Assessment of the Mid-East Coast orange roughy stock (ORH 2A South, ORH 2B & ORH 3A) to the end of the 2009–10 fishing year

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EXECUTIVE SUMMARY

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This report describes a quantitative stock assessment for the Mid-East Coast (MEC) stock including analyses of orange roughy catch per unit effort (CPUE) and the length frequency data collected onboard commercial fishing vessels. The MEC stock covers the area from the Ritchie Bank, east of Hawke's Bay, south to Banks Peninsula, and includes the quota management areas ORH 2A South, ORH 2B, and ORH 3A.

The stock assessment used the stock assessment program CASAL to estimate virgin and current biomass using a Bayesian estimation procedure, treating the stock as a single area but incorporating two fisheries (north and south) with separate catch histories and vulnerability ogives. The observational data included two standardised CPUE biomass indices, 25 commercial fishery length frequency distributions, four trawl survey biomass indices with accompanying length frequency distributions, two acoustic mature biomass surveys, an egg production spawning biomass survey, and two age frequency distributions. In each model run all demographic model parameters were assumed to be constant.

The catch per unit effort analyses excluded data from the spawning season, ORH 3A, and the 1988–89 fishing year. The analysis split the time series after 1996–97, to give an early time series using both the Catch Effort and Landing Return (CELR) daily summary forms and the more detailed tow-by-tow Trawl Catch Effort Processing Return (TCEPR) forms, and a later time series using only the TCEPR forms. The final standardised CPUE indices showed a decline between 1983–84 and the mid 1990s, followed by an increase in the early 2000s and then a decrease in the late 2000s.

The length frequency samples of orange roughy from catches of commercial trawlers were used to estimate separate annual length frequency distributions for the southern fishery (ORH 2B and ORH 3A), and northern fishery (ORH 2A South). The southern fishery included a higher proportion of small fish.

There was a conflict between the abundance indices, catch history, and productivity assumptions, which could not be resolved in a single model run. As a result, two alternative final model runs were presented, one with natural mortality (M) set to a relatively low value, which provided a relatively good fit to the trawl survey biomass index and indicated that the stock was depleted to below 10% of virgin biomass (B_0); the second included the age frequency distributions and estimated M within the model, resulting in an estimate of current biomass above 20% B_0.

The model run assuming low M indicated that future spawning stock biomass (SSB) would decrease at all levels of catch over 300 t. The model run estimating M indicated that SSB would slowly increase for all future levels of catch up to the current (2010–11) catch limit of 1500 t. Neither model was satisfactory. The assessment only produced MPDs rather than full Bayesian results from MCMC runs and the working group agreed to present the results so that some idea of stock status could be inferred from the alternative models.

1. INTRODUCTION

Orange roughy are the focus of an important deepwater fishery in New Zealand, and have been fished for over 20 years (Ministry of Fisheries 2011). The Mid-East Coast (MEC) orange roughy stock covers an area off the east coast of the North Island from the Ritchie Bank, east of Hawke's Bay, south to Banks Peninsula. It consists of the orange roughy Quota Management Areas (QMAs) ORH 2A South (the part of ORH 2A south of 38° 23' S), ORH 2B (Wairarapa), and ORH 3A (Kaikoura) (Figure 1). These areas have been treated together as a separate stock since 1995. Before that, the stock assessment area also included the northern part of ORH 2A. The latter area, known as the "East Cape stock", is now assessed separately (Ministry of Fisheries 2011).

This report addresses parts of objectives 2 and 4 of the Ministry of Fisheries project ORH2008/02 that deal with the Mid-East Coast orange roughy fishery: "*To update the unstandardised and standardised catch per unit effort analyses with the inclusion of data up to the end of the 2008/09 fishing year …*" and *"To update the stock assessment, including reviewing and summarising historical biological data collected by the MFish Observer Programme and other sources, and estimating biomass and sustainable yields for the MEC"*.

This report specifically addresses the collation and analysis of stock assessment input data, and the stock assessment model results, that were carried out in May 2011. The fishery is described in more detail by Anderson & Dunn (2011).

The fishing year for orange roughy is from 1 October to 30 September. Where only one year is provided in a table or figure, this represents the end year, e.g., 1992 means the 1991–92 fishing year.

2. STOCKS AND AREAS

Two major spawning locations have been identified in ORH 2A, one at the East Cape hills in ORH 2A North and the other on the Ritchie Bank in ORH 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 Kaikoura (ORH 3A). The major spawning area for the MEC stock is believed to be the Ritchie Bank. Results from allozyme studies show that orange roughy from the three areas, ORH 2A South, Wairarapa, and Kaikoura cannot be separated, but are distinct from fish on the eastern Chatham Rise (Smith & Benson 1997). These studies also show some support for a stock boundary between ORH 2A North and ORH 2A South and because of this, and the knowledge of spawning locations, orange roughy in this region are currently treated as two stocks: the mid–East Coast (MEC) stock (2A South, Wairarapa, and Kaikoura) and the East Cape (EC) stock (2A North).

No new information on MEC stock boundaries was available. Dunn (2008) described patterns in mean length within the MEC stock. Alternative stock hypotheses based on these data were investigated using population models in 2011 (Dunn submitted).

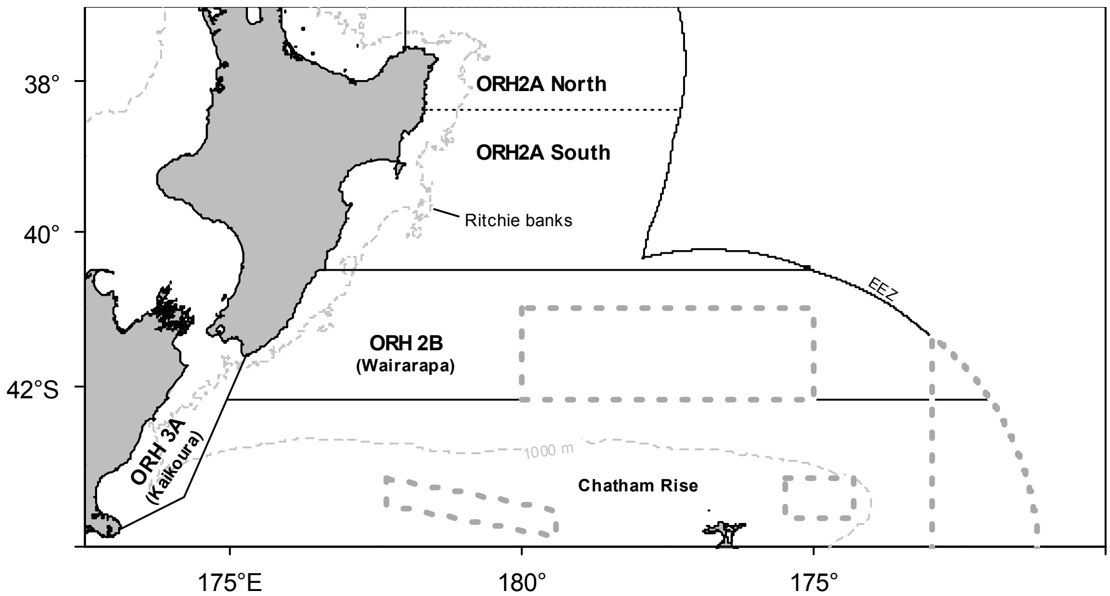

Figure 1: The Mid-East Coast fishery management QMAs and sub-areas. The heavy dashed grey lines mark the perimeters of Benthic Protection Areas (BPAs) closed to bottom trawling

3. DATA ANALYSES

3.1 Catches

In the early development of the MEC fishery there were catch overruns because of lost fish and discards. Therefore in this assessment, total removals were assumed to exceed reported catches by the overrun percentages given in Table 1. For each year, the catch was estimated by multiplying the total reported catch by the proportion of estimated catch in each QMA, estimated from tow-by-tow catch data, then applying the relevant QMA catch over-run, and summing across QMAs to give the total catch.

Table 1: Assumed catch over-runs (%) by QMA and fishing year. – no catches reported.

Fishing year	ORH2A (north and south)	ORH2B	ORH3A
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 subsequently	5	5	5

3.2 Standardised catch per unit effort

The collation and error-checking of catch and effort data were described in detail by Anderson & Dunn (2011). Following the practice in previous analyses (Dunn 2005; Dunn & Anderson 2008), the fishing year 1988–89 was excluded because of errors and missing data. The data were groomed by removing tows that appeared to have come fast, defined as those with a distance less than 100 m, a catch of less than 100 kg, and a duration of less than 1 minute. Where relevant, the data from tow-by-tow and daily summary forms were combined by summarising the tow-by-tow data records into a daily-summary equivalent format. Only tows that targeted orange roughy were used in the analyses. Tows with a recorded duration of zero were changed to 0.1 hour. In order to adequately estimate categorical predictor effects in the model, a continuity rule was applied, where each level (e.g., each vessel) must have accounted for at least 50 tows over three years, or 100 tows over two years.

The standardised catch per unit effort (CPUE) analyses were carried out by fitting a generalised linear model (GLM) to CPUE, using the stepwise multiple regression technique described by Francis (2001). The units of CPUE used were log(kg per tow). Because the proportion of tows with a zero catch was trivial (1–11% per year with no clear trend), only non-zero catch was modeled, using a GLM with a normal error distribution and identity link function. The predictor variable *fishing year* was forced into the model, and other variables then tested for inclusion (Table 2). A stepwise forward procedure was used to select predictor variables, and they were entered into the model in the order which gave the maximum decrease in the Akaike Information Criterion (AIC). Predictor variables were accepted into the final model if they explained at least 1% of the deviance and their predicted effects were sensible.

Table 2: Predictor variables used included in the standardised CPUE analyses. *, predictors not available for daily summarized catch and effort data.

Variable	Type	Comment	Variable	Type	Comment
Fishing year	Categorical	Forced into the model	*Bottom depth**	3^{rd} order polynomial	Depth of gear
Vessel	Categorical	Vessel key	*Duration*	3^{rd} order polynomial	Tow duration
Statistical area	Categorical	MFish statistical area	*Distance**	3^{rd} order polynomial	Tow distance in km
Month	Categorical	–	*Kw*	3^{rd} order polynomial	Vessel engine power
Type	Categorical	Whether TCEPR or CELR form	*Tonnes*	3^{rd} order polynomial	Vessel gross tonnage
QMA	Categorical	MFish quota management area	*Longitude**	3^{rd} order polynomial	Tow start longitude
Number of tows	3^{rd} order polynomial	Only for daily summarized data	*Latitude**	3^{rd} order polynomial	Tow start latitude
Fishing day	3^{rd} order polynomial	Day of the fishing year	*Time**	3^{rd} order polynomial	Tow start time
*Speed**	3^{rd} order polynomial	Tow speed			

3.3 Observer length frequency samples

Orange roughy length data from commercial fisheries have been collected since the early 1990s, mainly by MFish observers but also by industry observers (nominated crewmembers) from the late 1990s, and from shed sampling in the early 1990s and in 2002. Data for the MEC stock are available predominantly from MFish observers.

Observers collected random samples (usually about 100 fish per trawl tow) from usually one, but up to as many as eight, tows per day. Standard length (SL), sex, and reproductive condition of female fish were recorded, along with the total weight of the sample and of the entire orange roughy catch.

Each sample was assigned to a QMA, either ORH 2A South, ORH 2B, or ORH 3A, and the sample mean length calculated as the average of the male and female mean lengths. The sample mean lengths were examined to look for any trends in the data.

As an input to the stock assessment model, separate length frequencies were constructed for each year in which the available data comprised 10 or more fish per sex and 200 or more fish in total, from at least 2 tows. There was no merging of sample data from consecutive years.

The overall length frequency for each QMA and year was calculated as the mean of the catch-weighted total numbers at length for males and females (thereby scaling the length frequencies to a 50:50 sex ratio). Catch weights were unavailable for the shed samples, so the average catch from other (observer) samples in the same year was allocated to these samples.

In the stock assessment model it was assumed that the estimated proportions at length had multinomial errors, with the multinomial effective sample sizes estimated from regressions of log(proportion) against log(CV). Effective sample sizes were capped at 500 to limit the influence of individual samples.

4. RESULTS

4.1 Catch history

The estimated total catch including the assumed catch over-runs is shown in Table 3.

Table 3: Reported landings (t) ('Catch') and estimated catch after addition of over-runs ('Plus OR') for the Mid-East Coast stock quota management areas.

	ORH2A south		ORH2B		ORH3A		MEC total	
Fishing year	Catch	Plus OR	Catch	Plus OR	Catch	Plus OR	Catch	Plus OR
1981–82	–	0	554	720	0	0	554	720
1982–83	–	0	3 510	4 563	253	329	3 763	4 892
1983–84	162	243	6 685	8 691	554	720	7 401	9 654
1984–85	1 858	2 787	3 310	4 303	3 266	4 246	8 434	11 336
1985–86	2 778	4 167	867	1 127	4 326	5 624	7 971	10 918
1986–87	4 934	6 908	963	1 252	2 555	3 322	8 452	11 481
1987–88	6 203	8 064	982	1 277	2 510	3 263	9 695	12 604
1988–89	5 710	7 138	1 236	1 545	2 431	3 039	9 377	11 721
1989–90	6 239	7 487	1 400	1 680	2 878	3 454	10 517	12 620
1990–91	6 051	6 959	1 384	1 592	2 553	2 936	9 988	11 486
1991–92	6 329	6 962	1 327	1 460	2 443	2 687	10 099	11 109
1992–93	5 807	6 388	1 080	1 188	2 135	2 349	9 022	9 924
1993–94	3 173	3 490	1 259	1 385	2 131	2 344	6 563	7 219
1994–95	3 281	3 445	754	792	1 686	1 770	5 721	6 007
1995–96	1 033	1 085	245	257	612	643	1 890	1 985
1996–97	1 270	1 334	272	286	580	609	2 122	2 228
1997–98	1 416	1 487	254	267	570	599	2 240	2 352
1998–99	1 434	1 506	257	270	582	611	2 273	2 387
1999–00	1 666	1 749	234	246	617	648	2 517	2 643
2000–01	1 083	1 137	190	200	479	503	1 752	1 840
2001–02	901	946	180	189	400	420	1 480	1 555
2002–03	546	573	105	110	235	247	886	930
2003–04	533	560	103	108	250	263	886	930
2004–05	849	891	206	216	416	437	1 471	1 545
2005–06	858	901	172	181	415	436	1 445	1 517
2006–07	902	947	203	213	401	421	1 506	1 581
2007–08	868	911	209	219	432	454	1 509	1 584
2008–09	884	928	173	182	414	435	1 471	1 545
2009–10	850	893	213	224	390	410	1 453	1 526

4.2 Standardised catch per unit effort

Two final CPUE indices were calculated, one for the period 1983–84 to 1996–97 using TCEPR and CELR data combined, and one for the period 1997–98 to 2009–10 using only TCEPR data. The time split between these two indices was based upon changes in the fishery (Dunn submitted). Both indices used only records from the non-spawning fishery (August to May), and for the 1983–84 to 1996–97 indices the data from ORH3A were also removed because of suspected misreporting of catch during this period.

4.3 Index for 1983–84 to 1996–97

After data grooming and applying the data selection rules, 23 vessels were included in the data set, showing moderate overlap between vessels (Table 4).

Table 4: Number of tows by vessel and fishing year for the combined TCEPR and CELR data set used in the standardised CPUE analysis for 1983–84 to 1996–97, after application of the data selection criteria. Note that the 1988–89 fishing year was excluded.

Vessel	1984	1985	1986	1987	1988	1990	1991	1992	1993	1994	1995	1996	1997
1	69	86	60	–	–	–	–	–	–	–	–	–	–
2	114	196	148	106	111	–	–	–	–	–	–	–	–
3	–	41	18	35	–	–	–	–	–	–	–	–	–
4	6	90	42	64	18	–	–	–	–	–	–	–	–
5	125	7	4	17	–	18	–	–	–	2	25	–	–
6	–	3	107	73	45	–	–	–	–	–	–	–	–
7	–	57	56	108	105	–	–	–	–	–	–	–	–
8	328	257	16	37	29	26	48	71	67	125	–	–	–
9	212	41	78	110	88	66	120	101	181	242	201	–	–
10	132	12	29	1	108	63	7	44	72	6	177	38	27
11	169	35	92	24	57	89	118	127	145	235	200	23	–
12	–	–	–	–	–	199	212	130	–	–	–	–	–
13	–	–	–	–	–	123	98	177	31	–	–	–	–
14	–	–	–	–	–	32	99	49	22	–	–	3	–
15	134	7	–	–	4	–	72	116	167	143	49	25	49
16	–	–	–	–	–	100	119	157	33	16	30	37	–
17	–	–	–	–	–	22	92	47	131	–	–	12	1
18	–	–	–	–	–	39	65	172	96	107	3	–	–
19	–	–	–	–	71	49	134	272	295	253	67	23	7
20	–	122	6	31	–	–	239	348	265	297	244	145	192
21	–	–	–	–	–	10	57	27	66	130	22	–	–
22	–	–	–	–	–	–	–	–	–	–	49	46	48
23	–	–	–	–	–	–	–	–	–	–	50	103	86

The fit of the model was reasonable (Figure 2). While most of the data fitted the model, the departures towards the ends of the normal quantile plot indicated the model did not describe all of the extremes of the catch rate, for both small and large catches. The final model explained 32.8% of the deviance, with the additional predictors selected being *number of tows* and *vessel* (Table 5).

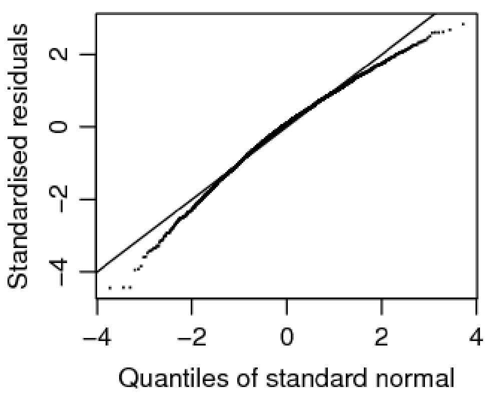

Figure 2: Normal quantile plot for the fit of the final CPUE model fit to the combined TCEPR and CELR data set used in the standardised CPUE analysis for 1983–84 to 1996–97.

Table 5: Predictor and percentage of deviance explained for the final normal model fit to the combined TCEPR and CELR data set used in the standardised CPUE analysis for 1983–84 to 1996–97. Df, degrees of freedom; AIC, Akaike Information Criterion; % dev. expl., % of deviance explained; Add % dev. expl., additional % deviance explained.

Predictor	Step	Df	AIC	% dev. expl.	Add % dev. expl.
Fishing year	1	11	20 145	11.5	11.5
Number of tows	2	3	19 216	26.4	14.9
Vessel	3	22	18 795	32.8	6.4

The model indicated a roughly 7-fold decline in CPUE, with a low point in 1994–95, an increase in CPUE with the number of tows recorded per day up to an effective maximum of around 10 tows per day, and a roughly 6-fold difference in catch rate between vessels, with one vessel performing particularly well (Figure 3).

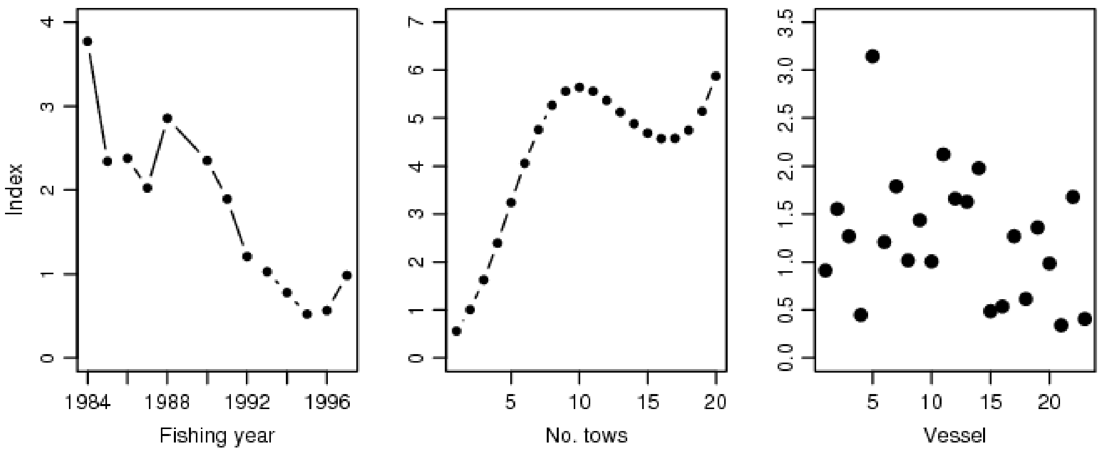

Figure 3: Model predictions by fishing year, number of tows, and vessel, for the final CPUE model fit to the combined TCEPR and CELR data set for 1983–84 to 1996–97, made with all other predictors set to the median (fixed) values. N.B., the predicted increase in CPUE over about 16 tows per day is unlikely to be real as it is based on few data and is partly an artefact of the fitting requirements of the polynomial function.

The standardisation procedure made little difference to the estimated CPUE trend, although it tended to increase the overall CPUE decline by elevating the index between 1983–84 and 1989–90 (Figure 4). The final index and coefficient of variation of the year effect are shown in Table 6.

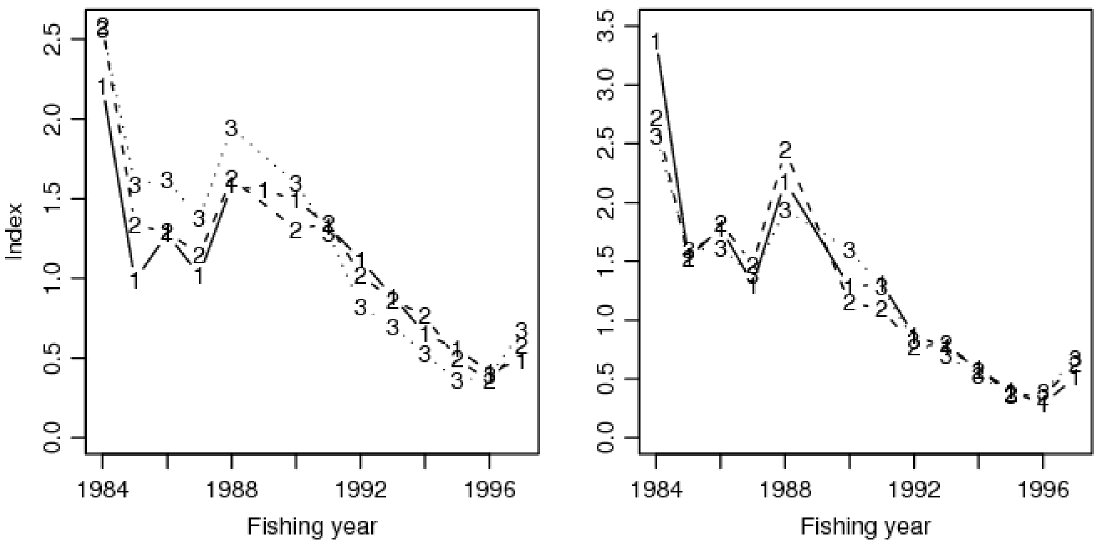

Figure 4: CPUE indices by fishing year for 1983–84 to 1996–97, all scaled to have a geometric mean of one. Left panel: 1, initial unstandardised CPUE; 2, subset of unstandardised CPUE used for standardised analyses; 3, standardised index. Right panel: 1, standardised index with year predictor only; 2, standardised index with predictors year and number of tows; 3, standardised index with predictors year, number of tows, and vessel.

Table 6: Standardised CPUE indices and c.v.s (%) for MEC orange roughy.

Fishing year	TCEPR and CELR	c.v.	TCEPR only	c.v.
1983–84	3.77	10.8	–	–
1984–85	2.34	11.6	–	–
1985–86	2.38	13.0	–	–
1986–87	2.02	13.4	–	–
1987–88	2.86	12.4	–	–
1988–89	–	–	–	–
1989–90	2.35	11.5	–	–
1990–91	1.89	6.1	–	–
1991–92	1.21	8.1	–	–
1992–93	1.03	8.1	–	–
1993–94	0.78	8.4	–	–
1994–95	0.52	9.3	–	–
1995–96	0.57	12.1	–	–
1996–97	0.98	12.5	–	–
1997–98	–	–	0.38	14.7
1998–99	–	–	0.40	14.6
1999–2000	–	–	0.37	14.7
2000–01	–	–	0.33	15.2
2001–02	–	–	0.64	16.4
2002–03	–	–	0.80	15.9
2003–04	–	–	0.98	16.0
2004–05	–	–	0.80	14.5
2005–06	–	–	0.84	15.8
2006–07	–	–	0.96	16.1
2007–08	–	–	0.82	16.5
2008–09	–	–	0.66	15.9
2009–10	–	–	0.49	16.6

4.4 Index for 1997–98 to 2009–10

After data grooming and applying the data selection rules, 15 vessels were included in the data set, with good overlap between vessels (Table 7).

Table 7: Number of tows by vessel and fishing year in the TCEPR data set used in the standardised CPUE analysis for 1997–98 to 2009–10, after application of the data selection criteria.

Vessel	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
1	359	164	44	–	–	–	–	–	–	–	–	–	–
2	41	31	17	5	1	–	–	–	–	–	–	–	–
3	23	149	48	–	–	–	–	–	–	–	–	–	–
4	10	14	22	–	–	–	–	–	–	–	–	–	–
5	335	347	307	287	100	–	–	–	–	–	–	–	–
6	186	186	169	84	35	22	12	8	–	–	–	–	1
7	63	46	71	21	4	9	7	12	8	7	6	–	–
8	1	1	31	49	22	7	4	–	–	–	–	–	–
9	2	62	149	96	12	121	74	195	110	–	–	–	–
10	56	127	50	30	64	48	114	85	69	100	52	23	35
11	202	254	283	139	73	74	40	75	101	143	217	286	192
12	27	6	–	–	8	23	22	56	26	29	–	11	–
13	–	–	–	–	16	16	26	46	24	–	4	–	–
14	–	1	–	–	–	–	–	–	2	23	27	3	16
15	–	19	–	–	–	–	5	19	6	19	78	117	115

The fit of the model was relatively good, with departures from the expected fit only at the extreme high catch rates (Figure 5). The final model explained 10.8% of the deviance, with the additional predictors selected being *vessel*, *longitude*, and *latitude* (Table 8).

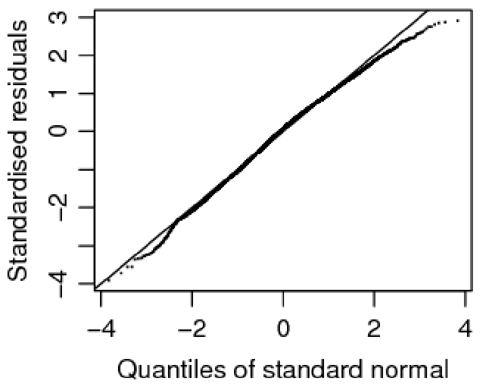

Figure 5: Normal quantile plot for the fit of the final CPUE model fit to the TCEPR data set standardised CPUE analysis for 1997–98 to 2009–10.

Table 8: Predictors and percentages of deviance explained for the final normal model fit to the TCEPR data set in the standardised CPUE analysis for 1997–98 to 2009–10. Df, degrees of freedom; AIC, Akaike Information Criterion; % dev. expl., % of deviance explained; Add % dev. expl., additional % deviance explained.

Predictor	Step	Df	AIC	% dev. expl.	Add % dev. expl.
Fishing year	1	11	31 628	3.7	3.7
Vessel	2	14	31 299	8.0	4.2
Longitude	3	3	31 145	9.8	1.8
Latitude	4	3	31 062	10.8	1.0

The model indicated steady CPUE from 1997–98 until 2000–01, and then a roughly 2-fold increase followed by a decrease; a roughly 3-fold difference in catch rate between vessels, and a decrease in CPUE to the west and north (Figure 6).

The standardisation procedure made little difference to the estimated CPUE trend, although it tended to flatten the increase in CPUE between 2003–04 and 2007–08 (Figure 7). The final index and coefficient of variation of the year effect are shown in Table 6.

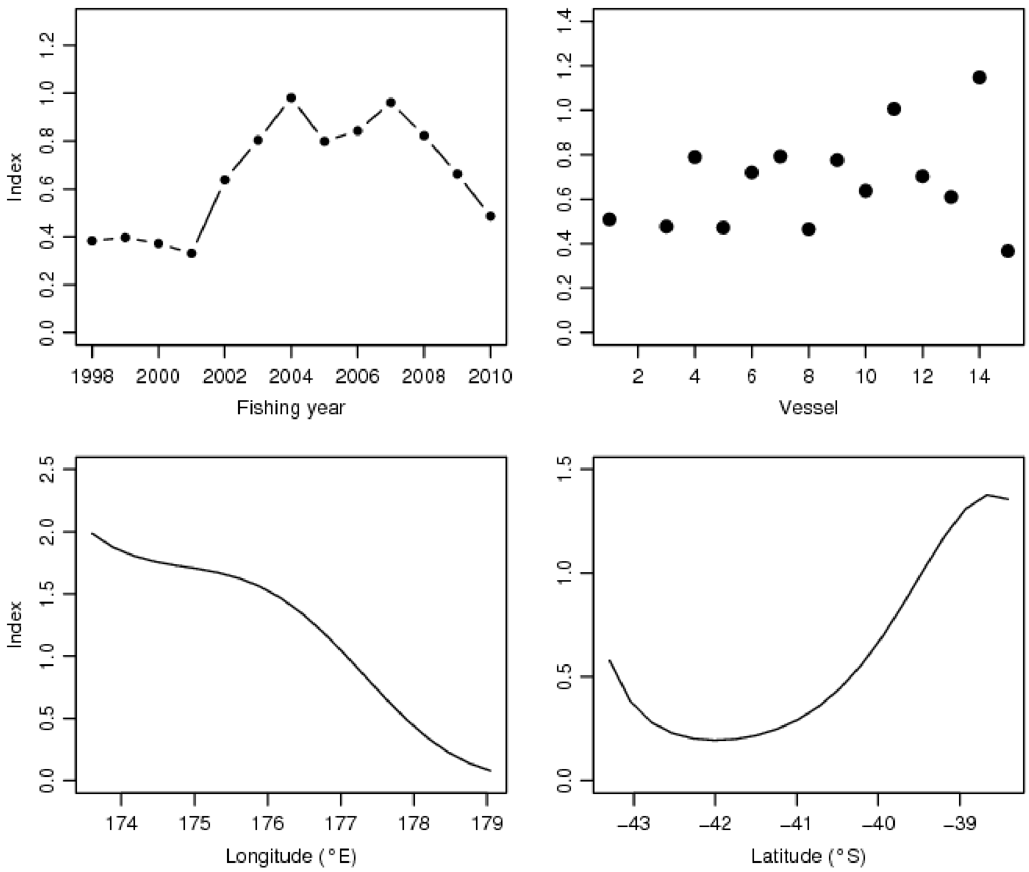

Figure 6: Model predictions by fishing year, vessel, longitude, and latitude, for the final CPUE model fit to the TCEPR data set in the standardised CPUE analysis for 1997–98 to 2009–10, made with all other predictors set to the median (fixed) values.

4.5 Commercial length frequency data

Plots of observer sample mean lengths against various independent variables indicated that there were no differences in mean length attributable to sampling programme (MFish or industry) or bottom depth, but QMA and catch size were important. Sample mean length from catches of less than about 2 t tended to be smaller than those from larger catches, and sample mean lengths from observed trips in ORH 3A were generally smaller than those from ORH 2B and ORH 2A South (Figure 8). Mean length also appeared to decrease over time in the two northern QMAs.

Assessment models for the Mid-East Coast stock have either treated the area as a single fishery (e.g., Anderson et al. 2002, Dunn 2005), or split the area into two fisheries (e.g., Branch 2002, McKenzie 2007). For this assessment the MEC was split into two fisheries; north (ORH 2A South and ORH 2B), and south (ORH 3A). This was because: 1, orange roughy spawn in the north fishery, but not in the south fishery; 2, there is a consistent size difference between fisheries (smaller fish in the south fishery); 3, CPUE indices apply to the north fishery only.

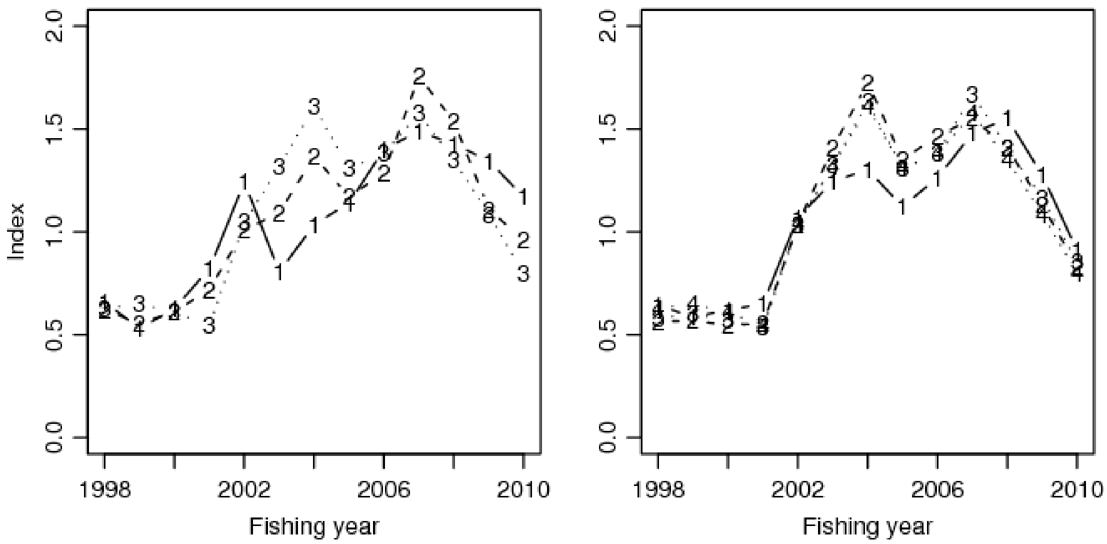

Figure 7: CPUE indices by fishing year for 1997–98 to 2009–10, all scaled to have a geometric mean of one. Left panel: 1, initial unstandardised CPUE; 2, subset of unstandardised CPUE used for standardised analyses; 3, standardised index. Right panel: 1, standardised index with year predictor only; 2, standardised index with predictors year and vessel; 3, standardised index with predictors year, vessel, and longitude; 4, standardised index with predictors year, vessel, longitude, and latitude.

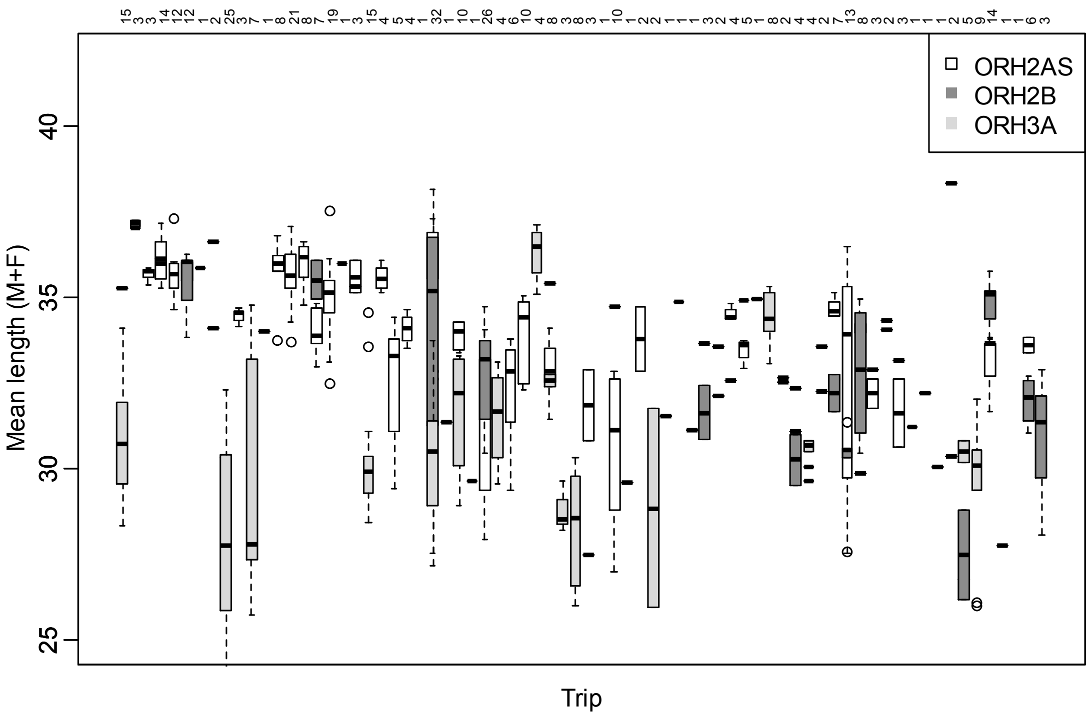

Figure 8: Box and whisker plots of sample mean lengths by trip and QMA. Trips are sorted from earliest to most recent using the mean of the sample dates within each trip. Numbers at the top of the plot indicate the number of samples taken on the trip. The boxes are bounded by the upper and lower quartiles, and show medians as horizontal bars; whiskers extend up to 1.5x the interquartile range, beyond which outliers are individually plotted.

There were many more commercial samples collected in the south fishery than in the north (Table 9), with 16 annual length frequencies possible for the north and 9 for the south. The length frequency distributions for the north and south fisheries differed substantially, with those from the southern fishery tending to show a wider range of fish sizes, including a higher proportion of small fish.

The estimated length frequencies and multinomial effective sample sizes are shown in Figures 9–12. Effective sample sizes were capped at 500 to limit the influence of individual samples, but only 6 of the 25 calculated effective sample sizes were substantially greater than this number.

The length distribution in the south fishery was highly variable from one year to the next and there is little in these plots to indicate a change in the size structure over time (Figure 11). The distributions in the north fishery are far less variable in comparison, but also show little evidence of a change in size structure or a shift in the mode over time (Figure 9).

Table 9: Number of orange roughy measured for length (length range 15–55 cm SL) and number of tows sampled, from commercial fishing vessels on the Mid-East Coast, by fishery.

Fishing year	North		South	
	Number measured	Number of samples	Number measured	Number of samples
1988–89	1538	3	–	–
1989–90	4641	37	1221	14
1990–91	3590	17	–	–
1991–92	–	–	–	–
1992–93	250	3	–	–
1993–94	380	4	2636	32
1994–95	5027	62	79	1
1995–96	86	1	4	1
1996–97	655	7	1311	15
1997–98	756	9	–	–
1998–99	2228	26	1361	17
1999–2000	3119	42	339	9
2000–01	484	6	1239	16
2001–02	1722	10	16	1
2002–03	814	10	–	–
2003–04	–	–	100	1
2004–05	138	2	–	–
2005–06	–	–	–	–
2006–07	1797	18	1224	13
2007–08	3179	45	695	7
2008–09	71	8	883	11
2009–10	1225	15	20	1

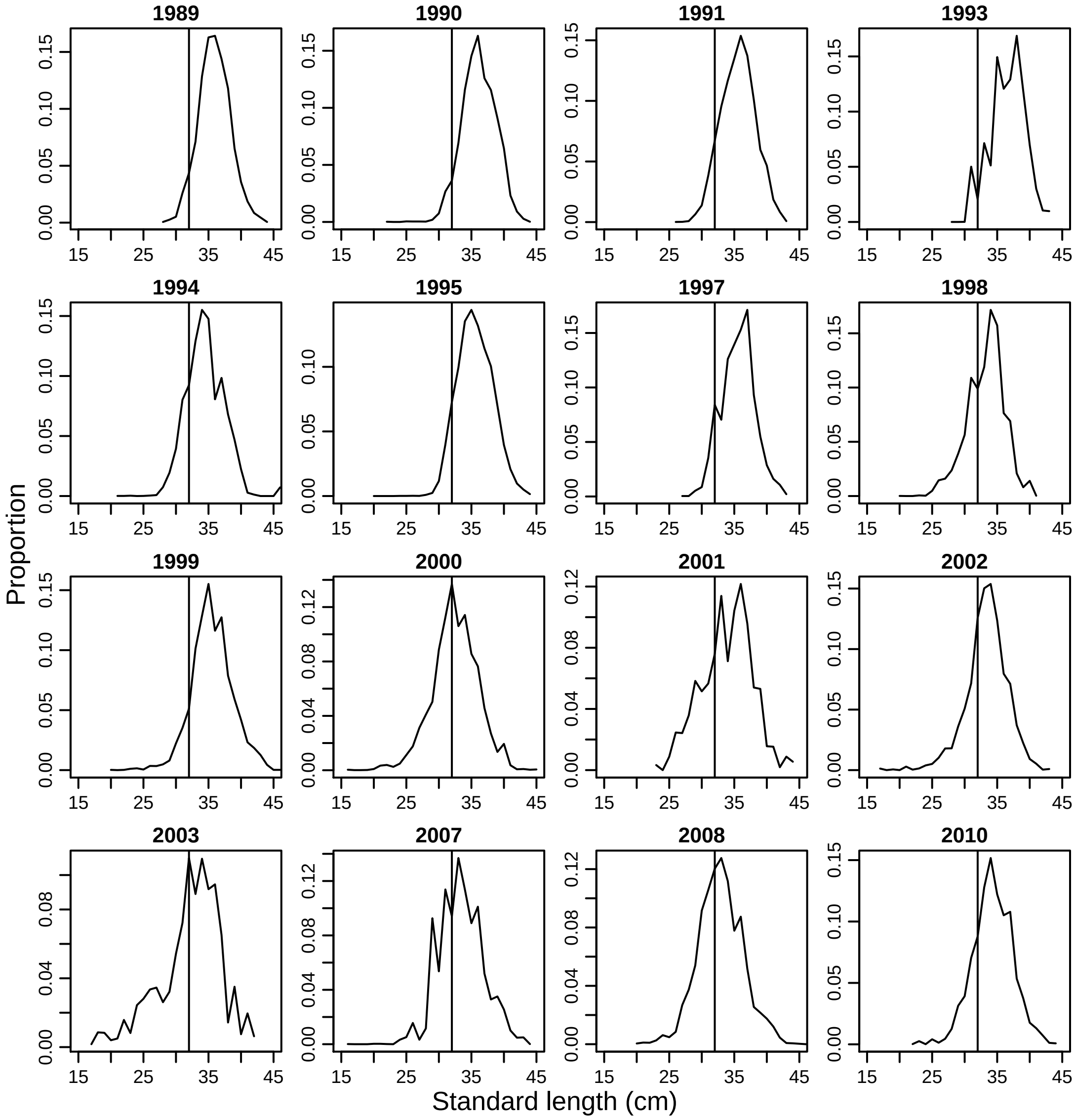

Figure 9: Orange roughy estimated length frequency distributions (catch weighted) for the north fishery of the Mid-East Coast, by fishing year. Vertical line is at 32 cm SL for reference.

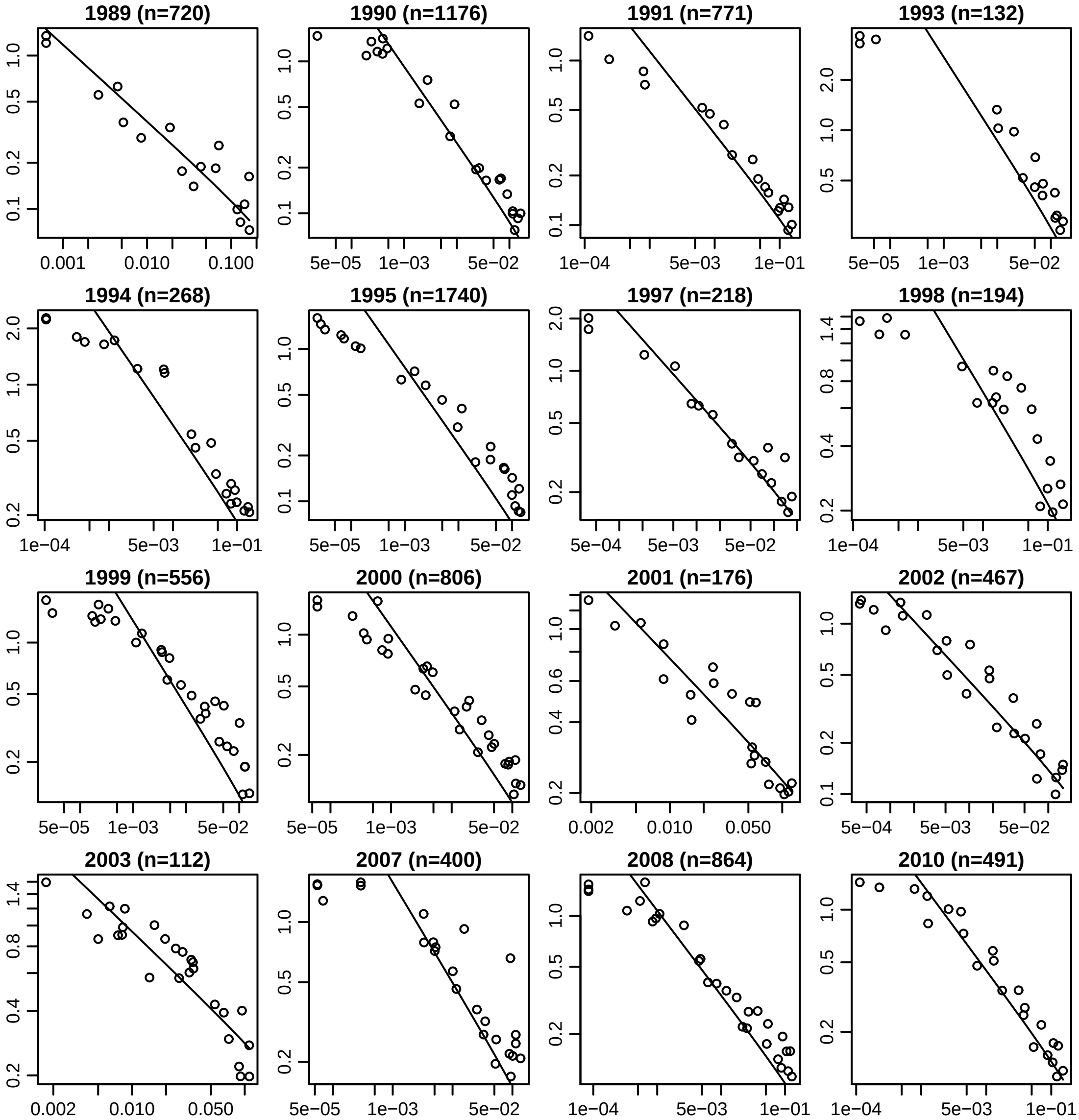

Figure 10: Log(proportion) (x-axis) plotted against log(c.v.) for the orange roughy length frequency distributions by fishing year from the north fishery of the Mid-East Coast, from which multinomial effective samples sizes were estimated (shown as *n*, in parentheses). Dots show the observations (numbers at length), and the line the fitted multinomial.

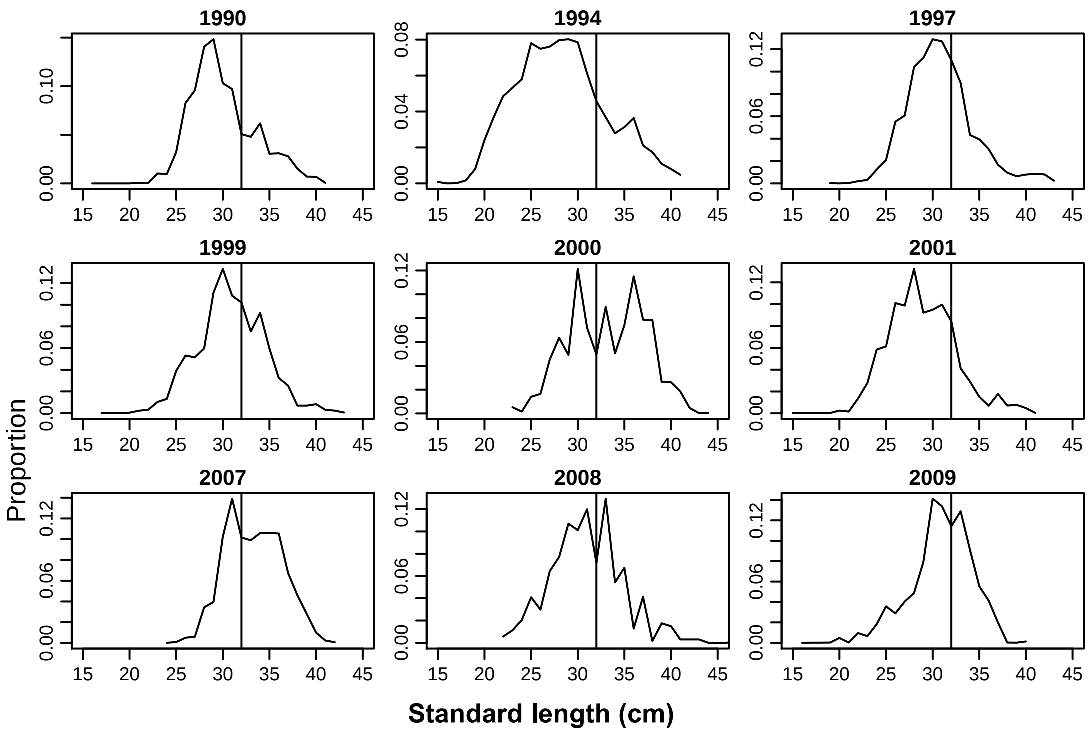

Figure 11: Orange roughy estimated length frequency distributions (catch weighted) for the south fishery of the Mid-East Coast, by fishing year. Vertical line is at 32 cm SL for reference.

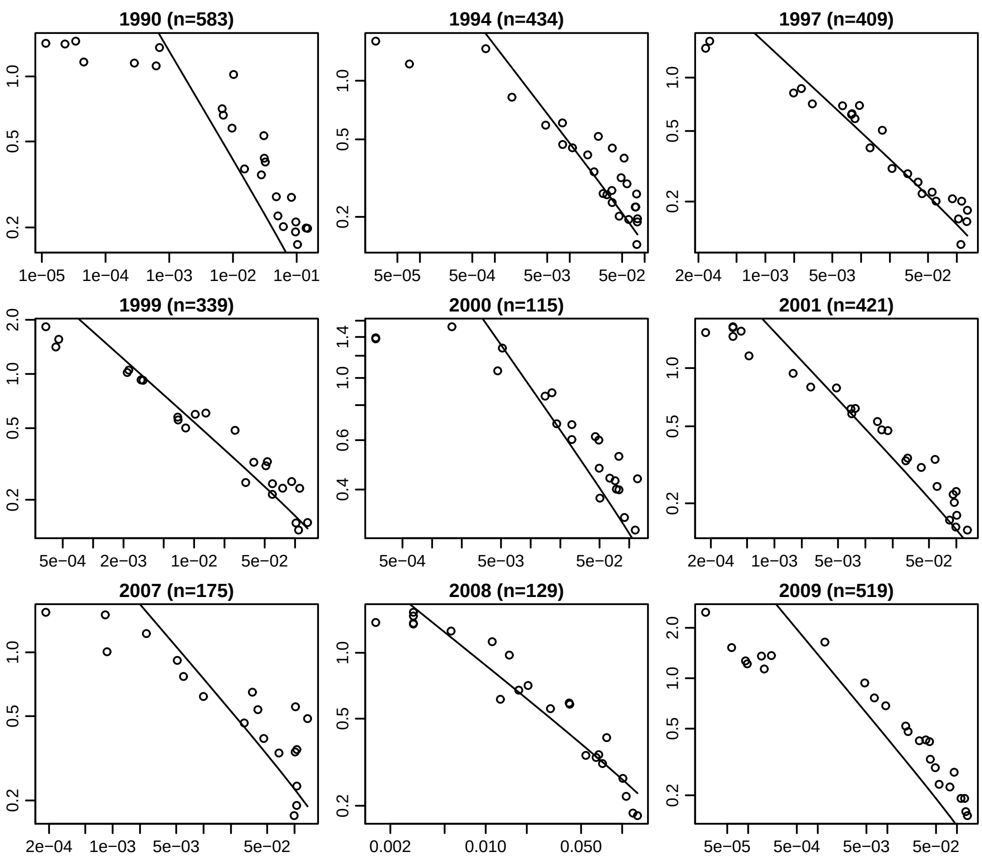

Figure 12: Log(proportion) (x-axis) plotted against log(c.v.) for the orange roughy length frequency distributions by fishing year from the south fishery of the Mid-East Coast, from which multinomial effective samples sizes were estimated (shown as *n*, in parentheses). Dots show the observations (numbers at length), and the line the fitted multinomial.

5. OTHER STOCK ASSESSMENT INPUTS

The biological parameters assumed for Mid-East Coast orange roughy are shown in Table 10. The plus group was set at 120 years instead of 80 years as assumed in previous assessments, because it was thought that this higher age was more appropriate when fitting lower values of natural mortality (which were investigated in model sensitivities).

Table 10: Biological parameters assumed for the Mid-East Coast orange roughy stock assessment.

Age structure		**Von Bertalanffy growth**	
Minimum age	1	L_∞	37.63 cm
Maximum age (plus group)	120+	k	0.065 yr
Recruitment		t_0	-0.5
Form	Beverton & Holt	**c.v. of mean length at age**	
Sigma r	1.1	Age 1	16%
Steepness	0.75	Age 80	5%
Age at maturity		**Length-weight (cm to tonnes)**	
a_{50}	25.73 yr	a	9.21e-8
a_{to95}	7.11 yr	b	2.71
Mortality			
Natural mortality	0.045 yr^{-1}		

The working group agreed to use an estimate of mean age at maturity from zone counts to the transition zone by NIWA readers (Table 11), with two other maturity estimates as sensitivity runs; (1) the mean of the Australian Central Ageing Facility (CAF) estimates; and (2) the average of mean CAF and NIWA estimates.

Table 11: Summary of the age to transition zone for MEC orange roughy otolith batches read by CAF and NIWA. The transition zone is assumed to mark the onset of sexual maturity. Based on Hicks (2007a, b).

Institute	Source of data	*n*	a_{50}	SE
CAF	Commercial landings, June-July 1989	105	32.49	0.51
CAF	Commercial landings, June-July 1990	131	30.85	0.40
CAF	Commercial landings, June-July 1991	129	31.11	0.41
CAF	Mean CAF value	365	31.5	–
NIWA	Research survey, October 1990	33	25.73	0.44
Combined	Average of mean CAF and NIWA estimates	398	28.6	–

The assumed natural mortality estimate was 0.045 yr^{-1}, which was derived from an ageing study on the Chatham Rise (Table 12). The working group agreed to consider sensitivities to M using the upper and lower 95% confidence intervals of an estimate from the Bay of Plenty (0.025 and 0.062 yr^{-1}). The Bay of Plenty estimate was used because the confidence intervals were slightly wider than obtained from the Chatham Rise estimate (Table 12).

Table 12: Published estimates of natural mortality (M) in orange roughy. The numbers in parentheses are the 95% confidence intervals of the M estimate.

Location	Year range	*n* aged	Method	M	Source
Chatham Rise	1984	432	Chapman-Robson	0.045 (0.030–0.060)	Doonan (1994)
Bay of Plenty	1995–96	362	Chapman-Robson	0.037 (0.025–0.062)	Doonan & Tracey (1997)

Other model biomass indices included research trawl surveys, which were used as relative biomass estimates and included a new observation for 2010 (Doonan & Dunn 2011); an egg survey which was used as an estimate of absolute spawning biomass (q = 1) (Zeldis et al.

1997); and two acoustic surveys which were used as absolute estimates of mature biomass but with an informed prior on the 2001 survey biomass estimate, and an informed prior on the ratio between the 2001 and 2003 surveys (Tables 13 and 14) (Doonan et al. 2003, 2004). The length frequency compositions (LFs) for the research trawl surveys were included, with each annual LF given an assumed effective sample size of 500.

Table 13: Research trawl survey vulnerable biomass estimates, egg survey and acoustic survey mature biomass estimates, and their calculated CVs, as used in the stock assessment for the MEC stock. –, no data. Note that fishing years when there was no survey have been excluded from the table

Fishing year	Trawl survey	CV (%)	Egg survey	CV (%)	Acoustic survey	CV (%)
1991–92	20 838	29	–	–	–	–
1992–93	15 102	27	22 000	49	–	–
1993–94	12 780	14	–	–	–	–
2000–01	–	–	–	–	25 300	38
2002–03	–	–	–	–	6 460	38
2009–10	7 074	19	–	–	–	–

Table 14: Informed priors for the acoustic biomass estimates (Cordue, pers. comm.). The parameters, μ and CV, defining the lognormal prior are in natural space.

Parameter	Prior
Catchability 2001 (q2001)	Lognormal (μ=0.907, CV=0.620)
Catchability 2003 (q2003)	Uniform
q2001/q2003	Lognormal (μ=1.909, CV=0.233)

Age compositions were estimated from otolith age estimates using samples from the commercial fishery on the spawning aggregations (Table 15), for the years 1989–1991 combined (labelled 1990), and for 2002 (Dunn 2005).

Table 15: Details of age samples from the spawn fishery as used for the stock assessment for the MEC stock, indicating the number of trips sampled, the number of age samples (N age) and accompanying length samples (N length), and the median, minimum, and maximum ages.

Year	Number of trips	N age	N length	Median Age	Age range
1989	3	150	1 538	65	26–164
1990	4	200	2 053	60	24–174
1991	5	249	2 529	53	17–192
2002	7	795	1 437	44	21–145

6. STOCK ASSESSMENT MODELLING

6.1 Model assumptions

Stock assessment was performed by NIWA using the stock assessment program CASAL (Bull et al. 2008) to estimate virgin and current biomass. The model was fitted using Bayesian estimation and partitioned the MEC stock population by age (age-groups used were 1–120, with a plus group).

The model assumed a single sex, with growth modelled using the von Bertalanffy growth formula. The stock was considered to reside in a single area, and to have a single maturation episode, with maturation modelled by a logistic ogive fixed to equal the north fishery vulnerability ogive.

Two fisheries were assumed, north (ORH 2A south and ORH 2B), and south (ORH 3A), each with separate fishery size vulnerabilities. Vulnerability of the north fishery was modelled by a logistic ogive, and of the south fishery by a double normal ogive, both fitted to length frequency data. The catch equation used was the instantaneous mortality equation from Bull et al. (2008), whereby half the natural mortality was applied, followed by the fishing mortality, then the remaining natural mortality.

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.

Vulnerability ogives and the coefficient of variation for mean length at age were estimated in a model run without abundance estimates and including only length frequencies from the north fishery, south fishery, and trawl survey; and maturity set to equal the north vulnerability to avoid cryptic biomass (Run B, see Table A1). The estimated ogives and coefficient of variation of mean length at age were then fixed at the values estimated from this run, and the length frequency data discarded. Subsequent model runs therefore fitted only to biomass indices and absolute estimates.

Where age frequency data were included (to estimate natural mortality), an ageing error misclassification matrix was applied, derived from an analysis of all orange roughy ageing data available to the working group (model runs Q, R, S, and U, see Table A3). All length frequencies assumed multinomial error distributions, and age frequencies assumed Coleraine error distributions, with effective sample sizes estimated outside of the model.

Lognormal errors, with known (sampling error) CVs were assumed for the CPUE and trawl survey indices, and egg and acoustic surveys. An additional estimated process error variance of 0.2 was added to the CVs from the early CPUE index, and 0.4 was added to the CVs from the late CPUE and trawl survey estimates (Run C, see Table A1). The CPUE, trawl survey, and acoustic survey series were treated as relative biomass indices, and the egg survey as an absolute biomass estimate.

Deterministic (constant) recruitment was the default assumption in the models runs. Runs estimating the variation in annual recruitment from the age frequency data were explored, but they did not improve fits to the age frequency and trawl survey data (model runs T, V, W, and X, see Table A3) and therefore detailed results are not presented here. The model estimated virgin biomass (B_0), five catchability coefficients (for the CPUE and survey indices), five vulnerability parameters, and two parameters for the CV of mean length at age (a total of thirteen parameters).

6.2 Model final runs and biomass estimates

Initial exploratory runs were carried out to consider the effect of varying the estimate of M, excluding all CPUE data, excluding the trawl and egg survey indices, and excluding the late CPUE index (Runs D to L, and N, see Tables A1 and A2). These were presented in detail to the Ministry of Fisheries Deepwater Fisheries Assessment Working Group, who agreed to use two model runs in the final stock assessment (Ministry of Fisheries 2011).

The first run, M2.5 (Run P, Table A2), provided the best fit to the trawl survey biomass index, by assuming a low M and excluding the late CPUE index. A significant conflict in the model was between the late CPUE index, which indicated a flat or increasing abundance, and the trawl survey index, which indicated a decline in abundance. The late CPUE index was considered to be less reliable than the trawl survey index. The late CPUE index is possibly also less reliable than the early CPUE index, as it was based on fewer tows and far fewer vessels, a much smaller catch, and covered a period when there was relatively little change in stock biomass. In run M2.5, the low M was set at 2.5%, the lower 95% confidence interval of the M estimate (see Table 12). This run estimated that the mature biomass declined continually during the fishery (Figure 13).

The second final model run, EstM (Run R, Table A3), differed in that the age frequency observations were included and M was estimated in the model. As the aim of using the age frequency data was to inform the estimate of M, the most important fit was to the right hand side of the age frequency distribution. The fit to the left hand size of the age frequency distributions was relatively poor (shown by Run Q, Table A3). As a result, Run R was fitted only to ages greater than the age of full vulnerability, which was estimated using the north fishery a_{50} + a_{to95} (= 53 years). Run R estimated a relatively high M (5.4%), and that the mature biomass started slowly rebuilding after 2001–02 (Figure 13). The run was a poor fit to the trawl survey biomass index, with the estimated biomass lower than 1992–94 observations, and higher than the 2010 observation (Figure 13).

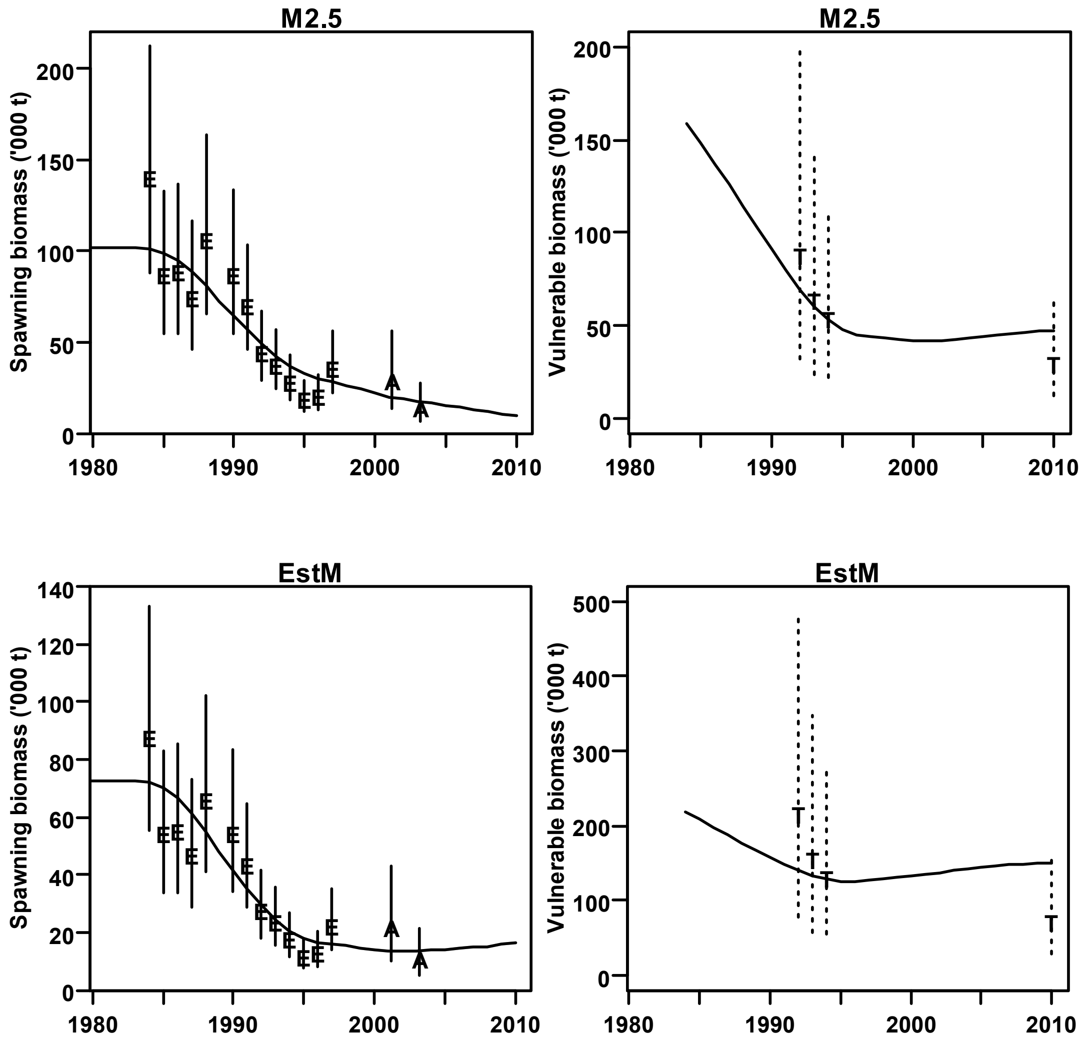

Figure 13: Estimated biomass trajectories (lines) and fitted data (points) from the M2.5 (top panels) and EstM (bottom panels) model runs. Data are identified by plotting symbol ('E' = CPUE (early series), 'A' = acoustic, 'T' = trawl survey). CPUE data are scaled up to the biomass. Vertical bars show 95% confidence intervals.

The two final model runs produced substantially different biomass estimates (Table 16). When assuming a low M, the stock was estimated to have been initially much larger but much more depleted in 2011.

Table 16: Biomass estimates (MPDs) for each model. B_{2011} is the mid-year biomass in 2011 (2010–11 fishing year).

Model run	B_0 (t)	B_{2011} (t)	% B_{2011}/B_0
M2.5	101 900	8 900	9.0
EstM	72 900	17 100	23.0

6.3 Sensitivity analyses

Many sensitivity analyses were conducted (Appendix A). Three of the more consequential analyses are summarised here.

The first set of sensitivity runs addressed the conflict between the increasing late CPUE index and the decreasing trawl survey biomass index. The Working Group agreed that the trawl survey biomass index was more reliable than the CPUE index, and therefore excluded the late CPUE index from final model runs. However, a sensitivity run with the trawl survey index excluded (Run Y, Table A4) showed that a good fit to the late CPUE index could be achieved by setting M at 6.2%, the higher 95% confidence interval of the M estimate (see Table 12). The model fit and biomass estimates from this run were not materially different to that estimated by the EstM run.

Other sensitivity runs excluded all CPUE data, producing models estimating a very large initial stock with relatively little depletion (Runs M and O, Table A2). This was inconsistent with other observations of the fishery, and indicated that such models lacked necessary information on the initial rate of biomass decline, or a precise absolute biomass estimate from early in the fishery. The egg survey provided a precise absolute biomass estimate (for 1993), but this was considered especially uncertain and unreliable, and has been excluded from most previous stock assessments. Therefore, despite the uncertain relationship between CPUE and abundance for orange roughy, the early CPUE index was considered to be a crucial input, and was therefore included in all final model runs.

To determine whether the decline in the trawl survey biomass index could be explained in the model by recruitment variability, sensitivities were conducted estimating recruitment deviates. These runs were done over a range of fixed values of M (3.5–6.2%). In these runs (Runs T, V–X, Table A3) the age frequencies and trawl survey length frequencies were included. The fits to the trawl survey biomass index from these runs became progressively worse with increasing M. The best fit to the trawl survey was with an M of 3.5% (Run V), which estimated a stock depletion slightly greater than estimated by the M2.5 run.

6.4 Five year projection results

Forward projections were carried out over a 5-year period using the maximum posterior density (MPD) model fit and a constant catch, set at the 2010–11 catch limit of 1500 t and various lower levels (Table 17). The projections predicted that the biomass would slowly increase for the EstM run, for all future levels of catch considered. For this run, the spawning biomass remained at over 20% at all catch levels and in all years. For the M2.5 run, biomass was predicted to decrease at all levels of future catch over 300 t and, at a constant catch of 300 t, decrease until 2013–14 and then increase slowly. For this run, the spawning biomass remained at less than 10% at all catch levels and in all years.

Table 17: Projected mid-year spawning biomass in tonnes and as a fraction of the initial biomass (%B_0, in parentheses) in the years 2010–11 to 2015–16 for the Mid-East Coast stock for the two model runs, with the annual catch set to a range of values between 300 and 1500 t.

		Mid-year spawning biomass (t) (%B_0)					
Model run	Catch (t)	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16
EstM	300	17 300 (24)	18 500 (25)	19 800 (27)	21 100 (29)	22 500 (31)	23 900 (33)
	600	17 300 (24)	18 300 (25)	19 400 (27)	20 600 (28)	21 900 (30)	23 100 (32)
	900	17 200 (24)	18 100 (25)	19 100 (26)	20 200 (28)	21 300 (29)	22 400 (31)
	1 200	17 100 (23)	17 900 (25)	18 800 (26)	19 700 (27)	20 700 (28)	21 700 (30)
	1 500	17 100 (23)	17 800 (24)	18 600 (26)	19 500 (27)	20 300 (28)	21 200 (29)
M2.5	300	9 300 (9)	9 000 (9)	8 900 (9)	8 700 (9)	8 700 (9)	8 800 (9)
	600	9 200 (9)	8 700 (9)	8 400 (8)	8 100 (8)	7 900 (8)	7 800 (8)
	900	9 100 (9)	8 500 (8)	7 900 (8)	7 500 (7)	7 100 (7)	6 900 (7)
	1 200	9 000 (9)	8 200 (8)	7 500 (7)	6 900 (7)	6 300 (6)	5 900 (6)
	1 500	8 900 (9)	8 000 (8)	7 200 (7)	6 500 (6)	5 900 (6)	5 500 (5)

7. CONCLUSIONS AND DISCUSSION

A major difficulty with this model was the conflict between the trawl survey index, and the likely stock size and assumed productivity of orange roughy. A substantial decline in abundance between 1983 and 1997 was supported by the early CPUE index, and the trawl survey index indicated a continuation of this decline between 1992 and 2010. Given the likely initial stock size indicated by the catch history (about 100 000 t were caught in about 10 years, suggesting an initial stock size of more than 50 000 t was likely) and natural mortality rate assumed or estimated within the model, the stock should have been rebuilding over the last 10–15 years after the catches were reduced. However, the 2010 trawl survey indicated a decline in biomass.

The trawl survey biomass index was considered by the Working Group to be a key observation, which should have a strong weighting in the assessment model. The assumptions required to fit this index cast doubt on the assumed productivity. A reasonably good fit was achieved in this run by applying a much lower estimate of M (2.5% instead of 4.5%) but there was little independent evidence to support this lower estimate. As a result, it was not clear whether the stock size or productivity assumptions were incorrect, or whether the trawl survey biomass index was incorrect (see also Dunn submitted).

The Working Group did not consider either of the two final model runs to be satisfactory. Both runs estimated the stock to be depleted (about 10% B_0 or about 20% B_0), with the Working Group considering the most likely stock status lay between these two estimates. However, under the Ministry of Fisheries Harvest Standard the management implications of the accepted stock status are quite different; if the stock was above 20% B_0, the 'soft limit', then no immediate management action is required, but if the stock is below 10% B_0, the 'hard limit', then the stock should be considered for closure. Clearly, future assessments would be more helpful if it was possible to resolve which model run was more likely to represent reality.

Future assessments would be improved by better knowledge of the productivity of orange roughy, specifically M and recruitment variability patterns. This could be achieved with more ageing data. We consider that new age frequency data would be the most useful new input to the assessment, and recommend that such ageing takes place. A future research trawl survey may also help to resolve the recent stock biomass trajectory, and confirm the relative biomass estimate from 2010 as accurate, rather than an anomalous observation.

The final stock assessment reported only MPDs. A full Bayesian assessment, using MCMCs to estimate posterior parameter distributions, was started but encountered some problems. Specifically, the parameter space investigated by the MCMC was limited (implying that the chain had ‘got stuck’). This was more pronounced for the M2.5 model run. There was insufficient time during the 2011 assessment period to resolve this problem, and the Working Group agreed to present the MPD estimates to allow some assessment of stock status in MEC orange roughy. No further investigations were subsequently done, and the cause of the MCMC problem remained obscure. If similar model runs are used in future stock assessments, then we recommend that the MCMC problem be resolved (if it was to occur again) before the assessment model is accepted.

8. ACKNOWLEDGMENTS

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APPENDIX A

Summary of sensitivity analyses conducted using CASAL model runs. Model runs are designated in the tables as Run A, Run B, etc. A brief description of each sensitivity model run is provided in Table A0, and summaries of model parameters and results (including biomass estimates and likelihood values) are provided in Tables A1–A4.

Table A0. Explanation of model runs in Tables A1–A4.

Run	Description
Run A	Estimating selectivities and mean length at age CVs with abundance estimates and all LFs included, process errors fixed.
Run B	Estimating fishery selectivities and mean length at age CVs, with abundance estimates excluded, all LFs included, and maturity fixed to equal north selectivity. These estimated values fixed in following runs unless stated.
Run C	Estimating CPUE and trawl survey process errors, with all abundance data included. Resulting values fixed in following runs.
Run D	M fixed at 2.5%, all abundance data included.
Run E	M fixed at 6.2%, all abundance data included.
Run F	M fixed at 2.5%, all CPUE indices excluded.
Run G	M fixed at 6.2%, all CPUE indices excluded.
Run H	M fixed at 4.5%, all CPUE indices excluded.
Run I	M fixed at 4.5%, egg survey and trawl survey indices excluded.
Run J	M fixed at 4.5%, trawl survey index excluded.
Run K	M fixed at 2.5%, trawl survey index excluded.
Run L	M fixed at 2.5%, egg survey and trawl survey indices excluded.
Run M	M fixed at 4.5%, egg survey and all CPUE indices excluded.
Run N	M fixed at 4.5%, egg survey and late CPUE index excluded.
Run O	M fixed at 2.5%, egg survey and all CPUE indices excluded.
Run P	(M2.5) M fixed at 2.5%, egg survey and late CPUE index excluded.
Run Q	Estimating M, age frequencies included (all ages), egg survey and late CPUE index excluded.
Run R	(EstM) Estimating M, age frequencies included (ages ≥53 y), egg survey and late CPUE index excluded.
Run S	Estimating M, age frequencies included (ages ≥53 y), egg survey and all CPUE indices excluded.
Run T	Estimating recruitment, M fixed at 4.5%, age frequencies included (ages ≥53 y), trawl survey LFs back in, egg survey and late CPUE index excluded.
Run U	Estimating M, age frequencies included (ages ≥53 y and max age raised to 165 y), egg survey and late CPUE index excluded.
Run V	Estimating recruitment, M fixed at 3.5%, age frequencies included (ages ≥53 y), trawl survey LFs back in, egg survey and late CPUE index excluded.
Run W	Estimating recruitment, M fixed at 5.4% (from Run R), age frequencies included (ages ≥53 y), trawl survey LFs back in, egg survey and late CPUE index excluded
Run X	Estimating recruitment, M fixed at 6.2%, age frequencies included (ages ≥53 y), trawl survey LFs back in, egg survey and late CPUE index excluded.
Run Y	Trawl survey index excluded, M fixed at 6.2%.
Run Z	Estimating M, age frequencies included (ages ≥53 y), trawl survey excluded.

Table A1. Summary of model runs A to H. * fixed parameter, – not estimated.

	RunA	RunB	RunC	RunD	RunE	RunF	RunG	RunH
B_0 (mid-year)	104 900	64 000	85 300	108 500	69 200	117 600	85 800	98 200
$B_{current}$ (mid-year)	26 000	2 700	19 400	14 300	21 700	22 200	37 700	31 800
$B_{current}(\%B_0)$	25	4	23	13	31	19	44	32
$B_{vuln2010}/B_{curr2010}$	0.39	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Umax	0.34	0.90	0.19	0.60	0.24	0.40	0.15	0.13
U2011	0.09	0.32	0.05	0.06	0.04	0.04	0.02	0.03
q CPUE early	5.7E-05	–	3.3E-05	2.4E-05	4.4E-05	–	–	–
q CPUE late	9.1E-05	–	3.4E-05	2.9E-05	3.7E-05	–	–	–
q acoustic 2001	1.08	–	0.87	0.69	0.99	0.55	0.57	0.58
q acoustic 2003	0.54	–	0.44	0.35	0.50	0.27	0.28	0.28
q 2001/q 2003	2.00	–	2.0	2.0	2.0	2.0	2.0	2.1
q research trawl	0.16	–	0.11	0.20	0.07	0.14	0.05	0.08
Process error CVs								
CPUE early	0.0*	–	0.2	0.2*	0.2*	–	–	–
CPUE late	0.0*	–	0.4	0.4*	0.4*	–	–	–
Trawl surveys	0.2*	–	0.4	0.4*	0.4*	0.4*	0.4*	0.4*
Natural mortality	0.045*	0.045*	0.045*	0.025*	0.062*	0.025*	0.062*	0.045*
Selectivities								
North: a50	38.78	43.57	43.57*	43.57*	43.57*	43.57*	43.57*	43.57*
ato95	9.30	9.25	9.25*	9.25*	9.25*	9.25*	9.25*	9.25*
South: a1	28.73	30.33	30.33*	30.33*	30.33*	30.33*	30.33*	30.33*
South: sL	6.50	6.75	6.75*	6.75*	6.75*	6.75*	6.75*	6.75*
South: sR	14.23	7.37	7.37*	7.37*	7.37*	7.37*	7.37*	7.37*
Res. Trawl: a50	13.39	13.79	13.79*	13.79*	13.79*	13.79*	13.79*	13.79*
ato95	4.38	4.44	4.44*	4.44*	4.44*	4.44*	4.44*	4.44*
Maturity: a50	31.5*	43.57	43.57*	43.57*	43.57*	43.57*	43.57*	43.57*
ato95	7.11*	9.25	9.25*	9.25*	9.25*	9.25*	9.25*	9.25*
Length at age: CV1	0.10	0.11	0.11*	0.11*	0.11*	0.11*	0.11*	0.11*
Length at age: CV2	0.04	0.03	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*
Likelihoods								
Sum	2080	1997	-30	-24	-33	6	5	6
CPUE (1984–1997)	29.0	–	-11.2	-8.7	-12.1	–	–	–
CPUE (1998–2010)	13.5	–	-4.6	-0.13	-6.7	–	–	–
acoustic 2001	0.34	–	-0.14	-0.42	0.09	-0.55	-0.40	-0.44
acoustic 2003	-0.87	–	-0.91	-0.90	-0.89	-0.82	-0.75	-0.79
egg 1993	-0.77	–	-0.54	0.34	-0.77	0.95	-0.20	0.18
Comm LF north	980	928	–	–	–	–	–	–
Comm LF south	756	740	–	–	–	–	–	–
trawl surveys	-0.136	–	-1.340	-2.382	-1.164	-2.000	-1.231	-1.304
trawl LF	311.5	313.3	–	–	–	–	–	–
Priors	9.1	11.1	-11.6	-11.5	-11.6	9.3	8.0	8.5
Penalties								
Catch penalty (N)	0	2.1	0	0	0	0	0	0
Catch penalty (S)	0	2.1	0	0	0	0	0	0
Acoustic q ratio	0.13	–	-0.10	-0.32	0.03	-0.53	-0.47	-0.47

Table A2. Summary of model runs I to P. * fixed parameter, – not estimated. RunP=Run M2.5

	RunI	RunJ	RunK	RunL	RunM	RunN	RunO	RunP
B_0 (mid-year)	83 900	83 100	108 400	111 200	136 100	81 500	161 400	101 900
$B_{current}$ (mid-year)	18 100	17 400	14 200	16 600	69 100	15 900	63 600	8 900
$B_{current}(\%B_0)$	22	21	13	15	51	20	39	9
$B_{vuln2010}/B_{curr2010}$	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Umax	0.18	0.19	0.61	0.53	0.09	0.20	0.18	0.90
U2011	0.05	0.05	0.06	0.05	0.01	0.06	0.01	0.10
q CPUE early	3.4E-05	3.5E-05	2.4E-05	2.3E-05	–	3.6E-05	–	2.7E-05
q CPUE late	3.6E-05	3.8E-05	3.0E-05	2.7E-05	–	–	–	–
acoustic q 2001	0.92	0.95	0.70	0.65	0.31	1.03	0.29	0.87
acoustic q 2003	0.47	0.49	0.35	0.32	0.14	0.53	0.13	0.44
q2001/q2003	2.0	2.0	2.0	2.0	2.1	2.0	2.1	2.0
q research trawl	–	–	–	–	0.05	0.12	0.08	0.24
Process error CVs								
CPUE early	0.2*	0.2*	0.2*	0.2*	–	0.2*	–	0.2*
CPUE late	0.4*	0.4*	0.4*	0.4*	–	–	–	–
Trawl surveys	–	–	–	–	0.4*	0.4*	0.4*	0.4*
Natural mortality	0.045*	0.045*	0.025*	0.025*	0.045*	0.045*	0.025*	0.025*
Selectivities								
Res. Trawl: a50	–	–	–	–	13.79*	13.79*	13.79*	13.79*
ato95	–	–	–	–	4.44*	4.44*	4.44*	4.44*
Likelihoods								
Sum	-26	-27	-20	-20	5	-15	5	-15
CPUE (1984–1997)	-11.3	-11.5	-8.8	-8.0	–	-11.9	–	-10.5
CPUE (1998–2010)	-4.4	-4.4	-0.1	-0.70	–	–	–	–
acoustic 2001	-0.10	-0.07	-0.42	-0.46	-0.79	-0.01	-0.84	-0.29
acoustic 2003	-0.92	-0.93	-0.90	-0.87	-0.54	-0.94	-0.54	-0.95
egg 1993	–	-0.63	0.32	–	–	–	–	–
Comm LF north	–	–	–	–	–	–	–	–
Comm LF south	–	–	–	–	–	–	–	–
trawl surveys	–	–	–	–	-1.438	-1.315	-1.847	-2.539
trawl LF	–	–	–	–	–	–	–	–
Priors	-9.2	-9.1	-9.8	-10.0	8.9	-0.9	9.7	-0.6
Penalties								
Catch penalty (N)	0	0	0	0	0	0	0	0.003
Catch penalty (S)	0	0	0	0	0	0	0	0.003
Acoustic q ratio	-0.05	-0.02	-0.32	-0.39	-1.00	0.05	-1.07	-0.12

Table A3. Summary of model runs Q to X. * fixed parameter, – not estimated. RunR=Run EstM.

	RunQ	RunR	RunS	RunT	RunU	RunV	RunW	RunX
B_0 (mid-year)	69 800	72 900	79 500	79 300	69 900	80 000	79 700	80 100
$B_{current}$ (mid-year)	12 100	17 100	24 700	13 600	18 600	6 000	20 700	26 100
$B_{current}(\%B_0)$	17	23	31	17 (6)	27	8 (3)	26 (9)	33 (11)
$B_{vuln2010}/B_{curr2010}$	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Umax	0.28	0.24	0.19	0.25	0.25	0.25	0.26	0.25
U2011	0.07	0.05	0.04	0.07	0.05	0.14	0.04	0.03
q CPUE early	4.9E-05	4.3E-05	–	4.6E-05	4.5E-05	4.6E-05	4.6E-05	4.5E-05
q CPUE late	–	–	–	–	–	–	–	–
acoustic q 2001	1.55	1.13	0.80	1.40	1.11	1.84	1.14	0.99
acoustic q 2003	0.81	0.58	0.40	0.73	0.56	1.00	0.58	0.50
q2001/q2003	1.9	2.0	2.0	1.9	2.0	1.8	2.0	2.0
q research trawl	0.11	0.10	0.08	0.11	0.09	0.18	0.08	0.06
Process error CVs								
CPUE early	0.2*	0.2*	–	0.2*	0.2*	0.2*	0.2*	0.2*
CPUE late	–	–	–	–	–	–	–	–
Trawl surveys	0.4*	0.4*	0.4*	0.4*	0.4*	0.4*	0.4*	0.4*
Natural mortality	0.051	0.054	0.055	0.045*	0.058	0.035*	0.054*	0.062*
Selectivities								
Res. Trawl: a50	13.79*	13.79*	13.79*	13.21	13.79*	12.65	13.73	14.20
ato95	4.44*	4.44*	4.44*	3.57	4.44*	3.20	3.86	4.11
Max. age in model	120	120	120	120	165	120	120	120
Min. age in age data	17	53	53	53	53	53	53	53
Likelihoods								
Sum	-500	-292	-269	-189	-595	-165	-195	-194
CPUE (1984–1997)	-12.1	-12.5	–	-12.5	-12.5	-12.2	-12.6	-12.4
acoustic 2001	0.48	0.17	-0.15	0.33	0.19	0.38	0.24	0.16
acoustic 2003	-0.98	-0.94	-0.86	-0.98	-0.92	-1.00	-0.92	-0.88
trawl surveys	-1.327	-1.326	-1.349	-1.505	-1.308	-2.237	-1.172	-1.026
trawl LF	–	–	–	117	–	121	115	115
Proportions at age	-487	-276	-275	-278	-579	-263	-280	-279
Priors	0.2	-0.9	8.5	-63.9	-1.0	-59.6	-65.1	-65.1
Penalties								
Catch penalty (N)	0	0	0	0	0	0	0	0
Catch penalty (S)	0	0	0	0	0	0	0	0
Mean YCS = 1	–	–	–	49	–	49	49	49
YCS smoothing	–	–	–	1.1	–	1.6	0.9	0.8
Acoustic q ratio	0.44	0.15	-0.17	0.34	0.14	0.61	0.16	0.04

Table A4. Summary of model runs J, K, Y, Z. * fixed parameter, – not estimated.

	RunY	RunZ
B_0 (mid-year)	68 800	72 600
$B_{current}$ (mid-year)	21 200	18 300
$B_{current}(\%B_0)$	31	25
$B_{vuln2010}/B_{curr2010}$	1.00	1.00
Umax	0.25	0.24
U2011	0.04	0.05
q CPUE early	4.5E-05	4.3E-05
q CPUE late	3.8E-05	4.2E-05
acoustic q 2001	1.01	1.08
acoustic q 2003	0.51	0.55
q2001/q2003	2.0	2.0
Natural mortality	0.062*	0.055
Likelihoods		
Sum	-29	-305
CPUE (1984–1997)	-12.2	-12.4
CPUE (1998–2010)	-6.7	-6.0
acoustic 2001	0.11	0.13
acoustic 2003	-0.90	-0.93
egg 1993	-0.76	-0.77
Proportions at age	–	-276
Priors	-8.9	-8.7
Penalties		
Catch penalty (N)	0	0
Catch penalty (S)	0	0
Acoustic q ratio	0.05	0.11