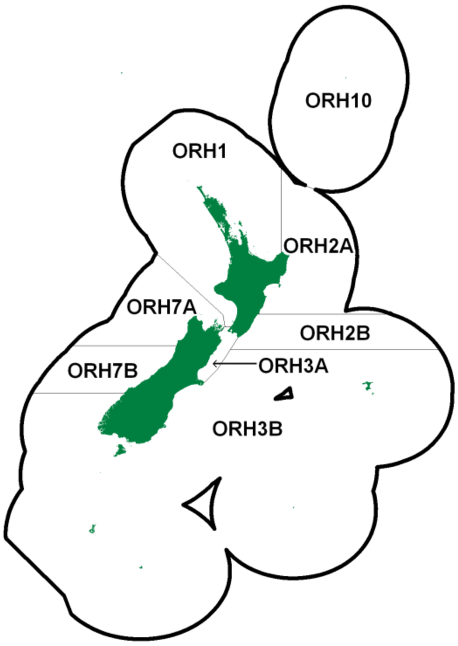
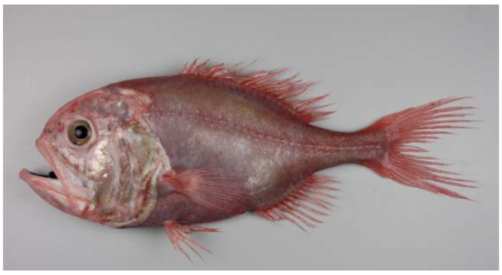
# ORANGE ROUGHY (ORH)

(*Hoplostethus atlanticus*)



## 1. INTRODUCTION

Orange roughy was introduced into the Quota Management System (QMS) on 1 October 1986. The main orange roughy fisheries have been treated separately for assessment and management purposes, and individual reports have been produced for each of six areas consisting of one or more stocks as follows:

1. Northern North Island (ORH 1)
   - Mercury-Colville stock
   - Other stocks
2. Cape Runaway to Banks Peninsula (ORH 2A, 2B, & 3A)
   - East Cape stock
   - Mid-East Coast stock
3. Chatham Rise and Puysegur (ORH 3B)
   - Northwest Chatham Rise stock
   - East and South Chatham Rise stock
   - Puysegur stock
   - Other minor stocks or subareas
4. Challenger Plateau (ORH 7A)
5. West coast South Island (ORH 7B)
6. Outside the EEZ
   - Lord Howe
   - Northwest Challenger
   - Louisville
   - West Norfolk
   - South Tasman

Recent orange roughy stock assessments have been conducted for Mid-East Coast, Northwest Chatham Rise, East and South Chatham Rise, and Challenger Plateau (2014), and Puysegur (2017). These assessments have used a similar approach and have relied on the use of ageing data and acoustic surveys of spawning plumes. The methods are described later in this introduction and a brief summary of the main results is also provided.

## 2. BIOLOGY

Orange roughy inhabit depths between 700 m and at least 1500 m within the New Zealand EEZ. They are most abundant between about 800 m and 1200 m. Their maximum depth range is unknown.

Orange roughy are slow-growing, long-lived fish. On the basis of otolith ring counts and radiometric isotope studies, orange roughy may live up to 120–130 years. Age determination from otolith rings has been validated by length-mode analysis for juveniles up to four years of age (Mace et al 1990), and adult ages have been validated using radiometric techniques in a study by Andrews & Tracey (2003).

Orange roughy otoliths have a marked transition zone in banding which is believed to be associated with the onset of maturity (Francis & Horn 1997). The estimates of transition-zone maturity range from 23 to 31.5 years for fish from various New Zealand fishing grounds (Horn et al 1998, Seafood Industry Council/NIWA unpublished data). However, spawning fish appear to be an older subset of the transition-zone mature fish as evidenced by the older ages and the larger sizes of fish caught on the spawning grounds. The age at which 50% of fish are spawning was estimated in the 2014 stock assessment models to range from 32–41 years (see Section 4.2). Orange roughy in New Zealand waters reach a maximum size of about 50 cm standard length (SL), and 3.6 kg in weight, but the maximum size appears to vary among local populations. Average size is around 35 cm SL, although there is variation between areas.

Spawning occurs once each year between June and early August in several areas within the New Zealand EEZ, from the Bay of Plenty in the north, to the Auckland Islands in the south. Spawning occurs in dense aggregations at depths of 700–1000 m and is often associated with bottom features such as pinnacles and canyons. Spawning fish are also found outside the EEZ on the Challenger Plateau, Lord Howe Rise, and Norfolk Ridge to the west, and the Louisville Ridge to the east.

Fecundity is relatively low, with females carrying on average about 40 000–60 000 eggs. The eggs are large (2–3 mm in diameter), are fertilised in the water column, and then drift upwards towards the surface and remain planktonic until they hatch close to the bottom after about 10 days. Details of larval biology are poorly known.

Orange roughy juveniles are first available to bottom trawls at age about 6 months, when they exhibit a mean length of about 2 cm. Juveniles have been found in large numbers in only one area, at a depth of 800–900 m about 150 km east of the main spawning ground on the north Chatham Rise.

Orange roughy also form aggregations outside the spawning period, presumably for feeding. Their main prey species include mesopelagic and benthopelagic prawns, fish and squid, with other organisms such as mysids, amphipods and euphausiids occasionally being important.

Natural mortality (*M*) has been estimated to be 0.045 $yr^{-1}$. This was based on otolith age data from a 1984 research survey of the Chatham Rise that used an estimation technique based on mean age. A similar estimate was obtained in 1998 from a lightly fished population in the Bay of Plenty.

Biological parameters used in the following assessments (Tables 1 and 2) were estimated by Doonan (1994) with modifications of $A_r$, $A_m$, $S_r$, and $S_m$ for the 1998 stock assessment meetings by Francis & Horn (1997), Horn et al (1998), and Doonan et al (1998), and further modifications for the 2006 assessment by Hicks (2006).

Biases in reading ages from otoliths were identified, leading to a recommendation by reviewers of orange roughy workshops in October 2005 and February 2006 that no age data should be used in assessments until the biases were quantified and corrected. Stemming from this recommendation, a new ageing methodology was developed for orange roughy in 2007, associated with an international ageing workshop for this species (Tracey et al 2007). In the 2014 stock assessments, age-frequency data were only used if the otoliths had been read using the new ageing protocol.

It is believed that ages derived from otoliths collected during the 1984 and 1990 trawl surveys of the East Chatham Rise, which were aged under the old NIWA protocol do not contain serious biases. The single-sex growth curve, the length-weight parameters and the maturity ogive based on transition zones, which are all based on ageing using the old-protocol data are still believed to be valid. The estimates of these biological parameters (Table 1) were used for both the East Chatham Rise and the Northwest Chatham Rise stock assessments, although the otoliths used were collected from the East Chatham Rise only (of which most were from the Spawning Box). The transition-zone maturity estimates were not used in the 2014 stock assessments as maturity was estimated in each of the models.

**Table 1: Biological parameters as used for orange roughy assessments. -, not estimated.**

| Parameter | Symbol | Male | Female | Both sexes |
|---|---|---|---|---|
| Natural mortality | *M* | - | - | 0.045 $yr^{-1}$ |
| Age of recruitment | $A_r$ ($a_{50}$) | - | - | =$A_m$ |
| Gradual recruitment | $S_r$ ($a_{to95}$) | - | - | =$S_m$ |
| Age at maturity | $A_m$ ($a_{50}$) | - | - | Table 2 |
| Gradual maturity | $S_m$ ($a_{to95}$) | - | - | Table 2 |
| von Bertalanffy parameters | | | | |
| - Chatham Rise (default) | $L_\infty$ | 36.4 cm | 38.0 cm | - |
| - Northwest Chatham Rise | $L_\infty$ | - | - | 37.78 cm |
| - East Chatham Rise | $L_\infty$ | - | - | 37.78 cm |
| - Ritchie Bank | $L_\infty$ | - | - | 37.63 cm |
| - Challenger Plateau | $L_\infty$ | 33.4 cm | 35.0 cm | - |
| - All areas (default) | k | 0.070 $yr^{-1}$ | 0.061 $yr^{-1}$ | - |
| - Northwest Chatham Rise | k | - | - | 0.059 $yr^{-1}$ |
| - East Chatham Rise | k | - | - | 0.059 $yr^{-1}$ |
| - Ritchie Bank | k | - | - | 0.065 $yr^{-1}$ |
| - All areas (default) | $t_0$ | -0.4 yr | -0.6 yr | - |
| - East Chatham Rise | $t_0$ | - | - | -0.491 |
| - Northwest Chatham Rise | $t_0$ | - | - | -0.491 |
| - Ritchie Bank | $t_0$ | - | - | -0.5 |
| Length-weight parameters | | | | |
| - default | a | - | - | 0.0921 |
| - East and Northwest Chatham Rise | a | | | 0.0800 |
| - default | b | - | - | 2.71 |
| - East and Northwest Chatham Rise | b | | | 2.75 |
| Recruitment variability | $\sigma_R$ | - | - | 1.1 |
| Recruitment steepness | | - | - | 0.75 |

**Table 2: Estimates of $A_m$ and $S_m$ by area for New Zealand orange roughy from transition zone observations.**

| | $A_m$ | | | $S_m$ | | |
|---|---|---|---|---|---|---|
| **Area** | **M** | **F** | **Both sexes** | **M** | **F** | **Both sexes** |
| Chatham Rise (default) | - | - | 29 | - | - | 3 |
| Northwest Chatham Rise | - | - | 28.51 | - | - | 4.56 |
| East Chatham Rise | - | - | 28.51 | - | - | 4.56 |
| Ritchie Bank | - | - | 31.5 | - | - | 7.11 |
| Challenger Plateau | - | - | 23 | - | - | 3 |
| Puysegur Bank | - | - | 27 | - | - | 3 |
| Bay of Plenty | 26 | 27 | - | 4 | 5 | - |

The method of Francis (1992) was used to estimate reference points and yields for orange roughy stocks. The differing parameter values in Tables 1 and 2 by stock meant that yield estimates varied across stocks (Table 3).

**Table 3: Estimates of *MCY*, $E_{CAY}$ and *MAY* for New Zealand orange roughy.**

| Area | *MCY* (%$B_0$) | $E_{CAY}$ | *MAY* (%$B_0$) |
|---|---|---|---|
| Bay of Plenty (ORH 1) | 1.47 | 0.063 | 1.94 |
| Ritchie Bank (ORH 2A) | 1.46 | 0.062 | 1.92 |
| Chatham Rise (ORH 3B) | 1.51 | 0.064 | 1.99 |
| Puysegur Bank (ORH 3B) | 1.47 | 0.062 | 1.94 |
| Challenger Plateau (ORH 7A) | 1.40 | 0.060 | 1.84 |

For all these stocks, the mean biomass when fishing using an *MCY* policy was estimated to be 51% of $B_0$, and for a *CAY* policy it was 30% of $B_0$ (these values varied by less than 1% between the various

stocks).
The reference points and yields given above are not used in the 2014 stock assessments. In these assessments, MCMC estimates of deterministic reference points and yields were made for the target biomass range of 30–40% $B_0$. However, the lower bound of this range was taken from the above results (the mean biomass under a CAY policy).

## 3. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

This section was updated for the 2018 Fishery Assessment Plenary. This summary is from the perspective of the deepwater trawl fisheries for orange roughy; an issue-by-issue analysis is available in the 2017 Aquatic Environment & Biodiversity Annual Review (MPI 2017, https://www.mpi.govt.nz/dmsdocument/27471-aquatic-environment-and-biodiversity-annual-review-aebar-2017-a-summary-of-environmental-interactions-between-the-seafood-sector-and-the-aquatic-environment).
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### 3.1 Role in the ecosystem

Orange roughy are the dominant demersal fish at depths of 750–1100 m on the north and east Chatham Rise, the east coast of the North Island south of about East Cape, and the Challenger Plateau (Clark et al 2000; Doonan & Dunn 2011; Tracey et al 1990). An analysis of New Zealand demersal fish assemblages using research trawl data showed that orange roughy was the most frequently occurring species (found in more than 40 % of tows) in the mid slope assemblage (Francis et al 2002). Fishing has reduced the abundance of orange roughy since the 1980s, and the effects of removing, for example, an average of about 18 000 t per year from ORH 3B between 1979–80 and 2009–10 are largely unknown. There are likely to have been ecosystem implications (Tracey et al 2012).

#### 3.1.1 Trophic interactions

The main prey species of orange roughy include mesopelagic and benthopelagic prawns, fish and squid, with other organisms such as mysids, amphipods and euphausiids occasionally being important (Rosecchi et al 1988). Koslow (1997) showed that orange roughy have a faster metabolism than deepwater fishes that are typically dispersed over the flat seafloor, and their food consumption is higher. Ontogenetic shifts occur in their feeding preferences with the smaller fish (up to 20 cm) feeding on crustaceans, and larger fish (31 cm and above) feeding on teleosts and cephalopods (Stevens et al 2011). Relative proportions of the three prey groups were similar between areas. Bulman & Koslow (1992) found that teleosts were more important than crustaceans by weight in the prey of Australian orange roughy, and that this dominance increased in adult-sized fish. Dunn & Forman (2011) inferred from diet analysis that juveniles feed more on the benthos compared with the benthopelagic foraging of adults. Where they co-occur, orange roughy and black oreo may compete for teleost and crustacean prey.

Predators of orange roughy are likely to change with fish size. Larger smooth oreo, black oreo and orange roughy were observed with healed soft flesh wounds, typically in the dorso-posterior region. Wound shape and size suggest they may be caused by one of the deepwater dogfishes (Dunn et al 2010). Giant squid and sperm whales have also been found to prey on orange roughy (Gaskin & Cawthorn 1967, Jereb & Roper 2010).

#### 3.1.2 Ecosystem Indicators

Tuck et al (2009) used data from the Sub-Antarctic and Chatham Rise middle-depth trawl surveys to derive indicators of fish diversity, size, and trophic level. However, fishing for orange roughy occurs mostly deeper than the depth range of these surveys and is only a small component of fishing in the areas considered by Tuck et al (2009).

### 3.2 Non-target fish and invertebrate bycatch

Anderson et al. (2017) summarised the bycatch of orange roughy and oreo trawl fisheries from 2001–02 to 2014–15. For orange roughy trawls since 2001–02, orange roughy accounted for 85% of the total observed catch and the remainder comprised mainly smooth oreo (7%), black oreo (1.6%), hoki (0.6%), and cardinalfish (0.3%). More than 700 species or species groups were recorded by observers, including various deepwater dogfishes (2%), morid cods (1%), rattails (<1%), and slickheads (0.5%). Total annual bycatch between 2001–02 and 2009–10 ranged from 3090 t to 6075 t per year and declined to less than 1100 in subsequent years following decline in catch in the fishery. Total annual discards also decreased over time, from about 2120 t in 2001–02 to about 184 t in 2013–14 and were almost entirely of non-QMS or invertebrate species (rattails, shovelnose dogfish, and other deepwater dogfishes, all discarded at a rate of 50% or more). From 2001–02 to 2014–15, the overall discard fraction value was 0.07 kg (range of 0.02-0.13 kg) and tended to be lower in recent years.

Invertebrate species are caught in low numbers in the orange roughy fishery (Anderson et al 2017). Squid (mostly warty squid, *Onykia* spp., 0.15%) were the largest component of invertebrate catch, followed by various groups of coral (0.12%), echinoderms (mainly starfish, 0.03%), and crustaceans (mainly king crabs, family Lithodidae, 0.01%). Tracey et al (2011) analysed the distribution of nine groups of protected corals based on bycatch records from observed trawl effort from 2007–08 to 2009–10, primarily from 800–1000 m depth. For the orange roughy target fishery, about 10% of observed tows in FMAs 4 and 6 included coral bycatch, but a higher proportion of tows in northern waters included coral (28% in FMA 1, 53% in FMA 9, Tracey et al 2011).

## 3.3 Incidental Capture of Protected Species (seabirds, mammals, and protected fish)

For protected species, capture estimates presented here include all animals recovered to the deck (alive, injured or dead) of fishing vessels but do not include any cryptic mortality (e.g., seabirds struck by a warp but not brought onboard the vessel, Middleton & Abraham 2007, Brothers et al 2010).

### 3.3.1 Marine mammal interactions

Trawlers targeting orange roughy, oreo, and black cardinalfish occasionally catch New Zealand fur seal (which were classified as "Not Threatened" under the NZ Threat Classification System in 2010, Baker et al 2016). Between 2002–03 and 2007–08, there were 14 observed captures of NZ fur seal in orange roughy, oreo, and black cardinalfish trawl fisheries. There has been one observed capture in the period between 2008–09 and 2016–17, during which time the average level of annual observer coverage was 26.7% (Table 4). Corresponding mean annual estimated captures in this period ranged 0–3 (mean 1.25) based on statistical capture models (Thompson et al 2013; Abraham et al 2016). All observed fur seal captures occurred in the Sub-Antarctic region.

**Table 4: Number of tows by fishing year and observed and model-estimated total NZ fur seal captures in orange roughy, oreo, and cardinalfish trawl fisheries, 2002–03 to 2016–17. No. Obs, number of observed tows; % obs, percentage of tows observed; Rate, number of captures per 100 observed tows, % inc, percentage of total effort included in the statistical model. Estimates are based on methods described in Abraham et al (2016), available via https://data.dragonfly.co.nz/psc. Estimates from 2002–03 to 2016–17 are based on data version 2018v1.**

| | | | | Observed | | Estimated | |
|---|---|---|---|---|---|---|---|
| | Tows | No.obs | %ob | Captures | Rate | Capture | 95%c.i. |
| 2002–03 | 8 872 | 1 384 | 15.6 | 0 | 0.0 | 4 | 0-13 |
| 2003–04 | 8 006 | 1 262 | 15.8 | 2 | 0.2 | 10 | 3-26 |
| 2004–05 | 8 428 | 1 619 | 19.2 | 4 | 0.2 | 15 | 6-32 |
| 2005–06 | 8 287 | 1 358 | 16.4 | 2 | 0.1 | 11 | 4-25 |
| 2006–07 | 7 361 | 2 324 | 31.6 | 2 | 0.1 | 3 | 2-7 |
| 2007–08 | 6 730 | 2 811 | 41.8 | 5 | 0.2 | 8 | 5-14 |
| 2008–09 | 6 132 | 2 372 | 38.7 | 0 | 0.0 | 2 | 0-8 |
| 2009–10 | 6 013 | 2 134 | 35.5 | 0 | 0.0 | 3 | 0-9 |
| 2010–11 | 4 177 | 1 205 | 28.8 | 0 | 0.0 | 4 | 0-11 |
| 2011–12 | 3 653 | 922 | 25.2 | 0 | 0.0 | 1 | 0-5 |
| 2012–13 | 3 098 | 346 | 11.2 | 0 | 0.0 | 0 | 0-3 |
| 2013–14 | 3 607 | 434 | 12.0 | 0 | 0.0 | 1 | 0-4 |
| 2014–15 | 3 809 | 978 | 25.7 | 1 | 0.1 | 2 | 1-4 |
| 2015–16 | 4 086 | 1 421 | 34.8 | 0 | 0.0 | 1 | 0-3 |
| 2016–17 | 3 964 | 1 226 | 30.9 | 0 | 0.0 | | |

### 3.3.2 Seabird interactions

Annual observed seabird capture rates in the orange roughy, oreo and cardinalfish trawl fisheries have ranged from 0 to 0.9 per 100 tows between 2002–03 and 2016–17 (Table 5). The average capture rate in deepwater trawl fisheries (including orange roughy, oreo and cardinalfish) for the period from 2002–03 to 2016–17 is about 0.29 birds per 100 tows, a very low rate relative to other New Zealand trawl fisheries, e.g. for scampi (4.43 birds per 100 tows) and squid (13.79 birds per 100 tows) over the same years.

**Table 5: Number of tows by fishing year and observed seabird captures in orange roughy, oreo, and cardinalfish trawl fisheries, 2002–03 to 2016–17. No. obs, number of observed tows; % obs, percentage of tows observed; Rate, number of captures per 100 observed tows. Estimates are based on methods described in Abraham et al (2016) and Abraham & Richard (2017, 2018) and available via http://www.fish.govt.nz/en-nz/Environmental/Seabirds/. Estimates from 2002–03 to 2016–17 are based on data version 2018v1.**

| | Fishing effort | | | Observed captures | | Estimated captures | |
|---|---|---|---|---|---|---|---|
| | Tows | No. obs | % obs | Captures | Rate | Mean | 95% c.i. |
| 2002–03 | 8 870 | 1 383 | 15.6 | 0 | 0.0 | 27 | 14-45 |
| 2003–04 | 8 006 | 1 262 | 15.8 | 3 | 0.2 | 27 | 15-42 |
| 2004–05 | 8 431 | 1 619 | 19.2 | 7 | 0.4 | 46 | 28-72 |
| 2005–06 | 8 290 | 1 358 | 16.4 | 8 | 0.6 | 33 | 21-50 |
| 2006–07 | 7 363 | 2 325 | 31.6 | 1 | 0.0 | 16 | 7-27 |
| 2007–08 | 6 729 | 2 810 | 41.8 | 7 | 0.2 | 19 | 11-29 |
| 2008–09 | 6 133 | 2 373 | 38.7 | 7 | 0.3 | 20 | 12-30 |
| 2009–10 | 6 006 | 2 130 | 35.5 | 19 | 0.9 | 35 | 26-46 |
| 2010–11 | 4 180 | 1 206 | 28.9 | 1 | 0.1 | 12 | 5-22 |
| 2011–12 | 3 655 | 923 | 25.3 | 2 | 0.2 | 10 | 5-18 |
| 2012–13 | 3 096 | 345 | 11.1 | 2 | 0.6 | 13 | 6-23 |
| 2013–14 | 3 608 | 435 | 12.1 | 2 | 0.5 | 14 | 6-24 |
| 2014–15 | 3 815 | 977 | 25.6 | 0 | 0.0 | 12 | 5-22 |
| 2015–16 | 4 091 | 1 421 | 34.7 | 4 | 0.3 | 13 | 6-20 |
| 2016–17 | 3 961 | 1 226 | 31.0 | 2 | 0.2 | 11 | 5-18 |

Salvin's albatross was the most frequently captured albatross (50% of observed albatross captures) but seven other albatross species have been observed captured since 2002–03. Cape petrels were the most frequently captured other taxon (36% of other taxon observed caught not including albatross species, Table 6). Seabird captures in the orange roughy, oreo, and cardinalfish fisheries have been observed mostly around the Chatham Rise and off the east coast South Island. These numbers should be regarded as only a general guide on the distribution of captures because the observer coverage is not uniform across areas and may not be representative.

**Table 6: Number of observed seabird captures in orange roughy, oreo, and cardinalfish fisheries, 2002–03 to 2016–17, by species and area. The risk category is an estimate of aggregate potential fatalities across trawl and longline fisheries relative to the Population Sustainability Thresholds, PST (from Richard & Abraham 2015 where full details of the risk assessment approach can be found). It is not an estimate of the risk posed by fishing for cardinal fish. These data are available via https://data.dragonfly.co.nz/psc, based on data version 2017v1.**

| Species | Risk Category | Chatham Rise | East Coast South Island | Fiordland | Sub-Antarctic | Stewart Snares Shelf | West Coast South Island | Total |
|---|---|---|---|---|---|---|---|---|
| Salvin's albatross | High | 13 | 4 | 0 | 3 | 0 | 0 | 20 |
| Southern Buller's albatross | High | 3 | 0 | 1 | 0 | 0 | 0 | 4 |
| Chatham Island albatross | High | 7 | 0 | 0 | 1 | 0 | 0 | 8 |
| New Zealand white-capped albatross | High | 3 | 0 | 0 | 0 | 0 | 1 | 4 |
| Gibson's albatross | High | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Antipodean albatross | Medium | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Northern royal albatross | Low | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Southern royal albatross | Negligible | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| **Total albatrosses** | **-** | **30** | **4** | **1** | **4** | **0** | **1** | **40** |

**Table 6[Continued]**

| Species | Risk Category | Chatham Rise | East Coast South Island | Fiordland | Sub-Antarctic | Stewart Snares Shelf | West Coast South Island | Total |
|---|---|---|---|---|---|---|---|---|
| Northern giant petrel | Medium | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| White-chinned petrel | Negligible | 2 | 1 | 0 | 0 | 0 | 0 | 3 |
| Grey petrel | Negligible | 1 | 0 | 0 | 1 | 0 | 0 | 2 |
| Sooty shearwater | Negligible | 0 | 3 | 0 | 0 | 0 | 0 | 3 |
| Common diving petrel | Negligible | 2 | 0 | 0 | 0 | 0 | 0 | 2 |
| White-faced storm petrels | Negligible | 3 | 0 | 0 | 0 | 0 | 0 | 3 |
| Cape petrel | - | 8 | 1 | 0 | 0 | 0 | 0 | 9 |
| Short-tailed shearwater | - | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| Petrels, prions and shearwaters | - | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| **Total other birds** | - | **17** | **5** | **0** | **2** | **1** | **0** | **25** |

The deepwater trawl fisheries (including the cardinal fish target fishery) contributes to the total risk posed by New Zealand commercial fishing to seabirds (see Table 7). The two species to which the fishery poses the most risk are Chatham Island albatross and Salvin’s albatross, with this suite of fisheries posing 0.06 and 0.022 of Population Sustainability Threshold (PST) (Table 7). Chatham albatross and Salvin’s albatross were assessed at high risk (Richard et al 2017).

**Table 7: Risk ratio of seabirds predicted by the level two risk assessment for the orange roughy and all fisheries included in the level two risk assessment, 2006–07 to 2016-17, showing seabird species with a risk ratio of at least 0.001 of PST (from Richard et al 2017 where full details of the risk assessment approach can be found). The risk ratio is an estimate of aggregate potential fatalities across trawl and longline fisheries relative to the PBR. The DOC threat classifications are shown (Robertson et al 2017 at http://www.doc.govt.nz/documents/science-and-technical/nztcs19entire.pdf).**

| | | Risk ratio | | | |
|---|---|---|---|---|---|
| Species name | PST (mean) | ORH, OEO, CDL target trawl | TOTAL | Risk category | DOC Threat Classification |
| Chatham Island albatross | 425.2 | 0.060 | 0.362 | High | At Risk: Naturally Uncommon |
| Salvin's albatross | 3 599.5 | 0.022 | 0.78 | High | Threatened: Nationally Critical |
| Northern giant petrel | 335.4 | 0.005 | 0.138 | Medium | At Risk: Naturally Uncommon |
| Northern Buller's albatross | 1 627.4 | 0.002 | 0.253 | Medium | At Risk: Naturally Uncommon |
| Black petrel | 437.1 | 0.002 | 1.153 | Very high | Threatened: Nationally Vulnerable |
| Antipodean albatross | 364.3 | 0.002 | 0.203 | Medium | Threatened: Nationally Critical |
| Gibson's albatross | 496.1 | 0.002 | 0.337 | High | Threatened: Nationally Critical |
| Northern royal albatross | 715.1 | 0.001 | 0.043 | Low | At Risk: Naturally Uncommon |
| Flesh-footed shearwater | 1452.8 | 0.001 | 0.669 | High | Threatened: Nationally Vulnerable |
| Southern Buller's albatross | 1368.4 | 0.001 | 0.392 | High | At Risk: Naturally Uncommon |
| Grey petrel | 5524.1 | 0.000 | 0.037 | Negligible | At Risk: Naturally Uncommon |
| Common diving petrel | 135 254.8 | 0.000 | 0.002 | Negligible | At Risk: Relict |
| New Zealand white-faced storm petrel | 331 778.5 | 0.000 | 0 | Negligible | At Risk: Relict |
| New Zealand white-capped albatross | 1 0900.3 | 0.000 | 0.353 | High | At Risk: Declining |
| Buller's shearwater | 55 991.9 | 0.000 | 0 | Negligible | At Risk: Naturally Uncommon |
| Westland petrel | 350.1 | 0.000 | 0.476 | High | At Risk: Naturally Uncommon |
| Sooty shearwater | 617 028.2 | 0.000 | 0.002 | Negligible | At Risk: Declining |
| Hutton's shearwater | 15 054.3 | 0.000 | 0.001 | Negligible | At Risk: Declining |
| Otago shag | 284 | 0.000 | 0.144 | Medium | Threatened: Nationally Vulnerable |
| White-headed petrel | 34 314.8 | 0.000 | 0.001 | Negligible | Not Threatened |

Mitigation methods such as streamer (tori) lines, Brady bird bafflers, warp deflectors, and offal management are used in the orange roughy, oreo, and cardinalfish trawl fisheries. Warp mitigation was voluntarily introduced from about 2004 and made mandatory in April 2006 (Department of Internal Affairs 2006). The 2006 notice mandated that all trawlers over 28 m in length use a seabird scaring device while trawling (being “paired streamer lines”, “bird baffler” or “warp deflector” as defined in the notice).

## 3.4 Benthic interactions

The spatial extent of seabed contact by trawl fishing gear in New Zealand’s EEZ and Territorial Sea has been estimated and mapped in numerous studies for trawl fisheries targeting deepwater species (Baird et al 2011, Black et al 2013, Black and Tilney 2015, Black and Tilney 2017, and Baird and Wood

2018) and species in waters shallower than 250m (Baird et al 2015). The most recent assessment of the deepwater trawl footprint was for the period 2007–08 to 2016–17 (Baird & Mules 2019).

Orange roughy, oreo, and cardinalfish are taken using bottom trawls and accounted for about 14% of all tows reported on TCEPR forms that fished on or close to the bottom between 1989–90 and 2004–05 (Baird et al 2011). During 1989–90 to 2015–16, about 128 000 orange roughy bottom trawls were reported on TCEPRs (Baird & Wood 2018): with between 5000 and at least 8000 tows reported most years up to 1999–2000; 3000–4500 annual tows between 2000–01 and 2009–10; and 1500–3000 tows a year during 2010–11 to 2015–16. The total footprint generated from these tows was estimated at about 34 725 $km^2$. This footprint represented coverage of 0.8% of the seafloor of the combined EEZ and the Territorial Sea areas; 2.4% of the ‘fishable area’, that is, the seafloor area open to trawling, in depths of less than 1600 m. For the 2016–17 fishing year, 2983 orange roughy bottom tows had an estimated footprint of 2700 $km^2$ which represented coverage of 0.1% of the EEZ and Territorial Sea and 0.2% of the fishable area (Baird & Mules 2019).

The overall trawl footprint for orange roughy (1989–90 to 2015–16) covered 8% of the seafloor in 800–1000 m, 6% of 1000–1200 m seafloor, and 3% of the 1200–1600 m seafloor (Baird & Wood 2018). In 2016–17, the orange roughy footprint contacted < 0.5%, < 0.5%, and 0.2% of those depth ranges, respectively (Baird & Mules 2019). Deepsea corals in the New Zealand region are abundant and diverse and, because of their fragility, are at risk from anthropogenic activities such as bottom trawling (Clark & O’Driscoll 2003, Clark & Rowden 2009, Williams et al 2010). All deepwater hard corals are protected under Schedule 7A of the Wildlife Act 1953. Baird et al (2013) mapped the likely coral distributions using predictive models and concluded that the fisheries that pose the most risk to protected corals are these deepwater trawl fisheries.

Tows are located in Benthic-optimised Marine Environment Classification (BOMEC, Leathwick et al 2012) classes J, K (mid-slope), M (mid-lower slope), N, and O (lower slope and deeper waters) (Baird & Wood 2012), and 94% were between 700 and 1200 m depth (Baird et al 2011). The BOMEC areas with the highest proportion of area covered by the orange roughy footprint were classes J (comprising mainly the Challenger Plateau and northern and southern slopes of the Chatham Rise) and N (deeper areas around the North Island and Chatham Rise). In 2016–17, the orange roughy footprint represented 0.7% of the 311 360 $km^2$ in class J and 0.1% of the 493 034 $km^2$ of class N (Baird & Mules 2019).
Trawling for orange roughy, like trawling for other species, is likely to have effects on benthic community structure and function (e.g., Rice 2006) and there may be consequences for benthic productivity (e.g., Jennings et al 2001, Hermsen et al 2003, Hiddink et al 2006, Reiss et al 2009). These consequences are not considered in detail here but are discussed in the Aquatic Environment and Biodiversity Annual Review 2017 (MPI, 2017).

The New Zealand EEZ contains Benthic Protection Areas (BPAs) and seamount closures that are closed to bottom trawl fishing for the protection of benthic biodiversity. These combined areas include 28% of underwater topographic features (including seamounts), 52% of all seamounts over 1000 m elevation and 88% of identified hydrothermal vents.

### 3.5 Other considerations

Fishing during spawning may disrupt spawning activity or success. Morgan et al (1999) concluded that Atlantic cod (*Gadus morhua*) “exposed to a chronic stressor are able to spawn successfully, but there appears to be a negative impact of this stress on their reproductive output, particularly through the production of abnormal larvae”. Morgan et al (1999) also reported that “Following passage of the trawl, a 300-m-wide "hole" in the [cod spawning] aggregation spanned the trawl track. Disturbance was detected for 77 min after passage of the trawl.” There is no research on the disruption of spawning orange roughy by fishing in New Zealand.

### 3.5.2 Genetic effects

Fishing, environmental changes, including those caused by climate change or pollution, could alter the genetic composition or diversity of a species. There are no known studies of the genetic diversity of orange roughy from New Zealand. Genetic studies for stock discrimination are reported under “stocks and areas”.

### 3.5.3 Habitat of particular significance to fisheries management

Habitat of particular significance for fisheries management (HPSFM) does not have a policy definition (MPI, 2013). Mace et al (1990) identified only one area of high abundance for juvenile orange roughy at 800–900 m depth about 150 km east of the main spawning ground on the north Chatham Rise. Orange roughy from 9 cm SL have also been located on the Challenger Plateau and O'Driscoll et al (2003) show other areas where immature fish are relatively common. Dunn et al (2009) showed that orange roughy juveniles are generally found close to the seabed, and in shallower water than the adults, starting off at depths of around 850–900 m and spreading deeper, and over a wider depth range, as they grow. Dunn & Forman (2011) also suggested that juveniles start on flat grounds shallower than the adults, that they shift deeper as they grow, and that seamounts and other features tend to be dominated by the largest orange roughy. It is not known if there are any direct linkages between the congregation of orange roughy around features and the corals found on those features. Bottom trawling for orange roughy has the potential to affect features of the habitat that could qualify as habitat of particular significance to fisheries management.

## 4. RECENT STOCK ASSESSMENTS[1]

Stock assessments were undertaken for ORH 7A areas in 2014, for Puysegur in 2017, and the Mid-east coast (MEC), Northwest Chatham Rise (NWCR), and East and South Chatham Rise (ESCR) in 2018. In this section, the methods that were common to these stock assessments are described and the main results are summarised.

### 4.1 Methods

The methods used in recent orange roughy assessments from 2014 were different from those used in previous years. The major differences were in the application of a more stringent data quality threshold, in model structure, and in the use of age data to estimate year class strengths.

### 4.1.1 Data quality and model structure

A high quality threshold was imposed on data before they were used in an assessment. This resulted in the exclusion of biomass estimates that had previously been used. In particular, CPUE indices were not used in any of the assessments because they were considered unlikely to be monitoring stock-wide abundance (e.g., non-spawning season catch rates from a single hill feature or complex within a large area cannot be monitoring stock wide abundance as the fishery would not have been sampling a large proportion of the stock; at best, such CPUE indices may index localised abundance; during the spawning season catches from a single hill or aggregation may be sampling a large proportion of the stock but the catch rates will depend on how the aggregation is fished rather than how much biomass is present). Also, estimates of biomass from egg surveys were not used as it was found that the available estimates were from surveys where the assumptions of the survey design were not met and/or there were major difficulties in analysing the survey data. Finally, acoustic-survey estimates of biomass were only used when mainly single-species aggregations were surveyed with suitable equipment. Estimates of spawning orange roughy biomass were accepted for plumes on the flat surveyed using hull-mounted transducers or towed systems, or for plumes on underwater features using towed systems only (otherwise the dead zone can be too large for reliable comparison).

The model structure assumed was similar across the assessments. In each case, the base models were single-sex, single-area models with separate categories for age and maturity. Maturity was estimated within the model from age-frequencies of spawning fish and, if available, from female proportion spawning at age data from pre-spawning wide-area trawl surveys (available for NWCR and MEC). All mature fish were assumed to spawn each year as this was consistent with the estimates of female proportion spawning at age (see the NWCR and MEC assessments). This is different to earlier assessments where acoustic and egg survey estimates of spawning biomass were scaled up using

[1] The information presented reflects the management settings that were in place since 2014 which guided the projections and advice provided. The management settings were updated in August 2014 and the management target range and a harvest control rule have been implemented for key orange roughy fisheries (ORH 3B Northwest Rise, ORH 3B East & South Rise, ORH 7A). The change does not change the status of the stocks in relation to reference points but it has led to a reduction in yield estimates. For more information on current management settings, please see Cordue, 2014. (http://deepwater.co.nz/wp-content/uploads/2014/08/Cordue-2014-A-Management-Strategy-Evaluation-for-Orange-Roughy.-ISL-Re....pdf)

estimates of transition-zone mature biomass before being used in an assessment. In the recent assessments, acoustic estimates of *spawning* biomass were used directly without scaling.

The recent assessment models now include more reliable age data using the new ageing methodology (Tracey et al 2007, Horn et al 2016). Previously, the stock assessments were not thought to be reliable as the models were found to be insensitive to the recent abundance data; i.e., results did not change whether or not recent abundance indices were included because the model assumptions - particularly the assumption of deterministic recruitment - overwhelmed the data. The modelled biomass trajectories were estimated as a strong increasing trend as catches were scaled back, a pattern that was not supported by the fishery-independent abundance indices.

#### 4.1.2 Acoustic *q* priors

The major sources of recent abundance information in the models are from acoustic surveys of spawning biomass. For each survey, the spawning biomass estimate was included in the appropriate assessment as an estimate of *relative* spawning biomass rather than *absolute* spawning biomass (the latter being used in previous assessments). The reason that the estimates are not used as absolute estimates of biomass is because there are two major potential sources of bias: (i) the estimates may be biased low or high because the estimate of orange roughy target strength is incorrect, and (ii) the survey is unlikely to have covered all of the spawning stock biomass. The unknown proportionality constant, or *q*, for each survey was estimated in the model using an informed prior for each *q*. Each prior was constructed from two components: orange roughy target strength and availability to the survey.

The target strength (TS) prior was derived from the estimates of Macaulay et al (2013) and Kloser et al (2013) who both obtained TS estimates (at 38 kHz) from visually verified orange roughy as they were herded by a trawl net (the “AOS” was mounted on the head of the net and acoustic echoes and stereo photos were obtained simultaneously). Macaulay et al (2013) estimated a TS (for 33.9 cm fish) of -52.0 dB with a 95% CI of -53.3 to -50.9 dB; Kloser et al (2013) gave a point estimate of -51.1 dB and gave a range, that allowed for the artificial tilt angles of the herded fish, from -52.2 to -50.7 dB. The prior was taken to be normal with a mean of -52.0 dB with 99% of the distribution covered by ± 1.5 dB (which covers both ranges). This results in a tight distribution for informed acoustic q priors, reflecting the high confidence in the target strength estimates.

For surveys that covered “most” of the spawning stock biomass (e.g., ESCR where in some years surveys covered the Old plume[2], the Rekohu plume, and the “Crack”), availability was modelled with a Beta(8,2) distribution (this has a mean of 0.8 – i.e., it is assumed *a priori* that 80% of the spawning stock biomass is being indexed). The acoustic *q* prior is the combination of the availability and TS priors (assuming they are independent). This was approximately normal with a mean of 0.8 and a CV of 19%. For surveys that were considered to have covered less than “most” of the spawning biomass, a similar prior was used for the *q* except that a lower mean value was assumed for the “availability” component of the prior (see individual assessments for how the mean was derived in these cases). When a higher CV was applied, the median estimates of biomass and stock status were slightly higher, and the confidence intervals were wider with a much higher upper bound.

#### 4.1.3 Year class strength estimation

The number of year class strengths (YCSs) estimated within each model depended on the timing and number of age frequency observations available. In general a YCS was estimated provided that it was observed in at least one age frequency when it was neither “too old” nor “too young”. “Old” YCSs were not estimated because it was considered that there was too little information about these cohorts as only a few of them remained. “Too young” YCSs were not estimated because the selectivity for these ages is low and consequently the YCS estimates would be unreliable.

The Haist parameterisation for estimating YCS was used for all models (Bull et al 2012). In the 2013 MEC assessment it was found that the alternative Francis parameterisation unduly restricted YCS estimates as evidenced by poor fits to the trawl survey biomass indices. In contrast, the Haist parameterisation, using uniform priors, resulted in a good fit to the abundance indices at the MPD stage

[2]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.

and an adequate fit at the MCMC stage. The YCS estimates were primarily driven by the composition data (age and length frequencies), but if unduly penalised, the estimates are restricted to a space which does not allow the trawl biomass indices to be fitted well. In the recent assessments a “nearly uniform” prior was used with the Haist parameterisation (lognormal with mode = 1, and log-space s.d. = 4).

#### 4.1.4 Model runs

For each assessment, a similar set of sensitivity runs was conducted. In addition to a base model, there were runs that estimated natural mortality (*M*); halved and doubled the recent acoustic biomass estimates (to show that the model was sensitive to recent biomass indices); assumed deterministic recruitment (to show the impact of estimating year class strengths); increased/decreased the mean of acoustic *q* priors; and two sensitivities that simultaneously increased/decreased *M* and decreased/increased the mean of the acoustic *q* priors by 20% (a lower stock status occurs when *M* is decreased and when the mean of the acoustic *q* priors is increased; similarly an increased stock status occurs for changes in the other direction). The runs estimating *M* (“EstM”) and those with the 20% changes in *M* and the mean of acoustic *q* priors (“LowM-Highq” and “HighM-Lowq”) were taken through to MCMC.

#### 4.1.5 Fishing intensity

Fishing intensity for each year of the assessment was measured in units of 100 – ESD (Equilibrium Stock Depletion). This quantity was estimated by running the model to deterministic equilibrium, given the exploitation rate and fishing pattern associated with each year. The equilibrium level of the spawning biomass will be the ESD for that year (e.g., if the stock is fished at a very high fishing intensity, the equilibrium spawning stock biomass will be close to zero: ESD = 0% $B_0$; if the stock is being very lightly fished, then ESD = 100% $B_0$). The quantity (100 – ESD) ranges from 0–100 with 100 denoting any pattern and level of fishing that would eventually reduce the stock down to zero spawning biomass. In general, the fishing intensity associated with a deterministic equilibrium of x% $B_0$ is denoted as $U_{x\%B0}$. To aid with the interpretation of fishing intensity in both the fishing intensity and “snail trail” plots (which have fishing intensity on the right hand y-axis), the value $U_{x\%B0}$ has been replaced with an associated exploitation rate proxy on the left hand y-axis. Exploitation rate, expressed as a percentage, is the number of fish caught from every 100 available fish. The exploitation rate labels represent a median exploitation rate, as each $U_{x\%B0}$ maps to a range of exploitation rates, rather than to a single number.

#### 4.1.6 Projections

Projections were generally conducted over a 5-year time period at the level of the current catch and at the long-term yield associated with $U_{35\%B0}$ (the fishing intensity associated with the mid-point of the target biomass range of 30–40% $B_0$. In each case, the future YCSs were assumed for immediately after the last estimated YCS and were resampled from the last 10 years of estimates (this is done because YCSs are correlated rather than being independent from year to year). For long-term projections (e.g., for MEC to estimate $T_{min}$, the number of years required for the stock to be rebuilt when there is no fishing), the YCSs were resampled from all estimated YCSs to ensure that the resampled YCSs will average to near 1 (so that there is no implied regime shift). Projections were done for the base model and, as a “worse-case scenario”, for the *LowM-Highq* model.

## 5. FUTURE RESEARCH

More age information is needed for all stocks. For most areas, this may simply necessitate reading otoliths that have previously been collected. Increasing the number of years with age-composition data should enable better estimation of year class strengths, and should increase the number of YCSs able to be estimated.

For those stocks where the proportion spawning at age is used (e.g. MEC), investigate alternatives for estimating the proportion spawning at age given the sparse data; for example, consider making it asymptotic at a younger age.

The design and implementation of the Challenger (ORH 7A) combined trawl and acoustic survey needs to be reviewed to ensure that it is fit for purpose for future years.

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# ORANGE ROUGHY NORTHERN NORTH ISLAND (ORH 1)

## 1. FISHERY SUMMARY

### 1.1 Commercial fisheries

This region extends northwards from west of Wellington around to Cape Runaway. Prior to 1993–94 there was no established fishery, and reported landings were generally small (Table 1). A new fishery developed in winter 1994, when aggregations were fished on two hill complexes in the western Bay of Plenty. In 1996 catches were also taken off the west coast of Northland. Figure 1 shows the historical landings and TACC values for ORH 1.

A TACC of 190 t was set from 1989–90. Prior to that there had been a 10 t TAC and various levels of exploratory quota. From 1995–96, ORH 1 became subject to a five year adaptive management programme, and the TACC was increased to 1190 t. A catch limit of 1000 t was applied to an area in the western Bay of Plenty (Mercury-Colville 'box'), with the former 190 t TACC applicable to the remainder of ORH 1. In 1994 and 1995, research fishing was also carried out under Special Permit (not included in the TACC). For the period June 1996–June 1997, a Special Permit was approved for exploratory fishing. This allowed an additional 800 t (not included in the TACC) to be taken in designated areas, although catches were limited from individual features (hills and seamounts etc).

**Table 1: Reported landings (t) and TACCs (t) from 1982–83 to present. - no TACC. The reported landings do not include catches taken under an exploratory special permit of 699 t in 1998–99 and 704 t in 1999–2000. QMS data from 1986-present.**

| | Reported landings | | | |
|---|---|---|---|---|
| Fishing year | West coast | North-east coast | Total | TACC |
| 1982–83* | < 0.1 | 0 | < 0.1 | - |
| 1983–84* | 0.1 | 0 | 0.1 | - |
| 1984–85* | < 0.1 | 96 | 96 | - |
| 1985–86* | < 1 | 2 | 2 | - |
| 1986–87* | 0 | < 0.1 | < 0.1 | 10 |
| 1987–88 | 0 | 0 | 0 | 10 |
| 1988–89 | 0 | 19 | 19 | 10 |
| 1989–90 | 37 | 49 | 86 | 190 |
| 1990–91 | 0 | 200 | 200 | 190 |
| 1991–92 | + | + | 112 | 190 |
| 1992–93 | + | + | 49 | 190 |
| 1993–94 | 0 | 189 | 189 | 190 |
| 1994–95 | 0 | 244 | 244 | 190 |
| 1995–96 | 55 | 910 | 965 | 1 190 |
| 1996–97 | + | + | 1 021 | 1 190 |
| 1997–98 | + | + | 511 | 1 190 |
| 1998–99 | + | + | 845 | 1 190 |
| 1999–00 | + | + | 771 | 1 190 |
| 2000–01 | + | + | 858 | 800 |
| 2001–02 | + | + | 1 294 | 1 400 |
| 2002–03 | + | + | 1 123 | 1 400 |
| 2003–04 | + | + | 986 | 1 400 |
| 2004–05 | + | + | 1 151 | 1 400 |
| 2005–06 | + | + | 1 207 | 1 400 |
| 2006–07 | + | + | 1 036 | 1 400 |
| 2007–08 | + | + | 1 104 | 1 400 |
| 2008–09 | + | + | 905 | 1 400 |
| 2009–10 | + | + | 825 | 1 400 |
| 2010–11 | + | + | 772 | 1 400 |
| 2011–12 | + | + | 1 114 | 1 400 |
| 2012–13 | + | + | 1 171 | 1 400 |
| 2013–14 | + | + | 1 055 | 1 400 |
| 2014–15 | + | + | 1 181 | 1 400 |
| 2015–16 | + | + | 1 004 | 1 400 |
| 2016–17 | + | + | 775 | 1 400 |
| 2017–18 | + | + | 881 | 1 400 |

* FSU data.
\+ Unknown distribution of catch.

Reported catches have varied considerably between years, and the location of the catch in the late 1980s/early 1990s is uncertain, as some may have been taken from outside the EEZ, as well as misreported from other areas. Research fishing carried out under Special Permit in 1994 and 1995 resulted in catches of 45.2 t and 200.7 t, respectively (not included in Table 1).

Based on an evaluation of the results of an Adaptive Management Programme (AMP) for the Mercury-Colville box initiated in 1995, the AMP was concluded and the TACC was reduced to 800 t for the 2000–01 fishing year. Catch limits of 200 t were established in each of four areas in ORH 1, with an individual seamount feature limit of 100 t. From 1 October 2001, ORH 1 was reintroduced into the AMP with different design parameters for the five years, and the TACC was increased from 800 to 1400 t and allocated an allowance of 70 t for other mortality caused by fishing. The AMP was discontinued in 2007.

In recent years the fishery has also developed off the west coast and sizeable catches have been taken off the Tauroa Knoll and West Norfolk Ridge.

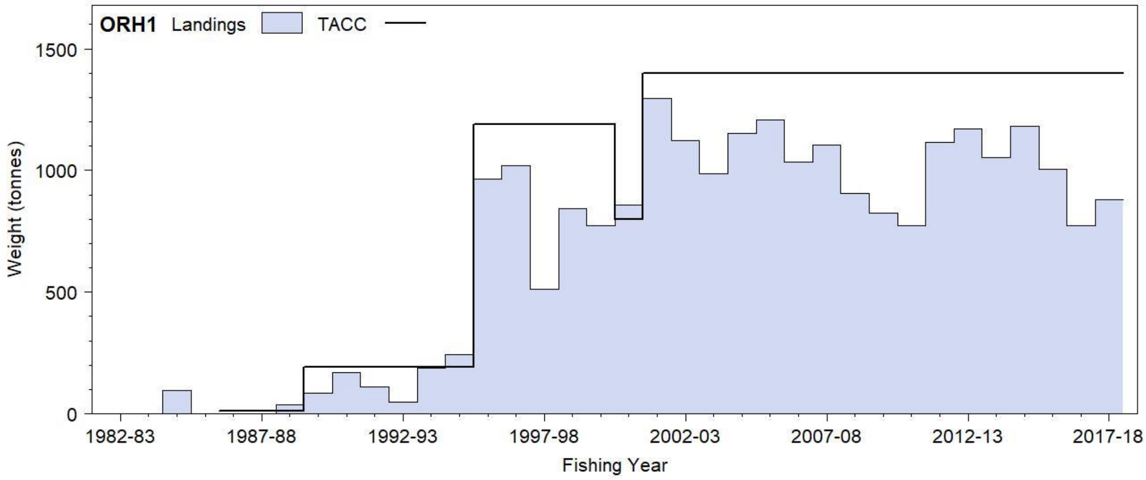


**Figure 1: Reported commercial landings and TACC for ORH 1 (Auckland).**

### 1.2 Recreational fisheries
There is no known non-commercial fishery for orange roughy in this area.

### 1.3 Customary non-commercial fisheries
No customary non-commercial fishing for orange roughy is known in this area.

### 1.4 Illegal catch
No quantitative information is available on the level of illegal catch in this area.

### 1.5 Other sources mortality
There may be some overrun of reported catch because of fish loss with trawl gear damage and ripped nets. In other orange roughy fisheries, a level of 5% has been estimated.

## 2. STOCKS AND AREAS

Orange roughy are distributed throughout the area. Spawning is known from several hills in the western Bay of Plenty as well as from features in the western regions of ORH 1. Stock status/affinities within the QMA are unknown. The Mercury-Colville grounds in the Bay of Plenty are about 120 n. miles from fishing grounds at East Cape (ORH 2A North), and spawning occurs at a similar time. Hence, it is likely that these are separate stocks. The Mercury and Colville Knolls in the Bay of Plenty are about 25 miles apart and may form a single stock. Stock affinities with other fishing hills in the southern and central Bay of Plenty are unknown. The Tauroa Knoll and outer Colville Ridge seamounts are distant from other commercial grounds, and these fish may also represent separate stocks.

## 3. STOCK ASSESSMENT

An assessment for the Mercury-Colville box was carried out in 2001 and is repeated here. A deterministic stock reduction technique (*after* Francis 1990) was used to estimate virgin biomass ($B_0$) and current biomass ($B_{current}$) for the Mercury-Colville orange roughy stock. The model was fitted to the biomass indices using maximum likelihood and assuming normal errors. In common with other orange roughy assessments, the maximum exploitation rate was set at 0.67. The model treats sexes separately, and assumes a Beverton-Holt stock-recruit relationship. Confidence intervals of the biomasss estimates were derived from bootstrap analysis (Cordue & Francis 1994).

### 3.1 Estimates of fishery parameters and abundance

A series of trawl surveys of the Mercury-Colville box to estimate relative abundance were agreed under an Adaptive Management Programme. The first survey was carried out in June 1995 with a second survey in winter 1998 (Table 2). The biomass index of the latter survey was much lower than 1995, and because of warmer water temperatures it was uncertain whether the 1998 results were directly comparable to the 1995 results. They were not incorporated in the decision rule for the adaptive management programme. A third survey was carried out in June 2000, with the results suggesting that the abundance of orange roughy in the box had decreased considerably and was at low levels. However, these estimates are uncertain because of the suggestion that environmental factors may have influenced the distribution of orange roughy. The abundance indices from trawl survey and commercial catch-effort data used in the assessment are given in Table 2. The trawl survey indices had CVs of 0.27, 0.39 and 0.29 for 1995, 1998, and 2000 respectively.

**Table 2: Biomass indices and reported catch used in estimation of $B_0$. Values in square brackets are included for completeness; they are not used in the assessment.**

| Year | 1993–94 | 1994–95 | 1995–96 | 1996–97 | 1997–98 | 1998–99 | 1999–00 |
|---|---|---|---|---|---|---|---|
| Trawl survey | - | 76 200 | - | - | [2 500] | - | 3 800 |
| CPUE | 8.3 | 9.1 | 5.4 | 4.2 | [0.5] | 1.5 | (2.0) |
| Catch (t) | 230 | 440 | 915 | 895 | 295 | 140 | 250 |

The CPUE series is mean catch per tow (sum of catches divided by number of tows, target ORH) from Mercury Knoll in the month of June. This is the only month when adequate data exist from the fishery to compare over time. A CV of 0.30 was assigned to the CPUE data.

Catch history information is derived from TCEPR records, scaled to the reported total catch for ORH 1. Overrun of reported catch (e.g., burst bags, inappropriate conversion factors) was assumed to be zero, as even if there was some, it is likely that it was similar between years. The catch in 1999–00 was assumed to be 250 t.

Assessments were carried out for three alternative sets of biomass indices (Table 3).

**Table 3: Three alternative sets of biomass indices used in the stock assessment.**

| Alternative | Trawl survey indices | CPUE indices |
|---|---|---|
| 1 | 1995, 2000 | All except 1998 |
| 2 | 1995, 2000 | None |
| 3 | 1995, 2000 | All except 1998 and 2000 |

Biological parameters used are those for the Chatham Rise stock, except for specific Bay of Plenty values for the maturity and recruitment ogives (Annala et al 2000).

### 3.2 Biomass estimates

The estimated virgin biomass ($B_0$) is very similar for all three alternative assessments (Table 4). With alternative 1 the estimated $B_0$ is 3200 t, with a current biomass of 15% $B_0$. For both alternatives 2 and 3, the estimated $B_0$ is 3000 t, which is $B_{min}$, the minimum stock size which enables the catch history to be taken given a maximum exploitation rate of 0.67.

**Table 4: Biomass estimates (with 95% confidence intervals in parentheses) for stock assessments with the three alternatives of Table 3. $B_0$ is virgin biomass; $B_{MSY}$ is interpreted as $B_{MAY}$, which is 30%$B_0$; $B_{current}$ is mid-season 1999–00; and $B_{beg}$ is the biomass at the beginning of the 2000–01 fishing year. Estimates are rounded to the nearest 100 t (for $B_0$), 10 t (for other biomasses), or 1%.**

| Biomass | Alternative 1 | | Alternative 2 | | Alternative 3 | |
|---|---|---|---|---|---|---|
| $B_0$ (t) | 3 200 | (3 000, 3 600) | 3 000 | (3 000, 3 500) | 3 000 | (3 000, 3 300) |
| $B_{MSY}$ (t) | 960 | (900, 1080) | 900 | (900, 1050) | 900 | (900, 990) |
| $B_{current}$ (t) | 490 | (290, 890) | 290 | (290, 790) | 290 | (290, 590) |
| $B_{current}$ (%B0) | 15 | (10, 25) | 10 | (10, 23) | 10 | (10, 18) |
| $B_{beg}$ (t) | 480 | (270, 900) | 270 | (270, 800) | 270 | (270, 590) |

The model fits the CPUE data reasonably well but estimates a smaller decline than is implied by the two trawl survey indices.

### 3.3 Yield estimates and projections

Yield estimates were determined using the simulation method described by Francis (1992) and the relative estimates of *MCY*, $E_{CAY}$ and *MAY*, as given by Annala et al (2000).

Yield estimates are all much lower than recent catches (Table 5). Estimates of current yields ($MCY_{\text{current}}$ and *CAY*) lie between 16 t and 35 t; long-term yields ($MCY_{\text{long-term}}$ and *MAY*) lie between 44 t and 67 t.

**Table 5: Yield estimates (t) for stock assessments with the three alternatives of Table 3.**

| Yield | Alternative 1 | | Alternative 2 | | Alternative 3 | |
|---|---|---|---|---|---|---|
| $MCY_{\text{curren}}$ | 35 | (22, 53) | 22 | (22, 51) | 22 | (22, 44) |
| $MCY_{\text{long-term}}$ | 47 | (44, 53) | 44 | (44, 51) | 44 | (44, 49) |
| *CAY* | 29 | (16, 54) | 16 | (16, 48) | 16 | (16, 36) |
| *MAY* | 67 | (58, 70) | 58 | (58, 68) | 58 | (58, 64) |

CSP for this stock is just under 100 t for any $B_0$ between 3000 t and 3600 t.

## 4. ANALYSIS OF ADAPTIVE MANAGEMENT PROGRAMME

The ORH 1 TACC was increased from 800 to 1400 t in October 2001/02 under the Adaptive Management Programme. The objectives of this AMP were to determine stock size, geographical extent, and long-term sustainable yield of the ORH 1 stock. This is a complex AMP, with ORH 1 divided into four sub-areas (see Figure 2), each with total catch and "feature" catch limits (Table 6) (a "feature" was defined as being within a 10 n. mile radius of the shallowest point).

**Table 6: Description of control rules implemented in the ORH 1 AMP.**

| ORH 1 Subarea | Proposed Catch Limit | Feature Limit (t/fishing year) |
|---|---|---|
| Area A | 200 t | 100 t |
| Area B | 500 t | 150 t |
| Area C | 500 t | 150 t |
| Area D | 200 t | 75 t |

Feature limits also serve as limits to the total catch in any area due to the limited number of available productive features. The Mercury-Colville "Box" (located within Area D) has been given a specific limit of 30 t per year to allow for the bycatch of orange roughy when fishing for black cardinalfish. The catch of orange roughy in the Mercury-Colville "Box" is included in the overall limit for Area D.

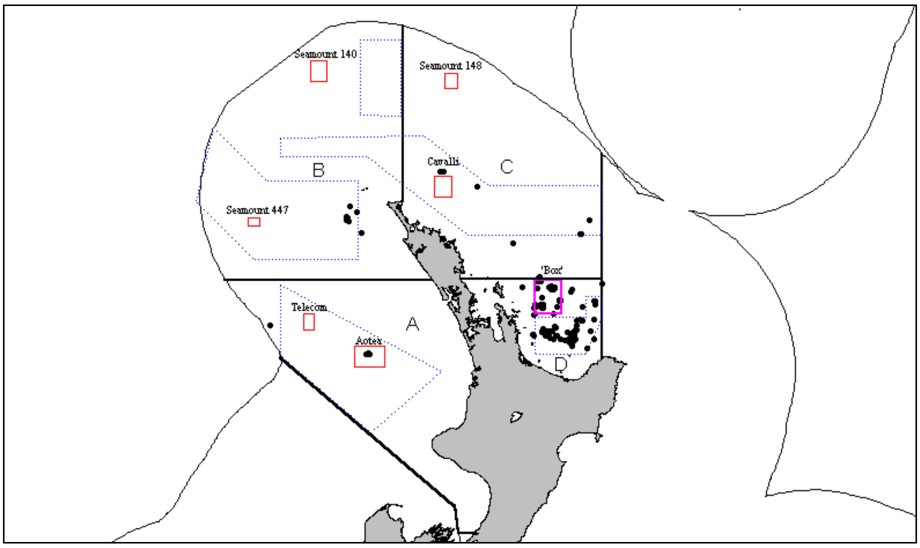


**Figure 2: Four sub-management areas for the ORH 1 AMP (labelled A-D). Dotted lines enclose the exploratory fishing areas defined in the special permit issued on 6 July 1998. Solid lines enclose seamount closures and the Mercury-Colville Ohena 'box' (labelled at their top). Trawls (dots) where orange roughy were reported as the target species and caught during 1997–98 and 1998–99 are shown. Note that the lines separating Areas A and D from Areas B and C are incorrectly drawn at 36° S latitude rather than 35°30' S latitude.**

From 1 October 2007 the stock is no longer part of the Adaptive Management Programme but stakeholders have agreed to continue with the sub-area and feature limits within the overall ORH 1 TACC.

### Review of ORH 1 AMP in 2007
In 2007 the AMP FAWG reviewed the performance of the AMP after the full 5-year term.

### Fishery Characterisation
- In most years, the total catch has been less than the TACC (Table 7).
- The area splits into A, B, C and D only occurred in 2001.
- Main fishery is in area B; the fishery in area A only began in 2002.
- Two main goals of the AMP:
  - Reduce fishing in area D, in particular the Mercury-Colville "box".
  - Look for new fishing areas, distributing effort across the QMA, with feature limits to reduce the possibility of localised overfishing.

**Table 7: Estimated target catches by sub-area, scaled to landings, reported landings, and TACC for ORH 1. The scaling factor is calculated as reported catch/estimated (all target) catch (source: Anderson 2007b)**

| | Sub-area target catch (t) | | | | Total target | Reported | TACC | Scaling |
|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | catch(t) | landings (t) | (t) | factor |
| 1998 | 0.5 | 5.6 | 0.0 | 491.0 | 497 | 511 | 1 190 | 0.99 |
| 1999 | 5.2 | 575.2 | 165.0 | 724.5 | 1 470 | 1 543 | 1 190 | 0.99 |
| 2000 | 0.8 | 644.6 | 164.8 | 597.5 | 1 408 | 1 476 | 1 190 | 1.03 |
| 2001 | 8.5 | 166.3 | 99.4 | 164.6 | 439 | 858 | 800 | 1.11 |
| 2002 | 122.7 | 440.5 | 265.8 | 227.1 | 1 056 | 1 294 | 1 400 | 1.06 |
| 2003 | 196.7 | 508.1 | 237.9 | 72.2 | 1 015 | 1 123 | 1 400 | 0.98 |
| 2004 | 223.2 | 421.7 | 117.0 | 110.1 | 872 | 986 | 1 400 | 1.01 |
| 2005 | 277.0 | 389.8 | 173.4 | 174.1 | 1 014 | 1 151 | 1 400 | 1.13 |
| 2006 | 151.0 | 473.2 | 372.6 | 186.0 | 1 183 | 1 201 | 1 400 | 1.13 |

### CPUE Analysis
- Unstandardised CPUE is in kg/tow. The short time series, the nature of the fishery (fishing aggregations spread over a wide area in different seasons) and the impact of catch limits on features and sub-areas prevent any useful relative abundance indices from being developed at this point for ORH 1.
- Where features are less than 10 n. mile apart, catch is apportioned according to the distance to the feature. Industry in-season reporting is based on the feature closest to the start of the tow.

- Possible problems with the area A observations in 2005–06, as there seem to be more reported tows than expected given the number of vessels operating in the area.

**Observer Programme**

- 50% observer coverage prior to 1 October 2006 (a high level relative to that for other deepwater stocks, with a large number of samples taken relative to the size of the fishery). From 1 October 2006, 100% coverage was requested by the Minister, but this has not been fully achieved, as some ORH 1 is taken as bycatch on trips that do not predominantly target ORH.
- The size frequency data show high levels of stock variability between fisheries on features or feature groups. Size variation does not seem to be linked to exploitation rate.

**Environmental Effects**

- Observer data from 2000 to 2003 indicated that incidental captures of seabirds did not occur in the ORH 1 target fishery (Baird 2005). Marine mammal interactions are also not .a problem.
- Only three non-fish bycatch records have been reported from observed trips (in 1994 and 1995). All were shearwaters that landed on deck and were released alive. It was verified that observers were briefed in the same way as for other MFish trips including recording non-fish bycatch i.e. seabirds and marine mammals. Note that this does not include benthic organisms.
- The overall impact of bottom trawling on seamounts in ORH 1 is not known. A number of seamounts have been closed to fishing and the Norfolk Deep BPA is included in the industry accord relating to benthic protection areas within New Zealand's EEZ.

**Sub-area D Directed Adaptive Exploratory Fishing Programme**

- The purpose of this exercise was to establish whether fish populations shift between features in different years in sub-area D.
- Based on the results from the exploratory fishing from 2002 to 2005 it is evident that catches from all features contained a high proportion of ripe or ripe running females and that synchronised spawning occurs on a range of hills during winter.
- In 2006 the AMP Working Group recommended some changes to the design of the exploratory survey; however, this was not achieved during the 2006 survey.

The abbreviated checklist questions for full- and mid-term reviews are:

1. Is stock abundance adequately monitored?

   The working group concluded that CPUE does not seem to be a proportional measure of abundance for this stock. However, CPUE is used in ORH 1 as a management tool. When CPUE drops on a feature, fishers are meant to move to another feature.
2. Is logbook coverage sufficient?

   As there are Ministry fisheries observers on these vessels, fishers are not required to complete detailed logbooks for the AMP. This is the highest level of monitoring of any ORH fishery in New Zealand.
3. Are additional analyses of current data necessary?

   No. The Working Group concluded that no other information can currently be extracted from the existing data that will provide insight into the status of the ORH 1 stocks. However, a potential problem with the 2005–06 catch records from Area A still needs to be checked.
4. Based on the biomass index, is current harvest sustainable?

   Unknown. The purpose of the AMP was to spread effort in an attempt to reduce fishing pressure on any one sub-area or feature (and Area D in particular). ORH 1 is a large area, with orange roughy aggregations spread across a number of areas and features. The amount of fishing in some areas appears to be low, but without any indication of current abundance, there is no way to determine if this level of fishing is in fact sustainable, or if current feature limits will avoid overexploitation of localised areas.
5. Where is stock, based on weight of evidence, in relation to $B_{MSY}$?

   Unknown. In 2001, when the AMP was initiated, the Working Group stated that the stock was likely to be above $B_{MSY}$; while the information collected since that time has

not improved the understanding about the status of the stock, the intent of the AMP design for ORH 1 was to spread effort to reduce the likelihood of the biomass declining below $B_{MSY}$.
ORH 1 is unlikely to be a single biological stock, and probably includes a number of constituent stocks. The Working Group concluded that it is not possible to estimate $B_{MSY}$ for any of the individual stocks, let alone aggregate up to an estimate for ORH 1 as a whole. Moreover, a better understanding is not possible in the near future. $B_{MSY}$ is difficult to estimate in situations involving an unknown number of constituent stocks.

6. Are the effects of fishing adequately monitored?
   Yes, there is good observer coverage. The Working Group noted that one consequence of deliberately spreading effort was to increase the possible benthic impact.
7. Are rates of non-fish bycatch acceptable?
   Yes.
8. Should the AMP be reviewed by the Plenary?
   This AMP does not need to be reviewed by the Plenary.

## 5. STATUS OF THE STOCKS

From 1 October 2001, the TACC for ORH 1 was increased to 1 400 t within the AMP, with sub-area and feature limits. From 1 October 2007 the stock is no longer part of the Adaptive Management Programme but stakeholders have agreed to continue with the sub-area and feature limits within the overall ORH 1 TACC.

In most years the total catch has been less than the TACC. However, it is not known if recent catch levels or current TACCs are sustainable in the long term. Except for the small area of the Mercury-Colville box no assessment of stock status is currently available.

An assessment of the Mercury-Colville box in 2001 indicated that biomass had been reduced to 10-15% $B_0$ (compared to an assumed $B_{MSY}$ of 30% $B_0$). As the stock was considered to be well below $B_{MSY}$, a catch limit of 30 t was set for the box. The assessment indicated that a catch level of about 100 t would probably maintain the stock at the 2000 stock size (assuming deterministic recruitment) and catch levels from 16 to 35 t (consistent with *CAY* or *MCY* strategies) might allow the stock to rebuild slowly.

In other areas of ORH 1 the status of the constituent stocks is unknown. The amount of fishing in some areas appears to be low, but without any indication of current abundance, there is no way to determine if this level of fishing is in fact sustainable or if current feature limits will avoid overexploitation of localised areas.

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# ORANGE ROUGHY, CAPE RUNAWAY TO BANKS PENINSULA (ORH 2A, 2B, 3A)

## 1. FISHERY SUMMARY

### 1.1 Commercial fisheries

The first reported landings of orange roughy between Cape Runaway and Banks Peninsula were in 1981–82 occurring with the development of the Wairarapa fishery. Total reported catches and TACCs grouped into the three orange roughy Fishstocks from 1981–82 to 2017–18 are shown in Table 1. The historical catches and TACCs for these stocks are shown in Figure 1.

**Table 1: Reported catches (t) and TACCs (t) from 1981–82 to 2017–18. QMS data from 1986–present.**

| Fishing Year | QMA 2A (Ritchie + E.Cape) | | QMA 2B (Wairarapa) | | QMA 3A (Kaikoura) | | All areas combined | |
|---|---|---|---|---|---|---|---|---|
| (1 Oct–30 Sep) | Catches | TACC | Catches | TACC | Catches | TACC | Catches | TACC or catch limit |
| 1981–82* | - | - | 554 | - | - | - | 554 | - |
| 1982–83* | - | - | 3 510 | - | 253 | - | 3 763 | - |
| 1983–84† | 162 | - | 6 685 | - | 554 | - | 7 401 | - |
| 1984–85† | 1 862 | - | 3 310 | 3 500 | 3 266 | § | 8 438 | - |
| 1985–86† | 2 819 | 4 576 | 867 | 1 053 | 4 326 | 2 689 | 8 012 | 8 318 |
| 1986–87 | 5 187 | 5 500 | 963 | 1 053 | 2 555 | 2 689 | 8 705 | 9 242 |
| 1987–88 | 6 239 | 5 500 | 982 | 1 053 | 2 510 | 2 689 | 9 731 | 9 242 |
| 1988–89 | 5 853 | 6 060 | 1 236 | 1 367 | 2 431 | 2 839 | 9 520 | 10 266 |
| 1989–90 | 6 259 | 6 106 | 1 400 | 1 367 | 2 878 | 2 879 | 10 537 | 10 352 |
| 1990–91 | 6 064 | 6 106 | 1 384 | 1 367 | 2 553 | 2 879 | 10 001 | 10 352 |
| 1991–92 | 6 347 | 6 286 | 1 327 | 1 367 | 2 443 | 2 879 | 10 117 | 10 532 |
| 1992–93 | 5 837 | 6 386 | 1 080 | 1 367 | 2 135 | 2 879 | 9 052 | 10 632 |
| 1993–94 | 6 610 | 6 666 | 1 259 | 1 367 | 2 131 | 2 300 | 10 000 | 10 333 |
| 1994–95 | 6 202 | 7 000 | 754 | 820 | 1 686 | 1 840 | 8 642 | 9 660 |
| 1995–96 | 4 268 | 4 261 | 245 | 259 | 612 | 580 | 5 125 | 5 100 |
| 1996–97 | 3 761 | 4 261 | 272 | 259 | 580 | 580 | 4 613 | 5 100 |
| 1997–98 | 3 827 | 4 261 | 254 | 259 | 570 | 580 | 4 651 | 5 100 |
| 1998–99 | 3 335 | 3 761 | 257 | 259 | 582 | 580 | 4 174 | 4 600 |
| 1999–00 | 3 120 | 3 761 | 234 | 259 | 617 | 580 | 3 971 | 4 600 |
| 2000–01 | 1 385 | 1 100 | 190 | 185 | 479 | 415 | 2 054 | 1 700 |
| 2001–02 | 1 087 | 1 100 | 180 | 185 | 400 | 415 | 1 667 | 1 700 |
| 2002–03 | 782 | 680 | 105 | 99 | 235 | 221 | 1 122 | 1 000 |
| 2003–04 | 703 | 680 | 103 | 99 | 250 | 221 | 1 056 | 1 000 |
| 2004–05 | 1 120 | 1 100 | 206 | 185 | 416 | 415 | 1 742 | 1 700 |
| 2005–06 | 1 076 | 1 100 | 172 | 185 | 415 | 415 | 1 663 | 1 700 |
| 2006–07 | 1 131 | 1 100 | 203 | 185 | 401 | 415 | 1 736 | 1 700 |
| 2007–08 | 1 068 | 1 100 | 209 | 185 | 432 | 415 | 1 709 | 1 700 |
| 2008–09 | 1 114 | 1 100 | 173 | 185 | 414 | 415 | 1 701 | 1 700 |
| 2009–10 | 1 117 | 1 100 | 213 | 185 | 390 | 415 | 1 720 | 1 700 |
| 2010–11 | 1 113 | 1 100 | 158 | 185 | 420 | 415 | 1 690 | 1 700 |
| 2011–12 | 876 | 875 | 140 | 140 | 428 | 415 | 1 445 | 1 430 |
| 2012–13 | 727 | #875 | 102 | #140 | 296 | #415 | 1 124 | #1 430 |
| 2013–14 | 732 | 875 | 108 | 140 | 331 | 415 | 1 171 | 1 430 |
| 2014–15 | 483 | 488 | 54 | 60 | 156 | 177 | 693 | 725 |
| 2015–16 | 474 | 488 | 59 | 60 | 178 | 177 | 710 | 725 |
| 2016–17 | 505 | 488 | 57 | 60 | 174 | 177 | 736 | 725 |
| 2017–18 | 485 | 488 | 46 | 60 | 117 | 177 | 647 | 725 |

* Ministry data † FSU data. § Included in QMA 3B TAC.

\# In 201213, shelving (an agreement that transfers ACE to a third party to effectively reduce the catch without adjusting the TACC) occurred (ORH 2A 165 t, ORH 2B 34 t and ORH 3A 101 t)

There was a major change in the ORH 2A fishery in 1993–94 with a shift of effort from the main spawning hill on Ritchie Bank to hills off East Cape. Although these hills had apparently only been lightly fished in the past, during 1993–94 52% of the total catch from ORH 2A was taken from the East Cape area (Table 2). This led to an agreement between industry and the Minister responsible for fisheries that, from 1994–95, the traditionally fished areas within ORH 2A (south of 38°23', hereafter referred to as “2A South”) would be managed separately from the new East Cape fishery (north of 38°23', “2A North”). ORH 2A South was combined with ORH 2B and ORH 3A to form the Mid-East Coast (MEC) stock for management purposes.

The catch limits for these two areas changed three times in the following four years, including a subdivision of 2A North (Table 3). Catches in the exploratory sub-area of 2A North never approached the catch limit, with only 37 t being caught in 1996–97 and less in subsequent years.

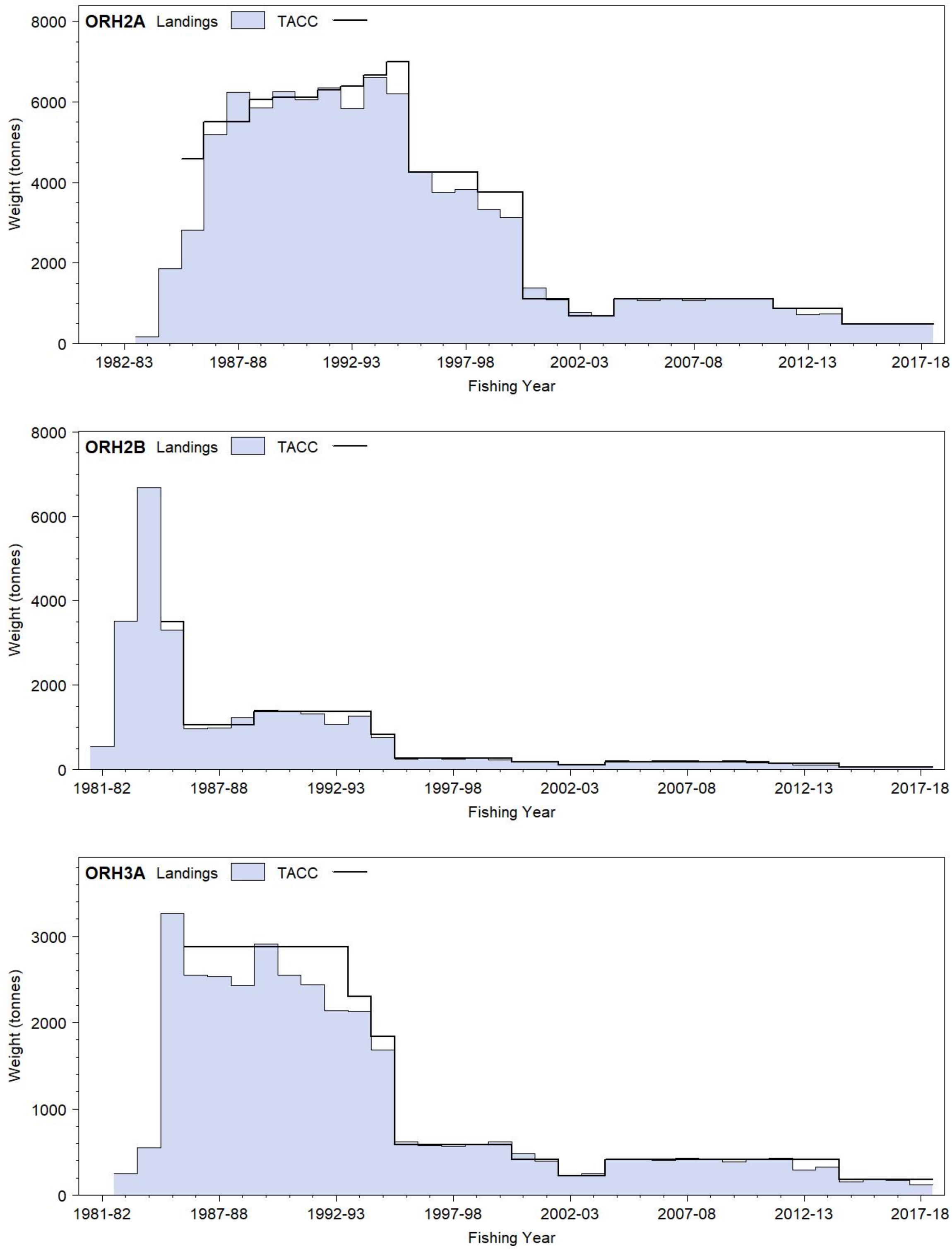



**Figure 1: Reported commercial landings and TACCs for ORH 2A (Central (Gisborne)), ORH 2B (Central (Wairarapa)), and ORH 3A (Central/Challenger/South-East (Cook Strait/Kaikoura)).**

For the 2000–01 fishing year, the TACC for ORH 2A was reduced to 1 100 t, that for ORH 2B to 185 t, and that for ORH 3A to 415 t. Within the TACC for ORH 2A, the catch limit for all of 2A North was reduced to 200 t, without specifying separate catch limits for the East Cape Hills and the exploratory area, while the catch limit for 2A South was reduced to 900 t. This gave a catch limit for the MEC stock of 1 500 t. The catch limit for MEC was reduced to 800 t (and ORH 2A South to 480 t) for the 2002–03 and 2003–04 fishing years. From 1 October 2004 there was an increase in the TACC to 1 100 t, 185 t, and 415 t in 2A, 2B, and 3A respectively. Furthermore, an allowance of 58 t, 9 t, and 21 t, for other mortality was allocated to 2A, 2B, and 3A in 2004 as well.

In 2012–13 the fishing industry voluntarily shelved (an agreement that transfers ACE to a third party to effectively reduce the catch without adjusting the TACC) approximately 25% of the MEC quota, resulting in effective catch limits of 510 t, 106 t, and 314 t for 2A South, 2B, and 3A respectively.

## 1.2 Recreational fisheries

Recreational fishing for orange roughy is not known in this area.

## 1.3 Customary non-commercial fisheries

No information on customary non-commercial fishing for orange roughy is available for this area.

## 1.4 Illegal catch

No information is available about illegal catch in this area.

**Table 2: North Mid-East Coast + East Cape (ORH 2A) catches by area, in tonnes and by percentage of the total ORH 2A catch. (Percentages up to 1993–94 and from 2007–08 calculated from Ministry data; 1994–95 to 1996–97 from NZFIB data, and 1997–98 to 2016–17 from Orange Roughy Management Co.) Mid-East Coast (MEC) stock (ORH 2A South, ORH 2B, and ORH 3A combined) catches in tonnes.**

| Fishing year | 2A North | | 2A South | | MEC (t) |
|---|---|---|---|---|---|
| | t | % | t | % | |
| 1983–84 | 0 | 0 | 162 | 100 | 7 401 |
| 1984–85 | 4 | < 1 | 1 858 | 99 | 8 434 |
| 1985–86 | 41 | 1 | 2 778 | 99 | 7 971 |
| 1986–87 | 253 | 5 | 4 934 | 95 | 8 452 |
| 1987–88 | 36 | < 1 | 6 203 | 99 | 9 695 |
| 1988–89 | 143 | 2 | 5 710 | 98 | 9 377 |
| 1989–90 | 20 | < 1 | 6 239 | 99 | 10 517 |
| 1990–91 | 13 | < 1 | 6 051 | 99 | 9 988 |
| 1991–92 | 18 | < 1 | 6 329 | 99 | 10 099 |
| 1992–93 | 30 | < 1 | 5 807 | 99 | 9 022 |
| 1993–94 | 3 437 | 52 | 3 173 | 48 | 6 563 |
| 1994–95 | 2 921 | 47 | 3 281 | 53 | 5 721 |
| 1995–96 | 3 235 | 76 | 1 033 | 24 | 1 890 |
| 1996–97 | 2 491 | 66 | 1 270 | 34 | 2 122 |
| 1997–98 | 2 411 | 63 | 1 416 | 37 | 2 240 |
| 1998–99 | 1 901 | 57 | 1 434 | 43 | 2 273 |
| 1999–00 | 1 456 | 47 | 1 666 | 53 | 2 517 |
| 2000–01 | 302 | 22 | 1 083 | 78 | 1 752 |
| 2001–02 | 186 | 17 | 901 | 83 | 1 480 |
| 2002–03 | 173 | 24 | 546 | 76 | 886 |
| 2003–04 | 170 | 24 | 533 | 76 | 886 |
| 2004–05 | 271 | 24 | 849 | 76 | 1 471 |
| 2005–06 | 216 | 20 | 859 | 80 | 1 445 |
| 2006–07 | 229 | 20 | 902 | 80 | 1 506 |
| 2007–08 | 200 | 24 | 868 | 76 | 1 509 |
| 2008–09 | 230 | 21 | 884 | 79 | 1 471 |
| 2009–10 | 267 | 24 | 850 | 76 | 1 453 |
| 2010–11 | 207 | 19 | 906 | 81 | 1 484 |
| 2011–12 | 184 | 21 | 692 | 79 | 1 260 |
| 2012–13 | 190 | 26 | 537 | 74 | 935 |
| 2013–14 | 176 | 25 | 530 | 75 | 5 315 |
| 2014–15 | 179 | 42 | 248 | 58 | 458 |
| 2015–16 | 186 | 40 | 280 | 60 | 466 |
| 2016–17 | 188 | 37 | 317 | 63 | |

## 1.5 Other sources of mortality

There has been a history of catch overruns in this area because of lost fish and discards, particularly in the early years of the fishery. In the assessments presented here total removals were assumed to exceed reported catches by the overrun percentages in Table 4.

All yield estimates and forward projections presented make an allowance for the current estimated level of overrun of 5%.

**Table 3: Catch limits (t) by sub-area within ORH 2A, as agreed between the industry and the Minister responsible for fisheries since 1994–95 and the catch limit for the Mid-East Coast (MEC) stock (ORH 2A South, ORH 2B, ORH 3A combined). (Note that 2A North was split, for the years 1996–97 to 1999–2000, into the area round the East Cape Hills and the remaining area, which is called the exploratory area).**

| Fishing year | 2A North | 2A South | MEC |
|---|---|---|---|
| 1994–95 | 3 000 | 4 000 | 6 660 |
| 1995–96 | 3 000 | 1 261 | 2 100 |
| 1996–97 | 3 000* | 1 261 | 2 100 |
| 1997–98 | 3 000* | 1 261 | 2 100 |
| 1998–99 | 2 500* | 1 261 | 2 100 |
| 1999–00 | 2 500* | 1 261 | 2 100 |
| 2000–01 | 200 | 900 | 1 500 |
| 2001–02 | 200 | 900 | 1 500 |
| 2002–03 | 200 | 480 | 800 |
| 2003–04 | 200 | 480 | 800 |
| 2004–05 | 200 | 900 | 1 500 |
| 2005–06 | 200 | 900 | 1 500 |
| 2006–07 | 200 | 900 | 1 500 |
| 2007–08 | 200 | 900 | 1 500 |
| 2008–09 | 200 | 900 | 1 500 |
| 2009–10 | 200 | 900 | 1 500 |
| 2010–11 | 200 | 900 | 1 500 |
| 2011–12 | 200 | 675 | 1 230 |
| 2012–13 | 200 | 510 | 930 |
| 2013–14 | 200 | 510 | 930 |
| 2014–15 | 200 | 288 | 525 |
| 2015–16 | 200 | 288 | 525 |
| 2016–17 | 200 | 288 | 525 |

*Catch limit for East Cape Hills including 500 t for the exploratory area.

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

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

## 2. BIOLOGY

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

## 3. STOCKS AND AREAS

Two major spawning locations have been identified in ORH 2A, one at the East Cape Hills in "2A North" and the other on the Ritchie Bank in "2A South". Spawning orange roughy were located in Wairarapa (ORH 2B) in winter 2001, but no large concentrations were found, and the significance of this spawning event is not known. Spawning orange roughy have not been located in Kaikoura

(ORH 3A). The major spawning area in ORH 2A South, ORH 2B, and ORH 3A is still believed to be the Ritchie Bank, although spawning aggregations were not seen here in the 2013 AOS survey.

Results from allozyme studies showed that orange roughy from the three areas, “2A South”, Wairarapa, and Kaikoura could not be separated, but were distinct from fish on the eastern Chatham Rise. Earlier analyses that suggested there was a genetic stock boundary between East Cape and Ritchie Bank were not supported by a more recent replicate sample from East Cape. For these reasons, orange roughy in this region are currently treated as two stocks: the Mid-East Coast (MEC) stock (2A South, Wairarapa, and Kaikoura) and the East Cape (EC) stock (2A North). The relationship between these areas and the location of the main fishing grounds is shown in Figure 2.

## 4. STOCK ASSESSMENT

Stock assessments are reported below for East Cape from 2003 and for Mid-East Coast (MEC) from 2014. In 2018 there was a preliminary update of the MEC stock assessment (Cordue 2017). The stock status and biomass trajectories from the preliminary stock assessment did not change or revise those reported for the 2014 assessment (Cordue 2014b). Because of the similarity in results, rather than report the preliminary results from the 2018 assessment, the 2014 assessment was retained in this report.

### 4.1 East Cape stock (2A North)

The stock assessment for the East Cape was last updated in 2003 and is summarised here (Anderson 2003b). An attempt to update the assessment with a new set of CPUE indices was made in 2006, but was rejected by the Working Group because of changes in the fishery which invalidated the utility of the CPUE series as an index of abundance. With no other abundance estimates available, an updated stock assessment was not possible.

#### 4.1.1 Assessment Inputs

A CPUE analysis was performed in 2006, but was considered unreliable because of a change in fishing patterns and fleet size corresponding to the reduction of the catch limit to 200 t in 2000–01. The CPUE analysis was updated in 2011 and was considered more reliable by the Working Group due to the increase in the number of trawls per year since 2006. The 2011 analysis showed that standardised CPUE decreased after a peak in 2003–04, and has subsequently remained at a level similar to that in the late 1990s to early 2000s (Table 5).

Previous concerns by the Working Group that the fishery was dominated by a single vessel were alleviated somewhat by the return or entry of three other vessels to the fishery since 2003–04, but the utility of CPUE analyses in fisheries where substantial catch limit reductions have caused major changes in fishing patterns remains an issue for this stock.

The model inputs for the 2003 stock assessment were catches, an egg survey, and CPUE indices (Table 5). The biological parameters used are presented in the Biology section at the beginning of the Orange Roughy section.

#### 4.1.2 Stock assessment

A stock assessment analysis for the East Cape stock was performed in 2003 using the stock assessment program, CASAL (Bull et al 2002) to estimate virgin and current biomass.

- The model was fitted using Bayesian estimation and partitioned the EC stock population by sex, maturity (the fishery was assumed to act on mature fish only) and age (age-groups used were 1–70, with a plus group).
- The model estimated virgin biomass, $B_0$, and the process error for the CPUE indices. Catchability, $q$, was treated as a nuisance parameter by the model.
- The stock was considered to reside in a single area, and to have a single maturation episode modelled by a logistic-producing ogive where 50% of fish of both sexes were mature at age 26 and 95% at age 29.

- The catch equation used was the instantaneous mortality equation from Bull et al (2002) whereby half the natural mortality was applied, followed by the fishing mortality, then the remaining natural mortality.
- The size at age model used was the von Bertalanffy.
- No stock recruitment relationship was assumed.
- A Bayesian estimation procedure was used with a penalty function included to discourage the model from allowing the stock biomass to drop below a level at which the historical catch could not have been taken.
- Lognormal errors, with known (sampling error) CVs were assumed for the CPUE and egg survey indices. Additionally, process error variance was estimated by the model and added to the CVs from the CPUE indices.
- Confidence intervals were calculated from the posterior profile distribution of $B_0$ estimates, where the process error parameter was fixed at the value previously estimated.

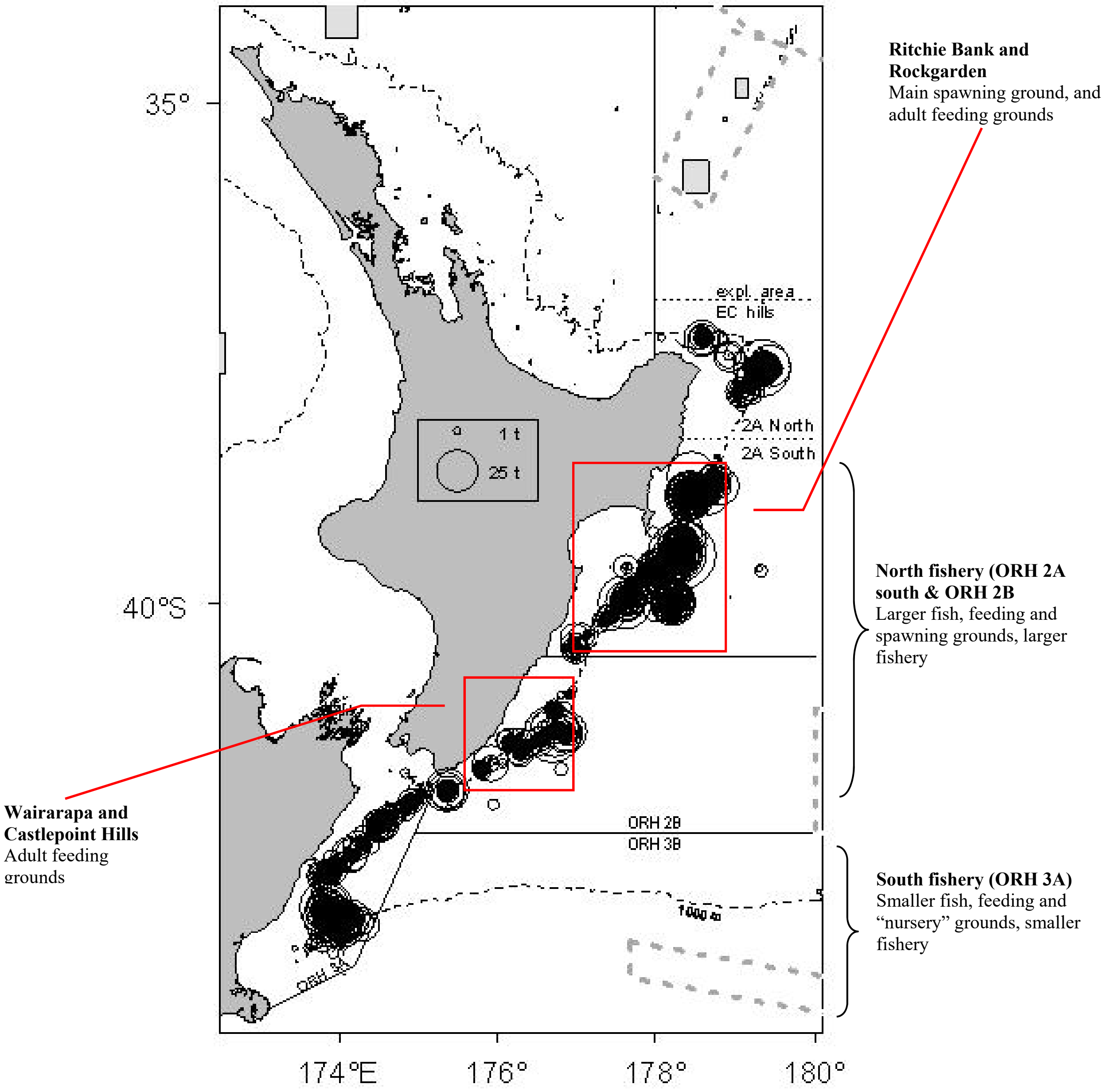



**Figure 2: Catch (t) per tow of orange roughy in ORH 2A, ORH 2B, and ORH 3A for the five fishing years from 2006–07 to 2010–11 (circles, with area proportional to catch size), location of the fisheries assumed during stock assessment, and the location of the main spawning, feeding, and nursery grounds. Perimeters of Benthic Protection Areas (BPAs) closed to bottom trawling are marked with dashed grey lines, and seamounts closed to trawling are marked as shaded rectangles.**

**Table 5: Standardised CPUE and egg survey indices, and CVs for the East Cape stock, as used in the 2003 assessment, and an updated standardised CPUE index derived in 2011. -, no data.**

| | CPUE index 2003 | CV(%) | Egg survey | CV(%) | CPUE index 2011 | CV(%) |
|---|---|---|---|---|---|---|
| 1993–94 | 1.00 | 12 | - | - | 0.95 | 23 |
| 1994–95 | 0.69 | 8 | 29 000 | 69 | 0.76 | 22 |
| 1995–96 | 0.60 | 8 | - | - | 0.61 | 23 |
| 1996–97 | 0.41 | 8 | - | - | 0.47 | 22 |
| 1997–98 | 0.25 | 7 | - | - | 0.27 | 23 |
| 1998–99 | 0.25 | 7 | - | - | 0.28 | 23 |
| 1999–00 | 0.22 | 9 | - | - | 0.23 | 23 |
| 2000–01 | 0.21 | 15 | - | - | 0.28 | 26 |
| 2001–02 | 0.22 | 16 | - | - | 0.23 | 27 |
| 2002–03 | - | - | - | - | 0.51 | 32 |
| 2003–04 | - | - | - | - | 0.50 | 30 |
| 2004–05 | - | - | - | - | 0.29 | 27 |
| 2005–06 | - | - | - | - | 0.37 | 28 |
| 2006–07 | - | - | - | - | 0.36 | 29 |
| 2007–08 | - | - | - | - | 0.27 | 28 |
| 2008–09 | - | - | - | - | 0.24 | 28 |
| 2009–10 | - | - | - | - | 0.20 | 27 |

### 4.1.3 Biomass estimates

Biomass estimates for this stock are given in Table 6 and the biomass trajectories, plotted against the scaled indices, are shown in Figure 3. The base case assessment of the EC stock included only the CPUE indices. An alternative assessment was carried out including the point estimate of biomass from the 1995 egg survey along with the CPUE indices. The CPUE indices agree well with the biomass estimates, with only the 1993–94 and 1997–98 indices departing from the biomass 95% confidence intervals. The egg survey biomass estimate, with the large associated CV, has little effect on the biomass trajectory.

**Table 6: Estimates of virgin biomass ($B_0$), $B_{MSY}$ (calculated as $B_{MAY}$, the mean biomass under a *CAY* policy), and $B_{2003}$, for the EC stock (with 95% confidence intervals in parentheses).**

| | | | | | $B_{2003}$ | | |
|---|---|---|---|---|---|---|---|
| Assessment | Index | $B_0$ (t) | | $B_{MSY}$ (t) | (t) | % $B_0$ | |
| Base case | CPUE | 21 100 | (19 650–23 350) | 6 300 | 5 100 | 24 | (20–32) |
| Alternative | CPUE + Egg survey | 21 200 | (19 700–23 550) | 6 380 | 5 200 | 25 | (20–33) |

The base case estimate of $B_{CURRENT}$ (the mid-year biomass in 2002–03) is 5100 t (24% $B_0$) with a 95% confidence interval of 3800 to 7550 t. This is almost twice the value of $B_{2003}$ estimated for mid-year 1999–2000 in the previous assessment (Anderson 2000). The alternative assessment gives a very similar estimate of $B_{2003}$.

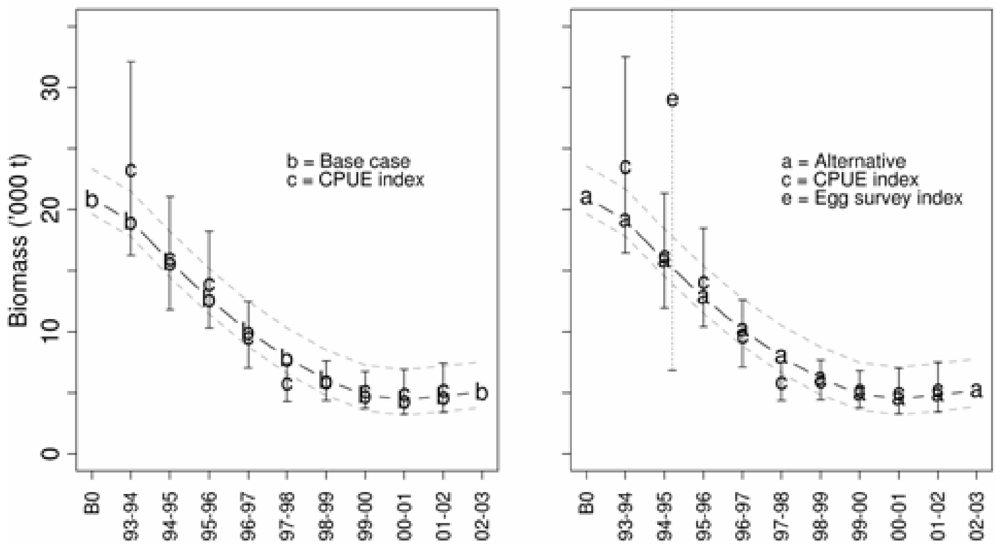



**Figure 3: Estimated biomass trajectories for the base case and alternative model runs for the EC stock. Annual biomass estimates are mean posterior density (MPD) values and 95% confidence intervals (grey dashed lines) are calculated from the posterior profile distribution of $B_0$ estimates. The CPUE index CVs (sampling error plus process error) are shown, as is the CV calculated for the egg survey biomass estimate.**

#### 4.1.4 Yield estimates and projections

Estimates of *MCY* and *CAY* for the *EC* stock were calculated from large numbers of simulation runs using posterior profile sampling of $B_0$ and a series of trial harvest levels. These estimates, together with *MAY* (the mean catch with a *CAY* harvesting strategy) and *CSP* (current surplus production) are given in Table 7. *CSP* is driven by recruitment of fish spawned before the fishery began.

**Table 7: Estimates of *MCY*, *CAY*, *MAY*, and *CSP* for the *EC* stock, with 95% confidence intervals in parentheses (all corrected for an assumed overrun of 5%).**

| Assessment | *MCY* (t) | *CAY* (t) | *MAY* (t) | *CSP* (t) |
|---|---|---|---|---|
| Base case | 350 | 370 | 410 | 550 |
| Alternative | 350 | 370 | 410 | 550 |

### 4.2 Mid-East Coast stock (2A South, 2B, 3A)

There was no new information available that would change the accepted stock definition of the MEC orange roughy stock i.e. comprising ORH 2A South, ORH 2B, and ORH 3A.

The Mid-East Coast (MEC) stock assessment was updated in 2014 using the methods common to the four assessments performed in 2014 (see Orange Roughy Introduction). The previous model based assessment was in 2013 but that assessment used data which did not meet the quality threshold applied in 2014 (i.e., CPUE indices, wide-area acoustic survey and egg-survey estimates). In 2014, an age-structured population model was fitted to the data described in Section 4.2.2 below.

#### 4.2.1 Model structure

The model was single-sex and age-structured (1–120 years with a plus group) with maturity in the partition (i.e., fish were classified by age and as mature or immature). A single area and a single time step were used with two year-round fisheries defined by different selectivities (a "southern" fishery catching young fish (double-normal selectivity) and a "northern" fishery catching older fish (logistic selectivity). The spawning season was assumed 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 catches in Tables 1 and 2, adding the catch over-run percentages in Table 4. The northern fishery combined catches from ORH 2A South and ORH 2B, and the southern fishery used ORH 3A. 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 the Orange Roughy Introduction.

#### 4.2.2 Input data and statistical assumptions

There were three main data sources for observations fitted in the assessment: a spawning biomass estimate from an acoustic survey (2013); a trawl-survey time series of relative biomass indices (1992–1994, 2010) with associated length frequencies (1992, 1994), and age frequencies and estimates of proportion spawning at age (1993, 2010); and length and age frequencies collected from the commercial fisheries, including four spawning-season age frequencies (1989–1991, 2010).

**Research surveys**

The MEC area has been surveyed using acoustic and trawl methods, and egg surveys have also been conducted. Not all survey data have been used in the 2014 assessment. The egg survey estimates have some quality issues associated with them; the 1993 survey data were post-stratified and "corrected" for turn-over of fish (Zeldis et al 1997). The 1993 egg-survey estimate was used in the 2013 assessment but was not considered to be reliable enough for the 2014 assessment (which had a higher "quality threshold"). Similarly, the wide-area acoustic survey estimates from 2001 and 2003 (Doonan et al 2003, 2004a) were rejected in 2014 as being not sufficiently reliable (in particular, the biomass estimates primarily came from mixed species marks and "orange roughy" marks identified subjectively; rather than being from easily identified spawning plumes).

### Trawl survey data

A time series of pre-spawning season, random, stratified, trawl surveys were conducted in March–April on *RV Tangaroa* in 1992–94 and 2010 (Grimes et al 1994, 1996a, 1996b; Doonan & Dunn 2011). The 2010 survey was specifically designed to be comparable with the earlier surveys and to produce an abundance index for the MEC home grounds (Doonan & Dunn 2011). In addition to the relative biomass indices (Table 8), the survey data were analysed to produce length frequencies from all years and age frequencies from 1993 and 2010 (Doonan et al 2011). Also, estimates of female proportion spawning at age were produced for the 1993 and 2010 surveys (Ian Doonan, pers. comm.).

**Table 8: Biomass indices and CVs used in the stock assessment.**

| Year | Trawl index (t) | CV (%) | Acoustic index (t) | CV (%) |
|---|---|---|---|---|
| 1992 | 20 838 | 29 | | |
| 1993 | 15 102 | 27 | | |
| 1994 | 12 780 | 14 | | |
| | | | | |
| 2010 | 7 074 | 19 | | |
| 2011 | | | | |
| 2012 | | | | |
| 2013 | | | 4 225 | 20 |

The biomass indices were fitted as relative biomass with a double-normal selectivity (it is apparent that the trawl survey did not fully select the largest/oldest fish) and an uninformed prior on the proportionality constant ($q$). The length frequencies from 1992 and 1994 were fitted as multinomial, as were the age frequencies from 1993 and 2010 (length frequencies from 1993 and 2010 had been used in the production of the age frequencies). The proportion spawning at age was assumed binomial at each age. Effective sample sizes were all taken from the 2013 assessment (Cordue 2014).

### Acoustic survey estimate

The only reliable acoustic estimate of spawning biomass for MEC came in 2013 when a multi-frequency "AOS" survey was conducted (acoustic and optical gear mounted on the trawl headline, e.g., see Kloser et al 2011). Four areas were visited in 2013 but the only substantial spawning plume was seen in the "Valley" (a known spawning site near Ritchie Bank). Four snapshots were taken and the estimates from 38 kHz were averaged to produce a biomass index (Table 8).

The "standard" assumption in the 2014 stock assessments, for acoustic estimates from spawning plumes, is that they collectively cover "most" of the spawning biomass where "most" is taken to be 80%. However, for MEC, only one spawning plume was found and it was in a very small area. There are many potential sites in the MEC for spawning plumes. For these reasons, "most" was taken to be 60% in the base model (and sensitivities were done at 40% and 80%). That is, the acoustic estimate was fitted as relative biomass with an informed prior: lognormal (mean = 0.6, CV = 19%) for the base model.

### Commercial age and length frequencies

As in 2011 and 2013, composition data were also used: length frequency samples from the northern commercial fishery (ORH 2A South and ORH 2B) for 16 years between 1988–89 and 2009–10, and from the southern commercial fishery (ORH 3A) for nine years between 1989–90 and 2008–09, and age frequency samples from commercial landings of the spawning fishery in ORH 2A south in 1989, 1990, 1991. The otoliths from the 1989–91 samples were re-aged for the 2013 assessment using the new ageing protocol (Tracey et al 2007). In addition, age samples taken from a single vessel in the 2010 spawning season were also used. These had been aged with the new protocol but because they were from a single vessel and a fishery 20 years later than in 1990 the age frequency was fitted with its own selectivity. The age frequencies from 1989–91 were assumed to be from spawning fish (i.e., no selectivity fitted). The composition data were all assumed to be multinomial and effective sample sizes from the 2013 assessment were used (except the southern fishery length frequencies were down-weighted following the iterative reweighting procedure of Francis (2011)).

### 4.2.3 Model runs and results

In the base model, natural mortality (*M*) was fixed at 0.045. There were numerous MPD sensitivity runs and six main sensitivities are presented in this report: estimate *M*; down-weight the trawl indices; separate selectivity for spawning age frequencies; mean acoustics *q* prior = 0.4; and the *LowM-Highq* and *HighM-Lowq* “standard” runs (see Orange Roughy Introduction).

In the base model, the main parameters estimated were: virgin biomass ($B_0$), the maturity ogive, the two fishery selectivities, the trawl survey selectivity, the 2010 age frequency selectivity, and year class strengths (YCS) from 1881 to 1996 (with the Haist parameterisation and “nearly uniform” priors on the free parameters). Additional estimated parameters included the CV of the length-at-age parameters and the proportionality constants (*q*s)for the trawl survey time series and the 2013 acoustics estimate.

**Model diagnostics**

The MPD fits to the biomass indices were excellent (Figure 4), although the MCMC fit was only just adequate for the trawl survey indices, particularly to the 2010 index (Figure 5). The poorer MCMC fit to the 2010 trawl index when compared to the MPD fit occurred because the MPD pattern of YCS did not match the posterior distribution of the same quantities, showing much greater year-to-year variation than seen in the MCMC posterior (Figure 6). This result highlights the difference between MPD estimates and MCMC estimates: the MPD finds the single vector of parameters which give the best fit to the data, while the MCMC procedure finds the parameter space that best explains the data. There is no reason why the MPD has to be in the “middle” of the posterior distribution, here we have an example where the MPD estimates are in the tail of the posterior distribution.

The MCMC fit to the acoustics index had also degraded when compared to the MPD fit (see Figures 4 and 5), as well as estimating a lower acoustics *q* (Figure 7). The cause of this is the same as for the 2010 trawl index; the MPD spawning biomass trajectory almost exactly matched the 2013 acoustic estimate but, given the less variable MCMC YCS trajectory, the resulting MCMC biomass trajectory was shifted higher (and the acoustic *q* shifted lower to compensate).

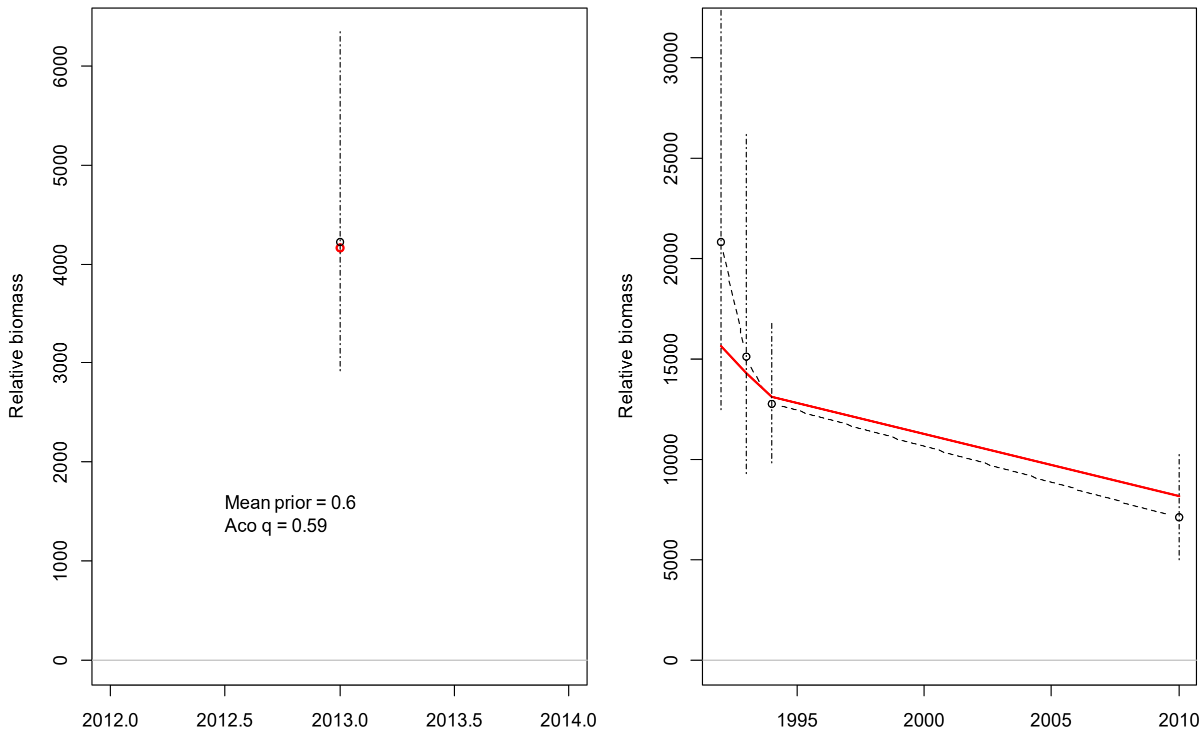



**Figure 4: MPD fit to biomass indices: left: acoustic-survey spawning biomass index (fitted with an informed *q* prior, mean = 0.6; MPD estimated *q* = 0.59); right: *Tangaroa* trawl-survey indices. Vertical lines are 95% CIs.**

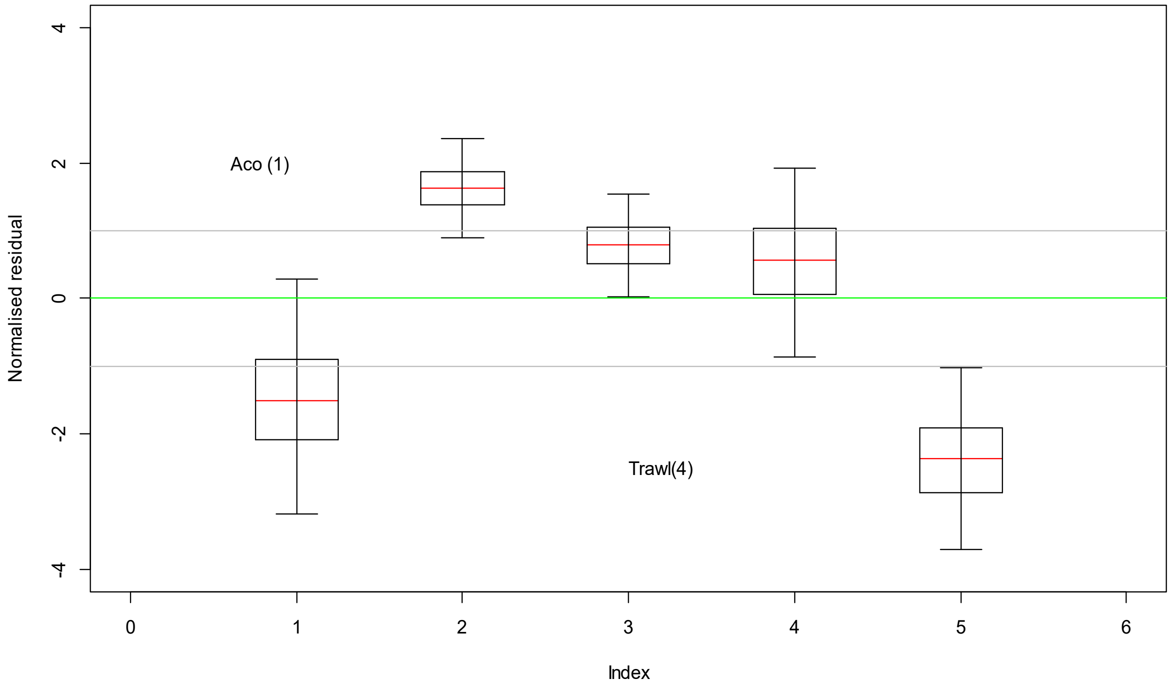



**Figure 5: MCMC base: normalised residuals for the biomass indices. The box covers 50% of the distribution for each index and the whiskers extend to 95% of the distribution. "Aco" denotes the acoustic estimate (2013). "Trawl" denotes the *Tangaroa* trawl-survey time series (1992–94, 2010).**

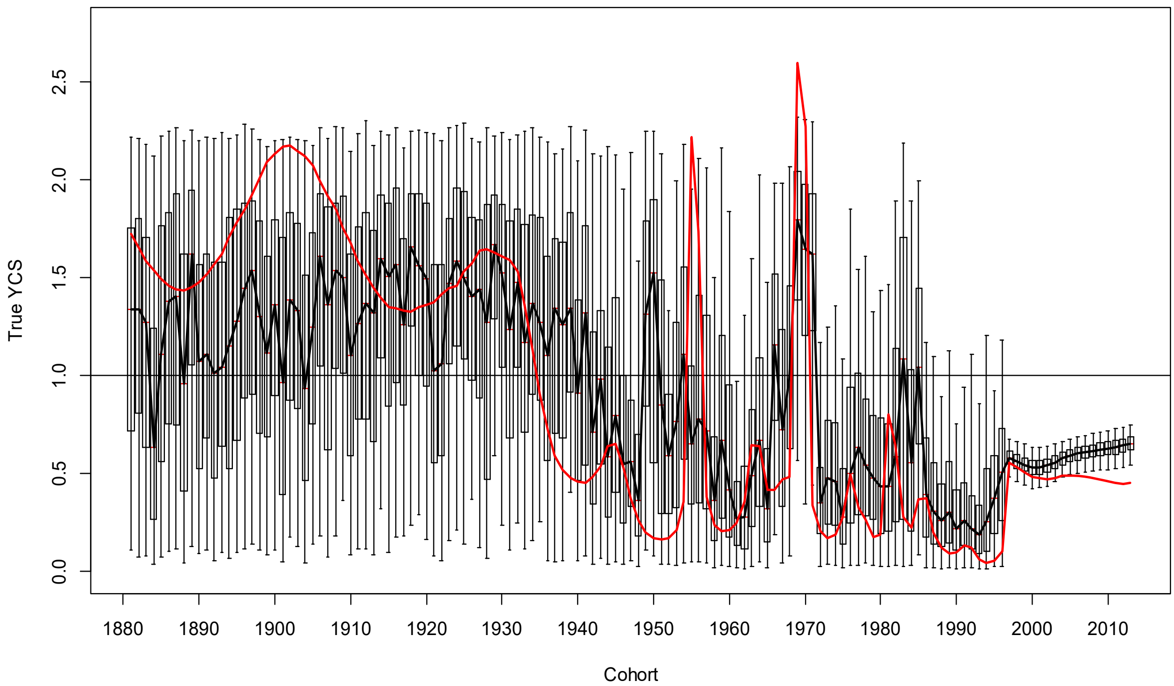



**Figure 6: Base model: MCMC estimated "true" YCS ($R_y/R_0$) (in black). The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The MPD estimates are shown in red.**

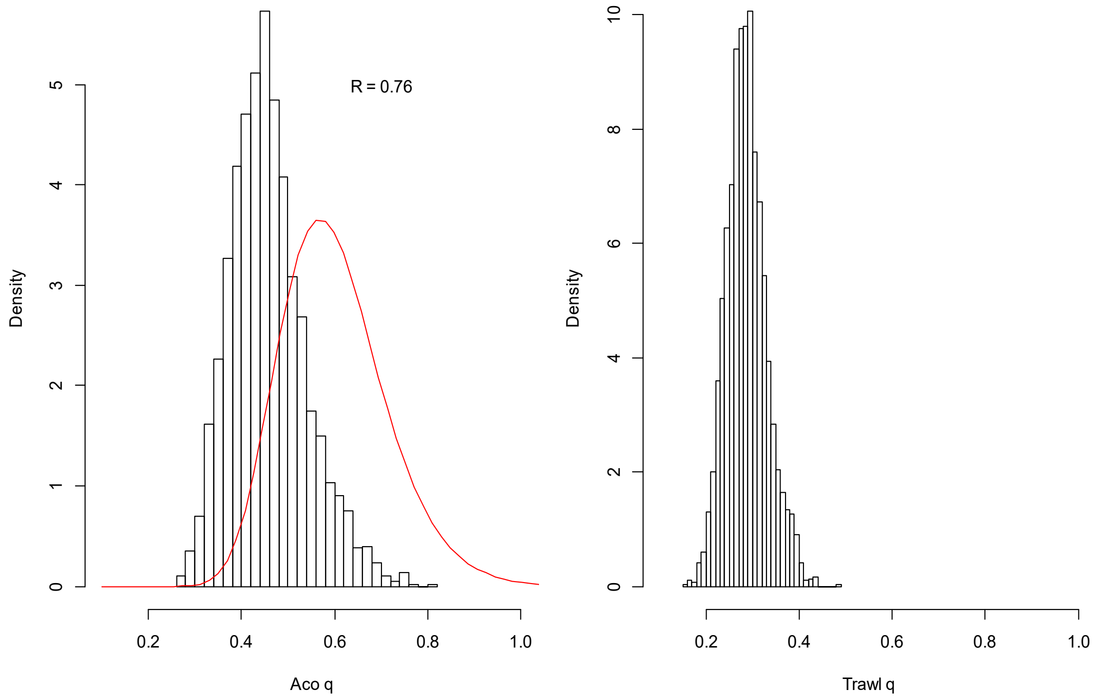



**Figure 7: Base model MCMC diagnostics: prior and posterior distributions for the acoustic *q* (prior in red, posterior black histogram) (left); posterior distribution for the trawl-survey *q* (the prior was uninformed) (right). R = 0.76 is the ratio of the mean of the acoustic *q* posterior to the mean of the prior.**

The MPD fits to the commercial length frequencies were adequate (Figures 8 and 9). They could never be very good because the length frequencies show a great deal of year-to-year variability, as evidenced by the annual mean lengths (Figure 10). The model predictions of annual mean length are necessarily fairly smooth from year-to-year; as they are only able to track the main trend but not the annual jumps (Figure 10).

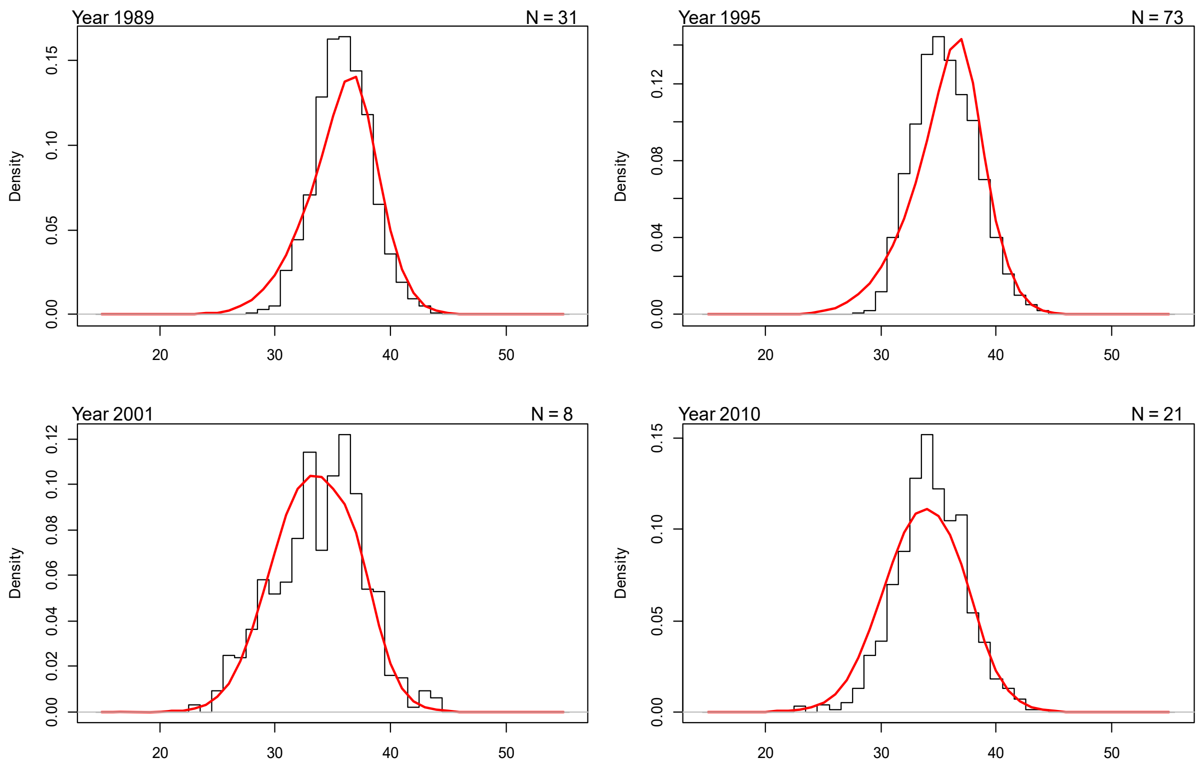



**Figure 8: Example MPD fits to northern fishery length frequencies (N is the assumed effective sample size in the given year; x-axis is fish length (cm)). Observations are black lines; model predictions are the red lines.**

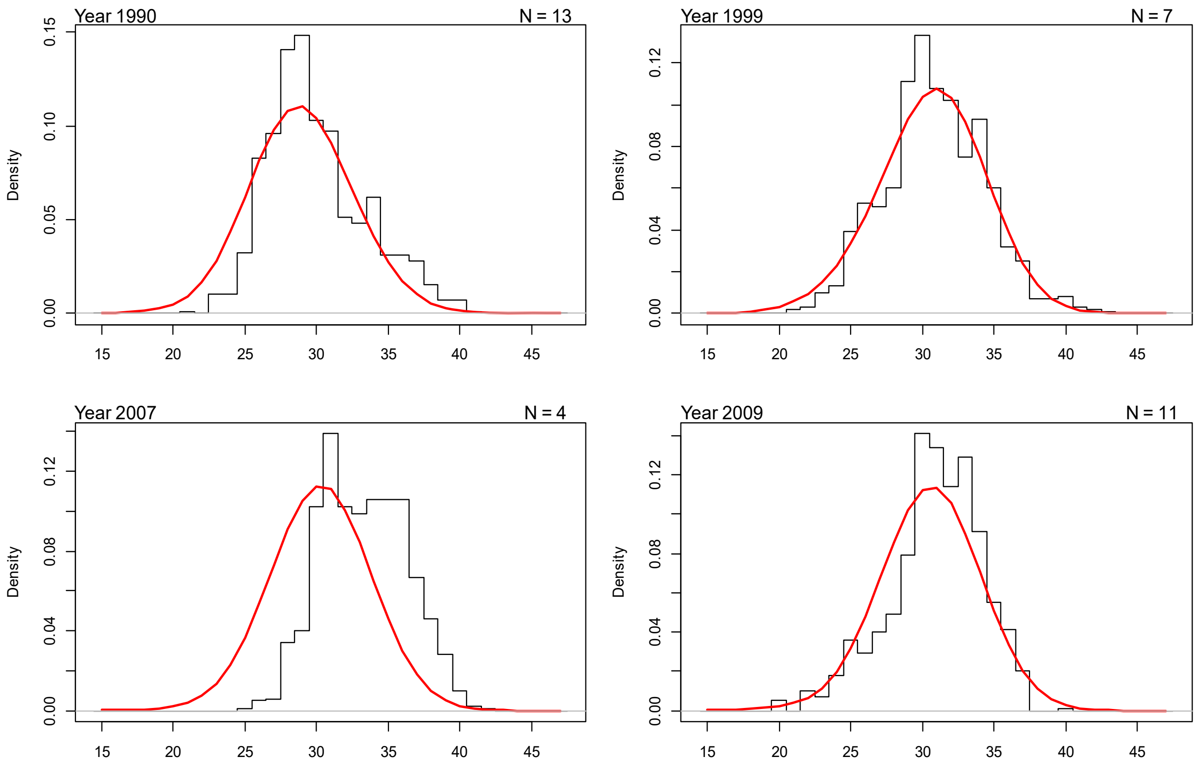



**Figure 9: Example MPD fits to southern fishery length frequencies (N is the assumed effective sample size in the given year; x axis is fish length (cm)). Observations are black lines; model predictions are the red lines.**

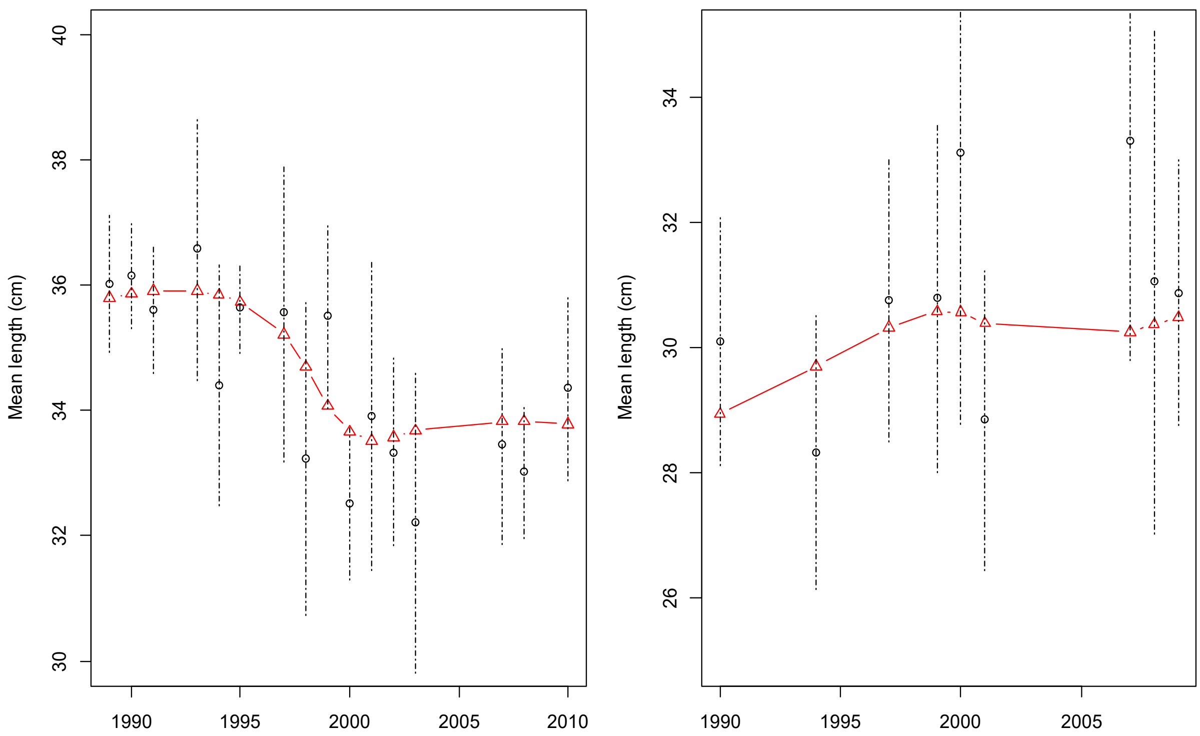



**Figure 10: Annual mean lengths from the commercial length frequencies (northern fishery on the left, southern on the right) with 95% CIs (black, circles, dashed vertical lines) and the base model predictions (red, triangles, solid lines).**

The MPD fits to the trawl-survey length frequencies and estimates of proportion spawning at age are good (Figure 11). It is notable that the model fits the different shape of the proportion spawning estimates in 1993 and 2010 (Figure 11). The spawning-season age frequencies are only adequately fitted (Figure 12). There is a misfit for the young ages (except for 2010 which had its own selectivity) as these data compete with the proportion spawning-at-age data to define the maturity ogive (see Figure 11 – young fish are spawning according to the proportion spawning data). In response to the misfit in Figure 12, a sensitivity run was done where the 1989–91 spawning age frequencies were allowed to have a logistic selectivity. This improved the fit substantially and raised the model estimate of the 2014 stock status from 14 to 17% $B_0$. The base model was preferred to be consistent across the four orange roughy stocks assessed in 2014, with the maturity ogive used to define the spawning-season selectivity and age frequencies.

The fit to the trawl-survey age frequencies is excellent, which should be expected given the large effective sample size of N = 200 (Figure 13). A number of sensitivity runs were done with alternative data weighting, including down-weighting the trawl-survey age frequencies, which demonstrated that the model was robust to a wide range of assumptions. For example, the only runs that made a substantial difference to the MPD estimates of stock status were doubling the acoustic index (10.2% $B_0$ compared to the base estimate of 6.5% $B_0$) and assuming deterministic recruitment (25.8% $B_0$); the other 16 runs had MPD estimates in the range 4–9% $B_0$.

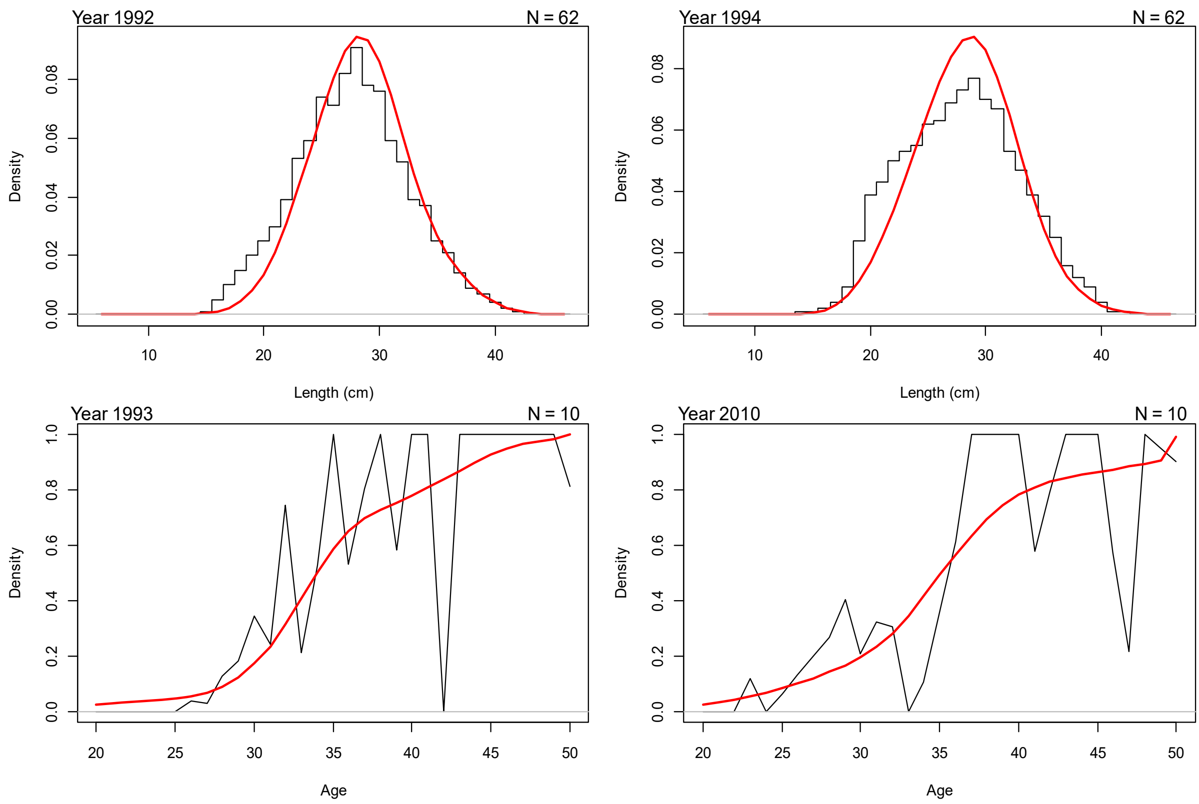



**Figure 11: Base, MPD fits to trawl-survey length frequencies (N is the assumed effective sample size in the given year) and proportion spawning-at-age (N =10 is the binomial sample size assumed for each age). Observations are black lines; model predictions are the red lines.**

## MCMC results

MCMC convergence diagnostics were very good for the base model and sensitivities. Virgin biomass ($B_0$) was estimated to be about 100 000 t for all runs (Table 9). Current stock status was similar for the base and the estimate-*M* run (Table 9). The slightly lower stock status when *M* was estimated reflects the lower estimate of *M* (0.032 rather than 0.045). Down-weighting the trawl indices (by adding process error CV of 20%) reduced the magnitude of the normalised residuals and raised the median estimate of 2014 stock status from 14 to 16% $B_0$ (Table 9). Giving the 1989–91 spawning age frequencies a selectivity improved the fit to younger age fish, decreased the estimate of $B_0$ from 95 000 t to 91 000 t and increased estimated stock status from 14 to 17% $B_0$ (Table 9). The reduction in the mean of the acoustic $q$ from 0.6 to 0.4 increased the median estimate of stock status to 19% $B_0$, but the median estimate was still below the soft limit (Table 9). The two "bounding runs" where $M$ and the mean of the acoustic $q$ were shifted by 20%, still had median estimates under the soft limit, with the "*LowM-Highq*" run at the hard limit (Table 9). Other sensitivities not reported here included several where the effective sample size on age frequencies was appreciably increased or decreased; in all cases, this had little impact on the estimates of stock status.

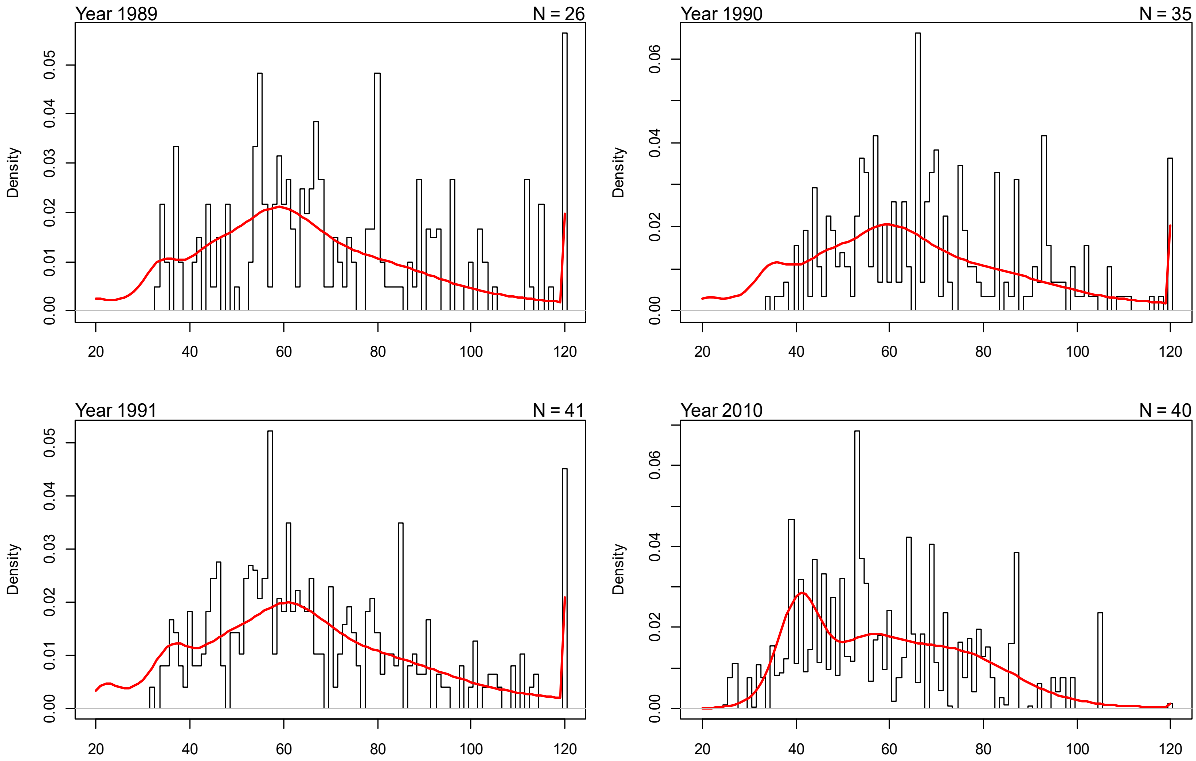



**Figure 12: Base, MPD fit to spawning-season age frequencies (N is the assumed effective sample size in the given year). Observations are black lines; model predictions are the red lines.**

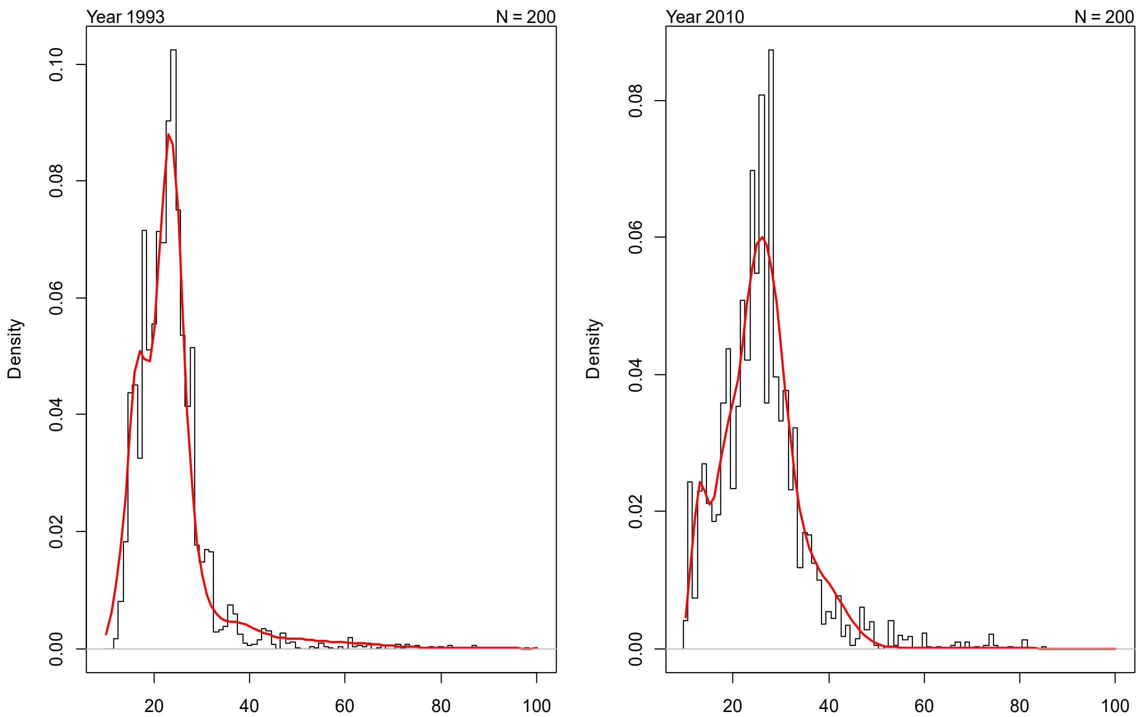



**Figure 13: Base, MPD fit to trawl-survey age frequencies (N = 200 is the assumed effective sample size). Observations are black lines; model predictions are the red lines.**

**Table 9: MCMC estimates of virgin biomass (B0) and stock status (B2014 as %B0) for the base model, and the six following sensitivity runs: a) estimating natural mortality; b) down-weighting the trawl indices by adding 20% process error to the CV; c) adding a selectivity to spawning age frequencies for 1989–91; d) reducing the mean acoustic catchability coefficient, q, from 0.6 to 0.4; e) decreasing M and increasing acoustic q by 20%; and f) increasing M and decreasing acoustic q by 20%.**

| *Assessment* | *M* | B0 (000 t) | 95% CI | B2014 (%B0) | 95% CI |
|---|---|---|---|---|---|
| Base model | 0.045 | 95 | 87–104 | 14 | 9–21 |
| a) Estimate M | 0.032 | 104 | 96–112 | 11 | 7–16 |
| b) Down-weight trawl | 0.045 | 97 | 88–108 | 16 | 11–22 |
| c) Spawn AF selectivity | 0.045 | 91 | 83–102 | 17 | 12–24 |
| d) Mean aco. $q = 0.4$ | 0.045 | 100 | 92–112 | 19 | 13–26 |
| e) LowM-Highq | 0.036 | 96 | 90–103 | 10 | 7–15 |
| f) HighM-Lowq | 0.054 | 99 | 89–114 | 19 | 13–27 |

The estimated fishery selectivities showed the northern fishery taking fish over 30 years with the southern fishery primarily taking fish from 20–40 years (Figure 14). The trawl-survey selectivity primarily sampled fish from 10–70 years with peak selection from 20–30 years (Figure 14). The 2010 age frequency appears to have been a subset of spawning fish focussed on those from about 50–90 years (Figure 14).

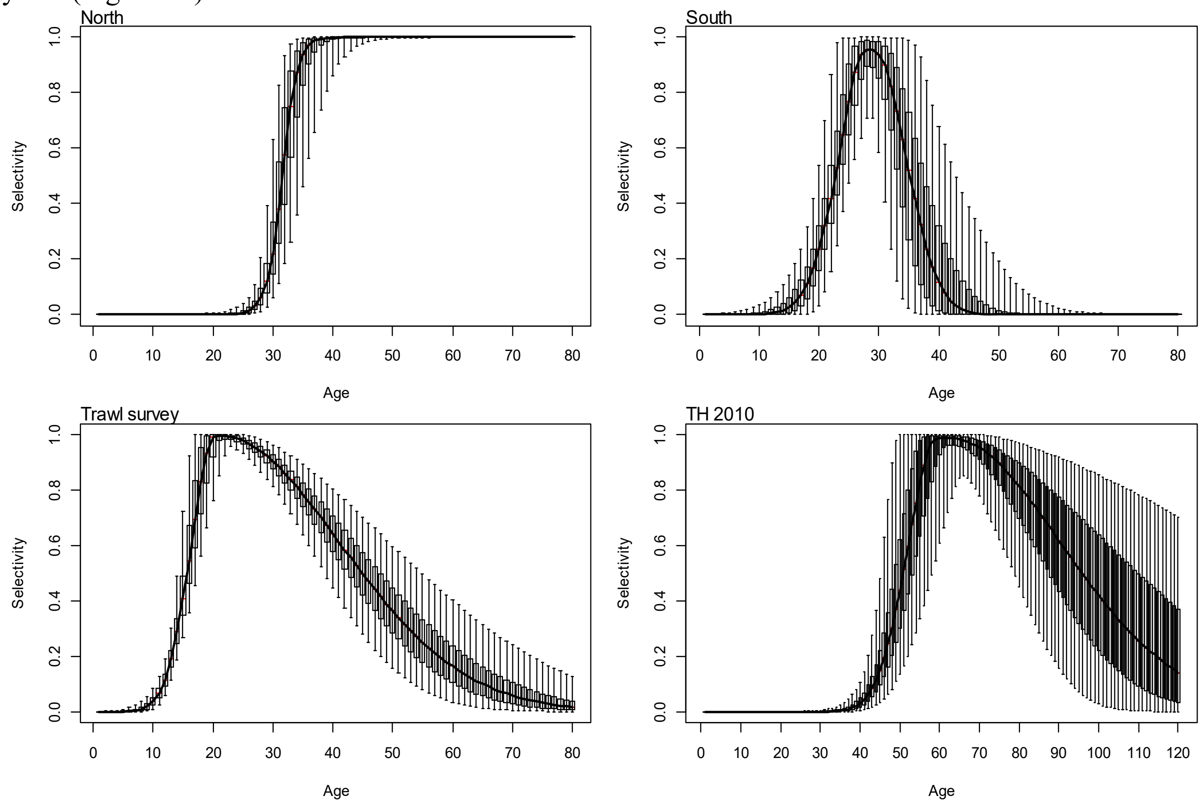



**Figure 14: Base, MCMC estimated selectivities (northern and southern fisheries, the trawl survey, and the 2010 age frequency). The box at each age covers 50% of the distribution and the whiskers extend to 95% of the distribution.**

The estimated YCS show strong variation across cohorts and exhibit a long-term trend, with recruitment well below average since the early 1970s (Figure 15). The most recent 10 years of estimates, 1986–1995 (those resampled for short-term projections) are well below average.

The stock status trajectory shows an increasing trend before the start of fishery as the above average recruitment estimated by the model feeds into the spawning biomass (Figure 16). Then there is a steep decline from the start of fishery until the year 2000 when the biomass reached 10% $B_0$, after which there was a slow increase (Figure 16).

Fishing intensity was estimated in each year for each MCMC sample to produce a posterior distribution for fishing intensity in each year. Fishing intensity is represented in terms 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 $U_{30\%B0}$ drives 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 the target range ($U_{30\%B0}$–$U_{40\%B0}$) from 1984 to 2012 (Figure 17). In the last two years, fishing intensity has decreased to within the target range.

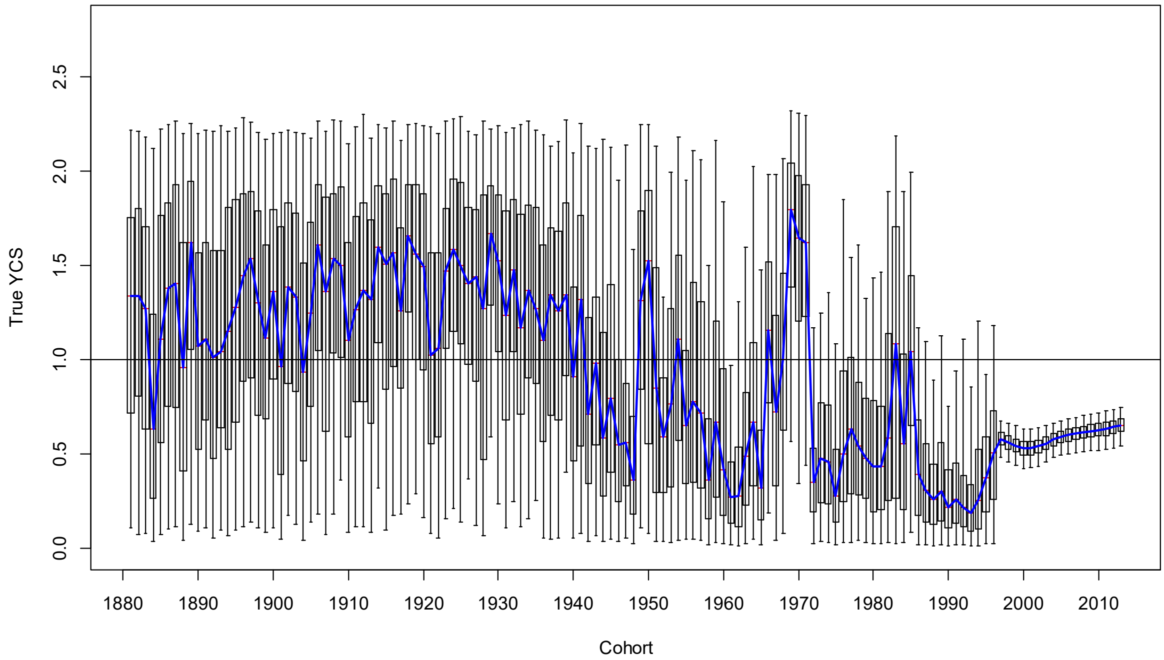



**Figure 15: Base, MCMC estimated "true" YCS ($R_y/R_0$). The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution.**

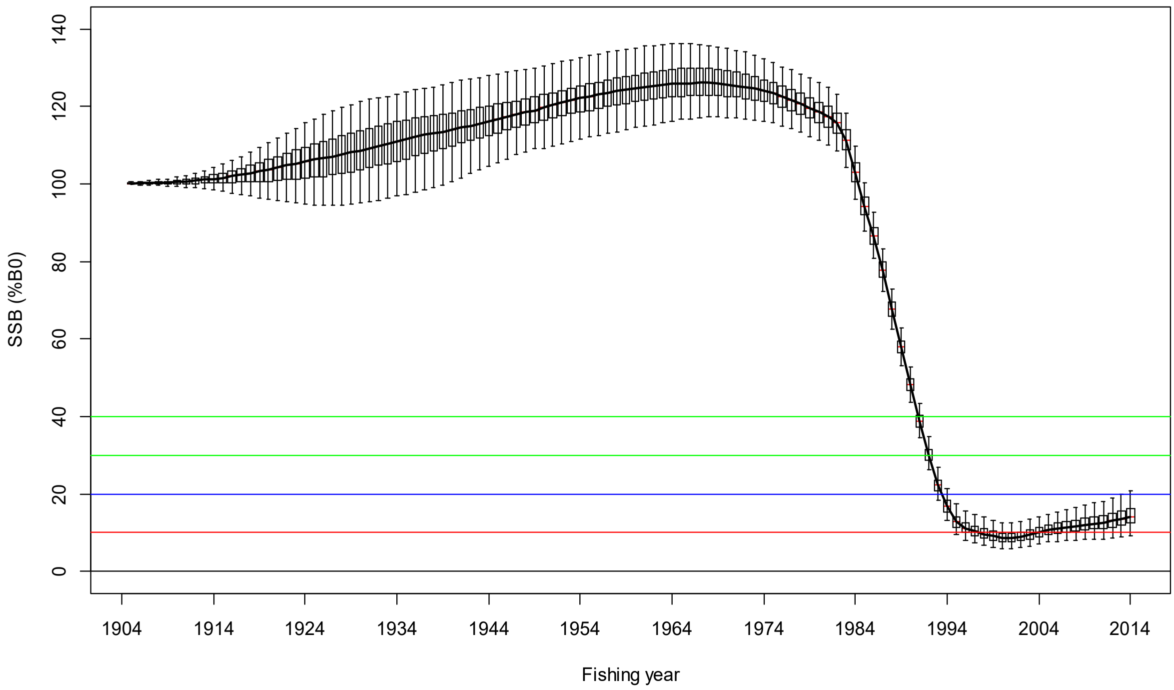



**Figure 16: Base, MCMC estimated spawning-stock biomass trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The hard limit, 10% *B₀* (red), soft limit, 20% *B₀* (blue), and biomass target range, 30–40% *B₀* (green) are marked by horizontal lines.**

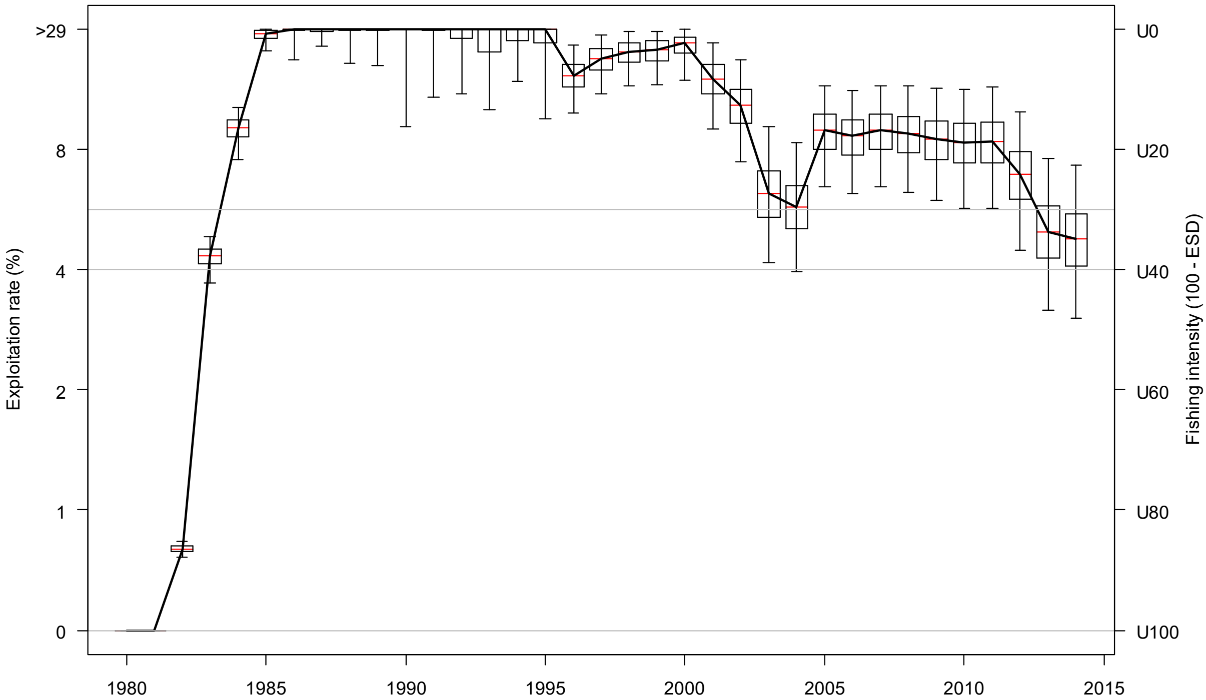



**Figure 17: Base, MCMC estimated fishing-intensity trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The fishing-intensity range associated with the biomass target of 30–40% $B_0$ is marked by horizontal lines.**

## 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: Base, MCMC estimates of deterministic equilibrium spawning stock biomass (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 | 22.5 | 2.3 | 2214 |
| | 95% CI | 21.8–23.0 | 2.3–2.4 | 2048–2415 |
| $U_{35\%B0}$ | Median | 35.0 | 2.2 | 2075 |
| | 95% CI | 35.0–35.0 | 2.2–2.2 | 1916–2264 |

## Projections

Five year projections were conducted (with resampling from the last 10 estimated YCS) for catch at the current catch limit of 930 t (with a 5% catch over-run assumed). Projections were done just for the base model. At the current catch limit (930 t), SSB is predicted to increase slowly over the next five years but still be well below the soft limit in 2019 (Figure 18). The estimated minimum time to rebuild (assuming zero catch and requiring a 70% probability of being above the lower bound of the 30–40% $B_0$ target range), is 21 years ($T_{min}$) (Figure 19).

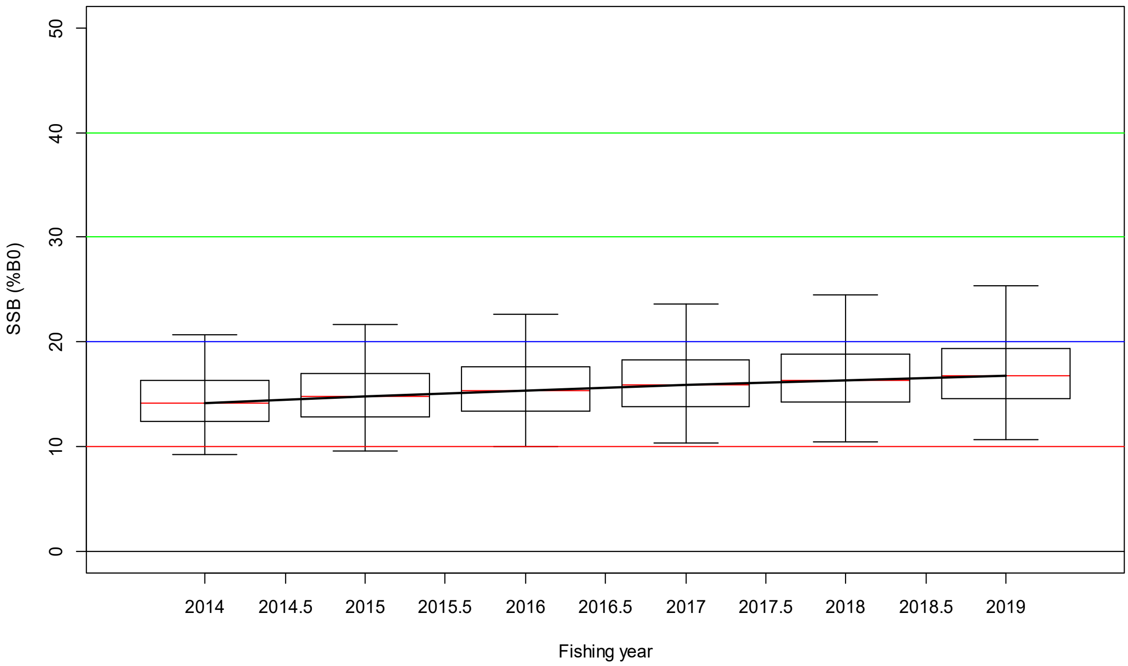



**Figure 18: Base, MCMC projections. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. An annual catch at the current catch limit of 930 t was assumed (with a 5% catch over-run in each year). The target range (30–40% $B_0$) is indicated by horizontal green lines, with the soft limit (20% $B_0$) in blue and the hard limit (10% $B_0$) in red.**

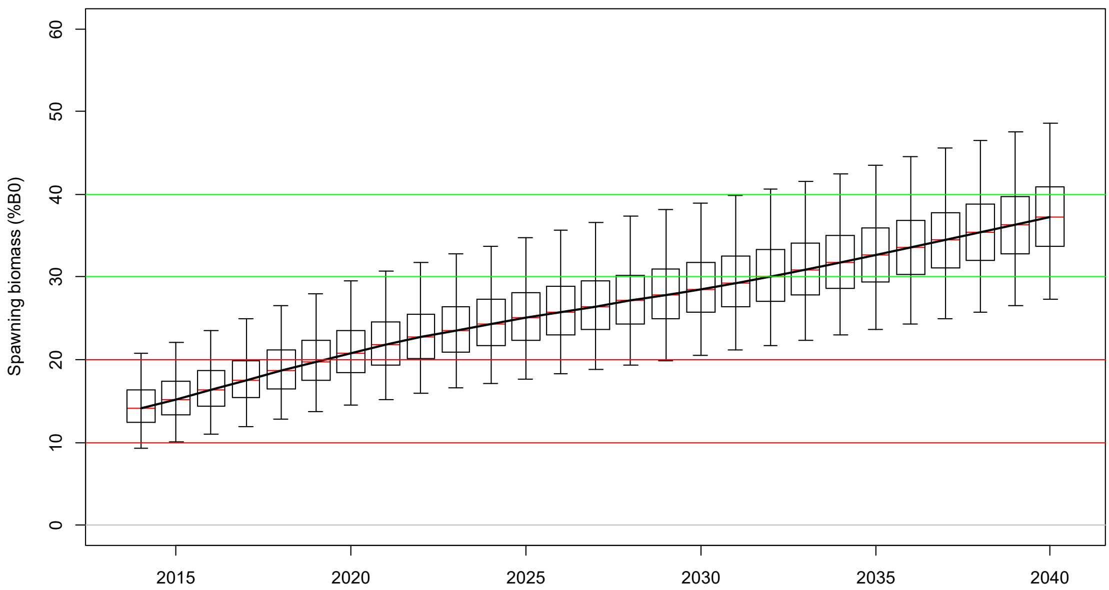



**Figure 19: Base, MCMC projections. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The annual catch used in these projections is zero tonnes. The target range (30–40% $B_0$) is indicated by horizontal green lines, with the soft limit (20% $B_0$) in blue and the hard limit (10% $B_0$) in red.**

# 5. STATUS OF THE STOCKS

## Stock Structure Assumptions

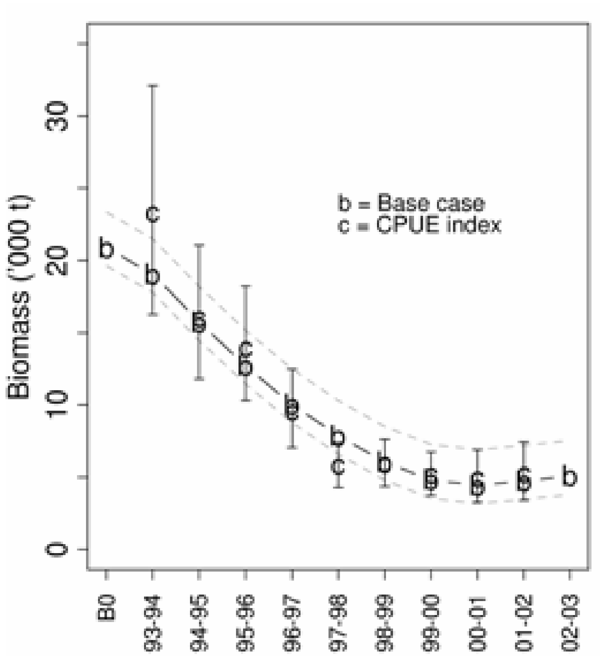
Orange roughy in ORH 2A, 2B and 3A are treated as two biological stocks based on the location of spawning grounds. These stocks are managed and assessed separately however some mixing has been shown to occur. The 2A North stock spawns around the East Cape hills off of the North Island. The 2A South, 2B and 3A stock is assumed to spawn on the Ritchie Bank.

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

- **ORH East Cape Stock (2A North)**

| **Stock Status** | |
|---|---|
| Year of Most Recent Assessment | 2003 |
| Assessment Runs Presented | A base case with one alternative |
| Reference Points | Management Target: 30% $B_0$<br>Soft Limit: 20% $B_0$<br>Hard Limit: 10% $B_0$<br>Overfishing threshold:- |
| Status in relation to Target | $B_{2003}$ was 24% $B_0$, which was Unlikely (< 40%) to be at or above the target. |
| Status in relation to Limits | $B_{2003}$ was Unlikely (< 40%) to be below the Soft Limit, and Very Unlikely (< 10%) to be below the Hard Limit |

**Historical Stock Status Trajectory and Current Status**




**Estimated biomass trajectory for the base model run for the EC stock. Annual biomass estimates are mean posterior density (MPD) values and 95% confidence intervals (grey dashed lines) are calculated from the posterior profile distribution of $B_0$ estimates. The CPUE index CVs (sampling error plus process error) are shown.**

| **Fishery and Stock Trends** | |
|---|---|
| Recent Trend in Biomass or Proxy | Biomass declined in the early 1990s but appeared to stabilise at around 5000 t. |
| Recent Trend in Fishing Mortality or Proxy | *F* has declined along with the agreed catch limit and remains stable at the current catch level of 200 t. |
| Other Abundance Indices | - |
| Trends in Other Relevant Indicators or Variables | - |

| **Projections and Prognosis (2003)** | |
|---|---|
| Stock Projections or Prognosis | The estimated *CAY* (370 t) and *MAY* (410 t) were both greater than the catch limit of 200 t, and this suggested the stock would start to rebuild. |
| Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits | Soft Limit: Unlikely (< 40%)<br>Hard Limit: Very Unlikely (< 10%) |
| Probability of Current Catch or | - |

| | |
|---|---|
| TACC causing Overfishing to continue or to commence | |

| Assessment Methodology and Evaluation | | |
|---|---|---|
| Assessment Type | Level 1 – Full Quantitative Stock Assessment | |
| Assessment Method | Statistical catch-at-age model implemented in CASAL with Bayesian estimation of posterior distributions | |
| Assessment Dates | Latest assessment: 2003 | Next assessment: Unknown |
| Overall assessment quality rank | - | |
| Main data inputs | - Catch data<br>- Standardised CPUE data<br>- 1994–95 ORH egg survey | |
| Data not used (rank) | - | |
| Changes to Model Structure and Assumptions | - | |
| Major Sources of Uncertainty | - | |

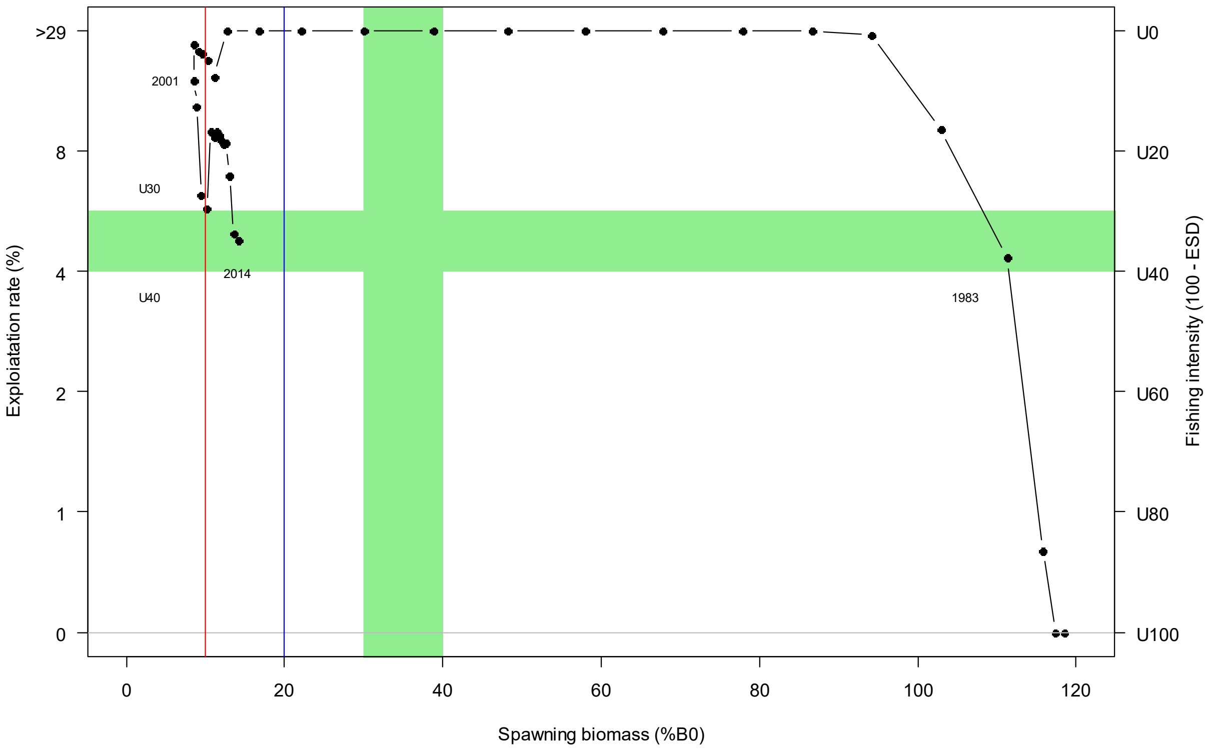
| Qualifying Comments |
|---|
| The most recent assessment (2003) is now 11 years out-of-date. In recent years, the ability of stock assessment models that assume deterministic recruitment for orange roughy stocks to reflect current or projected stock status has been called into question. |

| Fishery Interactions |
|---|
| The main bycatch species are cardinalfish and alfonsino. Low productivity bycatch species include deepwater sharks, deepsea skates and corals. Protected species bycatch includes seabirds and corals. |

- **ORH Mid-East Coast Stock (2A South, 2B, 3A)**

| Stock Status | |
|---|---|
| Year of Most Recent Assessment | 2014 |
| Assessment Runs Presented | Base model only |
| Reference Points | Management Target: Biomass range 30–40% $B_0$<br>Soft Limit: 20% $B_0$<br>Hard Limit: 10% $B_0$<br>Overfishing threshold: Fishing intensity range $U_{30\%B0}$–$U_{40\%B0}$ |
| Status in relation to Target | $B_{2014}$ was estimated to be 14% $B_0$<br>Very Unlikely (< 10%) to be at or above the lower end of the management target range |
| Status in relation to Limits | $B_{2014}$ is Likely (> 60%) to be below the Soft Limit<br>$B_{2014}$ is Unlikely (< 40%) to be below the Hard Limit |
| Status in relation to Overfishing | Fishing intensity in 2014 was estimated at $U_{35\%B0}$<br>Overfishing is About as Likely as Not (40–60%) 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 (fishing intensity) 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 | Estimated spawning biomass has been slowly increasing since about 2000. |
| Recent Trend in Fishing Intensity or Proxy | Estimated fishing intensity has been declining in recent years. |
| Other Abundance Indices | - |
| Trends in Other Relevant Indicators or Variables | - |
| Trends in Other Relevant Indicators or Variables | - |

| **Projections and Prognosis** | |
|---|---|
| Stock Projections or Prognosis | At the current catch limit, the stock is projected to increase slowly over the next 5 years but still be below the soft limit in 2019. The minimum rebuild period to reach 30% $B_0$ with 70% probability is estimated to be 21 years with no catch. |
| Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits | For the current catch and catch limit (in the short term):<br>Soft Limit: Very Likely (> 90%)<br>Hard Limit: Unlikely (< 40%) |
| Probability of Current Catch or TACC causing Overfishing to continue or to commence | For the current catch and catch limit:<br>As Likely as Not (40–60%) |

| **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: 2022 | |
| Overall assessment quality rank | 1 – High Quality | | |
| Main data inputs (rank) | - Acoustic biomass estimate (2013)<br>- Trawl-survey biomass indices (1992–94, 2010), age frequencies (1993, 2010), length frequencies (1992, 1994), proportion spawning at age (1993, 2010)<br>- Spawning-season age frequencies (1989–91, 2010)<br>- Commercial length-frequencies (1989–90 to 2009–10) | | 1 – High Quality<br><br>1 – High Quality<br><br>1 – High Quality<br><br>1 – High Quality |
| Data not used (rank) | - CPUE indices<br><br>- 2002 spawning-season age frequency<br><br>- Wide-area acoustic estimates<br><br>- Egg survey estimates | 3 – Low Quality: unlikely to be indexing stock-wide abundance<br>2 – Medium or Mixed Quality: needs to be re-aged<br>2 – Medium or Mixed Quality: too much potential bias due to target identification and mixed species issues<br>2 – Medium or Mixed Quality: too much potential bias due to survey design assumptions not being meet | |
| Changes to Model Structure and Assumptions | A more stringent data quality threshold was imposed on data inputs (e.g., wide-area acoustics, egg survey, and CPUE indices not used). | | |
| Major Sources of Uncertainty | - The proportion of the spawning stock biomass that was indexed by the 2013 acoustic survey (little survey effort has been expended in this area relative to other orange roughy grounds).<br>- Patterns in year class strengths are based on only 5 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. |

| **Fishery Interactions** |
|---|
| Fish bycatch is estimated to make up about 20% of the total catch in this fishery. The main bycatch species are alfonsino, smooth oreo and hoki. Low productivity bycatch species include deepwater sharks, deepsea skates and corals. Observed incidental captures of protected species include corals and small numbers of seabirds. |

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# 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 2016–17 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 | - |
| 2014–15 | 4 747 | 5 000 | - |
| 2015–16 | 4 529 | 5 000 | - |
| 2016–17 | 4 486 | 5 197 | - |
| 2017–18 | 4 942 | 5 197 | - |

† 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.

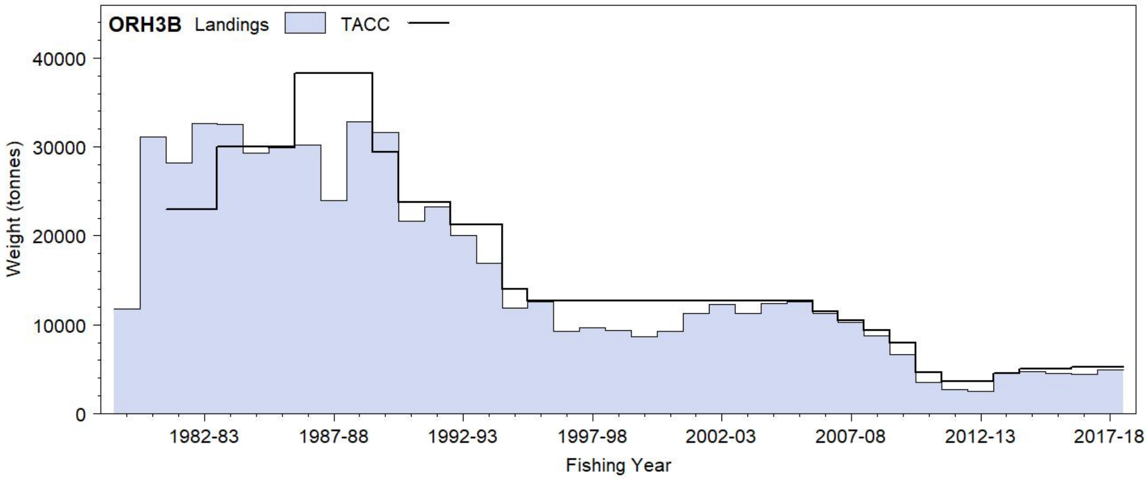



**Figure 1: Reported commercial landings and TACCs for ORH 3B.**

**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 | 800 | 18 | 500 | 12 | 1 420 | 33 | 1 240 | 29 | 540 | 12 |
| 2014–15 | 800 | 17 | 370 | 8 | 1 990 | 43 | 700 | 15 | 630 | 14 |
| 2015–16 | 700 | 16 | 360 | 8 | 1 220 | 28 | 1 800 | 42 | 460 | 11 |
| 2016–17 | 730 | 16 | 530 | 12 | 1 310 | 29 | 1 150 | 26 | 590 | 13 |
| 2017–18 | 840 | 17 | 445 | 9 | 1 285 | 26 | 1 532 | 31 | 840 | 17 |

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 5 000 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 3 600 t in 2011–12 (Table 1). The agreed catch limit for the East and South Chatham Rise is currently 3 100 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.

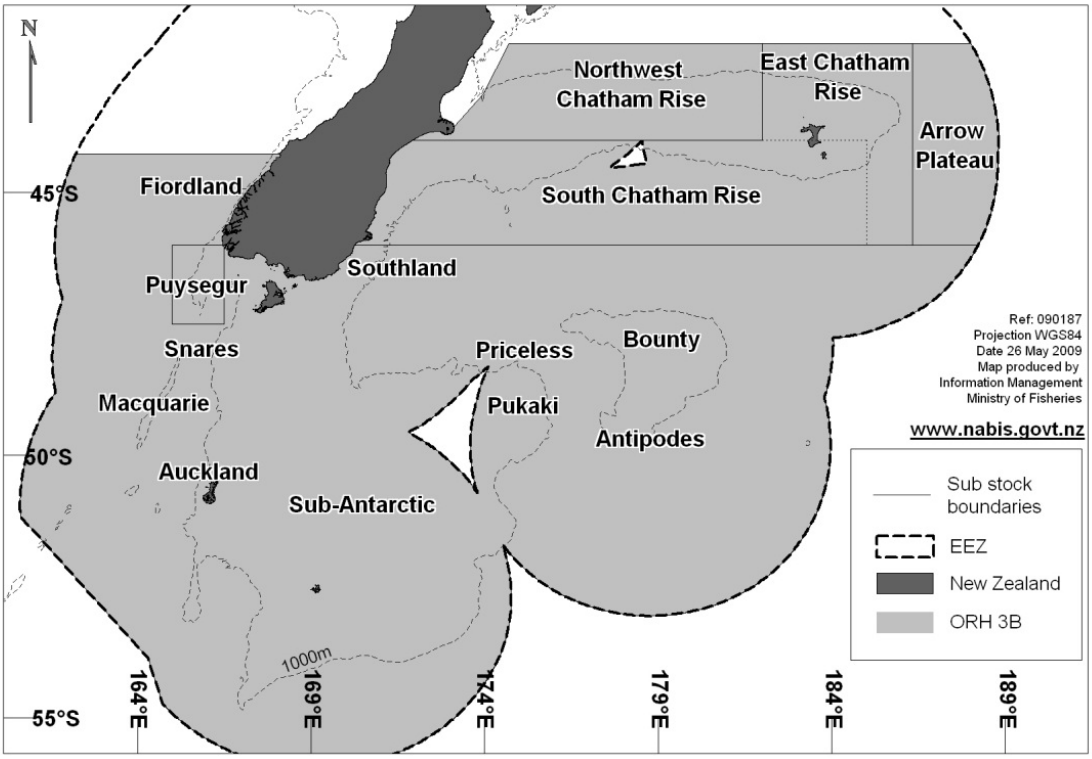



**Figure 2: ORH 3B sub-areas and the approximate position of other named fisheries outside of the Chatham Rise. The Spawning Box is in the western part of the East Rise (to the west of the vertical broken line at 175°W). The East and South Rise are currently managed as a single unit. The Arrow Plateau 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.**

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 (Table 4). 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. Quota owners then agreed to shelve 207 tonnes of Northwest Chatham Rise ACE for 2014–15 to 2017–18.

**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 |
| 2014–15 | 1 250 δ | 3 100 | * | 150 | 0 | 500 |
| 2015–16 | 1 250 δ | 3 100 | * | 150 | 0 | 500 |
| 2016–17 | 1 250 δ | 3 100 | * | 347 | 0 | 500 |
| 2017–18 | 1 150 δ | 3 957 | * | 347 | 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 agreed to avoid fishing the Northwest Rise.
δ Quota owners agreed to shelve 207 tonnes of Northwest Chatham Rise ACE for 2014–15 to 2017–18. This left 1043 tonnes available to catch.

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 (Table 4). 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 (Table 4).

**Table 4: Orange roughy estimated catches (to nearest 10 t) and unstandardised median catch rates (to nearest 0.1 t/tow) for four important hill complexes and the Spawning Box In season (spawning plume area, May-August) and Out season (September-April) on the Chatham Rise (letters indicating subareas, as in Table 3, in parentheses), using catch and effort data held by NIWA. Only tows targeted at orange roughy are included. (Approximate positions are: Big Chief, 44.7 S, 175.2 W; Smiths City and near-neighbours, 43.1 S, 174.2 W; Andes, 44.2 S, 174.6 W; Graveyard, 42.8 S, 180 W). -, catch < 10 t (2016–17 data are provisional, and catch totals are possibly incomplete). - means catch < 10 t. NA means catch >10 t but there were fewer than 3 vessels in the fishery.**

| | Andes (E) | | | Smith's City NE Hills (E) | | | Spawning Box In (E) | | | Spawning Box Out (E) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Catch | Tows | t/tow | Catch | Tows | t/tow | Catch | Tows | t/tow | Catch | Tows | t/tow |
| 1979–80 | - | - | - | 110 | 36 | 3.1 | 9 800 | 968 | 10.7 | 7 400 | 795 | 6.1 |
| 1980–81 | - | - | - | - | 2 | - | 11 100 | 890 | 11.5 | 6 240 | 462 | 11.5 |
| 1981–82 | - | - | - | 40 | 11 | 3.6 | 4 750 | 470 | 4.5 | 4 450 | 604 | 4.9 |
| 1982–83 | - | - | - | 40 | 2 | 17.8 | 3 980 | 227 | 13.4 | 3 840 | 386 | 8.1 |
| 1983–84 | - | - | - | 60 | 7 | 6.3 | 6 590 | 378 | 13.4 | 8 630 | 836 | 7.7 |
| 1984–85 | - | - | - | 10 | 3 | 3.2 | 9 320 | 676 | 10.4 | 7 460 | 537 | 10.0 |
| 1985–86 | - | - | - | 670 | 52 | 11.4 | 8 521 | 659 | 10.0 | 7 650 | 859 | 6.1 |
| 1986–87 | - | - | - | 210 | 34 | 3.9 | 8 090 | 597 | 8.9 | 12 010 | 1 036 | 6.2 |
| 1987–88 | - | - | - | 160 | 33 | 4.5 | 7 870 | 622 | 8.0 | 5 820 | 701 | 5.1 |
| 1988–89 | 30 | 18 | 0.3 | 310 | 48 | 3.9 | 7 070 | 598 | 9.6 | 6 500 | 811 | 5.0 |
| 1989–90 | 90 | 13 | 1.5 | 40 | 9 | 4.0 | 6 830 | 403 | 12.5 | 4 960 | 602 | 5.3 |
| 1990–91 | 80 | 12 | 3.2 | 4 890 | 633 | 3.5 | 2 820 | 238 | 8.0 | 2 810 | 206 | 8.0 |
| 1991–92 | 7 080 | 724 | 5.0 | 1 270 | 222 | 2.0 | 650 | 85 | 6.0 | 300 | 54 | 5.7 |
| 1992–93 | 2 940 | 345 | 5.0 | 600 | 84 | 2.0 | 50 | 2 | 27.0 | - | - | - |
| 1993–94 | 3 320 | 605 | 1.8 | 560 | 109 | 2.8 | - | - | - | - | - | - |
| 1994–95 | 1 650 | 573 | 1.0 | 1 140 | 345 | 1.0 | 490 | 86 | 0.3 | 10 | 25 | 0.1 |
| 1995–96 | 1 120 | 418 | 0.5 | 410 | 145 | 1.0 | 1 360 | 127 | 5.0 | 140 | 27 | 0.8 |
| 1996–97 | 730 | 260 | 1.0 | 720 | 164 | 1.0 | 930 | 101 | 3.0 | 620 | 130 | 2.3 |
| 1997–98 | 1 140 | 476 | 0.5 | 400 | 146 | 0.4 | 1 580 | 118 | 6.0 | 630 | 148 | 1.1.65 |
| 1998–99 | 1 260 | 448 | 1.0 | 810 | 272 | 1.0 | 510 | 73 | 2.7 | 490 | 139 | 2.0 |
| 1999–00 | 1 990 | 529 | 1.0 | 680 | 210 | 0.8 | 910 | 34 | 25.0 | 510 | 111 | 2.0 |
| 2000–01 | 980 | 354 | 1.1 | 650 | 191 | 1.0 | 810 | 59 | 5.5 | 430 | 123 | 2.0 |
| 2001–02 | 2 040 | 546 | 1.5 | 490 | 167 | 0.9 | 2 120 | 159 | 4.0 | 980 | 222 | 1.8 |
| 2002–03 | 2 230 | 872 | 1.0 | 400 | 124 | 0.5 | 2 150 | 166 | 8.0 | 1 000 | 216 | 2.3 |
| 2003–04 | 1 170 | 677 | 0.5 | 360 | 160 | 0.8 | 1 880 | 163 | 6.0 | 1 050 | 278 | 2.5 |
| 2004–05 | 1 090 | 518 | 0.6 | 310 | 127 | 0.9 | 1 910 | 214 | 4.4 | 850 | 230 | 3.8 |
| 2005–06 | 1 340 | 727 | 0.5 | 370 | 119 | 0.7 | 1 630 | 117 | 9.0 | 1 740 | 257 | 2.6 |
| 2006–07 | 1 160 | 583 | 0.5 | 570 | 201 | 0.7 | 1 980 | 121 | 11.2 | 1720 | 356 | 2.5 |
| 2007–08 | N/A | N/A | N/A | N/A | N/A | N/A | 2 550 | 200 | 5.0 | 750 | 192 | 3.0 |
| 2008–09 | N/A | N/A | N/A | N/A | N/A | N/A | 2 020 | 121 | 18.0 | 1 010 | 209 | 2.4 |
| 2009–10 | 440 | 243 | 0.5 | 160 | 84 | 0.5 | 1 980 | 136 | 8.5 | 850 | 248 | 1.7 |
| 2010–11 | 460 | 151 | 1.2 | 90 | 27 | 0.4 | 1 230 | 75 | 15.0 | 70 | 28 | 2.0 |
| 2011–12 | 450 | 164 | 1.0 | 130 | 26 | 0.5 | 660 | 39 | 22.5 | 80 | 24 | 3.8 |
| 2012–13 | N/A | N/A | N/A | - | - | - | N/A | N/A | N/A | N/A | N/A | N/A |
| 2013–14 | 790 | 218 | 1.0 | 140 | 39 | 0.9 | 390 | 40 | 4.9 | 30 | 18 | 2.0 |
| 2014–15 | 460 | 162 | 1.0 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 2015–16 | 1 180 | 437 | 0.4 | 130 | 75 | 0.2 | N/A | N/A | N/A | 390 | 96 | 3.0 |
| 2016–17 | 700 | 407 | 0.3 | 68 | 36 | 0.4 | 0 | 0 | 0 | 320 | 104 | 1.7 |
| 2017–18 | 761 | 483 | 0.3 | 202 | 73 | 1.0 | 0 | 0 | 0 | 396 | 111 | 2.0 |

| | Rest of East (E) | | | Graveyard (NW) | | | Rest of Northwest (NW) | | | Hegerville (S) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Catc | Tow | t/to | Catch | Tows | t/tow | Catch | Tows | t/tow | Catch | Tows | t/tow |
| 1979–80 | 560 | 206 | 2.2 | - | - | - | 840 | 81 | 7.7 | 20 | 2 | 8.1 |
| 1980–81 | 30 | 10 | 3.5 | 50 | 7 | 4.0 | 7 960 | 2 074 | 2.3 | 980 | 235 | 3.3 |
| 1981–82 | 360 | 77 | 4.0 | 90 | 12 | 6.4 | 3 830 | 616 | 4.4 | 40 | 9 | 4.3 |
| 1982–83 | 1 030 | 63 | 8.5 | 90 | 11 | 5.0 | 8 500 | 1 484 | 3.6 | 7 440 | 856 | 7.1 |
| 1983–84 | 1 190 | 139 | 6.4 | - | - | - | 2 780 | 657 | 2.9 | 3 370 | 493 | 4.5 |
| 1984–85 | 990 | 80 | 9.5 | - | - | - | 1 640 | 314 | 3.3 | 5 660 | 824 | 4.5 |
| 1985–86 | 3 030 | 306 | 8.1 | 30 | 11 | 2.5 | 3 400 | 564 | 2.8 | 3 660 | 840 | 1.8 |
| 1986–87 | 1 950 | 296 | 4.6 | 30 | 11 | 2.0 | 2 920 | 660 | 2.3 | 2 470 | 601 | 1.6 |
| 1987–88 | 2 100 | 324 | 5.3 | 130 | 19 | 4.7 | 1 360 | 386 | 2.4 | 2 020 | 673 | 0.8 |
| 1988–89 | 2 080 | 299 | 4.5 | 130 | 25 | 3.2 | 2 780 | 782 | 1.8 | 1 170 | 568 | 0.6 |
| 1989–90 | 360 | 86 | 3.0 | 160 | 28 | 5.5 | 2 100 | 602 | 2.0 | 470 | 237 | 0.6 |
| 1990–91 | 480 | 87 | 1.0 | 10 | 2 | 4.2 | 1 230 | 261 | 2.6 | 170 | 75 | 0.3 |
| 1991–92 | 3 050 | 366 | 5.0 | 70 | 25 | 1.3 | 180 | 60 | 2.0 | 30 | 52 | < 0.1 |
| 1992–93 | 570 | 75 | 2.0 | 3 300 | 297 | 5.1 | 170 | 69 | 1.4 | 290 | 83 | 1.5 |
| 1993–94 | 510 | 122 | 1.9 | 2 180 | 363 | 1.9 | 1 120 | 213 | 1.0 | 220 | 129 | 0.5 |
| 1994–95 | 440 | 195 | 1.0 | 1 510 | 363 | 1.0 | 720 | 268 | 1.0 | 100 | 95 | < 0.1 |
| 1995–96 | 450 | 120 | 0.5 | 1 790 | 355 | 1.0 | 430 | 212 | 0.8 | 80 | 104 | < 0.1 |
| 1996–97 | 370 | 117 | 1.0 | 870 | 243 | 0.5 | 1 210 | 400 | 2.0 | 170 | 75 | 0.2 |
| 1997–98 | 450 | 259 | 0.3 | 830 | 305 | 0.4 | 1 290 | 487 | 1.0 | 60 | 52 | 0.1 |
| 1998–99 | 350 | 214 | 0.3 | 930 | 186 | 0.8 | 1 510 | 550 | 1.0 | 50 | 1 | 0.5 |
| 1999–00 | 390 | 162 | 0.3 | 630 | 239 | 0.5 | 1 280 | 353 | 1.0 | 50 | 10 | 0.3 |
| 2000–01 | 580 | 155 | 1.0 | 1 010 | 301 | 0.5 | 1 310 | 613 | 1.0 | 100 | 21 | 3.0 |
| 2001–02 | 900 | 240 | 1.1 | 730 | 206 | 0.9 | 1 260 | 645 | 0.8 | 30 | 18 | 0.6 |
| 2002–03 | 1 280 | 397 | 0.8 | 1 080 | 253 | 0.8 | 1 050 | 593 | 0.8 | 150 | 42 | 1.4 |
| 2003–04 | 840 | 394 | 0.6 | 740 | 126 | 0.7 | 1 030 | 586 | 1.0 | 100 | 48 | 0.4 |
| 2004–05 | 1 330 | 405 | 0.9 | 920 | 170 | 1.1 | 560 | 331 | 0.7 | 100 | 23 | 2.2 |
| 2005–06 | 1 810 | 533 | 0.8 | 960 | 188 | 0.6 | 380 | 238 | 0.7 | 90 | 53 | 0.5 |
| 2006–07 | 1 540 | 573 | 0.9 | 590 | 78 | 1.8 | 80 | 29 | 0.2 | 160 | 38 | 0.6 |
| 2007–08 | N/A | N/A | N/A | 390 | 176 | 0.6 | 320 | 109 | 0.8 | 280 | 107 | 0.6 |
| 2008–09 | 1 170 | 443 | 1.0 | 390 | 75 | 1.3 | 280 | 110 | 0.5 | 500 | 182 | 0.5 |

**Table 4 [continued]**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2009–10 | 560 | 217 | 1.2 | 290 | 90 | 0.8 | 360 | 193 | 1.2 | 470 | 120 | 1.0 |
| 2010–11 | 130 | 43 | 0.6 | N/A | N/A | N/A | 30 | 5 | 1.0 | 150 | 32 | 2.0 |
| 2011–12 | 120 | 61 | 0.7 | - | - | - | 30 | 4 | 1.5 | N/A | N/A | N/A |
| 2012–13 | N/A | N/A | N/A | - | - | - | 30 | 7 | 1.6 | N/A | N/A | N/A |
| 2013–14 | 260 | 82 | 1.0 | 570 | 102 | 1.1 | 110 | 67 | 0.7 | N/A | N/A | N/A |
| 2014–15 | 200 | 52 | 1.4 | 550 | 164 | 0.5 | 180 | 106 | 0.7 | - | - | - |
| 2015–16 | 360 | 263 | 0.3 | 400 | 165 | 0.5 | 180 | 215 | 0.5 | - | - | - |
| 2016–17 | 269 | 154 | 0.4 | 187 | 137 | 0.5 | 473 | 329 | 0.7 | 21 | 34 | 0.1 |
| 2017–18 | 450 | 166 | 0.8 | 400 | 177 | 0.5 | 351 | 214 | 0.6 | N/A | N/A | N/A |

| | Big Chief (S) | | | Rest of South (S) | | | Rekohu | | |
|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Catc** | **Tow** | **t/to** | **Catc** | **Tow** | **t/to** | **Catch** | **Tow** | **t/to** |
| 1979–80 | - | - | - | 20 | 12 | < 0.1 | 30 | 8 | 3.1 |
| 1980–81 | - | - | - | 110 | 25 | 3.4 | 60 | 4 | 14.1 |
| 1981–82 | - | - | - | 30 | 28 | 1.1 | - | - | - |
| 1982–83 | - | - | - | 180 | 31 | < 0.1 | 30 | 4 | 3.9 |
| 1983–84 | - | - | - | 120 | 86 | 0.1 | - | - | - |
| 1984–85 | - | - | - | 870 | 289 | 0.6 | - | - | - |
| 1985–86 | - | - | - | 530 | 198 | 0.6 | 40 | 2 | 2.3 |
| 1986–87 | - | - | - | 1 440 | 433 | 1.1 | N\A | N/A | N/A |
| 1987–88 | - | - | - | 3 180 | 924 | 0.7 | 40 | 5 | 0.4 |
| 1988–89 | 1 010 | 199 | 1.7 | 4 650 | 1 | 0.3 | 60 | 5 | 0.6 |
| 1989–90 | 2 830 | 529 | 1.5 | 4 090 | 1 | 1.0 | N/A | N/A | N/A |
| 1990–91 | 3 150 | 453 | 2.1 | 1 620 | 500 | 0.3 | N/A | N/A | N/A |
| 1991–92 | 820 | 138 | 2.5 | 780 | 308 | 0.3 | - | - | - |
| 1992–93 | 3 310 | 703 | 2.0 | 1 190 | 462 | < 0.1 | - | - | - |
| 1993–94 | 2 350 | 698 | 0.6 | 2 060 | 1 | 0.1 | - | - | - |
| 1994–95 | 510 | 242 | 0.8 | 880 | 937 | < 0.1 | - | - | - |
| 1995–96 | 580 | 151 | 1.0 | 460 | 553 | < 0.1 | - | - | - |
| 1996–97 | 560 | 195 | 0.5 | 440 | 304 | < 0.1 | - | - | - |
| 1997–98 | 950 | 285 | 0.4 | 410 | 503 | 0.1 | - | - | - |
| 1998–99 | 560 | 215 | 0.5 | 390 | 258 | 0.3 | - | - | - |
| 1999–00 | 380 | 123 | 0.5 | 430 | 173 | 0.5 | - | - | - |
| 2000–01 | 1 020 | 213 | 0.8 | 400 | 203 | 0.5 | - | - | - |
| 2001–02 | 660 | 234 | 0.9 | 280 | 186 | 0.5 | - | - | - |
| 2002–03 | 660 | 276 | 0.5 | 480 | 204 | 0.5 | - | - | - |
| 2003–04 | 570 | 300 | 0.5 | 460 | 266 | 0.4 | 1 030 | 151 | 4.0 |
| 2004–05 | 790 | 308 | 0.5 | 490 | 231 | 0.6 | 1 030 | 200 | 2.9 |
| 2005–06 | 500 | 303 | 0.4 | 400 | 281 | 0.4 | 160 | 65 | 1.1 |
| 2006–07 | 510 | 282 | 0.4 | 200 | 187 | 0.3 | 80 | 43 | 0.7 |
| 2007–08 | 690 | 335 | 0.5 | 170 | 189 | 0.3 | N/A | N/A | N/A |
| 2008–09 | 330 | 307 | 0.2 | 120 | 158 | 0.1 | N/A | N/A | N/A |
| 2009–10 | 180 | 121 | 0.3 | 40 | 68 | 0.2 | 60 | 28 | 1.3 |
| 2010–11 | 210 | 60 | 0.5 | 30 | 34 | < 0.1 | 400 | 31 | 6.5 |
| 2011–12 | 180 | 72 | 0.5 | 10 | 20 | 0.5 | 670 | 36 | 19.5 |
| 2012–13 | N\A | N\A | N\A | 50 | 19 | 0.3 | 710 | 39 | 25.0 |
| 2013–14 | 350 | 77 | 1.0 | 90 | 40 | 0.9 | 950 | 40 | 24.2 |
| 2014–15 | 250 | 56 | 0.9 | 40 | 11 | 0.5 | 1 780 | 89 | 21.7 |
| 2015–16 | 190 | 159 | 0.1 | 110 | 61 | 0.1 | 700 | 54 | 10.8 |
| 2016–17 | 393 | 139 | 0.2 | 69 | 74 | 0.1 | 868 | 115 | 5.0 |
| 2017–18 | 340 | 172 | 0.2 | 20 | 30 | 0.4 | 801 | 83 | 5.5 |

**Table 5: Estimated ORH 3B catches (to the nearest 10 t) and unstandardised median catch rates (to nearest 0.1 t/tow) for areas outside the Chatham Rise, using estimated catch and effort data held by NIWA. Only tows targeted at orange roughy are included. For this table the areas were defined by the following rectangles: Arrow - 42.17-46°S, 173.67°W; Auckland - 49-52 °S, 165-167 °E; Bounty - 46-47.5°S, 177.5-180°E; Priceless - 48-48.44°S, 174.7-175.2°E; Other Pukaki - 47-50.4°S, 174-176.4°E (and not in Priceless); Puysegur - 46-47.5 °S, 165-166.5 °E. The area described as Antipodes in previous reports is now included in Other Pukaki. All years are from 1 October-30 September (2016-17 data are provisional and catch totals may be incomplete). - means catch < 10 t. N/A means catch greater than 10 t, but there were fewer than 3 vessels in the fishery.**

| | Arrow | | Auckland | | Bounty | | Priceless | | Other Pukaki | | Puysegur | | Other | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Catch** | **t/tow** | **Catch** | **t/tow** | **Catch** | **t/tow** | **Catch** | **t/tow** | **Catch** | **t/tow** | **Catch** | **t/tow** | **Catch** | **t/tow** |
| 1985–86 | 120 | 18.5 | - | - | - | - | - | - | - | - | - | - | - | - |
| 1986–87 | 110 | 10.6 | - | - | - | - | - | - | - | - | - | - | - | - |
| 1987–88 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 1988–89 | - | - | - | - | - | - | - | - | - | - | - | - | 30 | <0.1 |
| 1989–90 | - | - | - | - | - | - | - | - | - | - | 100 | 1.4 | 50 | 6.0 |
| 1990–91 | 150 | 4.5 | - | - | - | - | - | - | - | - | 600 | 4.6 | 20 | <0.1 |
| 1991–92 | 100 | 10.0 | - | - | - | - | - | - | - | - | 6 320 | 10.6 | 170 | 0.6 |
| 1992–93 | 10 | 6.5 | 30 | < 0.1 | - | - | - | - | - | - | 4 280 | 6.7 | 330 | < 0.1 |
| 1993–94 | 470 | 1.0 | 180 | < 0.1 | - | - | - | - | - | - | 2 410 | 1.9 | 80 | < 0.1 |
| 1994–95 | 750 | 0.3 | 880 | 0.2 | - | - | - | - | - | - | 1 260 | 7.9 | 20 | < 0.1 |
| 1995–96 | 170 | 0.1 | 370 | 0.1 | - | - | - | - | 3 060 | 5.0 | 730 | 2.4 | 520 | < 0.1 |
| 1996–97 | 280 | 0.1 | 120 | < 0.1 | 20 | < 0.1 | - | - | 670 | < 0.1 | 490 | 2.6 | 400 | < 0.1 |
| 1997–98 | 330 | 0.1 | 360 | 0.1 | 240 | < 0.1 | 10 | < 0.1 | 130 | < 0.1 | - | - | 1 050 | < 0.1 |
| 1998–99 | 730 | 0.3 | 440 | 0.1 | 130 | 0.1 | - | - | 120 | < 0.1 | - | - | 1 820 | 0.5 |

**Table 5 [continued]**

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1999–00 | 280 | 0.1 | 150 | < 0.1 | 170 | < 0.1 | - | - | - | - | - | - | 60 | < 0.1 |
| 2000–01 | 190 | 0.1 | 60 | < 0.1 | 150 | 0.3 | - | - | 20 | < 0.1 | - | - | 1 030 | 0.3 |
| 2001–02 | 70 | 0.2 | 130 | 0.1 | 40 | 0.1 | 550 | 22.3 | - | - | - | - | 460 | 0.4 |
| 2002–03 | 220 | 0.2 | - | - | 220 | 1.5 | 480 | 7.0 | - | - | - | - | 400 | 0.4 |
| 2003–04 | 140 | 0.1 | - | - | 90 | 0.2 | 450 | 0.3 | - | - | - | - | 440 | < 0.1 |
| 2004–05 | 60 | 0.1 | - | - | 100 | 0.4 | 540 | 0.3 | 520 | 9.8 | N/A | N/A | 550 | < 0.1 |
| 2005–06 | 100 | 0.1 | - | - | 40 | 0.2 | 540 | 0.9 | 740 | 4.0 | N/A | N/A | 250 | < 0.1 |
| 2006–07 | - | - | - | - | - | - | 470 | 0.5 | N/A | N/A | - | - | - | - |
| 2007–08 | - | - | N/A | N/A | - | - | N/A | N/A | N/A | N/A | - | - | - | - |
| 2008–09 | - | - | N/A | N/A | - | - | N/A | N/A | N/A | N/A | - | - | 150 | 0.5 |
| 2009–10 | - | - | N/A | N/A | N/A | N/A | 210 | < 0.1 | 320 | 0.3 | - | - | 60 | < 0.1 |
| 2010–11 | - | - | N/A | N/A | N/A | N/A | - | - | N/A | N/A | - | - | 20 | 0.4 |
| 2011–12 | - | - | N/A | N/A | - | - | - | - | - | - | - | - | - | - |
| 2012–13 | - | - | N/A | N/A | - | - | - | - | N/A | N/A | - | - | - | - |
| 2013–14 | - | - | N/A | N/A | - | - | - | - | - | - | - | - | - | - |
| 2014–15 | - | - | 350 | < 0.1 | - | - | - | - | - | - | - | - | 38 | 0.6 |
| 2015–16 | - | - | 380 | 0.6 | - | - | - | - | - | - | N/A | N/A | - | - |
| 2016–17 | - | - | 184 | 0.3 | N/A | N/A | - | - | N/A | N/A | N/A | N/A | 49 | 0.8 |
| 2017–18 | - | - | 105 | 0.1 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

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 5 000 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). A catch limit of 150 t was provided for research purposes in Puysegur from 2010-11 (Table 3). Following a stock assessment of Puysegur in 2017, a commercial catch limit was set at 347 t from 1 October 2017.

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 remained low until an increase in 2013–14. 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 3 000 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 1 000 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 Table 5).

In 1995–96, large catches were reported on the southeast Pukaki Rise, with a catch total of over 3 000 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. From 2008–09 the fishery extended over a relatively wide area, but catches and catch rates were low, and the fishery effectively ceased from 2010–11 (Table 5).

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, and none since 2011–12) (Table 5), 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 6. 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.

**Table 6: Chatham Rise 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 |

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; Horn et al 2016), there was a return to model-based assessment in 2014. 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 2018, using data up to 2016–17. This used an age-structured population model 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 a trawl survey, and 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 6. 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; an age-frequency taken from targeted trawls above Morgue, and length frequencies collected from the commercial fishery covering 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 7). An alternative treatment of the available acoustic data was to include additional survey estimates from 2002 and 2004 (Table 7). All of the data in Table 7 were used in the sensitivity run labelled "Extra acoustics".

**Table 7: 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 | 8 126 | 22 |
| 2002 | Towed-body | 38 kHz | GY+O | 2 | 9 414 | 20 |
| 2004 | Hill-mounted | 38 kHz | GY | 6 | 2 717 | 16 |
| 2012 | AOS | 38 kHz | GY | 3 | 5 550 | 17 |
| | AOS | 38 kHz | M | 4 | 9 087 | 11 |
| 2013 | AOS | 120 kHz | GY | 1 | 6 656 | 31 |
| 2016 | AOS | 38 kHz | GY | 1 | 0 | N/A |
| | AOS | 38 kHz | M | 3 | 14 051 | 13 |

The acoustic estimates in 1999, 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% (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 & Fenaughty 1997). An age-frequency for the trawl-selected biomass was estimated using 300 otoliths selected using the method of Doonan et al (2014). 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 one sixth 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.

**Age frequencies**
In addition to the age frequencies from the 1994 trawl survey, an age frequency was developed from samples taken above Morgue during the spawning season in 2016. Approximately 300 otoliths were randomly selected from three tows. The age frequency was fitted as multinomial with effective sample sizes of 60. The 2016 age frequency from Morgue was derived from the use of a demersal trawl fished a few metres off the bottom, and this in part led to concerns about the representativeness of this sampling.

### 4.1.3 Model runs and results
In the base model, the acoustic estimates from 1999, 2012, 2013, and 2016 were used, and the age-frequency from 2016 was excluded. There were four main sensitivity runs: add the extra acoustic data; the *LowM-Highq* and *HighM-Lowq* "standard" runs (see Orange Roughy Introduction); and including the 2016 age-frequency with its own (logistic) selectivity.

In the base model, the main parameters estimated were: virgin (unfished, equilibrium) biomass ($B_0$), maturity ogive, trawl-survey (logistic) selectivity, CV of length-at-mean-length-at-age for ages 1 and 100 years (linear interpolation 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). In the sensitivity run including the 2016 age-frequency the YCS were estimated from 1940 to 1992.

**Model diagnostics**
The model provided good MPD fits to the data (Figures 3 and 4). The acoustic indices, free to "move" somewhat as they are relative, were fitted well (Figure 3). 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 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).

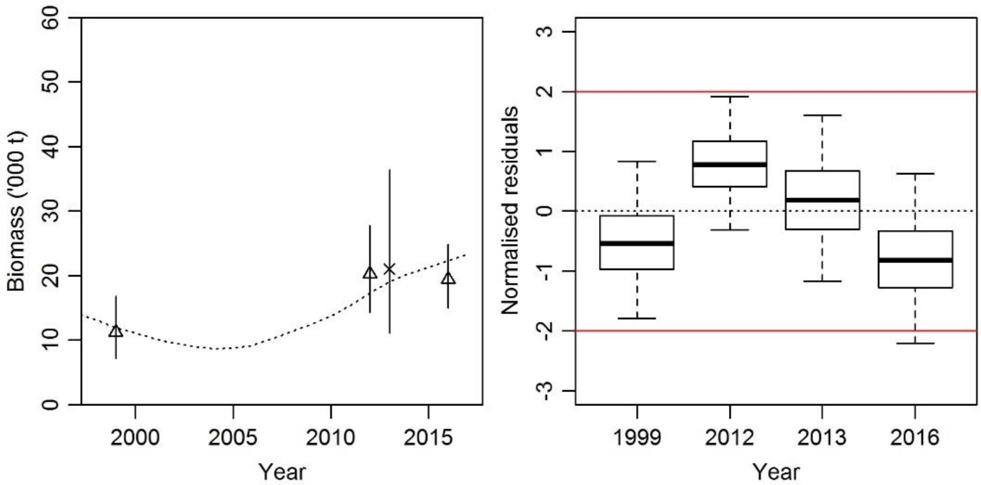



**Figure 3: NWCR, base, (left) MPD fits to the acoustic biomass indices; broken line, spawning biomass trajectory; scaled acoustic indices for x, Graveyard survey, and Δ, Graveyard and Morgue surveys; (right) MCMC normalised residuals for the acoustic biomass indices. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution.**

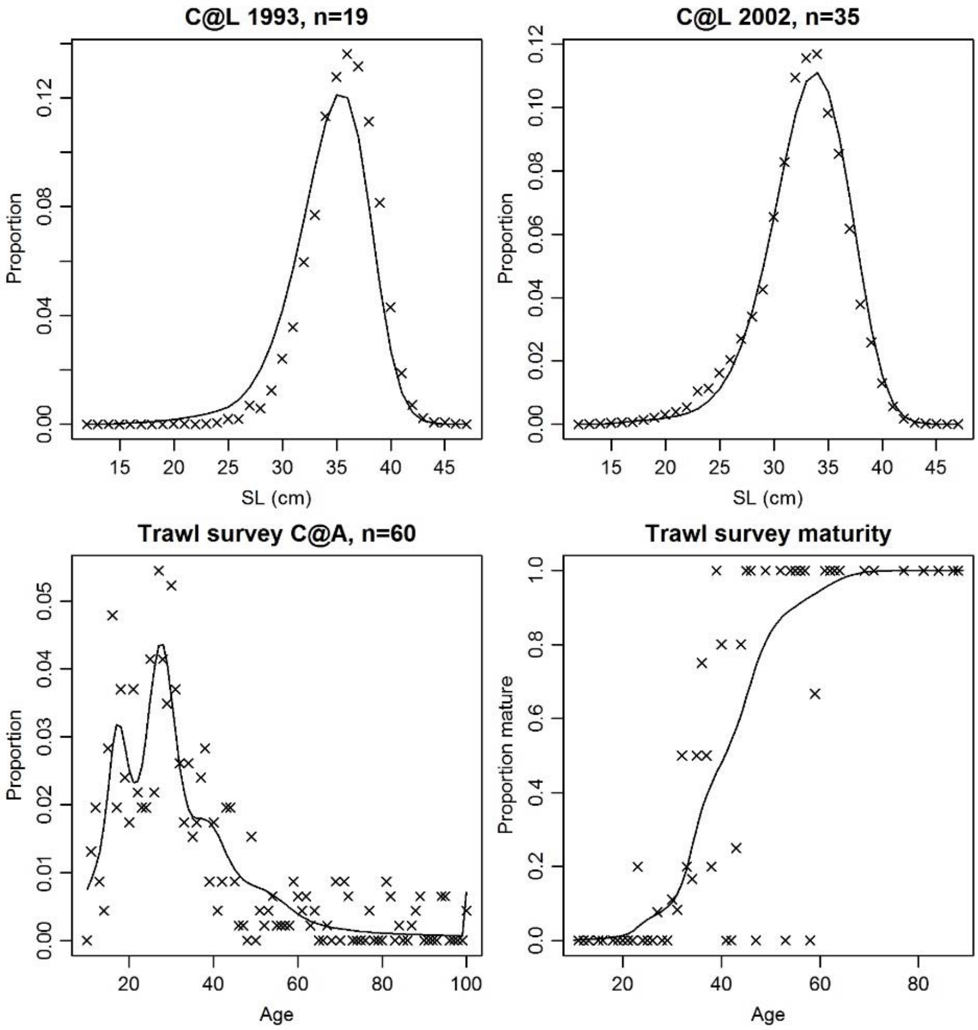



**Figure 4: NWCR, base, MPD fits: (x, observations; lines, predictions): (top) commercial catch-at-length samples (n is the effective sample size); (bottom) trawl survey catch-at-age and proportion mature at age.**

When the Morgue age-frequency was fitted assuming that the selectivity on Morgue was equal to maturity the fit was poor, particularly to the left-hand side of the age frequency distribution. When the

Morgue age frequency was fitted assuming a separate logistic selectivity ogive the fit was acceptable (Figure 6). The Morgue age frequency had an unexpectedly high proportion of older fish, and the sampling methodology was also unusual. As a result, it was agreed to exclude the Morgue age frequency data from the base model.

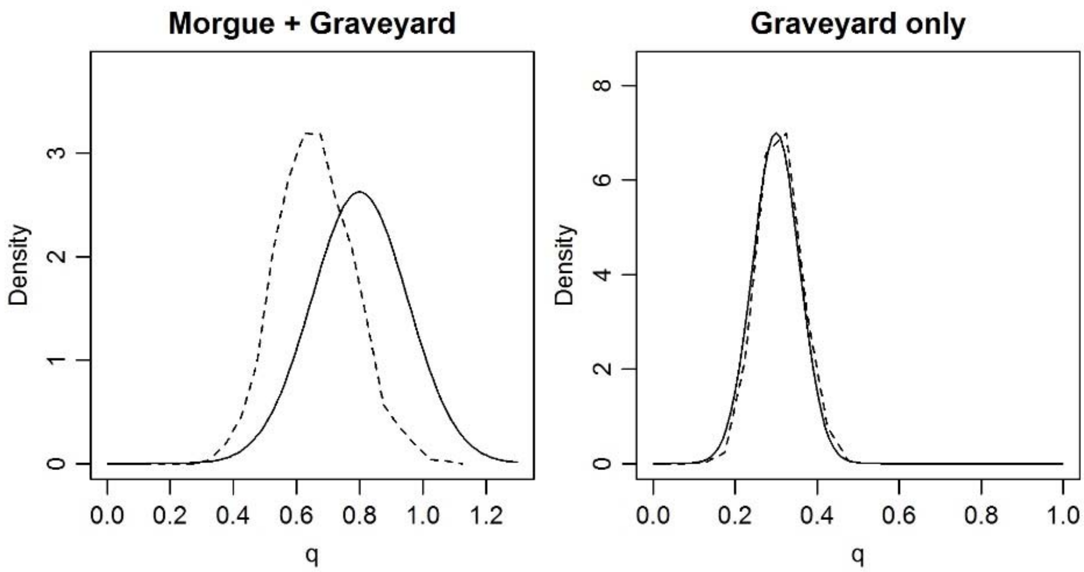



**Figure 5: NWCR base, MCMC diagnostics: prior (solid line) and posterior (broken line) distributions for the two acoustic *q*s (left, mean *q*-prior = 0.8; right, mean q-prior = 0.3).**

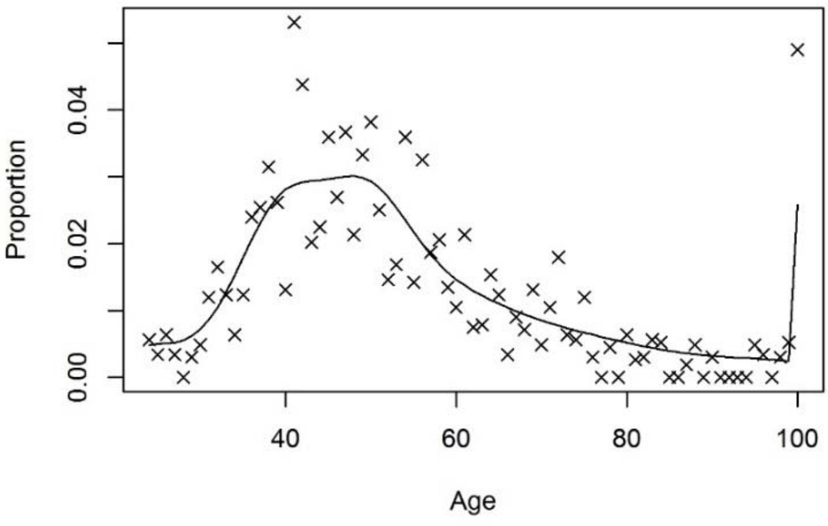



**Figure 6: NWCR, base, MPD fits: (x, observations; lines, predictions) to the Morgue age frequency (effective sample size n = 60).**

## MCMC Results

For the base model, and the sensitivity runs, MCMC convergence diagnostics indicated no lack of convergence. Virgin biomass, $B_0$, was estimated to be between 64 000–67 300 t for all runs (Table 8). Current stock status was similar across the base and the first two sensitivity runs (Table 8). 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 8).

**Table 8: NWCR, 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 AF | 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. For the sensitivity runs, the probability of being above 30% $B_0$ in 2017 was 98% (Extra acoustics), 97% (Include Morgue AF), 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 7).

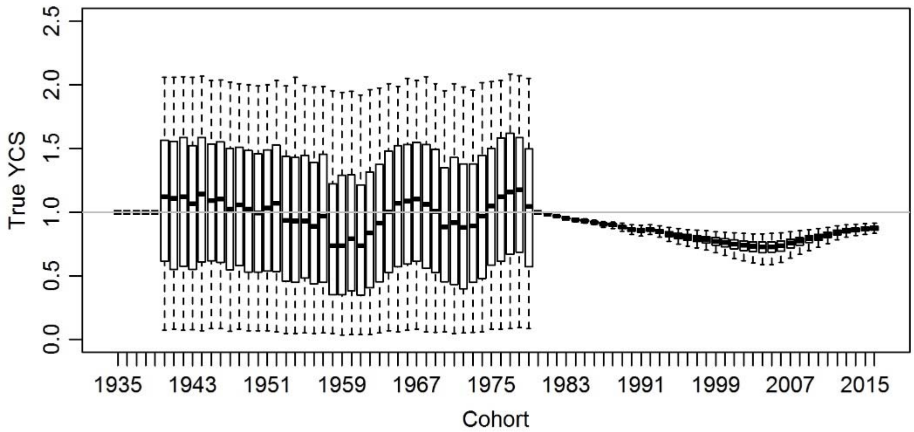



**Figure 7: NWCR base, MCMC estimated "true" YCS ($R_y/R_0$). The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution.**

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 8). Since 2005 the estimated biomass has increased steadily.

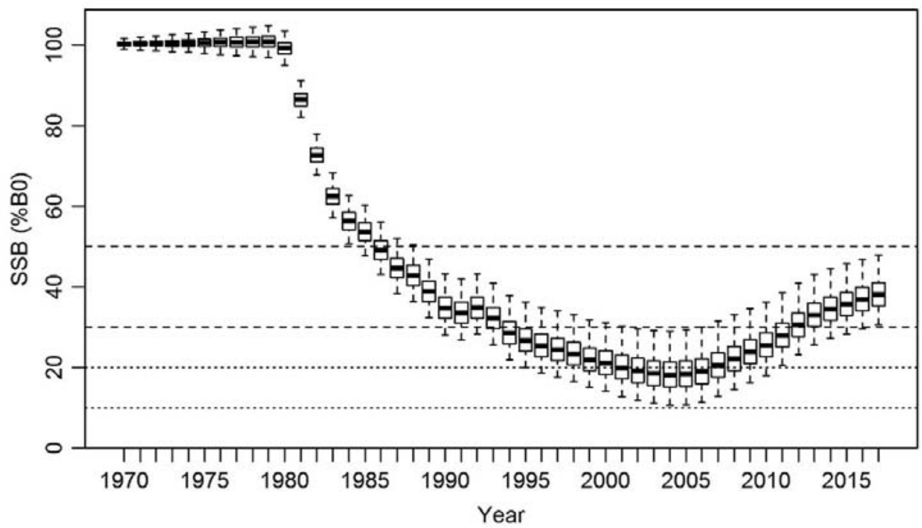



**Figure 8: NWCR base, MCMC estimated spawning-stock biomass trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. Dotted lines indicate the hard limit (10% $B_0$) and soft limit (20% $B_0$), dashed lines the management target range (30–50% $B_0$).**

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 (at that rate, not tonnage) 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 2009–2010 before dropping substantially when the industry agreed to curtail fishing the NWCR in 2011, and has been in or just below the target range since 2014 (Figure 9). There was less than a 1% probability that the exploitation rate in 2017 was below $U_{30\%B0}$.

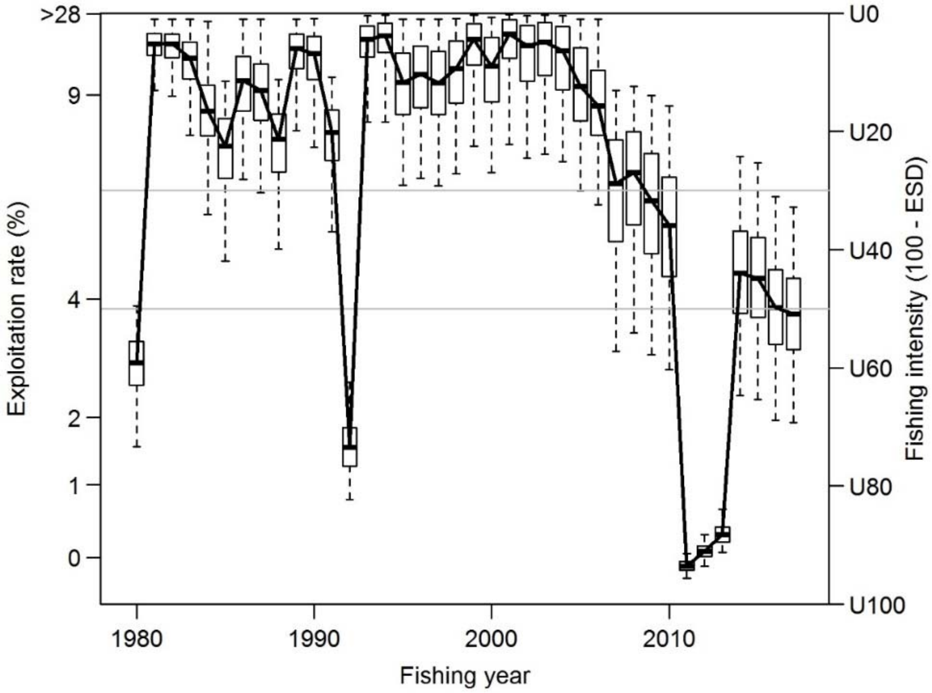



**Figure 9: NWCR base, MCMC estimated fishing-intensity trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The fishing-intensity range associated with the biomass target of 30–50% $B_0$ is marked by horizontal lines.**

## Projections

Five-year biomass projections were made for the Base model run assuming future catches to be the TACC (1 250 t), or the current agreed catch limit (1 043 t; 207 t has been shelved). For each projection scenario, future recruitment variability was sampled from actual estimates between 1940 and 1979.

At the TACC (1 250 t) and the current agreed catch limit (1 043 t), SSB is predicted to remain stable or slowly increase over the next five years, and the probability of the SSB going below the soft or hard limits is zero (Table 9).

**Table 9: ORH 3B NWCR Bayesian median and 95% credible intervals (in parentheses) of projected $B_{2022}$, $B_{2022}$ as a percentage of $B_0$, and $B_{2022}/B_{2017}$ (%) for the model runs.**

| Model run | Catch | $B_{2022}$ | $B_{2022}$ (%$B_0$) | $B_{2022}/B_{2017}$ (%) | p($B_{2022}$ < 0.2 $B_0$) | p($B_{2022}$ < 0.1 $B_0$) |
|---|---|---|---|---|---|---|
| Base | 1 043 | 26 500 (20 000–38 100) | 41 (33–51) | 107 (104–111) | 0 | 0 |
| | 1 250 | 25 600 (19 100–37 200) | 39 (31–50) | 104 (101–107) | 0 | 0 |

## Biological reference points, management targets and yield

Orange roughy stocks with model based stock assessments are managed according to the Harvest Control Rule (HCR) that was developed in 2014 using a Management Strategy Evaluation (MSE) (Cordue 2014b). The HCR has a target management range of 30–50% $B_0$.

Yield estimates are not reported for this stock.

### 4.2 East and South Chatham Rise

A Bayesian stock assessment was conducted for the East and South Chatham Rise (ESCR) stock in 2018, using data up to 2016–17. The model was 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 by apportioning the total ORH 3B reported catch across areas using catch proportions from estimated catch on TCEPR forms (Table 4). The over-run percentages in Table 6 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.

#### 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 (2002–2014, 2016), Rekohu (2011–2014, 2016) and the Crack (2011, 2013, 2016); age frequencies from the spawning areas (2012, 2013, and 2016); trawl survey biomass indices and length frequencies; and 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, which 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, 2013 and 2016, an additional (but known historically) 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 10. In order to make the estimates as comparable as possible across years, only biomass estimates from 38 kHz transducers 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).

A key question evaluated in the 2014 assessment was how long has the Rekohu plume been in existence (Cordue, 2014a). If the Rekohu plume had 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.

Following Cordue (2014a), 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, 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 proportionality constant or $q$. 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.

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 Orange Roughy Introduction). 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, which gave a mean of 0.7 for the 2012 and 2014 indices, 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 $q$s in years other than 2011 and 2013, the priors were given an increased CV of 30%.

**Table 10: 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 Waitaki* from 38 kHz transducers. Each estimate is the average of a number of snapshots as reflected by the estimated CVs. Some estimates have been revised since the 2014 assessment (Dunn & Doonan 2018).**

| | 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 | 15 554 | 14 | 33 348 | 10 | 5 471 | 16 |
| 2014 | 19 360 | 18 | 44 421 | 25 | – | – |
| 2015 | – | – | – | – | – | – |
| 2016 | 11 192 | 13 | 27 027 | 13 | 5 341 | 10 |

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 distribution of biomass between areas observed in 2011, 2013, and 2016. This means that the 2012 and 2014 surveys were assumed to cover 88% of the area (relative biomass) covered in 2011, 2013, and 2016, which 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.

## 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).

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.

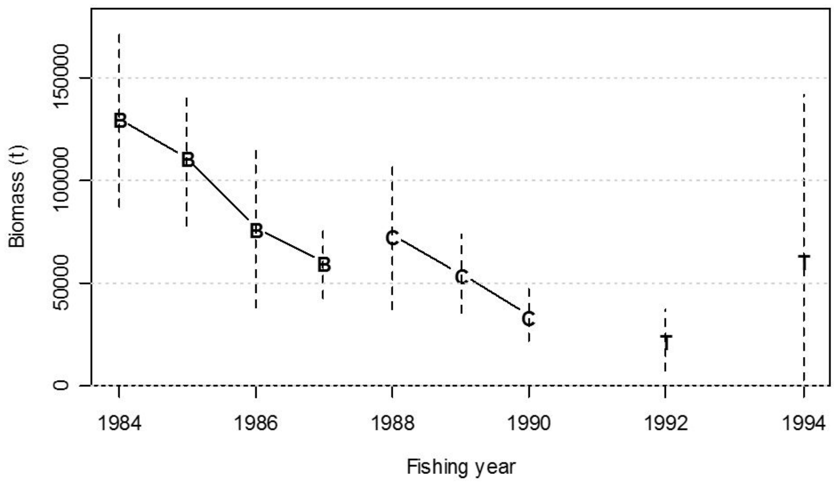



**Figure 10: The Spawning Box trawl survey biomass indices (assuming a catchability of 1 for each vessel), with 95% confidence intervals shown as vertical lines. Vessels indicated as B, FV *Otago Buccaneer*; C, FV *Cordella*; T, RV *Tangaroa*.**

The 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). Trawl survey length frequencies were fitted assuming that all mature fish were selected, but immature fish were selected assuming capped-logistic ogives. One selectivity ogive for immature fish was shared by the *Buccaneer, Cordella*, and *Tangaroa* Spawning Box surveys, with a second ogive for the immature fish caught in the *Tangaroa* wide-area survey.

Length frequencies from the commercial fisheries were developed by Hicks (2006) and also fitted in the model. 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.

**Age frequencies**

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 (Doonan et al 2014a, b; 2018). Approximately 300 otoliths were randomly selected from each area in 2012 and 2016, and 250 from each area in 2013. The fish in the Old-plume were noted to be generally older than those in the Rekohu plume. The fish from the Crack, showed a mixture of ages from new spawners (20–30 years) through to much older fish (80–100 years). In the base model, the age frequencies were combined across areas and fitted as multinomial with effective sample sizes of 50 (2012) and 60 (2013 and 2016) respectively, reflecting the low number of trawls from which samples were taken.

### 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 first occurred in 2007; adjust $M$ and the mean of the priors by 20% (the standard *LowM-Highq* and *HighM-Lowq* runs, see Orange Roughy Introduction); and assume penalties on acoustic $q$-ratios.
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 good, except the biomass observed in 2016 was lower than predicted (Figure 11). 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 12).

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 13). For the Old-plume time series, posteriors were sometimes shifted towards the left of the priors, but more often to the right, indicating the predicted biomass was more often lower than expected (Figure 13).

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 11). Also, the model did not fit the very large increase in the *Tangaroa* Spawning Box survey (Figure 11).

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 14).

The MPD fits to the commercial length frequencies were excellent except the 1990 Spawning Box and eastern flats commercial fishery length frequency (Figure 15). Likewise the fits to the trawl survey length frequencies were excellent (Figure 15). The capped-logistic selectivities assumed for immature fish estimated that a small proportion of immature fish were caught, and therefore were able to fit the long tails observed on the left-hand side of the Spawning Box survey length frequencies.

Numerous sensitivity runs were conducted at the MPD stage (see also Cordue 2014a). The sensitivity runs included in management advice from the 2014 assessment were maintained in the 2017 assessment (Table 11). These runs included evaluating the effect of estimating $M$, assuming the Rekohu plume was not formed until 2007, the two "bounding" runs, where $M$ and the mean of the acoustic $q$ priors were shifted by 20% (High $M$-low $q$; low-$M$ high $q$). Additional sensitivity runs included the ratio-$q$ run, and runs assuming lognormal priors for YCS.

In the ratio-$q$ sensitivity run, the fits to most acoustic indices were good, but the 2003 and 2016 biomass estimates were lower than predicted (Figure 16). 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.

With a lognormal YCS prior, the estimated stock size and status was sensitive to the assumed $\sigma_R$ (variability in YCS). Estimates from the nearly-uniform YCS prior (assumed in the base model) were roughly equivalent to a lognormal YCS prior with $\sigma_R = 0.6$.

The residuals of the base model indicated that additional process error of around 20% was needed to adequately fit the 2011–16 acoustic biomass index, notably the low estimate for 2016; however, adding the process error made no material difference to the outcome (%$B_0$ was still 33%). The 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, and after further observations had been added to the series.

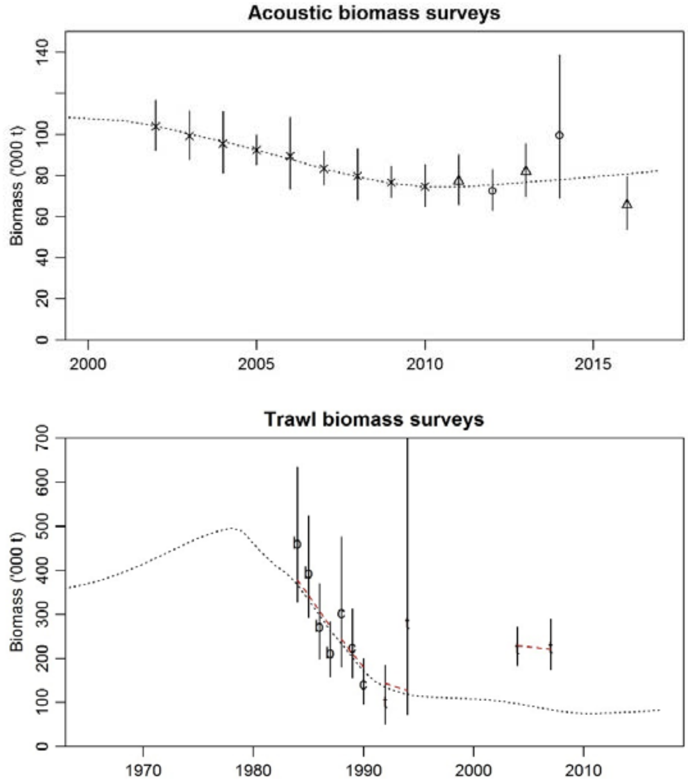



**Figure 11: ESCR, MPD, base: fit to the acoustic indices: (top) spawning biomass trajectory and scaled acoustic indices; x, Old plume surveys; Δ, three-area 2011, 2013 and 2016 surveys; o, two-area 2012 and 2014 surveys; (bottom) the spawning biomass trajectory (dotted line) and fits of the trawl surveys 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.**

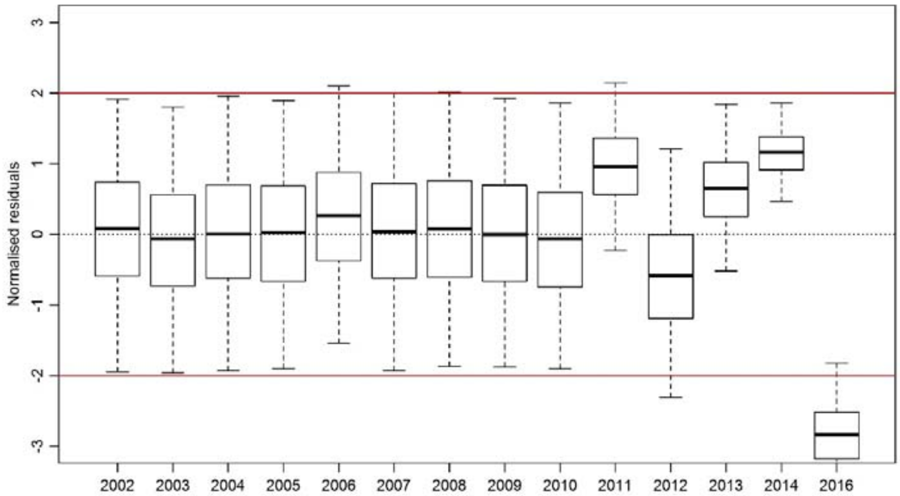



**Figure 12: ESCR, MCMC base: normalized residual for the acoustic indices. The box covers 50% of the distribution for each index and the whiskers extend to 95% of the distribution.**

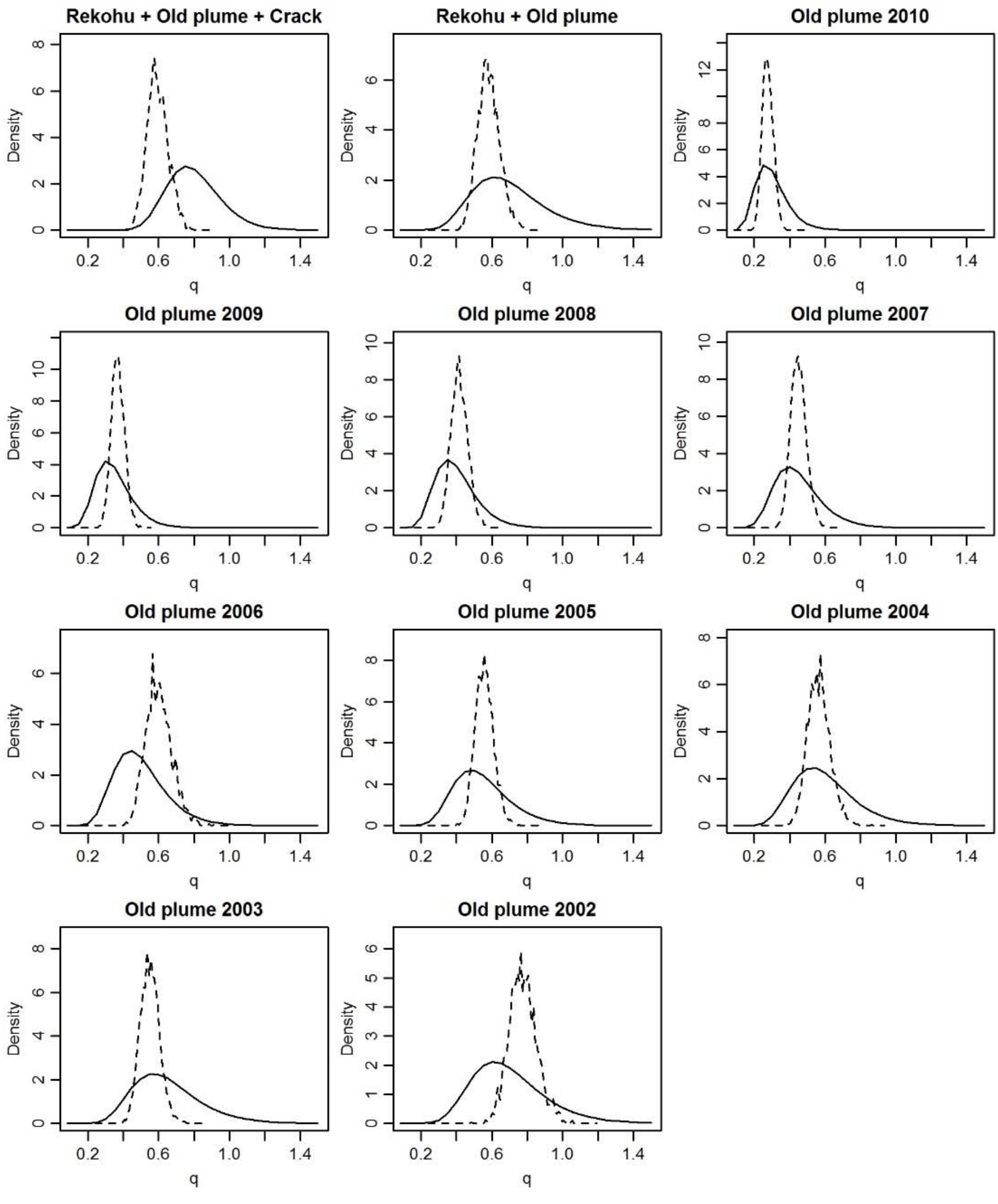



**Figure 13: ESCR, MCMC base: prior (solid lines) and posterior distributions (broken lines) for acoustic *q*s.**

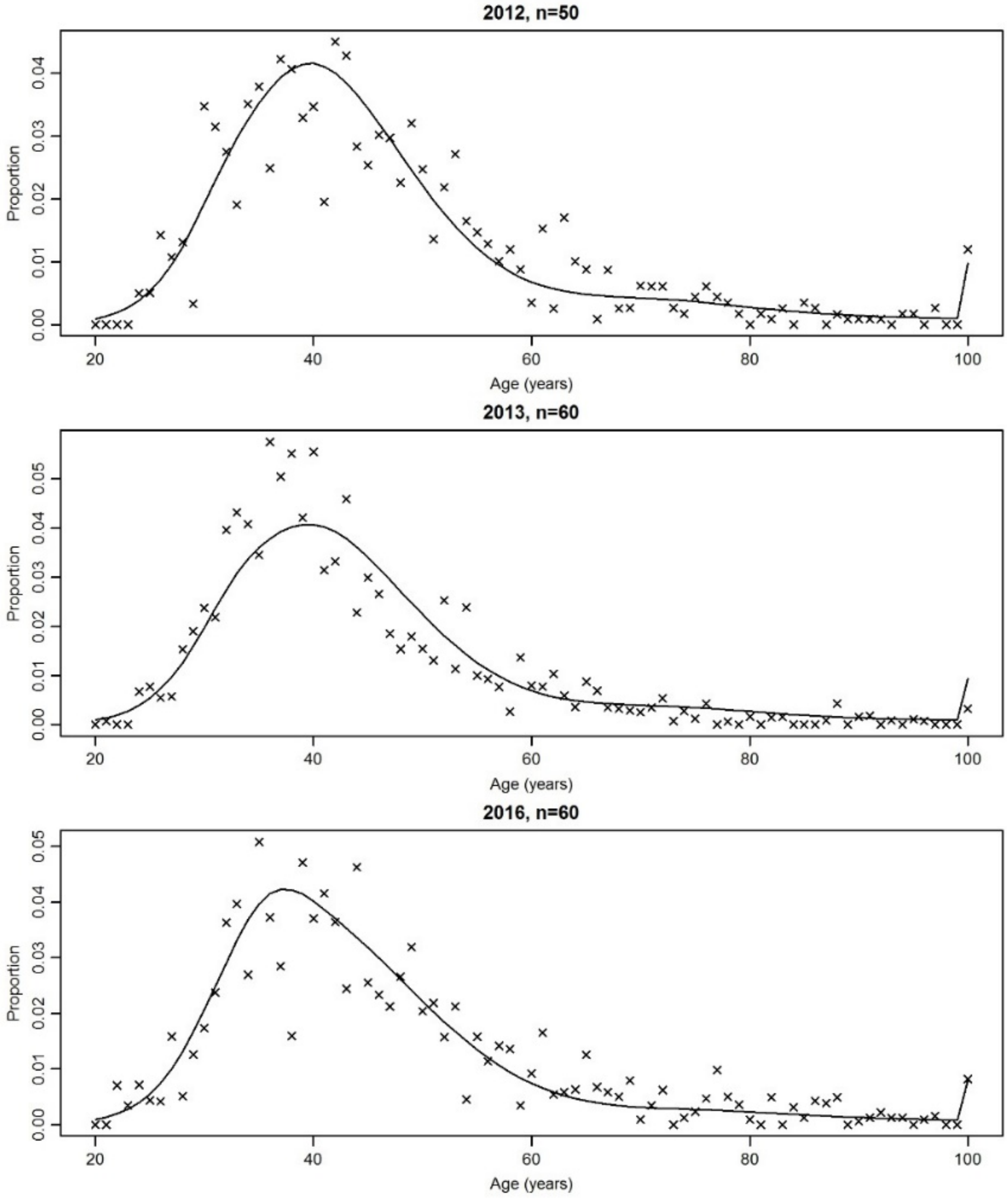



**Figure 14: ESCR, MPD base: fits (lines) to the spawning season age frequencies (points); n is the effective sample size.**

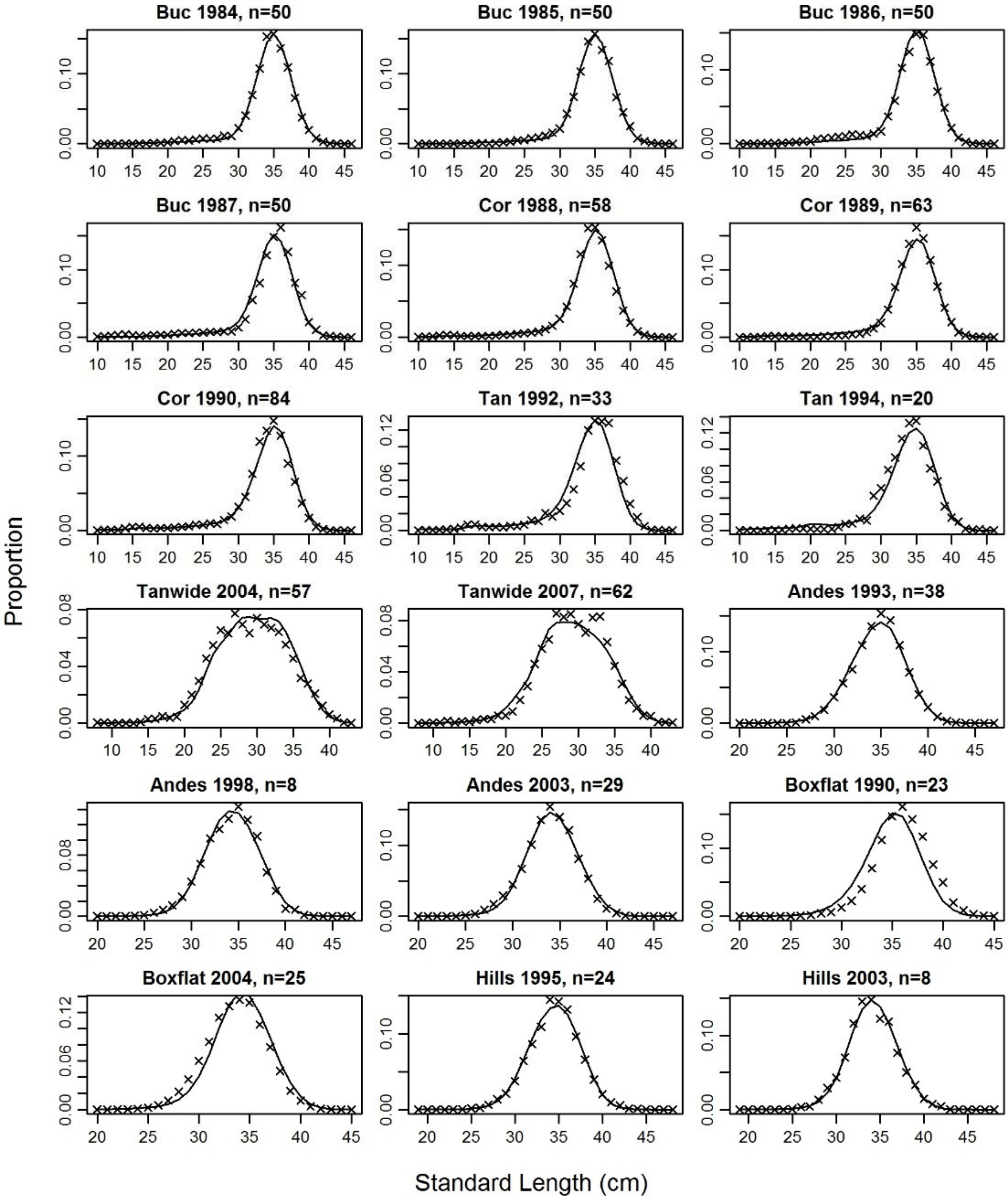



**Figure 15: ESCR, MPD base: fits (lines) to the length frequencies (x) for the *Buccaneer* surveys (Buc), *Cordella* surveys (Cor), *Tangaroa* Spawning Box surveys (Tan), *Tangaroa* wide-area surveys (Tanwide), commercial Andes fishery (Andes), commercial Spawning Box and eastern flats fishery (Boxflat), and eastern hills fishery (Hills); n is the effective sample size.**

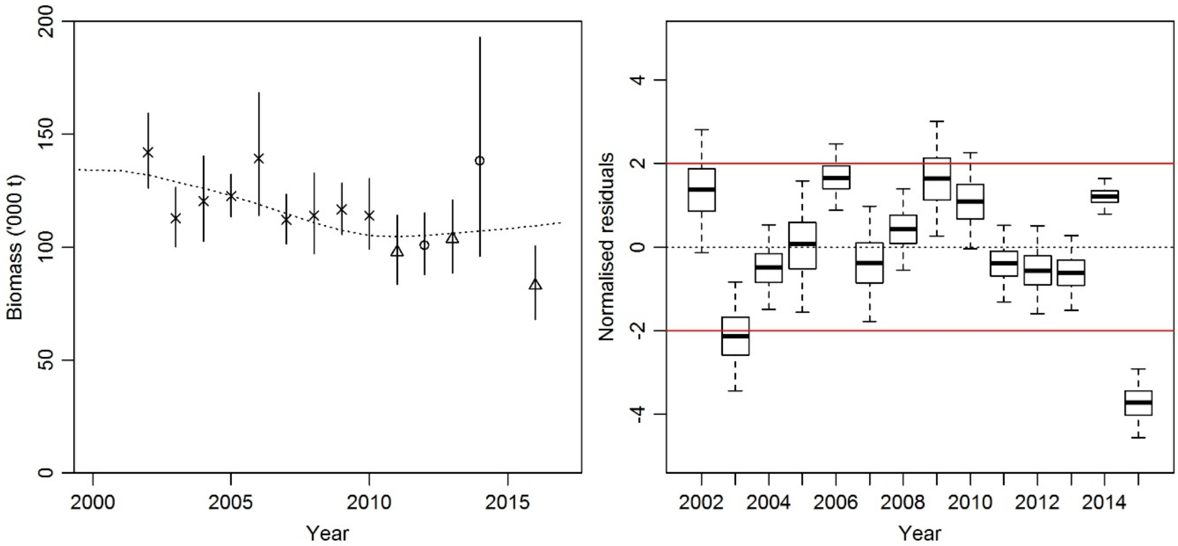



**Figure 16: ESCR, MPD, ratio-*q*: fit to the acoustic indices: (left) spawning biomass trajectory and scaled acoustic indices; x, Old plume surveys; Δ, three-area 2011, 2013 and 2016 surveys; o, two-area 2012 and 2014 surveys; (right) MCMC normalized residual for the acoustic indices (note 2016 is below -3 sd). The box covers 50% of the distribution for each index and the whiskers extend to 95% of the distribution.**

## MCMC results

For the base model, MCMC convergence diagnostics were good once the three chains (with random starting values near the MPD estimate) had been run for 15 million iterations. Some technical changes were made to improve chain convergence, including re-estimation of the covariance matrix; these improved diagnostics whilst giving results very similar to the model without the changes.

Virgin biomass, $B_0$, was estimated to be about 313 000 t for the base model with median estimates ranging from 300 600–363 100 t for the four sensitivity runs presented (Table 11). Current stock status was similar across the base and the first two sensitivity runs (Table 11). The lower stock status when *M* was estimated reflects the lower estimates 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 11).

**Table 11: ESCR, 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 |

The estimated YCS show little variation across cohorts but do exhibit a long-term trend (Figure 17). 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 18).

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).

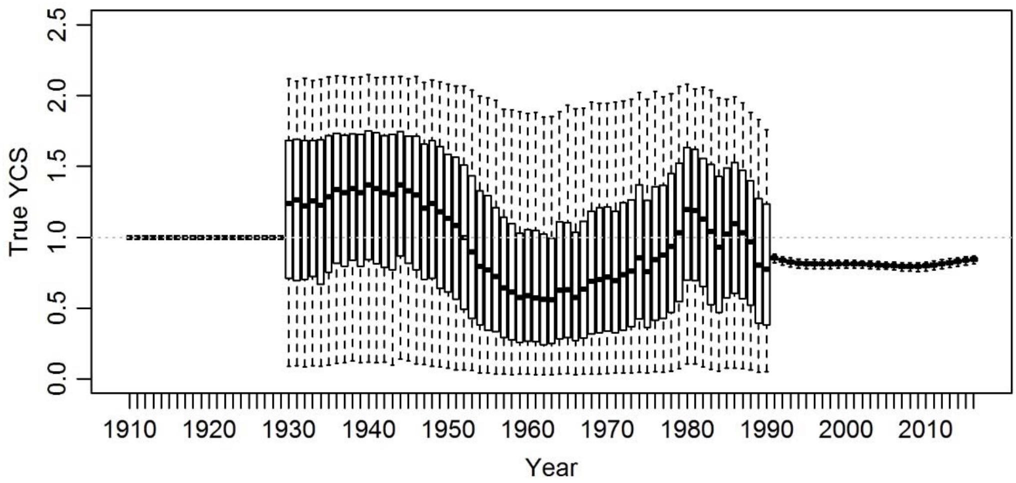



**Figure 17: ESCR base, MCMC estimated "true" YCS ($R_y/R_0$). The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution.**

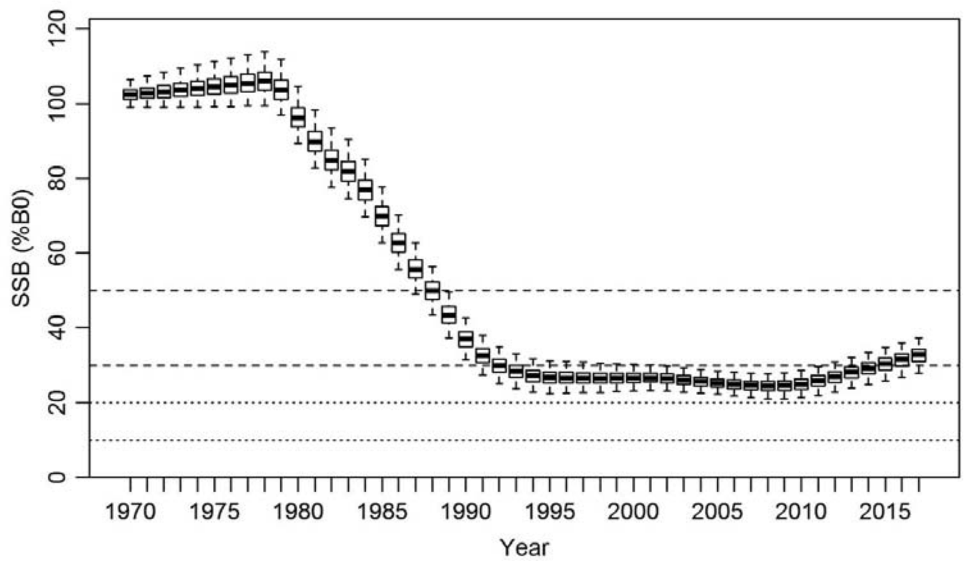



**Figure 18: ESCR base, MCMC estimated spawning-stock biomass trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. Dotted lines indicate the hard limit (10% $B_0$) and soft limit (20% $B_0$), dashed lines the biomass target range (30–50% $B_0$).**

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 terms 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 ($U_{30\%B0}$–$U_{50\%B0}$) for most years of the fishery except 1994–95 to 2000–01 and after 2009–10, after 2009–10 fishing intensity was below the target range (Figure 19).

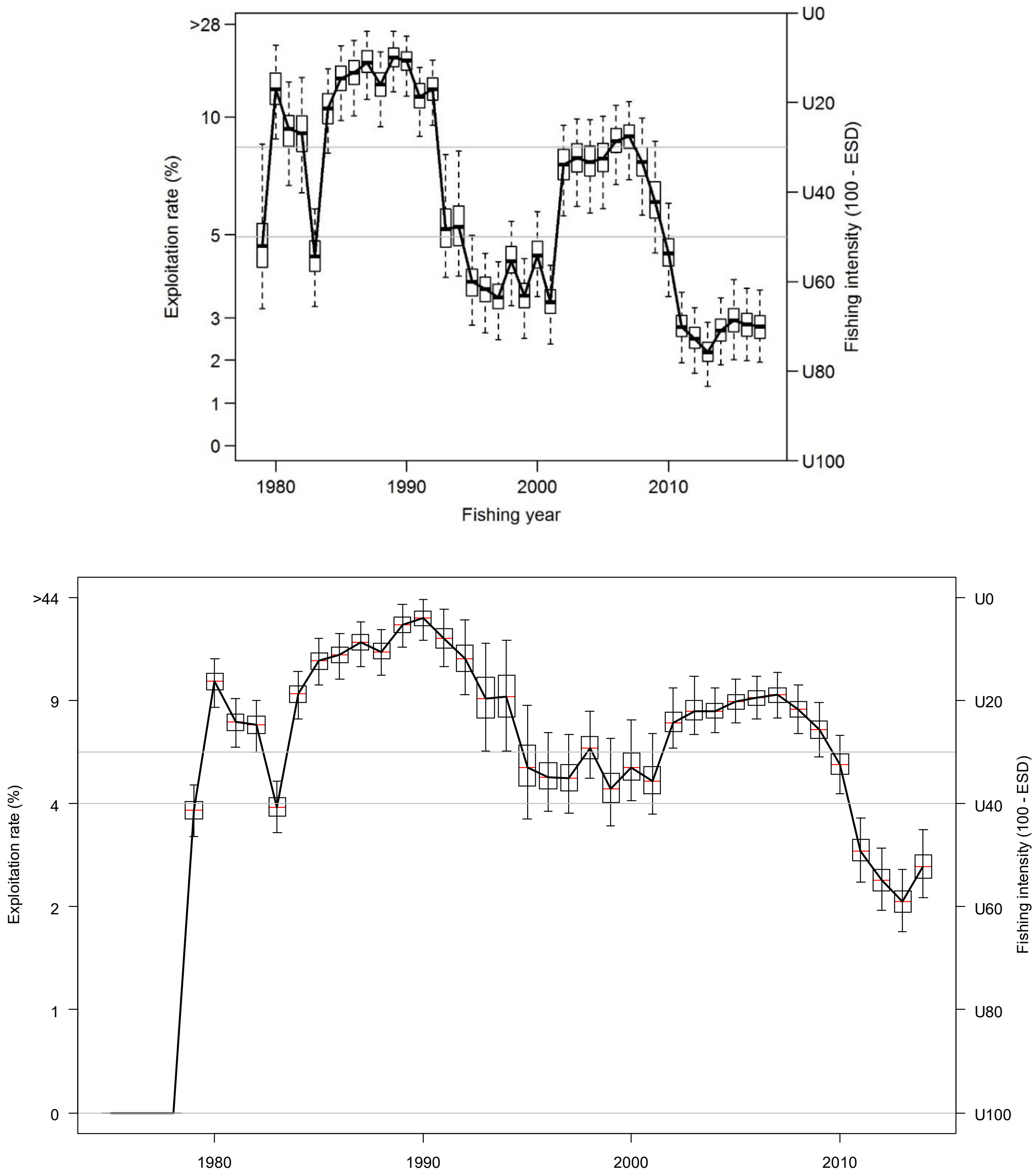



**Figure 19: ESCR base, MCMC estimated fishing-intensity trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The fishing-intensity range associated with the biomass target of 30–50% $B_0$ is marked by horizontal lines.**

## Projections

Five-year biomass projections were made for the Base model run assuming future catches to be the TACC (3 100 t). For each projection scenario, future recruitment variability was sampled from actual estimates between 1940 and 1979.

At the TACC, the SSB is predicted to slowly increase over the next five years, and the probability of the SSB going below the soft or hard limits is zero (Table 12).

**Table 12: ORH 3B ESCR Bayesian median and 95% credible intervals (in parentheses) of projected $B_{2022}$, $B_{2022}$ as a percentage of $B_0$, and $B_{2022}/B_{2017}$ (%) for the model runs.**

| Model run | Catch | $B_{2022}$ | $B_{2022}$ (%$B_0$) | $B_{2022}/B_{2017}$ (%) | p($B_{2022}$ < 0.2 $B_0$) | p($B_{2022}$ < 0.1 $B_0$) |
|---|---|---|---|---|---|---|
| Base | 3 100 | 120 300 (100 200–147 600) | 39 (34–45) | 119 (114–127) | 0 | 0 |

### Biological reference points, management targets and yield

Orange roughy stocks with model based stock assessments are managed according to the Harvest Control Rule (HCR) that was developed in 2014 using a Management Strategy Evaluation (MSE) (Cordue 2014b). The HCR has a target management range of 30–50% $B_0$.

Yield estimates are not reported for this stock.

## 4.3 Puysegur

A Bayesian stock assessment was conducted for the Puysegur stock in 2017 using very similar methods to those used in the 2014 orange roughy stock assessments of ESCR, NWCR, MEC, and ORH7A (Cordue 2014a). An age-structured population model was fitted to an acoustic-survey estimate of spawning biomass, two trawl-survey indices and associated length frequencies, two spawning-season age frequencies, and a small number of length frequencies from the commercial fishery.

### 4.3.1 Model structure

The model was single-sex and age-structured (1–120 years with a plus group), with maturity estimated separately (i.e., fish were classified by age and as mature or immature). Two time steps were used to model a non-spawning season fishery and a spawning season fishery. Spawning was taken to occur after 50% of the spawning-season mortality and 100% of mature fish were assumed to spawn each year.

The catch history as reported in Table 5 (see above) was split into a spawning (June-August) and a non-spawning season (October-May and September) using the ratio of estimated catches, with the addition of catches during 2005, 2006, and 2015 when fish were caught during acoustic surveys. The catch for 2016–17 was assumed to be zero. Natural mortality was 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 (ESCR growth parameters were assumed).

### 4.3.2 Input data and statistical assumptions

There were four main data sources used in the assessment: an acoustic-survey spawning biomass estimate in 2015 from the main spawning hill (Goomzy); two age frequencies during the spawning seasons in 1992 and 2015; biomass indices and length frequencies from trawl surveys in 1992 and 1994; and scaled length frequencies developed from Scientific Observer data collected from the commercial fishery in 1994 and 1997.

### Acoustic estimate

Two types of acoustic-survey estimates were available for use in the assessment: an estimate from a 38 kHz hull-mounted system during an AOS survey (AOS is a multi-frequency towed system, e.g., see Kloser et al 2011) and 38 kHz estimates from a hull-mounted system. The reliability of the data from the different surveys and the two main hills was considered and only the estimate from the 2015 survey on Goomzy was used in the base model (Table 13). The estimates from Godiva were unreliable because the surveyed marks contained a mix of species (Hampton et al 2005, 2006). In 2005 and 2006 it was not clear that the marks on Goomzy were exclusively orange roughy but in 2015 there was strong evidence from both trawling and the multi-frequency system that the surveyed marks were almost exclusively orange roughy (Ryan & Tilney 2016).

**Table 13: Acoustic survey estimates of spawning biomass available to the stock assessment. Only the 2015 estimate from Goomzy was used in the base model.**

| Year | Area | Snapshots | Estimate (t) | CV (%) |
|---|---|---|---|---|
| 2005 | Godiva | 3 | 2 600 | 23 |
| | Goomzy | 4 | 4 000 | 22 |
| 2006 | Godiva | 4 | 900 | 51 |
| | Goomzy | 3 | 3 200 | 50 |
| 2015 | Godiva | 2 | 180 | Not calculated |
| | Goomzy | 2 | 4 200 | 26 |

The acoustic estimate in 2015 from Goomzy was assumed to represent "most" of the spawning biomass in that year. This was modelled by treating the acoustic estimate as relative biomass and estimating the proportionality constant (*q*) with an informed prior. The prior was lognormally distributed with a mean of 0.8 (i.e., "most" = 80%) and a CV of 19% (see Orange Roughy Introduction section).

### Age frequencies

Age frequencies were developed for the *Giljanes* spawning-season trawl survey in 1992 (Clark & Tracey 1993) and the targeted trawling on spawning marks during the 2015 acoustic survey (Ryan & Tilney 2016)(Ian Doonan, NIWA, pers. comm.). Approximately 400 otoliths were used for each age frequency and CVs were calculated for each proportion at age from bootstrapping. In 2015, the mode (for the smoothed distribution) is at about 40 years whereas in 1992 the mode is closer to 60 years (Figure 20). It is notable that in both years the ages extend out to at least 130 years (Figure 20). In the base model, the age frequencies were fitted as multinomial with effective sample sizes of 80 and 60 respectively. The sample size of 80 is the approximate number of trawl stations during the survey in 1992 and the value of 60 was derived from the between year ratio of equivalent multinomial sample sizes derived from the bootstrap CVs.

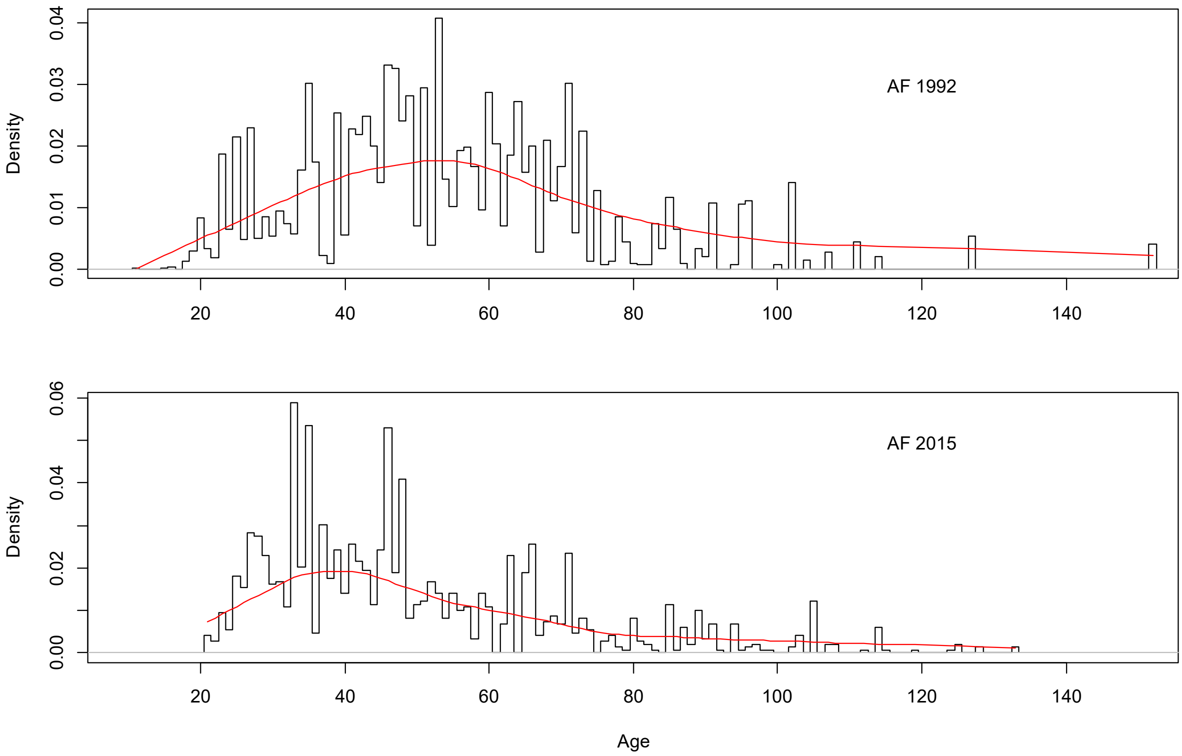



**Figure 20: Puysegur: age frequencies from 1992 and 2015 used in the base model. The red lines were produced using the lowess smoother in R.**

### Trawl survey data

Trawl surveys of the Puysegur area were undertaken on *Tangaroa* in 1992 and 1994 (Clark & Tracey 1994, Clark et al 1996). However, the timing of the surveys was not ideal with the second survey being more than a month later than the first (Puysegur strata occupied in 1992: 8 August–11 September, and in 1994: 24 September–23 October). An analysis of seasonal CPUE suggested that catch rates in the later period could be expected to be 50% of those in the earlier period. Also, an analysis of fish length data suggested that larger fish were caught in the June-August period – the period taken to be the "spawning season" in the model (although spawning occurs in July). It appears that during the June-August period larger fish are more available to the fishing fleet and could have been more available to the trawl survey. There was a very large reduction in the biomass indices for such a short period (Table 14).

To allow for a possible reduction in availability between the 1992 and 1994 surveys, due to the change in timing, the selectivity for the trawl survey was modelled separately for mature and immature fish and an availability parameter for mature fish was estimated for the 1994 survey. The length frequencies from the trawl surveys are bimodal which could be partly explained by two groups of fish distinguished by maturity (Figure 21).

**Table 14: Trawl survey biomass indices for all fish from the *Tangaroa* trawl surveys of the Puysegur area in 1992 and 1994. The CVs given are those used in the modelling and include no process error.**

| | Biomass index (t) | CV (%) |
|---|---|---|
| 1992 | 6630 | 28 |
| 1994 | 1160 | 24 |

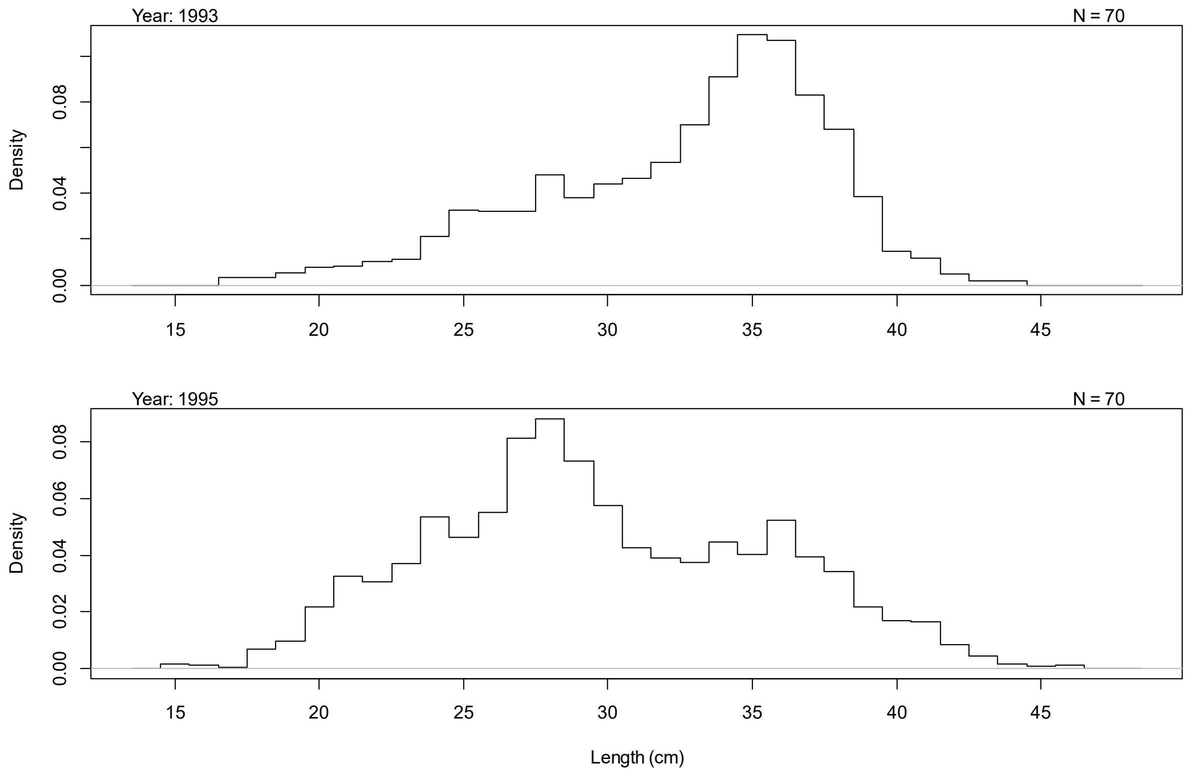



**Figure 21: Puysegur: length frequencies for the *Tangaroa* trawl surveys in 1992 and 1994 (fitted in the model as beginning of year in 1993 and 1995). The effective samples sizes of N = 70 were the approximate number of stations in each survey.**

## Length frequencies (commercial fishery)

Scientific observer coverage of the Puysegur fishery was very patchy over the small number of years when the fishery operated. The best coverage was in the 1993–94 fishing year when there were 15 samples in the non-spawning season and 44 samples in the spawning season. The next best year, when more than one month was sampled in the non-spawning season, was 1996–97 when there were 6 non-spawning season samples and 3 spawning season samples. Scaled length frequencies were produced in those two years for the spawning and non-spawning seasons. The data were assumed to be multinomial with effective sample sizes equal to the number of samples.

### 4.3.3 Model runs and results

In the base model, the acoustic estimate from Goomzy in 2015 was used, with the *Tangaroa* trawl survey data, and natural mortality ($M$) was fixed at 0.045. There were six main sensitivity runs: exclude the *Tangaroa* trawl survey data; low weight on the age frequencies; high weight on the age frequencies; estimate $M$; and the *LowM-Highq* and *HighM-Lowq* “standard” runs (see Orange Roughy Introduction section). There were additional sensitivities: treating the trawl surveys as strictly comparable; using lognormal priors on the free year class strength parameters; alternative fixed non-spawning season fishing selectivities; adding a 5% overrun to the catch history; and using a higher CV on the acoustic $q$ prior.

In the base model, the main parameters estimated were: virgin (unfished, equilibrium) spawning biomass ($B_0$), maturity ogive, trawl-survey selectivity, CV of length-at-mean-length-at-age for ages 1 and 120 years (linear relationship assumed for intermediate ages), and year class strengths (YCS) from 1917 to 1990 (with the Haist parameterisation and “nearly uniform” priors on the free parameters).

**Model diagnostics**

The model provided good MPD fits to the data. Residuals were examined mainly at the MCMC level and these were all acceptable suggesting that the data weightings (CVs and effective sample sizes) were reasonable.

The marginal posterior distribution of the acoustic *q* shifted somewhat to the left of the prior but remains well within the distribution of the prior (Figure 22).

The MPD sensitivity runs where the trawl surveys were assumed strictly comparable, despite the difference in timing, were unable to fit the decline in the trawl indices and showed poorer fits to the trawl survey length frequencies than the base model. The objective function decreased by 7 likelihood units when the availability parameter for 1994 was estimated (which supports the inclusion of the single additional parameter).

When lognormal priors were used for the free YCS parameters the trawl survey indices were fitted adequately (as the availability parameter was estimated) but the fits to the composition data (length and age frequencies) were degraded compared to the base model (which used nearly uniform priors on the free YCS parameters). The worst example of the poor fits was for the *Tangaroa* trawl survey length frequency in 1994. The reason for the poorer fits to the composition data was because the use of a lognormal prior severely constrained the estimated YCS. The near uniform prior allows much more freedom in the pattern of estimated YCS. Behaviour in the MCMC runs is much improved for the lognormal priors but there is the issue that the choice of sigmaR is arbitrary (see the Orange Roughy Introduction section).

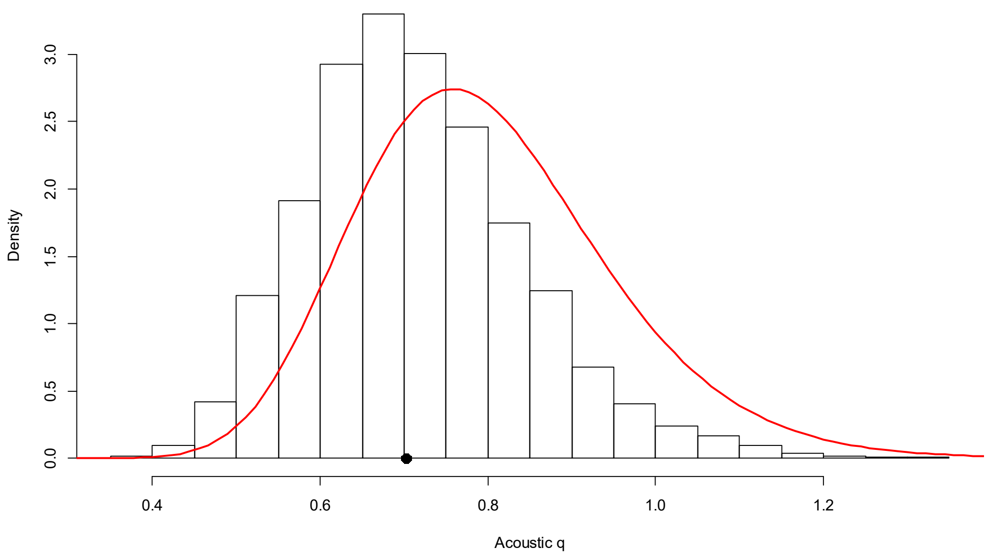



**Figure 22: Puysegur: the marginal posterior distribution of the acoustic *q* (histogram) compared to its prior (red line). The black dot marks the median of the marginal posterior.**

**MCMC Results**

For the base model, and the sensitivity runs, MCMC convergence diagnostics for virgin biomass ($B_0$) and stock status were very good. $B_0$ was estimated to be between 12 000–26 000 t for all runs (Table 15). Current stock status was similar across the base and the first four sensitivity runs (Table 15). 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* prior were shifted by 20%, median current stock status was within or above the biomass target range of 30–50% $B_0$ for both runs (Table 15). The sensitivity with a higher CV on the acoustic *q* prior gave similar results to the base model with a slighter higher $B_0$ and stock status. The 5% overrun model gave almost identical results to the base model. All other sensitivity runs gave stock status estimates within the range covered by the *LowM-Highq* and *HighM-Lowq* models.

**Table 15: Puysegur: MCMC estimates of virgin biomass ($B_0$) and stock status ($B_{2017}$ as %$B_0$) for the base model and six sensitivity runs.**

| | *M* | $B_0$ (000 t) | 95% CI | $B_{2017}$ (%$B_0$) | 95% CI |
|---|---|---|---|---|---|
| Base | 0.045 | 17 | 13–23 | 49 | 36–62 |
| No trawl | 0.045 | 17 | 13–24 | 51 | 39–64 |
| Low AF | 0.045 | 15 | 12–21 | 46 | 34–61 |
| High AF | 0.045 | 18 | 14–26 | 51 | 39–63 |
| Estimate M | 0.040 | 18 | 13–25 | 47 | 34–61 |
| LowM-Highq | 0.036 | 18 | 14–23 | 42 | 30–55 |
| HighM-Lowq | 0.054 | 17 | 12–25 | 57 | 44–69 |

For the base model, (and all sensitivities) 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).

The estimated YCS show a trend across cohorts with above average recruitment prior to 1950 with below average recruitment up until about 1980 (Figure 23). 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 relationship).

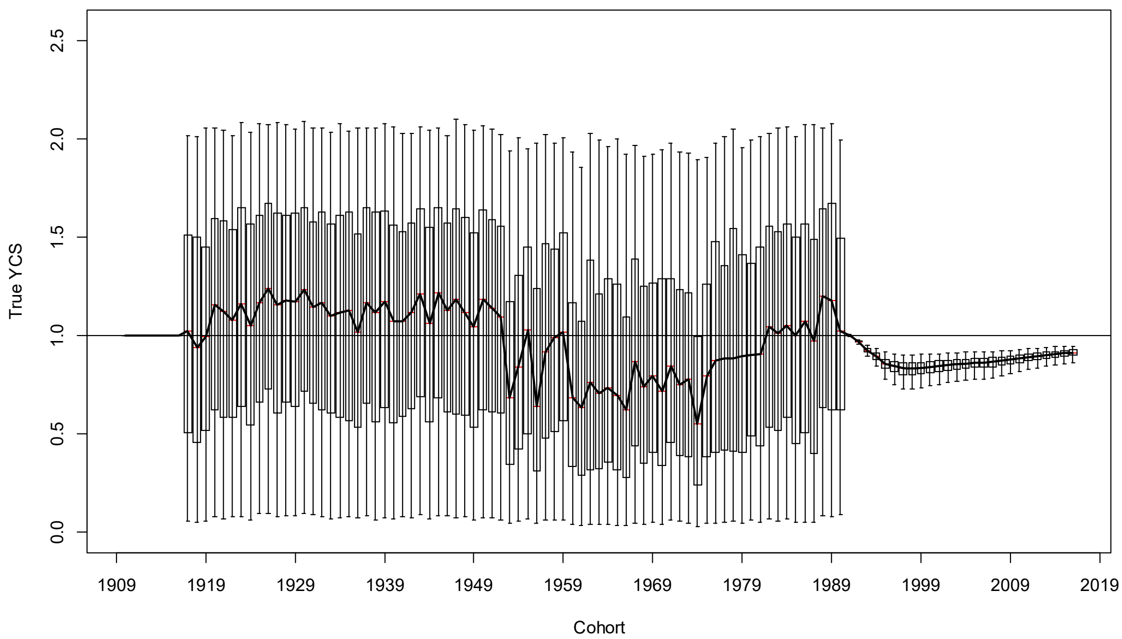



**Figure 23: Puysegur base, MCMC estimated "true" YCS ($R_y/R_0$). The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution.**

The estimated spawning-stock biomass (SSB) trajectory showed a declining trend from 1990 (when the fishery started) through to 1998 when the fishery was closed (Figure 24). Since 1998 the estimated biomass has increased steadily and has been well within the target range for the last decade (Figure 24).

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 terms 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 before it was closed in 1998; it was briefly in the target range ($U_{30\%B0}$–$U_{50\%B0}$) in 2006 when there was a combined acoustic and trawl survey (Figure 25).

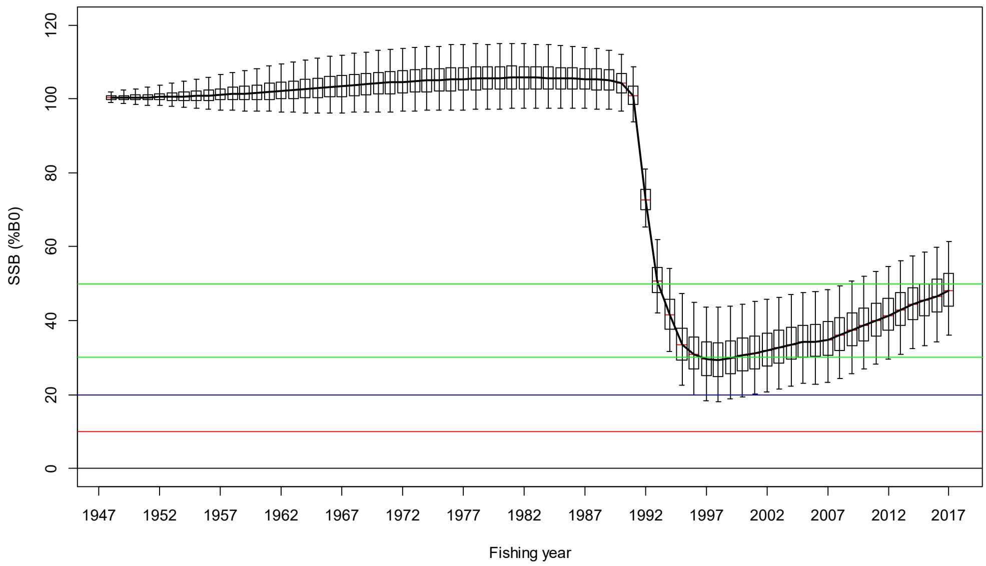



**Figure 24: Puysegur base, MCMC estimated spawning-stock biomass trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The hard limit (red), soft limit (blue), and biomass target range (green) are marked by horizontal lines.**

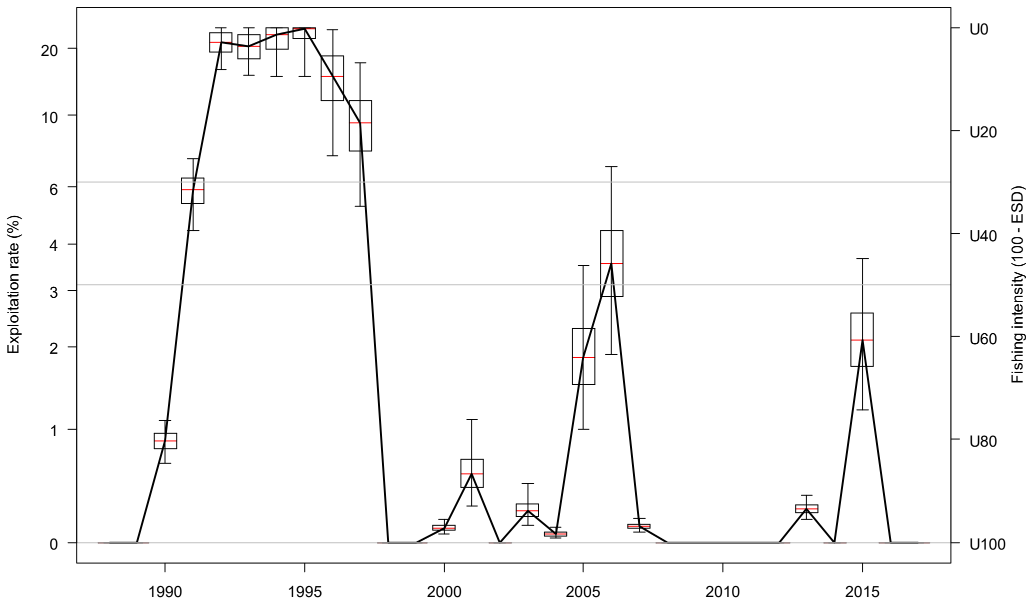



**Figure 25: Puysegur base, MCMC estimated fishing-intensity trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The fishing-intensity range associated with the biomass target of 30–50% $B_0$ is marked by horizontal lines.**

## Biological reference points, management targets and yield

Orange roughy stocks with model based stock assessments are managed according to the Harvest Control Rule (HCR) that was developed in 2014 using a Management Strategy Evaluation (MSE) (Cordue 2014b). The HCR has a target biomass range of 30–50% $B_0$.

Yield estimates are not reported for this stock.

## 4.4 Research needs

- Ongoing monitoring of the stock will be required if the fishery is reopened (Update: the Puysegur orange roughy fishery was reopened in 2017).
- This is best done with acoustic survey estimates conducted during the spawning season.
- Additional representative age frequencies from the commercial catch and from spawning aggregations will also be required.

- It would also be useful to estimate von Bertalanffy growth parameters specifically for Puysegur orange roughy, rather than using the estimates from the Chatham Rise.

## 5. STATUS OF THE STOCKS

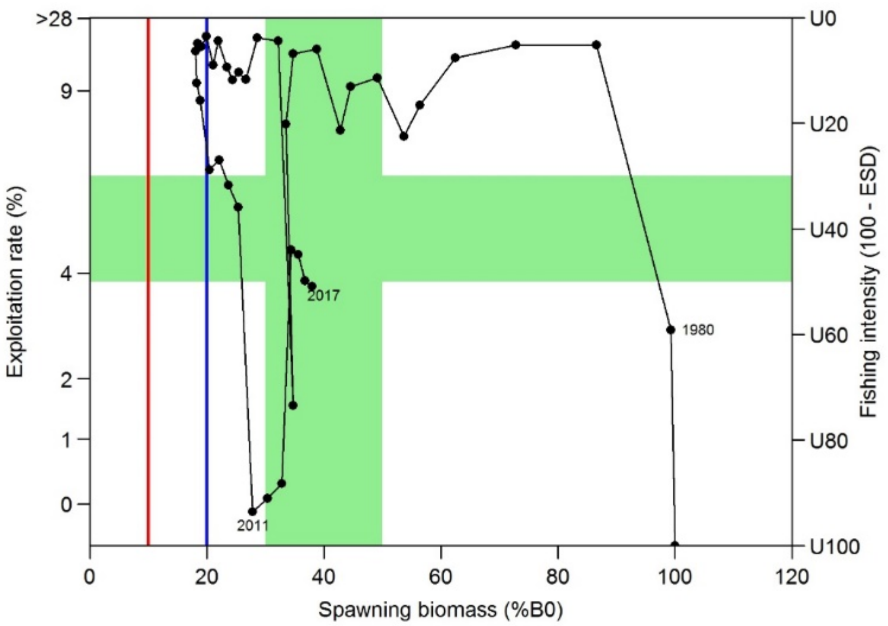
### 5.1 Chatham Rise

**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 | 2018 |
| Assessment Runs Presented | Base model only |
| Reference Points | Management Target: Biomass range 30–50% $B_0$<br>Soft Limit: 20% $B_0$<br>Hard Limit: 10% $B_0$<br>Overfishing threshold: Fishing intensity range $U_{30\%B0}$–$U_{50\%B0}$ |
| Status in relation to Target | $B_{2017}$ was estimated at 38% $B_0$. Very Likely (> 90%) to be at or above the lower end of the management target range |
| Status in relation to Limits | $B_{2017}$ is Exceptionally Unlikely (< 1%) to be below the Soft Limit. $B_{2017}$ is Exceptionally Unlikely (< 1%) to be below the Hard Limit |
| Status in relation to Overfishing | 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 30–50 % $B_0$ 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 considered to be fully rebuilt (at least a 70% probability that the lower end of the management target range of 30–50% $B_0$ has been achieved). |
| Recent Trend in Fishing Intensity or Proxy | Fishing intensity decreased sharply from 2010 to 2011 and has remained below the overfishing threshold since then. |
| Other Abundance Indices | - |
| Trends in Other Relevant Indicators or Variables | - |

| Projections and Prognosis | |
|---|---|
| Stock Projections or Prognosis | At both the TACC (1 250 t) and current agreed catch (1 043 t), the biomass is expected to stay steady or increase over the next 5 years. |
| Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits | At both TACC and current agreed catch limit:<br>Soft Limit: Exceptionally Unlikely (< 1%)<br>Hard Limit: Exceptionally Unlikely (< 1%) |
| Probability of Current Catch or TACC causing Overfishing to continue or to commence | Exceptionally Unlikely (< 1%) at both TACC and current agreed catch limit. |

| 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: 2018 | Next assessment: 2021 |
| 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, 2016). | 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 |
| | - Morgue age frequency (2016); only as a sensitivity | 2 – Medium or Mixed Quality: potential non-representative sampling |
| 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 (2010–2016) | 2 – Medium or Mixed Quality: variable indices |
| | - Egg survey estimate | 3 – Low Quality: survey design assumptions not met |

| | |
|---|---|
| Changes to Model Structure and Assumptions | - |
| 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.<br>- In the base case, patterns in year class strengths are based on only one year of age composition data.<br>- The time series of abundance indices is short and restricted to the period of lower stock status. |

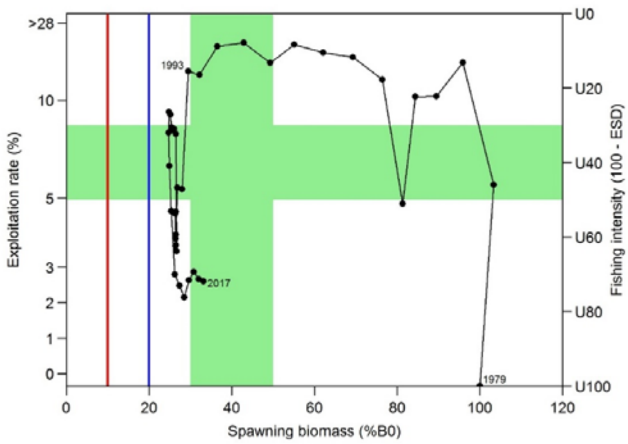
| **Qualifying Comments** |
|---|
| Estimates of stock biomass are sensitive to the means of the *q* priors. |

| **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. Observed incidental captures of protected species include corals, low numbers of seabirds and occasional New Zealand fur seals. |

- **East and South Chatham Rise**

| **Stock Status** | |
|---|---|
| Year of Most Recent Assessment | 2018 |
| Assessment Runs Presented | Base model only |
| Reference Points | Management Target: Biomass range 30–50% $B_0$<br>Soft Limit: 20% $B_0$<br>Hard Limit: 10% $B_0$<br>Overfishing threshold: Fishing intensity range $U_{30\%B0}$–$U_{50\%B0}$ |
| Status in relation to Target | $B_{2017}$ was estimated to be 33% $B_0$<br>Likely (> 60%) to be at or above the lower end of the management target range |
| Status in relation to Limits | $B_{2017}$ is Very Unlikely (< 10%) to be below the Soft Limit<br>$B_{2017}$ is Exceptionally Unlikely (< 1%) to be below the Hard Limit |
| Status in relation to Overfishing | 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 30–50 % $B_0$ 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 six 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 seven years. |
| Other Abundance Indices | - |
| Trends in Other Relevant Indicators or Variables | - |

| **Projections and Prognosis** | |
|---|---|
| Stock Projections or Prognosis | Biomass is expected to increase slowly at catches equal to the TACC. |
| Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits | At the catch limit (3 100 t):<br>Soft Limit: Exceptionally Unlikely (< 1%)<br>Hard Limit: Exceptionally Unlikely (< 1%) |

| **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: 2017 | Next assessment: 2021 |
| Overall assessment quality rank | 1 – High Quality | |
| Main data inputs (rank) | - Four short time series of biomass indices from research trawl surveys | 1 – High Quality |
| | - Acoustic indices from research surveys of spawning plumes (Old-plume, Rekohu plume, Crack) | 1 – High Quality |
| | - Age frequencies from the spawning plumes in 2012, 2013, and 2016 | 1 – High Quality |
| | - Length frequencies from commercial fisheries | 1 – High Quality |
| Data not used (rank) | - CPUE | 3 – Low Quality: unlikely to be indexing stock-wide abundance |
| | - Acoustic surveys of hills (hull-mounted transducers) | 3 – Low Quality: major species identification and dead zone issues |
| | - Wide-area acoustic survey estimates | 2 – Medium or Mixed Quality: large potential bias due to mixed-species |
| | - Chatham Rise deepwater trawl survey stations (2010–2016) | 2 – Medium or Mixed Quality: variable indices |
| Changes to Model Structure and Assumptions | None | |
| 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.<br>- Stock status is dependent on the timing of the appearance of the Rekohu spawning plume, which is unknown.<br>- Patterns in year class strengths are based on only 3 years of age composition data. | |

| **Qualifying Comments** |
|---|
| Estimates of stock biomass are sensitive to the means of the *q* priors. |
| |

| **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. Observed incidental captures of protected species include corals, low numbers of seabirds and occasional New Zealand fur seals. |

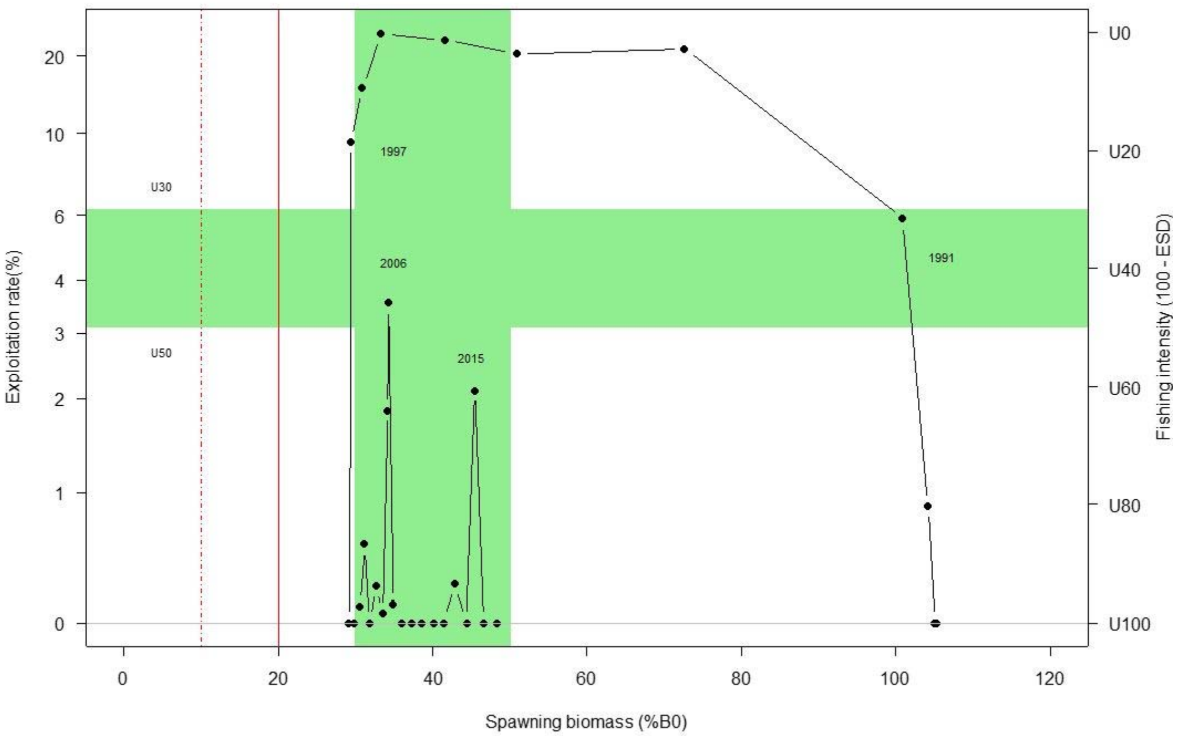
- **5.2 Southern ORH 3B fisheries**

There are several other small fisheries in ORH 3B in the southern waters of which Puysegur appears to be the largest stock.

**Puysegur**

| **Stock Status** | |
|---|---|
| Year of Most Recent Assessment | 2017 |
| Assessment Runs Presented | Base model only |
| Reference Points | Management Target: Biomass range 30–50% $B_0$<br>Soft Limit: 20% $B_0$<br>Hard Limit: 10% $B_0$<br>Overfishing threshold: Fishing intensity range $U_{30\%B0}$ |
| Status in relation to Target | $B_{2017}$ was estimated at 49% $B_0$. Very Likely (> 90%) to be at or above the lower end of the management target range |
| Status in relation to Limits | $B_{2017}$ is Exceptionally Unlikely (< 1%) to be below the Soft or Hard Limits |
| Status in relation to Overfishing | An agreed closure of the fishery was in place until 2017.<br>Overfishing in 2017 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 30–50% $B_0$ and the corresponding exploitation rate range are marked in green. The soft limit (20% $B_0$) and the hard limit (10% $B_0$) are marked in red. Note that the left-hand Y-axis is non-linear.**

| **Fishery and Stock Trends** | |
|---|---|
| Recent Trend in Biomass or Proxy | Biomass reached its lowest point in 1998 and has increased steadily 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 30–50% $B_0$ has been achieved). |
| Recent Trend in Fishing Intensity or Proxy | Fishing intensity has been close to zero since the fishery was closed in 1997-98 with the exception of 2005, 2006, and 2015 when surveys were conducted. |
| Other Abundance Indices | - |
| Trends in Other Relevant Indicators or Variables | - |

| **Projections and Prognosis** | |
|---|---|
| Stock Projections or Prognosis | No projections were conducted |
| Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits | Current catch is zero |
| Probability of Current Catch or TACC causing Overfishing to continue or to commence | Current catch is zero |

| **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: 2017 | Next assessment: 2020 |
| Overall assessment quality rank | 1 – High Quality | |
| Main data inputs (rank) | - Acoustic estimate of spawning biomass on Goomzy (2015)<br>- Trawl survey indices and length frequencies (1992, 1994)<br>- Age frequencies (1992, 2015)<br>- 2 years of length frequency data | 1 – High Quality<br><br>1 – High Quality<br>1 – High Quality<br>1 – High Quality |
| Data not used (rank) | - CPUE<br><br>- Winter trawl surveys (1991, 1992, 2006)<br><br>- Acoustic survey estimates (2005, 2006)<br><br>- Additional commercial length frequencies | 3 – Low Quality: unlikely to be indexing stock-wide abundance<br>2 – Medium or Mixed Quality: unlikely to be indexing stock-wide abundance<br>2 – Medium or Mixed Quality: large potential bias due to mixed species<br>2 – Medium or Mixed Quality: not enough months sampled within each year |
| Changes to Model Structure and Assumptions | - The previous assessment was in 1998.<br>- Model now based on spawning biomass rather than transition-zone mature biomass.<br>- Age data included to enable estimation of year class strengths rather than assuming deterministic recruitment.<br>- Trawl survey indices better modelled to allow for difference in timing | |

| | |
|---|---|
| | - A more stringent data quality threshold was imposed on data inputs (e.g., CPUE indices not used) |
| Major Sources of Uncertainty | -The largest source of uncertainty is the proportion of the Puysegur spawning stock that is indexed by the acoustic survey in 2015.<br>- The single acoustic estimate is the only recent biomass index.<br>- Patterns in year class strengths are based on only two years of age frequencies. |
| **Qualifying Comments** | |
| - | |
| **Fishery Interactions** | |
| Historically the Puysegur orange roughy fishery included black and smooth oreos, deepwater dogfish, black cardinal fish, slickheads and rattails as significant bycatch. Interactions with other species are currently being characterised. | |

- **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.

## 6. FOR FURTHER INFORMATION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# ORANGE ROUGHY CHALLENGER PLATEAU (ORH 7A)

## 1. FISHERY SUMMARY

### 1.1 Commercial fisheries

Historically, the fishery mainly occurred in the south-western region of the Challenger Plateau, both inside and outside the EEZ. Fish were caught throughout the year, with most effort in winter when the orange roughy form aggregations for spawning. Domestic vessels caught most of the quota. Total catches peaked at 10 000–12 000 t annually from 1986–87 to 1988–89 (Table 1). Total catch and ORH 7A catch were less than 2 100 t annually from 1990–91 until the closure in 2000–01 (Table 1, Figure 1), when the TACC for this stock was reduced to 1 t.

Recent surveys have shown an increase in biomass in the area. On 1 October 2010 the TACC was increased from 1 t to 500 t, with a 25 t allowance for other mortality, raising the TAC to a total of 525 t. This was to allow research surveys to be conducted using commercial fishing vessels. The TACC was further increased following a stock assessment in 2014.

**Table 1: Reported catches (t) and TACCs (t) from 1980–81 to present. QMS data from 1986-present. The last two columns are for research surveys on commercial vessels and give the research catch that was not recorded against ACE (WP = Westpac Bank).**

| Fishing year | EEZ | Outside EEZ | Total catch | TACC | EEZ extra | WP extra |
|---|---|---|---|---|---|---|
| 1980–81† | 1 | 32 | 33 | - | 0 | 0 |
| 1981–82† | 3 539 | 709 | 4 248 | - | 0 | 0 |
| 1982–83† | 4 535 | 7 304 | 11 839 | - | 0 | 0 |
| 1983–84† | 6 332 | 3 195 | 9 527 | - | 0 | 0 |
| 1984–85† | 5 043 | 74 | 5 117 | - | 0 | 0 |
| 1985–86† | 7 711 | 42 | 7 753 | - | 0 | 0 |
| 1986–87† | 10 555 | 937 | 11 492 | 10 000 | 0 | 0 |
| 1987–88 | 10 086 | 2 095 | 12 181 | 12 000 | 0 | 0 |
| 1988–89 | 6 791 | 3 450 | 10 241 | 12 000 | 0 | 0 |
| 1989–90 | 3 709 | 600 | *4 309 | 2 500 | 0 | 0 |
| 1990–91 | 1 340 | 17 | 1 357 | 1 900 | 0 | 0 |
| 1991–92 | 1 894 | 17 | 1 911 | 1 900 | 0 | 0 |
| 1992–93 | 1 412 | 675 | 2 087 | 1 900 | 0 | 0 |
| 1993–94 | 1 594 | 138 | 1 732 | 1 900 | 0 | 0 |
| 1994–95 | 1 554 | 82 | 1 636 | 1 900 | 0 | 0 |
| 1995–96 | 1 206 | 463 | 1 669 | 1 900 | 0 | 0 |
| 1996–97 | 1 055 | 253 | 1 308 | 1 900 | 0 | 0 |
| 1997–98 | + | + | 1 502 | 1 900 | 0 | 0 |
| 1998–99 | + | + | 1 249 | 1 425 | 0 | 0 |
| 1999–00 | + | + | 629 | 1 425 | 0 | 0 |
| 2000–01 | + | + | 0.2 | 1 | 0 | 0 |
| 2001–02 | + | + | 0.1 | 1 | 0 | 0 |
| 2002–03 | + | + | 4 | 1 | 0 | 0 |
| 2003–04 | + | + | < 0.1 | 1 | 0 | 0 |
| 2004–05 | + | + | < 1 | 1 | 141 | 17 |
| 2005–06 | + | + | < 1 | 1 | 196 | 22 |
| 2006–07 | + | + | < 0.1 | 1 | 0 | 0 |
| 2007–08 | + | + | < 0.1 | 1 | 0 | 0 |
| 2008–09 | + | + | 0.12 | 1 | 218 | 22 |
| 2009–10 | + | + | < 0.1 | 1 | 339 | 5 |
| 2010–11 | 476 | 0 | 476 | 500 | 0 | 5 |
| 2011–12 | 504 | 7 | 511 | 500 | 0 | 0 |
| 2012–13 | 513 | 0 | 513 | 500 | 259 | 4 |
| 2013–14 | 484 | 13 | 497 | 500 | 0 | 50 |
| 2014–15 | 1 594 | 0 | 1 594 | 1 600 | 0 | 0 |
| 2015–16 | 1 248 | 320 | 1 568 | 1 600 | 0 | 0 |
| 2016–17 | 1 595 | 28 | 1 623 | 1 600 | 0 | 0 |
| 2017–18 | 1 026 | 575 | 1 601 | 1 600 | 126 | 53 |

†FSU data
*This is a minimum value, because of unreported catches by foreign vessels fishing outside the EEZ.
+Unknown distribution of catch between inside and outside the EEZ

### 1.2 Recreational fisheries

There is no known recreational fishing for orange roughy in this area.

### 1.3 Customary non-commercial fisheries

There is no known customary non-commercial fishing for orange roughy in this area.

### 1.4 Illegal catch

There is no quantitative information available on illegal catch which is likely to be negligible.

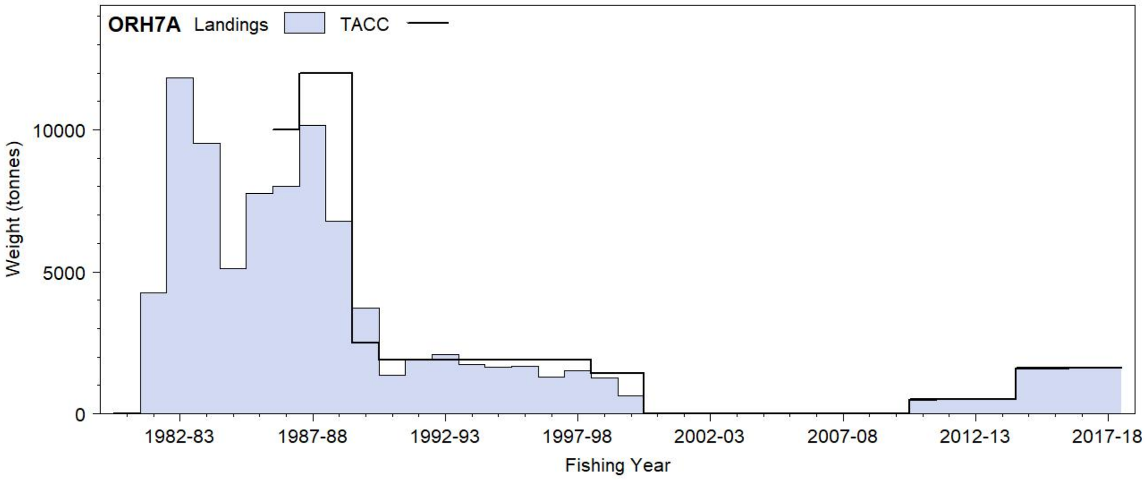



**Figure 1: Reported commercial landings and TACC for ORH 7A.**

### 1.5 Other sources of mortality

Catch overruns from various sources (including lost and/or discarded fish, use of nominal tray weights and low conversion factors) have been estimated as: 1980–81 to 1987–88, 30%; 1988–89, 25%; 1989–90, 20%; 1990–91, 15%; 1991–92 to 1992–93, 10%; 1993–94 onwards, 5%. These estimates are used in the current stock assessment.

## 2. BIOLOGY

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

## 3. STOCKS AND AREAS

There is no new information on orange roughy stock structure beyond that presented in previous assessment documents.

Orange roughy on the southwest Challenger Plateau (Area 7A, including Westpac Bank) are regarded as a single stock. Size structure, parasite composition, flesh mercury levels, allozyme frequency and mitochondrial DNA studies show differences to other major fisheries. Spawning occurs at a similar time to fish on the Chatham Rise, Puysegur Bank, Ritchie Banks, Cook Canyon and Lord Howe Rise.

## 4. STOCK ASSESSMENT

From 2010 to 2013, assessments were conducted using an ad hoc approach which combined the virgin biomass estimate from the 2000 assessment (Annala et al 2000, Field & Francis 2001) and current biomass estimates from annual combined acoustic and trawl surveys (see Clark et al 2006, NIWA & FRS 2009, Doonan et al 2010, Hampton et al 2013, Hampton et al 2014, Cordue 2010a, 2012, 2013). A model-based Bayesian stock assessment was carried out for this stock in 2019 following a similar assessment conducted in 2014 (Cordue 2014a).

The 2014 assessment for this stock was one of four orange roughy assessments carried out in 2014 which all used similar methods (see Orange Roughy Introduction). The same approach was continued in 2019 although there was a review of previous data inputs and a substantial amount of new data were available. An age-structured population model was fitted to acoustic and trawl-survey estimates of spawning biomass and six age frequencies.

### 4.1 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). Two time steps were used: a full year of natural mortality followed by an instantaneous spawning season and fishery on the spawning fish. Two fisheries were modelled, one within the EEZ and one on Westpac Bank (which is outside of the EEZ). The fishery selectivity for the EEZ was uniform across ages (for spawning fish) while a logistic selectivity (on spawning fish) was used for Westpac Bank where slightly older fish are caught. 100% of mature fish were assumed to spawn each year.

The catch history was constructed from the catches in Table 1 and the over-run percentages in Section 1.5. Natural mortality was assumed to be constant across ages 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 the Orange Roughy Introduction.

### 4.2 Input data and statistical assumptions

There were three main data sources for observations fitted in the assessment: spawning biomass estimates from acoustic and trawl surveys (2005, 2006, 2009–2014, 2018); an early trawl survey time series of relative spawning biomass (1987–1989); four age frequencies from the trawl surveys (1987, 2006, 2009, and 2018); and two age frequencies from Volcano (a UTF on the Westpac Bank) (2014 and 2018).

#### 4.2.1 Research surveys

Trawl surveys of orange roughy on the Challenger Plateau were conducted regularly from 1983 to 1990. However, a variety of vessels and survey strata were used which makes comparisons problematic (Dunn et al 2010). Wingtip biomass estimates in 1983–1986 ranged from 100 000–185 000 t but the 1989 and 1990 survey estimates were much lower at approximately 10 000 t. From these early trawl surveys a “comparable area” time series, defined by Clark & Tracey (1994) and covering the period 1987–89, was selected for use in the assessment to provide some information on the early rate of spawning biomass decline (see the *Amaltal Explorer* time series in Table 3).

In 2005, a new series of combined trawl and acoustic surveys was begun using the FV *Thomas Harrison* with a survey area comparable to that used from 1987–1990 (Clark et al 2005). The survey was repeated in 2006 (with an enlarged survey area) and was then conducted annually from 2009–2013 (Clark et al 2006, NIWA & FRS 2009, Doonan et al 2010, Hampton et al 2013, Hampton et al 2014) with another survey in 2018. It was apparent from the later surveys that the 2005 survey did not cover an appropriate area as the spawning biomass distribution had shifted somewhat in the intervening years. The surveys from 2006 onwards appear to have covered the bulk of the spawning biomass. Also, in 2014 an acoustic survey of Volcano was conducted using an Acoustic Optical System (AOS) (Ryan et al. 2015) in addition to a hull-mounted transducer. The data from all of the surveys since 2005 have been analysed to produce acoustic and trawl survey indices of spawning biomass.

**Acoustic survey indices**

For the 2014 assessment, the method of Cordue (2010a, 2012) was used to produce combined acoustic and trawl survey indices for 2010 and 2013. This method used an estimate of orange roughy trawl vulnerability to allow the trawl survey estimates to be combined with the acoustic estimates (trawl estimates were essentially scaled down by a vulnerability distribution with a mean of 1.66). This assumed that the scalar (1.66) had been reliably estimated. To avoid this assumption in the 2019 assessment the acoustic data and trawl data were used separately.

The acoustic biomass estimates from 2005 to 2018 were reviewed and a number of adjustments were required to ensure that the time series of estimates were consistent.

Acoustic estimates of spawning aggregations on Volcano and in the west and east of the flats within the EEZ were used in three separate time series (Table 2). Estimates from the hull-mounted transducer were adjusted as necessary so that they all used the latest length to target strength relationship, the Doonan et al (2003) absorption coefficient, and a combined motion and bubble layer correction (1.33) borrowed from work done on the Chatham Rise (Cordue 2010b, Doonan et al 2012). The estimates from the AOS

(2014 and 2018) were adjusted to use the Doonan et al (2003) absorption coefficient. In 2005, 2011, and 2013, the motion corrections applied to the snapshots were not documented and a factor of 1.06 (the mean for snapshots in 2006 and 2009) was used in the adjustment calculations. In those years the acoustic indices were assigned an additional 20% of process error to account for the approximate adjustment.

**Table 2: Acoustic biomass estimates of spawning aggregations surveyed on Volcano, and the West and the East within the EEZ. The model CV is the observation error CV with an additional 20% of process error in the years when the vessel motion correction was unknown (2005, 2011, and 2013).**

| | West | | East | | Volcano | |
|---|---|---|---|---|---|---|
| Year | Biomass (t) | Model CV (%) | Biomass (t) | Model CV (%) | Biomass (t) | Model CV (%) |
| 2005 | 4 210 | 53 | | | 2682 | 39 |
| 2006 | 4 383 | 59 | | | 6329 | 39 |
| 2009 | 13 555 | 22 | 8471 | 61 | | |
| 2010 | 8 114 | 14 | 1707 | 34 | | |
| 2011 | 13 340 | 33 | | | | |
| 2013 | 10 183 | 22 | 5365 | 26 | 4559 | 34 |
| 2014 | | | | | 3954 | 29 |
| 2018 | 9 966 | 9 | | | | |

The acoustic biomass estimate for each aggregation in each year is an average of a number of "snapshots" (individual surveys/estimates) of the aggregation in that year. Some of the snapshots in some years were not used in the average because they appeared to have been taken before the aggregation was fully formed (judged on the basis of female gonad stages from trawl catches at the time of the snapshot). Some snapshots in the eastern area (in 2010 and 2011) were not used as an examination of the distribution of backscatter on the transects showed that a genuine spawning aggregation was not surveyed (e.g., just a single transect on which positive backscatter was recorded).

In 2018 there were a number of snapshots of Volcano which showed substantial biomass (~ 4000 t) but it was unclear from the gonad staging whether spawning was underway. These snapshots were not used in the assessment (and there is no estimate for Volcano in 2018). In 2009, there was a single snapshot on Volcano which satisfied the timing criteria but it was a very low estimate (671 t) compared to all of the other years. It was considered that this estimate was unlikely to be representative of the spawning biomass on Volcano in 2009. It was not used in the base model but was used in a sensitivity.

Informed priors on the proportionality constants ($q$) were used for the acoustic time series. The means of the priors were derived from the 2013 proportions across aggregations and the assumption that all three aggregations combined represented "most" of the spawning biomass (80%). The prior used in this case for orange roughy assessments (since 2014) is LN(mean=0.8, CV=19%) (Cordue 2014a). Splitting this prior into three components gave priors for the West, East, and Volcano $q$s respectively: LN(0.41, 30%), LN(0.22, 30%), LN(0.18, 30%).

## Trawl survey indices

The spawning biomass estimates from the *Thomas Harrison* trawl surveys (Table 3) were used as relative biomass with an informed prior. They excluded the rough terrain strata 9–11 and the mean of the informed prior was: 0.9 × 0.85 × 1.25 = 0.95 (allowing for total-survey availability (0.9), exclusion of strata 9–11 (0.85) and trawl vulnerability – adjusted mean of estimated vulnerability distribution = 1.25). Given the problematic nature of these trawl surveys (fish pluming and moving within the area), a process error CV of 20% was added to the estimated CVs (Table 3).

**Table 3: Biomass indices from trawl surveys used in the stock assessment. The model CV is the observation error CV with an additional 20% of process error.**

| Vessel | Year | Biomass (t) | Model CV (%) |
|---|---|---|---|
| Amaltal Explorer | 1987 | 75 040 | 33 |
| | 1988 | 28 954 | 34 |
| | 1989 | 11 062 | 23 |
| | | | |
| Thomas Harrison | 2006 | 13 987 | 34 |
| | 2009 | 34 864 | 31 |
| | 2011 | 18 425 | 33 |
| | 2012 | 22 451 | 27 |
| | 2013 | 18 993 | 55 |
| | 2018 | 48 038 | 55 |

**Age frequencies**

Age frequencies were available from four of the trawl surveys for use in the assessment. A previous analysis produced age frequencies for the 1987 *Amaltal Explorer* survey and the 2009 *Thomas Harrison* survey (Doonan et al 2013), although that study was based on a relatively small number of otoliths, it showed that the 2009 age frequency had much younger fish than the 1987 age frequency. For the 2014 stock assessment, the existing age frequencies were augmented with an increased number of otoliths (for a total of about 300 for each survey) and a new age frequency (from about 300 otoliths) was produced for the 2006 *Thomas Harrison* survey. For the 2019 assessment the age data from the 2018 survey were used to produce an age frequency for the EEZ (750 otoliths) and Volcano (150 otoliths). An age frequency was also produced from the 2014 survey of Volcano (470 otoliths) (Doonan et al 2015).

The age frequencies were assumed to be multinomial and were mainly assigned effective sample sizes of 300/5 = 60 (with the sample size reflecting the number of trawl stations rather than the number of otoliths). However, the 2018 age frequency from Volcano was obtained from only one targeted trawl and this was given a much lower effective sample size of 30 (to reflect that it may not have been representative of the spawning plume). No reweighting was attempted because of the short time series.

There are no age frequencies from the commercial fishery.

### 4.3 Model runs and results

In the base model, natural mortality (*M*) was fixed at 0.045. There were numerous MPD and MCMC sensitivity runs but four main sensitivities are presented in this report: “All trend” (informed priors removed), estimate *M*, and the LowM-Highq and HighM-Lowq runs (see the Orange Roughy Introduction section for specifications).

In the base model the main parameters estimated were: virgin biomass ($B_0$), the maturity ogive, the selectivity for Westpac Bank and year class strengths (YCS) from 1925 to 1995 (with the Haist parameterisation and “nearly uniform” priors on the free parameters). There were also the five proportionality constants (*q*) for the two trawl and three acoustic survey time series.

#### 4.3.1 Model diagnostics

The MCMC (and MPD) fits to the data in the base model were very good except in two cases.

The *Amaltal Explorer* time series shows a very steep decline over only three years in the late 1980s (Figure 2). The steep decline cannot be fitted by the model unless a very high weight is placed on the time series and all other data are down-weighted. In this case the estimate of the minimum stock status is reduced to about 5% $B_0$ (compared to 15% $B_0$ for the base) but the estimate of current stock status is unchanged from the base model. It is likely that the *Amaltal Explorer* indices do not reflect true stock abundance in those years.

There are good fits to the main biomass indices, the West aggregation (Figure 3) and the *Thomas Harrison* trawl indices (Figure 4). Both sets of indices and the fits show an increase from 2005/2006 through to 2018.

The second poor fit is for the 2018 Volcano age frequency (Figure 5). This age frequency was obtained from a single large catch on Volcano and only 150 otoliths. It has much older fish than the age frequency from Volcano in 2014 which was obtained from samples from six trawl catches on Volcano. It is possible that the 2018 age frequency is not representative of the age distribution of the spawning aggregation on Volcano in 2018. Compared to 2018, the fit and associated residuals for the 2014 age frequency are excellent (Figure 6).

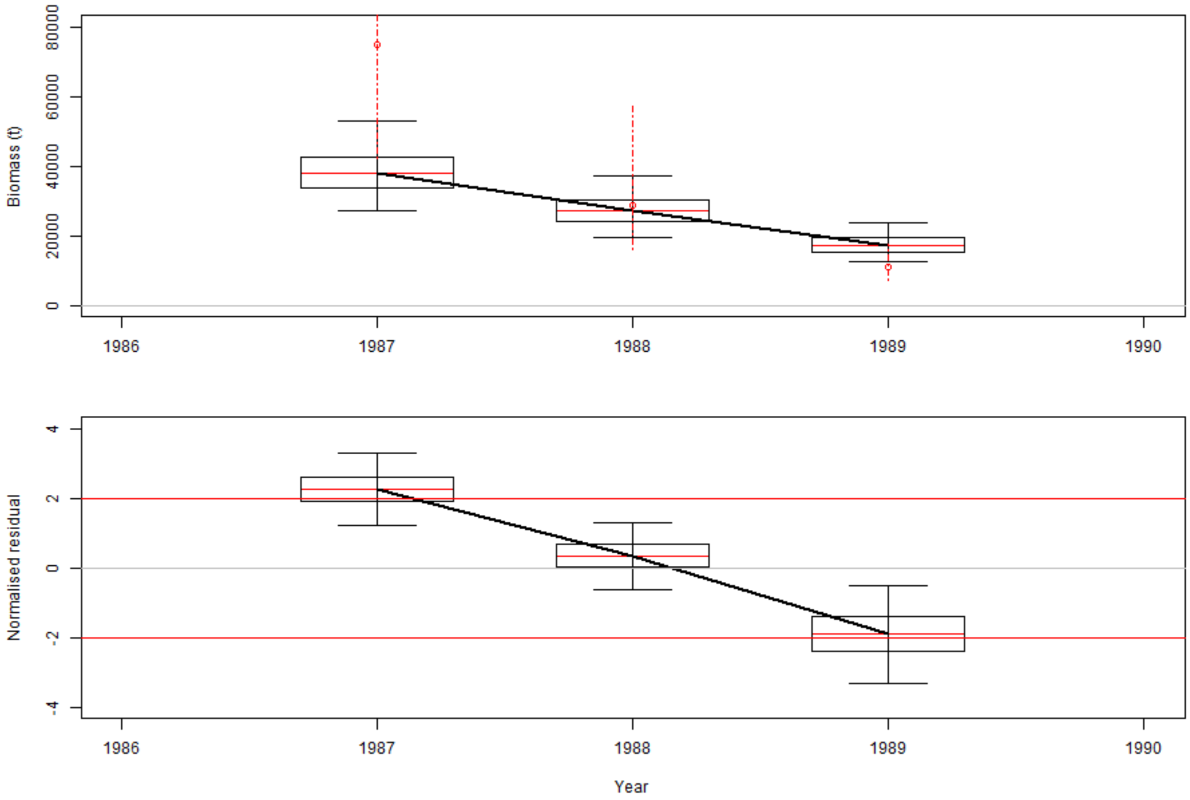



**Figure 2: Base, MCMC: fit to the *Amaltal Explorer* trawl indices (top panel) and the associated normalised residuals (bottom panel). Each box covers the middle 50% of the distribution and the whiskers extend to 95% CIs. The indices are plotted in the top panel (open circles) with 95% CIs (dashed red lines).**

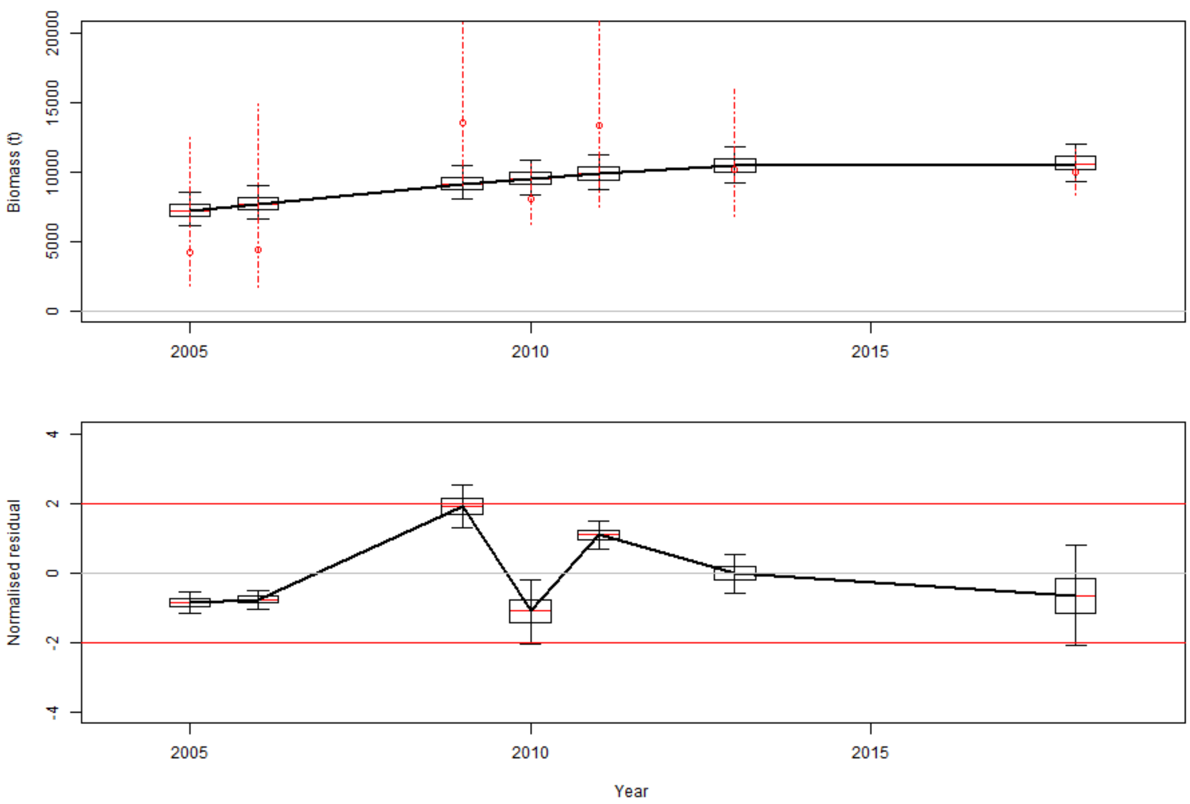



**Figure 3: Base, MCMC: fit to the West spawning aggregation (top panel) and the associated normalised residuals (bottom panel). Each box covers the middle 50% of the distribution and the whiskers extend to 95% CIs. The indices are plotted in the top panel (open circles) with 95% CIs (dashed red lines).**

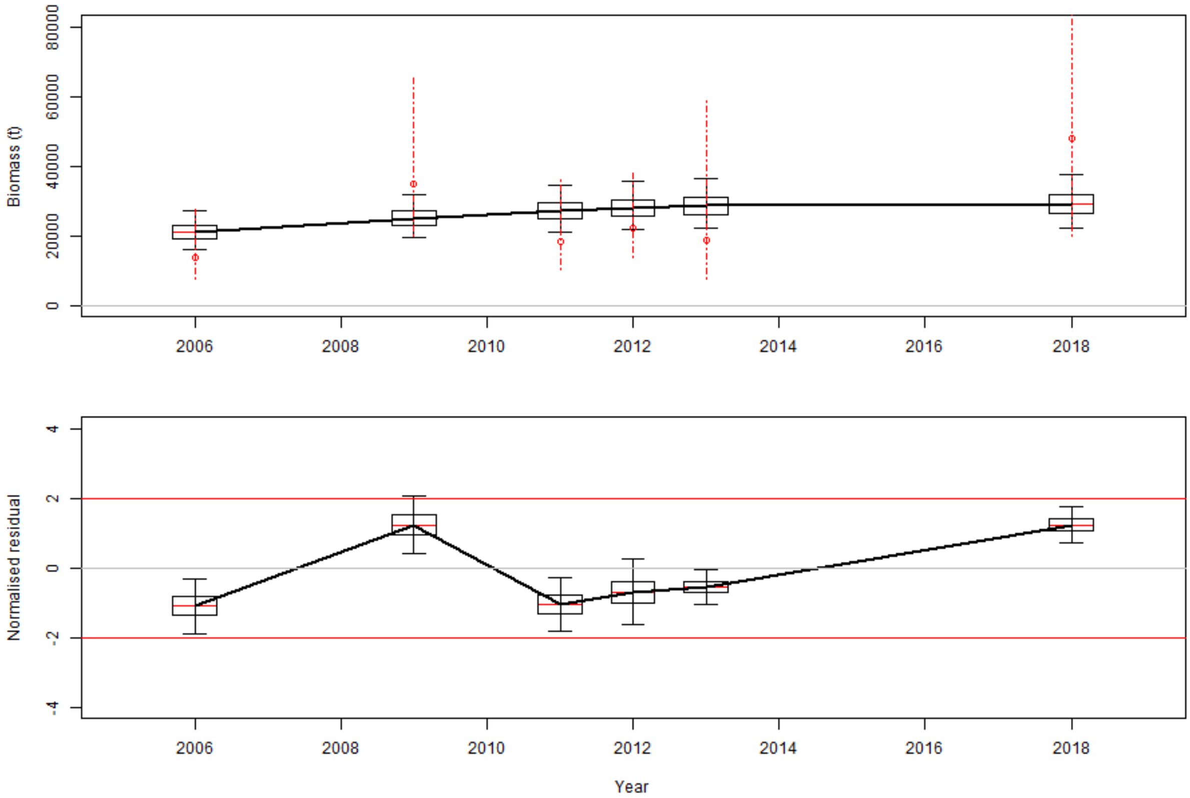



**Figure 4: Base, MCMC: fit to the *Thomas Harrison* trawl indices (top panel) and the associated normalised residuals (bottom panel). Each box covers the middle 50% of the distribution and the whiskers extend to 95% CIs. The indices are plotted in the top panel (open circles) with 95% CIs (dashed red lines).**

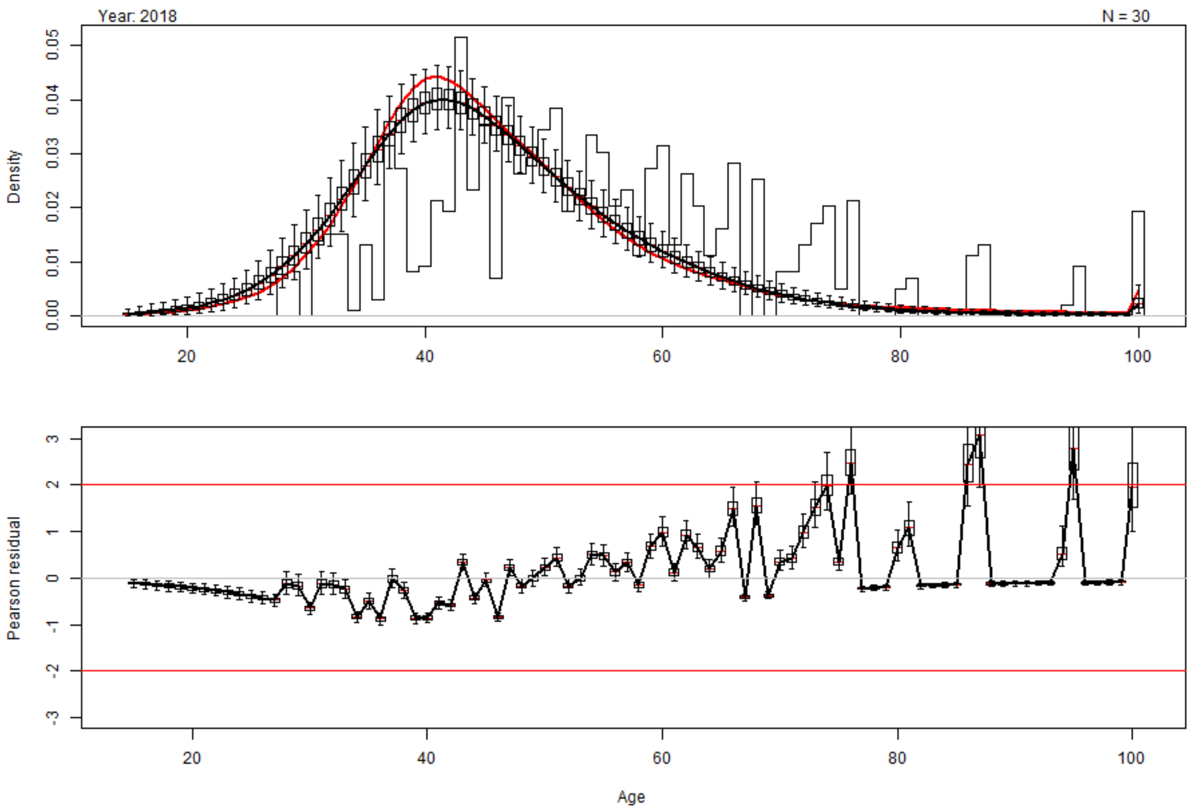



**Figure 5: Base, MCMC: fit to the 2018 Volcano age frequency (top panel) and the associated Pearson residuals (bottom panel). Each box covers the middle 50% of the distribution and the whiskers extend to 95% CIs. The indices are plotted in the top panel (open circles) with 95% CIs (dashed red lines). The MPD fit is shown in red (top panel).**

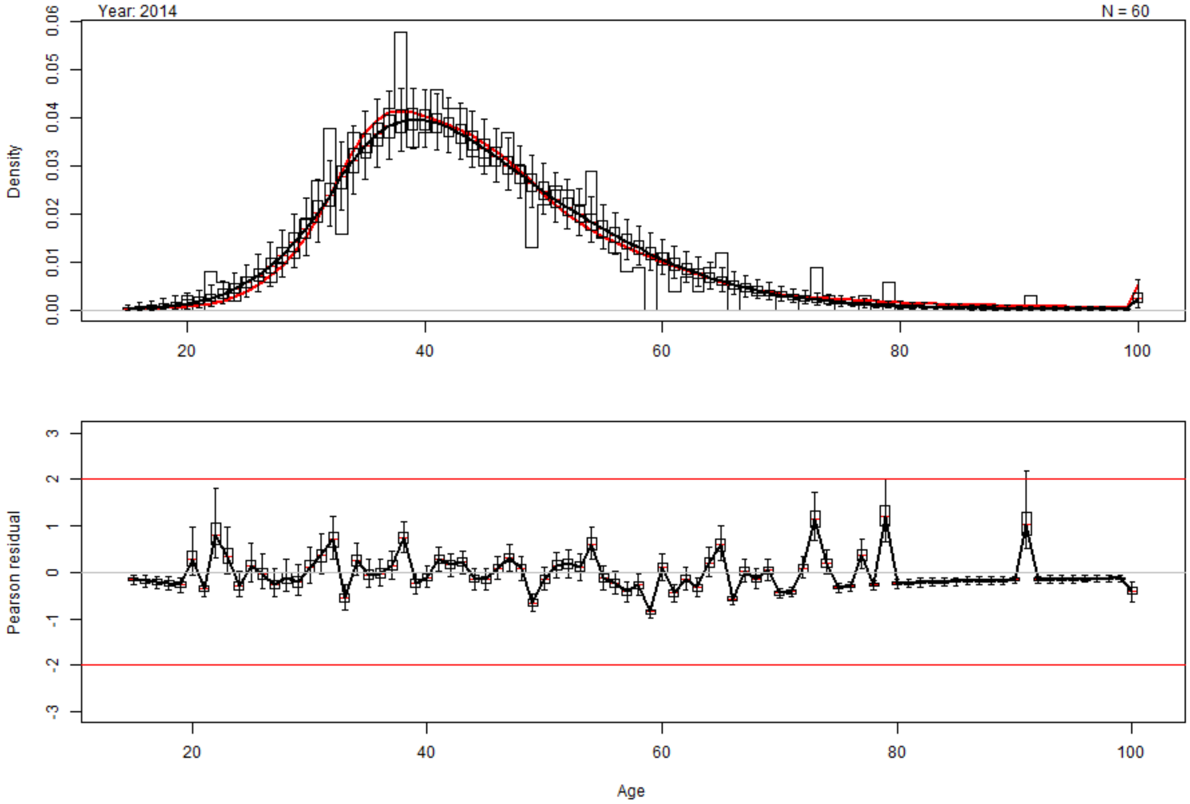



**Figure 6: Base, MCMC: fit to the 2014 Volcano age frequency (top panel) and the associated Pearson residuals (bottom panel). Each box covers the middle 50% of the distribution and the whiskers extend to 95% CIs. The indices are plotted in the top panel (open circles) with 95% CIs (dashed red lines). The MPD fit is shown in red (top panel).**

The posterior distributions of the *q*s, which had informed priors, show movement to lower values of *q* for *Thomas Harrison*, the West, and the East aggregations, with a shift to higher values for Volcano (Figure 7). Although there is a substantial move to the left (for West and East), the posterior distributions are still within the range of the prior distributions and so the estimates of *q* are credible. For Volcano, the move to higher values probably reflects the nature of the associated selectivity which is to the right of maturity (which is the selectivity for the West and East aggregations).

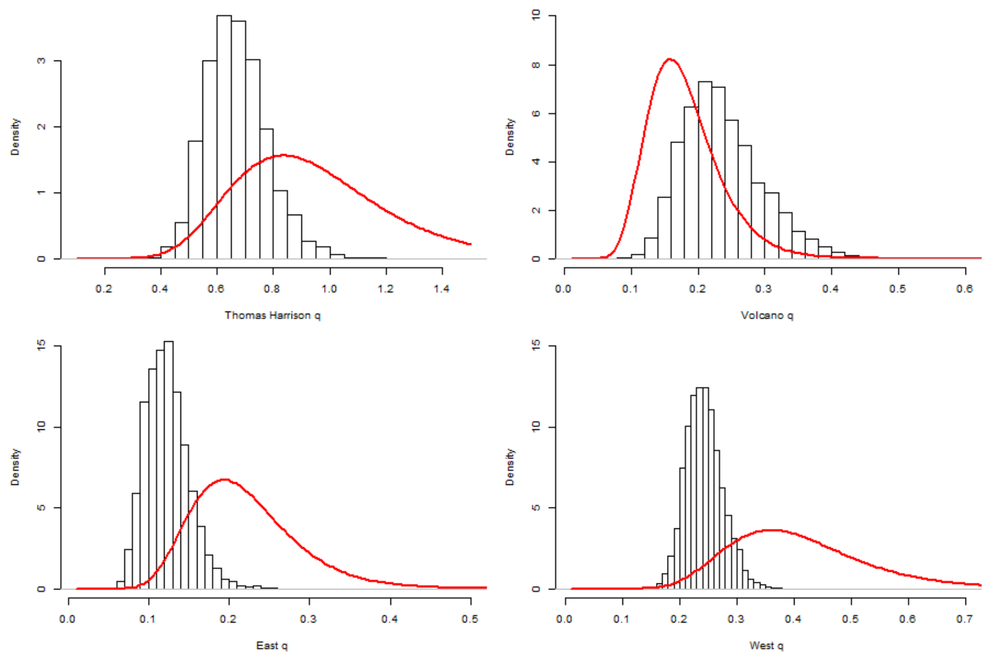



**Figure 7: Base, MCMC: Prior distributions (solid red lines) and marginal posterior distributions (histograms) for the *Thomas Harrison* and acoustic *q*s.**

## MCMC results

For the base model, and the sensitivity runs, MCMC convergence diagnostics were excellent. Virgin biomass ($B_0$) was estimated to be about 95 000 t for all runs except when the informed priors on the *q*s were removed (Table 4). When the informed priors were removed, virgin biomass was estimated to be higher than in the base model (Table 4). This indicates that the trend in the biomass indices, and to some extent the age frequencies, support a higher virgin biomass than was implied by information on the scale of the stock from the informed priors. The base model estimates are to be preferred as the informed priors contain information on orange roughy target strength and spawning biomass areal availability that is not otherwise available to the model. For all runs, current stock status was estimated to be within or above the target biomass range of 30–50% $B_0$ (Table 4).

**Table 4: MCMC estimates of virgin biomass ($B_0$) and stock status ($B_{2019}$ as %$B_0$) for the base model and four sensitivity runs.**

| | *M* | $B_0$ (000 t) | 95% CI | $B_{2019}$ (%$B_0$) | 95% CI |
|---|---|---|---|---|---|
| Base | 0.045 | 94 | 86–104 | 47 | 39–55 |
| All trend | 0.045 | 107 | 94–126 | 57 | 46–67 |
| Estimate M | 0.037 | 97 | 89–106 | 40 | 31–51 |
| LowM-Highq | 0.036 | 95 | 88–103 | 37 | 30–45 |
| HighM-Lowq | 0.054 | 94 | 85–106 | 56 | 48–65 |

The estimated YCS show little variation across cohorts but exhibit a long-term trend (Figure 8). The cohorts from 1989–1995 were spawned when SSB was at about 20% $B_0$ (Figure 9). It is encouraging that the YCS estimates for these cohorts was about average (Figure 8). This suggests that steepness in the assumed Beverton-Holt stock recruitment relationship for this stock is not particularly low.

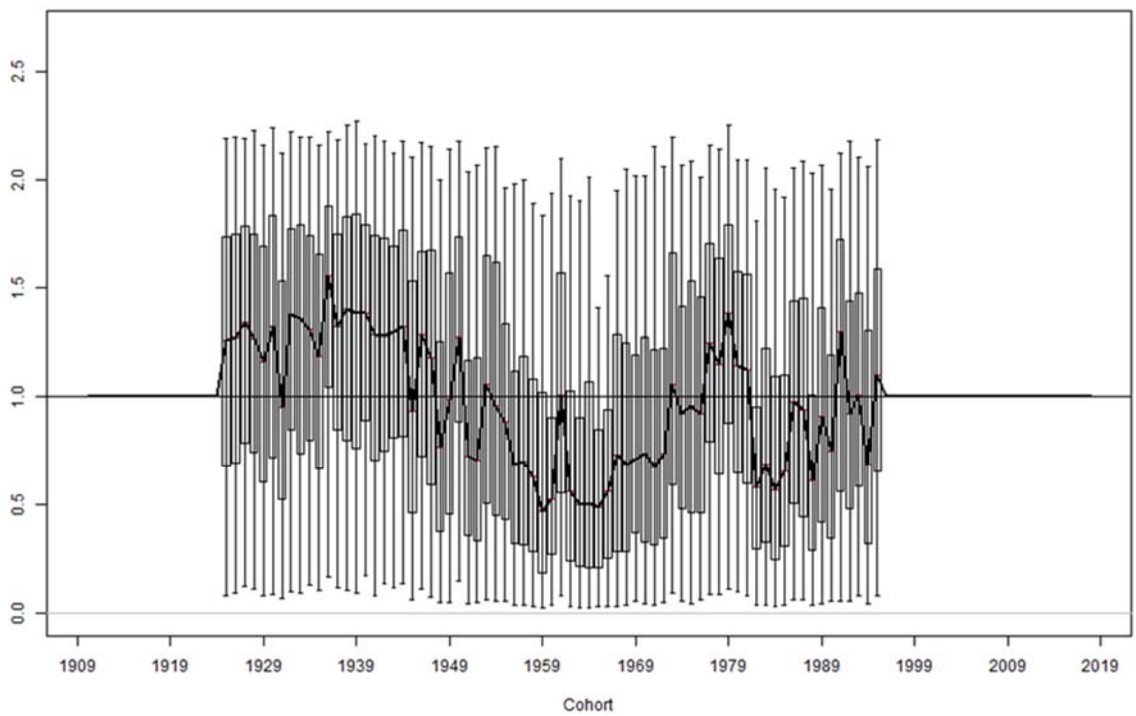



**Figure 8: Base, MCMC estimated YCS. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution.**

The stock status trajectory shows a steep decline to about 15% $B_0$ in 1990, reflecting the large removals during the initial fish-down phase of this stock (Figure 9). From 1990 stock status remains at about 15% $B_0$ until an upturn in the late 1990s (Figure 9). Biomass is estimated to have peaked in 2015, near the top the target biomass range, before the increased catches (enabled by a TACC increase) caused a levelling out of the biomass trajectory (Figure 9).

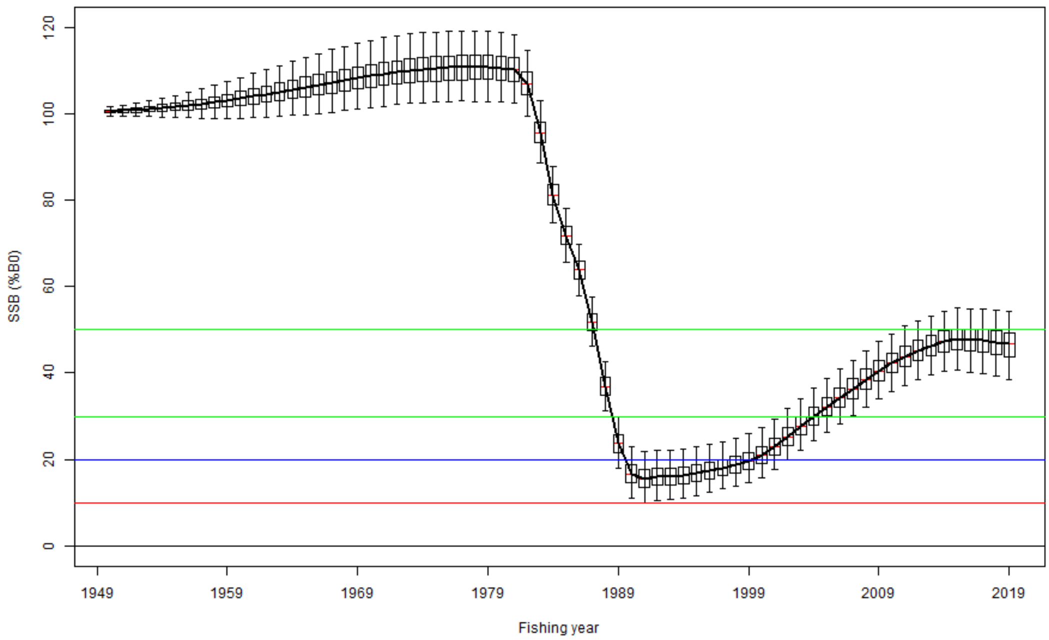



**Figure 9: Base, MCMC estimated spawning-stock biomass trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The hard limit 10% $B_0$ (red), soft limit 20% $B_0$ (blue), and biomass target range 30–50% $B_0$ (green) are marked by horizontal lines.**

Fishing intensity was estimated in each year as the total exploitation rate (total catch over beginning of fishing season spawning biomass) for each MCMC sample to produce a posterior distribution for fishing intensity by year. The fishing intensity reference points $U_{30\%B0}$ and $U_{50\%B0}$ were also calculated in terms of exploitation rate (for the assumed catch split in the 2018-19 fishing year).

Estimated fishing intensity was generally well above the target range ($U_{30\%B0}$–$U_{50\%B0}$) up until the closure of the fishery in 2001. Subsequently, it was well below the target range up until 2014, and from 2015 until now it is at the lower end of the range (Figure 10).

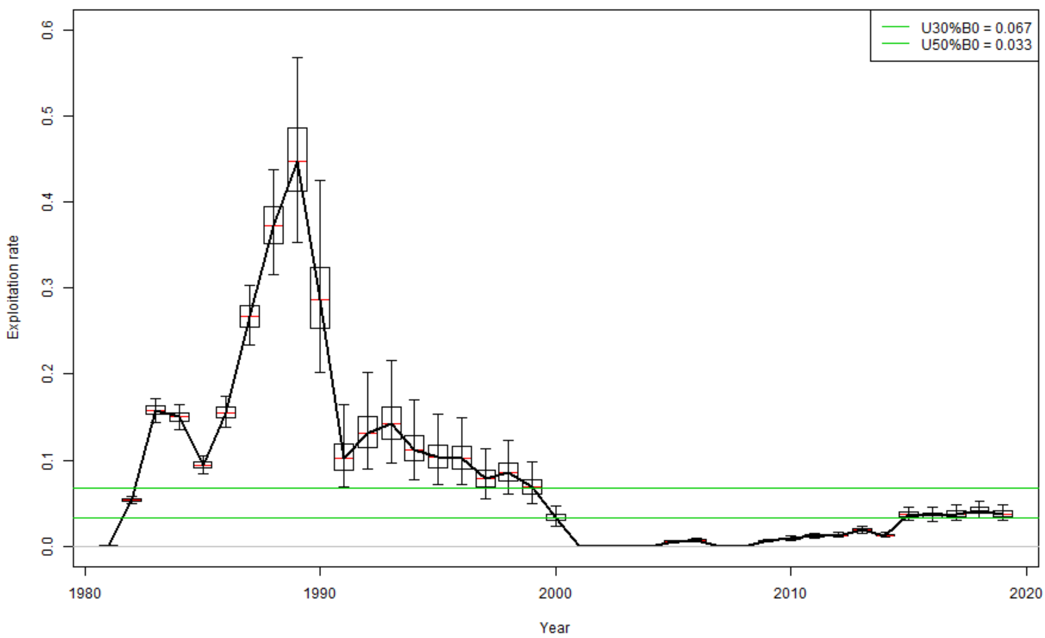



**Figure 10: Base, MCMC estimated fishing-intensity trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The fishing-intensity range associated with the biomass target of 30–50% $B_0$ is marked by horizontal lines.**

**Projections**
Five-year projections were conducted (with resampling from the last 10 estimated YCS, 1986–1995) for a constant catch of 1600 t (the current TACC). A 5% catch over-run was assumed. Projections were done for the base model and for the LowM-Highq sensitivity model (as a "worst case" scenario).

At the current TACC (1600 t), SSB is predicted to decrease slowly over the next five years for both models, while staying within the target biomass range (Figure 11). For both models the estimated probability of SSB going below either the soft limit (20% $B_0$) or the hard limit (10% $B_0$) is zero. For the base model projection, exploitation rates are predicted to slowly increase but still be at the lower end of the fishing intensity target range in 2024 (95% CI 0.030–0.054 compared to the target range of 0.033–0.067).

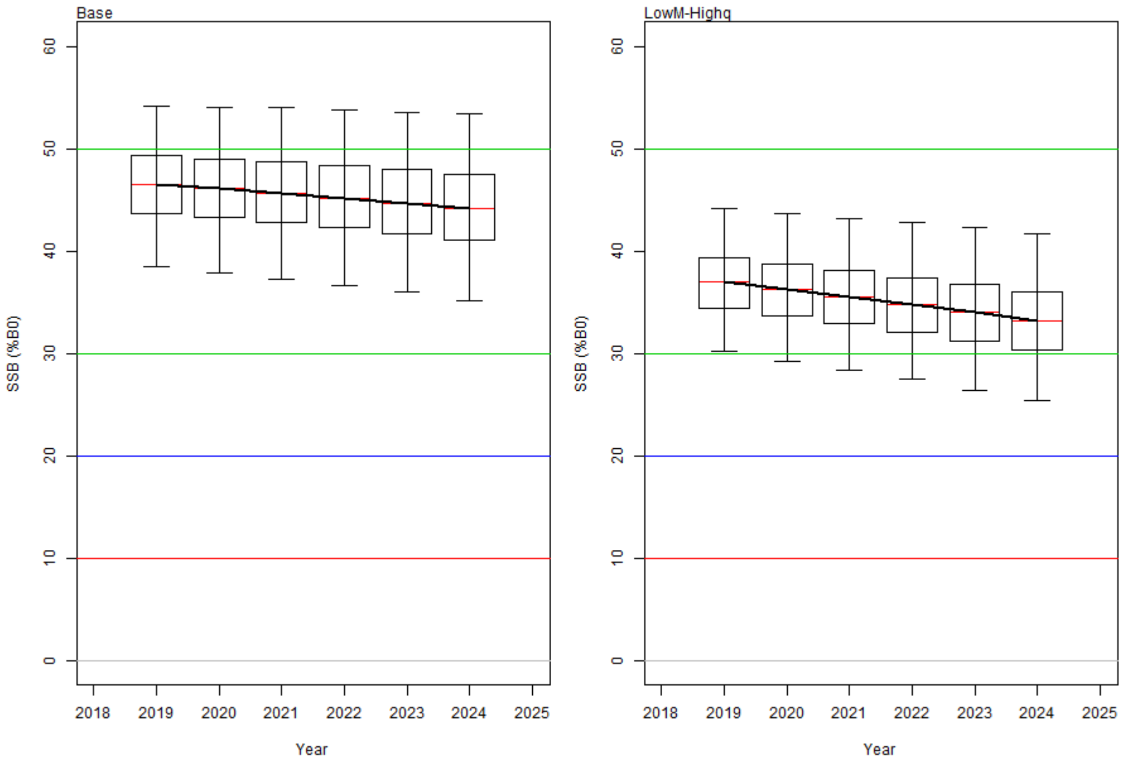



**Figure 11: MCMC projections for a constant catch of 1600 t (plus a 5% allowance for incidental catch) for the base model and the LowM-Highq model. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The target biomass range (30–50% $B_0$) is indicated by horizontal green lines, the hard limit (10% $B_0$) by a red line and the soft limit (20% $B_0$) by a blue line.**

## 5. FUTURE RESEARCH CONSIDERATIONS

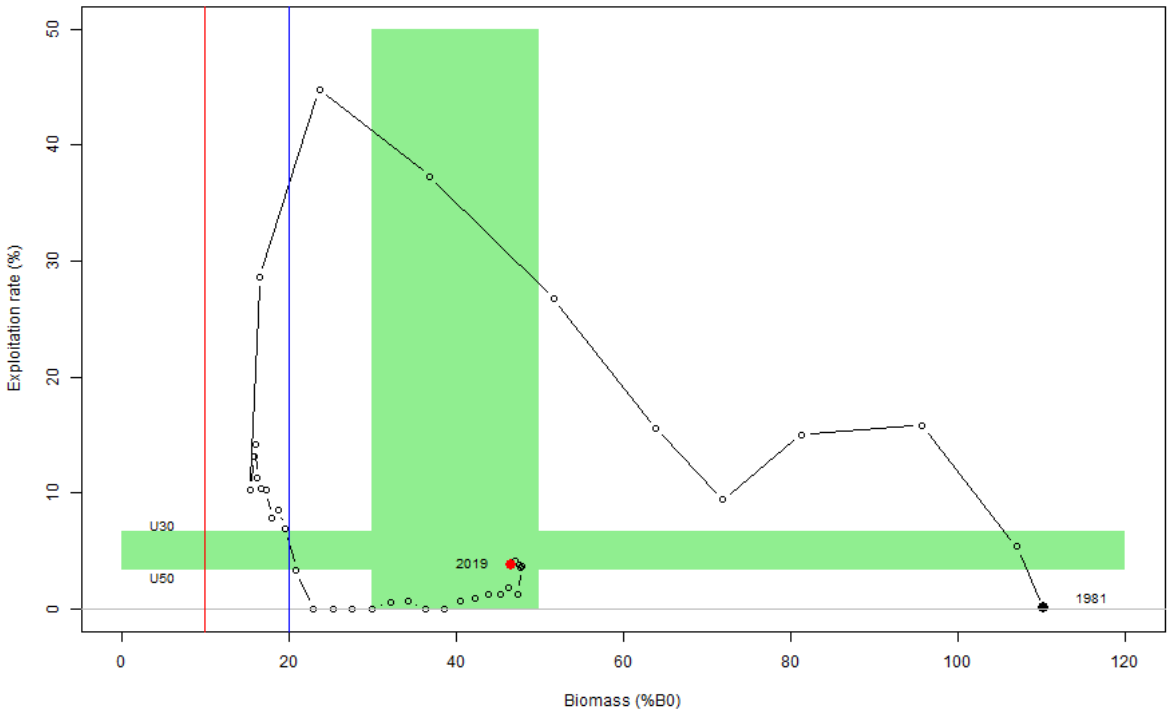
- Revise the acoustic survey design and implementation to ensure (i) improved estimation of the abundance in the 'East' aggregation and (ii) abundance estimates are obtained for all three aggregations ('East', 'West' and Volcano) in the same year.
- Reconsider the otolith sampling approach from acoustic surveys to ensure that adequate otoliths are obtained from each aggregation and that these are obtained from multiple tows to support the stock assessment.
- Review current arrangements for sampling commercial catches for age to ensure that adequate samples are being obtained from both spawning and non-spawning fisheries.

## 6. STATUS OF THE STOCK

Orange roughy on the southwest Challenger Plateau (Area 7A, including Westpac Bank) are regarded as a single stock.

| **Stock Status** | |
|---|---|
| Year of Most Recent Assessment | 2019 |
| Assessment Runs Presented | Base model only |
| Reference Points | Management Target: Biomass range 30–50% $B_0$<br>Soft Limit: 20% $B_0$<br>Hard Limit: 10% $B_0$<br>Overfishing threshold: Fishing intensity range $U_{30\%B0}$–$U_{50\%B0}$ |
| Status in relation to Target | $B_{2014}$ was estimated to be 47% $B_0$<br>Very Likely (> 90%) to be at or above the lower end of the management target range and About as Likely as Not (40–60%) to be at or above the upper end of the management target range |
| Status in relation to Limits | $B_{2019}$ is Exceptionally Unlikely (< 1%) to be below the Soft Limit<br>$B_{2019}$ is Exceptionally Unlikely (< 1%) to be below the Hard Limit |
| Status in relation to Overfishing | Fishing intensity in 2018–2019 was estimated to be below or within the fishing intensity range. Overfishing is Very Unlikely (< 10%) to be occurring. |

**Historical Stock Status Trajectory and Current Status**




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

| **Fishery and Stock Trends** | |
|---|---|
| Recent Trend in Biomass or Proxy | Spawning biomass is estimated to have peaked in 2014–2015 near the top of the target biomass range and to have declined slightly since then. |
| Recent Trend in Fishing Intensity or Proxy | Fishing intensity has been near the bottom of the fishing intensity target range since 2014–15. |
| Other Abundance Indices | - |

| | |
|---|---|
| Trends in Other Relevant Indicators or Variables | - |

| **Projections and Prognosis** | |
|---|---|
| Stock Projections or Prognosis | Biomass is expected to slowly decrease at the current TACC (1600 t) over the next 5 years, but to remain within the target range. |
| Probability of Current Catch or TACC causing Biomass to remain below, or to decline below, Limits | Soft Limit: Exceptionally Unlikely (< 1%) within the next 5 years<br>Hard Limit: Exceptionally Unlikely (< 1%) within the next five years |
| Probability of Current Catch or TACC causing Overfishing to continue or to commence | Very Unlikely (< 10%) within the next five years |

| **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: 2019 | Next assessment: 2023 |
| Overall assessment quality rank | 1 – High Quality | |
| Main data inputs (rank) | - Acoustic survey indices for West, East, and Volcano aggregations<br>- Two trawl survey time series: 1987–1989 and 2006, 2009–2012<br>- Age frequencies from the trawl surveys in 1987, 2006, 2009, and 2018<br>- Age frequencies from Volcano in 2014 and 2018 | 1 – High Quality<br>1 – High Quality<br>1 – High Quality<br>1 – High Quality |
| Data not used (rank) | - commercial CPUE<br>- Acoustic surveys of UTFs other than Volcano<br>- Other acoustic estimates which did not meet the selection criteria<br>- Early trawl surveys with different vessels covering different areas | 3 – Low Quality: unlikely to be indexing stock-wide abundance<br>2 – Medium or Mixed Quality: species identification and dead zone problems<br>2 – Medium or Mixed Quality: not surveys of a spawning aggregation or timing too early<br>2 – Medium or Mixed Quality: not a consistent time series |
| Changes to Model Structure and Assumptions | - Acoustic biomass estimates were adjusted using a combined correction for vessel motion and the bubble layer estimated for a different vessel on the Chatham Rise. In the 2014 assessment, estimates were not corrected for the bubble layer.<br>- Two fisheries were modelled instead of a single fishery. | |
| Major Sources of Uncertainty | - The proportion of the stock that is indexed by the acoustic and trawl surveys. | |

| Qualifying Comments |
|---|
| - |

| Fishery Interactions |
|---|
| Since the fishery re-opened with a low level of catch and effort, bycatch levels have been relatively low at about 4 to 5%, with spiky oreo being 1.4% of the average catch for 2008-09 to 2013-14. The bycatch of low productivity species over this period includes a number of deepwater shark and coral species. With limited fishing effort, there have been no observed or estimated incidental captures of seabirds or marine mammals between 2002–03 and 2015–16. |

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# ORANGE ROUGHY WEST COAST SOUTH ISLAND (ORH 7B)

## 1. FISHERY SUMMARY

### 1.1 Commercial fisheries

From 1 October 2007 the TACC for this stock was reduced to 1 t. Previously the fishery was centred on an area near the Cook Canyon in statistical areas 033, 034 and 705. Up until 1996–97 approximately 80% of the catch was taken in winter (June–July) when fish form aggregations for spawning. From 1997–98 onwards about 50% of the catch was taken in winter. Reported domestic landings and TACCs are shown in Table 1, while the historical landings and TACC for ORH 7B are depicted in Figure 1.

**Table 1: Reported landings (t) of orange roughy and TACCs (t) for ORH 7B from 1983–84 to present. QMS data from 1986–present.**

| Fishing year | Reported landings | TACC |
|---|---|---|
| 1983–84* | 2 | - |
| 1984–85* | 282 | - |
| 1985–86* | 1 763 | 1 558 |
| 1986–87* | 1 446 | 1 558 |
| 1987–88 | 1 413 | 1 558 |
| 1988–89 | 1 750 | 1 708 |
| 1989–90 | 1 711 | 1 708 |
| 1990–91 | 1 683 | 1 708 |
| 1991–92 | 1 604 | 1 708 |
| 1992–93 | 1 139 | 1 708 |
| 1993–94 | 701 | 1 708 |
| 1994–95 | 290 | 1 708 |
| 1995–96 | 446 | 430 |
| 1996–97 | 425 | 430 |
| 1997–98 | 330 | 430 |
| 1998–99 | 405 | 430 |
| 1999–00 | 284 | 430 |
| 2000–01 | 161 | 430 |
| 2001–02 | 95 | 110 |
| 2002–03 | 90 | 110 |
| 2003–04 | 119 | 110 |
| 2004–05 | 106 | 110 |
| 2005–06 | 77 | 110 |
| 2006–07 | 125 | 110 |
| 2007–08 | 5.95 | 1 |
| 2008–09 | 1.44 | 1 |
| 2009–10 | 0.04 | 1 |
| 2010–11 | 0.14 | 1 |
| 2011–12 | 0.06 | 1 |
| 2012–13 | 0.25 | 1 |
| 2013–14 | 0.62 | 1 |
| 2014–15 | 1.67 | 1 |
| 2015–16 | 0.27 | 1 |
| 2016–17 | 0.58 | 1 |
| 2017–18 | 1.42 | 1 |

*FSU data.

Catches in the early-mid 1990s (especially 1994–95) were well below the TACC. The TACC was reduced to 430 t for the 1995–96 fishing year, then was reduced further to 110 t from 1 October 2001, followed by a further reduction to 1 t in the 2007–08 fishing year.

### 1.2 Recreational fisheries

There is no known recreational fishery for orange roughy in this area.

### 1.3 Customary non-commercial fisheries

There is no known customary non-commercial fishing for orange roughy in this area.

### 1.4 Illegal catch

There is no quantitative information available on illegal catch.

### 1.5 Other sources of mortality

There is no quantitative information available on other sources of mortality in this fishery.

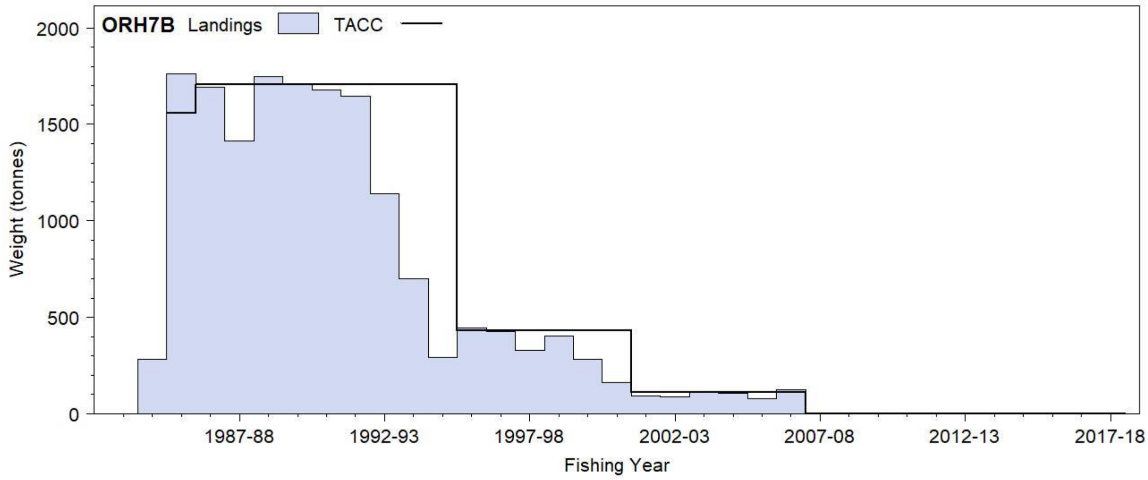



**Figure 1: Reported commercial landings and TACC for ORH 7B (Auckland East).**

## 2. STOCKS AND AREAS

There is no new information which would alter the stock boundaries given in previous assessment documents.

Orange roughy in this fishery are thought to be a single stock. Genetic studies have shown that samples of Cook Canyon orange roughy are significantly different from Challenger Plateau and Puysegur Bank samples. Moreover, the size structure and parasite composition differ from fish on the Challenger Plateau. Spawning occurs at a similar time to fish on the Challenger Plateau and the Puysegur Bank.

## 3. STOCK ASSESSMENT

The previous assessment for this stock was carried out in 2004 and is summarised in the 2006 Plenary Report. Biomass was estimated to be 17% $B_0$ (95% confidence interval 14–23%) when CPUE was assumed to be directly proportional to abundance.

An updated assessment was attempted in 2007 with the addition of catch data up to 2005–06 and new standardised CPUE indices. The Working Group rejected the assessment on the basis of the poor fit to the CPUE data. The effect was similar to the result from the 2004 assessment; namely a slow rebuild in recent years, which was not supported by the CPUE data.

### 3.1 Estimates of fishery parameters and abundance

Commercial catch and effort data are available from 1985 and were examined using both an unstandardised and a standardised analysis. Unstandardised catch rates have declined substantially over the course of the fishery but have shown no clear trend in more recent years (Table 2).

The standardised CPUE analysis has been divided into two series to address reporting form changes: (i) using TCEPR data from 1985–86 through to 1996–97, and (ii) using CELR data from 1990–91 through to 2005–06. In addition, in order to increase vessel linkage across years, it was decided to use all months of data not just that from the winter fishery (June–July) as has been done for previous standardisations.

The standardised analysis for the TCEPR data used catch per tow in a linear regression model. Indices from this model (Table 3, Figure 2) show a steep decline after the first two years, followed by a more gradual decline and a slight increase in catch rates in 1995–96 and 1996–97.

**Table 2: Summary of groomed data from TCEPR and CELR forms.**

| Fishing year | Number of vessel days | Number of tows | Total estimated catch (t) | Mean daily catch rate (t/tow) | Mean daily catch rate (t/h) |
|---|---|---|---|---|---|
| 1985–86 | 138 | 357 | 1 544 | 4.5 | 2.9 |
| 1986–87 | 132 | 405 | 1 250 | 4.0 | 2.7 |
| 1987–88 | 132 | 420 | 1 250 | 3.4 | 2.3 |
| 1988–89 | 133 | 368 | 827 | 2.5 | 1.6 |
| 1989–90 | 123 | 356 | 1 282 | 4.5 | 5.6 |
| 1990–91 | 208 | 632 | 1 657 | 2.8 | 3.3 |
| 1991–92 | 238 | 810 | 1 601 | 2.0 | 1.4 |
| 1992–93 | 258 | 784 | 1 128 | 1.5 | 2.3 |
| 1993–94 | 298 | 708 | 660 | 1.1 | 0.9 |
| 1994–95 | 162 | 361 | 320 | 0.9 | 1.6 |
| 1995–96 | 66 | 150 | 275 | 2.2 | 1.7 |
| 1996–97 | 90 | 182 | 244 | 1.3 | 7.5 |
| 1997–98 | 96 | 228 | 170 | 0.7 | 0.3 |
| 1998–99 | 188 | 566 | 359 | 0.6 | 0.2 |
| 1999–00 | 213 | 647 | 259 | 0.4 | 0.1 |
| 2000–01 | 149 | 442 | 162 | 0.4 | 0.1 |
| 2001–02 | 117 | 282 | 76 | 0.3 | 0.1 |
| 2002–03 | 97 | 292 | 112 | 0.4 | 0.2 |
| 2003–04 | 90 | 252 | 118 | 0.4 | 0.2 |
| 2004–05 | 121 | 393 | 102 | 0.3 | 0.1 |
| 2005–06 | 87 | 257 | 73 | 0.3 | 0.2 |

**Table 3: Standardised CPUE indices (relative year effect) based on TCEPR data with number of vessel tows from 1985–86 to 1996–97.**

| Year | CPUE index | CV | Number of tows | Year | CPUE index | CV | Number of tows |
|---|---|---|---|---|---|---|---|
| 1985–86 | 1.99 | 0.20 | 153 | 1991–92 | 0.48 | 0.23 | 231 |
| 1986–87 | 2.13 | 0.23 | 150 | 1992–93 | 0.29 | 0.23 | 230 |
| 1987–88 | 1.11 | 0.26 | 212 | 1993–94 | 0.14 | 0.25 | 341 |
| 1988–89 | 0.58 | 0.22 | 310 | 1994–95 | 0.13 | 0.27 | 172 |
| 1989–90 | 0.61 | 0.22 | 236 | 1995–96 | 0.51 | 0.33 | 37 |
| 1990–91 | 0.76 | 0.23 | 238 | 1996–97 | 0.41 | 0.26 | 104 |

The standardised analysis for the CELR data used daily catch in a linear regression model. Indices from this model (Table 4, Figure 2) show a steep decline for the first four years, followed by an increase to a peak in 1995–96, and subsequent low catch rates after then.

**Table 4: Standardised CPUE indices (relative year effect) based on CELR data with number of days from 1990–91 to 2005–06.**

| Year | CPUE index | CV | Number of days | Year | CPUE index | CV | Number of days |
|---|---|---|---|---|---|---|---|
| 1990–1991 | 2.17 | 0.27 | 110 | 1999–2000 | 0.34 | 0.27 | 131 |
| 1991–1992 | 1.11 | 0.27 | 108 | 2000–2001 | 0.34 | 0.28 | 88 |
| 1992–1993 | 0.74 | 0.27 | 126 | 2001–2002 | 0.33 | 0.28 | 73 |
| 1993–1994 | 0.28 | 0.28 | 81 | 2002–2003 | 0.61 | 0.26 | 67 |
| 1994–1995 | 0.53 | 0.30 | 46 | 2003–2004 | 0.59 | 0.25 | 75 |
| 1995–1996 | 1.16 | 0.33 | 29 | 2004–2005 | 0.35 | 0.24 | 114 |
| 1996–1997 | 0.53 | 0.38 | 19 | 2005–2006 | 0.36 | 0.26 | 80 |
| 1997–1998 | 0.36 | 0.30 | 52 | | | | |
| 1998–1999 | 0.39 | 0.28 | 112 | | | | |

## 3.2 Biomass estimates

No estimates of current biomass are available. Based on previous stock assessments using CPUE data the TACC was cut back severely from about 1700 t in 1994–95 to 110 t in 2000–01. By the late 1990s the stock was believed to be well below $B_{MSY}$ where it continued until at least 2004 (17% $B_0$ in the 2004 assessment, Figure 3). Despite the large reduction in annual removals from the stock after 2001–02, catch rates did not increase over the subsequent 5 years.

An updated assessment was attempted in 2007 with the addition of catch data up to 2005–06 and new standardised CPUE indices (Figure 2) based on TCEPR data (1986 to 1997) and a separate CELR series (1991 to 2006). These data were incorporated in a Bayesian stock assessment with deterministic recruitment to estimate stock size. The Working Group rejected the assessment on the basis of the poor fit to the recent CPUE data. The model was insensitive to the recent CPUE data and predicted a rebuild (driven by the recruitment assumptions) that is not supported by any observations in the fishery.

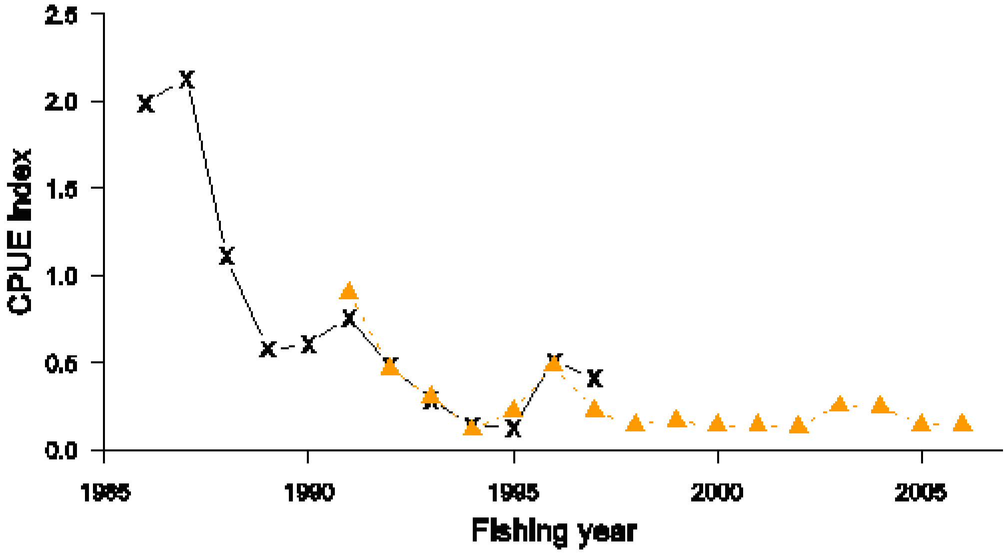



**Figure 2: The CPUE indices based on: (i) TCEPR data (solid line and crosses) covering 1985–86 to 1996–97, and (ii) CELR data (triangles and dashed line) covering 1990–91 to 2005–06. The CELR index has been scaled so that it has the same mean value as the TCEPR index in the years that they overlap.**

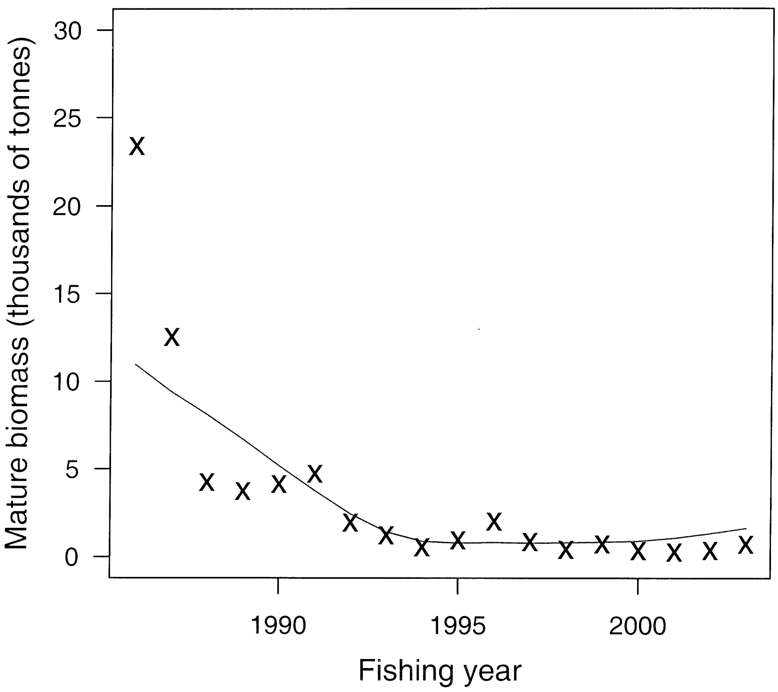



**Figure 3: Biomass trajectory derived from Maximum Posterior Density (MPD) estimate of the model parameters (2004 stock assessment). The biomass trajectory is shown by the solid line; crosses denote the CPUE index scaled to biomass.**

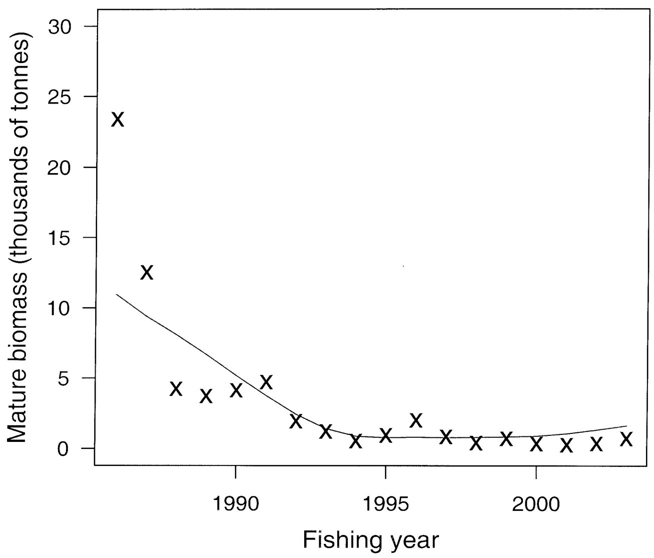
## 4. STATUS OF THE STOCK

**Stock Structure Assumptions**

The ORH 7B stock has been treated as a single spawning stock located around the Cook Canyon area. It is assessed and managed separately from other stocks and is assumed to be non-mixing with orange roughy stocks outside of the Cook Canyon area.

| **Stock Status** | |
|---|---|
| Year of Most Recent Assessment | 2004 |
| Assessment Runs Presented | One base case |
| Reference Points | Target: 30% $B_0$<br>Soft Limit: 20% $B_0$<br>Hard Limit: 10% $B_0$<br>Overfishing threshold: - |
| Status in relation to Target | $B_{2004}$ was estimated to be 17% $B_0$, Very Unlikely (< 10%) to be at or above the target |
| Status in relation to Limits | $B_{2004}$ was Likely (> 60%) to be below the Soft Limit and Unlikely (< 40%) to be below the Hard Limit |

**Historical Stock Status Trajectory and Current Status**




**Biomass trajectory derived from Maximum Posterior Density (2004 stock assessment model).**

| **Fishery and Stock Trends** | |
|---|---|
| Recent Trend in Biomass or Proxy | Unknown, but biomass is thought to be very low. |
| Recent Trend in Fishing Mortality or Proxy | The fishery has been effectively closed since October 2007. |
| Other Abundance Indices | - |
| Trends in Other Relevant Indicators or Variables | - |

| **Projections and Prognosis (2004)** | |
|---|---|
| Stock Projections or Prognosis | Stable at current catch level |
| Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits | Soft Limit: Already below the Soft Limit<br>Hard Limit: Very Unlikely (< 10%) |

| **Assessment Methodology and Evaluation** | | |
|---|---|---|
| Assessment Type | Level 1 – Fully Quantitative Stock Assessment | |
| Assessment Method | Age-structured model with Bayesian estimation of posteriors | |
| Assessment Dates | Latest assessment: 2004 | Next assessment: Unknown |
| Overall assessment quality rank | - | |
| Main data inputs (rank) | - Catch history<br>- CPUE indices (1985–2003) | |
| Data not used (rank) | N/A | |
| Changes to Model Structure and Assumptions | - CPUE indices based on mean catch per hour as opposed to previous measure of mean catch per tow | |
| Major Sources of Uncertainty | - Recruitment assumed to be deterministic<br>- CPUE assumed to be directly proportional to stock biomass in base model | |

| **Qualifying Comments (2010)** |
|---|
| A further assessment was attempted in 2007 with updated information; however, this was rejected by the working group as the model was insensitive to the CPUE data. The model indicated that the stock had been rebuilding since the mid 1990s, a trend not supported by any observations in the fishery. The fishery was closed from 1 October 2007 and stock size is expected to increase. |

| **Fishery Interactions** |
|---|
| Historically, the main bycatch species were oreos and deepwater dogfish. Other bycatch species recorded include deepwater sharks, deepsea skates, seabirds and corals. The fishery is currently closed. |

## 5. FOR FURTHER INFORMATION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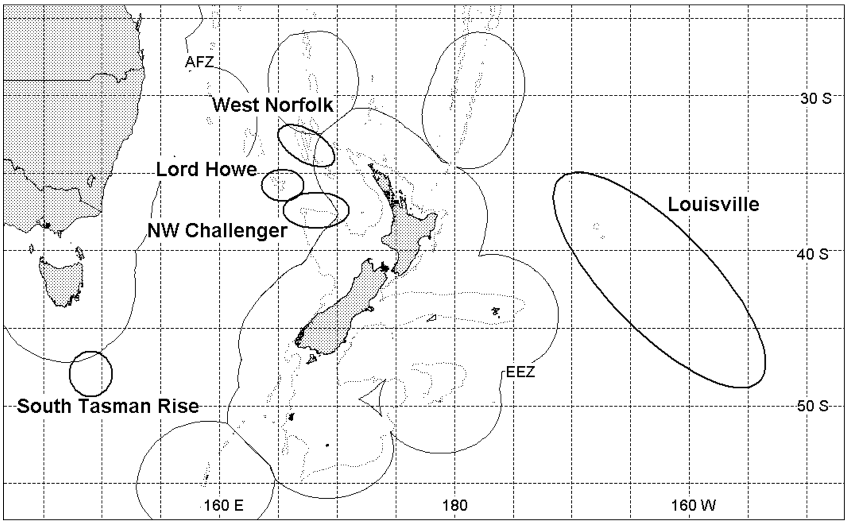
# ORANGE ROUGHY OUTSIDE THE EEZ (ORH ET)




## 1. FISHERY SUMMARY

### 1.1 Commercial fisheries

Fisheries outside the EEZ in the New Zealand region occur on ridge systems and seamount chains in the Tasman Sea and southwest Pacific Ocean. There are five main fishing areas: Lord Howe Rise, Northwest Challenger Plateau, West Norfolk Ridge, South Tasman Rise, and Louisville Ridge (see figure above).

The first orange roughy fishery outside the EEZ developed on the “Westpac Bank” close to the main fishing grounds on the southwest Challenger Plateau in the early–mid 1980s. Catches were recorded as part of the straddling stock crossing into ORH 7A, and therefore excluded from this chapter, up until 2007. Further exploration in the region resulted in the development of commercial fisheries on the Lord Howe Rise in 1987–88, Northwest Challenger Plateau in 1988–89, Louisville Ridge in 1993–94, South Tasman Rise in 1997–98, and West Norfolk Ridge in 2001–02. Catches from all of these fisheries are tabulated by fishing year up to 2006–07, excluding Westpac catches (Table 1), and by calendar year from 2007 to present (Table 2), as required by the South Pacific Fisheries Management Organisation (SPRFMO).

**Table 1: Estimated catches (t) of orange roughy for ORH ET fisheries from 1987–88 to 2006–07. (Data from New Zealand (FSU, QMS), Australia (AFMA), and various sources for other countries. Note that the fishing year for South Tasman Rise is March to February, all others are October to September). See Table 2 for catches from 2007 onwards.**

| Fishing year | Lord Howe | NW Challenger | Louisville | West Norfolk | South Tasman | Total ET |
|---|---|---|---|---|---|---|
| 1987–88 | 4 000 | 5 | 0 | 0 | 0 | 4 005 |
| 1988–89 | 2 430 | 297 | 0 | 0 | 0 | 2 727 |
| 1989–90 | 927 | 425 | 0 | 0 | 0 | 1 352 |
| 1990–01 | 282 | 123 | 0 | 0 | 0 | 405 |
| 1991–02 | 859 | 620 | 0 | 0 | 0 | 1 479 |
| 1992–03 | 2 300 | 2 463 | 0 | 0 | 0 | 4 763 |
| 1993–04 | 840 | 1 731 | 689 | 0 | 0 | 3 260 |
| 1994–05 | 761 | 1 138 | 13 252 | 0 | 0 | 15 151 |
| 1995–06 | 5 | 500 | 8 816 | 0 | 0 | 9 321 |
| 1996–07 | 139 | 332 | 3 209 | 0 | 5 | 3 685 |
| 1997–08 | 26 | 397 | 1 404 | 0 | 3930 | 5 757 |
| 1998–09 | 440 | 961 | 3 164 | 0 | 705 | 5 270 |
| 1999–00 | 52 | 473 | 1 369 | 0 | 4 110 | 6 004 |
| 2000–01 | 428 | 1 228 | 1 598 | 10 | 830 | 4 094 |
| 2001–02 | 120 | 2 075 | 1 004 | 649 | 170 | 3 729 |
| 2002–03 | 272 | 1 010 | 1 296 | 94 | 110 | 2 782 |
| 2003–04 | 324 | 654 | 1 419 | 90 | 3 | 2 490 |
| 2004–05 | 430 | 464 | 1 510 | 277 | 55 | 2 736 |
| 2005–06 | 240 | 201 | 675 | 727 | 12 | 1 855 |
| 2006–07 | 40 | 96 | 323 | 552 | 0 | 1 011 |

Catch totals include data from New Zealand and Australian vessels available from tow by tow fishing records, with estimated catches added for vessels from Japan, USSR, Korea, Norway, South Africa and China. Catch statistics are likely to be incomplete.

These fisheries were historically unregulated, with the exception of the South Tasman Rise area, where catches by Australian and New Zealand vessels have at times been restricted by a TAC imposed under a Memorandum of Understanding between the two countries. The South Tasman Rise fishery is currently closed.

## South Pacific Regional Fisheries Management Organisation (SPRFMO) Convention Area

Regulation of these fisheries was implemented following adoption of the SPRFMO interim measures in May 2007, and specific high sea fishing permits for the SPRFMO Area have been issued since 2007–08. Table 2 shows the number of New Zealand vessels that fished and their orange roughy catch by area. Since 2007, an orange roughy catch limit has been applied for New Zealand vessels, being the average annual catch between 2002 and 2006 (1852 t). Australia implements analogous limits for its vessels based on average catches between 2002 and 2006, and no other nations are currently fishing.

**Table 2: Annual catch (t) and effort data for orange roughy from New Zealand vessels for the SPRFMO Area (calendar years). Westpac Bank is on the Challenger Plateau but is considered part of the straddling stock ORH 7A so landings from that area are tabulated separately. Australian catches over this period, mostly from the Tasman Sea, ranged from 0 to 148 t, mean 46 t per annum). No other nations fished. 2018 numbers are preliminary.**

| Year | Number of Vessels | Number of tows | Lord Howe | NW Challenger | Westpac | Louisville | West Norfolk | Other | All areas |
|---|---|---|---|---|---|---|---|---|---|
| 2007 | 8 | 415 | 34 | 36 | - | 280 | 515 | - | 866 |
| 2008 | 4 | 208 | 380 | 31 | - | - | 426 | - | 837 |
| 2009 | 6 | 545 | 403 | 238 | 23 | - | 233 | 31 | 928 |
| 2010 | 7 | 1 170 | 385 | 415 | 5 | 584 | 79 | 6 | 1 474 |
| 2011 | 7 | 1 158 | 1 | 675 | 5 | 285 | 113 | - | 1 079 |
| 2012 | 6 | 652 | 121 | 247 | 8 | 288 | 49 | 8 | 721 |
| 2013 | 5 | 760 | 344 | 230 | 3 | 565 | 19 | 3 | 1 164 |
| 2014 | 5 | 403 | 79 | 57 | 54 | 754 | - | 54 | 998 |
| 2015 | 5 | 959 | 157 | 530 | 118 | 462 | 20 | - | 1 287 |
| 2016 | 6 | 943 | 208 | 486 | 234 | 27 | - | - | 954 |
| 2017 | 5 | 1 423 | 215 | 307 | 129 | 420 | 22 | - | 1 093 |
| 2018 | 6 | 1 003 | 180 | 399 | 569 | 81 | 5 | - | 1 232 |

The SPRFMO Convention was closed for signature in January 2011 and formally entered into force in August 2012. Since that time, monitoring and assessment of catches and fisheries, including for orange roughy, has been overseen by the SPRFMO Scientific Committee.

## South Tasman Rise

Exploratory fishing south of Tasmania located aggregations of orange roughy on the South Tasman Rise just outside the Australian Fishing Zone (AFZ) in late 1997. The fishery rapidly increased in the next four years (Table 3), with Australian and New Zealand vessels working several small hill features on the Rise. However, New Zealand vessels have not fished the South Tasman Rise since 2000–01. Effort dropped continuously from 2001–02, and mean catch per tow in 2004–05 was about 1 t/tow. Note that insufficient vessels have fished since 2005–06 to enable presentation of catch or effort summaries.

**Table 3: Catch and effort data from the South Tasman Rise (combined Australian and New Zealand data).**

| Fishing year | Number of tows | Total recorded catch (t) | Mean tow length (h) | Mean catch rate (t/tow) | Mean catch rate (t/h) |
|---|---|---|---|---|---|
| 1996–97 | 61 | 4 | 0.6 | 0.1 | 0.5 |
| 1997–98 | 1 132 | 3 930 | 0.7 | 3.5 | 17.4 |
| 1998–99 | 1 332 | 1 705 | 0.6 | 1.3 | 10.4 |
| 1999–00 | 1 086 | 3 360 | 0.5 | 3.1 | 21.1 |
| 2000–01 | 1 155 | 830 | 0.4 | 0.7 | 6.7 |
| 2001–02 | 201 | 170 | 0.8 | 1.0 | 3.5 |
| 2002–03 | 164 | 110 | 0.5 | 0.9 | 7.9 |
| 2003–04 | 67 | 2 | 0.3 | 0.1 | 0.4 |
| 2004–05 | 47 | 55 | 0.3 | 1.2 | 14.7 |

The fishery was formally regulated by a Memorandum of Understanding between Australia and New Zealand from December 1998. A precautionary TAC of 2100 t was applied, increased to 2400 t in 2000–01, and then progressively reduced to 600 t for 2004–05. The fishery was closed to all trawling in 2007.

### 1.2 Summary of trends in commercial fisheries

Information presented to the SPRFMO Scientific Committee shows that New Zealand catches of orange roughy have declined since the early 2000s and have been relatively stable at about 1000 t since about 2006 (Figure 1). This is well below the catch limit of 1 852 t. The distribution of catches between areas has varied substantially.

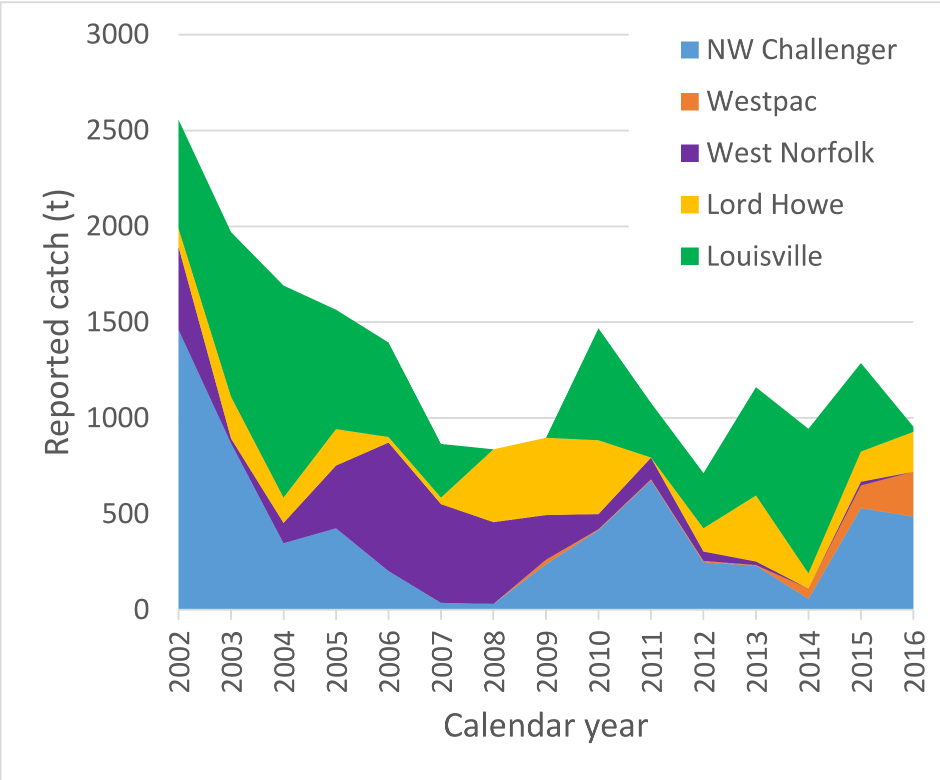



**Figure 1: Reported catch by area by New Zealand vessels, 2002–2016.**

Catch rates have varied considerably. Roux and Edwards (2017) developed a spatially-disaggregated CPUE index of stock abundance that corrects for some of the known issues with CPUE for orange roughy (Figure 2). This index shows less variability between years than unstandardized or standard GLM modelled-CPUE, but it is still not known whether it indexes biomass.

### 1.3 Recreational fisheries

There is no non-commercial fishery for orange roughy in these areas.

### 1.4 Customary non-commercial fisheries

There is no customary non-commercial fishing for orange roughy in these areas.

### 1.5 Illegal catch

In most of these areas, there were no regulations regarding limits on catch in international waters before 2007. The South Tasman Rise region has been subject to catch restrictions for Australian and New Zealand vessels under a Memorandum of Understanding between the two countries. In 1999–2000 vessels registered in South Africa and Belize fished the region. The estimated catch of at least 750 t has been included in the catch total for that year. No other information is available on any possible illegal catch on the South Tasman Rise, or the Westpac Bank part of ORH 7A.

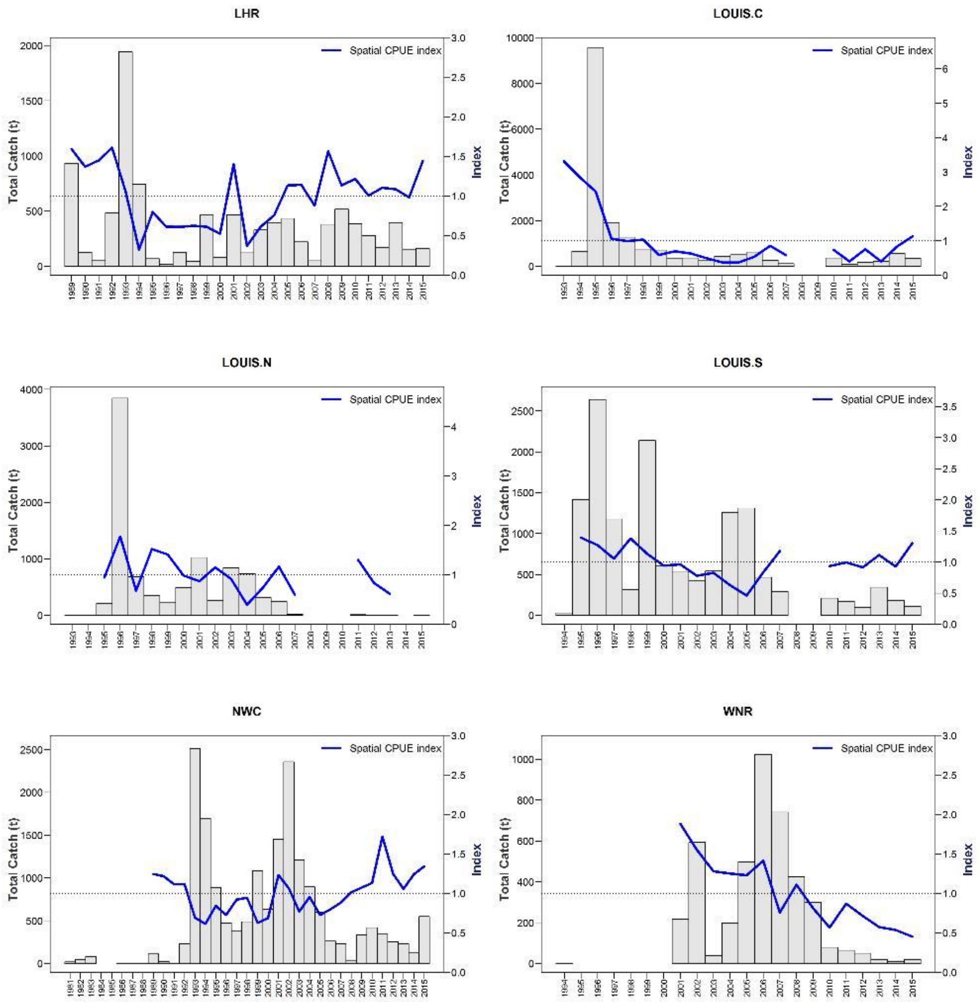



**Figure 2: Spatial CPUE indices from Roux & Edwards (2017) for the six orange roughy management areas considered in stock assessments presented to the SPRFMO Scientific Committee in 2017, with annual catch series (histograms).**

## 1.6 Other sources of mortality

There may be some overrun of reported catch because of fish loss with trawl gear damage, ripped nets, discards, and conversion factor inaccuracies. In a number of other orange roughy fisheries, a current level of 5% has been applied (higher in the past). No corrections are made here because of limited information on the sources which may differ with each fishery.

# 2. STOCKS AND AREAS

Stock structure is uncertain but Clark et al (2016) analysed multiple data sets and recommended that fishing grounds in the following areas be considered as separate units for the purpose of stock assessment: Lord Howe Rise; NW Challenger; SW Challenger; West Norfolk Ridge; South Tasman Rise, and North, Central, and South Louisville (Figure 3).

Orange roughy on the South Tasman Rise are regarded as a straddling stock with fish inside the AFZ. Those on the Westpac Bank on the SW Challenger Plateau are regarded as a straddling stock with fish inside New Zealand's EEZ and the ORH 7A stock.

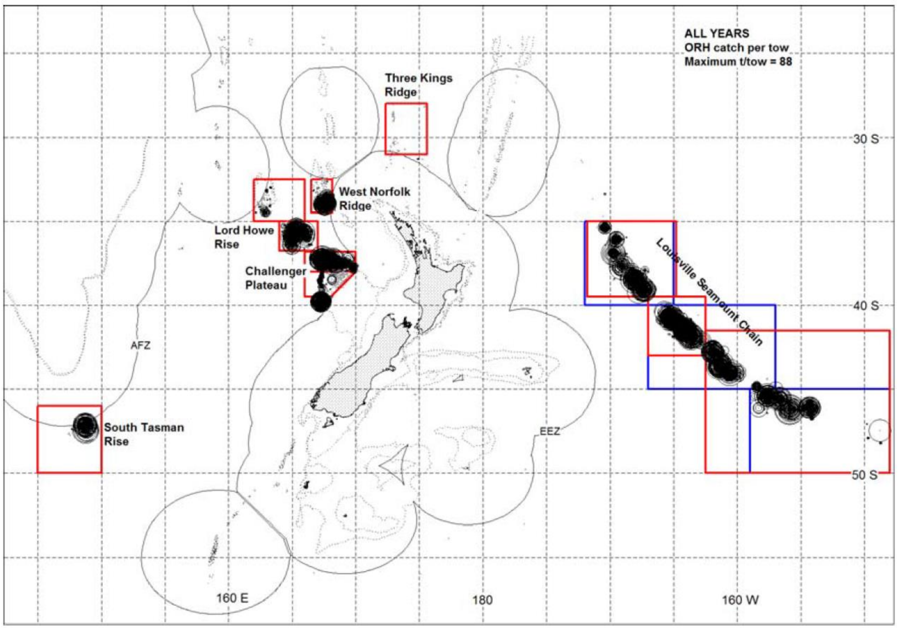



**Figure 3: Comparison of new areas assumed for stock assessment purposes (in red) and previous areas (in blue) overlaid on the total distribution of catch rates for orange roughy. Where both areas are coincident, red boxes overlay blue boxes. See Clark et al 2016 for details.**

## 3. STOCK ASSESSMENT

Several low-information stock assessments were presented to the SPRFMO Scientific Committee in 2015 and 2016 but these were not used by the committee to frame advice to the SPRFMO Commission until the 2017 meeting. The following is an extract from the report of the Scientific Committee's meeting in August 2017.

*98. Noting the urgent need to collect information to support robust assessments of orange roughy in the SPRFMO Area for sound management advice, the Scientific Committee considered the three approaches to assess SPRFMO orange roughy stocks as detailed in SC5-DW11 to DW14, SC5-INF03, and the Report of the 2nd Deepwater Workshop of the Scientific Committee (Annex 5). Although none of the methods is ideal for the assessment of SPRFMO orange roughy stocks, the SC considered them to be collectively indicative of stock status and potential yields. The development of advice on catch limits for individual stocks was considered but, because of the level of uncertainty in estimates of status and yield by stock, it was considered better to group the stocks for the development of advice.*

*99. The SC used the lower 95% CIs of estimated stock status to inform the level of precaution that might be appropriate. The group of stocks to the west of New Zealand (in the Tasman Sea) have a greater potential for low stock status than those to the east (Louisville Ridge) and a more precautionary approach was considered appropriate there.*

Papers adopted and cited by the Scientific Committee in framing this advice were as follows:

- Roux et al (2017), FAR 2017/01, tabled as paper SC5-DW11: Low information stock assessment of orange roughy in the SPRFMO Area. Available at: http://www.sprfmo.int/assets/SC5-2017/SC5-DW11-NZFAR-2017-01-Orange-roughy-SPRFMO-area.pdf
- Edwards & Roux (2017), tabled as paper SC5-DW12: A simple delay-difference model for assessment of data-poor orange roughy stocks. Available at: http://www.sprfmo.int/assets/SC5-2017/SC5-DW12-Edwards-Roux-Delay-difference-ORY-model.pdf
- Roux & Edwards (2017), tabled as paper SC5-DW13: A data limited approach for assessing small scale fisheries for orange roughy in the SPRFMO Area. Available at: http://www.sprfmo.int/assets/SC5-2017/SC5-DW13-rev1-Roux-Edwards-BDM-method-ORY.pdf

- Cordue (2017a), tabled as paper SC5-DW14: Catch-history based stock assessments of seven SPRFMO orange roughy stocks. Available at: http://www.sprfmo.int/assets/SC5-2017/SC5-DW14-Cordue-catch-history-method-ORY.pdf
- Cordue (2017b), tabled as paper SC5-INF03: A CPUE based stock assessment of the Louisville Central orange roughy stock. Available at: http://www.sprfmo.int/assets/SC5-2017/SC5-INF03-LouisCentralAssess.pdf
- Galvez et al (2017), tabled as paper SC5-Doc08: Report from the Deepwater Workshop in Hobart, May 2017. Available at: http://www.sprfmo.int/assets/SC5-2017/SC5-Doc08-rev1-DWG-Workshop-Report-Final27Sep17.pdf

## 4. STATUS OF THE STOCKS

The status of the stocks in the SPRFMO Convention Area is poorly known. The SPRFMO Scientific Committee based its precautionary advice to the Commission in 2017 on the papers cited in Section 3, using the lower limit of 95% confidence or credible intervals of the estimated status from a range of low-information methods. These were tabulated by Cryer et al (2017) (Table 4).

It is not known if recent catch levels are sustainable, or whether they will allow the stocks to move towards a size that will support the *MSY*.

**Table 4: Summary results from biomass dynamic modelling using a spatially disaggregated CPUE index (BDM) and catch-history age-structured assessment (CAS) for seven putative stocks of orange roughy. The lower 95% credible limits of depletion are from Roux & Edwards 2017 (BDM) and Cordue 2017a (CAS) and potential yield is here estimated as $B_{curr}$ x $HR_{MSY}$ (BDM) and the lower limit of Cordue's illustrative range of percentiles from the posterior distribution of long-term yield (CAS).**

| Management unit | Lower 95% CI from BDM | Potential Yield from BDM (t) | Lower 95% CI from CAS | Potential Yield from CAS (t) |
|---|---|---|---|---|
| Louisville North | 0.35 | 207 | 0.32 | 270 |
| Louisville Central* | 0.14 | 148 | 0.24 | 400 |
| Louisville South | 0.39 | 510 | 0.18 | 270 |
| West Norfolk Ridge | 0.26 | 60 | 0.19 | 110 |
| Lord Howe Rise** | 0.49 | N/A | 0.07 | 87 |
| Northwest Challenger | N/A | N/A | 0.13 | 170 |
| South Tasman Rise | N/A | N/A | 0.42 | N/A |

* An age-structured CPUE model for Louisville Central (Cordue 2017b) gave estimates of the lower 95% limits for depletion and yield intermediate between those of BDM and CAS models.

** The BDM fit for Lord Howe Rise included an implausibly high estimate of $r_{max}$ for orange roughy and the model was not considered useful.

## 5. FOR FURTHER INFORMATION

Anderson, O F (2006) A summary of biological information on the New Zealand fisheries for orange roughy (*Hoplostethus atlanticus*) for the 2003–04 fishing year. *New Zealand Fisheries Assessment Report 2006/16*. 25 p.

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Cordue, P L (2017a) Catch-history based stock assessments of seven SPRFMO orange roughy stocks. Paper SC05-DW14 for the Scientific Committee of the South Pacific Regional Fisheries Management Organisation, Shanghai, 23–28 August 2017.

Cordue, P L (2017b) A CPUE based stock assessment of the Louisville Central orange roughy stock. Paper SC05-INF03 for the Scientific Committee of the South Pacific Regional Fisheries Management Organisation, Shanghai, 23–28 August 2017.

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