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SIOFA Fisheries Summary: orange roughy (*Hoplostethus atlanticus*) 2023

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Abstract

This paper presents the SIOFA fishery summary for orange roughy (*Hoplostethus atlanticus*) 2023. The current version of this document has been produced during the SC8 meeting, by a specific workgroup within the meeting, and has been subsequently approved for publication in 2023 by MoP10. The published version includes figures with data updated to 2021.

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SIOFA Fisheries Summary: orange roughy (*Hoplostethus atlanticus*) 2023

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Contents

1. Purpose of this document

The SIOFA Fisheries Summaries describe specific SIOFA fisheries in the SIOFA Area (Figure 1) and summarizes the available information for each species, and their biology and ecology. This document is targeted at the general public and institutions and countries wanting to better understand SIOFA fisheries. It also describes SIOFA data available on SIOFA individual fisheries that could be used by scientists and consultants for scientific research.

The SIOFA Ecosystem Summary provides more detailed information on effects of SIOFA fisheries on ecosystems and species in the SIOFA Area. The SIOFA Fisheries Overview integrates these documents and describes general trends for the main fisheries in the SIOFA Area.

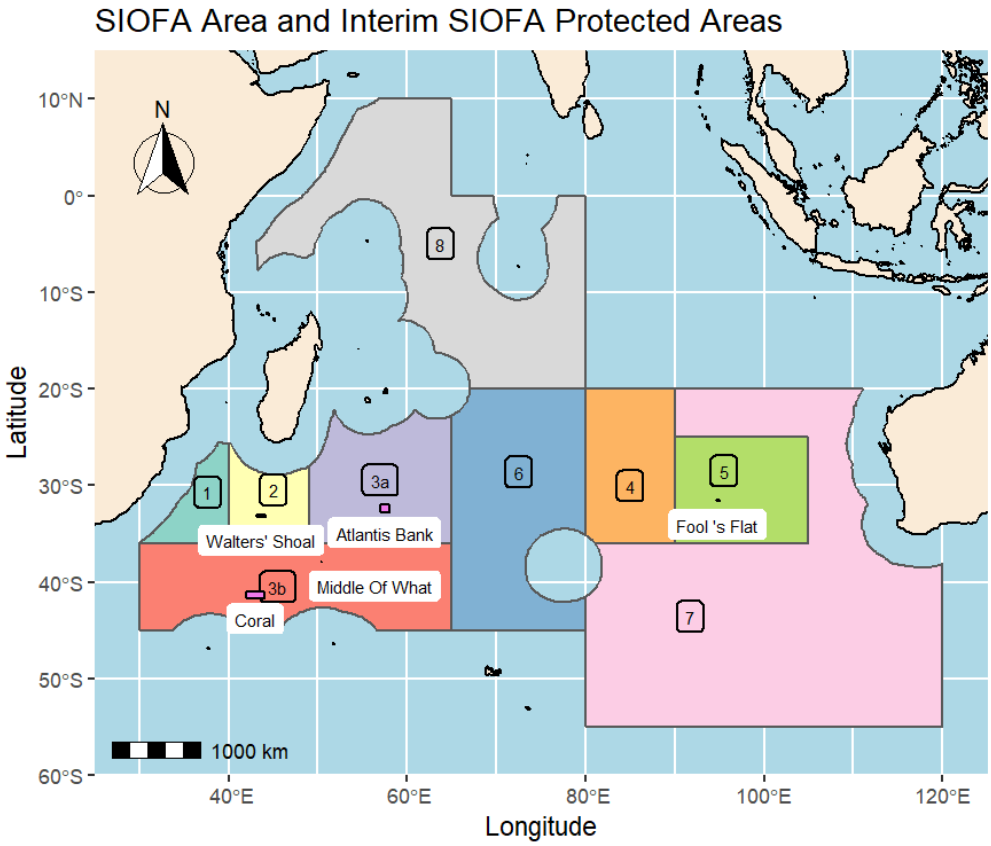


Figure 1 – The SIOFA Area and Subareas (source: SIOFA Spatial Database). The Subarea numbers and colour codes are used consistently throughout this summary to identify Subareas. The map highlights SIOFA Interim Protection Areas (in magenta) as defined in Annex 3 of CMM 01-2020. The interim protection areas have been labelled by name for easier recognition.

2. Data sources

2.1 Data availability

There are thirteen CCPs (Contracting Parties (CP), Cooperating non Contracting Parties (CNCP), and Participating Fisheries Entities of SIOFA (PPE)) that collectively are members of SIOFA. The SIOFA Secretariat receives data from CCPs pertaining to their fishing activities, biological sampling, and Scientific Observer reports as per CMM 02-2021 (Conservation and Management Measure for the Collection, Reporting, Verification and Exchange of Data relating to fishing activities in the Agreement Area). The SIOFA Secretariat acts as custodian for these data on behalf of its members. Requests to release or publish these data (e.g., for scientific purposes) is regulated under CMM 03-2016 (Conservation and Management Measure for Data Confidentiality and Procedures for access and use of data). Data requests can be made through the Secretariat (secretariat@siofa.org).

The SIOFA databases are organized as follows:

- AggregatedCatchEffort: this database contains the catch and effort data aggregated at different spatial resolutions, varying from the whole SIOFA Area to 20' squares, for years from 2000 to 2019.
- HBHCatchEffort: this database contains haul-by-haul catch and effort data at recorded at a range of spatial resolutions, varying from degrees to seconds, for the years from 1998 to 2021.
- SIOFA Observer Database: this database contains data from Scientific Observers including biological sampling and operational data, for the years from 2012 to 2021

The SIOFA databases are supported by other data assets such as:

- Spatial data layers (in various formats), including the GIS spatial layers available to the Secretariat (e.g., boundaries of the SIOFA Subareas, Management Unit boundaries, etc.). These are stored at the SIOFA Secretariat
- Codes, including countries, gears and FAO species codes etc. These are stored at FAO.

SIOFA databases and supporting data assets have been described in the reports of project SEC2021-05 (e.g., SC-07-08), where it was noted that some data are repeated in the AggregatedCatchEffort and HBHCatchEffort databases.

Further data (e.g., the number of active vessels) are available from Annual National Reports (2015–2021) that SIOFA CCPs submit to the Scientific Committee each year. These are available from the SIOFA website (https://siofa.org/meetings/groups/Scientific%20Committee%20Meeting).

2.2 Data used in this summary

The information presented in this summary has been extracted from different sources depending on the type of data required. To minimize the difficulty from having to interpret multiple data sources, explicit references have been made to data sources in each table/figure of this summary.

The Overview covers the last five years of available data (at a minimum), but note that the data used covers the 2013–2021 period (9 years of data), and that the period covered varies across the different sections as detailed below.

i. Main fisheries operating in the SIOFA Area (2000–2019): National Reports submitted CCPs to the Scientific Committee
ii. Total catches per CCP (2013–2020): SIOFA AggregatedCatchEffort database, combined with SIOFA HBHCatchEffort database

iii. Catch, Effort (including per Subarea) and discards (2013–2020): SIOFA HBHCatchEffort, SIOFA AggregatedCatchEffort database and spatial layers (excluding non-fish catch; see Sections 6 and 6.2 for definitions of target catch)
iv. VMEs (2020): SIOFA Observer database
v. Fishing in Interim Protected Areas (2013–2020): SIOFA HBHCatchEffort and Spatial databases Biological sampling (2020): SIOFA Observer database

3. Species Summary

Common name	Orange roughy
Scientific name	*Hoplostethus atlanticus* Collet 1889
Scientific synonyms	*Hoplostethus gilchristi, Hoplostethus islandicus*
FAO species code	ORY
Year of this report	2023
Assessment Areas/ Management Units	One assessment area, Walter's Shoal Ridge, within FAO area 51
Assessment method	Integrated stock assessment (using CASAL)
Most recent assessment	2022
Year of next assessment	2025
Harvest strategy	Not yet defined
Summary of current stock status	For the Walter's Shoal Ridge, there is a 76% probability that the stock was not overfished and no overfishing was taking place in 2020 (para 92, SC7 report 2022) No other assessments are available in other areas

This report describes the orange roughy fishery in the SIOFA Area and available biological parameters for orange roughy. Management advice for this species is given in the Report of the SIOFA Scientific Committee (2022) and management decisions are summarised in the Report of the SIOFA Meeting of Parties (2022).

Fisheries for orange roughy in the SIOFA Area are managed under CMM 01-2020 (Interim Management of Bottom Fishing) and CMM 15-2021 (Management of Demersal Stocks). A harvest strategy for the orange roughy stocks has not yet been developed (Brandao et al. 2022).

Orange roughy was assessed through an integrated stock assessment, using the CASAL software package (Bull et al. 2012). The current stock status of orange roughy provided in the SIOFA SC7 report was based on SC7-07-35 (Roa Ureta *et al*. 2022).

4. Biological Summary

Orange roughy is globally widespread in deeper waters. In the south-central Indian Ocean, it has been found in association with bottom features to a depth of 180–1800 m. For orange roughy, there is evidence for ontogeny changes with increasing depth (Dunn et al. 2009; Dunn & Forman 2011). Orange roughy are benthic pelagic and are usually found near the bottom, but sometimes up to 50–200 m above the seabed to forage, or in spawning plumes in areas of high-water mass movement and mixing (Lorance *et al*., 2002). Parasite and trace element analyses indicate orange roughy is a relatively sedentary species with little movement between fishery management areas (Edmonds et al. 1991.

Aggregations of orange roughy form in cold waters (3–9 ˚C) at depths between 700 and 1600 m on steep continental slopes, over canyons, ridges and other underwater topographical features such as seamounts, especially to spawn and feed (Clark *et al*. 2000, Uiblein et al. 2003, Clark et al. 2016), with individuals migrating up to 100 km to reach a spawning ground (Coburn & Doonan 1994, Francis & Clark 1998). Spawning occurs in specific areas, generally at depths of 700–1000 m near pinnacles and canyons from May to August (in the southern hemisphere), with differences in the onset of spawning between areas which seems to be consistent from year to year (Pankhurst 1988, Bell et al. 1992, Young et al. 2004). Not all mature fish spawn every year (see e.g., Doonan 2013), and the range of age-at-spawning is 32–41 years of age (Cordue 2014). Fecundity is variable, between about 16 000 and 115 000 eggs per kg in the Pacific (Pankhurst 1988, Clark *et al*. 1994, Koslow *et al*. 1995, Young *et al*. 2004), with differences between large regions.

Orange roughy are opportunistic predators feeding on prawns, squid, and small fishes (Rosecchi et al. 1988, Labbé & Arana 2001, Koslow & Bulman 2002), but also amphipods, mysids and decapod crustaceans (Rosecchi et al. 1988, Bulman & Koslow 1992).

Females are generally larger than males. Catches include both sexes, but individual trawl tows can be dominated by either sex, indicating potential sex substructure in aggregations, particularly during spawning (Anderson 2011).

The maximum age in orange roughy can exceed 200 years (Tracey & Horn 1999, Gili et al. 2002, Horn et al. 2016, Horn & Maolagáin 2019). Orange roughy have low productivity due to a combination of the late onset of maturity, and low annual growth rate in relation to size (Cordue 2014). Estimates of productivity parameters for orange roughy for the SIOFA Area are given in Saunders (2022).

5. Description of the fishery

5.1 Fleet and gear

Orange roughy are targeted in the SIOFA Area using bottom trawls but have been reported as being caught also in midwater trawls in the alfonsino fishery (2013–2021). The orange roughy fishery is a mixed fishery in itself, with different species being caught opportunistically and fishing gears being swapped accordingly. Some data have been aggregated to a daily level such that gear type can't be specified beyond 'trawl' but are most likely to be bottom trawls (2013–2021). The orange roughy fishery is thought to have been extensive in the early 2000s, with vessels flagged to different countries, but the fleet engaging in the orange roughy fishery was only 3 or fewer vessels since 2004. As a consequence of the low number of vessels participating in the fishery, the total tonnage of target catch taken tends to fluctuate from year to year. Vessels from Australia, the Cook Islands, Spain and Japan engaged in this fishery (see Section 7), but currently, only one vessel flagged to the Cook Islands engage in this fishery.

5.2 Fishing areas

Orange roughy fisheries in the southwestern part Indian Ocean (SWIO) (Figure 2) occur mainly on or around underwater topographic features. The spatial distribution of catches has not changed significantly over time.

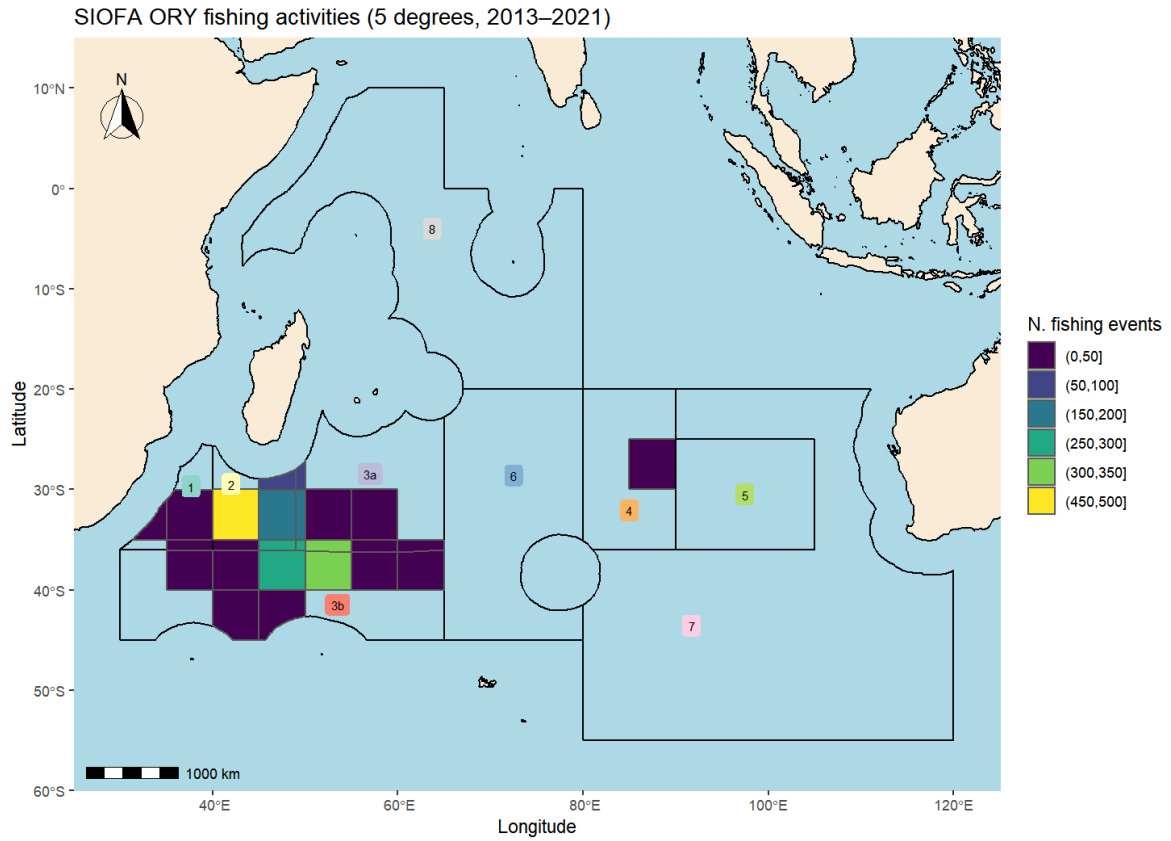


Figure 2 – Spatial distribution of orange roughy fishing in the SIOFA Area, derived from haul-by-haul level fishing data, aggregated at a 5 x5 degree resolution (source: SIOFA HBHCatchEffort databases 2013–2021). This map represents all fishing events that reported a catch of ORY, irrespective of declared target species.

5.3 Assessment Areas

Eight assessment areas were defined by Cordue (2018a and b, Figure 3) and used by Roa-Ureta et al. (2022). The assessment areas North Walter's, Walter's Shoal Ridge, West Walter's, Seamounts and Meeting were grouped in a spatial unit called the "Long Walter's Shoal Ridge" (LWSR) while the assessment areas North Ridge, Middle Ridge and South Ridge were grouped as the "South-west Indian Ocean Ridge" (SWIOR).

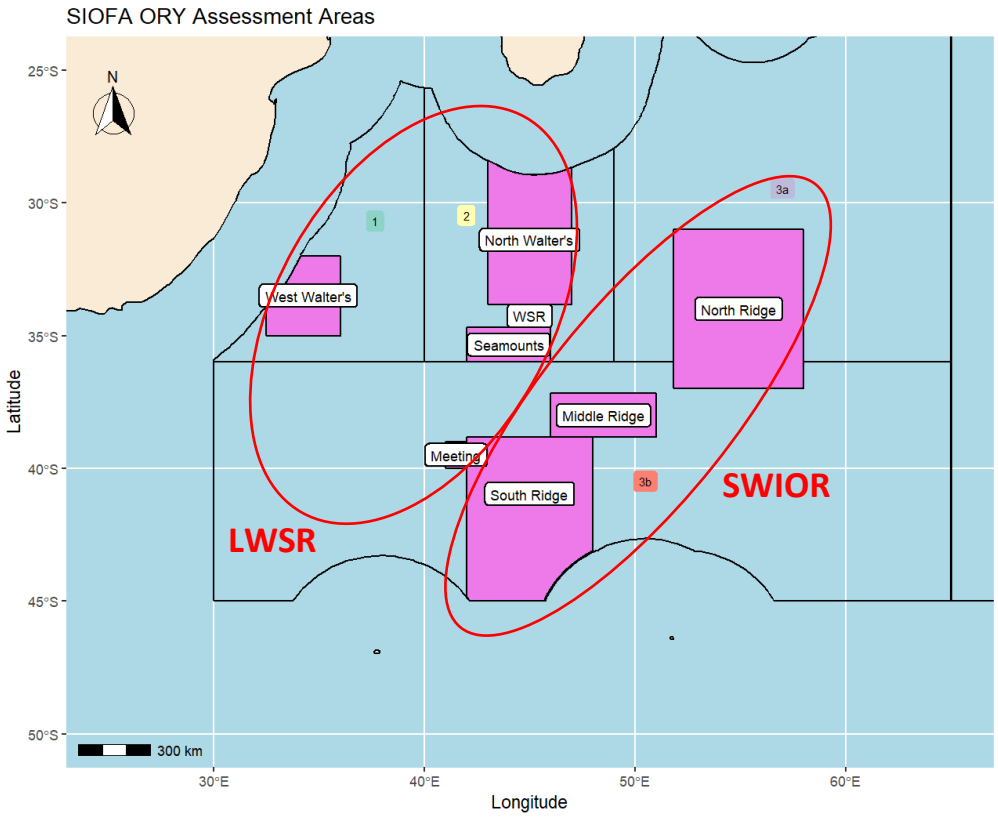


Figure 3 – Map of SIOFA areas used for assessments (in magenta) for orange roughy as defined by Cordue (2018a, 2018b) and used by Roa-Ureta et al. (2022) (source: SIOFA Spatial layers). Labels indicate names of single assessment areas. Red ovals denote the grouping of single assessment areas into two larger management units for purposes of stock assessment by Roa-Ureta et al (2022). These management units are labelled Long Walter's Shoal Ridge (LWSR) and South-west Indian Ocean Ridge (SWIOR).

5.4 Catch and effort

Note that fishing effort and catches reported in this section represent the total catch of orange roughy, irrespective of whether each particular fishing event had been targeting orange roughy or not. Consequently, CPUE represents the CPUE of all fishing events that caught orange roughy (even as bycatch), and hence if the proportion of operations actively targeting orange roughy increases then CPUE will likely increase as well. In this context CPUE cannot be considered a reliable index of abundance.

Catches of orange roughy have fluctuated between about 380 and 1400 t between 2013 and 2020 (Figure 4a), with the average annual catch over the most recent five years from which data are available (2016–2020) being approximately 985 t. In recent years fishing is prosecuted by only one or two vessels in the SIOFA orange roughy season, so variability in fleet deployment can cause large fluctuations in both catch and effort. Vessel maintenance periods, breakdowns, bad weather or market preference can significantly affect the total annual catch. Due to the seasonal nature of the fishery, vessel interruptions will also have a disproportionate effect on measures of effort.

Effort levels have decreased in recent years, from the higher values in 2015–2018 (Figure 4b). Orange roughy is mostly caught in the western SIOFA area, mainly Subareas 2 and 3a (Figure 4b).

Figure 4a and b – Yearly catch of orange roughy (t) and effort (number of tows) in the SIOFA area (upper panel, a) and in different SIOFA Subareas (lower panel, b) (source: SIOFA AggregatedCatchEffort and HBHCatchEffort databases 2013–2021). Values of the figure in panel a are provided in Table A.1 and values of the figure in panel b are provided in Table A.2 (both in Appendix A).

Recent years have seen lower levels of effort with higher catches (Figure 4), so unstandardised catch per units of effort (CPUEs) have been rising correspondingly (Figure 5). Standardised CPUE indices have not been developed, however it is likely that standardised CPUEs would have little information as an index of abundance for orange roughy aggregations on seamounts, especially when effort includes fishing events in which ORY was only caught as bycatch.

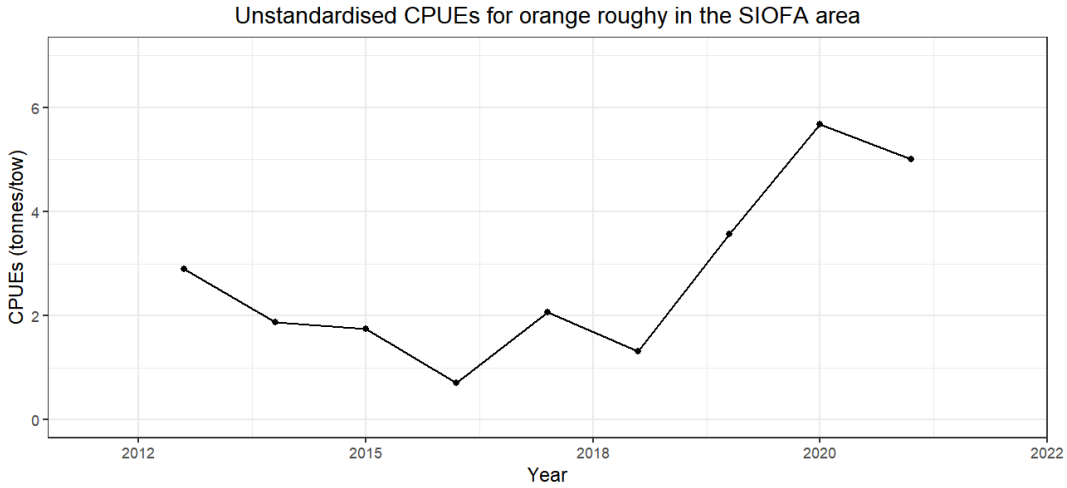


Figure 5 – Unstandardised catch per unit effort (CPUEs) of orange roughy in the SIOFA Area (t/tow) (source: SIOFA AggregatedCatchEffort and HBHCatchEffort databases 2013–2021).

For this section 'target catch' has been defined as the total catch of orange roughy. Every other species has been considered as bycatch in this particular context.

Orange roughy catch was distributed across nearly all orange roughy assessment areas but has been consistently higher in the South Ridge and WSR (Walter's Shoal Ridge) areas (Figure 6a). Catches of all species other than ORY has been highest in the North Ridge and North Walter's areas (Figure 7a). Effort levels were inconsistent in these areas across years.

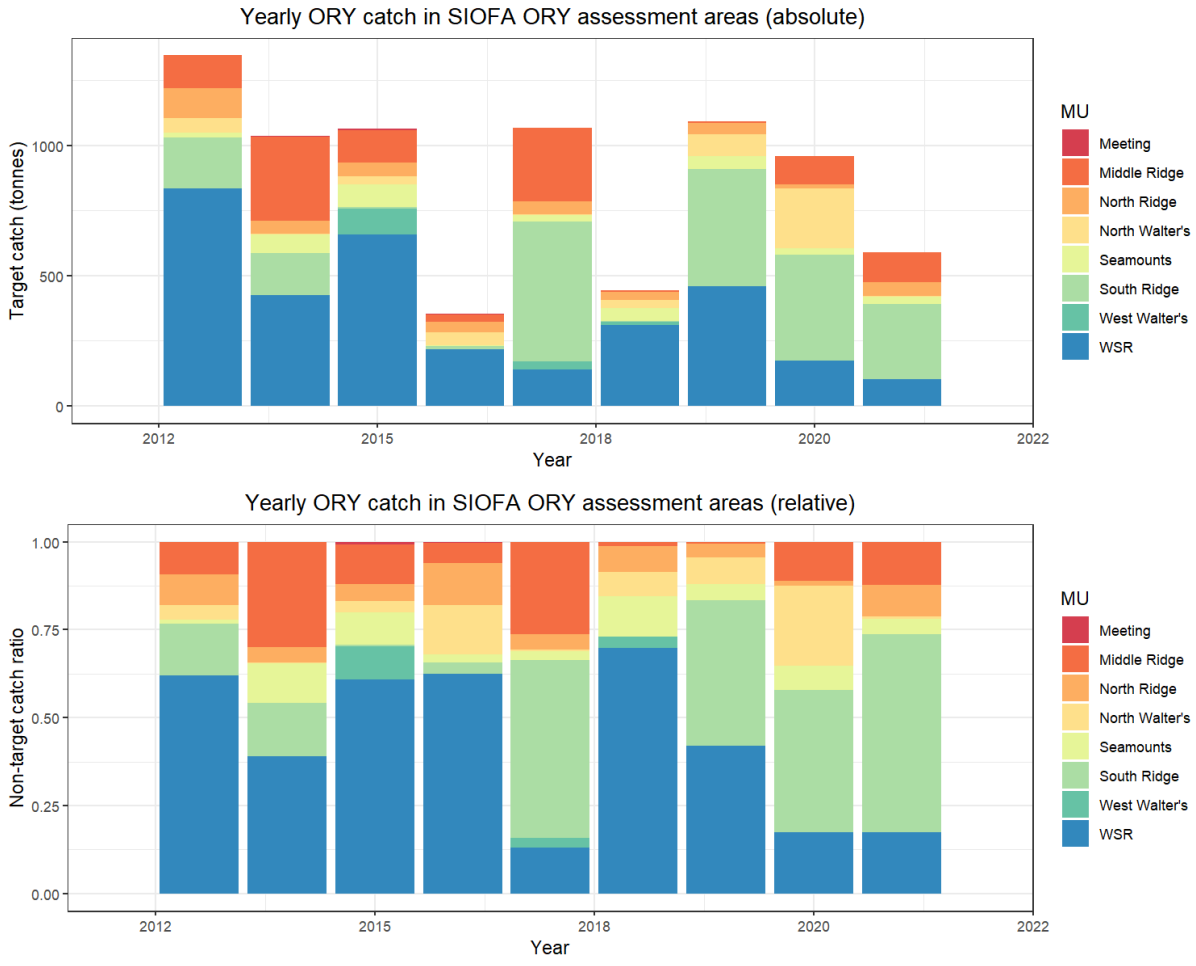


Figure 6a and b – Orange roughy catch in different SIOFA assessment areas for orange roughy as absolute (top panel, a) and relative (bottom panel, b) catch (source: SIOFA AggregatedCatchEffort and HBHCatchEffort database 2013–2021). Catches reported without location information are not included.

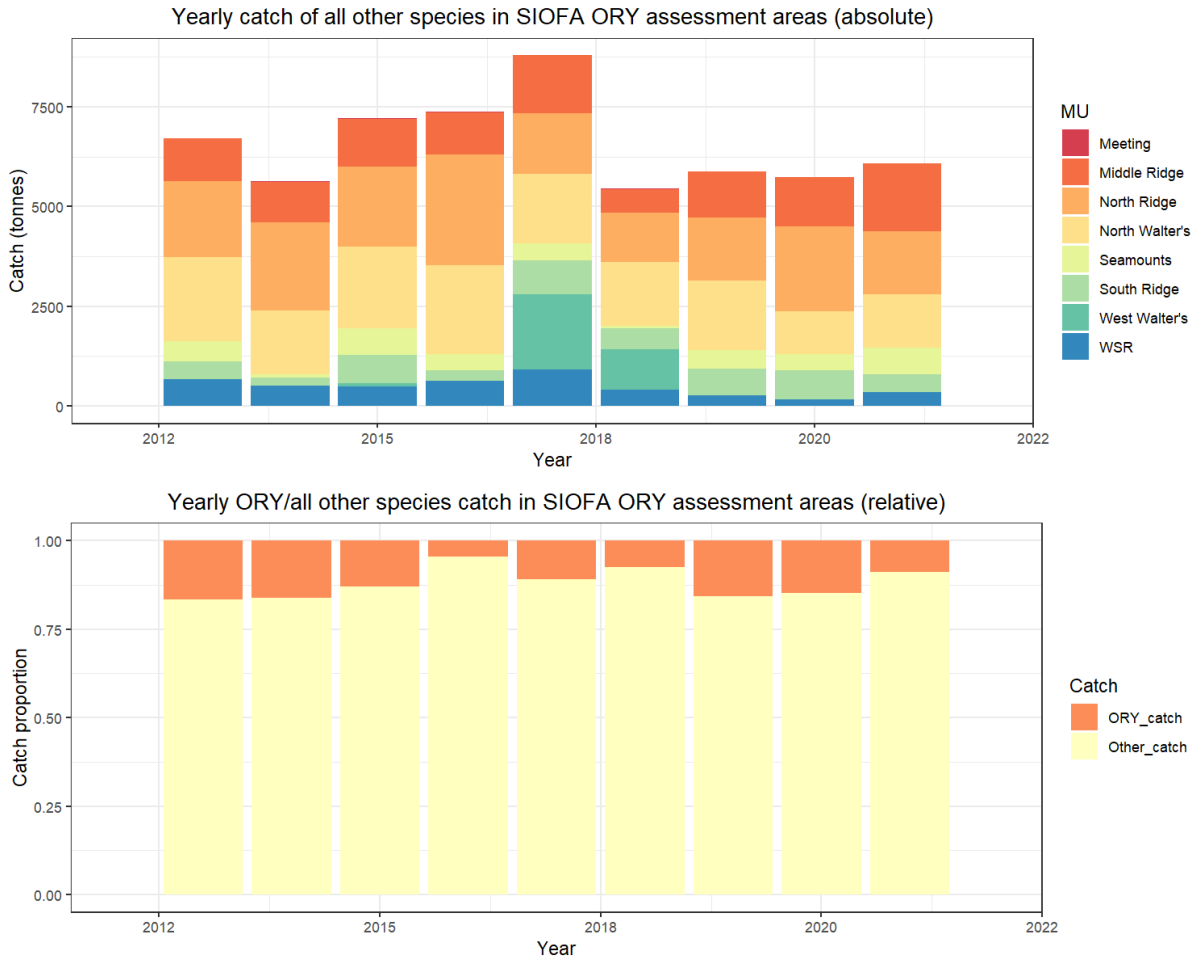


Figure 7a and b – Catch of all species other than ORY in the different SIOFA orange roughy assessment areas (top panel) and ratio between orange roughy catch and catch of all other species aggregated across all assessment areas (bottom panel), by year (source: SIOFA AggregatedCatchEffort and HBHCatchEffort database 2013–2020). Catches reported without location information are not included.

Table 1 shows the catch history of orange roughy catches in the different assessment areas from 1999-2000. Where reported catches are taken by a single vessel, the data is withheld for reasons of confidentiality.

Table 1 - Orange roughy catch per year and per assessment area (t).

[this table is not included in the public version of the manuscript, due to confidentiality limitations set out in CMM 13-2016]

In 2020, only one CCP (the Cook Islands) targeted and/or landed orange roughy.

5.5 Catch limits

There are currently no catch limits set for orange roughy in the SIOFA Agreement area or any of the single assessment areas.

5.6 Illegal Unreported and Unregulated (IUU) catch

No claims of Illegal Unreported and Unregulated (IUU) catches of orange roughy have been reported to SIOFA.

5.7 Other sources of fishing mortality

Some mortality associated with escapement from trawl nets is likely to occur, mostly of small fish that escape through the trawl mesh. The level of mortality associated with escapement is unknown.

6. Stock assessment and status

Integrated stock assessments were performed in 2014 (Cordue 2014), 2018 (Cordue 2018a and b) and 2022 (Roa-Ureta *et al*. 2022), using the CASAL software (Bull et al. 2012).

The most recent stock assessment (Roa-Ureta *et al*. 2022) was conducted using the following time series data: i) fishing effort (number of hauls) and catch (kg) from 2000 to 2020 from vessel logbook records; ii) annually aggregated length frequency data from 2011 to 2020; iii) acoustic biomass indices from 2004 to 2018; and iv) age composition data from the catch for 2017.

The assessment updated a previous assessment done with data up to 2017 (SAWG (2018)-01-05 and SAWG (2018)-01-06) using CASAL (Bull et al. 2012) for the WSR management unit (MU). This was updated with an age structured model developed for the stock in the WSR, both with migration among features (sub-localities) of the MU, and by aggregating features inside the WSR as suggested by the spatial analysis (Roa-Ureta et al 2022).

The spatial analysis suggested that the MUs could be aggregated into two larger spatial units, the the "Long Walter's Shoal Ridge" (LWSR) and the "South-west Indian Ocean Ridge" (SWIOR), leaving only the area to the west of Western Australia outside the scope of the assessments.

The age structure data and acoustic indices of biomass indicated that the available information was not sufficient to model migration among features inside the WSR without introducing large degrees of subjectivity. Roa-Ureta et al (2022) recommended that the age-structured model be continued but with the features aggregated into a single WSR MU, and migration among features be ignored. The model of this area showed high sensitivity to prior distributions of the acoustic catchability coefficient. Nevertheless, results of Roa-Ureta et al (2022) that assumed a target biological reference point (BRP) of 0.5 × B0 and steepness h = 0.57 suggested that the target BRP would be achieved with a constant exploitation rate of 3%. The model showed that the exploitation rate of the stock in the WSR was currently sustainable, with a low probability (p = 0.25) of the stock being overfished. Stock projections from 2021 to 2040 considered nine scenarios of constant catch using different multipliers of the 2020 catch level. All projected scenarios reported by Roa-Ureta et al (2022) had zero probability (p = 0.0) that the exploitation rate would be higher than the BRP exploitation rate at the end of the projected period.

Generalised depletion models combined with Pella-Tomlinson surplus production models for Long WSR and South-west Indian Ocean Ridge showed that the stock was more productive in Long WSR (Roa-Ureta et al 2022). This model for Long WSR was consistent with the age structured assessment in showing the stock as being harvested at sustainable rates, with annual catches well below the maximum sustainable yield (MSY). The MSY in the Long WSR was estimated at 3276 t but with very poor precision (CV=215.7 %). The MSY estimated for the South-west Indian Ocean Ridge was much lower, at 616 t, but with much better precision (CV=88.8 %). In the South-west Indian Ocean Ridge the stock was found to be being harvested close to the MSY with frequent annual catches much higher than the MSY.

Projections from the surplus production model from 2021 to 2040 were carried out for the Long WSR and the South-west Indian Ocean Ridge under three scenarios of constant catch: catch equal to the MSY, 75% of the MSY, and 50% of the MSY. In the South-west Indian Ocean Ridge annual catches at MSY led to a slow decay of biomass and high probability ($p \approx 0.6$) of failing to keep the stock at a biomass equal or higher than the biomass producing the MSY (BMSY) and failing to keep fishing mortality at less than the fishing mortality at the MSY (FMSY). Catches aimed at 75% of the MSY led to a slight increase and the stability of biomass with a moderately low probability ($p \approx 0.3$) of biomass lower than BMSY and fishing mortality higher than FMSY. Finally, catches aiming at 50% of the MSY led to a stronger rise in biomass and subsequent stability with a low probability ($p \approx 0.1$) of biomass lower than BMSY and even lower probability ($p < 0.1$) of fishing mortality higher than FMSY. In the Long WSR all scenarios for future annual catches led to falls in biomass but the rate of decline was substantially different. Aiming for the MSY led to a 3-times decline in biomass with high probability ($p \approx 0.8$) of biomass being below the BMSY and fishing mortality above FMSY. Aiming for annual catches at 75% of the MSY led to biomass dropping by about 30%, with a moderate probability ($p \approx 0.3$) of biomass below BMSY and fishing mortality being higher than FMSY ($p \approx 0.4$). Catches around 50% of the MSY led to a slight decrease in biomass with a low probability of biomass being less than BMSY ($p \approx 0.1$) and of fishing mortality being higher than FMSY ($p < 0.1$).

SC7 did not accept the surplus production model, though it did note that for the WSR there is a high probability (76%) that the stock was not overfished and no overfishing was taking place, suggesting that the stock status is safe. SC7 further noted that projections based recent catch levels (6-year average) would not result in any significant change in the stock exploitation rate. In light of the uncertainty in the stock assessments SC7 recommended precautionary measures to the MoP:

- The MoP agreed to bring forward the ORY stock assessment to the minimum interval of three years, at which time the assessment should also provide advice on whether fishing activity should be constrained on the SWIOR
- A range of measures to improve acoustic survey data collection
- Improvements in the otolith collection and aging processes

6.1 Harvest strategy and reference points

Harvest strategies for orange roughy in the SIOFA Area have not yet been agreed upon. Interim reference points for orange roughy were adopted by the Scientific Committee for scientific reporting purposes, but not necessarily for management, were a target reference point of BMSY using a proxy of = 0.4*B0, and a limit reference point of 0.2*B0 (SC6 report, para 125).

6.2 Data collection

Catch and effort fishery data are collected under CMM 02-2021 and were submitted by the CCPs listed in Table 2.

Table 2 – Orange roughy catch and effort data submitted by different SIOFA CCPs, by year (2000-2021). AUS=Australia; COK=Cook Islands; ESP=Spain; JPN=Japan. HBH= haul-by-haul level data; AG= aggregated data at different levels.

	AUS	COK	COK	ESP	ESP	JPN	JPN
Year	**HBH**	**AGG**	**HBH**	**AGG**	**HBH**	**AGG**	**HBH**
2000	x			x			
2001	x			x	x	x	
2002	x					x	
2003	x	x					
2004	x	x					
2005	x	x					
2006	x						
2007							
2008							
2009	x	x					
2010	x	x					
2011	x	x					
2012	x	x					
2013	x	x					
2014	x	x					
2015		x				x	
2016		x					
2017		x					
2018		x					
2019		x	x				
2020			x				
2021			x				

Scientific Observer data are collected as a requirement of CMM 02-2021, and were submitted by the CCPs listed in Table 3.

Table 3 – Orange roughy Scientific Observer data submitted by different SIOFA CCPs, by year. (source: SIOFA Observer database 2003–2019)

	CCP	
Year	**AUS**	**COK**
2003	x	
2004	x	
2005		
2006		
2007		
2008		
2009	x	
2010	x	
2011	x	
2012	x	
2013	x	
2014	x	
2015		
2016		
2017		
2018		x
2019		x

6.3 Biological data summaries

A summary of biological data collected by Scientific Observers, and counts of records by year for selected data fields, are shown in Table 4.

Table 4 – Orange roughy biological data collection by Scientific Observers, by year. Numbers of records per year are summarised for the following: weight, length, and gonad maturity stage (separately for males and females), and otoliths collected (source: SIOFA Observer database 2003–2019).

	Weight measurements					Length measurements					Maturity stage					Gonad weight	Otoliths
Year	F	I	J	M	total	F	I	J	M	total	F	I	J	M	total	total	total
2003	136		25	103	264	136		25	103	264	136		25	103	264		174
2004	197		3	173	373	276		3	275	554	277		3	275	555		99
2005																	
2006																	
2007																	
2008																	
2009	379	3		524	906	379	3		524	906	379			524	903		1006
2010	51		27	33	111	22		27	16	65	51		27	33	111		84
2011	9		11	3	23	9		11	3	23	9		11	3	23		557
2012	632	29		699	1360	631	29		699	1359	631	29		699	1359		
2013	23			9	32	23			9	32	22			9	31		1
2014	139	2		142	283	139	2		142	283	139	2		142	283		74
2015																	
2016																	
2017																	
2018	4895	409		3372	8676	4896	409		3372	8677	4159			2858	7017	9012	426
2019						4978	506		2809	8293	4978	110		2809	7897		763
2020	3642	503	20	2634	6799	3642	503	20	2634	6799	3639	2	18	2632	6291		680
2021	32			10	42	32			10	42	32			10	42		

6.4 Tag data

SIOFA does not require or conduct any tagging of orange roughy, and any such tagging program is unlikely to be successful.

7. Summaries of abundance indices and other observational data

7.1 Scaled length frequencies

Length frequencies were estimated by Cordue (2018) but were not published.

7.2 Scaled age frequencies

Fish from one feature (a seamount called Sleeping Beauty) were sampled for otoliths in 2017 so that an age frequency could be constructed and growth parameters established. These data were used in conjunction with a stock hypothesis, a catch history, and acoustic biomass estimates to perform a Bayesian stock assessment as described in Cordue (2018a). The same parameters were later used in the updated stock assessment described in Roa-Ureta (2022). The scaled age frequencies are shown in Figure 8.

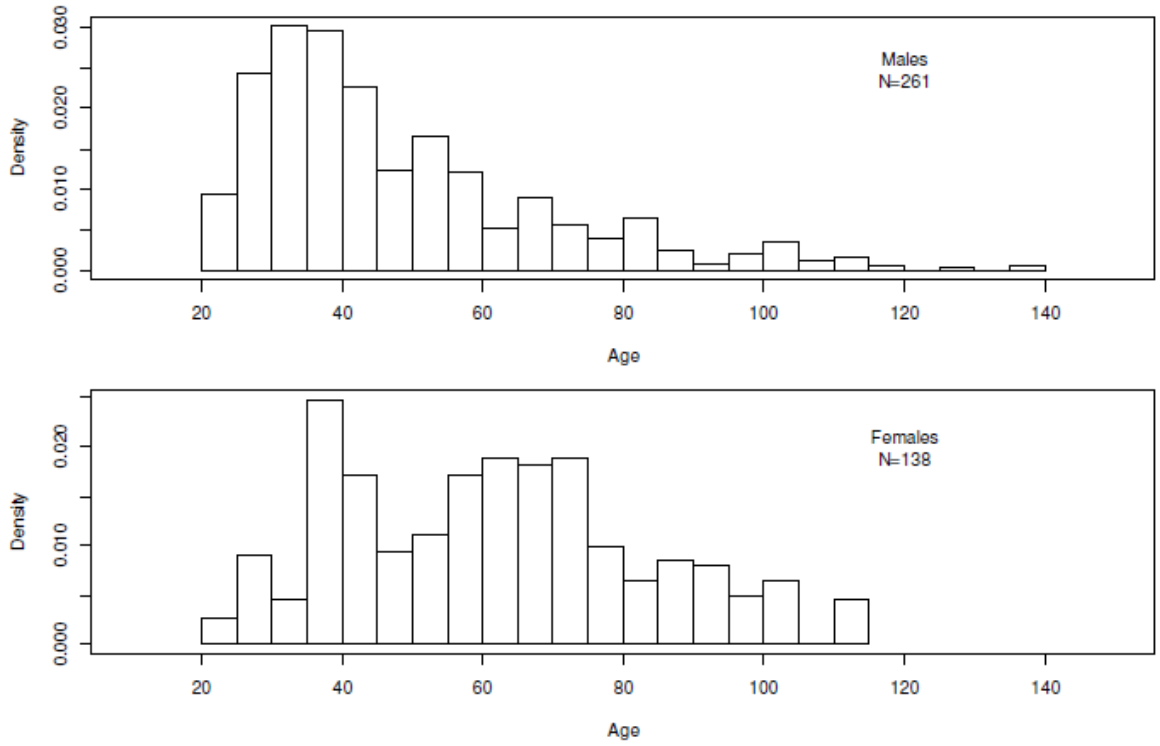


Figure 8 – Scaled age frequencies by sex used as used in the stock assessment described in Cordue (2018a).

7.3 CPUE indices

Recent years have seen lower levels of effort (hauls) with higher catches (Figure 3a), so unstandardised catch per unit of effort (CPUE) have been rising correspondingly (Figure 4). Standardised CPUE indices have not been developed, however it is likely that standardised CPUE

would have little information as an index of abundance for orange roughy aggregations on seamounts.

7.4 Acoustic biomass indices

Macaulay (2022) calculated acoustic biomass indices (Table 5) that was presented at SC7 in paper SC-07-23.

Table 5 – Biomass, sampling coefficient of variation (CV), fish areal density, and metadata for surveys that had identified orange roughy backscatter.

Area	Feature	Survey start date	Transect type	Mean fish density [fish/m²]	Biomass [t]	Sampling CV [%]	Number of transects	Survey area [km²]
North Ridge	Fruitsalad	2018-07-25	parallel	0.31	1800	43	6	2.1
		2018-08-30	star	0.11	400	36	11	1.2
North Walter's	Angelo's	2019-06-07	parallel	0.16	500	15	3	1.1
	Da Vinci's	2018-06-20	parallel	0.07	300	104	5	1.6
South Ridge	Crayfish	2018-08-28	parallel	1.21	6900	23	14	2.1
	Boulder	2018-07-03	parallel	0.51	4100	29	6	2.9
		2018-07-03	parallel	0.44	2000	41	6	1.7
		2018-07-03	parallel	0.66	3000	20	5	1.7
WSR	Grover	2018-07-05	parallel	0.40	1000	14	4	0.9
	Porky's	2018-07-01	parallel	0.19	700	18	8	1.4
		2018-07-09	parallel	0.01	200	68	7	5.0
	Sleeping Beauty	2018-07-01	parallel	0.35	2500	25	6	2.6
		2018-07-02	parallel	0.11	1400	33	6	4.7
		2018-07-04	parallel	0.27	1800	29	4	2.5
		2018-07-12	parallel	0.04	800	53	6	7.9
	Wrongford's	2018-06-22	parallel	0.08	1700	49	7	7.6
		2018-06-24	parallel	0.16	1100	28	4	2.5
		2018-06-27	parallel	0.04	1000	104	8	10.3
		2018-06-28	parallel	0.01	300	98	7	12.8
		2018-07-05	parallel	0.44	11 000	40	7	9.1
		2018-07-05	parallel	1.36	50 400	89	7	13.5
		2018-07-19	parallel	0.35	6900	23	7	7.0
		2019-06-22	parallel	0.27	2500	21	5	3.5
		2019-06-23	parallel	0.25	400	21	4	0.6
		2019-06-23	parallel	0.23	1300	17	5	2.1
		2020-07-13	star	0.57	6400	66	18	4.1

7.5 Trawl survey indices

No trawl surveys have been undertaken for orange roughy in the SIOFA Area.

7.6 Tag based abundance estimates

SIOFA does not require or conduct tagging of orange roughy and no orange roughy tagging experiments in the SIOFA Area have been reported to SIOFA, hence no tag-based abundance indices of abundance are not available.

8. Biological parameters

Biological parameters for orange roughy used in the most recent stock assessment were collected in a single table (Table 6).

Table 6 – Biological parameters for orange roughy used in the most recent stock assessment by Roa-Ureta et al. (2022)

Relationship	Parameter (units)	Area	Value			References
			Both	Male	Female	
Natural mortality	M (y^{-1})		0.042 (0.032-0.054)			Roa-Ureta et al. (2022)
Von Bertalanffy growth coefficient	t_0 (y)			-0.5	-0.5	Cordue (2018a)
	k (y^{-1})		0.069	0.073	0.065	Cordue (2018a)
	L_∞ (cm)		46.75	45.2	48.3	Cordue (2018a)
	c.v.					
Length-weight	a ($t.cm^{-1}$)			0.000316	0.000215	Cordue (2018a)
	b			2.38	2.50	Cordue (2018a)
Maturity	a_{50} ($\pm a_{to95}$)		37 (±12)			Cordue (2018a)
Stock recruitment relationship			Beverton-Holt			
Stock recruitment steepness	h		0.57			Roa-Ureta et al. (2022)
Recruitment variability	σ_R	stable				
Ageing error type	Normal					
Ageing error parameters	c.v.			0.1		Cordue (2018a)

8.1 Natural mortality

Natural mortality was estimated by Roa-Ureta et al. (2022) within the age-structured stock assessment and was estimated to be 0.042 y^{-1} (0.032-0.054).

8.2 Growth parameters

Growth parameters were estimated by Brouwer *et al*. (2022, SERAWG-04-09) and are given in Table 7. Note that these are not the same growth parameters that were used in the most recent stock assessment by Roa-Ureta et al. (2022) as given in Table 6.

Brouwer et al. (2022) noted that otolith and associated biological data collection has been inconsistent in SIOFA orange roughy fisheries, and recommended that in future a stratified sampling selection should be employed for otolith collection to ensure more representatives samples are collected across the size range of fish and between areas to estimate growth. However, it was noted that age-length keys may be an imprecise method for calculate age-frequencies and that random age sampling may be better for determining age frequencies for orange roughy (R. Saunders, NIWA, pers. Comm.).

Table 7 – Growth parameters for orange roughy in different assessment units and the overall SIOFA Agreement area (source: Brouwer et al. 2022, SERAWG-04-09).

Parameters	Combined	Male	Female
Walters Shoal			
L_∞	46.6 (45.98 , 47.22)	45.09 (44.5 , 45.68)	48.61 (47.78 , 49.44)
k	0.07 (0.07 , 0.08)	0.08 (0.07 , 0.09)	0.07 (0.06 , 0.07)
t_0	3.49 (2.49 , 4.49)	4.1 (3.07 , 5.13)	3.31 (4.48 , 2.14)
CV	0.08	0.06	
South			
L_∞	54.99 (52.88 , 57.1)	53.38 (51.18 , 55.59)	57.13 (53.77 , 60.48)
k	0.05 (0.03 , 0.07)	0.13 (0.02 , 0.23)	0.04 (0.02 , 0.06)
t_0	7.65 (-1.77 , 17.07)	18.35 (10.85 , 25.85)	4.44 (18.94 , 10.05)
CV	0.08	0.07	
West			
L_∞	50.7 (49.34 , 52.06)	50.53 (48.5 , 52.55)	51.51 (49.8 , 53.23)
k	0.04 (0.03 , 0.06)	0.03 (0.02 , 0.04)	0.06 (0.04 , 0.08)
t_0	-7.91 (-16.46 , 0.64)	-29.93 (-47.01 , -12.86)	4.18 (10.39 , 2.03)
CV	0.08	0.08	
SIOFA			
L_∞	48.78 (48.23 , 49.32)	47.03 (46.32 , 47.75)	50.83 (49.95 , 51.71)
k	0.06 (0.06 , 0.07)	0.07 (0.06 , 0.08)	0.06 (0.05 , 0.06)
t_0	2.6 (1.49 , 3.71)	2.17 (0.14 , 4.2)	2.66 (1.23 , 4.08)
CV	0.08	0.08	

8.3 Length/weight relationship

The length-weight relationship used in the most recent stock assessment by Roa-Ureta et al. (2022) was carried forward from Cordue (2018a) and is shown below in Figure 9.

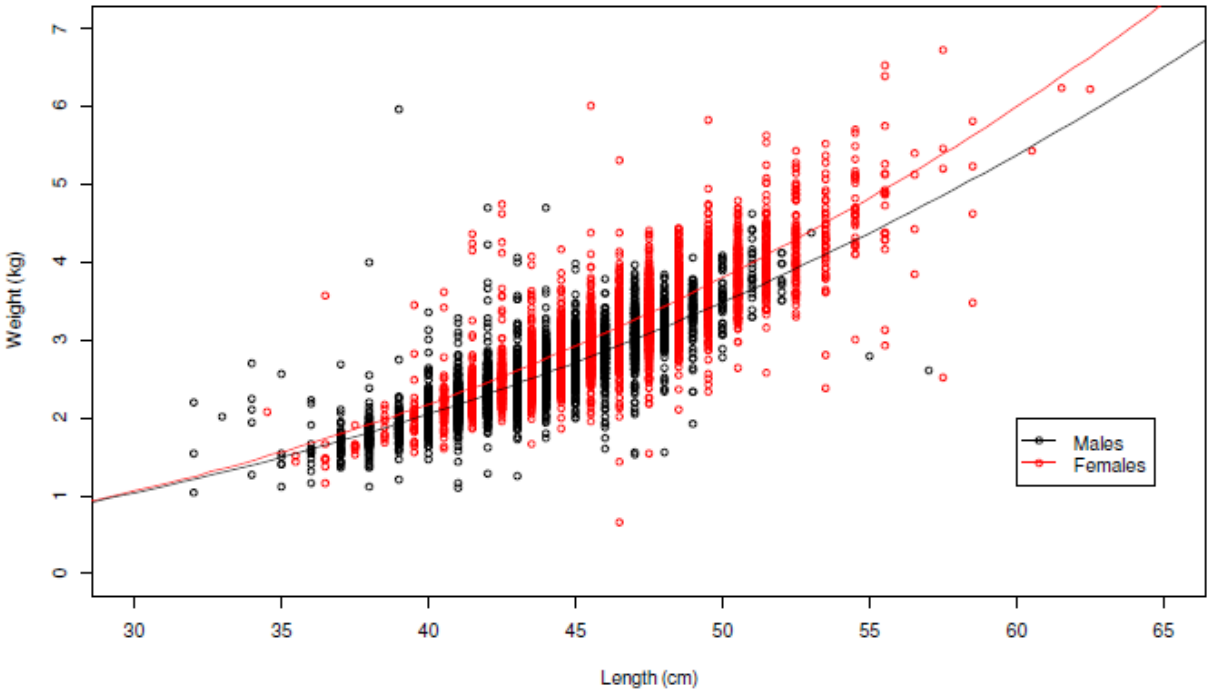


Figure 9 – Length-weight data from Beauty Seamount used in the stock assessment described in Cordue (2018a) and carried forward also in the stock assessment described in Roa-Ureta et al. (2022). Fitted curves are shown separately form males and females; female lengths are offset by 0.5 cm for display purposes.

8.4 Maturity and spawning

Maturity parameters representing the median age at which male and female fish become sexually mature are shown below in Table 8. These were derived from gonad staging data from samples collected in the SIOFA area as described in Brouwer et al. (2022). These authors note that biological sampling has been inconsistent in time and space in the SIOFA orange roughy fishery, recommend revision of the sampling protocols to prioritise biological data collection in tows made on the Southern Rise, Western Rise and areas to the East within the SIOFA area.

Table 8 – Orange roughy length-at-50% maturity for each sex, by region area (source: Brouwer et al. 2022, SERAWG-04-09).

Area	Female length (cm)	Male length (cm)
South Ridge	35.3	40.45
Walters Shoal	39.15	39.55
Western Rise	34.97	38.08
SIOFA area	33.08	36.85

8.5 Stock recruitment relationship

The stock-recruitment relationship for orange roughy has not yet been investigated in the SIOFA Agreement area. The stock assessment described in Roa-Ureta (2022) assumed a Beverton-Holt stock recruitment relationship with a steepness value (h) of 0.57, based on a ratio between length at 50% maturity and asymptotic length, as proposed in a meta-analysis by Wiff et al. (2018). This is lower than the steepness value of 0.75 used in the assessment by Cordue (2018a).

8.6 Tag parameters

SIOFA does not require or conduct any tagging for orange roughy.

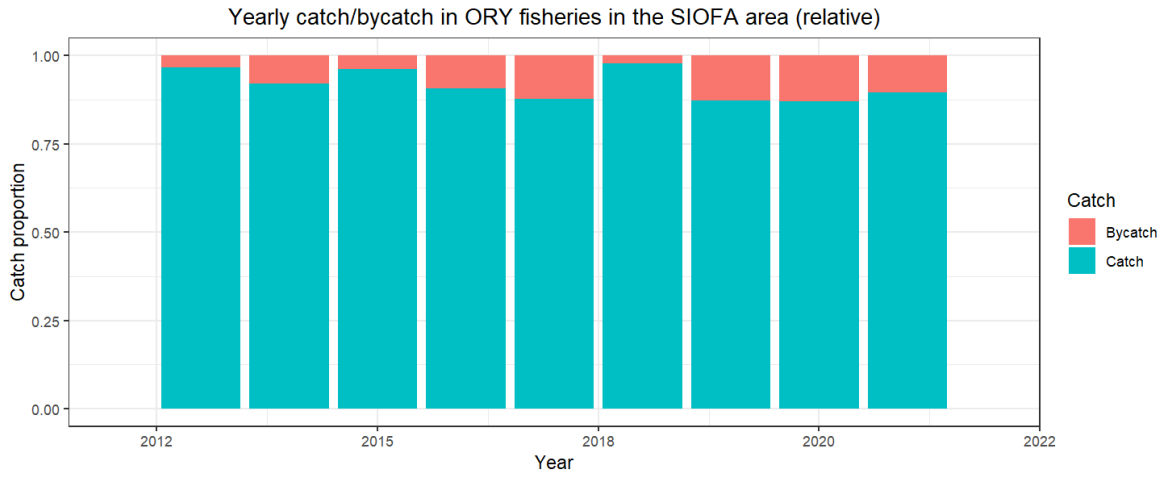
9. Catch/bycatch and ecosystem impacts

Bycatch commonly refers to the capture of all fish species that were not intended as a target in a given fishing event. All fish caught but not declared as targets (CMM 02-2021) are considered bycatch for the purpose of this section.

9.1 Orange roughy catch and bycatch

The ratio of catch and bycatch in the orange roughy fisheries suffers from a lack of reported target species for fishing events that caught orange roughy before 2019, hence it was not possible to determine catch/bycatch ratios before 2019. As a practical means of estimating the catch/bycatch ratio for that period, WS2022-SUM1 suggested using a catch threshold whereby hauls in which at least 50% of the catch was orange roughy are designated as orange roughy target hauls and hauls that caught less than 50% orange roughy considered as orange roughy bycatch. This criterion identified as targeted to orange roughy hauls that contributed 90–95% of the total annual catch of orange roughy.

Catch/bycatch is depicted in Figure 10. Note that the 50% catch threshold rule to define orange roughy target hauls was applied only to fishing effort before 2019, and the pre-2019 ratios are not strictly comparable to the data from 2019 onwards in this figure. Future work should consider harmonizing this time series.



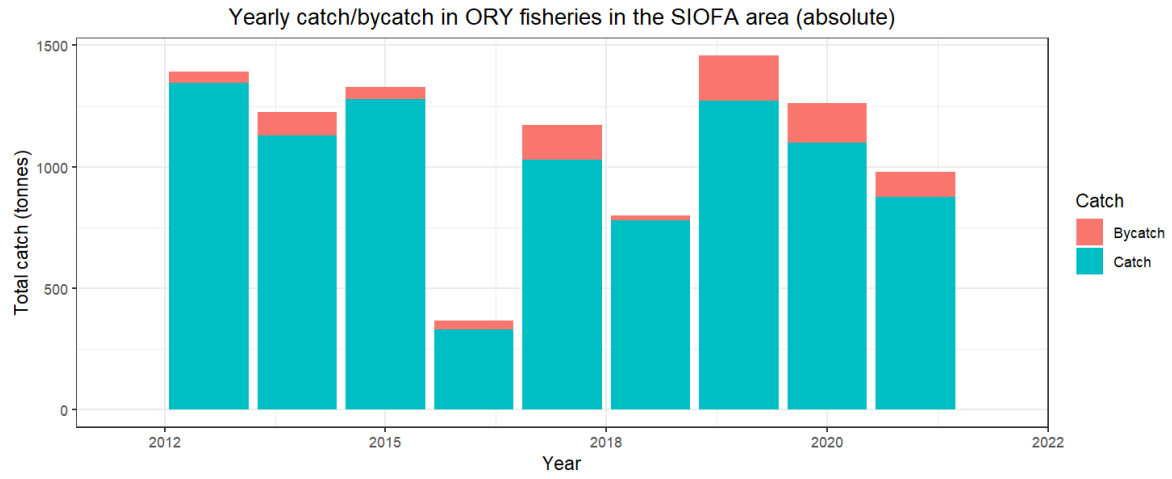


Figure 10a and b – Catch of orange roughy and other species in SIOFA fisheries that targeted orange roughy, shown as relative values (upper panel, a) and absolute values (lower panel, b) (source: SIOFA AggregatedCatchEffort and HBHCatchEffort databases 2013–2020). Catches reported without location information are not included. Note that catch data for years prior to 2019 did not record orange roughy as a target species, so data in these years reflect an assumption that orange roughy target hauls are those that caught greater than 50% orange roughy by weight.

Figure 11 illustrates the species that compose the majority of bycatch in fisheries targeting orange roughy.

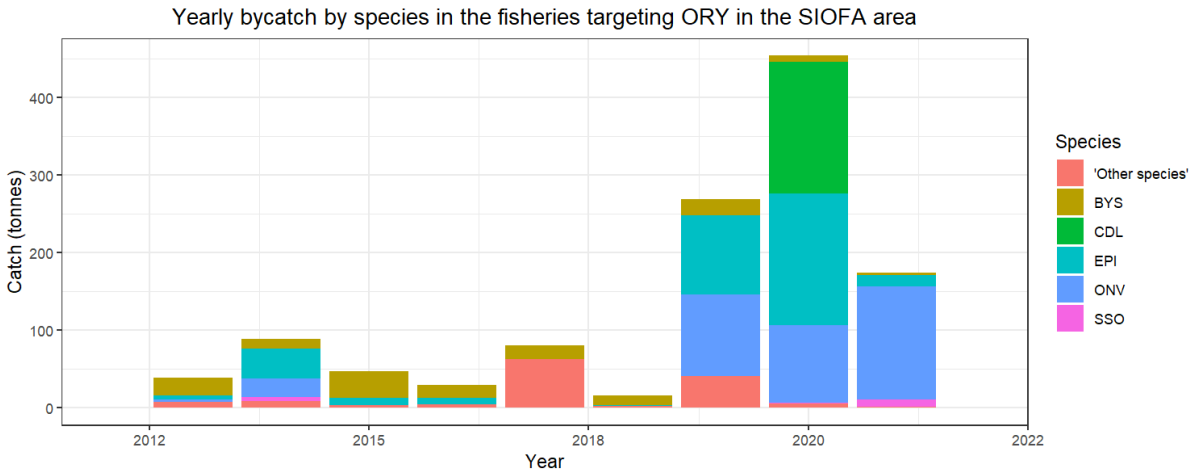


Figure 11 – Yearly bycatch in fisheries targeting orange roughy in the SIOFA area, by species (source: SIOFA AggregatedCatchEffort and HBHCatchEffort databases 2013–2020). Species are identified by their 3-letter FAO code.

Bycatch of shark species is shown in Figure 12; however shark catches (comprising only little sleeper shark, SOR) were only reported in the CatchEffort database in a single year (2017). See also Section 9.4 for sharks reported in Observer database.

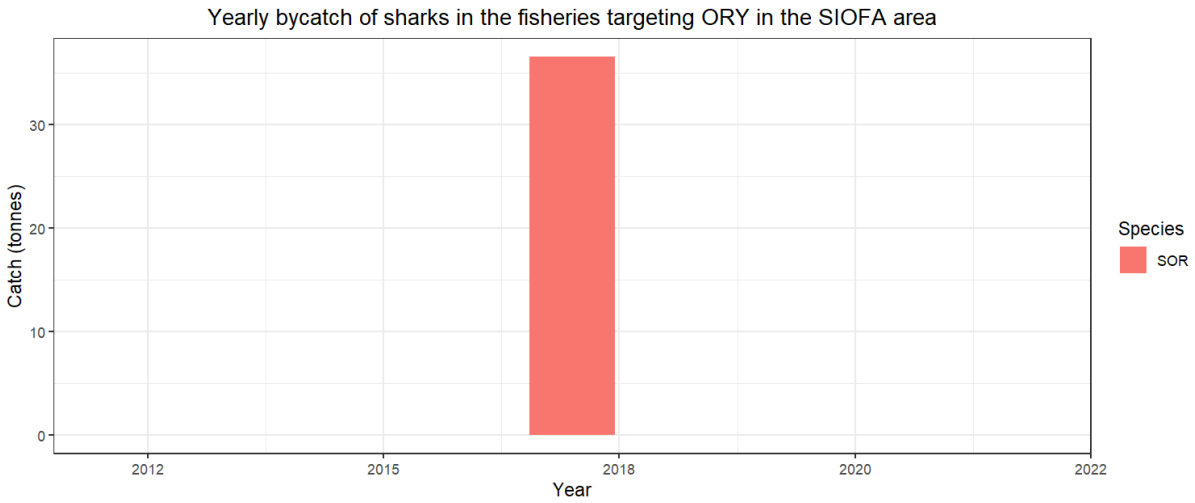


Figure 12 – Reported bycatch of shark species in fisheries targeting orange roughy (source: SIOFA AggregatedCatchEffort and HBHCatchEffort databases 2013–2021).

9.2 Catch/bycatch by SIOFA Subarea

Target catch and bycatch species in fisheries targeting orange roughy in the SIOFA area were largely concentrated in Subareas 2 and 3b for target catch (Figure 13).

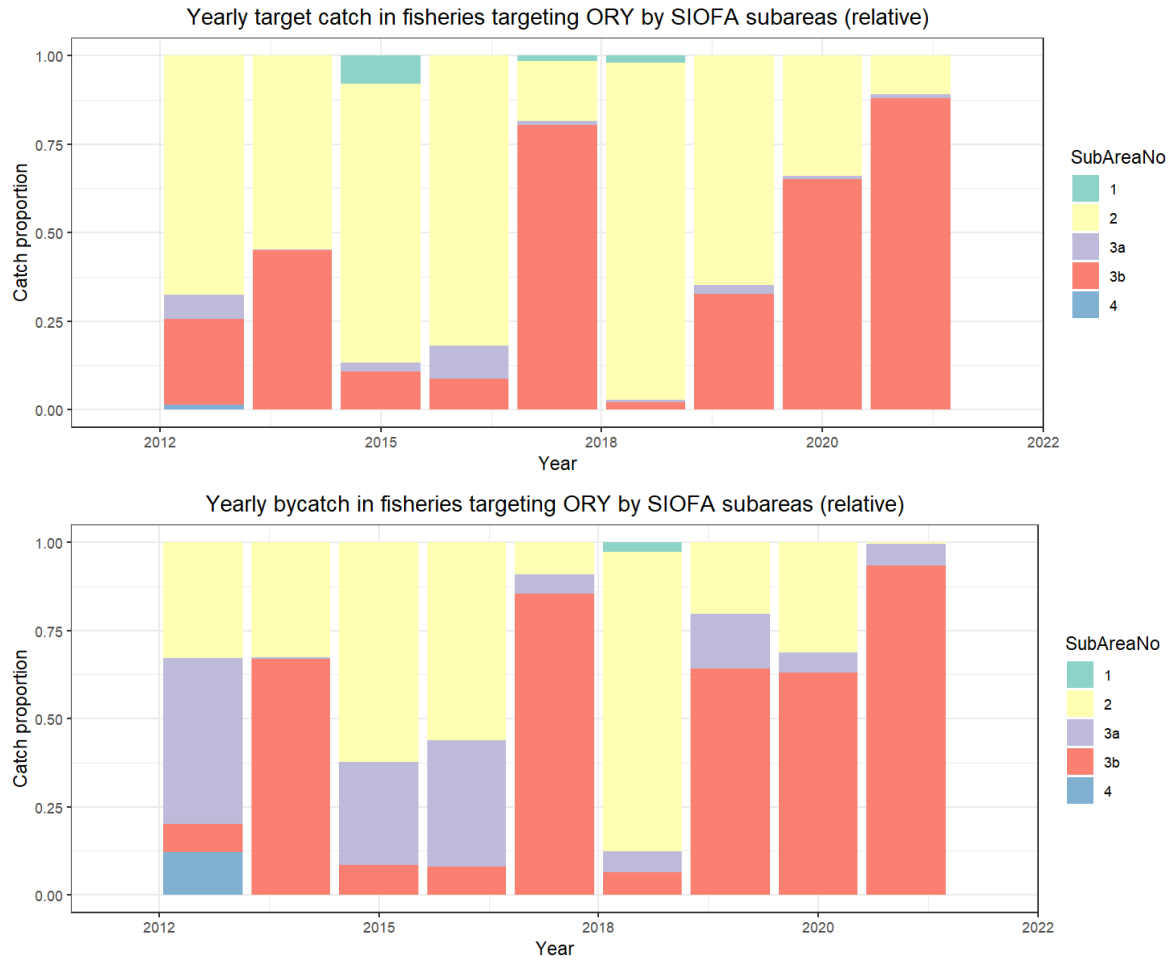


Figure 13a and b – Distribution of target catch and bycatch in fisheries targeting orange roughy in different SIOFA Subareas (source: SIOFA AggregatedCatchEffort and HBHCatchEffort databases 2013–2021). Catches reported without location information are not included. Values of the figure panels are provided in Table A.3 (Appendix A).

9.3 Catch/bycatch in orange roughy Assessment Areas

[this section is not included in the public version of the manuscript, due to confidentiality limitations set out in CMM 13-2016]

9.4 Incidental catch of VME taxa and other invertebrates

SIOFA Scientific Observers recorded the incidental captures of VME indicator taxa in fishing operations targeting orange roughy starting in 2003. While early years saw large (> 2 t) yearly incidental captures, these have been much more limited (< 500 kg) in recent years (Figure 15).

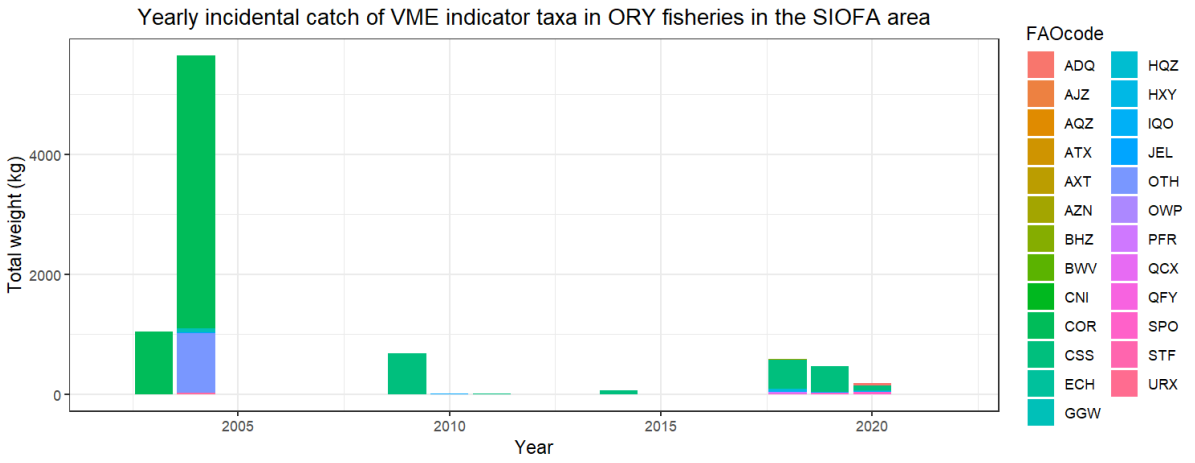


Figure 14 – Yearly incidental catch of VME indicator taxa in fisheries targeting ORY within the SIOFA Area, by taxa group (source: SIOFA Observer and HBHCatchEffort databases 2003–2021). Taxa are indicated by their 3-letter FAO code (see Appendix C). Captures were recorded in 2021, but the total weight was negligible and thus difficult to visualise in this figure.

10. Interactions with seabirds, mammals, turtles, sharks and other species of concern

10.1 Seabirds

Incidental captures of seabirds in orange roughy fisheries consist of a single fatal capture of Hall's giant petrel (*Macronectes halli*) in 2012 by a vessel operating a bottom trawl.

Provisions for the mitigation of accidental capture of seabirds in orange roughy fisheries are in CMM 13-2022 (Conservation and Management Measure on mitigation of seabird's bycatch in demersal longlines and other demersal fishing gears fisheries).

10.2 Marine mammals

Incidental captures of mammals in orange roughy fisheries consist of a single non-fatal capture of a sperm whale (*Physeter macrocephalus*) in 2012 by a vessel operating a bottom trawl.

10.3 Turtles

No interactions with turtles have been reported.

10.4 Sharks

No shark captures of species included in Annex 1 of CMM 12-2022 (Sharks) were reported in the SIOFA Observer database for fisheries that targeted orange roughy between 2013 and 2020.

11. Effects of the fishery on the ecosystem

The effects of this fishery on the ecosystems have not yet been investigated.

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Appendix A – Supplementary tables and figures

Table A.1 – Total catch of orange roughy per year (source: SIOFA AggregatedCatchEffort and HBHCatchEffort databases 2013–2020). Total catch includes both catch and bycatch.

Year	Total catch (t)
2013	1391.1
2014	1194.8
2015	1339.8
2016	378.8
2017	1118.4
2018	822.9
2019	1272.5
2020	1129.6

Table A.2 – Total catch (t) of orange roughy per year by SIOFA Subareas (source: SIOFA AggregatedCatchEffort and HBHCatchEffort databases 2013–2020). Total catch includes both catch and bycatch.

Year	Subarea				
	1	2	3a	3b	4
2013		931.9	109.6	330.3	19.2
2014		644.4	40.4	504.9	
2015	101.7	1035.3	42.2	148.6	
2016		297.2	38.6	43	
2017	29.1	183	29.2	877	
2018	13.8	694.2	31.3	15.6	
2019		772.9	34	465.6	
2020	0	488.3	12.8	628.5	

Table A.3 – Catch vs bycatch (t) in orange roughy target fisheries per year by SIOFA Subareas (source: SIOFA AggregatedCatchEffort and HBHCatchEffort databases 2013–2020). Note that prior to 2019 target species was not reported.

Year	Subarea	Bycatch (t)	Catch (t)
2019	2	63	4629.9
2019	3a	47.6	170.1
2019	3b	198.3	2327.1
2020	2	143.6	2291.2
2020	3a	25.9	59
2020	3b	280.4	4399.2