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Stock assessment of Chatham Rise orange roughy in 2025

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PLAIN LANGUAGE SUMMARY

- The orange roughy fishery on Chatham Rise is split into two stock areas. The East & South Chatham Rise stock catch limit was about 80% caught in 2023–24, and the Northwest Chatham Rise stock catch limit was about 18% caught.
- The assessment research identified inconsistencies in the acoustic spawning biomass estimates used to track abundance. The cause of this divergence was not resolved, and therefore two alternative indices of abundance were used.
- Inconsistent age frequency samples made estimating changes in stock productivity over time less reliable.
- The 2025 assessment used a simplified approach where the model fitted only acoustic biomass data. For the East & South Chatham Rise, model runs were also done using acoustic biomass plus age frequency data.
- The virgin size of the East & South Chatham Rise stock was estimated to be around 350 000–440 000 t, with stock status in 2024–25 around 8–18% of that initial level. The recruitment after 1980 was estimated to have decreased substantially.
- The virgin size of the Northwest Chatham Rise stock was estimated to be around 59 000 t, with stock status in 2024–25 around 35% of that level. In contrast to the East & South Chatham Rise stock, the average productivity for the Northwest Chatham Rise stock was close to the expected level.

EXECUTIVE SUMMARY

Dunn, M.R.¹; Datta, S.¹; Doonan, I.J.¹ (2025). Stock assessment of Chatham Rise orange roughy in 2025.

New Zealand Fisheries Assessment Report 2025/46. 59 p.

The orange roughy fishery on Chatham Rise (part of ORH 3B) has been dominated by catches from the Spawning Box on the northeast Rise. The Chatham Rise fishery has recently been largely a pre-spawning and spawning fishery (May-July), with little catch from the south and southeast Rise. The East & South Chatham Rise stock catch limit was about 80% caught in 2023–24, and the Northwest Chatham Rise stock catch limit about 18% caught. Most of the fishing effort used to be short tows on features or spawning aggregations, but this has recently become largely longer tows on flat ground.

The assessment in 2025 identified inconsistencies in the acoustic spawning biomass estimates from the 38 kHz and 120 kHz echosounders, which had been historically similar but diverged in the most recent two sampled years, now suggesting different biomass trends. The cause of this divergence was not resolved, so biomass estimates from the 38 kHz and 120 kHz echosounders were treated as alternative biomass indices. The recent acoustic biomass estimates were assumed to represent 80% of the spawning biomass.

Previous research excluded research trawl surveys and length frequency data from stock assessments because these data were considered less reliable. Age frequency data continued to be used, although there were known inconsistencies in the orange roughy age frequency samples, which made estimating year class strengths and stock biomass problematic. Model runs in 2025 included or excluded the age frequencies; the latter being a model fitted only to the acoustic biomass estimates.

Acoustic spawning biomass estimates have been lower than expected from the average productivity expected from orange roughy stocks. The model was allowed to estimate stock productivity as a constant natural mortality rate (M , a determinant of average stock productivity), or by allowing recruitment to have one of two levels (R_0 or R_1), with a change point in 1980 (when the fishery started).

The virgin size (B_0) of the East & South Chatham Rise stock was estimated to be around 350 000–440 000 t, with stock status in 2024–25 around 8–18 % B_0 . The recruitment after 1980 was estimated to have decreased substantially, to around 14–40% of that before 1980.

The virgin size (B_0) of the Northwest Chatham Rise stock was estimated to be around 59 000 t, with stock status in 2024–25 around 35 % B_0 . In contrast to the East & South Chatham Rise stock, the average productivity for the Northwest Chatham Rise stock (here estimated using M) was close to the expected level.

Projections of stock size under future catch levels were completed but considered especially uncertain; this is because orange roughy productivity is poorly known (the fishery has only existed for around one orange roughy generation), and even average biomass rebuilds may take many decades to occur.

¹ New Zealand Institute for Earth Science Limited (ESNZ).

1. INTRODUCTION

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 2025).

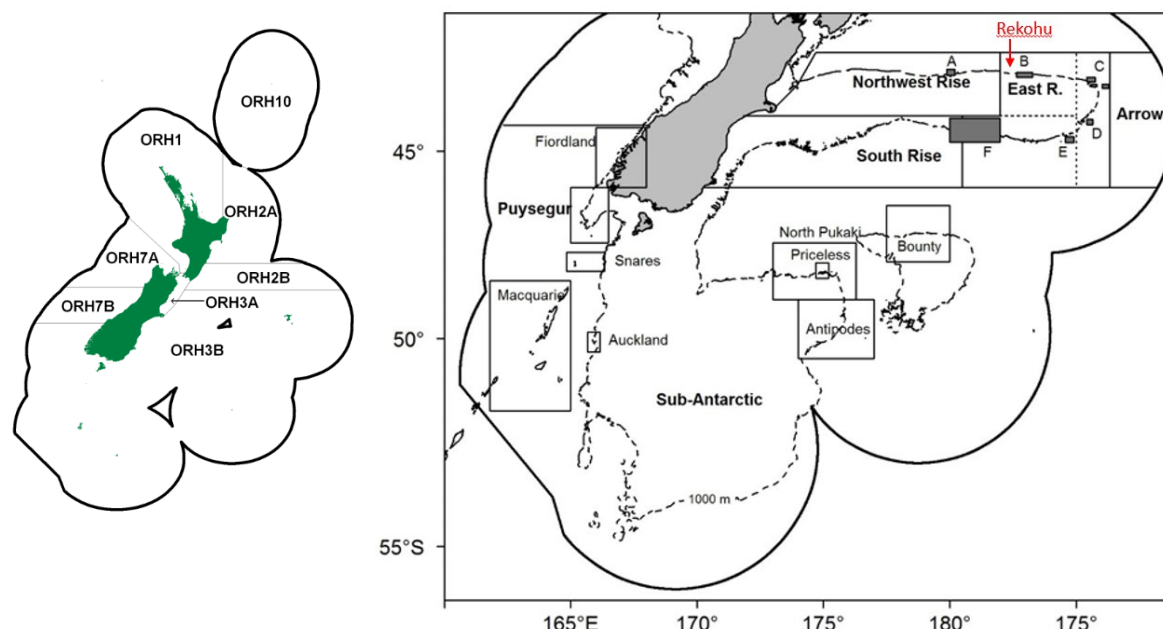


Figure 1: New Zealand Quota Management Areas for orange roughy (left panel), and the ORH 3B fishery areas (right panel) with approximate positions of the main fishing grounds/ A, Graveyard hills; B, Spawning Box; C, Smith's City & neighbours; D, Andes complex; E, Big Chief & neighbours; F, South Rise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

The overall objective of Fisheries New Zealand research project SEA2024 -07 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 an updated 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 to the end of the 2023–24 fishing year as required.
- (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 may also include follow up discussions of possible management options with MPI Fisheries Science staff; and if necessary giving expert evidence in any litigation in relation to matters covered by the work undertaken.

Research in 2023 raised some concerns about the results of the most recent stock assessment models of the Northwest Chatham Rise (2018) and East & South Chatham Rise (2020) which estimated both stocks to be in the target zone of 30–50% virgin (unfished, equilibrium) biomass B_0 (Fisheries New Zealand 2022). For the Northwest Chatham Rise stock, the predicted spawning biomass size and rebuild was consistent with the trend in acoustic biomass estimates, and the most recent assessment (2018) was therefore accepted in 2023 although considered more uncertain than originally thought; however, a research focus on the East & South Chatham Rise stock meant that the 2020 assessment

was not updated. The reduced size of the recent Northwest Chatham Rise fishery, which was catching less than 20% of the agreed catch limit, was attributed to most fish being on the closed Morgue hill and therefore unavailable to the fishery. 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 2024). For the East & South Chatham Rise stock, the predicted spawning biomass size and rebuild in 2023 was inconsistent with the absolute biomass estimates and flat or declining trend from the acoustic biomass surveys. Although the agreed catch limit was taken, the catch-per-unit-effort (CPUE) were at or close to historically low levels for the main non-spawning fisheries. The East & South Chatham Rise assessment was therefore rejected in 2023.

Research in 2024 examined fishers' experience of orange roughy fishing on Chatham Rise, evidence for fish disturbance from fishing, CPUE trends including disturbance and environmental covariates, and spatial stock assessment models (Dunn et al. 2025). The latter found that changes in observed age frequencies to 2022 for the East & South Chatham Rise stock, which could not be fitted by a model assuming constant recruitment and fishery selectivity, could be explained by a substantial drop in year class strength occurring once the fishery started. This explanation required that the age of fishery selectivity was close to age 30; approximately the age at maturity estimated from otolith transition zones (Fisheries New Zealand 2024).

The assessment of the Puysegur stock (ORH 3B) was last completed in 2017 using data to 2015–16 (Fisheries New Zealand 2024). 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 remain unknown (Fisheries New Zealand 2024).

This report provides a summary and additional information for the stock assessments reported in the Working Group Report for 2025 (Fisheries New Zealand 2025). A summary of the main issues and previous research is provided in that document and is not all repeated here. This includes: exclusion of length frequency data; ageing protocols and inconsistent age frequency data; unreliable estimation of year class strengths; exclusion of CPUE indices; disturbance of fish by fishing; options for estimating productivity; and problems with acoustic biomass indices.

2. METHODS

All stock assessment modelling used the CASAL2 software package (Doonan et al. 2016; CASAL2 Development Team 2020). All other 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 Fisheries New Zealand Data Confidentiality rules; in particular, maps of catches and effort are not reported here.

2.1 Catch and effort data for fishery characterisation

Commercial catch and effort data were requested from Fisheries New Zealand for all fishing trips between 1 October 1989 and 30 September 2024 that landed or targeted orange roughy in any fishing event (Fisheries New Zealand extract code 16446A). 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 2024, Dunn et al. 2025).

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 data and modelling

Stock assessment modelling is not a linear process, and the final assumptions and data sets are not always as expected at the start of the work. As a result, a description of the methods and assumptions, and why they were used, is often not simple. To simplify, the methods described here are “high level” across both assessed stocks, with more detailed aspects described in the subsequent results sections.

Stock productivity

The longevity of orange roughy, which provides the potential for the population to encounter and withstand extended periods of low recruitment, makes estimation of B_0 problematic. This is because the fishery, and scientific monitoring, is unlikely to have existed long enough to have encountered average productivity; the generation time of orange roughy (from birth to the average age of a reproductive adult) is likely to be in the range 40–60 years, and the fishery has only existed for 46 years (since 1979).

Options considered for estimating productivity included: estimating natural mortality M (with deterministic year class strengths YCS); estimating year class strengths (with fixed M); and estimating time-varying recruitment (i.e., a model having two R_{0s} ; with fixed M). The latter assumed a change point in 1980, which was supported by likelihood profiles of the change year for the East & South Chatham Rise stock (see Section 3.2), and by the investigations of the potential influence of fishing disturbance on spawning (Dunn et al. 2025).

After review and revision of orange roughy ageing protocols (Horn et al. 2016), stock assessments until 2020 were successfully fitted using a small number of age frequencies (in 2014: two for the East & South Chatham Rise; one for the Northwest Chatham Rise). The subsequent addition of new age frequency data found variability similar to that encountered in the early 2000s, which had originally led to the ageing review, and unrepresentative sampling was considered to be the most likely cause of the problem (Dunn et al. 2025). For 2025, stock assessments therefore included model runs that excluded the age frequency data, and set fishery and acoustic survey selectivity equal to the maturity ogive estimated from otolith transition zones.

In 2025, it was shown that acoustic biomass estimates from a vessel-mounted 38 kHz echosounder and an Acoustic-Optical System (AOS) 38 kHz echosounder, and an AOS 120 kHz echosounder, have diverged since 2022 (see Results). Various hypotheses to explain this change were considered, but the cause was not resolved (summarised in Appendix 1). For 2025, the acoustic biomass estimates from the different frequencies were therefore treated as alternative series, being the vessel 38 kHz and AOS 38 kHz, and the AOS 120 kHz. Although the acoustic biomass estimates were calculated for all three echosounders separately, ultimately the vessel and AOS 38 kHz were combined to ensure consistency with the previously agreed 38 kHz biomass estimates.

Because of issues described above, assessment model runs in 2025 investigated permutations of observational data and productivity assumptions (see Results). The final runs used were similar across both stocks.

3. RESULTS

3.1 Fishery characterisation

For the Northwest Chatham Rise, effort has declined since 2017–18, and catch rates (t/tow and t/hour) have been variable but in 2023–24 were relatively high (Table 1). Tow duration has recently increased and in 2022–23 and 2023–24 was on average 4 hours, with a decline in short tows, and in the last two years only about 10% of tows were less than one hour duration.

Table 1: Northwest Chatham Rise, summary statistics for the commercial fishery using tow-by-tow estimated catch and effort data: number of vessels, percentage of tows targeting orange roughy (i.e., data are for orange roughy target fishing only), catch rate per tow and hour (total catch divided by total effort), percentage of tows that caught more than 10 t, percentage of tows that had duration less than one hour, and total hours fished. –, data excluded where there were <3 vessels. Number of tows and estimated catch were seen by the Working Group but removed from this table under Confidentiality rules.

Fishing year	Vessels	% Target	t/tow	t/hr	Duration (hr)	% >10t	% duration <1 hr	Hours
1989–90	19	100	4.07	1.54	2.63	9.4	13.3	1 569
1990–91	16	100	4.84	1.49	3.08	13.6	7.2	764
1991–92	7	100	4.08	2.65	1.00	8.6	46.2	143
1992–93	12	100	9.33	11.88	0.18	30.8	83.2	286
1993–94	13	100	5.95	6.18	0.22	18	82.7	513
1994–95	12	100	3.49	3.42	0.25	7.2	76.2	653
1995–96	12	100	4.34	4.47	0.20	12.2	77.2	486
1996–97	14	100	3.50	1.52	2.37	5.9	41.6	1 221
1997–98	14	100	2.70	1.63	0.68	5.0	52.6	1 285
1998–99	19	100	3.37	1.45	1.85	7.7	39.1	1 658
1999–00	11	100	3.32	2.25	0.25	9.2	67.8	849
2000–01	12	100	2.55	1.26	0.35	4.9	57.2	1 816
2001–02	12	100	2.35	1.1	1.75	4.5	45.0	1 703
2002–03	16	100	2.53	1.1	1.33	4.3	48.1	1 929
2003–04	13	100	2.44	0.74	3.98	4.4	27.4	2 348
2004–05	14	100	2.99	1.23	2.38	6.8	39.2	1 174
2005–06	10	100	2.79	1.46	0.45	5.7	54.4	798
2006–07	7	100	6.16	10.36	0.29	22.9	82.7	65
2007–08	7	100	2.50	2.45	0.28	5.7	73.0	288
2008–09	7	100	3.44	2.23	1.21	9.5	45.2	325
2009–10	7	100	2.33	0.92	2.01	4.8	41.5	690
2010–11	2	100	–	–	–	–	–	–
2011–12	2	100	–	–	–	–	–	–
2012–13	2	100	–	–	–	–	–	–
2013–14	7	100	3.88	3.11	0.32	11.1	66.7	236
2014–15	10	100	2.64	1.77	0.42	6.3	65.1	424
2015–16	11	100	1.48	0.69	1.97	2.0	37.4	873
2016–17	10	100	1.29	0.46	3.03	0.6	34.0	1 301
2017–18	9	100	1.86	0.67	2.52	2.8	31.4	1 102
2018–19	9	100	1.17	0.37	3.08	0.9	32.4	709
2019–20	8	100	1.39	0.42	3.9	1.7	29.8	585
2020–21	11	100	1.70	0.47	4.31	1.5	21.6	742
2021–22	8	100	1.21	0.46	2.24	0.6	32.5	401
2022–23	7	100	1.36	0.37	4.00	1.6	9.7	449
2023–24	5	100	2.24	0.62	4.02	6.0	13.0	364

The number of tows on the East & South Chatham Rise has decreased in the last two years although the number of vessels has remained similar (Table 2). The hours fished have declined after a peak in 2020–21, which had been the highest since 1989–90. The proportion of the tows that were short was about 40%, and the lowest in the time series. The catch rates in t/tow were slightly higher for the last three fishing years, but the t/hour in 2023–24 were at a time-series low; the last five fishing years had the five lowest t/hour catch rates.

Table 2: East & South Chatham Rise, summary statistics for the commercial fishery using tow-by-tow estimated catch and effort data: number of vessels and tows, percentage of tows targeting orange roughy (i.e., data are for orange roughy target fishing only), estimated catch, catch rate per tow and hour (total catch divided by total effort), percentage of tows that caught more than 10 t, percentage of tows that had duration less than one hour, and total hours fished. Number of tows and estimated catch were seen by the Working Group but removed from this table under Confidentiality rules.

Fishing year	Vessels	% Target	t/tow	t/hr	Duration (hr)	% >10t	% duration <1 hr	Hours
1989–90	25	100	6.32	3.54	0.67	19.0	60.9	4 599
1990–91	16	100	7.28	6.44	0.25	21.8	71.6	2 140
1991–92	14	100	7.24	12.12	0.20	22.4	92.0	1 144
1992–93	17	100	5.21	8.80	0.22	15.7	94.4	1 047
1993–94	17	100	3.24	5.83	0.23	8.4	91.4	1 561
1994–95	15	100	2.16	4.47	0.23	5.0	92.2	1 228
1995–96	11	100	3.12	4.26	0.27	7.4	84.8	964
1996–97	12	100	3.61	5.12	0.23	9.3	84.2	770
1997–98	14	100	2.66	4.27	0.25	5.8	87.8	1 285
1998–99	23	100	2.61	3.78	0.23	6.0	88.7	1 241
1999–00	14	100	3.87	7.15	0.2	9.7	92.8	797
2000–01	14	100	3.78	8.55	0.22	9.4	90.9	611
2001–02	13	100	4.20	6.03	0.23	10.9	85.1	1 293
2002–03	16	100	3.57	6.44	0.25	9.6	89.3	1 279
2003–04	16	100	3.03	3.64	0.28	7.4	80.7	2 040
2004–05	17	100	3.47	3.65	0.27	9.1	75.4	2 185
2005–06	13	100	3.25	4.61	0.25	8.7	84.6	1 823
2006–07	14	100	3.34	3.22	0.28	8.0	76.8	2 496
2007–08	7	100	3.50	4.29	0.25	9.2	80.1	1 632
2008–09	6	100	3.09	3.06	0.23	7.7	76.3	1 970
2009–10	7	100	3.67	2.92	0.30	8.6	68.9	1 625
2010–11	6	100	5.48	8.43	0.30	16.1	85.1	327
2011–12	6	100	4.94	8.10	0.30	12.7	86.3	293
2012–13	4	100	5.18	8.32	0.30	14.4	90.5	217
2013–14	6	100	4.72	6.20	0.30	13.2	85.5	420
2014–15	4	100	7.09	12.35	0.30	22.7	89.3	246
2015–16	5	100	2.62	3.37	0.28	7.6	84.9	866
2016–17	5	100	2.49	2.76	0.33	6.4	79.0	985
2017–18	5	100	2.56	2.59	0.35	6.0	78.1	1 152
2018–19	8	100	2.96	3.17	0.30	8.2	80.3	1 175
2019–20	7	100	3.29	2.00	0.43	9.7	62.6	2 265
2020–21	9	100	3.66	1.71	1.27	10.8	48.2	3 125
2021–22	12	100	5.57	2.21	2.52	16.7	37.4	2 564
2022–23	7	100	7.14	2.56	2.50	24.9	36.1	2 178
2023–24	7	100	4.65	1.85	2.93	16.5	39.4	1 249

Considering sub-areas, there has been a persistent trend to increase the proportion of effort and catch in the Spawning Box, with a continued increase in effort and catch from the Spawning Box after 2019–20 (Figure 2). Effort has declined substantially for the Andes and Chiefs on the southwest Chatham Rise (where catches were almost negligible for the last four fishing years), and northwest Chatham Rise. The last year, 2023–24, had a slightly greater proportion of the effort, and a substantial increase in proportion of catch, from the East Chatham Rise.

The Northwest Chatham Rise fishery took 18% of the agreed catch limit in 2023–24. About 20% of the recent catch was taken during the spawning season, compared with 60–85% historically (Anderson & Dunn 2012). 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. However, fish are believed to move off Morgue on some occasions, out of the area closed to fishing.

The recent fishery used more long tows on flat ground, rather than short tows on features; about 50% of the catch was taken in tows > 4 hours duration after 2015–16, compared historically with about 50–90% from tows < 1 hour (Figure 5).

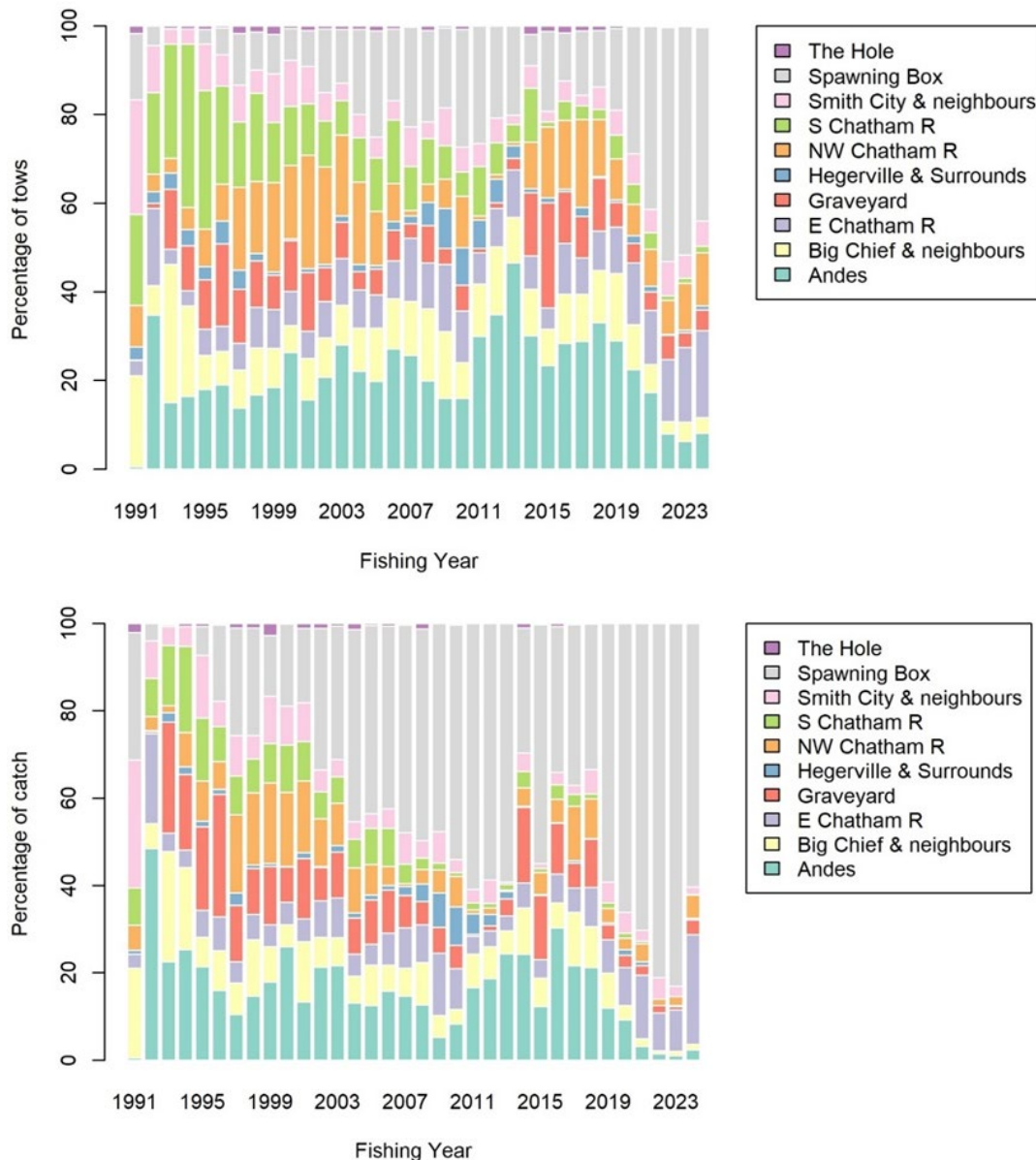


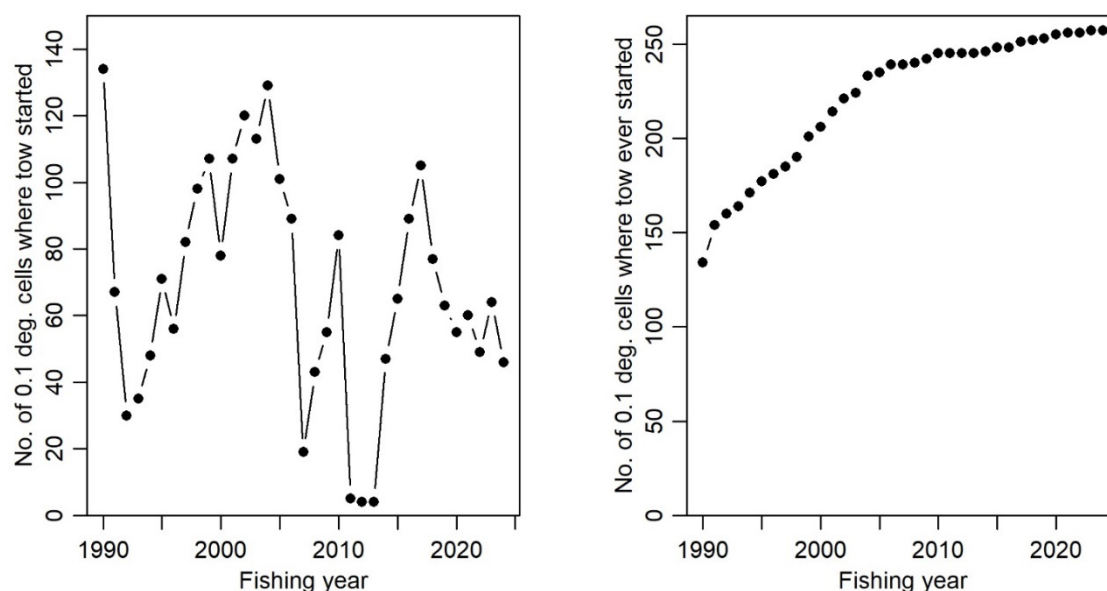
Figure 2: Proportion of orange roughy target tows (top panel) and estimated catch (bottom panel) by fishing year for selected areas. Area definitions given in Fisheries New Zealand (2025), with Spawning Box (north Rise 175–178° W); South Chatham Rise (excluding Hegerville & Surrounds, and Big Chief & Neighbours); Northwest Chatham Rise (excluding Graveyard and The Hole); and East Chatham Rise (excluding Andes and Smith City & neighbours). Fishing year labelled by year ending.

A simple measure of the spatial extent of the fishery was calculated by counting the number of tows that started in each 0.1° latitude and longitude cell (Figure 3). Overall, the recent fishing extent is lower than seen in the 1990s, when catches were much greater and fishing expanded spatially (as a result of the closure of the Spawning Box in the early 1990s). The spatial extent has recently been declining for the Northwest Chatham Rise, although the area ever fished has continued to slowly increase. The spatial extent for the East & South Chatham Rise has shown little change over the last nine fishing years.

Within the last decade, the proportion of tows that started on a feature (i.e., the trawl position, after offsetting for the difference between vessel and trawl location, was within three nautical miles of the top of the feature), increased to about 4% of tows for the East & South Chatham Rise, and 20% for

the Northwest Chatham Rise (Figure 4). This change in fishing pattern happened after 2015–16 for the Northwest Chatham Rise, where most of these “feature-starting long tows” were on the Graveyard complex, and after 2018–19 for the East & South Chatham Rise, where most were on the east Chatham Rise (e.g., the feature Not Till Sunday).

Northwest Chatham Rise



East & South Chatham Rise

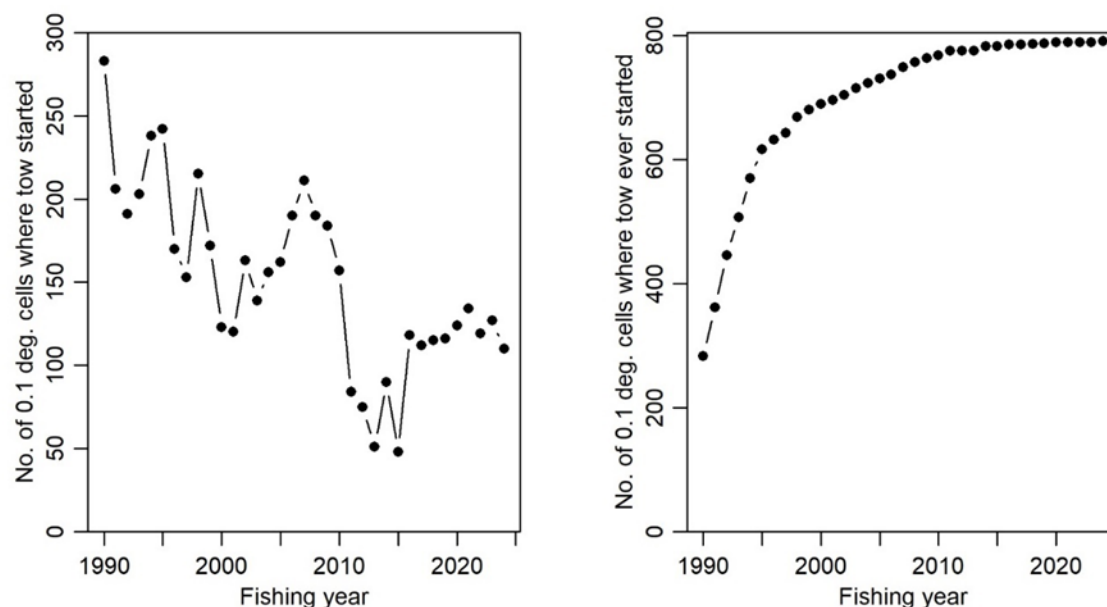


Figure 3: Left panels, number of 0.1° latitude and longitude cells in which one or more orange roughy target tows started in each year; Right panels, cumulative number of cells ever fished. Fishing year labelled by year ending.

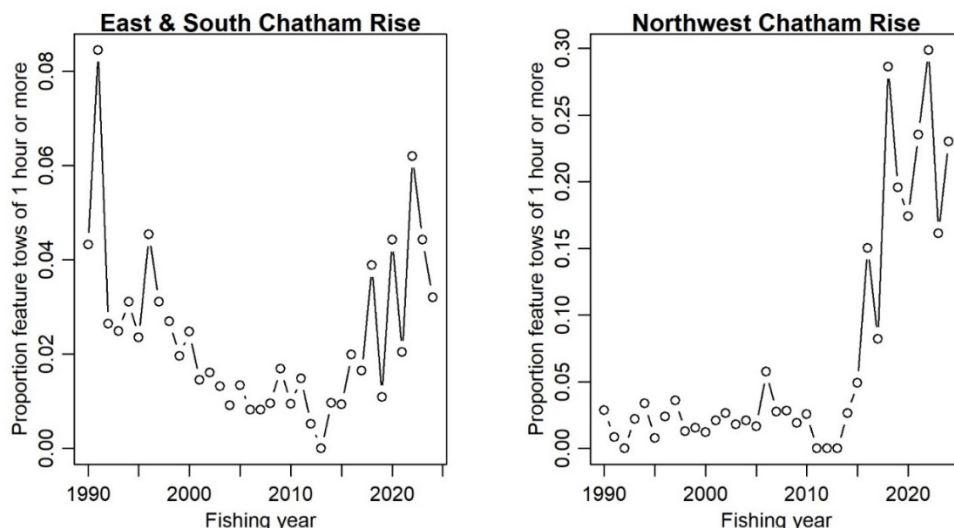


Figure 4: Proportion of orange roughy target tows that started within three nautical miles of a feature (after applying an offset for vessel versus trawl position) and had a duration of one hour or more by fishing year (labelled by year ending).

The recent fishery used more long tows on flat ground, rather than short tows on features; about 50% of the catch was taken in tows >4 hours duration after 2015–16, compared historically with about 50–90% from tows <1 hour (Figure 5). The shift from short tows on features or targeting spawning aggregations to long tows occurs in both stocks.

The East & South Chatham Rise fishery has steadily shifted to being a pre-spawning and spawning fishery (Figure 6). In recent years there has been very little fishing before May, and often substantial temporal gaps in fishing. In 2023–24, about two thirds of the catch was taken by the end of June.

The Northwest Chatham Rise fishery used to have a steady catch uptake through the year but has become more sporadic (Figure 6). In 2023–24, there was some fishing in December, taking a small proportion of the annual catch, then June (again not much catch), then about 70% of the annual catch was taken from mid-August to September, after the spawning period (June-July). Note that the annual catch for the Northwest Chatham Rise was relatively small (about 200 t).

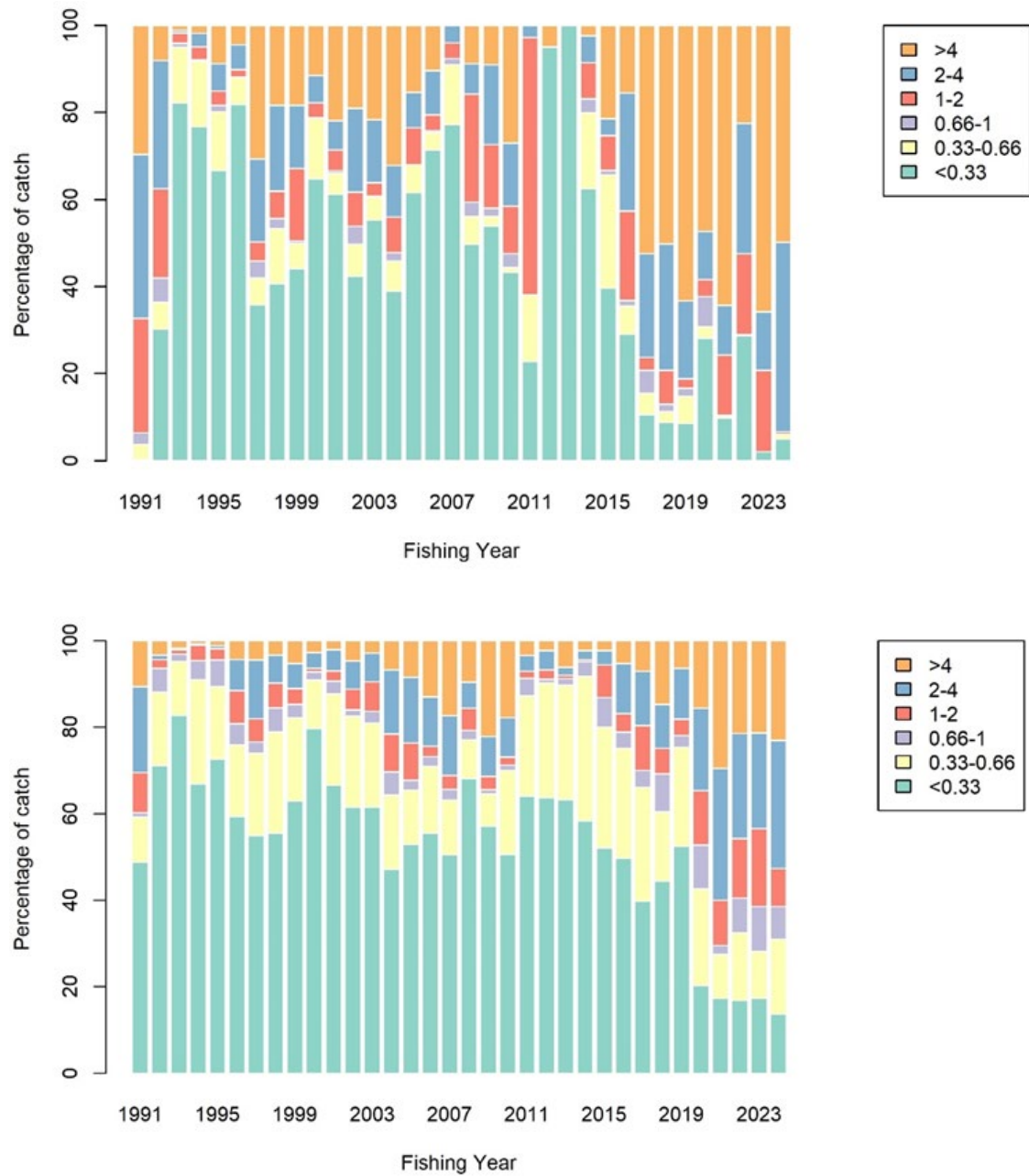


Figure 5: Northwest Chatham Rise (top panel) and East & South Chatham Rise (bottom panel) percentage of orange roughy target tows by duration (hours) and fishing year. Fishing year labelled as year ending.

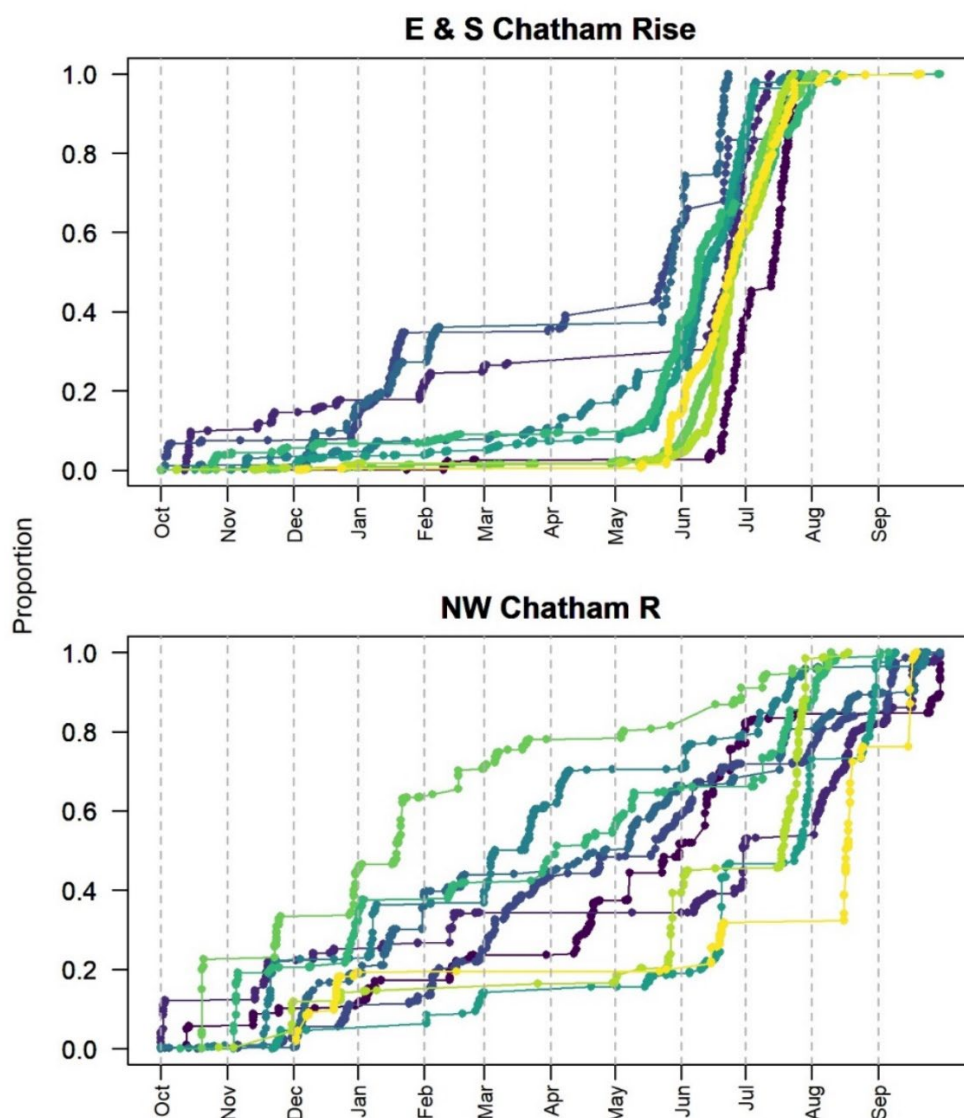


Figure 6: Seasonal uptake of annual orange roughy catch for the East & South Chatham Rise and Northwest Chatham Rise. Catches are summed in chronological order through the fishing year and scaled to a maximum of the total estimated catch for the year. Each point represents the relative accumulated catch. Vertical lines show the increase in catch to the next tow (point), and horizontal lines periods where there was no fishing. The last ten fishing years are shown from dark blue (2014–15) to yellow (2023–24).

For the East & South Chatham Rise, unstandardised CPUE has generally been flat or slowly declining since 2010–11 and were at historical lows within the last five years for fisheries at Andes complex, Smith City & neighbours, Big Chief & neighbours, Rekohu, and Spawning Box in season (during spawning), but with an increase since then at Andes complex and Big Chief & neighbours (Figure 7). A full time series of unstandardised CPUE back to 1979–80 is reported by Dunn (2024).

For the Northwest Chatham Rise, unstandardised CPUE was relatively high before 2015–16 and then was variable but without obvious trend. The CPUE in t/tow for the Graveyard increased in 2023–24, the t/hour did not.

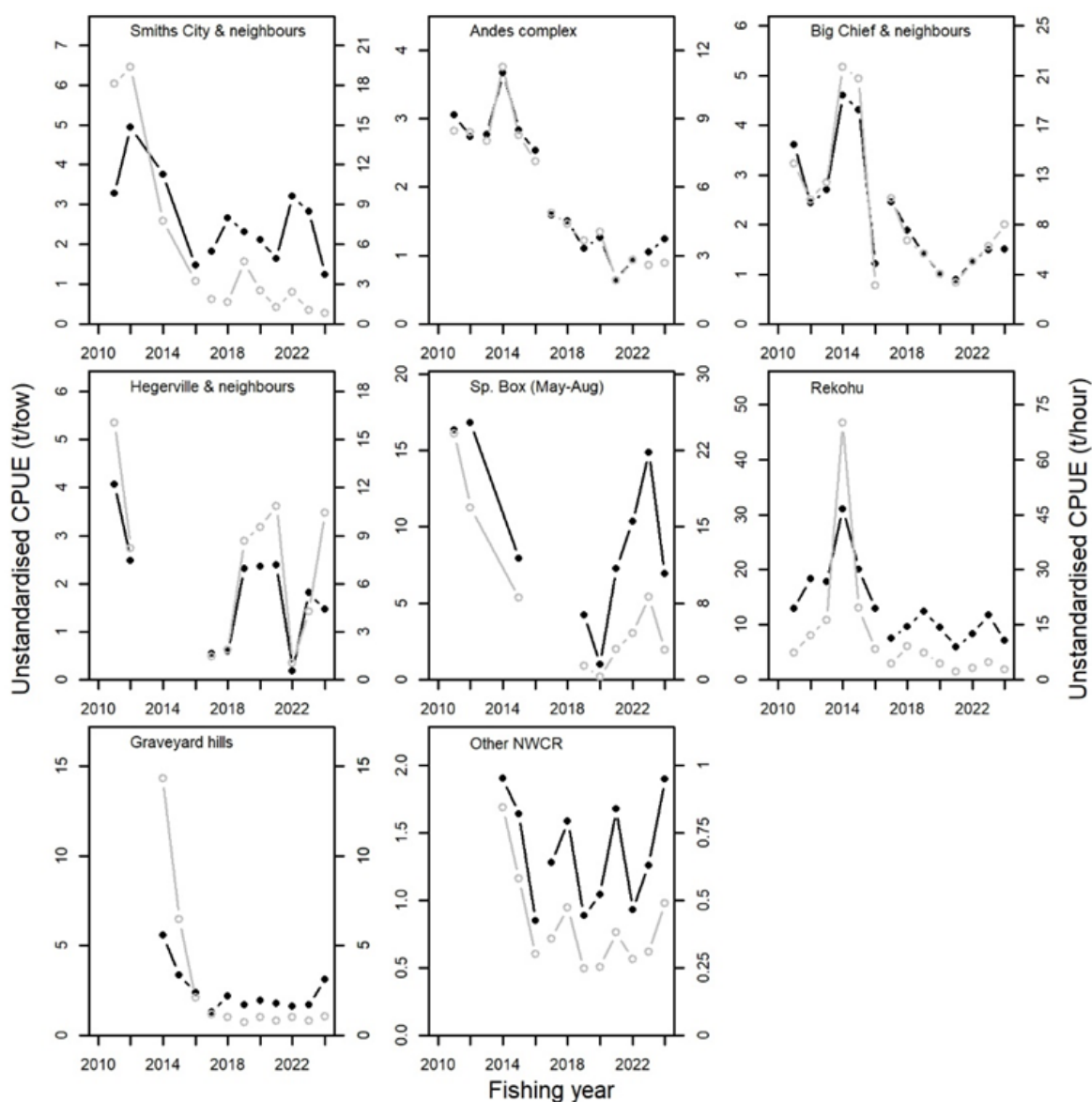


Figure 7: ORH 3B fishery sub-areas and annual unstandardised CPUE for the periods 2009–10 to 2015–16 (period of lower catches and catch limit); 2016–17 to 2023–24 (recent years within which fishery characteristics have changed). Black lines and points, t/tow (left y-axis); Grey lines and points, t/hour (right y-axis). Graveyard Hills and Other Northwest Chatham Rise (NWCR) are within the NWCR stock, the other sub-areas being within the East & South Chatham Rise. Years only plotted when 20 or more tows were completed. Allocation to area takes account of the positional offset between vessel and trawl. Fishing year labelled as year ending.

3.2 Stock assessment modelling for the East & South Chatham Rise

A Bayesian stock assessment was conducted using data up to 2023–24. This used an age-structured population model fitted to two series of acoustic survey estimates of spawning biomass (covering 2002–10 and 2011–24), and proportions-at-age from targeted trawling of spawning aggregations across a range of years and three locations.

Acoustic biomass observations

Acoustic biomass indices are available from three sources: the vessel-mounted 38 kHz sounder; the Acoustic-Optical System (AOS) 38 kHz sounder; and the AOS 120 kHz sounder. Up until 2016, the

biomass estimates from these three instruments were similar (Figure 8). However, in 2022 and 2024 the estimates from the 38 kHz and 120 kHz sounders diverged and suggested different biomass trends. For the East & South Chatham Rise, the acoustic series options were therefore considered to be: (a) the 2011–24 vessel 38 kHz; (b) the 2011–24 AOS 120 kHz; (c) the 2011–24 AOS 38 kHz; plus options (a), (b) and (c) also including the 2002–10 vessel 38 kHz Old Spawning Plume series. The calculation of these estimates is described in Appendix 2.

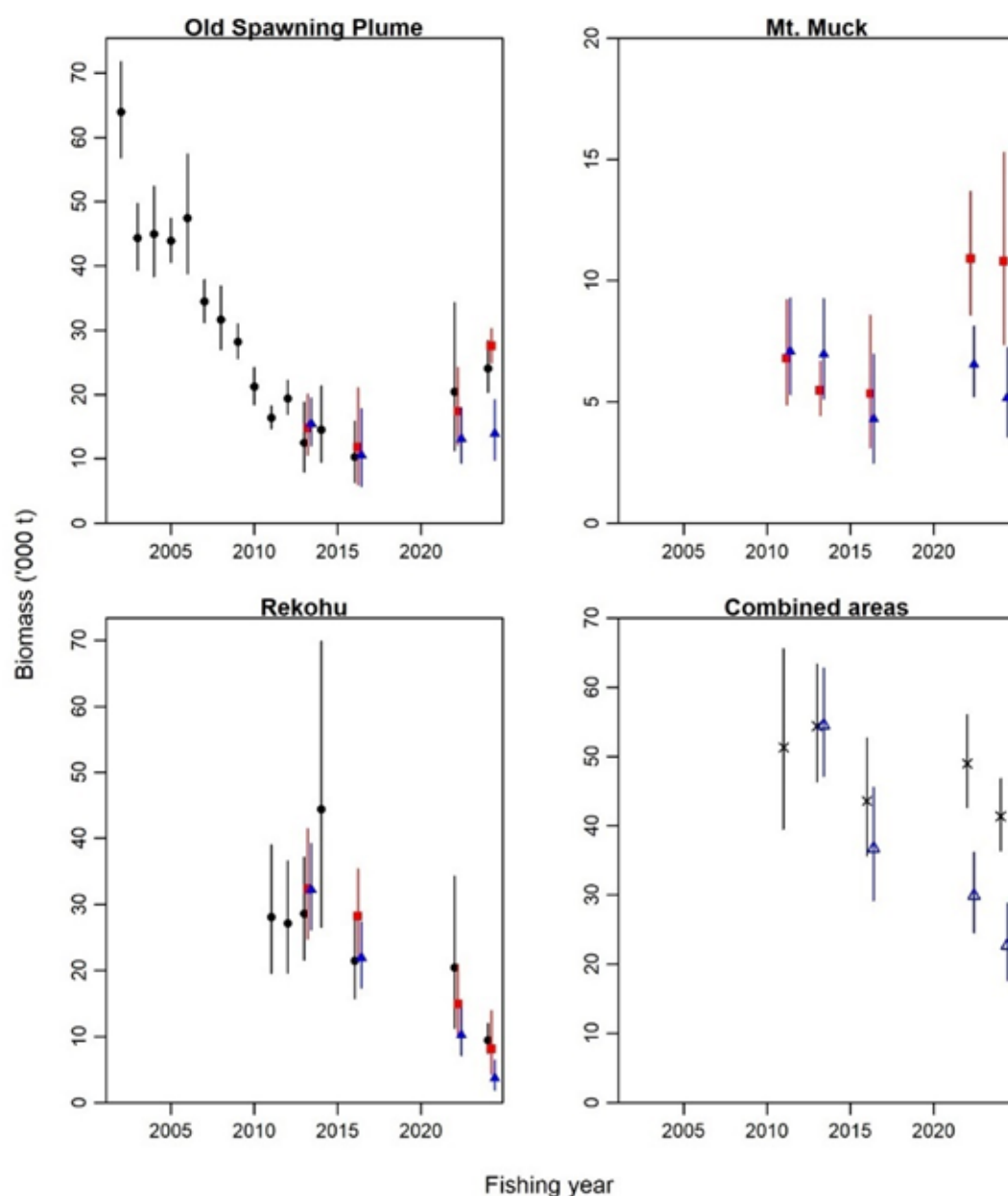


Figure 8: Acoustic biomass estimates for East & South Chatham Rise orange roughy. Combined areas is the Old Spawning plume, Mt. Muck, and Rekohu (all East & South Chatham Rise). Black circles, vessel 38 kHz; red squares, AOS 38 kHz; blue triangles, AOS 120 kHz. In combined areas panel: black cross, vessel 38 kHz; blue triangle, AOS 120 kHz.

The acoustic biomass estimates were calculated for each of the three main plumes in the Spawning Box, but ultimately combined for the years when all three areas were surveyed (Table 3). Biomass estimates used in the assessment were the vessel 38 kHz series for the Old Spawning Plume for 2002 to 2010, and either the 2011–24 vessel and AOS 38 kHz series, or the 2011–24 AOS 120 kHz series.

Table 3: East & South Chatham Rise orange roughy, acoustic survey estimates of spawning biomass used in the assessment model. The CVs do not include any process error. From 2011 only years when all three plumes were surveyed are included, and biomass estimates are shown for each echosounder.

Year	Location	Frequency	Estimate (t)	CV
2002	Old Spawning Plume	Vessel 38 kHz	63 950	0.06
2003	Old Spawning Plume	Vessel 38 kHz	44 316	0.06
2004	Old Spawning Plume	Vessel 38 kHz	44 968	0.08
2005	Old Spawning Plume	Vessel 38 kHz	43 923	0.04
2006	Old Spawning Plume	Vessel 38 kHz	47 450	0.10
2007	Old Spawning Plume	Vessel 38 kHz	34 427	0.05
2008	Old Spawning Plume	Vessel 38 kHz	31 668	0.08
2009	Old Spawning Plume	Vessel 38 kHz	28 199	0.05
2010	Old Spawning Plume	Vessel 38 kHz	21 205	0.07
2011	Old Spawning Plume + Rekohu + Mt.Muck	Vessel & AOS 38 kHz	51 329	0.13
2013	Old Spawning Plume + Rekohu + Mt.Muck	Vessel & AOS 38 kHz	54 363	0.08
	Old Spawning Plume + Rekohu + Mt.Muck	AOS 120 kHz	54 542	0.08
2016	Old Spawning Plume + Rekohu + Mt.Muck	Vessel & AOS 38 kHz	43 560	0.10
	Old Spawning Plume + Rekohu + Mt.Muck	AOS 120 kHz	36 716	0.11
2022	Old Spawning Plume + Rekohu + Mt.Muck	Vessel & AOS 38 kHz	48 981	0.07
	Old Spawning Plume + Rekohu + Mt.Muck	AOS 120 kHz	29 939	0.10
2024	Old Spawning Plume + Rekohu + Mt.Muck	Vessel & AOS 38 kHz	41 375	0.06
	Old Spawning Plume + Rekohu + Mt.Muck	AOS 120 kHz	22 723	0.13

Model runs fitting only to the recent acoustic data (2011–2024) were evaluated but excluded in favour of using as much of the higher quality data as possible (i.e., always including the acoustic Old Spawning Plume 2002–10 series).

The biomass estimates from 2011–24 were assumed to represent ‘most’ of the spawning biomass each year. This was modelled by treating the acoustic estimates as relative biomass and estimating the proportionality constant (q) with an informed prior. The prior was normally distributed with a mean of 0.8 (i.e., ‘most’ = 80%) and a CV of 19%. The CV of 19% was derived from the acoustic target strength uncertainty using the 38 kHz echosounder. The Old Spawning Plume series for 2002–10 was fitted with an uninformative (uniform) prior.

Model runs treating the acoustic biomass estimates as relative with uninformed (uniform) priors on the catchability (q) were found to produce either implausibly high Spawning Stock Biomass (SSB) estimates, or implausibly low SSB estimates (i.e., implausibly high q s; Figure 9).

The likely reason for the model estimating high acoustic q s when an uninformed acoustic q was assumed is that with productivity being constant, the biomass series is expected to respond to catch history (Figure 10). For the higher catches during 2001–02 to 2007–08 (of about 8000 t) to produce the observed biomass decline, then lower catches during 2010–11 to 2018–19 (of about 3000 t) to produce a flat trend, the vulnerable biomass must be relatively low. A low biomass estimate, when compared against the acoustic observations, results in a relatively high q . When informed q priors were used they were influential, and the estimated q was more plausible (Figure 11). Although q s higher than one were not considered plausible, the observed biomass trend being a decline, then flat/increase, then decline (Figure 8), does broadly agree with the timing of the catch history being relatively high, then low, then high (Figure 10).

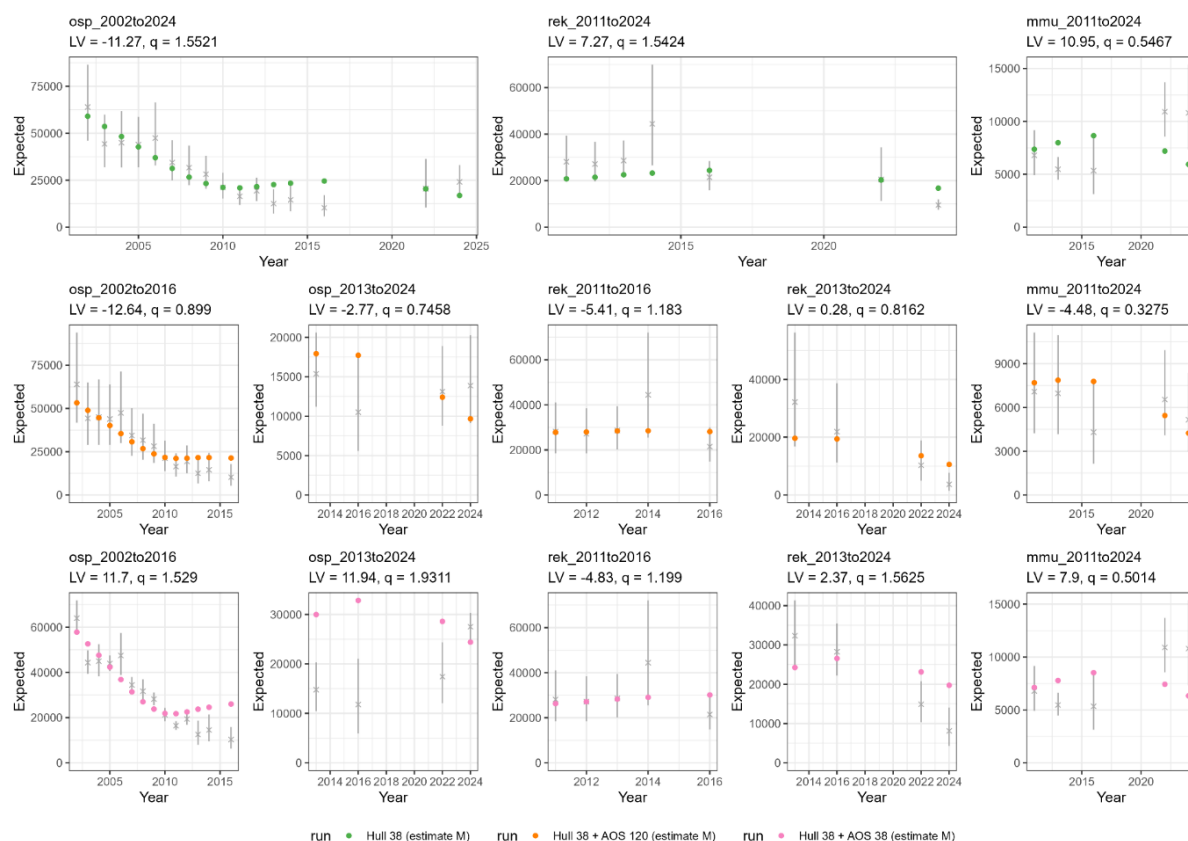


Figure 9: East & South Chatham Rise, example fit (coloured points) to acoustic biomass series (grey points with vertical lines indicating 95% CI), for different combinations of acoustic biomass series, all with uniform priors on the acoustic q s and estimating natural mortality rate (M). osp, old spawning plume; rek, Rekohu; mmu, Mt. Muck; LV, likelihood objective function. In this example the acoustic series were fitted separately; this was not the assumption used in final model runs. Year is the fishing year, as year ending.

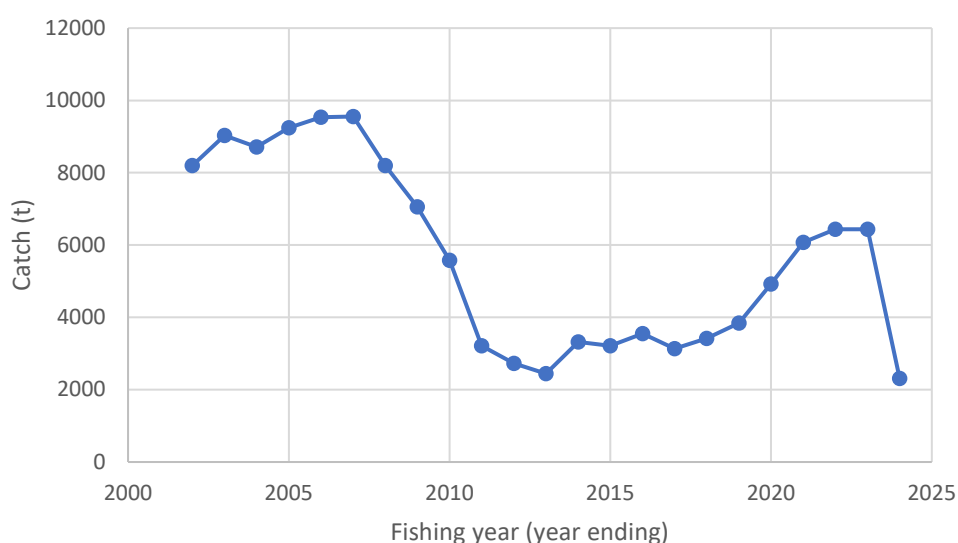


Figure 10: East & South Chatham Rise catch history (2001–02 to 2023–24). Year is the fishing year, as year ending.

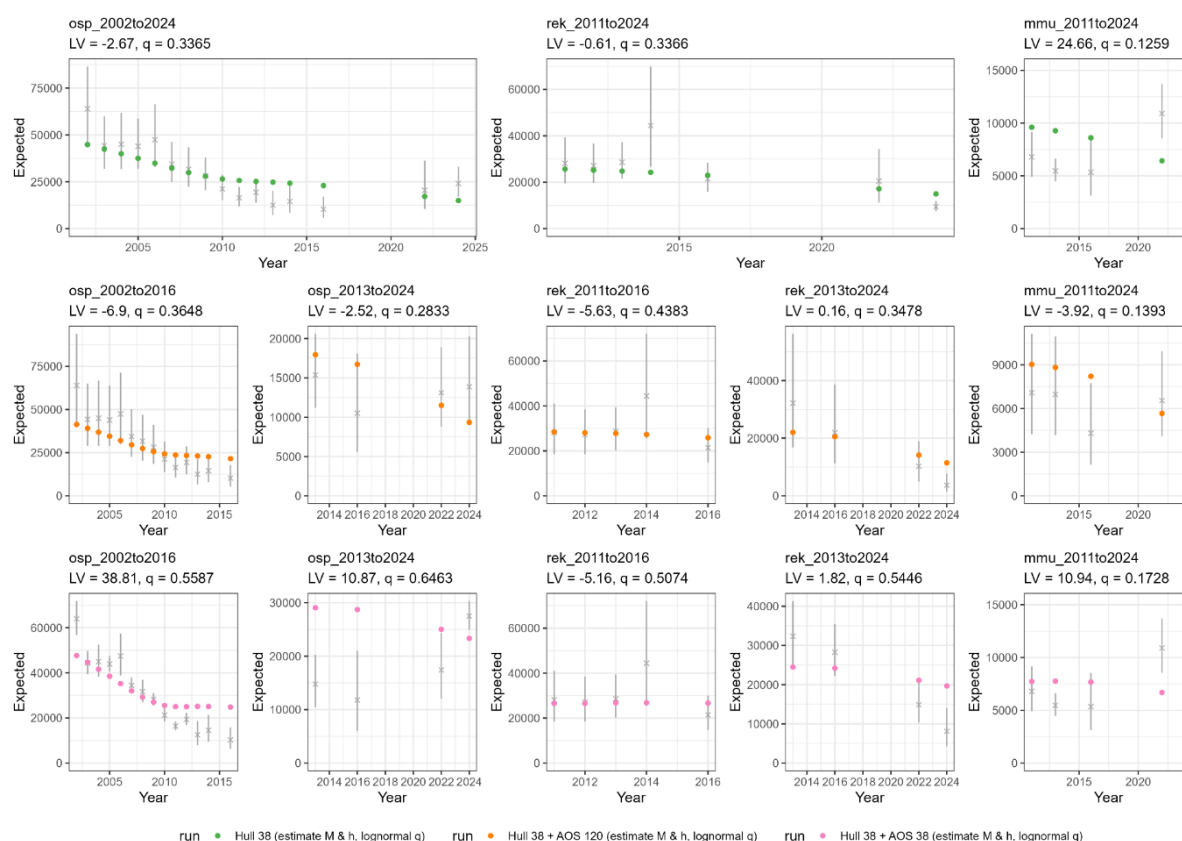


Figure 11: East & South Chatham Rise, example fit (coloured points) to acoustic biomass series (grey points with vertical lines indicating 95% CI), for different combinations of acoustic biomass series, all with informed (lognormal, LN) priors on the acoustic q s and estimating natural mortality rate (M). osp, old spawning plume; rek, Rekohu; mmu, Mt. Muck; LV, likelihood objective function. In this example the acoustic series were fitted separately; this was not the assumption used in final model runs. The priors used here were osp LN(mean=0.264, CV=0.2); rek LN(mean=0.408, CV=0.2); mmu LN(mean=0.128, CV=0.2). Year is the fishing year, as year ending.

Having separate informed q priors for the three acoustic biomass series is problematic under the “fleets as areas” approach that was used in model development (see Dunn et al. 2025). This is because the three acoustic series are each indexing parts of the SSB and, importantly, it is therefore assumed that each part shares the same trend. If the biomass trends differ (which they do), then each series (using the constant q) would imply different underlying SSB trends, and magnitudes. A solution would be to treat each area as independent, i.e., a true spatial model, but the data were considered insufficient to attempt this approach. Therefore, the approach taken was to sum the biomass estimates where all three areas were surveyed, requiring a single q relating the estimates to the SSB. The 2002–10 old spawning plume series was considered separate, with an uninformed (uniform) q prior.

Stock productivity assumptions

The CASAL2 model is not able to estimate the change year for time-varying (TV) recruitment alongside other model parameters. A likelihood profile for the change year was therefore completed, and showed that the most likely change year overall was around 1975 (Figure 12). The 2011–24 38 kHz acoustic series and age frequency from Mt. Muck indicated an earlier change point, around 1970, and the age frequency from Rekohu a later change point, around 1985. Hypotheses of disturbance of spawning aggregations by fishing, which started in the late 1970s (Dunn et al. 2025), were broadly

consistent with the change point estimated from the likelihood profiles. The change point was set at 1980 for both stocks (both had a similar fishing history) and was not modified in any subsequent model runs.

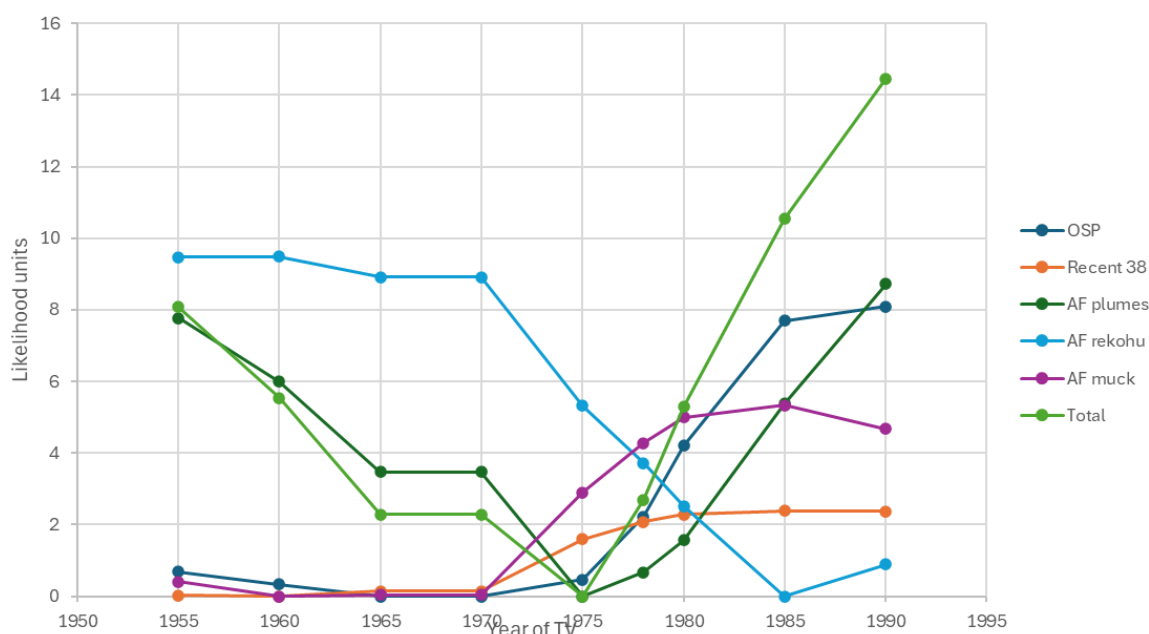


Figure 12: East & South Chatham Rise, likelihood profiles for the year at which time-varying recruitment (TV) changed. Likelihoods: OSP, old spawning plume 2002–10 acoustic biomass index; Recent 38, 2011–24 acoustic biomass index using the 38 kHz sounder; AF plumes, age frequencies for the old spawning plume; AF rekohu, age frequencies for Rekohu; AF muck, age frequencies for Mt. Muck. All likelihood profiles scaled to have a minimum of zero. Year is the fishing year, as year ending.

Model structure and assumptions

The model was single-sex and age-structured (1–100 years with a plus group). A single time-step was used, with spawning taken to occur after 75% of the mortality and 100% of mature fish were assumed to spawn each year. Four fisheries were assumed (Old Spawning Plume, Mt. Muck, Rekohu, with the remainder being allocated to a “Non-spawn” fishery), with a catch history constructed from the reported ORH 3B catch (Fisheries New Zealand), scaled to fishery areas using estimated catch data, and then increased by assumed catch over-run percentages (Fisheries New Zealand). The catches used in the assessment are given in Appendix 3.

The three spawning fisheries (Old Spawning Plume, Rekohu, Mt. Muck) are all in the Spawning Box, and are the only spawning aggregations recently fished. The age frequencies from these three areas have been collected from the target fishing of orange roughy by the vessel doing the acoustic survey, and suggest differences in age composition between the areas; whilst the acoustic biomass indices for the areas were summed, the age frequencies were therefore kept separate. Keeping the areas separate for age data also allowed age frequencies taken before 2010, from only the Old Spawning Plume, to be included in the model. There are no age frequencies available for the non-spawning fishery. Multinomial effective sample sizes for the age frequencies were all assumed to be 10, except for the old spawning plume in 2003 where the effective sample size was 2.

For model runs when only acoustic data were used, fishery selectivity was assumed equal to the otolith transition zone maturity estimate (logistic with $a50 = 28.51$, $ato95 = 4.56$). When age frequencies were included in the model, maturity was set equal to the selectivity for Rekohu and Old

Spawning Plume fisheries. The Mt. Muck fishery had its own selectivity, estimated as a logistic ogive.

Natural mortality rate was assumed to be fixed at 0.045 yr^{-1} . A single step change in productivity was allowed by estimating one R_0 for the period 1911 to 1979, and a second R_0 for the period 1980 to 2025. A stock-recruitment relationship was not assumed (i.e., steepness = 1). Process error was added manually to the acoustic series to ensure that the mode of the posterior distribution (MPD) passed through the 95% CI. The remaining fixed biological parameters are detailed in Appendix 3.

Selecting final model runs

Final model runs used:

- (a) the 2002–10 old spawning plume vessel 38 kHz series, plus one of either the 38 kHz or 120 kHz series from 2011–2024, and estimated time-varying recruitment (two levels changing at 1980); or
- (b) as (a), including the age frequencies.

Model runs using only the acoustic series and estimating M were excluded because of poor Markov Chain Monte Carlo (MCMC) diagnostics, with poor mixing (correlated chains) and bimodal parameter estimates (Figure 13). When the informed prior on M was made more informative (initial lognormal with mean 0.045 and CV 0.33, was given a CV of 0.1), the covariance matrix re-estimated, M log-transformed, and the MCMC chain lengthened and more infrequently sampled, the diagnostics improved (Figure 14). However, this is a rather “contrived” solution and offers little benefit over using a fixed M . It also reflects a problem in parameter estimation (high correlation between M and R_0).

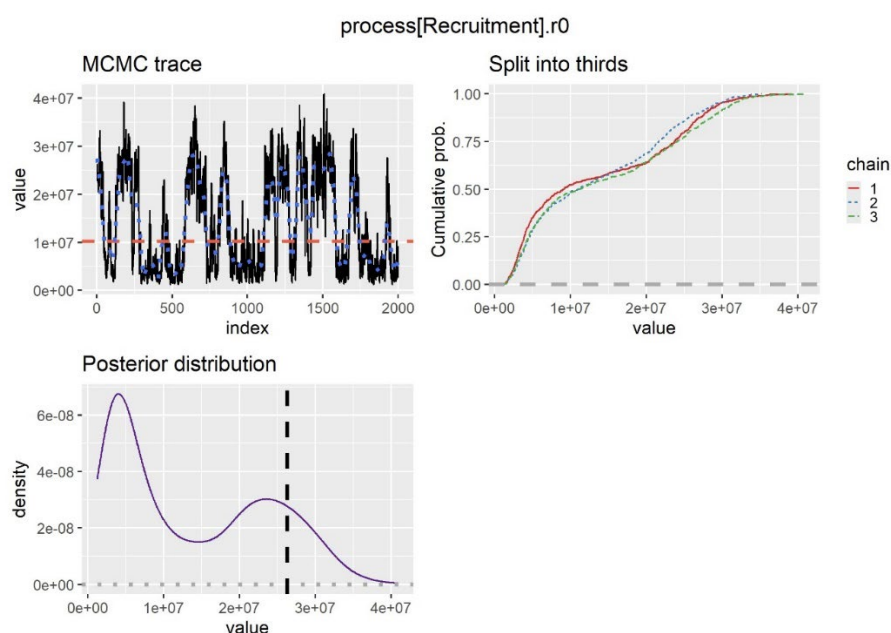


Figure 13: East & South Chatham Rise, MCMC diagnostics for the estimated virgin recruitment level (r_0) in a model run using the 120 kHz acoustic series and estimating M (YCS being constant).

Model runs including the age and length frequency data and estimating year class strengths were excluded because the data were considered insufficiently informative for year class strength estimation. Length data were ultimately excluded from all East & South Chatham Rise model runs.

The model parameters estimated were the virgin (unfished, equilibrium) recruitment (R_0), recruitment for the period 1980–2025 (R_I), and the acoustic survey catchability scalars (q_s) for the 2002–10 and

2011–24 series. When age frequencies were included logistic selectivity parameters were also estimated for Mt. Muck ($A_{50} = 34.9$; $A_{1095} = 9.0$).

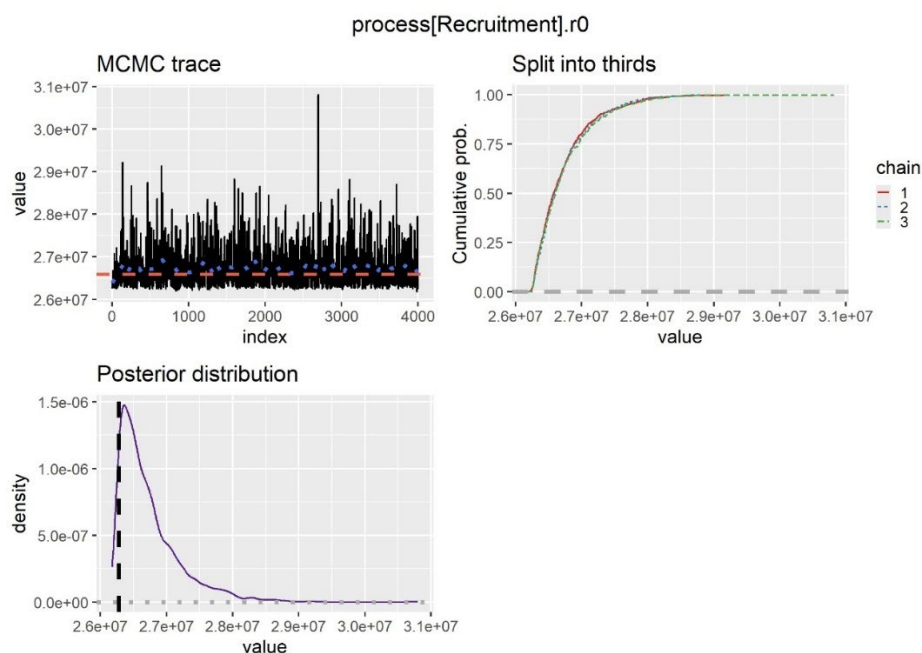


Figure 14: East & South Chatham Rise, MCMC diagnostics for the estimated virgin recruitment level (R_0) in a model run using the 120 kHz acoustic series and estimating M (YCS being constant), with more informed prior on M , and technical changes made to the MCMC settings (see text).

The model provided accepted fits to the acoustic series, but the 2002–10 acoustic series declined faster than could be fitted by the model (Figure 15).

When only the acoustic series were included, the posterior estimates for the acoustic q s were not very different from the priors (Figure 16). When the age frequencies were included, the q s were estimated to be lower than the prior, meaning the estimated acoustic series biomass (2011–24) was greater (by about 20–40%) than observed. The overall fit to the age frequencies was accepted by the Deepwater Working Group, but some individual age frequencies were not well fitted (Figure 17).

All age frequencies could not be fitted well by a model assuming constant selectivity because the samples implied a change in age structure, which is not possible in an orange roughy population. For example, the substantial proportion of old fish present in the Old Spawning Plume in 1984 were absent in 2003, but then returned in 2012; at Rekohu, fish aged less than about 30 years were present in 2016, greatly reduced in 2022, but present again in 2024; at Mt. Muck, a large proportion in the plus group was only present in 2016.

ESCR

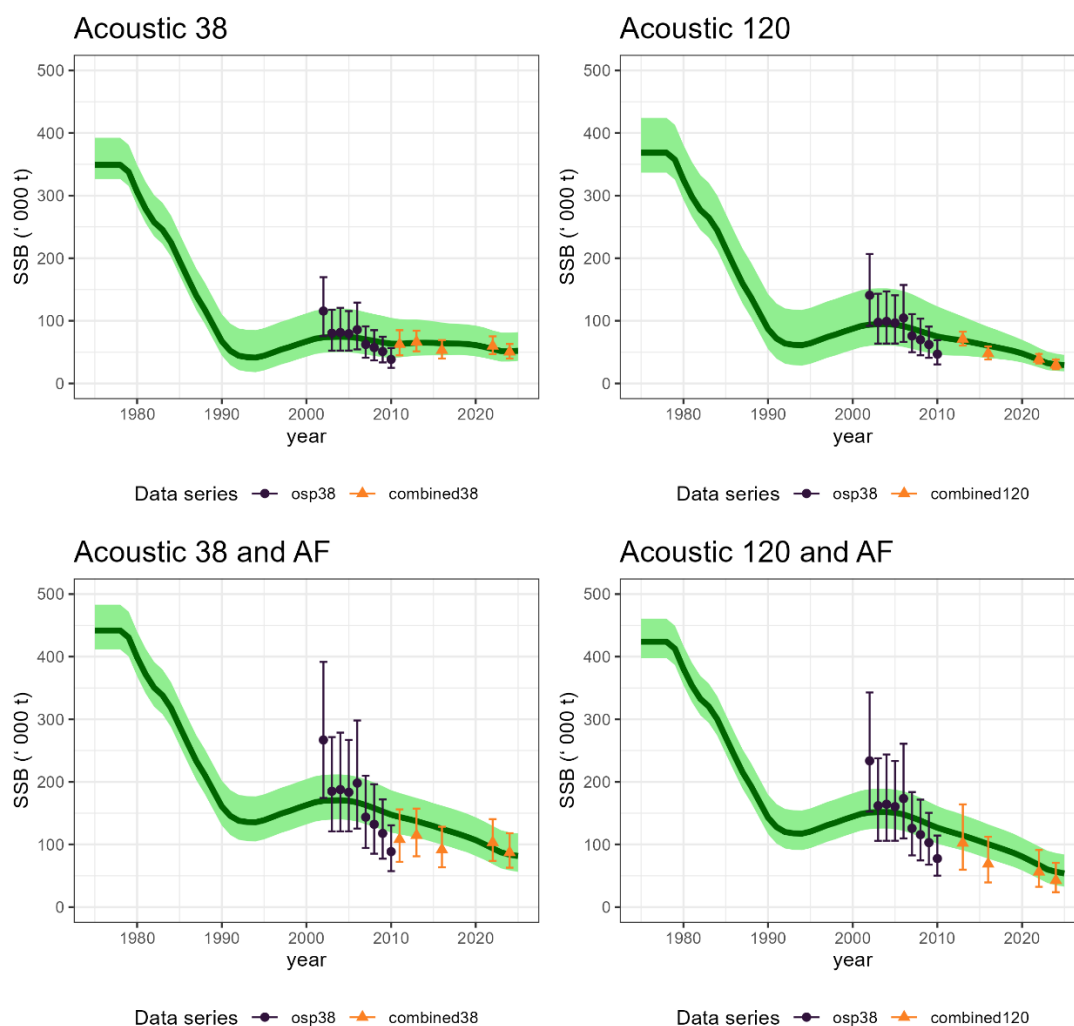


Figure 15: East & South Chatham Rise assessment model runs using the acoustic (vessel) 38 kHz from 2002–10, and either the vessel 38 kHz (2011–24) or AOS 120 kHz (2013–24) acoustic biomass series, MCMC implied fits of SSB (solid line, median; shaded region, 95% credible intervals) to the acoustic biomass indices (points with vertical lines indicating the 95% CI). Year is the fishing year, as year ending.

ESCR

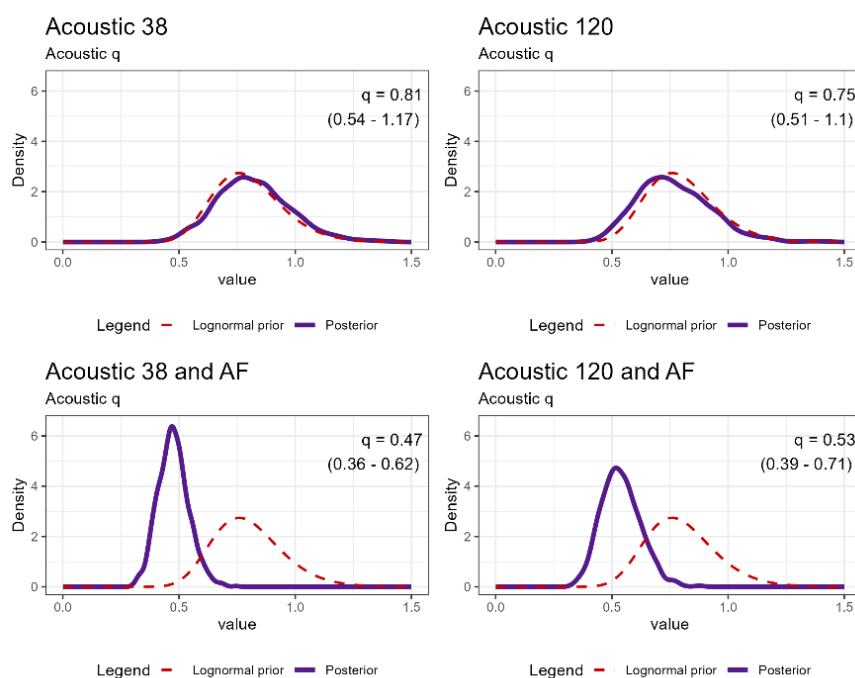


Figure 16: East & South Chatham Rise assessment model prior (broken line) and MCMC posterior (solid line) for the acoustic q (series from 2011) with text giving the median and 95% credible intervals.

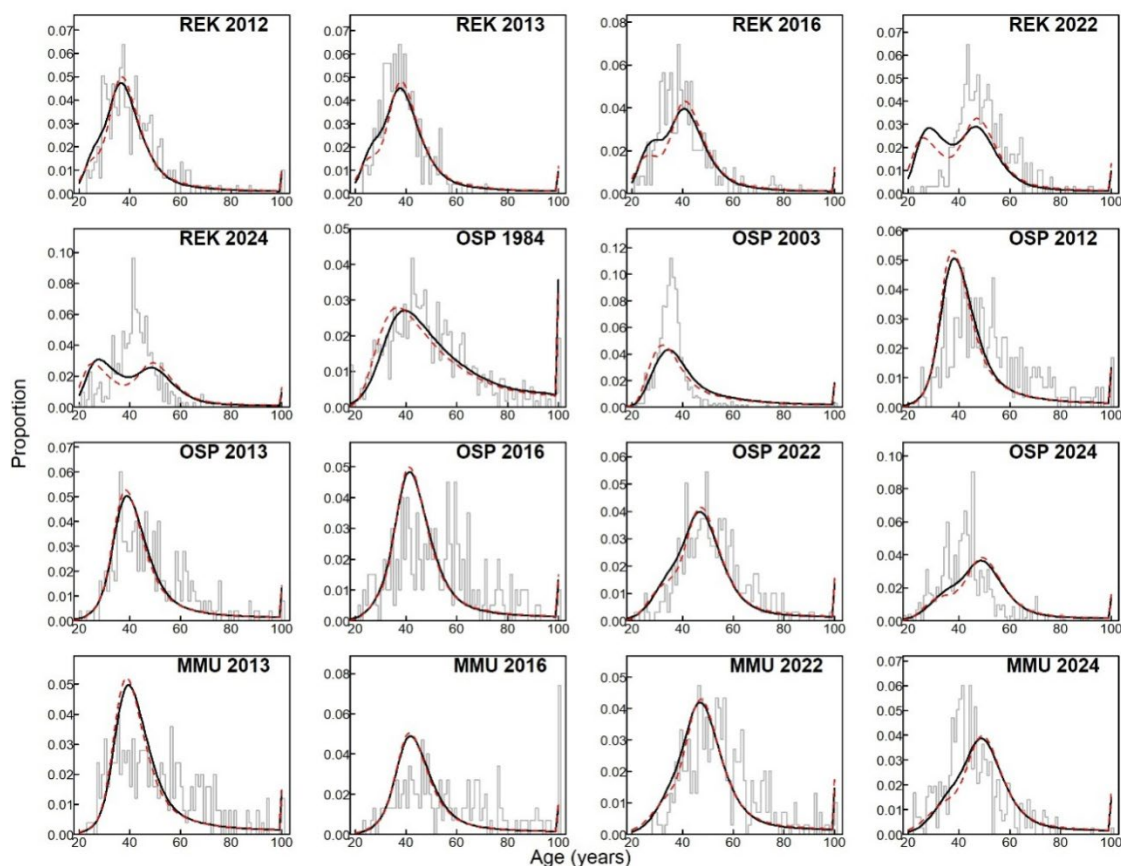


Figure 17: East & South Chatham Rise assessment model MPD fits (“best fits”) to the age frequencies from REK, Rekohu; OSP, Old Spawning Plume; and MMU, Mt. Muck. Solid line, Acoustic 38 and AF; broken red line, Acoustic 120 and AF.

All model runs estimated a productivity decline between the 1911–1979 and 1980–2025 periods of between 14% and 40% of the initial value (Table 4). The decline was greater in model runs using the 120 kHz acoustic series. The decline in recruitment occurs because the model is attempting to fit the absolute level of recent acoustic biomass estimates, and also a shift to the right of the age frequencies (most obviously seen in 2022).

Table 4: East & South Chatham Rise MCMC estimates of recruitment at age one (with 95% credible intervals) for the period 1911–1979 (R_0) and 1980–2025 (R_I).

Data sets	R_0 (millions)	R_I (millions)	R_I (median) / R_0 (median)
Acoustic 38	39.5 (36.9–44.4)	15.8 (11.7–20.7)	0.40
Acoustic 120	41.7 (38.1–48.0)	7.9 (2.4–11.5)	0.19
Acoustic 38 and AF	49.9 (46.5–54.6)	11.1 (6.7–17.1)	0.22
Acoustic 120 and AF	48.0 (45.0–52.1)	6.5 (3.7–11.1)	0.14

Sensitivity runs showed that the estimated stock size and status was sensitive to the mean of the assumed q prior for the 2011–24 acoustic series when only acoustic data were used, giving a smaller and more depleted stock with higher q , and a larger and less depleted stock with lower q (Table 5).

Table 5: East & South Chatham Rise Mode of Posterior Distribution (MPD) estimates of biomass (with 95% credible intervals) for different acoustic survey catchability (q) prior assumptions.

Mean of q prior	B_0 ('000 t)	B_{2025}	B_{2025}/B_0
0.80	506.5	50.4	0.100
0.96	489.3	42.7	0.087
0.64	518.8	62.5	0.120

The model was sensitive to some assumptions about, and estimation of, selectivity and maturity. For example, if maturity was assumed equal to estimated selectivity for Rekohu (i.e., maturity was relatively young, at about age 25), and estimated separately for the Old Spawning Plume and Mt. Muck, then the stock was more depleted. This outcome is most likely to be because the proportion of the stock selected as SSB is different; permutations of selectivity when maturity was fixed were much less sensitive (Table 6). The selectivity parameters could vary substantially with similar fits to data; for example, in investigative model runs the Old Spawning Plume a_{50} varied overall from around 25 to 45 years.

Table 6: East & South Chatham Rise; example runs with permutations of the selectivity used to fit the age frequencies and acoustic biomass series. In runs (1) and (2), all acoustic series were fitted using the maturity ogive. Run (3) is the same as (2) except the Old Spawning Plume (osp) acoustic biomass series is fitted using the estimated osp selectivity. * fixed parameter. The maturity ogive in all three runs is the same and set equal to the otolith transition zone estimate ($a_{50} = 28.51$, $a_{95} = 4.56$).

Parameter or likelihood (LL) estimate	Selectivity assumption		
	(1) mmu estimated, rek and osp = maturity	(2) mmu and osp estimated, rek = maturity	as (2) except the osp selectivity is used to fit the osp acoustic series
B_0	332 000	341 000	337 000
B_{2025}	69 000	78 000	72 000
B_{2025}/B_0	0.21	0.23	0.21
q 2002–10	0.43	0.67	0.44
q 2011–24	0.70	0.98	0.69
mmu a_{50}	51.3	50.2	48.7
mmu a_{95}	15.3	16.0	14.8
osp a_{50}	28.51*	35.5	37.8
osp a_{95}	4.56*	8.58	10.2
rek a_{50}	28.51*	28.51*	28.51*
rek a_{95}	4.56*	4.56*	4.56*
LL osp	152.09	141.06	140.06
LL rek	98.07	98.86	99.42
LL mmu	89.78	89.60	90.27

The rate of decline in the 2002–10 acoustic series could only be fitted by estimating year class

strengths and/or a very low M ($<0.02 \text{ yr}^{-1}$) (Figure 18), which were not considered acceptable assumptions; these runs also incurred a catch penalty, indicating that the SSB was at the smallest size possible that could explain the historical catches ($B_{\min}$).

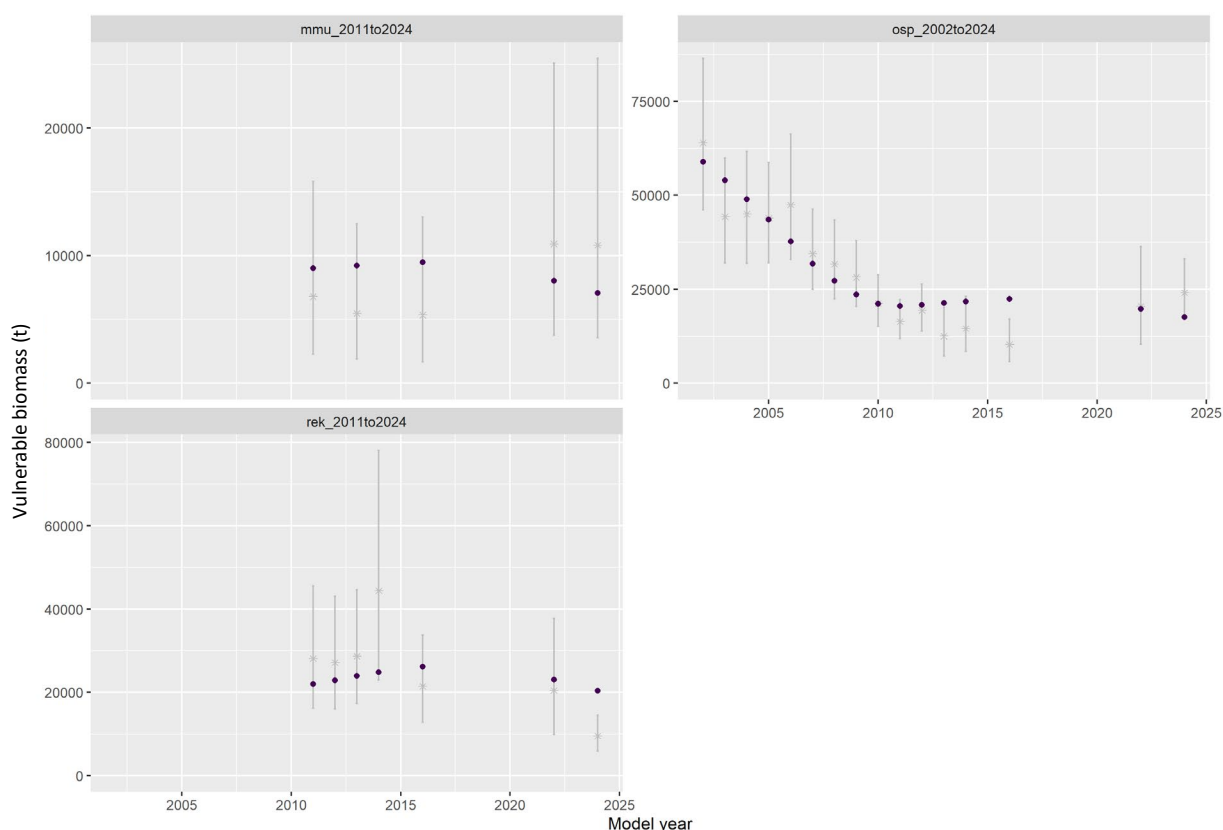


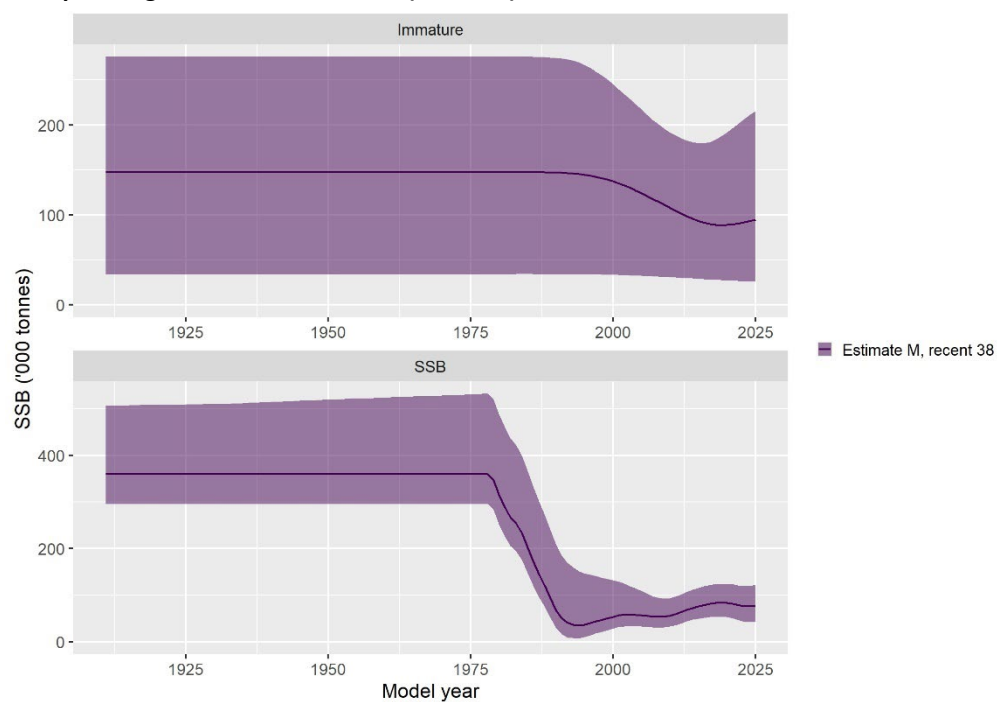
Figure 18: East & South Chatham Rise, example of a relatively good fit (solid points) to acoustic biomass estimates (grey points with vertical lines indicating 95% CI). The Old Spawning Plume (osp) acoustic biomass series in this run was assumed to be a single series for 2002–2024. The model estimated year class strengths and M (at 0.023). mmu, Mt. Muck acoustic biomass; rek, Rekohu acoustic biomass. Year is the fishing year, as year ending.

The Old Spawning Plume 2002–10 acoustic biomass series used an uninformative (uniform) prior and had little influence on absolute biomass but was influential on the spawning stock trajectory. When the Old Spawning Plume acoustic biomass series 2002–10 was included the stock trajectory through that period was a decline, and when excluded it was flat (Figure 19).

Virgin biomass, B_0 , was estimated to be similar for the acoustic-only runs at 349 200 or 368 600 t, and higher and similar for the acoustic and age frequencies runs at 441 800 or 423 900 t (Table 7). The runs using the vessel 38 kHz series from 2011–24 estimated a higher stock status, at 16 or 18% B_0 , than those using the AOS 120 kHz series from 2013–24, at 8 and 13% B_0 .

The probability that the stock was below the soft limit (20% B_0) in 2025 was 72–100%. The probability that the stock was below the hard limit (10% B_0) in 2025 was 1% or less for the runs using the acoustic 38 kHz series (runs Acoustic 38, and Acoustic 38 and AF), and higher at 14% or 91% for the runs using the acoustic 120 kHz series (runs Acoustic 120, and Acoustic 120 and AF) (Table 7).

Old Spawning Plume acoustic series (2002–10) excluded



Old Spawning Plume acoustic series (2002–10) included

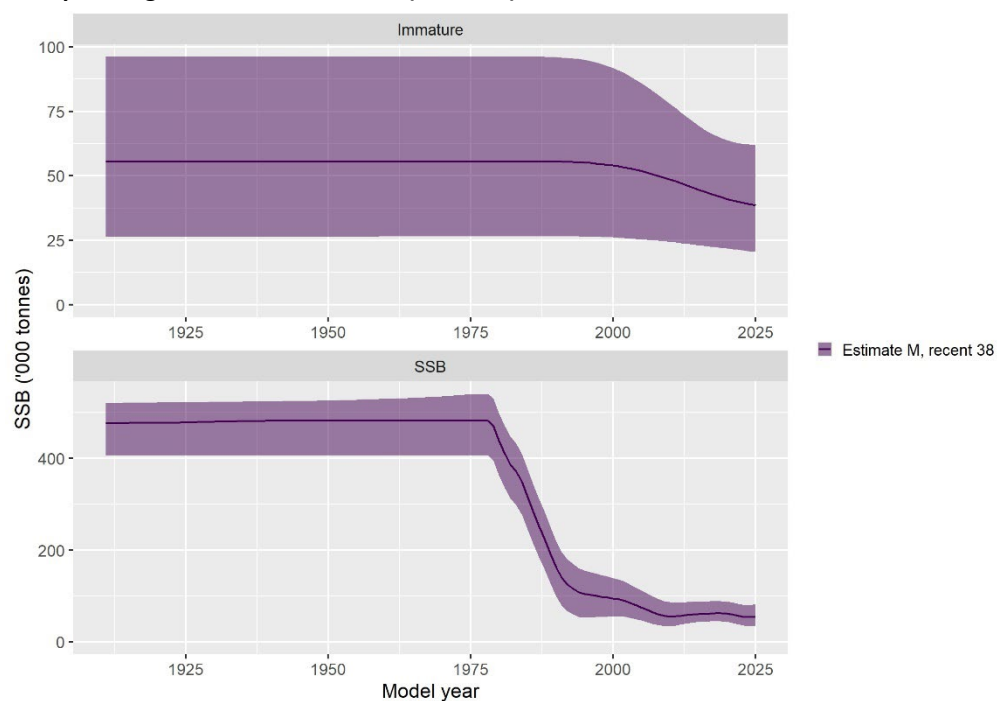


Figure 19: East & South Chatham Rise, MCMC estimates of immature and mature biomass (line, median; shaded area, 95% credible intervals), for model runs including or excluding the 2002–10 Old Spawning Plume acoustic biomass series. Model runs used the 38 kHz series for 2011–24 and estimated M . Year is the fishing year, as year ending.

Table 7: East & South Chatham Rise, MCMC median estimates and 95% credible intervals of virgin spawning stock biomass (B_0), spawning stock biomass in 2025, stock status (B_{2025} as % B_0), and probability of being below the soft (20% B_0) and hard (10% B_0) limits. All model runs include the Old Spawning Plume acoustic series (2002–10), one recent (2011–24) acoustic series, and assume time-varying recruitment (TV).

Model run	B_0 (000 t)	B_{2025} (000 t)	B_{2025} (% B_0)	p(B_{2025} <20% B_0)	p(B_{2025} <10% B_0)
Acoustic 38	349.2 (326.5–392.3)	52.0 (36.1–81.9)	16 (11–22)	94	1
Acoustic 120	368.6 (336.7–424.2)	29.3 (19.4–45.5)	8 (6–11)	100	91
Acoustic 38 and AF	441.8 (411.6–483.0)	81.5 (56.2–117.5)	18 (13–25)	72	<1
Acoustic 120 and AF	423.9 (398.0–460.6)	53.7 (32.7–84.0)	13 (8–19)	99	14

The estimated spawning stock biomass (SSB) trajectory showed a declining trend from 1980 (when the fishery started) through to 1994 when the biomass was between the soft and hard limit (acoustic only runs) or at the lower bound of the target zone (acoustics and age frequency runs) (Figure 20). The SSB then rebuilt until 2005, after which it declined, with the rate of decline least in the Acoustic 38 run, and greatest in the Acoustic 120 and AF run.

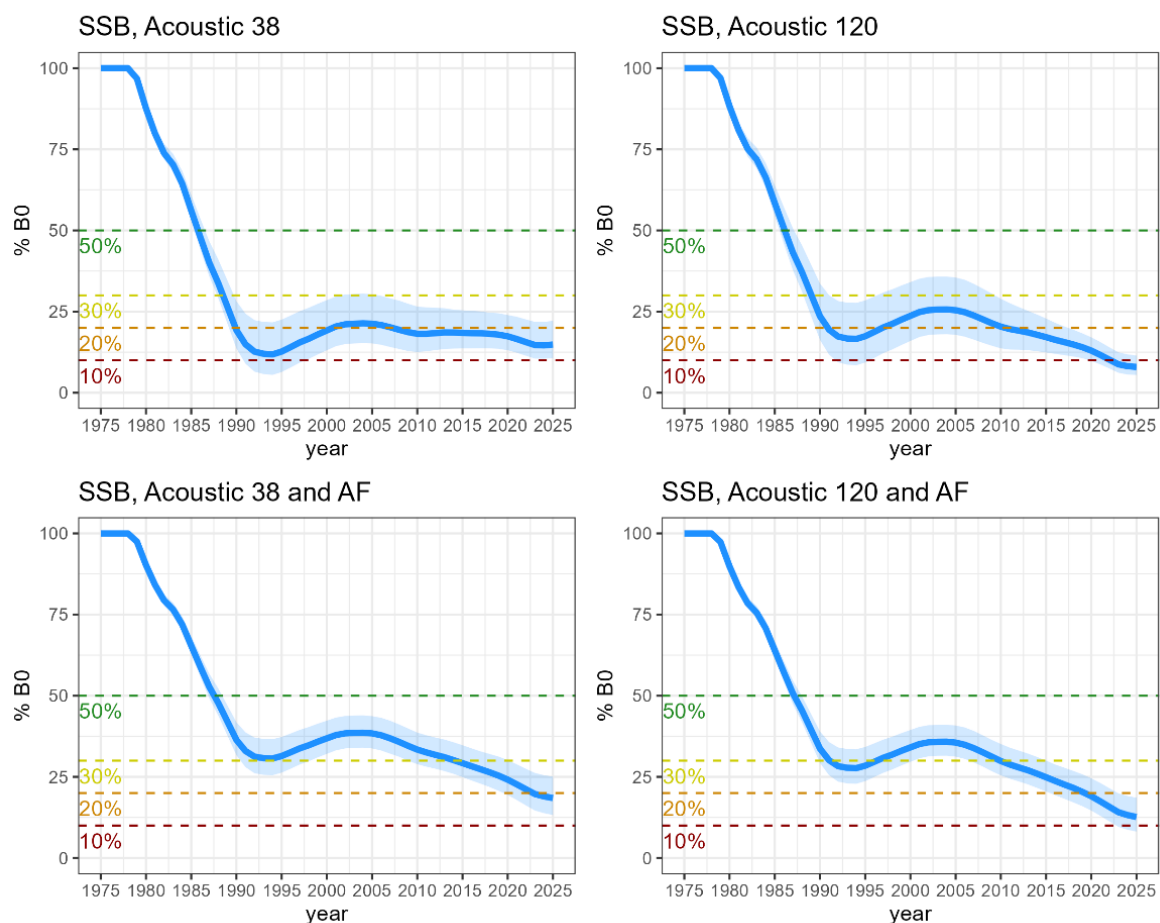


Figure 20: East & South Chatham Rise, MCMC estimated spawning-stock status trajectory for the four assessment model runs (solid line, median; shaded region, 95% credible intervals) Dashed lines indicate the hard limit (10% B_0) (red) and soft limit (20% B_0) (orange), and the management target range (30–50% B_0) (yellow–green). Year is the fishing year, as year ending.

Use of the 38 kHz acoustic biomass estimates throughout the assessment (runs Acoustic 38, Acoustic 38 and AF) has the advantage that it maintains the use of the same frequency instrument (38 kHz echosounder) from 2002 through to 2024. The 38 kHz has greater penetration through the water column than 120 kHz. The use of the 120 kHz series after 2010 (runs Acoustic 120, Acoustic 120 and AF) has the advantage that the 120 kHz should be more accurate for orange roughy (because it has a better signal to noise ratio for orange roughy) and it avoids the use of a substantial correction factor for the 2024 survey (one of four transmitters in the 38 kHz transducer failed in 2024, resulting in the transducer reading low and biomass estimates being multiplied by 1.86).

The estimated exploitation rate (as catch/*SSB*) peaked in 1990–91, then declined to the upper bound of the target zone estimated from all YCS (Acoustic 38, and Acoustic 38 and AF), within the all-YCS target zone (Acoustic 120), or remained above the all-YCS target zone (Acoustic 120 and AF) by the late 1990s (Figure 21). Exploitation rate was higher from 2002–03 to 2009–10, then dropped into the all-YCS target zone after about 2009–10 for all runs except Acoustic 120 and AF, and then increased from 2019–20 as catches were increased, until a substantial drop coinciding with the TACC reduction in 2023–24, after which exploitation rate was in the all-YCS target zone for all runs except Acoustic 120 and AF. The exploitation rate target zone for recent YCS was substantially lower than for all YCS, and so low (<1%) for the Acoustic 38 and Acoustic 38 and AF runs that it appears as a narrow bar in Figure 21.

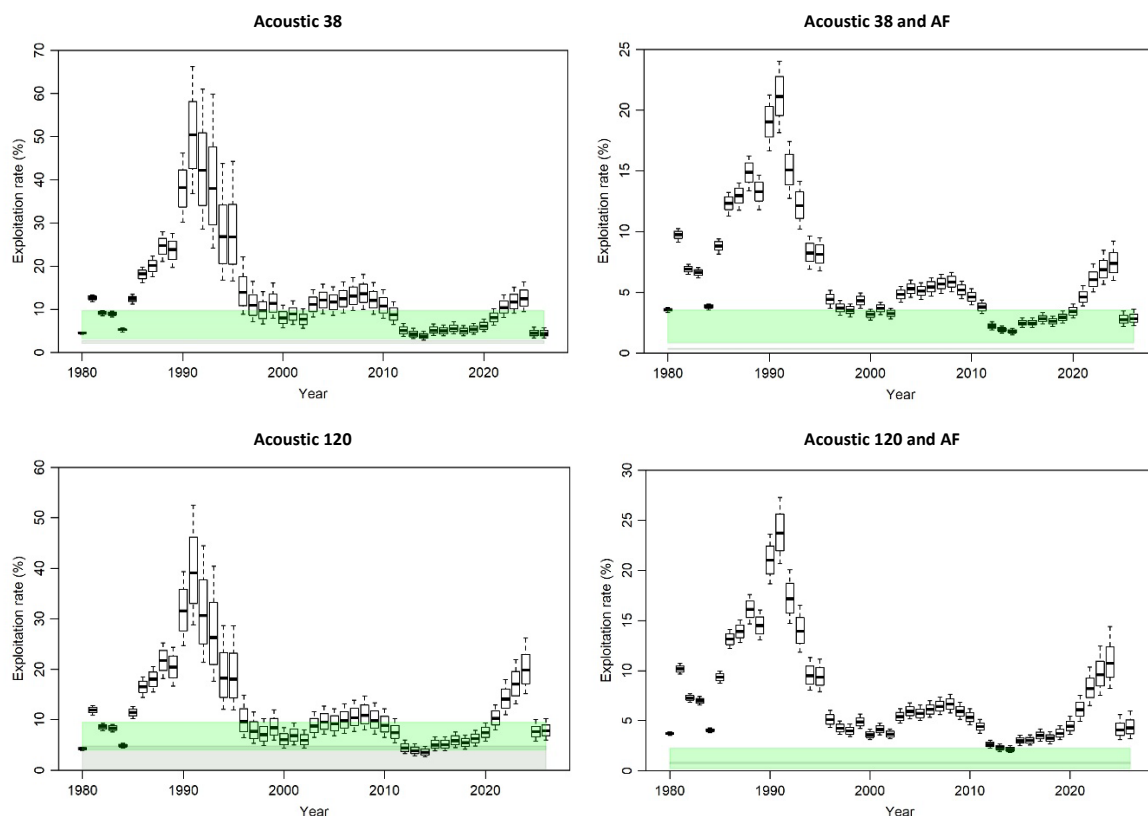


Figure 21: East and South Chatham Rise, MCMC estimated exploitation rate trajectory for the four assessment model runs (boxplot where solid line, median; outer box, interquartile range; whiskers 95% CI) Green (upper) shaded area indicates the exploitation rate corresponding to the target zone ($U_{30\%}$ to $U_{50\%}$) after sampling from all year class strengths (1911–2025); Grey (lower) shaded area indicates the exploitation rate corresponding to the target zone ($U_{30\%}$ to $U_{50\%}$) after sampling from recent year class strengths (1980–2025). Year is the fishing year, as year ending.

Model projections

One hundred-year biomass projections were made, with the Deepwater Working Group considering future catches to be the current agreed catch limit (2755 t), or the 2023–24 catch (2198 t), with 5% catch over-runs added.

Assuming recent (1980–2025) recruitment, or sampling from all years (1911–2025), made no difference to short-term (five year, to 2030) projections (Table 8). This is because the extended age structure of orange roughy stocks means changing the size of a few (five) incoming cohorts make little difference. There was little difference in projections at the TACC or recent catch (80% of the TACC).

Short-term projections using only acoustic data (Acoustic 38, Acoustic 120) show a slow SSB increase, and those including age frequencies (Acoustic 38 and AF, Acoustic 120 and AF) show a slow SSB decrease (Table 8). Runs using the 120 kHz acoustic series were slightly more pessimistic. After five years, all projections were Likely (> 60%) to remain below the soft limit, the Acoustic 120 run was still Very Likely (> 90%) to be below the hard limit, the Acoustic 120 and AF run Unlikely (< 40%) to be below the hard limit, and the Acoustic 38 and Acoustic 38 and AF runs Very Unlikely (< 10%) to be below the hard limit.

Table 8: East & South Chatham Rise, Bayesian median and 95% credible intervals (in parentheses) of projected B_{2030} , B_{2030} as a percentage of B_0 , B_{2030}/B_{2025} (%), and probability of SSB being above the lower bound of the target zone ($0.3 B_0$) in 2030 and below the soft limit ($0.2 B_0$) and hard limit ($0.1 B_0$) in 2030. Projections made for current catch (2198 t) and TACC (2755 t), to which a 5% assumed catch over-run is added. Future productivity either assumes the recent (post-1980) level of recruitment, or empirical re-sampling of YCS over the entire assessment period (1911–2025).

Model run	YCS	Catch (t)	B_{2030} (‘000 t)	B_{2030} (% B_0)	B_{2030}/B_{2025} (%)	$p(B_{2030} > 0.3 B_0)$	$p(B_{2030} < 0.2 B_0)$	$p(B_{2030} < 0.1 B_0)$
(1) Acoustic 38	Recent	2 198	61.1 (45.2–93.5)	17.4 (13.0–24.8)	118 (105–130)	<1	78	0
	All	2 198	61.1 (45.2–93.5)	17.4 (13.0–24.8)	118 (105–130)	<1	78	0
	Recent	2 755	59.8 (43.9–92.2)	17.1 (12.6–24.4)	116 (103–127)	<1	81	<1
	All	2 755	59.8 (43.9–92.2)	17.1 (12.6–24.4)	116 (103–127)	<1	81	<1
(2) Acoustic 120	Recent	2 198	32.3 (22.6–46.0)	8.7 (5.8–12.1)	109 (84–136)	0	100	80
	All	2 198	32.3 (22.6–46.0)	8.7 (5.8–12.1)	109 (84–136)	0	100	80
	Recent	2 755	31.0 (21.3–44.7)	8.4 (5.5–11.7)	105 (80–130)	0	100	85
	All	2 755	31.0 (21.3–44.7)	8.4 (5.5–11.7)	105 (80–130)	0	100	85
(3) Acoustic 38 and AF	Recent	2 198	76.7 (50.5–114.0)	17.3 (12.0–24.3)	94 (87–100)	0	81	<1
	All	2 198	76.7 (50.5–114.0)	17.3 (12.0–24.3)	94 (87–100)	0	81	<1
	Recent	2 755	75.4 (49.3–112.7)	17.0 (11.7–24.0)	92 (86–98)	0	83	<1
	All	2 755	75.4 (49.3–112.7)	17.0 (11.7–24.0)	92 (86–98)	0	83	>1
(4) Acoustic 120 and AF	Recent	2 198	47.3 (26.6–77.3)	11.1 (6.6–17.1)	88 (80–95)	0	100	32
	All	2 198	47.3 (26.6–77.3)	11.1 (6.6–17.1)	88 (80–95)	0	100	32
	Recent	2 755	46.0 (25.4–76.0)	10.9 (6.3–16.8)	86 (76–93)	0	100	38
	All	2 755	46.0 (25.4–76.0)	10.9 (6.3–16.8)	86 (76–93)	0	100	38

A part of the short-term SSB rebuilds can be attributed to the somatic growth of survivors. Some longer-term projections showed a biomass increase and then plateau or decline, once the lower recruitment levels had permeated through the age structure (Figure 22). Longer-term recruitment trends are highly uncertain.

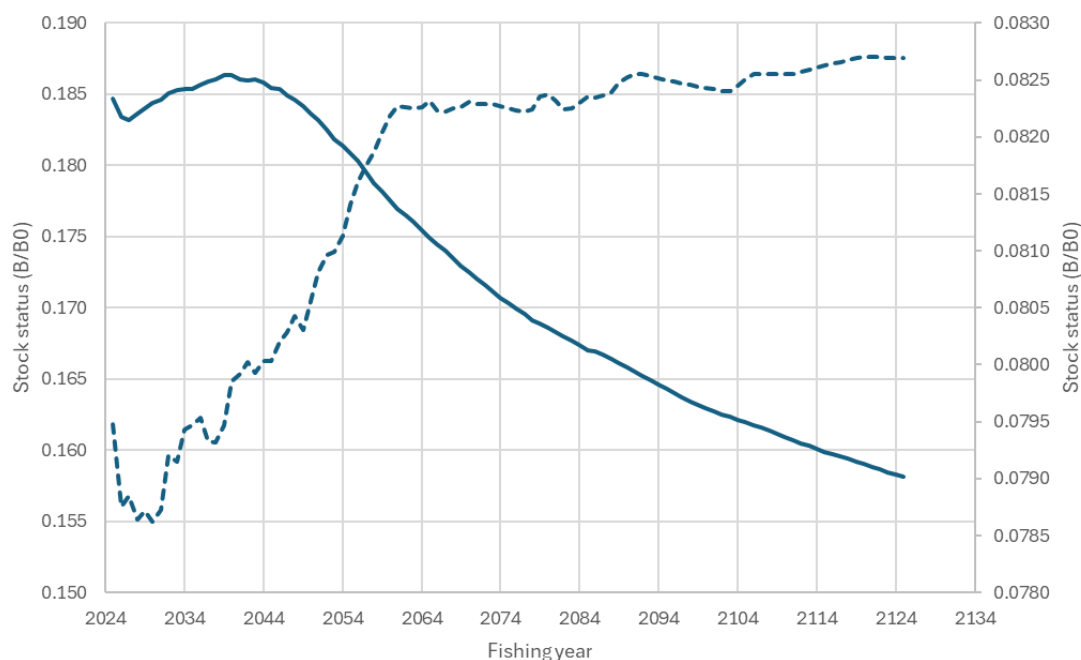


Figure 22: East & South Chatham Rise, examples of projections of median stock status made from MCMC parameter estimates and under constant future catches of 1 t and recent (1980–2025) recruitment, for solid line, the Acoustic 38 and AF run (left y-axis); broken line, the Acoustic 120 run (right y-axis; note the small range of this axis, such that the apparent “wobbles” in the estimates are actually trivial). Fishing year labelled as year ending. Stock status is calculated relative to the SSB from R_0 .

The phase (Kobe-style) plots for the stock assessment are shown in the Working Group Report (Fisheries New Zealand 2025).

3.3 Stock assessment modelling for the Northwest Chatham Rise

The Northwest Chatham Rise assessment followed the same general approach and assumptions as the East & South Chatham Rise.

A Bayesian stock assessment was conducted using data up to 2023–24. There were three main data sources for observations available to the assessment: acoustic-survey spawning biomass estimates from the main spawning hills (Graveyard and Morgue, 2012, 2016, 2021, 2022); an age frequency and an estimate of proportion-spawning-at-age taken from a 1994 wide-area trawl survey; an age frequency taken from targeted trawls above Morgue (2016, 2021, 2022); and length frequencies collected from the commercial fishery covering 1989–2005.

Acoustic biomass observations

Only biomass estimates from the AOS and the Graveyard and Morgue hills were used in the model (Table 9). Two alternative acoustic series were assumed, using just the AOS 38 kHz estimates

(Acoustic 38), or just the 120 kHz estimates (Acoustic 120). Similar to the East & South Chatham Rise, the acoustic biomass estimates from the different instruments diverged after 2016 (Figure 23).

Table 9: Northwest Chatham Rise, acoustic survey estimates of spawning biomass used in the assessment model. Surveys covered both the Graveyard and Morgue hills. Only biomass estimated from the AOS system are included. The CVs do not include any process error.

Year	Frequency	Acoustic snapshots	Estimate (t)	CV
2012	38 kHz	3	5 550	0.16
	120 kHz	3	4 254	0.16
2016	38 kHz	3	14 052	0.13
	120 kHz	3	12 494	0.10
2021	38 kHz	3	16 332	0.09
	120 kHz	3	13 228	0.09
2022	38 kHz	4	19 273	0.08
	120 kHz	4	13 680	0.08

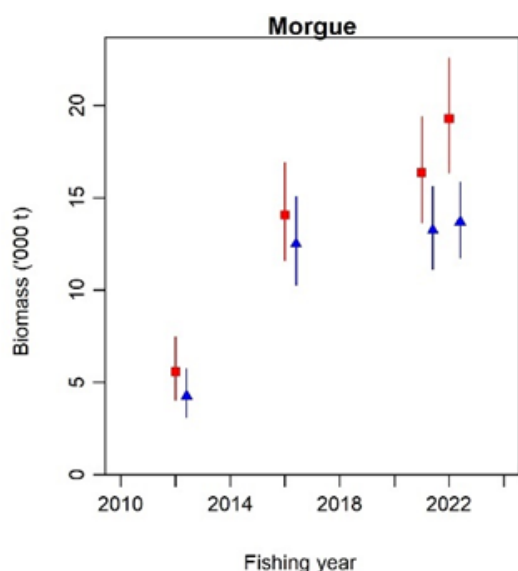


Figure 23: Northwest Chatham Rise, acoustic biomass estimates for Morgue and Graveyard hill. Red squares, AOS 38 kHz; blue triangles, AOS 120 kHz.

The biomass estimates were assumed to represent ‘most’ of the spawning biomass each year. This was modelled by treating the acoustic estimates as relative biomass and estimating the proportionality constant (q) with an informative prior. The prior was normally distributed with a mean of 0.8 (i.e., ‘most’ = 80%) and a CV of 19%. The CV of 19% was derived from the acoustic target strength uncertainty using the 38 kHz echosounder. The mean of 0.8 followed the East & South Chatham Rise, but no data exist to support the use of this value for the Northwest Chatham Rise.

Model structure and assumptions

The model was single-sex and age-structured (1–100 years with a plus group), with maturity assumed equal to the otolith transition zone estimate (logistic with $a_{50} = 28.51$, $a_{95} = 4.56$). A single time step was used, with spawning taken to occur after 75% of the mortality and 100% of mature fish were assumed to spawn each year. A single fishery was assumed with a catch history constructed from the Northwest catches with catch over-runs (see Appendix 4). Natural mortality rate was estimated with a normal prior ($\mu = 0.045$, $cv = 0.33$). The stock-recruitment relationship was Beverton-Holt with steepness 0.75. A process error of 0.2 was added to the acoustic series. The remaining biological

parameters are detailed in Appendix 4.

Selecting final model runs

Model runs including the age and length frequency data were excluded because the data were considered insufficiently informative for year class strength (YCS) estimation. There were inconsistencies in the age frequencies that could not be fitted with a constant selectivity ogive (Figure 24), and estimated year class strengths had high uncertainty as a result (Figure 25). The single age frequency from the trawl survey included a greater proportion of younger fish and fewer older fish and was best fitted with a double normal ogive (full selectivity around age 32), but as such contributed very little information to the stock assessment estimate.

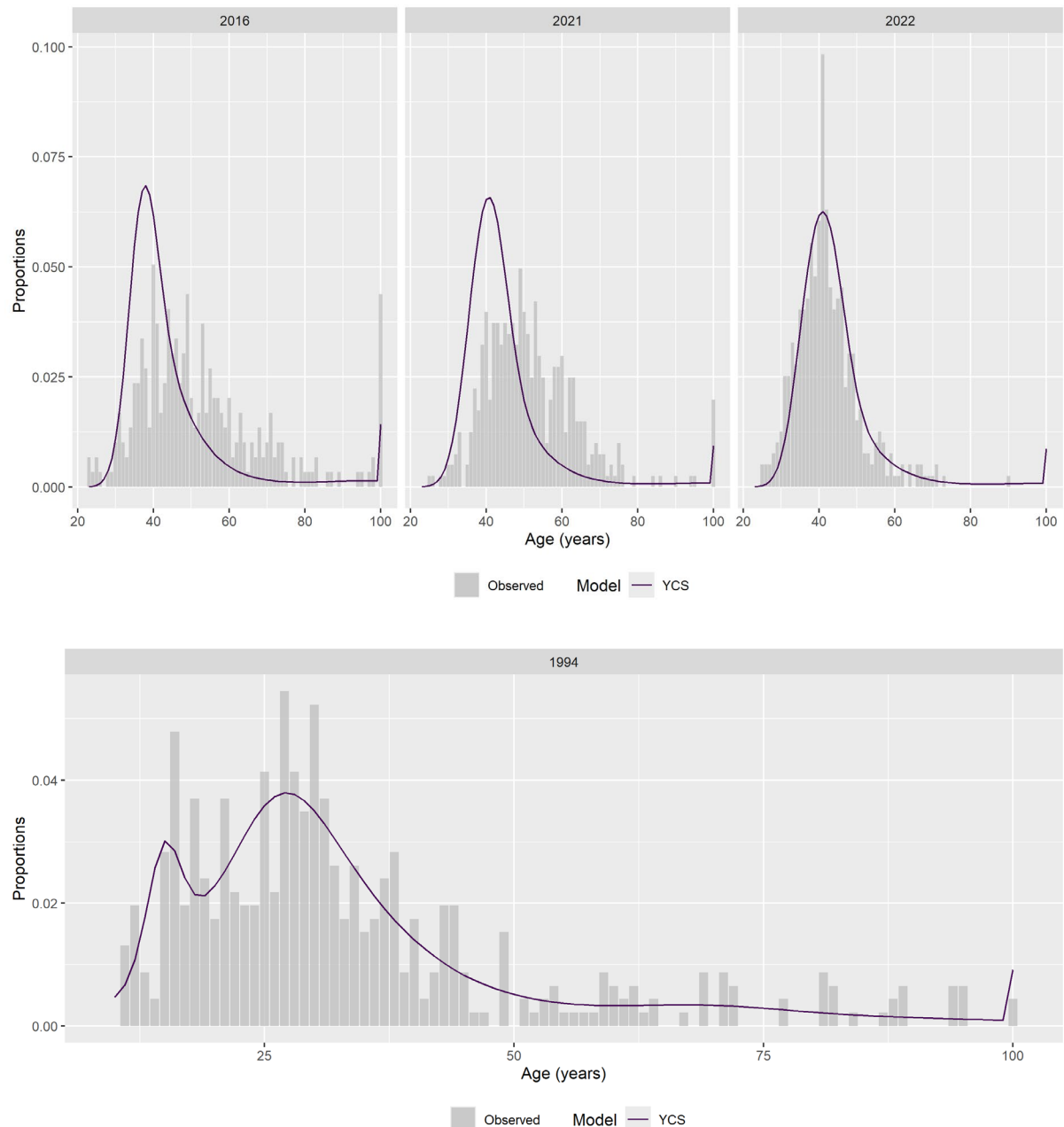


Figure 24: Northwest Chatham Rise, fits (lines) to age frequencies (bars) for the Morgue (top panels) and trawl survey (bottom panel), using a constant logistic selectivity for the Morgue, and a double normal selectivity for the trawl survey, in a model run estimating year class strengths and using the 120 kHz acoustic series (see Figure 25). All age frequencies had an assumed multinomial effective sample size of 10.

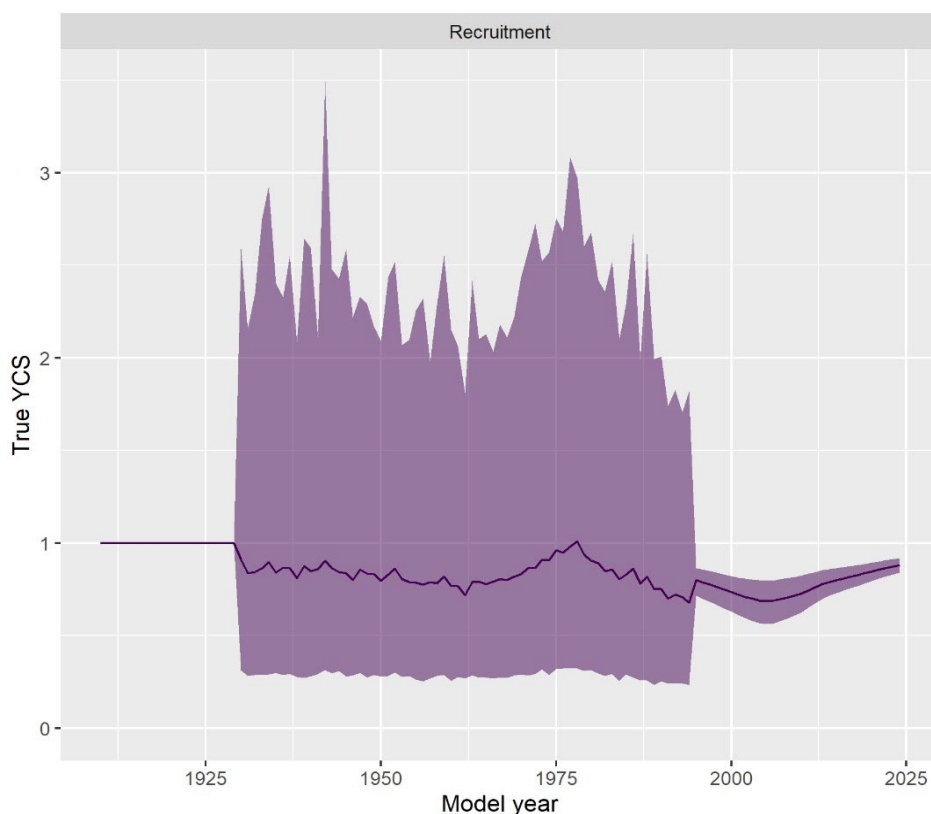


Figure 25: Northwest Chatham Rise, MCMC estimates of year class strength (line, median; shaded area 95% credible intervals), for a model run estimating year class strengths and using the 120 kHz acoustic series. The lognormal prior on year class strengths had mean 1 and CV = 0.6.

For runs using only the acoustic series (with selectivity and maturity assumed), having excluded YCS estimation, the productivity options were to estimate M , or time-varying recruitment (i.e., R_0 and R_I with a change point in 1980). The problems with estimating M using MCMC encountered for the East & South Chatham Rise were not found for the Northwest Chatham Rise (Figure 26).

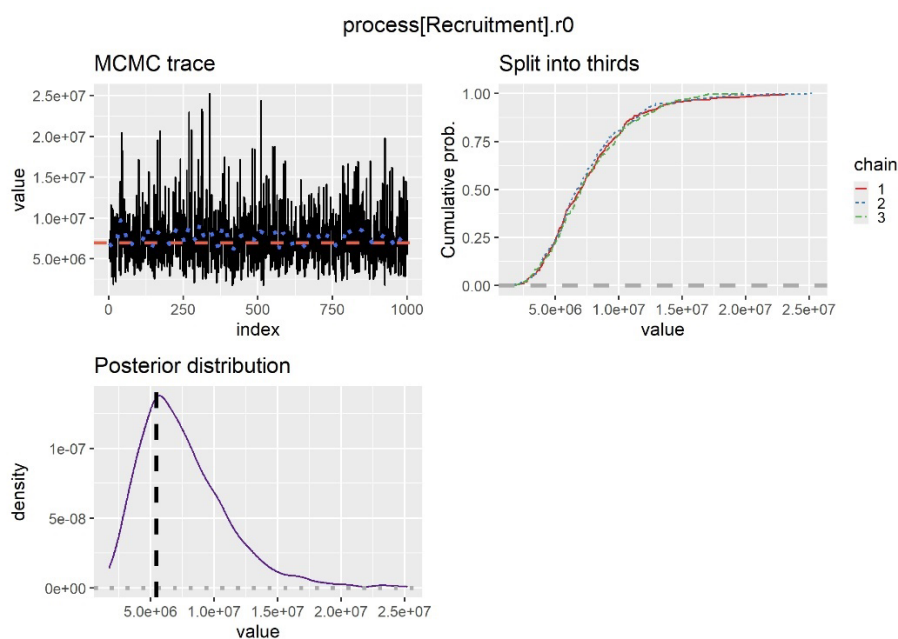


Figure 26: Northwest Chatham Rise, MCMC diagnostics for the estimated virgin recruitment level (R_0) in a model run using the 38 kHz acoustic series and estimating M (YCS being constant).

A time varying change in productivity, as assumed for the East & South Chatham Rise assessment, was tested but rejected because it estimated an implausibly large increase in recruitment after 1980 to fit the increasing Morgue acoustic biomass series (Figures 27 & 28). Final model runs therefore used only the acoustic biomass estimates, and estimated M .

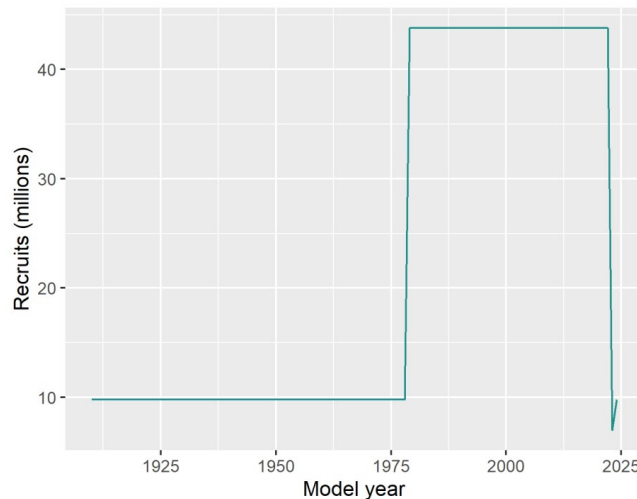


Figure 27: Northwest Chatham Rise, estimated time-varying (TV) recruitment (two levels, R_0 and R_1), for a model run fitting the 38 kHz acoustic series only.

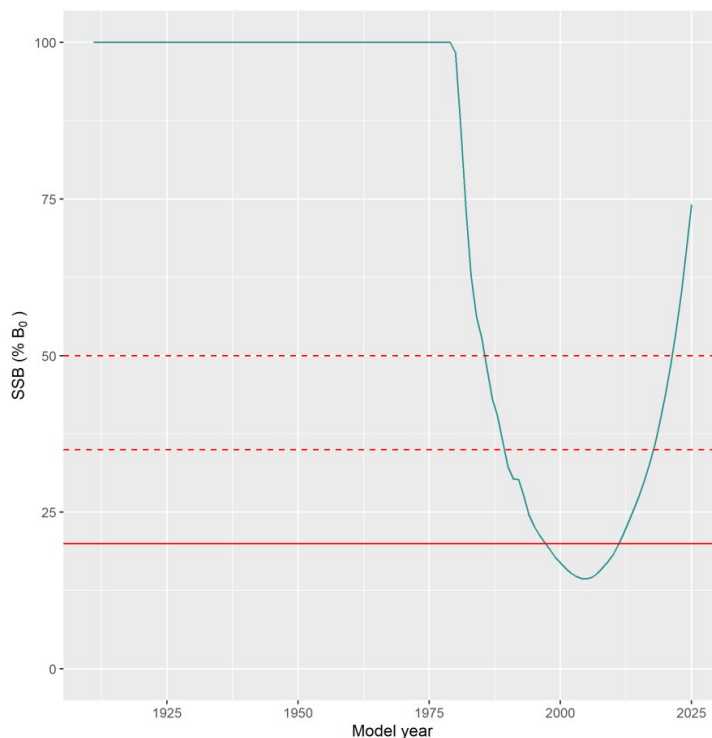


Figure 28: Northwest Chatham Rise, estimated SSB for a model run estimating TV recruitment (Figure 27) and fitting the 38 kHz acoustic series only. Horizontal lines mark 50%, 30%, and 20% of B_0 .

The model parameters estimated were the virgin (unfished, equilibrium) recruitment (R_0), the acoustic survey catchability scalar (q), and the natural mortality rate (M). The model provided acceptable fits

to the data (Figure 29). The posterior estimates for the acoustic q s and M were not very different from the priors (Figure 30). The model runs therefore estimated SSB to be very close to the acoustic biomass estimates. The assessment model therefore fits the recent acoustic biomass estimates according to the q prior, then back-calculates the B_0 using the catch history and estimated productivity, with the key productivity parameter (M) following the prior. The uncertainty in SSB estimates follows the assumed uncertainty in the q and M priors.

NWCR

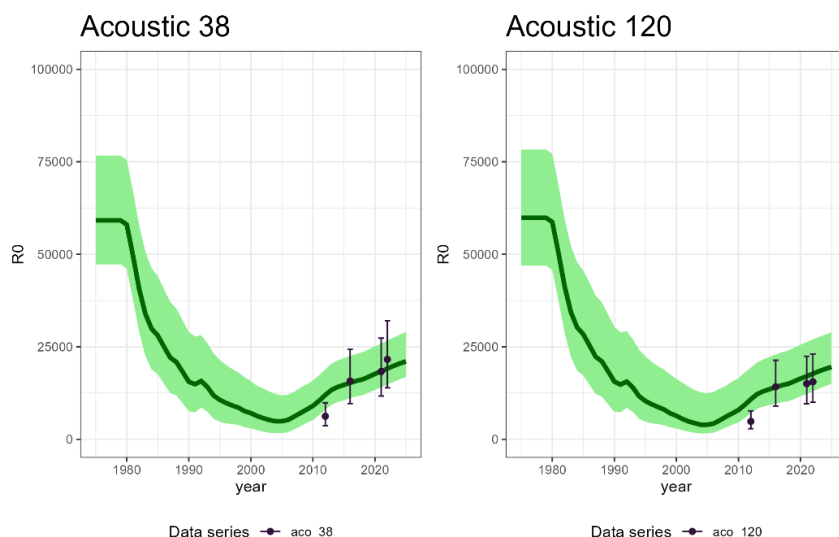
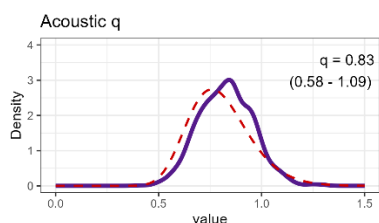


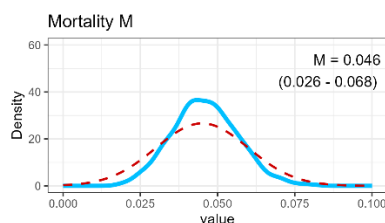
Figure 29: Northwest Chatham Rise, assessment model runs Acoustic 38 and Acoustic 120, MCMC estimates of SSB (solid line, median; shaded region, 95% credible intervals) and implied fits to the acoustic series (points; vertical lines, 95% CI).

NWCR

Acoustic 38

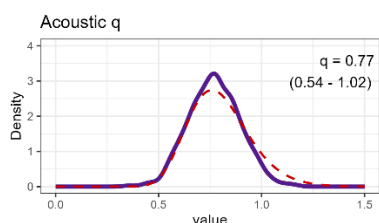


Legend — Lognormal prior — Posterior

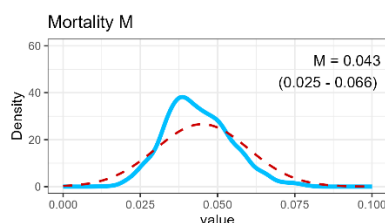


Legend — Normal prior — Posterior

Acoustic 120



Legend — Lognormal prior — Posterior



Legend — Normal prior — Posterior

Figure 30: Northwest Chatham Rise, assessment model runs Acoustic 38 and Acoustic 120, (left) prior (broken line) and MCMC posterior (solid line) for the acoustic q , with text giving the median and 95% credible intervals; (right) prior (broken line) and MCMC posterior (solid line) for natural mortality rate (M) with text giving the median and 95% credible intervals.

MPD sensitivity runs showed that the estimated stock size and status was sensitive to the mean of the assumed q prior (a 20% decrease in the mean of the prior produced a slightly larger stock and an increase in stock status from 32% to 37% B_0 ; a 20% increase in the mean of the prior produced a slightly smaller stock and a decrease in stock status to 28% B_0).

Virgin biomass (B_0) was estimated to be similar at around 59 000 t (Table 10). Current stock status was also similar, at 34% or 36% B_0 (Table 10). The probability that the stock was above 30% B_0 in 2025 was 85% for the Acoustic 38 run and 73% for the Acoustic 120 run.

Table 10: Northwest Chatham Rise, MCMC median estimates and 95% credible intervals) of virgin spawning stock biomass (B_0), spawning stock biomass in 2025, and stock status (B_{2025} as % B_0) for the two model runs.

	B_0 (000 t)	B_{2025} (000 t)	B_{2025} (% B_0)
Acoustic 38	59.2 (47.3–76.7)	21.1 (16.8–29.0)	36 (25–49)
Acoustic 120	59.9 (46.9–78.3)	19.5 (15.0–28.9)	34 (21–49)

The estimated spawning stock biomass (SSB) trajectory showed a declining trend from 1980 (when the fishery started) through to 2004 when the biomass was close to the hard limit (Figure 31). From 2005 the estimated biomass increased steadily.

Although there is only a small difference between the results of the two model runs, the Acoustic 38 run has the advantage that it uses the principal echosounder historically used in orange roughy surveys, and which has greater penetration through the water column than 120 kHz. The use of the 120 kHz series has the advantage that the 120 kHz should be more accurate for orange roughy (because it has a better signal to noise ratio for orange roughy).

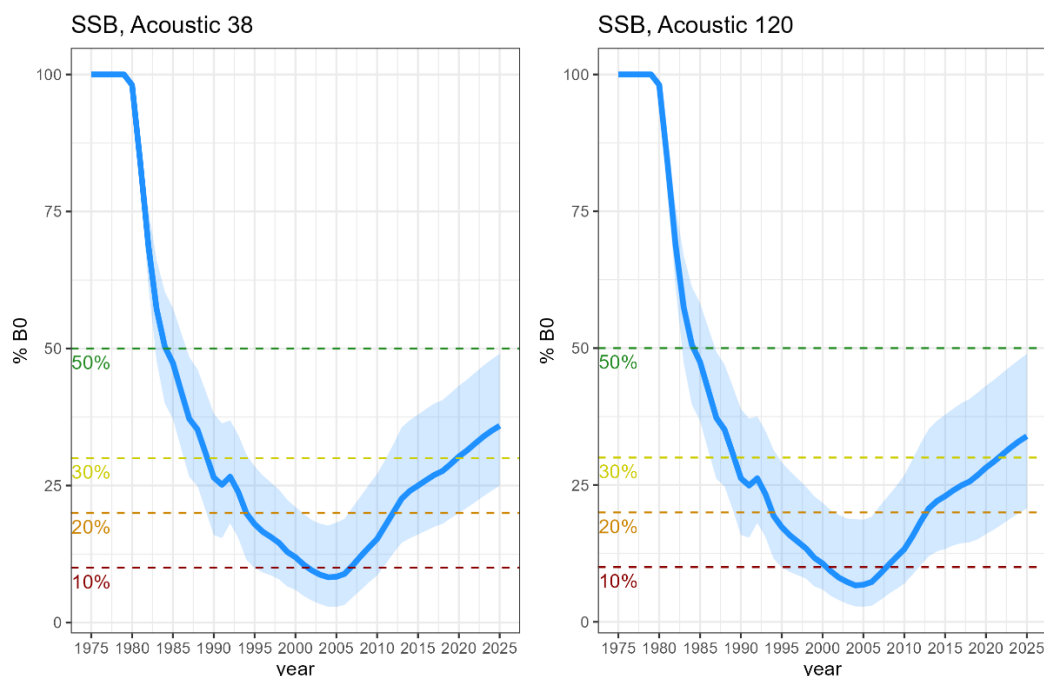


Figure 31: Northwest Chatham Rise, MCMC estimated spawning-stock status trajectory for assessment model runs using the 38 kHz AOS or 120 kHz AOS acoustic biomass series (solid line, median; shaded region, 95% credible intervals) Dashed lines indicate the hard limit (10% B_0) (red) and soft limit (20% B_0) (orange), and the management target range (30–50% B_0) (yellow–green). Year is the fishing year, as year ending.

The fishery exceeded the target exploitation rate ($U_{30\%}$ – $U_{50\%}$) in almost every year until 2010–11, after which it was just below or just above the target range, being Very Likely ($> 80\%$) to be below the target range in 2023–24 (Figure 32).

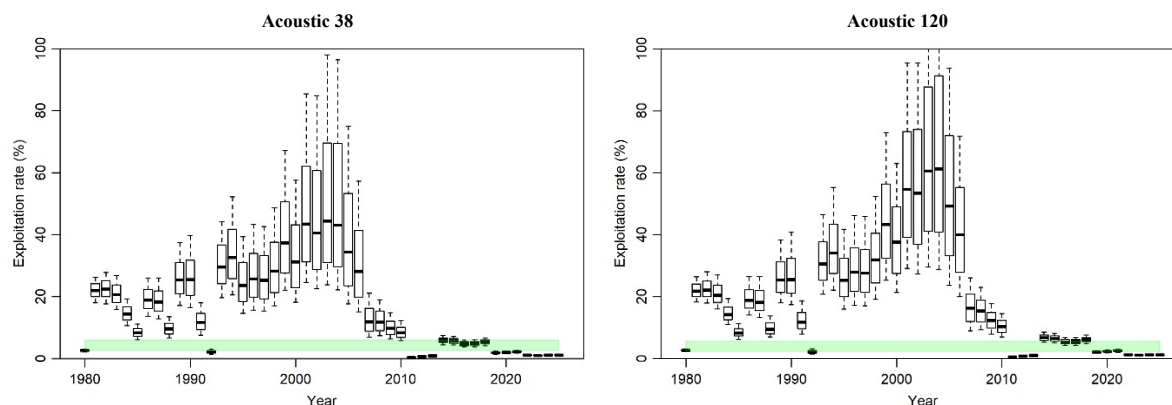


Figure 32: Northwest Chatham Rise, MCMC estimated exploitation rate trajectory for the two assessment model runs (boxplot where solid line, median; outer box, interquartile range; whiskers 95% CI) Green shaded area indicates the exploitation rate corresponding to the target zone ($U_{30\%}$ to $U_{50\%}$).

Model projections

Five-year biomass projections were made assuming future catches to be the current agreed catch limit (1150 t), or the 2023–24 catch (212 t), plus 5% over-run. At the current catch (212 t), SSB is predicted to slowly increase over the next five years, and the probability of the SSB going below the soft limit is less than 1% (Table 11). At the current agreed catch limit (1150 t), SSB is predicted to slowly decrease over the next five years, and the probability of the SSB going below the soft limits is 5% or less.

Table 11: Northwest Chatham Rise, Bayesian median and 95% credible intervals (in parentheses) of projected B_{2030} , B_{2030} as a percentage of B_0 , B_{2030}/B_{2025} (%), and probability (%) of SSB being above the lower bound of the target zone ($0.3 B_0$) and below the soft limit ($0.2 B_0$) in 2030. Projections made for current catch (212 t) and agreed catch limit (1150 t), to which a 5% assumed catch over-run is added.

Model run	Catch (t)	B_{2030}	B_{2030} (% B_0)	$B_{2030}/$ B_{2025} (%)	$p(B_{2030}$ $> 0.3 B_0)$	$p(B_{2030}$ $< 0.2 B_0)$
Acoustic 38 212	22 950 (17 940–31 620)	39 (29–53)	109 (101–114)	95	0	
Acoustic 38 1 150	18 620 (13 660–27 350)	31 (22–46)	89 (78–95)	59	1	
Acoustic 120 212	20 490 (16 970–29 550)	36 (25–49)	110 (101–116)	84	<1	
Acoustic 120 1 150	16 170 (12 630–25 170)	28 (19–42)	86 (78–94)	34	5	

The phase (Kobe-style) plots for the stock assessment are shown in the Working Group Report (Fisheries New Zealand 2025).

4. DISCUSSION

The stock status for the Northwest Chatham Rise estimated here was similar to that from previous estimates (Fisheries New Zealand 2022). The estimated stock status of the Northwest Chatham Rise seems consistent with the acoustic biomass estimates, but not with the reduced catches and low catch rates of the fishery. It has been speculated that the reduced catches and catch rates are because “all of the fish are on Morgue”, which has been closed to bottom fishing since 2001.

The stock status for the East & South Chatham Rise was previously estimated to be in the target zone with biomass increasing, whereas here it was estimated to be between the hard and soft limits and biomass flat or decreasing (Fisheries New Zealand 2022). The estimated stock status for the East & South Chatham Rise is now much more consistent with the performance of the fishery.

The stock assessments in 2025 were rather unsatisfactory, being reduced to what was essentially a stock production model informed with only a biomass index, and that biomass index was relatively short and recent in comparison to the fishery. A large amount of data was not used (Dunn et al. 2025; Fisheries New Zealand 2025). The inconsistencies and uncertainties of age frequencies and acoustic biomass indices, combined with potential model over-parameterisation when year class strengths are estimated, and productivity being apparently much lower than expected, precluded a more sophisticated and data-inclusive approach being taken at this time (Dunn et al., 2025).

5. POTENTIAL RESEARCH

The Deepwater Working Group discussed and determined future research needs, which are reported in the Working Group Report (Fisheries New Zealand 2025) and are not repeated here.

6. FULFILMENT OF BROADER OUTCOMES

The findings of this research inform fisheries management and business decisions for the offshore commercial fisheries sector. As part of this project, we purposefully transferred knowledge from our most experienced stock assessment scientists Ian Doonan to Matt Dunn and the relatively early-career (in stock assessment) Samik Datta. Knowledge transfer is a gradual process, with skills, expertise, and institutional knowledge needed over multiple projects.

7. ACKNOWLEDGEMENTS

This research was funded by Fisheries New Zealand project SEA2024/07. We thank attendees of the Fisheries New Zealand Deepwater Working Group for review. We thank Steven Holmes (ESNZ) and Gretchen Skea (Fisheries New Zealand) for supervision of the project, Ian Tuck (Fisheries New Zealand) for review of the draft report, and Ian Tuck and Marianne Vignaux (Fisheries New Zealand) for editorial checks and review of the final report.

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APPENDIX 1: Discussion of acoustic biomass estimates

The divergence of acoustic biomass estimates from the 38 kHz and 120 kHz echosounders was discussed by Matt Dunn, Ian Doonan, Pablo Escobar-Flores, and Richard O’Driscoll (all ESNZ), Gavin Macaulay (Aqualyd Ltd and ESNZ), and Tim Ryan (CSIRO). The scope of that discussion is described here.

Time-series

Until 2025, the AOS 120 kHz frequency has primarily been used as the contrast frequency for species discrimination, while additionally providing biomass estimates as a semi-independent measure. Since acoustic surveys of ORH 3B commenced in 1998, the 38 kHz frequency biomass estimates have informed stock assessments and remains the primary biomass series. Utilising all available frequencies provides a broader understanding, enhances confidence, and highlights potential biases between systems. Until the last two survey years, there was reasonable consistency between the frequencies.

Comparisons between historical vessel and AOS 38 kHz data, including the direct examination of the 2024 vessel echograms at 38 kHz, clearly demonstrated that the 2024 AOS 38 kHz data were significantly lower (approximately 2–3 dB by visual inspection). An empirical correction factor was derived through legitimate cross-comparison analysis with a known reference (vessel 38 kHz with stable calibration) to account for a technical issue identified with the transceiver in 2024, which was found to have caused the lower AOS 38 kHz readings. The correction factor was determined by comparing high signal-to-noise water column backscatter regions from AOS and vessel echograms. Multiple sections were chosen to manage natural sampling variability, resulting in appropriate error bars. The derived linear correction factor of 1.83 (2.6 dB) matched initial visual estimates, bringing the AOS 38 kHz data into alignment with other observations.

However a 3 dB difference between 120 kHz and 38 kHz frequencies is a well-established reliable indicator for orange roughy. Since with high confidence, the AOS 38 kHz was confirmed to be low due to the identified transceiver issue it was surprising that the expected 3 dB difference between AOS 120 kHz and uncorrected AOS 38 kHz was still observed. This suggests that the AOS 120 kHz frequency must also be reading lower than expected to maintain the 3 dB difference with the low reading AOS 38 kHz. Consequently, adopting the AOS 120 kHz frequency as a reliable index is not straightforward, and we considered possible reasons for the difference between the frequencies.

Hypotheses for the difference between 38 kHz and 120 kHz

Differences in vertical distribution of fish, therefore availability at both frequencies (120 kHz has a shorter range)

This would have to be different for 2022 and 2024 compared to the earlier years. There are no obvious differences in the vertical distributions of fish over the years, although no formal analysis has been done. Both frequencies are corrected for distance to the target so a depth distributional change will not have any effect, except when the signal is within the ambient noise level. The vertical extent can be very large sometimes (e.g., Mt Muck, and more so at Morgue). Noise performance of the AOS 120 kHz has been improved in recent years, allowing the system to be towed higher in the water column – reducing the chance of fish reacting. Absorption at 120 kHz is about 3 times greater than 38 kHz so there is greater opportunity for error in the absorption estimates, and with the AOS flying higher this might be a higher error than in previous years – but absorption uncertainty is unlikely to account for the size in discrepancy observed between systems.

Target strength differences

Changes in backscatter magnitude due to changes in fish behaviour (e.g., tilt angle) could cause the differences we see between 38 and 120 kHz, but we have no other information to support that at this stage. However, it is hard to imagine a behavioural change in tilt angle occurring for the last two survey years. Biomass estimates are driven by the large stable aggregations.

Presence of other species

Differing sensitivity of the frequencies to species mix might explain the change, e.g., as the plumes have got smaller, the 38 kHz is more biased by other species mixing amongst the orange roughy aggregations. However, the same species change would have to be happening at all survey locations, including on Morgue where orange roughy abundance has been increasing. Available data did not suggest any substantive change in trawl bycatch.

Acoustic dead zone estimates

Dead zone depends on the beam angle, but the beamwidths on the 38 and 120 kHz AOS are the same (7 degrees). The 120 kHz transducer has: a) better side lobe suppression so deadzone can be reduced; and b) higher sensitivity to orange roughy. Separate lines are drawn to define the 38 and 120 kHz 'acoustic' bottom with some variability due to operator decisions.

The 38 kHz or 120 kHz instrument has become biased

This requires further exploration. The hull and AOS 38 kHz estimates are relatively similar; it is the 120 kHz that stands out. A calibration should have removed any differences between instruments, but there could be a calibration bias.

The 120 kHz transducer and transceiver have not changed. The receiver amplifier response looks ok. Likewise, with the transmit pulse. Deepwater calibrations have far more year-to-year variability than survey vessel. Achieving deep deployments with lots of sphere targets through the entire depth range is a very difficult exercise.

The Deepwater Working Group agreed that further study of potential calibration biases, and at-sea between-instrument studies, was a priority for future research.

APPENDIX 2: Acoustic time-series

In 2025, acoustic biomass estimates were derived from existing data for the vessel 38 kHz, AOS 38 kHz, and AOS 120 kHz sounders. In the final model runs, the 38 kHz were combined because they gave similar biomass estimates, and to reduce the permutations of acoustic biomass indices. The following section documents the numbers used to produce the estimates. Information on the surveys and the biomass estimates were from the sources below; many of these are not publicly available nor available via the Ministry for Primary Industries website, but are archived in the ESNZ project management system for SEA2024/07.

- CSIRO (2013). Biomass estimation of orange roughy, Chatham Rise and Challenger Plateau region using a net attached Acoustic Optical System. Presentation to the Deepwater Working Group.
- Doonan, I.J.; Hart A.C.; Bagley, N.; Dunford, A. (2012). Orange roughy abundance estimates of the north Chatham Rise Spawning Plumes (ORH3B), San Waitaki acoustic survey, June-July 2011. *New Zealand Fisheries Assessment Report 2012/28*. 35 p.
- Doonan, I.J.; Hart A.C.; Wood, B.; Dunford, A. (2016). Orange roughy abundance estimates of the north Chatham Rise Spawning Plumes (ORH3B), San Waitaki acoustic survey, June-July 2014. *New Zealand Fisheries Assessment Report 2016/31*. 31 p.
- Dunn, M.R.; Doonan, I.J. (2018). Assessment of the Chatham Rise orange roughy stocks for 2017. *New Zealand Fisheries Assessment Report 2018/59*. 60 p.
- Hampton, I.; Nelson, J.C.; Tilney, R.L. (2012). Acoustic survey of ORH on Rekohu and in Spawning Plume, North Chatham Rise, July 2012. Presentation to the Deepwater Working Group.
- Kloser, R.; Ryan, T.; Cordell, J.; Green, M. (2011). Trial of a net-attached acoustic optical system (AOS) to assess orange roughy biomass and species composition for the Chatham Rise region. Presentation to the Deepwater Working Group.
- Kloser, R.; Ryan, T. (2013). 2011 AOS survey of the east Chatham. Presentation to the Deepwater Working Group.
- Ryan, T.; Kloser, T. (2012). Surveys of New Zealand orange roughy on the Chatham Rise and Challenger Plateau seamounts using a net-attached Acoustic-Optical System. Presentation to the Deepwater Working Group.
- Ryan, T.; Kloser, R. (2013). Biomass estimates of orange roughy in June 2012 at Northwest Chatham Rise using a net attached acoustic optical system. Presentation to the Deepwater Working Group May 20th 2013.
- Ryan, T.; Kloser, R. (2013). Biomass estimates of orange roughy using a net-attached Acoustic Optical System Mt Muck, 2011. Presentation to the Deepwater Working Group.
- Ryan, T.; Kloser, R. (2013). Surveys of New Zealand orange roughy on the Chatham Rise and Mid East Coast using a net-attached Acoustic-Optical System – Objective 2. Presentation to the Deepwater Working Group December 4th 2013.
- Ryan, T.E.; Kloser, R.J. (2013). Biomass estimates of orange roughy in June 2012 at Northwest Chatham Rise using a net attached acoustic optical system. Report to Deepwater Group New Zealand. Copy held at CSIRO Marine and Atmospheric Research, Hobart.
- Ryan, T.; Kloser, R. (2014). Biomass estimates of New Zealand orange roughy in June and July 2013 using a net attached acoustic optical system Mid-East Coast and Chatham Rise. Report to Sealord Group, New Zealand.
- Ryan, T.; Tilney, R. (2016). Voyage report for estimates of biomass of orange roughy spawning aggregations in ORH3B NWCR and ESCR management sub-areas in June-July 2016 using a net attached acoustic optical system. Report to Deepwater Group Ltd., New Zealand.
- Ryan, T.E.; Tilney, R. L. (2017). Biomass surveys of orange roughy spawning aggregations in ORH3B NWCR and ESCR management sub-areas in June-July 2016 using a net attached acoustic optical system.
- Ryan, T.; Tilney, R. (2022). Acoustic Biomass Surveys of Orange Roughy in ORH 3B, Northwest and East Chatham Rise – June, July 2022. Presentation to the Deepwater Working Group.
- Ryan, T.E.; Tilney, R.; Downie, R. (2023). Acoustic biomass surveys of orange roughy in ORH 3B North Chatham Rise, June/July 2021. *New Zealand Fisheries Assessment Report 2023/45*. 49 p.

Ryan, T.; Tilney, R.; Kunnath, H.; Goad, D. (2024). Biomass Surveys of Orange Roughy in ORH 3B, North East Chatham Rise – June, July 2024. Presentation to the Deepwater Working Group, 19 December 2024.

Ryan, T.E.; Tilney, R.L. (draft). Acoustic Biomass Surveys of Orange Roughy Spawning Aggregations in ORH 3B NWCR and ORH 3B ESCR Chatham Rise, June/July 2022. 57 p.

Below, the “existing” series are those previously used (Fisheries New Zealand 2022), and for each area and instrument the “a” is the snapshot biomass estimates, and “a_cv” the CVs of those estimates (in R code format).

Old Spawning Plume vessel 38

```
existing<- c(63950,44316,44968,43923,47450,34427,31668,28199,21205)
```

```
existing_cvs<- c(0.06,0.06,0.08,0.04,0.10,0.05,0.08,0.05,0.07)
```

```
existing_years<- c(2002,2003,2004,2005,2006,2007,2008,2009,2010)
```

hull 2011

```
a<- c(21773,19864,13566,14210,15260,13053,14409,17856,19477,20048,13595,13928)
```

```
a_cv<- c(0.28,0.54,0.22,0.34,0.27,0.26,0.24,0.34,0.40,0.27,0.18,0.36)
```

hull 2012

```
a<- c(21773,19864,13566,14210,15260,13053,14409,17856,19477,20048,13595,13928)
```

```
a_cv<- c(0.28,0.54,0.22,0.34,0.27,0.26,0.24,0.34,0.40,0.27,0.18,0.36)
```

hull 2013

```
a<- c(15976,16647,4910)
```

```
a_cv<- c(0.44,0.26,0.35)
```

hull 2014

```
a<- c(17831,20628,17507,2147)
```

```
a_cv<- c(0.21,0.23,0.60,0.31)
```

hull 2016

```
a<- c(9870,10716)
```

```
a_cv<- c(0.26,0.39)
```

hull 2022

Only single snapshot

```
a2022_mean<- 20479
```

```
a2022_CV<- 0.29
```

hull 2024

```
a<- c(22756,23088,25359,23919,14452,32561,26532)
```

```
a_cv<- c(0.29,0.27,0.27,0.25,0.22,0.28,0.27)
```

Old Spawning Plume AOS 38

aos 2024

```
a<- c(19809,36140,26604)
```

```
a_cv<- c(0.08,0.08,0.09)
```

aos 2013

```
a<- c(9649,19907)
```

```
a_cv<- c(0.32,0.19)
```

```
aos 2022
a<- c(12468,15888,23905)
a_cv<- c(0.36,0.29,0.28)
```

```
aos 2016
a<- c(4519,18971,11882)
a_cv<- c(0.32,0.52,0.52)
```

Old Spawning Plume AOS 120

```
aos 2024
a<- c(9181,18049,14395)
a_cv<- c(0.28,0.28,0.32)
```

```
aos 2013
a<- c(9202,21560)
a_cv<- c(0.28,0.13)
```

```
aos 2016
a<- c(6277,16430,8816)
a_cv<- c(0.32,0.48,0.51)
```

```
aos 2022
a<- c(9814,12177,17379)
a_cv<- c(0.36,0.29,0.25)
```

Rekohu vessel 38

```
hull 2011
a<- c(15021,36061,22146,35243,44434,15788)
a_cv<- c(0.44,0.30,0.20,0.48,0.26,0.23)
```

```
hull 2012
a<- c(21773,19864,13566,14210,15260,13053,14409,17856,19477,20048,13595,13928)
a_cv<- c(0.28,0.54,0.22,0.34,0.27,0.26,0.24,0.34,0.40,0.27,0.18,0.36)
```

```
hull 2013
a<- c(23345,33910)
a_cv<- c(0.22,0.18)
```

```
hull 2014
a<- c(46304,42538)
a_cv<- c(0.38,0.32)
```

```
hull 2016
a<- c(20620,17485,28198,19505)
a_cv<- c(0.43,0.25,0.24,0.28)
```

```
hull 2022
a<- c(9311,22880,12737,16810)
a_cv<- c(0.35,0.14,0.17,0.17)
```

```
hull 2024
a<- c(3919,8059,13825,12207)
```

```
a_cv<- c(0.38,0.22,0.23,0.19)
```

Rekohu AOS 38

```
aos 2024
```

```
a<- c(4477,11778)
```

```
a_cv<- c(0.10,0.42)
```

```
aos 2013
```

```
a<- c(23216,36523,37221)
```

```
a_cv<- c(0.27,0.20,0.23)
```

```
aos 2022
```

```
a<- c(13088,16713)
```

```
a_cv<- c(0.22,0.28)
```

```
aos 2016
```

```
a<- c(9637,27355,45157,30874)
```

```
a_cv<- c(0.49,0.25,0.17,0.24)
```

Rekohu AOS 120

```
aos 2024
```

```
a<- c(2056,5311)
```

```
a_cv<- c(0.34,0.42)
```

```
aos 2013
```

```
a<- c(24331,33148,34088,37211)
```

```
a_cv<- c(0.23,0.16,0.20,0.23)
```

```
aos 2022
```

```
a<- c(9287,11249)
```

```
a_cv<- c(0.21,0.28)
```

```
aos 2016
```

```
a<- c(8605,20314,34556,24142)
```

```
a_cv<- c(0.48,0.25,0.16,0.23)
```

Mt. Muck AOS 38

```
aos 2024
```

```
a<- c(12092,9514)
```

```
a_cv<- c(0.288,0.22)
```

```
aos 2013
```

```
a<- c(4806,5949,5657)
```

```
a_cv<- c(0.15,0.17,0.21)
```

```
aos 2022
```

```
a<- c(9218,12603)
```

```
a_cv<- c(0.14,0.18)
```

```
aos 2016
```

```
a<- c(7427,4216,4380)
```

```
a_cv<- c(0.52,0.24,0.31)
```

```
aos 2011
a<- c(7461,6126)
a_cv<- c(0.23,0.23)
```

Mt. Muck AOS 120

```
aos 2024
a<- c(5396,4934)
a_cv<- c(0.288,0.22)
```

```
aos 2013
a<- c(5799,8135)
a_cv<- c(0.25,0.19)
```

```
aos 2022
a<- c(5528,7567)
a_cv<- c(0.14,0.17)
```

```
aos 2016
a<- c(6121,3236,3554)
a_cv<- c(0.52,0.24,0.31)
```

```
aos 2011
a<- c(8297,5869)
a_cv<- c(0.19,0.22)
```

Estimate for East & South Chatham Rise for 2024, 38 kHz

The estimate was an average of the following three series:

```
osp<- c(14509,22756,23088,25359,23919,14452,32561,56532,19809,36140,26604)
osp_CV<- c(0.18,0.29,0.27,0.27,0.25,0.22,0.28,0.27,0.08,0.08,0.09)
rek<- c(3919,8059,9348,13825,12207,4477,11778)
rek_CV<- c(0.38,0.22,0.23, 0.19,0.4,0.1,0.42)
mmu<- c(1292,9514)
mmu_CV<- c(0.288,0.22)
```

Morgue and Graveyard 38

```
aos 2012
a<- c(6670,5828,4153)
a_cv<- c(0.31,0.22,0.25)
```

```
aos 2016
a<- c(15029,12840,14288)
a_cv<- c(0.18,0.17,0.15)
```

```
aos 2021
a<- c(19837,13481,15678)
a_cv<- c(0.14,0.18,0.15)
```

```
aos 2022
a<- c(9979,15727,22735,28653)
a_cv<- c(0.14,0.18,0.15,0.15)
```

Morgue and Graveyard 120

aos 2012

a<- c(4930,4550,3283)

a_cv<- c(0.31,0.22,0.25)

aos 2016

a<- c(14027,12919,10536)

a_cv<- c(0.18,0.17,0.15)

aos 2021

a<- c(15843,11405,12435)

a_cv<- c(0.14,0.17,0.14)

aos 2022

a<- c(7886,11435,15624,19776)

a_cv<- c(0.14,0.17,0.14,0.14)

APPENDIX 3: CASAL2 input file East & South Chatham Rise

East & South Chatham Rise

Population file

```
@model
start_year 1911
final_year 2025
projection_final_year 2125
min_age 1
max_age 100
base_weight_units tonnes
age_plus true
initialisation_phases Equilibrium_phase
time_steps step1
length_bins 1:80

@categories
format maturity
names immature mature
age_lengths AL AL

@initialisation_phase Equilibrium_phase
type Derived

@time_step step1
processes Ageing Recruitment Maturity Fishing

@process Recruitment
type recruitment_beverton_holt
categories immature mature
proportions 1.0 0
r0 7e7
steepness 1
ssb SSB
age 1
standardise_years 1911:2025
recruitment_multipliers 1*115

@time_varying TV_R0
type constant
parameter process[Recruitment].r0
years 1980:2025
values 7e6

@process Ageing
type ageing
categories *

@process Maturity
type transition_category
from immature
to mature
selectivities MaturationSel
proportions 1

@age_length AL
type von_bertalanffy
k 0.059
```

t0 -0.491
linf 37.78
cv_first 0.088
cv_last 0.044
by_length F
distribution normal
length_weight size_weight
compatibility_option casal

@length_weight size_weight
type basic
units tonnes
a 8.0e-8
b 2.75

@process Fishing
type mortality_instantaneous
m 0.045 0.045
time_step_proportions 1.0
relative_m_by_age One
categories immature mature
table catches

year	boxflat	hills	andes	south	crack	rekohu
1979	11597	2240	0	31	1289	184
1980	27831	5325	0	1205	4431	78
1981	15341	2317	0	4994	3037	77
1982	19291	2630	0	721	582	47
1983	5772	182	0	6422	598	26
1984	19122	1348	0	6936	674	0
1985	21336	1817	0	10544	1959	0
1986	23587	2028	0	6894	1250	0
1987	24324	2218	0	5960	2114	35
1988	16646	1317	0	8491	1541	28
1989	18928	3573	0	11357	1415	71
1990	14705	2615	0	15418	1189	34
1991	5799	6897	110	8522	637	0
1992	2107	3277	8159	3076	117	17
1993	90	1201	3557	6306	67	0
1994	121	1210	3729	5951	0	0
1995	197	2039	1836	2008	74	0
1996	610	1585	1269	1617	246	21
1997	982	1564	793	1601	304	5
1998	946	1799	1323	2084	463	0
1999	600	1300	1285	1588	267	0
2000	610	1251	1993	1496	634	0
2001	601	1605	988	1966	300	0
2002	1843	2514	2105	1466	262	8
2003	1878	2790	2393	1698	271	0
2004	2187	2248	1360	1612	122	1185
2005	2578	2033	1229	2024	249	1127
2006	3621	2102	1481	1720	440	172
2007	4080	2265	1347	1462	315	86
2008	2654	2531	1024	1441	336	213
2009	3133	1750	395	1263	395	120
2010	2072	1436	503	983	525	61
2011	582	1015	527	511	122	456
2012	226	759	511	348	120	759
2013	159	316	573	347	147	905
2014	478	375	999	644	3	820
2015	138	302	492	386	77	1822

2016	756	277	1235	405	39	838
2017	515	236	807	584	0	995
2018	918	264	860	469	7	904
2019	454	434	473	427	12	2046
2020	890	457	472	325	5	2774
2021	3305	760	201	249	207	1355
2022	2812	1403	97	64	245	1815
2023	2744	1604	64	90	290	1649
2024	1145	469	60	55	69	512
2025	1145	469	60	55	69	512

end_table

table method

method	category	selectivity	u_max	time_step	penalty
boxflat	mature	One	0.8	step1	CatchMustBeTaken
hills	mature	One	0.8	step1	CatchMustBeTaken
andes	mature	One	0.8	step1	CatchMustBeTaken
south	mature	One	0.8	step1	CatchMustBeTaken
crack	mature	One	0.8	step1	CatchMustBeTaken
rekohu	mature	One	0.8	step1	CatchMustBeTaken

end_table

@derived_quantity SSB

type biomass

time_step step1

categories mature

time_step_proportion 0.75

time_step_proportion_method weighted_sum

selectivities One

@derived_quantity Immature

type biomass

time_step step1

categories immature

time_step_proportion 0.75

time_step_proportion_method weighted_sum

selectivities One

@selectivity One

type constant

c 1

@selectivity MaturationSel

type logistic_producing

l 10

h 100

a50 28.51

ato95 4.56

alpha 1.0

Observation file

@observation osp38

type biomass

time_step step1

categories mature

time_step_proportion 0.75

likelihood lognormal

selectivities One

catchability osp_acoq

```

process_error 0.2
years 2002 2003 2004 2005 2006 2007 2008 2009 2010
table obs
2002    63950    0.06
2003    44316    0.06
2004    44968    0.08
2005    43923    0.04
2006    47450    0.10
2007    34427    0.05
2008    31668    0.08
2009    28199    0.05
2010    21205    0.07
end_table

```

```

@catchability osp_acoq
type free
q 0.5

```

```

@observation combined38
type biomass
time_step step1
categories mature
time_step_proportion 0.75
likelihood lognormal
selectivities One
catchability combined_acoq
process_error 0.1
years 2011 2013 2016 2022 2024
table obs
2011    51329    0.13
2013    54363    0.08
2016    43560    0.10
2022    48981    0.07
2024    41375    0.06
end_table

```

```

@catchability combined_acoq
type free
q 0.5

```

```

@observation combined120
type biomass
time_step step1
categories mature
time_step_proportion 0.75
likelihood lognormal
selectivities One
catchability combined_acoq
process_error 0.25
years 2013 2016 2022 2024
table obs
2013    54542    0.08
2016    36716    0.11
2022    29939    0.10
2024    22723    0.13
end_table

```

```

@catchability combined_acoq
type free
q 0.5

```

@observation AFplumes84_24

type proportions_at_age

time_step_proportion 0.75

categories mature

years 1984 2003 2012 2013 2016 2022 2024

time_step step1

sum_to_one True

min_age 18

max_age 100

plus_group True

selectivities One

likelihood multinomial

ageing_error ageing_error

table obs

1984	0.011845501	0	0.001736111	0.002212389	0.005208333	0.002212389					
	0.008373279	0.007897001	0.013581613	0.018789946	0.015317724	0.017530113					
	0.014534169	0.017053835	0.020049779	0.007897001	0.01848267	0.028115782					
	0.021002335	0.020526057	0.019742502	0.028899336	0.019266224	0.024167281					
	0.041697394	0.031588004	0.028115782	0.027639503	0.028423058	0.032847837					
	0.022738446	0.020218781	0.01232178	0.018006391	0.029375615	0.013105334					
	0.020526057	0.024474558	0.020218781	0.021171337	0.008373279	0.013581613					
	0.011845501	0.017530113	0.020695059	0.011845501	0.009156834	0.009156834					
	0.011369223	0.010892945	0.003472222	0.006944444	0.009156834	0.005684612					
	0.007897001	0.01010939	0.003472222	0.0039485	0	0.007897001					
	0.007897001	0.001736111	0.005684612	0.005208333	0.002212389	0.005208333					
	0	0	0.007420723	0.002212389	0.002212389	0.005684612	0				
	0.001736111	0	0.003472222	0.0039485	0	0.002212389	0	0			
	0.0039485	0.019266224									
2003	0	0.001432665	0.001432665	0.00286533	0.00286533	0.00286533	0.025787966				
	0.012893983	0.023940952	0.014326648	0.032519383	0.040493848	0.051730434					
	0.076275353	0.075429097	0.091585201	0.111986628	0.097470364	0.088702315					
	0.06355343	0.037196612	0.031897859	0.020246924	0.012893983	0.015137789					
	0.007163324	0.008595989	0.007163324	0	0.005730659	0.005730659					
	0.001432665	0.001432665	0.00286533	0.001432665	0.00286533	0					
	0.00286533	0.001432665	0	0.004297994	0	0.001432665	0				
	0.001432665	0	0.001432665	0	0	0	0	0	0		
	0.001432665	0	0	0	0.001432665	0	0.001432665	0	0		
	0	0	0	0	0	0	0	0	0		
	0	0	0	0	0	0	0	0	0		
	0	0	0	0	0.00286533						
2012	0	0	0	0	0.003378378	0.013513514	0.003378378	0	0		
	0.010135135	0.010135135	0.013513514	0.006756757	0.02027027	0.037162162					
	0.010135135	0.013513514	0.013513514	0.030405405	0.030405405	0.023648649					
	0.047297297	0.037162162	0.016891892	0.037162162	0.02027027	0.037162162					
	0.02027027	0.037162162	0.033783784	0.013513514	0.02027027	0.027027027					
	0.043918919	0.023648649	0.016891892	0.013513514	0.023648649	0.023648649					
	0.006756757	0.016891892	0.003378378	0.016891892	0.006756757	0.02027027					
	0.003378378	0.013513514	0.003378378	0.010135135	0.013513514	0.010135135					
	0.013513514	0.010135135	0.006756757	0.006756757	0.013513514	0.006756757					
	0.010135135	0.003378378	0	0.003378378	0.003378378	0.003378378	0				
	0.006756757	0.006756757	0	0	0.003378378	0.003378378	0.003378378				
	0.003378378	0	0.003378378	0.006756757	0	0.006756757	0	0			
	0	0.016891892									
2013	0	0.004	0.000	0.000	0.004	0.004	0.000	0.000	0.016	0.012	0.020
	0.012	0.028	0.020	0.016	0.040	0.060	0.032	0.032	0.028	0.028	0.036
	0.040	0.020	0.036	0.020	0.044	0.024	0.024	0.036	0.012	0.040	0.016
	0.016	0.008	0.012	0.008	0.008	0.028	0.016	0.008	0.028	0.020	0.008
	0.016	0.012	0.008	0.008	0.004	0.008	0.004	0.008	0.004	0.000	0.004
	0.016	0.000	0.000	0.000	0.004	0.000	0.004	0.004	0.000	0.000	0.000

	0.000	0.008	0.000	0.004	0.004	0.000	0.000	0.000	0.000	0.004	0.000		
	0.000	0.000	0.000	0.008									
2016	0	0	0.000	0.005	0.000	0.010	0.005	0.015	0.015	0.015	0.005	0.000	0.010
		0.020	0.010	0.010	0.030	0.005	0.020	0.010	0.040	0.020	0.040	0.030	
		0.015	0.010	0.035	0.020	0.010	0.025	0.020	0.030	0.020	0.030	0.020	
		0.010	0.010	0.020	0.045	0.025	0.005	0.045	0.025	0.010	0.020	0.005	
		0.035	0.005	0.010	0.005	0.010	0.000	0.005	0.020	0.000	0.005	0.005	
		0.010	0.020	0.010	0.005	0.000	0.000	0.015	0.000	0.010	0.005	0.010	
		0.010	0.010	0.000	0.000	0.000	0.005	0.005	0.000	0.000	0.000	0.000	
		0.000	0.000	0.005	0.010								
2022	0	0	0.000	0.003	0.003	0.000	0.000	0.010	0.003	0.000	0.000	0.003	0.003
		0.007	0.007	0.013	0.003	0.010	0.020	0.013	0.030	0.023	0.017	0.050	
		0.023	0.030	0.023	0.030	0.033	0.037	0.037	0.054	0.030	0.027	0.027	
		0.023	0.037	0.033	0.037	0.017	0.027	0.033	0.013	0.020	0.010	0.010	
		0.010	0.013	0.013	0.007	0.017	0.017	0.010	0.003	0.010	0.003	0.003	
		0.010	0.010	0.003	0.000	0.010	0.003	0.003	0.000	0.003	0.003	0.003	
		0.000	0.000	0.000	0.000	0.003	0.003	0.000	0.000	0.000	0.000	0.000	
		0.000	0.003	0.000	0.000								
2024	0.00321694	0		0.004049937		0.001242888	0		0.006613316		0.01122657	0	
		0.01522589		0.0308746		0.01663436		0.01571973		0.01169123		0.02040861	
		0.01566242		0.02738594		0.04453261		0.05954732		0.02566563		0.01801032	
		0.03983351		0.02280165		0.04854867		0.05272224		0.06636896		0.05201341	
		0.02670807		0.09026526		0.02471614		0.01548435		0.03034753		0.02636725	
		0.01733225		0.03085053		0.01896616		0.01448895		0.002749217		0.00960336	
		0.006970087		0.009507513		0.00238832	0		0.002619823		0.008662655		
		0.000671886		0.000692675		0.009874383	0		0.001778088		0.005860646	0	
		0.006395521		0.01476787	0	0	0		0.003970502	0	0	0	
	0	0		0.003777452		0.000891286	0	0	0	0	0	0	0
	0.00195817		0		0.001337312	0	0	0	0	0	0	0	0
	0	0		0									

end_table

table error_values

1984 10

2003 2

2012 10

2013 10

2016 10

2022 10

2024 10

end_table

@observation AFrekohu12_24

type proportions_at_age

time_step_proportion 0.75

categories mature

years 2012 2013 2016 2022 2024

time_step step1

sum_to_one True

min_age 20

max_age 100

plus_group True

selectivities One

likelihood multinomial

ageing_error ageing_error

table obs

2012	0	0	0	0.010067114	0.006711409	0.010067114	0.013422819	0.020134228
		0.006711409		0.05033557	0.046979866	0.040268456	0.023489933	0.046979866
		0.036912752		0.033557047	0.053691275	0.063758389	0.036912752	0.036912752
		0.016778523		0.040268456	0.05033557	0.033557047	0.023489933	0.030201342

	0.026845638	0.030201342	0.033557047	0.013422819	0.010067114	0.020134228
	0.023489933	0.006711409	0.006711409	0.010067114	0.006711409	0.010067114
	0	0	0.013422819	0.003355705	0.010067114	0
	0.003355705	0.003355705	0	0	0.003355705	0
	0	0.003355705	0	0	0	0
	0	0	0.003355705	0	0	0
	0	0	0	0	0.010067114	0
2013	0.000	0.000	0.000	0.012	0.012	0.008
	0.056	0.056	0.056	0.044	0.060	0.044
	0.044	0.032	0.016	0.032	0.004	0.016
	0.028	0.008	0.008	0.004	0.000	0.004
	0.004	0.004	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000
2016	0.000	0.008	0.004	0.008	0.008	0.004
	0.052	0.056	0.032	0.048	0.056	0.028
	0.032	0.052	0.020	0.020	0.020	0.028
	0.004	0.008	0.004	0.012	0.008	0.000
	0.004	0.004	0.000	0.000	0.000	0.000
	0.008	0.004	0.000	0.004	0.000	0.000
	0.004	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000
2022	0.000	0.003	0.000	0.000	0.000	0.003
	0.003	0.010	0.007	0.003	0.003	0.020
	0.047	0.064	0.040	0.040	0.044	0.051
	0.020	0.030	0.020	0.034	0.013	0.020
	0.024	0.000	0.013	0.003	0.013	0.000
	0.000	0.007	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.003	0.003
	0.000	0.000	0.000	0.000	0.000	0.000
2024	0.001325644	0.009565202	0	0.004971521	0.02267114	0
	0.01221472	0.01603716	0.003417791	0.007085062	0.005430532	0.01860574
	0.04647702	0.0215126	0.02819191	0.02118802	0.04920479	0.03802378
	0.04122813	0.04765291	0.0962167	0.06319968	0.06111589	0.0483014
	0.04141466	0.05883775	0.03329254	0.03507828	0.02508625	0.02056335
	0.01135792	0.02837506	0.003647643	0.01559821	0.001983624	0.00991569
	0.007932067	0	0.006139024	0.00295878	0	0
	0.00295878	0	0.008258052	0.003647643	0.001983624	0.002417387
	0.003338385	0	0	0	0	0
	0	0	0	0	0	0
	0	0	0	0	0	0

end_table

table error_values

2012 10

2013 10

2016 10

2022 10

2024 10

end_table

@observation AFcrack13_24

type proportions_at_age

time_step_proportion 0.75

categories immature+mature

years 2013 2016 2022 2024

time_step step1

sum_to_one True

min_age 20

```

max_age 100
plus_group True
selectivities MMUsetl MMUsetl
likelihood multinomial
ageing_error ageing_error
table obs
2013 0.000      0.000      0.000      0.004      0.004      0.004      0.000      0.024      0.012      0.020      0.032
      0.016      0.024      0.024      0.024      0.040      0.020      0.028      0.024      0.028      0.016      0.032
      0.012      0.024      0.028      0.028      0.028      0.016      0.024      0.016      0.016      0.012      0.024
      0.020      0.012      0.008      0.036      0.012      0.024      0.024      0.016      0.008      0.004      0.008
      0.016      0.008      0.020      0.016      0.020      0.004      0.016      0.016      0.000      0.020      0.008
      0.008      0.000      0.008      0.000      0.008      0.000      0.008      0.000      0.000      0.000      0.000
      0.008      0.004      0.000      0.000      0.008      0.000      0.004      0.000      0.012      0.000      0.000
      0.000      0.000      0.004      0.012
2016 0.000      0.000      0.000      0.007      0.000      0.000      0.007      0.013      0.000      0.007      0.013
      0.013      0.013      0.013      0.013      0.013      0.027      0.013      0.020      0.027      0.013      0.034
      0.027      0.020      0.020      0.013      0.047      0.020      0.040      0.020      0.013      0.000      0.013
      0.027      0.007      0.020      0.027      0.013      0.007      0.013      0.007      0.007      0.013      0.013
      0.027      0.007      0.013      0.027      0.027      0.007      0.013      0.020      0.000      0.007      0.000
      0.000      0.034      0.013      0.007      0.007      0.000      0.000      0.000      0.007      0.000      0.007
      0.007      0.007      0.000      0.007      0.007      0.013      0.007      0.007      0.000      0.007      0.007
      0.000      0.000      0.000      0.074
2022 0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.007      0.007      0.003
      0.003      0.000      0.003      0.007      0.013      0.010      0.023      0.017      0.033      0.020      0.020
      0.030      0.013      0.020      0.013      0.047      0.043      0.027      0.037      0.023      0.027      0.033
      0.043      0.040      0.030      0.043      0.017      0.017      0.003      0.027      0.023      0.023      0.033
      0.017      0.000      0.003      0.017      0.010      0.007      0.007      0.017      0.020      0.007      0.020
      0.003      0.007      0.003      0.000      0.007      0.007      0.003      0.000      0.003      0.010      0.003
      0.000      0.000      0.003      0.003      0.000      0.000      0.013      0.000      0.007      0.000      0.003
      0.003      0.000      0.003      0.010
2024 0 0      0.01677657      0.007036031      0.007036031      0.002704509      0      0.01514956
      0.01948108      0.01677657      0.01948108      0.002704509      0.02110809      0.01514956
      0.01948108      0.008113526      0.0238126      0.04707568      0.03733514      0.05032971
      0.05466123      0.06007025      0.02596759      0.03029911      0.06007025      0.02651711
      0.05140721      0.02055857      0.0248901      0.03625765      0.03029911      0.0238126
      0.02922162      0      0.01514956      0.02218559      0.009740539      0.005409018
      0.008113526      0.02055857      0.01514956      0.01407206      0.002704509      0
      0.01244505      0.009740539      0.002704509      0.01407206      0.002704509      0.009740539
      0      0      0      0.009740539      0.007036031      0.002704509      0      0
      0.007036031      0      0      0      0      0      0      0      0      0      0
      0      0      0      0.002704509      0      0      0      0      0      0      0
      0.002704509
end_table

table error_values
2013 10
2016 10
2022 10
2024 10
end_table

@ageing_error ageing_error
type normal
cv 0.1

Estimation file

@minimiser      adolc
type            betadiff
iterations      100000

```

```

evaluations      100000
tolerance        0.0001
covariance       True

@mcmc mcmc
type             random_walk
start            0
length           4000000
keep             4000
step_size        0.2
burn_in          200000
adapt_stepsize_at 20000 40000 60000 80000 100000
adapt_stepsize_method double_half
proposal_distribution normal
max_correlation 0.8

@estimate R0
parameter process[Recruitment].r0
lower_bound 1e6
upper_bound 1e9
type uniform_log

@estimate shift_R0
parameter time_varying[TV_R0].values{1980}
lower_bound 3
upper_bound 6e8
same time_varying[TV_R0].values{1981:2025}
type uniform_log

@estimate osp38_acoq.q
parameter catchability[osp_acoq].q
type uniform
lower_bound 0.01
upper_bound 5

@estimate combined38_acoq.q
parameter catchability[combined_acoq].q
type lognormal
mu 0.8
cv 0.19
lower_bound 0.01
upper_bound 5

@penalty CatchMustBeTaken
type process
log_scale True
multiplier 200

```

APPENDIX 4: CASAL2 input file Northwest Chatham Rise

Northwest Chatham Rise

Population file

```
@model
start_year 1911
final_year 2025
projection_final_year 2125
min_age 1
max_age 100
base_weight_units tonnes
age_plus true
initialisation_phases Equilibrium_phase
time_steps step1
length_bins 1:80

@categories
format maturity
names immature mature
age_lengths AL AL

@initialisation_phase Equilibrium_phase
type Derived

@time_step step1
processes Ageing Recruitment Maturity Fishing

@process Recruitment
type recruitment_beverton_holt
categories immature mature
proportions 1.0 0
r0 7e7
steepness 0.75
ssb SSB
age 1
standardise_years 1911:2025
recruitment_multipliers 1*115

@process Ageing
type ageing
categories *

@process Maturity
type transition_category
from immature
to mature
selectivities MaturationSel
proportions 1

@age_length AL
type von_bertalanffy
k 0.059
t0 -0.491
linf 37.78
cv_first 0.088
cv_last 0.044
by_length F
distribution normal
```

length_weight size_weight
compatibility_option casal

@length_weight size_weight
type basic
units tonnes
a 8.0e-8
b 2.75

@process Fishing
type mortality_instantaneous
m 0.045 0.045
time_step_proportions 1.0
relative_m_by_age One
categories immature mature
table catches

year	nwcr
1980	1560
1981	10920
1982	9100
1983	7020
1984	4290
1985	2340
1986	4736
1987	4032
1988	1984
1989	4636
1990	3960
1991	1725
1992	330
1993	4180
1994	3850
1995	2520
1996	2520
1997	2310
1998	2415
1999	2835
2000	2205
2001	2730
2002	2310
2003	2310
2004	2100
2005	1680
2006	1470
2007	735
2008	840
2009	788
2010	756
2011	42
2012	74
2013	116
2014	840
2015	840
2016	735
2017	767
2018	882
2019	319
2020	359
2021	411
2022	212

2023 194
 2024 223
 2025 223
 end_table

table method
 method category selectivity u_max time_step penalty
 nwcr mature One 0.67 step1 CatchMustBeTaken
 end_table

@derived_quantity SSB
 type biomass
 time_step step1
 categories mature
 time_step_proportion 0.75
 time_step_proportion_method weighted_sum
 selectivities One

@derived_quantity Immature
 type biomass
 time_step step1
 categories immature
 time_step_proportion 0.75
 time_step_proportion_method weighted_sum
 selectivities One

@selectivity One
 type constant
 c 1

@selectivity matsel
 type logistic
 a50 28.51
 ato95 4.56

@selectivity MaturationSel
 type logistic_producing
 l 10
 h 100
 a50 28.51
 ato95 4.56

Observation file

@observation aco_38
 type biomass
 time_step step1
 categories mature
 time_step_proportion 0.75
 likelihood lognormal
 selectivities One
 catchability acoq_38
 process_error 0.2
 years 2012 2016 2021 2022
 table obs
 2012 5550 0.16
 2016 14052 0.13
 2021 16332 0.09
 2022 19273 0.08
 end_table

```
@catchability acoq_38
type free
q 0.5
```

```
@observation aco_120
type biomass
time_step step1
categories mature
time_step_proportion 0.75
likelihood lognormal
selectivities One
catchability acoq_120
process_error 0.2
years 2012 2016 2021 2022
table obs
2012 4254 0.16
2016 12494 0.10
2021 13228 0.09
2022 13680 0.08
end_table
```

```
@catchability acoq_120
type free
q 0.5
```

Estimation file

```
@minimiser      adolc
type            betadiff
iterations      100000
evaluations     100000
tolerance       0.0001
covariance      True
```

```
@mcmc mcmc
type            random_walk
start           0
length          4000000
keep            4000
step_size       0.2
burn_in         100000
adapt_stepsize_at 20000 40000 60000 80000 100000
adapt_stepsize_method double_half
proposal_distribution normal
max_correlation 0.85
```

```
@estimate R0
parameter process[Recruitment].r0
lower_bound 1e6
upper_bound 1e9
type uniform_log
```

```
@estimate acoq_38.q
parameter catchability[acoq_38].q
type normal
mu 0.8
cv 0.19
lower_bound 0.1
upper_bound 5
```

```
@estimate acoq_120.q
parameter catchability[acoq_120].q
type normal
mu 0.3
cv 0.19
lower_bound 0.03
upper_bound 3
```

```
@estimate M.immature
parameter process[Fishing].m{immature}
same process[Fishing].m{mature}
lower_bound 0.001
upper_bound 1
type normal
mu 0.045
cv 0.333
```

```
@penalty CatchMustBeTaken
type process
log_scale True
multiplier 200
```