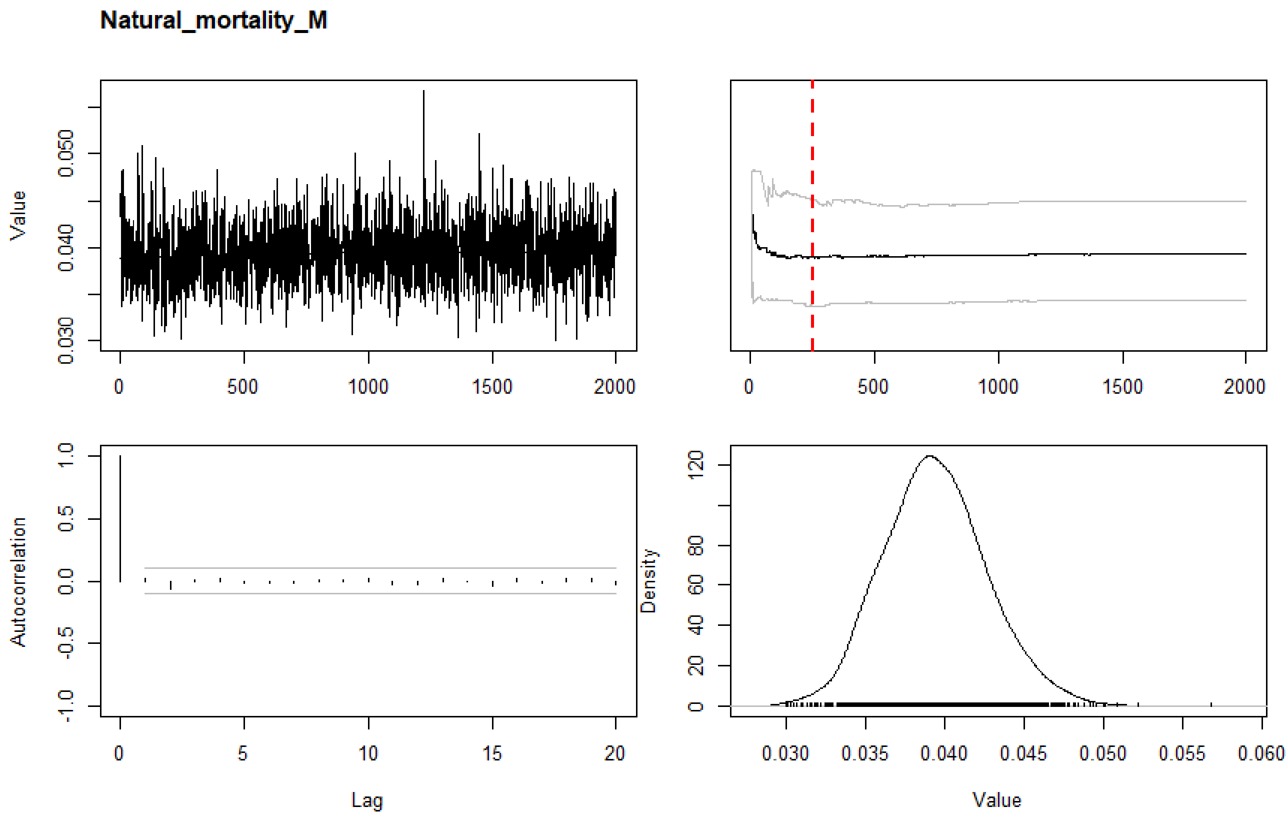

Figure A 10.3. Plots of traces (top left), moving average (top right), autocorrelations (bottom left), and density (bottom right) for natural mortality from 2,000 samples of the posterior from the MCMC analysis of the 2021 base-case model. The dashed red line indicates the additional burn-in of 250 samples that has been excluded for providing management advice.

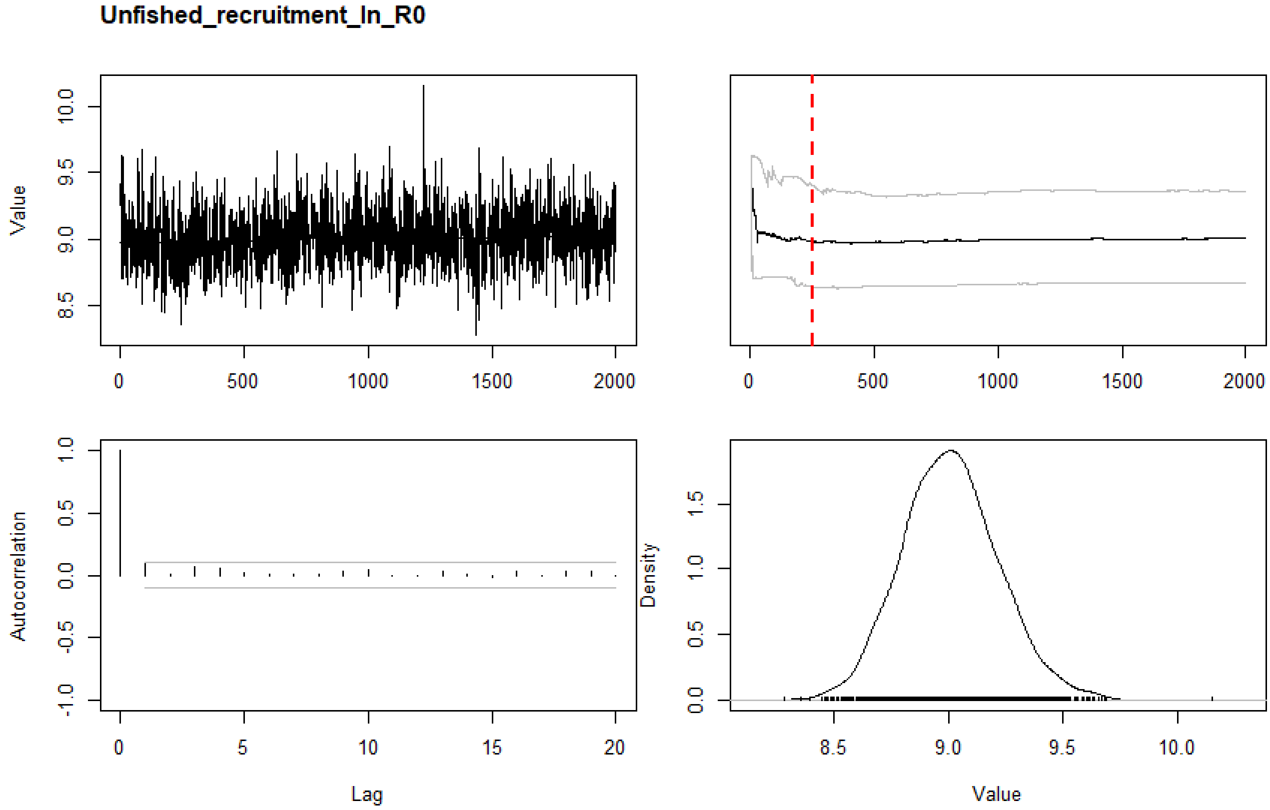

Figure A 10.4. Plots of traces (top left), moving average (top right), autocorrelations (bottom left), and density (bottom right) for unfished recruitment (ln(R0)) from 2,000 samples of the posterior from the MCMC analysis of the 2021 base-case model. The red dashed line indicates the additional burn-in of 250,000 samples from the posterior that has been excluded for providing management advice.

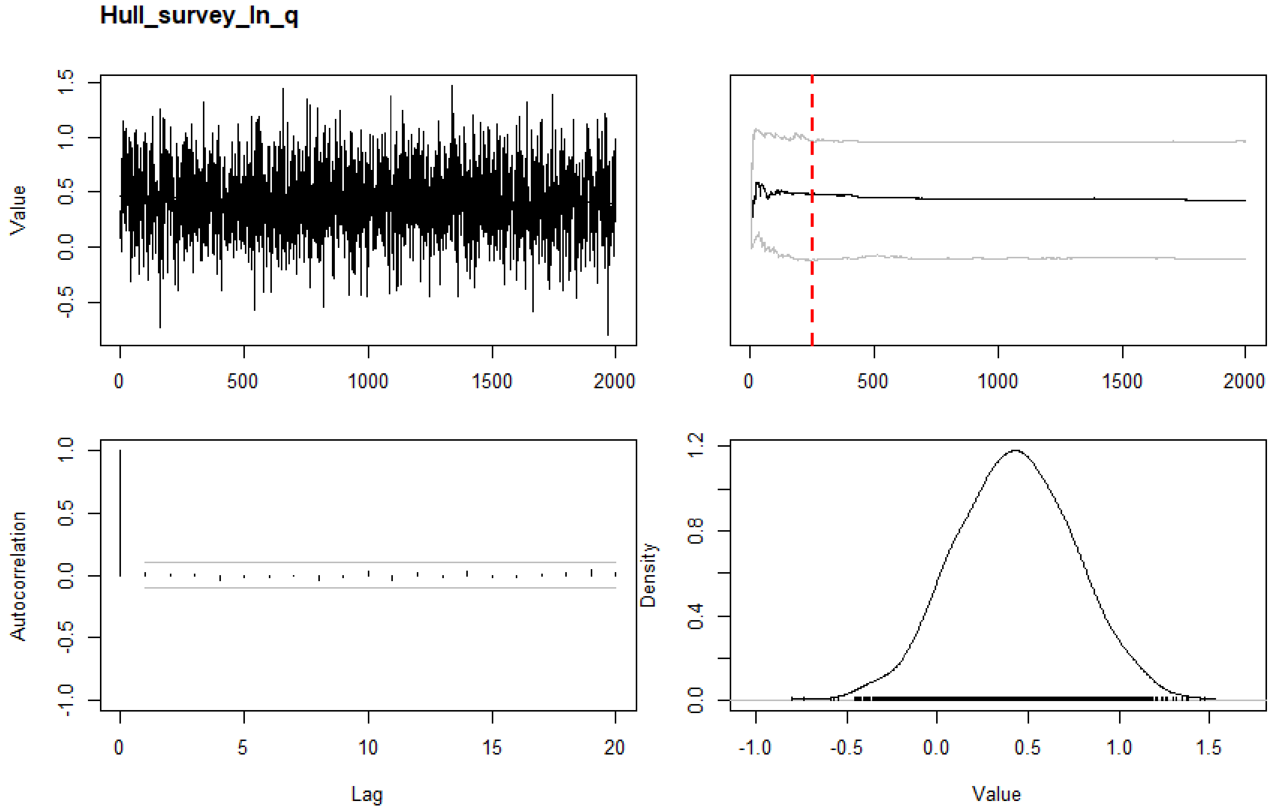

Figure A 10.5. Plots of traces (top left), moving average (top right), autocorrelations (bottom left), and density (bottom right) for catchability of the hull acoustic survey (ln(q)) from 2,000 samples of the posterior from the MCMC analysis of the 2021 base-case model. The red dashed line indicates the additional burn-in of 250,000 samples from the posterior that has been excluded for providing management advice.

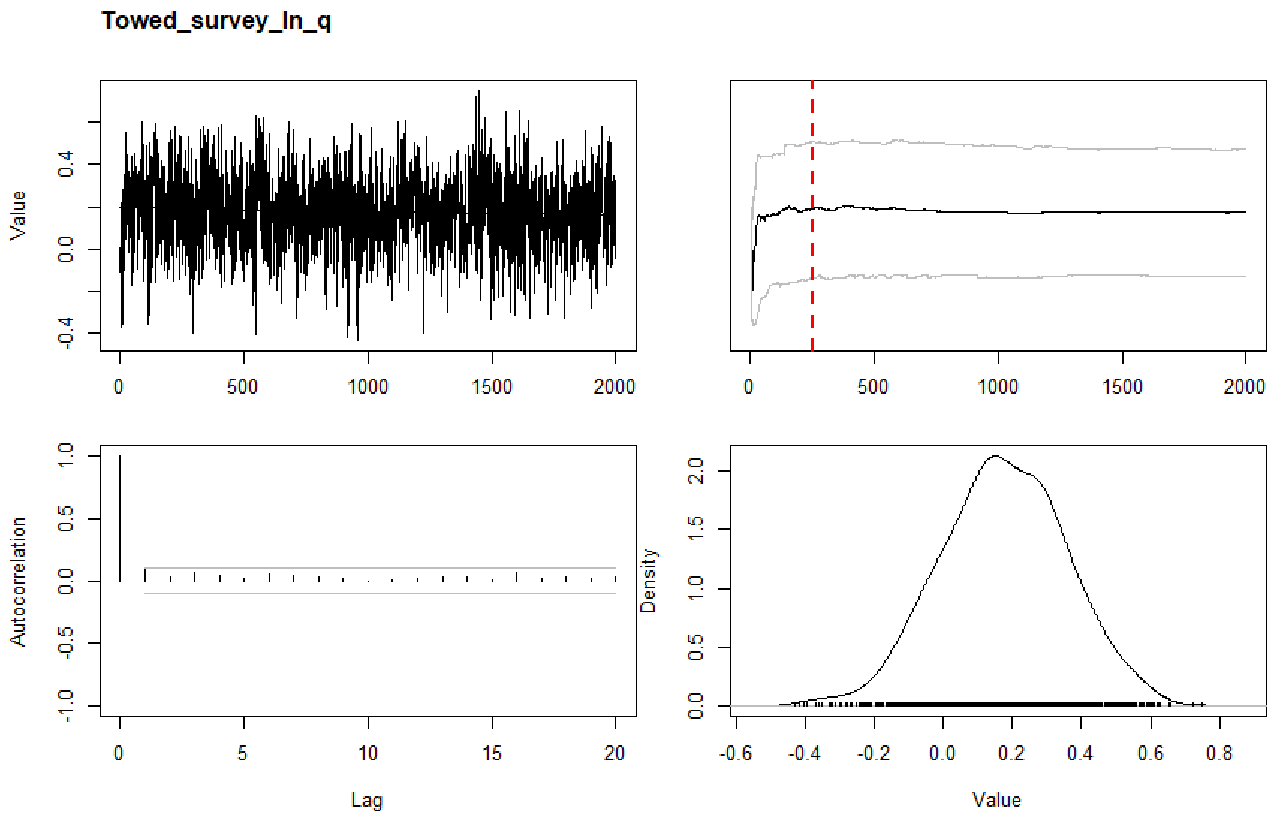

Figure A 10.6. Plots of traces (top left), moving average (top right), autocorrelations (bottom left), and density (bottom right) for catchability of the towed body acoustic survey (ln(*q*)) from 2,000 samples of the posterior from the MCMC analysis of the 2021 base-case model. The red dashed line indicates the additional burn-in of 250,000 samples from the posterior that has been excluded for providing management advice.

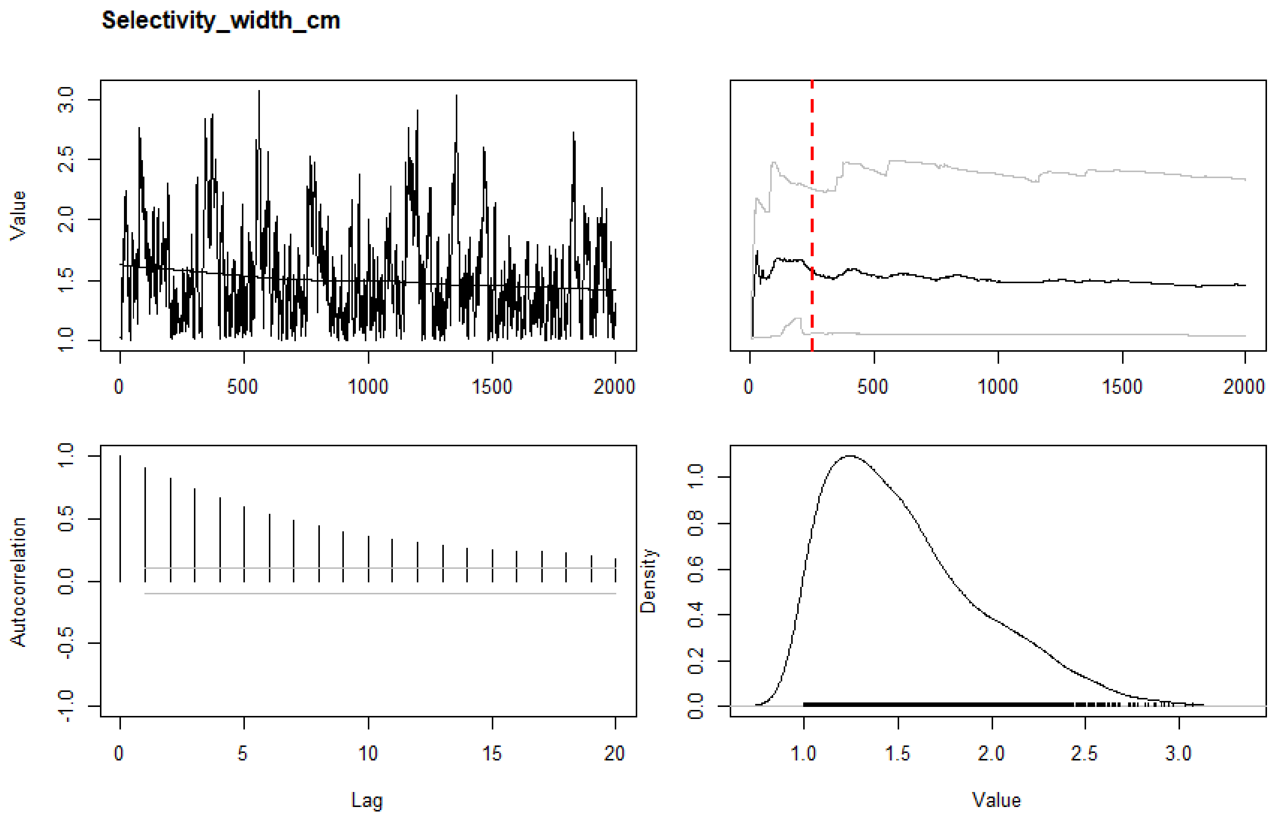

Figure A 10.7. Plots of traces (top left), moving average (top right), autocorrelations (bottom left), and density (bottom right) for the width parameter of the logistic selectivity function from 2,000 samples of the posterior from the MCMC analysis of the 2021 base-case model. The red dashed line indicates the additional burn-in of 250,000 samples from the posterior that has been excluded for providing management advice.

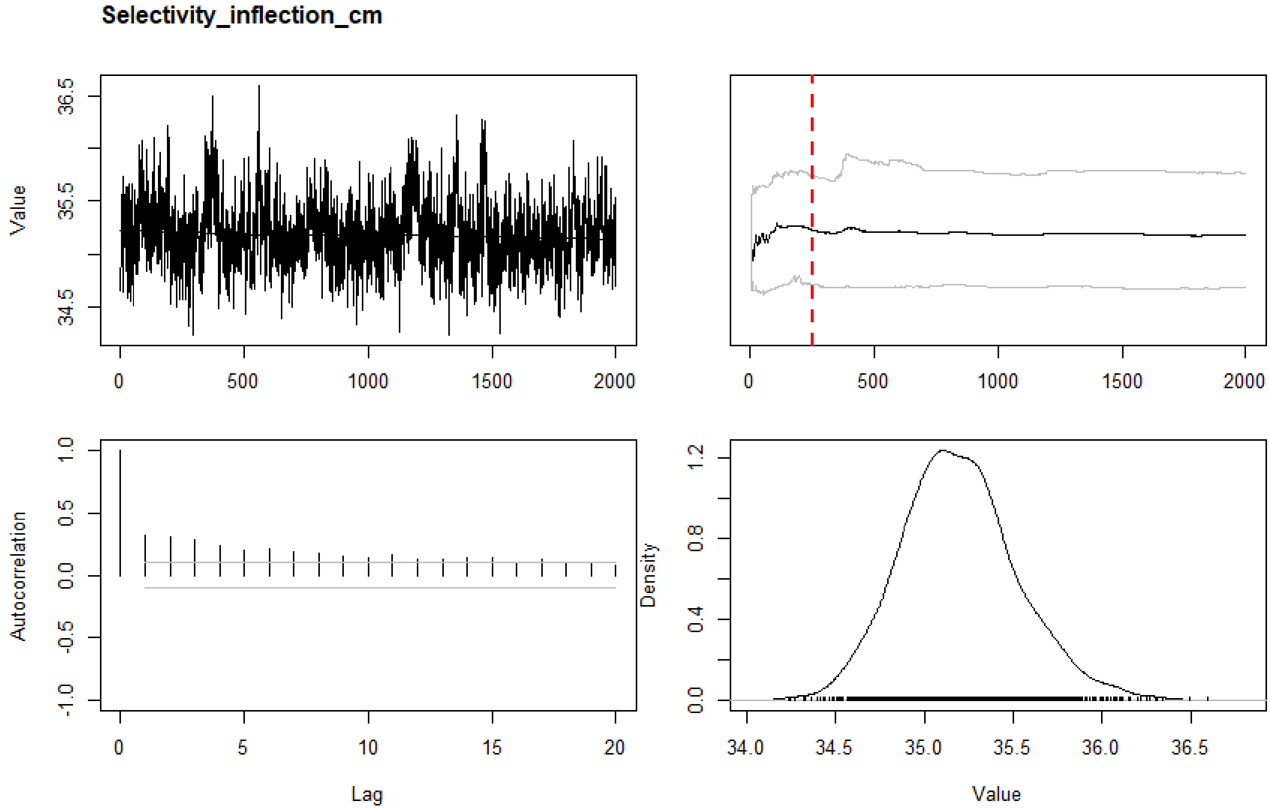

Figure A 10.8. Plots of traces (top left), moving average (top right), autocorrelations (bottom left), and density (bottom right) for the inflection parameter of the logistic selectivity function from 2,000 samples of the posterior from the MCMC analysis of the 2021 base-case model. The red dashed line indicates the additional burn-in of 250,000 samples from the posterior that has been excluded for providing management advice.

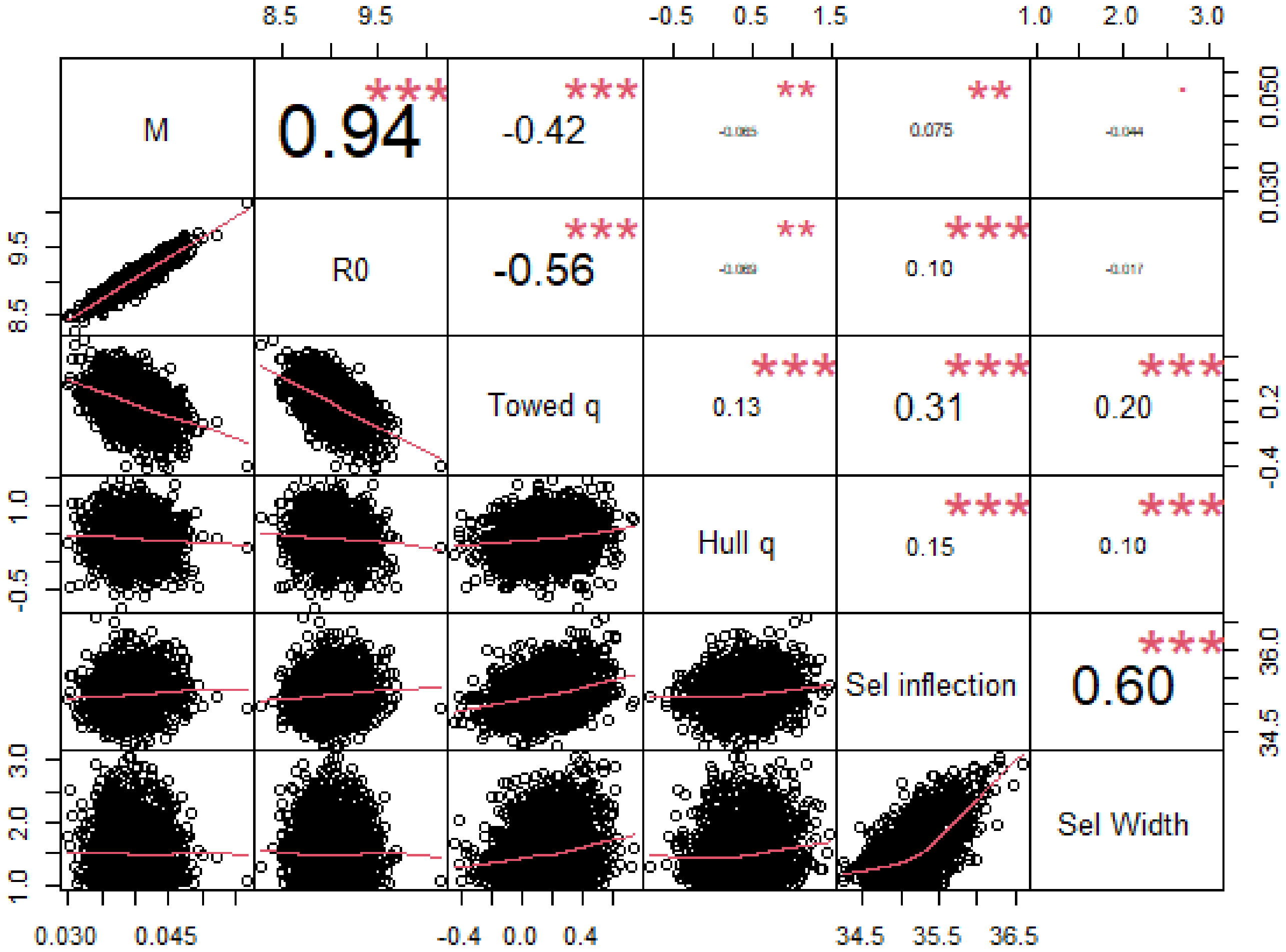

Figure A 10.9. Cross correlations between parameters estimated parameters from 1,750 samples of the posterior from the MCMC analysis of the 2021 base-case model. The numbers in the diagonal above the parameter names are the Pearson correlation coefficients.

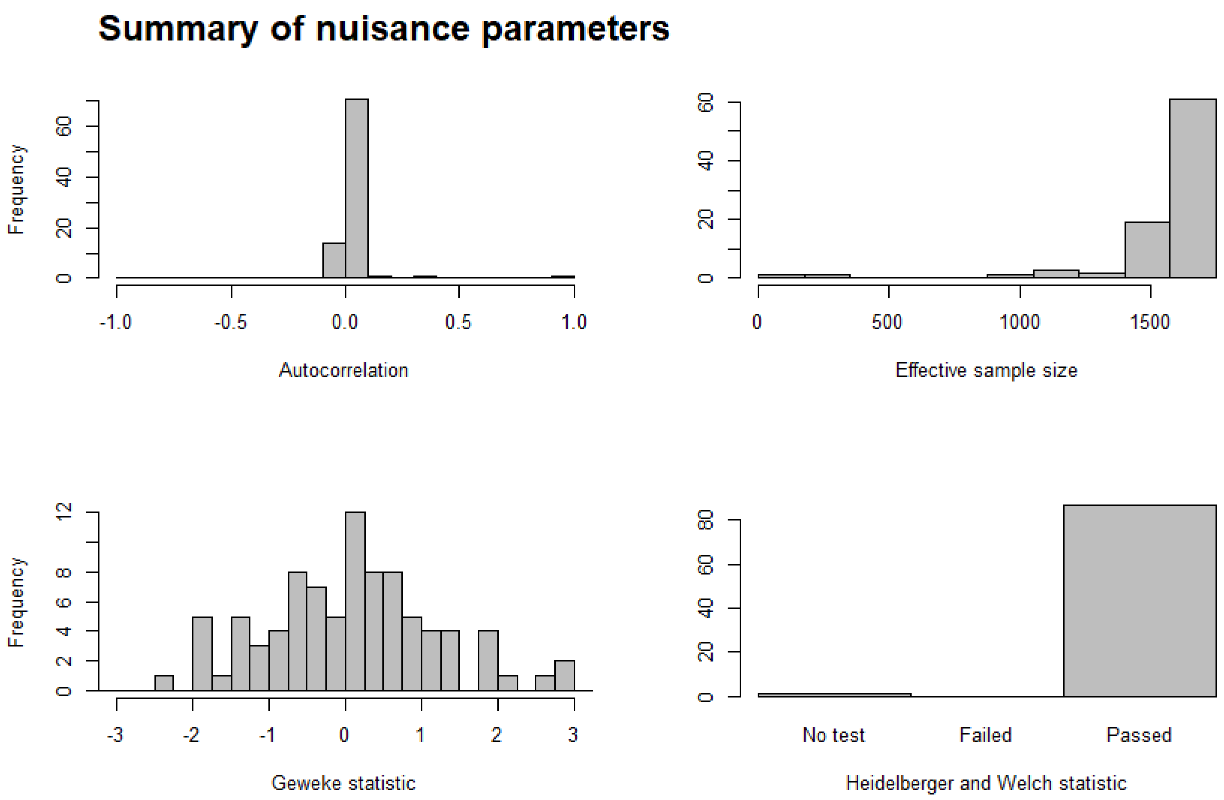

Figure A 10.10. Histograms of autocorrelation, the Geweke statistic, the effective sample size (N_{eff}/N) and the Heidelberger-Welch convergence diagnostics for the 82 estimated recruitment deviations from 1,750 samples of the posterior from the MCMC analysis of the 2021 base-case model.

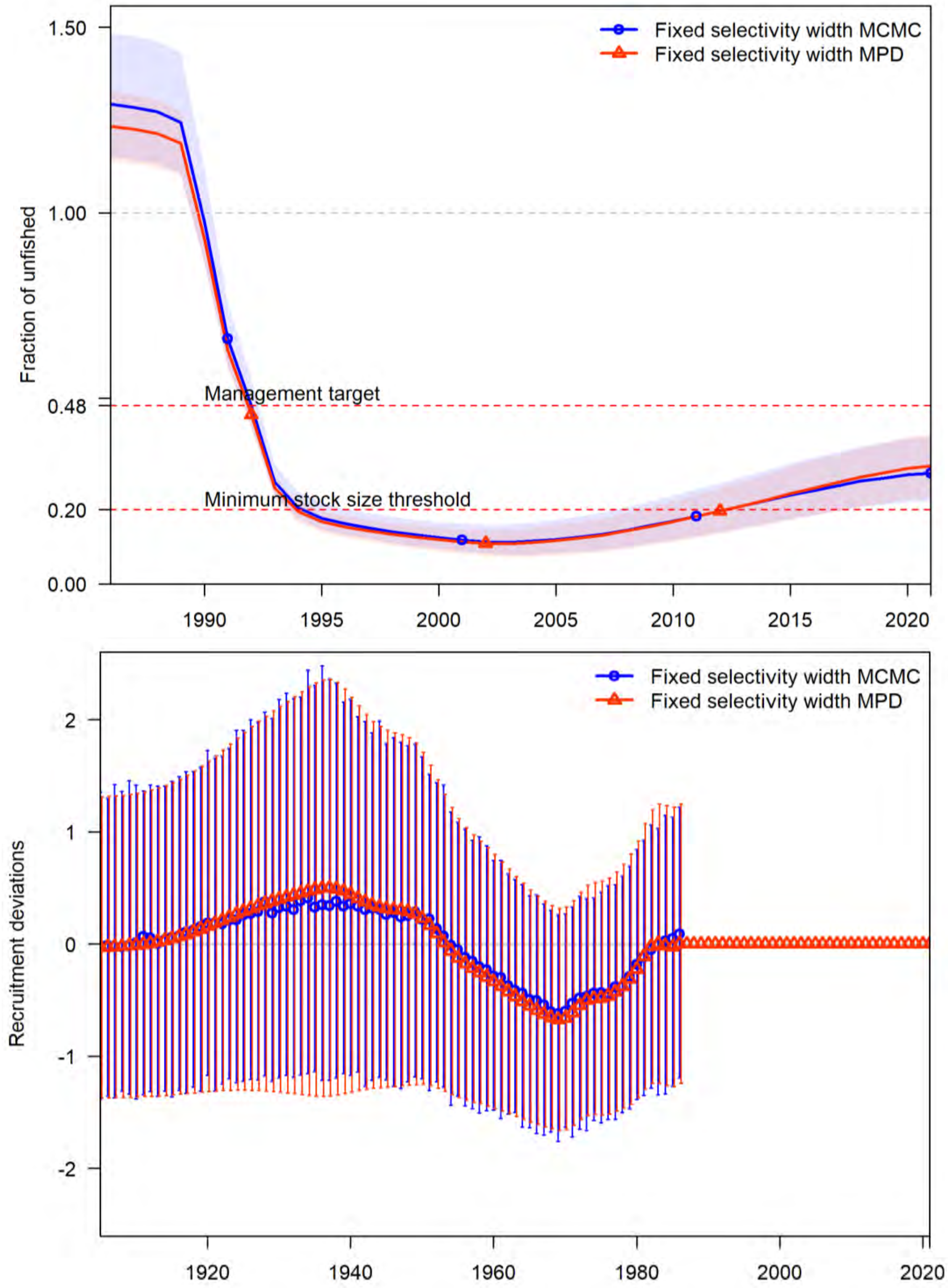

Figure A 10.11. Comparison MPD and MCMC estimates of time-series of relative spawning biomass and recruitment residuals (with ~95% intervals) for the sensitivity to the 2021 base-case model with the selectivity width parameter fixed at its MPD estimate. The red line and shading represent the point estimate and uncertainty from the MPD while the blue line and shading represents the median and uncertainty from 1,750 samples of the posterior from the MCMC.

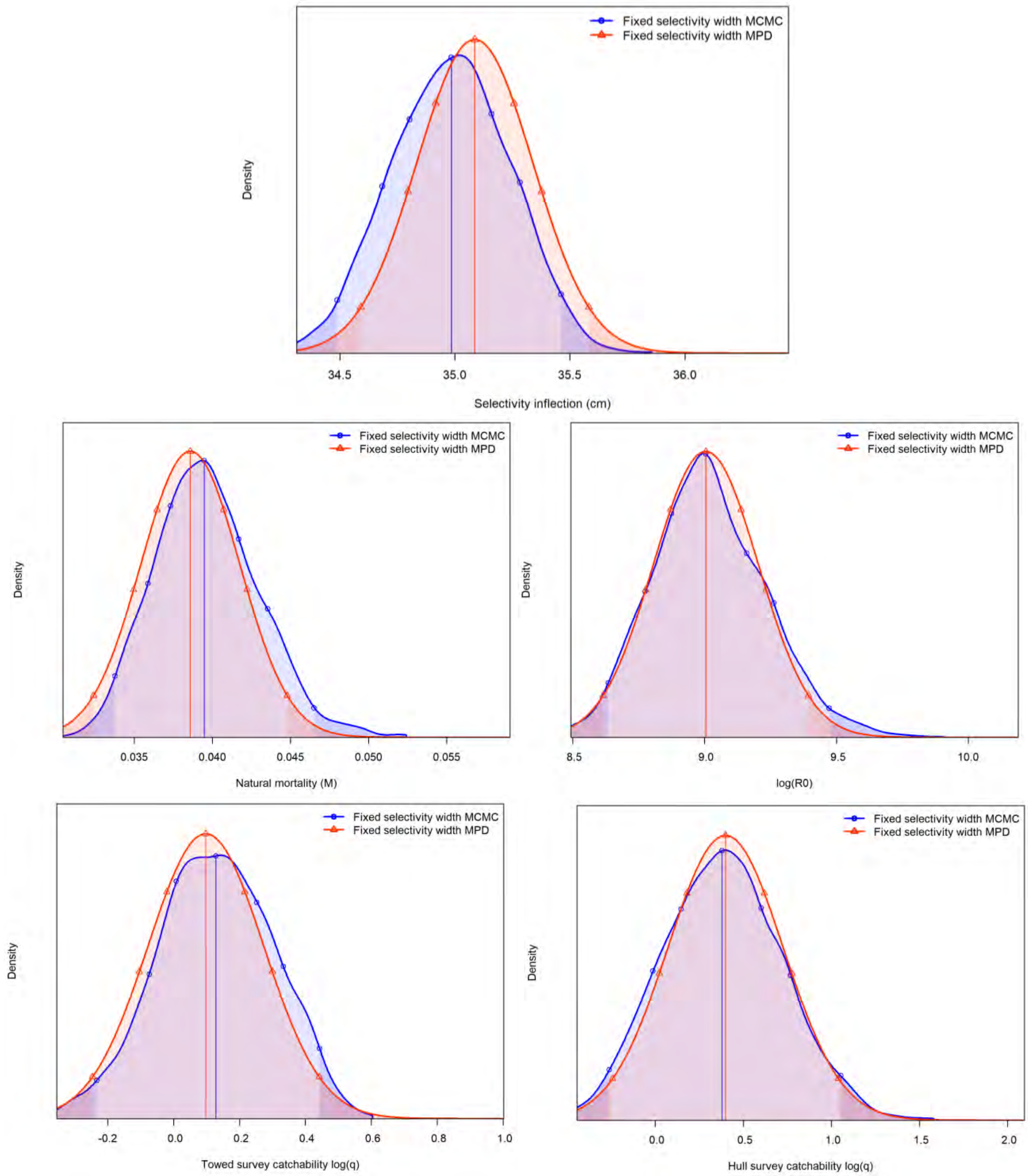

Figure A 10.12. Comparison MPD and MCMC estimates of the logistic selectivity inflection (top), natural mortality (middle left) unfished recruitment (middle right) and catchability for the towed (bottom left) and hull (bottom right) acoustic surveys for the sensitivity to the 2021 base-case model with the selectivity width parameter fixed at its MPD estimate. The red line and shading represent the point estimate and uncertainty from the MPD while the blue line and shading represents the median and uncertainty from 1,750 samples of the posterior from the MCMC. Note the acoustic catchability parameters are presented here as log(q), while they are presented as exp(log(q)) elsewhere in this report.

10.9 Appendix B – AFMA Species Summary

Following resource assessment group (RAG) meetings each year AFMA prepare summaries of the stock information and RAG advice for the Management Advisory Committee (MAC) and the AFMA Commission to assist in setting TACs for the following fishing season. This Appendix provides the summary for the 2021 eastern zone Orange Roughy stock assessment for inclusion in the AFMA species summary report.

10.9.1 *Stock structure*

Based on the existing data and fishery dynamics, multiple regional stocks of Orange Roughy are assumed and the fishery is managed and assessed as a number of discrete regional stocks. Recent genetic studies indicate little genetic diversity between all South East Australian stocks (Gonçalves et al, 2015). However, they may be demographically separate.

The 2021 eastern zone Orange Roughy assessment (Burch et al 2022) assumes the "combined" stock hypothesis of Wayte (2007), i.e., that the Eastern Zone (primarily St Helens Hill and St Patricks Head) and Pedra Branca from the Southern Zone form a single stock.

10.9.2 *Stock trend and other indicators*

Stock status: The most recent assessment (Burch et al. 2022) indicates that the stock is above the limit reference point, and is estimated to be at 30% of unfished biomass for the beginning of 2022. This is a decline from the previous assessment (Haddon 2017) where stock was estimated to be at 33% of unfished biomass for the beginning of 2018.

Biomass trend: the 2021 stock assessment indicates that biomass is continuing to increase. Recent acoustic surveys (1999, 2006, 2010, 2012, 2013, 2016 and 2019) undertaken at St. Helen's Hill and St. Patricks' Head have estimated an increase in abundance, which supports the estimated increase in abundance from the Tier 1 stock assessments.

10.9.3 *Key model technical assumptions/parameters*

The model assumptions include ;

- The "combined" stock hypothesis Eastern Zone spawning Orange Roughy and Pedra Branca non-spawning Orange Roughy.
- A single fishing fleet with logistic selectivity that combines commercial demersal trawler and the two acoustic surveys.
- Recruitment follows the Beverton-Holt stock recruitment relationship, with steepness fixed at h=0.75 and recruitment variability fixed at s_R=0.7.
- Maturity and growth are both fixed within the assessment model.
- Biomass was unfished at the start of 1979, however, the assessment estimates the stock was around 125% of the estimated unfished equilibrium spawning biomass in 1980.
- Natural mortality is now estimated within the model using an informative prior developed from five New Zealand Orange Roughy assessments for ORH 2A+2B+3A, ORH 3A (NWCR), ORH 3B (ESCR), ORH (Puysegur). The estimate of natural mortality from the assessment is 0.0393 yr^{-1}.

- The plus group age in the model is now set at 120 years (increased from 80 years in the 2017 assessment) to provide more information to estimate natural mortality within the assessment.

The estimated stock status relative to unfished levels and the resulting RBCs were different between the point estimate from the MPD and the MCMC analysis. SERAG supported the advice from the Orange Roughy Steering Committee to use of the MCMC analysis for management.

10.9.4 *Significant changes to data inputs*

The plus group age was increased from 80 years to 120 years. Natural mortality was estimated within the model using an informative prior developed from five New Zealand Orange Roughy assessments (ORH 2A+2B+3A, ORH 3A (NWCR), ORH 3B (ESCR), ORH (Puysegur)).

10.9.5 *Project biomass*

Estimates of female spawning biomass, stock status and the probability of being below the limit reference point in 2024 and 2031 for RBCs estimated from the SESSF harvest control rule five fixed catch scenarios are provided in Table B 10.1. While natural mortality is now estimated within the model, the assessment is still very sensitive to the estimated value of natural mortality. To quantify the uncertainty in natural mortality, sensitivities were undertaken using fixed natural mortality values chosen as the 12.5% and 85% quantiles from the posterior of *M* from the MCMC analysis. The MPD estimates of current stock status (SSB_0/SSB_{2022}) for the low (M=0.0358 yr^{-1}) and high (M=0.0432 yr^{-1}) natural mortality scenarios are 29.7% and 37.0% respectively, compared with the MPD estimate from the base-case of 32.4%. Note the current stock status estimate from the MCMC analysis of the base-case is 30.0%.

Table B 10.1. Estimated female spawning stock biomass (SSB), stock status relative to unfished and the probability of being below the limit reference point in 2024 and 2031 for catches from the SESSF harvest control rule (HCR) and fixed catch scenarios of 550, 650, 737, 850 and 950t and an industry proposal of 1,166 t in 2022, 1,055 t in 2023 and 950 t yr^{-1} thereafter.

Catch Scenario	SSB 2024	SSB 2031	Status 2024	Status 2031	Prob < LRP 2024	Prob < LRP 2031
HCR	12,269	12,831	0.3162	0.3295	<0.001	<0.001
550t	12,378	13,609	0.3165	0.3481	<0.001	<0.001
650t	12,325	13,364	0.3152	0.3419	<0.001	<0.001
737t	12,279	13,149	0.3139	0.3363	<0.001	<0.001
850t	12,215	12,887	0.3129	0.3294	0.001	0.001
950t	12,123	12,583	0.3115	0.3230	0.003	0.002
Industry	12,041	12,504	0.3093	0.3208	0.004	0.002

10.9.6 *State catches and discards*

There are no reported State catches of Orange Roughy in the eastern or southern zones (Table B 10.2). Discards are estimated externally to the assessment by Deng et al. (2021) using the method of Bergh et al. (2009) and are added to the catches of the trawl fleet in the assessment.

Table B 10.2. Reported State catches and estimated discards in tonnes from 2017–2020 used in the 2021 eastern zone Orange Roughy stock assessment and the four year weighted means (weights of 1, 2, 4 and 8 for the earliest to most recent year are used).

Year	State Catch	Discards
2017	0	6
2018	0	3
2019	0	1
2020	0	18
Four year weighted mean	0	10.7

10.9.7 *References*

Bergh, M., Knuckey, I., Gaylard, J., Martens, K., and Koopman, M. (2009). A revised sampling regime for the Southern and Eastern Scalefish and Shark Fishery – Final Report.

Burch P, Curin Osorio S and Bessell-Browne P (2022). Eastern zone Orange Roughy (*Hoplostethus atlanticus*) stock assessment based on data up to 2020. Revised after the South East Resource Assessment Group meeting 29 November – 1 December 2021. CSIRO Oceans and Atmosphere and Institute for Marine and Antarctic Studies, University of Tasmania.

Deng, R., Cannard, T., Burch, P. (2021). Integrated scientific monitoring program for the Southern and Eastern Scalefish and Shark Fishery – discards for 2020. Prepared for the SESSFRAG Data Meeting, 24-26 August 2021 (Report for the Australian Fisheries Management Authority). CSIRO Oceans and Atmosphere.

Gonçalves da Silva, A., Appleyard, S.A. and Upston, J., (2015). Establishing the evolutionary compatibility of potential sources of colonizers for overfished stocks: A population genomics approach. Molecular Ecology, 24(3), pp. 564-579.

Haddon, M. (2017) Orange Roughy East (*Hoplostethus atlanticus*) stock assessment using data to 2016. CSIRO, Oceans and Atmosphere.

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10.10 Appendix C – Summary for ABARES

The Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) is responsible for Commonwealth fishery status reports (e.g. Patterson et al. 2021). This Appendix provides a summary of recent catches and stock status estimates for the 2021 eastern zone Orange Roughy stock assessment (Burch et al., 2022) to assist the preparation for inclusion in the ABARES fishery status reports.

The 2021 eastern zone Orange Roughy assessment (Burch et al., 2022) assumes the "combined" stock hypothesis of Wayte (2007), i.e., that the Eastern Zone (primarily St Helens Hill and St Patricks Head) and Pedra Branca from the Southern Zone form a single stock. Orange Roughy stock structure hypotheses and historical catches and discards were reviewed at a workshop between AFMA, CSIRO, industry representatives and New Zealand scientists, held in Hobart in May 2014 (AFMA 2014). The workshop concluded that it is unlikely to be able to improve on the previously agreed catch time series but may still be worth examining the assessment implications of different catch histories on stock assessments. Agreed catches up to the end of 2014 are provided in Table B 10.2. Recent catches from the eastern zone, Pedra Branca from the southern zone and estimated discards are provided in Table C 10.1. Discards are estimated externally to the assessment by Deng et al. (2021) using the method of Bergh et al. (2009) and are added to the catches of the trawl fleet in the assessment. Since 2015 there has been zero reported State catch of eastern zone or southern zone Orange Roughy.

Table C 10.1. Recent catches from the eastern zone (East), Pedra Branca from the southern zone, State catches, discards estimated using the method of Bergh et al (2009) and total removals in tonnes used in the 2021 of eastern zone Orange Roughy assessment.

Year	East	Pedra	State catch	Discards	Total Removals
2015	422	29	0	7	457.3
2016	352	29	0	3	384.5
2017	302	56	0	6	364.0
2018	862	45	0	3	909.5
2019	619	75	0	1	695.1
2020	1,320	60	0	18	1,397.5

The estimated relative spawning biomass in 2017–2021 from the MCMC analysis along with the 75% and 95% credible intervals are provided in Table C 10.2.

Table C 10.2. Estimated stock status of eastern zone Orange Roughy from the MCMC analysis of the base-case model for the five most recent years.

Year	Median	2.5%	12.5%	87.5%	97.5%
2017	0.264	0.199	0.223	0.314	0.355
2018	0.276	0.209	0.234	0.328	0.370
2019	0.285	0.216	0.241	0.338	0.380
2020	0.294	0.223	0.249	0.349	0.391
2021	0.298	0.226	0.252	0.353	0.397

10.10.1 ***References***

Australian Fisheries Management Authority (AFMA), (2014). Orange Roughy (eastern zone) workshop meeting minutes, CSIRO Hobart, 15-16 May 2014.

Bergh, M., Knuckey, I., Gaylard, J., Martens, K., and Koopman, M. (2009). A revised sampling regime for the Southern and Eastern Scalefish and Shark Fishery – Final Report.

Burch P, Curin Osorio S and Bessell-Browne P (2022). Eastern zone Orange Roughy (*Hoplostethus atlanticus*) stock assessment based on data up to 2020. Revised after the South East Resource Assessment Group meeting 29 November – 1 December 2021. CSIRO Oceans and Atmosphere and Institute for Marine and Antarctic Studies, University of Tasmania.

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Patterson, H, Bromhead, D, Galeano, D, Larcombe, J, Woodhams, J and Curtotti, R (2021), Fishery status reports 2021, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra. CC BY 4.0. https://doi.org/10.25814/vahf-ng93.

Wayte, S.E. (2007) Eastern Zone Orange Roughy. pp 429 – 447 in Tuck, G.N. (ed) (2007) Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2006-2007. Volume 1: 2006. Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 570 p.

11. School Whiting (*Sillago flindersi*) RBC projections from 2020 stock assessment – using modified target MEY reference proxy (40%)

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11.1 Alternative target reference point: 40% compared to 48%

11.1.1 *Projected RBCs*

11.1.1.1 20:35:48 harvest controle rule

The 2020 School Whiting stock assessment (Day et al. 2020) estimates that current spawning stock biomass (at the beginning of 2021) is 41% of unexploited spawning stock biomass (SSB_0). Under the agreed 20:35:48 harvest control rule, the 2021 recommended biological catch (RBC) is 2,140 t (Table 11.1, reproduced from Day et al. 2020) and the long-term yield (assuming average recruitment in the future) is 2,448 t (Table 11.2, reproduced from Day et al. 2020). The RBCs for the base case are listed for each individual year from 2021-2025 in Table 11.1. The RBC averaged over the three-year period of 2021-2023 is 2,237 t (Table 11.2) and over the five-year period 2021-2025, is 2,295 t (Table 11.2).

Table 11.1. Yearly projected RBCs (tonnes) across all fleets under the 20:35:48 harvest control rule assuming average recruitment from 2017.

Year	RBC (t)
2021	2,140
2022	2,250
2023	2,321
2024	2,368
2025	2,398

Table 11.2. Projected recommended biological catches (RBCs) for the five-fleet model under the 20:35:48 harvest control rule for: 2021; the three-year average from 2021-2023; the five-year average for 2021-2025; and the long-term RBC (from 2039).

Period	RBC (t)
1-year: 2021	2,140
3-year average: 2021-2023	2,237
5-year average: 2021-2025	2,295
long-term: 2039	2,448

11.1.1.2 20:35:40 harvest control rule

If the default (proxy) target reference point (48%) used in the SESSF harvest control rule, and specifically as used by AFMA for School Whiting, is reduced to 40%, a modified 20:35:**40** harvest control rule can be applied. This lower target allows the stock to be fished to a lower target biomass (40% of unfished spawning stock biomass (SSB_0)). Such a reduced target would allow a greater catch to be taken and allows the stock to be fished down to a lower relative spawning stock biomass. However, reducing the target biomass is also likely to increase the probability of the stock falling below the limit reference point, 20% of SSB_0. Quantifying the increase in risk to the stock would probably require MCMC analysis of the 2020 School Whiting assessment, using both forms of this harvest control rule. Such analysis is beyond the scope of this report.

Under a revised 40% target, the 2021 recommended biological catch (RBC) would be 2,753 t (Table 11.3) and the long-term yield (assuming average recruitment in the future) is 2,723 t (Table 11.4). The RBCs for the base case, with a 20:35:40 harvest control rule, are listed for each individual year from 2021-2025 in Table 11.3. The RBC, calculated under a 20:35:40 harvest control rule, averaged over the three-year period of 2021-2023 is 2,730 t (Table 11.4) and over the five-year period, 2021-2025, is 2,727 t (Table 11.4).

Table 11.3. Yearly projected RBCs (tonnes) across all fleets under the 20:35:40 harvest control rule assuming average recruitment from 2017.

Year	RBC (t)
2021	2,753
2022	2,721
2023	2,717
2024	2,721
2025	2,722

Table 11.4. Projected recommended biological catches (RBCs) for the five-fleet model under the 20:35:40 harvest control rule for: 2021; the three-year average from 2021-2023; the five-year average for 2021-2025; and the long-term RBC (from 2039).

Period	RBC (t)
1-year: 2021	2,753
3-year average: 2021-2023	2,730
5-year average: 2021-2025	2,727
long-term: 2039	2,723

Figure 11.1 shows the relative spawning biomass for both forms of the harvest control rule, with differences only occurring from 2022 onwards, as expected. Figure 11.2 shows a time series of 1-SPR ratio, a proxy of fishing mortality, integrating fishing mortality across fleets in the fishery for School Whiting using the 20:35:48 harvest control rule. This is indicative of years where fishing is above and below the target fishing mortality (F_{48}). Figure 11.3 shows a time series of 1-SPR ratio, for School Whiting using the 20:35:40 harvest control rule, which clearly demonstrates a higher target fishing mortality than Figure 11.2, but with the same relative pattern in the time series.

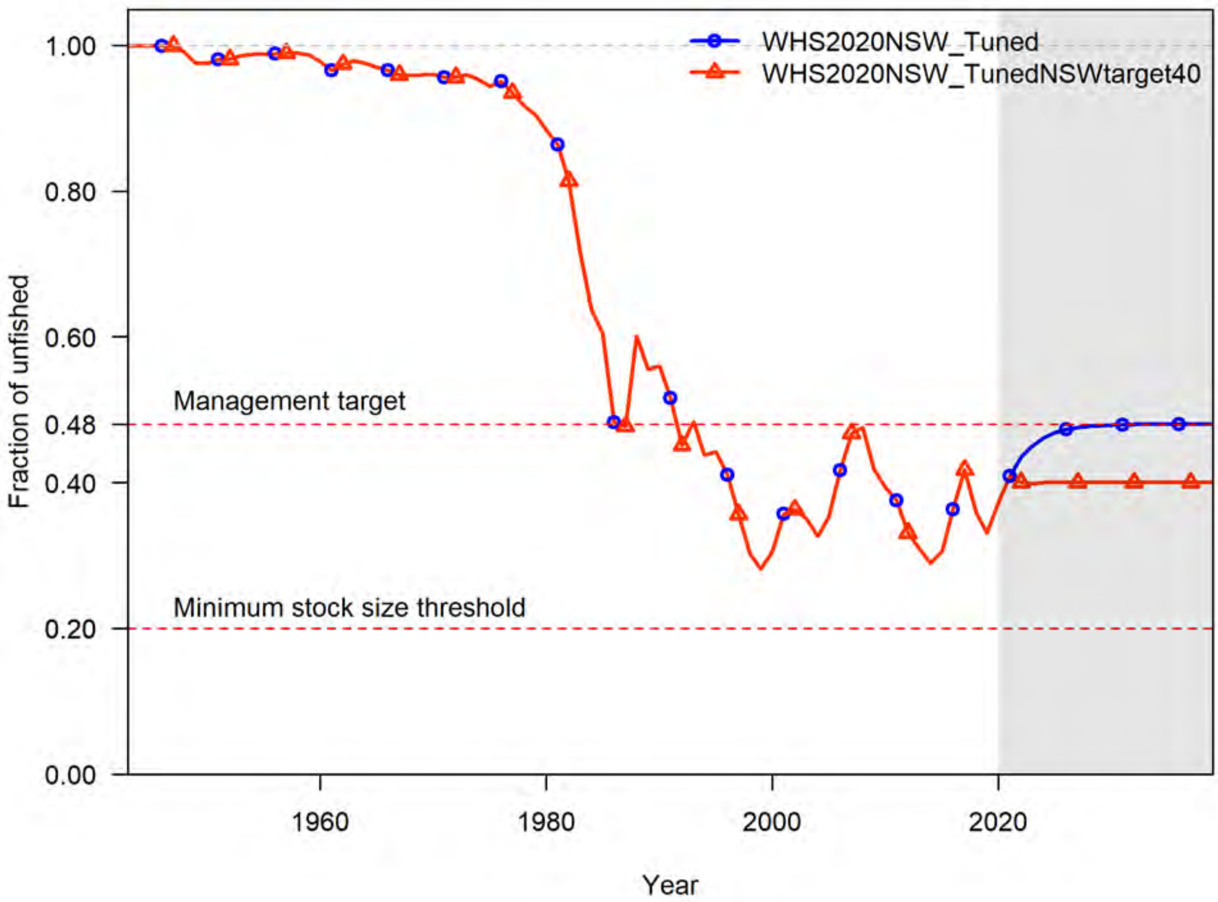

Figure 11.1. Comparison of the relative spawning biomass time series for School Whiting using the 20:35:48 harvest control rule (WHS2020NSW_Tuned – in blue) and using the 20:35:48 harvest control rule (WHS2020NSW_TunedNSWtarget40 in red).

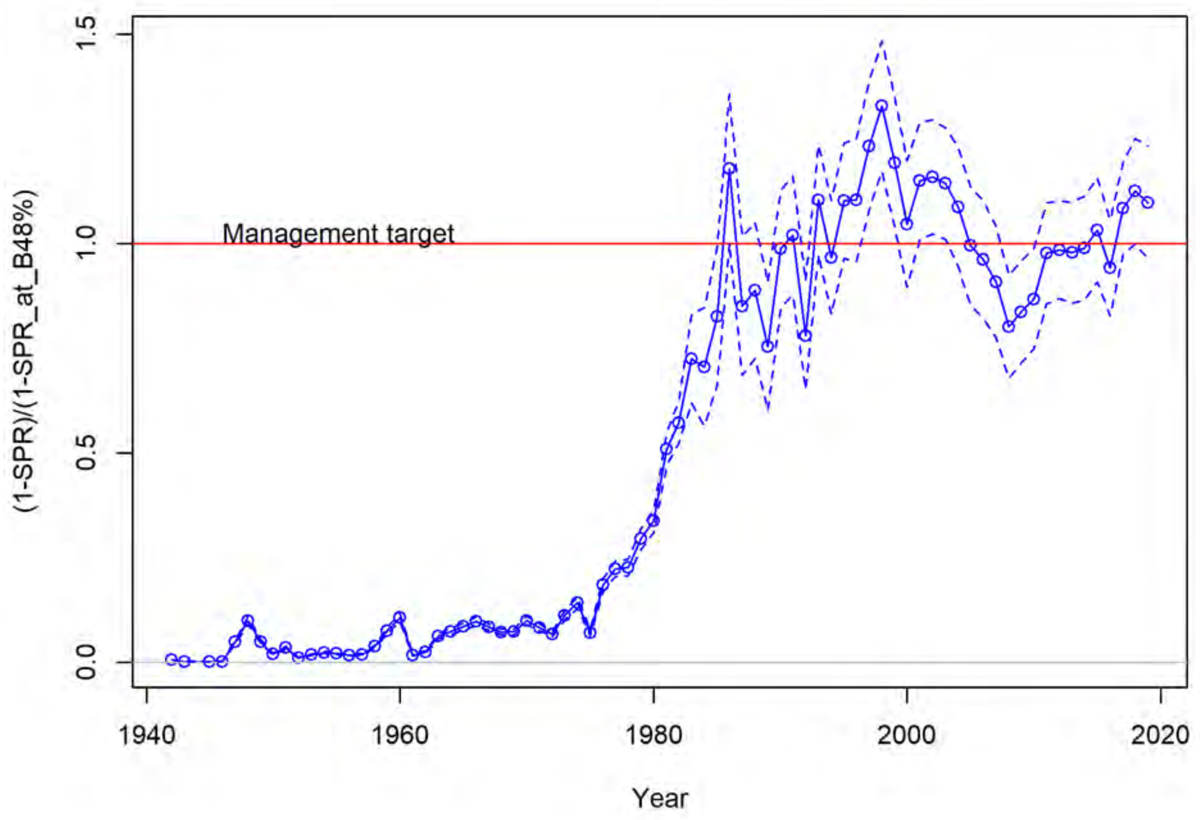

Figure 11.2. Time series of 1-SPR ratio, a proxy for fishing mortality, integrating fishing mortality across fleets in the fishery for School Whiting using the 20:35:48 harvest control rule.

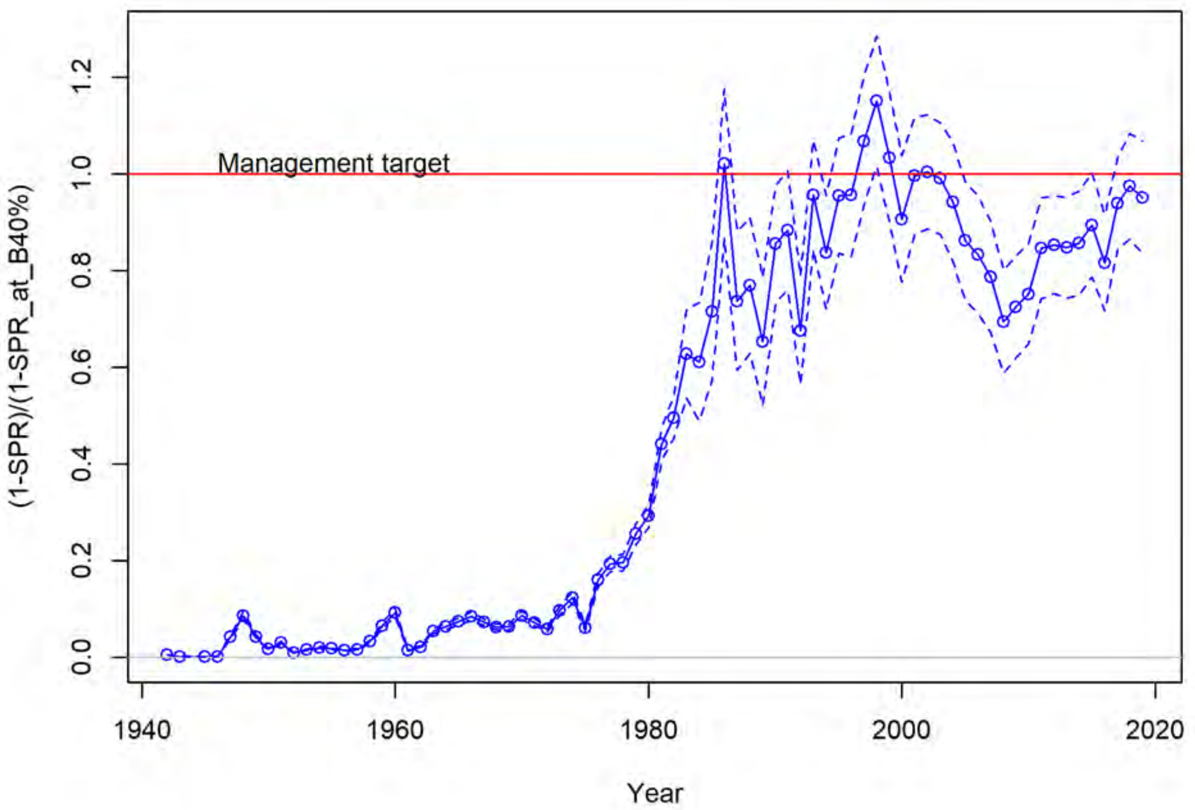

Figure 11.3. Time series of 1-SPR ratio, a proxy for fishing mortality, integrating fishing mortality across fleets in the fishery for School Whiting using the 20:35:40 harvest control rule.

11.1.2 *Referfences*

Day J, Hall K, Bessell-Browne P and Sporcic M 2020. School Whiting (*Sillago flindersi*) stock assessment based on data to 2019. Unpublished report to SERAG. 158 pp.

12. Silver Warehou (*Seriolella punctata*) stock assessment based on data up to 2020 – development of a preliminary base case

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12.1 Executive Summary

This document presents a base case for an updated quantitative Tier 1 assessment of Silver Warehou (*Seriolella punctata*) for presentation at the first SERAG meeting in 2021. The last full assessment was presented in 2018 (Burch et al., 2018b). The preliminary base case has been updated with the inclusion of data up to the end of 2020, which entails an additional three years of catch, discard, CPUE, length and age data and ageing error updates since the 2018 assessment. This document describes the process used to develop a preliminary base case for Silver Warehou through the sequential updating of recent data to the stock assessment, using the stock assessment package Stock Synthesis (SS-V3.30, Methot and Wetzel (2013)), referred to hereon as base case 2.

In addition to the standard Bridge 1, which updates the assessment to the most recent version of Stock Synthesis, ensures correct settings are used and updates the historical catch series, Bridge 2, which sequentially incorporates updated data, a third bridging step (Bridge 3) is presented here. This third bridging step adds an additional time block on retention of the east trawl fleet from 2018 onwards. This allows the model to fit the large increase in discarding observed between 2018 and 2020. It also only adds one additional recruitment deviation rather than the usual three to account for a residual pattern that estimates above average recruitment deviations at the end of the series which are revised downwards when additional data is included in the assessment. This updated preliminary base case is referred to as base case 3 throughout this document and is proposed as the base case for the 2021 assessment.

The results from base case 3 show reasonably good fits to the conditional age-at-length data and standardised catch rates. The fits to the standardised catch rates in the east trawl fleet have improved from the previous assessment, while fits to the west trawl fleet remain similar. Fits to both discard data and standardised catch rates improved in base case 3 compared to those in base case 2. Fits to the length data have remained poor, as has been observed in previous assessments, with length frequency inputs highly variable, often showing multiple modes in the distributions that are not consistent from one year to the next. The estimated length frequencies are also not able to fit the small fish that were observed across both fleets over the past five years.

Base case 3 estimates that the projected 2021 spawning stock biomass will be 35.43% of virgin stock biomass (projected assuming 2020 catches in 2021), compared to 26.04% at the start of 2018 from the last assessment (Burch et al., 2018b). This assessment suggests that spawning stock biomass was as low as 21.11% in 2016. The increase in estimated stock status since the 2018 assessment is likely due to slight increases in standardised catch rates and increasing recruitment combined with low catches.

12.2 Introduction

12.2.1 2021 Silver Warehou assessment base case

The 2021 preliminary base case assessment of Silver Warehou uses an age- and size-structured model implemented in the generalized stock assessment software package, Stock Synthesis (SS) (Version 3.30.17.00, Methot et al. (2021)). The methods utilised in SS are based on the integrated analysis paradigm. SS can allow for multiple seasons, areas and fleets, but most applications are based on a single season and area. Recruitment is governed by a stochastic Beverton-Holt stock-recruitment relationship, parameterized in terms of the steepness of the stock-recruitment function (h), the expected average recruitment in an unfished population (R_0), and the degree of variability about the stock-recruitment relationship (σ_r). SS allows the user to choose among a large number of age- and length-specific selectivity patterns. The values for the parameters of SS are estimated by fitting to data on catches, catch-rates, discard rates, discard and retained catch length-frequencies, and conditional age-at-length data. The population dynamics model and the statistical approach used in fitting the model to the various data types are given in the SS technical documentation (Methot, 2005).

The base case model includes the following key features:

A single region, single stock model is considered with two fleets, one in the east including SESSF zones 10, 20 and 30 (east trawl), and one in the west including SESSF zones 40 and 50 (west trawl). Selectivity is modelled separately for each fleet, with both selectivity patterns assumed to be length-specific and logistic. The parameters of the selectivity function for each fleet were estimated within the assessment.

The model does not account for males and females separately and fits one growth curve across both sexes.

The initial and final years are 1980 and 2020.

The CVs of the CPUE indices were initially set at a value equal to the standard error from a loess fit (0.174; Sporcic (2021)), before being re-tuned to the model-estimated standard errors within SS.

Discard tonnage was estimated through the assignment of a retention function. This was defined as a logistic function of length, and the inflection and slope of this function were estimated where discard information was available. In the 2018 assessment two retention functions were estimated, one for each 'block' period: namely 1980–2001 and 2002–2020. The first block allows the model to fit discarding across all length classes due to limited markets, while the second block allows the model to fit to size based discarding once markets for the species were established. The proposed updated preliminary base case includes an additional retention function between 2018 and 2020 for the east trawl fleet to account for increased discarding observed in these years.

The rate of natural mortality, M, is assumed to be constant with age, and also time-invariant. The value for M is assumed to be 0.3 y^{-1}.

Recruitment to the stock is assumed to follow a Beverton-Holt 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 is set to 0.75.

The initial value of the parameter determining the magnitude of the process error in annual recruitment, σ_R, is set to 0.7.

The population plus-group is modelled at age 23 years.

Growth is assumed to follow a von Bertalanffy length-at-age relationship, with the parameters of the growth function estimated together for females and males inside the assessment model.

Retained and discarded onboard length sample sizes were capped at 200, with greater than 100 fish sampled annually required for inclusion in the model. For port samples, numbers of trips were used as the sampling unit, with a cap of 100 (which was not reached). The sample size is reduced because the appropriate sample size for length frequency data is probably more closely related to the number of shots (onboard) or trips (port) sampled, rather than the number of fish measured.

The values assumed for some of the (non-estimated) parameters of the base case models are shown in Table 12.1.

Table 12.1. Parameter values assumed for some of the non-estimated parameters of the base-case model.

Parameter	Description	Value
M	Natural mortality	0.3
h	steepness' of the Beverton-Holt stock-recruit curve	0.75
x	age observation plus group	23 years
a	allometric length-weight equations	0.0000065 g-1 cm
b	allometric length-weight equations	3.27
l_m	Female length at 50% maturity	37 cm

12.3 Bridging methodology

The previous full quantitative assessment for Silver Warehou was performed in 2018 by Burch et al. (2018b) using Stock Synthesis (version SS-V3.30.12.00, Methot et al. (2018)). The 2021 assessment uses the current version of Stock Synthesis (version SS-V3.30.17.00, Methot et al. (2021)).

As a first step in the process of bridging to a new model, the data used in the 2018 assessment was used in the new software (SS-V3.30.17.00). Once this translation was complete, improved features unavailable in SS-V3.12.00 were incorporated into the SS-V3.30.17 assessment. The catch series was then updated to include any amended estimates for the historical period from 1980 to 2018 since the 2018 assessment. Following this step, the model was re-tuned using the most recent tuning protocols (Pacific Fishery Management Council, 2018), 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 may lead to changes to key model outputs, such as the estimates of stock status and the trajectory of spawning biomass. This initial bridging phase (Bridge 1) highlights changes that have occurred since 2018 simply through changes to software and assessment practices.

The subsequent bridging exercise (Bridge 2) then sequentially updates the model with new data through to 2020. These additional data included new catch, discard estimates, CPUE, length composition data, conditional age-at-length data and an updated ageing error matrix. The last year of recruitment estimation was extended to 2017 (from 2014 in Burch et al. (2018b)). The final step is to re-tune the model.

A third bridging step (Bridge 3) has also been included. This bridging step has expanded on the preliminary base case (results of Bridge 2) by incorporating an additional time block on retention to allow the model to fit the increased discard estimated for the east trawl fleet between 2018 and 2020. In addition, this bridging step has also fixed rather than estimated the 2016 and 2017 recruitment deviations. These deviations were estimated to be above average in Bridge 2 and previous assessments have observed a retrospective pattern in their estimation, with future assessments generally observing a downward shift in their estimation when additional years of data are included in the assessment.

12.4 Bridge 1

The 2018 Silver Warehou assessment was converted to the most recent version of the software, Stock Synthesis version SS-V3.30.17.00. This resulted in no changes to the stock status estimates throughout the timeseries (Figure 12.1).

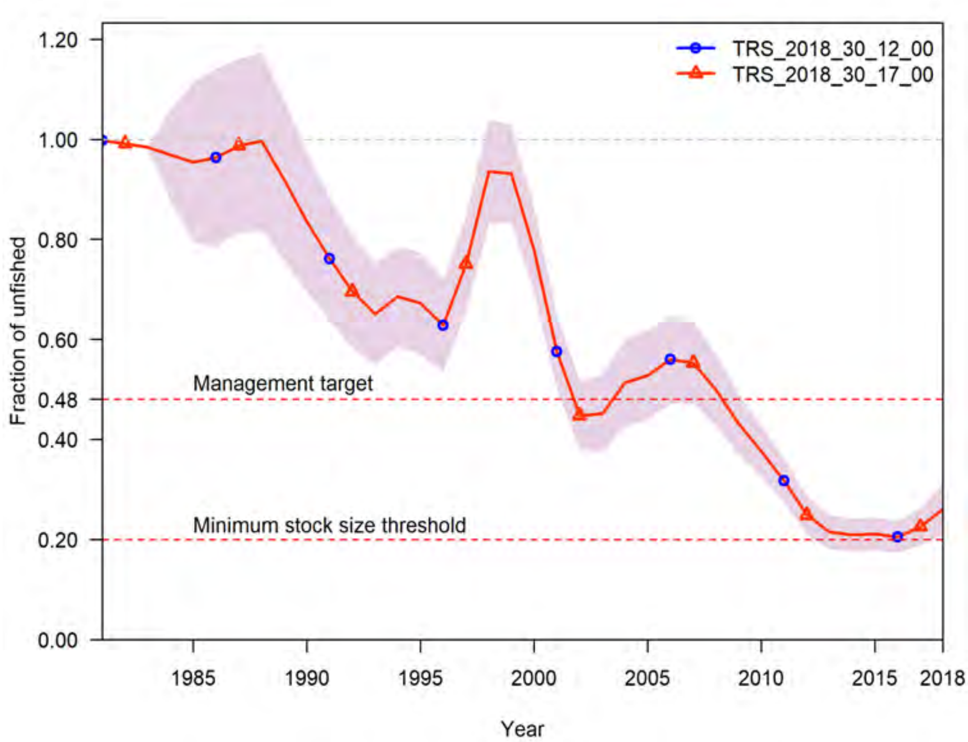

Figure 12.1. Comparison of the relative spawning biomass time series for the 2018 assessment (SS3-30.12) and a model converted to SS-V3.30.17.

New features available in the latest versions of Stock Synthesis, such as allowing smaller lower bounds on minimum sample sizes and estimating additional standard deviation to abundance indices were then incorporated (labelled 'New'). This step resulted in minor changes to the estimated depletion trajectory, with slight differences apparent between 1994 and 2003 (Figure 12.2). There were no other discernible changes that resulted from alteration of these settings.

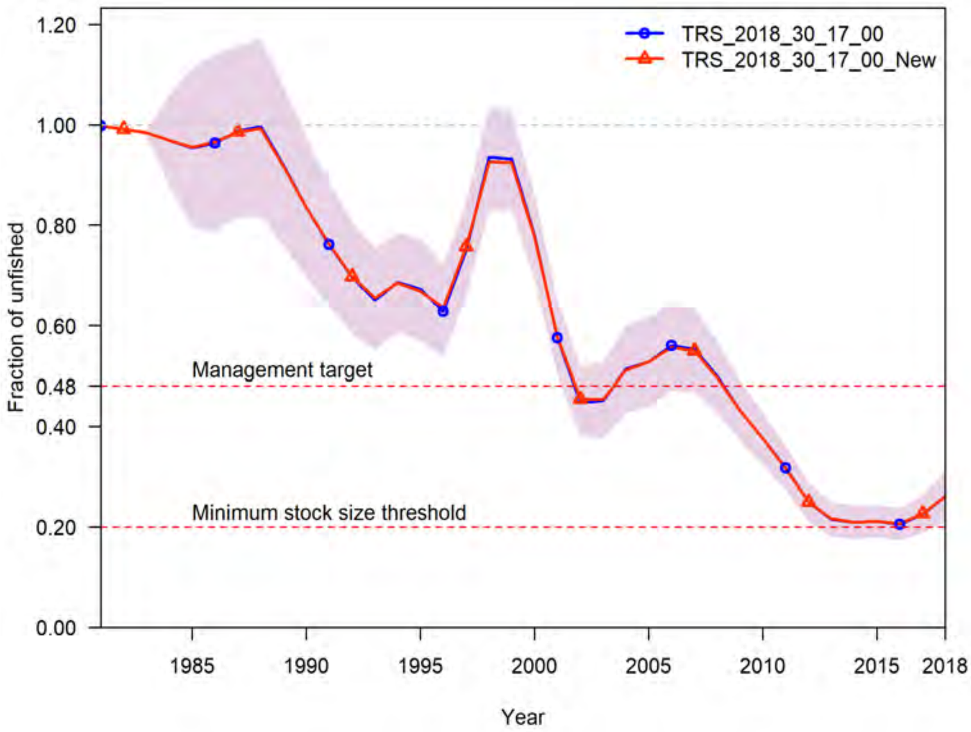

Figure 12.2. Comparison of the relative spawning biomass time series for the 2018 assessment updated to the latest Stock Synthesis version (SS-V3.30.17), with new settings applied to the model (New).

Incorporating amended historical catches resulted in minor changes to depletion estimates, which are only just evident (Figure 12.3). This change also resulted in minor upward revision of recruitment deviations between 1991 and 1993 (Figure 12.4).

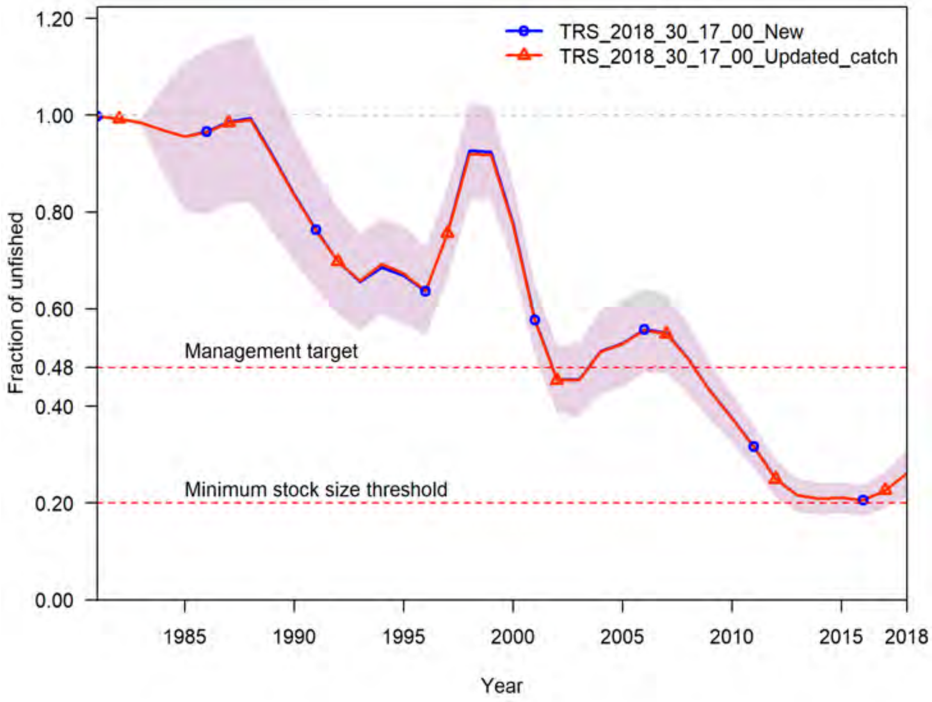

Figure 12.3. Comparison of the relative spawning biomass time series for the 2018 assessment with updated settings (New) with the 2018 assessment with both updated settings and amended historical catch series (Updated catch).

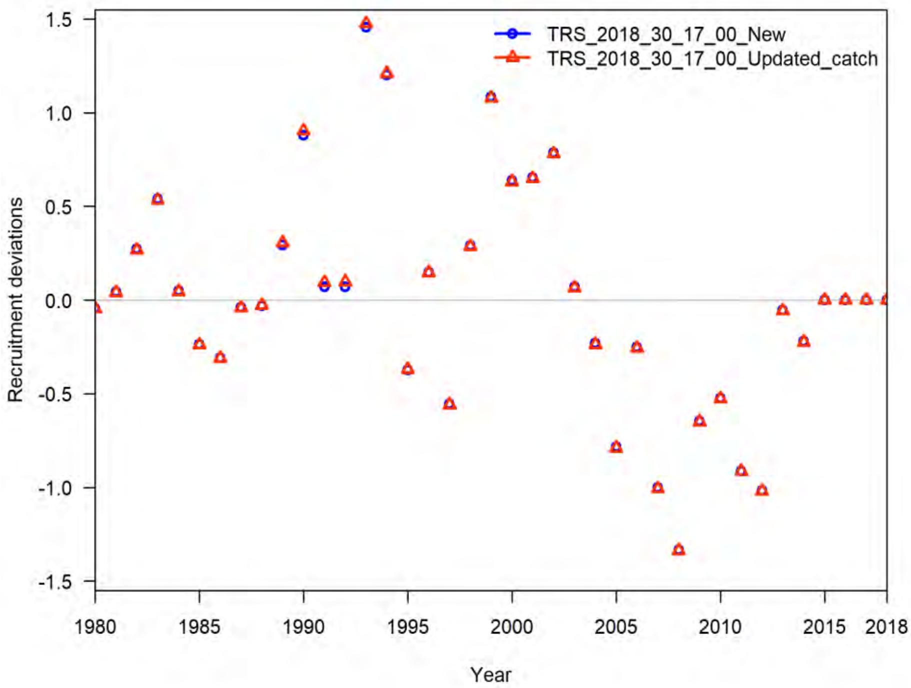

Figure 12.4. Comparison of the estimated recruitment deviations for the 2018 assessment with updated settings (New) with the 2018 assessment with both updated settings and amended historical catch series (Updated catch).

The assessment was then tuned using the latest tuning protocol (labelled 'Tuned') (Figure 12.5, Figure 12.6). 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 2018. This initial bridging step, Bridge 1, does not incorporate any data after 2017 or any structural changes to the assessment.

When these series are plotted together, there are minor changes resulting from transitioning to the new version of Stock Synthesis and incorporating new features (Figure 12.5, Figure 12.6). The new tuning procedures result in no change to the stock status estimates or estimated recruitment deviations (Figure 12.5, Figure 12.6, orange and red lines).

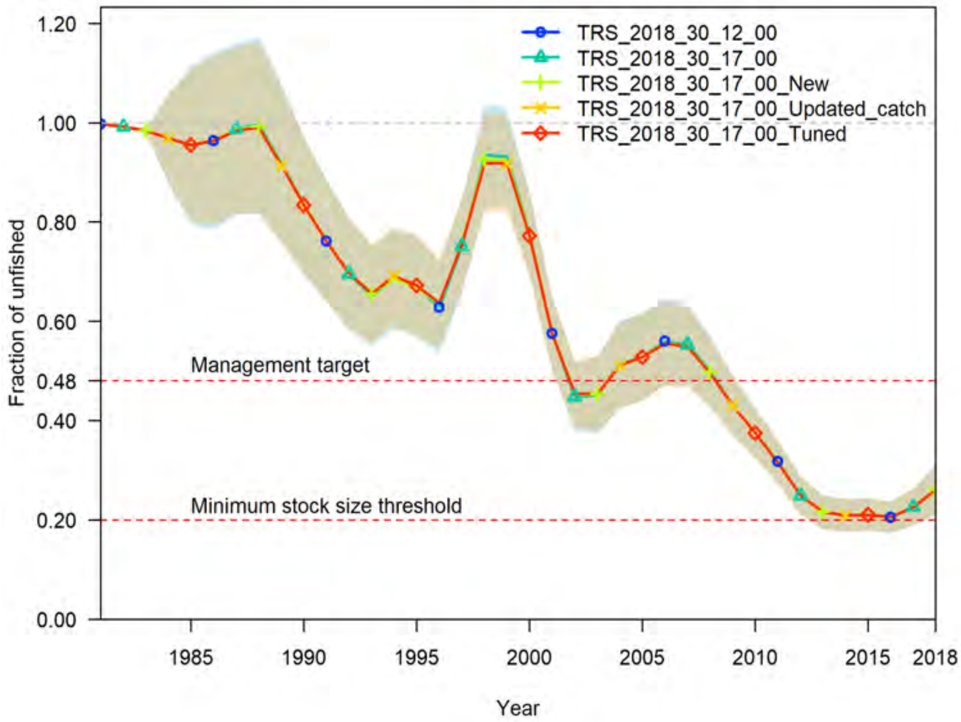

Figure 12.5. Comparison of the relative spawning biomass time series for the four steps included in the first bridging.

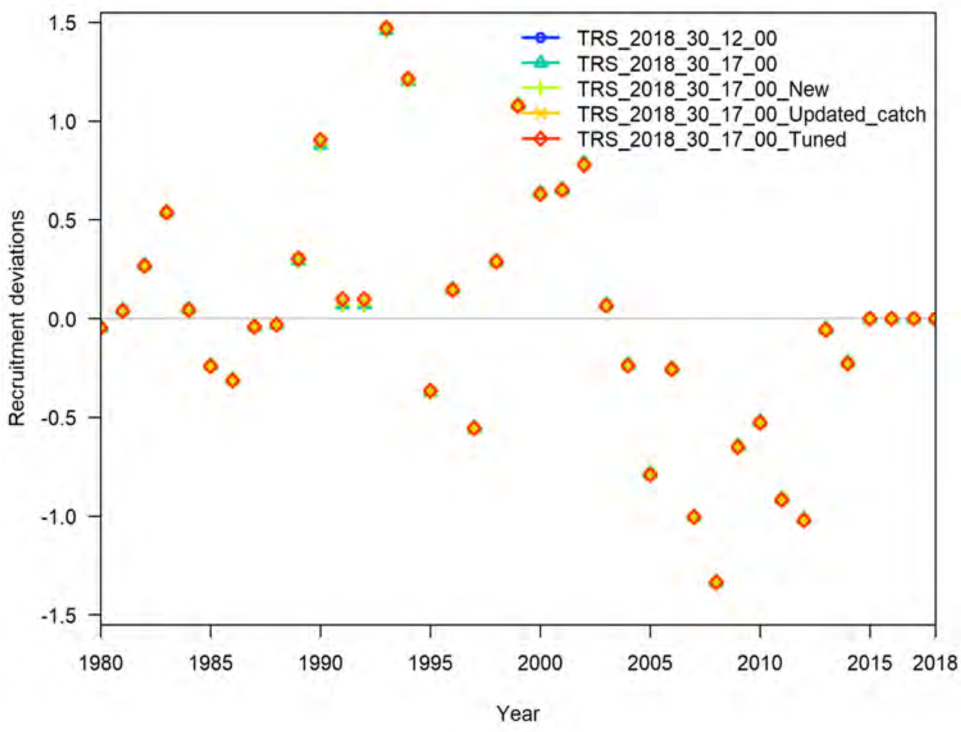

Figure 12.6. Comparison of the estimate recruitment deviations for the four steps included in the first bridging.

12.5 Bridge 2

12.5.1 *Inclusion of new data*

The data inputs to the assessment comes from multiple sources, including: length and conditional age-at-length data from the trawl fishery, updated standardized CPUE series (Sporcic, 2021), the annual total mass landed, discard rates, and age-reading error. Data were formulated by calendar year (i.e. 1 Jan to 31 Dec) and were split into two fleets: east trawl (SESSF zones 10, 20, 30) and west trawl (SESSF zones 40 and 50).

Starting from the converted 2018 base case model (labelled TRS_2018_Updated) additional and updated data to 2020 were added sequentially to develop a preliminary base case for the 2021 assessment, these steps included:

1. Change final assessment year to 2020, add catch to 2020 (addCatch2020).
2. Add CPUE to 2020 (from Sporcic (2021)) (addCPUE2020).
3. Add updated discard fraction estimates to 2020 (add_Discards2020).
4. Update length frequency data, including both port and onboard length frequencies (addLengths2020).
5. Add updated age error matrix and age-at-length data to 2020 (addAge2020).
6. Change the final year for which recruitments are estimated from 2014 to 2017 (extendRec2017).

7. Retune using latest tuning protocols, including Francis weighting on length-compositions and conditional age-at-length data (Tuned).

12.5.2 *Results – base case 2*

Inclusion of the new data resulted in a series of changes to the outputs of the model. The addition of catch data made no difference to the estimated spawning biomass (Figure 12.7). The addition of updated CPUE series resulted in decreased spawning biomass from 1980 to 1990, had no influence on spawning biomass between 1991 and 2015 and reduced estimated spawning biomass from 2015 onwards (Figure 12.7). The addition of updated discard estimates further reduced initial estimates of spawning biomass, however increased estimates between 1985 and 1996 (Figure 12.7). There were minimal changes resulting from the addition of discard data between 1997 and 2015, however, from 2018 the addition of new discard data reduced estimates of absolute spawning biomass (Figure 12.7). The addition of length and age data generally increased estimates of spawning biomass between 1980 and 2010, while there was little impact between 2010 and 2020 (Figure 12.7). Extending recruitment deviations and then tuning resulted in slight downward revisions throughout the series (Figure 12.7). The impacts on relative spawning biomass from the addition of each of the updated and extended data sets was similar as those observed in absolute spawning biomass (Figure 12.7, Figure 12.8).

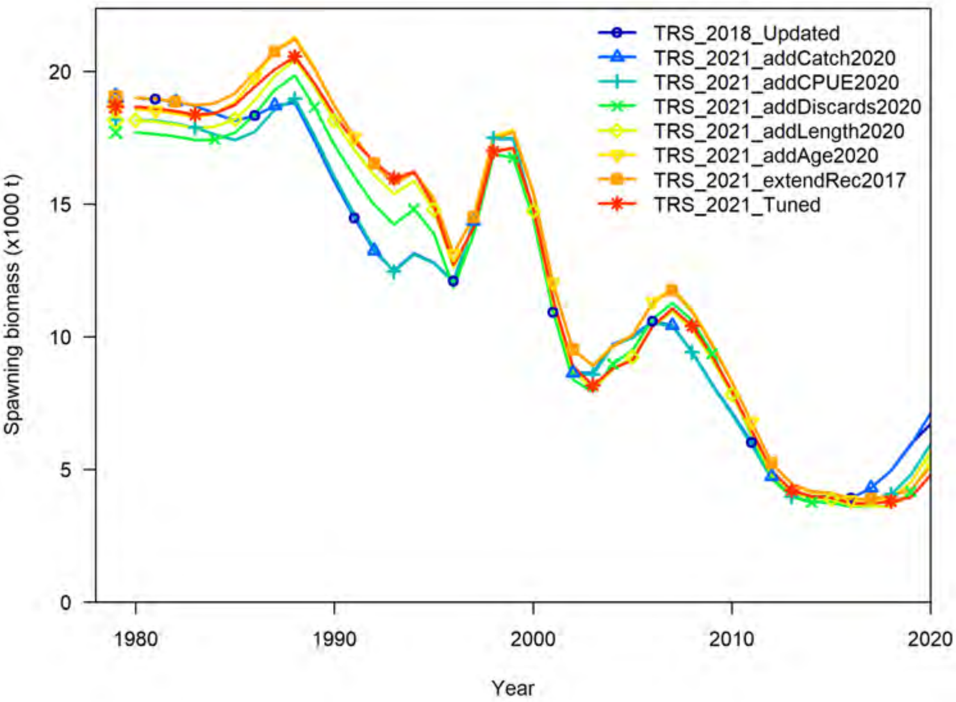

Figure 12.7. Comparison of the absolute spawning biomass for the updated 2018 assessment converted to SS-V3.30.17 (TRS_2018_Updated - blue) with various bridging models leading to the 2021 base case 2 (TRS_2021_Tuned - red)

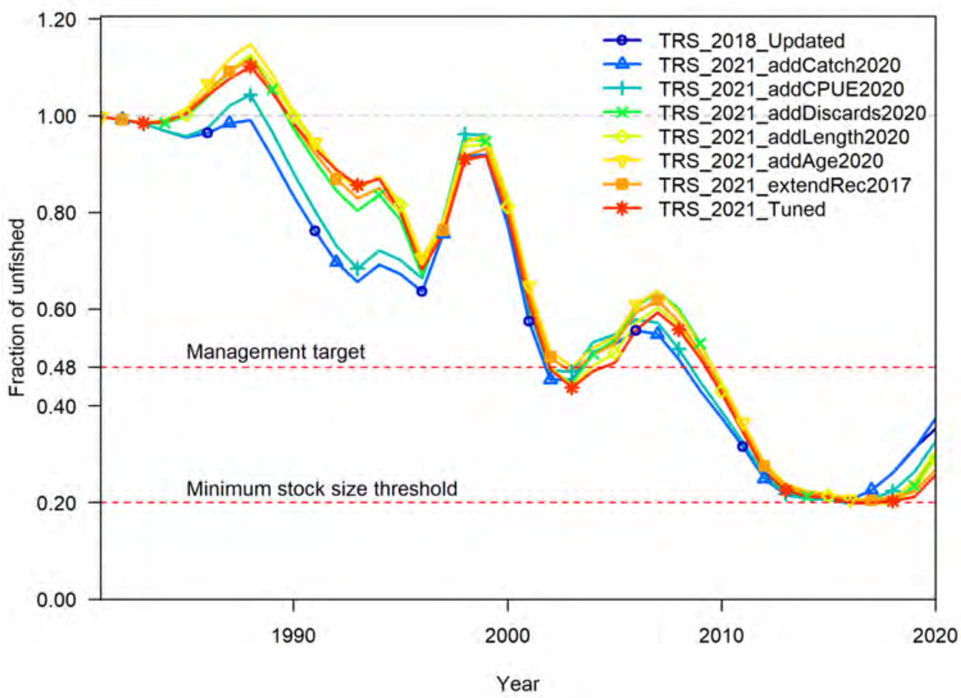

Figure 12.8. Comparison of the fit to the relative spawning biomass for the updated 2018 assessment model converted to SS-V3.30.17 (TRS_2018_Updated - blue) with various bridging models leading to the 2021 base case 2 (TRS_2021_Tuned - red)

The sequential addition of data resulted in increased recruitment estimates between 1980 and 1990, with this also apparent in the recruitment deviations (Figure 12.9, Figure 12.10). In 1991 and 1992 the addition of discard data considerably reduced recruitment estimates, while also increasing estimates in 1993 (Figure 12.9). This is also apparent in the recruitment deviations, where in 1991, deviations were just above average until discard data were included, resulting in downward revision to well below average (Figure 12.10). Recruitment estimates were again revised upwards in 2001 with the addition of discard data (Figure 12.9, Figure 12.10). In 2007 and 2008, the addition of discard data resulted in downward revision of recruitment and recruitment deviations (Figure 12.9, Figure 12.10). The three last recruitment deviation estimates from the previous assessment (2012 to 2014) were also revised downwards with the inclusion of new data (Figure 12.9, Figure 12.10), with this consistent with a pattern observed in previous assessments (Burch et al., 2018a). The new 2015 recruitment deviation was estimated below average, however estimates in 2017 and 2018 were above average, again following a retrospective pattern observed in previous assessments. The impact of these recruitment deviations is explored further below.

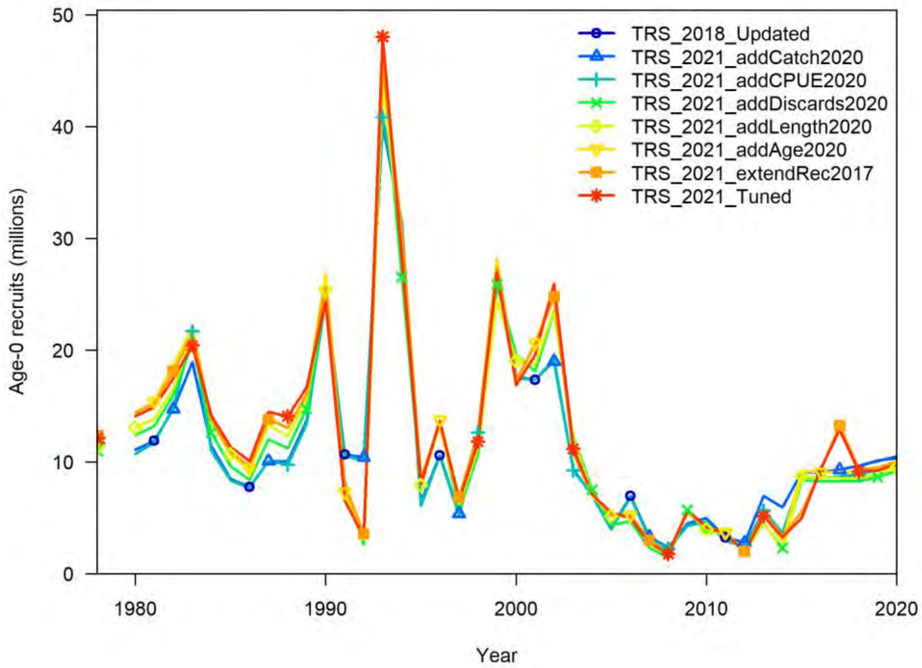

Figure 12.9. Comparison of the estimated absolute recruitments for the updated 2018 assessment model converted to SS-V3.30.17 (TRS_2018_Updated - blue) with various bridging models leading to the 2021 base case 2 (TRS_2021_Tuned - red)

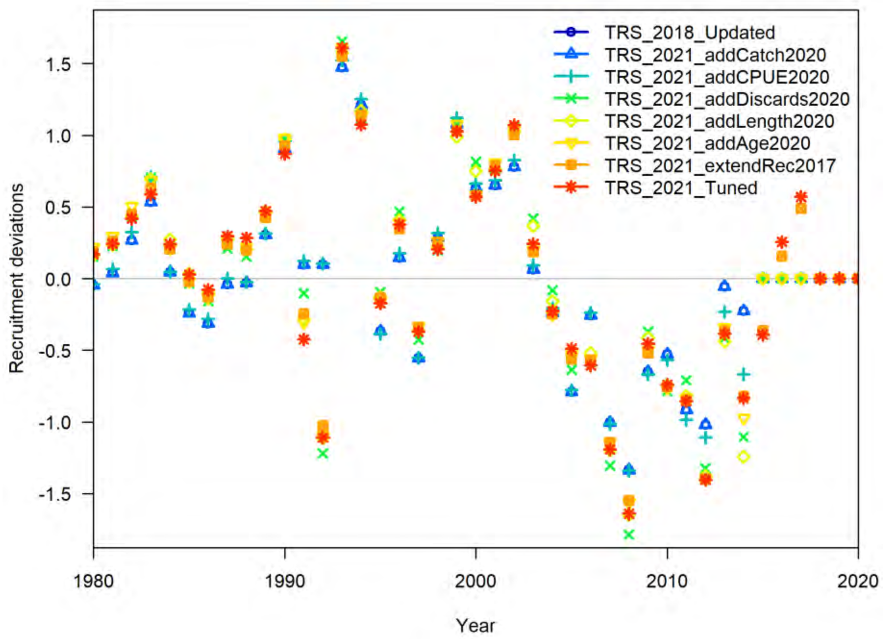

Figure 12.10. Comparison of the estimated recruitment deviations for the updated 2018 assessment model converted to SS-V3.30.17 (TRS_2018_Updated - blue) with various bridging steps leading to the 2021 base case 2 (TRS_2021_Tuned - red)

The impacts of inclusion of new data on fits to CPUE series were generally small. Fits to the east trawl fleet CPUE series were improved between 1985 and 1995, where estimates were higher and closer to the estimated inputs, although this resulted in worse fits to the west trawl CPUE over this period (Figure 12.11, Figure 12.12). Fits between 1995 and 2015 were similar for the east trawl fleet, however from 2015 estimates were lower than in the previous assessment fitting more closely to the inputs (Figure 12.12). Again, fits to the west trawl input data were similar between 1996 and 2017, with the addition of data resulting in sequential improvement to fits between 2018 and 2020 (Figure 12.12).

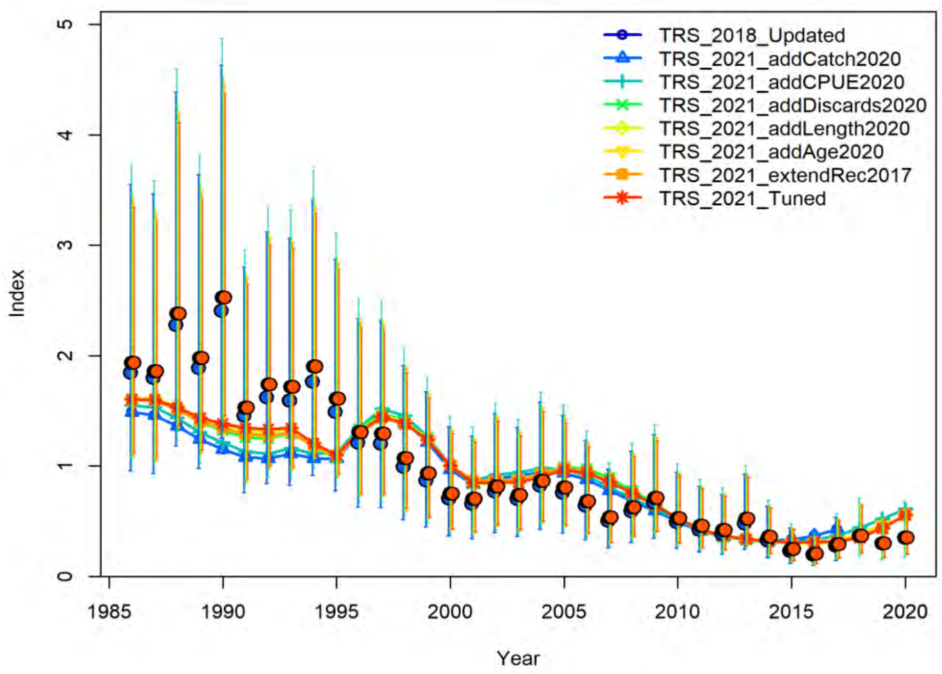

Figure 12.11. Comparison of the fit to the east trawl CPUE index for the updated 2018 assessment model converted to SS-V3.30.17 (TRS_2018_Updated - blue) with various bridging models leading to the 2021 preliminary base case (TRS_2021_Tuned - red)

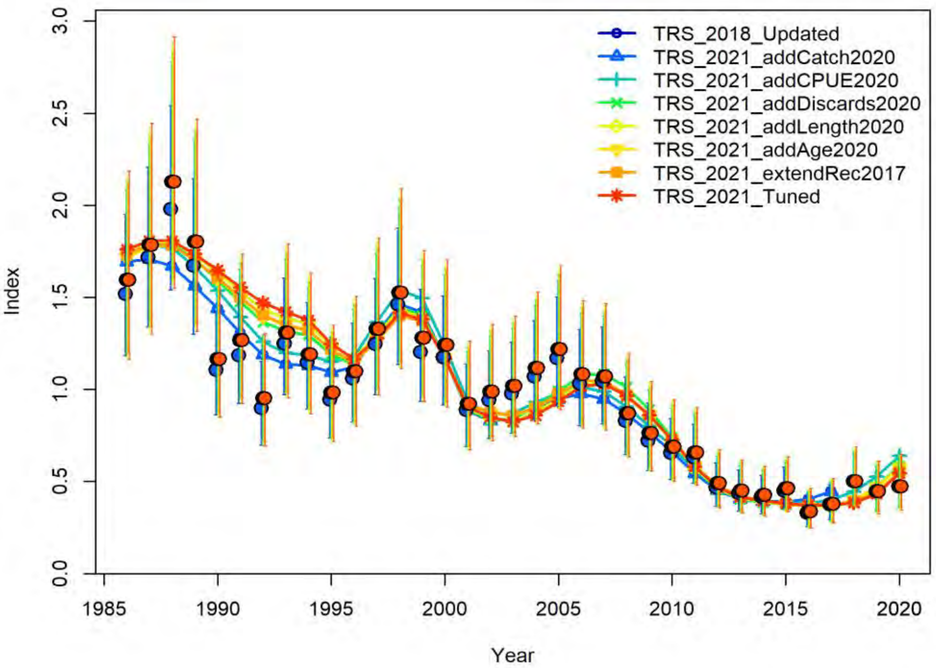

Figure 12.12. Comparison of the fit to the west trawl CPUE index for the updated 2018 assessment model converted to SS-V3.30.17 (TRS_2018_Updated - blue) with various bridging models leading to the 2021 preliminary base case (TRS_2021_Tuned - red).

12.5.3 *Recruitment deviations*

Previous assessments have noted a tendency for the model to estimate higher than average recruitment deviations at the end of the assessment series when investigating retrospecive patterns (Burch et al., 2018b). In subsequent assessments these recruitments are generally revised downwards. The estimation of above average recruitment deviations in 2016 and 2017 follows this same pattern, suggesting that they will likely be revised down to below average in future assessments.

The addition of the extra three recruitment deviations at the end of the series resulted in minor revisions of stock status downwards between 1980 and 2000 and this change was mostly associated with the addition of the last recruitment deviation in 2017 (Figure 12.13).

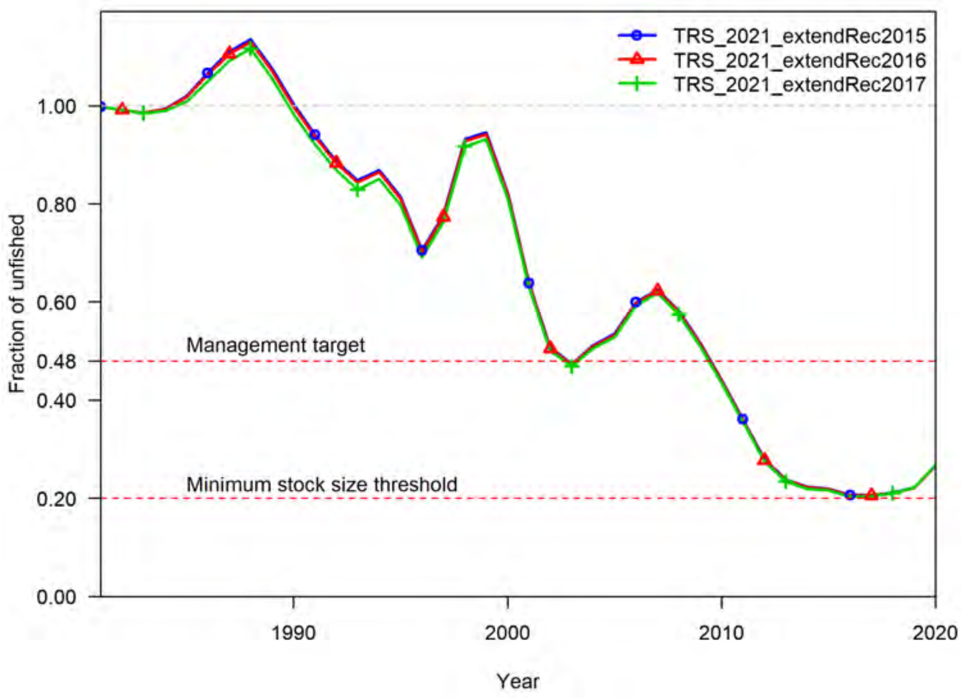

Figure 12.13. Comparison of the relative spawning biomass estimates when extending recruitment deviations to 2015, 2016 and 2017 (blue, red and green respectively)

There is no noticeable difference in the estimated number of recruits with the addition of the three extra recruitment deviations at the end of the series, although the addition of the 2017 deviation resulted in an increase in the estimate (Figure 12.14). Recruitment deviations were revised slightly downwards between 1980 and 2012 with the addition of the 2017 deviation (Figure 12.14). The recruitment deviation in 2016 was revised upwards with addition of the 2016 and 2017 deviations, while the 2017 recruitment was revised upwards with inclusion of the 2017 assessment (Figure 12.14).

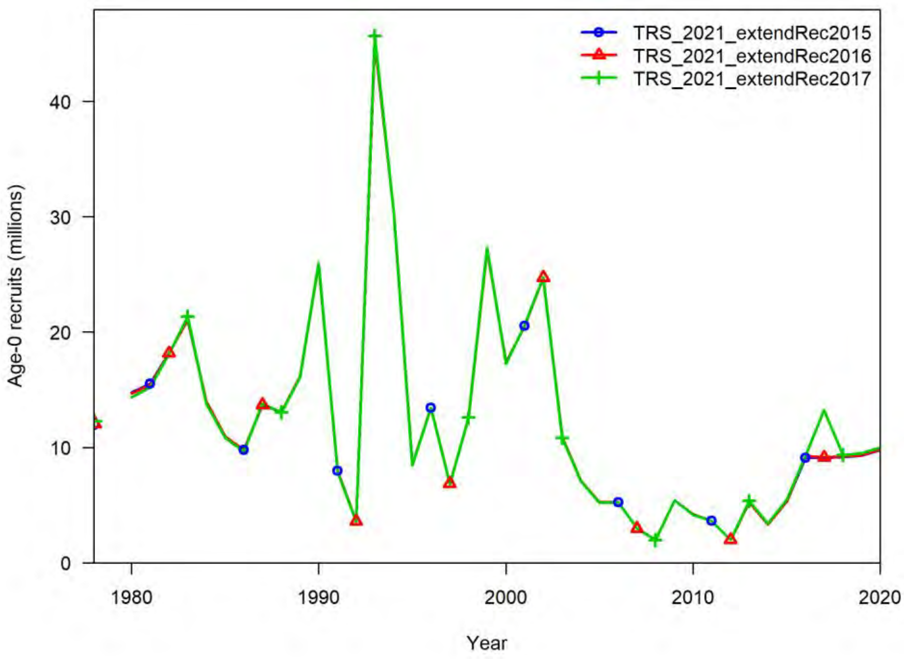

Figure 12.14. Comparison of the estimated recruitment when extending the year of estimation to 2015, 2016 and 2017 (blue, red and green respectively)

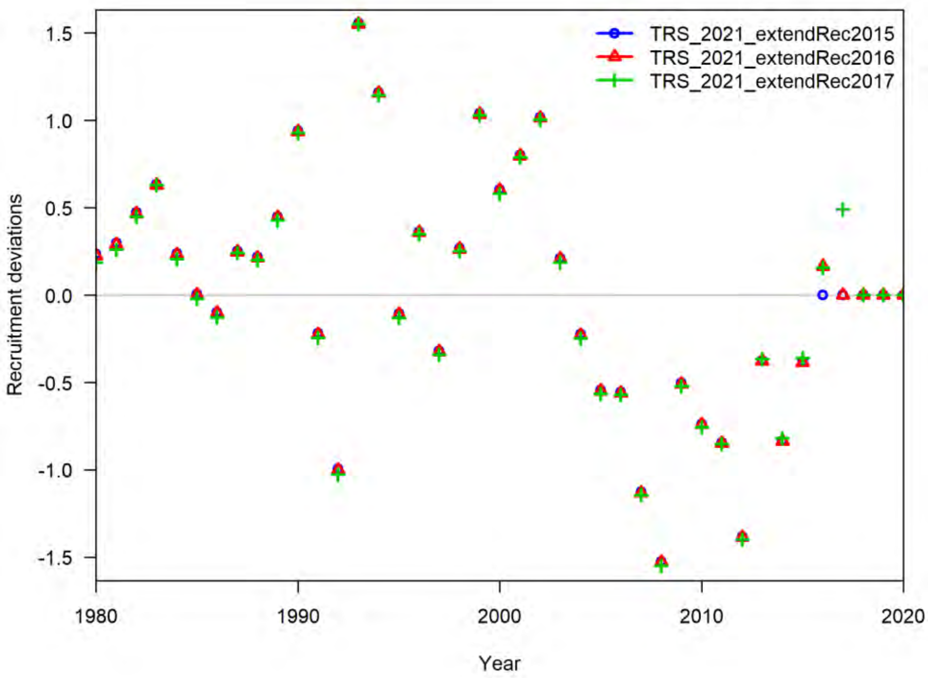

Figure 12.15. Comparison of the estimated recruitment deviations when extending the year of estimation to 2015, 2016 and 2017 (blue, red and green respectively)

12.5.4 *Fits to data – base case 2*

Estimated outputs and fits to data base case 2 are presented in Figure 12.16-Figure 12.23. While most fits are comparable to those in the previous assessment (see Burch et al. (2018b)), the fits to the last three discard estimates for the east trawl fleet are poor (Figure 12.21). This appears to be due to a change in discarding practices over the past 3 years, with substantial increases in discarding. In order to improve fits to these data, an additional retention time block is required, and this is explored further in section Bridge 3.

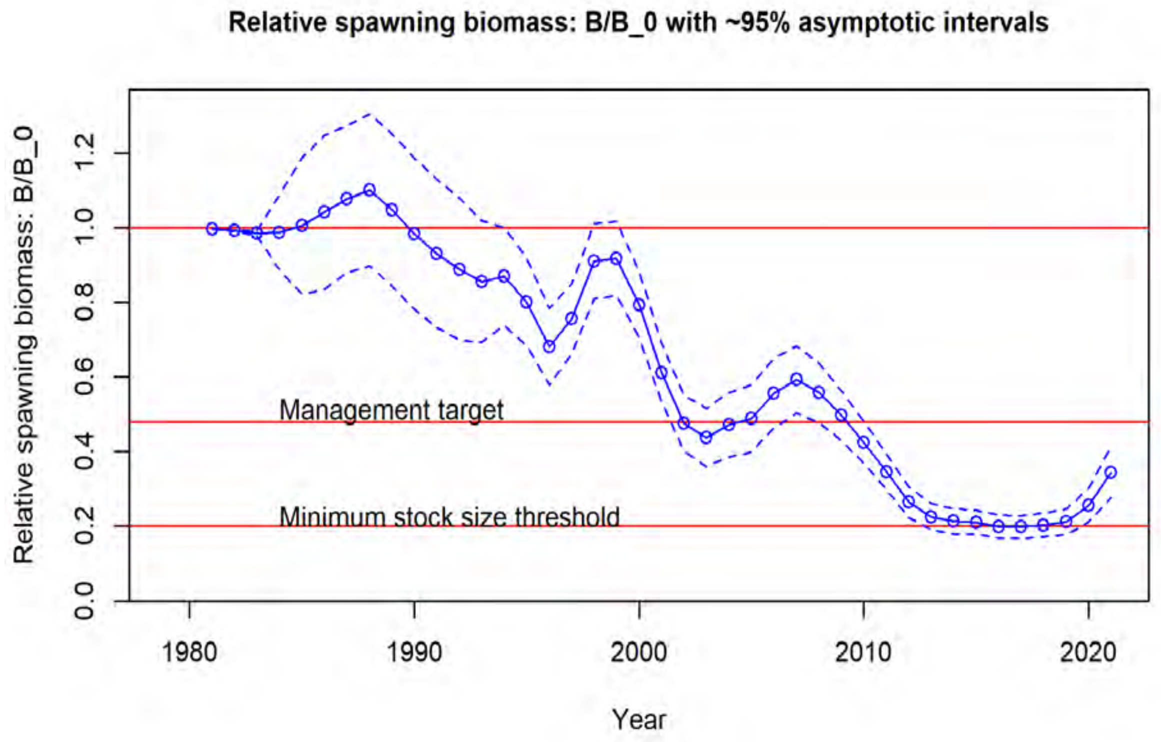

Figure 12.16. The estimated time-series of relative spawning biomass for the 2021 preliminary base case assessment

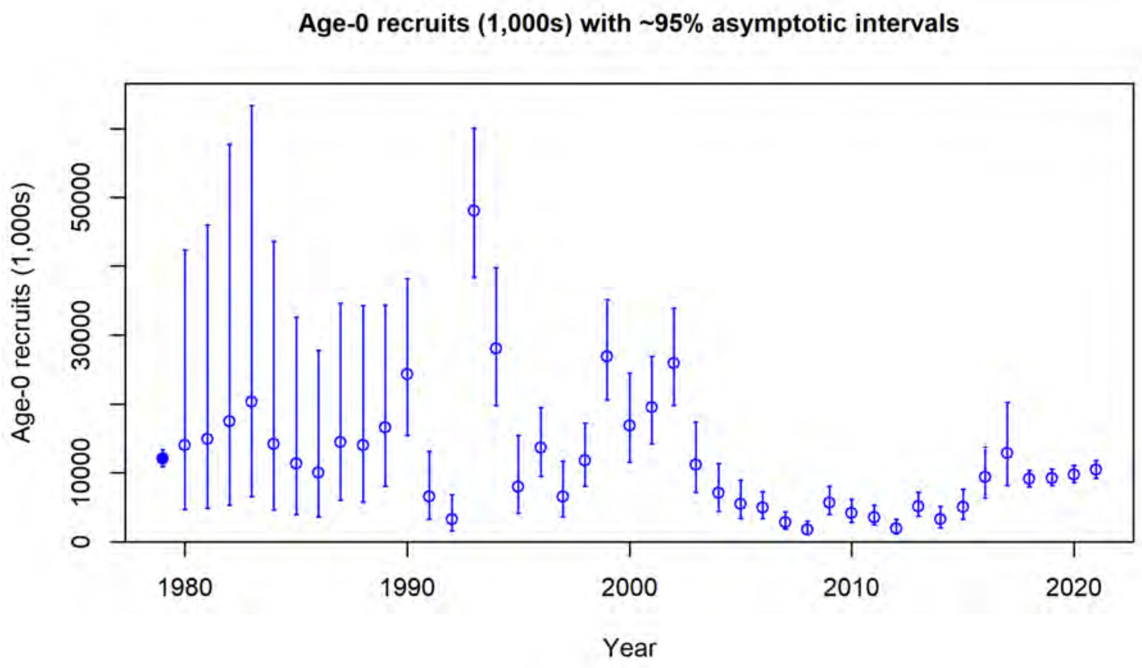

Figure 12.17. The estimated time-series of recruitment for the 2021 preliminary base case assessment

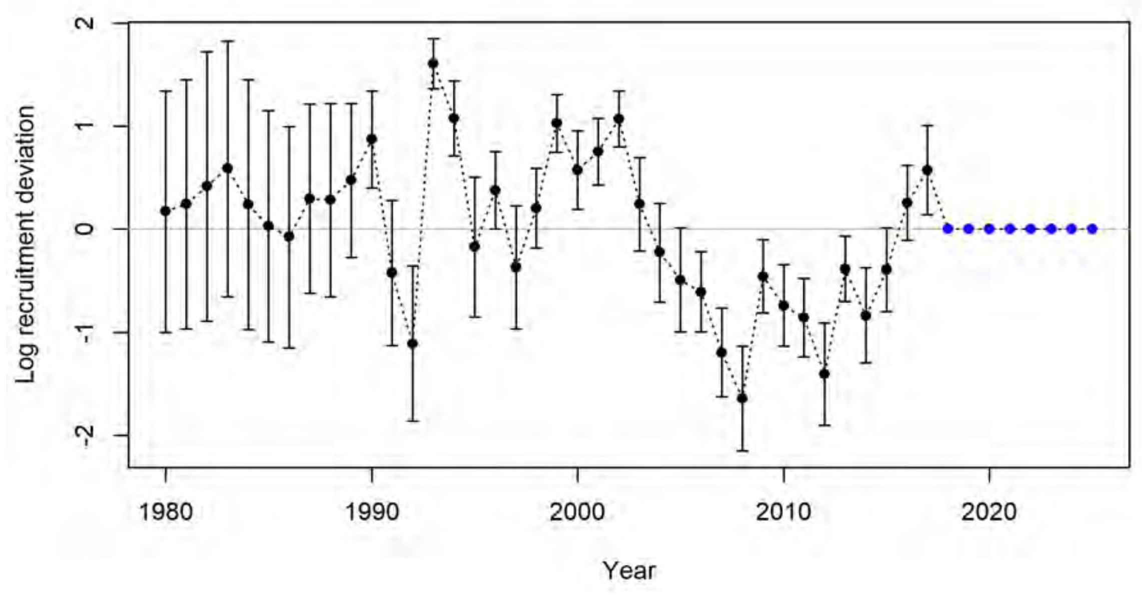

Figure 12.18. The estimated time-series of recruitment deviations for the 2021 preliminary base case assessment

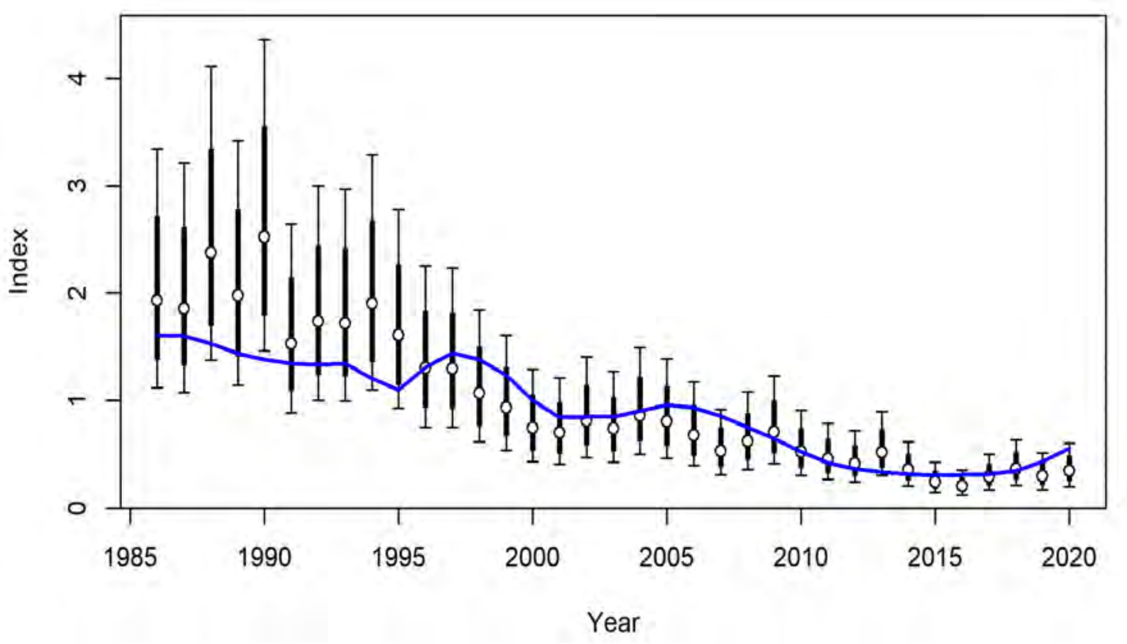

Figure 12.19. Fits to the east trawl CPUE for the 2021 preliminary base case assessment

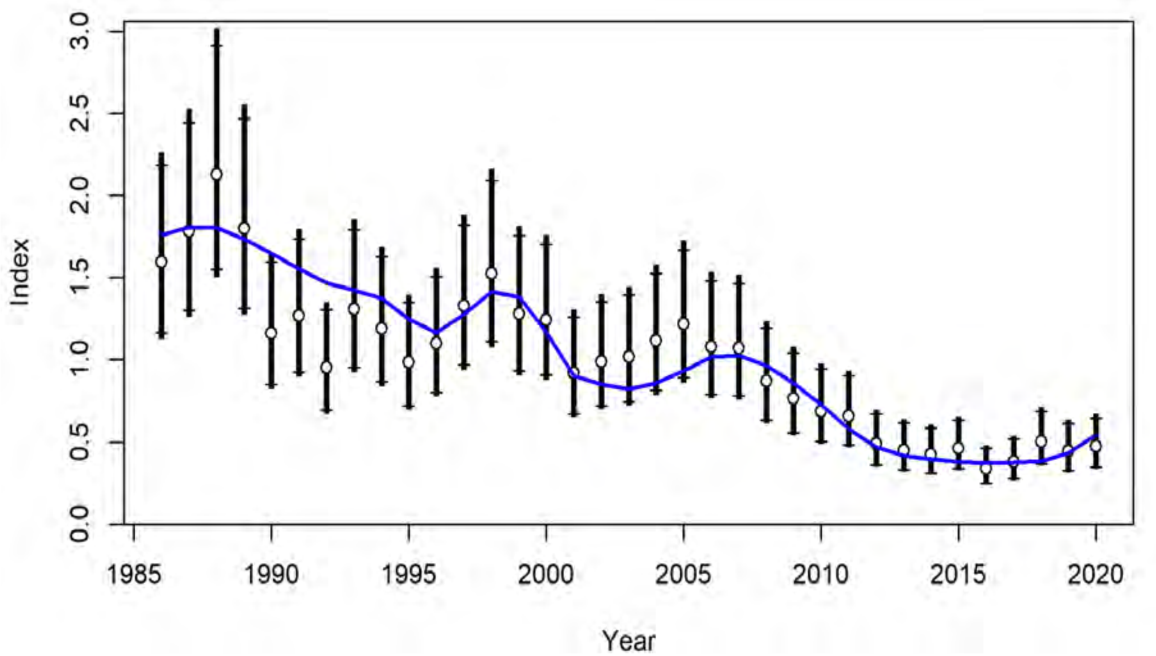

Figure 12.20. Fits to the west trawl CPUE for the 2021 preliminary base case assessment

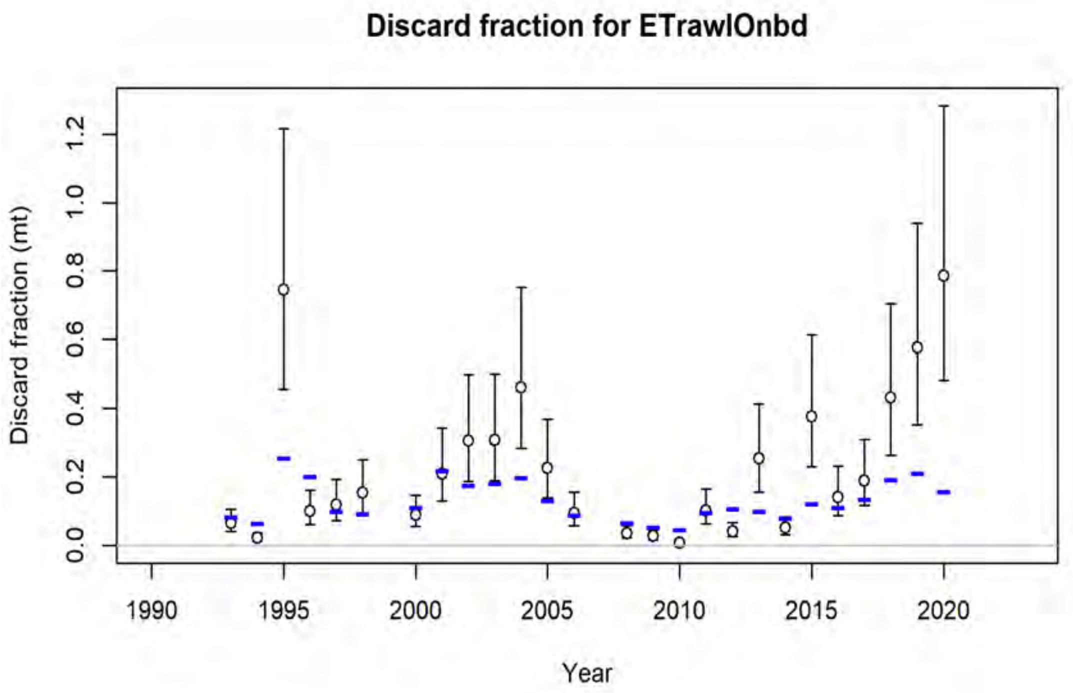

Figure 12.21. Fits to the east trawl discards for the 2021 preliminary base case assessment

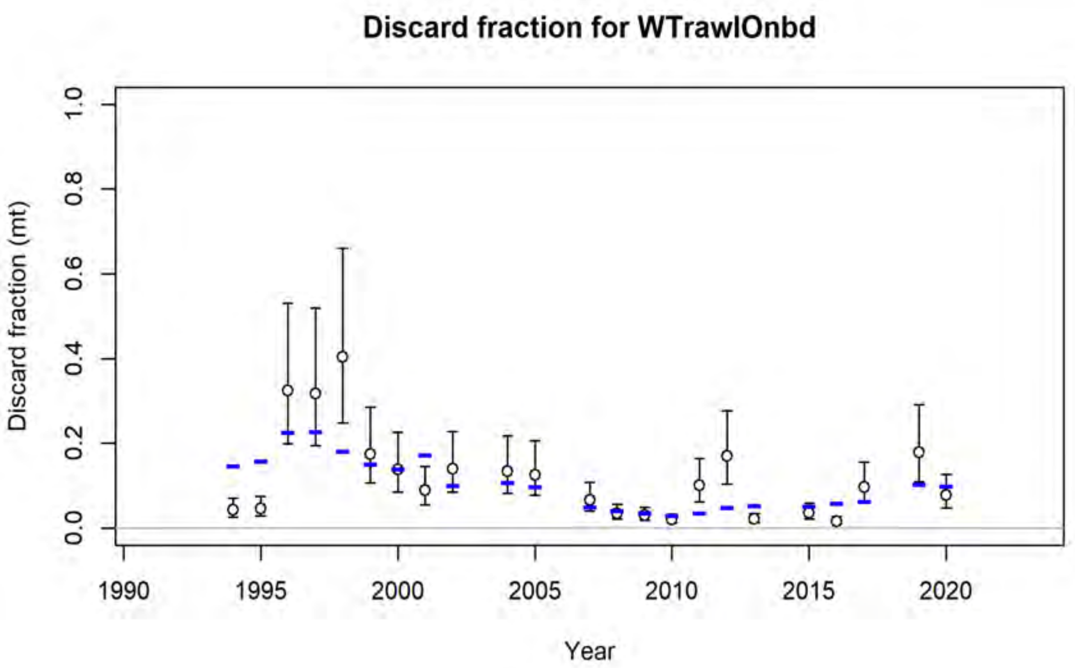

Figure 12.22. Fits to the west trawl discards for the 2021 preliminary base case assessment

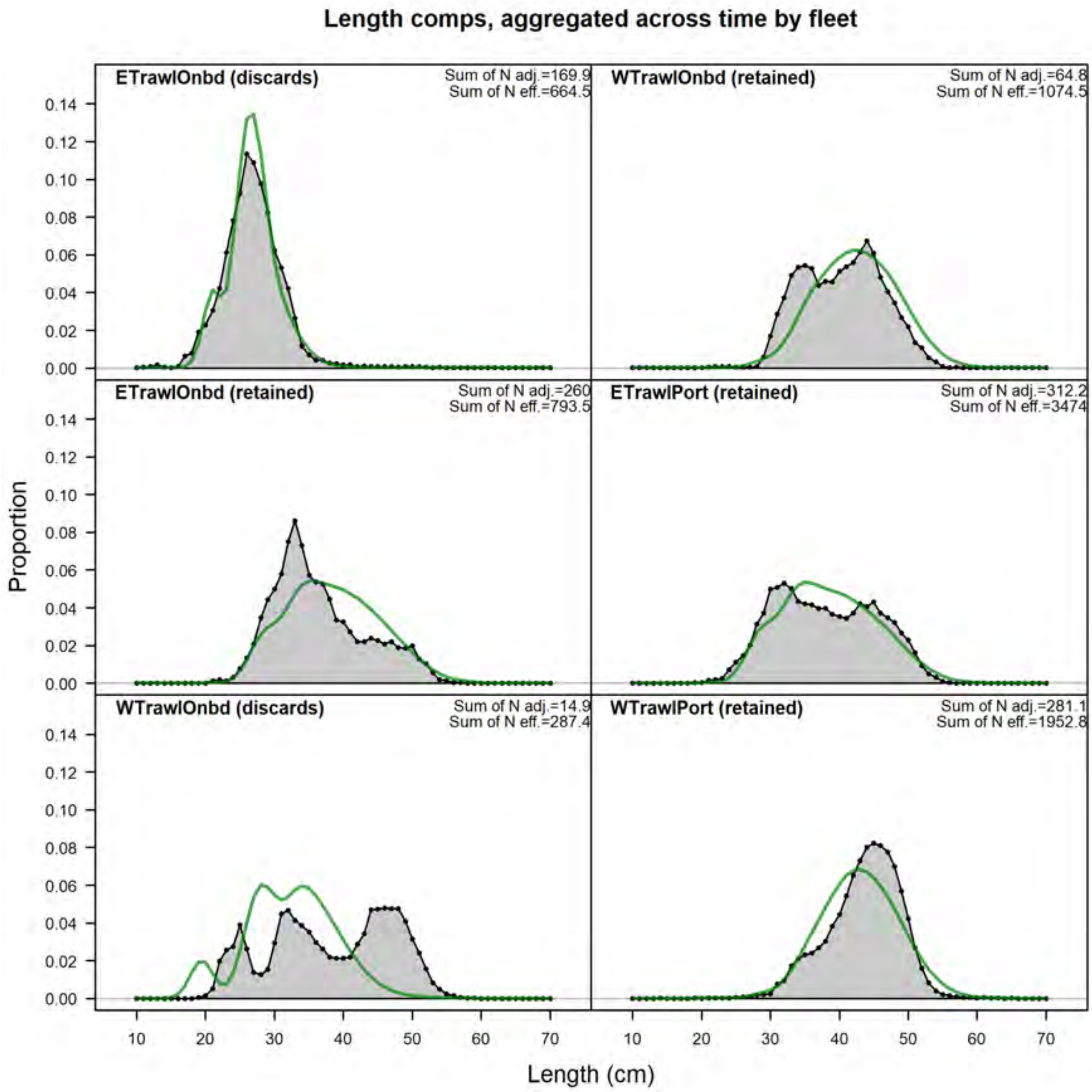

Figure 12.23. Fits to the aggregated length data for the 2021 preliminary base case assessment

12.6 Bridge 3

12.6.1 *Including an additional retention time block and removing recruitment deviations – base case 3*

The model diagnostics and comparisons for base case 2 show poor fits to the discard data for the east trawl fleet (see Bridge 2). There appears to have been a change in discarding practices in this fleet between 2018 and 2020 with increased discard estimates observed over these three years, reaching 79% of the total catch in 2020. In order to adequately fit these increased discard estimates an additional time block on retention for the east trawl fleet from 2018 onwards is required. As part of this last bridging step this retention time block has been included and results are compared with those from base case 2.

In addition to including the extra time block on retention for the east trawl fleet, the last two recruitment deviations have been removed as previous assessments have found these to fit a retrospective pattern which revises recent recruitments downwards with the inclusion of additional years of data (see Burch et al. (2018b)). For a more detailed description and investigation of these trends see Burch et al. (2018b) and Bridge 2. This model with the extra retention time block and removed recruitment deviations is referred to as base case 3.

Including the extra retention time block resulted in little change to both the stock status and absolute spawning biomass estimates, while there was almost no impact on these when removing the last two recruitment deviations (Figure 12.24). Stock status was slightly higher than in base case 2 (TRS_2021_Tuned) between 1985 and 1995 and again at the end of the time series from 2015 when including the extra retention time block (TRS_2021_exra_ret_Tuned), with very little difference observed when removing the last two recruitment deviations (TRS_2021_extra_ret_remove_dev_Tuned, Figure 12.24). Spawning biomass estimates were slightly higher throughout the majority of the timeseries in both models with the extra time block and the removed recruitment deviations (Figure 12.25).

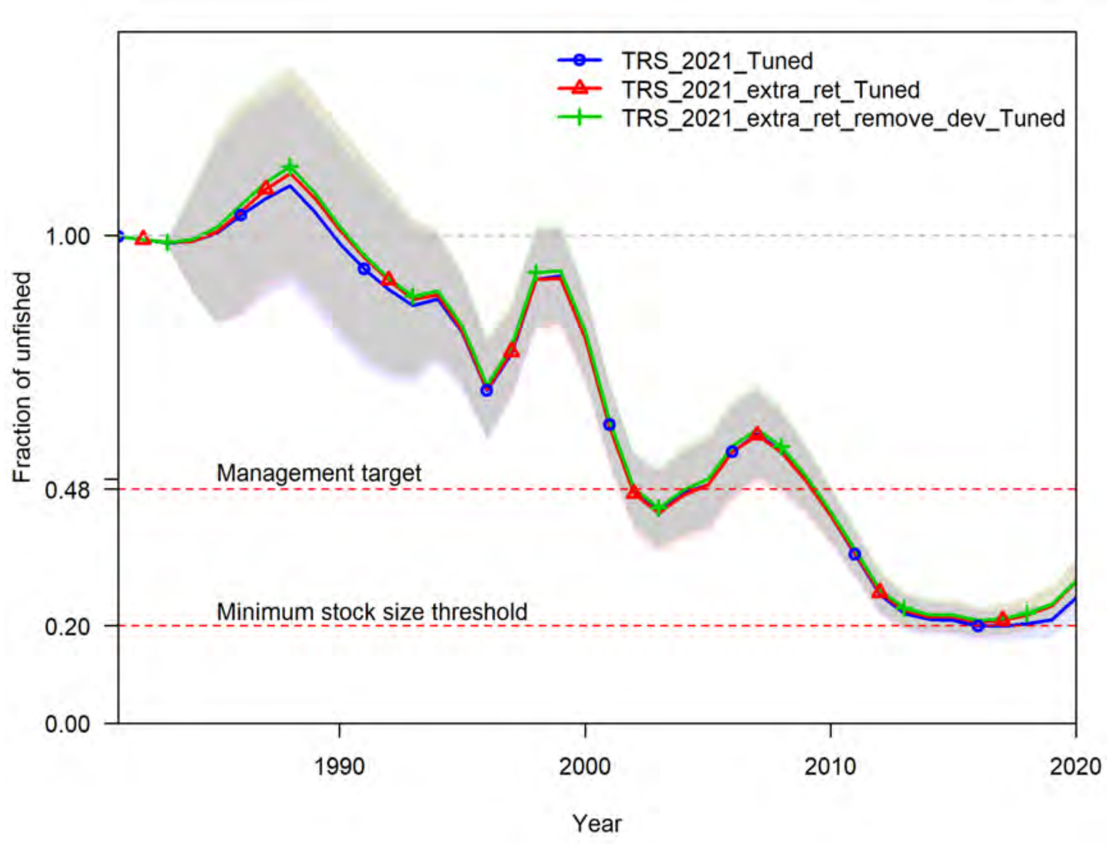

Figure 12.24. Comparison of relative spawning biomass from base case 2 (TRS_2020_Tuned - blue) with the model including an additional retention time block (TRS_2021_extra_ret_Tuned - red) and that with the last two recruitment deviations removed (base case 3, TRS_2021_extra_ret_remove_dev_Tuned - green)

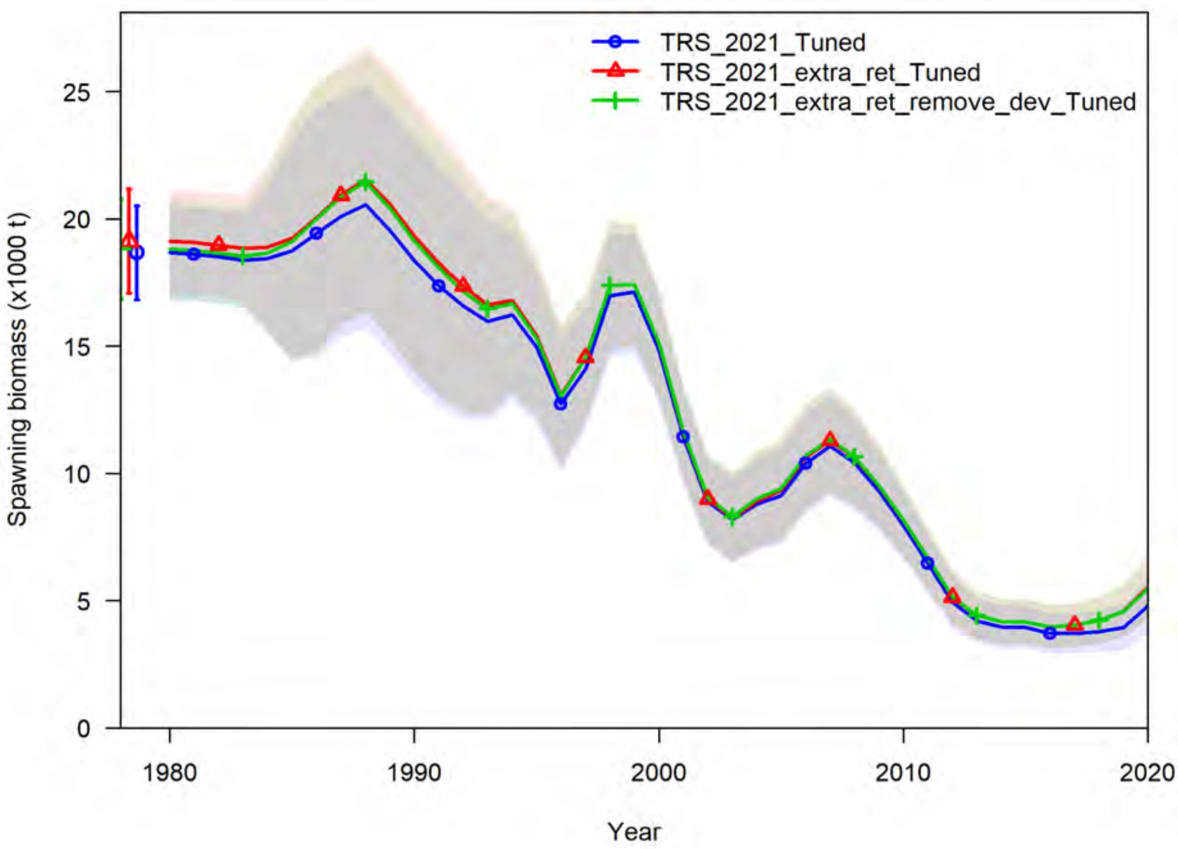

Figure 12.25. Comparison of absolute spawning biomass from base case 2 (TRS_2020_Tuned - blue) with the model including an additional retention time block (TRS_2021_extra_ret_Tuned - red) and that with the last two recruitment deviations removed (base case 3, TRS_2021_extra_ret_remove_dev_Tuned - green)

There were minor differences in the recruit estimates throughout the series, shifting estimates both above and below previous estimates (Figure 12.26). This result was also evident in the recruitment deviation estimates (Figure 12.27). When removing the recruitment deviations from the model with the additional time block there was almost no change in estimated recruitment, besides the removal of the spike in 2017 (Figure 12.26).

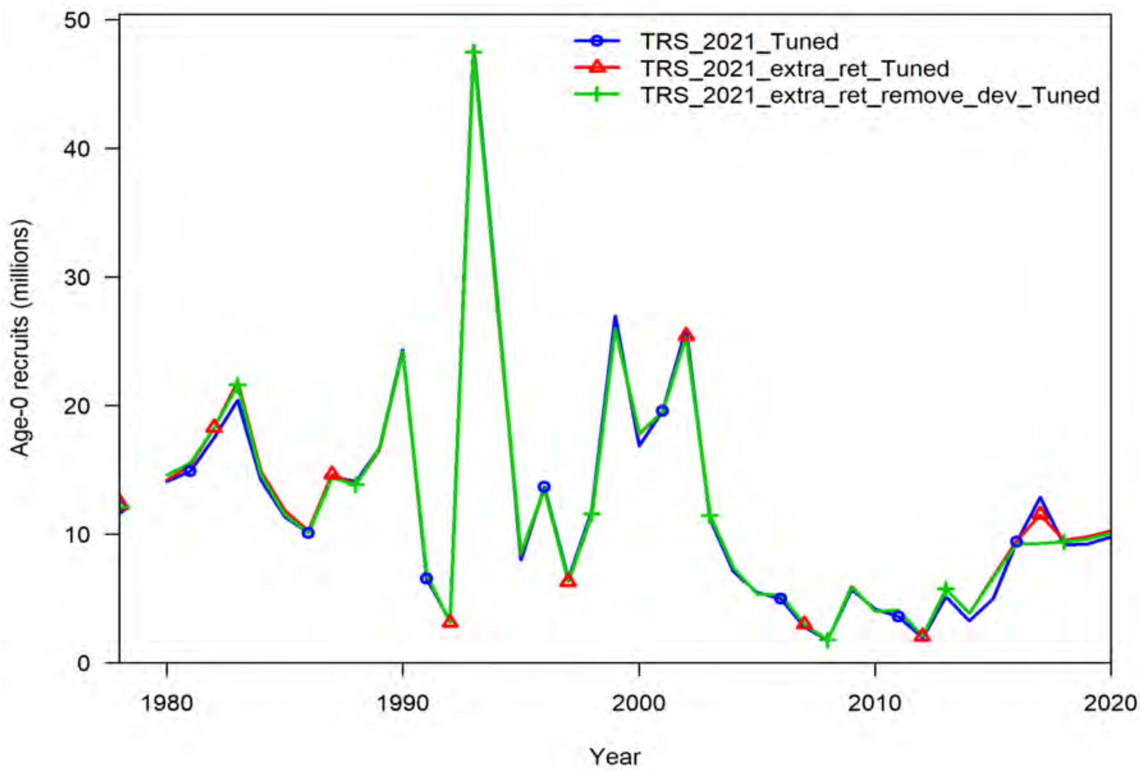

Figure 12.26. Comparison of estimated recruitments for the 2021 base case 2 (TRS_2020_Tuned - blue) with the model including an additional retention time block (TRS_2021_extra_ret_Tuned - red) and that with the last two recruitment deviations removed (base case 3, TRS_2021_extra_ret_remove_dev_Tuned - green)

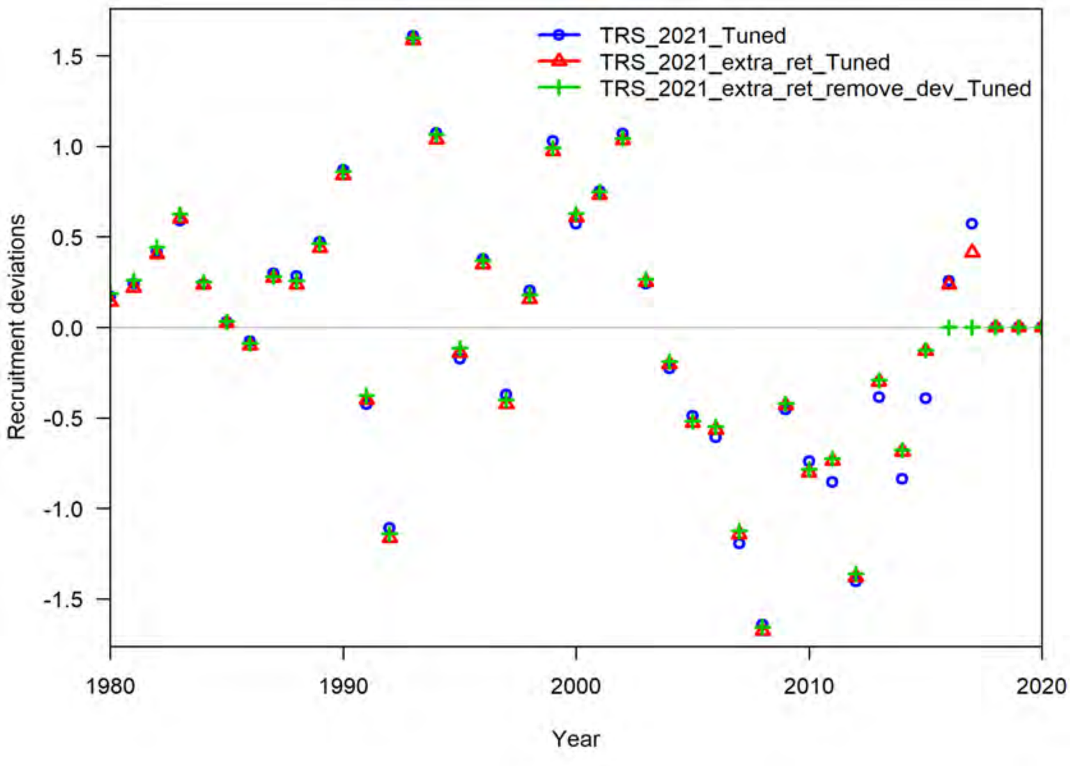

Figure 12.27. Comparison of the estimated recruitment for the 2021 base case 2 (TRS_2020_Tuned - blue) with the model including an additional retention time block (TRS_2021_extra_ret_Tuned - red) and that with the last two recruitment deviations removed (base case 3, TRS_2021_extra_ret_remove_dev_Tuned - green)

From 2017 base case 3 showed improved fits to the CPUE series (Figure 12.28). Fits to the west trawl CPUE series were similar for the majority of the timeseries, however, fits to the last three years slightly worse than in base case 2 (Figure 12.29). There was no discernible difference when moving to the model with the recruitment deviation series shortened (Figure 12.28, Figure 12.29).

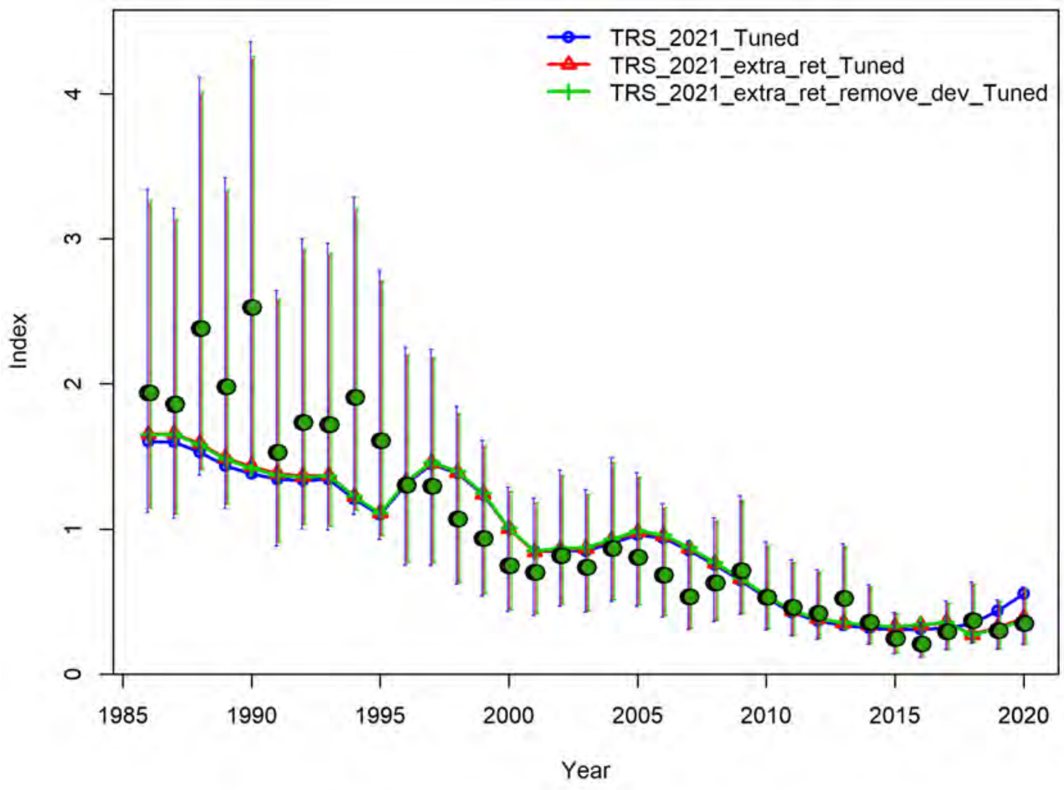

Figure 12.28. Comparison of the fit to CPUE for the east trawl fleet for the 2021 base case 2 (TRS_2020_Tuned - blue) with the model including an additional retention time block (TRS_2021_extra_ret_Tuned - red) and that with the last two recruitment deviations removed (base case 3, TRS_2021_extra_ret_remove_dev_Tuned - green)

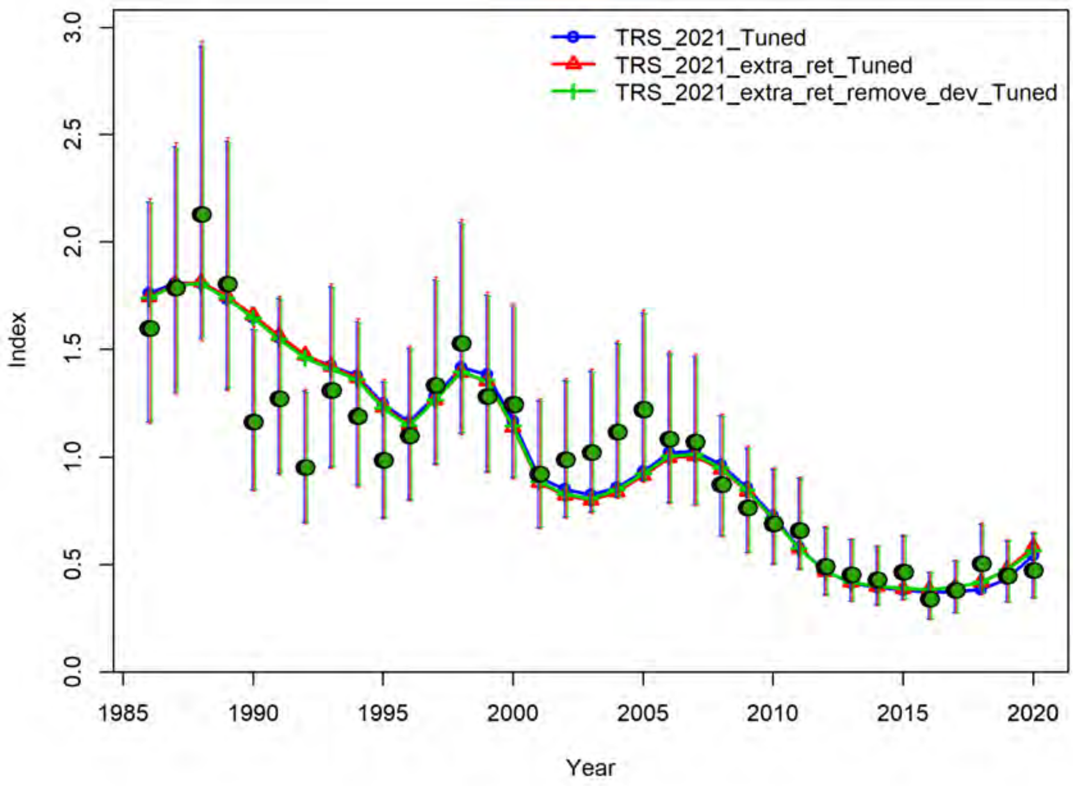

Figure 12.29. Comparison of the fit to CPUE for the west trawl fleet for the 2021 base case 2 (TRS_2020_Tuned - blue) with the model including an additional retention time block (TRS_2021_extra_ret_Tuned - red) and that with the last two recruitment deviations removed (base case 3, TRS_2021_extra_ret_remove_dev_Tuned - green)

12.6.2 *Fits to data – base case 3*

The base case specifications agreed by SERAG in 2018 are maintained into base case 2 presented in Bridge 2. Two changes to this model have been made, including the addition of a retention time block to the east trawl fleet to allow the model to fit the increased discarding, which has changed since the previous assessment and removing estimation of recruitment deviations in 2016 and 2017 due to a retrospective pattern in these recruitments which is revised down with the inclusion of additional years of data. Both of these changes have had minimal impacts on estimated stock status and have improved fits to the data input to the model. This update is referred to as ‘base case 3.

The results from this model show good fits to CPUE abundance indices for both fleets. Fits to the conditional age at length data are also good. Discard data in the east is fit more closely than before, although it is still not fitting the highest estimate in 2020. Fits to discard data in the west are similar as in the previous model specification. As with previous models, fits to the length data are poor. Model diagnostics are presented in Figure 12.30-Figure 12.83.

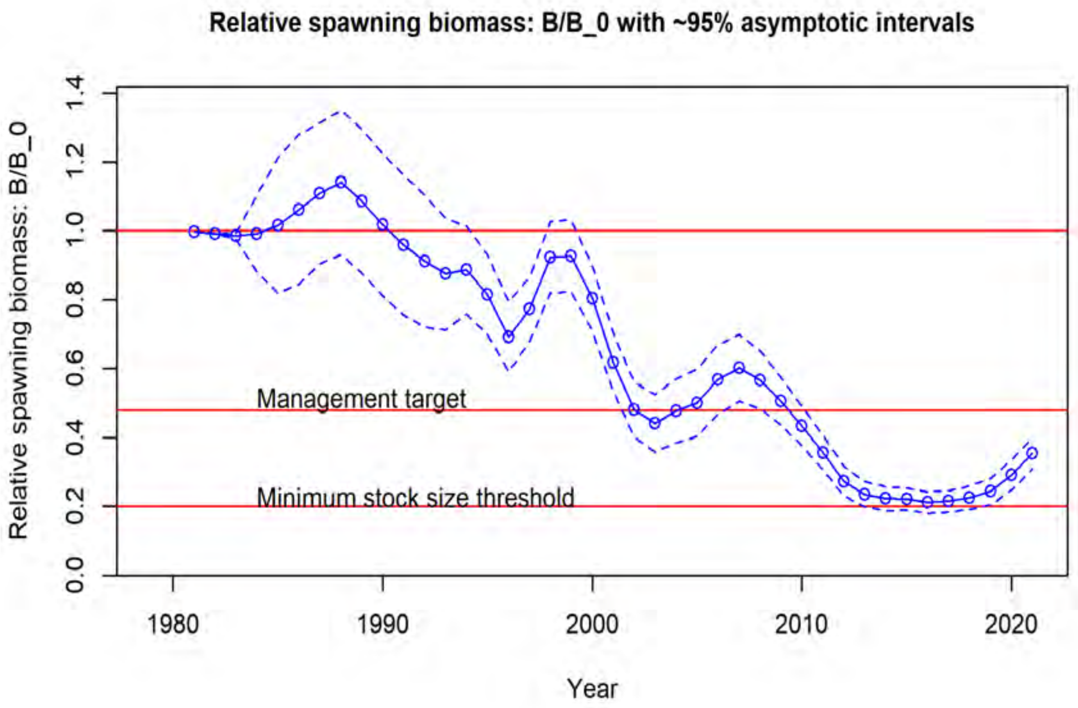

Figure 12.30. The estimated time-series of relative spawning biomass for the 2021 base case 3

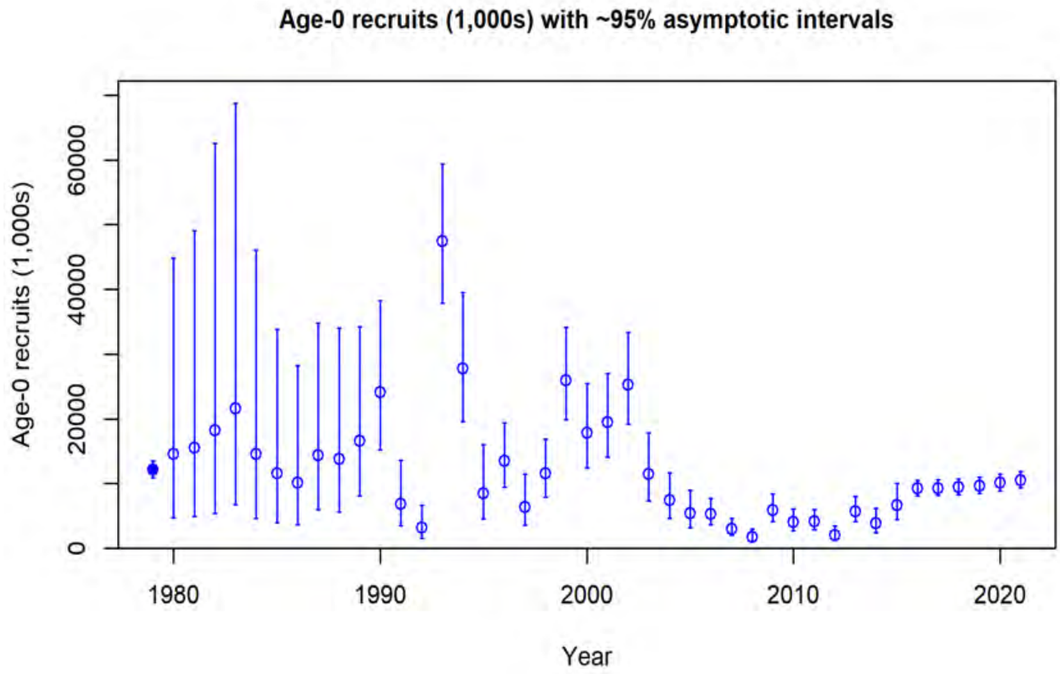

Figure 12.31. The estimated time-series of recruitment for the 2021 base case 3

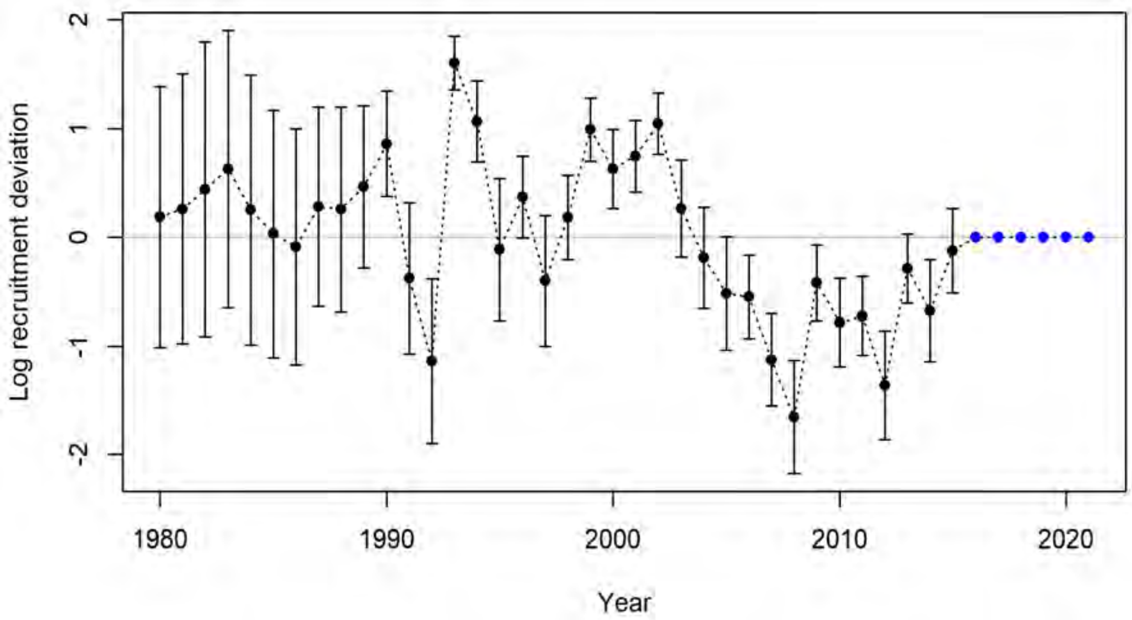

Figure 12.32. The estimated time-series of recruitment deviations for the 2021 base case 3

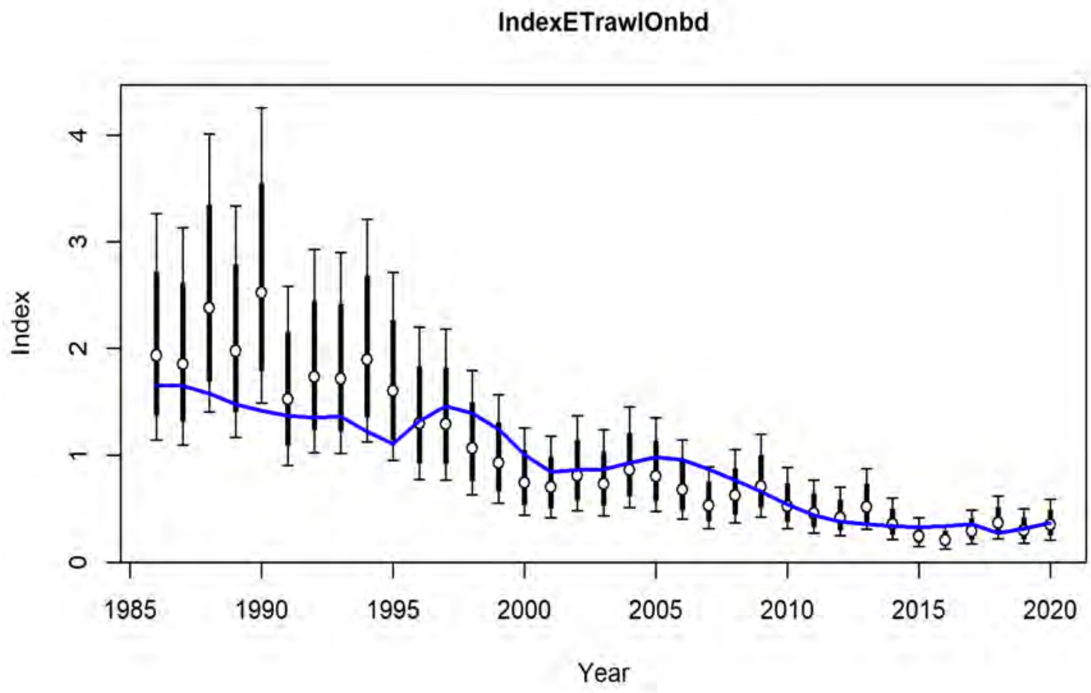

Figure 12.33. Fits to the east trawl CPUE for the 2021 base case 3

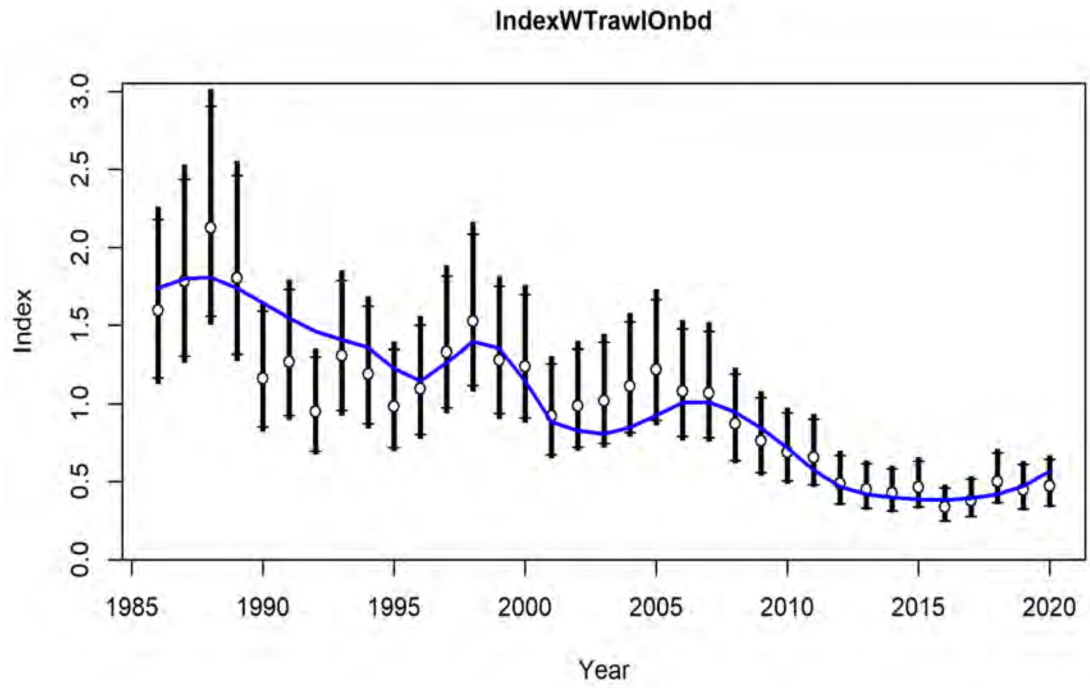

Figure 12.34. Fits to the west trawl CPUE for the 2021 base case 3

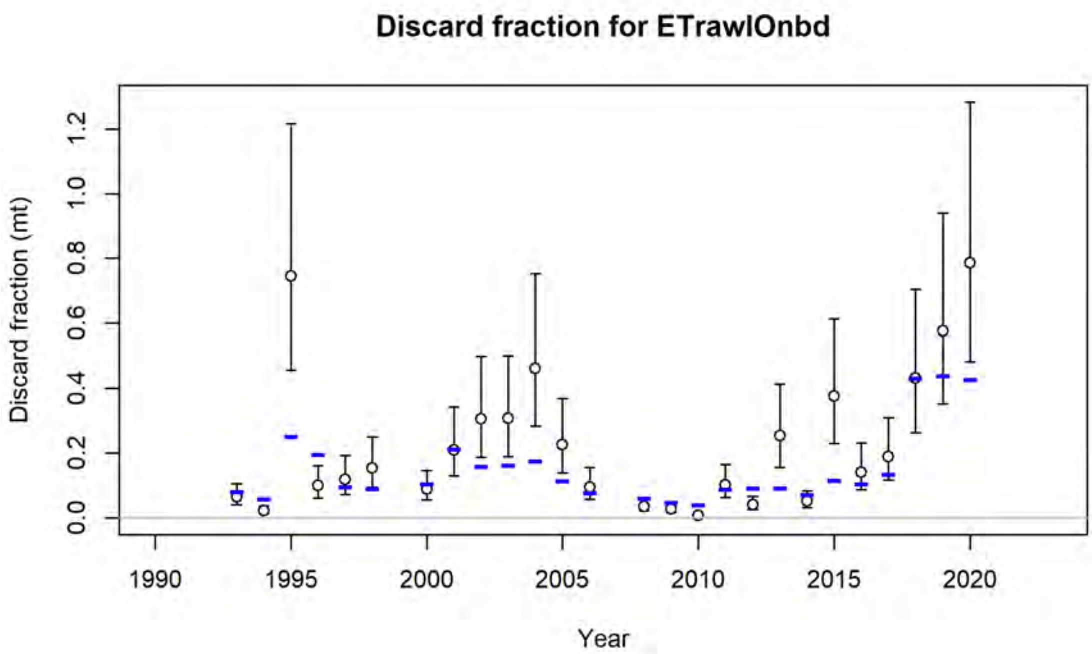

Figure 12.35. Fits to the east trawl discards for the 2021 base case 3

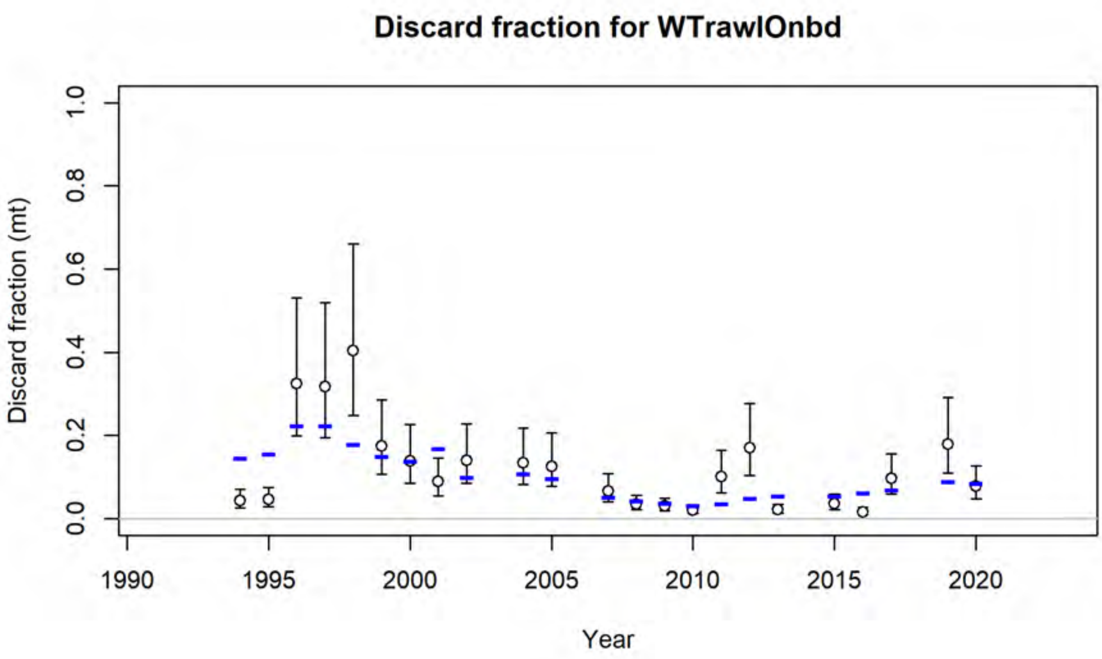

Figure 12.36. Fits to the west trawl discards for the 2021 base case 3

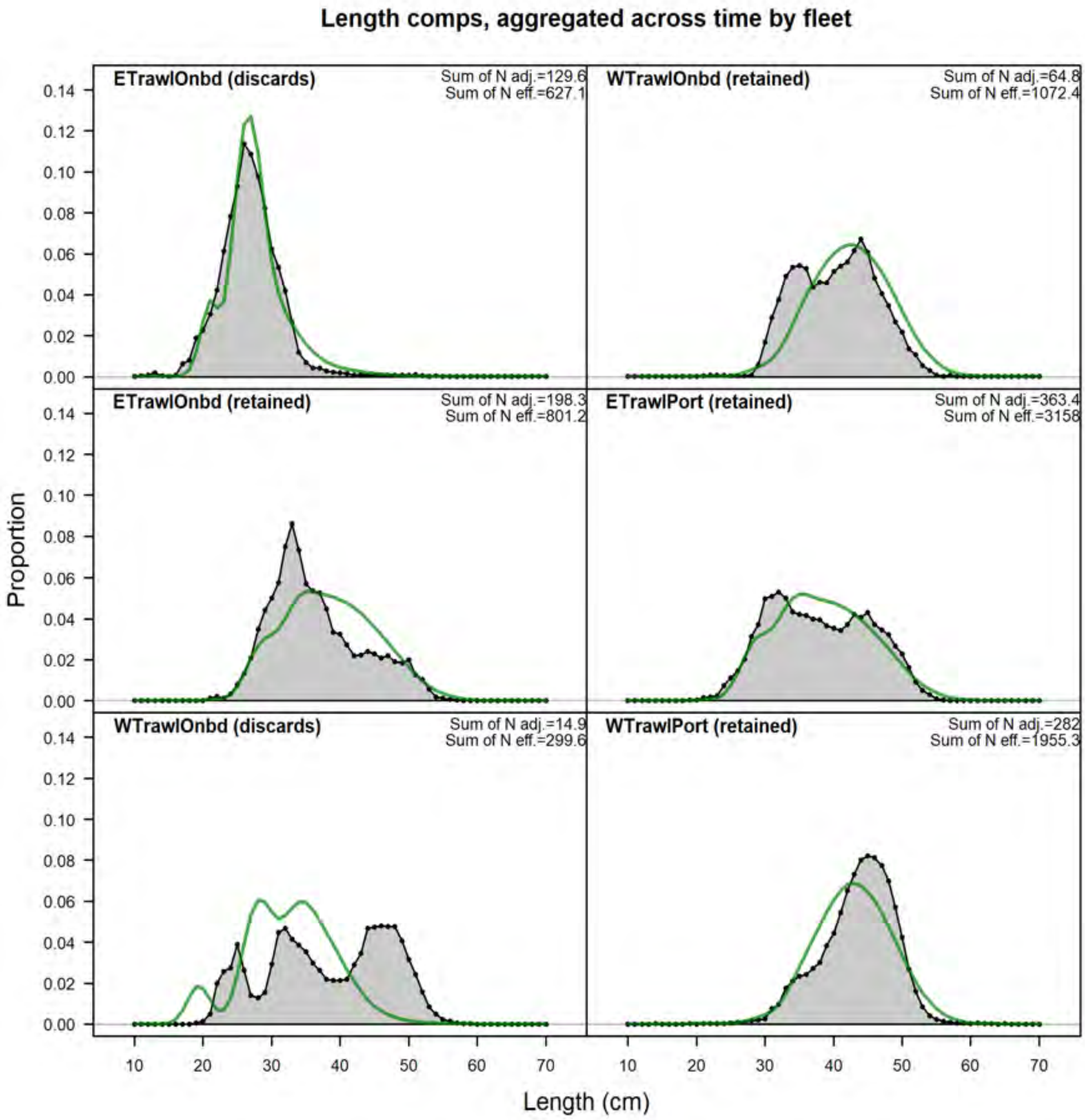

Figure 12.37. Fits to the aggregated length data for the 2021 base case 3

12.7 Acknowledgements

Age data were provided by Kyne Krusic-Golub (Fish Ageing Services), ISMP and AFMA logbook and CDR data were provided by John Garvey (AFMA). Mike Fuller, Paul Burch, Robin Thomson, Roy Deng, Franzis Althaus, Toni Cannard and Caroline Sutton (CSIRO) pre-processed the data. Miriana Sporcic provided standardised CPUE. Malcolm Haddon provided useful code for auto-balancing, Athol Whitten provided useful R code for organising plots. Paul Burch provided an updated ageing error matrix. Geoff Tuck, Jemery Day, Robin Thomson and Paul Burch (CSIRO) provided valuable review and discussion of this work. Ian Taylor, Chantel Wetzel, Kathryn Doering and Kelli Johnson (NOAA) are thanked for helpful reccomendations and fixes in relation to the the r4ss package. The r4ss package maintained by Ian Taylor (https://github.com/r4ss/r4ss) was critical for producing multiple diagnostic plots, and tuning models. Geoffrey Liggins is thanked for discussions on the catch history.

12.8 References

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12.9 Appendix

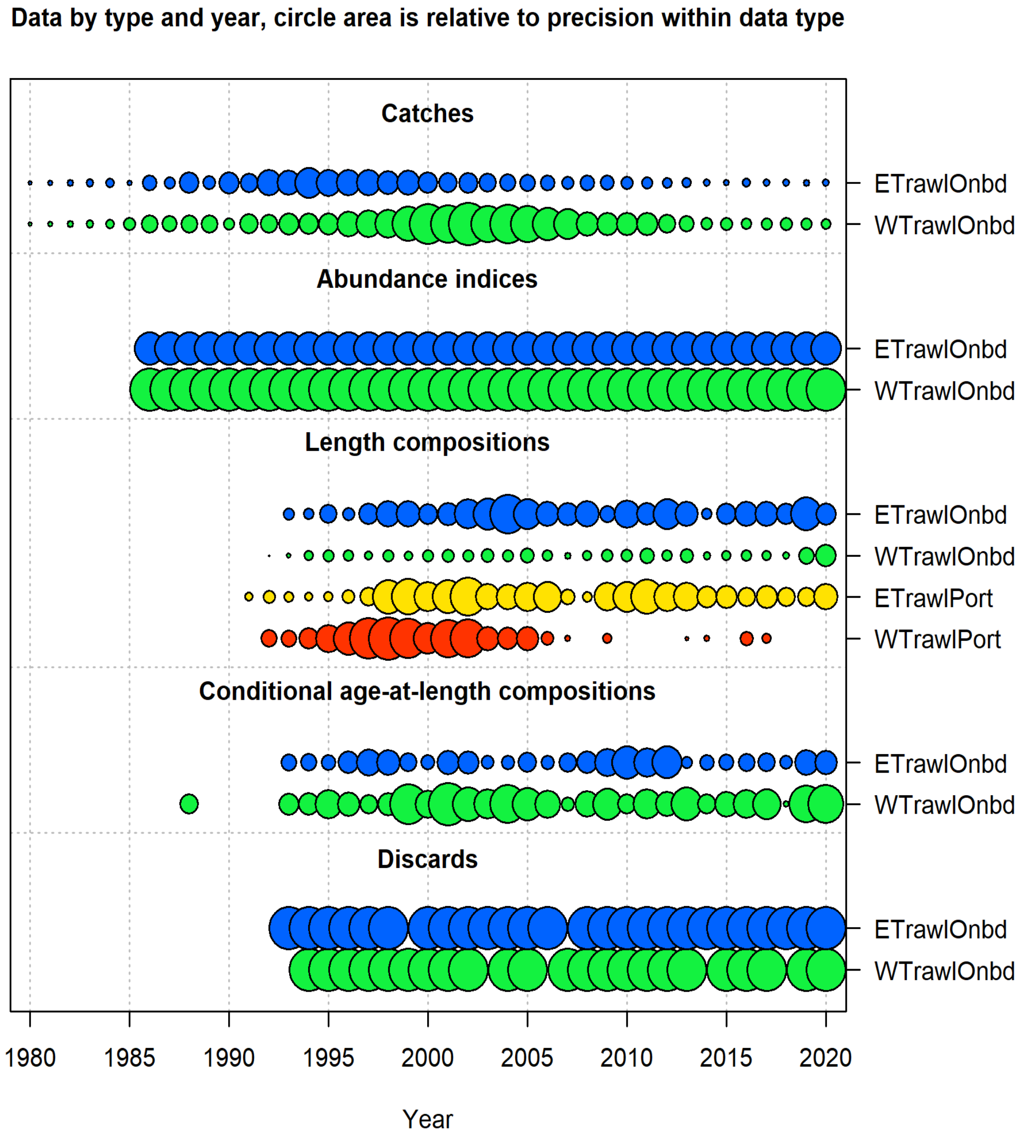

Figure 12.38. Summary of Silver Warehou data sources

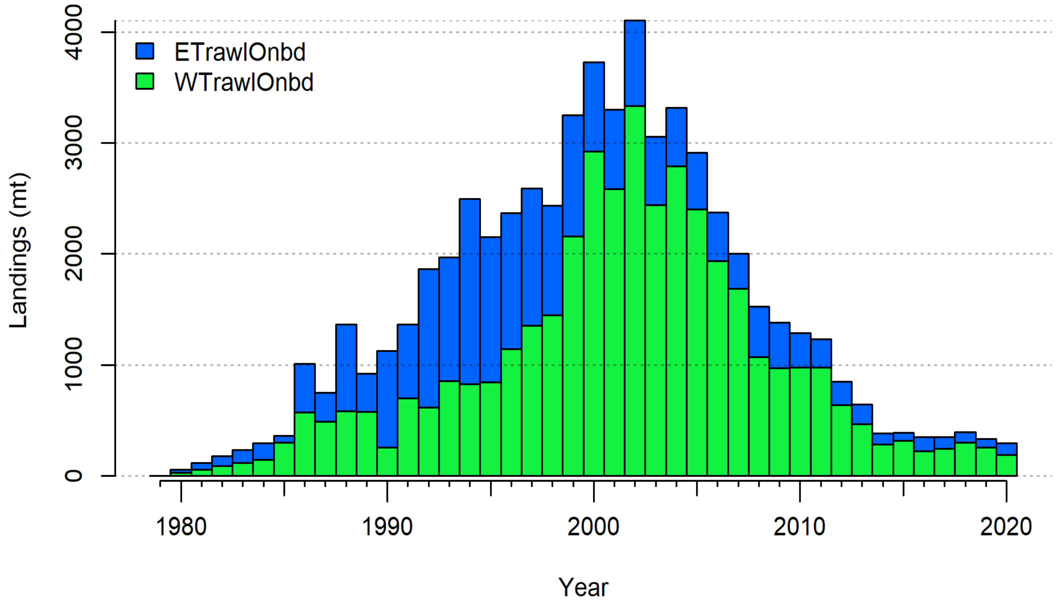

Figure 12.39. Summary of catch by fleet

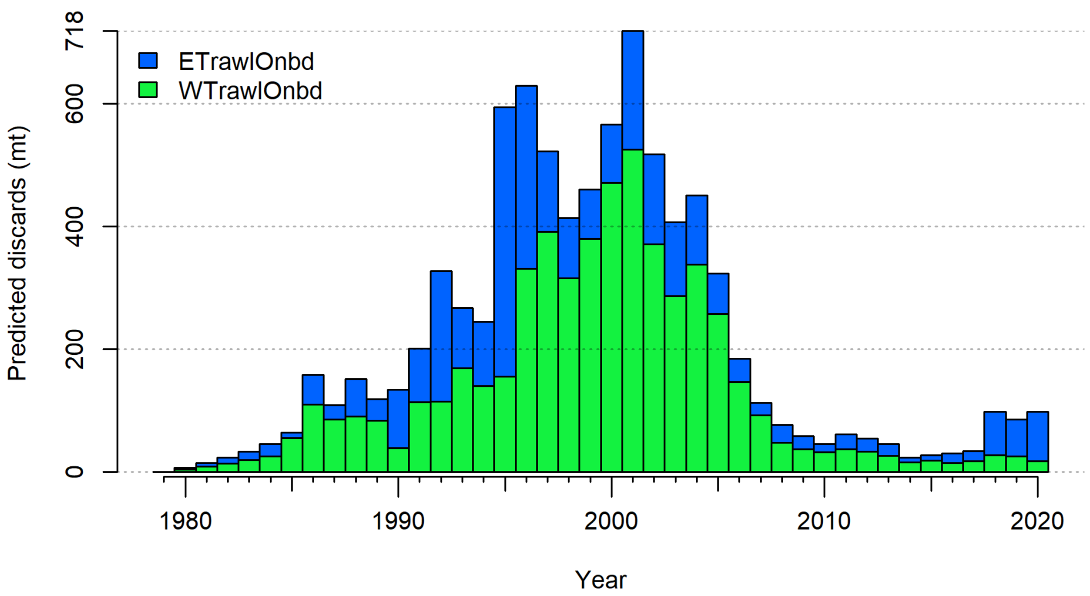

Figure 12.40. Summary of total discards by fleet

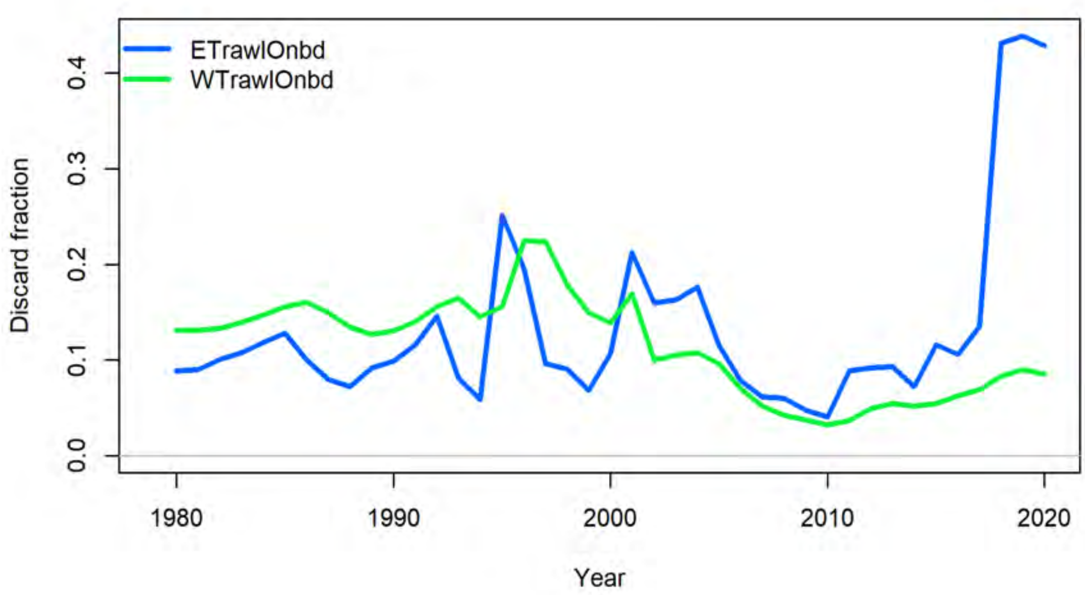

Figure 12.41. Summary of proportional discards by fleet

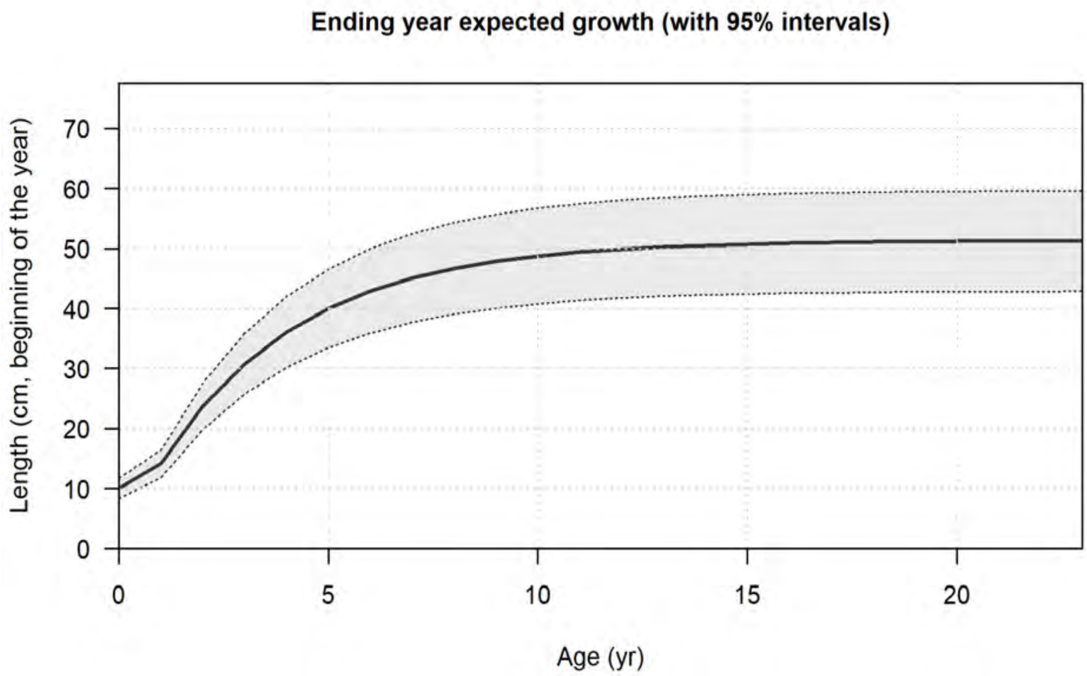

Figure 12.42. Estimated growth curve for base case 3

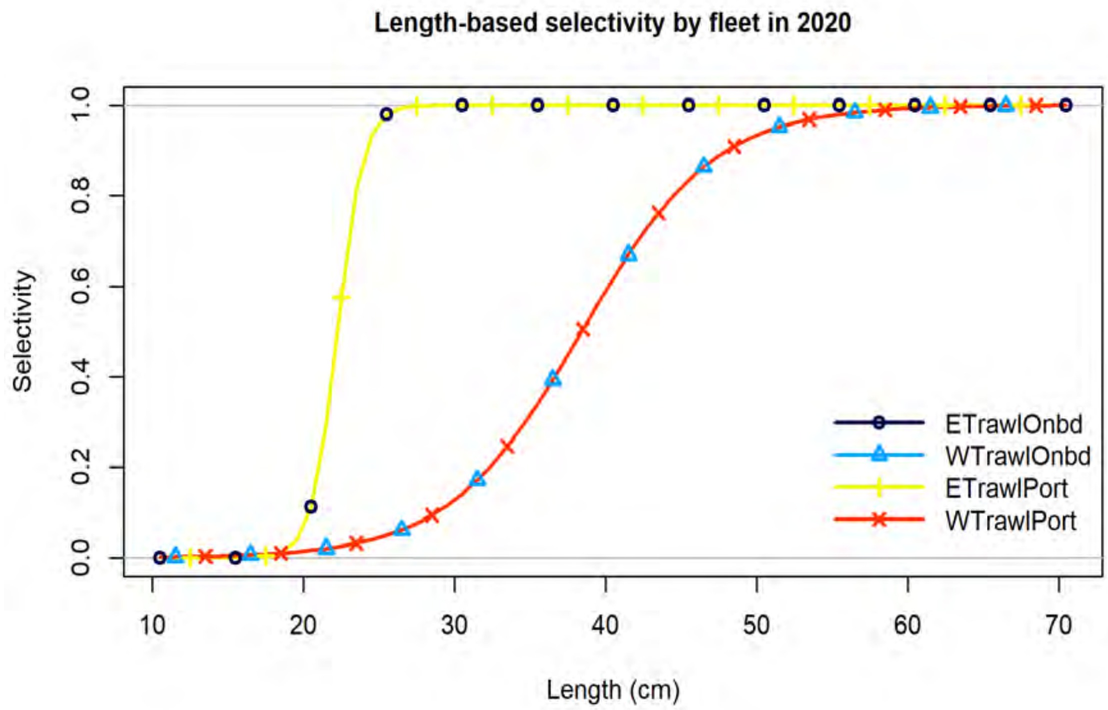

Figure 12.43. Estimated selectivity by fleet for base case 3

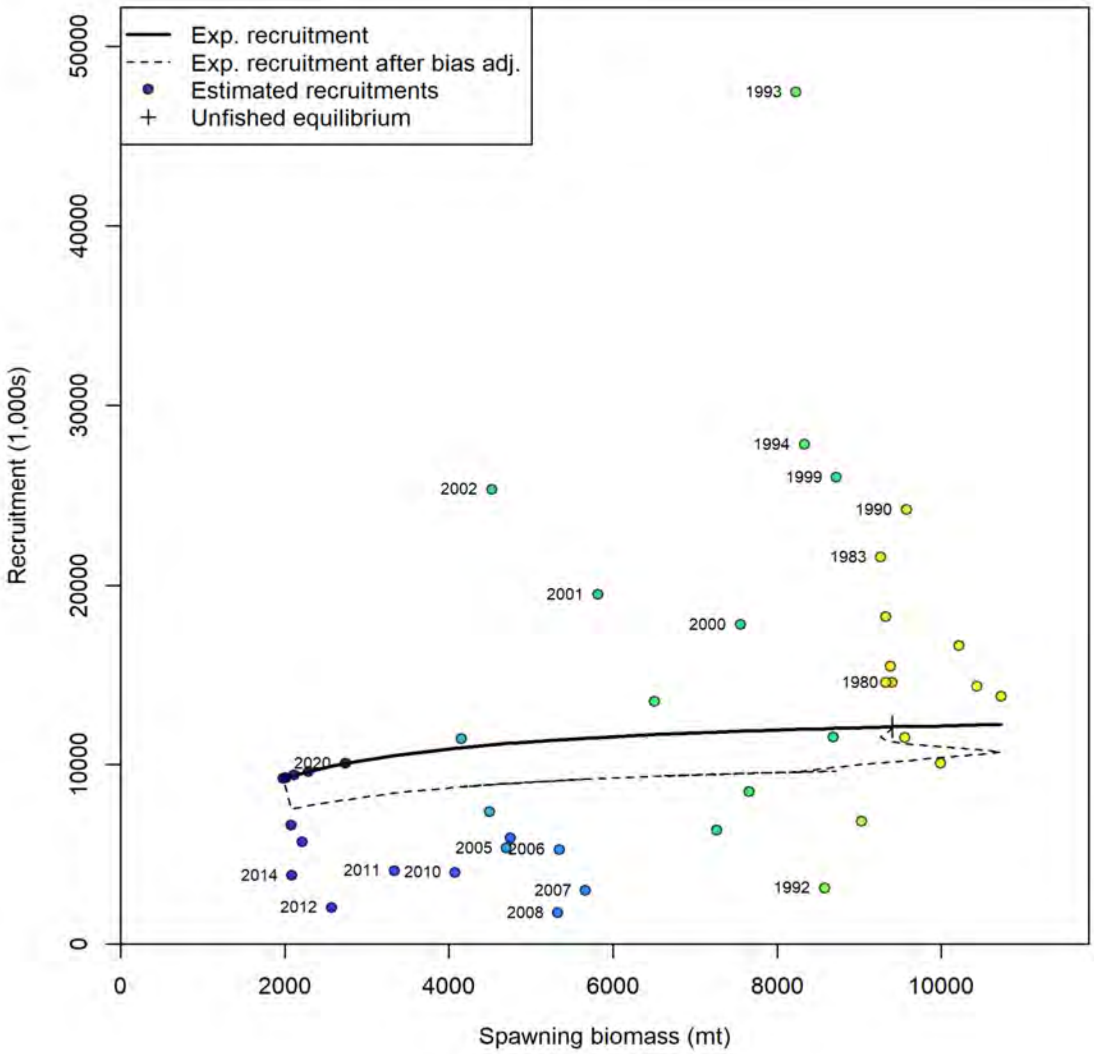

Figure 12.44. Time series showing stock recruitment curve for base case 3

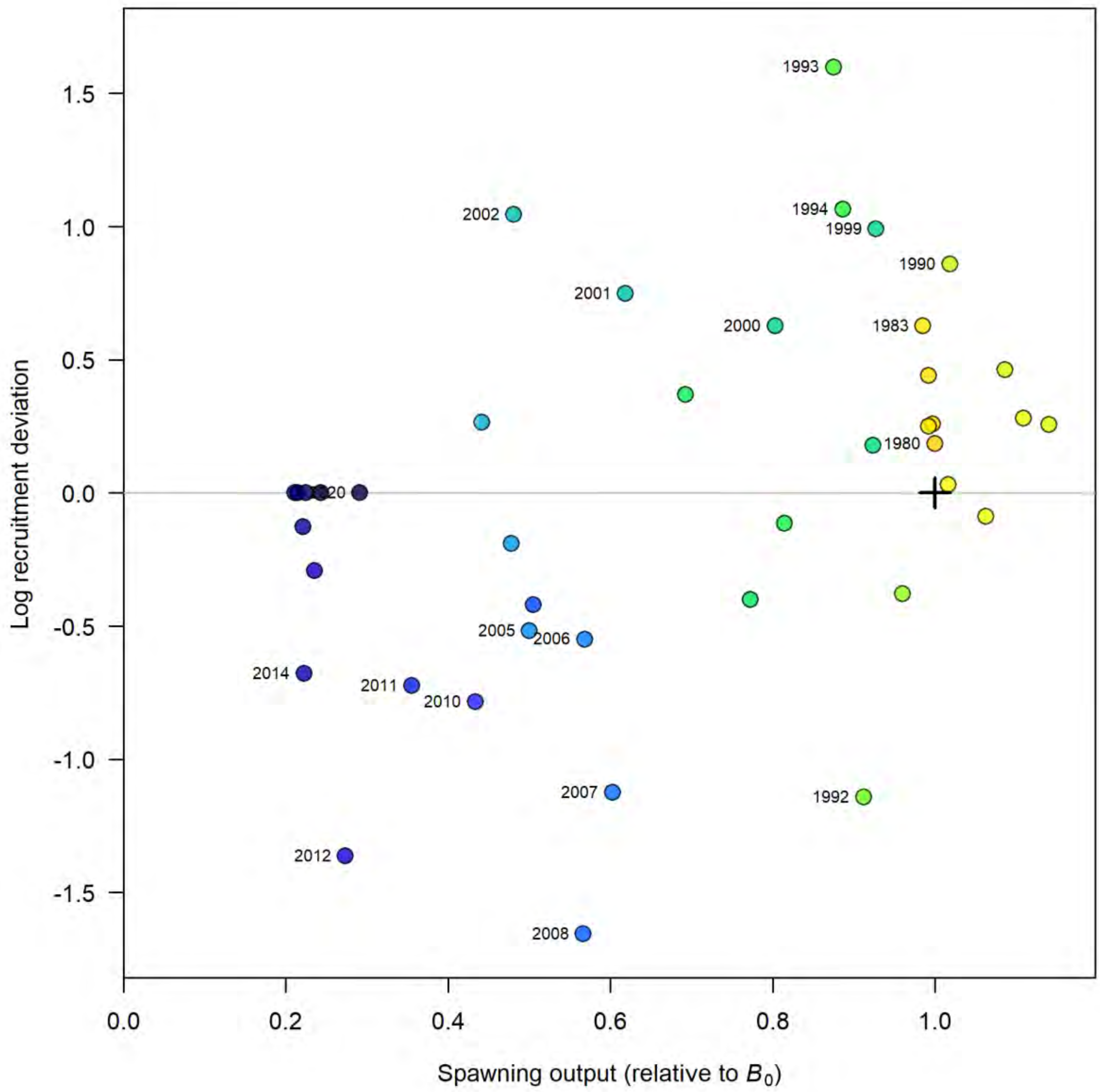

Figure 12.45. Time series showing stock recruitment deviations for base case 3

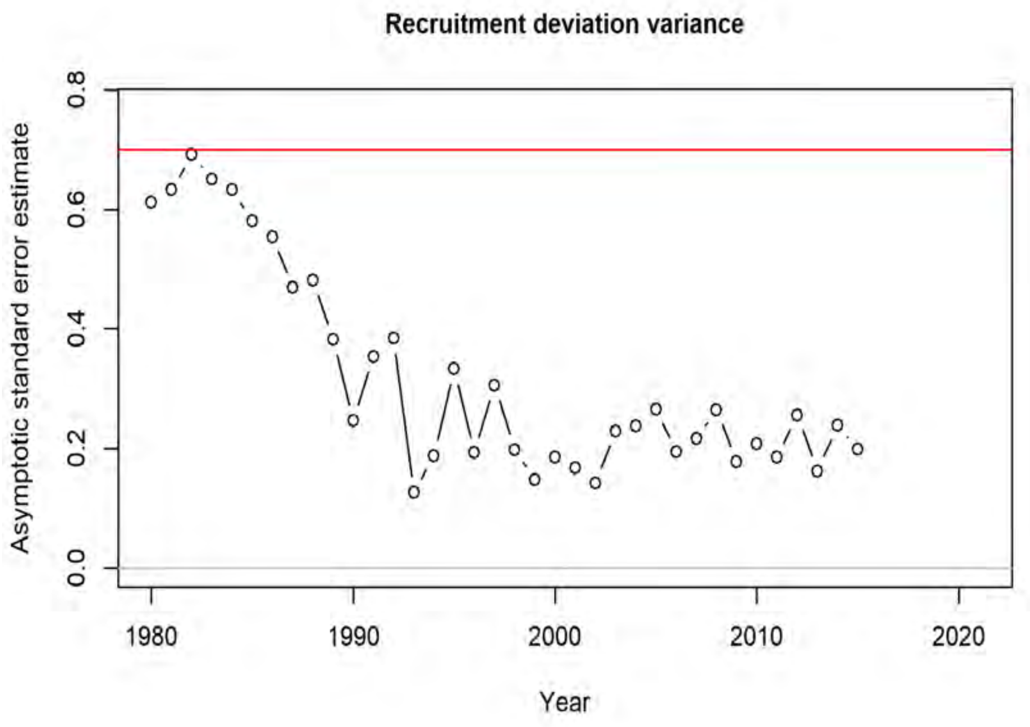

Figure 12.46. Recruitment deviation variance check for base case 3

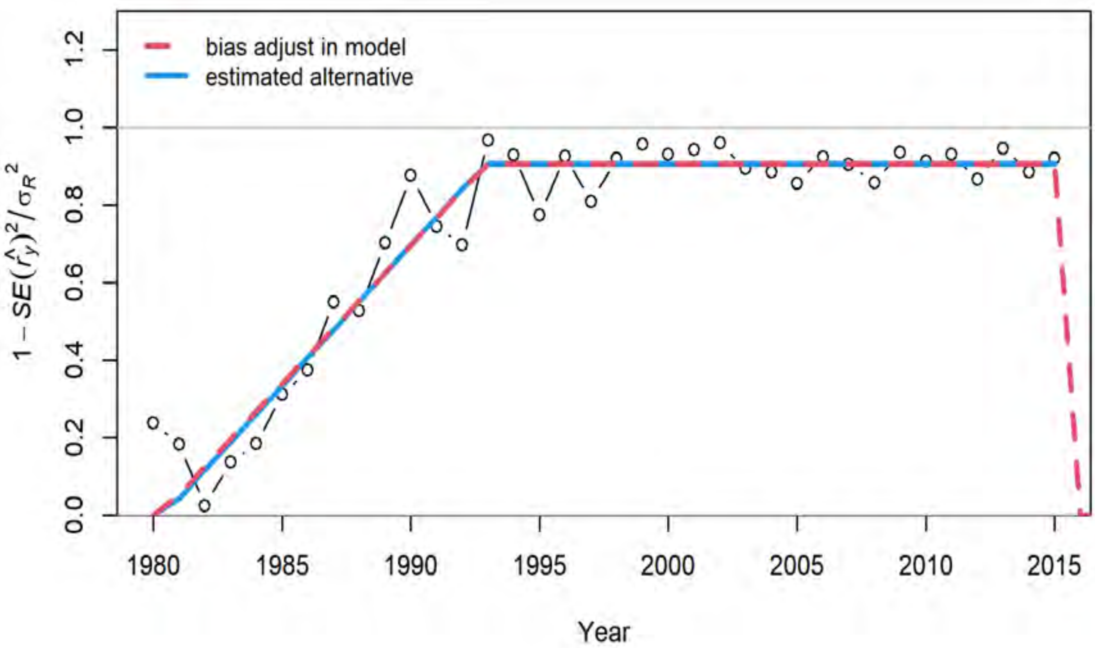

Figure 12.47. Recruitment deviation bias ramp adjustment for base case 3

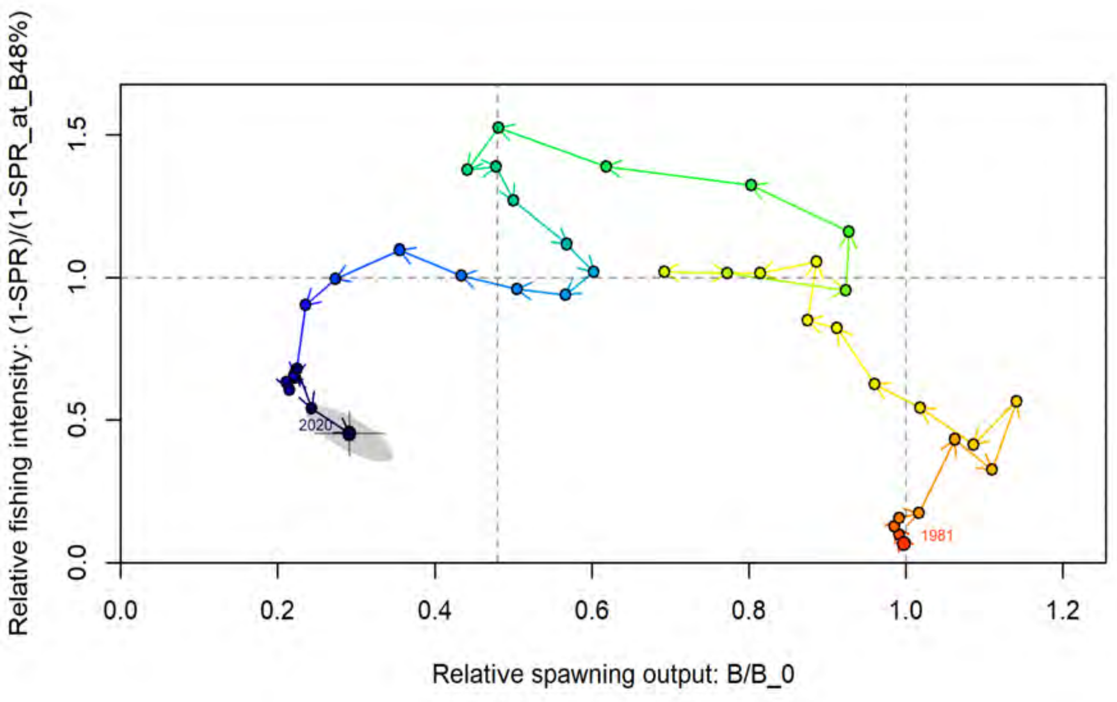

Figure 12.48. Phase plot of biomass vs SPR ratio for base case 3

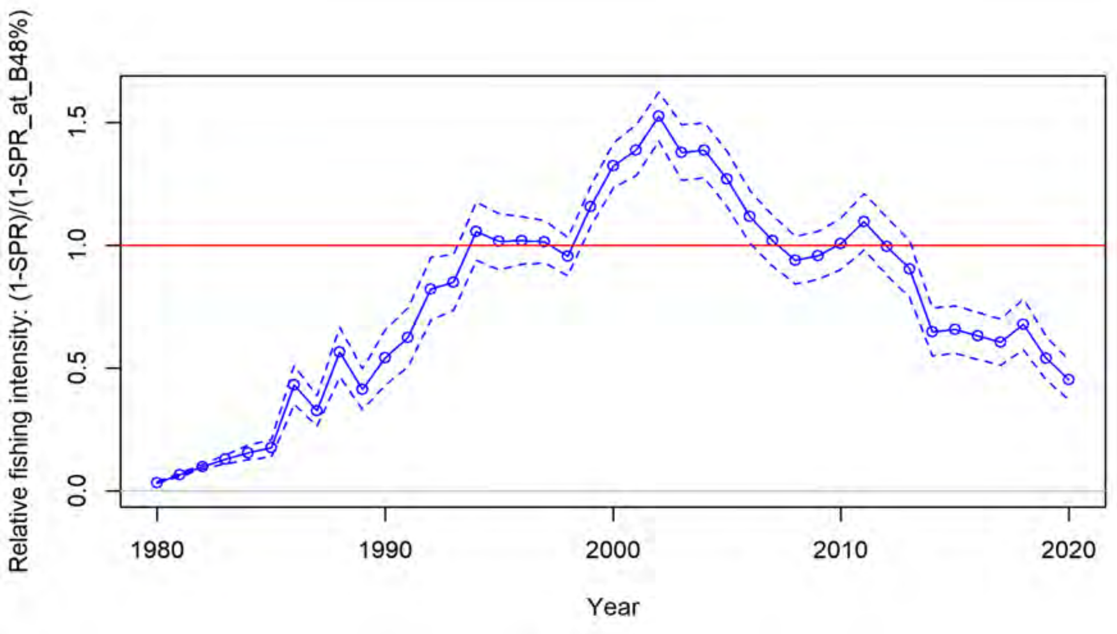

Figure 12.49. SPR ratio through time, the red line represents the target fishing mortality and each point is a year in the model, starting on the left hand side of the figure

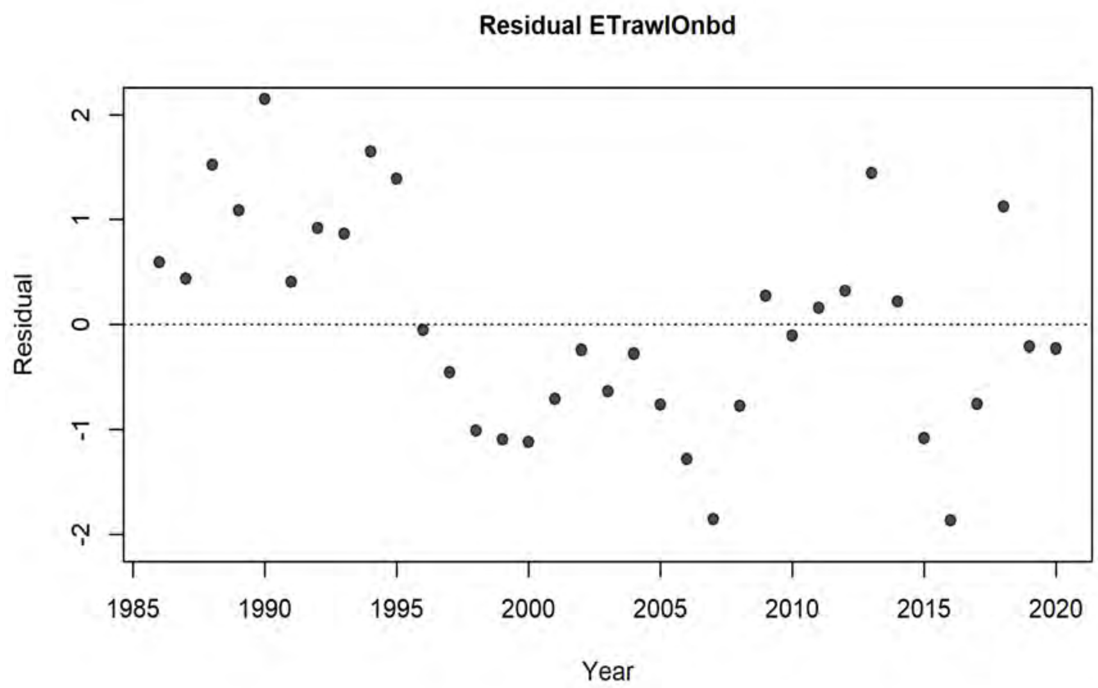

Figure 12.50. Residuals for fits to CPUE for the east trawl fleet for base case 3

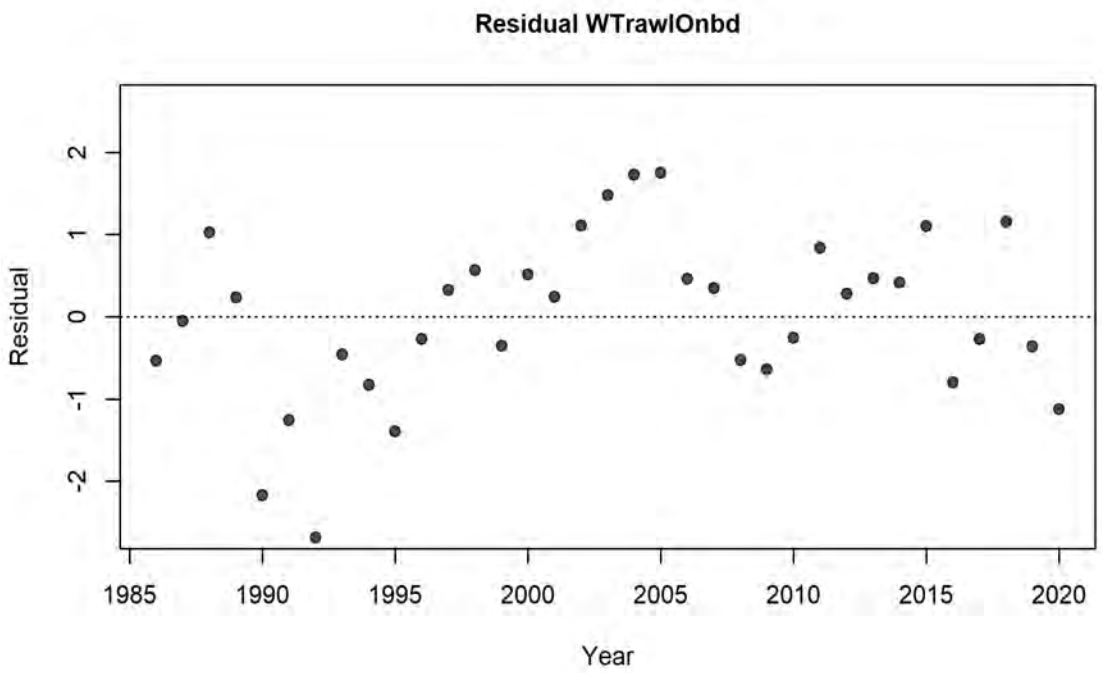

Figure 12.51. Residuals for fits to CPUE for the west trawl fleet for base case 3

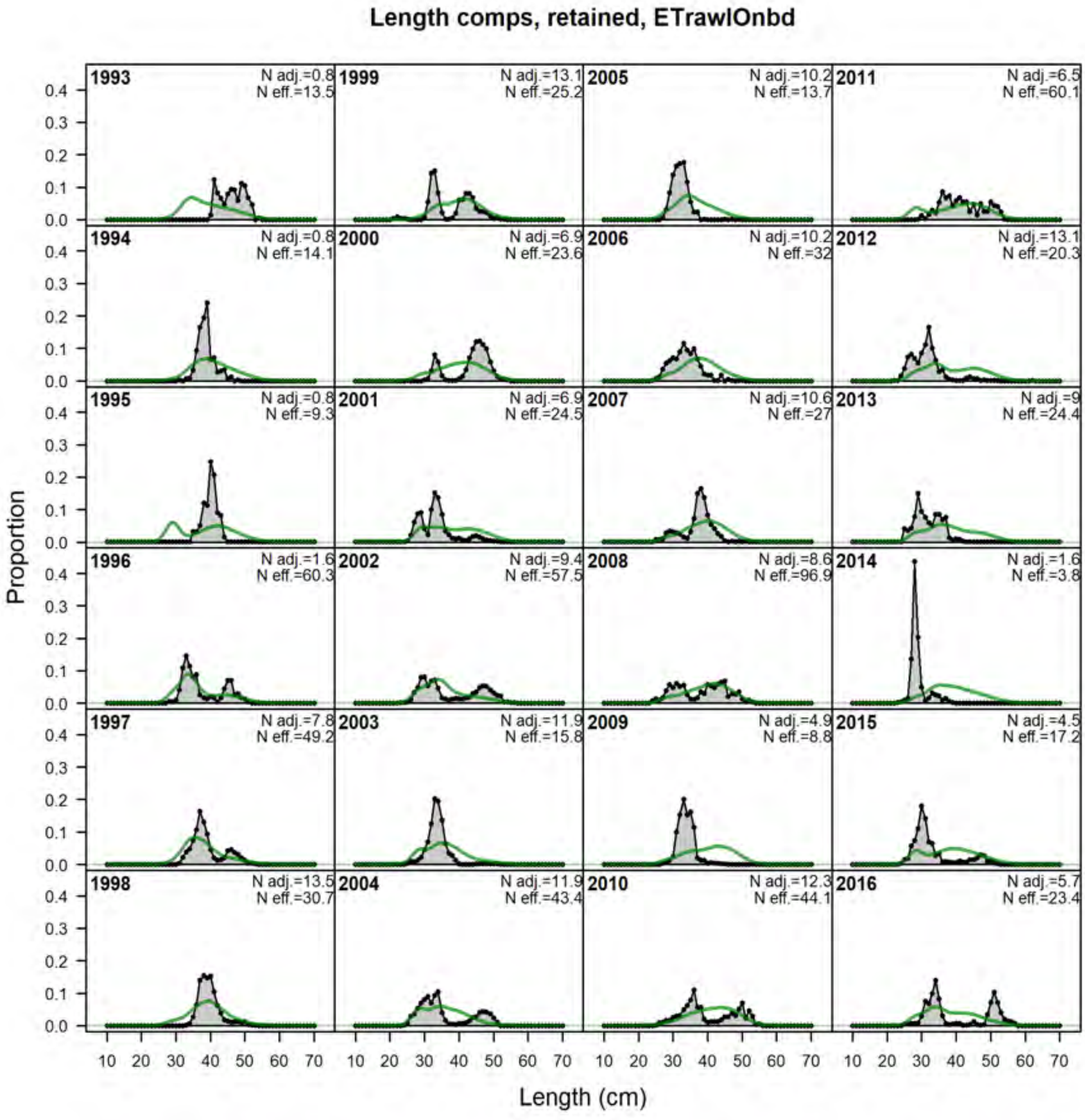

Figure 12.52. Fits to onboard retained length compositions for the east trawl fleet for base case 3

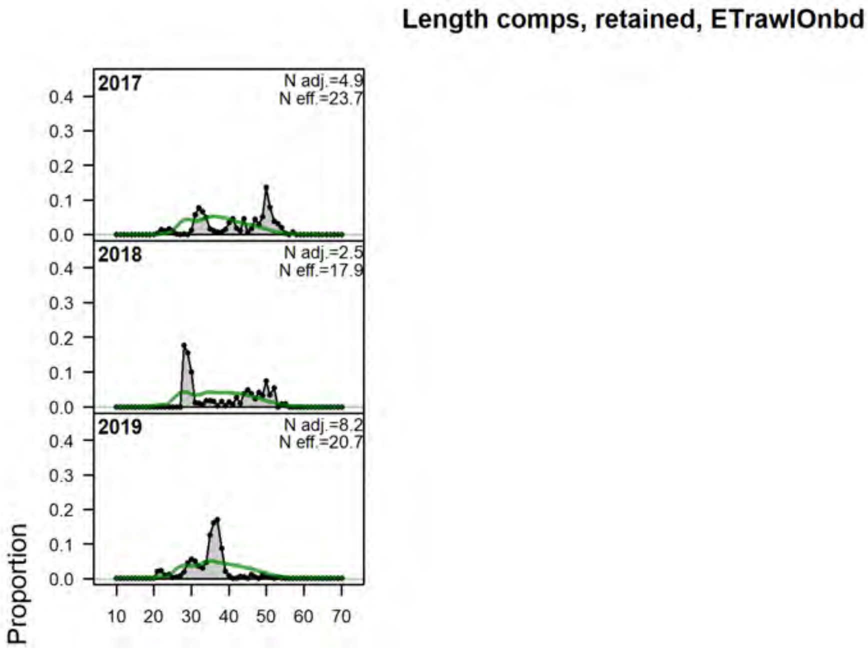

Figure 12.53. Fits to onboard retained length compositions for the east trawl fleet for base case 3

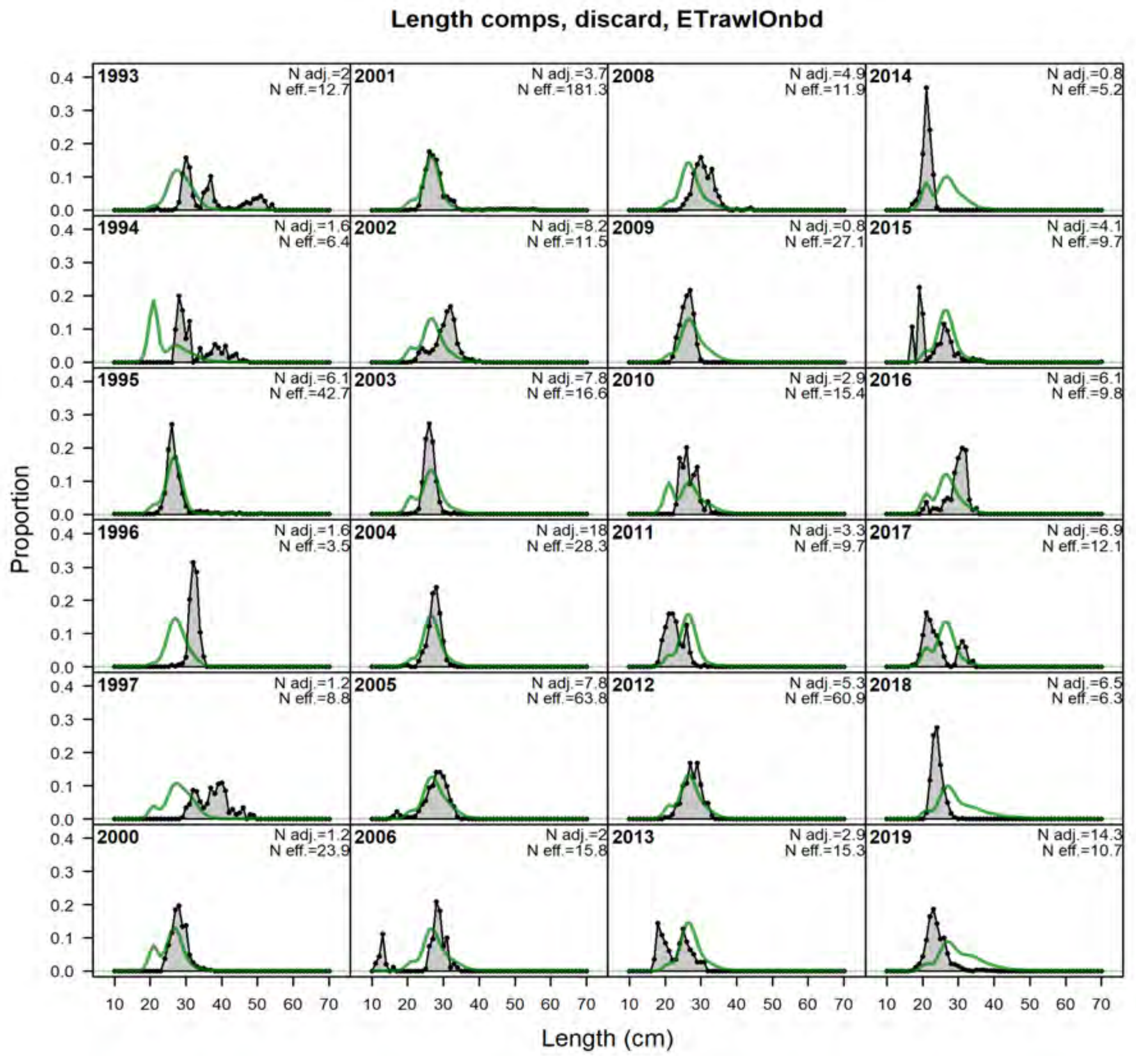

Figure 12.54. Fits to onboard discarded length compositions for the east trawl fleet for base case 3

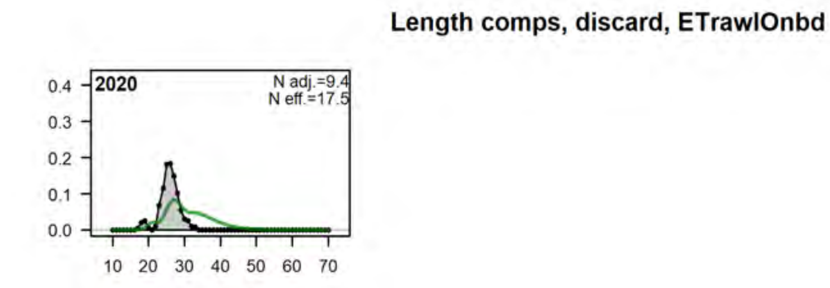

Figure 12.55. Fits to onboard discarded length compositions for the east trawl fleet for base case 3 continued

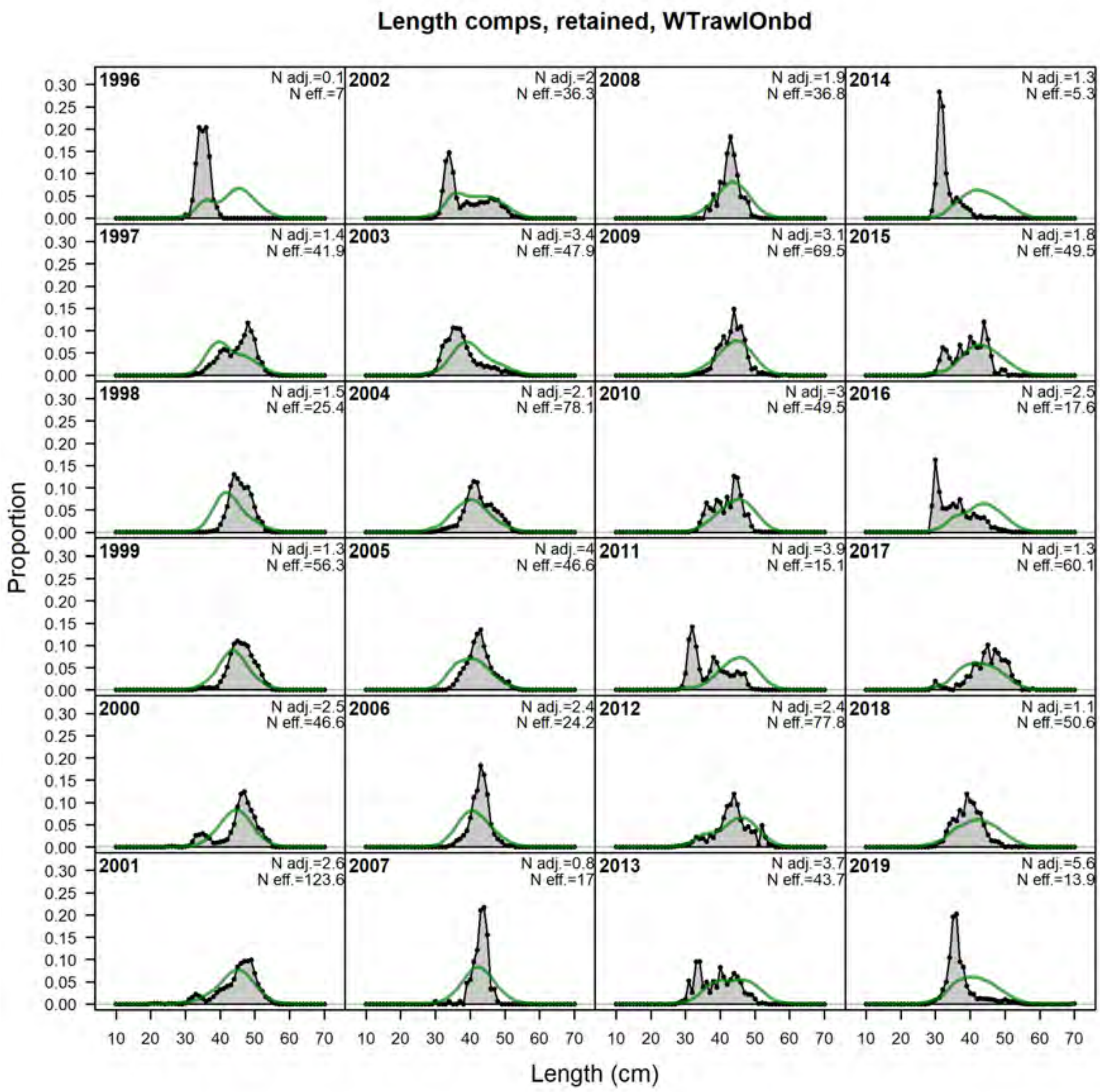

Figure 12.56. Fits to onboard retained length compositions for the west trawl fleet for base case 3

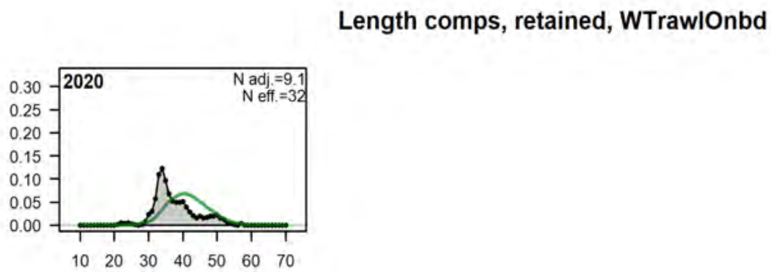

Figure 12.57. Fits to onboard retained length compositions for the west trawl fleet for base case 3 continued

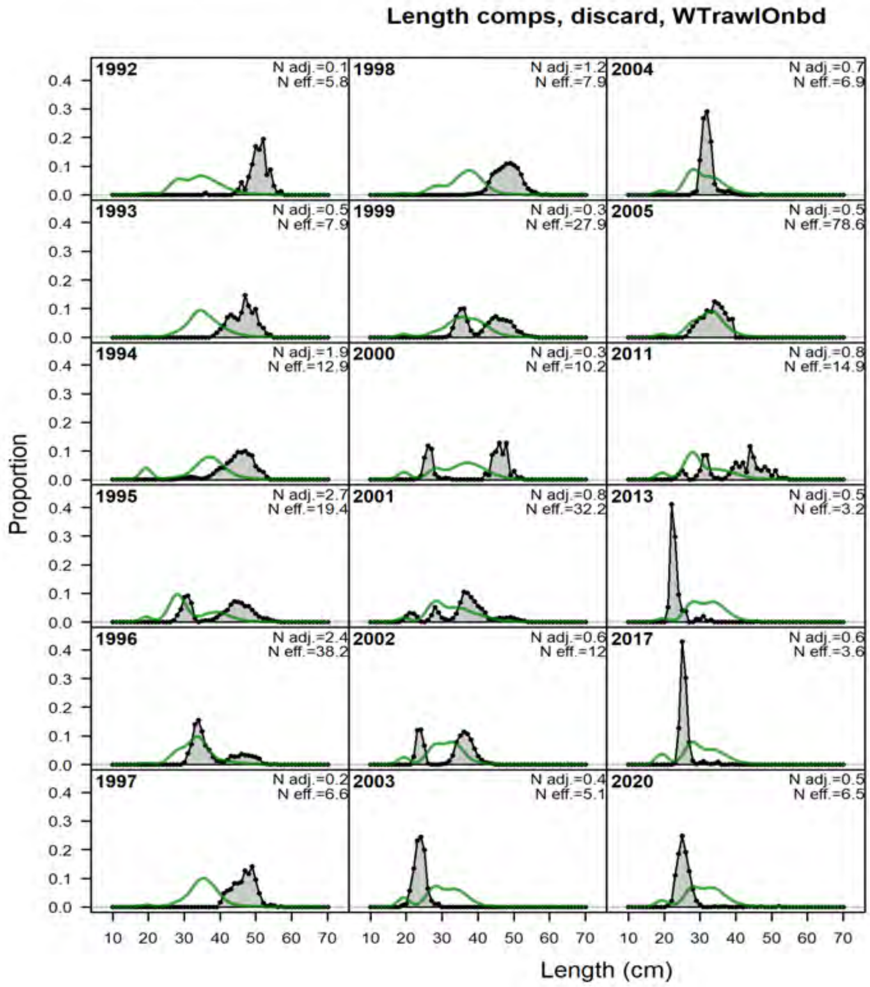

Figure 12.58. Fits to onboard discarded length compositions for the west trawl fleet for base case 3

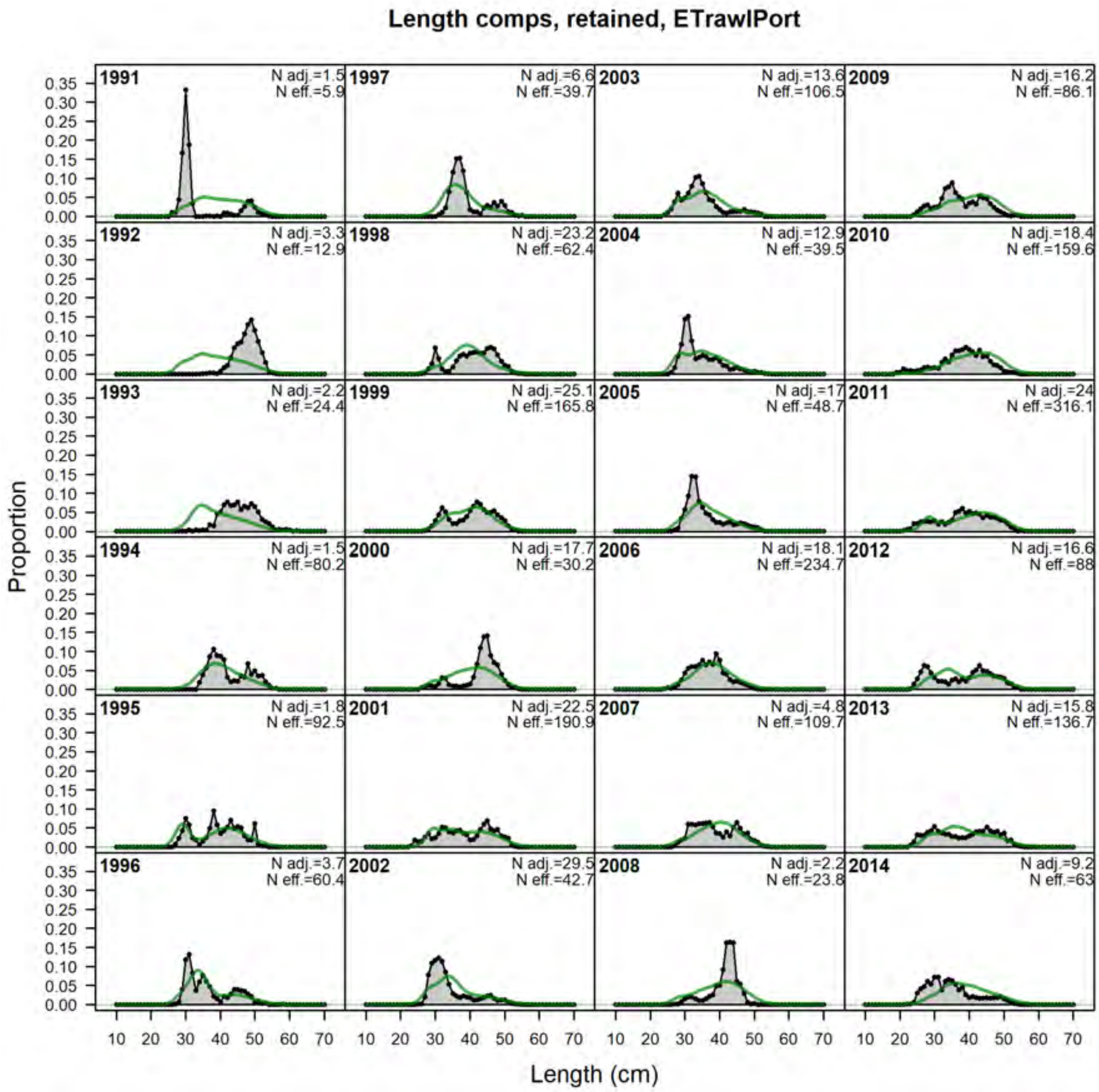

Figure 12.59. Fits to port length compositions for the east trawl fleet for base case 3

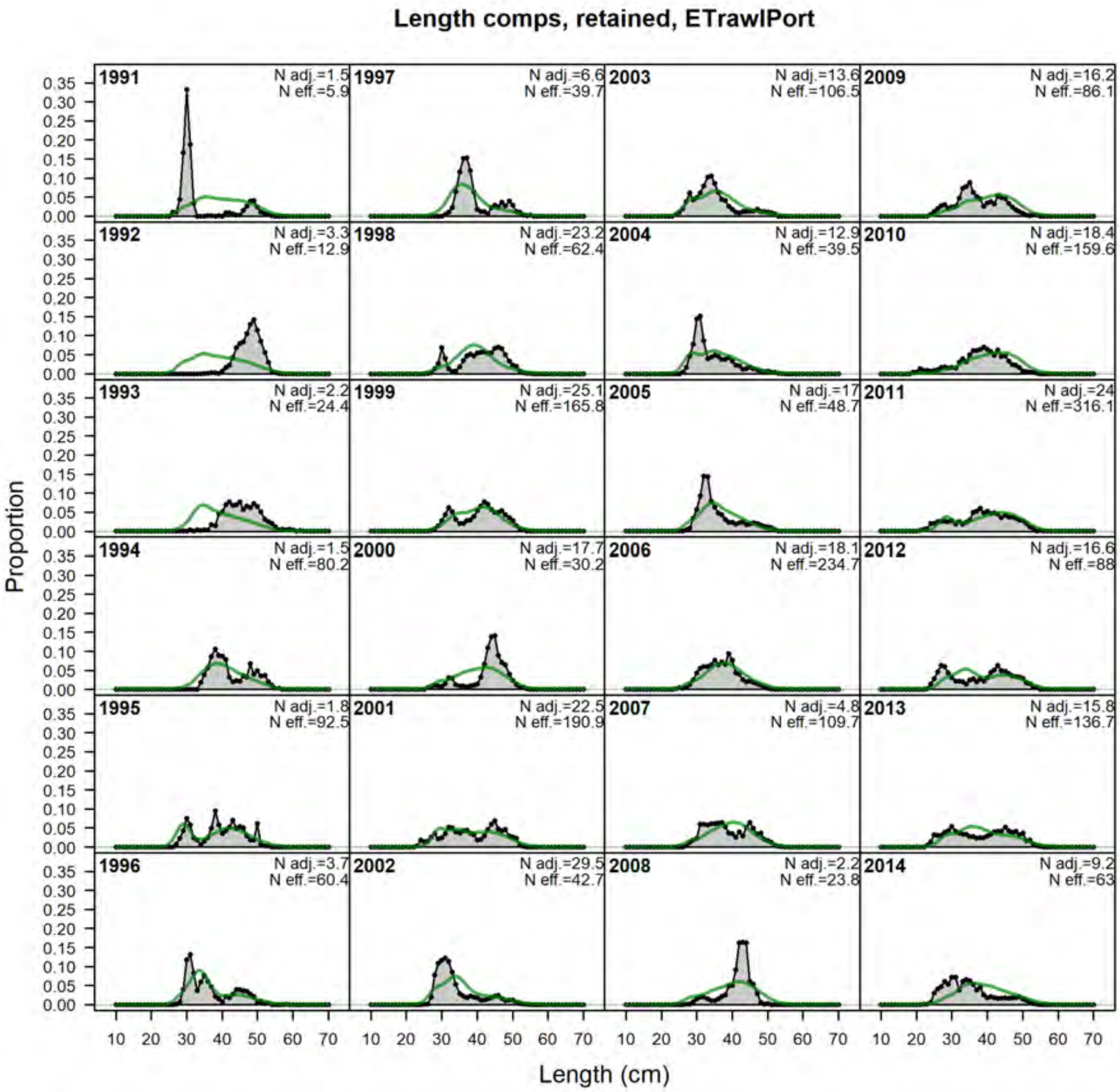

Figure 12.60. Fits to port length compositions for the east trawl fleet for base case 3 continued

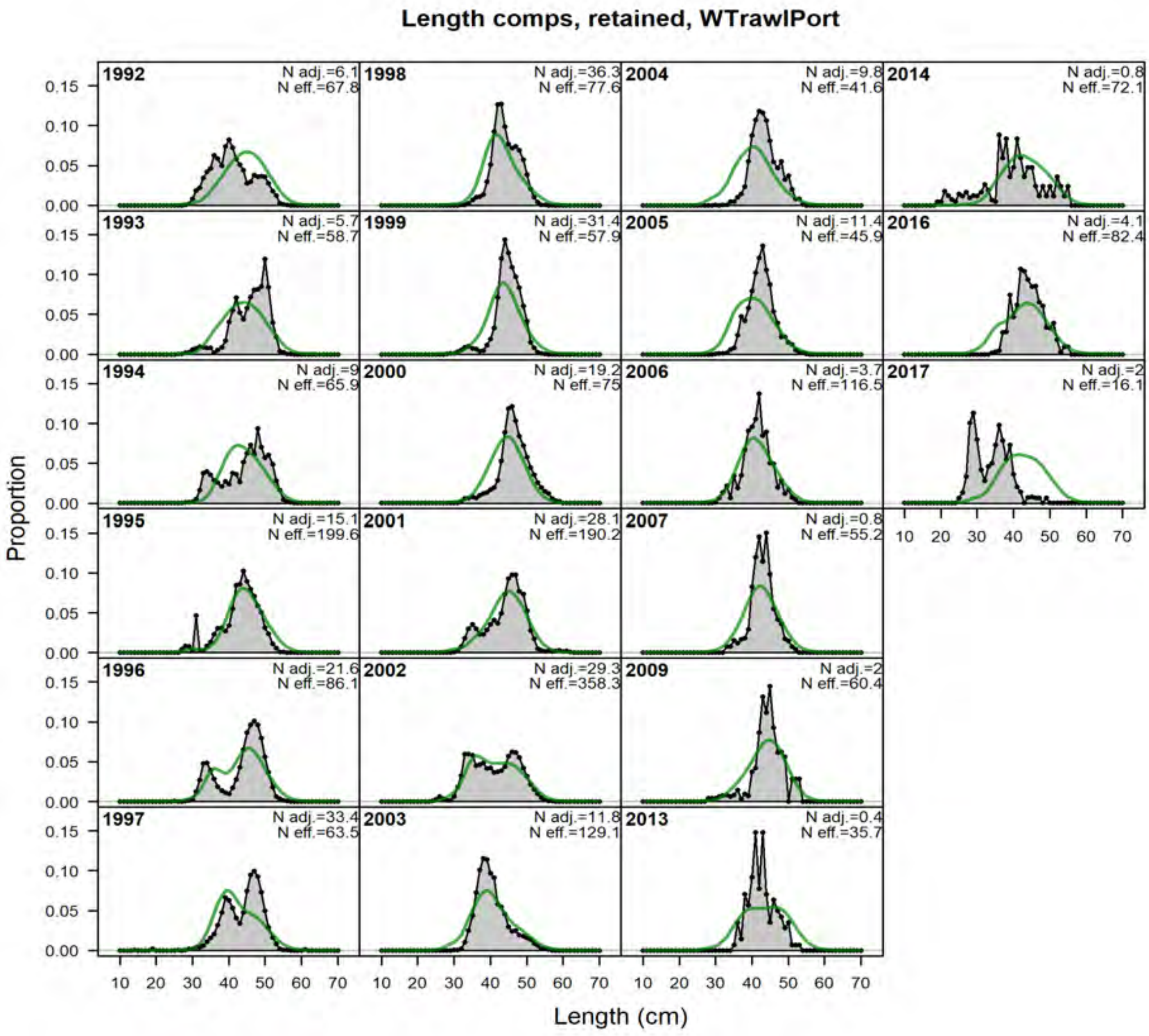

Figure 12.61. Fits to port length compositions for the west trawl fleet for base case 3

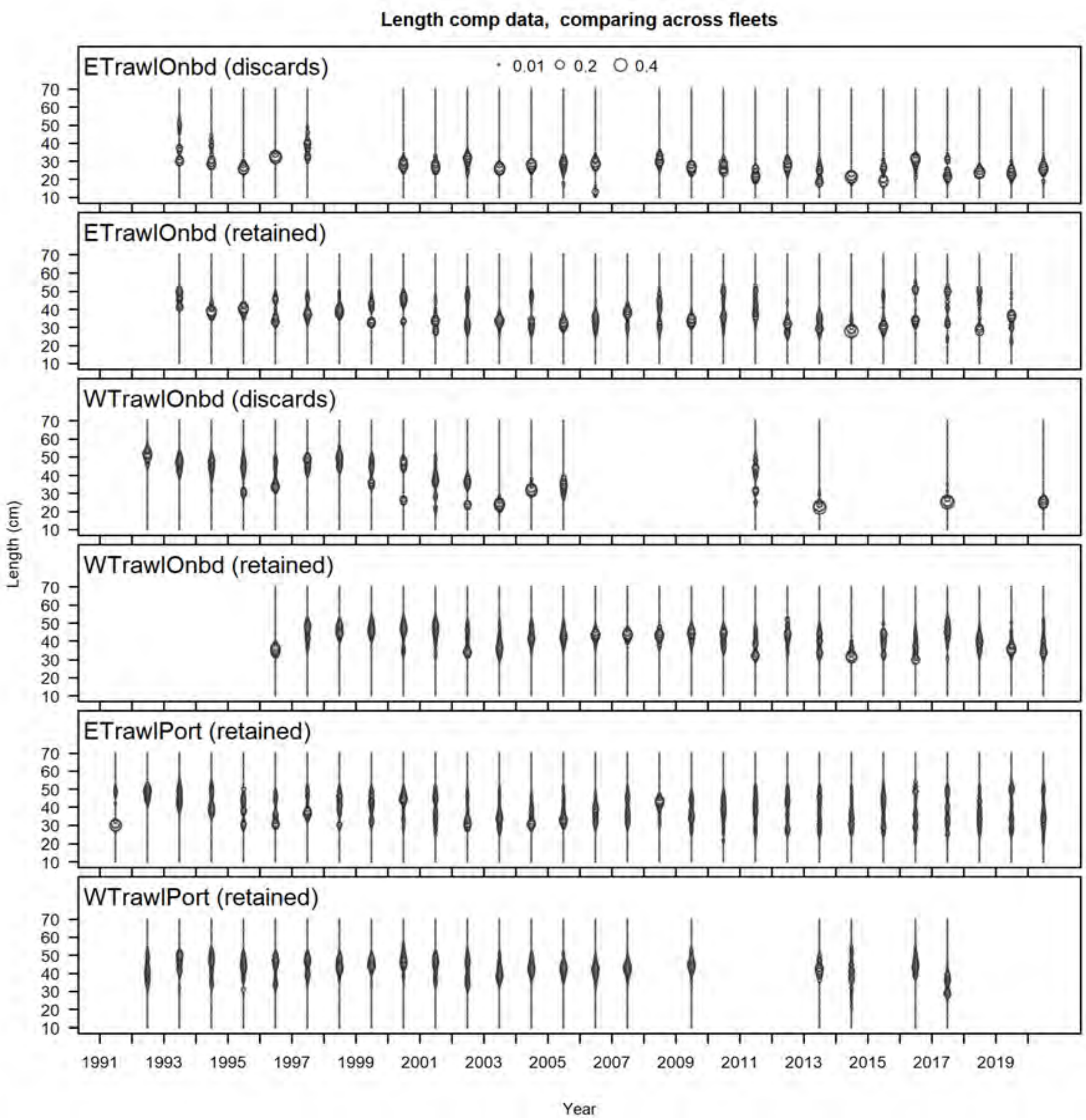

Figure 12.62. Residuals from the annual length compositions for both the east the west trawl fleets for base case 3

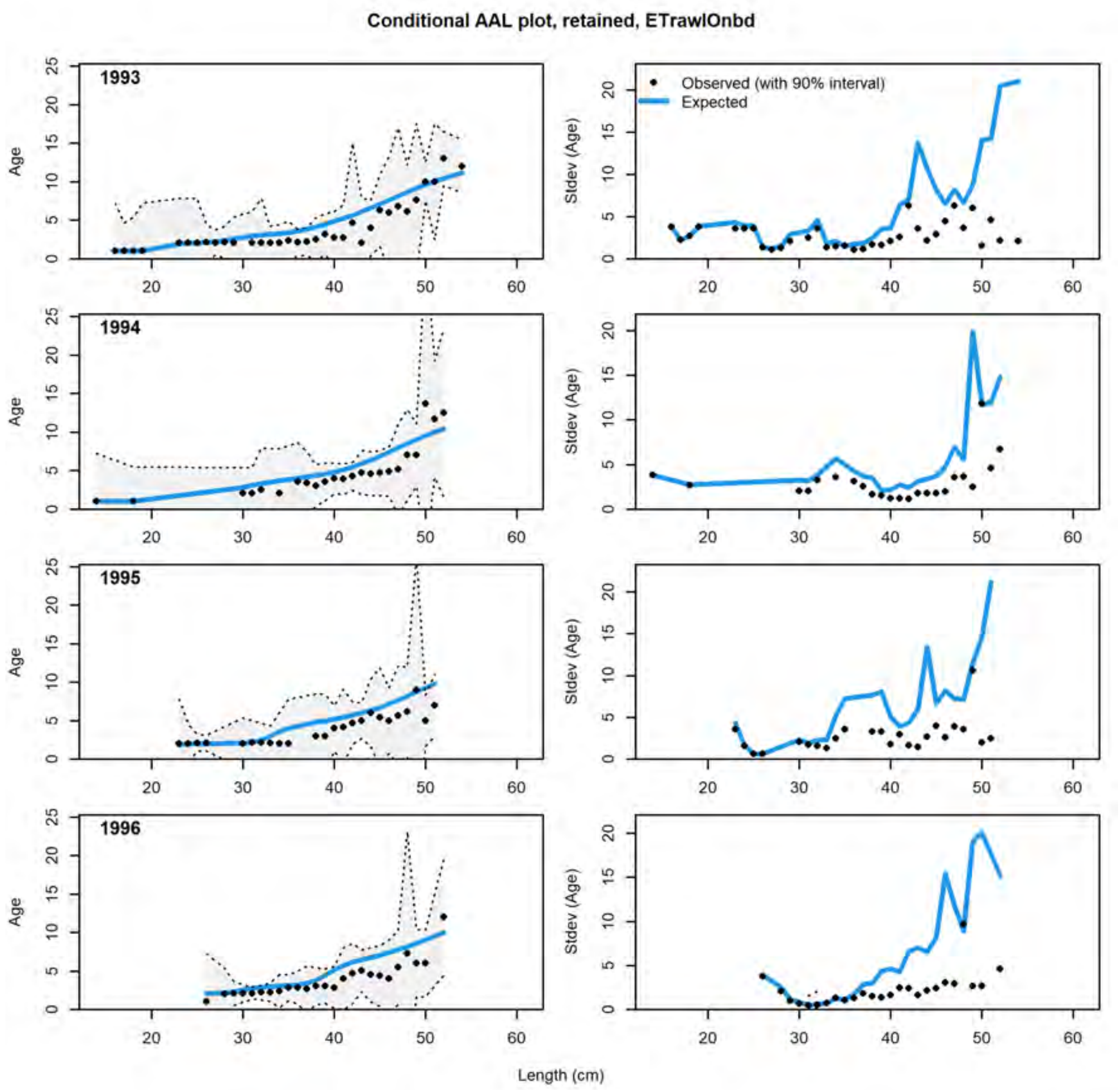

Figure 12.63. Fits to conditional age at length data for the east trawl fleet for base case 3

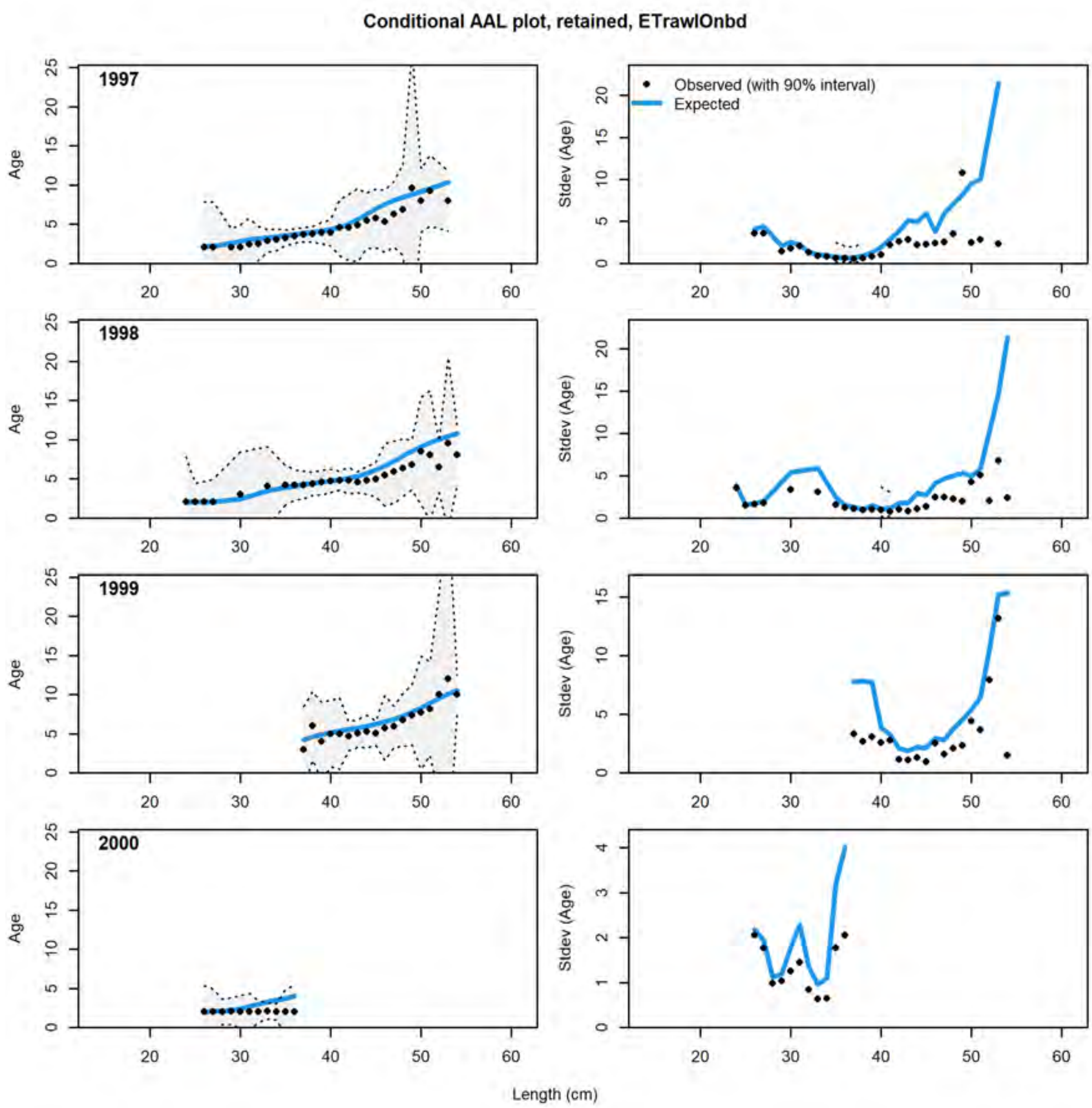

Figure 12.64. Fits to conditional age at length data for the east trawl fleet for base case 3

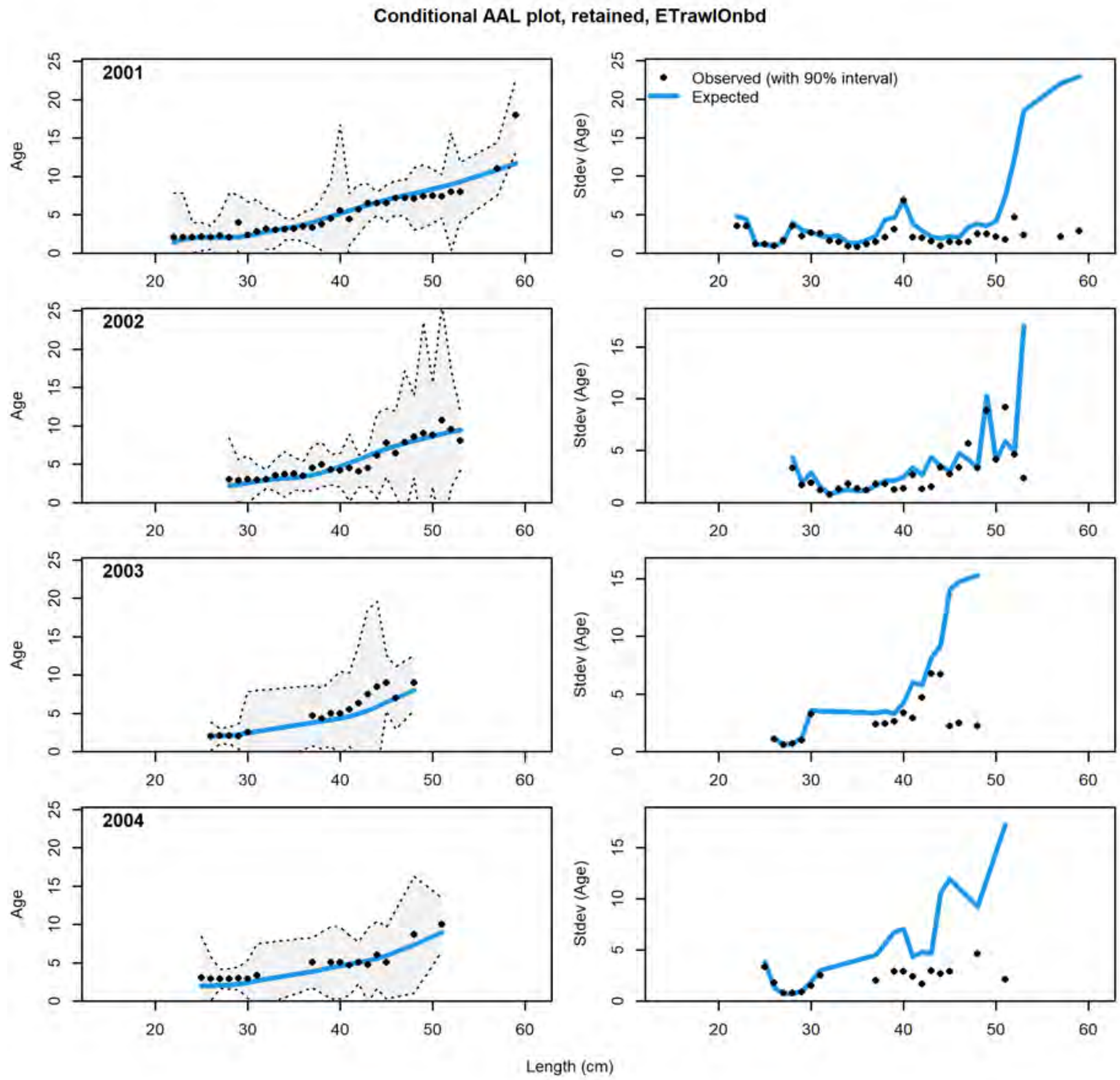

Figure 12.65. Fits to conditional age at length data for the east trawl fleet for base case 3

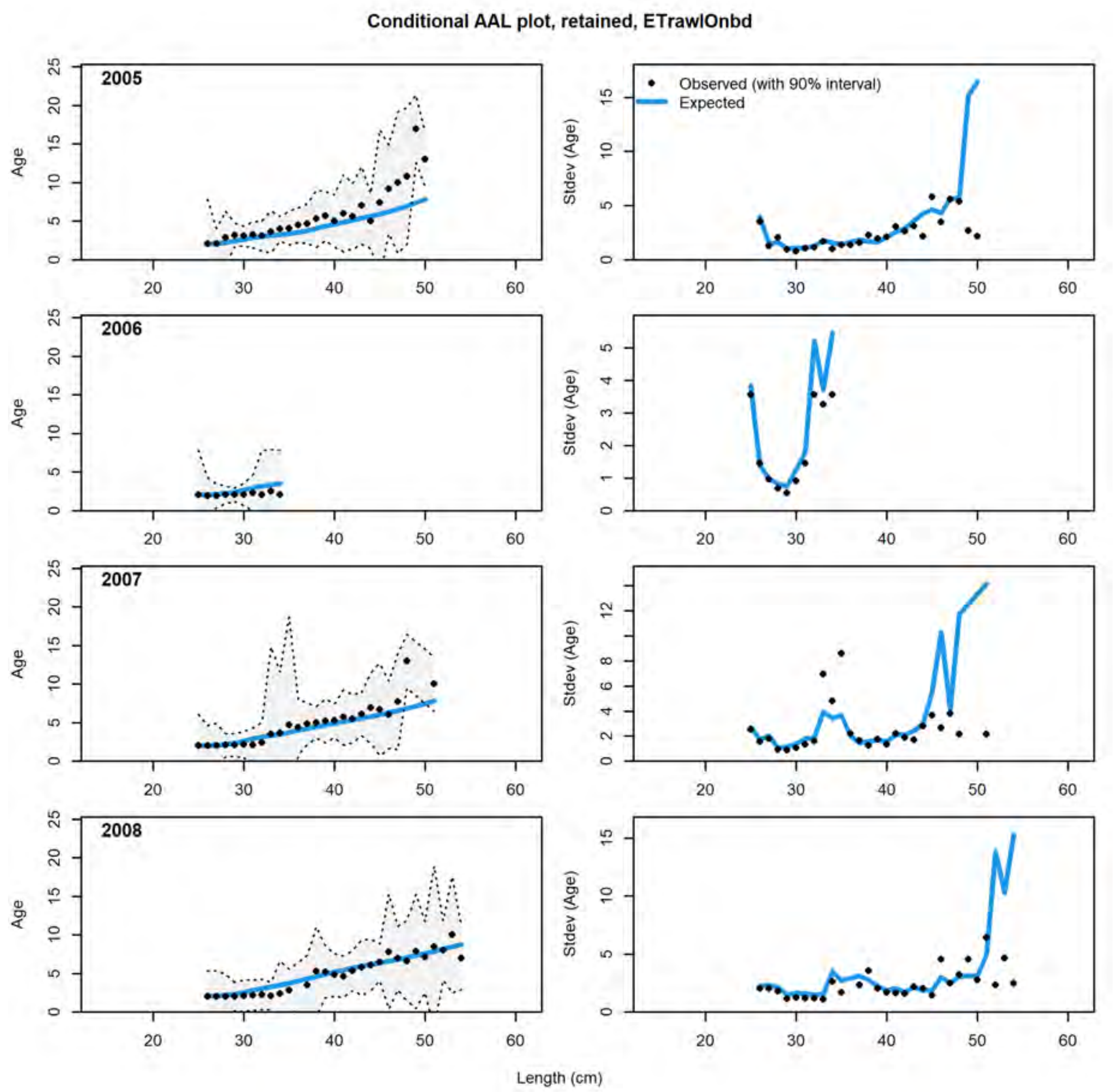

Figure 12.66. Fits to conditional age at length data for the east trawl fleet for base case 3

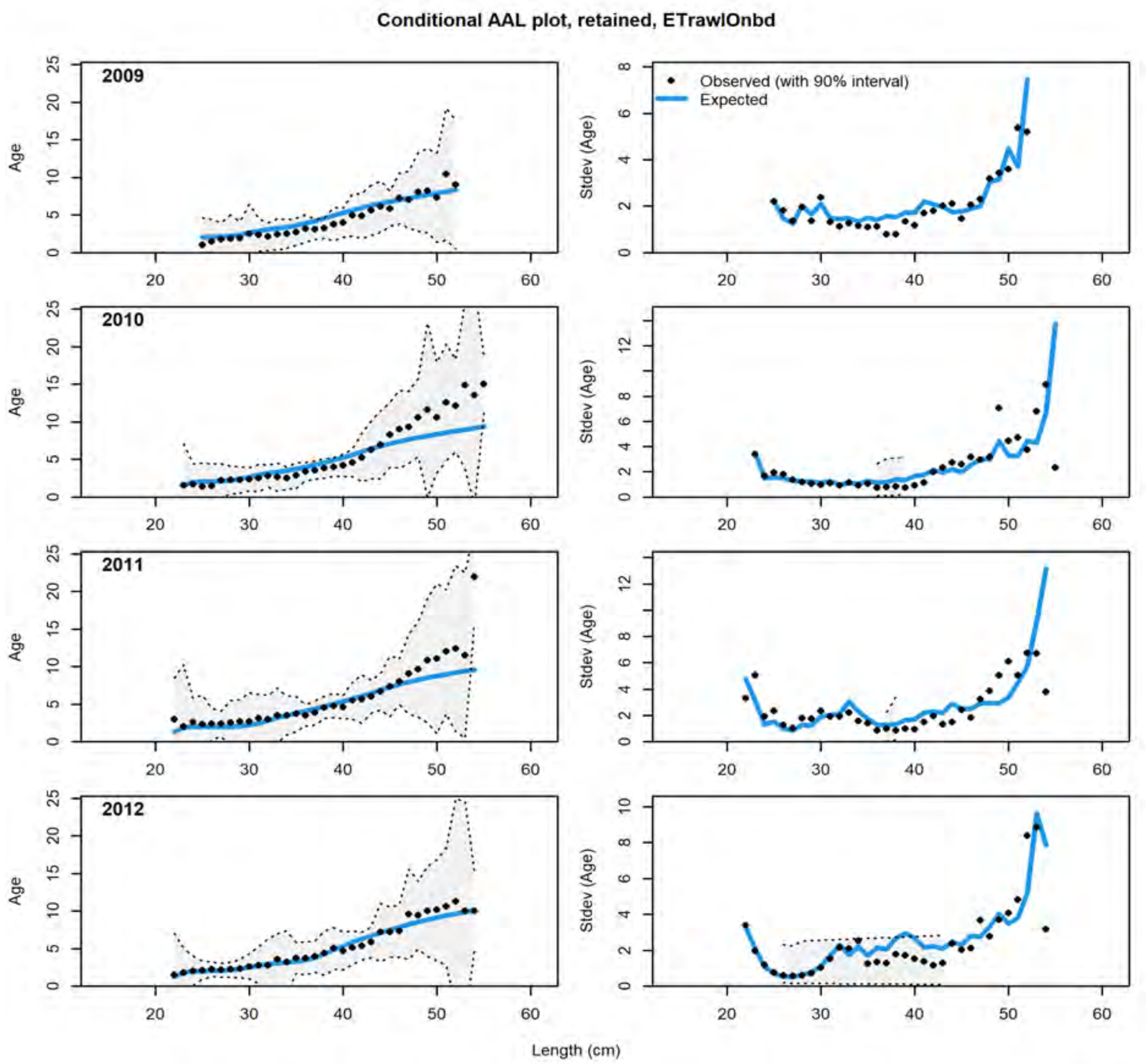

Figure 12.67. Fits to conditional age at length data for the east trawl fleet for base case 3

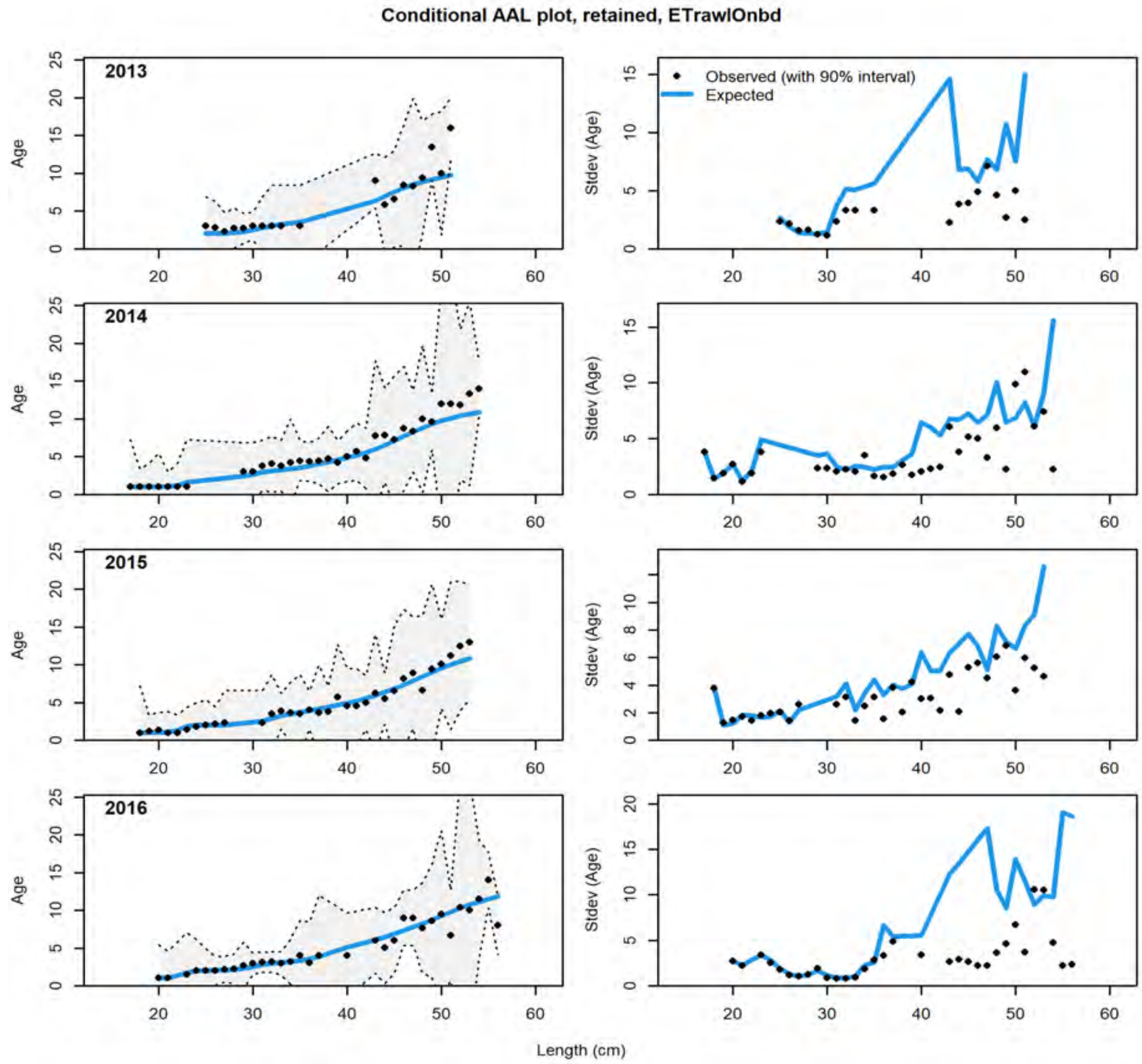

Figure 12.68. Fits to conditional age at length data for the east trawl fleet for base case 3

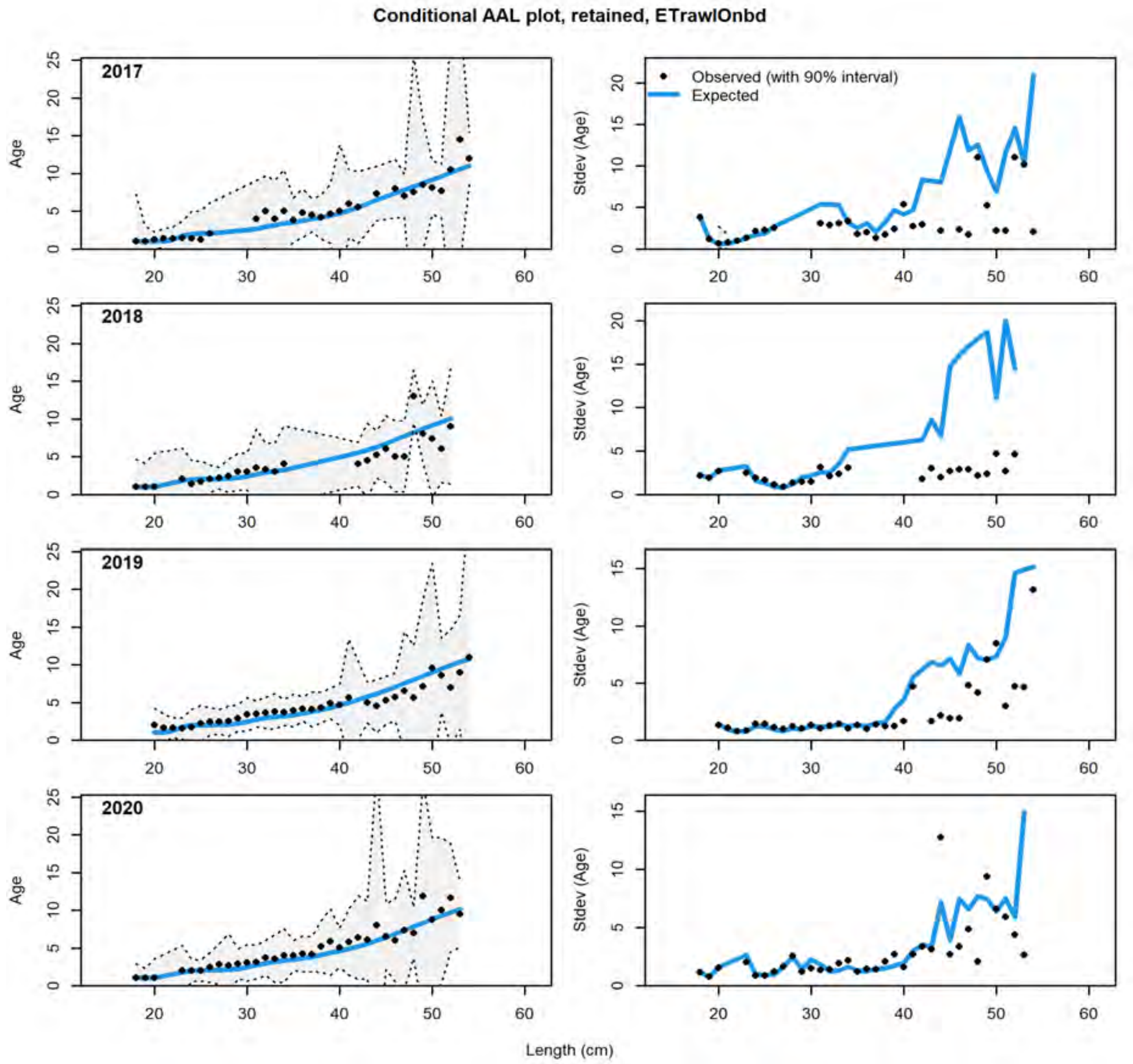

Figure 12.69. Fits to conditional age at length data for the east trawl fleet for base case 3

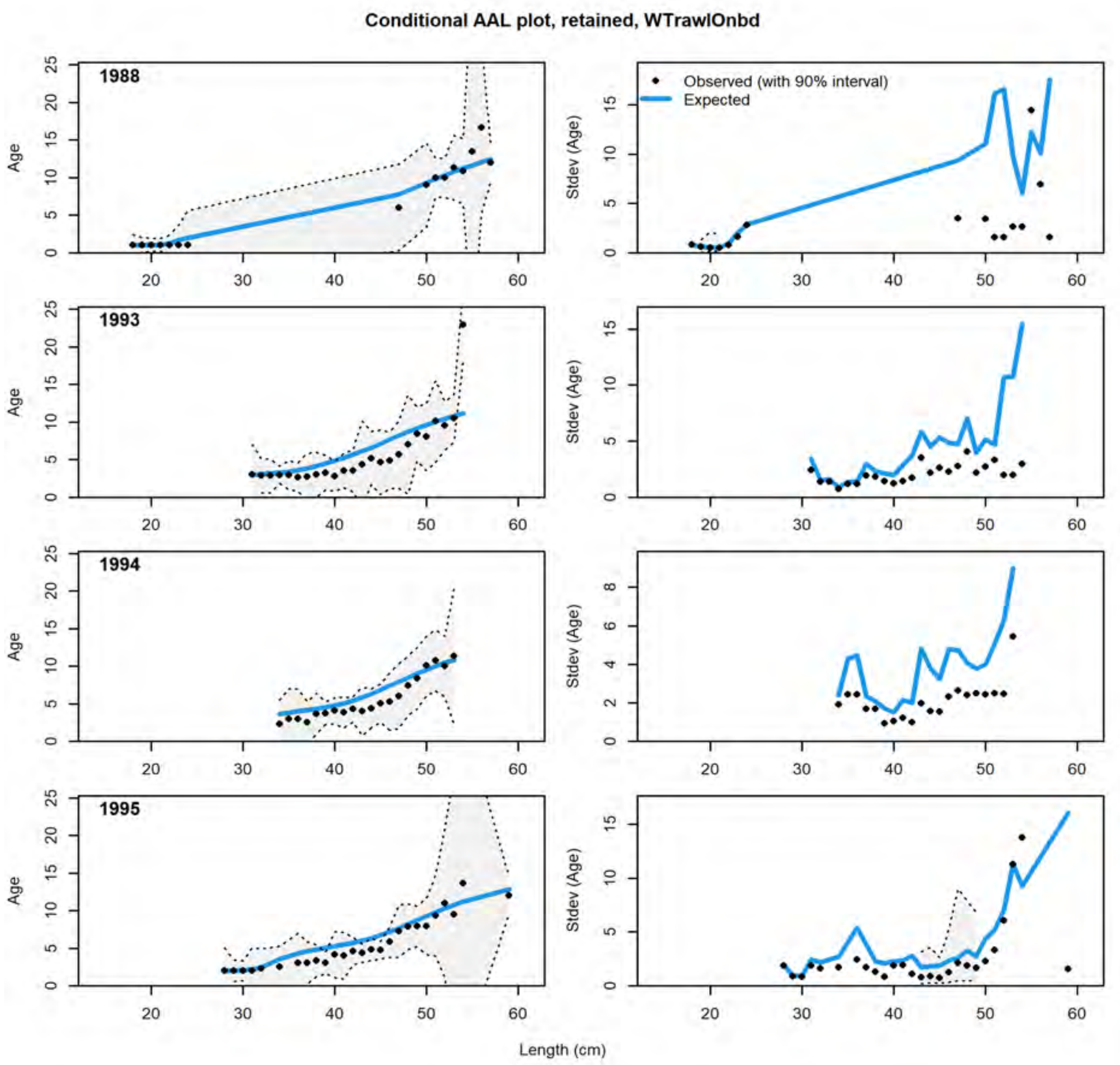

Figure 12.70. Fits to conditional age at length data for the west trawl fleet for base case 3

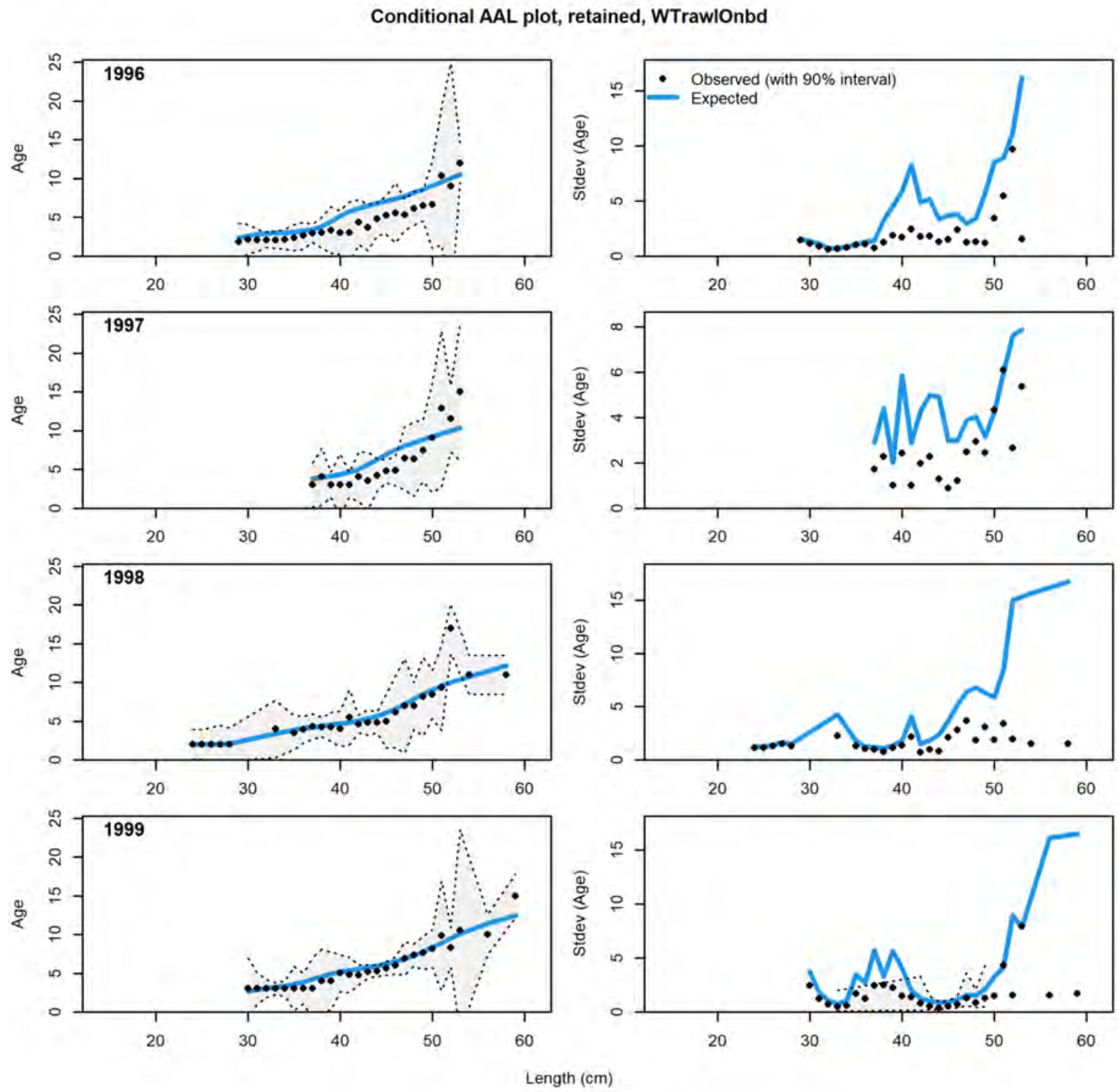

Figure 12.71. Fits to conditional age at length data for the west trawl fleet for base case 3

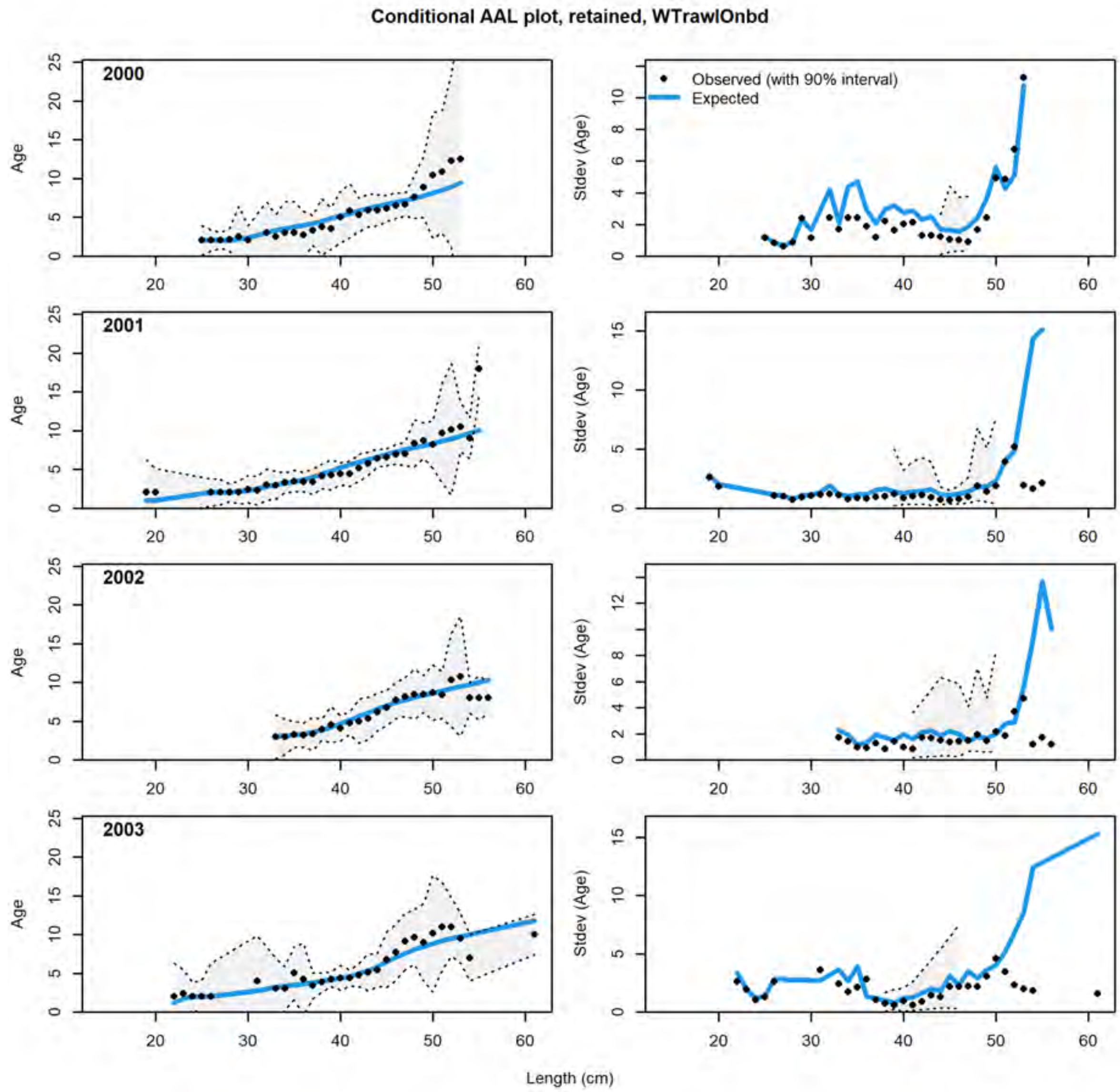

Figure 12.72. Fits to conditional age at length data for the west trawl fleet for base case 3

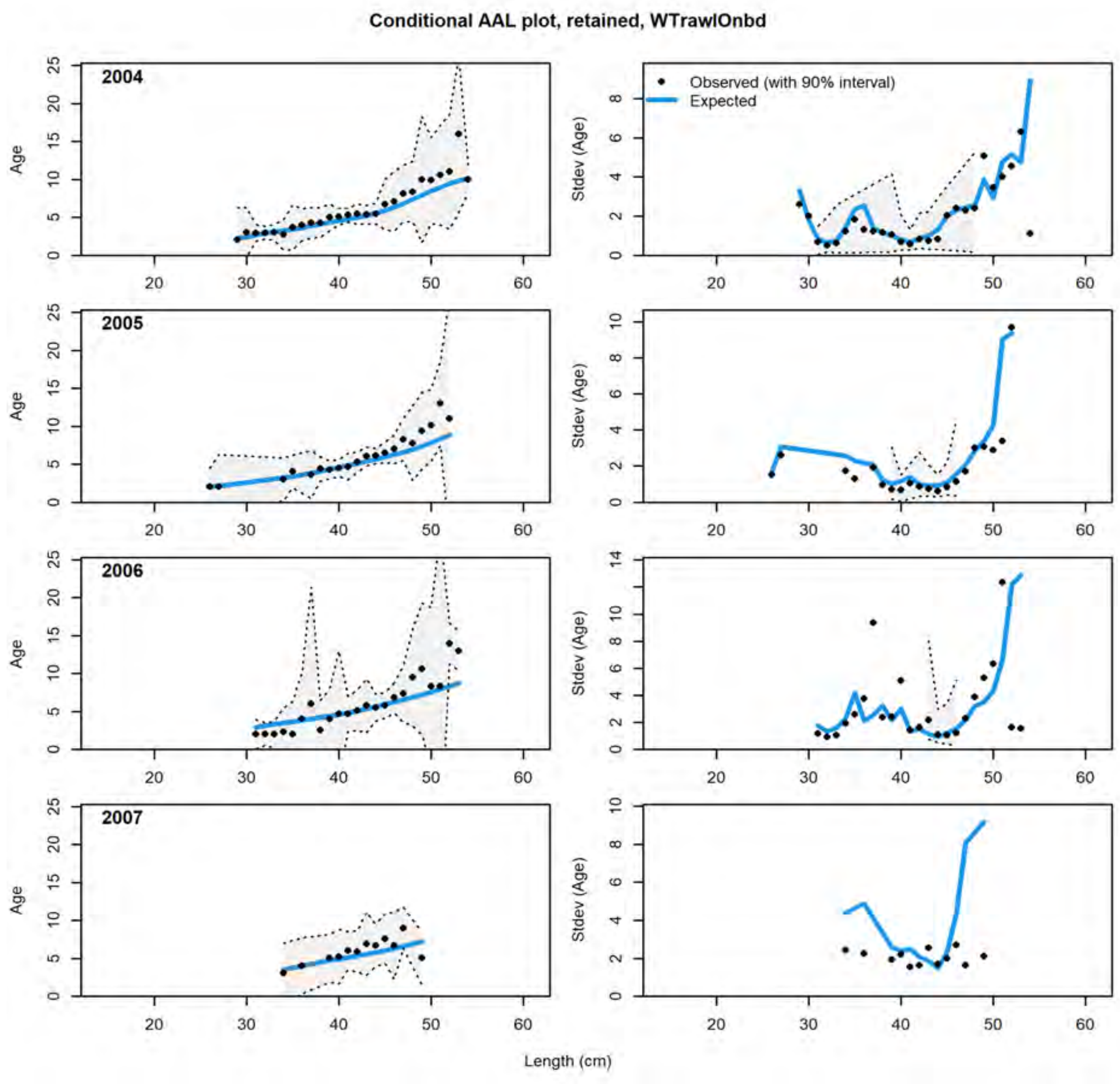

Figure 12.73. Fits to conditional age at length data for the west trawl fleet for base case 3

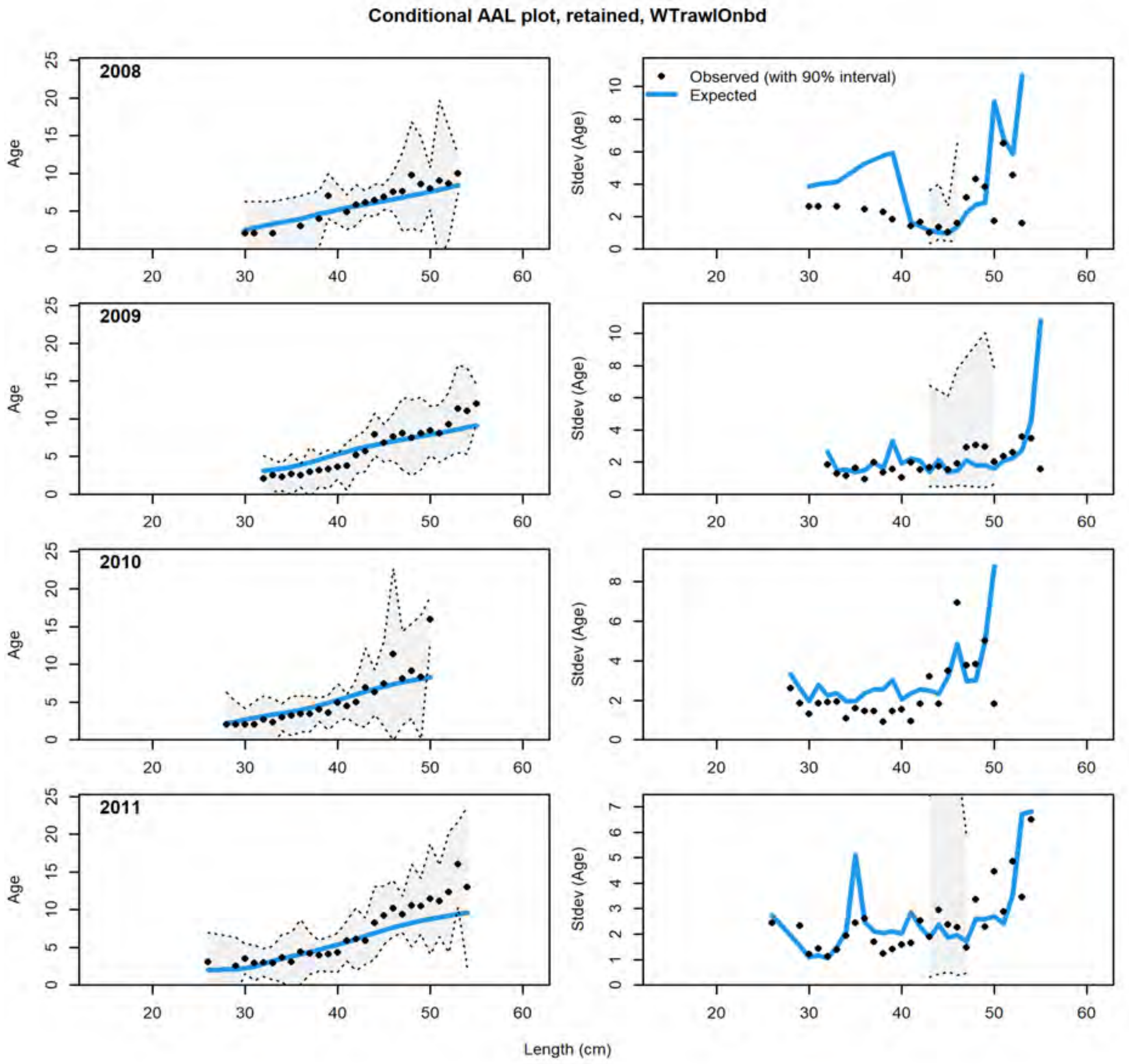

Figure 12.74. Fits to conditional age at length data for the west trawl fleet for base case 3

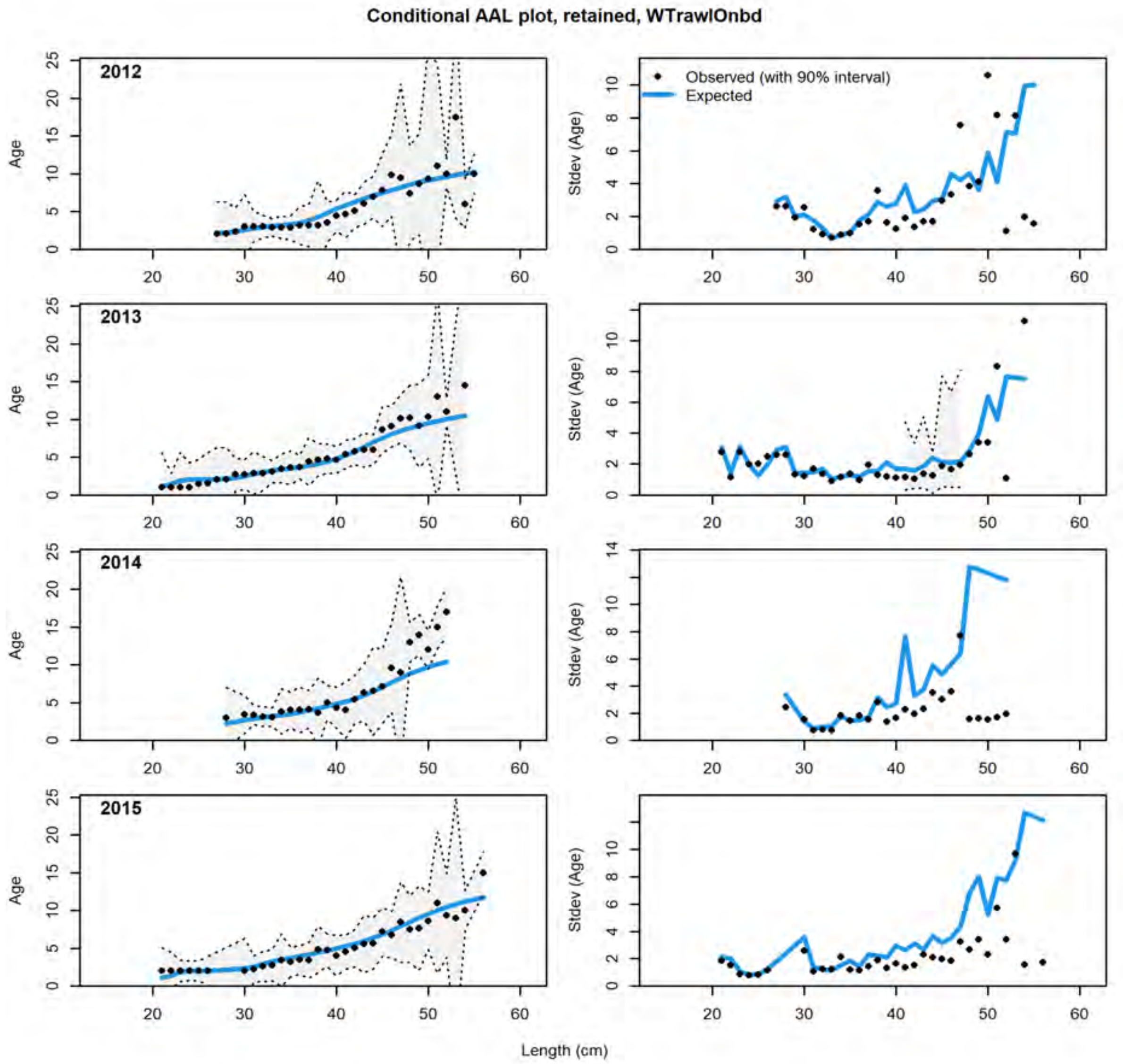

Figure 12.75. Fits to conditional age at length data for the west trawl fleet for base case 3

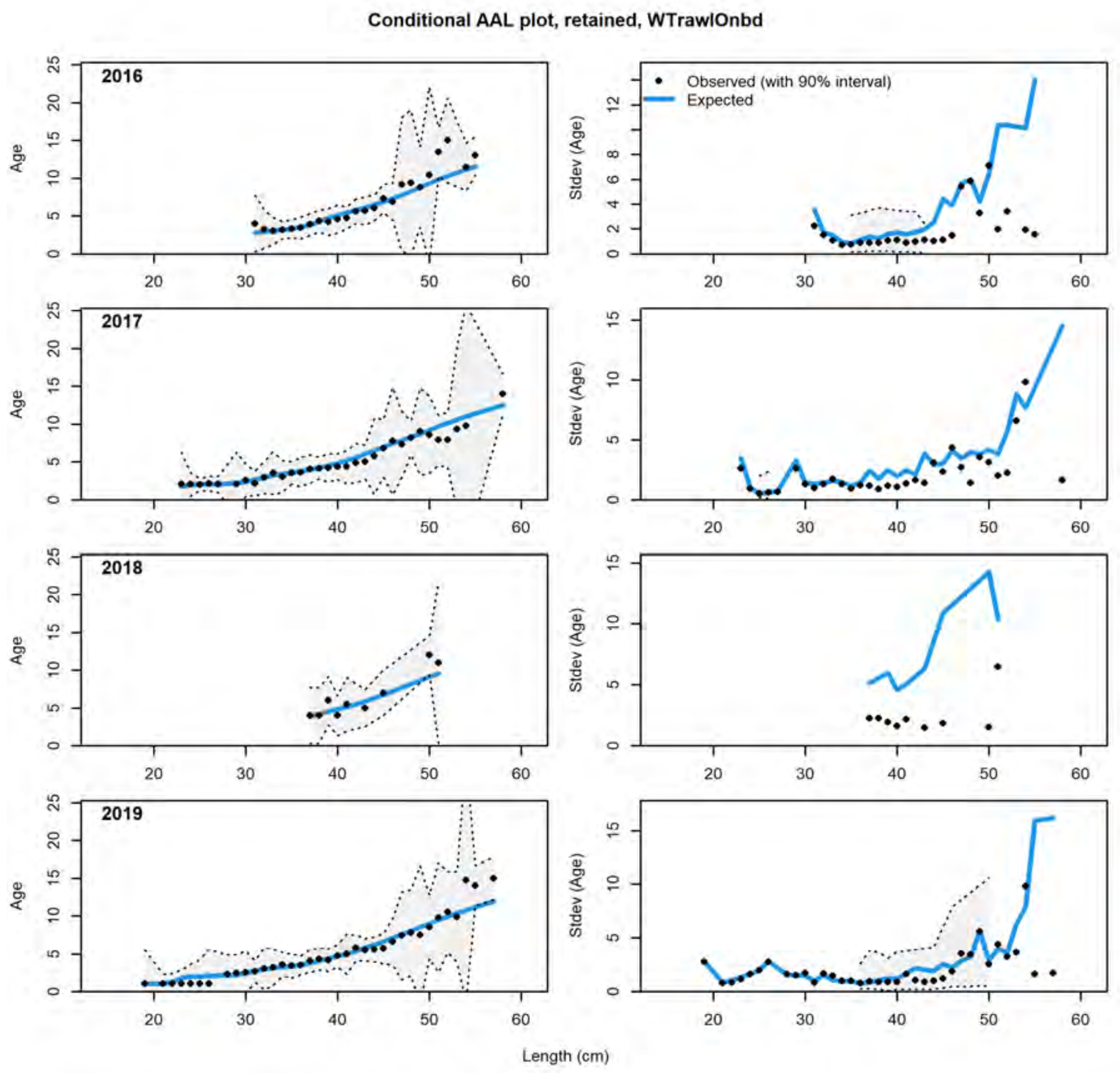

Figure 12.76. Fits to conditional age at length data for the west trawl fleet for base case 3

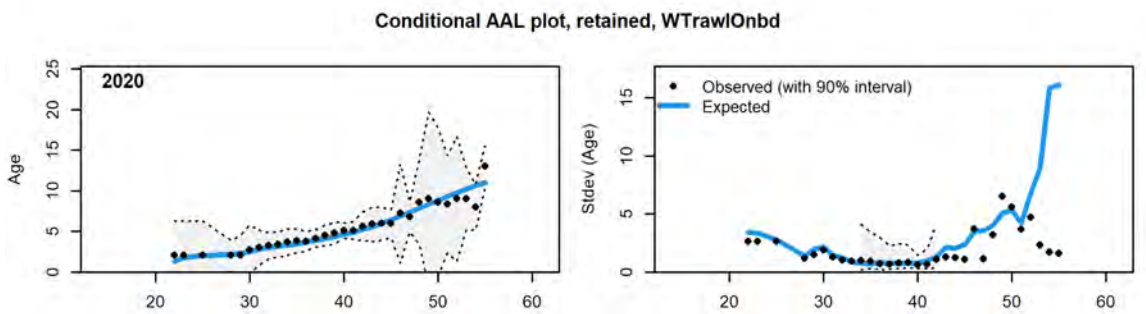

Figure 12.77. Fits to conditional age at length data for the west trawl fleet for base case 3

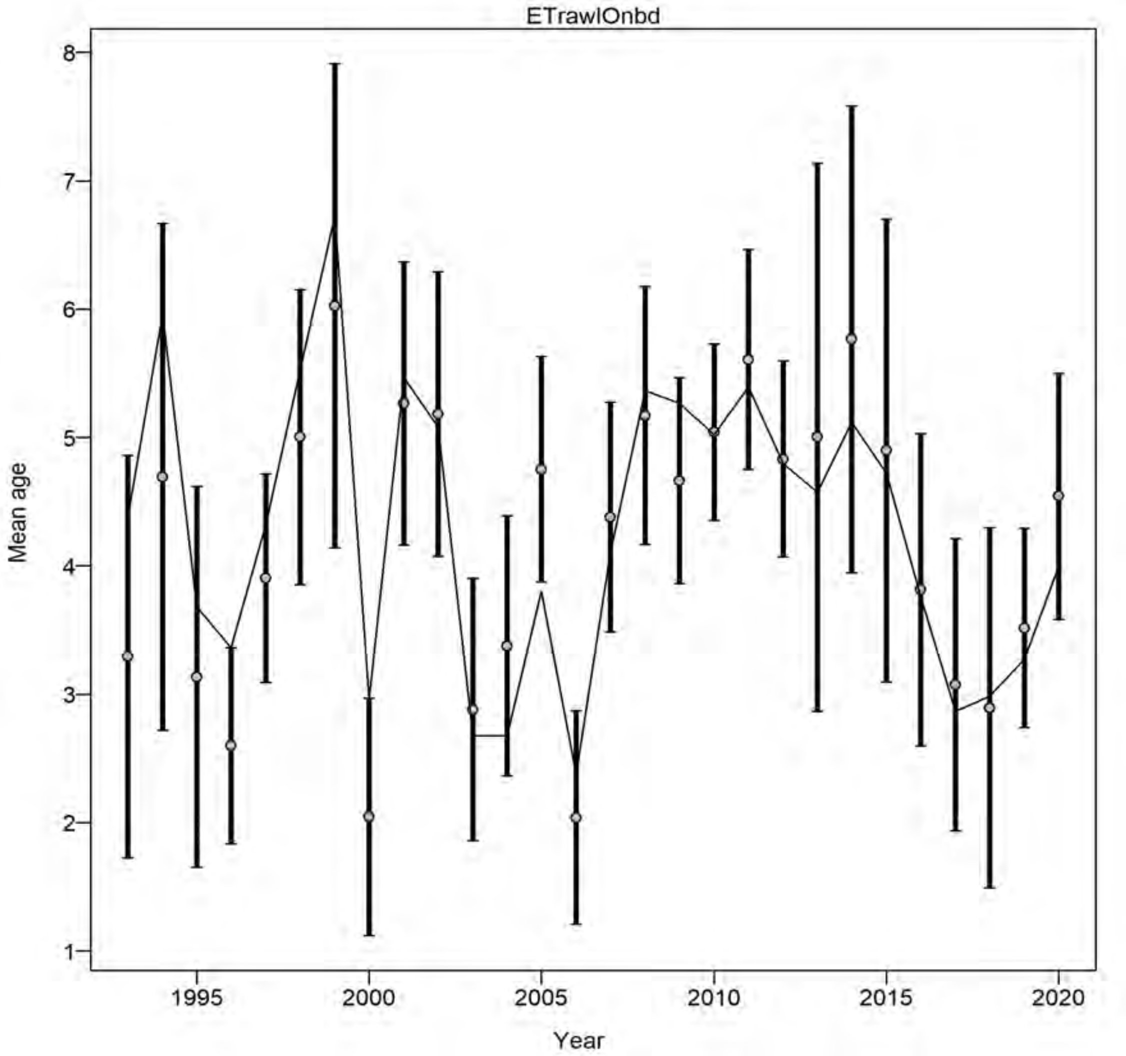

Figure 12.78. Data weighting of conditional age at length data for the east trawl fleet for base case 3

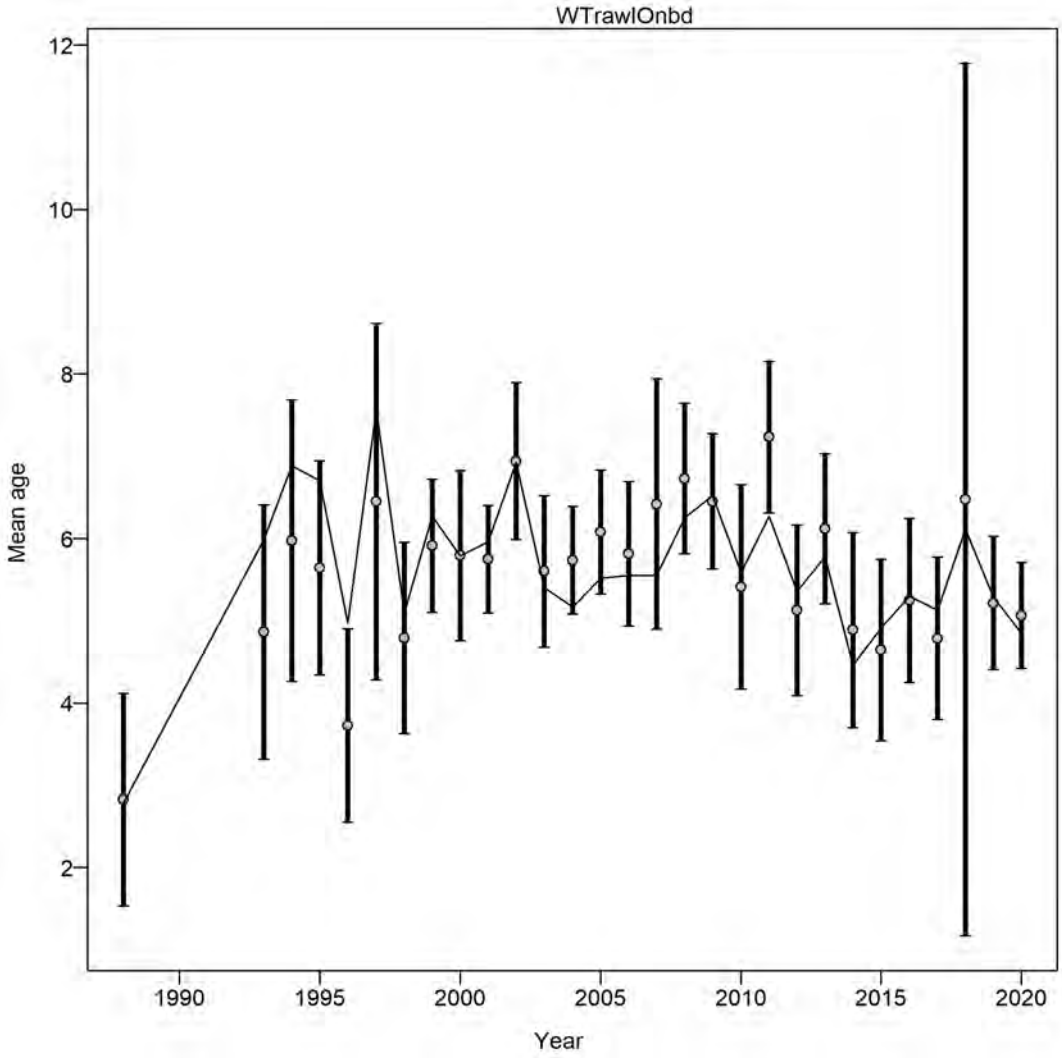

Figure 12.79. Data weighting of conditional age at length data for the west trawl fleet for base case 3

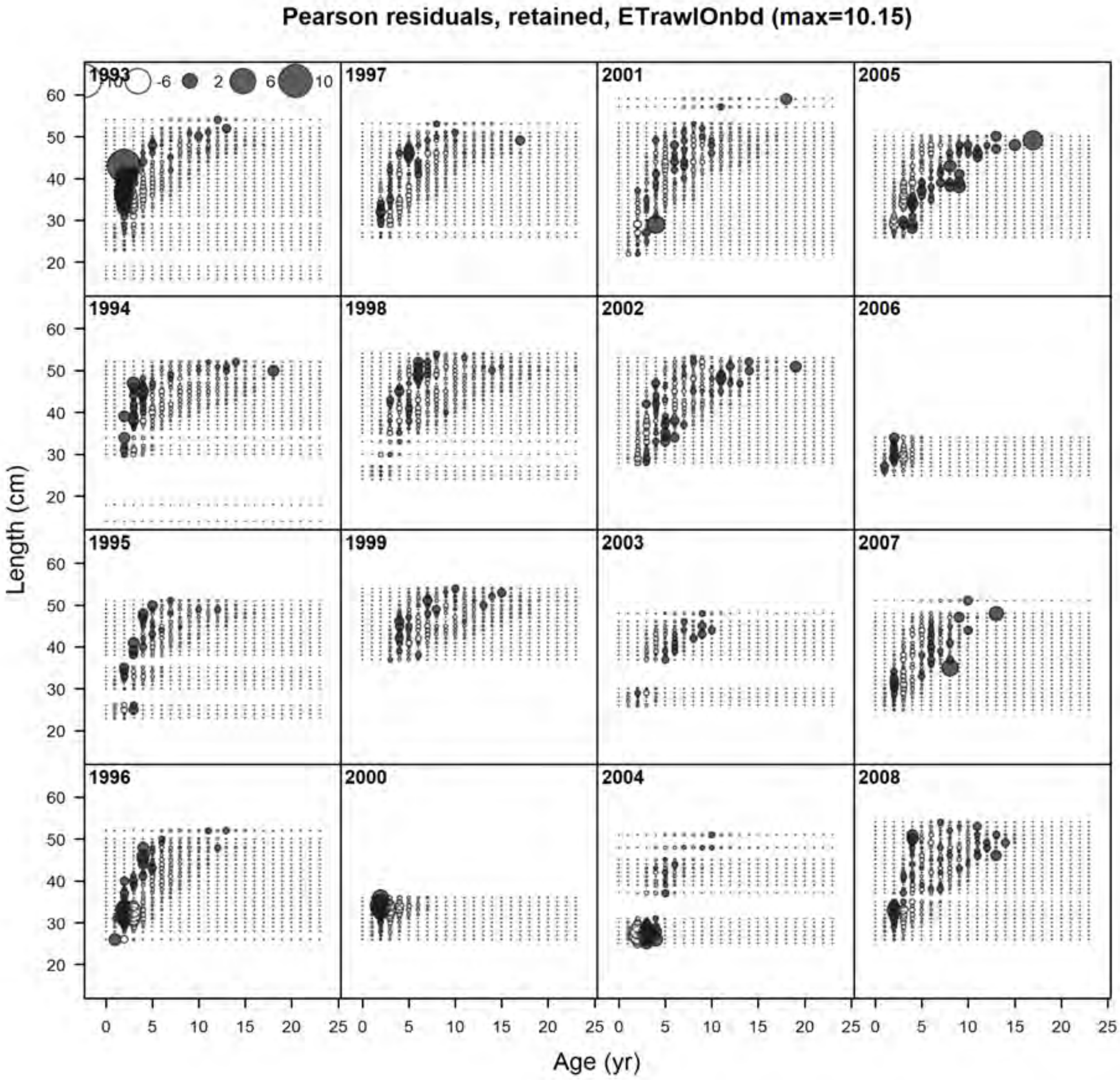

Figure 12.80. Pearson residuals of conditional age at length data for the east trawl fleet for base case 3

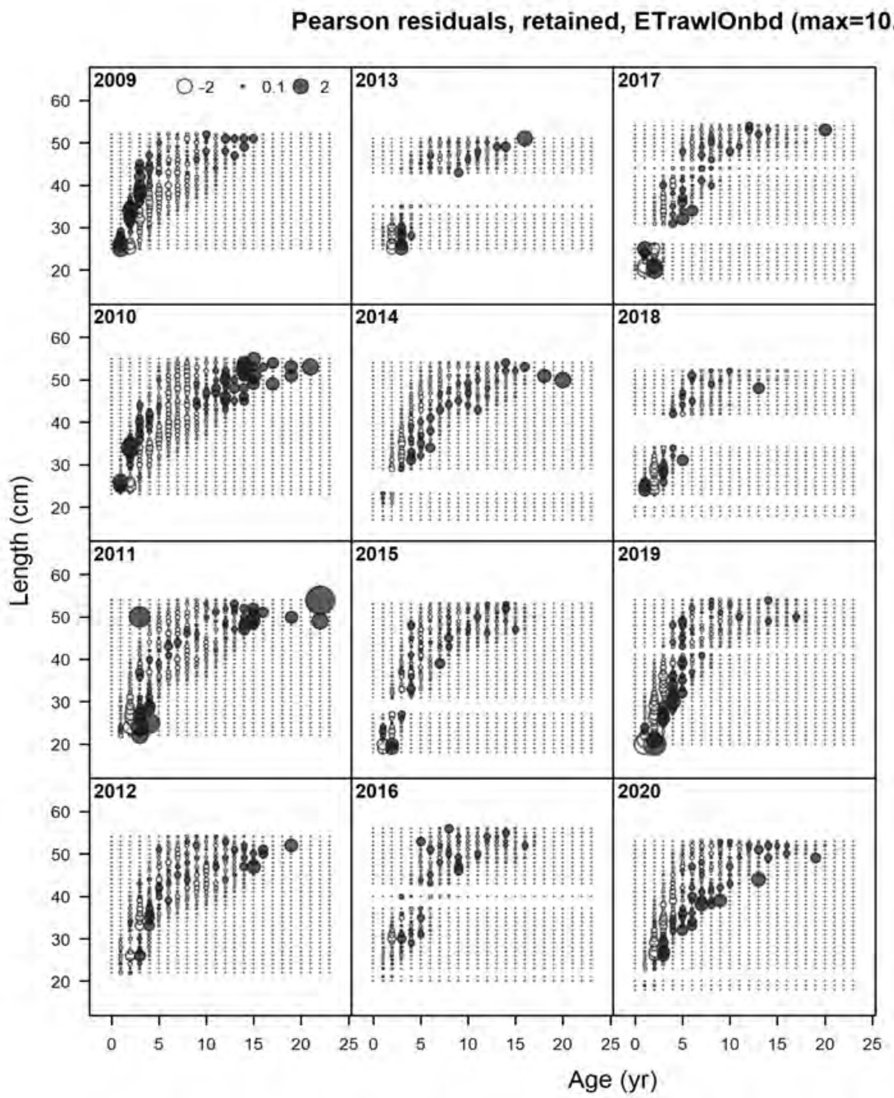

Figure 12.81. Pearson residuals of conditional age at length data for the east trawl fleet for base case 3 continued

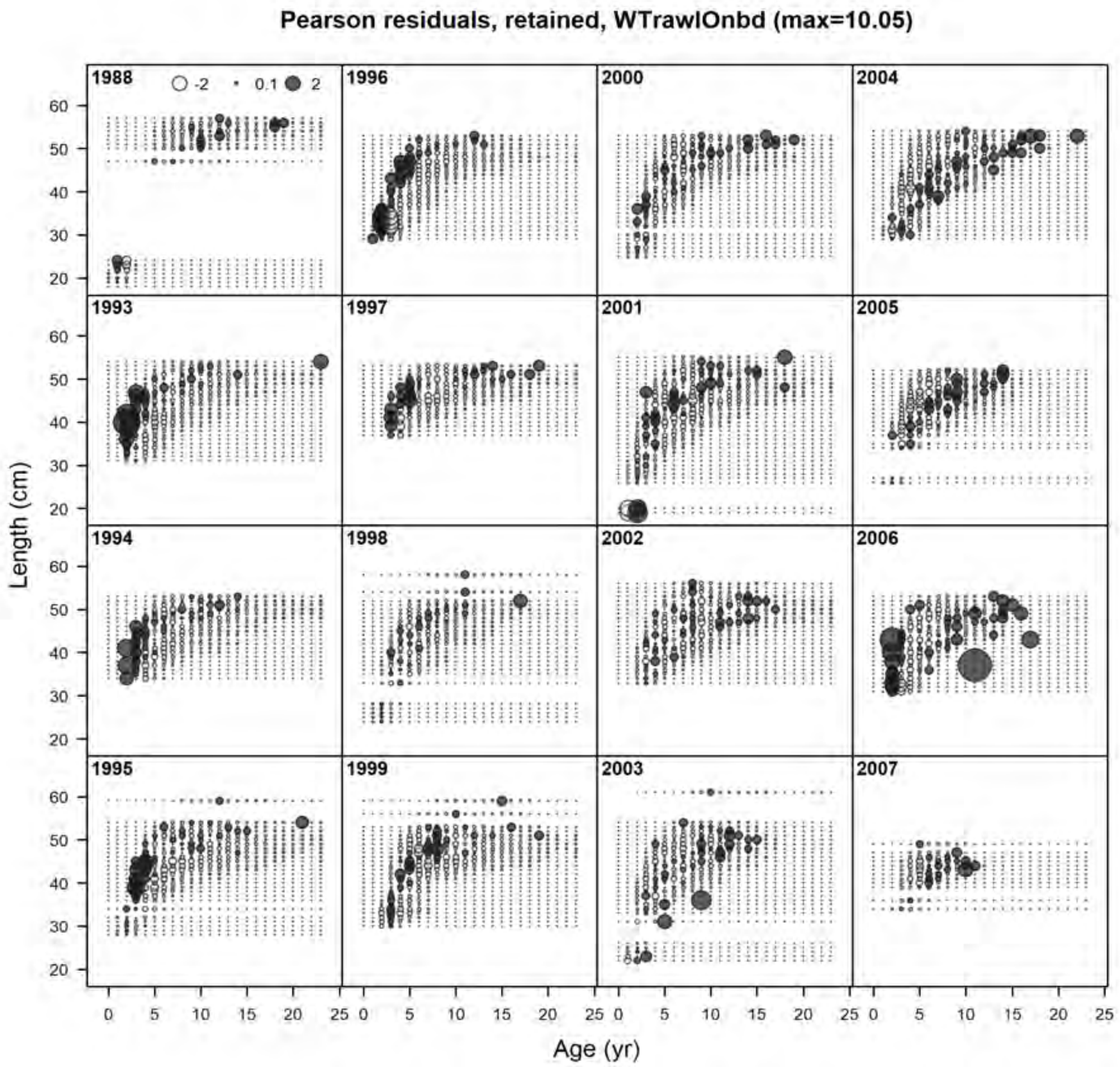

Figure 12.82. Pearson residuals of conditional age at length data for the west trawl fleet for base case 3

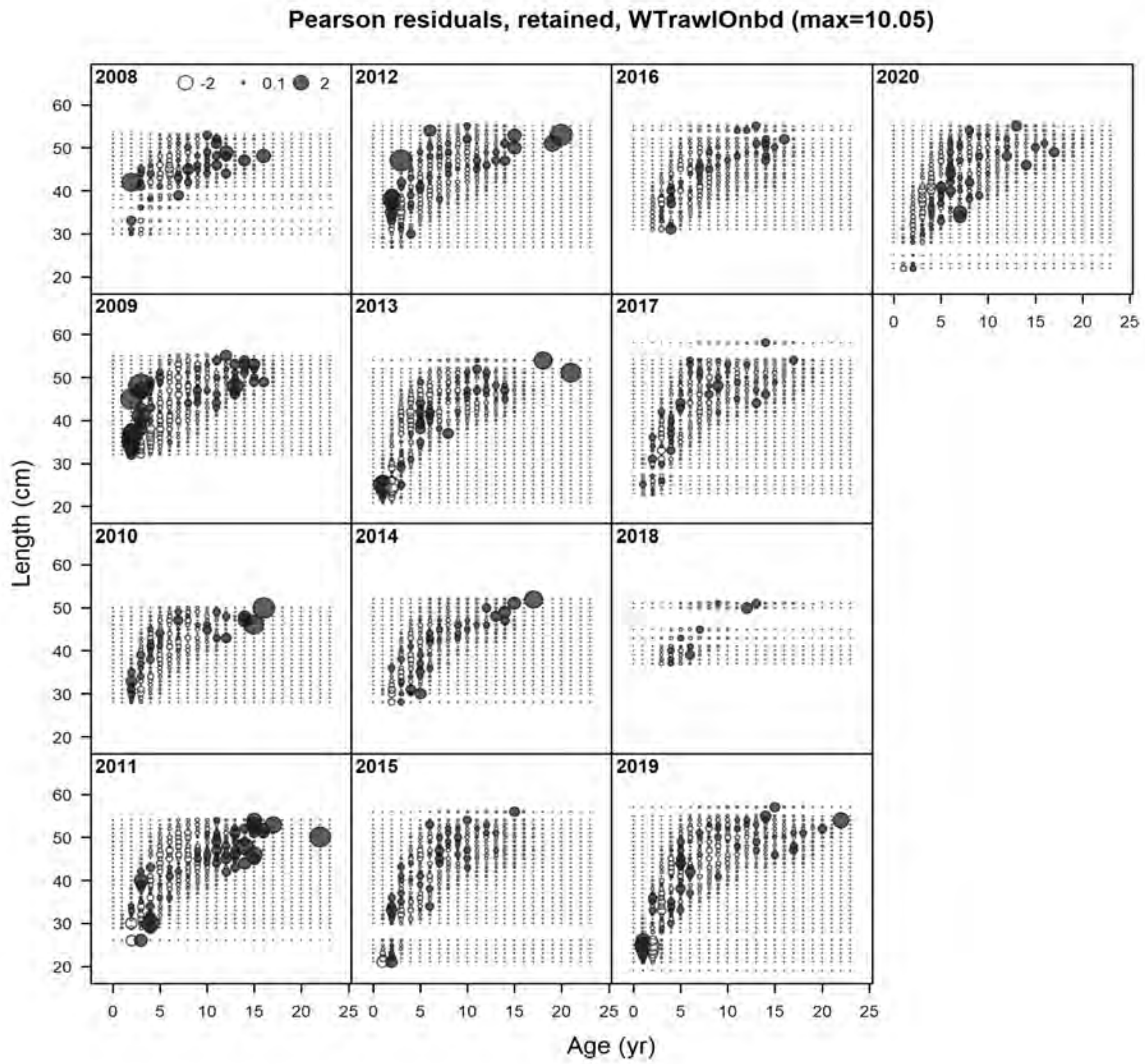

Figure 12.83. Pearson residuals of conditional age at length data for the west trawl fleet for base case 3 continued

13. Silver Warehou (*Seriolella punctata*) stock assessment based on data up to 2020

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13.1 Executive Summary

This document presents a quantitative Tier 1 assessment of Silver Warehou (*Seriolella punctata*) to provide stock status estimates at the start of 2022 and describes the base case. The assessment was performed using the stock assessment package Stock Synthesis (SS3.30.17). The 2018 base case has been updated with the inclusion of data up to the end of 2020, which entails an additional three years of catch, discard, CPUE, length and age data, along with ageing error updates, revisions to historical catch series, length frequencies and discard rates.

The assessment estimates that the projected 2022 stock status will be 29% of unfished spawning stock biomass (SSB_0), projected assuming 2020 catches in 2021, with recruitment from 2016 onwards assumed to be below average, fixed at the average of 2011-2015 levels. The assessment suggests that stock status was as low as 21% of SSB_0 in 2016. Under the 20:35:48 harvest control rule, the 2022 recommended biological catch (RBC) is 587 t, while the long-term yield (assuming continuation of low recruitment) is 591 t. The average RBC over the three-year period 2022-2024 is 581 t and over the five-year period 2022-2026, the average RBC is also 581 t. If recruitment from 2016 onwards is assumed to be average, the projected 2022 spawning stock biomass would be 42% of SSB_0. It is important to note that these RBCs do not result in an increase in stock status towards the target level of 48% SSB_0 due to reduced productivity under sustained low recruitment projections, which break the assumption of projected average recruitment in the HCR.

This assessment has seen a continuation of below average recruitment noted in the last three assessments with the last 12 years of estimated recruitment all below average. This continuation of below average recruitment resulted in the base case for this assessment moving to low recruitments projected forward from 2016. This change reduced the severity of retrospective patterns observed in previous assessments. Previous assessments have generally predicted sharp increases in stock status at the end of the assessment, which have not been realised in subsequent assessments. This trend of overly optimistic recent biomass is reduced when projecting forward with below average recruitment. This low recruitment projection has also reduced the productivity potential of the stock, with recovery to 100% of SSB_0 no longer possible, with the population now only able to reach 49% of SSB_0 if fishing mortality was to cease.

The 2018 assessment predicted that 2019 stock status would be 31% of SSB_0, with a long-term yield of 1,772 t. The stock status and the long-term yield have been revised downwards in the current assessment. This was mainly due to including low recruitment projections in the base case, but also continued low catches and improved fits to the low values at the end of the CPUE series have also contributed to the reduced estimate of stock status.

Likelihood profiles on various parameters have demonstrated clear conflicts in data inputs and between the two fleets for individual data components. These conflicts between fleets suggest that splitting the

assessment between the east and the west in the future may help to alleviate this and may also further improve retrospective patterns and fits to length frequencies.

13.2 Introduction

13.2.1 *The Fishery*

Silver Warehou occur in waters of southern Australia and New Zealand, and are possibly found off South America (Tilzey, 1998). In Australia, they are found in waters of the south-east including New South Wales, Victoria, Tasmania and South Australia. Adults are generally found on the continental shelf and upper slope, while juveniles are initially pelagic and subadults are often found in large estuaries and bays during the summer and autumn (Tilzey, 1998). In the SESSF they are found in depths to 600 m and are predominantly caught by demersal trawl (Bessell-Browne et al., 2021; Morison et al., 2007; Sporcic et al., 2015). Silver Warehou have also been captured off western Tasmania as bycatch of the winter spawning Blue Grenadier (*Macruronus novaezelandiae*) fishery. In addition to demersal trawl, there have also been some gillnet catches (Morison et al., 2007) and catches by the small pelagic fishery (SPF) using mid-water trawl.

Large catches of Silver Warehou were first taken in the 1970's (Smith, 2007) and landed catches increased to around 2,000 t in the early 1990's peaking at 4,100 t in 2002. Catches declined to less than 2,000 t from 2007 onwards, with further declines to less than 1,000 t since 2012. Catches have remained relatively stable since 2014 at between 350 t and 400 t.

For 2019, 2020 and 2021 the agreed total allowable catches (TACs) were all 450 t. These TACs were set following the last assessment in 2018 assuming a low recruitment scenario (Burch et al., 2018).

13.2.2 *Stock Structure*

Prior to 2015, Silver Warehou was assessed as a single population using a single trawl fleet in SESSF zones 10–50 (Day et al., 2012). However, differences in standardised catch rates, length and age distribution east and west of longitude 147°E were identified by Sporcic et al. (2015). This led to the development of a preliminary assessment which split the data into two fleets, an eastern fleet (SESSF zones 10, 20 and 30) and a western fleet (SESSF zones 40 and 50) (Thomson et al., 2015). This fleet structure was adopted as the base case for the 2015 assessment (Day et al., 2015), 2018 assessment (Burch et al., 2018) and has been retained as the base case for the current assessment.

13.2.3 *Previous Assessments*

The previous full quantitative assessment for Silver Warehou was performed in 2018 (Burch et al., 2018) using Stock Synthesis (SS-V3.30.12.00, Methot et al. (2018)). The 2018 assessment indicated that the spawning stock biomass levels in 2019 were 31% of unfished biomass, however, recruitment for the last 11 years years was estimated to be below average and the TACs for 2019–2021 were set assuming below average future recruitment from fixed catch projections.

The 2015 assessment (Day et al., 2015) used Stock Synthesis (SS-V3.24U, Methot (2015)). The 2015 assessment indicated that the spawning stock biomass levels in 2016 were 40% of unfished biomass, however, recruitment for nine out of the ten most recent years was estimated to be below average and the TACs for 2016-2018 were set assuming below average future recruitment.

The 2015 assessment was the first to split the assessment between east trawl (SESSF zones 10–30) and west trawl fleets (SESSF zones 40–50). This change was implemented following investigations by Sporcic et al. (2015) and Thomson et al. (2015). Sporcic et al. (2015) highlighted differences in standardised catch rates, along with age and length distributions in the east and west. Thomson et al. (2015) investigated the relationship between depth and length frequencies and concluded there was a strong relationship with larger fish caught in deeper water in the west, and smaller fish caught in the east and in shallow waters. These investigations led to the development of a preliminary base case assessment which split the single trawl fleet into eastern and western fleets (Thomson et al., 2015).

Thomson et al. (2015) also identified evidence of changing discarding practices within the fishery with both size and market-based discarding occurring up until 2001 and only size-based discarding from 2002 onwards. This permitted discard rates to be estimated within the 2015 assessment using separate retention functions pre and post 2002 (Day et al., 2015). The changes to the fleet structure and fitting to discard rates led to improvements in the fits to the length and age composition data compared with previous assessments (Day et al., 2012; Tuck and Fay, 2009).

The 2012 assessment (Day et al., 2012) used Stock Synthesis (SS-V3.23b, Methot (2012)). This assessment modelled the stock using a single trawl fleet in SESSF zones 10–50, which continued the fleet structure from previous assessments (Tuck and Fay, 2009). This assessment suggested the 2013 spawning stock biomass was 47% of unfished levels.

Prior to 2012, an assessment for Silver Warehou was performed in 2009 (Tuck and Fay, 2009) using Stock Synthesis (version SS-V3.03a, Methot (2009)) and this assessment indicated that the spawning stock biomass levels in 2010 were around 48% of unfished biomass.

Before the 2009 assessment, other Stock Synthesis based assessments for Silver Warehou were performed in: 2008 (Tuck, 2008) with a spawning biomass estimate for 2007/8 of 53% of the unfished level; 2007 (Tuck and Punt, 2007) with a spawning biomass estimate for 2007/8 of 49% of unfished levels. Even earlier assessments include Taylor and Smith (2004) and Thomson (2002).

13.2.4 *Modifications to the previous assessment*

The base case specifications agreed by SERAG in 2018 are maintained into the assessment presented here, with three changes. Firstly, an additional time block on retention for the east trawl fleet has been included to allow the model to fit the increased recent discarding, which has occurred since the previous assessment. Secondly the assessment has only estimated one additional recruitment deviation rather than the usual three due to a retrospective pattern which revises down recruitment with the inclusion of additional years of data. Lastly the base case assessment now includes low recruitment projections rather than an assumed return to average recruitment levels post 2015. These changes have improved fits to the data inputs and reduced retrospective patterns within the assessment. These changes are described in further detail in Bessell-Browne (2021).

The 2018 assessment (Burch et al., 2018) made a number of changes to the structure of the assessment, these included:

1. Catches from the Gillnet, Hook and Trap sector (GHAT) and the SPF are included in the assessment;
2. Estimated annual discard rates that are fitted to by the assessment have been split into eastern and western components;

3. Factory trawlers are now included in the estimation of annual discard rates when there is observer coverage;
4. FIS abundance indices for east and west fleets are removed from the base case assessment and are instead considered as a sensitivity.

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 by Bessell-Browne (2021).

13.3 Methods

13.3.1 Model Structure

The 2021 base case assessment of Silver Warehou uses an age- and size-structured model implemented in the generalized stock assessment software package, Stock Synthesis (SS) (Version 3.30.17.00, Methot et al. (2021)). The methods utilised in SS are based on the integrated analysis paradigm. SS can allow for multiple seasons, areas and fleets, but most applications are based on a single season and area. Recruitment is governed by a stochastic Beverton-Holt stock-recruitment relationship, parameterised in terms of the steepness of the stock-recruitment function (h), the expected average recruitment in an unfished population (R_0), and the degree of variability about the stock-recruitment relationship (σ_R). SS allows the user to choose among a large number of age- and length-specific selectivity patterns. The values for the parameters of SS are estimated by fitting to data on catches, catch-rates, discard rates, discard and retained catch length-frequencies, and conditional age-at-length data. The population dynamics model and the statistical approach used in fitting the model to the various data types are given in the SS technical documentation (Methot, 2005).

The base case model includes the following key features:

A single region, single stock model is considered with two fleets, one in the east including SESSF zones 10, 20 and 30 (east trawl), and one in the west including SESSF zones 40 and 50 (west trawl). Selectivity is modelled separately for each fleet, with both selectivity patterns assumed to be length-specific and logistic. The parameters of the selectivity function for each fleet were estimated within the assessment. The model does not account for males and females separately and fits one growth curve across both sexes. The initial and final years are 1980 and 2020.

13.3.1.1 Biological parameters and stock structure assumptions

The rate of natural mortality, M, is assumed to be constant with age, and also time-invariant. The value for M is assumed to be 0.3 y^{-1}.

Recruitment to the stock is assumed to follow a Beverton-Holt 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 is fixed at 0.75.

The initial value of the parameter determining the magnitude of the process error in annual recruitment, σ_R, is set to 0.7.

The population plus-group is modelled at age 23 years.

Growth is assumed to follow a von Bertalanffy length-at-age relationship, with the parameters of the growth function estimated together for females and males inside the assessment model.

Silver Warehou become sexually mature at around 42 cm length, when they are around five years old. Maturity is modelled as a logistic function, with 50% maturity fixed at 37 cm in the assessment. Fecundity-at-length is assumed to be proportional to weight-at-length. The parameters of the length-weight relationship are obtained from Taylor and Smith (2004).

The values assumed for some of the (non-estimated) parameters of the base case models are shown in Table 13.1.

Table 13.1. Parameter values assumed for some of the non-estimated parameters of the base-case model

Parameter	Description	Value
$\boldsymbol{M}$	Natural mortality	0.3
$\boldsymbol{h}$	steepness' of the Beverton-Holt stock-recruit curve	0.75
$\boldsymbol{x}$	age observation plus group	23 years
$\boldsymbol{a}$	allometric length-weight equations	0.0000065 g^{-1} cm
$\boldsymbol{b}$	allometric length-weight equations	3.27
$\boldsymbol{l_m}$	Female length at 50% maturity	37 cm

13.3.2 *Data*

A summary of the data available in the assessment is presented in Figure 13.1.

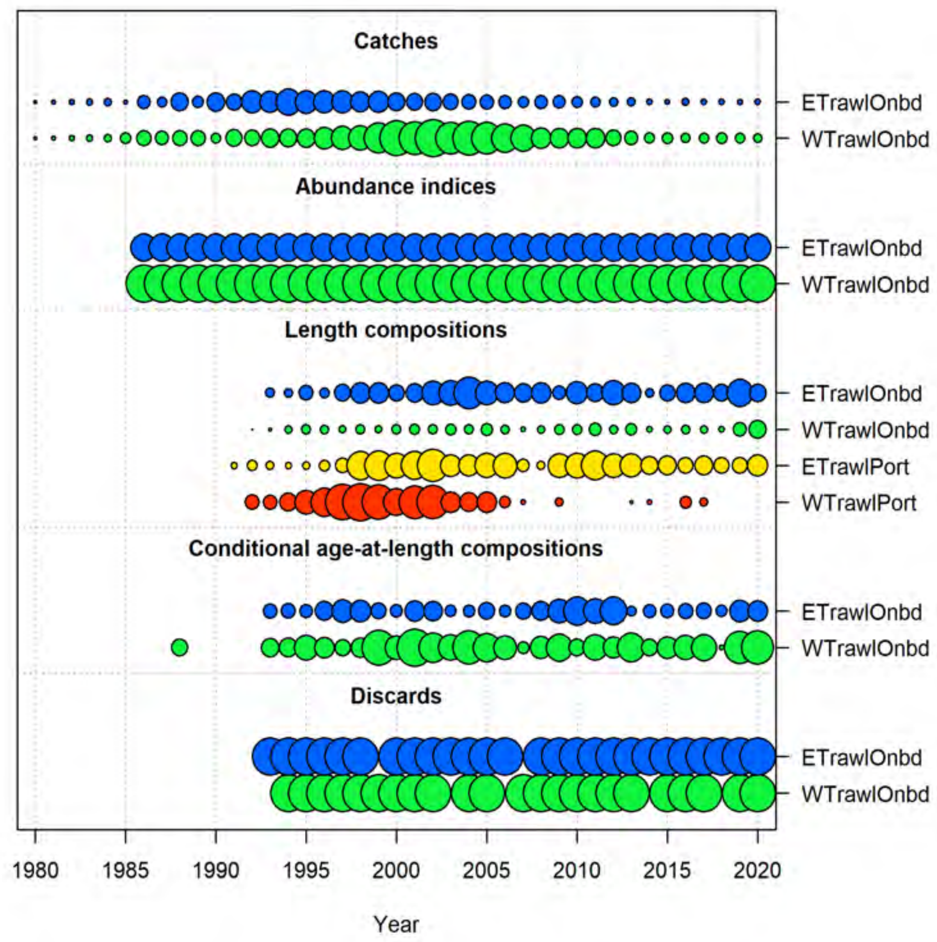

Figure 13.1. Summary of Silver Warehou data sources

13.3.2.1 Catch data

The model uses a calendar year for all catch data. The first model year is 1980, however, SEF1 record-keeping did not begin until 1985. Landings of Silver Warehou prior to 1985 are not considered to have been large and a linear increase in catch from 1980 to 1985 was assumed, following Punt et al. (2005). Silver Warehou are closely related to Blue Warehou (*Seriolella brama*) and historically catches have often been reported mixed, or with all Warehou species combined and referred to as Tassie Trevally (Sporcic et al., 2015). This practice was most prevalent in the late 1980s with it unclear which species was caught and recorded in Commonwealth logbooks. For this reason, catches prior to 1994 have not been revised and are instead taken from Table 13.11 of Sporcic et al. (2015) and shown in the first column of Table 13.2, although separated into east trawl and west trawl fleets.

The catch history of Silver Warehou from 1994 onwards has been revised in the current assessment to account for updates to the database made by AFMA (Althaus et al., 2021).

As was done in the 2018 assessment, catches of Silver Warehou from both the small pelagic fishery (SPF) and the gillnet hook and trap sector (GHT) were included with Commonwealth trawl (CTS) catches when compiling the catch series (Burch et al., 2018). Catches recorded within the SESSF, those taken by state jurisdictions, total catches prepared for the assessment and historical TACs are detailed in Table 13.2, with catches used in the assessment presented in Figure 13.2.

To calculate the RBC for 2022, it is necessary to estimate the catch for 2021. Without any other information, the 2021 catch is assumed to be identical to the 2020 catch.

The percentage of the TAC that has been caught through time has been variable, ranging from a high of 104% in 1997 to a low of 16% in 2014 and 2015 (Table 13.2). From 2018 to 2020 between 66% and 74% of the TAC has been caught (Table 13.2).

Table 13.2. Catch summary including the agreed historical catch series between 1980 and 1993 (Total East and Total West), and catches compiled for the current assessment (1994-2020). Catches are split between the fleets and presented by total SESSF catches (SESSF East and SESSF West), total state catches (State East and State West), along with the total catch (Total East, Total West), and also summarised to represent all Silver Warehou catches (Total Catch). The catch series included in the assessment are presented in the *Total East* and *Total West* columns. Agreed TACs are also included. * denotes catches that are assumed to be the same as the previous year.

YEAR	SESSF EAST	SESSF WEST	STATE EAST	STATE WEST	TOTAL EAST	TOTAL WEST	TOTAL CATCH	TAC
1980	-	-	-	-	29.5	29.5	59.0	-
1981	-	-	-	-	59.0	59.0	118.0	-
1982	-	-	-	-	88.6	88.6	177.2	-
1983	-	-	-	-	118.1	118.1	236.2	-
1984	-	-	-	-	147.6	147.6	295.2	-
1985	-	-	-	-	58.4	301.6	360.0	-
1986	-	-	-	-	433.3	574.7	1,008.0	-
1987	-	-	-	-	261.0	487.8	748.8	-
1988	-	-	-	-	781.6	584.0	1,365.6	-
1989	-	-	-	-	342.8	577.6	920.4	-
1990	-	-	-	-	866.8	258.7	1,125.5	-
1991	-	-	-	-	664.3	698.9	1,363.2	-
1992	-	-	-	-	1,246.0	618.8	1,864.8	2000
1993	-	-	-	-	1,115.7	853.5	1,969.2	2000
1994	1,545.8	763.5	126.0	62.2	1,671.8	825.7	2,497.5	2500
1995	1,213.0	788.9	94.0	54.8	1,307.0	843.7	2,150.7	2500
1996	1,128.5	1,057.6	93.7	87.8	1,222.1	1145.4	2,367.6	2500
1997	1,213.2	1,339.7	22.9	15.1	1,236.1	1,354.8	2,590.9	2500
1998	964.8	1,445.0	22.7	1.4	987.5	1,446.4	2,434.0	3500
1999	1,089.4	2,158.7	1.8	0.0	1,091.1	2,158.7	3,249.8	4000
2000	802.5	2,923.6	0.5	0.0	803.0	2,923.7	3,726.6	4000
2001	713.0	2,583.2	0.3	0.1	713.4	2,583.3	3,296.6	4400
2002	770.8	3,330.6	0.4	0.1	771.3	3,330.7	4,101.9	4400
2003	618.0	2,439.1	0.9	0.2	618.8	2,439.3	3,058.1	4488
2004	524.5	2,786.8	3.7	0.7	528.2	2,787.5	3,315.6	4039
2005	507.2	2,400.6	4.1	0.0	511.3	2,400.6	2,911.9	4400
2006	440.4	1,933.2	2.5	0.0	442.9	1,933.2	2,376.1	4400
2007	309.6	1,688.8	4.4	0.0	313.9	1,688.9	2,002.8	3088
2008	449.8	1,073.1	0.7	0.5	450.5	1,073.6	1,524.1	3227
2009	409.3	968.9	3.8	0.0	413.1	968.9	1,382.1	3000
2010	312.0	976.4	0.2	0.6	312.2	977.0	1,289.2	2566
2011	252.5	976.4	0.0	0.0	252.5	976.4	1,228.9	2566
2012	209.3	638.4	0.0	0.0	209.3	638.4	847.7	2566
2013	181.2	464.4	0.0	0.0	181.3	464.4	645.7	2329
2014	95.9	285.7	0.0	0.0	95.9	285.7	381.5	2329
2015	71.3	315.3	0.1	0.0	71.4	315.3	386.8	2417
2016	128.3	222.3	0.0	0.0	128.3	222.3	350.5	1209
2017	105.8	242.4	0.1	0.0	105.8	242.4	348.2	605
2018	94.3	299.0	0.2	0.0	94.5	299	393.4	600
2019	77.5	256.1	0.0	0.0	77.5	256.1	333.6	450
2020	106.6	190.7	0.0	0.0	106.6	190.7	297.3	450
2021	106.6*	190.7*	0.0*	0.0*	106.6*	190.7*	297.3*	450

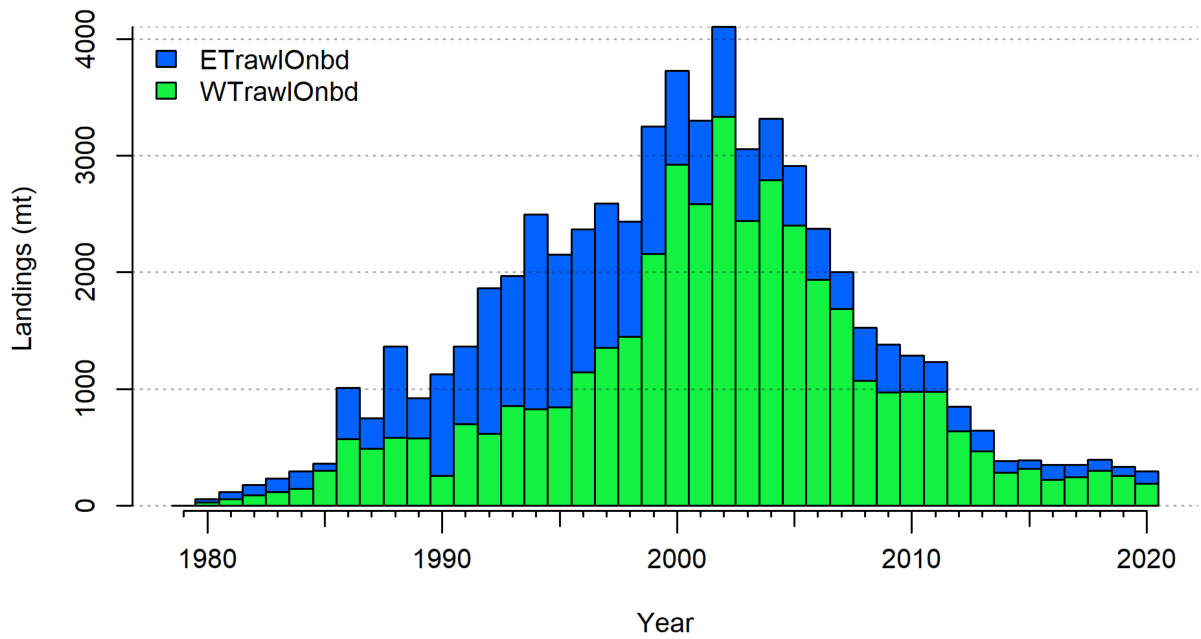

Figure 13.2. Total landed catch by fleet

13.3.2.2 Discard rates

Information on the discarded catches of Silver Warehou are available from the integrated scientific monitoring program (ISMP) for 1993-2020. This program was run by PIRVic from 1992-2006 and by AFMA from 2007 onwards.

Discard tonnage was estimated through the assignment of a retention function. This was defined as a logistic function of length, and the inflection and slope of this function were estimated where discard information was available. In the 2018 assessment two retention functions were estimated, one for each ‘block’ period: namely 1980–2001 and 2002–2020. The first block allows the model to fit discarding across all length classes due to limited markets, while the second block allows the model to fit to size based discarding once markets for the species were established. For the east trawl fleet an additional retention time block was included between 2018 and 2020 to account for an increase in discard estimates over this period. Discarding periods are detailed below:

1980–2001: Market driven discarding

- Discards across all size ranges due to limited markets

2002–2020: Sized based discarding

- Markets for Silver Warehou have been established
- Discarding is mainly of small fish
- Occasional discarding of larger fish due to low market prices

2018–2020: Increased discarding (East trawl fleet only)

- Large increase in discarding in the east trawl fleet (not observed in the west)
- These discards are mainly small fish

Estimated discard fractions in the east were variable with highs of 74% in 1995, 46% in 2004, 38% in 2015 and 43%, 58% and 79% in 2018, 2019 and 2020 respectively (Table 13.3, Figure 13.3). The remainder of estimates in the east trawl fleet were generally below 15% (Table 13.3). In the west estimated discard fractions were generally lower than those in the east with only the 1996-1998 estimates being above 20% (Table 13.3, Figure 13.3). The discarded weights for 1980 to 2020 are displayed in Figure 13.4.

Table 13.3. Discard proportions for east trawl and west trawl fleets from 1993 to 2020 (prop) with sample sizes for each data point (n). Entries in the 'used' columns indicate data that are either used (y) or not used (n) either due to small sample size (less than 10 samples) or because the value is too close to zero (0.01 or less)

YEAR	East trawl PROP	East trawl n	East trawl USED	West trawl PROP	West trawl n	West trawl USED
1992	0.00	6	n	0.00	7	n
1993	0.06	182	y	0.00	52	n
1994	0.02	199	y	0.04	109	y
1995	0.74	123	y	0.05	127	y
1996	0.10	173	y	0.33	120	y
1997	0.12	285	y	0.32	90	y
1998	0.15	174	y	0.40	120	y
1999	0.01	155	n	0.17	121	y
2000	0.09	135	y	0.14	94	y
2001	0.21	228	y	0.09	161	y
2002	0.31	209	y	0.14	184	y
2003	0.31	262	y	0.00	129	n
2004	0.46	343	y	0.13	123	y
2005	0.23	299	y	0.13	263	y
2006	0.09	271	y	0.00	125	n
2007	0.01	53	n	0.06	71	y
2008	0.03	155	y	0.03	143	y
2009	0.03	108	y	0.03	159	y
2010	0.01	106	y	0.02	233	y
2011	0.10	108	y	0.10	229	y
2012	0.04	76	y	0.17	165	y
2013	0.25	70	y	0.02	161	y
2014	0.05	42	y	0.02	57	n
2015	0.37	89	y	0.01	77	y
2016	0.24	121	y	0.02	54	y
2017	0.19	99	y	0.10	78	y
2018	0.43	98	y	0.00	71	n
2019	0.58	149	y	0.18	213	y
2020	0.79	71	y	0.08	416	y

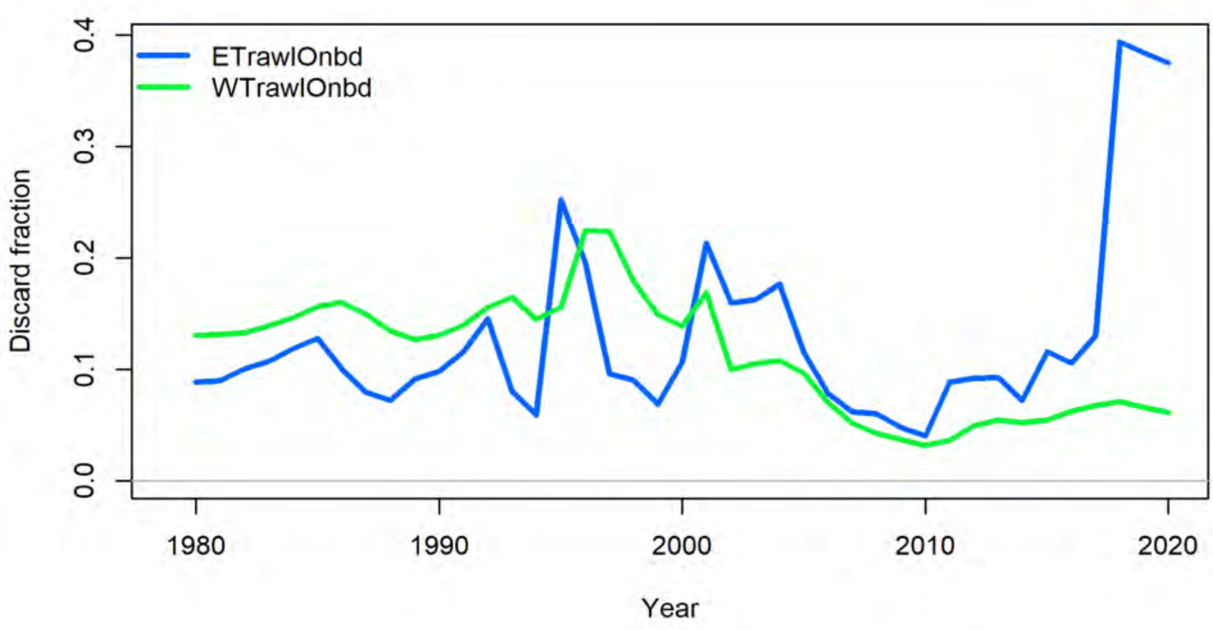

Figure 13.3. Model estimated discards as a proportion of catch by fleet

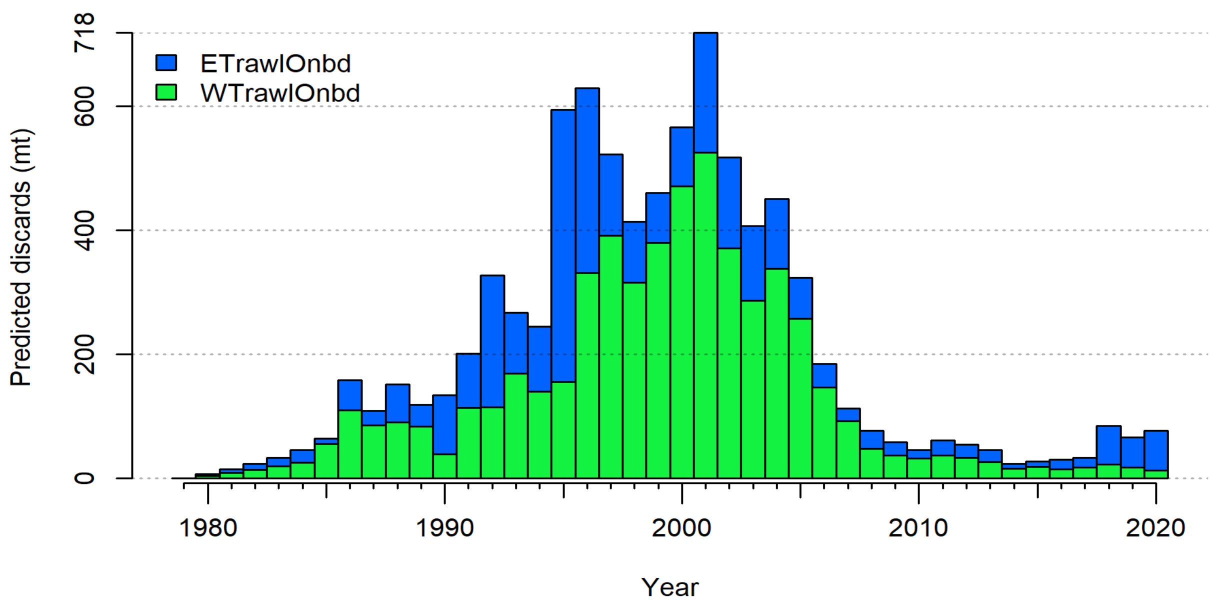

Figure 13.4. Total model estimated discards as weight by fleet

13.3.2.3 Standardised catch rates

Catch and effort data from the SEF1 logbook database from the period 1986 to 2020 were standardised using GLMs to obtain indices of relative abundance (Figure 13.5) (Sporcic 2021). Data used in this standardisation were restricted to trawl shots between 0 and 600 m depth from zones 10, 20 and 30 for the eastern trawl fleet and zones 40 and 50 for the western trawl fleet. The CVs of the CPUE indices were initially set at a value equal to the standard error from a loess fit (east trawl = 0.174, west trawl = 0.178; Sporcic (2021)), before being re-tuned to the model-estimated standard errors within SS.

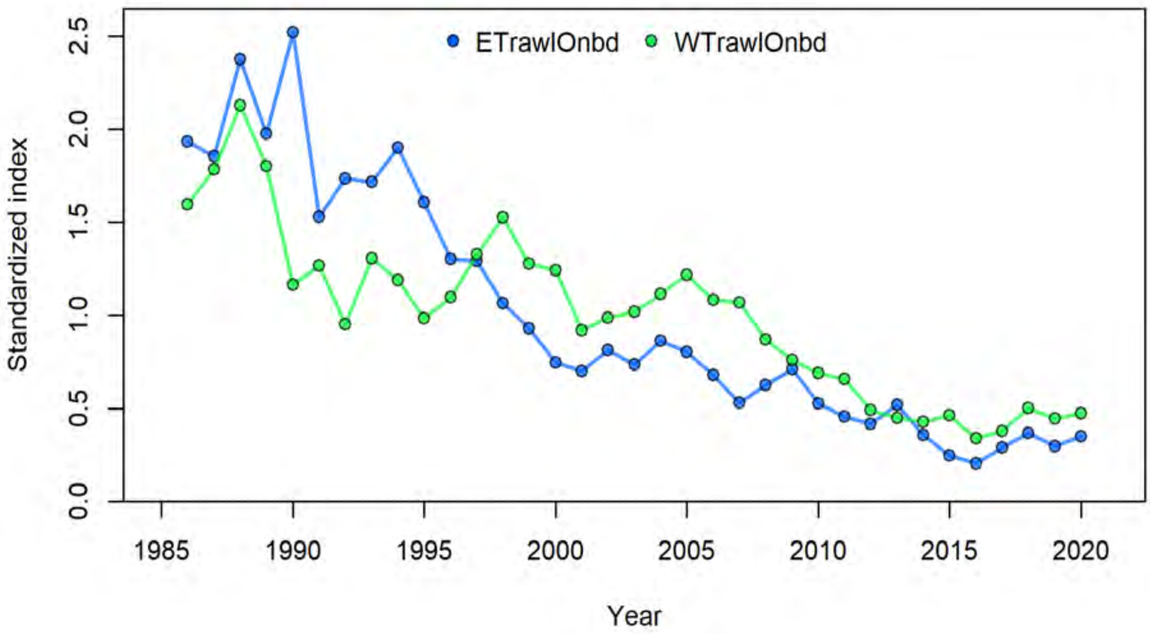

Figure 13.5. Input standardised catch rates for the east and west trawl fleets

13.3.2.4 Length frequencies

Both onboard and port length frequency data was included in the assessment, consistent with previous assessments. These data sources are included separately, with the gear selectivity estimated jointly from both data sets from each fleet (east trawl and west trawl), as is the standard practice in SESSF stock assessments. Onboard data includes length frequencies from both retained and discarded fish, while port length frequencies only contain retained samples.

For onboard data, the number of shots is used as the initial sample size before the length frequency data are re-weighted in the tuning process. This is considered more representative of the true sample size than the number of fish measured (Francis, 2011). For port data, the number of shots is not available, but the number of trips is used instead. Data was excluded for years with less than 100 individual fish measured per fleet, as small samples are potentially unrepresentative.

Length composition data from onboard samples is available from 1993-2019 for retained east trawl samples, 1993-2020 for discarded east trawl samples, 1996-2020 for retained west trawl samples and 1992-2020 for discarded west trawl samples (Table 13.4, Table 13.5). Port samples were available between 1991-2020 for the east trawl fleet and 1992-2017 for the west trawl fleet (Table 13.4, Table 13.5).

Sample sizes for retained length frequencies, including both the number of individuals measured and numbers of shots or trips, are listed in Table 13.4 for the east trawl fleet and Table 13.5 for the west trawl fleet.

Table 13.4. Number of retained lengths, shots and trips included in the base case assessment for the east trawl fleet. Samples with less than 100 fish measured were not included in the assessment and are denoted with a *.

YEAR	ONBOARD DISCARD: LENGTHS	ONBOARD DISCARD: SHOTS	ONBOARD RETAINED: LENGTHS	ONBOARD RETAINED: SHOTS	PORT: LENGTHS	PORT: TRIPS
1991	0*	0	0*	0	273	4
1992	0*	0	0*	0	1,648	9
1993	290	5	225	2	1,087	6
1994	136	4	172	2	215	4
1995	706	15	142	2	500	5
1996	382	4	293	4	1,014	10
1997	234	3	1,585	19	1,762	18
1998	79*	1	3,060	33	6,386	63
1999	10*	1	2,449	32	6,347	68
2000	210	3	1,642	17	8,239	48
2001	888	9	1,446	17	7,958	61
2002	1,805	20	2,554	23	12,978	80
2003	1,597	19	2,050	29	5,431	37
2004	3,319	44	2,749	29	4,980	35
2005	1,332	19	2,028	25	10,147	46
2006	140	5	1,923	25	7,994	49
2007	0*	0	727	26	2,206	13
2008	298	12	584	21	971	6
2009	127	2	397	12	2,650	44
2010	174	7	1,419	30	1,714	50
2011	159	8	371	16	2,038	65
2012	471	13	848	32	1,748	45
2013	109	7	731	22	1,919	43
2014	163	2	142	4	1,391	25
2015	337	10	282	11	1,844	28
2016	518	16	452	14	1,516	20
2017	465	17	404	12	1,861	28
2018	593	16	321	6	1,229	20
2019	1,378	35	541	20	1,044	20
2020	634	23	5*	1	1,702	36

Table 13.5. Number of retained lengths, shots and trips included in the base case assessment for the west trawl fleet. Samples with less than 100 fish measured were not included in the assessment and are denoted with a *.

YEAR	ONBOARD DISCARD: LENGTHS	ONBOARD DISCARD: SHOTS	ONBOARD RETAINED: LENGTHS	ONBOARD RETAINED: SHOTS	PORT: LENGTHS	PORT: TRIPS
1991	0*	0	0*	0	51*	1
1992	158	1	0*	0	1,769	15
1993	243	6	0*	0	1,742	14
1994	2,401	25	0*	0	1,802	22
1995	4,082	35	0*	0	4,651	37
1996	3,766	31	122	1	6,023	53
1997	232	2	1,883	18	8,874	82
1998	1,998	16	2,671	20	9,704	89
1999	477	4	1,952	17	7,849	77
2000	283	4	3,698	33	5,424	47
2001	1,371	11	4,743	34	6,978	69
2002	1,257	8	4,047	26	9,064	72
2003	193	5	5,174	45	3,455	29
2004	1,111	9	3,788	27	2,760	24
2005	658	7	6,617	52	3,319	28
2006	0*	0	3,763	32	855	9
2007	0*	0	147	11	491	2
2008	36*	3	808	25	0*	0
2009	95*	2	1,021	41	333	5
2010	89*	3	1,341	39	47*	1
2011	152	10	1,242	51	0*	0
2012	6*	1	991	31	0*	0
2013	189	6	1,696	48	141	1
2014	0*		900	17	152	2
2015	66	4	934	24	0*	0
2016	2*	2	656	33	240	10
2017	723	8	549	17	226	5
2018	0*	0	1,094	15	69*	1
2019	86*	5	1,905	74	0*	0
2020	276	7	2,704	119	0*	0

13.3.2.5 Conditional age at length

Age-at-length measurements, based on sectioned otoliths, were available for 1993-2020 for the east trawl fleet and 1988, 1993-2020 for the west trawl fleet, with the number of aged otoliths available for the assessment presented in Table 13.6.

Table 13.6. Number of conditional age-at-length samples in the base case assessment

YEAR	EAST	WEST	TOTAL
1988	0	132	132
1993	172	163	335
1994	186	173	359
1995	157	294	451
1996	317	198	515
1997	443	123	566
1998	404	181	585
1999	220	562	782
2000	139	267	406
2001	366	631	997
2002	327	395	722
2003	122	302	424
2004	126	512	638
2005	250	375	625
2006	132	261	393
2007	237	69	306
2008	313	234	547
2009	493	345	838
2010	687	135	822
2011	543	309	852
2012	659	214	873
2013	89	383	472
2014	153	139	292
2015	165	218	383
2016	206	273	479
2017	220	316	536
2018	118	13	131
2019	414	475	889
2020	371	510	881

13.3.2.6 Age-reading error

An estimate of the standard deviation of age-reading error for the entire fishery (east and west combined) was calculated by Paul Burch (pers. comm. 2021) using data supplied by Kyne Krusic-Golub of Fish Ageing Services Pty Ltd using a variant of the method of Richards et al. (1992) (Table 13.7).

Table 13.7. Standard deviation (SD) of age reading error

AGE	SD
0	0.170607
1	0.170607
2	0.229462
3	0.290210
4	0.352911
5	0.417629
6	0.484427
7	0.553373
8	0.624537
9	0.697988
10	0.773802
11	0.852053
12	0.932821
13	1.016190
14	1.102230
15	1.191040
16	1.282710
17	1.377330
18	1.474980
19	1.575780
20	1.679820
21	1.787210
22	1.898040
23	2.012440

13.3.3 *Tuning method*

Iterative 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 inputs (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 data 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 apparently 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 length composition data and the approach of Punt (2017) for conditional age-at-length 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. 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 fleet, retained status and year were excluded.

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). This is done by:

1. Set the standard error for the log of relative abundance indices (CPUE) 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. SS-V3.30 then allows an estimate to be made for an additional adjustment to 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 Silver Warehou. 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 iterative tuning procedure was used for the remaining adjustments. For the conditional age-at-length 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 3–4, until all are converged and stable (proposed changes < 1%).

This procedure constitutes current best practice for tuning assessments, however, it may be amended in the future.

13.3.4 *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 total allowable catches (TACs) in the SESSF quota management system from 2006 onwards. The HSF uses harvest control rules (HCRs) to determine a recommended biological catch (RBC) for each stock in the SESSF quota management system. Each stock is assigned to a Tier level depending on the quality and quantity of data for that stock. Silver Warehou is assessed as a Tier 1 stock as it has an agreed quantitative stock assessment.

The Tier 1 HCR specifies a target and a limit biomass reference point, as well as a target fishing mortality rate. In 2009, AFMA directed that the 20:35:48 (B_{lim}: B_{break}: F_{targ}) form of the rule is used, assuming a F_{targ} of F_{48}, the default economic target for B_{MEY} in the SESSF.

13.3.5 *Low recruitment scenario*

Estimates of recruitment strength for Silver Warehou have been below average since the early 2000s, potentially as a consequence of directional environmental change. If this below average recruitment trend continues into the future, assuming a return to average recruitment would result in overly optimistic biomass and stock status estimates. Due to these concerns the base case for this assessment incorporates low, rather than average, recruitment projected into the future. The projected value is based on the average recruitment deviations between 2011 and 2015 (average = -0.64).

13.3.6 *Retrospective analyses*

A retrospective analysis (Cadrin and Vaughan, 1997; Mohn, 1999) has been undertaken to identify whether below average recruitment and declining stock size would have been identified by previous assessments using the same assumptions, data and tuning as this assessment.

The retrospective analysis was undertaken using the following procedure:

1. One year of data was removed sequentially from the 2021 base case assessment;
2. Time dependent model parameters (e.g. last year of recruitment) were changed to be one year earlier;
3. The model was run to determine stock status estimates when less data is available;
4. Steps 1–3 were repeated for five subsequent years.

Trends in spawning biomass and estimated recruitment are then examined to help understand how reliable the most recent few years of estimated recruitments and spawning biomass are in the current assessment. The severity of retrospective patterns can be quantified using a statistic called Mohn's rho, which is defined as the average of the relative differences between an estimate from an assessment with a truncated time series and an estimate of the same quantity from an assessment using the full time series (Hurtado-Ferro et al., 2015). Mohn's rho values are calculated for a range of effects, including SSB, recruitment, F and stock status. As a general rule of thumb values of Mohn's rho higher than 0.20 or lower than −0.15 are cause for concern in an assessment (Hurtado-Ferro et al., 2015).

13.3.7 *Likelihood profiles*

Likelihood profiles are a standard component of the toolbox of applied statisticians and are most often used to obtain a 95% confidence interval for a parameter of interest (Punt, 2018). Many stock assessments "fix" key parameters such as natural mortality 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 range of the 95% confidence interval of the total likelihood profile, this provides no support from the data to change the fixed value. If the fixed value is outside the 95% confidence interval, and there is evidence that the data holds information about this parameter, 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 should 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 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).

13.3.8 *Jitter analyses*

Jitter analysis is a technique used to test the optimality, robustness and stability of the maximum likelihood estimate obtained for a particular model. This involves randomly changing the starting values used for all estimated parameters and re-running the model, to test what alternative solutions may be found by the optimisation algorithm from different initial locations, which is sometimes referred to as sensitivity to initial conditions. Two diagnostics are of interest with a jitter analysis, initially a check on whether a better "optimal solution" may be found, with a higher likelihood value, and also to see how frequently the optimal solution is found. As all estimated parameters are randomly modified, or "jittered," simultaneously, this can sometimes result in a model either failing to converge or finding a local maximum in a different (suboptimal) part of the multi-dimensional parameter space. A jitter analysis was conducted with 25 replications, modifying initial values by 0.1.

13.3.9 *Sensitivity tests*

A number of standard sensitivity tests are used to examine the sensitivity of the results of the 2021 base case to some of the assumptions and data inputs:

a) M = 0.25 and 0.35 yr^{-1}.

b) h = 0.65, 0.85 and estimated.

c) 50% maturity occurs at length 34 and 40 cm.

d) σ_R = 0.6 and 0.8.

e) Double and halve the weighting on the CPUE series.

f) Double and halve the weighting on the length composition data.

g) Double and halve the weighting on the age-at-length data.

h) The assessment with average recruitment projections.

The results of the sensitivity tests are summarized by the following quantities:

1. SSB_0: the average unexploited female spawning biomass.
2. SSB_{2022}: the female spawning biomass at the start of 2022.
3. SSB_{2022}/SSB_0: the female spawning biomass depletion level at the start of 2022.

13.4 Results

13.4.1 *The base case assessment model*

The development of a preliminary base case, and a bridging analysis from the 2018 assessment (Burch et al., 2018), was presented at the September 2021 SERAG 1 meeting (Bessell-Browne, 2021), including updating the version of Stock Synthesis and sequentially updating data. This bridging analysis is not repeated in this report.

13.4.1.1 Parameter estimates

Figure 13.6 shows the estimated growth curve for Silver Warehou. L_∞ or the average maximum length was estimated to be 51.3 cm, with the upper confidence interval estimated at around 60 cm, while the lower interval was around 42 cm (Figure 13.6). The length at a_{min} was estimated at 14.1 cm for one year olds (Figure 13.6). The κ parameter of the von Bertalanffy growth equation is estimated to be 0.30.

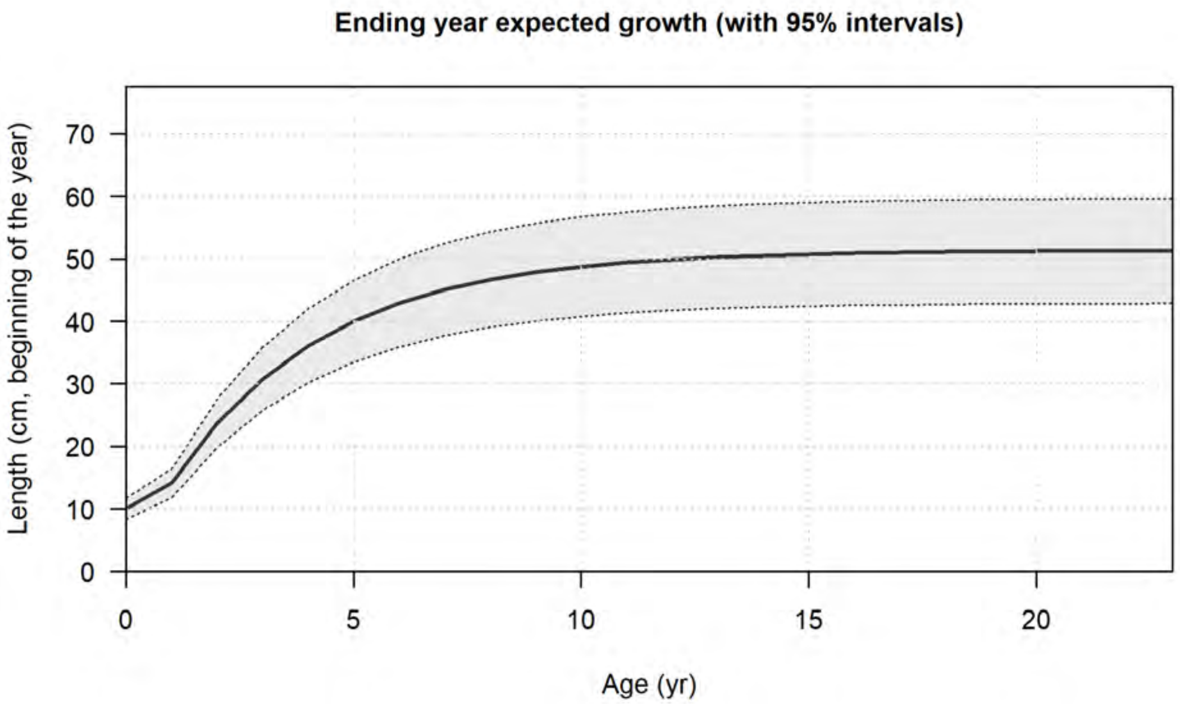

Figure 13.6. The model estimated growth curve, with 95% confidence intervals

Selectivity is assumed to be logistic and to differ between the two 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 selectivity curve estimated by the model is displayed in Figure 13.7, with parameter estimates specified in Table 13.8. Separate retention functions were estimated for each fleet to allow for different discarding practices. The two estimated retention functions are displayed in Figure 13.8 and Figure 13.9.

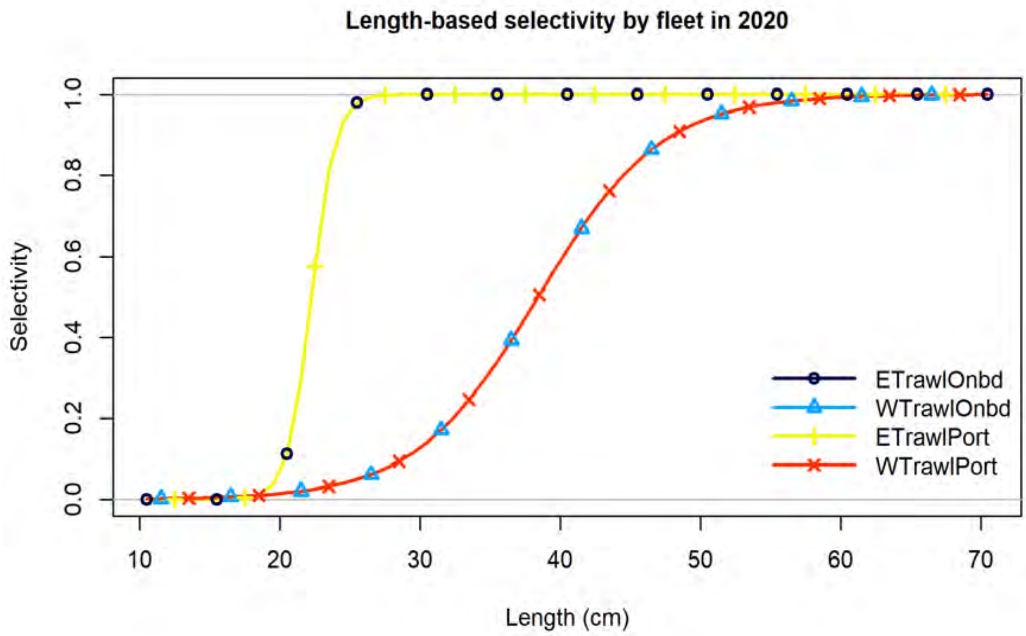

Figure 13.7. Estimated selectivity curves

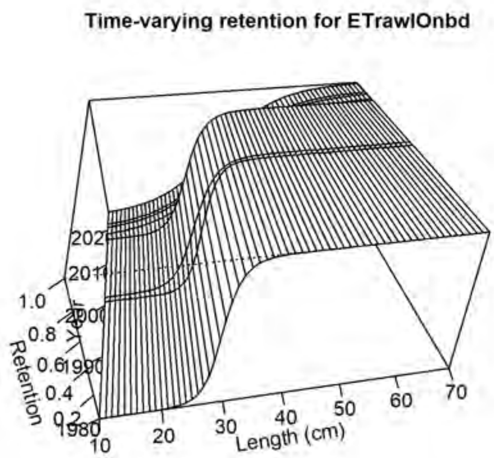

Figure 13.8. Estimated retention for the east trawl fleet

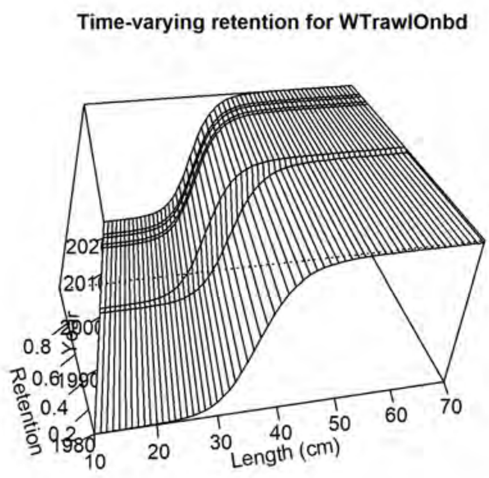

Figure 13.9. Estimated retention for the west trawl fleet

Parameters estimated within the model are presented in Table 13.8.

Table 13.8. Parameter values estimated by the base-case model

Parameter	Value
L_at_amin	14.12
L_at_amax	51.30
VonBert_K	0.30
CV_young	0.08
Q_EastTrawl	9.40
Q_WestTrawl	-0.02
Size inflection Etrawl	22.24
Size 95% width Etrawl	2.50
Size inflection Wtrawl	38.40
Size 95% width Wtrawl	12.91

13.4.1.2 Fits to data

The results from this model show good fits to CPUE abundance indices for both fleets (Figure 13.10, Figure 13.11). These fits are similar to those observed in the 2018 assessment, however, fits to the start of the west trawl series have improved. The model estimates an additional standard error on top of that input for the east trawl fleet, suggesting higher variability associated with this series than the standardisation suggested (Figure 13.10). The opposite trend is observed for the west trawl fleet, where a smaller standard deviation was estimated than that of the loess fit (Figure 13.11).

The model is also unable to fit the high east trawl CPUE estimates between 1985 and 1995, which suggest there was a larger decline in abundance in the early 1990s and 2000s than the model suggests (Figure 13.10). Residuals of the fits to CPUE for the east trawl fleet show potential problems, with all residuals above zero prior to 1995, residuals between 1996 and 2008 are then all below zero and a mix of points above and below zero are only observed from 2010 (Figure 13.12). In contrast the residuals of the fit to the west trawl CPUE are well mixed above and below zero suggesting good fits to the data (Figure 13.13). This discrepancy between residual fits between the two fleets is not unexpected as the model is fitting to the two series simultaneously and this appears to be the best compromise under this constraint.

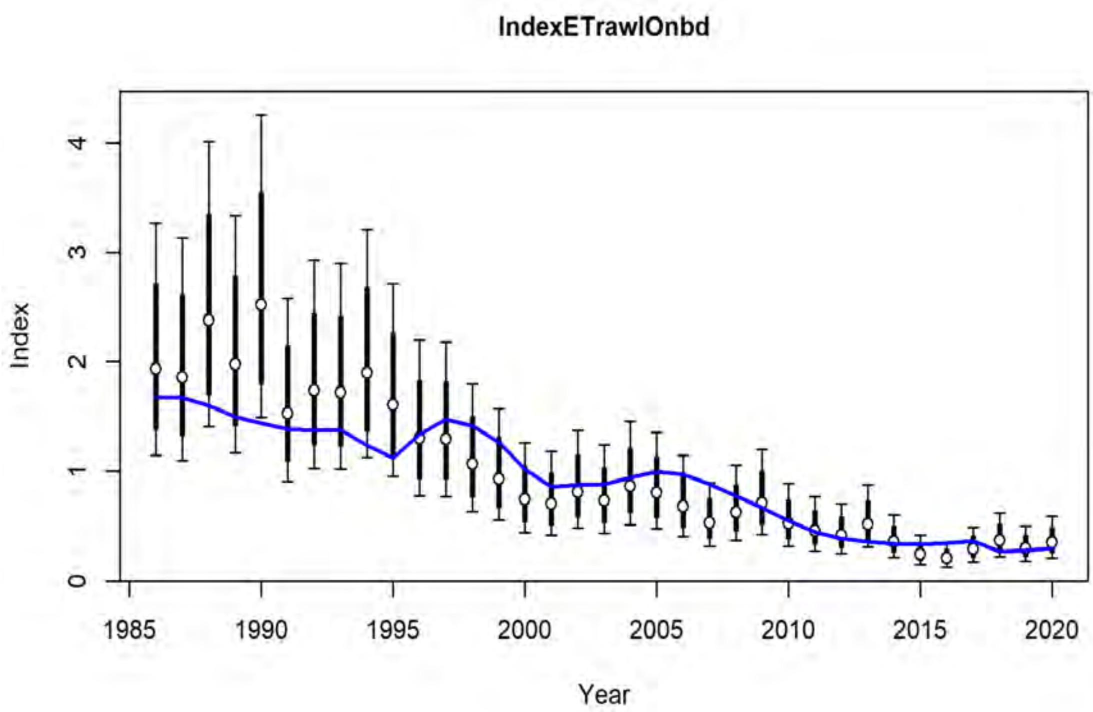

Figure 13.10. Fits to the east trawl CPUE

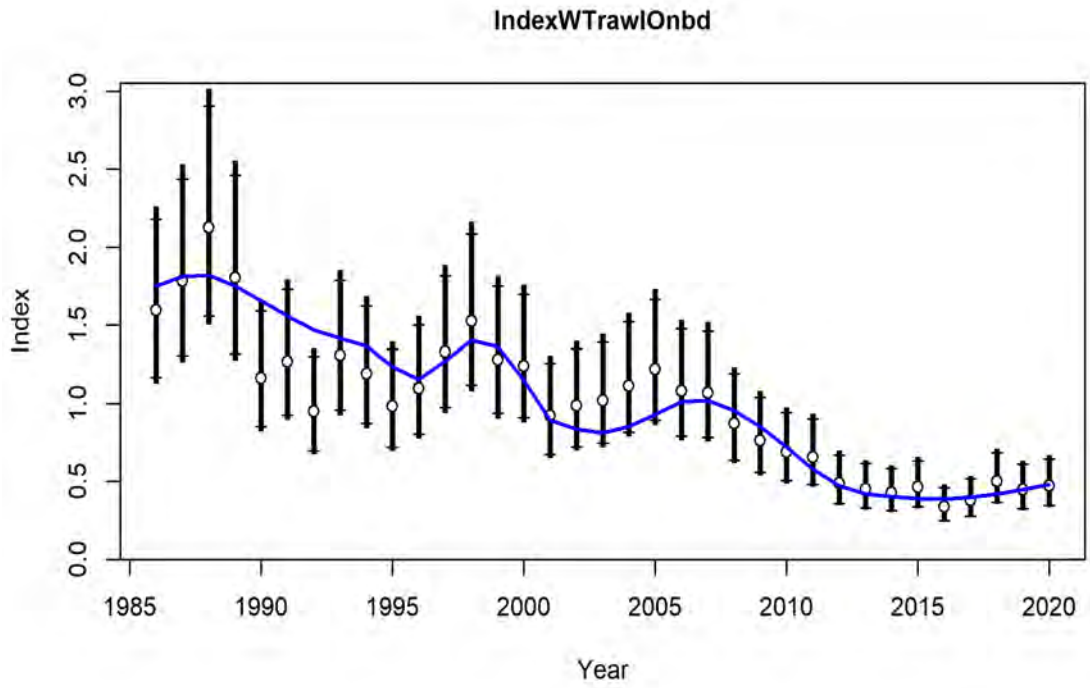

Figure 13.11. Fits to the west trawl CPUE

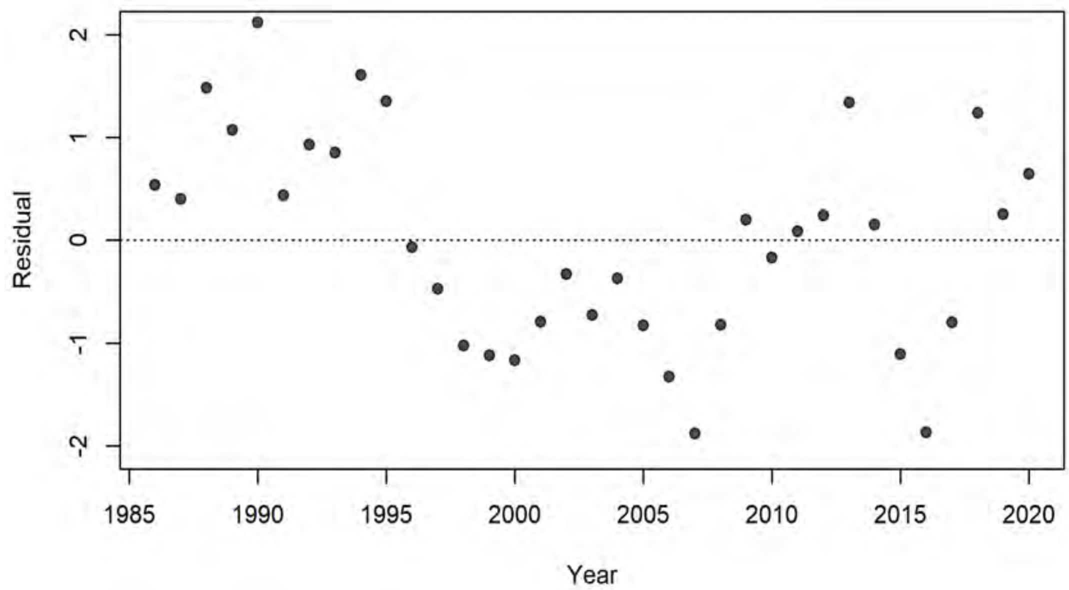

Figure 13.12. Residuals for fits to CPUE for the east trawl fleet

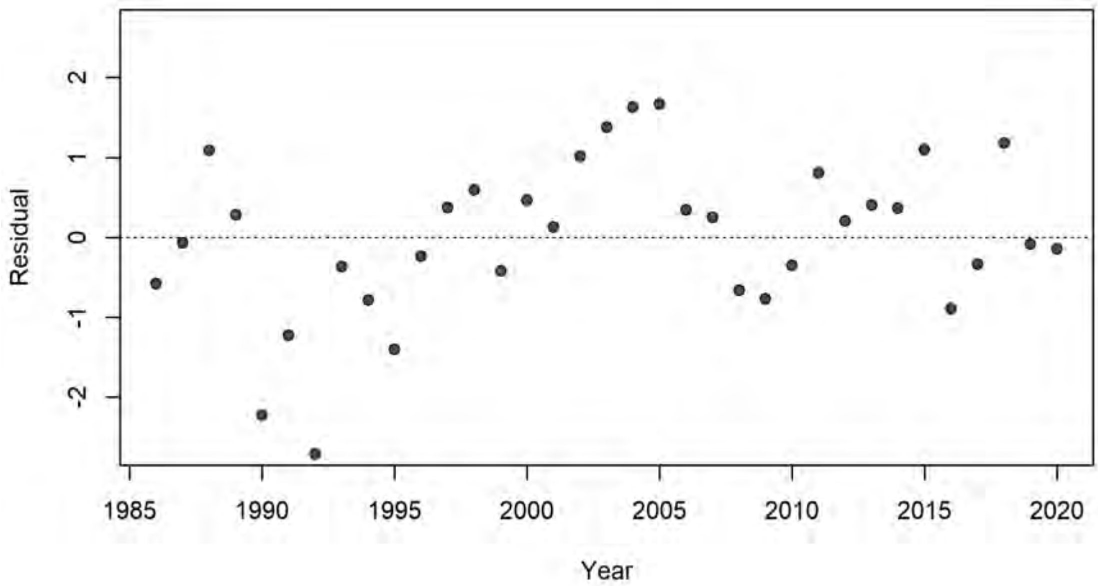

Figure 13.13. Residuals for fits to CPUE for the west trawl fleet

The fits to the discard rate data are reasonable given the variability in the data. Discard data in the east trawl fleet fit more closely than observed in previous assessments, although it is still not fitting the highest east trawl estimates in 1995 and 2020 (Figure 13.14). Fits to discard data in the west are similar to those observed in previous assessments and fit the data reasonably well (Figure 13.15). Generally discarding in the west trawl fleet has been lower and less variable than that observed in the east trawl fleet (Figure 13.14-Figure 13.15).

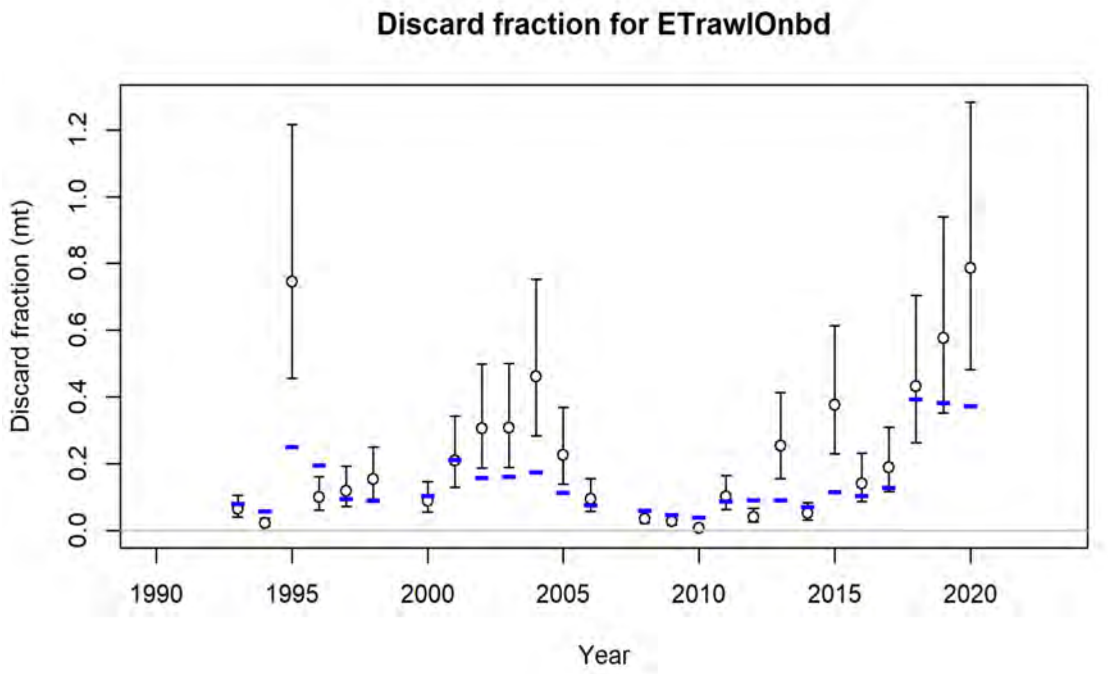

Figure 13.14. Fits to the east trawl discards

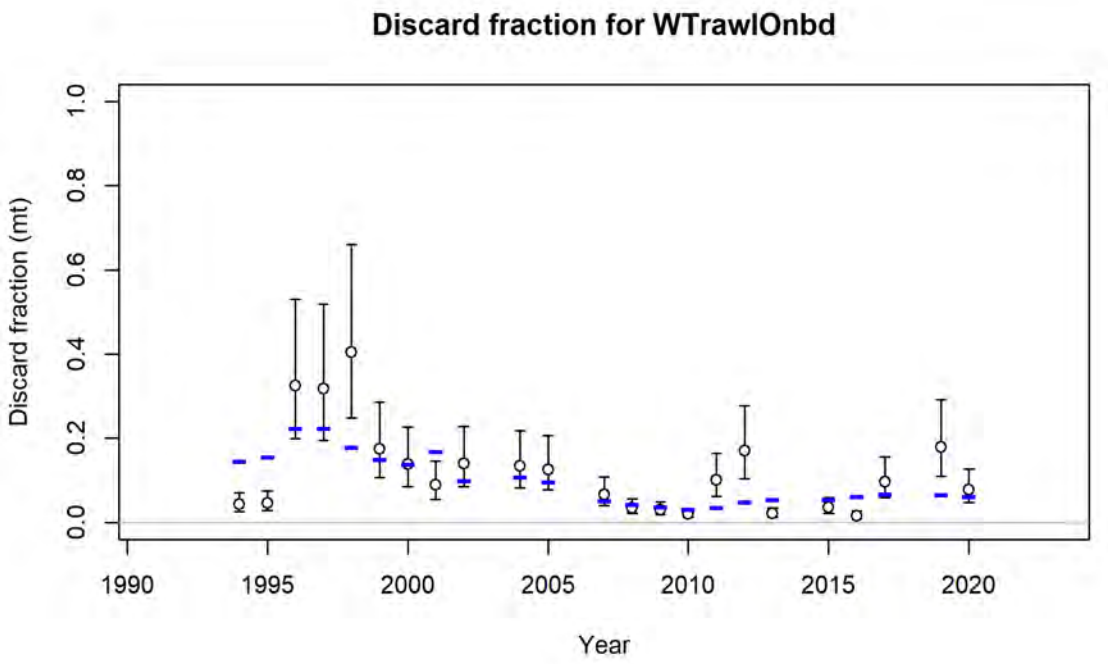

Figure 13.15. Fits to the west trawl discards

As with previous models, fits to the aggregated length frequencies are poor across both fleets (Figure 13.16). These poor fits are driven by highly variable length frequencies, often showing multiple modes in the distributions that are not consistent from one year to the next (Figure 13.16). This is most likely due to unrepresentative spatial and temporal sampling of this schooling species. The estimated length frequencies are also not able to fit the small fish that were observed across both fleets over the past five years. Fits to individual years of length frequency data by fleet and sampling type are presented in Figure 13.49–Figure 13.54, while residual patterns are presented in Figure 13.55.

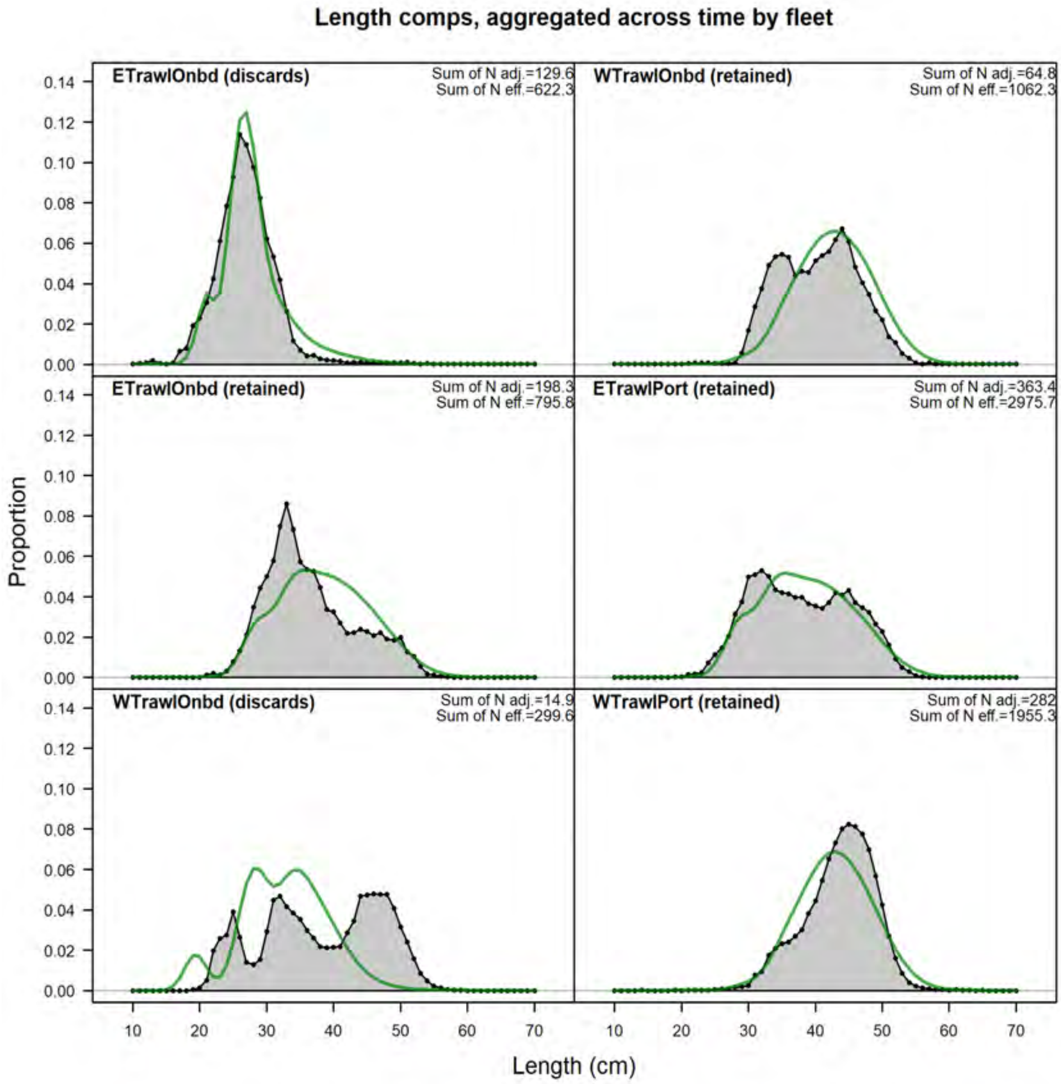

Figure 13.16. Fits to the aggregated length data

Fits to the conditional age at length data are good, with fits for individual years presented in Figure 13.56–Figure 13.67. The mean age varies between two and six years for east trawl fish and three and six for west trawl fish, however since 1993 this range has been between four and six (Figure 13.68–Figure 13.69). Residuals for these fits and mean age for each year are shown in Figure 13.70–Figure 13.73.

13.4.1.3 Likelihood components

The contributions to the total negative log likelihood by fleet and data source is shown in Table 13.9. This gives an indication of the contribution to the total negative log likelihood from different data components. These likelihood components decrease as the fit improves yet increase as the number of data points used for this fit increases, so a direct comparison is not always useful. Both east trawl and west trawl CPUE series have the same number of data points so comparisons are available, with the west trawl showing a lower negative log likelihood and therefore a better fit to the data than the east trawl fleet (Table 13.9). For the discard data, different numbers of data points are available for each fleet so comparisons are not directly available. For the length data there is clearly much poorer fits to the east trawl onboard data than observed for the east trawl port data and also west trawl onboard and port data (Table 13.9). For the age data, the east trawl fleets shows improved fits when compared to the west trawl fleet (Table 13.9).

Table 13.9. Negative log likelihood contributions by fleet and data source

Fleet	CPUE	Discard	Length	Age
East trawl (onboard)	-27.4	65.1	172.5	124.5
East trawl (port)			66.6	
West trawl (onboard)	-49.6	59.5	46.7	199.4
West trawl (port)			46.3	

13.4.1.4 Assessment outcomes

This assessment estimates that the projected 2022 spawning stock biomass will be 29% of SSB_0 (projected assuming 2020 catches in 2021; Figure 13.17), compared to 31% at the start of 2019 from the 2018 assessment (Burch et al., 2018). Moving to the model with low recruitment projections as the base case for this assessment has been the main driver of this downward revision of stock status.

Between 2013 and 2018 estimated biomass was close to the limit reference point and only in the past three years has stock status increased towards the target reference point, with this particularly concerning when error around estimates is considered (Figure 13.17). It is likely that this increase in stock status has been driven by decreases in catch below TAC levels.

The base case assessment estimated the unexploited spawning stock biomass, SSB_0, to be 18,806 t (Figure 13.18). This decreases to 5,374 t by 2022 (Figure 13.18).

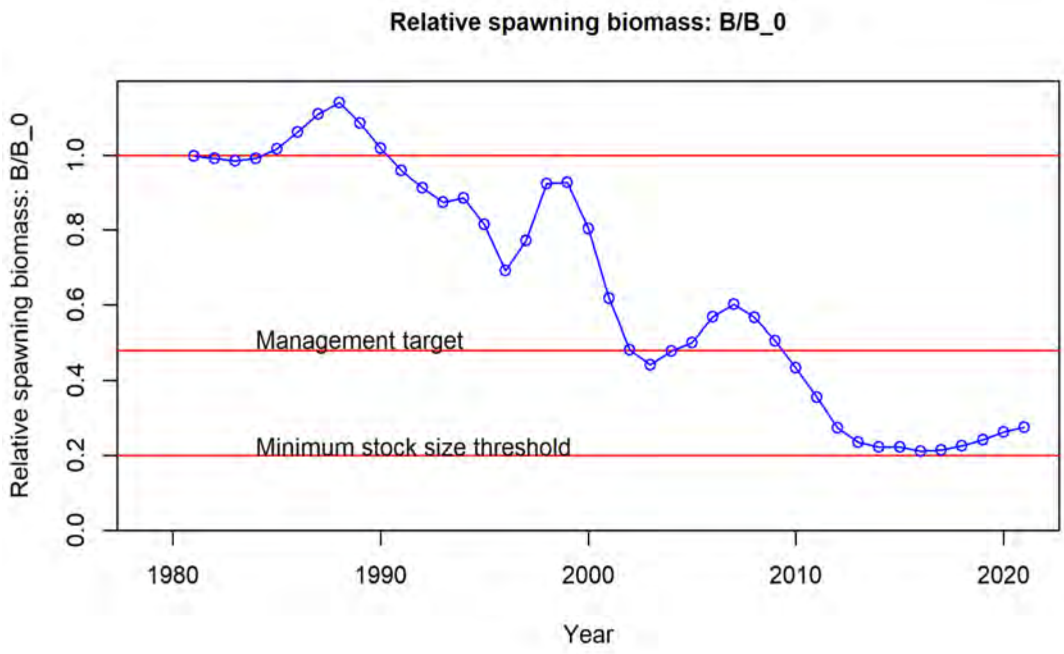

Figure 13.17. The estimated time-series of relative spawning biomass

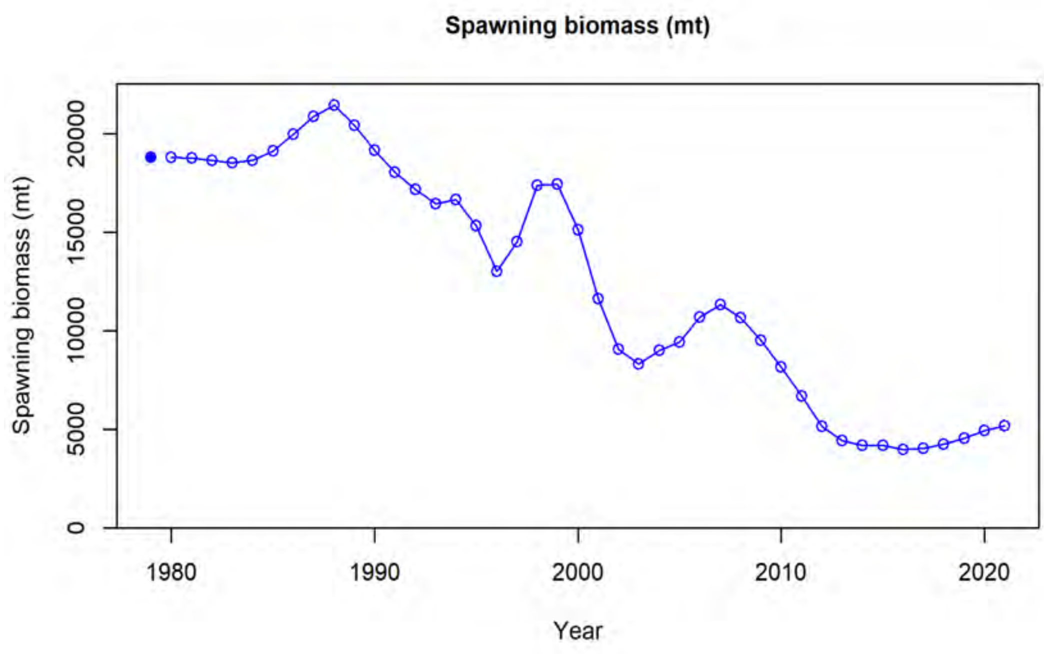

Figure 13.18. The estimated time-series of absolute spawning biomass

Recruitments show a fluctuating pattern, with a recent period of poor, below average, recruitment from 2004 to the last estimated recruitment in 2015. The 2015 and 2013 recruitments are closer to the average, however, previous assessment have highlighted that recruitment deviations at the end of the series are often revised downwards with the inclusion of additional years of data so these should be interpreted with caution (Figure 13.19, Figure 13.20).

The estimated stock recruitment curve demonstrates the relationship between the size of the population and the number of recruits produced in a year. The relationship shows that at the start of the time series, between 1975 and 1980, the spawning biomass was large and many recruits were produced (Figure 13.21). This was followed by a period of reduced spawning biomass but high recruitment between 1990 and 2000 (Figure 13.21). Since 2000, both spawning biomass and recruitment have been low (Figure 13.21).

The variance associated with estimation of recruitment deviations is shown in Figure 13.23. Between 1970 and 1990 there is a gradual decline in variance as more data is available to the model to inform estimation (Figure 13.23). The variance between 1990 and 2015 at the end of the recruitment deviation time series is relatively stable, suggesting that the model has sufficient information to inform the estimation of these deviations (Figure 13.23).

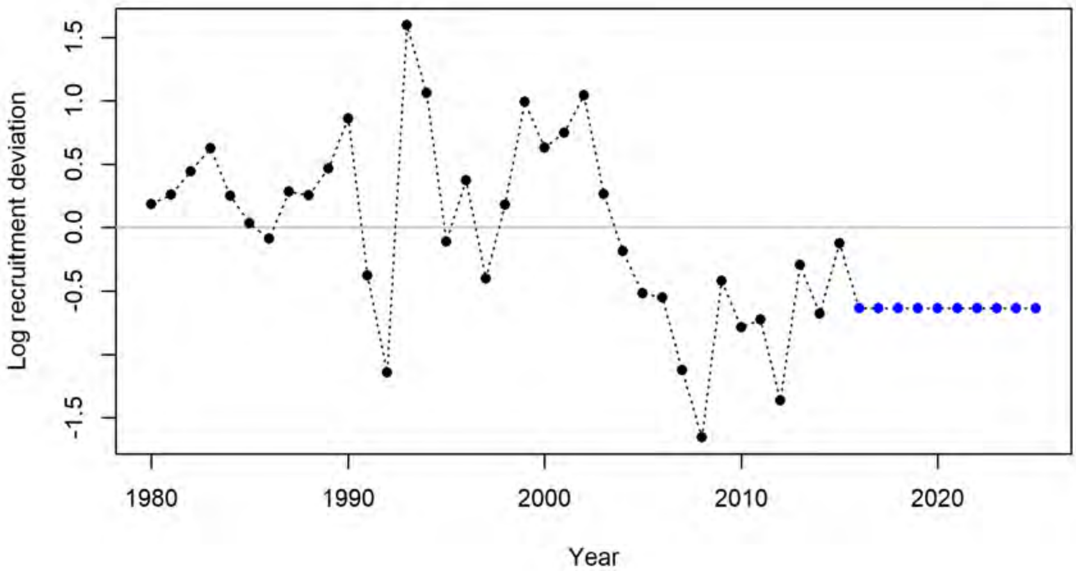

Figure 13.19. Estimated recruitment deviations

Figure 13.20. Absolute recruitment estimates

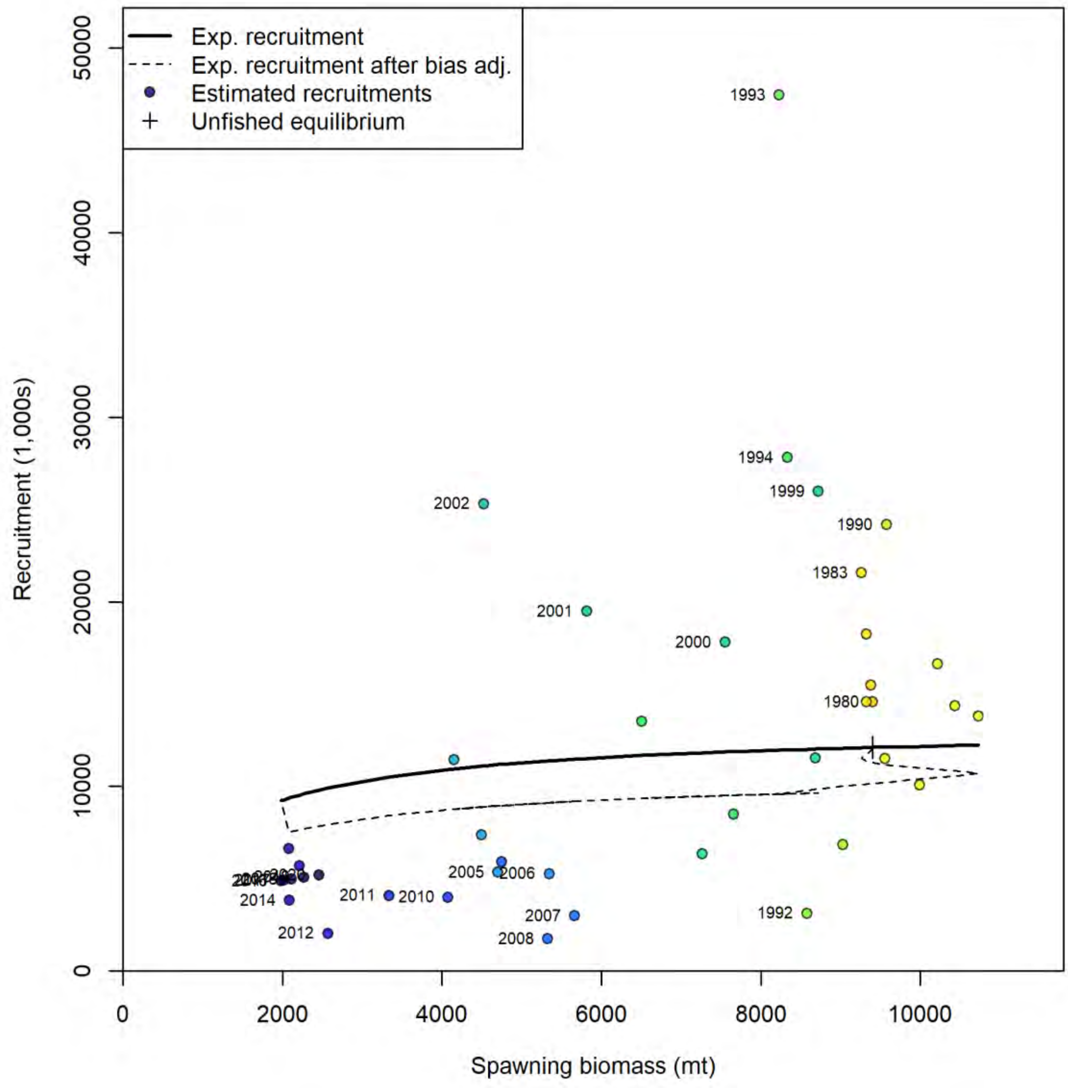

Figure 13.21. Stock recruitment curve

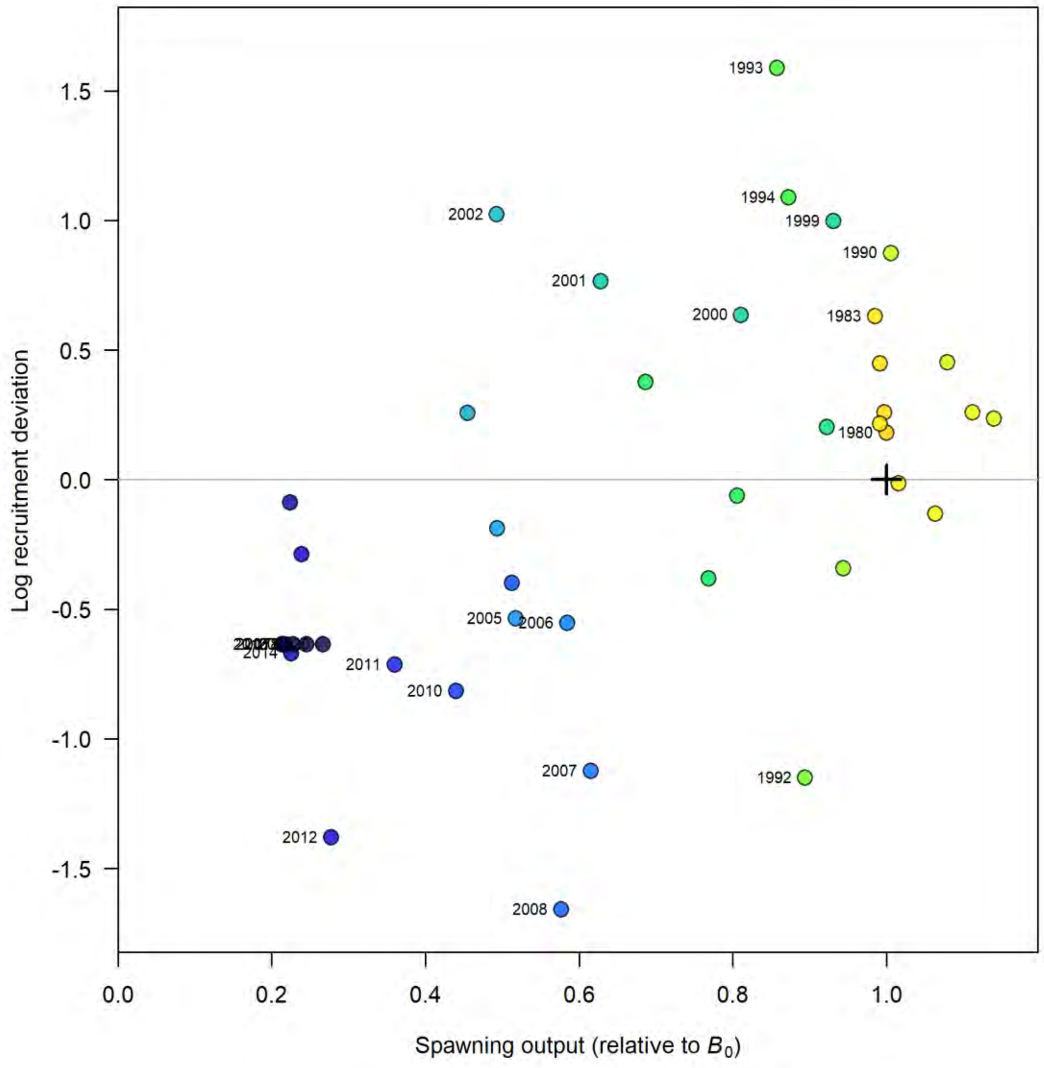

Figure 13.22. Residuals from the stock recruitment curve

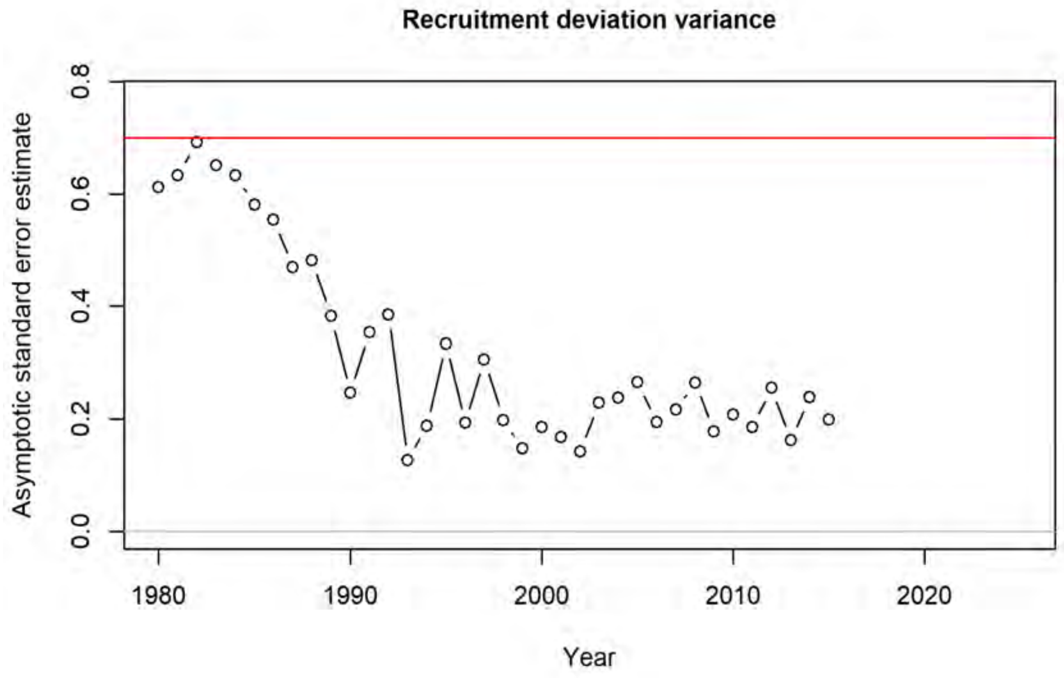

Figure 13.23. Recruitment deviation variance check

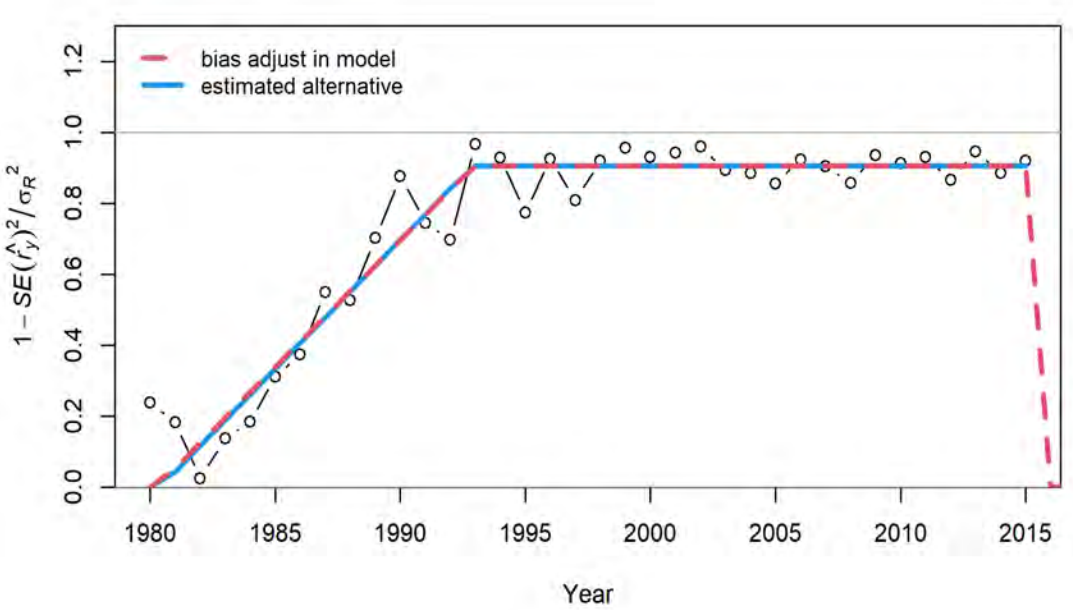

Figure 13.24. Recruitment deviation bias ramp adjustment

Figure 13.25 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. The assessment starts in the bottom right corner, when there was low fishing mortality and high biomass, fishing pressure then increased to around target levels, resulting in a decline in biomass, before fishing pressures dropped for a period before stabilising around the target and then falling to below the target with a small increase in biomass in the last few years (Figure 13.25).

The relationship between fishing pressure and time is presented in Figure 13.26, demonstrating that fishing pressure has been above the target from the late 1990s to the late 2000s. For the past eight years fishing pressure has dropped below the target level (Figure 13.26).

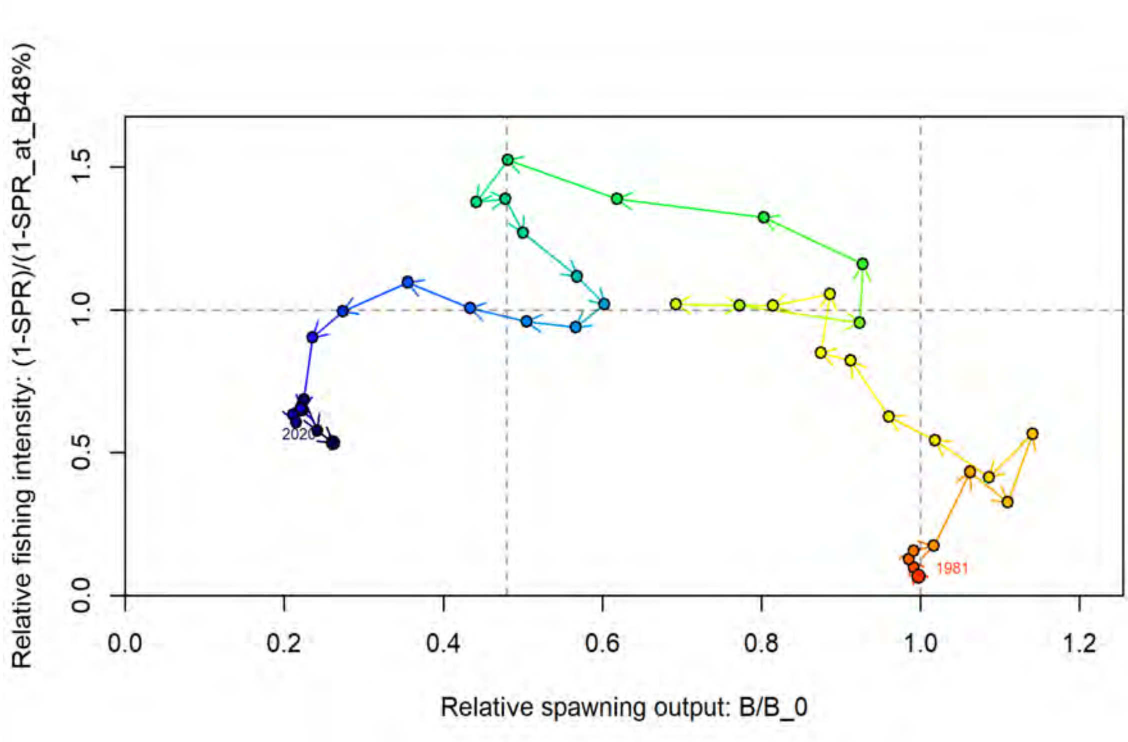

Figure 13.25. Kobe plot of biomass vs SPR ratio, the grey, horizontal dashed line represents the target fishing mortality, while the two vertical dashed lines represent the target and unfished spawning biomass respectively from left to right

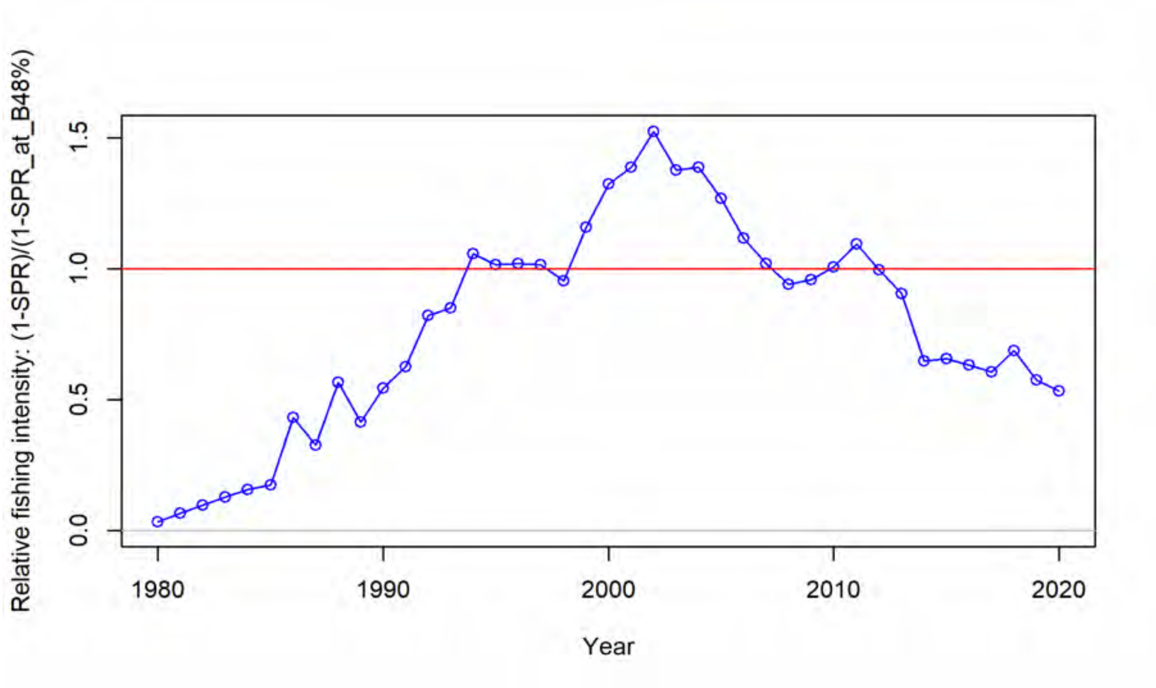

Figure 13.26. SPR ratio through time, the red line represents the target fishing mortality and each point is a year in the model, starting on the left hand side of the figure at 1980

13.4.2 *Application of the HCR*

An estimate of the catch for the 2021 calendar year is needed to run the model forward to calculate the 2022 spawning biomass and estimated stock status. We assume the same catch in 2021 as was caught in 2020, which was 375 t. The assessment estimates the 2022 stock status to be 29% of SSB_0 (Figure 13.27). Stock status was below 23% between 2015 and 2018, and was as low as 21% in 2016, close to the limit reference point of 20% of SSB_0 (Figure 13.27).

Figure 13.27 demonstrates that the application of the current HCR does not increase the stock size to the target reference point of 48% SSB_0. This is because the current HCR assumes that future recruitment will be at average levels, whereas the accepted base case for this assessment projects forward below average recruitment.

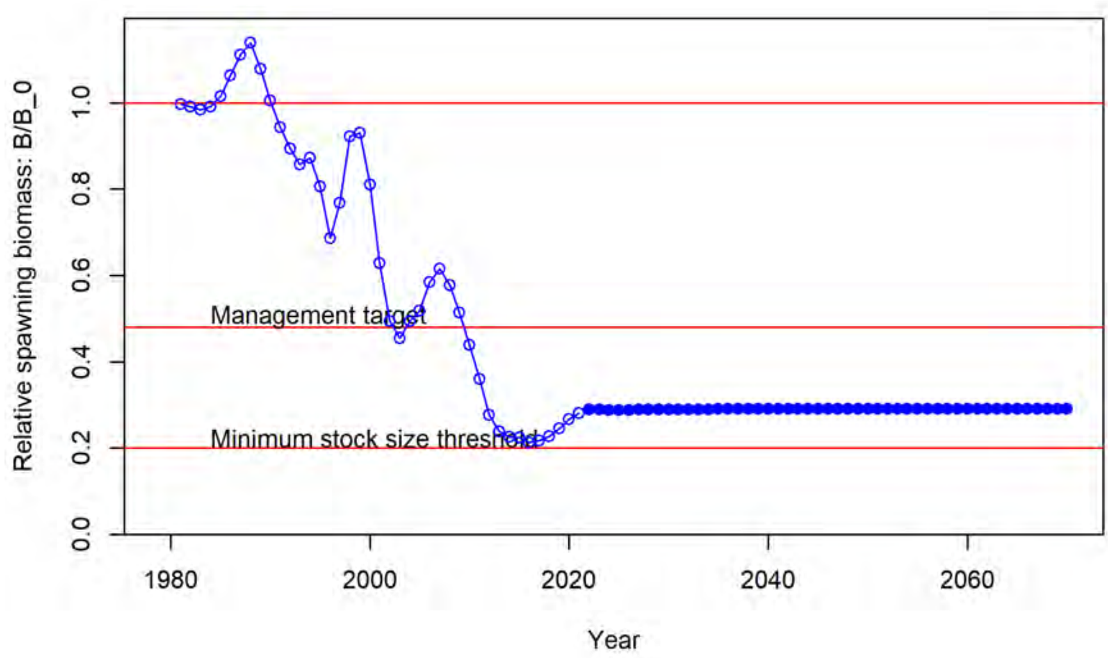

Figure 13.27. The estimated time-series of relative spawning biomass with projections applying the HCR to 2070

The predicted RBCs resulting from the application of the HCR, along with stock status estimates and retained catch and discards are presented in Table 13.10 from 2022 to 2025, with estimates of stock status, retained catch and discard estimates provided for 2018 to 2025.

Table 13.10. Summary of estimated stock status, RBCs and estimated discard mass for the base case assuming low recruitment projections under the 20:35:48 harvest control rule.

Year	Stock status (%)	RBC (t)	Retained catch (t)	Estimated discard (t)
2018	23	-	393	89
2019	25	-	334	70
2020	27	-	297	80
2021	29	-	297	78
2022	28	587	467	120
2023	29	580	461	119
2024	29	575	457	118
2025	29	575	457	118

13.4.3 *Fixed catch, low recruitment projections*

Estimates of recruitment strength for Silver Warehou have been below average since the early 2000s (Figure 13.19), with this potentially a consequence of directional environmental change. If this below average recruitment trend continues into the future, assuming a return to average recruitment would result in overly optimistic biomass and stock status estimates. Due to these concerns, the base case for this assessment incorporates low, rather than average, recruitment projected into the future. The projected value is based on the average recruitment deviations between 2011 and 2015 (average = -0.64). Constant annual catches have been projected with this low recruitment level to explore biomass trajectories into the future. The recruitment deviation series with projections is presented in Figure 13.19.

As the low recruitment scenario markedly reduces stock productivity, the population is no longer able to recover to unfished levels, with this apparent in the 0 t catch projection scenario, where the population only recovers to 49% of SSB_0 (Figure 13.28, blue line).When various fixed catches are projected into the future (250 t, 350 t, 450 t and the RBC), the recovery of the population declines to a different stable level for each fixed catch scenario (Figure 13.28). The RBC is calculated from the base case assessment with low recruitment projections. Any catches above 450 t limit further recovery of stock status towards the target reference point (Figure 13.28).

Table 13.11 provides annual stock status, retained catches and estimated discards for the low recruitment scenarios with zero catch (0 t), 250 t, 350 t and 450 t catches and applying the standard SESSF harvest control rule (HCR, 587 t catch in 2022), with catches and discards summed across both the east trawl and west trawl fleets.

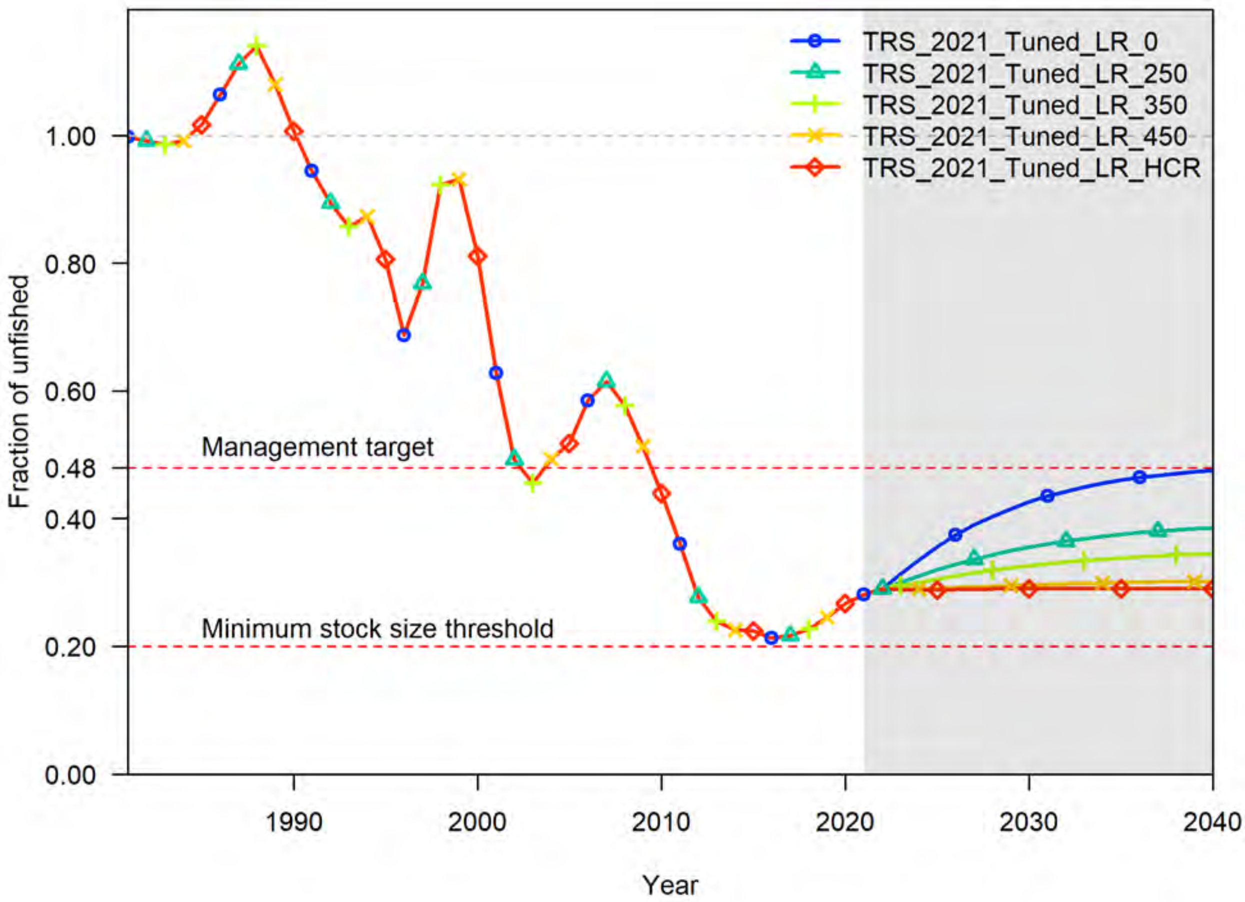

Figure 13.28. Relative spawning biomass time-series for the RBC calculated by the SESSF harvest control rule (red, HCR), and four alternative constant catch scenarios 0 t, 250 t, 350 t, 450 t. All scenarios assume low recruitment for the entire forecast period

Table 13.11. Stock status (SS), retained catch (RET, t) and estimated discards (DIS, t) corresponding to the low recruitment, fixed catch projection scenarios with the zero catch (0 t), 250 t constant catch, 350 t constant catch, 450 t constant catch and applying the HCR (587 t in 2022)

YEAR	0 t			250 t			350 t			450 t			HCR		
	SS	RET	DIS	SS	RET	DIS	SS	RET	DIS	SS	RET	DIS	SS	RET	DIS
2022	0.29	0	0	0.29	250	61	0.29	350	86	0.29	450	110	0.29	587	120
2023	0.31	0	0	0.30	250	60	0.30	350	85	0.29	450	110	0.29	580	119
2024	0.34	0	0	0.31	250	59	0.30	350	85	0.29	450	110	0.29	575	118
2025	0.36	0	0	0.32	250	59	0.31	350	84	0.29	450	110	0.29	575	118
2026	0.37	0	0	0.33	250	58	0.31	350	84	0.29	450	110	0.29	580	119
2027	0.39	0	0	0.34	250	58	0.31	350	83	0.29	450	110	0.29	585	120
2028	0.40	0	0	0.34	250	57	0.32	350	83	0.29	450	110	0.29	588	121
2029	0.42	0	0	0.35	250	57	0.32	350	83	0.30	450	110	0.29	590	121
2030	0.43	0	0	0.36	250	56	0.33	350	82	0.30	450	110	0.29	590	121
2031	0.44	0	0	0.36	250	56	0.33	350	82	0.30	450	110	0.29	591	121
2032	0.44	0	0	0.36	250	56	0.33	350	82	0.30	450	110	0.29	591	121
2033	0.45	0	0	0.37	250	56	0.33	350	81	0.30	450	109	0.29	591	122
2034	0.46	0	0	0.37	250	55	0.34	350	81	0.30	450	109	0.29	591	122
2035	0.46	0	0	0.38	250	55	0.34	350	81	0.30	450	109	0.29	591	122
2036	0.46	0	0	0.38	250	55	0.34	350	81	0.30	450	109	0.29	591	122
2037	0.47	0	0	0.38	250	55	0.34	350	81	0.30	450	109	0.29	591	122
2038	0.47	0	0	0.38	250	55	0.34	350	81	0.30	450	109	0.29	591	122
2039	0.47	0	0	0.38	250	55	0.34	350	81	0.30	450	109	0.29	591	122
2040	0.48	0	0	0.39	250	55	0.35	350	80	0.30	450	109	0.29	591	122

13.4.4 *Retrospective analysis*

The retrospecives analyses were conduced on the base case with low rectuitment projections and retrospecives with average recruitment projections are also presented for comparison. A retrospective analysis for absolute spawning biomass is shown in Figure 13.29, with the data after 2020 removed initially (shown in light blue), then successive years of data removed back to 2015 (shown in red). The same analysis is plotted in terms of relative stock in Figure 13.31. In both cases there is downward revision when additional years of data are included, with this particuarily evident between 2016 and 2017 and again to a lesser extent between 2018 and 2019 (Figure 13.29, Figure 13.31). These retrospective patters are much smaller than those observed for the model without low recruitment projections (Figure 13.30, Figure 13.32).

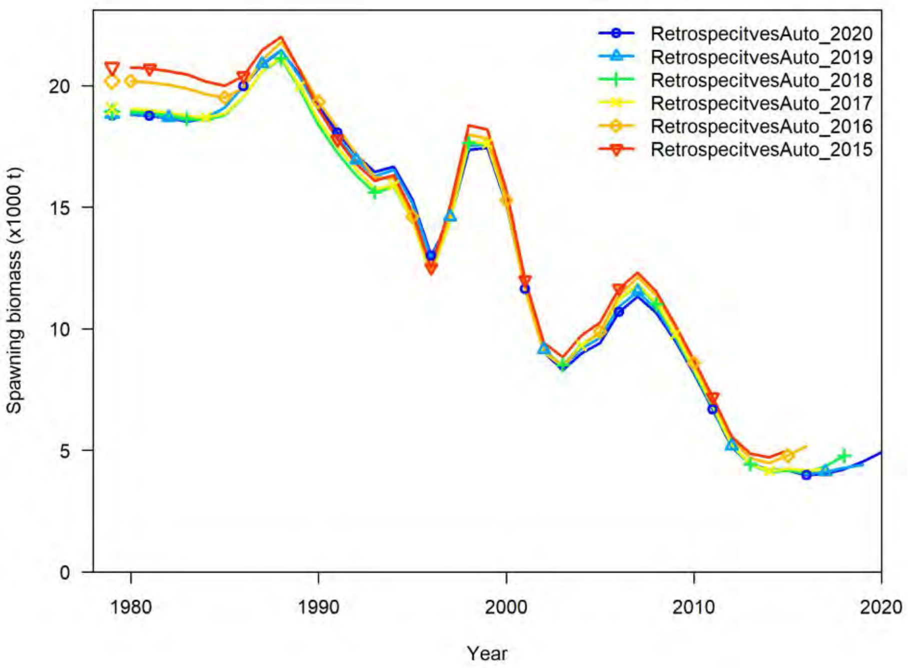

Figure 13.29. Retrospectives for absolute spawning biomass for the base case assessment with low recruitment projections, with data included to 2020 (blue) and then successive years removed back to 2015 (red)

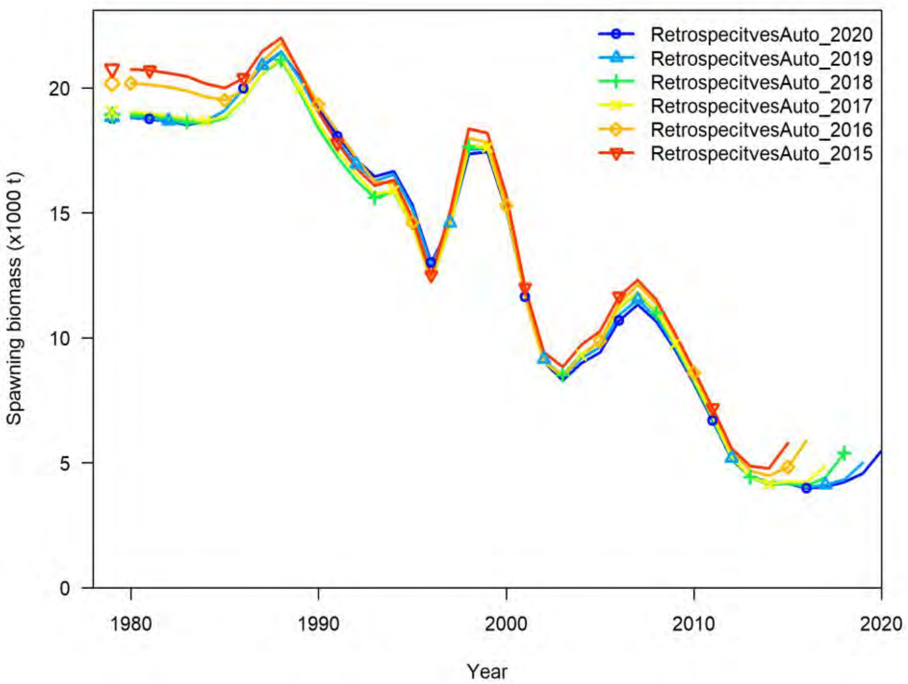

Figure 13.30. Retrospectives for absolute spawning biomass for the model with average recruitment projections, with data included to 2020 (blue) and then successive years removed back to 2015 (red)

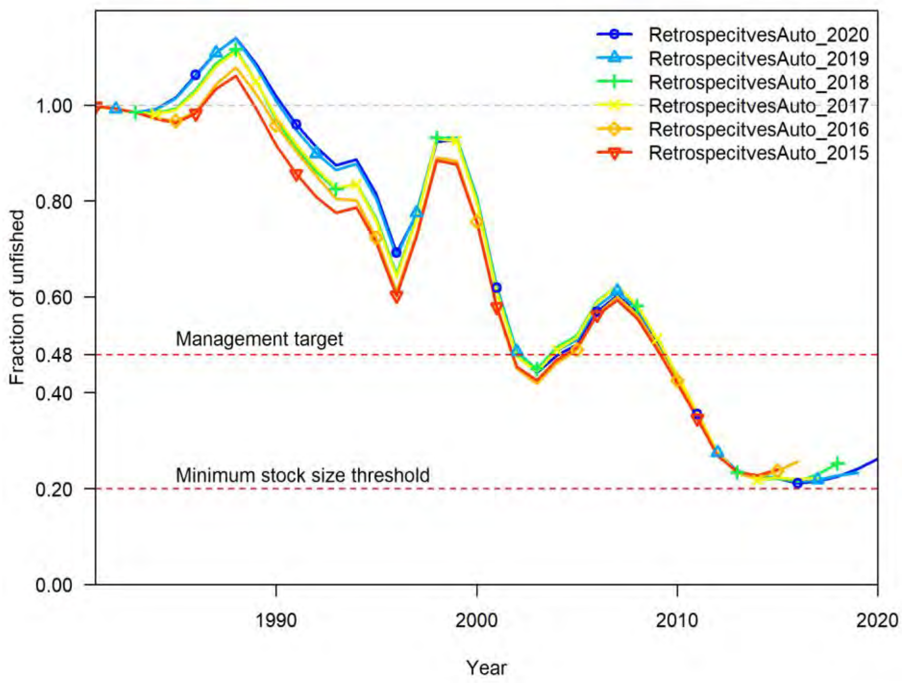

Figure 13.31. Retrospectives for relative stock status for the base case assessment with low recruitment projections, with data included to 2020 (blue) and then successive years removed back to 2015 (red)

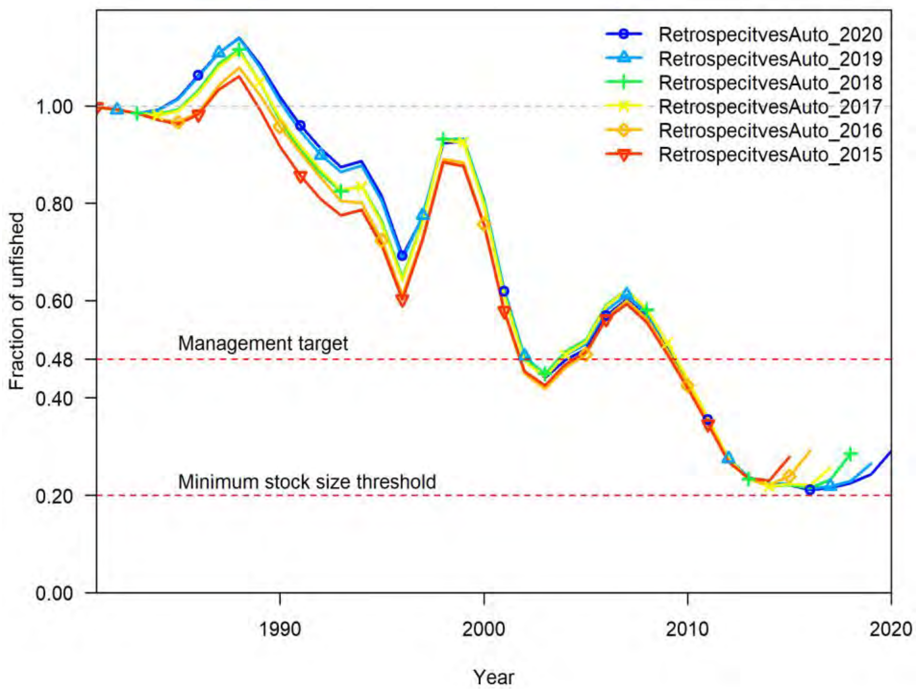

Figure 13.32. Retrospectives for relative stock status for the model with average recruitment projections, with data included to 2020 (blue) and then successive years removed back to 2015 (red)

When this retrospective analysis is applied to the recruitment time series (Figure 13.33), inclusion of data in 2017 results in a downward revision to the recruitment estimate in 2011 and 2012, while addition of 2018 data resulted in upward revision of the 2013 recruitment estimate (Figure 13.33). Recruitment from 2014 onwards has small revisions both up and down with the inclusion of data from 2018 Figure 13.33). Similar trends are observed in the recruitment deviations as were observed in absolute recruitment (Figure 13.35). Retrospective patterns in recruitment are much worse when not using low recruitment projections, with all estimates being revised downwards with the inclusion of additional years of data (Figure 13.34, Figure 13.36).

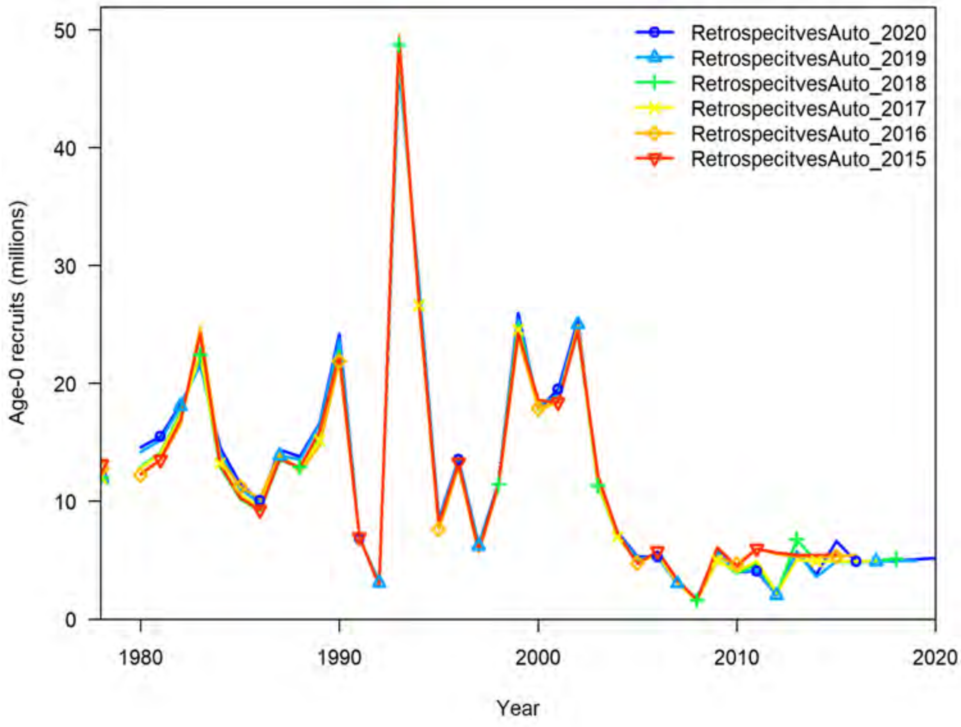

Figure 13.33. Retrospectives for the absolute number of recruits for the base case assessment with low recruitment projections, with data included to 2020 (blue) and then successive years removed back to 2015 (red)

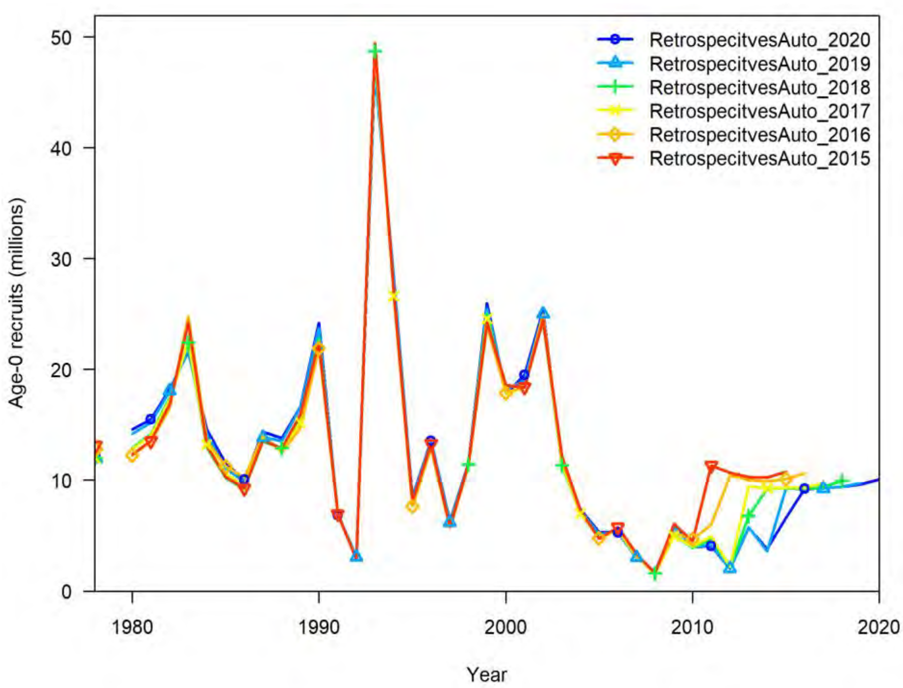

Figure 13.34. Retrospectives for the absolute number of recruits for the model with average recruitment projections, with data included to 2020 (blue) and then successive years removed back to 2015 (red)

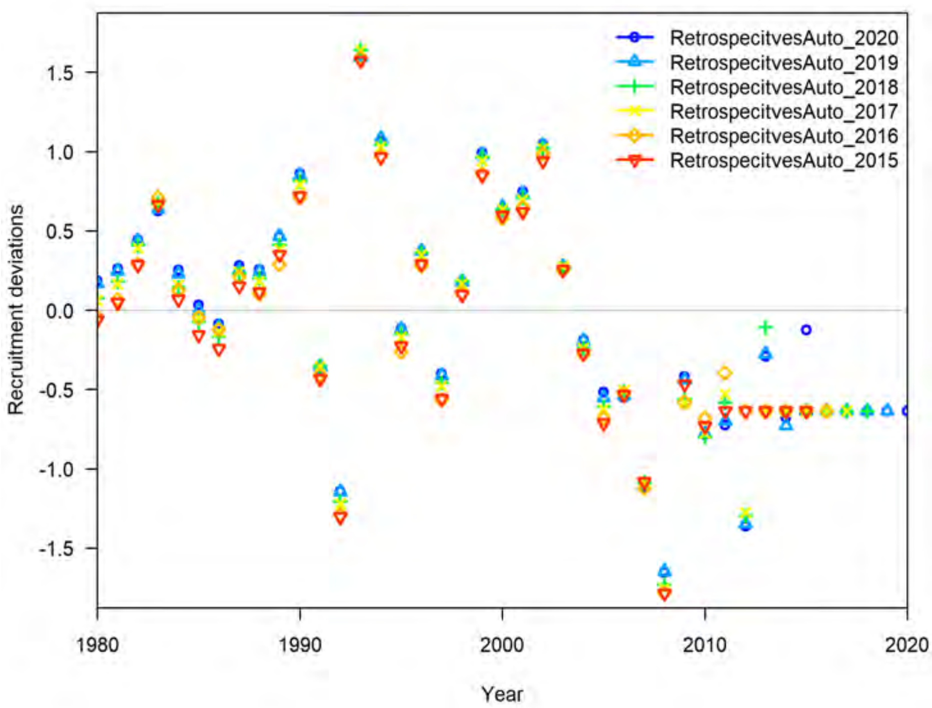

Figure 13.35. Retrospectives for recruitment deviations for the base case assessment with low recruitment projections, with data included to 2020 (blue) and then successive years removed back to 2015 (red)

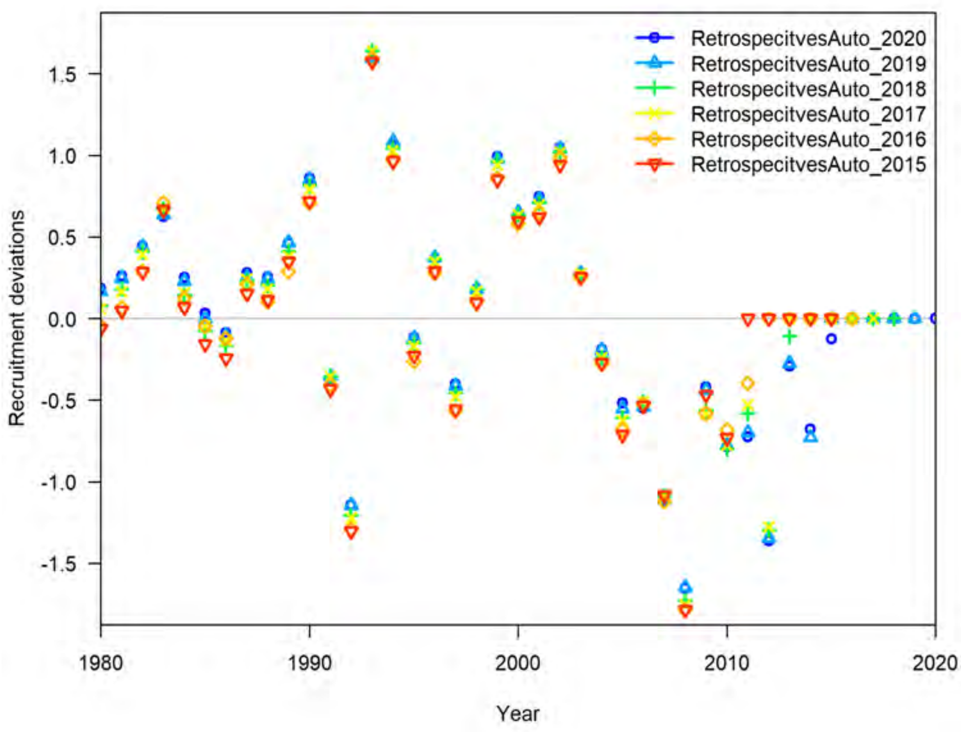

Figure 13.36. Retrospectives for recruitment deviations for the model with average recruitment projections, with data included to 2020 (blue) and then successive years removed back to 2015 (red)

An alternative presentation of the retrospective analysis applied to the recruitment time series is shown in a "squid plot" (Figure 13.37). Squid plots follow 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 base case model using data up to 2020 and then one more point for each of the five different retrospectives. Each string can be followed from right to left as successive years of data are removed. The changes to the estimates of recruitment deviation, as each year of data is removed, are measured by changes in the y-axis, with a negative value indicting a revision upwards and a positive value indicating a revision downwards, relative to the most recent estimate. Large changes on the y-axis indicate large revisions, and if all the changes have the same sign (positive or negative) this indicates a series of changes in the same direction, which may provide evidence of bias rather than random revisions to parameter estimates.

The squid plot for the base case assessment with low recruitment projections shows a mix of deviations both above and below zero, suggesting that there is no pathological retrospective pattern in recruitment deviation estimates (Figure 13.37). This result contrasts with the squid plot for the model with average recruitment projected into the future, where all cohort lines from 2010 to 2015 are positive, suggesting that these recruitment deviations have all been revised downwards (Figure 13.38). This pattern is typical of a pathological pattern and suggest misspecification in this model.

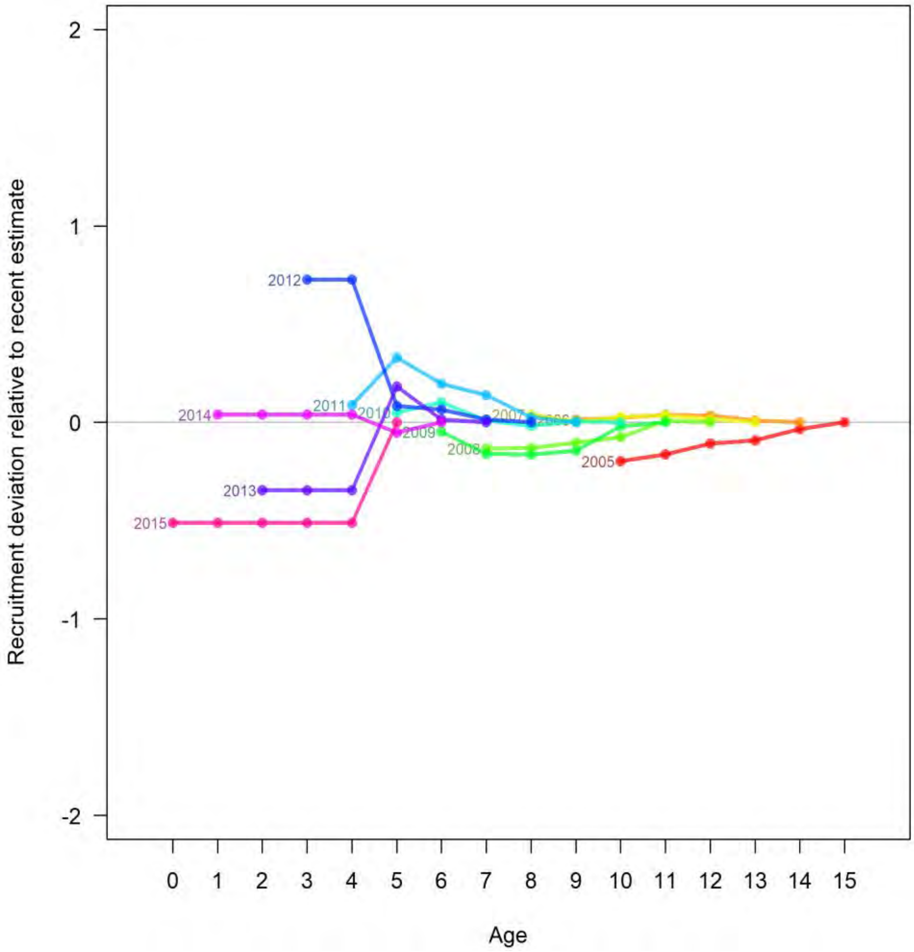

Figure 13.37. Retrospective analysis of recruitment deviations (squid plot), for the base case assessment with low recruitment projections, with data removed in successive years back to 2015

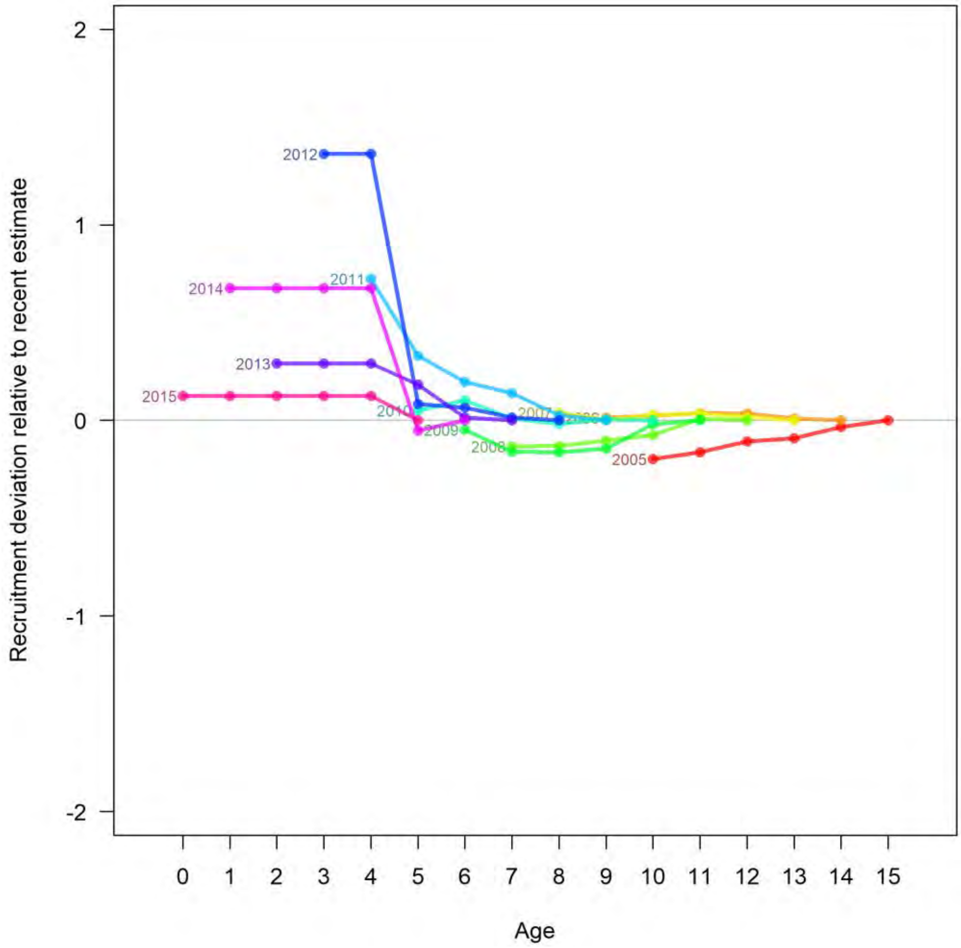

Figure 13.38. Retrospective analysis of recruitment deviations (squid plot), for the base case assessment with low recruitment projections, with data removed in successive years back to 2015

Mohn's Rho estimates for SSB, recruitment, F and stock status were 0.13, -0.008, -0.15 and 0.08 respectively, with SSB, recruitment and stock status estimates within the range of acceptable values, whereas the F estimate is on the edge of acceptability. To compare, when conducting retrospectives on the model without low recruitment projections, these values were 0.29, 0.18, -0.33 and 0.24 for SSB, recruitment, F and stock status respectively, with SSB, F and stock status failing acceptability criteria. These results demonstrate the improvement in reducing model misspecification when using the low recruitment projections compared to the assessment assuming average recruitment into the future.

13.4.5 *Likelihood profiles*

The likelihood profile for M suggests that this parameter could range from 0.375 and 0.475 year^{-1}, with these bounds higher than the fixed value in the model of 0.3 year^{-1} (Figure 13.39). This high estimate of M is driven by both the length and index data, and to a lesser extent the age data (Figure 13.39). There is little information on M in the discard data (Figure 13.39). This high estimate of M is unrealistic compared to the biology of the species, with a plus group age of 23, and as a result M will remain fixed at 0.3 in the assessment, as has been done in previous assessments.

The fleet contribution to each of the likelihood components are presented in Figure 13.40. For survey or index likelihoods the high M estimates are driven by the west trawl fleet, with little information apparent in the east trawl fleet (Figure 13.40). For the discard component of the likelihood, higher values of M are suggested by the east trawl fleet, while lower values are preferred by the west trawl fleet (Figure 13.40). Higher values of M in the length component of the likelihood are driven by the east trawl onboard, west trawl onboard and west trawl port data, conflicting trends from east trawl port data (Figure 13.40). Age composition data suggests a value of M around 0.4 from the west trawl fleet, while there is very little data to inform M in the east trawl age data (Figure 13.40). Overall, there is considerable conflicting data informing the value of M in the assessment and the suggested preference for higher values of M above those considered biologically sensible for this species are unrealistic.

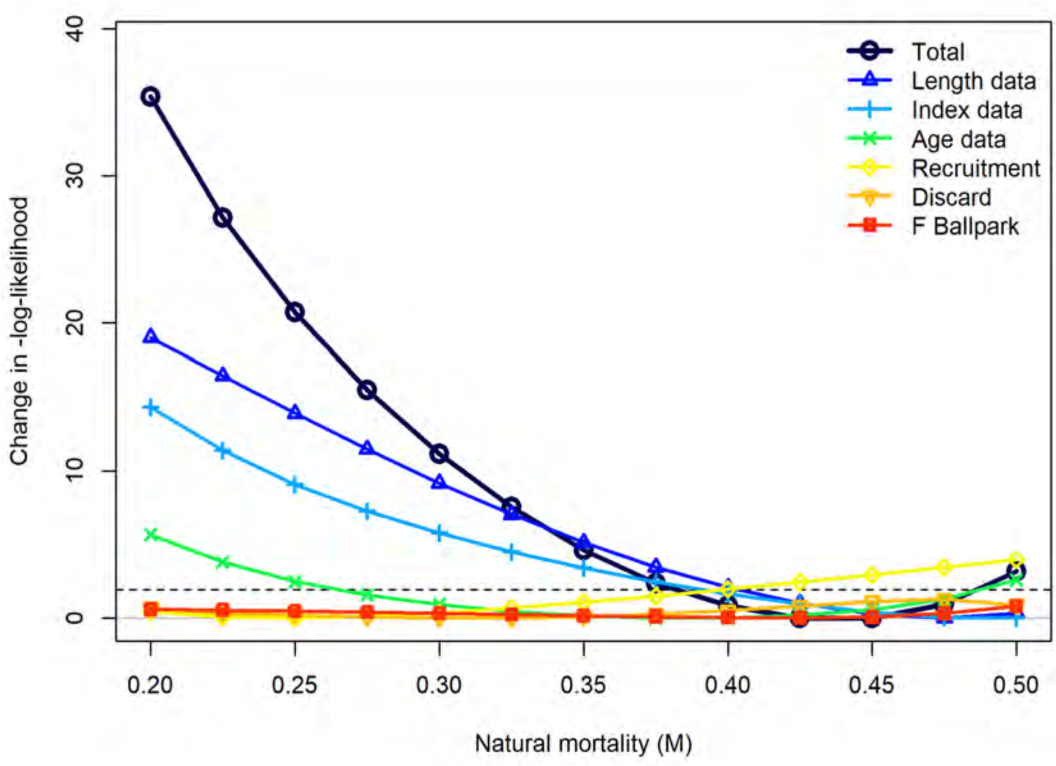

Figure 13.39. The likelihood profile for natural morality (***M***). ***M*** is fixed in the base case at 0.3 year^{-1}

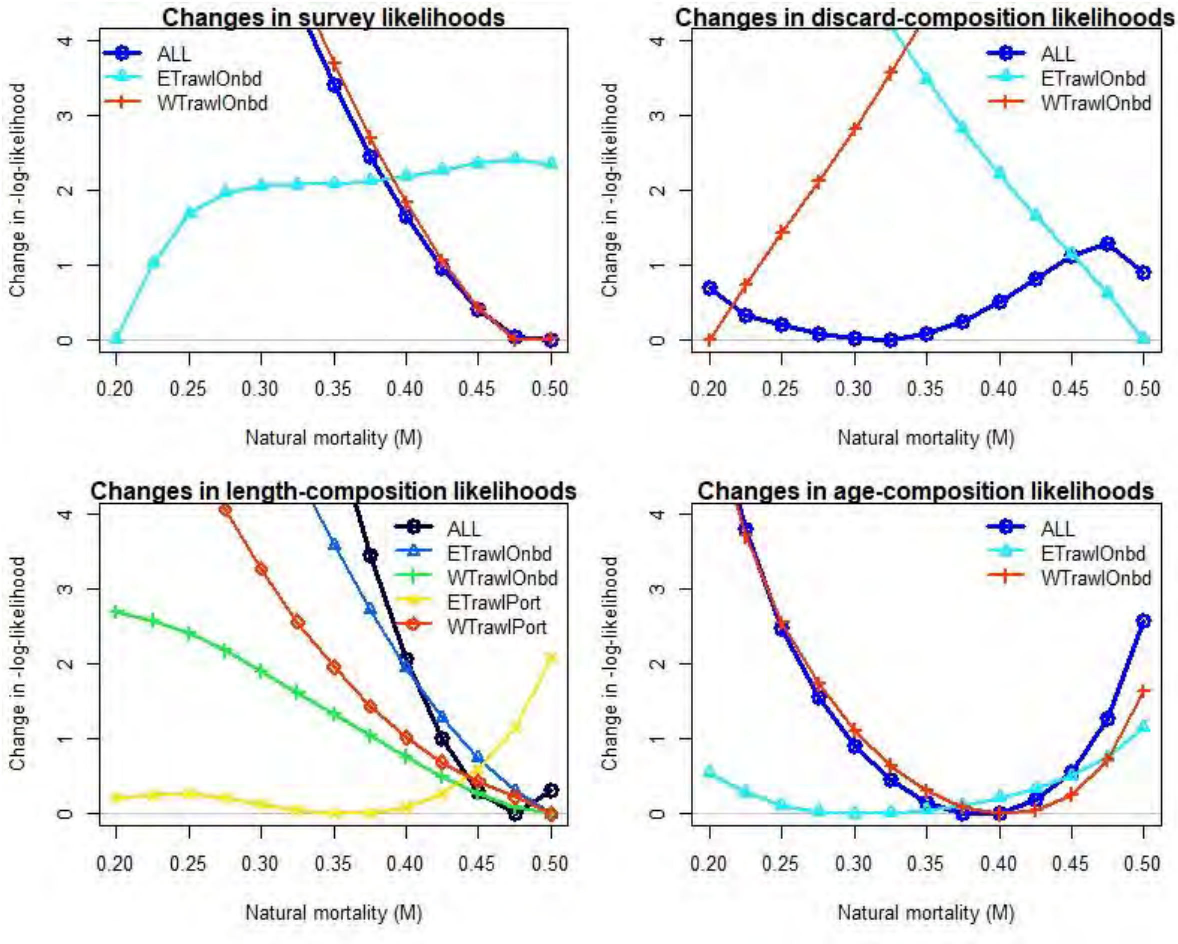

Figure 13.40. Piner plot for likelihood profile on ***M***

The likelihood profile on h suggests there is little information in the model that can inform estimation of this parameter (fixed at 0.75 in the model, Figure 13.41). The model suggests that h could range between 0.56 to well above 0.85, demonstrating a large range of plausible values (Figure 13.41). There is conflict in the data inputs, with discard and length data suggesting a higher value of h is preferable, while recruitment penalties, age and index data suggest lower values are more appropriate (Figure 13.41).

For survey or index likelihoods, the west trawl fleet is driving the profile towards a lower estimate of h, while there is no information in the east trawl fleet (Figure 13.42). From the discard likelihood, both the east and west trawl fleet data suggests that higher estimates of h are preferable (Figure 13.42). For the length component of the likelihood, the east trawl onboard data and to a lesser extent the west trawl onboard data suggests higher estimates of h are preferable, while there is no information on estimates in the east and west trawl port length data (Figure 13.42). For both east trawl and west trawl age composition data suggest lower estimates of h are preferred (Figure 13.42).

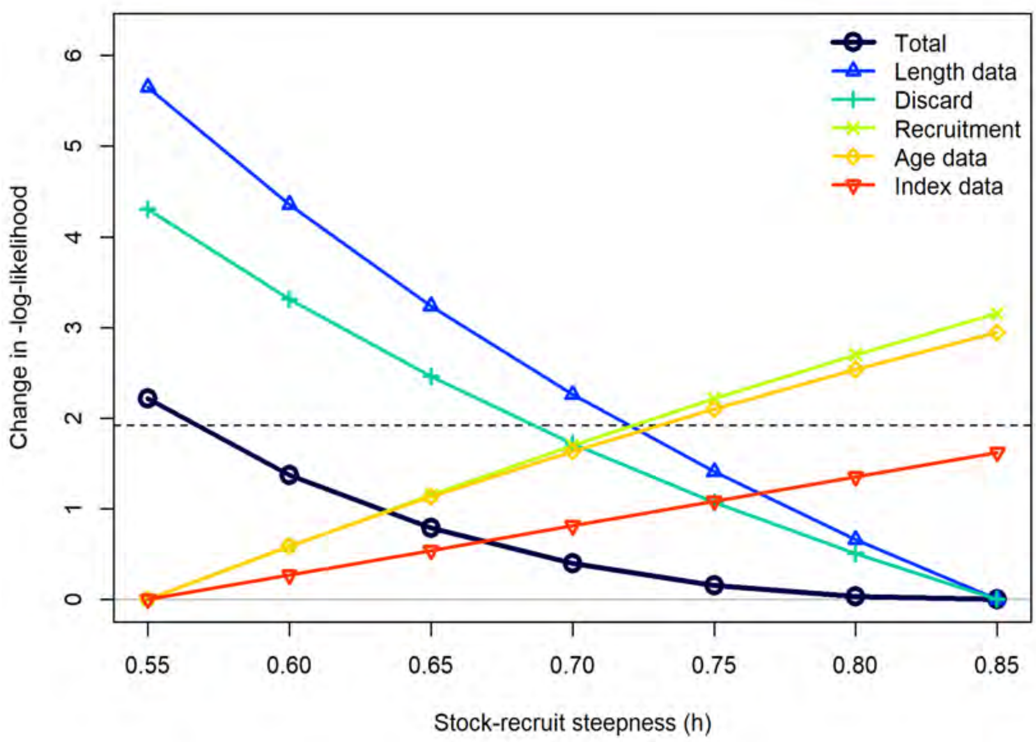

Figure 13.41. The likelihood profile for stock-recruitment steepness (***h***), ***h*** is fixed in the base case at 0.75

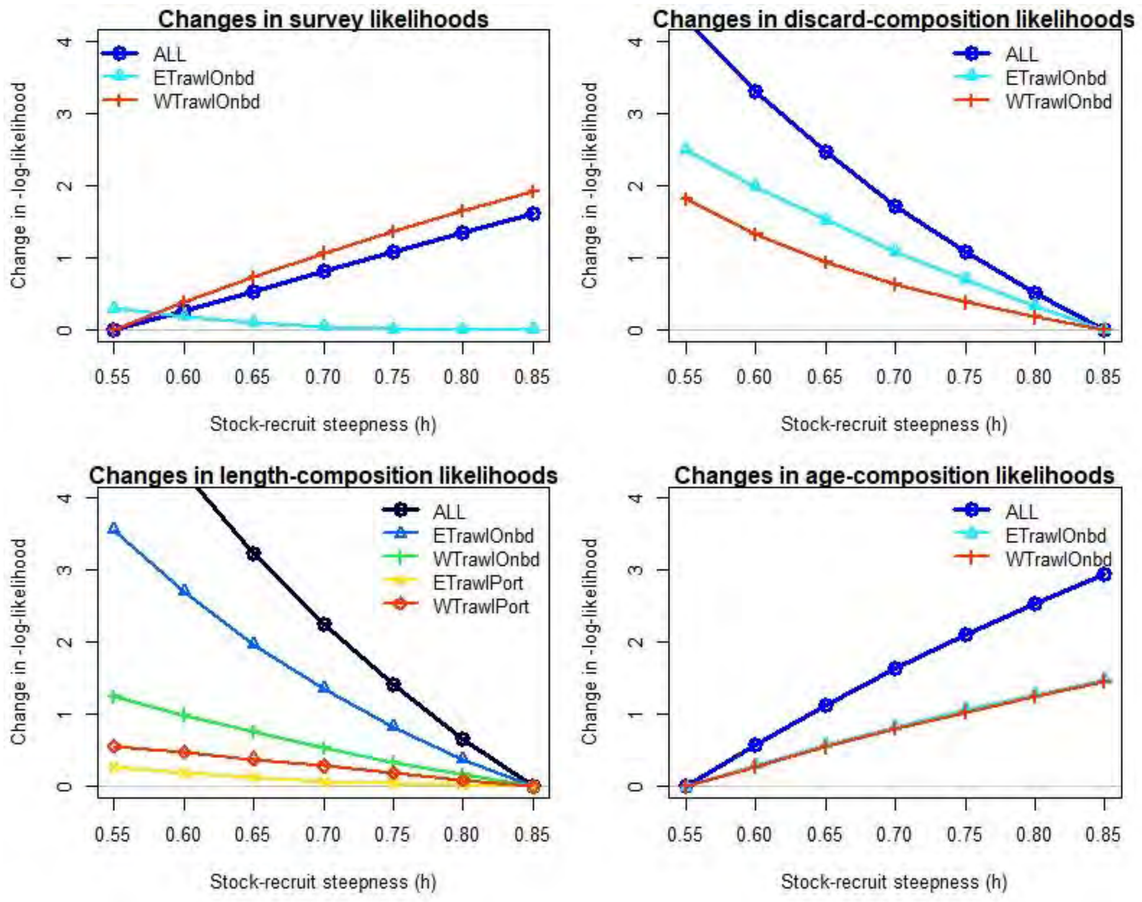

Figure 13.42. Piner plot for likelihood profile on ***h***

The stock status likelihood profile suggests that estimates in 2020 were between 25% and 34% (Figure 13.43). Index data is driving this estimate suggesting a stock status of 30%, while length data suggests lower estimates, there is little information in discard or recruitment penalties on this estimate (Figure 13.43).

The survey component of the likelihood is being mainly informed by the west trawl fleet, with the east trawl fleet suggesting lower estimates of stock status are more appropriate (Figure 13.44). For the discard component, east trawl data suggests higher stock status estimates, while the west trawl fleet suggests lower estimates (Figure 13.44). For the length composition likelihood component, east trawl onboard data strongly suggests lower stock status estimates, while west trawl port data suggests higher estimates, there is little information in east trawl port or west trawl onboard data (Figure 13.44). For the age composition component, both east trawl and west trawl data suggests higher estimates of stock status are most appropriate (Figure 13.44).

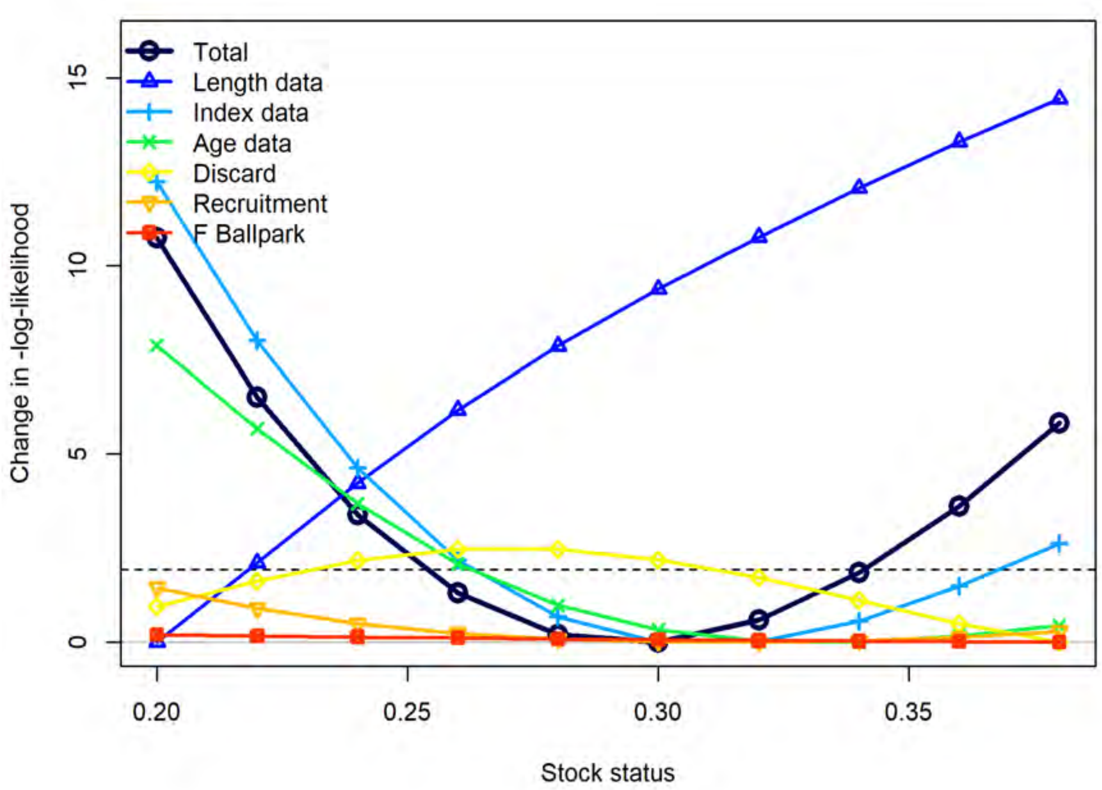

Figure 13.43. The likelihood profile for stock status in 2020, the base case without low recruitment projections estimates 2020 depletion to be 0.29 or 29%

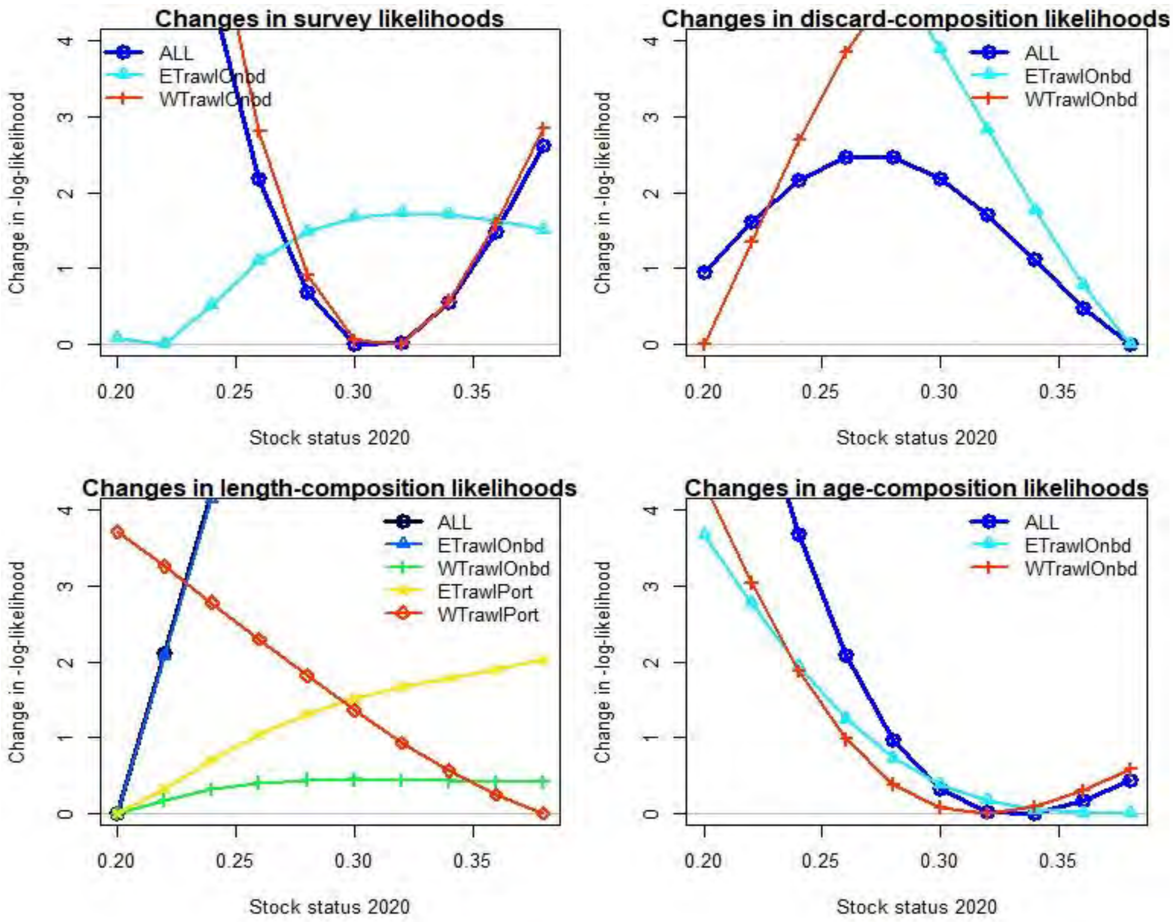

Figure 13.44. Piner plot for likelihood profile on 2020 stock status

The likelihood profile on SSB_0 suggests that estimates range between 17,000 t and 21,000 t (Figure 13.45). There is conflict in the data sources with recruitment penalties and to a lesser extent age data suggesting higher estimates of SSB_0, while discard data suggests lower estimates (Figure 13.45). There is no information in length and index data to inform estimation of SSB_0 (Figure 13.45).

There is conflict between data for the east trawl and west trawl fleet index data informing the profiles, with the east trawl index suggesting higher SSB_0, while west trawl index suggests lower estimates (Figure 13.46). For the discard component of the likelihood, east trawl data strongly suggests lower estimates are preferable, while west trawl data suggest higher estimates (Figure 13.46). There are no strong drivers in the length data, although west trawl onboard and west trawl port data suggests higher estimates of SSB_0, while east trawl onboard and west trawl port data suggests lower estimates (Figure 13.46). There is no information in east trawl age data to inform estimation of SSB_0, however, west trawl data suggests higher estimates are preferable (Figure 13.46).

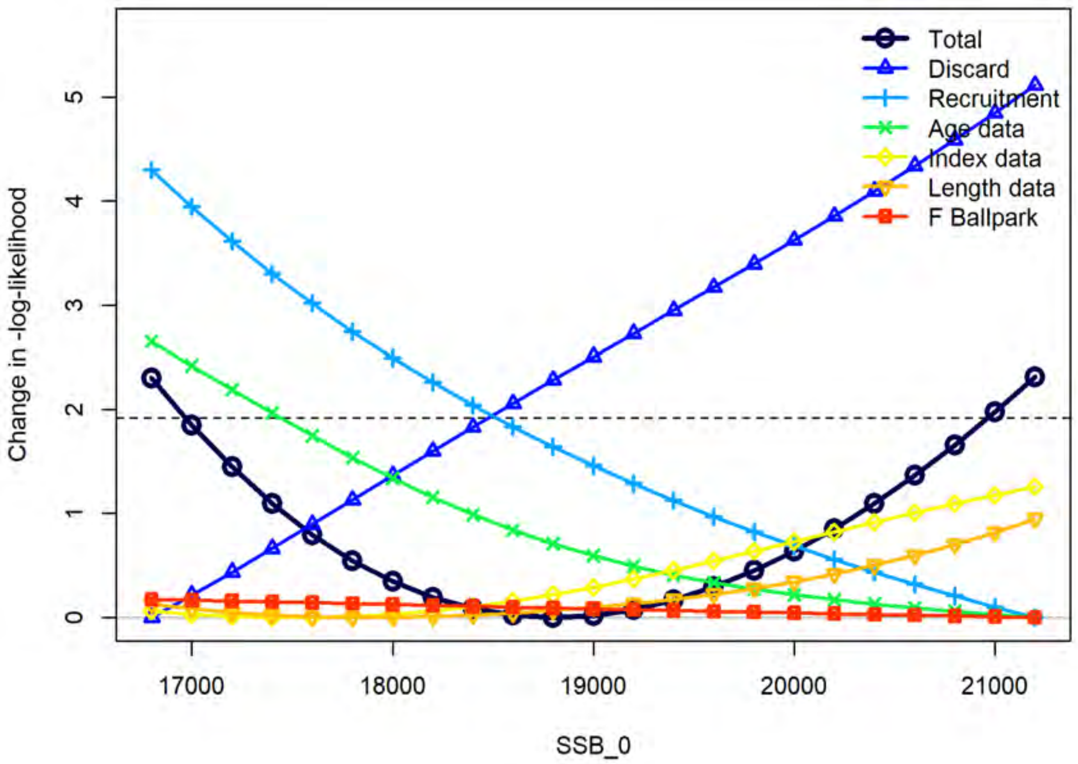

Figure 13.45. The likelihood profile for unfished spawning stock biomass, the base case estimate of SSB_0 is 18,806 t

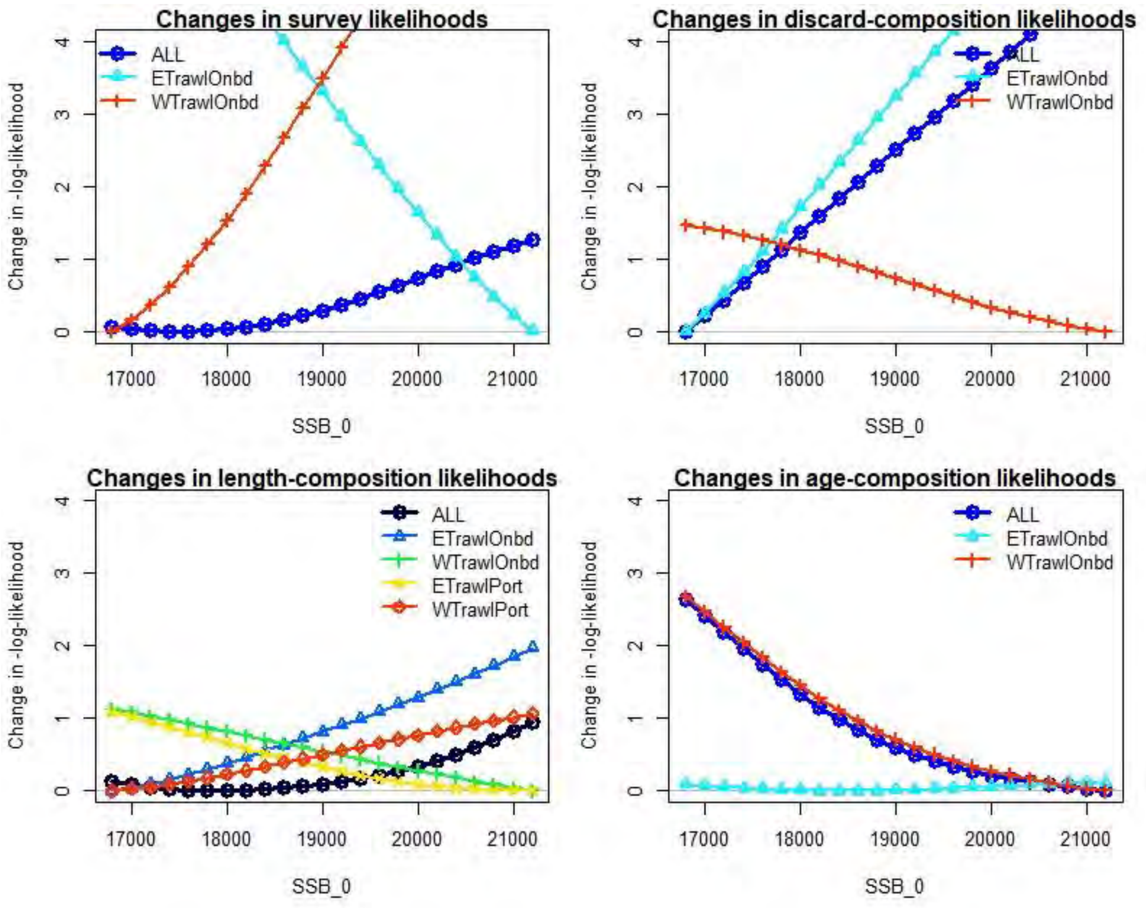

Figure 13.46. Piner plot for likelihood profile on $\boldsymbol{SSB_0}$

The likelihood profile over SSB in 2020 (SSB_{2020}) suggests that estimates range between 4,600 t and 6,700 t (Figure 13.47). Again, there is conflict in the data inputs associated with this profile, with age data and to a lesser extent recruitment data suggesting higher estimates are better, while length and discard data prefer lower estimates (Figure 13.47). There is limited information to inform estimates in the index data (Figure 13.47).

For survey or index likelihoods, the west trawl fleet is driving the profile towards lower estimates around 5,000 t, while the east trawl fleet prefers higher estimates (Figure 13.48). From the discard likelihood, both the east and west trawl fleet data suggests that lower estimates are preferable (Figure 13.48). For the length component of the likelihood, the east trawl onboard data suggests lower estimates of SSB_{2020} are preferable, while there is little information in the other fleets to inform estimation (Figure 13.48). For both east trawl and west trawl age composition data suggest higher estimates of SSB_{2020} are preferred (Figure 13.48).

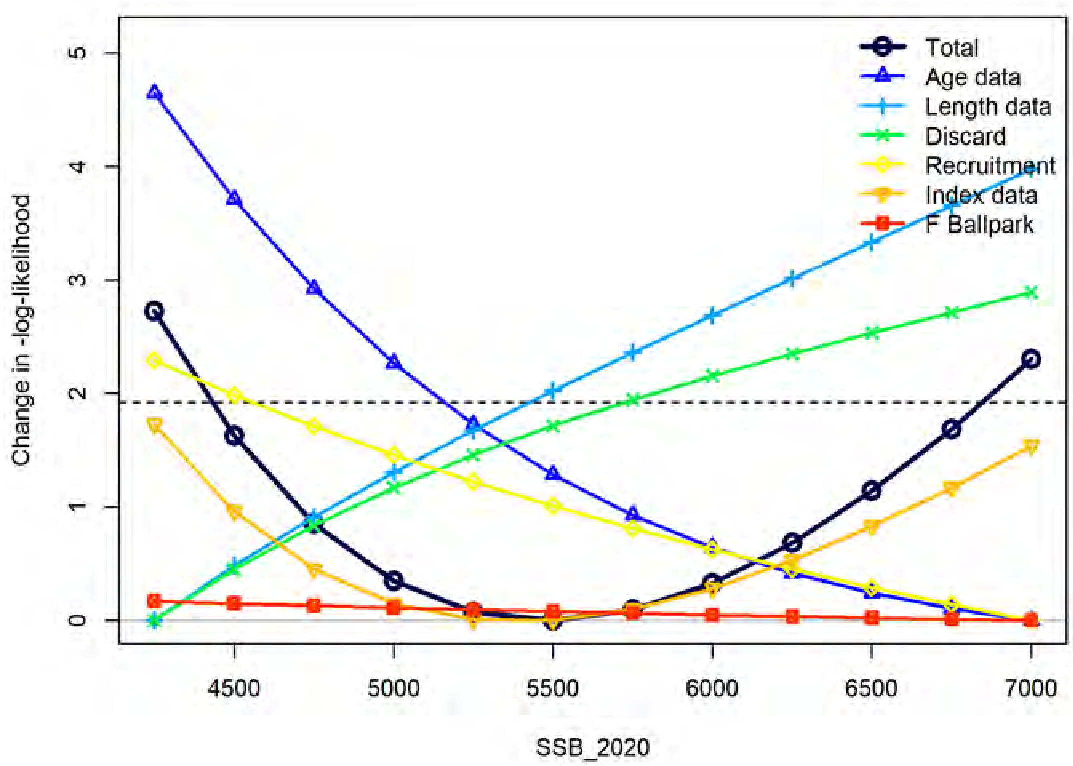

Figure 13.47. The likelihood profile for 2020 spawning stock biomass, the base case estimate of $\boldsymbol{SSB_{2020}}$ is 5,480 t

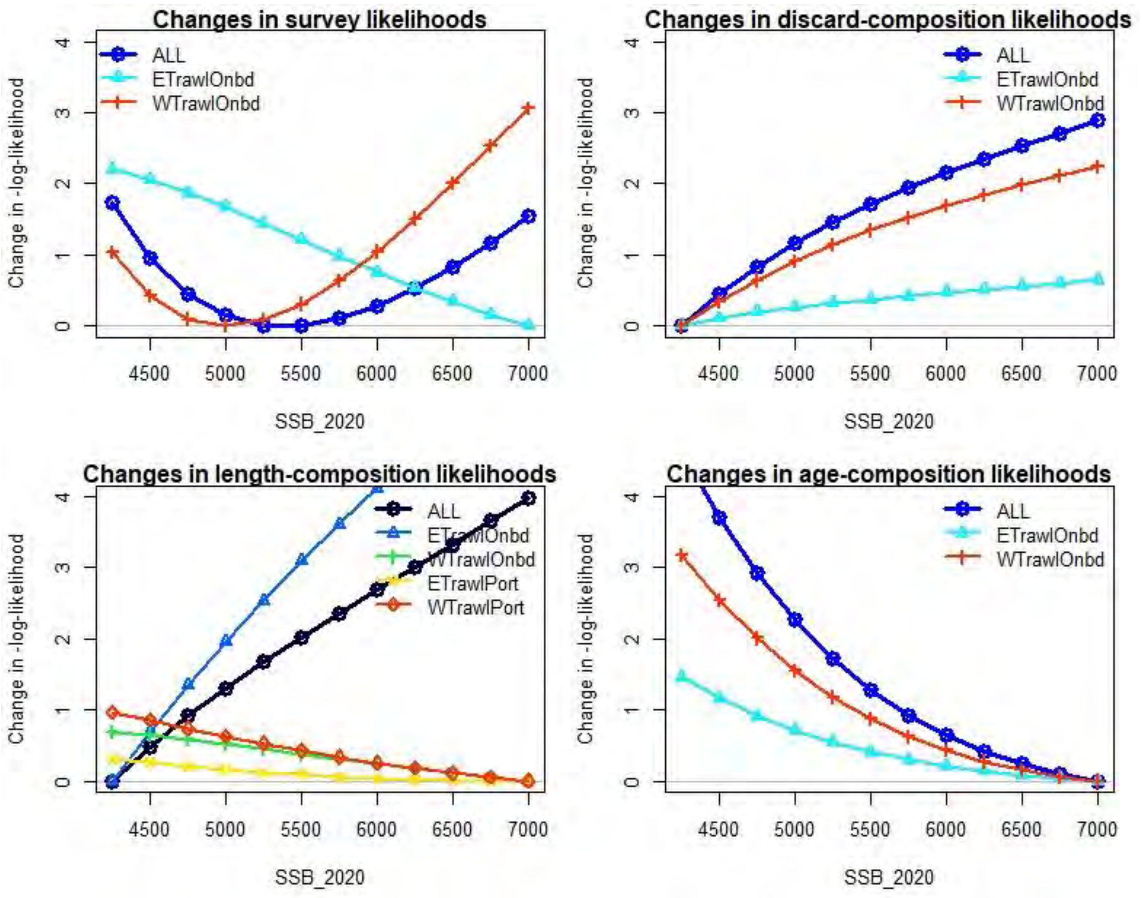

Figure 13.48. Piner plot for likelihood profile on $\boldsymbol{SSB_{2020}}$

13.4.6 *Jitter analysis*

For the base case, 22 of the 25 jitter replicates found the same optimal solution, with negative log likelihood of 720.387. The remaining three replicates found different (worse) "optimal" solutions, with a negative log likelihood of 720.578 for two replicates and 731.222 for the last replicate.

13.4.7 *Sensitivities to the base case model*

Standard sensitivities to alternative natural mortality values (M = 0.25, 0.35), steepness (h = 0.65, 0.85, and h estimated), length at maturity (34 and 40 cm), variation in recruitment (σ_R = 0.6 and 0.8), variation in data weighting and a model with average recrutiment projections were considered (Table 13.12 and Table 13.13). The base-case model and sensitivities all have stock status' that were between the target and limit reference points, ranging between 24% and 33% for models with low recruitment and up to 42% with average recruitment (Table 13.12).

Interestingly changing the weighting of the length data had the largest impact on the negative log likelihood of the models, with doubling the likelihood weighting on length data resulting in a considerable improvement to the likelihood (improved by 47 units), while having the weighting resulted in a much poorer likelihood (increased by 122, Table 13.12). However, these changes in length weighting only resulted in relatively small changes in stock status with estimates ranging between 26% and 30% (Table 13.12).

The high variability in the length data the model means the model is unable to fit the length compositions well, with this most likely resulting in the high sensitivity to the length data weighting in the likelihoods (Table 13.13). Other sensitivity scenarios had little impact on the likelihoods (Table 13.13).

Table 13.12. Summary of results for the base case and sensitivity tests. Spawning stock biomass includes both male and female biomass in the total.

MODEL	NLL	NLL CHANGE	SSB_0	SSB_{2022}	SSB_{2022} / SSB_0
base case (*M* = 0.3, *h* = 0.75, 50% mat = 37)	745.33	-	18,806	5,374	0.29
***M* = 0.25**	756.45	11.6	19,076	4,490	0.24
***M* = 0.35**	737.21	-7.96	20,551	6,867	0.33
***h* = 0.65**	747.52	2.52	19,535	5,102	0.26
***h* = 0.85**	743.18	-1.82	18,306	5,651	0.31
estimate *h*	743.26	-1.74	18,328	5,636	0.31
50% maturity at 34cm	744.74	-0.26	20,565	6,120	0.30
50% maturity at 40cm	745.21	0.2	16,508	4,474	0.27
σ_R**= 0.6**	752.85	4.12	18,122	5,359	0.30
σ_R **= 0.8**	740.14	-2.44	19,727	5,435	0.28
wt x 2 CPUE	748.39	3.06	18,740	5,394	0.29
wt x 0.5 CPUE	747.03	1.7	18,938	5,398	0.29
wt x 2 length comp	698.01	-47.32	18,634	4,811	0.26
wt x 0.5 length comp	867.82	122.49	18,897	5,645	0.30
wt x 2 age comp	752.00	6.25	19,525	5,866	0.30
wt x 0.5 age comp	752.74	7.41	18,546	5,137	0.28
Average recruitment	730.71	-14.62	18,806	7,824	0.42

Table 13.13. Summary of likelihood components for the base case and sensitivity tests. Likelihood components are unweighted and all cases below the primary base case are shown as differences from the base case. A negative value either in the total or individual components of likelihood indicates an improvement in fit compared to the primary base case. A positive value indicates deterioration in the fit.

MODEL	TOTAL	SURVEY	DISCARD	LENGTH	AGE	RECRUITMENT
base case (*M* = 0.3, *h* = 0.75, 50% mat = 37)	745.33	-75.87	126.25	362.84	311.62	9.83
***M* = 0.25**	11.60	3.31	0.70	5.86	1.93	-0.35
***M* = 0.35**	-7.95	-2.17	-0.30	-4.98	-1.07	0.72
***h* = 0.65**	2.52	-0.17	1.86	2.57	-0.67	-1.06
***h* = 0.85**	-1.82	0.16	-1.52	-2.00	0.60	0.94
estimate *h*	-1.74	0.16	-1.45	-1.91	0.57	0.90
50% maturity at 34cm	-0.26	-0.01	-0.11	-0.17	0.00	0.03
50% maturity at 40cm	0.20	0.05	0.05	0.15	0.05	-0.09
σ_R**= 0.6**	4.12	0.09	3.10	0.32	-1.20	1.81
σ_R **= 0.8**	-2.44	0.03	-2.45	-0.50	1.04	-0.57
wt x 2 CPUE	3.06	-8.82	9.62	5.63	-4.41	1.38
wt x 0.5 CPUE	1.70	6.29	-5.19	-3.69	4.96	-0.34
wt x 2 length comp	-47.32	4.56	22.70	-79.63	5.69	-0.31
wt x 0.5 length comp	122.49	-1.42	-11.09	135.98	-1.34	0.70
wt x 2 age comp	6.25	-5.34	24.37	8.06	-18.71	-1.80
wt x 0.5 age comp	7.41	6.30	-17.92	-5.97	23.55	1.78
Average recruitment	-14.62	0.35	-7.12	-10.93	3.09	0.00

13.5 Discussion

This document presents an updated assessment of Silver Warehou (*Seriolella punctata*) in the SESSF using data up to 31 December 2020. A full stock assessment for Silver Warehou was last performed in 2018 by Burch et al. (2018) using the stock assessment package Stock Synthesis version SS-V3.30.12.00 (Methot et al., 2018). Changes from the 2018 assessment include:

a) migration to the latest version of Stock Synthesis (SS-V3.30.17, Methot et al. (2021));
b) updates of all catch, CPUE, discard, length, age and ageing error data;
c) extending the last year of recruitment estimation (2015);
d) including an additional time block on retention for the east trawl fleet between 2018 and 2020 and
e) using low recruitment projections in the base case.

Results show reasonable fits to the CPUE abundance index for the western trawl fleet, however, fits to the eastern trawl fleet are poor prior to 1996, although these have improved from the 2018 assessment. Fits to the discard data are reasonable, although the model still struggles to fit the high estimates in the east trawl fleet in 2020, even when including an additional time block. The fits to the length data for both fleets and both onboard and port samples were poor. The length frequency data is highly variable from year to year, which has resulted in these poor fits. The assessment is also sensitive to weighting of the length frequency data. The overall fits to the conditional age-at-length data are good.

The assessment shows retrospective patterns, which is consistent with previous assessments. These patterns have been substantially improved through inclusion of the low recruitment projections and are within acceptability criteria. Generally, the increase in SSB and relative stock status is revised downwards at the end of the series with the inclusion of additional years of data, resulting in overoptimistic estimates of stock status at the end of the series. These patterns suggest there is some misspecification in the model.

Likelihood profiles have demonstrated there are considerable conflicts in different data sources. This is particularly concerning where conflicts in individual components are apparent between the two fleets in the assessment. Given these conflicts, future assessments should consider splitting the assessment between the east and the west to investigate whether this results in a more stable assessment with less evidence of model misspecification and conflict between data sources.

Previous assessments in 2015 and 2018 have observed downward revisions in stock status towards the limit reference point from 2015 to 2017, however, this downward revision appears to have stabilised in the current assessment and no further revisions below the limit reference point were observed. There does appear to have been some recovery above the limit reference point in the last 3 years due to low catches below the TAC, however projections suggest this recovery will not continue at current catch levels and while recruitment remains below average.

In this new low productivity state, with below average recruitment, the population is no longer able to recover to unfished levels observed in the 1980s, as projections with zero catch suggest the population is now only capable of recovering to 49% of unfished levels by 2040.

This assessment estimates that the projected 2022 spawning stock biomass will be 29% of unfished SSB. The RBC from the base case model for 2022 is 587 t for the 20:35:48 harvest control rule, however, as the base case has violated the assumptions of the HCR, catches of this magnitude result in no increase in projected stock status. In comparison, the 2018 assessment estimated stock status to be 31% of unfished levels in 2019, while the 2015 assessment estimated the 2016 percentage of the unfished spawning biomass to be 40%. However, both the 2015 and 2018 assessments assumed recruitment will return to average levels, while the current assessment assumes recruitment will remain low into the future.

The current SESSF HCR assumes that there is average recruitment into the future and therefore applying the HCR with low recruitment projections does not result in recovery of stocks towards the target reference point if the calculated RBCs are caught. Further work is required to develop and test an HCR that could be used in such scenarios, as recent and continued poor recruitment appears to be occurring more commonly across multiple species the SESSF.

13.6 Acknowledgements

Age data were provided by Kyne Krusic-Golub (Fish Ageing Services), ISMP and AFMA logbook and CDR data were provided by John Garvey (AFMA). Mike Fuller, Paul Burch, Robin Thomson, Roy Deng, Franzis Althaus, Toni Cannard and Caroline Sutton (CSIRO) pre-processed the data. Miriana Sporcic provided standardised CPUE. Malcolm Haddon provided useful code for auto-balancing, Athol Whitten provided useful R code for organising plots. Paul Burch provided an updated ageing error matrix. Geoff Tuck, Brett Stacy, Robin Thomson and Paul Burch (CSIRO) provided valuable review and discussion of this work. Ian Taylor, Chantel Wetzel, Kathryn Doering and Kelli Johnson (NOAA) are thanked for helpful recommendations and fixes in relation to the the r4ss package. The r4ss package maintained by Ian Taylor (https://github.com/r4ss/r4ss) was critical for producing multiple diagnostic plots, and tuning models. Geoffrey Liggins is thanked for discussions on the catch history.

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13.8 Appendix

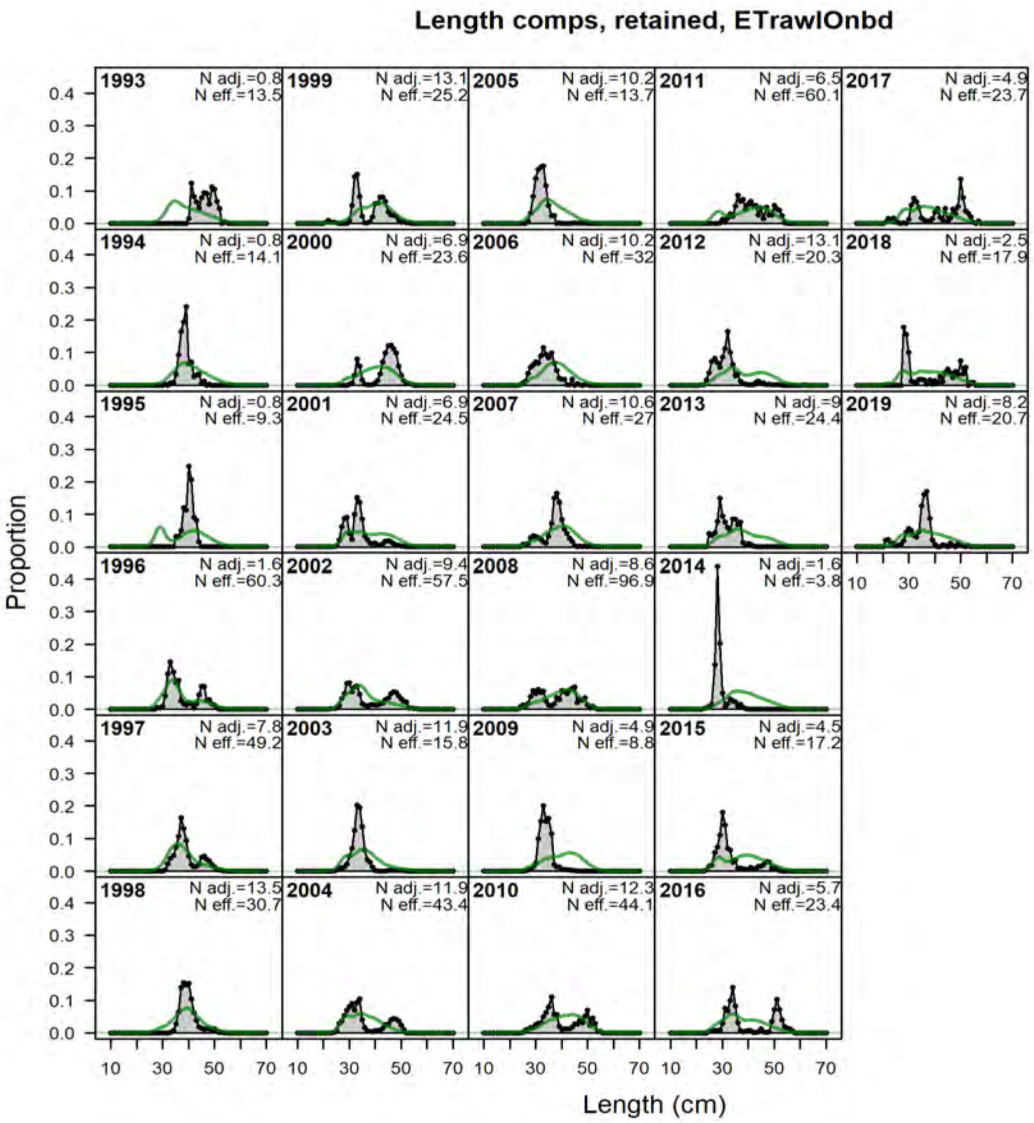


Figure 13.49. Fits to onboard retained length compositions for the east trawl fleet

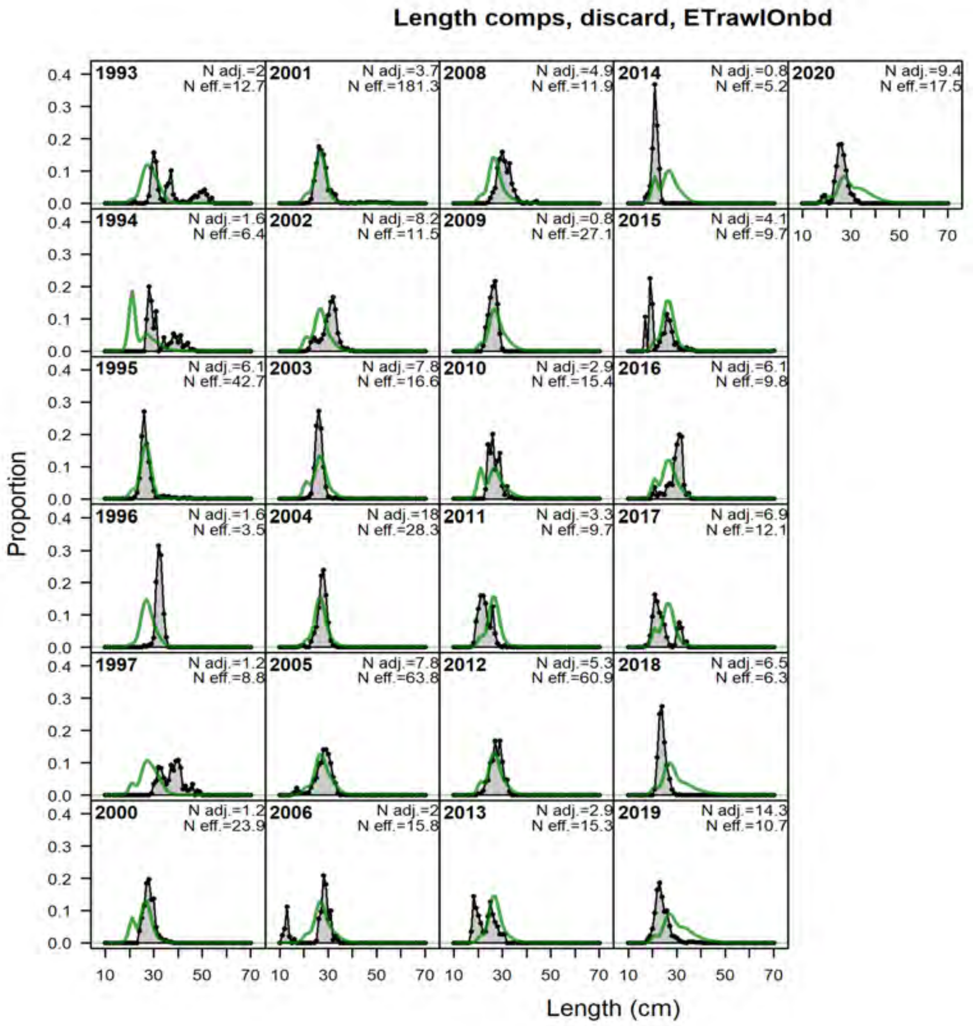


Figure 13.50. Fits to onboard discarded length compositions for the east trawl fleet

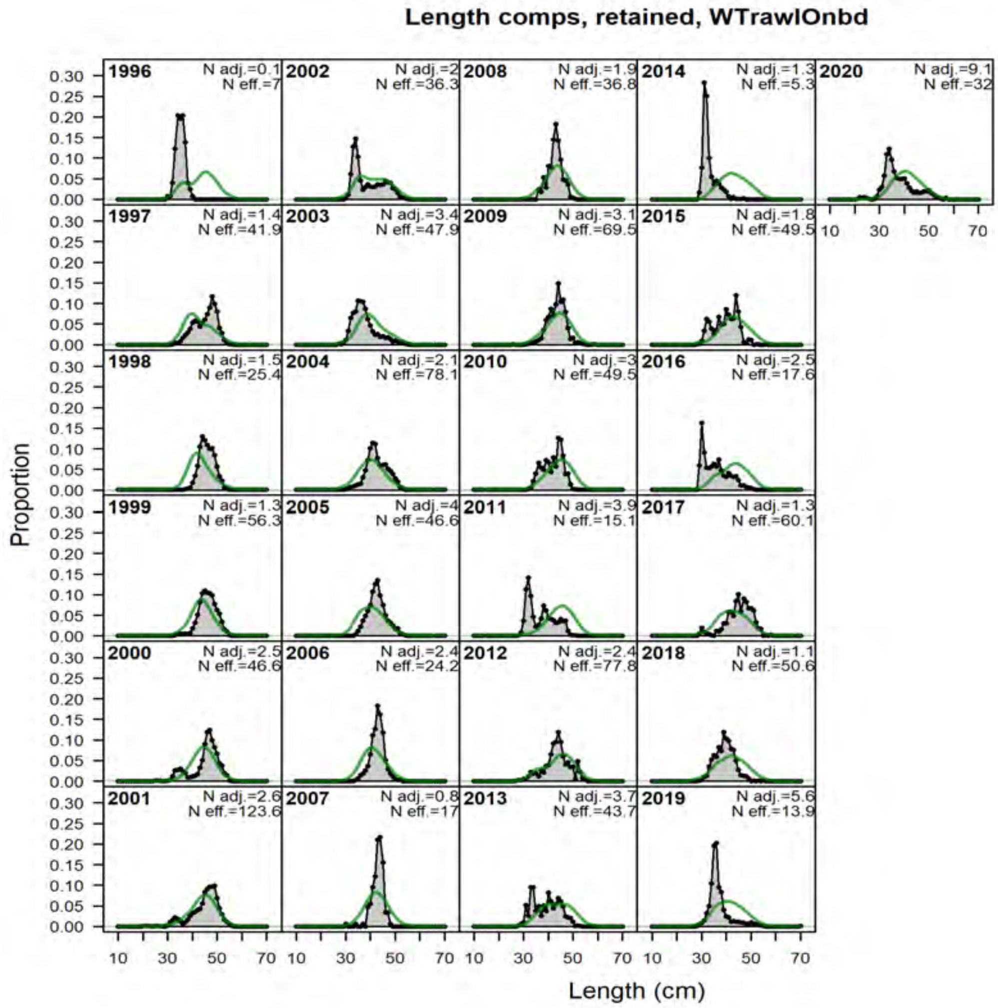


Figure 13.51. Fits to onboard retained length compositions for the west trawl fleet

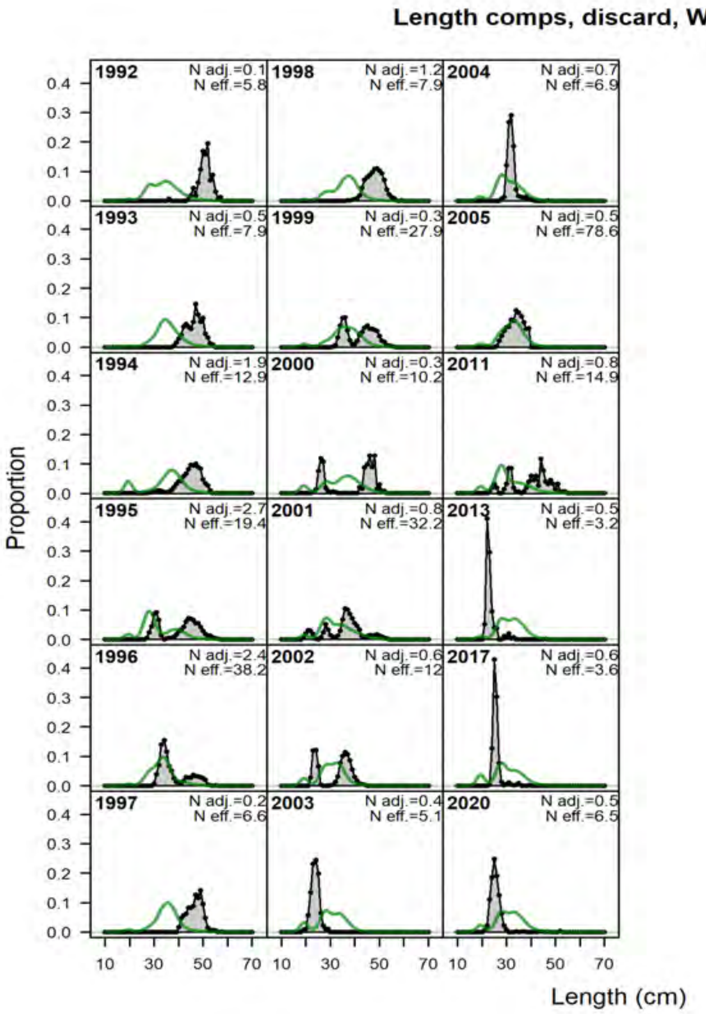


Figure 13.52. Fits to onboard discarded length compositions for the west trawl fleet

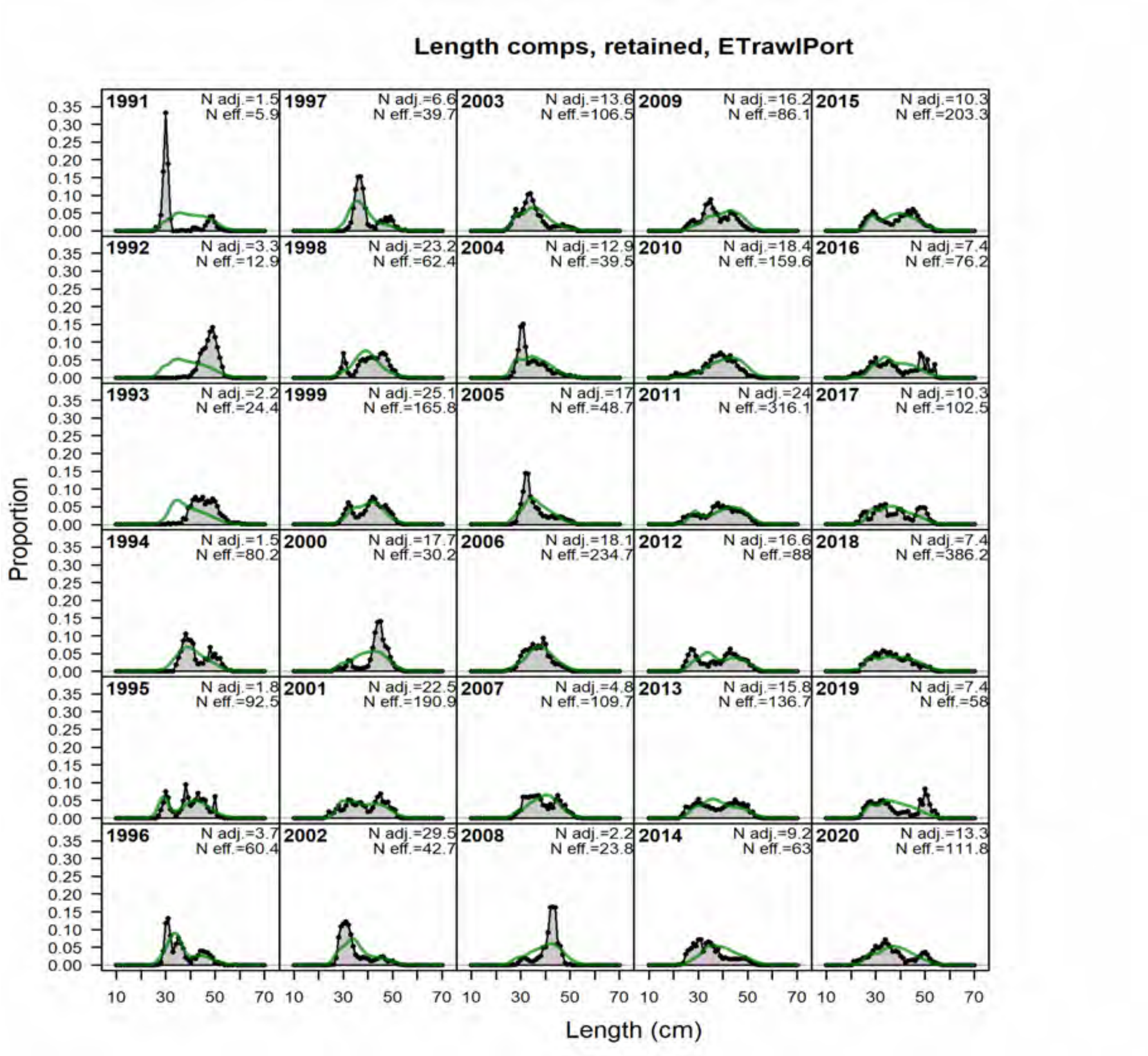


Figure 13.53. Fits to port length compositions for the east trawl fleet

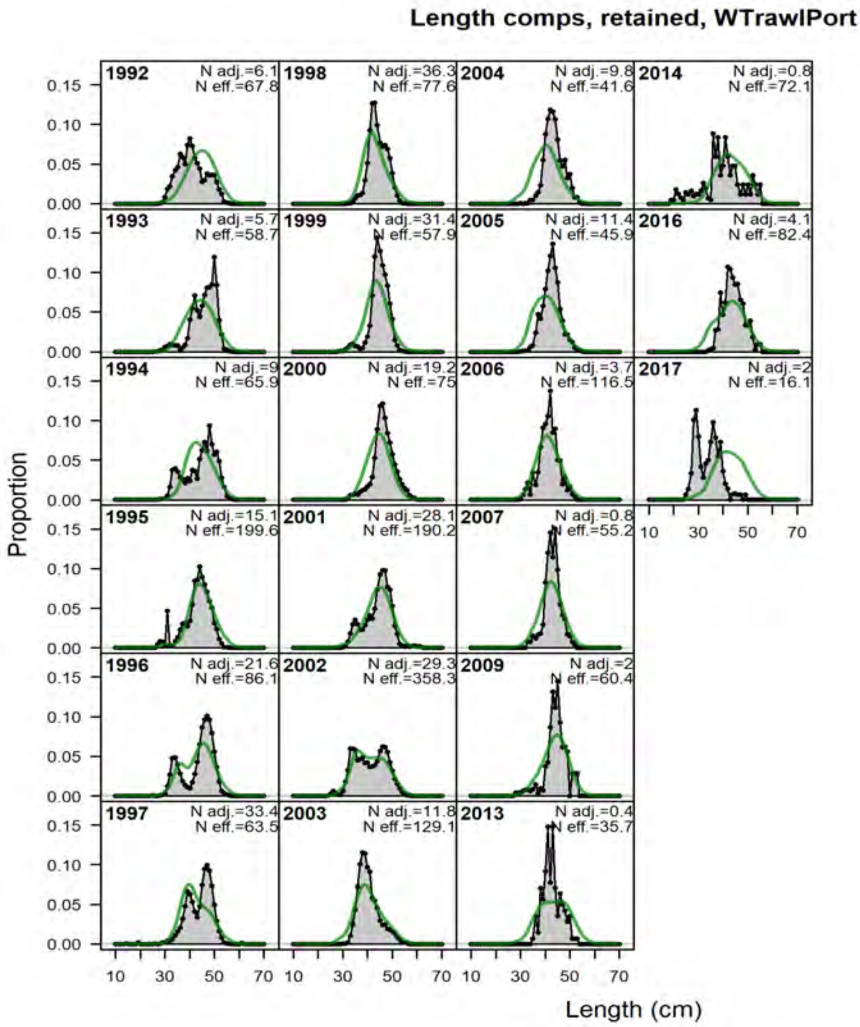


Figure 13.54. Fits to port length compositions for the west trawl fleet

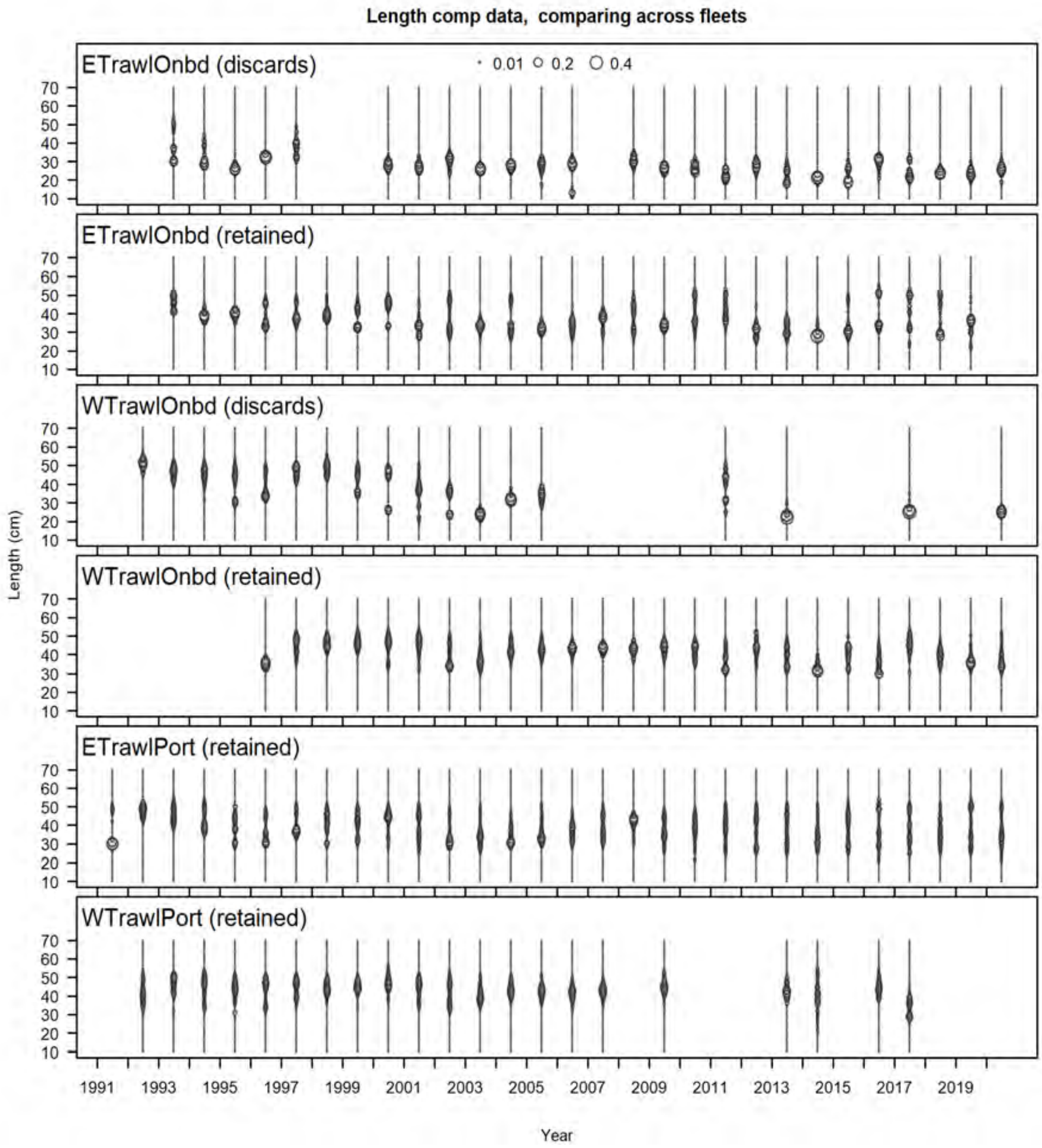


Figure 13.55. Residuals from the annual length compositions for both the east the west trawl fleet

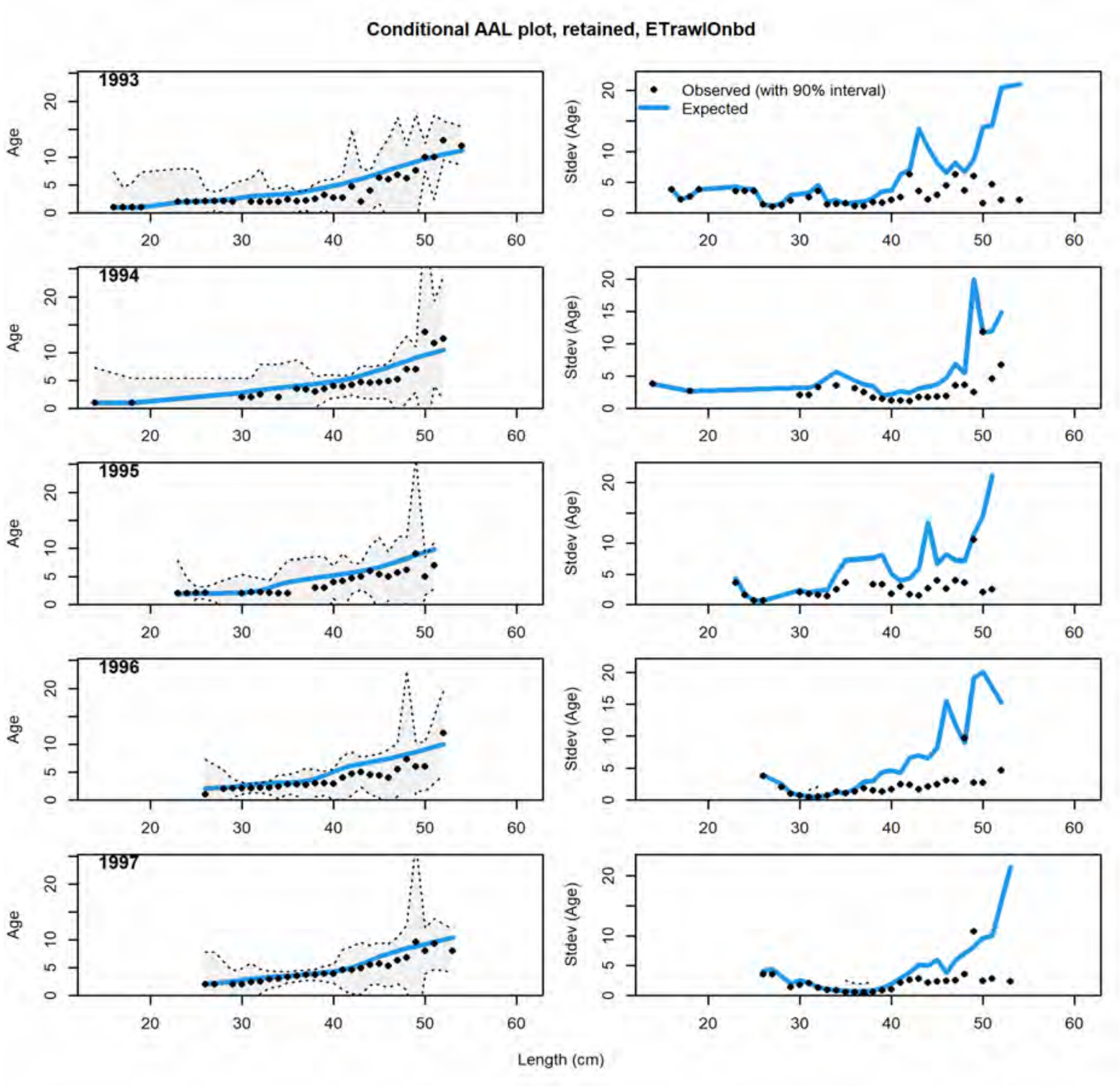
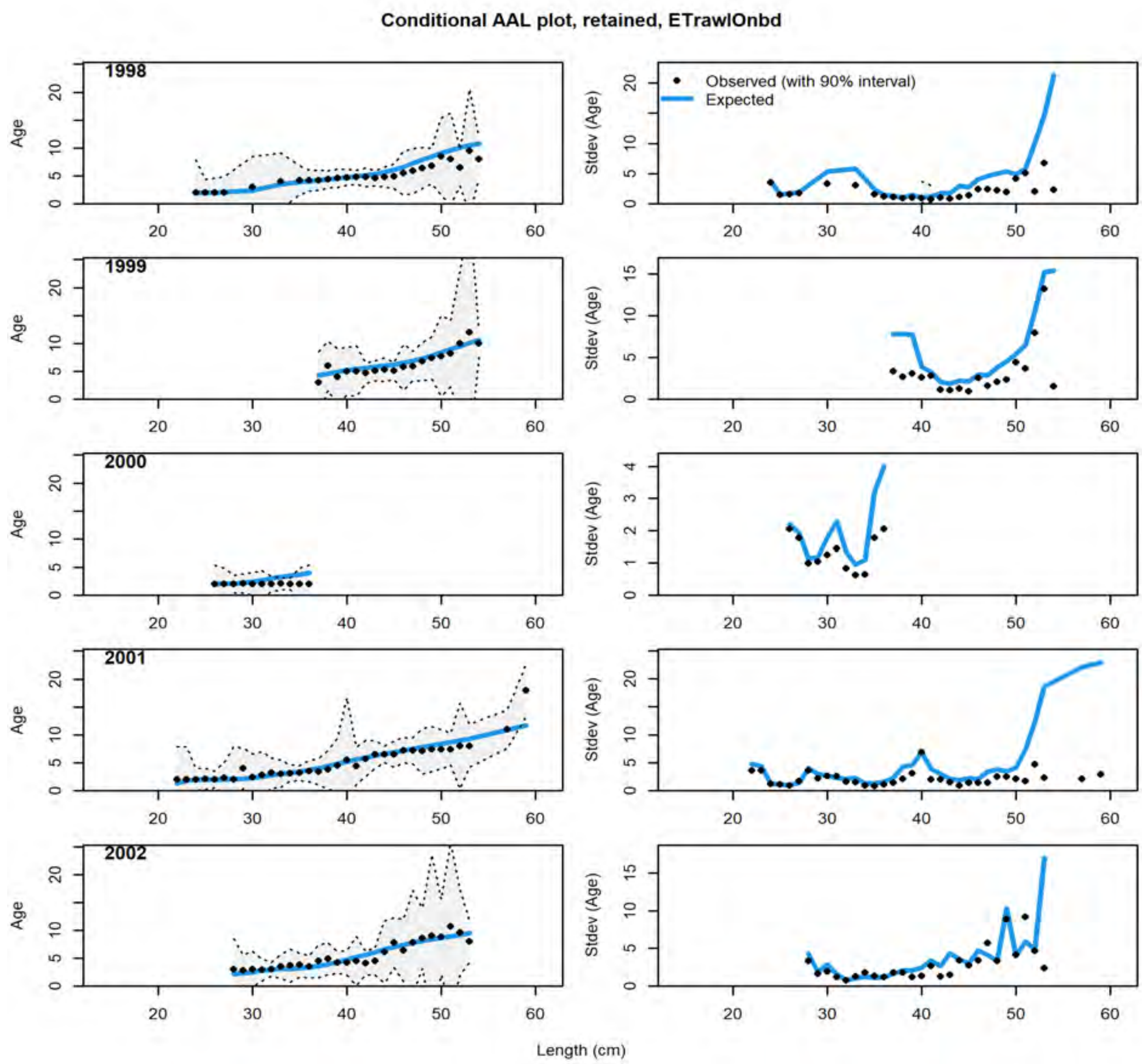


Figure 13.56. Fits to conditional age at length data for the east trawl fleet



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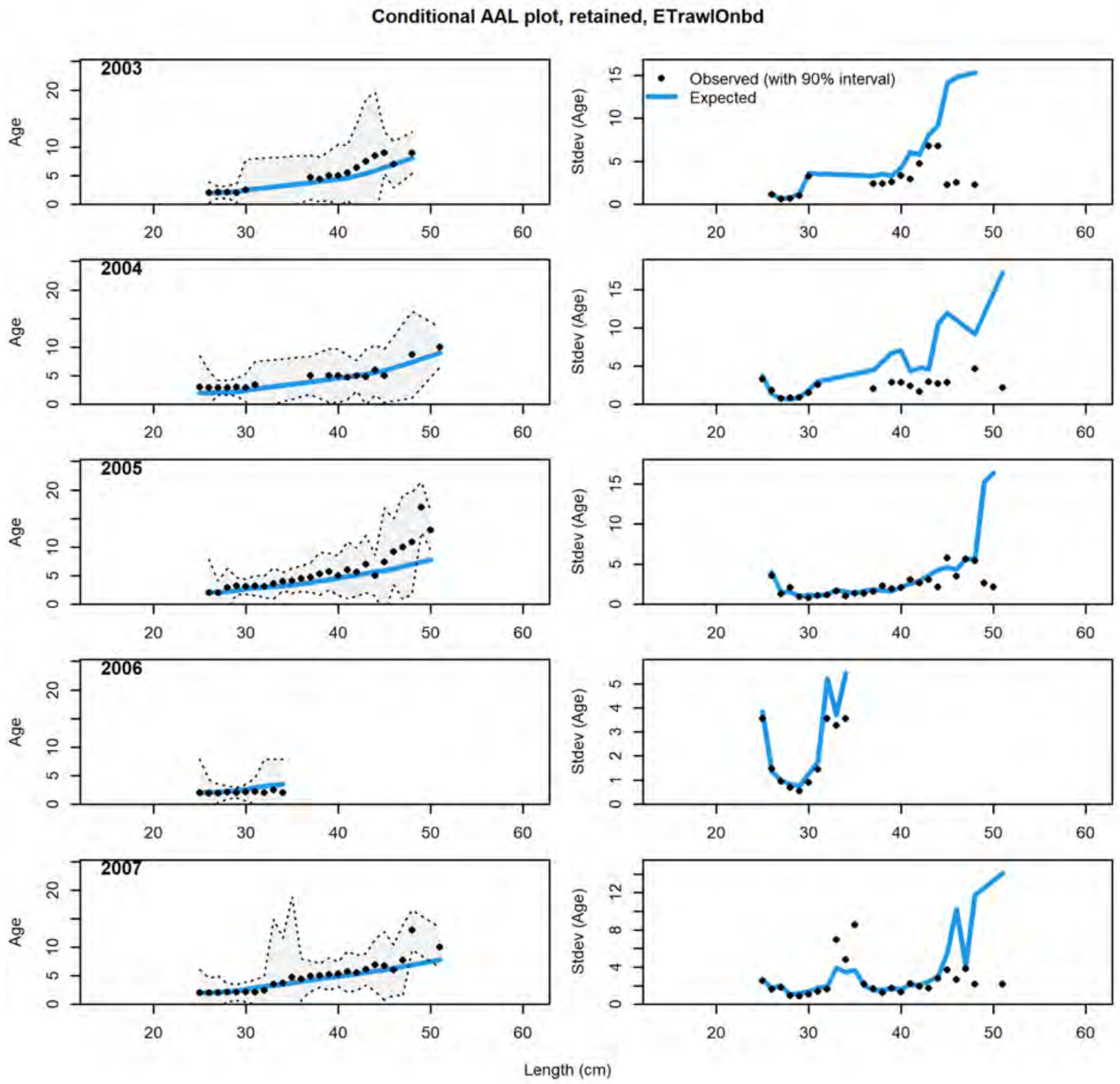
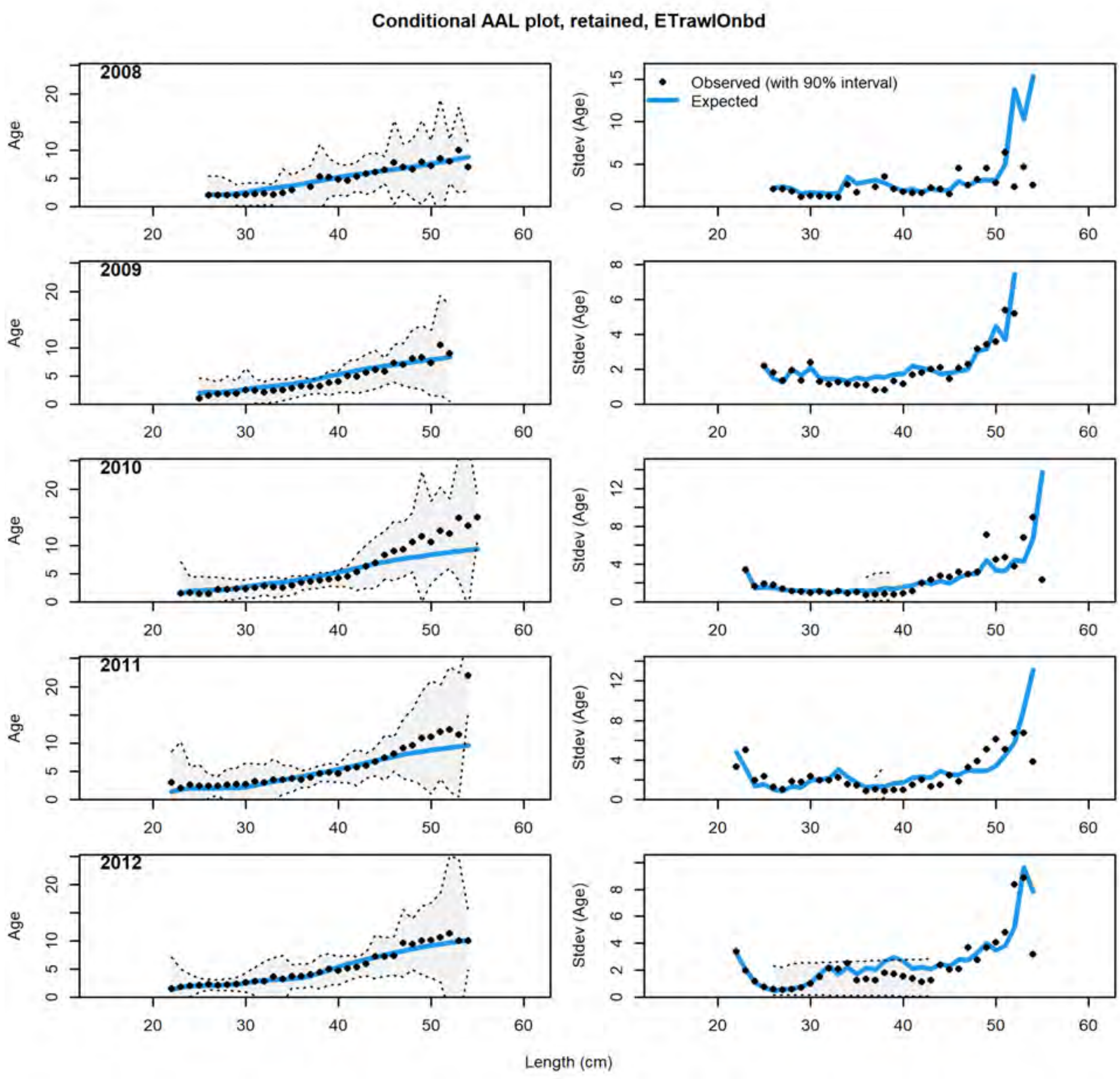


Figure 13.58. Fits to conditional age at length data for the east trawl fleet



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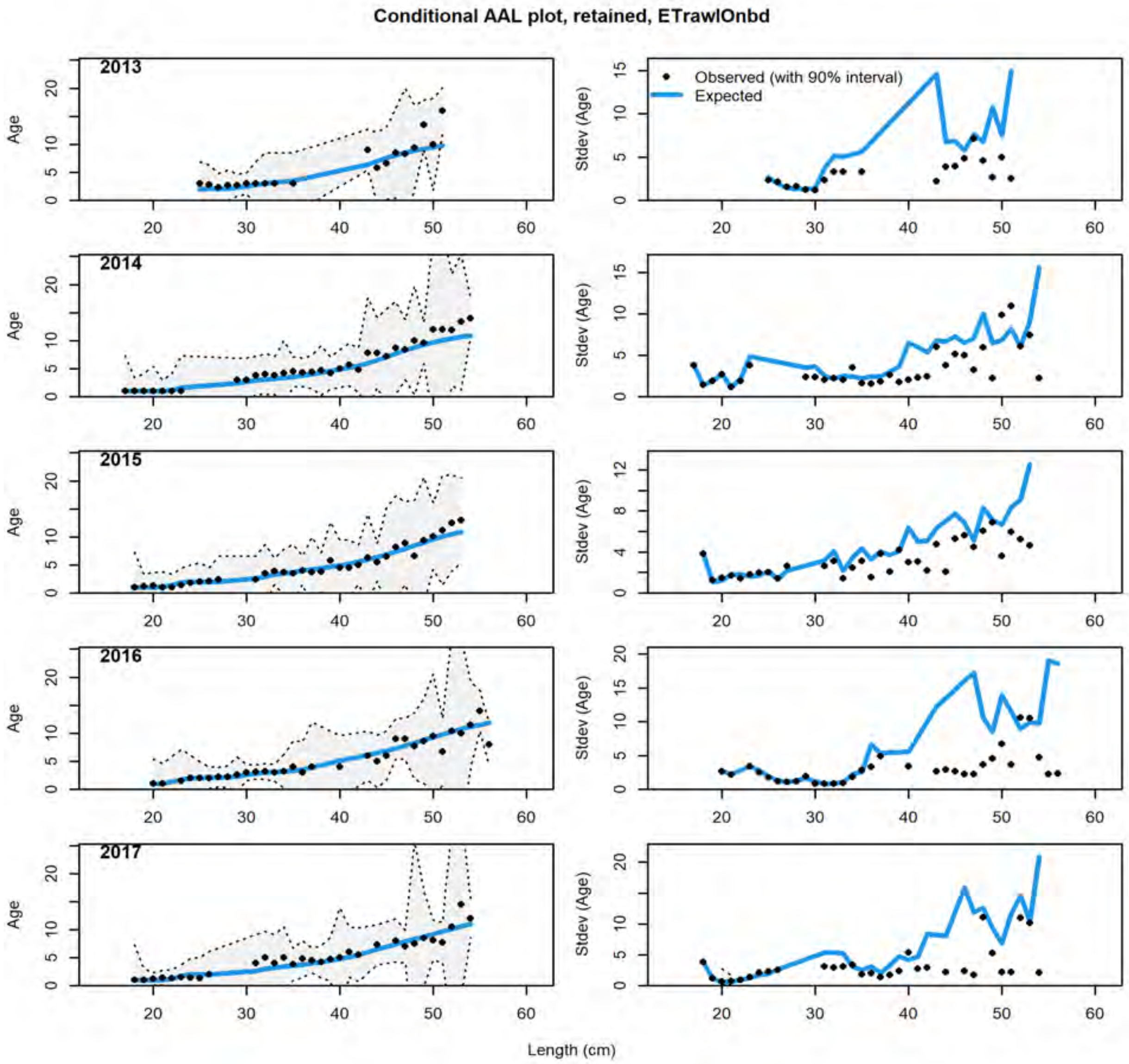

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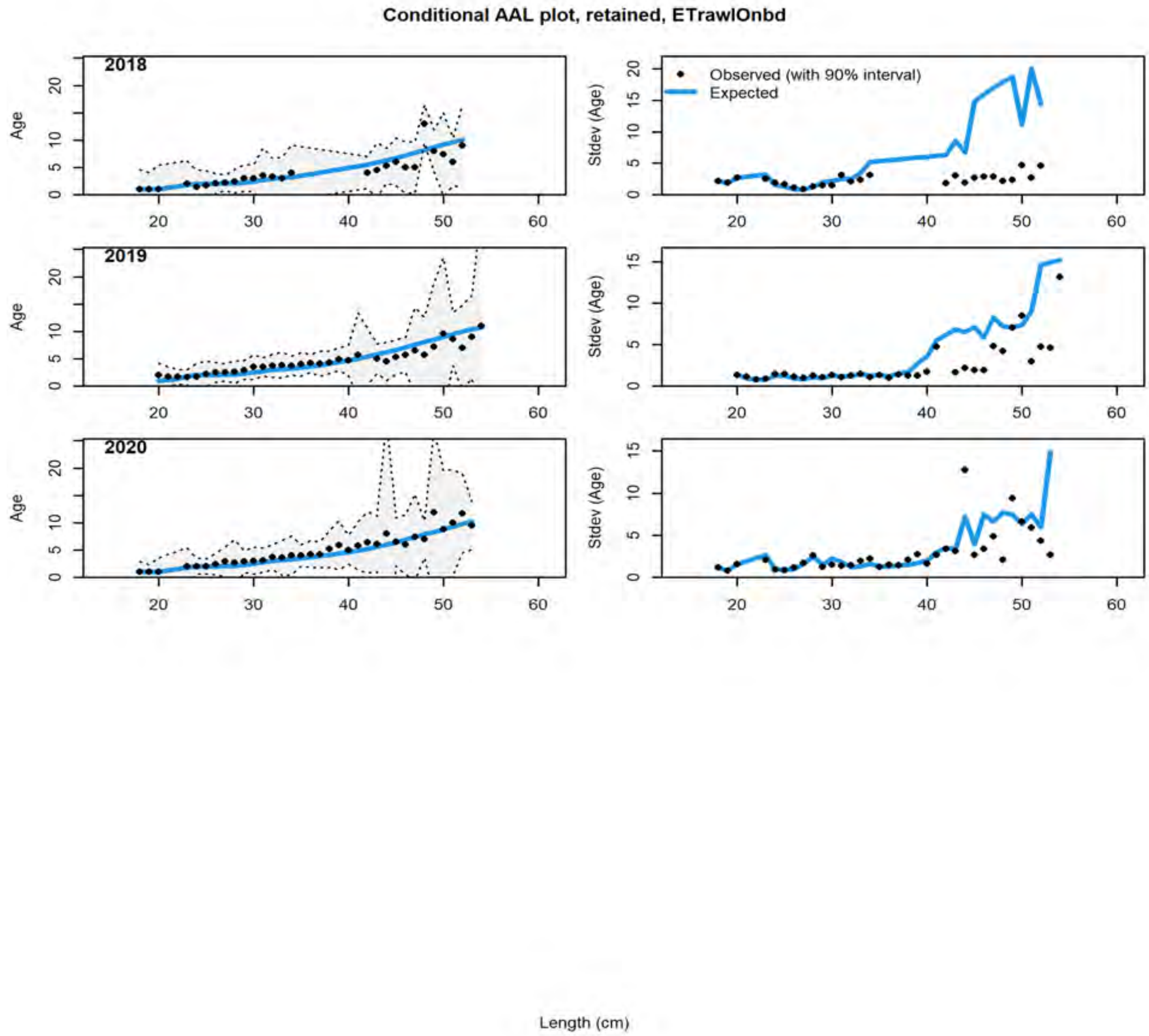


Figure 13.61. Fits to conditional age at length data for the east trawl fleet

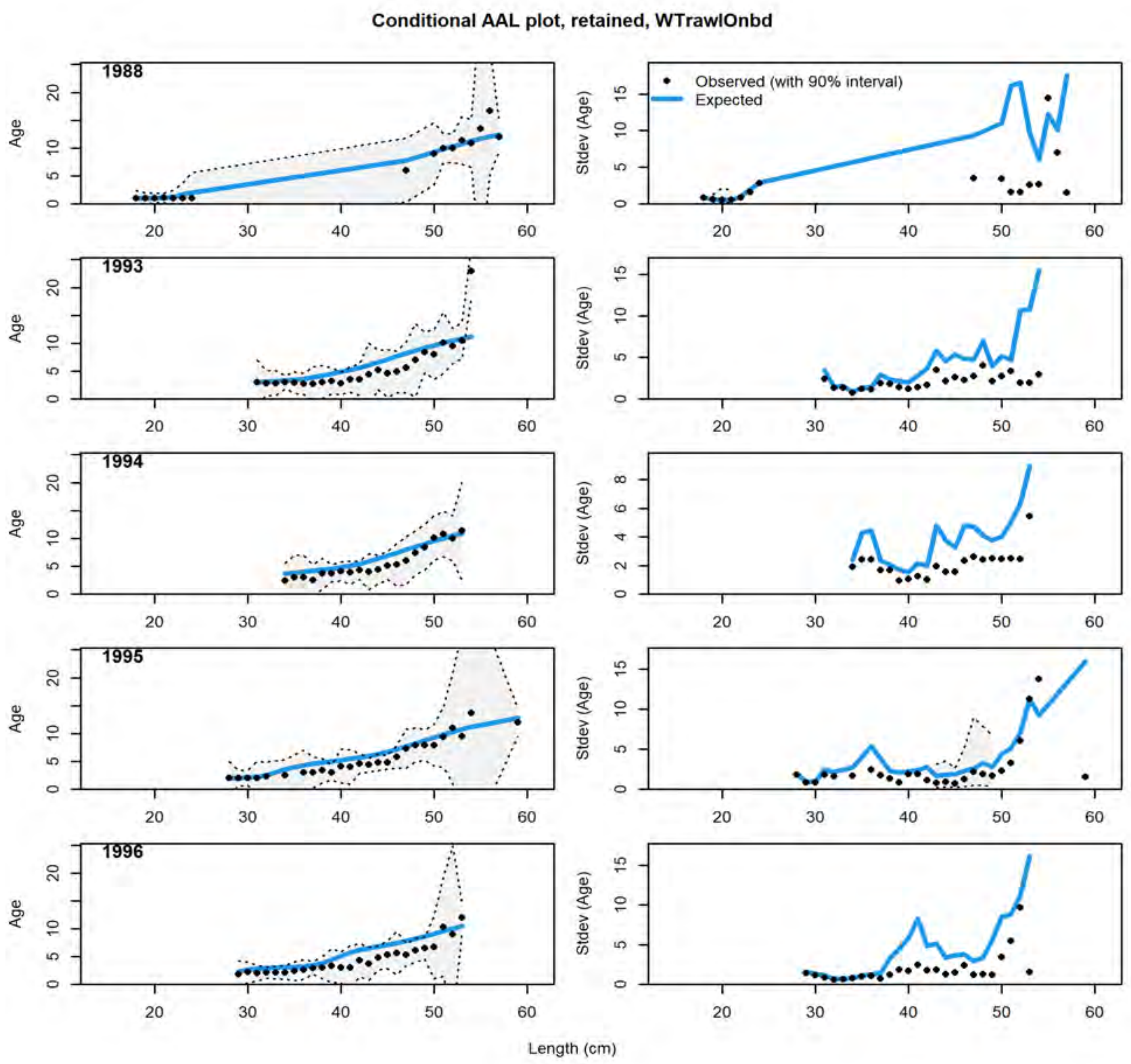


Figure 13.62. Fits to conditional age at length data for the west trawl fleet

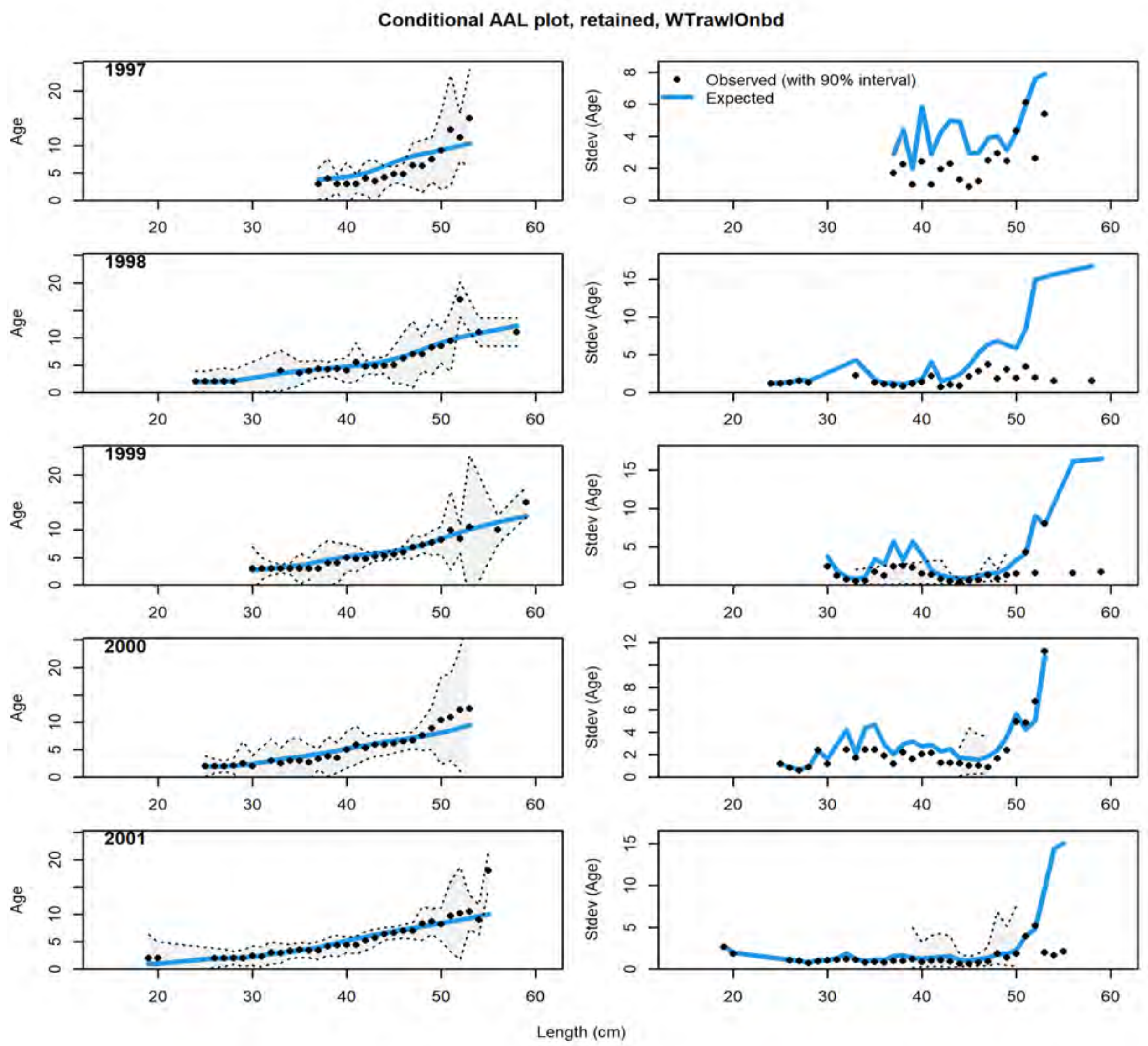
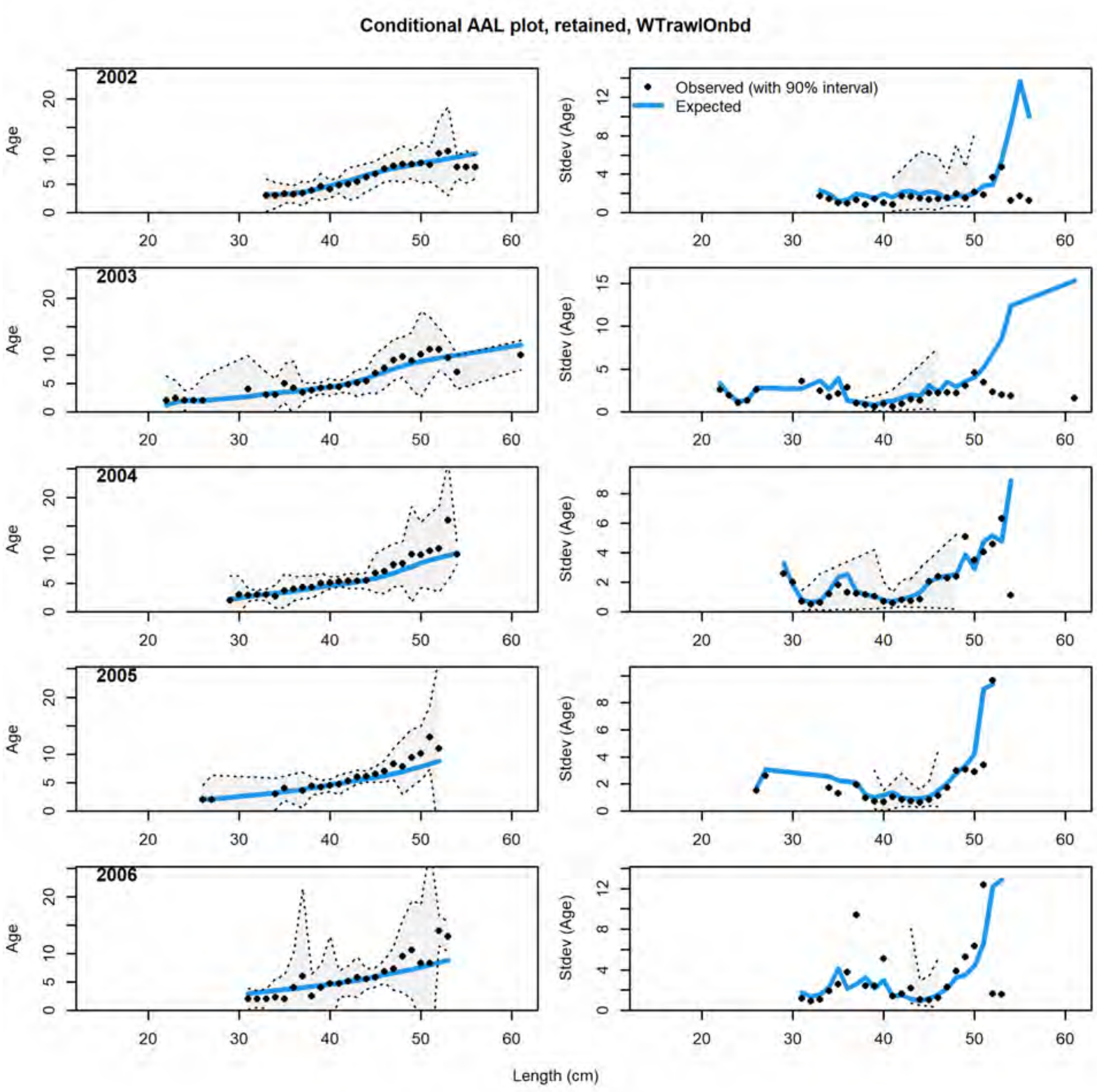


Figure 13.63. Fits to conditional age at length data for the west trawl fleet



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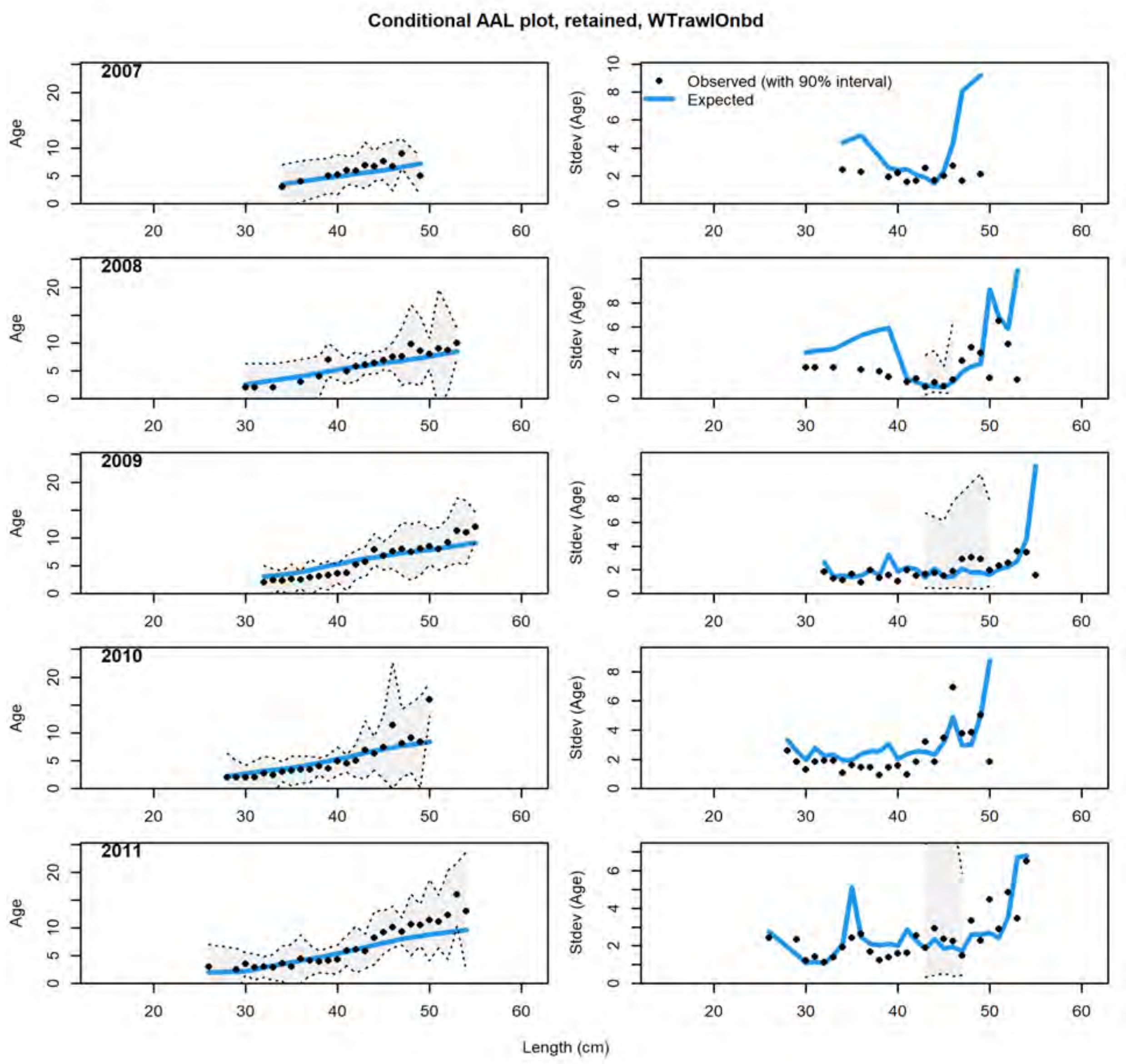

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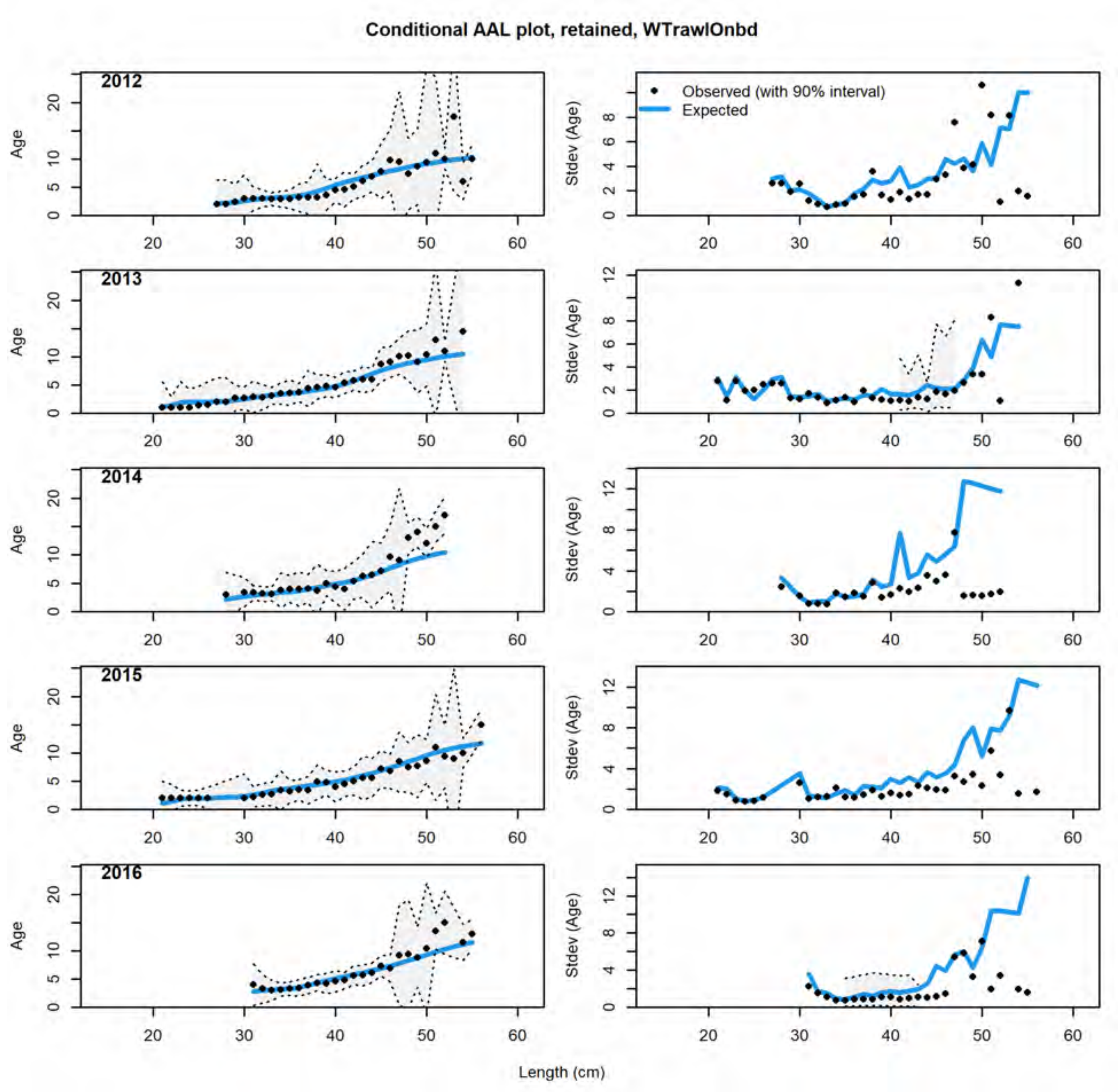

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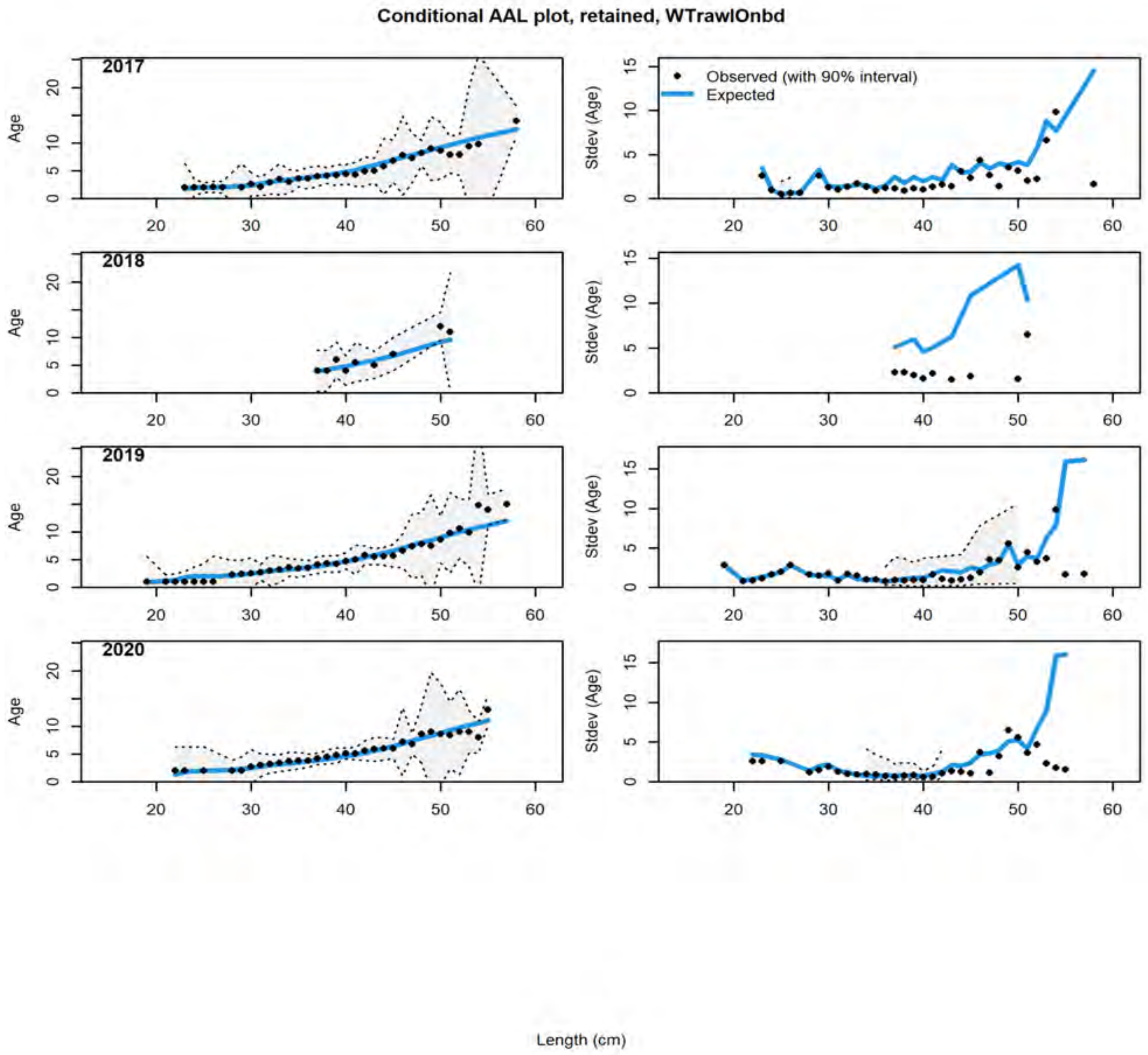

Figure 13.67. Fits to conditional age at length data for the west trawl fleet

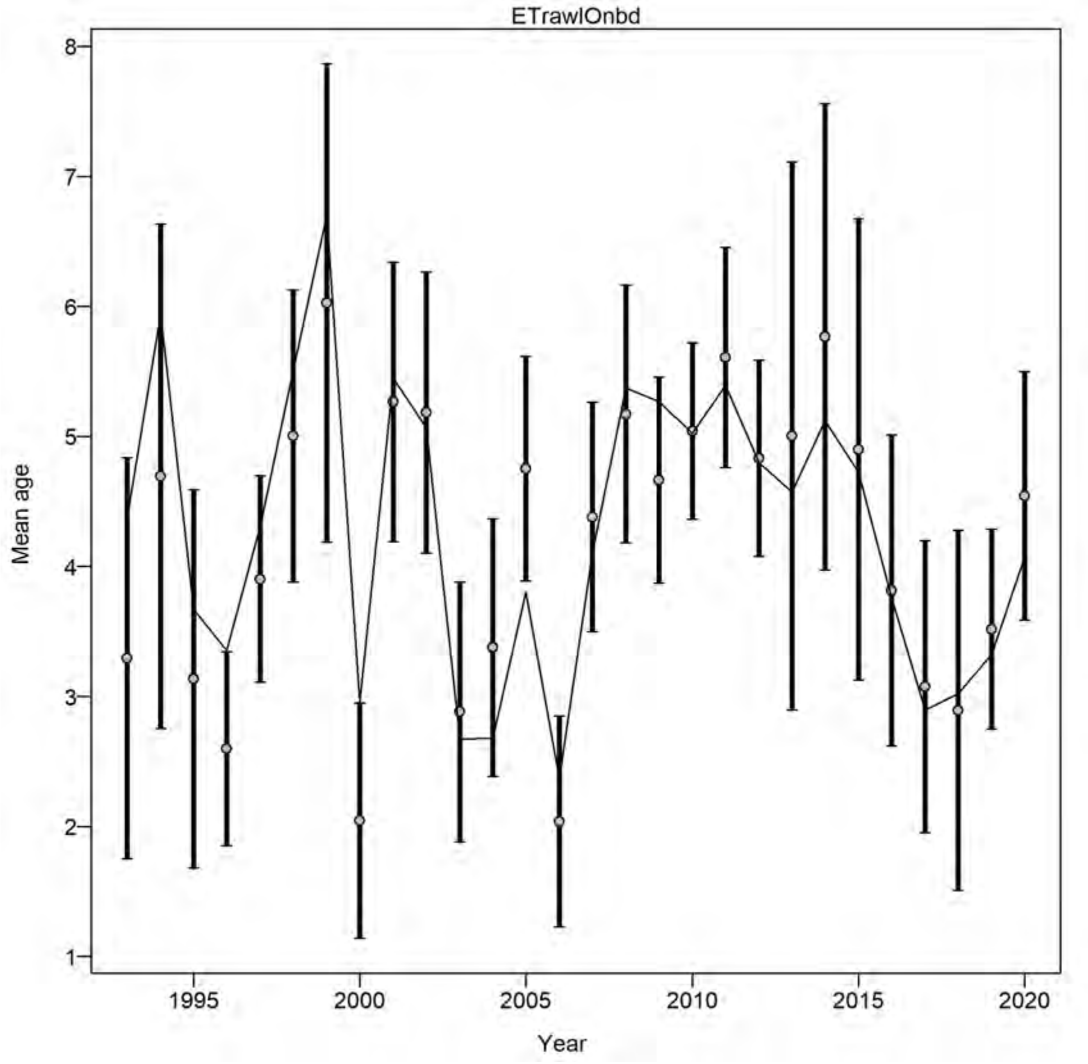

Figure 13.68. Data weighting of conditional age at length data for the east trawl fleet

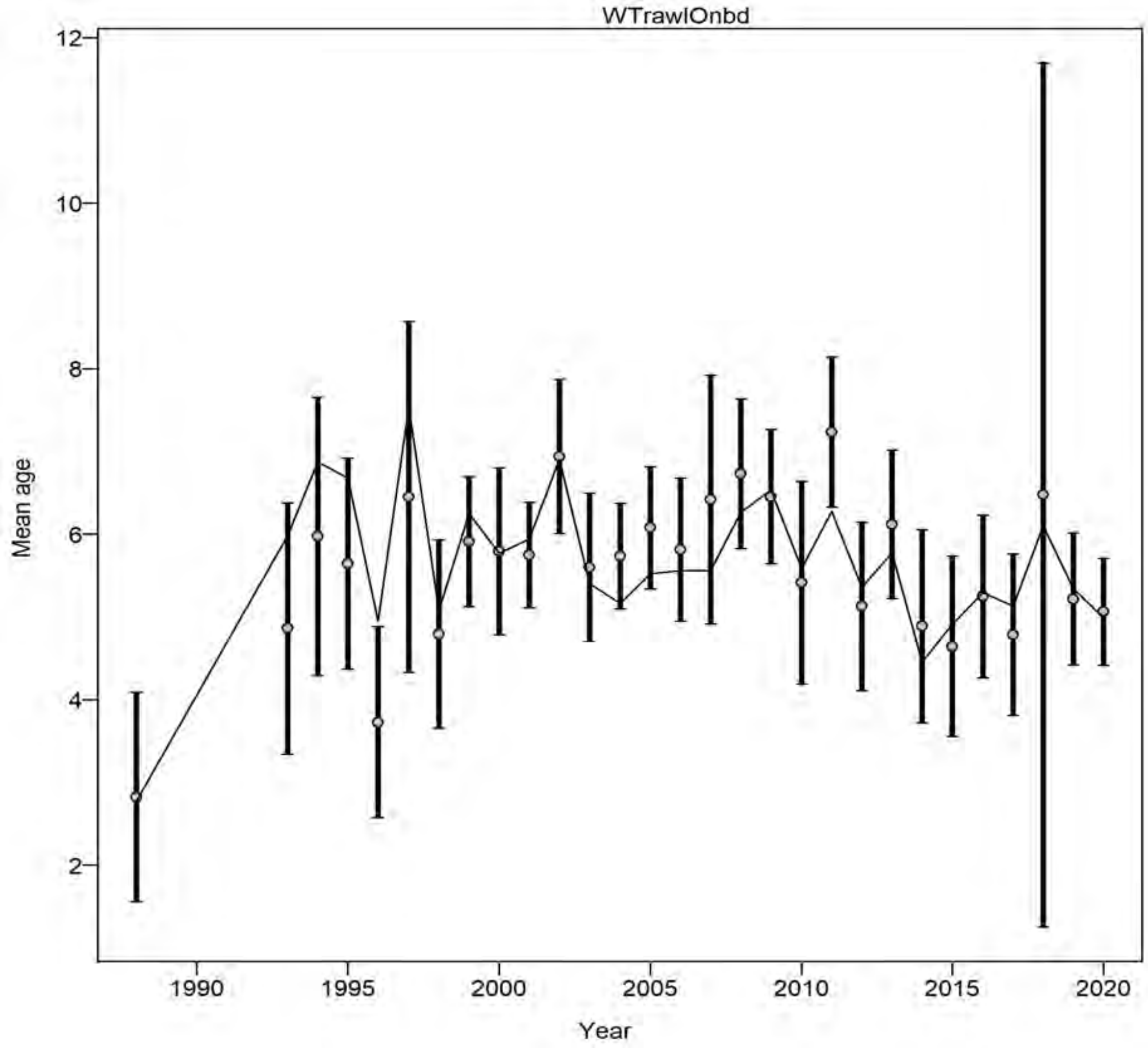

Figure 13.69. Data weighting of conditional age at length data for the west trawl fleet

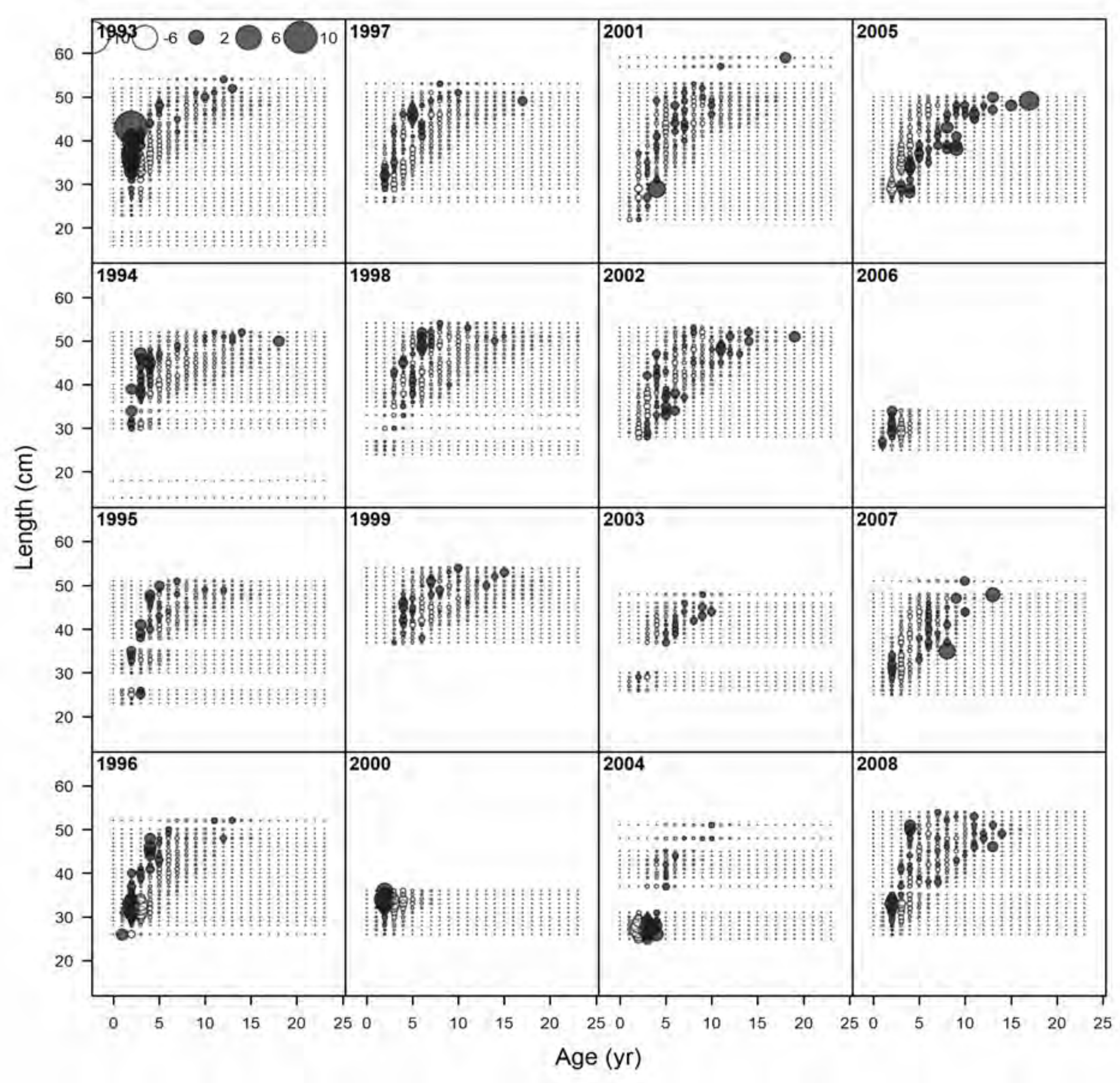

Figure 13.70. Pearson residuals of conditional age at length data for the east trawl fleet

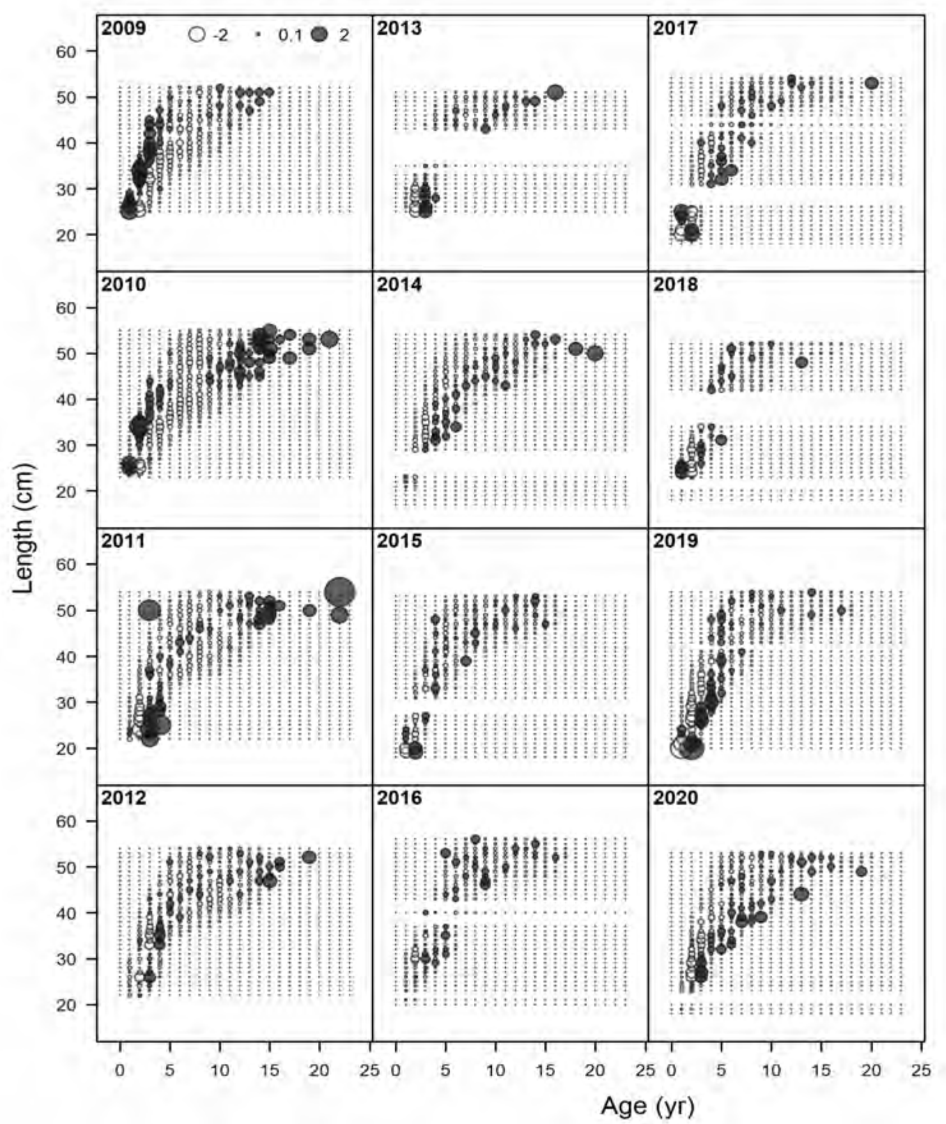

Figure 13.71. Pearson residuals of conditional age at length data for the east trawl fleet

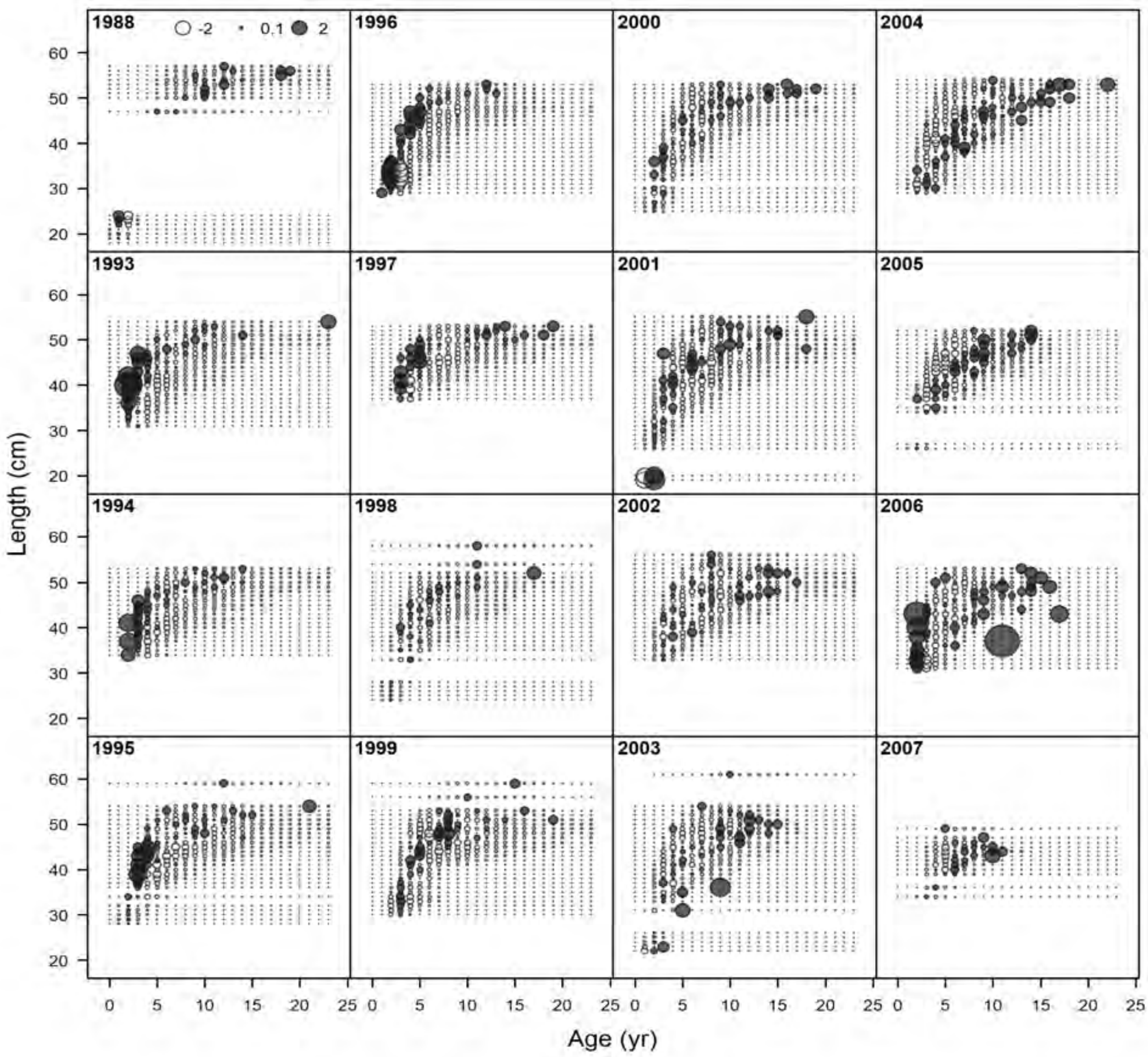

Figure 13.72. Pearson residuals of conditional age at length data for the west trawl fleet

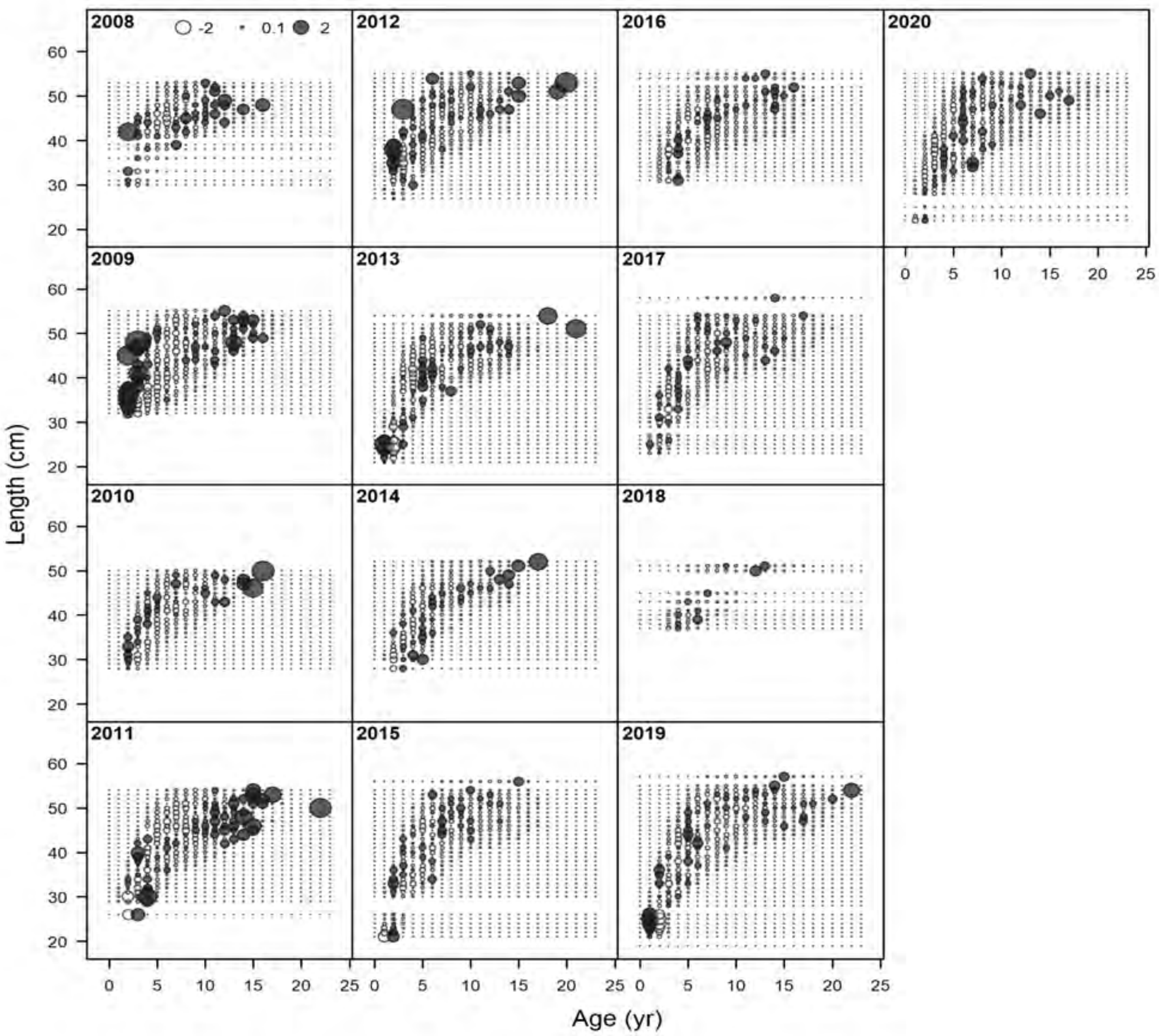

Figure 13.73. Pearson residuals of conditional age at length data for the west trawl fleet

14. Tiger Flathead (*Neoplatycephalus richardsoni*) projections based on CPUE updates to 2020, estimated catch to 2021 and projected catch scenarios to 2025

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14.1 Executive Summary

This document presents results of fixed catch projections for Tiger Flathead (*Neoplatycephalus richardsoni*) to provide information on possible projected stock status in light of changes to both catches and CPUE following the 2019 Tiger Flathead stock assessment.

Updated data used from the 2019 assessment, including preliminary catch (combined Commonwealth and state catch) for 2019-2020, estimated 2021 catch and updated CPUE series to the end of 2020 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 2020 stock status, from 34% in the last stock assessment to 32% in this analysis. These changes are due to revisions to the catches (2017-2021) and to the revised CPUE series, which has a downturn at the end of the time series (2019-2020) for the Danish seine CPUE. The eastern trawl and Tasmanian trawl CPUE series do not show the same downturn at the end of the CPUE series as Danish seine, with both trawl CPUE relatively flat in the period 2019-2020. Projecting forward to 2022 takes the stock status to 35% at the start of 2022, and this is expected to recover to 37% at the start of 2025, assuming that the RBC is caught in 2023 and 2024 and there is average recruitment from 2017 onwards.

Changes to the projected stock status when the 2019 base case is updated are a consistent 1% reduction in stock status in the period 2020-2025, assuming the RBC is caught each year. If projections are made under a constant catch of 2,400 t, there is a lightly faster recovery of the stock status towards B_{40}, the target reference point for Tiger Flathead.

14.2 Previous assessment and changes to data

14.2.1 *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.

14.2.2 *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 (2005) 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, 2019) 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, 2019), 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, 2005).

14.2.3 *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 – 2020)
3. Eastern trawl – diesel otter trawlers from NSW, eastern Victoria and Bass Strait (1971 – 2020)
4. Tasmanian trawl – diesel otter trawlers from eastern Tasmania (1985 – 2020)
5. Fishery Independent Survey – (2008 – 2016)

14.2.4 *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 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.

14.2.5 *Previous assessment*

The most recent full quantitative stock assessment for Tiger Flathead using data up to 2018 was performed in 2019 (Day, 2019) using Stock Synthesis version SS-V3.30.14.05, (Methot et al., 2018).

14.2.6 *Landed catches*

A landed catch history for tiger flathead, separated into the four ‘fleets’, is available for all years from 1915 to 2018 (Table 14.1, Figure 14.1 and Figure 14.2). 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 state catches have been added to the eastern trawl fleet, Victorian state catches added to the Danish seine fleet and Tasmanian state catches have been added to the Tasmanian fleet.

In order to calculate the Recommended Biological Catch (RBC) for 2022, it is necessary to estimate the Commonwealth calendar year catch for 2021. The TAC (Table 14.2) was reduced in 2020 and increased closer to the 2019 TAC in 2021. For simplicity, catches by fleet in 2021 were assumed to be the same as catches by fleet in 2020.

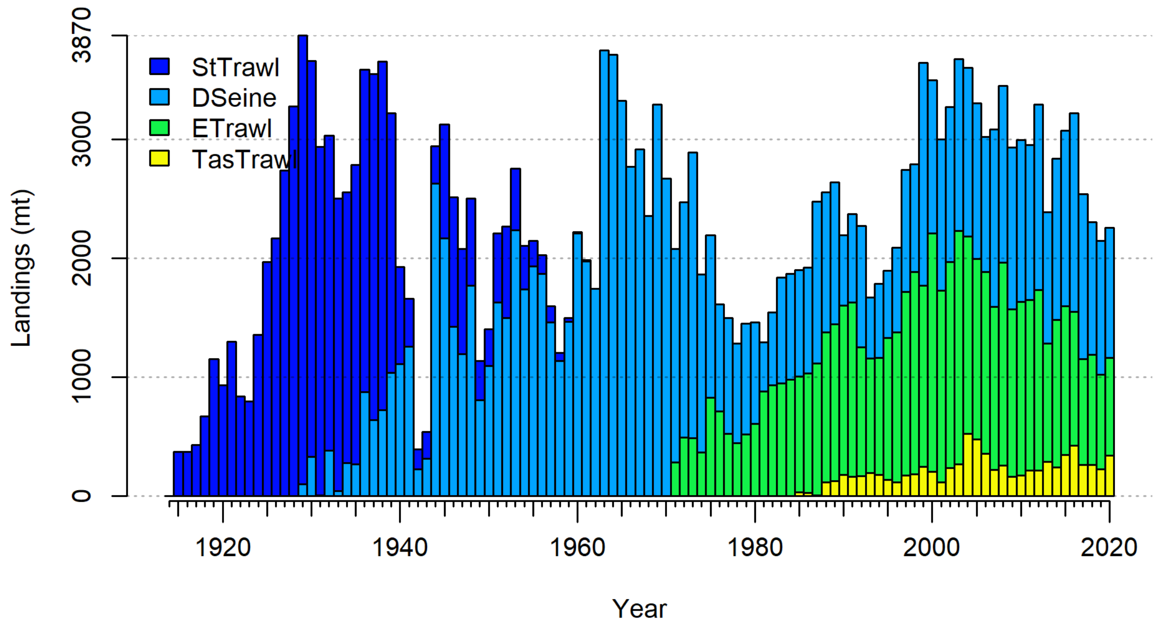

Figure 14.1. Total landed catch of tiger flathead by fleet (stacked) from 1915-2020.

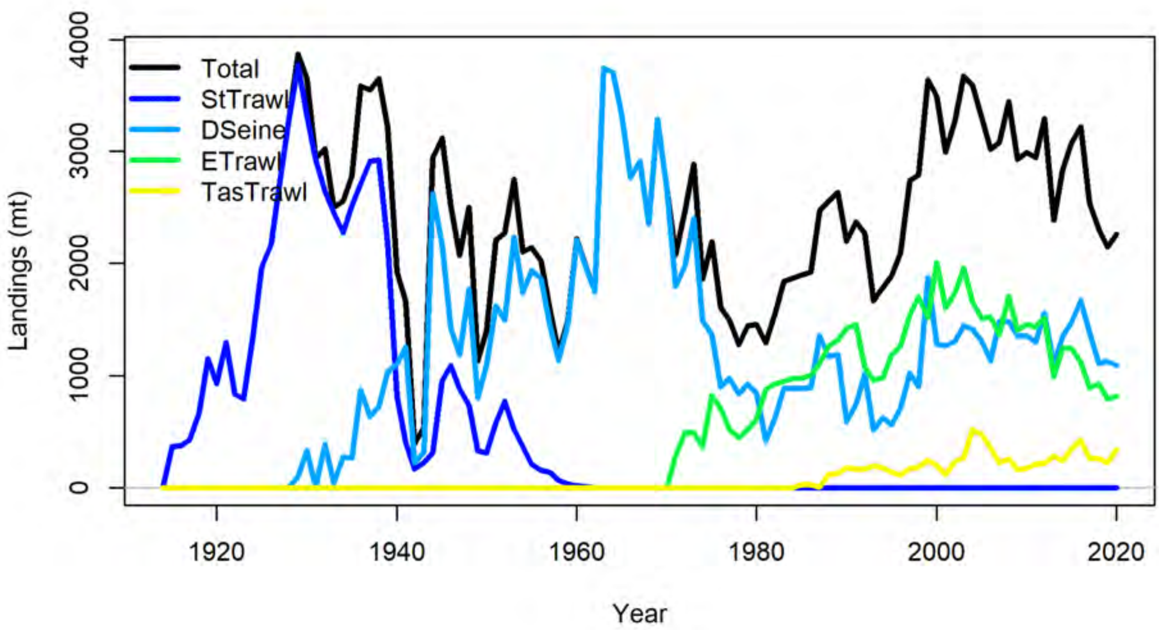

Figure 14.2. Total landed catch of tiger flathead by fleet from 1915-2020.

Table 14.1. Total retained catches (tonnes) of tiger flathead per fleet for calendar years from 1915-2021, used in the 2021 assessment update. Catches listed in bold (2017-2021) indicate updated catches, compared to the catches used in the 2019 assessment

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	1,269	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	**1,386**	**893**	**260**
1946	1,088	1,425	0	0	1982	0	615	930	0	2018	0	**1,110**	**926**	**264**
1947	884	1,193	0	0	1983	0	889	950	0	2019	0	**1,127**	**796**	**224**
1948	735	1,767	0	0	1984	0	890	978	0	2020	0	**1,096**	**819**	**342**
1949	330	804	0	0	1985	0	890	978	30	2021*	0	**1,096**	**819**	**362**
1950	310	1,095	0	0	1986	0	892	1,005	26					

*2021 catches are estimated

Table 14.2. Total allowable catch (t) from 1992 to 2021/22.

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
2020/21	2010
2021/22	2333

14.2.7 *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, 2006; Table 14.3). An unstandardised catch rate index for early Danish seine has been used in tiger flathead assessments since Cui *et al.* (2004) (Table 14.4).

Catch and effort data from the SEF1 logbook database were standardised using GLMs to obtain indices of relative abundance (Sporcic 2021b; Table 14.5) from the period 1986-2020 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 14.6). 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.

Table 14.3. Standardised catch rates for the steam trawl fleet (Klaer 2006).

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 14.4. 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 14.5. 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, 2021a, Sporcic 2021b).

Year	Fleet D Seine	CV	E Trawl	CV	Tas Trawl	CV
1986	1.1600	0.170	0.8046	0.143	0.9589	0.189
1987	1.6316	0.170	1.0722	0.143	0.5620	0.189
1988	1.7890	0.170	1.1740	0.143	0.9849	0.189
1989	1.5506	0.170	1.1741	0.143	0.7217	0.189
1990	1.0414	0.170	1.3964	0.143	0.7263	0.189
1991	1.4126	0.170	1.3118	0.143	0.6821	0.189
1992	1.5151	0.170	1.0357	0.143	0.6524	0.189
1993	0.9376	0.170	1.0502	0.143	0.6081	0.189
1994	0.8076	0.170	0.7624	0.143	0.6355	0.189
1995	0.8295	0.170	0.8049	0.143	0.7174	0.189
1996	0.7771	0.170	0.7196	0.143	0.6519	0.189
1997	1.0101	0.170	0.7199	0.143	0.8053	0.189
1998	0.8502	0.170	0.7611	0.143	0.9640	0.189
1999	1.2371	0.170	0.9197	0.143	1.0797	0.189
2000	0.9221	0.170	1.0110	0.143	0.8747	0.189
2001	0.8649	0.170	0.9704	0.143	0.7383	0.189
2002	1.0208	0.170	1.0535	0.143	1.3196	0.189
2003	1.0597	0.170	1.0396	0.143	1.3586	0.189
2004	1.0418	0.170	0.9042	0.143	1.8548	0.189
2005	1.0551	0.170	0.7789	0.143	1.6896	0.189
2006	1.0383	0.170	0.9428	0.143	1.3682	0.189
2007	1.2495	0.170	1.1483	0.143	1.1167	0.189
2008	1.1203	0.170	1.2105	0.143	1.0469	0.189
2009	1.1575	0.170	1.1215	0.143	1.0185	0.189
2010	1.0486	0.170	1.0799	0.143	1.0148	0.189
2011	0.9719	0.170	1.0645	0.143	0.9582	0.189
2012	0.9248	0.170	1.1676	0.143	1.2184	0.189
2013	0.6676	0.170	0.8824	0.143	1.1774	0.189
2014	0.7186	0.170	1.0361	0.143	1.3689	0.189
2015	0.7132	0.170	1.1682	0.143	1.2842	0.189
2016	0.7418	0.170	1.0666	0.143	1.0493	0.189
2017	0.7159	0.170	0.8804	0.143	1.1820	0.189
2018	0.5127	0.170	0.8825	0.143	0.8325	0.189
2019	0.4662	0.170	0.9411	0.143	0.8498	0.189
2020	0.4392	0.170	0.9436	0.143	0.9287	0.189

Table 14.6. 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

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, 2021a, 2021b) and additional variance is estimated for each abundance index to tune the input and output variances.

14.2.8 *Model structure for projected catch scenarios*

The same model structure and assumptions described in the 2019 assessment (Day, 2019) are used for the projected catch scenarios presented here. Changes include updating to the latest version of Stock Synthesis, SS-V3.30.17.00 (Methot et al., 2021), using preliminary catches for 2019, 2020 and 2021 and updating the Danish seine, eastern trawl and Tasmanian trawl CPUE series up to the end of 2020. 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 2019 assessment.

14.3 Alternative catch scenarios

14.3.1 *Update catch from 2017 to 2021 and update CPUE to 2020*

Initial data updates to the 2019 base case model were performed in a stepwise manner, with four scenarios considered in this data update section.

1. 2019 base case (FLT2019)
2. Update from SS- V3.30.14.05to SS-V3.30.17.00
3. Update catch to 2020 (FLT2021UpdateCatch)
4. Update CPUE to 2020, with updated catch retained (FLT2021CatchRBC)
5. Update CPUE to 2020, with updated catch retained, with fixed projected catches at 2,400t (including both retained and estimated discarded catch) from 2022-2025 (FLT2021Catch2400)

Under the first four scenarios, projections are made under average recruitment, with future (projected) catches set to the RBC. The first two scenarios, based on the 2019 base case, project catches from 2020 onwards, set to the RBC. Scenarios 3 and 4, which feature fixed catches until 2021, project catches from 2022 onwards at the RBC. Scenario 5, which also feature fixed catches until 2021, project catches from 2022 onwards, with the total catch (retained plus discarded) set to 2400 t from 2022-2025 and then set to the RBC from 2026 onwards.

The update to SS-V3.30.17.00 (scenario 2) made no discernible difference, so the results of this scenario are not shown here. Similarly, the difference for scenario 3 made little difference, so are not shown here.

The values of the projected catches for scenarios 1, 4 and 5, and the subsequent (calculated) RBC, are listed in Table 14.7 for the period 2020-2025. These values are calculated from 2020 onwards, for the 2019 base case, and calculated or fixed from 2022 onwards, for the scenario with updated catch and CPUE, with all calculated values shown in bold in Table 14.7. Similarly the calculated stock status at the beginning of each year from 2020-2025, assuming average recruitment, is shown in Table 14.8 and displayed in Figure 14.5, showing the relative stock status over the full time series from 1915-2025 and in Figure 14.6, showing the relative stock status from 2010-2025.

Table 14.7. Fixed and RBC catch projections (including discards) for 2020-2025 after applying these projected catches (under average recruitment) for the 2019 base case, the 2021 updated catch and CPUE scenario, and the 2021 updated catch and CPUE scenario with fixed catch projections. RBC catch projections are shown in bold.

	Catch		
Year	FLT2019	FLT2021CatchRBC	FLT2021Catch2400
2020	**2,334**	2,428	2,428
2021	**2,648**	2,423	2,281
2022	**2,706**	**2,593**	2,400
2023	**2,755**	**2,675**	2,400
2024	**2,796**	**2,730**	2,400
2025	**2,830**	**2,777**	2,400

Table 14.8. Projected stock status for 2020-2025 following application of fixed and RBC catch projections (including discards) for 2020-2025 after applying these projected catches and RBCs from Table 14.7 (from average recruitment) for the 2019 base case, the 2021 updated catch and CPUE scenario, and the 2021 updated catch and CPUE scenario with fixed catch projections.

	Stock status (%)		
Year	FLT2019	FLT2021CatchRBC	FLT2021Catch2400
2020	33.7	32.2	32.2
2021	35.2	33.5	33.5
2022	36.1	34.9	35.2
2023	36.8	35.9	36.7
2024	37.4	36.7	38.0
2025	37.9	37.3	39.3

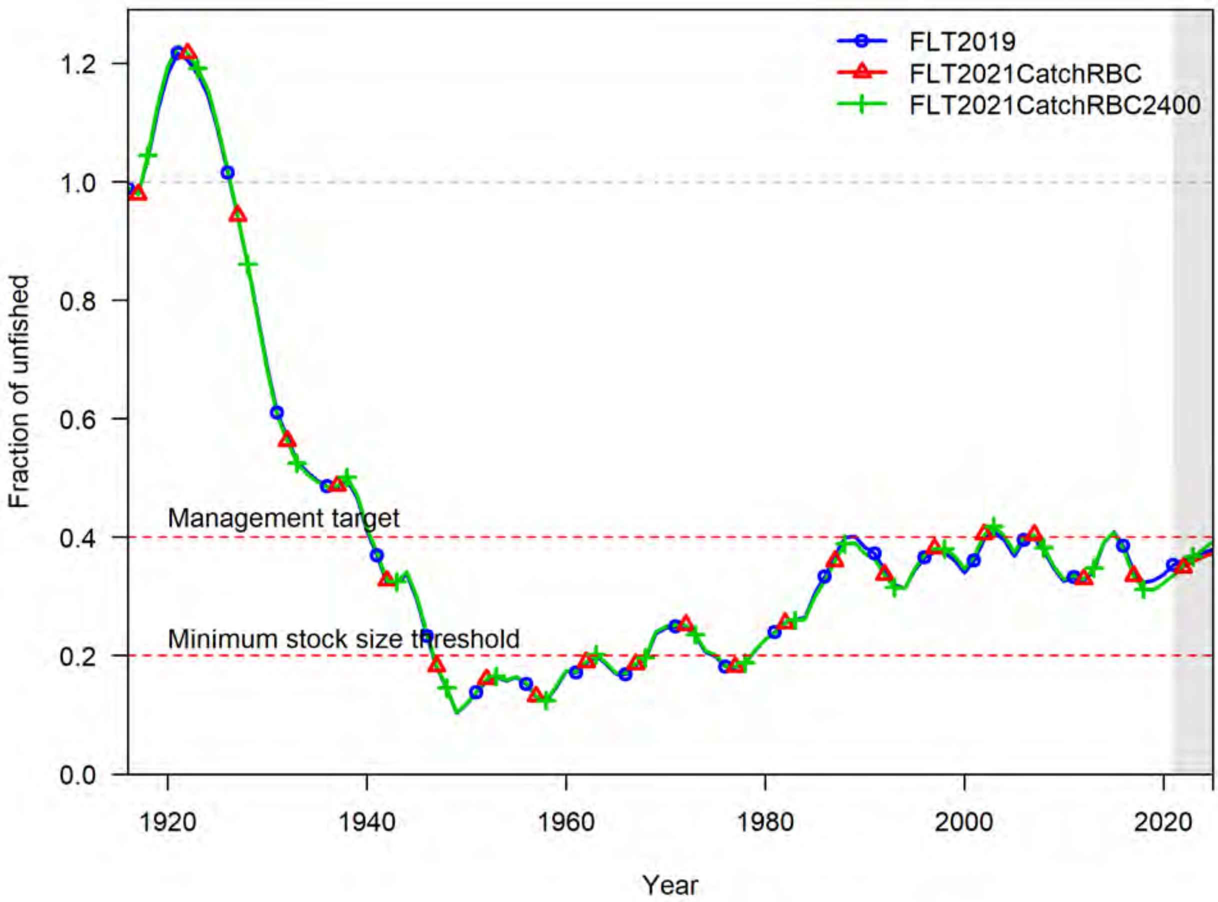

Figure 14.3. Relative spawning biomass (1915-2025) for the 2019 base case, the 2021 updated catch and CPUE scenario, and the 2021 updated catch and CPUE scenario with fixed catch projections.

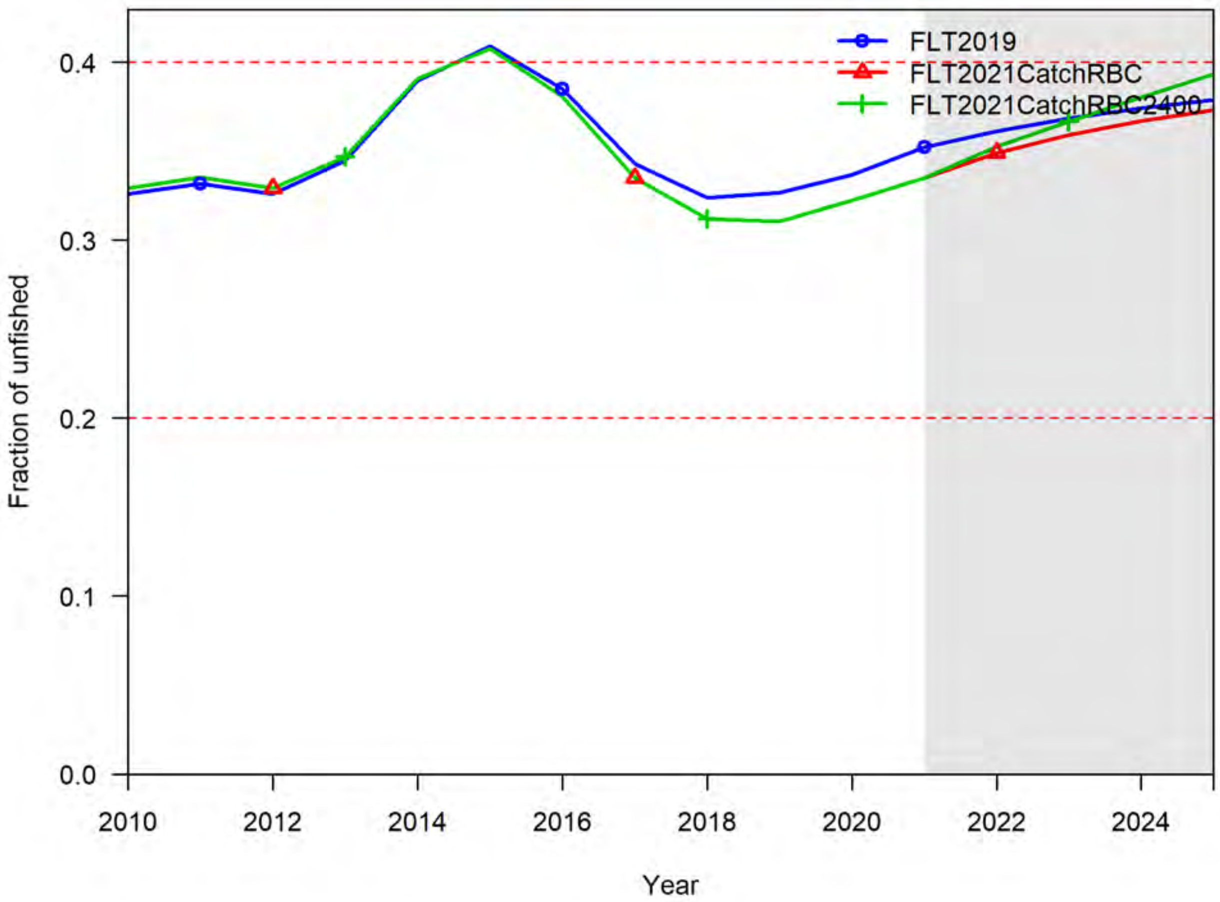

Figure 14.4. Relative spawning biomass (2010-2025) for the 2019 base case, the 2021 updated catch and CPUE scenario, and the 2021 updated catch and CPUE scenario with fixed catch projections.

Recruitment deviations for the 2019 base case, the 2021 updated catch and CPUE scenario, and the 2021 updated catch and CPUE scenario with fixed catch projections are shown in Figure 14.7. This shows that recruitment is set to average recruitment from 2016 for all three scenarios. Note that the recent estimated recruitment events are revised downwards, and more so in 2016, 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 for the Danish seine fleet, with subsequent improvements to the fit to the updated CPUE.

Updating both the catch data and CPUE results in minor changes to predicted spawning biomass. The relative stock status in 2023 is 37% for scenario 1 (after applying the RBC, given the projected stock status) compared to 36% for scenario 4 (catch and CPUE updated). The relative stock status in 2024 is 38% for scenario 1 (after applying the RBC, given the projected stock status) compared to 37% for scenario 4 (catch and CPUE updated).

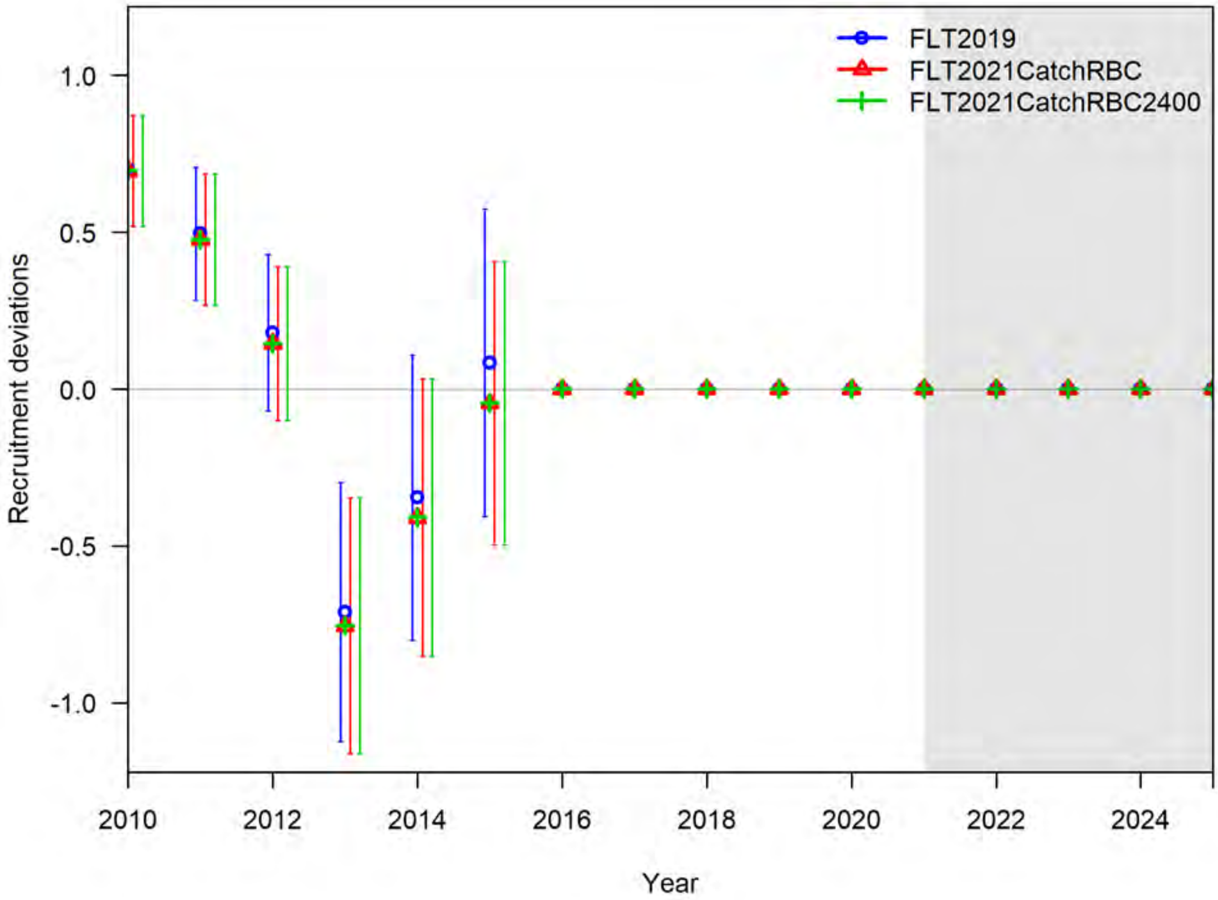

Figure 14.5. Recruitment deviations (2010-2023) for the 2017 base case, the updated catch and updated CPUE scenarios (showing average recruitment).

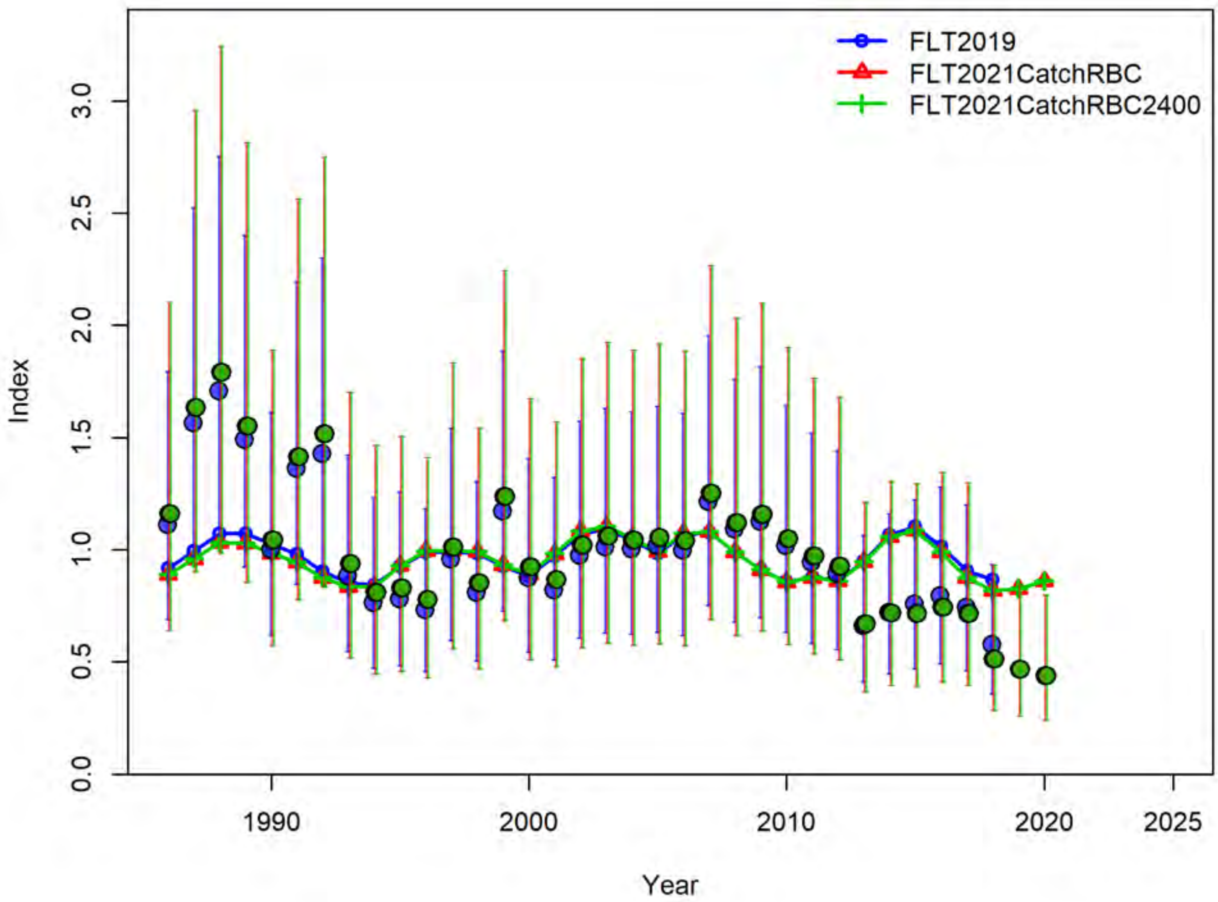

Figure 14.6. Fits to the Danish seine CPUE series for the 2019 base case, the 2021 updated catch and CPUE scenario, and the 2021 updated catch and CPUE scenario with fixed catch projections.

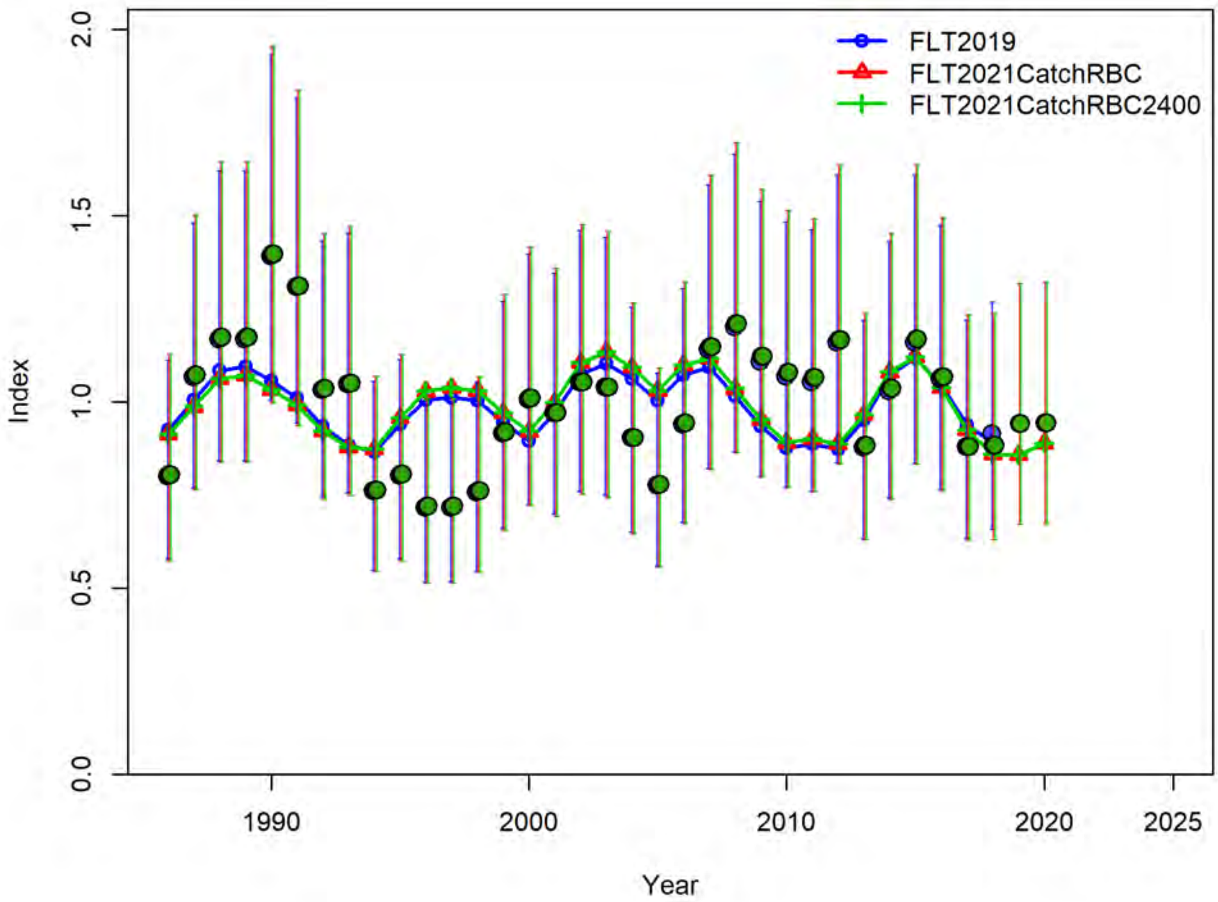

Figure 14.7. Fits to the eastern trawl CPUE series for the 2019 base case, the 2021 updated catch and CPUE scenario, and the 2021 updated catch and CPUE scenario with fixed catch projections.

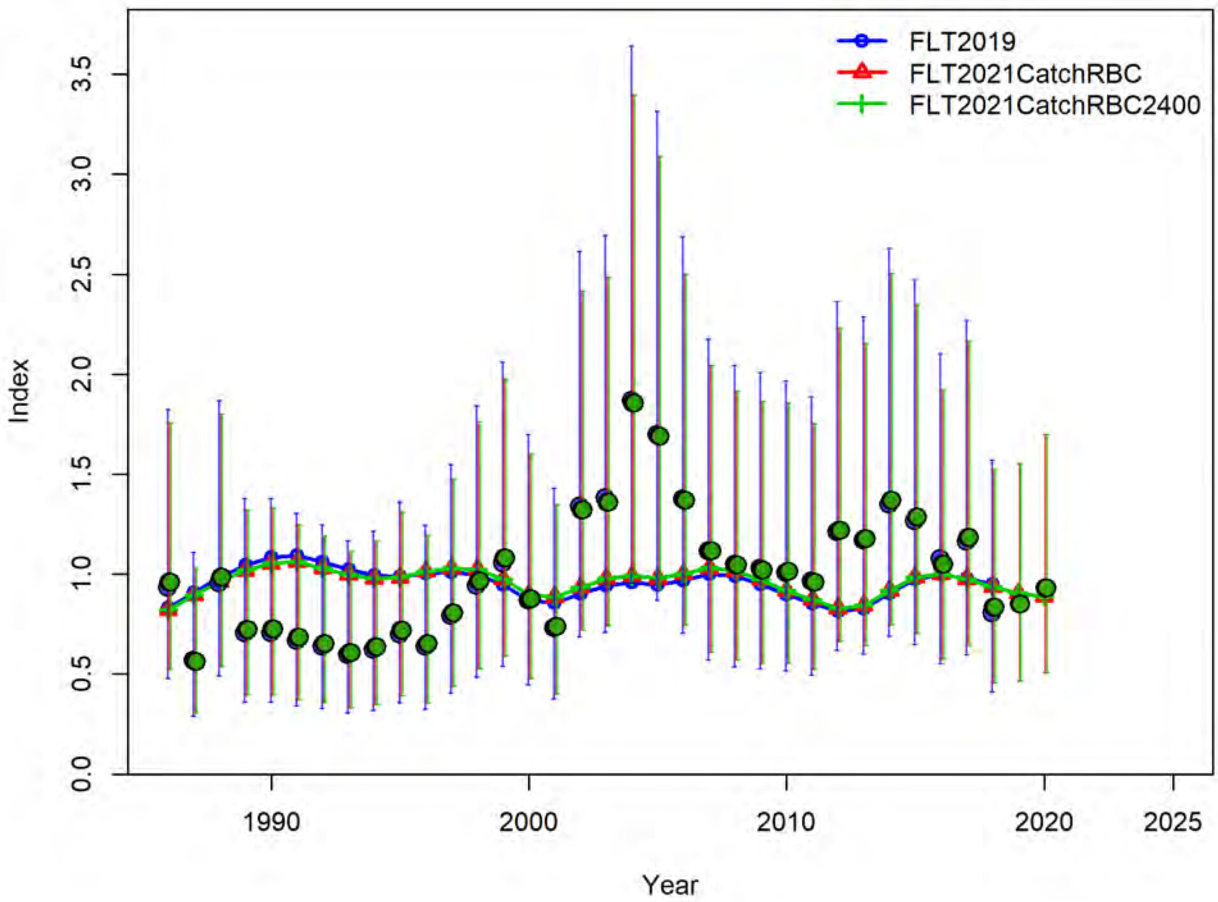

Figure 14.8. Fits to the Tasmanian trawl CPUE series for the 2019 base case, the 2021 updated catch and CPUE scenario, and the 2021 updated catch and CPUE scenario with fixed catch projections.

14.4 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, Paul Burch, Robin Thomson, Roy Deng, Franzis Althaus, Toni Cannard and Caroline Sutton (CSIRO) were all involved in pre-processing the data. Malcolm Haddon provided useful code for auto-balancing, Athol Whitten provided R code for organising plots. Geoff Tuck, Pia Bessell-Browne and Miriana Sporcic are thanked for helpful discussions on this work.

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15. 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.

16. Conclusion

The 2021 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 (Blue Grenadier, Silver Warehou, Eastern Jackass Morwong and Eastern Zone Orange Roughy), projection updates for School Whiting and Tiger Flathead, as well as CPUE standardisations for shelf, slope, deepwater and shark species, Tier 4 and Tier 5 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):

For Blue Grenadier, the estimated virgin female spawning biomass (SSB_0) is 37,445 tonnes and the projected 2022 spawning stock biomass will be 155% of SSB_0 (projected assuming 2020 catches in 2021). The 2022 recommended biological catch (RBC) under the 20:35:48 harvest control rule is 23,777 t, with 245 t estimated discards (23,532 t retained). The long-term RBC is 7,100 t, with 183 t discards.

For Eastern Jackass Morwong, the base-case assessment estimates that the projected 2022 spawning stock biomass will be 15% of SSB_0, with recruitment from 2016 onwards projected using a low recruitment scenario, using the average of the ten most recently estimated recruitment deviations, from 2006-2015. Under the agreed 20:35:48 harvest control rule, the 2022 RBC is 0 t, with the long-term yield (assuming low recruitment in the future) of 91 t.

For Eastern Orange Roughy, the median estimate of $SSB_0$from the MCMC analysis was 38,924 t, slightly lower than the MPD estimate of 40,479 t. The current 2022 female spawning biomass is estimated to be 11,644 t from the MCMC and 13,126 t from the MPD. Relative spawning biomass in 2022 is estimated at 30.0% of unfished levels from the MCMC and 32.4% of unfished levels from the MPD. The RBC for 2022 from the MCMC analysis is 681 t, lower than the MPD estimate for 2022 of 944 t. The average RBC over the next three years (2022-2024) is 737 t from the MCMC analysis and 1,025 t from the MPD.

For Silver Warehou, the assessment estimates that the projected 2022 stock status will be 29% ofSSB_0, projected assuming 2020 catches in 2021, with recruitment from 2016 onwards assumed to be below average, fixed at the average of 2011-2015 levels. The assessment suggests that stock status was as low as 21% of SSB_0 in 2016. Under the 20:35:48 harvest control rule, the 2022 RBC is 587 t, while the long-term yield (assuming continuation of low recruitment) is 591 t.

For School Whiting, if the default (proxy) target reference point (48%) used in the SESSF harvest control rule, and specifically as used by AFMA for School Whiting, is reduced to 40%, a modified 20:35:40 harvest control rule can be applied. This lower target allows the stock to be fished to a lower target biomass (40% of SSB_0). Under a revised 40% target, the 2021 RBC would be 2,753 t.

For Tiger Flathead, updates to catch and CPUE resulted in a revision downwards to the 2020 stock status, from 34% in the last stock assessment to 32% in this analysis. These changes are due to revisions to the catches (2017-2021) and to the revised CPUE series, which has a downturn at the end of the time series (2019-2020) for the Danish seine CPUE. The eastern trawl and Tasmanian trawl CPUE series do not show the same downturn at the end of the CPUE series as Danish seine, with both trawl CPUE relatively flat in the period 2019-2020. Projecting forward to 2022 takes the stock status to 35% at the start of 2022, and this is expected to recover to 37% at the start of 2025, assuming that the RBC is caught in 2023 and 2024 and there is average recruitment from 2017 onwards

17. Appendix: Intellectual Property

No intellectual property has arisen from the project that is likely to lead to significant commercial benefits, patents or licenses.

18. Appendix: Project Staff

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