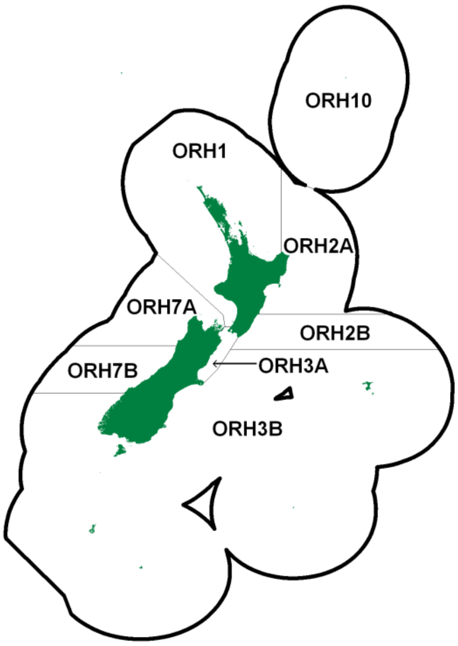
ORANGE ROUGHY (ORH)

(*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

Four new stock assessments were conducted in 2014: Mid-East Coast, Northwest Chatham Rise, East and South Chatham Rise, and Challenger Plateau. All assessments used similar methods and relied on the use of ageing data and recent acoustic surveys of spawning plumes. The methods, which were common to the assessments, 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from 23 to 31.5 years for fish from various New Zealand fishing grounds (Horn et al 1998, Seafood Industry Council/NIWA unpublished data).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_∞	36.4 cm	38.0 cm	-
- Northwest Chatham Rise	L_∞	-	-	37.78 cm
- East Chatham Rise	L_∞	-	-	37.78 cm
- Ritchie Bank	L_∞	-	-	37.63 cm
- Challenger Plateau	L_∞	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	σ_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 2016 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 2015 Aquatic Environment and Biodiversity Annual Review (www.mpi.govt.nz/document-vault/11521).

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 Bycatch (fish and invertebrates)

Anderson (2011) summarised the bycatch of orange roughy and oreo trawl fisheries from 1990–91 to 2008–09. For orange roughy trawls since 2005–06, orange roughy accounted for about 84% of the total observed catch and the remainder comprised mainly oreos (10%), hoki (0.4%), and cardinalfish (0.3%). About 240 other species or species groups were recorded by observers, including various deepwater dogfishes (1.8%), rattails (1.0%), morid cods (0.8%), and slickheads (0.3%). Total annual bycatch in the orange roughy fishery has been as high as 27 000 t but has declined with the TACC and was less than 4000 t between 2005–06 and 2008–09 (non-commercial species comprising only 5–10% of the total). Total annual discards also decreased over time, from about 3400 t in 1990–91 to about 300 t in 2007–08 and, since about 2000, has been almost entirely of non-QMS species (rattails, shovelnose spiny dogfish, and other deepwater dogfishes).

Invertebrate species are caught in low numbers in the orange roughy fishery (Anderson 2011). Squid (mostly warty squid, *Moroteuthis* spp.) were the largest component of invertebrate catch, followed by various groups of coral, echinoderms (mainly starfish), and crustaceans (mainly king crabs, family Lithodidae). 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)[1].

3.3.1 Marine mammal interactions

Deepwater trawlers targeting orange roughy, oreo and cardinalfish have occasionally incidentally captured NZ fur seals (which were classified as “Not Threatened” under the New Zealand Threat Classification System in 2010, Baker et al 2010). Between 2002–03 and 2014–2015, there were 15 observed captures of New Zealand fur seals in the orange roughy, oreo and cardinalfish trawl fisheries, (Table 4). Six of the observed fur seal captures occurred in the Sub-Antarctic region and one on the Chatham Rise. The average rate of capture for 2002–03 to 2012–15 is 0.07 per 100 tows (range 0 to 0.25), a very low rate compared with other New Zealand trawl fisheries by between one and two orders of magnitude.

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 2014–15. 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 Thompson et al (2013), available via http://www.fish.govt.nz/en-nz/Environmental/Seabirds/. Estimates from 2002–03 to 2013–14 are based on data version 2015001 and preliminary estimates for 2014–15 are based on data version 2016v1.

				Observed		Estimated		
	Tows	No.obs	%ob	Captures	Rate	Capture	95%c.i.	%inc.
2002–03	8 871	1 383	15.6	0	0	3	0–13	100
2003–04	8 006	1 262	15.8	2	0.16	6	2–20	100
2004–05	8 423	1 619	19.2	4	0.25	13	4–51	100
2005–06	8 293	1 360	16.4	2	0.15	8	2–27	100
2006–07	7 371	2 325	31.5	2	0.09	3	2–6	100
2007–08	6 730	2 812	41.8	4	0.14	7	4–17	100
2008–09	6 131	2 373	38.7	0	0	2	0–12	100
2009–10	6 011	2 135	35.5	0	0	2	0–10	100
2010–11	4 178	1 205	28.8	0	0	2	0–12	100
2011–12	3 655	922	25.2	0	0	1	0–8	100
2012–13	3 098	346	11.2	0	0	0	0–1	100
2013–14	3 607	434	12	0	0	0	0–4	100
2014–15†	3 786	978	25.8	1	0.1	-	-	-

† Provisional data, no model estimates available.

3.3.2 Seabird interactions

Annual observed seabird capture rates in the orange roughy, oreo and cardinalfish trawl fisheries have ranged from 0.00 to 1.24 per 100 tows between 2002–03 and 2014–15 (Table 5). The average capture

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[1] As part of its data reconciliation processes, MPI has identified that less than 2% of observed protected species captures between 2002 and 2015 were not recorded in Centralised Observer Database (COD). Steps are being taken to update the database and estimates of protected species captures and associated risks.

rate in deepwater trawl fisheries (including orange roughy, oreo and cardinalfish) for the period from 2002–03 to 2014–15 is about 0.25 birds per 100 tows, a very low rate relative to other New Zealand trawl fisheries, e.g. for scampi (4.64 birds per 100 tows) and squid (13.96 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 2014–15. 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 Thompson et al (2013) and available via http://www.fish.govt.nz/en-nz/Environmental/Seabirds/. Estimates from 2002–03 to 2013–14 are based on data version 2015001 and preliminary estimates for 2014–15 are based on data version 2016v1.

	Fishing effort			Observed captures		Estimated captures		
	Tows	No. obs	% obs	Captures	Rate	Mean	95% c.i.	% included
2002–03	8 871	1 383	15.6	0	0	39	23–58	100
2003–04	8 006	1 262	15.8	3	0.24	34	22–50	100
2004–05	8 423	1 619	19.2	20	1.24	74	54–97	100
2005–06	8 293	1 360	16.4	8	0.59	40	26–58	100
2006–07	7 371	2 325	31.5	1	0.04	20	10–31	100
2007–08	6 730	2 812	41.8	5	0.18	18	11–27	100
2008–09	6 131	2 373	38.7	8	0.34	23	15–32	100
2009–10	6 011	2 135	35.5	19	0.89	40	29–52	100
2010–11	4 178	1 205	28.8	2	0.17	25	14–38	100
2011–12	3 655	922	25.2	2	0.22	13	7–21	100
2012–13	3 098	346	11.2	2	0.58	22	13–34	100
2013–14	3 607	434	12	2	0.46	23	13–36	100
2014–15†	3 786	978	25.8	0	0	-	-	-

Salvin’s albatross was the most frequently captured albatross (50% of observed albatross captures, n=19) but seven different species have been observed captured since 2002–03. Cape petrels were the most frequently captured other taxon (41%, n=9 of non-albatross other birds, 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 2014–15, by species and area. The risk ratio is an estimate of aggregate potential fatalities across trawl and longline fisheries relative to the Potential Biological Removals, PBR (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 orange roughy. Other data, version 2016v01.

Species	**Risk Ratio**	**Chatham Rise**	**East Coast South Island**	**Fiordland**	**Sub-Antarctic**	**Stewart Snares Shelf**	**West Coast South Island**	**Total**
Salvin's albatross	Very high	13	3	0	3	0	0	19
Southern Buller's albatross	Very high	3	0	1	0	0	0	4
Chatham Island albatross	Very high	7	0	0	1	0	0	8
NZ White capped albatross	Very high	0	0	0	0	0	1	1
Gibson's albatross	High	1	0	0	0	0	0	1
Northern royal albatross	Medium	1	0	0	0	0	0	1
Southern royal albatross		1	0	0	0	0	0	1
Albatross	N/A	2	1	0	0	0	0	3
Total albatrosses	**N/A**	**28**	**4**	**1**	**4**	**0**	**1**	**38**
Cape petrel	High	8	1	0	0	0	0	9
Northern giant petrel	Medium	1	0	0	0	0	0	1
White chinned petrel	Medium	0	1	0	0	0	0	1
Grey petrel	Medium	1	0	0	1	0	0	2

Table 6 [Continued]

Species	Risk Ratio	Chatham Rise	East Coast South Island	Fiordland	Sub-Antarctic	Stewart Snares Shelf	West Coast South Island	Total
Sooty shearwater	Very low	0	3	0	0	0	0	3
Common diving petrel	-	2	0	0	0	0	0	2
White-faced storm petrel	-	2	0	0	0	0	0	2
Campbell black-browed albatross		1	0	0	0	0	0	1
Short-tailed shearwater	-	0	0	0	0	1	0	1
Total other birds	N/A	**15**	**5**	**0**	**1**	**1**	**0**	**22**

The deepwater trawl fisheries (including the orange roughy 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 0.082 and 0.032 of PBR$_{\text{rho}}$ (Table 7). Chatham albatross were assessed at high risk while the Salvin’s albatross at very high risk (Richard & Abraham 2015).

Table 7: Risk ratio of seabirds predicted by the level two risk assessment for the southern orange roughy fishery and all fisheries included in the level two risk assessment, 2006–07 to 2014–15, showing seabird species with a risk ratio of at least 0.001 of PBR$_{\text{rho}}$. The risk ratio is an estimate of aggregate potential fatalities across trawl and longline fisheries relative to the Potential Biological Removals, PBR$_{\text{rho}}$ (from Richard and Abraham 2015 where full details of the risk assessment approach can be found). The DOC threat classifications are shown (Robertson et al 2013 at http://www.doc.govt.nz/documents/science-and-technical/nztcs4entire.pdf).

	PBR$_{\text{rho}}$	Risk ratio			
Species name	**(mean)**	**SNA target bottom longline**	**TOTAL**	**Risk category**	**DOC Threat Classification**
Black petrel	100.3	0.003	10.951	Very high	Threatened: Nationally Vulnerable
Salvin's albatross	1024.6	0.032	3.384	Very high	Threatened: Nationally Critical
Southern Buller's albatross	449.3	0.001	1.683	Very high	At risk: Naturally Uncommon
Flesh-footed shearwater	513.9	0.001	1.380	Very high	Threatened: Nationally Vulnerable
Gibson's albatross	180.8	0.003	1.144	Very high	Threatened: Nationally Critical
New Zealand white-capped albatross	4044.8	0.002	1.078	Very high	At risk: Declining
Northern Buller's albatross	540.4	0.004	0.976	Very high	At risk: Naturally Uncommon
Antipodean albatross	136.5	0.005	0.786	High	Threatened: Nationally Critical
Chatham Island albatross	139.1	0.082	0.759	High	At risk: Naturally Uncommon
Northern giant petrel	164.4	0.007	0.145	Medium	At risk: Naturally Uncommon
Northern royal albatross	259.2	0.002	0.121	Medium	At risk: Naturally Uncommon
Southern royal albatross	386.6	0.002	0.066	Low	At risk: Naturally Uncommon

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

Orange roughy, oreo, and cardinalfish are taken using bottom trawls and accounted for about 14% of all tows reported on TCEPR forms to have been fished on close to the bottom between 1989–90 and 2004–05 (Baird et al 2011). Black et al (2013) estimated that, between 2006–07 and 2010–11, 98% of orange roughy catch was reported on TCEPR forms. Tows are located in Benthic Optimised Marine Environment Classification (BOMEC, Leathwick et al 2009) 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 1 200 m depth (Baird et al 2011). 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 (2012) 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.

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 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 2013 (MPI, 2013).

The NZ EEZ contains 17 Benthic Protection Areas (BPAs) that are closed to bottom trawl fishing and include about 52% of all seamounts over 1500 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 (1997) 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) although work is currently underway to generate one. 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. SUMMARY OF 2014 STOCK ASSESSMENTS

Stock assessments were undertaken for the Mid-east coast (MEC), Northwest Chatham Rise (NWCR), East and South Chatham Rise (ESCR) and ORH7A in 2014. In this section, the methods that were common to these four stock assessments are described and the main results are summarised.

4.1 Methods used in 2014

The methods used in 2014 were different from those used in previous orange roughy assessments in a number of respects. 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 threshold was imposed on data before they were used in an assessment. This resulted in the exclusion of a number 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).

Model structure was similar across the four assessed stocks. 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 a major contrast to earlier assessments where acoustic and egg survey estimates of spawning biomass were scaled up using estimates of transition-zone mature biomass before being used in an assessment. In the 2014 assessments, acoustic estimates of *spawning* biomass were used directly without scaling.

The use of age data was crucial to the success of the 2014 assessments. Model-based assessments of orange roughy stocks were abandoned in recent years because the model results were found to be insensitive to the 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. Age data were generally not used in these assessments because the (old) ageing methodology was considered unreliable, resulting in the unrealistic assumption of deterministic recruitment being used. This resulted in modelled biomass trajectories showing strong increasing trends as catches were scaled back but which were not supported by the fishery-independent abundance indices. The new ageing methodology (Tracey et al. 2007) has provided more reliable age data, which in turn has led to the abandonment of the deterministic recruitment assumption and models that fit trends in recent abundance indices.

4.1.2 Acoustic *q* priors

The major sources of recent abundance information in the models are 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 survey availability.

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 an excellent fit to the abundance indices at the MPD stage and an adequate fit at the MCMC stage. The YCS estimates were primarily driven by the composition data (age and length frequencies), but if they unduly penalised, the estimates are restricted to a space which does not allow the trawl biomass indices to be fitted well. In the 2014 assessments a "nearly uniform" prior was used with the Haist parameterisation: LN(mode = 1, log-space s.d. = 4).

4.1.4 Model runs

As far as was appropriate, a consistent set of sensitivity runs was conducted for each assessment. 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 importance 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 force 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,

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[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.

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 random YCSs were brought in 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.

4.2 Summary of 2014 stock assessment results

The main results of the 2014 stock assessments are summarised below: these include estimated natural mortality, maturity ogive parameter estimates, year class strength, virgin biomass, and stock status; deterministic B_{MSY} and MSY, and deterministic long-term yields at $U_{35\%B0}$ (35% B_0 being the mid-point of the target biomass range).

For each of the four stock assessments the median estimate of natural mortality (*M*) from the "EstM" model was lower than the assumed value in the base model of 0.045 (Table 8). This was despite a fairly tight informed prior on *M* with a mean of 0.045 and CV=0.15. In each stock assessment there appears to be very little information in the data on the value of *M*; this information can only come from the right-hand limb of age frequencies, where the relative proportion of old fish is related to *M*, but it is also confounded by fishing mortality, selectivity, and year class strength. It seems premature to move to a new value of *M* for the base models. However, as more age data are gathered the estimates of *M* may improve.

Table 8: Estimates of natural mortality for each stock assessed in 2014. These are MCMC estimates from the "EstM" models which are identical to the base models except that *M* is estimated using an informed prior N(mean = 0.045, CV = 0.15)

Stock	*M* (median)	95% CI
NWCR	0.041	0.033–0.051
ESCR	0.037	0.027–0.048
MEC	0.032	0.028–0.037
ORH7A	0.038	0.031–0.047

Estimates of the 50% maturity parameter (a_{50}) for the four stocks range from 32–41 years (Table 9). This is considerably older than the estimates of transition-zone maturity which range from 23–33 years (see Table 2). The slopes of the estimated maturity curves are also much shallower than those for transition-zone maturity (10–13 years from Table 9 compared to 3–7 years in Table 2).

Table 9: Base model, median MCMC estimates of maturity for each stock assessed in 2014. a_{50} is the age, in the virgin population, at which 50% of the fish are mature; a_{to95} is the number of years that need to be added to a_{50} to get the age at which 95% of the fish are mature.

Stock	a_{50} (years)	a_{to95} (years)
NWCR	37	13
ESCR	41	12
MEC	35	10
ORH7A	32	10

There were some similarities in the estimates of year class strength (YCS) across the four stocks (Figure 1). The MEC assessment used the most age data and therefore it had the largest number of YCS estimated. Early YCS were generally estimated to be above average and recent YCS estimated to be below average. This same pattern was evident for ORH7A and ESCR (though over a shorter duration and of slightly lesser magnitude – see Figure 1). The NWCR was the only assessment where the pattern of recruitment was consistent with average (deterministic) recruitment (Figure 1).

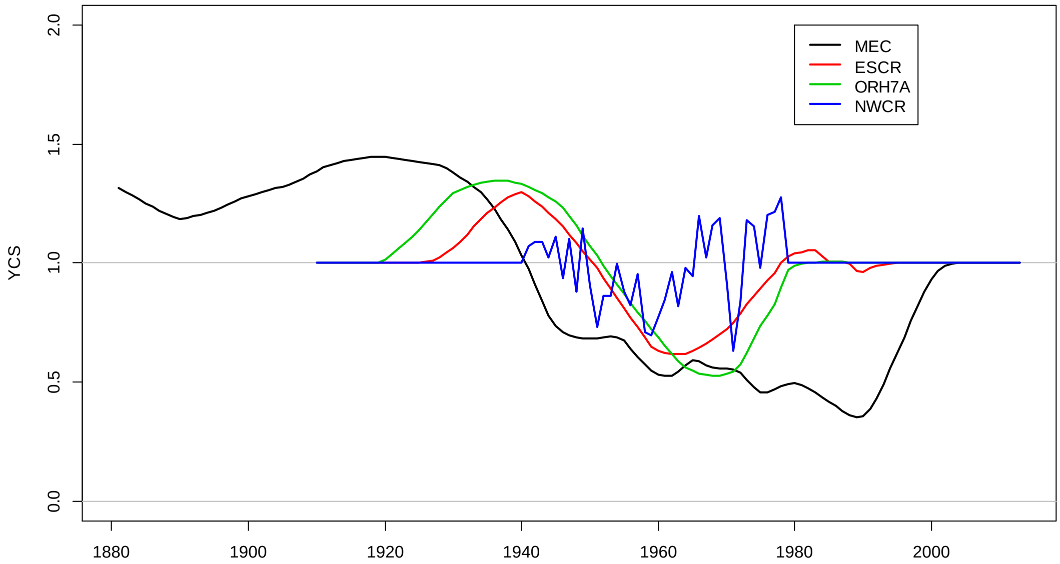

Figure 1: MCMC base models: smoothed (where possible) median estimates of year class strength (YCS) for the four stocks assessed in 2014. A lowess smoother (f = 0.15) was applied to the MCMC median estimates for each cohort.

The estimated size of the four stocks varies considerably for both virgin and current biomass (Table 10). The ESCR stock had by far the largest virgin biomass, B_0, estimated at over 300 000 t while the other stocks are smaller, with estimates of less than 100,000 t (Table 10). In terms of current biomass, three of the four stocks have median current biomass estimates within the 30–40% B_0 target range (Table 10, Figure 2). The fourth stock, the MEC stock, has a median estimate below the soft limit of 20% B_0.

Table 10: Base case models, median MCMC estimates of virgin biomass (B_0), current biomass (B_{2014}) and current stock status (B_{2014}/B_0).

Stock	B_0 (000 t)	B_{2014} (000 t)	B_{2014} (%B_0)
NWCR	66	24	37
ESCR	320	93	30
MEC	95	14	14
ORH7A	88	37	42

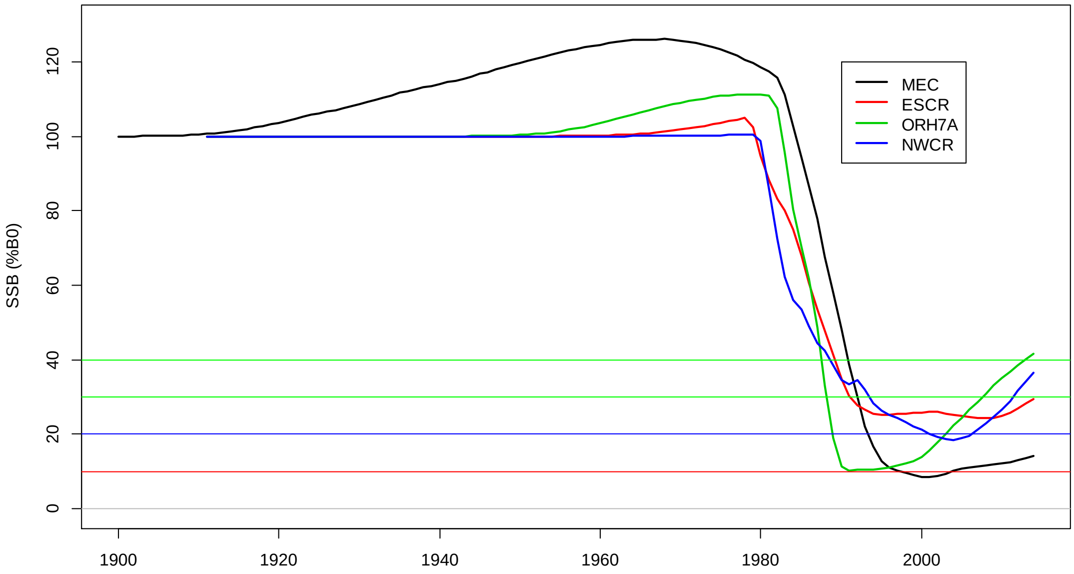

Figure 2: MCMC base models: median estimates of stock status trajectory for the four stocks assessed in 2014. The biomass target range of 30–40% B_0 is shown by green lines, and the soft and hard limits by blue and red line respectively.

For each assessment, long-term deterministic projections were conducted for each posterior sample to determine the ESD and yield curves as a function of fishing intensity. This enabled estimation of deterministic reference points and yields (Table 11). Deterministic estimates of B_{MSY} are similar for all four stocks, falling within in the range 21.5–24.5% B_0 (Table 11). In each case, the expectation is that very little yield will be is lost if the equilibrium biomass level increases from deterministic B_{MSY} to 35% B_0 (the mid-point of the biomass target range). The estimated long-term yields when fishing at U_{35} (the fishing intensity that forces the stock to deterministic equilibrium at 35% B_0) range from 1300–2100 t for the smaller stocks and is 7180 t for the ESCR stock (Table 11). These yield estimates are unrealistic in that they are derived using deterministic recruitment and maintaining an exact level of fishing intensity. More realistic estimates of long-term yield, such as those derived from a management strategy evaluation, would likely be lower.

Table 11: Base model, median MCMC estimates of deterministic B_{MSY}, MSY, deterministic long-term yield at $U_{35\%B0}$, and the exploitation rate corresponding to $U_{35\%B0}$.

Stock	B_{MSY} (%B_0)	MSY (%B_0)	$U_{35\%B0}$ yield (%B_0)	$U_{35\%B0}$ exploitation rate (%)	$U_{35\%B0}$ long-term yield (t)
NWCR	23.7	2.1	2.0	5.3	1320
ESCR	21.8	2.4	2.3	5.3	7180
MEC	22.5	2.3	2.2	5.1	2080
ORH7A	24.5	2.1	2.0	5.4	1740

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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