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Tini a Tangaroa

Assessment of the Chatham Rise orange roughy stocks for 2017

New Zealand Fisheries Assessment Report 2018/59

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EXECUTIVE SUMMARY

Dunn, M.R.; Doonan, I.J. (2018). Assessment of the Chatham Rise orange roughy stocks for 2017.

***New Zealand Fisheries Assessment Report 2018/59.* 60 p.**

This report describes the 2017 assessment of the two orange roughy stocks on Chatham Rise; the Northwest Chatham Rise, and East & South Chatham Rise.

The previous assessments were conducted in 2014. The additional observational data available to the 2017 assessment were: for the Northwest Chatham Rise, a revised acoustic biomass estimate for 2013, a new acoustic biomass estimate for 2016, and a new age composition for 2016; for the East & South Chatham Rise, a revised acoustic biomass estimate for 2013, new acoustic biomass estimates for 2014 and 2016, and a new age composition for 2016.

The 2014 assessments evaluated the sensitivity of the base model to many alternative assumptions. The representative sensitivity runs completed in 2014 were repeated in 2017. Additional sensitivity runs evaluated in the 2017 assessment included the addition and weighting of the new data, and for the East & South Chatham Rise the selectivity assumed for mature fish caught in trawl surveys, the assumptions for the acoustic biomass catchabilities (to treat the biomass indices more as relative than absolute), the addition of process error on acoustic surveys, the assumed prior for year class strengths, and the number of assumed stocks. Technical changes were also made to the MCMC to improve diagnostics.

For the Northwest Chatham Rise, virgin biomass, B_0, was estimated to be between 64 000–67 300 t (median values range for the base model and sensitivities), and recent biomass was increasing. For the base model, there was a 98% probability that the stock was above the lower bound of the management target range (30% B_0) in 2017.

For the East & South Chatham Rise, virgin biomass, B_0, was estimated to be between 300 600 and 363 100 t, and recent biomass was increasing. For the base model, there was an 86% probability that the stock was above 30% B_0 in 2017.

1. INTRODUCTION

The New Zealand orange roughy Quota Management Area 3B (ORH 3B) includes Chatham Rise, the Campbell Plateau (sub-Antarctic), and the lower part of the South Island (Figure 1).

The work described in this report was carried out under Ministry for Primary Industries project DEE2016/21 Specific Objective 2, "*To carry out stock assessments of the Northwest Chatham Rise and East & South Chatham Rise*". The characterisation of the fisheries conducted under Specific Objective 1 is described elsewhere.

This report updates the stock assessments for the Northwest Chatham Rise (NWCR) and East and South Chatham Rise (ESCR) conducted in 2017, including data to the end of the 2015–16 fishing year (New Zealand fishing years start 1 October), and updates the stock assessment described by Cordue (2014) and Ministry for Primary Industries (2016). The management of the Chatham Rise orange roughy fisheries is described by Ministry for Primary Industries (2016).

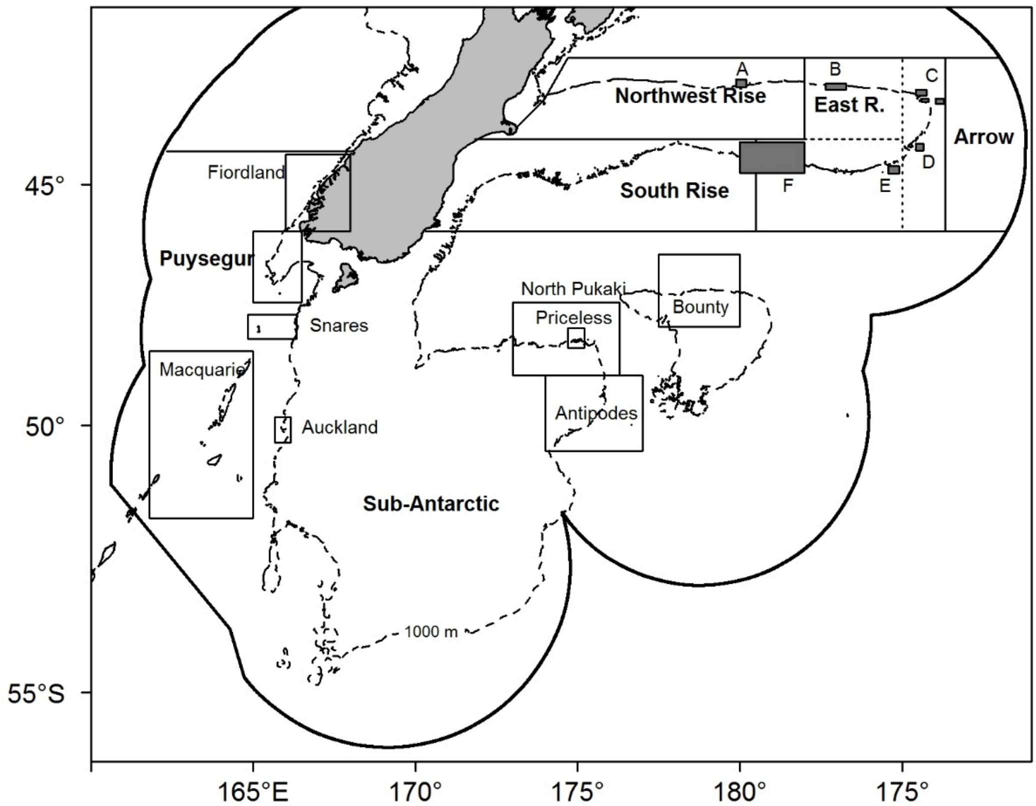

Figure 1: The ORH 3B fishery area. The recognised stocks are indicated by bold text. The rectangles mark the main fishing grounds, with those on Chatham Rise shaded: A, Graveyard (180) hills; B, Spawning Box; C, northeast hills; D, Andes;, E, Chiefs; F, south Rise (Mt. Kiso & Hegerville).

2. CATCHES AND BIOLOGY

2.1 Catch history

The catch and effort data for the fisheries are described in Dunn (in press). No recreational fishing, or customary non-commercial fishing for orange roughy, is known. No information is available on illegal catch in this quota management area, however, there has been a history of catch overruns on the Chatham Rise because of lost fish and discards, and discrepancies in tray weights and conversion factors (Ministry for Primary Industries, 2016). In assessments, total removals from each part of the Chatham Rise were assumed to exceed reported catches by the overrun percentages in Table 1.

Table 1: Catch history for orange roughy Chatham Rise stocks assumed in the stock assessments. Official catch from Dunn (in press). For the assessment, catches for 2017 were assumed to be the same as those in 2016.

Fishing year	Official catch (t)	Assumed over-run (%)	Assessment catch (t)				
			East & South Chatham Rise				Northwest Chatham Rise
			Boxflat	Hills	Andes	South	
1978–79	11 800	30	15 338	0	0	0	0
1979–80	29 900	30	37 660	160	0	1 040	1 560
1980–81	19 800	30	20 910	20	0	4 810	10 920
1981–82	17 900	30	22 560	60	0	650	9 100
1982–83	10 000	30	6 760	0	0	6 240	7 020
1983–84	21 600	30	21 360	90	0	6 630	4 290
1984–85	27 400	30	25 350	0	0	10 270	2 340
1985–86	26 400	28	26 720	290	0	6 784	4 736
1986–87	27 500	26	28 270	200	0	6 174	4 032
1987–88	22 600	24	19 220	370	0	8 432	1 984
1988–89	29 000	22	23 710	400	50	11 224	4 636
1989–90	28 300	20	20 320	200	240	13 200	3 960
1990–91	19 100	15	7 570	6 370	100	7 935	1 725
1991–92	15 200	10	2 590	3 100	8 620	2 420	330
1992–93	10 200	10	190	1 280	3 820	5 940	4 180
1993–94	10 000	10	90	1 250	4 060	5 610	3 850
1994–95	5 600	5	570	1 740	1 900	1 680	2 520
1995–96	5 100	5	1 800	810	1 380	1 365	2 520
1996–97	5 000	5	1 800	1 170	820	1 470	2 310
1997–98	6 300	5	2 570	710	1 550	1 785	2 415
1998–99	4 800	5	1 280	1 120	1 390	1 260	2 835
1999–00	5 700	5	1 640	930	2 270	1 155	2 205
2000–01	5 200	5	1 500	880	1 300	1 785	2 730
2001–02	7 800	5	3 460	1 040	2 540	1 155	2 310
2002–03	8 600	5	3 720	870	2 870	1 575	2 310
2003–04	8 300	5	5 026	616	1 528	1 409	2 100
2004–05	8 800	5	5 482	543	1 381	1 757	1 680
2005–06	9 100	5	5 711	544	1 776	1 310	1 470
2006–07	9 100	5	5 857	836	1 448	1 273	735
2007–08	7 800	5	5 260	383	1 307	1 419	840
2008–09	6 720	5	4 625	686	514	1 231	788
2009–10	5 320	5	3 787	247	577	976	756
2010–11	3 060	5	1 966	202	558	484	42
2011–12	2 590	5	1 659	218	529	320	74
2012–13	2 330	5	1 558	59	528	307	116
2013–14	3 197	5	1 791	150	875	528	830
2014–15	3 306	5	2 451	46	524	412	840
2015–16	3 398	5	1 680	148	1 132	376	761
2016–17	–	–	1 680	148	1 132	376	761

2.2 Biological parameters

The biological parameters assumed for the Chatham Rise orange roughy stocks were those used by Cordue (2014) and described by Ministry for Primary Industries (2016). Age at maturity, and age of selectivity to the fisheries, were estimated in the models. Sensitivity runs estimating the natural mortality rate, *M*, have previously been described (Cordue, 2014).

Although new length at age data were available for the 2016–17 assessment (see later Sections), the growth parameters (von Bertalanffy model) were not updated.

3. REVISED ACOUSTIC BIOMASS INDICES

There were some changes to acoustic biomass estimates during the 2016–17 stock assessment. These changes revised biomass estimates for years since 2013; older estimates were unchanged (Ministry for Primary Industries, 2016). The issues examined in these analyses are described here, and the revised estimates given in Table 2, and previous, and new or revised biomass estimates, are shown in Figures 2 and 3.

3.1 Extreme acoustic signal regions

One potential source of bias is the increasing occurrence of extreme signal regions (ESR), which are thought to be caused by the presence of high target strength fish (species with large air bladders). Distinguishing these species from orange roughy requires (at least) dual frequency data (Ryan & Kloser 2015). ESR are sometimes present within or adjacent to orange roughy marks, and they clearly need removing before estimating orange roughy biomass. Observed ESR have been estimated to contain targets equivalent to at least 4 orange roughy m^{-3}, and up to 800 orange roughy m^{-3} (which is clearly not plausible), and often have 120/38 kHz differences that indicate that species with air swim bladders were present, even though none were caught in the trawls. CSIRO analyses have excluded ESR where possible. ESR have been detected at Morgue and Graveyard, but not in the spawning plume in the Spawning Box ("old spawning plume") and Rekohu, although there are large swimbladder signals in the "fuzz" surrounding the Rekohu spawning aggregation.

Tim Ryan (CSIRO, pers. comm.) reported that it "seems highly unlikely ESRs could be roughy". However, some ESRs are nevertheless identified as having orange roughy in them by the 120/38 kHz difference, and hull surveys could not distinguish between areas of the mark with air swimbladder species, and those with orange roughy. In addition, hull surveys cannot detect ESR unless they have a large volume relative to the orange roughy volume.

3.2 Snapshot selection criteria

All snapshots that met data quality standards were considered for selection. To be included, surveys should be during active spawning activity; this is identified through an observed reduction over time in the percentage maturing, and a catch that includes some running-ripe females. Excluding snapshots because the resulting biomass estimate was unlikely (i.e., because a biomass estimate was "too high" or "too low") was previously not considered valid, except in the case where sustained reduced abundances were detected in a series of consecutive surveys. When detected, the reduced abundance series was excluded from the mean (e.g., 2014 Old Spawning Plume series, as below). This was applied in surveys having a long sequence of snapshots taken during a commercial fishing trip, where detecting a reduced abundance on consecutive snapshots was possible.

Surveys using a dual frequency acoustic-optical system (AOS) were focused on collecting acoustic data, and so were always shorter than commercial fishing trips, which limited their ability to detect a persistent reduction in abundance. There is also a hypothesis that fluctuations in the aggregation abundance available to the acoustic system over a short timescale means that low values should be excluded from the mean. This assumes that the highest values are genuine and not spurious, e.g., no bias from undetected large air bladder species. In 2016–17 analyses, the Welch's t-tests was used to identify snapshots having significantly low biomass estimates.

Table 2: Acoustic biomass estimates added to the 2016–17 stock assessment. GY, Graveyard; MO, Morgue; OSP, Old Spawning Plume; RE, Rekohu; MM, Mt Muck; op, operation; SZ, acoustic shadow zone; B1, rule to exclude a snapshot if more than 10% of biomass was on a boundary transect; B2, rule to include a snapshot that would otherwise be excluded under B1 if the estimate was greater than the mean of the accepted snapshots; D1, rule to exclude a snapshot if the backscatter distribution was clearly different from that seen in other (easily) accepted snapshots.

Year	Snapshots	Aggregation	Used in assessment	Biomass (t)	CV (%)	Previous assessment biomass (t)	Comment
Northwest Chatham Rise							
2012	3	GY		5 550	17		
	4	MO		9 087	11		
	3+4	total	Yes	14 637	17		No change from last assessment.
2013	1	GY	Yes	6 656	31	7 379	One successful AOS survey with a revised estimate of 6 656 t, CV 31% (op 19). Survey CV was 16%. (51% of abundance in SZ.) The 38 kHz transducer partially failed so these results are for the 120 kHz transducer. Large mark that was up to 70 m off the bottom.
2016	3	MO		14 051	13		
	1	GY		0	–		Not analysed, so set to zero, but had about a 50–70 m high mark (*cf.* 70 m in 2013 when surveyed), but intensity was much lower than that in 2013.
	3+1	total	Yes	14 051	13		Accepted as MO + GY estimate.
East & South Chatham Rise							
2013	4	RE		33 348	10		Was two hull surveys. Added 3 AOS surveys, and removed 1 hull survey that was concurrent with the AOS.
	4	OSP		15 544	14		Was two snapshots. Revised estimates. Op 69 removed (under D1) and very low biomass; Op 61 included (under B2).
	3	MM		5 471	16		No revision, except CV slightly higher (was 15%).
	4+4+3	Total	Yes	54 363	8		
2014	2	RE		44 421	25		Excluded op Op. 10 as low biomass and temporally separate from others.
	4	OSP		19 360	18		exclude snapshots after 14 July; persistent lower mean biomass
	2+4	Total	Yes	63 784	18		
2016	7	RE		27 027	13		Exclude op57 (under B1).
	5	OSP		11 192	19		Op 75 had low biomass, but it was completed on the same day as op77, which was included. If op 75 is dropped, then biomass is 12 859 t (24%, CV1).
	3	MM		5 341	23		
	7+5+3	Total	Yes	43 560	10		

The coefficient of variation of the biomass estimate is calculated in two possible ways: using the estimated CVs from each snapshot (CV1) or using the CV calculated from the snapshots' abundance estimates (CV2). The latter is preferred when there are five or more acceptable snapshots. When using CV1, an assumed CV of 60% for the shadow zone component was included, i.e., the original snapshot CVs applied only to the acoustic estimate above the shadow zone.

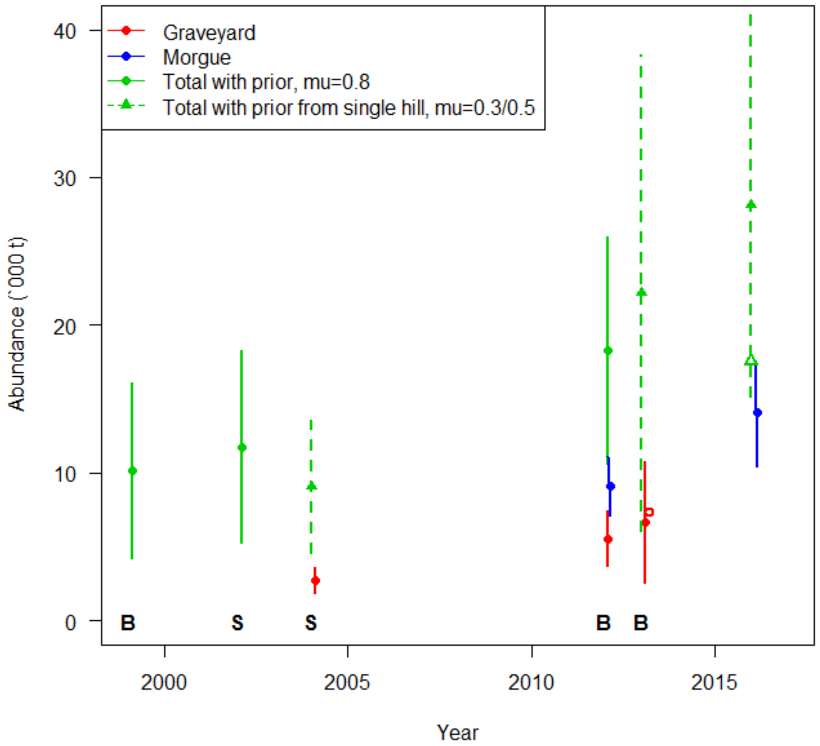

Figure 2: Acoustic estimates for the Northwest Chatham Rise (±2 standard deviation indicated by vertical lines). The red open square in 2013 is the value from Cordue (2014). Total biomass is the estimate divided by the mean of the acoustic prior, e.g., in 2013 there was only a Graveyard estimate and the prior mean was 0.3. B, estimates used in the base case in the last assessment; S, included in sensitivity runs. Red and blue indicate empirical estimates; green indicate estimates scaled by the assumed catchability (*q*). Open green triangle in 2016 is the total using a *q* prior with mean (mu) of 0.8.

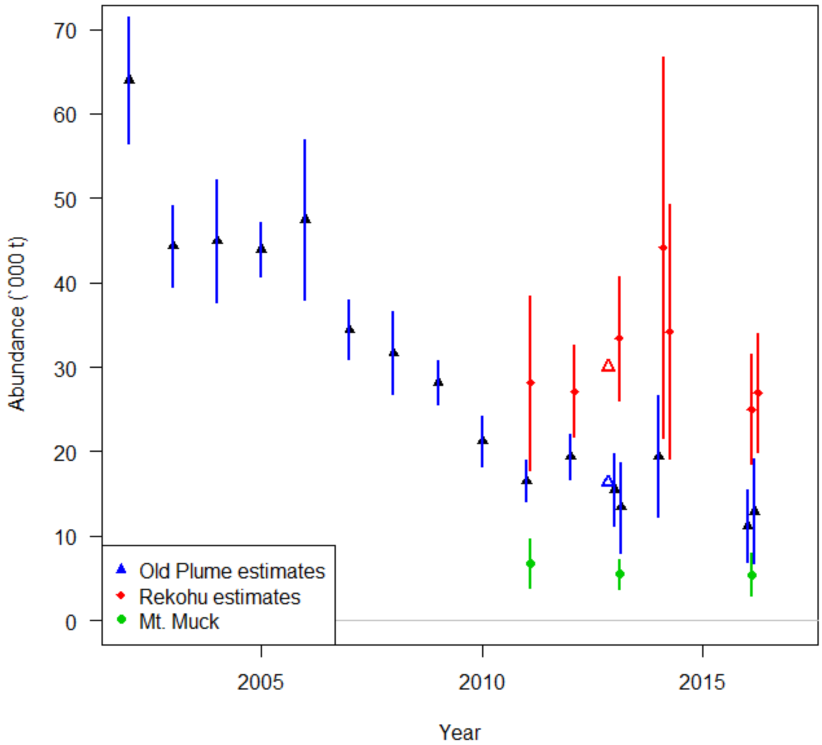

Figure 3: Acoustic estimates for the East & South Chatham Rise (±2 standard deviation indicated by vertical lines). Blue, Old Plume; green, Mt Muck; red, Rekohu. For 2013, values used by Cordue (2014) are marked by the unfilled triangles (no revision of the 2013 Mt. Muck estimate). Alternative values for 2013, 2014, and 2016 illustrate differences from changing snapshot selection.

4. NORTHWEST CHATHAM RISE

This assessment model for the Northwest Chatham Rise followed Cordue (2014), and used an age-structured population model implemented in CASAL (Bull et al., 2012), fitted to acoustic-survey estimates of spawning biomass, proportion-at-age from a trawl survey and targeted trawling on a spawning aggregation, proportion-spawning-at-age from the same trawl survey, and length frequencies from the commercial fishery.

4.1 Model structure

Following Cordue (2014), the model was single-sex and structured by age (1–100 years with a plus group) and maturity (i.e., fish were classified by age and as mature or immature). A single-time step was used and the single fishery was assumed to be year-round on mature fish. Spawning stock biomass was recorded after 75% of the mortality had taken place, and 100% of mature fish were assumed to spawn each year; the latter assumption means all mature biomass was being indexed by the acoustic surveys on the spawning aggregations (other than an offset for fish assumed to be spawning elsewhere, see below). Natural mortality was assumed to be constant at 0.045 yr^{-1} and the stock-recruitment relationship was assumed to follow a Beverton-Holt function with steepness of 0.75. Ageing error was assumed to be 10%. Fixed and estimated model parameters and priors are summarised in Table 3.

Table 3: Fixed and estimated model parameters for the Northwest Chatham Rise assessment, base model.

Parameter	*n*	Prior	Comments
B_0	1	Uniform-log	–
CV of length for mean length at age	2	Uniform	–
Maturity	2	Uniform	Logistic. Estimated from (a) trawl survey proportion mature at age, and (b) fishery length composition
Trawl survey selectivity	2	Uniform	Logistic. Fishery selectivity is assumed same as maturity
Year class strengths	40	Nearly-uniform; Haist parameterisation	–
Acoustic biomass *q*	3	Informed lognormal, see below	All mature biomass
Natural mortality *M*	1	Fixed	Default M = 0.045
Length at age	3	Fixed	Von Bertalanffy K = 0.059; t_0 = -0.491; L_∞ = 37.78.
Length to weight	2	Fixed	$a = 8.0 \times 10^{-8}$; b = 2.75

4.2 Input data and statistical assumptions

There were three main data sources of observations fitted in the assessment: acoustic-survey spawning biomass estimates from the main spawning hills (Graveyard and Morgue); an age composition and an estimate of proportion-spawning-at-age taken from a 1994 wide-area trawl survey; an age composition taken from targeted trawls above Morgue in 2016; and length compositions collected from the commercial fishery covering 1989–2005. The new data for the 2017 assessment were a revised biomass estimate for 2013, one new acoustic biomass estimate for 2016, and one age composition from Morgue in 2016.

Three types of acoustic-survey estimates were available for use in the assessment (see Cordue 2014; Table 4). The reliability of the data from the different systems in each year was considered and estimates from only the AOS and towed-body systems were considered acceptable for use in the 2014 base model (Cordue, 2014). An alternative treatment of the available acoustic data was to include additional survey estimates from 2002 and 2004 (Table 4). All data in Table 4 were used in the sensitivity run labelled "Extra acoustics".

Table 4: Acoustic survey estimates of spawning biomass used in the base model (excludes 2002 and 2004) and the sensitivity run "Extra acoustics" (uses all data). "GY" = Graveyard, "M" = Morgue, "O" = other hills. The observation CVs are those used in the model and do not include any process error. *, included in sensitivity runs only. Priors are lognormal (CV in parentheses).

Year	System	Frequency	Areas	Snapshots	Estimate (t)	Observation CV(%)	Prior
1999	Towed-body	38 kHz	GY+M+O	1	8 126	22	0.8 (19)
2002*	Towed-body	38 kHz	GY+O	2	9 414	20	0.8 (19)
2004*	Hull-mounted	38 kHz	GY	6	2 717	16	0.3 (19)
2012	AOS	38 kHz	GY+M	3+4	14 637	17	0.8 (19)
2013	AOS	120 kHz	GY	1	6 656	31	0.3 (19)
2016	AOS	38 kHz	GY+M	1+3	14 051	13	0.8 (19)

Following Cordue (2014), the acoustic estimates in 1999, 2002, 2012 (total = 14 637 t, CV 17%), and 2016, were assumed to represent "most" of the spawning biomass in each year. This was modelled by treating the acoustic estimates as relative biomass and estimating the proportionality constant (*q*) with an informed prior. The prior was normally distributed with a mean of 0.8 (i.e., "most" = 80%) and a CV of 19% (Cordue, 2014). The 2004 and 2013 Graveyard estimates were modelled as relative biomass with an informed prior on the *q* with a mean of 0.3 (derived from the relative proportions of the Graveyard and Morgue estimates in 2012, with the 80% assumption). The MPI Deepwater Fisheries Assessment Working Group concluded that the failure of the survey to measure orange roughy marks on Graveyard in 2016 indicated zero biomass (despite around 200 t being caught there during the spawning season; see Dunn, in press).

A wide-area trawl survey of the northwest flats was conducted in late May and early June of 1994 (72 stations; Tracey & Fenaughty 1997). The female proportion spawning-at-age was also estimated (reported in Cordue, 2014). These data were fitted in the model: age frequency (multinomial with an effective sample size of 60); proportion-spawning-at-age (binomial with effective sample size at each age equal to the number of female otoliths at age).

The length compositions from the previous assessment in 2006 were used: nine years of length-composition data from the period 1989–97 were combined into a single length-composition that was centred on the 1993 fishing year. Eight years of length-composition data from the period 1998–2005 were combined into a single length-composition that was centred on the 2002 fishing year. The multinomial effective sample size was set at 1/6 of the number of tows for each period: 19 for the "1993" period and 35 for the "2002" period (A. Hicks, unpublished).

The trawl survey age composition for 1994 was from a 3-month wide area trawl survey covering both pre-spawning and spawning periods (Tracey & Fenaughty, 1997), with 300 otoliths selected following a catch and area weighted design (Doonan et al. 2014). The Morgue age composition was from three acoustic mark identification pelagic tows (bottom trawl "flown" above the seabed) taken during winter of 2016, with 300 otoliths selected following a catch weighted design (Doonan, pers. comm.). Both age compositions were allocated a multinomial effective sample size of 60 (following the Cordue (2014) weighting for the 1994 age composition).

4.3 Model runs and results

In the base model, as agreed by the MPI Deepwater Fisheries Assessment Working Group, the acoustic estimates from 1999, 2012, 2013, and 2016 were used, and the age composition from 2016 was excluded. There were four main sensitivity runs: add the extra acoustic data; the LowM-Highq and HighM-Lowq "standard" runs (Ministry for Primary Industries, 2016); and including the 2016 age composition with its own (logistic) selectivity. Sensitivity runs estimating *M* were excluded following uncertainty about the weighting of the age composition data, which indicated quite different age structures (see below), making estimation of *M* less plausible.

When the 2016 age composition was excluded the year class strengths (YCS) were estimated from 1940 to 1979 (n = 40). In the sensitivity run including the 2016 age-frequency the YCS were estimated from 1940 to 1992 (n = 53).

Both MPD and MCMC runs were completed for all models. The following sections describe results from both, with the MCMC estimates for the model runs used in management advice (chosen by the MPI Deepwater Fisheries Assessment Working Group) subsequently shown in detail.

The model provided good MPD fits to the data (Figures 4 and 5). The acoustic indices, free to "move" somewhat as they are relative, were fitted well (Figure 4). The posterior estimates for the acoustic *q*s were not very different from the priors, but there was some movement in the Graveyard and Morgue *q*, with the posterior slightly lower (and therefore SSB slightly higher) than expected (Figure 6).

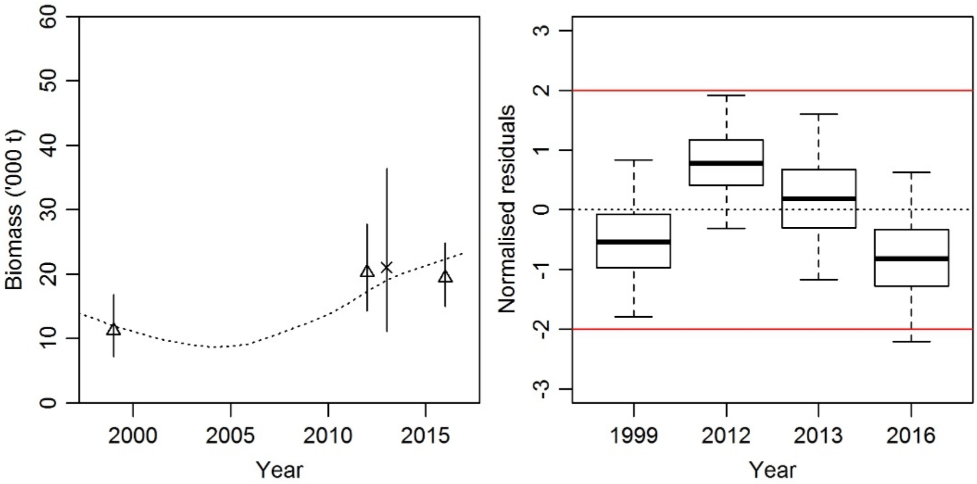

Figure 4: Northwest Chatham Rise, base model run, (left) MPD fits to the acoustic biomass indices; broken line, spawning biomass trajectory; scaled acoustic indices for x, Graveyard survey, and Δ, Graveyard and Morgue surveys; (right) MCMC normalised residuals for the acoustic biomass indices. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution.

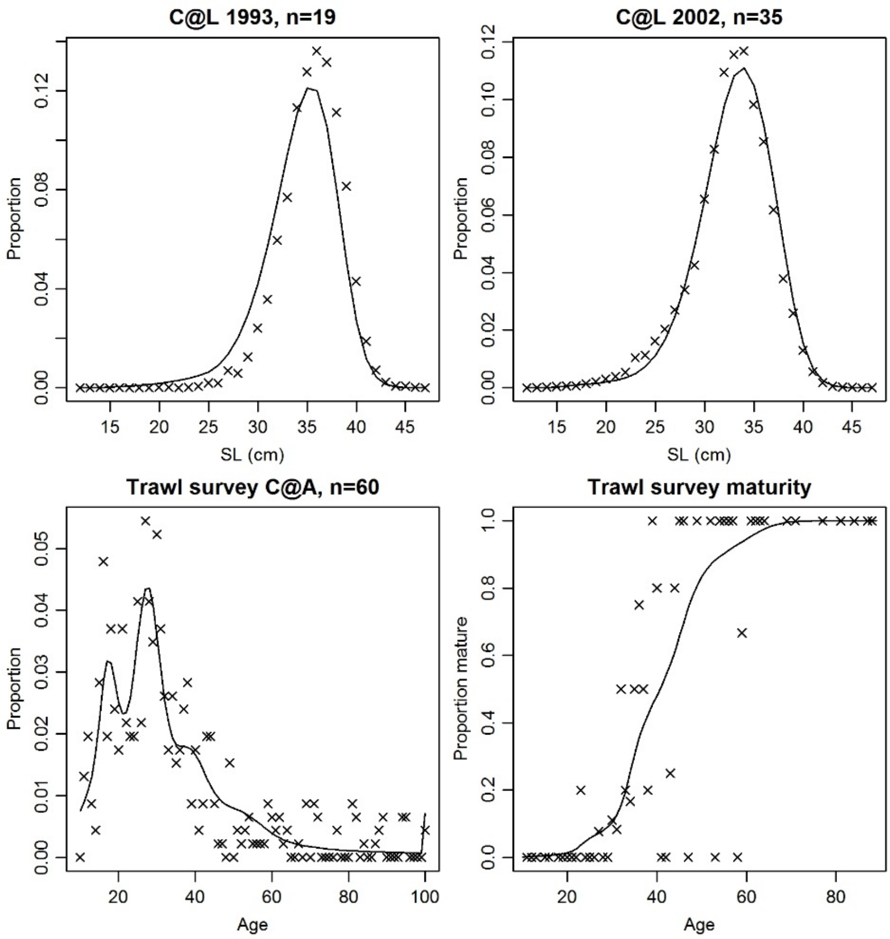

Figure 5: Northwest Chatham Rise, base model run, MPD fits: (x, observations; lines, predictions): (top) commercial catch-at-length samples (n is the effective sample size); (bottom) trawl survey catch-at-age and proportion mature at age.

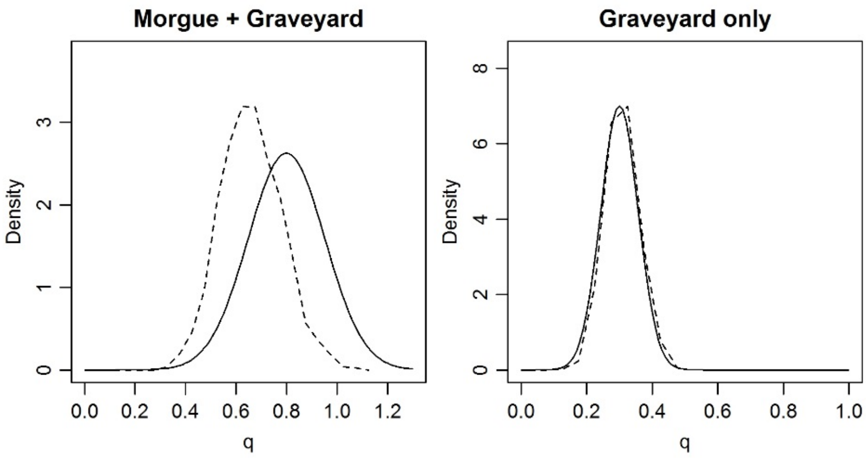

Figure 6: Northwest Chatham Rise, base model run, MCMC diagnostics: prior (solid line) and posterior (broken line) distributions for the two acoustic qs (left, mean q-prior = 0.8; right, mean q-prior = 0.3).

When the Morgue age-frequency was fitted assuming that the selectivity on Morgue was equal to maturity the fit was poor, with the fit to the left-hand side indicating that the age of selectivity on Morgue was older than maturity (Figure 7).

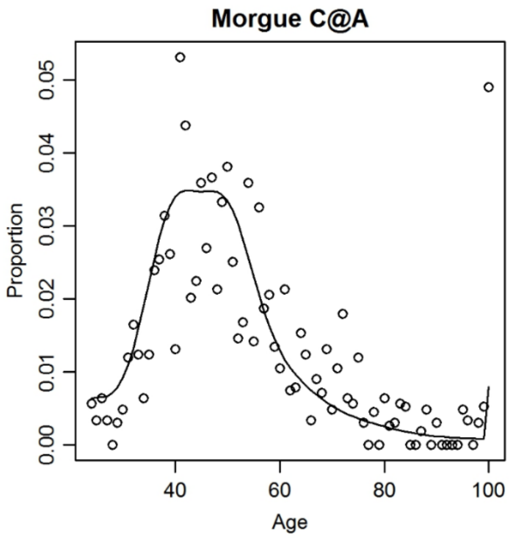

Figure 7: Northwest Chatham Rise, base model with Morgue catch composition included assuming selectivity at age equal to maturity, MPD fits: (o, observations; lines, predictions) to the Morgue catch-at-age sample (effective samples size = 60).

When the Morgue catch-at-age was fitted assuming a separate logistic selectivity ogive the fit was more acceptable (Figure 8). The estimated selectivity ogive indicated that the fish on Morgue were not fully selected until they were relatively old (selectivity A_{50} = 64.4 years, 95% CI 50.1–80.6). Therefore, the younger mature fish (given maturity A_{50} = 36.8 years), although a large proportion of the sample (see Figure 8), were barely selected.

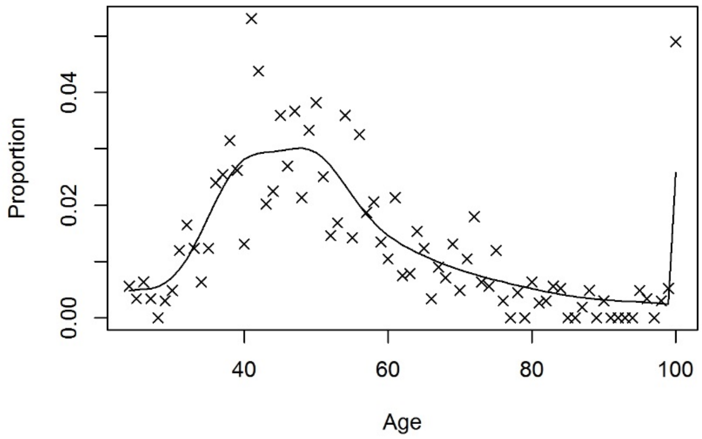

Figure 8: Northwest Chatham Rise, base model with Morgue catch composition included fitted with a separate selectivity at age, MPD fits: (x, observations; lines, predictions) to the Morgue catch-at-age sample (effective samples size = 60).

The implications of the run assuming a separate selectivity for Morgue, where the fish on Morgue were relatively old and the younger but mature fish were barely selected, is illustrated in Figure 9. If we assume that the age composition for Morgue was representative of the fish on Morgue, then the Morgue selectivity should be applied to the Morgue acoustic biomass estimate as well (in the model run allowing a separate selectivity for the Morgue age composition the acoustic survey selectivity was assumed equal to maturity, i.e., much younger than the estimated selectivity). This inconsistency was not addressed during the model runs, because the few age samples (2016 only) meant that the representativeness of these samples was unclear. However, if the Morgue acoustic biomass estimate assumed the selectivity estimated for Morgue, with the maturity at age as estimated elsewhere (e.g., from proportion mature at age observations) then, given the biomass estimate for Morgue (about 14 000 t), this would imply a very large SSB elsewhere.

Various other assumptions for fitting the Morgue age composition were attempted, including changing the selectivity of the fishery and the trawl survey, , including assuming different effective sample sizes (sample weighting) for the trawl survey and Morgue age compositions, and assuming or estimating *M* (to see if a lower *M* might provide a better fit to the Morgue age composition); none of these options provided an acceptable fit, and parameters for more complex selectivity ogives could not be estimated (either theoretically, e.g., capped logistic, or parameters were poorly determined, e.g., double normal, Figure 10).

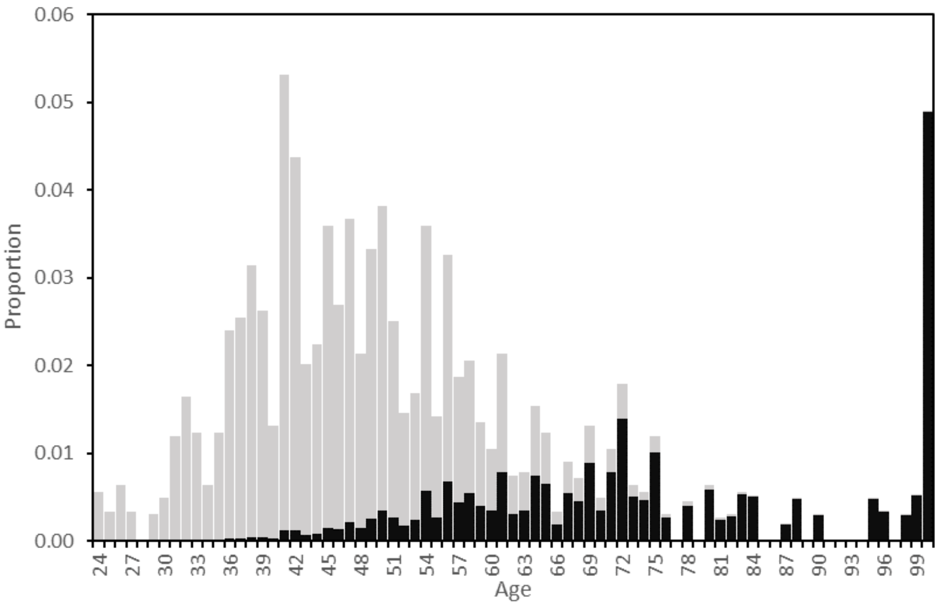

Figure 9: Northwest Chatham Rise, observed age composition on Morgue (bars; total height), and the proportion at age that was estimated to be selected (black part of bars) with the logistic selectivity parameters estimated in the base model run (A_{50} = 64.4 years).

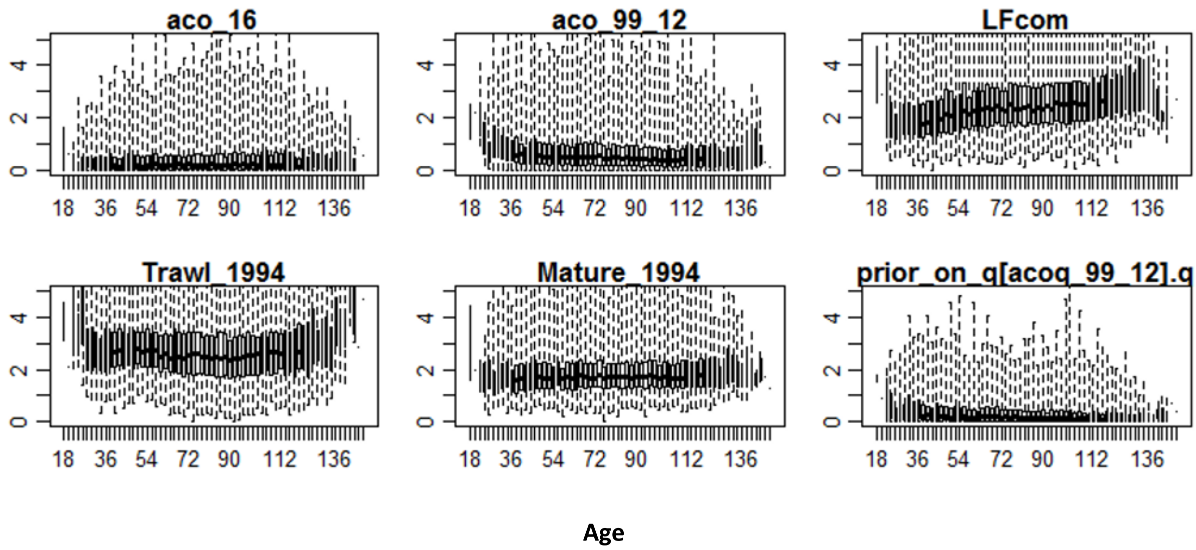

Figure 10: Northwest Chatham Rise, selected likelihood profiles from MCMC samples (n=1000) for the a1 parameter (age at which selectivity = 1) of a double normal ogive assumed for the trawl survey (in principle, a domed shaped selectivity for the trawl survey might reduce conflict between the age composition samples by allowing for the older fish observed in the Morgue age composition). The weak influence of the trawl survey age composition data on the selectivity a1 parameter is shown in the panel Trawl_1994; more information on this parameter apparently came from the commercial fishery length compositions (LFcom).

The reason that the logistic selectivity ogive for Morgue was shifted to older ages seemed to be (at least in part) because of an inconsistency in the year class strength pattern indicated by the trawl age composition, and the acoustic biomass indices. The trawl age composition indicated a period of relatively strong recruitment during the 1970s, which were at around age 15–20 in 1994 (see Figure 5). The high age at selectivity for Morgue, although strongly influence by the age composition, was also supported by the acoustic biomass observations (Figure 11). The strong recruitment from the 1970s was consistent with the observed biomass rebuild at the end of the assessment time series (see Figure 2).

However, this strong recruitment was not observed in the Morgue age composition, therefore to obtain a good fit, the selectivity was moved to the right (to a higher A_{50}) (Figure 12).

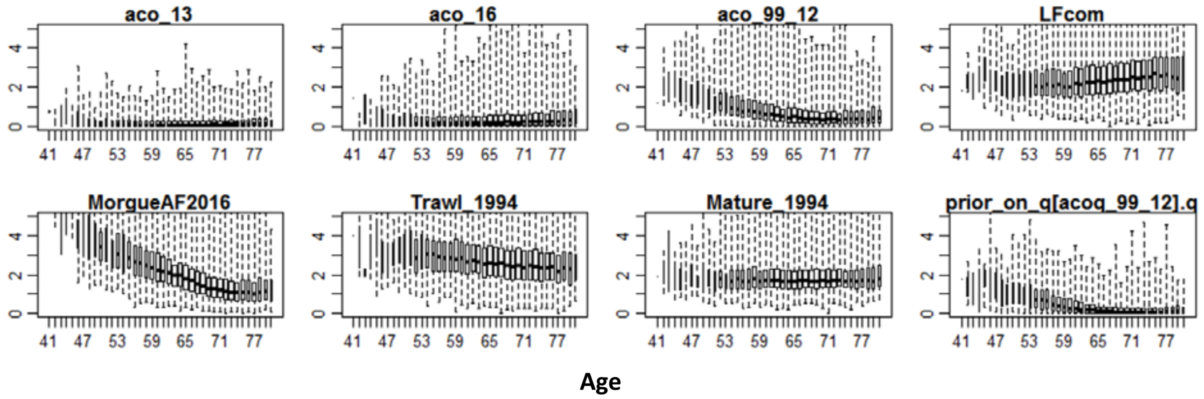

Figure 11: Northwest Chatham Rise, selected likelihood profiles from MCMC samples (n=1000) for the A_{50} parameter of a logistic ogive assumed for the Morgue age composition. The influence of the Morgue age composition is shown in panel MorgueAF2016, and the moderate contribution from biomass estimates in aco_99_12 (observations) and prior_on_q[acoq_99_12].q (prior); small influence of the trawl survey age composition shown in panel Trawl_1994.

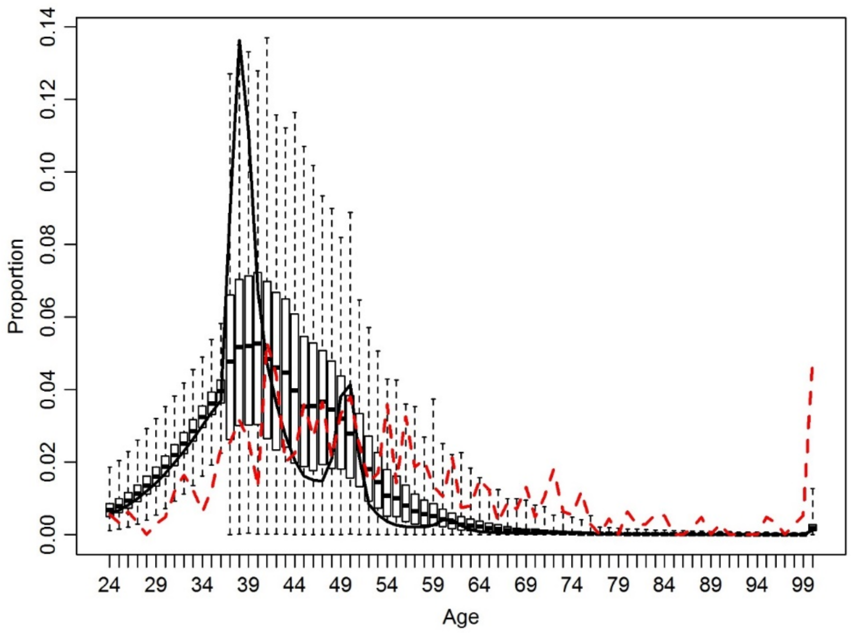

Figure 12: Northwest Chatham Rise, expected age composition in 2016 from the base run, without the Morgue age composition data included, shown for MPD (solid line) and MCMC (bar and whisker). The red broken line indicates the observed 2016 age composition on Morgue. The variability around the MCMC estimates of age composition up until age 36 reflects uncertainty in selectivity; the variability for ages above this also includes the uncertainty from YCS estimation (uncertainty therefore increases).

The descriptive analyses of the fishery have not indicated a large spawning stock occurring outside of Morgue, e.g., an acoustic biomass of zero tonnes estimated for the Graveyard hill in 2016, and no other areas of high catch rates during spawning (see Dunn, in press). Nevertheless, the MPI Deepwater Fisheries Assessment Working Group considered that the hypothesis that almost all young mature fish (ages around 40–50) were not on Morgue but elsewhere remained plausible. For example, a new spawning aggregation of predominantly young fish was recently found at Rekohu on the northeast

Chatham Rise. However, a new spawning aggregation had not been found on the northwest Chatham Rise, and as a result, the MPI Deepwater Fisheries Assessment Working Group agreed to exclude the Morgue catch-at-age data from the base model until the veracity of this assumption could be investigated further, or until a plausible assumption for providing an acceptable fit to the Morgue age compositions was found.

Other MPD sensitivity runs performed during this assessment concerned the relative weighting of observational data, estimating or fixing *M*, changing the mean of the acoustic *q* priors, removing the assumed catch history over-runs, and adding acoustic surveys (as specified in Table 4). Many other sensitivity runs were also conducted with the previous model (Cordue, 2014). The sensitivity runs showed that the main drivers of the estimated stock status were natural mortality (*M*) and the means of the acoustic *q* priors (lower *M* and higher mean *q* give lower stock status; higher *M* and lower mean *q* give higher stock status).

4.4 MCMC results

For the base model, and the selected sensitivity runs (Table 5), MCMC diagnostics indicated no lack of convergence (Appendix A).

Virgin biomass, B_0, was estimated to be between 64 000–67 300 t for all runs (Table 5). Current stock status was similar across the base and the first two sensitivity runs (Table 5). For the two “bounding” runs, where *M* and the mean of the acoustic *q* priors were shifted by 20%, median current stock status was estimated to be close to the lower bound, or upper bound, of the target range of 30–50% B_0 (Table 5).

Table 5: Northwest Chatham Rise, MCMC estimates of virgin biomass (B_0) and stock status (B_{2017} as %B_0) for the base model and four sensitivity runs.

	M	B_0 (000 t)	95% CI	B_{2017} (%B$_0$)	95% CI
Base	0.045	65.2	59.9–75.0	38	31–48
Extra acoustics	0.045	64.0	60.0–76.7	36	31–43
Include Morgue C@A	0.045	65.1	58.6–76.5	38	30–48
Low *M*-High q	0.036	67.3	63.0–73.9	29	23–36
High *M*-Low q	0.054	65.5	58.2–77.7	48	40–58

For the base model, there was a 98% probability that the stock was above 30% B_0 in 2017. Therefore, for the base model, the stock was considered to be fully rebuilt according to the Harvest Strategy Standard (at least a 70% probability that the lower end of the management target range of 30–50% B_0 has been achieved). For the sensitivity runs, the probability of being above 30% B_0 in 2017 was 98% (Extra acoustics), 97% (Include Morgue C@A), 36% (Low *M*-High *q*), and 100% (High *M*-low *q*).

The estimated YCS showed little variation across cohorts, but recruitment was relatively high in 1940–52, 1965–68, and 1975–79 (Figure 13).

The estimated spawning-stock biomass (SSB) trajectory showed a declining trend from 1980 (when the fishery started) through to 2004 when the biomass was around the level of the soft limit (Figure 14). Since 2005 the estimated biomass increased steadily.

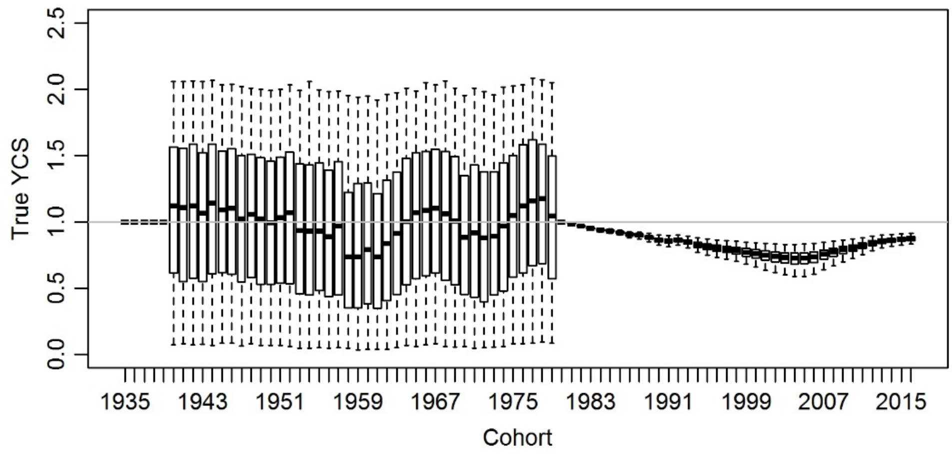

Figure 13: Northwest Chatham Rise base, MCMC estimated "true" YCS (Ry/R0). The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution.

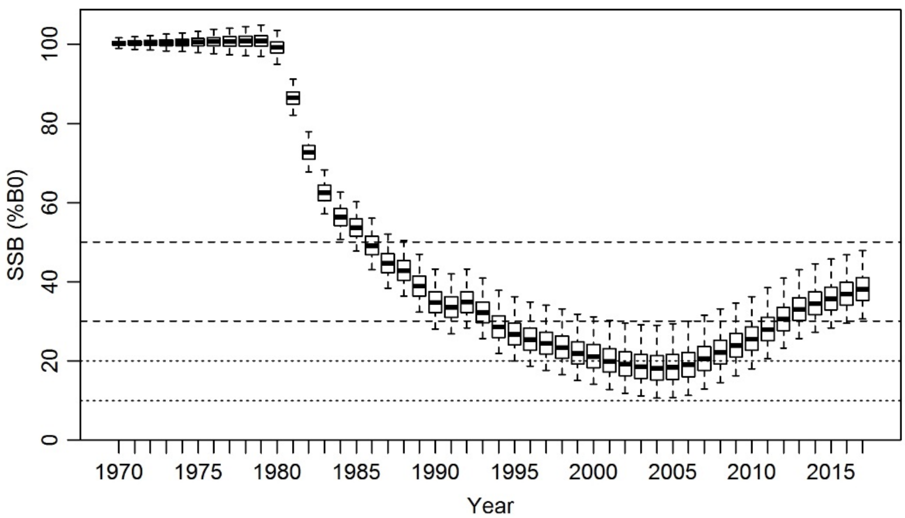

Figure 14: Northwest Chatham Rise base, MCMC estimated spawning-stock biomass trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. Dotted lines indicate the hard limit (10% B_0) and soft limit (20% B_0), dashed lines the biomass target range (30–50% B_0).

Estimated fishing pressure decreased substantially from 2007, and was close to zero while the stock was voluntarily closed during 2011–13, and since 2014 has remained at the lowest persistent level since the fishery started (Figure 15).

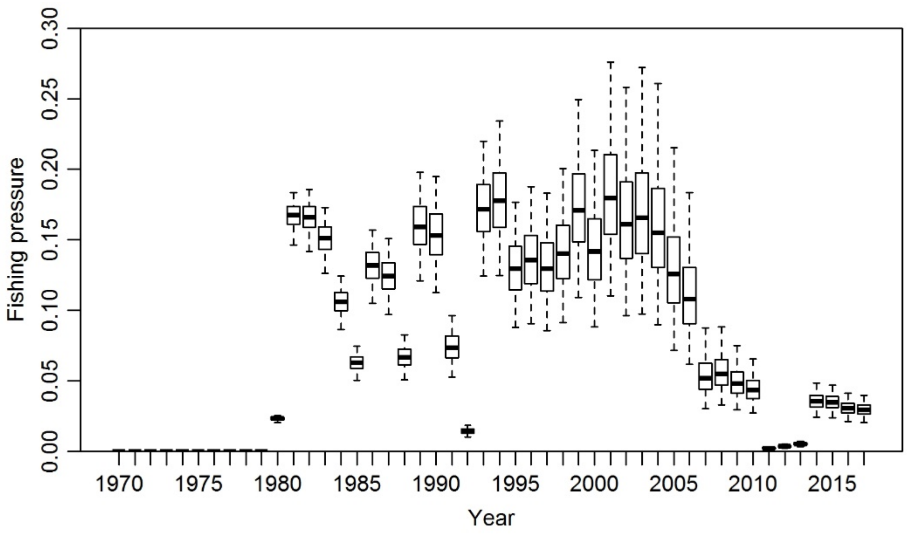

Figure 15: Northwest Chatham Rise base, MCMC estimated fishing pressures. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution.

5. EAST AND SOUTH CHATHAM RISE

This assessment model for the East & South Chatham Rise followed Cordue (2014), and used an age-structured population model implemented in CASAL (Bull et al., 2012), fitted to acoustic-survey estimates of spawning biomass, trawl surveys of spawning aggregations, proportion-at-age from trawling on a spawning aggregation, and length frequencies from the commercial fishery.

5.1 Model structure

Following Cordue (2014), the model was single-sex and structured by age (1–100 years with a plus group) and maturity (i.e., fish were classified by age and as mature or immature). A single-time step was used and four year-round fisheries, with logistic selectivities, were modelled: Box & flats, Eastern hills, Andes, and South Rise. No length frequencies were available from the South Rise fishery and its selectivity was assumed to be the same as the Andes (so effectively there were three fisheries in the model). Spawning was taken to occur after 75% of the mortality, and 100% of mature fish were assumed to spawn each year; the latter assumption means all mature biomass was being indexed by the acoustic surveys on the spawning aggregations (other than an offset for fish spawning elsewhere, see below). Natural mortality was assumed to be constant at 0.045 yr^{-1} and the stock-recruitment relationship was assumed to follow a Beverton-Holt function with steepness of 0.75. Ageing error was assumed to be 10%. Estimated model parameters and priors are summarised in Table 6; fixed parameters were the same as the Northwest Chatham Rise (see Table 3).

5.2 Input data and statistical assumptions

For 2017, there were four main data sources of observations fitted in the assessment: acoustic-survey spawning biomass estimates from the main spawning grounds covering 2002 to 2016; trawl survey estimates of spawning biomass covering 1984 to 1994; age compositions from spawning aggregations in 2012, 2013, and 2016; and length compositions collected from the commercial fishery covering various years (depending on fishery) between 1989 and 2005. The new data for the 2017 assessment were a revised acoustic biomass estimate for 2013, and two new acoustic biomass estimates (2014 and 2016), and one new age composition (2016).

Table 6: Estimated model parameters for the East & South Chatham Rise assessment, base model.

Parameter	*n*	Prior	Comments
B_0	1	Uniform-log	–
CV of length for mean length at age	2	Uniform	–
Maturity	2	Uniform	Estimated from age compositions (assumed selectivity = maturity)
Fishery selectivity	6	Uniform	–
Trawl survey selectivity	14	Uniform	Initial setting; eventually reduced to $n = 6$
Trawl survey *q*	4	Uniform	–
Year class strengths	65	Nearly-uniform; Haist parameterisation	–
Acoustic biomass *q*	11	Informed lognormal, see below	All mature biomass

Like the Rekohu plume, which was first noted in 2010 and first surveyed in 2011, the Old plume occurs on an area of relatively flat seabed and is assumed to be adequately acoustically surveyed using a hull-mounted transducer. In 2011, 2013 and 2016, an additional (but well-known historically) spawning area known as the Crack (also known as Mount Muck) was surveyed. This is an area of rough ground (a hill) which requires a towed acoustic system to be used to reduce the height of the shadow or dead zone (i.e., with the transducer at a depth of about 500–700 m). The acoustic biomass estimates selected by the MPI Deepwater Fisheries Assessment Working Group for use in the stock assessment are shown in Table 7 (Ministry for Primary Industries 2016).

Following Cordue (2014), in the base model it was assumed that the Old plume time series could not be relied on to provide a consistent index for any part of the spawning biomass. In 2011, 2013 and 2016, the estimates of average spawning biomass across the three areas were summed to form comparable indices for each year. The 2012 and 2014 estimates from Rekohu and the Old plume were summed to provide a 2012 and 2014 index with a different *q*. The Old plume indices from 2002–2010 were used, but each point in the time series was given its own *q*. Informed priors were used for all of the *q*s in the Old plume series, for the 2012 and 2014 biomass indices, and the indices comprising 2011, 2013, and 2016 observations (Table 7).

For 2011, 2013, and 2016, it was assumed that "most" of the biomass was being indexed so the "standard" acoustic *q* prior was used: lognormal (mean = 0.8, CV = 19%) (see Cordue, 2014). The mean of the *q* prior for 2012 and 2014 was derived from the observed biomass proportions across the three areas and the assumption that 80% of the spawning biomass was indexed in 2011, 2013 and 2016. This gave a mean of 0.7 for the 2012 and 2014 indices, a reflection that this index did not include an estimate for Mount Muck. For 2002 to 2010 the means of the *q* priors were assumed to decrease linearly from 0.7 (2002) down to 0.30 (2010), reflecting the gradual increase in the relative importance of the Rekohu plume (Cordue, 2014).

Table 7: Acoustic and trawl survey estimates of biomass, and assumed *q*s, as used in the assessment. Spawn. Box trl, research trawl surveys of biomass in the Spawning Box; OP acou, acoustic spawning biomass estimate of the Old plume; TAN wide area trl, biomass estimate from the *Tangaroa* wide-area trawl survey; OP + RE + MM acou, acoustic spawning biomass estimate from the Old plume, Rekohu, and Mount Muck.

Year	Name	Biomass (CV)	Biomass *q* / *q* prior (LN mean; CV)	Biomass *q* prior (LN mean; CV)	Ratio penalty ($q_y/q_{2011,13,16}$)	Ratio *q* / Ratio penalty (q_y/q_{y+1})
1984	BUC Spawn. Box trl	130 000 (17)	uniform	–	–	–
1985	BUC Spawn. Box trl	111 000 (15)	uniform	–	–	–
1986	BUC Spawn. Box trl	77 000 (16)	uniform	–	–	–
1987	BUC Spawn. Box trl	60 000 (15)	uniform	–	–	–
1988	COR Spawn. Box trl	73 000 (25)	uniform	–	–	–
1989	COR Spawn. Box trl	54 000 (18)	uniform	–	–	–
1990	COR Spawn. Box trl	34 000 (19)	uniform	–	–	–
1991	–	–	–	–	–	–
1992	TAN Spawn. Box trl	22 000 (34)	uniform	–	–	–
1993	–	–	–	–	–	–
1994	TAN Spawn. Box trl	61 000 (67)	uniform	–	–	–
~						
2002	OP acou.	63 950 (6)	0.70 (30)	–	–	1.091 (10)
2003	OP acou.	44 316 (6)	0.65 (30)	–	–	1.101 (10)
2004	OP acou.	44 968 (8)	0.60 (30)	–	–	1.112 (10)
	TAN wide area trl	16 878 (10)	uniform	–	–	–
2005	OP acou.	43 923 (4)	0.55 (30)	–	–	1.126 (10)
2006	OP acou.	47 450 (10)	0.50 (30)	–	–	1.144 (10)
2007	OP acou.	34 427 (5)	0.45 (30)	–	–	1.169 (10)
	TAN wide area trl	17 000 (13)	uniform	–	–	–
2008	OP acou.	31 668 (8)	0.40 (30)	–	–	1.203 (10)
2009	OP acou.	28 199 (5)	0.35 (30)	–	–	1.254 (10)
2010	OP acou.	21 205 (7)	0.30 (30)	–	0.29 (7.5)	–
2011	OP + RE + MM acou.	51 329 (8)	0.80 (19)	0.80 (19)	–	–
2012	OP + RE acou.	46 513 (7)	0.70 (30)	–	0.88 (1.4)	–
2013	OP + RE + MM acou.	54 363 (8)	0.80 (19)	0.80 (19)	–	–
2014	OP + RE acou.	63 781 (18)	0.70 (30)	–	0.88 (1.4)	–
2015	–	–	–	–	–	–
2016	OP + RE + MM acou.	43 560 (10)	0.80 (19)	0.80 (19)	–	–

A sensitivity run was conducted that, similar to the base run, assumed for 2011, 2013, and 2016, the "standard" acoustic *q* prior: lognormal (mean = 0.8, CV = 19%). However, the *q* for the 2012 and 2014 surveys was estimated with a uniform prior, but with a penalty on the ratio between the *q* estimated for the 2011, 2013, and 2016 surveys (which covered all three areas), and the *q* estimated for the 2012 and 2014 surveys (which covered only two). The penalty was lognormal (mean = 0.88, CV = 1.4%), and estimated from the ratios between 100 000 random draws from the distributions of biomass between areas observed in 2011, 2013, and 2016 (Figure 16). Although the resulting ratios were better described by a beta distribution, CASAL was only able to apply the lognormal distribution (Figure 17). This meant that the 2012 and 2014 surveys were assumed to cover 88% of the area (relative biomass) covered in 2011, 2013, and 2016, with high precision (low CV). Similarly, the *q* for the Old plume survey in 2010 was uniform, with a penalty on the ratio on the *q* between the 2011, 2013, and 2016 surveys and that on the 2010 survey (which covered just one area): lognormal (mean = 0.3, CV = 0.075). Subsequent Old plume survey *q*s for 2009–2002 were all uniform, but with penalties on their sequential *q* ratios, where the mean of the penalty changed linearly such that the *q* for the 2002 Old plume survey would be 0.7; all penalties were lognormal, with assumed CVs of 0.1 (CVs for these penalties could not be estimated). Compared to the base run, this "ratio-*q*" sensitivity run placed greater emphasis on maintaining the relativity between sequential acoustic biomass estimates.

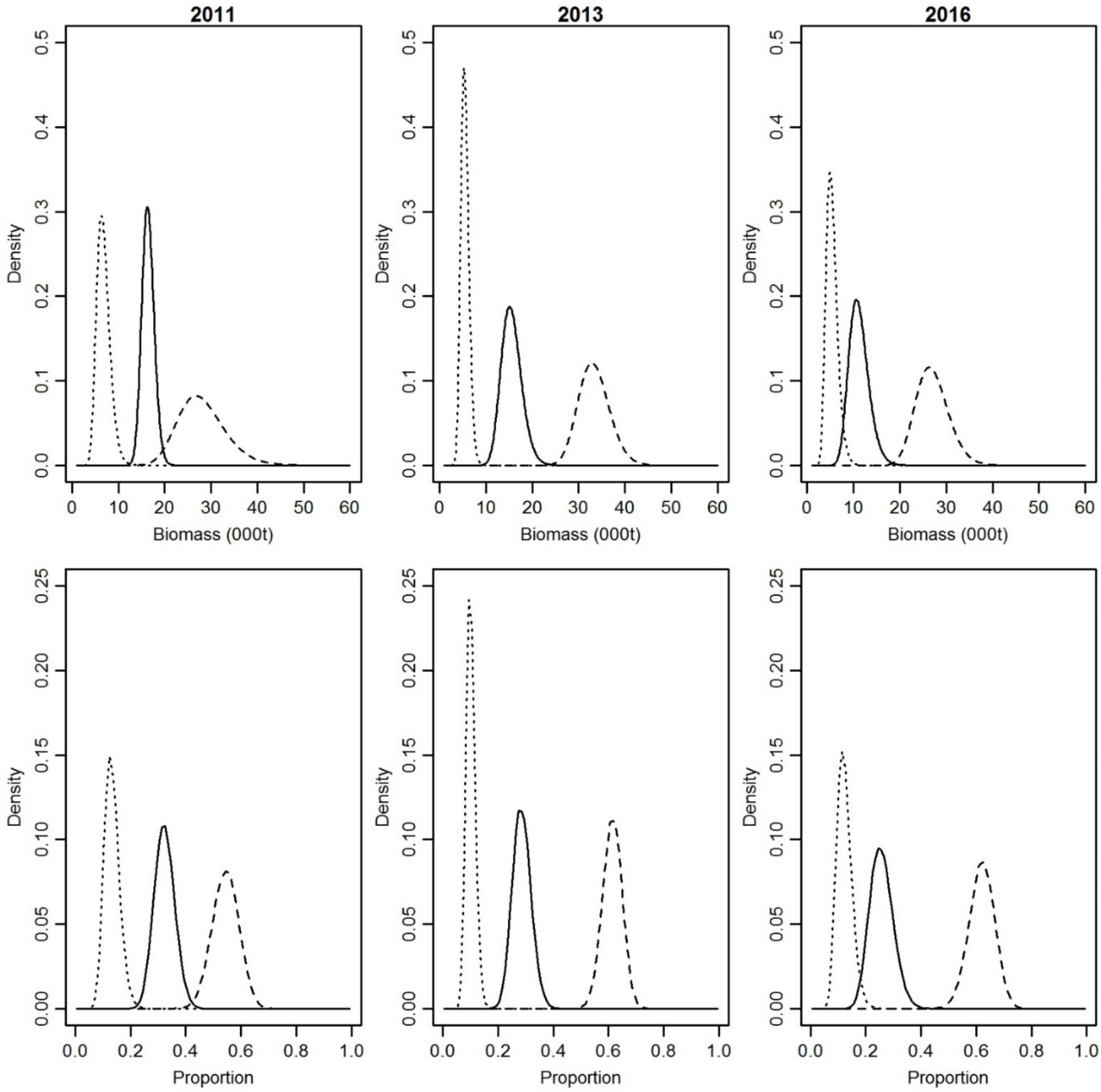

Figure 16: East & South Chatham Rise, estimated acoustic spawning biomass distributions (top panels) and as a proportion for each year (bottom panels) for the three spawning plumes in 2011, 2013, and 2016 (plumes from left to right in all three panels: Mt. Muck, Old plume, Rekohu).

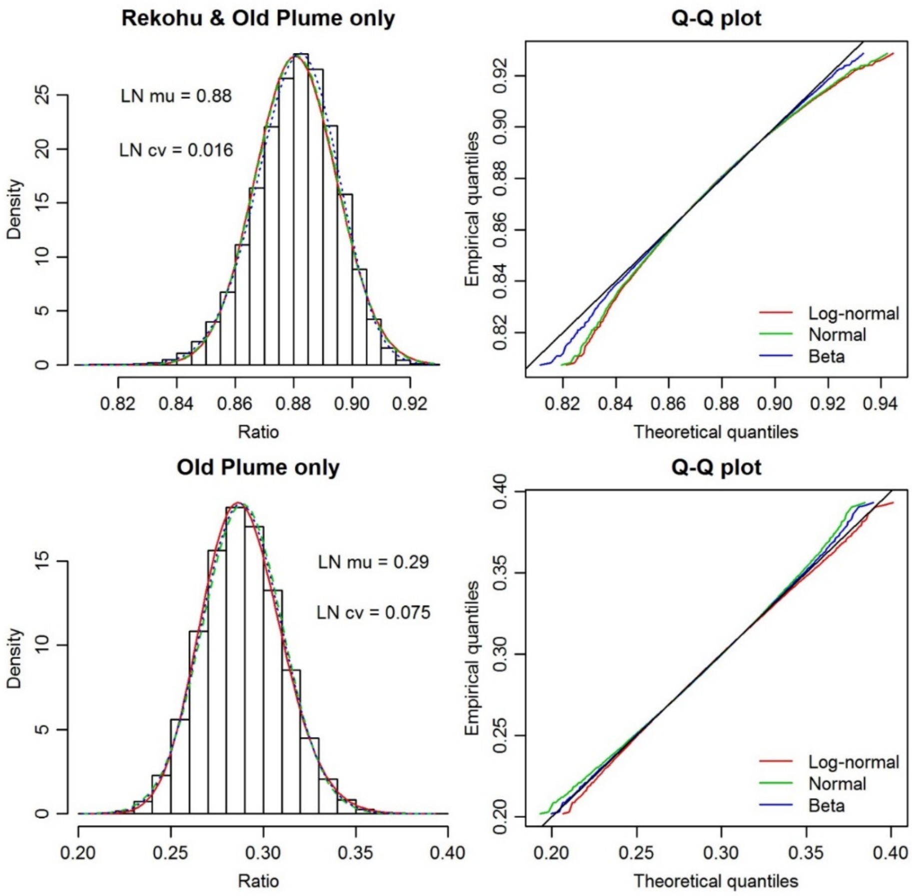

Figure 17: East & South Chatham Rise, fit of the lognormal, normal, and beta distributions to the estimated ratios between spawning plumes. Mean (mu) and CV shown for the lognormal distribution.

The acoustic biomass surveys from the northeast hills (2000, 2003, and 2004), and acoustic biomass estimates from wide-area surveys (2004 and 2007) have been considered unreliable by the MPI Deepwater Fisheries Assessment Working Group, and have not been used in the assessment.

Research trawl surveys of the Spawning Box during July were completed from 1984 to 1994, using three different vessels: *FV Otago Buccaneer*, *FV Cordella*, and *RV Tangaroa*. The biomass indices were fitted as relative indices with a separate time series for each vessel (Table 7).

Data from two wide-area surveys by *Tangaroa* in 2004 and 2007 were also used. These surveys covered the area which extends from the western edge of the Spawning Box around to the northern edge of the Andes. The surveys had similar estimates of total biomass, and were fitted as relative biomass with an uninformed prior on the *q* (Table 7).

The length frequencies from the commercial fisheries were developed by Hicks (2006), and have been used (unchanged) in assessments since 2007 (Cordue, 2014) (Table 8). For the Spawning Box and associated flat ground fishery, three years of length-frequency data from the period 1989–91 were combined into a single length-frequency that was centred on 1990, and four years 2002–05 were combined and centred on 2004. In a similar way, for Andes four years 1992–95 were combined and centred on 1993, three years 1997–99 combined and centred on 1998, and five years combined 2001–05 and centred on 2003. For the eastern hills, seven years 1991–97 were combined and centred on 1995, and five years 2001–05 combined and centred on 2003. These were fitted as multinomial with effective sample sizes ranging from 8–38 (following Cordue, 2014).

Cordue (2014) fitted separate logistic ogives to the mature length compositions for the trawl surveys. In the present assessment, an alternative assumption was evaluated where the selectivity for mature fish in the trawl surveys was assumed to be equal to maturity; this assumption reduced the number of estimated parameters by eight. Selectivity for immature fish in trawl surveys was capped logistic, and separate for the Spawning Box and wide-area surveys.

Age frequencies were developed for the Old plume and Rekohu plume in 2012, and for the Old plume, Rekohu, and the Crack in 2013 and 2016 (Ministry for Primary Industries, 2016; Ian Doonan, NIWA, pers. comm.) (Table 8). Approximately 300 otoliths were randomly selected from each area in 2012 and 2016, and 250 from each area in 2013. For 2016, otoliths were read from the Old plume (n = 200), Rekohu (n = 250), and Mt. Muck (n = 150).

As in previous samples, the fish in the Old plume were noted to be generally older than those in the Rekohu plume (Figure 18). Fish from Mt. Muck were of similar ages to those in the Old plume.

Table 8: Multinomial effective sample sizes assumed for the length and age composition samples for the East & South Chatham Rise assessment. C@L, catch at length; C@A, catch at age; Sp. Box, spawning box; OP, Old plume; RK, Rekohu; MM, Mt. Muck.

	Trawl survey C@L		Fishery C@L			C@A	
Year	Sp. Box	Wide area	BoxFlat	Hills	Andes	OP+RK	OP+RK+MM
1984	50	–	–	–	–	–	–
1985	50	–	–	–	–	–	–
1986	50	–	–	–	–	–	–
1987	50	–	–	–	–	–	–
1988	58	–	–	–	–	–	–
1989	63	–	–	–	–	–	–
1990	84	–	23	–	–	–	–
1992	33	–	–	–	–	–	–
1993	–	–	–	–	38	–	–
1994	20	–	–	–	–	–	–
1995	–	–	–	24	–	–	–
1998	–	–	–	–	8	–	–
2003	–	–	–	8	29	–	–
2004	–	57	25	–	–	–	–
2007	–	62	–	–	–	–	–
2012	–	–	–	–	–	50	–
2013	–	–	–	–	–	–	60
2016	–	–	–	–	–	–	60

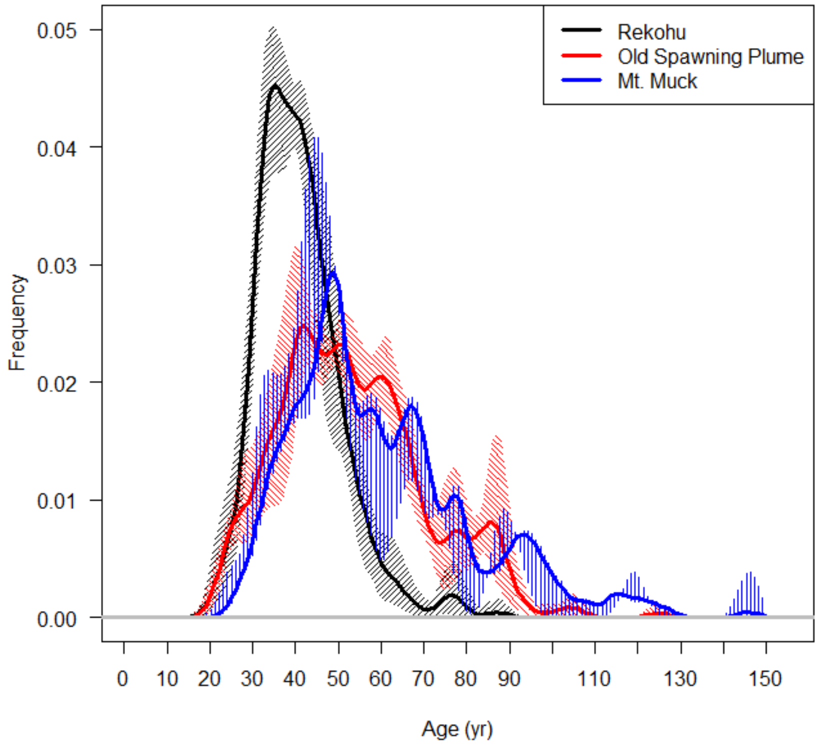

Figure 18: East & South Chatham Rise, smoothed age compositions for 2016. Stippled area shows pairwise 95% CI.

5.3 Model runs and results

The base model, as agreed by the MPI Deepwater Fisheries Assessment Working Group, followed the previous assessment (Cordue, 2014), but with the inclusion of the new data. The key sensitivity runs also followed the previous assessment and were the LowM-Highq and HighM-Lowq "standard" runs (Ministry for Primary Industries 2016), a run assuming Rekohu was formed more recently (in 2007), and a run estimating *M*. Other sensitivity runs investigated in the 2016–17 assessment included the assumption of penalties on the ratio between acoustic biomass *q*s, changing the prior on year class strengths, and a two-stock assumption. Other sensitivity runs, not reported in detail here, included the influence of changing the relative weights of the composition data.

The base model provided good MPD fits to the data. The MPD fits to the acoustic indices were good, except that the biomass observed in 2016 was lower than predicted (Figure 19). The normalised residuals of the acoustic indices for the base MCMC model were similarly good, and showed no apparent trend, although the 2016 biomass estimate was substantially lower than predicted (Figure 20).

The posteriors for the acoustic *q*s were shifted to the left of the priors for the surveys covering all three spawning aggregations (2011, 2013, and 2016), indicating that the predicted biomass was higher than expected (Figure 21). For the Old plume time series, posteriors were sometimes shifted towards the left of the priors, but more often to the right, indicating that the predicted biomass was more often lower than expected (Figure 21).

The MPD fits to the trawl indices were good but the model-predicted biomass had a shallower decline than that estimated from the indices from the *Buccaneer* and *Cordella* surveys (Figure 19). Also, the model did not fit the very large increase in the *Tangaroa* Spawning Box survey (Figure 19).

The fits to the age frequencies were as good as can be expected given the inconsistent shape of the age frequencies in the consecutive years, for example relatively more fish aged 30–40 years in 2013 (Figure 22). The base model fits assumed that the selectivity of the mature fish was equal to maturity, as estimated from the spawning age compositions (where selectivity = maturity).

The MPD fits to the commercial length frequencies were good except the 1990 Spawning Box and Eastern Flats commercial fishery length frequency (Figure 23). The fits to the trawl survey length frequencies were also good (Figure 23). The capped-logistic selectivities assumed for immature fish allowed estimated a small proportion of immature fish were caught.

The reduction in fit to the length compositions from making this assumption (compared to estimating separate selectivity ogives) was very small (roughly one likelihood unit for eight additional parameters; Table 9), changes in fit were not visibly distinguishable, and the outcome of the models was very similar (Table 10). The difference in the estimated selectivity for the mature part of the partition was large, and indicated that when individual logistic selectivities were estimated the younger fish (less than about 50 years) were not as available as implied by the maturity ogive, but the outcome, in terms of the difference in fit to the length compositions and stock size and status, was little different.

Table 9: East & South Chatham Rise, MPD likelihood estimates for the fits to length compositions for the mature part of the partition, with different selectivity assumptions. Buc, *Buccaneer*; Cord, *Cordella*; Tan, *Tangaroa* Spawning Box survey; Tanwide, *Tangaroa* wide-area survey.

	all logistic	all = mature	difference
BucLF	92.916	93.836	-0.921
CorLF	77.872	78.257	-0.384
TanLF	37.736	37.753	-0.171
TanwideLF	59.375	59.038	+0.338
All comp.	525.288	526.375	-1.086

Table 10: East & South Chatham Rise, MCMC parameter estimates for selectivities, and stock size and status, under different selectivity assumptions (logistic ogives) for the mature part of the partition in the trawl surveys. Estimates for immature selectivity are also shown (capped logistic).

	capped logistic/logistic	selectivity=maturity
BucCorTan Immature	23.3, 19.2, 0.61	21.3, 23.7, 0.027
Buc Mature	24.2, 11.1	42.1, 13.8
Cor Mature	25.3, 8.8	42.1, 13.8
Tan Mature	31.7, 28.1	42.1, 13.8
Tanwide Immature	16.9, 6.8, 0.56	16.4, 6.5, 0.61
Tanwide Mature	31.4, 31.7	42.1, 13.8
Mature	38.1, 10.4	42.1, 13.8
B_0	315.5 (277.7-350.0)	318.3 (282.4-353.1)
$\%B_0$	32.2 (26.7-37.2)	33.0 (27.9-37.6)

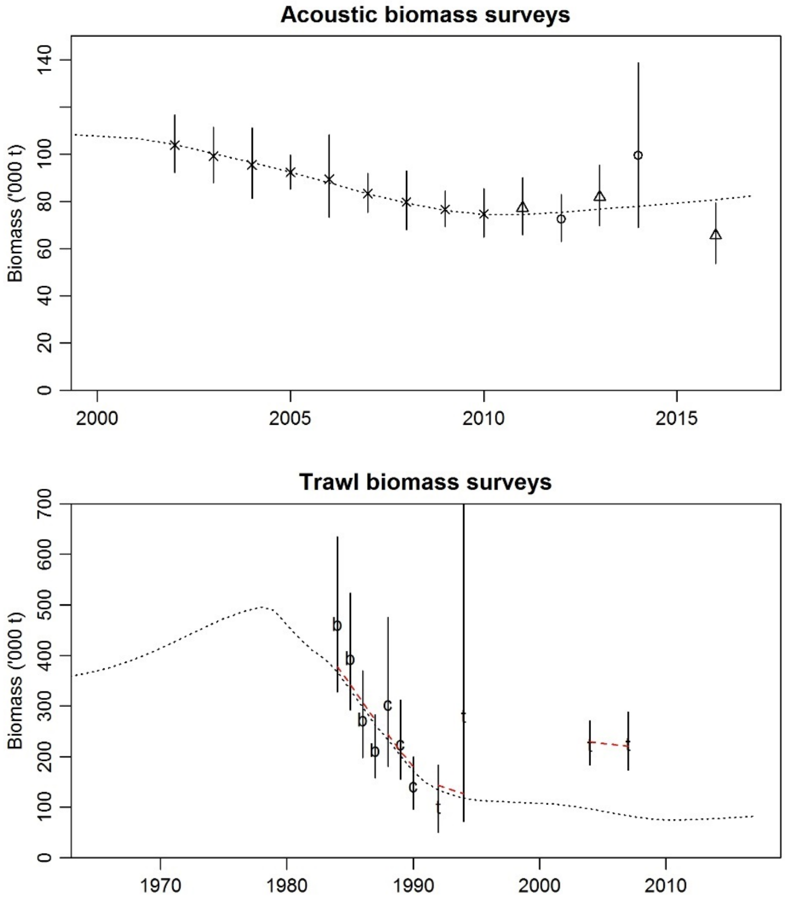

Figure 19: East & South Chatham Rise, MPD, base: fit to the acoustic indices: (top) spawning biomass trajectory and scaled acoustic indices; x, Old plume surveys; Δ, three-area 2011, 2013 and 2016 surveys; o, two-area 2012 and 2014 surveys; (bottom) the spawning biomass trajectory (dotted line) and fits of the trawl surveys to their respective vulnerable biomass (red dashed lines), for b, *Buccaneer*; c, *Cordella*; t (1992 and 1994), *Tangaroa* Spawning Box; t (2004 and 2007), *Tangaroa* wide-area. Vertical lines indicate 95% confidence intervals.

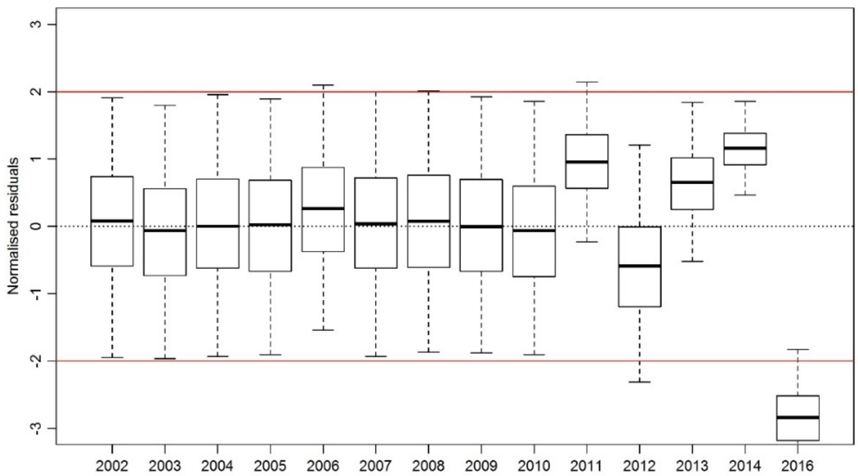

Figure 20: East & South Chatham Rise, MCMC base: normalized residual for the acoustic indices. The box covers 50% of the distribution for each index and the whiskers extend to 95% of the distribution.

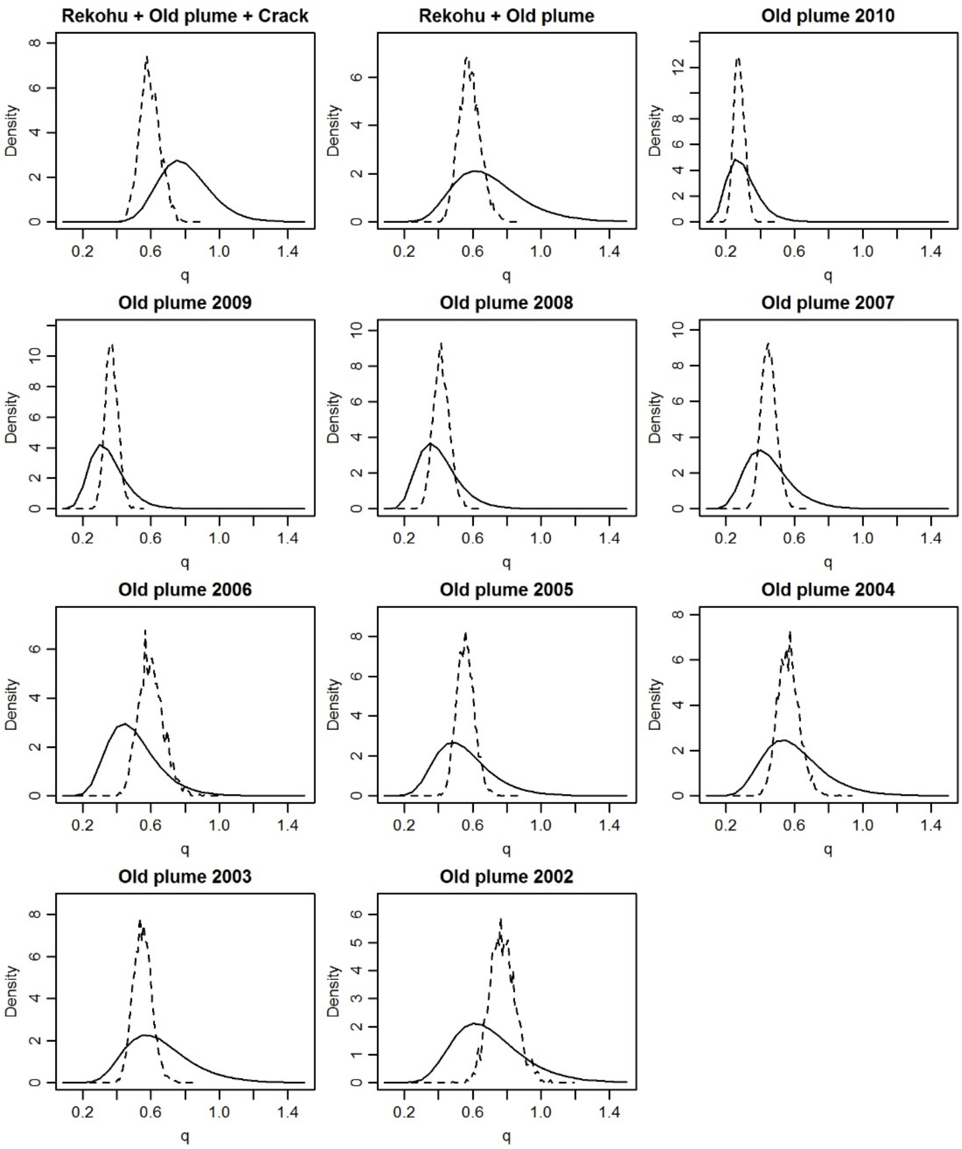

Figure 21: East & South Chatham Rise, MCMC base: prior (solid lines) and posterior distributions (broken lines) for acoustic *q*s.

Numerous sensitivity runs were conducted at the MPD stage (see also Cordue 2014). The sensitivity runs included for management advice from the 2014 assessment were maintained in the 2017 assessment. Additional sensitivity runs included the ratio-*q* run, and runs assuming lognormal priors for YCS.

In the ratio-*q* sensitivity run with an assumed penalty CV of 10%, the fits to most acoustic indices were good, but the 2003 and 2016 biomass estimates were lower than predicted (Figure 24). The MCMC normalised residuals for the acoustic indices had a similar pattern, with the 2016 biomass estimate substantially lower than predicted. The median estimates of stock size and status were very similar to those from the base run (<1% difference); however, the 95% credible intervals from the ratio-*q* run were about 30% broader (see Table 13).

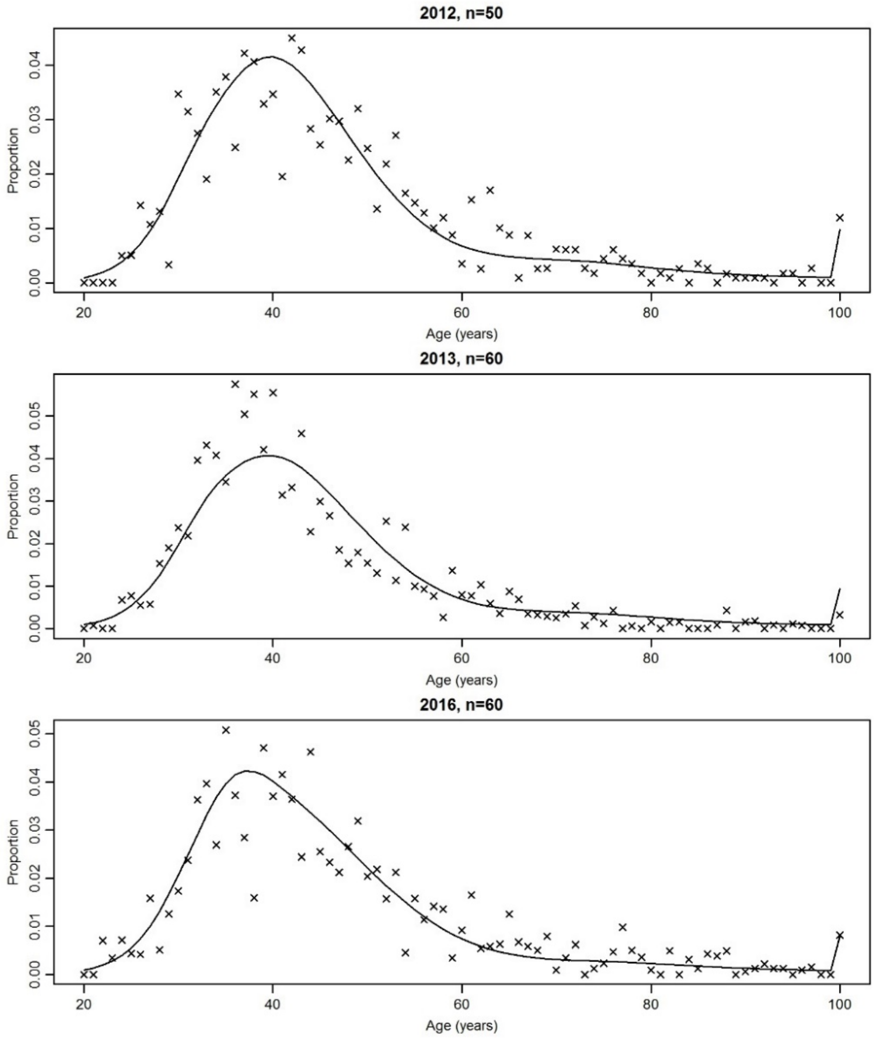

Figure 22: East & South Chatham Rise, MPD base: fits (lines) to the spawning season age frequencies (points); n is the effective sample size.

The assumed CV for the lognormal penalty on the acoustic *q* ratios made little difference to the fit and outcome at levels of 5% or greater (Table 11). With a low CV (1%), there was relatively little opportunity for movement in the ratios, and the biomass trend became quite different, and MCMC diagnostics became poor (Figure 25). The MPI Deepwater Fisheries Assessment Working Group agreed that the CV for the *q* ratio penalty should be set at 10%.

Table 11: East & South Chatham Rise, MCMC model estimates for stock size and status assuming different CV for the lognormal penalty on the ratio between acoustic *q*s, and the result for the base model (independent *q*s).

Assumed CV (%)	B_0	$\%B_0$
1	320.1 (269.4–377.8)	36.1 (30.1–43.0)
5	317.2 (268.0–368.9)	33.5 (26.9–40.6)
10	316.9 (258.4–372.0)	33.0 (25.5–40.8)
20	307.3 (248.2–364.5)	33.5 (26.4–41.1)
30	320.0 (265.9–372.0)	32.8 (25.5–40.4)
Base model	315.5 (277.7–350.0)	32.2 (26.7–37.2)

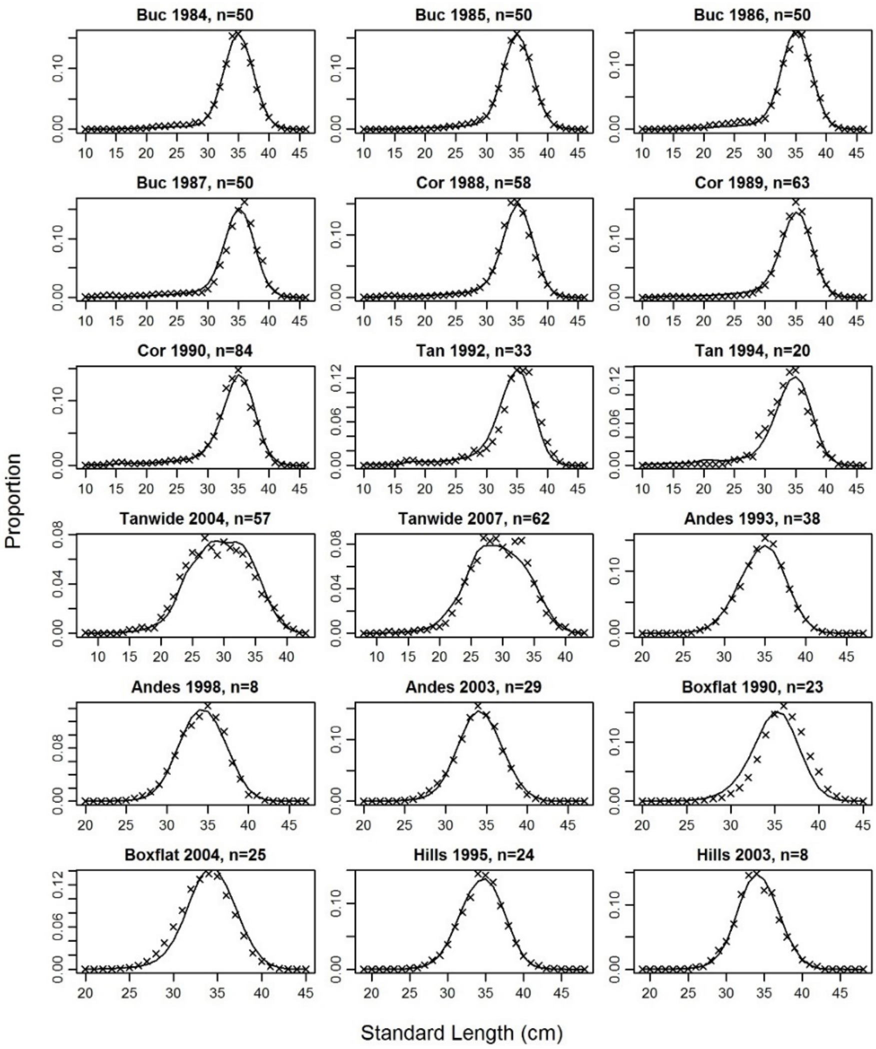

Figure 23: East & South Chatham Rise, MPD base: fits (lines) to the length frequencies (x) for the *Buccaneer* surveys (Buc), *Cordella* surveys (Cor), *Tangaroa* Spawning Box surveys (Tan), *Tangaroa* wide-area surveys (Tanwide), commercial Andes fishery (Andes), commercial Spawning Box and eastern flats fishery (Boxflat), and eastern hills fishery (Hills); n is the effective sample size.

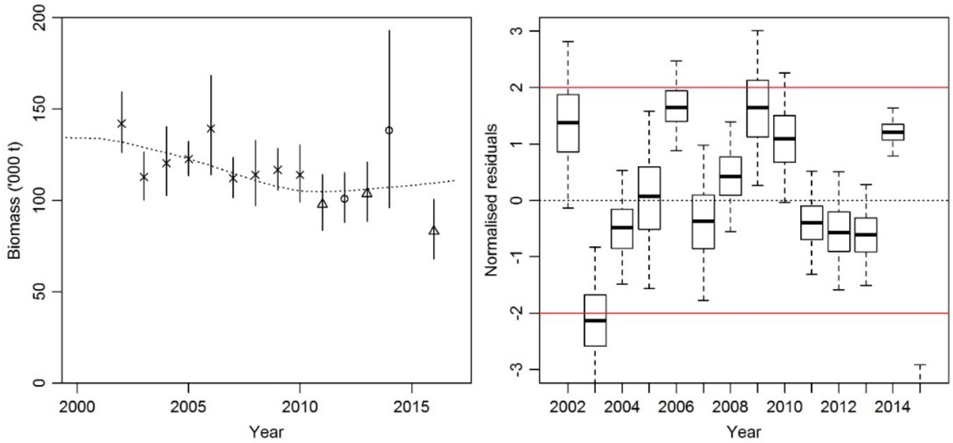

Figure 24: East & South Chatham Rise, MPD, ratio-*q*: MPD fit to the acoustic indices: (left) spawning biomass trajectory and scaled acoustic indices; x, Old plume surveys; Δ, three-area 2011, 2013 and 2016 surveys; o, two-area 2012 and 2014 surveys; (right) MCMC normalized residual for the acoustic indices (Note: the 2016 value is below -3 sd and therefore does not show on the graph). The box covers 50% of the distribution for each index and the whiskers extend to 95% of the distribution.

Independent priors

5% CV penalty

1% CV penalty

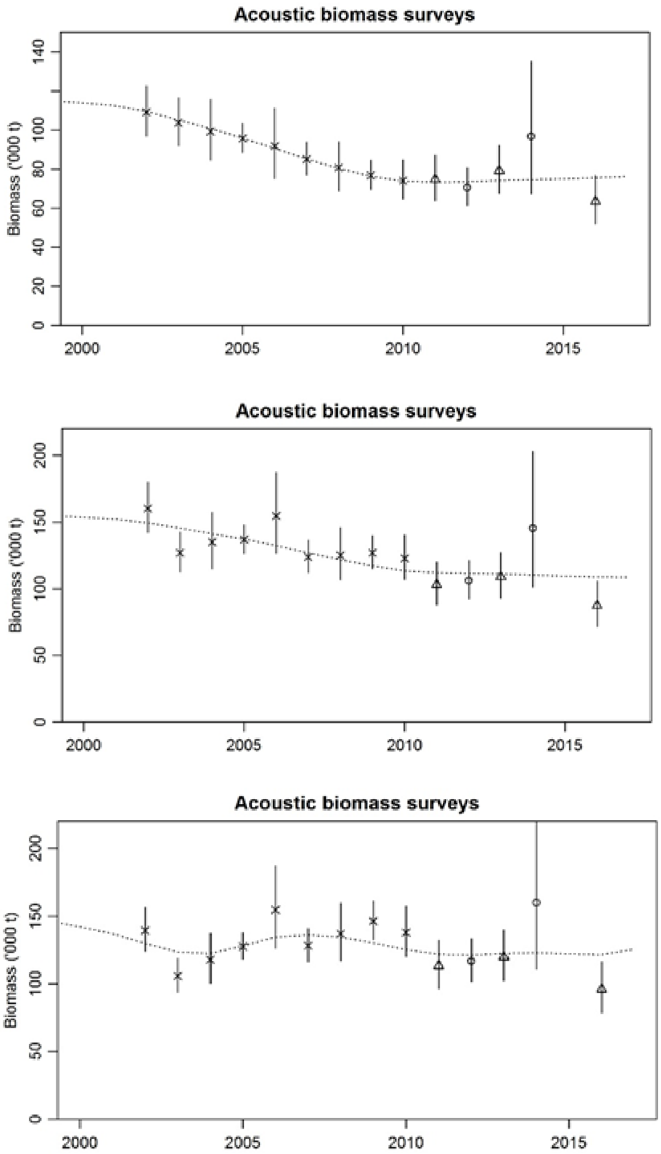

Figure 25: East & South Chatham Rise, MPD, ratio-*q*, fits to the 2002–10 acoustic biomass index assuming different CVs on the lognormal ratio penalty.

The residuals of the base model indicated that additional process error of around 20% was needed to adequately fit the 2011–16 acoustic biomass indices, and notably the low estimate for 2016 (Figure 26). However, the MPI Deepwater Fisheries Assessment Working Group concluded that additional process error should only be added when there was a clear rationale for this to take place (rather than only a statistical argument based on model fit); in the absence of an accepted argument, and because adding process error made no difference to stock size and status, the model assumption of zero process error was maintained in the base and sensitivity runs.

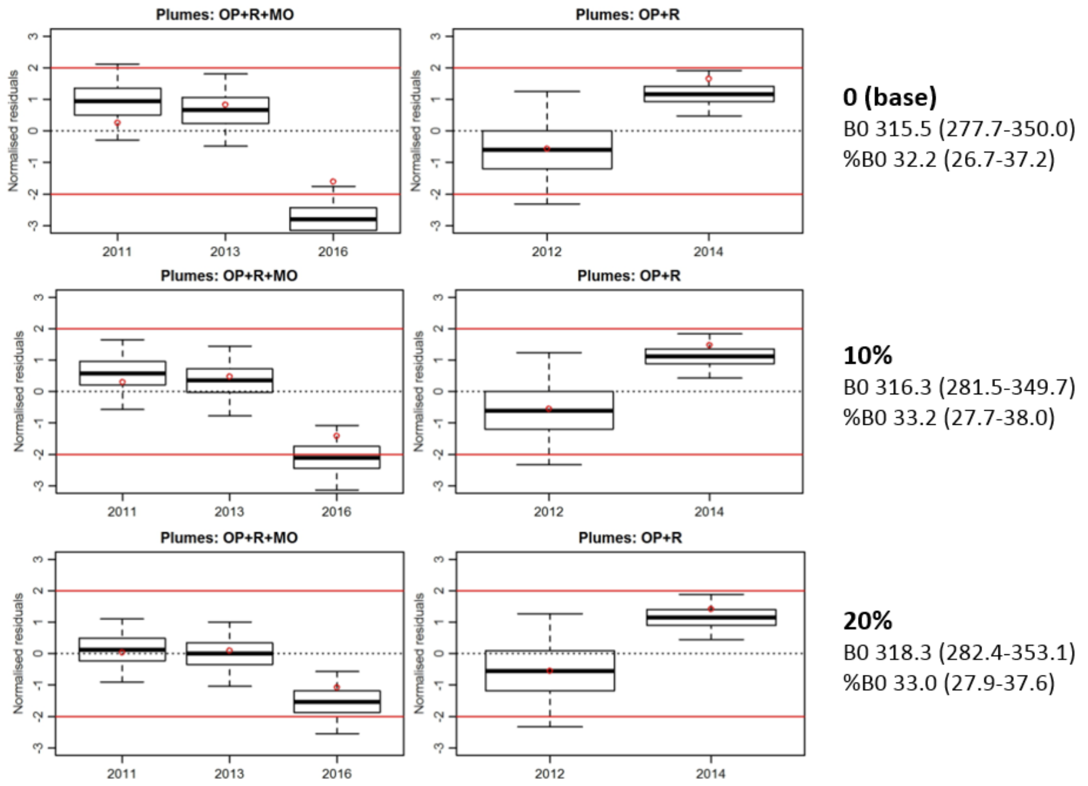

Figure 26: East & South Chatham Rise, MCMC residuals for the acoustic biomass estimates 2011–2016, varying process error on the 2001–16 series to 10% and 20%, with MCMC estimates of model size (B0; '000 t) and status (%B0). OP, Old plume; R, Rekohu; MO, Mt. Muck.

With a lognormal YCS prior, the estimated stock size and status were sensitive to the assumed σ^R (variability in YCS) (Table 12). Francis & Fu (2015) found lognormal σ^R was often estimated to be around 0.5. MCMC estimates from the nearly-uniform YCS prior (assumed in the base model) were close to a lognormal YCS prior with σ^R = 0.6. With the nearly uniform prior, the MPD estimates were placed close to (B_0) or outside (%B_0) of the 95% CI from the MCMC samples; with the lognormal prior this was not the case (Figure 27). At the MPD there was much greater variability in YCS compared to the MCMC, and the MCMC estimated greater variability in YCS with the lognormal prior compared to nearly uniform prior (Figure 28). The YCS estimated at the MPD inflated the SSB prior to the start of the fishery (see Figure 19), whereas this effect was greatly reduced in the MCMC (see Figure 33).

Table 12: East & South Chatham Rise, MPD and MCMC estimates of stock size and status with different year class strength (YCS) prior assumptions.

	MCMC		MPD	
YCS prior	B_0	%B_0	B_0	%B_0
Nearly uniform (base)	315.5 (277.7–350.0)	32.2 (26.7–37.2)	348.9	23.7
Lognormal σ^R = 1.2	323.9 (289.8–356.9)	27.8 (21.5–34.3)	338.3	28.7
Lognormal σ^R = 0.8	319.0 (283.9–351.6)	29.8 (24.2–35.6)	334.3	31.3
Lognormal σ^R = 0.6	314.3 (279.9–348.6)	32.4 (27.1–37.5)	329.4	33.5
Lognormal σ^R = 0.4	304.0 (268.8–337.4)	34.4 (30.1–38.6)	322.6	35.6
Lognormal σ^R = 0.2	294.9 (259.8–324.6)	36.4 (33.0–40.0)	311.2	37.8

Likelihood profiles from the MCMC samples showed that the high MPD estimates for YCS in the early 1940s were primarily supported by age compositions (by about 1.5–2 likelihood units), and acoustic biomass observations and priors (by about 2–4 likelihood units) (Figure 29).

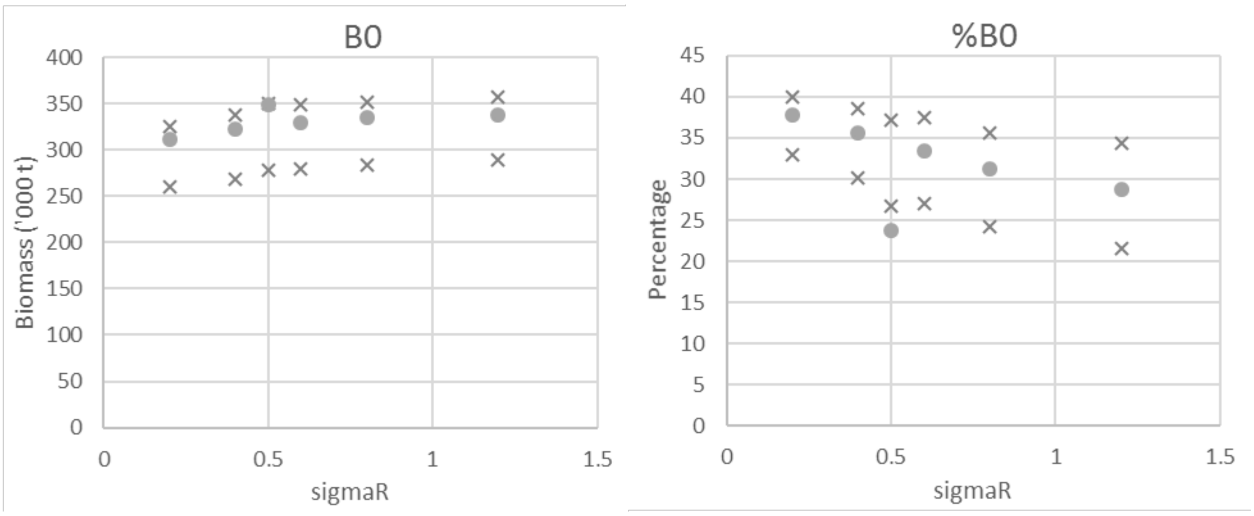

Figure 27: East & South Chatham Rise; x, the 95% CI from the MCMC samples for different YCS strength priors; assumed lognormal for different σ^R (Table 15); •, the MPD estimate; results for the nearly uniform assumption are plotted at a σ^R = 0.5.

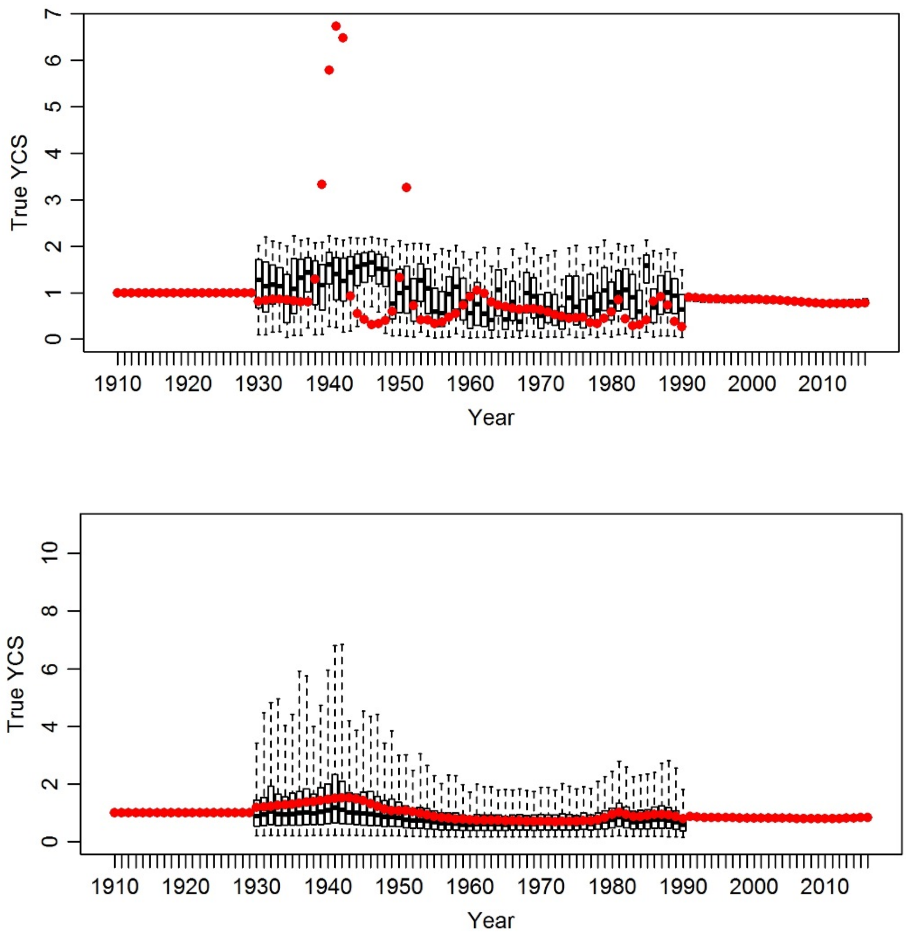

Figure 28: East & South Chatham Rise, estimated YCS from MPD (points) and MCMC (box and whiskers; whiskers extend to 95% CI), for the runs assuming a nearly uniform prior (top panel), and lognormal prior with σ^R = 0.6 (bottom panel).

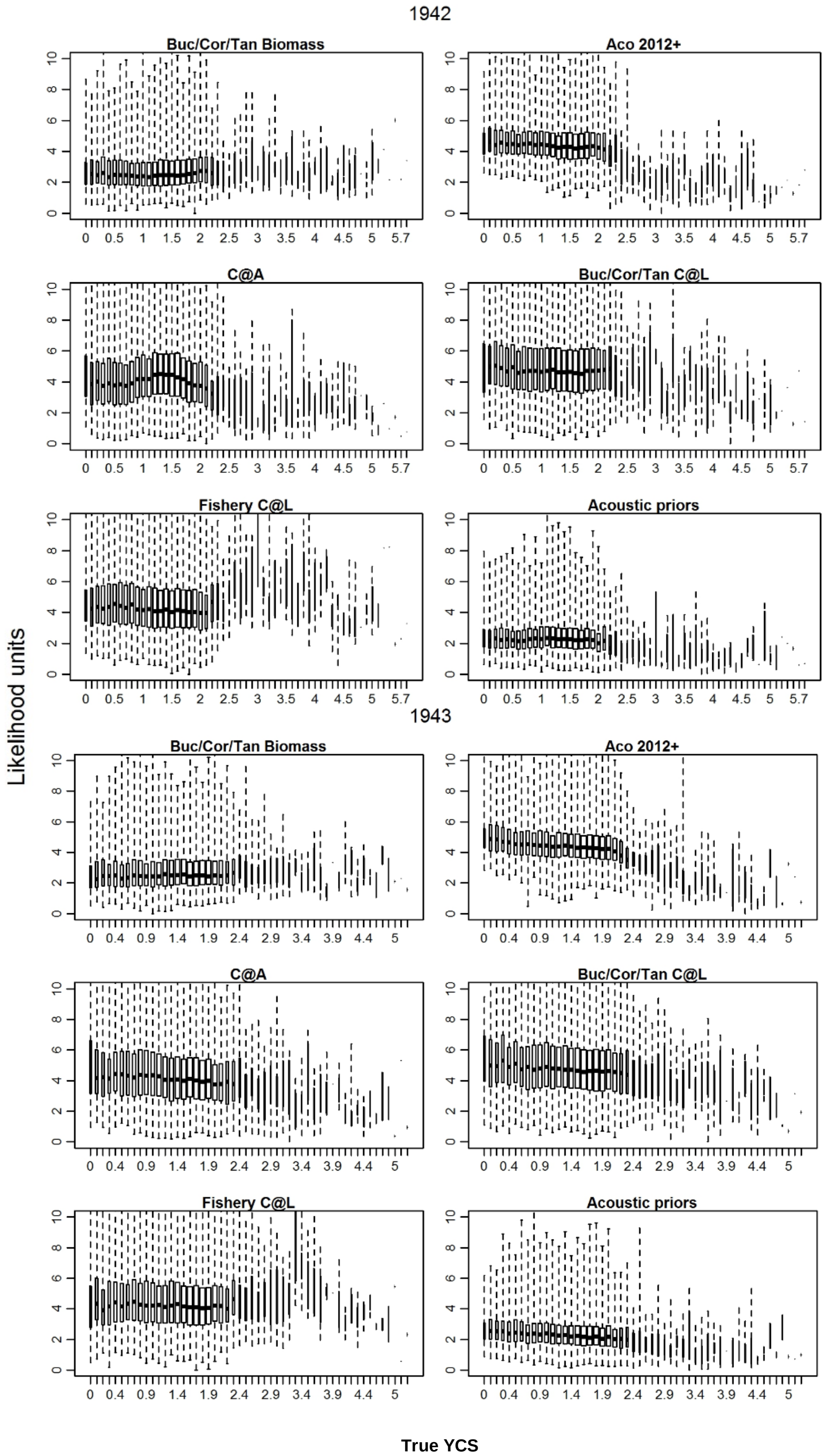

Figure 29: East & South Chatham Rise, Examples of true YCS likelihood profiles from MCMC samples for selected observations in the early 1940s; Buc/Cor/Tan Biomass, Spawning Box biomass indices; Aco 2012+, acoustic biomass surveys from 2012 to 2016; C@A, age compositions; C@L, length compositions. The width of the box and whisker plots is proportional to the number of observations (samples).

Likelihood profiles also showed that, although the MPD was outside of the MCMC 95% CI for the base run, the MPD was correctly estimated (Figure 30). The age compositions, and to a lesser extent length compositions and some acoustic priors, favoured high B_0; the only components strongly restricting the upper limit of B_0 were the 2011, 2013, and 2016 acoustic biomass estimates ('aco' in Figure 30) and accompanying prior. The upper limit of the B_0 estimate was therefore strongly influenced by our prior belief on the proportion of the mature biomass that was observed in the recent acoustic biomass surveys. These results are consistent with the MPD likelihood profiles reported by Cordue (2014).

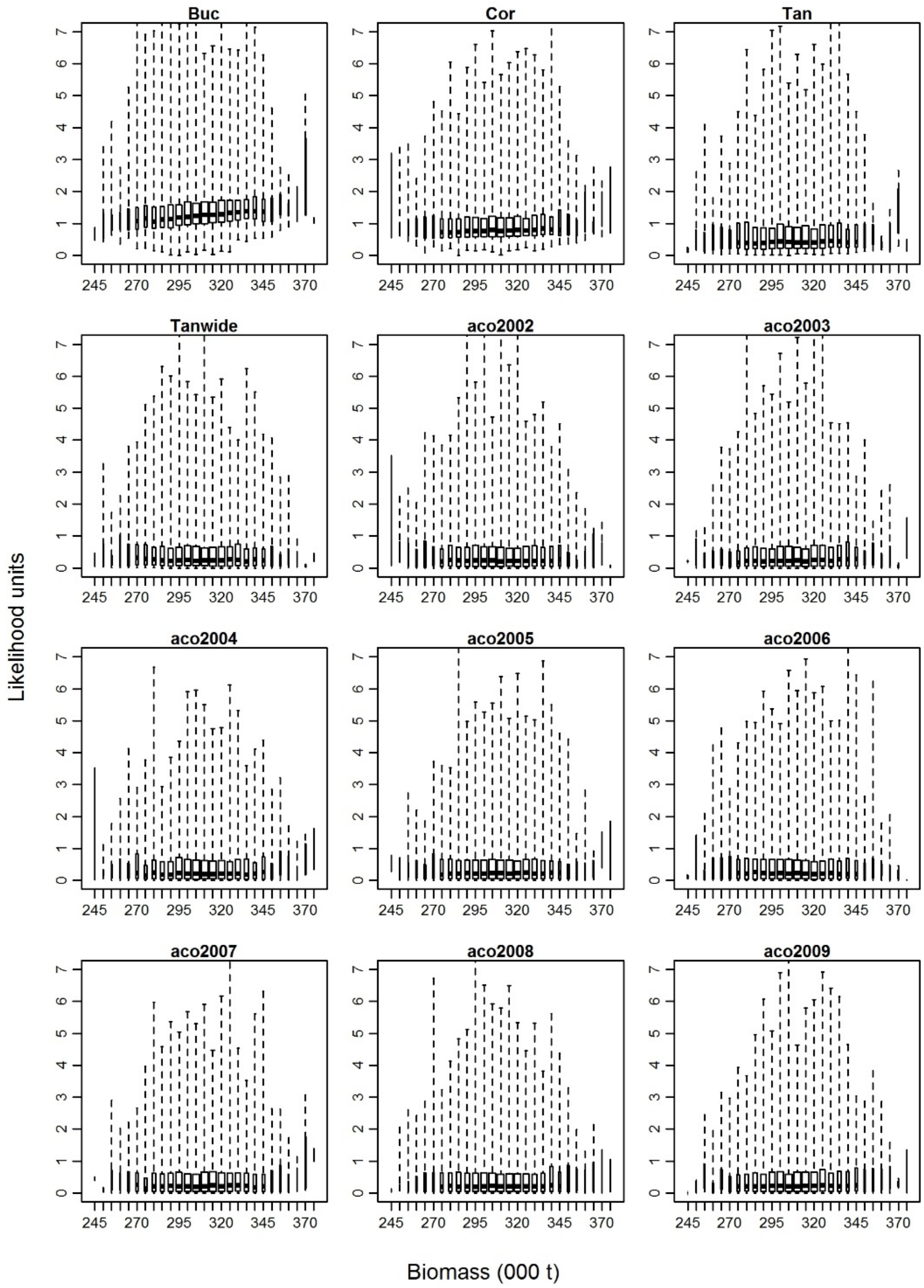

Figure 30: East & South Chatham Rise, base model, observation and prior likelihood profiles for B_0 from MCMC samples. The width of the box and whisker plots is proportional to the number of observations (samples). The point, bottom right in the "total" panel, shows the location of the MPD estimate.

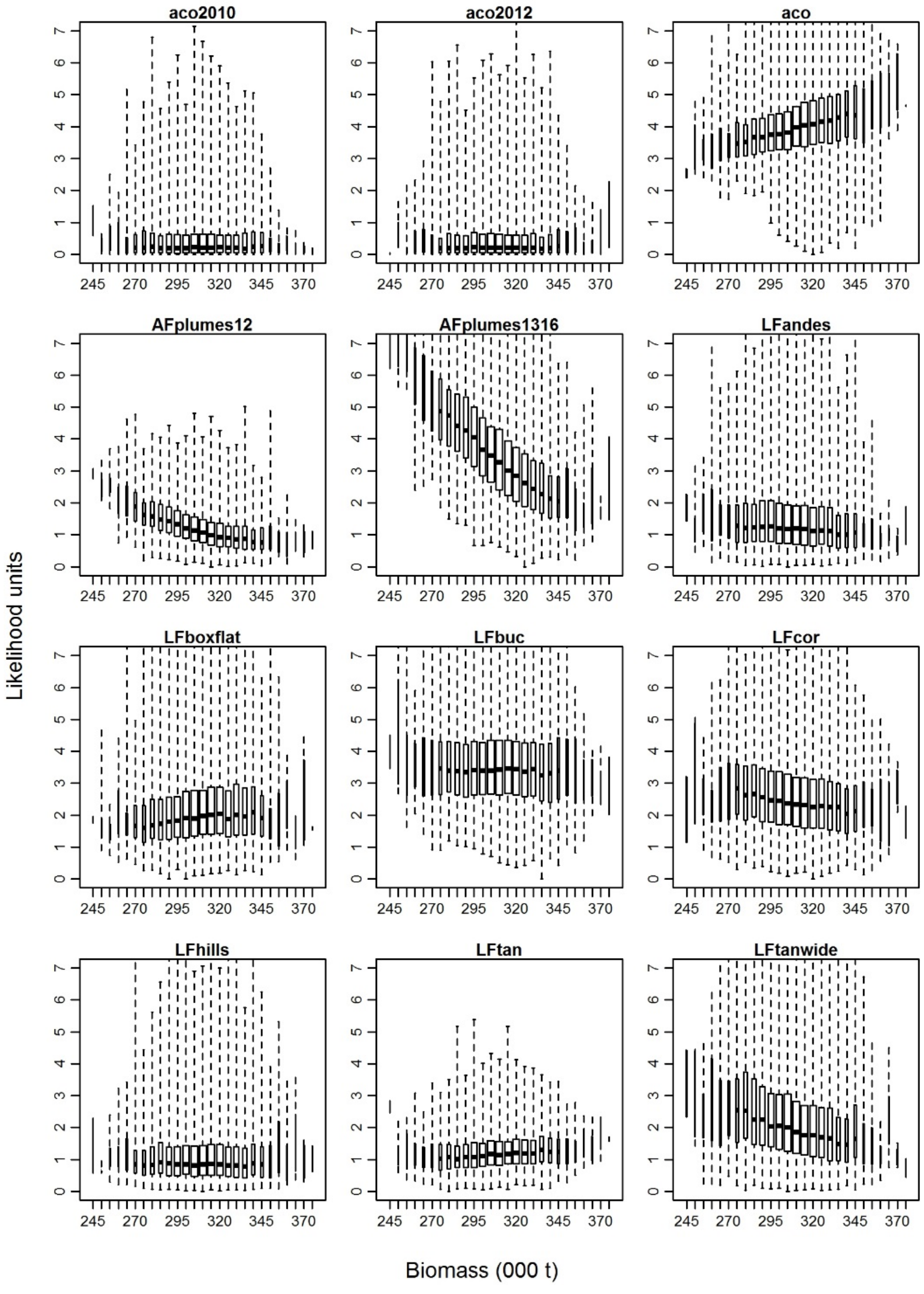

Figure 30 (cont.): East & South Chatham Rise, base model, observation and prior likelihood profiles for B_0 from MCMC samples. The width of the box and whisker plots is proportional to the number of observations (samples). The point, bottom right in the "total" panel, shows the location of the MPD estimate.

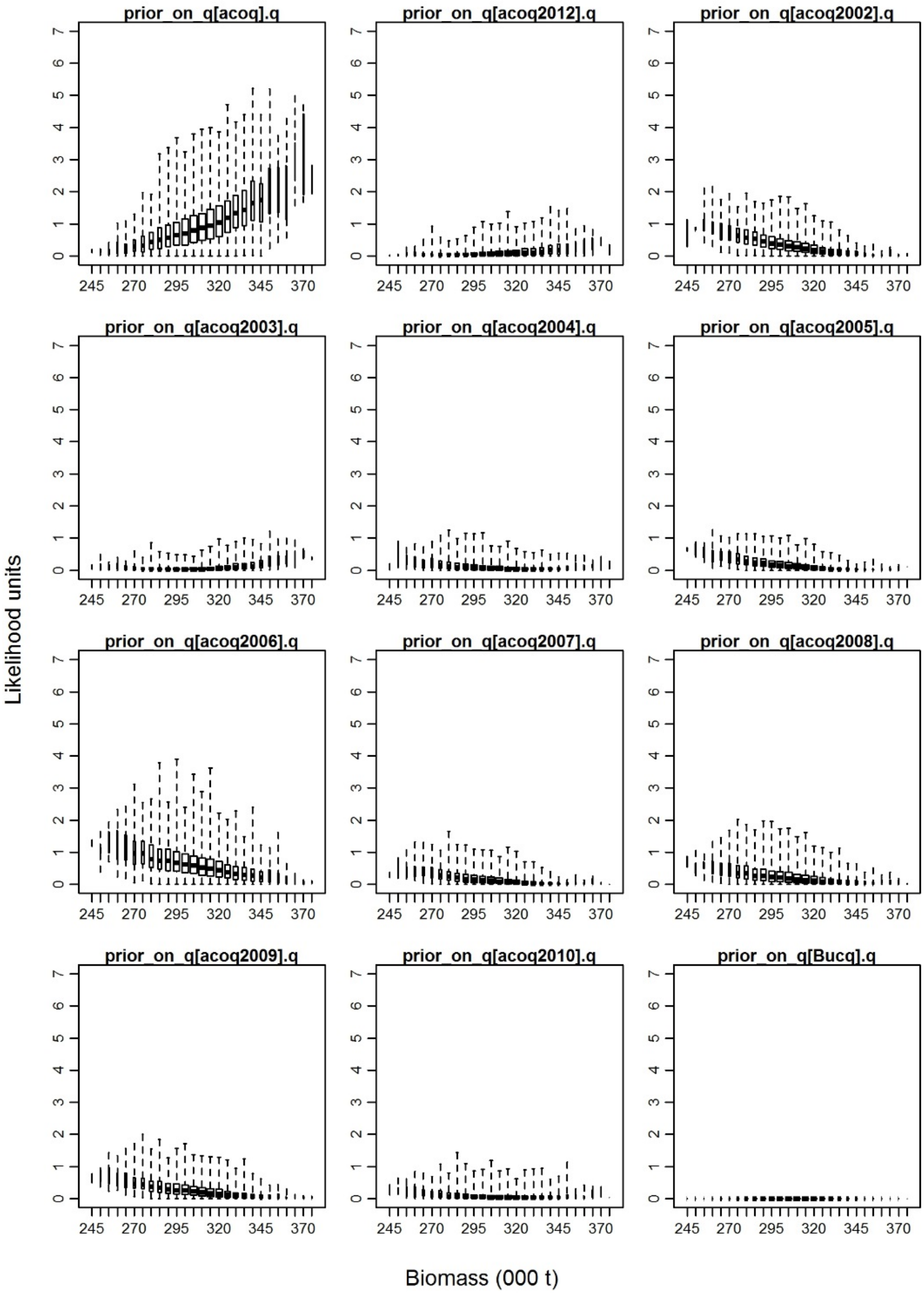

Figure 30 (cont.): East & South Chatham Rise, base model, observation and prior likelihood profiles for B_0 from MCMC samples. The width of the box and whisker plots is proportional to the number of observations (samples). The point, bottom right in the "total" panel, shows the location of the MPD estimate.

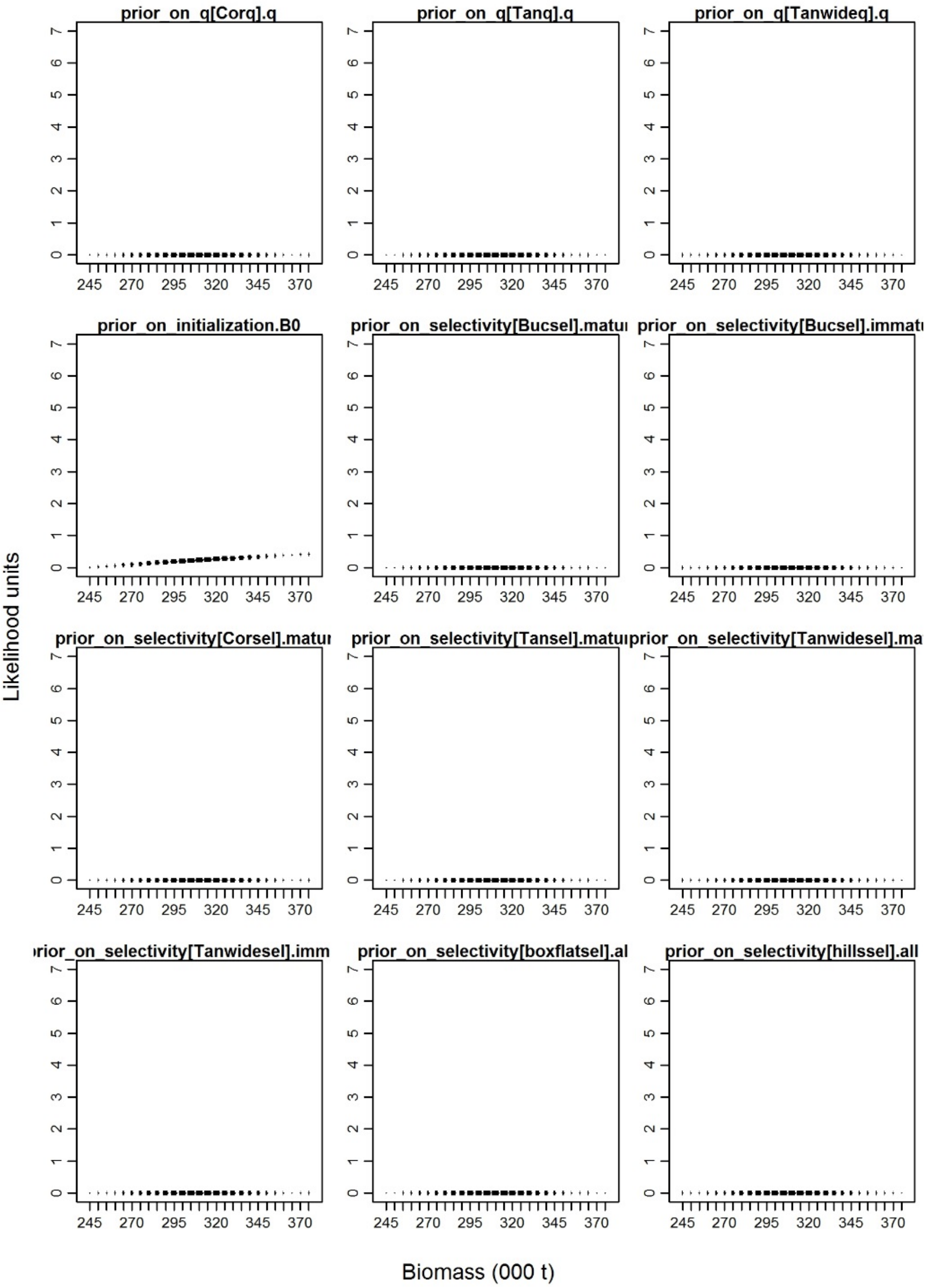

Figure 30 (cont.): East & South Chatham Rise, base model, observation and prior likelihood profiles for B_0 from MCMC samples. The width of the box and whisker plots is proportional to the number of observations (samples). The point, bottom right in the "total" panel, shows the location of the MPD estimate.

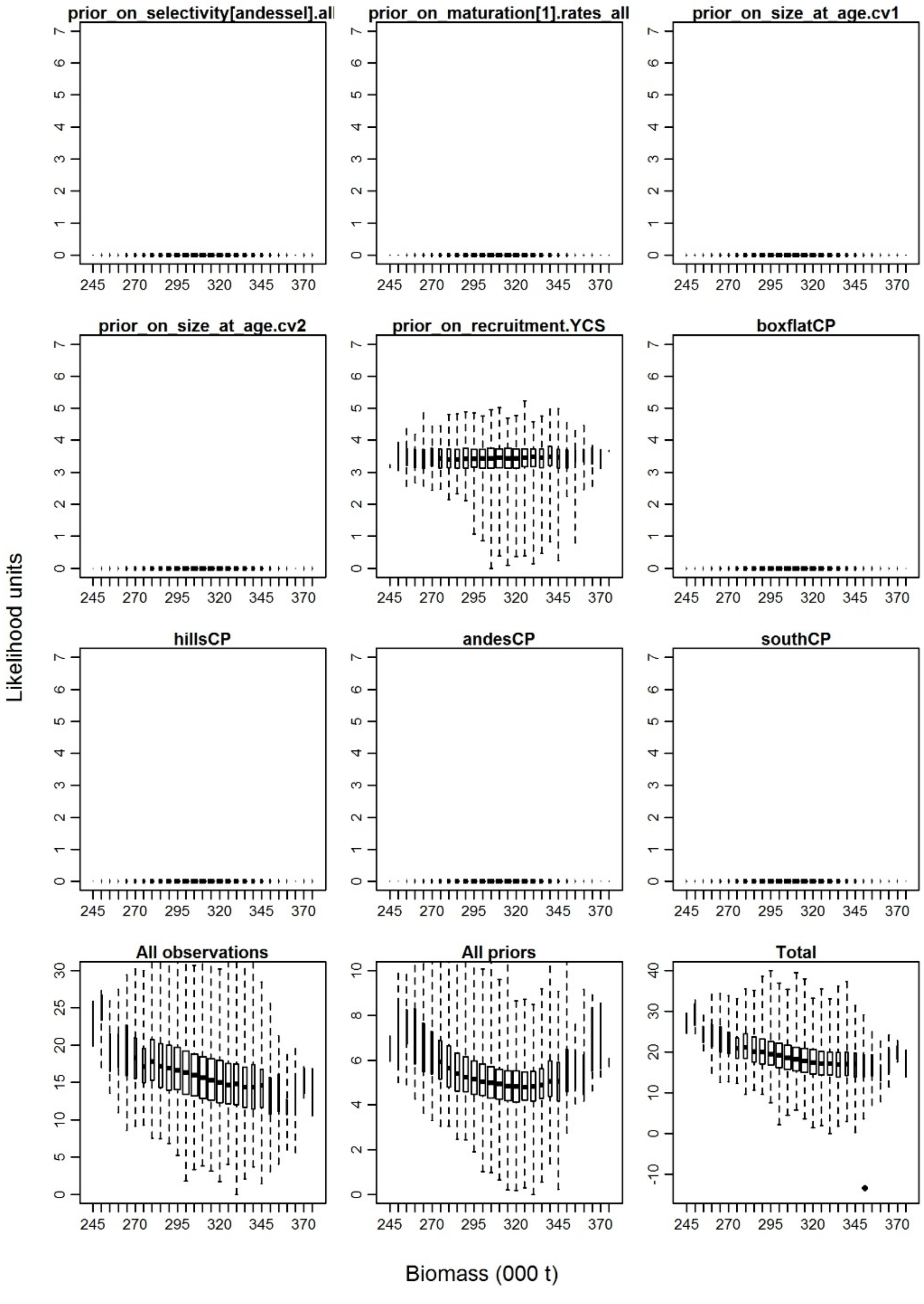

Figure 30 (cont.): East & South Chatham Rise, base model, observation and prior likelihood profiles for B_0 from MCMC samples. The width of the box and whisker plots is proportional to the number of observations (samples). The point, bottom right in the "total" panel, shows the location of the MPD estimate.

5.4 MCMC results

Some technical changes were made to improve chain convergence, including small changes to the proposal, using adaptive step-size changes and, having particular influence, re-running the chains after re-estimation of the covariance matrix (Figure 31); these improved diagnostics whilst giving results very similar to the model without the changes. For the base model, and the selected sensitivity runs (Table 13), MCMC diagnostics indicated no lack of convergence (Appendix B).

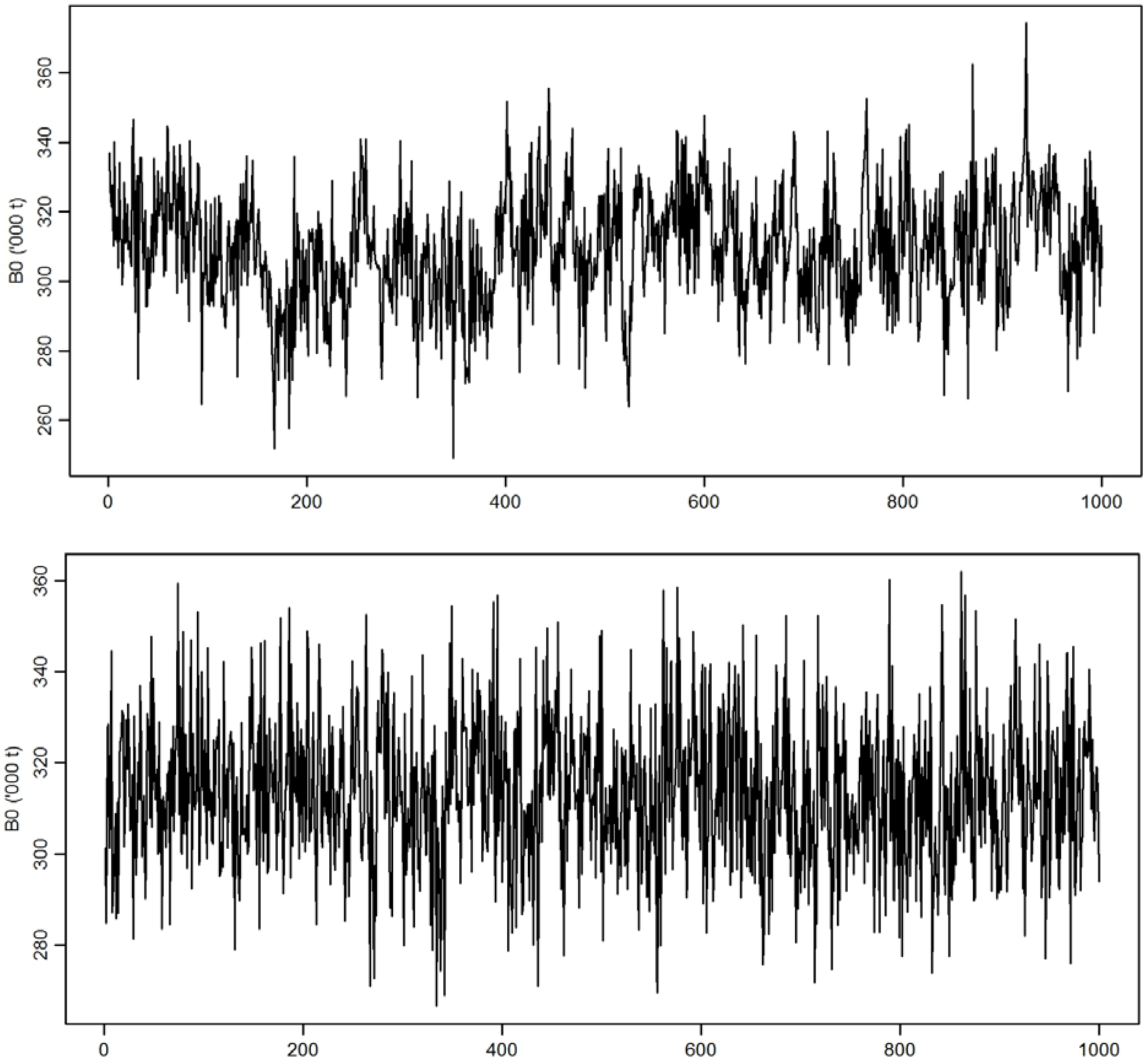

Figure 31: East & South Chatham Rise, base model run, B_0 estimated from 1000 samples through the MCMC chains before (top panel) and after (bottom panel) the re-estimation of the covariance matrix.

Table 13: East & South Chatham Rise, MCMC estimates of virgin biomass (B_0) and stock status (B_{2017} as %B_0) for the base model and four sensitivity runs.

	M	B_0 (000 t)	95% CI	B_{2017} (%B_0)	95% CI
Base	0.045	313.3	281.2–346.9	33	28–37
Estimate *M*	0.034	363.1	304.3–416.1	27	21–34
Rekohu 2007	0.045	300.6	270.8–332.4	31	26–35
Low *M*-High *q*	0.036	335.5	308.3–362.8	25	20–29
High *M*-Low *q*	0.054	306.3	272.8–342.7	42	36–47

Virgin biomass, B_0, was estimated to be about 313 000 t for the base model with median estimates ranging from 300 600 to 363 100 t for the four sensitivity runs presented (Table 13). Current stock status was similar across the base and the first two sensitivity runs (Table 13). The lower stock status when *M* was estimated reflected the lower estimate of *M* (0.034 rather than 0.045). For the two "bounding" runs, where *M* and the mean of the acoustic *q* priors were shifted by 20%, current stock status was estimated below the biomass target range of 30–50% B_0 for the pessimistic *LowM-Highq* run and within the target range for the optimistic *HighM-Lowq* run (Table 16).

The estimated YCS showed little variation across cohorts but did exhibit a long-term trend (Figure 32). The stock status trajectory shows a steady decline from the start of fishery until the mid-1990s, where it remained in the 20–30% range until an upturn in about 2010 (Figure 33).

For the base model, there was an 86% probability that the stock was above 30% B_0 in 2017. Therefore, for the base model, the stock is considered to be fully rebuilt according to the Harvest Strategy Standard (at least a 70% probability that the lower end of the management target range of 30–50% B_0 has been achieved). For the sensitivity runs, the probability of being above 30% B_0 in 2017 was 1% (Low *M*-High *q*), 20% (Estimate *M*), 65% (Rekohu 2007), and 100% (High *M*-Low *q*).

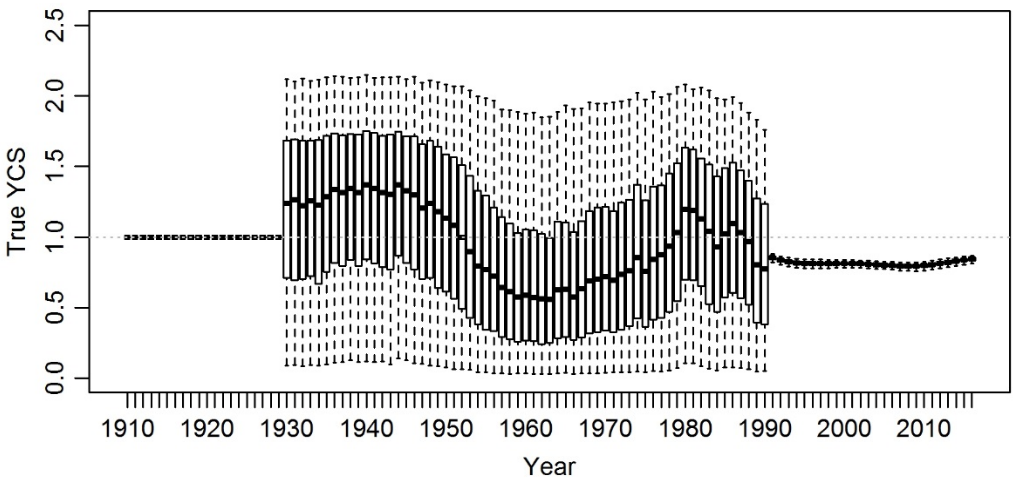

Figure 32: East & South Chatham Rise base, MCMC estimated "true" YCS (R_y/R_0). The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution.

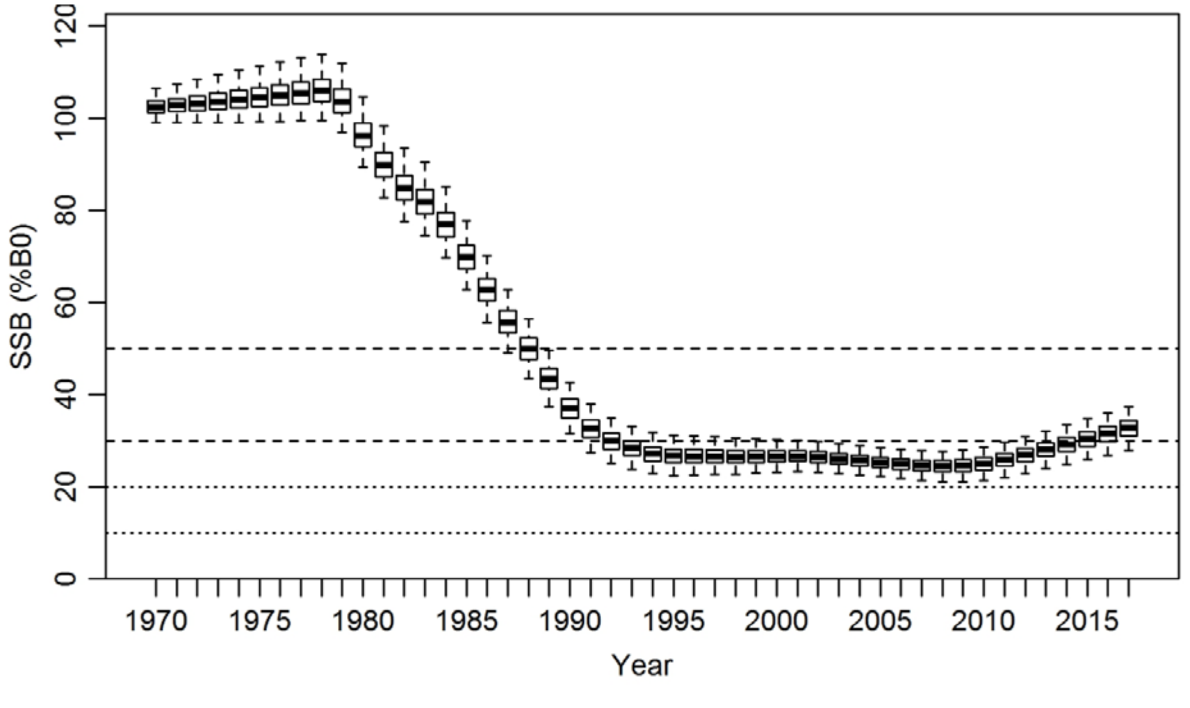

Figure 33: East & South Chatham Rise base, MCMC estimated spawning-stock biomass trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. Dotted lines indicate the hard limit (10% B_0) and soft limit (20% B_0), dashed lines the biomass target range (30–50% B_0).

Estimated fishing pressure peaked at around 1990, and then declined, peaking again in 2006 then decreasing, such that since 2011 fishing pressure has remained at the lowest persistent level since the fishery started (Figure 34).

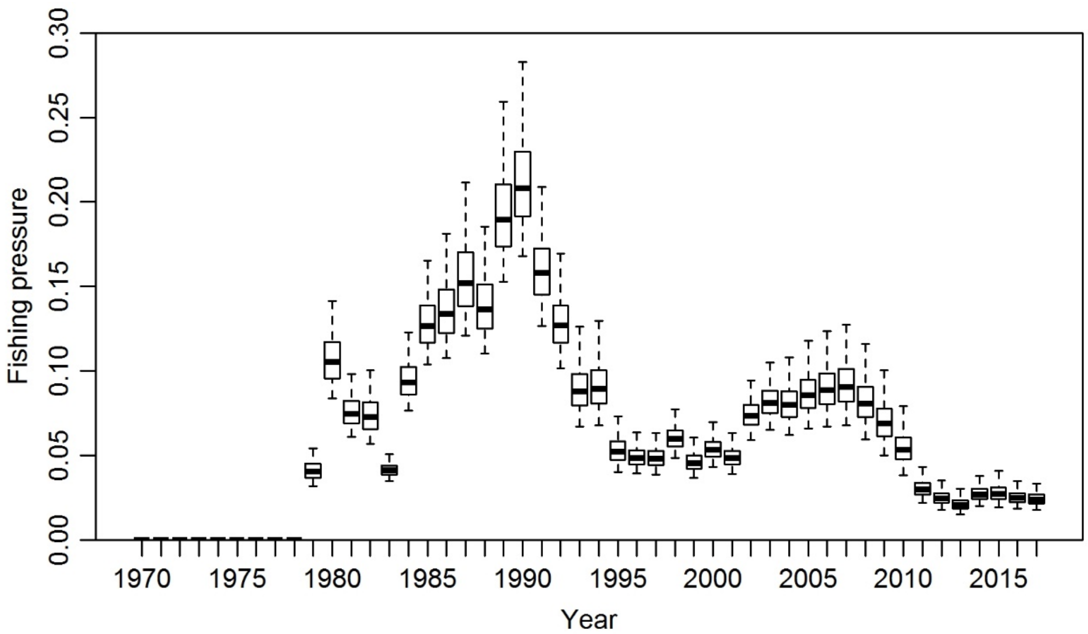

Figure 34: East & South Chatham Rise base, MCMC estimated fishing-pressure trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution.

5.5 A two-stock model

MPD sensitivity runs were also completed assuming that the East & South Chatham Rise consisted of two stocks. The first stock comprised Rekohu only, with input data for that area only (catch history following Dunn, in press). The second stock included the plumes in the Spawning Box ("old plume") and at Mount Muck, in addition to the remainder of the east and south Chatham Rise (catch history was the total, as used in the base run above, minus the Rekohu catch). The acoustic biomass and age composition observations were partitioned by stock accordingly.

The run for the stock including the Old plume, hereafter referred to as the Old Plume (OP) stock, assumed an acoustic biomass prior which followed the base run, being lognormal with mean = 0.8 for surveys indexing both the Old plume and Mount Muck (2011, 2013, and 2016), and mean = 0.64 (80% of 0.8) for surveys indexing the Old plume only (2002–2010, 2012, and 2014).

For the OP stock and assuming a lognormal YCS prior with $\sigma^R = 0.6$, the acoustic *q* for the two-area surveys was 0.87, and for the OP index the *q* was 1.03. The fits to the acoustic indices were fairly good, with SSB declining to a relatively low level then increasing slowly from about 2010 (Figure 35). YCS peaked in the 1940s, then remained lower than average from the late 1950s, being particularly low in the 1970s (Figure 36). Fits to the age compositions were good (Figure 37). B_0 was estimated to be 243 000 t, and B_{2017} was 25 300 t, giving a stock status in 2017 of 10.4% B_0. Selectivity and maturity parameters were very similar to the base case model, and fits to the length composition data were similarly good (Figure 38). Assuming the nearly uniform prior, the fits to the acoustic biomass indices were improved (Figure 39), a substantially different YCS pattern was estimated (Figure 40), and recent biomass was very slowly declining, with stock status in 2017 at 9% B_0.

For the Rekohu stock, the fishery was assumed to have selectivity equal to maturity, which was estimated from the age compositions. The acoustic biomass surveys were fitted with a lognormal prior having mean of 1.0 (we have no prior knowledge of a proportion of the stock that is spawning elsewhere). Because of the reduced number of ages observed, the YCS were estimated over a reduced number of years; 1950–1990.

For the Rekohu stock and assuming a lognormal YCS prior with $\sigma^R = 0.6$, the acoustic *q* was estimated to be 0.94, and the fit to the acoustic index was not good, with the fit outside of the 95% confidence intervals for three of the five observations (Figure 41); however, a fit to all observations would be highly unlikely, particularly the low 2012 estimate (without adding process error). The fits to the age compositions tended to underestimate the proportion at ages around 40, and overestimate the proportion at ages around 60 and in the plus group (Figure 42). YCS peaked in the late 1970s, and tended to be relatively low either side of this (Figure 43). B_0 was estimated to be 30 200 t, and B_{2017} was 24 200 t, giving a stock status in 2017 of 80.0% B_0. Maturity (and selectivity) was estimated to be relatively early, at 28.9 years. Assuming the nearly uniform prior, the fits to the acoustic biomass indices and the age compositions were marginally improved although the fit to the plus group remained poor (Figures 44 and 45), and YCS peaked in the early 1960s and was low either side of that (Figure 46). B_0 was estimated to be 26 400 t, and B_{2017} was 24 500 t, giving a stock status in 2017 of 92.8% B_0.

If the estimates from the two stocks are combined, the B_0 was estimated to be 273 200 t, and B_{2017} was 55 000 t, giving a combined stock status in 2017 of 20.3% B_0.

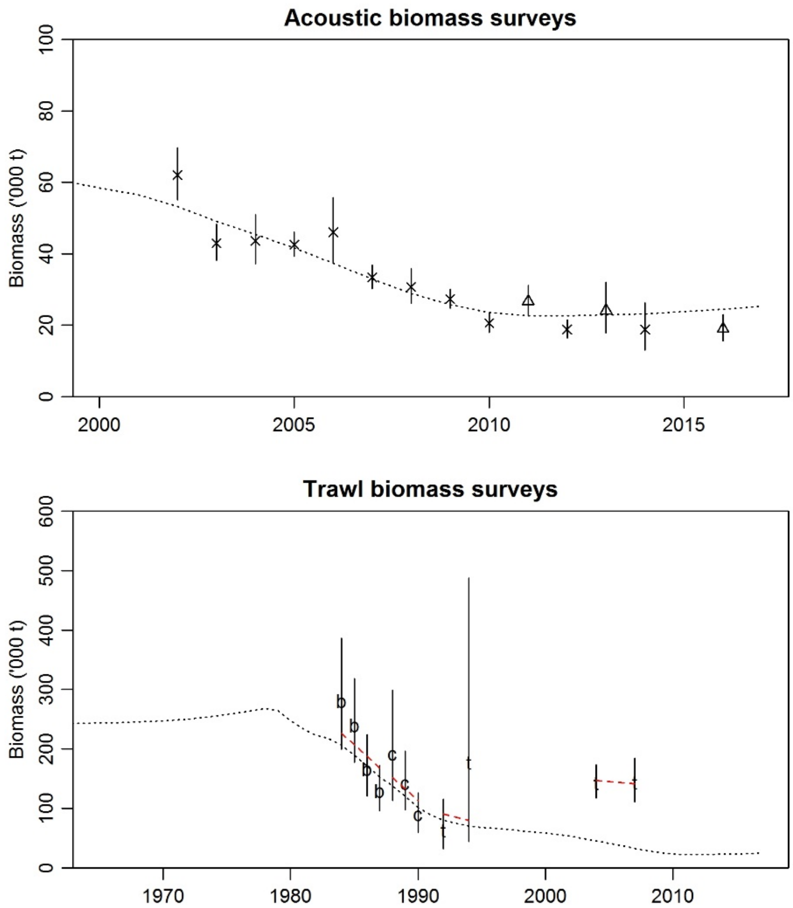

Figure 35: Old Plume stock, YCS prior σ^R = 0.6, MPD, base: fit to the acoustic indices: (top) spawning biomass trajectory and scaled acoustic indices; x, Old plume surveys; Δ, two-area 2011, 2014, and 2016 surveys; (bottom) the spawning biomass trajectory (dotted line) and fits of the trawl surveys to their respective vulnerable biomass (red dashed lines), for b, *Buccaneer*; c, *Cordella*; t (1992 and 1994), *Tangaroa* Spawning Box; t (2004 and 2007), *Tangaroa* wide-area. Vertical lines indicate 95% confidence intervals.

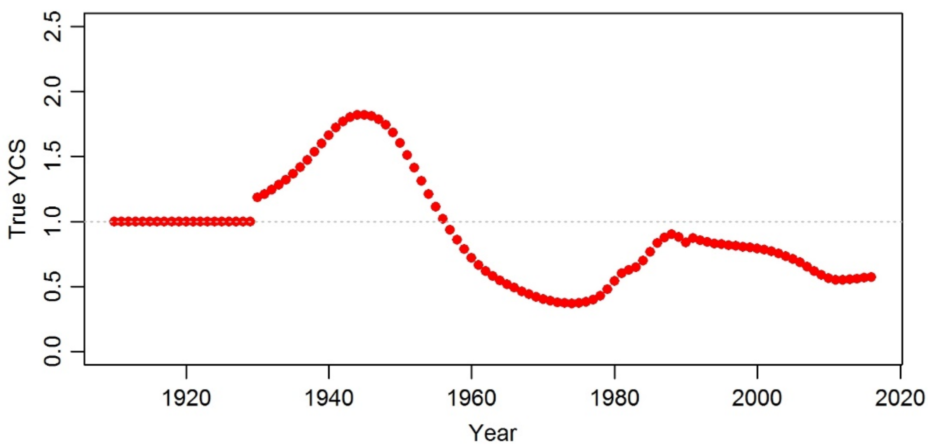

Figure 36: Old Plume stock, YCS prior σ^R = 0.6, estimated YCS from MPD.

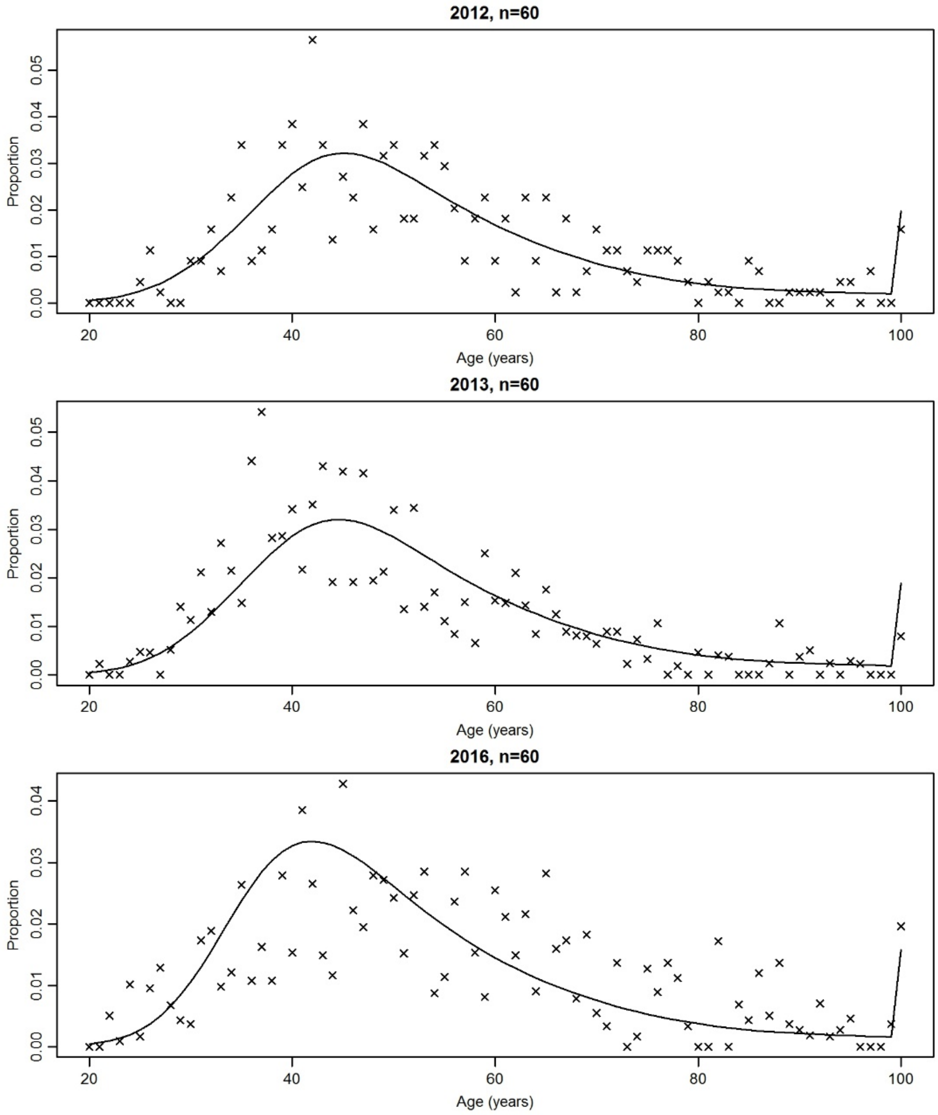

Figure 37: Old Plume stock, YCS prior σ^R = 0.6, MPD base: fits (lines) to the spawning season age frequencies (points); n is the effective sample size.

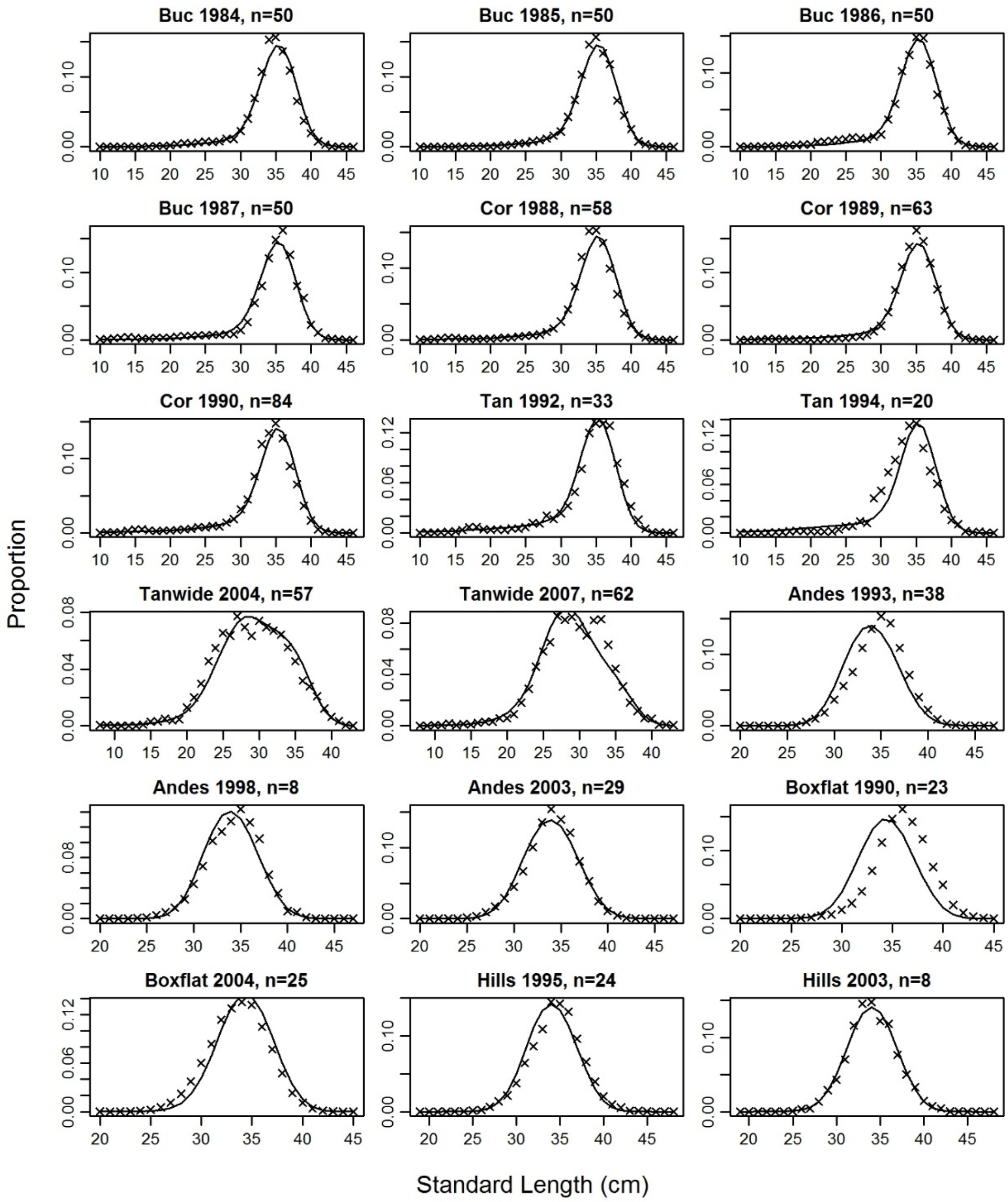

Figure 38: Old Plume stock, YCS prior σ^R = 0.6, MPD base: fits (lines) to the length frequencies (x) for the *Buccaneer* surveys (Buc), *Cordella* surveys (Cor), *Tangaroa* Spawning Box surveys (Tan), *Tangaroa* wide-area surveys (Tanwide), commercial Andes fishery (Andes), commercial Spawning Box and eastern flats fishery (Boxflat), and eastern hills fishery (Hills); n is the effective sample size.

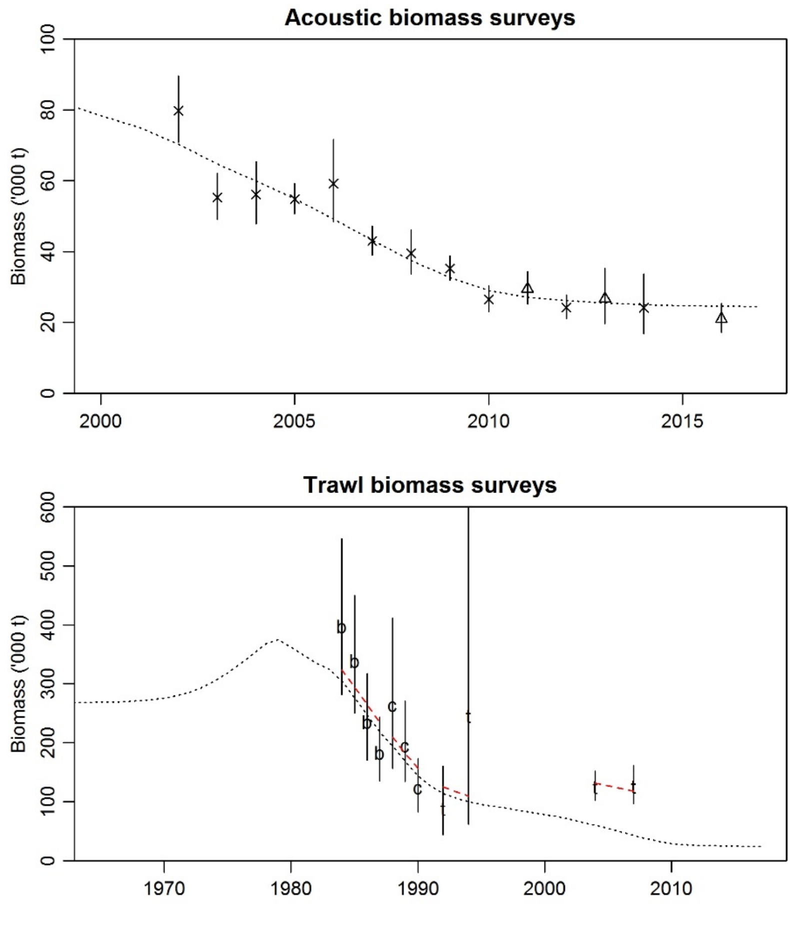

Figure 39: Old Plume stock, nearly uniform YCS prior, MPD, base: fit to the acoustic indices: (top) spawning biomass trajectory and scaled acoustic indices; x, Old plume surveys; Δ, two-area 2011, 2014, and 2016 surveys; (bottom) the spawning biomass trajectory (dotted line) and fits of the trawl surveys to their respective vulnerable biomass (red dashed lines), for b, *Buccaneer*; c, *Cordella*; t (1992 and 1994), *Tangaroa* Spawning Box; t (2004 and 2007), *Tangaroa* wide-area. Vertical lines indicate 95% confidence intervals.

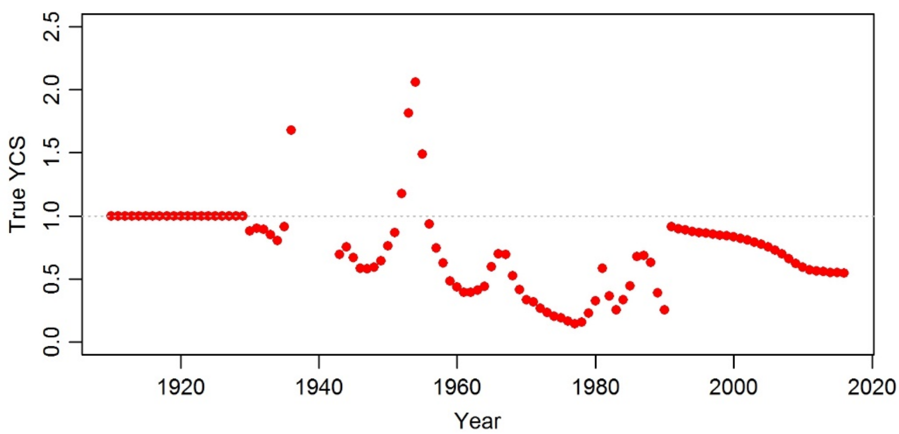

Figure 40: Old Plume stock, nearly uniform YCS prior, estimated YCS from MPD.

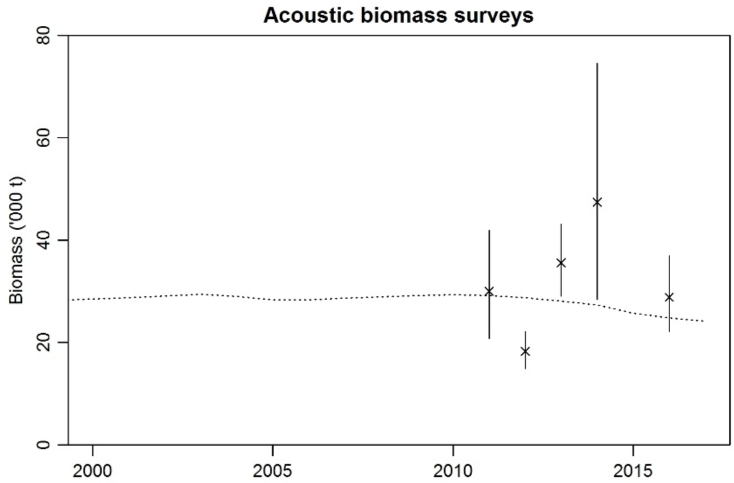

Figure 41: Rehoku, YCS prior σ^R = 0.6, MPD, base: fit to the acoustic index. Vertical lines indicate 95% confidence intervals.

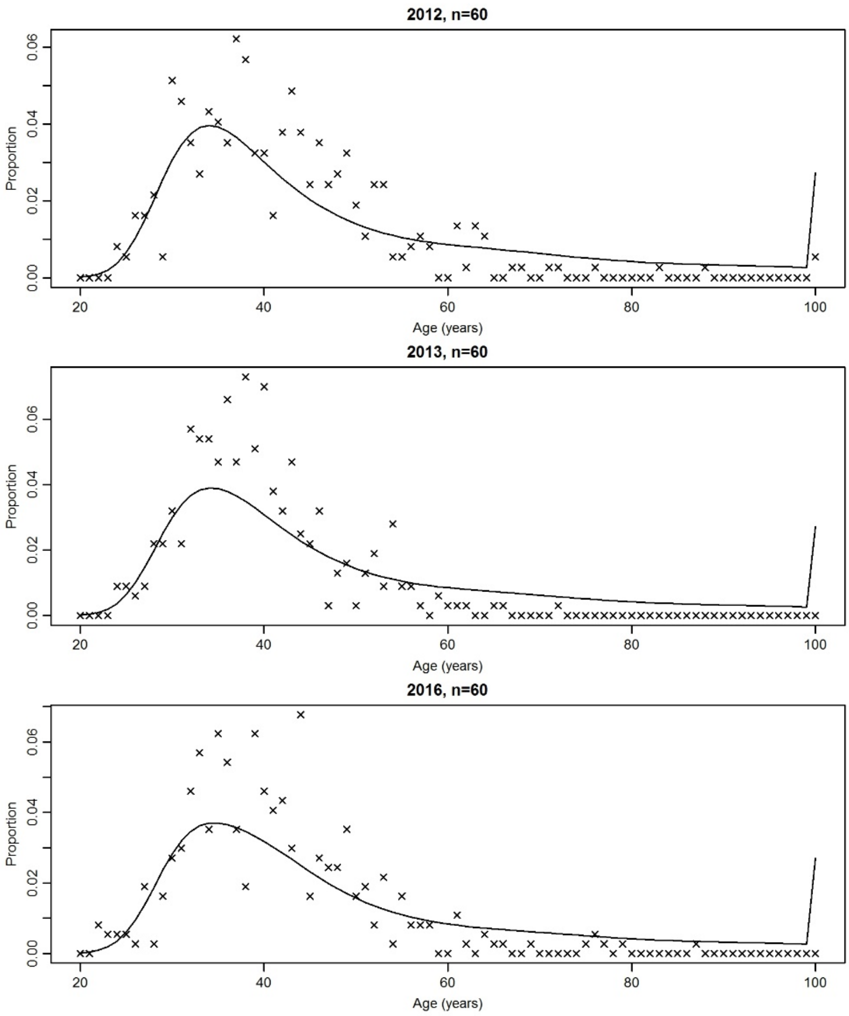

Figure 42: Rekohu, YCS prior σ^R = 0.6, MPD base: fits (lines) to the spawning season age frequencies (points); n is the effective sample size.

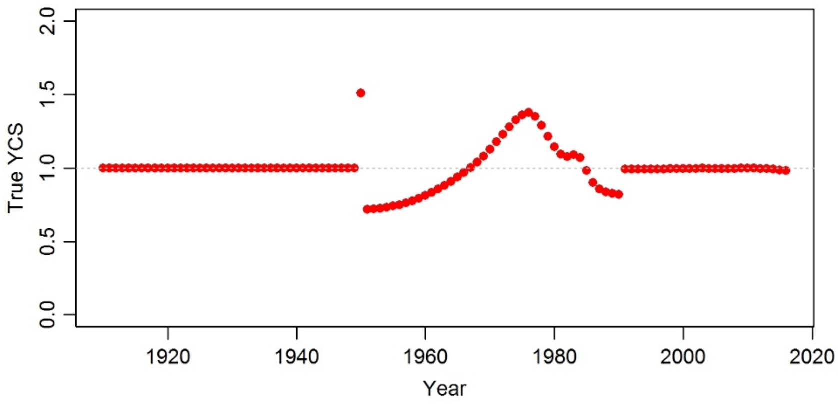

Figure 43: Rekohu, YCS prior σ^R = 0.6, estimated YCS from MPD.

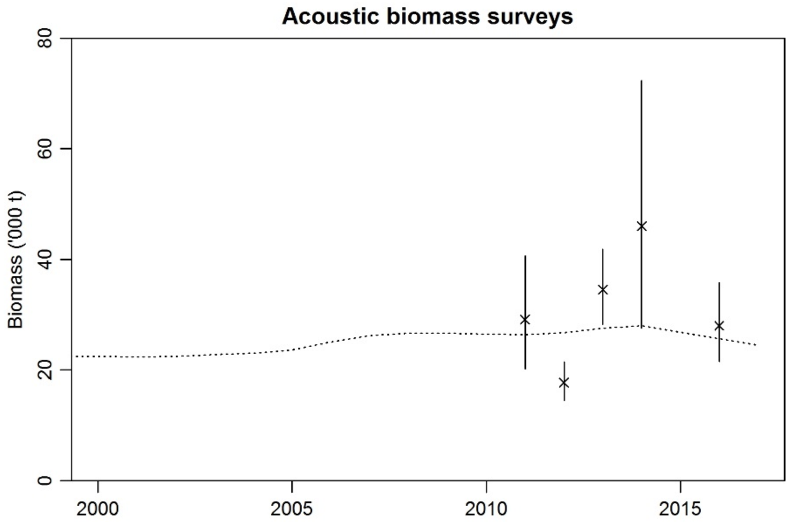

Figure 44: Rehoku, YCS prior nearly uniform, MPD, base: fit to the acoustic index. Vertical lines indicate 95% confidence intervals.

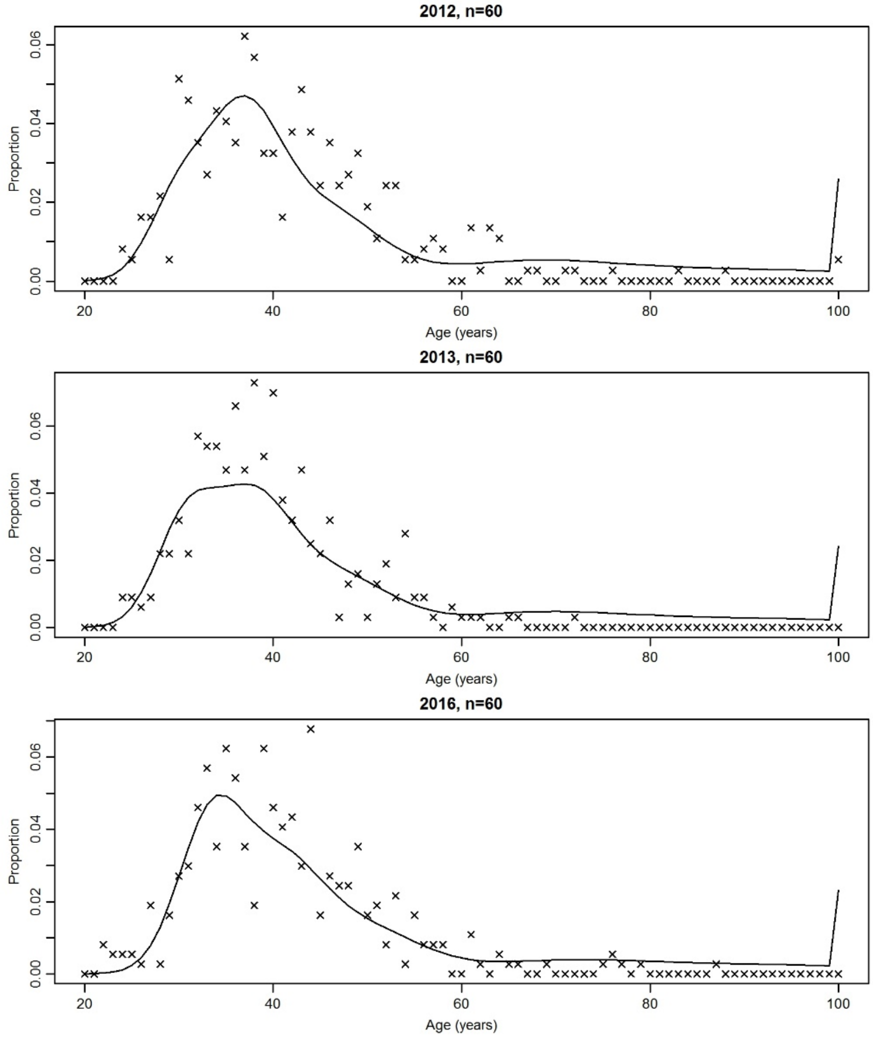

Figure 45: Rekohu, YCS prior nearly uniform, MPD base: fits (lines) to the spawning season age frequencies (points); n is the effective sample size.

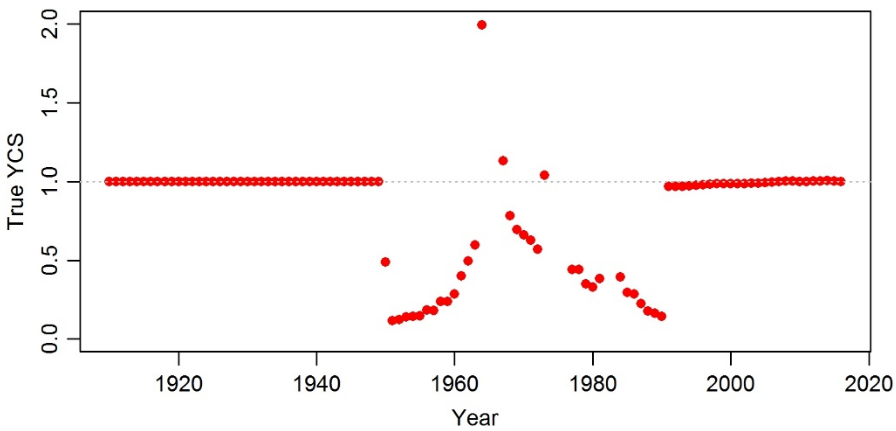

Figure 46: Rekohu, YCS prior nearly uniform, estimated YCS from MPD.

6. DISCUSSION

The 2017 stock assessment extended the work completed by Cordue (2014). Both Chatham Rise orange roughy stocks were estimated to have a spawning stock biomass that was increasing, and within the management target range.

Both stock assessments were found to be reasonably robust to changes in data and model assumptions. The assumed proportion of biomass believed to be available to the acoustic biomass surveys (the *q* priors) was known to be influential, and the basis of key sensitivity runs (Cordue, 2014). For the East & South Chatham Rise, very good fits to the acoustic observations had been achieved by assuming most surveys were independent (had their own *q*s), but when this assumption was reduced (in the ratio-*q* run) the model estimates of stock size and status were essentially unchanged.

The use of the nearly uniform prior on YCS allowed the model to achieve better fits for MPD model runs than the more "conventional" lognormal YCS prior assuming a σ^R of around 1 (Francis & Fu, 2015). However, when MCMC estimates were run assuming the nearly uniform prior, the MPD estimates were sometimes outside of the 95% CI of the MCMC estimates, with the MCMC having a different stock size, status, and biomass trajectory to the MPD. The MCMC estimates assuming a nearly uniform YCS prior gave results that were similar to those achieved assuming a lognormal YCS prior with $\sigma^R = 0.6$, but with the lognormal YCS prior the MPD was within the MCMC posterior. Therefore, when the MPD is used as a guide to the likely MCMC results, a lognormal YCS prior assuming $\sigma^R = 0.6$ may be more indicative.

The estimation of YCS for orange roughy has allowed for better fits to data, with YCS estimates influenced by several observational data sets (not just age compositions). With an ageing error of 10%, substantial differences between some age samples (Northwest Chatham Rise), and marked differences within age composition estimates from the same location (e.g., Morgue; I. Doonan, pers. comm.), it seems sensible to approach the estimation of YCS, and/or *M*, with some caution.

The two-stock assessment for the East & South Chatham Rise estimated a smaller and more depleted stock, with the acoustic catchability estimates closer to one than in the base model, and accordingly the predicted biomass was much closer to the observed biomass. The two-stock model estimated spawning biomass in 2016 to be around 55 000 t, much closer to the observed 44 000 t than the one-stock base model, which estimated SSB to be about 100 000 t. How reasonable it is to assume that more than half of the spawning biomass was not observed in the acoustic surveys is unclear (potential hypotheses supporting this level of un-observed biomass might include more fish than estimated hidden in the acoustic shadow zone, turnover of fish in the plumes, fish dispersed in the mesopelagic, or fish not attending the spawning aggregations every year).

Assuming the lognormal prior for YCS with $\sigma^R = 0.6$, the peak in YCS for the Rekohu stock occurred in the period of lowest recruitment for the Old Plume stock (1960–1980). This negative correlation would be consistent with a scenario, in the base (one-stock) model, where recruitment to the two regions alternated. As such, the results of the two-stock model were not inconsistent with the assumptions made for the one-stock model. The life history parameters of orange roughy also mean that an unexploited stock would be expected to have moderate amounts of fish in the plus group (100+ years), which was not observed in the Rekohu samples; this would be consistent with Rekohu being a result of relatively recent recruitment, rather than a previously unexploited aggregation. The base model estimated a YCS pattern similar to that estimated for the Old plume model, where recruitment during the 1960–1970 period was relatively low, suggesting that the Old plume data may have greater influence on YCS estimation.

Future assessments could consider updating and/or adding more recent length composition data, and estimating (Northwest Chatham Rise) or re-estimating (East & South Chatham Rise) the growth parameters from the new age data. A model assuming Morgue to be a separate subarea of the Northwest

Chatham Rise could be attempted, to which movement-at-age is estimated such that the predicted age composition better fits the observed (this could be implemented in CASAL).

7. ACKNOWLEDGMENTS

This work was funded by the Ministry for Primary Industries project DEE2016/21. My thanks to the members of the MPI Deepwater Fisheries Assessment Working Group for peer-review of the research, Andy McKenzie (NIWA) for comments on the draft report, and Kevin Sullivan and Marianne Vignaux (both MPI) for comments and editorial suggestions on the final draft.

8. REFERENCES

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.

Cordue, P.L. (2014). The 2014 orange roughy stock assessments. *New Zealand Fisheries Assessment Report* 2014/50. 135 p.

Doonan, I.J.; Horn, P.L.; Ó Maolagáin, C. (2014). Age composition of orange roughy from ORH 3B (Chatham Rise: northwest ,1994, and northeast,2013), and from ORH 7A (Challenger Plateau in 1987, 2006 and 2009). *New Zealand Fisheries Assessment Report* 2014/59. 33 p.

Dunn, M.R. (in press). Orange roughy fisheries on Chatham Rise and Campbell Plateau (ORH 3B). *New Zealand Fisheries Assessment Report*. 57 p.

Francis, R.I.C.C.; Fu, D. (2015). A rationale for year-class strength priors. *New Zealand Fisheries Assessment Report* 2015/62. 23 p.

Hicks, A. (2006). Updated length data for the NECR and NWCR. Presentation to the MFish Deepwater Working Group 7 March 2006.

Ministry for Primary Industries (2016). Ministry for Primary Industries. Fisheries Assessment Plenary, May 2016: stock assessments and stock status. Compiled by the Fisheries Science Group, Ministry for Primary Industries, Wellington, New Zealand.

Ryan, T.E.; Kloser, R.J. (2015). Improved estimates of orange roughy Biomass using an acoustic-optical system in commercial trawlnets. *ICES Journal of Marine Science* 73(8), 2112–2124.

Tracey, D.M.; Fenaughty, J.M. (1997). Distribution and relative abundance of orange roughy on the Chatham Rise, May–July 1994. *New Zealand Fisheries Technical Report* 44. 43 p.

9. APPENDIX A

MCMC diagnostics for the Northwest Chatham Rise base model and key sensitivities. MCMC chains were run for 15 million iterations, keeping every 1000th sample, with the first 1 million removed (as a burn-in; within which adaptive step sizes allowed). Three separate chains were run, starting at different random steps from the MPD. A key diagnostic requirement was that the posterior estimates from the three chains were similar; if this was the case, then all three chains were combined for estimation of quantities.

9.1 Base model

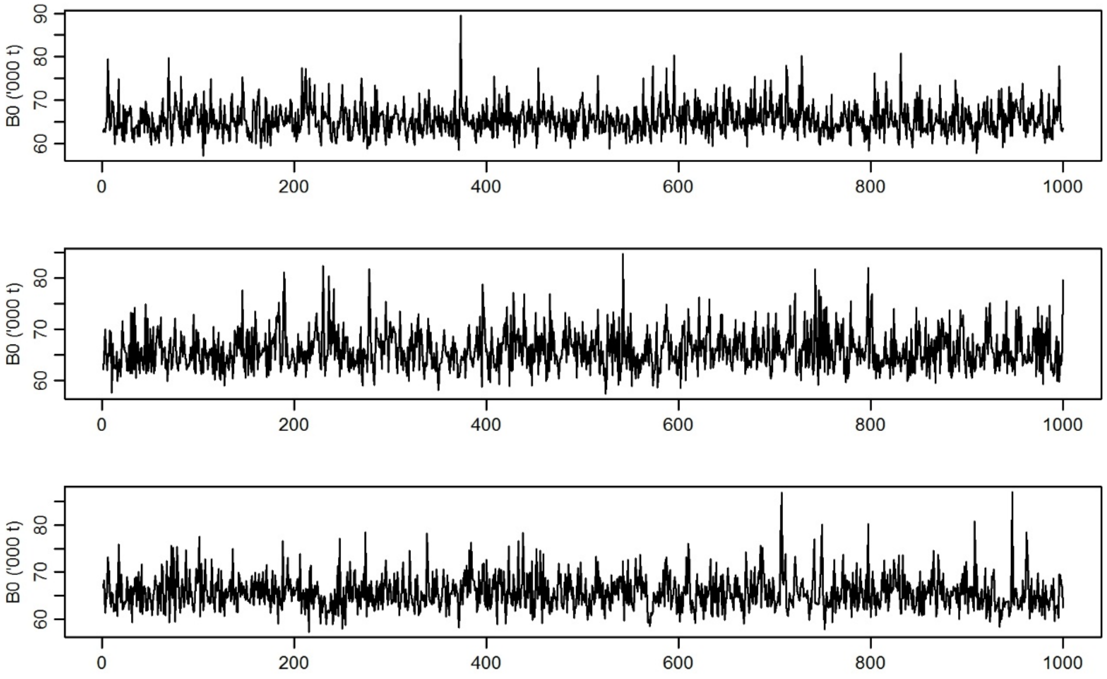

Figure 9.1: Northwest Chatham Rise, Base model, B_0 samples from the three MCMC chains.

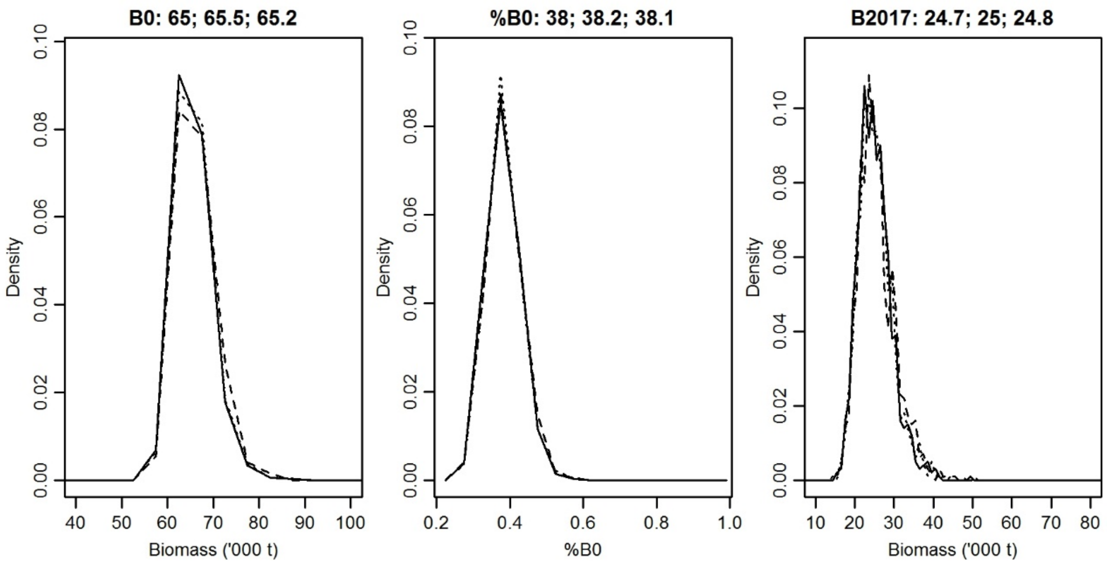

Figure 9.2: Northwest Chatham Rise, Base model, quantity estimates from the three MCMC chains.

9.1 Extra acoustics

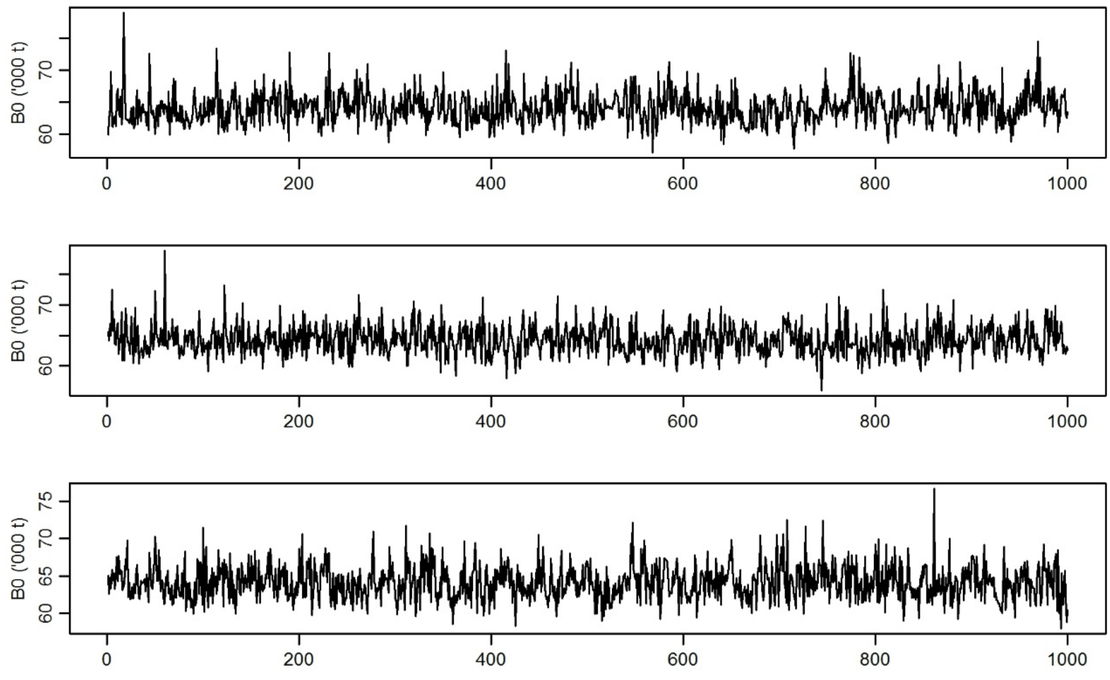

Figure 9.3: Northwest Chatham Rise, extra acoustics run, B_0 samples from the three MCMC chains.

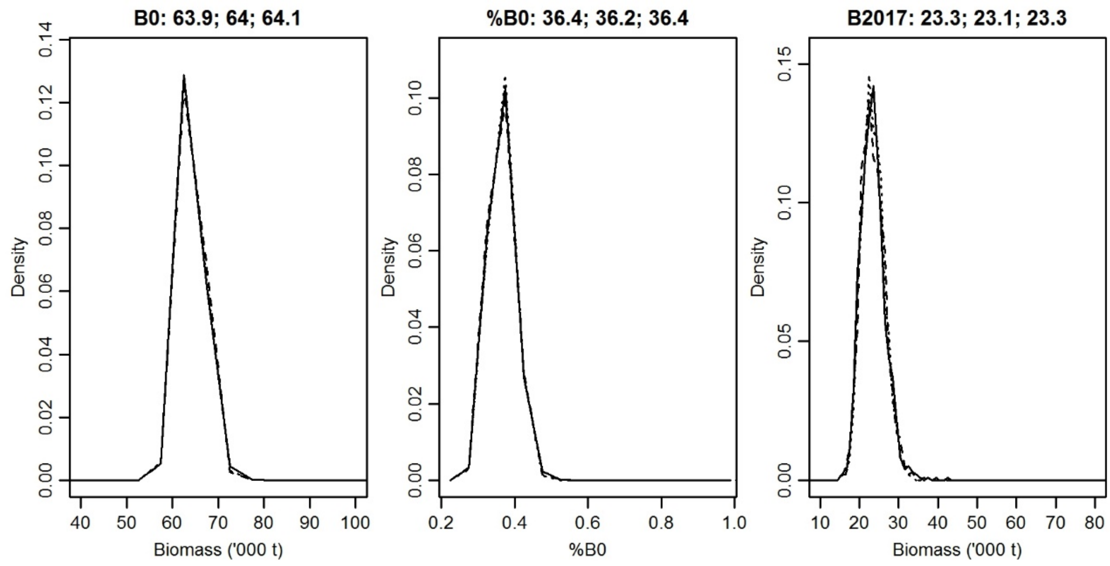

Figure 9.4: Northwest Chatham Rise, extra acoustics run, quantity estimates from the three MCMC chains.

9.2 Include Morgue C@A

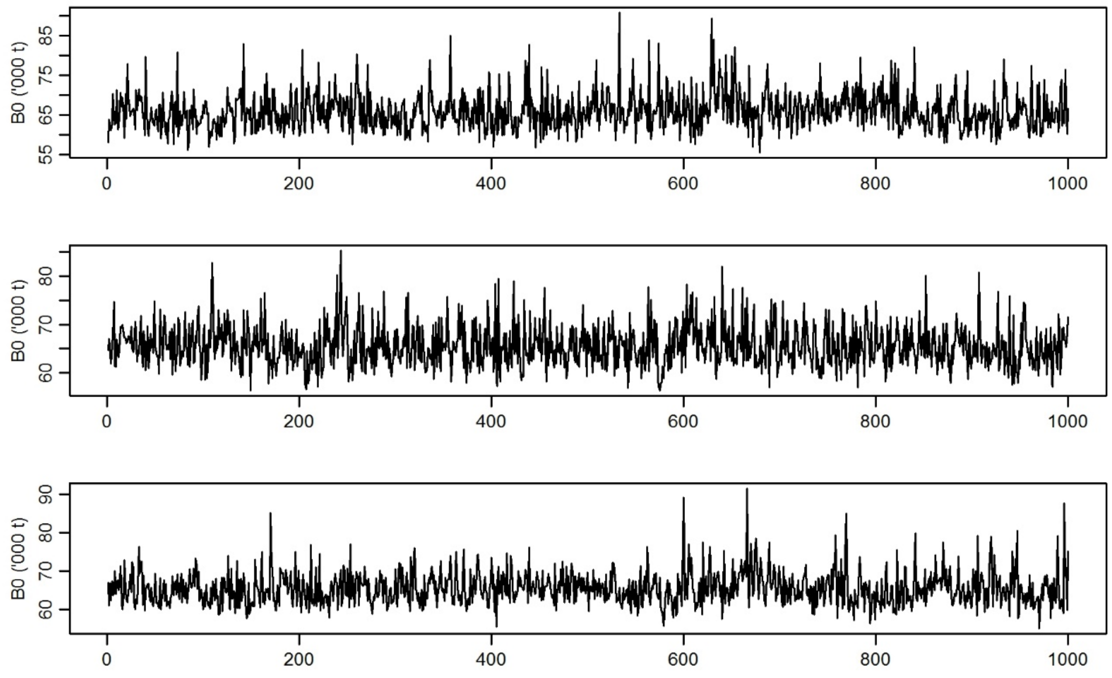

Figure 9.5: Northwest Chatham Rise, include Morgue C@A run, B_0 samples from the three MCMC chains.

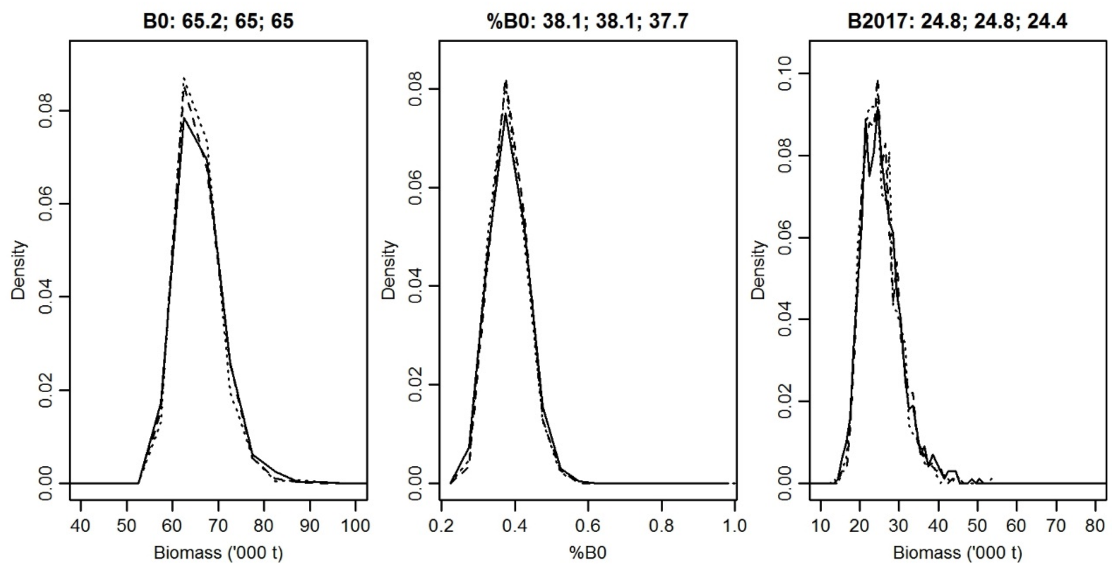

Figure 9.6: Northwest Chatham Rise, include Morgue C@A run, quantity estimates from the three MCMC chains.

9.3 Low *M*–High *q*

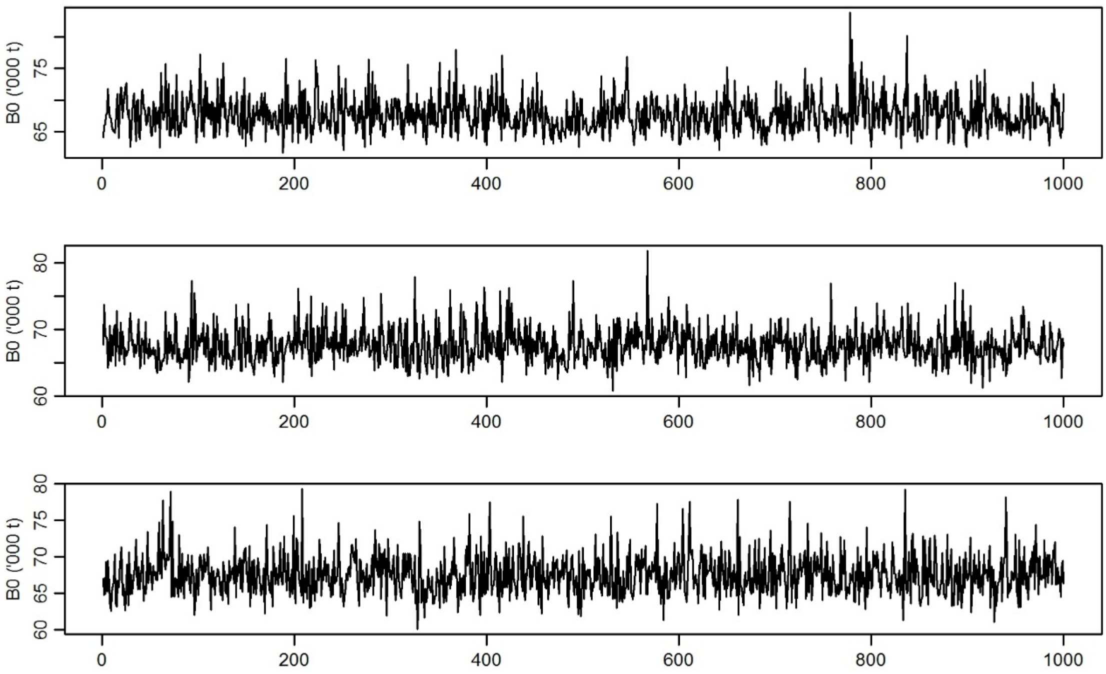

Figure 9.7: Northwest Chatham Rise, Low *M*-High *q* run, B_0 samples from the three MCMC chains.

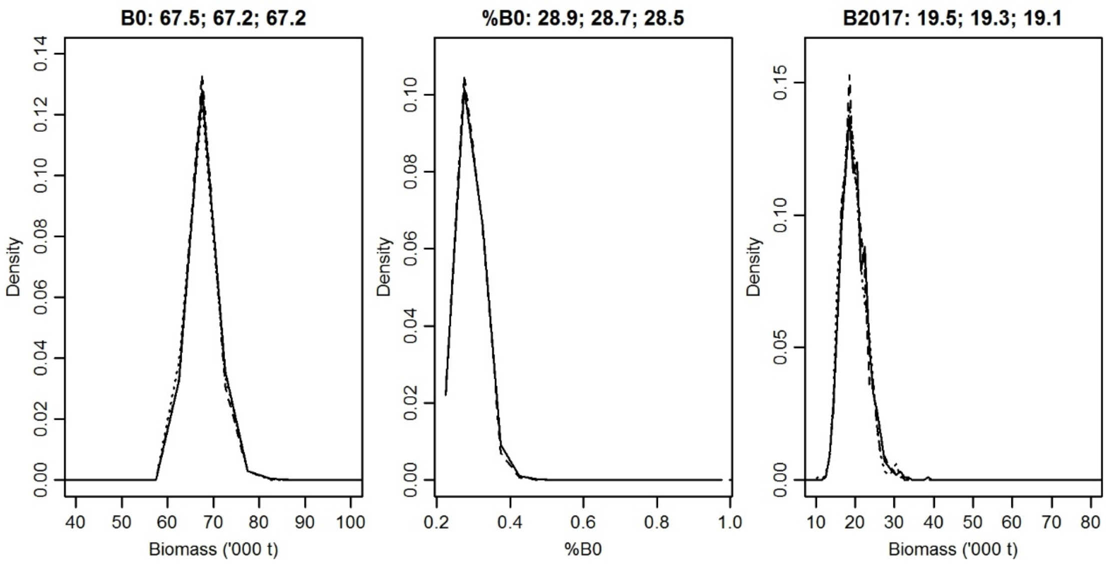

Figure 9.8: Northwest Chatham Rise, Low *M*-High *q* run, quantity estimates from the three MCMC chains.

9.4 High *M*–Low *q*

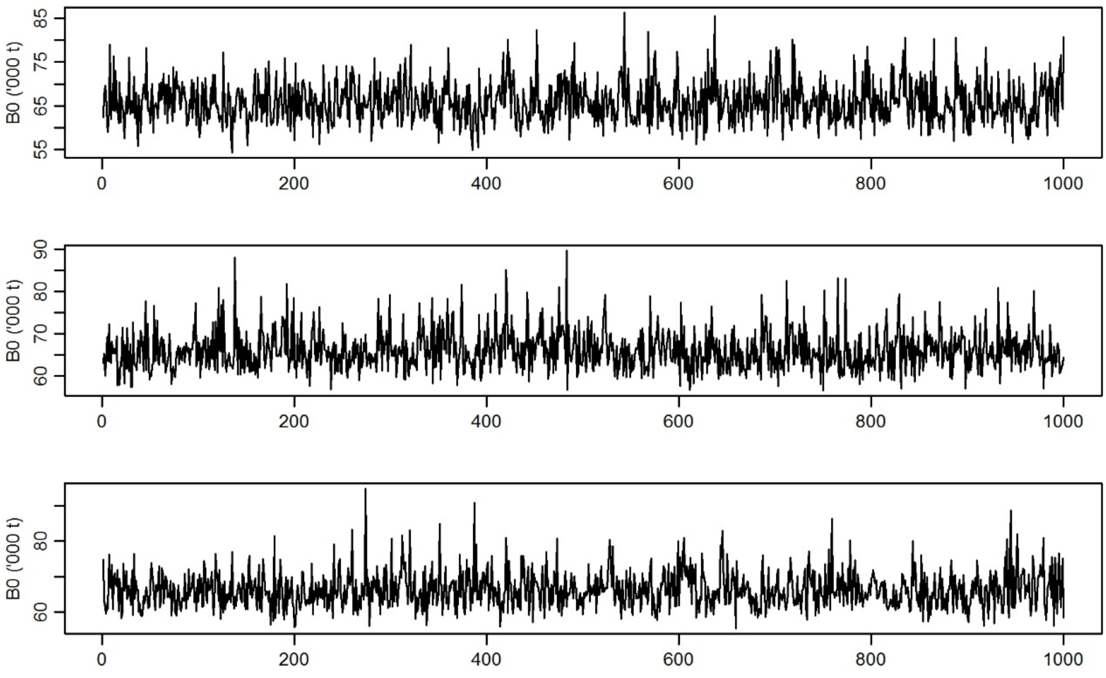

Figure 9.9: Northwest Chatham Rise, High *M*-Low *q* run, B_0 samples from the three MCMC chains.

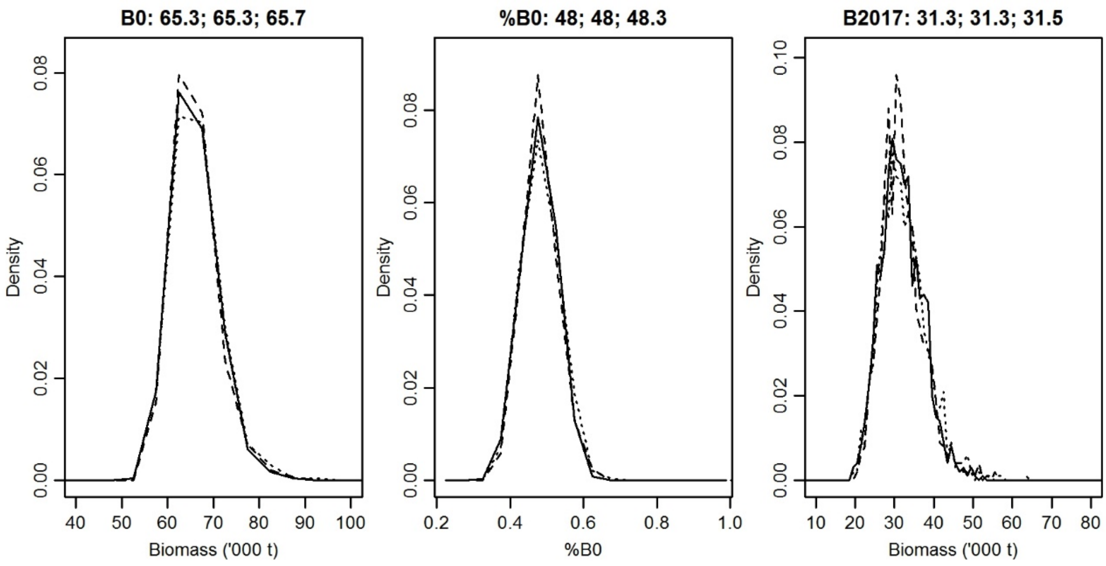

Figure 9.10: Northwest Chatham Rise, High *M*-Low *q* run, quantity estimates from the three MCMC chains.

10. APPENDIX B

MCMC diagnostics for the East & South Chatham Rise base model and key sensitivities. MCMC chains were run for 15 million iterations, keeping every 1000th sample, with the first 1 million removed (as a burn-in; within which adaptive step sizes allowed). The covariance matrix was re-estimated from a single chain run, and this was then used in the three final chains, each of which started at different random steps from the MPD. A key diagnostic requirement was that the posterior estimates from the three chains were similar (Cordue, 2014); if this was the case, then all three chains were combined for estimation of quantities.

10.1 Base model

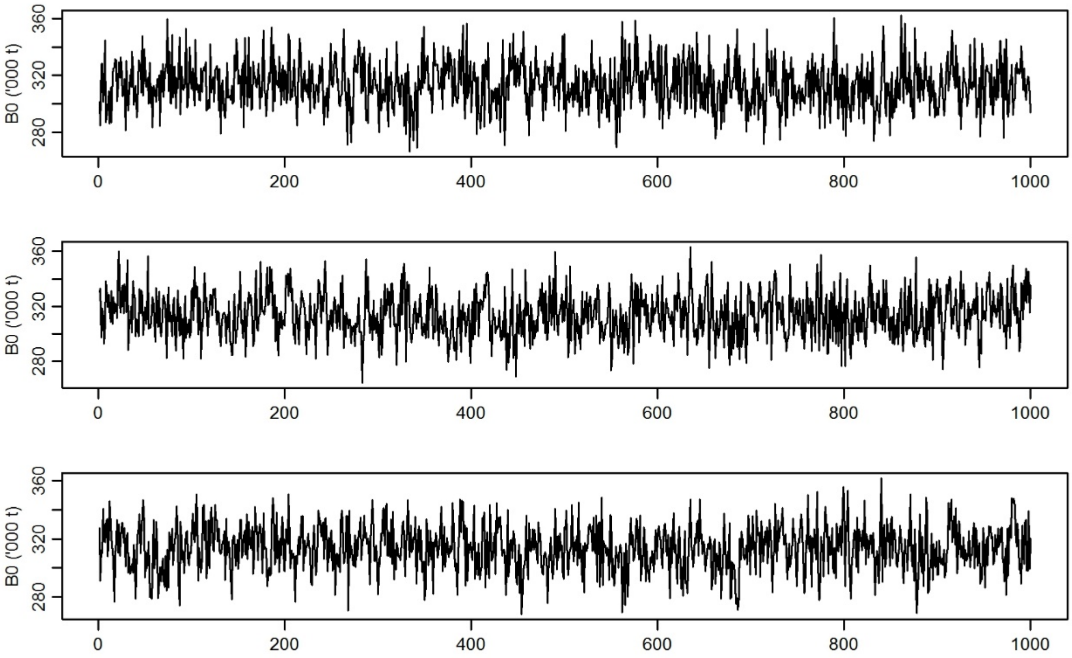

Figure 10.1: East & South Chatham Rise, Base model, B_0 samples from the three MCMC chains.

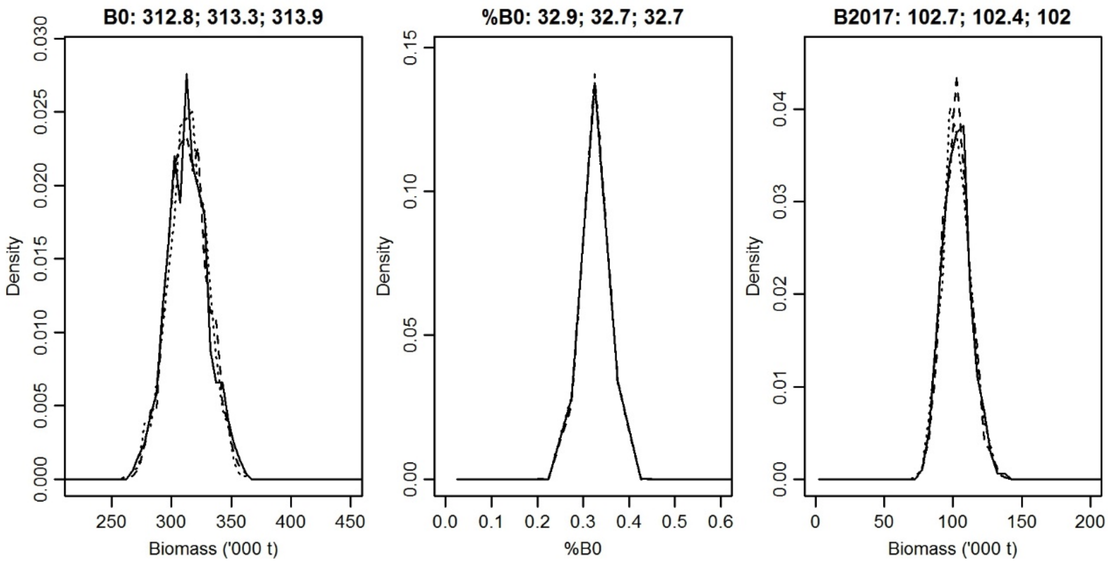

Figure 10.2: East & South Chatham Rise, Base model, quantity estimates from the three MCMC chains.

10.2 Estimate *M*

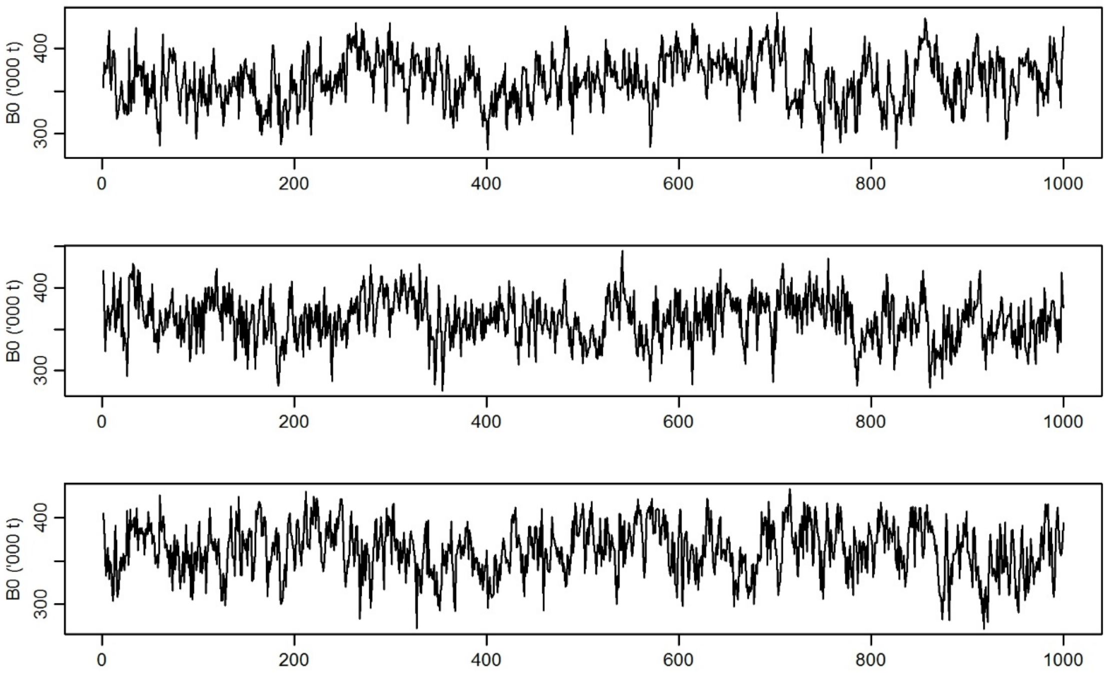

Figure 10.3: East & South Chatham Rise, estimate *M* run, B_0 samples from the three MCMC chains.

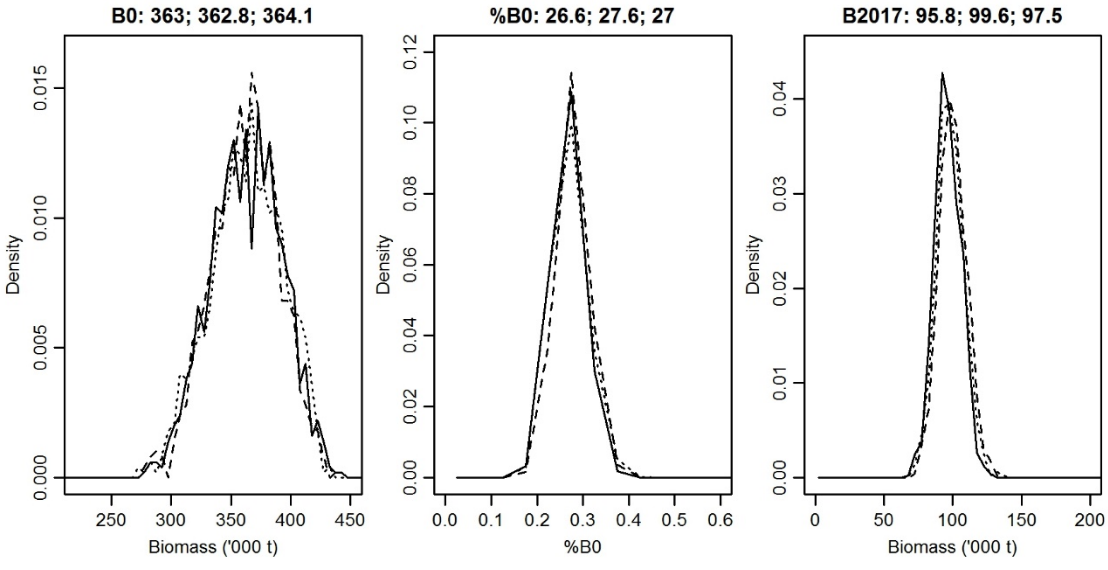

Figure 10.4: East & South Chatham Rise, estimate *M* run, quantity estimates from the three MCMC chains.

10.3 Rekohu 2007

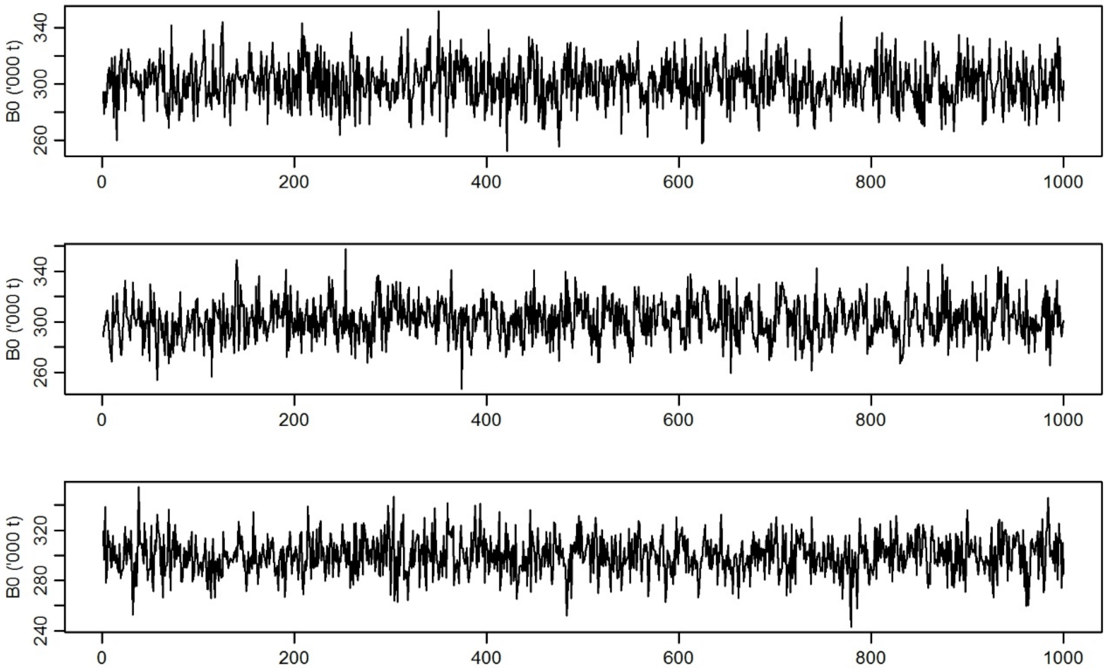

Figure 10.5: East & South Chatham Rise, Rekohu 2007 run, B_0 samples from the three MCMC chains.

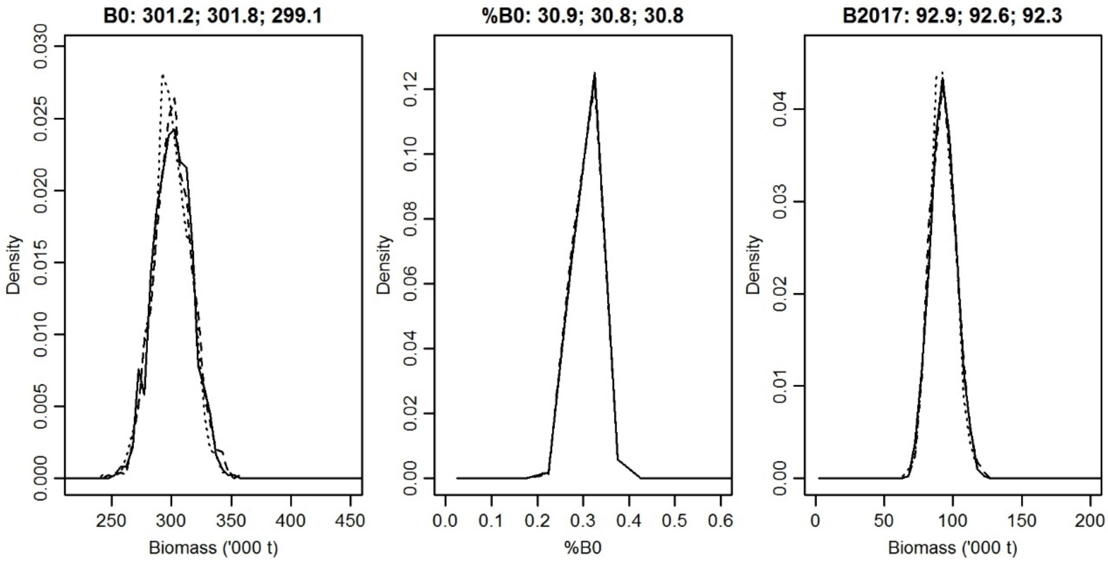

Figure 10.6: East & South Chatham Rise, Rekohu 2007 run, quantity estimates from the three MCMC chains.

10.4 Low *M*–High *q*

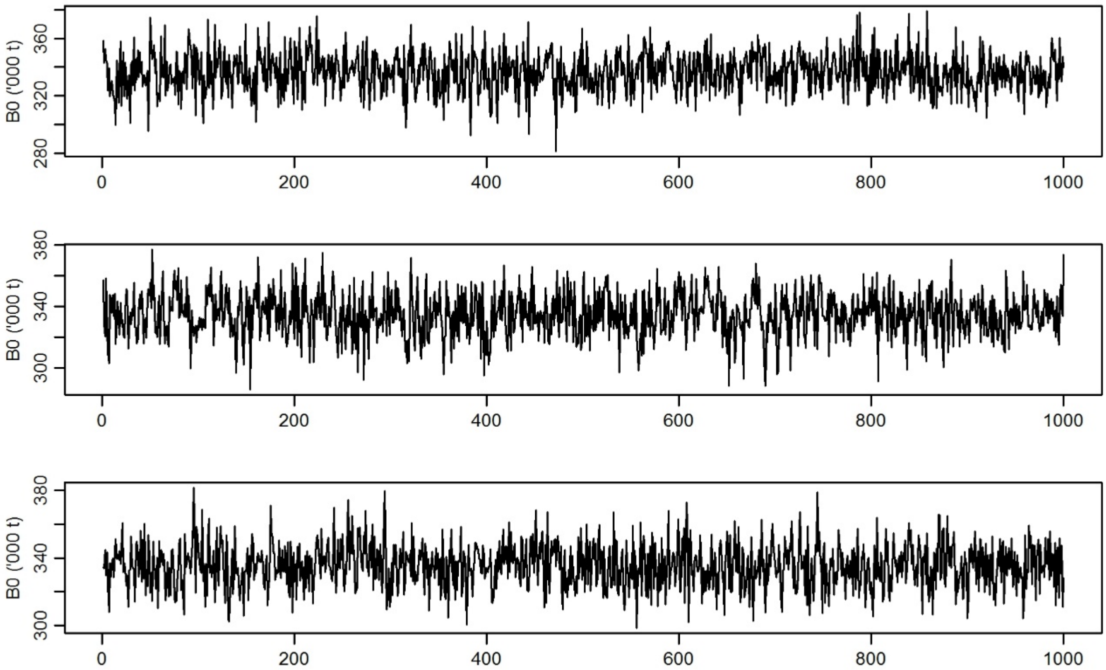

Figure 10.7: East & South Chatham Rise, Low *M*-High *q* run, B_0 samples from the three MCMC chains.

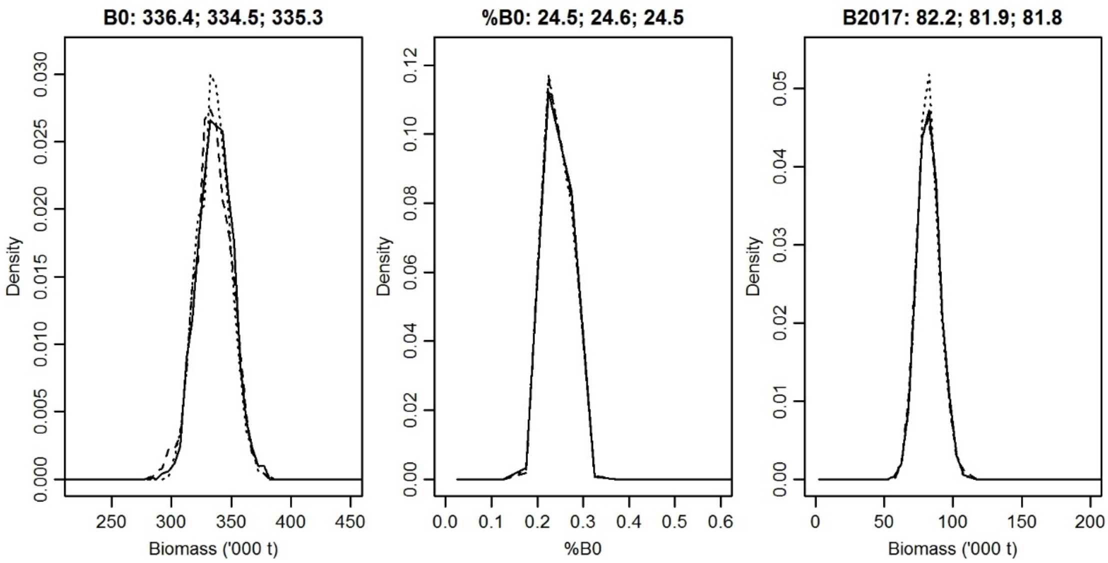

Figure 10.8: East & South Chatham Rise, Low *M*-High *q* run, quantity estimates from the three MCMC chains.

10.5 High *M*–Low *q*

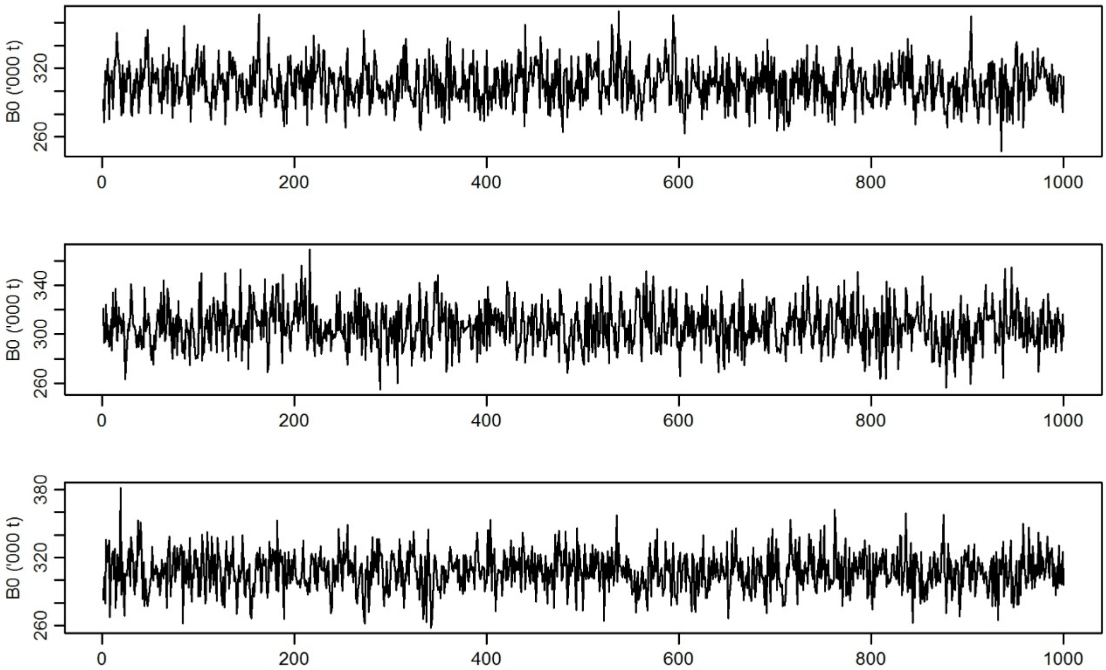

Figure 10.9: East & South Chatham Rise, High *M*-Low *q* run, B_0 samples from the three MCMC chains.

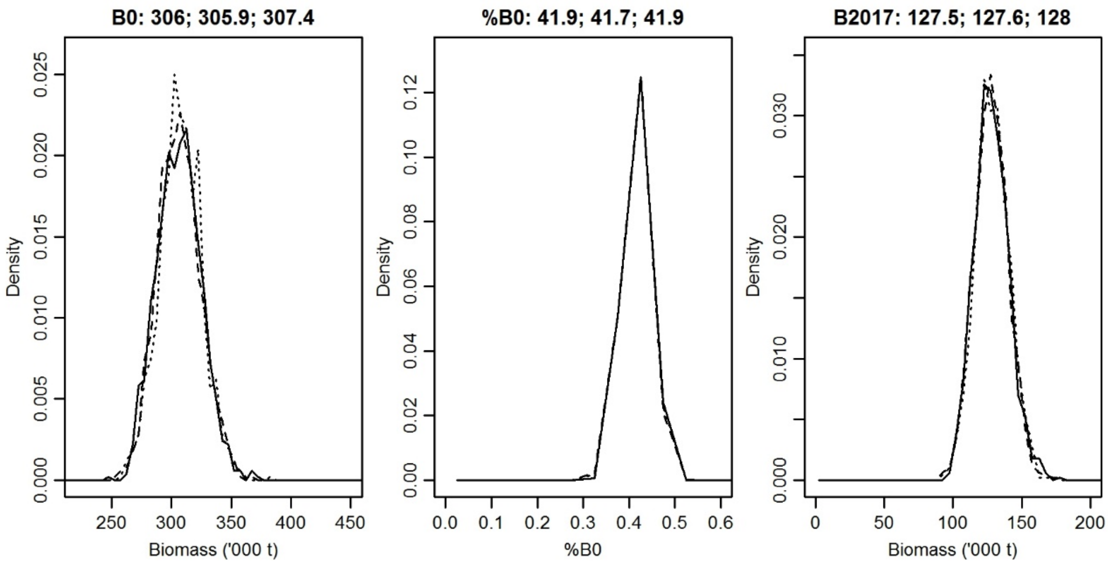

Figure 10.10: East & South Chatham Rise, High *M*-Low *q* run, quantity estimates from the three MCMC chains.