Australian Government

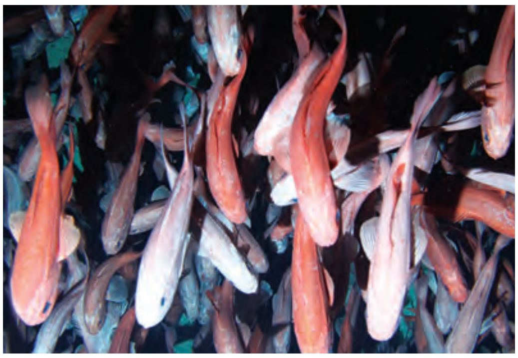
Australian Fisheries Management Authority

2019/0800 May 2022

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

PART 1

2021



Principal investigator **G.N. Tuck**

CSIRO

Box 7051, Canberra Business Centre, ACT 2610 Tel **(02) 6225 5555** Fax (02) 6225 5440 **AFMA Direct 1300 723 621**

Preferred way to cite this report

Tuck, G.N. (ed.) 2022. Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2020 and 2021. Part 1, 2021. Australian Fisheries Management Authority and CSIRO Oceans and Atmosphere, Hobart. 731p.

Acknowledgements

All authors wish to thank the science, management and industry members of the south east, GAB and shark resource assessment groups for their contributions to the work presented in this report. Authors also acknowledge support from Fish Ageing Services (for fish ageing data) and AFMA (for the on-board and port length-frequencies, and in particular John Garvey, for the log book data). Toni Cracknell is greatly thanked for her assistance with the production of this report.

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
May 2022
Report 2019/0800

Australian Fisheries Management Authority

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

TABLE OF CONTENTS

1. Non-Technical Summary

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

PRINCIPAL INVESTIGATOR: Dr Geoffrey N. Tuck

ADDRESS: CSIRO Oceans and Atmosphere
GPO Box 1538
Hobart, TAS 7001
Australia
Telephone: 03 6232 5222 Fax: 03 6232 5053

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

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

Paul Burch[1] and Sandra Curin Osorio[1,2]

[1]CSIRO Oceans and Atmosphere, Castray Esplanade, Hobart TAS 7000, Australia
[2]Institute for Marine and Antarctic Studies, University of Tasmania, Hobart TAS 7001, Australia

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.

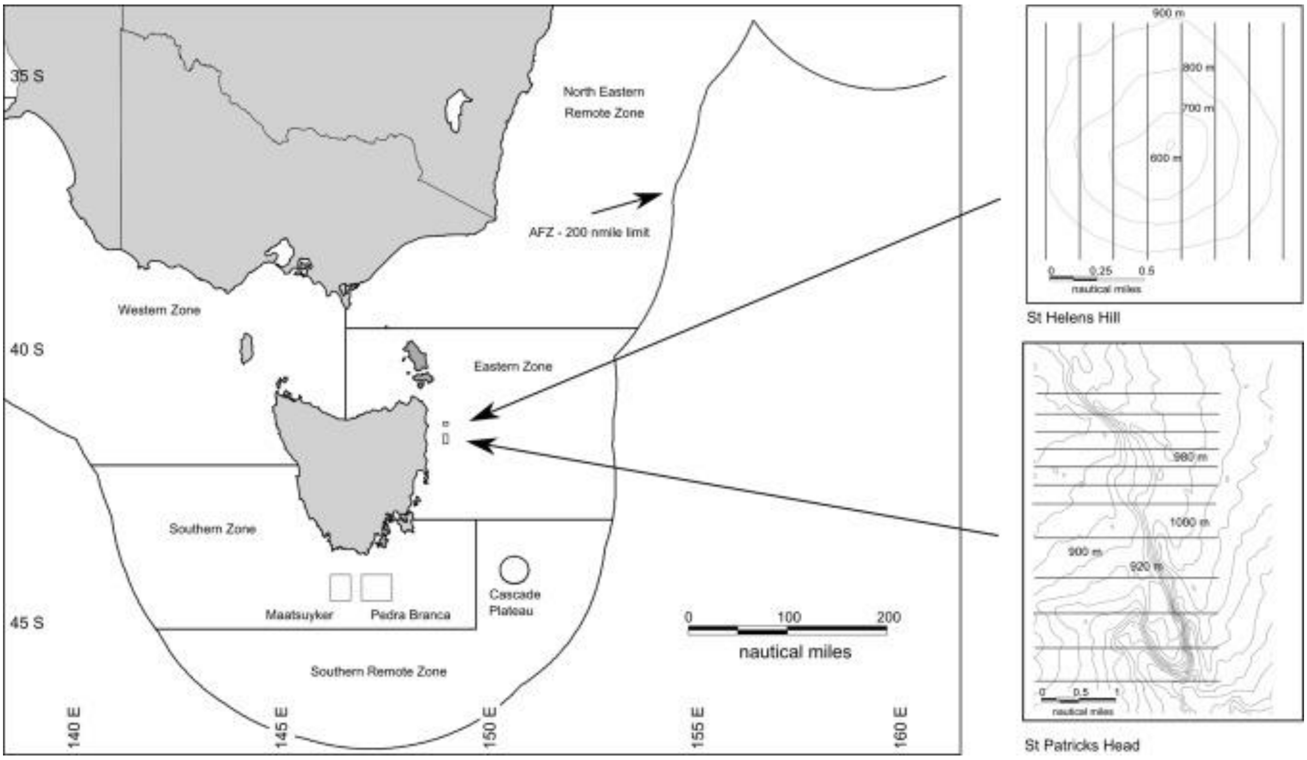


Figure 9.1. Map of Australian Orange Roughy management zones and areas.

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 x 10^{-5}	Female	Lyle et al. (1991)
	3.83 x 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.

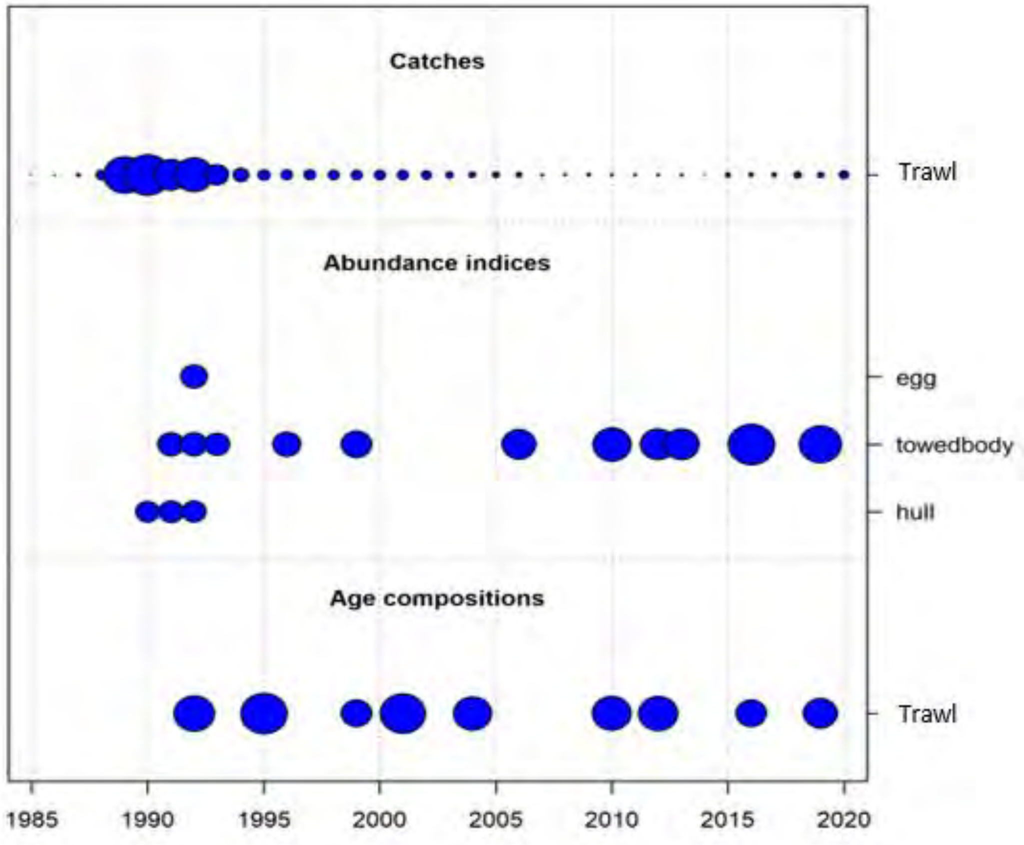


Figure 9.2. Data availability for the eastern zone Orange Roughy assessment by type and year.

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.

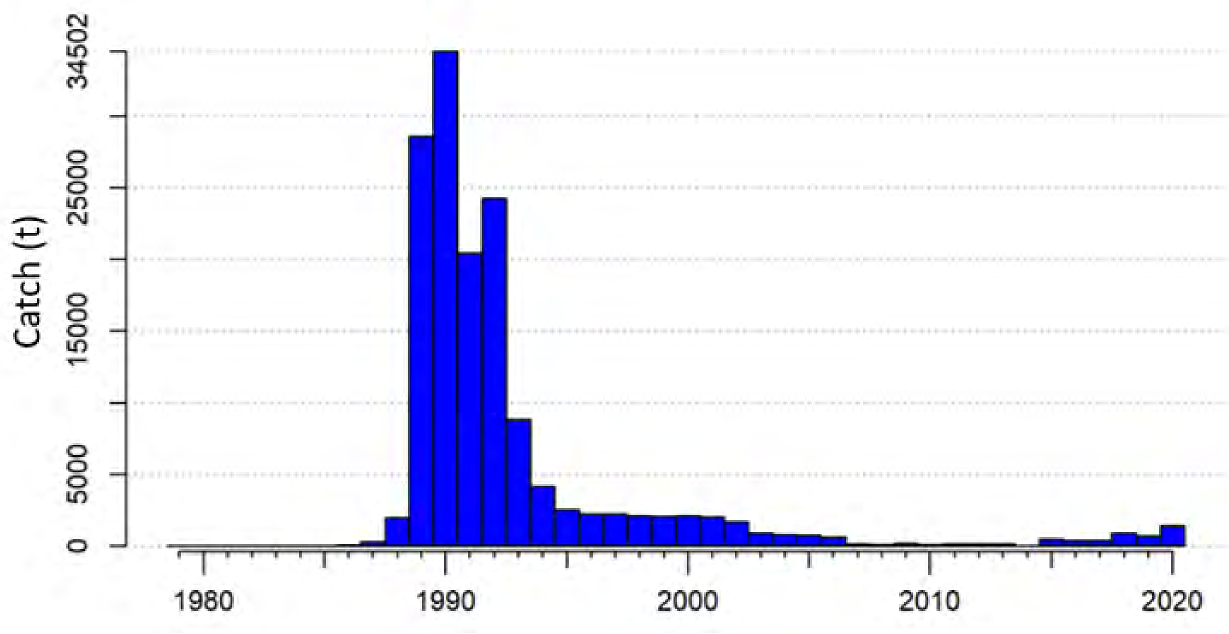


Figure 9.3. Catch, including discards, of the eastern zone Orange Roughy assessment. Catches for 1989 – 1994 incorporate adjustments for the proportion lost due to lost gear and burst bags/ burst panels, other losses, and misreporting (CSIRO & TDPIF 1996; Wayte 2007).

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).

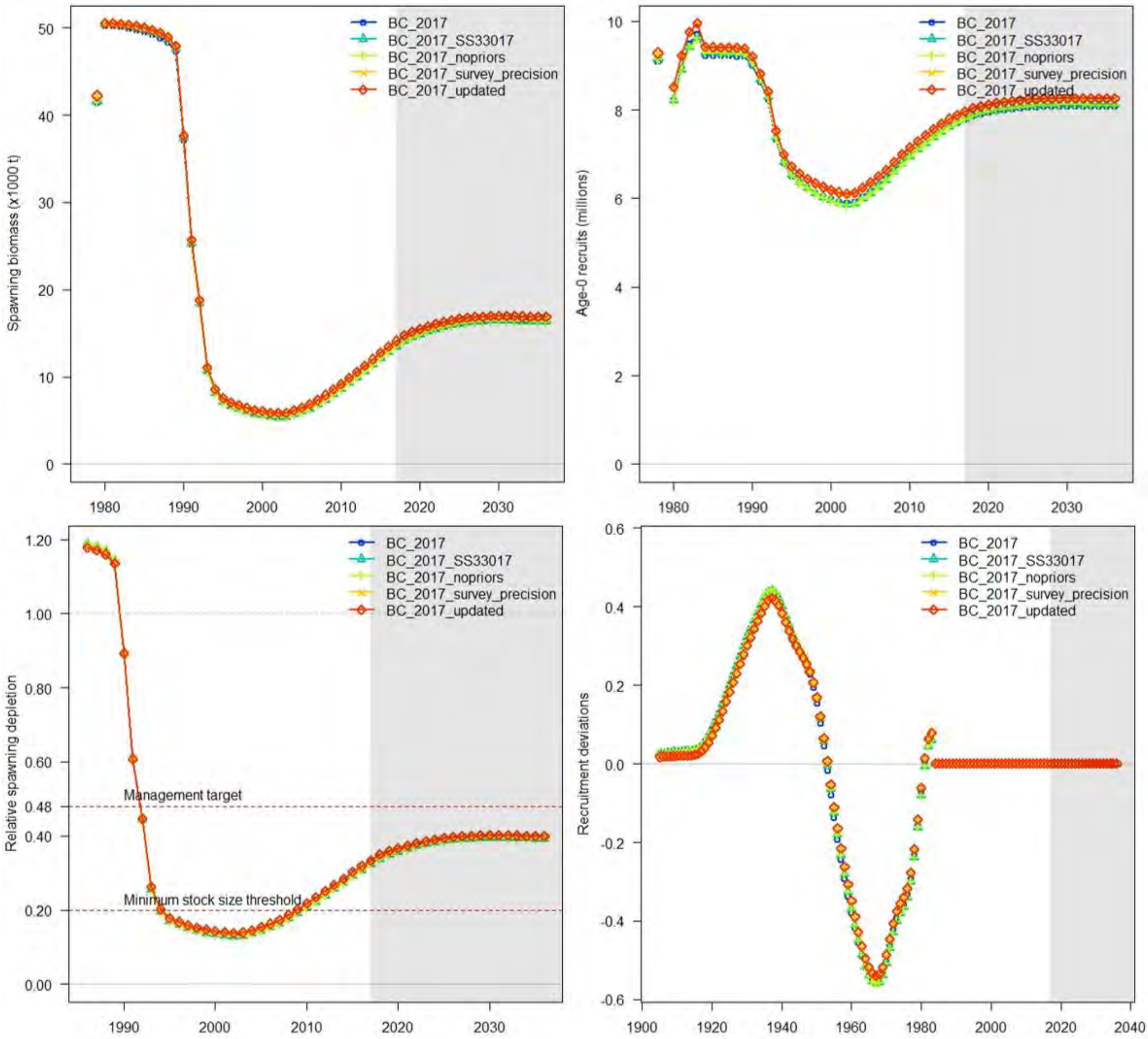


Figure 9.4. Comparison of absolute (top left) and relative (bottom left) spawning biomass, absolute recruitment (top right) and recruitment deviations (bottom right) from the four bridging models that update the software and model assumptions.

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".

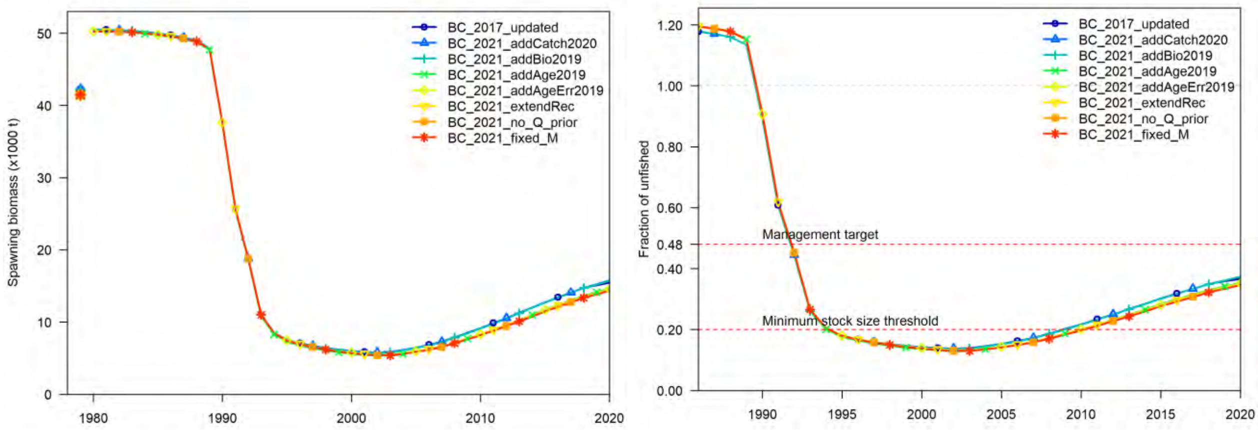


Figure 9.5. Comparison of the time-series of absolute (left) and relative (right) spawning biomass for the updated 2017 assessment model with bridging models that add new data sources leading to the 2021 preliminary base-case model with a fixed natural mortality of *M*=0.04 yr^{-1}.

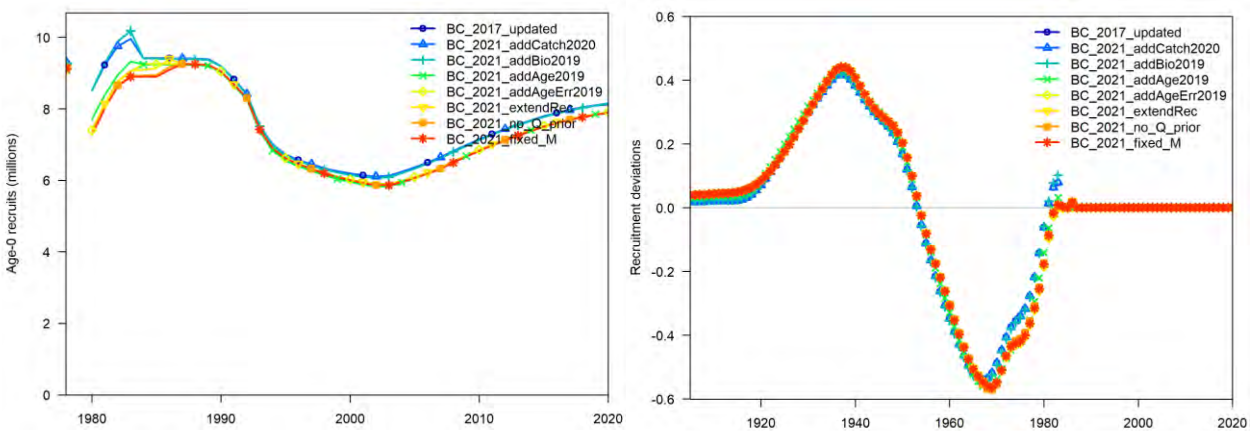


Figure 9.6. Comparison of the time-series of absolute recruitment (left) and recruitment deviations (right) for the updated 2017 assessment model with bridging models that add new data sources leading to the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1}.

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**

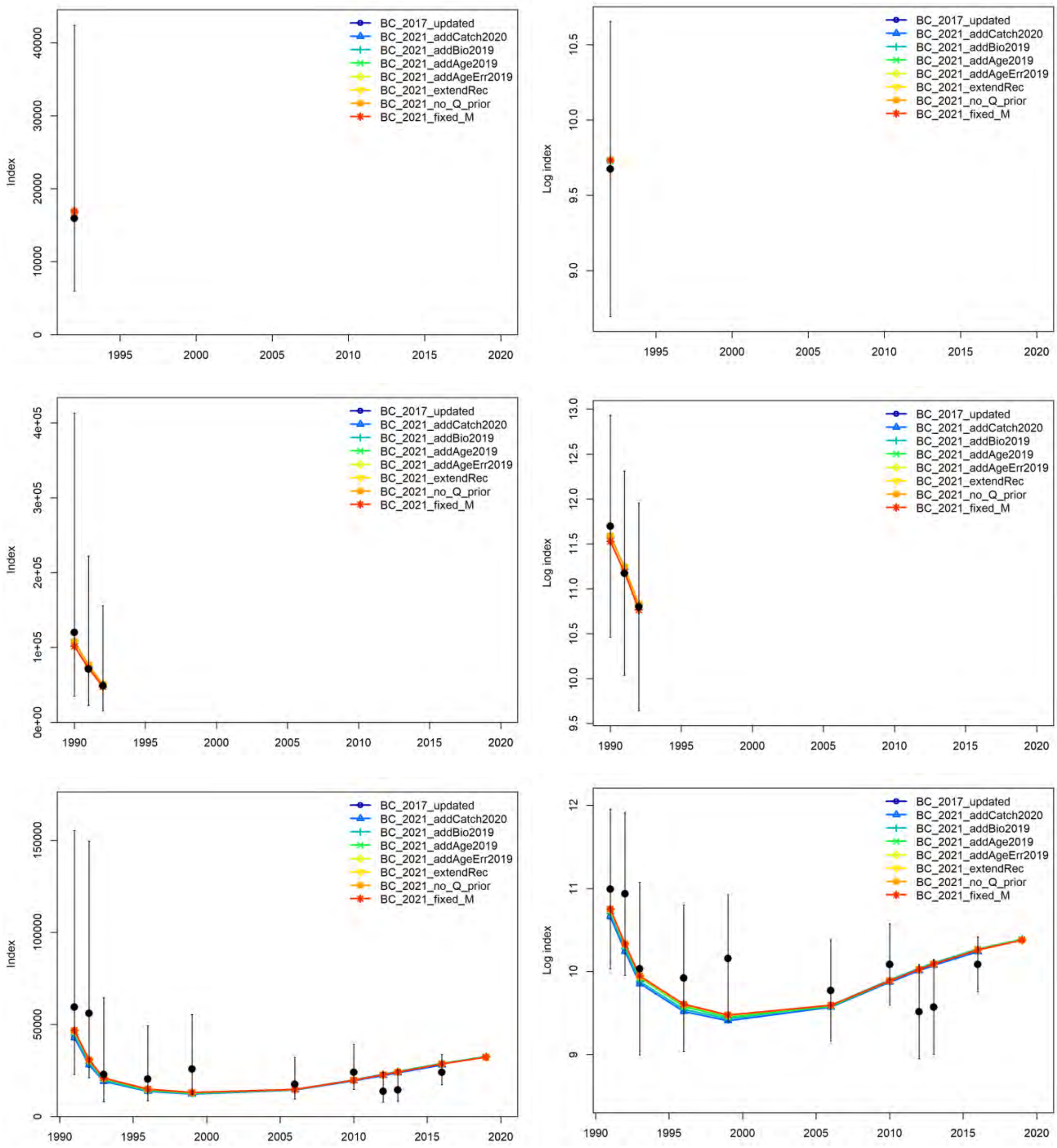


Figure 9.7. Comparison of the fits to the biomass indices (left) and log indices (right) for the egg (top), hull (middle) and towed (bottom) surveys for the updated 2017 assessment model with selected bridging models that sequentially add new data sources leading to the 2021 preliminary base-case model 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).

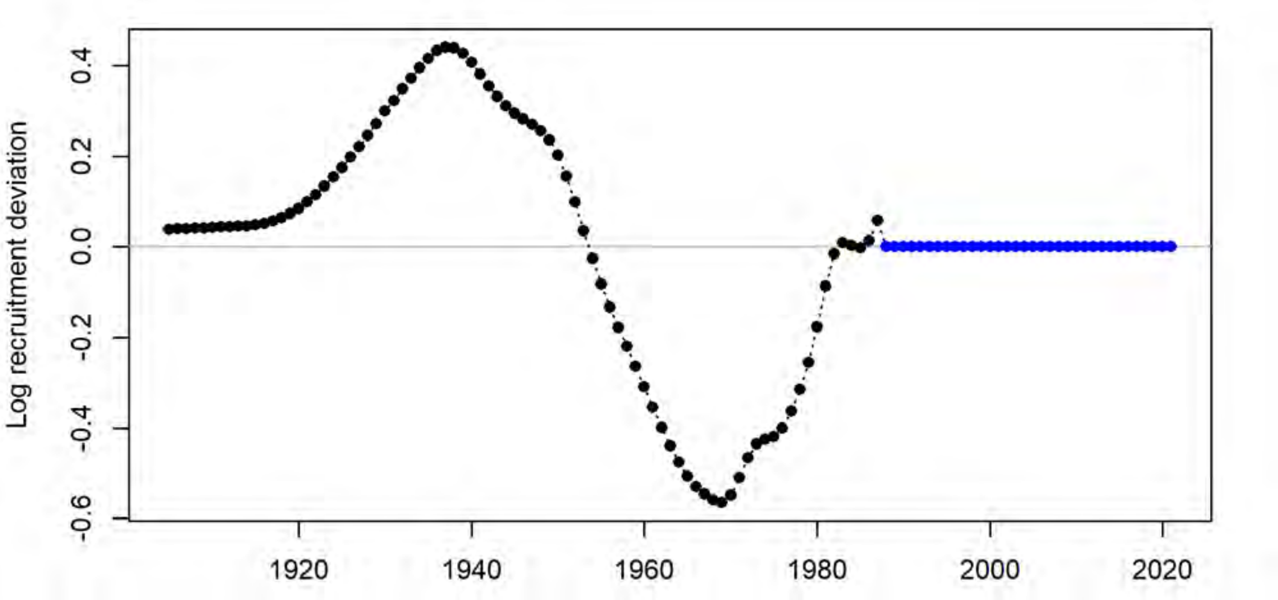


Figure 9.8. Recruitment deviations (log scale) from a sensitivity to 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1} that estimates an additional recruitment deviation for 1987.

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.

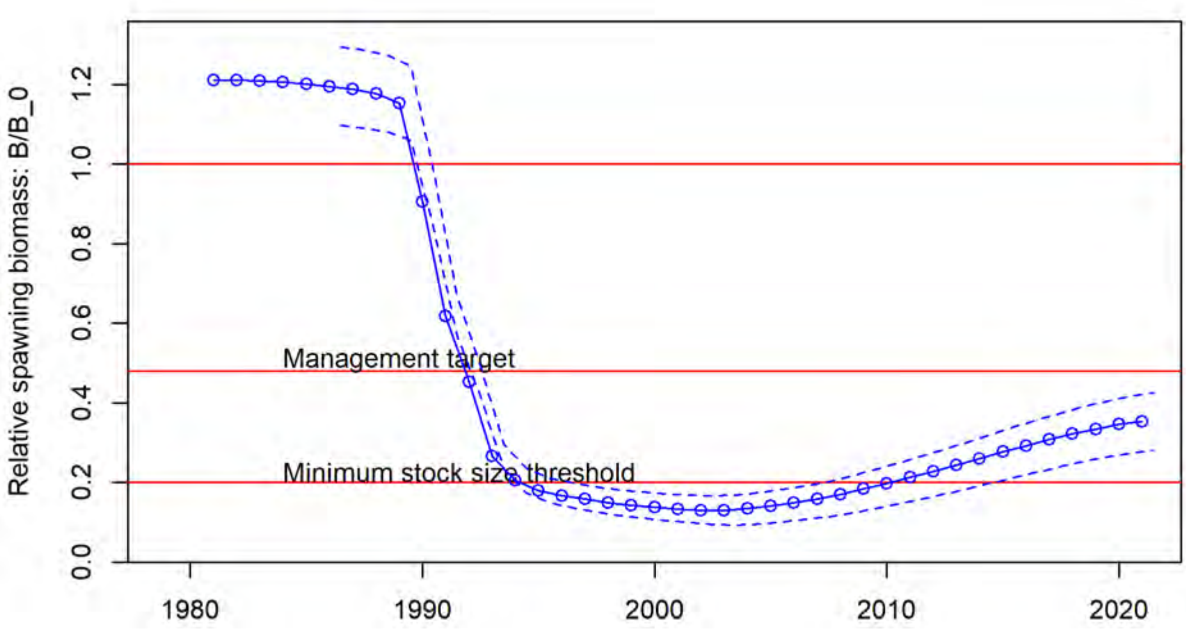


Figure 9.9. The estimated time-series of relative spawning biomass with asymptotic 95% confidence intervals for the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1}.

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)

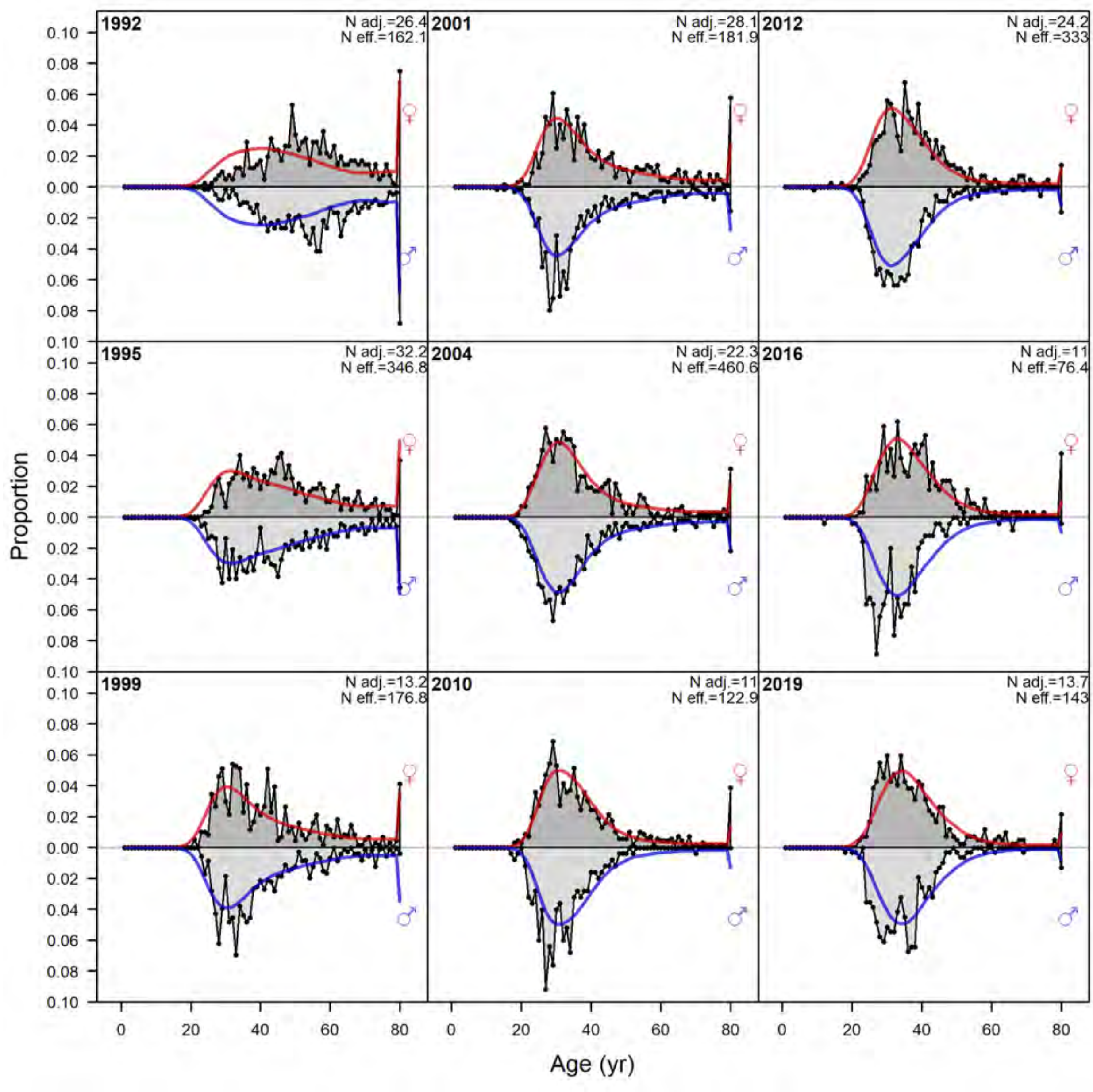


Figure 9.10. Fits to the age composition data for the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1}.

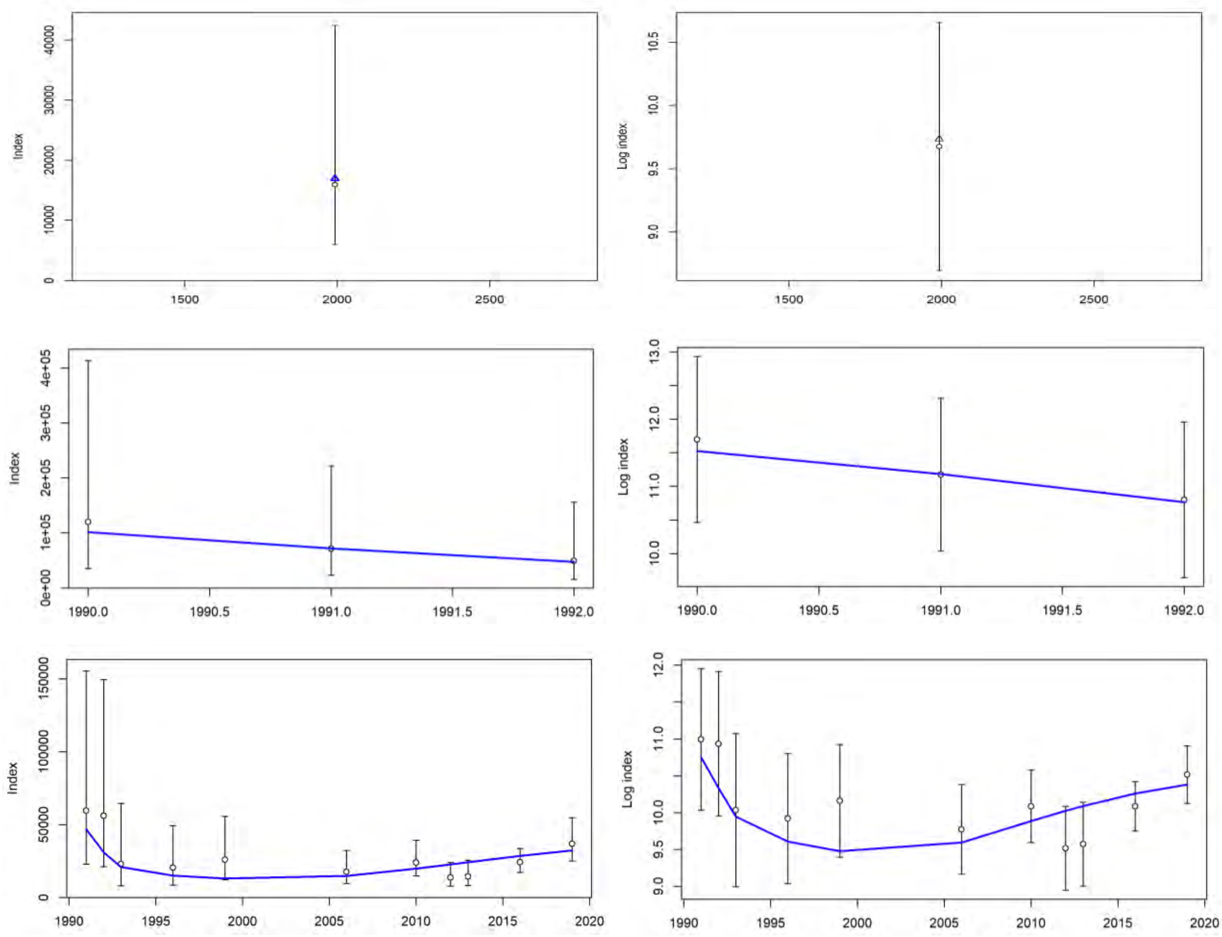


Figure 9.11. Fits to the biomass indices (left) and log indices (right) for the egg (top), hull (middle) and towed (bottom) surveys for the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1}.

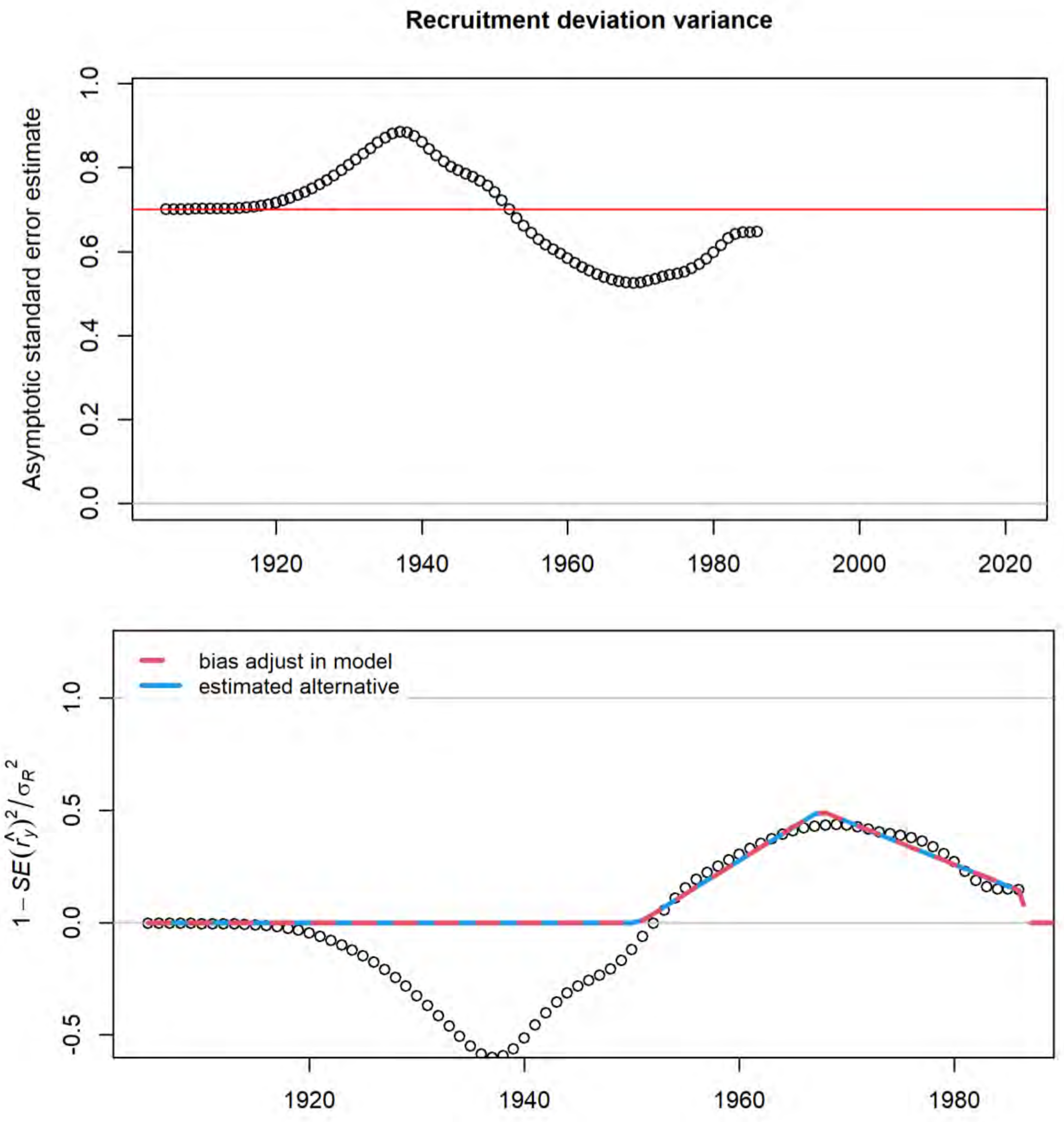


Figure 9.12. Recruitment deviation variance check and bias ramp adjustment for the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1}.

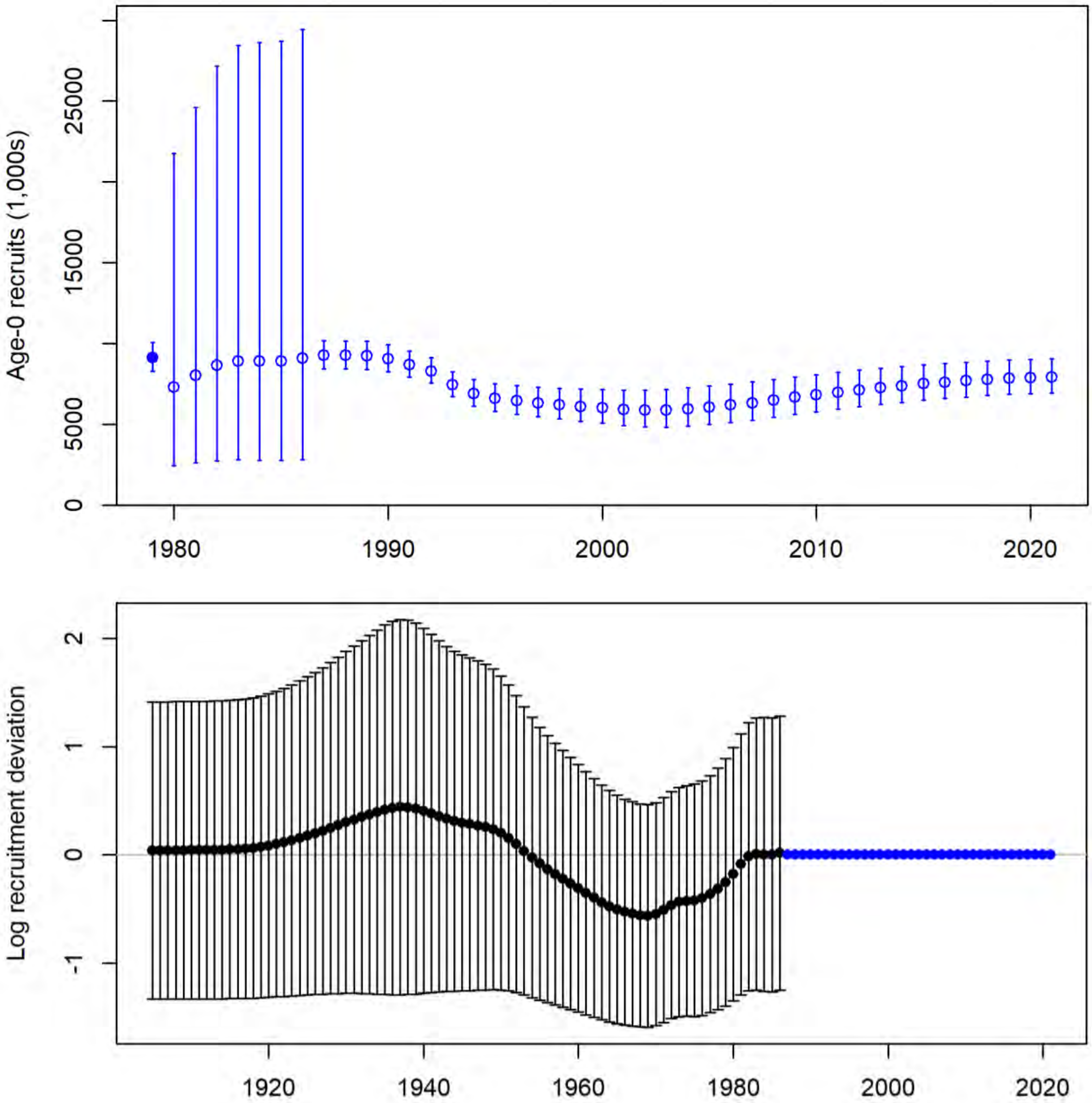


Figure 9.13. Time series of absolute recruitment estimates with confidence intervals (top) and recruitment deviations with confidence intervals (bottom) for the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1}. The projections beyond 2021 ignores variation in recruitment about the stock-recruitment relationship.

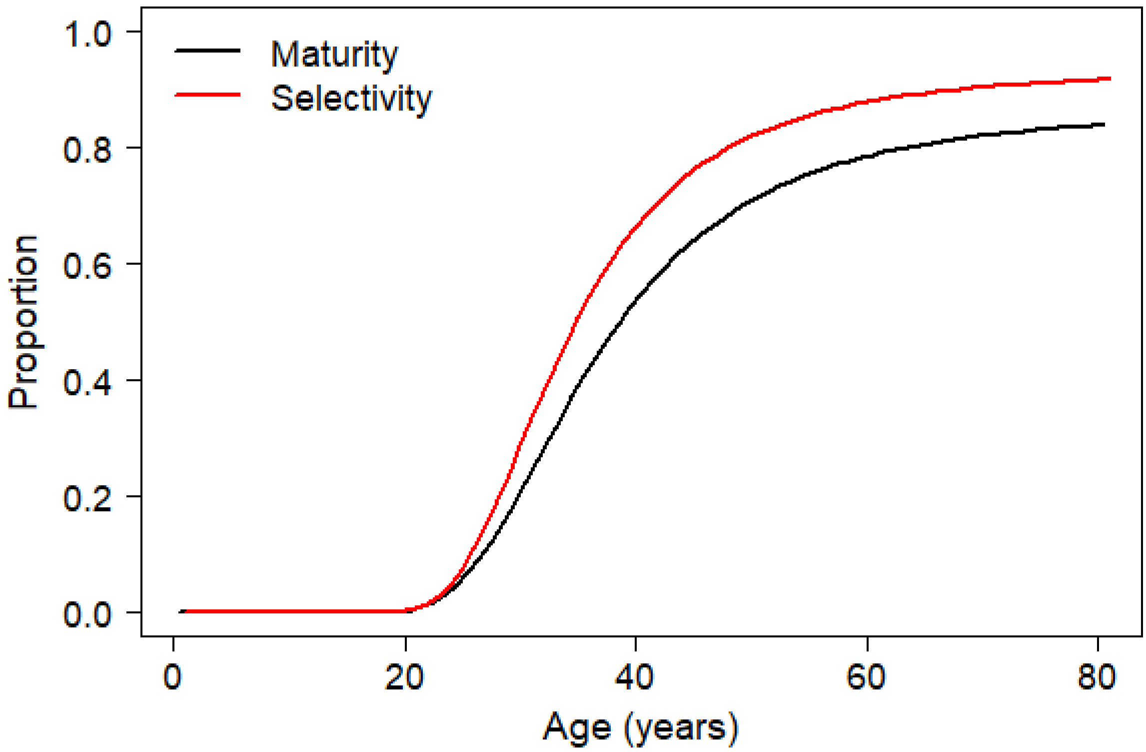


Figure 9.14. Estimated selectivity and fixed maturity ogives for the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1}.

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.

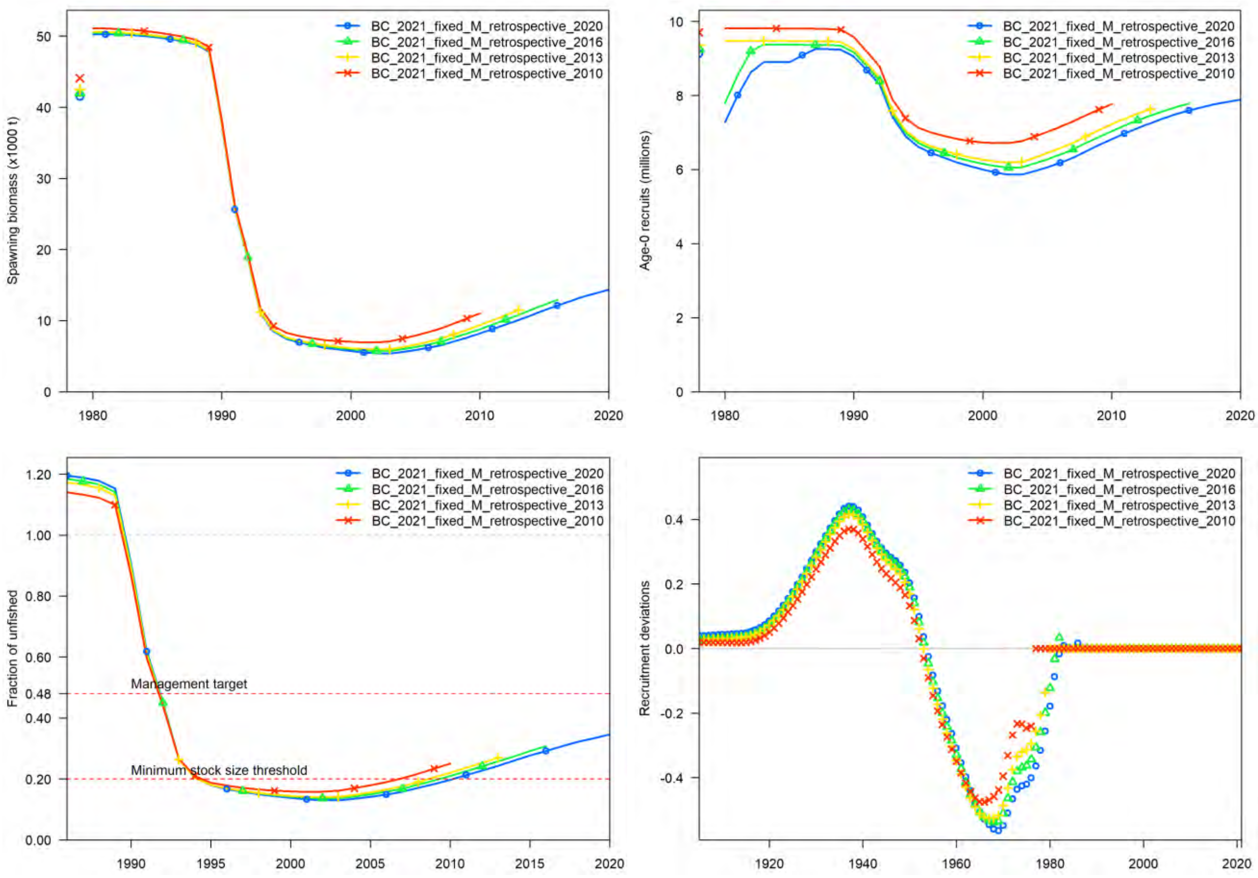


Figure 9.15. Retrospective analysis showing the absolute (top left) and relative (bottom left) spawning biomass, absolute recruitment (top right) and recruitment deviations (bottom right) from assessments that were undertaken after removing four, seven and ten years of data from the 2021 preliminary 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).

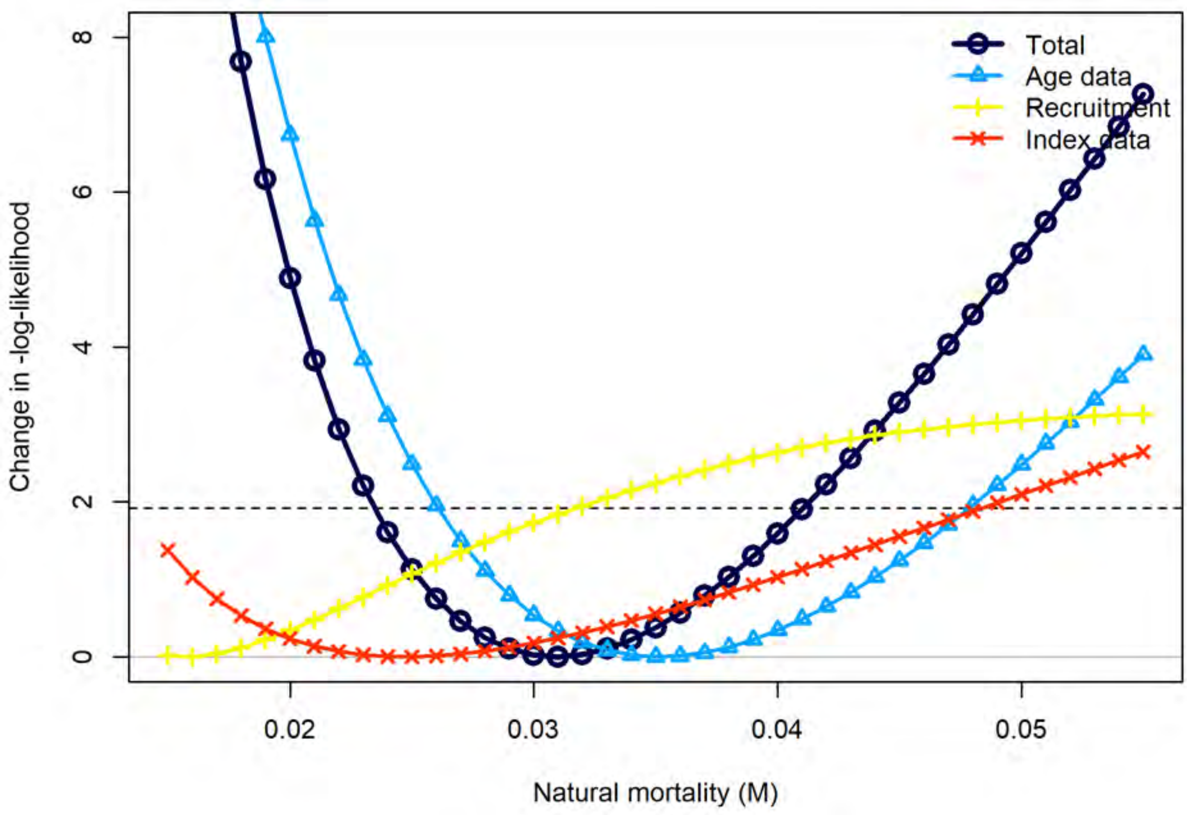


Figure 9.16. Likelihood profile for natural mortality. The fixed value of natural mortality in the 2021 preliminary base-case model is M=0.04 yr^{-1}.

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

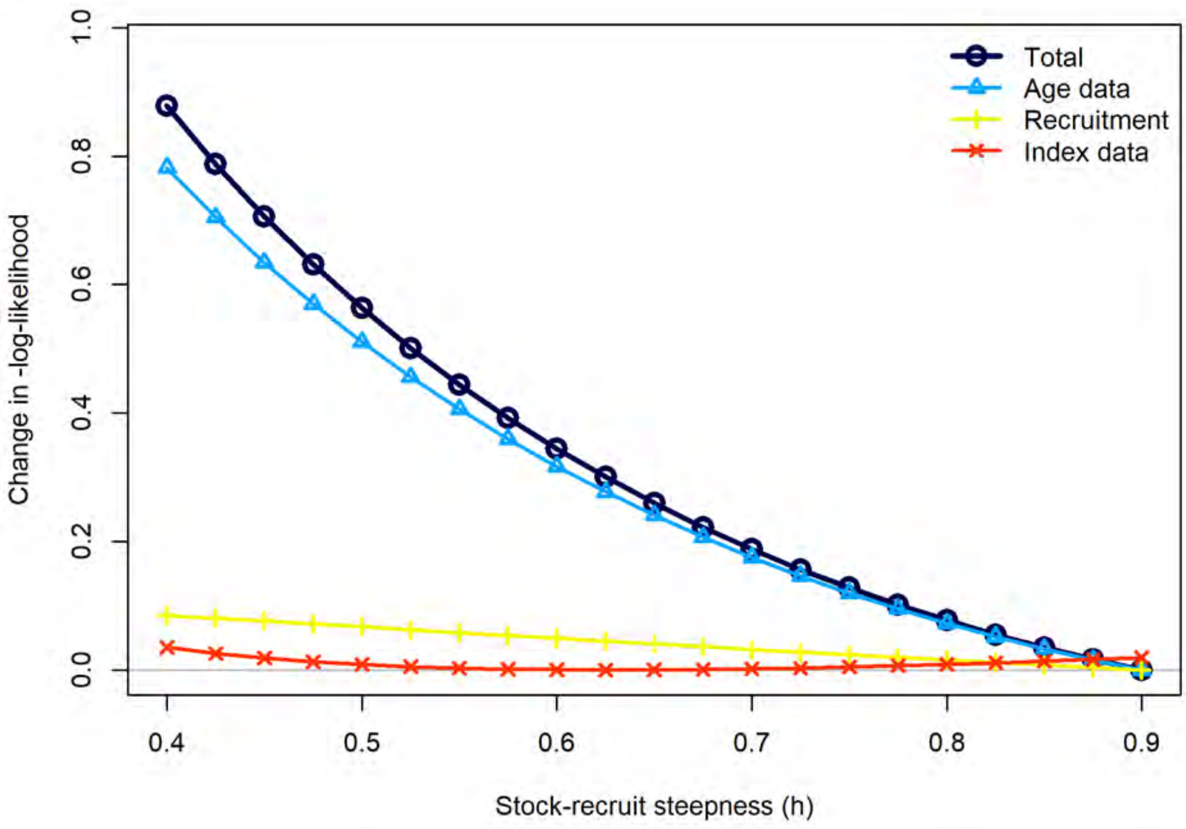


Figure 9.17. Likelihood profile for steepness of the stock recruitment relationship. The fixed value of steepness used in the 2021 preliminary base-case assessments is h=0.75.

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.

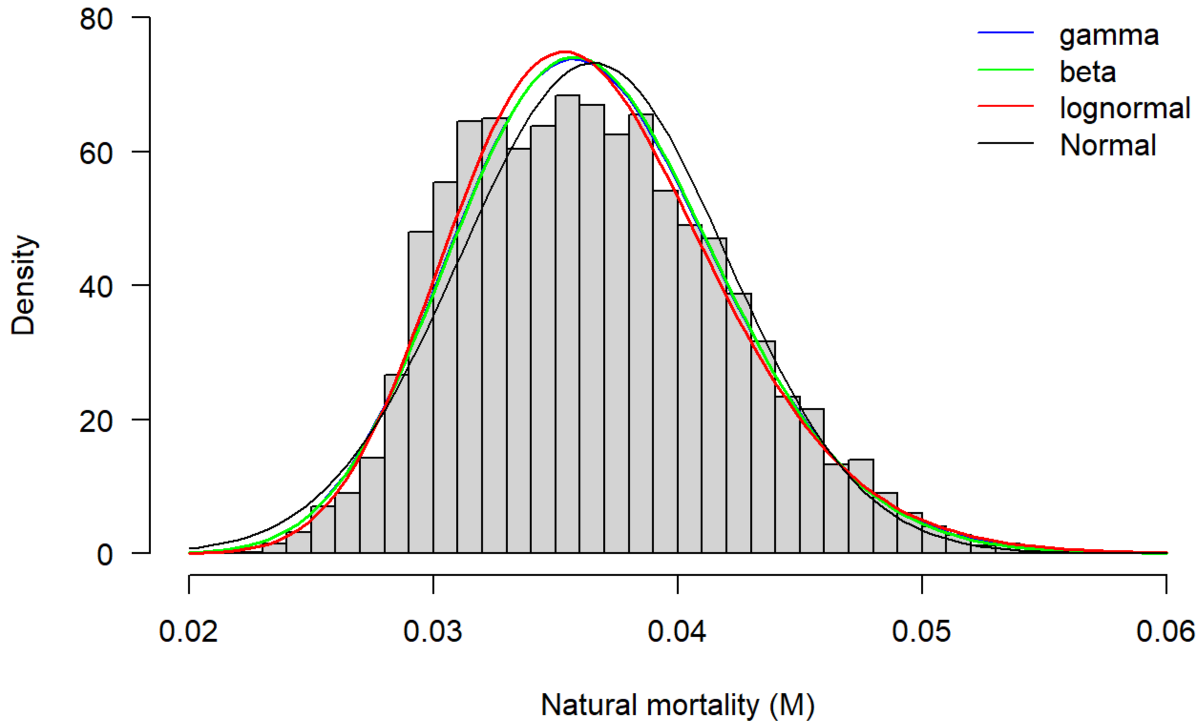


Figure 9.18. Combined posterior for New Zealand Orange Roughy stock assessments with fitted Gamma, Beta, log-normal and Normal distributions. Distribution supplied by Patrick Cordue (ISL).

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).

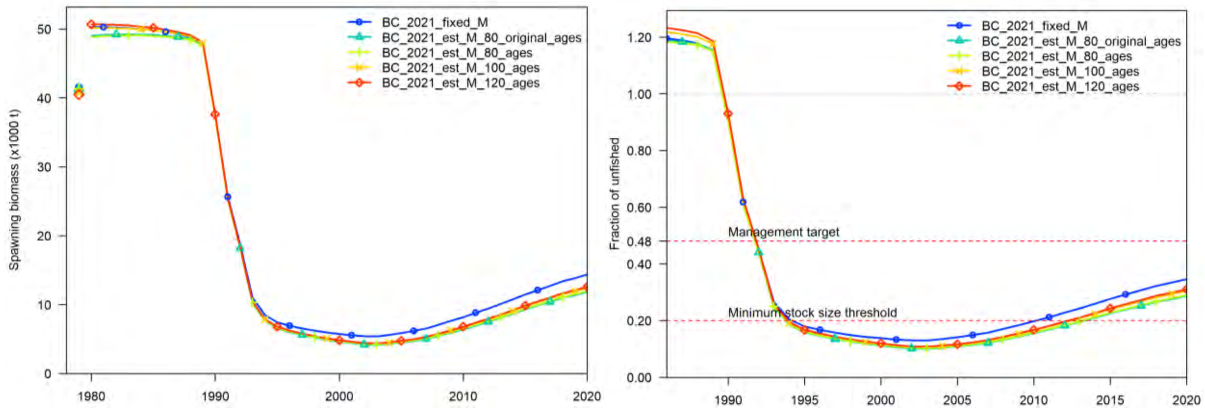


Figure 9.19. Comparison of the time-series of absolute (left) and relative (right) spawning biomass for the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1} and candidate preliminary base-case models with plus-groups of 80, 100 and 120 years.

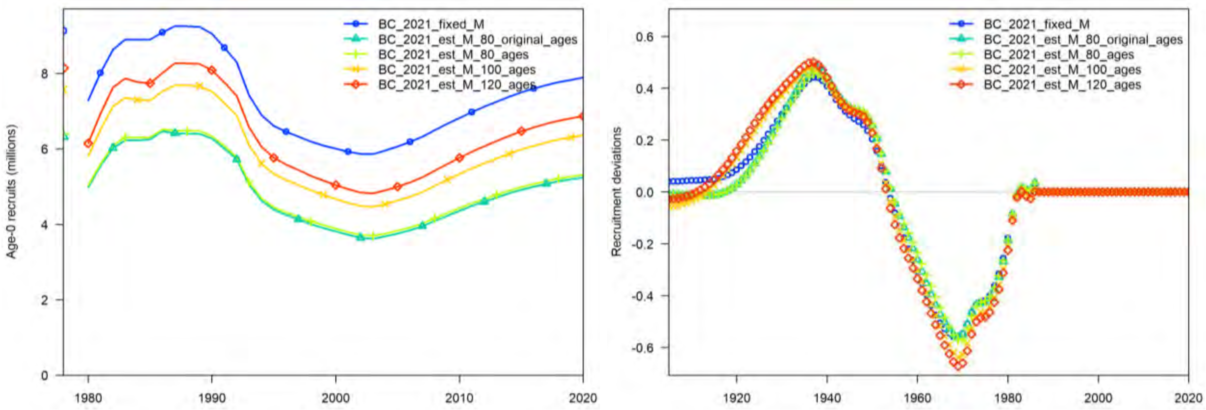


Figure 9.20. Comparison of the time-series of absolute recruitment (left) and recruitment deviations (right) for the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1} and candidate 2021 preliminary base-case models with plus-groups of 80, 100 and 120 years where M is estimated 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

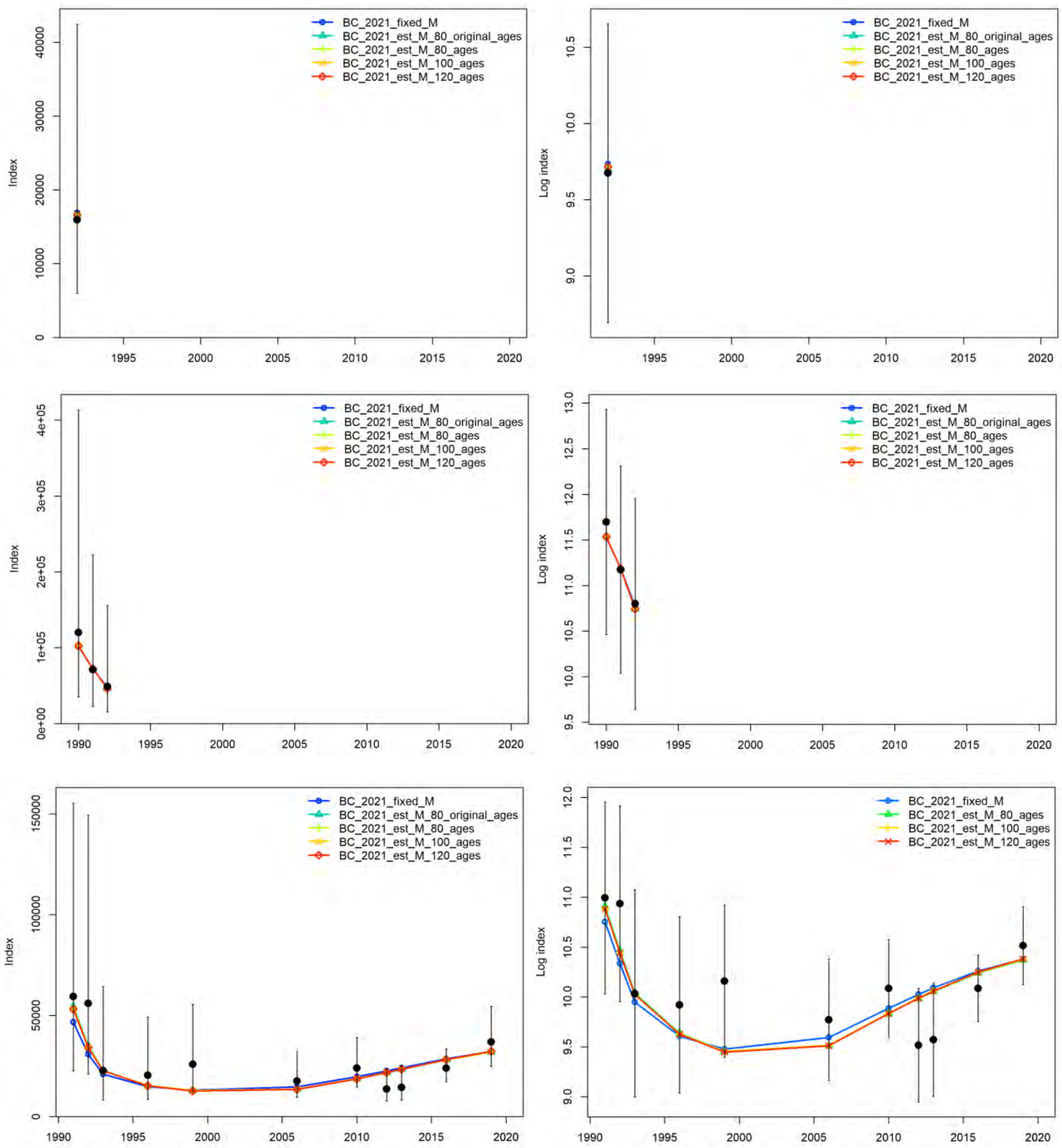


Figure 9.21. Comparison of the fits to the biomass indices (left) and log indices (right) for the egg (top), hull (middle) and towed (bottom) surveys for the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1} and candidate 2021 preliminary base-case models with plus-groups 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

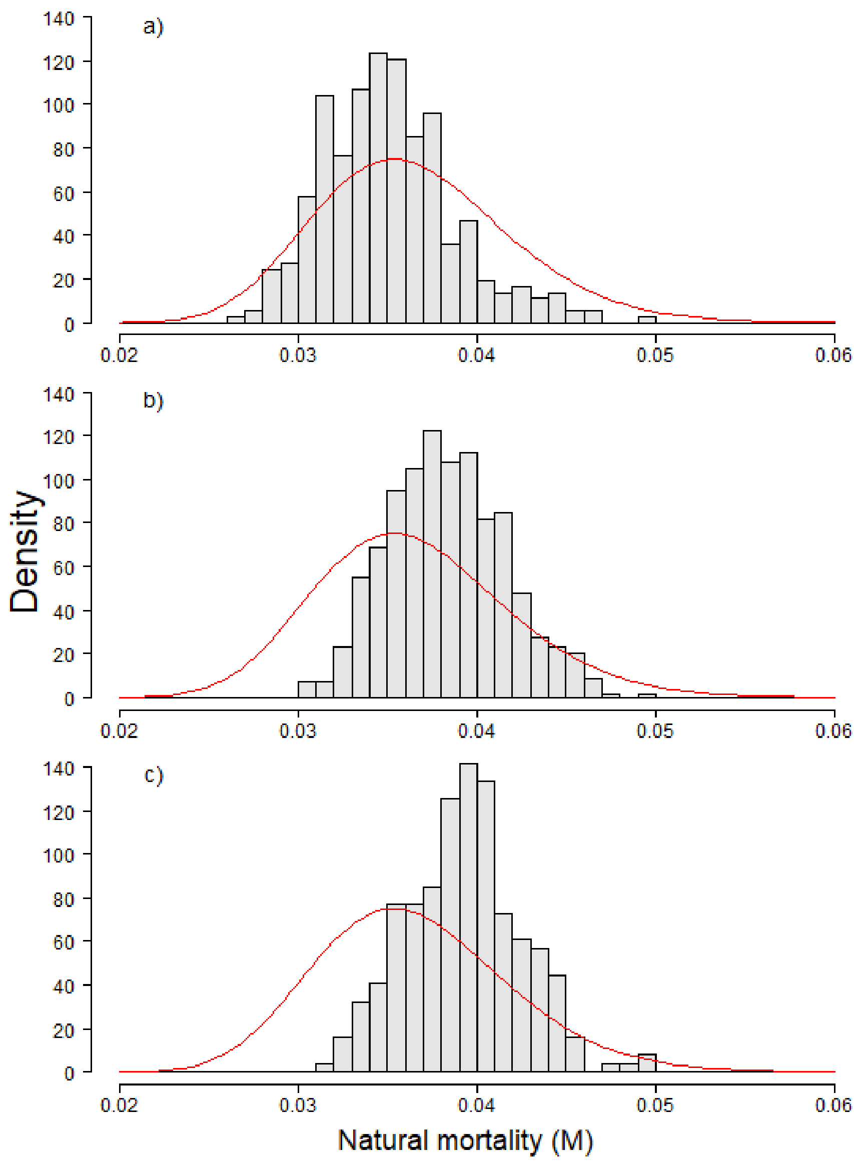


Figure 9.22. Histograms of natural mortality estimates from posteriors of candidate 2021 preliminary base-case models with plus-groups at 80 (a), 100 (b) and 120 (c) years. The red line represents the log-normal prior used to estimate M within the models.

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

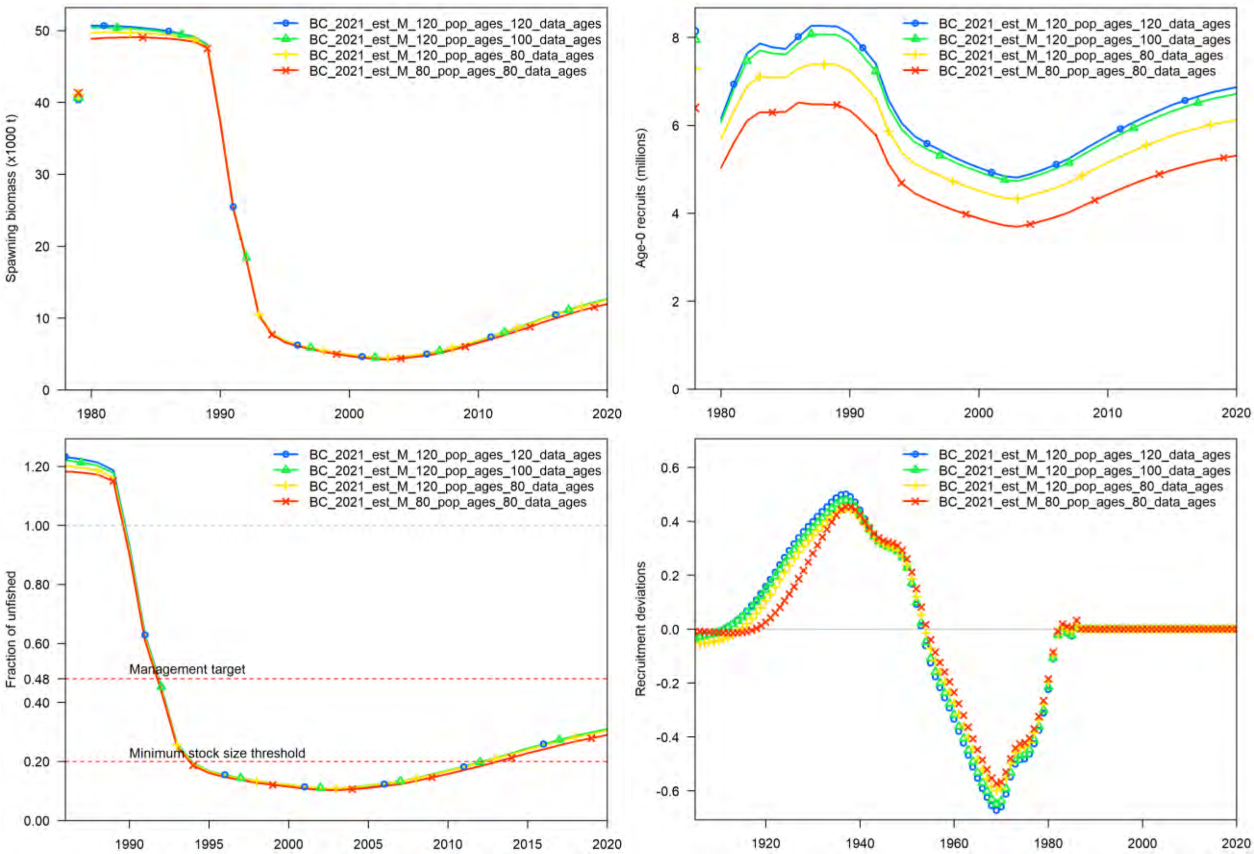


Figure 9.23. Comparison of absolute (top left) and relative (bottom left) spawning biomass, absolute recruitment (top right) and recruitment deviations (bottom right) from the 2021 preliminary base-case model with a plus group at 80 years and models with a population plus group at 120 years and data 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).

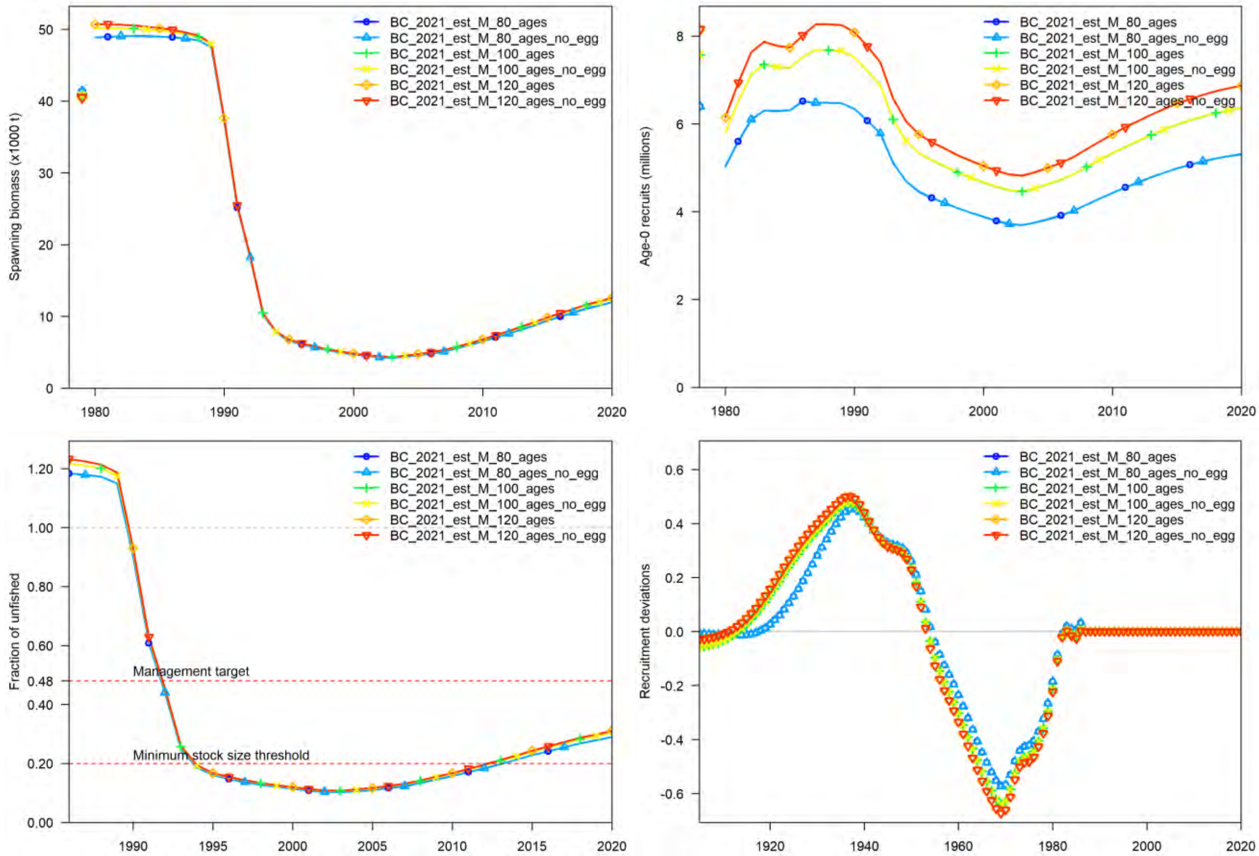


Figure 9.24. Comparison of absolute (top left) and relative (bottom left) spawning biomass, absolute recruitment (top right) and recruitment deviations (bottom right) from the three candidate 2021 preliminary base-case models with plus groups at 80, 100 and 120 years where *M* is estimated and sensitivities 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.

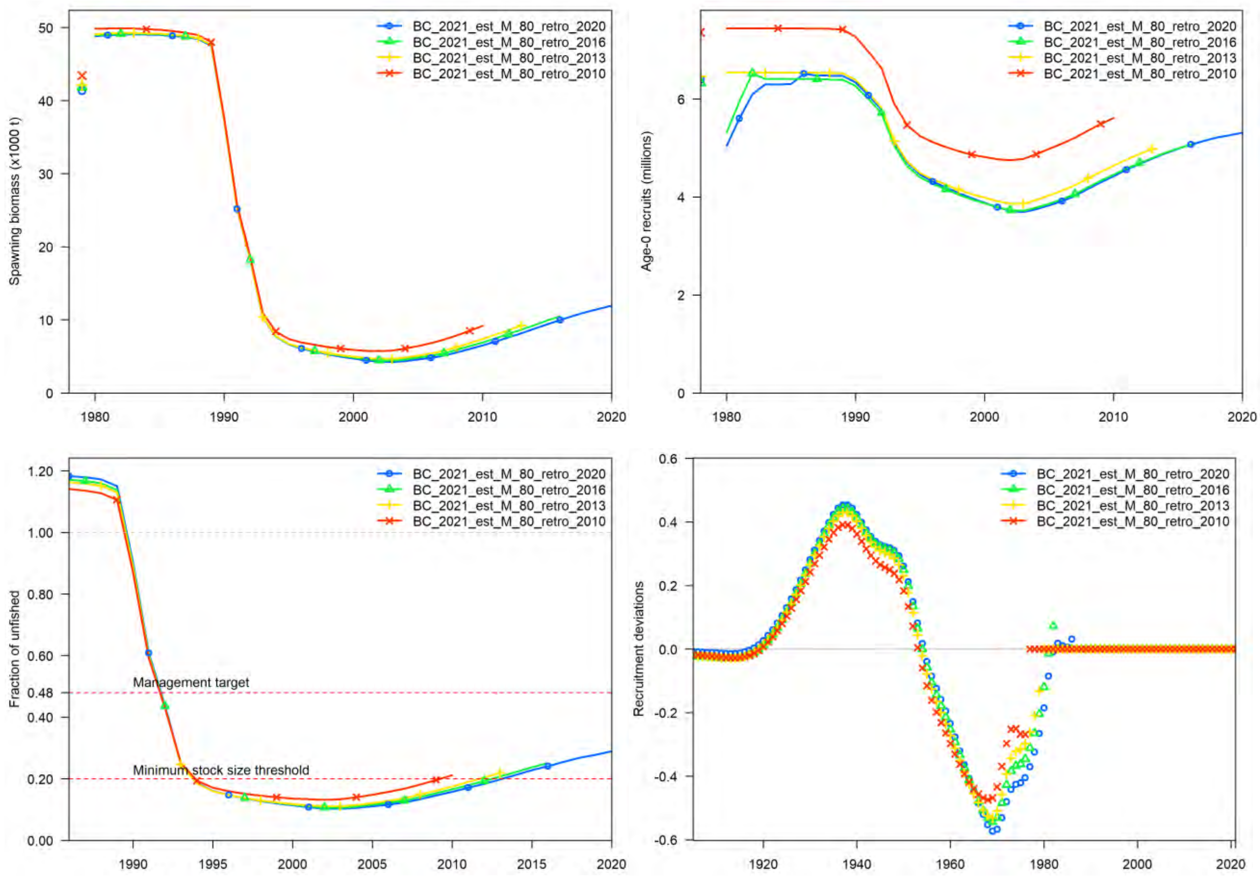


Figure 9.25. Retrospective analysis showing the absolute (top left) and relative (bottom left) spawning biomass, absolute recruitment (top right) and recruitment deviations (bottom right) from assessments that were undertaken after removing four, seven and ten years of data from the candidate 2021 preliminary base-case model with a plus group at 80 years where *M* is estimated.

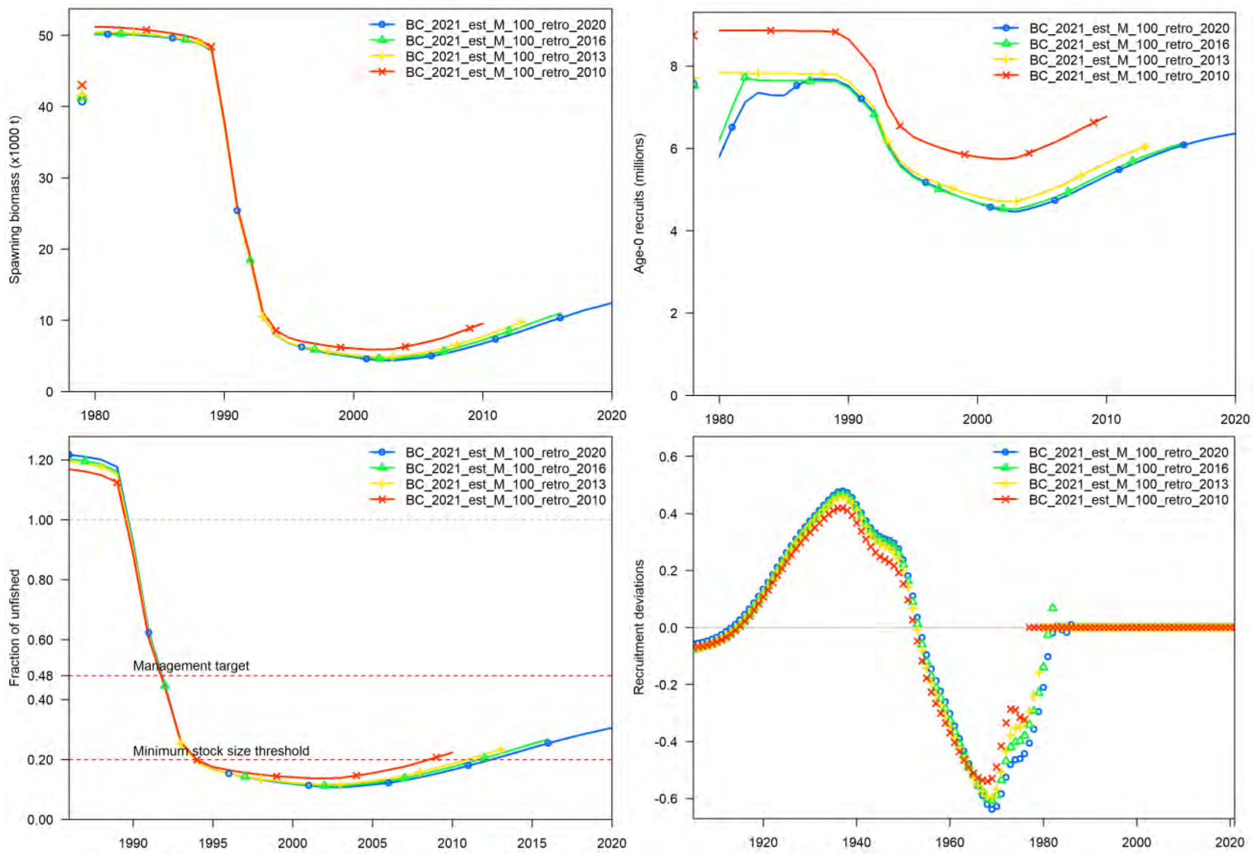


Figure 9.26. Retrospective analysis showing the absolute (top left) and relative (bottom left) spawning biomass, absolute recruitment (top right) and recruitment deviations (bottom right) from assessments that were undertaken after removing four, seven and ten years of data from the candidate 2021 preliminary base-case model with a plus group at 100 years where *M* is estimated.

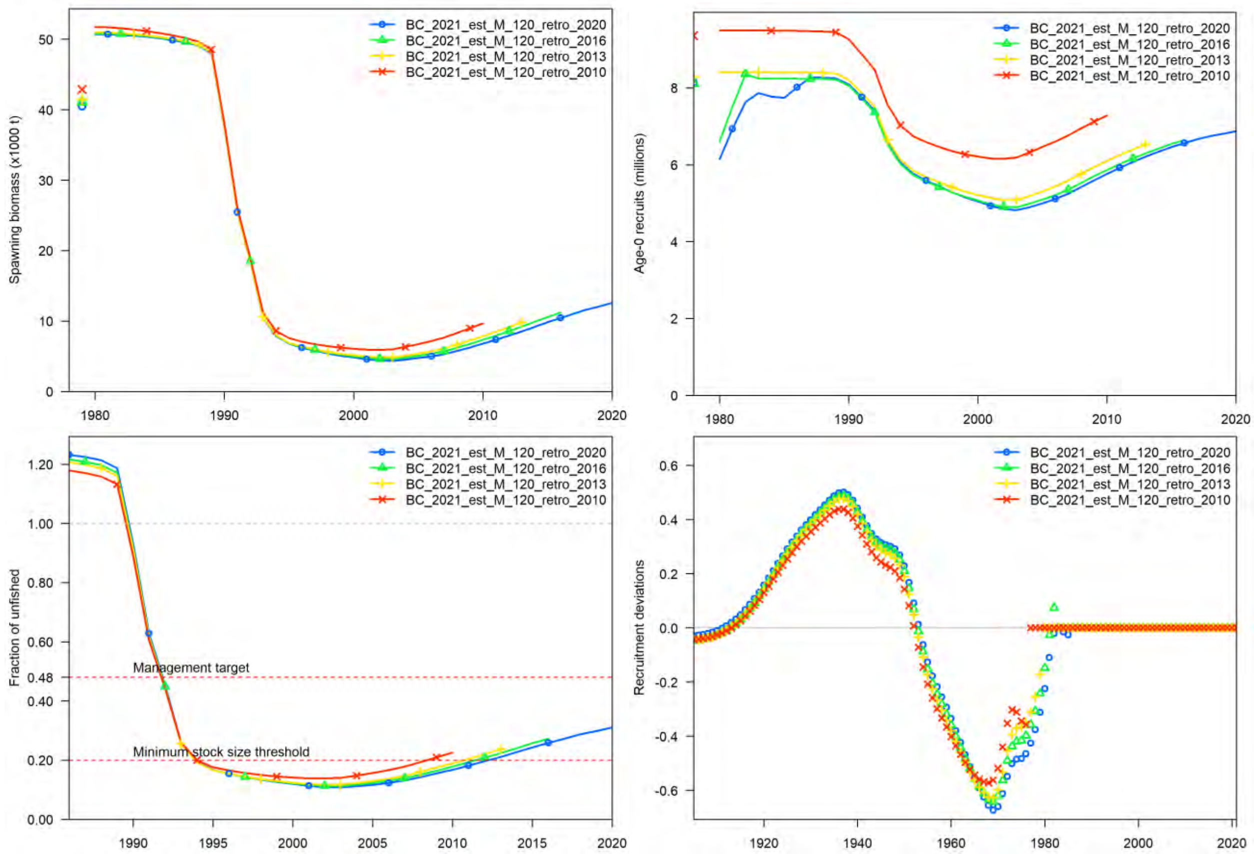


Figure 9.27. Retrospective analysis showing the absolute (top left) and relative (bottom left) spawning biomass, absolute recruitment (top right) and recruitment deviations (bottom right) from assessments that were undertaken after removing four, seven and ten years of data from the candidate 2021 preliminary 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).

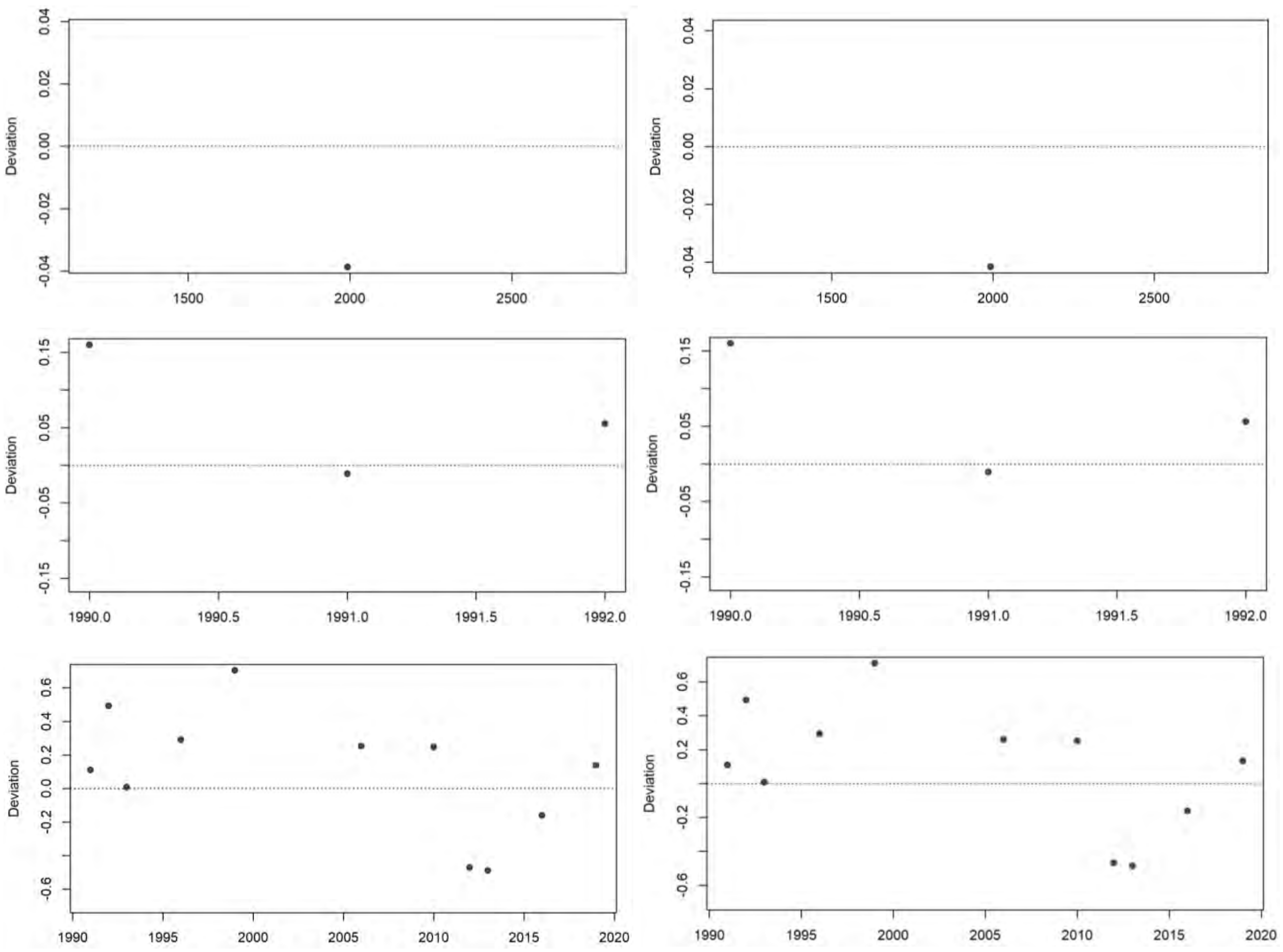


Figure 9.28. Residuals from fits to the egg survey (top), hull survey (middle) and vessel survey (bottom) indices for the 2021 preliminary base-case models with plus groups at 100 (left) and 120 years (right).

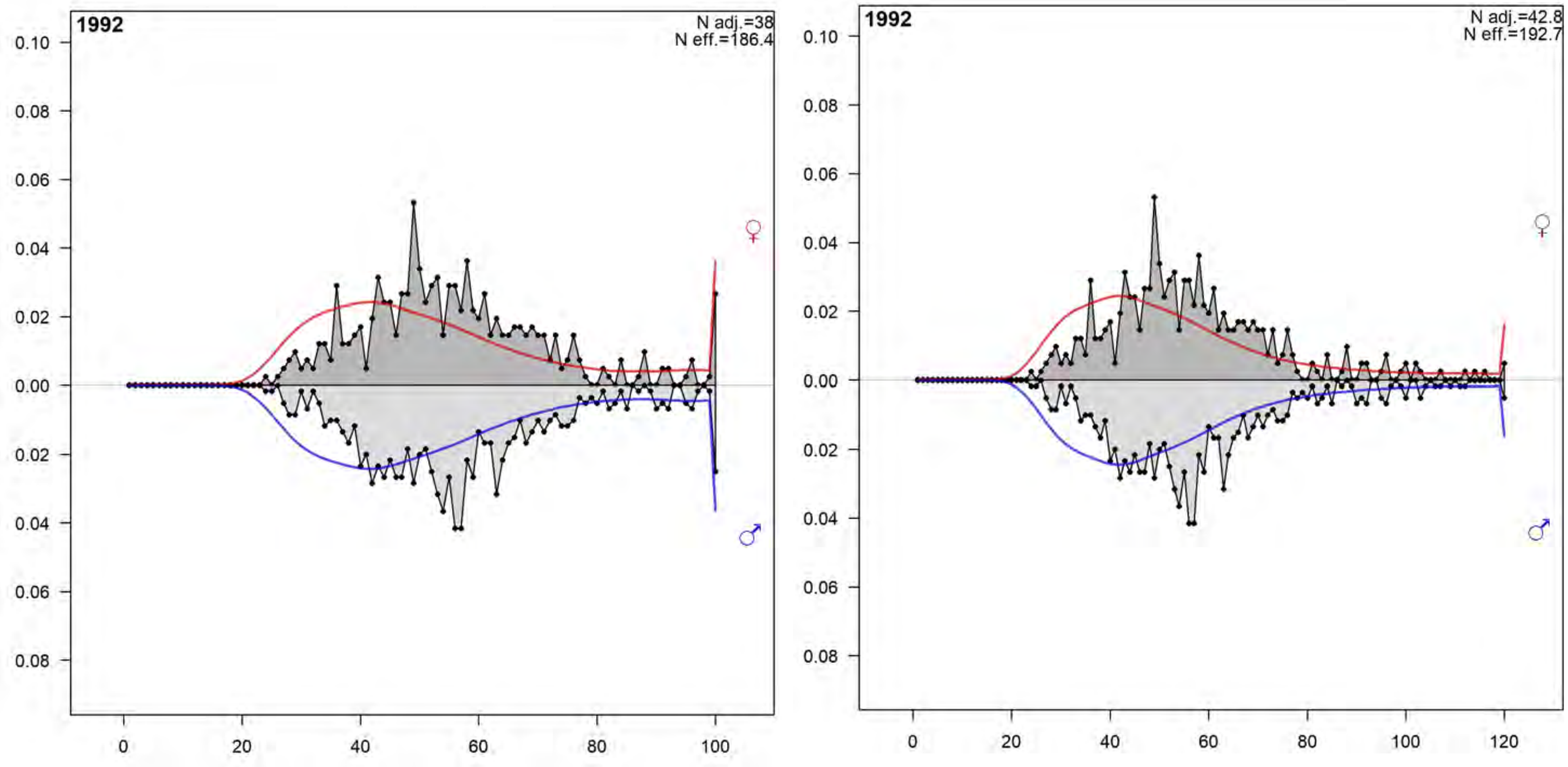


Figure 9.29. Fits to the 1992 age data for the 2021 preliminary base-case models that estimates *M* with a plus group at 100 years (left) and a plus group at 120 years (right).

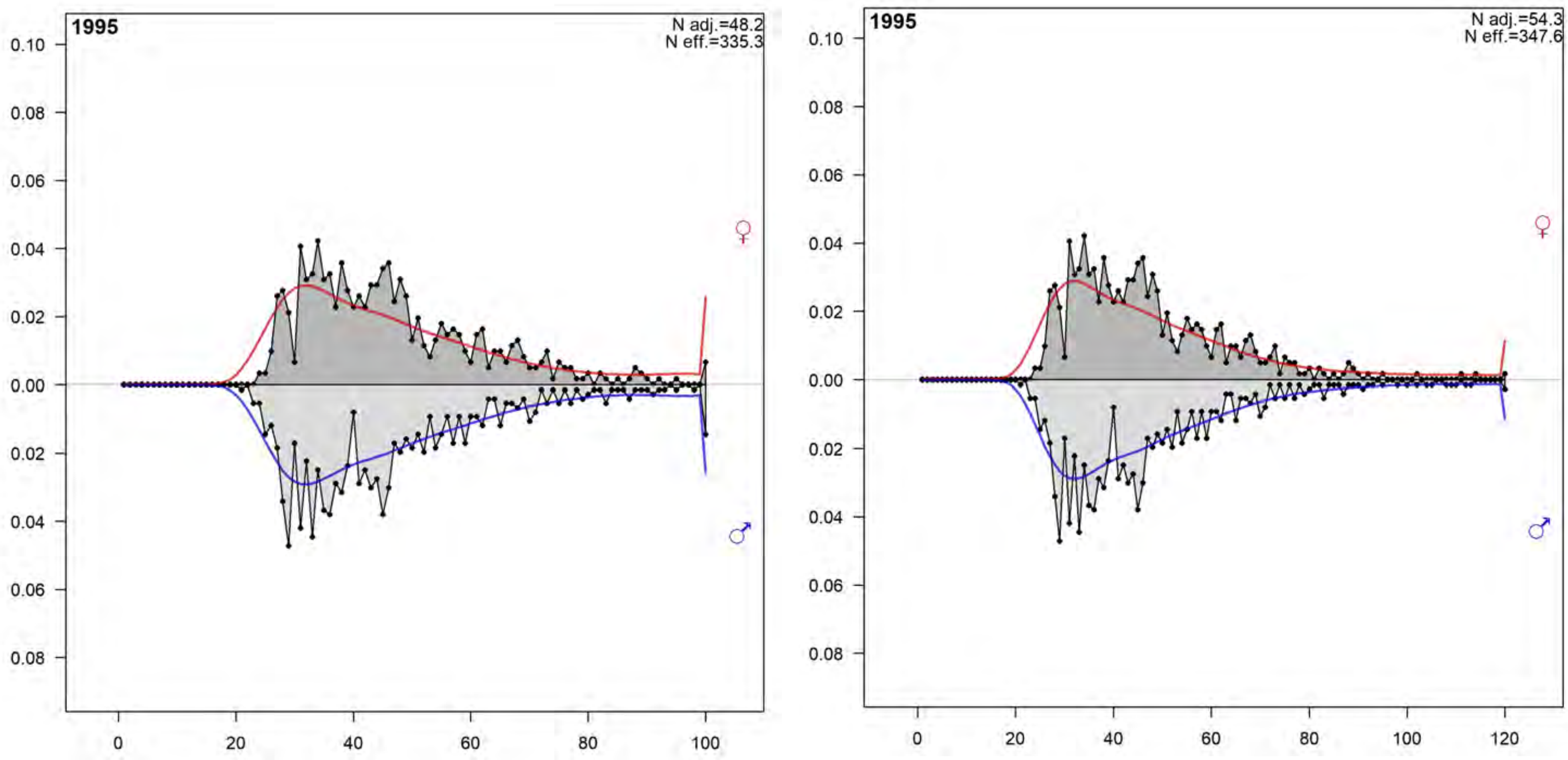


Figure 9.30. Fits to the 1995 age data for the 2021 preliminary base-case models that estimates *M* with a plus group at 100 years (left) and a plus group at 120 years (right).

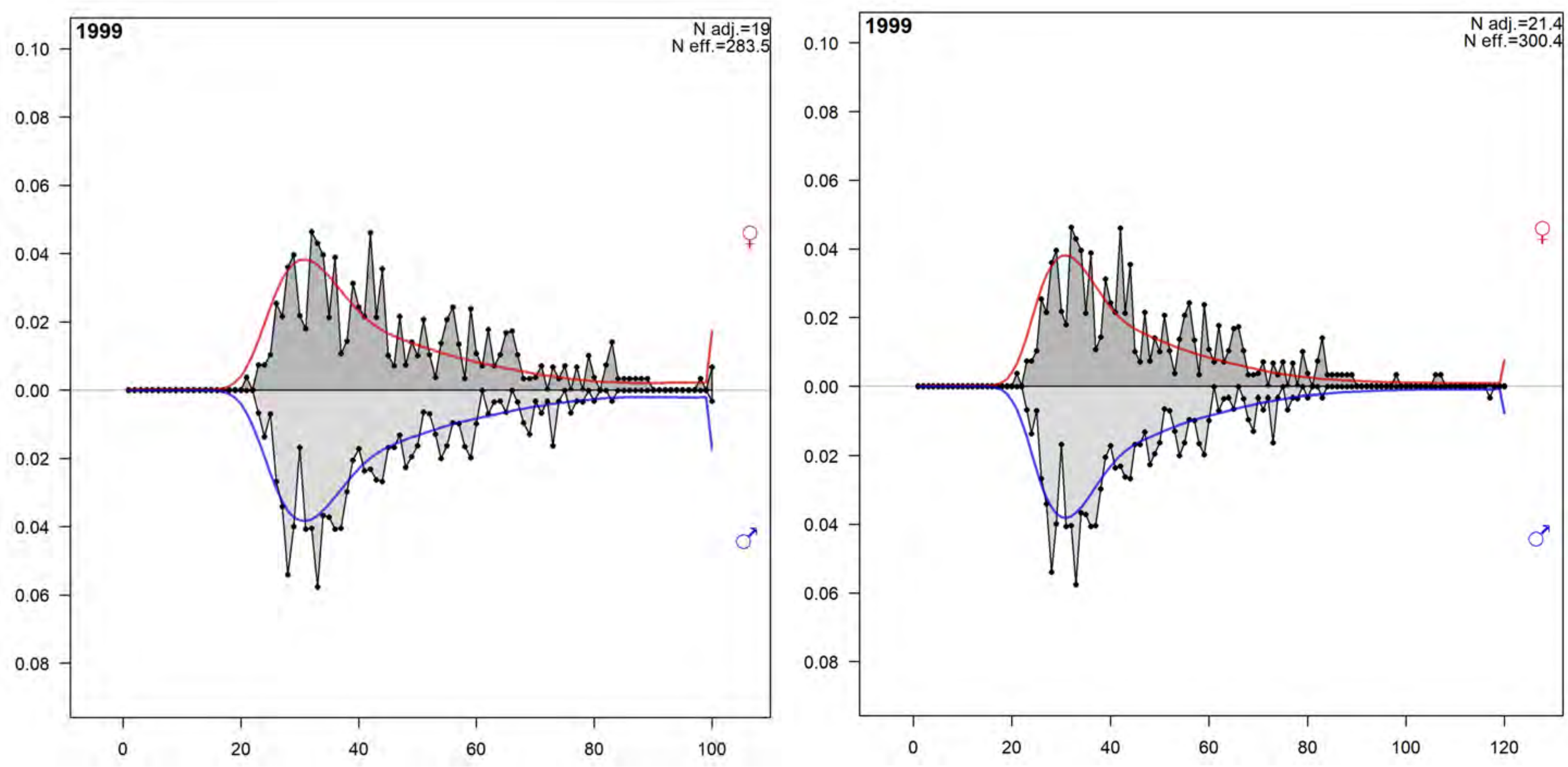


Figure 9.31. Fits to the 1999 age data for the 2021 preliminary base-case models that estimates *M* with a plus group at 100 years (left) and a plus group at 120 years (right).

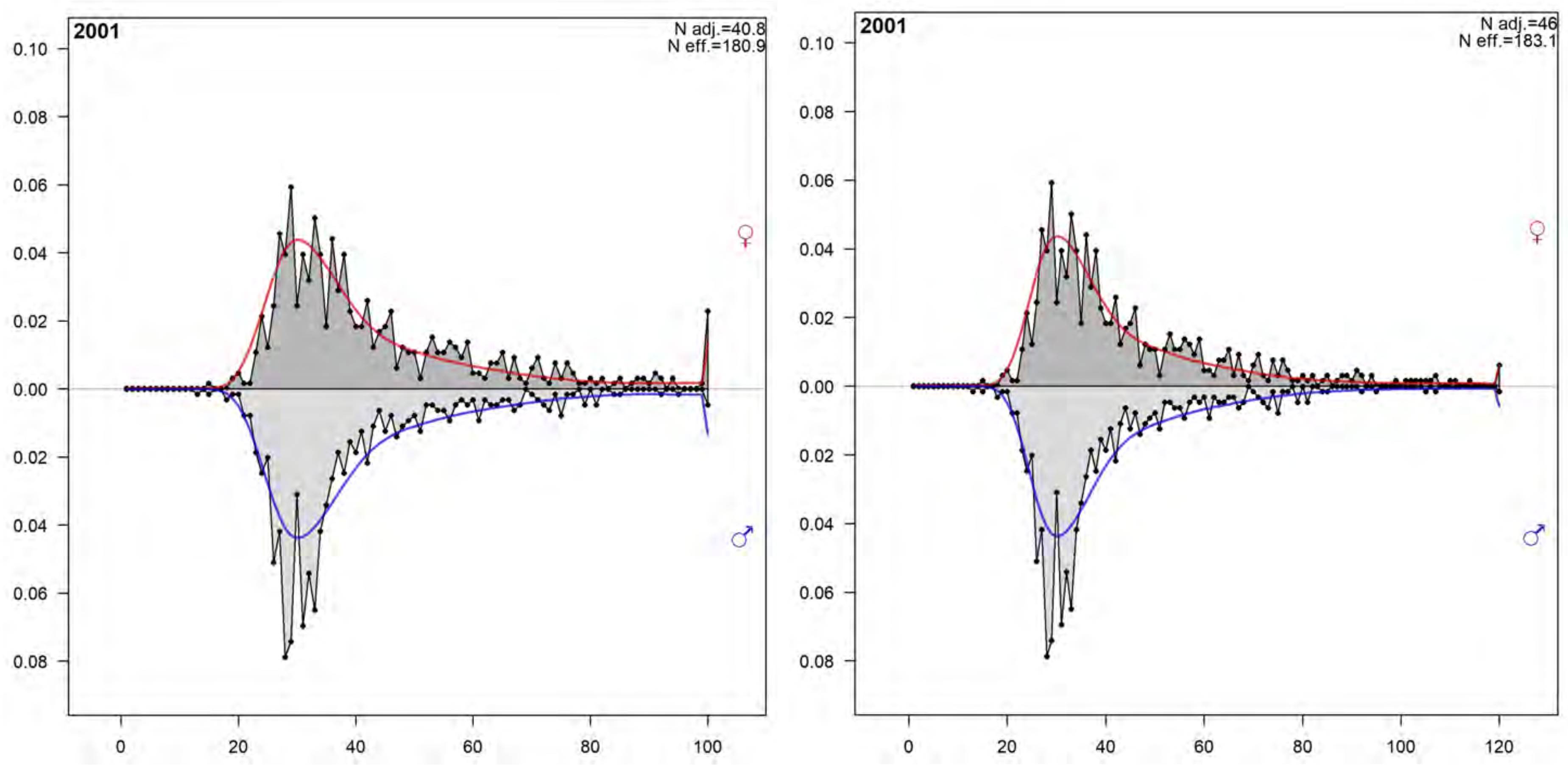


Figure 9.32. Fits to the 2001 age data for the 2021 preliminary base-case models that estimates *M* with a plus group at 100 years (left) and a plus group at 120 years (right).

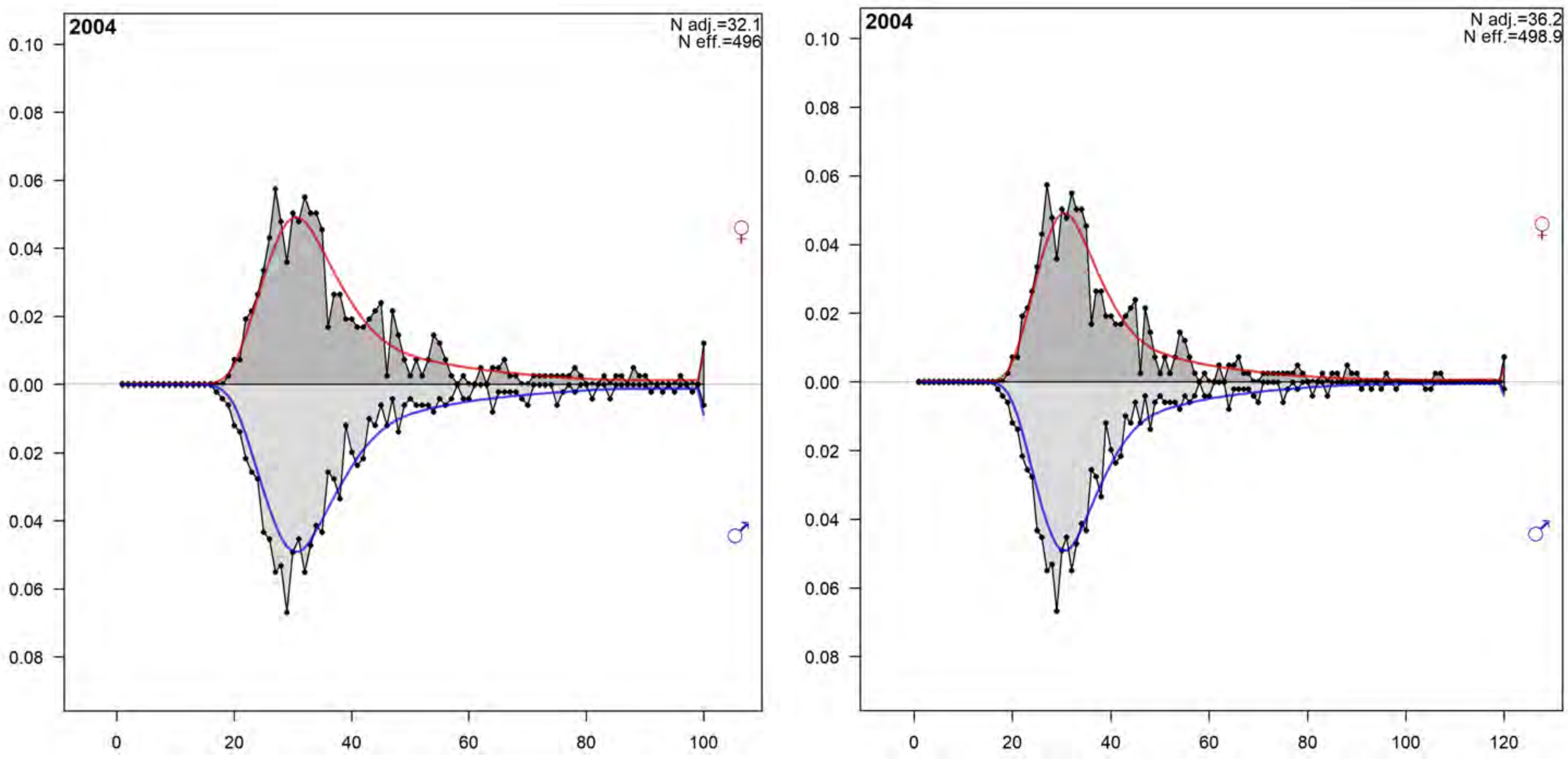


Figure 9.33. Fits to the 2004 age data for the 2021 preliminary base-case models that estimates *M* with a plus group at 100 years (left) and a plus group at 120 years (right).

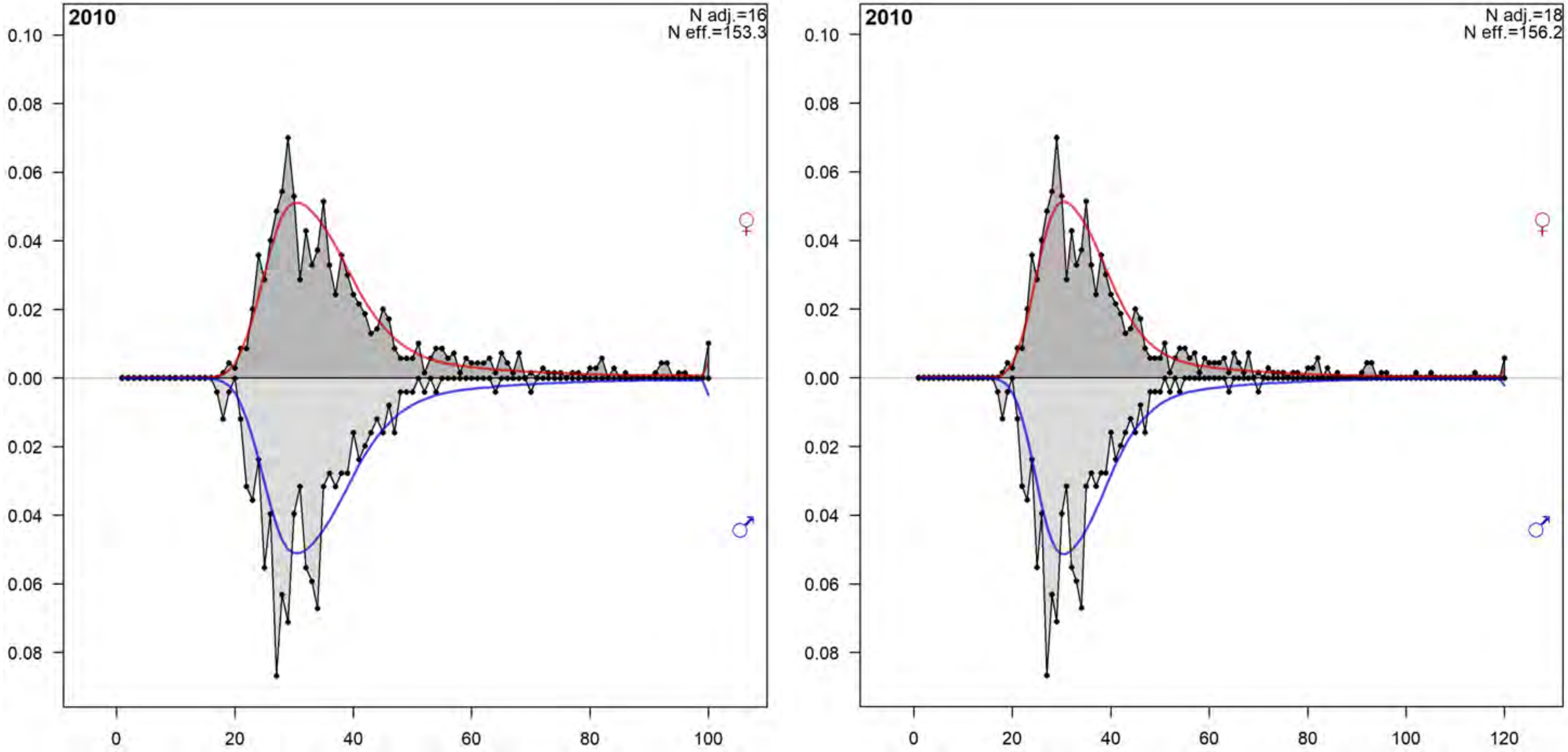


Figure 9.34. Fits to the 2010 age data for the 2021 preliminary base-case models that estimates *M* with a plus group at 100 years (left) and a plus group at 120 years (right).

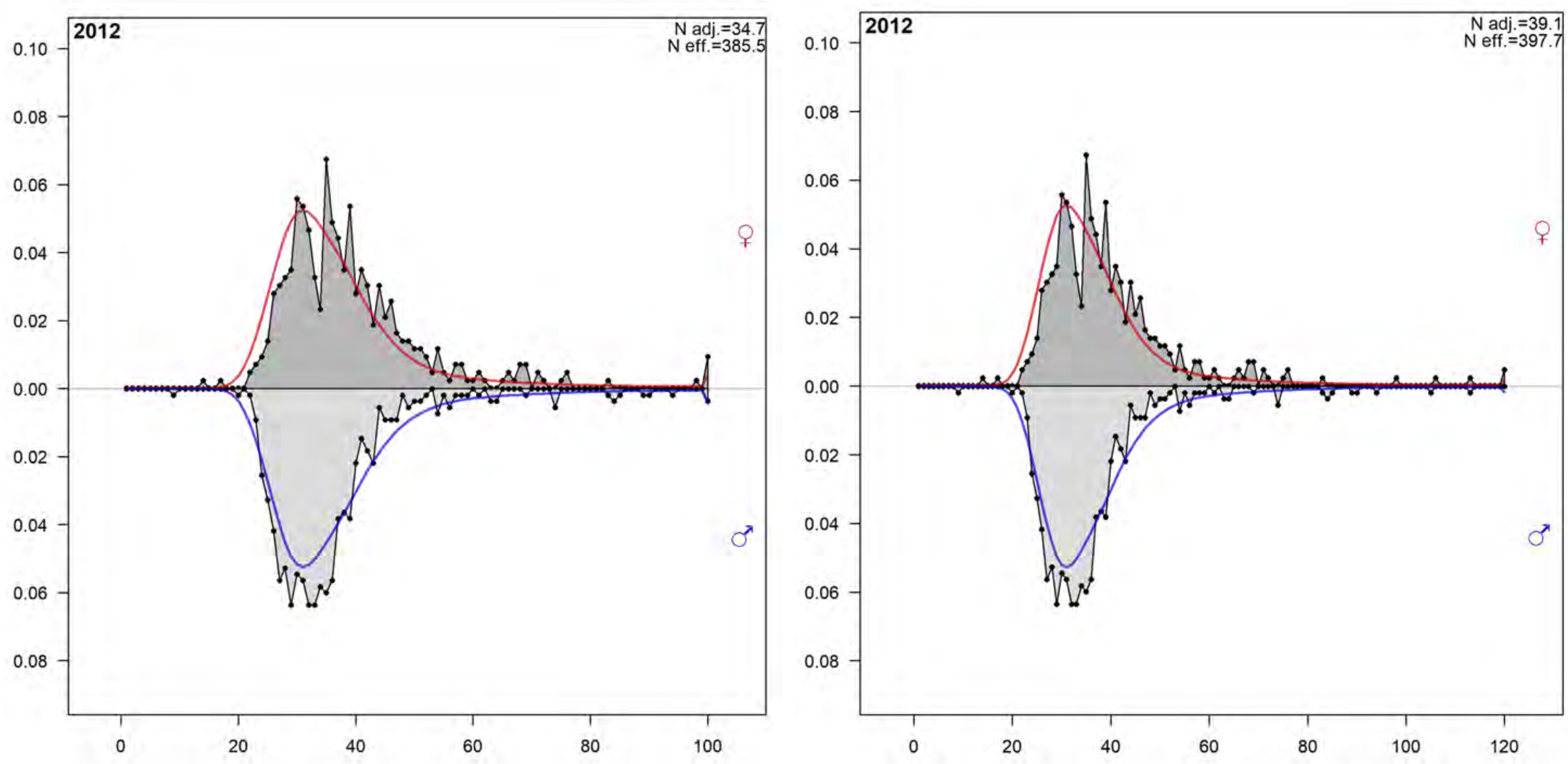


Figure 9.35. Fits to the 2012 age data for the 2021 preliminary base-case models that estimates *M* with a plus group at 100 years (left) and a plus group at 120 years (right).

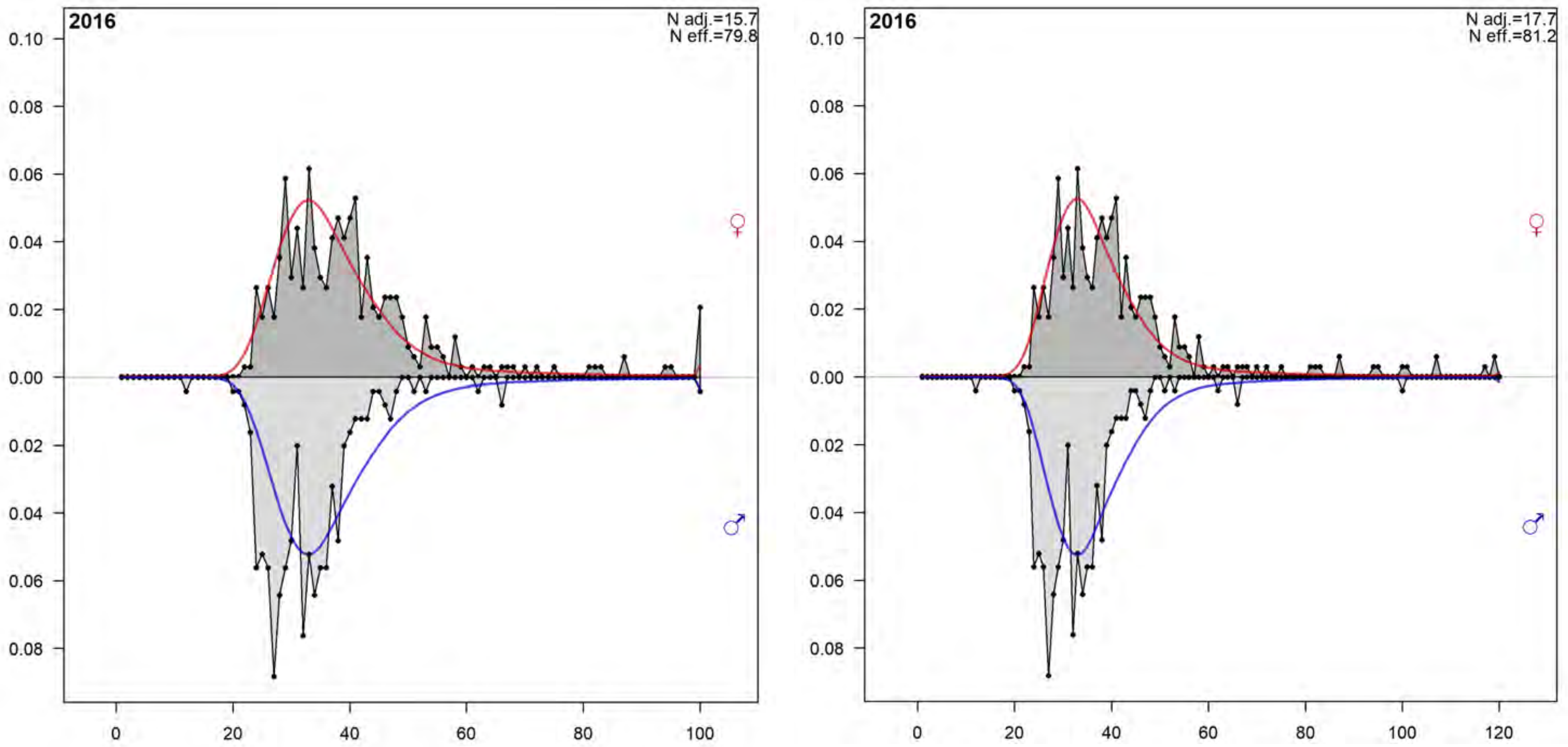
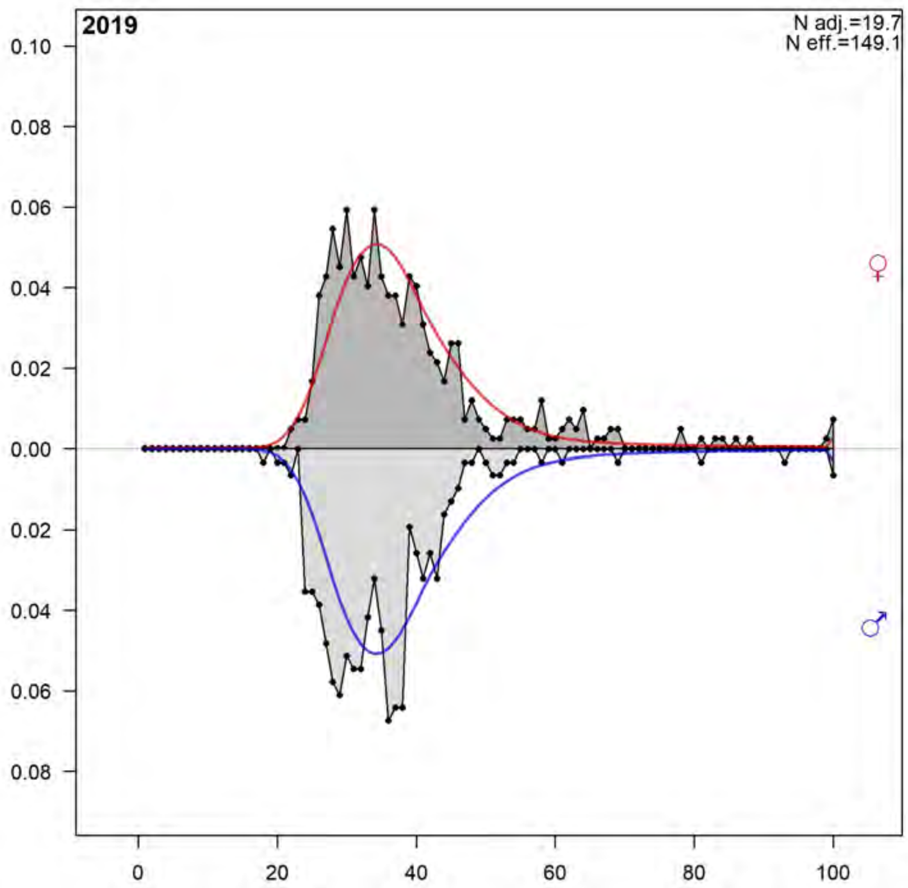


Figure 9.36. Fits to the 2016 age data for the 2021 preliminary base-case models that estimates *M* with a plus group at 100 years (left) and a plus group at 120 years (right).



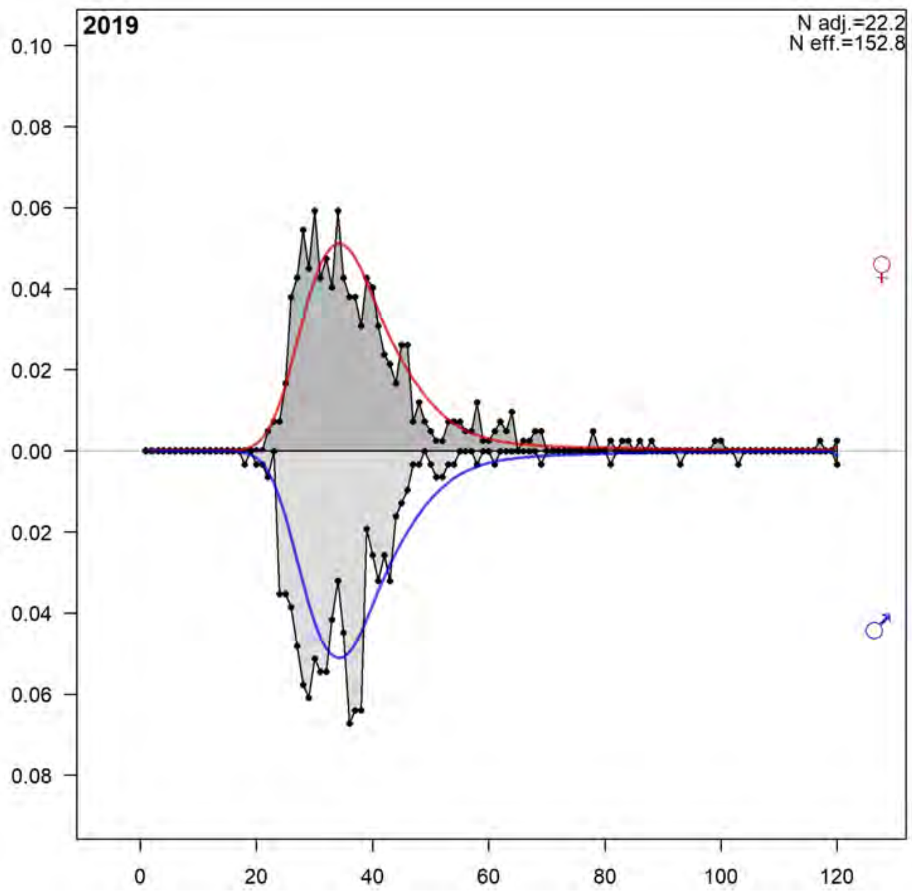


Figure 9.37. Fits to the 2019 age data for the 2021 preliminary base-case models that estimates *M* with a plus group at 100 years (left) and a plus group at 120 years (right).

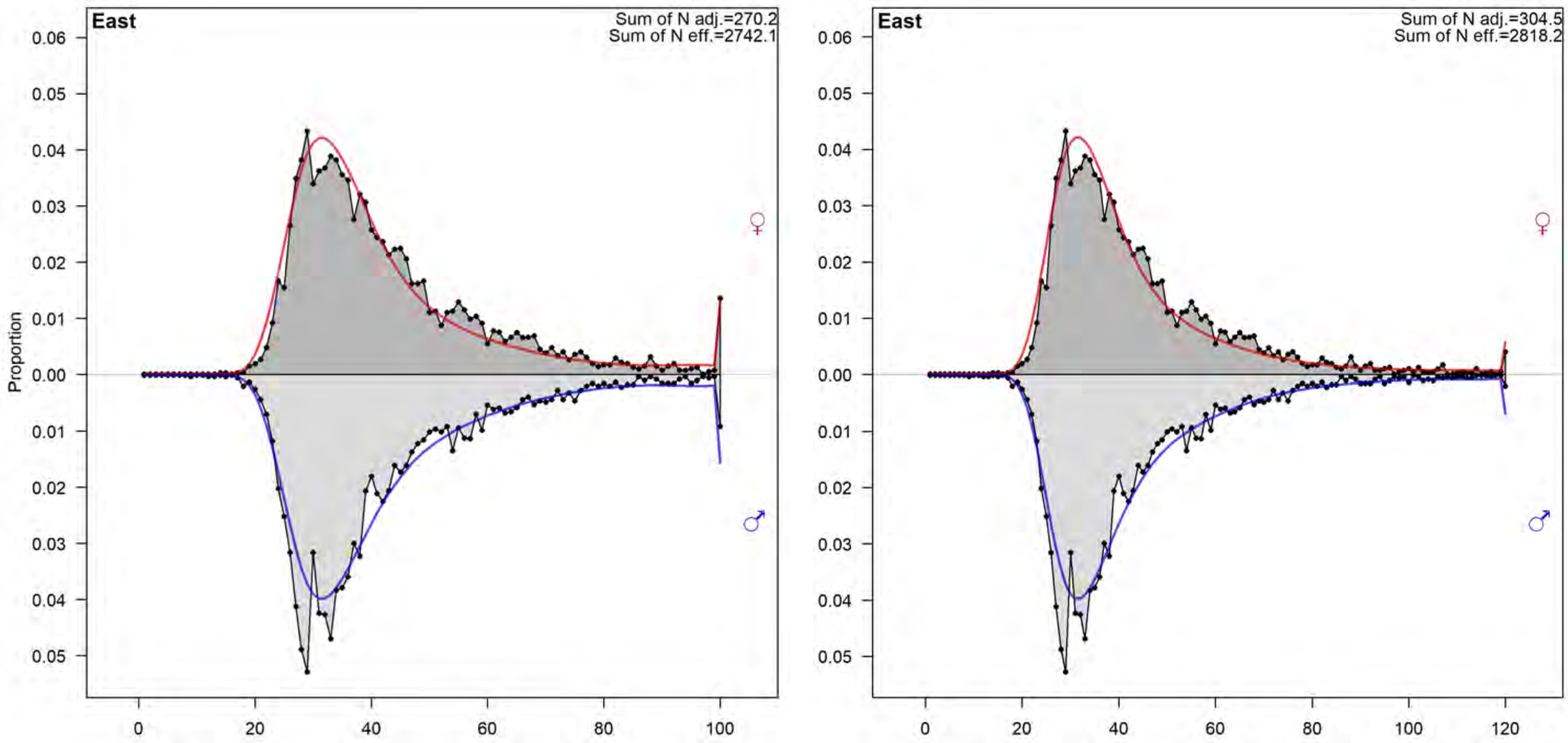


Figure 9.38. Fits to the combined age data (all years) for the 2021 preliminary base-case models that estimates *M* with a plus group at 100 years (left) and a plus group at 120 years (right).

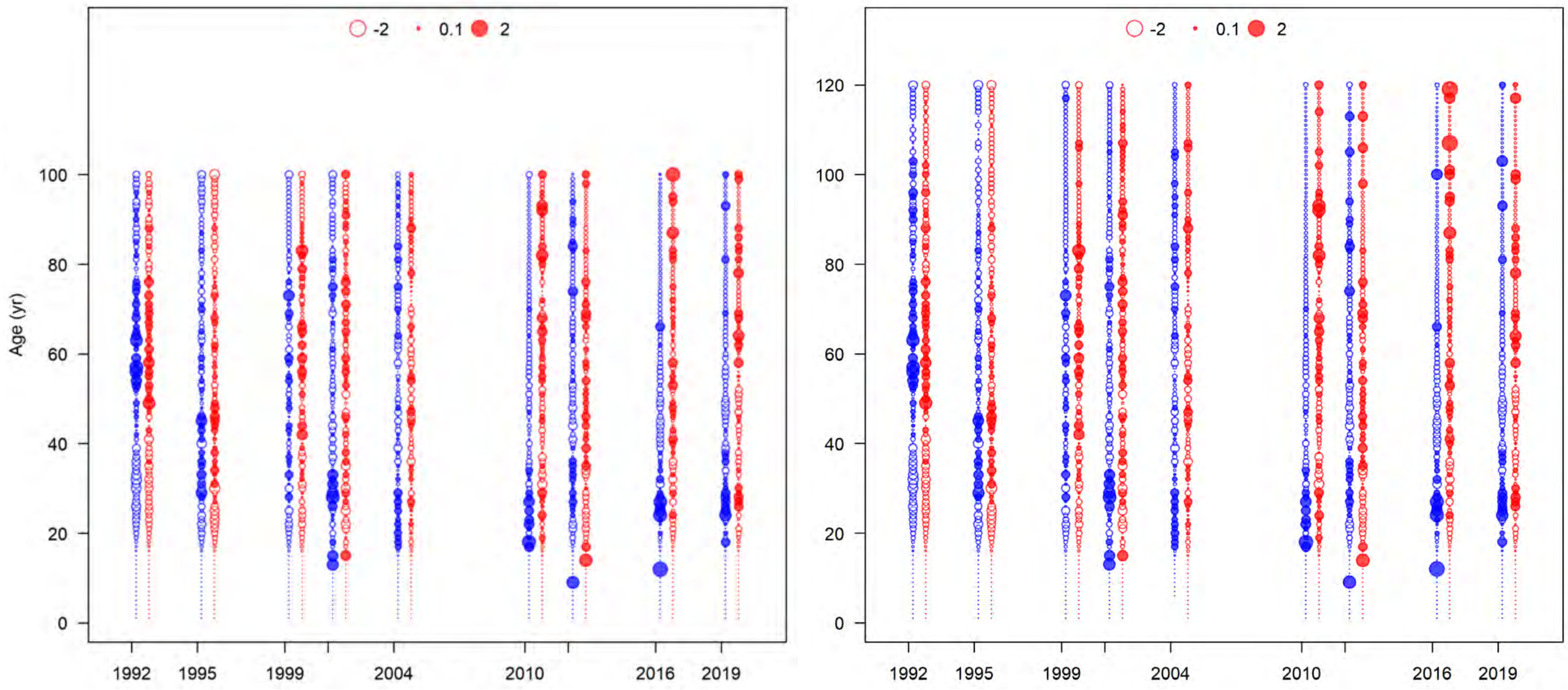


Figure 9.39. Pearson residuals for age data for the 2021 preliminary base-case models that estimates *M* with a plus group at 100 years (left) and a plus group at 120 years (right). Residuals for males are represented by blue circles and residuals for females by red circles.

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.

9.7 References

Annala, J.H. (Comp.) (1994) Report from the Special Fishery Assessment Plenary, 27 May 1994: stock assessments and yield estimates for ORH 2A, 2B, and 3A. (Cited in CSIRO and TDPIF, 1996) 17 p.

Bax, N. (1997). Stock Assessment Report 1997: Orange roughy. Report for the South East Fishery Stock Assessment Group. Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 64 p. (Unpublished report held by CSIRO, Hobart).

Bax, N. (2000a). Stock Assessment Report: Orange roughy 1995, Stock Assessment Report, South East Fishery Stock Assessment Group, Australian Fisheries Management Authority, Canberra, 55 p. (Unpublished report held by AFMA, Canberra).

Bax, N. (2000b). Stock Assessment Report: Orange roughy 1996, Stock Assessment Report, South East Fishery Stock Assessment Group, Australian Fisheries Management Authority, Canberra, 37 p. (Unpublished report held by AFMA, Canberra).

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.

Bell, J.D., Lyle, J.M., Bulman, C.M., Graham, K.J., Newton, G.M. and Smith, D.C. (1992) Spatial variation in reproduction, and occurrence of non-reproductive adults, in orange roughy, *Hoplostethus atlanticus* Collett (Trachichthyidae), from south-eastern Australia. Journal of Fish Biology 40: 107-122.

Burch P and Curin Osorio S (2021). Eastern zone Orange Roughy (*Hoplostethus atlanticus*) stock assessment based on data up to 2020 – development of a preliminary base-case DRAFT. Prepared for the Orange Roughy Steering Committee video conference, 13 August 2021. CSIRO Oceans and Atmosphere.

CSIRO and TDPIF (1996). Orange roughy 1994, Stock Assessment Report, South East Fishery Assessment Group. Australian Fisheries Management Authority, 204 p. (Unpublished report held by AFMA, Canberra).

Cordue, P.L., (2014). A management strategy evaluation for orange roughy (ISL Client Report for Deepwater Group Ltd.).

Deng, R., Burch, P., Thomson, R., (2020). Integrated scientific monitoring program for the Southern and Eastern Scalefish and Shark Fishery – discards for 2019. Revised after the SERAG meeting, 9-10 December 2020 (Report for the Australian Fisheries Management Authority). CSIRO Oceans and Atmosphere.

Francis, C. (2011) Data weighting in statistical fisheries stock assessment models. Canadian Journal of Fisheries and Aquatic Science 68: 1124-1138.

Haddon, M. (2017) Orange Roughy East (*Hoplostethus atlanticus*) stock assessment using data to 2016. CSIRO, Oceans and Atmosphere.

Kloser, R, Ryan, T. (2002) Review of Analysis methodologies and data holdings for acoustic assessments of orange roughy on St Helens Hill, 1989 - 1999. CSIRO Marine Research 40p.

Kloser, R., Sutton, C., Kunnath, H. and R. Downie (2016) Orange roughy eastern zone spawning biomass 2016. Report for South East Trawl Industry Association. CSIRO Oceans and Atmosphere, Hobart.

Kloser, R., Sutton, C., 2020. Orange roughy eastern zone spawning biomass 2019 (report for SETFIA). CSIRO Oceans and Atmosphere.

Koslow, J.A., Bulman, C.M., Lyle, J.M. and Haskard, K. (1995) Biomass assessment of a deep-water fish, the orange roughy (*Hoplostethus atlanticus*), based on an egg survey. Mar. Freshwater Res., 46: 819-830.

Lyle, J.M., Kitchener, J. & Riley, S.P. (1991) An assessment of orange roughy resource off the coast of Tasmania. Final report to FIRDC, Project 87/65.

Methot, R.D. and C.R. Wetzel (2013) Stock Synthesis: a biological and statistical framework for fish stock assessment and fishery management. Fisheries Research 142, 86-99.

Pacific Fishery Management Council. (2020). Terms of Reference for the Groundfish and Coastal Pelagic Species Stock Assessment Review Process for 2021-2022, https://www.pcouncil.org/documents/2021/01/terms-of-reference-for-the-coastal-pelagic-species-stock-assessment-review-process-for-2021-2022-december-2020.pdf/.

Punt, A.E., Smith, D.C., Krusic Golub, K. and S. Robertson (2008) Quantifying age-reading error for use in fisheries stock assessments, with application to species in Australia's southern and eastern scalefish and shark fishery. Canadian Journal of Fisheries and Aquatic Science 65: 1991–2005.

Punt A.E. 2018. On the use of likelihood profiles in fisheries stock assessment. Technical paper for SESSFRAG, August 2018.

Smith, D.C., Fenton, G.E., Robertson, S.G. and Short, S.A. (1995) Age determination and growth of orange roughy (*Hoplostethus atlanticus*): a comparison of annulus counts with radiometric ageing. Canadian Journal of Fisheries and Aquatic Sciences 52: 391-401.

Stokes, K. (2009). Orange roughy Assessment Review. Report completed for the Australian Fisheries Management Authority, 33 p. (Unpublished report held by AFMA, Canberra).

Tuck, G., Castillo-Jordán, C., Burch, P., 2018. Orange roughy east (*Hoplostethus atlanticus*) cross-catch risk assessment based upon the 2017 stock assessment. For discussion at SERAG, 14-16 November 2018 (Report for the Australian Fisheries Management Authority). CSIRO Oceans; Atmosphere.

Upston, J. and S. Wayte (2011) Orange roughy (*Hoplostethus atlanticus*) Eastern Zone preliminary stock assessment incorporating data up to 2010 – definition of the base-case model.

Upston, J., Punt, A.E., Wayte, S., Ryan, T., Day, J. and M. Sporcic (2015) Orange roughy (*Hoplostethus atlanticus*) Eastern Zone stock assessment incorporating data up to 2014. pp 10 – 81 in Tuck, G.N. (ed) Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2014. Part 1. Australian Fisheries Management Authority and CSIRO Oceans and Atmosphere Flagship, Hobart. 170p.

Venables, W. N. and Ripley, B. D. (2002) Modern Applied Statistics with S. Fourth Edition. Springer, New York. ISBN 0-387-95457-0.

Wayte, S. (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.

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.

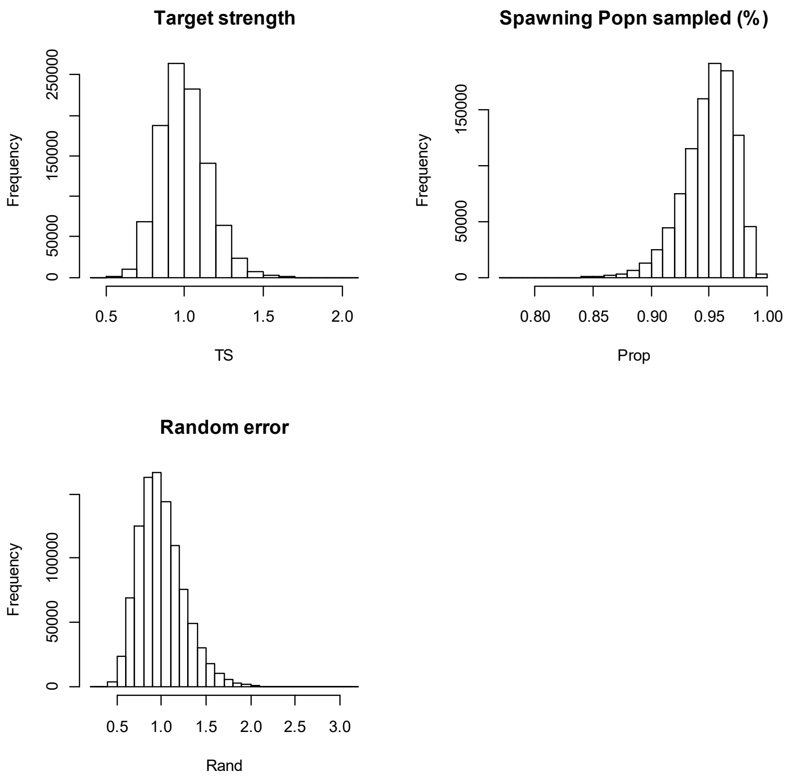


Figure A 9.1. Prior component distributions for target strength, spawning population sampled, and random error for acoustics towed (reproduced from Upston et al. 2015).

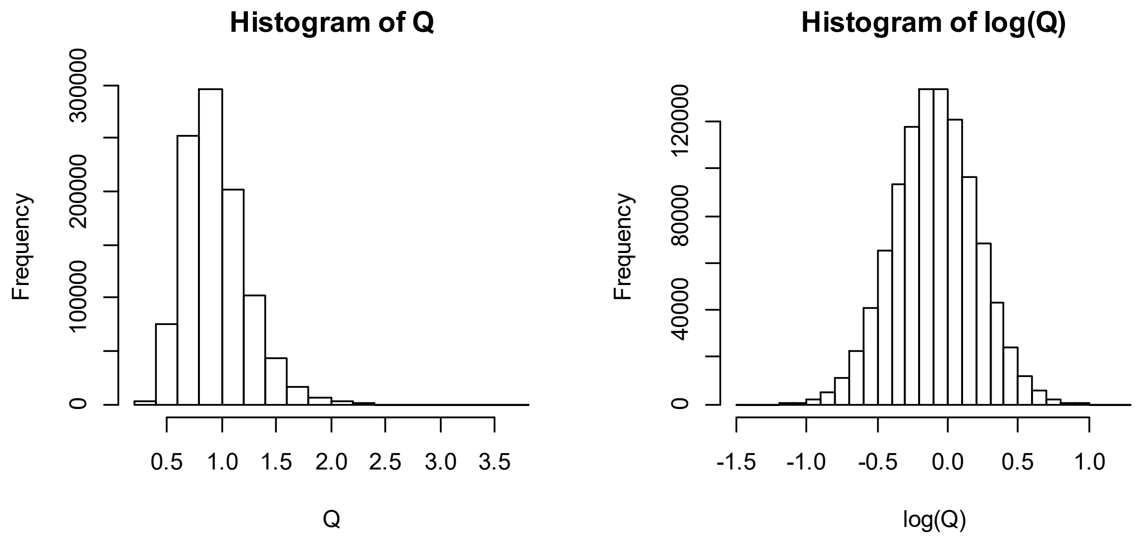


Figure A 9.2. Priors for q and $\ln(q)$ for acoustics towed (reproduced from Upston et al. 2015).

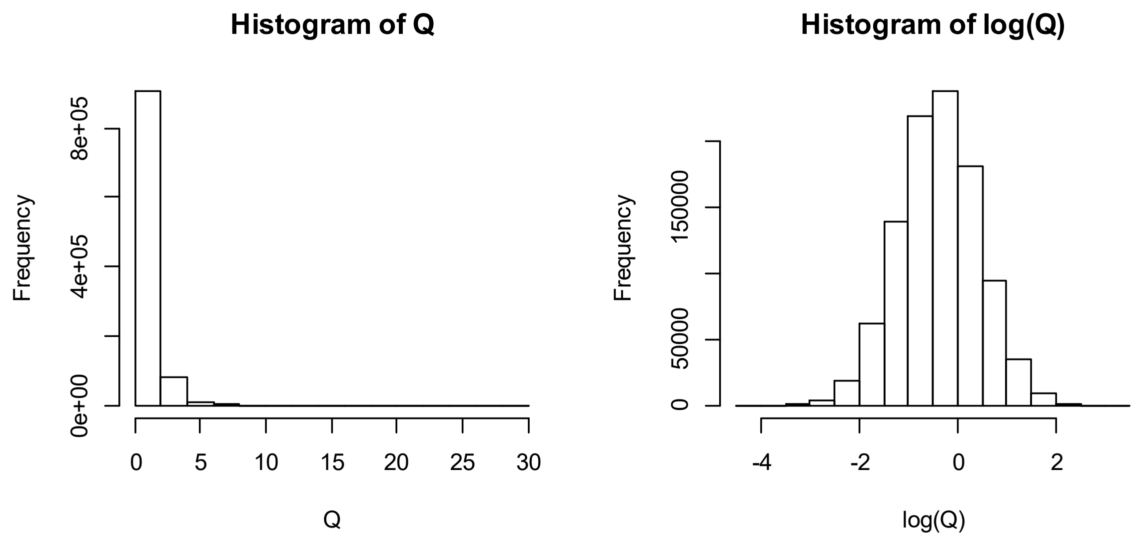


Figure A 9.3. Priors for q and $\ln(q)$ hull. The random error component is greater than that for towed body (reproduced from Upston et al. 2015).

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*

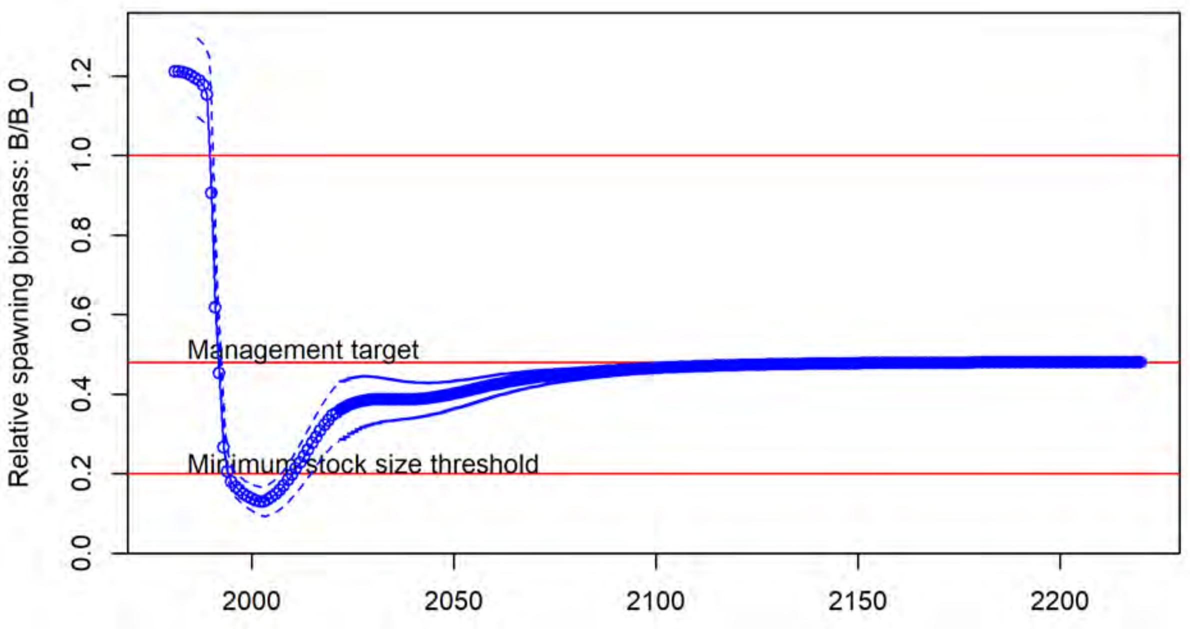


Figure A 9.4. The estimated time-series of relative spawning biomass for the 2021 preliminary base-case model with fixed *M* forecast 200 years into the future with catches set using the SESSF 20:35:48 harvest control rule.

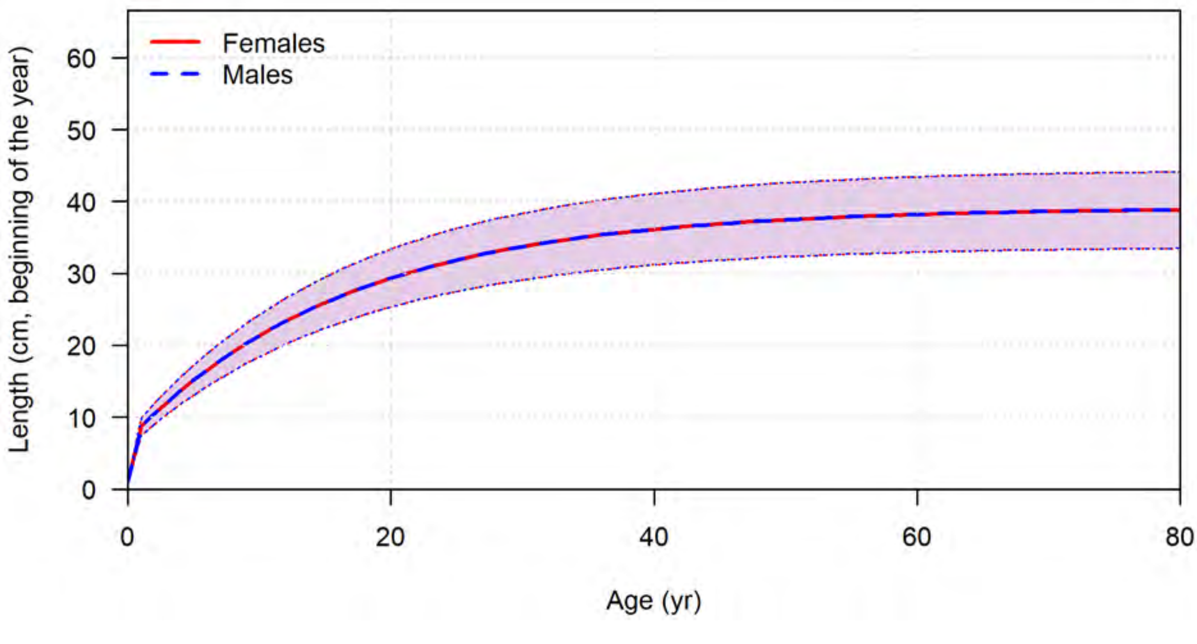


Figure A 9.5. Growth for the 2021 preliminary base-case model.

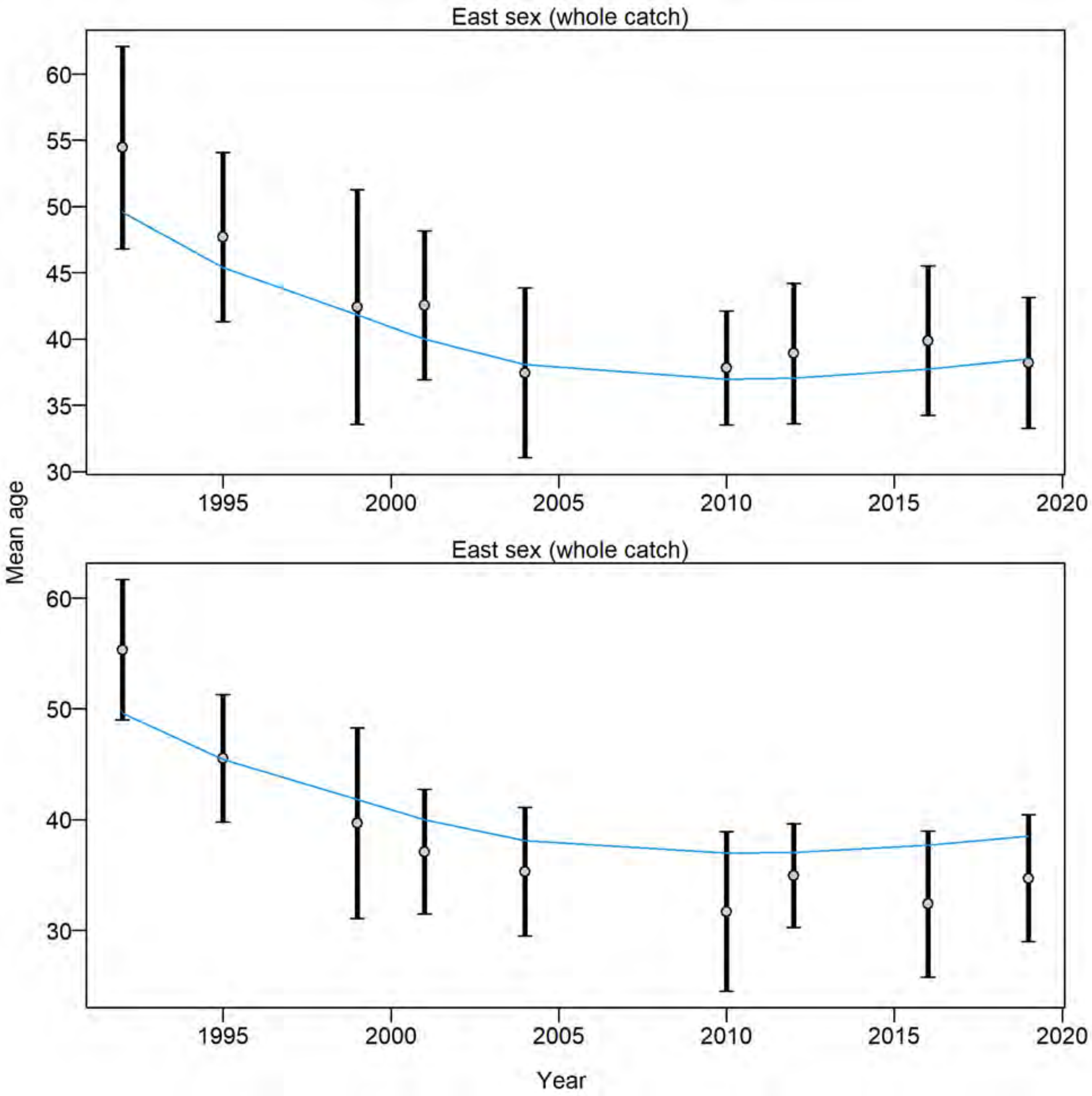


Figure A 9.6. Mean age for male and female samples with 95% confidence intervals based on current samples sizes for the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1}. Suggested multiplier for Francis data weighting method TA1.8 of age data with 95% interval is 0.9991 (0.6902-1.8461).

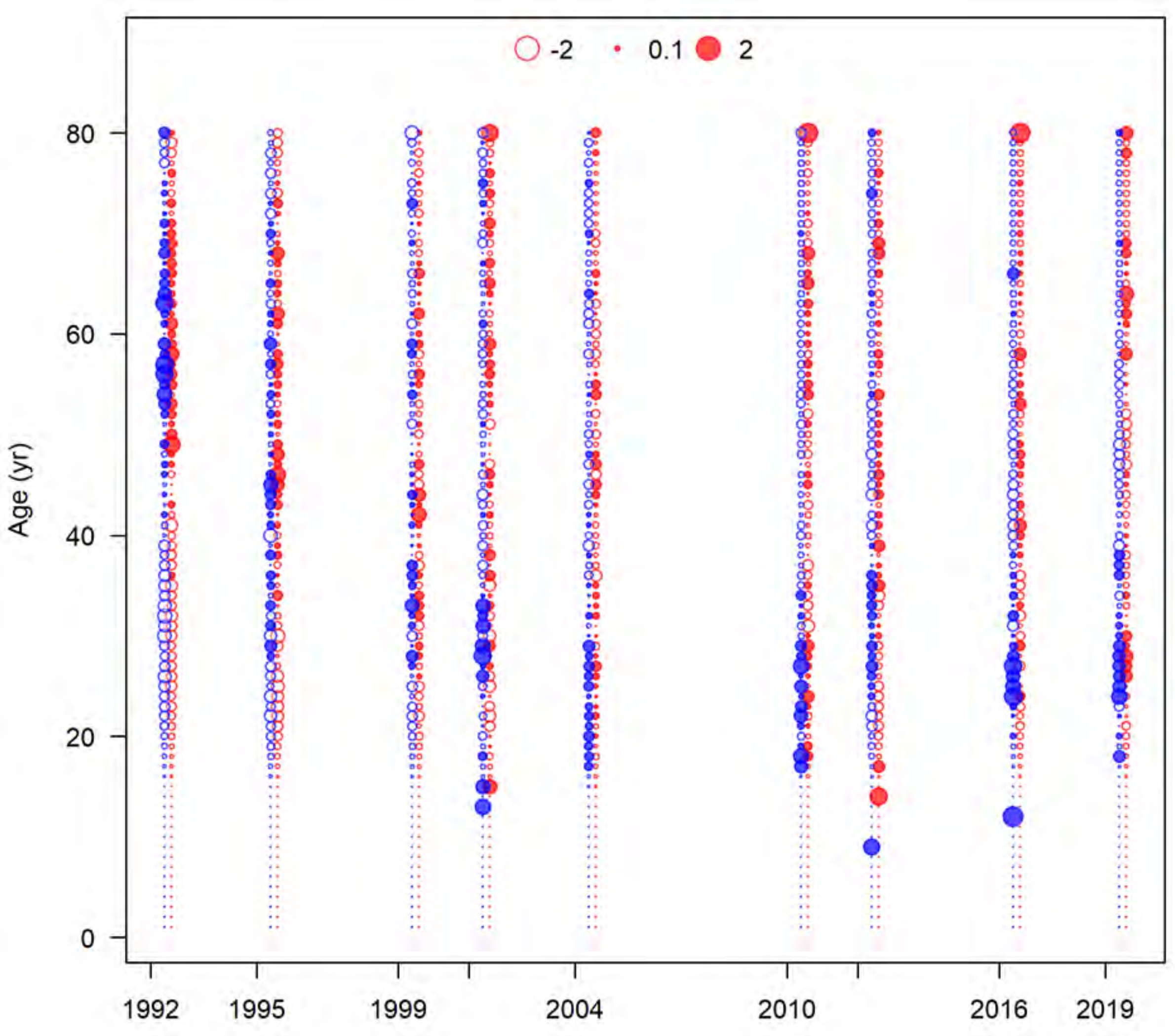


Figure A 9.7. Pearson residuals from the age composition data for the 2021 preliminary base-case model with a fixed natural mortality of M=0.04 yr^{-1}.

9.8.4 *Additional diagnostics for candidate base-cases with M estimated*

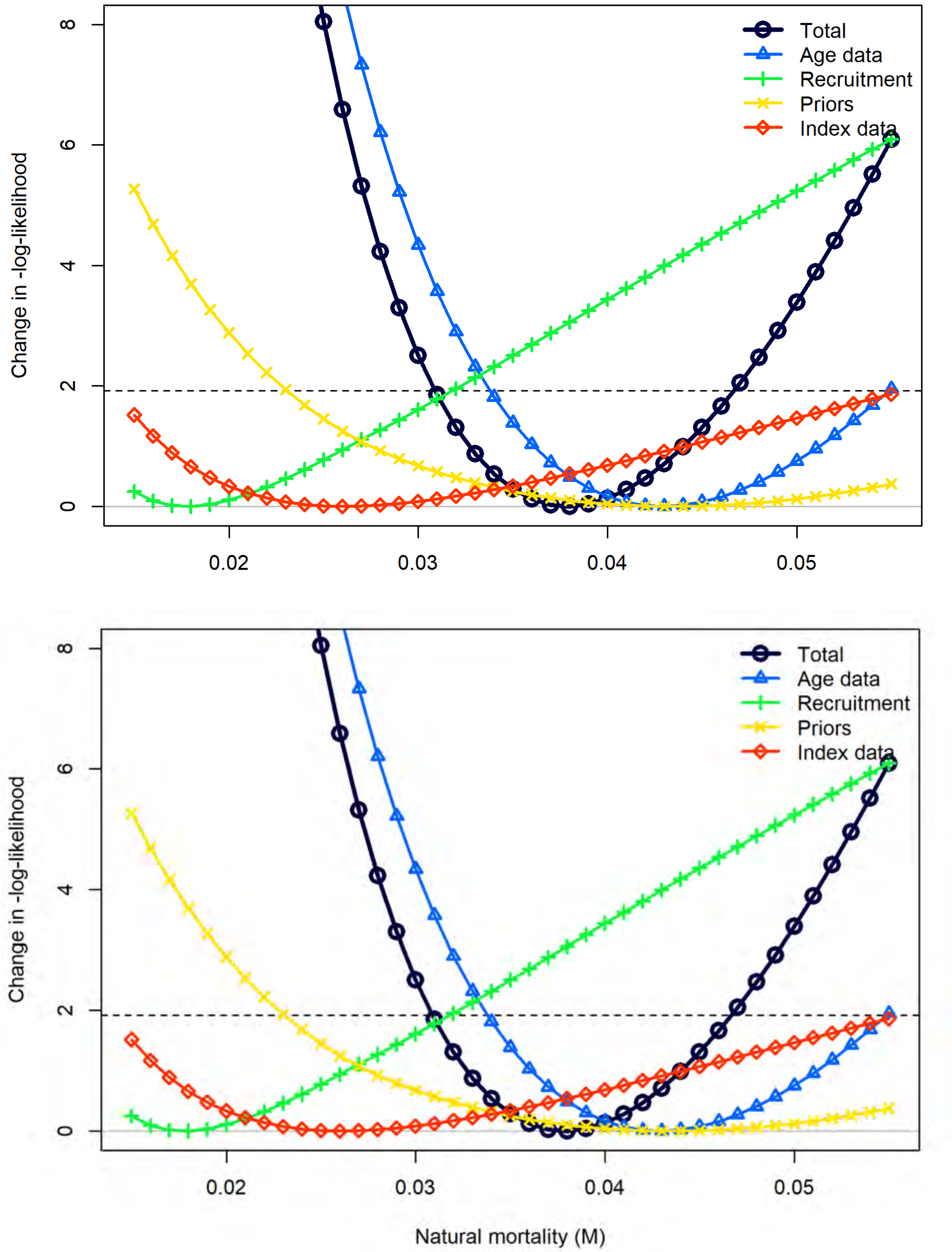
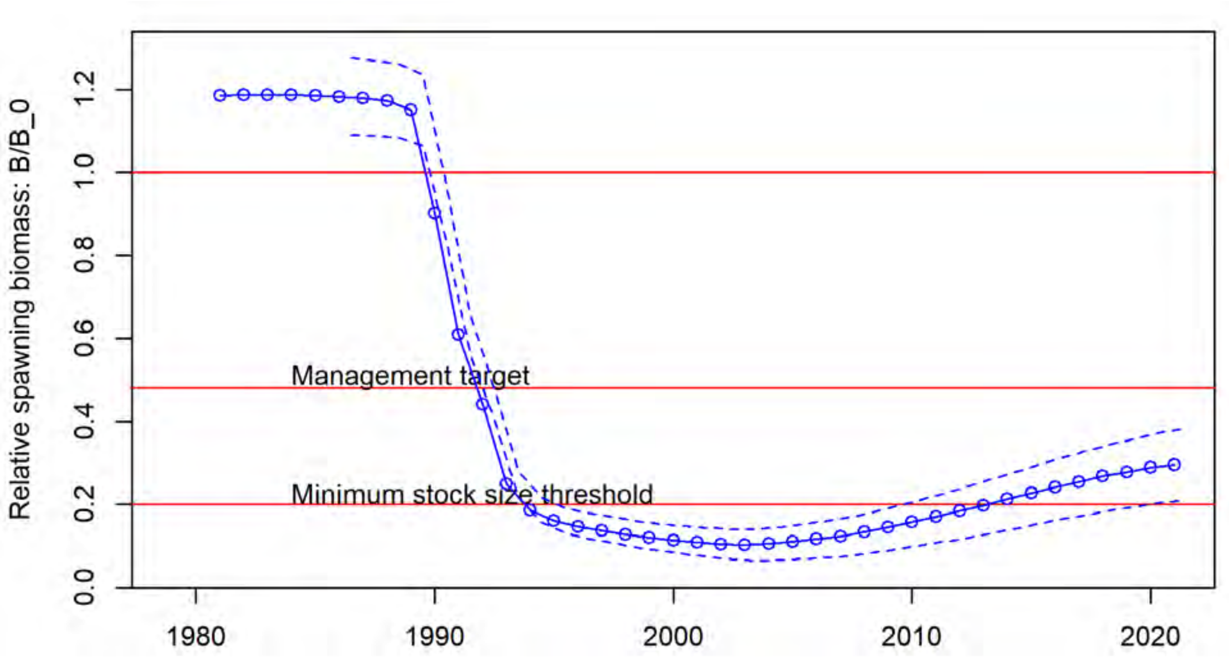


Figure A 9.8. Likelihood profiles for natural mortality for models with plus-groups of 100 (top) and 120 (bottom). When M was estimated, the model with a plus-group at 100 estimated natural mortality at M=0.0373 yr^{-1} and the model with a plus-group at 120 estimated natural mortality at M=0.0386 yr^{-1}.

9.8.5 *Diagnostics for model with 80 age-classes and M estimated*



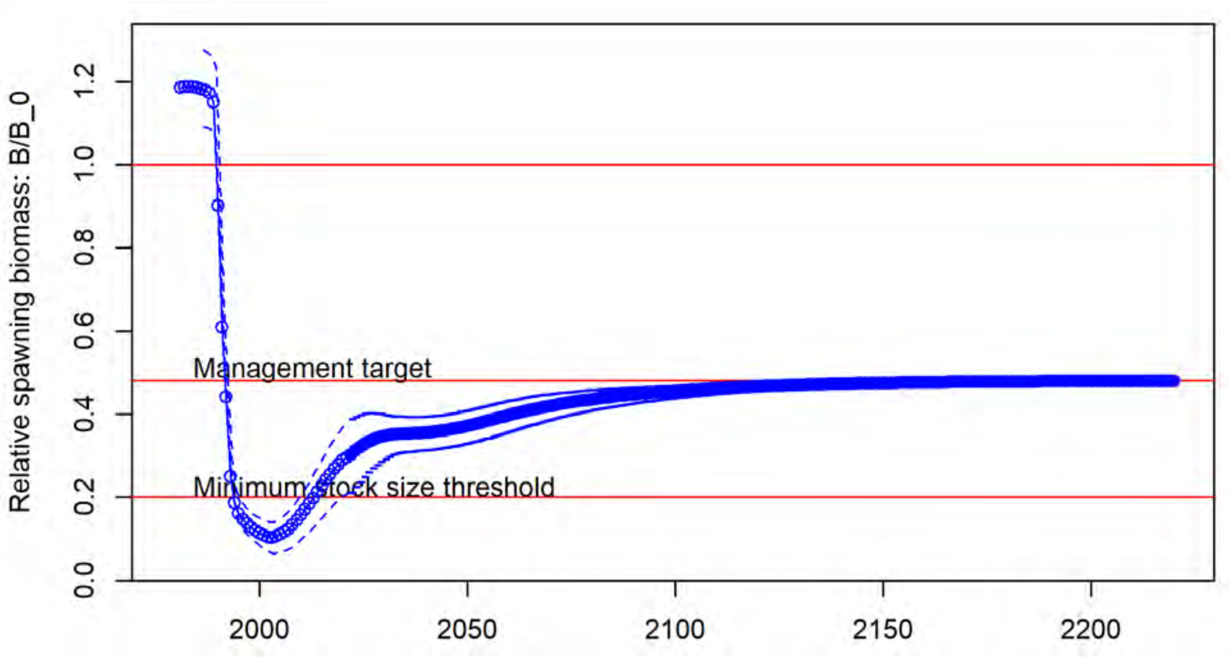


Figure A 9.9. The estimated time-series of relative spawning biomass with asymptotic 95% confidence intervals (top) and forecast 200 years into the future with catches set using the SESSF 20:35:48 harvest control rule (bottom) for the 2021 preliminary base-case model with a plus-group at 80 years and *M* estimated.

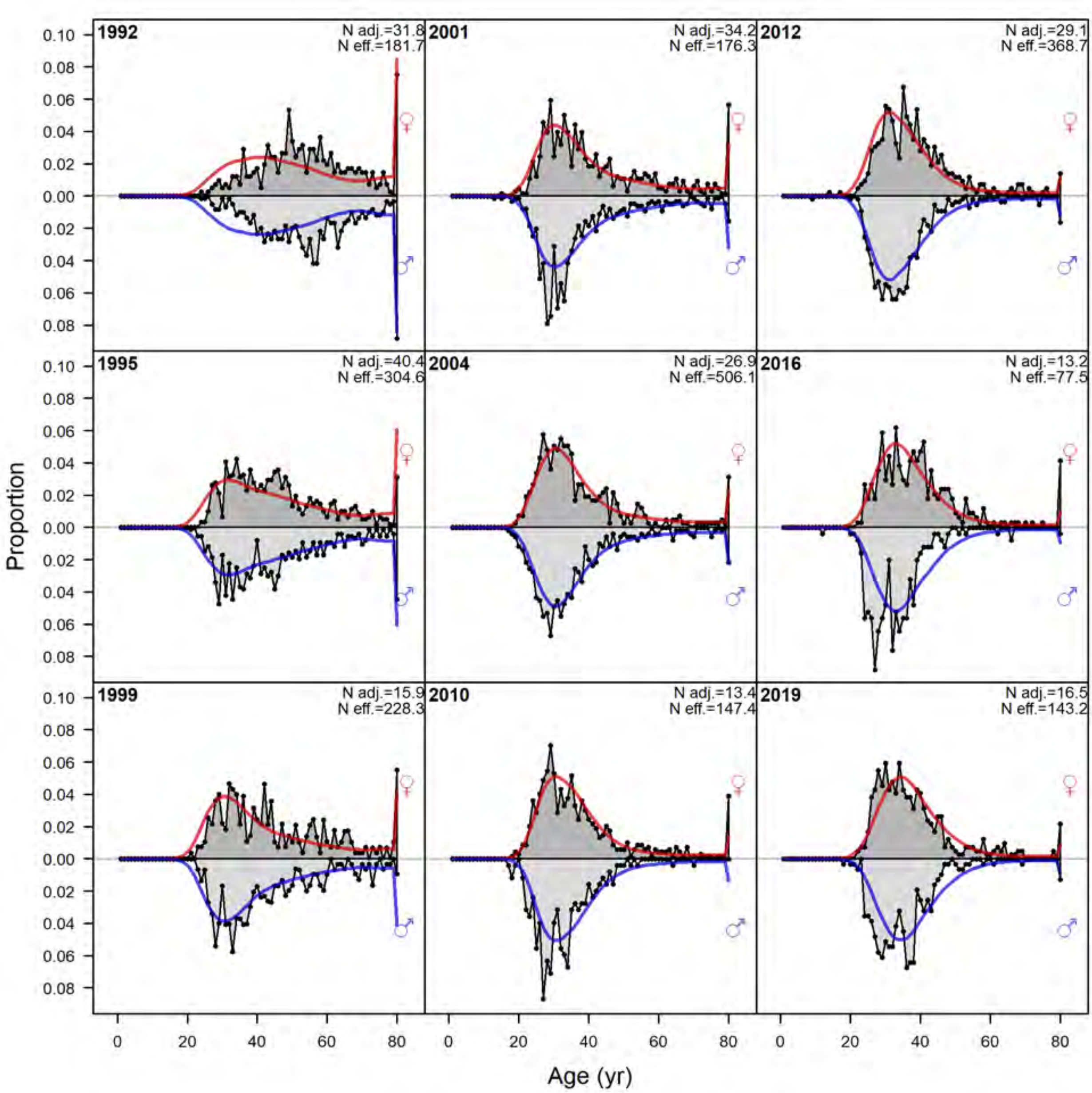


Figure A 9.10. Fits to the age composition data for the 2021 preliminary base-case model with a plus-group at 80 years and *M* estimated.

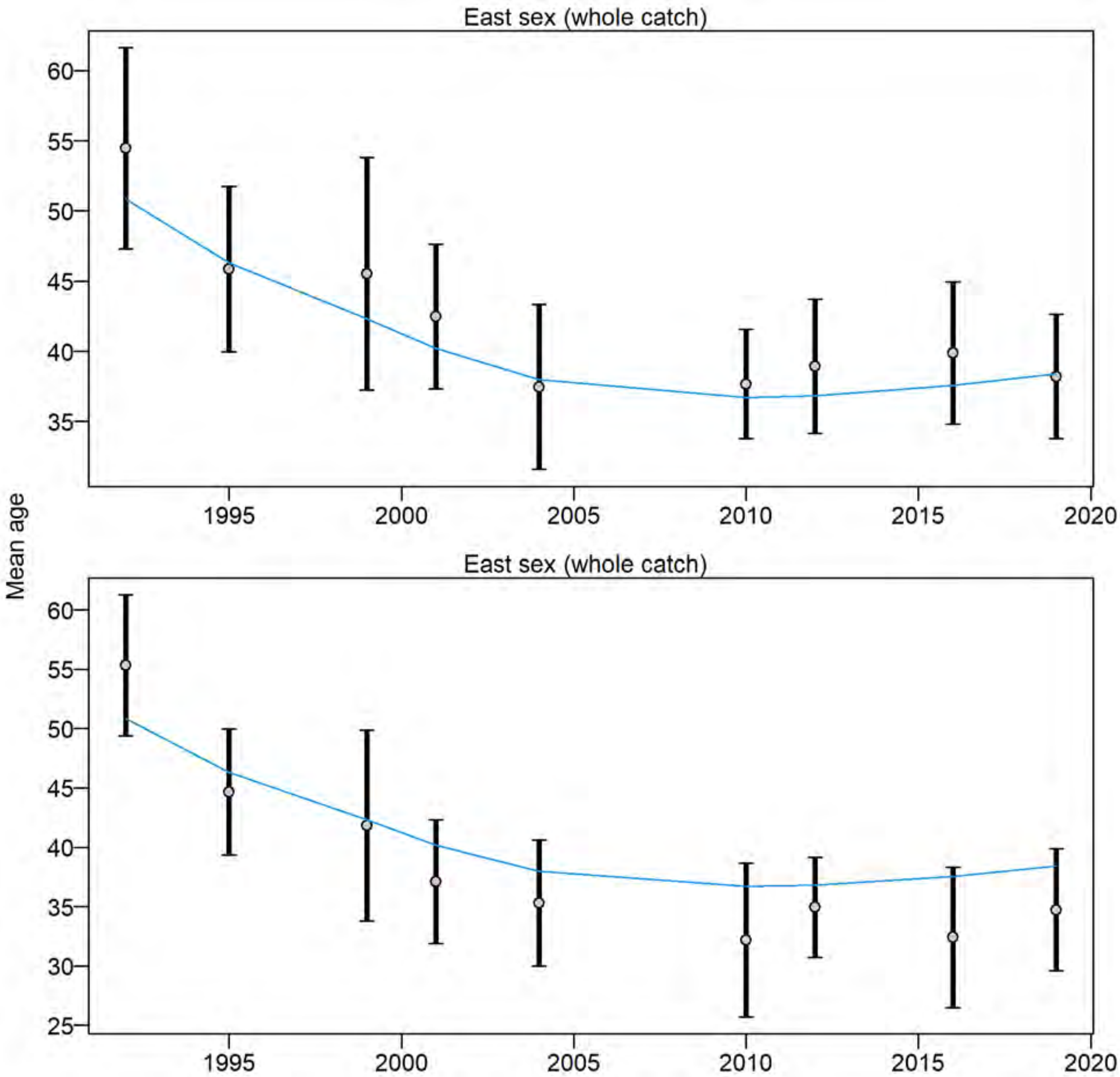


Figure A 9.11. Mean age for male and female samples with 95% confidence intervals based on current samples sizes for the 2021 preliminary base-case model with a plus-group at 80 years and *M* estimated. Suggested multiplier for Francis data weighting method TA1.8 of age data with 95% interval is 1.0002 (0.7479-1.8131).

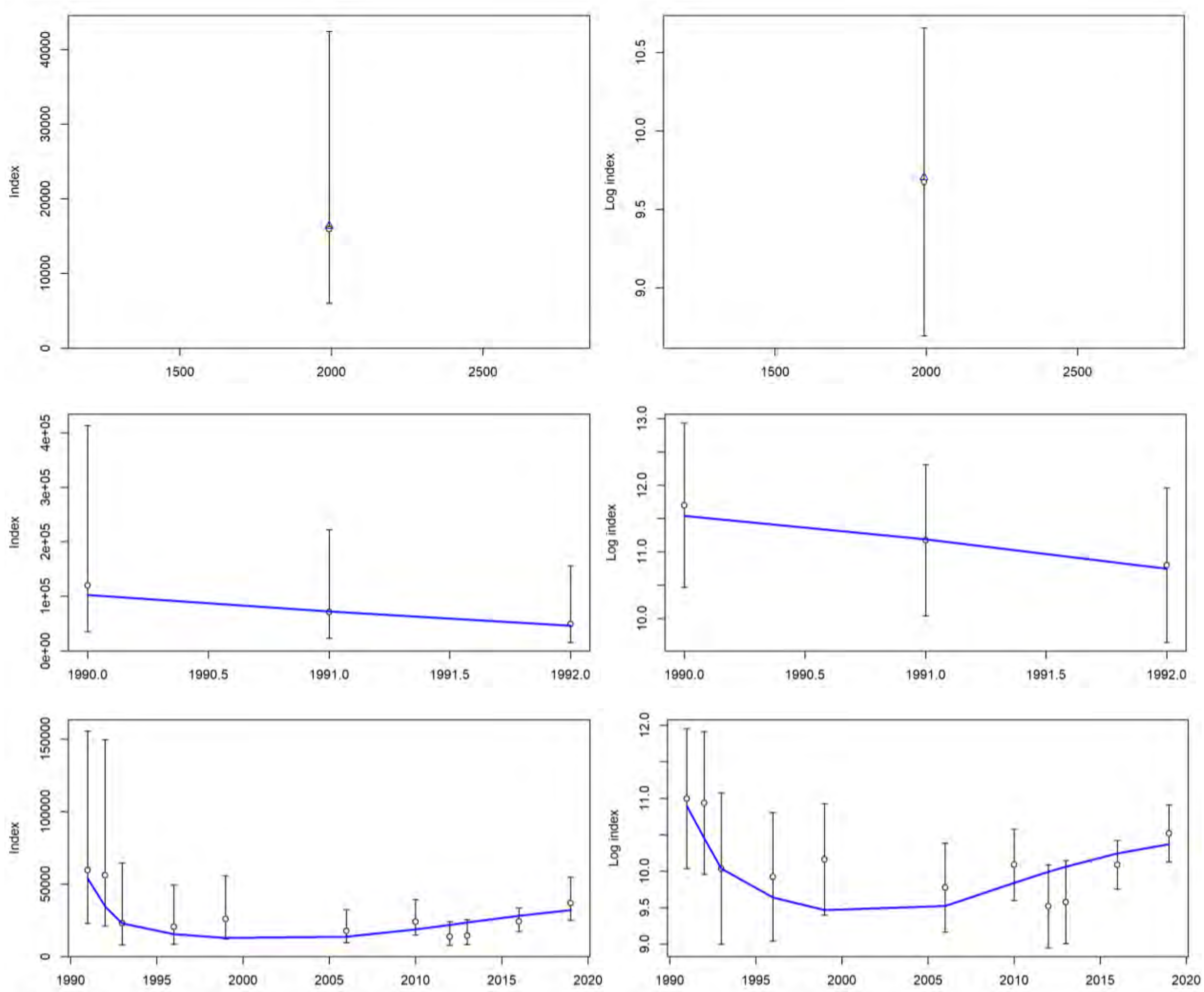


Figure A 9.12. Fits to the biomass indices (left) and log indices (right) for the egg (top), hull (middle) and towed (bottom) surveys for the 2021 preliminary base-case model with a plus-group at 80 years and *M* estimated.

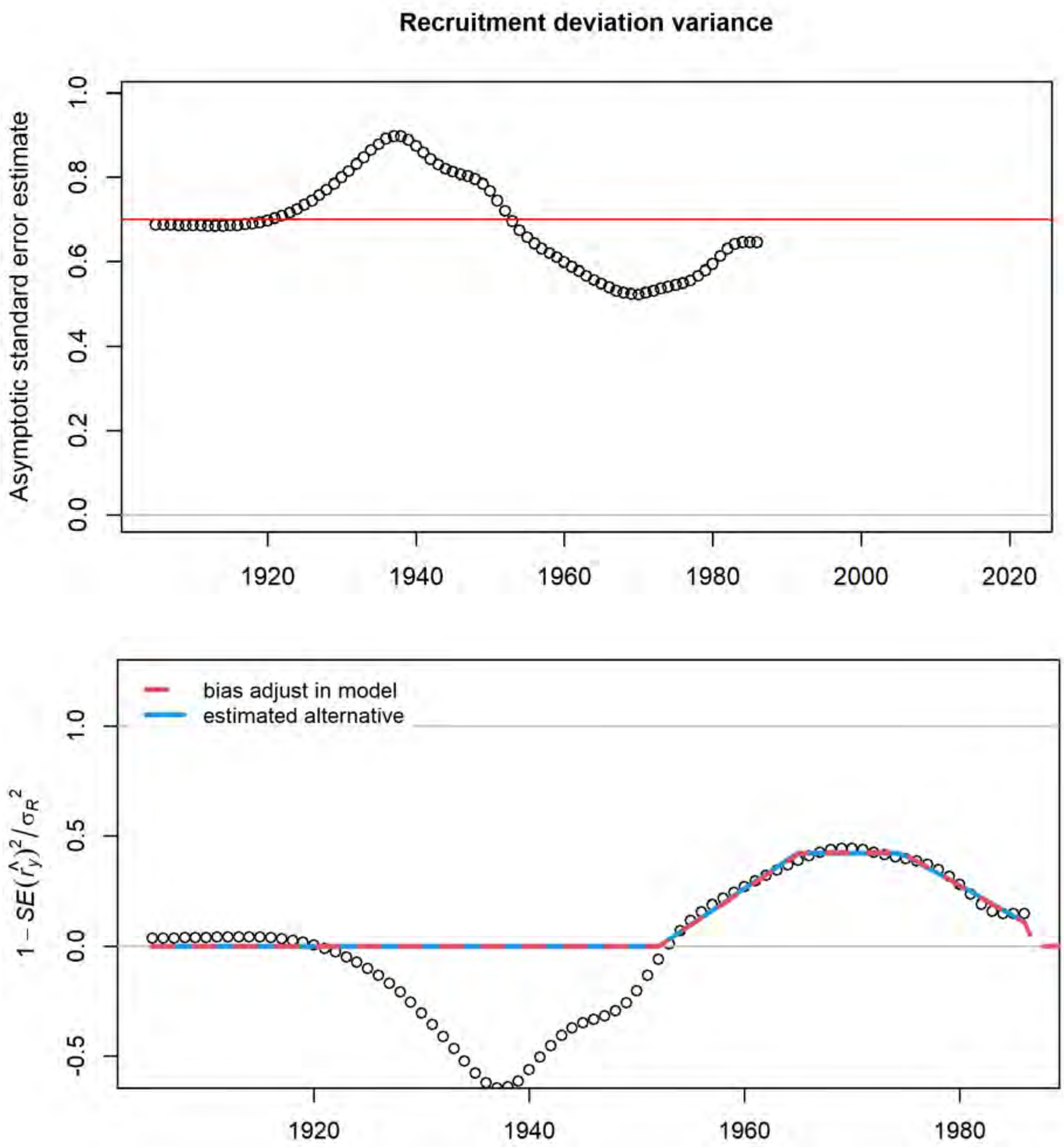


Figure A 9.13. Recruitment deviation variance check (top) and bias ramp adjustment (bottom) for the 2021 preliminary base-case model with a plus-group at 80 years and *M* estimated.

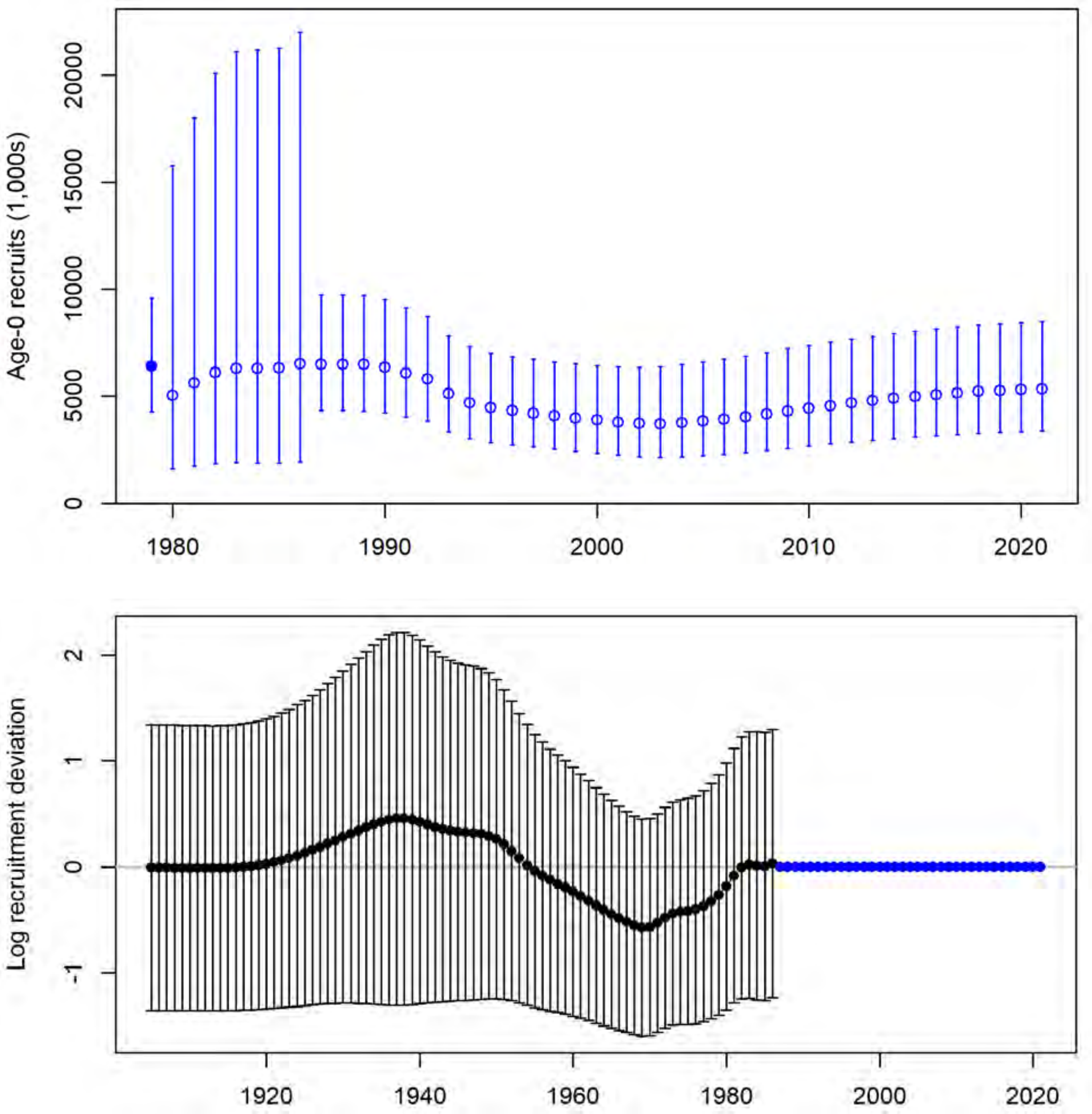


Figure A 9.14. Time series showing absolute recruitment estimates with confidence intervals (top) and recruitment deviations with confidence intervals (bottom) for the 2021 preliminary base-case model with a plus-group at 80 years and *M* estimated.

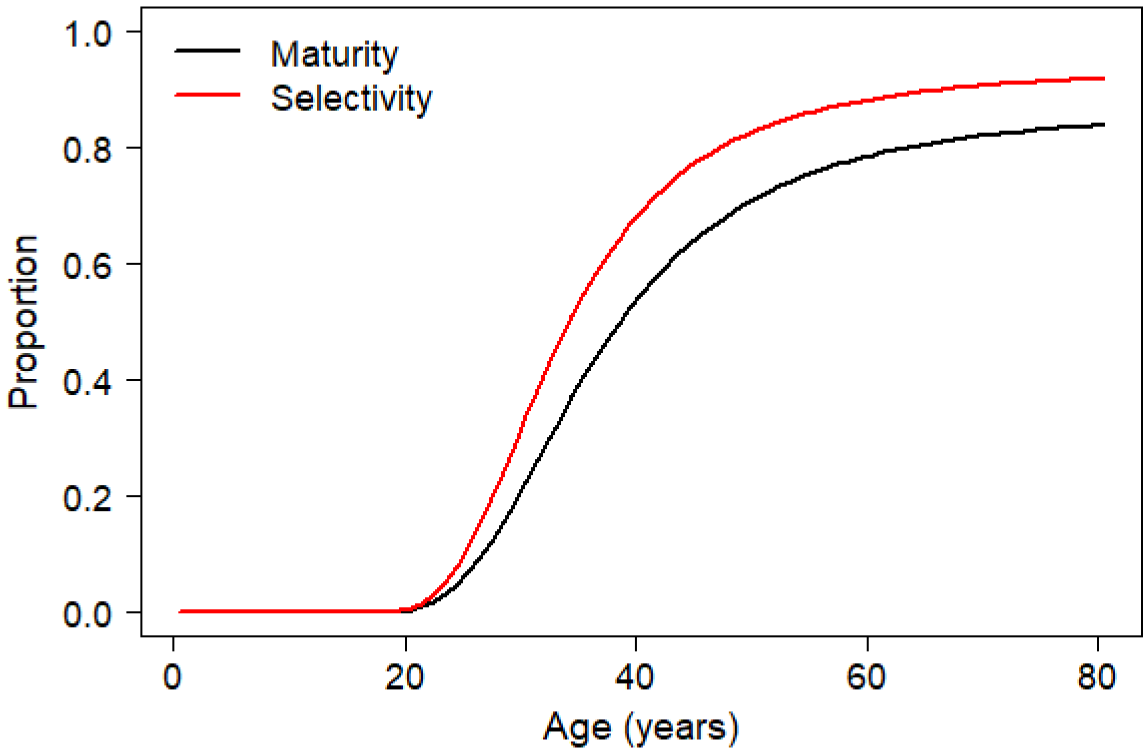


Figure A 9.15. Estimated selectivity and fixed maturity for the 2021 preliminary base-case model with a plus-group at 80 years and *M* estimated.

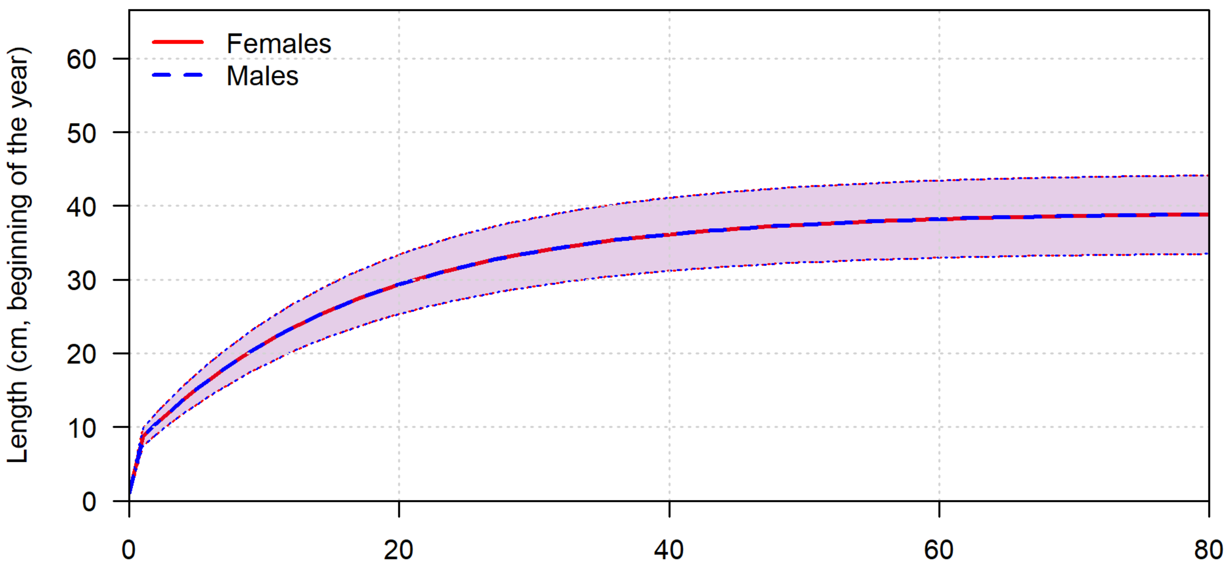


Figure A 9.16. Growth for the 2021 preliminary base-case model with 80 age-classes and *M* estimated.

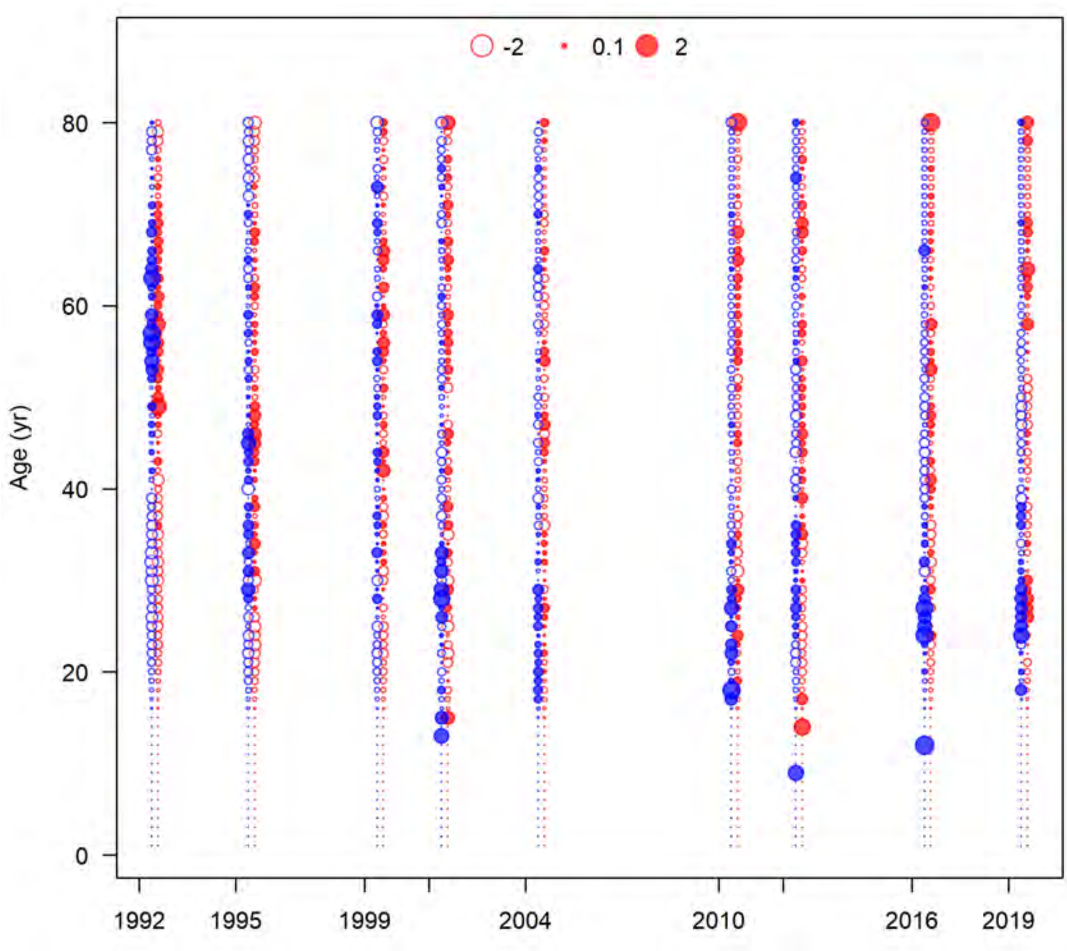


Figure A 9.17. Pearson residuals from the age composition for the 2021 preliminary base-case model with a plus-group at 80 years and *M* estimated.

9.8.6 *Diagnostics for model with 100 age-classes and M estimated*

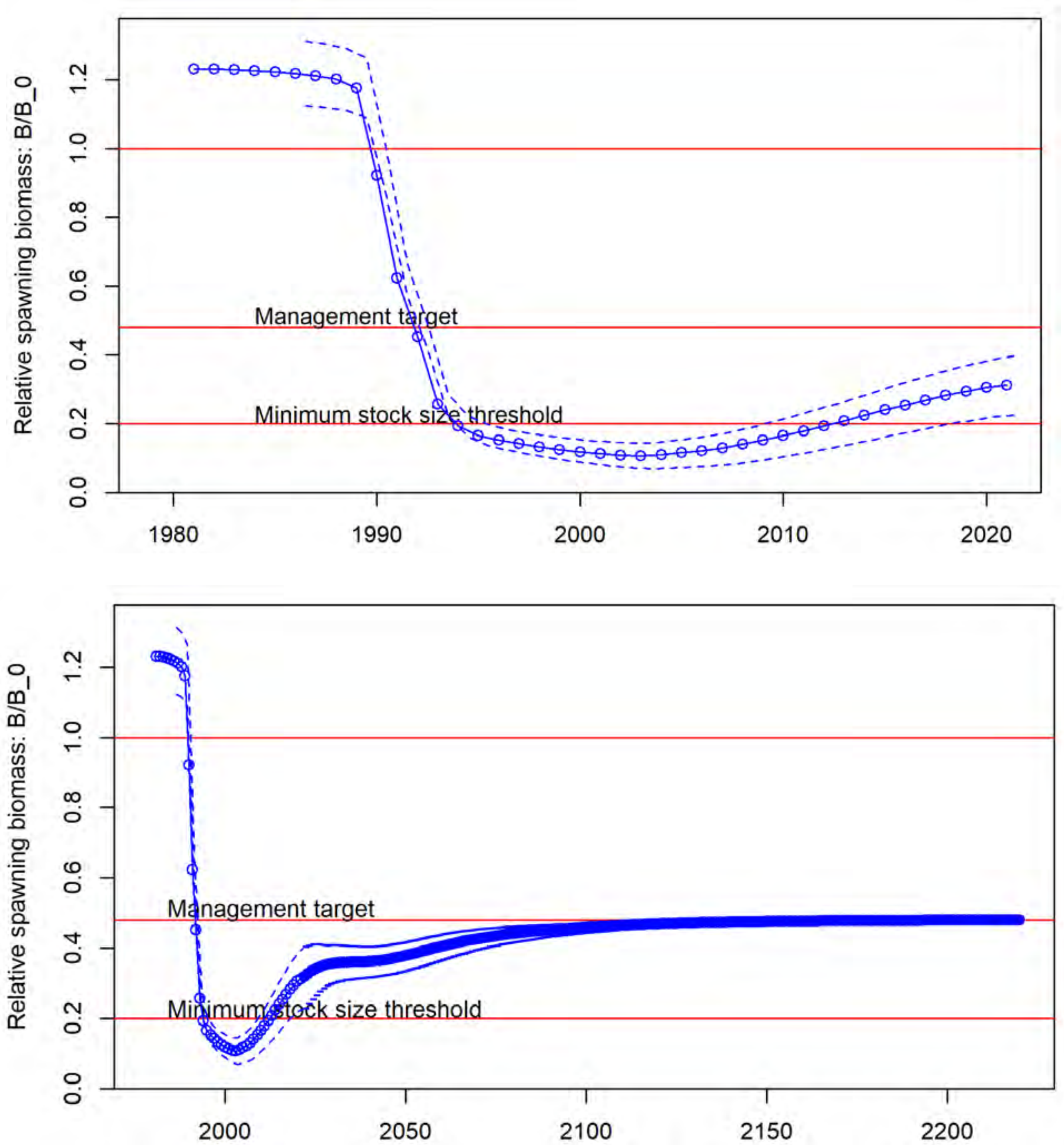


Figure A 9.18. The estimated time-series of relative spawning biomass with asymptotic 95% confidence intervals (top) and forecast 200 years into the future with catches set using the SESSF 20:35:48 harvest control rule (bottom) for the 2021 preliminary base-case model with a plus-group at 100 years and *M* estimated.

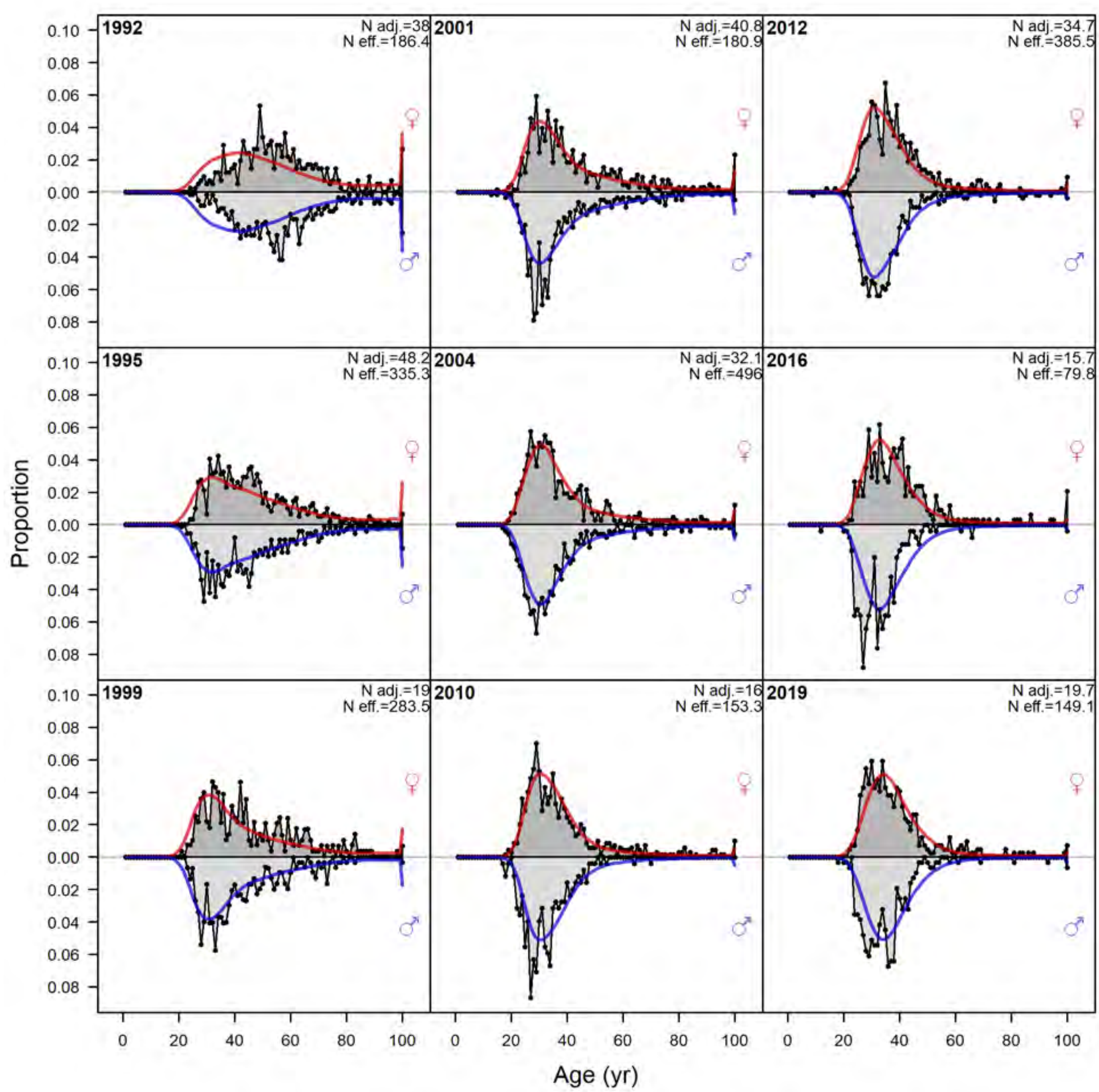


Figure A 9.19. Fits to the age composition data for the 2021 preliminary base-case model with a plus-group at 100 years and *M* estimated.

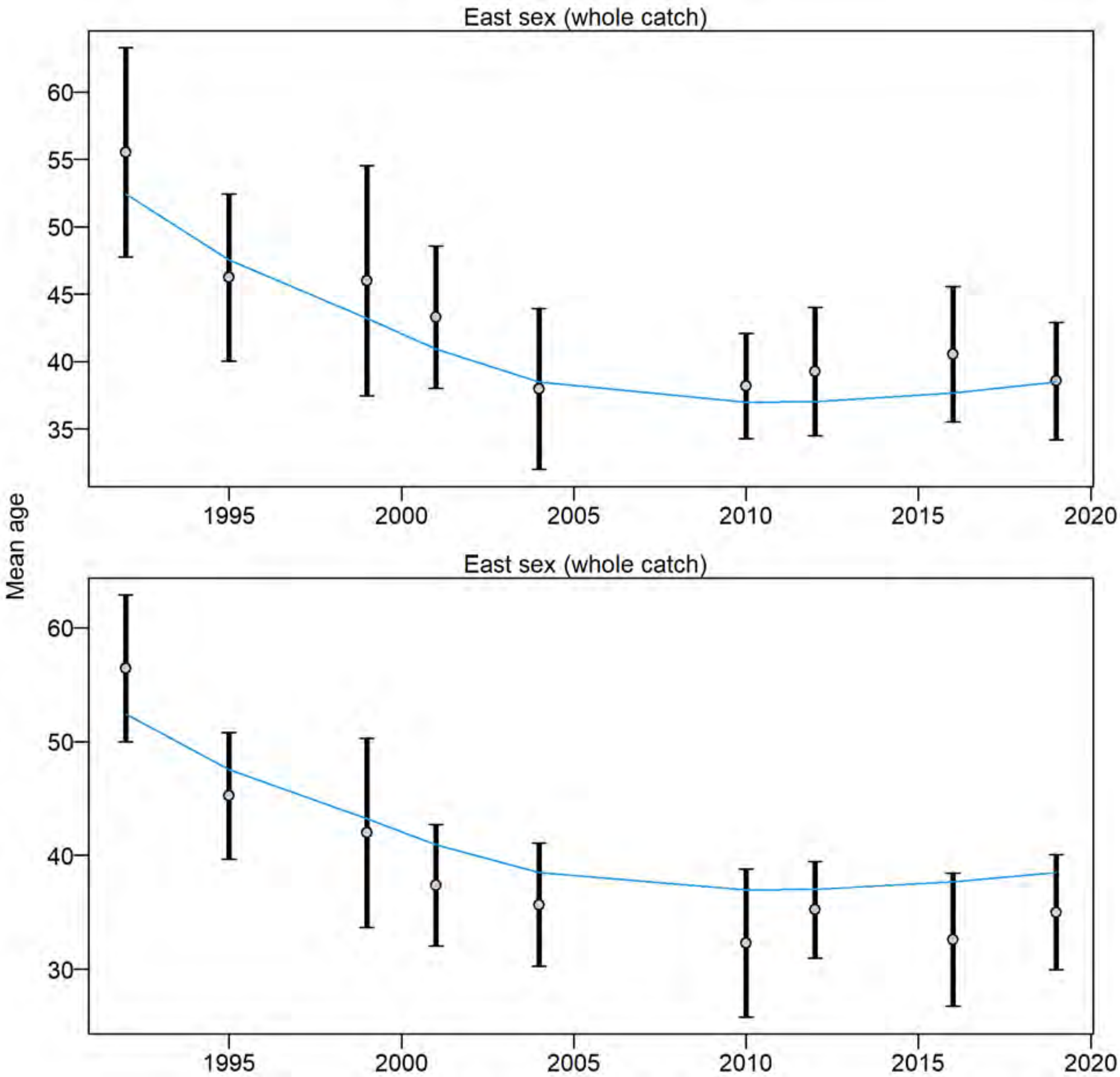


Figure A 9.20. Mean age for male and female samples with 95% confidence intervals based on current samples sizes for the 2021 preliminary base-case model with a plus-group at 100 years and *M* estimated. Suggested multiplier for Francis data weighting method TA1.8 of age data with 95% interval is 1.0014 (0.7852-1.7022).

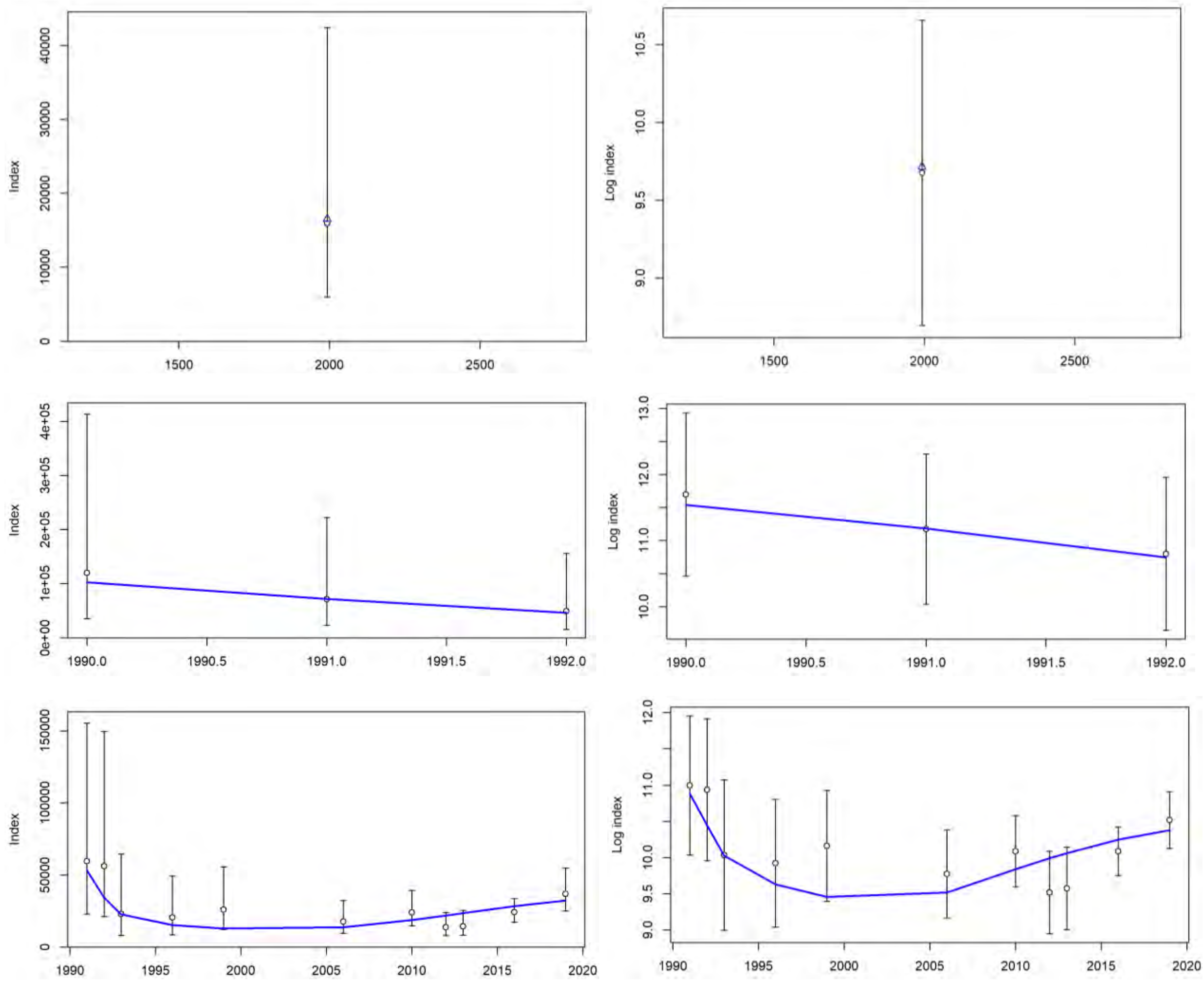


Figure A 9.21. Fits to the biomass indices (left) and log indices (right) for the egg (top), hull (middle) and towed (bottom) surveys for the 2021 preliminary base-case model with a plus-group at 100 years and *M* estimated.

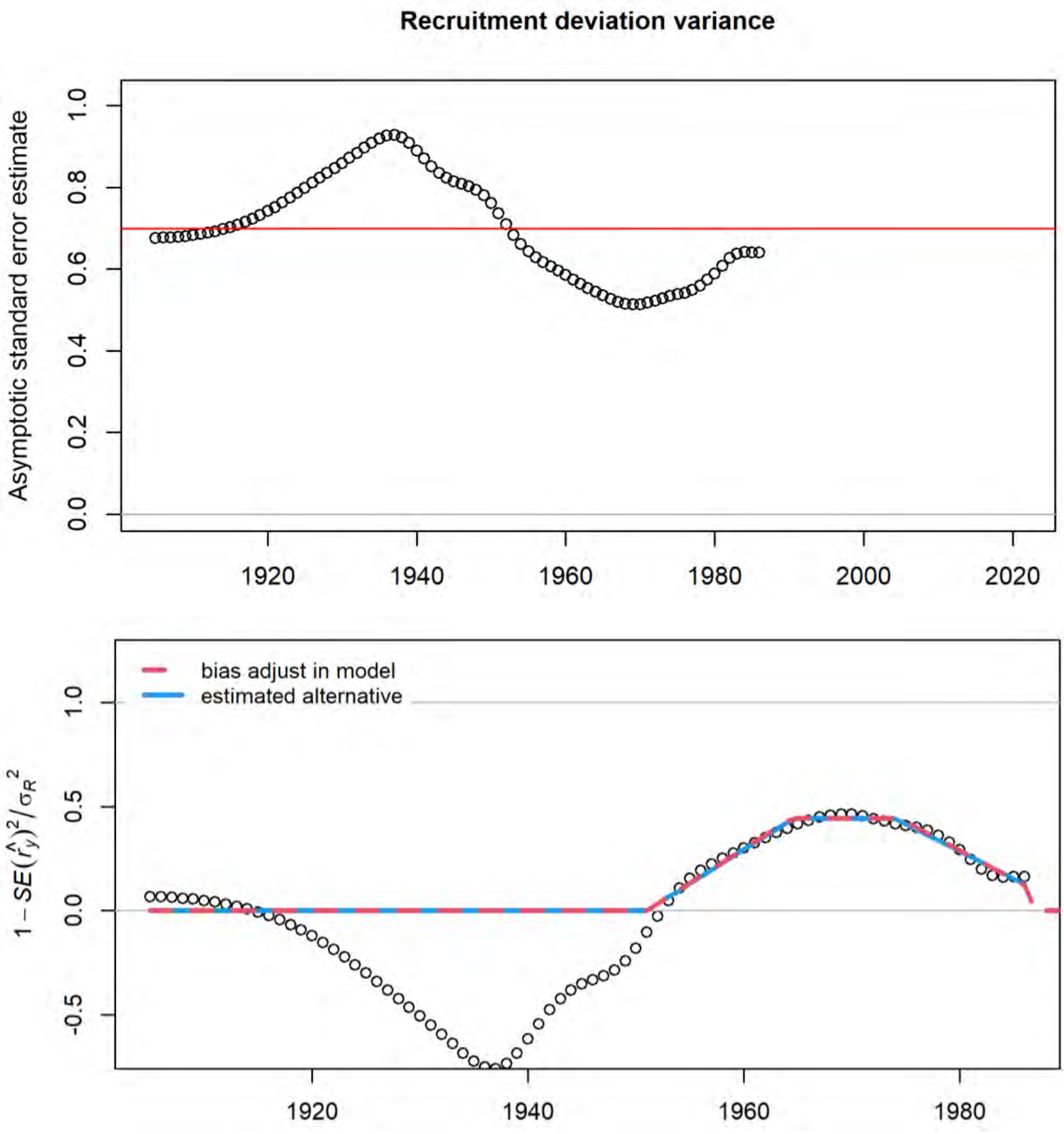


Figure A 9.22. Recruitment deviation variance check and bias ramp adjustment for the 2021 preliminary base-case model with a plus-group at 100 years and *M* estimated.

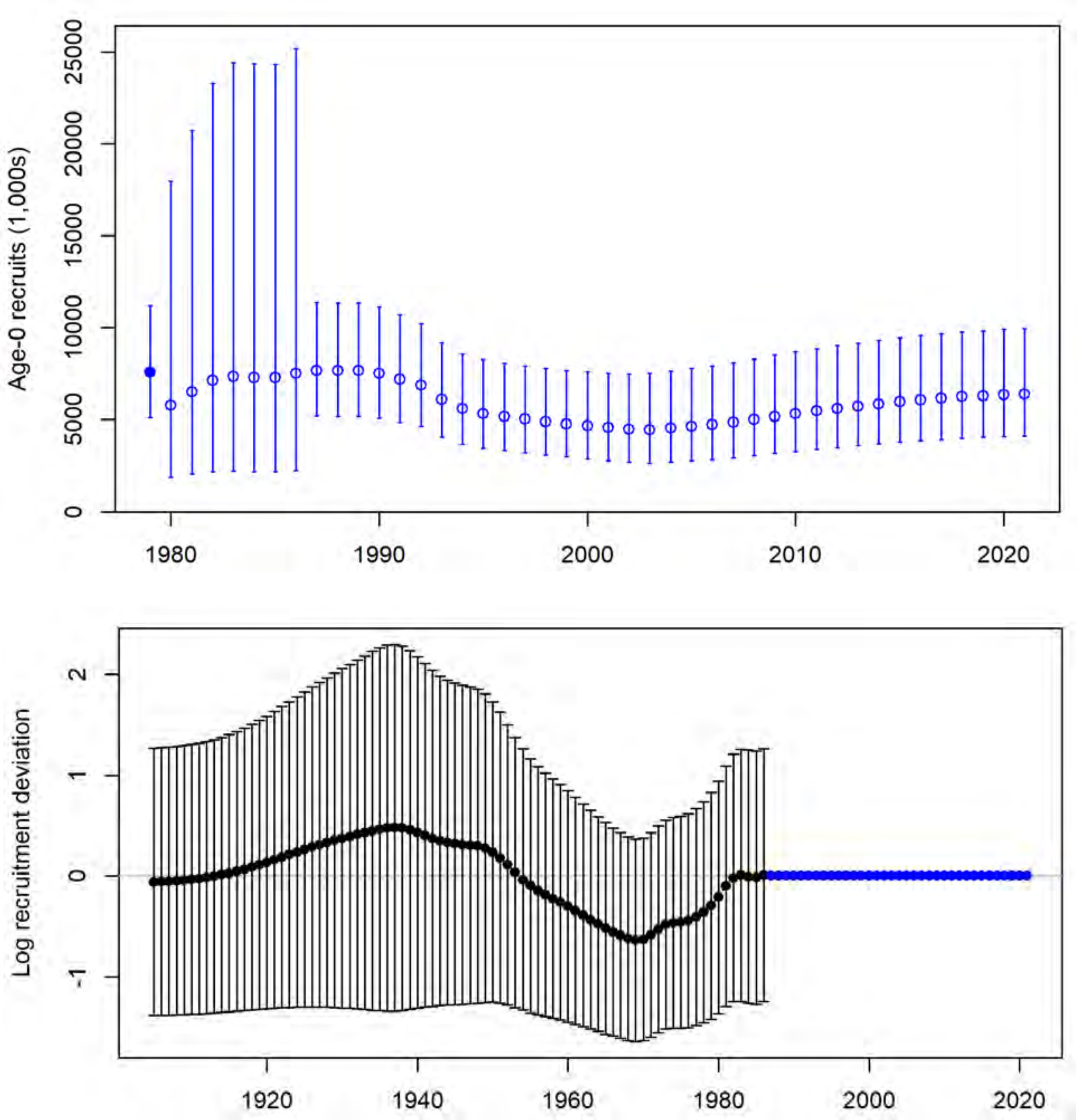


Figure A 9.23. Time series showing absolute recruitment estimates with confidence intervals (top) and recruitment deviations with confidence intervals (bottom) for the 2021 preliminary base-case model with a plus-group at 100 years and *M* estimated.

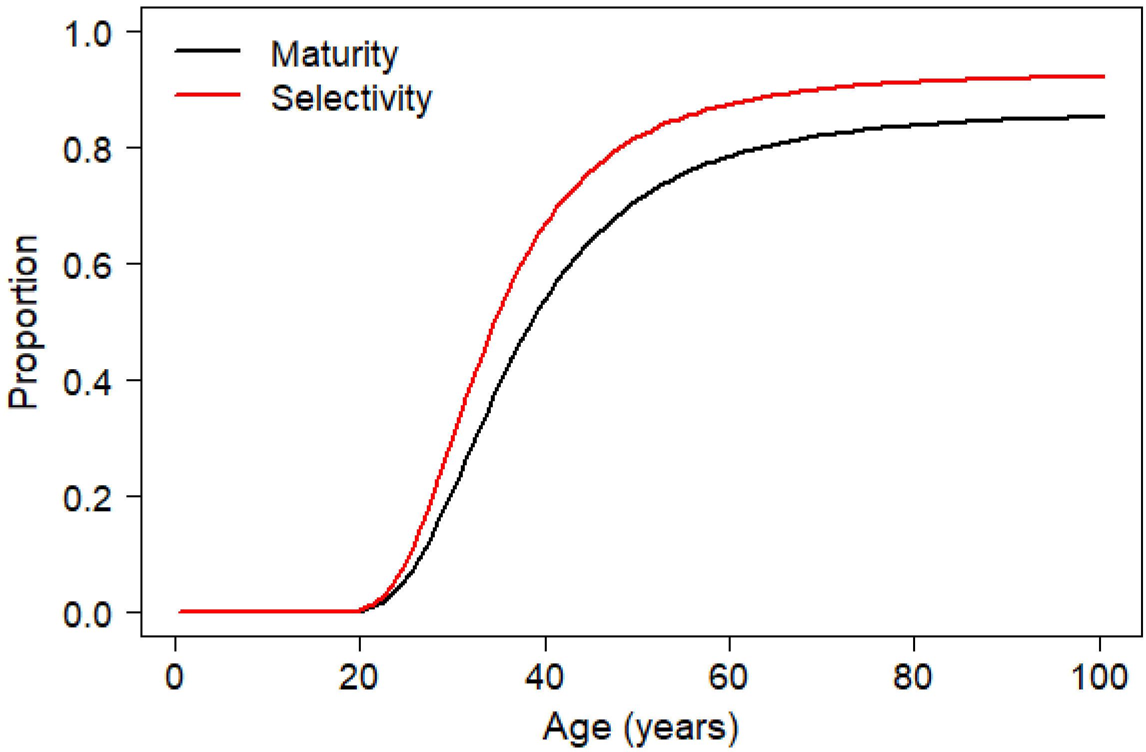


Figure A 9.24. Estimated selectivity and fixed maturity for the 2021 preliminary base-case model with a plus-group at 100 years and *M* estimated. Note maturity and selectivity are not independent above age 80.

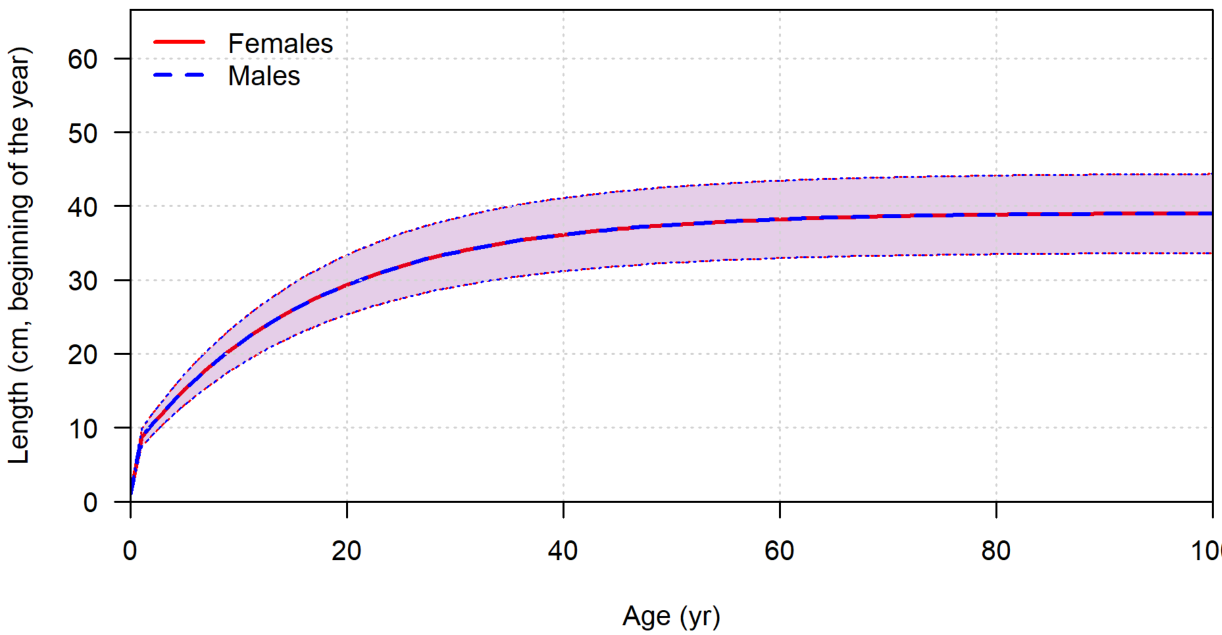


Figure A 9.25. Growth for the 2021 preliminary base-case model with a plus-group at 100 years.

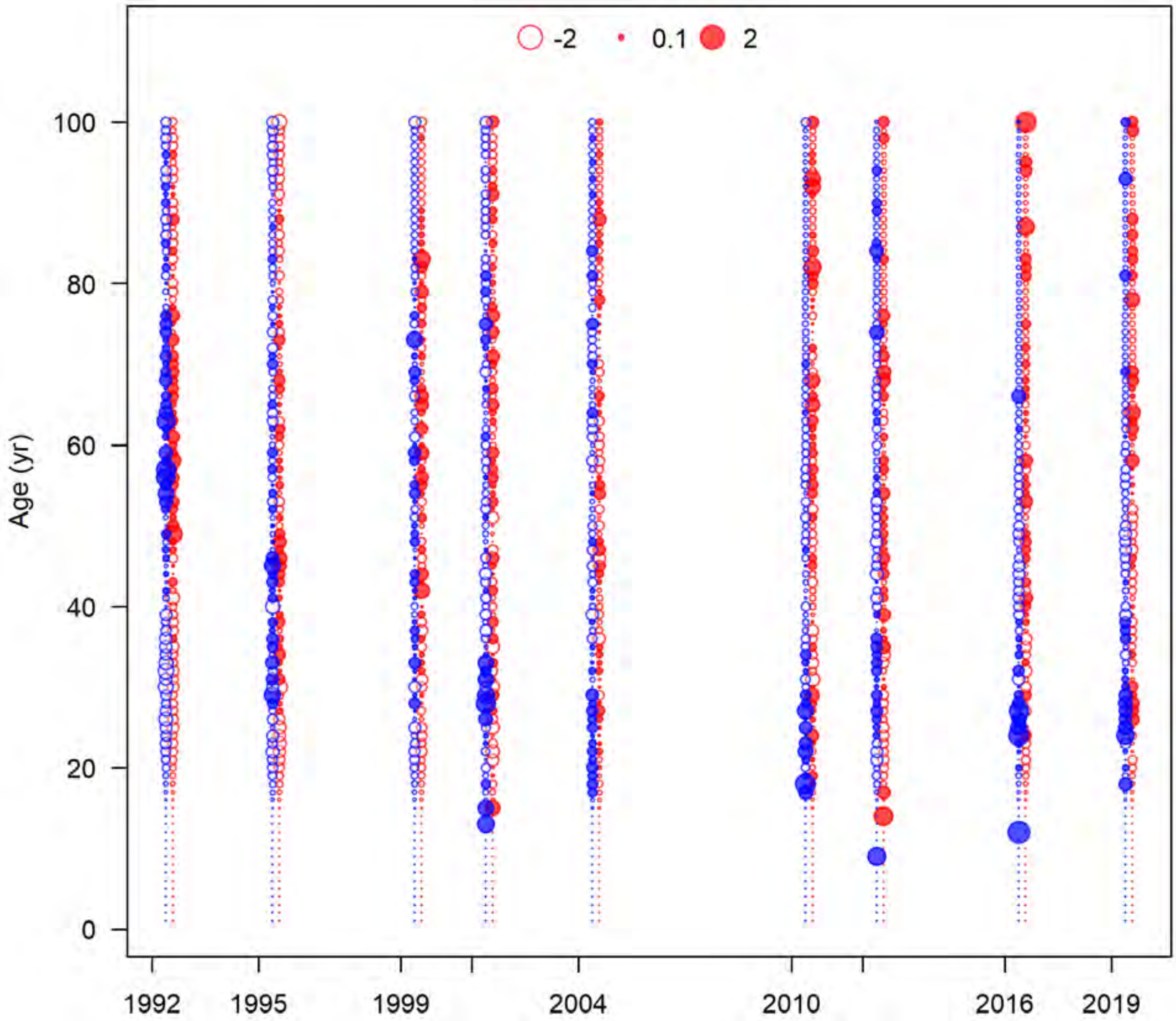
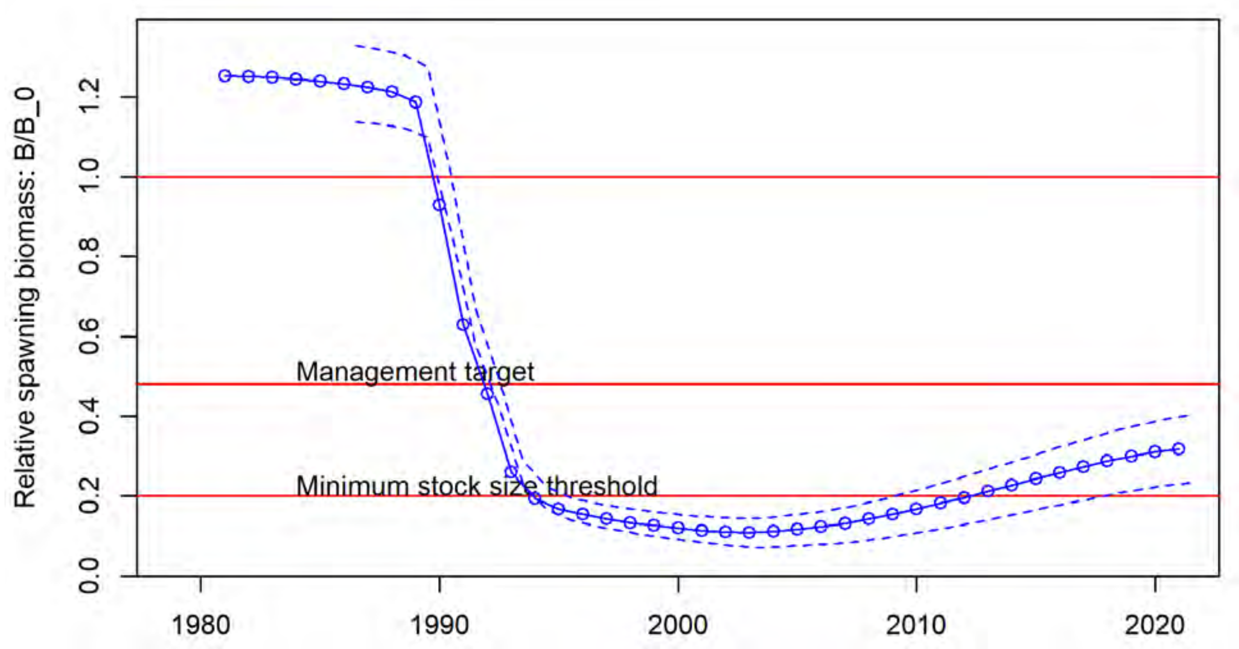


Figure A 9.26. Pearson residuals from the age composition data for the 2021 preliminary base-case model with a plus-group at 100 years and *M* estimated.

9.8.7 *Diagnostics for model with 120 age-classes and M estimated*



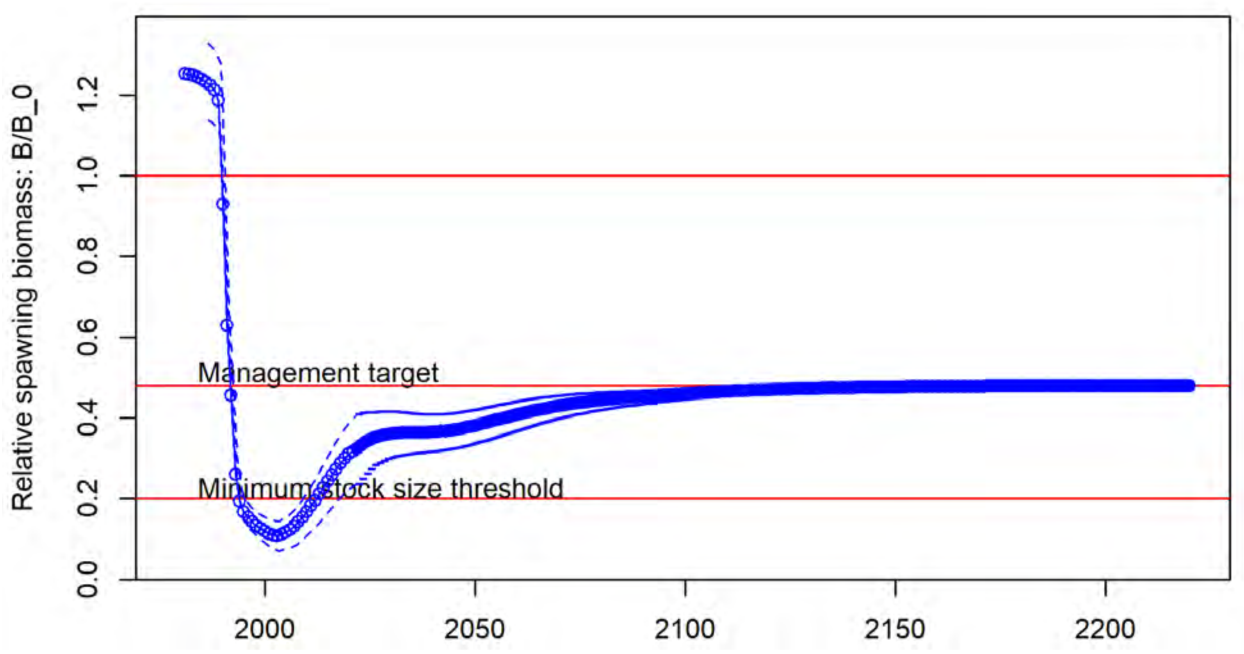


Figure A 9.27. The estimated time-series of relative spawning biomass with asymptotic 95% confidence intervals (top) and forecast 200 years into the future with catches set using the SESSF 20:35:48 harvest control rule (bottom) for the 2021 preliminary base-case model with a plus-group at 120 years and *M* estimated.

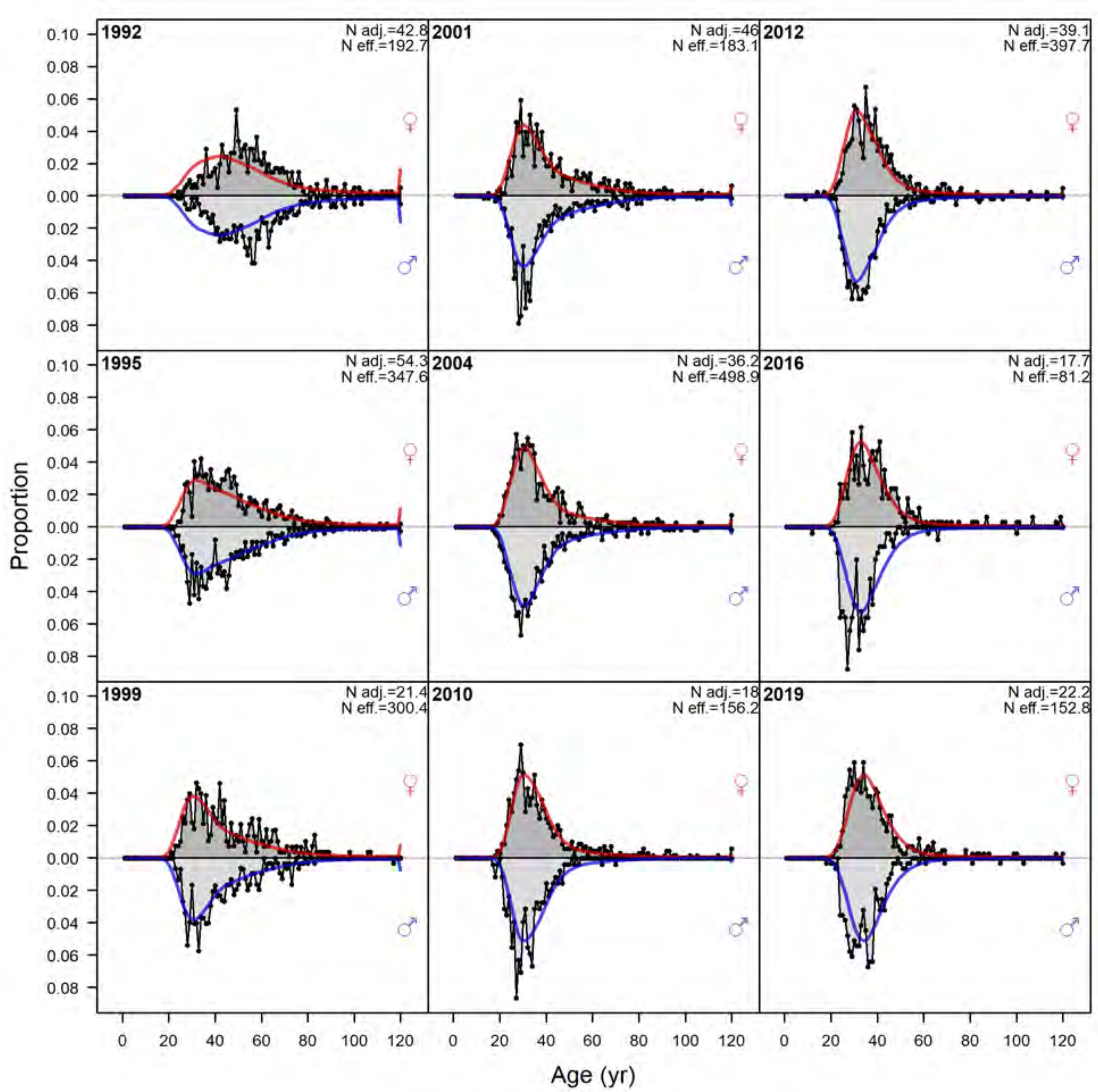


Figure A 9.28. Fits to the age composition data for the 2021 preliminary base-case model with a plus-group at 120 years and *M* estimated.

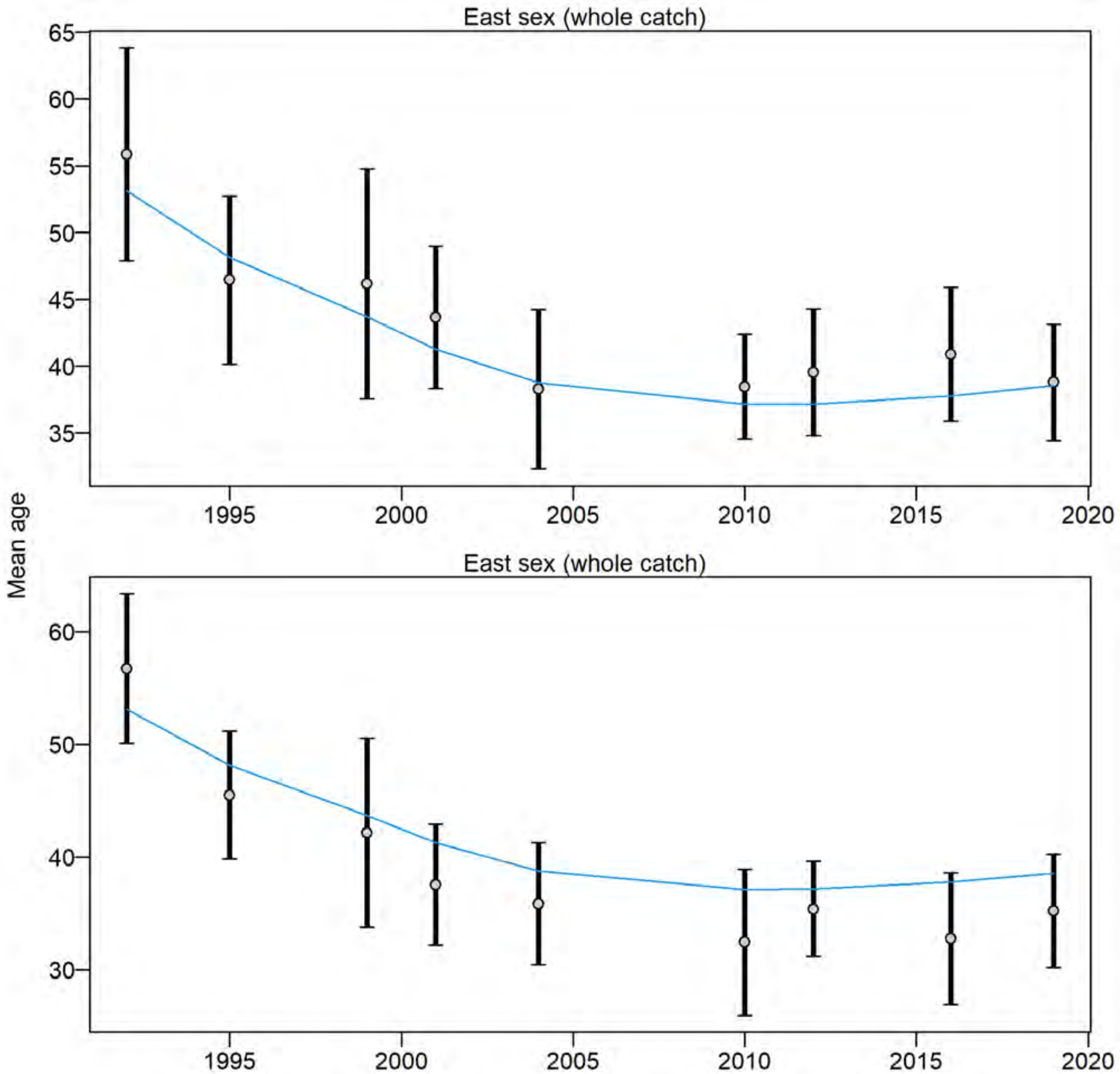


Figure A 9.29. Mean age for male and female samples with 95% confidence intervals based on current samples sizes for the 2021 preliminary base-case model with a plus-group at 120 years and *M* estimated. Suggested multiplier for Francis data weighting method TA1.8 of age data with 95% interval is 1.0022 (0.7615-1.7396).

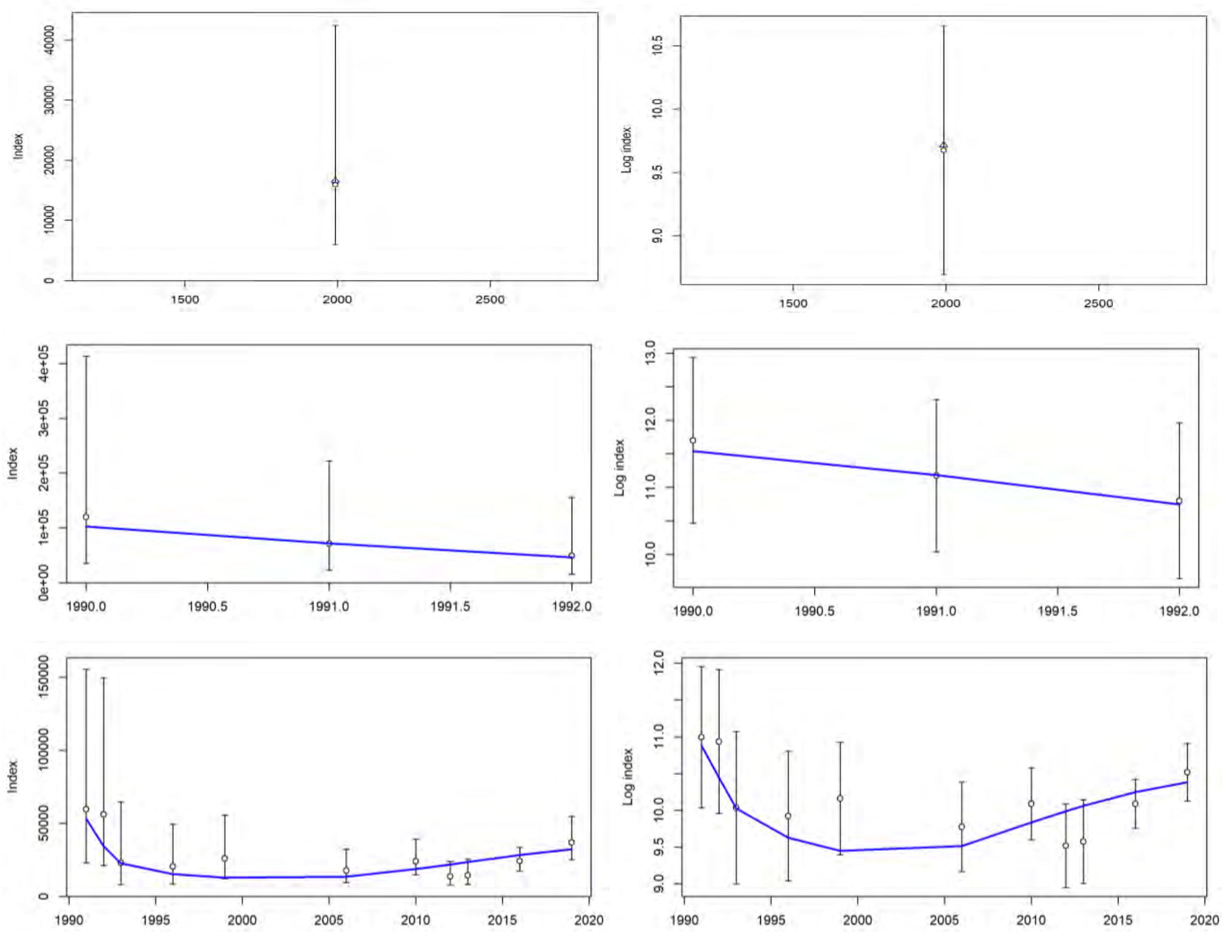


Figure A 9.30. Fits to the biomass indices (left) and log indices (right) for the egg (top), hull (middle) and towed (bottom) surveys for the 2021 preliminary base-case model with a plus-group at 120 years and *M* estimated.

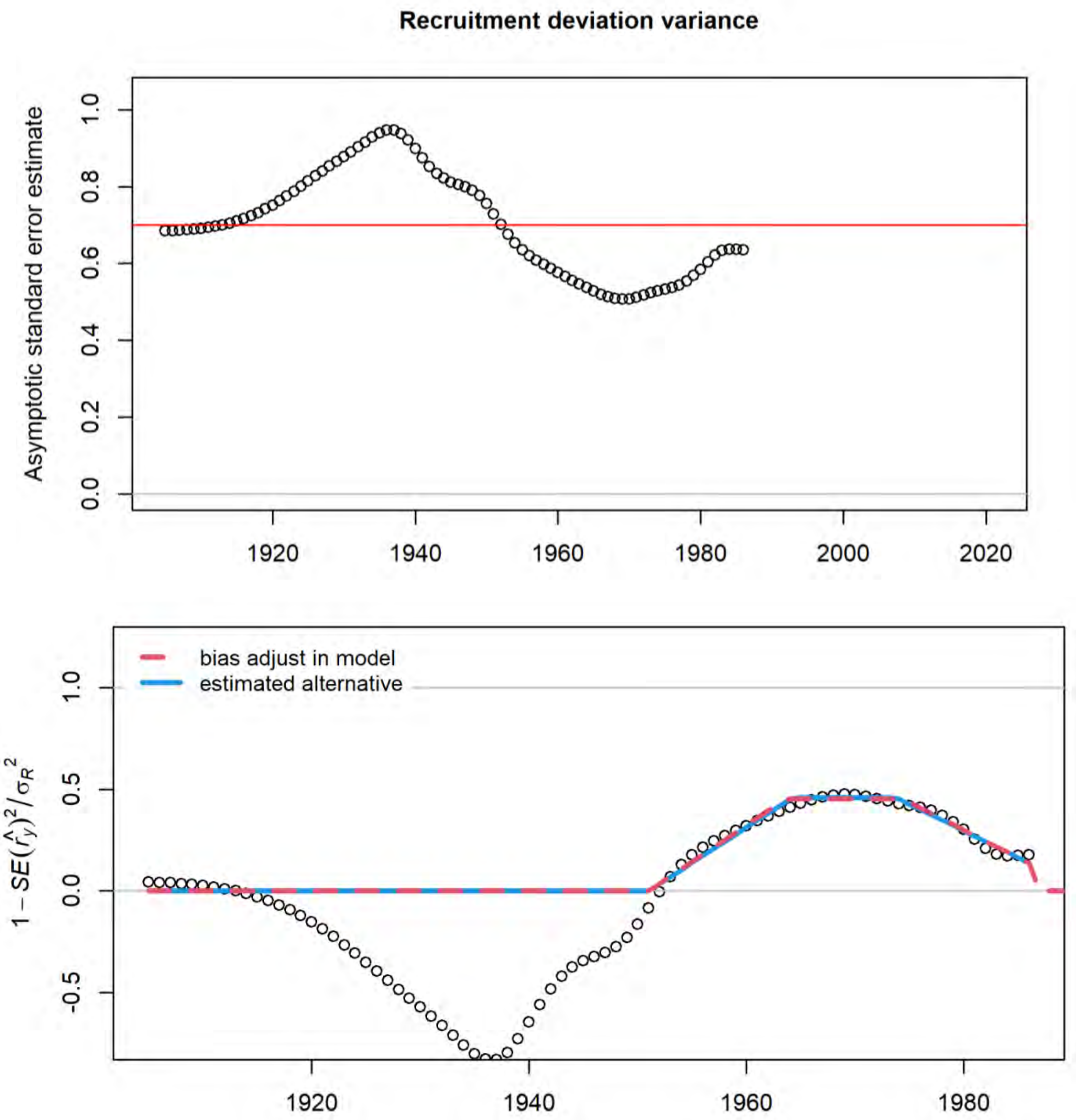


Figure A 9.31. Recruitment deviation variance check and bias ramp adjustment for the 2021 preliminary base-case model with a plus-group at 120 years and *M* estimated.

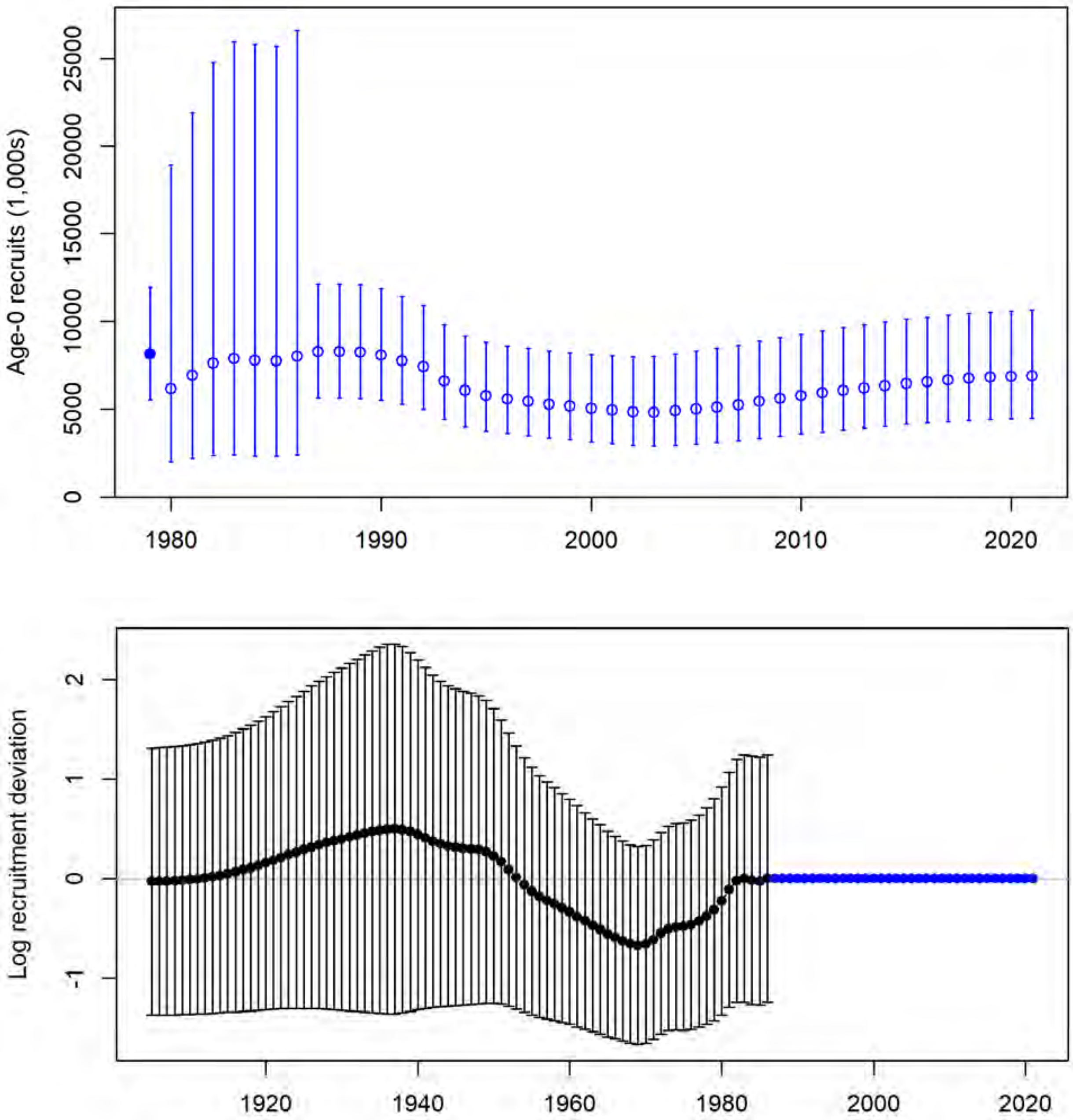


Figure A 9.32. Time series showing absolute recruitment estimates with confidence intervals (top) and recruitment deviations with confidence intervals (bottom) for the 2021 preliminary base-case model with a plus-group at 120 years and *M* estimated.

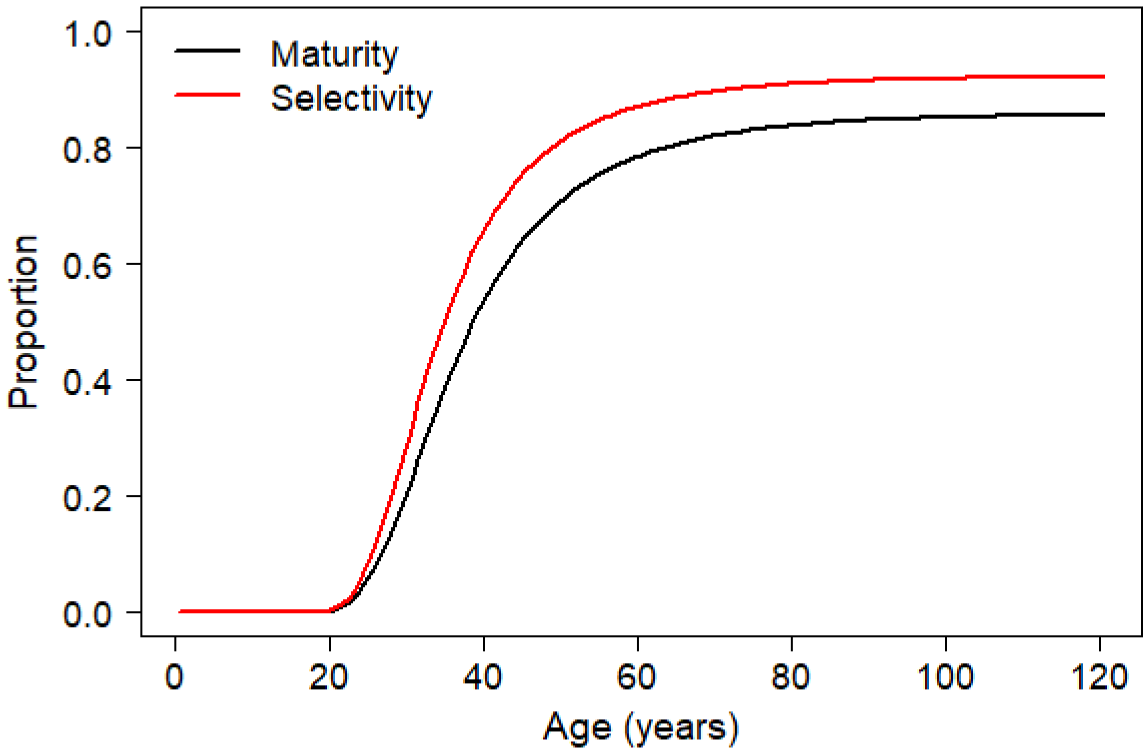


Figure A 9.33. Estimated selectivity and fixed maturity for the 2021 preliminary base-case model with a plus-group at 120 years and *M* estimated. Note maturity and selectivity are not independent above age 80.

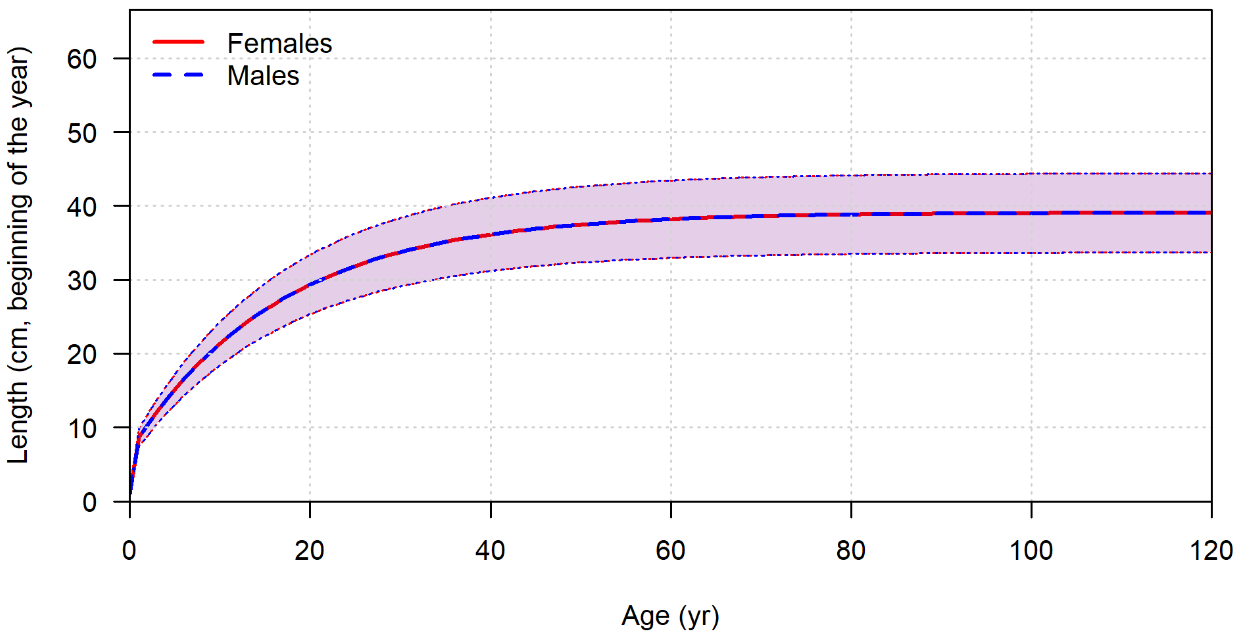


Figure A 9.34. Growth for the 2021 preliminary base-case model with a plus-group at 120 years.

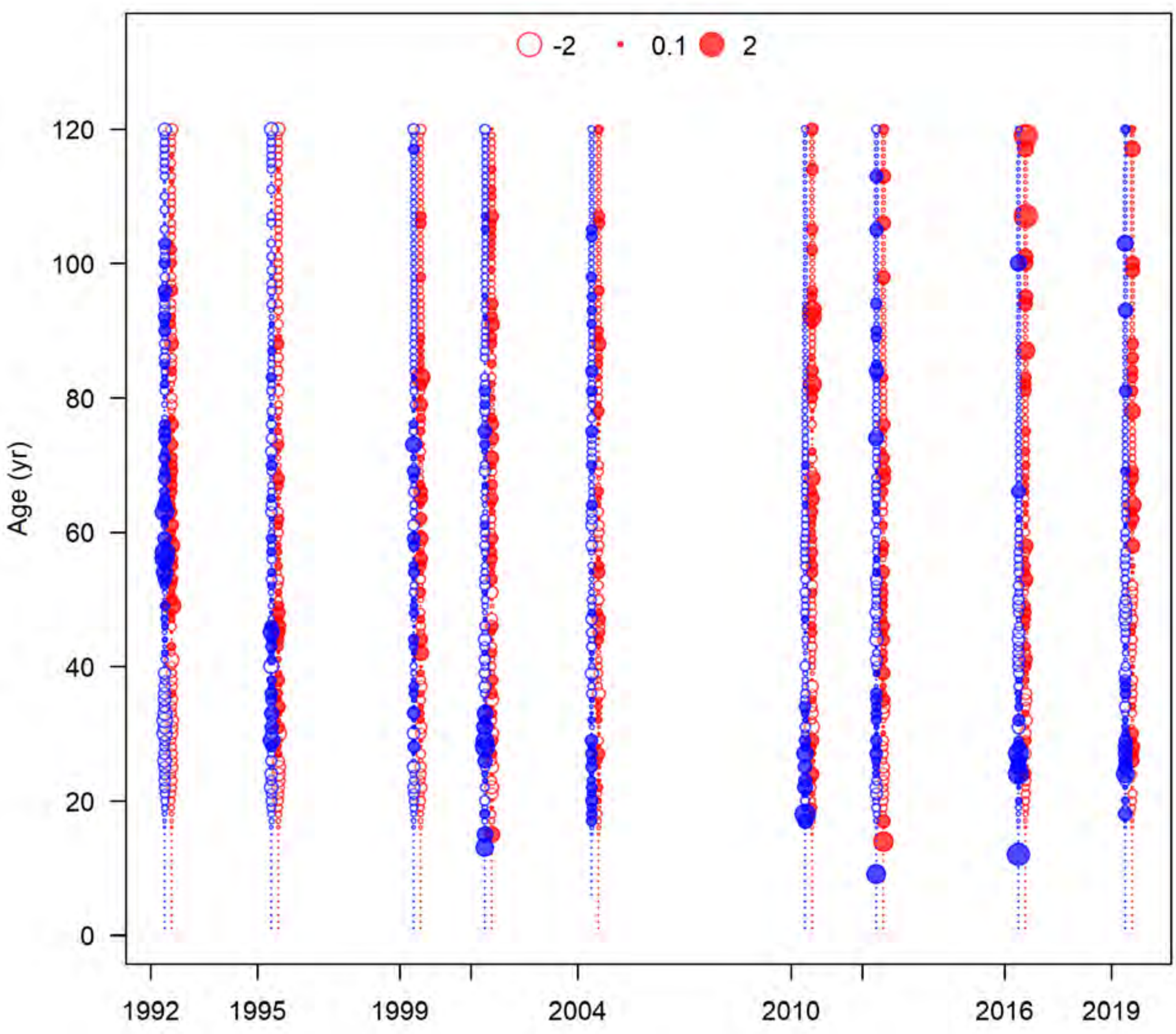


Figure A 9.35. Pearson residuals from the age composition data for the 2021 preliminary base-case model with a plus-group at 120 years and *M* estimated.

10. Eastern zone Orange Roughy (*Hoplostethus atlanticus*) stock assessment based on data up to 2020

Paul Burch[1], Sandra Curin Osorio[1,2] and Pia Bessell-Browne[1]

[1]CSIRO Oceans and Atmosphere, Castray Esplanade, Hobart TAS 7000, Australia
[2]Institute for Marine and Antarctic Studies, University of Tasmania, Hobart TAS 7001, Australia

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).

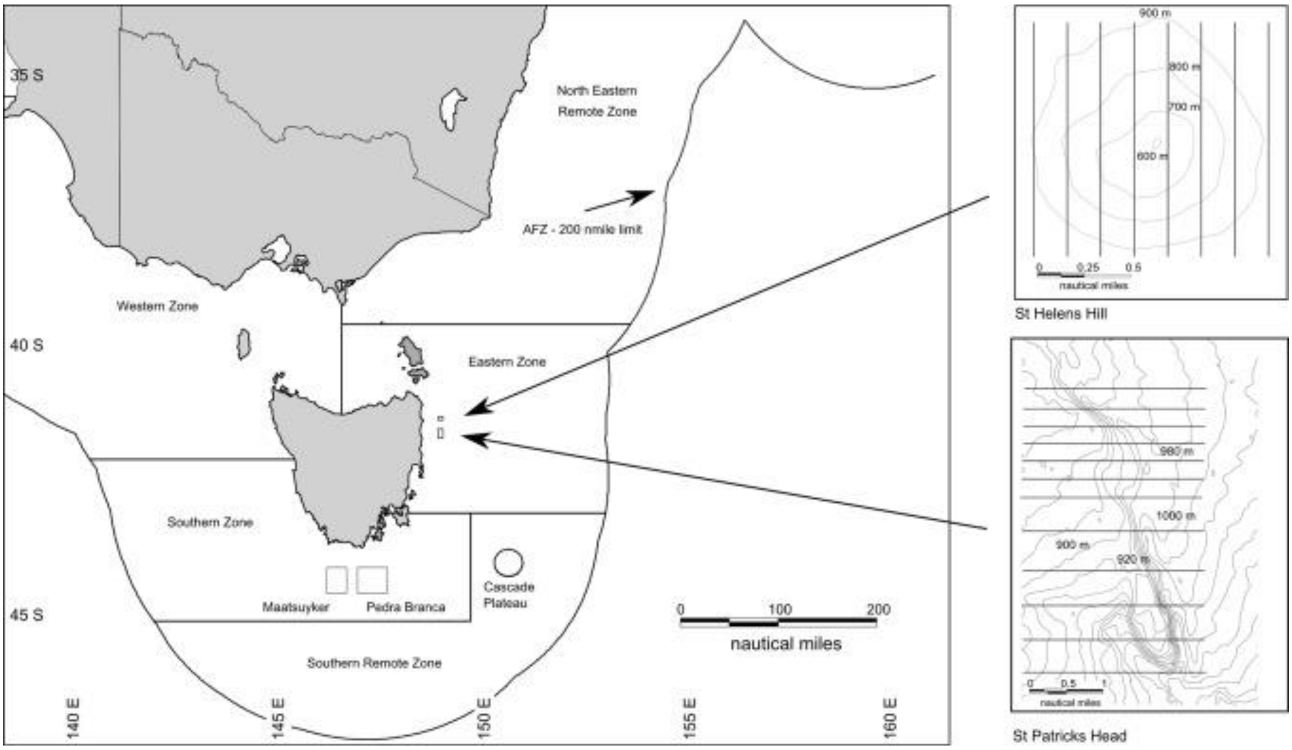


Figure 10.1. Map of Australian Orange Roughy management zones and areas.

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 x 10^{-5}	Female	Lyle et al. (1991)
	3.83 x 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.

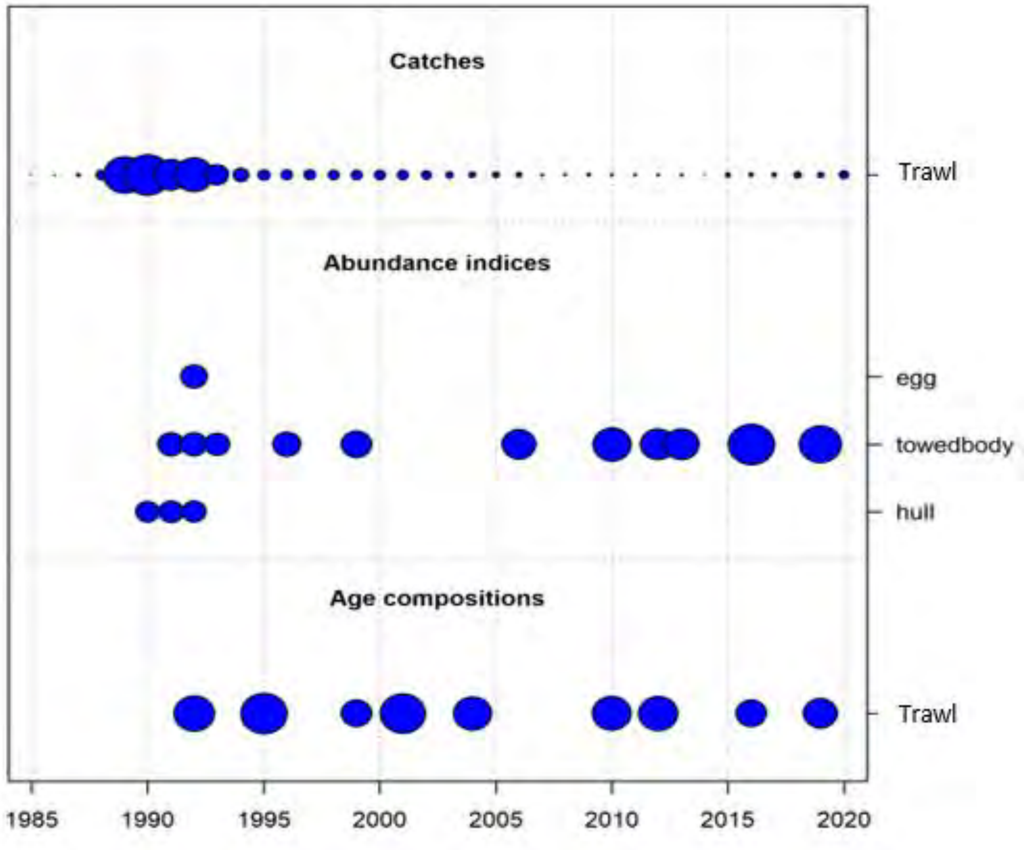


Figure 10.2. Data availability for the eastern zone Orange Roughy assessment by type and year.

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.

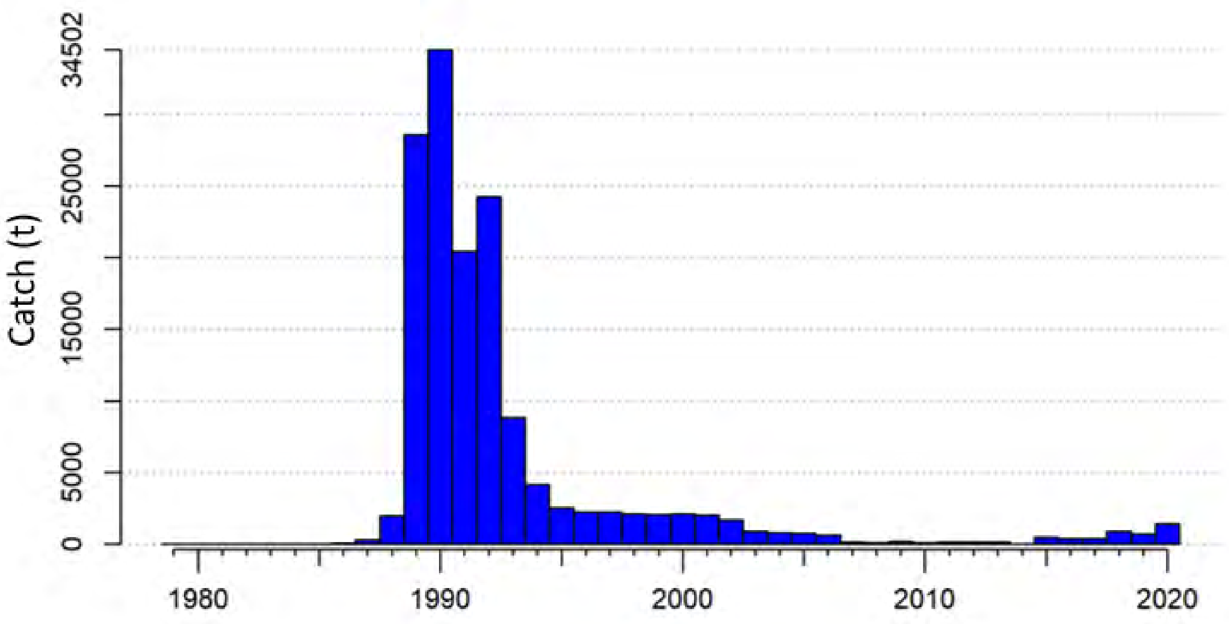


Figure 10.3. Catch, including discards, for the eastern zone Orange Roughy assessment. Catches for 1989–1994 incorporate adjustments for the proportion lost due to lost gear and burst bags/burst panels, other losses, and misreporting (Wayte 2007).

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 $\log_e(10^{ts/10})$ ~ 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.

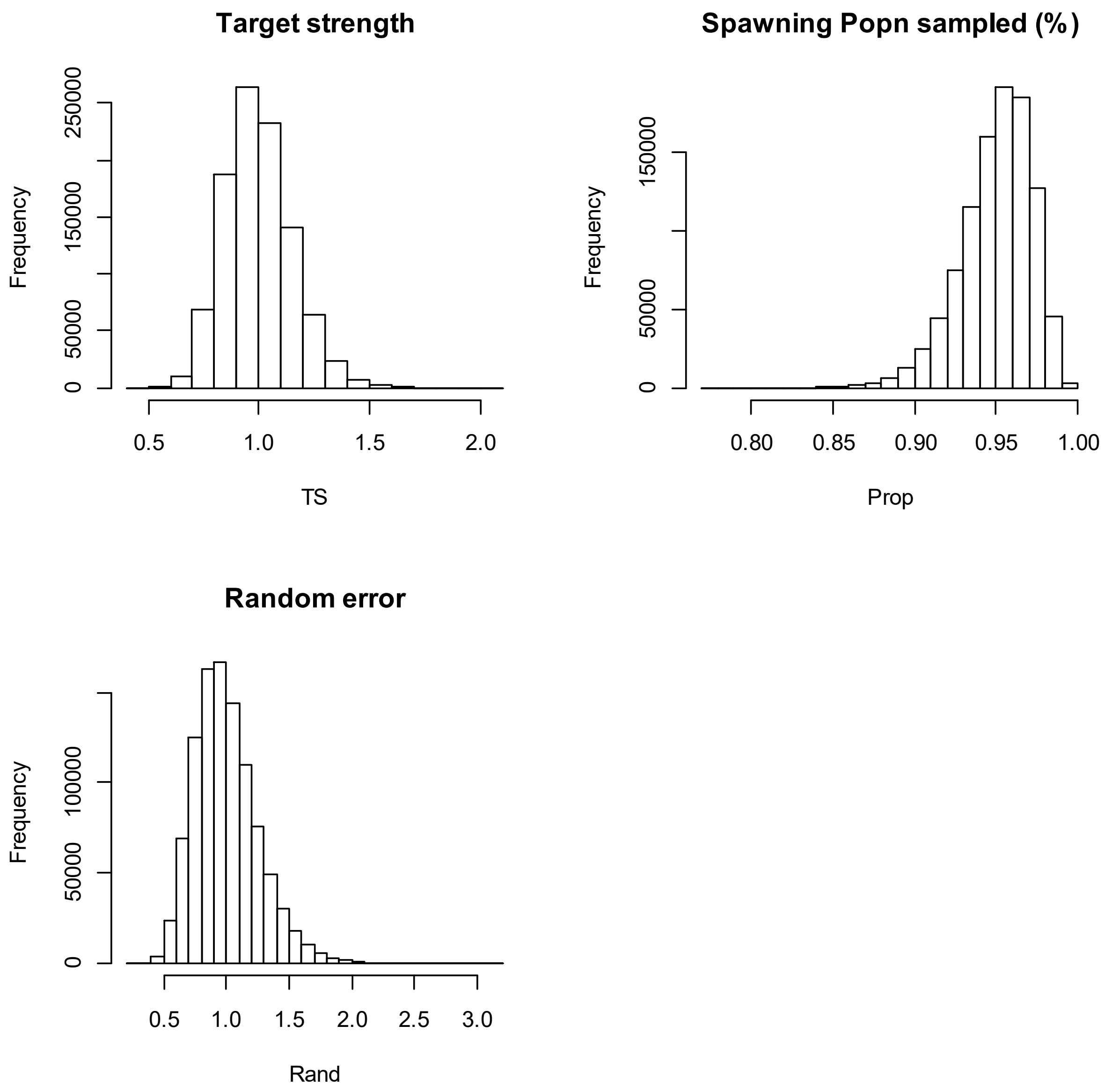


Figure 10.4. Prior component distributions for target strength, spawning population sampled, and random error for acoustics towed (reproduced from Upston et al. 2015).

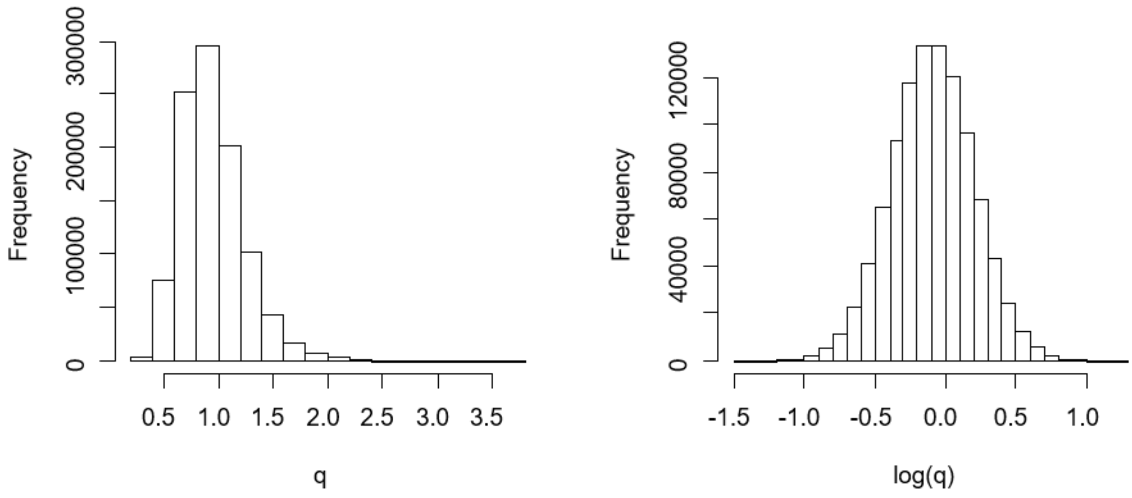


Figure 10.5. Histograms of data used to create priors for *q* and ln(*q*) for acoustics towed (reproduced from Upston et al. 2015).

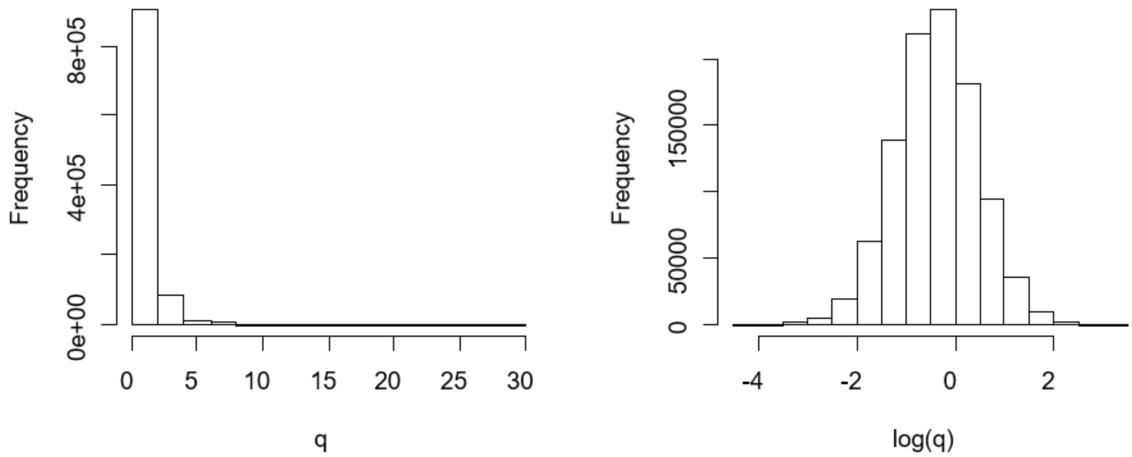


Figure 10.6. Histograms of data used to create priors for *q* and log(*q*) hull. The random error component is greater than that for towed body (reproduced from Upston et al. 2015).

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*.

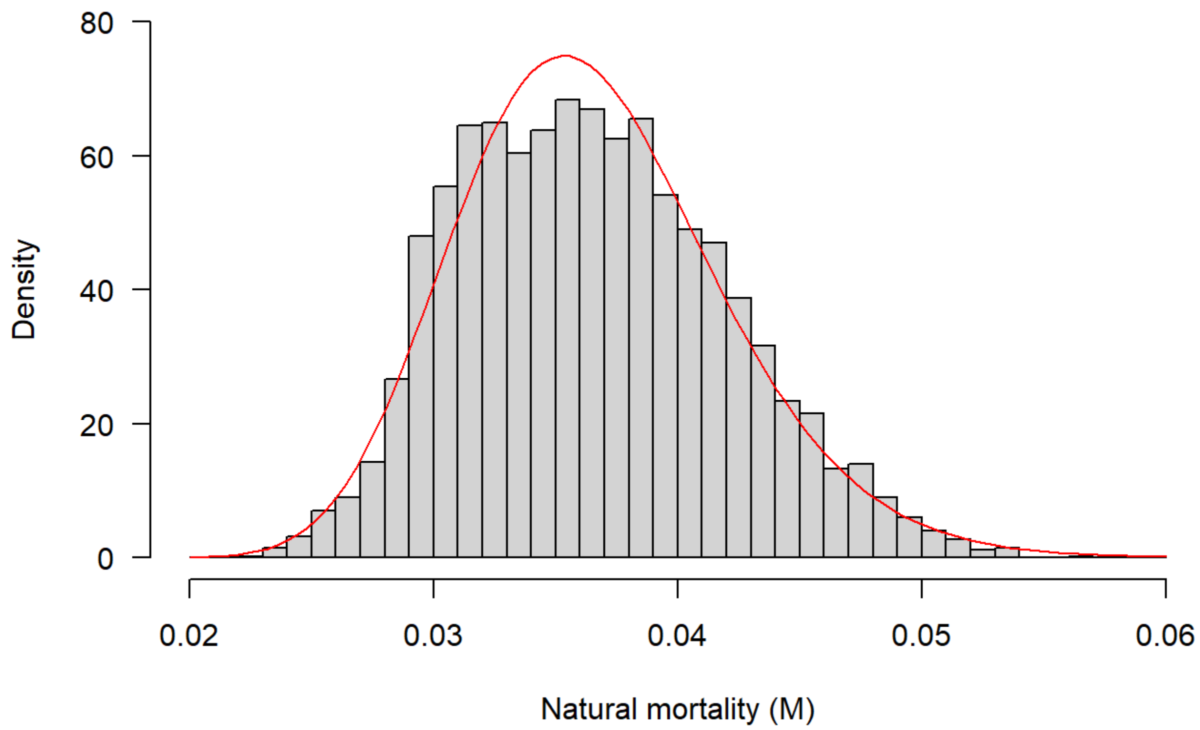


Figure 10.7. Combined posterior of *M* for New Zealand Orange Roughy stock assessments with fitted log-normal distribution. Distribution supplied by Patrick Cordue (ISL).

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 unusual 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**					

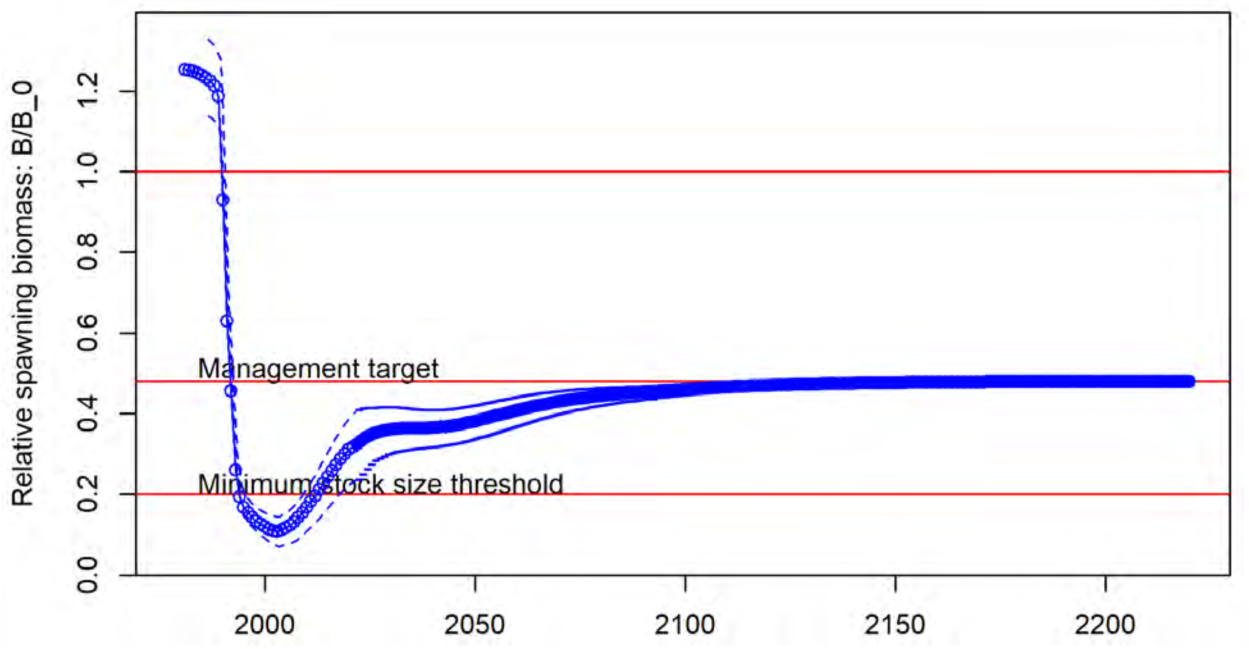


Figure 10.8. The MPD (point estimate) time-series of relative spawning biomass forecast 200 years into the future with catches set using the SESSF 20:35:48 harvest control rule for the 2021 base-case model. The dashed line indicates approximate 95% confidence intervals.

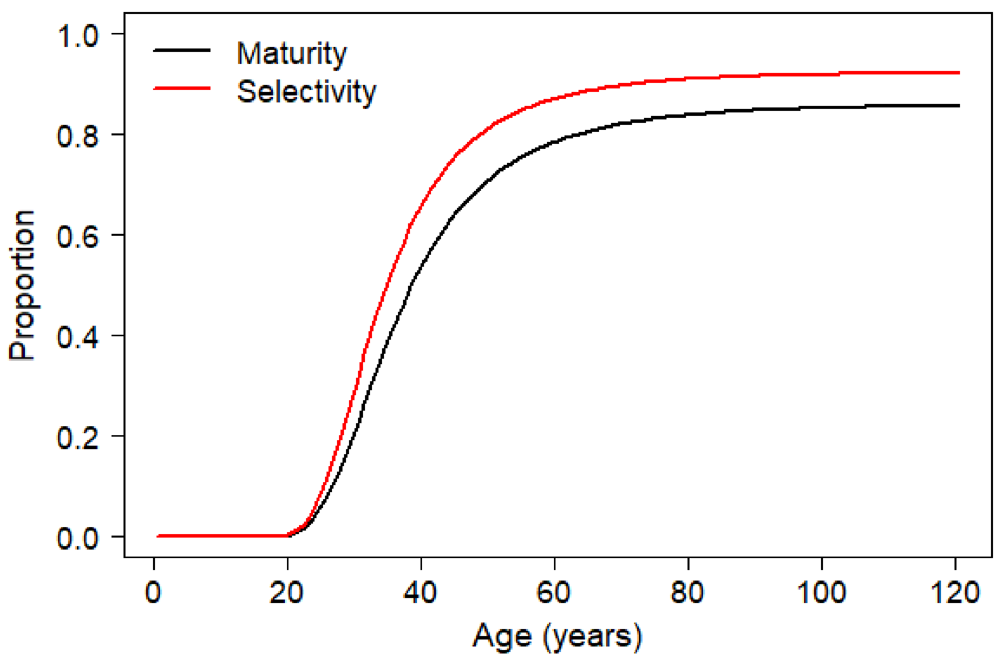


Figure 10.9. The estimated selectivity curve and prespecified maturity ogive for the 2021 base-case model.

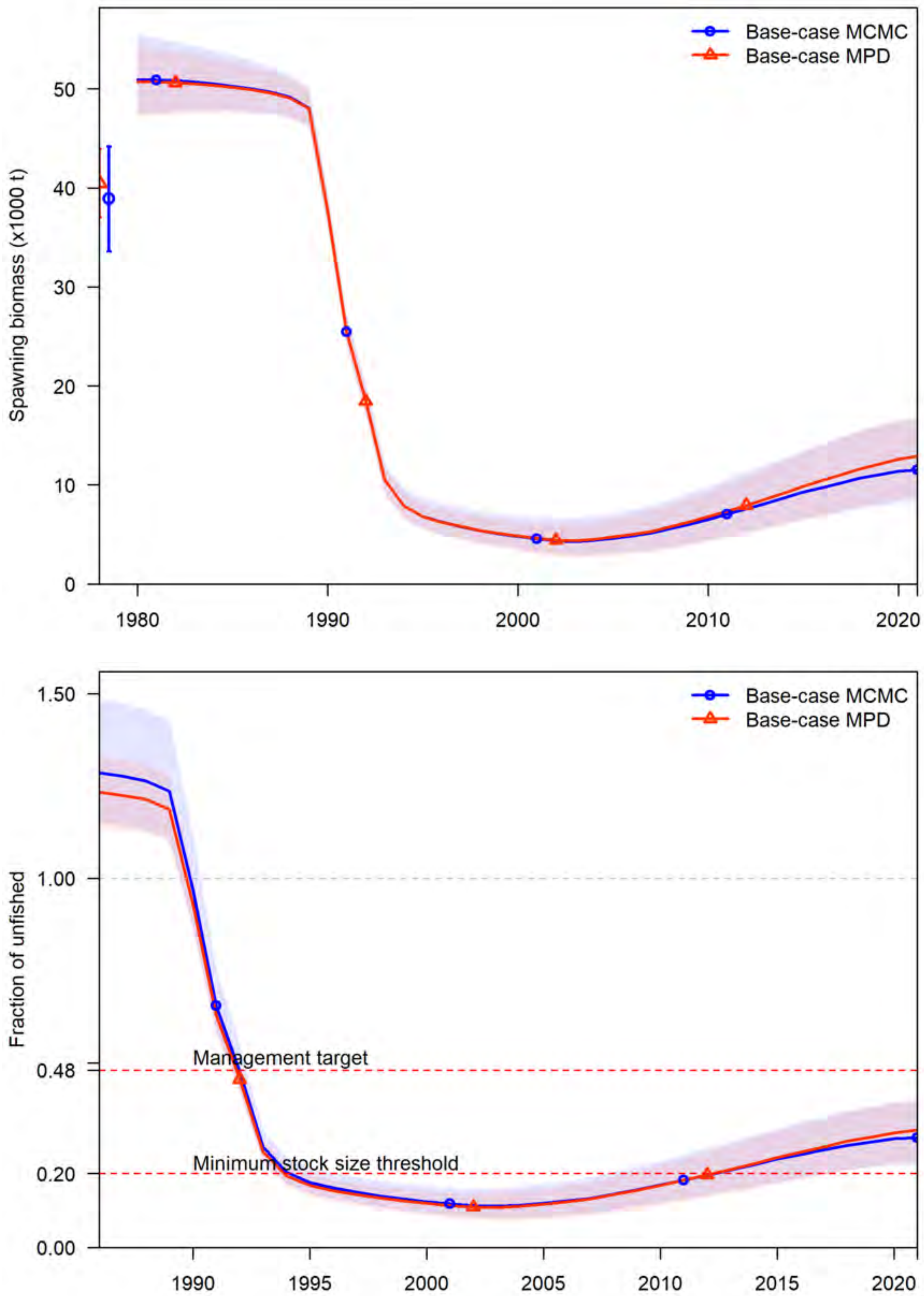


Figure 10.10. Comparison of time-series of absolute (top) and relative (bottom) spawning biomass (with ~95% intervals) for the 2021 base-case model. The red line and shading represent the point estimate and uncertainty from the MPD while the blue line and shading represents the median and uncertainty from 1,750 samples of the posterior from the MCMC.

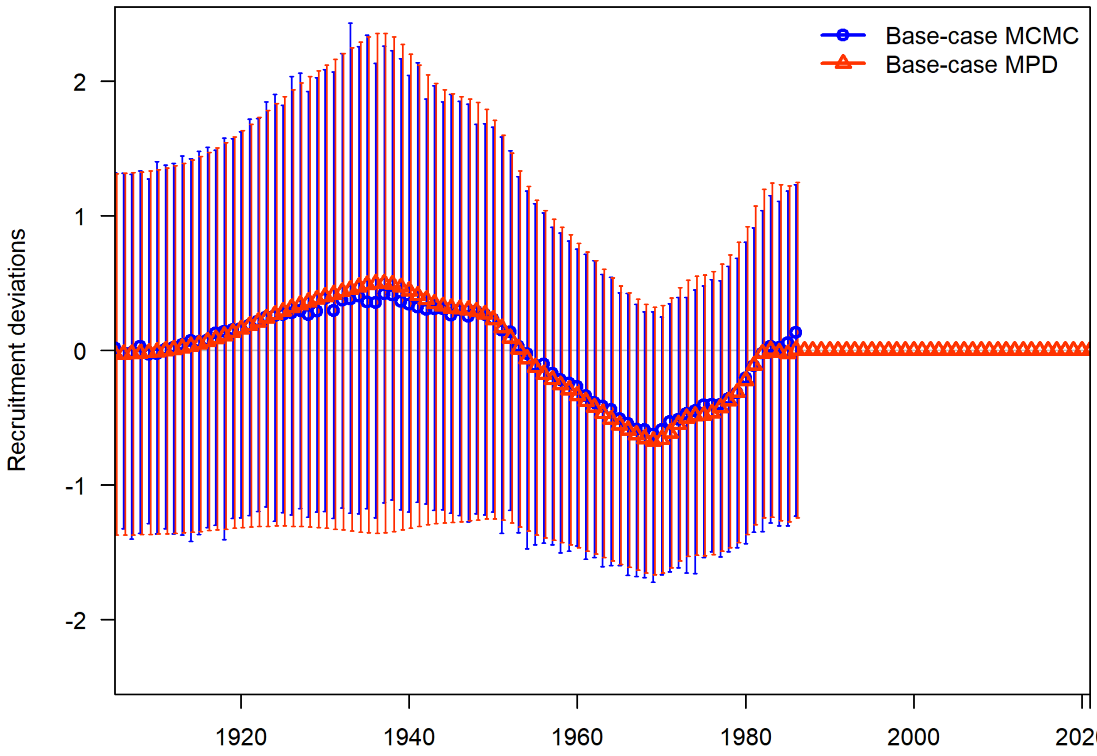


Figure 10.11. Comparison of time-series of recruitment deviations with ~95% intervals for the 2021 base-case model. The red line and shading represent the point estimate and uncertainty from the MPD while the blue line and shading represents the median and uncertainty from 1,750 samples of the posterior from the MCMC.

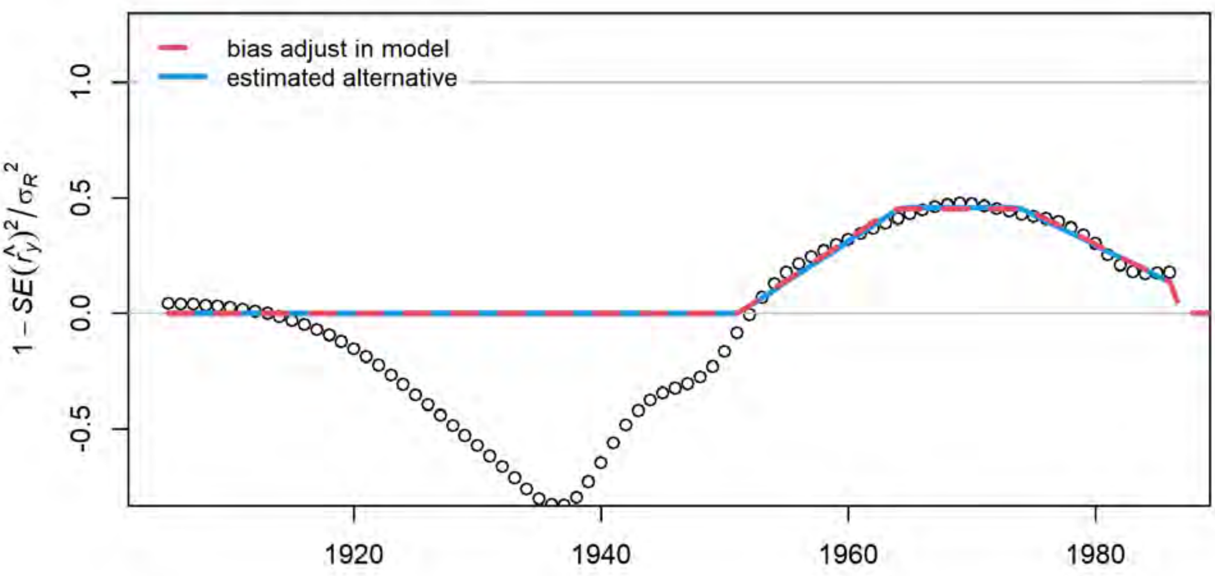


Figure 10.12. Bias ramp adjustment for the 2021 base-case model.

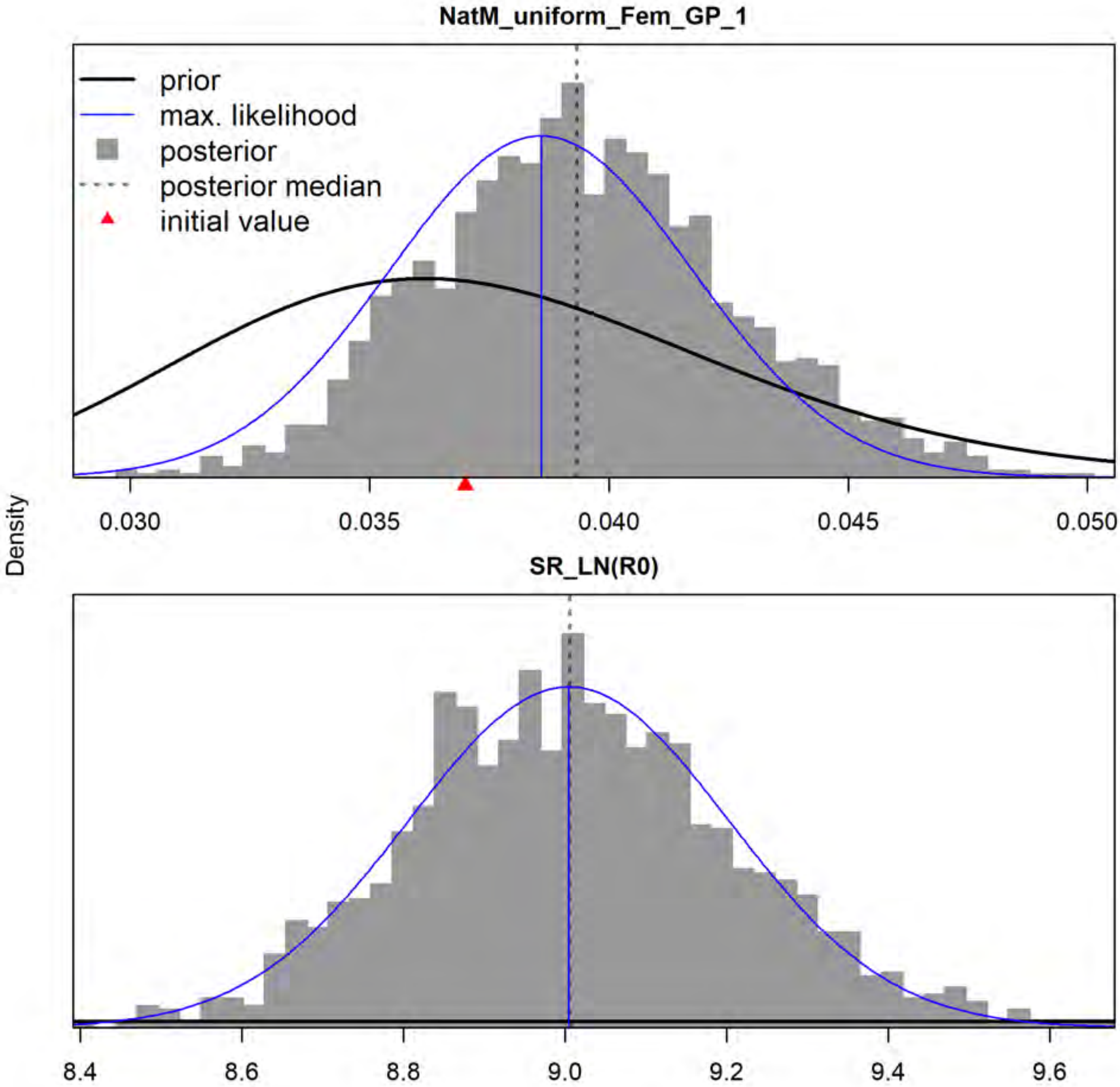


Figure 10.13. Histograms of the posterior of natural mortality (top) and the log of unfished mean recruitment (bottom) for the 2021 base-case model. The histogram comprises 1,750 samples from the posterior, the blue vertical and curved lines are the MPD estimate and asymptotic uncertainty and the black line is the prior.

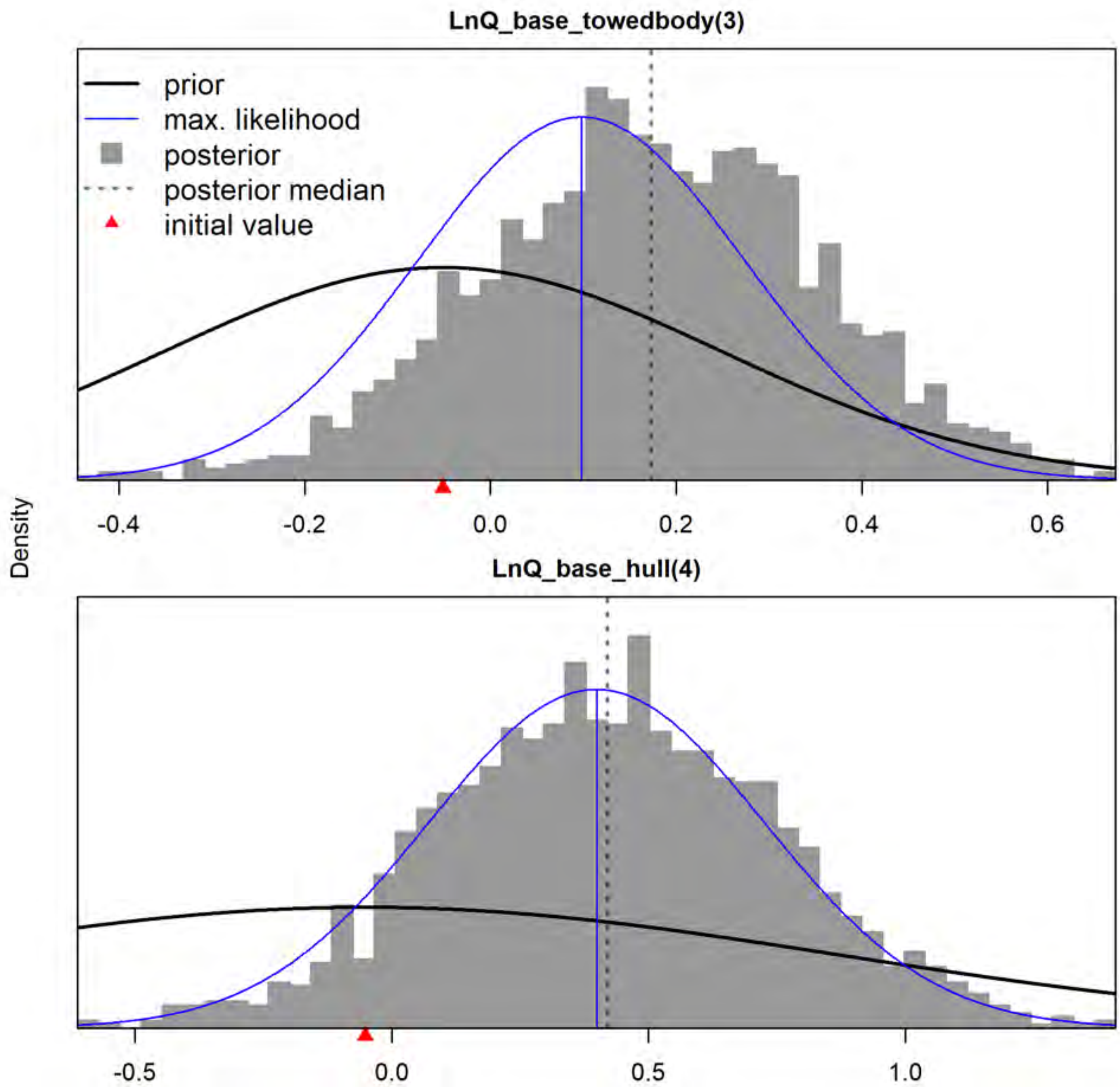


Figure 10.14. Histograms of the posterior of log catchability from the towed (top) and hull (bottom) acoustic surveys from the 2021 base-case model. The histogram comprises 1,750 samples from the posterior, the blue vertical and curved lines are the MPD estimate and asymptotic uncertainty and the black 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.

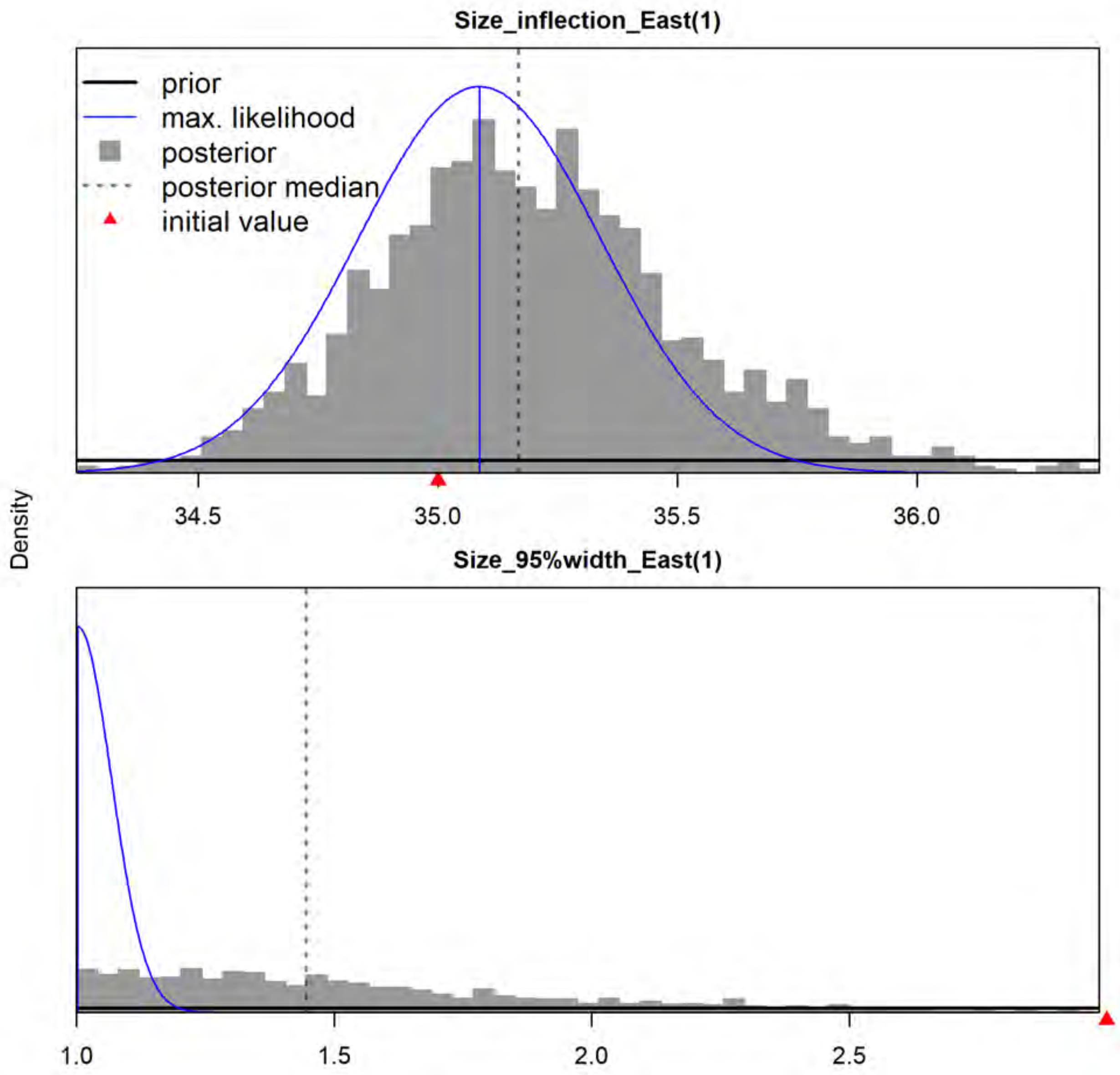


Figure 10.15. Histograms of the posterior of the inflection (top) and width (bottom) parameters of the length-based selectivity logistic selectivity for the 2021 base-case model. The histogram comprises 1,750 samples from the posterior, the blue vertical and curved lines are the MPD estimate and asymptotic 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).

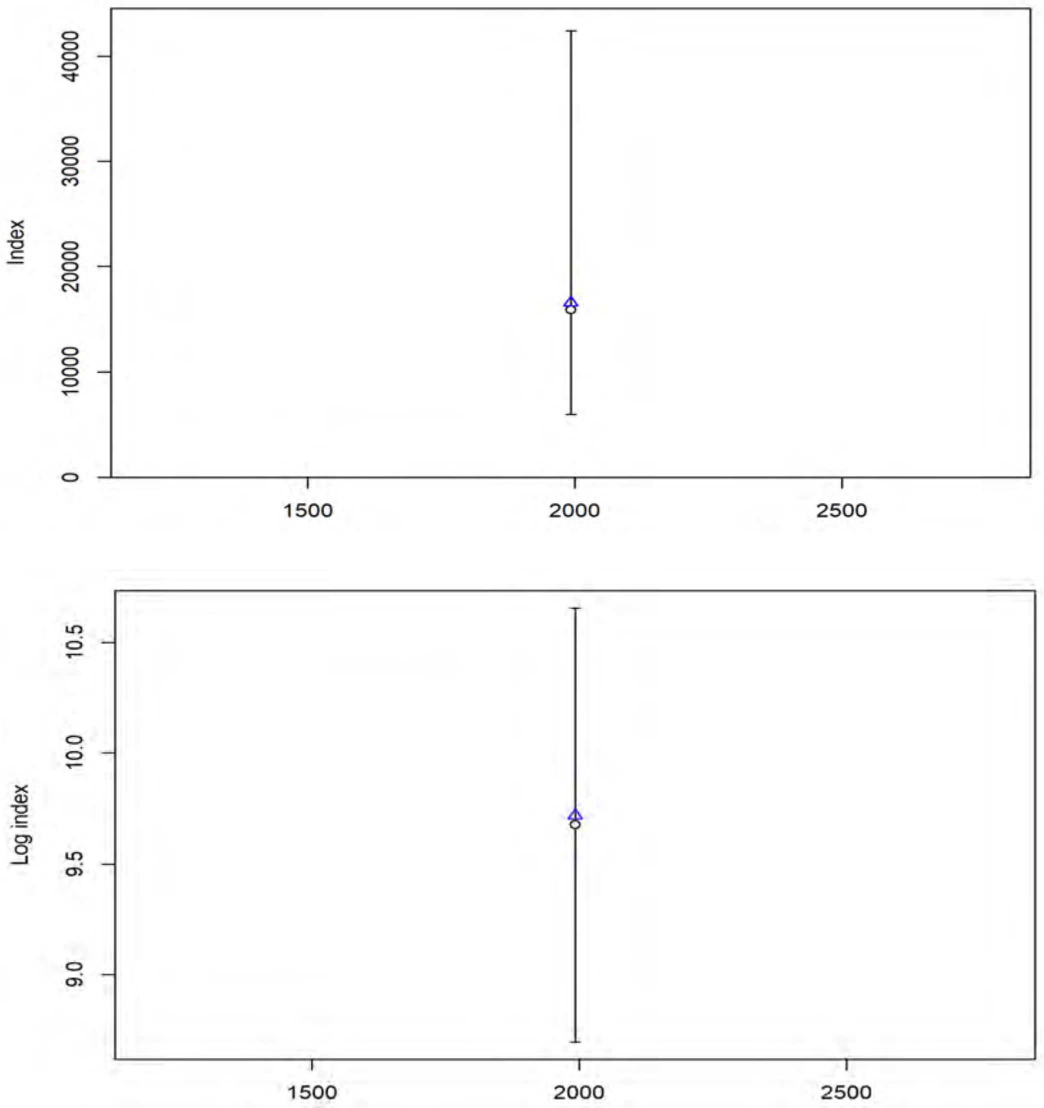


Figure 10.16. Fits to the biomass index (top) and log index (bottom) for the 1992 egg survey for the base-case model.

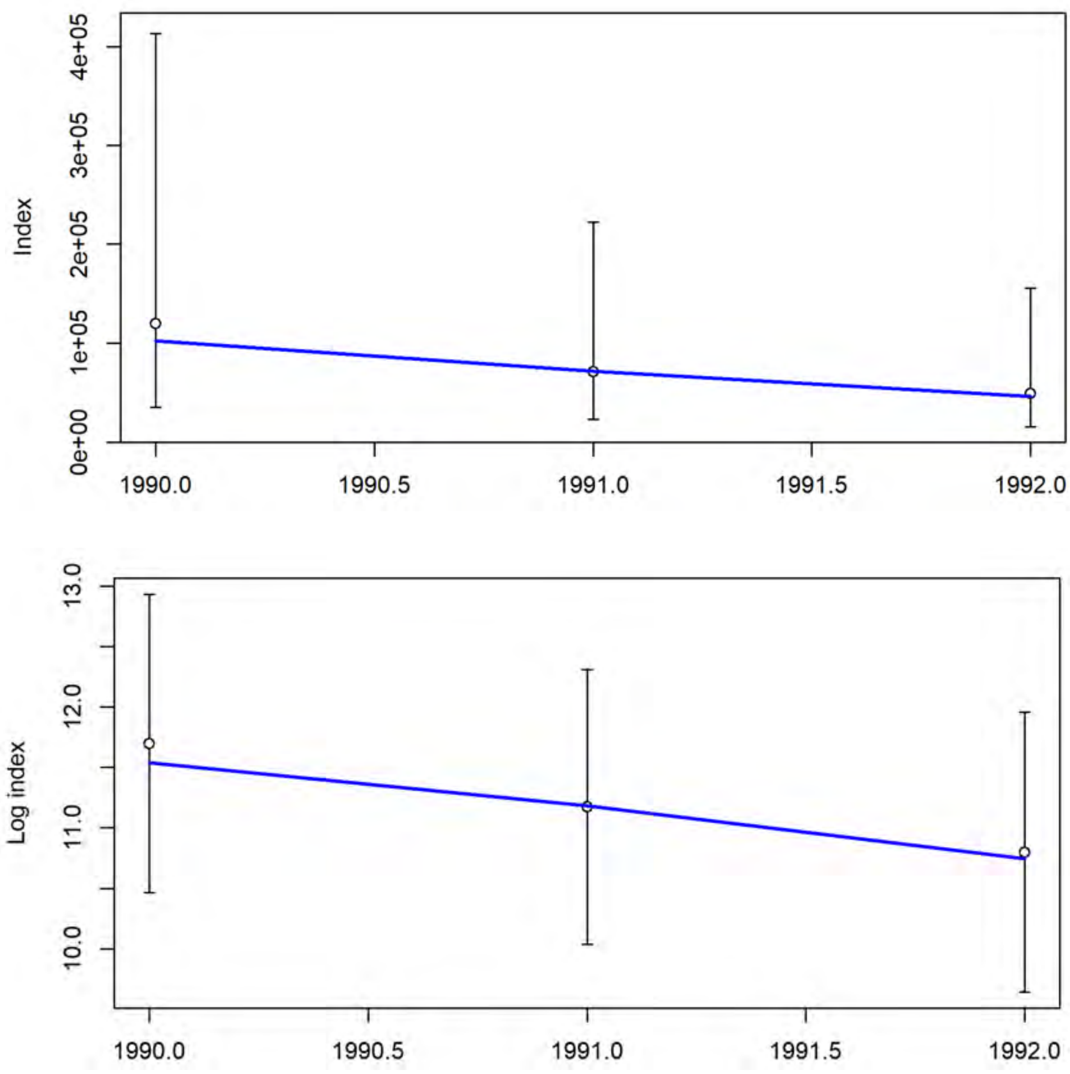


Figure 10.17. Fits to the biomass indices (top) and log indices (bottom) for the hull surveys for the 2021 base-case model.

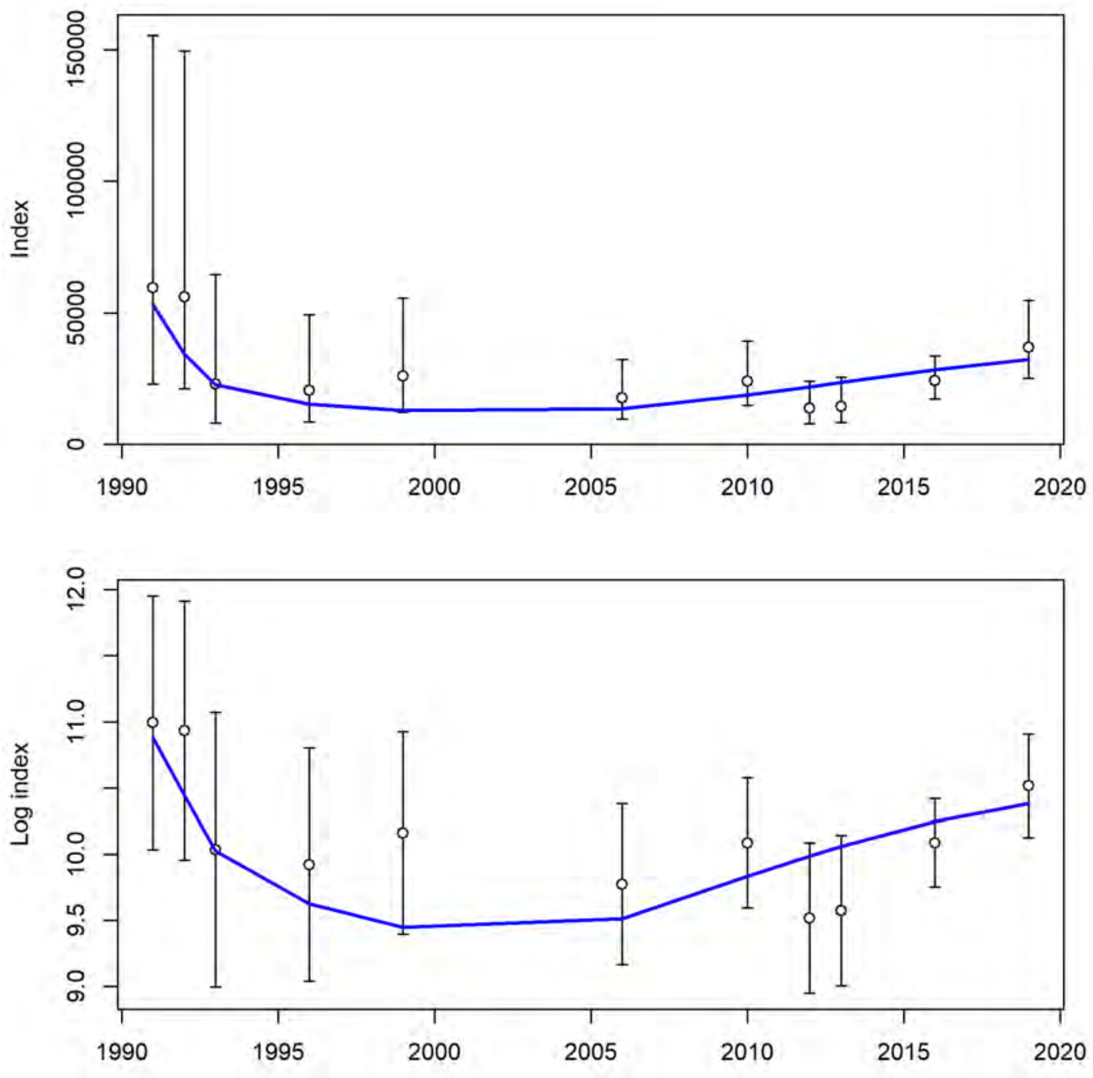


Figure 10.18. Fits to the biomass indices (top) and log indices (bottom) for the towed surveys for the 2021 base-case model.

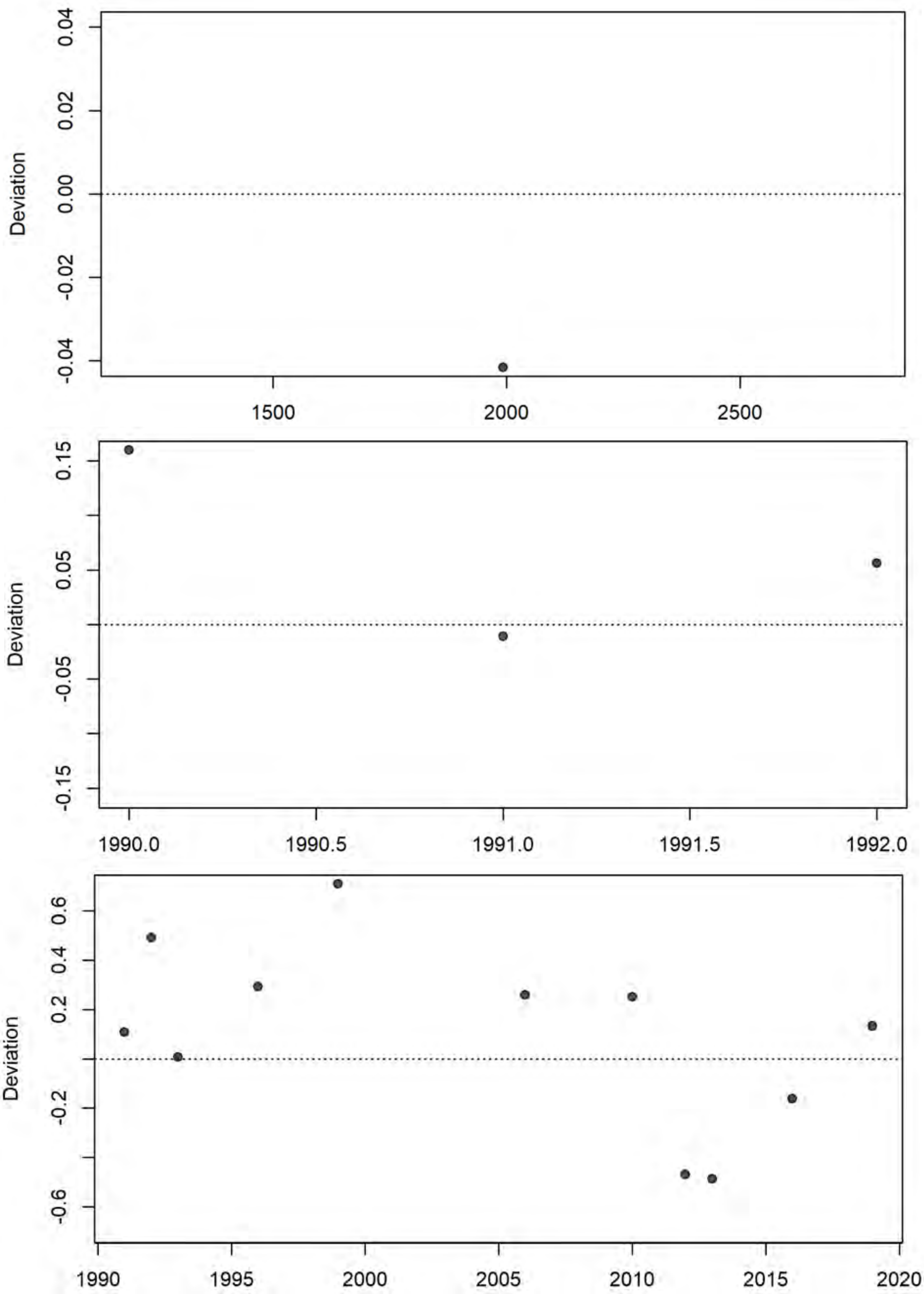


Figure 10.19. Standardized residuals from fits to the egg survey (top), hull survey (middle) and towed survey (bottom) indices for the 2021 base-case model.

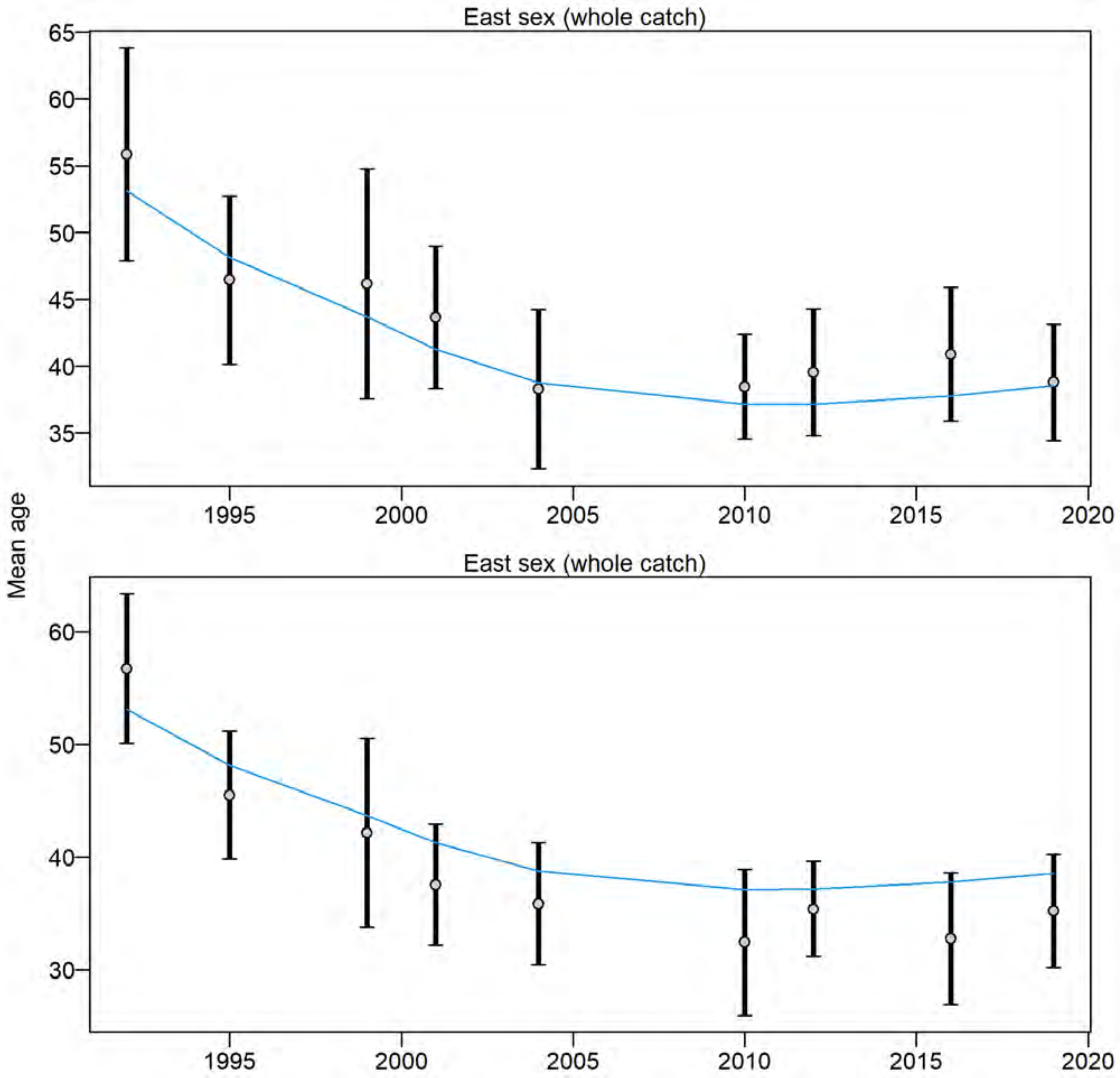


Figure 10.20. Mean age for male and female samples with 95% confidence intervals based on current sample sizes for the 2021 base-case model. The suggested multiplier for Francis data weighting method TA1.8 of age data with 95% interval is 1.0022 (0.7615-1.7396).

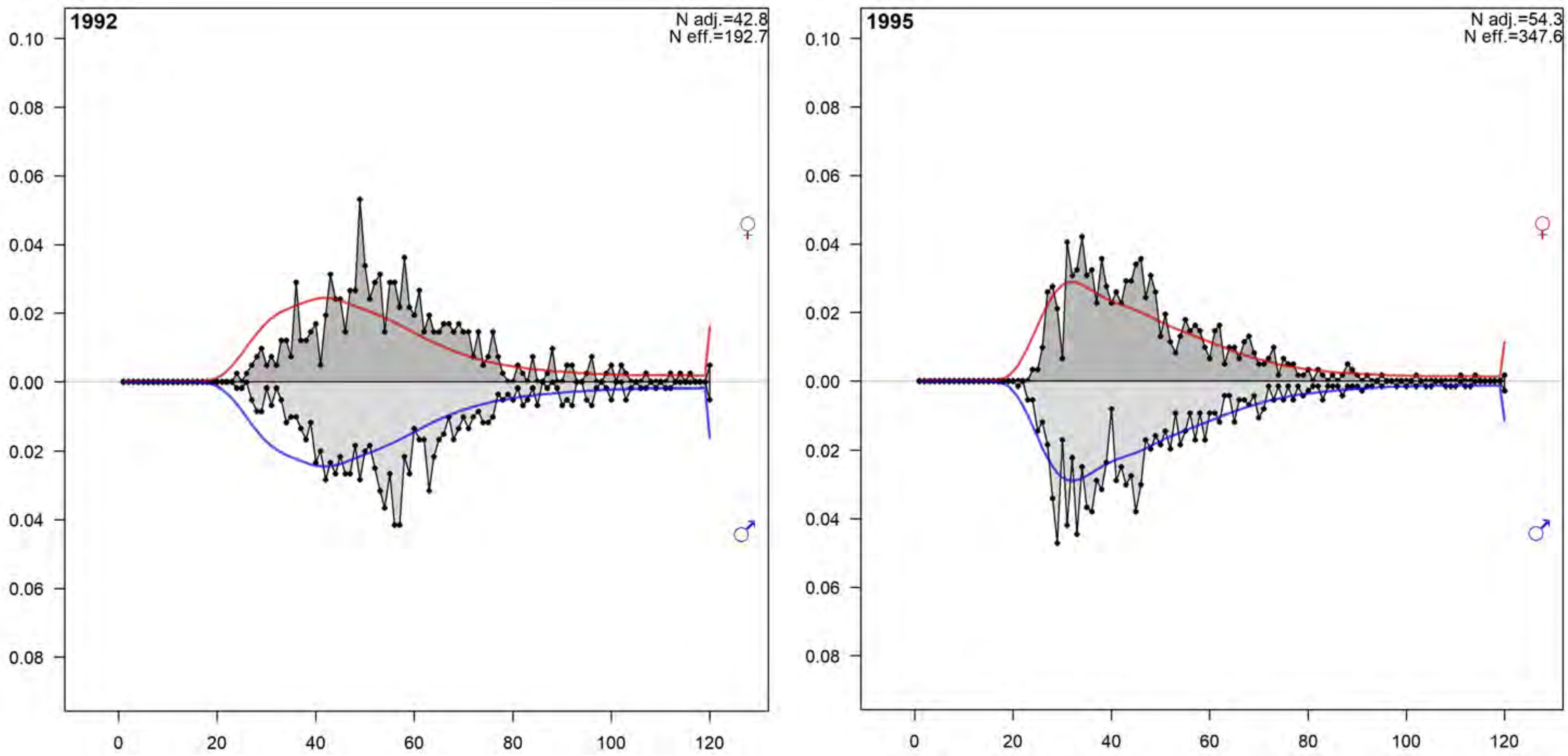


Figure 10.21. Fits to the 1992 and 1995 age data for the 2021 base-case model.

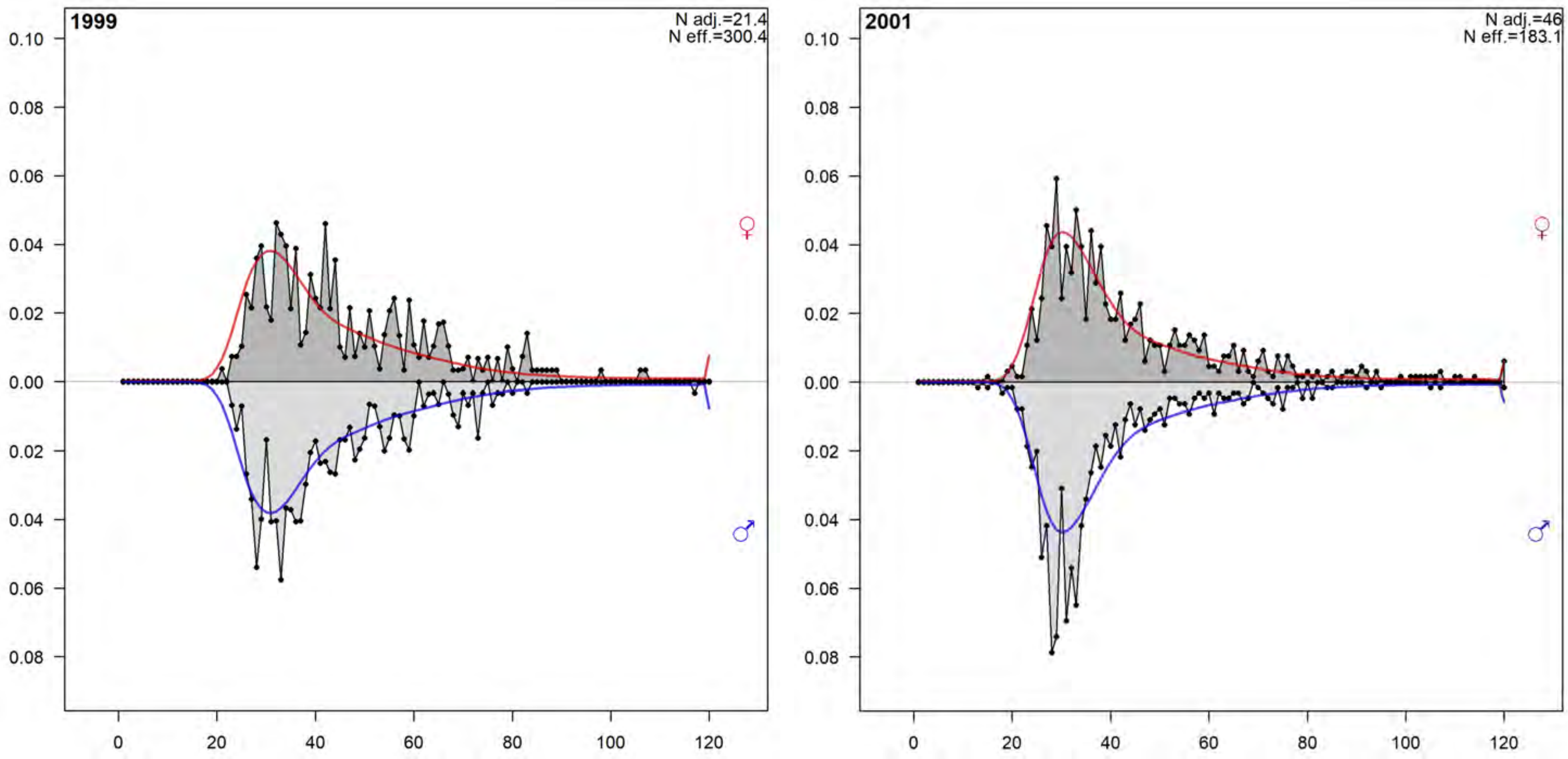


Figure 10.22. Fits to the 1999 and 2001 age data for the 2021 base-case model.

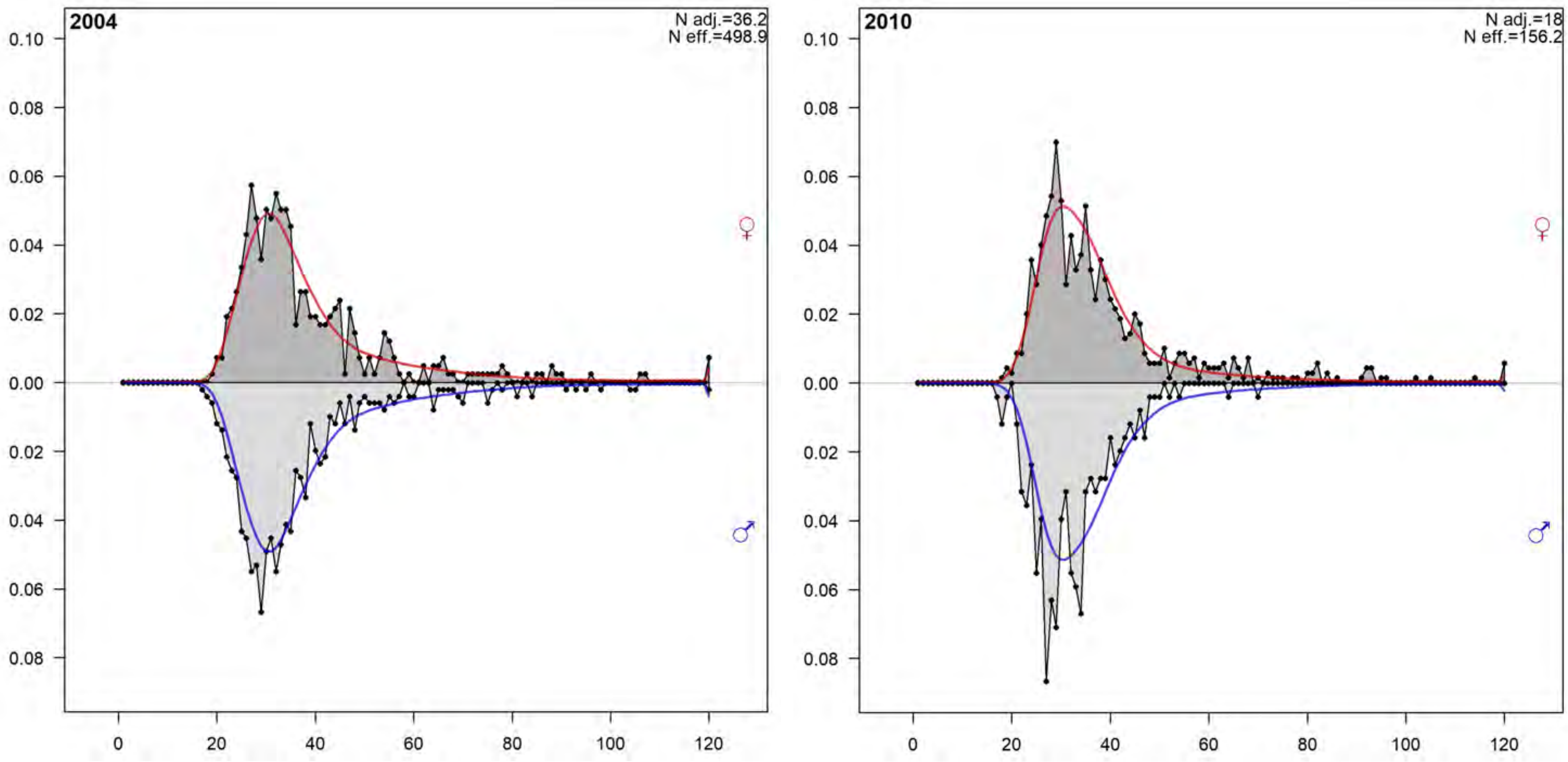


Figure 10.23. Fits to the 2004 and 2010 age data for the 2021 base-case model.

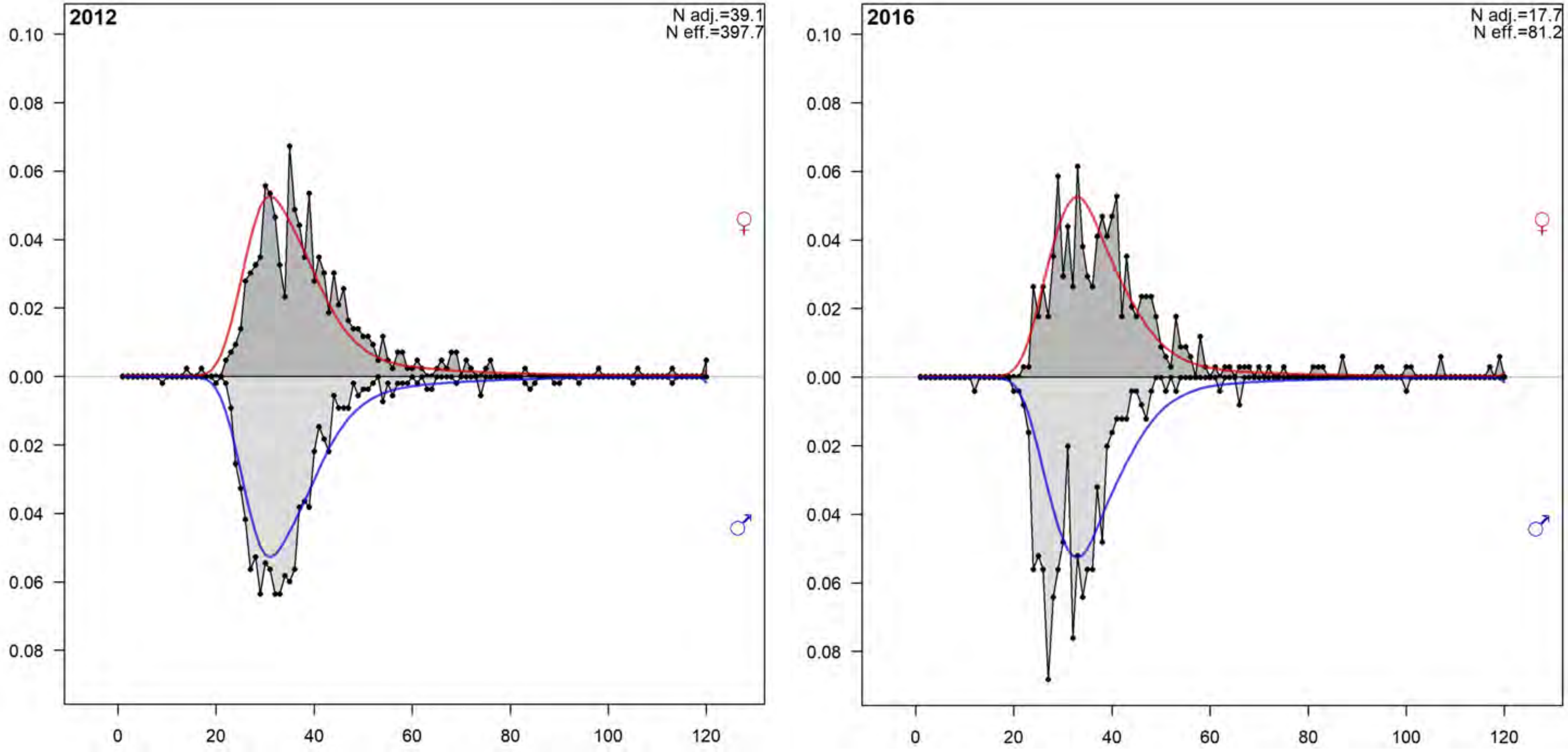


Figure 10.24. Fits to the 2012 and 2016 age data for the 2021 base-case model.

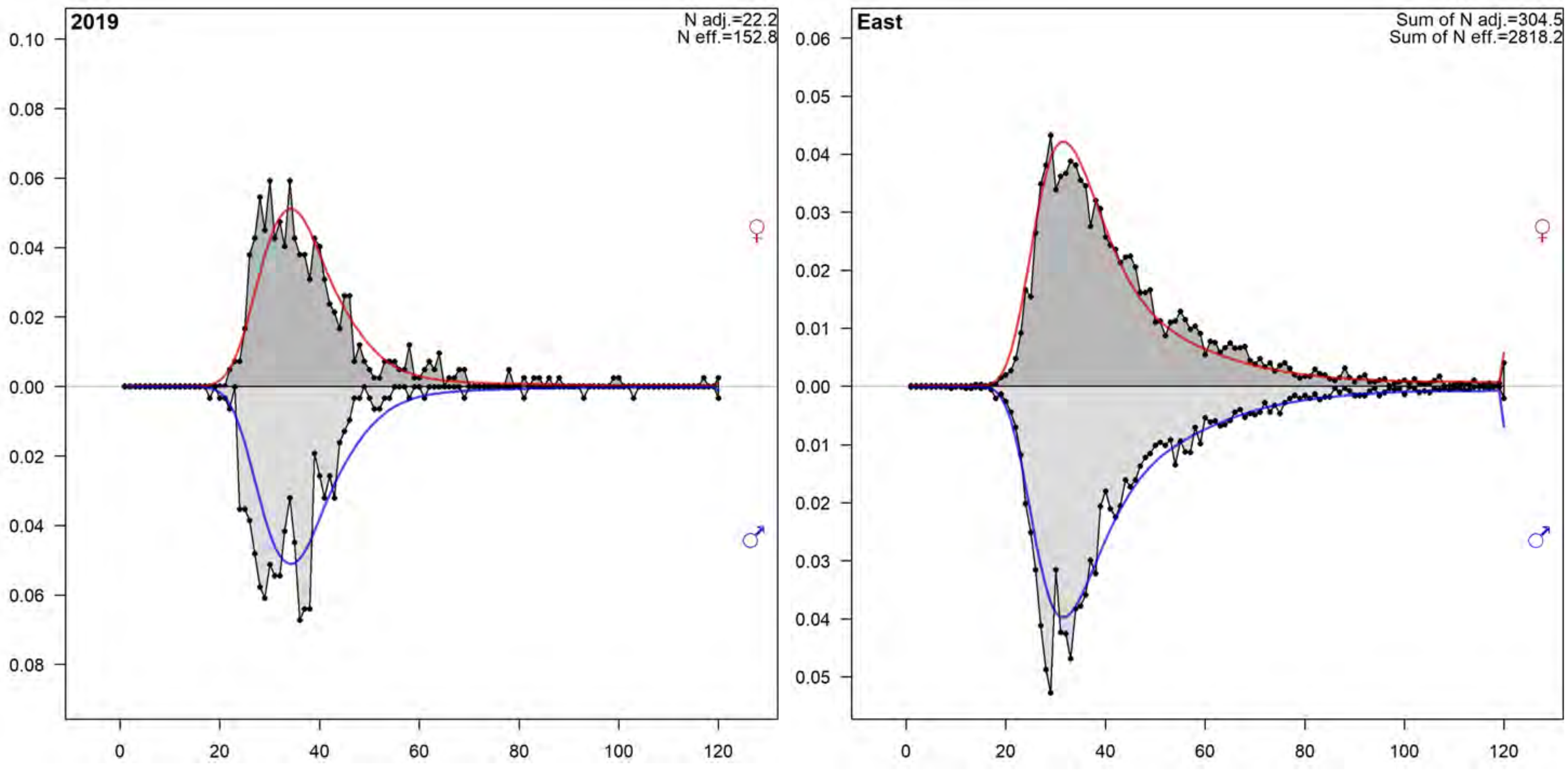


Figure 10.25. Fits to the 2019 age data and the age data combined for all years for the 2021 base-case model.

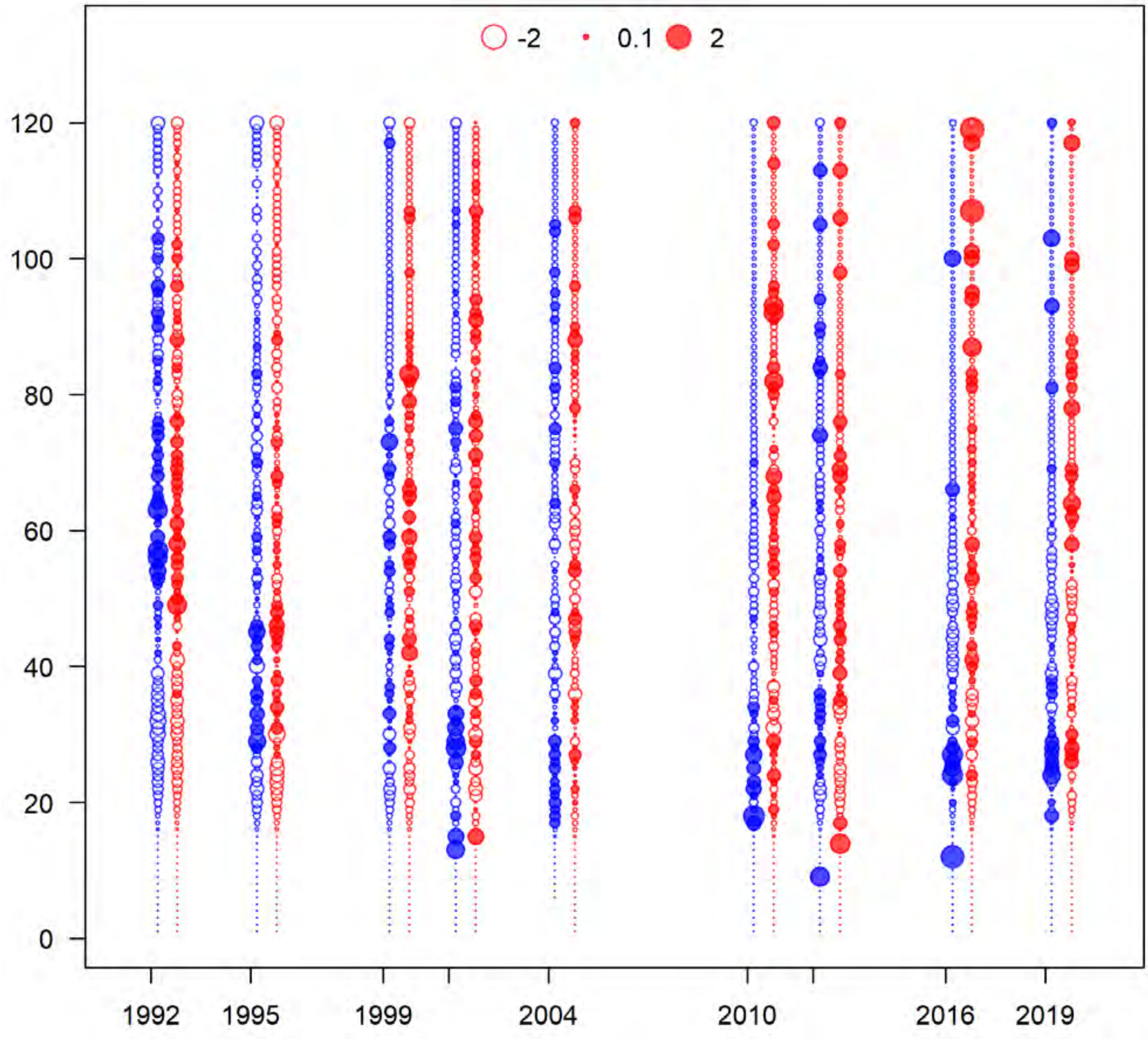


Figure 10.26. Pearson residuals for age data for the 2021 base-case model. Residuals for males are represented by blue circles and residuals for females by red circles. Filled circles represent positive residuals and unfilled circles represent negative residuals.

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).

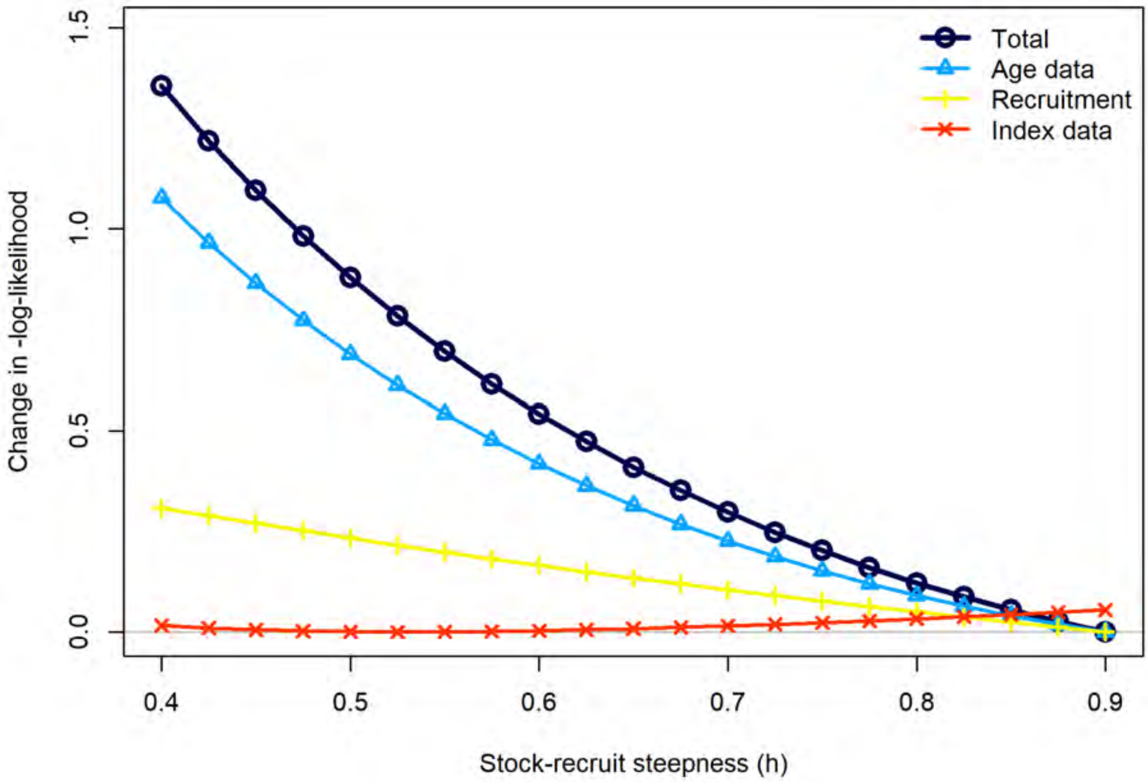


Figure 10.27. Likelihood profile for steepness of the stock recruitment relationship. The fixed value of steepness used in the 2021 base-case assessment is *h*=0.75.

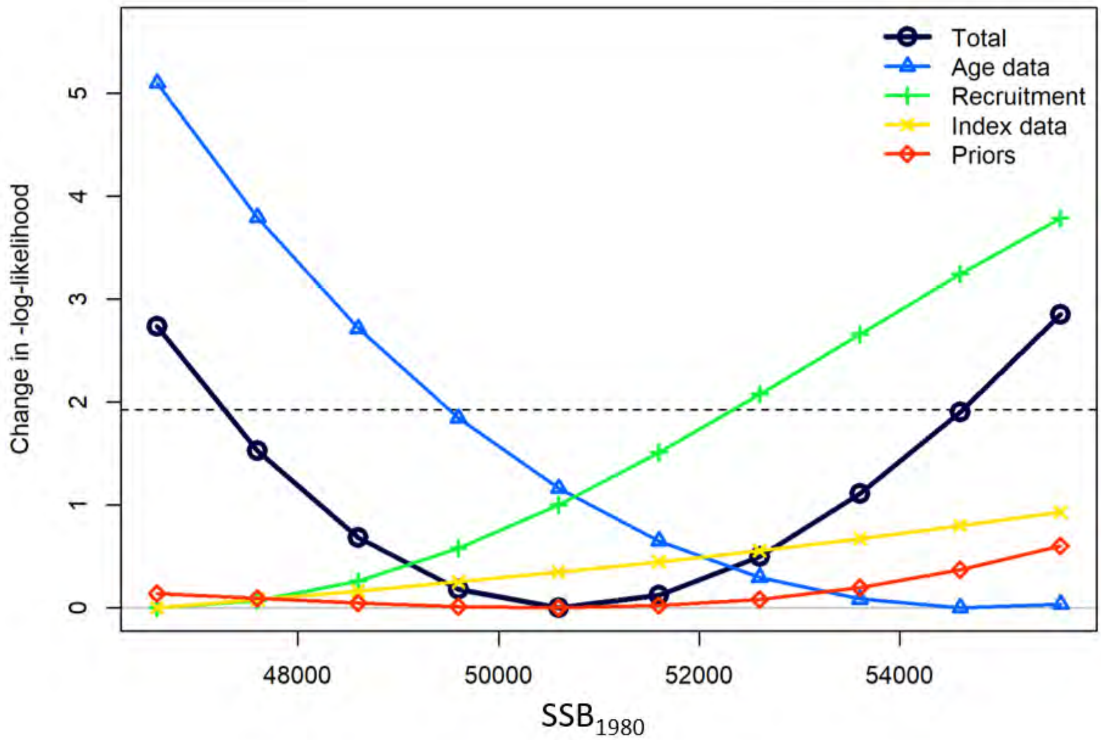


Figure 10.28. Likelihood profile for unfished female spawning biomass immediately prior to the beginning of the fishery (SSB_{1980}) for the 2021 base-case model. The MPD estimate of SSB_{1980} is 50,685 t. Note the estimate of female spawning biomass in 1980 is above the unfished equilibrium.

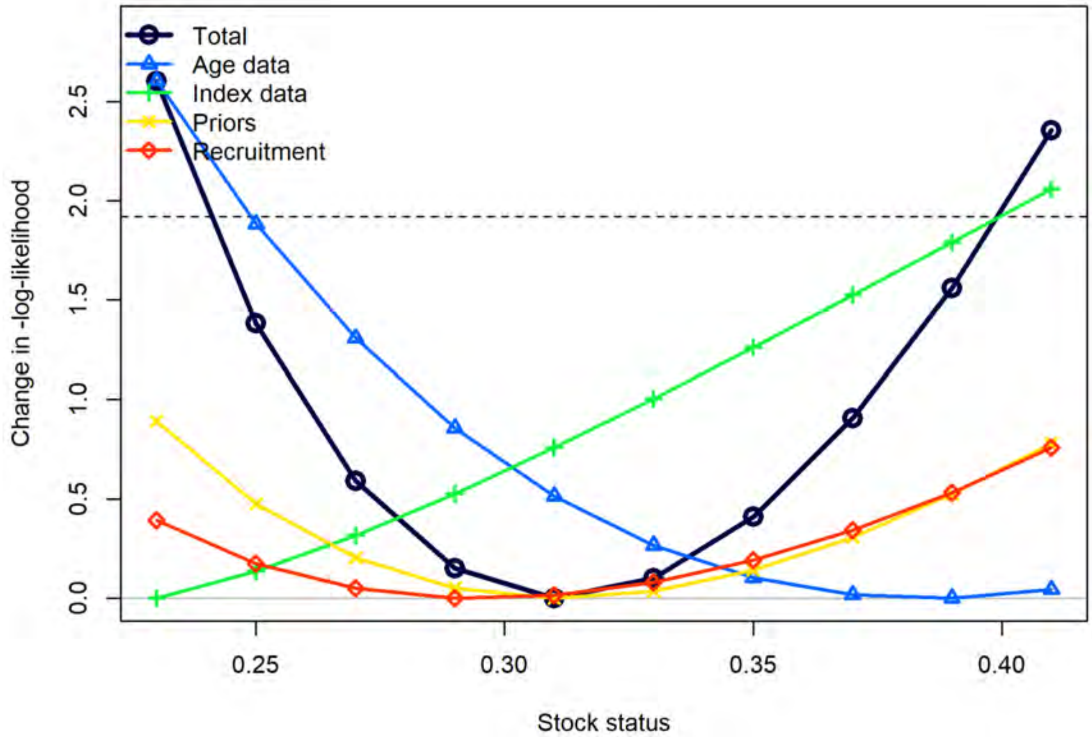


Figure 10.29. Likelihood profile for stock status in 2020 (SSB_{2020}/SSB_0) for the 2021 base-case model. The MPD estimate of 2020 stock status is 0.312.

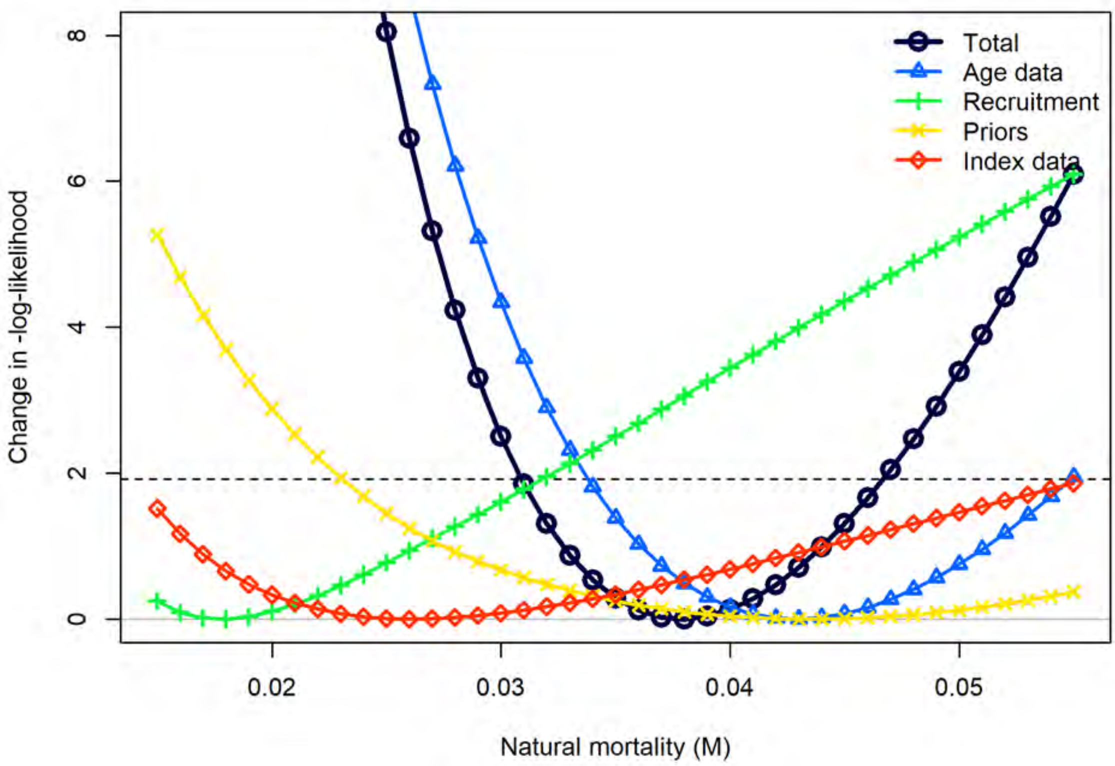


Figure 10.30. Likelihood profile for natural mortality for the 2021 base-case model. The MPD estimate of natural mortality is M=0.0386 yr^{-1}.

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

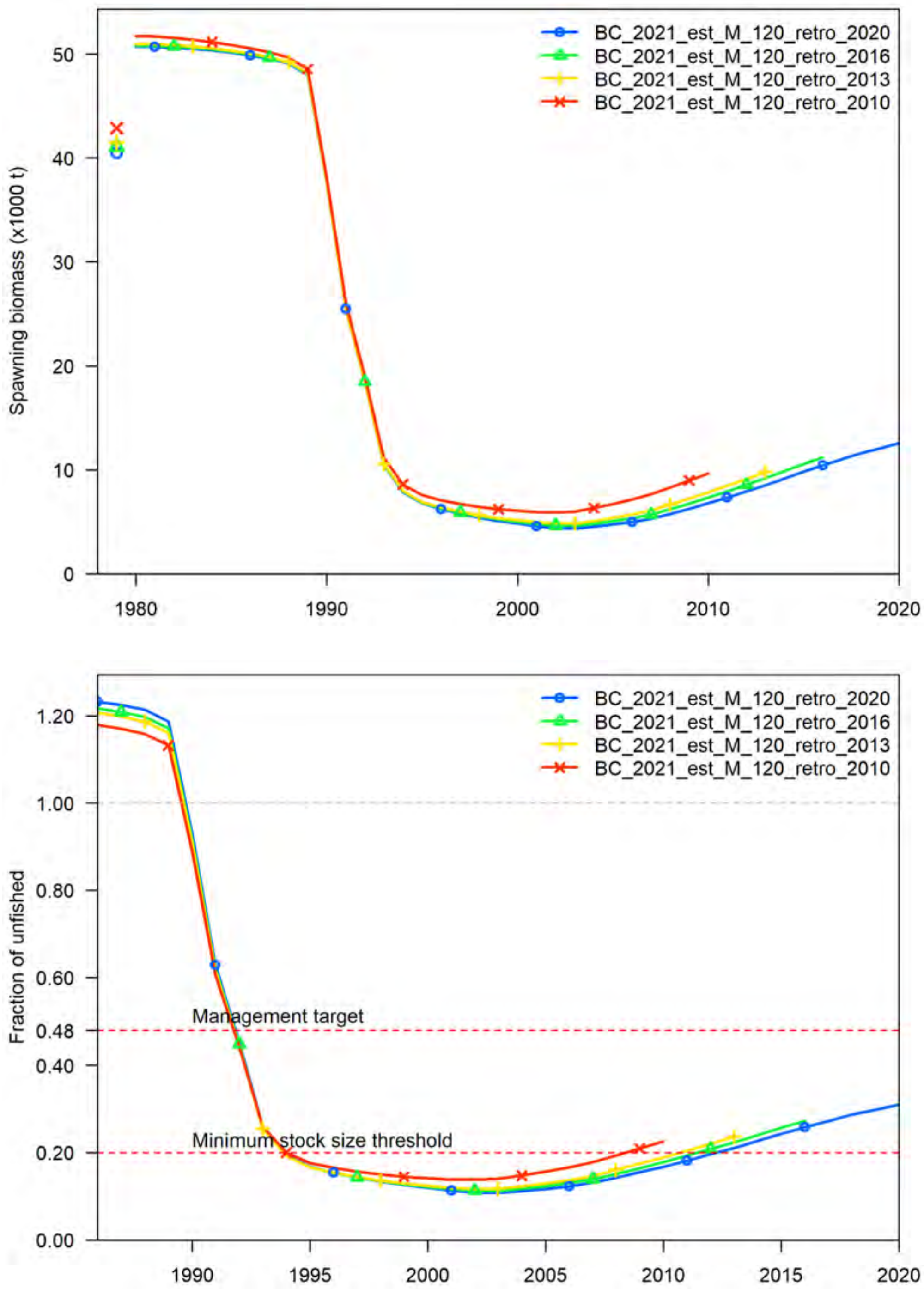


Figure 10.31. Retrospective analysis showing the absolute (top) and relative (bottom) spawning biomass from assessments that were undertaken after removing four, seven and ten years of data from the 2021 base-case model.

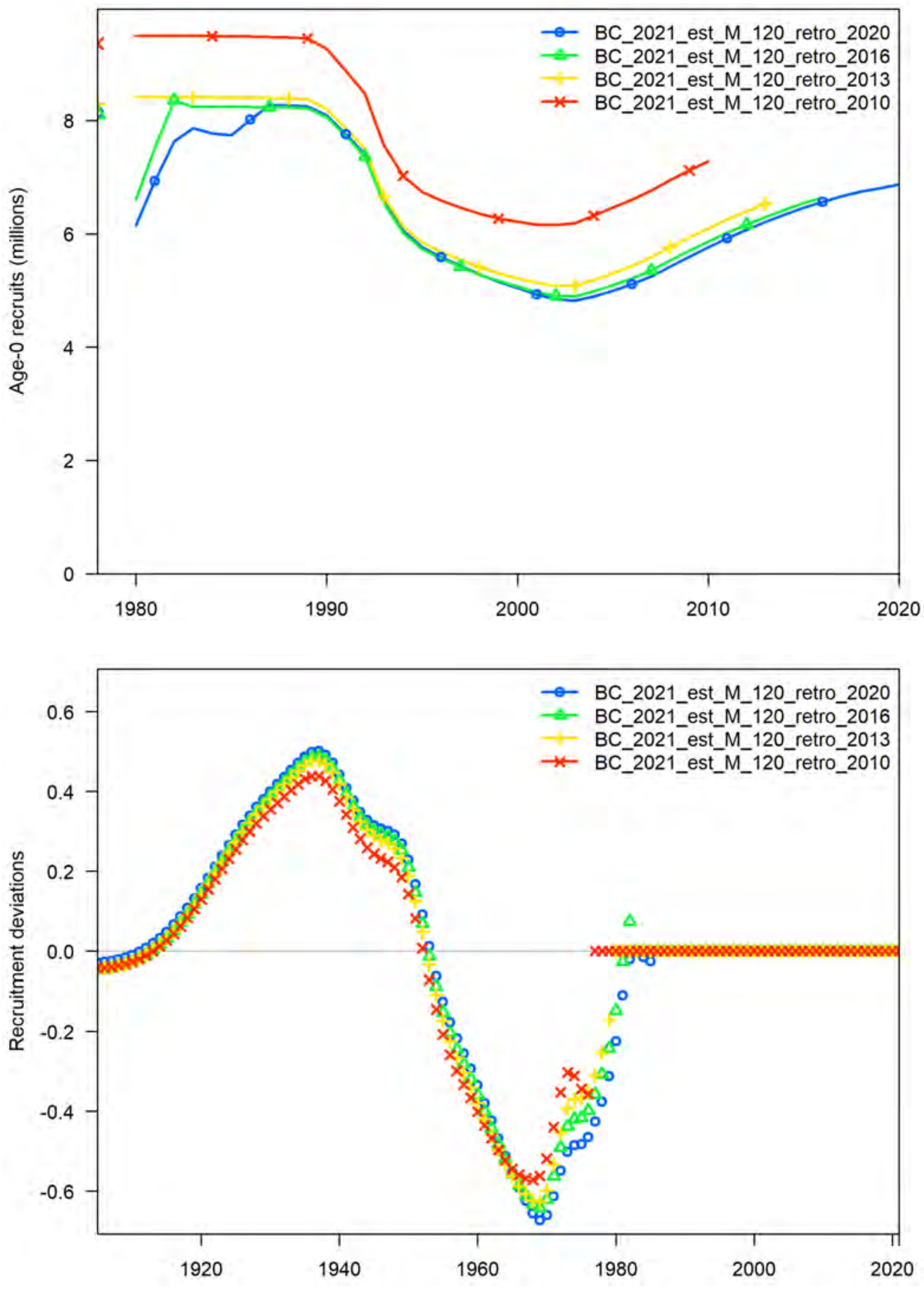


Figure 10.32. Retrospective analysis showing the absolute recruitment (top) and recruitment deviations (bottom) from assessments that were undertaken after removing four, seven and ten years of data from the 2021 base-case model.

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).

10.6 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. 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.

10.7 References

Australian Fisheries Management Authority (AFMA), (2014). Orange Roughy (eastern zone) workshop meeting minutes, CSIRO Hobart, 15-16 May 2014.

Annala, J.H. (Comp.) (1994) Report from the Special Fishery Assessment Plenary, 27 May 1994: stock assessments and yield estimates for ORH 2A, 2B, and 3A. (Cited in CSIRO and TDPIF, 1996) 17 p.

Bax, N. (1997). Stock Assessment Report 1997: Orange roughy. Report for the South East Fishery Stock Assessment Group. Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 64 p. (Unpublished report held by CSIRO, Hobart).

Bax, N. (2000a). Stock Assessment Report: Orange roughy 1995, Stock Assessment Report, South East Fishery Stock Assessment Group, Australian Fisheries Management Authority, Canberra, 55 p. (Unpublished report held by AFMA, Canberra).

Bax, N. (2000b). Stock Assessment Report: Orange roughy 1996, Stock Assessment Report, South East Fishery Stock Assessment Group, Australian Fisheries Management Authority, Canberra, 37 p. (Unpublished report held by AFMA, Canberra).

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.

Bell, J.D., Lyle, J.M., Bulman, C.M., Graham, K.J., Newton, G.M. and Smith, D.C. (1992) Spatial variation in reproduction, and occurrence of non-reproductive adults, in orange roughy, *Hoplostethus atlanticus* Collett (Trachichthyidae), from south-eastern Australia. Journal of Fish Biology 40: 107-122.

Brooks, E. N., and Legault, C. M. (2016). Retrospective forecasting—evaluating performance of stock projections for New England groundfish stocks. Canadian Journal of Fisheries and Aquatic Sciences, 73: 935–950.

Burch P and Curin Osorio S (2021). Eastern zone Orange Roughy (*Hoplostethus atlanticus*) stock assessment based on data up to 2020 – development of a preliminary base-case DRAFT.

Prepared for the Orange Roughy Steering Committee video conference, 13 August 2021. CSIRO Oceans and Atmosphere.

Burch, P, Day, J, Castillo-Jordán, C, and Curin Osorio, S, (2019). Silver warehou (*Seriolella punctata*) stock assessment based on data up to 2017. Revised after the SERAG meeting 14-16 November 2018.

CSIRO and TDPIF (1996). Orange roughy 1994, Stock Assessment Report, South East Fishery Assessment Group. Australian Fisheries Management Authority, 204 p. (Unpublished report held by AFMA, Canberra).

Cordue, P.L., (2014). A management strategy evaluation for orange roughy (ISL Client Report for Deepwater Group Ltd.).

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.

Dunn, M.R., Devine, J.A. (2010). An holistic approach to determining stock structure of orange roughy on the Chatham Rise. New Zealand Fisheries Assessment Report 2010/17.

Francis, C. (2011) Data weighting in statistical fisheries stock assessment models. Canadian Journal of Fisheries and Aquatic Science 68: 1124-1138.

Gelman, A., Carlin, J.B., Stern, H.S. and Rubin, D.B. (2003) Bayesian Data Analysis. 2nd Edition. Chapman & Hall/CRC Press, Florida. 668 p.

Haddon, M. (2017) Orange Roughy East (*Hoplostethus atlanticus*) stock assessment using data to 2016. CSIRO, Oceans and Atmosphere.

Heidelberger, P. and Welch, P.D., 1981. A spectral method for confidence interval generation and run length control in simulations. Communications of the ACM, 24(4), pp.233-245.

Heidelberger, P. and Welch, P.D., 1983. Simulation run length control in the presence of an initial transient. Operations Research, 31(6), pp.1109-1144.

Hurtado-Ferro, F., Szuwalski, C.S., Valero, J.L., Anderson, S.C., Cunningham, C.J., Johnson, K.F., Licandeo, R., McGilliard, C.R., Monnahan, C.C., Muradian, M.L. and Ono, K., (2015). Looking in the rear-view mirror: bias and retrospective patterns in integrated, age-structured stock assessment models. ICES Journal of Marine Science, 72(1): 99-110.

Kimura, D., Balsiger, J. and Ito, D. (1984) Generalized stock reduction analysis. Canadian Journal of Fisheries and Aquatic Sciences 41: 1325–1333.

Kloser, R, Ryan, T. (2002) Review of Analysis methodologies and data holdings for acoustic assessments of orange roughy on St Helens Hill, 1989 - 1999. CSIRO Marine Research 40p.

Kloser, R., Sutton, C., Kunnath, H. and R. Downie (2016) Orange roughy eastern zone spawning biomass 2016. Report for South East Trawl Industry Association. CSIRO Oceans and Atmosphere, Hobart.

Kloser, R., Sutton, C., (2020). Orange roughy eastern zone spawning biomass 2019 (report for SETFIA). CSIRO Oceans and Atmosphere.

Koslow, J.A., Bulman, C.M., Lyle, J.M. and Haskard, K. (1995) Biomass assessment of a deep-water fish, the orange roughy (*Hoplostethus atlanticus*), based on an egg survey. Marine and Freshwater Research, 46: 819-830.

Legault, C.M., (2020). Rose vs. Rho: a comparison of two approaches to address retrospective patterns in stock assessments. ICES Journal of Marine Science, 77(7-8): 3016-3030.

Lyle, J.M., Kitchener, J. & Riley, S.P. (1991) An assessment of orange roughy resource off the coast of Tasmania. Final report to FIRDC, Project 87/65.

Methot Jr., R.D. and C.R. Wetzel (2013) Stock Synthesis: a biological and statistical framework for fish stock assessment and fishery management. Fisheries Research, 142, 86-99.

Methot Jr., R.D., Wetzel, C.R., Taylor, I.G., Doering, K.L. and Johnson, K.F. (2021) Stock Synthesis User Manual Version 3.30.17. NOAA Fisheries Seattle, WA June 11, 2021.

Mohn, R. (1999). The retrospective problem in sequential population analysis: an investigation using cod fishery and simulated data. ICES Journal of Marine Science, 56: 473–488.

Pacific Fishery Management Council. (2020). Terms of Reference for the Groundfish and Coastal Pelagic Species Stock Assessment Review Process for 2021-2022, https://www.pcouncil.org/documents/2021/01/terms-of-reference-for-the-coastal-pelagic-species-stock-assessment-review-process-for-2021-2022-december-2020.pdf/.

Plummer, M., Best, N., Cowles, K., & Vines, K. (2006). Coda: Convergence diagnosis and output analysis for MCMC. R News, 6 , 7–11. URL: https: //journal.r-project.org/archive/.

Penney, A. and Klaer, N. (2016) Use of Markov chain Monte Carlo analysis in fisheries stock assessments. Unpublished document for the Australian Fisheries Management Authority.

Punt, A.E., Smith, D.C., Krusic Golub, K. and S. Robertson (2008) Quantifying age-reading error for use in fisheries stock assessments, with application to species in Australia's southern and eastern scalefish and shark fishery. Canadian Journal of Fisheries and Aquatic Science 65: 1991–2005.

Punt A.E. (2018). On the use of likelihood profiles in fisheries stock assessment. Technical paper for SESSFRAG, August 2018.

Smith, D.C., Fenton, G.E., Robertson, S.G. and Short, S.A. (1995) Age determination and growth of orange roughy (*Hoplostethus atlanticus*): a comparison of annulus counts with radiometric ageing. Canadian Journal of Fisheries and Aquatic Sciences 52: 391-401.

Smith, A.D.M., Smith, D.C., Tuck, G.N., Klaer, N.,Punt, A.E., Knuckey, I., Prince, J., Morison, A., Kloser, R., Haddon, M., Wayte, S., Day, J., Fay, G., Fuller, M., Taylor, B. and Little, L.R. (2008). Experience in implementing harvest strategies in Australia's south-eastern fisheries. Fisheries Research, 94: 373-379.

Stokes, K. (2009). Orange roughy Assessment Review. Report completed for the Australian Fisheries Management Authority, 33 p. (Unpublished report held by AFMA, Canberra).

Taylor, I.G., Stewart, I.J., Hicks, A., Garrison, T.M., Punt, A.E., Wallace, J.R., Wetzel, C.R. 2014. r4ss: R code for Stock Synthesis. R package version 1.16. http://R-Forge.R-project.org/projects/r4ss/.

Tuck, G., Castillo-Jordán, C., Burch, P., (2018). Orange roughy east (*Hoplostethus atlanticus*) cross-catch risk assessment based upon the 2017 stock assessment. For discussion at SERAG, 14-16 November 2018 (Report for the Australian Fisheries Management Authority). CSIRO Oceans; Atmosphere.

Upston, J. and S. Wayte (2011) Orange roughy (*Hoplostethus atlanticus*) Eastern Zone preliminary stock assessment incorporating data up to 2010 – definition of the base-case model.

Upston, J., Punt, A.E., Wayte, S., Ryan, T., Day, J. and M. Sporcic (2015) Orange roughy (*Hoplostethus atlanticus*) Eastern Zone stock assessment incorporating data up to 2014. pp 10 –

81 in Tuck, G.N. (ed) Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2014. Part 1. Australian Fisheries Management Authority and CSIRO Oceans and Atmosphere Flagship, Hobart. 170p.

Venables, W. N. and Ripley, B. D. (2002) Modern Applied Statistics with S. Fourth Edition. Springer, New York. ISBN 0-387-95457-0

Wayte, S.E. and Bax, N. (2002) Orange roughy Stock Assessment pp 167 – 208 in Smith, A.D.M. and S. Wayte (eds) (2002) The South East Fishery 2002, Fishery Assessment Report compiled by the South East Fishery Assessment Group. Australian Fisheries Management Authority, Canberra.

Wayte, S.E. (2006) Eastern Zone Orange Roughy. Preliminary 2006 assessment. Discussion document provided to Deepwater Assesament Group August 2006.

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

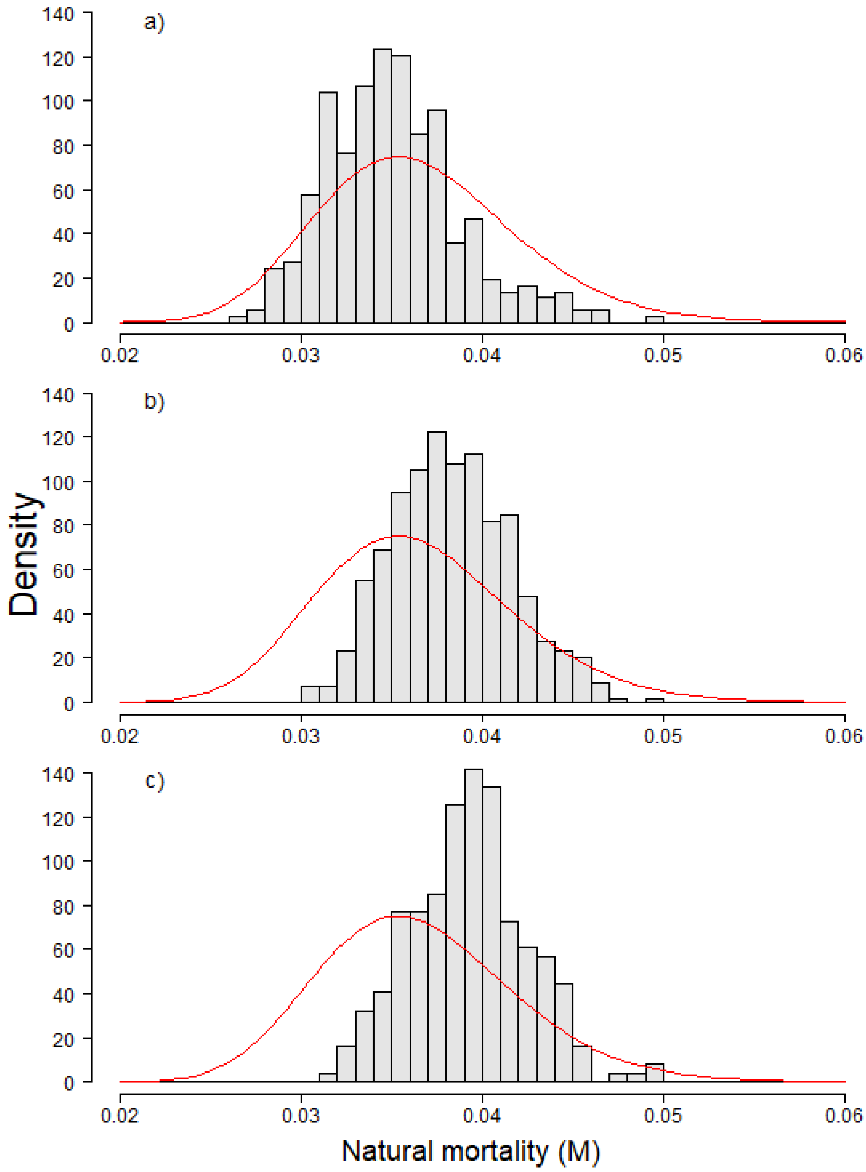


Figure A 10.1. Histograms of natural mortality estimates from posteriors of candidate 2021 preliminary base-case models with plus-groups at 80 (a), 100 (b) and 120 (c) years. The red line represents the log-normal prior used to estimate *M* within the models. Reproduced from the preliminary base-case assessment (Burch and Curin Osorio 2021).

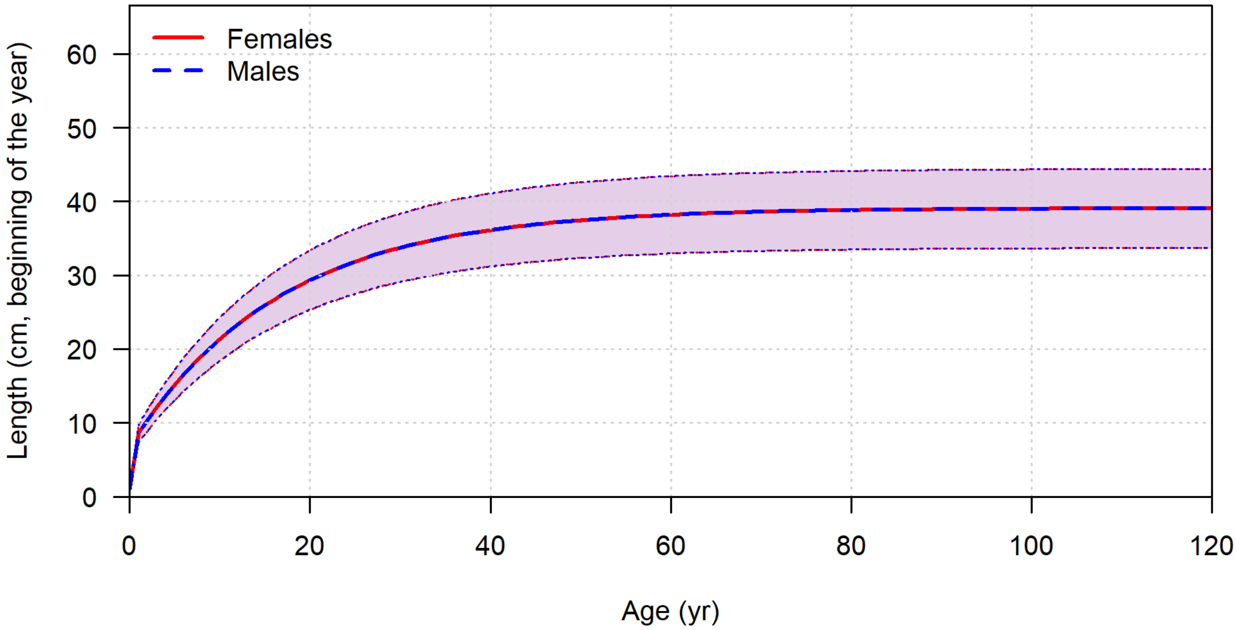


Figure A 10.2. Prespecified growth for the 2021 base-case model.

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(R₀) → $ln(R_0)$	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

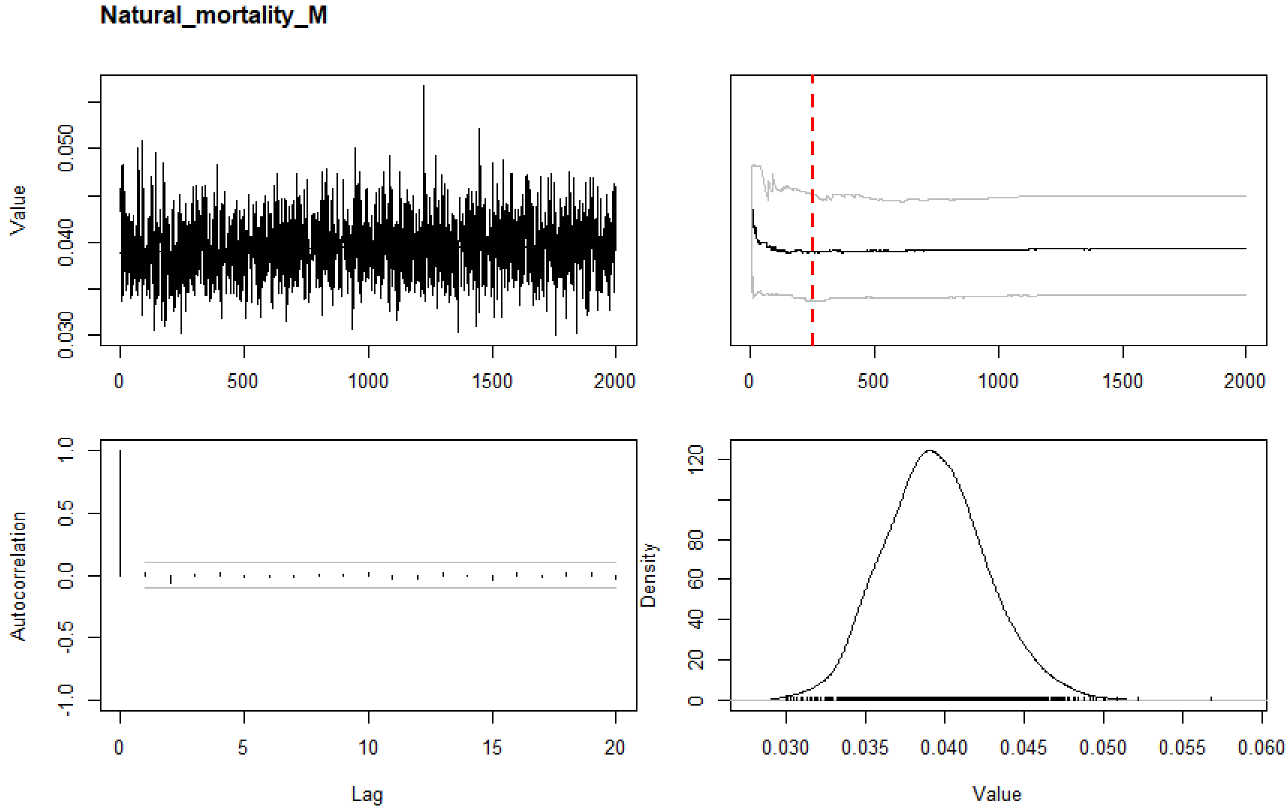


Figure A 10.3. Plots of traces (top left), moving average (top right), autocorrelations (bottom left), and density (bottom right) for natural mortality from 2,000 samples of the posterior from the MCMC analysis of the 2021 base-case model. The dashed red line indicates the additional burn-in of 250 samples that has been excluded for providing management advice.

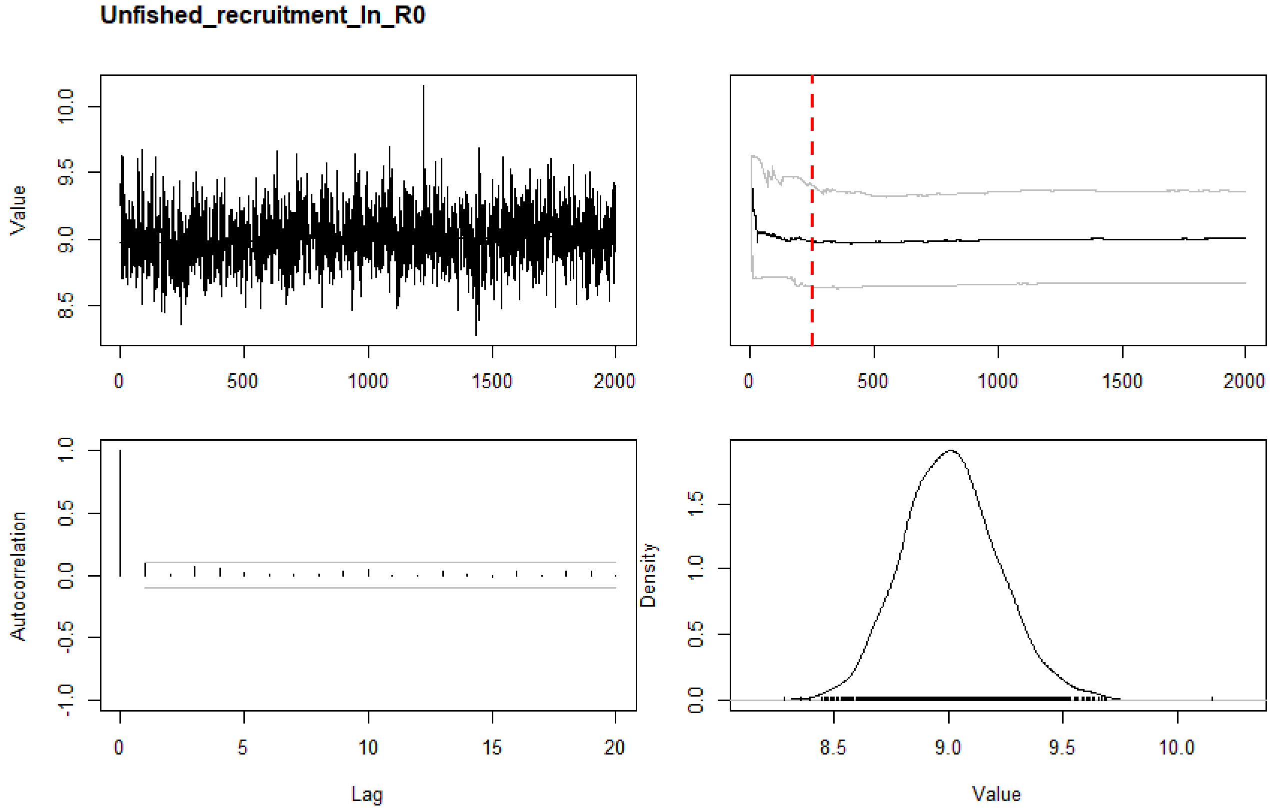


Figure A 10.4. Plots of traces (top left), moving average (top right), autocorrelations (bottom left), and density (bottom right) for unfished recruitment (ln(R0)) from 2,000 samples of the posterior from the MCMC analysis of the 2021 base-case model. The red dashed line indicates the additional burn-in of 250,000 samples from the posterior that has been excluded for providing management advice.

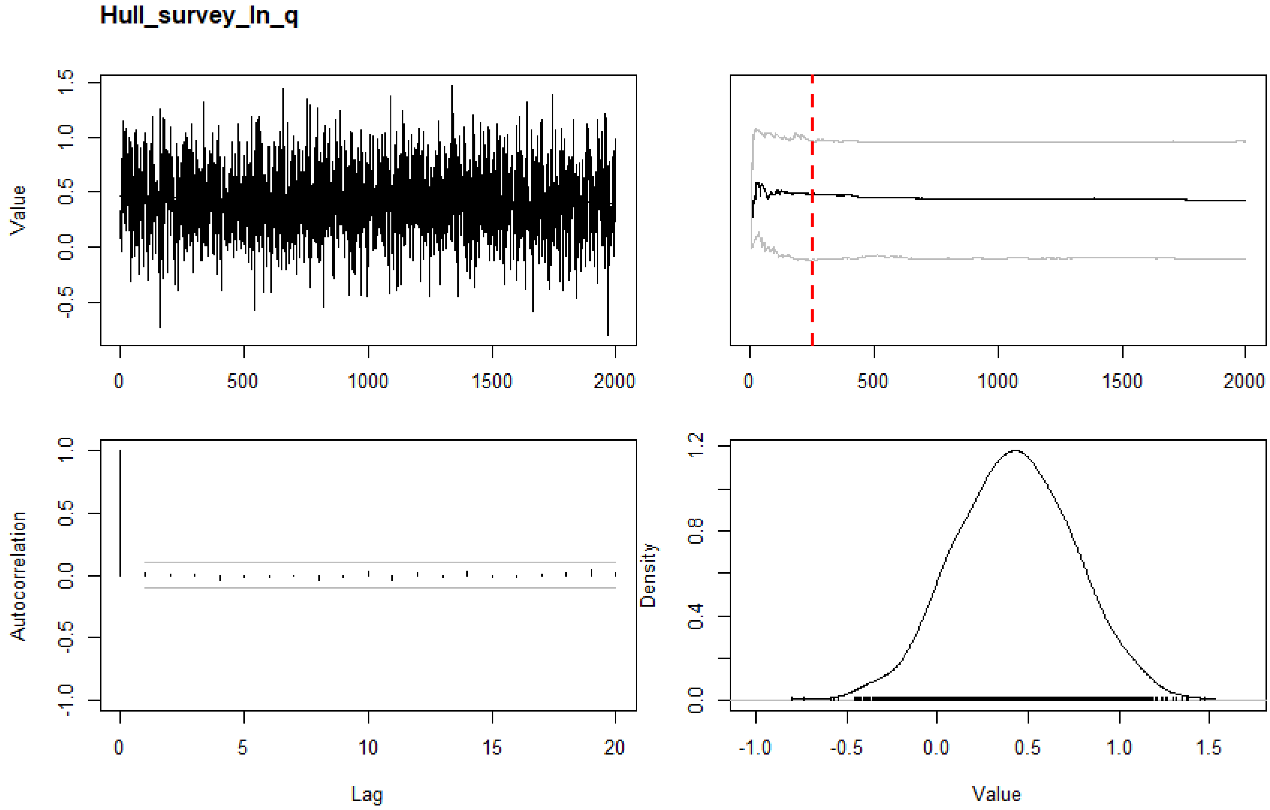


Figure A 10.5. Plots of traces (top left), moving average (top right), autocorrelations (bottom left), and density (bottom right) for catchability of the hull acoustic survey (ln(q)) from 2,000 samples of the posterior from the MCMC analysis of the 2021 base-case model. The red dashed line indicates the additional burn-in of 250,000 samples from the posterior that has been excluded for providing management advice.

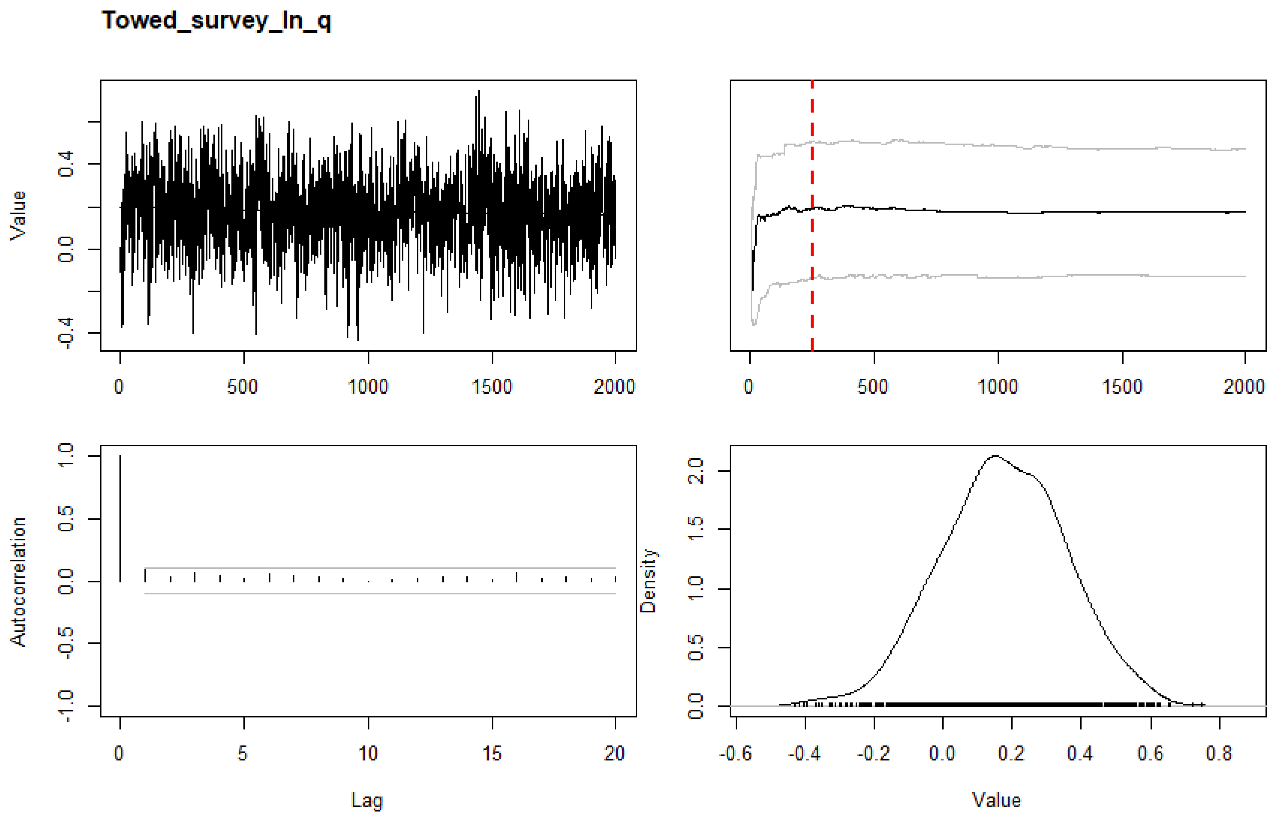


Figure A 10.6. Plots of traces (top left), moving average (top right), autocorrelations (bottom left), and density (bottom right) for catchability of the towed body acoustic survey (ln(*q*)) from 2,000 samples of the posterior from the MCMC analysis of the 2021 base-case model. The red dashed line indicates the additional burn-in of 250,000 samples from the posterior that has been excluded for providing management advice.

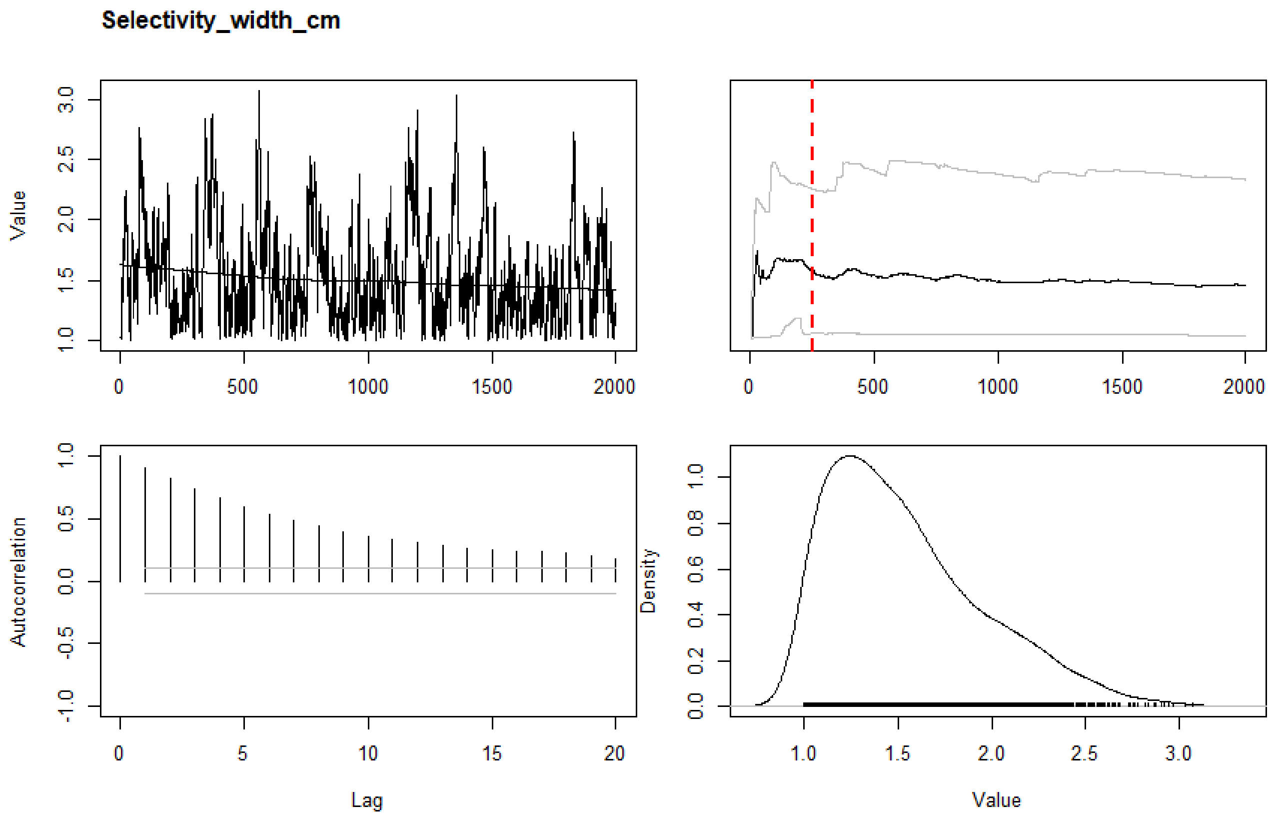


Figure A 10.7. Plots of traces (top left), moving average (top right), autocorrelations (bottom left), and density (bottom right) for the width parameter of the logistic selectivity function from 2,000 samples of the posterior from the MCMC analysis of the 2021 base-case model. The red dashed line indicates the additional burn-in of 250,000 samples from the posterior that has been excluded for providing management advice.

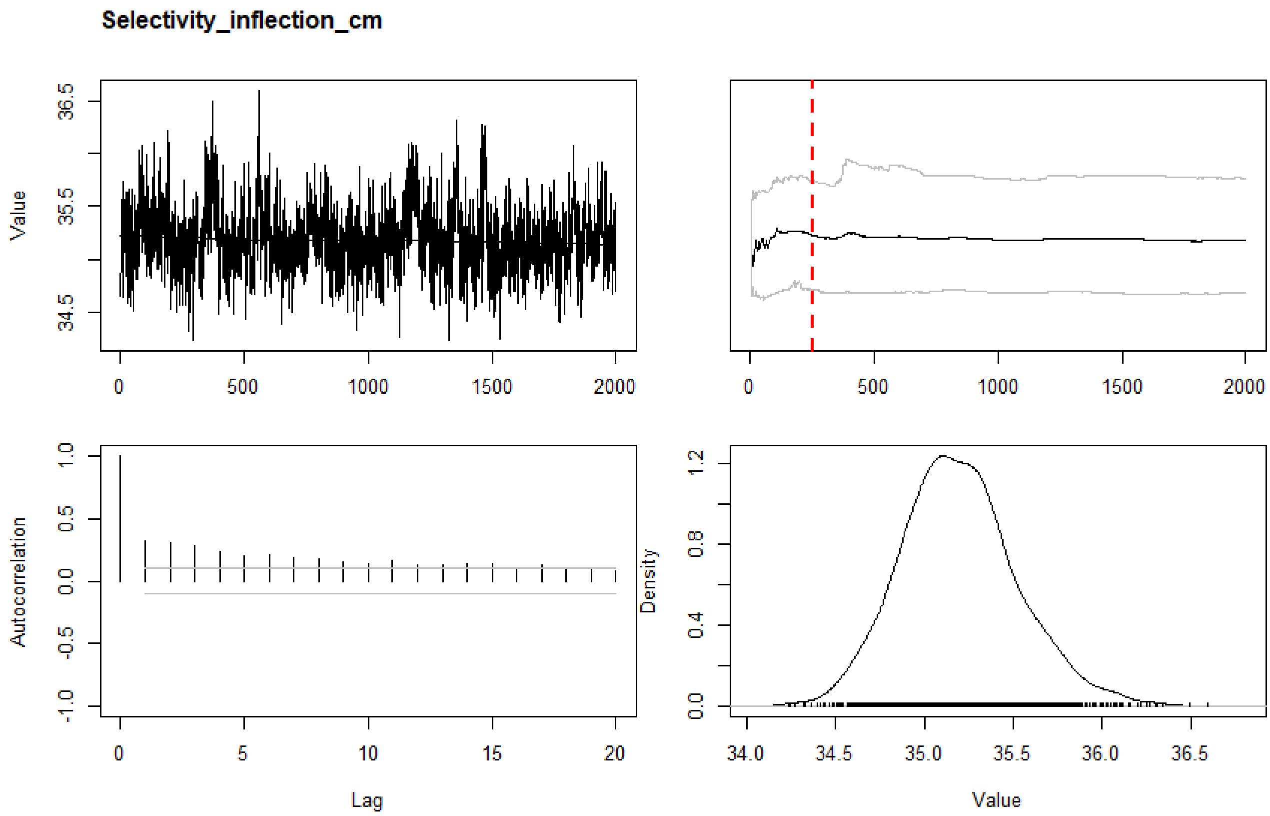


Figure A 10.8. Plots of traces (top left), moving average (top right), autocorrelations (bottom left), and density (bottom right) for the inflection parameter of the logistic selectivity function from 2,000 samples of the posterior from the MCMC analysis of the 2021 base-case model. The red dashed line indicates the additional burn-in of 250,000 samples from the posterior that has been excluded for providing management advice.

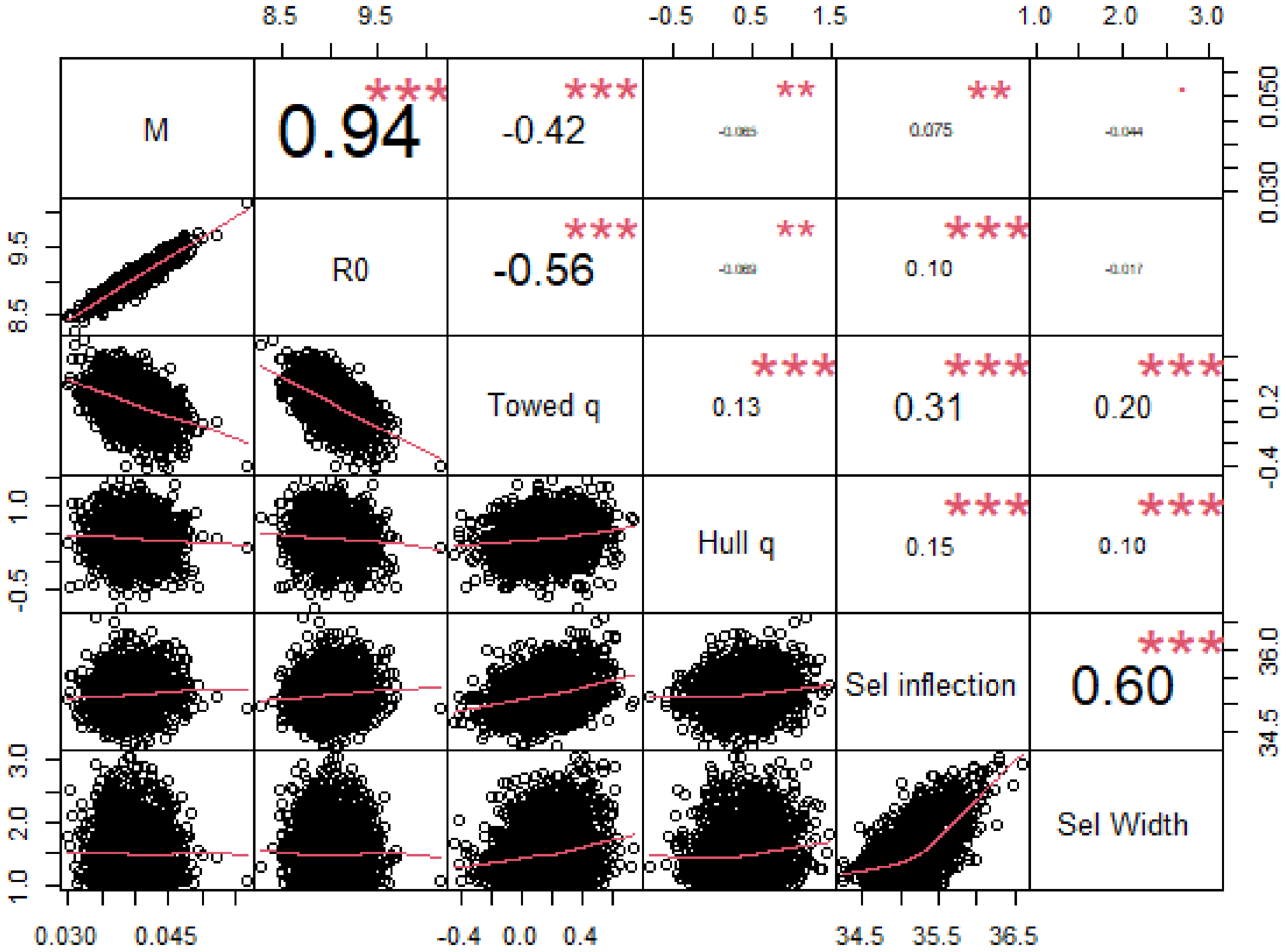


Figure A 10.9. Cross correlations between parameters estimated parameters from 1,750 samples of the posterior from the MCMC analysis of the 2021 base-case model. The numbers in the diagonal above the parameter names are the Pearson correlation coefficients.

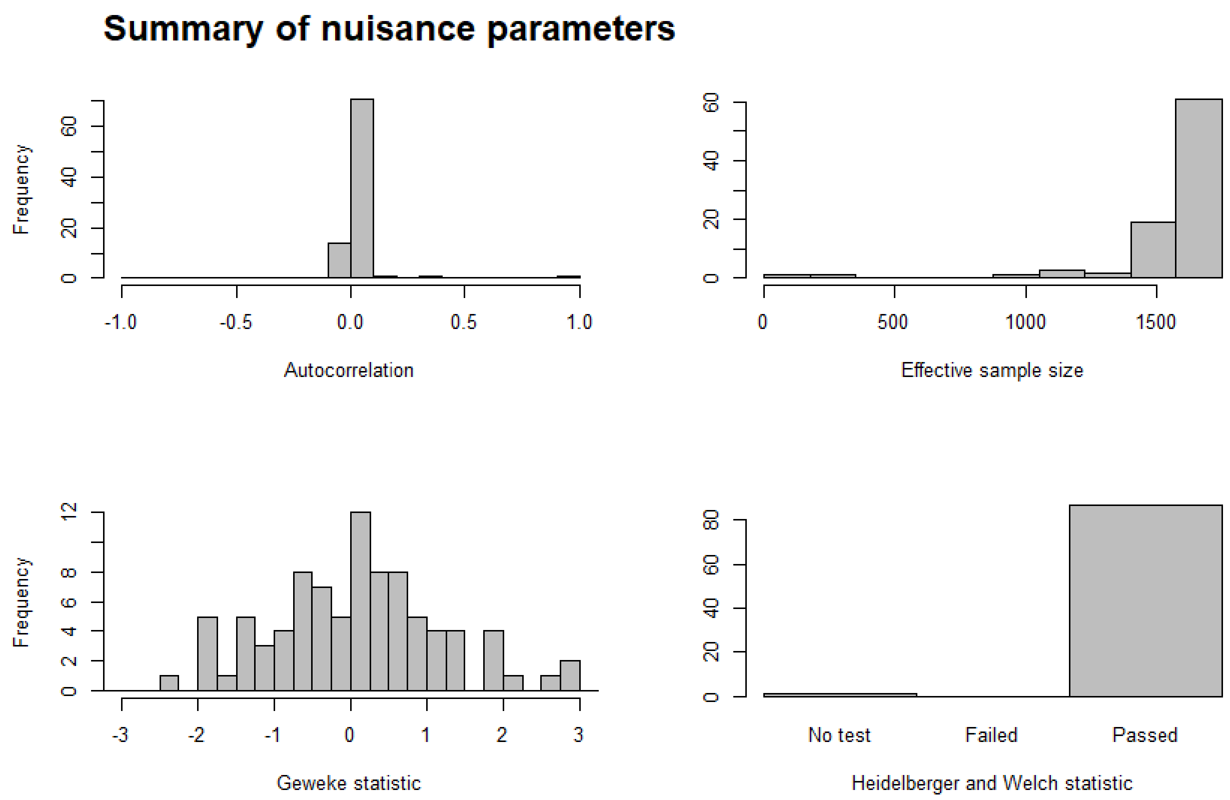


Figure A 10.10. Histograms of autocorrelation, the Geweke statistic, the effective sample size (N_{eff}/N) and the Heidelberger-Welch convergence diagnostics for the 82 estimated recruitment deviations from 1,750 samples of the posterior from the MCMC analysis of the 2021 base-case model.

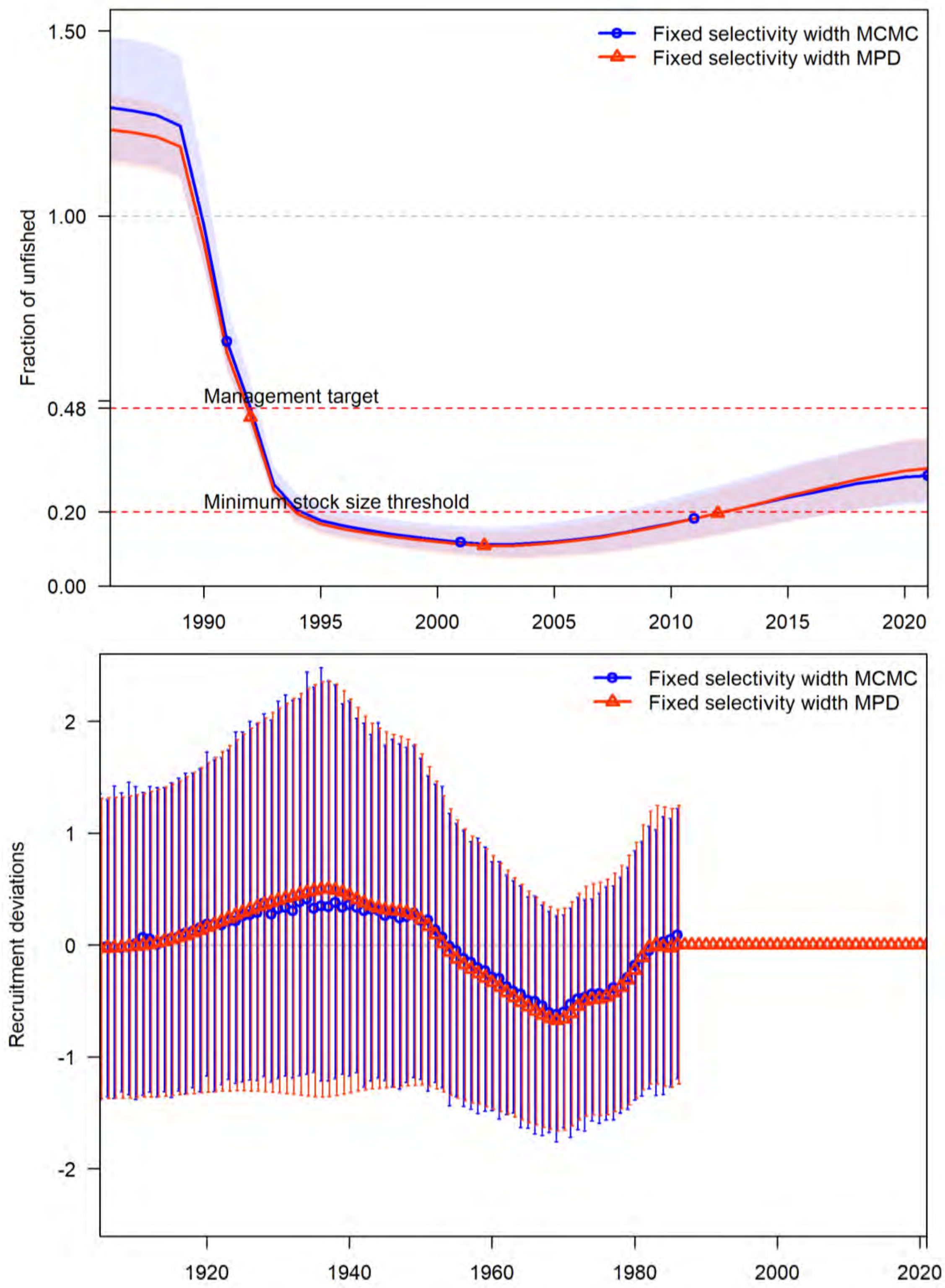


Figure A 10.11. Comparison MPD and MCMC estimates of time-series of relative spawning biomass and recruitment residuals (with ~95% intervals) for the sensitivity to the 2021 base-case model with the selectivity width parameter fixed at its MPD estimate. The red line and shading represent the point estimate 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.

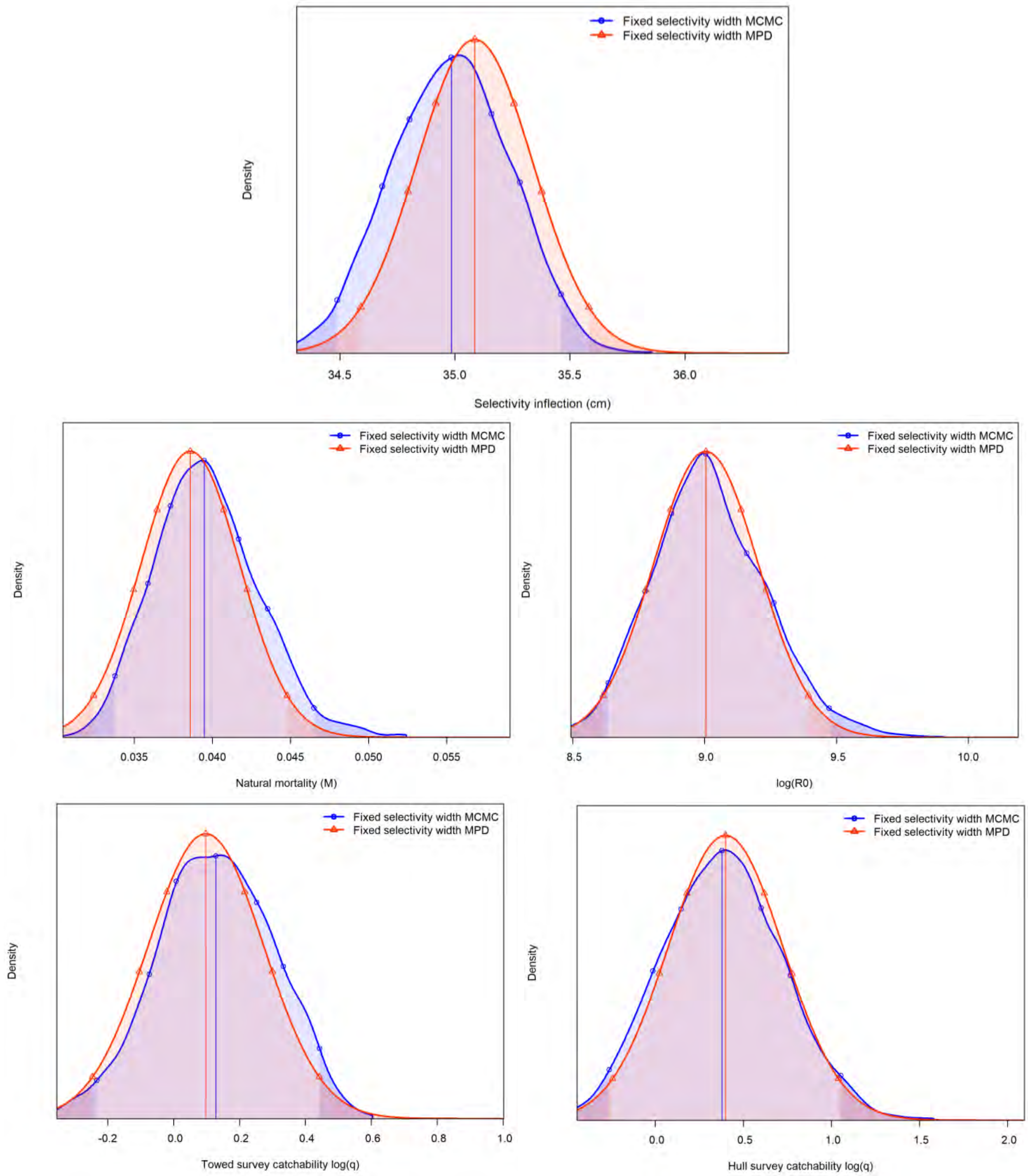


Figure A 10.12. Comparison MPD and MCMC estimates of the logistic selectivity inflection (top), natural mortality (middle left) unfished recruitment (middle right) and catchability for the towed (bottom left) and hull (bottom right) acoustic surveys for the sensitivity to the 2021 base-case model with 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.

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.

10.10 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.

Deng, R., Cannard, T., Burch, P. (2021). Integrated scientific monitoring program for the Southern and Eastern Scalefish and Shark Fishery – discards for 2020 Draft. Prepared for the SESSFRAG Data Meeting, 24-26 August 2021 (Report for the Australian Fisheries Management Authority). CSIRO Oceans and Atmosphere.

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.

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

Franzis Althaus	CSIRO Oceans and Atmosphere, Hobart, Tasmania
Pia Bessell-Browne	CSIRO Oceans and Atmosphere, Hobart, Tasmania
Paul Burch	CSIRO Oceans and Atmosphere, Hobart, Tasmania
Jemery Day	CSIRO Oceans and Atmosphere, Hobart, Tasmania
Roy Deng	CSIRO Oceans and Atmosphere, Hobart, Tasmania
Mike Fuller	CSIRO Oceans and Atmosphere, Hobart, Tasmania
André Punt	CSIRO Oceans and Atmosphere, Hobart, Tasmania
Miriana Sporcic	CSIRO Oceans and Atmosphere, Hobart, Tasmania
Robin Thomson	CSIRO Oceans and Atmosphere, Hobart, Tasmania
Geoff Tuck	CSIRO Oceans and Atmosphere, Hobart, Tasmania