Standardised CPUE analyses for two North Island orange roughy fisheries (ORH 1 and ORH2A North) to the end of the 2009–10 fishing year

O. Anderson

NIWA
PO Box 14–901
Wellington

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EXECUTIVE SUMMARY

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This report describes the standardisation of orange roughy commercial catch per unit effort (CPUE) data for the northern North Island (ORH 1) and East Cape (ORH 2A North) fisheries, to the end of the 2009–10 fishing year. This represents the first attempt at a standardised CPUE for ORH 1 as a whole, and updates the previous standardisation for ORH 2A North with the addition of data from five additional fishing years.

The ORH 1 fishery encompasses the waters offshore of the west and northeast coastlines of the North Island and lies adjacent to the ORH 2A North fishery in the east. This fishery dates from about the same time as ORH 2A North and although the maximum annual landings were less than half that of that fishery, a combination of the widespread nature of the fishery and strict management controls have led to more even harvest levels, averaging about 1000 t since 1995–96. A stock assessment for the Mercury-Colville Box (the centre of effort during the initial stages of the fishery) was carried out in 2001. This has not been updated and no stock assessment for ORH 1 as a whole has been attempted.

The ORH 2A North fishery encompasses the northern part of the ORH 2A Quota Management Area (north of a line at 38° 23´S) and was developed in 1993–94 after major winter spawning aggregations were discovered. Since then annual catches have ranged between 170 t and 3400 t, but have been limited by a catch limit of 200 t since 2000–01, after an initial stock assessment for the fishery. This assessment was last updated in 2003.

Commercial catch and effort (tow-by-tow) data were used to estimate standardised annual CPUE indices, using data from a core set of vessels that fished consistently over time. In ORH 1, the analysis was also limited to a core set of undersea features. Only records for tows which targeted orange roughy were used. A standard approach was applied, using a forward stepwise procedure to select predictors within a generalised linear model framework. Binomial models, based on the success or failure of target tows to catch any orange roughy, were not considered due to the likely inconsistent recording of zero catch.

The final model for ORH 1 incorporated four predictor variables, fishing year (forced into the model), feature, vessel, and month. Model predictions indicated that catch rates were higher during winter spawning than at other times, that the best performing vessel had a catch rate 4–5 times that of the worst vessel, and that there were significant differences in catch rates among the 22 features examined, with Tauroa Knoll and Manukau the best performing. The predicted year effects showed a general decline between 1993–94 and 2009–10, although the indices were highly variable in the first few years. The CPUE indices may have been influenced by the complex and changing management controls used in this fishery, particularly the annual subarea and feature catch limits.

For ORH 2A North, the final model incorporated three predictor variables, fishing year (forced into the model), month, and vessel. Model predictions showed about a five-fold difference between the catch rates of the worst and best vessels, and June catch rates were predicted to be at least triple (and July catch rates about double) those of months outside the spawning period. The predicted year effects showed a rapid decline between 1993–94 and 1997–98 and quite variable levels thereafter, declining in the last four years of the series. Some of the variability and lack of precision in the annual indices may be due to the relatively small size of the fishery after 2000–01, with two years including only 65–70 tow records.

1. INTRODUCTION

Orange roughy have been the focus of an important deepwater fishery in New Zealand since the early 1980s (Ministry of Fisheries 2011). Fishing in the two management areas covered by this report developed more recently, with substantial effort and catch not occurring until the 1993–94 fishing year.

The work described in this report was carried out under Ministry of Fisheries project ORH2008/02: Objective 2, "*To update the unstandardised and standardised catch per unit effort analyses with the inclusion of data up to and including the 2008/09 fishing year for the following areas:*

a) ORH 1
b) East Cape
c) MEC"

Unstandardised catch per unit effort analyses for these fisheries, as well as the standardised catch per unit effort analyses for the MEC area will be reported elsewhere (Dunn & Anderson, unpublished results).

The coastline of the northern North Island (ORH 1) fishery extends northwards from north of Wellington on the west coast of the North Island, to Cape Runaway east of the Bay of Plenty on the east coast of the North Island. This QMA is bounded offshore by ORH 2A in the east, ORH 7A in the south, and the New Zealand EEZ elsewhere. There is little information with which to determine whether or not the orange roughy within ORH 1 represent a distinct stock. There are several seamounts closed to trawling in the region (some within known fishing regions), and two Benthic Protection Areas, which are closed to bottom trawling (Figure 1).

Prior to 1985 it was considered that orange roughy were unlikely to be present in commercial quantities in ORH 1, and an early exploratory survey of deepwater resources which included the Bay of Plenty and North Cape caught only small amounts of orange roughy (McMillan 1985). This appeared to be confirmed by the exploratory cruises of the Wanaka in 1985 and 1986 (Clark & King 1989) and the TACC for ORH 1 was set at 10 t (Table 1). However, in 1985 a commercial vessel took a catch of about 100 t of orange roughy from a seamount in the Bay of Plenty. Further large catches of orange roughy were not taken again until 1989, despite some exploratory fishing. This catch, taken when targeting black cardinalfish, was again from a Bay of Plenty seamount.

These catches led to the gradual development of a fishery on two seamount complexes in the western Bay of Plenty (the Mercury-Colville Box) and a TACC of 190 t was set from 1989–90 (up from 10 t plus exploratory quota). Fishing was mostly confined to this area during the initial development of the fishery, but catches of orange roughy began to be taken from off the west coast of Northland from 1995–96.

The Mercury-Colville fishery came under the control of an Adaptive Management Programme (AMP) from 1 October 1995, with a catch limit set at 1000 t after a trawl survey in winter of 1995 (Clark & Field 1998) produced a biomass estimate of 78 500 t (although repeat surveys in 1998 (Clark & Anderson 1999) and 2000 (Clark & Francis 2000) gave an estimate of only 2500 t and 3800 t respectively). The existing 190 t TACC was allocated to the remainder of ORH 1 to encourage exploratory fishing, and this led to the initial discovery of the Tauroa Knoll fishery in 1995–96. To allow further exploration of the wider ORH 1 region, a special permit was granted for the 1996–97 to 1999–2000 fishing years, providing an extra 1000 t to be taken annually, spread evenly among five areas and with a "feature" limit of 100 t. It was only during the last two years of this period that serious exploratory fishing took place, leading to development of the Tauroa Knoll fishery and the first catches being taken from the West Norfolk Ridge and Northland fisheries.

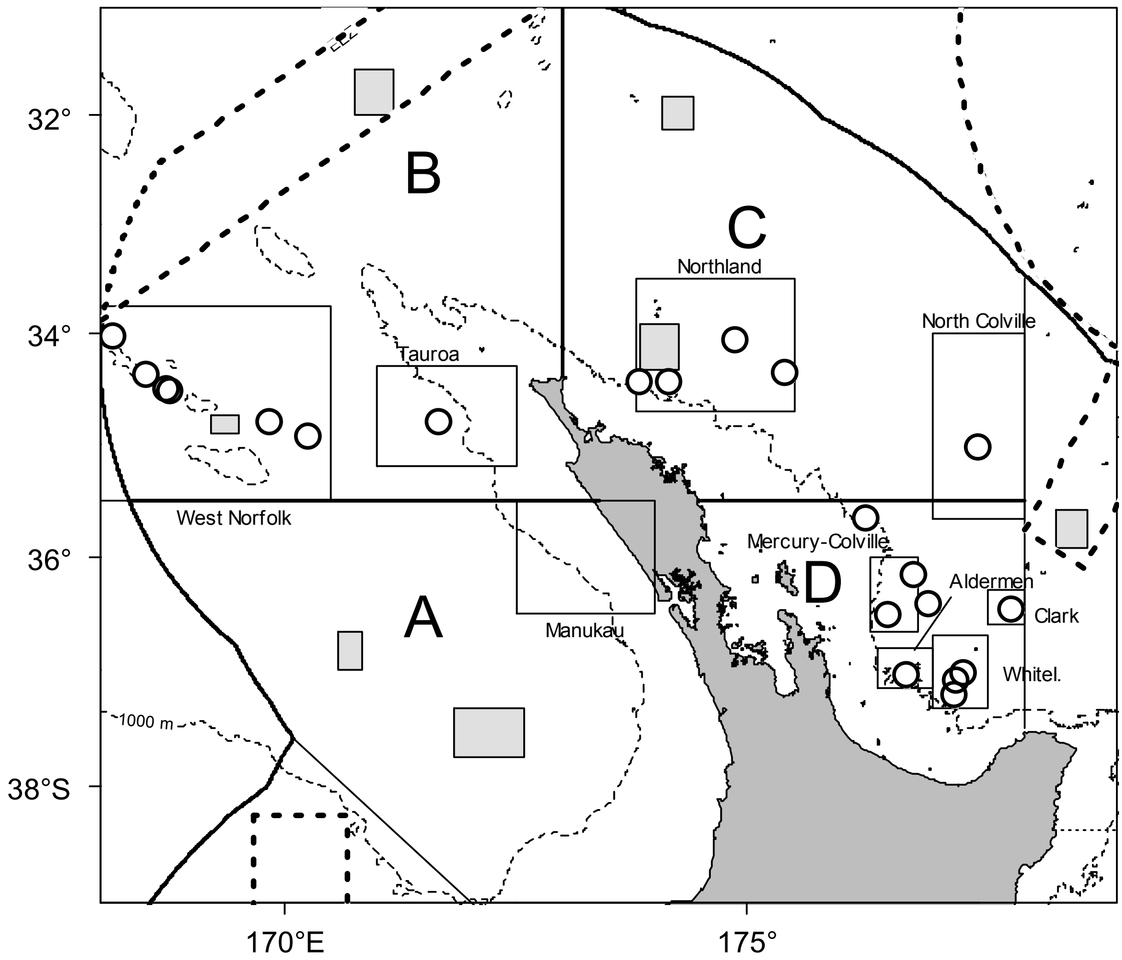

Figure 1: The ORH 1 fishery area. The position of the main grounds are marked as open rectangles, thick solid lines indicate the boundaries of the AMP areas (A–D) and the EEZ, perimeters of Benthic Protection Areas (BPAs) closed to bottom trawling are marked with thick dashed lines, seamounts closed to trawling are marked as shaded rectangles, the core fishing features are marked as open circles.

Annual catches in the fishery peaked in 1998–99 at about 1500 t (Table 1) and have slowly decreased since. As a result of the Mercury-Colville surveys of 1998 and 2000, the TACC for 2000–01 was dropped to 800 t (without any feature limits) and the Minister of Fisheries requested that a joint MFish/Industry management plan be developed which would split the TACC among four broad areas and limit feature catches to 100 t. A 30 t catch limit was set at this time for the Mercury–Colville fishery, to allow for bycatch during the black cardinalfish target fishery.

A second AMP programme came into force for the five years from 2001–02 to 2005–06, with the TACC increased to 1400 t. The fishery was divided into four areas (A–D) with a complex arrangement of area catch limits, feature catch limits, CPUE decision rules, and a requirement for detailed monthly reporting of catches (summarised by Melvin 2004). The TACC of 1400 t has remained in place since this AMP expired, with feature limits and area catch limits retained by voluntary agreement, up until 2009–10.

Formal stock assessment for ORH 1 is limited to the Mercury-Colville box (Clark et al 2000). This indicated a virgin biomass of about 3000 t with the current (1999–2000) biomass at about 10–15% of this value, and long-term annual yields of about 50 t. It is unknown whether the current catch levels for areas outside of Mercury-Colville box are sustainable.

Table 1: ORH 1 and ORH 2A North. Reported landings (t) and TACCs/catch limits (t), for 1984–85 to 2009–10. The figures in parentheses indicate combined exploratory (under special permit) and TACC landings.

	ORH 1		ORH 2A North	
Fishing year	Landings	TACC	Landings	Catch limit
1984–85	96	–	4	–
1985–86	2	–	41	§
1986–87	0	10	253	§
1987–88	0	10	36	§
1988–89	19	10	143	§
1989–90	86	190	20	§
1990–91	200	190	13	§
1991–92	112	190	18	§
1992–93	49	190	30	§
1993–94	189	190	3 437	§
1994–95*	244	190	2 921	3 000
1995–96	965	1 190	3 235	3 000
1996–97	1 021	1 190	2 491	3 000
1997–98	511	1 190	#2 411	3 000
1998–99	845 (1 543)	1 190	#1 901	2 500
1999–00	771 (1 476)	1 190	#1 456	2 500
2000–01	858	800	#302	200
2001–02	1 294	1 400	#186	200
2002–03	1 123	1 400	#173	200
2003–04	986	1 400	#170	200
2004–05	1 151	1 400	#271	200
2005–06	1 201	1 400	#216	200
2006–07	1 036	1 400	#229	200
2007–08	1 104	1 400	#200	200
2008–09	905	1 400	#230	200
2009–10	825	1 400	#268	200

§ Included in MEC Catch Limit; #Based on ORMC figures or estimated catches for allocation of catch between ORH 2AN and ORH 2AS (pro-rated to QMS data for ORH 2A where necessary); * Reported landings for 1994–95 do not include about 250 t of orange roughy caught under special permit, but TCEPR records do.

The ORH 2A North fishery (also referred to as the EC (East Cape) stock) extends eastwards from Cape Runaway in the north, extending out to the New Zealand EEZ and around East Cape southwards to a line at 38° 23′ S (Figure 2). This line splits the Quota Management Area ORH 2A into north and south components, the latter forming part of the Mid-East Coast (MEC) stock. There is a Benthic Protection Area and two seamounts closed to trawling in the north of the ORH 2A North region, but very little fishing effort has been recorded there. The east coast stock boundaries are based upon knowledge of spawning locations, with some support from allozyme studies (Ministry of Fisheries 2011).

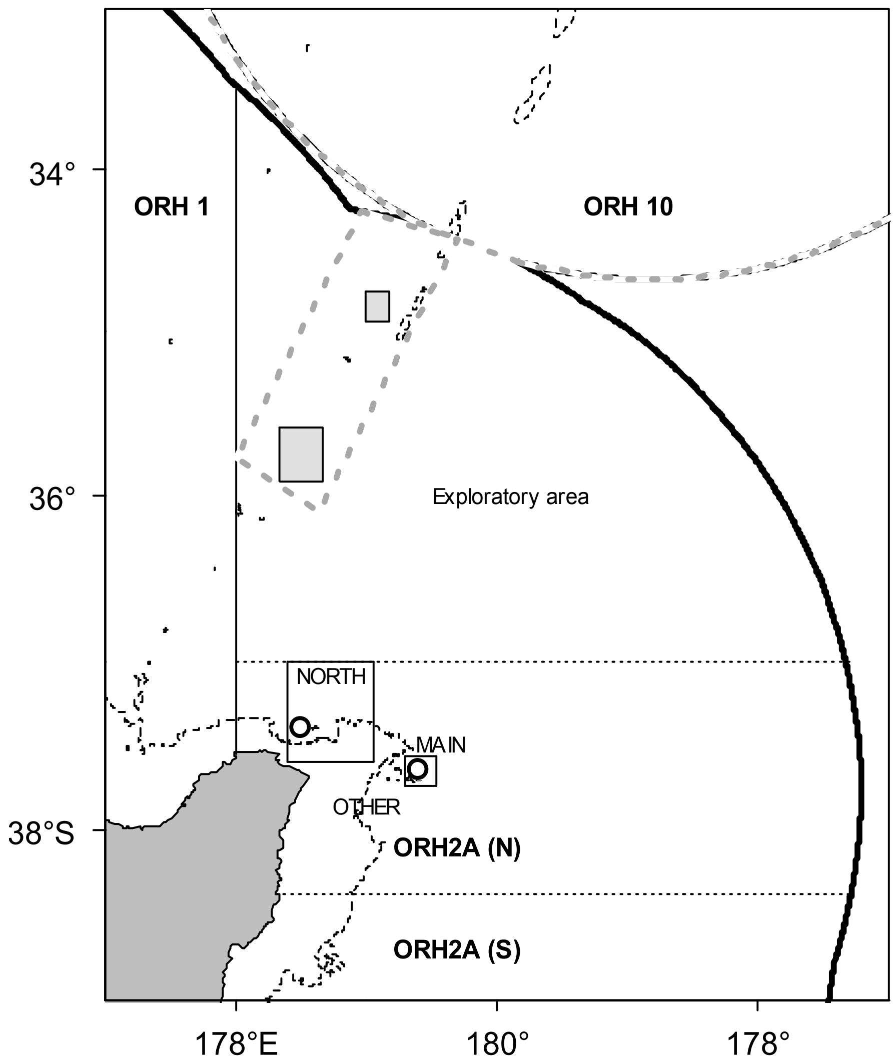

Figure 2: The ORH 2A North fishery area. Open circles mark the position of the main hills, thin solid lines mark the QMA boundary, thick solid lines the EEZ, thick dashed lines the perimeters of Benthic Protection Areas (BPAs) closed to bottom trawling, open rectangles the fishery subareas, and shaded rectangles the seamounts closed to trawling.

Although orange roughy have been caught in the northern part of ORH 2A since the mid-1980s (Table 1), catches increased considerably in 1993–94 after the discovery of spawning aggregations of orange roughy on the East Cape hills. This led to a substantial shift of effort in ORH 2A away from the fisheries on Ritchie Bank and further south, with more than half the ORH 2A catch in that year coming from these East Cape hills. Since 1994–95 an agreement has been in place between quota holders and the Minister of Fisheries that ORH 2A be split into two with separate catch limits for each area. The catch limit for ORH 2A North was set at 3000 t in 1994–95. Uncertainty regarding the sustainability of this catch level provoked measures to ease fishing pressure on the main hills in the 1996–97 fishing year. A catch limit for the East Cape hills (the part of ORH 2A North south of 37° S) was set at 2500 t with the remaining 500 t of the ORH 2A North catch limit to be caught in relatively unexplored areas in the north. This split was retained until 2000–01 when a stock assessment indicated that current catches were unsustainable (Anderson 2000) and the catch limit was reduced to 200 t. Catches in the exploratory area were negligible, with a maximum total catch of 37 t in 1996–97.

The ORH 2A North fishery can be logically split into three sub-areas, representing three distinct geographical areas with distinct fishing histories: MAIN, the main spawning hill feature due east of East Cape which was first and almost exclusively fished in the first year of the fishery, and fished consistently in every year since; NORTH, the northwest quadrant of the fishery containing a distinct hill feature which was first fished two years after the main spawning hill was discovered; OTHER, all other areas, but mostly comprising a series of about 10 seamounts running generally north-south to the west of the MAIN hill feature, and fished consistently since the second year of the fishery (Figure 2).

2. DATA SOURCES

Estimated catch and effort data for the ORH 1 and ORH 2A North orange roughy fisheries have mostly been recorded on Trawl Catch Effort (TCE) type forms which give detailed tow-by-tow information, including the location, depth, and estimated catch for each trawl. The alternative Catch Effort Landing (CEL) type forms, which provide only daily summaries of estimated catch, account for only a small fraction of the historical catch in these fisheries (Anderson & Dunn 2011) and were not used for these analyses.

Data used were all tows where orange roughy were the declared target species, thereby ignoring those in which orange roughy were caught from fishing directed at other species. The latter included fisheries targeting mainly black cardinalfish in the eastern half of ORH 1 and in ORH 2A North. Overall, about 10% of the ORH 1 orange roughy estimated catch, and 2% of the ORH 2A North orange roughy estimated catch, has been caught whilst targeting black cardinalfish.

Catch effort data were error-checked using routines developed in the statistical software package R (Ihaka & Gentleman 1996). Error checks were performed for bottom depth, fishing depth, location, trawl speed and duration, and time of day. Missing or erroneous values were replaced with imputed average values where available. For example: where depth was missing for a tow it was replaced with the median depth from all other tows recorded within 1 n.mile of that tow position. Obvious errors in position, due to confusion of the western with the eastern hemisphere, were also corrected. Any records containing significant errors that could not be resolved or corrected were excluded from the analyses.

It is possible that the data received for the 2009–10 fishing year may have been incomplete. This is because any forms submitted by fishing vessels after the data request date will not have been entered into the Ministry database.

The initial dataset of recorded tows, where orange roughy were the declared target species, totalled 8319 records for ORH 1 and 8347 records for ORH 2A North.

3. STANDARDISED CATCH PER UNIT EFFORT

Because EC and ORH 1 are primarily feature-based fisheries, with trawling often on very rough terrain, there are many failed tows (tows which come fast, miss the hill top, etc), with no catch recorded. It is likely that there is some variation in how these failed tows are recorded by fishers, and some may not record them at all. In addition to these tows with no catch, other tows may have come fast on rocky outcrops. Tows less than 1 minute in duration AND less than 100 m long AND which caught less than 100 kg of orange roughy were also considered fast tows. Because of the likely inconsistency in how zero catch tows were recorded, and because previous studies have shown that binomial models typically have little influence on final indices, records with no orange roughy catch were ignored and binomial models not considered. Other details of data selection and predictor variables differed between ORH 1 and ORH 2A North, and they are described for each fishery analysis in subsequent sections.

The standardised CPUE analyses were carried out by fitting a generalised linear model (GLM) to CPUE data, following a forward stepwise multiple regression technique based on Francis (2001). The units of CPUE used were tonnes per tow (t/tow), and the dependent variable was log(t/tow). The GLM assumed a normal error distribution and identity link function. The variable fishing year was forced into the model and other potential predictors tested for inclusion, including interaction terms between selected predictors. The criterion used for determining which predictor variable to add to the model at each step was the Akaike Information Criterion (AIC) (Akaike 1973). In addition, predictors were accepted into the model only if they explained at least 1% additional deviance and if their predicted effects were sensible.

Model predictions were calculated from the model in units which relate to median (or equivalent) values of the other explanatory variables.

3.1 ORH 1 (Northern North Island)

3.1.1 Data selection and model variables

Assignment of tows to feature

The NIWA SEAMOUNTS database (Rowden et al. 2008) identifies 136 "seamounts" (defined as discrete raised features with an elevation of at least 100 m) in ORH 1. Four other "features" which did not meet the criteria for inclusion in the database but which were important fishing locations, were added to this set. This included the Manukau subarea (Figure 1), where fishing is not on well-defined features, but runs along a section of slope, roughly following the 1000 m contour.

The distance from the start of each tow to the summit of each feature was estimated and the catch from each tow was assigned to a feature if the start position was within approximately 5 n. mile of it. If there were two or more features within 5 n. miles of a tow, the record was assigned to the nearest feature. It is worth noting here that for the purposes of setting feature limits in the 2001–02 to 2005–06 AMP, any catch taken within 10 n. miles of a feature was attributed to that feature (Mormede 2010).

Core data selection

To ensure that the data set used for each of the models comprised only vessels with some experience, vessels were retained in the analysis only if they had completed 50 tows or more, spread over at least three fishing years. The analysis was further restricted to features on which there had been a reasonable level of fishing over a period of time, in the same way that the core set of vessels were selected. Therefore only features with 50 tows or more, spread over at least three fishing years, were retained. Because of this removal of data subsequent to the initial core vessel selection, these two selection processes were repeated in turn until there was no further loss of vessel or feature. Only one repeat cycle was required, with the loss of one additional vessel. Although this process resulted in the removal of 73% of the vessels (33 to 9) and 53% of the fished features (47 to 22), 86% of the records and 89% of the catch were retained.

The annual number of vessels operating in this fishery ranged from 14 in 1995–96 to 3 in 2009–10 (Figure 3). Core vessel selection removed proportionately more vessels in the first few years and last few years of the fishery, but only in 1993–94 did this result in fewer than 2 vessels being retained.

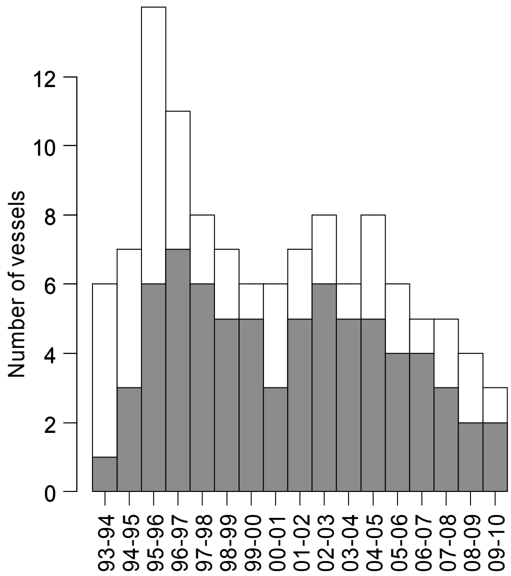

Figure 3. Number of fishing vessels in ORH 1 by fishing year; white bars plus shaded bars, all vessels; shaded bars, core vessels.

The nine vessels remaining after core vessel and feature selection cover the temporal extent of the fishery well (Table 2). Although only a single vessel was included in the first year of the fishery, this vessel continued to operate in most years until 2007–08. There was considerable overlap of vessels between years, due to the continued presence of one or two vessels for most of the 17 years of the fishery, with four to five vessels overlapping successive years for half of this period and an overlap of fewer than two vessels only between the first two years of the fishery.

Table 2: Number of tows by vessel and fishing year as used in the standardised CPUE analysis, after application of the core selection criteria.

									Vessel
	A	B	C	D	E	F	G	H	I
1993–94	–	–	–	–	54	–	–	–	–
1994–95	1	14	–	–	37	–	–	–	–
1995–96	42	9	29	14	181	21	–	–	–
1996–97	4	18	106	60	182	–	7	90	–
1997–98	–	13	260	96	253	–	–	209	7
1998–99	–	32	198	4	247	–	–	222	–
1999–00	–	–	287	5	62	–	–	204	18
2000–01	–	–	1	–	–	–	26	85	–
2001–02	–	–	78	40	–	–	11	198	11
2002–03	–	–	–	79	54	29	23	172	59
2003–04	–	–	–	–	140	38	32	118	28
2004–05	–	–	–	3	86	–	9	189	39
2005–06	–	–	–	15	44	–	–	201	116
2006–07	–	–	62	–	114	–	–	190	100
2007–08	–	–	–	–	34	–	–	294	59
2008–09	–	–	–	–	–	–	–	236	62
2009–10	–	–	–	–	–	–	–	138	38

Model variables

The 22 core features were well spread over the spatial extent of the fishery, including 9 in the wider Bay of Plenty region, 4 in Northland, and 6 in the West Norfolk Ridge (see Figure 1). Overlap of fishing between features is also important, so that the relative coefficients in the GLM are estimated adequately. Such overlap was reasonable, with 2–8 features overlapping successive years up to 1998–99, increasing to 10–21 features thereafter (Table 3). Tauroa Knoll has been the most consistently fished feature, with a relatively high number of tows in most years between 1995–96 and 2008–09. Other features with regular fishing over a long period include Waitotahi, Nukuhou, and Clark.

Table 3: Number of tows by feature and fishing year as used in the standardised CPUE analysis, after application of the core selection criteria.

	Colville	Mercury	Ohena	Jasons	Waiotahi	470	Nukuhou	N.Colville	Coral	Clark	Tauroa	Explorer	Mokohinau	Milans	Manukau	441	Hiroshima	Yasmins	Devils	Birdflue	TonyB	Boulder
1993–94	14	37	–	–	–	–	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
1994–95	15	31	4	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–
1995–96	119	150	6	–	–	–	–	4	–	–	17	–	–	–	–	–	–	–	–	–	–	–
1996–97	208	111	69	39	18	8	1	6	–	–	7	–	–	–	–	–	–	–	–	–	–	–
1997–98	408	119	28	76	175	17	1	–	–	–	14	–	–	–	–	–	–	–	–	–	–	–
1998–99	143	59	20	19	76	9	250	9	–	37	63	–	–	1	–	17	–	–	–	–	–	–
1999–00	51	44	10	35	32	39	149	29	22	32	127	–	–	3	–	2	–	–	–	1	–	–
2000–01	1	–	1	1	11	–	19	9	32	5	3	27	–	–	–	2	–	–	–	–	1	–
2001–02	16	15	2	11	3	2	35	32	36	8	20	72	–	22	44	6	2	10	–	–	2	–
2002–03	3	6	1	11	15	17	24	42	8	22	62	34	42	46	51	10	10	–	–	12	–	–
2003–04	5	8	3	16	27	6	53	12	7	14	12	58	9	22	80	3	2	–	19	–	–	–
2004–05	2	4	–	7	20	3	45	24	8	6	32	9	–	25	28	2	48	29	24	–	10	–
2005–06	3	17	1	9	2	–	14	4	5	11	60	4	1	16	94	14	9	8	8	38	30	28
2006–07	2	18	1	7	1	–	10	7	13	7	30	14	13	14	67	43	24	25	29	43	70	28
2007–08	2	3	–	–	14	–	14	2	5	11	16	5	6	16	–	23	16	22	44	48	62	44
2008–09	2	4	7	6	10	3	1	–	4	20	67	7	–	5	13	1	2	4	11	62	38	31
2009–10	–	1	4	2	8	–	3	–	1	2	40	20	4	7	10	3	–	–	7	13	31	20

The set of potential predictor variables offered to the model is shown in Table 4. All continuous variables entered the model as 3^{rd} order polynomials. All tows before the 1993–94 fishing year, when significant catches began to be made in the Bay of Plenty, were excluded. Missing values for predictor variables were removed (10 records). Records with depths less than 600 m were set to 600 m (6 records). The “disturbance” variable was derived from the trawl position and the number of other trawls made within 0.5 km in the previous 24 h. A large number of recent, nearby trawls would indicate a high level of disturbance to the local population which may affect catch rates.

Some of the variables listed are highly correlated, e.g., vessel, vessel power, and vessel tonnage; distance and duration, and are included here as alternatives. The choice between these alternatives was left to the model.

Table 4: Summary of independent predictor variables tested in the standardised CPUE GLM model for ORH 1, number of categories in parentheses.

Variable	Type	Description
Year	categorical (17)	fishing year
Vessel	categorical (9)	vessel identification no.
Month	categorical (12)	month in which tow occurred
Feature	categorical (22)	feature in which tow occurred (*see* Table 5)
Longitude	3^{rd} order polynomial	decimal longitude at start of tow
Latitude	3^{rd} order polynomial	decimal latitude at start of tow
Start time	3^{rd} order polynomial	time (decimal hours) at start of tow
Depth	3^{rd} order polynomial	depth (m) of groundrope at start of tow
Distance	3^{rd} order polynomial	distance (km) of tow
Duration	3^{rd} order polynomial	duration of tow (h)
Speed	3^{rd} order polynomial	speed (knots) of vessel at start of tow
Vessel tonnage	3^{rd} order polynomial	gross tonnage of vessel
Vessel power	3^{rd} order polynomial	vessel engine power (kW)
Disturbance	3^{rd} order polynomial	number of tows within 0.5 km in previous day

3.1.2 Examination of the core features

The catch and effort associated with each core feature in ORH 1 were examined to look for evidence of "sequential fishing" (fishing a feature until catch rates dropped substantially then abandoning and moving on to the next feature). If such patterns were evident, then conventional CPUE analysis may be biased by "hyperstability" whereby CPUE is maintained even though real abundance is in decline.

In only 8 of the 22 features did the core vessels accumulate a total estimated orange roughy catch greater than 500 t (Table 5). Of these, the most important features in ORH 1 were Tauroa Knoll, Mercury Knoll, the Manukau subarea, Nukuhou Knoll, and Colville Knolls. Most features supported a relatively modest level of total catch, with less that 200 t taken from 8 of the 22 features. The total annual catch on these features (excluding Mercury and Colville Knolls, which were managed separately) has been limited since 2001–02 by the requirements of the AMP programme, and adhered to subsequent to its expiry in 2005–06. Under the AMP, the total annual individual feature catch was not permitted to exceed 100 t in AMP area A, 150 t in areas B and C, and 75 t in area D (see Figure 1 for area boundaries). Annual feature limits between 1996–97 and 1999–2000 in all areas (again excluding Mercury and Colville Knolls) were limited by the requirements of the special permits in place to 100 t. In the following year (2000–01), prior to the AMP, fishing was conducted without the restriction of area or feature limits.

Table 5: Total accumulated estimated catches (up to 2009–10) from each of the core seamounts or features in ORH 1 by the core vessels. Registered numbers are individual feature identity codes from NIWAs "SEAMOUNTS" database (Rowden et al. 2008).

Feature	Registered No.	Location (subarea, *see* Figure 1)	Total catch (t)
Tauroa Knoll	540	Tauroa	2361
Mercury Knoll	548	Mercury-Colville	1372
Manukau subarea	N/A	Manukau	1274
Nukuhou Knoll	473	White Island	936
Colville Knolls	230	Mercury-Colville	917
TonyB	1199	West Norfolk	709
North Colville	213	North Colville	613
Birdflue	10010	Northland	520
Boulder Ridge	10011	Northland	465
Explorer Hill	1200	West Norfolk	414
Jasons Hill	824	Aldermen	382
Coral Hill	1201	West Norfolk	264
Milans	1208	Northland	226
Devils Spur	1207	West Norfolk	222
Ohena	463	Mercury-Colville	197
Waiotahi Knoll	471	White Island	194
Hill 441	441	Northland	184
Hill 470	470	White Island	167
Clark	464	Clark	142
Yasmins	1203	West Norfolk	129
Hiroshima	1202	West Norfolk	63
Mokohinau Knoll	528	Northern Bay of Plenty	32

Evidence of sequential fishing

The abrupt decline of catch and effort in 2000–01 on Mercury Knoll and Colville Knolls (Figure 4), where fishing in ORH 1 originated, was due to the effective closure of the Mercury-Colville box in that year (leaving just a 30 t limit to cover bycatch in the black cardinalfish fishery). This closure and the shift of the fishery focus to other features within the Bay of Plenty and further afield may be considered an example of sequential fishing, although unstandardised catch rates were still relatively high on Mercury Knoll and Colville Knoll at the time of the closure.

The total catch from Tauroa Knoll is about 1000 t greater than the next highest contributing feature, Mercury Knoll (Table 5). The catch and effort on Tauroa Knoll varied considerably from year to year (Figure 4), but this feature remained productive and fishing has continued through to 2009–10.

The Manukau subarea fishery developed in 2001–02 and effort was steady for several years before reducing to low levels since 2007–08. CPUE has been variable but has not matched the recent decrease in effort, with very high catch rates from the few trawls made in 2008–09 and 2009–10.

Catch rates on Nukuhou Knoll have been highly variable, but in recent years both effort and CPUE have declined substantially, with very little fishing since 2004–05.

Several of the more recently developed features with high total catches (e.g., Birdflue, Boulder Ridge, Tony B.) showed initially high CPUE, then declining effort and CPUE in the last one or two years. However, most of the other features are characterised by highly variable CPUE, due to the relatively low numbers of trawls and low level of catch in many years. The patterns in Figure 4 also indicate that although catch and effort decrease on features as new ones are developed, fishing has tended to continue in most areas through to 2009–10.

The total accumulated catch, and the annual catch and effort for each feature, have been restricted in many cases by the feature limits. Because of the small size of these features and small numbers of vessels fishing them, sudden changes in catch rates may sometimes be due to a change in skipper or the attendance of a particular vessel. This has been suggested as a likely reason for the sharp decline in catch rates on Birdflue and Boulder Ridge (Milan Barbarich, Antons Seafoods, pers. comm.).

Evidence for sequential depletion in this fishery was also examined by Anderson & Dunn (2011) by examining the catch rates over time for each 1/10th degree square over the whole fishery. They found that although new areas have continued to be an important part of this fishery right up to 2008–09, there was no strong pattern of sequential depletion.

While the fishery has spread outward from the Mercury-Colville Box and the Bay of Plenty over time, becoming widespread across the ORH 1 region, the fishery has continued to operate on most of the major individual features. Sequential fishing, where a feature is abandoned after being fished to a low level, is not a major consideration this fishery. A factor that may have helped prevent sequential fishing is the feature catch limits imposed by the AMP programme.

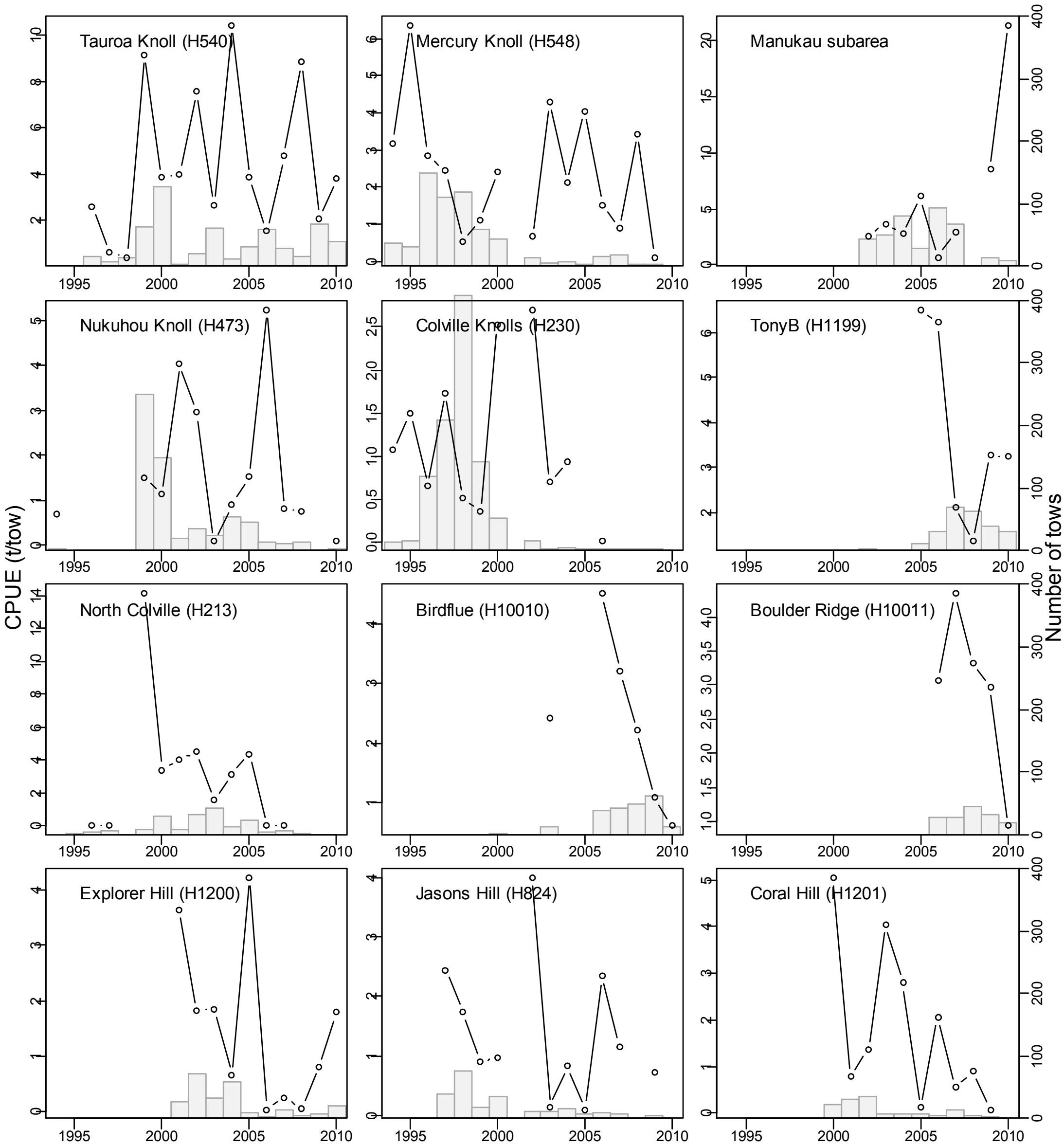

Figure 4: CPUE (kg/tow, lines), and effort (number of tows, bars) by year for each of the core seamounts (core vessels only) in ORH 1. CPUE only calculated for years with more than two tows. Seamounts are ordered (across then down) from greatest to least total accumulated catch. Note that the axis has a constant scale for number of tows, but varies for CPUE. On the x-axis, 2000 = fishing year 1999–2000, etc.

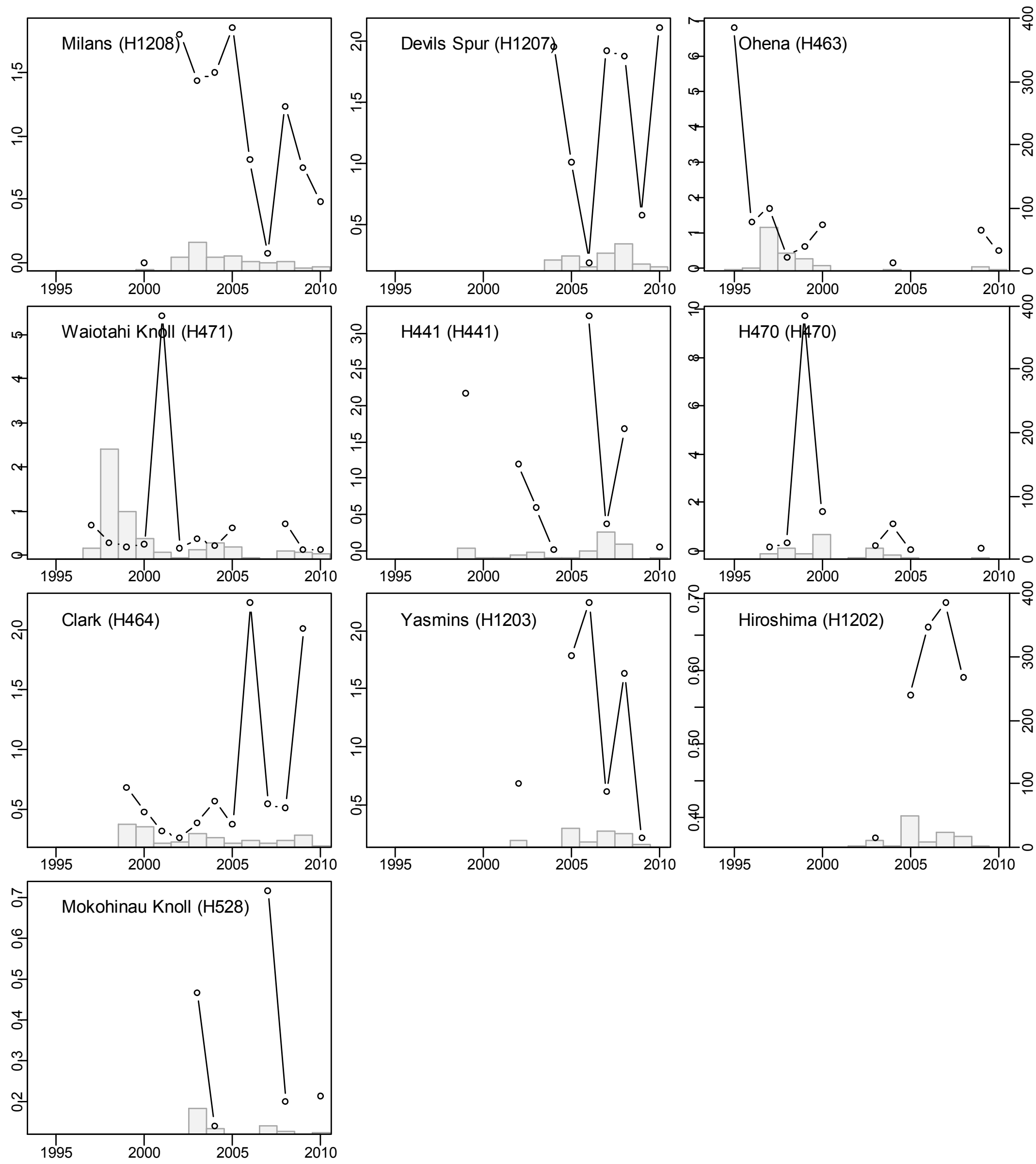

Figure 4:—*Continued*

3.1.3 Model results

The stepwise fitting procedure produced a GLM with four predictor variables, plus an interaction term (Table 6). Fishing year explained only a small amount of the total deviance. The greatest deviance was explained by the feature variable (8.8%). The variables vessel and month contributed to a lesser degree, but an interaction between these two terms was accepted. Examination of this interaction term showed that most vessels have a slightly higher CPUE in June/July, coinciding with the usual orange roughy spawning period. One vessel, however, exhibited an extraordinarily high CPUE for January (about 6 times greater than for any other vessel/month combination) and this single value is likely to be responsible for the inclusion of the interaction term in the model. This did not seem reasonable, and the interaction term was therefore excluded from the final model.

Table 6: Standardised CPUE model fits for ORH 1 in the stepwise order determined by AIC (see Section 3).

Predictor	Degrees of freedom	AIC	Percentage deviance explained	Additional % deviance explained
Fishing year	16	21794	2.6	2.6
Feature	21	21366	11.4	8.8
Vessel	8	21260	13.5	2.1
Month	11	21145	15.9	2.3
Vessel:month	58	21091	18.7	2.8

Model predictions show a general decline in CPUE between 1993–94 and 2009–10, although the indices are highly variable in the first few years (Figure 5). The model predicts higher catch rates in June and July than in other months, as would be expected in a fishery that often targets winter spawning aggregations. The best performing vessel has an expected catch rate about 4.5 times that of the worst vessel, and although the three smallest vessels have the lowest expected catch rates there is otherwise no trend in catch rates with vessel size. Two features stand out with much higher average catch rates than the rest, Tauroa Knoll and Manukau. Plots of feature coefficients against seamount physical variables (depth of top and base, elevation, slope, and area) revealed no obvious relationships. The model diagnostics show a good fit to the data for all but the extreme values (Figure 6).

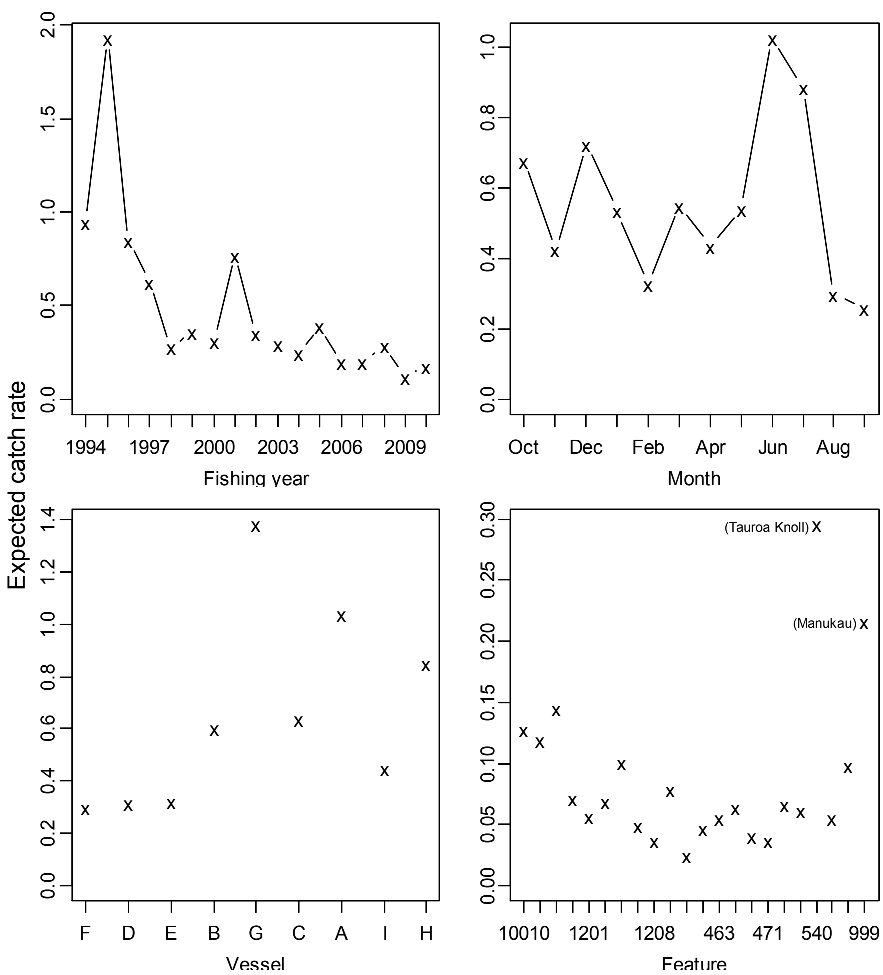

Figure 5: ORH 1 CPUE model predictions. Where the values of the predictors are not specified in the plot, predictions are for trawls by vessel "F" in August 2003 on feature H540 (Tauroa Knoll). Vessels are ordered in the plot by size, from smallest to largest; features are unordered. In the top left plot, 1994 = 1993–94, etc.

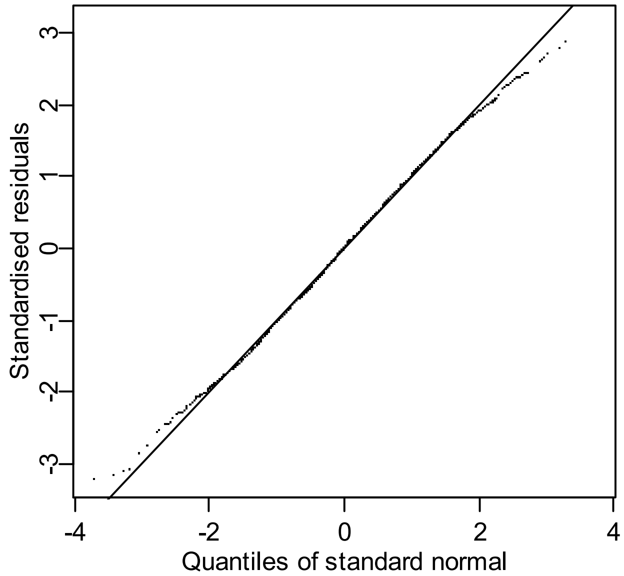

Figure 6: Diagnostics for the ORH 1 CPUE model.

The annual CPUE indices have wide confidence intervals, especially in years in which there are relatively few records (Figure 7, Table 7). In both 1993–94 and 1994–95 in particular, there were less than 50 records available.

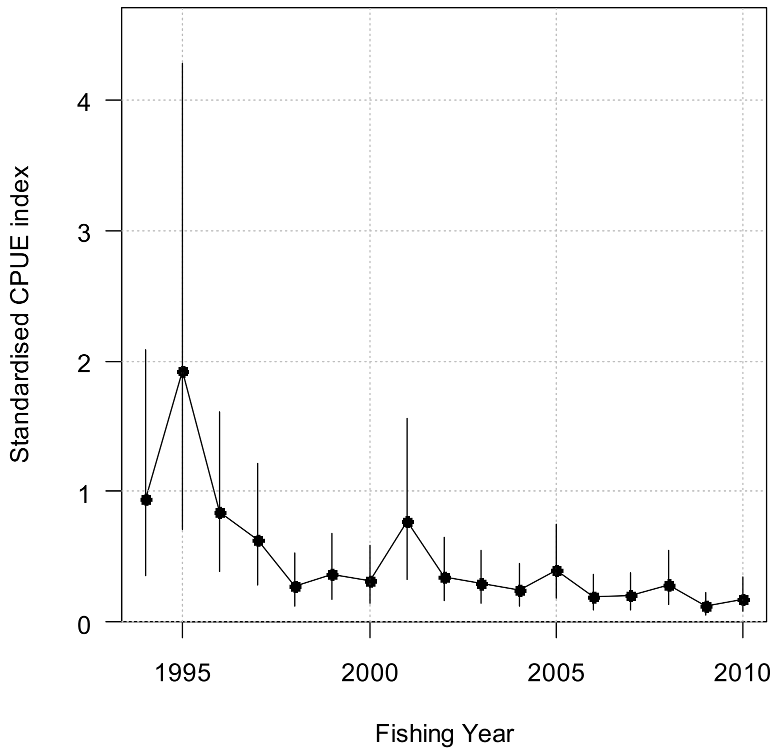

Figure 7: Standardised annual CPUE indices for the ORH 1 fishery. Vertical bars show 95% confidence intervals, derived from model estimated errors.

The high value of CPUE in 2000–01 occurred in the only year between 1996–97 and 2009–10 in which there were no feature or area limits in place. The combination of this and the reduction of the TACC for this year to 800 t may have contributed to the annual catch being taken with less effort required, as fishing could be more limited to the most productive features. Indeed, as Table 3 shows, effort was much reduced in this year on several of the Bay of Plenty features, and there were only four features on which the core vessels made more than ten tows, compared to eleven in both the preceding and following years; and catch rates on three of these four features were very high compared with other years (see Figure 4).

Table 7. Number of tows, CPUE index, and model c.v.s, by fishing year for the ORH 1 fishery.

Fishing year	No. tows	CPUE index	c.v. (%)
1993–94	46	0.95	0.47
1994–95	47	1.93	0.47
1995–96	213	0.85	0.37
1996–97	269	0.63	0.38
1997–98	465	0.28	0.37
1998–99	530	0.36	0.36
1999–00	474	0.32	0.36
2000–01	99	0.77	0.41
2001–02	280	0.35	0.35
2002–03	369	0.30	0.35
2003–04	330	0.25	0.34
2004–05	304	0.39	0.37
2005–06	356	0.20	0.36
2006–07	424	0.20	0.36
2007–08	334	0.29	0.36
2008–09	279	0.12	0.36
2009–10	157	0.18	0.38

3.2 ORH 2A North (East Cape)

This is the fourth analysis of CPUE in the ORH 2A North fishery. Anderson (2000) produced a set of indices covering six fishing years (1993–94 to 1998–99) based on data from vessels making more than 100 tows over at least three years, with log (t/tow) as the unit of CPUE. A combined normal/binomial model was produced, each sub- model constructed from the same variables; vessel, month, and depth.

This analysis was updated in 2003 (Anderson 2003) after an additional three years of fishing. The approach to the analysis was similar, with only some fine tuning of the vessel selection criteria, and a similar set of variables. This produced a combined model with similar indices to that of the previous analysis for the overlapping years.

The most recent analysis, in 2006, incorporated slight changes in data selection criteria and an examination of the disturbance effect of recent fishing (Anderson 2006a). Vessel, month, and disturbance were the main explanatory variables in a model that predicted variable and imprecise indices for recent years. The CPUE index, covering the period 1993–94 to 2004–05, was considered unreliable by the working group because of the lack of data collected since the reduction of the catch limit to 200 t in 2000–01. Because of this, the planned assessment for ORH 2A North did not proceed.

3.2.1 Data selection and model variables

General

A total of 188 tows outside of the East Cape hills area (i.e. in the exploratory area north of 37° S) were removed, 37 tows occurring before 1 October 1993 were removed, and 17 tows with missing values for other critical model variables were removed. Tow depths outside the range 600 to 1500 m were truncated to these values. One minute was added to tows of zero duration, and 10 m added to tows of zero distance.

Core vessel selection

In order to limit the analysis to vessels with some experience in the fishery, vessels with a total of less than 50 tows over a minimum of three fishing years were removed, but vessels with only two years experience were retained if they had made 100 or more tows. This restriction removed 51% of the vessels, but retained 91% of the catch and 92% of the records.

The annual number of vessels operating in this fishery ranged from 18 in 1996–97 to 5 in 2008–09 (Figure 8). Core vessel selection removed less than half the vessels in each year, less than a quarter in most years, and in 2000–01 all vessels were retained. In the last six years no more than 2 vessels were removed in any year and there were between 4 and 14 vessels per year in the core data set.

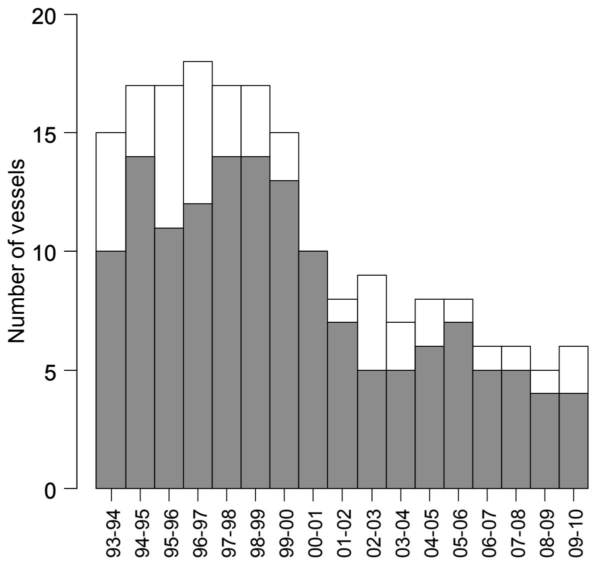

Figure 8. Number of vessels in the ORH 2A North fishery by fishing year; white bars plus shaded bars, all vessels; shaded bars, core vessels.

Continuity and overlap of vessels between years is good over the 17 years of the fishery, with three vessels having fished in more than 10 years, and one vessel (S) which has fished in every year from 1994–95 to 2009–10 (Table 8). Between six and nine vessels overlapped successive years up until 2002–03, and three to five vessels since.

Table 8: Number of tows by core vessel and fishing year used in the standardised CPUE analysis, after application of the core vessel selection criteria.

	Fishing year																
Vessel	1993–94	1994–95	1995–96	1996–97	1997–98	1998–99	1999–00	2000–01	2001–02	2002–03	2003–04	2004–05	2005–06	2006–07	2007–08	2008–09	2009–10
A	30	83	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
B	65	18	–	–	–	–	5	3	–	–	–	–	–	–	–	–	–
C	19	47	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–
D	15	63	–	1	4	4	3	–	–	–	–	–	–	–	–	–	–
E	–	130	118	–	–	–	–	–	–	–	–	–	–	–	–	–	–
F	20	–	64	–	–	1	–	–	–	–	–	–	–	–	–	–	–
G	125	121	137	54	20	34	–	–	–	–	–	–	–	–	–	–	–
H	52	137	264	95	50	1	–	–	7	–	–	1	–	–	–	–	–
I	–	42	71	89	43	19	4	–	–	–	–	–	–	–	–	–	–
J	82	83	–	3	–	–	42	–	–	5	–	4	11	3	8	–	–
K	39	47	–	–	–	–	–	1	–	–	10	19	4	–	–	–	–
L	–	96	54	65	389	172	–	–	–	–	–	–	–	–	–	–	–
M	–	–	–	35	12	–	5	–	–	–	–	–	1	–	–	–	–
N	–	78	71	54	145	94	88	26	14	–	–	–	–	–	–	–	–
O	5	42	72	84	369	172	83	17	11	2	–	–	–	–	–	–	–
P	–	–	–	101	219	123	195	20	6	–	–	–	–	–	–	–	–
Q	–	–	–	–	31	18	10	2	3	–	–	–	–	–	–	–	–
R	–	–	22	33	1	54	15	12	–	11	8	19	38	–	–	–	–
S	–	6	58	133	218	107	102	25	34	9	3	7	17	34	49	76	74
T	–	–	–	–	22	172	98	70	81	50	52	59	26	46	44	15	30
U	–	–	–	–	19	62	51	10	–	–	–	–	–	1	6	43	24
V	–	–	–	–	–	–	–	–	–	–	1	–	13	31	41	12	50

Model variables

The set of model variables offered to the model is shown in Table 9. In addition to fishing year, a further fifteen potential explanatory variables were offered to the model, 5 categorical and 10 continuous, the latter as 3rd order polynomials.

Table 9: Summary of independent variables tested in the standardised CPUE GLM model for ORH 2A North, number of categories in parentheses.

Variable	Type	Description
Year	categorical (17)	fishing year
Vessel	categorical (22)	vessel identification no.
Month	categorical (12)	month in which tow occurred
Season	categorical (2)	spawning or non-spawning season
Area	categorical (3)	area in which tow occurred (*see* Figure 2)
Longitude	3rd order polynomial	decimal longitude at start of tow
Latitude	3rd order polynomial	decimal latitude at start of tow
Start time	3rd order polynomial	time (decimal hours) at start of tow
Depth	3rd order polynomial	depth (m) of groundrope at start of tow
Distance	3rd order polynomial	distance (km) of tow
Duration	3rd order polynomial	duration of tow (h)
Speed	3rd order polynomial	speed (knots) of vessel at start of tow
Vessel tonnage	3rd order polynomial	gross tonnage of vessel
Vessel power	3rd order polynomial	vessel engine power (kW)
Disturbance	3rd order polynomial	number of tows within 0.5 km in previous day

The season variable has two categories, spawning and non-spawning. The spawning season was defined as the winter period from when the median catch rate increased to above the annual median to when it drops below the median (17 May to 26 July) – calculated from the intersection of a locally weighted regression smoother line (fitted to catch per tow plotted against day of fishing year) with the calculated median (Figure 9). This plot shows that catch rates (t/tow) tended to decline slowly but steadily from the beginning of the fishing year through to about day 200 (mid-April). As the spawning period approached catch rates began to increase, peaking at about day 258 (15 June), and then steadily declining again through to the end of the fishing year.

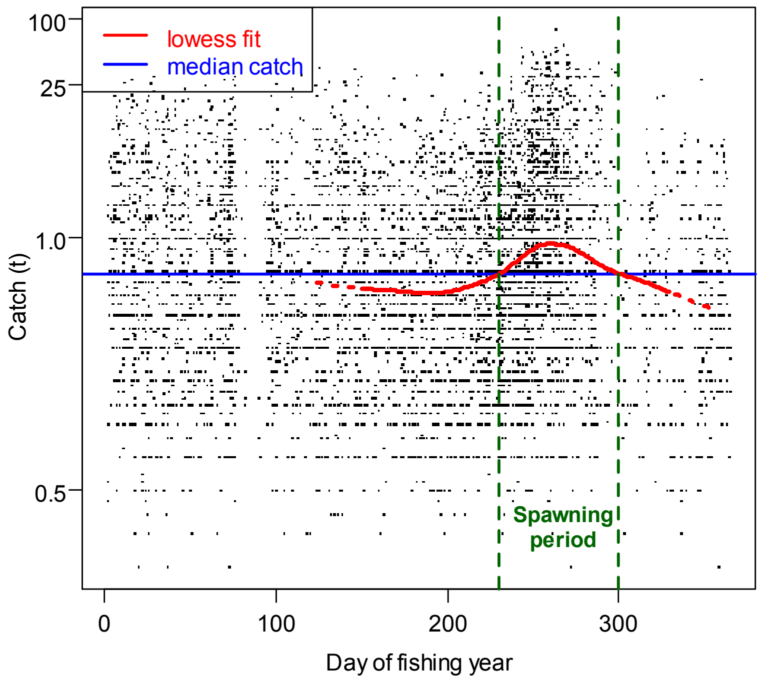

Figure 9: Variation in orange roughy catch with day of the fishing year, based on the core data used for the CPUE model. The lowess fit is a locally weighted regression smoother line fitted to the data (Cleveland 1981).

3.2.2 Model results

The stepwise fitting procedure produced a model with three predictors; (fishing year), month, and vessel, resulting in a model with relatively low explanatory power (Table 10). Interaction terms were tested between selected variables. There was a significant interaction between month and vessel, suggesting that the variability in catch rates over the season differed among vessels, but examination of the model output indicated that this was based on a few very high values for one or two month/vessel combinations and did not appear to reflect any consistent patterns that could be explained outside of the model. This term was therefore disregarded.

Table 10: Standardised CPUE model fits for ORH 2A North in the stepwise order determined by AIC (see Section 3).

Predictor	Degrees of freedom	AIC	Percentage deviance explained	Additional % deviance explained
Fishing year	16	28448	3.5	3.5
Month	11	27997	10.0	6.5
Vessel	21	27774	13.4	3.4

The year effect indices show a strong and steady decline between 1993–94 and 1997–98 (Figure 10). The indices then fluctuate around a level of about 30% of the initial index between 1997–98 and 2001–02, then show higher but variable values between 2001–02 and 2005–06, including very high values for 2002–03 and 2003–04, followed by a decline over the last four years of the series. There is about a five-fold difference between the predicted catch rates of the worst and best vessels. The month effect is very strong, with June catch rates predicted to be at least triple (and July catch rates about double) those for months outside of the spawning period. The model diagnostics show the residuals to be close to normally distributed over most of their range, but deviations from this at high catch rates indicate that these are slightly underestimated by the model.

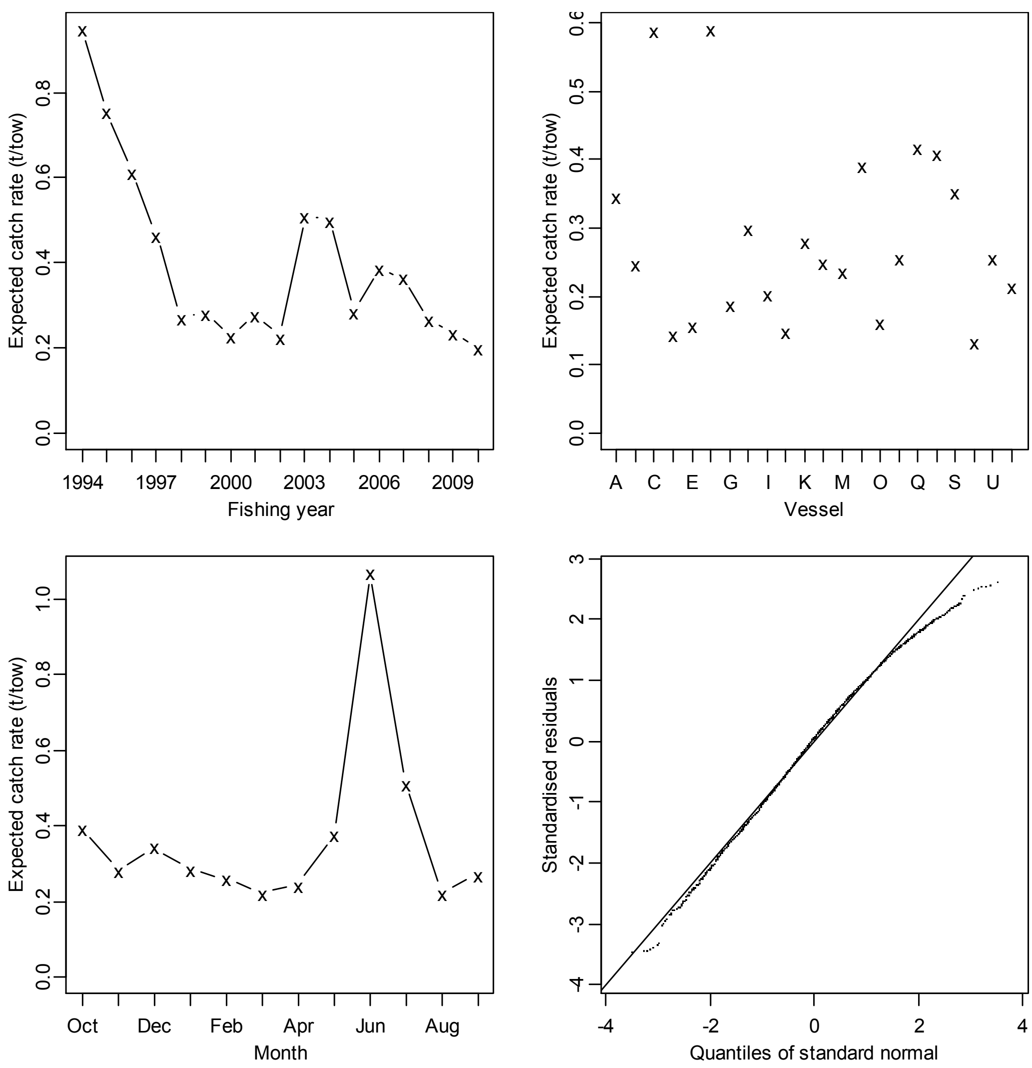

Figure 10: ORH 2A North model predictions and model diagnostics. Where the values of the predictors are not specified in the plot, predictions are for trawls by vessel "K" in November 1999. In the top left plot, 1994 = 1993–94, etc.

The annual CPUE indices have wide confidence intervals (Figure 11), which are wider for years in which the number of records was low (Table 11). Model c.v.s range from 21.7% to 31.8% and tend to increase over time, as the number of tows per year decreases. Although there is no clear trend in the indices after 1997–98, the lowest value in the series occurs in the most recent year and is equivalent to 21% of the initial (1993–94) value. The sharp increase in CPUE in 2002–03 and 2003–04 appears to be related to the effect of vessel T, which had the lowest average CPUE of any vessel (Figure 10) but dominated the fishery, in terms of numbers of tows, in these two years (see Table 8). The indices for these two years are based on by far the least number of records. If this CPUE series was to be used as an index of abundance in a stock assessment a cut-off in the number of records could be applied as in, e.g, Francis (2001) and Anderson (2005), which would exclude these years.

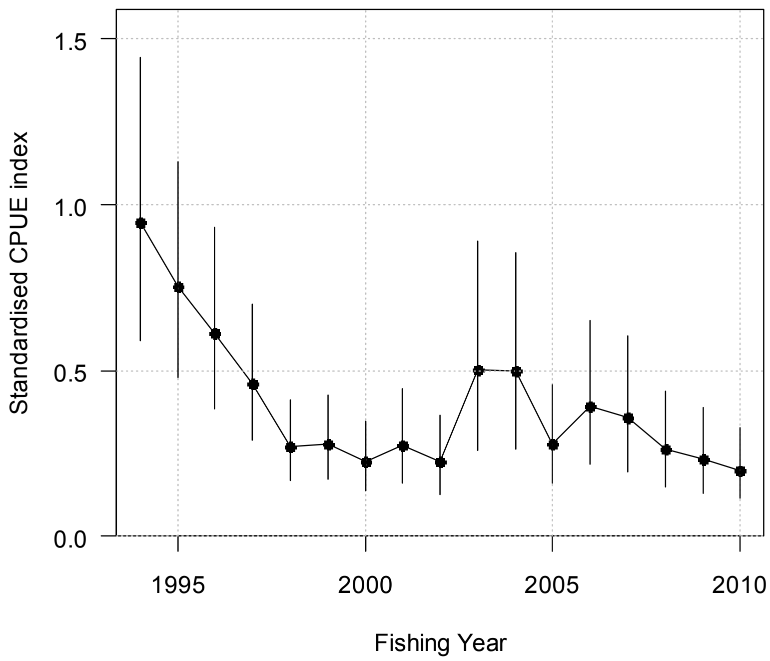

Figure 11: Standardised annual CPUE indices for the ORH 2A North fishery, vertical bars are 95% confidence intervals, derived from model estimated errors.

Table 11: Number of tows, CPUE indices, and model c.v.s, by fishing year for the ORH 2A North fishery.

Fishing year	No. tows	CPUE index	c.v. (%)
1993–94	360	0.949	22.7
1994–95	875	0.755	21.7
1995–96	825	0.613	22.5
1996–97	652	0.465	22.4
1997–98	1353	0.271	22.7
1998–99	909	0.281	22.9
1999–00	625	0.227	23.4
2000–01	174	0.278	25.8
2001–02	140	0.226	26.9
2002–03	65	0.510	31.8
2003–04	70	0.501	30.1
2004–05	103	0.285	26.5
2005–06	105	0.386	27.8
2006–07	110	0.364	28.7
2007–08	139	0.265	27.8
2008–09	139	0.236	27.6
2009–10	166	0.201	26.9

3. DISCUSSION

ORH 1

A number of factors complicate the interpretation of CPUE indices in the ORH 1 fishery. One major factor is the lack of knowledge regarding fish movements in and out of the management area and the relationship between the spawning and feeding aggregations on the numerous features which make up the fishery. The fishery may comprise a single distinct stock or it may comprise several stocks.

Simultaneous spawning has been used to infer separate stocks in ORH 2A and elsewhere, and there is some information on the timing of spawning in ORH 1. Observer records of female gonad stages (Anderson 2006b, 2006c, 2008a, 2008b) show that significant spawning events occur in a number of locations within ORH 1, with the peak of spawning generally occurring in the three-week period between 20 June and 10 July. Spawning appears to take place at a very similar time in the Aldermen, Mercury-Colville, White Island, North Colville, and Manukau fisheries, but is a week or so later in the East Northland fishery. In 2007 spawning occurred one to two weeks later than usual in each of three fisheries that could be compared (Aldermen, Mercury-Colville, and East Northland).

Fish sizes also differ between areas, with mean lengths of ORH often over 40 cm in the fisheries separated from the New Zealand continental shelf (West Norfolk Ridge, East Northland, and North Colville) (Anderson op. cit.).

If orange roughy have high spawning ground fidelity, then the simultaneous spawning observed would suggest that the ORH 1 fishery operates on several stocks. If not, then it may be argued that East Northland represents one stock, because of a combination of larger fish size and later spawning, and the rest of ORH 1 a second stock. Either way, it seems unlikely that the ORH 1 fishery comprises a single stock.

Another complicating factor in ORH 1 is the effect on CPUE caused by the management rules applied in this fishery. The requirement for vessels to cease fishing on a feature, or within a certain area, after a certain catch limit has been reached will have tended to spread the effort across the fishery. This may have slowed the decline of catch rates on features where the catch limits were set below sustainable levels, and accelerated it where the catch limits were set above sustainable levels. This effect is further complicated by the various changes made to area definitions and catch limits over time including, in 2000–01, the closure of the Mercury–Colville fishery and removal of feature limits in other areas for this year. The overall effect of these management actions on annual CPUE indices is unknown but despite the clear potential for bias there is the possibility that, because serial depletion was averted due to the forced spread of effort, they may be more reliable than they would otherwise have been.

It is worth noting that there were fewer than 50 records used to estimate the year effect for the first two years in the series, 1993–94 and 1994–95, when fishing was restricted to the Mercury-Colville fishery. It could be appropriate to restrict the analysis to years in which there are more than 50 records available in the core data set. This would have the effect of restricting the model to the years after the fishery begun to expand into the wider Bay of Plenty and other parts of ORH 1 with the introduction of the first AMP programme in 1995–96.

ORH 2A North

Management of the ORH 2A fishery has, by comparison with ORH 1, been very “hands-off”. Although exploratory fishing in the wider area was encouraged with a catch split for several years this had little effect on the total catch achieved and the only other management actions have been to twice lower the catch limit. The reduction of the catch limit from 2500 t to 200 t in 2000–01 did have an effect on CPUE as an index of abundance, however. This is because in some of the following years one or two large catches took a large fraction of the catch limit leaving overall too few tows to produce a reliable index. The number of annual tows has since increased but this is still a small fishery with high variability in catch rates, and therefore imprecision is likely to continue.

9. ACKNOWLEDGMENTS

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