ORANGE ROUGHY, CHATHAM RISE AND SOUTHERN NEW ZEALAND (ORH 3B)

1. FISHERY SUMMARY

1.1 Commercial fisheries

Orange roughy are found in waters deeper than 750 m throughout Quota Management Area 3B. Historically, the main fishery has been concentrated on the Chatham Rise. Annual reported orange roughy catches in ORH 3B ranged between 24 000–33 000 t in the 1980s, progressively decreased from 1989–90 to 1995–96 because of a series of TACC reductions, were stable over the mid-1990s–mid-2000s and decreased further from 2005–2006 as TACCs were further reduced (Table 1 and Figure 1).

Table 1: Annual reported catches and TACCs of orange roughy from ORH 3B. (Catches from 1978–79 to 1985–86 are from Robertson & Mace 1988) and from 1986–87 to 2013–14 from Fisheries Statistics Unit and Quota Monitoring System data). ‡

Fishing year	Reported catch (t)	TACC (t)	Agreed catch limit (t) *β*
1979–80†	11 800	-	-
1980–81†	31 100	-	-
1981–82†	28 200	23 000	-
1982–83*	32 605	23 000	-
1983–84*	32 535	30 000	-
1984–85	29 340	30 000	-
1985–86	30 075	29 865	-
1986–87	30 689	38 065	-
1987–88	24 214	38 065	-
1988–89	32 785	38 300	-
1989–90	31 669	32 787	-
1990–91	21 521	23 787	-
1991–92	23 269	23 787	-
1992–93	20 048	21 300	-
1993–94	16 960	21 300	-
1994–95	11 891	14 000	-
1995–96	12 501	12 700	-
1996–97	9 278	12 700	-
1997–98	9 638	12 700	-
1998–99	9 372	12 700	-
1999–00	8 663	12 700	-
2000–01	9 274	12 700	-
2001–02	11 325	12 700	-
2002–03	12 333	12 700	-
2003–04	11 254	12 700	-
2004–05	12 370	12 700	-
2005–06	12 554	12 700	-
2006–07	11 271	11 500	-
2007–08	10 291	10 500	-
2008–09	8 758	9 420	-
2009–10	6 662	7 950	-
2010–11	3 486	4 610	3 860
2011–12	2 765	3 600	2 850
2012–13	2 515	3 600	2 850
2013–14	4 492	4 500	-

† Catches for 1979–80 to 1981–82 are for an April–March fishing year.
* Catches for 1982–83 and 1983–84 are 15 month totals to accommodate the change over from an April–March fishing year to an October–September fishing year. The TACC for the interim season, March to September 1983, was 16 125 t.
‡ Catches from 1984–85 onwards are for a 1 October–30 September fishing year.
β Agreed, non-regulatory catch limits between industry and MPI, which includes 'shelving' (an agreement that transfers ACE to a third party to effectively reduce the catch without adjusting the TACC).

There have been major changes in the distribution of catch and effort over the history of this fishery (Table 2). Initially, it was confined to the Chatham Rise and, until 1982, most of the catch was taken from areas of relatively flat bottom on the northern slopes of the Rise (in the Spawning Box), between mid-June and mid-August, when the fish form large aggregations for spawning (Figure 2).

From 1983 to 1989 about one third of the catch was taken from the south and east Chatham Rise, where new fishing grounds developed on and around knolls and hill features. Much of the catch from these areas was taken outside the spawning season as the fishery extended to most months of the year.

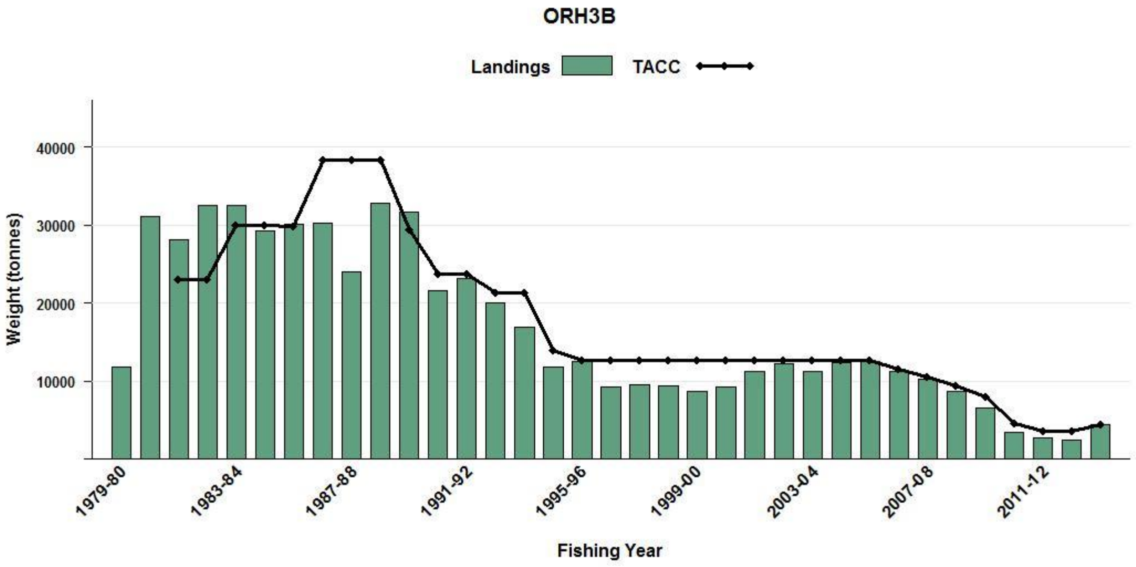

Figure 1: Reported commercial landings and TACCs for ORH 3B. Note that this figure does not show data prior to entry into the QMS.

Table 2: ORH 3B catches by area, to the nearest 10 t or 100 t, and by percentage (to the nearest percent) of the total ORH 3B reported catch. Catches are equivalent to those shown in Table 1, but allocated to area using the ratio of estimated catches, and revised such that all years are from 1 October–30 September. Note that catches for the East Rise are given by the sum of Spawning Box and Rest of East Rise.

Year	Northwest Rise		South Rise		Spawning box		Rest of East Rise		Non-Chatham	
	t	%	t	%	t	%	t	%	t	%
1978–79	0	0	0	0	11 500	98	300	2	0	0
1979–80	1 200	4	800	3	27 900	90	1 200	4	0	0
1980–81	8 400	30	3 700	13	16 000	57	100	0	0	0
1981–82	7 000	28	500	2	16 600	67	800	3	0	0
1982–83	5 400	35	4 800	31	4 600	30	600	4	0	0
1983–84	3 300	13	5 100	21	15 000	61	1 500	6	0	0
1984–85	1 800	6	7 900	27	18 400	63	1 100	4	0	0
1985–86	3 700	12	5 300	18	17 000	56	4 100	13	0	0
1986–87	3 200	10	4 900	16	20 200	66	2 400	8	0	0
1987–88	1 600	7	6 800	28	13 500	56	2 300	10	0	0
1988–89	3 800	12	9 200	28	16 700	51	3 100	9	0	0
1989–90	3 300	10	11 000	35	16 200	51	1 100	3	200	1
1990–91	1 500	7	6 900	32	6 100	28	6 100	29	900	4
1991–92	300	1	2 200	9	1 000	4	12 000	51	7 800	34
1992–93	3 800	19	5 400	27	100	0	4 700	23	6 100	30
1993–94	3 500	21	5 100	30	0	0	4 900	29	3 500	20
1994–95	2 400	20	1 600	13	500	5	3 500	30	3 800	32
1995–96	2 400	19	1 300	10	1 600	13	2 200	17	5 000	40
1996–97	2 200	24	1 400	15	1 700	19	1 900	21	1 900	21
1997–98	2 300	23	1 700	17	2 400	24	2 200	22	1 600	16
1998–99	2 700	28	1 200	13	1 100	11	2 500	27	1 900	21
1999–00	2 100	24	1 100	13	1 500	17	3 100	36	800	9
2000–01	2 600	27	1 700	18	1 200	13	2 300	24	1 500	17
2001–02	2 200	19	1 100	10	3 100	28	3 600	31	1 300	12
2002–03	2 200	19	1 500	13	3 200	27	3 900	33	1 500	7
2003–04	2 000	18	1 400	12	4 300	38	2 600	23	1 000	9
2004–05	1 600	13	1 700	14	4 100	33	3 000	24	2 000	16
2005–06	1 400	11	1 300	10	3 900	31	3 900	31	2 100	16
2006–07	700	7	1 200	11	4 200	37	3 700	32	1 500	16
2007–08	800	8	1 300	13	3 800	37	2 700	26	1 600	16
2008–09	750	8	1 170	14	3 400	39	2 150	25	1 290	15
2009–10	720	11	940	14	3 120	47	1 260	19	620	9
2010–11	40	1	460	13	1 860	53	740	21	380	11
2011–12	70	3	300	11	1 520	55	770	28	100	3
2012–13	110	4	290	12	1 450	58	590	24	70	3
2013-14										

In the early 1990s, effort within the Chatham Rise further shifted from the Spawning Box to eastern and northwestern parts of the Rise. The Spawning Box was closed to fishing from 1992–93 to 1994–95. In more recent years, catches from the main fishing grounds on the Chatham Rise have declined due to TACC reductions.

The early 1990s also saw the Puysegur fishery develop, followed by other fishing grounds near the Auckland Islands and on the Pukaki Rise, which was also a focus for the fishery south of the Chatham Rise.

Since 1992–93, the distribution of the catch within ORH 3B has been affected by a series of catch-limit agreements between the fishing industry and the Minister responsible for fisheries. Initially, the agreement was that at least 5000 t be caught south of 46° S. Subsequently, the catch limits, and the designated sub-areas to which they apply, have changed from year to year.

The TACC was reduced to 3600 t in 2011–12 (Table 1). The agreed catch limit for the East and South Chatham Rise is currently 3100 t (Table 3). A three-year staged process to reduce F to F_{MSY} was initiated on 1 October 2008. Under this approach, the catch limit was to be set at 4.5% ($F_{MSY} = M$) of the estimated current biomass in each year from 1 October 2010. However, for 2013–14 the TACC was increased to 4500 t (Table 1) in response to the increased biomass estimates following the discovery of the Rekohu plume.

The catch limit for the Sub-Antarctic has been substantially undercaught since 2009–10. However, the combined East and South Rise sub-area catch limits were exceeded by 450 t in 2005–06 and by 350 t in 2006–07 (100 t were taken against the allowance for research surveys). Taking the research allowance into account, catch limits for the combined east and south Rise sub-area have not been exceeded in subsequent years. Since 2004–05, 250 t of the ORH 3B TACC has been set aside for industry research surveys (Table 3), although this has sometimes been used in areas outside the East and South Chatham Rise.

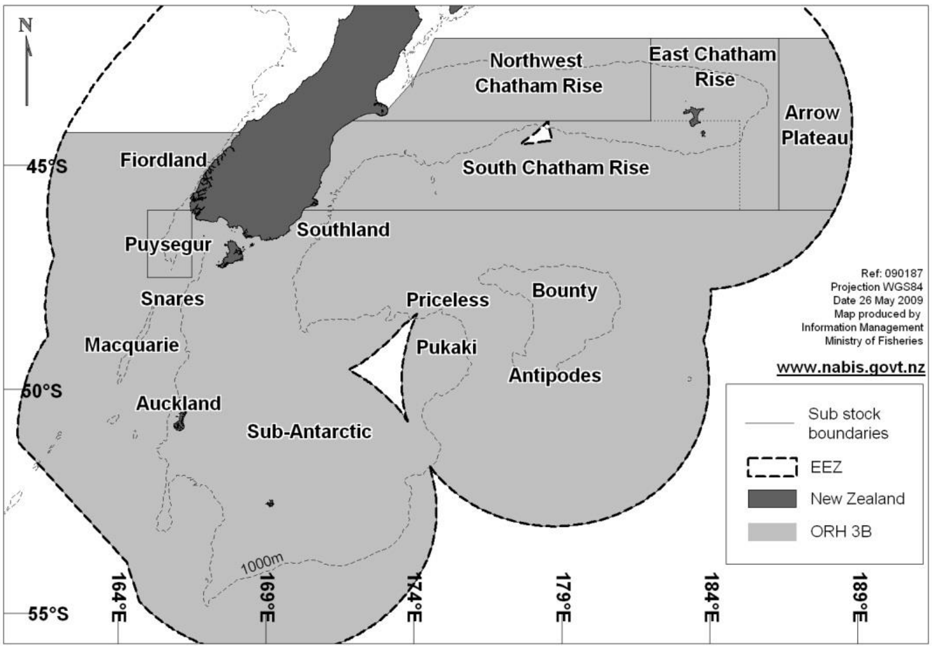

Figure 2: ORH 3B sub-areas and the approximate position of other named fisheries outside of the Chatham Rise. The Spawning Box is in the western part of the East Rise (to the west of the vertical broken line at 175°W). The East and South Rise are currently managed as a single unit. The Arrow Plateau has been designated a Benthic Protected Area. The Sub-Antarctic is all areas below 46°S on the east coast, and 44°16'S on the west coast, except Puysegur.

Table 3: Catch limits (t) by designated sub-area within ORH 3B, as agreed between the industry and the Ministers responsible for fisheries since 1992–93. Note that East Rise includes the Spawning Box, closed between 1992–93 and 1994–95. Sub-area boundaries have varied somewhat between years. * South Rise included in East Rise catch limit. ** Arrow Plateau included in Sub-Antarctic.

Year	Northwest Chatham Rise	East Chatham Rise	South Chatham Rise	Puysegur	Arrow Plateau	Sub-Antarctic
1992–93	3 500	4 500	6 300	5 000	-	2 000
1993–94	3 500	4 500	6 300	5 000	-	2 000
1994–95	2 500	3 500	2 000	2 000	3 000	1 000
1995–96	2 250	4 950	*	1 000	**	4 500
1996–97	2 250	4 950	*	500	**	5 000
1997–98	2 250	4 950	*	0	1 500	4 000
1998–99	2 250	4 950	*	0	1 500	4 000
1999–00	2 250	4 950	*	0	1 500	4 000
2000–01	2 250	4 950	*	0	1 500	4 000
2001–02	2 000	7 000	1 400	0	1 000	1 300
2002–03	2 000	7 000	1 400	0	1 000	1 300
2003–04	2 000	7 000	1 400	0	1 000	1 300
2004–05†	1 500	7 250	1 400	0	1 000	1 300
2005–06†	1 500	7 250	1 400	0†	1 000	1 300
2006–07	750	8 650‡	*	0	0	1 850
2007–08†	750	7 650#	*	0	0	1 850
2008–09†	750	6 570§	*	0	0	1 850
2009–10†	750	5 100	*	0	0	1 850
2010–11	750*β*	2 960†	*	150	0	500
2011–12	750*β*	1 950†	*	150	0	500
2012–13	750 *β*	1 950†	*	150	0	500
2013–14	750	3 100	*	150	0	500

† an additional 250 t set aside for industry research surveys.

‡ 8650 t allocated to the East and South Chatham Rise combined, with no more than 2000 t from the South Rise, and no more than 7250 t from the East Rise.

Combined East and South Rise catch not to exceed 7650 t; East Rise not to exceed 6500 t; South Rise catch not to exceed 1750 t.

§ In 2008–09, the catch from the spawning plume was not to exceed 3285 t.

β From 2010–11 to 2012–13, quota owners have agreed to avoid fishing the Northwest Rise.

Outside the Spawning Box, catches increased in the 1990s and catch rates have been highly variable, sustained largely by the discovery of new fishing areas. Flat areas on the Northwest Rise and several major hills on the South Rise were important in the late 1980s, but currently do not support their previous levels of catch, now accounting for less than 5% of the estimated catch. High catch rates can still occur, but these are less frequent than observed in the early years of the fishery. Catches from the Northwest Rise fell to near zero in 2010–11 as a result of an agreement among quota owners to avoid fishing in this area (Table 2). This agreement was extended to the 2011–12 and 2012–13 fishing years.

Between 1991–92 and 2000–01, more than half of the Chatham Rise catch came from four hill complexes: the Andes, Smith City and neighbours, Graveyard, and Big Chief and neighbours. All of these have shown a decline in unstandardised catch rate since the early years of the fishery, and in recent years, catch rates in these hill complexes have remained relatively low. After 2000–01, the proportion of the catch from these hill complexes decreased, as a greater proportion of the catch came from the Spawning Box (about 39% in 2008–09). In addition, large catches have been made in recent years outside of the spawning season, in recently developed areas of the southeast Rise. Catches from the Spawning Box taken during the spawning season (which peaks in July) have been relatively high since 2001–02, although unstandardised catch rates have been variable.

The first fishery to be developed south of the Chatham Rise was on Puysegur Bank, where spawning aggregations of orange roughy were found during a joint Industry-Ministry exploratory fishing survey in 1990–91. The fishery developed rapidly, but from 1993–94 catch limits were substantially under-caught. Catch limits were subsequently reduced from the initial level of 5000 t, and the industry implemented a catch limit of 0 t beginning in the 1997–98 fishing year (reported catches in 2004–05 and 2005–06 were taken during industry surveys). No fishing in this area occurred in 2010–11 in spite of an increase in the catch limit to 150 t (Table 3).

Exploratory fishing on the Macquarie Ridge south of Puysegur in 1993 led to the development of a fishery off the Auckland Islands. Total catch rose to around 900 t in 1994–95, but then dropped to less than 200 t by 1999–00, and catches have since been infrequent.

In 1993–94, catches were taken on the 'Arrow Plateau', and became the first major fishery to develop on the easternmost section of the Chatham Rise. A catch limit of 3000 t was put in place for 1994–95, with an additional limit of 500 t for each hill. Only a few hills in this area have been fished successfully, and the catch has never reached the catch limit, which was reduced to 1000 t by the early 2000s (Table 3). The Arrow Plateau was closed to orange roughy fishing when it was designated a Benthic Protected Area in 2007.

In 1995–96, large catches were reported on the southeast Pukaki Rise, with a catch total of over 3000 t. However, the catches dropped rapidly and the fishery effectively ceased within a few years. From 2001–02, a fishery developed on the northeast Pukaki Rise, including the area known as Priceless, where catches were mostly taken at the start of the fishing year. Catches at Priceless reached the feature limit of 500 t for each of the six years up to 2006–07, but catches and catch rates declined substantially from 2007–08, and have remained low since. Areas of the northeast Pukaki Rise outside of Priceless were developed in 2004–05 and also showed a rapid decline in catches and catch rates. By 2007–08, the fishery in the sub-Antarctic was limited to the Auckland Islands and northeast Pukaki Rise areas. Since 2008–09, the fishery has extended over a relatively wide area, but catches and catch rates have been low.

Catches of orange roughy have also been taken off the Bounty Islands (around 100–200 t per year from 1997–98 to 2004–05, but infrequently since then), off the Snares Islands (up to around 500 t per year, but infrequently in recent years), areas of the Macquarie Ridge (100–500 t per year from 2000–01 to 2004–05, and in 2008–09), and off Fiordland (around 500 t in 2000–01, but subsequent catches rapidly decreased).

1.2 Recreational fisheries

No recreational fishing for orange roughy is known in this quota management area.

1.3 Customary non-commercial fisheries

No customary non-commercial fishing for orange roughy is known in this quota management area.

1.4 Illegal catch

No information is available on illegal catch in this quota management area.

1.5 Other sources of mortality

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. In assessments, total removals from each part of the Chatham Rise were assumed to exceed reported catches by the overrun percentages in Table 4.

Table 4: Catch overruns (%) by year.

Year	1978–79	1979–80	1980–81	1981–82	1982–83	1983–84	1984–85	1985–86	1986–87	1987–88
Overrun	30	30	30	30	30	30	30	28	26	24

Year	1988–89	1989–90	1990–91	1991–92	1992–93	1993–94	1994–95 and subsequently
Overrun	22	20	15	10	10	10	5

For Puysegur and other southern fisheries there is no reason to believe that, if there was an overrun in catches, this shows any trend over time. For this reason, it was assumed that there was no overrun for this area.

Within the TAC an allowance of 5% of the TACC is allocated for other sources of mortality (currently 225 t).

2. BIOLOGY

Biological parameters used in this assessment are presented in the Biology section at the beginning of the Orange Roughy section.

3. STOCKS AND AREAS

For the purposes of this report the term “stock” refers to a biological unit with a single major spawning ground, in contrast to a “Fishstock” which refers to a management unit.

Genetically two main stocks are recognised within ORH 3B (Chatham Rise and Puysegur; Smith & Benson 1997) and these are considered to be distinct from stocks in adjacent areas (Cook Canyon and Ritchie Bank). However, it is likely, because of their geographical separation and discontinuities in the distribution of orange roughy, that concentrations of spawning fish on the Arrow Plateau, near the Auckland Islands, and west of the Antipodes Islands also form separate stocks.

Genetic data have been applied to define stock boundaries, both within ORH 3B, and between it and adjacent areas. Mitochondrial DNA shows that there are considerable differences between Puysegur fish and fish from the geographically adjacent areas Cook Canyon and Chatham Rise. Allozyme frequency studies suggest that Chatham Rise fish are distinct from those on the Ritchie Bank (ORH 2A). These data also suggest multiple stocks within the Chatham Rise, but do not indicate clear stock boundaries. Although there is significant heterogeneity amongst allozyme frequencies from different areas of the Rise, these frequencies varied as much in time (samples from the same location at different times) as in space (samples from different locations at the same time).

Chatham Rise

The stock structure of orange roughy on the Chatham Rise was comprehensively reviewed in 2008 (Dunn & Devine 2010). This review evaluated all available data as no single dataset seemed to provide definitive information about likely stock boundaries. The data analysed included: catch distribution and CPUE patterns; location of spawning and nursery grounds; inferred migrations; size, maturity and condition data; genetic studies, and habitat and natural boundaries.

There is evidence that a separate stock exists on the Northwest Rise. The Northwest Rise contains a large spawning ground on the Graveyard Hills, and also nursery grounds around, and primarily to the west of, the Graveyard Hills. There is a gap in the distribution of early juveniles (under 15 cm SL) between the Graveyard area and the Spawning Box at approximately 178°W. A research trawl survey found post-spawning adult fish to the west, but not to the east, of the Graveyard Hills, and a westerly post-spawning migration was inferred. Analyses of median length from commercial and research trawls found that orange roughy on the Northwest Chatham Rise and Graveyard Hills were smaller than those on the East Rise. A substantial decline in the size of 50% maturity after 1992 was found for both the Graveyard Hills and the Northwest Rise, but not for other areas. The only information that does not support the Northwest Rise being a separate stock is an indication from patterns in commercial catch rates that some fish arriving to spawn in the Spawning Box may come from the west (Coburn & Doonan 1994, 1997). Catch data and genetic studies do not shed any further light on stock structure. Oceanographic models suggest that a gyre to the east of the Graveyard may provide a mechanism for a separation between the Northwest Chatham Rise and the East Rise. Based on the available data, the Northwest Chatham Rise is considered to be a separate stock.

The separation of the Northeast Hills and Andes as separate stocks from the Spawning Box and Eastern Flats was based on observations of simultaneous spawning aggregations occurring on these hills, and because stock assessment models indicated a mismatch between the standardised CPUE trends. On the other hand, the occurrence of a continuous nursery ground throughout the area; similar trends in size of 50% maturity in each area; the essentially continuous habitat with similar environmental conditions and inferred post-spawning migrations from the Spawning Box towards the east Rise all suggest that all of these areas are a single stock. Analyses of median lengths from commercial catches showed no obvious differences between areas. In addition, the spawning aggregations found on the Northeast Hills and Andes appear to have been minor compared to that in the Spawning Box. The spawning aggregation on the Northeast Hills is also associated with an increase in mean length and catch rates, suggesting that fish spawning on these hills are not resident, and thus are not separate from the surrounding area. Based on the available data the Northeast Hills and Andes are therefore considered to be from the same stock as the Spawning Box and Eastern Flats.

The only evidence to separate the eastern area of the South Rise (Big Chief and surrounds) from the East Rise is the lack of spawning migrations inferred from an absence of a seasonal effect in standardised CPUE analyses. The evidence that the Big Chief area is the same stock as the East Rise includes the fact that the nursery grounds and habitat are continuous; there were no splits between the areas identified from analyses of median length; and the fisheries are similar. The reports of spawning fish around Big Chief have been infrequent, and so are considered equivocal on stock structure. The Big Chief area is therefore considered part of the East Rise stock.

There is weak evidence that the area of the South Rise west of and including Hegerville is a separate stock. The evidence includes median length analyses which indicated a split in this area, and an oceanographic front at 177°W. However, very few catches of spawning orange roughy have been reported in this area, and there appears to be no substantial nursery ground. Both of these factors support the idea that this area does not have a separate stock. In the area to the west of the suggested split the fish are relatively small during spawning, and relatively large during non-spawning. Combined with a standardised CPUE which shows a decline in abundance around July (peak spawning), and a somatic condition factor which declines during September–November (post-spawning), this supports a hypothesis of adult fish leaving the area to spawn elsewhere.

The South Rise could provide feeding habitat for the stock, which is estimated to have had an initial biomass of over 300 000 t, an amount that was probably too large to inhabit only the East Rise. There is more evidence to support orange roughy in this area being part of the East Rise stock than there is to the contrary. The current hypothesis is that the area to the west of the current convergence may be relatively marginal habitat, where larger juvenile, maturing and adult orange roughy were once predominant, and there is little spawning and few juveniles because the water is relatively cold.

Based on these analyses, the Chatham Rise has been divided into two areas: the Northwest, and the East and South Rise combined (Figure 2). The centre of the Northwest stock is the Graveyard Hills. The centre of the East and South Rise stock is the Spawning Box during spawning, and the southeast corner of the Rise during non-spawning.

4. STOCK ASSESSMENT

No model-based stock assessments were conducted for ORH 3B stocks from 2007 to 2013 inclusive. This was primarily because the 2006 stock assessment, which assumed deterministic recruitment, showed an increasing trend in biomass which was not supported by recent biomass indices. Deterministic recruitment was assumed because ageing data were considered to be unreliable. With the successful assessment of the MEC stock in 2013, which used age data from the new ageing methodology (Tracey et al. 2007), there has been a return to model-based assessment in 2014. In addition to an update of the MEC stock assessment, three further stocks have also been assessed, including two stocks in ORH 3B (the Northwest Chatham Rise, the East and South Chatham Rise). There are no other reliable assessments for stocks within ORH 3B. Recruitment in all of these assessments has been derived from limited age data.

4.1 Northwest Chatham Rise

A Bayesian stock assessment was conducted for the Northwest Chatham Rise (NWCR) stock in 2014. This used age-structured population model fitted to acoustic-survey estimates of spawning biomass, a trawl-survey estimate of proportion-at-age and proportion-spawning-at-age, and a limited number of length frequencies from the commercial fishery.

4.1.1 Model structure

The model was single-sex and age-structured (1-100 years with a plus group), with maturity estimated separately (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 was taken to occur after 75% of the mortality and 100% of mature fish were assumed to spawn each year.

The catch history was constructed from the Northwest catches in Table 2 using the catch over-run percentages in Table 4. Natural mortality was assumed to be fixed at 0.045 and the stock-recruitment relationship was assumed to follow a Beverton-Holt function with steepness of 0.75. The remaining fixed biological parameters are given in Table 2 of the Orange Roughy Introduction section.

4.1.2 Input data and statistical assumptions

There were three main data sources for observations fitted in the assessment: acoustic-survey spawning biomass estimates from the main spawning hills (Graveyard and Morgue); an age frequency and an estimate of proportion-spawning-at-age taken from a 1994 wide-area trawl survey; and length frequencies collected from the commercial fishery from 1989–2005.

Acoustic estimates

Three types of acoustic-survey estimates were available for use in the assessment: AOS estimates (from a multi-frequency towed system, e.g., see Kloser et al. 2011); 38 kHz estimates from a towed-body system; and 38 kHz estimates from a hull-mounted system. The reliability of the data from the different systems in each year was considered and estimates from the AOS and towed-body systems were used in the base model (Table 5). An alternative treatment of the available acoustic data was to include additional survey estimates from 2002 and 2004 (Table 5). All of the data in Table 5 were used in the sensitivity run labelled “Extra acoustics”.

Table 5: 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 CVs are those used in the model and do not include any process error.

Year	System	Frequency	Areas	Snapshots	Estimate (t)	CV (%)
1999	Towed-body	38 kHz	GY+M+O	1	8126	22
2002	Towed-body	38 kHz	GY+O	2	9414	20
2004	Hill-mounted	38 kHz	GY	6	2717	16
2012	AOS	38 kHz	GY	3	5550	17
	AOS	38 kHz	M	4	9087	11
2013	AOS	120 kHz	GY	1	7379	31

The acoustic estimates in 1999 and 2012 (total = 14 637 t, CV 17%) 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% (see orange roughy Introduction). The 2013 Graveyard estimate was 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).

Trawl survey data

A wide-area trawl survey of the northwest flats was conducted in late May and early June of 1994 (72 stations; Tracey and Fenaughty 1997). An age-frequency for the trawl-selected biomass was estimated using 300 otoliths selected using the method of Doonan et al (2013). The female proportion spawning-at-age was also estimated. 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).

Length frequencies

The length frequencies from the previous assessment in 2006 were used: nine years of length-frequency data from the period 1989-97 were combined into a single length-frequency that was centred on the 1993 fishing year. Eight years of length-frequency data from the period 1998-2005 were combined into a single length-frequency that was centred on the 2002 fishing year. The 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 pers. comm.). The data were assumed to be multinomial.

4.1.3 Model runs and results

In the base model, the acoustic estimates from 1999, 2012, and 2013 were used and natural mortality (*M*) was fixed at 0.045. There were five main sensitivity runs: estimate *M*; add the extra acoustic data and fix *M*; add the extra acoustic data and estimate *M*; and the LowM-Highq and HighM-Lowq “standard” runs (see orange roughy Introduction).

In the base model, the main parameters estimated were: virgin (unfished, equilibrium) biomass (B_0), maturity ogive, trawl-survey selectivity, CV of length-at-mean-length-at-age for ages 1 and 100 years (linear relationship assumed for intermediate ages), and year class strengths (YCS) from 1940 to 1979 (with the Haist parameterisation and “nearly uniform” priors on the free parameters).

Model diagnostics

The model provided good MPD fits to the data (Figures 3 & 4). The acoustic indices, free to “move” somewhat as they are relative, were very well fitted with the normalised residuals close to zero except in 2013 (Figure 3, top right). The estimated acoustic *q*s were not very different from the mean of the informed priors (Figure 3, bottom). The same is not quite true for the MCMCs, because, although the posteriors for the acoustic *q*s are not very different from the priors, there has clearly been some movement (Figure 5).

Numerous MPD sensitivity runs were performed. These 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).

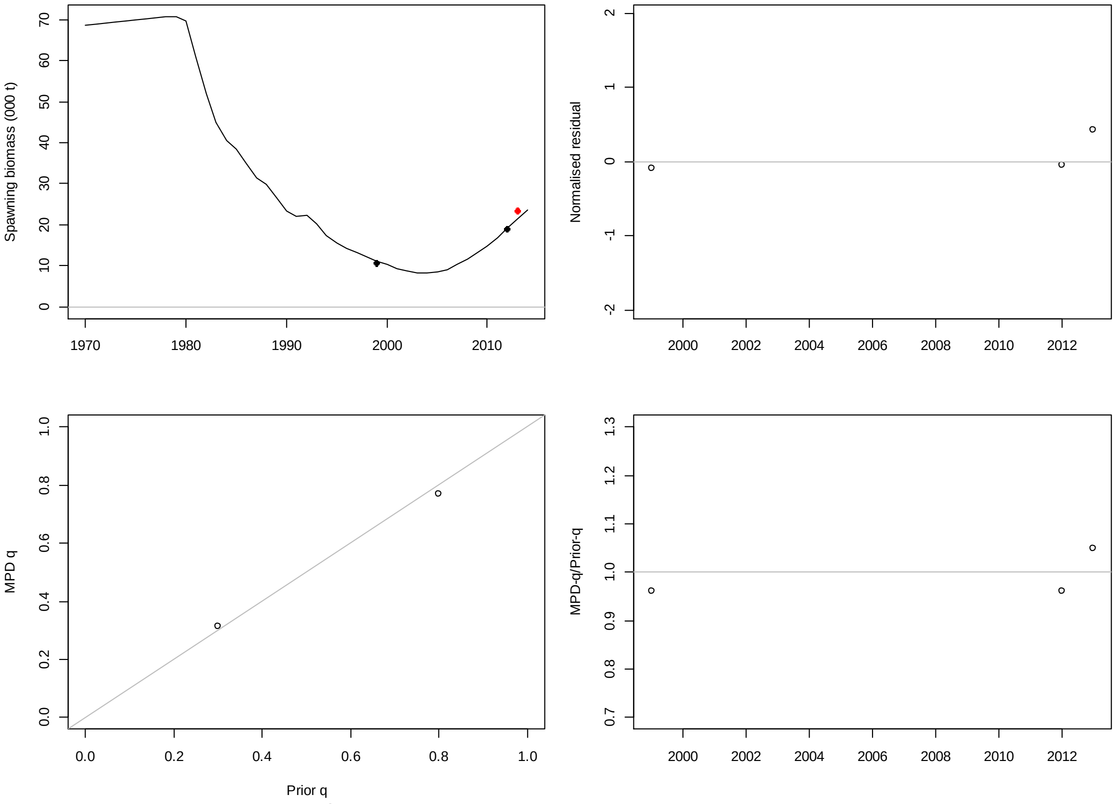

Figure 3: NWCR, base, MPD: fits to the acoustic indices: (top) spawning biomass trajectory and unscaled acoustic indices; normalised residuals; (bottom) estimated *q*s as a function of the mean of the *q* prior; the ratio of the estimated *q* to the mean of the *q* prior.

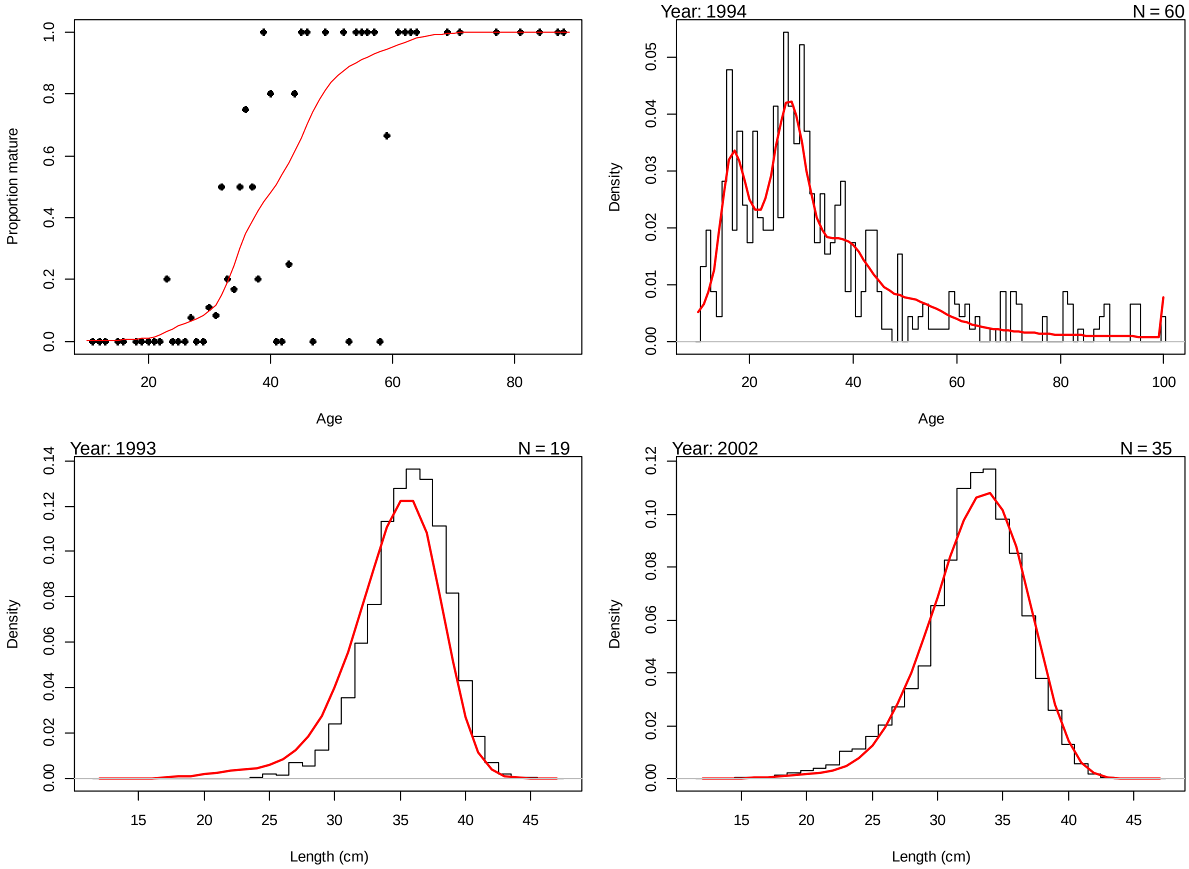

Figure 4: NWCR, base, MPD fits: (observations in black; predictions in red): (top) proportion mature at age; trawl survey age frequency ; (bottom) commercial length frequencies (N is the effective sample size).

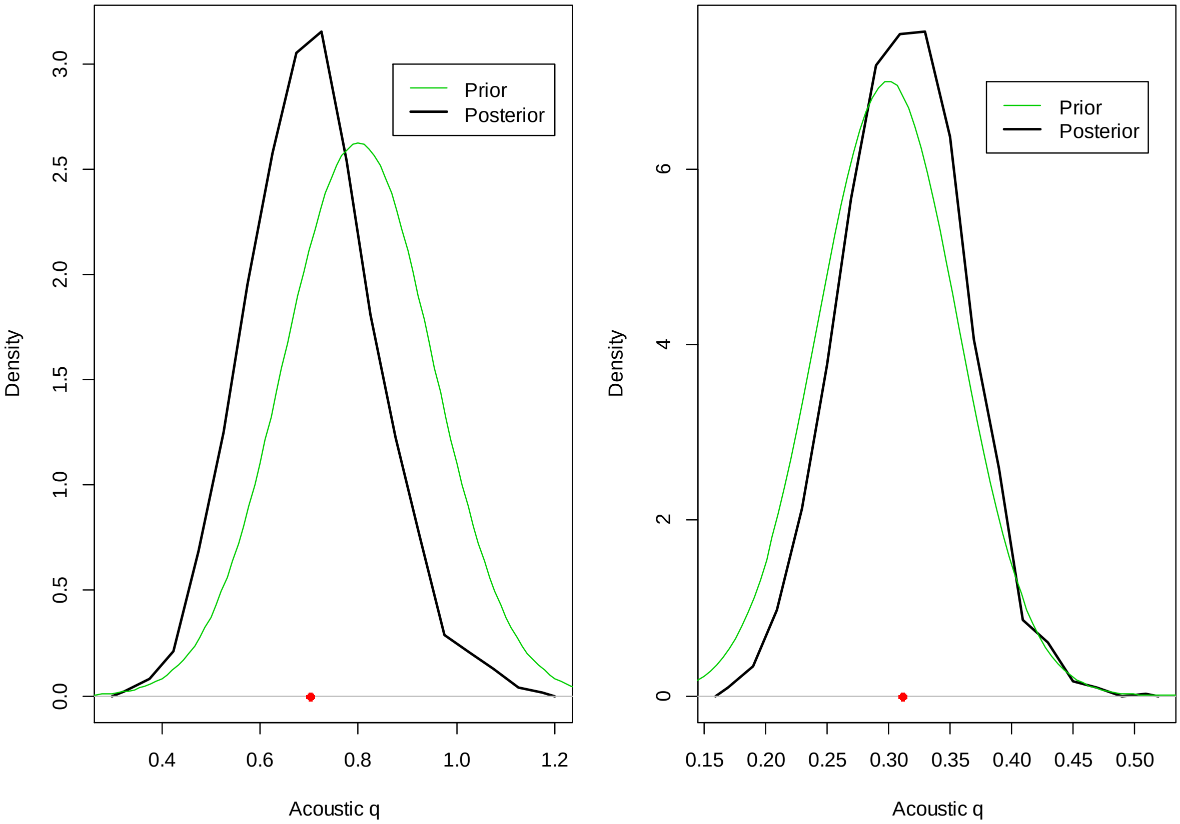

Figure 5: NWCR base, MCMC diagnostics: prior and posterior distributions for the two acoustic *q*s (left, mean *q*-prior = 0.8; right, mean q-prior = 0.3). The red dot shows the median of the posterior.

MCMC Results

For the base model, and the sensitivity runs, MCMC convergence diagnostics were excellent. Virgin biomass, B_0, was estimated to be between 64 000–68 000 t for all runs (Table 6). Current stock status was similar across the base and the first three sensitivity runs (Table 6). The slightly lower stock status when M was estimated reflects the lower estimates of M (0.040 rather than 0.045). 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 outside of the biomass target range of 30–40% B_0 for both runs (Table 6).

Table 6: NWCR, MCMC estimates of virgin biomass (B_0) and stock status (B_{2014} as %B_0) for the base model and five sensitivity runs.

	M	B_0 (000 t)	95% CI	B_{2014} (%B_0)	95% CI
Base	0.045	66	61-76	37	30-46
Extra acoustics	0.045	64	60-69	34	29-41
Estimate M	0.041	68	61-78	34	26-45
Extra & Est. M	0.040	67	60-74	32	25-40
LowM-Highq	0.036	68	64-76	28	23-36
HighM-Lowq	0.054	66	59-78	46	38-56

For the base model, the stock is now 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 30–40% B_0 has been achieved).

The estimated YCS showed little variation across cohorts (Figure 6). The variation in the more recent (true) YCS is due to variation in depletion levels across the MCMC samples (and hence different levels of recruitment were generated from the stock-recruitment function).

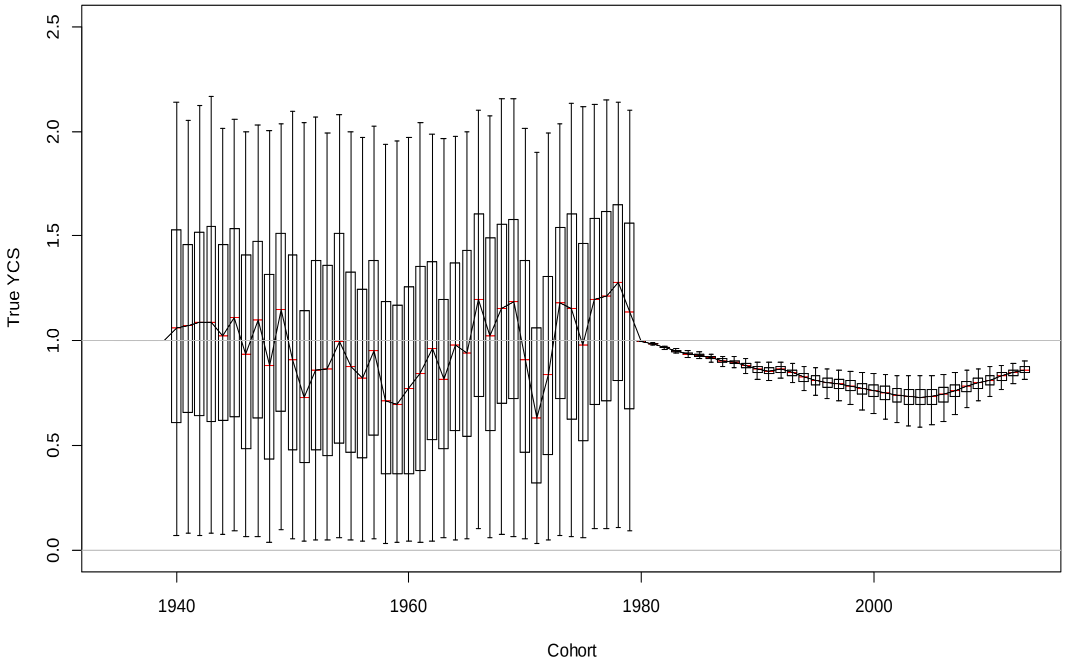

Figure 6: NWCR base, MCMC estimated "true" YCS (R_y/R_0). The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution.

The estimated spawning-stock biomass (SSB) trajectory showed a declining trend from 1980 (when the fishery started) through to 2004 when the biomass was About as Likely as Not (40-60%) to be below the soft limit (Figure 7). Since 2005 the estimated biomass has increased steadily.

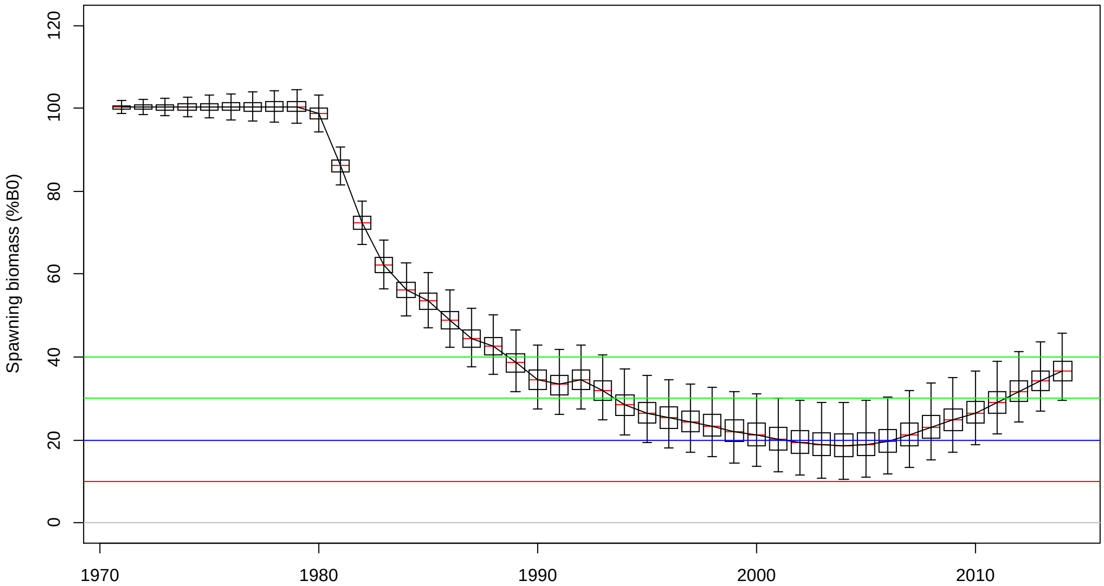

Figure 7: NWCR base, MCMC estimated spawning-stock biomass trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The hard limit (red), soft limit (blue), and biomass target range (green) are marked by horizontal lines.

Fishing intensity was estimated in each year for each MCMC sample to produce a posterior distribution for fishing intensity by year. Fishing intensity is represented in term of the median exploitation rate and the Equilibrium Stock Depletion (ESD). For the latter, a fishing intensity of $U_{x\%B0}$ means that fishing (forever) at that intensity will cause the SSB to reach deterministic equilibrium at x% B_0 (e.g., fishing at $U_{30\%B0}$ forces the SSB to a deterministic equilibrium of 30% B_0). Fishing intensity in these units is plotted as 100–ESD so that fishing intensity ranges from 0 ($U_{100\%B0}$) up to 100 ($U_{0\%B0}$).

Estimated fishing intensity was above $U_{20\%B0}$ for most of the history of the fishery; it was briefly in the target range ($U_{30\%B0}$–$U_{40\%B0}$) from 2006-2010 before dropping substantially when the industry agreed to curtail fishing the NWCR in 2011 (Figure 8).

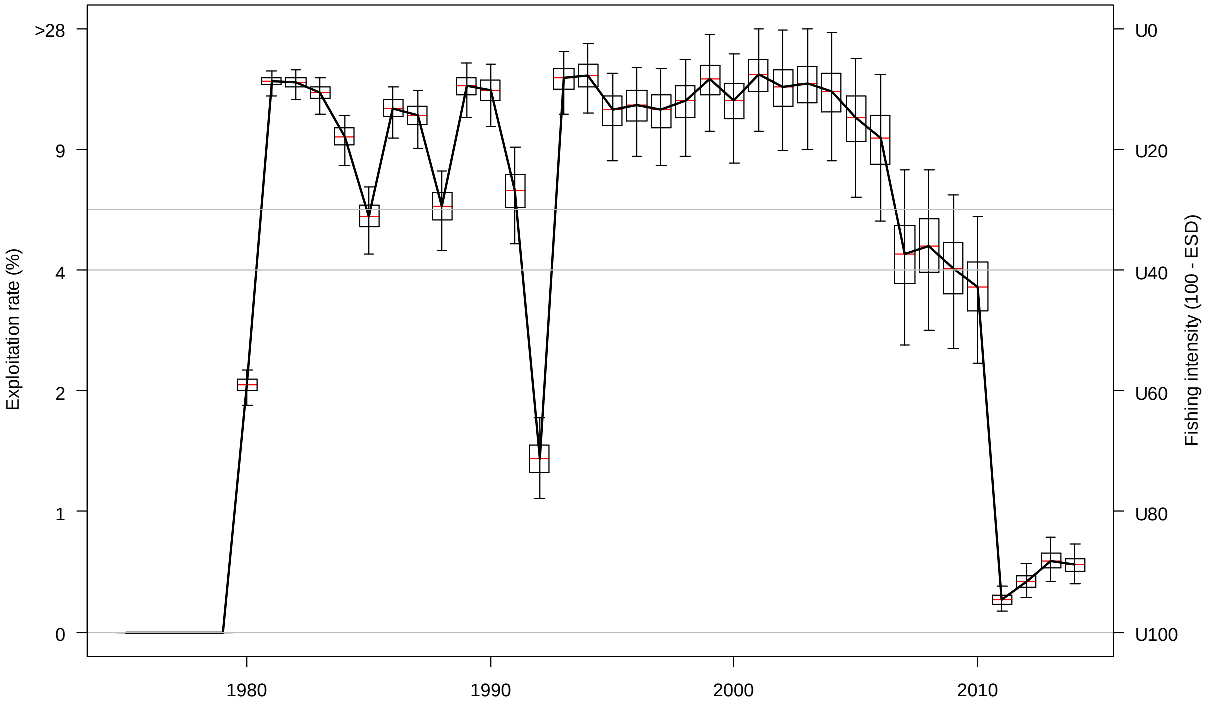

Figure 8: NWCR base, MCMC estimated fishing-intensity trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The fishing-intensity range associated with the biomass target of 30-40% *B*₀ is marked by horizontal lines.

Biological reference points, management targets and yield MCMC estimates of deterministic B_{MSY} and associated values were produced for the base model. The yield at 35% B_0 (the mid-point of the target range) was also estimated. There is very little variation in the reference points and associated values across the MCMC samples (Table 7).

There are several reasons why deterministic B_{MSY} is not a suitable target for use in fisheries management. First, it assumes a harvest strategy that is unrealistic in that it involves perfect knowledge (current biomass must be known exactly in order to calculate the target catch) and annual changes in TACC (which are unlikely to happen in New Zealand and not desirable for most stakeholders). Second, it assumes perfect knowledge of the stock-recruit relationship, which is often poorly known. Third, it would be very difficult with such a low biomass target to avoid the biomass occasionally falling below 20% B_0, the default soft limit according to the Harvest Strategy Standard.

Table 7 : NWCR base, MCMC estimates of deterministic equilibrium SSB and long-term yield (% B_0 and tonnes) for U_{MSY} and $U_{35\%B0}$. The equilibrium SSB at U_{MSY} is deterministic B_{MSY} and the yield is deterministic MSY.

Fishing intensity		SSB (%B_0)	Yield (%B_0)	Yield t)
U_{MSY}	Median	23.7	2.1	1391
	95% CI	23.2-24.7	2.0-2.2	1277–1593
$U_{35\%B0}$	Median	35.0	2.0	1322
	95% CI		1.9-2.1	1214–1512

The estimate of yield associated with $U_{35\%B0}$ for the 2014-15 fishing year is 1414 t (95% CI 1069-1984 t).

Projections

Five year projections were conducted (with resampling from the last 10 estimated YCS) for two different constant catch assumptions: 750 t (the current catch limit); and 1400 t (the current estimated yield at $U_{35\%B0}$). In each case a 5% over-run was assumed. Projections were done for the base model and also for the LowM-Highq model (as a “worst case” scenario).

At the current catch limit (750 t), SSB is predicted to increase over the next five years even for the LowM-Highq model (Figure 9). At the catch associated with $U_{35\%B0}$ (1400 t), SSB is predicted to rise slightly and then stay steady for both models (Figure 10). For both models and both constant catch scenarios, the estimated probability of SSB going below the soft or hard limits is virtually zero (the maximum is 0.01 for the soft limit in the latter years for LowM-Highq at 1400 t).

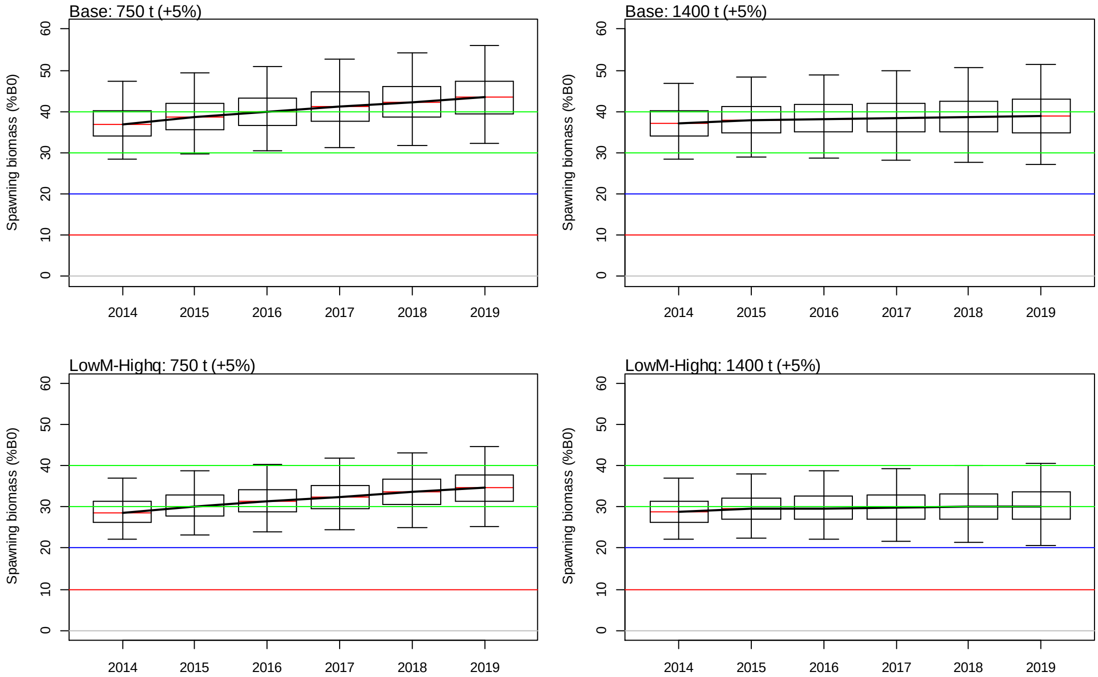

Figure 9: NWCR base, MCMC projections. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The projections are for the model and annual catch indicated (a 5% over-run was included in each year). The target range is indicated by horizontal green lines.

4.2 East and South Chatham Rise

A Bayesian stock assessment was conducted for the East and South Chatham Rise (ESCR) stock in 2014. This used an age-structured population model fitted to acoustic-survey estimates of spawning biomass, trawl-survey biomass indices, age frequencies from spawning aggregations, and length frequencies from trawl surveys and commercial fisheries.

4.2.1 Model structure

The model was single-sex and age-structured (1-100 years with a plus group), with maturity estimated separately (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. These fisheries were chosen following Dunn (2007) who assessed the Box & flats, Eastern hills, and Andes as separate stocks and hence had already prepared length frequency data for those fisheries. 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 catch history was constructed using the catches given in Dunn (2007) from 1979-80 to 2002-2003 and from a new data extract from MPI for 2003-04 to 2012-13 (with total ORH 3B reported catch apportioned across areas using catch proportions from estimated catch on TCEPR forms). The over-run percentages in Table 4 were applied. Natural mortality was assumed fixed at 0.045 and the stock-recruitment relationship was assumed to follow a Beverton-Holt function with steepness of 0.75. The remaining fixed biological parameters are given in Table 2 of the Orange Roughy Introduction section.

In one sensitivity run, which assumed that the spawning plume first found near Rekohu canyon in 2010 had always existed, a spatially-explicit model structure was used. There were four areas to allow for the three known spawning sites (Rekohu, Old-plume[1], the Crack) and an additional area to hold the remaining spawning fish. The areas were only used at (an instantaneous) spawning time to allow the fitting of area-specific data (acoustic estimates and age frequencies). The four year-round fisheries were unchanged.

4.2.2 Input data and statistical assumptions

There were four main data sources for observations fitted in the assessment: acoustic-survey spawning biomass estimates from the Old-plume (2002–2013), Rekohu (2011–2013) and the Crack (2011, 2013); age frequencies from the spawning areas (2012 and 2013); trawl survey biomass indices and length frequencies; and early length frequencies collected from the commercial fisheries.

Acoustic estimates

The Old plume was acoustically surveyed as early as 1996, but the survey estimates are only considered to represent a consistent time series from 2002–2012 (see Cordue 2008; Hampton et al. 2008, 2009, 2010; Doonan et al. 2012). Like the Rekohu plume, that was first noted in 2010 and first surveyed in 2011, the Old plume occurs on an area of flat bottom and can be adequately surveyed using a hull-mounted transducer. In 2011 and 2013, an additional spawning area was surveyed; known as the Crack (also known as Mt. Muck), it is an area of rough terrain which requires a towed-body or trawl-mounted 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 estimates selected by the DWFAWG for use in the stock assessment are shown in Table 8. In 2013 there were a variety of estimates to choose from as surveys were conducted with a hull-mounted system and a multi-frequency AOS system mounted on a trawl net. In order to make the estimates as comparable as possible across years only the 38 kHz estimates were used and those from the hull-mounted system were weather-adjusted in the same way as earlier estimates (see presentations from Kloser and Ryan to the DWFAWG meetings in 2013 and 2014).

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[1] For clarity, what was previously described as the Spawning plume’ located in the Spawning Box has been renamed the ‘Old-plume’ so as to differentiate it from the Rekohu plume, which is also a spawning plume.

Table 8: Acoustic estimates of average pluming spawning biomass in the three main spawning areas as used in the assessment. All estimates were obtained from surveys on *FV San Wataki* from 38 kHz transducers. Each estimate is the average of a number of snapshots as reflected by the estimated CVs.

	Old plume		Rekohu		Crack	
	Estimate (t)	CV (%)	Estimate (t)	CV (%)	Estimate (t)	CV (%)
2002	63 950	6				
2003	44 316	6				
2004	44 968	8				
2005	43 923	4				
2006	47 450	10				
2007	34 427	5				
2008	31 668	8				
2009	28 199	5				
2010	21 205	7				
2011	16 422	8	28 113	18	6 794	21
2012	19 392	7	27 121	10		
2013	16 312	25	29 890	14	5 471	15

A key question that needed to be answered in order to use the acoustic data appropriately is: how long has the Rekohu plume been in existence? If the Rekohu plume has always existed (and was not discovered until 2010) then it would be one of three major spawning sites and could be modelled as such along with the Old plume and the Crack. This would imply that the Old-plume time series was tracking a consistent part of the spawning biomass (and its decline over time was therefore an important indicator of stock status). If, on the other hand, the Rekohu plume had very recently formed, this would imply that the Old-plume time series was a biomass index only up until the year before the Rekohu plume came into existence.

In the base model, it is assumed that the Old-plume time series cannot be relied on to provide a consistent index for any part of the spawning biomass. In 2011 and 2013, the estimates of average spawning biomass across the three areas were summed to form comparable indices for each year. The 2012 estimates from Rekohu and the Old-plume were summed to provide a 2012 index with a different proportionality constant or q than the preceding or following years. 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 qs in the Old-plume series, for the 2012 biomass index and the indices comprising 2011 and 2013 observations.

For 2011 and 2013, 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 orange roughy Introduction). The mean of the q prior for 2012 was derived from the observed biomass proportions across the three areas and the assumption that 80% of the spawning biomass was indexed in 2011 and 2013, which gave a mean of 0.7 for the 2012 index., a reflection that this index did not include an estimate for the Crack. 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. The linear sequence was derived by assuming 0.7 in 2002 (i.e., assuming that the Rekohu plume did not exist and only the Crack was missing from the survey estimate) and using the observed biomass proportions in 2011 with the 80% assumption (which gave the Old-plume being about 25% of the total spawning biomass). To reflect the increased uncertainty in the acoustic qs in years other than 2011 and 2013, the priors were given an increased CV of 30%.

For the sensitivity run where the Rekohu plume was assumed to have always existed, the specification of priors was done by splitting the two parts of the standard acoustic q prior. The proportion of spawning biomass indexed across all three areas combined was assigned a *Beta* (8,2) prior (which has a mean of 0.8). This is the availability part of the standard acoustic q prior. A single q was assumed for the spawning biomass estimates in each area and this was given the target strength part of the standard acoustic q prior (which has a mean of 1).

Trawl survey data

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* (Figure 10). A consistent area was surveyed using fixed station positions (with some random second phase stations each year).

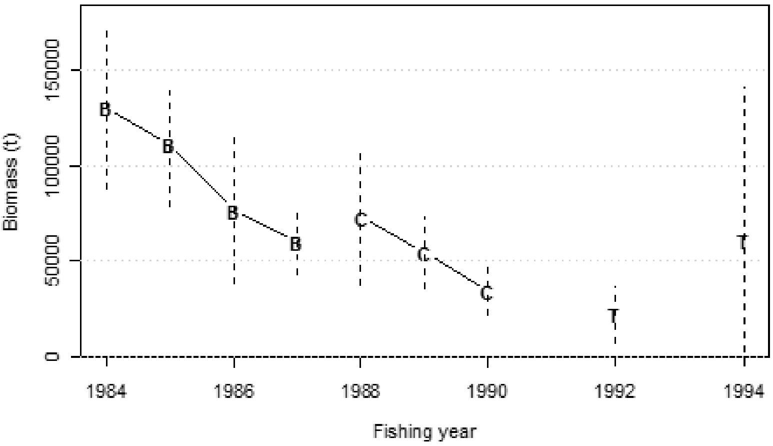


Figure 10: The Spawning Box trawl survey biomass indices (assuming a catchability of 1 for each vessel), with 95% confidence intervals shown as vertical lines. Vessels indicated as B, *FV Otago Buccaneer*; C, *FV Cordella*; T, *RV Tangaroa*.

The biomass indices were fitted as relative indices with a separate time series for each vessel (with uninformed priors on the *q*s). The second point in the Tangaroa time series, although very large (driven by a single high catch), has a large CV and so is unlikely to have had much effect on the assessment results.

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 area surveyed did not include the Old-plume, the Northeast Hills, or the Andes. The survey used a random design over sixteen strata grouped into five sub-areas. The trawl net used was the full-wing and relatively fine mesh ‘ratcatcher’ net. The surveys covered the same survey area as the Spawning Box trawl surveys from 1984 to 1994 as well as additional strata to the east. In 2007, the survey ran from 4–27 July and 62 trawl tows were completed. In 2004, the survey ran from 7–29 July and 57 trawl tows were completed.

The surveys had almost identical estimates of total biomass in each year (17 000 t) with low CVs (10% and 13% respectively). They were fitted as relative biomass with an uninformed prior on the *q*.

Length frequencies

The length frequencies from all of the trawl surveys were fitted in the model as multinomial random variables. Effective sample sizes (N) were taken from Dunn (2007) for the Spawning Box surveys and were assumed equal to the number of tows for the wide-area surveys (across all surveys the effective Ns ranged from about 20–80).

Length frequencies from the commercial fisheries developed by Dunn (2007) were also fitted in the model. These were fitted as multinomial with effective sample sizes ranging from 8–38.

Age frequencies

Age frequencies were developed for the Old-plume and Rekohu plume in 2012 and 2013 and also for the Crack in 2013 (Ian Doonan, NIWA, pers. comm.). Approximately 300 otoliths were randomly selected from each area in 2012 and 250 from each area in 2013. In 2012, the fish in the Old-plume were noted to be generally older than those in the Rekohu plume. This pattern was also apparent in 2013 (Figure 11). The fish from the Crack, showed a mixture of ages from new spawners (20–30 years) through to much older fish (80–100 years) (Figure 11). In the base model, the age frequencies were combined across areas and fitted as multinomial with effective sample sizes of 50 and 60 respectively (reflecting the low number of trawls from which samples were taken).

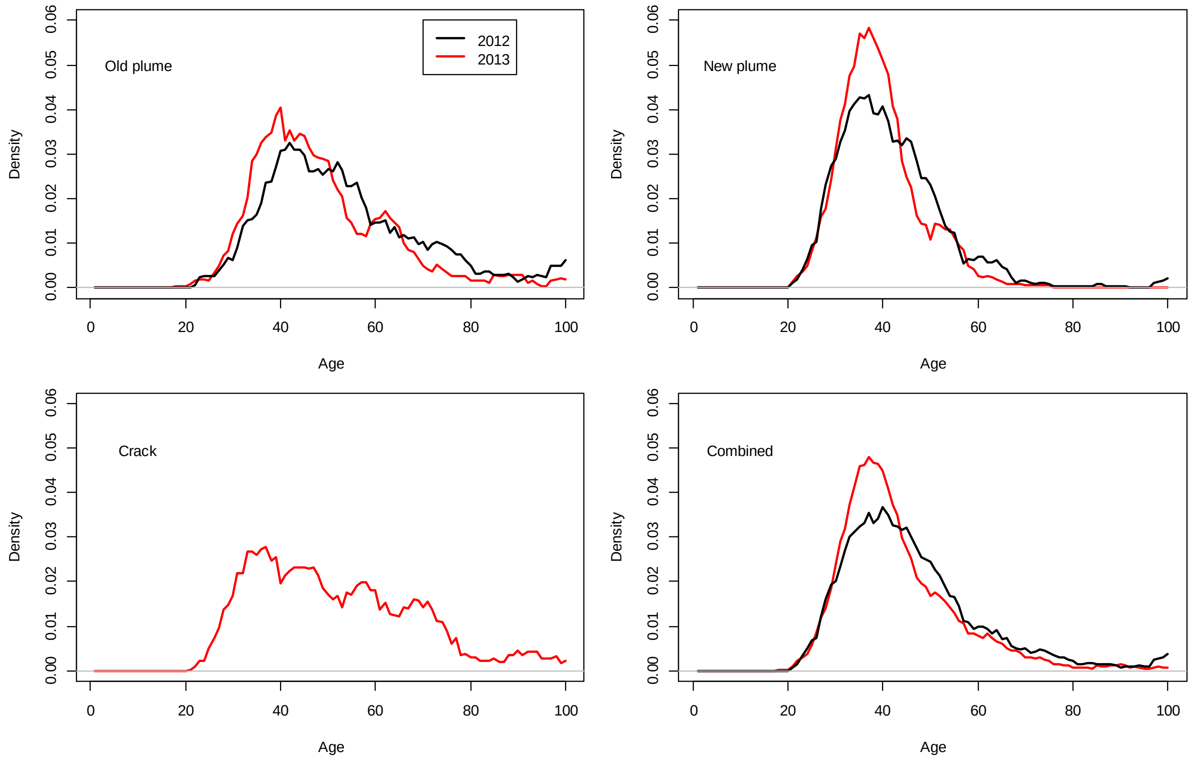


Figure 11: ESCR: *smoothed* spawning season age frequencies for the Old-plume (2012, 2013), Rekohu plume (2012, 2013), the Crack (2013) and for all three areas combined (2012, 2013).

4.2.3 Model runs and results

In the base model, the Old-plume time series was assumed to be unreliable in terms of trend and therefore each point from 2002 to 2010 was given its own *q*; also, natural mortality (*M*) was fixed at 0.045. There were several important sensitivity runs: assume that the Rekohu plume had always existed; assume that it first occurred in 2007; assume it first occurred in 2010; estimate *M*; adjust M and the mean of the priors by 20% (the standard LowM-Highq and HighM-Lowq runs, see orange roughy Introduction).

In the base model, the main parameters estimated were: virgin (unfished, equilibrium) biomass (B_0), maturity ogive, trawl-survey selectivities, fisheries selectivities, CV of length-at-mean-length-at-age for ages 1 and 100 years (linear relationship assumed for intermediate ages), and year class strengths (YCS) from 1930 to 1990 (with the Haist parameterisation and “nearly uniform” priors on the free parameters). There were also the numerous acoustic and trawl-survey *q*s.

Model diagnostics

The base model provided good MPD fits to the data. The MPD fits to the acoustic indices were excellent with normalised residuals all very small (Figure 12). Most of the MPD estimated *q*s were lower than the corresponding means of the priors, but the lowest ratio was only about 0.7 (Figure 12). The posteriors for the acoustic *q*s were shifted to the left of the priors for 2011 & 2013 and also for 2012, but remained well within the prior distribution (Figure 13). For the Old-plume time series, posteriors were sometimes shifted to the left of the priors but also sometimes to the right (e.g., see Figure 13 for 2002 and 2003) and the ratio of the mean of the posterior to the mean of the prior had a limited range from 0.85 (2003) to 1.2 (2006). The normalised residuals of the acoustic indices for the base MCMC model were also excellent, showing no apparent trend (Figure 14).

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 15). Also, the model does not fit the very large increase in the *Tangaroa* Spawning Box survey (Figure 15).

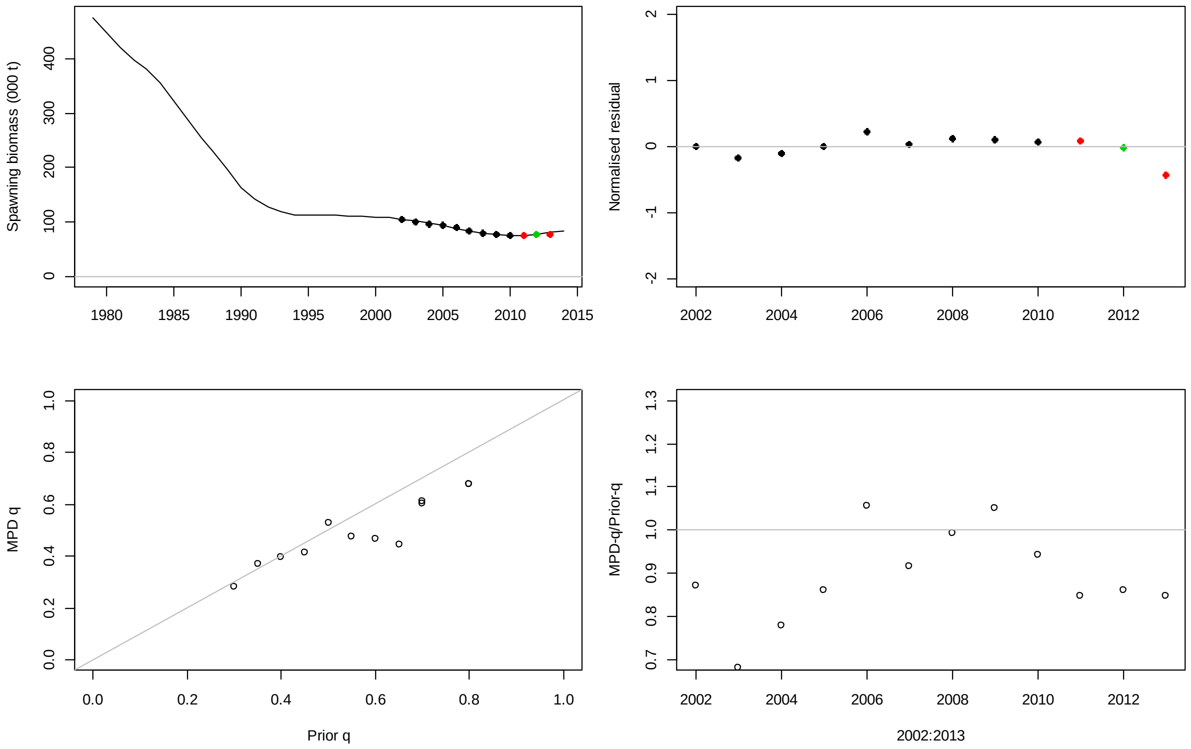


Figure 12: ESCR, MPD, base: fit to the acoustic indices: (top) spawning biomass trajectory and unscaled acoustic indices; normalised residuals; (bottom) estimated *q*s as a function of the mean of the *q* prior; the ratio of the estimated *q* to the mean of the *q* prior.

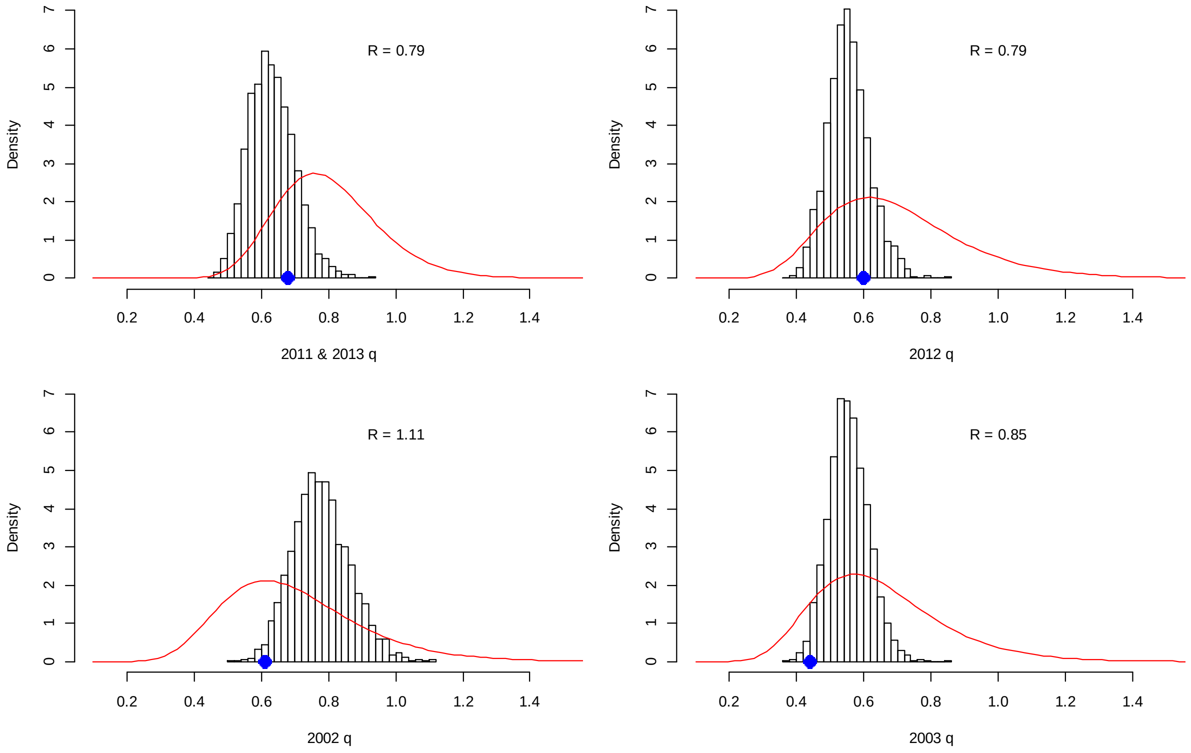


Figure 13: ESCR, MCMC base: prior (in red) and posterior distributions for a selection of acoustic *q*s. The blue dot is the MPD estimate and R is the ratio of the mean of the posterior to the mean of the prior.

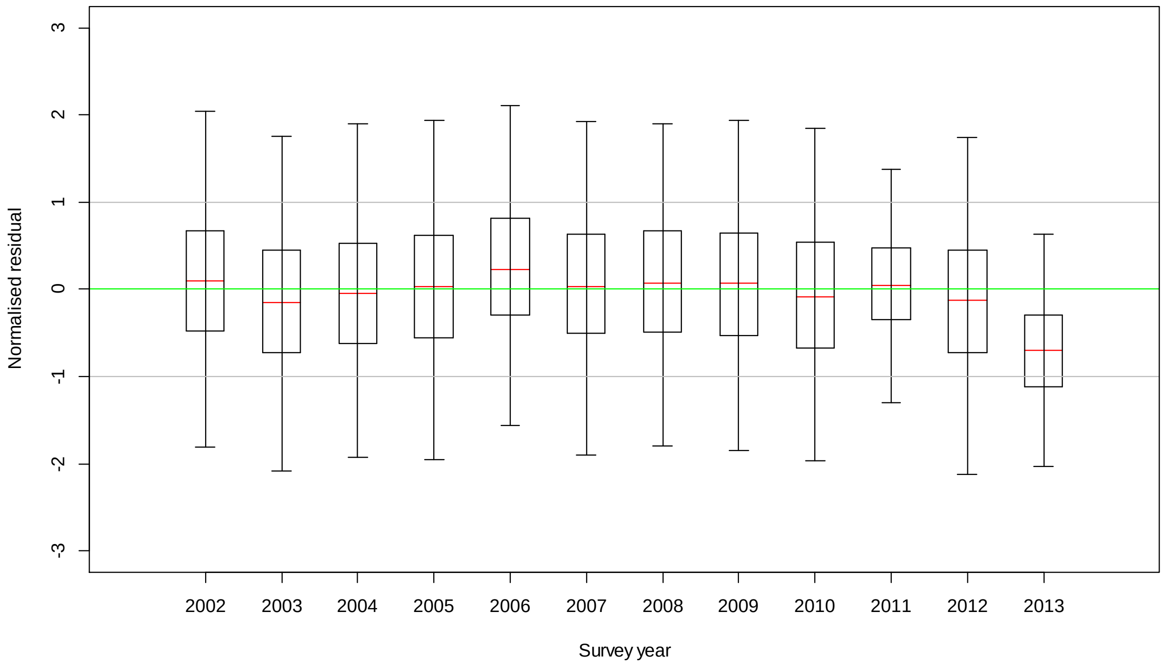


Figure 14: ESCR, MCMC base: normalized residual for the acoustic indices. The box covers 50% of the distribution for each index and the whiskers extend to 95% of the distribution.

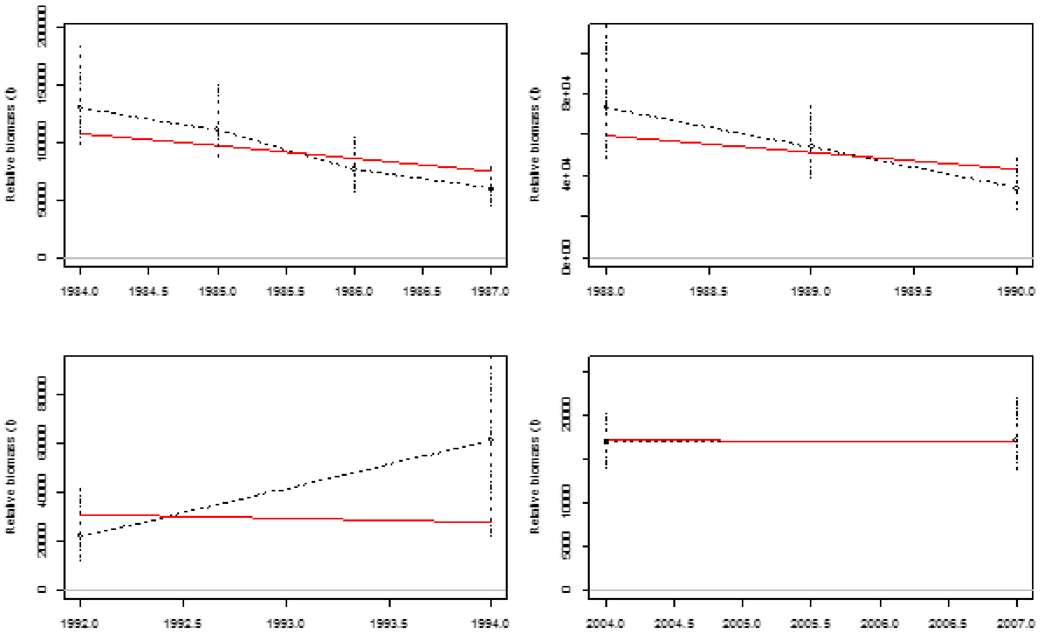


Figure 15: ESCR, MPD base: fits (in red) to the trawl-survey biomass indices (from top to bottom and left to right: *Buccaneer, Cordella, Tangaroa,* wide-area *Tangaroa*).

The fits to the age frequencies are as good as can be expected given the inconsistent shape of the age frequencies in the two consecutive years (Figure 16). The inconsistency is not caused by having the Crack included in 2013 and not 2012; the problem is too many 30-40 year old fish in 2013 (whereas the Crack had a wide mix of ages).

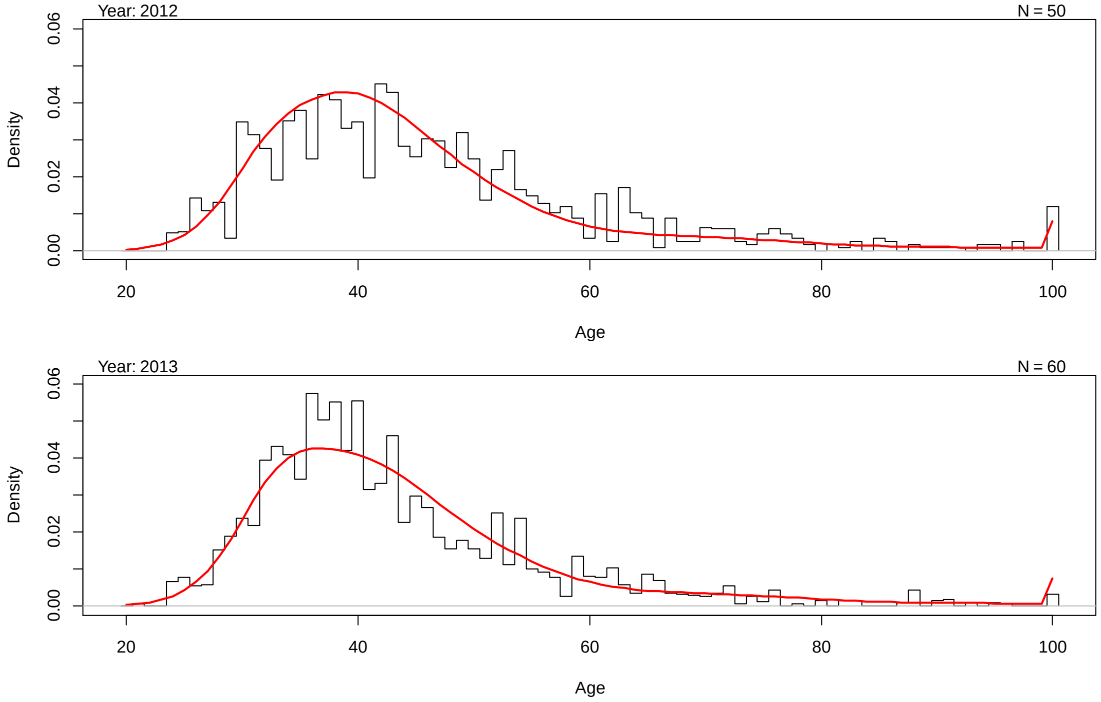


Figure 16: ESCR, MPD base: fits (in red) to the spawning season age frequencies. N is the effective sample size.

The MPD fits to the commercial length frequencies were excellent except the 1990 Box and flats length frequency (see Figure 17). Likewise the fits to the trawl survey length frequencies were excellent (e.g., see Figure 18). The long tail to the left, which was present in all of the trawl-survey length frequencies from the Spawning Box, was easily fitted in the 2014 models, as selectivities were fitted for mature and immature fish. The three Spawning Box trawl surveys all had a common immature selectivity which allowed a small proportion of the immature fish to be selected (and hence to fit the left-hand tail). The *Tangaroa* wide-area trawl survey also had separate mature and immature selectivities which allowed a much larger proportion of immature fish to be selected and hence allowed a very good fit to the broad mode of the length frequencies (Figure 18).

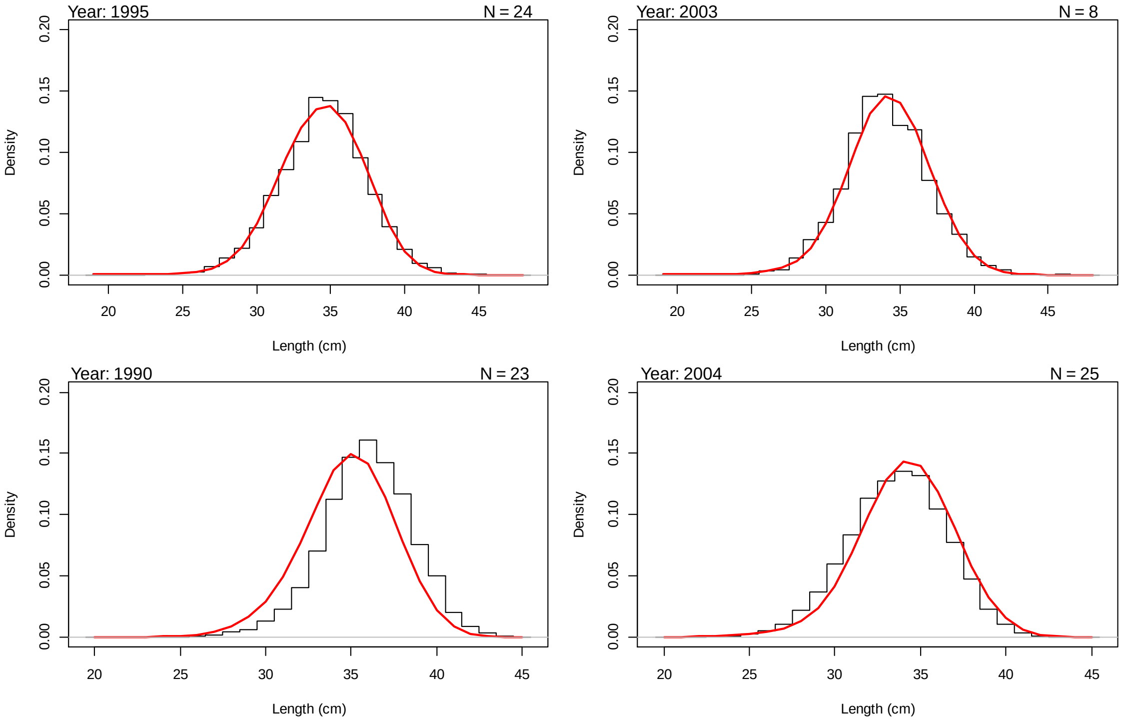


Figure 17: ESCR, MPD base: fits (in red) to the commercial length frequencies for the Eastern hills (top) and the Box and flats (bottom). N is the effective sample size.

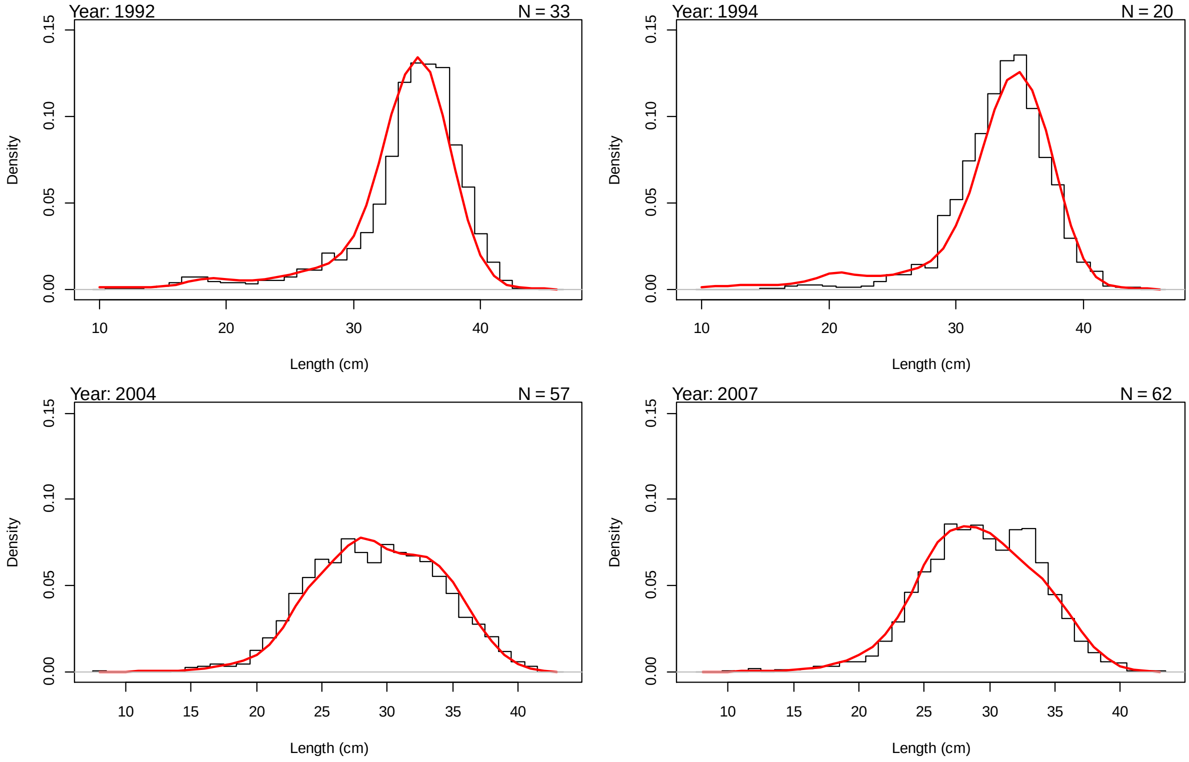


Figure 18: ESCR, MPD base: fits (in red) to the *Tangaroa* length frequencies for the Spawning Box (top) and the wide-area surveys (bottom). N is the effective sample size.

Numerous sensitivity runs were conducted at the MPD stage. Model estimates were robust to changes in effective sample sizes for composition data. The model was also robust to changes in M (0.03, 0.06 compared to base of 0.045) or changes in the mean of the acoustic q priors for 2011 & 2013 (0.6, 0.9 compared to base of 0.8). Major differences in the MPD estimate of current stock status occurred when the acoustic indices were halved or doubled, also and when deterministic recruitment was assumed (respectively: 14% B_0, 39% B_0, and 35% B_0, compared to the base estimate of 24% B_0).

The sensitivities that explored the timing of the appearance of the Rekohu plume provided another validation for the robustness of the base model estimates. The “Always” model (which assumed that the Rekohu plume had always existed) provided an adequate fit to the data, but the results lacked credibility in three respects: (i) the posterior distribution for the acoustic q was pushed a long way to the right of the prior (Figure 19), (ii) as was the posterior for the proportion of spawning biomass being indexed by the three spawning areas combined (Figure 19), and (iii) the model estimated that the Rekohu plume had contained over 100,000 t of spawning biomass up until the early 1980s (Figure 20), which seemed unlikely, given the high level of fisheries exploration at that time (it also seemed unlikely that the fleet would have missed the 40-50,000 t estimated to have existed in the early 1990s when the spawning box (Old plume) was closed and the fleet may have been actively searching for other aggregations). These three factors combined caused the DWFAWG to conclude that the “Always” run was not a credible alternative to the base model.

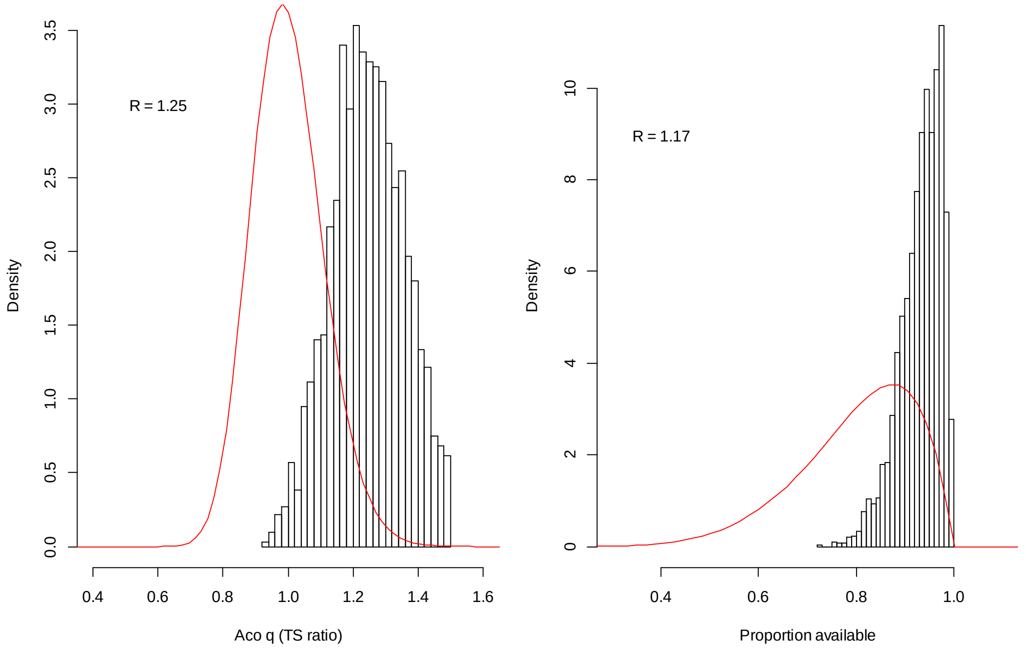


Figure 19: ESCR, MCMC: "Always" sensitivity run: prior (in red) and posterior distributions for the acoustic *q* (left) and the proportion of spawning biomass available to the Old-plume, Rekohu plume, and the Crack combined (right). R is the ratio of the mean of the prior to the mean of the prior.

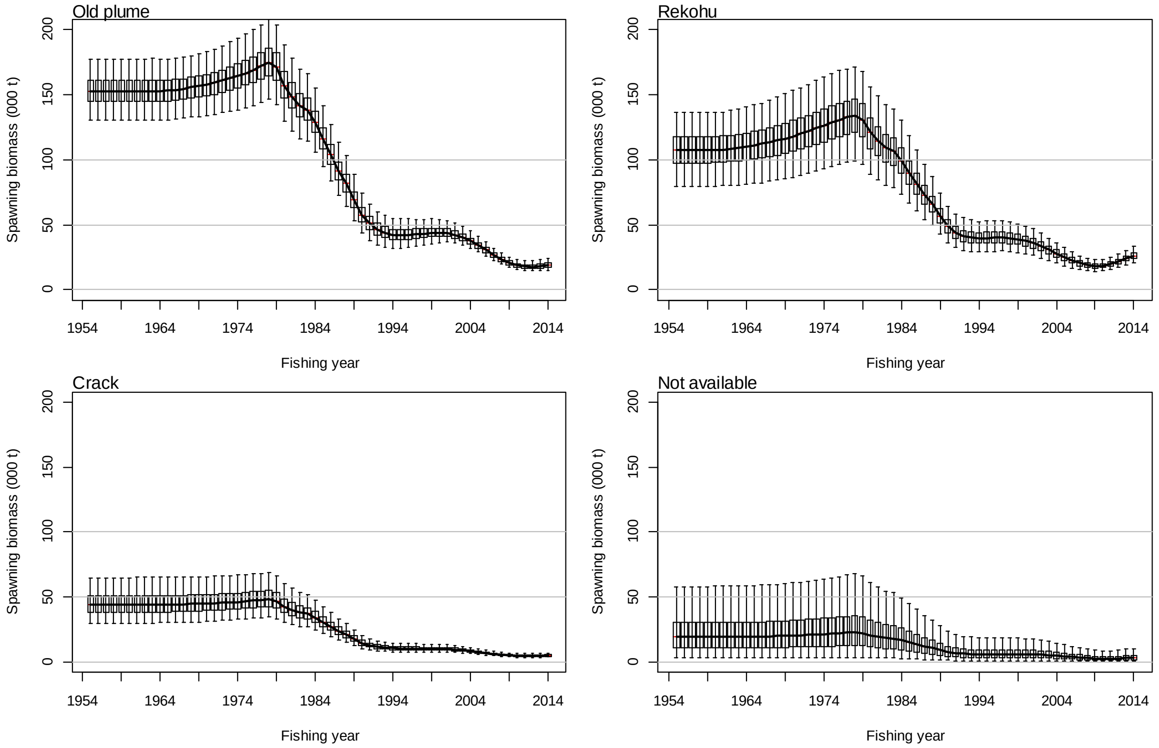


Figure 20: ESCR, MCMC: "Always" sensitivity model: spawning biomass trajectories for each area in the model including the Rekohu plume which is assumed, in this run, to have always existed. The box covers 50% of the distribution in each year and the whiskers extend to 95% of the distribution.

The sensitivities that assumed the first occurrence of the Rekohu plume in 2007 or 2010 were also critically examined to see if they were able to adequately explain the data, as well as being consistent with other ancillary information. It was found that a creation year of 2010 did not allow enough time for the Rekohu plume to build up to the levels of biomass observed in 2011 (unless fish spawning outside the three surveyed areas suddenly began joining the Rekohu plume, another assumption thought unlikely by the DWFAWG). However, a creation year of 2007 did provide sufficient time to allow for the Rekohu plume to build up to the size observed in 2011, without the need to assume that existing spawning fish would change their spawning sites. The Rekohu 2007 model also fitted the data adequately. The Rekohu 2007 model was taken through to MCMC but it was not considered as a base model because there was no evidence to support the assumption that the Rekohu plume first occurred in 2007.

MCMC results

For the base model, MCMC convergence diagnostics were adequate once the three chains (with random starting values near the MPD estimate) had been run for 15 million iterations. These chains were much longer than those normally required and it appeared that the slow convergence was due to a high correlation between B_0 and the age at 50% maturity. Some technical changes were made to improve chain convergence; they were successful and gave identical results to the base model without the changes. The technical changes were used in the sensitivity runs to avoid running chains out to 15 million.

Virgin biomass, B_0, was estimated to be about 320,000 t for the base model with median estimates ranging from 310,000–360,000 t for the four sensitivity runs presented (Table 9). Current stock status was similar across the base and the first two sensitivity runs (Table 9). The lower stock status when *M* was estimated reflects the lower estimates of *M* (0.036 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 well below the biomass target range of 30–40% B_0 for the pessimistic *LowM-Highq* run and primarily within the target range for the optimistic *HighM-Lowq* run (Table 9).

Table 9: ESCR, MCMC estimates of virgin biomass (B_0) and stock status (B_{2014} as %B_0) for the base model and four sensitivity runs.

	M	B_0 (000 t)	95% CI	B_{2014} (%B_0)	95% CI
Base	0.045	320	280-350	30	25-34
Estimate M	0.036	360	300-410	26	20-32
Rekohu 2007	0.045	310	280-340	26	22-30
LowM-Highq	0.036	340	320-370	22	19-26
HighM-Lowq	0.054	310	280-350	38	32-43

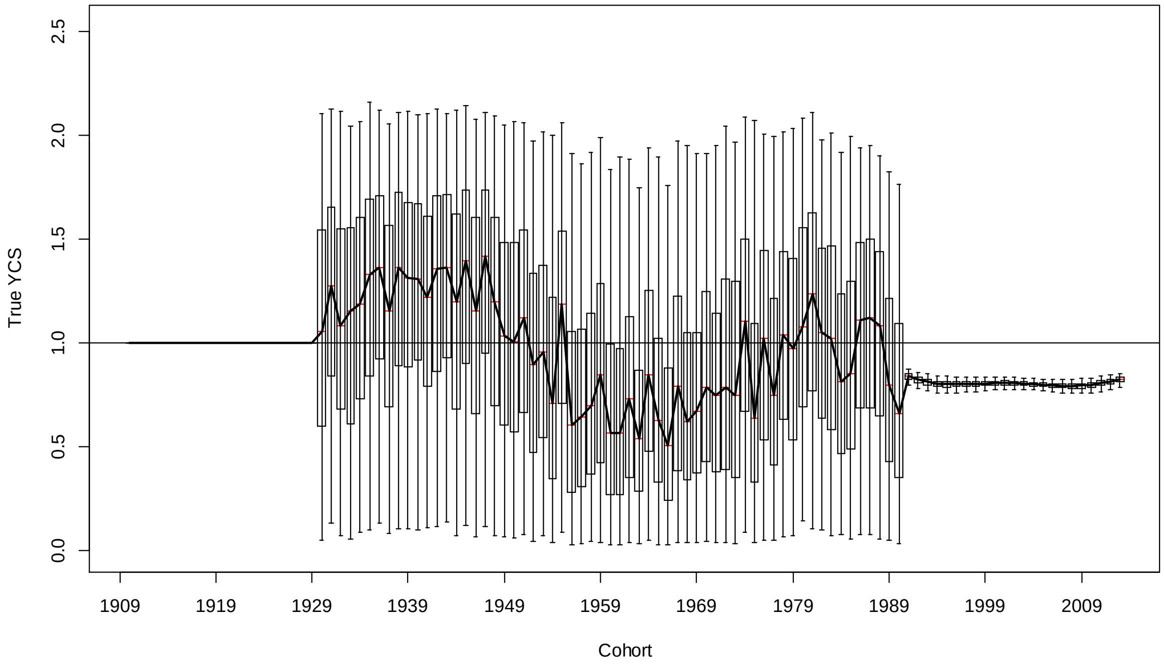


Figure 21: ESCR base, MCMC estimated “true” YCS (R_y/R_0). The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution.

The estimated YCS show little variation across cohorts but do exhibit a long-term trend (Figure 21). The most recent 10 years of estimates (those resampled for short-term projections) are a little above average.

The stock status trajectory shows a steady decline from the start of fishery until the mid 1990s where it remains in the 20-30% range until an upturn in about 2010 (Figure 22)

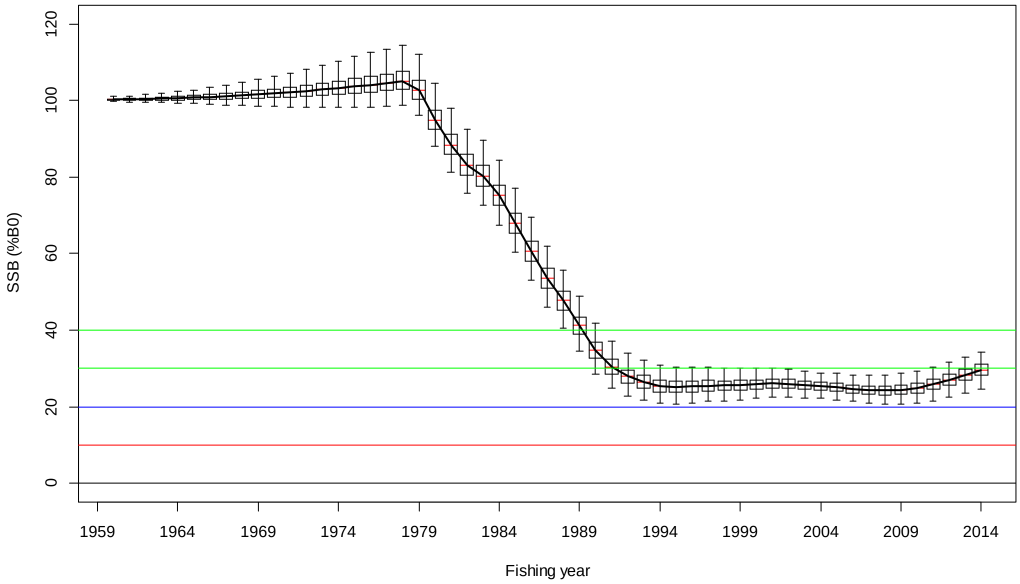


Figure 22: ESCR base, MCMC estimated spawning-stock biomass trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The hard limit 10% B_0 (red), soft limit 20% B_0 (blue), and biomass target range 30–40% B_0 (green) are marked by horizontal lines.

Fishing intensity was estimated in each year for each MCMC sample to produce a posterior distribution for fishing intensity by year. Fishing intensity is represented in term of the median exploitation rate and the Equilibrium Stock Depletion (ESD). For the latter, a fishing intensity of $U_{x\%B0}$ means that fishing (forever) at that intensity will cause the SSB to reach deterministic equilibrium at x% B_0 (e.g., fishing at $U_{30\%B0}$ forces the SSB to a deterministic equilibrium of 30% B_0). Fishing intensity in these units is plotted as 100–ESD so that fishing intensity ranges from 0 ($U_{100\%B0}$) up to 100 ($U_{0\%B0}$).

Estimated fishing intensity was within or above the target range ($U_{30\%B0}$–$U_{40\%B0}$) for most of the history of the fishery; it has been below the target range since 2010 (Figure 23).

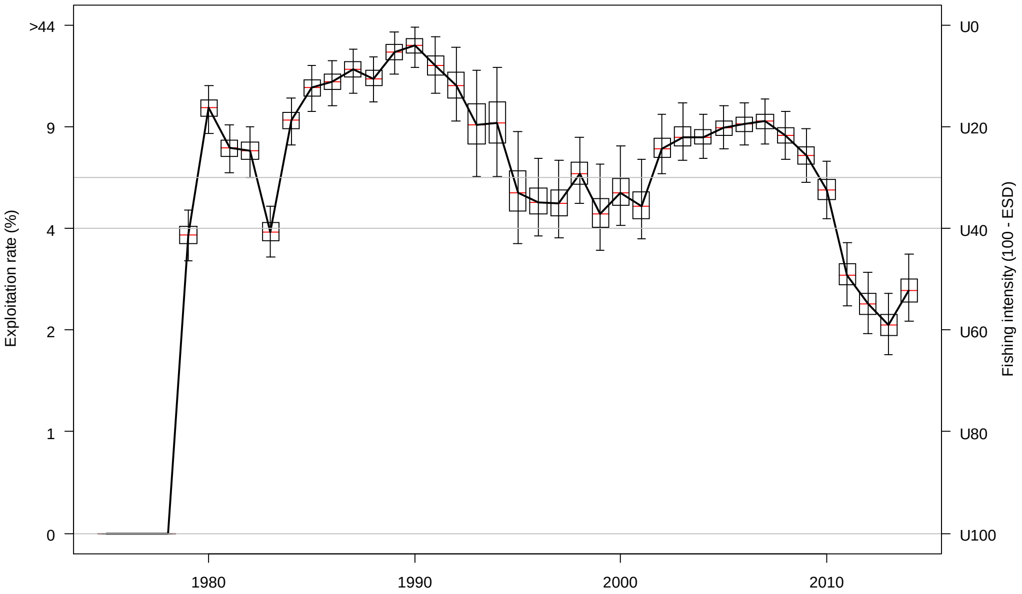


Figure 23: ESCR base, MCMC estimated fishing-intensity trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The fishing-intensity range associated with the biomass target of 30–40% B_0 is marked by horizontal lines.

Biological reference points, management targets and yield

MCMC estimates of deterministic B_{MSY} and associated values were produced for the base model. The yield at 35% B_0 (the mid-point of the target range) was also estimated. There is little variation in the reference points and associated values across the MCMC samples (Table 10).

There are several reasons why deterministic B_{MSY} is not a suitable target for use in fisheries management. First, it assumes a harvest strategy that is unrealistic in that it involves perfect knowledge (current biomass must be known exactly in order to calculate the target catch) and annual changes in TACC (which are unlikely to happen in New Zealand and not desirable for most stakeholders). Second, it assumes perfect knowledge of the stock-recruit relationship, which is often poorly known. Third, it would be very difficult with such a low biomass target to avoid the biomass occasionally falling below 20% B_0, the default soft limit according to the Harvest Strategy Standard.

Table 10: ESCR base, MCMC estimates of deterministic equilibrium SSB and long-term yield (% B_0 and tonnes) for U_{MSY} and $U_{35\%B0}$. The equilibrium SSB at U_{MSY} is deterministic B_{MSY} and the yield is deterministic MSY.

Fishing intensity		SSB (%B_0)	Yield (%B_0)	Yield (t)
U_{MSY}	Median	21.8	2.4	7716
	95% CI	20.2-23.4	2.3-2.7	7264–8237
$U_{35\%B0}$	Median	35.0	2.3	7175
	95% CI		2.1-2.5	6740–7666

Projections

Five year projections were conducted (with resampling from the last 10 estimated YCS) for two different constant catch assumptions: 3100 t (the current catch limit); and 6400 t (the current estimated yield at $U_{35\%B0}$). In each case a 5% catch over-run was assumed. Projections were done for the base model and also for the LowM-Highq model (as a “worst case” scenario).

At the current catch limit (3100 t), SSB is predicted to increase steadily over the next five years for both models (Figure 24). At the catch associated with $U_{35\%B0}$ (6400 t), SSB is predicted to rise slightly for both models (Figure 24). For both models and both constant catch scenarios the estimated probability of SSB going below the hard limit is zero over the next five years. There is also zero probability for the base model of going below 20% B_0 under either catch scenario. For the LowM-Highq model there is a small but non-zero probability that the SSB is already below 20% in 2014 but this decreases over time for both catch scenarios (Figure 24).

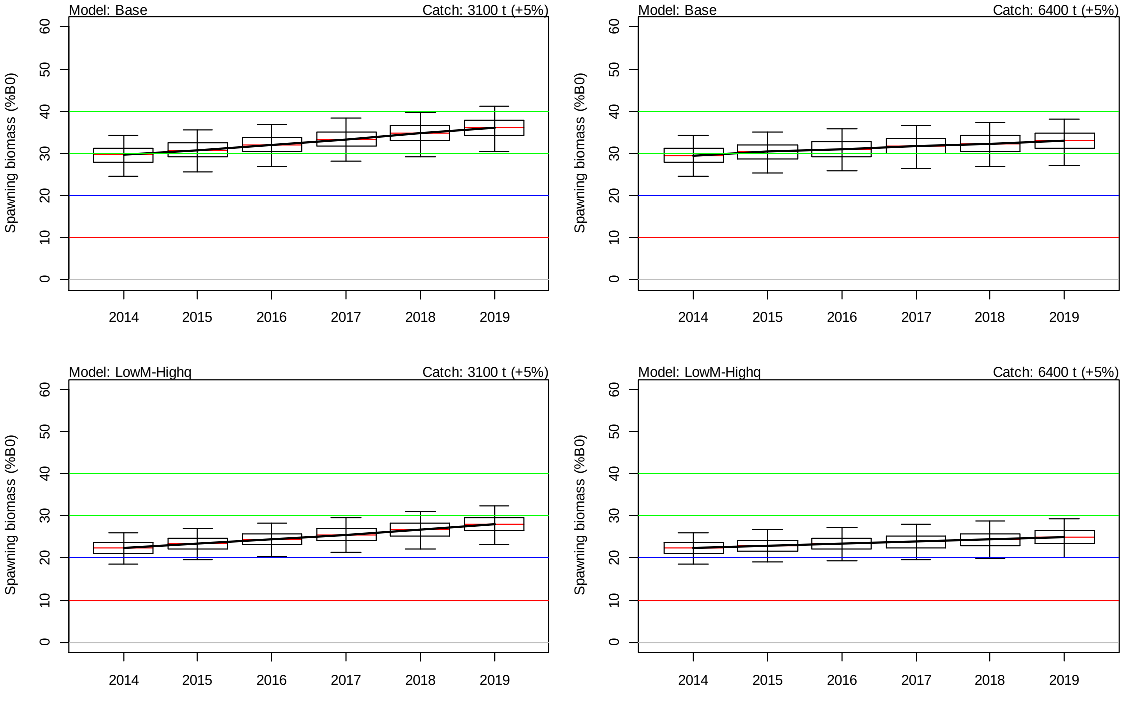


Figure 24: ESCR base, MCMC projections. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The projections are for the model and annual catch indicated (a 5% catch over-run was included in each year). The 30–40% B_0 target range is indicated by horizontal green lines and the hard limit 10% B_0 and soft limit 20% B_0 by red and blue lines respectively.

5. STATUS OF THE STOCKS

For orange roughy stocks, the management target is a biomass range from 30–40% B_0.

5.1 Chatham Rise

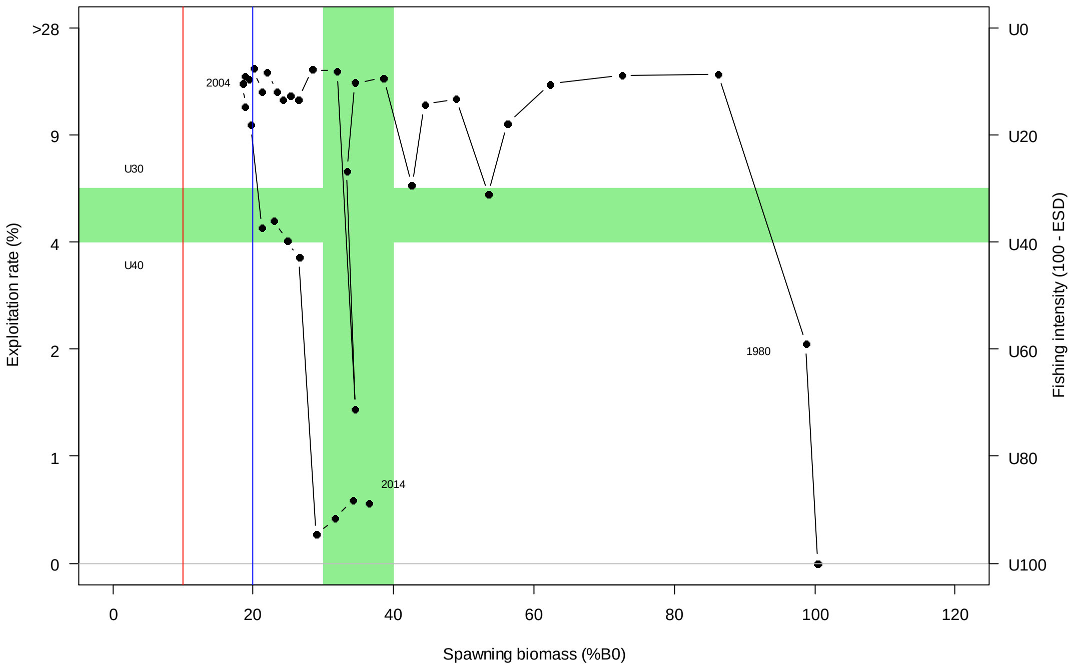
Stock Structure Assumptions

Chatham Rise orange roughy are believed to comprise two biological stocks; these are assessed and managed separately: one on the Northwest of the Chatham Rise and the other ranging throughout the East and South Rise. This assumed stock structure is based on the presence of two main areas where spawning takes place simultaneously, and observed and inferred migration patterns of adults and juveniles. These two biological stocks form the bulk of the ORH 3B Fishstock. They are geographically separated from all other ORH 3B biological stocks.

Northwest Chatham Rise

Stock Status	
Year of Most Recent Assessment	2014
Assessment Runs Presented	Base model only
Reference Points	Management Target: Biomass range 30–40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: Fishing intensity range $U_{30\%B0}$–$U_{40\%B0}$
Status in relation to Target	B_{2014} was estimated at 37% B_0. Likely (> 60%) to be at or above the lower end of the management target range
Status in relation to Limits	B_{2014} is Very Unlikely (< 10%) to be below the Soft Limit B_{2014} is Exceptionally Unlikely (< 1%) to be below the Hard Limit
Status in relation to Overfishing	Fishing intensity in 2014 was estimated at $U_{89\%B0}$ Overfishing is Exceptionally Unlikely (< 1%) to be occurring

Historical Stock Status Trajectory and Current Status



Historical trajectory of spawning biomass (%B_0), median exploitation rate (%) and fishing intensity (100-ESD) (base model, medians of the marginal posteriors). The biomass target range of 30-40 % B_0 and the corresponding exploitation rate range are marked in green. The soft limit (20% B_0) is marked in blue and the hard limit (10% B_0) in red. Note that the Y-axis is non-linear.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass reached its lowest point in 2004 and has increased consistently since then. According to the Harvest Strategy Standard, the stock is now considered to be fully rebuilt (at least a 70% probability that the lower end of the management target range of 30–40% B_0 has been achieved).
Recent Trend in Fishing Intensity or Proxy	Fishing intensity decreased sharply from 2010 to 2011 and has remained well below the overfishing threshold since then.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Biomass is expected to increase or stay steady over the next 5 years at annual catches of up to 1400 t.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	At both current catch (110 t) or current catch limit (750 t): Soft Limit: Very Unlikely (< 10%) Hard Limit: Exceptionally Unlikely (< 1%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	At current catch: Exceptionally Unlikely (< 1%) At current catch limit: Very Unlikely (< 10%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full quantitative stock assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2014	Next assessment: unknown
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	-Acoustic estimates of spawning biomass on Graveyard (1999, 2012-13) and Morgue (1999, 2012).	1 – High Quality
	-Trawl survey age frequency and proportion-spawning-at-age (1994).	1 – High Quality
	-17 years of length frequency data.	1 – High Quality
Data not used (rank)	-CPUE	3 – Low Quality: unlikely to be indexing stock-wide abundance
	-Trawl surveys of hills (1990-2002)	3 – Low Quality: unlikely to be indexing stock-wide abundance
	-Wide-area acoustic survey estimates	2 – Medium or Mixed Quality: large potential bias due to mixed-species
	-Chatham Rise trawl survey deepwater stations (2010-2014)	2 – Medium or Mixed Quality: variable indices
	-Egg survey estimate	3 – Low Quality: survey design assumptions not met

Changes to Model Structure and Assumptions	The previous assessment was in 2006. -Model now based on spawning biomass rather than transition-zone mature biomass. -Age data included to enable estimation of year class strengths rather than assuming deterministic recruitment. - A more stringent data quality threshold was imposed on data inputs (e.g., CPUE indices not used, egg survey and wide-area acoustic estimates also excluded).
Major Sources of Uncertainty	-The largest source of uncertainty is the proportion of the NWCR spawning stock that is indexed by the acoustic survey in each year. -Patterns in year class strengths are based on only one year of age composition data. -The time series of abundance indices is short and restricted to the period of lower stock status.

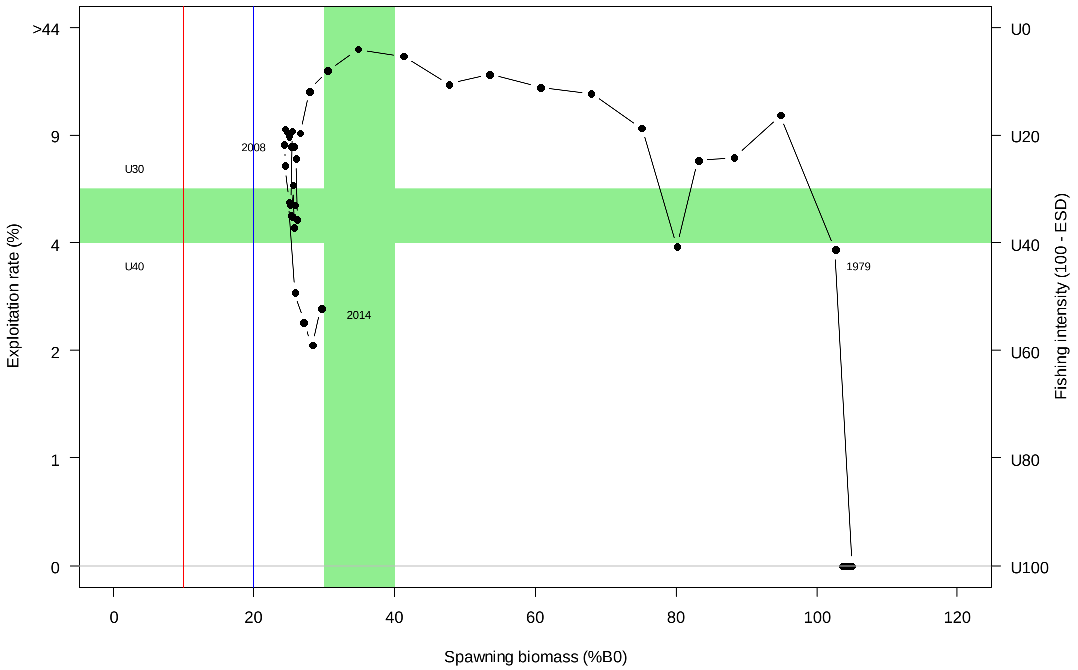
Qualifying Comments
Estimates of stock biomass are sensitive to the means of the *q* priors. In addition, when higher CVs were used for the informed acoustic *q* priors, the median estimates of biomass and stock status were slightly higher and the confidence intervals were wider with a much higher upper bound.

Fishery Interactions
Main bycatch species are smooth oreo, black oreo, rattails, deepwater dogfish and hoki, with lesser bycatches of Johnson’s cod and ribaldo. Low productivity bycatch species include deepwater sharks, skates and corals. Overall, bycatch usually comprises about 20% of the total catch. Observed incidental captures of protected species include corals, low numbers of seabirds and occasional NZ fur seals.

East and South Chatham Rise

Stock Status	
Year of Most Recent Assessment	2014
Assessment Runs Presented	Base model only
Reference Points	Management Target: Biomass range 30–40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: Fishing intensity range $U_{30\%B0}$–$U_{40\%B0}$
Status in relation to Target	B_{2014} was estimated to be 30% B_0 About as Likely as Not (40–60%) to be at or above the lower end of the management target range
Status in relation to Limits	B_{2014} is Unlikely (< 40%) to be below the Soft Limit B_{2014} is Very Unlikely (< 10%) to be below the Hard Limit
Status in relation to Overfishing	Fishing intensity in 2014 was estimated at $U_{52\%B0}$ Overfishing is Very Unlikely (< 10%) to be occurring

Historical Stock Status Trajectory and Current Status



Historical trajectory of spawning biomass (%B_0), median exploitation rate (%) and fishing intensity (100-ESD) (base model, medians of the marginal posteriors). The biomass target range of 30-40 % B_0 and the corresponding exploitation rate range are marked in green. The soft limit (20% B_0) is marked in blue and the hard limit (10% B_0) in red. Note that the Y-axis is non-linear.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	The spawning biomass is estimated to have been slowly increasing over the last four years.
Recent Trend in Fishing Intensity or Proxy	Fishing intensity (exploitation rate) is estimated to have been below the lower end of the target range in the last four years.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Biomass is expected to increase or stay steady over the next 5 years at annual catches of up to 6400 t.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	At current catch or catch limit (3100 t) Soft Limit: Unlikely (< 40%) Hard Limit: Very Unlikely (< 10%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full quantitative stock assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2014	Next assessment: 2015
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	-Four short time series of biomass indices from research trawl surveys -Acoustic indices from research surveys of spawning plumes (Old-plume, Rekohu plume, Crack)	1 – High Quality 1 – High Quality

	-Age frequencies from the spawning plumes in 2012 and 2013 -Length frequencies from commercial fisheries	1 – High Quality 1 – High Quality
Data not used (rank)	-CPUE -Acoustic surveys of hills (hull-mounted transducers) -Wide-area acoustic survey estimates -CR deepwater trawl survey stations (2010-2014)	3 – Low Quality: unlikely to be indexing stock-wide abundance 3 – Low Quality: major species identification and dead zone issues 2 – Medium or Mixed Quality: large potential bias due to mixed-species 2 – Medium or Mixed Quality: variable indices
Changes to Model Structure and Assumptions	The most recent model-based assessment was in 2006. Subsequent assessments have been based on an expert assessment of data, principally acoustic biomass estimates. -The current assessment is fully quantitative and based on spawning biomass rather than transition-zone mature biomass. -Age data have been included to enable estimation of year class strengths rather than assuming deterministic recruitment. - A more stringent data quality threshold was imposed on data inputs (e.g. CPUE indices and wide-area acoustic estimates not used)	
Major Sources of Uncertainty	-The largest source of uncertainty is the proportion of the ESCR spawning stock that is indexed by the acoustic survey in each year. -Stock status is dependent on the timing of the appearance of the Rekohu spawning plume, which is unknown. -Patterns in year class strengths are based on only 2 years of age composition data.	

Qualifying Comments
-Estimates of stock biomass are sensitive to the means of the *q* priors. In addition, when higher CVs were used for the informed acoustic *q* priors, the median estimates of biomass and stock status were slightly higher and the confidence intervals were wider with a much higher upper bound. -There were some concerns about a potential lack of convergence in the MCMCs.

Fishery Interactions
Main bycatch species are smooth oreo, black oreo, deepwater dogfish, hoki and rattails, with lesser bycatches of slickhead, Johnson’s cod and morids. Low productivity bycatch species include deepwater sharks and dogfish and also corals. Overall, bycatch usually comprises about 25% of the total catch, the majority of which are QMS species. Observed incidental captures of protected species include corals, low numbers of seabirds and occasional NZ fur seals.

5.2 Southern ORH 3B fisheries

Puysegur

The 1998 assessment for this stock (Annala et al 1998) was uncertain because the three time series of biomass indices on which it was based are all very short. However, all three series (two of trawl surveys and one of CPUE) suggested that the biomass was reduced substantially up to 1998. The point estimate of biomass from this assessment was probably below B_{MSY}, but it was uncertain. Estimates of *MCY* and *CAY* were 420 t or less. The fishery was voluntarily closed in 1997–98 in order to maximise the rate of rebuilding. It was re-opened in 2010–11 with a catch limit of 150 t (Table 3).

Auckland Islands (Pukaki South)

The Deepwater Working Group examined the data on orange roughy catch and effort from the Auckland Islands area in 2006, and found that there had been relatively little fishing activity in this area in the previous few years. There were insufficient data to conduct a standardised CPUE analysis, and it was believed that unstandardised CPUE did not provide a suitable index of relative abundance. Therefore, a stock assessment could not be carried out.

Other fisheries

In 2006 the Deepwater Working Group examined the data on orange roughy catch and effort from other parts of ORH 3B – the Bounty Islands, Pukaki Rise, Snares Island and the Arrow Plateau – and agreed that there were insufficient data to carry out standardised CPUE analyses for any of these areas.

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