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

1. FISHERY SUMMARY

1.1 Commercial fisheries

The first reported landings of orange roughy between Cape Runaway and Banks Peninsula were in 1981–82 occurring with the development of the Wairarapa fishery. Total reported landings and TACCs grouped into the three orange roughy Fishstocks from 1981–82 to 2020–21 are shown in Table 1. The historical landings and TACCs for these stocks are shown in Figure 1.

Table 1: Reported landings (t) and TACCs (t) from 1981–82 to present. QMS data from 1986–present.

Fishing Year	QMA 2A (Ritchie + E.Cape)		QMA 2B (Wairarapa)		QMA 3A (Kaikōura)		All areas combined	
(1 Oct–30 Sep)	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC or catch limit
1981–82*	–	–	554	–	–	–	554	–
1982–83*	–	–	3 510	–	253	–	3 763	–
1983–84†	162	–	6 685	–	554	–	7 401	–
1984–85†	1 862	–	3 310	3 500	3 266	§	8 438	–
1985–86†	2 819	4 576	867	1 053	4 326	2 689	8 012	8 318
1986–87	5 187	5 500	963	1 053	2 555	2 689	8 705	9 242
1987–88	6 239	5 500	982	1 053	2 510	2 689	9 731	9 242
1988–89	5 853	6 060	1 236	1 367	2 431	2 839	9 520	10 266
1989–90	6 259	6 106	1 400	1 367	2 878	2 879	10 537	10 352
1990–91	6 064	6 106	1 384	1 367	2 553	2 879	10 001	10 352
1991–92	6 347	6 286	1 327	1 367	2 443	2 879	10 117	10 532
1992–93	5 837	6 386	1 080	1 367	2 135	2 879	9 052	10 632
1993–94	6 610	6 666	1 259	1 367	2 131	2 300	10 000	10 333
1994–95	6 202	7 000	754	820	1 686	1 840	8 642	9 660
1995–96	4 268	4 261	245	259	612	580	5 125	5 100
1996–97	3 761	4 261	272	259	580	580	4 613	5 100
1997–98	3 827	4 261	254	259	570	580	4 651	5 100
1998–99	3 335	3 761	257	259	582	580	4 174	4 600
1999–00	3 120	3 761	234	259	617	580	3 971	4 600
2000–01	1 385	1 100	190	185	479	415	2 054	1 700
2001–02	1 087	1 100	180	185	400	415	1 667	1 700
2002–03	782	680	105	99	235	221	1 122	1 000
2003–04	703	680	103	99	250	221	1 056	1 000
2004–05	1 120	1 100	206	185	416	415	1 742	1 700
2005–06	1 076	1 100	172	185	415	415	1 663	1 700
2006–07	1 131	1 100	203	185	401	415	1 736	1 700
2007–08	1 068	1 100	209	185	432	415	1 709	1 700
2008–09	1 114	1 100	173	185	414	415	1 701	1 700
2009–10	1 117	1 100	213	185	390	415	1 720	1 700
2010–11	1 113	1 100	158	185	420	415	1 690	1 700
2011–12	876	875	140	140	428	415	1 445	1 430
2012–13	727	#875	102	#140	296	#415	1 124	#1 430
2013–14	732	875	108	140	331	415	1 171	1 430
2014–15	483	488	54	60	156	177	693	725
2015–16	474	488	59	60	178	177	710	725
2016–17	505	488	57	60	174	177	736	725
2017–18	485	488	46	60	117	177	647	725
2018–19	491	488	60	60	129	177	680	725
2019–20	377	488	61	60	138	177	576	725
2020–21	503	488	59	60	182	177	744	725

* Ministry data, † FSU data. § Included in QMA 3B TAC.
# In 2012–13, shelving (an agreement that transfers ACE to a third party to effectively reduce the catch without adjusting the TACC) occurred (ORH 2A 165 t, ORH 2B 34 t, and ORH 3A 101 t).

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

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

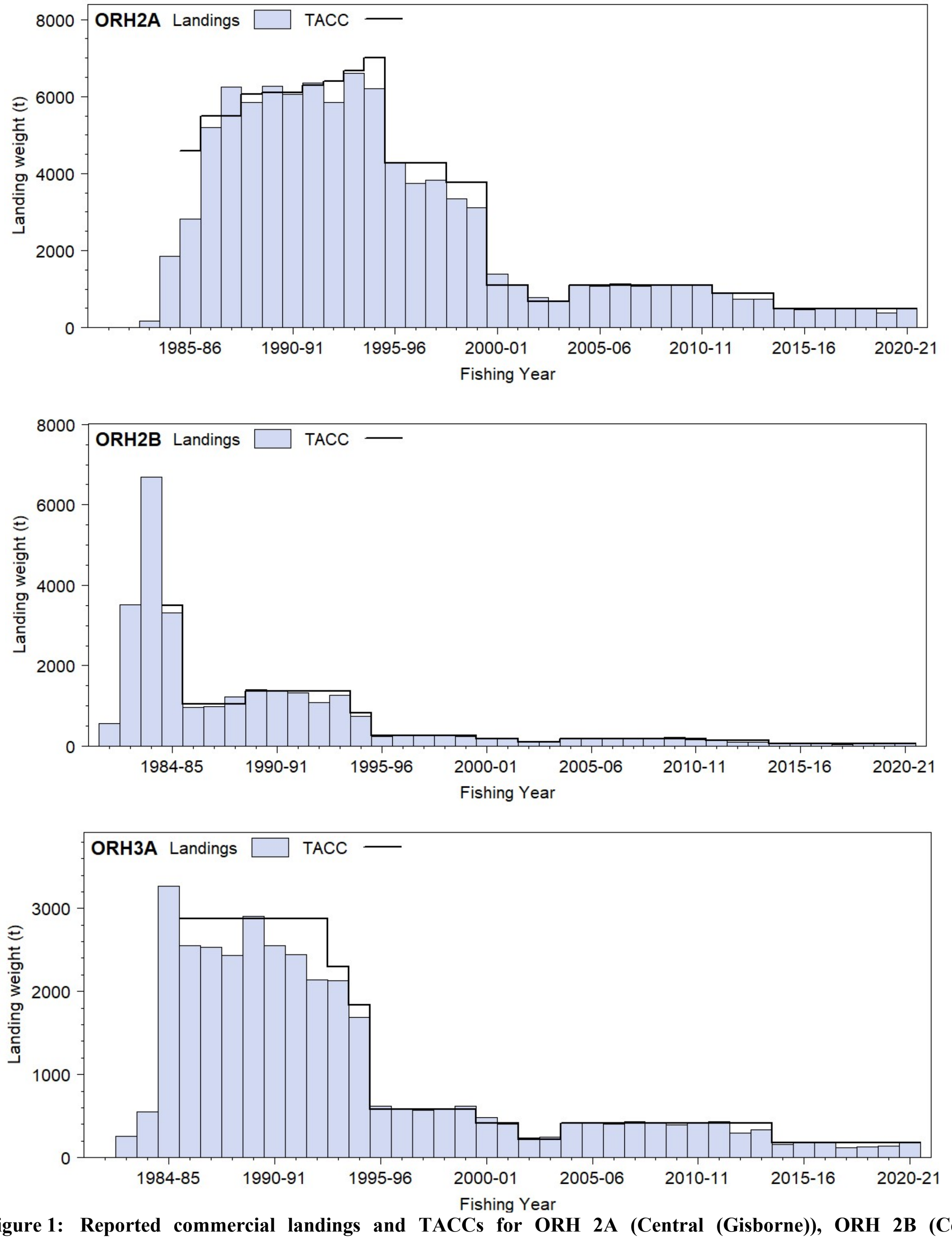


Figure 1: Reported commercial landings and TACCs for ORH 2A (Central (Gisborne)), ORH 2B (Central (Wairarapa)), and ORH 3A (Central/Challenger/South-East (Cook Strait/Kaikōura)).

For the 2000–01 fishing year, the TACC for ORH 2A was reduced to 1100 t, that for ORH 2B to 185 t, and that for ORH 3A to 415 t. Within the TACC for ORH 2A, the catch limit for all of 2A North was reduced to 200 t, without specifying separate catch limits for the East Cape Hills and the exploratory area, while the catch limit for 2A South was reduced to 900 t. This gave a catch limit for the MEC stock of 1500 t. The catch limit for MEC was reduced to 800 t (and ORH 2A South to 480 t) for the 2002–03 and 2003–04 fishing years. From 1 October 2004 there was an increase in the TACC to 1100 t, 185 t, and 415 t in 2A, 2B, and 3A, respectively. Furthermore, an allowance of 58 t, 9 t, and 21 t, for other mortality was allocated to 2A, 2B, and 3A in 2004 as well.

In 2012–13 the fishing industry voluntarily shelved (an agreement that transfers ACE to a third party to effectively reduce the catch without adjusting the TACC) approximately 25% of the MEC quota, resulting in effective catch limits of 510 t, 106 t, and 314 t for 2A South, 2B, and 3A, respectively. In 2014–15 TACCs were lowered further, to 488 t, 60 t, and 177 t in 2A, 2B, and 3A, respectively. Reported commercial landings have closely followed the decreasing TACCs in all three orange roughy stocks and totalled 576 t in 2019–20 and 744 t in 2020–21, slightly over the TACC of 725 t.

Table 2: North Mid-East Coast + East Cape (ORH 2A) catches by area, in tonnes and by percentage of the total ORH 2A catch. (Percentages up to 1993–94 and from 2007–08 calculated from Ministry data; 1994–95 to 1996–97 from NZFIB data, and 1997–98 to 2020–21 from Orange Roughy Management Co.) Mid-East Coast (MEC) stock (ORH 2A South, ORH 2B, and ORH 3A combined) catches in tonnes.

Fishing year	2A North		2A South		MEC (t)
	t	%	t	%	
1983–84	0	0	162	100	7 401
1984–85	4	< 1	1 858	99	8 434
1985–86	41	1	2 778	99	7 971
1986–87	253	5	4 934	95	8 452
1987–88	36	< 1	6 203	99	9 695
1988–89	143	2	5 710	98	9 377
1989–90	20	< 1	6 239	99	10 517
1990–91	13	< 1	6 051	99	9 988
1991–92	18	< 1	6 329	99	10 099
1992–93	30	< 1	5 807	99	9 022
1993–94	3 437	52	3 173	48	6 563
1994–95	2 921	47	3 281	53	5 721
1995–96	3 235	76	1 033	24	1 890
1996–97	2 491	66	1 270	34	2 122
1997–98	2 411	63	1 416	37	2 240
1998–99	1 901	57	1 434	43	2 273
1999–00	1 456	47	1 666	53	2 517
2000–01	302	22	1 083	78	1 752
2001–02	186	17	901	83	1 480
2002–03	173	24	546	76	886
2003–04	170	24	533	76	886
2004–05	271	24	849	76	1 471
2005–06	216	20	859	80	1 445
2006–07	229	20	902	80	1 506
2007–08	200	24	868	76	1 509
2008–09	230	21	884	79	1 471
2009–10	267	24	850	76	1 453
2010–11	207	19	906	81	1 484
2011–12	184	21	692	79	1 260
2012–13	190	26	537	74	935
2013–14	176	25	530	75	5 315
2014–15	179	42	248	58	458
2015–16	186	40	280	60	466
2016–17	188	37	317	63	626
2017–18	196	41	280	59	444
2018–19	197	39	304	61	493
2019–20	173	41	204	59	423
2020–21	217	41	285	59	524

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

Fishing year	2A North	2A South	MEC
1994–95	3 000	4 000	6 660
1995–96	3 000	1 261	2 100
1996–97	3 000*	1 261	2 100
1997–98	3 000*	1 261	2 100
1998–99	2 500*	1 261	2 100
1999–00	2 500*	1 261	2 100
2000–01	200	900	1 500
2001–02	200	900	1 500

Table 3 [Continued]

Fishing year	2A North	2A South	MEC
2002–03	200	480	800
2003–04	200	480	800
2004–05	200	900	1 500
2005–06	200	900	1 500
2006–07	200	900	1 500
2007–08	200	900	1 500
2008–09	200	900	1 500
2009–10	200	900	1 500
2010–11	200	900	1 500
2011–12	200	675	1 230
2012–13	200	510	930
2013–14	200	510	930
2014–15	200	288	525
2015–16	200	288	525
2016–17	200	288	525

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

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

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

1.4 Illegal catch
No information is available about illegal catch in this area.

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

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

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

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

2. BIOLOGY

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

3. STOCKS AND AREAS

Two major spawning locations have been identified in ORH 2A, one at the East Cape Hills in "2A North" and the other on the Ritchie Bank in "2A South". Spawning orange roughy were located in Wairarapa (ORH 2B) in winter 2001, but no large concentrations were found, and the significance of this spawning event is not known. Spawning orange roughy have not been located in Kaikōura (ORH 3A). The major spawning area in ORH 2A South, ORH 2B, and ORH 3A was historically on the Ritchie Bank, but spawning aggregations were not seen there in the 2013, 2017, or 2021 acoustic biomass surveys, and persistent and large catch rates consistent with a spawning aggregation have rarely been seen there in the commercial fishery since the early 2000s. The main spawning aggregations now seem to be to the south at Rockgarden, and to the west at Sea Valley.

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

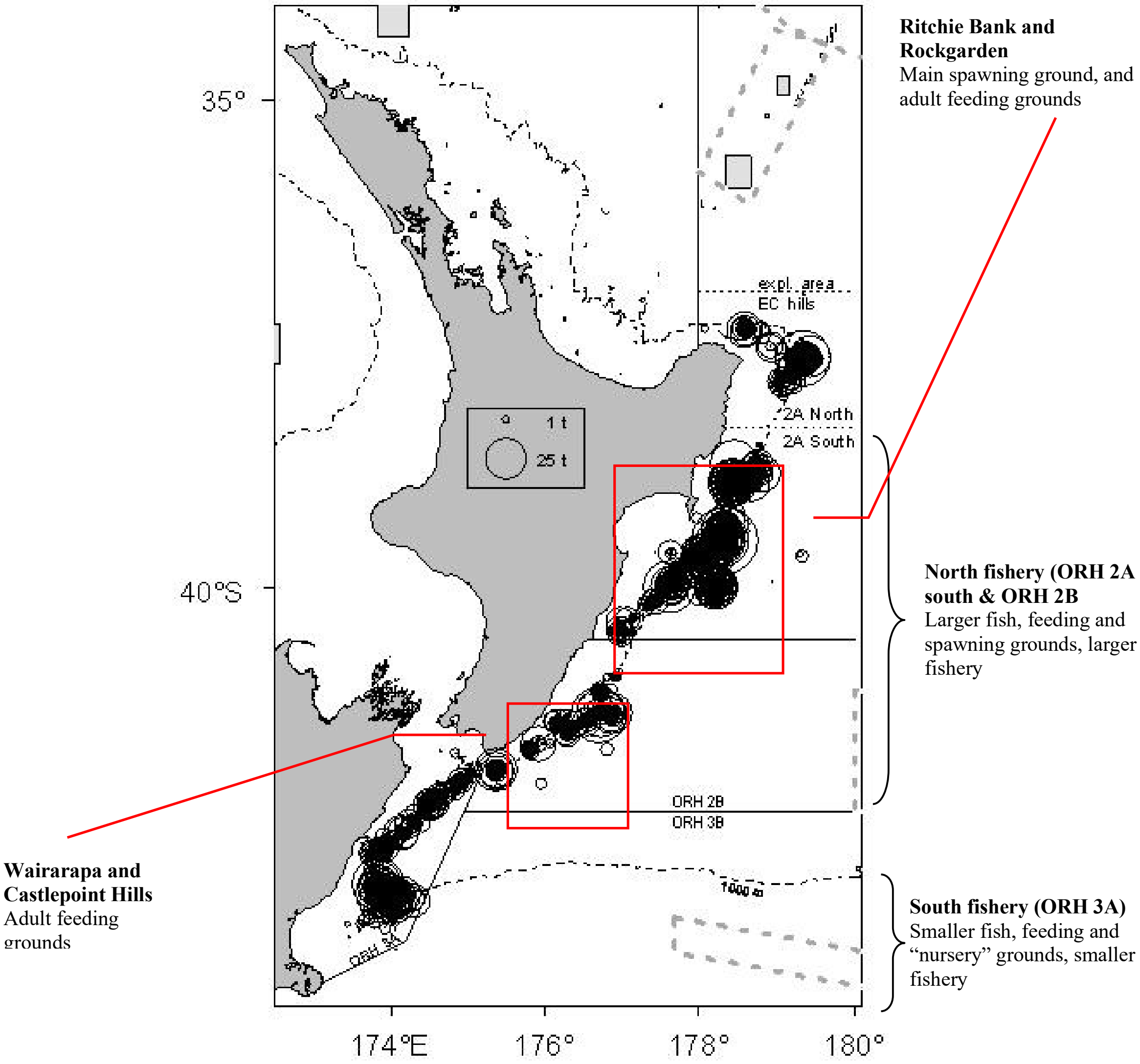


Figure 2: Catch (t) per tow of orange roughy in ORH 2A, ORH 2B, and ORH 3A for the five fishing years from 2006–07 to 2010–11 (circles, with area proportional to catch size), location of the fisheries assumed during stock assessment, and the location of the main spawning, feeding, and nursery grounds.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

4. STOCK ASSESSMENT

Stock assessments are reported below for East Cape (EC) from 2003 and for Mid-East Coast (MEC) from 2022.

4.1 East Cape stock (2A North)

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

4.1.1 Assessment Inputs

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

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

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

4.1.2 Stock assessment

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

- The model was fitted using Bayesian estimation and partitioned the EC stock population by sex, maturity (the fishery was assumed to act on mature fish only) and age (age-groups used were 1–70, with a plus group).
- The model estimated virgin biomass, B_0, and the process error for the CPUE indices. Catchability, q, was treated as a nuisance parameter by the model.
- The stock was considered to reside in a single area, and to have a single maturation episode modelled by a logistic-producing ogive where 50% of fish of both sexes were mature at age 26 and 95% at age 29.
- The catch equation used was the instantaneous mortality equation from Bull et al (2002) whereby half the natural mortality was applied, followed by the fishing mortality, then the remaining natural mortality.
- The size at age model used was the von Bertalanffy.
- No stock recruitment relationship was assumed.
- A Bayesian estimation procedure was used with a penalty function included to discourage the model from allowing the stock biomass to drop below a level at which the historical catch could not have been taken.
- Lognormal errors, with known (sampling error) CVs were assumed for the CPUE and egg survey indices. Additionally, process error variance was estimated by the model and added to the CVs from the CPUE indices.
- Confidence intervals were calculated from the posterior profile distribution of B_0 estimates, where the process error parameter was fixed at the value previously estimated.

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

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

4.1.3 Biomass estimates

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

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

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

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

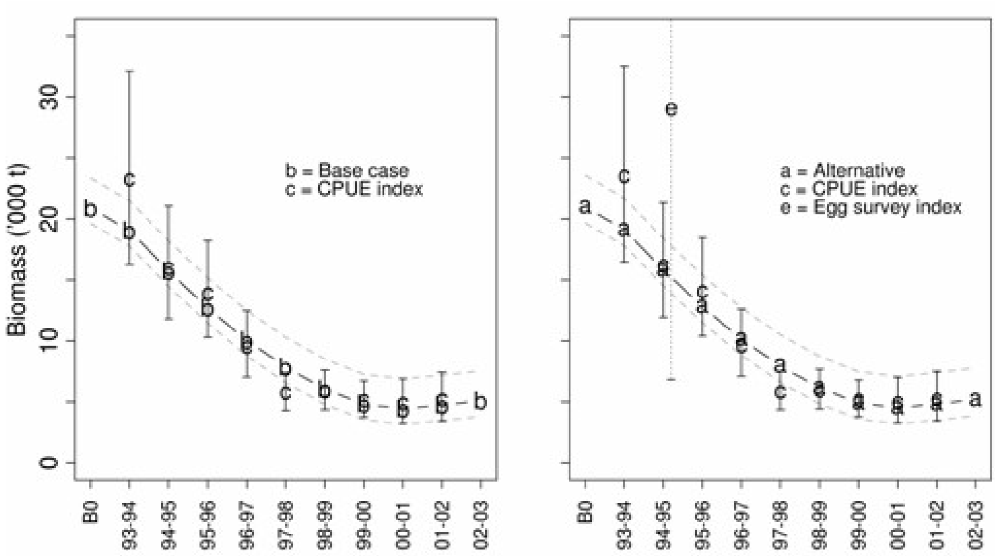


Figure 3: Estimated biomass trajectories for the base case and alternative model runs for the EC stock. Annual biomass estimates are mean posterior density (MPD) values and 95% confidence intervals (grey dashed lines) are calculated from the posterior profile distribution of B_0 estimates. The CPUE index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

4.1.4 Yield estimates and projections

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

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

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

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

A new stock assessment was conducted in 2022. The previous assessment was 2014 (Cordue 2014c). There was no new information available that would change the accepted stock definition of the MEC orange roughy stock as comprising ORH 2A South, ORH 2B, and ORH 3A.

4.2.1 Model structure

The model was sex and age-structured (1–120 years with a plus group) with sex and maturity in the partition (i.e., fish were classified by age, sex, and as mature or immature). A single area and a single time step were used with four year-round fisheries defined by different selectivities (a "south" fishery catching young fish (double-normal selectivity), a "north" fishery catching older fish (logistic selectivity), a "Pegasus" fishery at the Pegasus Canyon since 1999 (logistic selectivity), and a "Spawn" fishery focused on spawning aggregations (logistic selectivity). The spawning season was assumed to occur after 75% of the mortality and 100% of spawning fish were assumed to spawn each year. The spawning ogive (which defines *SSB* and may be different from the maturity ogive in orange roughy) was assumed to be the same as the selectivity for the Spawn fishery, and therefore described the age composition of the spawning fish (Spawning Stock Biomass).

The catch history was constructed by scaling the catches in Table 1 by the catch overrun percentages in Table 4 and partitioning using estimated catch and effort data (Table 8). Catches for 2021–22 were assumed to be same as 2020–21. Natural mortality was assumed to be fixed at 0.045 and the stock-recruitment relationship was assumed to follow a Beverton-Holt function with steepness of 0.75. Growth was modelled by sex and used empirical length-at-age (Figure 4). An ageing error of 0.1 was assumed. All fitted observations were unsexed.

Table 8: Mid-East Coast orange roughy catch (t) history by fishery, including catch overruns, as used in the 2022 stock assessment model.

Fishing year	Spawn	North	South	Pegasus
1981–82	0	153	567	0
1982–83	38	1 000	3 854	0
1983–84	214	2 025	7 414	0
1984–85	2 000	2 599	6 738	0
1985–86	2 907	2 689	5 323	0
1986–87	4 132	3 744	3 605	0
1987–88	4 753	4 272	3 578	0
1988–89	4 224	3 883	3 613	0
1989–90	4 871	3 484	4 266	0
1990–91	3 424	4 500	3 562	0
1991–92	4 371	3 681	3 057	0
1992–93	4 570	2 749	2 606	0
1993–94	2 493	2 095	2 632	0
1994–95	3 097	1 221	1 688	0
1995–96	925	419	640	0
1996–97	1 126	477	626	0
1997–98	859	835	658	0
1998–99	638	1 108	492	149
1999–00	1 154	809	488	192
2000–01	592	723	366	158
2001–02	637	452	383	83
2002–03	201	446	181	101
2003–04	250	370	223	86
2004–05	356	677	371	141
2005–06	518	497	346	157
2006–07	409	661	368	144
2007–08	459	586	411	128
2008–09	460	597	329	158
2009–10	512	563	289	163
2010–11	533	549	238	238
2011–12	591	240	339	154
2012–13	374	290	195	124
2013–14	499	138	217	163
2014–15	229	69	143	39
2015–16	275	73	120	75
2016–17	157	197	143	79
2017–18	128	199	117	21
2018–19	269	105	120	23
2019–20	132	132	118	41
2020–21	225	120	89	118
2021–22	225	120	89	118

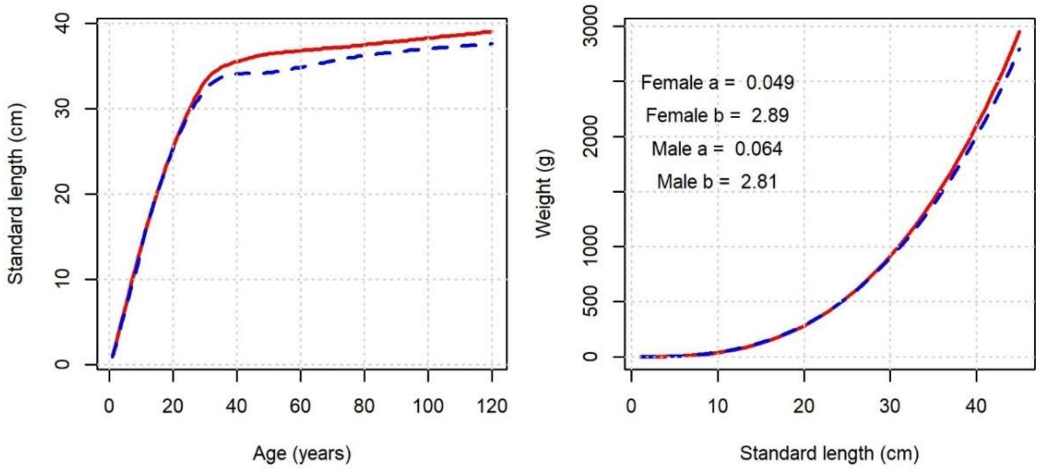


Figure 4: Mid-East Coast orange roughy median length-at-age by sex estimated using a smoother and the length-weight relationship used in the assessment model. The parameters are of the length (L) to weight (W) relationship W = aL^b. The red line represents females and the dashed blue line represents males.

4.2.2 Input data and statistical assumptions

There were four main data sources for observations fitted in the assessment: spawning biomass estimate from acoustic surveys (2013, 2017, and 2021); a trawl survey time series of relative biomass indices (1992–1994, 2010) with associated age frequencies (1993 and 2010) and length frequencies (1992, 1994), age frequencies from the Spawn fishery (commercial 1989, 1990, 1991 and 2010; research 2017 and 2021), and length frequencies (LFs) collected from the commercial fisheries. Estimates of proportions mature-at-age were used in the previous assessment (2014) but excluded in 2022 because they were inconsistent with the spawning age frequencies.

Research surveys

The MEC area has been surveyed using acoustic and trawl methods, and egg surveys have also been conducted. Not all survey data were used in the 2022 assessment. The egg survey estimates have some quality issues associated with them; the 1993 survey data were post-stratified and "corrected" for turnover of fish (Zeldis et al 1997). The 1993 egg survey estimate was used in the 2013 assessment but was not considered to be reliable enough for assessments since 2014 (which had a higher "quality threshold"). Similarly, the wide-area acoustic survey estimates from 2001 and 2003 (Doonan et al 2003, 2004a) have been rejected since 2014 as being not sufficiently reliable (in particular, the biomass estimates primarily came from mixed species marks and "orange roughy" marks identified subjectively; rather than being from easily identified spawning plumes).

Trawl survey data

A time series of pre-spawning season, random, stratified trawl surveys were conducted in March–April on RV *Tangaroa* in 1992–94 and 2010 (Grimes et al 1994, 1996a, 1996b; Doonan & Dunn 2011). The 2010 survey was specifically designed to be comparable with the earlier surveys and to produce an abundance index for the MEC home grounds (Doonan & Dunn 2011). In addition to the relative biomass indices (Table 9), the survey data were analysed to produce length frequencies from all years and age frequencies from 1993 and 2010 (Doonan et al 2011).

Table 9: Mid-East Coast orange roughy biomass indices and CVs used in the 2022 stock assessment.

Year	Trawl index (t)	CV (%)	Acoustic index (t)	CV (%)
1992	20 838	29		
1993	15 102	27		
1994	12 780	14		
2010	7 074	19		
2013			4 225	20
2017			6 969	14
2021			6 326	20

The biomass indices were fitted as relative biomass with a double-normal selectivity on the immature fish, and a constant selectivity on the mature fish, with an uninformed prior on the proportionality constant (*q*). A process error of 20% was added to the CVs. The length frequencies from 1992 and 1994 were fitted as multinomial, as were the age frequencies from 1993 and 2010 (length frequencies from 1993 and 2010 had been used in the production of the age frequencies).

Acoustic survey estimate
The only reliable acoustic estimates of spawning biomass for MEC came from multi-frequency "AOS" surveys (acoustic and optical gear mounted on the trawl headline, e.g., see Kloser et al. 2011). Four areas were visited in 2013, but the only substantial spawning plume was seen in the "Sea Valley". A similar search for spawning aggregations was completed in 2017 and 2021, when spawning plumes were found at both Sea Valley and Rockgarden. All valid snapshot estimates from 38 kHz were averaged to produce the biomass index (see Table 9). No process error was added to the CVs.

A base assumption used for all orange roughy acoustic spawning biomass estimates was that they collectively covered "most" of the spawning biomass, where "most" was taken to be 80%. The previous (2014) assessment for the Mid-East Coast stock reduced this to 60%. Because 2017 and 2021 surveys searched all known substantial spawning grounds for Mid-East Coast orange roughy, in 2022 "most" was revised back to 80%, and sensitivities were conducted for 60% and 100%. The acoustic estimates were therefore fitted as relative biomass with an informed prior: lognormal (mean = 0.8, CV = 19%) for the base model.

Commercial age and length frequencies
Twelve length frequencies between 1991 and 2018 were available for the North fishery, four between 1994 and 2016 for the South fishery, seven between 1990 and 2017 for the Spawn fishery, and two samples, in 2000 and 2016, for the Pegasus fishery. For the Spawn fishery, the length frequency (seven LFs between 1990 and 2017) and age frequency (AF) samples (five AFs from 1989–91, 2010, and 2017) were assumed to represent spawning fish, with selectivity set equal to estimated logistic maturity. The spawning age frequency from 2021 contained a greater proportion of younger fish and was inconsistent with the earlier samples, and so was fitted with its own logistic selectivity. The composition data were all assumed to be multinomial, with effective sample sizes initially based upon Cordue (2014a) for age frequencies, and the number of tows for LFs, but then down-weighted to ensure primacy of the biomass data and more balanced patterns of residuals. Final effective samples sizes for the Spawn AFs were between 13 and 25 (mean 20), the trawl survey AFs were 20, and the LFs were between 1 and 10 (mean 3.2).

4.2.3 Model runs and results
In the base model, natural mortality (*M*) was fixed at 0.045 yr^{-1}. There were numerous MPD sensitivity runs and three main sensitivities are presented in this chapter: $M = 0.035$ yr^{-1}; mean acoustics *q* prior = 0.6; and mean acoustics *q* prior = 1.0. The latter assumed all the spawning biomass was observed by the acoustic surveys.

In the base model, the main parameters estimated were virgin spawning stock biomass (SSB_0), the spawning ogive, three fishery selectivities (North, South, Pegasus), the trawl survey selectivities (immature and mature), the 2021 age frequency selectivity, and year class strengths (YCS) from 1881 to 1996 (with the Haist parameterisation and lognormal priors with CV=0.8). Additional estimated parameters were the CV of the length-at-age parameters and the proportionality constants (*q*s) for the trawl survey time series and the acoustic biomass estimates.

Model fits
The MPD fits to data were similar to the MCMC implied fits. The fits to the biomass indices were acceptable, although the decline in the trawl surveys could not be fitted well (Figure 5).

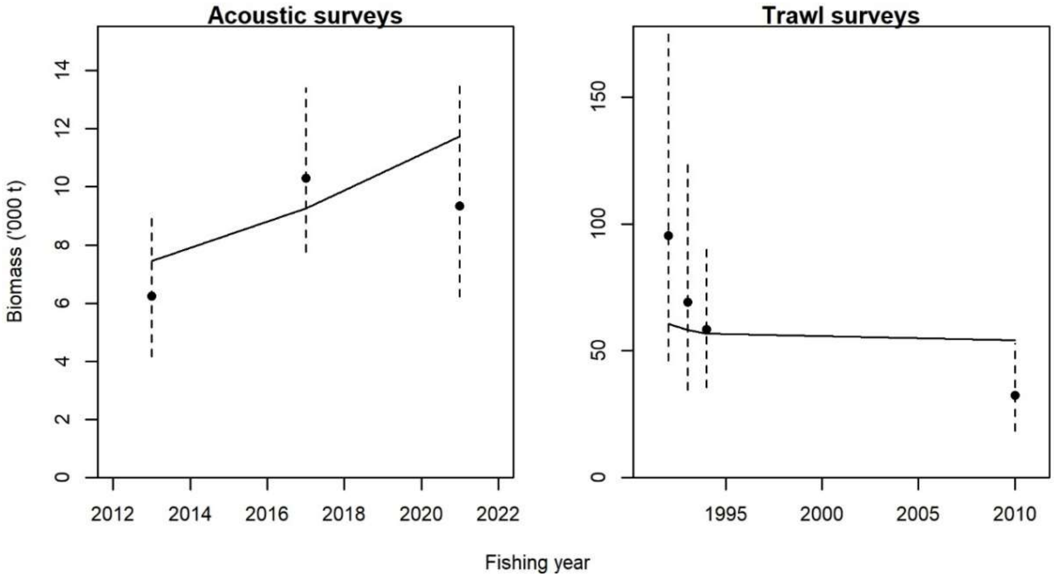


Figure 5: Mid-East Coast orange roughy MPD fit to biomass indices for the base model run: left: acoustic spawning biomass indices (estimated *q* of 0.68); right: *Tangaroa* trawl survey indices. Vertical broken lines are 95% CIs.

The spawning season age frequencies were noisy, but the general shape was fitted well (Figure 6). The fit to the trawl survey age frequencies was good (Figure 6). The MPD fits to the commercial length frequencies were adequate considering the length frequencies showed substantial year-to-year variability (Figure 7). The spawning ogive (which was different from the maturity ogive) was estimated with an A_{50} of 55.2 years and A_{to95} of 18.1 years. The spawning season age frequency for 2021 had a greater proportion of younger fish, with an A_{50} of 35.6 years and A_{to95} of 11.0 years. The age of 50% maturity of orange roughy has been estimated from transition zones on otoliths to be at around 30 years, but assessments have shown that the age of 50% spawning is typically greater. One hypothesis to explain this difference is skipped spawning, where younger mature fish spawn less often. The relatively high proportion of young mature fish observed for 2021 could have been sample bias, or a due to a temporal change in the prevalence of skipped spawning. A separate selectivity was used for this age frequency.

MPD model runs showed that the results were relatively insensitive to changes in the growth model, alternative CVs on the year class strength priors, changes to the weight given to the length frequencies, and alternative selectivity models for the trawl survey data. Simplifying the model to have two fisheries, following the previous assessment (2014), estimated a larger stock at a similar level of depletion, but incurred catch penalties with a poorer fit to data and less plausible YCS and biomass trends. Assuming a higher *M* of 0.06 year^{-1} estimated a smaller and less depleted stock but fitted the data less well, with several implausible selectivity parameters. Using the 2021 spawn age frequency and proportion mature data (as used in 2014) to estimate spawning selectivity, with a separate selectivity then used for the base model "spawn" fishery, estimated a larger and more depleted stock, with a markedly poorer fit to data. MPD runs across a range of *M* and stock-recruitment steepness values indicated the base assumption of *M* was supported by data, and could plausibly be a little lower, and that the model had no information to determine steepness. A sensitivity run estimating *M* was not completed because of the noisy age data with substantial uncertainties in the spawning and fishery selectivity ogives.

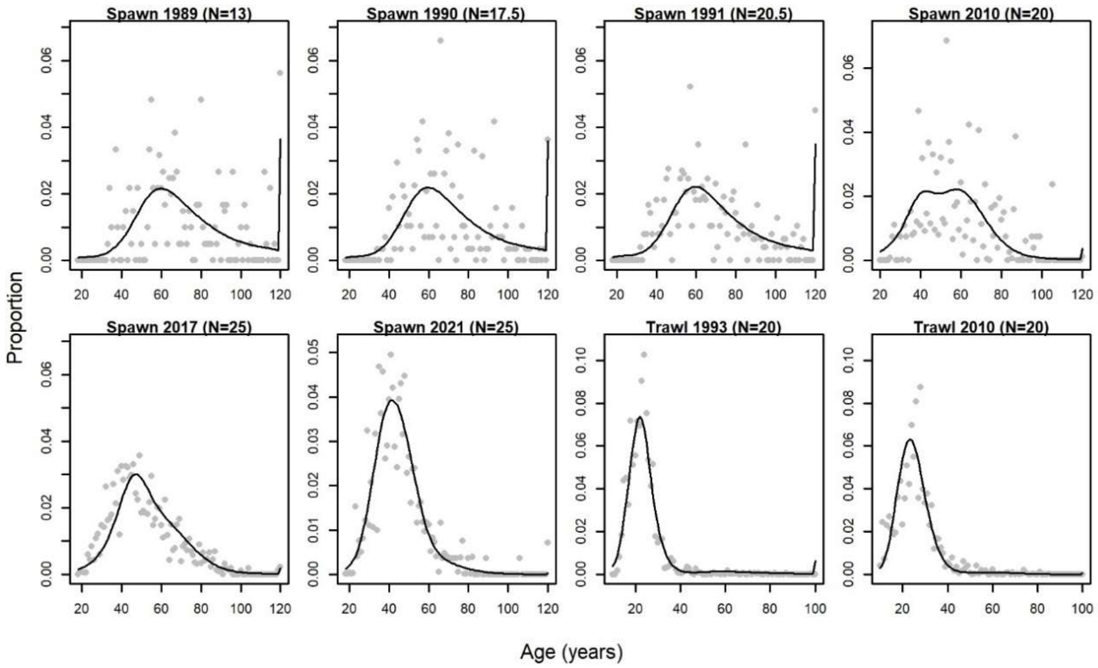


Figure 6: Mid-East Coast orange roughy MPD fits of the base model run to age frequencies (N is the assumed effective sample size). Observations are grey points; model predictions are the black lines.

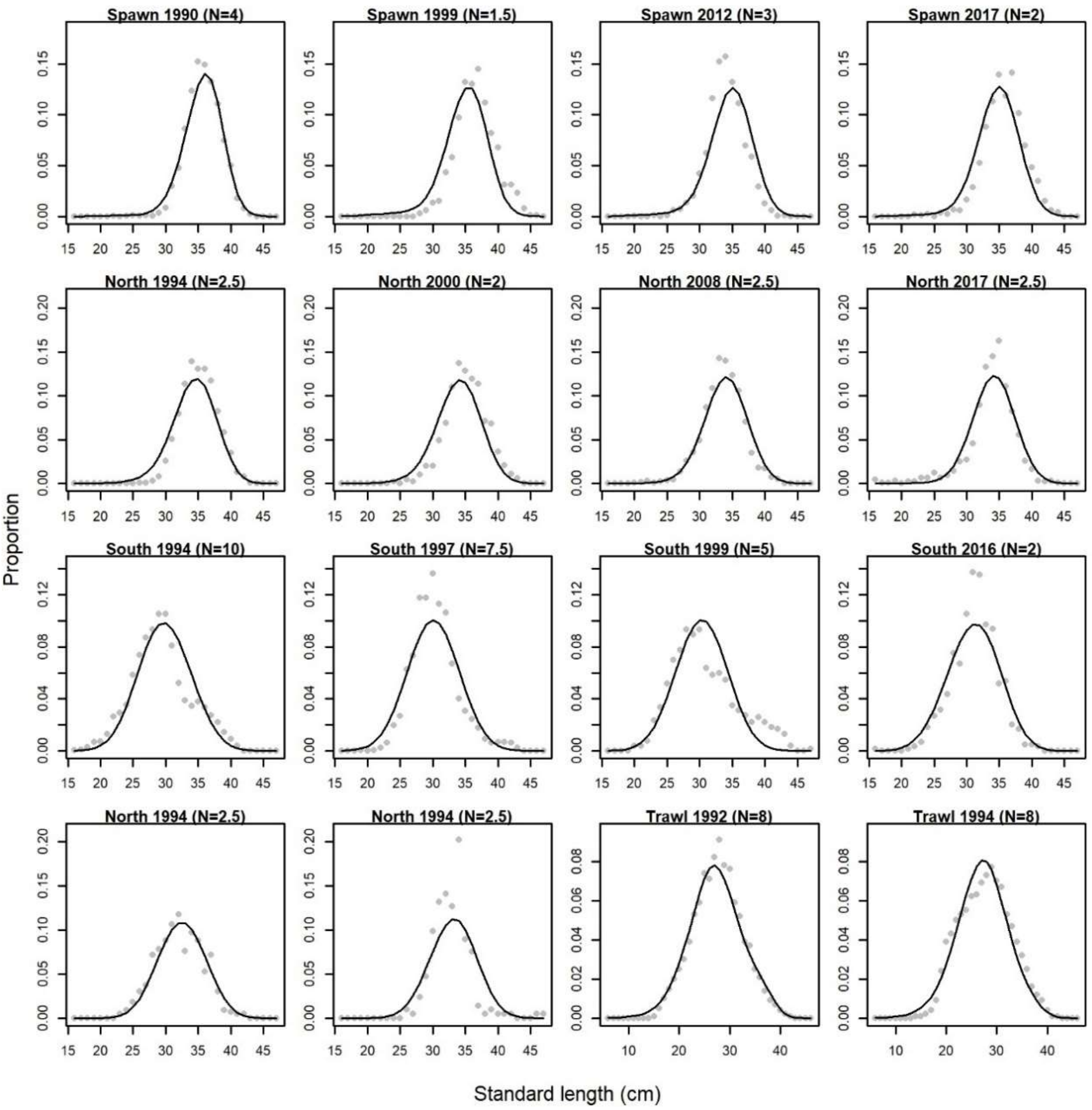


Figure 7: Mid-East Coast orange roughy base model example MPD fits to length frequencies (N is the assumed effective sample size). Observations are grey points; model predictions are the black lines.

MCMC results

MCMC convergence diagnostics were acceptable for the base model and sensitivities. In all model runs, the spawning stock biomass was reduced through the 1980s to below 10% SSB_0 in the 1990s, and then slowly rebuilt. Virgin spawning biomass (SSB_0) was estimated to be about 53 000 t for the base case, and the current stock status 22% SSB_0 (Table 10). When the mean of the acoustic q was reduced (q = 0.6), the spawning stock was estimated to be slightly larger and currently less depleted, and vice versa when the higher q was assumed (q = 1.0). The base and acoustic q sensitivity runs all estimated the current stock status to be at or above the soft limit (20% SSB_0). Assuming a lower M estimated a larger SSB_0 and stock status just below the soft limit.

Table 10: Mid-East Coast orange roughy MCMC estimates of virgin spawning biomass (SSB_0) and stock status (SSB_{2022} as % SSB_0), and overall vulnerable biomass (VB_0) and status (VB_{2022} as % VB_0) calculated assuming a logistic selectivity with parameters averaged from base model run MPD selectivity estimates, for the base model and the three sensitivity runs: a) reducing the mean acoustic catchability coefficient, q, from 0.8 to 0.6; b) increasing the mean acoustic q from 0.8 to 1.0; c) decreasing M to 0.035 year^{-1}.

Spawning biomass

Assessment	SSB_0 (000 t)	95% CI	SSB_{2022} (% SSB_0)	95% CI
Base model	53 350	46 550 – 63 670	22.4	16.7 – 29.2
Acoustic q = 0.6	57 590	49 070 – 69 120	26.3	20.2 – 33.5
Acoustic q = 1.0	51 280	45 480 – 60 010	19.8	14.7 – 26.4
M = 0.035	69 060	60 340 – 79 860	16.7	12.2 – 22.1

Vulnerable biomass

Assessment	VB_0 (000 t)	95% CI	VB_{2022} (% VB_0)	95% CI
Base model	144 720	121 180 – 171 900	47.0	31.8 – 66.6
Acoustic q = 0.6	149 390	122 160 – 178 370	52.8	37.4 – 72.6
Acoustic q = 1.0	143 170	118 310 – 171 430	44.0	30.2 – 62.1
M = 0.035	136 130	114 500 – 156 910	36.3	23.3 – 51.7

The estimates of stock size and status were relatively precise given that some selectivities were relatively poorly estimated, particularly for the South fishery, the mature fish in the trawl survey, and the Spawn 2021 age frequency. A sensitivity run was completed with normal priors placed on the parameters of the South fishery selectivity, with mean values taken from the MPD estimates and assumed CVs, and while this prevented the improbable capture of very young fish it made almost no difference to the estimates of stock size and status. The use of model estimates to construct priors for use in the same model is statistically incorrect, so the base run was preferred. Orange roughy were estimated to first recruit to the South fishery, then the Pegasus and North fisheries, and then the Spawn fishery (Figure 8). The spawning ogive was relatively precisely estimated, indicating spawning started at about age 40 and all fish spawned by about age 80.

Assuming a logistic selectivity with parameters averaged from base model run MPD estimates, the overall vulnerable biomass (VB_0) did not decline as much as the spawning biomass, reaching just below 40% VB_0 in the late 1990s and then slowly rebuilding (Table 10, Figure 9). The biomass vulnerable to the southern fisheries, where recruitment was at a younger age, declined to about 50% and then remained steady from the early 2000s until the last five years, when it slowly declined. The recent decline in vulnerable biomass for the South fishery (*VB*s) was because recruitment was estimated to be approaching an historical low, caused by the reduction of the spawning biomass in the 1980s (Figure 10). The estimated YCS showed a slight decrease from about 1940, a peak around 1970, and then lowest levels of YCS between 1980 and 1993 with a minimum in 1989 (Figure 10).

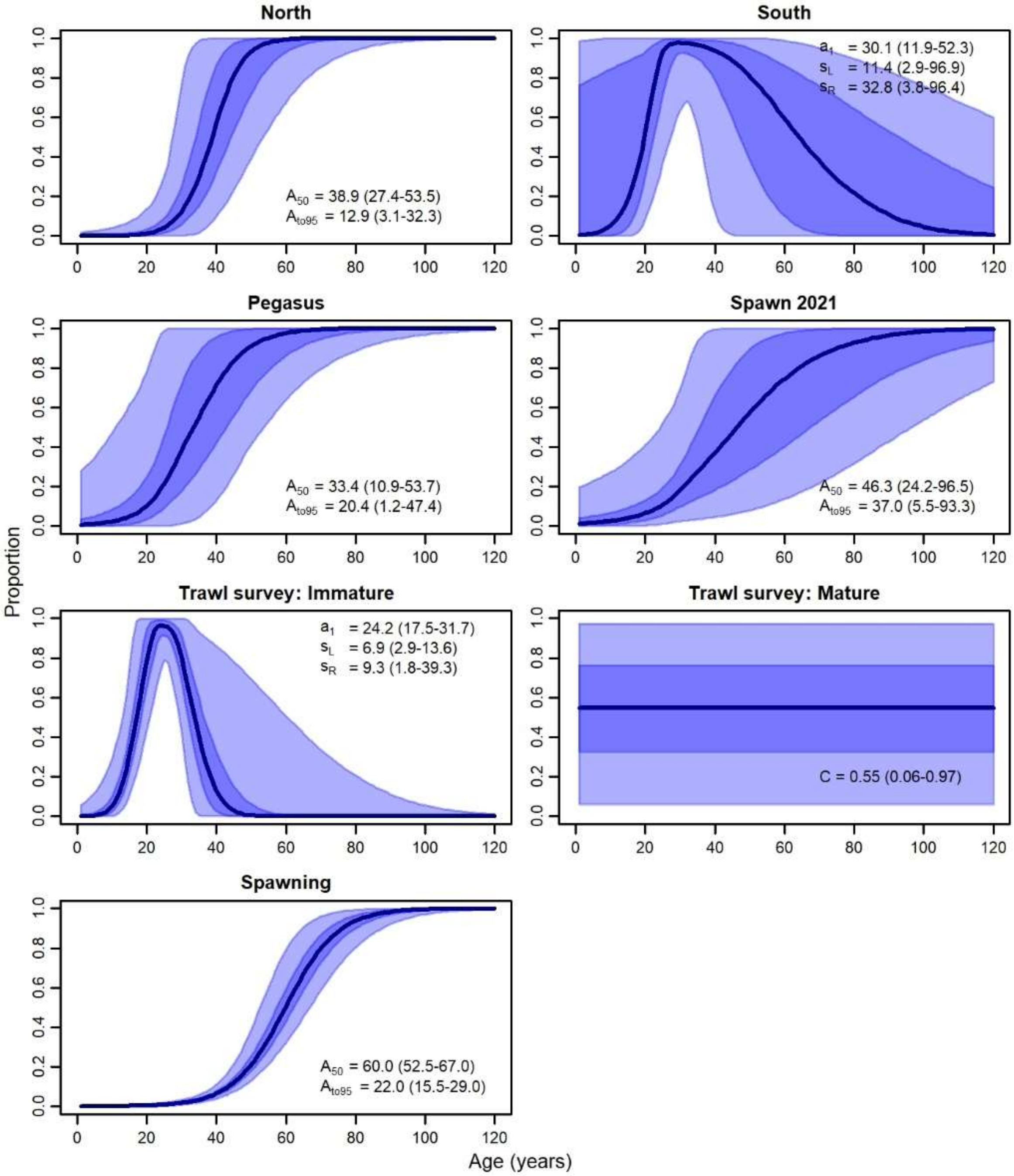


Figure 8: Mid-East Coast orange roughy base case MCMC estimates of selectivities and the spawning ogive. The estimated selectivity model parameters (and 95% credible intervals) are shown on each panel. The light shaded area covers the 95% credible intervals, the darker shaded area the 50% credible intervals, and the solid line the median.

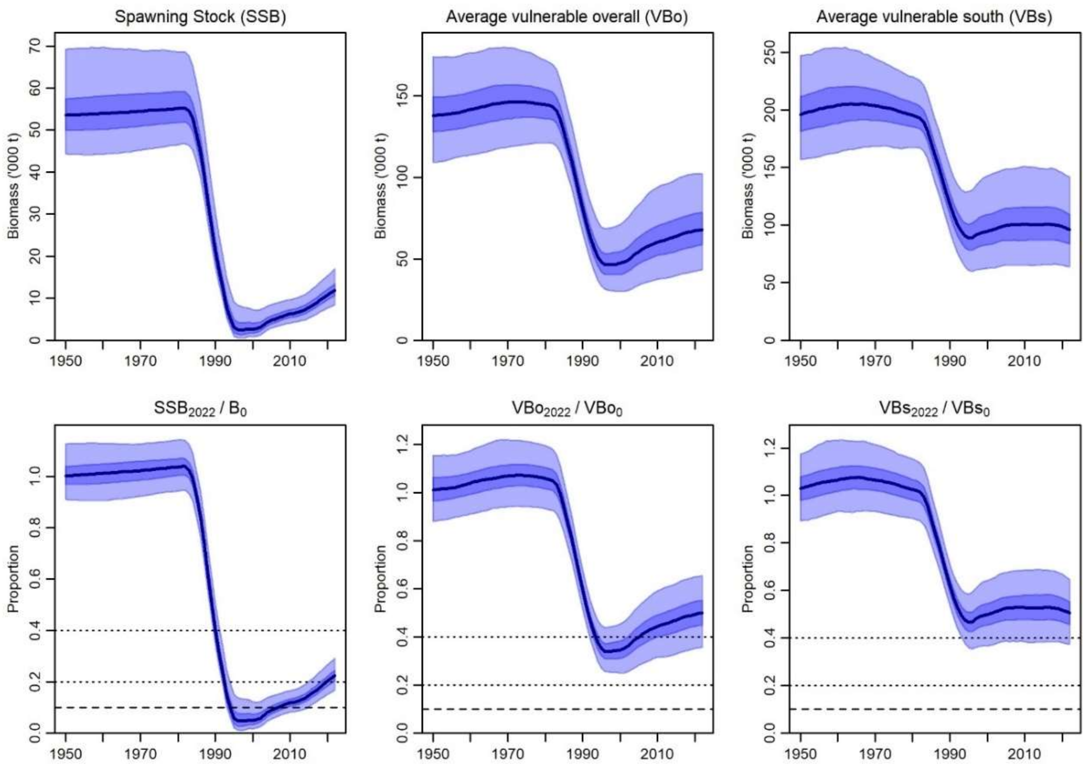


Figure 9: Mid-East Coast orange roughy base case MCMC estimates of upper panels: the Spawning Stock Biomass (*SSB*), and vulnerable biomass trends estimated using logistic selectivity parameters averaged across all fisheries (average vulnerable biomass, VB_0; A_{50} = 34, A_{to95} = 8), and in the southern fisheries (South and Pegasus, *VB*s; A_{50} = 24, A_{to95} = 2). Lower panels, biomass in each year as a proportion of initial biomass. The light shaded area covers the 95% credible intervals, the darker shaded area the 50% credible intervals, and the solid line the median. The horizontal broken lines indicate the hard limit (10% of virgin biomass), soft limit (20% of virgin biomass), and 40% of virgin biomass.

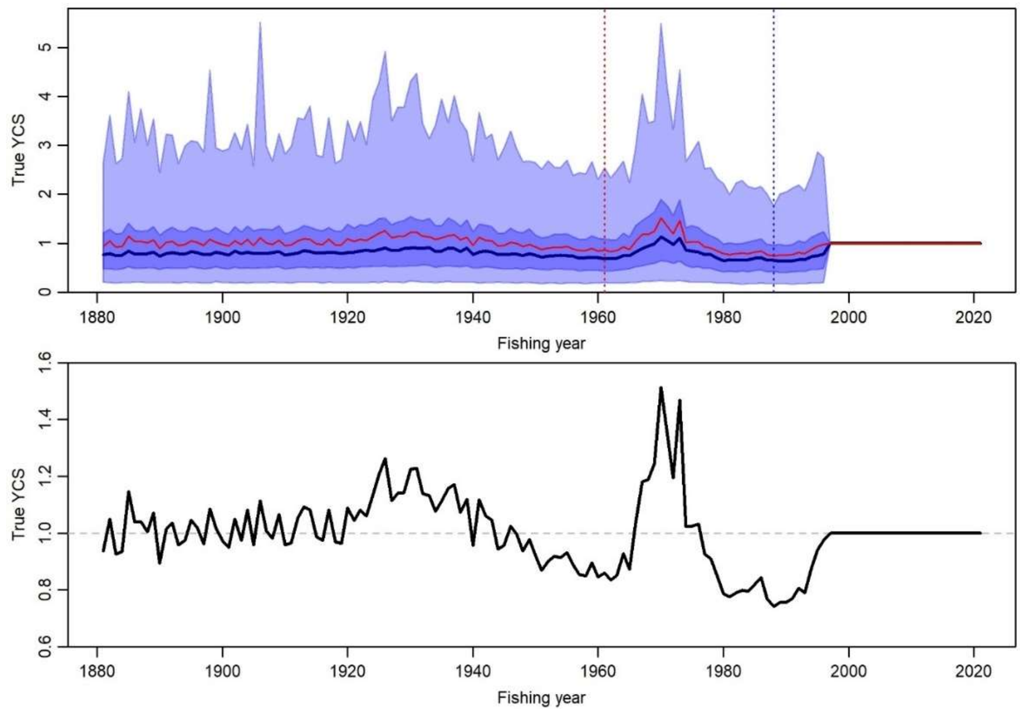


Figure 10: Mid-East Coast orange roughy base case MCMC estimates "true" YCS (R_y/R_0). Upper panel: The light shaded area covers the 95% credible intervals, the darker shaded area the 50% credible intervals, the solid black line the median, and the solid red line the mean. The vertical blue line (to the right) indicates the year class estimated to by 50% recruited to the Pegasus fishery in 2022 (the second largest fishery, after the spawn fishery, in 2022). The vertical red line (to the left) indicates the year class 50% recruited to the spawning stock in 2022. Lower panel: mean "true" YCS.

Estimated exploitation rate peaked in 1991–92 and 1992–93 and was above the target range (*$U_{30\%B0}$*–*$U_{50\%B0}$*) from 1982–83 to 2002–03, and 2004–05 to 2011–12 (Figure 11). Exploitation rate has been well below the target since 2014–15.

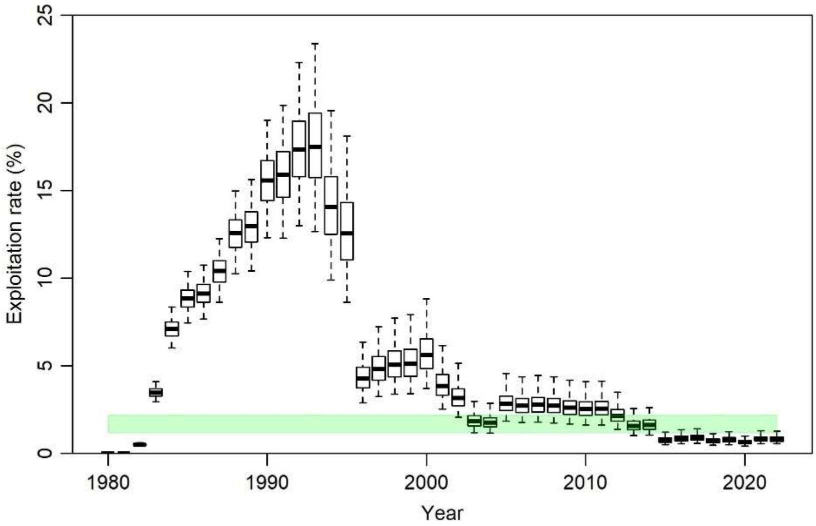


Figure 11: Mid-East Coast orange roughy base case MCMC estimates of exploitation rate (catch/vulnerable biomass). The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The exploitation rate associated with a biomass target of 30–50% *SSB_0* is marked by shaded box.

Projections

Projections were conducted with resampling of YCS estimated from the base model (1881–1996), for catch at the 2021 level of 524 t (plus a 5% catch overrun assumed). *SSB* was predicted to increase slowly (Figure 12, Table 11). The *SSB* was estimated to be greater than the lower bound of the target zone (30% *SSB_0*) with at least 70% probability by 2037.

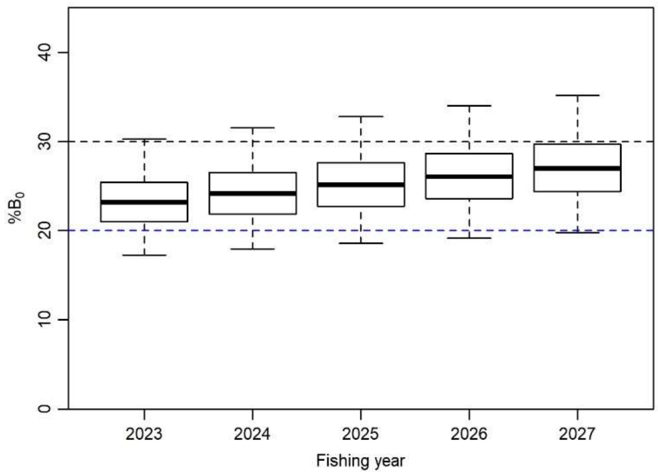


Figure 12: Mid-East Coast orange roughy base case MCMC projections of spawning stock biomass with constant future catch. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The lower bound of the target range (30% *SSB_0*) is indicated by the black horizontal broken line, with the soft limit (20% *SSB_0*) in blue.

Table 11: Mid-East Coast orange roughy MCMC estimates of projected spawning stock biomass (*SSB*) for the base model, and the probability of above the hard limit (10% SSB_0), soft limit (20% SSB_0), and lower bound of the target range (30% SSB_0).

	$p(SSB$<X% $SSB_0)$		
Fishing year	**X=10%**	***X*=20%**	**$p(SSB$>30% $B_0)$**
2021–22	0.00	0.21	0.01
2022–23	0.00	0.16	0.03
2023–24	0.00	0.10	0.05
2024–25	0.00	0.06	0.09
2025–26	0.00	0.04	0.15
2026–27	0.00	0.03	0.23

5. FUTURE RESEARCH CONSIDERATIONS

Relationship between maturity and spawning and prevalence of skipped spawning

- The estimated age of 50% spawning was unexpectedly high (about 55 years) given that orange roughy have generally been estimated to have an age of 50% maturity of about 30–35 years. To be plausible, the later age of 50% spawning relative to maturity requires an assumption of skipped spawning that is more prevalent in younger fish. There is theoretical support for this assumption and evidence from Mid-East Coast trawl survey gonad samples that not all female Mid-East Coast orange roughy were spawning by age 50.
    - The theoretical expectations for skipped spawning, and the availability of existing data to inform skipped spawning estimates, need to be investigated.
    - A simulation model to investigate the skipped spawning hypothesis should be constructed.

Collection of biological data including aged otoliths

- Additional biological samples should be collected, including maturity evaluations and aged otoliths, to better inform assumptions about maturity and spawning. Because variability in biological characteristics seems to be greater between than within catches, sample collection should focus on collecting adequate samples from many catches (including surveys). Sampling across years is also required to allow temporal variability in the age structure of spawning aggregations, and potential skipped spawning, to be investigated.
- Obtain more data on macroscopic versus histological staging for a range of known ages including those beyond 50. Ensure historical data are fully utilised.
- Obtain further samples from research or commercial trawls to investigate maturity outside the main spawning areas. Review the overall approach to collecting age frequencies, length frequencies, and maturity data both from spawning and non-spawning fisheries, and research surveys and commercial fisheries to improve coverage and representativeness.
- Collect age data from both acoustic and commercial catches in the same year.

Stock structure

- Review the existing information with respect to stock structure, including genetic, morphometric, and other information, including from adjacent stock areas. This review could then be used to guide the development of stock structure assumptions in assessment models.

Age frequencies for commercial fisheries

- The estimates of selectivity for three of the four fisheries in the 2022 assessment model were informed only by length frequency samples, and estimated selectivity parameters were particularly uncertain. Aged otolith samples from the non-spawning fisheries are needed to improve these estimates of fishery selectivity.
- Re-age the 2002 otolith samples using the new protocol.

Loss of some historical spawning aggregations

- Some historical spawning aggregations have been depleted, and no longer seem to occur. For the Mid-East Coast, this includes the aggregation on Strawberry Mountain. 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, should be investigated.

Catch history

- Investigate whether alternative assumptions about historical catches could result in better model fits, posteriors, and other outputs, specifically with reference to uncertainty in catch overruns relating to discarding and lost fish.

CPUE

- The existing fisheries catch and -effort data are not considered to be useful for generating a relative abundance index for this stock. However, given the sparsity of relative abundance information from formal surveys, an exploration of existing fisheries catch rate information, standardising for the effects of vessel, month, and location, etc., may yield longer time series of abundance information for specific locations that can be used to compare with model outputs.

Fishing intensity

- Reconsider how a consistent, combined U or F is best calculated.

East Cape stock assessment

- Options for updating the assessment of ORH 2A North (East Cape) should be investigated.

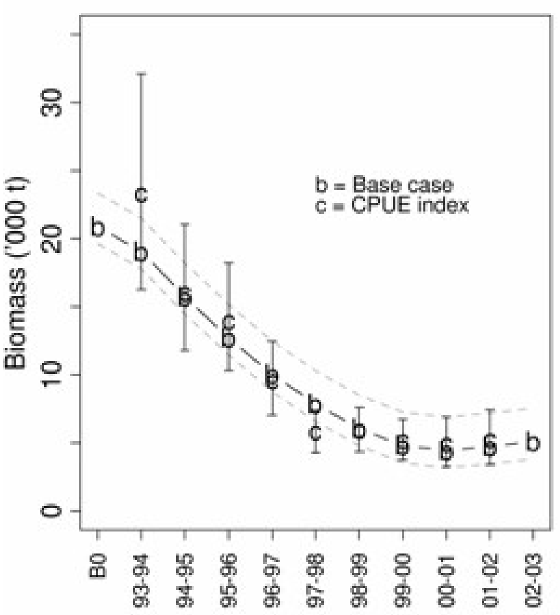
6. STATUS OF THE STOCKS

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

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

Stock Status	
Year of Most Recent Assessment	2003
Assessment Runs Presented	A base case with one alternative
Reference Points	Management Target: 30–50% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold:-
Status in relation to Target	B_{2003} was 24% B_0, which was Unlikely (< 40%) to be at or above the target.
Status in relation to Limits	B_{2003} was Unlikely (< 40%) to be below the Soft Limit, and Very Unlikely (< 10%) to be below the Hard Limit

Historical Stock Status Trajectory and Current Status



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

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

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

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

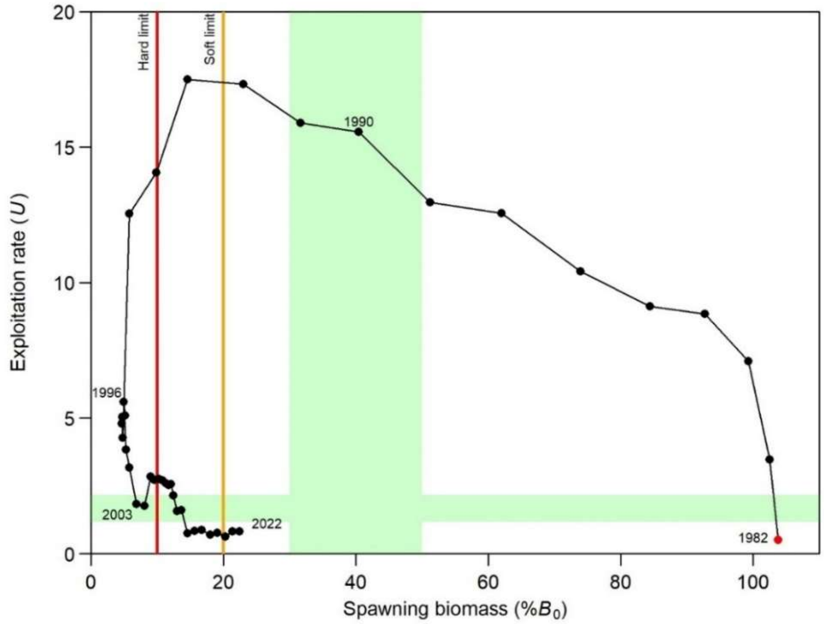
Qualifying Comments
The most recent assessment (2003) is now 11 years out-of-date. In recent years, the ability of stock assessment models that assume deterministic recruitment for orange roughy stocks to reflect current or projected stock status has been called into question.

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

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

Stock Status	
Year of Most Recent Assessment	2022
Assessment Runs Presented	Base model
Reference Points	Management Target: Biomass range 30–50% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: Fishing intensity range $U_{30\%B0}$–$U_{50\%B0}$
Status in relation to Target	B_{2022} was estimated to be 22% B_0 Very Unlikely (< 10%) to be at or above the lower end of the management target range
Status in relation to Limits	B_{2022} is About as Likely as Not (40–60%) to be below the Soft Limit B_{2022} is Unlikely (< 40%) to be below the Hard Limit
Status in relation to Overfishing	Fishing intensity in 2022 was estimated to be 0.8% (37% of $U_{30\%B0}$) Overfishing is Very Unlikely (< 10%) to be occurring

Historical Stock Status Trajectory and Current Status



Historical trajectory over time of exploitation rate (*U*) and spawning biomass (% B_0), for the Mid-East Coast orange roughy base model, from the start of the fishery (represented by a red point), to 2022. The red vertical line at 10% B_0 represents the hard limit, the orange line at 20% B_0 is the soft limit, and green shaded areas are the % B_0 target (30–50% B_0) and the corresponding exploitation rate (U_{30}– U_{50}). Biomass and exploitation rate estimates are medians from MCMC results.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Estimated spawning biomass has been slowly increasing since about 2000. Average vulnerable biomass has also been increasing over the same period.
Recent Trend in Fishing Intensity or Proxy	Estimated fishing intensity has been low and stable since 2014–15.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	At the current catch limit, the stock is projected to increase slowly over the next five years and to be above the soft limit but below the lower bound of the target in 2027.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	For the current catch and catch limit (over the next 5 years): Soft Limit: Unlikely (< 40%) Hard Limit: Very Unlikely (< 10%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	For the current catch and catch limit: Very Unlikely (< 10%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2022	Next assessment: 2025
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Acoustic biomass estimates (2013, 2017, 2021)	1 – High Quality
	- Trawl survey biomass indices (1992–94, 2010), age frequencies (1993, 2010), length frequencies (1992, 1994), proportion spawning at age (1993, 2010)	1 – High Quality
	- Spawning season age frequencies (1989–91, 2010, 2017, 2021)	1 – High Quality
	- Commercial length frequencies (1989–90 to 2017–18)	1 – High Quality
Data not used (rank)	- CPUE indices	3 – Low Quality: unlikely to be indexing stock-wide abundance
	- 2002 spawning season age frequency	2 – Medium or Mixed Quality: needs to be re-aged with new protocol
	- Wide-area acoustic estimates	2 – Medium or Mixed Quality: too much potential bias due to target identification and mixed species issues
	- Egg survey estimates	2 – Medium or Mixed Quality: too much potential bias due to survey design assumptions not being met
Changes to Model Structure and Assumptions	- Four fisheries instead of two, including a spawning fishery - Spawning ogive set equal to the spawning fishery selectivity (with an assumption of mature fish skipping spawning) - CV of YCS prior set at 0.8, rather than "nearly uniform" - Acoustic *q* mean set in the base case at 0.8 rather than 0.6 - Growth parameters have been updated - Sex is now included in the partition, but only for estimating	

	growth - Trawl survey fitted with double-normal (immature) and constant (mature) selectivity
Major Sources of Uncertainty	- The proportion of the spawning stock biomass that was indexed by the acoustic surveys - Recent recruitment, where a lack of observational data meant year class strengths were assumed to be average since 1997 - The age-specific proportion of mature fish that spawn - Spatial population structure - Historical catches uncertain

Qualifying Comments
-

Fishery Interactions
Fish bycatch is estimated to make up about 20% of the total catch in this fishery. The main bycatch species are alfonsino, smooth oreo, and hoki. Low productivity bycatch species include deepwater sharks, deepsea skates, and corals. Observed incidental captures of protected species include corals, low numbers of seabirds, and a New Zealand fur seal. Orange roughy are caught using bottom trawl gear. Bottom trawling interacts with benthic habitats.

6. FOR FURTHER INFORMATION

Anderson, O F (2000) Assessment of the East Cape hills (ORH 2A North) orange roughy fishery for the 2000–01 fishing year. *New Zealand Fisheries Assessment Report 2000/19*. 29 p.

Anderson, O F (2003a) A summary of biological information on the New Zealand fisheries for orange roughy (*Hoplostethus atlanticus*) for the 2001–02 fishing year. *New Zealand Fisheries Assessment Report 2003/21*. 25 p.

Anderson, O F (2003b) CPUE analysis and stock assessment of the East Cape hills (ORH 2A North) orange roughy fishery for 2003. *New Zealand Fisheries Assessment Report 2003/24*. 20 p.

Anderson, O F (2005) CPUE analysis and stock assessment of the South Chatham Rise orange roughy fishery for 2003–04. *New Zealand Fisheries Assessment Report*. 2005/07.

Anderson, O F; Dunn, M R (2007a) 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 2003–04 fishing year. *New Zealand Fisheries Assessment Report. 2006/20.*

Anderson, O F; Dunn, M R (2007b) 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.*

Anderson, O F; Francis, R I C C; Hicks, A C (2002) CPUE analysis and assessment of Mid-East Coast orange roughy stock (ORH 2A South, 2B, 3A). *New Zealand Fisheries Assessment Report 2002/56*. 23 p.

Bull, B; Francis, R I C C; Dunn, A; Gilbert, D J (2002) CASAL (C++ algorithmic stock assessment laboratory): CASAL user manual v1.02.2002/10/21. *NIWA Technical Report 117*. 199 p.

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.

Clark, M; Anderson, O; Dunn, M (2003) 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 2001–02 fishing year. *New Zealand Fisheries Assessment Report 2003/60*. 51 p.

Clark, M R; Taylor, P; Anderson, O F; O'Driscoll, R (2002) 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 2000–01 fishing year. *New Zealand Fisheries Assessment Report. 2002/62*.

Cordue, P L (2012) Fishing intensity metrics for use in overfishing determination. *ICES Journal of Marine Science, 69*: 615–623

Cordue, P L (2014a) A 2013 stock assessment of Mid-East Coast orange roughy. *New Zealand Fisheries Assessment Report 2014/32*.

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.)

Cordue, P L (2014c) The 2014 orange roughy stock assessments. *New Zealand Fisheries Assessment Report 2014/50*. 135 p.

Cordue, P L (2017) A stock assessment update to the end of the 2017–18 fishing year for the Mid-East Coast orange roughy stock. ISL Client Report for Deepwater Group. 45 p.

Doonan, I J (1994) Life history parameters of orange roughy: estimates for 1994. New Zealand Fisheries Assessment Research Document 1994/19. 13 p. (Unpublished document held by NIWA library, Wellington.)

Doonan, I J; Coburn, R P; Hart, A C (2004a) Acoustic estimates of the abundance of orange roughy for the Mid-East Coast fishery, June 2003. *New Zealand Fisheries Assessment Report 2004/54*. 21 p.

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.*

Doonan, I J; Hicks, A C; Coombs, R F; Hart, A C; Tracey, D (2003) Acoustic estimates of the abundance of orange roughy in the Mid-East Coast fishery, June–July 2001. *New Zealand Fisheries Assessment Report 2003/4*. 22 p.

Doonan, I J; Horn, P L; Krusic-Golub, K (2013) Comparison of age between 1993 and 2010 for mid-east coast orange roughy (ORH 2Asouth, 2B & 3A). *New Zealand Fisheries Assessment Report 2013/44.*

Doonan, I J; Tracey, D M; Grimes, P J (2004b) Relationships between macroscopic staging and microscopic observations of oocyte progression in orange roughy during and after the mid-winter spawning period, Northwest Hills, Chatham Rise, July 2002. *New Zealand Fisheries Assessment Report 2004/6*. 28 p.

Dunn, M R (2005) CPUE analysis and assessment of the Mid-East Coast orange roughy stock (ORH 2A South, 2B, 3A) to the end of the 2002–03 fishing year. *New Zealand Fisheries Assessment Report 2005/18*. 35 p.

Dunn, M R; Anderson, O F; McKenzie, A (2005) 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 2002–03 fishing year. *New Zealand Fisheries Assessment Report 2005/19*. 60 p.

Field, K D; Francis, R I C C; Zeldis, J R; Annala, J H (1994) Assessment of the Cape Runaway to Banks Peninsula (ORH 2A, 2B, and 3A) orange roughy fishery for the 1994–1995 fishing year. New Zealand Fisheries Assessment Research Document 1994/20. 24 p. (Unpublished document held by NIWA library, Wellington.)

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 by NIWA library, Wellington.)

Francis, R I C C (2011) Data weighting in statistical fisheries stock assessment models. *Canadian Journal of Fisheries and Aquatic Sciences 68*: 1124–1138.

Francis, R I C C; Clark, M R; Coburn, R P; Field, K D; Grimes, P J (1995) Assessment of the ORH 3B orange roughy fishery for the 1994–95 fishing year. New Zealand Fisheries Assessment Research Document 1995/4. 43 p. (Unpublished document held by NIWA library, Wellington.)

Francis, R I C C; Field, K D (2000) CPUE analysis and assessment of the Mid-East Coast orange roughy stock (ORH 2A South, 2B, 3A). *New Zealand Fisheries Assessment Report 2000/29*. 20 p.

Francis, R I C C; Horn, P L (1997) Transition 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; Hurst, R J; Renwick, J A (2001) An evaluation of catchability assumptions in New Zealand stock assessments. *New Zealand Fisheries Assessment Report 2001/1*. 37 p.

Grimes, P (1994) Trawl survey of orange roughy between Cape Runaway and Banks Peninsula, March–April 1992 (TAN9203). *New Zealand Fisheries Data Report No. 42*. 36 p.

Grimes, P (1996a) Trawl survey of orange roughy between Cape Runaway and Banks Peninsula, March–April 1993 (TAN9303). *New Zealand Fisheries Data Report No. 76*. 31 p.

Grimes, P (1996b) Trawl survey of orange roughy between Cape Runaway and Banks Peninsula, March–April 1994 (TAN9403). *New Zealand Fisheries Data Report No. 82*. 31 p.

Hart, A; Doonan, I J; Coombs, R F (2003) Classification of acoustic fish marks for the 2001 Mid-East Coast orange roughy fishery, June–July 2001. *New Zealand Fisheries Assessment Report. 2003/18*.

Kloser, R J; Macaulay, G; Ryan, T; Lewis, M (2011) Improving acoustic species identification and target strength using frequency difference and visual verification: example for a deep-sea fish orange roughy. DWWG 2011-52. (Unpublished report held by the Fisheries New Zealand, Wellington).

Tracey, D; Ayers, D (2005) Biological data from the orange roughy abundance surveys in the Mid-East Coast fishery. *New Zealand Fisheries Assessment Report. 2005/10.*

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 DWWG. (Unpublished report held by Fisheries New Zealand, Wellington.)

Zeldis, J R; Francis, R I C C; Field, K D; Clark, M R; Grimes, P J (1997) Description and analyses of the 1995 orange roughy egg surveys at East Cape and Ritchie Bank (TAN9507), and reanalyses of the 1993 Ritchie Bank egg survey. New Zealand Fisheries Assessment Research Document 1997/28. 34 p. (Unpublished document held by NIWA library, Wellington.)