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Stock assessment research for Chatham Rise orange roughy in 2023

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PLAIN LANGUAGE SUMMARY

- The orange roughy stock assessment research conducted in 2023 is described.

- A description of the fishery, including the spatial distribution, and commercial fishery catch rates, was completed for two ORH 3B stocks, the Northwest Chatham Rise, and the East & South Chatham Rise.

- Updated stock assessments were not completed. The reasons for this were problems caused by inconsistent orange roughy age data, the productivity of the stock (reproduction) being lower than expected, undue reliance on certain data sets in determining the results (especially orange roughy age and length data), problems in interpreting the biomass survey data used to inform the model about stock trends, and problems with technical population model specifications, including how model parameters were estimated.

- Possible solutions to the problems are discussed, including the possible benefits of spatially resolved population models, or alternatively the use of greatly simplified population models.

- Future research is suggested to help resolve the problems encountered in 2023.

EXECUTIVE SUMMARY

Dunn, M.R.[1] **(2024). Stock assessment research for Chatham Rise orange roughy in 2023.**

New Zealand Fisheries Assessment Report 2024/46. **36 p.**

The overall objective of this research was to complete assessments of the orange roughy (*Hoplostethus atlanticus*) stocks within ORH 3B on the Northwest Chatham Rise and on the East & South Chatham Rise. The fisheries were characterised but the stock assessments were not completed. There were three main reasons why the assessments were not a simple update of the previous assessments:

(1) The characterisation of the fishery was not consistent with the previous stock assessment model stock status estimates, which suggested that the model(s) may be wrong. The models estimated the stocks to be increasing and within the management target zone, but the fishery statistics suggested catching orange roughy had instead become harder.

(2) The stock assessment models estimated stock biomass to be substantially greater than measured by acoustic surveys. For the Northwest Rise, the model spawning stock biomass (SSB) was 40% higher than observed, and for the east & south Chatham Rise the SSB just over 100% larger than observed. For the east & south stock, the acoustic survey series was flat or declining whilst the model SSB was increasing.

(3) The new age data could not be fitted in the existing model structure, and the cause of the variability in age samples was not determined. The availability of age data was used to justify the estimation of year class strengths, and year class strength estimation was necessary to get acceptable fits to data, and thus accepted stock assessment models. Without age data the models would need to assume constant recruitment, and this assumption has been comprehensively rejected for New Zealand orange roughy.

Trials with CASAL stock assessment models identified some other issues with the model structure and assumptions, including: stock productivity was lower than expected; there was potential model over-parameterisation; length frequency data were too influential or unreliable; there was inconsistent biomass information from related data sets; trawl surveys of an area known as the Spawning Box were potentially biased; and there were changes in the spatial distribution of spawning biomass which were assumed but not measured. The research did not progress sufficiently to provide accepted revised stock assessments before May 2023.

[1] National Institute of Water & Atmospheric Research Ltd.

1. INTRODUCTION

The orange roughy (*Hoplostethus atlanticus*) have been the target of commercial fisheries around New Zealand, Australia, Indian Ocean, southeast Pacific, southeast Atlantic, and north Atlantic (Tingley & Dunn 2018). In New Zealand, the largest orange roughy fisheries have been on Chatham Rise (part of ORH 3B; Figure 1) (Fisheries New Zealand 2023).

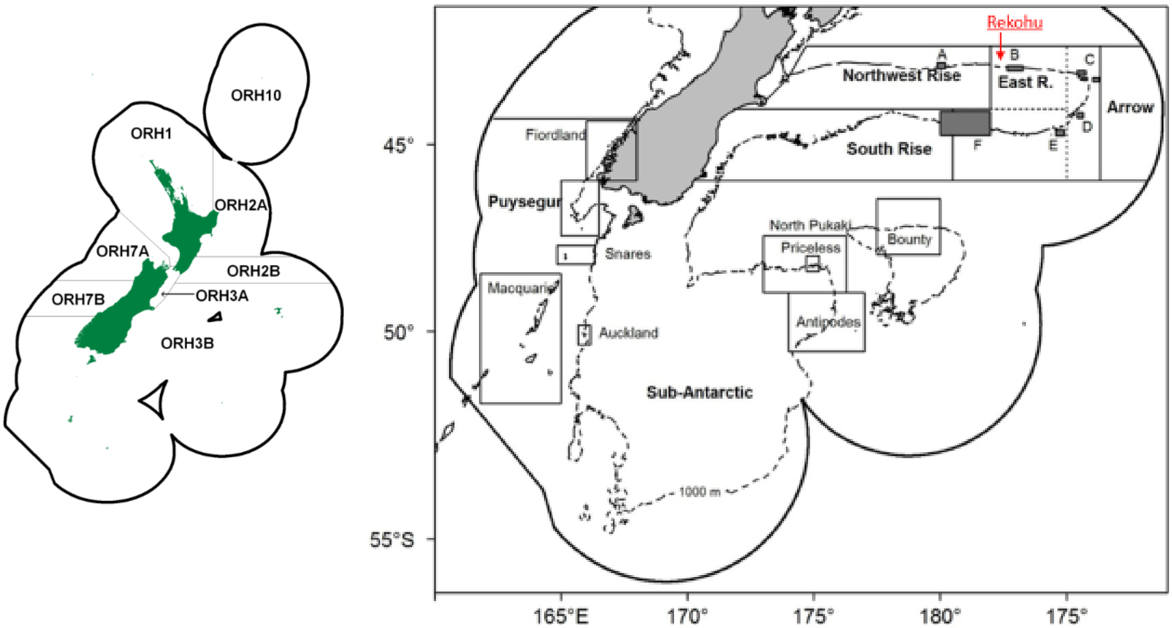


Figure 1: New Zealand Quota Management Areas for orange roughy (left panel), and the ORH 3B fishery areas (right panel) with approximate positions of the main fishing grounds/ A, Graveyard hills; B, Spawning Box; C, Smith's City & neighbours; D, Andes complex; E, Big Chief & neighbours; F, South Rise (including Mt. Kiso & Hegerville). The Old Spawning Plume, Rehoku, and Mt Muck are all within the Spawning Box (B).

The overall objective of Fisheries New Zealand research project ORH2021-02 was to "To carry out stock assessments of the orange roughy stocks within ORH 3B on the Northwest Chatham Rise and on the East & South Chatham Rise including estimating biomass and sustainable yields", with specific objectives:

(1) To carry out a descriptive analysis of the commercial catch and effort data, survey data, and observer data for orange roughy on the Northwest Chatham Rise and in the East & South Chatham Rise.

(2) To complete stock assessments of the Northwest Chatham Rise and East & South Chatham Rise orange roughy stocks including biomass and sustainable yields, the status of the stocks in relation to management reference points, and future projections of stock status as required to support management.

This project was planned to be completed during the 2021–22 year but was deferred by one year. The deferral was because an acoustic biomass survey in winter 2021 was not completed, because of technical problems at sea. The survey was successfully completed in winter 2022.

The last descriptive analysis for the ORH 3B fisheries was reported by Anderson & Dunn (2012), using data to the end of the 2008–09 fishing year (New Zealand fishing years run 1 October to 30 September). Whilst several stock assessments were completed after 2008–09, the descriptive analyses were not updated. As part of the stock assessment research undertaken in 2023, this report updates those descriptive analyses to the 2021–22 fishing year.

The last accepted stock assessment of the Northwest Chatham Rise was completed in 2018 using data to 2016–17, and East & South Chatham Rise was completed in 2020 using data to 2018–19 (Fisheries New Zealand 2023). The Northwest Chatham Rise assessment in 2018 encountered problems incorporating new age data from 2016, which were ultimately excluded, and no progress was subsequently made in how to incorporate them (Dunn & Doonan 2018; Fisheries New Zealand 2023). This left the Northwest Chatham Rise assessment model informed by only a single age frequency (data from 1994) and, unlike the East & South Chatham Rise, the assessment was not updated after 2018. The East & South Chatham Rise assessment completed in 2018 (Dunn & Doonan 2018) was updated later that same year (Cordue 2018), and again in 2020 (Cordue 2021), although no new data other than catch history were added after Dunn & Doonan (2018).

The assessment of the Puysegur stock was last completed in 2017 using data to 2015–16 (Fisheries New Zealand 2023). Stock assessments for the other fisheries in the SubAntarctic region, including the fishery on Pukaki (North Pukaki, Priceless, and Antipodes) which was substantial in the early 2000s, have not been completed and their size and status remains unknown (Fisheries New Zealand 2023).

The New Zealand orange roughy stocks on the Challenger Plateau and Westpac Bank (ORH 7A), Northwest Chatham Rise, and South & East Chatham Rise, were first certified as well-managed and sustainable by the Marine Stewardship Council in December 2016 (fisheries.msc.org/en/fisheries/new-zealand-orange-roughy). The stocks were recertified in August 2022, with this certification expiring in August 2027.

This report should be read alongside the Fisheries New Zealand Fisheries Plenary report (Fisheries New Zealand 2023). A stock assessment was ultimately not completed in 2023. The confidence in the Northwest Chatham Rise assessment model (2018) was reduced, and the East &South Chatham Rise assessment status of the stock section was removed (Fisheries New Zealand 2023). This report does not describe all aspects of the research and modelling completed, rather it provides a summary and further information on the problems encountered.

2. METHODS

All data analyses were completed using R 4.2.2 (R Core Team 2022). The fishery characterisation that was completed and presented to the Fisheries New Zealand Deepwater Working Group is not shown in full in this report in accordance with the Fisheries New Zealand Data Release Clauses.

2.1 Catch and effort data

Commercial catch and effort data were requested from Fisheries New Zealand for all fishing trips between 1 October 1989 and 30 September 2022 that landed or targeted orange roughy in any fishing event (Fisheries New Zealand extract code 14587A). The data provided included the reported landings, effort, estimated catches, and vessel information.

Basic data grooming was conducted. Catch ranges were checked. Logged catch and its standard deviation were calculated for each vessel day, and any catches outside of the mean plus/minus three standard deviations were examined. Out of range checks (and median imputation by vessel day) were used for effort variables, depths, and target species. Missing depths were set to the median depth from all other fishing events reported within 1 nautical mile of the fishing location. Obvious errors in target species code were corrected, and highly unlikely target species codes replaced with NA. Missing catch weights were replaced with zeros, and if green weight was missing the records were deleted. Detailed standardised CPUE analyses were not conducted because of concerns in the interpretation of CPUE for orange roughy (Fisheries New Zealand 2023).

Ministry observer and orange roughy age data were obtained from the relevant Fisheries New Zealand databases. No grooming of these data was conducted during this project.

2.2 Stock assessment modelling

All stock assessment modelling used the CASAL software package (Bull et al. 2012), and initial CASAL input files were obtained from Dunn & Doonan (2018) and Cordue (2020 unpublished).

3. RESULTS

3.1 Characterisation of the fishery

Detailed descriptions of the fishery were presented to the Deepwater Working Group, but these are not presented here because of FNZ data restrictions.

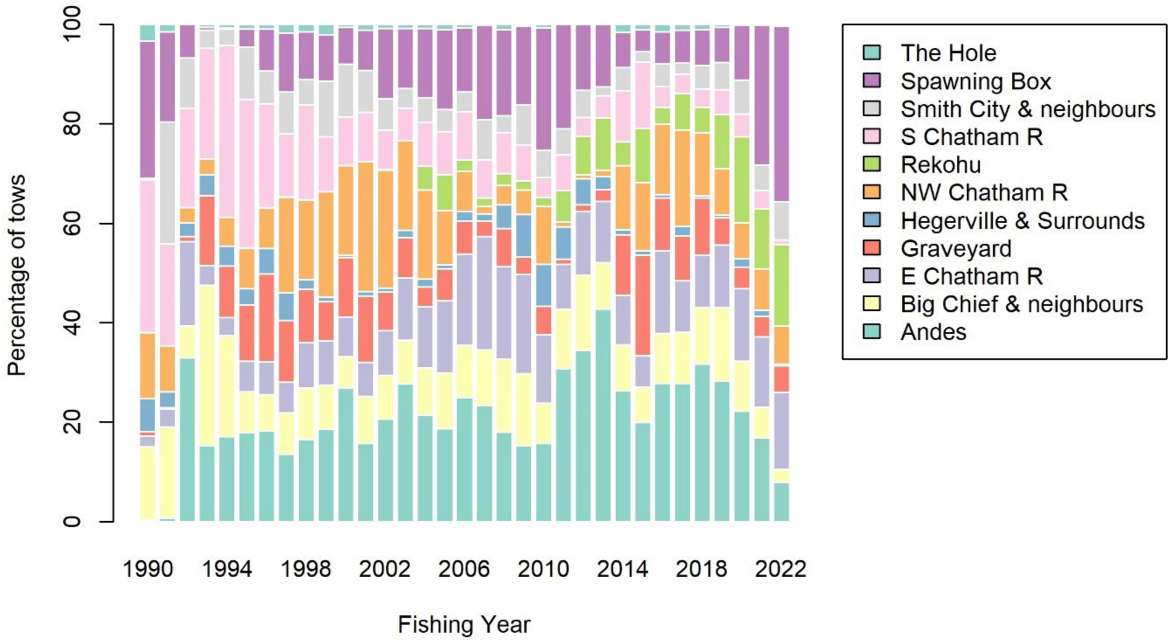
At the end of the period covered by the previous fishery characterisation (to 2008–09; Anderson & Dunn 2012), the orange roughy fishery had reduced in spatial coverage, and was focused on the Spawning Box extending to the eastern flank of Chatham Rise, Graveyard hill complex on Chatham Rise, Priceless and Pukaki region of the SubAntarctic, and a number of other catch 'hotspots' around the North Island. The Arrow Plateau was closed to orange roughy fishing when it was designated a Benthic Protection Area in 2007. By 2010–11 the Priceless and Pukaki fishery had largely ceased, the east and south Chatham Rise fishery was focused on the Spawning Box and southeast Rise (Andes, Chiefs hill complexes), on the northwest Chatham Rise around the Graveyard hill and at the far west of Chatham Rise, the latter actually being part of the Mid-East Coast stock. By 2013–14, the Graveyard fishery and SubAntarctic fisheries were greatly reduced. From 2017–18, the eastern Chatham Rise fishery slightly increased in spatial coverage, and the Puysegur fishery was more apparent. After 2018–19, the New Zealand orange roughy fisheries were essentially dominated by the Spawning Box, with the northwest Chatham Rise and areas around the North Island reduced. In 2020–21, the fishery was more extensive along the northeast Chatham Rise, and the southeast Chatham Rise area was further reduced; the spatial expansion of the Challenger fishery was also particularly apparent in this year. Therefore, over the last decade the orange roughy fishery reduced from around 10 (or more) catch hotspots around New Zealand, to one main fishery in the Spawning Box, with three lesser areas on Challenger Plateau, at Puysegur, and the eastern part of the West Norfolk Ridge (west of the northern tip of the North Island).

On Chatham Rise, effort in 2021–22 in the Spawning Box reached a since-1990 historical high, and accounted for just over half of the catch (Figure 2). Rekohu has been reported separately, but geographically is within the Spawning Box, and if included then about 60% of effort and nearly 90% of catch in 2021–22 was taken in the Spawning Box and Rekohu fisheries. The south Chatham Rise fisheries were developed from the early 1990s (when the Spawning Box was closed), and for much of the fishery history around 30–40% of the effort and 20% or more of the catch was taken from these fisheries, including notably the Chiefs and Andes hill complexes. However, effort and catches in the south Chatham Rise fisheries decreased substantially after 2018–19, such that in 2021–22 effort was still apparent but catch was negligible.

On the east & south Chatham Rise, about two thirds of the catch in 2018–19 was taken from the non-spawning fishery, but this steadily shifted towards a greater contribution from the spawning fishery, which in 2021–22 accounted for about 90% of the catch (Figure 3). The fishery on northwest Chatham Rise has shown a contrasting trend, with the proportion of the catch coming from the spawning fishery (June and July) decreasing, to about 20% in 2020–21. When last characterised (Anderson & Dunn, 2012), the fishery was predominantly a spawning fishery with around 60–85% of the catch taken during June and July. On northwest Chatham Rise, the main spawning aggregation was historically found on the Graveyard hill (open to fishing), but recently has been on Morgue (closed to fishing since 2001); this likely accounts for the trend away from spawning season catches.

In the SubAntarctic, when last characterised about 50% of the catch was taken during the spawning season, largely because of what was then a 'new' fishery at Priceless. In recent years, the SubAntarctic was often unfished for half or more of the year, with substantial gaps in fishing trips, and an increase in catch uptake during the spawning season (June and July) was not apparent.

Tows of short duration (often half an hour or less) are associated with targeting orange roughy aggregations and/or fishing tow lines on features where orange roughy are known to aggregate. For the northwest Chatham Rise, before 2016–17 at least half the catch was taken from tows with duration of an hour or less, and in many years most catch was taken by tows of less than 20 minutes. Since 2016–17, more than half the catch was taken from tows that were long, with about 50–80% taken by tows of two hours or more (Figure 4). For the east & south Chatham Rise, until 2018–19 most catch was taken from tows of 40 mins or less, and about half from tows 20 mins or less. However, from 2019–20 half or more of the catch was taken by longer tows of an hour or more.



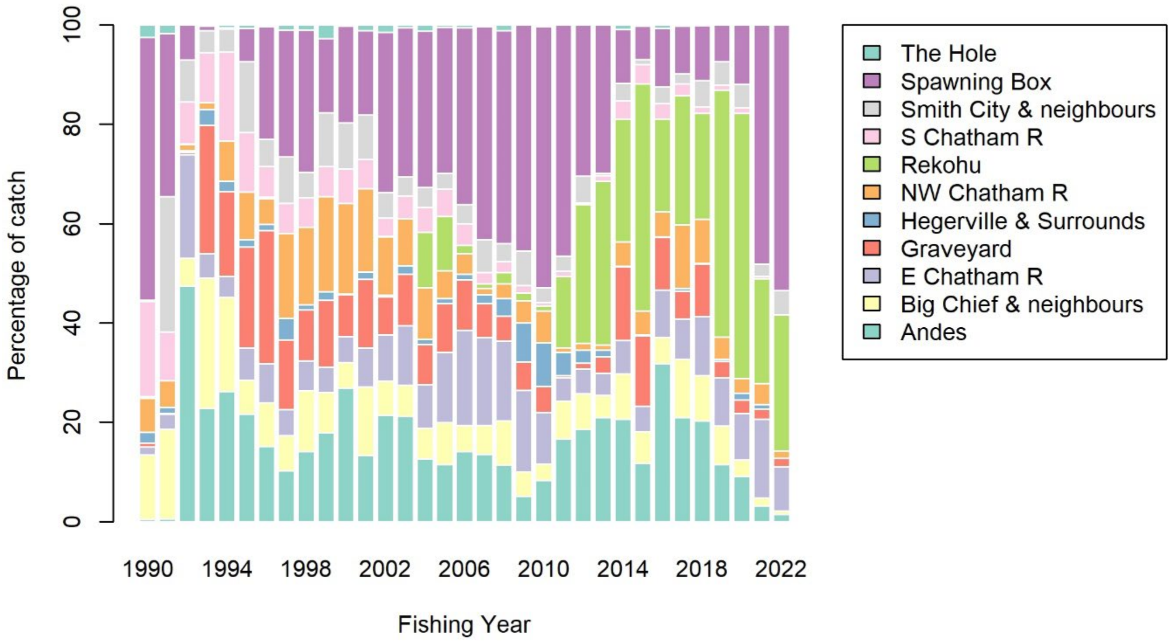


Figure 2: Percentage of orange roughy target catch (bottom) and effort (as tows) (top) on Chatham Rise by subarea and fishing year. Years are labelled with the final calendar year such that e.g., 2022 refers to the fishing year 2021–22.

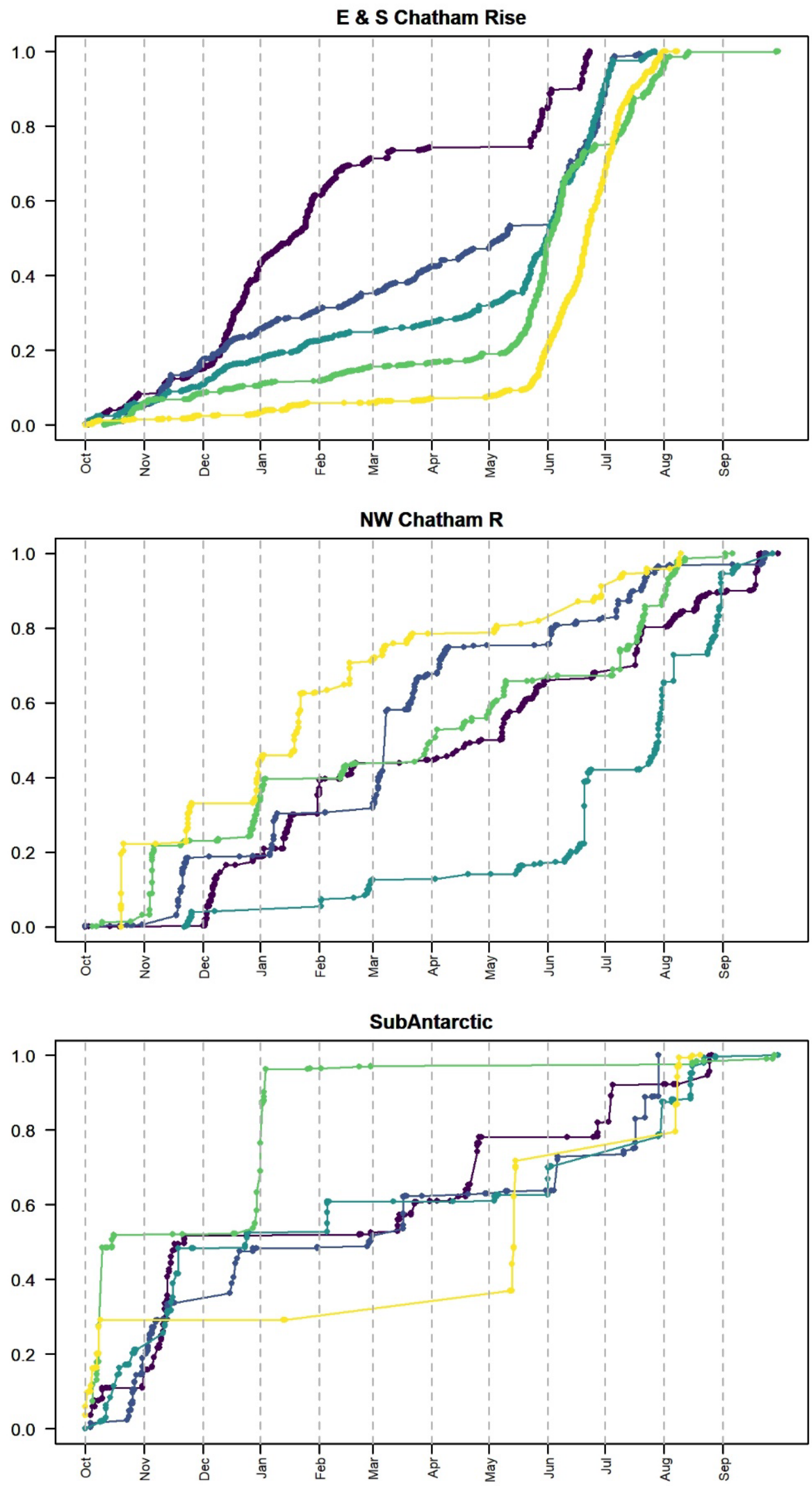
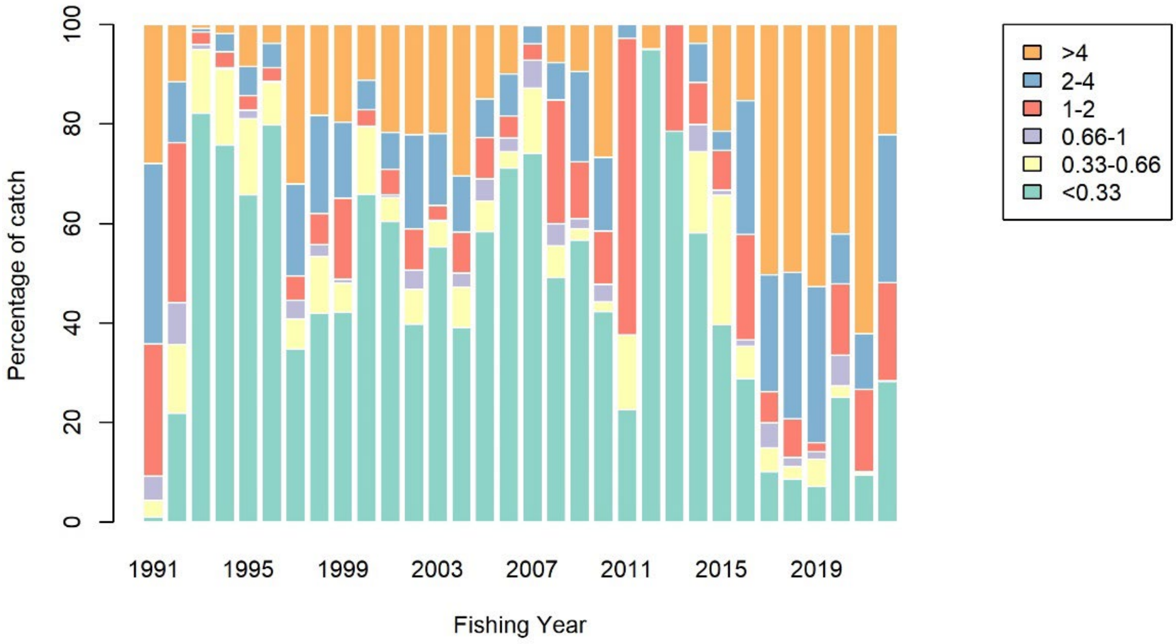


Figure 3: Cumulative catches and effort in ORH 3B. Catches are summed in chronological order through the fishing year and scaled to the total estimated catch for the year. Each point represents the relative accumulated catch after the addition of the catch from each new trawl. The last five fishing years are shown, from yellow (2021–22), through light green, blue/green, dark blue, and then purple (2017–18).



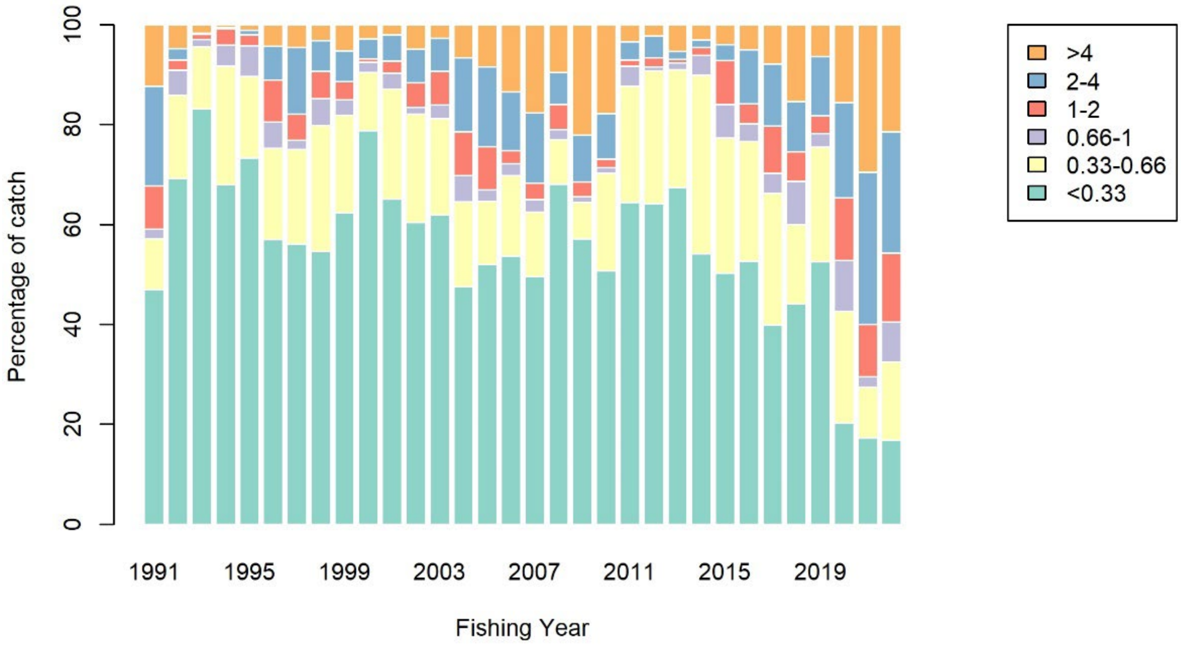


Figure 4: Orange roughy Chatham Rise percentage of catch taken by fishing year and tow duration (hours). Top panel, northwest Chatham Rise; bottom panel, east & south Chatham Rise. Years are labelled with the final calendar year such that e.g., 2022 refers to the fishing year 2021–22.

At the last characterisation (to 2008–09), the SubAntarctic was still showing a pattern of sequential fishing of features, but since then the fishery has remained relatively stable, with fishing resuming at Puysegur, and a few new areas added also in that region. Many areas of the SubAntarctic that historically supported orange roughy catches were no longer or rarely being fished.

The northwest Chatham Rise and east & south Chatham Rise do not show the same pronounced sequential fishing pattern. Since 2016–17, catches and effort on the northwest Chatham Rise were the most widespread since the early 1990s, including some new areas being recently fished. The spatial distribution of catches on the east & south Chatham Rise included few or no new areas fished since the early 1990s but was recently quite different to that in the early 1990s.

One vessel has fished the SubAntarctic for over 30 years, but during the 1990s there was a steady progression of other vessels joining and then leaving, and another vessel joined in 1998–99, such that two vessels subsequently dominated the fishery. On the northwest Chatham Rise, there was a transition in fleet composition in the late 1990s, then after 2008–09 one or two vessels have tended to dominate the catch in any given year. The east & South Chatham Rise showed the same transition in fleet composition in the late 1990s, with two or three vessels dominating the catch after then, until 2019–20, when the number of vessels increased and eight notably contributed to the catch in 2021–22.

On the northwest Chatham Rise, unstandardised CPUE have been flat or declining, and were at historical lows in 2016–17 and 2021–22 (Figure 5, bottom two rows). On the east & south Chatham Rise, unstandardised CPUE have generally been flat or slowly declining since 2010–11, and were at historical lows within the last two years for non-spawning fisheries at Andes complex, Big Chief & neighbours, and Hegerville & neighbours; but generally flat or variable for Smith City & neighbours and the spawning fisheries.

3.2 Fishery performance and assessment model results

The 2018 accepted stock assessment estimated that the Northwest Chatham Rise Spawning Stock Biomass (SSB) declined until about 2003–04, followed by a steady biomass rebuild. The biomass was estimated to have roughly doubled between the low point, 2003–04, and 2016–17, and was at 38% B_0 in 2016–17 (Figure 6).

The Northwest Chatham Rise fishery took 17% of the agreed catch limit in 2021–22 (Fisheries New Zealand 2023, ORH 3B chapter tables 2 and 3). About 20% of the recent catch was taken during the spawning season, compared to 60–85% historically. This may be because the main spawning aggregation now occurs on the Morgue hill which was closed to bottom fishing in 2001, rather than the Graveyard hill which remains open to fishing. The recent fishery used more long tows on flat ground, rather than short tows on features. Unstandardised CPUE have been flat or declining and were at historical lows in 2016–17 and 2021–22.

The 2020 East & South Chatham Rise assessment estimated that the SSB trend was roughly flat from about 1994–95, with a steady rebuild after 2009–10. The biomass was estimated to have increased by about 45% between the low point, 2007–08, and 2019–20, and was at 36% B_0 in 2019–20 (Figure 7).

The East & South Chatham Rise fishery took 103% of the agreed catch limit in 2021–22 (Fisheries New Zealand 2023, ORH 3B chapter tables 2 and 3). Since about 2015–16, the fishery changed from 65–90% caught in short tows of <1 hour duration on features and outside of the spawning season, to 50–60% caught in long tows of >2 hours duration and about 90% taken during the spawning season. The number of vessels in the fishery recently increased. Unstandardised CPUE were flat or slowly declining since 2010–11, and were at historical lows within the last two years for non-spawning fisheries at Andes complex, Big Chief & neighbours, Hegerville & neighbours, and Rest of South, but generally flat or variable for Smith City & neighbours and the spawning fisheries.

The stock biomass and trends estimated by the models therefore seemed inconsistent with the performance of the fishery. The assessment models estimated current stock size to be similar to that last seen in the early 1990s, when unstandardised catch rates in the non-spawning fisheries were roughly 2–10 times greater. Rather than increasing, recent catch rates were flat or declining.

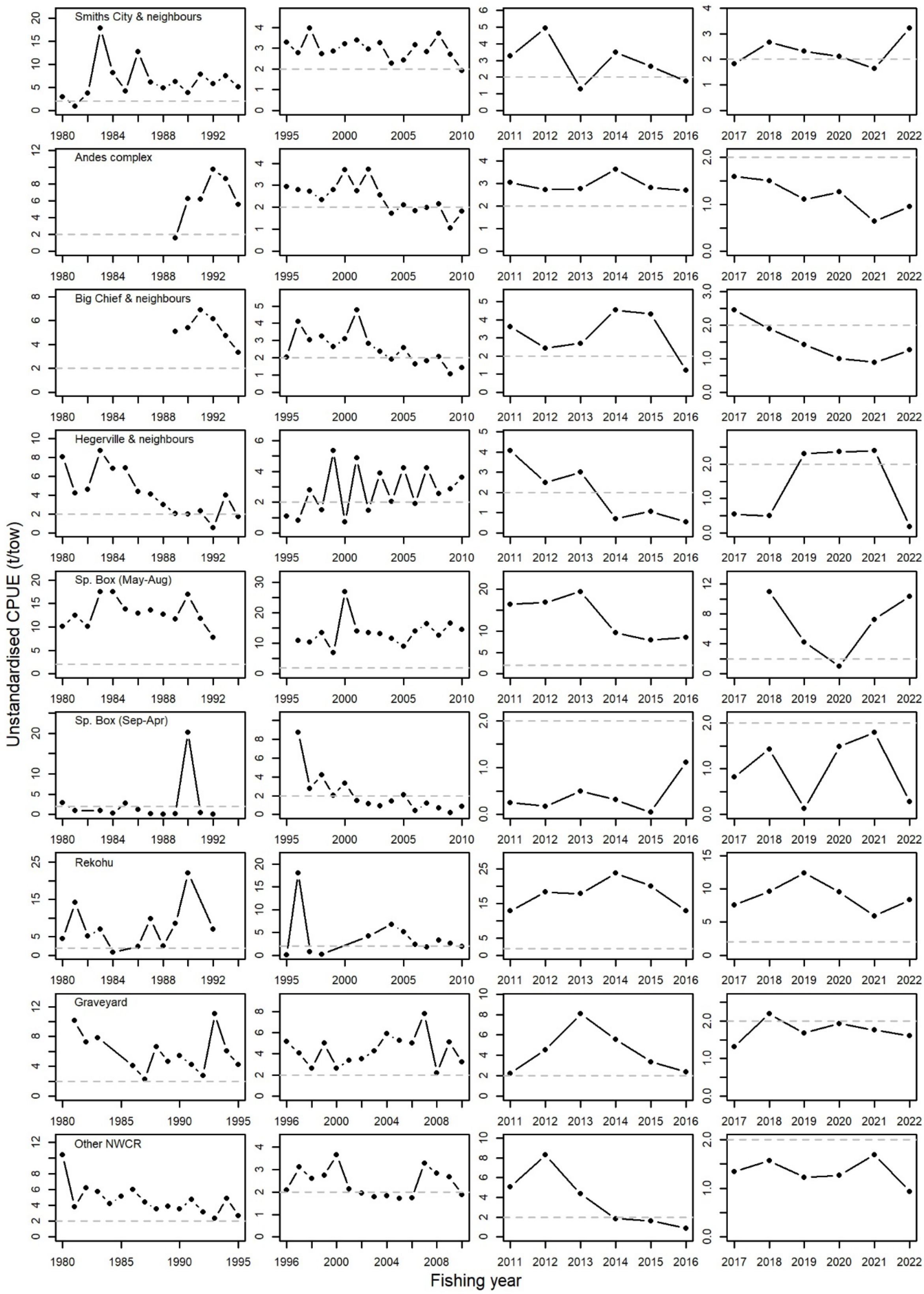


Figure 5: Unstandardised ORH target catch per unit effort (total tonnes divided by total tows) for selected subareas of the Chatham Rise, for selected time periods. The horizontal broken line marks 2 t/tow in all panels, and is only included to aid comparison across time periods.

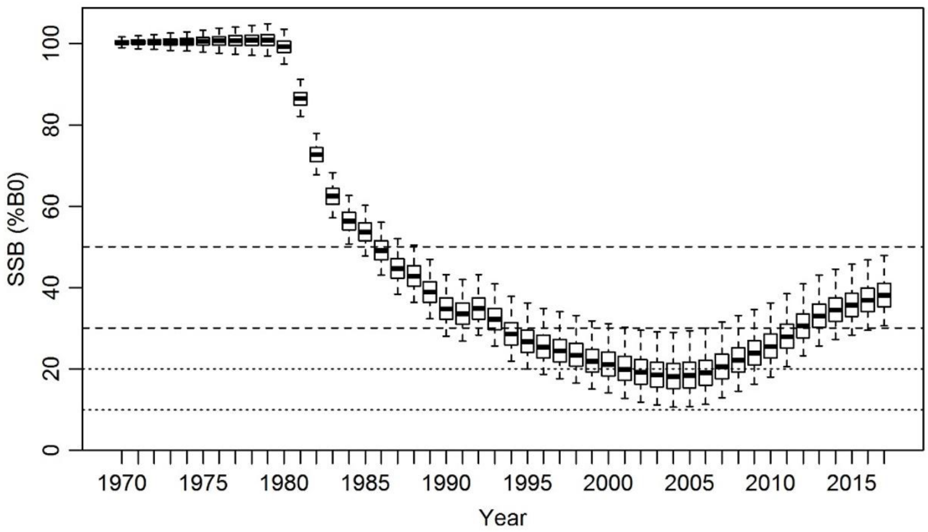


Figure 6: Northwest Chatham Rise, stock assessment model MCMC estimated spawning-stock biomass trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. Dotted lines indicate the hard limit (10% B_0) and soft limit (20% B_0), and dashed lines the management target range (30–50% B_0). Reproduced from Fisheries New Zealand (2023).

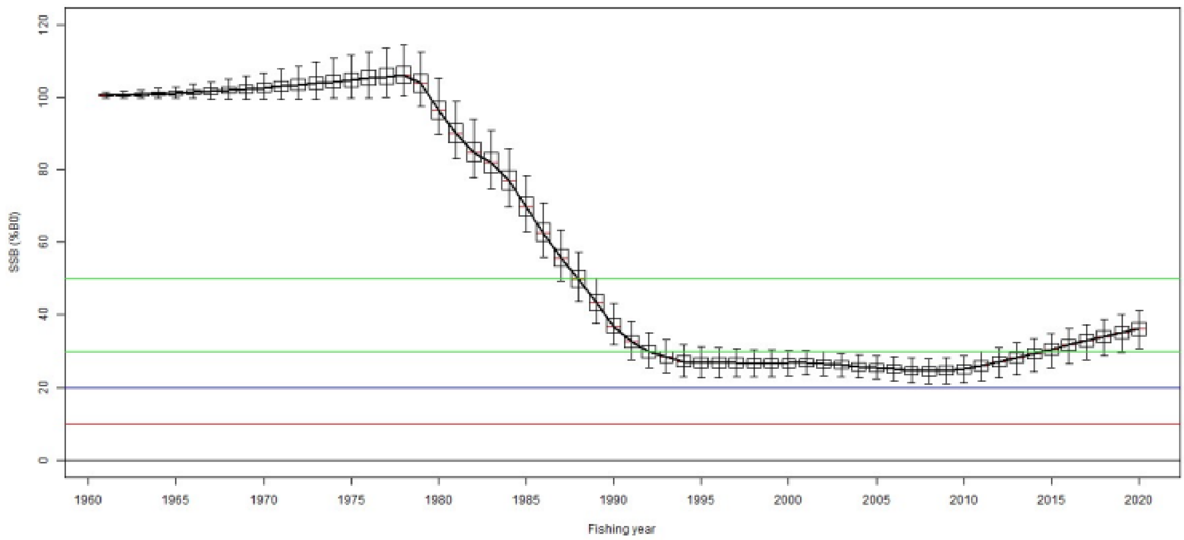


Figure 7: East & South Chatham Rise, stock assessment model MCMC estimated spawning-stock biomass trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. Lines indicate the hard limit (10% B_0) and soft limit (20% B_0), and the management target range (30–50% B_0). Reproduced from Fisheries New Zealand (2022).

3.3 Acoustic spawning biomass surveys

New acoustic biomass estimates were available from surveys in 2021 (Morgue) and 2022 (Old Spawning Plume, Rekohu, Mt. Muck, Graveyard, Morgue) (Figure 8). Acoustic biomass estimates for these years and locations were calculated as the arithmetic mean of snapshot biomass estimates. For

2022, the snapshots included were all derived from the 38 kHz system of either the vessel or the towed Acoustic Optical System (AOS), and the snapshots included in each estimate were:

- Morgue: Snapshots 1–4 (all AOS).
- Graveyard: Snapshot 1 (AOS, only one estimate available).
- Old Spawning Plume: Snapshots 1 (vessel sounder) and 2–4 (AOS) combined.
- Rekohu: Snapshots 1–4 (vessel) and 5–6 (AOS) combined.
- Mt. Muck: Snapshots 1–2 (AOS).

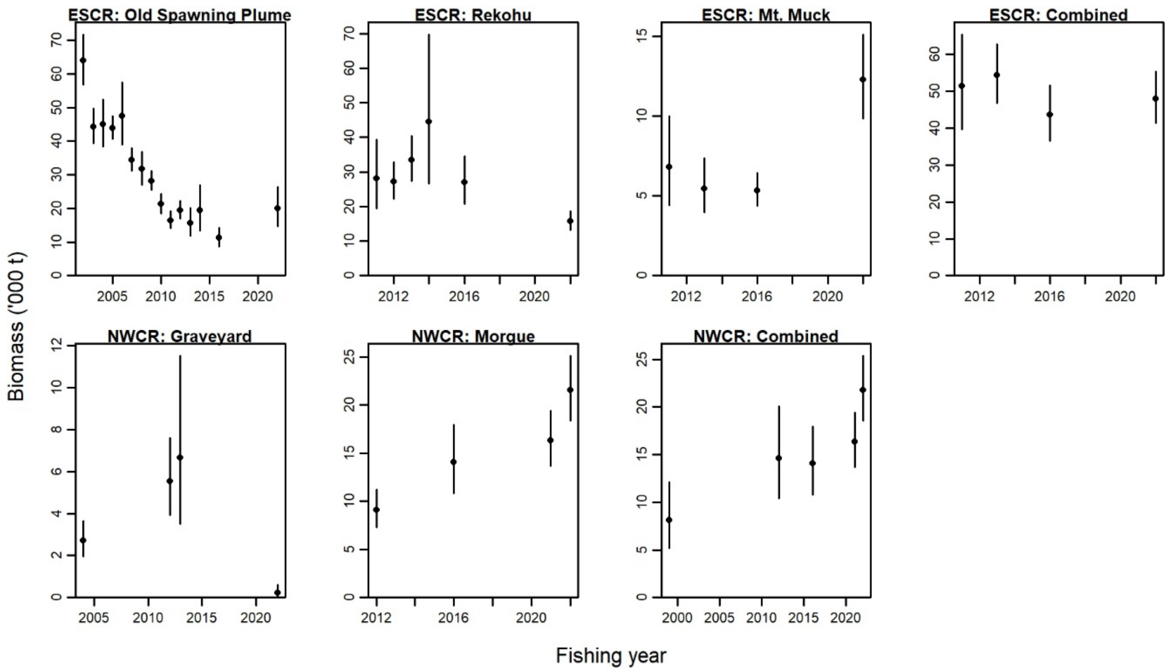


Figure 8: ORH 3B sub-areas and biomass estimates from acoustic surveys. ESCR, East & South Chatham Rise; NWCR, northwest Chatham Rise. Vertical lines indicate 95% CI.

3.4 Age frequency compositions

Otoliths were aged following selection of otoliths using the pre-ageing weighted sample selection method of Doonan et al. (2013). To produce total estimates for each stock the samples from the various spawning aggregations were combined, which was done as a weighted mean, weighting each age frequency by the number of fish (the associated acoustic biomass estimate divided by mean fish weight).

Whilst the age frequencies for the northwest Chatham Rise (Morgue) were broadly similar in 2016 and 2021, they were different for 2022, when the modal age was younger (Figure 9). The age frequency from 2016 was found to include a greater proportion of old fish than expected from the stock assessment model (and the same would be true for the 2021 sample), to the extent that the 2016 sample was excluded from the most recent stock assessment (Dunn & Doonan 2018).

The difference in the age frequencies from the east & south Chatham Rise in 2012 and 2013 was noted previously (Cordue, 2014). Whilst the 2016 age frequency was similar to 2012, the 2022 age frequency was different and included relatively few fish aged less than 40 years (Figure 10).

The estimated ages at length for the east & south Chatham Rise samples in 2022 barely overlapped with those from earlier years for Old Spawning Plume and Rekohu. For Morgue the 2022 ages at length tended to be substantially smaller for lengths less than 36 cm (Figure 11). Such patterns have been seen before (Figure 12), and although Hicks (Deepwater Working Group presentation, 2015) concluded at the time "the differences in age at length cannot easily be attributed to bias in the readings", the variability in age frequencies stimulated a revision of the orange roughy ageing protocols (Horn et al., 2016).

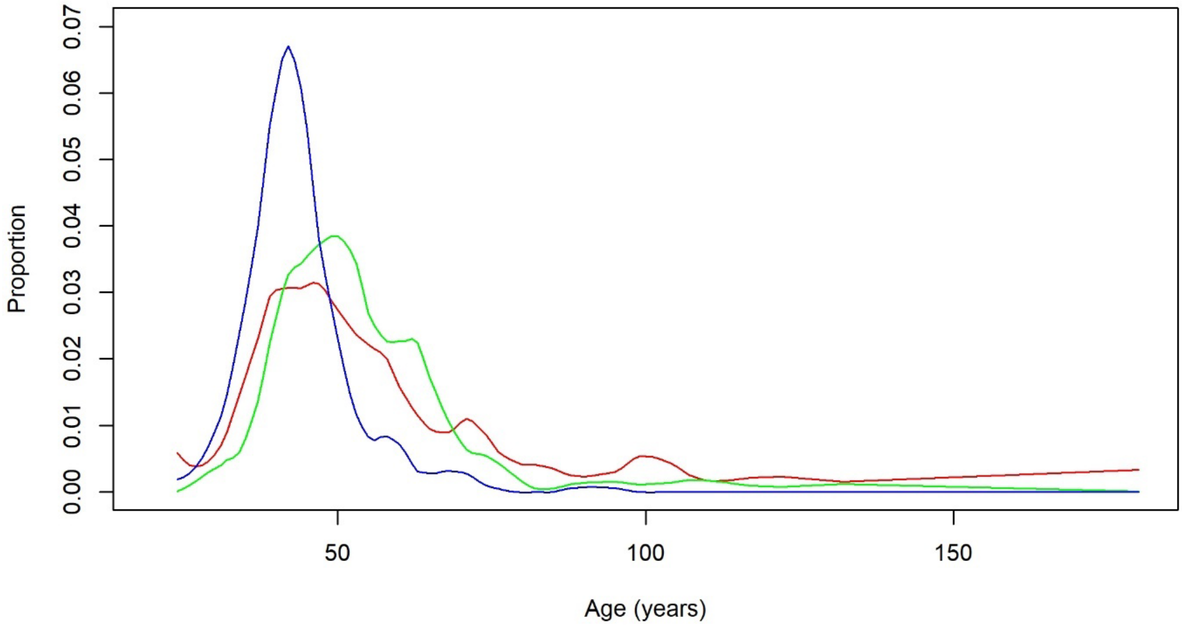


Figure 9: Northwest Chatham Rise, Morgue hill smoothed age frequency distributions: red line, 2016; green line, 2021; blue line 2022.

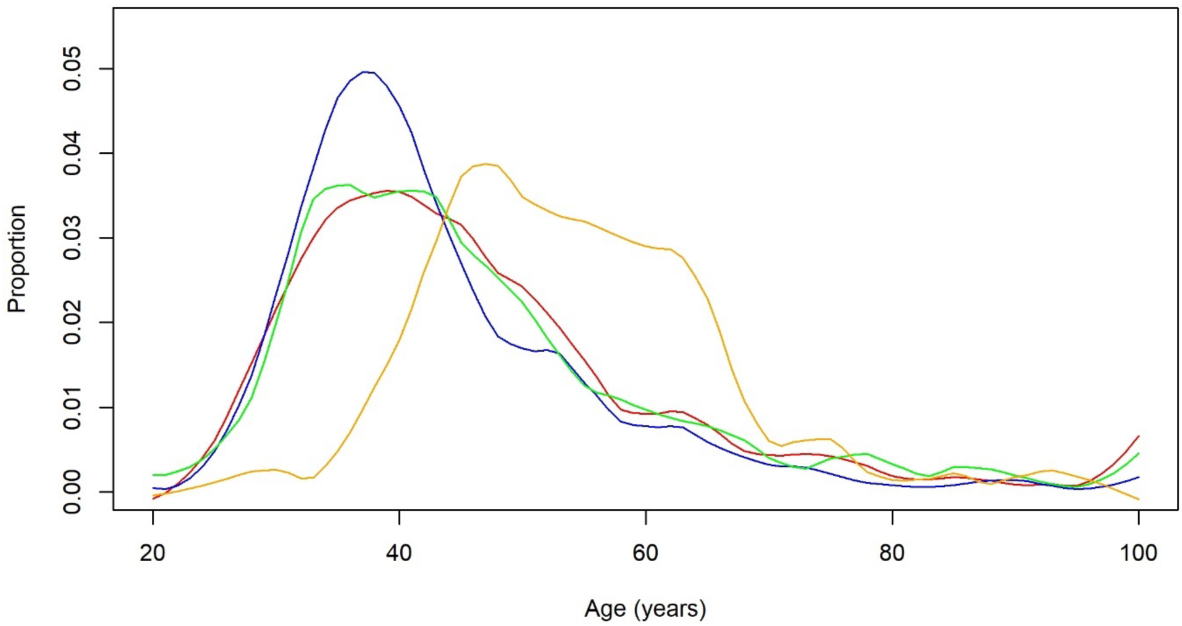


Figure 10: East & south Chatham Rise, combined area (Old Spawning Plume, Rekohu, Mt. Muck) smoothed age frequency distributions: red line, 2012; blue line, 2013; green line, 2016; orange line 2022.

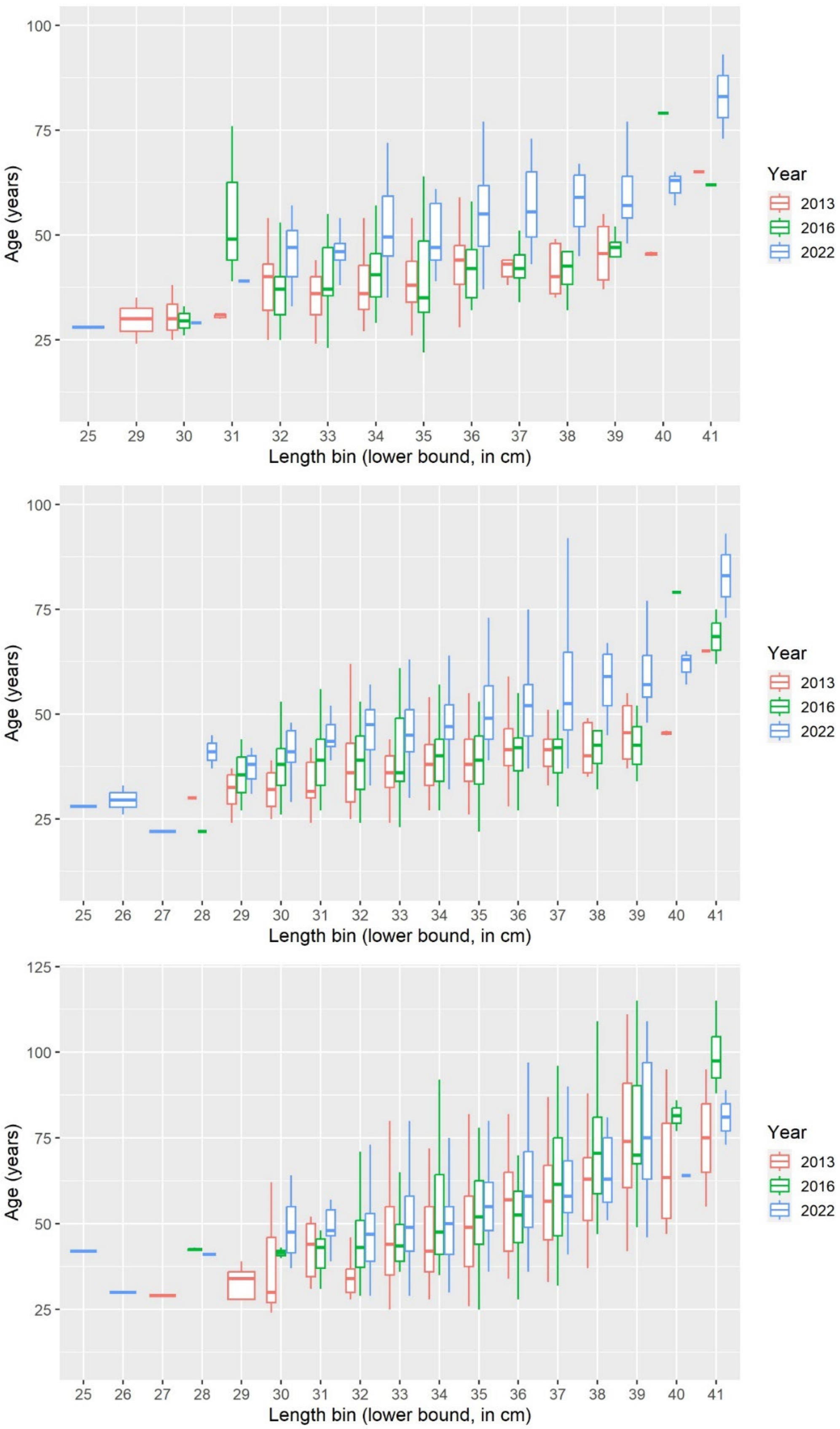


Figure 11: Age (years) at length (standard length) for selected age samples from the Chatham Rise: top panel, Old Spawning Plume; middle panel, Rekohu; bottom panel, Morgue. Data for both sexes combined. Width of box plots proportional to sample size.

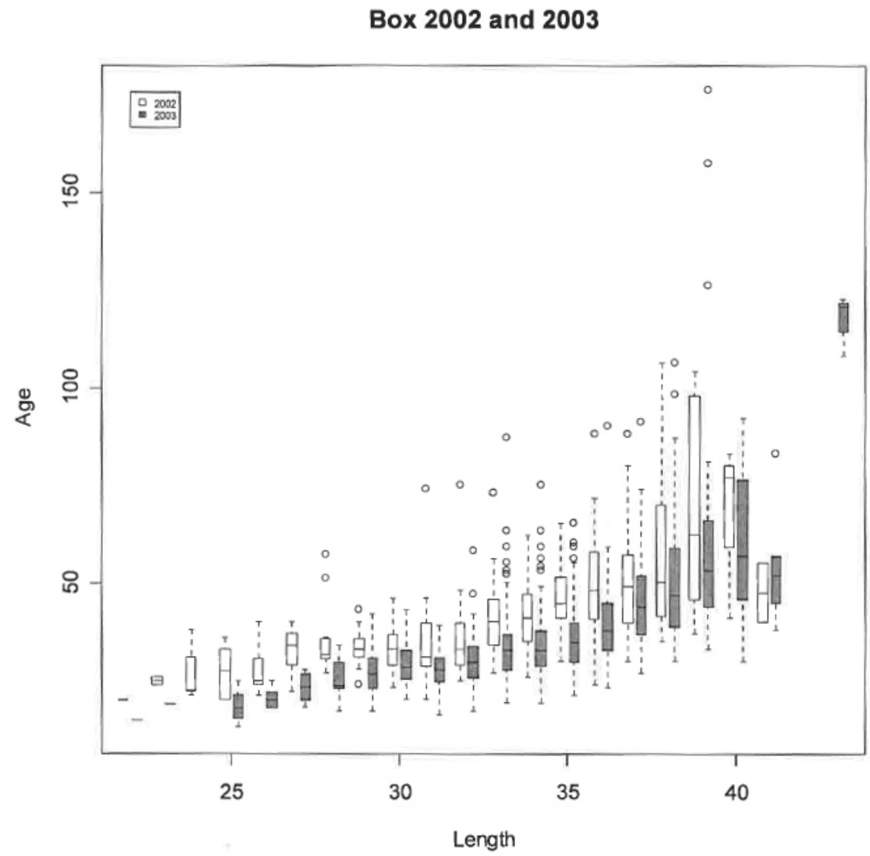


Figure 12: Age (years) at length (standard length) for age samples from the Spawning Box (Old Spawning Plume) in 2002 and 2003. Reproduced from A. Hicks (Deepwater Working Group presentation, 2005).

The similar variability in age frequencies encountered in 2022 and the early 2000s suggests that the cause may not be ageing bias, as believed in the early 2000s, but that samples are not representative of the population.

Trials with stock assessment models could not fit the northwest Chatham Rise age frequencies. For the east & south Chatham Rise, the best fit (albeit still not good) to the age frequencies was produced when recruitment was assumed to drop to a very low level (close to zero) for all years since the fishery started (~1980) (Figure 13). The shift of the age frequency towards higher ages in 2022 was then caused by the arrival of a recruitment 'hole'. The hole in recruitment produced a steepening stock biomass decline at the end of the time series, which conflicted with the acoustic biomass indices, which were roughly flat or slowly declining (Figure 14). The assumption of a recruitment hole, although also suspected from trawl surveys in 2004 and 2007 (Dunn et al., 2008; Doonan et al., 2009), does not seem to be supported, and sampling errors seem more plausible.

The only other information available on recruitment is potentially the Chatham Rise trawl survey series (Stevens et al., 2023). This survey captures orange roughy from about 10–40 cm SL, often with a mode around 20 cm SL, which would be fish of about 12–13 years of age. Fish of these ages would have originated around 2010, suggesting that recruitment of orange roughy is continuing, albeit how this level of recruitment compares to that before the fishery is unknown. Nevertheless, the biomass trend for orange roughy in this survey series does seem to be declining (Figure 15). The Chatham Rise trawl survey biomass index and length frequencies have not yet been included in an orange roughy assessment model.

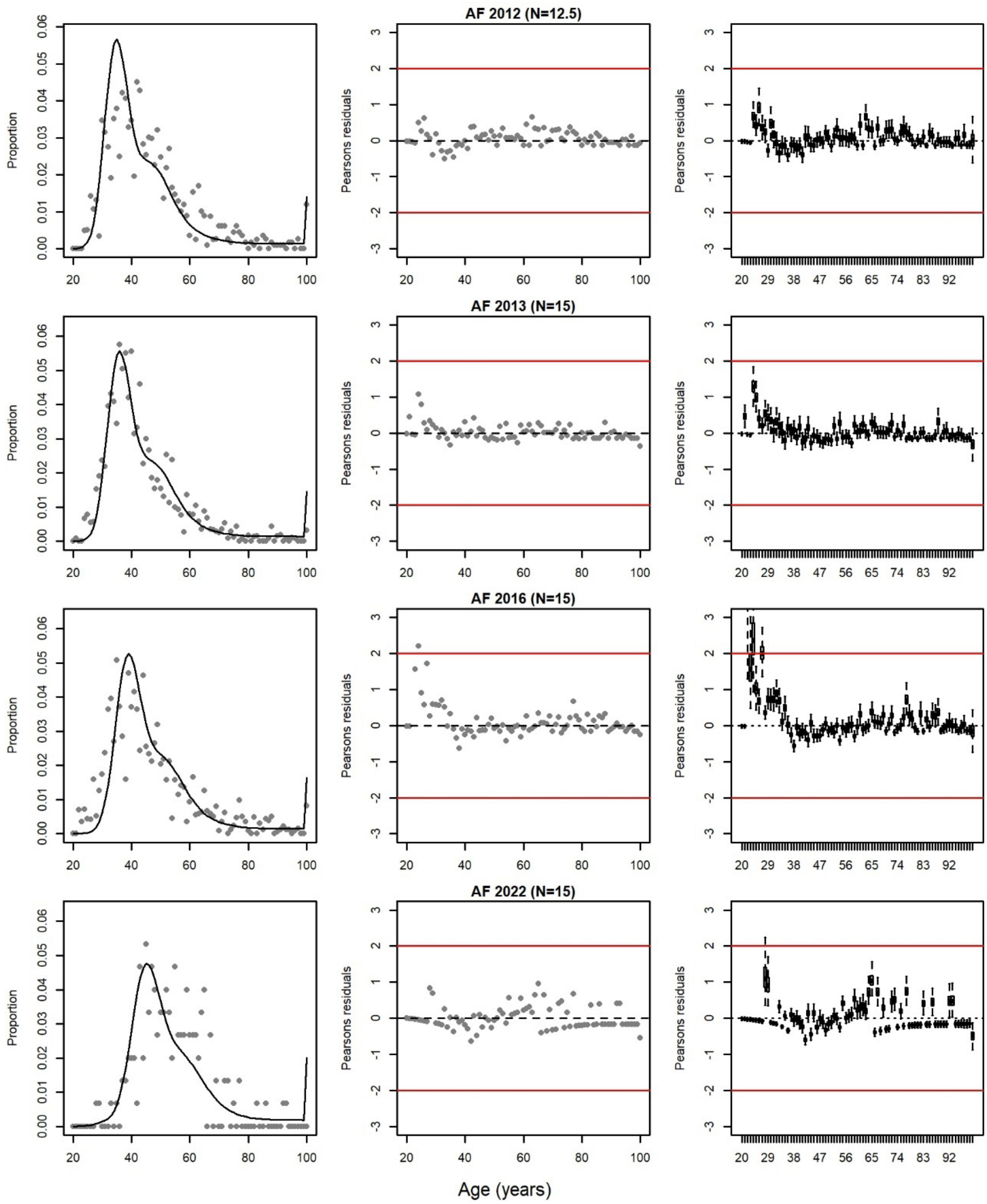


Figure 13: Fits of an east & south Chatham Rise stock assessment model assuming negligible recruitment since 1980 to the age frequency (AF) data. N, multinomial effective sample size. Left panels, MPD fits (lines) to proportions at age (points). Middle panels, MPD residuals. Right panels, MCMC implied residuals (as boxplots).

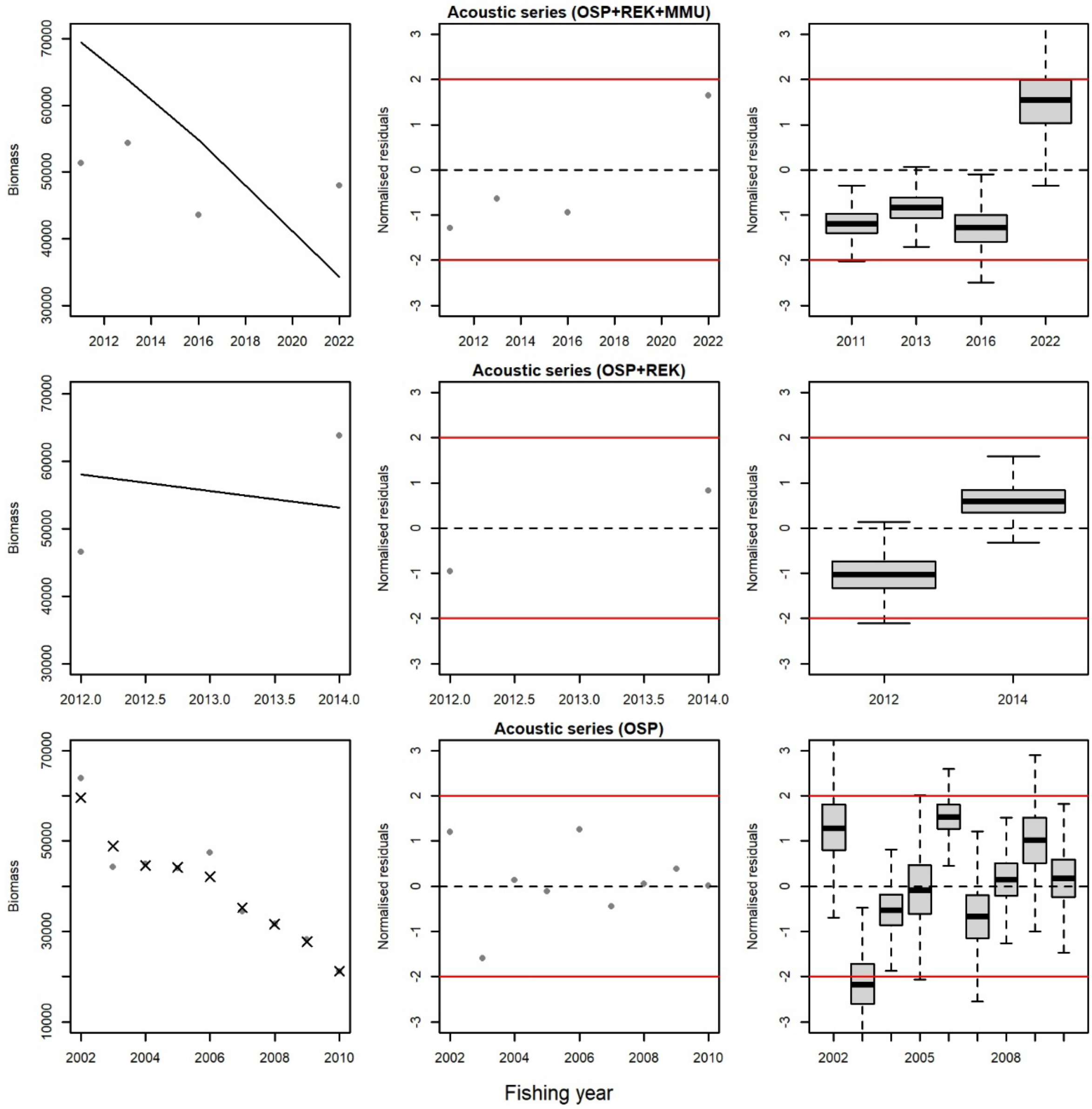


Figure 14: Fits of an east & south Chatham Rise stock assessment model assuming negligible recruitment since 1980 to the biomass data. Top row, acoustic biomass surveys for all plumes combined (Old Spawning Plume, Rekohu, and Mt. Muck 2011, 2013, 2016, and 2022); middle row, acoustic biomass surveys for the two main plumes combined (Old Spawning Plume, Rekohu 2012, 2014). Bottom row, acoustic biomass surveys for only the Old Spawning Plume. Left panels, MPD fits (lines) to survey biomass estimates (points). Middle panels, MPD residuals. Right panels, MCMC implied residuals (as boxplots).

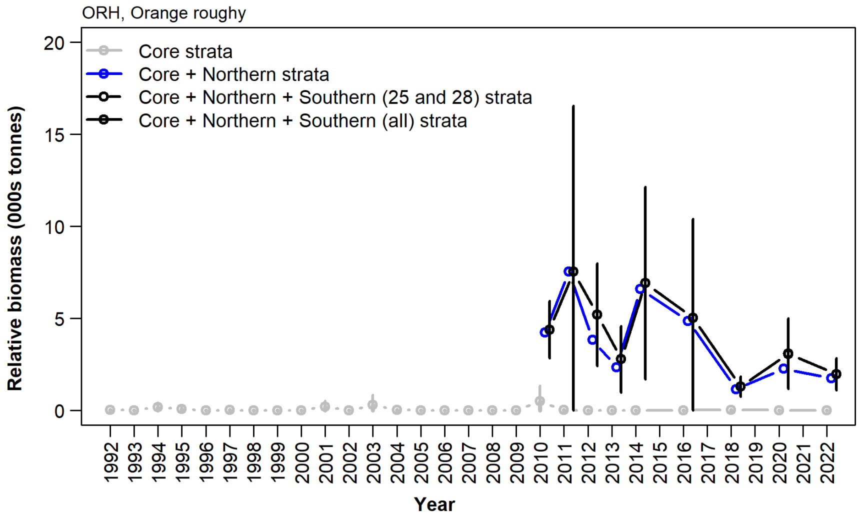


Figure 15: Orange roughy biomass estimates from the Chatham Rise trawl survey. Vertical lines indicate 95% CI. The deeper water strata (>800 m) were added to the survey from 2010 (referred to here as "Northern" and "Southern" strata).

3.5 The 2023 assessment problem

There were three main reasons why the 2023 assessments were not a simple update:

- The characterisation of the fishery was not consistent with the stock assessment model stock status estimates, which suggested that the model(s) may be wrong. The models estimated the stocks to be increasing and within the management target zone, but the fishery statistics suggested catching orange roughy had become harder and some catch rates were at or near historical lows.

- The stock assessment models estimated stock biomass to be substantially greater than measured by acoustic surveys. For the Northwest Rise, the model spawning stock biomass (SSB) was 40% higher than observed, and for the east & south Chatham Rise the SSB was just over 100% larger than observed. For the east & south stock, the acoustic survey series was flat or declining (corroborating fishery performance) whilst the model SSB was increasing.

- The age data could not be fitted in the existing model structure, and the cause of the variability in age samples was not determined. The inclusion of age data was used to justify the estimation of year class strengths, and year class strength estimation was necessary to get acceptable fits to data, and thus accepted stock assessment models (Dunn et al., 2008; Cordue 2014; Fisheries New Zealand 2023). Without age data the models would need to assume constant recruitment, and this assumption has been uniformly rejected for New Zealand orange roughy assessments (Fisheries New Zealand 2023).

In the absence of new age data, the 2018 northwest Chatham Rise stock assessment was informed only by a single age frequency from 1995, meaning that any extension of this model would require some incoming year classes to be assumed to be constant (last year class estimated was 1979 + age of maturity and recruitment of 37 years = constant recruitment assumed after 2016; Dunn & Doonan, 2018). Updating a 2023 assessment with similar assumptions to 2018, meaning the new age data (2016, 2021, 2022) were excluded and the model was informed only by new acoustic surveys (2021, 2022), was therefore undesirable because the most recent eight years, and any projections, would have received constant recruitment.

The 2020 east & south Chatham Rise stock assessment was informed by three age frequencies, from 2012, 2013, and 2016, with year classes estimated until 1994, and therefore an extension of that model would not require a constant recruitment assumption.

3.6 Research towards a revised stock assessment model

Further investigations using the CASAL assessment model in 2023 focused on the larger and more problematic east & south Chatham Rise stock. In no particular order, some emerging issues included:

Stock productivity lower than expected

That realised stock productivity has been lower than expected from virgin stock size, growth and productivity parameters, and constant recruitment, has been a perennial observation in New Zealand orange roughy stock assessments (Fisheries New Zealand 2023). It has also been seen in Australian orange roughy assessments, where updated models persistently revised productivity downwards; a pattern that was resolved by estimating average productivity (natural mortality rate, M) to be lower than expected (Tuck 2022).

With M at the assumed default value (0.045 yr^{-1}), recruitment was estimated to decline before the fishery started and then generally remain low. In model runs the recruitment dropped below average between about 1950 and 1970, and this varied with model assumptions and data (Figure 16). In the 2018 assessment, recruitment first dropped below average in around 1952 and reached a low point in about 1966 (Cordue 2018). The start of lower recruitment approximately coincided with the end of the fish down period minus the age of recruitment, for the east & south Chatham Rise roughly 1995 - 40 = 1955.

When M was estimated it was generally lower than the assumed value. Several data sets influenced M, with the acoustic biomass estimates favouring a lower M, and the Spawning Box trawl survey favouring higher values of M (Figure 17). The former is presumably because a lower M would reduce the biomass rebuild, so the estimated SSB would be lower and closer to the observed biomass. The latter because the steep Spawning Box trawl survey biomass decline could not be fitted (and never has), but a smaller and more productive (higher M) stock would be able to decline more rapidly and so provide a better fit. The steep decline in the trawl survey index may be biased (see section 'Potential bias in Spawning Box trawl surveys' below). Note that very low values of M would be inconsistent with the observed age structure.

Some model runs were conducted estimating stock-recruitment steepness (h), but this only had influence in the most recent years because of the high age of recruitment (about 40 years). When h was estimated, it went to the lower bound of the prior (0.2). In common with other orange roughy stock assessments, the east & south Chatham Rise model estimated a 'hump' of above average recruitment early in the time series; here generally around 1940–50 (e.g., Figure 18). The hump was generally more pronounced in the MPD estimates, and it seems likely to be a 'productivity adjustment'. The hump could be removed if R_0 was estimated not over the whole series, but only over those higher recruitment years; but this meant the subsequent drop in recruitment was larger, and current stock status was poorer. Conversely, if R_0 was estimated through the period of poor recruitment, the early hump in recruitment and subsequently SSB was exaggerated, and current stock status was better. The model runs with the alternative R_0 calculations provided basically the same fits to data (likelihoods for fits to data differed by a total of 1.7 units), meaning the model could not resolve between these alternative hypotheses and different stock status outcomes.

Therefore, the longevity of orange roughy might allow potentially extended gaps or peaks in recruitment, meaning that we have seen an incomplete representation of stock productivity. This makes estimation of B_0 and stock status problematic. Basically, the fishery, and scientific monitoring, may not have existed long enough to have experienced average productivity.

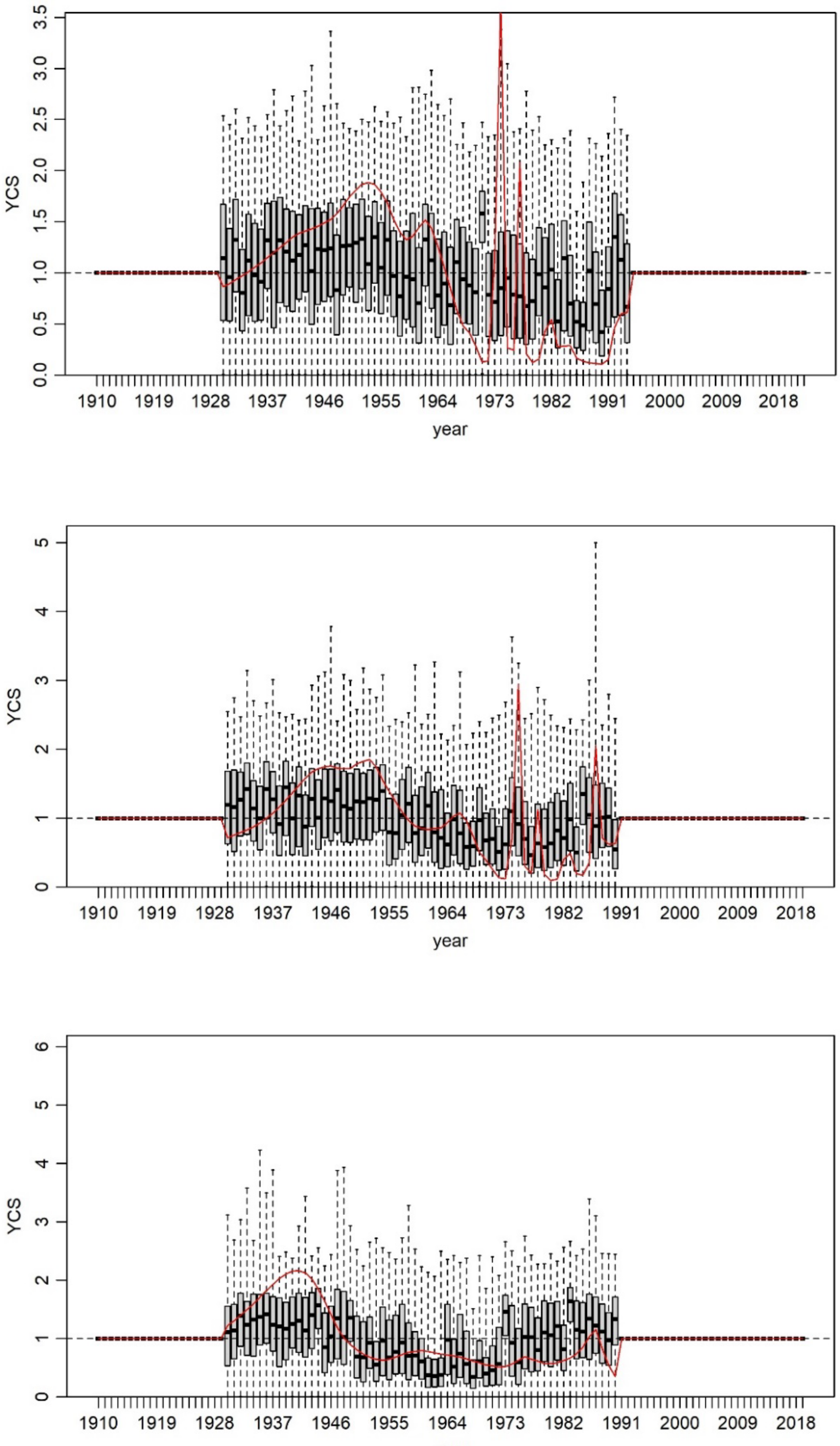


Figure 16: East & south Chatham Rise stock assessment model, examples of estimated year class strength from MPD (red line) and MCMC (boxplots). Top panel, 2018 model updated with new data to 2022; middle panel, 2018 model with separate fisheries (as 2014); bottom panel, 2018 model with the Spawning Box trawl survey excluded.

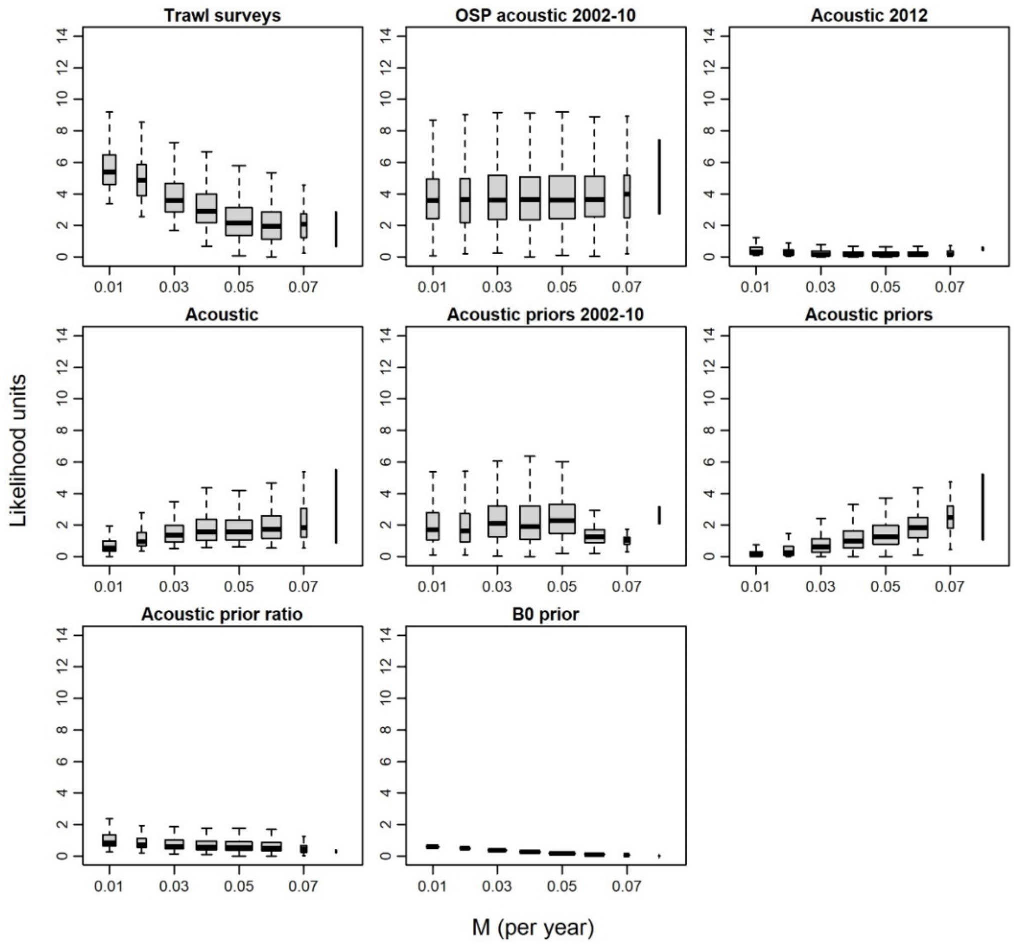


Figure 17: Likelihood profiles by component derived from MCMC samples (n = 1000) for a model run estimating *M*. The median estimate of *M* was 0.038 yr^{-1}. Trawl surveys, Spawning Box trawl surveys; OSP acoustic 2002–10, Old Spawning Plume surveys; Acoustic 2012, the 2012 and 2014 acoustic surveys; Acoustic, the 2011, 2013, and 2016 acoustic surveys.

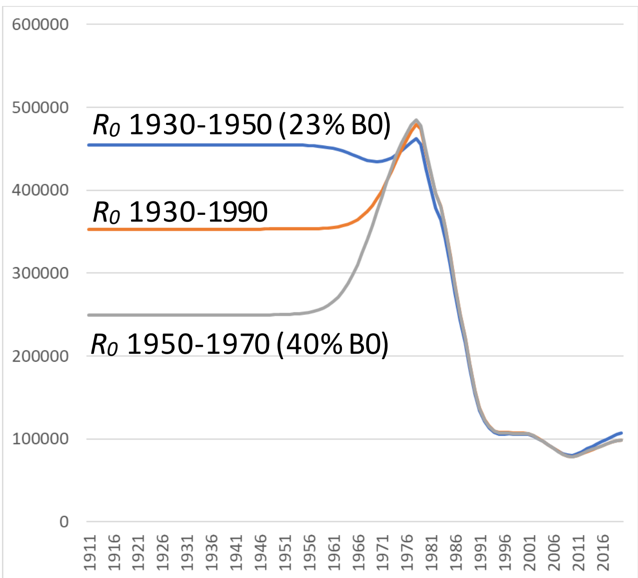


Figure 18: Estimated SSB trajectories (MPD) for model runs with R_0 estimated over different year periods (stock status in 2018 in parentheses); R_0 1930–90 was the base case.

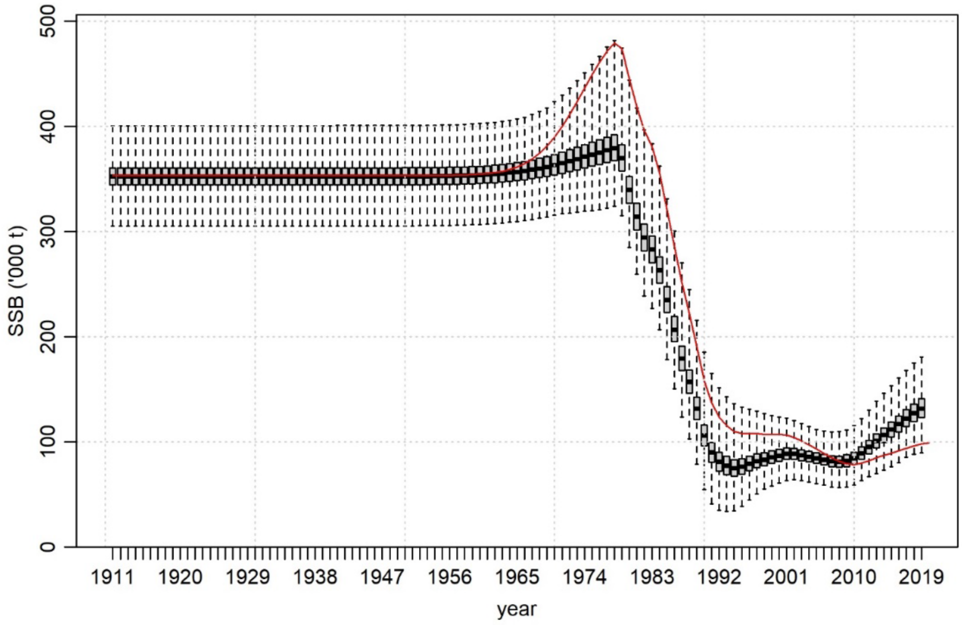
Potential model over-parameterisation

The longevity and extended age structure of orange roughy populations means that recruitment estimation has to cover a wide range of year classes. Simulation studies based upon an orange roughy stock on the High Seas found that this can cause model over-parameterisation, and poorly defined parameters, potentially resulting in unreliable estimates of stock size and status (Stephenson et al. 2022).

One of the potentially concerning characteristics of High Seas stock assessments suspected was MPD estimates occurring outside of MCMC posterior estimates (Stephenson et al., 2022); this has also occurred in Chatham Rise orange roughy assessments (Francis & Fu, 2015; Dunn & Doonan 2018). Divergence of MPD and MCMC estimates seemed to be related to the model having very weak information on year class strengths, as the divergence could be resolved by using a smaller and more conventional σ_R in the lognormal year class strength priors (Dunn & Doonan, 2018). However, although this made MPD and MCMC estimates consistent, the year class strengths would still be poorly known (now just informed by the prior rather than data). The MPD estimates with a more restrictive prior also produced poorer and potentially unacceptable fits to data.

The northwest Chatham Rise stock assessment estimates 50 parameters, including 40 year class strengths, with one age frequency in the model. The east & South Chatham Rise assessment estimates 87 parameters, including 63 year class strengths, with three age frequencies (noted to be inconsistent; Cordue 2014).

The 2018 east & south Chatham Rise base model estimated a similar B_0 from MPD and MCMC, but the biomass trajectory then diverged and stock status from MPD was in the tail of the MCMC estimate (Figure 19). When constant recruitment was assumed, the MPD biomass trajectory (and fits to data) were quite different; such models had historically been rejected on the basis of poor MPD fits. However, because the information on recruitment was weak, at MCMC the difference between the 2018 base model and one assuming deterministic recruitment was reduced. Although there were differences in stock dynamics and biomass trajectory (Figure 19), the key output quantities were fairly similar: base model B_0 = 341 200 t, B_{2018}/B_0 = 0.35; constant recruitment model B_0 = 347 290 t; B_{2018}/B_0 = 0.39.



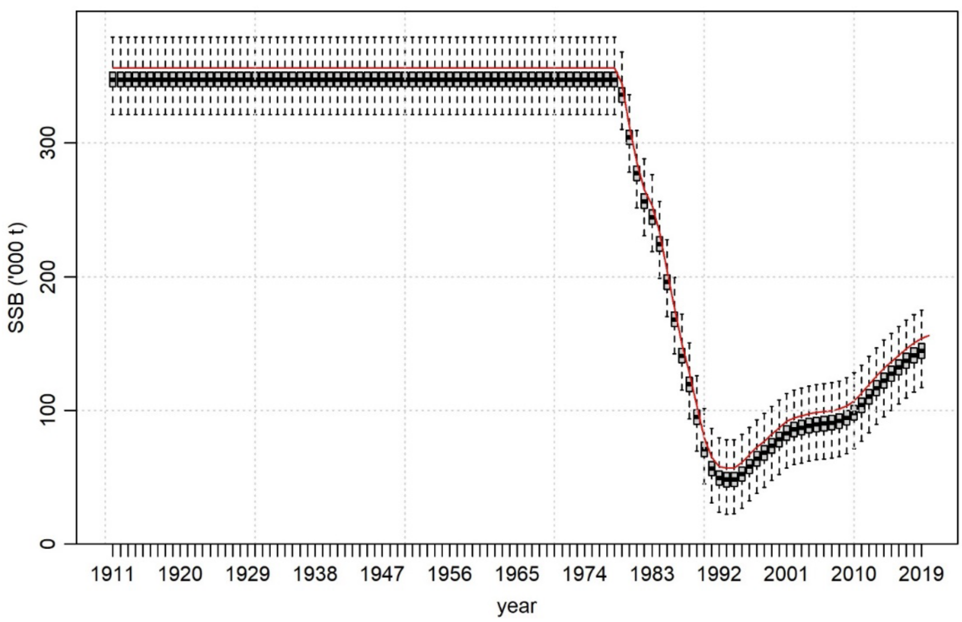
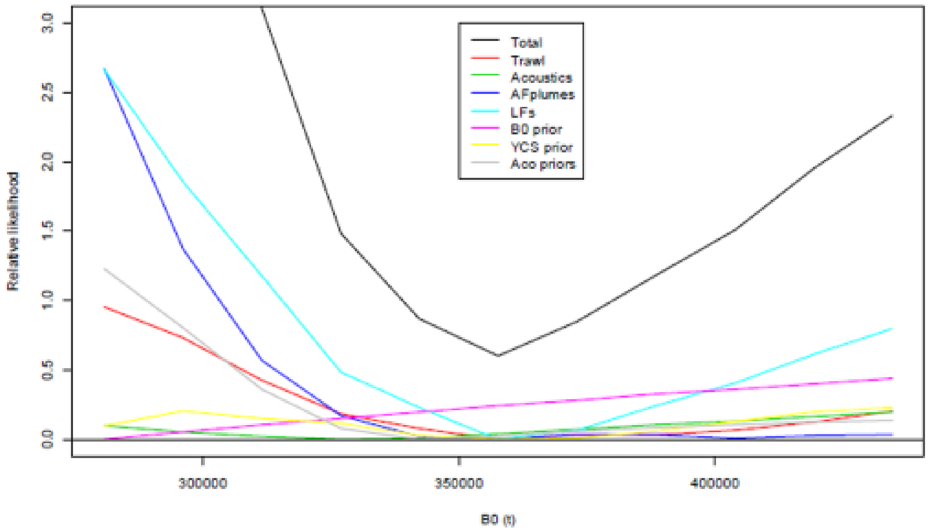


Figure 19: MCMC (boxplot) and MPD (red line) spawning stock biomass estimates for the east & south Chatham Rise assuming top panel, year class strength estimated with "nearly uniform" prior; bottom panel, deterministic (constant) year class strength.

Length frequency data too influential or unreliable

Because of the slow growth of orange roughy and known structure and variability in length composition (e.g., Dunn et al. 2009; Dunn & Forman 2011), length frequencies are not expected to provide reliable information on stock status. A difference in mean length from 30 cm to 29 cm would imply a difference in mean age of three or four years, and a difference from 37 cm to 36 cm would imply a difference of about 15 years.

The length frequency compositions in the 2018 and 2020 assessments had a predominant influence on model biomass estimates for the east & south Chatham Rise and had, by far, the greatest contribution to determining the upper bound of B_0 (Figure 20). The length compositions had lesser influence for the northwest Chatham Rise assessment, but the sample of proportions mature had a relatively strong (and perhaps unexpected) influence on the upper bound of B_0 (Figure 20). Following best practice recommendations (Francis 2011), the acoustic biomass data should have had the dominant influence in orange roughy stock size estimates, and the undue influence of length (and maturity) data should not have been accepted.



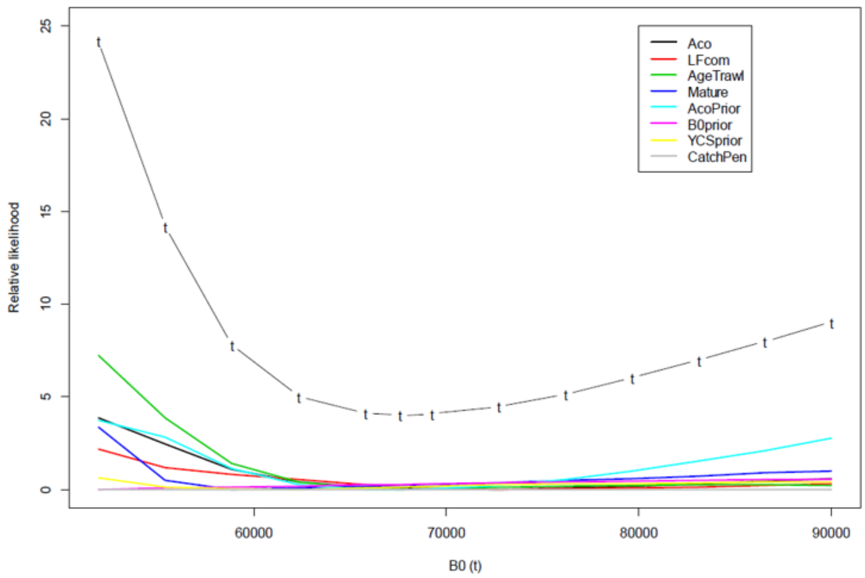


Figure 20: Likelihood profiles on B_0 from 2014 stock assessments (Cordue 2014). Each component of the objective function had its minimum subtracted so that the lines sit on the x-axis except for the total which is shifted above the x-axis arbitrarily. Top panel, east & south Chatham Rise; bottom panel, northwest Chatham Rise. Figures reproduced from Cordue (2014).

Length frequencies from the research trawl surveys were found to provide some information on recruitment in the east & south Chatham Rise model, but the surveys were not representative (they were not designed for year class strength estimation), and this influence was misleading. In the Spawning Box trawl survey length frequencies, a small mode was present at about 16 cm in 1990 and 17 cm in 1992, but absent in 1994 (Figure 21). As a result of this mode the model was found to estimate an above average recruitment around 1982 (Figure 22).

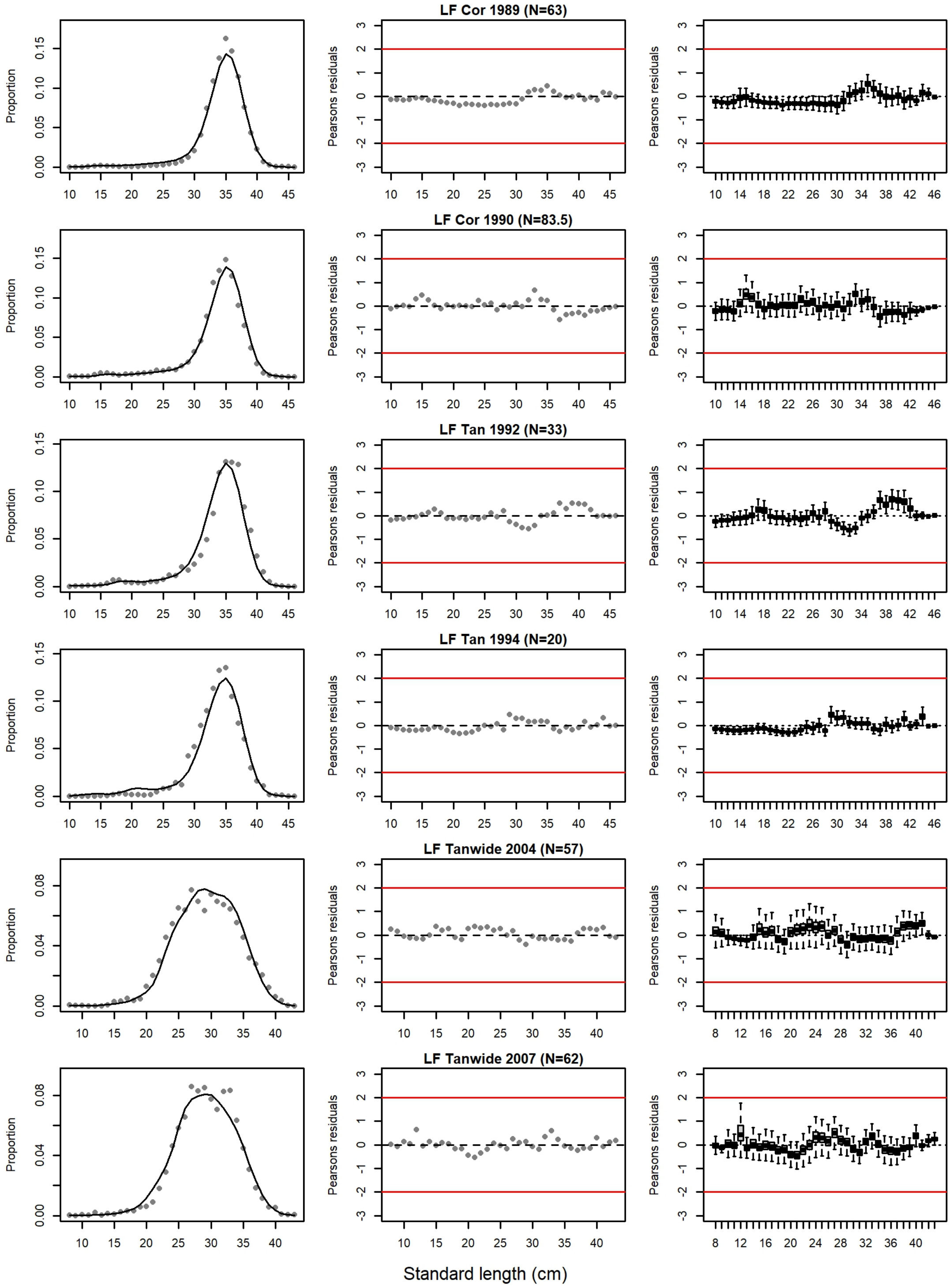


Figure 21: Fits of an east & south Chatham Rise stock assessment model to selected length frequency data. N, multinomial effective sample size. Left panels, MPD fits (lines) to proportions at age (points). Middle panels, MPD residuals. Right panels, MCMC implied residuals (as boxplots).

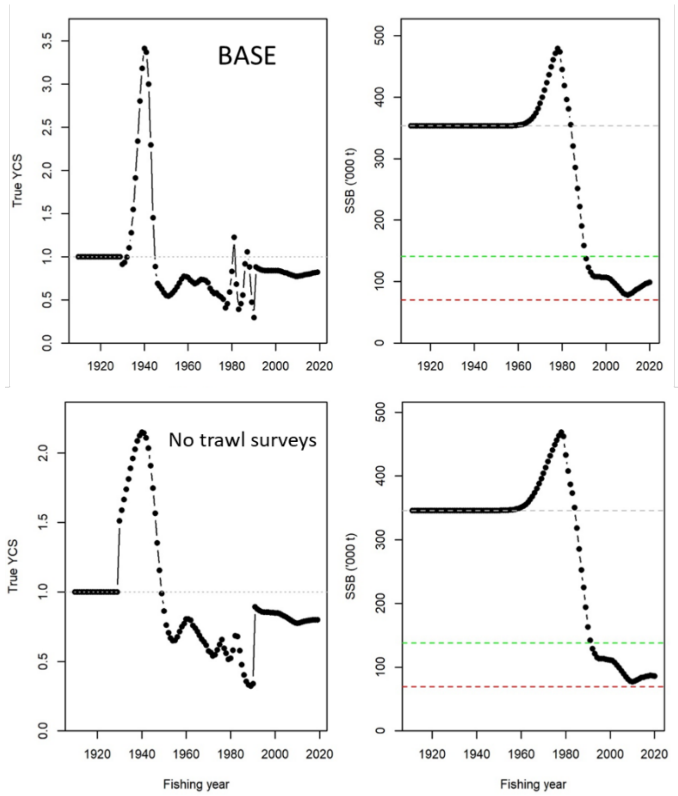


Figure 22: East & south Chatham Rise model MPD estimates of recruitment (True YCS) and SSB. Horizontal lines in the SSB plots mark the virgin biomass, 20% B_0, and 10% B_0. Top panels, the 2018 base model run; bottom panel, the same run with the Spawning Box and wide area trawl survey length frequencies excluded and relevant selectivity parameters set to MPD values from the base run.

The Spawning Box trawl survey was designed to survey spawning biomass, and deliberately did not cover areas preferred by juveniles. Conversely, the RV *Tangaroa* wide area surveys in 2004 and 2007 deliberately excluded spawning grounds, which were instead surveyed by acoustic methods. As a result, the length frequencies from the wide area surveys were dominated by juveniles (Figure 21) and were found to inform the above average recruitment around 1988 (Figure 22). The wide area surveys used a fine mesh "ratcatcher" net (a "scraper" style net) to capture smaller orange roughy, whereas the Spawning Box trawl surveys used an "alfredo" style net with larger rollers on the ground gear, larger meshes, and cut away lower wings. The selectivity parameters estimated by the model were contrary to expectations, with the wide area survey net estimated to capture fish at an older age than the Spawning Box survey net (selectivity A_{50} respectively 17 years, and 11 years). The length frequency samples from these surveys do not therefore seem credible sources of information for estimating recruitment trends. When the length frequency data from the trawl surveys are excluded, the model estimates of recruitment and SSB rebuild are reduced (Figure 22).

Inconsistent biomass information from related data sets

In the 2018 stock assessments, the information on stock size and status from the acoustic surveys came primarily from the informed priors on catchability (q). The only acoustic series for the east & south Chatham Rise having a single q was the 2011, 2013, and 2016 series, and as a result the trend in these survey estimates was influential (these are the "Acoustic" series in Figure 28). The Old Spawning Plume surveys from 2002 to 2010, although a consistent series, had a separate q prior for every year, so the trend carried no information on B_0.

The Old Spawning Plume series q priors favoured a relatively large B_0 (around 350–380 kt) (Figure 23). The subsequent combined area acoustic series provided information through both the q prior and the series trend, with both favouring a lower B_0 (< 320 kt). It is not good practice to include data with conflicting information in the same model run (Francis 2011), as the result will be, by definition, an incorrect average. Given that the conflict identified arises from surveys of the same thing (the spawning plumes), it also suggests the assumptions used to interpret these series might be incorrect.

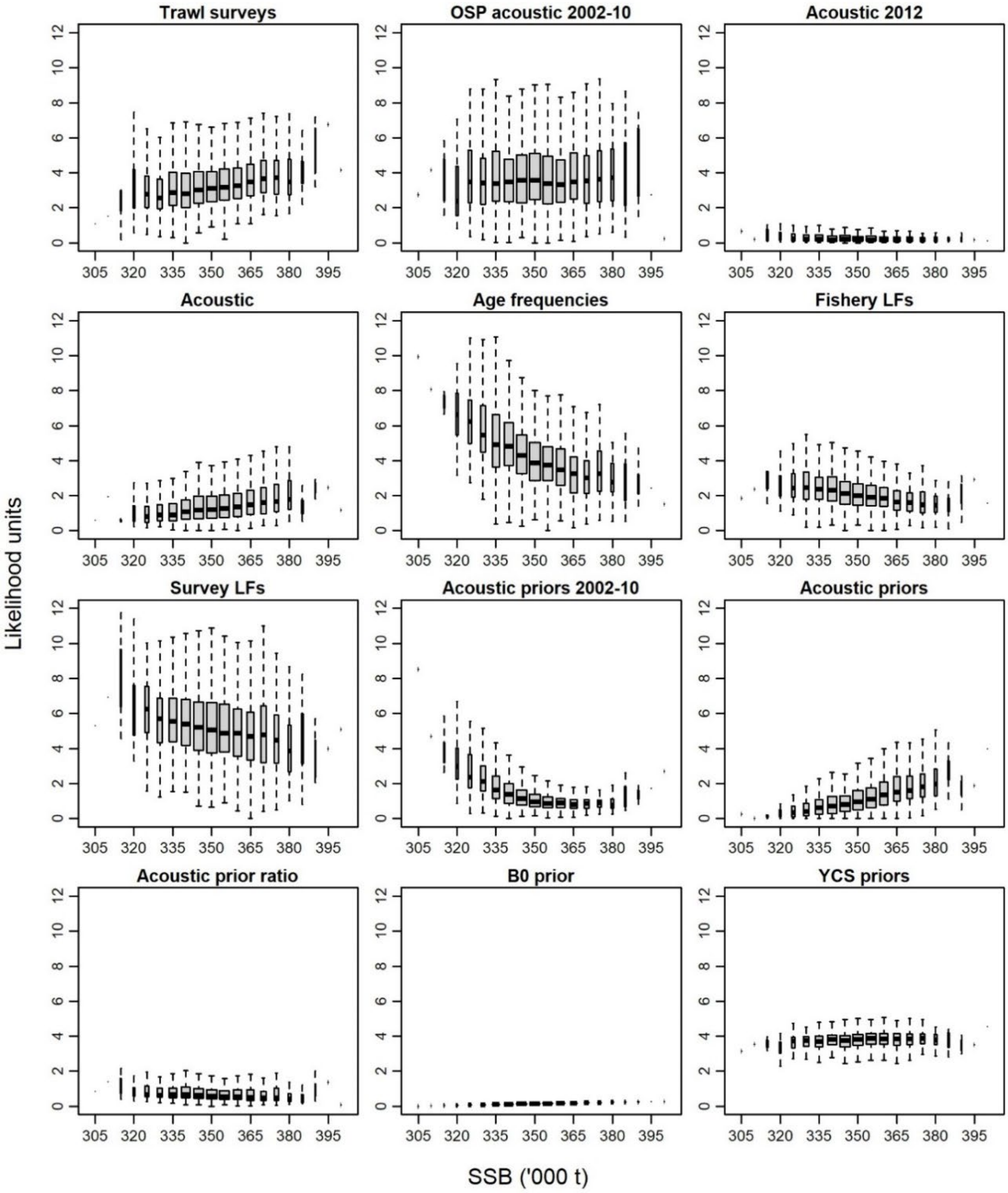


Figure 23: Likelihood profiles for B_0 by component derived from MCMC samples (n = 1000) for the 2018 base model run. Trawl surveys, Spawning Box trawl surveys; OSP acoustic 2002–10, Old Spawning Plume surveys; Acoustic 2012, the 2012 and 2014 acoustic surveys; Acoustic, the 2011, 2013, and 2016 acoustic surveys.

Potential bias in Spawning Box trawl surveys

The decline in the Spawning Box trawl survey biomass series was too steep to be fitted by the model, and to my knowledge has never been adequately fitted. This lack of fit can influence estimates of biomass (Figure 23), M (when estimated; Figure 17), and age at maturity (Figure 24). The Spawning Box trawl surveys are the only data set to favour a higher maturity A_{50} (>40 years), possibly because this reduces the vulnerable biomass, allowing the (fixed) catch to produce a greater rate of biomass decline.

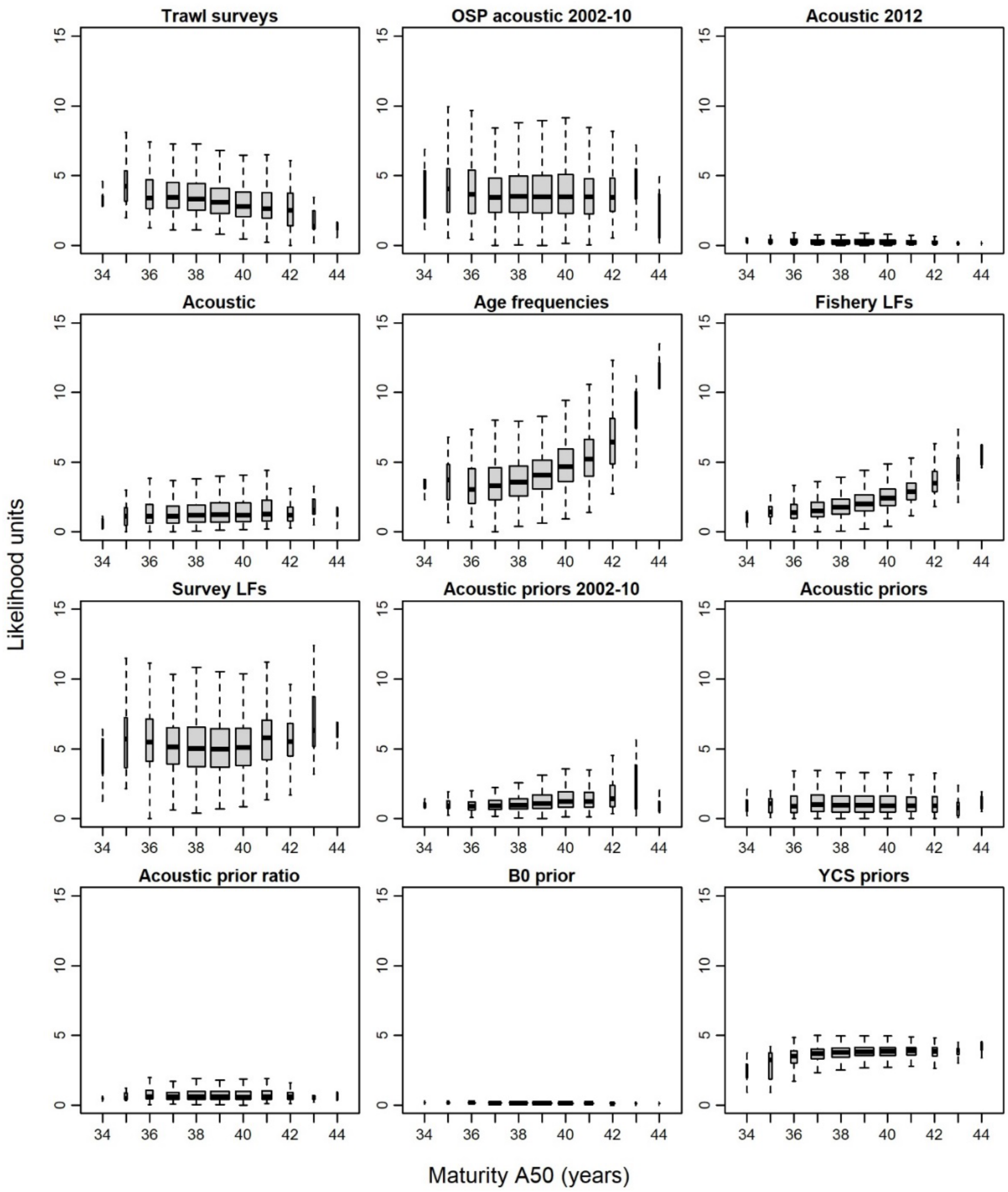


Figure 24: Likelihood profiles for selectivity (=maturity) A_{50} by component derived from MCMC samples (n = 1000) for the 2018 base model run. Trawl surveys, Spawning Box trawl surveys; OSP acoustic 2002–10, Old Spawning Plume surveys; Acoustic 2012, the 2012 and 2014 acoustic surveys; Acoustic, the 2011, 2013, and 2016 acoustic surveys.

Disturbance of spawning aggregations by fishing may have influenced trawl survey results (Figure 25). In 1992 research (RV) trawl catches of moderate size were spread along the Spawning Box area. In

1994, with the Spawning Box closed to commercial fishing, RV trawl catches were more concentrated, suggesting that fish aggregated more fully for spawning.

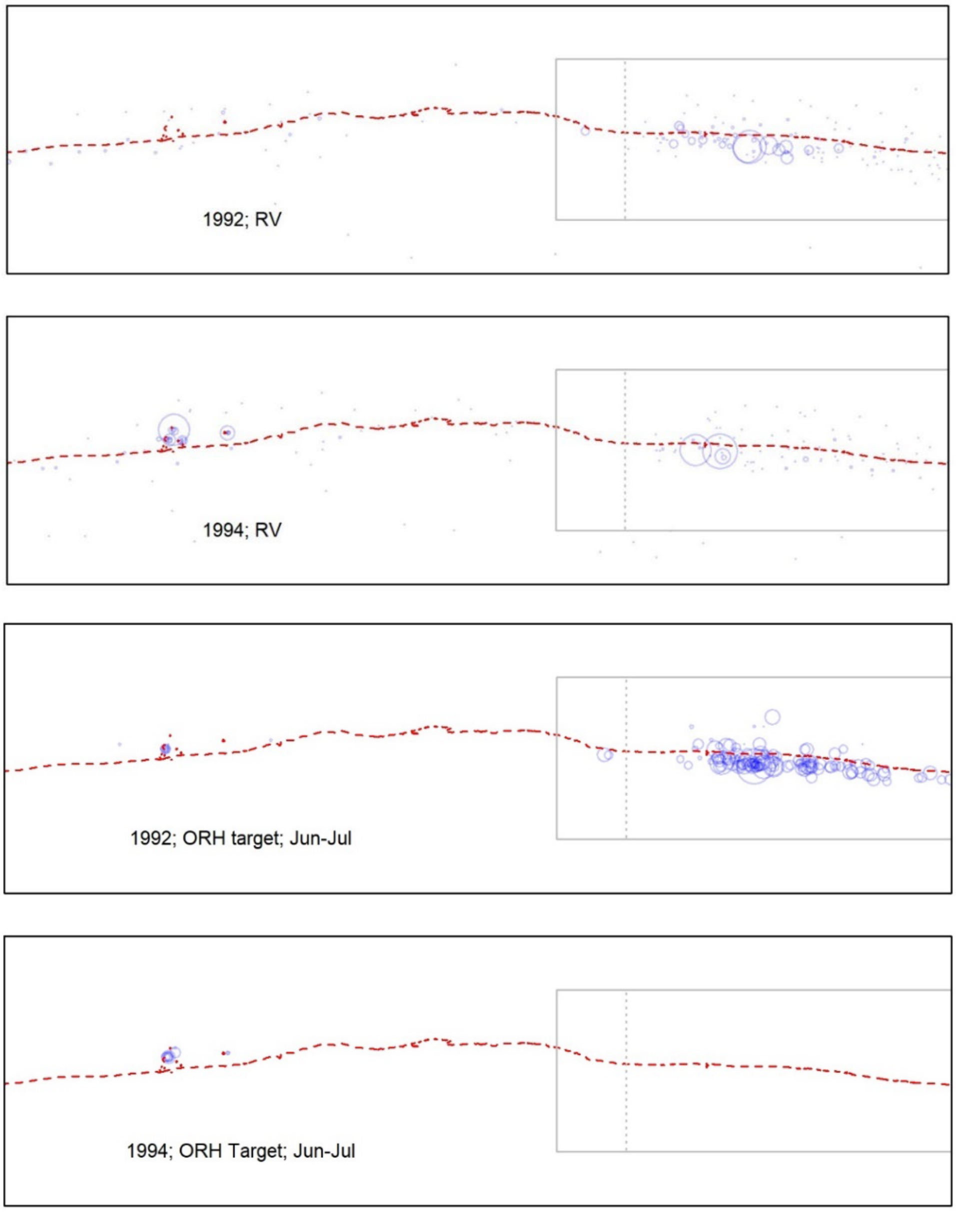


Figure 25: Distribution of catches from research (RV) trawl catches in 1992 and 1994 on the north Chatham Rise (top two panels), and distribution of commercial orange roughy catches targeting orange roughy ("ORH target") at the same time (bottom two panels). The dashed line marks the 1000 m isobath. The grey box marks the Spawning Box survey area, with the area to the west of the grey dotted line indicating the Rekohu area. The Spwaning Box surveys extended further east than shown here; these plots also show the Graveyard hill complex (features and catches at the western end). The Spawning Box was closed to commercial fishing in 1994.

Further, an additional SSB outside of the survey coverage might explain the observed steep biomass decline. The residuals of the fit of the base model (MPD; MCMC fit is worse) had a strong pattern (Figure 26), but residuals could be improved by adding a fixed biomass to the survey estimates. For the *Otago Buccaneer* surveys this value was about 120 000 t, and for the *Cordella* about 80 000 t. The largest SSB outside of the trawl survey coverage has been found at Rekohu. Although orange roughy have been caught during the spawning season at Rekohu since the 1970s, including a 3 t catch in the

Spawning Box trawl survey in 1992 (Figure 25), there was no evidence for a persistent and large biomass present there until perhaps 2003–04 when about 1000 t were caught, with the commercial fishery not starting in earnest until 2010–11 (see table 4 of the ORH 3B chapter in Fisheries New Zealand 2023).

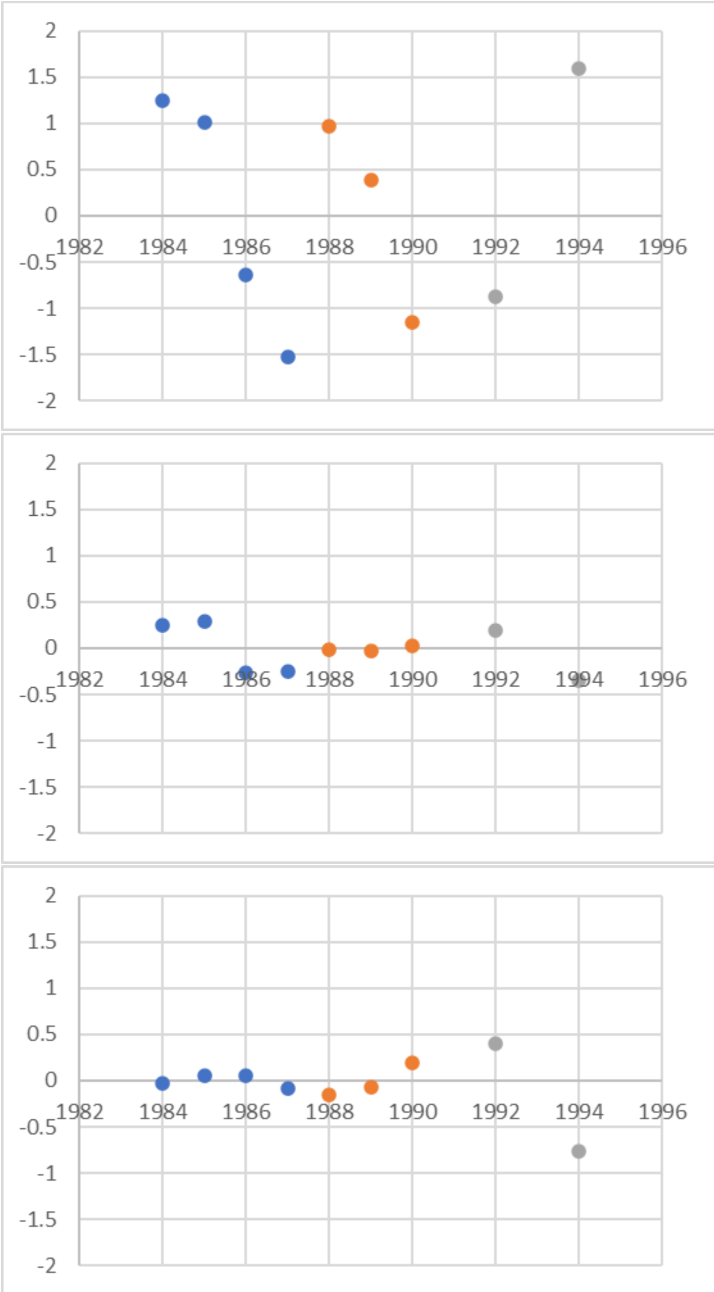


Figure 26: Standardised residuals for the east & south Chatham Rise stock assessment 2018 base model (top panel), and with a constant biomass of 80 000 t (middle panel) or 120 000 t (bottom panel) added to all Spawning Box trawl survey biomass estimates. Blue, points *Otago Buccaneer* surveys; orange points, *Cordella* surveys; grey points, *Tangaroa* surveys.

Potential for changes in the spatial distribution of spawning biomass

A hypothesis used in the accepted assessment model was that the Old Spawning Plume acoustic biomass series between 2002 and 2010 was not representative of the SSB, and the series decline was caused by fish moving from the Old Spawning Plume to Rekohu (Fisheries New Zealand 2023). A stock assessment for Rekohu confirmed that the age structure was consistent with Rekohu being a stock formed recently, rather than a remnant and previously unfished component of the stock (Dunn & Doonan 2018). However, the recent problems with representative sampling of age structure now cast doubt on this result. Uncertainty therefore remains in the assumed relationship between Rekohu and other spawning locations. As the aggregation at Rekohu was essentially unknown until 2010–11, it was not monitored or sampled before then, so sufficient data to evaluate between alternative hypotheses do not exist.

The assumed rate at which fish relocated between the Old Spawning Plume and Rekohu was such that what was a declining biomass index became flat in the model (Figure 27). Allowing separate q's for each survey also weaken the information in what would otherwise be a relative biomass series with a single *q*. Linking the Old Spawning Plume surveys through a series of *q*-ratio priors rather than individual *q* priors (Dunn & Doonan, 2018) also weakens the information in the data, as only one survey is then linked directly to SSB and the remainder can 'pivot' from this one. When a model was run with the Old Spawning Plume series as relative, or all acoustic series as relative, the information in the data became stronger and the model outcome was quite different (Figure 28).

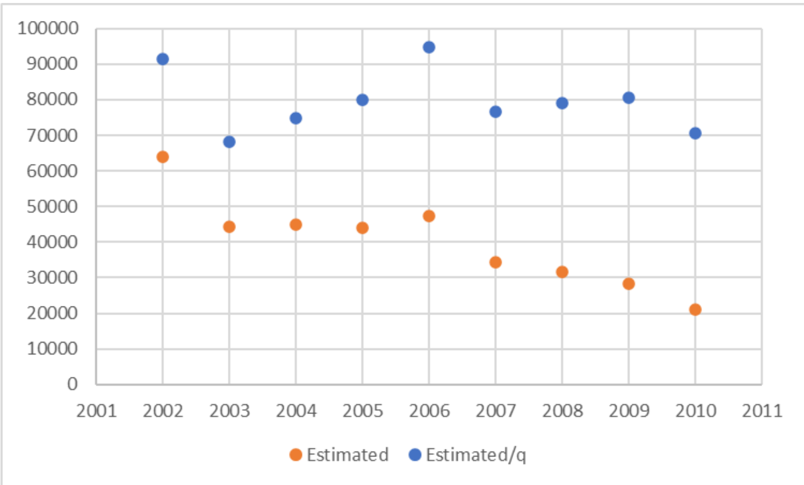
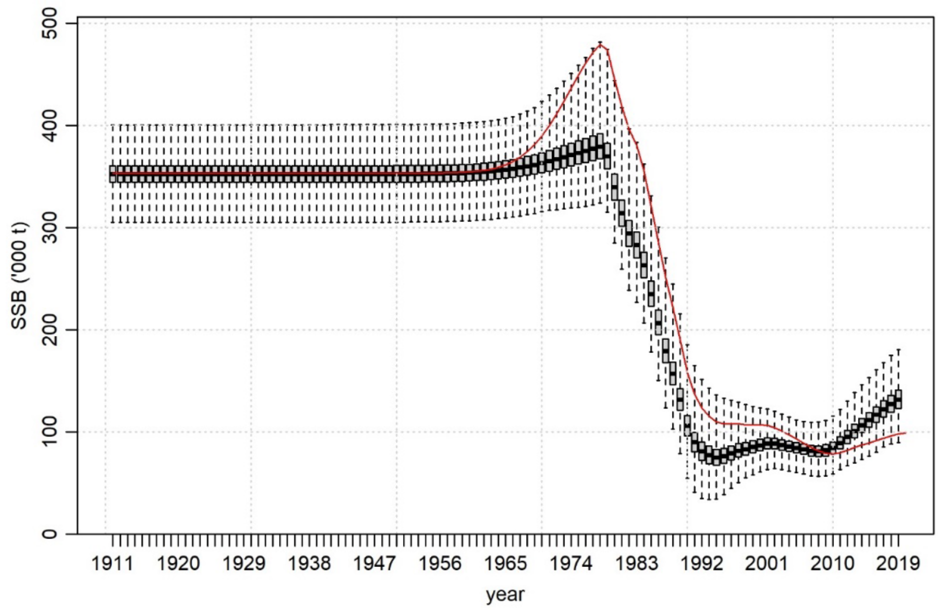


Figure 27: East & south Chatham Rise Old Spawning Plume biomass estimates (t; orange points), and those estimates adjusted by the mean of the q prior (blue points).



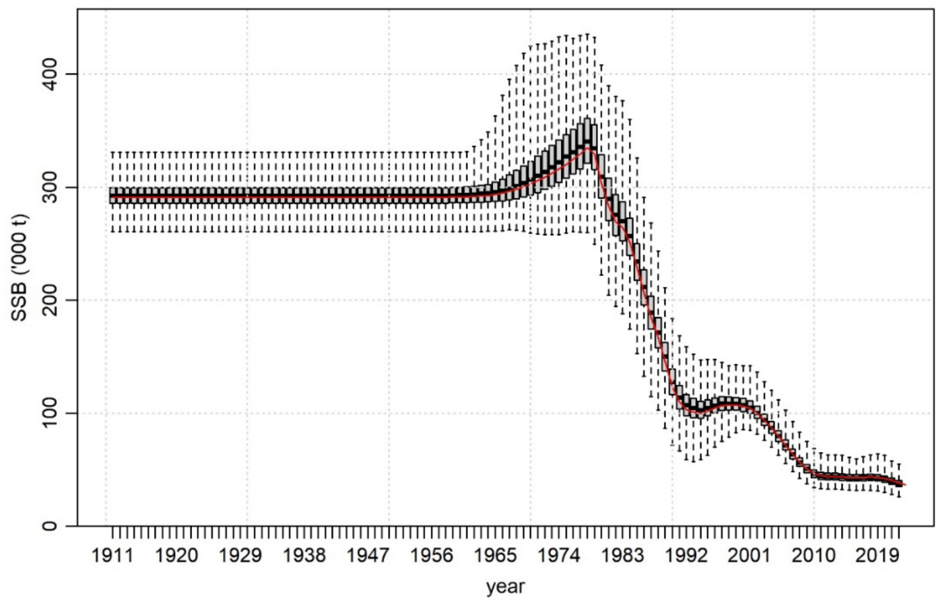


Figure 28: East & south Chatham Rise stock assessment model (updated to 2022) spawning stock biomass MCMC estimates (boxplots) and MPD estimate (red lines). Upper panel, model run with assumptions following the 2018 base model; lower panel, model run with all acoustic biomass indices treated as relative, and recruitment prior $\sigma_R = 0.8$.

4. DISCUSSION

Research to revise the Chatham Rise orange roughy stock assessment remains work in progress.

A change in the market for orange roughy remains a plausible explanation for changes in the fishing pattern. Anecdotally, the Asian market prefers small fish, which would be more available in tows away from features, and the higher price means continued fishing of locations would remain economically viable despite declines in catch rates caused by fishing disturbance. However, the Asian market has reportedly declined over the last few years. The issue of fishing activity disturbing orange roughy and influencing commercial catch rates, availability of fish to acoustic surveys and in trawl catches sampled for age, remains plausible (perhaps likely). This effect has never been scientifically established but could help in the design of more accurate biomass surveys and understanding of patterns in commercial CPUE.

5. POTENTIAL RESEARCH

A list of future research was agreed by the Deepwater Working Group and is reported by Fisheries New Zealand (2023). The reader should consult that list first, as only additional (and more speculative) ideas are reported here.

It may be worth reconsidering stock structure. An evaluation of stock structure was last completed by Dunn & Devine (2010). It is hard to ignore the apparent loss of younger (30–40 years old) fish in the east & south Chatham Rise spawning plume samples, and conversely the gain of those ages at Morgue. This may of course be sampling error and coincidence, but it is possible that aggregating the areas might provide a more consistent age structure. If Rekohu aggregations formed because fish that would have joined the Old Spawning Plume instead moved further west, maybe the Morgue is the next choice if fish moved further again to the west of Rekohu?

The change in age composition might be caused by age-specific changes in proportion spawning (skipped spawning). This hypothesis was suggested to explain the best fit of the Mid-East Coast orange roughy model (Dunn et al. 2022), although sampling error is a second plausible hypothesis. It may be worth trying independent logistic selectivity for individual or sets of age frequencies. With this hypothesis, the absence of ages 30–40 in the east & south Chatham Rise spawning plumes would be due to younger fish not spawning that year, and the acoustic biomass estimates would describe different proportions of the stock each year (Figure 29). Although this would be relatively quick to investigate, it wasn't included in model runs this year. Also, with limited data the variable selectivity might obscure biomass trends.

A simpler stock assessment model remains a potential approach. A Schaeffer model fitted to acoustic relative biomass indices (no informed priors) estimated K (B_0) to be 316 000 t (very similar to the 2020 CASAL assessment estimate of 312 000 t; Fisheries New Zealand 2021) and r to be 0.15, but with stock status in 2022 at about 7% K (B_0) (Figure 30) rather than 36% B_0 (Fisheries New Zealand 2021). The difference in stock status is most likely to be because the acoustic indices in the Schaeffer model were treated as relative (i.e., similar to the CASAL model run when the same assumption regarding acoustic data were made). A similar result was obtained when a 30 year time-lag between biomass and production was made. This approach avoids the problems with age and length composition data, maturity/selectivity estimation, and estimating numerous recruitment parameters. However, statistical and structural improvements would need to be made before it could be considered as a viable stock assessment alternative.

Metapopulation dynamics seem plausible for orange roughy populations given Orange Roughy's global distribution, expansive habitats, and longevity. Some trials during this research with two linked Schaeffer models showed that B_0 for one stock might be correctly estimated but productivity over-estimated when that stock was receiving recruitment from elsewhere (i.e., it was a 'sink' rather than a 'source'). However, when both stocks were fished, as would be the case here, the results were variable and sometimes not intuitive. Results changed with, for example, the stocks' catch history, movement rates, and the years covered by the assessment. Such metapopulation complexity might be worth considering but as a proof-of-concept only, because the model parameters are very unlikely to be estimable with the data available for orange roughy.

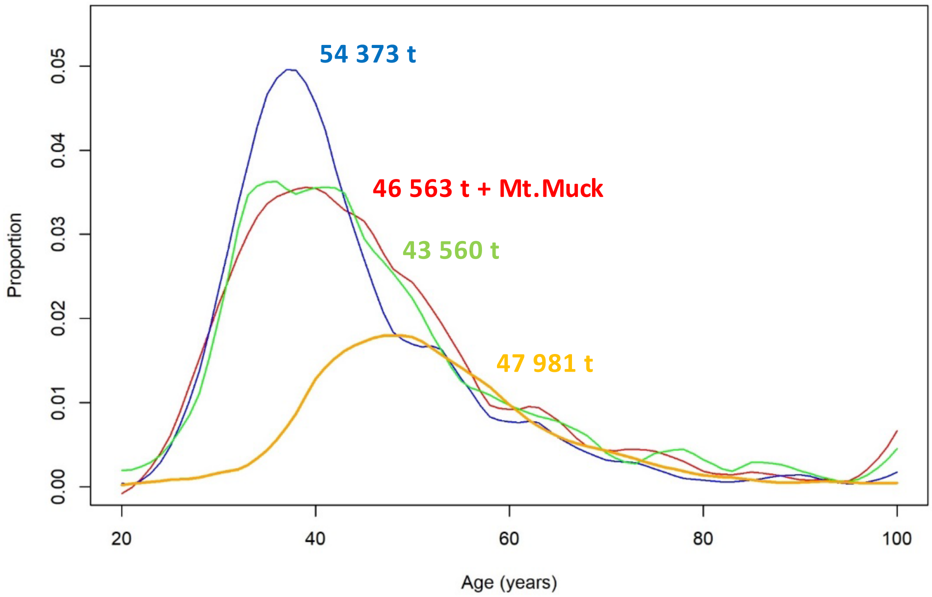


Figure 29: East & south Chatham Rise, combined area (Old Spawning Plume, Rekohu, Mt. Muck) smoothed age distributions: red line, 2012; blue line, 2013; green line, 2016; orange line 2022. The samples have been scaled (by eye) such that the slope of the right-hand matches that of the other samples, approximately from age 55 (assumption that all older fish are fully selected in each case); the y-axis therefore refers to the proportions in samples 2012–2016, and not 2022. The difference in the size of the mode between ages 20–50 would then be attributed to changes in the availability of these fish. The numbers refer to the acoustic biomass estimates for that year, with 2013, 2016, and 2022 include the Old Spawning Plume, Rekohu, and Mt. Muck, and 2012 including only the Old Spawning Plume and Rekou (hence there would be an additional biomass for Mt. Muck that is not included in that estimate).

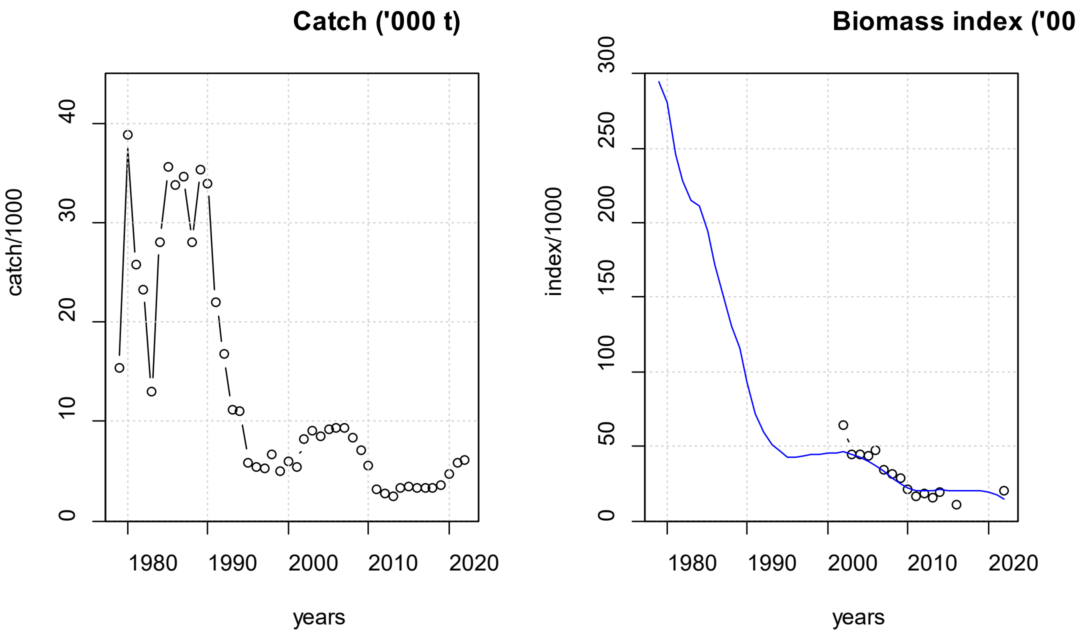


Figure 30: East & south Chatham Rise example Schaeffer model; left panel, catch history; right panel, estimated biomass trajectory fitted to acoustic biomass indices (blue line). Points show the Old Spawning Plume acoustic biomass series. Model fitted with lognormal likelihood, and with no additional time lag between biomass and recruitment.

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