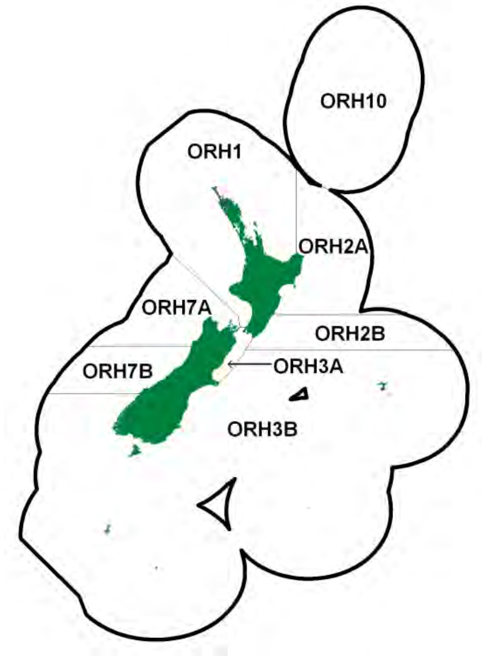
INTRODUCTION – ORANGE ROUGHY (ORH)

(*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 stocks or subareas
4. Challenger Plateau (ORH 7A)
5. West coast South Island (ORH 7B)
6. Outside the EEZ
    - Lord Howe
    - Northwest Challenger
    - North, Central, and Southern Louisville stocks
    - West Norfolk
    - South Tasman

Recent orange roughy stock assessments have been conducted for the Mid-East Coast (2022), East and South Chatham Rise (2020), Northwest Chatham Rise (2018) and Puysegur (2017), Challenger Plateau (2019), and West coast South Island (a preliminary assessment in 2020). These assessments used a generally similar approach, with the preferred method for monitoring stock biomass being acoustic surveys of spawning plumes. The methods common to these assessments are described later in this introduction.

2. BIOLOGY

Orange roughy inhabit depths between about 700 m and 1500 m within the New Zealand EEZ. They are most abundant between about 800 m and 1200 m. Their maximum depth range is less well known. Knowledge of orange roughy biology and fisheries was most recently reviewed by Tingley & Dunn (2018).

Orange roughy are slow-growing, long-lived fish. On the basis of otolith ring counts and radiometric isotope studies, orange roughy may live to at least 100 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 et al. (2009).

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). 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. 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 varies among assumed stocks. 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 northwest coast of the North Island and 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 may be 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. Early juveniles have been found in large numbers in only one area to date, at a depth of 800–900 m about 150 km east of the main spawning ground on the north Chatham Rise. Larger juveniles are widespread and have been caught by bottom trawls around most of New Zealand (Dunn et al., 2009).

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 (0.037 yr^{-1}) was obtained from a lightly fished population in the Bay of Plenty in 1996.

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 by Hicks (2006), and for the Mid-East Coast 2022 assessment (Dunn, pers.comm.).

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; Horn et al., 2016). In stock assessments since 2014, 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 are not used in current stock assessments as maturity was estimated in each of the models.

Table 1: Biological parameters as used for orange roughy assessments. -, not estimated. Fish length is standard length.

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
- Mid-East Coast	L_∞	36.8 cm	39.0 cm	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}
- Mid-East Coast	k	0.059	0.053	0.065 yr^{-1}
- All areas (default)	t_0	-0.4 yr	-0.6 yr	-
- East Chatham Rise	t_0	-	-	-0.491 yr
- Northwest Chatham Rise	t_0	-	-	-0.491 yr
- Mid-East Coast	t_0	-0.5 yr	-0.5 yr	-0.5 yr
Length-weight parameters				
- default	a	-	-	0.0921
- East and Northwest Chatham Rise	a			0.0800
- Mid-East Coast	a	0.064	0.049	
- default	b	-	-	2.71
- East and Northwest Chatham Rise	b			2.75
- Mid-East Coast	b	2.81	2.89	
Recruitment steepness	h	-	-	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	-

3. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

The tables and accompanying text in this section were updated for the 2021 Fishery Assessment Plenary. A more detailed summary from an issue-by-issue perspective is available in the Aquatic Environment and Biodiversity Annual Review 2021 (Fisheries New Zealand 2021), online at https://www.mpi.govt.nz/dmsdocument/51472-Aquatic-Environment-and-Biodiversity-Annual-Review-AEBAR-2021-A-summary-of-environmental-interactions-between-the-seafood-sector-and-the-aquatic-environment. Some tables in this section have not been updated as data were unavailable at the time of publication.

3.1 Role in the ecosystem

Orange roughy are the dominant bottom trawl-caught 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, 2014) 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, 2014).

3.2 Non-target fish and invertebrate bycatch

Anderson & Finucci (2022) summarised the bycatch of orange roughy and oreo trawl fisheries from 2002–03 to 2019–20. Total non-target catch in the orange roughy fishery ranged from a low of 535 t in 2012–13 to a high of 4834 t in 2003–04. Levels dropped sharply for a few years after 2009–10, then increased thereafter, but with a declining trend overall. Total non-target catch was strongly correlated with effort, with effort also having generally decreased over time. During the period 2015-16 to 2019-2020, orange roughy accounted for approximately 80% of the total observed catch and the remainder comprised mainly smooth oreo (4.8%), rattails (1.7%), shovelnose dogfish (1.3%) and ribaldo (1.0%). More than 700 species or species groups were recorded by observers, including various deepwater dogfishes (2%), morid cods (1%), rattails (<1%), and slickheads (0.5%). Total estimated annual discards of non-target QMS species were very low, ranging from only 1 t in 2007–08 to 46 t in 2015–16, while discards of non-QMS species ranged from 108 t in 2013–14 to 1504 t in 2017–18, both showed no obvious trend over time.

Invertebrate species are caught in low numbers in the orange roughy fishery (Anderson & Finucci 2022) with squid (0.3%; mostly warty squid, *Onykia* spp., 0.22%) being the largest component of invertebrate catch followed by various echinoderms (0.3%) and cnidarians (0.2%). . 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).

Finucci et al. (2019) analysed bycatch trends in deepwater fisheries, including orange roughy trawl, from 1990–91 until 2016–17. They found that the most common bycatch species by weight (t) were smooth oreo (*Pseudocyttus maculatus*, SSO), black oreo (BOE), and unspecified sharks (SHA). Moreover, among the 557 bycatch species examined, 94 showed a decrease in catch over time (29 were statistically significant) and 62 showed an increase (14 were significant). The species showing the greatest decline were dark ghost shark (*Hydrolagus novaezealandiae*, GSH), black oreo (*Allocyttus niger*, BOE), and lanternshark (*Etmopterus* sp., ETM), while the greatest increases were found for longnose velvet dogfish (*Centroscymnus crepidater*, CYP), Portuguese dogfish (*Centroscymnus coelolepis*, CYL), and Owston's dogfish (*Centroscymnus owstonii*, CYO).

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 on board the vessel, Middleton & Abraham 2007, Brothers et al., 2010).

3.3.1 Marine mammal captures

Trawlers targeting orange roughy, oreo, and black cardinalfish occasionally catch New Zealand fur seal (which were classified as "Not Threatened" under the New Zealand Threat Classification System in 2010, Baker et al., 2016; Baker et al., 2019). Between 2002–03 and 2007–08, there were 15 observed captures of New Zealand fur seal in orange roughy, oreo, and black cardinalfish trawl fisheries. There have been two observed captures in the period between 2008–09 and 2019–20, during which time the average level of annual observer coverage was 26.2% (Table 3). 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 3: Number of tows by fishing year and observed and model-estimated total New Zealand fur seal captures in orange roughy, oreo, and cardinalfish trawl fisheries, 2002–03 to 2019–20. Annual fishing effort (tows), and observer coverage (%) in deepwater trawl fisheries; number of observed captures and observed capture rate (captures per hundred tows) of New Zealand fur seal; estimated captures and capture rate of New Zealand fur seal (mean and 95% credible interval). Estimates are based on methods described by Abraham et al (2021), available online at https://data.dragonfly.co.nz/psc. Observed and estimated protected species captures in these tables derive from the PSC database version PSCV6. [Continued on next page]

	Fishing effort			Obs. captures		Est. captures		Est. capture rate	
Fishing year	Tows	No. Obs	% obs	Captures	Rate	Mean	95% c.i.	Mean	95% c.i.
2002–03	8 871	1 384	15.6	0	0	4	0–12	0.04	0.00–0.14
2003–04	8 007	1 262	15.8	2	0.16	9	3–23	0.12	0.04–0.29
2004–05	8 420	1 619	19.2	4	0.25	14	6–28	0.16	0.07–0.33
2005–06	8 292	1 359	16.4	2	0.15	10	3–23	0.13	0.04–0.28
2006–07	7 365	2 324	31.6	2	0.09	3	2–7	0.05	0.03–0.10
2007–08	6 731	2 811	41.8	5	0.18	8	5–13	0.12	0.07–0.19
2008–09	6 130	2 372	38.7	0	0	2	0–7	0.03	0.00–0.11
2009–10	6 008	2 133	35.5	0	0	3	0–8	0.05	0.00–0.13
2010–11	4 178	1 205	28.8	0	0	3	0–10	0.08	0.00–0.24
2011–12	3 655	923	25.3	0	0	1	0–5	0.04	0.00–0.14
2012–13	3 098	346	11.2	0	0	0	0–2	0.02	0.00–0.06
2013–14	3 606	434	12.0	0	0	1	0–3	0.02	0.00–0.08
2014–15	3 814	978	25.6	1	0.1	2	1–4	0.04	0.03–0.10
2015–16	4 088	1 421	34.8	0	0	1	0–3	0.01	0.00–0.07
2016–17	3 962	1 226	30.9	0	0	0	0–2	0.01	0.00–0.05
2017–18	3 753	903	24.1	0	0	1	0–3	0.01	0.00–0.08
2018–19	3 906	1 190	30.5	1	0.1				
2019–20	3 952	1 171	29.6	0	0				

3.3.2 Seabird captures

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 2019–20 (Table 4). The average observed capture rate in deepwater trawl fisheries (including orange roughy, oreo and cardinalfish) for the period from 2002–03 to 2019–20 is about 0.33 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 4: Number of tows by fishing year and observed seabird captures in orange roughy, oreo, and cardinalfish trawl fisheries, 2002–03 to 2019–20. 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 by Abraham & Richard (2020) and are available online at https://protectedspeciescaptures.nz/PSCv6/released/. Observed and estimated protected species captures in this table derive from the PSC database version PSCV6.

	Fishing effort			Obs. captures		Est. captures		Est. capture rate	
Fishing year	Tows	No. Obs	% obs	Captures	Rate	Mean	95% c.i.	Mean	95% c.i.
2002–03	8 871	1 384	15.6	0	0.00	36	17-60	0.40	0.19-0.68
2003–04	8 007	1 262	15.8	3	0.24	33	17-54	0.41	0.21-0.67
2004–05	8 420	1 619	19.2	7	0.43	44	25-68	0.52	0.3-0.81
2005–06	8 292	1 359	16.4	8	0.59	42	25-66	0.51	0.3-0.8
2006–07	7 365	2 324	31.6	2	0.09	22	10-40	0.30	0.14-0.54
2007–08	6 731	2 811	41.8	7	0.25	24	13-40	0.35	0.19-0.59
2008–09	6 130	2 372	38.7	8	0.34	26	15-42	0.42	0.24-0.69
2009–10	6 008	2 133	35.5	19	0.89	36	25-51	0.60	0.42-0.85
2010–11	4 178	1 205	28.8	1	0.08	17	7-33	0.42	0.17-0.79
2011–12	3 655	923	25.3	2	0.22	13	5-26	0.37	0.14-0.71
2012–13	3 098	346	11.2	2	0.58	15	6-30	0.50	0.19-0.97
2013–14	3 606	434	12.0	2	0.46	18	7-33	0.49	0.19-0.92
2014–15	3 814	978	25.6	0	0.00	15	5-30	0.40	0.13-0.79
2015–16	4 088	1 421	34.8	4	0.28	15	7-28	0.38	0.17-0.68
2016–17	3 962	1 226	30.9	2	0.16	14	5-26	0.35	0.13-0.66
2017–18	3 753	903	24.1	4	0.44	17	8-29	0.44	0.21-0.77
2018–19	3 906	1 190	30.5	9	0.76	21	13-34	0.55	0.33-0.87
2019–20	3 952	1 171	29.6	2	0.17	13	5-25	0.34	0.13-0.63

Table 5: Number of observed seabird captures in orange roughy, oreo, and cardinalfish fisheries, 2002–03 to 2019–20, 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 et al., 2017, where full details of the risk assessment approach can be found). It is not an estimate of the risk posed by fishing for black cardinalfish. Observed protected species captures in this table derive from the PSC database version PSCV6.

Species	Risk Category	Chatham Rise	East coast South Island	Fiordland	Sub-Antarctic	Stewart-Snares shelf	West coast South Island	West coast North Island	Total
Salvin's albatross	High	12	4	0	3	0	0	0	19
Southern Buller's albatross	High	3	0	1	0	0	0	0	4
Chatham Island albatross	Medium	11	0	0	1	0	0	0	12
New Zealand white-capped albatross	Medium	4	0	0	0	0	2	0	6
Gibson's albatross	High	1	0	0	0	0	0	0	1
Antipodean albatross	Medium	1	0	0	0	0	0	0	1
Northern royal albatross	Low	1	0	0	0	0	0	0	1
Southern royal albatross	Negligible	2	1	0	1	0	0	0	4
Albatrosses	–	2	1	0	0	0	0	0	3
Total albatrosses	–	37	6	1	5	0	2	0	51
Black petrel	Very High	0	0	0	0	0	0	1	1
Northern giant petrel	Medium	1	0	0	0	0	0	0	1
White-chinned petrel	Low	3	2	0	0	1	0	0	6
Grey petrel	Negligible	1	0	0	1	0	0	0	2
Sooty shearwater	Negligible	1	3	0	0	0	1	0	5
Common diving petrel	Negligible	3	0	0	0	0	0	0	3
White-faced storm petrels	Negligible	3	0	0	0	0	0	0	3
Cape petrel	–	8	1	0	0	0	0	0	9
Petrels, prions, and shearwaters	–	0	0	0	1	0	0	0	1
Total other birds	–	20	6	0	2	1	1	1	31

Salvin’s albatross was the most frequently captured albatross (38% of observed albatross captures) but eight different albatross species have been observed captured since 2002–03. Cape petrels were the most frequently captured other taxon (29% of observed captures of taxa other than albatross, Table 5). 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.

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 6). 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 respectively of Population Sustainability Threshold (PST) (Table 6). Chatham albatross and Salvin’s albatross were assessed at high risk (Richard et al., 2020).

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).

Table 6: 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 and Richard et al., 2020 where full details of the risk assessment approach can be found). The risk ratio is an estimate of aggregate potential fatalities across trawl and longline fisheries relative to the PBR. The DOC threat classifications are shown (Robertson et al., 2017 at http://www.doc.govt.nz/documents/science-and-technical/nztcs19entire.pdf).

		Risk ratio			
Species name	**PST (mean)**	**ORH, OEO, CDL target trawl***	**TOTAL**	**Risk category**	**DOC Threat Classification**
Chatham Island albatross	428	0.060	0.28	High	At Risk: Naturally Uncommon
Salvin's albatross	3 460	0.022	0.65	High	Threatened: Nationally Critical
Northern giant petrel	337	0.005	0.15	Medium	At Risk: Naturally Uncommon
Northern Buller's albatross	1 640	0.002	0.26	Medium	At Risk: Naturally Uncommon
Black petrel	447	0.002	1.23	Very high	Threatened: Nationally Vulnerable
Antipodean albatross	369	0.002	0.17	Medium	Threatened: Nationally Critical
Gibson's albatross	497	0.002	0.31	High	Threatened: Nationally Critical
Northern royal albatross	723	0.001	0.05	Low	At Risk: Naturally Uncommon
Flesh-footed shearwater	1 450	0.001	0.49	High	Threatened: Nationally Vulnerable
Southern Buller's albatross	1 360	0.001	0.37	High	At Risk: Naturally Uncommon
Grey petrel	5 460	0.000	0.03	Negligible	At Risk: Naturally Uncommon
Common diving petrel	137 000	0.000	<0.01	Negligible	At Risk: Relict
New Zealand white-faced storm petrel	331 000	0.000	<0.01	Negligible	At Risk: Relict
New Zealand white-capped albatross	10 800	0.000	0.29	Medium	At Risk: Declining
Buller's shearwater	56 200	0.000	<0.01	Negligible	At Risk: Naturally Uncommon
Westland petrel	351	0.000	0.54	High	At Risk: Naturally Uncommon
Sooty shearwater	622 000	0.000	<0.01	Negligible	At Risk: Declining
Hutton's shearwater	14 900	0.000	<0.01	Negligible	At Risk: Declining
Otago shag	283	0.000	0.13	Medium	Threatened: Nationally Vulnerable
White-headed petrel	34 400	0.000	<0.01	Negligible	Not Threatened

*ORH, OEO, CDL from Richard et al 2017

3.3.3 Protected fish species captures

Deepwater trawling for orange roughy and oreo typically exceeds the depth at which protected fish species are usually found. Fisheries-reported records include the capture of a basking shark (*Cetorhinus maximus*) in 2019, a species classified as "Endangered" by IUCN in 2013 and as "Threatened – Nationally Vulnerable" in 2016, under the New Zealand Threat Classification System (Duffy et al 2018). Basking shark has been a protected species in New Zealand since 2010, under the Wildlife Act 1953, and is also listed in Appendix II of the CITES convention. However, basking sharks have been occasionally confused with bluntnose sixgill shark (*Hexanchus griseus*), a "Not Threatened" species according to the DOC latest assessment (Duffy et al., 2018), and this report is being verified.

An observer reported capture includes the smalltooth sandtiger shark (deepwater nurse shark) *Odontaspis ferox* in 2012, classified as "Critically Endangered" by the IUCN Red List and "At Risk-Naturally Uncommon" under the New Zealand Threat Classification System (Duffy et al., 2018).

3.4 Benthic interactions

The spatial extent of seabed contact by trawl fishing gear in New Zealand's EEZ and Territorial Sea has been estimated and mapped in numerous studies for trawl fisheries targeting deepwater species (Baird et al., 2011, Black et al., 2013, Black & Tilney 2015, Black & Tilney 2017, Baird & Wood 2018, and Baird & Mules 2019, 2021a, 2021b), species in waters shallower than 250 m (Baird et al., 2015, Baird & Mules 2020a), and all trawl fisheries combined (Baird & Mules 2021a, 2021b). The most recent assessment of the deepwater trawl footprint was for the period 1989–90 to 2018–19 (Baird & Mules 2021b).

Orange roughy, oreo, and cardinalfish are taken using bottom trawls and accounted for about 15% of all tows reported on TCEPR forms that fished on or close to the bottom between 1989–90 and 2019–20 (Baird & Mules 2021b). From 1989–90 to 2018–19, about 168 000 orange roughy bottom trawls were reported on TCEPRs and ERS (Baird & Mules 2021b): with between 5000 and at least 8000 tows reported most years up to 1999–2000; 3000–4500 annual tows between 2000–01 and 2009–10; and 1500–3500 tows a year during 2010–11 to 2018–19. The total footprint generated from these tows was estimated at about 41 175 km^2. This footprint represented coverage of 1% of the seafloor of the combined EEZ and the Territorial Sea areas; 3% of the 'fishable area', that is, the seafloor area open to trawling, in depths of less than 1600 m. For the 2018–19 fishing year, 3135 orange roughy bottom tows had an estimated footprint of 3008 km^2 which represented coverage of < 0.1% of the EEZ and Territorial Sea and 0.2% of the fishable area (Baird & Mules 2021b).

The overall trawl footprint for orange roughy (1989–90 to 2018–19) covered 11% of the seafloor in 800–1000 m, 9% of 1000–1200 m seafloor, and 3% of the 1200–1600 m seafloor (Baird & Mules 2021b). In 2018–19, the orange roughy footprint contacted 1%, 0.6%, and 0.2% of those depth ranges, respectively (Baird & Mules 2021b). Deepsea corals in the New Zealand region are diverse and, because of their fragility, are at risk from anthropogenic activities such as bottom trawling (Clark & O'Driscoll 2003, Clark & Rowden 2009, Williams et al., 2010). All deepwater hard corals are protected under Schedule 7A of the Wildlife Act 1953. Baird et al. (2013) mapped the likely coral distributions using predictive models and concluded that the fisheries that pose the most risk to protected corals are these deepwater trawl fisheries.

Tows are located in Benthic-optimised Marine Environment Classification (BOMEC, Leathwick et al., 2012) classes J, K (mid-slope), M (mid-lower slope), N, and O (lower slope and deeper waters) (Baird & Wood 2012), and 94% were between 700 and 1200 m depth (Baird et al., 2011). The BOMEC areas with the highest proportion of area covered by the orange roughy footprint were classes J (comprising mainly the Challenger Plateau and northern and southern slopes of the Chatham Rise) and N (deeper areas around the North Island and Chatham Rise). In 2018–19, the orange roughy footprint represented 0.69% of the 312 645 km^2 in class J and 0.1% of the 495 154 km^2 of class N (Baird & Mules 2021b).

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 2021 (Fisheries New Zealand 2021).

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

3.5 Other considerations

Fishing during spawning may disrupt spawning activity or success. There is no research on the disruption of spawning orange roughy by fishing in New Zealand.

Some orange roughy spawning aggregations were historically abundant but depleted by fishing, predominantly during the 1980s and 1990s, and no longer seem to occur. This includes the large aggregations on Strawberry Mountain in the Mid-East Coast stock, and on Central Flats in the Challenger stock. On Chatham Rise, the main spawning aggregation no longer occurs in the Spawning Box but at Rekohu. The relationship between different spawning aggregations within the same assumed stock, and the implications of the loss of spawning aggregations for orange roughy and the wider ecosystem, is unknown.

3.5.2 Genetic effects

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

3.5.3 Habitat of particular significance to fisheries management

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

4. RECENT STOCK ASSESSMENTS

In this section, methods and assumptions common to stock assessments since 2014 are described.

4.1 Methods

The methods used in recent orange roughy assessments were different from those used prior to 2014. 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 in base model runs.

4.1.1 Data quality and model structure

A high-quality threshold imposed on data before they were used in an assessment 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, despite often pronounced trends, they were considered unlikely to be monitoring stock-wide abundance. Estimates of biomass from egg surveys were not used as assumptions of the survey design were not met, and/or there were major difficulties in analysing the survey data. 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. On underwater features, estimates were accepted when the shadow zone estimate was no more than about 10% of the total estimate. For hull-mounted transducers, this requires that the plumes are high in the water column or near the top of the feature (and not on the side of the feature where shadow zone corrections are often large).

The model structure assumed was similar across the assessments. In particular, maturity was estimated within the model from age-frequencies of spawning fish. This is different to earlier assessments where maturity was estimated from otolith transition-zones. The ogive used to define Spawning Stock Biomass (SSB) is therefore explicitly a *spawning* ogive, and the SSB is not necessarily the same as mature biomass.

The recent assessment models now include more reliable age data using the new ageing methodology (Tracey et al., 2007, Horn et al., 2016). This has allowed recruitment (year class strengths) to be more plausibly estimated. Previously, deterministic recruitment produced stock biomass rebuilds that 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.

4.1.2 Acoustic *q* priors

The major sources of recent abundance information in the models are from acoustic surveys of spawning biomass. For each survey, the spawning biomass estimate was included in the appropriate assessment as an estimate of *relative* spawning biomass rather than *absolute* spawning biomass. The 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 a 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[1], 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%.

4.1.3 Year class strength estimation

The number of year class strengths (YCSs) estimated within each model depends on the timing and number of age frequency observations available. In general, a YCS is estimated provided it is observed in at least one age frequency. The Haist parameterisation for estimating YCS is used for all models (Bull et al., 2012).

5. FUTURE RESEARCH CONSIDERATIONS

The research considerations below are generic to all or most of the orange roughy assessments.

- Continue to improve methods to reduce contamination by swim bladder species when using current AOS technology to estimate orange roughy acoustic biomass, and determine the potential magnitude of possible errors.
- Greater detail is needed on the performance of tows or transects from surveys, especially when there are issues with them. Such detail should be included in the comment field and will enable analysts to determine how or whether to include them in models.
- Provide a more detailed protocol for otolith collections in surveys to ensure sufficient otoliths are collected. For example, it may be useful to oversample in case insufficient samples are collected subsequently.
- Re-examine the M=0.045 and h=0.75 assumptions for each orange roughy assessment, including estimation within and outside models and the determination of appropriate priors.
- Review the appropriateness of assuming a 5% catch overrun for current and recent years.
- Adequate age information is needed for all stocks including from commercial fisheries.
- Locate data on Enterprise Allocation (the system used to award quota for deepwater species in the 3 years prior to the full introduction of the QMS – a precursor to the QMS) catches and limits for 1983–86 and include these in Plenary catch tables and graphs, as well as in stock assessments.

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

- Review the Management Strategy Evaluation and the resulting Harvest Control Rule, along with their application, in a technical Working Group to ensure that the approach still represents best practice.
- Re-evaluate stock structure assumptions as new data become available, potentially making use of relevant novel techniques (genetics, tagging).
- Further investigate the relationship between maturity and spawning, and the potential for age-dependent skipped spawning.

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. (2020). Estimated capture of seabirds in New Zealand trawl and longline fisheries, to 2017–18. *New Zealand Aquatic Environment and Biodiversity Report* No. 249. 86 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; 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; Finucci, B (2022) Non-target fish and invertebrate catch and discards in New Zealand orange roughy and oreo trawl fisheries from 2002–03 to 2019–20. *New Zealand Aquatic Environment and Biodiversity Report* No. 282.

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.)

Andrews, A.H.; Tracey, D.M.; Dunn, M.R. (2009). Lead-radium dating of orange roughy (*Hoplostethus atlanticus*): validation of a centenarian lifespan. *Canadian Journal of Fisheries and Aquatic Science* 66: 1130–1140.

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; Hewitt, J E; Wood, B A (2015) Benthic habitat classes and trawl fishing disturbance in New Zealand waters shallower than 250 m. *New Zealand Aquatic Environment and Biodiversity Report No. 144*. 184 p

Baird, S J; Mules, R (2019) Extent of bottom contact by New Zealand commercial trawl fishing for deepwater Tier 1 and Tier 2 target species determined using CatchMapper software, fishing years 2008–17. *New Zealand Aquatic Environment and Biodiversity Report No. 229*. 106 p.

Baird, S J; Mules, R (2021a) Extent of bottom contact by commercial fishing activity in New Zealand waters, for 1989–90 to 2017–18. *New Zealand Aquatic Environment and Biodiversity Report No. 259*. 143 p.

Baird, S J; Mules, R (2021b) Extent of bottom contact by commercial trawling and dredging in New Zealand waters, 1989–90 to 2018–19. *New Zealand Aquatic Environment and Biodiversity Report. No. 260*. 157 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. (2018). Extent of bottom contact by New Zealand commercial trawl fishing for deepwater Tier 1 and Tier 2 target fishstocks, 1989–90 to 2015–16. *New Zealand Aquatic Environment and Biodiversity Report No. 193*. 102 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; Boren, L; Childerhouse, S; Constantine, R; van Helden, A; Lundquist, D; Rayment, W; Rolfe, J R (2019) Conservation status of New Zealand marine mammals, 2019. *New Zealand Threat Classification Series 29*. Department of Conservation, Wellington. 18 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 (2016) 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; Tilney, R (2015) Monitoring New Zealand's trawl footprint for deepwater fisheries: 1989– 1990 to 2010–2011. *New Zealand Aquatic Environment and Biodiversity Report No. 142*. 56 p.

Black, J; Tilney, R (2017) Monitoring New Zealand's trawl footprint for deepwater fisheries: 1989–90 to 2012–13. *New Zealand Aquatic Environment and Biodiversity Report No. 176*. 65 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. (2014a) The 2014 orange roughy stock assessments. *New Zealand Fisheries Assessment Report 2014/50*. 135 p.

Cordue, P L (2014b) 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 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.)

Duffy, C; Francis, M; Dunn; M; Finucci, B; Ford, R; Hitchmough, R; Rolfe, J (2018) Conservation status of New Zealand chondrichthyans (chimaeras, sharks and rays), 2016. *New Zealand Threat Classification Series 23*. Department of Conservation, Wellington. 13 p.

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.

Finucci, B; Edwards, C T T; Anderson, O F; Ballara, S L (2019) Fish and invertebrate bycatch in New Zealand deepwater fisheries from 1990–91 until 2016–17. *New Zealand Aquatic Environment and Biodiversity Report No. 210*. 77 p.

Fisheries New Zealand (2021) Aquatic Environment and Biodiversity Annual Review 2021. Compiled by the Aquatic Environment Team, Fisheries Science and Information, Fisheries New Zealand, Wellington, New Zealand. 779 p.

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.

Hermsen, 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. Complied 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, Ehrich, 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).

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.

Richard, Y; Abraham, E R; Berkenbusch, K (2020) Assessment of the risk of commercial fisheries to New Zealand seabirds, 2006–07 to 2016–17. *New Zealand Aquatic Environment and Biodiversity Report No. 237.* 57 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, *Hoplosthethus 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.

Tingley, G., & Dunn, M., Eds. (2018). Global review of orange roughy (*Hoplostethus atlanticus*), their fisheries, biology and management. FAO Fisheries and Aquaculture Technical Paper No. 622. Rome. 128. Licence: CC BY-NC-SA 3.0 IGO.

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

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.

Tuck, I D; Pinkerton, M H; Tracey, D M; Anderson, O A; Chiswell, S M (2014) Ecosystem and environmental indicators for deepwater fisheries. *New Zealand Aquatic Environment and Biodiversity Report No. 127*. 143 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.