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Orange roughy fisheries around northern New Zealand (ORH 1)

New Zealand Fisheries Assessment Report 2017/46

M. Dunn

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EXECUTIVE SUMMARY

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This report updates descriptive analyses of commercial catch and effort data for the orange roughy fishery around the north of the North Island of New Zealand (ORH 1), using data to the end of the 2014–15 fishing year. Data are summarised back to the start of most of the fisheries, and are analysed in detail for the most recent fishing years. This report also analyses samples of orange roughy catch composition provided by the Ministry for Primary Industries Observer Programme, and summarises trawl and acoustic research surveys. The report then reviews the information available for assessing stock structure.

The annual Total Allowable Commercial Catch (TACC) for ORH 1 has been under-caught since 2000–01. Orange roughy have been caught by bottom trawl, and most often in trawl tows targeting orange roughy on and around underwater features (e.g., hills). The number of vessels operating in the fishery has become relatively small (no more than six each year), with some locations only fished by a single vessel each year. The spatial extent of the fishery in ORH 1 has declined since around 2010, and focused in three subareas: Tauroa, Manukau, and the Bay of Plenty. The majority of the fishing effort and catches were reported early in the fishing year (between October and March) for Tauroa, in June and July for Manukau, and in June for the Bay of Plenty. There has been a moderate pattern of sequential fishing of features within ORH 1, but no substantive new fishing locations have been added since around 2007.

Substantial data on catch composition were collected by Ministry for Primary Industries observers. The mean length of orange roughy in catches was highly variable between locations, and included some of the largest orange roughy caught around New Zealand. The largest fish were caught offshore, and in inshore areas relatively large fish were caught close to features. Smaller fish (less than 30 cm standard length) were sparse in catch samples. Spawning fish were sampled at numerous locations throughout ORH 1, with a peak in spawning in late June. The sex composition of sampled fish often favoured males.

An analysis of cumulative catch associated with known features was conducted. Cumulative catch in some areas appeared to be reaching an asymptote, whereas in others it was increasing linearly or showing a variable pattern depending on the time period analysed.

The stock structure of ORH 1 remains unclear. There is little evidence for more than one orange roughy population within ORH 1, However, the locations fished have been separate and distinct, and persistent differences in fish lengths from different locations suggests population structuring. Oceanographic studies show that there may be relatively weak links between water masses on the west coast of the North Island and those on the east. Stocks assumed for management purposes may therefore reflect these differences. Further options for researching stock structure are discussed.

1. INTRODUCTION

The coastline of New Zealand orange roughy Quota Management Area 1 (ORH 1) 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 (Figure 1).

The work described in this report was carried out under Ministry for Primary Industries (MPI) project DEE2015/04 Specific Objective 1, "*To update the descriptive analysis of orange roughy fisheries in ORH 1 with the inclusion of commercial and observer data up to the end of the 2014/15 fishing year*", and Specific Objective 2, "*To update the analyses of cumulative catch and CPUE on a feature by feature basis with the inclusion of data up to the end of the 2014/15 fishing year for ORH 1*".

This report updates the descriptive analysis of catch and effort data to the end of the 2008–09 fishing year for ORH 1 by Anderson & Dunn (2012), and the CPUE analysis to the end of the 2007–08 fishing year by Mormede (2010). The management of the ORH 1 fishery has been relatively complex, and is described by Ministry for Primary Industries (2016).

Some tabulated results in this report were removed according to the MPI data confidentiality rules. A confidential version of this report showing all data was submitted to MPI.

2. DESCRIPTION OF THE FISHERY

2.1 Catch and Effort data sources and methods

Estimated catch and effort data for the orange roughy fishery have mostly been recorded on either Trawl Catch Effort Processing Return (TCEPR) or Catch, Effort and Landing Return (CELR) forms. The TCEPR forms give tow-by-tow information, with location and estimated catch for each trawl. The CELR forms provided daily estimated catch records with effort as the number and total duration of tows in the day. CELR forms have mostly been used by smaller inshore vessels. Larger deepwater vessels (over 28 m in length) are required to complete TCEPR forms. There are also "high-seas" versions of both form types for use by vessels fishing outside the New Zealand EEZ. A new form, the Trawl Catch Effort Return (TCER), was introduced on 1 October 2007 and records similar catch and effort data to the TCEPR forms, and effectively replaces the CELR forms previously used. Up-to-date data from each form type until the end of the 2014–15 fishing year were requested from the Ministry for Primary Industries catch-effort database. TCEPR/TCER data were combined with data from previous extracts to provide full tow-by-tow data for the entire history of the fishery. CELR data were stored in a spreadsheet file. This report focuses on data from the more detailed TCEPR/TCER forms. Although CELR forms were widely used in earlier years their use in most fisheries has declined over time, representing less than 10% of the total estimated catch since 1993–94, and they have not been used to record any orange roughy fishing since 2007–08 (Anderson & Dunn 2012).

Data were selected from all trawls where orange roughy were either the declared target species, or were caught. TCEPR/TCER data were error-checked using routines developed in the statistical software package R. Error checks were performed for recorded bottom depth, fishing depth, location, trawl speed and duration, and time of day. Missing or erroneous values were replaced with imputed average values. For example: where depth was missing it was replaced with the median depth from all other tows recorded within 1 n.mile of that tow position. Obvious errors in the recording of target species, or due to confusion of the western with the eastern hemisphere, were also corrected. All tows were then assigned to a QMA and fishery or subarea. As in previous analyses, nine subareas have been defined:

- **West Norfolk Ridge.** The area within the boundary of 34.3°–35.5° S and from the EEZ boundary in the west to 170.5° E. The area was extended to the northwest in 2004–05 to encompass new fishing grounds.
- **Tauroa.** The area within the boundary of 34.3°–35.2° S and 171°–172.5° E.
- **Manukau**. The area within the boundary of 35.5°–36.5° S and 172.5°–174° E.
- **Northland**. The area within the boundary of 33.5°–34.7° S and 173.8°–175.5° E.
- **North Colville**. The area within the boundary of 34°–35.67° S and 177°–178° E.
- **Mercury–Colville**. The area within the boundary of 36°–36.67° S and 176.33°–176.83° E.
- **White Island**. The area within the boundary of 36.7°–37.33° S and 177°–177.6° E.
- **Aldermen**. The area within the boundary of 36.8°–37.15° S and 176.4°–177° E.
- **Clark**. The area within the boundary of 36.3–36.6°S and 177.6–178°E.

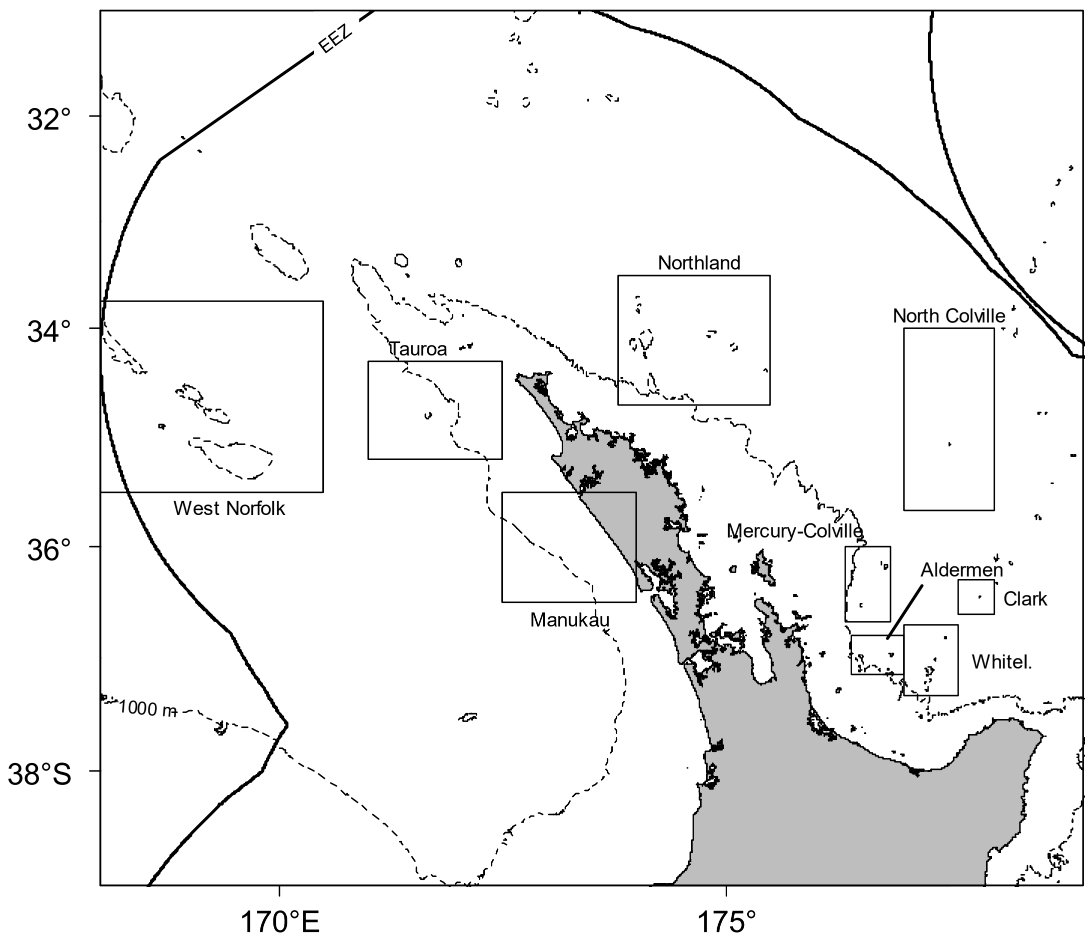


Figure 1: The ORH 1 fishery area. The position of the main grounds are marked as open rectangles.

2.2 Data grooming

The data grooming had only a small effect on the data set. Grooming for tow location resolved 13 803 missing data fields (4% of the data set), allocating the tow to a median position for that vessel and day fished; almost all of these records were in the historical data prior to 1999–2000. Grooming resolved 244 missing depth records, and 1513 missing tow speed records (both less than 0.1% of the data set). After grooming, the median depth changed from 922 m to 910 m (quartiles change from 840–1002 m to 852–982 m), and the tow speed median and quartiles were unchanged. The data set contained 5311 tows where tow distance was more than 50 km. For these records positions were replaced with the median for that vessel and day, or if this did not resolve the problem the start position was maintained and speed, duration, and distance set to NA (738 records; only 10 of these records occurred after 2008–09). Tows in the data set were centred around 900 m depth, a speed of 3 knots (5.6 km h^{-1}), a length of 2.6 km or just over half an hour, an average of 6.5 km from a seamount summit, and spread evenly throughout the day and night (Figure 2).

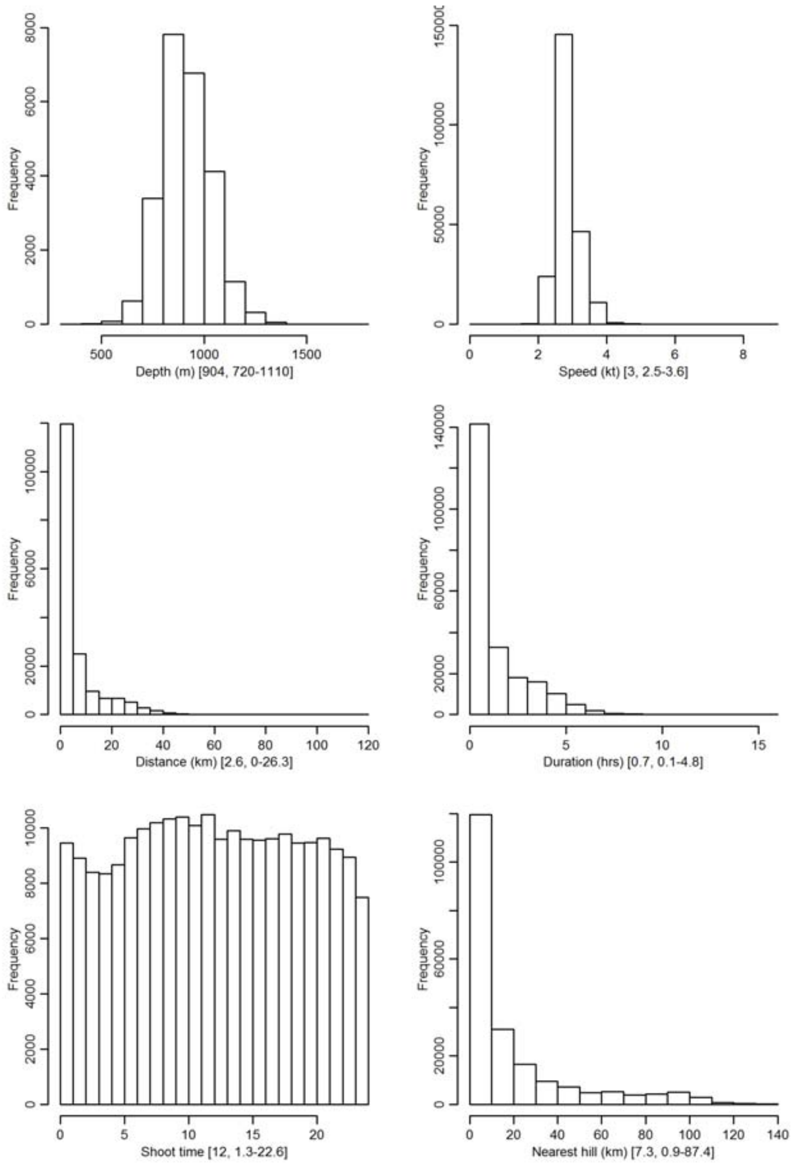


Figure 2: Frequency distributions for the groomed data set. Values in square parentheses give the median and 5–95% quantiles.

2.3 Description of the ORH 1 fishery

The catches from ORH 1 peaked in 2001–02, under the first year of the reintroduced AMP programme. The TACC then remained at 1400 t and catches fluctuated, being relatively low between 2008–09 and 2010–11 (Table 1). The amount of catch reported on TCEPR and TCER forms has been 80% or more of the total since 1993–94, except in 2009–10, and on average 92% since 1995–96. The ORH 1 TACC of 1400 t has always been undercaught.

Table 1: ORH 1 Reported landings (t), TACC (t), percentage of TACC caught, and percentage of catches recorded on TCEPR or TCER forms, for 1989–90 to 2014–15. The figures in parentheses indicate combined exploratory (under special permit) and TACC landings.

Fishing year	Landings	TACC	% of TACC caught	Estimated TCEPR & TCER as % of catch
1989–90	86	190	45	73
1990–91	200	190	105	0
1991–92	112	190	59	0
1992–93	49	190	26	75
1993–94	189	190	99	100
1994–95	244	190	128	*160
1995–96	965	1 190	81	97
1996–97	1 021	1 190	86	97
1997–98	511	1 190	43	101
1998–99	845 (1 543)	1 190	71 (130)	101
1999–00	771 (1 476)	1 190	65 (124)	97
2000–01	858	800	107	90
2001–02	1 294	1 400	92	94
2002–03	1 123	1 400	80	90
2003–04	986	1 400	70	92
2004–05	1 151	1 400	82	88
2005–06	1 201	1 400	86	89
2006–07	1 036	1 400	74	93
2007–08	1 104	1 400	79	91
2008–09	905	1 400	65	82
2009–10	825	1 400	59	70
2010–11	772	1 400	55	79
2011–12	1 114	1 400	80	93
2012–13	1 171	1 400	84	94
2013–14	1 055	1 400	75	99
2014–15	1 181	1 400	84	97

* Reported landings for 1994–95 do not include about 250 t of orange roughy caught under special permit, but TCEPR records do.

The fishery descriptive report subareas have continued to encompass all of the main fishery areas (Figure 3). The overall spatial distribution of catch and effort has contracted in recent years, with no new distinct fishing areas being developed. The fishery was spatially most expansive in the ten years from 1999–2000. Since 2011–12, the fishery has been focused in the Bay of Plenty (largely the White Island subarea), Tauroa, and Manukau, with low catch rates outside of those three areas.

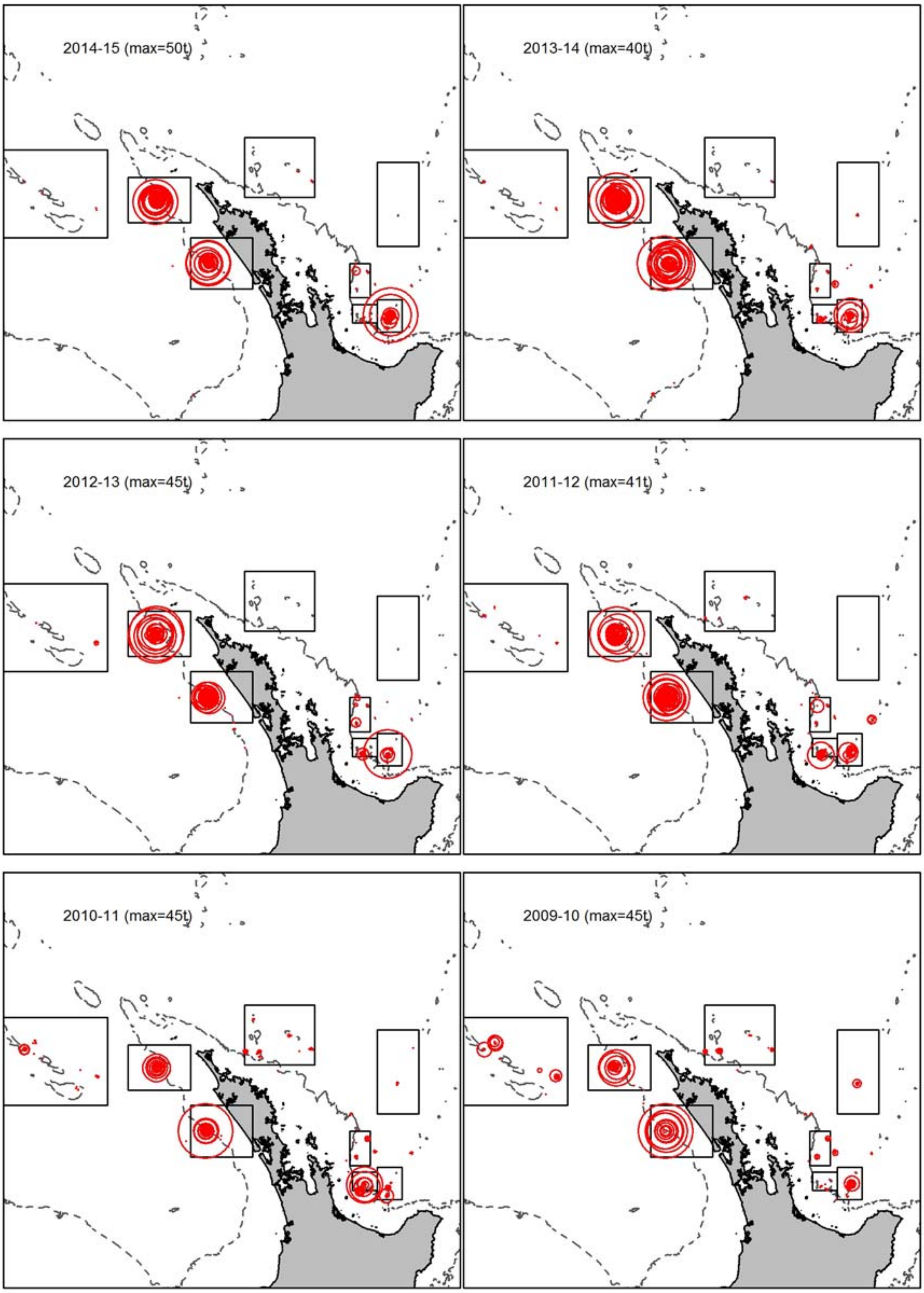


Figure 3: Distribution of trawls and orange roughy catch rate (t/tow) in ORH 1 by fishing year. Circle area proportional to catch rate, with maximum catch rate for each year given in parentheses. Rectangles show the descriptive report fishery subareas.

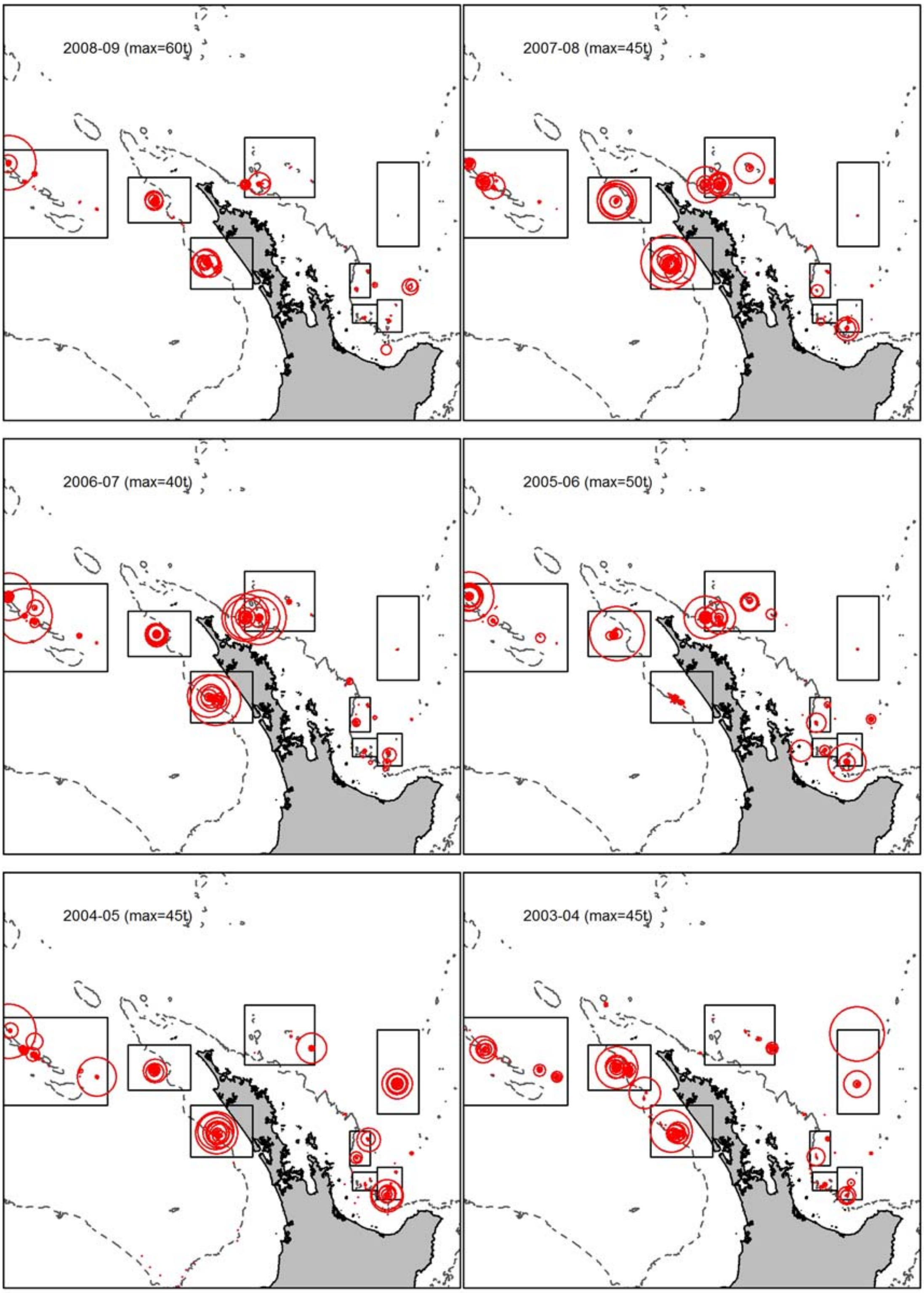
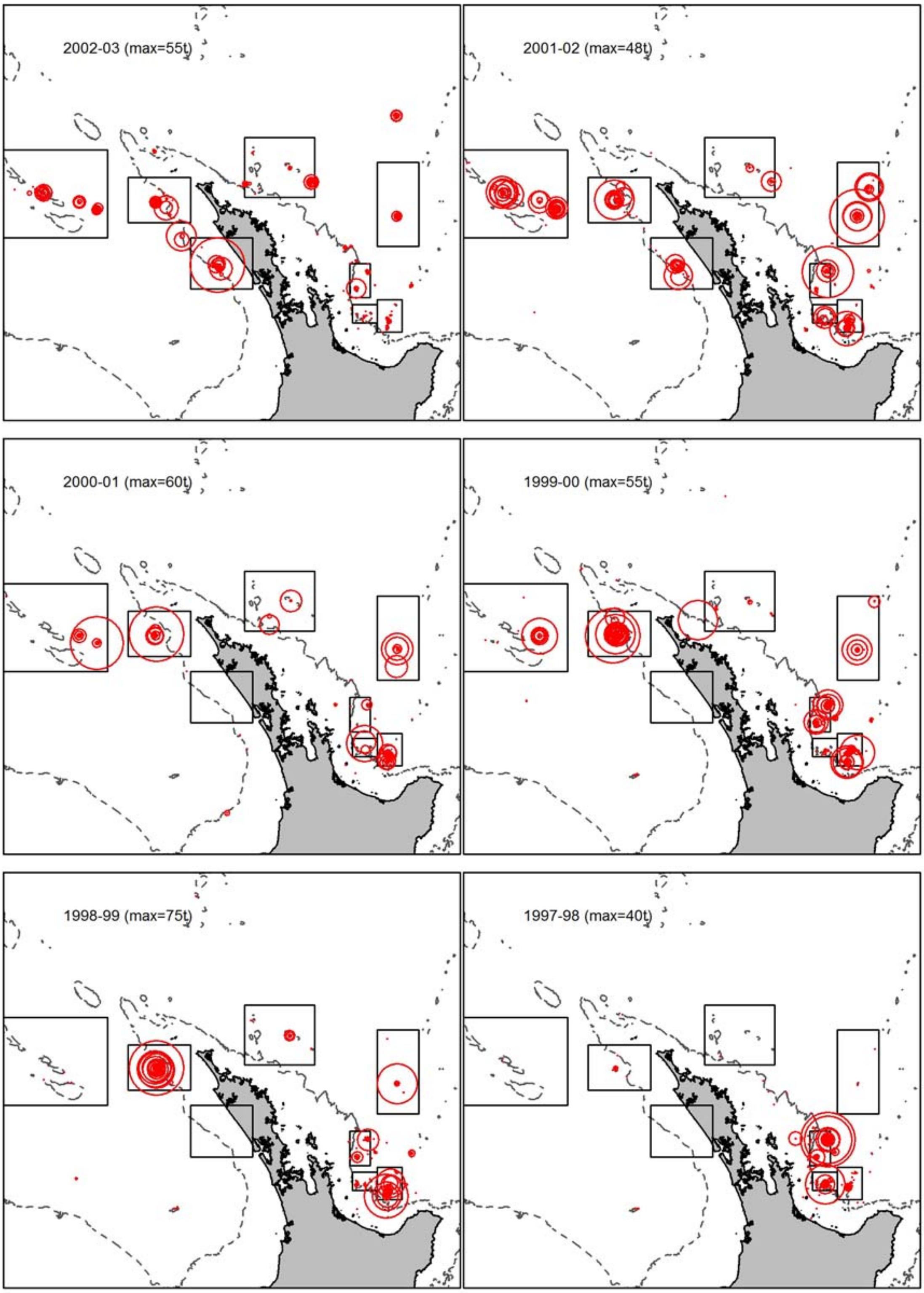


Figure 3 (cont.): Distribution of trawls and orange roughy catch rate (t/tow) in ORH 1 by fishing year. Circle area proportional to catch rate, with maximum catch rate for each year given in parentheses. Rectangles show the descriptive report fishery subareas.



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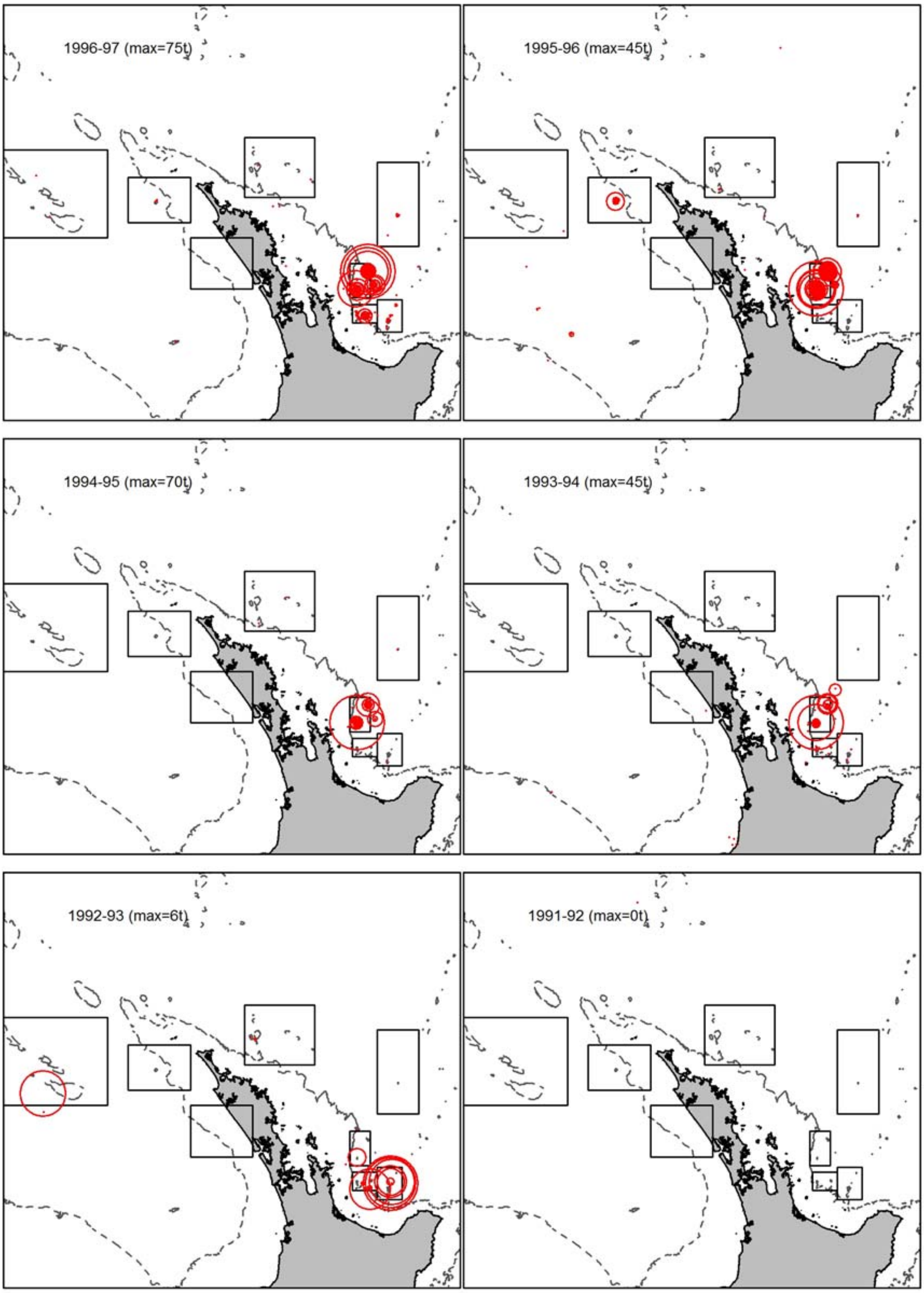


Figure 3 (cont.): Distribution of trawls and orange roughy catch rate (t/tow) in ORH 1 by fishing year. Circle area proportional to catch rate, with maximum catch rate for each year given in parentheses. Rectangles show the descriptive report fishery subareas.

In the earlier years of the ORH 1 fishery, effort was generally at the highest level in June or July (Clark et al. 2003). In the last three fishing years, fishing has taken place throughout the year, with on average around half of the catch taken by May, with 40–50% of the remaining catch then taken by early July (Figure 4).

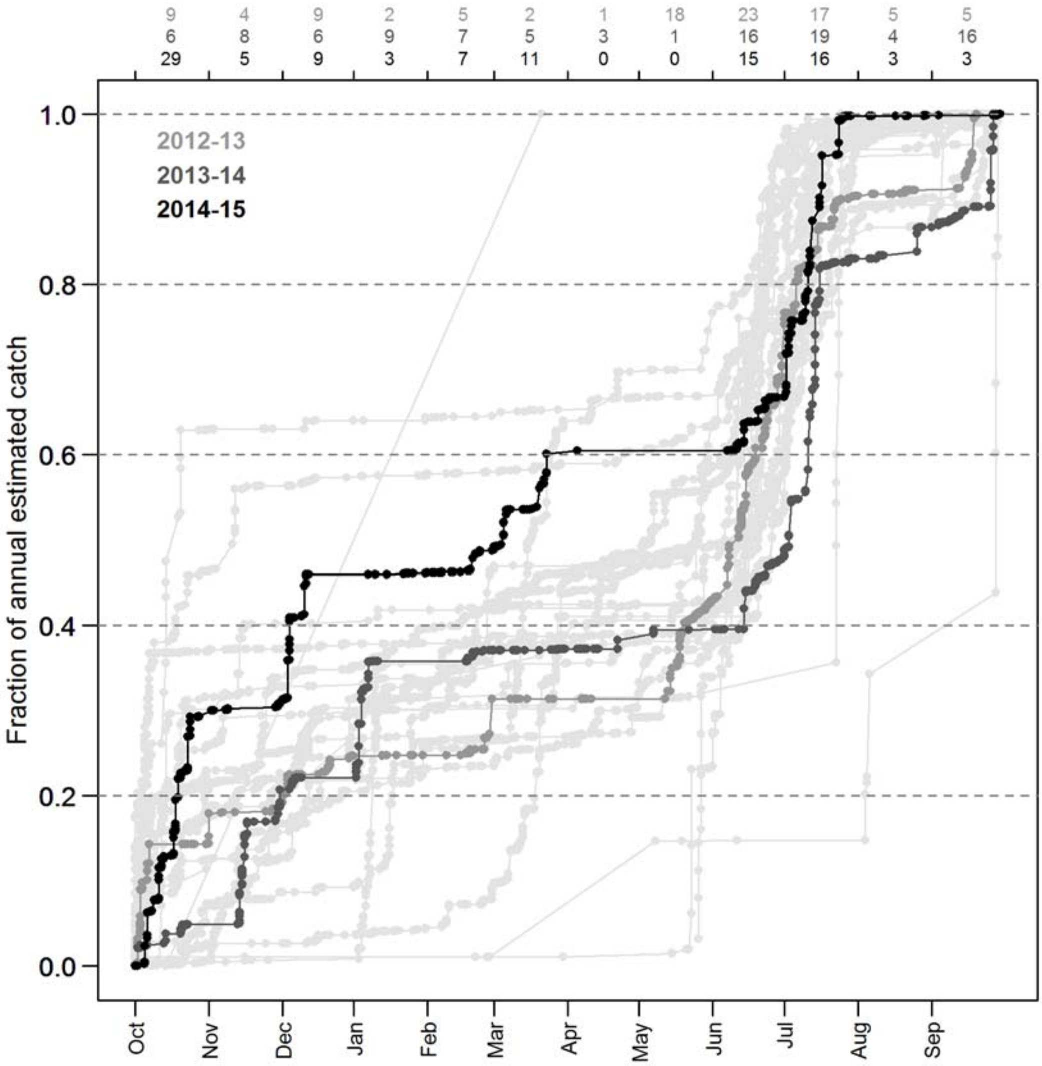


Figure 4: Cumulative catches and effort in ORH 1. Catches are summed in chronological order through the fishing year, and scaled to the total estimated catch for the year. Each point represents the relative accumulated catch after the addition of the catch from each new trawl. The 2012–13, 2013–14, and 2014–15 fishing years are shown individually in grey, dark grey, and black. The percentage of trawls by month is shown above each panel, using the same shading to represent years. Cumulative catches for all previous years are shown in light grey.

Most of the fishing effort and catch from the fishery in the Bay of Plenty has come from June, although historically fishing has also taken place earlier in the year (Figure 5). In 2012–13 and 2013–14 the fishing before July yielded little orange roughy catch, but in 2014–15 almost two thirds of the annual catch was taken by the end of December (almost entirely (over 99%) from the White Island subarea), with almost all of the remainder of the catch taken in June (again largely (87%) from the White Island subarea). In 2012–13 and 2013–14 the amount of catch taken before June was similar between White Island and Mercury-Colville, and the June fishery catches were greatest in White

Island (around 70–80%), followed by Aldermen, then Mercury Colville. Although the Bay of Plenty has been a relatively substantial fishery within ORH 1 in recent years (see Table 3), often a substantial proportion of the annual catch was taken in a small number of tows.

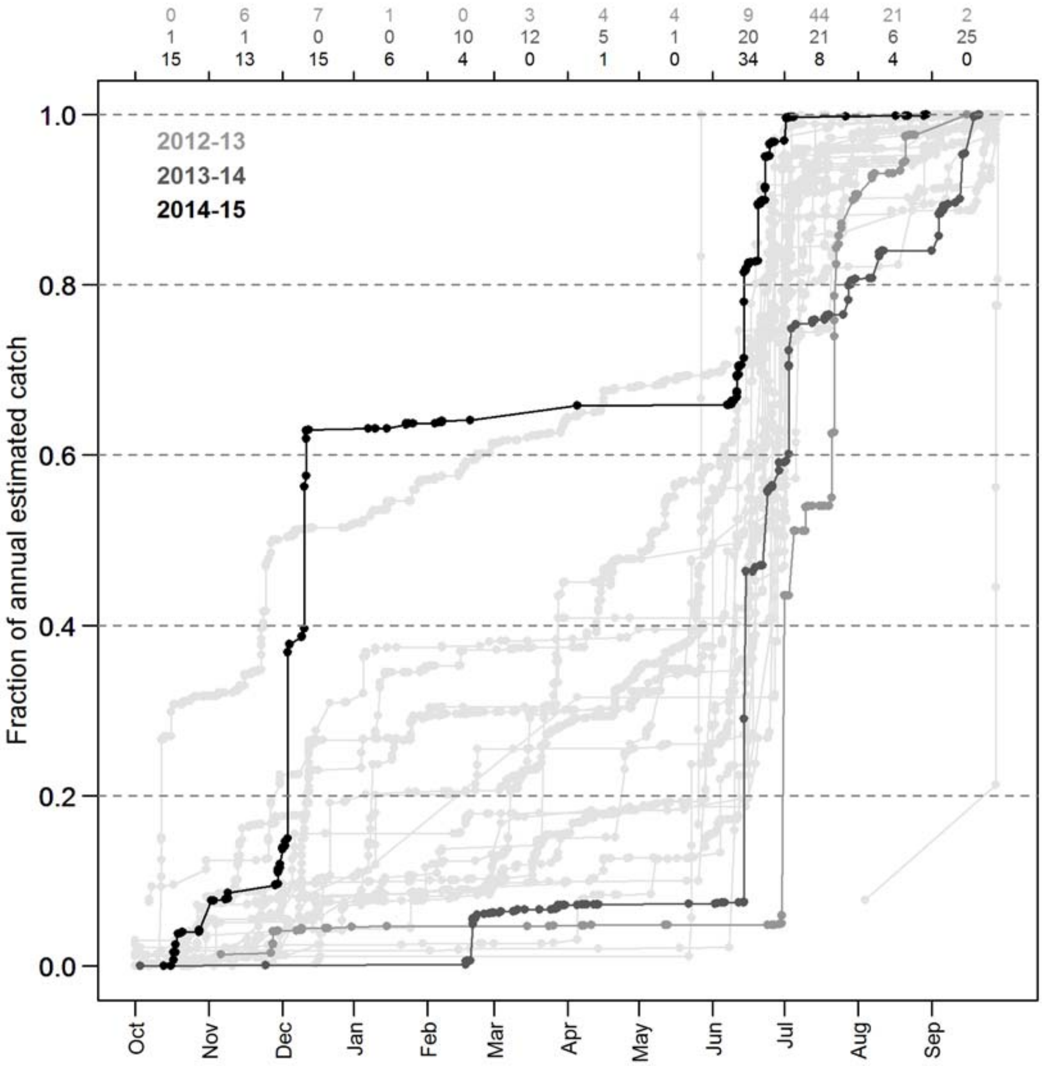


Figure 5: Cumulative catches and effort in Bay of Plenty subareas (Mercury-Colville, White Island, and Aldermen combined). Catches are summed in chronological order through the fishing year, and scaled to the total estimated catch for the year. Each point represents the relative accumulated catch after the addition of the catch from each new trawl. The 2012–13, 2013–14, and 2014–15 fishing years are shown individually in grey, dark grey, and black. The percentage of trawls by month is shown above each panel, using the same shading to represent years. Cumulative catches for all previous years are shown in light grey.

In the Tauroa subarea, the fishery has historically been focused on and around a feature (Tauroa Knoll) and at the start of the fishing year (Figure 6). The substantial catches taken in October started in 2000–01, and were less than 200 t (mean 140 t) in all years except 2014–15, when they increased to 325 t. In the three most recent fishing years, around two thirds of the catch was taken by March, with the fishery ending in March in 2014–15, and largely completed during July and September in 2012–13 and 2013–14. There has persistently been little or no catch and effort in April-June, and August.

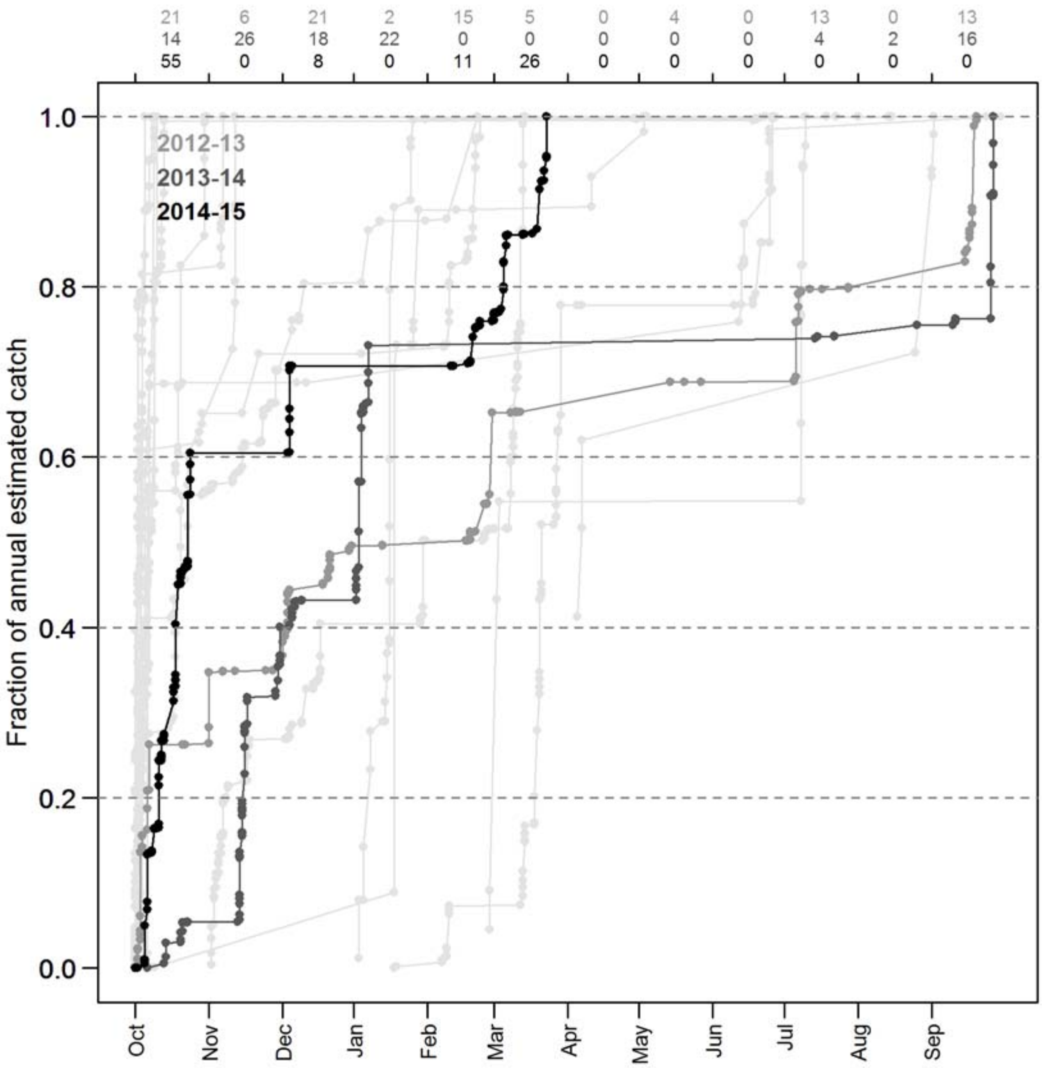


Figure 6: Cumulative catches and effort in the Tauroa subarea. Catches are summed in chronological order through the fishing year, and scaled to the total estimated catch for the year. Each point represents the relative accumulated catch after the addition of the catch from each new trawl. The 2012–13, 2013–14, and 2014–15 fishing years are shown individually in grey, dark grey, and black. The percentage of trawls by month is shown above each panel, using the same shading to represent years. Cumulative catches for all previous years are shown in light grey.

In the Manukau subarea, the fishery has been focused (over 90% of catch) between the middle of May and the end of July (Figure 7). There has been little fishing effort between November and May, and when effort had occurred at this time, the catches were negligible. Substantial catches were reported at the start of the fishing year only in 2009–10, 2010–11, and 2011–12 (213 t, 193 t, and 150 t respectively), with no effort after October reported for 2009–10 and 2010–11.

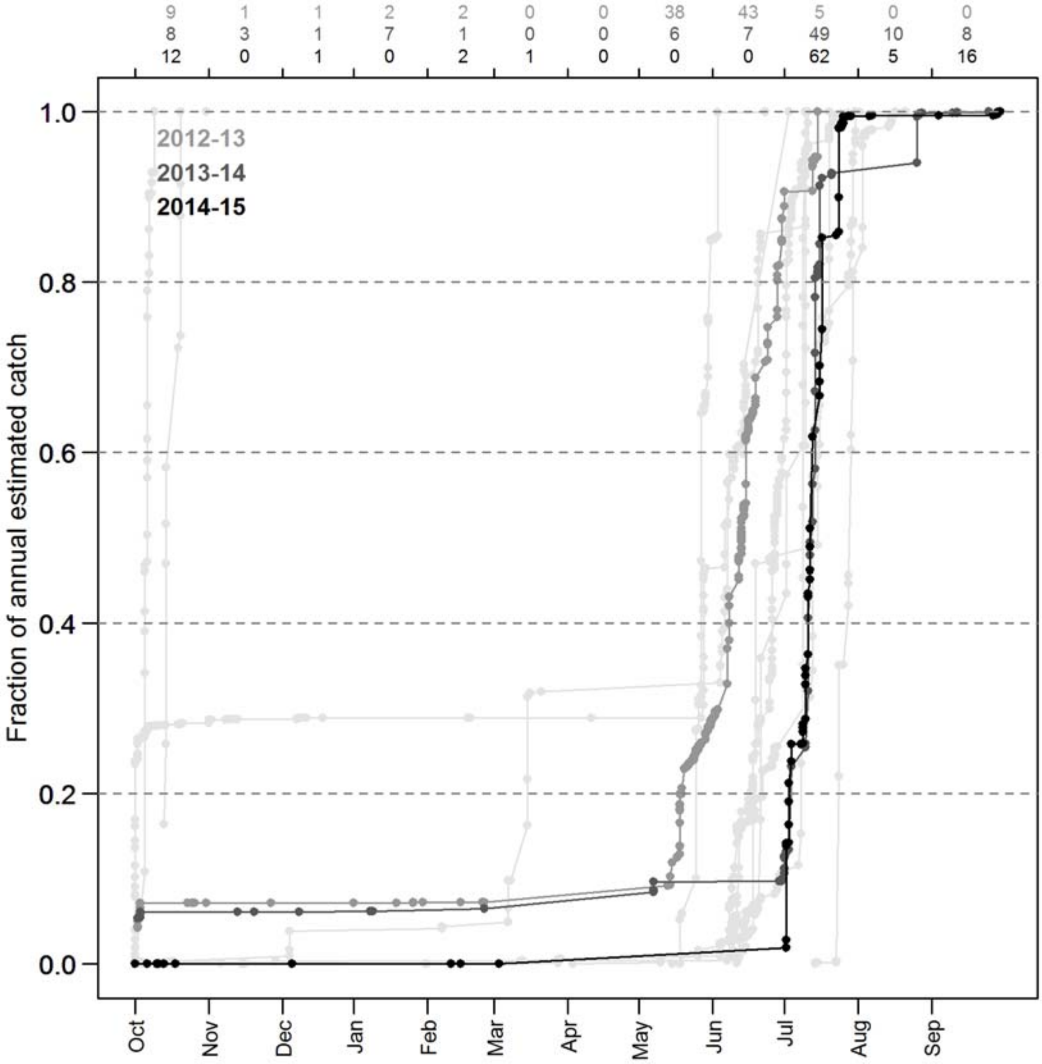
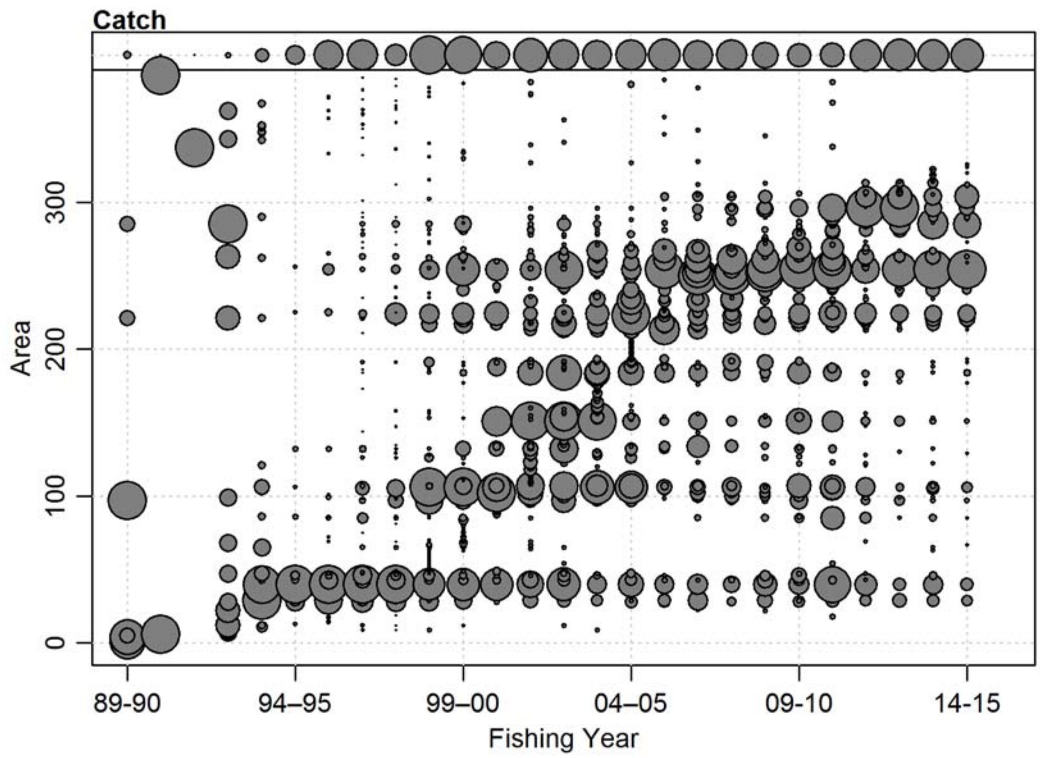


Figure 7: Cumulative catches and effort in the Manukau subarea. Catches are summed in chronological order through the fishing year, and scaled to the total estimated catch for the year. Each point represents the relative accumulated catch after the addition of the catch from each new trawl. The 2012–13, 2013–14, and 2014–15 fishing years are shown individually in grey, dark grey, and black. The percentage of trawls by month is shown above each panel, using the same shading to represent years. Cumulative catches for all previous years are shown in light grey.

Since the late 1990s, the ORH 1 fishery has not shown a particularly strong pattern of sequential fishing of areas, and although new fishery areas were regularly developed after 1996–97, some fishing tended to continue in most of these areas through until 2014–15 (Figure 8). However, the catches associated with these areas tended to decrease after a few years (thereby implying CPUE reduction also), and there was a stronger pattern of sequential movement in the catch. The most recent notable new fishery area started in 2006–07 (index value of about 300 in Figure 8), and was the development of the fishery in the Manukau box (see Figure 3).



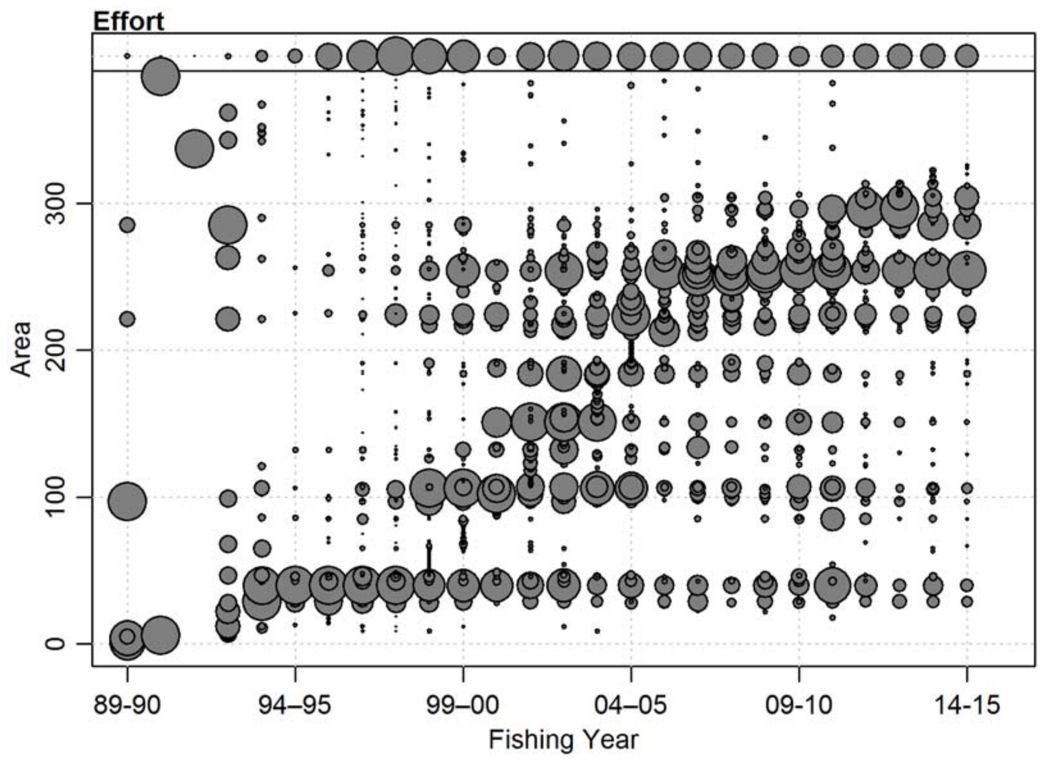


Figure 8: The distribution of orange roughy estimated catch (top panel) and effort (number of tows, bottom panel) by fishing year and area (where area is a square of 1/10th of a degree latitude and longitude) for the ORH 1 fishery. Catch and effort are proportional to circle size. The top panel in each plot shows the (relative) total catch (upper) and total effort (lower) by year. The maximum circle size in each year is set to be equal. Areas were ordered, in both plots, by the mean year in which the catch was taken.

Most of the tows that caught orange roughy were reported as targeting orange roughy (Table 2). The only notable fishery taking a by-catch of orange roughy was that for black cardinalfish, which was predominantly in the Bay of Plenty, and took place a little shallower than the orange roughy target fishery (median depth 780 m compared to 900 m). The other reported target species where orange roughy was caught were mostly alfonsino, followed by hoki, and oreos. The reason for, or veracity of, the apparent drop in targeting in 1994–95 is unknown.

Table 2: Percentage of tows in ORH 1 catching orange roughy, by target species and fishing year.

	Target species		
	Orange roughy	Black cardinalfish	Other species
1992–93	100	0	0
1993–94	99	0	1
1994–95	41	56	3
1995–96	80	20	0
1996–97	90	10	0
1997–98	95	5	0
1998–99	90	10	0
1999–00	85	15	0
2000–01	53	44	3
2001–02	85	13	2
2002–03	83	16	1
2003–04	79	16	5
2004–05	72	26	2
2005–06	94	5	1
2006–07	94	6	0
2007–08	92	8	0
2008–09	84	15	1
2009–10	86	13	1
2010–11	86	13	1
2011–12	89	11	0
2012–13	99	1	0
2013–14	94	6	0
2014–15	95	5	0

For ORH 1 as a whole, total catch peaked at over 1500 t in 1998–99, and catches remained at just over 1000 t in most years since then. In 2009–10 the catch dropped to 579 t, and the four vessels operating in the fishery were the fewest since 1991–92, but the unstandardized catch rate did not decline (Table 3). The recent catch, catch rate, and proportion of tows with large catches (>10 t), were at their highest levels since the early 2000s, but fishing effort was relatively low.

The fishery subarea divisions used in previous analyses encompassed all of the main fishery areas (see Figure 3).

On the West Norfolk Ridge, the focus of catch and effort has historically been to the northwest, close to the edge of the EEZ (see Figure 3). Catches in this fishery peaked at about 350 t in 2001–02, and then declined after 266 t was taken in 2006–07 down to less than 1 t in 2011–12. Since 2011–12 the fishery has essentially ceased, with only a single vessel, very little catch and effort, and low CPUE (Table 4).

On Tauroa Knoll, annual catches have increased from 144 t in 2010–11 to 537 t in 2014–15, making the fishery in recent years the largest it has been since 1998–2000 (Table 4). Fishing effort and catch rates have also been relatively high, with 2–4 vessels active in the fishery, although the proportion of tows with large catches has not been as high as in earlier years of the fishery.

Table 3: Summary of effort, catch (t), catch rates, tow duration, and proportion of large catches, for the ORH 1 fishery (tows that caught or targeted orange roughy). Catch rates and tow duration are calculated only for years in which there were ten or more tows. #, years where less than three vessels, excluded under MPI data confidentiality rules (*no group contains data less than 3 vessels*).

Fishing year	Number of vessels	Total number of tows	% ORH target	Total estimated catch	Median catch rate (t/tow)	Median catch rate (t/h)	Median tow duration	Proportion of tows > 10 t
1989–90	#	–	–	–	–	–	–	–
1990–91	#	–	–	–	–	–	–	–
1991–92	#	–	–	–	–	–	–	–
1992–93	4	23	100	37	0.3	1.1	0.7	0.00
1993–94	6	99	99	189	<0.1	0.1	0.3	0.04
1994–95	7	149	41	397	0.2	1.0	0.2	0.05
1995–96	14	519	80	937	0.1	0.3	0.3	0.05
1996–97	11	759	90	988	<0.1	<0.1	0.3	0.03
1997–98	8	1 128	95	514	<0.1	<0.1	0.3	0.01
1998–99	7	944	90	1 564	0.1	0.1	0.8	0.03
1999–00	6	823	85	1 437	0.1	0.3	0.4	0.04
2000–01	6	231	53	774	0.5	1.5	0.3	0.08
2001–02	7	567	85	1 222	0.1	0.4	0.2	0.08
2002–03	8	717	83	1 013	0.2	0.5	0.2	0.02
2003–04	6	609	79	906	0.2	0.5	0.3	0.03
2004–05	8	585	72	1 019	0.2	0.6	0.3	0.04
2005–06	6	569	94	1 065	0.4	0.6	0.3	0.03
2006–07	5	591	94	964	0.2	0.7	0.2	0.04
2007–08	5	491	92	1 004	0.2	0.9	0.2	0.05
2008–09	4	490	84	741	0.1	0.6	0.2	0.03
2009–10	4	303	86	579	0.2	0.6	0.2	0.05
2010–11	4	375	86	613	0.1	0.5	0.2	0.04
2011–12	5	484	89	1 036	0.1	0.2	0.5	0.06
2012–13	4	479	99	1 103	0.4	0.8	0.3	0.05
2013–14	6	450	94	1 047	0.2	0.6	0.2	0.07
2014–15	6	416	95	1 141	0.2	1.0	0.2	0.07

In Manukau, catches and effort have not been as high as in Tauroa, but more vessels were active in the fishery; Manukau is the one subarea that was fished by all vessels active in the ORH 1 fishery in 2014–15. In 2009–10 the tow duration shortened considerably, and indicated a switch from longer tows on flat ground to targeted fishing of features. The catch rate in the first year of this period, 2009–10, was exceptionally high, with 70% of tows yielding more than 10 t, but the catch rate then declined substantially over the following two years, and subsequently remained relatively low. The average tow duration also steadily increased after 2009–10. Catches and effort, however, peaked after the decline in CPUE, in 2011–12 and 2012–13.

In Northland, the fishing grounds developed in the southwest area in 2005–06 (features "Birdflue" and "Boulder Ridge"; Anderson & Dunn 2012) provided most of the catch from this region, but catches and effort effectively ceased from 2012–13, with low CPUE and no large catches (Table 3).

There has been little catch and effort in the North Colville region since 2005–06, and no fishing at all in four of the last seven years (Table 3). Annual catches peaked at over 200 t in 2001–02 but halved the following year, despite a similar level of effort, and the fishery has been largely unattended since 2005–06.

Table 4: Summary of effort, catch (t), catch rates, tow duration, and proportion of large catches, for tows targeting or catching orange roughy. Catch rates and tow duration are calculated only for years in which there were ten or more tows. #, years where less than three vessels, excluded under MPI data confidentiality rules (*no group contains data less than 3 vessels*).

Fishing year	Number of vessels	Total number of tows	% ORH target	Total estimated catch	Median catch rate (t/tow)	Median catch rate (t/h)	Median tow duration	Proportion of tows > 10 t
West Norfolk Ridge								
1989–90	0	0	–	–	–	–	–	–
1990–91	0	0	–	–	–	–	–	–
1991–92	0	0	–	–	–	–	–	–
1992–93	#	1	100	5	–	–	–	0.00
1993–94	0	0	–	–	–	–	–	–
1994–95	0	0	–	–	–	–	–	–
1995–96	#	–	–	–	–	–	–	–
1996–97	#	–	–	–	–	–	–	–
1997–98	#	–	–	–	–	–	–	–
1998–99	#	–	–	–	–	–	–	–
1999–00	#	–	–	–	–	–	–	–
2000–01	#	–	–	–	–	–	–	–
2001–02	#	–	–	–	–	–	–	–
2002–03	#	–	–	–	–	–	–	–
2003–04	3	171	66	157	0.1	0.6	0.2	0.01
2004–05	#	–	–	–	–	–	–	–
2005–06	#	–	–	–	–	–	–	–
2006–07	3	195	97	266	0.2	1.1	0.2	0.02
2007–08	#	–	–	–	–	–	–	–
2008–09	#	–	–	–	–	–	–	–
2009–10	#	–	–	–	–	–	–	–
2010–11	#	–	–	–	–	–	–	–
2011–12	#	–	–	–	–	–	–	–
2012–13	#	–	–	–	–	–	–	–
2013–14	#	–	–	–	–	–	–	–
2014–15	#	–	–	–	–	–	–	–
Tauroa								
1989–90	0	0	–	–	–	–	–	–
1990–91	0	0	–	–	–	–	–	–
1991–92	0	0	–	–	–	–	–	–
1992–93	0	0	–	–	–	–	–	–
1993–94	0	0	–	–	–	–	–	–
1994–95	0	0	–	–	–	–	–	–
1995–96	#	–	–	–	–	–	–	–
1996–97	3	8	100	5	–	–	–	0.00
1997–98	3	25	100	6	0.0	0.0	0.5	0.00
1998–99	3	72	100	583	2.0	4.8	0.5	0.19
1999–00	4	144	100	517	1.0	1.4	0.7	0.10
2000–01	#	–	–	–	–	–	–	–
2001–02	#	–	–	–	–	–	–	–
2002–03	4	78	100	209	0.5	2.6	0.2	0.04
2003–04	6	59	98	229	2.0	3.3	0.5	0.10
2004–05	#	–	–	–	–	–	–	–
2005–06	4	103	100	197	0.5	2.7	0.3	0.01
2006–07	#	–	–	–	–	–	–	–

Fishing year	Number of vessels	Total number of tows (TCEPR)	% ORH target	Total estimated catch	Median catch rate (t/tow)	Median catch rate (t/h)	Median tow duration	Proportion of tows > 10 t
2007–08	#	–	–	–	–	–	–	–
2008–09	3	83	100	141	0.4	1.8	0.2	0.04
2009–10	3	48	100	151	0.5	3.5	0.2	0.08
2010–11	#	–	–	–	–	–	–	–
2011–12	3	72	99	339	1.0	7.5	0.2	0.18
2012–13	4	127	100	466	0.6	8.5	0.1	0.08
2013–14	3	133	100	478	1.0	6.0	0.2	0.11
2014–15	#	–	–	–	–	–	–	–
Manukau								
1989–90	0	0	–	–	–	–	–	–
1990–91	0	0	–	–	–	–	–	–
1991–92	0	0	–	–	–	–	–	–
1992–93	0	0	–	–	–	–	–	–
1993–94	#	–	–	–	–	–	–	–
1994–95	0	0	–	–	–	–	–	–
1995–96	0	0	–	–	–	–	–	–
1996–97	0	0	–	–	–	–	–	–
1997–98	0	0	–	–	–	–	–	–
1998–99	0	0	–	–	–	–	–	–
1999–00	0	0	–	–	–	–	–	–
2000–01	0	0	–	–	–	–	–	–
2001–02	#	–	–	–	–	–	–	–
2002–03	3	52	100	185	0.9	0.6	2.0	0.08
2003–04	4	81	100	220	1.0	0.3	2.5	0.06
2004–05	6	59	100	243	0.7	0.3	3.0	0.14
2005–06	5	156	100	134	0.5	0.2	3.3	0.00
2006–07	3	86	99	199	0.2	0.1	4.0	0.07
2007–08	#	–	–	–	–	–	–	–
2008–09	3	54	100	172	0.2	0.1	4.3	0.09
2009–10	#	–	–	–	–	–	–	–
2010–11	3	27	100	193	4.5	9.3	0.5	0.19
2011–12	5	165	100	530	0.3	0.3	0.8	0.08
2012–13	4	199	100	491	0.7	0.7	1.0	0.07
2013–14	5	72	100	408	1.0	0.8	1.2	0.17
2014–15	6	82	99	371	0.3	0.3	1.4	0.11
Northland								
1989–90	0	0	–	–	–	–	–	–
1990–91	0	0	–	–	–	–	–	–
1991–92	0	0	–	–	–	–	–	–
1992–93	#	–	–	–	–	–	–	–
1993–94	0	0	–	–	–	–	–	–
1994–95	#	–	–	–	–	–	–	–
1995–96	#	–	–	–	–	–	–	–
1996–97	#	–	–	–	–	–	–	–
1997–98	#	–	–	–	–	–	–	–
1998–99	#	–	–	–	–	–	–	–
1999–00	#	–	–	–	–	–	–	–
2000–01	#	–	–	–	–	–	–	–
2001–02	#	–	–	–	–	–	–	–

Fishing year	Number of vessels	Total number of tows (TCEPR)	% ORH target	Total estimated catch	Median catch rate (t/tow)	Median catch rate (t/h)	Median tow duration	Proportion of tows > 10 t
2002–03	4	96	98	105	0.1	1.4	0.1	0.01
2003–04	3	51	71	49	0.1	1.1	0.1	0.00
2004–05	#	–	–	–	–	–	–	–
2005–06	#	–	–	–	–	–	–	–
2006–07	3	166	100	276	0.1	1.5	0.1	0.04
2007–08	#	–	–	–	–	–	–	–
2008–09	#	–	–	–	–	–	–	–
2009–10	3	66	100	32	<0.1	0.3	0.1	0.00
2010–11	#	–	–	–	–	–	–	–
2011–12	#	–	–	–	–	–	–	–
2012–13	0	0	–	–	–	–	–	–
2013–14	#	–	–	–	–	–	–	–
2014–15	#	–	–	–	–	–	–	–
North Colville Ridge								
1989–90	0	0	–	–	–	–	–	–
1990–91	0	0	–	–	–	–	–	–
1991–92	0	0	–	–	–	–	–	–
1992–93	0	0	–	–	–	–	–	–
1993–94	0	0	–	–	–	–	–	–
1994–95	#	–	–	–	–	–	–	–
1995–96	#	–	–	–	–	–	–	–
1996–97	3	17	100	0.8	0.0	0.0	0.1	0.00
1997–98	#	–	–	–	–	–	–	–
1998–99	#	–	–	–	–	–	–	–
1999–00	#	–	–	–	–	–	–	–
2000–01	#	–	–	–	–	–	–	–
2001–02	#	–	–	–	–	–	–	–
2002–03	3	77	70	109	0.5	4.0	0.2	0.00
2003–04	#	–	–	–	–	–	–	–
2004–05	#	–	–	–	–	–	–	–
2005–06	#	–	–	–	–	–	–	–
2006–07	#	–	–	–	–	–	–	–
2007–08	#	–	–	–	–	–	–	–
2008–09	0	0	–	–	–	–	–	–
2009–10	#	–	–	–	–	–	–	–
2010–11	#	–	–	–	–	–	–	–
2011–12	0	0	–	–	–	–	–	–
2012–13	0	0	–	–	–	–	–	–
2013–14	#	–	–	–	–	–	–	–
2014–15	0	0	–	–	–	–	–	–
Mercury-Colville								
1989–90	0	0	–	–	–	–	–	–
1990–91	0	0	–	–	–	–	–	–
1991–92	0	0	–	–	–	–	–	–
1992–93	#	–	–	–	–	–	–	–
1993–94	3	70	100	175	0.1	0.4	0.2	0.06
1994–95	6	138	37	369	0.2	1.0	0.2	0.04
1995–96	11	454	79	873	0.1	0.3	0.3	0.05
1996–97	10	482	85	747	0.0	0.0	0.3	0.04
1997–98	6	639	96	280	0.0	0.0	0.3	0.01

Fishing year	Number of vessels	Total number of tows (TCEPR)	% ORH target	Total estimated catch	Median catch rate (t/tow)	Median catch rate (t/h)	Median tow duration	Proportion of tows > 10 t
1998–99	4	238	92	131	0.0	0.0	0.3	0.01
1999–00	4	164	69	285	0.1	0.4	0.3	0.04
2000–01	3	36	3	30	0.1	0.4	0.2	0.03
2001–02	#	–	–	–	–	–	–	–
2002–03	6	69	51	39	0.0	0.3	0.2	0.01
2003–04	4	29	48	27	0.0	0.2	0.2	0.03
2004–05	3	49	14	57	0.1	0.3	0.2	0.04
2005–06	#	–	–	–	–	–	–	–
2006–07	3	43	53	22	0.0	0.3	0.1	0.00
2007–08	4	21	29	13	0.1	0.5	0.2	0.00
2008–09	#	–	–	–	–	–	–	–
2009–10	3	21	5	15	0.2	1.0	0.2	0.00
2010–11	#	–	–	–	–	–	–	–
2011–12	#	–	–	–	–	–	–	–
2012–13	3	33	79	17	<0.1	<0.1	0.1	0.00
2013–14	#	–	–	–	–	–	–	–
2014–15	#	–	–	–	–	–	–	–
White Island								
1989–90	#	–	–	–	–	–	–	–
1990–91	0	0	–	–	–	–	–	–
1991–92	0	0	–	–	–	–	–	–
1992–93	#	–	–	–	–	–	–	–
1993–94	#	–	–	–	–	–	–	–
1994–95	#	–	–	–	–	–	–	–
1995–96	0	0	–	–	–	–	–	–
1996–97	5	47	96	16	0.0	0.0	0.3	0.00
1997–98	6	249	89	64	0.1	0.1	0.7	0.00
1998–99	5	474	85	612	0.2	0.2	1.0	0.01
1999–00	4	293	86	295	0.1	0.1	0.6	0.02
2000–01	4	57	53	184	0.6	1.4	0.5	0.07
2001–02	3	70	70	130	0.1	0.1	0.3	0.06
2002–03	8	98	76	18	0.0	0.1	0.3	0.00
2003–04	4	106	83	66	0.1	0.2	0.5	0.02
2004–05	5	103	84	144	0.2	0.3	0.4	0.04
2005–06	#	–	–	–	–	–	–	–
2006–07	3	18	67	23	0.1	0.2	0.2	0.00
2007–08	3	51	65	64	0.2	0.6	0.3	0.04
2008–09	#	–	–	–	–	–	–	–
2009–10	3	42	83	43	0.1	0.3	0.2	0.02
2010–11	#	–	–	–	–	–	–	–
2011–12	4	83	80	67	<0.1	0.2	0.3	0.01
2012–13	3	79	100	94	<0.1	0.1	0.2	0.03
2013–14	4	117	97	106	<0.1	0.3	0.1	0.03
2014–15	#	–	–	–	–	–	–	–
Aldermen Knoll								
1989–90	0	0	–	–	–	–	–	–
1990–91	0	0	–	–	–	–	–	–
1991–92	0	0	–	–	–	–	–	–
1992–93	#	–	–	–	–	–	–	–

Fishing year	Number of vessels	Total number of tows (TCEPR)	% ORH target	Total estimated catch	Median catch rate (t/tow)	Median catch rate (t/h)	Median tow duration	Proportion of tows > 10 t
1993–94	#	–	–	–	–	–	–	–
1994–95	0	0	–	–	–	–	–	
1995–96	#	–	–	–	–	–	–	–
1996–97	5	67	100	98	0.2	0.6	0.2	0.03
1997–98	6	119	98	137	0.1	0.6	0.3	0.02
1998–99	4	33	97	24	0.1	0.0	1.0	0.00
1999–00	#	–	–	–	–	–	–	–
2000–01	#	–	–	–	–	–	–	–
2001–02	#	–	–	–	–	–	–	–
2002–03	4	19	100	2	0.0	0.1	0.6	0.00
2003–04	3	29	97	16	0.1	0.0	2.0	0.00
2004–05	#	–	–	–	–	–	–	–
2005–06	#	–	–	–	–	–	–	–
2006–07	#	–	–	–	–	–	–	–
2007–08	#	–	–	–	–	–	–	–
2008–09	#	–	–	–	–	–	–	–
2009–10	#	–	–	–	–	–	–	–
2010–11	#	–	–	–	–	–	–	–
2011–12	4	54	98	65	0.1	<0.1	2.0	0.02
2012–13	#	–	–	–	–	–	–	–
2013–14	4	41	100	25	0.2	0.1	2.0	0.00
2014–15	3	7	100	1	0.1	<0.1	2.1	0.00
Clark								
1996–97	0	0	–	–	–	–	–	–
1997–98	#	–	–	–	–	–	–	–
1998–99	3	40	100	25	0.1	0.1	0.83	0.00
1999–00	#	–	–	–	–	–	–	–
2000–01	#	–	–	–	–	–	–	–
2001–02	#	–	–	–	–	–	–	–
2002–03	6	30	100	9	0.1	0.4	0.21	0.00
2003–04	4	20	85	8	0.1	0.7	0.22	0.00
2004–05	3	10	60	9	0.6	1.3	0.31	0.00
2005–06	#	–	–	–	–	–	–	–
2006–07	#	–	–	–	–	–	–	–
2007–08	#	–	–	–	–	–	–	–
2008–09	#	–	–	–	–	–	–	–
2009–10	3	7	86	1	<0.1	<0.1	0.17	0.00
2010–11	#	–	–	–	–	–	–	–
2011–12	#	–	–	–	–	–	–	–
2012–13	#	–	–	–	–	–	–	–
2013–14	#	–	–	–	–	–	–	–
2014–15	#	–	–	–	–	–	–	–

The catch limit for the Mercury–Colville Box was reduced to 30 t in 2000–01, to be caught as bycatch in the cardinalfish fishery. Catches of orange roughy have remained below this level in most years since (Table 4), and the target species has mostly been recorded as cardinalfish. Large catches of orange roughy have been rare, even during the peak of this fishery in the mid-1990s, and median catch rates have been especially low since 2010–11.

Catches in the White Island fishery declined from over 600 t in 1998–99 to 8 t in 2008–09, but since then have increased back up to 219 t in 2014–15 (Table 4). Fishing effort in 2014–15 was at the highest level since 1999–00. Tow duration has typically been short, but decreased between 2010–11 and 2014–15. Catch rates show no strong trend, but were relatively high in 2014–15.

Annual catch in the Aldermen fishery peaked at 100–140 t in the late 1990s, but with declining effort the catch declined to less than 20 t per year until 2010–11, when catches increased to 106 t, and catch rates peaked (Table 4). Tow duration was typically short until 2005–06, after which it was relatively long (2–3 hr) suggesting fishing away from features; this is the only region within ORH 1 outside of Manukau where this type of fishing (long tows) has occurred. Effort was relatively high in 2011–12 following larger catches in 2010–11, with the number of vessels also increasing to four, however effort and catch was low in 2014–15. The region Clark was added to analyses in 2009–10, after 41 t were caught in 2008–09. However, in subsequent years effort and catch returned to a relatively low level.

3. OBSERVER DATA

The Ministry for Primary Industries Observer Programme (OP) has collected orange roughy sex, maturity stage, and length data in ORH 1 since 1991–92; except in 1992–93, 1994–95, and 2000–01 (Table 5). Observer coverage was relatively low in 1993–94, 1996–97, 2004–05, 2012–13 and 2013–14. Up to 10 131 fish were measured each year, and roughly 40% of these were females also sampled for maturity stage. Observers typically took samples from about 13% of the tows, and 28% of the catch, indicating that they preferentially took samples from larger catches. The percentage of the catch weight that was actually measured each year was about 0.7%.

A classification tree analysis was used to investigate patterns in the length samples. The response variable was the median length (Standard Length, SL) in each tow where at least twenty fish were measured, and two different sets of predictors were evaluated; the first used the potential categorical predictors subarea, fishing year, month, and vessel key, and continuous predictors longitude, latitude, depth, sample weight, green weight (catch weight), proportion female, and fishing year (fishing year was offered as both a categorical and continuous variable); the second added as potential continuous predictors the distance between the start position of the tow and the summit of the nearest feature (seamount, hill or pinnacle) from the NIWA database *seamounts* (Rowden et al. 2008), and also the summit depth, area (km^2), mean slope, and distance to the shelf edge for that feature. Distance from the shelf was calculated as the shortest distance between the feature and the 250 m isobath (Mackay 2006). The addition of the feature information reduced the size of the data set, because not all features had the desired covariates (specifically, the distance from shelf). The tree was pruned using 10-fold cross validation and complexity parameter *rp*, using the R library *rpart*.

In the first analysis (excluding feature predictors), the estimated stratification by median length was entirely spatial (Figure 9); the temporal predictors fishing year and month were not selected, and nor was the predictor for vessel. Orange roughy with a smaller mean length were found in Manukau, Aldermen, Mercury-Colville, White Island, and Tauroa subareas. Of these, the smallest fish were found in Manukau, and the largest in Mercury-Colville. Larger fish were found to the north in Northland, and within this subarea larger fish were found to the north, and were similar in size to those in West Norfolk. The largest fish were found in Clark and North Colville. Subsequent analyses and catch-weighted length frequency distributions were therefore completed with Northland split into two subareas at 34.35°S (Northland_N, and Northland_S).

In the second analysis (including feature predictors), the spatial complexity was replaced with the distance to the nearest feature, the proximity of the sample to a feature, and then subarea (Figure 10). The largest fish were found offshore, at distances equal to or greater than 69.8 km from the shelf edge. In more inshore waters, fish were larger when they were closer to features (within 13.31 km), and in the subareas Aldermen and White Island (southern subareas within the Bay of Plenty), Northland, and Tauroa. The model therefore split Northland into an offshore (larger fish) and inshore region, rather than northern (larger fish) and southern regions as above (Figure 11). The smallest fish were away from hills and inshore, with this category including the Manukau subarea. The median depth of the summits of features categorised as inshore (within 69.8 km of the shelf edge) and offshore were fairly similar, at 876 m and 898 m respectively.

Table 5: Summary of Ministry of Primary Industries observer samples taken of orange roughy from ORH 1, showing: the number of tows, trips, and vessels sampled; the weight of fish sampled and the catch weight from which this sample was taken; the number of fish measured and number of females sampled for maturity stage; and the coverage of the fishery as the percentage of tows and the catch weight in terms of the sampled catch weight, and actual measured weight (i.e., for 2014–15, 12.4% of the tows were sampled; these tows caught 34.8% of the total catch; but because the sample actually measured for fish length was a subsample of the catch, the actual weight sampled was just 0.38% of the total catch).

								% of fishery		
Fishing year	Tows	Trips	Vessels	Sample (t)	Catch (t)	Fish measured	Fish staged	Tows	Catch	Sample
1991–92	1	1	1	<0.1	0	1	0	100.0	0	0
1992–93	0	–	–	–	–	–	–	–	–	–
1993–94	2	1	1	<0.1	90.4	230	21	2.0	47.8	0
1994–95	0	–	–	–	–	–	–	–	–	–
1995–96	68	7	3	5.0	350.2	3 380	1 124	13.2	36.3	0.52
1996–97	27	3	3	3.4	111.2	2 558	1 028	3.6	10.9	0.33
1997–98	11	2	2	1.8	12.3	1 191	552	1.0	2.4	0.35
1998–99	61	6	3	10.2	563.8	6 073	1 703	6.5	36.5	0.66
1999–00	224	9	2	16.7	671.0	9 720	4 040	27.2	45.5	1.13
2000–01	0	–	–	–	–	–	–	–	–	–
2001–02	51	5	2	7.0	235.6	3 428	1 360	22.1	27.5	0.82
2002–03	116	7	5	13.8	321.0	7 131	3 068	20.5	24.8	1.07
2003–04	90	4	2	6.9	287.7	3 576	1 443	12.6	25.6	0.61
2004–05	56	2	2	5.4	146.2	3 121	1 602	9.2	14.8	0.55
2005–06	108	3	1	9.0	483.3	5 414	2 248	18.5	42.0	0.78
2006–07	182	15	5	18.1	452.5	10 131	4 666	32.0	37.7	1.51
2007–08	109	5	3	15.4	427.4	8 636	3 264	18.4	41.3	1.49
2008–09	87	4	2	12.6	354.3	7 035	3 304	17.7	32.1	1.14
2009–10	62	3	1	7.9	490.0	4 960	2 073	12.7	54.1	0.87
2010–11	36	3	2	4.5	159.1	2 722	1 045	11.9	19.3	0.55
2011–12	42	4	3	2.1	137.7	2 086	856	11.2	17.8	0.27
2012–13	3	1	1	0.3	13.5	204	105	0.6	1.2	0.03
2013–14	7	3	1	0.5	45.1	394	181	1.5	3.9	0.04
2014–15	56	4	3	4.0	367.6	3 118	1 449	12.4	34.8	0.38

The representativeness of observer sampling of orange roughy trawls was evaluated by plotting the proportion of landed catch for each year by subarea and by month as circles, and overlaying this with the proportion of the observed catch for those same cells as crosses (Figure 12). If the proportions are the same, the cross dimensions equal the circle diameters; if over- or under-sampling has occurred, the crosses are either larger or smaller than the circles. Sampling at Manukau has represented the catch relatively well (Figure 12). Sampling at Tauroa has been fairly good in October, except in earlier years of the fishery (before 2004–05), but outside of October sampling has been sporadic. Sampling at White Island has represented the catch quite well in June, until recent years (from 2012–13), and outside of June the catch has generally been under-sampled, with some oversampling in October. In Mercury-Colville, sampling has been representative in June, with catches under-sampled outside of

June. Sampling at Aldermen, North Colville, Northland_N, and Northland_S, has represented the catch reasonably well, where the catch was largely taken during June and July. In West Norfolk both catches and sampling have been sporadic, and so samples do not represent catches well. Sampling at Clark has also been sporadic. In general, sampling has focused in June and July, which is when orange roughy are normally aggregated for spawning in New Zealand waters. This is consistent with a greater proportion of catch than tows being sampled (Table 5), because tows during June and July would be from spawning aggregations and so relatively large. Therefore spawning fishery catches are likely to be over-represented in the catch sampling.

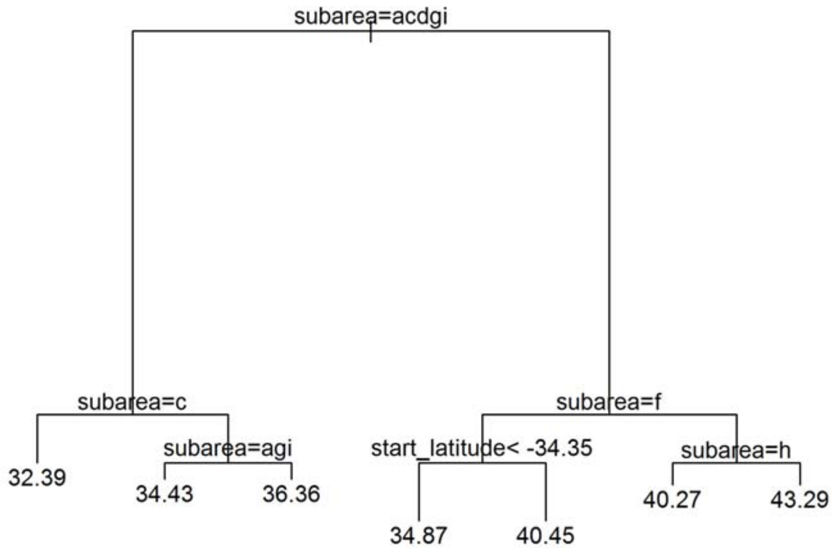


Figure 9: Classification tree for median orange roughy length by tow in ORH 1, excluding feature predictors (*n* tows = 1279). Subareas: a, Aldermen; b, Clark; c, Manukau; d, Mercury-Colville; e, North Colville; f, Northland; g, Tauroa; h, West Norfolk; I, White Island. Model explained 69% of the deviance. The number at each terminal node ("leaf") is the mean of the mean lengths of the samples in that group.

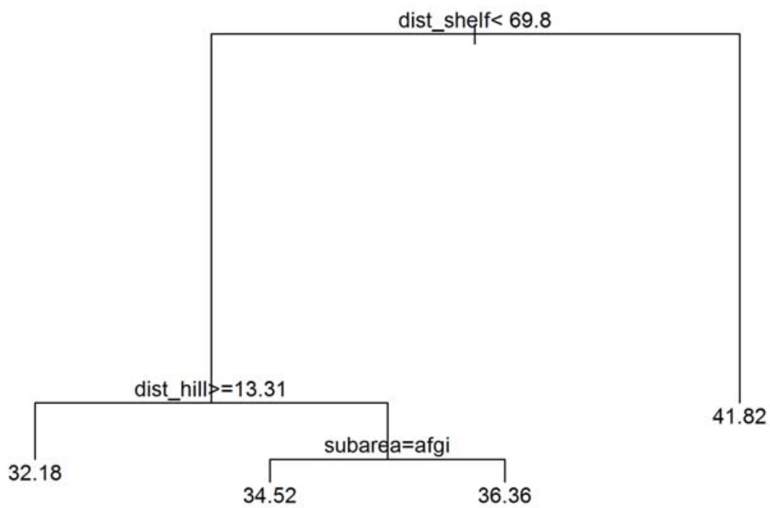


Figure 10: Classification tree for median orange roughy length by tow in ORH 1, including feature predictors (*n* tows = 874). Subareas: a, Aldermen; b, Clark; c, Manukau; d, Mercury-Colville; e, North Colville; f, Northland; g, Tauroa; h, West Norfolk; I, White Island. Model explained 62% of the deviance. The number at each terminal node ("leaf") is the mean of the mean lengths of the samples in that group.

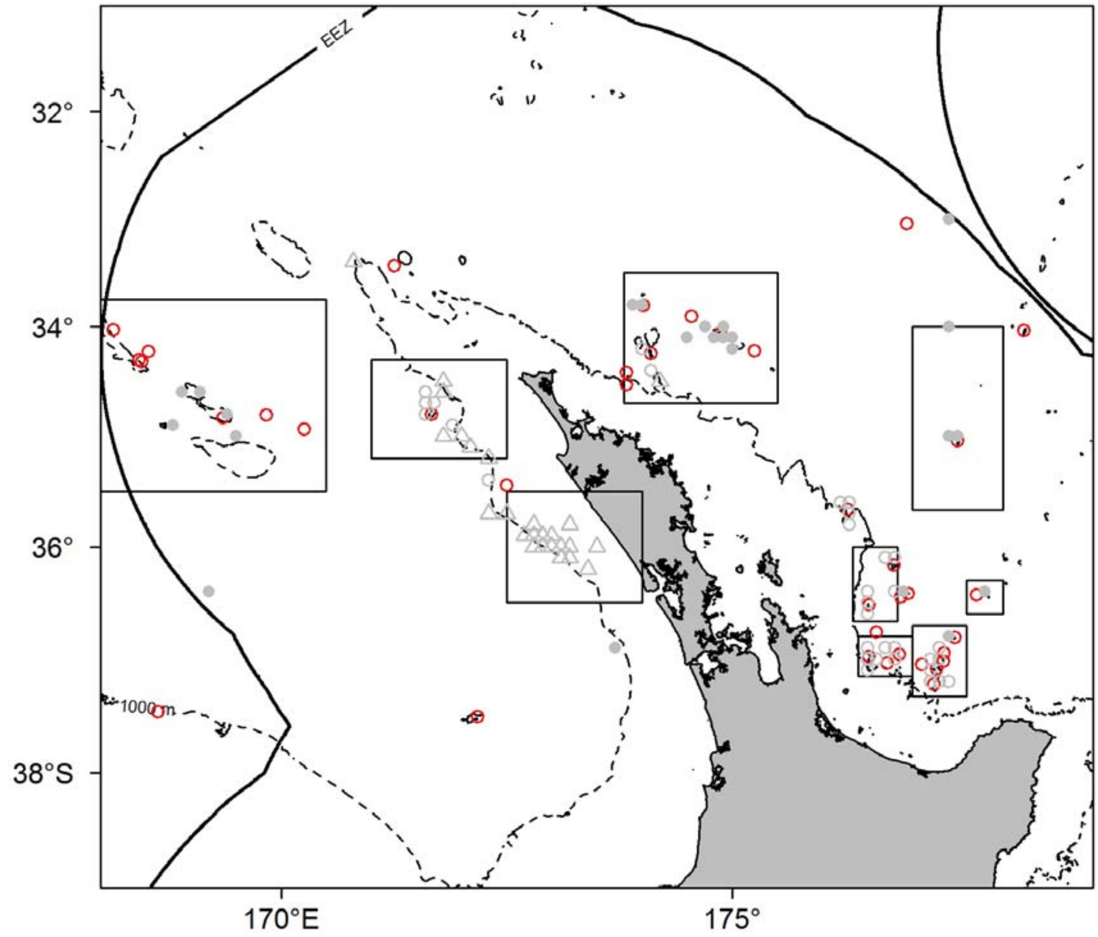


Figure 11: Location and classification of orange roughy tows by mean length following the classification tree analysis including feature. Open triangles, tows classified as inshore (<69.8 km) and away (≥13.31 km) from features; Open circles, tows classified as inshore and close (<13.31 km) to features; Closed grey circles, tows classified as offshore. Open red circles, locations of features.

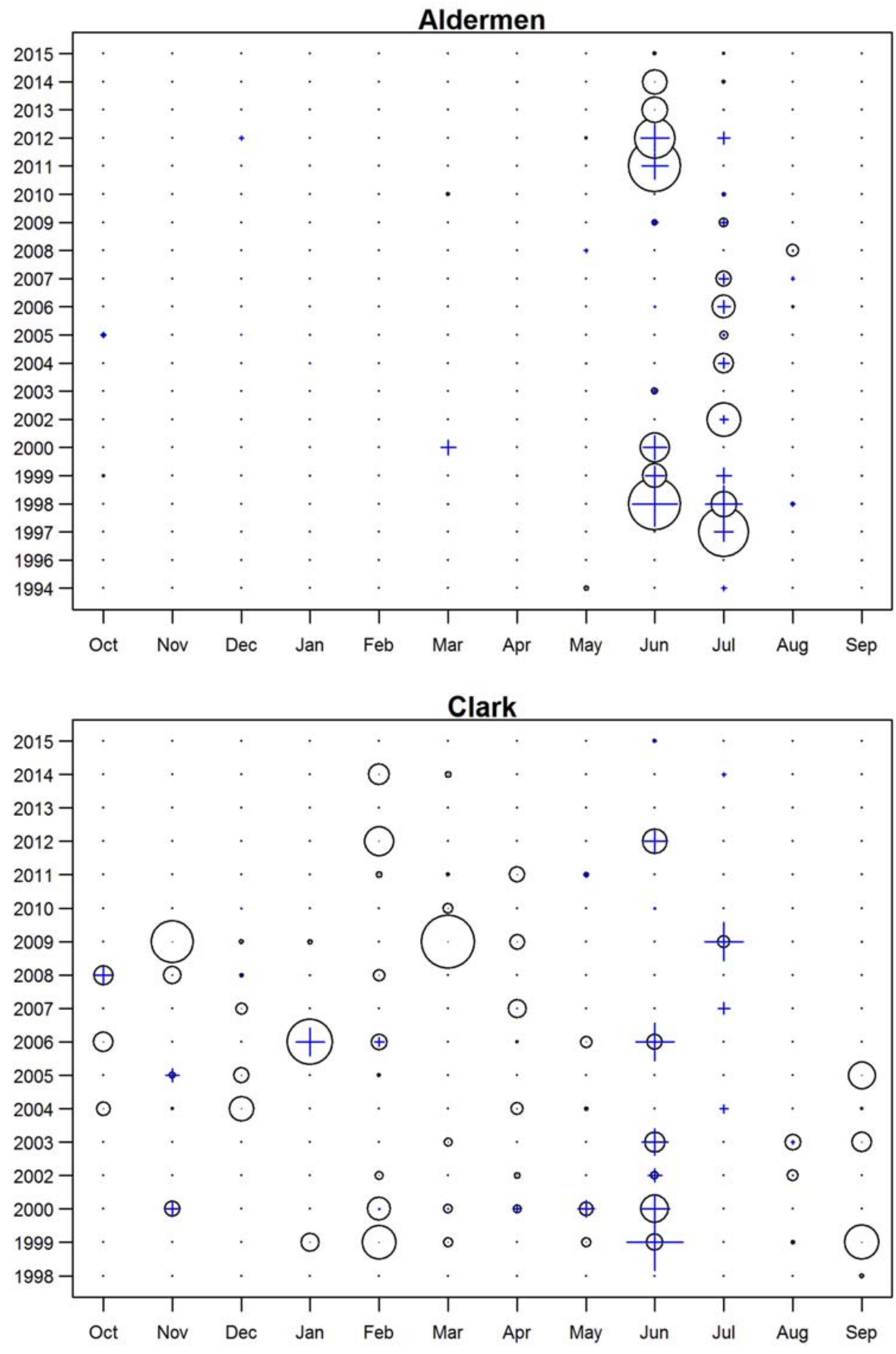
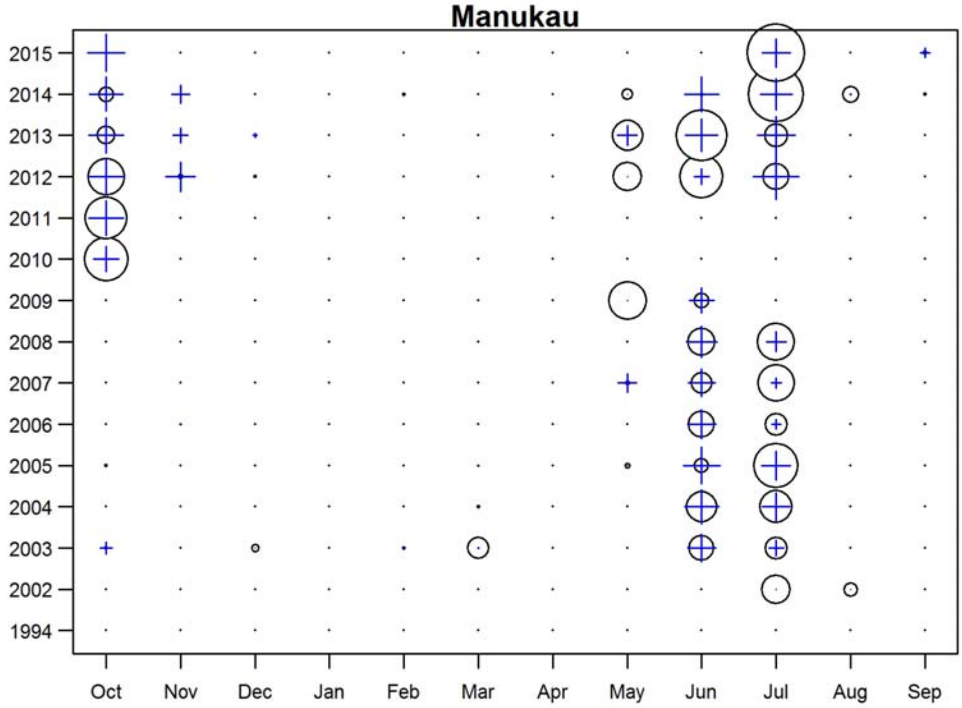


Figure 12: Representativeness of observer sampling of orange roughy catch by fishing year and month, by subarea of ORH 1. Circles show the proportion of target catch by month within a year, crosses show the proportion of observed target catch for the same cells. Representation is demonstrated by how closely the cross dimensions match the circle diameter.



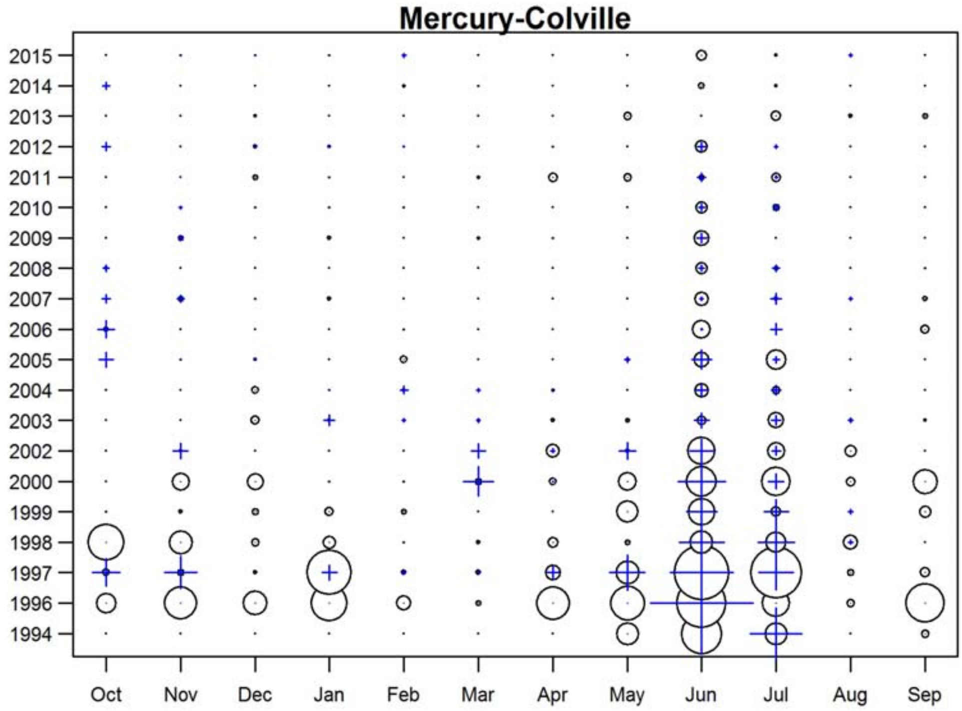
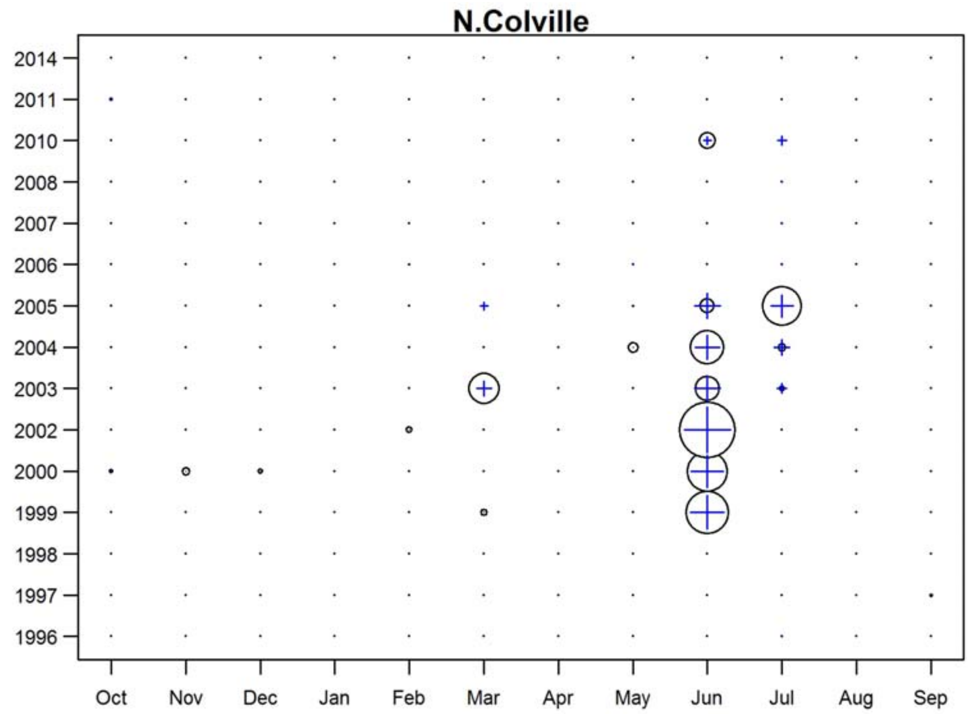


Figure 12 (cont.): Representativeness of observer sampling of orange roughy catch by fishing year and month, by subarea of ORH 1. Circles show the proportion of target catch by month within a year, crosses show the proportion of observed target catch for the same cells. Representation is demonstrated by how closely the cross dimensions match the circle diameter.



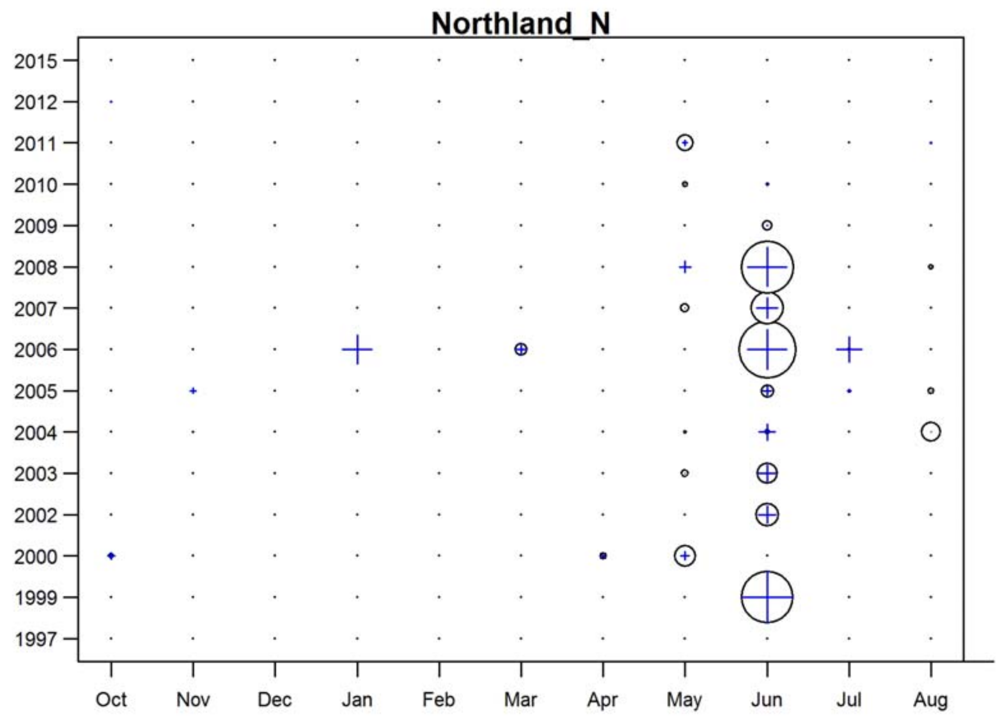


Figure 12 (cont.): Representativeness of observer sampling of orange roughy catch by fishing year and month, by subarea of ORH 1. Circles show the proportion of target catch by month within a year, crosses show the proportion of observed target catch for the same cells. Representation is demonstrated by how closely the cross dimensions match the circle diameter.

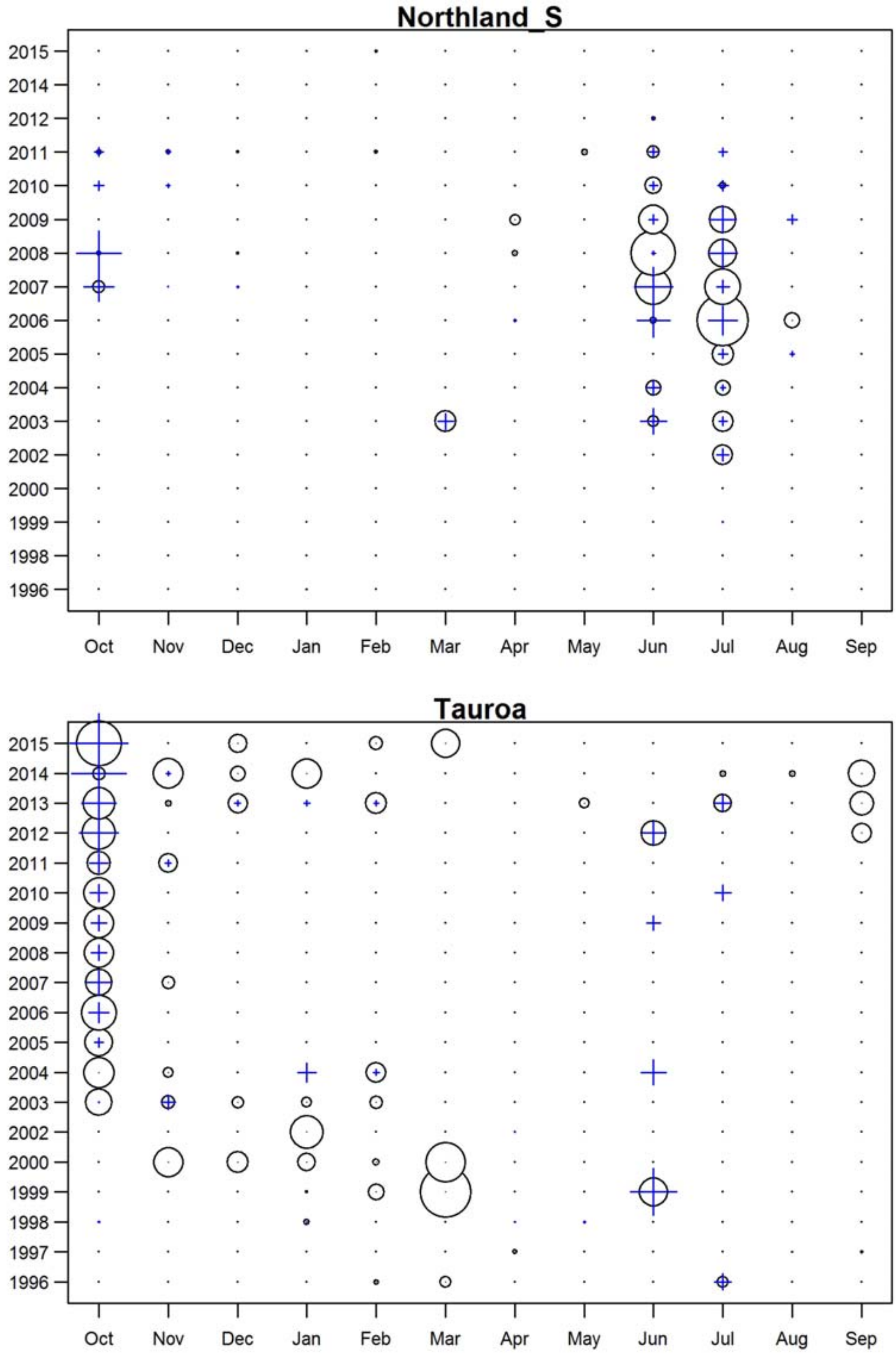


Figure 12 (cont.): Representativeness of observer sampling of orange roughy catch by fishing year and month, by subarea of ORH 1. Circles show the proportion of target catch by month within a year, crosses show the proportion of observed target catch for the same cells. Representation is demonstrated by how closely the cross dimensions match the circle diameter.

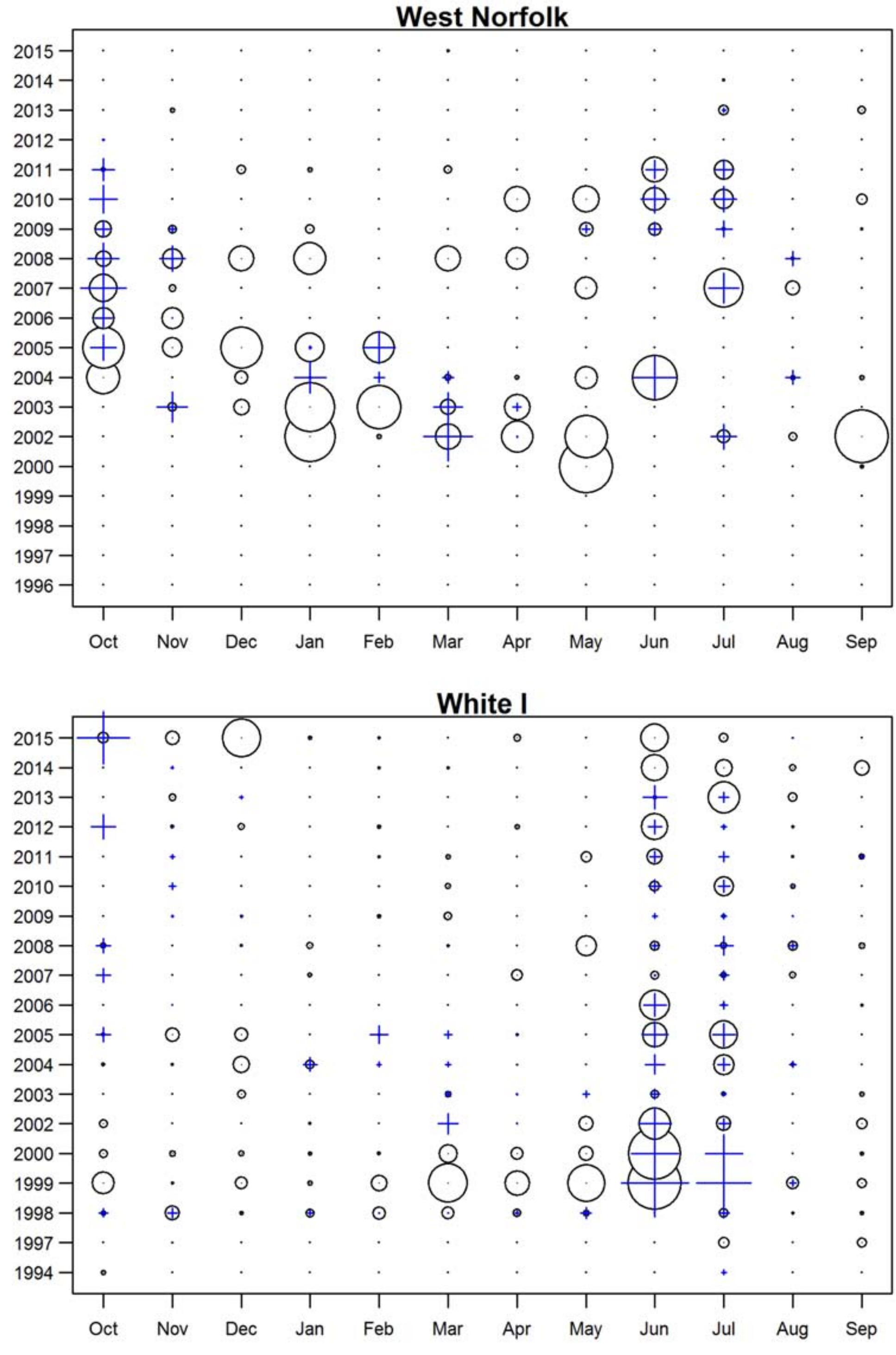


Figure 12 (cont.): Representativeness of observer sampling of orange roughy catch by fishing year and month, by subarea of ORH 1. Circles show the proportion of target catch by month within a year, crosses show the proportion of observed target catch for the same cells. Representation is demonstrated by how closely the cross dimensions match the circle diameter.

The mean length of orange roughy in samples from the ORH 1 fishery was around 36 cm until 1999–2000, then relatively high for a couple of years then appeared to decline between 2003–04 and 2011–12, remaining at around 35 cm thereafter (Figure 13).

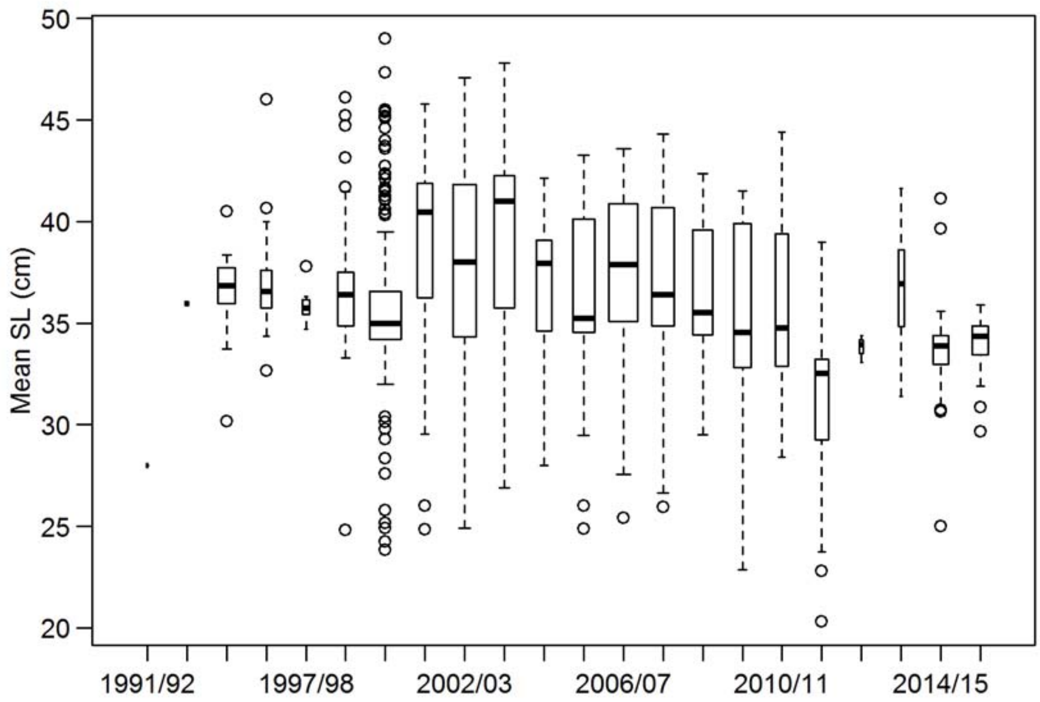


Figure 13: Box plot of annual mean lengths (SL) of orange roughy by tow (unweighted). Width of boxes is proportional to sample size. Box plots show the median (thick line), 25% to 75% quantiles (box), the broken lines indicate the most extreme data point or extend no more than the interquartile range from the box, and points beyond this are "outliers".

The overall pattern of mean length (Figure 13) was influenced by the relative contribution of subareas, because of the pronounced spatial structure in fish size (Figure 14). The median of the sample mean lengths may have declined over time in Mercury-Colville, White Island, Tauroa, and Northland (Figure 14); but note that these lengths are not catch weighted. The step-wise decline in mean lengths in Northland is associated with the change in fishing location to the more inshore and southerly region (Northland_S). The samples from Northland were taken at a similar time of year (largely June), suggesting that this change reflects spatial structure.

Catch-weighted length-frequency distributions for each subarea are shown in Figures 15–24, and Appendix A. All length frequency distributions were unimodal, with relatively little skew, and any changes over time were subtle. In Manukau, the mode appeared to move to the left (towards smaller fish) from 2009–10 (Figure 15) – without ageing it is unknown if this is recruitment. In West Norfolk, the fish in earlier years tended to be smaller (mode below 40 cm SL) and larger (mode over 40 cm) from 2005–06 (Figure 16). The length distributions were relatively broad in North Colville, with very few fish less than 40 cm present; the same was true for Clark. Smaller fish (less than 30 cm) were generally sparse, but some were sampled at Manukau, and a few were sampled between 1999–2000 and 2001–02 across several subareas (Tauroa, Northland, White Island, Mercury-Colville). The fish in Northland_S were relatively large in just 2003–04. The possible declining trend in length at Tauroa (Figure 14) was not apparent in the weighted length frequencies (see Figure 24).

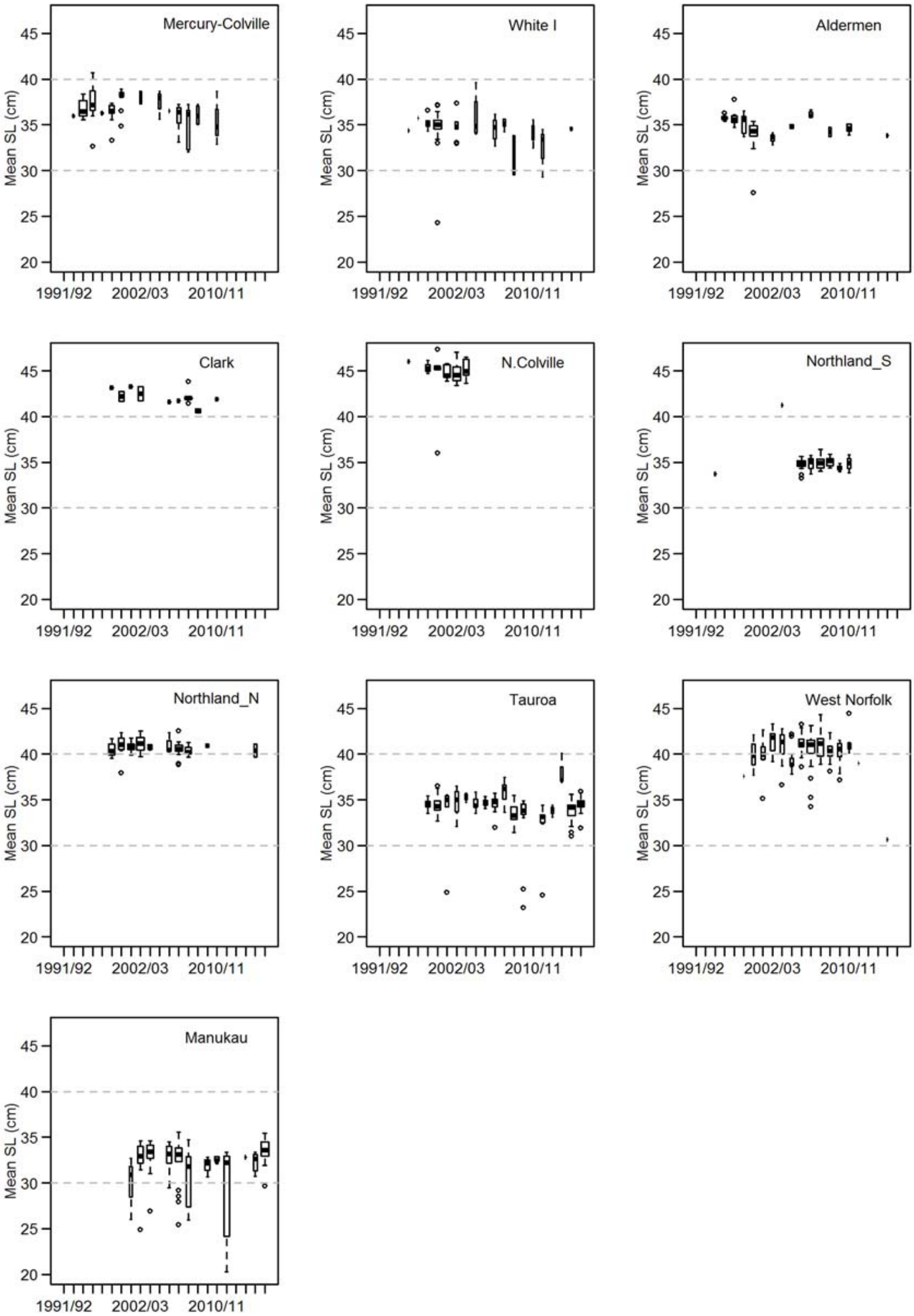


Figure 14: Box plot of annual mean lengths (SL) of orange roughy by tow (unweighted) by subarea. Horizontal broken lines mark 30 and 40 cm SL (arbitrary points for reference). Width of boxes is proportional to sample size.

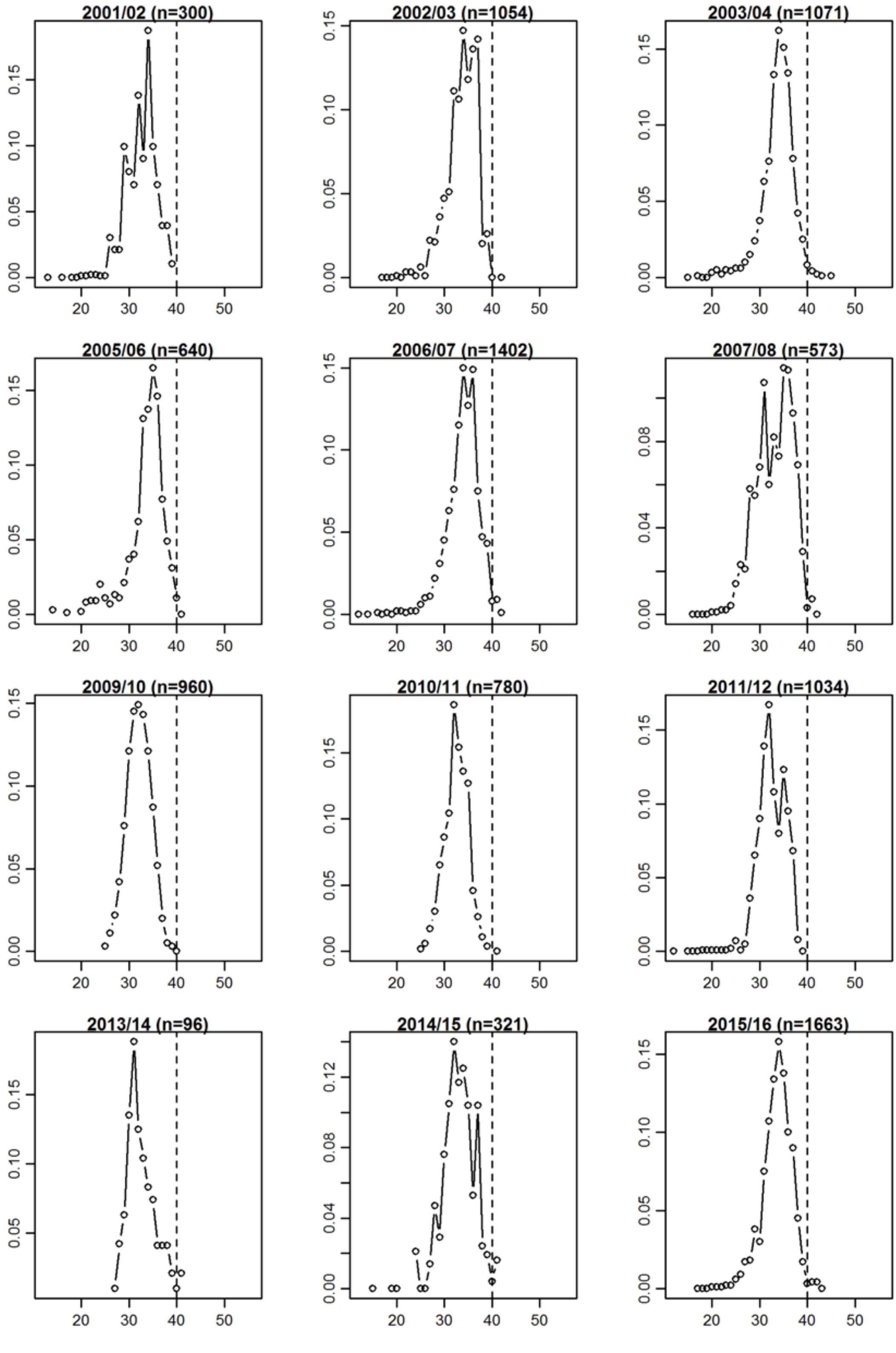


Figure 15: Catch-weighted length-frequency distributions for orange roughy in the Manukau subarea of ORH 1. Vertical broken line marks 40 cm SL (arbitrary point shown for reference). Sample sizes given in Appendix A.

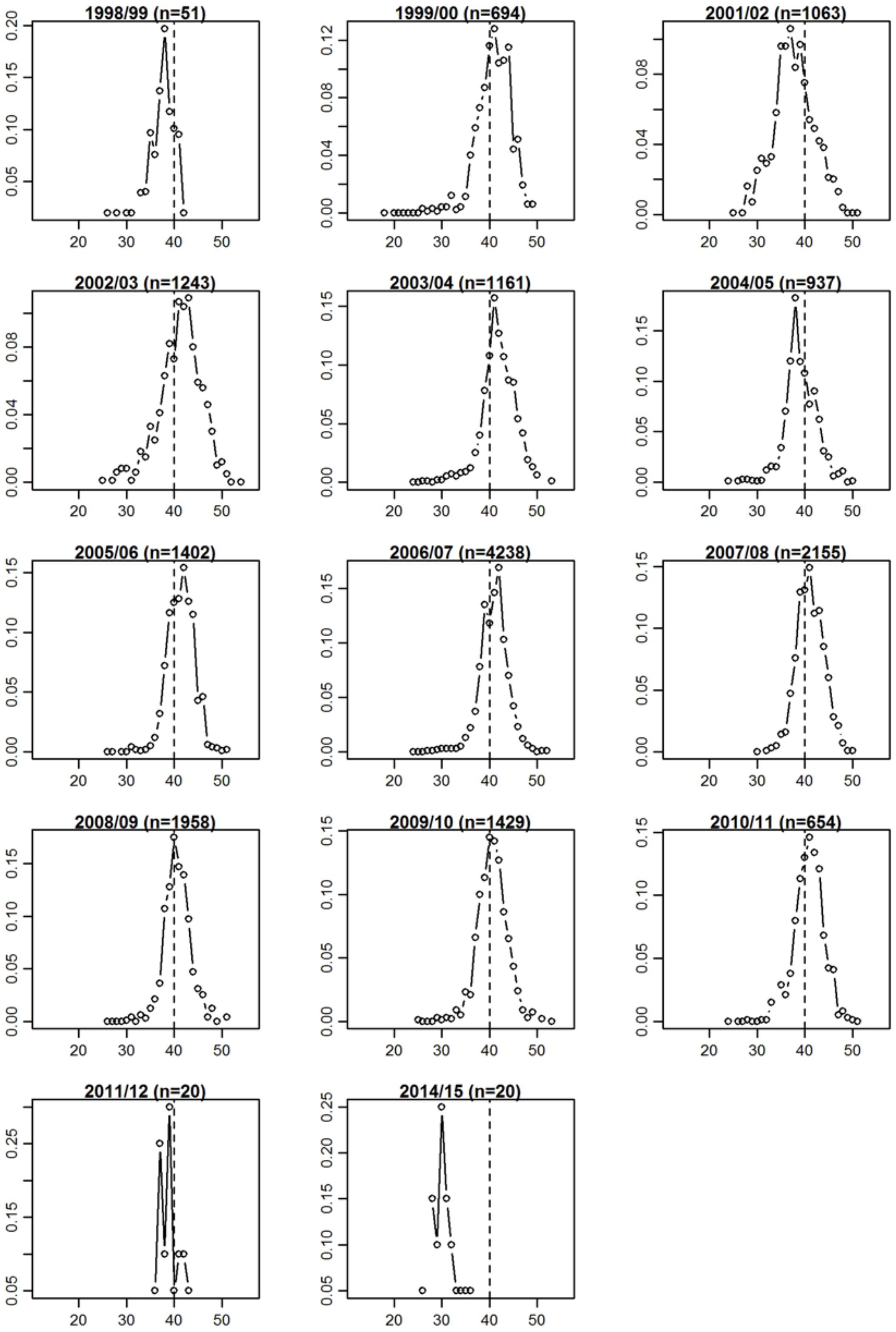


Figure 16: Catch-weighted length-frequency distributions for orange roughy in the West Norfolk subarea of ORH 1. Vertical broken line marks 40 cm SL (arbitrary point shown for reference). Sample sizes given in Appendix A.

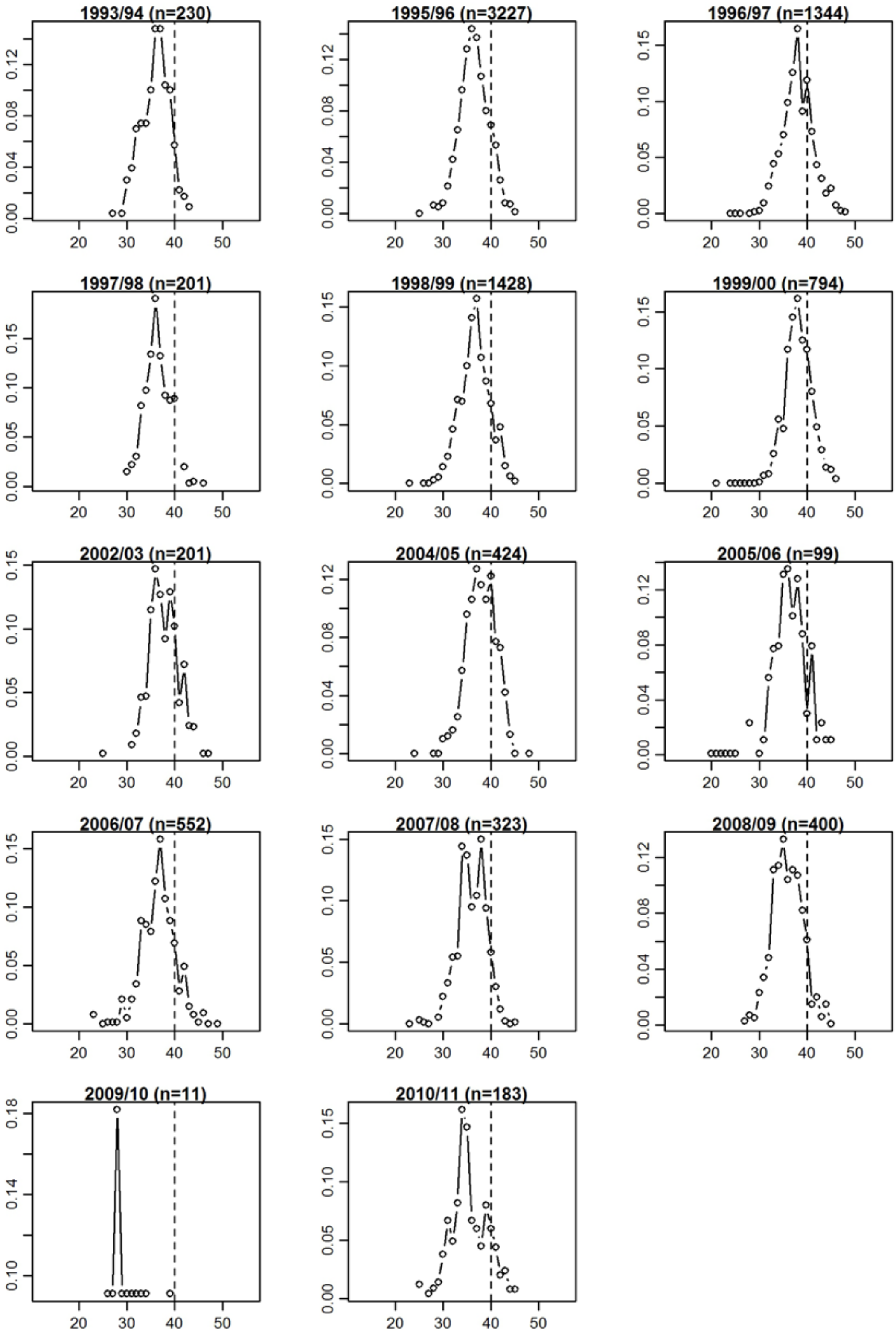


Figure 17: Catch-weighted length-frequency distributions for orange roughy in the Mercury-Colville subarea of ORH 1. Vertical broken line marks 40 cm SL (arbitrary point shown for reference). Sample sizes given in Appendix A.

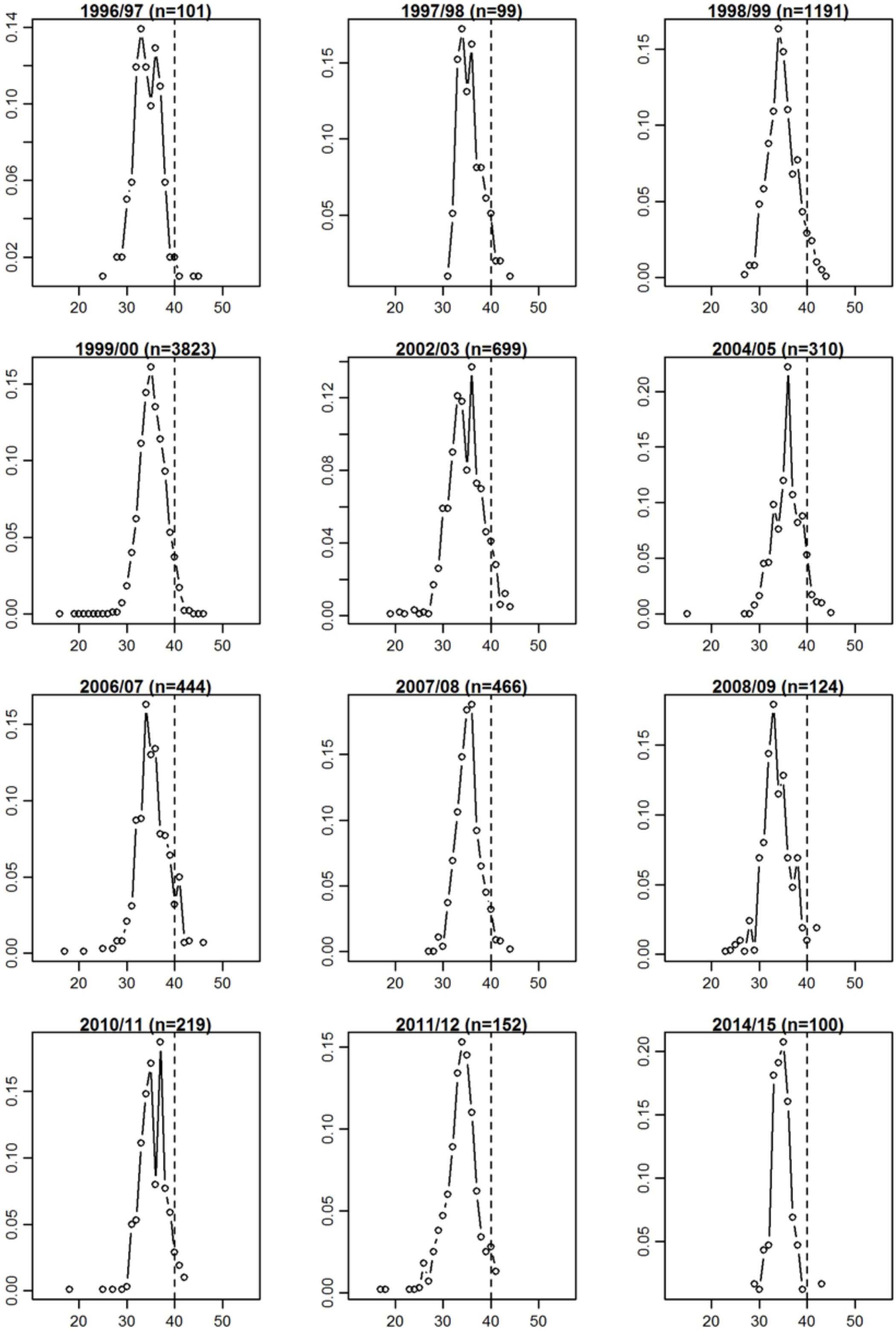


Figure 18: Catch-weighted length-frequency distributions for orange roughy in the White Island subarea of ORH 1. Vertical broken line marks 40 cm SL (arbitrary point shown for reference). Sample sizes given in Appendix A.

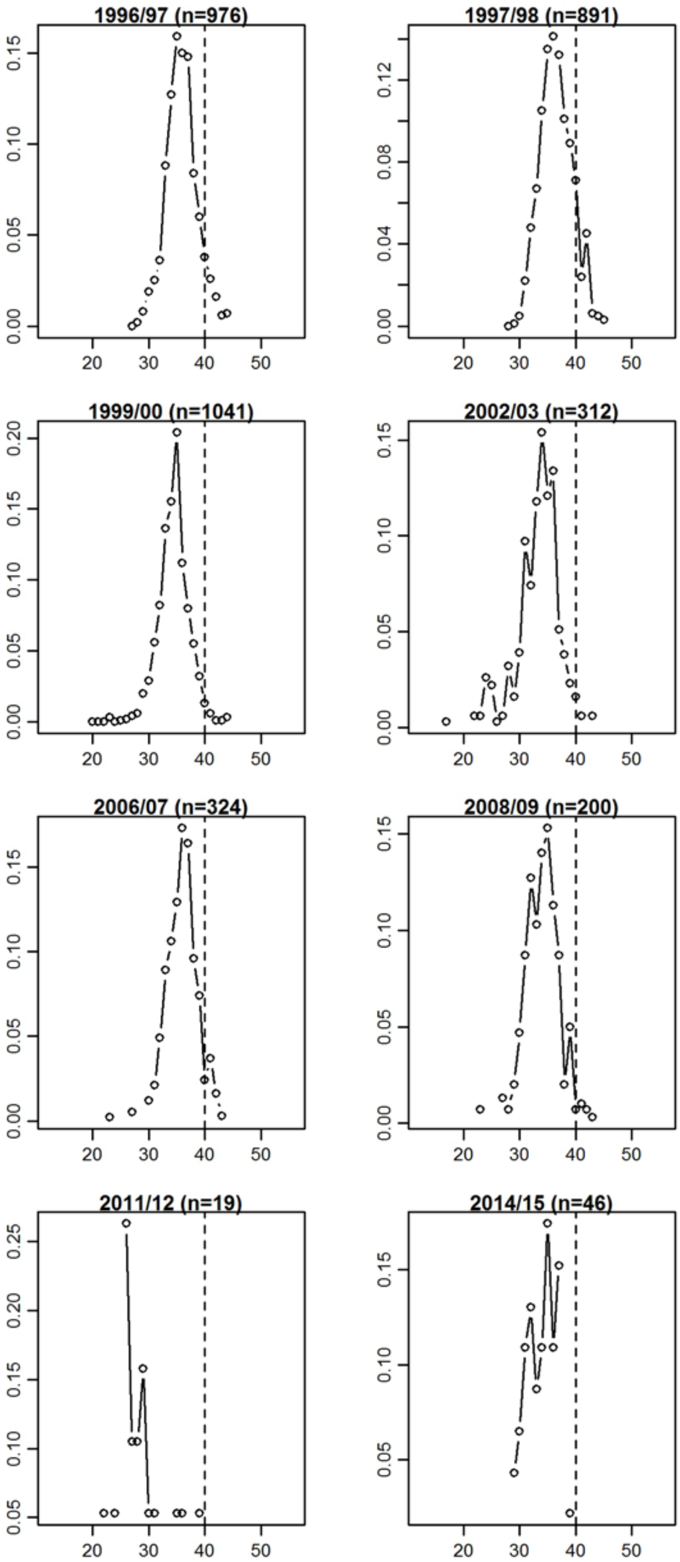


Figure 19: Catch-weighted length-frequency distributions for orange roughy in the Aldermen subarea of ORH 1. Vertical broken line marks 40 cm SL (arbitrary point shown for reference). Sample sizes given in Appendix A.

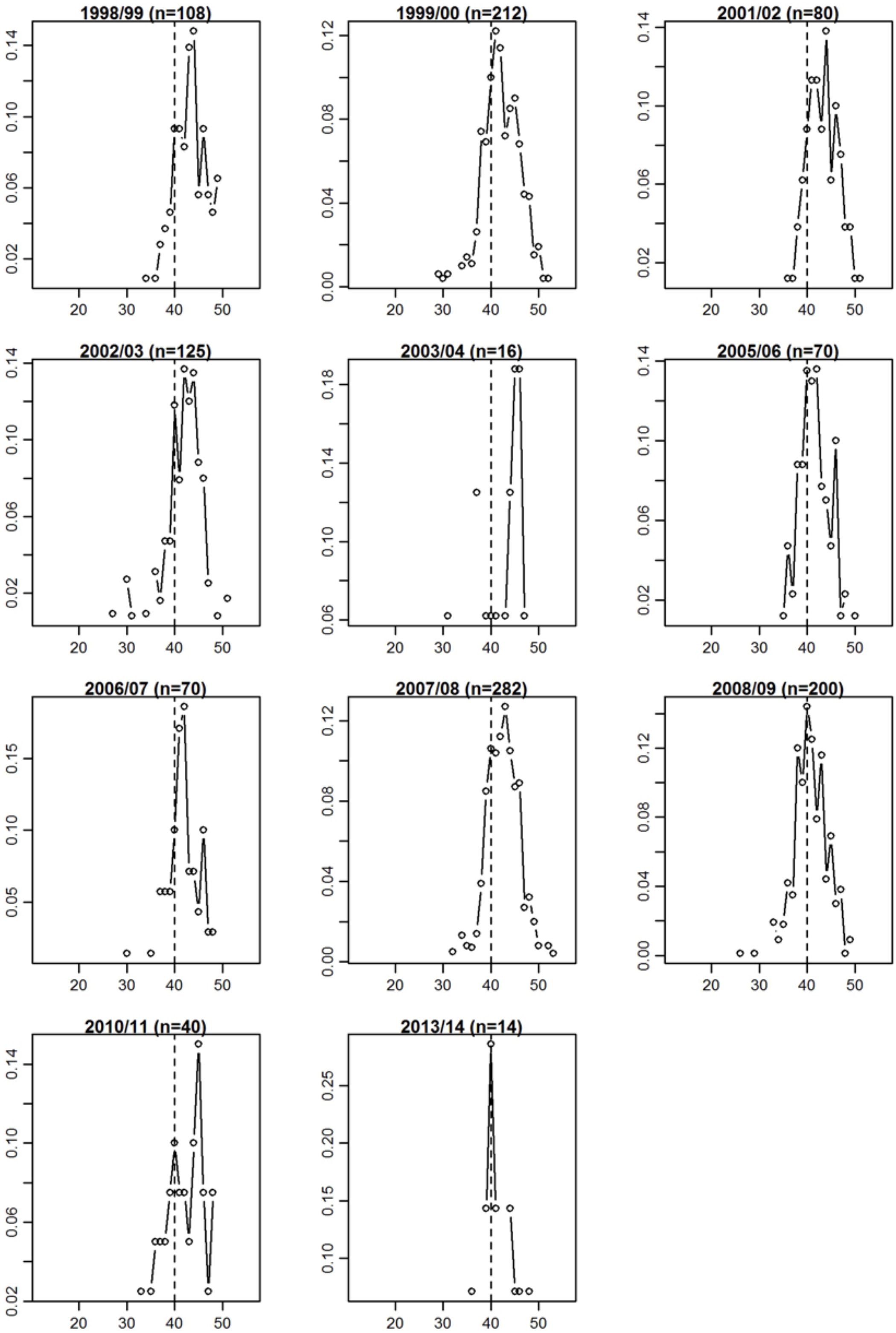


Figure 20: Catch-weighted length-frequency distributions for orange roughy in the Clark subarea of ORH 1. Vertical broken line marks 40 cm SL (arbitrary point shown for reference). Sample sizes given in Appendix A.

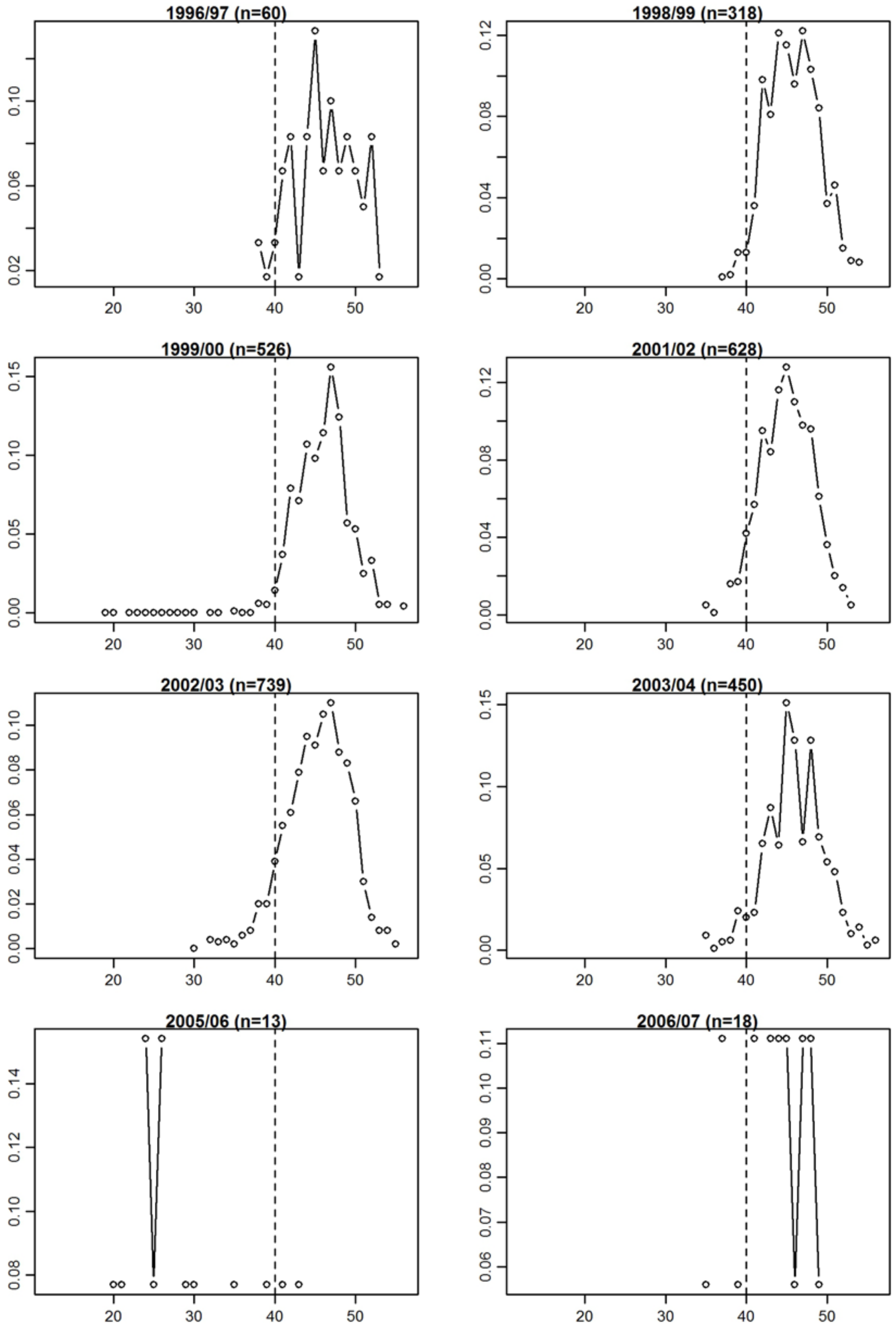


Figure 21: Catch-weighted length-frequency distributions for orange roughy in the North Colville subarea of ORH 1. Vertical broken line marks 40 cm SL (arbitrary point shown for reference). Sample sizes given in Appendix A.

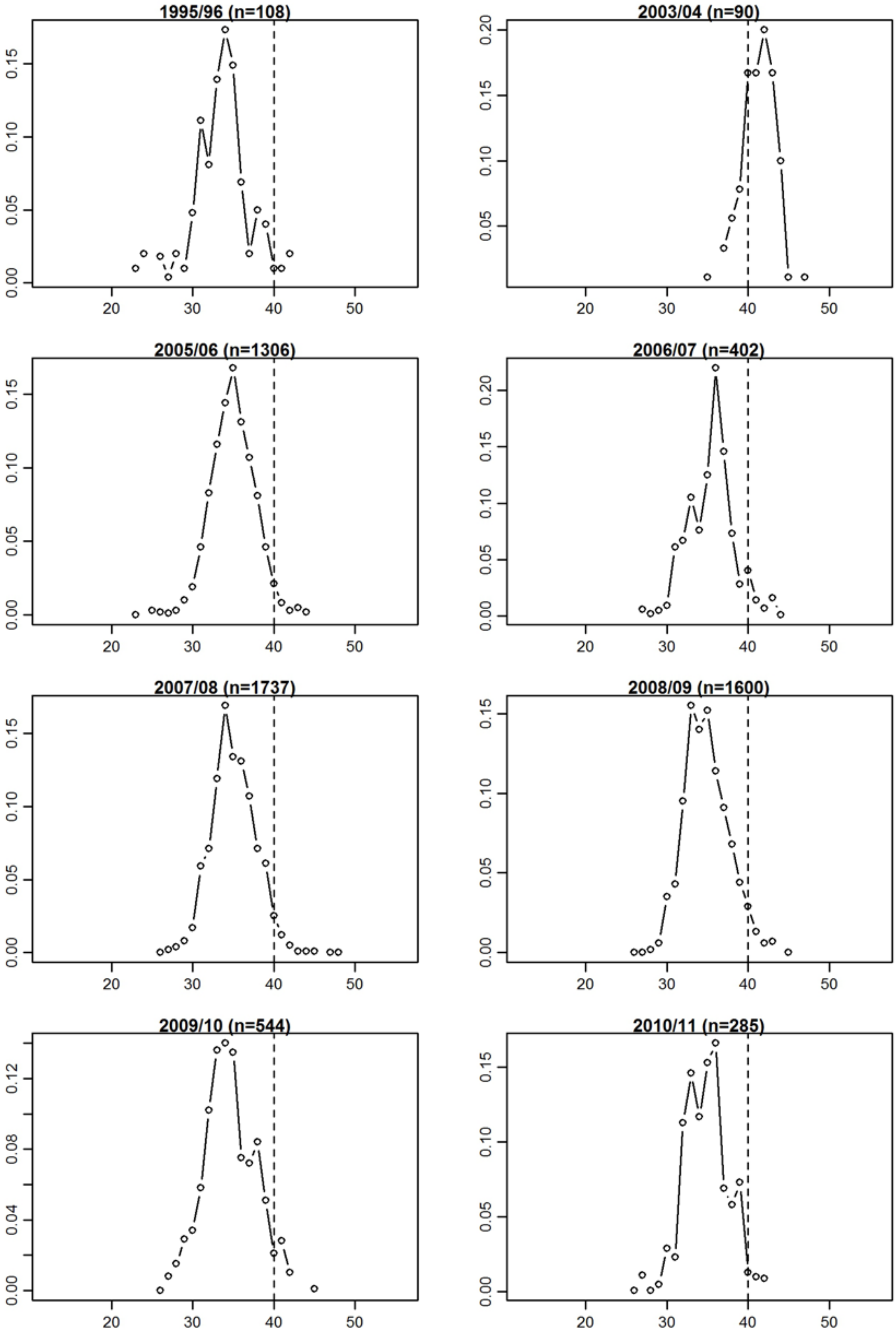


Figure 22: Catch-weighted length-frequency distributions for orange roughy in the Northland South (Northland_S) subarea of ORH 1. Vertical broken line marks 40 cm SL (arbitrary point shown for reference). Sample sizes given in Appendix A.

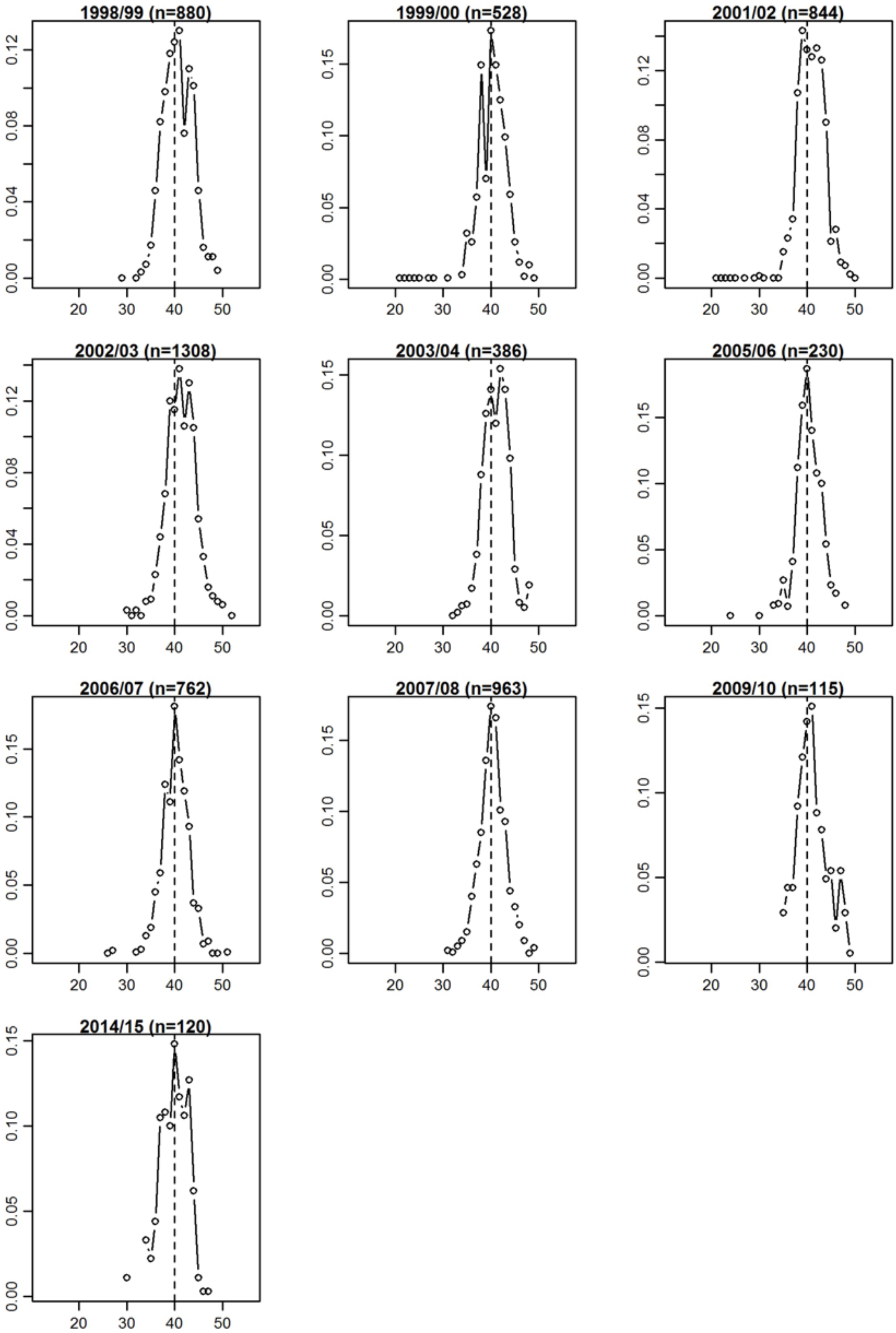


Figure 23: Catch-weighted length-frequency distributions for orange roughy in the Northland North (Northland_N) subarea of ORH 1. Vertical broken line marks 40 cm SL (arbitrary point shown for reference). Sample sizes given in Appendix A.

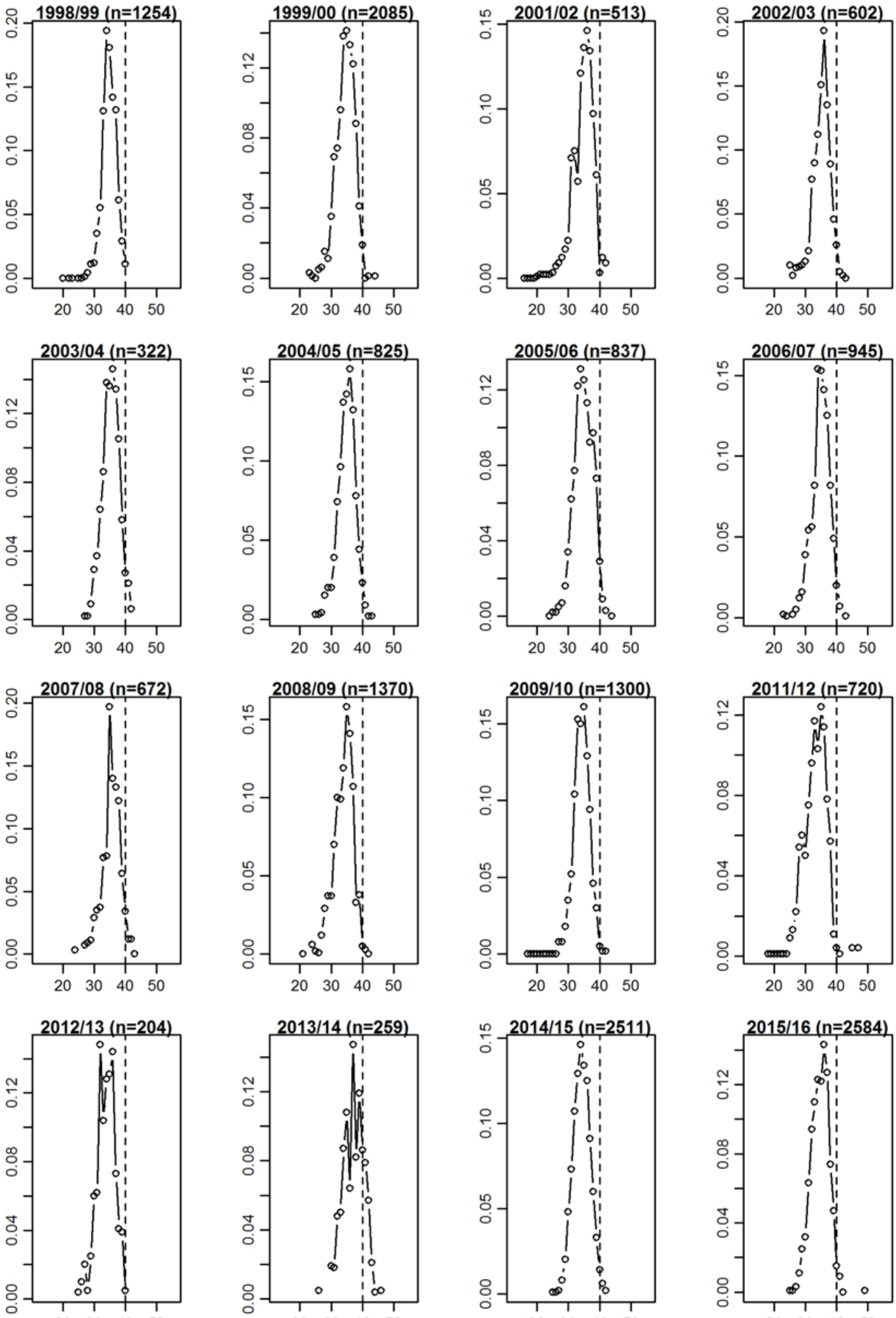


Figure 24: Catch-weighted length-frequency distributions for orange roughy in the Tauroa subarea of ORH 1. Vertical broken line marks 40 cm SL (arbitrary point shown for reference). Sample sizes given in Appendix A.

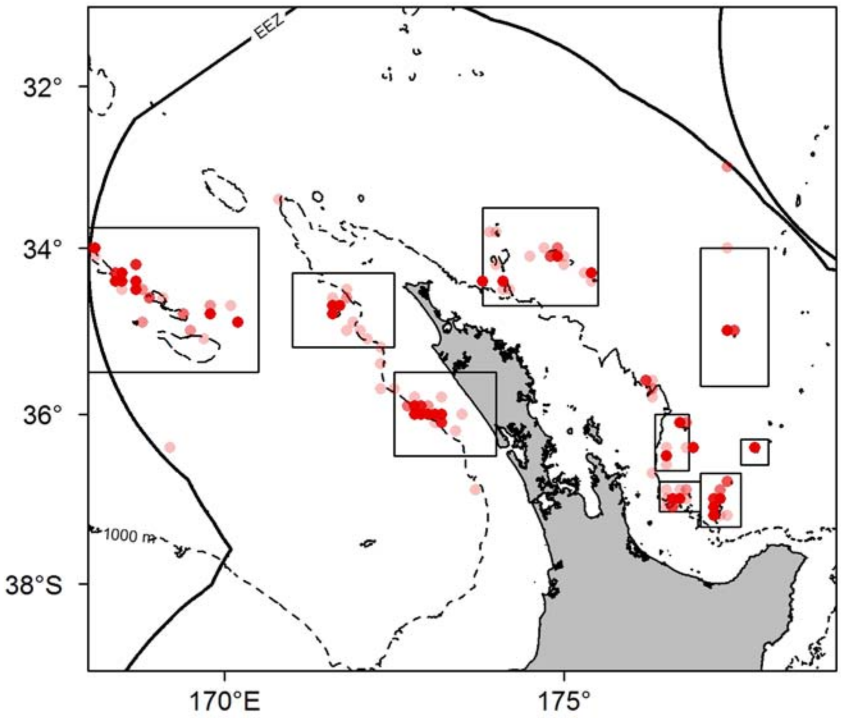
The samples of female orange roughy maturity stage have a relatively limited spatial coverage (Figure 25). Females at stage 3 (ripe) were found in most areas sampled and those at stage 4 (running ripe) were found in many discrete locations (at least 20) throughout ORH 1, suggesting that spawning is widespread. Samples including stage 4 females where catches were relatively large (over 2 t) were in a similar number of locations but more spatially distinct. For example, in Manukau the large (over 2 t) catches including stage 4 females suggested two distinct spawning locations, rather than the single location indicated from all catches containing stage 4 females.

The timing of spawning can be measured by the progression of stages 3, 4, and 5 (spent), with 50% at stage 4 or 5 often used as measures of the time of the start and end of spawning respectively. The female maturity stage data suggested that spawning was simultaneous throughout ORH 1, and generally started in the third week of June and was completed in the first week of July (Figure 26). Differences between areas were small, although spawning at Manukau appeared to be a little later, and in West Norfolk a little earlier (Figure 26).

The sex ratio of orange roughy in ORH 1 was persistently skewed towards males, and overall had no trend over years (Figure 30). A classification tree analysis was used to investigate patterns in the sex ratio. The response was the proportion female in each tow where at least twenty fish were measured, and the potential predictors were subarea, longitude, latitude, depth, fishing year, month, vessel key, sample weight, and green weight (catch weight). The tree was pruned using 10-fold cross validation and complexity parameter *rp*, using the R library *rpart*. A classification tree using information from features was also attempted, but the model with this reduced dataset (*n* tows = 579) explained less than 1% of deviance and is not shown here.

The resulting estimated stratification by sex ratio included subarea, catch size, year, and month (Figure 31). In subareas Mercury-Colville, Northland_N, and Northland_S, the proportion female was greater when catch sizes (greenweight) were less than 1775 kg. In the other subareas, the proportion female was lower in 1998–99, 2007–08, and 2009–10 to 2011–12. Outside of these years, the proportion female was higher in April, July, and August. The inclusion of catch size and month is suggestive of sex ratio being influenced by aggregations and/or spawning aggregations.

The proportion female varied over subarea and year (Figure 32). The proportion female tended to be relatively low in Mercury-Colville, Northland_N, and Northland_S, and prior to the mid-2000s in Mercury-Colville, Tauroa, and Manukau. The sex ratio was closest to 50:50 in North Colville and West Norfolk. Although the pattern of sex ratio in Manukau and Tauroa has some similarity, with two sequences of increasing proportion female, the timing of these is different in each area (e.g., the initial increase peaks in Tauroa about 5 years earlier than in Manukau).



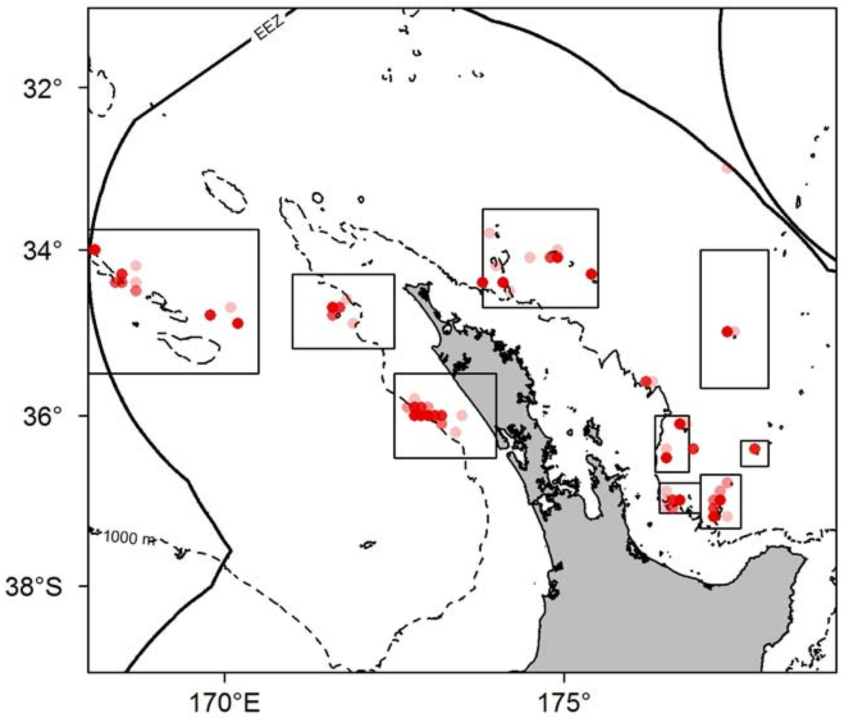
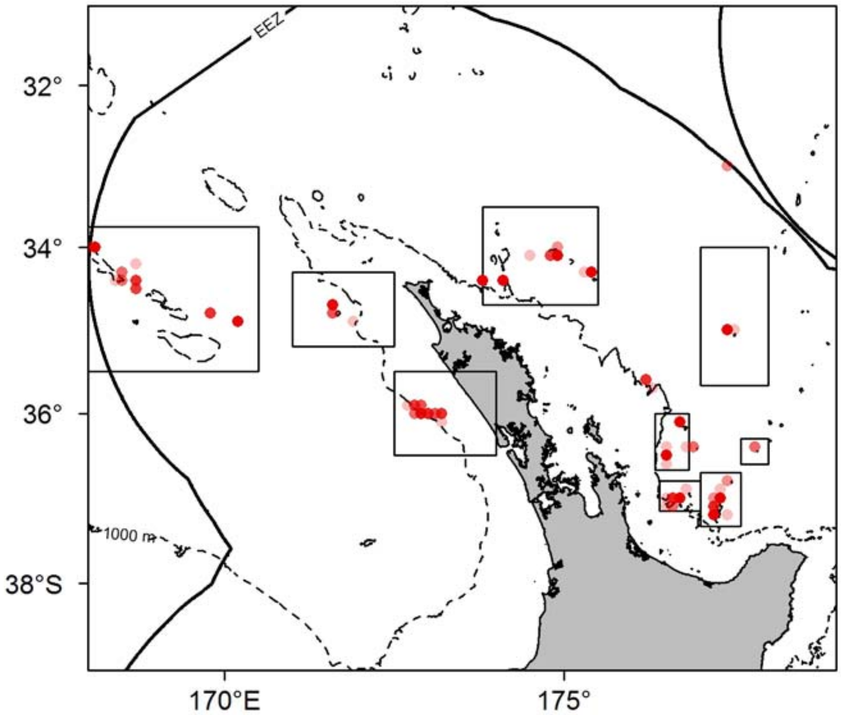


Figure 25: Location of female orange roughy sampled for maturity stage in ORH 1 (light red points; darker red areas indicate overlapping points). Tows which sampled female orange roughy at any maturity stage (top panel), and those that were ripe (stage 3; bottom panel).



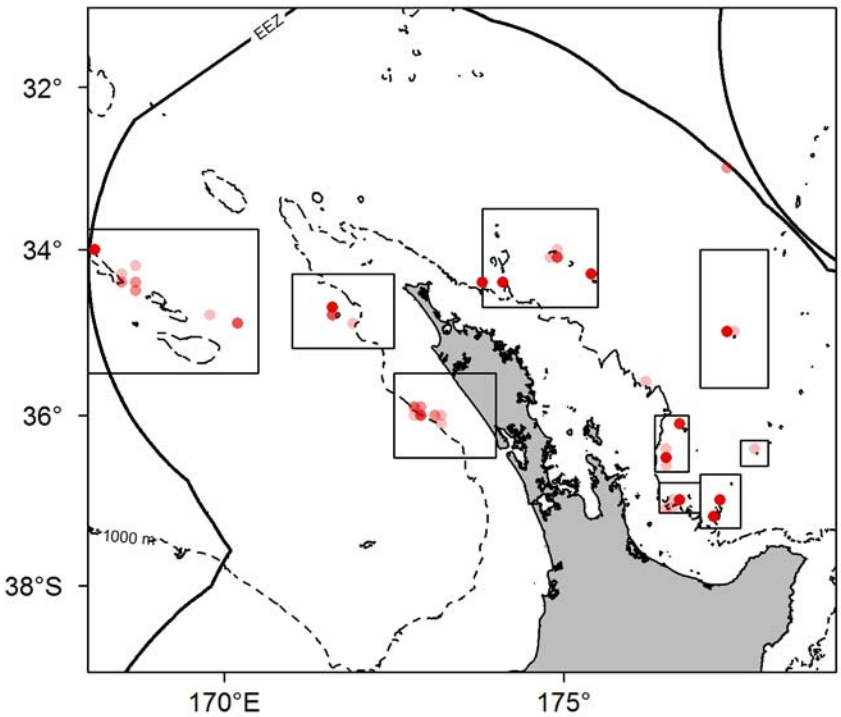


Figure 25 (cont.): Location of female orange roughy sampled for maturity stage in ORH 1 (light red points; darker red areas indicate overlapping points). Tows which sampled female orange roughy that were ripe and running (stage 4; top panel), and those that were ripe running and where catch weight was >2 t (bottom panel).

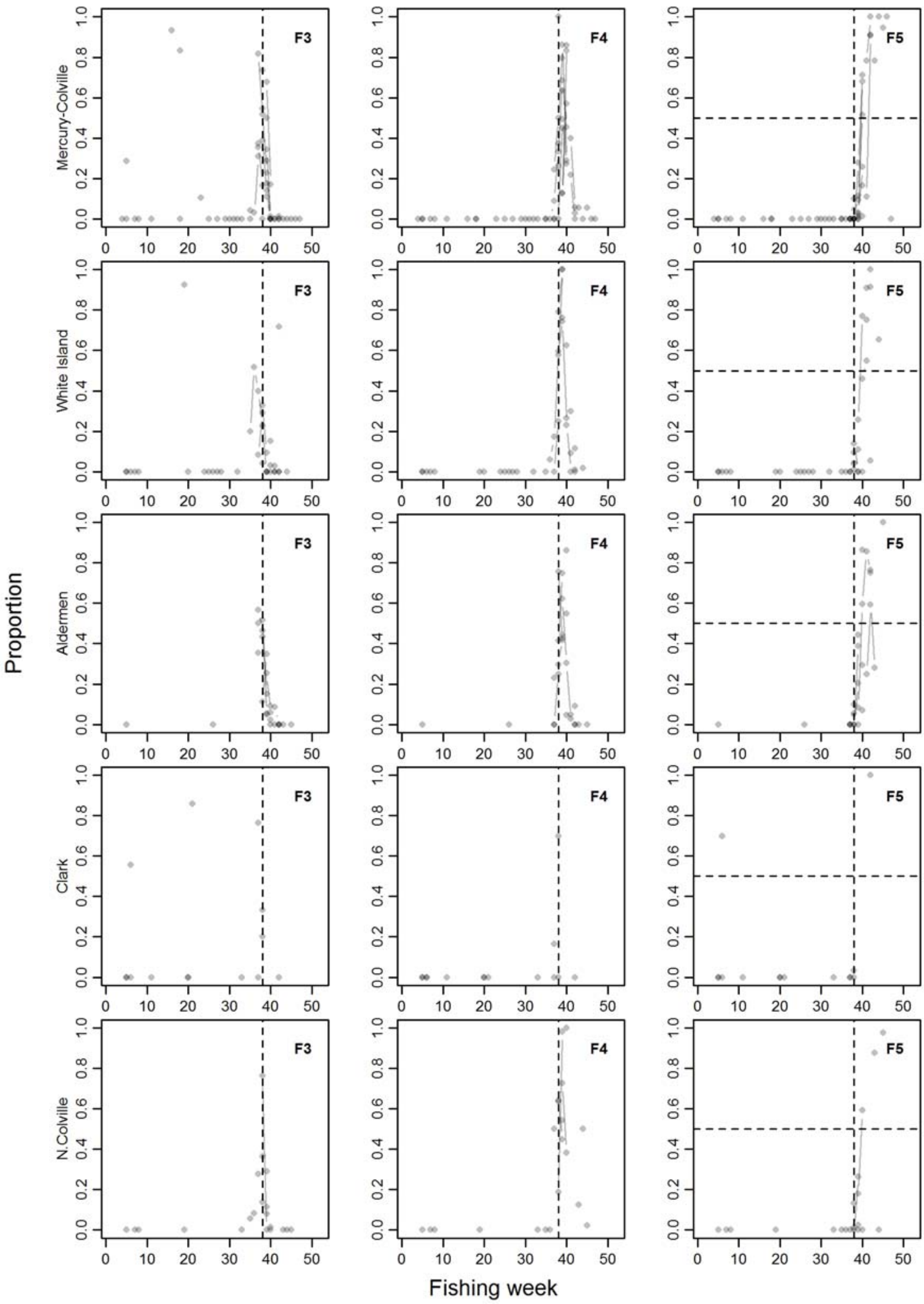


Figure 26: Proportion of female orange roughy in samples (dots) at maturity stages ripe (F3), running ripe (F4), and spent (F5), by week of the fishing year, and by subarea. The vertical broken line marks week 38, which is the 3rd week of June. The horizontal broken line in panels for F5 mark 0.5.

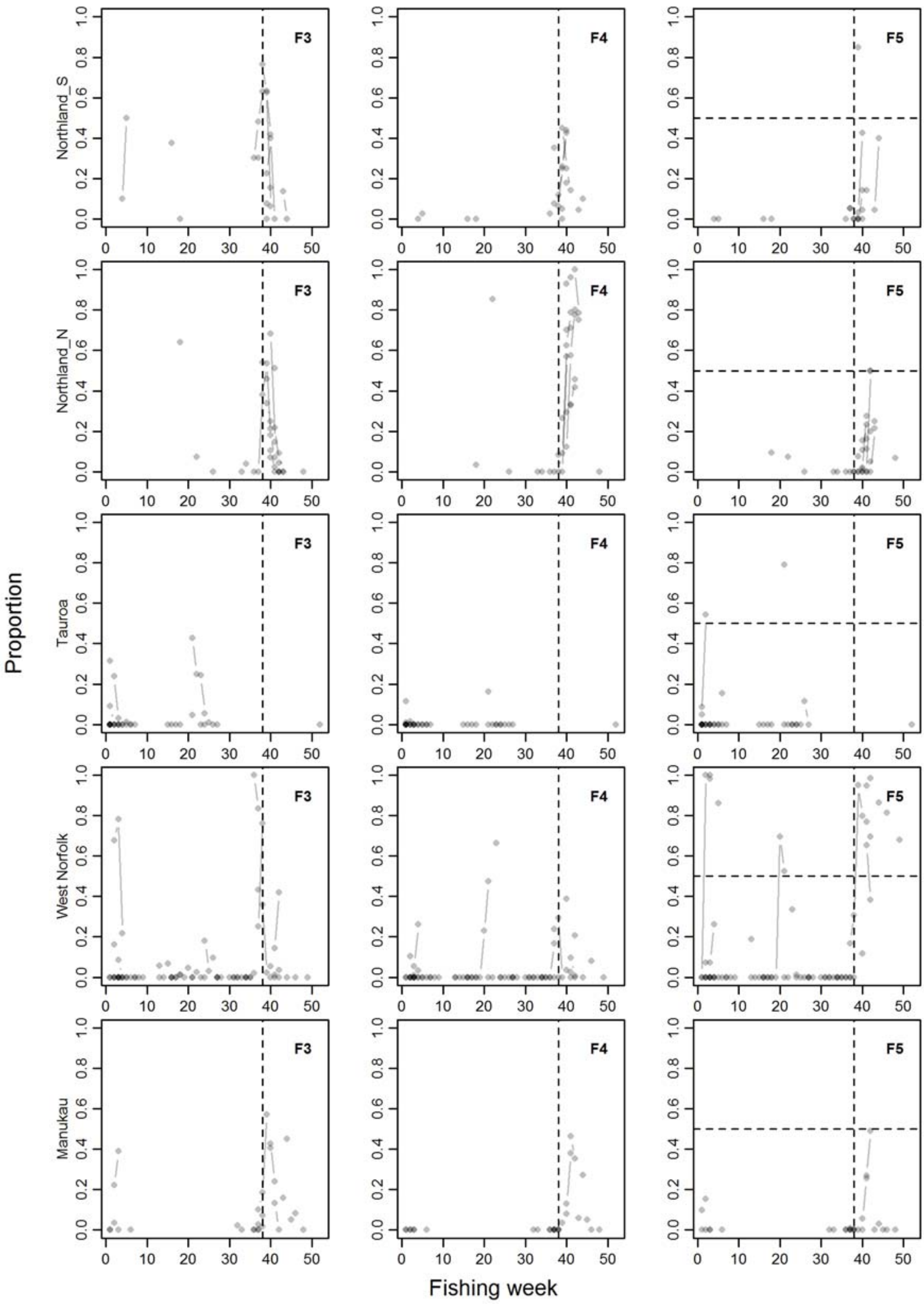


Figure 26 (cont.): Proportion of female orange roughy in samples (dots) at maturity stages ripe (F3), running ripe (F4), and spent (F5), by week of the fishing year, and by subarea. The vertical broken line marks week 38, which is the 3rd week of June. The horizontal broken line in panels for F5 mark 0.5.

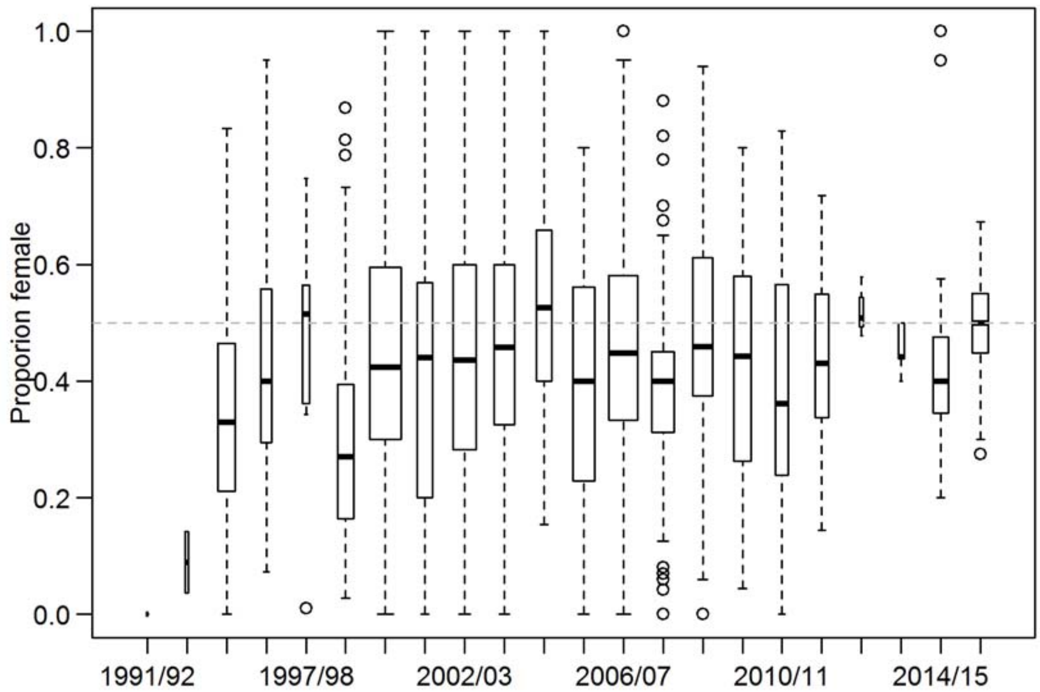


Figure 27: Box plot of annual proportion female of orange roughy by tow (unweighted).

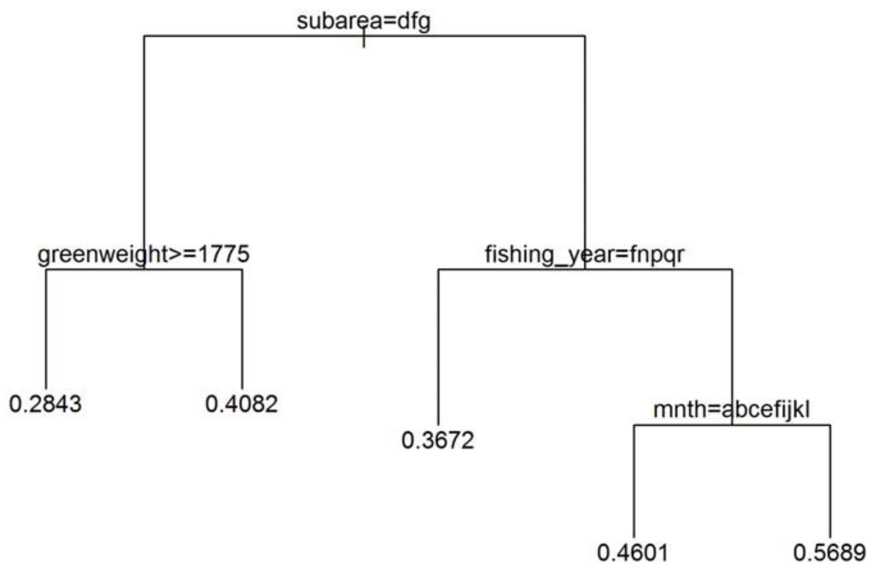


Figure 28: Classification tree for orange roughy proportion female by tow in ORH 1 (*n* tows = 1279). Subareas: a, Aldermen; b, Clark; c, Manukau; d, Mercury-Colville; e, North Colville; f, Northland_N; g, Northland_s; h, Tauroa; i, West Norfolk; j, White Island. Model explained just 12% of the deviance. The number at each terminal node ("leaf") is the mean of the proportion female in the samples in that group.

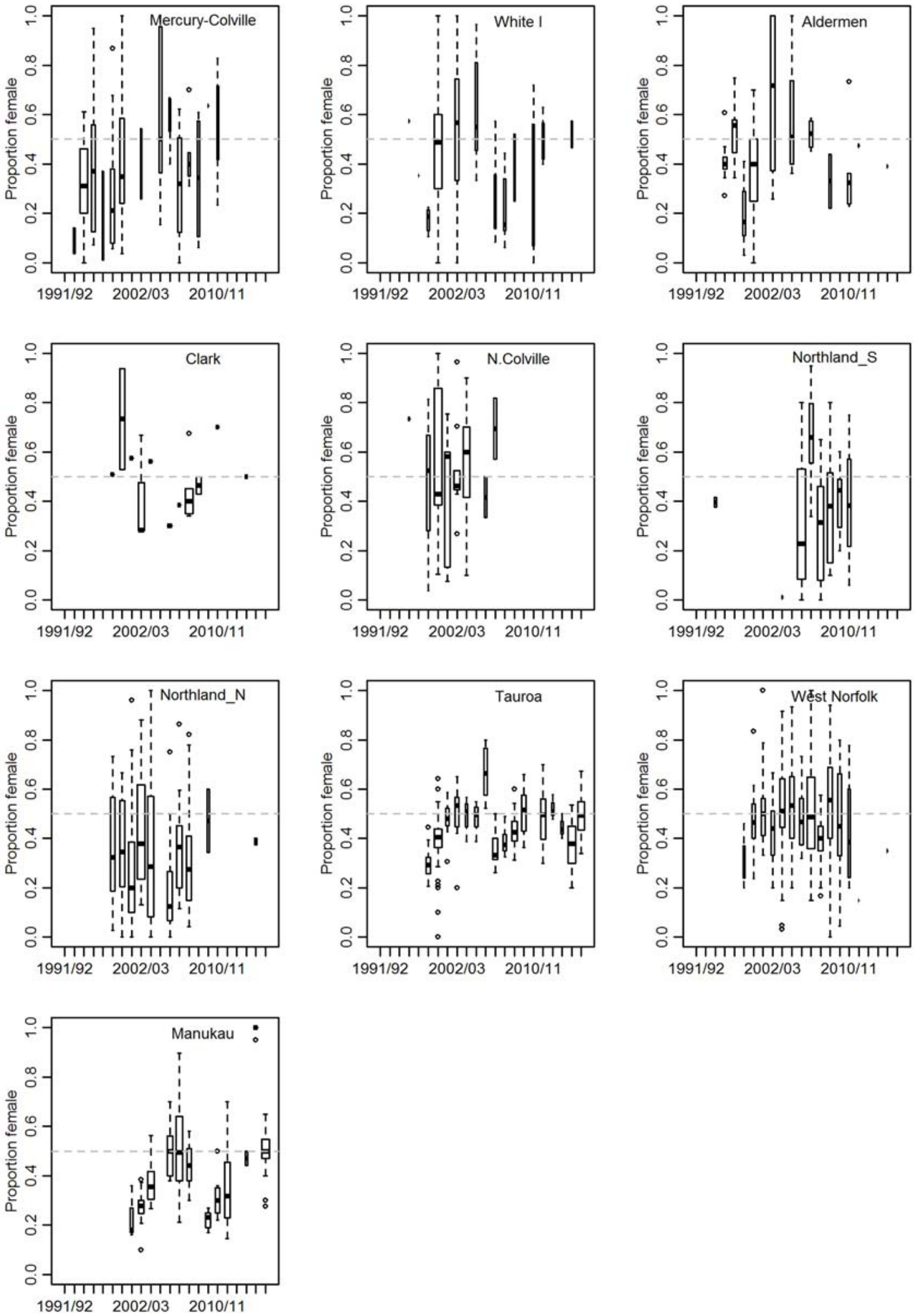


Figure 29: Box plot of annual proportion female of orange roughy by tow (unweighted) by subarea. Horizontal broken lines mark 50% female.

4. SURVEY DATA

Research surveys in ORH 1 are summarised in this section, but the data have not been analysed as part of this project.

Early surveys of orange roughy and other deepwater resources were conducted using trawls in the 1980s (Table 6). A later series of three trawl surveys by the *FV* Seamount Enterprise were used to inform a stock assessment of orange roughy in the Mercury Colville Box (Ministry for Primary Industries 2016). Aspects of these trawl surveys were described by Clark & Field (1998), Clark & King (1989), and Clark & Anderson (1999).

Table 6: Trawl surveys conducted in ORH 1. Source: MFish Research Planning Working Group, Appendix I, 2007, and Ministry for Primary Industries 2016.

Dates	Survey objective	*FV*	Region	Biomass (t)
May 1985 – June 1986	Biomass/exploratory	Wanaka (x5)	Northern North Island	NA
July–October 1986	Exploratory	Multi-vessel (27)	Northern North Island	NA
June 1995	Biomass	Seamount Enterprise (SMT9501)	Mercury-Colville	76 200
June 1998	Biomass	Seamount Enterprise (SMT9801)	Mercury-Colville	2 500
June 2000	Biomass	Seamount Enterprise (SMT2001)	Mercury-Colville	3 800

Table 7: Acoustic surveys from industry vessels in ORH 1, giving details of when and where trawling took place, the number of trawls, and the number of orange roughy measured for length and macroscopic maturity stage, mean length, predominant maturity stages observed, and number of otolith pairs (Ots.) collected. NC, not calculated. Biomass estimates are shown for snapshots considered most representative, where CV estimates were possible, or as ranges where there were several surveys varying by snapshot and sounder frequency; NR, marks seen but biomass estimates not reported; –, few orange roughy seen, or marks seen but suspected to include other species.

Survey details				Orange roughy measured				
FV	Dates	Location	*n* trawls	*n*	Mean SL (cm)	Maturity	*n* Ots.	Biomass t (CV)
Seamount Explorer[1]	9–10 July 2012	Manukau	8	1607	33.4	Spawn	800	NR
Seamount Explorer[2]	28 June – 1 July 2013	Manukau	13	1350	33.3	Pre- and spawn	560	471 (41)
Seamount Explorer[2]	J July – 8 July 2013	Tauroa	14	920	33.7	Spawn and spent	430	–
San Rakaia[2]	26 – 30 June 2013	Mercury–Colville	8	90	NC	Maturating to spawn	90	–
Thomas Harrison[3]	4 – 17 July 2014	Manukau	19	5160	Volcano: 34.1 Kaipara: 33.3	Spawn and spent	1418	Volcano: 4592 (18) – 9442 (19) Kaipara: 1054 (54) – 2477 (23)
Thomas Harrison[3]	14–15 July 2014	Tauroa	3	833	34.2	Spent	199	3920 (20), 5176 (20)

1. O'Driscoll (pers.comm.). Voyage Report: Acoustic Survey of orange roughy off Kaipara (ORH 1) using Seamount Explorer, July 2012. Prepared for Anton's Trawling Company Limited. NIWA, Wellington.
2. O'Driscoll (pers.comm.) Acoustic surveys in ORH1, June-July 2013. Prepared for Anton's Trawling Company Limited. NIWA, Wellington.
3. R. O'Driscoll (pers.comm.) 2014. NIWA, Wellington.

More recent orange roughy surveys have used acoustic biomass estimation from commercial fishing vessels, with trawling between acoustic snapshots for commercial purposes or for identification of mark species composition. The areas surveyed have included Manukau, with the flat grounds there referred to as “Kaipara Flats”, and the hill area as “Volcano”, the Tauroa Knoll area to the north of Manukau, and the Mercury-Colville region in the Bay of Plenty (Table 7).

The reported estimates of orange roughy mean length from survey trawls in Manukau were similar to those estimated there from observer samples in other years, with mean length on Volcano larger than Kaipara Flats, consistent with a feature influence on size (see Figure 10).

5. CATCH PER UNIT EFFORT ANALYSES

5.1 Methods

Catch and effort data were analysed following Mormede (2010). The catch and effort data set used comprised tows that caught or targeted orange roughy; analogous to the “Orange roughy dataset” of Mormede (2010). Catches and effort from each tow were assigned to a feature if its (vessel) start position was within 10 n. miles of the feature summit. If a tow was within 10 n. miles of multiple features, the proportion of both tow and catch was allocated to each feature relative to its distance from that feature; this resulted in non-integer number of tows per feature. After the feature allocation, Mormede (2010) assumed a number of additional features within the roughly 20% of unallocated tows based upon visual clustering of tow records (“hot spots”), but in the present analysis these were not recreated as their exact locations were unknown. For each feature, raw catch per unit effort and cumulative catch with increasing number of tows were plotted.

5.2 Results

After the allocation of tows to features, 20.9% of the tows were more than 10 n. miles (18.5 km) from a known feature. These were excluded from further analyses. The median distance between the start position of a tow and the summit of a known feature was 3.7 km, and 38% of the tows were split between two or more hills.

The CPUE and cumulative catch were plotted for 50 features, plus the Tauroa and Manukau boxes (Figures 30 and 31). Overall, the fishery was dominated by catches at three features, the Colville Knolls, followed by Tauroa, and Mercury Knoll (Figure 30).

Mormede (2010) noted that the cumulative catches per feature were still increasing on most features, and therefore CPUE on those features was not showing localised depletion. The present analysis found that almost linearly increasing cumulative catch had continued between 2009 and 2015 on several features, including Tauroa Knoll, Manukau, Alderman Knoll, Nukuhou Knoll, Waiotahi Knoll, Hill 470 (H470t), and Clark (Figure 31). A substantially decreased or potentially asymptotic cumulative catch in 2009 was continued to 2015 for Colville Knolls (asymptote at around 1700 t), Coral Hill (300 t), and Major Knolls (2.5 t). However, a potential asymptote in cumulative catch in 2009 was not continued to 2015 in other locations, where cumulative catch after 2009 increased substantially, such as Jasons Hill, Otata Knoll, Teina Knoll, Otara (nth) and Waioeka (sth) Knolls, Ohena Knoll, and Doogies. The cumulative catch on other features was increasing in 2009, but by 2015 was substantially decreasing and approaching an asymptote, for Hill 213 (asymptote at around 800 t), Mercury Knoll (1500 t), Explorer Hill (500 t), Birdflue (450 t), Maungaiti Knoll (220 t), Tauroa (160 t), Mahina Knoll (200 t), and Boulder Ridge (around 120 t).

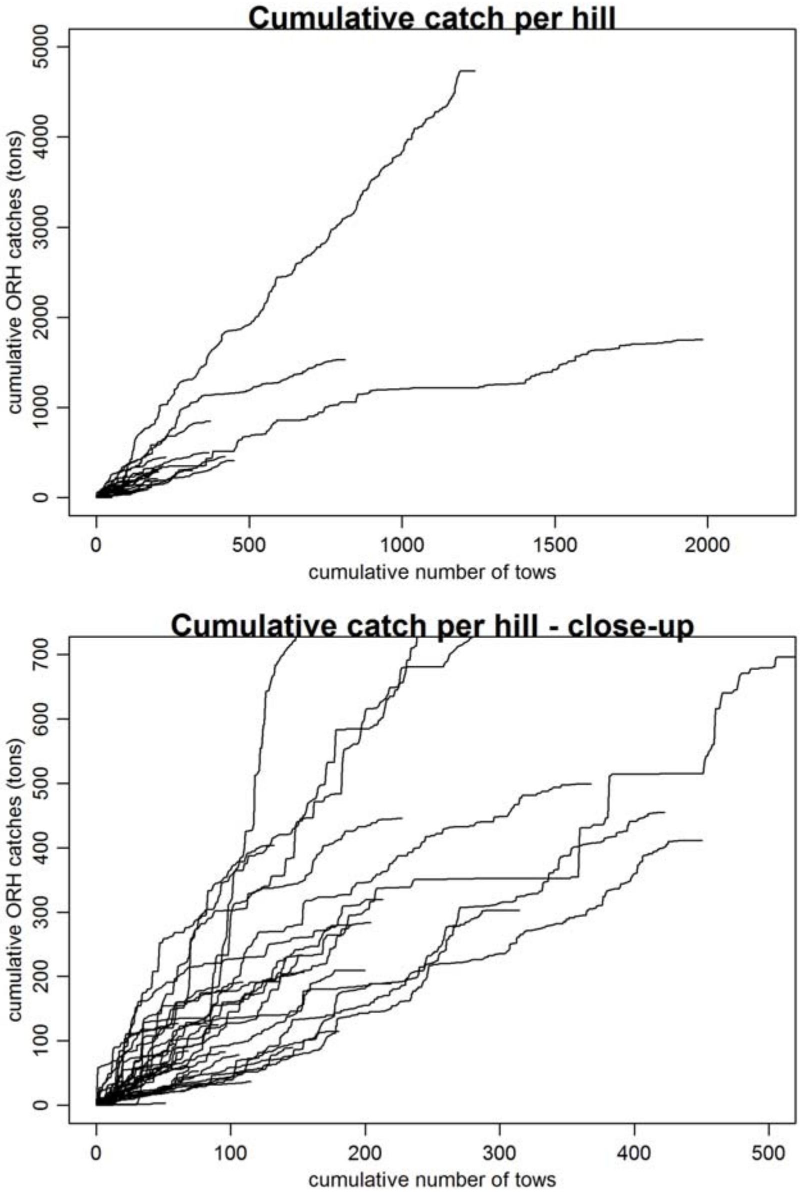


Figure 30: Cumulative catch of orange roughy (ORH) with increasing number of tows for each of 50 features in ORH 1.

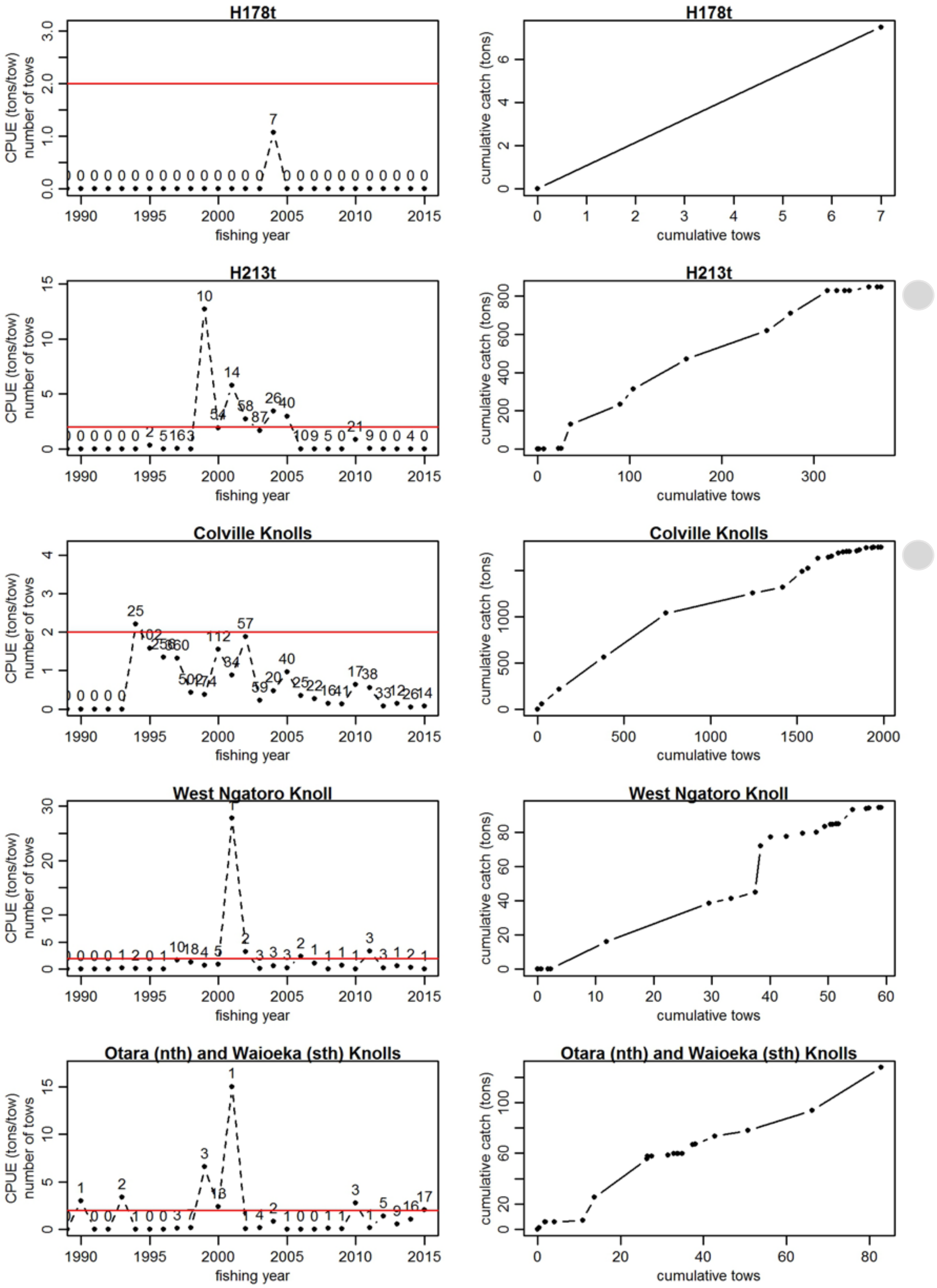


Figure 31: CPUE and cumulative catches of ORH by feature in ORH 1. Left panels show orange roughy raw CPUE by year and associated number of tows; the horizontal line represents 2 t/tow. Right panels show yearly cumulative catches as a function of cumulative number of tows. Grey filled circle to the right of the panels indicates a feature from which substantial catch (>400 t) of orange roughy has been taken.

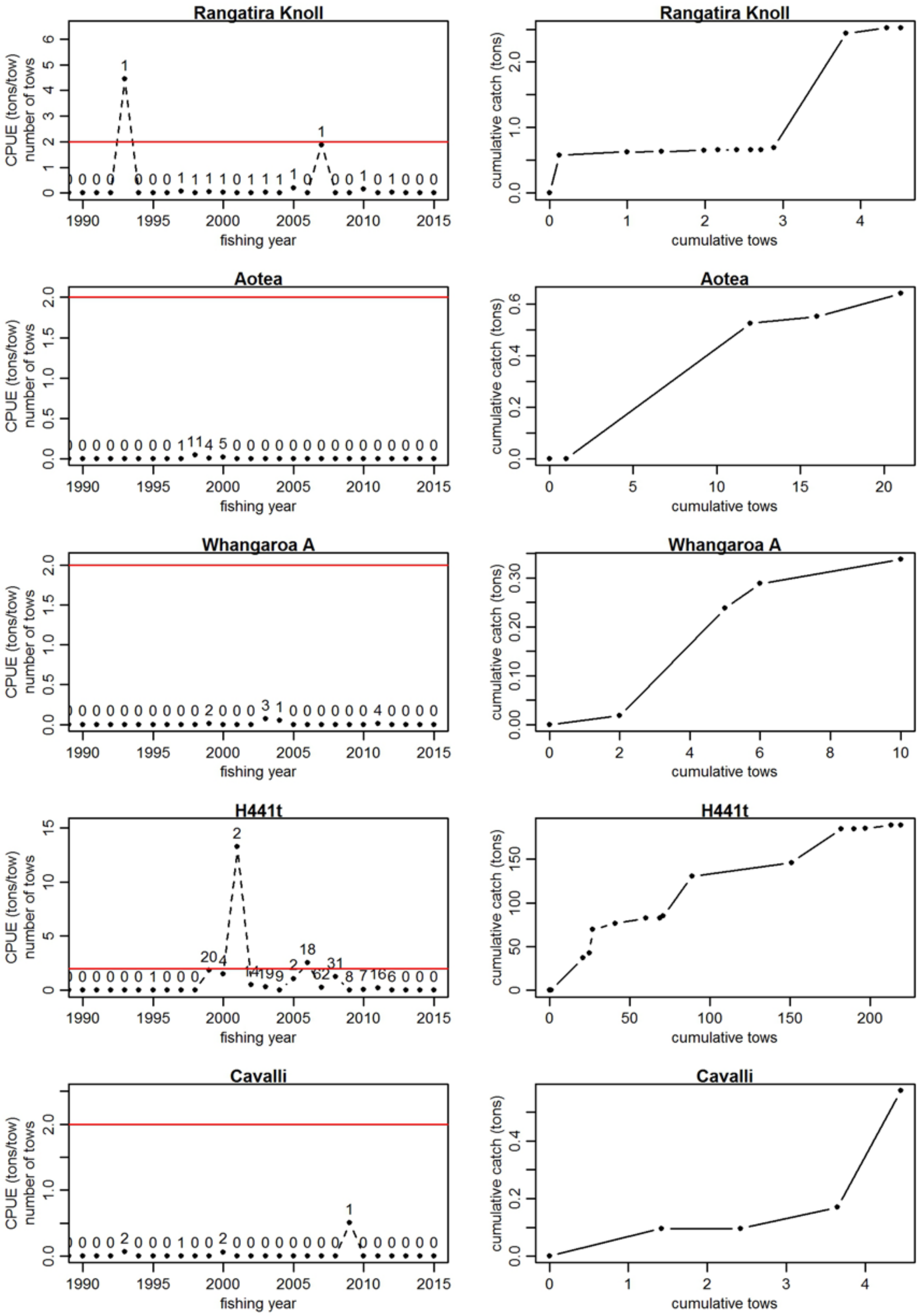


Figure 31 (cont.): CPUE and cumulative catches of ORH by feature in ORH 1. Left panels show orange roughy raw CPUE by year and associated number of tows; the horizontal line represents 2 t/tow. Right panels show yearly cumulative catches as a function of cumulative number of tows. Grey filled circle to the right of the panels indicates a feature from which substantial catch (>400 t) of orange roughy has been taken.

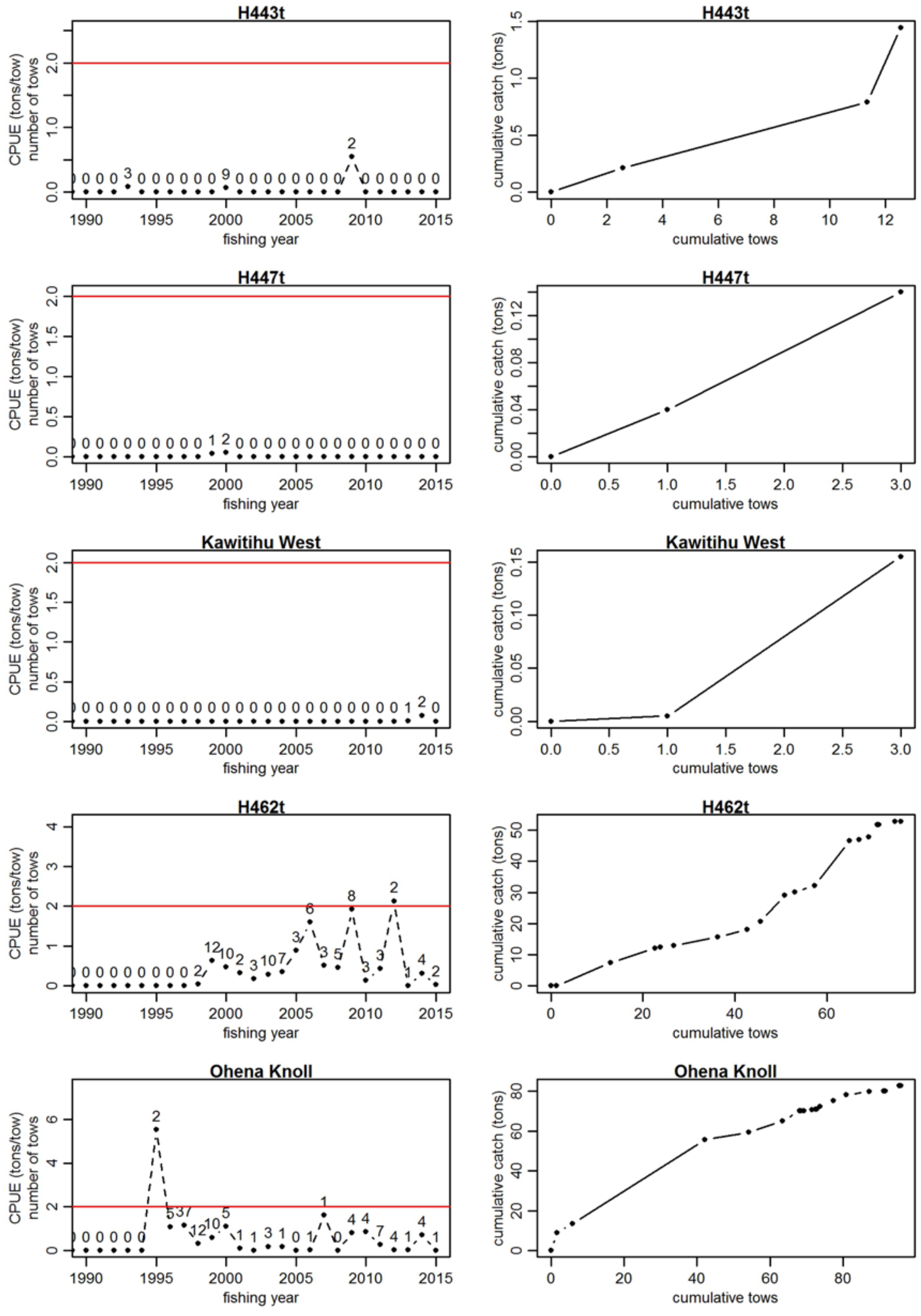


Figure 31 (cont.): CPUE and cumulative catches of ORH by feature in ORH 1. Left panels show orange roughy raw CPUE by year and associated number of tows; the horizontal line represents 2 t/tow. Right panels show yearly cumulative catches as a function of cumulative number of tows. Grey filled circle to the right of the panels indicates a feature from which substantial catch (>400 t) of orange roughy has been taken.

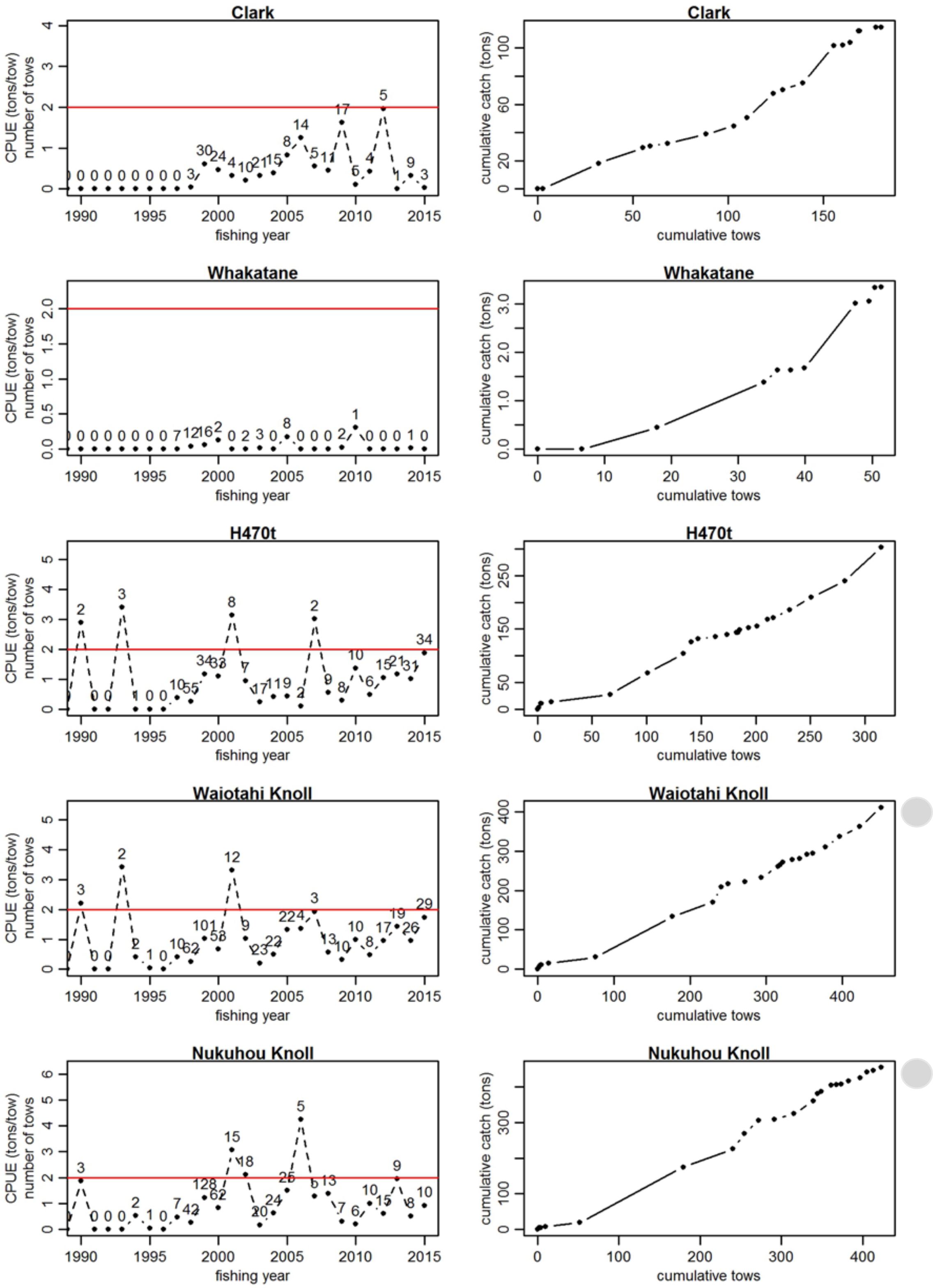


Figure 31 (cont.): CPUE and cumulative catches of ORH by feature in ORH 1. Left panels show orange roughy raw CPUE by year and associated number of tows; the horizontal line represents 2 t/tow. Right panels show yearly cumulative catches as a function of cumulative number of tows. Grey filled circle to the right of the panels indicates a feature from which substantial catch (>400 t) of orange roughy has been taken.

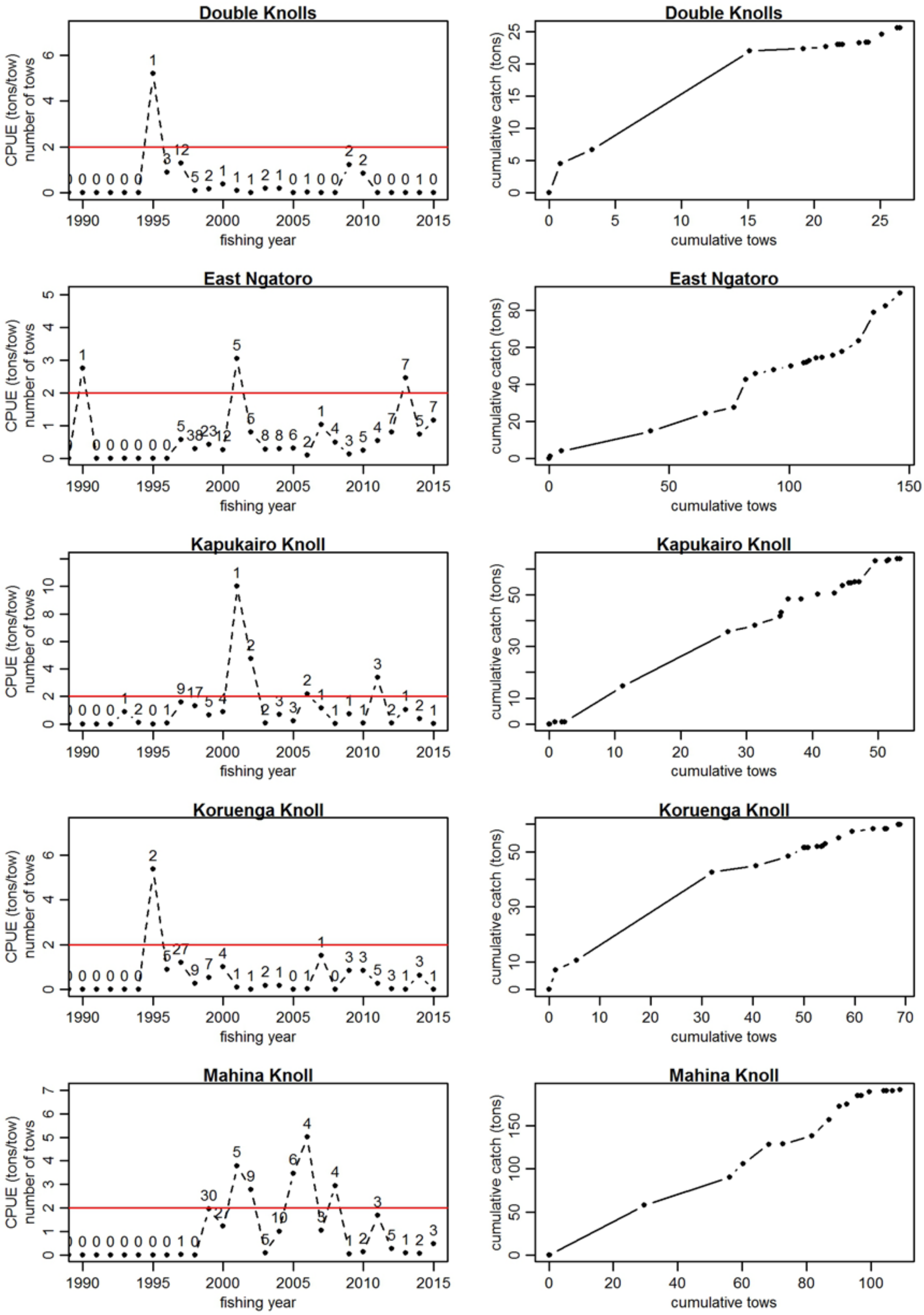


Figure 31 (cont.): CPUE and cumulative catches of ORH by feature in ORH 1. Left panels show orange roughy raw CPUE by year and associated number of tows; the horizontal line represents 2 t/tow. Right panels show yearly cumulative catches as a function of cumulative number of tows. Grey filled circle to the right of the panels indicates a feature from which substantial catch (>400 t) of orange roughy has been taken.

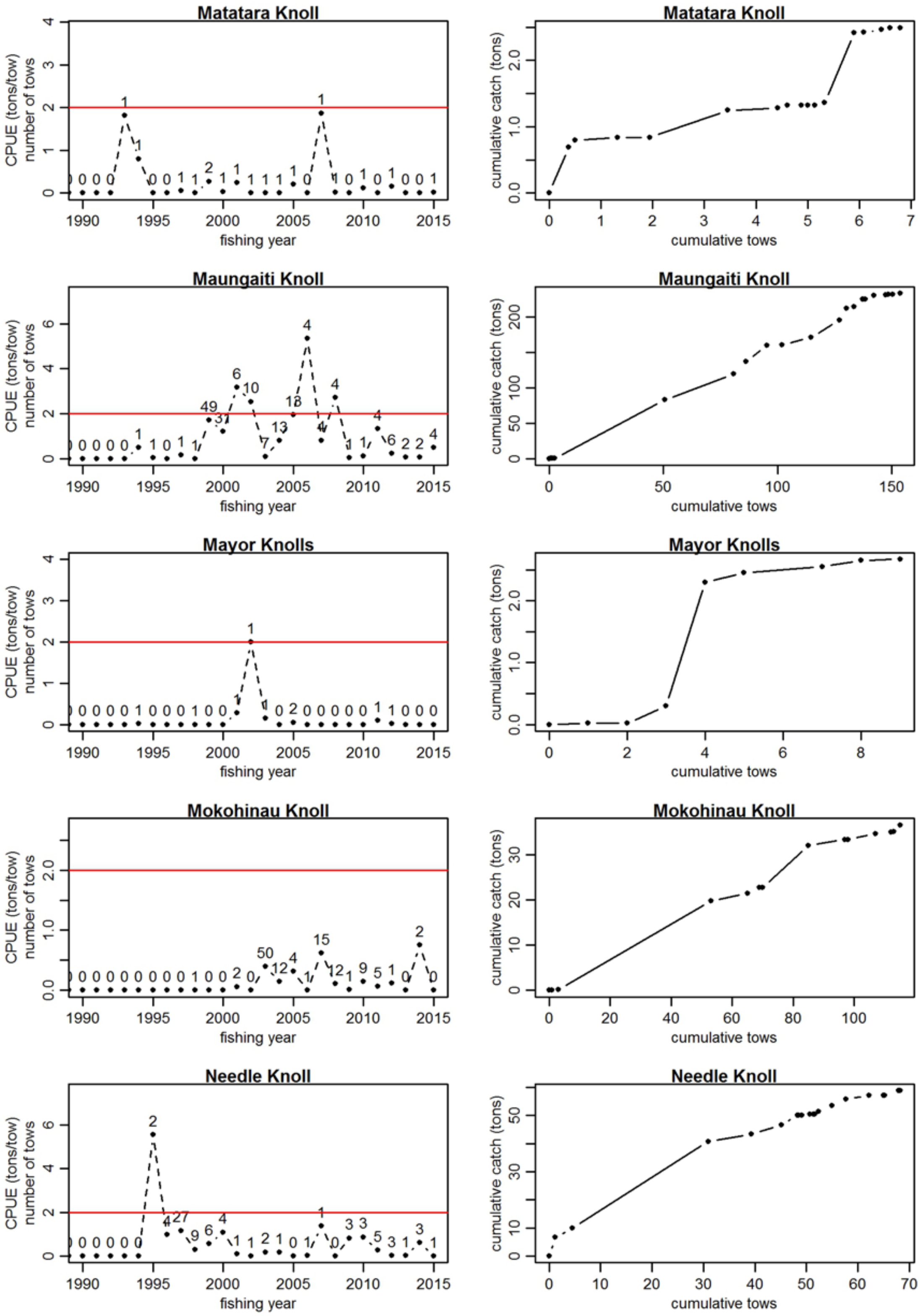


Figure 31 (cont.): CPUE and cumulative catches of ORH by feature in ORH 1. Left panels show orange roughy raw CPUE by year and associated number of tows; the horizontal line represents 2 t/tow. Right panels show yearly cumulative catches as a function of cumulative number of tows. Grey filled circle to the right of the panels indicates a feature from which substantial catch (>400 t) of orange roughy has been taken.

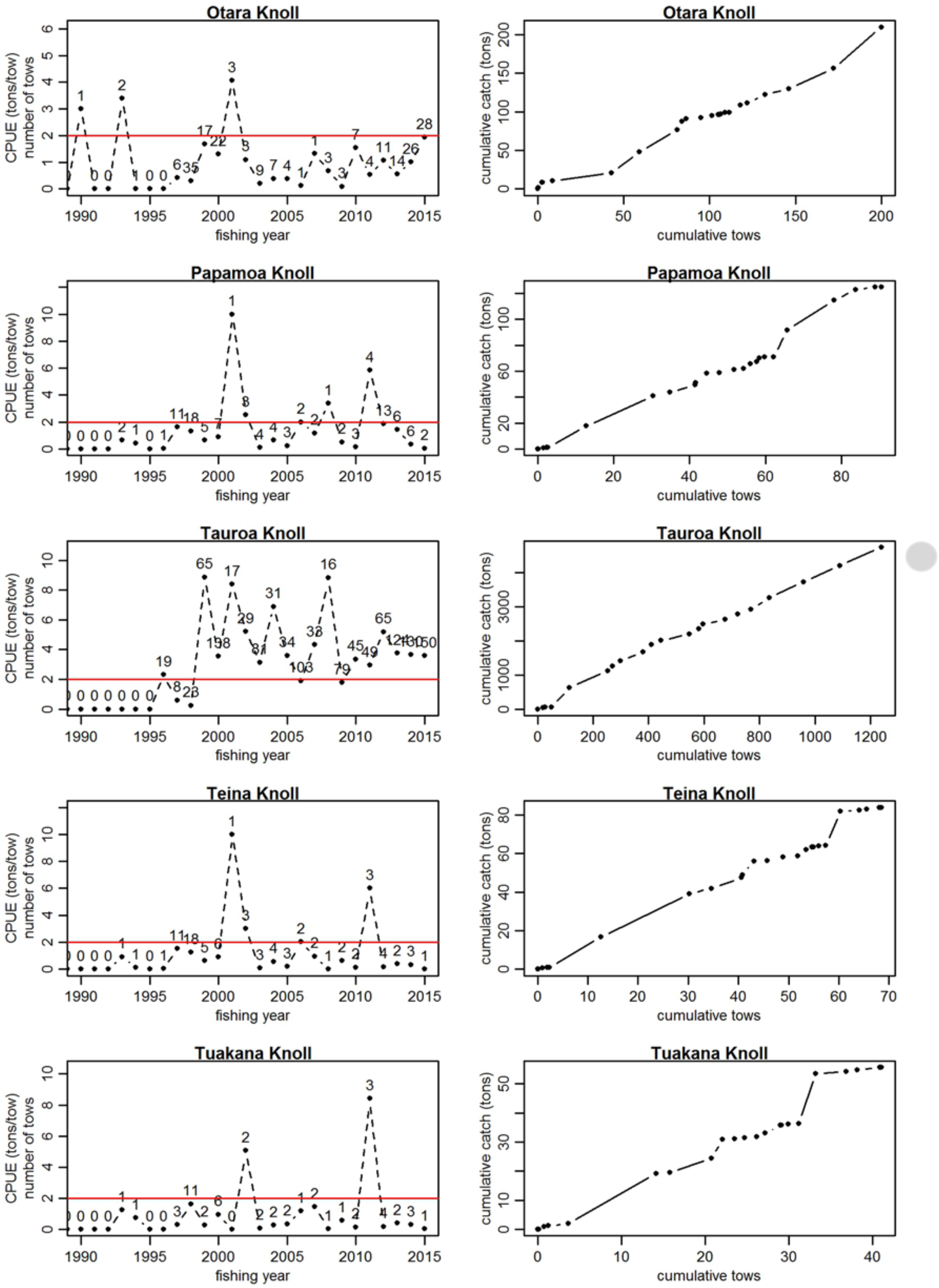


Figure 31 (cont.): CPUE and cumulative catches of ORH by feature in ORH 1. Left panels show orange roughy raw CPUE by year and associated number of tows; the horizontal line represents 2 t/tow. Right panels show yearly cumulative catches as a function of cumulative number of tows. Grey filled circle to the right of the panels indicates a feature from which substantial catch (>400 t) of orange roughy has been taken.

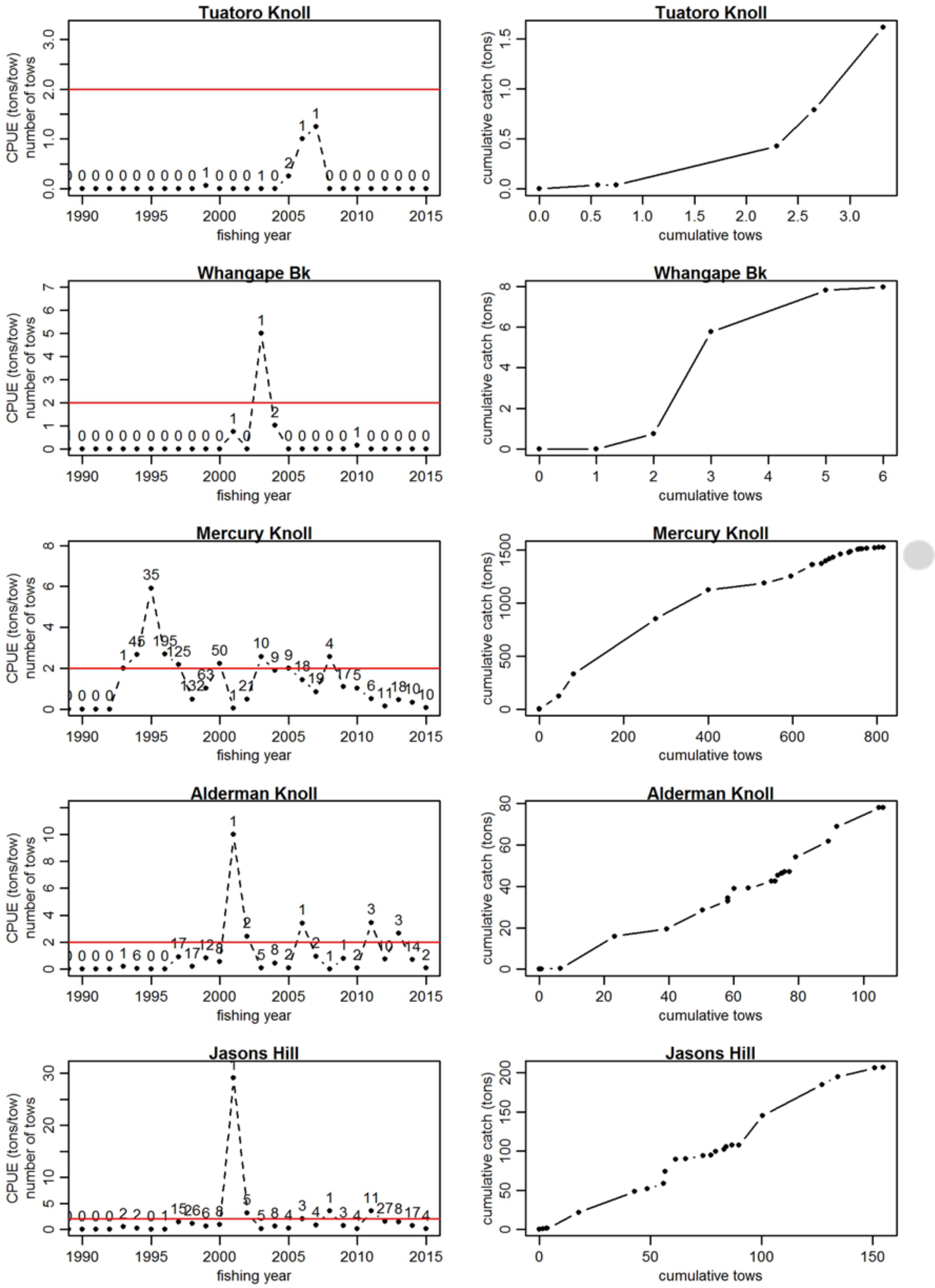


Figure 31 (cont.): CPUE and cumulative catches of ORH by feature in ORH 1. Left panels show orange roughy raw CPUE by year and associated number of tows; the horizontal line represents 2 t/tow. Right panels show yearly cumulative catches as a function of cumulative number of tows. Grey filled circle to the right of the panels indicates a feature from which substantial catch (>400 t) of orange roughy has been taken.

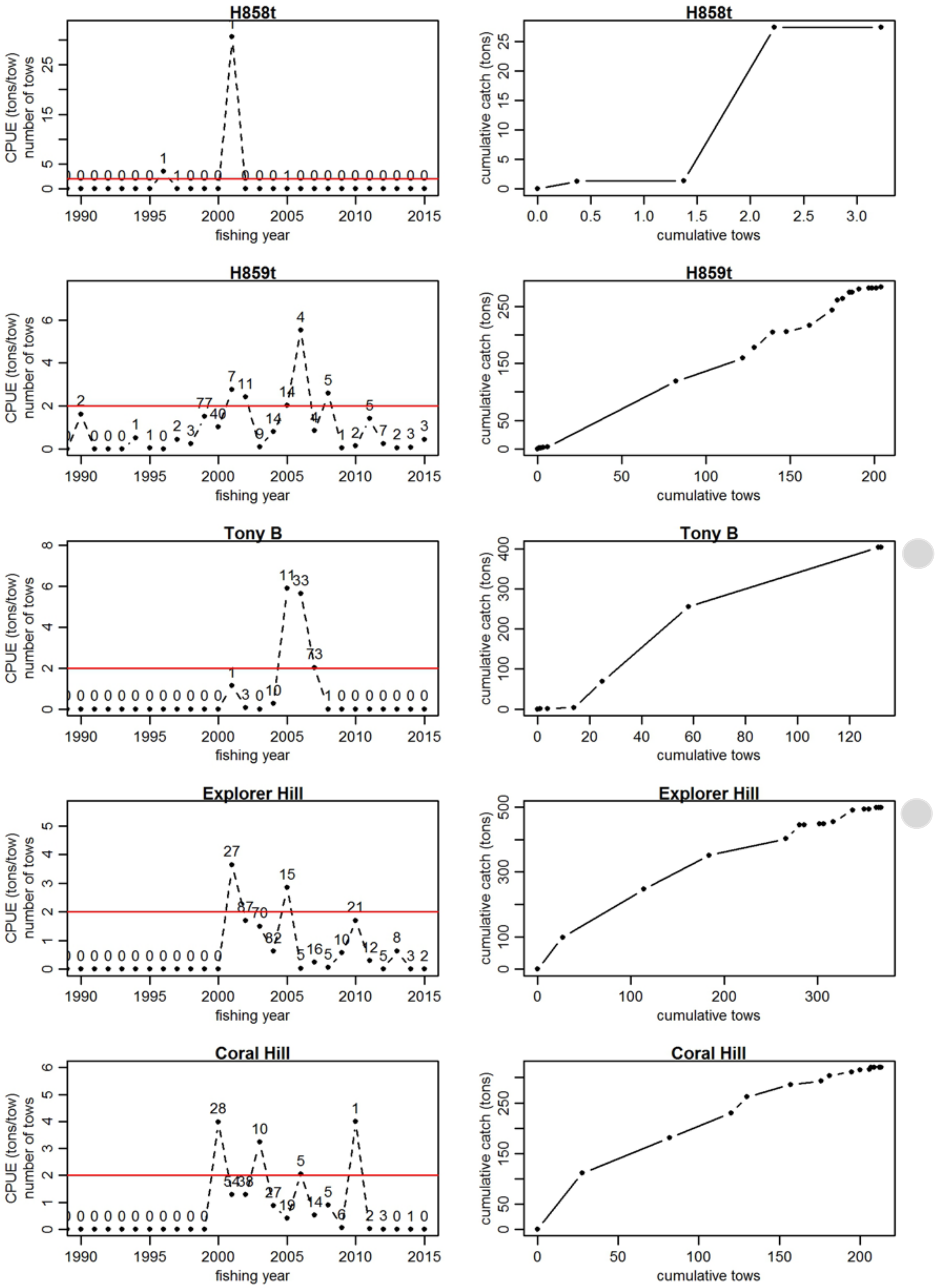


Figure 31 (cont.): CPUE and cumulative catches of ORH by feature in ORH 1. Left panels show orange roughy raw CPUE by year and associated number of tows; the horizontal line represents 2 t/tow. Right panels show yearly cumulative catches as a function of cumulative number of tows. Grey filled circle to the right of the panels indicates a feature from which substantial catch (>400 t) of orange roughy has been taken.

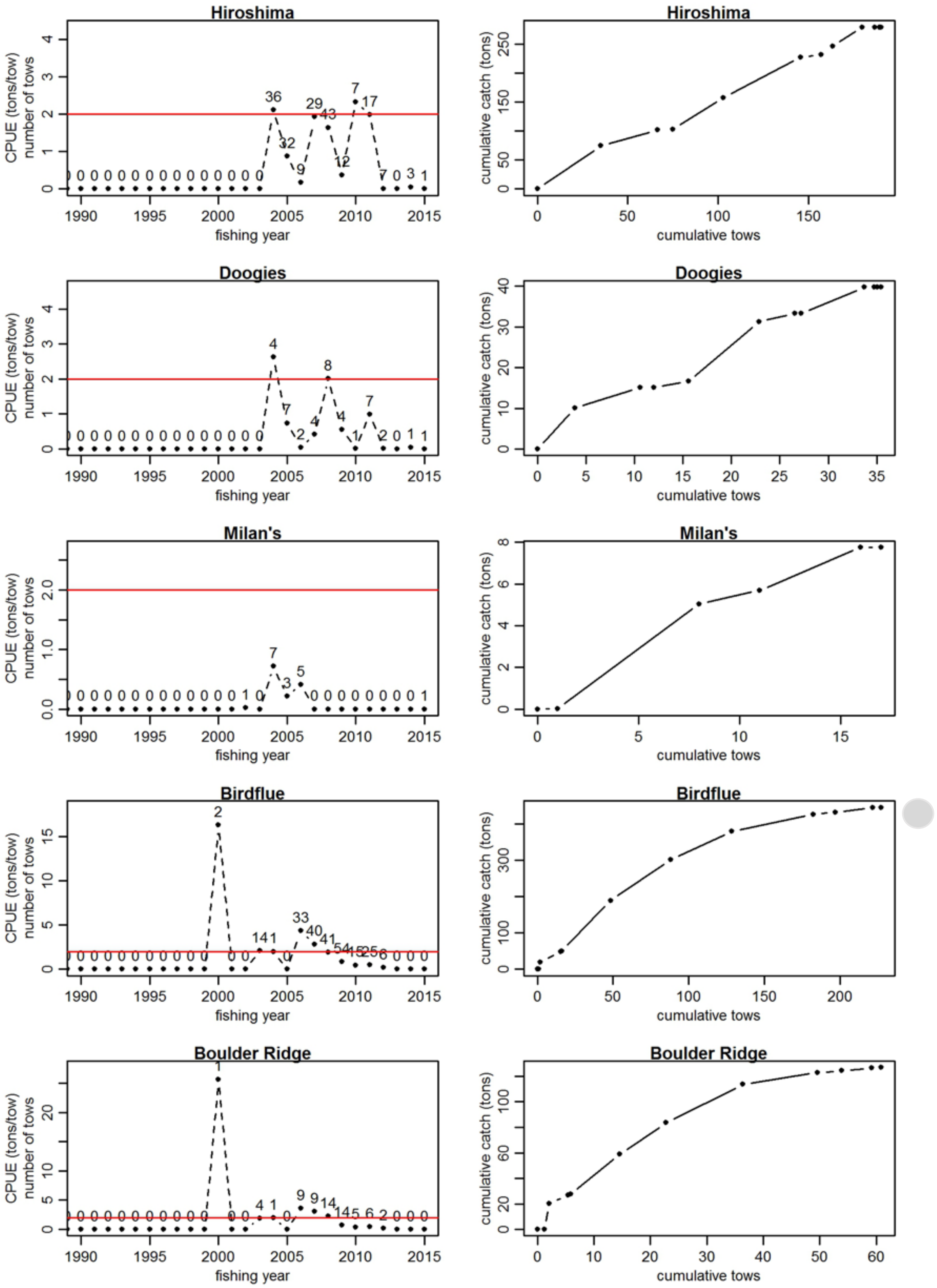


Figure 31 (cont.): CPUE and cumulative catches of ORH by feature in ORH 1. Left panels show orange roughy raw CPUE by year and associated number of tows; the horizontal line represents 2 t/tow. Right panels show yearly cumulative catches as a function of cumulative number of tows. Grey filled circle to the right of the panels indicates a feature from which substantial catch (>400 t) of orange roughy has been taken.

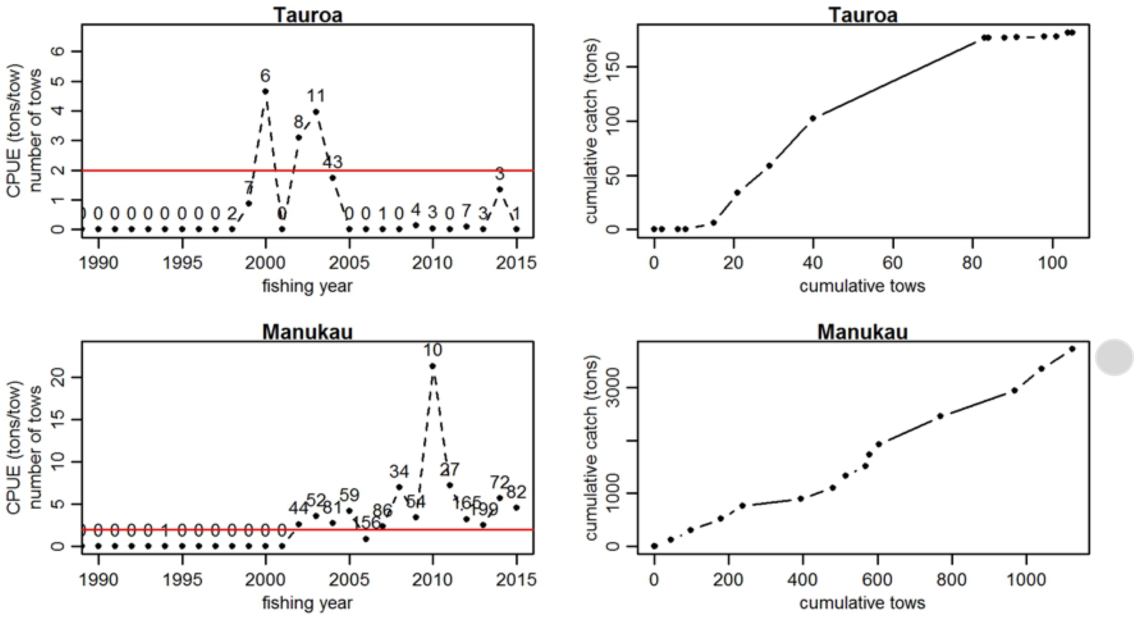


Figure 31 (cont.): CPUE and cumulative catches of ORH by feature in ORH 1. Left panels show orange roughy raw CPUE by year and associated number of tows; the horizontal line represents 2 t/tow. Right panels show yearly cumulative catches as a function of nuumulative mber of tows. Grey filled circle to the right of the panels indicates a feature from which substantial catch (>400 t) of orange roughy has been taken.

6. DISCUSSION

Simple comparisons of length frequency distributions, or mean lengths, have often been used as indicators of stock structure (Ward & Elliott 1993; Elliott et al. 1995; Smith et al. 2002; Dunn & Devine (2010); Ministry for Primary Industries 2016). In this analysis, variability in the mean lengths of orange roughy sampled by MPI observers in ORH 1 was primarily spatial. It was possible to explain a large part of this variability by the distance of the sample from the continental shelf, and when inshore, a combination of subarea and proximity to a known feature. The distance from the continental shelf may alias for habitat changes, including depth, with smaller orange roughy known to inhabit shallower water than adults (Dunn et al. 2009). Catch samples from both east and west coast locations had similar mean fish lengths, and in the cluster analysis were combined in the same terminal nodes. Spawning was widespread, and simultaneous. Despite large differences in mean fish length by subarea, catches of fish at sizes expected to be immature (less than 30 cm SL) were at best infrequent, and often completely absent. Nursery grounds are expected to be on flat areas, and inshore of adults (Dunn et al. 2009). As a result, the location of nursery grounds remains unknown and, in particular, whether the locations more distant from the shelf (those that appear to be geographically isolated) have associated nursery grounds is unknown. The implication of a variable sex ratio, often skewed towards males, remains unknown, but may reflect either a population bias, or a catchability bias (Pankhurst 1988). The orange roughy caught in offshore areas of ORH 1 are notably larger than those caught elsewhere in central or southern New Zealand (Ministry for Primary Industries 2016).

Simultaneous spawning in separate locations has been used to justify separate stocks before, with Ministry for Primary Industries (2016) stating that for ORH 1 "*The Mercury-Colville grounds in the Bay of Plenty are about 120 n. miles from fishing grounds at East Cape (ORH 2A North), and spawning occurs at a similar time. Hence, it is likely that these are separate stocks. The Mercury and Colville Knolls in the Bay of Plenty are about 25 miles apart and may form a single stock.*" However, for more intensively researched fisheries on Challenger Plateau and Chatham Rise, simultaneous spawning at separate locations, each consisting of different size frequencies of fish, has been accepted to occur within the same stock (Ministry for Primary Industries 2016).

The apparent spatial separation of spawning locations is also reflected in the distribution of catches, with most catches associated with discrete features, and as a result many of the fishing grounds appear to be separate. Although discontinuities in catch have been used to indicate stock structure (alongside other data; Dunn & Devine 2010), for ORH 1 the feature-focused fishing makes interpretation of catch patterns for inferring stock distribution particularly unreliable.

The interpretation of the CPUE by feature or subarea is not straightforward, and Mormede (2010) made no comment on her results. Similarly, no comment is made here, other than to note that some potential trends observed in Mormede (2010) were not necessarily continued into the present analysis.

Although spatially separate areas have been found to have similar CPUE trends within other orange roughy fisheries (Clark et al. 2010), the fishing effort within ORH 1 is relatively variable and effort sparse (often fewer than three effective tows per feature per year), and the CPUE used in the present analyses were not standardised for the influence of e.g., vessel, and time of year. Nevertheless, some visual similarity in CPUE trend existed between Mercury and Colville Knolls in the Bay of Plenty, and many areas showed similar timing of peaks in CPUE, for example some had a peak in CPUE around 2001 and/or 2011, but in general these few examples were based upon few tows and could be simply considered to be outliers, rather than indicative of some common exploitation pattern. Whether this is spurious, or reflects common patterns of fish biomass or fishing pattern, is unknown. The CPUE was also not standardised, and so changes over time could be caused by changes in season fished, management restrictions, changes in vessel skipper or technology, and a number of other reasons. Therefore the CPUE presented here (and in general) cannot be considered to be a reliable indication of stock structure.

Varela et al. (2013) examined orange roughy population connectivity using microsatellite DNA in samples from Australia, Namibia, Chile, Northeast Atlantic, and New Zealand, including 12 locations around northern New Zealand (Kaipara Flats/Manukau, Tauroa Knoll, Explorer Hill, Birdflue, Boulder Ridge, Milans, Nukuhou Knoll, Colville Knoll, Mercury Knoll, Clark, and Tony B and Yasmin's on the West Norfolk Ridge). Of all sites sampled, Milans showed the greatest allelic diversity (implying greatest adaptive potential), with orange roughy globally showing low genetic differentiation, and signs of a population bottleneck followed by rapid population growth and accumulation of mutations (Varela et al., 2012). Panmixia between the New Zealand samples could not be rejected, nor between pooled New Zealand samples and Australian samples, but the latter samples were distant from samples from Namibia, Chile, and the Northeast Atlantic. Temporal samples for eight of the sites within ORH 1 also showed a lack of significant differentiation, suggesting temporal stability and panmixia for orange roughy at this spatial scale (although power to detect significant divergence was limited by relatively small sample sizes). Genetics studies therefore support a single population of orange roughy within ORH 1.

The general physical oceanography around the North Island is most recently described by Chiswell et al. (2015). Both surface and intermediate water (about 1000 m depth) flows southwards down the east coast of the North Island of New Zealand, and onto the northern flank of Chatham Rise. At one point there was thought to be a southward-flowing current off the west coast of the North Island (the West Auckland Current), but his was based upon data from the 1950s, and more recent studies have found weak flows dominated by variability. The conclusion presented in Chiswell et al. (2015) is that there is no evidence for a southward-flowing West Auckland Current. Currents therefore seem to be equivocal, with no clear boundaries caused by ocean currents; the only major physical boundary to stock structure is therefore the North Island itself, with no strong current linking the east with the west coasts. There is no more evidence to link the eastern and western part of ORH 1 than there would be to link the eastern part of ORH 1 with ORH 2A, 2B, 3A, and those latter areas with Chatham Rise (ORH 3B).

The speed of the East Auckland Current is variable, but assuming a mean speed of 25 cm s^{-1} (Stanton et al. 1997), a time to hatching of 7.3 days (Bulman & Koslow 1995), and no local current gyres to retain eggs, then orange roughy eggs would hatch around 160 km (about 86 n.miles) from the point of spawning. Because currents on the west coast of Northland are weak, eggs from Tauroa, Manukau, and the West Norfolk Ridge subareas would seem to be unlikely to hatch close to any of the other subareas. On the east coast, eggs from Northland would hatch midway between Northland and Mercury Colville, and eggs spawned within the subareas of the Bay of Plenty would be expected to mix. Eggs spawned in the eastern part of the Bay of Plenty would hatch close to East Cape.

I believe the current evidence for more than one orange roughy population within ORH 1 is weak. This does not, however, preclude separate stocks from being assumed for management purposes. The rationale for stock separation would seem to be strongest for separating the west and east coast; this is primarily justified by geography and ocean currents; also, the history of exploitation (and possibly stock status) would be different, e.g., west coast (started late 1990s - early 2000s) compared to Bay of Plenty (started early-mid 1990s).

A number of options exist for increasing the amount of information available to inform stock structure. For example, otolith samples could be collected (or processed if they are already available) to provide location specific estimates of growth. The persistent large differences in fish length between locations does not tend to indicate extensive mixing, but rather local residence, and differences in growth pattern between locations would augment this length data.

Mortality and recruitment patterns have not yet been used to infer stock structure, but might also be used after successful ageing. Some age data already exist for ORH 1, as natural mortality rate was estimated from age samples in the Bay of Plenty by Doonan & Tracey (1997). Differences in length or age at maturity would provide further evidence for stock structure, and the former could be evaluated using existing data sets (estimates have already been published for the Bay of Plenty; Horn et al. 1998). Estimates of maturity might be confounded with spawning migrations (Francis & Clark 1998), so samples taken during and around spawning would ideally be excluded.

Otolith chemistry is also influenced by exposure of the fish to different water bodies (Thresher & Proctor 2007), and given the oceanography of ORH 1 it might help elucidate differences between the west and east coasts within ORH 1, and perhaps even the inshore and offshore areas.

7. ACKNOWLEDGMENTS

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APPENDIX A

Catch-weighted length frequencies by subareas and year, as used in Figures 18–27. Final rows of each table show the sample size (N) and the weight of the raised sample (t).

Mercury-Colville

SL	1994	1996	1997	1998	1999	2000	2003	2005	2006	2007	2008	2009	2010	2011
20	–	–	–	–	–	–	–	–	0.001	–	–	–	–	–
21	–	–	–	–	–	0	–	–	0.001	–	–	–	–	–
22	–	–	–	–	–	–	–	–	0.001	–	–	–	–	–
23	–	–	–	–	0	–	–	–	0.001	0.008	0	–	–	–
24	–	–	0	–	–	0	–	0	0.001	–	–	–	–	–
25	–	0	0	–	–	0	0.002	–	0.001	0	0.003	–	–	0.012
26	–	–	0	–	0	0	–	–	–	0.001	0.001	–	0.091	–
27	0.004	–	–	–	0	0	–	–	–	0.001	0	0.003	0.091	0.004
28	–	0.006	0	–	0.003	0	–	0	0.023	0.001	–	0.007	0.182	0.009
29	0.004	0.005	0.001	–	0.005	0	–	0	–	0.021	0.005	0.005	0.091	0.014
30	0.03	0.008	0.002	0.015	0.014	0.001	–	0.01	0.001	0.005	0.022	0.023	0.091	0.038
31	0.039	0.021	0.009	0.022	0.023	0.007	0.009	0.012	0.011	0.021	0.033	0.034	0.091	0.067
32	0.07	0.042	0.024	0.03	0.046	0.008	0.018	0.016	0.056	0.034	0.054	0.048	0.091	0.049
33	0.074	0.065	0.044	0.082	0.071	0.026	0.046	0.025	0.077	0.088	0.055	0.111	0.091	0.082
34	0.074	0.096	0.053	0.097	0.07	0.056	0.047	0.057	0.079	0.085	0.144	0.114	0.091	0.162
35	0.1	0.128	0.07	0.134	0.1	0.048	0.115	0.096	0.131	0.079	0.137	0.133	–	0.147
36	0.148	0.144	0.099	0.19	0.141	0.117	0.147	0.106	0.135	0.122	0.095	0.104	–	0.067
37	0.148	0.137	0.126	0.132	0.157	0.145	0.127	0.127	0.101	0.158	0.104	0.111	–	0.06
38	0.104	0.107	0.165	0.092	0.107	0.161	0.092	0.116	0.128	0.107	0.15	0.107	–	0.045
39	0.1	0.08	0.091	0.087	0.087	0.125	0.129	0.106	0.088	0.088	0.094	0.082	0.091	0.08
40	0.057	0.069	0.119	0.089	0.068	0.117	0.102	0.122	0.03	0.069	0.058	0.061	–	0.06
41	0.022	0.053	0.073	–	0.037	0.08	0.042	0.077	0.079	0.028	0.03	0.015	–	0.044
42	0.017	0.026	0.043	0.02	0.048	0.049	0.072	0.073	0.011	0.049	0.012	0.02	–	0.02
43	0.009	0.008	0.031	0.003	0.015	0.029	0.024	0.042	0.023	0.015	0.002	0.006	–	0.024
44	–	0.007	0.018	0.005	0.006	0.014	0.023	0.013	0.011	0.008	0	0.015	–	0.008
45	–	0.001	0.022	–	0.002	0.012	–	0	0.011	0.001	0.001	0.001	–	0.008
46	–	–	0.007	0.003	–	0.004	0.002	–	–	0.009	–	–	–	–
47	–	–	0.002	–	–	–	0.002	–	–	0	–	–	–	–
48	–	–	0.001	–	–	–	–	0	–	–	–	–	–	–
49	–	–	–	–	–	–	–	–	–	0	–	–	–	–
N	230	3227	1344	201	1428	794	201	424	99	552	323	400	11	183
t	90.4	348.1	71.9	3.5	55.5	66.1	7.7	33.9	3.4	7.8	12.8	10.0	0.01	3.8

White Island

SL	1997	1998	1999	2000	2003	2005	2007	2008	2009	2011	2012	2015
15	–	–	–	–	–	0	–	–	–	–	–	–
16	–	–	–	0	–	–	–	–	–	–	–	–
17	–	–	–	–	–	–	0.001	–	–	–	0.002	–
18	–	–	–	–	–	–	–	–	–	0.001	0.002	–
19	–	–	–	0	0.001	–	–	–	–	–	–	–
20	–	–	–	0	–	–	–	–	–	–	–	–
21	–	–	–	0	0.002	–	0.001	–	–	–	–	–
22	–	–	–	0	0.001	–	–	–	–	–	–	–
23	–	–	–	0	–	–	–	–	0.002	–	0.002	–
24	–	–	–	0	0.003	–	–	–	0.003	–	0.002	–
25	0.01	–	–	0	0.001	–	0.003	–	0.007	0.001	0.003	–
26	–	–	–	0	0.002	–	–	–	0.01	–	0.018	–
27	–	–	0.002	0.001	0.001	0	0.003	0	0.002	0.001	0.007	–
28	0.02	–	0.008	0.001	0.017	0	0.008	0	0.024	–	0.025	–
29	0.02	–	0.008	0.007	0.026	0.008	0.008	0.011	0.003	0.001	0.038	0.016
30	0.05	–	0.048	0.018	0.059	0.016	0.021	0.004	0.069	0.003	0.047	0.012
31	0.059	0.01	0.058	0.04	0.059	0.045	0.031	0.037	0.08	0.05	0.06	0.043
32	0.119	0.051	0.088	0.062	0.09	0.046	0.087	0.069	0.144	0.053	0.089	0.047
33	0.139	0.152	0.109	0.111	0.121	0.098	0.088	0.106	0.179	0.111	0.134	0.181
34	0.119	0.172	0.163	0.144	0.118	0.076	0.163	0.148	0.115	0.148	0.153	0.191
35	0.099	0.131	0.148	0.161	0.08	0.12	0.13	0.184	0.128	0.171	0.145	0.207
36	0.129	0.162	0.11	0.135	0.137	0.222	0.134	0.188	0.069	0.08	0.11	0.16
37	0.109	0.081	0.068	0.114	0.073	0.107	0.078	0.092	0.048	0.187	0.062	0.069
38	0.059	0.081	0.077	0.093	0.07	0.082	0.077	0.065	0.069	0.077	0.034	0.047
39	0.02	0.061	0.043	0.053	0.046	0.088	0.064	0.045	0.019	0.059	0.025	0.012
40	0.02	0.051	0.029	0.037	0.041	0.053	0.032	0.032	0.01	0.029	0.028	–
41	0.01	0.02	0.024	0.017	0.028	0.017	0.05	0.009	–	0.019	0.013	–
42	–	0.02	0.01	0.002	0.006	0.011	0.007	0.008	0.019	0.01	–	–
43	–	–	0.005	0.002	0.012	0.01	0.008	–	–	–	–	0.016
44	0.01	0.01	0.001	0	0.005	–	–	0.002	–	–	–	–
45	0.01	–	–	0	–	0.001	–	–	–	–	–	–
46	–	–	–	0	–	–	0.007	–	–	–	–	–
N	101	99	1191	3823	699	310	444	466	124	219	152	100
t	0.1	0.2	241.5	209.5	2.1	6.6	2.2	10.0	1.0	11.8	0.8	0.6

Aldermen

SL	1997	1998	1999	2000	2003	2005	2007	2009	2011	2012	2015
17	–	–	–	–	0.003	–	–	–	–	–	–
18	–	–	–	–	–	–	–	–	–	–	–
19	–	–	–	–	–	–	–	–	–	–	–
20	–	–	–	0	–	–	–	–	–	–	–
21	–	–	–	0	–	–	–	–	–	–	–
22	–	–	–	0	0.006	–	–	–	–	0.053	–
23	–	–	–	0.003	0.006	–	0.002	0.007	–	–	–
24	–	–	–	0	0.026	–	–	–	–	0.053	–
25	–	–	0.001	0.001	0.022	–	–	–	0.006	–	–
26	–	–	0.001	0.002	0.003	–	–	–	0.009	0.263	–
27	0	–	0.001	0.004	0.006	0	0.005	0.013	0.007	0.105	–
28	0.002	0	0.004	0.006	0.032	0.008	–	0.007	0.004	0.105	–
29	0.008	0.001	0.011	0.02	0.016	0.024	–	0.02	0.024	0.158	0.043
30	0.019	0.005	0.019	0.029	0.039	0.016	0.012	0.047	0.036	0.053	0.065
31	0.025	0.022	0.045	0.056	0.097	0.046	0.021	0.087	0.048	0.053	0.109
32	0.036	0.048	0.084	0.082	0.074	0.072	0.049	0.127	0.06	–	0.13
33	0.088	0.067	0.098	0.136	0.118	0.095	0.089	0.103	0.124	–	0.087
34	0.127	0.105	0.132	0.155	0.154	0.129	0.106	0.14	0.157	–	0.109
35	0.159	0.135	0.191	0.204	0.121	0.195	0.129	0.153	0.112	0.053	0.174
36	0.15	0.141	0.113	0.112	0.134	0.193	0.173	0.113	0.122	0.053	0.109
37	0.148	0.132	0.112	0.08	0.051	0.092	0.164	0.087	0.09	–	0.152
38	0.084	0.101	0.069	0.055	0.038	0.054	0.096	0.02	0.086	–	–
39	0.06	0.089	0.054	0.032	0.023	0.046	0.074	0.05	0.07	0.053	0.022
40	0.038	0.071	0.039	0.013	0.016	0.017	0.024	0.007	0.023	–	–
41	0.026	0.024	0.015	0.006	0.006	0.009	0.037	0.01	0.016	–	–
42	0.016	0.045	0.007	0.001	–	–	0.016	0.007	0.001	–	–
43	0.006	0.006	0.003	0.001	0.006	0.002	0.003	0.003	–	–	–
44	0.007	0.005	–	0.003	–	–	–	–	0.006	–	–
N	976	891	593	1041	312	415	324	200	441	19	46
t	38.9	8.6	10.8	36.1	0.4	3.2	8.1	4.5	47.8	0.02	0.5

Clark

SL	1999	2000	2002	2003	2004	2006	2007	2008	2009	2011	2014
26	–	–	–	–	–	–	–	–	0.001	–	–
27	–	–	–	0.009	–	–	–	–	–	–	–
28	–	–	–	–	–	–	–	–	–	–	–
29	–	0.006	–	–	–	–	–	–	0.001	–	–
30	–	0.004	–	0.027	–	–	0.014	–	–	–	–
31	–	0.006	–	0.008	0.062	–	–	–	–	–	–
32	–	–	–	–	–	–	–	0.005	–	–	–
33	–	–	–	–	–	–	–	–	0.019	0.025	–
34	0.009	0.01	–	0.009	–	–	–	0.013	0.009	–	–
35	–	0.014	–	–	–	0.012	0.014	0.008	0.018	0.025	–
36	0.009	0.011	0.012	0.031	–	0.047	–	0.007	0.042	0.05	0.071
37	0.028	0.026	0.012	0.016	0.125	0.023	0.057	0.014	0.035	0.05	–
38	0.037	0.074	0.038	0.047	–	0.088	0.057	0.039	0.12	0.05	–
39	0.046	0.069	0.062	0.047	0.062	0.088	0.057	0.085	0.1	0.075	0.143
40	0.093	0.1	0.088	0.118	0.062	0.135	0.1	0.106	0.144	0.1	0.286
41	0.093	0.122	0.113	0.079	0.062	0.13	0.171	0.104	0.125	0.075	0.143
42	0.083	0.114	0.113	0.137	–	0.136	0.186	0.112	0.079	0.075	–
43	0.139	0.072	0.088	0.12	0.062	0.077	0.071	0.127	0.116	0.05	–
44	0.148	0.085	0.138	0.135	0.125	0.07	0.071	0.105	0.044	0.1	0.143
45	0.1	0.1	0.1	0.1	0.2	0.0	0.0	0.1	0.1	0.2	0.1
46	0.093	0.068	0.1	0.08	0.188	0.1	0.1	0.089	0.03	0.075	0.071
47	0.056	0.044	0.075	0.025	0.062	0.012	0.029	0.027	0.038	0.025	–
48	0.046	0.043	0.038	–	–	0.023	0.029	0.032	0.001	0.075	0.071
49	0.065	0.015	0.038	0.008	–	–	–	0.02	0.009	–	–
50	–	0.019	0.012	–	–	0.012	–	0.008	–	–	–
51	–	0.004	0.012	0.017	–	–	–	–	–	–	–
52	–	0.004	–	–	–	–	–	0.008	–	–	–
53	–	–	–	–	–	–	–	0.004	–	–	–
N	108	212	80	125	16	70	70	282	200	40	14
t	2.9	2.9	0.7	0.3	0.04	4.6	1.1	7.9	17.8	0.6	1.5

North Colville

SL	1997	1999	2000	2002	2003	2004	2006	2007
19	–	–	0	–	–	–	–	–
20	–	–	0	–	–	–	0.077	–
21	–	–	–	–	–	–	0.077	–
22	–	–	0	–	–	–	–	–
23	–	–	0	–	–	–	–	–
24	–	–	0	–	–	–	0.154	–
25	–	–	0	–	–	–	0.077	–
26	–	–	0	–	–	–	0.154	–
27	–	–	0	–	–	–	–	–
28	–	–	0	–	–	–	–	–
29	–	–	0	–	–	–	0.077	–
30	–	–	0	–	0	–	0.077	–
31	–	–	–	–	–	–	–	–
32	–	–	0	–	0.004	–	–	–
33	–	–	0	–	0.003	–	–	–
34	–	–	–	–	0.004	–	–	–
35	–	–	0.001	0.005	0.002	0.009	0.077	0.056
36	–	–	0	0.001	0.006	0.001	–	–
37	–	0.001	0	–	0.008	0.005	–	0.111
38	0.033	0.002	0.006	0.016	0.02	0.006	–	–
39	0.017	0.013	0.005	0.017	0.02	0.024	0.077	0.056
40	0.033	0.013	0.014	0.042	0.039	0.02	–	–
41	0.067	0.036	0.037	0.057	0.055	0.023	0.077	0.111
42	0.083	0.098	0.079	0.095	0.061	0.065	–	–
43	0.017	0.081	0.071	0.084	0.079	0.087	0.077	0.111
44	0.083	0.121	0.107	0.116	0.095	0.064	–	0.111
45	0.1	0.1	0.1	0.1	0.1	0.2	–	0.1
46	0.067	0.096	0.114	0.11	0.105	0.128	–	0.056
47	0.1	0.122	0.156	0.098	0.11	0.066	–	0.111
48	0.067	0.103	0.124	0.096	0.088	0.128	–	0.111
49	0.083	0.084	0.057	0.061	0.083	0.069	–	0.056
50	0.067	0.037	0.053	0.036	0.066	0.054	–	–
51	0.05	0.046	0.025	0.02	0.03	0.048	–	–
52	0.083	0.015	0.033	0.014	0.014	0.023	–	–
53	0.017	0.009	0.005	0.005	0.008	0.01	–	–
54	–	0.008	0.005	–	0.008	0.014	–	–
55	–	–	–	–	0.002	0.003	–	–
56	–	–	0.004	–	–	0.006	–	–
N	60	318	526	628	739	450	13	18
t	0.2	73.8	59.2	109.5	36.4	86.9	0.01	0.05

Northland_S

SL	1996	2004	2006	2007	2008	2009	2010	2011
23	0.01	–	0	–	–	–	–	–
24	0.02	–	–	–	–	–	–	–
25	–	–	0.003	–	–	–	–	–
26	0.018	–	0.002	–	0	0	0	0.001
27	0.004	–	0.001	0.006	0.002	0	0.008	0.011
28	0.02	–	0.003	0.002	0.004	0.002	0.015	0.001
29	0.01	–	0.01	0.005	0.008	0.006	0.029	0.005
30	0.048	–	0.019	0.009	0.017	0.035	0.034	0.029
31	0.111	–	0.046	0.061	0.059	0.043	0.058	0.023
32	0.081	–	0.083	0.067	0.071	0.095	0.102	0.113
33	0.139	–	0.116	0.105	0.119	0.155	0.136	0.146
34	0.173	–	0.144	0.076	0.169	0.14	0.14	0.117
35	0.149	0.011	0.168	0.125	0.134	0.152	0.135	0.153
36	0.069	–	0.131	0.22	0.131	0.114	0.075	0.166
37	0.02	0.033	0.107	0.146	0.107	0.091	0.072	0.069
38	0.05	0.056	0.081	0.073	0.071	0.068	0.084	0.058
39	0.04	0.078	0.046	0.028	0.061	0.044	0.051	0.073
40	0.01	0.167	0.021	0.04	0.025	0.029	0.021	0.013
41	0.01	0.167	0.008	0.014	0.012	0.013	0.028	0.01
42	0.02	0.2	0.003	0.007	0.005	0.006	0.01	0.009
43	–	0.167	0.005	0.016	0.001	0.007	–	–
44	–	0.1	0.002	0.001	0.001	–	–	–
45	–	0.0	–	–	0.0	0.0	0.0	–
46	–	–	–	–	–	–	–	–
47	–	0.011	–	–	0	–	–	–
48	–	–	–	–	0	–	–	–
N	108	90	1306	402	1737	1600	544	285
t	0.3	6.5	130.6	46.2	97.7	95.4	10.5	3.9

Northland_N

SL	1999	2000	2002	2003	2004	2006	2007	2008	2010	2015
21	–	0.001	0	–	–	–	–	–	–	–
22	–	0.001	0	–	–	–	–	–	–	–
23	–	0.001	0	–	–	–	–	–	–	–
24	–	0.001	0	–	–	0	–	–	–	–
25	–	0.001	0	–	–	–	–	–	–	–
26	–	–	–	–	–	–	0	–	–	–
27	–	0.001	0	–	–	–	0.002	–	–	–
28	–	0.001	–	–	–	–	–	–	–	–
29	0	–	0	–	–	–	–	–	–	–
30	–	–	0.001	0.003	–	0	–	–	–	0.011
31	–	0.001	0	0	–	–	–	0.002	–	–
32	0	–	–	0.003	0	–	0.001	0.001	–	–
33	0.003	–	0	0	0.002	0.008	0.003	0.005	–	–
34	0.007	0.003	0	0.008	0.006	0.009	0.013	0.009	–	0.033
35	0.017	0.032	0.015	0.009	0.007	0.027	0.019	0.015	0.029	0.022
36	0.046	0.026	0.023	0.023	0.017	0.007	0.045	0.04	0.044	0.044
37	0.082	0.057	0.034	0.044	0.038	0.041	0.059	0.063	0.044	0.105
38	0.098	0.149	0.107	0.068	0.088	0.112	0.124	0.085	0.092	0.108
39	0.118	0.07	0.143	0.12	0.126	0.159	0.111	0.136	0.121	0.1
40	0.124	0.173	0.132	0.115	0.141	0.187	0.181	0.174	0.142	0.148
41	0.13	0.149	0.128	0.138	0.12	0.14	0.142	0.166	0.151	0.117
42	0.076	0.125	0.133	0.106	0.154	0.108	0.119	0.101	0.088	0.106
43	0.11	0.099	0.126	0.13	0.141	0.1	0.093	0.093	0.078	0.127
44	0.101	0.059	0.09	0.105	0.098	0.054	0.037	0.044	0.049	0.062
45	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0
46	0.016	0.012	0.028	0.033	0.008	0.017	0.007	0.02	0.02	0.003
47	0.011	0.002	0.009	0.016	0.005	–	0.009	0.009	0.054	0.003
48	0.011	0.01	0.007	0.011	0.019	0.008	0	0	0.029	–
49	0.004	0.001	0.002	0.008	–	–	0	0.004	0.005	–
50	–	–	0	0.006	–	–	–	–	–	–
51	–	–	–	–	–	–	0.001	–	–	–
52	–	–	–	0	–	–	–	–	–	–
N	880	528	844	1308	386	230	762	963	115	120
t	32.0	14.1	37.4	44.1	22.1	10.8	6.3	18.9	2.8	1.4

Tauroa

SL	1999	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010	2012	2013	2014	2015
16	–	–	0	–	–	–	–	–	–	–	–	–	–	–	–
17	–	–	0	–	–	–	–	–	–	–	0	–	–	–	–
18	–	–	0	–	–	–	–	–	–	–	0	0.001	–	–	–
19	–	–	0	–	–	–	–	–	–	–	0	0.001	–	–	–
20	0	–	0.001	–	–	–	–	–	–	–	0	0.001	–	–	–
21	–	–	0.002	–	–	–	–	–	–	0	0	0.001	–	–	–
22	0	–	0.002	–	–	–	–	–	–	–	0	0.001	–	–	–
23	0	0.003	0.002	–	–	–	–	0.002	–	–	0	0.001	–	–	–
24	–	0.001	0.002	–	–	–	0	0.001	0.003	0.006	0	0.001	–	–	–
25	0	0	0.003	0.01	–	0.003	0.002	–	–	0.002	0	0.009	0.004	–	0.001
26	0	0.005	0.007	0.002	–	0.003	0.002	0.002	–	0.001	0	0.013	0.01	0.005	0.001
27	0.001	0.006	0.009	0.008	0.002	0.004	0.005	0.005	0.007	0.012	0.008	0.022	0.02	–	0.002
28	0.004	0.015	0.012	0.009	0.002	0.015	0.007	0.012	0.009	0.029	0.008	0.054	0.005	–	0.008
29	0.011	0.011	0.017	0.01	0.009	0.02	0.016	0.016	0.011	0.037	0.018	0.06	0.025	–	0.02
30	0.012	0.035	0.022	0.013	0.029	0.02	0.034	0.039	0.029	0.037	0.035	0.05	0.06	0.019	0.048
31	0.035	0.069	0.071	0.021	0.037	0.039	0.062	0.054	0.035	0.07	0.052	0.075	0.062	0.018	0.073
32	0.055	0.074	0.075	0.077	0.064	0.074	0.077	0.056	0.037	0.1	0.104	0.096	0.148	0.048	0.107
33	0.131	0.096	0.057	0.09	0.086	0.096	0.122	0.082	0.077	0.099	0.153	0.117	0.104	0.05	0.129
34	0.194	0.138	0.121	0.112	0.138	0.137	0.131	0.154	0.078	0.119	0.15	0.103	0.128	0.087	0.146
35	0.181	0.141	0.136	0.151	0.136	0.142	0.125	0.153	0.197	0.158	0.161	0.124	0.131	0.108	0.134
36	0.142	0.133	0.146	0.193	0.146	0.158	0.113	0.141	0.14	0.141	0.129	0.114	0.144	0.064	0.125
37	0.132	0.122	0.134	0.135	0.134	0.132	0.092	0.125	0.133	0.107	0.094	0.078	0.073	0.147	0.091
38	0.061	0.088	0.097	0.089	0.105	0.078	0.097	0.082	0.122	0.033	0.046	0.057	0.041	0.082	0.06
39	0.029	0.041	0.061	0.046	0.058	0.044	0.073	0.049	0.064	0.038	0.03	0.011	0.039	0.119	0.033
40	0.011	0.019	0.003	0.026	0.027	0.023	0.029	0.02	0.034	0.005	0.005	0.004	0.005	0.086	0.014
41	–	0	0.012	0.005	0.021	0.009	0.009	0.007	0.012	0.003	0.002	0.001	–	0.079	0.006
42	–	0.001	0.009	0.002	0.006	0.002	0.003	–	0.012	0	0.002	–	–	0.057	0.002
43	–	–	–	0	–	0.002	–	0.001	0	–	–	–	–	0.021	–
44	–	0.001	–	–	–	–	0	–	–	–	–	–	–	0.004	–
45	–	–	–	–	–	–	–	–	–	–	–	0.0	–	–	–
46	–	–	–	–	–	–	–	–	–	–	–	–	–	0.005	–
47	–	–	–	–	–	–	–	–	–	–	–	0.004	–	–	–
N	1254	2085	513	602	322	825	837	945	672	1370	1300	720	204	259	2511
t	145.1	191.1	44.6	62.8	80.7	64.7	31.6	91.9	100.9	90.4	124.0	65.6	13.5	32.8	312.5

West Norfolk

SL	1999	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2015
18	–	0	–	–	–	–	–	–	–	–	–	–	–	–
19	–	–	–	–	–	–	–	–	–	–	–	–	–	–
20	–	0	–	–	–	–	–	–	–	–	–	–	–	–
21	–	0	–	–	–	–	–	–	–	–	–	–	–	–
22	–	0	–	–	–	–	–	–	–	–	–	–	–	–
23	–	0	–	–	–	–	–	–	–	–	–	–	–	–
24	–	0	–	–	0	0.001	–	0	–	–	–	0	–	–
25	–	0	0.001	0.001	0	–	–	0	–	–	0.001	–	–	–
26	0.02	0.003	–	–	0.001	0.001	0	0	–	0	0	0	–	0.05
27	–	0.001	0.001	0.001	0.001	0.003	0	0.001	–	0	0	0	–	–
28	0.02	0.003	0.016	0.006	0	0.003	–	0.001	–	0	0	0.001	–	0.15
29	–	0.001	0.007	0.008	0.002	0.002	0	0.002	–	0	0.003	0	–	0.1
30	0.02	0.004	0.025	0.008	0.002	0.001	0	0.003	0	0.001	0.001	0	–	0.25
31	0.02	0.004	0.032	0.001	0.005	0.002	0.004	0.003	–	0.004	0.003	0.001	–	0.15
32	–	0.012	0.029	0.006	0.007	0.012	0.002	0.003	0.001	0	0.002	0.001	–	0.1
33	0.039	0.002	0.033	0.018	0.005	0.016	0.001	0.003	0.003	0.006	0.009	0.015	–	0.05
34	0.04	0.004	0.058	0.015	0.008	0.015	0.002	0.005	0.005	0.003	0.005	–	–	0.05
35	0.097	0.011	0.096	0.033	0.009	0.034	0.005	0.013	0.014	0.012	0.023	0.029	–	0.05
36	0.076	0.04	0.096	0.025	0.012	0.07	0.012	0.022	0.016	0.021	0.021	0.021	0.05	0.05
37	0.137	0.059	0.106	0.041	0.025	0.12	0.032	0.037	0.047	0.036	0.066	0.038	0.25	–
38	0.197	0.073	0.084	0.063	0.04	0.182	0.072	0.078	0.076	0.107	0.1	0.08	0.1	–
39	0.117	0.087	0.097	0.082	0.078	0.119	0.116	0.135	0.129	0.128	0.113	0.113	0.3	–
40	0.101	0.116	0.075	0.073	0.108	0.108	0.125	0.118	0.131	0.175	0.145	0.13	0.05	–
41	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	–
42	0.02	0.104	0.049	0.104	0.127	0.09	0.154	0.169	0.112	0.139	0.127	0.134	0.1	–
43	–	0.106	0.042	0.109	0.107	0.062	0.126	0.103	0.114	0.097	0.086	0.121	0.05	–
44	–	0.115	0.038	0.08	0.087	0.031	0.115	0.07	0.085	0.047	0.065	0.068	–	–
45	–	0.044	0.021	0.059	0.085	0.025	0.043	0.042	0.06	0.031	0.043	0.042	–	–
46	–	0.051	0.02	0.056	0.054	0.006	0.046	0.023	0.028	0.025	0.024	0.041	–	–
47	–	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–	–
48	–	0.006	0.004	0.03	0.019	0.011	0.004	0.006	0.007	0.012	0.003	0.008	–	–
49	–	0.006	0.001	0.01	0.013	0	0.003	0.003	0.001	0	0.007	0.003	–	–
50	–	–	0.001	0.012	0.006	0.001	0.001	0	0.001	–	–	0.001	–	–
51	–	–	0.001	0.005	–	–	0.002	0.001	–	0.004	0.002	0	–	–
52	–	–	–	0	–	–	–	0.001	–	–	–	–	–	–
53	–	–	–	–	0.001	–	–	–	–	–	0	–	–	–
54	–	–	–	0	–	–	–	–	–	–	–	–	–	–
N	51	694	1063	1243	1161	937	1402	4238	2155	1958	1429	654	20	20
t	0.1	92.0	32.2	43.6	60.7	37.5	186.0	156.0	59.4	107.0	119.2	22.1	0.5	0.2

Manukau

SL	2002	2003	2004	2006	2007	2008	2010	2011	2012	2014	2015
12	–	–	–	–	0	–	–	–	0	–	–
13	0	–	–	–	–	–	–	–	–	–	–
14	–	–	–	0.003	0	–	–	–	–	–	–
15	–	–	0	–	–	–	–	–	0	–	0
16	0	–	–	–	0.001	0	–	–	0	–	–
17	–	0	0.001	0.001	0	0	–	–	0	–	–
18	0	0	0	–	0.001	0	–	–	0.001	–	–
19	0	0	0	–	0	0	–	–	0.001	–	0
20	0.001	0.001	0.003	0.002	0.002	0.001	–	–	0.001	–	0
21	0.001	0	0.005	0.008	0.002	0.001	–	–	0.001	–	–
22	0.002	0.003	0.002	0.009	0.001	0.002	–	–	0.001	–	–
23	0.002	0.003	0.005	0.009	0.002	0.002	–	–	0.001	–	–
24	0.001	0.001	0.004	0.02	0.002	0.004	–	–	0.002	–	0.021
25	0.001	0.006	0.006	0.011	0.006	0.014	0.003	0.002	0.007	–	0
26	0.03	0.001	0.006	0.007	0.01	0.023	0.011	0.006	0.001	–	0
27	0.021	0.022	0.01	0.013	0.011	0.021	0.022	0.017	0.005	0.01	0.014
28	0.021	0.021	0.015	0.011	0.022	0.058	0.042	0.03	0.036	0.042	0.047
29	0.099	0.036	0.024	0.021	0.031	0.055	0.076	0.065	0.065	0.063	0.029
30	0.08	0.047	0.037	0.037	0.045	0.068	0.121	0.086	0.09	0.135	0.076
31	0.07	0.051	0.063	0.04	0.063	0.107	0.145	0.104	0.139	0.188	0.105
32	0.138	0.111	0.076	0.062	0.076	0.06	0.149	0.186	0.167	0.125	0.14
33	0.09	0.106	0.133	0.131	0.115	0.082	0.143	0.154	0.108	0.104	0.117
34	0.187	0.147	0.162	0.137	0.15	0.073	0.121	0.136	0.08	0.083	0.125
35	0.099	0.118	0.151	0.165	0.127	0.114	0.087	0.127	0.123	0.074	0.104
36	0.07	0.136	0.134	0.146	0.149	0.113	0.052	0.046	0.095	0.041	0.053
37	0.039	0.142	0.078	0.077	0.075	0.093	0.02	0.026	0.068	0.041	0.104
38	0.039	0.02	0.042	0.049	0.047	0.069	0.005	0.011	0.008	0.041	0.024
39	0.01	0.026	0.025	0.031	0.043	0.029	0.003	0.004	0	0.021	0.019
40	–	0	0.008	0.011	0.008	0.003	0	–	–	0.01	0.004
41	–	–	0.0	0.0	0.0	0.0	–	0.0	–	0.0	0.0
42	–	0	0.002	–	0.001	0	–	–	–	–	–
43	–	–	0.001	–	–	–	–	–	–	–	–
44	–	–	–	–	–	–	–	–	–	–	–
45	–	–	0.001	–	–	–	–	–	–	–	–
N	300	1054	1071	640	1402	573	960	780	1034	96	321
t	11.3	95.8	27.8	12.5	43.6	51.8	229.0	64.8	70.3	5.6	52.5