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Assessment of the Challenger Plateau orange roughy stock for 2024

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Tini a Tangaroa

Assessment of the Challenger Plateau orange roughy stock for 2024

New Zealand Fisheries Assessment Report 2024/58

M.R. Dunn

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PLAIN LANGUAGE SUMMARY:

This report describes research done on an orange roughy fishery on the Challenger Plateau, west of New Zealand, including a small area outside of New Zealand's Exclusive Economic Zone known as Westpac Bank. The stock was assessed used a computer population model fitted to various data. Those data were fishery catches, scientific surveys of the spawning grounds using bottom trawls and acoustic methods, and estimated ages of the fish, The newest data available to the research was an estimate of the size of the spawning stock in 2023 from a survey.

Some substantial changes were made to the way the modelling was done. The most important was that estimates of the size of the stock from different areas on the Challenger were added up to give a total stock size. Previously, three areas (Volcano, West, and East) had been treated independently. There were other changes to the way the productivity of the stock was estimated, the relative importance given to each of the data sets, which data sets were included in the model, with some other changes to the statistical settings of the model.

The size of the stock before fishing started (the virgin spawning stock size, B_0), was estimated to be about 99 400 t, and the stock in 2024 reduced to about 35% of this level. The future productivity of the stock was a concern. The stock was substantially reduced by fishing in the 1980s and 1990s, and if that caused a reduction in reproduction, then the consequences will now be felt, as a current reduction in the numbers of young fish arriving into the fishery.

EXECUTIVE SUMMARY

Dunn, M.R.[1] (2024). Assessment of the Challenger Plateau orange roughy stock for 2024.

***New Zealand Fisheries Assessment Report 2024/58.* 42 p.**

This report describes the assessment of the southwest Challenger Plateau and Westpac Bank orange roughy stock (quota management area ORH 7A) completed in May 2024. 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 main data sets used were fishery catches, spawning ground trawl surveys, acoustic biomass surveys of spawning aggregations, and age frequency compositions. The new data available for the 2024 assessment were catches since 2017–18, and an acoustic biomass survey estimate for 2023.

The 2024 assessment differed substantially from the previous (2019) assessment. The most notable change was that the acoustic biomass estimates for the three known spawning areas (Volcano, West, and East) were summed and used as a single index, rather than each assumed to provide an independent index of spawning stock biomass (SSB). Additional changes were that one fishery was modelled instead of two; recruitment was assumed to be deterministic and the natural mortality rate (M) was estimated rather than recruitment estimated and M fixed; an empirical prior was used in the estimation of M; the statistical weighting of the age data were substantially reduced; the FV *Amaltal Explorer* trawl survey series was excluded (considered to be implausible/biased); and the informed q prior on the FV *Thomas Harrison* trawl survey and the B_0 prior were set to uniform.

The virgin spawning stock size (B_0) in the base case model run was estimated to be 99 400 t (95% CI 87 600 – 117 200 t), and stock status (B_{2024}/B_0) was estimated to be 35% (16–57%). Incoming recruitment was influenced by the stock-recruitment relationship and was assumed be declining because of the spawning stock biomass (SSB) reduction in the 1980s. As a result, the stock was estimated to be slowly declining. At the current Total Allowable Commercial Catch (TACC), the stock was expected to continue to decline. To fully arrest the decline, the model estimated a (TACC) cut of 57% would be required.

Summary
This report updates the Challenger and Westpac Bank orange roughy stock assessment for 2024. The fishery, observational data from trawl surveys, acoustic surveys, and age composition data, and the assessment model structure and assumptions, are described. The stock was estimated to be within the lower end of the target zone and declining. The assessment was accepted for providing scientific advice.

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

1. INTRODUCTION

The New Zealand orange roughy (*Hoplostethus altanticus*) Challenger Plateau stock consists of Quota Management Area ORH 7A and a hill area just outside of New Zealand's Exclusive Economic Zone (EEZ) known as Westpac Bank (Figures 1 and 2). This report describes a fisheries characterisation using fisheries data to the end of the 2022–23 fishing year (New Zealand fishing years start on 1 October), and a stock assessment completed in 2024. 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 2019 (Cordue 2019; Fisheries New Zealand 2023).

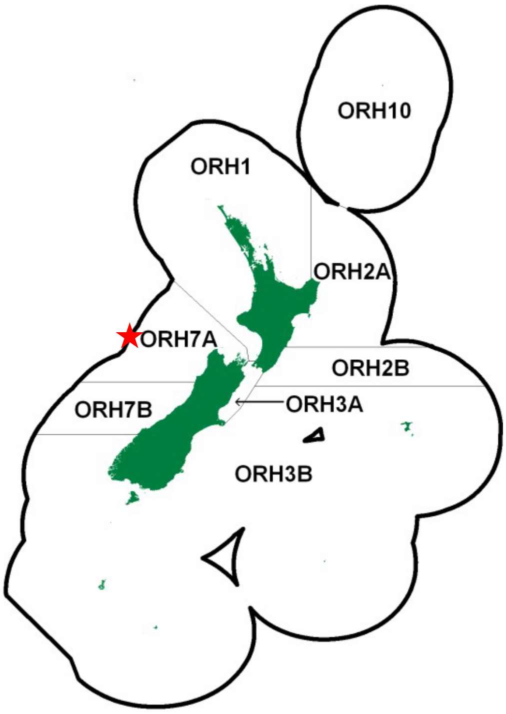

Figure 1: New Zealand Quota Management Areas for orange roughy. The star shows the approximate position of the orange roughy spawning ground and survey area (Figure 2).

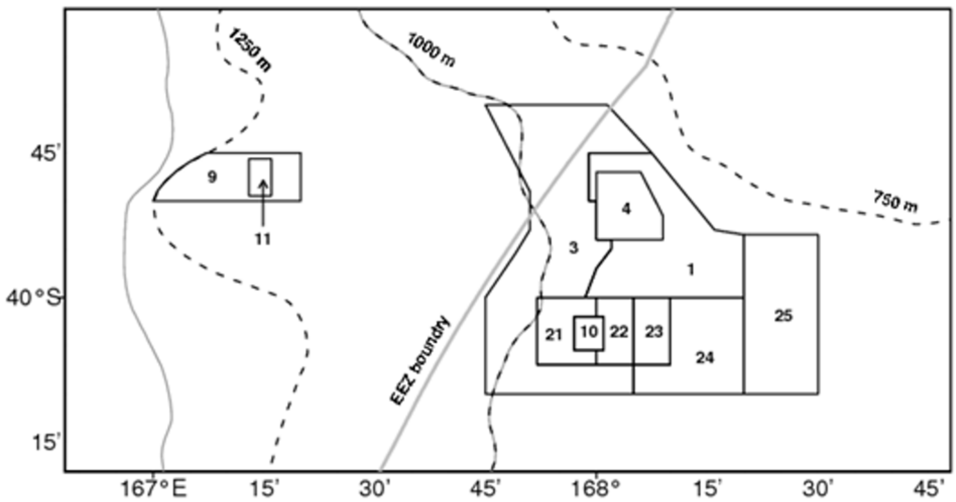

Figure 2: Location of the core survey strata for trawl surveys of orange roughy on Challenger Plateau. The Central Flat (historical main spawning ground) is stratum 4; the Westpac Bank is strata 9 (bank) and 11 (hill features); the Pinnacles are in stratum 10. Figure reproduced from Doonan et al. (2018).

The work described in this report was carried out under Fisheries New Zealand project ORH2022–01 Stock assessment of orange roughy on the southwest Challenger Plateau (including Westpac Bank) (ORH 7A), having the specific objectives:

(1) To carry out a descriptive analysis of the commercial catch and effort data, survey data, and observer data for orange roughy in ORH 7A and the Westpac Bank, and

(2) To complete stock assessments of ORH 7A, including Westpac Bank, for the 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 Challenger Plateau and Westpac Bank 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 were presented to the Fisheries New Zealand Deepwater Working Group on 13 June 2023 and 27 February 2024.

Catch and effort data were requested for all trips within which at least one event (tow) caught or targeted orange roughy (FNZ extract 15447_rerun_15096). 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 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.

2.1 Catch distribution

Maps of the historical catch distribution were presented to the Fisheries New Zealand Deepwater Working Group on 13 June 2023 and 27 February 2024 but are not shown here due to Fisheries New Zealand data reporting rules. Through the 1980s and into the 1990s the orange roughy target fishery was focused on the Central Flats, Pinnacles, and Westpac Bank area (the area included in the research surveys), with the footprint increasing from 1997 as the stock and catch rates declined and the fishery expanded to the south, the footprint peaking in 2000 before the fishery was closed in October 2000 (Figure 3). When the fishery was reopened in 2011 it was again predominantly within the research survey area, although no spawning aggregation was found on the Central Flats. From 2017 the fishing footprint started to again increase, spreading south notably from 2021, with a centre of catches in the southern area in 2023. The overall fishing footprint increased again from 2015 and by 2023 reached a level similar to that in the late 1990s, although the footprint after 2015 included areas new to the fishery.

2.2 Summary statistics

During the spawning season (late June to early July), the overall orange roughy target fishing when the fishery was reopened was almost entirely short tows (on features or aggregation). Tow duration increased from 2018 to a median of 4.55 hours in 2023, with catch rates over the same period reducing from about 5–10 t/hr to 1–2 t/hr, and the incidence of large catches (>10 t) decreasing from >50% to 1% (Table 1).

During the non-spawning season effort has recently increased substantially to a peak in 2022, with tow duration increasing to about 8 hours, and recently no catches greater than 10 t (Table 2). Recent catch rates have declined to a relatively low level, although not quite as low as seen in the late 1990s.

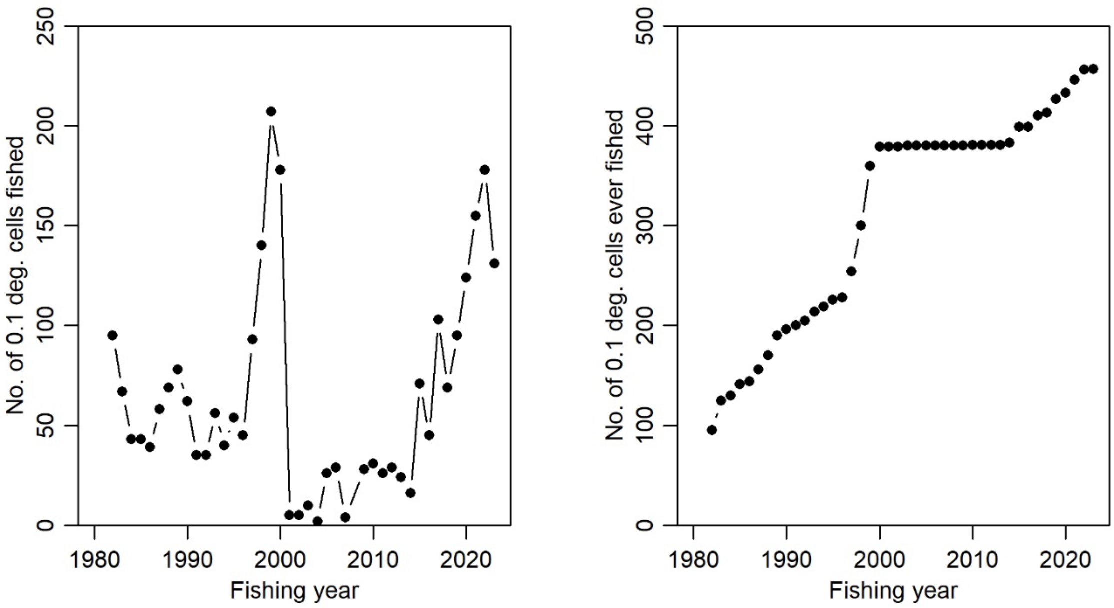

Figure 3: Fishing footprint of the ORH 7A including Westpac Bank bottom trawl fishery targeting orange roughy, expressed as the number of 0.1° latitude and longitude cells fished.

2.3 Unstandardised Catch-Per-Unit-Effort

Unstandardised catch per unit effort (CPUE) for orange roughy target fishing on pinnacle/hill areas (defined as <1 hour tow duration and less than 4.5 n.mile from the top of a feature), short tows on the flat in the north (assumed fishing on aggregations; north of 40.3°S), and flat areas (i.e., not hill), decreased during the 1980s and 1990s and reached an historical low in 1999 or 2000 (Figures 4). Catch rates were moderate compared to historical levels when the fishery reopened and then remained at a similar level with a few outliers. However, the effort reallocated substantially since the reopening, with effort on pinnacles or short tows in the north decreasing, and effort on flat ground in the south increasing (Figure 5); this is a move from areas where catch rates were highest to where they were lowest.

Table 1: Orange roughy catch and effort summary for Challenger Plateau and Westpac Bank (ORH 7A), for bottom trawls targeting orange roughy during June and July. Vessels, number of vessels catching orange roughy; Catch, estimated catch in tonnes; Tows, number of tows; Hours, total hours fished; Duration, median tow duration (decimal hours); Duration<1, percentage of tows with duration less than one hour; t/tow, total catch divided by total number of tows; t/hr median tonnes/hours for tows where duration was recorded. Data not shown where there were less than three vessels.

Fishing year	Vessels	Tows	Target	Catch	t/tow	>10t	Duration	Duration<1	Hours	t/hr
1990	16	564	100	2 674	4.74	13.1	0.67	54.3	1 025	2.61
1991	9	278	100	1 308	4.71	11.9	3.50	21.3	902	1.45
1992	11	433	100	1 874	4.33	11.1	2.70	37.8	1 120	1.67
1993	12	679	100	1 895	2.78	4.9	2.98	35.5	1 854	1.02
1994	11	476	100	1 609	3.38	8.2	2.80	33.7	1 168	1.38
1995	14	382	100	1 580	4.14	9.4	1.97	31.8	907	1.74
1996	12	474	100	1 609	3.39	7.4	3.08	29.4	1 369	1.18
1997	16	671	100	1 237	1.84	2.2	4.03	24.7	2 537	0.49
1998	15	778	100	1 420	1.83	2.7	4.33	11.4	3 230	0.44
1999	11	752	100	826	1.10	0.4	4.75	12.9	3 460	0.24
2000	10	303	100	416	1.37	1.7	4.25	3.4	1 383	0.30
2001	1	–	–	–	–	–	–	–	–	–
2002	2	–	–	–	–	–	–	–	–	–
2003	3	12	100	22	1.80	0	4.82	0	5	4.49
2004	1	–	–	–	–	–	–	–	–	–
2005	3	86	100	188	2.19	4.7	0.47	100	25	7.62
2006	5	93	100	227	2.43	9.7	0.45	100	29	7.80
2007	2	–	–	–	–	–	–	–	–	–
2008	0	–	–	–	–	–	–	–	–	–
2009	3	94	100	253	2.69	6.4	0.48	87.2	48	5.25
2010	1	–	–	–	–	–	–	–	–	–
2011	3	100	100	412	4.12	15.0	0.50	84.0	76	5.44
2012	3	84	100	410	4.88	15.5	0.50	91.7	50	8.24
2013	3	99	100	434	4.38	14.1	0.43	85.9	68	6.35
2014	1	–	–	–	–	–	–	–	–	–
2015	2	–	–	–	–	–	–	–	–	–
2016	4	69	100	769	11.14	39.1	0.5	68.1	75	10.24
2017	4	60	100	1 054	17.56	68.3	0.87	56.7	60	17.6
2018	5	145	100	860	5.93	20.0	1.65	46.9	280	3.07
2019	5	144	100	1 048	7.28	20.1	1.80	40.3	329	3.19
2020	8	204	100	1 169	5.73	18.1	2.66	25.5	599	1.95
2021	5	185	100	1 205	6.51	22.2	2.98	33.5	557	2.16
2022	7	173	100	1 327	7.67	26.0	4.23	12.7	636	2.09
2023	8	319	100	1 415	4.43	9.1	4.55	7.5	1 354	1.04

Table 2: Orange roughy catch and effort summary for Challenger Plateau and Westpac Bank (ORH 7A), for bottom trawls targeting orange roughy during August to May. Vessels, number of vessels catching orange roughy; Catch, estimated catch in tonnes; Tows, number of tows; Hours, total hours fished; Duration, median tow duration (decimal hours); Duration<1, percentage of tows with duration less than one hour; t/tow, total catch divided by total number of tows; t/hr median tonnes/hours for tows where duration was recorded. Data not shown where there were less than three vessels.

Fishing year	Vessels	Tows	Target	Catch	t/tow	>10t	Duration	Duration<1	Hours	t/hr
1990	9	142	100	716	5.04	14.8	0.23	71.1	123	5.82
1991	5	29	100	50	1.71	10.3	1.52	22.2	81	0.61
1992	2	–	–	–	–	–	–	–	–	–
1993	4	18	100	58	3.25	5.6	0.27	81.2	33	1.79
1994	7	43	100	21	0.48	0	1.08	47.6	114	0.18
1995	8	82	100	29	0.36	0	1.54	25.6	277	0.11
1996	3	5	100	2	0.37	0	0.08	66.7	3	0.53
1997	1	–	–	–	–	–	–	–	–	–
1998	6	42	100	62	1.46	2.4	4.83	21.6	135	0.45
1999	8	306	100	159	0.49	0	4.25	7.1	1 261	0.12
2000	6	263	100	109	0.42	0	4.17	3.6	1 036	0.11
2001	2	–	–	–	–	–	–	–	–	–
2002	2	–	–	–	–	–	–	–	–	–
2003	4	18	100	18	0.88	0	6.22	0	6	2.55
2004	1	–	–	–	–	–	–	–	–	–
2005	2	–	–	–	–	–	–	–	–	–
2006	4	12	100	30	1.66	0	0.07	100.0	0	297.9
2007	1	–	–	–	–	–	–	–	–	–
2008	0	–	–	–	–	–	–	–	–	–
2009	1	–	–	–	–	–	–	–	–	–
2010	1	–	–	–	–	–	–	–	–	–
2011	2	–	–	–	–	–	–	–	–	–
2012	3	40	100	109	2.72	5	1.50	47.5	64	1.70
2013	4	62	100	271	4.37	11.3	0.26	74.2	52	5.24
2014	4	57	100	308	5.40	15.8	2.00	29.8	136	2.27
2015	6	510	100	1 073	2.10	4.1	3.59	28.2	1 463	0.73
2016	7	352	100	644	1.83	3.1	1.83	42.0	829	0.78
2017	5	387	100	425	1.10	0.5	4.55	8.3	1 702	0.25
2018	4	376	100	803	2.14	4.3	0.60	52.4	952	0.84
2019	5	311	100	464	1.49	1.0	5.98	14.5	1 598	0.29
2020	6	331	100	575	1.74	1.5	5.78	19.3	1 539	0.37
2021	5	449	100	761	1.70	0.4	6.90	4.0	2 776	0.27
2022	4	495	100	736	1.49	0	7.98	1.6	3 670	0.20
2023	5	201	100	328	1.63	0	7.97	1.0	1 456	0.23

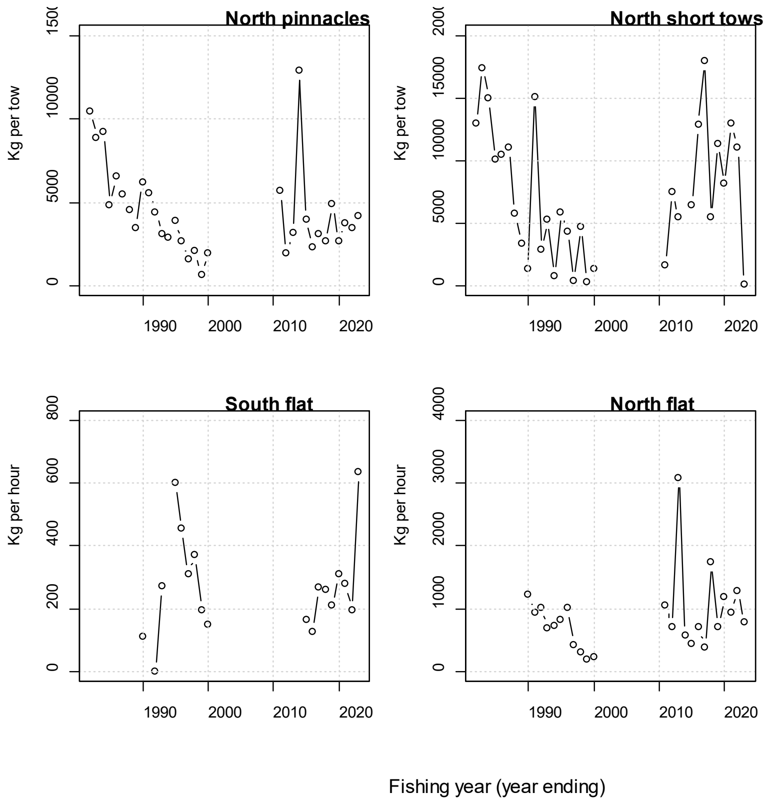

Figure 4: Unstandardised catch per unit effort for orange roughy target tows in north pinnacles (duration <1 hour and <4.5 n.mile from top of pinnacle), north short tows (northern area, <1 hours and not a hill tow), south flat (not hill or north flat) and north flat (not hill or north flat). North is north of 40.3° S.

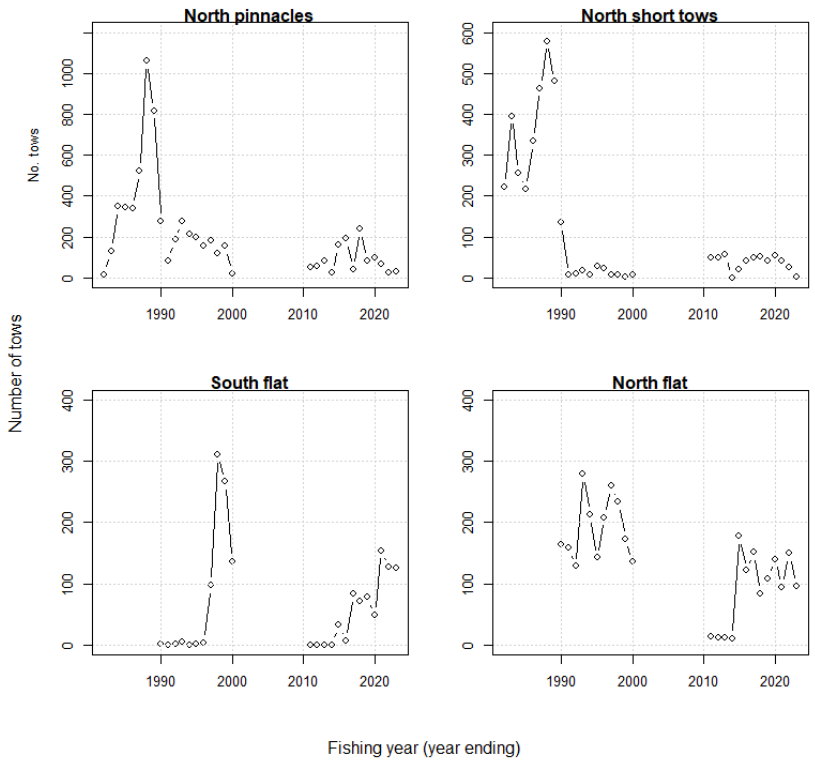

Figure 5: Fishing effort (number of tows) for orange roughy target tows in north pinnacles (duration <1 hour and <4.5 n.mile from top of pinnacle), north short tows (northern area, <1 hours and not a hill tow), south flat (not hill or north flat) and north flat (not hill or north flat). North is north of 40.3° S.

3. STOCK ASSESSMENT MODEL

A model-based Bayesian stock assessment using CASAL (Bull et al. 2012) was carried out for this stock in 2024, following similar assessments conducted in 2014 and 2019 (Cordue 2014, 2019).

3.1 Model structure and assumptions

The model was single-sex and age-structured (1–100 years with a plus group), with maturity in the partition (i.e., fish were classified by age and as mature or immature). Two time-steps were used: a full year of natural mortality followed by an instantaneous spawning season and fishery on the spawning fish. One fishery was modelled, including fishing within the EEZ and on Westpac Bank. The fishery selectivity was estimated and assumed equal to maturity. 100% of mature fish were assumed to spawn each year. Natural mortality rate (*M*) was estimated, and the stock-recruitment relationship was a Beverton-Holt function with steepness of 0.75. The remaining fixed biological parameters for growth are reported by Fisheries New Zealand (2023; also see Appendix A).

Productivity and the prior on *M*

Previous assessments have assumed an *M* of 0.045 yr^{-1}, and usually conducted sensitivity runs to the *M* assumption. Year class strengths have been estimated and these allow the model to correct for temporal trends in productivity given the catch history. The pattern repeatedly estimated for orange roughy stocks has been a period of high recruitment at the start of the times series, with low recruitment starting roughly *x* years before the fishery starts, where *x* is the age at maturity (Fisheries New Zealand 2023; Figure 6).

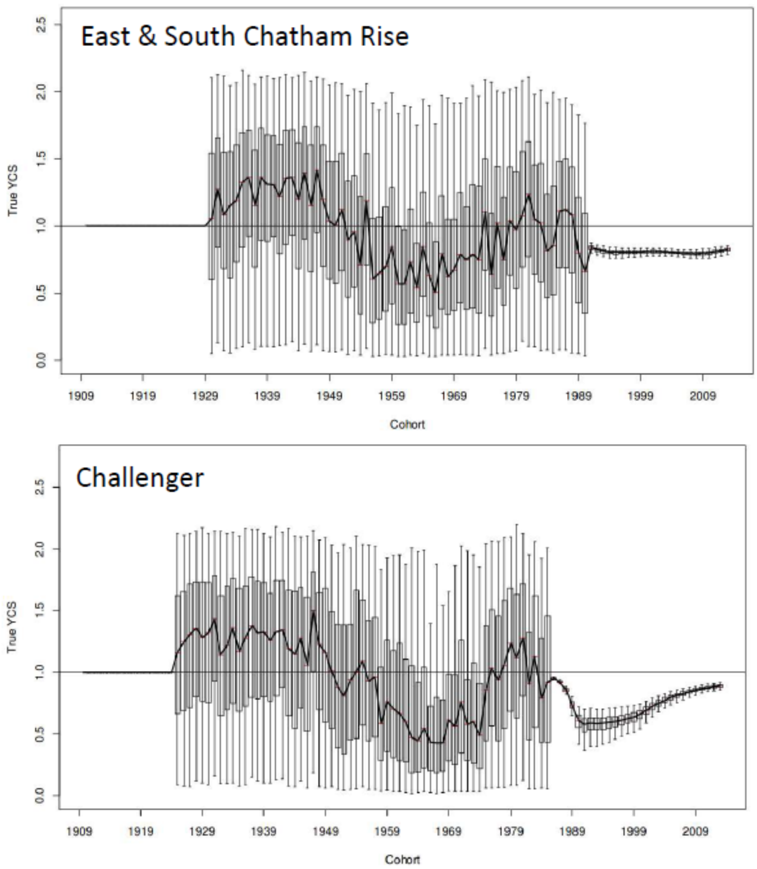

Figure 6: Example year class strength (YCS) estimates from stock assessment base model runs reported by Cordue (2014).

Model runs for the Challenger stock in 2024 found little benefit in fits to data when YCS were estimated in addition to *M*, despite the addition of 71 free YCS parameters (Table 3). The uncertainty in stock size and status estimated using Markov chain Monte Carlo (MCMC) when YCS were included was also not noticeably greater; potentially due to strong correlations between YCS.

Table 3: Challenger orange roughy stock assessment model runs, and the stock status (proportion of virgin biomass (B_0)) when Year Class Strength (YCS) are estimated (Est YCS) and when YCS are constant (Deterministic), and the change in Mode of the Posterior Distribution (MPD) likelihood for observed data (acoustic, trawl survey, and age frequency data) when YCS were added (negative is better). Model run key: All6, all six acoustic estimates used (see later); All 2, two acoustic estimates used; 3series, acoustic estimates following Cordue (2019); natural mortality (*M*) prior (or pr.) means *M* estimated, with the prior being empirical (described below) or assuming a mean of 0.045 and lognormal CV of either 0.3 or 0.5; no 2023, excluding the acoustic biomass survey for 2023.

Run	Est YCS	Deterministic	AF likelihood change
All6, *M* prior empirical	0.14	0.13	-1.19
All6, *M* prior=0.045, cv=0.5	0.15	0.15	-0.76
All6, M prior=0.045, cv=0.3	0.2	0.22	-0.58
All2 *M* prior empirical	0.35	0.35	-0.29
All2 *M* pr. empirical no 2023	0.35	0.34	-0.29
All6 *M* pr. empirical no 2023	0.26	0.27	-0.35
3series *M* pr. empirical no 2023	0.28	0.29	-0.28

Other concerns over estimating YCS include:

(1) Demonstrable model over-parameterisation because of the weak or conflicting information contained in age frequencies (Stephenson et al. 2022).

(2) The Mode of the Posterior Distribution (MPD) estimates are often in the tails (or even outside) of the posterior samples (e.g., Dunn & Doonan, 2018), indicating that the MPD includes YCS estimates that are “extreme”.

(3) YCS trends can be different when the weighting of the age frequencies is changed (rather than being a moderated version of the same trend).

(4) MCMC estimates of stock status are often more optimistic than the MPD runs. This may be because the MPD can use “extreme” YCS to fit data, but at MCMC those extreme estimates of YCS are rarely sampled because of weak information in age data, and the YCS estimates instead tend towards the YCS prior. This means that the assumed *M* becomes more influential and when the assumed *M* is too high, the MCMC is more optimistic than the MPD. Model sensitivity runs found that when *M* was estimated or assumed to be lower than the default 0.045 yr^{-1}, the YCS tended towards a flatter trend (Figure 7).

Instead, in this assessment *M* was estimated, and YCS were assumed to be constant. *M* was estimated using a prior, using the online tool described by Cope & Hamel (2022). To maintain objectivity, no *M* estimates were excluded as being implausible (Figure 8). The parameters used were: longevity, 150 years; von Bertalanffy Growth Function (VBGF) $L_{infinity}$, 34.2 cm; k, 0.065; t0, 0.5 years; Age (yr) for Chen-Wat, 50; Length (cm) for Gislason, 32; age at maturity, 35 years; water temperature, 5° C; VGBF W_{inf}, 1322 g; VGBF kw, 0.036, GSI, 0.03, and a user *M* input, 0.041 (mean of two empirical estimated values from New Zealand). The resulting prior was assumed to be lognormal, with mean 0.078 and CV 1.2 (Figure 9), and is referred to in model runs as the “empirical prior” (i.e., based upon empirical *M* estimation methods).

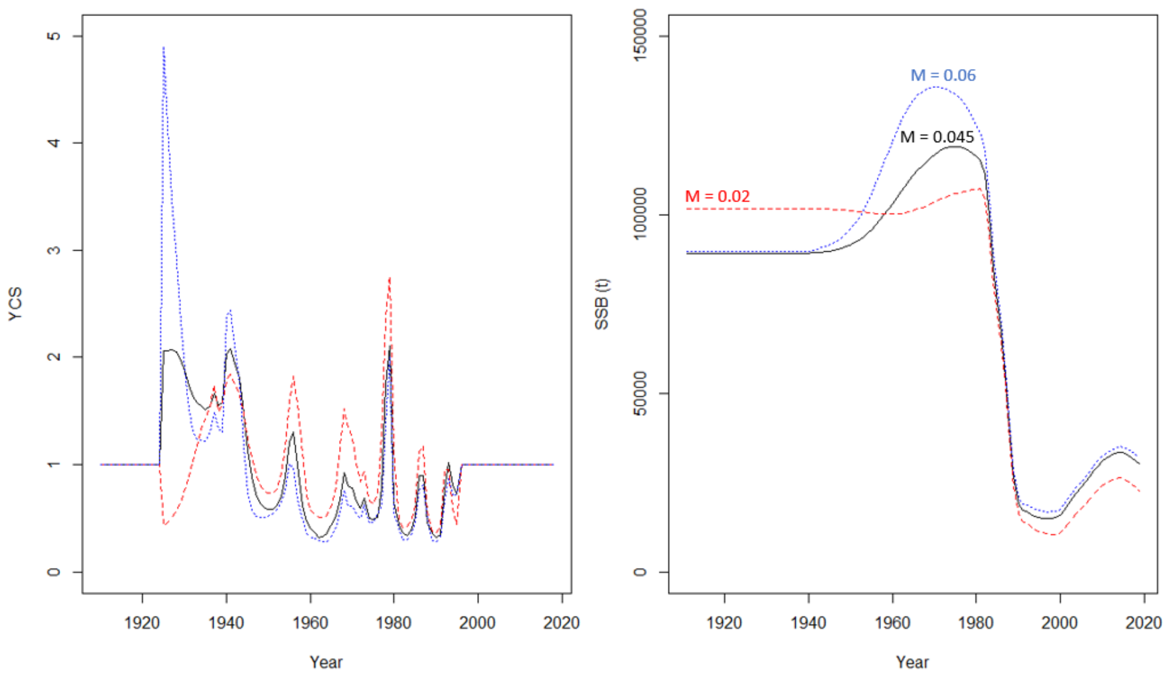

Figure 7: ORH 7A estimates of recruitment and stock size under three different *M* assumptions. Left panel, year class strength (YCS); right panel, spawning stock biomass (SSB) trajectory.

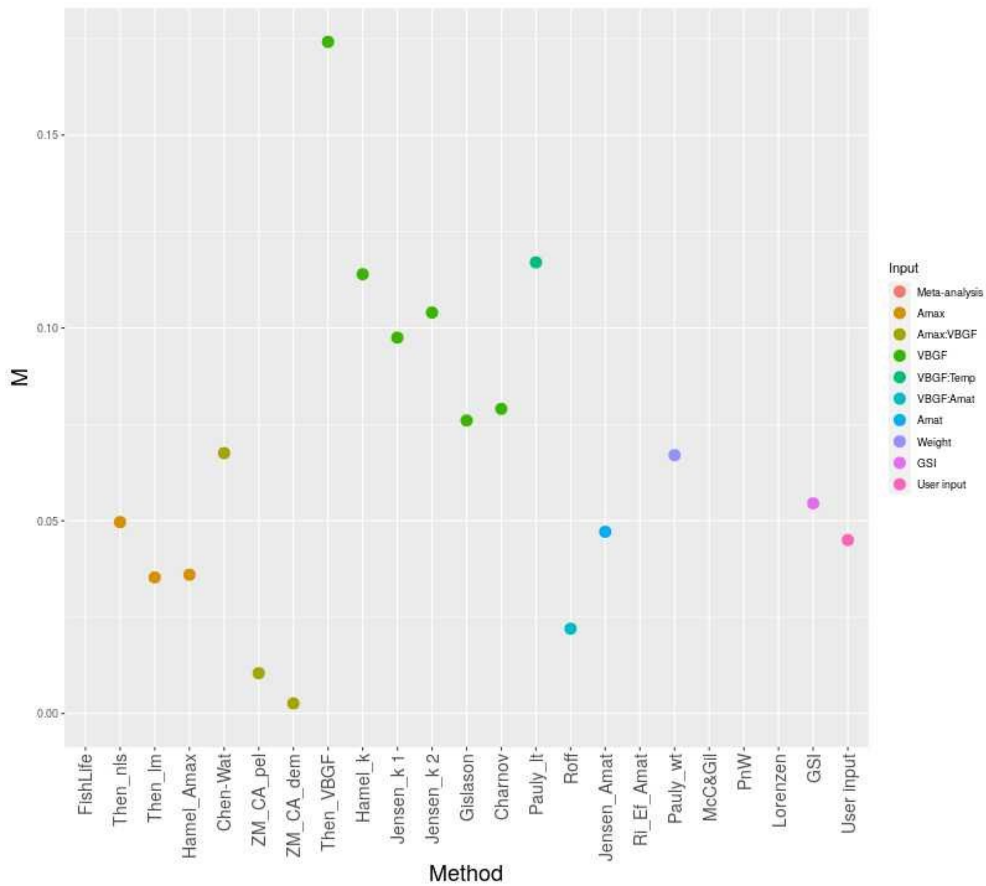

Figure 8: Point estimates (with 95% lognormal error bars; left column panels) of *M* by method for orange roughy using The Natural Mortality Tool of Cope & Hamel (2022): http://barefootecologist.com.au/shiny_m

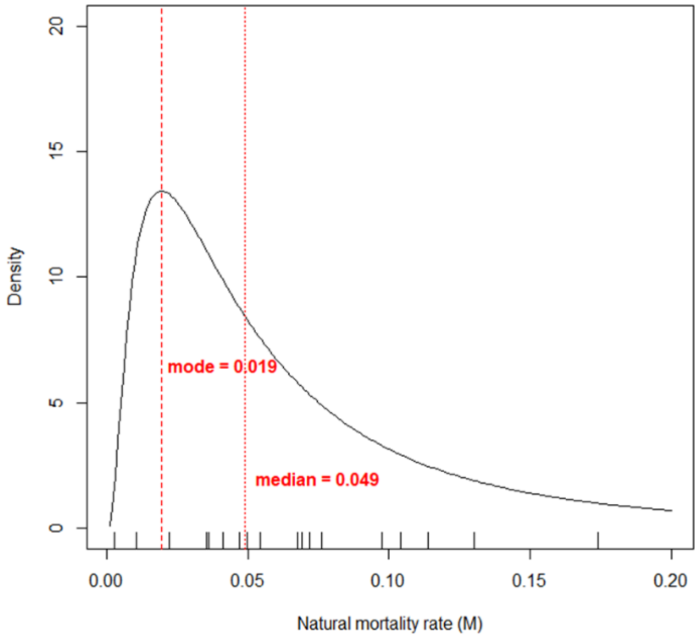

Figure 9: The "empirical" prior for *M* derived from point estimates, being lognormal with mean 0.078 and CV 1.2. The model and median are marked by the vertical broken lines.

3.2 Input data and statistical assumptions

The main data sources for observations fitted in the assessment were spawning biomass estimates from acoustic and trawl research surveys (2005, 2006, 2009–2014, 2018) and acoustic survey only (2023); four age frequencies from the trawl surveys (1987, 2006, 2009, and 2018); and two age frequencies from Volcano (an Underwater Topographical Feature (UTF) on the Westpac Bank) (2014 and 2018).

Catch history

The catch history was obtained from Fisheries New Zealand (2023). Catch overruns from various sources (including lost and/or discarded fish, use of nominal tray weights and low conversion factors) have been estimated as: 1980–81 to 1987–88, 30%; 1988–89, 25%; 1989–90, 20%; 1990–91, 15%; 1991–92 to 1992–93, 10%; 1993–94 onwards, 5% (Fisheries New Zealand 2023). The catch history used in the stock assessment, including catch over-runs, is shown in Table 4. Catches for 2023–24, the year in which the assessment was conducted, were assumed to be the same as 2022–23.

Table 4: Orange roughy ORH 7A stock assessment catch history (t) including over-runs. *2023–24 assumed to be the same as 2022–23.

Fishing year	Catch (t)	Fishing year	Catch (t)	Fishing year	Catch (t)	Fishing year	Catch (t)
1980–81	43	1991–92	2 102	2002–03	5	2013–14	574
1981–82	5 523	1992–93	2 296	2003–04	0	2014–15	1 674
1982–83	15 391	1993–94	1 819	2004–05	166	2015–16	1 646
1983–84	12 386	1994–95	1 718	2005–06	229	2016–17	1 704
1984–85	6 652	1995–96	1 752	2006–07	0	2017–18	1 869
1985–86	10 179	1996–97	1 374	2007–08	0	2018–19	1 670
1986–87	14 940	1997–98	1 577	2008–09	252	2019–20	1 990
1987–88	15 836	1998–99	1 311	2009–10	361	2020–21	2 178
1988–89	12 801	1999–2000	660	2010–11	505	2021–22	2 301
1989–90	5 171	2000–01	0	2011–12	536	2022–23	1 860
1991–91	1 561	2001–02	0	2012–13	815	2023–24*	1 860

Research surveys
Trawl surveys of orange roughy on the Challenger Plateau were conducted regularly from 1983 to 1990. However, a variety of vessels and survey strata were used which makes comparisons problematic. Although a "comparable area" time series covering the period 1987–89 using the FV *Amaltal Explorer* was selected for use in the 2019 assessment, these data were rejected for the 2024 assessment. This was because the decline in the biomass estimates over 1987–89 was far too large to be attributed to catches alone, and the Working Group has previously concluded that the series did not reflect true stock abundance (Fisheries New Zealand 2023).

The combined trawl and acoustic surveys using FV *Thomas Harrison* began in 2005 with a survey area comparable to that used from 1987–1990. The survey was repeated in 2006 with an enlarged survey area, and was then conducted annually from 2009–2013 with another survey in 2018. The data from all of the surveys since 2005 have been analysed to produce separate acoustic and trawl survey indices of spawning biomass. In 2023, only an acoustic survey was completed. Since 2019 assessment the acoustic data and trawl data were used separately (Cordue 2019), and the same approach was used here.

Changes in 2024 to which indices were used, and how they were used, are described below.

Trawl survey indices
The spawning biomass estimates from the FV *Thomas Harrison* trawl surveys excluding the rough terrain strata 9–11 (Table 5), which were used as relative biomass with an uninformed q prior. This use of an uninformed prior is a change from the previous assessment, which had used an informed q prior, which was lognormal with mean 0.95 and CV 0.3. A q of 0.95 for the trawl surveys seemed in conflict with a q of 0.8 on the accompanying acoustic biomass estimates (i.e., a combined q of 1.75).

Table 5: Biomass indices from trawl surveys used in the stock assessment. The CV is the observation error CV with an additional 20% of process error (Cordue 2019).

Vessel	Year	Biomass (t)	Model CV (%)
FV *Thomas Harrison*	2006	13 987	34
	2009	34 864	31
	2011	18 425	33
	2012	22 451	27
	2013	18 993	55
	2018	48 038	55

Acoustic survey indices
The acoustic biomass estimates from 2005 to 2018 were reviewed, and a number of adjustments were required to ensure that the time series of estimates was consistent (Cordue 2019; Fisheries New Zealand, 2023). Those estimates were used here.

An acoustic survey was conducted in 2023, and notably it failed to measure a spawning aggregation within the EEZ on the western or eastern flat strata. The previous survey, in 2018, had also failed to measure an aggregation in the eastern stratum. The biomass estimates used for the assessment were therefore for Volcano only, including four snapshots conducted using the Acoustic Optical System (AOS) and AOS/DuFT, with an arithmetic mean biomass of 8132 t and CV 17%. The hull survey estimates were not used because doing so would have required the use of an arbitrary correction factor (P. Escobar-Flores, NIWA, pers.comm.).

The acoustic indices were used in one of two ways:

(1) Acoustic estimates of spawning aggregations on Volcano and in the West and East of the flats within the EEZ were used as three separate time series each providing an index of SSB (Table 6). This assumption followed the 2019 assessment, and assumed that the three spawning aggregations were independent, the proportion of the total SSB in each area was constant over time, and that each area

shared the same recruitment and exploitation pattern. This assumption has been given the label “3Series”. The acoustic estimates included in this series followed the estimates used by Cordue (2019) with the addition of the 2023 estimate for Volcano. Estimates were excluded where biomass was substantially lower than adjacent years and the Working Group concluded that the survey had missed the aggregation (specifically Volcano in 2009 and, and East in 2011) and where the timing of the survey in relation to peak spawning was uncertain (specifically Volcano in 2010 and 2018).

Table 6: Acoustic biomass estimates of spawning aggregations surveyed on Volcano, and the West and the East within New Zealand’s Exclusive Economic Zone, and the total for all three areas. The CV is the observation error CV with an additional 20% of error in the years when the vessel motion correction was unknown (2005, 2011, and 2013). –, no survey conducted; a, included in All6 but not 3Series.

	West		East		Volcano		Total	
Year	Biomass (t)	CV (%)	Biomass (t)	CV (%)	Biomass (t)	CV (%)	Biomass (t)	Model CV (%)
2005	4 210	53	–	–	2 682	39	–	–
2006	4 383	59	–	–	6 329	39	–	–
2009	13 555	22	8 471	61	671_a	21_a	22 697	26
2010	8 114	14	1 707	34	$1\ 132_a$	24_a	10 953	12
2011	13 340	33	136_a	56_a	171_a	44_a	13 647	32
2013	10 183	22	5 365	26	4 559	34	20 107	15
2014	–	–	–	–	3 954	29	–	–
2018	9 966	9	0_a	NA	$3\ 834_a$	16_a	13 800	8
2023	0_a	NA	0_a	NA	$8\ 132_a$	17_a	8 132	17

(2) Acoustic estimates of spawning aggregations on Volcano in the East and West of the flats were summed, providing a total SSB for each year when all three areas were surveyed (Table 6). This assumption is the same as used for assessments of the Chatham Rise and Mid-East Coast orange roughy stocks (Fisheries New Zealand, 2023), and allows for movement of SSB between aggregations. Movement of aggregations from west to east was noted in Challenger acoustic surveys in 2012 and 2018, and variable allocation of spawning biomass between spawning areas has been assumed in the East & South Chatham Rise assessment.

Two alternatives for assumption 2 were used:

The first alternative included acoustic biomass estimates that were accepted and where biological samples showed that the survey timing was likely to be around peak spawning. This included surveys of all areas in 2009 and 2013, and was given the label “All2”. The 2009 estimate for Volcano had been rejected from previous assessments (which used assumption 1) because it was a relatively low estimate compared to previous years. Assuming the potential for movement of SSB between locations meant that the 2009 Volcano estimate could be included in this alternative.

The second alternative added biomass estimates from four years to All2 from surveys where acoustic biomass was measured but it was not certain whether the timing was around peak spawning (surveys of Volcano 2010, East & Volcano 2011; Volcano in 2018 and 2023), or where aggregations could not be located and surveyed despite search efforts (surveys of East in 2018; East & West in 2023). This included surveys in 2009, 2010, 2011, 2013, 2018, and 2023, and was given the label “All6”.

An acoustic survey of the East and West strata was also conducted in 2012 but rejected because substantial uncertainty in species mix made the biomass estimates unreliable (Fisheries New Zealand, 2023). The acoustic survey in 2014 only surveyed the Volcano before moving to ORH 1.

Informed lognormal priors on the proportionality constants (q) were used for the acoustic time series. For 3Series, the means of the priors for each area were derived from the 2013 SSB proportions across aggregations, and the assumption that all three aggregations combined represented “most” of the spawning biomass (80%; Cordue 2014). Splitting this prior into three components gave priors for the West, East, and Volcano *q* values of lognormal(μ=0.41, CV=30%), lognormal(μ=0.22, CV=30%), and lognormal(μ=0.18, CV=30%), respectively, based on the biomass split between areas from the 2013 survey. For the All2 and All6 runs, there was a single acoustic biomass *q* with prior lognormal(μ=0.80, CV=30%) based on acoustic biomass estimates from the early 2000s on the north east Chatham Rise.

Process error was added to the acoustic series to balance MCMC implied residuals. The process errors added were in 3Series Volcano 0.2 and East 0.35 (none for West); in All6 0.15; no process error was added in All2 runs.

Age frequencies

Age frequencies were available from four of the trawl surveys for use in the assessment. The sample of otoliths collected during the 2023 survey was considered unlikely to be representative of the stock (they almost all came from a single catch) and was not aged.

The age frequencies were assumed to be multinomial and were assigned effective sample sizes of 10, except for the 2018 age frequency from Volcano which was reduced to 5 to reflect that it may not have been representative of the aggregation. No statistical reweighting was attempted because of the short time series. These effective samples sizes were substantially lower than used in 2019 (60, 30 for Volcano in 2018) to give greater weight to the acoustic biomass estimates.

There are no age frequencies from the commercial fishery. Although length frequency data are available, none have been compiled and used in this assessment.

3.3 Model runs and results

The main parameters estimated were: virgin biomass (B_0), the logistic maturity (=selectivity) ogive, and *M*. The prior on *M* was informed from empirical *M* estimators and was very broad: Lognormal(μ=0.078, CV=120%). Proportionality constants (*q*) were also estimated for the trawl survey and the three (3Series) or one (All2, All6) acoustic survey time series. Year class strength (YCS) was assumed to be constant (deterministic).

YCSs were estimated in the 2019 assessment, for the years 1925 to 1995 (71 parameters), but in 2024 YCS was assumed to be constant (deterministic recruitment). Productivity estimation was instead achieved by estimating a single parameter (*M*).

Initial parameter estimates were made as the MPD, with later runs and model uncertainty estimated using MCMC (Appendix B).

Sensitivity model runs

Sensitivity runs were conducted assuming, for example, different acoustic series (as above), different *M* priors, dropping the 2023 acoustic estimate, including the FV *Amaltal Explorer* trawl series, excluding Volcano age data, or all age data (and fixing selectivity), changing the effective samples sizes assumed for the age data, and removing acoustic *q* priors. The fits to the data were generally similar, and within comparable runs there was very little change in the likelihoods for fits to trawl, age frequencies, and acoustic series (Table 7). As a result, it was not possible to use fits to data to distinguish between the alternative hypotheses.

The All6 runs were found to be most sensitive, and some incurred a catch penalty indicating that the biomass estimates were close to the minimum level able to satisfy the catch history (B_{min}) when the estimated acoustic *q* was closest to the mean of the *q* prior.

Table 7: Some example MPD runs. Acoustic series, the Acoustic series used (PE, process error was added (compared to adjacent run); q uni, unform rather than informed acoustic *q* used); YCS est., prior, whether year class strength (YCS) were estimated and if they were, the form on the lognormal prior (n.uni., nearly uniform); AF EFS, the age frequency effective samples sizes used (no Vol, no Volcano AFs included; None, no AFs with A_{50} fixed at 32 and A_{to95} at 15); AE incl., whether the FV *Amaltal Explorer* series was included; trawls, the likelihood from trawl observations; AFs, the likelihood from age frequency observations; Aco obs+priors, the likelihood from acoustic series and acoustic *q* priors; catch penalty, the catch penalty incurred; *M* estimate (NA means *M* was fixed at 0.045). * several All6 runs were encountered that were close to B_{min} (incurred the catch penalty), and may not have satisfactorily converged.

Acoustic series	*M* est., prior	YCS est, prior	AF EFS	AE incl.	Trawls	AFs	Aco obs + priors	Catch penalty	*M* estimate	B_0	B_{2024}/B_0
All6	empirical	yes, u=1, cv=0.7	10,5	Yes	-3.671	116.460	-4.281	0	0.0239	99 598	0.171
All6	empirical	yes, u=1, cv=0.7	10,5	No	-3.025	116.273	-4.388	0	0.0220	99 598	0.166
All2	empirical	yes, u=1, cv=0.7	10,5	Yes	-4.097	115.693	-2.749	0	0.0350	94 081	0.347
All2	empirical	yes, u=1, cv=0.7	10,5	No	-3.155	115.068	-2.783	0	0.0319	100 846	0.354
3series	empirical	yes, u=1, cv=0.7	10,5	Yes	-4.024	115.761	-10.112	0	0.0335	94 490	0.327
3series	empirical	yes, u=1, cv=0.7	10,5	No	-3.175	115.304	-10.104	0	0.0301	99 943	0.320
All6	0.045	yes, u=1, cv=0.7	10,5	Yes	-3.547	116.840	-4.205	0	NA	97 280	0.135
All6	0.045	yes, n. uni.	10,5	Yes	-3.729	114.841	-4.572	0	NA	73 657	0.170
All6*	empirical	yes, u=1, cv=0.7	10,5	Yes	-5.162	72.156	-4.508	0.0013	0.0217	97 280	0.135
All6	0.045cv50	yes, u=1, cv=0.7	10,5	Yes	-3.780	116.697	-3.895	0	0.0238	95 291	0.153
All6	0.045cv30	yes, u=1, cv=0.7	10,5	Yes	-4.337	116.694	-3.053	0	0.0291	90 834	0.197
All6	empirical	no	10,5	Yes	-3.490	117.651	-3.955	0	0.0195	100 955	0.132
All6	0.045cv50	no	10,5	Yes	-3.750	117.460	-3.387	0	0.0215	99 502	0.154
All6	0.045cv30	no	10,5	Yes	-4.464	117.278	-1.636	0	0.0276	95 314	0.223
3series	empirical	yes, u=1, cv=0.7	10,5	Yes	-4.015	115.817	-5.696	0	0.0334	95 094	0.333
3series	0.045cv50	yes, u=1, cv=0.7	10,5	Yes	-4.070	115.834	-5.680	0	0.0339	94 643	0.337
3series	0.045cv30	yes, u=1, cv=0.7	10,5	Yes	-4.294	115.937	-5.603	0	0.0363	92 809	0.353
All6	empirical	no	10,5	Yes	-3.490	117.651	-3.955	0	0.0195	100 955	0.132
All6	empirical	no	20,10	Yes	-3.540	183.948	-2.909	0	0.0260	99 292	0.242
All6	empirical	no	5,2.5	Yes	-3.931	71.253	-4.596	0	0.0216	98 729	0.147
3series	empirical	yes, u=1, cv=0.7	10,5	Yes	-4.015	115.817	-5.696	0	0.0334	95 094	0.333
3series + PE	empirical	yes, u=1, cv=0.7	10,5	Yes	-4.024	115.761	-10.112	0	0.0335	94 490	0.328

Acoustic series	*M* est., prior	YCS est, prior	AF EFS	AE incl.	Trawls	AFs	Aco obs + priors	Catch penalty	*M* estimate	B_0	B_{2024}/B_0
All6	empirical	yes, u=1, cv=0.7	10,5	Yes	-3.548	116.840	-4.206	0	0.0217	97 280	0.135
Acoustic series	*M* est., prior	YCS est, prior	AF EFS	AE incl.	Trawls	AFs	Aco obs + priors	Catch penalty	*M* estimate	B_0	B_{2024}/B_0
All6 + PE	empirical	yes, u=1, cv=0.7	10,5	Yes	-3.671	116.460	-4.552	0	0.0239	96 409	0.171
All2	empirical	yes, u=1, cv=0.7	10,5	Yes	-4.097	115.693	-2.953	0	0.0350	94 080	0.347
All2	empirical	no	10,5	Yes	-4.071	115.987	-2.972	0	0.0340	94 786	0.342
All6	empirical	no	10,5	Yes	-3.671	116.460	-4.552	0	0.0240	96 409	0.171
All6	empirical	yes, u=1, cv=0.7	10,5	Yes	-4.048	116.007	-3.561	0	0.0290	94 710	0.261
All6	empirical	no	10,5	Yes	-4.084	116.359	-3.474	0	0.0290	96 331	0.266
3series	empirical	yes, u=1, cv=0.7	10,5	Yes	-4.024	115.761	-10.112	0	0.0340	94 490	0.328
3series	empirical	yes, u=1, cv=0.7	10,5	Yes	-3.803	115.766	-11.562	0	0.0310	94 728	0.282
3series	empirical	no	10,5	Yes	-3.857	116.048	-11.346	0	0.0300	96 927	0.290
All6	empirical	yes, u=1, cv=0.7	10 no Vol	Yes	-3.880	81.762	-4.384	0	0.0240	96 542	0.134
3series	empirical	yes, u=1, cv=0.7	10 no Vol	Yes	-4.424	80.855	-9.954	0	0.0330	92 712	0.327
All2	empirical	yes, u=1, cv=0.7	20,10	Yes	-3.312	181.561	-2.858	0	0.0346	96 576	0.362
All2	empirical	yes, u=1, cv=0.7	5,2.5	Yes	-5.136	70.816	-2.971	0	0.0382	89 975	0.352
All2	empirical	no	10,5	Yes	-4.071	115.987	-2.972	0	0.0344	94 786	0.342
All6	empirical	no	None	Yes	-5.174	NA	-4.830	0.0002	0.0253	93 215	0.135
All6 q uni	empirical	yes, u=1, cv=0.7	10,5	Yes	-3.849	115.790	-3.303	0	0.0306	94 444	0.273
3series q uni	empirical	yes, u=1, cv=0.7	10,5	Yes	-3.763	115.486	-7.363	0	0.0404	94 886	0.432

The estimates of *M* were influenced by the acoustic series estimates and *q* priors as well as by the age data, meaning that the *M* was being modified to fit the apparent productivity driven by the *q* prior rather than providing the most accurate fit to species longevity. The *q* prior and the age data implied slightly different *M* values, but both were substantially lower than the default assumption of 0.045 yr^{-1} (Figure 10). When included, the FV *Amaltal Explorer* trawl series implied a relatively small SSB and high *M*.

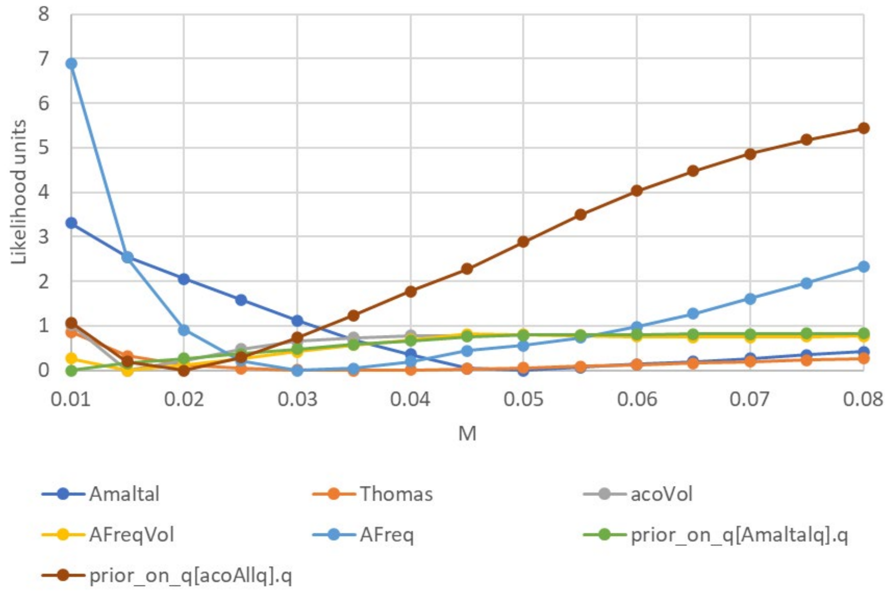

Figure 10: Likelihood profile for *M*, using a 3series model run including the Amaltal Explorer trawl series. AFreq, age frequency; aco, acoustic, Amaltal = FV *Amaltal Explorer*, Thomas – FV *Thomas Harrison*, Vol, Volcano.

Model fits

The model fits to the acoustic indices were acceptable, with the greater changes in the 3Series acoustic time series proving more difficult to fit with constant *q*s and selectivity, leading to a higher process error required to fit this data (Figure 11). The fits to the trawl series were good, although the high CV for 2013 and 2018 meant that the trend was not very informative (Figure 12).

The posterior distributions of the acoustic *q*s, which had informed priors, were estimated to be lower than the prior (All2 and All6), or close to or lower than the prior (3Series) (Figure 13). The persistent move to lower *q*s shows that the model estimated SSB was greater than prior expectations across all model runs.

Natural mortality rate was estimated to be lower than the orange roughy default (0.045 yr^{-1}) in all model runs (Figure 14). Estimated *M* was lowest for the All6 run (0.024), where the estimated SSB was lowest and the acoustic *q* was closest to the prior; *M* was similar for the All2 and 3Series runs (0.033 and 0.031 respectively). In this context, estimated *M* is not directly comparable to natural mortality but includes other undefined factors and is interpreted as a general descriptor of productivity.

The selectivity was assumed equal to maturity, and A_{50} in all runs was close to 34 years (Figure 15). The variability between age frequencies, in particular for Volcano, meant that they could not all be fitted well with the single logistic selectivity (Figure 16; Appendix C). The age sample for Volcano 2018, for example, included a much greater proportion of older fish than 2014. The misfit to the plus group for the age frequency from within the EEZ (not including Volcano) in 1987 is also apparent, and occurred because of a low *M* estimate, but the residual is no worse than for several individual cohorts at ages 30–40 in other samples. The fits to the age data were very similar across all model runs.

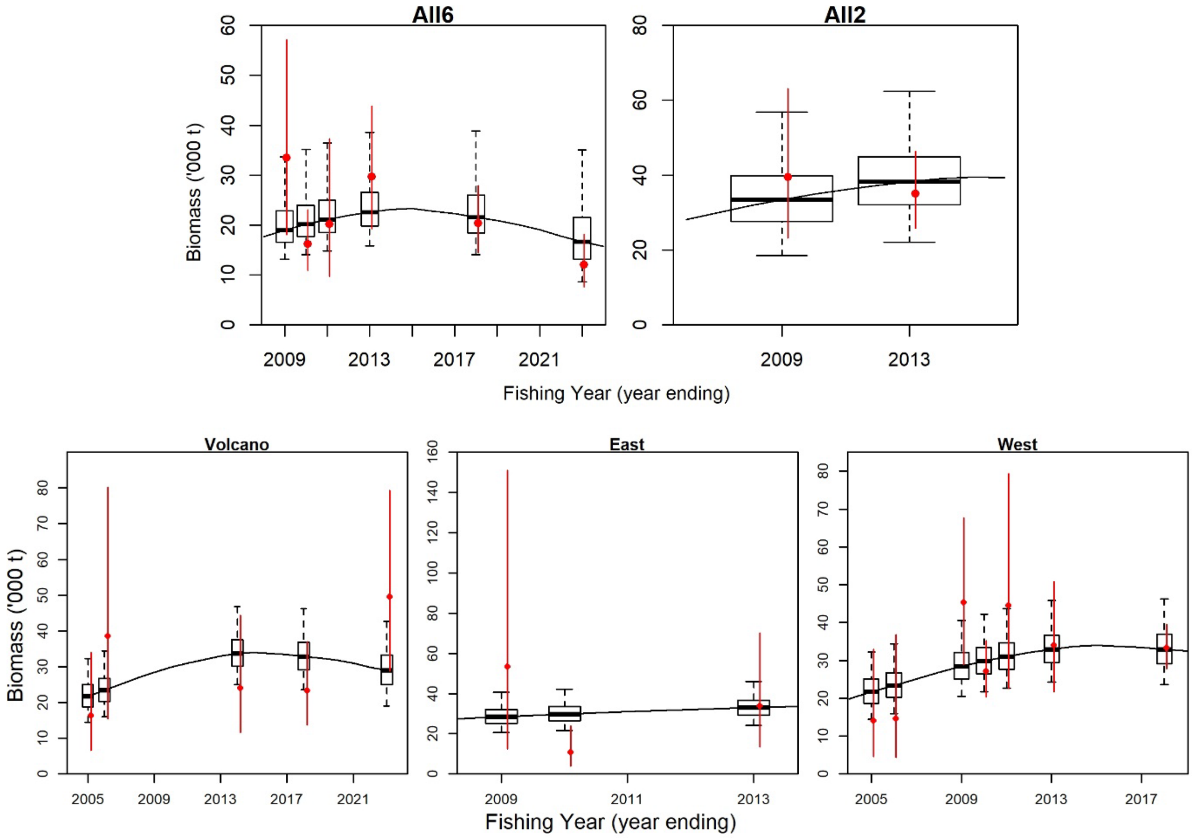

Figure 11: MCMC implied fits to the acoustic indices of the All6 and All2 runs (top panels) and Volcano, East, and West areas of the 3Series run (bottom panel). Each box covers the middle 50% of the distribution and the whiskers extend to 95% CIs. The solid black indicates the median fitted SSB. The observations are plotted as red points with red lines indicating 95% CIs (with a small offset by year to make them more visible).

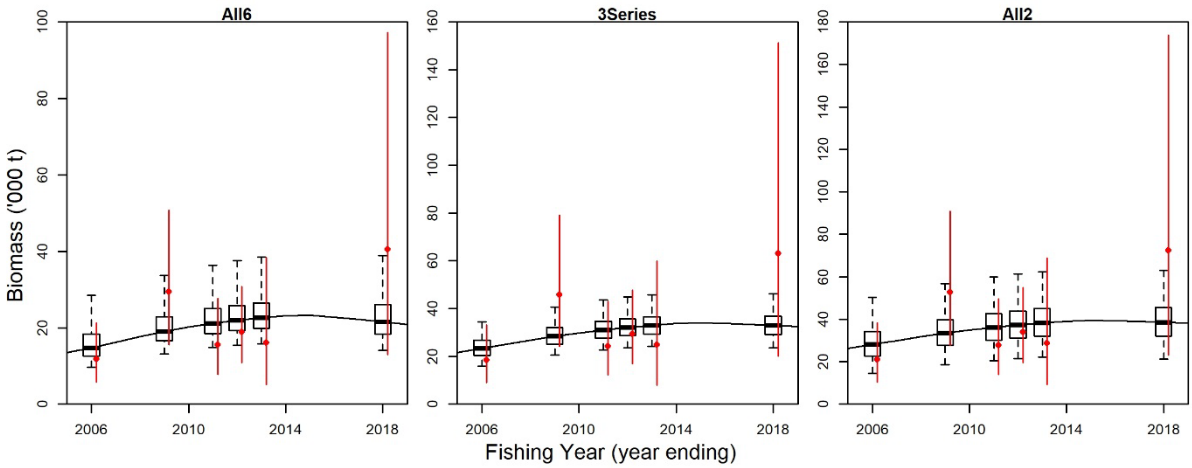

Figure 12: MCMC implied fits to the FV *Thomas Harrison* trawl survey series for the All6, 3Series, All2 runs. Each box covers the middle 50% of the distribution and the whiskers extend to 95% CIs. The solid black indicates the median fitted SSB. The observations are plotted as red points with red lines indicating 95% CIs (with a small offset by year to make them more visible).

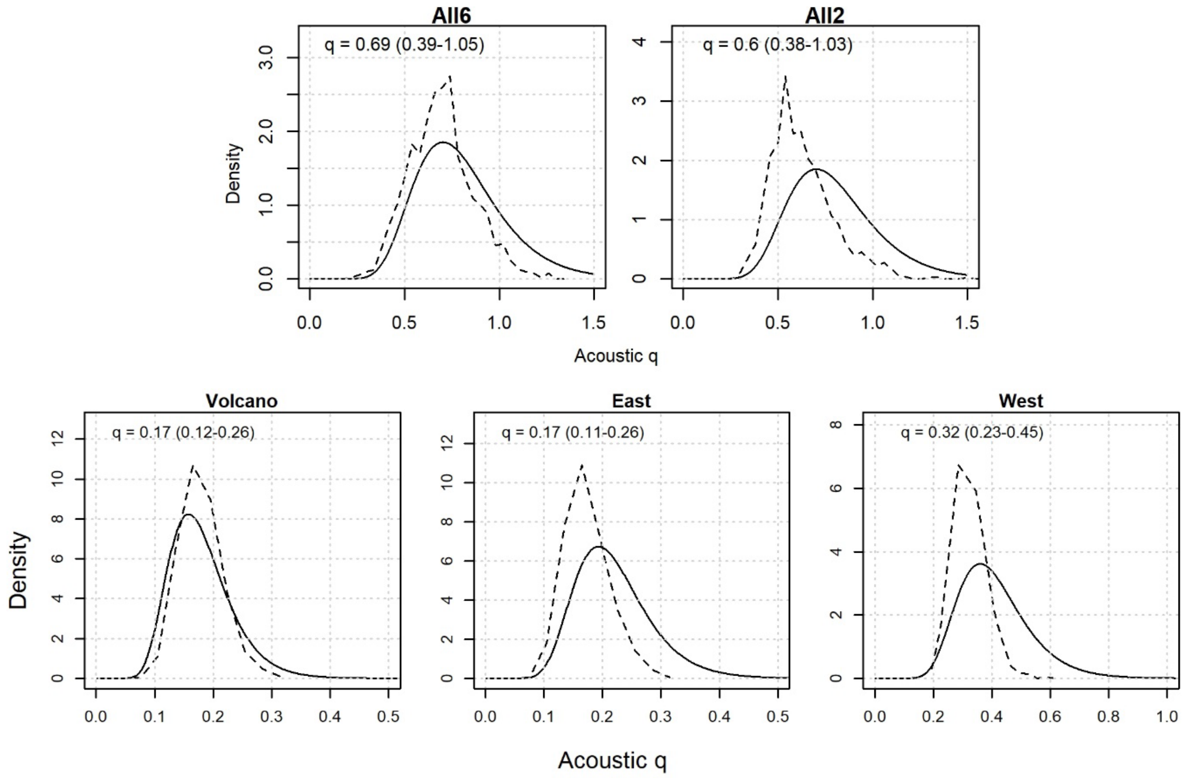

Figure 13: MCMC Prior distributions (solid lines) and marginal posterior distributions (dashed lines) for the All6 and All2 acoustic *q*s (top panels) and the Volcano, East, and West acoustic *q*s in the 3Series run (bottom panels). Inset values are the median and 95% credible intervals of the *q* estimates.

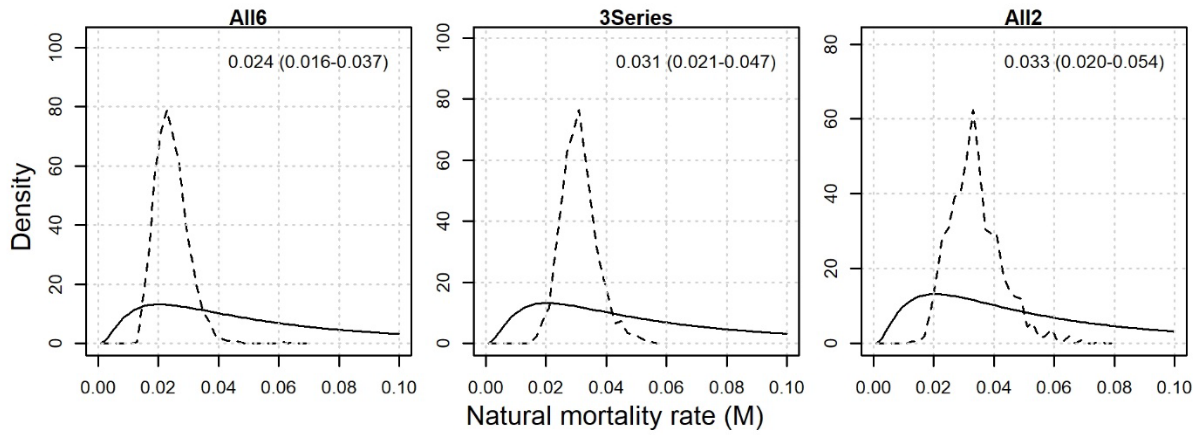

Figure 14: MCMC Prior distributions (solid lines) and marginal posterior distributions (dashed lines) for natural mortality rate in the All6, All2, and 3Series runs. Inset values are the median and 95% credible intervals of the *M* estimates.

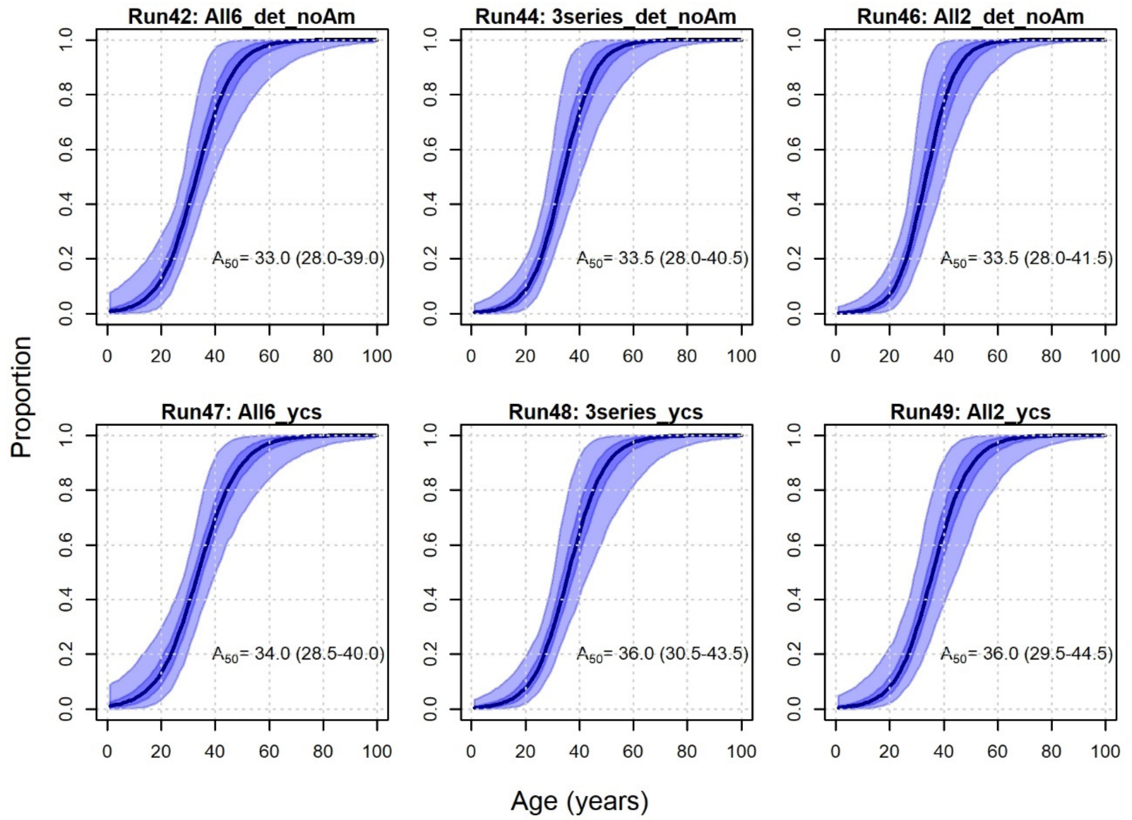

Figure 15: Maturity (=selectivity) curves for All6, All2, and 3series runs with YCS being estimated, and without (deterministic YCS). Numbers in parentheses are the 95% CI). Solid line indicates the median, dark shaded area the 75% CI, and light shaded area the 95% CI. Run numbers in the titles were indices from model runs.

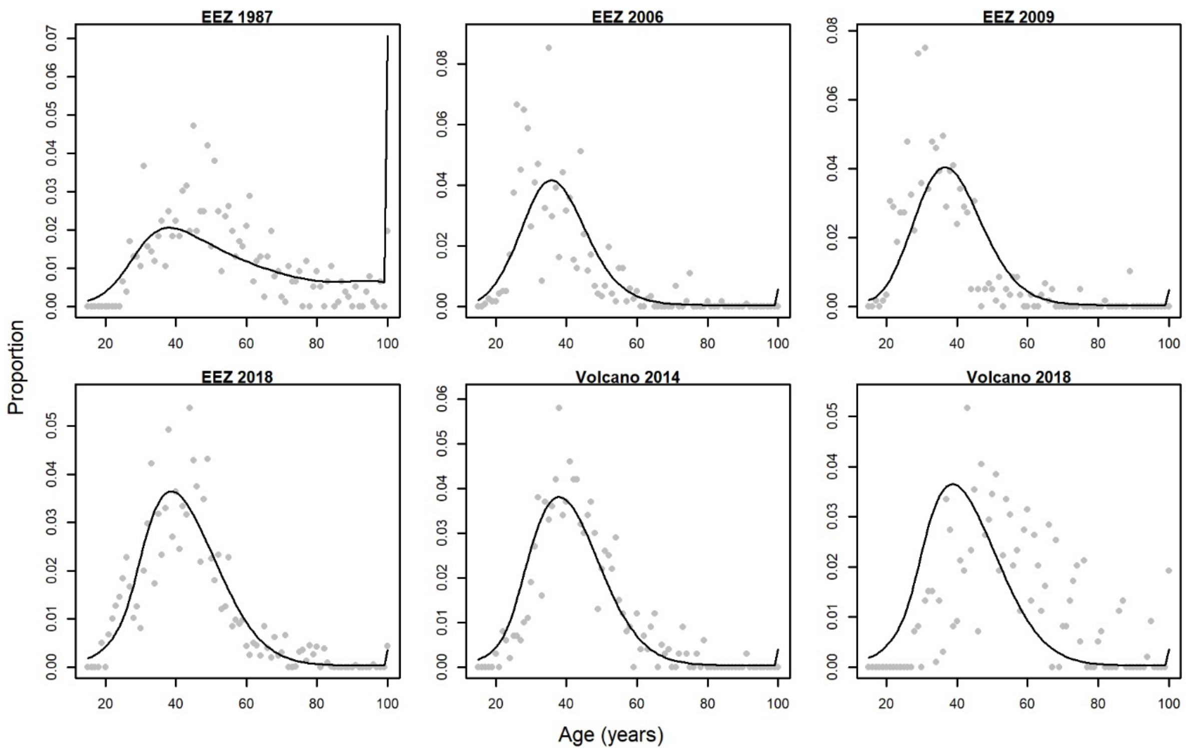

Figure 16: MPD fits (solid lines) to age frequencies (grey points) for the EEZ and Volcano for the All2 run.

3.4 Final biomass estimates

The All2 run was chosen by the Deepwater Working Group as a base model. The All6 run estimates appeared to be at or close to B_{min}, and were relatively sensitive to model assumptions. The 3Series run was analogous to the 2019 assessment, but the independence of the three acoustic series indexing SSB was considered less plausible than the total acoustic estimates used in the All2 and All6 runs. The lack of recent data in the All2 run was reflected in relatively high uncertainty in current stock status (Table 8).

Virgin biomass (B_0) was estimated to be just under 100 000 t for all runs (Table 8). The main difference between runs was the productivity (*M*) estimates, which led to different current SSB size and status. For the base (All2) and 3Series runs, current stock status was estimated to be close to the lower bound of the target biomass range of 30–50% B_0. For the All6 run, with a lower *M*, current stock status was lower and between the hard (10% B_0) and soft (20% B_0) limits.

Table 8: MCMC estimates of estimated natural mortality rate (*M*), virgin biomass (B_0), stock status (B_{2024} as %B_0), and probability of being in the target range (30–50% B_0) and below the soft (20% B_0) and hard limit (10% B_0), for the base (All2) model, All6, and 3Series sensitivity runs.

	M	B_0 (000 t)	B_{2024} (%B_0)	p(>30%B$_0$)	p(<20%B$_0$)	p(<10%B$_0$)
Base (All2)	0.033	99.4	35	0.66	0.07	0
	(0.020–0.054)	(87.6–117.2)	(16–57)			
All6	0.024	98.5	16	0.06	0.71	0.12
	(0.016–0.037)	(91.3–110.3)	(8–35)			
3Series	0.031	97.5	29	0.44	0.05	0
	(0.020–0.045)	(89.3–110.5)	(18–44)			

In the base case, the stock status trajectory shows a steep decline to 11% B_0 in 1991, reflecting the large removals during the initial fish-down phase of this stock (Figure 17). From 1990, the All2 stock status remains low and slowly rebuilds until an upturn from about 2000. Biomass is estimated to have peaked in 2015 in all model runs, within the target range (All2 and 3Series runs) or just above the soft limit (All6 run), before the increased catches (enabled by a Total Allowable Commercial Catch (TACC) increase), combined with a reduction in recruitment, caused a levelling out and then decline of the biomass trajectory after 2015.

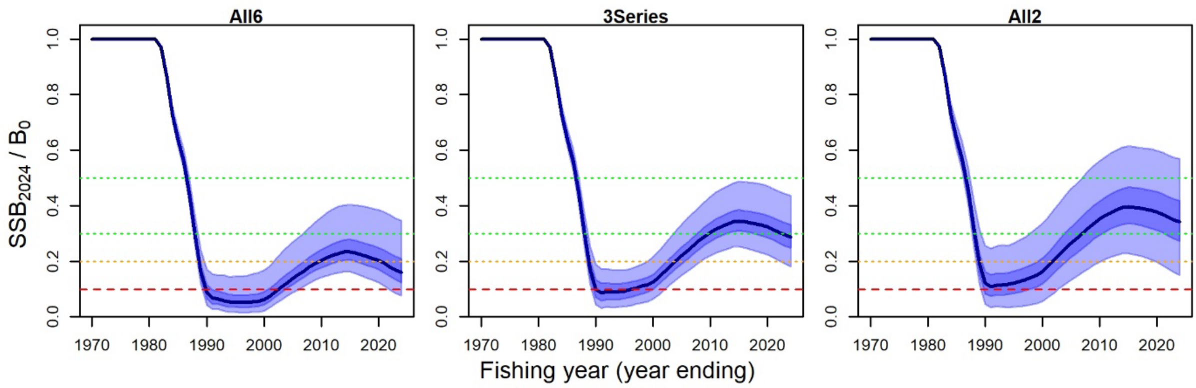

Figure 17: MCMC estimated spawning-stock status (SSB_{2024}/B_0) trajectory. The solid line shows the median, the darker shaded areas covers 50% of the distribution, and the lighter shaded areas 95% of the distribution. The hard limit 10% B_0 (dashed red), soft limit 20% B_0 (dotted orange), and biomass target range 30–50% B_0 (green) are marked by horizontal lines.

The reduction in recruitment is a consequence of reduced SSB from the late 1980s, lagged by the estimated age of selectivity and maturity (A_{50}) of about 34 years, finally entering the fishery. The model predicts that recruitment will start to increase after about 2034 (2000 + 34) (Figure 18).

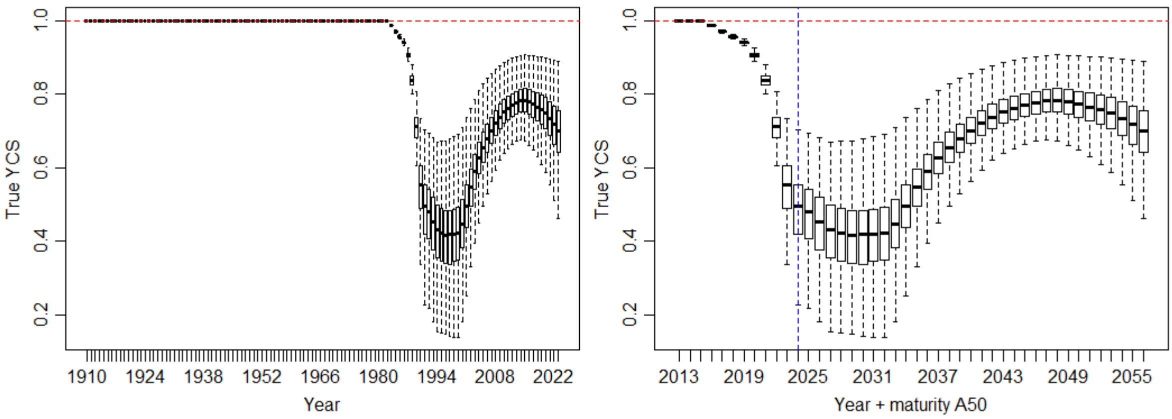

Figure 18: MCMC estimates of YCS for an All6 model run estimating *M* with constant YCS. Left panel, the YCS estimated by model year. Right panel, the recruitment arriving into the commercial fishery (i.e., YCS + maturity A_{50}). The vertical broken line indicates the assessment year.

The target range for the exploitation rate (catch/SSB) was calculated from simulations: Model projections were run across a range of constant future catches, the equilibrium exploitation rate for each was calculated, and then an interpolation made to identify the exploitation rate leading to the target depletion of 30–50% B_0. The exploitation rate was generally well above the target range ($U_{30\%B0}$–$U_{50\%B0}$) during the fishing down period (1982–1989), above the target range in the period 1990–1993, and returning to the target range in the period 1994–1999. Subsequently, it was well below the target range up until 2014, and from 2015 until 2024 it has remained in the lower half of the target range (Figures 19 and 20).

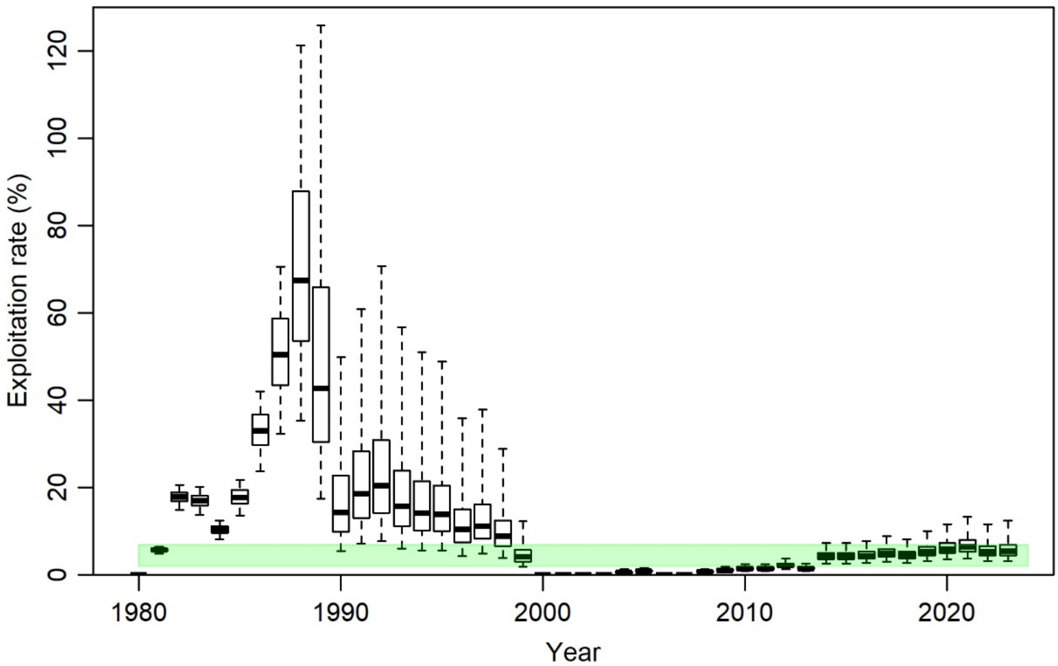

Figure 19: Base (All2) run, MCMC estimated exploitation rate trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The fishing-intensity range associated with the biomass target of 30–50% B_0 is marked by the green shaded area. The exploitation rate exceeds 100% for about 1% of model runs in 1987–88 and 1988–89 because the catch is the sum for the year, but the SSB is measured after half of the natural mortality has been applied; this means that the fishery took the entire recruited SSB in these cases.

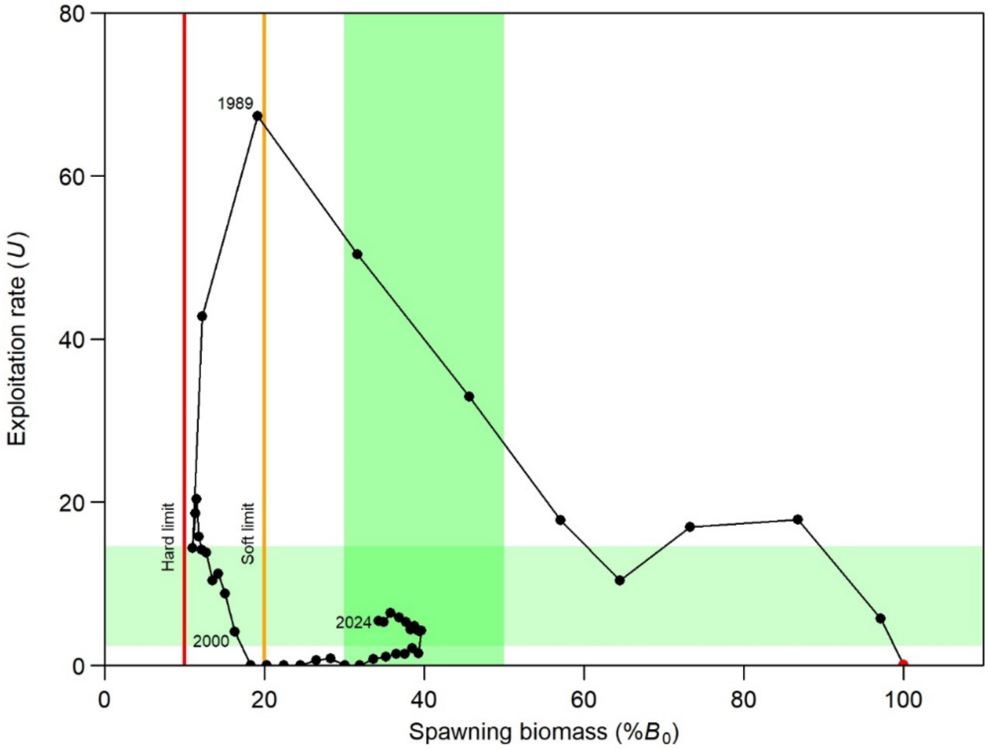

Figure 20: Historical trajectory of spawning biomass (%*B_0*) and fishing intensity (exploitation rate) for the base (All2) model (medians of the marginal posteriors). The biomass target range of 30–50% *B_0* and the corresponding exploitation rate target range are shaded in green. The soft limit (20% *B_0*) is marked in orange and the hard limit (10% *B_0*) in red.

3.5 Projections

Five-year projections were conducted for a constant catch equal to the current TACC (2058 t), 0.8×TACC, and 0.7×TACC. A 5% catch over-run was assumed. At all future constant catch levels, the SSB is predicted to decrease slowly over the next five years (Table 9), with for the base (All2) remaining within the target biomass range and with at most a 19% probability of being below the soft limit, and with at most a 2% probability of being below the hard limit, during the next five years. The TACC reduction required for the predicted SSB in 2028–29 to be the same as 2023–24 was 0.43×TACC for the base (All2) run, 0.30×TACC for the All6 run, and 0.46×TACC for the 3Series run.

Table 9: MCMC estimates of stock status (B_{2024} as $\%B_0$) for the base model (All2) and two sensitivity runs with constant future catches, and the probability of the stock being above the soft limit (20% B_0) and hard limit (10% B_0). SSB, spawning stock biomass; B_0, virgin biomass; TACC, Total Allowable Commercial Catch.

SSB/B_0	2023–24	2024–25	2025–26	2026–27	2027–28	2028–29
All2						
TACC	35 (16–57)	34 (15–56)	33 (14–56)	32 (13–55)	31 (11–54)	30 (10–53)
0.8×TACC	35 (16–57)	34 (15–57)	33 (14–56)	33 (14–56)	32 (13–55)	32 (12–55)
0.7×TACC	35 (16–57)	34 (15–57)	34 (15–56)	33 (14–56)	33 (14–56)	33 (13–56)
0.6×TACC	35 (16–57)	34 (15–57)	34 (15–57)	34 (15–57)	34 (14–57)	33 (14–57)
0.5×TACC	35 (16–57)	34 (16–57)	34 (15–57)	34 (15–57)	34 (15–58)	34 (15–58)
All6						
TACC	16 (8–35)	15 (6–34)	14 (5–33)	12 (3–32)	11 (2–31)	10 (1–30)
0.8×TACC	16 (8–35)	15 (6–34)	14 (6–34)	14 (5–33)	13 (4–33)	12 (3–32)
0.7×TACC	16 (8–35)	15 (7–35)	15 (6–34)	14 (5–34)	14 (4–33)	13 (3–33)
0.6×TACC	16 (8–35)	15 (7–35)	15 (6–34)	15 (6–34)	14 (5–34)	14 (4–34)
0.5×TACC	16 (8–35)	16 (7–35)	15 (6–35)	15 (6–35)	15 (5–35)	15 (5–35)
3Series						
TACC	29 (18–44)	28 (17–43)	27 (16–42)	26 (15–41)	25 (14–40)	24 (13–39)
0.8×TACC	29 (18–44)	28 (18–43)	28 (17–43)	27 (16–42)	27 (15–42)	26 (14–41)
0.7×TACC	29 (18–44)	29 (18–43)	28 (17–43)	28 (17–43)	27 (16–42)	27 (15–42)
0.6×TACC	29 (18–44)	29 (18–43)	28 (17–43)	28 (17–43)	28 (16–43)	28 (16–43)
0.5×TACC	29 (18–44)	29 (18–44)	29 (18–44)	29 (18–44)	29 (17–44)	29 (17–44)

p(SSB > 0.5)	2023–24	2024–25	2025–26	2026–27	2027–28	2028–29
All2						
TACC	0.09	0.08	0.07	0.06	0.05	0.05
0.8×TACC	0.09	0.08	0.08	0.07	0.06	0.05
0.7×TACC	0.09	0.08	0.08	0.08	0.07	0.07
0.6×TACC	0.09	0.08	0.08	0.08	0.08	0.08
0.5×TACC	0.09	0.09	0.09	0.09	0.09	0.10
All6						
TACC	0	0	0	0	0	0
0.8×TACC	0	0	0	0	0	0
0.7×TACC	0	0	0	0	0	0
0.6×TACC	0	0	0	0	0	0
0.5×TACC	0	0	0	0	0	0
3Series						
TACC	0	0	0	0	0	0
0.8×TACC	0	0	0	0	0	0
0.7×TACC	0	0	0	0	0	0
0.6×TACC	0	0	0	0	0	0
0.5×TACC	0	0	0	0	0	0

p(SSB > 0.3)	2023–24	2024–25	2025–26	2026–27	2027–28	2028–29
All2						
TACC	0.66	0.63	0.60	0.56	0.53	0.49
0.8×TACC	0.66	0.64	0.62	0.60	0.58	0.56
0.7×TACC	0.66	0.64	0.63	0.62	0.60	0.59
0.6×TACC	0.66	0.65	0.64	0.64	0.63	0.62
0.5×TACC	0.66	0.65	0.65	0.65	0.65	0.65
All6						
TACC	0.06	0.05	0.05	0.04	0.03	0.03
0.8×TACC	0.06	0.06	0.05	0.05	0.04	0.04
0.7×TACC	0.06	0.06	0.05	0.05	0.05	0.04
0.6×TACC	0.06	0.06	0.06	0.05	0.05	0.05
0.5×TACC	0.06	0.06	0.06	0.06	0.06	0.06
3Series						
TACC	0.44	0.39	0.33	0.28	0.24	0.20
0.8×TACC	0.44	0.41	0.37	0.34	0.31	0.28
0.7×TACC	0.44	0.41	0.39	0.36	0.34	0.32
0.6×TACC	0.44	0.42	0.41	0.40	0.38	0.37
0.5×TACC	0.44	0.42	0.43	0.43	0.43	0.43

p(SSB < 0.2)	2023–24	2024–25	2025–26	2026–27	2027–28	2028–29
All2						
TACC	0.07	0.09	0.11	0.14	0.16	0.19
0.8×TACC	0.07	0.08	0.1	0.11	0.13	0.14
0.7×TACC	0.07	0.08	0.09	0.10	0.11	0.12
0.6×TACC	0.07	0.08	0.08	0.09	0.09	0.09
0.5×TACC	0.07	0.08	0.08	0.08	0.08	0.08
All6						
TACC	0.71	0.75	0.79	0.82	0.85	0.87
0.8×TACC	0.71	0.75	0.77	0.79	0.81	0.83
0.7×TACC	0.71	0.74	0.76	0.78	0.79	0.81
0.6×TACC	0.71	0.74	0.75	0.76	0.77	0.78
0.5×TACC	0.71	0.73	0.74	0.74	0.75	0.75
3Series						
TACC	0.05	0.08	0.12	0.16	0.21	0.27
0.8×TACC	0.05	0.07	0.10	0.12	0.15	0.17
0.7×TACC	0.05	0.07	0.09	0.10	0.12	0.14
0.6×TACC	0.05	0.07	0.08	0.09	0.10	0.11
0.5×TACC	0.05	0.06	0.07	0.07	0.07	0.08

p(SSB < 0.1)	2023–24	2024–25	2025–26	2026–27	2027–28	2028–29
All2						
TACC	0	0	0.01	0.01	0.02	0.02
0.8×TACC	0	0	0.01	0.01	0.01	0.01
0.7×TACC	0	0	0	0.01	0.01	0.01
0.6×TACC	0	0	0	0	0.01	0.01
0.5×TACC	0	0	0	0	0	0.01
All6						
TACC	0.12	0.18	0.27	0.35	0.43	0.50
0.8×TACC	0.12	0.17	0.23	0.28	0.33	0.39
0.7×TACC	0.12	0.17	0.21	0.25	0.29	0.33
0.6×TACC	0.12	0.16	0.18	0.21	0.24	0.27
0.5×TACC	0.12	0.16	0.17	0.18	0.20	0.21
3Series						
TACC	0	0	0	0	0	0.01
0.8×TACC	0	0	0	0	0	0
0.7×TACC	0	0	0	0	0	0
0.6×TACC	0	0	0	0	0	0
0.5×TACC	0	0	0	0	0	0

4. DISCUSSION

4.1 Summary

The 2022 assessment differed from the Cordue (2019) assessment in the following ways:

- Acoustic SSB estimates for the three areas (Volcano, West, and East) were summed and used as a single index, rather than each assumed to provide an independent index of SSB.
- One fishery was modelled instead of two.
- Recruitment was assumed deterministic and M estimated, rather than recruitment estimated and M fixed.
- An empirical prior was used in the estimation of M.
- The statistical weights (effective sample sizes) of the age data were substantially reduced.
- The FV *Amaltal Explorer* trawl survey series was excluded.
- The informed q prior on the FV *Thomas Harrison* trawl survey, and the prior on B_0, were set to uniform.

Concern remains that the stock status may be different from indicated by the base (All2) run, simply because that run was not informed by any biomass data after 2013. Whilst this is an obvious problem, the model run did assume deterministic recruitment, so the outcome in 2024 was influenced only by catch history (not any YCS trend). In other words, if the acoustic surveys in 2011 and 2013 were accurate and are adequately fit, and if deterministic recruitment is correct, then the model estimate in 2024 would change little with the addition of more recent accurate biomass data (although precision should improve).

A more general concern is the absence of spawning aggregations in the west stratum in 2023, and the east stratum in both 2018 and 2023. Further (survey) work is required to evaluate whether the survey might have "missed" the fish. If the survey was accurate, and the fish are not there, then stock status is more like the All6 run (16% B_0).

The recruitment "hole" arriving into the fishery in the 2020s is predicted from the stock-recruit relationship, which is a model assumption. The Deepwater Working Group discussed the likely influence of steepness (h) but considered it an unnecessary complication to the scientific advice at this stage. If a recruitment "hole" is true, then a substantial catch reduction will be required to maintain or rebuild biomass over the next decade or so. Note that the timing of this "hole" would be influenced by the maturity A_{50}, meaning that if the true A_{50} was lower, then the recruitment hole would have arrived earlier.

4.2 Future research

The Deepwater Working Group identified the following issues that require future consideration:

- Revise the acoustic survey design and implementation to maximise probability that abundance estimates are obtained for all three aggregations ('East', 'West' and Volcano) in the same year.
- Reconsider the otolith sampling approach from acoustic surveys to maximise probability that adequate otoliths are obtained from each aggregation and that these are obtained from multiple tows to support the stock assessment.

- Review current arrangements for sampling commercial catches for age to ensure that adequate samples are being obtained from both spawning and non-spawning fisheries to support the development of useable age frequencies.

- Review and update the acoustic *q* prior, in particular the assumption that 80% of the SSB is present in the three surveyed areas.

- Review and update the natural mortality rate (*M*) prior.

- Run alternative models with either a strong *M* prior or a strong acoustic prior.

The author would add the following:

- Evaluate existing data, and preferably collect new data, to test the stock assumption. In particular, evaluate whether the northwest Challenger (outside of the EEZ) is separate from the assumed ORH 7A stock.

5. ACKNOWLEDGMENTS

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7. APPENDIX A: CASAL files

```
##############
# population file #
##############

# PARTITION
@size_based False
@min_age 1
@max_age 100
@plus_group True
@sex_partition False
@mature_partition True
@n_areas 1

# TIME SEQUENCE
@initial 1911
@current 2024
@final 2174
@annual_cycle
time_steps 2

# recruitment
recruitment_time 1

# spawning
spawning_time 2
spawning_part_mort 0.5
spawning_p 1

# growth and mortality
aging_time 1
M_props 1 0
baranov False

# maturation
n_maturations 1
maturation_times 1

# fishery
fishery_names fishery #EEZ Westpac
fishery_times 2 #2

# RECRUITMENT
@y_enter 1
@standardise_YCS True
@recruitment
YCS_years 1910 1911 1912 1913 1914 1915 1916 1917 1918 1919 1920 1921 1922 1923 1924 1925 1926 1927 1928 1929
1930 1931 1932 1933 1934 1935 1936 1937 1938 1939 1940 1941 1942 1943 1944 1945 1946 1947 1948 1949 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 2023
YCS 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
SR BH
steepness 0.75
sigma_r 1.1
first_free 1925
last_free 1995

# recruitment variability
@randomisation_method lognormal

# FISHERIES
@fishery fishery
years       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   2023   2024
catches     43    5523  15391  12386  6652  10079  14940  15836  12801  5171  1561  2102
            2296  1819  1718   1752   1374  1577   1311   660    0      0     5     0
            166   229   0      0      252   361    505    536    815    574   1674  1646
            1704  1869  1670   1990   2178  2301   1860   1860
selectivity SELspawn
```

```
U_max     0.8

# MATURITY
@maturation
rates_all logistic_producing 1 100 30 3

# SELECTIVITIES
@selectivity_names SELspawn #SELvolcano
@selectivity SELspawn
mature constant 1
immature constant 0

# NATURAL MORTALITY
@natural_mortality
all 0.045

# SIZE AT AGE
@size_at_age_type von_Bert
@size_at_age_dist normal
@size_at_age
k 0.065
t0 -0.5
Linf 34.2
cv1 0.10
cv2 0.05
by_length True
@size_weight
a 9.21e-8
b 2.71

# INITIALISATION
@initialization
B0 130000

##############
# estimation file #
##############

# ESTIMATION
@estimator Bayes
@max_iters 1000
@max_evals 3000
@grad_tol 0.0001

# MCMC
@MCMC
start 0
length 5000000
keep 1000
stepsize 0.06
burn_in 1000

@proportions_at AFreq
years 1987 2006 2009 2018
step 2
proportion_mortality 0.5
sexed F
sum_to_one True
at_size False
plus_group True
ogive SELspawn
min_class 15
max_class 100
ageing_error True
1987 0 0 0 0 0 0 0 0 0 0 0.00656168 0.003937008 0.01706037 0.01312336 0.01312336 0.01049869 0.03674541 0.01574803
0.0144357 0.01181102 0.0183727 0.02230971 0.01049869 0.02493438 0.0183727 0.02230971 0.0183727 0.03018373
0.03149606 0.01968504 0.04724409 0.01968504 0.02493438 0.02493438 0.04199475 0.01574803 0.03805774 0.02493438
0.009186352 0.02362205 0.02624672 0.01968504 0.01312336 0.01706037 0.01574803 0.02099738 0.02887139 0.00656168
0.01181102 0.01312336 0.002624672 0.01312336 0.01968504 0.007874016 0.009186352 0.002624672 0.001312336
0.01049869 0.00656168 0.00656168 0.009186352 0 0.01181102 0 0.005249344 0.009186352 0.005249344 0 0.00656168
0.01049869 0 0.001312336 0.00656168 0.003937008 0.002624672 0 0.005249344 0 0 0.003937008 0.007874016
0.001312336 0 0.00656168 0 0.01968504
2006 0 0 0.0008532423 0.002559727 0.001706485 0.001706485 0.004266212 0.005119454 0.005119454 0.01706485
0.03754266 0.0665529 0.04522184 0.06484642 0.05887372 0.02645051 0.04095563 0.04692833 0.008532423 0.03242321
0.08532423 0.02986348 0.03924915 0.0162116 0.0443686 0.03156997 0.03583618 0.01535836 0.01279863 0.05119454
```

```
0.02389078 0.01194539 0.01706485 0.006825939 0.004266212 0.003412969 0.006825939 0.01962457 0.004266212
0.001706485 0.01279863 0.01279863 0.001706485 0.005972696 0.002559727 0.005119454 0 0 0.002559727 0.003412969 0
0 0 0 0 0 0.006825939 0 0 0.001706485 0.01109215 0 0 0 0 0.001706485 0 0 0 0.001706485 0 0 0 0 0 0 0.0008532423 0 0 0
0 0 0 0 0 0
2009 0 0 0.001703578 0 0.001703578 0.003407155 0.0306644 0.02896082 0.01873935 0.02725724 0.02725724 0.04770017
0.03236797 0.02214651 0.07325383 0.03577513 0.07495741 0.03407155 0.04770017 0.04599659 0.03918228 0.04940375
0.02896082 0.03918228 0.04088586 0.02385009 0.03407155 0.02896082 0.02725724 0.005110733 0.0306644 0.005110733
0 0.005110733 0.00681431 0.005110733 0.001703578 0.008517888 0 0.005110733 0.003407155 0.008517888 0.008517888
0.003407155 0 0 0.003407155 0 0 0.003407155 0.00681431 0.001703578 0.005110733 0 0 0 0 0 0 0 0.005110733 0 0 0 0 0 0
0.001703578 0 0 0 0 0 0 0.01022147 0 0 0 0 0 0 0 0 0 0 0
2018 0 0 0 0 0.005060266 0 0.006761356 0.01002867 0.01268612 0.0146093 0.01844751 0.02278862 0.01672607
0.01019668 0.01251519 0.008008393 0.01998815 0.02982031 0.04219187 0.01733302 0.03176847 0.02335195 0.03298992
0.04931774 0.02693554 0.03646654 0.02449202 0.03340329 0.03163068 0.05372512 0.04284767 0.03743045 0.02181655
0.0348701 0.04319939 0.02246943 0.0179859 0.02329616 0.01198962 0.0125024 0.02281883 0.008449655 0.009778681
0.009010675 0.009834479 0.004297498 0.002530133 0.004963169 0.004455632 0.002292933 0.008403726 0.003914957
0.001997012 0.006246265 0.002372 0.003083599 0.006552056 0 0 7.906665e-05 0.00312429 0.003552761 0.001265066
0.004448078 0.002570824 0.004264361 0 0.003795199 0.0008569413 0.0001581333 0 0 0 0 0 0 0.0003953333 0 0 0 0
0.0005534666 0 0 0 0.004284706
dist multinomial
r 0.00001
N_1987 10 #60
N_2006 10 #60
N_2009 10 #60
N_2018 10 #60

@proportions_at AFreqVol
years 2014 2018
step 2
proportion_mortality 0.5
sexed F
sum_to_one True
at_size False
plus_group True
#ogive SELvolcano
ogive SELspawn
min_class 15
max_class 100
ageing_error True
2014 0 0 0 0 0 0.003 0 0.008 0.006 0.002 0.007 0.007 0.006 0.01 0.011 0.019 0.027 0.038 0.016 0.037 0.033 0.036 0.042
0.058 0.034 0.037 0.046 0.042 0.042 0.032 0.03 0.034 0.037 0.03 0.013 0.022 0.026 0.025 0.022 0.029 0.015 0.012 0.008
0.009 0 0.012 0.004 0.007 0.004 0.009 0.012 0 0.005 0.003 0.004 0 0 0.003 0.009 0.003 0 0 0.003 0 0.006 0 0 0 0 0 0 0 0 0
0 0.003 0 0 0 0 0 0 0 0 0
2018 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.00708502 0.008097166 0 0.01315789 0.01518219 0.01518219 0.001012146 0.01315789
0.003036437 0.03340081 0.02732794 0.008097166 0.009109312 0.02125506 0.01923077 0.05161943 0.02327935
0.0354251 0.00708502 0.04048583 0.02631579 0.02935223 0.03441296 0.03846154 0.01923077 0.02226721 0.03340081
0.03036437 0.02024291 0.02327935 0.0111336 0.02732794 0.03137652 0.01315789 0.02631579 0.02024291 0.0111336
0.01619433 0.02834008 0 0.02530364 0 0.008097166 0.008097166 0.01315789 0.01720648 0.02024291 0.005060729
0.02125506 0 0 0 0.005060729 0.00708502 0 0 0 0 0.0111336 0.01315789 0 0 0 0 0 0 0.002024291 0.009109312 0 0 0 0
0.01923077
dist multinomial
r 0.00001
N_2014 10 #60
N_2018 5 #30

@ageing_error
type normal
c 0.1

{
# Amaltal Explorer trawl indices; excluded from base run
@relative_abundance Amaltal
step 2
biomass True
ogive SELspawn
proportion_mortality 0.5
dist lognormal
q Amaltalq
years 1987 1988 1989
1987 75040
1988 28954
1989 11062
cv_1987 0.33
cv_1988 0.34
cv_1989 0.23
```

```
@estimate
parameter q[Amaltalq].q
lower_bound 0.10
upper_bound 2.00
prior uniform-log
}

# Thomas Harrison trawl indices
@relative_abundance Thomas
step 2
biomass True
ogive SELspawn
proportion_mortality 0.5
dist lognormal
q Thomasq
years 2006 2009 2011 2012 2013 2018
2006 13987
2009 34864
2011 18425
2012 22451
2013 18993
2018 48038
cv_2006 0.34
cv_2009 0.31
cv_2011 0.33
cv_2012 0.27
cv_2013 0.55
cv_2018 0.55

@estimate
parameter q[Thomasq].q
lower_bound 0.10
upper_bound 2.00
prior uniform-log

@relative_abundance aco
step 2
biomass True
ogive SELspawn
proportion_mortality 0.5
dist lognormal
q acoAllq
years 2009 2013
2009 22697         # one of two in All2
#2010 10953
#2011 13647
2013 20107         # two of two in All2
#2018 13800
#2023 8132
cv_2009 0.26
#cv_2010 0.12
#cv_2011 0.32
cv_2013 0.15
#cv_2018 0.08
#cv_2023 0.17

@estimate
parameter q[acoAllq].q
lower_bound 0.01
upper_bound 1.5
prior lognormal
mu 0.8
cv 0.30

{
# blocks for the 3series run
@relative_abundance acoVol
step 2
biomass True
ogive SELvolcano
proportion_mortality 0.5
dist lognormal
q acoVolq
years 2005 2006 2014 2018 2023
2005 2682
```

```
2006 6329
2013 4559
2014 3954
2018 3834
2023 8132
cv_2005 0.39
cv_2006 0.39
cv_2013 0.34
cv_2014 0.29
cv_2018 0.16
cv_2023 0.17
cv_process_error 0.2

@estimate
parameter q[acoVolq].q
lower_bound 0.01
upper_bound 1.5
prior lognormal
mu 0.18
cv 0.30

@relative_abundance acoEast
step 2
biomass True
ogive SELspawn
proportion_mortality 0.5
dist lognormal
q acoEastq
years 2009 2010 2013
2009 8471
2010 1707
2013 5365
cv_2009 0.61
cv_2010 0.34
cv_2013 0.26
cv_process_error 0.35

@estimate
parameter q[acoEastq].q
lower_bound 0.01
upper_bound 1.5
prior lognormal
mu 0.22
cv 0.30

@relative_abundance acoWest
step 2
biomass True
ogive SELspawn
proportion_mortality 0.5
dist lognormal
q acoWestq
years 2005 2006 2009 2010 2011 2013 2018
2005 4210
2006 4383
2009 13555
2010 8114
2011 13340
2013 10183
2018 9966
cv_2005 0.53
cv_2006 0.59
cv_2009 0.22
cv_2010 0.14
cv_2011 0.33
cv_2013 0.22
cv_2018 0.09

@estimate
parameter q[acoWestq].q
lower_bound 0.01
upper_bound 1.5
prior lognormal
mu 0.41
cv 0.30
```

```
@q acoVolq
q 0.3
@q acoWestq
q 0.5
@q acoEastq
q 0.5
}

@q_method free

@acoAllq
q 0.7
@q Thomasq
q 0.7

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

@estimate
parameter initialization.B0
lower_bound 30000
upper_bound 200000
prior uniform

@estimate
parameter natural_mortality.all
lower_bound 0.01
upper_bound 0.1
prior lognormal
mu 0.078
cv 1.2

{
# YCS not estimated in base run
@estimate
parameter recruitment.YCS
lower_bound 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 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 1 1 1 1
upper_bound 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 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 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
cv      0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7
        0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7
        0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7
        0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7
        0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7
        0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7
        0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7
        0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7
        0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7
        0.7 0.7 0.7 0.7 0.7 0.7
}

# CATCH PENALTIES
@catch_limit_penalty
label CatchPenalty
fishery fishery
multiplier 200
log_scale T
```

8. APPENDIX B: MCMC chains

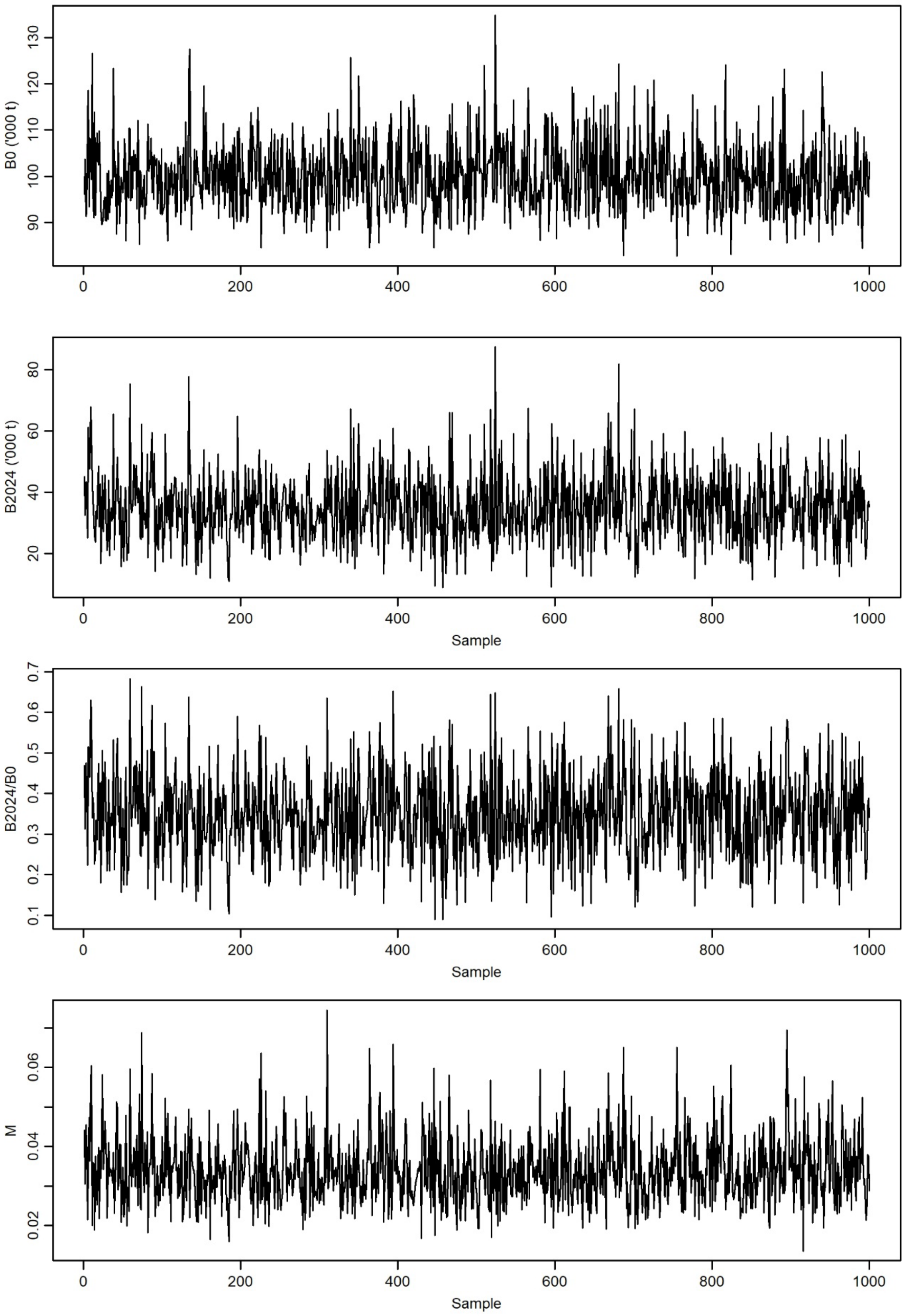

Figure 8.1: MCMC posterior samples for the All2 model run. Panels from top, B_0, B_{2024}, B_{2024}/B_0, M.

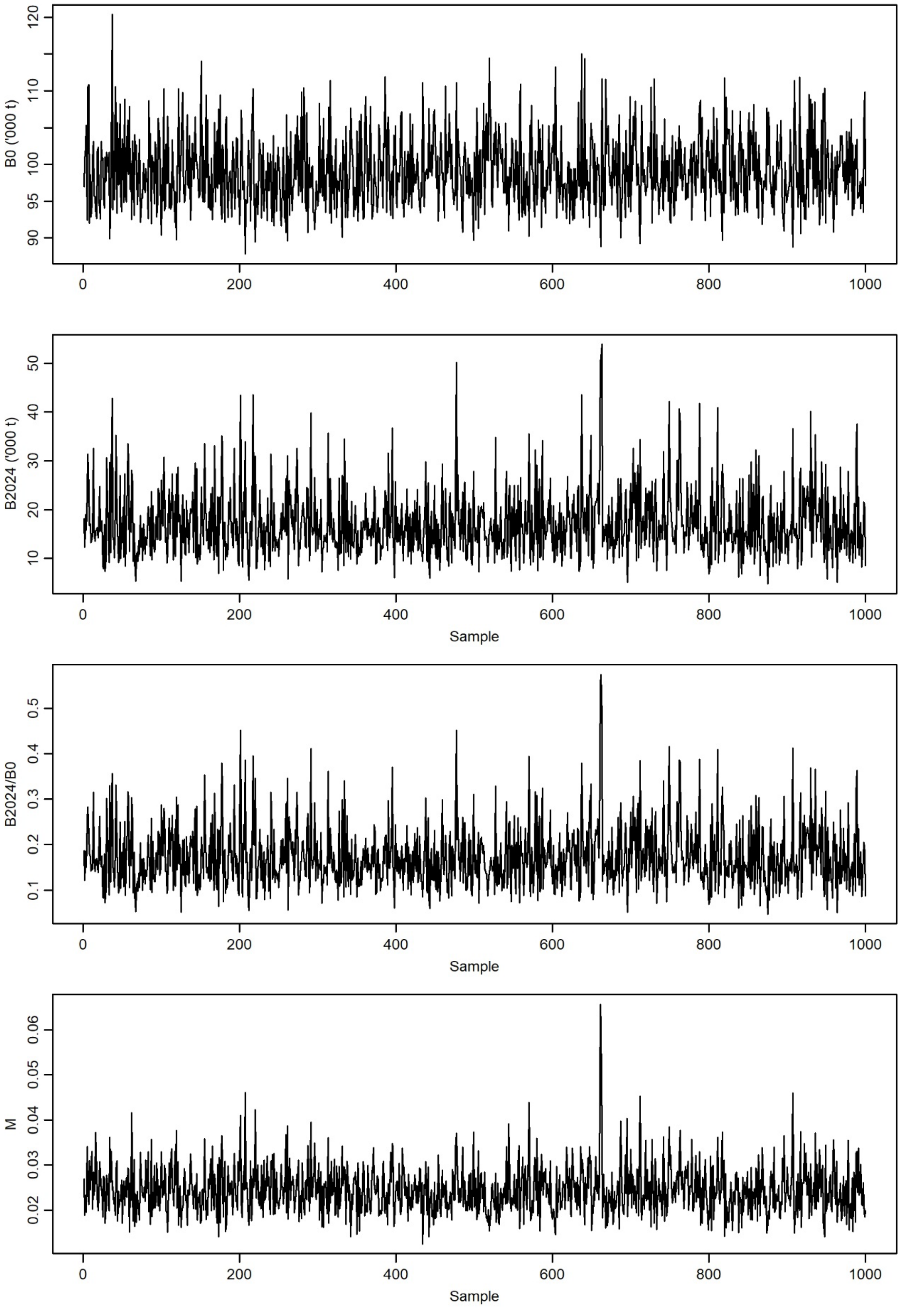

Figure 8.2: MCMC posterior samples for the All6 model run. Panels from top, B_0, B_{2024}, B_{2024}/B_0, M.

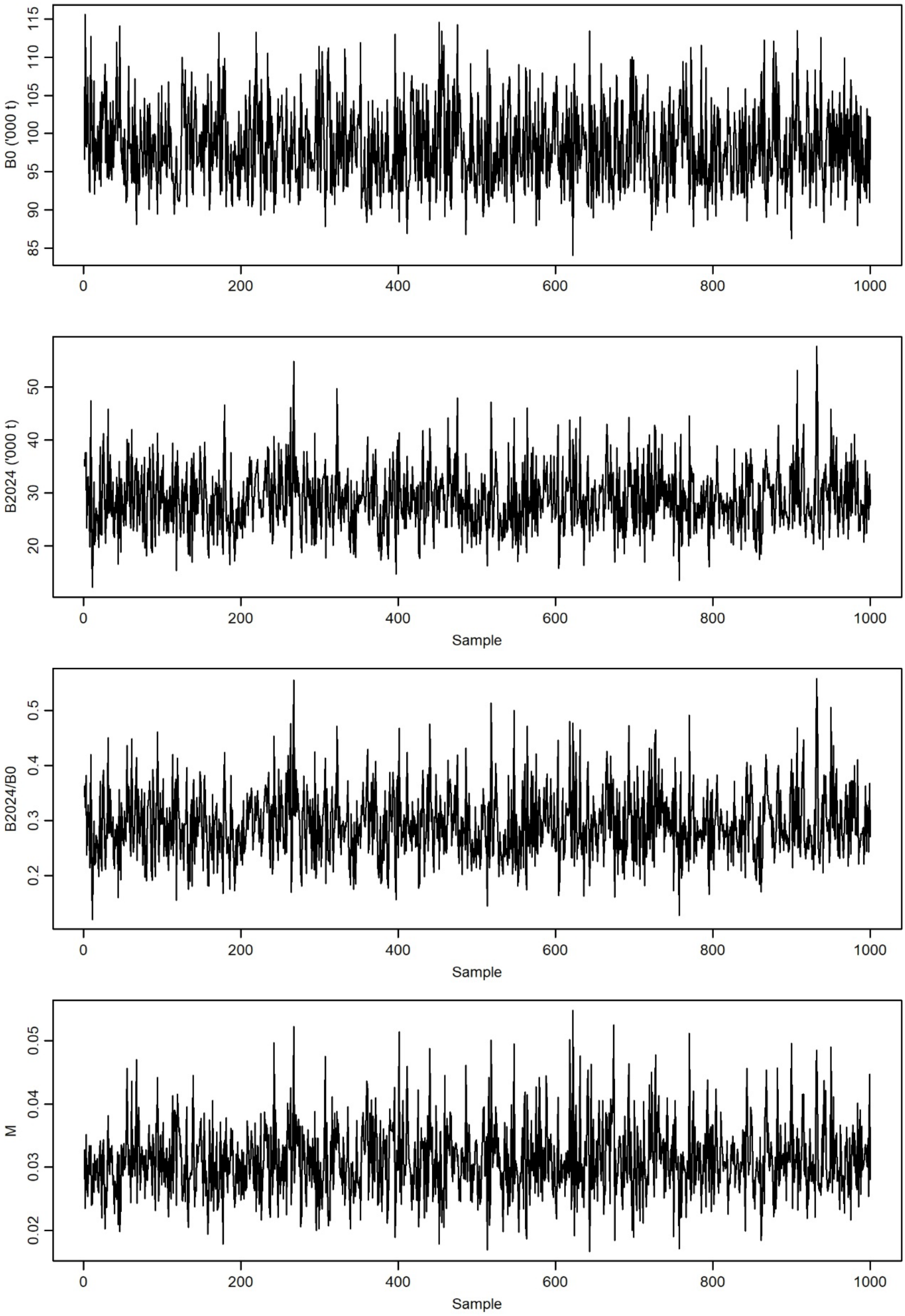

Figure 8.3: MCMC posterior samples for the A3series model run. Panels from top, B_0, B_{2024}, B_{2024}/B_0, M.

9. APPENDIX C: Implied residuals to age frequency data from MCMC estimates

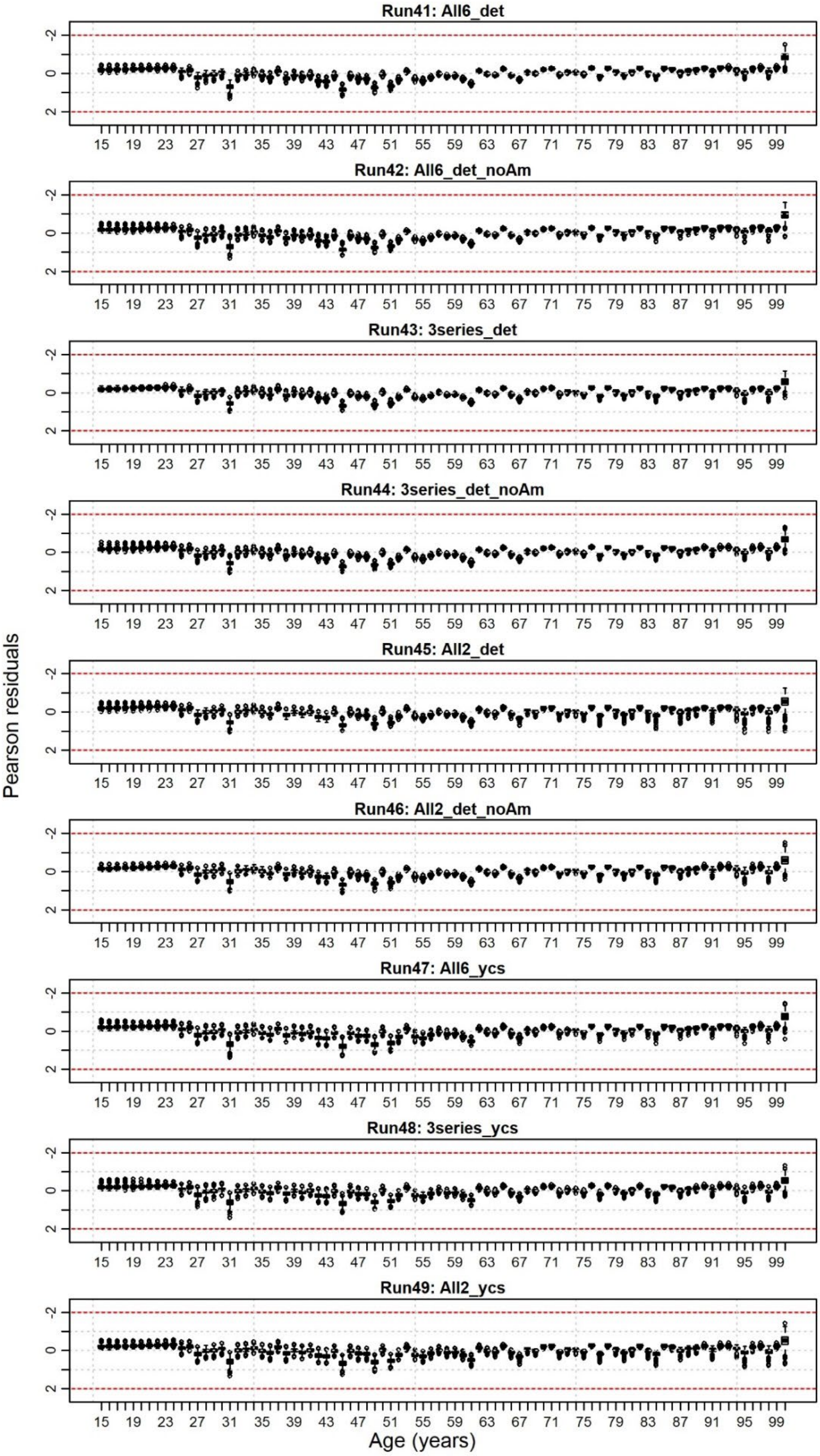

Figure 9.1: EEZ 1987 age frequency MCMC implied residuals for various model runs with acoustic series All2, All6, and 3series, estimating YCS (ycs) or with constant recruitment (det), and with the Amaltal Explorer series (no label) or without (noAm).

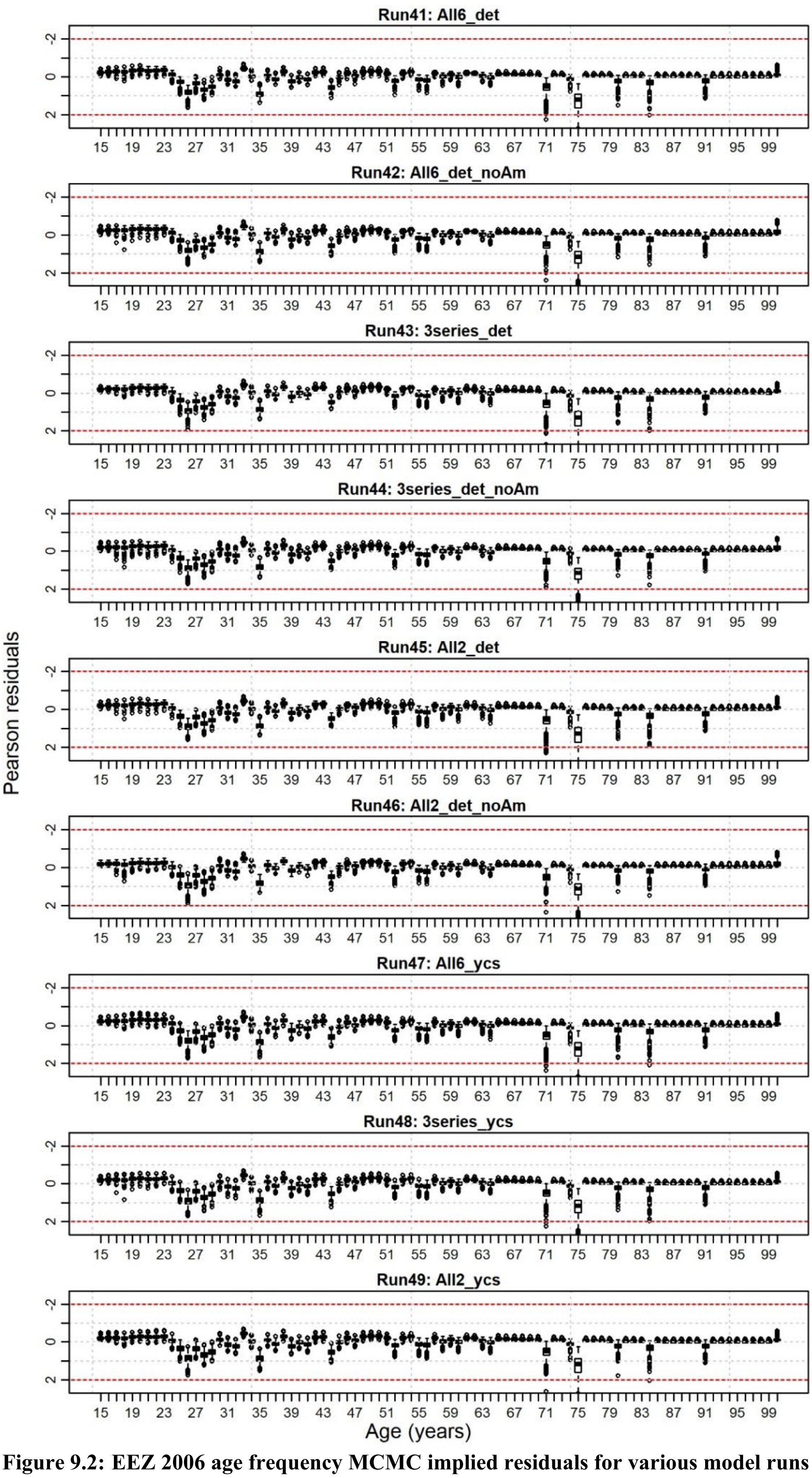

Figure 9.2: EEZ 2006 age frequency MCMC implied residuals for various model runs with acoustic series All2, All6, and 3series, estimating YCS (ycs) or with constant recruitment (det), and with the Amaltal Explorer series (no label) or without (noAm).

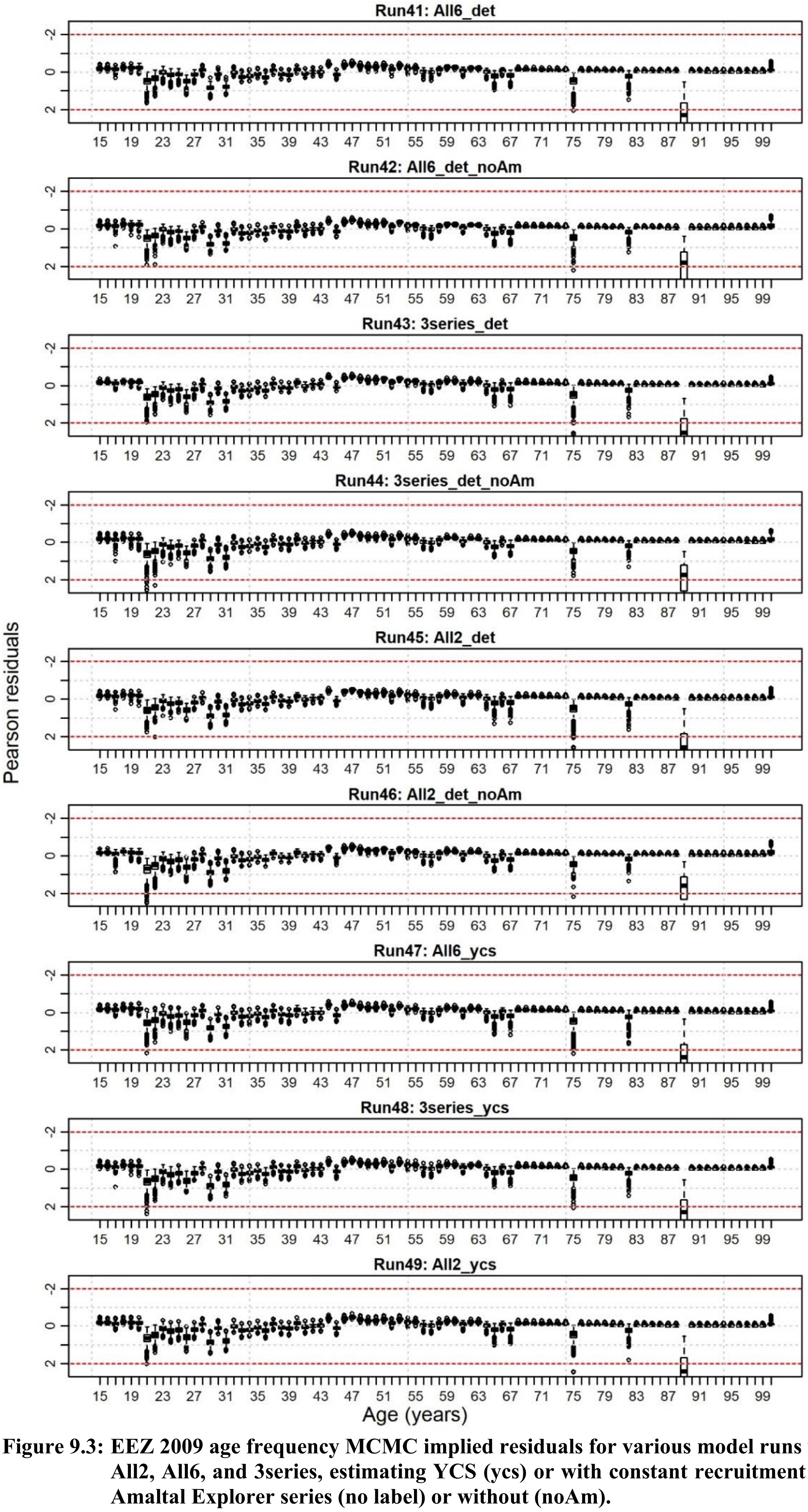

Figure 9.3: EEZ 2009 age frequency MCMC implied residuals for various model runs with acoustic series All2, All6, and 3series, estimating YCS (ycs) or with constant recruitment (det), and with the Amaltal Explorer series (no label) or without (noAm).

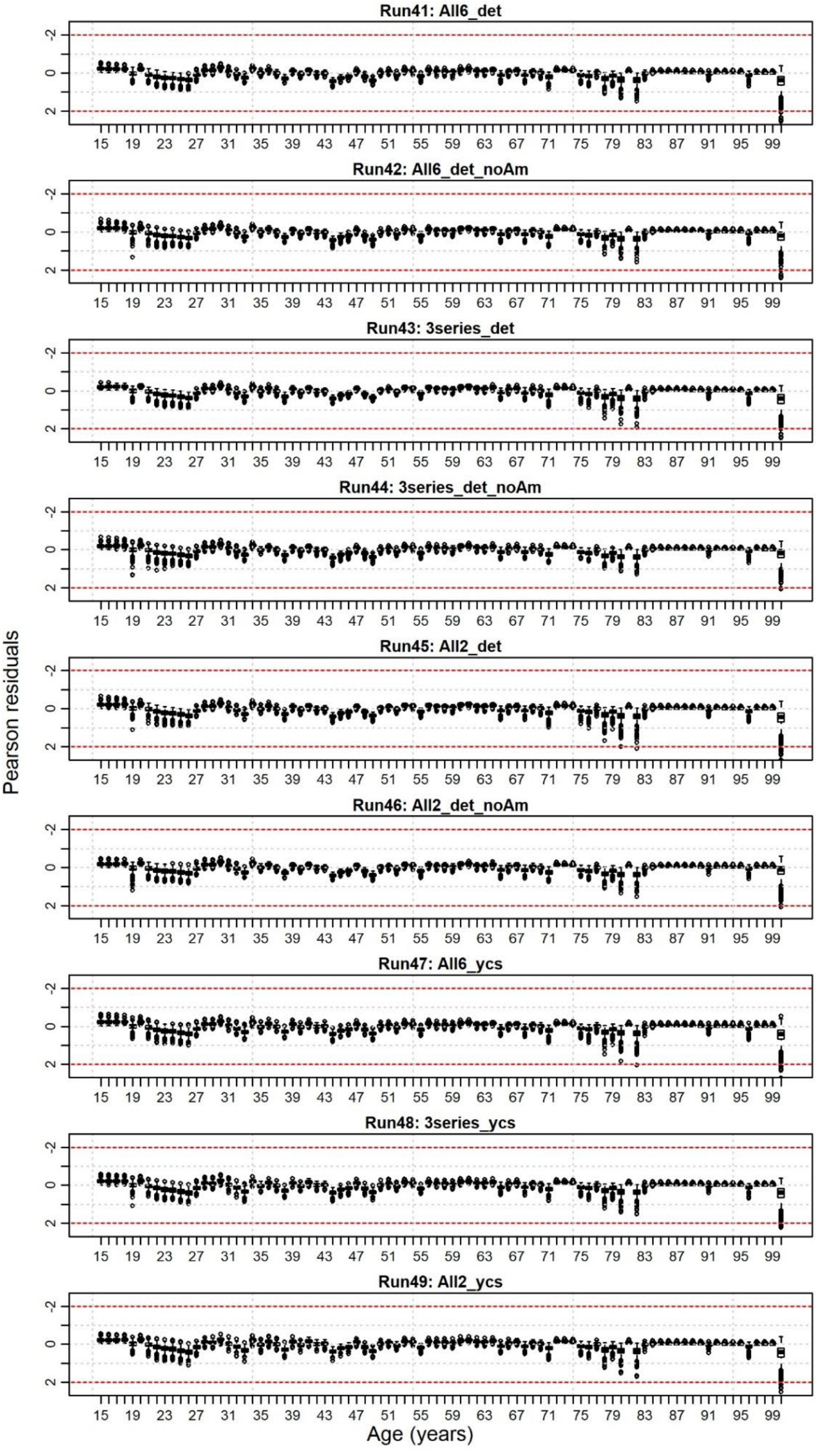

Figure 9.4: EEZ 2018 age frequency MCMC implied residuals for various model runs with acoustic series All2, All6, and 3series, estimating YCS (ycs) or with constant recruitment (det), and with the Amaltal Explorer series (no label) or without (noAm).

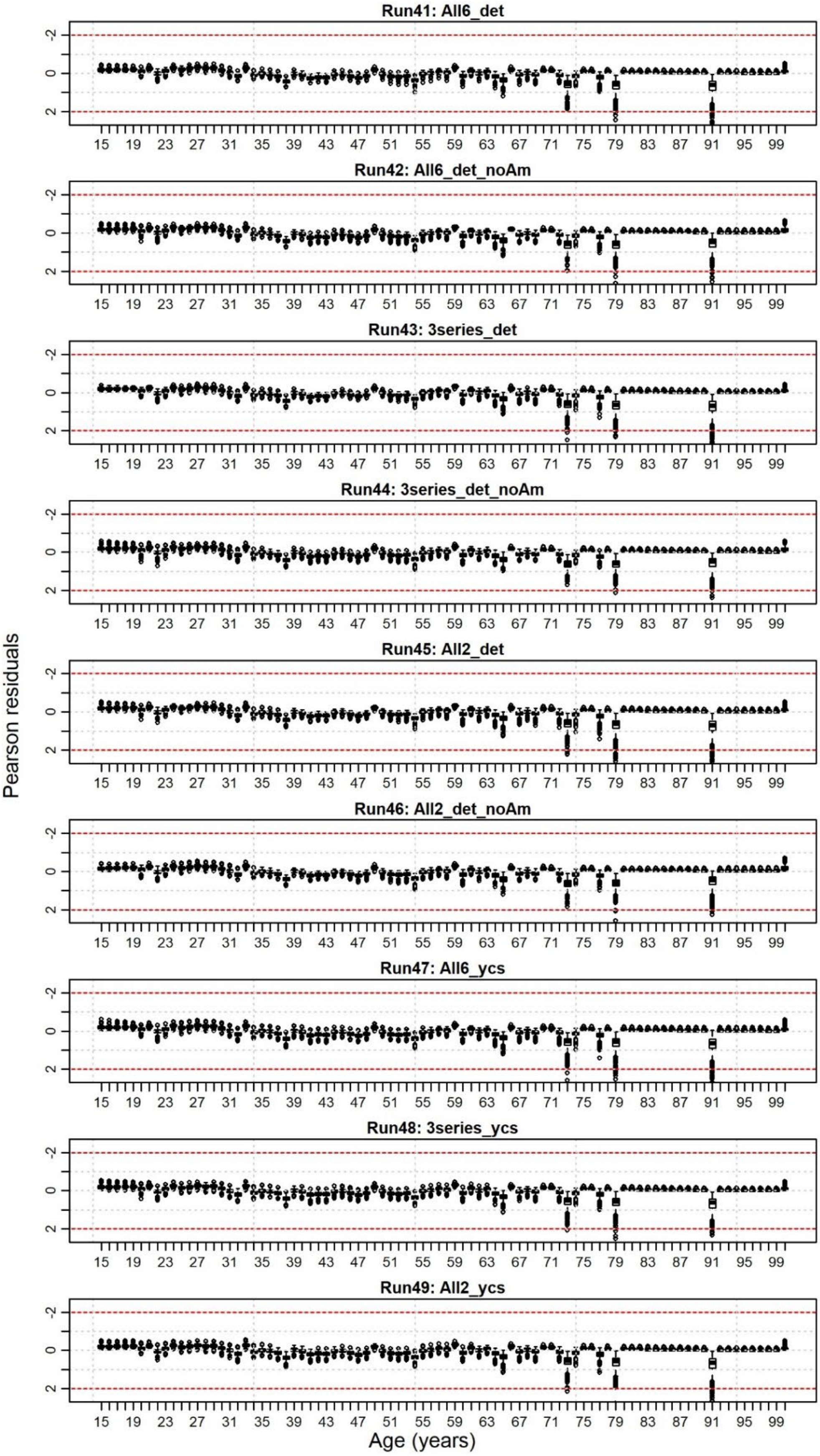

Figure 9.5: Volcano 2014 age frequency MCMC implied residuals for various model runs with acoustic series All2, All6, and 3series, estimating YCS (ycs) or with constant recruitment (det), and with the Amaltal Explorer series (no label) or without (noAm).

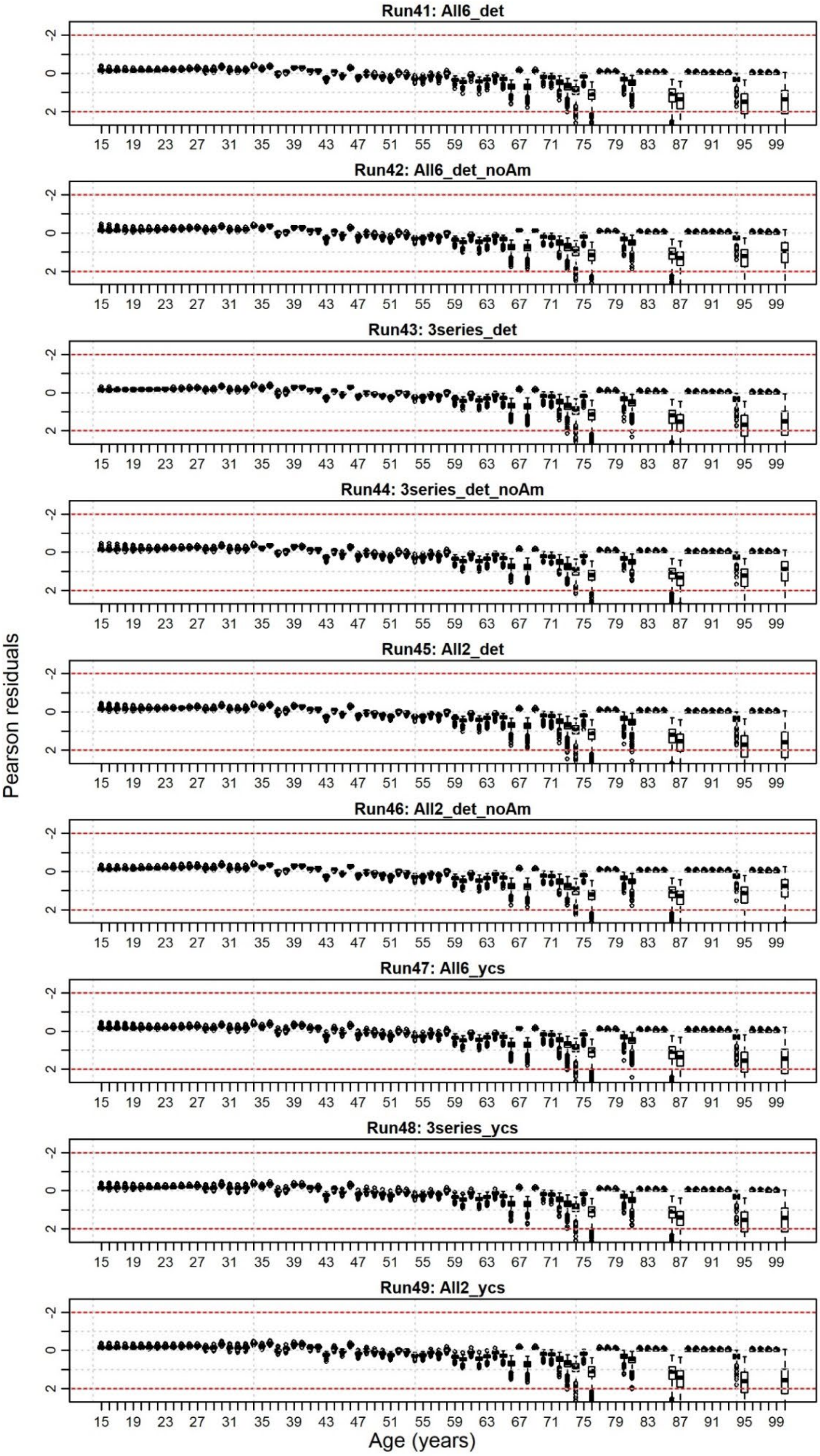

Figure 9.6: Volcano 2018 age frequency MCMC implied residuals for various model runs with acoustic series All2, All6, and 3series, estimating YCS (ycs) or with constant recruitment (det), and with the Amaltal Explorer series (no label) or without (noAm).