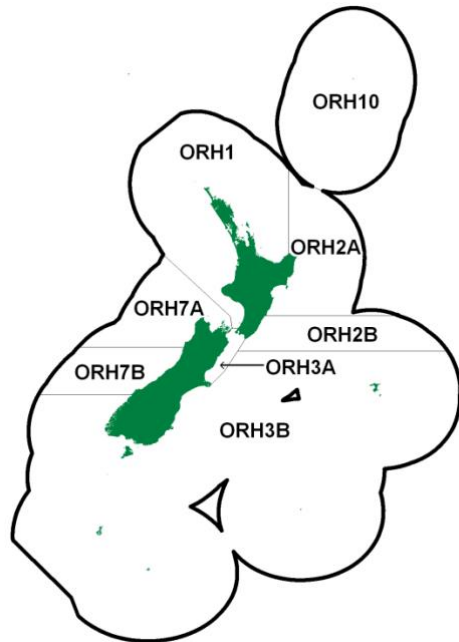


ORANGE ROUGHY (ORH)*(Hoplostethus atlanticus)***1. INTRODUCTION**

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.

ORANGE ROUGHY (ORH)

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from 23 to 31.5 years for fish from various New Zealand fishing grounds (Horn et al 1998, Seafood Industry Council/NIWA unpublished data).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

ORANGE ROUGHY (ORH)

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	$S_r(a_{1095})$	-	-	= S_m
Age at maturity	$A_m(a_{50})$	-	-	Table 2
Gradual maturity	$S_m(a_{1095})$	-	-	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.

Area	A_m			S_m		
	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

ORANGE ROUGHY (ORH)

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>).

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 4 000 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).

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 2015–16 are based on data version 2017v1.

	Tows	No.obs	%ob	Observed		Estimated	
				Captures	Rate	Capture	95% c.i.
2002–03	8 870	1 383	15.6	0	0	3	0–11
2003–04	8 007	1 262	15.8	2	0.2	7	2–23
2004–05	8 419	1 619	19.2	4	0.2	11	4–35
2005–06	8 294	1 361	16.4	2	0.1	8	2–27
2006–07	7 372	2 326	31.6	2	0.1	3	2–7
2007–08	6 728	2 811	41.8	5	0.2	8	5–17
2008–09	6 133	2 374	38.7	0	0	3	0–14
2009–10	6 013	2 135	35.5	0	0	2	0–12
2010–11	4 182	1 206	28.8	0	0	2	0–12
2011–12	3 655	923	25.3	0	0	2	0–9
2012–13	3 097	345	11.1	0	0	0	0–1
2013–14	3 611	435	12	0	0	0	0–2
2014–15	3 811	961	25.2	1	0.1	1	1–2
2015–16	4 085	1 367	33.5	0	0	0	0–2
2016–17	3 971	1 226	30.9	0	0		

ORANGE ROUGHY (ORH)

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 2015–16 are based on data version 2017v1.

	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	29	15–48
2003–04	8 007	1 262	15.8	3	0.2	28	16–45
2004–05	8 419	1 619	19.2	7	0.4	48	29–74
2005–06	8 294	1 361	16.4	8	0.6	34	21–51
2006–07	7 372	2 326	31.6	1	0	17	8–28
2007–08	6 728	2 811	41.8	7	0.2	19	12–29
2008–09	6 133	2 374	38.7	7	0.3	20	12–30
2009–10	6 013	2 135	35.5	19	0.9	36	27–49
2010–11	4 182	1 206	28.8	1	0.1	15	6–27
2011–12	3 655	923	25.3	2	0.2	11	5–19
2012–13	3 097	345	11.1	2	0.6	13	6–23
2013–14	3 611	435	12	2	0.5	14	6–24
2014–15	3 811	961	25.2	0	0	13	5–24
2015–16	4 085	1 367	33.5	4	0.3	12	6–20
2016–17	3 971	1 226	30.9	2	0.2		

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

ORANGE ROUGHY (ORH)

albatross

Total albatrosses - 30 4 1 4 0 1 40

ORANGE ROUGHY (ORH)

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/nztes19entire.pdf>).

Species name	PST (mean)	Risk ratio		Risk category	DOC Threat Classification
		ORH, OEO, CDL target trawl	TOTAL		
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 baffle” 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 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 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 (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 ASSESSMENTS¹

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 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

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>)

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 plume², 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 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%

²For 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.

ORANGE ROUGHY (ORH)

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 $U_{x\%B_0}$. 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 $U_{x\%B_0}$ 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 $U_{x\%B_0}$ 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 $U_{35\%B_0}$ (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.

6. FOR FURTHER INFORMATION

- Abraham, E R; Richard, Y (2017) Summary of the capture of seabirds in New Zealand commercial fisheries, 2002–03 to 2013–14. *New Zealand Aquatic Environment and Biodiversity Report* No. 184. 88 p.
- Abraham, E R; Richard, Y (2018) Estimated capture of seabirds in New Zealand trawl and longline fisheries, 2002–03 to 2014–15. *New Zealand Aquatic Environment and Biodiversity Report* No. 197. 97 p.
- Abraham, E R; Richard, Y; Berkenbusch, K; Thompson, F (2016) Summary of the capture of seabirds, marine mammals, and turtles in New Zealand commercial fisheries, 2002–03 to 2012–13. *New Zealand Aquatic Environment and Biodiversity Report* No. 169. 205 p.
- Abraham, E R; Thompson, F N (2011) Summary of the capture of seabirds, marine mammals, and turtles in New Zealand commercial fisheries, 1998–99 to 2008–09. *New Zealand Aquatic Environment and Biodiversity Report* No. 80.
- Abraham, E R; Thompson, F N; Berkenbusch, K (2013) Estimated capture of seabirds in New Zealand trawl and longline fisheries, 2002–03 to 2010–11. Final Research Report for Ministry for Primary Industries project PRO2010-01 (Unpublished report held by Fisheries New Zealand, Wellington).
- Abraham, E R; Thompson, F N; Oliver, M D (2010) Summary of the capture of seabirds, mammals, and turtles in New Zealand commercial fisheries, 1998–99 to 2007–08. *New Zealand Aquatic Environment and Biodiversity Report* No.45. 149 p.
- Anderson, O F (2011) Fish and invertebrate bycatch and discards in orange roughy and oreo fisheries from 1990–91 until 2008–09. *New Zealand Aquatic Environment and Biodiversity Report* No. 67.
- Anderson, O F; Dunn, M R (2007) Descriptive analysis of catch and effort data from New Zealand orange roughy fisheries in ORH 1, 2A, 2B, 3A, 3B and 7B to the end of the 2004–05 fishing year. *New Zealand Fisheries Assessment Report 2007/29*. 71 p.
- Anderson, O F; Gilbert, D J; Clark, M R (2001) Fish discards and non-target catch in the trawl fisheries for orange roughy and hoki in New Zealand waters for the fishing years 1990–91 to 1998–99. *New Zealand Fisheries Assessment Report 2001/16*. 57 p.
- Andrews, A H; Tracey, D M (2003) Age validation of orange roughy, oreos, and black cardinalfish. Final Research Report for Ministry of Fisheries Research Project DEE2000/02. 25 p. (Unpublished report held by Fisheries New Zealand, Wellington.)
- Baird, S J (2004a) Estimation of the incidental capture of seabird and marine mammal species in commercial fisheries in New Zealand waters, 1999–2000. *New Zealand Fisheries Assessment Report 2004/41*. 56 p.
- Baird, S J (2004b) Incidental capture of seabird species in commercial fisheries in New Zealand waters, 2000–01. *New Zealand Fisheries Assessment Report 2004/58*. 63 p.
- Baird, S J (2004c) Incidental capture of seabird species in commercial fisheries in New Zealand waters, 2001–02. *New Zealand Fisheries Assessment Report 2004/60*. 51 p.
- Baird, S J (2005) Incidental capture of seabird species in commercial fisheries in New Zealand waters, 2002–03. *New Zealand Fisheries Assessment Report 2005/2*. 50 p.
- Baird, S J; Smith, M H (2007) Incidental capture of New Zealand fur seals (*Arctocephalus forsteri*) in commercial fisheries in New Zealand waters, 2003–04 to 2004–05. *New Zealand Aquatic Environment and Biodiversity Report* No. 14. 98 p.
- Baird, S J; Tracey, D; Mormede, S; Clark, M (2012) The distribution of protected corals in New Zealand waters DOC12303 / POP2011-06. NIWA Client Report No: WLG2012-43. Prepared for Marine Conservation Services, Department of Conservation and Te Papa Atawhai 93 p. <http://www.doc.govt.nz/conservation/marine-and-coastal/commercial-fishing/conservation-services-programme/meetings-and-project-updates/27-november-2012/>
- Baird, S J; Wood, B A (2012) Extent of coverage of 15 environmental classes within the New Zealand EEZ by commercial trawling with seafloor contact. *New Zealand Aquatic Environment and Biodiversity Report* 89. 43 p.
- Baird, S J; Wood, B A; Bagley, N.W. (2011) Nature and extent of commercial fishing effort on or near the seafloor within the New Zealand 200 n. mile Exclusive Economic Zone, 1989–90 to 2004–05. *New Zealand Aquatic Environment and Biodiversity Report* 73. 143 p.
- Baker, C S; Chilvers, B L; Constantine, R; DuFresne, S; Mattlin, R H; van Helden, A; Hitchmough, R (2010) Conservation status of New Zealand marine mammals (suborders *Cetacea* and *Pinnipedia*), 2009. *New Zealand Journal of Marine and Freshwater Research* 44: 101–115.
- Baker, C S; Chilvers, B L; Childerhouse, S; Constantine, R; Currey, R; Mattlin, R; van Helden, A; Hitchmough, R; Rolfe, J (2010) Conservation status of New Zealand marine mammals 2013. *New Zealand Threat Classification Series 14*. Department of Conservation. 22 p.
- Ballara, S L; Anderson, O F (2009) Fish discards and non-target fish catch in the trawl fisheries for arrow squid and scampi in New Zealand waters. *New Zealand Aquatic Environment and Biodiversity Report* No. 38. 102 p.
- Black, J; Wood, R; Berthelsen, T; Tilney, R (2013) Monitoring New Zealand's trawl footprint for deepwater fisheries: 1989–1990 to 2009–2010. *New Zealand Aquatic Environment and Biodiversity Report* No. 110. 57 p.
- Brothers, N; Duckworth, A R; Safina, C; Gilman, E L (2010) Seabird bycatch in pelagic longline fisheries is grossly underestimated when using only haul data. *PLoS One* 5: e12491. doi: 10.1371/journal.pone.001249
- Bull, B; Francis, R I C C; Dunn, A; Gilbert, D J; Bian, R; Fu, D (2012) CASAL (C++ algorithmic stock assessment laboratory): CASAL User Manual v2.30-2012/03/21. *NIWA Technical Report 135*. 280 p.
- Bulman, C M; Koslow, J A (1992). Diet and food consumption of a deep-sea fish, orange roughy *Hoplostethus atlanticus* (Pisces: Percichthyidae), of southeastern Australia. *Marine Ecology Progress Series* 82, 115–129.
- Clark, M R (1999) Fisheries for orange roughy (*Hoplostethus atlanticus*) on seamounts in New Zealand. *Oceanologica Acta* 22(6): 593–602.
- Clark, M R (2006) Descriptive analysis of orange roughy fisheries in the New Zealand region outside the EEZ: Lord Howe Rise, Northwest Challenger Plateau, West Norfolk Ridge, South Tasman Rise, and Louisville Ridge to the end of the 2004–05 fishing year. *New Zealand Fisheries Assessment Report 2006/56*. 38 p.
- Clark, M R (2008) Descriptive analysis of orange roughy fisheries in the New Zealand region outside the EEZ: Lord Howe Rise, northwest Challenger Plateau, west Norfolk Ridge, south Tasman Rise and Louisville Ridge to the end of the 2005–06 fishing year. *New Zealand Fisheries Assessment Report 2008/12*. 45 p.
- Clark, M R; Anderson, O F; Francis, R I C C; Tracey, D M (2000) The effects of commercial exploitation on orange roughy (*Hoplostethus atlanticus*) from the continental slope of the Chatham Rise, New Zealand, from 1979 to 1997. *Fisheries Research*, 45(3), 217–238.
- Clark, M R; Fincham, D J; Tracey, D M (1994) Fecundity of orange roughy (*Hoplostethus atlanticus*) in New Zealand waters. *New Zealand Journal of Marine and Freshwater Research* 28: 193–200.
- Clark, M; O'Driscoll, R (2003) Deepwater fisheries and aspects of their impact on seamount habitat in New Zealand. *Journal of Northwest Atlantic Fisheries Science* 31: 441–458.
- Clark, M R; Rowden, A A (2009) Effect of deepwater trawling on the macro-invertebrate assemblages of seamounts on the Chatham Rise, New Zealand. *Deep Sea Research Part I: Oceanographic Research Papers*, 56(9), 1540–1554.
- Cordue, P L (2014) A Management Strategy Evaluation for orange roughy. ISL Client Report for Deepwater Group. (Unpublished report held by Fisheries New Zealand, Wellington.)
- Department of Internal Affairs (2006) Seabird Scaring Devices – Circular Issued Under Authority of the Fisheries (Commercial Fishing) Amendment Regulations 2006 (No. F361). *New Zealand Gazette* 6 April 2006 : 842–846.
- Doonan, I J (1994) Life history parameters of orange roughy; estimates for 1994. New Zealand Fisheries Assessment Research Document: 1994/19. 14 p. (Unpublished document held in NIWA library, Wellington.)
- Doonan, I J; Dunn, M R (2011) Trawl survey of Mid-East Coast orange roughy, March-April 2010. *New Zealand Fisheries Assessment Report*

ORANGE ROUGHY (ORH)

2011/20. 62 p.

- Doonan, I J; Francis, R I C C; Horn, P; Tracey, D M (1998) Update of biological parameters for orange roughy. Report to Deepwater Stock Assessment Working Group, 98/16. (Unpublished report held by Fisheries New Zealand, Wellington.)
- Doonan, I J; Tracey, D M (1997) Natural mortality estimates for orange roughy in ORH 1 (Bay of Plenty). New Zealand Fisheries Assessment Research Document 1997/26. 9 p. (Unpublished document held in NIWA library, Wellington.)
- Dunn, M R; Forman, J S (2011) Hypotheses of spatial stock structure in orange roughy *Hoplostethus atlanticus* inferred from diet, feeding, condition, and reproductive activity. *PLoS ONE* 6(11): e26704.
- Dunn, M R; Rickard, G J; Sutton, P J H; Doonan, I J (2009) Nursery grounds of the orange roughy around New Zealand. *ICES Journal of Marine Science* 66: 871–885.
- Dunn, M R; Stevens, D W; Forman, J S; Connell, A (2013) Trophic Interactions and Distribution of Some Squaliforme Sharks, Including New Diet Descriptions for *Deania calcea* and *Squalus acanthias*. *PLoS ONE* 8(3):e59938. doi:10.1371/journal.pone.0059938
- Dunn, M R; Szabo, A; McVeagh, M S; Smith, P J (2010) The diet of deepwater sharks and the benefits of using DNA identification of prey. *Deep-Sea Research I* 57 923–930.
- Francis, M P; Hurst, R J; McArdle, B H; Bagley, N W; Anderson, O F (2002) New Zealand demersal fish assemblages. *Environmental Biology of Fishes*, 65(2), 215–234.
- Francis, R I C C (1992) Recommendations concerning the calculation of maximum constant yield (MCY) and current annual yield (CAY). New Zealand Fisheries Assessment Research Document 1992/8. 27 p. (Unpublished document held in NIWA library, Wellington.)
- Francis, R I C C; Horn, P L (1997) The transitions zone in otoliths of orange roughy (*Hoplostethus atlanticus*) and its relationship to the onset of maturity. *Marine Biology* 129: 681–687.
- Francis, R I C C; Robertson, D A; Clark, M R; Doonan, I J; Coburn, R P; Zeldis, J R (1993) Assessment of the ORH 3B orange roughy fishery for the 1993/94 fishing year. New Zealand Fisheries Assessment Research Document 1993/7. 44 p. (Unpublished document held in NIWA library, Wellington.)
- Gaskin, D E; Cawthorn, M W (1967) Diet and feeding habits of the sperm whale (*Physeter catodon* L.) in the Cook Strait region of New Zealand. *New Zealand Journal of Marine and Freshwater Research* 1: 156–179.
- Hallet, C S; Daley, R K (2011) Feeding ecology of the southern lanternshark (*Etmopterus baxteri*) and the brown lanternshark (*E. unicolor*) off southeastern Australia. *ICES Journal of Marine Science* 68: 157–165.
- Hermesen, J M; Collie, J S; Valentine, P C (2003) Mobile fishing gear reduces benthic megafaunal production on Georges Bank. *Marine Ecology Progress Series* 260: 97–108.
- Hicks, A C (2006) Growth, length-weight, and maturity estimates for the Northeast Chatham Rise. WG-Deepwater-06/13. (Unpublished report held by Fisheries New Zealand, Wellington.)
- Hiddink, J G; Jennings, S; Kaiser, M J; Queiros, A M; Duplisea, D E; Piet, G J (2006) Cumulative impacts of seabed trawl disturbance on benthic biomass, production, and species richness in different habitats. *Canadian Journal of Fisheries and Aquatic Sciences* 63:721–36.
- Hilborn, R; Walters, C J (1992) *Quantitative fisheries stock assessment: choice, dynamics, and uncertainty*. Chapman and Hall, New York, 570 p.
- Horn, P L; Tracey, D M; Clark, M R (1998) Between-area differences in age and length at first maturity of orange roughy (*Hoplostethus atlanticus*). *Marine Biology* 132 (2): 187–194.
- Horn, P L; Tracey, D M; Doonan, I J; Krusic-Golub, K (2016) Age determination protocol for orange roughy (*Hoplostethus atlanticus*). *New Zealand Fisheries Assessment Report 2016/03*. 30 p.
- Jennings, S; Dinmore, T A; Duplisea, D E; Warr, K J; Lancaster, J E (2001) Trawling disturbance can modify benthic production processes. *Journal of Animal Ecology*, 70: 459–475.
- Jereb, P; Roper, C F E (2010) (eds) *Cephalopods of the world. An annotated and illustrated catalogue of cephalopod species known to date. Volume 2. Myopsid and Oegopsid Squids. FAO Species Catalogue for Fishery Purposes. No. 4, Vol. 2*. Rome, FAO. 2010. 605 p.
- Kloser, R J; Macaulay, G J; Ryan, T E; Lewis, M (2013) Identification and target strength of orange roughy (*Hoplostethus atlanticus*) measured in situ. *Journal of the Acoustical Society of America*, 134: 97–108.
- Koslow, J A (1997) Seamounts and the Ecology of Deep-sea Fishes. *American Scientist*. Vol. 85. 168–176.
- Leathwick, J R; Rowden, A; Nodder, S; Gorman, R; Bardsley, S; Pinkerton, M; Baird, S J; Hadfield, M; Currie, K; Goh, A (2012) Benthic-optimised marine environment classification for New Zealand waters. *New Zealand Aquatic Environment and Biodiversity Report No. 88*. 54 p.
- Macaulay, G J; Kloser, R J; Ryan, T E (2013) *In situ* target strength estimates of visually verified orange roughy. *ICES Journal of Marine Science*, 70: 215–222.
- Mace, P M; Fenaughty, J F; Coburn, R P; Doonan, I J (1990) Growth and productivity of orange roughy (*Hoplostethus atlanticus*) on the north Chatham Rise. *New Zealand Journal of Marine and Freshwater Research* 24: 105–119.
- MacKenzie, D; Fletcher, D (2006) Characterisation of seabird captures in commercial trawl and longline fisheries in New Zealand 1997/98 to 2003/04. Final Research Report for Ministry of Fisheries project ENV2004/04. (Unpublished report held by Fisheries New Zealand, Wellington.) 102 p.
- Middleton, D A J; Abraham, E R (2007) The efficacy of warp strike mitigation devices: Trials in the 2006 squid fishery. Final Research Report for Ministry of Fisheries project IPA2006/02. (Unpublished report held by Fisheries New Zealand, Wellington.)
- Morgan, M J; Wilson, C E; Crim, L W (1999) The effect of stress on reproduction in Atlantic cod. *Journal of Fish Biology*, 54(3), 477–488.
- MPI (2013) Aquatic Environment and Biodiversity Annual Review 2013. Compiled by the Fisheries Management Science Team, Ministry for Primary Industries, Wellington, New Zealand. 538 p.
- O'Driscoll, R L; Booth, J D; Bagley, N W; Anderson, O F; Griggs, L H; Stevenson, M L; Francis, M P (2003) Areas of importance for spawning, pupping or egg-laying, and juveniles of New Zealand deepwater fish, pelagic fish, and invertebrates. *NIWA Technical Report* 119. 377 p.
- O'Driscoll, R L; MacGibbon, D; Fu, D; Lyon, W; Stevens, D W (2011) A review of hoki and middle depth trawl surveys of the Chatham Rise, January 1992–2010. *New Zealand Fisheries Assessment Report 2011/47*. 814 p.
- Pankhurst, N W (1988) Spawning dynamics of orange roughy, *Hoplostethus atlanticus*, in mid-slope waters of New Zealand. *Environmental biology of fishes* 21: 101–116.
- Paul, L J; Tracey, D M; Francis, R I C C (2002) Age validation of deepwater fish species, with particular reference to New Zealand orange roughy and oreos: a literature review. Final Research Report for Ministry of Fisheries Research Project DEE200002. 33 p. (Unpublished report held by Fisheries New Zealand, Wellington)
- Ramm, K (2012) Conservation Services Programme Observer Report: 1 July 2010 to 30 June 2011. FINAL REPORT. Conservation Services Programme, Department of Conservation, November 2012. (Unpublished report held by Department of Conservation, Wellington.)
- Reiss, H, Greenstreet, S P R, Siebe, K, Ehrlich, S, Piet, G J, Quirijns, F, Robinson, L, Wolff, W J, Kronke, I (2009) Effects of fishing disturbance on benthic communities and secondary production within an intensely fished area. *Marine Ecology Progress Series* 394:201–213.
- Rice, J (2006) Impacts of Mobile Bottom Gears on Seafloor Habitats, Species, and Communities: A Review and Synthesis of Selected International Reviews. *Canadian Science Advisory Secretariat Research Document 2006/057*. 35 p. (available from http://www.dfo-mpo.gc.ca/CSAS/Csas/DocREC/2006/RES2006_057_e.pdf).

ORANGE ROUGHY (ORH)

- Richard, Y; Abraham, E R (2013) Risk of commercial fisheries to New Zealand seabird populations. *New Zealand Aquatic Environment and Biodiversity Report* No. 109. 58 p.
- Richard, Y; Abraham, E R (2015) Assessment of the risk of commercial fisheries to New Zealand seabirds, 2006–07 to 2012–13. *New Zealand Aquatic Environment and Biodiversity Report* 162. 85 p.
- Richard, Y; Abraham, E R; Berkenbusch, K (2017) Assessment of the risk of commercial fisheries to New Zealand seabirds, 2006–07 to 2014–15. *New Zealand Aquatic Environment and Biodiversity Report* 191. 133 p.
- Robertson, H A; Baird, K; Dowding, J E; Elliott, G P; Hitchmough, R A; Miskelly, C M; McArthur, N; O'Donnell, C F J; Sagar, P M; Scofield, R P; Taylor, G A (2017) Conservation status of New Zealand birds, 2016. *New Zealand Threat Classification Series* 19. Department of Conservation, Wellington.
- Rossechi, E; Tracey, D M; Weber, W R (1988) Diet of orange roughy, *Hoplostethus atlanticus* (Pisces: Trachichthyidae), on the Challenger Plateau, New Zealand. *Marine Biology* 99: 293–306.
- Stevens, D W; Hurst, R J; Bagley, N W (2011) Feeding habits of New Zealand fishes: a literature review and summary of research trawl database records 1960 to 2000. *New Zealand Aquatic Environment and Biodiversity Report* No. 85.
- Thompson, F N; Abraham, E R; Oliver, M D (2010). Estimation of fur seal bycatch in New Zealand sea lions trawl fisheries, 2002–03 to 2007–08. *New Zealand Aquatic Environment and Biodiversity Report* No. 56. 29 p.
- Thompson, F N; Berkenbusch, K; Abraham, E R (2013) Marine mammal bycatch in New Zealand trawl fisheries, 1995–96 to 2010–11. *New Zealand Aquatic Environment and Biodiversity Report* No. 105. 73 p.
- Tracey, D M; McMillan, P J; Armstrong, J M; Banks, D A (1990) Orange roughy trawl survey: Challenger Plateau and west coast South Island, 1983. *New Zealand Fisheries Technical Report* No. 22. 34 p.
- Tracey, D; Baird, S J; Sanders, B M; Smith, M H (2011) Distribution of protected corals in relation to fishing effort and assessment of accuracy of observer identification. NIWA Client Report No: WLG2011-33 prepared for Department of Conservation, Wellington. 74 p.
- Tracey, D; Clark, M; Bull, B; Mackay, K (2004) Fish species composition on seamounts and adjacent slope in New Zealand waters. *New Zealand Journal of Marine and Freshwater Research* 38: 163–182.
- Tracey, D M; Clark, M R; Anderson, O F; Kim, S W (2012) Deep-Sea Fish Distribution Varies between Seamounts: Results from a Seamount Complex off New Zealand. *PLoS ONE* 7(6): e36897. [oi:10.1371/journal.pone.0036897](https://doi.org/10.1371/journal.pone.0036897)
- Tracey, D M; Horn, P L (1999) Background and review of ageing orange roughy (*Hoplostethus atlanticus*, Trachichthyidae) from New Zealand and elsewhere. *New Zealand Journal of Marine and Freshwater Research* 33: 67–86.
- Tracey, D; Horn, P; Marriott, P; Krusic-Golub, K; Gren, C; Gili, R; Mieres L C (2007). Orange Roughy Ageing Workshop: otolith preparation and interpretation. Draft report to DWFAWG.
- Tuck, I; Cole, R; Devine, J (2009) Ecosystem indicators for New Zealand fisheries. *New Zealand Aquatic Environment and Biodiversity Report* No. 42. 188 p.
- Williams, A; Schlacher, T A; Rowden, A A; Althaus, F; Clark, M R; Bowden, D A; Stewart, R; Bax, N J; Consalvey, M; Kloser, R J (2010) Seamount megabenthic assemblages fail to recover from trawling impacts. *Marine Ecology*, 31: 183–199.
- Zeldis, J R; Grimes, P J; Ingerson, J K V (1994) Ascent rates, vertical distribution, and a thermal history model of development of orange roughy (*Hoplostethus atlanticus*) eggs in the water column. *Fishery Bulletin (United States)* 93: 373–385.