



Fisheries New Zealand

Tini a Tangaroa

Assessment of the Mid-East Coast orange roughy stock for 2022

New Zealand Fisheries Assessment Report 2022/38

M.R. Dunn,
T. A'mar,
I. Doonan

ISSN 1179-5352 (online)
ISBN 978-1-99-103990-3 (online)

August 2022



Te Kāwanatanga o Aotearoa
New Zealand Government

Disclaimer

This document is published by Fisheries New Zealand, a business unit of the Ministry for Primary Industries (MPI). The information in this publication is not government policy. While every effort has been made to ensure the information is accurate, the Ministry for Primary Industries does not accept any responsibility or liability for error of fact, omission, interpretation, or opinion that may be present, nor for the consequence of any decisions based on this information. Any view or opinion expressed does not necessarily represent the view of Fisheries New Zealand or the Ministry for Primary Industries.

Requests for further copies should be directed to:

Fisheries Science Editor
Fisheries New Zealand
Ministry for Primary Industries
PO Box 2526
Wellington 6140
NEW ZEALAND

Email: Fisheries-Science.Editor@mpi.govt.nz
Telephone: 0800 00 83 33

This publication is also available on the Ministry for Primary Industries websites at:
<http://www.mpi.govt.nz/news-and-resources/publications>
<http://fs.fish.govt.nz> go to Document library/Research reports

© Crown Copyright – Fisheries New Zealand

Please cite this report as:

Dunn, M.R.; A'mar, T.; Doonan, I. (2022). Assessment of the Mid-East Coast orange roughy stock for 2022. *New Zealand Fisheries Assessment Report 2022/38*. 77 p.

TABLE OF CONTENTS

EXECUTIVE SUMMARY	1
1. INTRODUCTION	2
2. FISHERY CHARACTERISATION	3
3. MODEL FISHERY STRUCTURE	8
4. CATCH HISTORY	11
5. LENGTH AND AGE FREQUENCY DATA	12
5.1 Length compositions	12
5.2 Age compositions	13
6. GROWTH	18
7. MATURATION	22
8. ACOUSTIC BIOMASS SURVEYS	23
9. RESEARCH TRAWL SURVEYS	24
10. STOCK ASSESSMENT MODEL	25
10.1 Model assumptions	25
10.2 Year class strengths	25
10.3 Updating the 2014 model	30
10.4 Data weighting	31
10.5 Base model	32
10.6 Sensitivity runs	35
11. BAYESIAN ESTIMATES	40
11.1 Projections	44
12. COMMENTS ON THE SKIPPED SPAWNING HYPOTHESIS	45
13. DISCUSSION	49
13.1 Summary	49
13.2 Future research	51
14. ACKNOWLEDGEMENTS	51
15. REFERENCES	51
16. APPENDIX A: Length frequency compositions	54
17. APPENDIX B: MCMC diagnostics	59
17.1 Parameter density plots	59
17.2 Trace plots	62
17.3 Running means	63
17.4 Comparison of partial and full chains	64
17.5 Autocorrelation	65
17.6 Cross-correlation	66
18. APPENDIX C: CASAL files	67

EXECUTIVE SUMMARY

Dunn, M.R.¹; A'mar, T.¹; Doonan, I.¹ (2022). Assessment of the Mid-East Coast orange roughy stock for 2022.

New Zealand Fisheries Assessment Report 2022/38. 77 p.

This report describes the assessment of the Mid-East Coast orange roughy (*Hoplostethus atlanticus*, ORH) stock (quota management areas ORH 3A, ORH 2B, and southern part of ORH 2A) completed in May 2022. The assessment was accepted by the Fisheries New Zealand Deepwater Working Group and Plenary and used to update the scientific information on the size and status of the stock.

The previous assessment was accepted in 2014. The main data sets used were fishery catches, wide-area trawl surveys, acoustic biomass surveys of spawning aggregations, and age and length frequency compositions. The new data available for the 2022 assessment were catches since 2013–14, acoustic biomass surveys in 2017 and 2021, age frequency compositions of spawning aggregations in 2017 and 2021, and seven length frequency distributions for various years and fisheries.

The 2022 assessment differed from the previous (2014) assessment in assuming four fisheries rather than two, excluding proportions mature-at-age data and setting the spawning ogive instead equal to the Spawn fishery selectivity, changing the year class strength prior, changing the base assumption for the acoustic catchability scalar q to 0.8 instead of 0.6, including sex in the model partition, updating growth and length-weight conversion and assuming a different growth form, fitting the trawl survey age and length compositions to immature and mature fish separately, and including the 2010 age sample in a time series of age data (it was previously assumed to be separate). In 2022 however, the new 2021 age frequency composition could not be fitted as part of a consistent time series and was assumed to be separate.

The 2022 assessment estimated a relatively high mean age of spawning, at about age 60, and accordingly a smaller spawning stock biomass (SSB), although total stock biomass was slightly larger than estimated previously. The higher age of spawning produced a better fit to the age frequencies, estimated a lower SSB more consistent with the acoustic SSB survey prior, and mitigated the need for strong and poorly informed year class strength trends and/or estimating a low natural mortality rate.

The hypothesis most likely to explain the high age of spawning was thought to be skipped spawning, where younger mature fish skipped spawning more often than older fish. This hypothesis was discussed, but it needs to be tested in future research.

The virgin spawning stock size (B_0) in the base case model run was estimated to be 53 350 t (95% CI 46 550–63 670 t), and stock status (B_{2022}/B_0) estimated to be 22.4% (16.7–29.2%). The stock was estimated to have been slowly and steadily rebuilding since 1994–95. At recent catch levels, the stock was expected to continue to slowly rebuild, with spawning stock biomass estimated to be greater than the lower bound of the target zone (30% B_0) with at least 70% probability by 2037.

¹ National Institute for Water & Atmospheric Research Ltd (NIWA), New Zealand.

1. INTRODUCTION

The New Zealand orange roughy (*Hoplostethus atlanticus*, ORH) Mid-East Coast stock consists of Quota Management Area ORH 3A, ORH 2B, and the southern part of ORH 2A (Figure 1). The northern part of ORH 2A is referred to as the East Cape stock and is assessed separately. This report describes a fisheries characterisation using fisheries data to the end of the 2020–21 fishing year (New Zealand fishing years start on 1 October), and a stock assessment completed in 2022. Prior to this, the last characterisation of fisheries catch and effort used data to the end of the 2008–09 fishing year (Anderson & Dunn 2012), and the previous accepted stock assessment was in 2014 (Cordue 2014, Fisheries New Zealand 2021). The first accepted assessment of the Mid-East Coast stock was completed in 1988, and the 2022 assessment was the thirteenth to be completed (Figure 2).

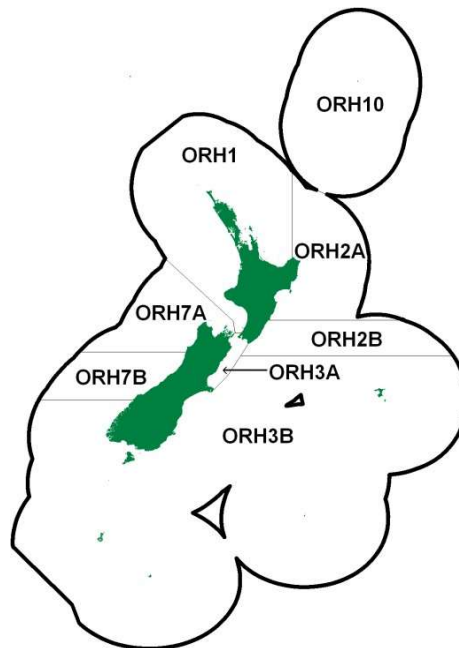


Figure 1: New Zealand Quota Management Areas for orange roughy.

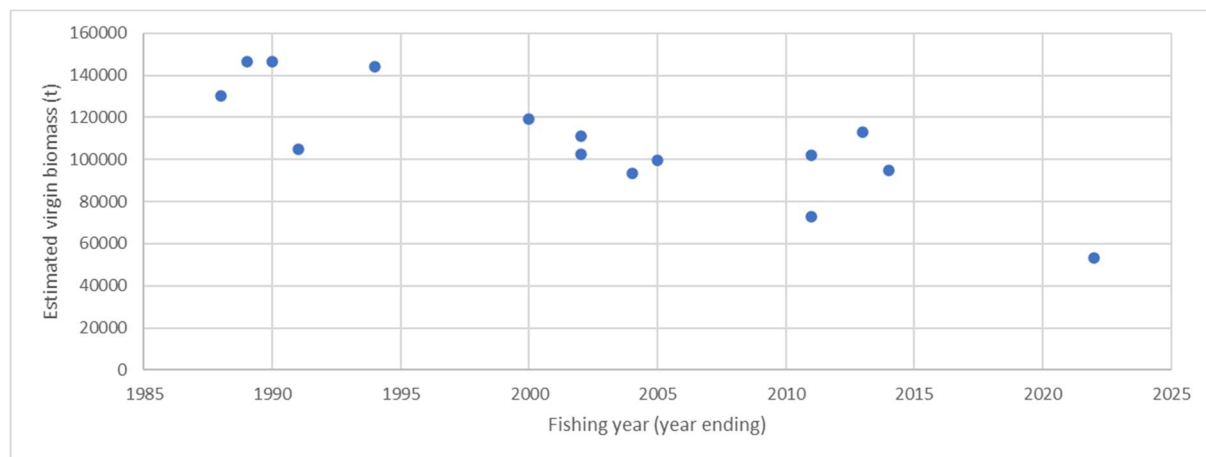


Figure 2: Estimates of Mid-East Coast orange roughy virgin stock size from accepted assessments, compiled from the Fisheries New Zealand plenary reports (the most recent being Fisheries New Zealand 2021). Where more than one estimate was available from the assessment, the estimate shown is the 'base run', or if two runs were presented with equal plausibility, both estimates are shown. B_0 estimated from this assessment is shown for 2022.

The work described in this report was carried out under Fisheries New Zealand project ORH2021–01 Stock assessment of orange roughy Mid-East Coast stock, having specific objectives (1) “To carry out a descriptive analysis of the commercial catch and effort data, survey data, and observer data for orange roughy fisheries on the Mid-East Coast”, and (2) “To complete stock assessments of the Mid-East Coast orange roughy stock including estimating 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”.

2. FISHERY CHARACTERISATION

The spatial and temporal structure, and changes over time, of the Mid-East Coast and East Cape orange roughy fisheries were described using groomed estimated catch and effort data. The Fisheries New Zealand data presentation rules prevent information from less than three vessels from being shown, therefore the results shown here are summaries. Further analyses, if required, may be obtained by requesting the Deepwater Working Group presentation made on 24 February 2020 from Fisheries New Zealand.

Catch and effort data were requested for all trips within which at least one event (tow) caught or targeted orange roughy (Fisheries New Zealand extract 14186). Data grooming corrected errors in catch species codes, imputed missing target species codes, corrected, imputed, or excluded errors in tow distance, duration, depth, location (e.g., east/west reflection; tows on land), corrected errors in Fishery Management Area (FMA), and derived data fields required for analyses, e.g., decimal times, Julian date, fishing years, tow duration, estimated distance to nearest known underwater feature, allocation to fishery subareas.

Orange roughy fisheries are generally focused on fish aggregations forming on specific underwater features. Historically, the largest Mid-East Coast fishery was on spawning aggregations occurring on Ritchie Bank (‘Strawberry Mountain’, ‘North Hill’), at about 39.4° S, and to a lesser extent on ‘Rock Garden’, at about 40° S (Figure 3). The Ritchie Bank fishery had declined substantially by the late 1990s, and since then only small catches were taken from that area. The contemporary spawning aggregations and fisheries have occurred primarily at Rock Garden, and at a location inshore of Ritchie Bank known as ‘Sea Valley’. Fisheries further north at Tolaga Knoll (at about 38.8° S) yielded good catches in the early 2000s for about five years and then persisted at a lower level. The fisheries at about 38° S are on hills in the East Cape stock, which started in the mid-1990s as the Ritchie Bank fishery declined. The larger catches taken in the far south of the Mid-East Coast stock area, at about 43° S and 174° E, are at the base of the Pegasus Canyon. Catch shown in Figure 3 at about 43° S and to the east of about 175° E are those in the Northwest Chatham Rise stock. The spatial footprint of the Mid-East Coast is greatly reduced from historical levels.

There was no evidence of strong sequential depletion of fishing locations for the Mid-East Coast and East Cape stocks, with many areas being persistently fished. In all years other than the late 1990s to early 2000s, almost all orange roughy catches (over 95%) were taken from orange roughy target fishing, with small bycatches when targeting hoki (*Macruronus novaezelandiae*), black cardinalfish (*Epigonus telescopus*), alfonsino (*Beryx splendens*), and oreos (largely smooth oreo, *Pseudocyttus maculatus*). Bycatch of orange roughy in fisheries targeting other species has been highest in ORH 2B, with little targeting of orange roughy in this QMA since the late 1990s. The vessels operating in the Mid-East Coast are relatively small for orange roughy fisheries, and access has been recently limited to vessels under 46 m length (J. Fenaughty, pers.comm.).

The Mid-East Coast fishery has taken place year around (with a gap over Christmas), although in recent years about half of the catch was taken during the spawning season (June) (Figure 4). For East Cape, in early years close to 100% of the catch was taken during the spawning season, although in recent years this percentage has declined to as little as 40% (Figure 4). The East Cape spawning fishery appears to have slowly come forward in time by a couple of weeks.

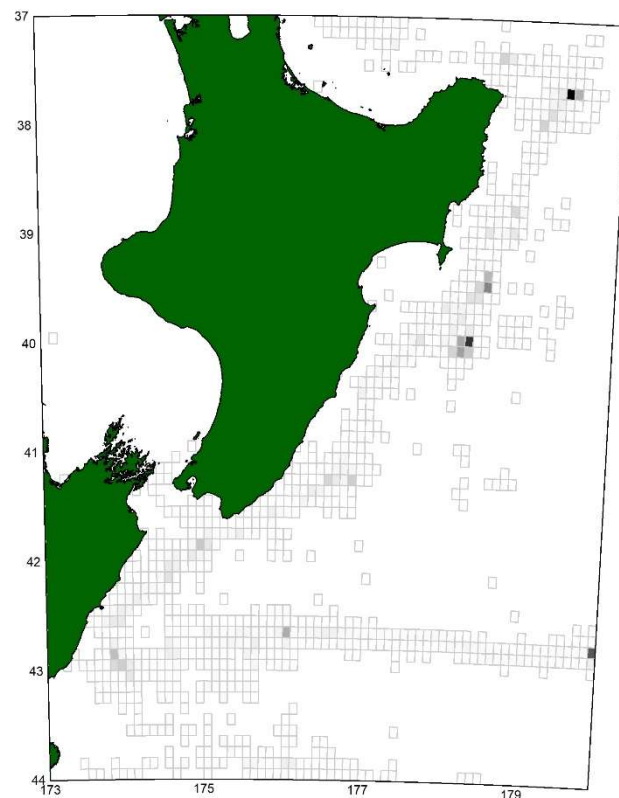
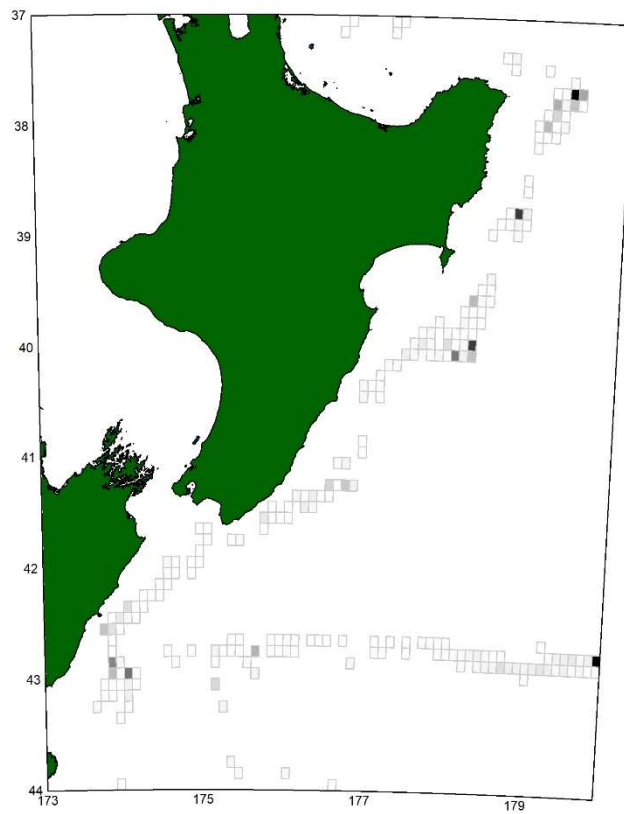


Figure 3: Spatial distribution of orange roughy catch by bottom trawls targeting orange roughy, cardinalfish, or oreo, for 0.1° latitude and longitude cells. Top panel, 2017–18 to 2020–21. Bottom panel, 1989–90 to 2016–17.

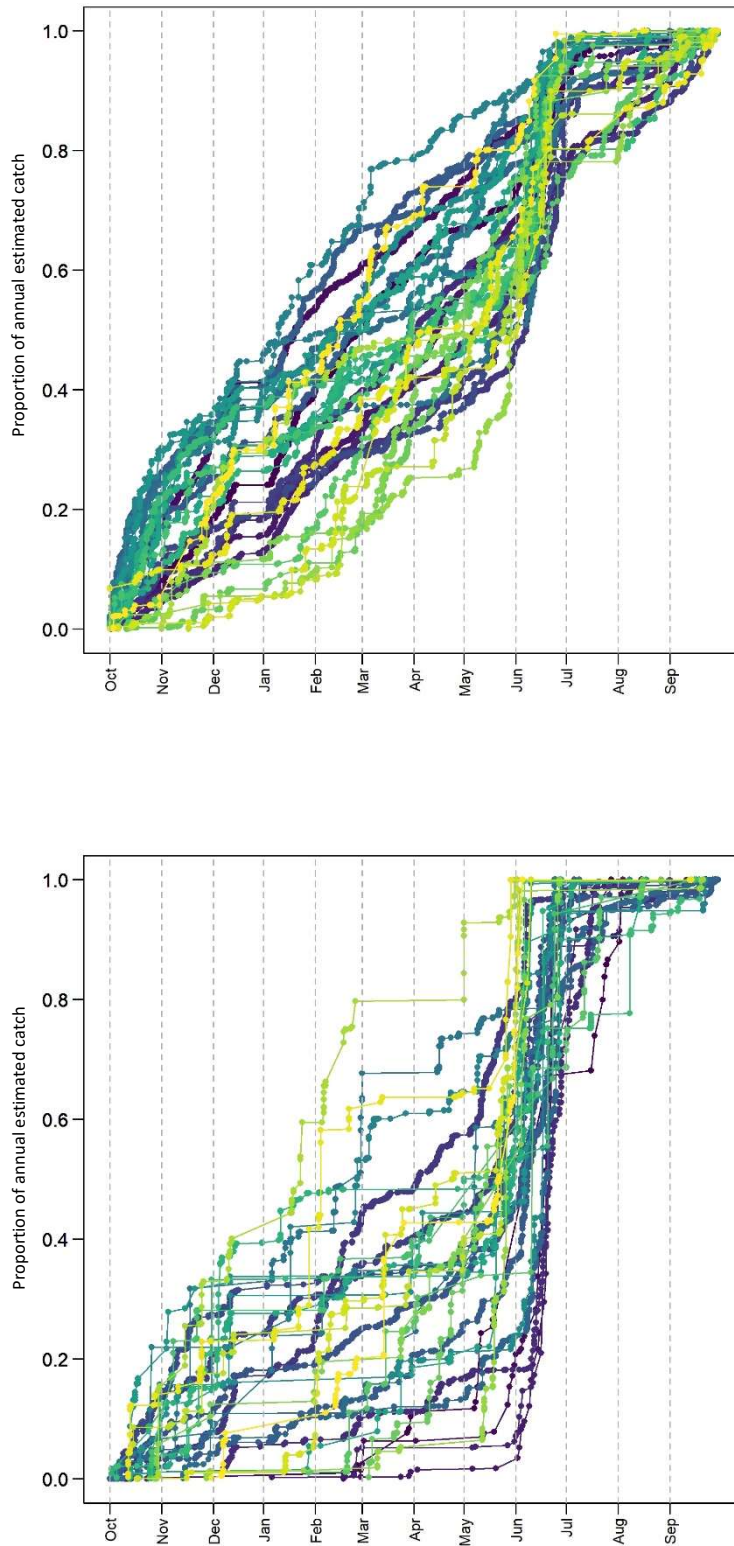


Figure 4: Proportion of cumulative catches for the Mid-East Coast (top panel) and East Cape (bottom panel) orange roughy target bottom trawl fishing. Catches are summed in chronological order through the fishing year and scaled to the total estimated catch for the year. Each point represents the relative accumulated catch after the addition of the catch from each new trawl. Fishing years are indicated by colour, with earliest years being dark blue and most recent being yellow.

For Mid-East Coast, the fishery was substantial in the mid to late-1980s and peaked at over 30 vessels (Table 1). Since the most recent Total Allowable Commercial Catch (TACC) reduction, in 2014–15, catches and effort have been reduced, and between 6 and 12 vessels have targeted and caught orange roughy, but the core fishery (75% of the catch) has included only three or four vessels. Tow duration has recently been short (typically about 30–40 minutes), consistent with fishing on features, although tows were longer in the past (before the early 2000s). Unstandardised catch rates declined from the 1980s into the mid-1990s, then recovered to a high around 2006–07 to 2007–08, and then were level or slowly declined, reaching a low point in 2019–20 (Table 1).

Table 1: Orange roughy catch and effort summary for Mid-East Coast, for bottom trawls targeting orange roughy. Vessels, number of vessels catching orange roughy; Vessels75, number of vessels catching 75% of the orange roughy; Catch, estimated catch in tonnes; Tows, number of tows; Hours, total hours fished; Duration, median tow duration (decimal hours); tperrow, total catch divided by total number of tows; tperhr_median, median tonnes per hours for tows where duration was recorded.

Fishing year	Vessels	Vessels75	Catch	Tows	Hours	Duration	tperrow	tperhr_median
1989–90	22	7	7 299.3	1 630	1 634	0.92	4.48	3.3
1990–91	21	7	7 904.5	1 951	1 717	0.75	4.05	3.9
1991–92	22	8	8 428.8	2 895	3 357	0.92	2.91	2.3
1992–93	32	8	8 013.1	3 514	4 617	1.00	2.28	1.7
1993–94	31	8	5 958.7	3 609	5 119	1.03	1.65	1.2
1994–95	31	10	4 231.9	3 256	4 501	1.00	1.30	0.9
1995–96	22	7	1 094.3	709	1 101	1.08	1.54	1.0
1996–97	19	6	1 326.2	688	1 000	1.00	1.93	1.3
1997–98	23	5	2 031.5	1 648	2 157	1.00	1.23	0.9
1998–99	24	7	1 979.7	2 074	3 137	1.08	0.95	0.6
1999–2000	24	8	2 246.5	1 915	2 753	1.00	1.17	0.8
2000–01	17	6	1 562.2	957	1 543	1.07	1.63	1.0
2001–02	17	7	1 181.6	490	736	1.03	2.41	1.5
2002–03	16	7	847.6	427	662	0.98	1.99	1.2
2003–04	15	6	906.0	431	622	1.00	2.10	1.4
2004–05	13	5	1 524.4	693	1 002	1.00	2.20	1.4
2005–06	10	3	1 308.2	474	682	0.82	2.76	1.8
2006–07	10	4	1 510.4	460	468	0.57	3.28	3.0
2007–08	10	3	1 545.0	526	481	0.50	2.94	3.2
2008–09	9	3	1 362.0	581	704	0.78	2.34	1.9
2009–10	9	4	1 406.1	619	796	0.83	2.27	1.8
2010–11	8	3	1 438.8	656	721	0.68	2.19	2.0
2011–12	11	4	1 164.2	465	408	0.60	2.50	2.9
2012–13	9	4	866.9	486	619	0.92	1.78	1.4
2013–14	9	3	946.2	490	481	0.62	1.93	2.0
2014–15	7	3	474.5	288	289	0.63	1.65	1.6
2015–16	7	3	499.2	334	353	0.67	1.49	1.4
2016–17	12	4	612.1	326	317	0.50	1.88	1.9
2017–18	8	4	438.1	306	309	0.63	1.43	1.4
2018–19	8	3	475.9	318	275	0.55	1.50	1.7
2019–20	6	3	382.1	391	370	0.68	0.98	1.0
2020–21	6	3	512.5	289	267	0.57	1.77	1.9

The East Cape fishery produced greater catches than the Mid-East Coast in the mid-1990s (1995–96 to 1997–98) (Table 2). The East Cape fishery peaked from 1993–94 to 1999–2000, with up to 19 active vessels, but since the mid-2000s only three or four vessels have been catching orange roughy, with most catch taken by just two or three vessels. The catches and effort have been fairly stable since the TACC was reduced to 200 t in 2000–01 (Fisheries New Zealand 2021). The unstandardised catch rates have shown variability with no persistent trend since the mid-1990s (Table 2).

Table 2: Orange roughy catch and effort summary for East Cape, for bottom trawls targeting orange roughy. Vessels, number of vessels catching orange roughy; Vessels75, number of vessels catching 75% of the orange roughy; Catch, estimated catch in tonnes; Tows, number of tows; Hours, total hours fished; Duration, median tow duration (hours); tpertow, total catch divided by total number of tows; tperhr_median, median tonnes per hours for tows where duration was recorded.

Fishing year	Vessels	Vessels75	Catch	Tows	Hours	Duration	tpertow	tperhr_median
1989–90	1	1	88.8	27	0	–	3.29	–
1990–91	3	2	219.4	43	16	0.95	5.10	0.0
1991–92	5	2	230.8	43	5	1.21	5.37	0.1
1992–93	3	2	270.3	42	3	0.78	6.44	0.7
1993–94	18	6	3 013.0	564	564	0.92	5.34	5.1
1994–95	19	9	2 916.4	1 218	1 162	0.75	2.39	2.4
1995–96	16	6	2 674.1	961	826	0.48	2.78	3.2
1996–97	17	5	1 920.5	797	775	0.50	2.41	2.5
1997–98	18	5	2 142.9	1 635	1 346	0.67	1.31	1.5
1998–99	18	5	1 697.0	1 141	1 088	0.75	1.49	1.5
1999–2000	18	4	1 356.9	756	576	0.60	1.79	2.2
2000–01	9	4	269.1	181	127	0.58	1.49	2.1
2001–02	8	3	146.5	155	115	0.49	0.95	1.3
2002–03	8	4	120.7	123	77	0.50	0.98	1.6
2003–04	8	4	191.9	124	96	0.50	1.55	1.7
2004–05	6	3	217.5	104	84	0.47	2.09	2.6
2005–06	7	3	196.0	102	56	0.43	1.92	3.5
2006–07	4	2	153.1	86	47	0.48	1.78	3.3
2070–08	6	2	170.1	123	62	0.43	1.38	2.8
2008–09	5	2	210.4	125	67	0.38	1.68	3.1
2009–10	6	3	238.5	160	101	0.38	1.49	2.4
2010–11	5	2	214.4	129	63	0.35	1.66	3.4
2011–12	5	3	155.3	53	19	0.23	2.93	8.0
2012–13	6	3	176.1	85	73	0.47	2.07	2.4
2013–14	4	2	165.2	105	89	0.58	1.57	1.9
2014–15	5	2	173.5	104	89	0.56	1.67	2.0
2015–16	4	2	185.0	110	84	0.61	1.68	2.2
2016–17	5	3	175.6	100	96	0.52	1.76	1.8
2017–18	5	3	184.9	71	46	0.42	2.60	4.1
2018–19	5	2	185.2	141	62	0.35	1.31	3.0
2019–20	5	2	159.2	116	63	0.42	1.37	2.5
2020–21	5	3	205.3	91	48	0.40	2.26	4.3

3. MODEL FISHERY STRUCTURE

The spatial structure of the orange roughy fisheries was investigated using Ministry observer catch composition samples. All fishing location and orange roughy length sample data within the stock area were extracted from the Central Observer Database (cod), covering the period 24 November 1986 to 8th October 2021. The data were not groomed.

Following Dunn (2008), cluster analyses of median orange roughy length by tow with the only predictor being 0.1° latitude and longitude cell references showed tows with fish of similar median lengths were geographically close to one another, indicating spatial structure by fish length (Figure 5). Fish in the north of the stock area had a larger median length and narrower length range. In the northern area, samples away from the main hill areas tended to have a wider length range. In the south, the area on the northern flank of the Pegasus Canyon also had larger fish with a narrower length range. The number of 0.1° cells fished over time peaked at about 110 cells during the early 1990s, and then declined steadily over time to about 45 since 2017–18. The number of cells ever fished increased over time but with no new cells added since 2016–17.

Clustering by median length but using other covariates to determine stratum splits (covariates offered were vessel, depth, latitude, longitude, tow speed, time of day, month, subarea, distance from the nearest feature (from the NIWA Seamounts database, with the bottom of Pegasus Canyon added), depth of the top of that feature, tow duration) selected the covariates longitude, tow duration, distance from the nearest feature, and month (Table 3). Tow duration was shorter when fishing on features, and accordingly if the tow duration covariate was removed it was replaced with distance from the nearest feature. Because of the shape of the stock area, the longitude cut-off (176.2° E) effectively divided the area into north and south. Larger fish were found closer to features, and on the northern hills fish were generally smaller during the summer. A 2 cm length difference between 33 and 35 cm standard length (SL) is equivalent to about 10 years of age.

Table 3: Covariates selected in the cluster analysis to partition Mid-East Coast orange roughy median length by tow. *n*, number of tows; SL, median standard length (cm); Under terminal node (cluster the number indicates the cluster number (see text).

Step	Node	<i>n</i>	SL (cm)	Terminal cluster
1	root	515	33.8	–
2	start_longitude < 176.2	92	30.1	4
4	tow_duration ≥ 0.245	81	29.6	5
5	tow_duration < 0.245	11	34.4	–
3	start_longitude ≥ 176.2	423	34.6	–
6	distance_feature ≥ 10.1	36	31.6	1
7	distance_feature < 10.1	387	34.8	–
8	month = 1, 2, 11	55	33.1	2
9	month = 3, 4, 5, 6, 7, 8, 10, 12	332	35.1	3

The cluster analysis was used to define five fishery strata: [1] ‘north’, east of 176° E and away from features; [2] ‘hills_summer’, < 10 km of a feature and Nov–Feb; [3] ‘hills_res’, < 10 km from a feature and Mar–Oct; [4] ‘south’, west of 176° E and ≥ 10 km from the bottom of Pegasus Canyon; [5] ‘south_feature’ < 10 km around the base of Pegasus Canyon (at the time of these analyses this area had not been identified and named). Using the cluster analysis to stratify the length compositions, and catch and effort data, there was an increase in the size of fish at Pegasus Canyon [2] at around 1998–99, coinciding with an increase in catch and increase (and then decline) in unstandardised catch-per-unit-effort (CPUE) (Figure 6). This suggested the fisheries before and after this time were not consistent. In the wider southern area [1] fish lengths decreased until around 2000 and then increased, with catch and unstandardised CPUE relatively stable. The northern strata had generally similar patterns [3–5], with the main hill fishery (not summer) [5] having slightly larger fish. There was a decline in fish size until about 2000–2010, and then an increase. The unstandardised CPUE initially declined substantially, and then was variable without persistent trend [3,4] or increased until about 2012–13 then decreased [5].

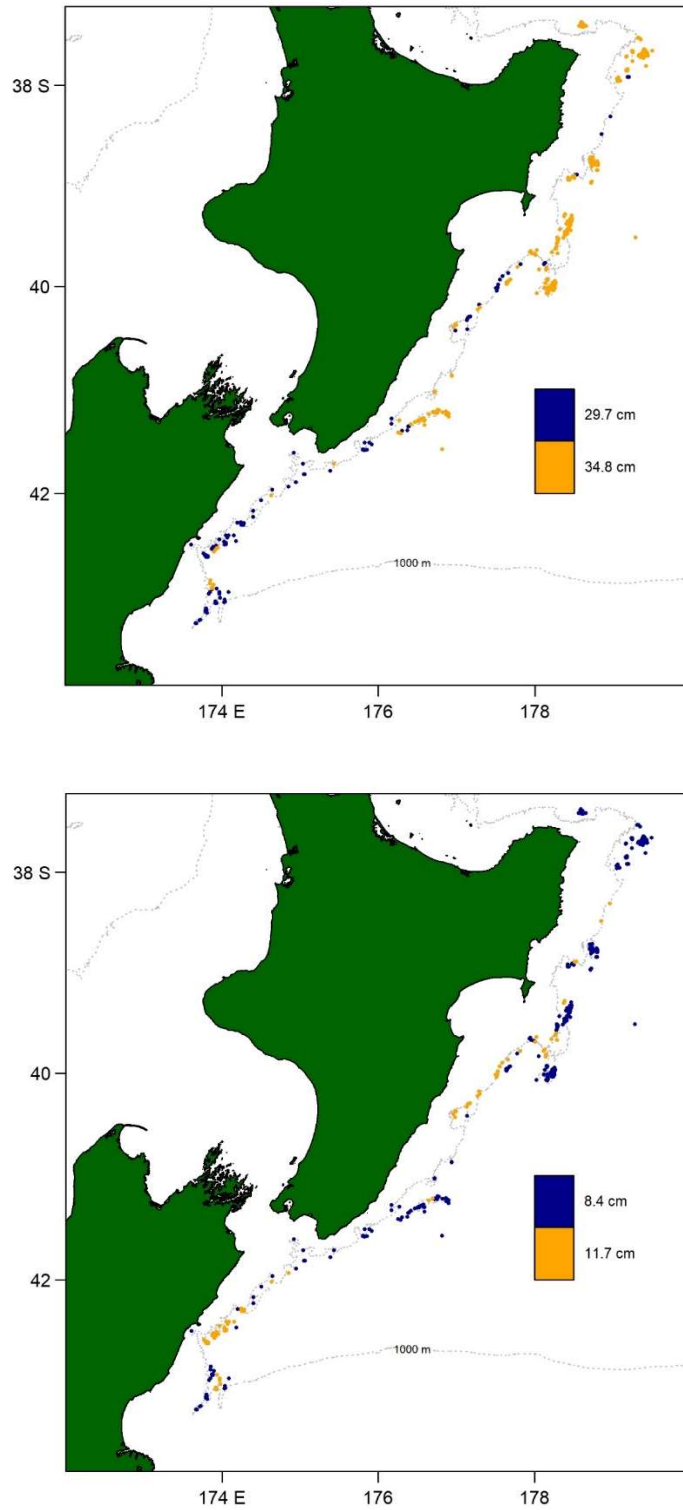


Figure 5: Spatial cells clustered by orange roughy median length from observer samples. Top panel, median length; bottom panel, difference in observed length based on 95% quantiles.

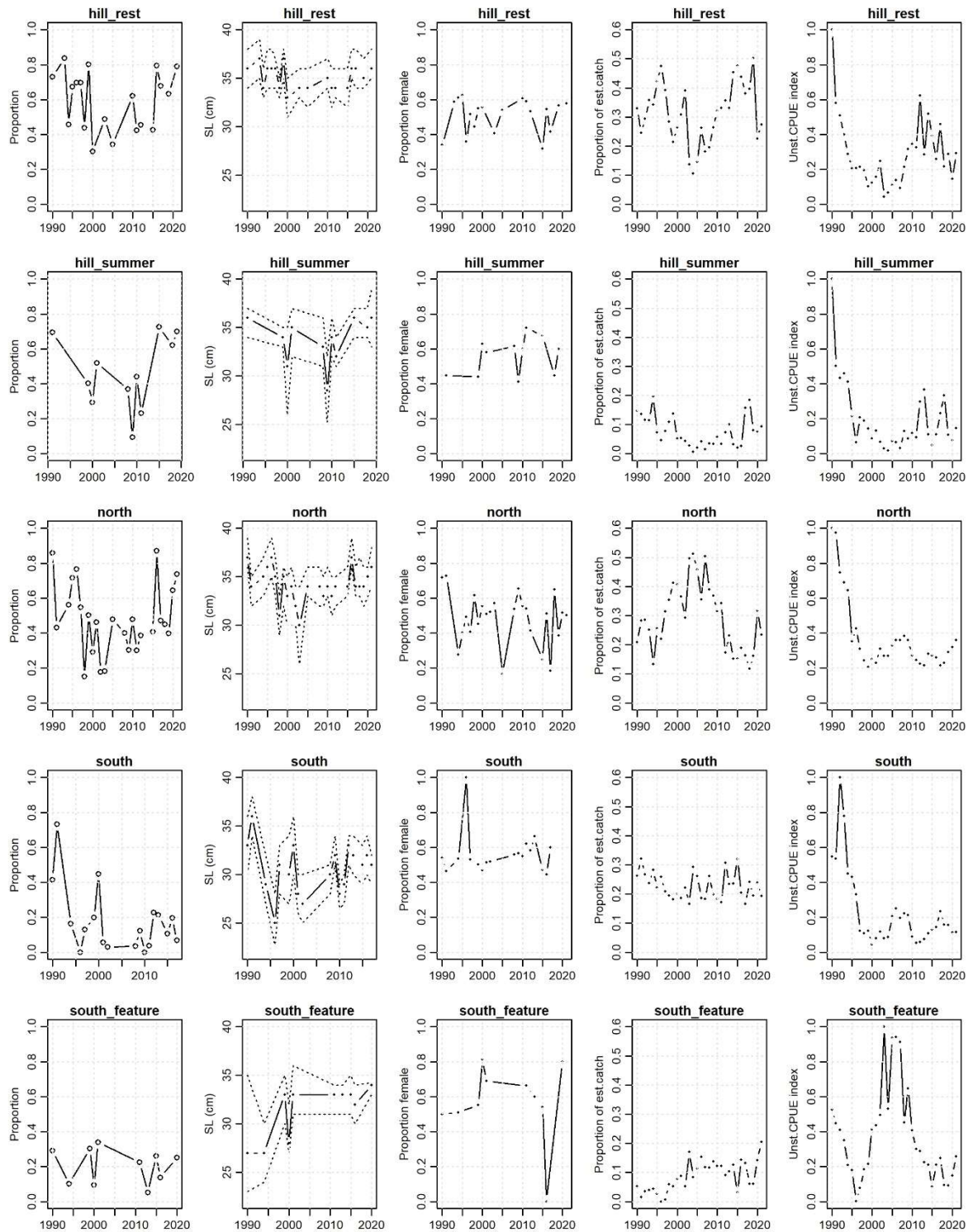


Figure 6: For each of the fishery strata, columns from left show: proportion of fish greater than 35 cm SL; median SL (points and solid line) and 90% CI (broken lines); proportion female; proportion of the Mid-East Coast estimated catch taken from the stratum; unstandardised CPUE (total catch / *n* tows). Fishing years shown as year ending (2020 means 2019–20).

The strata listed here were not the fisheries ultimately assumed in the stock assessment model (see Section 10.1). The ‘hill_rest’ fishery was relabelled as ‘Spawn’. Data were insufficient to assume Pegasus Canyon before 1997–98 to be a separate fishery, and it was combined with ‘south’, labelled as the ‘South’ fishery. The ‘south_feature’ fishery was kept separate after 1997–98 and labelled ‘Pegasus’.

There was also no material difference between ‘hills_summer’ and ‘north’, and they were combined in ‘North’.

4. CATCH HISTORY

The reported catch history for ORH 2A (Fisheries New Zealand 2021) was scaled for ORH 2A North (East Cape stock) and ORH 2A South (Mid-East Coast) using the estimated catch and effort data. Because catch and effort data were not available before 1989–90, the catches by fishery for this period were estimated using the ratio of catches by fishery averaged over 1989–90 to 1991–92. The reported catches were then increased by assumed catch overruns (Table 4). Catches for 2021–22, the year in which the assessment was conducted, were assumed to be the same as 2020–21 (Table 5).

The catch-over runs used in the current assessment (Table 4) were first implemented for the 1993 Mid-East Coast stock assessment, i.e., towards the end of the peak catch years of the fishery (Field et al., 1993). Prior to the 1993 assessment, an over-run of 30% was assumed throughout (Annala & Francis 1991). The Plenary suggests the origin of the catch over-run estimates was “examination of reports from the Scientific Observer Programme”, and states for the Mid-East Coast the over-runs were “not inconsistent with the estimated level of recent illegal catches and losses during fishing from burst bags, discards etc.” (Annala 1992, 1993).

Table 4: Assumed catch overruns (%) by QMA and year. -, no catches reported.

Year	2A			Year	2A		
	(North & South)	2B	3A		(North & South)	2B	3A
1981–82	–	30	–	1988–89	25	25	25
1982–83	–	30	30	1989–90	20	20	20
1983–84	50	30	30	1990–91	15	15	15
1984–85	50	30	30	1991–92	10	10	10
1985–86	50	30	30	1992–93	10	10	10
1986–87	40	30	30	1993–94	10	10	10
1987–88	30	30	30	1994–95 and subsequent years	5	5	5

Table 5: Mid-East Coast orange roughy catch history by fishery as used in the 2022 stock assessment model (units are tonnes).

Fishing year	Spawn	North	South	Pegasus	Fishing year	Spawn	North	South	Pegasus
1981–82	0	153	567	0	2002–03	201	446	181	101
1982–83	38	1 000	3 854	0	2003–04	250	370	223	86
1983–84	214	2 025	7 414	0	2004–05	356	677	371	141
1984–85	2 000	2 599	6 738	0	2005–06	518	497	346	157
1985–86	2 907	2 689	5 323	0	2006–07	409	661	368	144
1986–87	4 132	3 744	3 605	0	2007–08	459	586	411	128
1987–88	4 753	4 272	3 578	0	2008–09	460	597	329	158
1988–89	4 224	3 883	3 613	0	2009–10	512	563	289	163
1989–90	4 871	3 484	4 266	0	2010–11	533	549	238	238
1990–91	3 424	4 500	3 562	0	2011–12	591	240	339	154
1991–92	4 371	3 681	3 057	0	2012–13	374	290	195	124
1992–93	4 570	2 749	2 606	0	2013–14	499	138	217	163
1993–94	2 493	2 095	2 632	0	2014–15	229	69	143	39
1994–95	3 097	1 221	1 688	0	2015–16	275	73	120	75
1995–96	925	419	640	0	2016–17	157	197	143	79
1996–97	1 126	477	626	0	2017–18	128	199	117	21
1997–98	859	835	658	0	2018–19	269	105	120	23
1998–99	638	1 108	492	149	2019–20	132	132	118	41
1999–2000	1 154	809	488	192	2020–21	225	120	89	118
2000–01	592	723	366	158	2021–22	225	120	89	118
2001–02	637	452	383	83					

5. LENGTH AND AGE FREQUENCY DATA

5.1 Length compositions

Most years saw some sampling of orange roughy catches for the Mid-East Coast (27/32), but when partitioned by fishery the coverage was more irregular (Table 6). Catch-weighted length frequencies were estimated for all fisheries and years where at least 200 fish and 10 or more tows were sampled; this provided 20 year-fishery combinations. To provide greater temporal and fishery coverage the following years were aggregated to estimate a length frequency (LF): South fishery, years 2014–15 to 2016–17 (input as 2015–16); North fishery, Hill_summer fishery, 1998–99 to 200–01 (input as 1999–2000) and 2017–18 to 2018–19 (input as 2017–18); Pegasus fishery, 1998–99 to 2000–01 (input as 1999–2000) and 2010–11 to 2019–20 (input as 2015–16).

The estimated length frequencies are shown for all years in Appendix A. The length compositions used in the stock assessment are shown in the results (Section 10.5). These were twelve length frequencies between 1991 and 2018 for the North fishery, four between 1994 and 2016 for the South fishery, seven between 1990 and 2017 for the Spawn fishery, and two samples, in 2000 and 2016, for the Pegasus fishery.

Table 6: Number of orange roughy measured (number of tows sampled) by Ministry observers by fishery strata and fishing year. Shaded cells show years and areas used in the assessment model.

Fishing year	Spawn	North			Pegasus
		hill_summer	north	South	
1989–90	2 517 (32)	–	71 (1)	518 (6)	72 (1)
1990–91	–	894 (10)	81 (1)	86 (1)	–
1991–92	–	–	–	–	–
1992–93	250 (3)	–	–	–	–
1993–94	306 (3)	–	3 082 (20)	1 643 (20)	763 (9)
1994–95	4 838 (60)	–	1 126 (14)	–	–
1995–96	86 (1)	–	1 119 (12)	4 (1)	–
1996–97	458 (5)	–	1 161 (13)	1 311 (15)	–
1997–98	582 (7)	–	174 (2)	–	–
1998–99	999 (12)	748 (8)	752 (9)	772 (10)	274 (3)
1999–2000	1 781 (25)	187 (3)	1 245 (16)	253 (8)	86 (1)
2000–01	–	411 (5)	248 (3)	616 (8)	74 (1)
2001–02	–	–	480 (7)	102 (1)	–
2002–03	157 (2)	–	657 (8)	–	–
2003–04	–	–	–	–	–
2004–05	138 (2)	–	303 (3)	–	–
2005–06	–	–	–	–	–
2006–07	–	–	–	–	–
2007–08	–	602 (13)	1 353 (25)	175 (5)	–
2008–09	–	28 (4)	416 (9)	196 (4)	–
2009–10	254 (3)	615 (7)	615 (7)	20 (10)	–
2010–11	612 (8)	152 (3)	720 (12)	402 (5)	80 (1)
2011–12	1 584 (22)	–	736 (9)	84 (1)	–
2012–13	–	–	–	80 (1)	20 (1)
2013–14	–	–	–	–	–
2014–15	495 (6)	40 (1)	856 (12)	240 (3)	50 (1)
2015–16	832 (12)	–	283 (4)	328 (4)	43 (2)
2016–17	1 183 (17)	–	917 (19)	30 (1)	–
2017–18	–	140 (4)	20 (1)	–	–
2018–19	192 (6)	20 (1)	241 (6)	–	–
2019–20	–	–	165 (5)	–	20 (1)
2020–21	403 (5)	–	485 (6)	–	–
Total	17 667 (232)	3 837 (59)	17 306 (224)	6 860 (95)	1 482 (21)

Where there were two length frequencies in the model for the North fishery and the same period (1999–2000 and 2007–08), both were maintained, and became independent estimates of the same length structure.

For the Spawn fishery, the length frequency (seven LFs between 1990 and 2017), along with age frequency (AF) samples (five AFs from 1989–91, 2010, and 2017; Section 5.2), were assumed to represent spawning fish, with fishery selectivity set equal to estimated logistic maturity in the assessment model.

5.2 Age compositions

Orange roughly otoliths have been sampled by researchers and observers throughout the fishery, and aged for 1989–91, 1993, 2010, 2017, and 2021 (Table 7).

Table 7: Age data available to the Mid-East Coast orange roughly assessment from otoliths. Prop. female, proportion female of aged fish; *n*, number of aged fish; Strawberry, Strawberry Mountain.; T. survey, trawl survey; A. survey, acoustic biomass survey including trawls. T. survey, trawl survey; A. survey, acoustic survey; DWG, Deepwater Group.

Year	Origin	Age database tripcode	Dates	Location details	<i>n</i>	Prop. female
1989	Market; 1 vessel	89055	19/6/89	2 tows Strawberry	50	0.48
		89059	25/6/89	1 tow Strawberry	50	0.12
		89063	9/7/89	3 tows Strawberry	50	0.12
1990	Market; 4 vessels	90026	16/6/90	Strawberry	50	0.14
		90028	17/6/90	ORH2A	50	0.12
		90032	25/6/90	Strawberry	50	0.12
		90040	20/6/90	ORH2A	50	0.32
1991	Market; n/a ¹	91027	1991	n/a ¹	49	0.29
		91030	1991	n/a ¹	50	0.52
		91033	1991	n/a ¹	50	0.32
		91038	1991	n/a ¹	50	0.40
		91060	1991	n/a ¹	50	0.34
1993	T. survey; NIWA	tan9303	16/3/93 – 10/4/93	Wide-area stratified	501	0.57
2010	T. survey; NIWA	tan1003	20/3/10 – 10/4/10	Wide-area stratified	520	0.57
2010	Industry (DWG)	thh1002	5/6/10 – 18/6/10	Ritchie Bank ²	283 ³	0.48
Data new to this assessment						
2017	A. survey; CSIRO	aex1701	16/6/17 – 28/6/17	Sea Valley & Rock Garden	900	0.57
2021	A. survey; NIWA	tan2105	19/6/21 – 27/6/21	Sea Valley & Rock Garden	992	0.51
Data omitted from previous assessment						
2002 ⁴	Industry (DWG)	n/a	n/a	West of Ritchie Bank, Rock Garden	697 ⁵	n/a

1. Although age data were present, sample information could not be located on Fisheries New Zealand databases. Dunn (2005) reported these samples as coming from ‘Ritchie Bank’.
2. Largely North Hill and Strawberry Mountain area (not Sea Valley, Rock Garden).
3. Fourteen otolith samples were also taken from the East Cape Hills during this trip. It is unclear whether these were previously excluded.
4. Data not found in the Fisheries New Zealand *age* database.
5. 65 fish were excluded by Dunn (2005) because they were non-random samples, chosen because they were large fish.

Cordue (2014) confirmed the 1989–91 otoliths were re-read with the new protocol (Horn et al. 2016; these otoliths were re-read under project MID2010-01C), but the 2002 otoliths were not re-read which is why they were omitted from the previous assessment. Doonan et al. (2013) confirmed that the 1993 and 2010 trawl survey otoliths were read with the new protocol.

The sex ratio between samples was highly variable (Tables 8 & 9), potentially due to sampling error when sample sizes were small but also through suspected sex-specific differences in catchability during

spawning (Pankhurst 1988). Intermittent spawning is also thought to occur and, if synchronous within sex but different between sexes, could result in inter-annual changes in sex ratio (Tingley & Dunn 2018). Estimation of age frequencies scaled to a 50:50 sex ratio, to adjust for potentially biased sampling, was not done for the following reasons:

- The previous assessment did not re-scale any age compositions (a weak rationale on its own, but one that maintains consistency).
- There were often insufficient samples to permit estimating the age structure of both sexes adequately; for example, there were only 38 males aged 31–161 in 1989, 35 males aged 30–173 in 1990, and, despite higher levels of sampling, only 98 males aged 20–77 for Sea Valley in 2021, and 113 females aged 25–109 for Rock Garden in 2021.
- Samples from trawling during acoustic biomass surveys returned an overall sex ratio that was relatively close to 50:50 (57% and 51% female).
- The trawl surveys samples were spatially stratified, over 171 tows in 1993 and 118 in 2010 so, with relatively extensive sampling and being outside the spawning season, no correction for sex ratio would be expected.
- Rescaling by sex would admit age structure might be different by sex, which would be inconsistent with the assessment model assumption (Section 10.1).

Table 8: Summary of fishing locations and otolith samples for orange roughy from tripcode aex1701. The station order appears incorrect for the dates but is as recorded in the *age* database. Two fish were unsexed and have been excluded.

Region	Station	Date (June)	<i>n</i> (<i>n</i> female)	Median age (range)	Proportion Female
Sea Valley	1	16	74 (6)	47.0 (24–87)	0.08
	2,3	17	167 (102)	45.0 (22–104)	0.61
	10–13	21	233 (206)	52.0 (23–128)	0.88
	16	23	14 (11)	48.0 (30–69)	0.79
	15	24	19 (3)	47.0 (32–78)	0.16
	18	28	20 (9)	59.0 (36–89)	0.45
Total	–	16–28	523 (337)	49.0 (22–128)	0.64
Rock Garden	4–6	18	198 (94)	36.0 (19–87)	0.47
	7–9	20	152 (66)	41.0 (20–100)	0.43
	17	25	16 (7)	42.0 (33–68)	0.44
Total	–	18–25	366 (167)	38.0 (19–100)	0.46
Overall	–	16–28	889 (504)	44.0 (19–128)	0.57

Table 9: Summary of fishing locations and otolith samples for orange roughy from tripcode tan2105.

Region	Station	Date (June)	<i>n</i> (<i>n</i> female)	Median age (range)	Prop. Female
Sea Valley	7	22	116 (90)	43.0 (21–79)	0.78
	10	24	117 (52)	45.5 (20–86)	0.44
	13	26	257 (250)	43.0 (23–134)	0.97
Total	–	22–26	490 (392)	43.0 (20–134)	0.80
Rock Garden	3	19	97 (73)	40.0 (23–109)	0.75
	9	23	128 (7)	36.5 (23–60)	0.05
	11	25	112 (8)	36.0 (18–64)	0.07
	14	27	162 (25)	43.0 (20–81)	0.15
Total	–	19–27	499 (113)	39.0 (18–109)	0.23
North Hill	5	21	3 (3)	22.0 (18–52)	1.00
Overall	–	19–27	992 (508)	41.0 (18–134)	0.51

A pattern of behaviour where male fish arrive first at spawning grounds, are more active during spawning, and leave after females has been observed from tagging exercises in, for example, mackerel (Eltink 1987), flatfish (Solmundsson et al. 2003), and cod (Grabowski et al. 2014). For orange roughy, the 1989–91 samples from spawning aggregations were predominantly male (70%), and if males suffered a higher rate of mortality from the spawning fisheries due to lingering on spawning grounds then a reduction in males would be expected; in the 2017 and 2021 samples the proportion of males was reduced to about 46%. The sex ratio in ages recruited after the stock depletion might also be expected to skew from predominantly females back towards males as new recruits entered the fishery, which is suggested in the 2017 and 2021 samples (see ‘All samples’ in Figures 7 and 8; sex ratio should skew back towards males at an age around the age at recruitment (about 30) plus the number of years from the bottom of the fish down (about 1995) to the sample (2017, 2021) = 30 + 22,26 = about age 52,56). If correct, the sex ratio of the population would have changed over time, and rescaling all age frequencies to an equal sex ratio may be misleading. Testing the influence this might have on assessment results through simulation was beyond current project scope. Further consideration of sex and potentially age stratification in orange roughy spawning plumes requires more research.

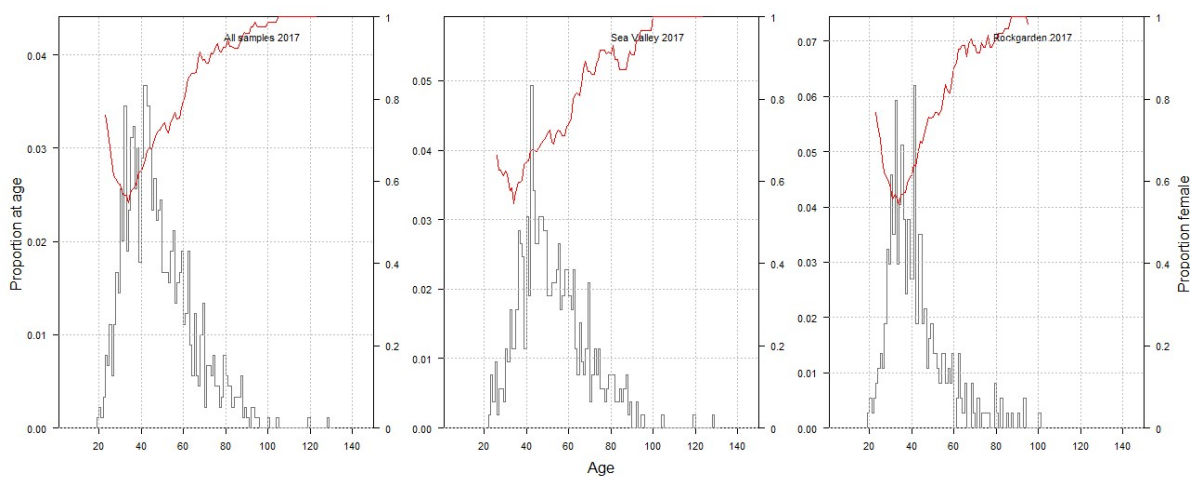


Figure 7: Unscaled age frequency distributions for orange roughy from trip aex1701. Red line indicates a moving-average estimate of the proportion female.

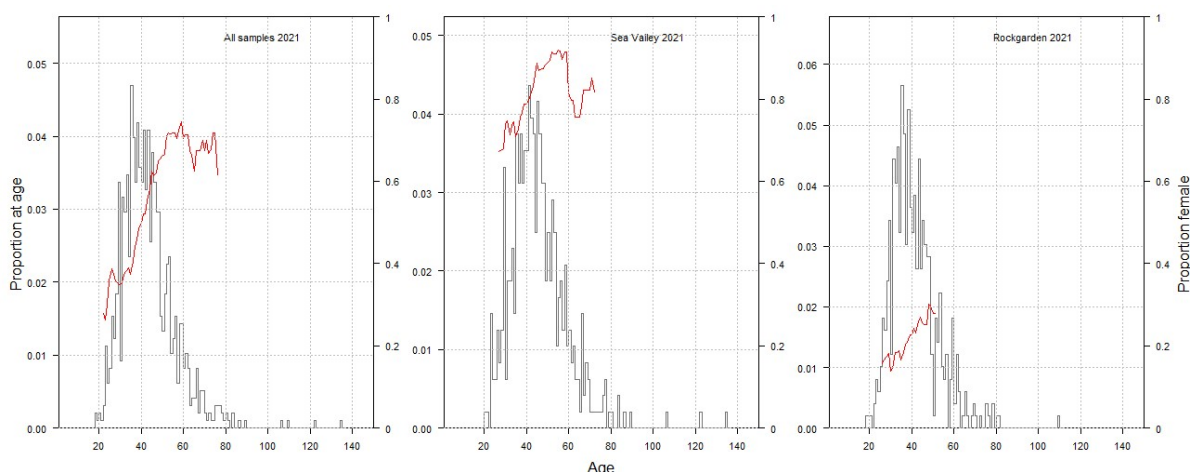


Figure 8: Unscaled age frequency distributions for orange roughy from trip tan2105. Red line indicates a moving-average of the proportion female.

The spawning age frequency from 2021 contained a greater proportion of younger fish and was inconsistent with the earlier samples and, in the assessment model, was ultimately fitted with its own logistic selectivity (Section 10.1).

In 2021, the majority of the fish sampled were spawning (Table 10), but a transition zone had not yet formed in 20% of the otoliths, and a gradual transition in growth zones with none or one of the transition zone criteria met, was counted in a further 24% of samples. The otolith samples were taken from spawning aggregations, and the absence of a recorded transition zone in 44% of the samples therefore suggests nearly half the orange roughy were new or relatively new recruits to the spawning biomass. Transition zones were identified in virtually all samples older than about 60 years (Figure 9). The length composition of 2017 and 2021 were very similar (Figure 10).

Table 10: Number of fish by sex and macroscopic maturity stage of aged orange roughy from the 2021 spawning aggregation survey trawl catches. Stages: 2, resting/maturing; 3, ripening; 4, ripe; 5, running-ripe; 6, partially spent; 7, spent.

	Macroscopic maturity stage					
	2	3	4	5	6	7
Male	2	18	22	207	129	99
Female	4	29	172	157	95	45

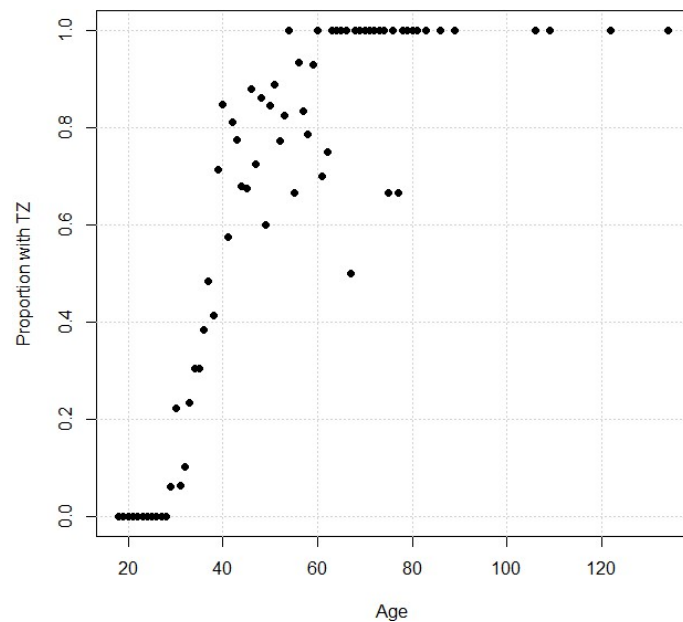


Figure 9: Proportion of orange roughy otolith samples from 2021 with a recorded transition zone (TZ).

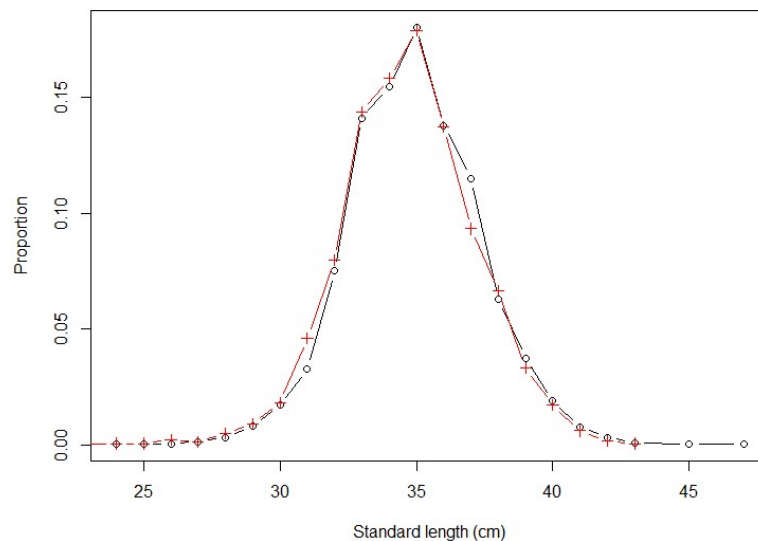


Figure 10: Orange roughy length frequency composition from tows on spawning grounds. Black open circles, 2021; red pluses, 2017.

A check was made on whether the age data new to this assessment had been collected in a random manner, as assumed (and requested). For both surveys the length distribution of the aged samples was not significantly different from the length distribution of the un-aged samples (Chi² test; $p > 0.8$) (Figure 11). This provides some evidence that the age samples were selected at random by length, and that scaling the age samples using an age-length key was not required.

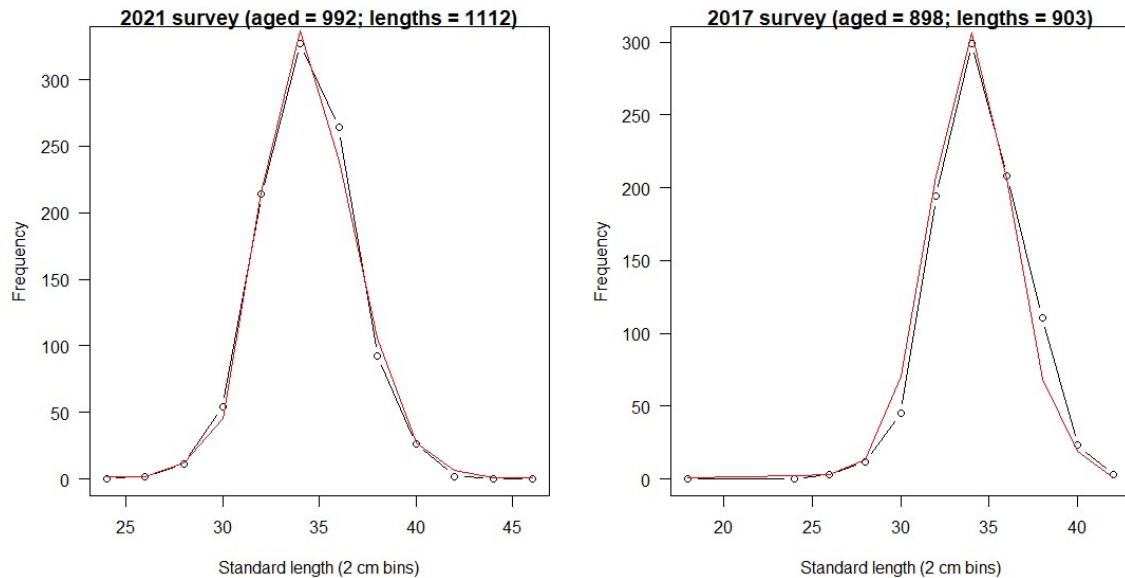


Figure 11: Length distribution of the aged samples (black line and points), and the un-aged samples (red line), from the trawl catches made during the 2017 and 2022 acoustic biomass surveys.

Catch-weighting of the age frequency samples from the 2017 and 2022 surveys shifted the age distribution slightly to the right, by 2–3 years (Figure 12). This could be explained if there was a similar number of otoliths taken from each catch, as is specified in the sampling design, but larger catches included a higher proportion of older fish.

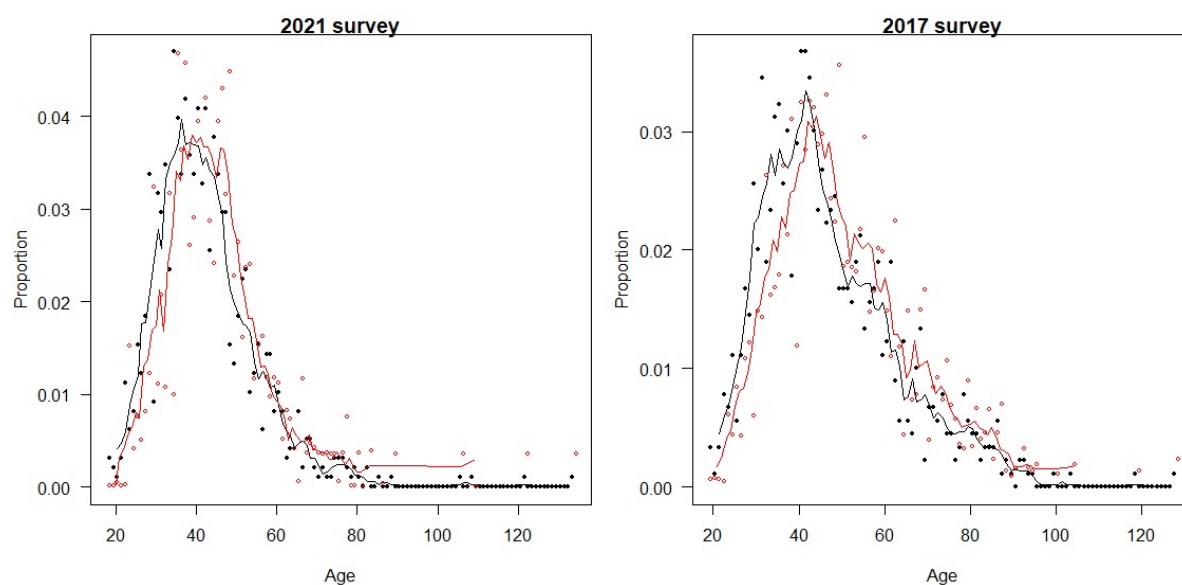


Figure 12: Age frequency distributions for orange roughy estimated for the 2022 and 2017 acoustic biomass survey trawl catches. Black points and line, unweighted; Red points and line, weighted by catch. Lines are estimated using a smoother (running average).

The age sample distributions used in the assessment models are shown in Figure 13. The trawl surveys caught a much higher proportion of young fish, and the trawl survey in 2010 had a greater proportion of younger fish than the survey in 1993. The proportion of older fish in samples from spawning aggregations appeared to have declined over time, being lowest in 2021.

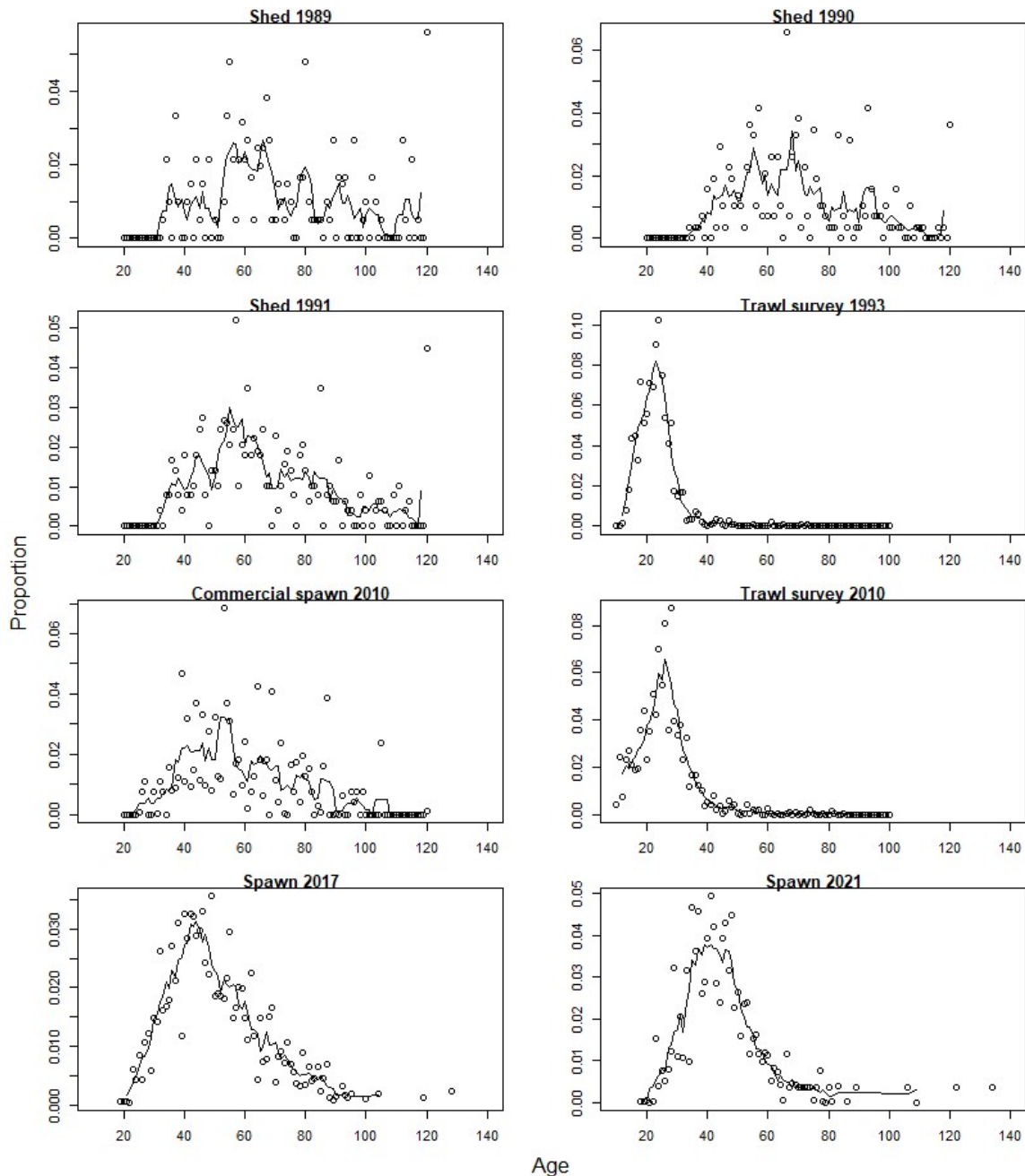


Figure 13: Proportions-at-age estimates (points) used in the assessment model. Lines are smoothers (moving average).

6. GROWTH

Orange roughy length at age did not follow the smooth asymptotic von Bertalanffy (VB) growth curve, but had relatively fast and roughly linear growth until about age 40, and then slow and roughly linear growth (a 'broken stick' form) (Figure 14). The von Bertalanffy parameters were estimated from all orange roughy age data for the Mid-East Coast held on the Fisheries New Zealand age database

(Table 11), but the stock assessment model used empirical length at age by sex estimated from a LOESS smoother (Figure 14). The resulting lengths at age were very similar for males and females up until an age of about 30, with females then growing larger, and then both sexes growing at a roughly similar rate (Figure 15).

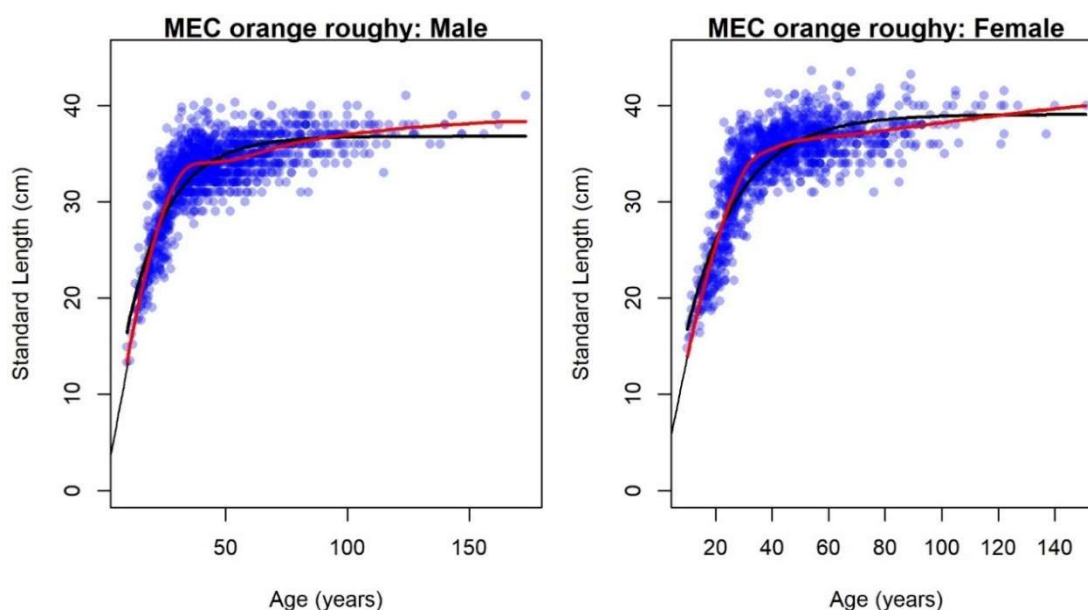


Figure 14: Orange roughy length at age (points) by sex, with the fitted von Bertalanffy growth curve (black line), and mean size at age from a LOESS smoother (red line). A thin black line links the estimated length from the LOESS smoother for the first observed age with a length of zero at age -0.5 years ($t_0 = -0.5$).

Table 11: Mid-East Coast orange roughy estimated parameters of the von Bertalanffy growth curve (95% CI), with t_0 fixed at -0.5. Length as standard length in cm.

Parameter	Male	Female
L_∞	36.78 (36.51–37.05)	39.05 (38.69–39.41)
K	0.059 (0.058–0.061)	0.053 (0.052–0.055)

The parameters of the length-weight conversion were estimated by sex using the same data set (Figure 16). The estimated weight-at-age values were similar to those provided by the previous parameters (Table 12).

Table 12: Length (cm) to weight (g) parameters (95% CI) for male and female orange roughy from the Mid-East Coast and mean weight (g) at lengths 10, 20, 30, and 40 cm. Previous model is Cordue (2014).

	Male	Female	Previous model (combined sex)
a	0.064 (0.062–0.067)	0.049 (0.047–0.050)	0.092
b	2.81 (2.79–2.82)	2.89 (2.88–2.90)	2.71
10 cm	41	38	47
20 cm	287	283	309
30 cm	896	914	927
40 cm	2 008	2 100	2 022

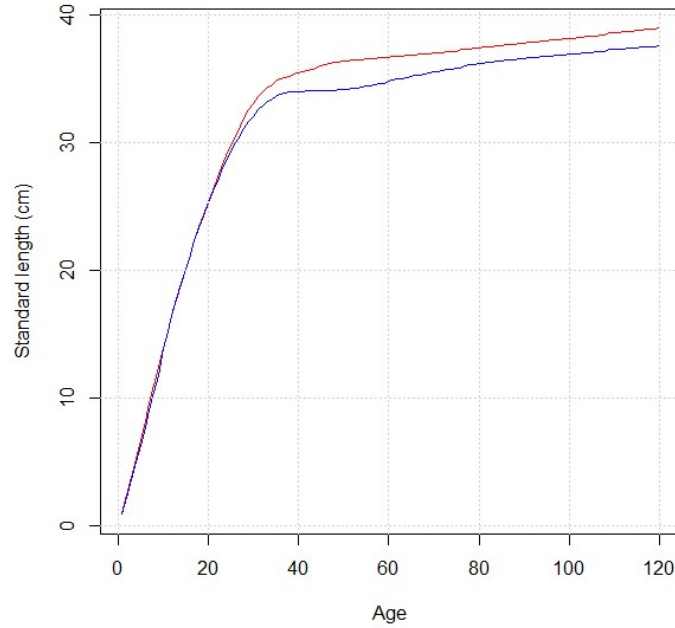


Figure 15: Orange roughy mean length at age from the LOESS smoother for males (blue line) and female (red line), as used in the stock assessment model.

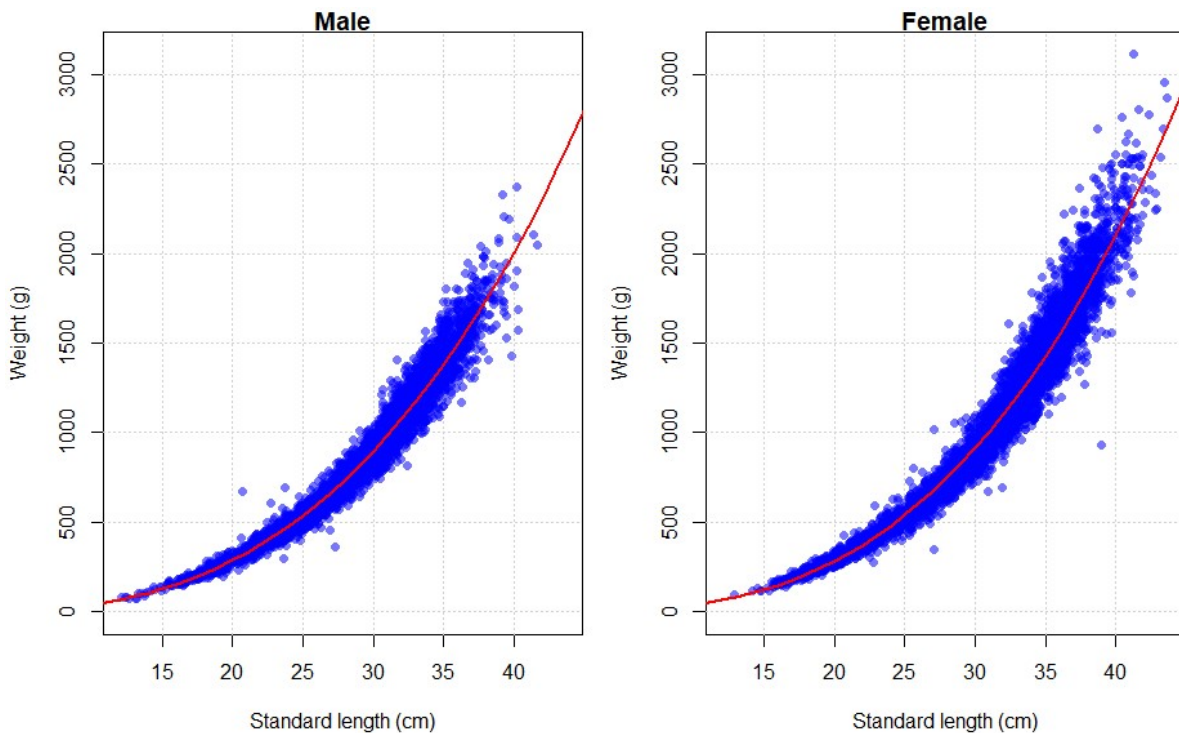


Figure 16: Orange roughy length-weight observations (points) and fitted model (line). Data shown in natural space, but model was fitted on log transformed data.

The samples of length at age suggested selectivity by length in samples from spawning aggregations, where few fish less than 30 cm were sampled regardless of age (Figure 17). Use of age data from commercial fisheries alone would give a correct estimate of age and length structure of the catch, but a biased estimate of population length at age. Samples from *Tangaroa* trawl surveys in 1993 and 2010, and trawling during acoustic surveys during 2017 and 2021, tended to be larger at age than those from commercial fishing in 2010 and market samples during 1989–91 (Figure 17). A temporal change in

length at age may be anticipated as fish density is reduced by fishing (compensatory density dependence), but the overlap in years sampled may also indicate there was a spatial influence on length at age.

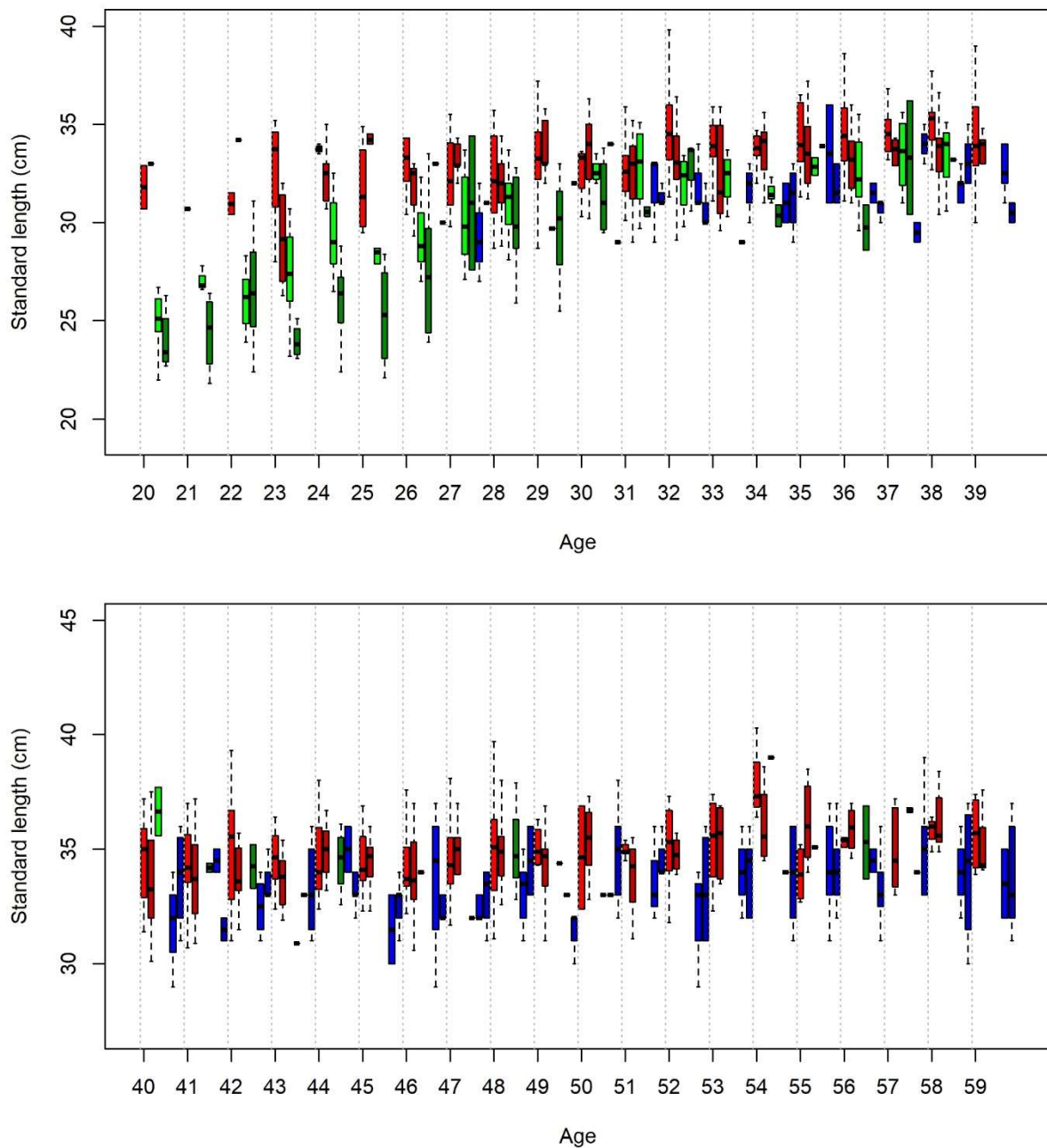


Figure 17: Boxplot of male orange roughy length at age for ages 20–39 (top panel) and 40–59 (bottom panel). For each age the boxes are samples (from left to right): lighter red, tan2105; darker red, aex1701; light green, tan1003; dark green, tan9303; lighter blue, thh1002; darker blue, market samples 1989–91 (see Table 7). Vertical broken lines separate the samples for each age. (Continued on next page)

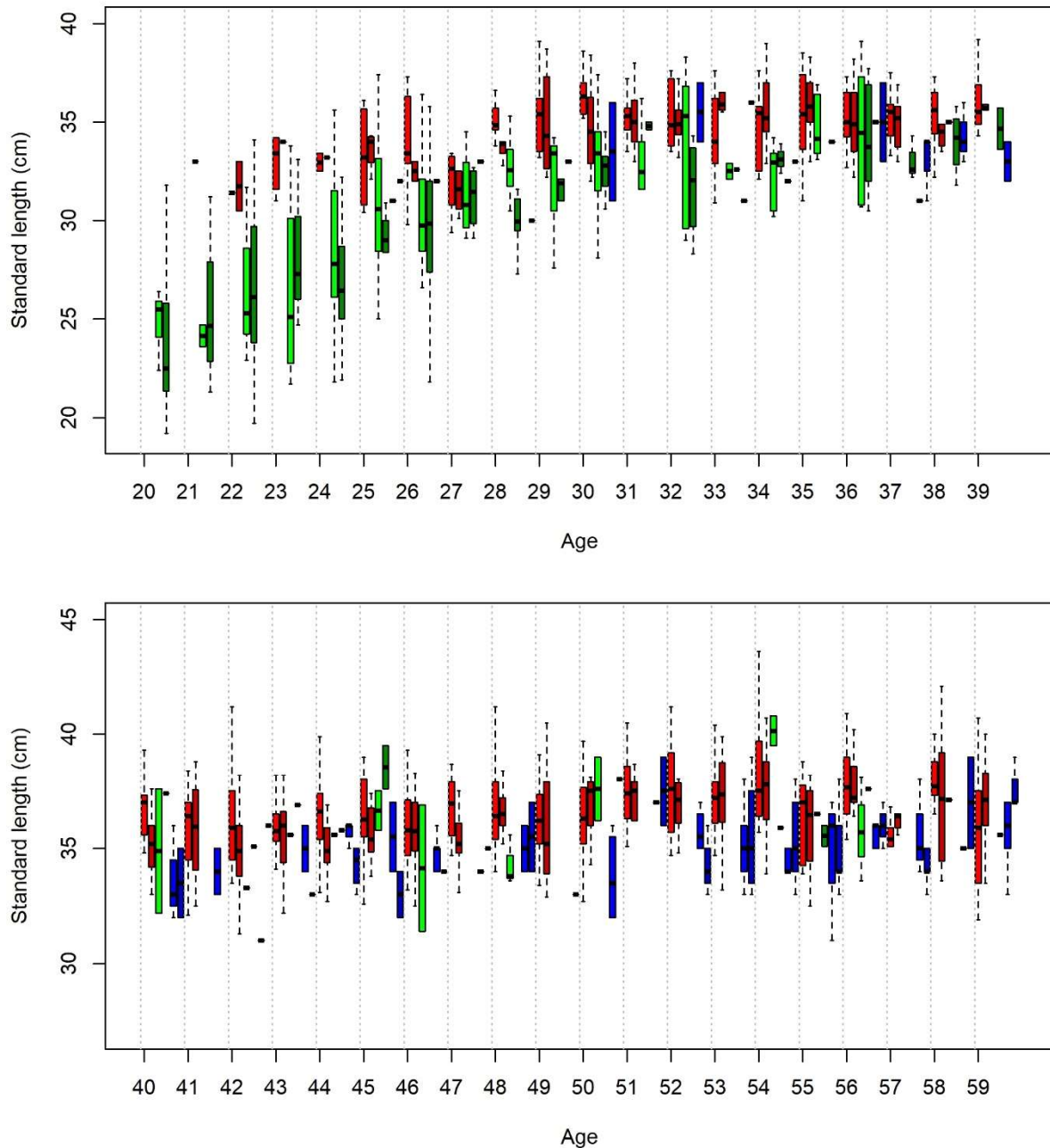


Figure 17: (cont.) Boxplot of female orange roughy length at age for ages 20–39 (top panel) and 40–59 (bottom panel). For each age the boxes are samples (from left to right): lighter red, tan2105; darker red, aex1701; light green, tan1003; dark green, tan9303; lighter blue, thh1002; darker blue, market samples 1989–91 (see Table 7). Vertical broken lines separate the samples for each age.

7. MATURATION

Orange roughy have been estimated to mature at about age 30, if maturity was estimated using the age reading and transition zone on otoliths (Horn et al. 2016). The assumption that the transition zone marked the change in energy allocated from somatic growth to gamete production is well established, but since the early 2010s it was no longer used in orange roughy stock assessments (Scott & Heikkonen 2012, Fisheries New Zealand 2021). Orange roughy assessments have instead assumed age at maturity was equal to the age of selectivity from samples of the spawning aggregations, which has resulted in an age at spawning being estimated to be older than age at maturity (Table 13). The previous assessment

for the Mid-East Coast did not assume age of maturity was equal to spawning selectivity, but maturity was instead estimated from proportions mature at age derived from samples taken during the April–May trawl surveys. In this estimate, females at macroscopic stage three or above (ripening) were assumed to be in spawning condition in June. It was found that the age of maturity estimated this way was inconsistent with the age of selectivity estimated for the spawning aggregations, which was found to be older (Cordue 2014). The proportions mature at age were ultimately excluded from the 2022 assessment because of the inconsistency of the proportions mature at age observations with the ages observed in the spawning aggregations.

Table 13: Estimates of orange roughy mean age at first maturity from otolith transition zones, and mean age at first spawning from stock assessments assuming spawning aggregation selectivity was equal to age at spawning. Estimates as reported by Fisheries New Zealand (2021), from running the CASAL files given by Cordue (2014), or from the 2022 assessment for the Mid-East Coast (see Section 10.5).

Stock	Maturity (years)	Spawning (years)	Difference (years)
Northwest Chatham Rise	28.5	37.0	8.5
East & South Chatham Rise	28.5	42.0	13.5
Mid-East Coast (Ritchie Bank)	31.5	55.0	23.5
Challenger Plateau	23.0	32.0	9.0
Puysegur	27.0	40.0	13.0

8. ACOUSTIC BIOMASS SURVEYS

The only accepted acoustic estimates of spawning biomass for MEC have come from surveys using towed dual-frequency acoustic systems (either an acoustic and optical system (AOS) mounted on the trawl headline, e.g., see Kloser et al. 2013, or a deep-towed system, e.g., Escobar-Flores & Ladroit in press). Four areas were visited in 2013, but the only substantial spawning plume was seen in Sea Valley. A similar search for spawning aggregations was completed in 2017 and 2021, when spawning plumes were found at both Sea Valley and Rock Garden. All valid snapshot estimates from 38 kHz were averaged to produce the biomass index (Table 14). No process error was added to the CVs.

An assumption used in the 2014 stock assessments, for acoustic estimates from spawning plumes, was that they collectively covered ‘most’ of the spawning biomass, where ‘most’ was taken to be 80%. The previous assessment for the Mid-East Coast stock reduced this to 60% (Cordue 2014). In 2022, ‘most’ was revised back to 80%, on the basis that the surveys had covered all the known main spawning grounds, with sensitivities done at 60% and 100%. The acoustic estimates were therefore fitted as relative biomass with an informed prior: lognormal (mean = 0.8, CV = 19%) for the base model (mean = 0.6 or 1.0 for sensitivities).

Acoustic survey data from 2017 and 2021 were new for the 2022 assessment. All acoustic biomass estimates were arithmetic means from accepted acoustic snapshots for each area, using estimates from the 38 kHz transducer mounted on the AOS. Areas from each survey area were combined to produce the final estimates for each survey (Table 15). Previous surveys from late 1980s, 2001, and 2003 had previously been examined and excluded.

9. RESEARCH TRAWL SURVEYS

No changes to the trawl survey data were made for the 2022 assessment. A time series of pre-spawning season stratified trawl surveys was conducted in March–April on RV *Tangaroa* in 1992–94 and 2010 (Grimes et al. 1994, 1996a, 1996b; Doonan & Dunn 2011). The survey design was intended to have random fishing locations within strata, but restricted areas available to trawling made the survey partially a fixed-station design. The 2010 survey was specifically designed, and earlier surveys re-analysed, to be comparable series (Doonan & Dunn 2011). In addition to the relative biomass indices (Table 16), the survey data were analysed to produce length frequencies from all years and age frequencies from 1993 and 2010 (Doonan et al. 2013).

The biomass indices were fitted as relative biomass with a double-normal selectivity on the immature fish, and a constant selectivity on the mature fish, with an uninformed prior on the proportionality constant (q). The length frequencies from 1992 and 1994 were fitted as multinomial, as were the age frequencies from 1993 and 2010. Length frequencies for 1993 and 2010 were not included, because they were used in the calculation of the age frequencies.

Table 14: Orange roughy acoustic biomass estimates. AOS estimates only (hull surveys excluded).

Year	Area	Snapshot	Date	Biomass (CV)	
2017	Sea Valley	OP34	20 June	4 714 (0.46)	
		OP37	20 June	7 362 (0.46)	
		OP45	23 June	2 469 (0.59)	
		OP47	23 June	2 844 (0.44)	
		OP62	27 June	2 660 (0.40)	
	Rock Garden	OP11	17 June	3 009 (0.16)	
		OP27	19 June	2 700 (0.23)	
		OP28	19 June	2 070 (0.18)	
		OP49	24 June	3 226 (0.45)	
		OP50	24 June	1 697 (0.30)	
	Tolaga	OP43	22 June	419 (0.51)	
	Total	–	–	6 969 (0.14)	
2021	Sea Valley	1	21 June	3 469 (0.53)	
		2	23 June	5 844 (0.56)	
		3	25 June	3 501 (0.52)	
		4	25 June	7 206 (0.23)	
	Rock Garden	1	18 June	1 246 (0.99)	
		2	22 June	723 (0.54)	
		3	24 June	1 359 (0.96)	
		4	26 June	1 953 (0.58)	
		Total	–	–	6 326 (0.20)

Table 15: Mid-East Coast orange roughy acoustic survey biomass indices and lognormal CVs used in the 2022 stock assessment.

Year	Acoustic index (t)	CV (%)
2013	4 225	20
2017	6 969	14
2021	6 326	20

Table 16: Mid-East Coast orange roughy trawl survey total biomass indices and lognormal CVs used in the 2022 stock assessment.

Year	Trawl index (t)	CV (%)
1992	20 838	29
1993	15 102	27
1994	12 780	14
2010	7 074	19

10. STOCK ASSESSMENT MODEL

The stock assessment was completed using CASAL (Bull et al. 2012). The base model run was also duplicated in Casal2 (CASAL2 Development Team 2021) and gave an almost identical maximum posterior density (MPD) result (minor difference in a few year class strengths).

10.1 Model assumptions

The model was sex- and age-structured (1–120 years with a plus group) with sex and maturity in the partition (i.e., fish were classified by age, sex, and as mature or immature). A single area and a single time step were used with four year-round fisheries defined by different selectivities (a ‘south’ fishery catching young fish (double-normal selectivity), a north’ fishery catching older fish (logistic selectivity), a ‘Pegasus’ fishery at the Pegasus Canyon since 1999 (logistic selectivity), and a ‘Spawn’ fishery focused on spawning aggregations (logistic selectivity) (Table 17). The spawning season was assumed to occur after 75% of the mortality and 100% of mature fish were assumed to spawn each year. The maturity ogive was assumed to be the same as the selectivity for the Spawn fishery and, therefore, described the age composition of the spawning fish (Spawning Stock Biomass).

The catch history was constructed by scaling the reported catches by the catch over-run percentages and partitioning using estimated catch and effort data. Catches for 2021–22 were assumed to be the same as 2020–21. Natural mortality was assumed to be fixed at 0.045 and the stock-recruitment relationship was assumed to follow a Beverton-Holt function with steepness of 0.75. Growth was modelled by sex and used empirical length at age. An ageing error of 0.1 was assumed. All fitted observations were unsexed.

Table 17: Mid-East Coast orange roughy assumed fisheries, selectivity assumptions, and observational data (see also Sections 3 & 4).

Fishery/survey	Selectivity	Informed by	Description
Spawn	Maturity (logistic)	AFs: 1989, 1990, 1991, 2010 ¹ , 2017 LFs: 1990, 1995, 1999, 2000, 2012, 2016, 2017	A hill fishery focused on the spawn.
	Maturity (logistic), or own logistic	2021	
North	Logistic	LFs: 1991, 1994, 1995, 1996, 1997, 2000, 2008, 2015, 2017, 2018	Northern areas away from the hills, where fish expected to be smaller. Catches and data from Hills_summer were included in the North fishery.
South	Double normal	LFs: 1994, 1997, 1999, 2016	Southern areas away from the hills, where fish expected to be smaller.
Pegasus	Pegasus (logistic)	LFs: 2000, 2016	At Pegasus Canyon, starting in 1998–99. Catches before 1998–99 included in South.
Trawl survey	Trawl (double normal on immature, constant on mature)	AFs: 1993, 2010 LFs: 1992, 1994	Research trawl survey.

1. Previously (2014 model) separate with its own double-normal selectivity.

10.2 Year class strengths

The youngest year class strength (YCS) seen in the previous assessment data was age 10 in the 2010 trawl survey, being the year class spawned in 2000. The previous model estimated year classes to 1996 (Cordue 2014). The youngest age seen in the current assessment data was age 18 in the 2021 acoustic survey, being spawned in 2003. However, the most recent year class strength estimated by the 2022 model was kept at 1996. This was because the most recently recruiting YCSs were rarely observed and their relative size poorly determined. The oldest age class to be observed at least once was 122 in 1989,

being the 1867 year class. The previous model started in 1881 (perhaps chosen as 100 years before the fishery started), with YCS estimation from 1881, which would be age 108 in 1989. Although there were data to allow YCS estimation to be started earlier, this was not done simply to avoid increasing the number of estimable parameters.

The previous assessment by Cordue (2014) estimated (MPD estimates) the most likely virgin spawning biomass (B_0) and stock status (B_{2014} as % B_0) to be 111 000 t and 6.5%, respectively. The Markov chain Monte Carlo (MCMC) estimates from the same model were 95 000 t (95% CI 87 000–104 000 t) and 14% (9–21%). The MPD and MCMC results were therefore quite different, with the MPD estimate outside the MCMC 95% CI. The likelihood profiles for the Cordue (2014) model suggested the upper bound to biomass was poorly informed, with most information coming from the length and age frequency distributions and ‘operational’ priors (YCS and B_0), and very little from the biomass indices (Figures 18 & 19). When a more conventional YCS prior was used, having a mean of one and lognormal CV of 0.8, the upper bound to biomass appeared better informed, and the biomass data had the greatest influence.

The mixing of the MCMC chain was very poor for YCS (Figure 20). From an MCMC profile (MCMCs run across a range of fixed B_0), it might be expected that the MCMC for the base model run include B_0 estimates having similar negative log-likelihood estimates to those of fixed B_0 . The quartiles of the base run (upper and lower horizontal lines within the base model ‘violin’) encompassed negative log-likelihoods that occurred in fixed B_0 estimates between 80 000–145 000 t. However, the 95% CI of B_0 from the base model MCMC were 85 000–104 000 t (Table 18). This suggested the MCMC chain for the base model may not have adequately sampled parameter combinations with higher B_0 values—in other words, mixing was not adequate. An MCMC profile showed that the upper bound to biomass was better informed in the MCMC than indicated by the MPD, because the increase in negative log-likelihood as B_0 increased between 110 000 t and 150 000 t was steeper at MCMC (about 26 units) than MPD (about 2.5 units) (Figure 21). The authors hypothesise that the flexibility in YCS estimates allowed by the ‘nearly uniform’ YCS prior, combined with relatively uninformative (noisy) age frequency data, allowed an MPD fit that was very unlikely within the overall parameter space (as sampled by MCMC). As such, the biomass information could be ‘neutered’ by the YCS, i.e., any pattern of YCS could be chosen with little or no likelihood penalty to fit the biomass observations. When YCS was more constrained, with a CV of 0.8, this could no longer happen, and the biomass data became more informative. This indicates the 2014 assessment was an over-determined (over-parametrised) model.

Therefore, the previous (Cordue 2014) assessment showed undesirable model behaviour, which is believed to be a consequence of the ‘nearly uniform’ prior on YCS. The undesirable behaviour was also misleading, because (1) the MPD was not representative when evaluating model fit, i.e., the previous model was considered acceptable on the basis of fits to data at the MPD (Cordue 2014), but that set of model parameters did not feature in the final model (MCMC) estimates; (2) the MPDs were not reliable for investigating the influence of model assumptions using likelihood profiles and MPD sensitivity runs; and (3), the MPD was not representative of the model actually used for advice.

Table 18: MCMC and MPD estimates of Mid-East Coast orange roughy B_0 and B_{2014} as % B_0 , for different lognormal priors having mean of one and σ^R of 0.2–1.2, and the ‘nearly uniform’ Cordue (2014) prior.

σ^R CV	B_0 (t)		% B_0	
	MCMC	MPD	MCMC	MPD
0.2	94 539 (88 713–101 682)	93 626	25 (20–31)	24.5
0.4	95 250 (88 142–103 480)	93 769	22 (16–28)	21.4
0.6	96 371 (88 417–106 288)	94 046	17 (13–24)	18.3
0.8	97 466 (88 204–109 076)	94 922	15 (10–21)	15.4
1.0	98 981 (89 514–109 239)	95 784	13 (8–18)	13.6
1.2	100 266 (89 981–111 448)	96 675	12 (8–17)	12.4
‘Nearly uniform’	94 993 (86 211–104 131)	111 126	15 (10–21)	6.5

When the ‘nearly uniform’ YCS prior was replaced with a lognormal prior having mean one and CV 0.8, the MPD was close to the mode of the MCMC estimates, unlike the ‘nearly uniform’ model (Table 18). The MCMC stock status estimated from a ‘nearly uniform’ prior was closest to that from a prior with mean one and CV of 0.8, and this was therefore chosen as the base case assumption for subsequent model runs.

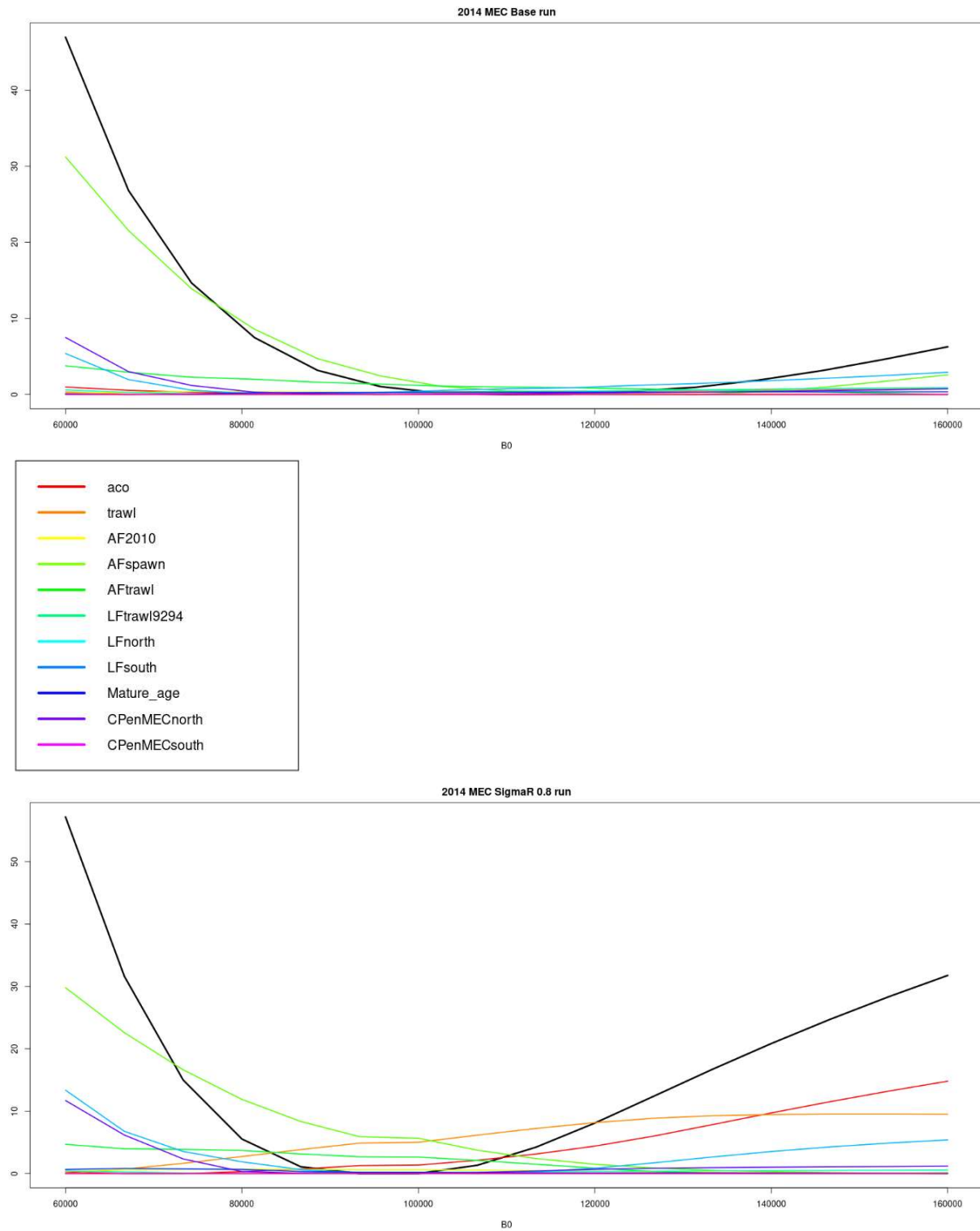


Figure 18: MPD B_0 likelihood profiles for for observational data sets when assuming the ‘nearly uniform’ YCS prior (top panel) and YCS prior with mean one and CV = 0.8 (bottom panel). All likelihoods scaled to have a minimum of zero. The black line shows the total likelihood.

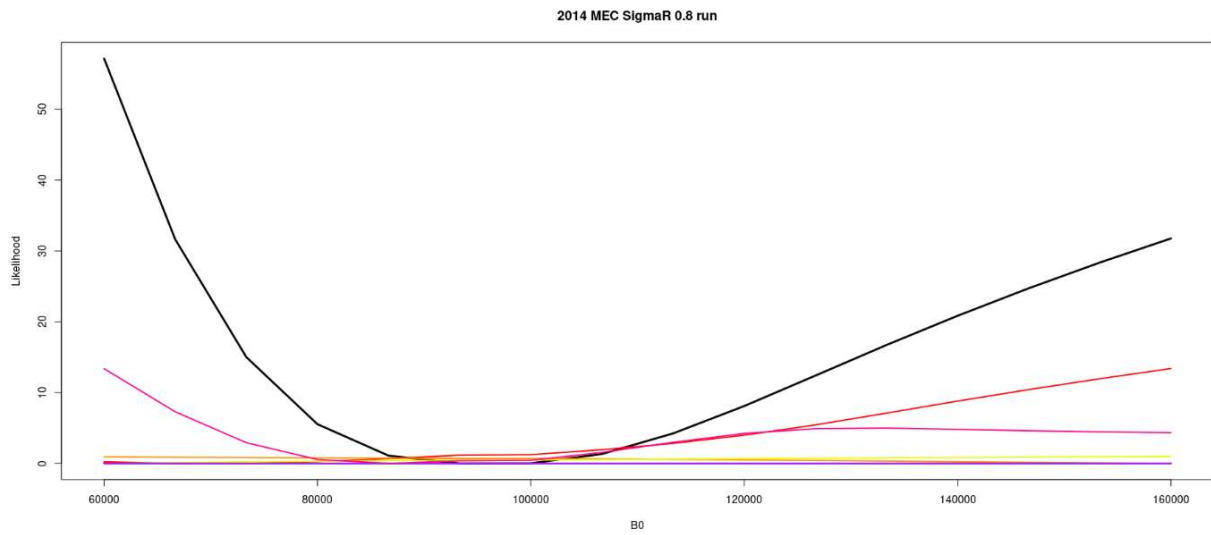
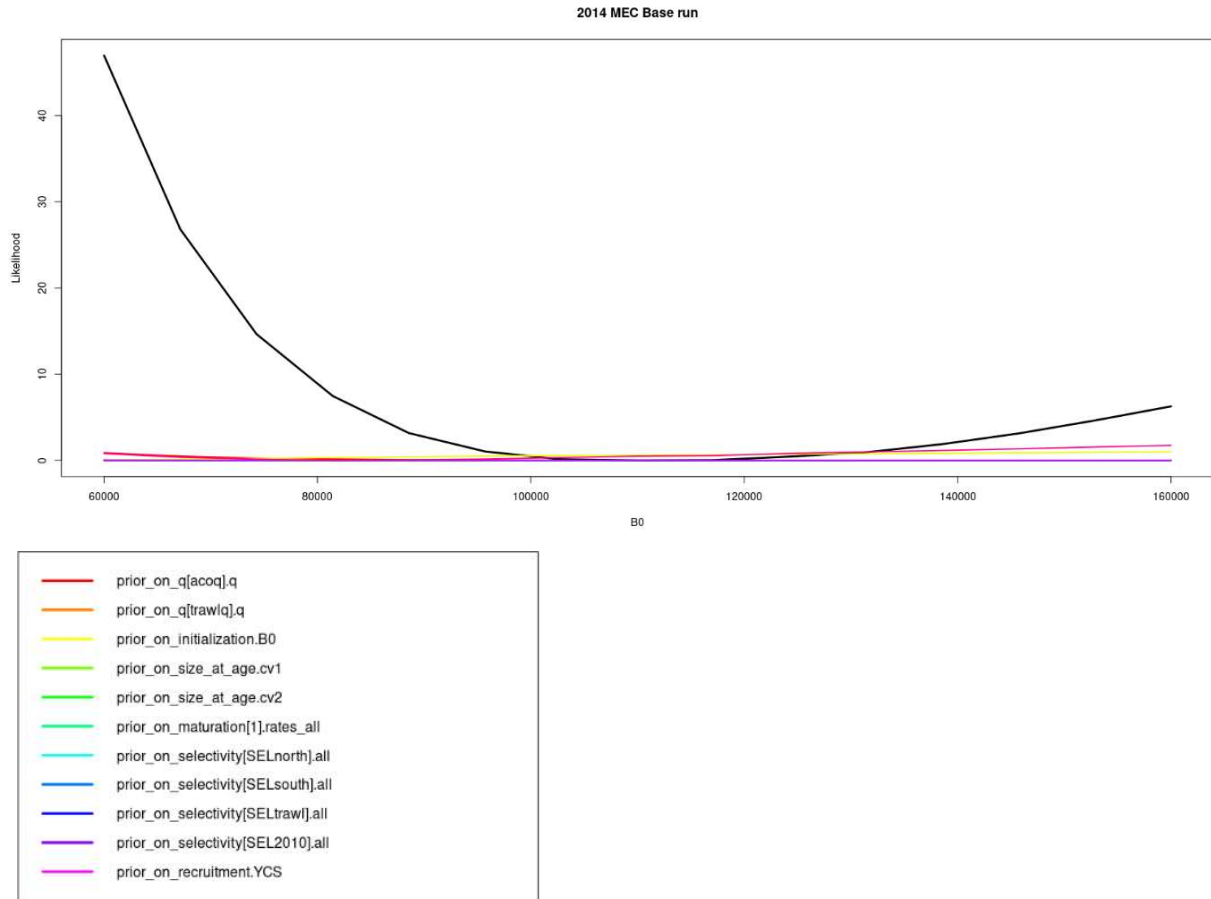


Figure 19: MPD B_0 likelihood profiles for for priors when assuming the ‘nearly uniform’ YCS prior (top panel) and YCS prior with mean one and CV = 0.8 (bottom panel). All likelihoods scaled to have a minimum of zero. The black line shows the total likelihood.

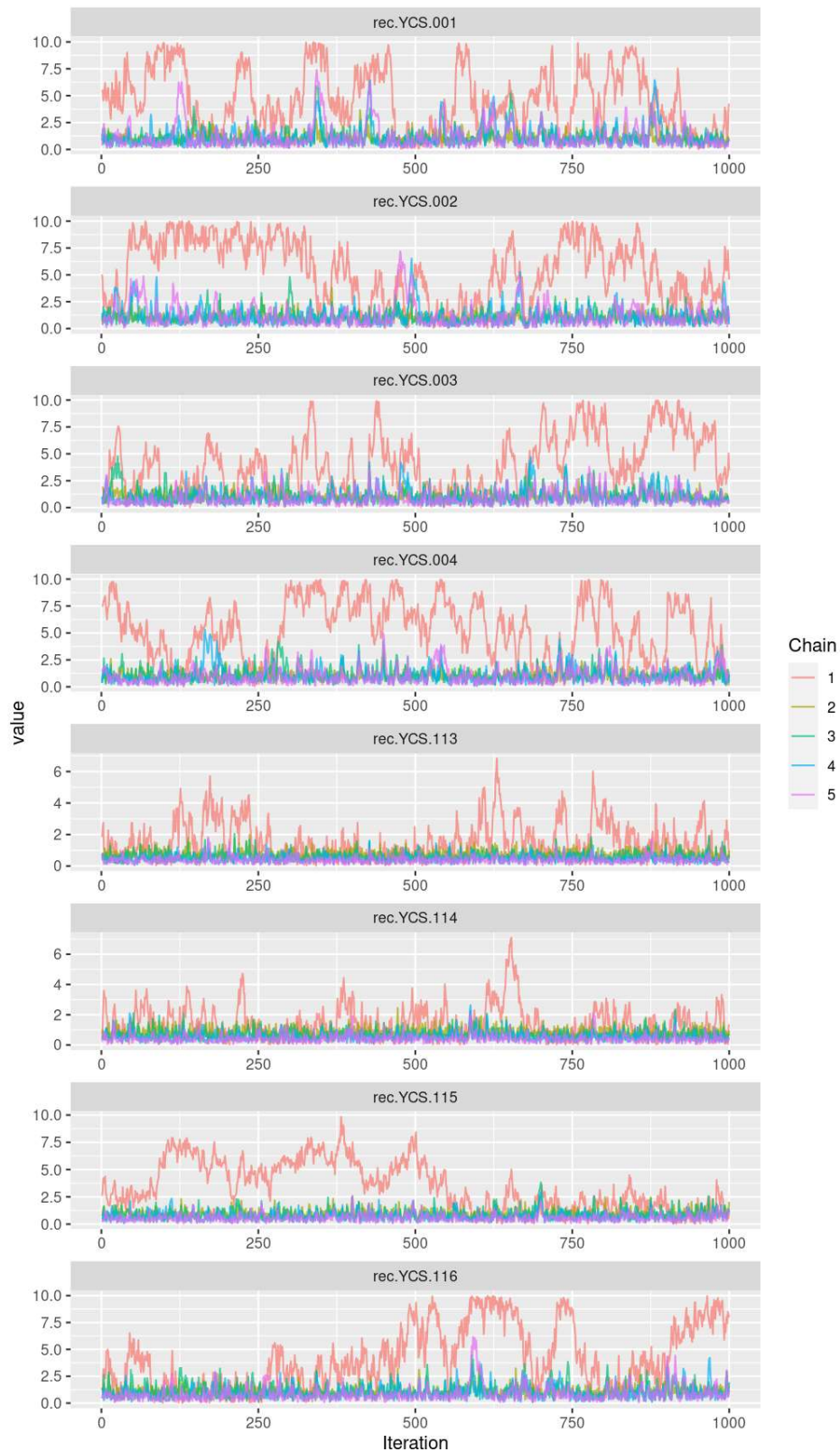


Figure 20: Examples of MCMC chains for YCS parameters, showing 1000 samples from chains of length 15 million after discarding the first 5 million and subsampling, for: Chain 1, the ‘nearly uniform’ YCS prior; Chains 2–5, YCS priors of mean one and CVs respectively 0.4, 0.6, 0.8, and 1.0. rec.YCS.001 is the first estimated YCS (the 1881 year class).

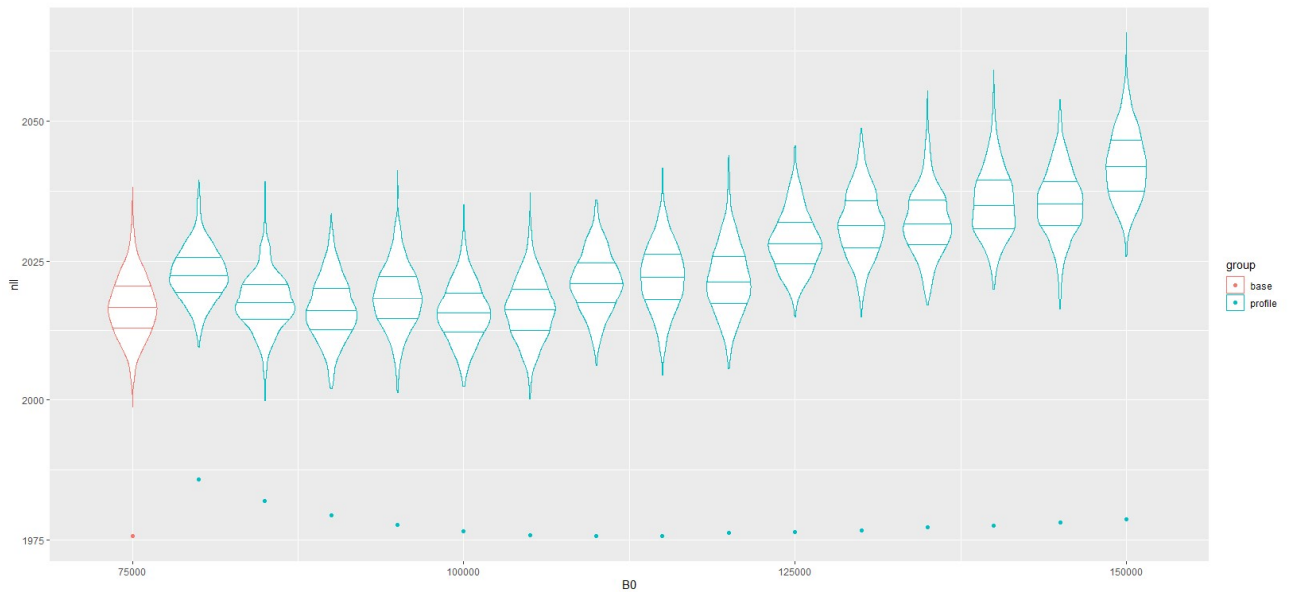


Figure 21: Likelihood profile from MCMC estimates at fixed and estimated B_0 values, for the 2014 assessment model. The density of negative log-likelihood estimates at each B_0 are shown as ‘violin’ plots. The run on the far left (in red) is plotted at 75 000 t for convenience and is that from the MCMC with estimated B_0 (i.e., the negative log-likelihood estimates from the 2014 base model MCMC), and the blue ‘violins’ show (from left to right) negative log-likelihood estimates for fixed B_0 values from 80 000 t to 150 000 t in 5 000 t increments. The dots at the bottom of the plot show the negative log-likelihood of the MPD, which had a minimum at $B_0 = 111\ 000$ t.

10.3 Updating the 2014 model

The 2014 model was updated to 2022 sequentially adding data and changing assumptions (Table 19). The ‘nearly uniform’ and CV=0.8 versions gave similar results for stock size and status at MCMC, as did the MPD for CV=0.8, but the MPD for the ‘nearly uniform’ gave a different stock status.

The stock status in 2014 changed very little when the model was updated with catches to 2022. The stock status in 2022 was higher than 2014 due to the biomass rebuild. None of the new data or assumptions had a large influence on stock size or status, with the change in B_0 being about 11% with the ‘nearly uniform’ YCS prior, and 10% with CV=0.8. The stock status increased when age frequencies were added but decreased with all other changes. The fully updated model had a higher stock size and lower stock status than the initial 2022 model (updated catch history only). The fits to the age frequencies tended to improve as the model was updated, with the best fit in the fully updated model. With an updated model, the fit to the trawl survey biomass index improved with CV=0.8, but not with ‘nearly uniform’. The fits to the northern fishery length frequencies got worse when the new growth model was added.

Table 19: The influence of new data and assumptions on the Mid-East Coast orange roughy stock assessment model assuming either the ‘nearly uniform’ YCS prior, or lognormal mean = 1 and CV = 0.8 YCS prior. Stock size (B_0) and status (% B_0 , for 2014 in ‘2014 base’ and thereafter for 2022) shown for MPD and MCMC median estimates (of 1000 samples from a chain of 15 M), with likelihood values shown for the 2014 base model runs, and for subsequent model runs the changes in likelihood (only comparable values are shown). Changes from the 2014 base model run are to (1) add catches to 2022, (2) add the two new acoustic surveys, (3) add the two new age frequencies (AFs), (4) update to the new growth model and add sex to the partition, (5) add the new fisheries and revised length frequencies (LFs). Data weighting was kept the same or similar throughout, with new observations set at initial values shown in Table 20.

‘Nearly uniform’	2014 base	+catches to 2022	+aco 2017 & 2021	+ AFs 2017 & 2021	+ growth	+ new fisheries & LFs
MCMC B_0	94 808	93 210	94 891	95 138	97 136	105 124
MCMC % B_0	14.9	21.1	20.4	21.7	20.7	18.5
MPD B_0	111 126	110 519	111 779	107 307	113 839	107 477
MPD % B_0	6.5	7.6 ¹	9.8	11.0	9.5	12.6
Likelihoods						
Trawl survey	-5.274	0.054	0.723	-0.009	0.188	0.321
Trawl AFs	150.675	0.167	0.412	-0.053	-1.179	-2.146
AFspawn	167.792	-0.115	0.076	–	–	–
North LF	245.305	0.031	-0.108	3.621	3.321	–
South LF	89.022	0.517	0.584	0.562	0.137	–
Aco. 2013	-1.605	0.009	–	–	–	–
Maturity@age	138.022	-0.170	-0.089	0.625	1.728	5.172
CV=0.8	2014 base	+catches to 2022	+aco 2017 & 2021	+ AFs 2017 & 2021	+ growth	+ new fisheries & LFs
MCMC B_0	97 473	97 001	95 993	97 151	100 588	107 425
MCMC % B_0	14.5	20.4	19.9	23.5	21.6	19.2
MPD B_0	94 922	94 308	93 814	95 557	98 071	103 794
MPD % B_0	15.4	22.1	21.3	24.9	23.1	23.6
Likelihoods						
Trawl survey	-0.308	-0.020	-1.373	-1.617	-0.997	-1.254
Trawl AFs	157.534	0.215	-1.559	-0.621	-1.771	-2.716
AFspawn	177.546	-0.041	0.003	–	–	–
North LF	243.894	0.045	4.571	4.023	6.553	–
South LF	89.568	0.015	0.626	0.148	-0.214	–
Aco. 2013	-0.308	0.008	–	–	–	–
Maturity@age	141.027	-0.219	0.557	1.437	1.110	5.908

1. Stock status in 2014 was 6.4% B_0 .

10.4 Data weighting

The composition data were all assumed to be multinomial, with effective sample sizes initially based upon Cordue (2014) for age frequencies, and the number of tows sampled for length frequencies, but these were down-weighted to ensure primacy of the biomass data (evaluated from MPD likelihood profiles), a more balanced patterns of residuals (meaning a similar variance of standardised residuals between data sets, with ideally 19/20 standardised residuals spread between +2 and -2 standard deviations), and sufficient weight on composition data to estimate selectivity parameters (weights on the Pegasus length frequencies were initially set so low that the selectivity became poorly determined). The biomass data were considered insufficient to apply the iterative approach of Francis (2011). The final data weighting was therefore determined during initial MPD and MCMC model run, and then fixed throughout (Table 20). Final effective samples sizes for the Spawn fishery age frequencies were between 13 and 25 (mean 20), the trawl survey age frequencies were 20, and the length frequencies were between 1 and 10 (mean 3.2).

Table 20: Lognormal process error for acoustic and trawl surveys, and multinomial effective sample size for the length and age composition data sets (relevant fishery in parentheses). Init., initial value in the 2022 model, which was the same as given by Cordue (2014) for those in bold, was chosen to be comparable to Cordue (2014), or was the number of tows sampled. Final, the final value assumed. Cordue (2014) effective sample sizes for length frequencies varied between 8 and 73 for the North fishery (mean 25), and between 3 and 13 for the South fishery (mean 8).

Data set	Years	Init.	Final	Data set	Years	Init.	Final
Acoustic (Spawn)	2013, 2017, 2021	0	0	LFhills_summer (North)	1991	10	1.25
Trawl survey	1993, 1994, 1995, 2010	0	0.2		2000	16	2
AFspawn (Spawn)	1989	26	13		2008	13	1.6
	1990	35	17.5		2018	5	0.6
	1991	41	20.5	Pegasus (Pegasus)	2000	5	5
	2017	50	25		2016	6	6
	2021	50	25	LFtrawl_survey	1992, 1994	62	7.75
AF2010 (Spawn)	2010	40	20	LFsouth (South)	1994	20	10
AFtrawl_survey	1993, 2010	200	20		1997	15	7.5
Prop. Mature	1993, 2010	10	–*		1999	10	5
LFnorth (North)	1994	20	2.5		2016	8	4
	1995	14	1.75	LFhills_main (Spawn)	1990	32	4
	1996	12	1.5		1995	60	7.5
	1997	13	1.625		1999	12	1.5
	2000	16	2		2000	25	3.125
	2008	21	2.625		2012	22	2.75
	2015	12	1.5		2016	12	1.5
	2017	19	2.375		2017	17	2.125

* When included in MPD runs had a binomial likelihood with random sample size of 5.

10.5 Base model

This section describes the base model run and fits to observational data as accepted by the Fisheries New Zealand Deepwater Working Group and Plenary in May 2022. In the base model, the main parameters estimated were: virgin spawning stock biomass (B_0), the maturity ogive, three fishery selectivities (North, South, Pegasus), the trawl survey selectivities (immature and mature), the 2001 age frequency selectivity, and year class strengths from 1881 to 1996 (with the Haist parameterisation and lognormal priors with $CV=0.8$). Additional estimated parameters were the CV of the length-at-age parameters and the proportionality constants (qs) for the trawl survey time series and the acoustic biomass estimates. In the base model, the mean of the acoustic q prior was 0.8 and natural mortality (M) was fixed at 0.045 yr^{-1} . There were numerous MPD sensitivity runs and three main sensitivities were selected to demonstrate key uncertainties by the working group: $M = 0.035 \text{ yr}^{-1}$; mean acoustics q prior = 0.6; and mean acoustics q prior = 1.0. The latter assumed all the spawning biomass was observed by the acoustic surveys. Further sensitivities are presented in section 10.6.

The MPD fits to data were similar to the MCMC implied fits. The fits to the biomass indices were acceptable, although the decline in the trawl surveys could not be fitted well (Figure 22).

The spawning season age frequencies were noisy but the general shape was fitted well (Figure 23). The fit to the trawl survey age frequencies was good (Figure 23). The MPD fits to the commercial length frequencies were adequate (Figure 24). They could never be very good because the length frequencies showed substantial year-to-year variability. The spawning (maturity) ogive was estimated with an A_{50} of 55.2 years and A_{1095} of 18.1 years.

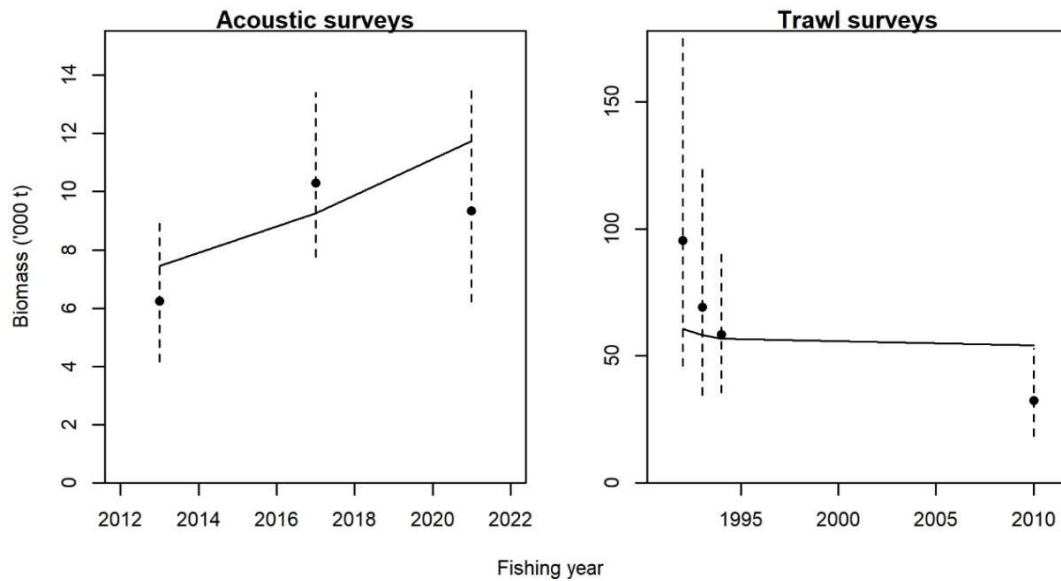


Figure 22: Mid-East Coast orange roughy MPD fit to biomass indices for the base model run: left: acoustic spawning biomass indices (estimated q of 0.68); right: RV *Tangaroa* trawl survey indices. Vertical broken lines are 95% CIs.

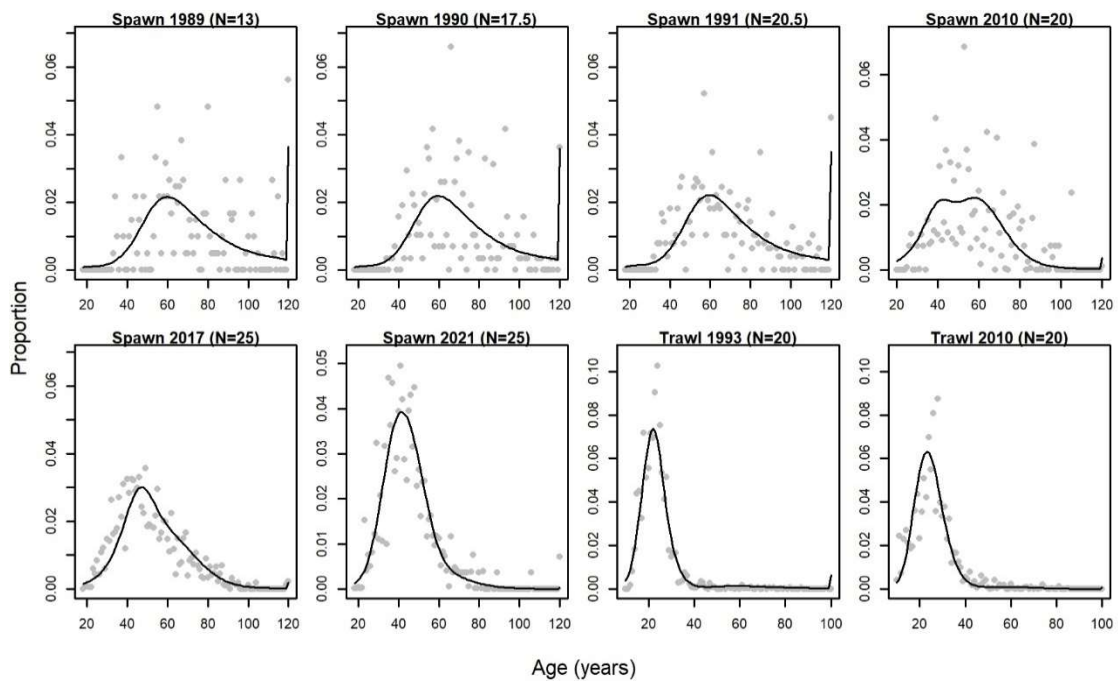


Figure 23: Mid-East Coast orange roughy MPD fits of the base model run to age frequencies (N is the assumed effective sample size). Observations are grey points; model predictions are the black lines.

The spawning season age frequency for 2021 had a greater proportion of younger fish, with an A_{50} of 35.6 years and A_{1095} of 11.0 years. One hypothesis to explain the relatively large difference between maturity and spawning (estimated selectivity for the spawning fishery) was skipped spawning, where younger mature fish were spawning less often (see Discussion Section 13).

The relatively high proportion of young mature fish observed for 2021 could have been sample bias, or a due to a temporal change in the prevalence of skipped spawning. The working group could not resolve the most likely hypothesis (although sample bias probably received more support), but agreed to treat the acoustic biomass estimate as part of a consistent series fitted with the same selectivity (spawning ogive), but the age frequency from 2021 was considered as different and fitted with its own logistic selectivity; this meant the difference in relative abundance of younger fish in 2021 had no influence on the fit to the other age frequencies.

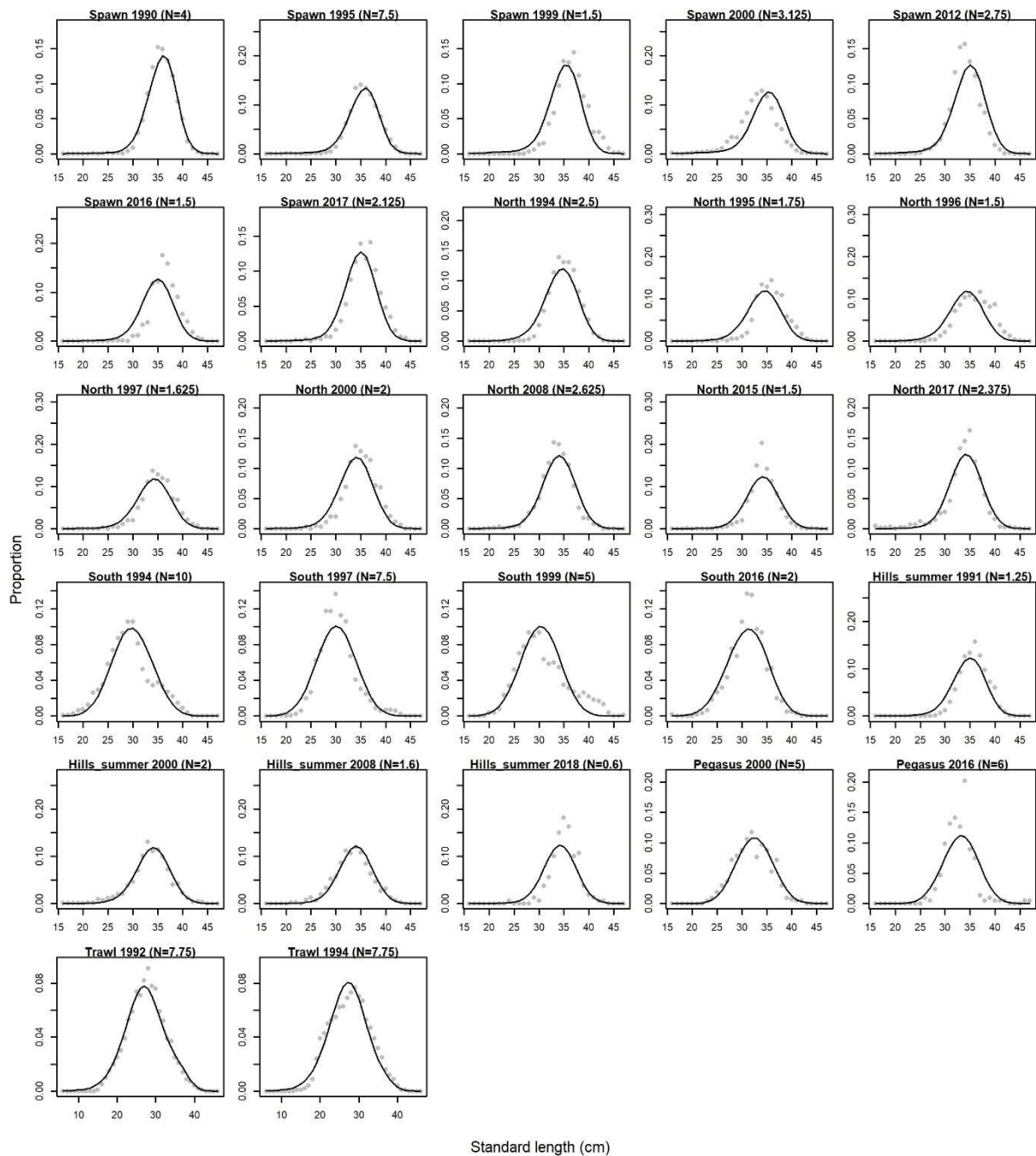


Figure 24: Mid-East Coast orange roughy base model MPD fits to length frequencies (N is the assumed effective sample size). Observations are grey points; model predictions are the black lines.

10.6 Sensitivity runs

MPD model runs showed that the results were relatively insensitive to changes in the growth model, alternative CVs on the year class strength priors, changes to the weight given to the length frequencies, and alternative selectivity models for the trawl survey data (Table 21).

Table 21: Summary of selected MPD sensitivity runs for the Mid-East Coast orange roughy stock assessment model.

Model run	Description	B_0	B_{2022} as $\%B_0$	Change in comparable observation likelihoods and acoustic q prior	Comment
1	Base	55 460	22.2	–	–
2	acoQ0.6	58 650	25.9	-0.55	–
3	acoQ1.0	53 490	19.6	+0.56	–
4	Mature	91 170	12.1	+8.21	Parameters at bounds. Same LFs retained in base and sensitivity runs.
5	Two fisheries	70 250	25.3	+5.39	Analogous to the 2014 assessment.
6	Double-normal plateau	55 420	22.2	-0.26	Worse MCMC diagnostics, with no change to biomass and status estimates.
7	EFS1	55 150	22.4	-0.06	–
8	NoLFs	54 870	22.5	-0.01	YCS trend unaffected.
9	Double aco2013	57 390	24.5	-0.42	Arbitrary doubling of only 2013 biomass.
10	2021separate	60 350	25.3	+1.00	Worse fit despite greater df.
11	YCS cv0.6	55 490	22.5	+0.90	–
12	YCS cv1.1	54 440	21.5	-1.11	–
13	L@A cv0.6	56 030	22.1	+1.54	Less consistent with observed data.
14	L@A cv0.8	55 810	22.1	+0.39	Less consistent with observed data.
15	Growth	55 750	21.7	+0.46	Little difference in outcome.
16	High M	39 990	33.6	+4.75	Parameters at bounds, with non-zero catch penalty.
17	Low M	70 690	16.4	-0.04	–

When the trawl survey age compositions were fitted with a double-normal ogive, as in the 2014 assessment, there was a ‘U-shaped’ pattern in residuals (Figure 25). Fitting the immature with a double-normal selectivity and mature with a constant selectivity (i.e., using the partition), which added one parameter to the model, resolved the residual pattern well. An alternative selectivity ogive, a double-normal plateau, was more easily interpreted and produced a similar fit, but it added another parameter, the MCMC diagnostics were poor, and the stock size and status estimates were the same (run 6 in Table 21). As a result, the double-normal and constant selectivity assumption was preferred for the base case.

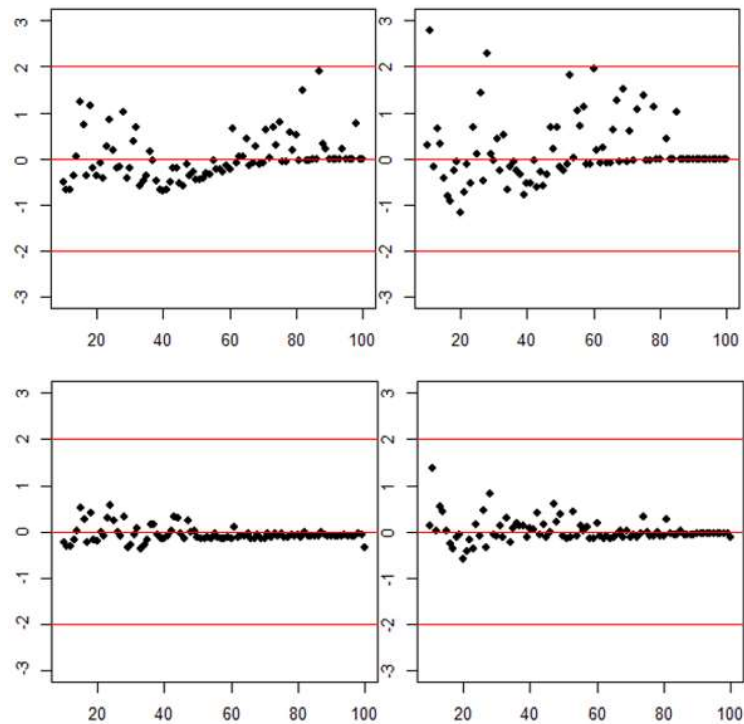


Figure 25: Pearson residuals for the fit of the trawl survey proportions at age for 1993 (left panels) and 2010 (right panels). Top panels, fitted with a double-normal ogive; Bottom panels, fitted with a double-normal ogive on immature, and a constant selectivity on mature.

When the proportions mature-at-age data were included in the model, the spawning ogive A_{50} was estimated to be around age 30–35, and there was a conflict between those data and the age samples from the spawning aggregations (also noted by Cordue 2014). This was visible as negative residuals in the age compositions at about age 40, particularly for the market sample data (1989–91) (Figure 26). When the proportions mature-at-age data were excluded the MPD fits were improved, but the fit to the 2021 age frequency was poor (Figure 27), because this sample included a greater proportion of young fish. This difference was found to be too large to be explained by ageing bias, e.g., from difficulties identifying transition zones (Horn et al. 2016). When the age data for 1989–91, 2010, and 2017 were fitted using a single logistic selectivity ogive, and the 2021 observation was fitted with a separate logistic selectivity ogive, the residuals were acceptable (Figure 26).

A sensitivity run was completed that ‘reversed’ the spawning ogive assumption, with the proportions mature at age reinstated and the logistic spawning ogive estimated from those data and the 2021 age frequency (these data sets appeared relatively consistent); the 1989–91, 2010, and 2017 age frequencies were then fitted independently of the spawning ogive. This run estimated several parameters at bounds, a pattern of YCS similar to the 2014 assessment (Cordue 2014) was estimated, and the fit to observed data was the poorest obtained (Table 21: ‘Mature’, run 4). The degrading of fit was largely to the acoustic surveys (+0.47 likelihood units), acoustic prior (+0.99), the trawl survey biomass index (+2.2), and the 2021 age frequency (+1.75); the fit to the other age frequencies improved slightly (-0.47). The spawning ogive in the ‘mature’ run had a A_{50} of 34 years, and A_{1095} of 9.1 years.

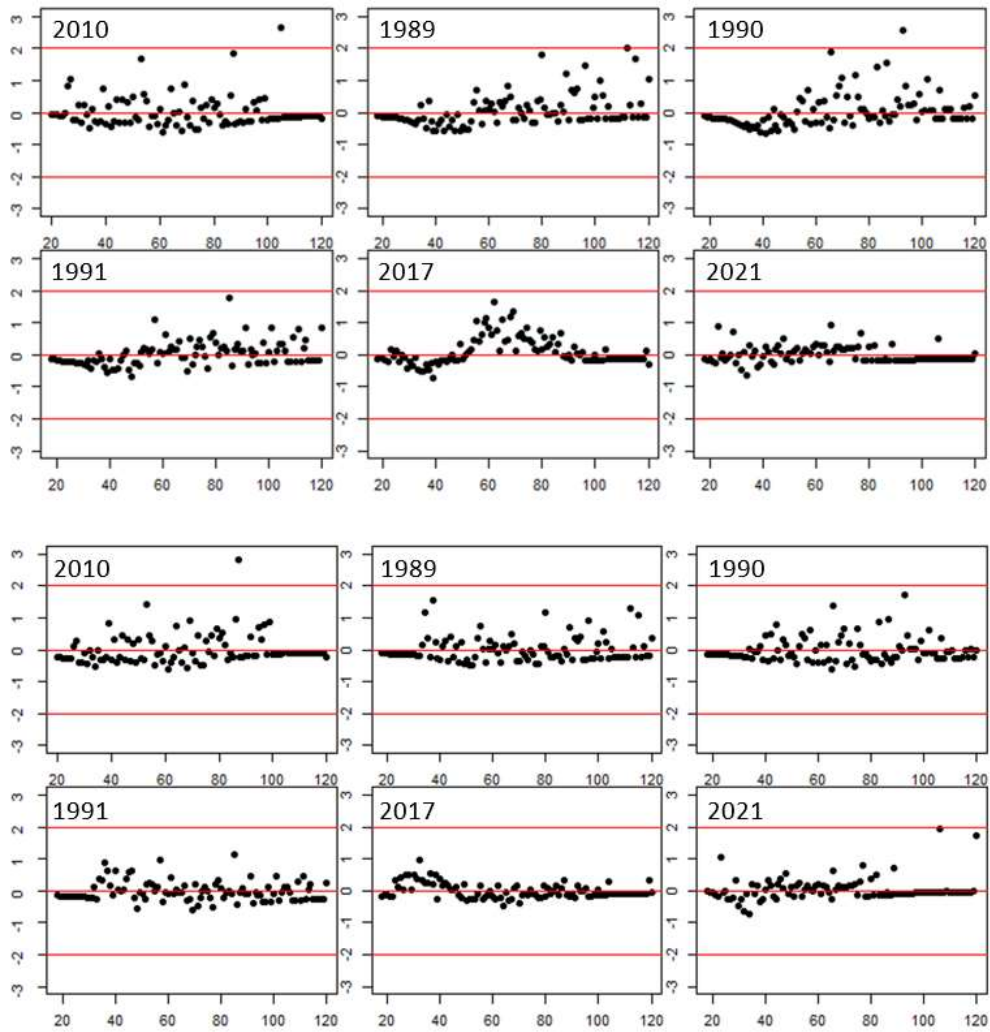


Figure 26: Normalised residuals for the fit to the age data when proportions mature at age were included in the model run (top six panels), and when they were excluded and 1989–91, 2010, and 2017 fitted with a logistic selectivity, and 2021 fitted with a separate logistic selectivity (the base model run assumption).

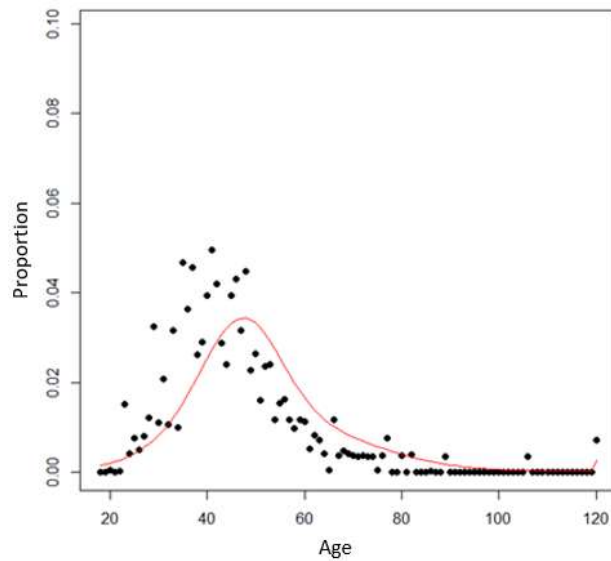


Figure 27: Model fit (line) to the proportions at age (points) for the 2021 age frequency when assumed to have the same selectivity as the 1989–91, 2010, and 2017 age frequencies.

Simplifying the model to have two fisheries, following the previous assessment (2014), estimated a larger stock at a similar level of depletion, but incurred catch penalties with a poorer fit to data and less plausible YCS and biomass trends.

Assuming a higher M of 0.06 y^{-1} estimated a smaller and less depleted stock but fitted the data less well, with several implausible selectivity parameters. MPD runs across a range of M and stock-recruitment steepness values indicated the base assumption of M was supported by data, and could plausibly be a little lower, and that the model had no information to determine steepness (Figure 28). A sensitivity run estimating M was not completed because of the noisy age data with substantial uncertainties in the spawning (maturity) and fishery selectivity ogives.

										<i>h</i>
<i>M</i>	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8	0.85	0.9
0.02	8.1	7.9	7.7	7.7	7.6	7.7	7.7	7.9	8	8.2
0.025	2.5	2.3	2.1	2	2	1.9	2	2	2.2	2.3
0.03	0	0	0	0	0.1	1.6	0.4	0.4	0.5	0.7
0.035	2.8	2.7	2.7	2.8	2.8	2.9	3.1	3.2	3.4	3.6
0.04	8.5	8.4	8.3	8.3	8.4	8.5	8.6	8.7	8.9	9.1
0.045	16	15.9	15.8	15.8	15.8	15.9	16	16.1	16.3	16.5
0.05	24.8	24.6	24.4	24.4	24.4	24.4	24.5	24.6	24.8	25
0.055	34.6	34.3	34.1	34.1	34	34.1	34.1	34.3	34.4	34.6
0.06	45.3	45	44.8	44.7	44.7	44.7	44.8	44.9	45.1	45.3
0.065	56.8	56.4	56.2	56.1	56	56.1	56.1	56.3	56.4	56.6
0.07	68.8	68.4	68.2	68	68	68	68.1	68.2	68.4	68.6

										<i>h</i>
<i>M</i>	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8	0.85	0.9
0.02	9.54	9.54	9.55	9.57	9.6	9.64	9.68	9.73	9.78	9.84
0.025	5.11	5.1	5.14	5.17	5.17	5.25	6.12	6.16	6.2	6.25
0.03	2.05	2.07	2.1	2.14	2.18	2.23	2.28	2.33	2.39	2.44
0.035	0.749	0.764	0.787	0.816	0.851	0.89	0.933	0.98	1.03	1.08
0.04	0	0.01	0.027	0.052	0.082	0.116	0.156	0.2	0.246	0.297
0.045	0.057	0.062	0.076	0.098	0.126	0.16	0.2	0.244	0.293	0.347
0.05	0.769	0.765	0.773	0.79	0.815	0.847	0.886	0.932	0.984	1.04
0.055	1.87	1.86	1.99	1.87	1.89	1.92	1.95	2	2.06	2.13
0.06	3.17	3.14	3.13	3.14	3.15	3.17	3.21	3.25	3.3	3.37
0.065	4.51	4.47	4.45	4.45	4.45	4.47	4.49	4.52	4.56	4.62
0.07	5.83	5.79	5.76	5.94	5.79	5.95	5.97	6	6.01	6.06

Figure 28: Changes in total negative log-likelihood for MPD runs at different assumed values of natural mortality rate (*M*) and Beverton-Holt stock-recruitment steepness (*h*), with shading increasing for poorer fits (less likely outcomes). Likelihood values are differences from the global minimum. Top panel, results for the 2014 assessment model with catches updated to 2022, but no other changes (suggesting *M* around 0.03, as reported by Cordue 2014); Bottom panel, results for the 2022 model.

The length frequencies should not be influential in orange roughy stock assessments, because of the variability in length samples, and the considerable overlap in length at age. Sensitivity runs on the weighting of the length frequency data sets, and the assumptions of the growth model, found they did not have a large influence on stock size and status estimates (Table 21). The influence of the CVs of length at age were examined, because these were estimated in the base model, and the estimated values reproduced well the spread of lengths at age observed outside the model (Figure 29). Other sensitivities included changing assumptions for the 2013 and 2021 acoustic biomass surveys (investigative runs only to understand model behaviour), and CV of the YCS prior (model estimates not sensitive) (Table 21).

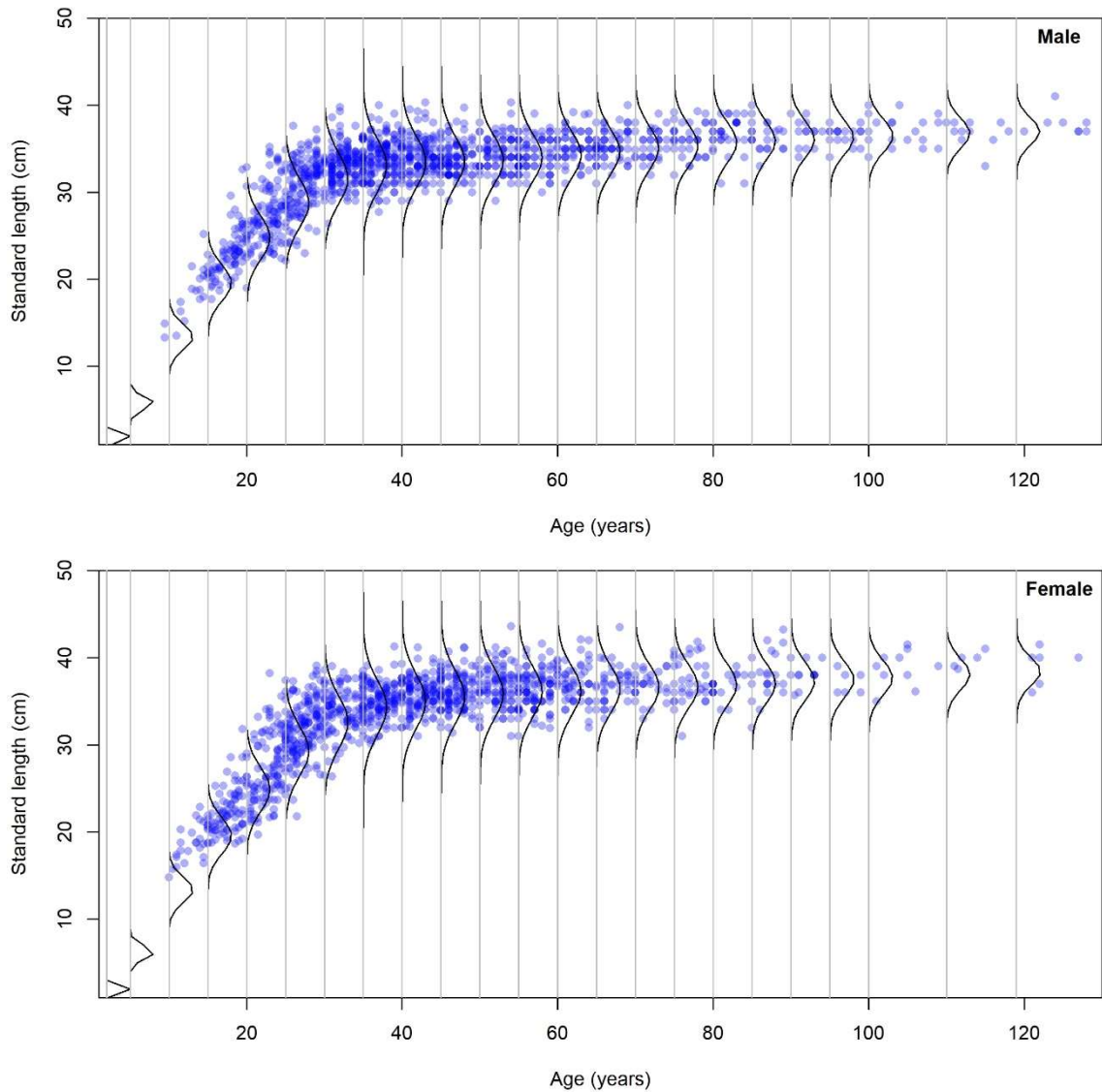


Figure 29: Predicted distribution of lengths at age (every five years are plotted as vertical distributions) given the empirical length at age and estimated CV of length at age (cv1, at age one; and cv2, at the plus group) in the base model run, compared with data for length at age (points); these data were not fitted in the model.

Sensitivity runs that changed the mean of the acoustic q prior, or assumed a lower M , were chosen by the Deepwater Working Group as ‘final runs’, and produced slightly different estimates of stock size and status; however, the fits were visually indistinguishable (-0.04 to +0.56 likelihood unit change in objective function) (Table 21).

11. BAYESIAN ESTIMATES

MCMC convergence diagnostics were acceptable for the base model and sensitivities (Appendix B). In all final model runs, the spawning stock biomass was reduced through the 1980s to below 10% B_0 in the 1990s, and then slowly rebuilt. Virgin biomass (B_0) was estimated to be about 53 000 t for the base case, and the current stock status 22% B_0 (Table 22). When the mean of the acoustic q was reduced ($q=0.6$), the spawning stock was estimated to be slightly larger and currently less depleted, and vice versa when the higher q was assumed ($q = 1.0$). The base and acoustic q sensitivity runs all estimated the current stock status to be at or above the soft limit (20% B_0). Assuming a lower M estimated a larger B_0 and stock status just below the soft limit.

Table 22: Mid-East Coast orange roughy MCMC estimates of virgin biomass (B_0) and stock status (B_{2022} as % B_0) for the base model, and the three sensitivity runs: a) reducing the mean acoustic catchability coefficient, q , from 0.8 to 0.6; b) increasing the mean acoustic q from 0.8 to 1.0; c) decreasing M to 0.035 y^{-1} .

Model run	B_0 (t)	95% CI	B_{2022} (% B_0)	95% CI
Base model	53 350	46 550 – 63 670	22.4	16.7 – 29.2
Acoustic $q = 0.6$	57 590	49 070 – 69 120	26.3	20.2 – 33.5
Acoustic $q = 1.0$	51 280	45 480 – 60 010	19.8	14.7 – 26.4
$M = 0.035$	69 060	60 340 – 79 860	16.7	12.2 – 22.1

The estimates of stock size and status were relatively precise given that some selectivities were relatively poorly estimated, particularly for the South fishery, the mature fish in the trawl survey, and the Spawn 2021 age frequency. An MCMC sensitivity run was completed with normal priors placed on the parameters of the South fishery selectivity, with mean values taken from the MPD estimates and assumed CVs, and whilst this prevented the improbable capture of very young fish it made almost no difference to the estimates of stock size and status. The use of model estimates to construct priors for use in the same model is statistically incorrect, so the base run was preferred. Orange roughy were estimated to first recruit to the South fishery, then the Pegasus and North fisheries, and then the Spawn fishery (Figure 30). The spawning ogive was relatively precisely estimated, indicating spawning started at about age 40 and all fish spawned by about age 80.

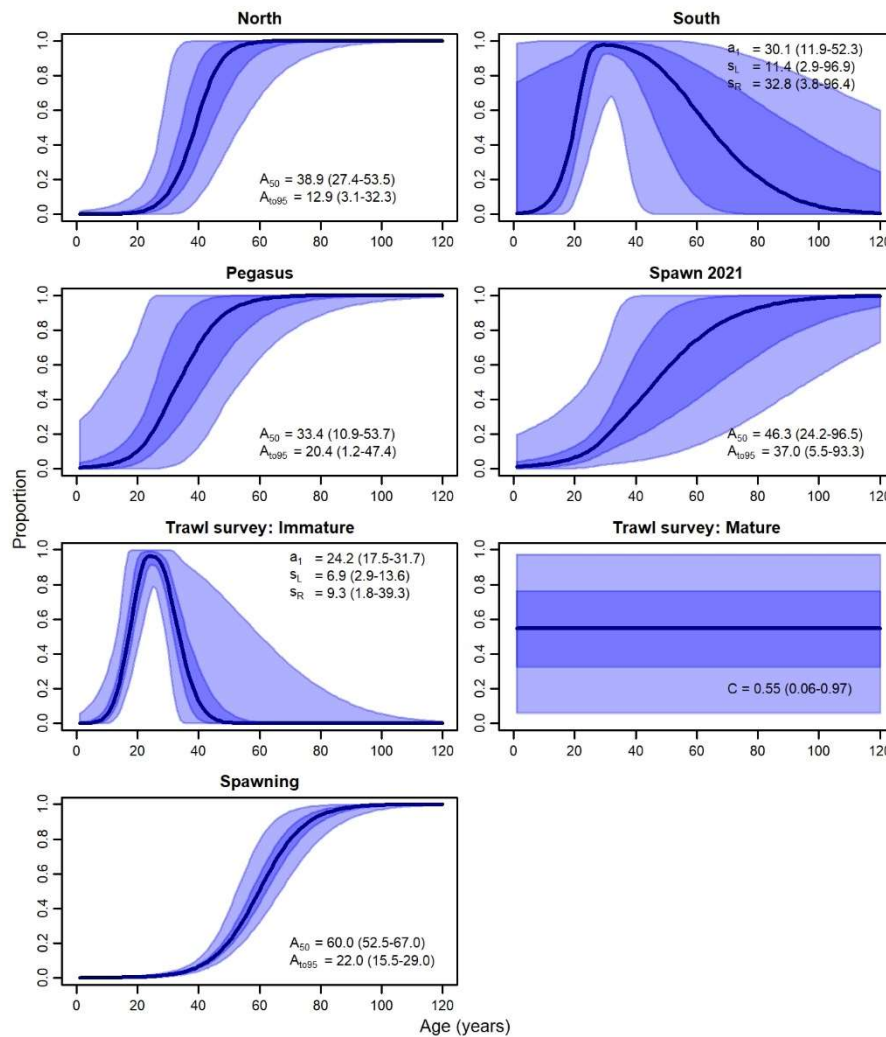


Figure 30: Mid-East Coast orange roughy base case MCMC estimates of selectivities and the spawning ogive. The estimated selectivity model parameters (and 95% credible intervals) are shown on each panel. The light shaded area covers the 95% credible intervals, the darker shaded area the 50% credible intervals, and the solid line the median.

Assuming a logistic selectivity with parameters averaged from base model run MPD estimates, the overall vulnerable biomass (vB_0) did not decline as much as the spawning biomass, reaching just below 40% vB_0 in the late 1990s and then slowly rebuilding (Figure 31). The biomass vulnerable to the southern fisheries, where recruitment was at a younger age, declined to about 50% and then remained steady from the early 2000s until then last five years, when it slowly declined. The recent decline in vulnerable biomass for the South fishery (vBs) was because recruitment was estimated to be approaching an historical low, caused by the reduction of the spawning biomass in the 1980s (Figure 32). The estimated YCS showed little trend, other than a slight decrease from about 1940, a peak around 1970, and then lowest levels of YCS between 1980 and 1993 with a minimum in 1989 (Figure 32).

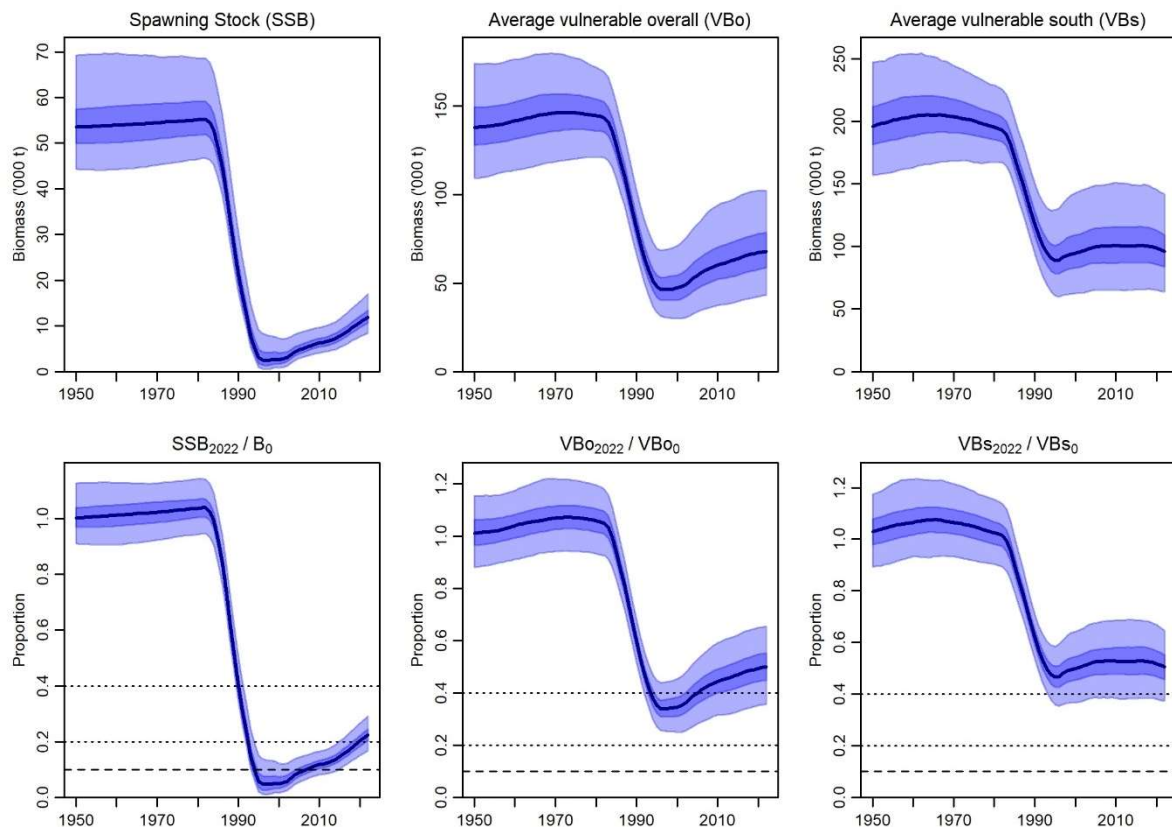


Figure 31: Mid-East Coast orange roughly base case MCMC estimates of upper panels: the Spawning Stock Biomass (SSB), and vulnerable biomass trends estimated using logistic selectivity parameters averaged across all fisheries (average vulnerable biomass, vB_0 ; $A_{50} = 34$, $A_{1095} = 8$), and in the southern fisheries (South and Pegasus, vBs ; $A_{50} = 24$, $A_{1095} = 2$). Lower panels, biomass in each year as a proportion of initial biomass. The light shaded area covers the 95% credible intervals, the darker shaded area the 50% credible intervals, and the solid line the median. The horizontal broken lines indicate the hard limit (10% of virgin biomass), soft limit (20% of virgin biomass), and 40% of virgin biomass.

Estimated exploitation rate peaked in 1991–92 and 1992–93 and was above the target range ($U_{30\%B_0}$ – $U_{50\%B_0}$) from 1982–83 to 2002–03, and 2004–05 to 2011–12 (Figure 33). Exploitation rate has been well below the target since 2014–15. The estimates of exploitation rate were sensitive to the selectivity pattern, which in this model meant the distribution of catches amongst fisheries. As a result, the target range shown in Figure 33 would be quite different if future fishing catches orange roughly only from the Spawn fishery.

The phase plot (Figure 34) showed the stock would be considered to currently be in an ‘amber’ status, being overfished but with overfishing not occurring.

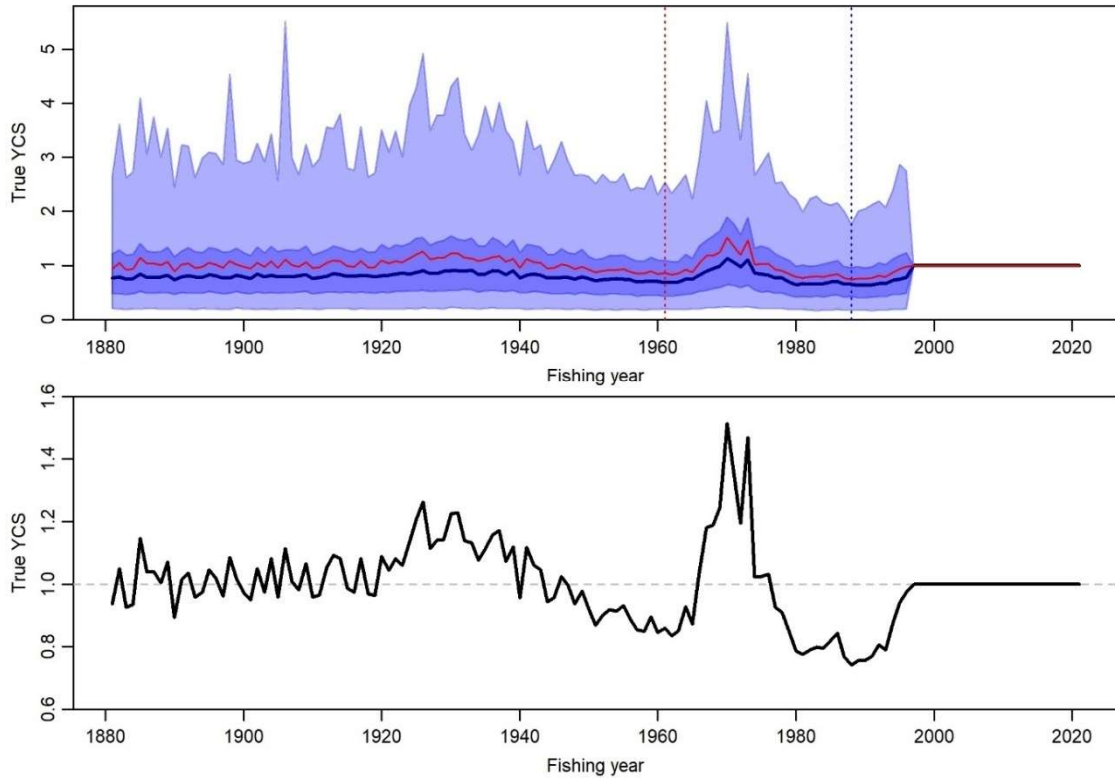


Figure 32: Mid-East Coast orange roughy base case MCMC estimates ‘true’ YCS (R_y/R_0). Upper panel: The light shaded area covers the 95% credible intervals, the darker shaded area the 50% credible intervals, the solid black line the median, and the solid red line the mean. The vertical blue dashed line (to right) indicates the year class estimated to be 50% recruited to the Pegasus fishery in 2022 (the second largest fishery, after the Spawn fishery, in 2022). The vertical red dashed line (to left) indicates the year class 50% recruited to the spawning stock in 2022. Lower panel: mean ‘true’ YCS (same as the red line in the top panel, but plotted separately to more clearly show the trend).

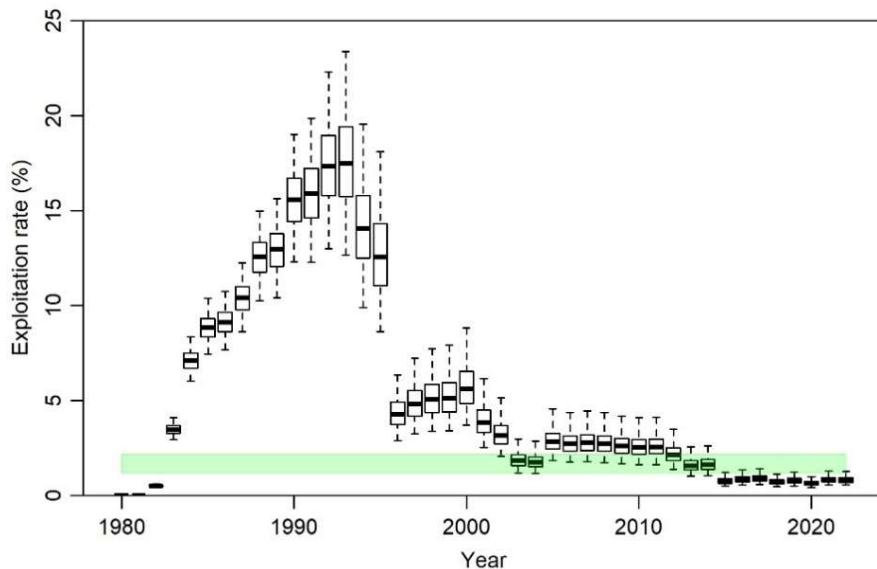


Figure 33: Mid-East Coast orange roughy base case MCMC estimates of exploitation rate (catch/vulnerable biomass). The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The exploitation rate associated with a biomass target of 30–50% B_0 is marked by shaded box.

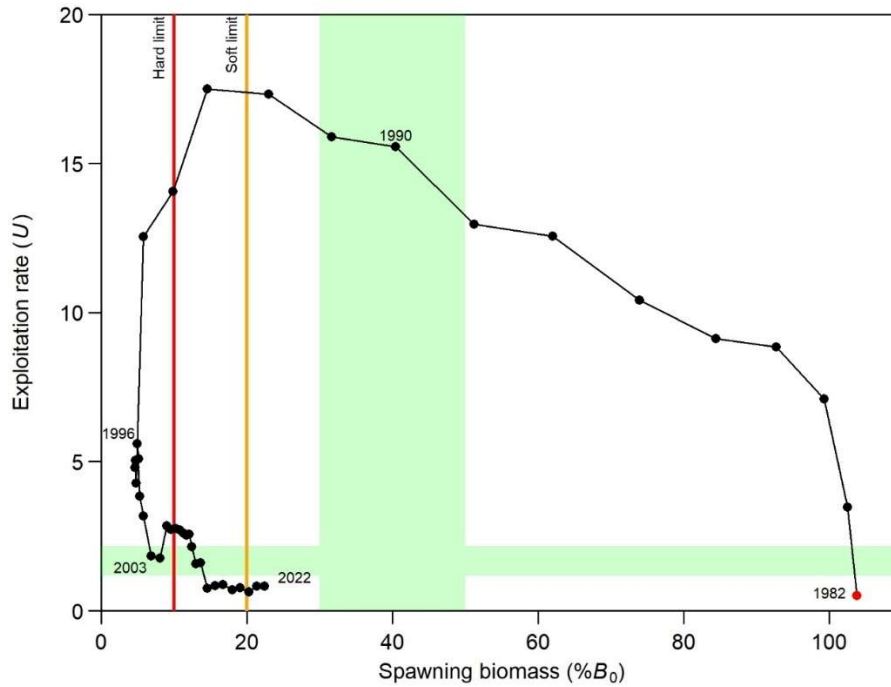


Figure 34: Historical trajectory over time of exploitation rate (U %) and spawning biomass ($\% B_0$), for the Mid-East Coast orange roughy base model, from the start of the fishery (represented by a red point), to 2022. The red vertical line at $10\% B_0$ represents the hard limit, the orange line at $20\% B_0$ is the soft limit, and green shaded area shows the $\% B_0$ target ($30\text{--}50\% B_0$) and the corresponding exploitation rate ($U_{30\text{--}50}$). Biomass and exploitation rate estimates are medians from MCMC results.

11.1 Projections

Projections were conducted with resampling of YCS estimated from the base model (1881–1996), with future catch constant at the 2021 level of 524 t (plus a 5% catch over-run assumed). The SSB was predicted to increase slowly (Figure 35, Table 23). The SSB was estimated to be greater than the lower bound of the target zone ($30\% B_0$) with at least 70% probability by 2027.

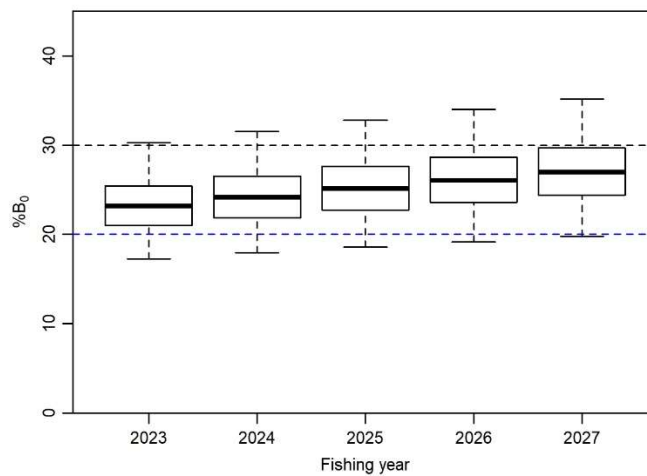


Figure 35: Mid-East Coast orange roughy base case MCMC projections of spawning stock biomass with constant future catch. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The lower bound of the target range ($30\% B_0$) is indicated by the black horizontal broken line, with the soft limit ($20\% B_0$) in blue.

Table 23: Mid-East Coast orange roughy MCMC estimates of projected spawning stock biomass (SSB) for the base model, and the probability of above the hard limit (10% B_0), soft limit (20% B_0), and lower bound of the target range (30% B_0).

Fishing year	$p(SSB > 10\% B_0)$	$p(SSB > 20\% B_0)$	$p(SSB > 30\% B_0)$
2021–22	1.00	0.79	0.01
2022–23	1.00	0.84	0.03
2023–24	1.00	0.90	0.05
2024–25	1.00	0.94	0.09
2025–26	1.00	0.96	0.15
2026–27	1.00	0.97	0.23

12. COMMENTS ON THE SKIPPED SPAWNING HYPOTHESIS

This section summarises some of the work on the skipped spawning hypothesis completed in 2022, but it is not a review of skipped spawning, nor is it a collation and analysis of relevant data; those remain for future research.

The idea of skipped spawning is not new (e.g., Jørgensen et al. 2006, Rideout & Tomkiewicz 2011), and it has previously been discussed for orange roughy on several occasions (e.g., Francis & Clark 1998, Doonan et al. 2000, Bull et al. 2001, Doonan et al. 2004, Doonan 2011;). Theoretically, skipped spawning is expected to be more prevalent when mature fish are relatively young, natural mortality rate is low, fish travel further from home grounds to the spawning ground, fish are female, and population size is relatively high (via habitat competition). Orange roughy would seem to be a very good candidate for skipped spawning.

The 2022 assessment model did not explicitly model skipped spawning; rather the spawning ogive was aliasing for both maturity and any skipped spawning (Figure 36).

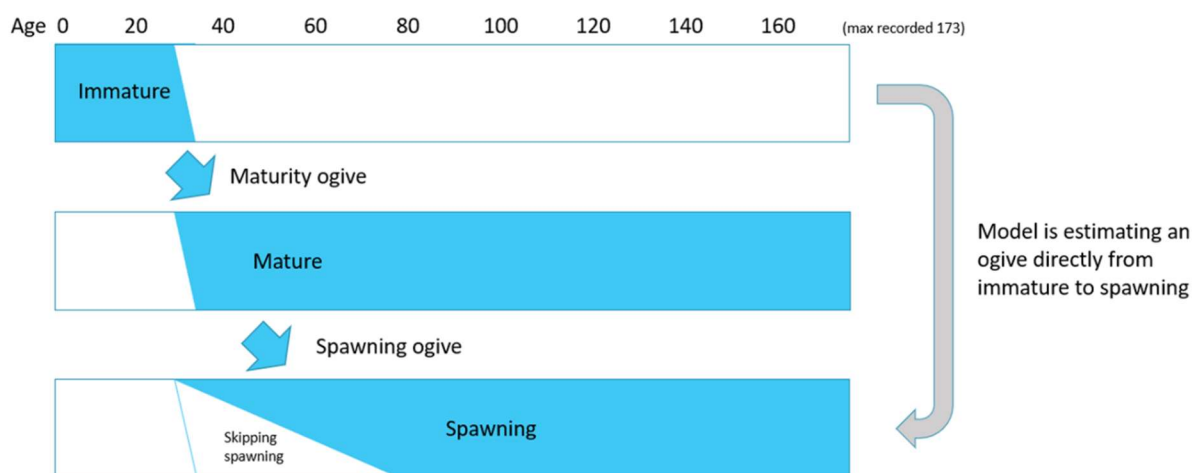


Figure 36: Schematic of skipped spawning in Mid-East Coast orange roughy, where maturity may take place at about age 30, and skipped spawning would be inferred to be high for young spawners, and zero for fish greater than about 80 years of age. The spawning ogive relates immature to spawning, without explicit consideration of maturity.

The ability of a logistic ogive to adequately fit skipped spawning was investigated with a simple simulation model. This model assumed an exponential decline in fish numbers with age, with logistic maturity increasing to a proportion mature cap, then from the 95% mature the ogive increased linearly until it reached a value of one. The model therefore had four parameters (A_{50} , A_{1095} , cap , and a rate, r). With the cap set at one, and a rate parameter of zero, the ogive is a standard logistic. The logistic ogive

generally captured the proportion spawning across a range of model settings, although when the proportion spawning increased only slowly after maturity (the *cap* was intermediate and *r* was low) the true A_{50} tended to be slightly overestimated (Figure 37). The one scenario where the logistic ogive was substantially misleading was when the proportion spawning never reached one. The age frequency that would be observed with age-dependent skipped spawning was similar to observed age frequencies, particularly those from the Mid-East Coast 1989–91 and 2010, where the age frequency tended to be ‘flat topped’ between about ages 30 and 70 (in particular see the red line in the middle panel, second row, in Figure 37). In such cases, visual evaluation of the age frequency might suggest full selectivity (A_{95} , age at 95% selected) to be at about age 40, because this is the top of the increasing left-hand side. However, the A_{95} would actually be substantially higher, at about age 60, i.e., the age at which the true population decline and selected population decline became equal. Skipped spawning might therefore produce a substantial conflict between spawning ogives as expected from visual examination, and those estimated by a model.

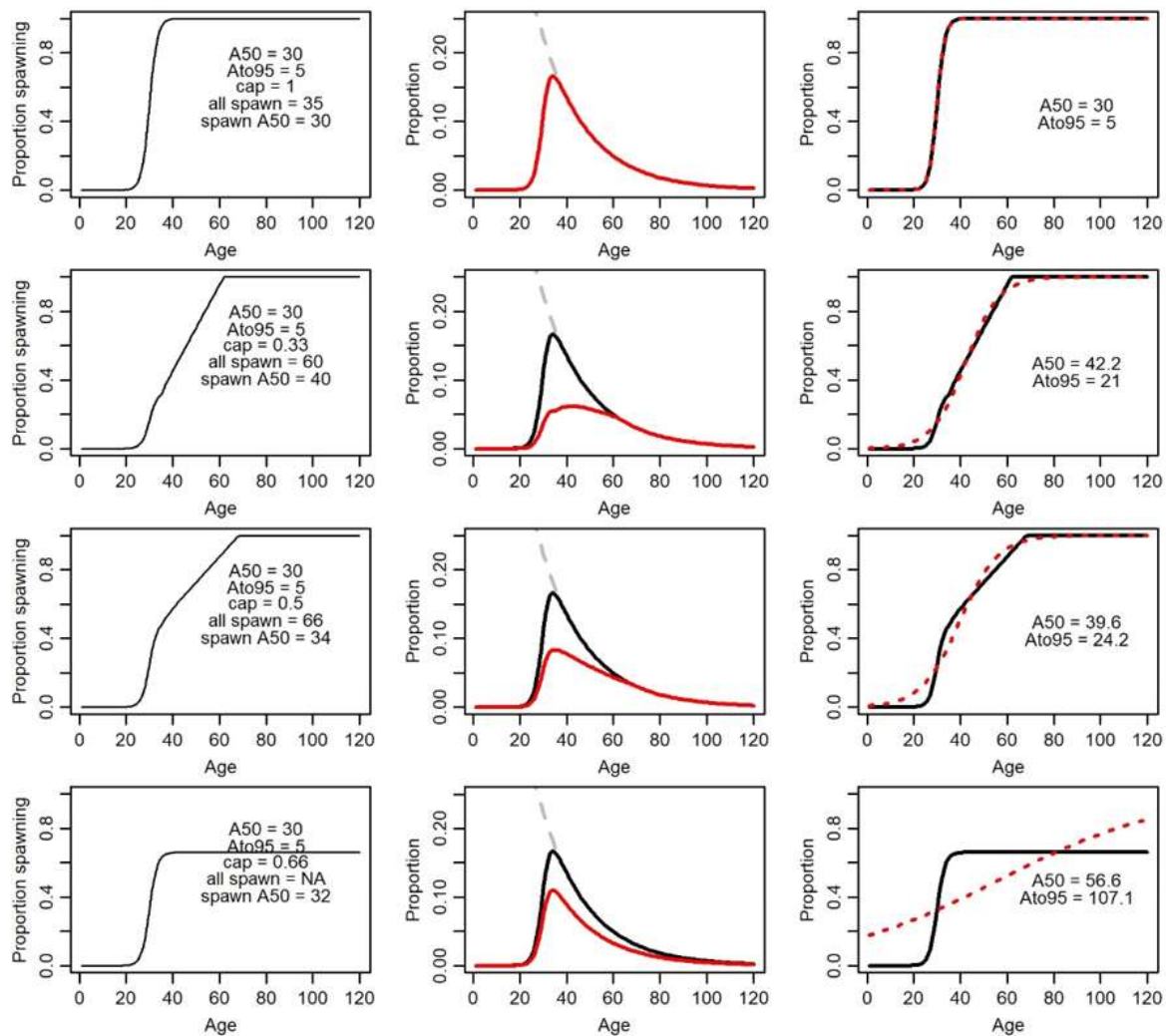


Figure 37: Simulation model for a population showing exponential decline in numbers, with: in left panels, the assumed spawning ogive and ogive parameters settings; middle panels, the proportion of fish in the population (grey broken line), the proportion mature (black line), and the proportion spawning (red line); right panels, the true spawning ogive (black line; which is the same as the left panels) and a logistic ogive fitted to that ogive (red broken line). In the left panels, the parameters are as described in the text except for ‘spawn A_{50} ’ which is the derived true age at which 50% were spawning. In the right panels, the parameters are those for the logistic model fitted to the spawning ogive (as might be estimated by the 2022 stock assessment model).

A model solution to achieving a lower rebuild that would be expected given historical catches and expected productivity is to make the spawning biomass smaller (make the spawning A_{50} higher). This is because an older SSB declines relatively fast as the mortality rate increases and longevity decreases, and then rebuilds more slowly. A sensible check is therefore that the spawning ogive parameters were being informed by the spawning age frequencies and not other data informing the scale of biomass rebuild, such as the acoustic biomass surveys. An MPD likelihood profile for the spawning ogive A_{50} found it was, as expected, almost entirely informed by the spawning age frequency data (AFspawn) (Figure 38).

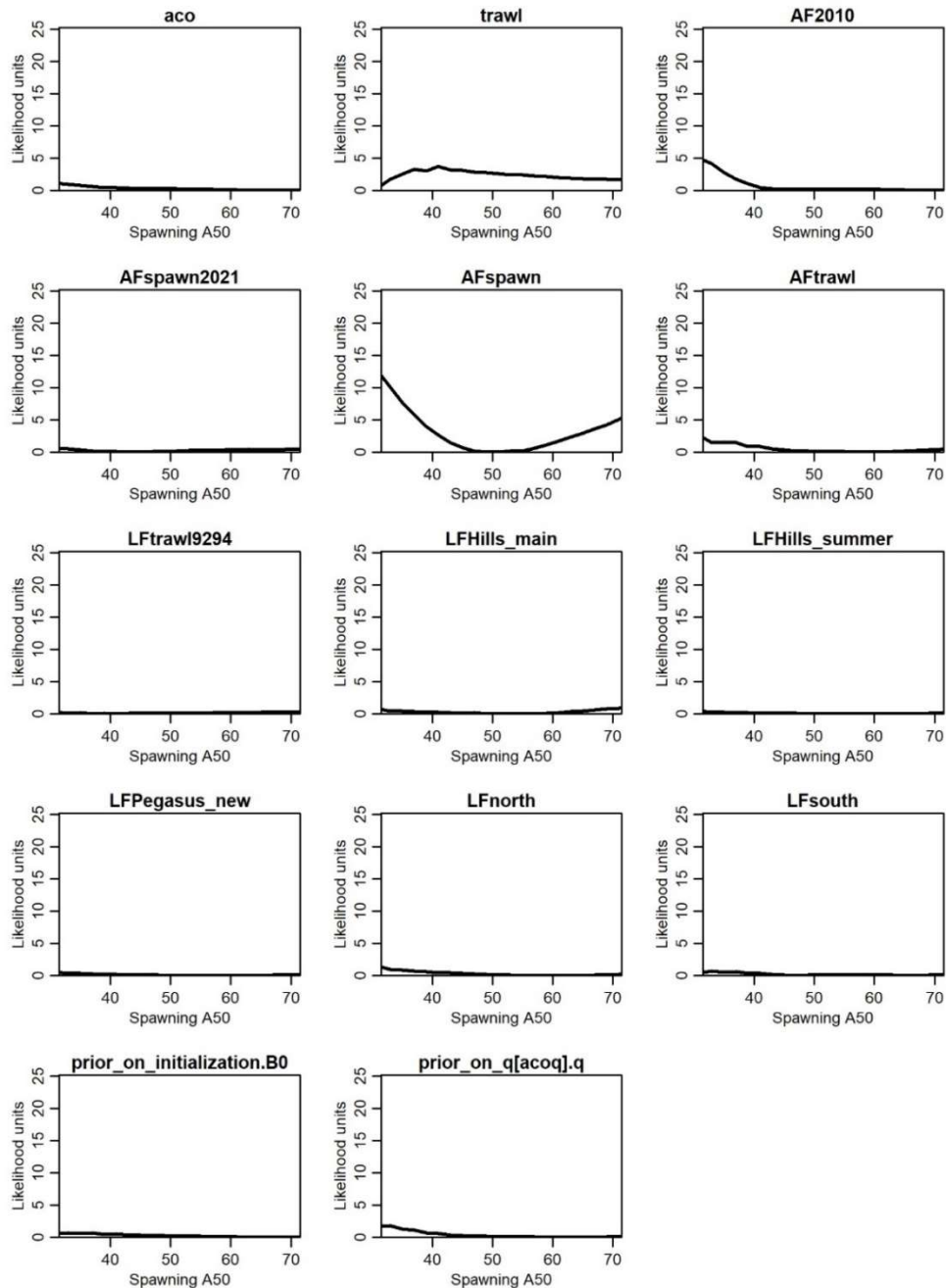


Figure 38: Spawning ogive A_{50} MPD likelihood profiles for the base model observational data sets and priors. aco, acoustic biomass estimates, prior_on_q[acoq].q, the informed acoustic q prior; trawl, the trawl survey biomass index. AF, age frequencies; LF, length frequencies. AF2010 and AFspawn (the 1989–91 AFs) were fitted with the same (spawn) selectivity ogive.

The age frequency data for the Spawn fishery therefore had greatest influence on the spawning A_{50} . Nevertheless, the hypothesis that biomass data would prefer a relatively small SSB seemed to be supported. Likelihood profiles for B_0 showed that the biomass data indicated a low B_0 , particularly the trawl survey and acoustic survey including q prior (Figure 39). A B_0 below about 40 000 t would start to incur a catch penalty in the base model ($U >$ assumed U_{max}). The AFs resisted the smaller stock size. The LFs indicated a larger stock but were down-weighted. Although the prior on YCS looked like it would be influential, it was not, and changing the CV didn't change the result (CV = 0.8, $B_0 = 54\ 939$ t and $B_{2022}/B_0 = 22.2\%$; CV = 1.1, $B_0 = 54\ 439$ t and $B_{2022}/B_0 = 21.5\%$; CV = 0.6, $B_0 = 55\ 489$ t and $B_{2022}/B_0 = 22.5\%$).

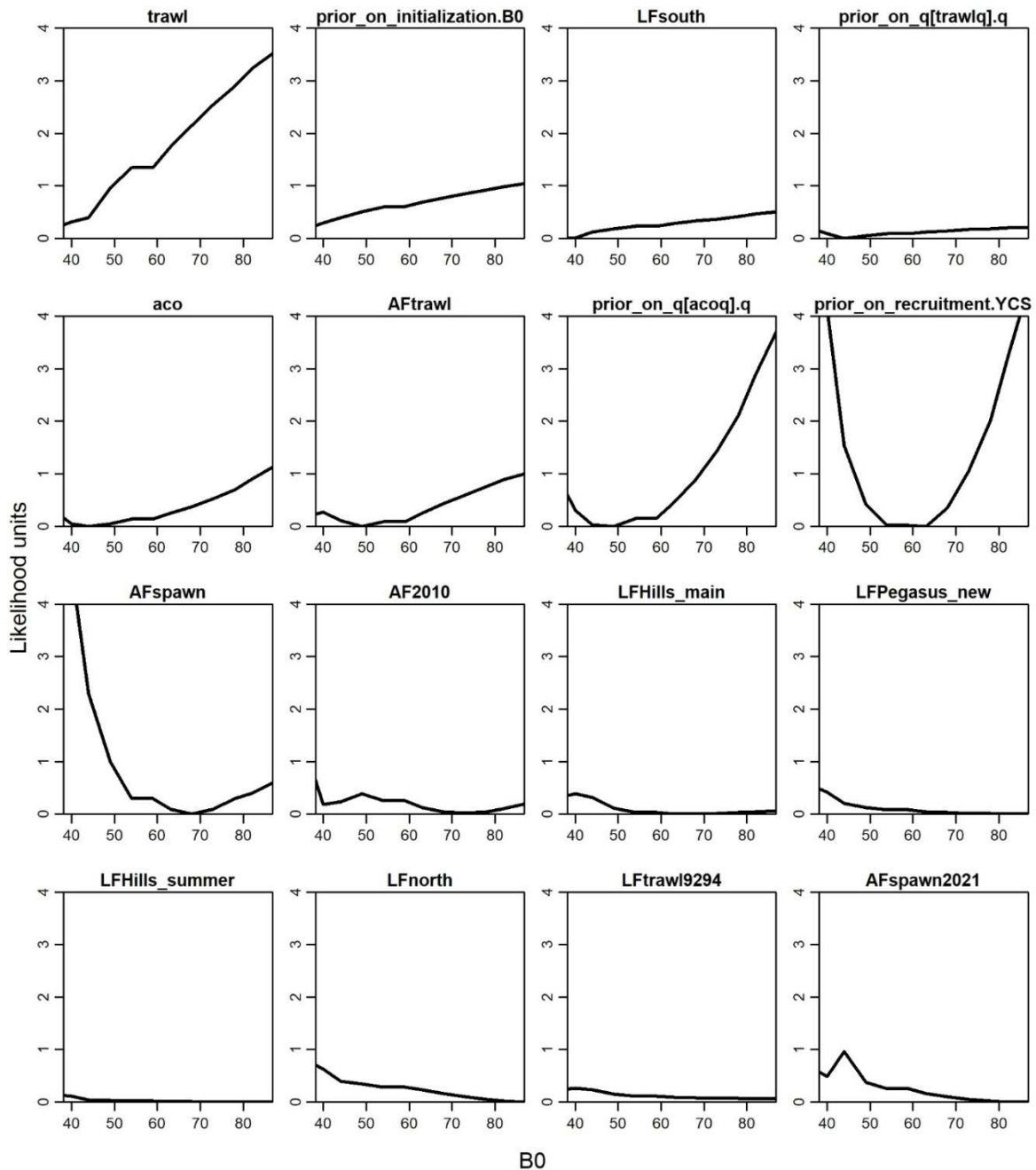


Figure 39: Virgin spawning stock biomass (B_0) MPD likelihood profiles for the base model observational data sets and priors. aco, acoustic biomass estimates, prior_on_q[acoq].q, the informed acoustic q prior; trawl, the trawl survey biomass index. AF, age frequencies; LF, length frequencies. AF2010 and AFspawn (the 1989–91 AFs) were fitted with the same (spawn) selectivity ogive.

Studies of orange roughy reproduction from macroscopic and/or histological gonad examination have found maturity and spawning proportions to be spatially and temporally variable, and that not all orange roughy are likely to spawn every year (e.g., Francis & Clark 1998, Doonan et al. 2000, Bull et al. 2001, Doonan et al. 2004). The proportions mature observations for the Mid-East Coast were fitted by Cordue (2014) with a logistic ogive, and an assumption that all fish older than 50 years were mature (Figure 40). However, the data suggest this was not true, with the proportion expected to spawn in 2010 being less than one in four of the five oldest ages. These data suggest the age at which all fish would be spawning was about ages 45–50 in 1993, and over age 50 in 2010.

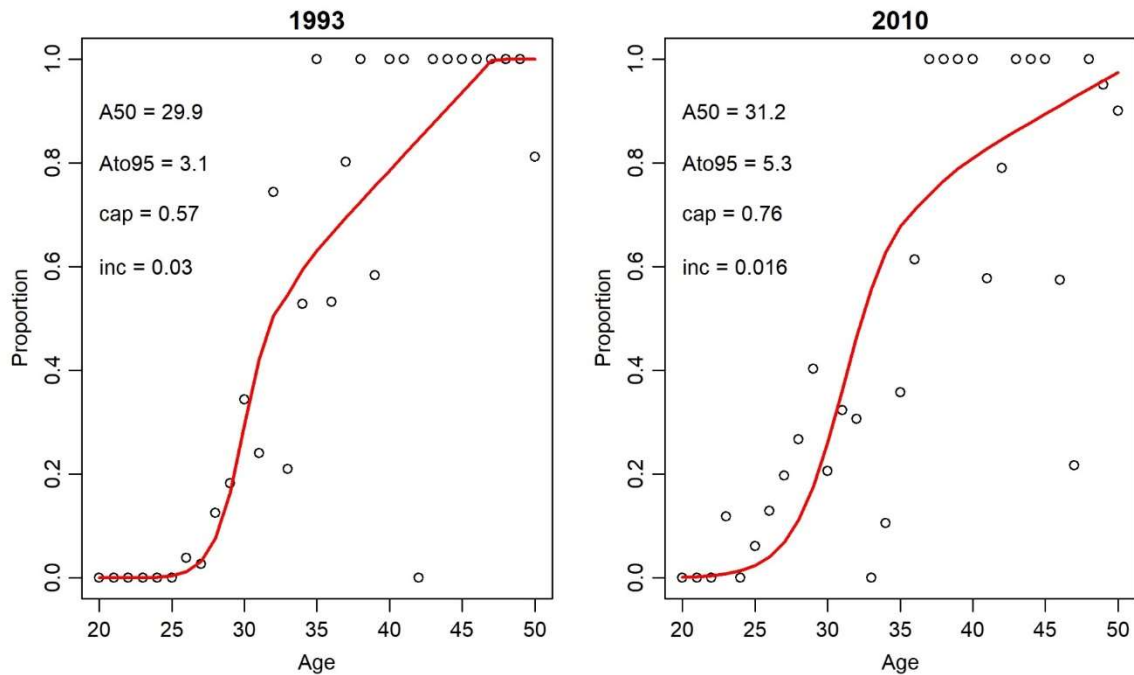


Figure 40: Proportions expected to spawn at age from gonad examination during the Mid-East Coast trawl surveys (points), and the simulation model flexible spawning ogive (as in Figure 37) fitted to these data (estimated parameters shown on the plot).

An appropriate model for skipped spawning requires more thought, and an appropriate ogive formulation developed. The data that would best inform a ‘spawning ogive’ that relates mature fish to spawning also needs to be investigated. A spawning ogive, if capped, would be correlated with a q , so it may not be desirable to estimate ogive parameters within the model; they may be best estimated outside the model, as is currently done for e.g., growth.

It remains plausible that the high age at spawning, and hypothesis of skipped spawning, are wrong. It would be prudent for future models to continue to evaluate alternative hypotheses, including one where maturity and spawning take place at a similar age.

13. DISCUSSION

13.1 Summary

The 2022 assessment differed from the previous (2014) assessment in having:

- Four fisheries instead of two, including a spawning fishery.
- Proportions mature (assumed to spawn later that year) at age from the trawl survey were excluded, and no longer used to estimate maturity.

- Spawning ogive was set equal to the Spawn fishery selectivity (with an assumption to explain the older age of spawning that younger mature fish more frequently skipped spawning).
- YCS prior set with mean of one and $CV = 0.8$, rather than the ‘nearly uniform’.
- Acoustic q set in the base case to be 0.8, rather than 0.6.
- Sex included in the partition.
- Updated growth, with empirical length at age used, and revised parameters for the length to weight conversion.
- Trawl survey fitted with double-normal (immature) and constant (mature) selectivity, rather than a double-normal selectivity fitted to all fish.
- The age frequency for 2010 was included as part of a series with 1989–91, 2010, 2017, rather having a separate selectivity.

The 2022 model had a relatively old age of spawning, but this:

- Produced a better fit to the age frequencies. The previous assessment rated the MPD fit as ‘adequate’ but the least well fitted of the observational data (Cordue 2014). These are the only composition data that can be compared; gonad stage data having been excluded and length frequencies revised with new fisheries structure.
- Estimated a lower SSB as a proportion of the overall stock, which is more consistent with the acoustic SSB survey prior. The 2014 model stock status in 2014 was 14% B_0 , and the 2022 model stock status in 2014 was similar at 13.6% B_0 . However, in absolute terms the SSB estimated for 2014 was 14 500 t in the 2014 assessment, and 7300 t in 2022, with the SSB observed in the 2013 acoustic biomass survey being 4200 t. This implies a scaling factor of about 3.5 in the Cordue (2014) assessment, and 1.7 in the 2022 assessment.
- Mitigated the need for strong and debatable (and poorly informed) YCS trends; the SSB increase estimated in the 2014 assessment to coincide with the fishery starting was greatly reduced. The MCMC median R_0 : 2014 model = 13.2 million; 2022 model = 18.3 million (39% larger). But because the YCS trends are quite different the difference at the start of the fishery was much smaller: The MCMC median overall vulnerable biomass in 1970; 2014 model = 129 000 t; 2022 model = 146 000 t (13% larger).
- Produced an estimated M (profile) that was more consistent with expectations. The Cordue (2014) assessment estimated M to be 0.032 y^{-1} ; here, profiles indicated it would be between 0.04 and 0.045 y^{-1} , the latter being the base case assumed value.
- Gave a smaller SSB , but a vulnerable biomass still consistent with expectations given the catch history. The average vulnerable biomass before fishing was estimated in this assessment to be about 140 000 t, which was actually similar to stock size estimates made early in the history of the fishery, when maturity and selectivity were assumed equal and the biomass trend was indexed with commercial catch-per-unit-effort (Figure 2).

Many orange roughy assessments have observed biomass rebuilds after catches were reduced that were not consistent with, or strongly informed by, the observational data (Fisheries New Zealand 2021). The models routinely estimated biomass rebuilds that were greater than observed. The biomass rebuilds were expected given the estimated SSB (which was largely informed by the catch history) and the assumed mean productivity (M , with stock-recruit steepness not yet influential). Essentially, the 2014 assessment model resolved this conflict by estimating a pattern of YCS that produced recruitment near-failure once the fishery started. The 2022 model resolved the conflict by estimating a smaller proportion of the stock to be spawning (smaller SSB), achieved by an older age of spawning. Whilst the ‘nearly uniform’ YCS assumption ‘worked’ at MPD, the model was over-parametrised and at MCMC the MPD was an outlier and the conflict was less well resolved. The 2022 model resolved the issue more

effectively in that the MCMC estimates gave a better ‘fit’ to observational data (age frequencies and, in particular, the estimated *SSB* was much closer to the mean of the acoustic survey *q* prior). However, an explanation for the older age of spawning was required. The 2022 assessment therefore shifted discussions from YCS trends to the dynamics of orange roughy spawning.

13.2 Future research

The future research considerations agreed by the Deepwater Working Group and Plenary are not repeated here, but had the headings (1) Relationship between maturity and spawning and prevalence of skipped spawning; (2) Collection of biological data including aged otoliths; (3) Age frequencies for commercial fisheries; (4) Loss of some historical spawning aggregations; and (5) East Cape stock assessment (Fisheries New Zealand 2022).

Other considerations include: moving the assessment model from CASAL to Casal2, which would allow more flexibility in the calculation of *SSB* (e.g., partitioning immature, mature, and spawning fish separately); and evaluation of the scaling of length frequencies to a 50:50 sex ratio, and whether this increases or reduces accuracy of biomass estimates; this might also include further investigations of the sex and potentially age stratification of orange roughy spawning plumes.

14. ACKNOWLEDGEMENTS

This work was funded by Fisheries New Zealand project ORH2021-01. We thank Vidette McGregor and Richard O’Driscoll (NIWA), and Gretchen Skea, Marianne Vignaux, and Suze Baird (Fisheries New Zealand), for constructive review and edits to the draft report.

15. REFERENCES

- Anderson, O.F.; Dunn, M.R. (2012). Descriptive analysis of catch and effort data from New Zealand orange roughy fisheries in ORH 1, 2A, 2B, 3A, 3B, 7A, and 7B to the end of the 2008–09 fishing year. *New Zealand Fisheries Assessment Report 2012/20*. 82 p.
- Annala, J.H. (1992). Report from the fishery assessment plenary, May 1992: stock assessments and yield estimates. (Available from the NIWA library, Wellington.) 222 p.
- Annala, J.H. (1993). Report from the fishery assessment plenary, May 1993: stock assessments and yield estimates. (Available from the NIWA library, Wellington.) 241 p.
- Annala, J.H.; Francis, R.I.C.C. (1991). Assessment of the Cape Runaway to Banks Peninsula (ORH 2A, 2B, and 3A) orange roughy fishery for the 1991–92 fishing year. New Zealand Fisheries Assessment Research Document 91/4. (Held by the NIWA library, Wellington.) 21 p.
- Bull, B.; Doonan, I.J.; Tracey, D; Hart, A. (2001). Diel variation in spawning orange roughy (*Hoplostethus atlanticus*) abundance over a seamount feature on the Northwest Chatham Rise. *New Zealand Journal of Marine and Freshwater Research* 35: 435–444.
- Bull, B.; Francis, R.I.C.C.; Dunn, A.; McKenzie, A.; Gilbert, D.J.; Smith, M.H.; Bian, R.; Fu, D. (2012). CASAL (C++ algorithmic stock assessment laboratory): CASAL User Manual v2.30-2012/03/21. *NIWA Technical Report 135*. 280 p.
- CASAL2 Development Team (2021). CASAL2 User Manual, v2021-07-09 (rev. a99e4839). National Institute of Water & Atmospheric Research Ltd. *NIWA Technical Report 139*. 260 p.
- Cordue, P.L. (2014). The 2014 orange roughy stock assessments. *New Zealand Fisheries Assessment Report 2014/50*. 135 p.
- Doonan, I. (2011). Estimating the non-spawning proportion of mature orange roughy. (Unpublished Final Research Report for project ORH2009-04 held by Fisheries New Zealand.)
- Doonan, I.J.; Dunn, M.R. (2011). Trawl survey of Mid-East Coast orange roughy, March-April 2010. *New Zealand Fisheries Assessment Report 2011/20*.

- Doonan, I.J.; Tracey, D.M.; Bull, B.; Hart A.C.; Grimes, P.J. (2000). Turnover and spawning dynamics of orange roughy on the Northwest hills, Chatham Rise, 1999. (Unpublished Final Research Report for Ministry of Fisheries Research Project ORH9801 held by Fisheries New Zealand.) 45 p.
- Doonan, I.J.; Tracey, D.; Grimes, P. (2004). Relationship between macroscopic staging and microscopic observations of oocyte progression in orange roughy during and after the mid-winter spawning period, Northwest Hills, Chatham Rise, July 2002. *New Zealand Fisheries Assessment Report 2004/6*. 28 p.
- Doonan, I.J.; Horn, P.L.; Krusic-Golub, K. (2013). Comparison of age between 1993 and 2010 for mid-east coast orange roughy (ORH 2A south, 2B & 3A). *New Zealand Fisheries Assessment Report 2013/44*. 19 p.
- Dunn, M.R. (2005). CPUE analysis and assessment of the Mid-East Coast orange roughy stock (ORH 2A South, 2B, 3A) to the end of the 2002–03 fishing year. *New Zealand Fisheries Assessment Report 2005/18*.
- Dunn, M.R. (2008). Ontogenetic habitat shifts and stock assessment of orange roughy. *ICES CM2008/C:28*.
- Eltink, A.T.G.W. (1987). Changes in age—size distribution and sex ratio during spawning and migration of Western mackerel (*Scomber scombrus* L.). *ICES Journal of Marine Science* 44: 10–22.
- Escobar-Flores, P.C.; Ladroit, Y. (in press). Acoustic survey of orange roughy in ORH Mid-East Coast (ORH 2A, 2B, & 3A), June 2021. *New Zealand Fisheries Assessment Report*.
- Field, K.D.; Francis, R.I.C.C.; Annala, J.H. (1993). Assessment of the Cape Runaway to Banks Peninsula (ORH 2A, 2B, and 3A) orange roughy fishery for the 1993–94 fishing year. *New Zealand Fisheries Assessment Research Document 93/8*. 24 p.
- Fisheries New Zealand (2021). Fisheries Assessment Plenary, May 2021: stock assessments and stock status. Compiled by the Fisheries Science Team, Fisheries New Zealand, Wellington, New Zealand. 1782 p.
- Fisheries New Zealand (2022). Fisheries Assessment Plenary, May 2022: stock assessments and stock status. Compiled by the Fisheries Science Team, Fisheries New Zealand, Wellington, New Zealand. 1886 p.
- Francis, R.I.C.C. (2011). Data weighting in statistical fisheries stock assessment models. *Canadian Journal of Fisheries and Aquatic Sciences* 68: 1124–1138.
- Francis, R.I.C.C.; Clark, M.R. (1998). Inferring spawning migrations of orange roughy (*Hoplostethus atlanticus*) from spawning ogives. *Marine and Freshwater Research* 49(2): 103–108.
- Grabowski, T.B.; Thorsteinsson, V.; Marteinsdottir, G. (2014). Spawning behavior in Atlantic cod: analysis by use of data storage tags. *Marine Ecology Progress Series* 506: 279–290.
- Grimes, P. (1994). Trawl survey of orange roughy between Cape Runaway and Banks Peninsula, March–April 1992 (TAN9203). *New Zealand Fisheries Data Report No. 42*. 36 p.
- Grimes, P. (1996a). Trawl survey of orange roughy between Cape Runaway and Banks Peninsula, March–April 1993 (TAN9303). *New Zealand Fisheries Data Report No. 76*. 31 p.
- Grimes, P. (1996b). Trawl survey of orange roughy between Cape Runaway and Banks Peninsula, March–April 1994 (TAN9403). *New Zealand Fisheries Data Report No. 82*. 31 p.
- Horn, P.L.; Tracey, D.M.; Doonan, I.J.; Krusic-Golub, K. (2016). Age determination protocol for orange roughy (*Hoplostethus atlanticus*). *New Zealand Fisheries Assessment Report 2016/03*. 30 p.
- Jørgensen, C.; Ernande, B.; Fiksen, Ø.; Dieckmann, U. (2006). The logic of skipped spawning in fish. *Canadian Journal of Fisheries and Aquatic Sciences* 63(1): 200–211.
- Kloser, R.J.; Macaulay, G.J.; Ryan, T.E.; Lewis, M. (2013). Identification and target strength of orange roughy (*Hoplostethus atlanticus*) measured in situ. *Journal of the Acoustical Society of America* 134: 97–108.
- Pankhurst, N.W. (1988). Spawning dynamics of orange roughy, *Hoplostethus atlanticus*, in mid-slope waters of New Zealand. *Environmental Biology of Fishes* 21: 101–116.
- Rideout, R.M.; Tomkiewicz, J. (2011). Skipped spawning in fishes: More common than you might think. *Marine and Coastal Fisheries* 3(1): 176–189.

- Scott, R.D.; Heikkonen, J. (2012). Estimating age at first maturity in fish from change-points in growth rate. *Marine Ecology Progress Series* 450: 147–157.
- Solmundsson J.; Karlsson H.; Pálsson J. (2003). Sexual differences in spawning behaviour and catchability of plaice (*Pleuronectes platessa*) west of Iceland. *Fisheries Research* 61: 57–71.
- Tingley, G.; Dunn, M.R. (2018). Global review of orange roughy (*Hoplostethus atlanticus*), their fisheries, biology, and management. *FAO Fisheries and Aquaculture Technical Paper No. 622*. Rome. 128 p.

16. APPENDIX A: Length frequency compositions

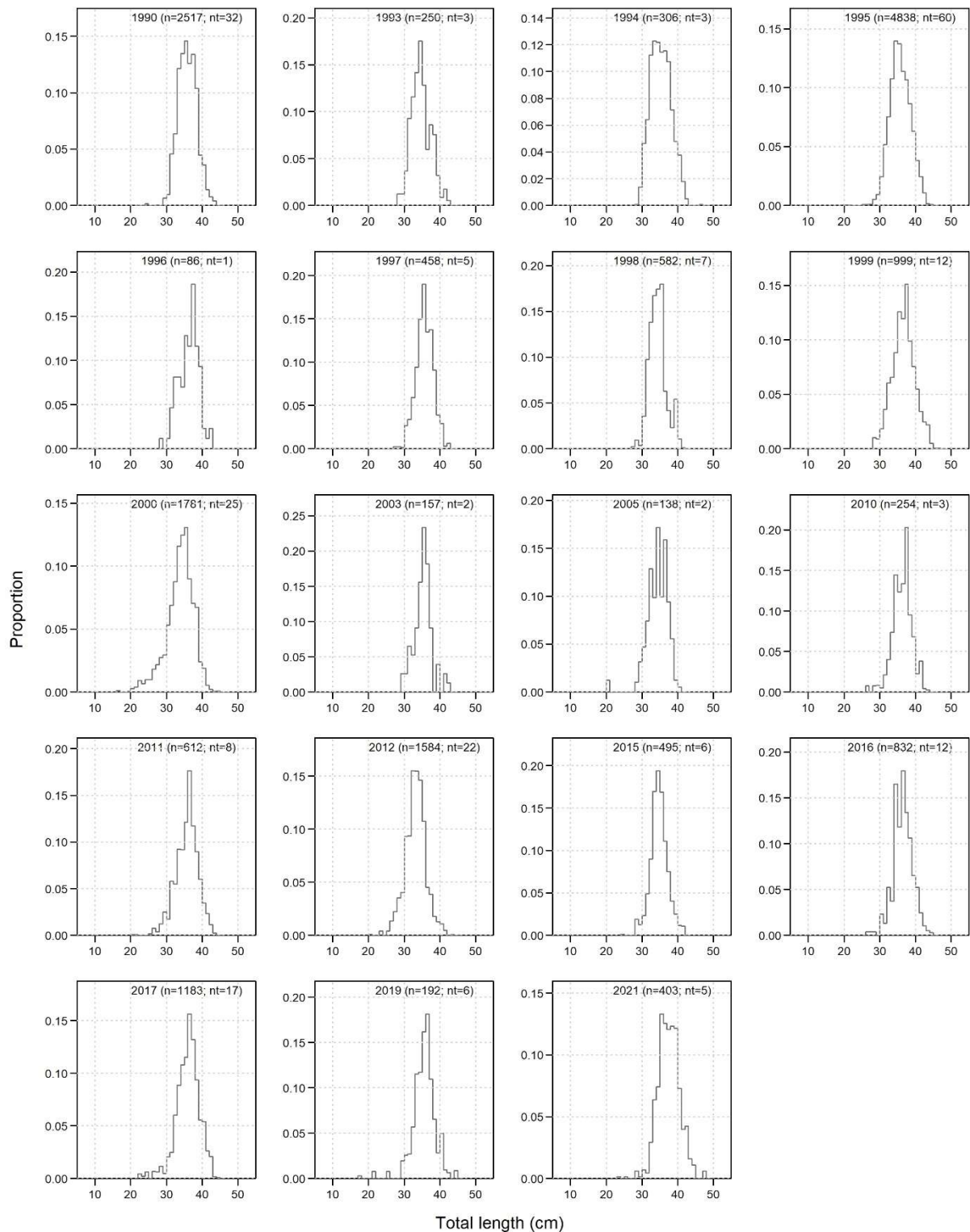


Figure A1: Catch-weighted length frequency compositions for the ‘Hill rest’ fishery. n, number of fish measured; nt, number of tows sampled. Fishing years shown as year ending (2021 means 2020–21). Samples are assumed random and are not scaled by sex.

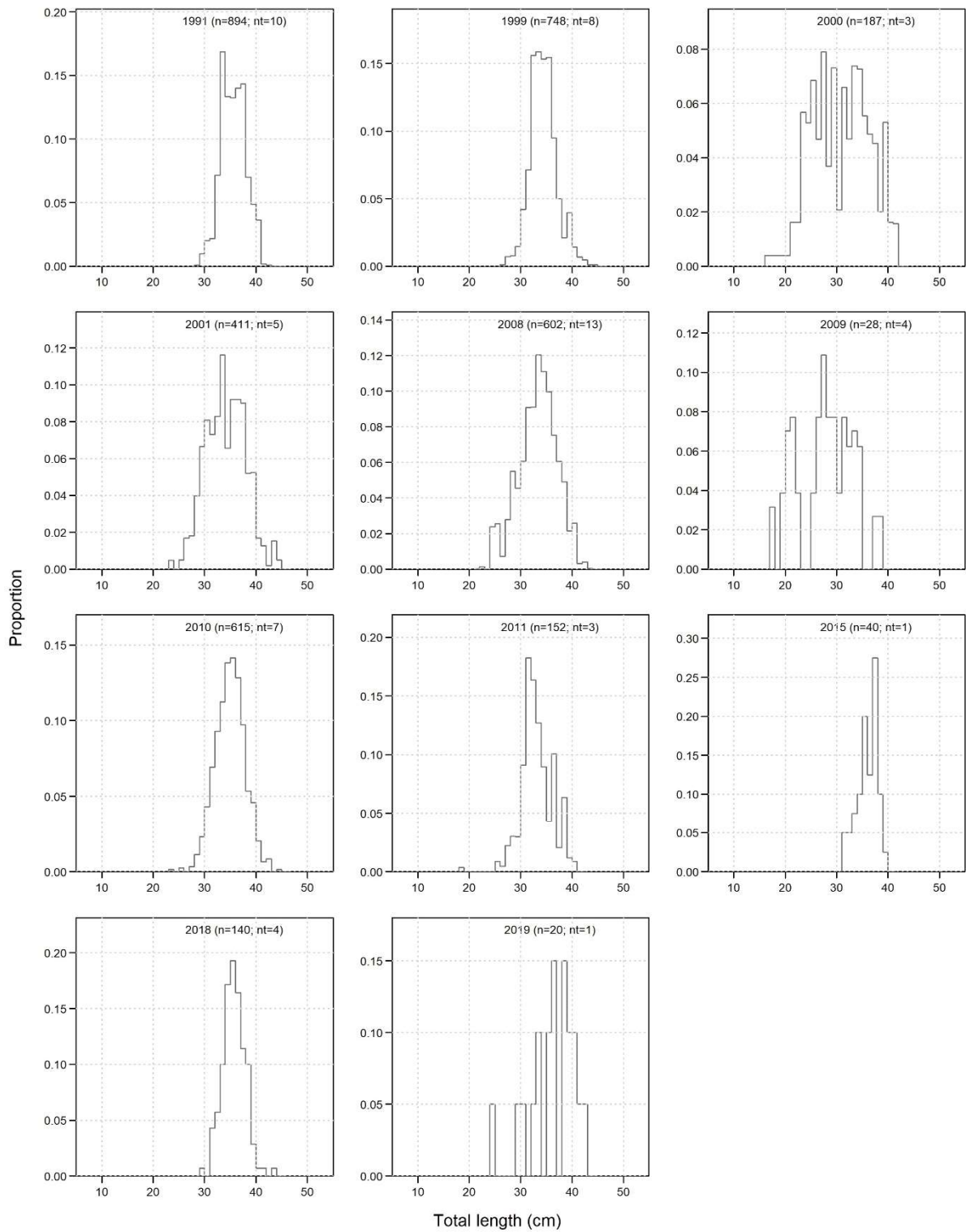


Figure A2: Catch-weighted length frequency compositions for the 'Hill summer' fishery. n, number of fish measured; nt, number of tows sampled. Fishing years shown as year ending (2021 means 2020–21). Samples are assumed random and are not scaled by sex.

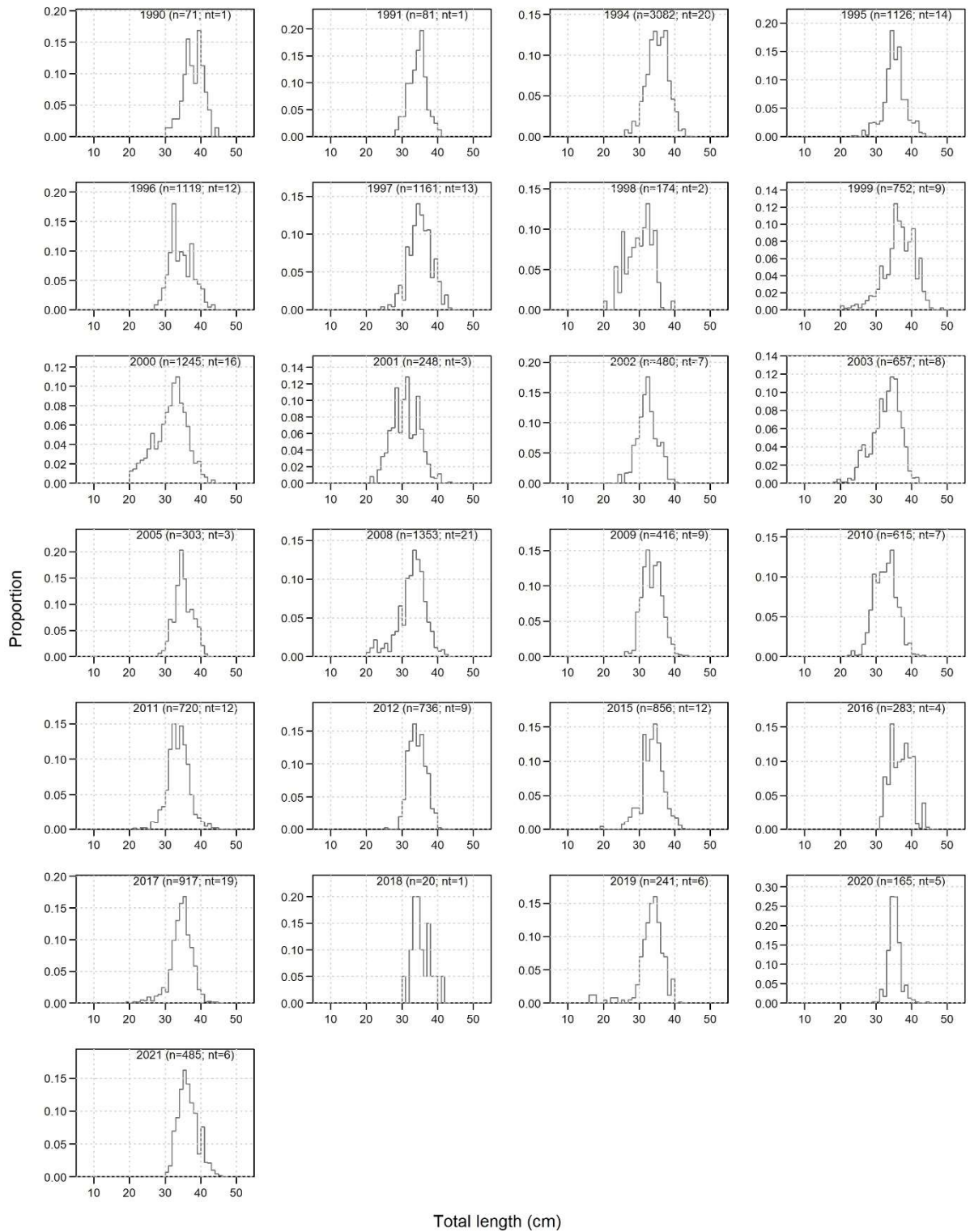


Figure A3: Catch-weighted length frequency compositions for the 'north' fishery. n, number of fish measured; nt, number of tows sampled. Fishing years shown as year ending (2021 means 2020–21). Samples are assumed random and are not scaled by sex.

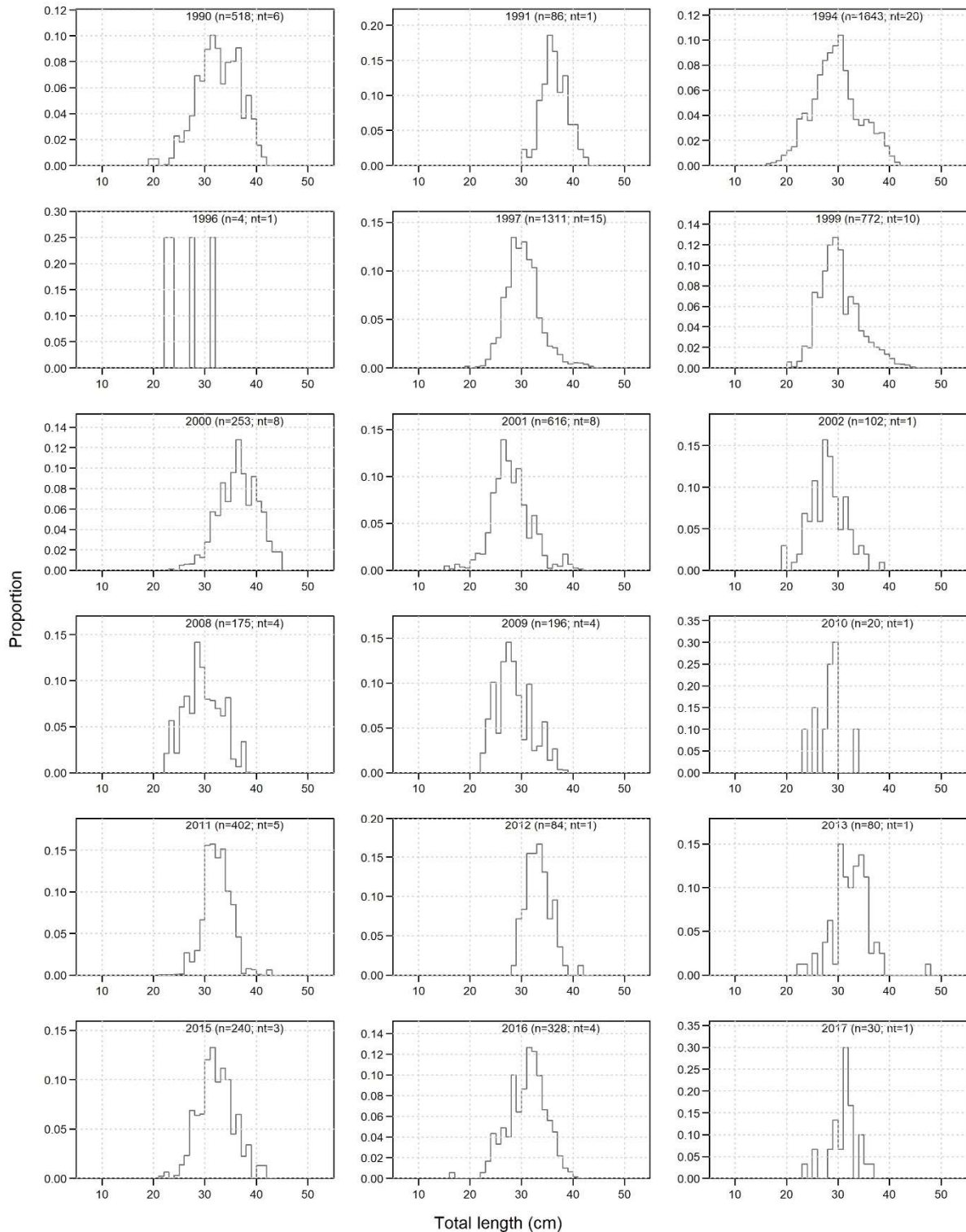


Figure A4: Catch-weighted length frequency compositions for the 'south' fishery. n, number of fish measured; nt, number of tows sampled. Fishing years shown as year ending (2021 means 2020–21). Samples are assumed random and are not scaled by sex.

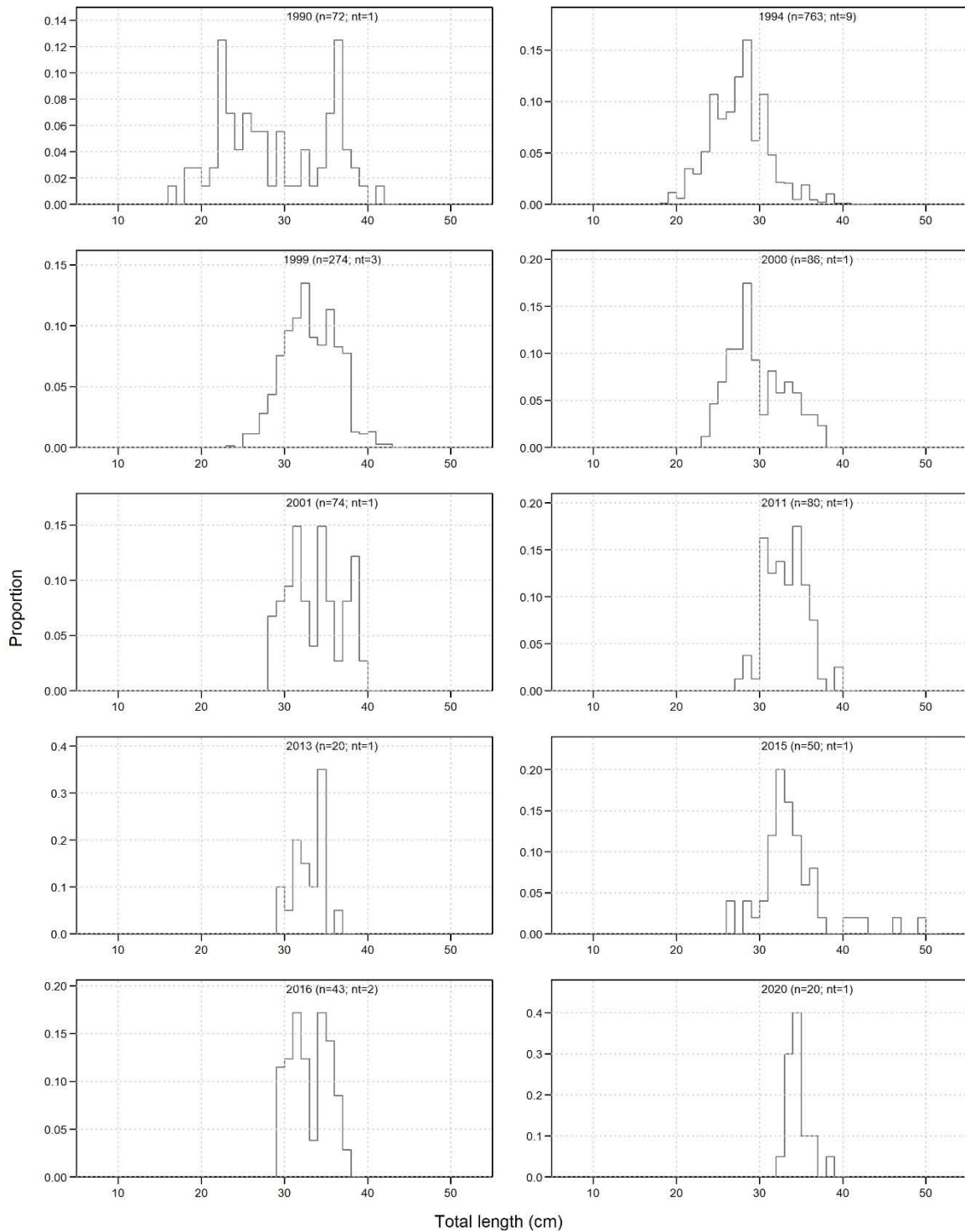


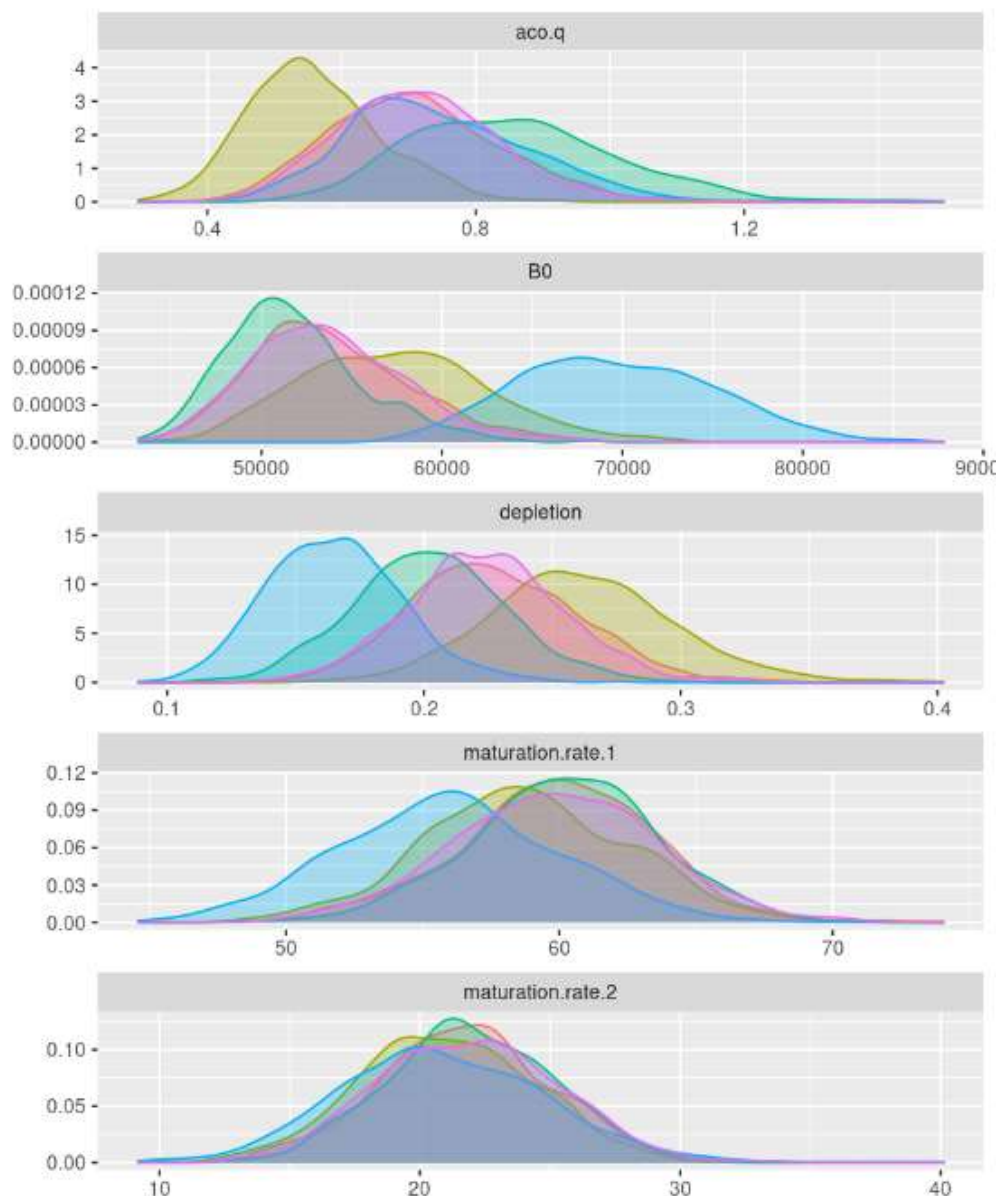
Figure A5: Catch-weighted length frequency compositions for the 'south feature' fishery (Pegasus Canyon). n, number of fish measured; nt, number of tows sampled. Fishing years shown as year ending (2021 means 2020–21). Samples are assumed random and are not scaled by sex.

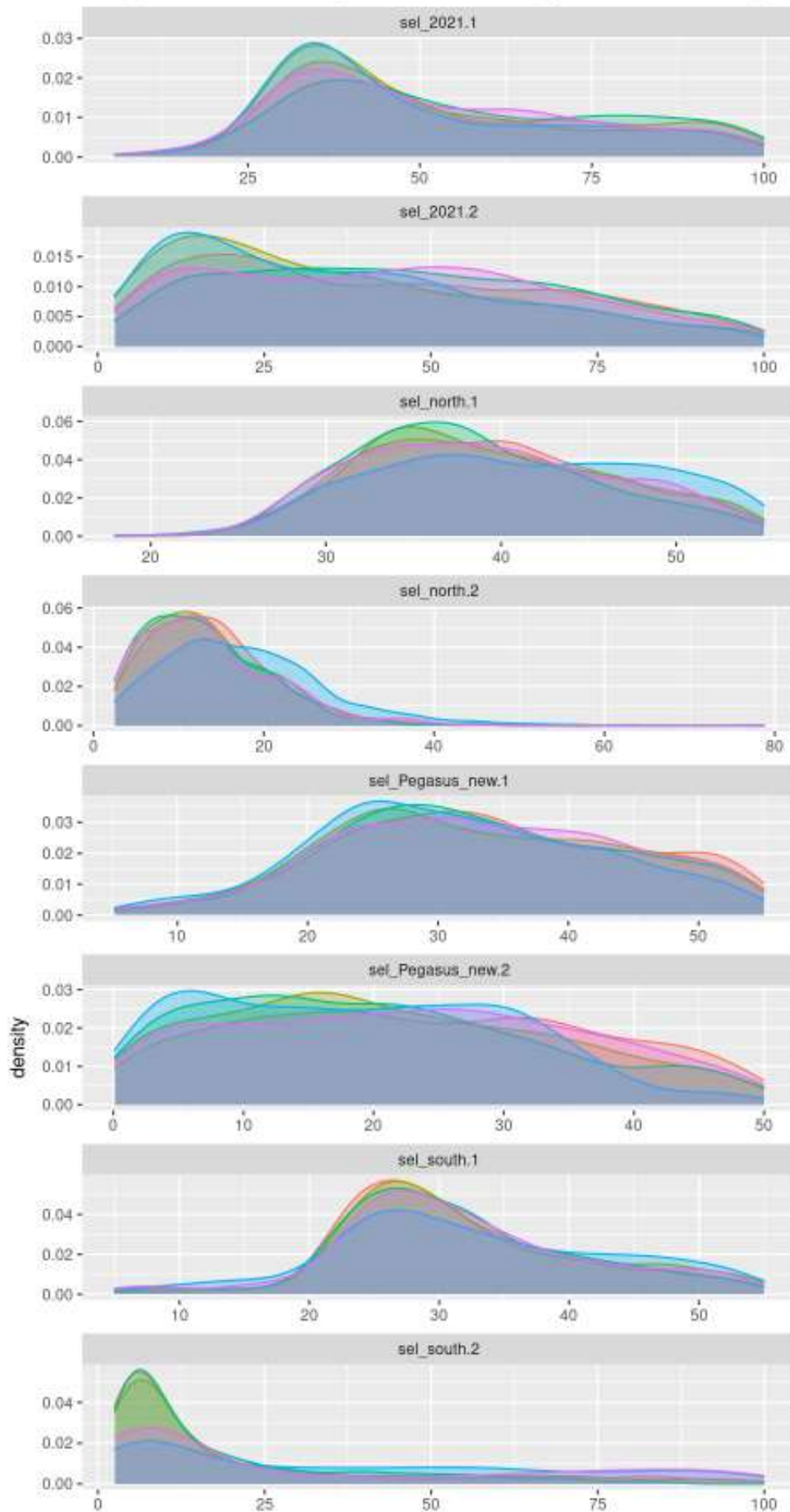
17. APPENDIX B: MCMC diagnostics

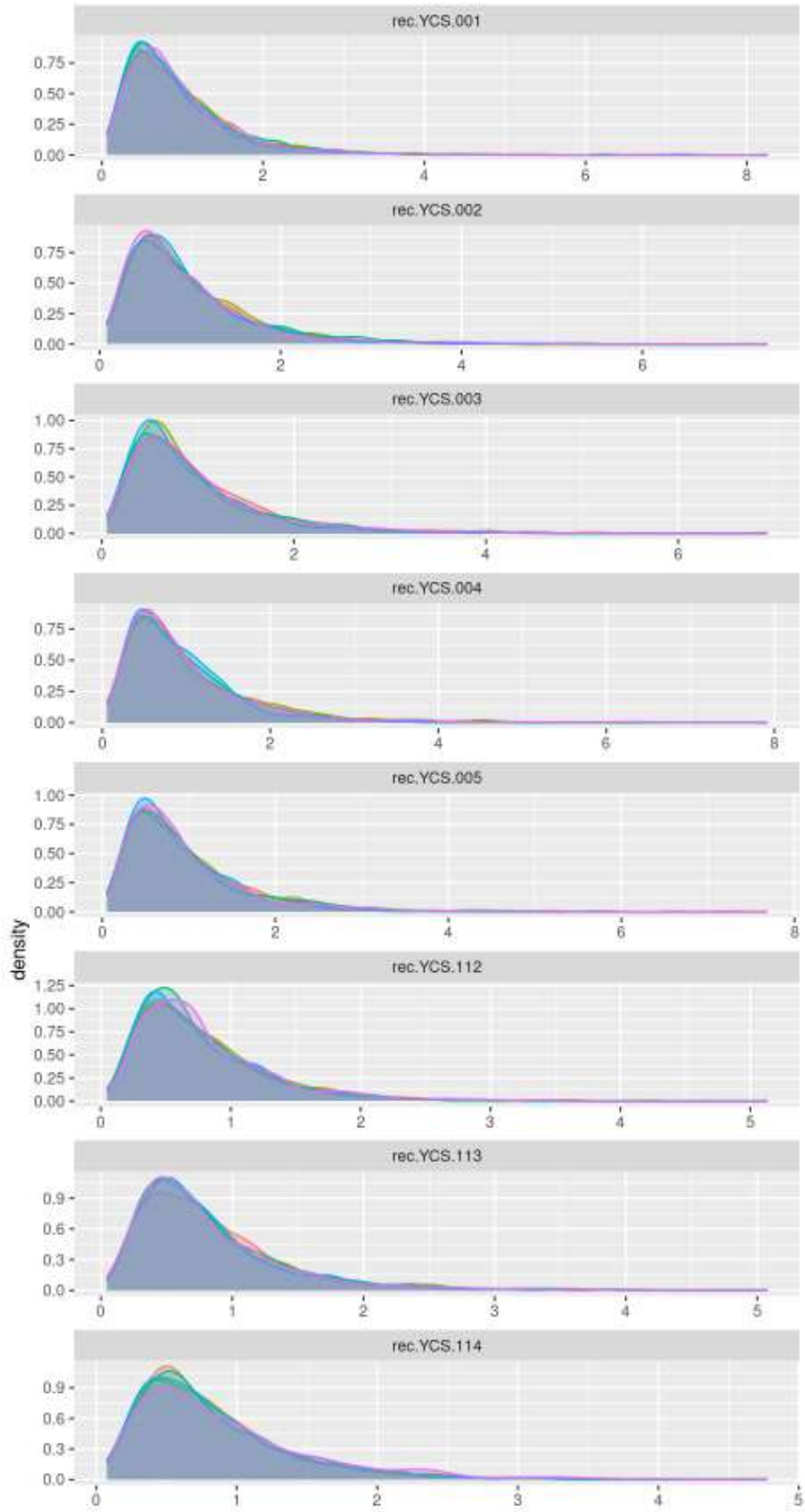
MCMC chain diagnostics for a range of model runs, diagnostics, and parameters, showing the scope of diagnostics considered and general MCMC performance of the models. The chains shown are:

Chain	
1	- base (Table 21, run 1)
2	- acoQ06 (Table 21, run 2)
3	- acoQ10 (Table 21, run 3)
4	- M035 (Table 21, run 17)
5	- Double-normal plateau (Table 21, run 6)

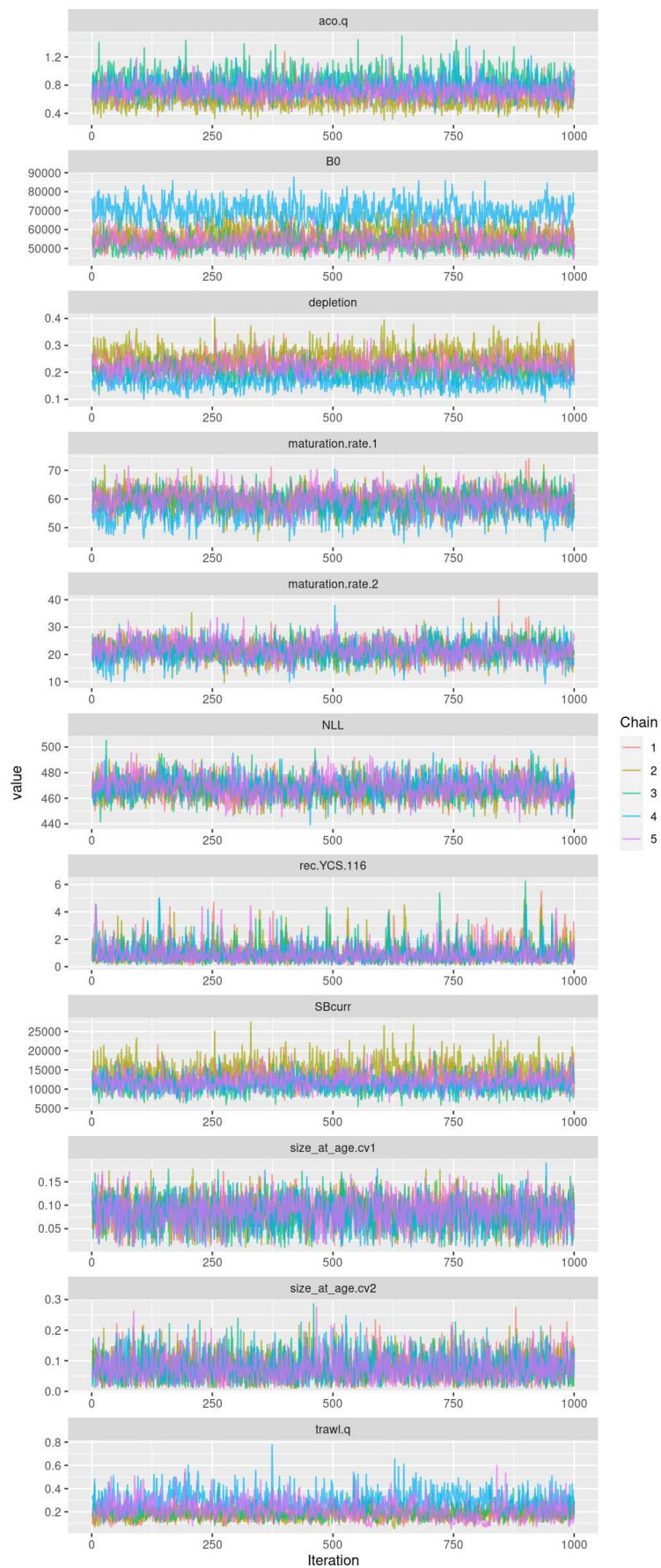
17.1 Parameter density plots



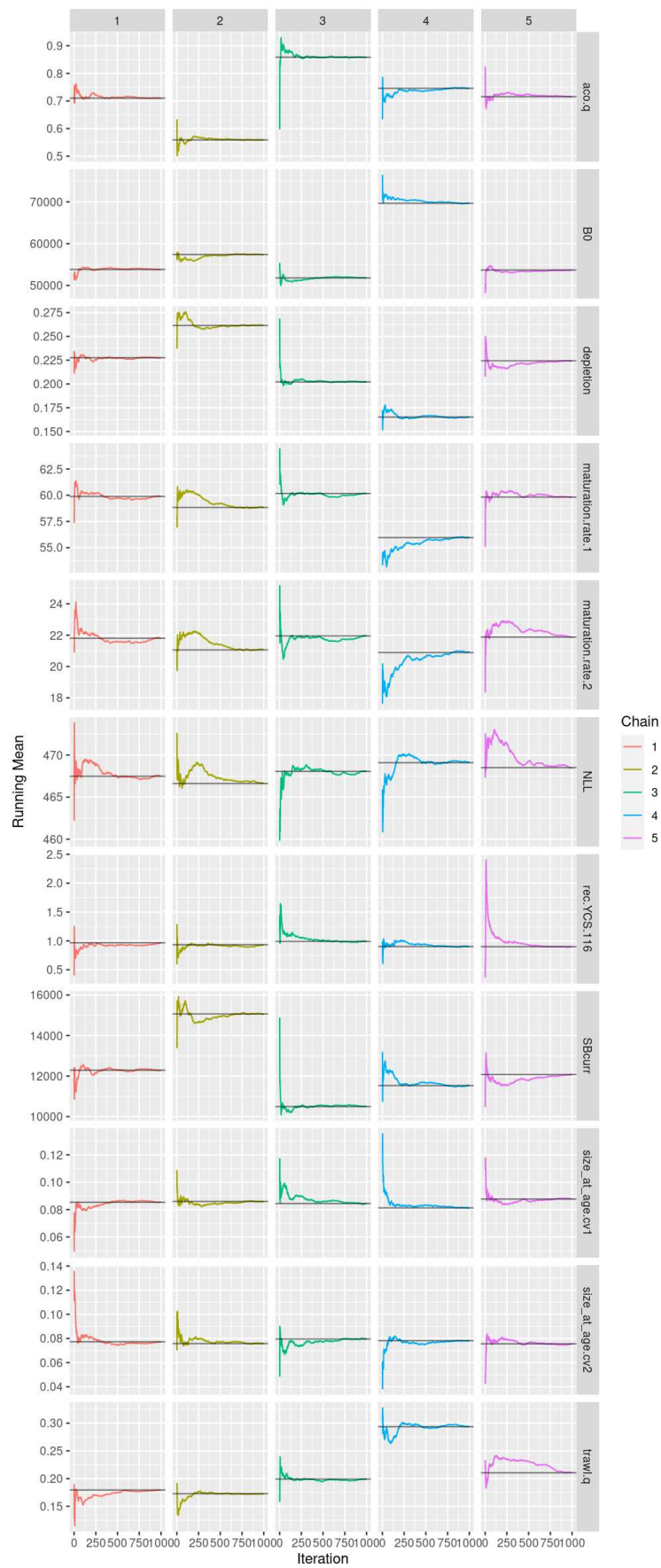




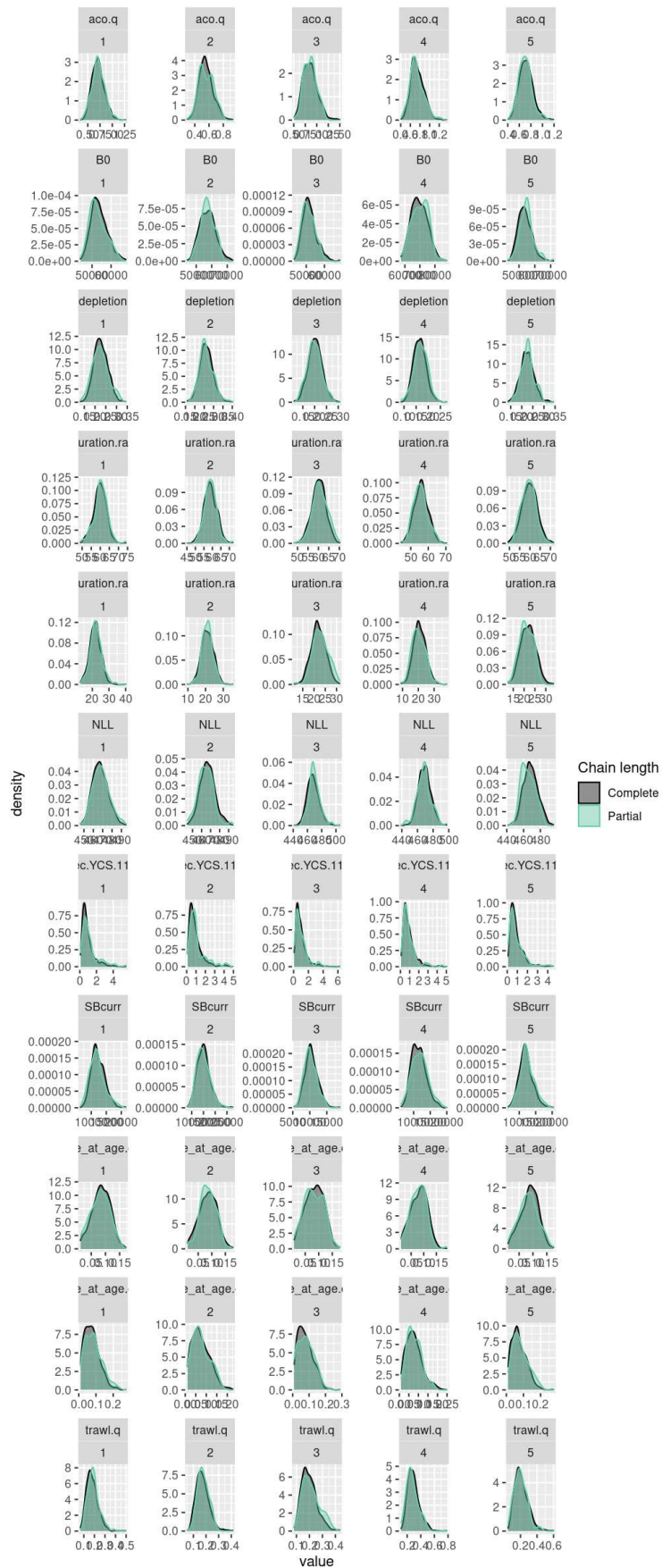
17.2 Trace plots



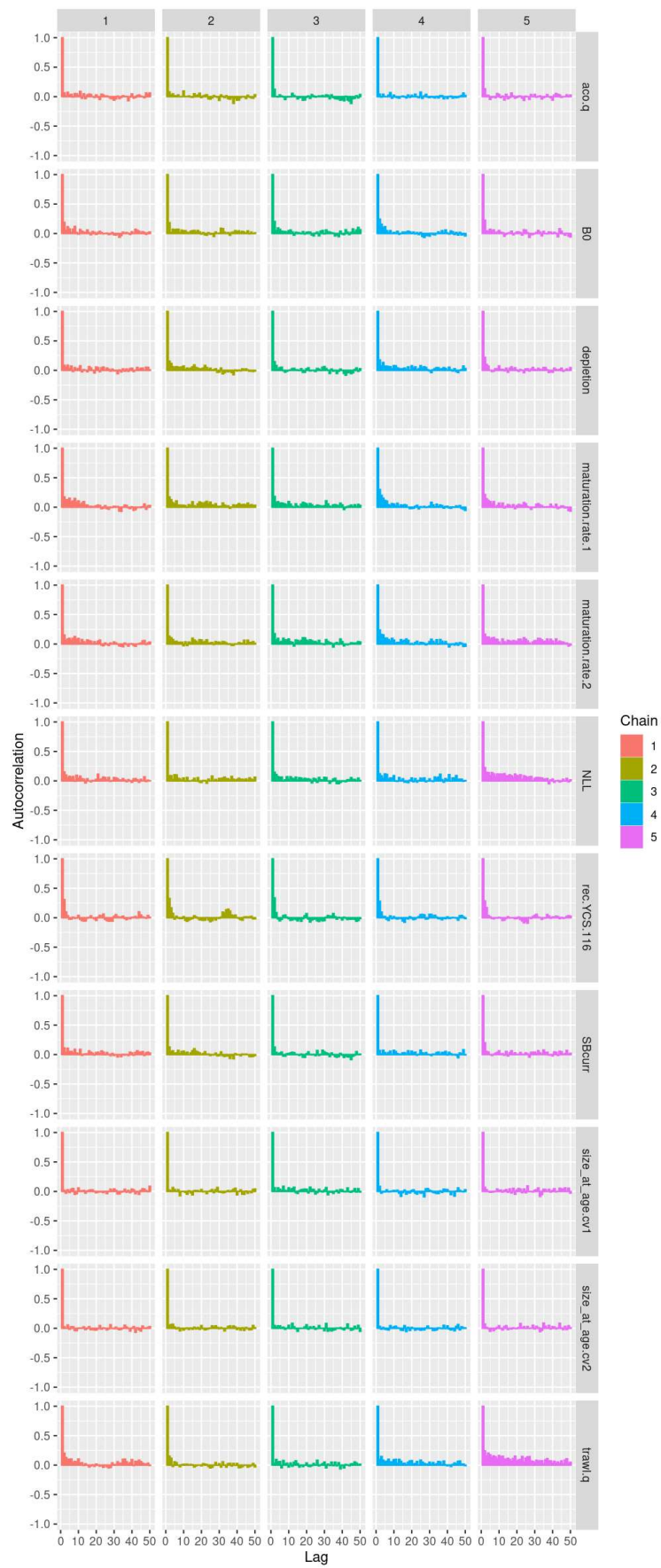
17.3 Running means



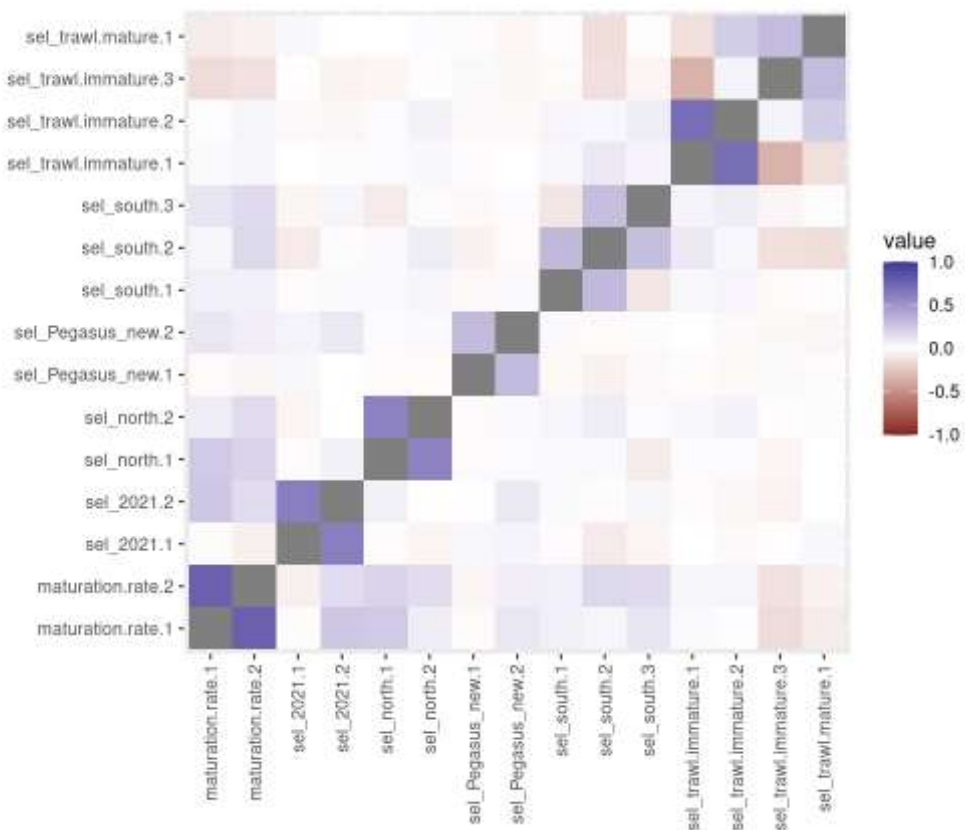
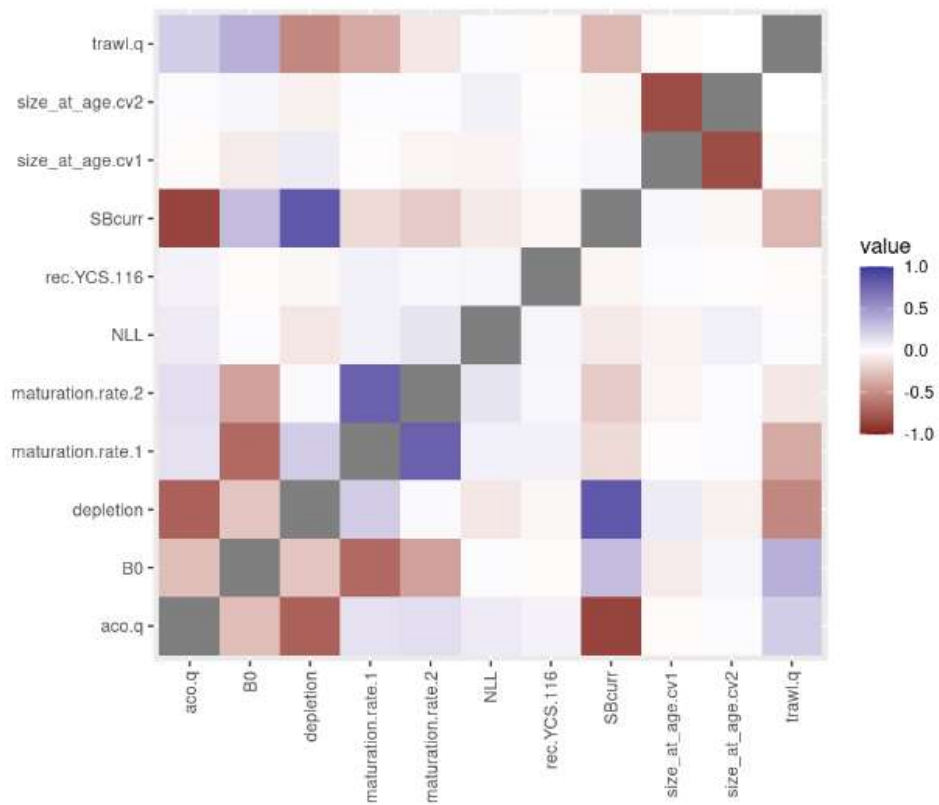
17.4 Comparison of partial and full chains



17.5 Autocorrelation



17.6 Cross-correlation



@fishery South												
years	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961
	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	2022											
catches	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	0	0	0	0	0	0	0	567	3795	7285	5975
	4312	3008	2992	3067	3261	3276	2717	2194	2240	1554	640	612
	529	492	488	366	383	181	223	371	346	368	411	329
	289	238	339	195	217	143	120	143	117	120	118	89
	89											
selectivity SELsouth												
U_max 0.95												
@fishery Hills_main												
years	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961
	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	2022											
catches	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	0	0	0	0	0	0	0	0	38	214	2000
	2907	4132	4753	4224	4871	3424	4371	4570	2493	3097	925	1126
	859	638	1154	592	637	201	250	356	518	409	459	460
	512	533	591	374	499	229	275	157	128	269	132	225
	225											
selectivity SELspawn												
U_max 0.95												
@fishery Hills_summer												
years	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961
	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	2022											
catches	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	0	0	0	0	0	0	0	0	20	139	1346
	1967	2889	3334	2960	2945	3638	2294	1466	1462	481	89	259
	315	543	217	156	84	31	63	121	54	34	63	62
	131	84	163	110	31	12	11	116	122	38	91	84
	84											
selectivity SELnorth												
U_max 0.95												
@fishery Pegasus_old												
years	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961
	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	2022											
catches	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	0	0	0	0	0	0	0	0	59	129	763
	1011	597	586	546	1005	286	340	412	392	134	0	14
	129	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
	0											
selectivity SELsouth												
U_max 0.95												
@fishery Pegasus_new												

years	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961
	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	2022											
catches	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	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
	0	149	192	158	83	101	86	141	157	144	128	158
	163	238	154	124	163	39	75	79	21	23	41	118
	118											

selectivity SELPegasus_new
U_max 0.95

@selectivity_names SELnorth SELsouth SELspawn SELtrawl SELPegasus_new SEL2021 SELvuln SELn SELs

@selectivity SELnorth
all logistic 30.3334 6.74983

@selectivity SELsouth
all double_normal 30.3334 6.74983 7.36724

@selectivity SELPegasus_new
all logistic 20 5

@selectivity SELtrawl
immature double_normal 20 5 20
mature constant 0.4

@selectivity SELspawn
mature constant 1
immature constant 0

@selectivity SEL2021
all logistic 30 5

@selectivity SELvuln
all logistic 34 8

@selectivity SELs
all logistic 24 2

@selectivity SELn
all logistic 41 12

@size_at_age_type data
@size_at_age_years 1882
@size_at_age_step 1
@size_at_age_dist normal
@size_at_age_miss mean
@size_at_age_
cv1 0.1
cv2 0.05
by_length False

male_1882 0.9 2.2 3.6 5.0 6.3 7.7 9.1 10.5 11.8 13.9 15.2 16.5 17.8 19.0 20.1 21.2 22.3 23.3 24.3 25.3 26.2 27.0 27.8 28.6 29.3
30.0 30.6 31.1 31.7 32.1 32.6 32.9 33.2 33.4 33.6 33.8 33.9 34.0 34.0 34.0 34.1 34.1 34.1 34.1 34.1 34.1 34.1 34.1 34.1 34.2
34.2 34.2 34.3 34.3 34.4 34.5 34.5 34.6 34.7 34.7 34.8 34.9 35.0 35.0 35.1 35.2 35.3 35.3 35.4 35.5 35.6 35.6 35.7 35.8
35.8 35.9 35.9 36.0 36.1 36.1 36.2 36.2 36.3 36.3 36.4 36.4 36.5 36.5 36.6 36.6 36.6 36.7 36.7 36.7 36.7 36.7 36.8 36.8 36.8 36.9
36.9 36.9 37.0 37.0 37.0 37.1 37.1 37.1 37.2 37.2 37.2 37.3 37.3 37.3 37.3 37.4 37.4 37.4 37.4 37.5 37.5 37.5 37.5 37.6
female_1882 0.9 2.4 3.8 5.2 6.7 8.1 9.6 11.0 12.4 13.9 15.2 16.5 17.7 18.9 20.1 21.2 22.3 23.4 24.4 25.4 26.3 27.3 28.1 29.0 29.8
30.5 31.3 31.9 32.6 33.1 33.6 34.0 34.3 34.5 34.8 35.0 35.1 35.2 35.4 35.5 35.6 35.7 35.8 35.9 36.0 36.1 36.2 36.3 36.3
36.4 36.4 36.5 36.5 36.5 36.6 36.6 36.6 36.7 36.7 36.7 36.8 36.8 36.8 36.9 36.9 36.9 37.0 37.0 37.0 37.1 37.1 37.1 37.2
37.2 37.2 37.3 37.3 37.3 37.4 37.4 37.5 37.5 37.5 37.6 37.6 37.7 37.7 37.7 37.7 37.8 37.8 37.9 37.9 37.9 37.9 38.0 38.0 38.1 38.1
38.1 38.2 38.2 38.2 38.3 38.3 38.4 38.4 38.4 38.5 38.5 38.6 38.6 38.6 38.7 38.7 38.7 38.8 38.8 38.8 38.9 38.9 38.9 39.0

@size_weight
a_male 6.4e-8
b_male 2.81
a_female 4.9e-8
b_female 2.89
verify_size_weight 30 0.8 1.2

@initialization
B0 140000

estimation file #
#####

Mid-East Coast

@estimator Bayes
@max_iters 4000
@max_evals 4000
@grad_tol 0.0001

@MCMC
start 0.2
length 15000000
keep 1000
stepsize 0.06
proposal_t True
df 2
adaptive_stepsize true
adapt_at 15000 50000 100000 200000 800000
burn_in 1000
subsample_size 3000
systematic False
max_cor 0.99

@relative_abundance aco
step 1
proportion_mortality 0.75
biomass True
ogive SELspawn
years 2013 2017 2021
2013 4225
2017 6969
2021 6326
cv_2013 0.20
cv_2017 0.14
cv_2021 0.20
dist lognormal
q acoq

@relative_abundance trawl
step 1
q trawlq
proportion_mortality 0.5
biomass True
ogive SELtrawl
years 1992 1993 1994 2010
1992 20838
1993 15102
1994 12780
2010 7074
cv_1992 0.29
cv_1993 0.27
cv_1994 0.14
cv_2010 0.19
dist lognormal
cv_process_error 0.2

@proportions_at AFspawn
years 1989 1990 1991 2017
step 1
proportion_mortality 0.75
sexed F
sum_to_one TRUE
at_size FALSE
plus_group TRUE
ageing_error True
ogive SELspawn
min_class 18
max_class 120

```

1989 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.004950495 0.02161716 0.00990099 0 0.03333333 0.00990099 0 0 0.00990099
0.01485149 0 0.02161716 0.004950495 0.01485149 0 0.02161716 0 0.004950495 0 0 0.00990099 0.03333333 0.04818482
0.02161716 0.004950495 0.02161716 0.03151815 0.02161716 0.02656766 0.01666667 0.004950495 0.02475248
0.01980198 0.02475248 0.03828383 0.02656766 0.004950495 0.004950495 0.01485149 0.00990099 0.004950495
0.01485149 0.00990099 0 0.01666667 0.01666667 0.04818482 0.00990099 0.004950495 0.004950495 0.004950495
0.004950495 0 0.00990099 0.004950495 0.02656766 0 0.01666667 0.01485149 0.01666667 0 0 0.02656766 0 0
0.004950495 0.00990099 0 0.01666667 0.00990099 0 0.004950495 0 0 0 0 0.02656766 0.004950495 0.02161716 0
0.004950495 0 0 0.05627063
1990 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.003448276 0.003448276 0.003448276 0.006896552 0 0.015625 0 0.01907328
0.003448276 0.0294181 0.01034483 0.003448276 0.02252155 0.01907328 0.01034483 0.0137931 0.01034483 0.003448276
0.02252155 0.03631466 0.03286638 0.01034483 0.04159483 0.006896552 0.02068966 0.006896552 0.02596983
0.006896552 0.02596983 0.01034483 0 0.06594828 0.006896552 0.02596983 0.03286638 0.03814655 0.003448276
0.02252155 0.006896552 0 0.03469828 0.01907328 0.01034483 0.01034483 0.006896552 0.003448276 0.003448276
0.003448276 0.03286638 0 0.006896552 0.003448276 0.03125 0 0.003448276 0.003448276 0.01034483 0.006896552
0.04159483 0.015625 0.006896552 0.006896552 0.006896552 0 0.01034483 0.003448276 0.003448276 0.015625
0.003448276 0.003448276 0 0.01034483 0.003448276 0.003448276 0.003448276 0 0 0 0.003448276 0.003448276 0
0.03631466
1991 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.003937008 0 0.007874016 0.007874016 0.01659524 0.01420313 0.007874016
0.003937008 0.01814014 0.007874016 0.007874016 0.01026612 0.01814014 0.02446925 0.02755906 0.007874016 0
0.01420313 0.01420313 0.01026612 0.02446925 0.02686136 0.02601415 0.02053224 0.02446925 0.05217781 0.01026612
0.02053224 0.01814014 0.03473537 0.01814014 0.02207715 0.01898734 0.01814014 0.02446925 0.01026612 0.01026612 0
0.02292435 0.003937008 0.01026612 0.01574803 0.01898734 0.01420313 0.007874016 0 0.01814014 0.02053224
0.01420313 0.006329114 0.01026612 0.01026612 0.007874016 0.03473537 0 0.007874016 0.01026612 0.006329114
0.006329114 0.01659524 0 0.006329114 0.003937008 0.003937008 0 0.007874016 0 0.003937008 0.01265823 0
0.003937008 0.006329114 0.006329114 0.003937008 0 0.007874016 0 0.01026612 0 0.003937008 0.006329114 0 0 0 0
0.0450015
2017 0 0.000647699 0.000716773 0.000647699 0.000478829 0.000648716
0.004428106 0.008427608 0.004289197 0.010790921 0.012183262 0.005957635
0.014824633 0.014271392 0.026329581 0.016198148 0.016817193 0.017885434
0.027131311 0.02130143 0.03106782 0.011874894 0.032502062 0.028450221
0.03254915 0.032045067 0.028887584 0.029808222 0.033088881 0.024307582
0.022328226 0.035610714 0.018571919 0.018970911 0.018513588 0.018142575
0.021717962 0.029557792 0.014755472 0.016560445 0.020115132 0.019818857
0.014820493 0.011048323 0.022482737 0.011830138 0.004355917 0.014872091
0.007360936 0.007818891 0.014974786 0.016660896 0.003937293 0.008373984
0.009181053 0.00730461 0.010607909 0.006885049 0.005713808 0.003624872
0.003256124 0.008987364 0.003380674 0.006586922 0.004050708 0.004600114
0.006494076 0.002303718 0.004543591 0.006950266 0.001324815 0.000861544
0.001552517 0 0.003218777 0.001621591 0.001324815 0.001893962 0
0 0 0 0.001055167 0 0 0 0.001893962 0 0
0 0 0 0 0 0 0 0 0 0 0
0.001324815 0.002300057

```

dist multinomial

r 0.00001

N_1989 13

N_1990 17.5

N_1991 20.5

N_2017 25

@proportions_at AFspawn2021

years 2021

step 1

proportion_mortality 0.75

sexed F

sum_to_one TRUE

at_size FALSE

plus_group TRUE

ageing_error True

ogive SEL2021

min_class 18

max_class 120

```

2021 0.000113287 0.000112688 0.000444115 8.55568E-05 0.00022238 0.01522793
0.004084248 0.007596346 0.005058326 0.008109364 0.01222534 0.03237519
0.01112723 0.02072145 0.0107246 0.03169952 0.009928178 0.04681288
0.03636131 0.04575621 0.02611825 0.02902655 0.03942187 0.04949989
0.04202723 0.02871995 0.02408052 0.03948906 0.0430301 0.0316127
0.04478943 0.02279815 0.02646074 0.01610971 0.02367834 0.02400226
0.01165626 0.01542149 0.01622596 0.0117907 0.009734926 0.01182571
0.01125114 0.005190709 0.008205582 0.007279575 0.004128478 0.000592783
0.01166637 0.003682566 0.004707572 0.004237571 0.0037079 0.003597009
0.0037079 0.003597009 0.003597009 0.000555005 0.003720344 0.007527243
0.000148668 8.55568E-05 0.0037079 0.00011089 0.003930234 0 0
0 0.000333224 0 0 0.003597009 0 0 0 0
0 0 0 0 0 0 0 0 0

```

0.003597009 0 0 3.77777E-05 0 0 0 0 0 0
0 0 0 0.007194018
dist multinomial
r 0.00001
N_2021 25

@proportions_at AF2010
years 2010
step 1
proportion_mortality 0.75
sexed F
sum_to_one TRUE
at_size FALSE
plus_group TRUE
ageing_error True
ogive SELspawn
min_class 20
max_class 120
2010 0 0 0 0 0.0008569541 0.00738454 0.01105906 0 0 0.00738454 0.0002884425 0.01083565 0.00738454 0 0.0154158
0.008031263 0.008587893 0.01207627 0.04663494 0.01099546 0.03192034 0.009134918 0.01463622 0.03680318
0.01145306 0.03312438 0.009478425 0.02739578 0.008031263 0.03211817 0.01282013 0.01156077 0.06861253
0.03704274 0.03099879 0.006540953 0.01701115 0.01807374 0.009473022 0.02430277 0.001780238 0.00738454
0.01250276 0.0424366 0.01836219 0.006329673 0.01829331 0 0.0406665 0.01135584 0.004280971 0.02370649
0.0004038196 0 0.01638619 0.007672983 0.0172267 0.003971296 0.01940522 0.01267348 0.01505752 0.00738454 0
0.002600658 0.0006922621 0.01596809 0.03862918 0 0 0.0004038196 0 0.006050017 0 0 0.00738454 0.003971296
0.00738454 0 0.00738454 0 0 0 0.02367885 0 0 0 0 0 0 0 0 0 0 0.001103655
dist multinomial
r 0.00001
N_2010 20

@proportions_at AFtrawl
years 1993 2010
step 1
proportion_mortality 0.5
ogive SELtrawl
sexed F
sum_to_one True
at_size False
min_class 10
max_class 100
plus_group True
ageing_error True
1993 0 0 0.00163 0.00804 0.01833 0.04376 0.04505 0.03249 0.07162 0.05118 0.05558 0.07139 0.06942 0.09030 0.10252
0.07508 0.05355 0.04137 0.05142 0.01761 0.01476 0.01697 0.01660 0.00288 0.00316 0.00372 0.00754 0.00597 0.00234
0.00087 0.00047 0.00061 0.00148 0.00341 0.00302 0.00063 0.00000 0.00253 0.00088 0.00100 0.00008 0.00000 0.00000
0.00026 0.00008 0.00095 0.00027 0.00016 0.00000 0.00024 0.00000 0.00187 0.00021 0.00041 0.00036 0.00092 0.00000
0.00005 0.00047 0.00000 0.00000 0.00067 0.00008 0.00059 0.00026 0.00054 0.00000 0.00000 0.00029 0.00010 0.00021
0.00000 0.00047 0.00000 0.00000 0.00000 0.00000 0.00047 0.00008 0.00005 0.00000 0.00000 0.00000 0.00000 0.00005
0.00000 0.00000 0.00000 0.00017 0.00000 0.00000
2010 0.00412 0.02428 0.00740 0.02305 0.02692 0.02117 0.01857 0.01954 0.03591 0.04367 0.02330 0.03533 0.05091
0.04214 0.06975 0.05477 0.08077 0.03580 0.08743 0.03967 0.03327 0.03762 0.02308 0.03218 0.01185 0.01690 0.01660
0.01245 0.00998 0.00360 0.00540 0.00430 0.00772 0.00170 0.00338 0.00048 0.00135 0.00600 0.00277 0.00392 0.00049
0.00000 0.00024 0.00404 0.00036 0.00192 0.00123 0.00170 0.00000 0.00000 0.00226 0.00030 0.00000 0.00030 0.00000
0.00000 0.00049 0.00086 0.00000 0.00085 0.00000 0.00030 0.00000 0.00042 0.00205 0.00044 0.00000 0.00000 0.00030
0.00000 0.00000 0.00121 0.00011 0.00000 0.00000 0.00024 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
dist multinomial
r 0.00001
N 20

@proportions_at LFtrawl9294
years 1992 1994
step 1
proportion_mortality 0.5
sexed F
sum_to_one True
at_size True
plus_group False
ogive SELtrawl
class_mins 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43
44 45 46 47
1992 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.001 0.005 0.010 0.015 0.020 0.025 0.030 0.039 0.053 0.059
0.074 0.071 0.082 0.091 0.078 0.076 0.059 0.052 0.039 0.037 0.025 0.021 0.014 0.009 0.007 0.004 0.002 0.001 0.000 0.000
0.000 0.000

class_mins	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48				
2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00461	0.00922	0.01843	0.02995	0.03687	0.07143	0.07834	0.08756	0.10599	0.11751	0.07604	0.09677	0.08756	0.053	0.07143
	0.02995	0.00922	0.00691	0.00461	0.00461	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	0	0	0	0	0	0	0
2016	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	0	0	0	0	0	0	0	0	0	0	0	0.00939
	0.00469	0.02347	0.04695	0.09859	0.13146	0.14085	0.12676	0.20188	0.0892	0.07512	0.01408	0.00469	0.00939	0.00469	0.00469	0.00469	0	0	0	0	0	0	0.00469	0.00469	0.00469	0.00469	0.00469	0.00939	0.00469	0.00469	0.00469	0.00469	0.00469	0.00469	0.00469	0.00469	0.00469

dist multinomial
r 0.00001
N_2000 5
N_2016 6

@estimate
parameter initialization.B0
lower_bound 10000
upper_bound 500000
prior uniform-log
phase 1

@q_method free

@q acoq
q 0.8

@q trawlq
q 0.5

@estimate
parameter q[acoq].q
prior lognormal
mu 0.8
cv 0.19
lower_bound 0.1
upper_bound 1.5

@estimate
parameter q[trawlq].q
lower_bound 1e-2
upper_bound 10
prior uniform-log

@estimate
parameter maturation[1].rates_all
lower_bound 10 2.5
upper_bound 100 100
prior uniform
phase 1

@estimate
parameter size_at_age.cv1
lower_bound 0.01
upper_bound 1
prior uniform

@estimate
parameter size_at_age.cv2
lower_bound 0.01
upper_bound 1
prior uniform

@estimate
parameter selectivity[SELnorth].all
lower_bound 5 2.5
upper_bound 55 100
prior uniform
phase 1

@estimate
parameter selectivity[SELSouth].all
lower_bound 5 2.5 2.5
upper_bound 55 100 100
prior uniform
phase 1

@estimate

parameter selectivity[SELtrawl].immature
 lower_bound 5 2.5 1
 upper_bound 50 50 100
 prior uniform
 phase 1

@estimate
 parameter selectivity[SELtrawl].mature
 lower_bound 0.001
 upper_bound 1
 prior uniform
 phase 1

@estimate
 parameter selectivity[SELPegasus_new].all
 lower_bound 5 0.1
 upper_bound 55 50
 prior uniform
 phase 1

@estimate
 parameter selectivity[SEL2021].all
 lower_bound 5 2.5
 upper_bound 100 100
 prior uniform
 phase 1

@estimate
 parameter recruitment.YCS
 lower_bound 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1
 upper_bound 10 10 10 10 10 10 10 10 10 10 10 10
 10 10 10 10 10 10 10 10 10 10 10 10
 10 10 10 10 10 10 10 10 10 10 10 10
 10 10 10 10 10 10 10 10 10 10 10 10
 10 10 10 10 10 10 10 10 10 10 10 10
 10 10 10 10 10 10 10 10 10 10 10 10
 10 10 10 10 10 10 10 10 10 10 10 10
 10 10 10 10 10 10 10 10 10 10 10 10
 10 10 10 10 10 10 10 10 10 10 10 10
 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1
 prior lognormal
 mu 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1
 cv 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8

0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8

@ageing_error
type normal
c 0.1

@catch_limit_penalty
label CPenNorth
fishery North
multiplier 100
log_scale True

@catch_limit_penalty
label CPenSouth
fishery South
multiplier 100
log_scale True

@catch_limit_penalty
label CPenHills_main
fishery Hills_main
multiplier 100
log_scale True

@catch_limit_penalty
label CPenHills_summer
fishery Hills_summer
multiplier 100
log_scale True

@catch_limit_penalty
label CPenPegasusNew
fishery Pegasus_new
multiplier 100
log_scale True

@catch_limit_penalty
label CPenPegasusOld
fishery Pegasus_old
multiplier 100
log_scale True

@vector_average_penalty
label YCS_average_1
vector recruitment.YCS
k 1
multiplier 20