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The Louisville Ridge orange roughy fishery: an update of commercial catch-effort data and CPUE analysis of the fishery to the end of the 1999–2000 fishing year

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EXECUTIVE SUMMARY

Clark, M.R.; Anderson, O.F. (2001). The Louisville Ridge orange roughy fishery: an update of commercial catch-effort data and CPUE analysis of the fishery to the end of the 1999–2000 fishing year

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This report updates information on catch and effort by New Zealand vessels fishing orange roughy (*Hoplostethus atlanticus*) outside the EEZ on the Louisville Ridge up to the end of the 1999–2000 fishing year. Catch and effort summaries have been compiled for the New Zealand fishery using data from the Quota Management System (QMS). Estimates of catch are updated for fishing years 1998–99 and 1999–2000, based on records from Trawl-Catch-Effort-Processing-Returns.

The fishery developed in the early 1990s. Reported New Zealand catch increased rapidly from about 200 t in 1993–94, to peak at over 11 000 t in 1994–95, before decreasing each year to 1400 t in 1997–98. Catches increased in 1998–99 to 3000 t. A total of 1300 t has been reported in 1999–2000, although this may be incomplete. The level of effort in the fishery (both number of vessels and number of trawls) changed in a similar pattern to the overall catch.

Australian effort was significant for the first two years of the fishery. Catch data are not available for 1993–94, but catch in 1994–95 reached about 2000 t. In 1995–96 this dropped to 50 t. There were catches of 140 t in 1998–99, and no vessels are known to have fished the Ridge in 1999–2000.

Information on catch and effort of the New Zealand fleet is presented for three regions within the general fishery area. The fishery developed in the central region, where almost all the reported catch was taken in 1994–95. Fishing grounds to the north and south were also discovered, and in 1995–96 most catch was from the northern region. From 1996–97 to 1999–2000 the focus of catch shifted back to the central area.

Standardised CPUE indices have been calculated for three seamount groups. A combined linear–binomial regression analysis was applied. The main variables identified in the models having a significant effect on CPUE each year were week of the winter period and fishing vessel. CPUE in each seamount area showed a peak in 1998, with lower, but variable, levels in other years.

A deterministic stock reduction analysis was attempted for the seamount groups using the standardised CPUE indices. The model was unable to estimate virgin biomass within reasonable bounds, as with little overall trend in the data the model could not determine an upper bound for biomass. Estimates of B_{min} (the minimum virgin biomass consistent with the catch history and stock productivity) are presented for each seamount group.

1. INTRODUCTION

The Louisville Ridge is a chain of seamount and guyot features, extending for over 4000 km from the Kermadec Ridge southeastwards well to the east of the Chatham Islands. It is a "hotspot" chain of more than 60 volcanoes, most of which rise to peaks of 200–500 m from the surrounding seafloor at depths around 4000 m. The Ridge is outside the New Zealand EEZ in international waters.

A fishery for orange roughy (*Hoplostethus atlanticus*) developed on the Louisville Ridge in 1994, mainly by Australian and New Zealand vessels. A summary of the fishery through to the 1996–97 fishing year (1 October–30 September) was given by Clark (1998a, 1998b). Catch and effort data from New Zealand sources were updated for 1997–98 and a full standardised analysis of CPUE was undertaken to evaluate the usefulness of CPUE as an index of abundance for future stock assessment (Clark 1999a). On the basis of results from this last piece of research, the Deepwater Working Group in 2000 approved use of CPUE as an index of abundance in stock assessment modelling. The assessment was updated by Clark (2000) for the 1998–99 fishing year.

The stocks on the Louisville Ridge are regarded as separate from those inside the New Zealand EEZ. The main fishing grounds lie about 600 km east of those on the Chatham Rise. Apart from several knolls on the "Arrow Plateau" just inside the EEZ, there is deep water (over 1500 m) between the New Zealand shelf and slope waters and the Louisville Ridge. Genetic differences may exist between Louisville Ridge and Chatham Rise orange roughy. Allozyme frequencies differed between the Louisville Ridge-Arrow Plateau and the northeastern hills of the Chatham Rise (Smith & Benson 1997) and the Spawning Box (Smith 1998). Smith & Benson (1997) noted that Louisville Ridge fish had relatively high average heterozygosity.

The present work was carried out by NIWA as part of the Ministry of Fisheries research project ORH2000/03 ("Orange roughy fisheries outside the EEZ") for the 2000–01 year. The specific objectives were to update descriptive analyses of commercial catch and effort data and standardised and unstandardised CPUE analyses for the orange roughy fishery with the inclusion of data up to the end of the 1999–2000 fishing year, and to develop stock assessment models and carry out a stock assessment for the fishery. An additional objective of the project, to analyse biological data for the fishery, has been reported by Anderson (2001).

2. REVIEW OF THE FISHERY

2.1 Data sources

Data on catch and effort are recorded by all New Zealand registered deepwater fishing vessels, including charter vessels, on Trawl-Catch-Effort-Processing-Returns (TCEPRs), including when they fish outside the EEZ. These give tow by tow information, with specific location, duration, and estimated catch for each trawl. These data are extracted from the Ministry of Fisheries catch-effort database for use in a number of orange roughy and oreo fisheries. They have been loaded into a database at NIWA and this was the source of all catch and effort information presented here. Other fishing return types (e.g., Catch-Effort-Landing-Returns) are not used in this fishery. Data where orange roughy was the declared target species, or where orange roughy was caught, were extracted from the NIWA database into an Excel spreadsheet for analysis. No data were available for other countries that have fished the area at times (e.g., China, Russia), except Australia.

Data were error-checked. Obvious mistakes in position (e.g., large differences in start and finish coordinates) were corrected, as were positions well outside any other fished area where typing or recording mistakes could be resolved (by examining that vessel's tows in sequence). A large number of tows had misreported longitude, with east and west being confused. This meant tows actually carried out on the Louisville Ridge were reported from off the west coast of the South Island, the Challenger Plateau, and Lord Howe Rise. These mistakes were corrected before analysis:

Fishing year	No. tows corrected
1993–94	28
1994–95	313
1995–96	249
1996–97	41
1997–98	74
1998–99	76
1999–2000	52

The more complete data for the 1999–2000 fishing year means that some of the catch totals and regional catch figures presented in this report differ from those given in previous reports.

Information on Australian catches was provided by the Bureau of Resource Sciences (BRS, Canberra). Data for the 1995 calendar year were obtained from the principal fishing company working the Louisville Ridge. There was previously no requirement for vessels working outside the Australian EEZ to provide tow by tow logs to the Australian Fisheries Management Authority (AFMA), and so details are not readily available. The data from BRS are incomplete, in particular for the last part of 1994, when it is believed that substantial catches were taken (Richard Tilzey, BRS, pers. comm.). No position coordinates were given, and so analysis beyond presentation of general catch totals has not been undertaken. On at least one occasion, an Australian vessel was chartered by a New Zealand company, and landed Louisville fish in New Zealand. New Zealand commercial fishing logbooks were used for this trip, and so the data are included in the New Zealand fleet analyses. An Australian vessel was involved in the fishery in 1998–99, and trawl location data have been provided.

Trawls on the Louisville Ridge have been clustered in three general areas for a number of analyses in this report (following the division by Clark 1998a, 1998b):

- North: from latitudes 35° S to 39.9° S, longitudes 165° W to 172° W.
- Central: latitudes 40° S to 44.9° S, longitudes 160° W to 167° W.
- South: latitudes 45° S to 50° S, longitudes 150° W to 159° W.

2.2 Distribution of the fishery

Fishing activity on the Louisville Ridge has extended from about 35° S to beyond 45° S and from longitudes 172° W to 152.5° W.

The distribution of trawls and catch rate (catch per trawl) of orange roughy are shown in Figure 1. There is a marked change between years. The fishery developed in the central region, and then expanded both north and south as new seamounts were worked. The distribution extended further during 1995–96 and 1996–97 with catches being taken from up to 35° S in the northwest and as far east as 155° W in the south, a distance of about 1800 km. In 1997–98 and 1998–99, fishing focused more in the central region, with less effort and more sporadic catches in the north and south. This trend continued into 1999–2000, with effort in the south dropping further.

2.3 Catch and effort in the fishery

New Zealand vessels first fished the Louisville Ridge in the 1993–94 fishing year. Reported catches rose from about 200 t in that year to over 11 000 t the following year (Table 1). Catches subsequently dropped for the next three years, before an increase in 1998–99. The Australian catch is believed to have been substantial in 1993–94 (primarily August–September 1994) when the fishery first developed. This increased to about 2000 t in 1994–95 before Australian vessels left the fishery. Other nations (e.g., China, Russia) are known to have had some vessels in the area, but their catch is unknown.

Table 1: Reported catch (t) of orange roughy (ORH), smooth oreo (SSO), and black oreo (BOE) from the Louisville Ridge, 1993–94 to 1999–2000 (AUS, Australia; NZ, New Zealand).

Year/Region	Aus ORH	NZ ORH	Total ORH	SSO	BOE
1993–94					
Total	>500	189	>689	9	<1
North		1		0	0
Central		188		9	<1
South		0		0	0
1994–95					
Total	>1 912	11 340	>13 250	251	143
North		159		0	0
Central		10 839		188	10
South		342		63	133
1995–96					
Total	52	8 764	8 816	276	662
North		4 037		3	2
Central		2 876		13	4
South		1 851		260	656
1996–97					
Total	0	3 210	3 210	28	33
North		843		<1	<1
Central		1 666		12	3
South		701		15	29
1997–98					
Total	0	1 404	1 404	39	26
North		335		0	0
Central		1005		35	<1
South		64		4	26
1998–99					
Total	139	3 025	3 164	50	138
North		230		<1	0
Central	139	2580	2 719	6	117
South		214		44	20
1999–2000					
Total		1 333	1333	5	64
North		417		<1	<1
Central		815		3	55
South		101		3	8

There was a marked decrease in New Zealand catch from the central region between 1994–95 and 1995–96 as the other grounds developed (Figure 1). Most catch in 1995–96 came from new grounds worked in the northern region of the Ridge, with southern hills also yielding good catch rates. Catches from the northern region have decreased in recent years, and although up in 1999–2000 are still much lower than in the mid 1990s. Catches in the south have continued to drop.

Oreos have been taken as bycatch in the fishery. Several hundred tonnes were caught in 1994–95 and 1995–96, but reported catches have been relatively small since 1996–97. This is partly a reflection of the reduced effort in southern parts of the ridge, where most oreo (especially black oreo) had been taken previously (Clark 1998a).

Levels of effort in the fishery have varied considerably between years and between regions. Summary statistics of annual catch and effort data are given in Table 2, covering number of vessels, tows, catch, and averages for catch per tow, depth of trawl, distance towed, and vessel tonnage.

Table 2: Summary of orange roughy catch and effort data for New Zealand vessels in the Louisville Ridge fishery, 1993–94 to 1999–00 (number of vessels with ≥ 10 tows in parentheses; No, number; Av, average).

Fishing year	1993–94	1994–95	1995–96	1996–97	1997–98	1998–99	1999–2000
No. tows	134	4294	4024	1849	787	1093	861
No. vessels	7(3)	31(29)	26(24)	16(15)	13(10)	17(15)	12(11)
No. tows ORH target	134	4280	3920	1845	779	1089	848
No. tows zero catch	54	1475	1522	666	423	474	319
% zero catch	40	34	38	36	54	43	37
ORH catch (t)	189	11 340	8 764	3 209	1 404	3 025	1 033
Av. catch ORH (t/tow)	1.4	2.6	2.2	1.7	1.8	2.7	1.5
Av. depth (m)	810	843	851	862	850	810	863
Av. distance (n.m)	3.2	1.6	1.5	1.6	1.2	1.6	1.2
Av. vessel tonnage	1 157	953	1 269	1 468	1 063	712	798

The number of trawls carried out in recent years is about one-quarter of the number in the 1994–95 and 1995–96 years. The number of vessels involved in the fishery has also decreased. Orange roughy is almost exclusively the target species in the fishery, although few records each year specify oreo as the target. Despite the high level of targeting in the fishery, the number of trawls where no orange roughy was caught is high, typically between 30 and 40%. Average catch over the entire year has varied between 1 t/tow and 3 t/tow. The average depth fished, and duration of trawls has varied slightly between years. The size of vessels, as indicated by their gross tonnage, has decreased markedly in the last 2 years.

Data on levels of catch and effort (represented by number of trawls) by month for the three regions are presented in Table 3. The northern area developed in 1995–96 with large catches in the winter months and high levels of effort each month between January and July. Fishing effort in 1997–98, and particularly 1998–99, has been concentrated in June and July. Catch rates in June 1999 were much higher than during 1996–97 and 1997-98. The central region has consistently had the most effort, and yielded most of the catch. Initially catches were large throughout much of the year, but, as typically seen in new fisheries for orange roughy, catches outside the spawning season are not maintained for long. Monthly catch rates started to decrease in 1995–96, and effort in months other than June–August dropped, and have been at relatively low levels since 1996–97. Average catch per trawl during these months have been maintained at similar levels in the last three years. Fishing in the southern area has been sporadic. Most trawls, and catch, have occurred later than in the central and north regions, primarily in July and August.

Daily values of catch and effort are plotted in Figure 2. Each point represents the catch of a single trawl. In the early years of the fishery, effort and good catches were spread over much of the year, but between 1997–98 and 1999–2000 the period of fishing contracted, with most large catches in the June–August months.

Table 3: Summary of catch (t) and effort (number of tows (Nt)) of New Zealand vessels by month by region on the Louisville Ridge. CPUE is given as tonnes per tow, where >10 trawls were carried out; *,<0.1 t/tow.

Area/month	1993–94			1994–95			1995–96			1996–97			1997–98			1998–99			1999–2000		
	t	Nt	CPUE	t	Nt	CPUE	t	Nt	CPUE	t	Nt	CPUE	t	Nt	CPUE	t	Nt	CPUE	t	Nt	CPUE
North																					
Oct		0			0		2.1	18	0.1	4.1	10	0.4	1.2	2			0			0	
Nov		0			0		64.0	24	2.7	118.6	89	1.3		0			0		0.2	6	
Dec		0		0	1		123.8	107	1.2	29.9	83	0.4		0			0			0	
Jan		0		0.1	14	*	22.9	82	0.3		0		58.0	34	1.7		0		0.3	7	
Feb		0		0	1		400.8	147	2.7	81.5	59	1.4	0.4	4			0		5.2	7	
Mar		0		0.5	6		328.0	183	1.8	20.9	37	0.6	0	6			0		16.0	6	
Apr	0.1	2		0.1	5		88.0	164	0.5	76.0	69	1.1	5.9	31	0.2		0			0	
May	0.1	2		2.2	19	0.1	140.1	128	1.1	24.3	36	0.7	50.4	3			0		31.9	104	0.3
Jun		0		151.0	19	7.9	1 381.4	267	5.2	312.2	267	1.2	160.8	68	2.4	208.1	46	4.5	242.8	136	1.8
Jul		0		1.3	18	0.1	1 481.8	202	7.3	175.3	73	2.4	58.6	46	1.3	22.2	61	0.4	121.0	25	4.8
Aug		0		0.4	2		3.4	9			0			0		0	2			0	
Sep	1.0	3		3.5	9		0.5	3			0			0			0			0	
Central																					
Oct		0		24.9	13	1.9	101.8	166	1.6	1.7	19	0.1		0			0			0	
Nov		0		144.3	102	1.4	59.0	160	0.4	2.1	22	0.1		0			0		5.8	39	0.1
Dec		0		338.8	141	2.4	48.4	87	0.6	5.0	29	0.2		0			0			0	
Jan	7.3	2		763.2	293	2.6	537.3	323	1.7	34.0	12	2.8	188.9	58	3.2		0		1.5	2	
Feb		0		1 529.5	303	5.0	48.6	111	0.4	3.8	19	0.2	30.8	36	0.9	0.2	3		0	1	
Mar		0		1 881.2	736	2.5	48.4	87	0.5	2.0	2		12.1	29	0.4		0		27.0	9	
Apr		0		980.6	322	3.0	26.6	58	0.4	227.3	73	3.1	3.9	53	0.1	*	3			0	
May		0		992.5	455	2.2	98.0	132	0.7	37.0	69	0.5		0			0		2.9	9	
Jun		0		1 957.1	497	3.9	1 026.2	701	1.5	545.2	336	1.6	198.8	94	2.1	138.2	94	1.5	254.8	72	3.5
Jul	107.4	52	2.1	1 660.4	751	2.2	820.5	144	5.7	637.0	192	3.3	340.2	143	2.4	1 313.4	440	3.0	255.9	303	0.8
Aug	0.5	6		270.5	269	1.0	61.4	53	1.1	170.5	139	1.2	230.5	85	2.7	1 043.1*	318	3.3	267.4	90	3.0
Sep	72.3	67	1.1	295.8	173	1.7		0			0			0		85.0	4		0	1	
South																					
Oct		0			0		69.2	38	1.8		0			0			0			0	
Nov		0			0		32.1	71	0.4	1.5	12	0.1		0			0		0.6	7	
Dec		0			0		13.9	36	0.4		0			0			0			0	
Jan		0			0		8.0	74	0.1		0		0.1	2			0			0	
Feb		0			0		0.2	9			0			0		42.0	10	4.2		0	
Mar		0			0		0	1			0			0			0			0	
Apr		0			0			0			0			0		0.3	6			0	
May		0			0			0		0	3			0			0			0	
Jun		0			0		0	1			0			0			0			0	
Jul		0			0		560.1	131	4.3	132.3	39	3.4	4.1	17	0.2	3.2	10	3.2	3.7	11	0.3
Aug		0		263.7	24		1 167.9	307	3.8	567.3	160	3.5	59.2	76	0.8	168.8	94	1.8	96.3	25	3.8
Sep		0		77.8	121			0			0			0		0	1			0	

3. CATCH PER UNIT EFFORT

3.1 Unstandardised CPUE

Unstandardised CPUE has been examined previously (e.g., Clark 1998a, 1998b, 1999a), based on mean catch per trawl (i.e., total catch divided by number of tows). This is updated in Table 4. It is clear from Figure 2 that the distribution of effort and catch has changed over time, with a progressive contraction towards the winter months. Consequently unstandardised CPUE is also presented for June to August which have been fished consistently each year.

Most fishing grounds showed reductions in CPUE from peak values in the first 2–3 years to relatively low values in 1997–98. CPUE has increased in all areas in 1998–99, and declined in North and South regions in 1999–2000. The magnitude of these catch rates is, however, much lower than normally experienced in the first few years of the main New Zealand orange roughy fisheries.

Table 4: Average catch rate (t per tow) of orange roughy by New Zealand vessels from the Louisville Ridge, 1993–94 to 1999–00, and by sub-area. The top line is for the entire year, the second line is for June-August.

Area	1993–94	1994–95	1995–96	1996–97	1997–98	1998–99	1999–2000
Total	1.4	2.6	2.2	1.7	1.8	2.7	1.5
	1.9	2.7	3.6	2.1	2.0	2.7	1.9
North	–	1.7	3.0	1.2	1.7	2.0	1.4
		3.9	6.0	1.4	1.9	2.1	2.2
Central	1.5	2.7	1.4	1.8	2.0	3.0	1.5
	1.9	2.6	2.1	2.0	2.4	2.9	1.7
South	–	2.3	2.8	3.3	0.7	1.8	2.3
		11.0	3.9	3.5	0.7	1.7	2.8

The CPUE in winter months is generally higher than for the entire year (Figure 3). The trend in earlier years in North and South differed, but recently the pattern of CPUE has been similar between winter and all months.

The frequency of catches by size has been examined over the last six years of the fishery (Figure 4). There was a steady increase until 1998–99 in the proportion of small catches, with catches of less than 1 t rising from 65% of all tows in 1994–95 to over 80% in 1997–98. Intermediate catch sizes (1–10 t) have tended to decrease in frequency through until 1997–98. Large catches (20 t or more per trawl) have remained similar over time. In 1999–2000 there was an increase in the proportion of small catches.

3.1.1 Individual seamounts CPUE

The Louisville Ridge consists of an extensive chain of seamounts. The distribution of fishing has varied over time between seamounts, and this is thought to have been a confounding factor in previous CPUE analyses (Clark 2000) where broad regions have been considered. The distribution of catch by longitude (Figure 5) shows the location of the main seamounts that have been fished over time. Nine seamounts have been chosen to examine changes in catch and effort on the scale of an individual seamount. These contribute the peaks in catch per tow in Figure 5:

Seamount "name"	Latitude (S)	Longitude (W)
North 1	38.0	191.7
North 2	38.2	192.2
North 3	39.2	192.5
Mt Ghost	40.7	194.6
Mt Whales	40.9	195.0
East 1	41.4	195.7
East 2	41.9	196.3
East 3	42.8	198.1
East 4	43.5	198.6

Over the duration of the fishery, these nine features have accounted for 77% of the tows by New Zealand vessels, and 75% of the orange roughy catch.

All the seamounts have experienced a general decrease in catch rates over time (Figure 6), with broadly similar patterns in winter as the entire year. However, as one might expect, the extent of the decrease has varied between seamounts, indicating that the extent of depletion is unlikely to have been consistent over the large area covered by the fishery. Northern and western seamounts have seen large fluctuations in catch rates, the large central seamounts of Mts Ghost and Whales a more gradual and consistent decline, while those further east are more variable, with East 3 and 4 catch rates dropping markedly in the last fishing year.

The Working Group felt that a combination of seamounts based on the patterns in the unstandardised CPUE was appropriate. This has been followed here, with modification depending upon geographical distribution, and amount of data available.

There are "natural" geographic groupings of these seamounts:

- **North hills:** North 1, North 2, North 3, which are separated by 30 and 45 n.miles respectively
- **Ghost-Whales:** Mts Ghost and Whales. These are distant from the north group by 135 n.miles, and are themselves only 15 n.miles apart
- **East hills:** East 1 and East 2 are 30 n.miles apart, 60 n.miles SE of Mt Whales.
- **East hills(2):** East 3 and East 4 are 50 n.miles apart, but separated from East 2 by 95 n.miles.

The last East group was excluded from the standardised CPUE analysis because of a short time series of data, and a relatively low number of trawls.

The distribution of catch and effort has varied over time between these seamounts (Figure 7). The fishery early on centred on Mts Ghost and Whales, and then quickly spread out to features to the northwest and southeast. Catch rates on the northern seamounts, and Mts Ghost and Whales, have decreased in the last two years.

3.2 Standardised CPUE

3.2.1 Methods

A standardised CPUE analysis was carried out, based on stepwise multiple regression methods described by Doonan (1991), Field (1992), and Vignaux (1994, 1997).

Catch per distance towed was used as the dependent variable, although catch per tow was tested as a sensitivity. Although the fishery is focused on seamounts of the Louisville Ridge, the size of these varies considerably, as does the possible trawl duration along the top and down the sides. Therefore, although catch per tow is often used in this type of fishery assessment (e.g., Field 1992), here it was felt appropriate to use a more robust estimate of catch rate. This was derived from a tow duration times speed calculation, as recorded tow positions were not sufficiently accurate to be meaningful with short tows. Only tows that reported orange roughy as the target species were used.

A combined linear/binomial regression approach was used with the year variable forced into each model, and each regression was run using a forward stepwise procedure. Clark (1999a) evaluated both log-linear and combined methods, and the Working Group concluded the combined approach was the most appropriate. The data generally contained a high proportion of zero catches (40%, 34%, 38%, 36%, 54%, 42%, and 37% in the years 1993–94 to 1999–2000 respectively), and therefore it was likely that a standard log-linear model would not be as appropriate as a "combined model" in which zero and non-zero components are modelled separately and then combined.

The criterion used for determining which predictor variable to add to the model at each stage was the maximum decrease in the Akaike Information Criterion (AIC) which takes into account the degrees of freedom associated with the variables. In addition, an increase in the percentage deviance explained of more than 0.5% was required for a variable to be included in the model.

The year effect indices were calculated from the model using a similar procedure to that of Francis (2001) which provides model prediction in terms of natural units, catch per distance towed or catch per tow (for the linear model) or the probability of a non-zero catch (for the binomial model). To produce these indices, fixed values of the model coefficients must be entered into the model. Hence a mean coefficient value was calculated for each variable, weighted by the number of records associated with each level of the variable. In this way a standardised index is calculated for each year with units which have some meaning. This procedure was also used to examine the effect of the other variables in the model. A final set of indices for the combined model was calculated by simple multiplication of the year indices from the linear model by the indices from the binomial model.

Data from winter months are mainly considered, as the fishery in recent years has operated almost exclusively in June-August. Preliminary analyses were carried out on data from the entire year, and these showed similar results to the more appropriate winter data set. They are not considered in this report.

The Louisville Ridge fishery has had a variable number of vessels over time, and the fleet composition has also varied considerably (Table 4). Although 50 different vessels have fished the area, few have consistently remained in the fishery, or carried out a reasonable number of trawls each year. Individual vessel is input as a categorical variable (as a proxy for fishing experience), but when a vessel has been in the fishery for only 1–2 years, or carried out a small number of tows, the value of including these data is questionable. Therefore only vessels which fished the area in 4 or more years and carried out more than 20 tows per year have been considered (Table 4). These criteria apply to the whole fishery, and effort is often lower and more variable on small groups of seamounts, but it means that vessels which were new to the fishery, or only fished for a few years, and were therefore likely to have less consistent catch rates than the more experienced core group, were excluded. Ten vessels met the criteria, and were included in standardised analyses.

The response variable was either log(tonnes/n.mile) or binomial (0,1), and the set of predictor variables shown in Table 5 was tested in each model. Interactions between sensible combinations of selected variables were also tested. For the regression to be meaningful, the values of the dependent variable should be approximately normally distributed, and therefore a log transformation was made.

For the log-linear regressions, records that showed no orange roughy catch (referred to as "zero tows") were ignored. In a log-linear model these values distort the distribution of values of CPUE, giving them a non-normal spread. By considering the successful tows separately this can be avoided.

Table 4: Distribution of trawls (number of tows) by different vessels (each vessel given a different number) by fishing year. Vessel numbers in bold type are the ten which met the criteria for inclusion in the analyses.

Vessel	1993–94	1994–95	1995–96	1996–97	1997–98	1998–99	1999–2000
1		132			179		
2		72					
3		80	290	37	16	71	126
4		185	27		1		
5		81					
6		127	199	60			
7		512	97		1	55	
8		221					
9		98					
10		150	12	26	30	59	10
11		11					
12		18					
13		6					
14	2	316	15				
15		252	440	4	107	168	
16	23	120	15				
17		28					
18	4	332	468	99	74	94	
19	6	175	176	158	29	16	5
20	52	326	364	440	218		
21		176	34	10	44	91	242
22		57	58	181	50	44	
23		191					
24		275	85	140			
25	41	151				69	148
26		30					
27		27					
28		43	117	16		26	
29	6						
30		82					
32		13	37				
33			208				
34			56				
35		7	717	367	2		
36			75				
37			3				
38			116				
39			9				
40			79	16		44	46
41						5	
42			132	128	36	141	55
43			167	107			
44						65	30
45						23	30
46						118	
47						8	
48							94
49							34
50							39

All records were used in the binomial model and tows were coded 0 or 1 according to whether orange roughy were caught (1) or not (0). The dependent variable then becomes a vector of 1s and 0s. The binomial model will have more influence on the final indices when the proportion of zero tows is high and shows a trend over time. When there is no strong trend and zero tows are infrequent, the model tends to have less influence, adjusting the indices calculated from the log-linear model only slightly.

The three month winter period was split into 13 "week" categories, providing an additional variable to track the progress of the fishery through the known spawning period of orange roughy. The final "week" was 8 days long.

Table 5: Summary of independent variables tested, number of categories in parenthesis (North, Ghost-Whales, East).

Variable	Type	Description
Year	Categorical (7)	Fishing year
Vessel	Categorical (10, 9, 10)	Vessel identification no.
Hill	Categorical (3, 2, 2)	Seamount on which tow occurred
Week	Categorical (13)	Week 1–13 for winter month period
Start time	Continuous	Time (decimal hours) at start of tow
Finish time	Continuous	Time (decimal hours) at end of tow
Longitude	Continuous	Decimal longitude at start of tow
Latitude	Continuous	Decimal latitude at end of tow
Speed	Polynomial	Speed (kts) of vessel at start of tow
Depth	Polynomial	Depth (m) of groundrope at start of tow
Vessel tonnage	Polynomial	Gross tonnage of vessel
Vessel power	Polynomial	Vessel power (kw)
Tow distance	Polynomial	Tow distance (n.miles) – used in catch/tow sensitivities only

3.2.2 Results

(a) Ghost-Whales

The initial log-linear regression on successful tows produced a model describing CPUE with *(year), week, vessel,* and *finish time*. An examination of the effect of finish time on CPUE showed increasing CPUE over the course of a day with a sudden drop in CPUE at midnight. This makes little sense and indicates that the variable may be poorly constructed. The model was re-run without this term but including in interaction between *week* and *vessel*. The interaction term met the model criteria for inclusion but the model did not produce a sensible solution, predicting unrealistically high CPUE values for few variable combinations, and so this interaction was disregarded. Although it is likely that the pattern of fishing success over these 13 weeks will differ between vessels, as the interaction term indicates, the data are not well balanced and the model is likely to have been fitting to unusual values in a few cells based on a small amount of data. The final log-linear model includes *year, week,* and *vessel* only.

The predictor *year* explained 7.2% deviance, and *week* provided the most explanatory power increasing the percentage deviance explained by 12.7% (Table 6). A moderate amount of the total deviance (26%) is explained by the three predictors selected.

Table 6: Final model fits for the log/linear regression for Ghost-Whales. DoF, degrees of freedom; AIC, Akaike Information Criteria.

	DoF	Deviance	Residual DoF	Residual deviance	Percentage deviance explained	Additional % deviance explained	AIC
Year	6	174.7	606	2 249.7	7.2	7.2	811.0
Week	12	307.3	594	1 942.5	19.9	12.7	745.0
Vessel	8	164.8	586	1 777.6	26.7	6.8	706.6

The binomial model for Ghost-Whales data selected four variables into the model in addition to *year*: *vessel*, *week*, and third order polynomials of *depth* and *speed*. Interactions were tested for each combination of these selected variables and, as in the linear regression, *vessel:week* was selected. This term explained an additional 7% deviance but was rejected as again the model produced an unrealistic solution with either very high or very low probabilities predicted for most combinations. The *vessel* term provides the most explanatory power (10.5% increase), followed by *year* and *week*, with *depth* and *speed* only weakly influential. These four predictors explain a total of 25.3% of the total deviance (Table 7).

Table 7: Final model fits for the binomial regression for Ghost-Whales. DoF, degrees of freedom; AIC, Akaike Information Criteria.

	DoF	Deviance	Residual DoF	Residual deviance	Percentage deviance explained	Additional % deviance explained	AIC
Year	6	60.6	841	940.4	6.1	6.1	954.4
Vessel	8	105.5	833	834.8	16.6	10.5	864.8
Week	12	65.3	821	769.5	23.1	6.5	823.5
Poly(depth, 3)	3	11.5	818	758.1	24.3	1.1	818.1
Poly(speed, 3)	3	10.0	815	748.1	25.3	1.0	814.1

Predicted CPUE or non-zero catch probability for the selected model variables in the linear and binomial models is shown in Figure 8. The scales on the y-axis represent either the predicted catch rate (for the linear model) or the predicted probability of a non-zero catch (for the binomial model). The model predicts very high catch rates for the 1997–98 fishing year and low values for all other years. Several very high catch rates in the 1997–98 fishing year are strongly influencing this result. The probability of a non-zero catch shows little pattern over time. The model also predicts the highest catch rates in the early part of this winter period with a rapid reduction in the central period followed by increasing catch rates late in the period. This is accompanied by a declining probability of a non-zero catch throughout most of the period. Predicted mean catch rates vary widely between vessels (from about 0.1 to 2.1 t/n.mile) but the probability of a non-zero catch is fairly consistent between vessels. The probability of a non-zero tow increases with depth to a maximum at about 800 m. The right hand tail of this plot shows a subsequent increase in the likelihood of a non-zero catch at depths greater than 1200 m, but this is likely to be the result of a combination of a lack of data for these deeper tows and the fitting requirements of the polynomial function. A similar pattern is shown for the influence of vessel speed on CPUE. More than 75% of tows recorded a vessel speed of 2.5 knots and it is at about this speed that CPUE is predicted to be at a maximum.

The year indices from each model and the combined index (linear index*binomial index) are given in Table 8. The binomial model has little influence on the final indices and with a high value for 1997–98 does nothing to offset the large index from the linear model.

Table 8: Year indices for Ghost-Whales from the log-linear, binomial, and combined models.

Year	Log-linear index	Binomial index	Combined index
1993–94	0.83	0.94	0.79
1994–95	1.24	0.88	1.10
1995–96	0.76	0.72	0.55
1996–97	0.24	0.81	0.19
1997–98	31.59	0.94	29.71
1998–99	1.08	0.89	0.96
1999–2000	4.12	0.94	3.86

(b) North hills

The log-linear regression described CPUE for the North hills complex with *(year)*, *week*, the square of *speed*, and *vessel*. No interaction terms were accepted into the model. The *year* variable explains most of the variability in the data (17% deviance) with *week* the next most influential (Table 9). This model explains a moderate amount (27.4%) of the total deviance in the data.

Table 9: Final model fits for the log/linear regression for North hills. DoF, degrees of freedom; AIC, Akaike Information Criteria.

	DoF	Deviance	Residual DoF	Residual deviance	Percentage deviance explained	Additional % deviance explained	AIC
Year	5	394.3	440	1 875.6	17.4	17.4	652.6
Week	9	114.0	431	1 761.6	22.4	5.0	642.7
Speed^2	1	44.4	430	1 717.2	24.3	2.0	633.3
Vessel	9	69.3	421	1 647.9	27.4	3.1	632.9

The binomial model for this area includes the variables *(year)*, *vessel*, *hill*, and the cubic polynomial of *depth* (expressed in Table 10 as individual terms). This model is weak in its explanatory power with only 8.7% of the total deviance explained.

Table 10: Final model fits for the binomial regression for North hills. DoF, degrees of freedom; AIC, Akaike Information Criteria.

	DoF	Deviance	Residual DoF	Residual deviance	Percentage deviance explained	Additional % deviance explained	AIC
Year	5	13.3	674	862.2	1.5	1.5	86 233.0
Vessel	9	46.6	665	815.6	6.8	5.3	81 586.1
Hill	2	10.3	663	805.2	8.0	1.2	80 558.8
Depth	1	4.5	662	800.7	8.5	0.5	80 108.2
Depth^3	1	1.1	661	799.6	8.7	0.1	79 998.8
Depth^2	1	0.0	660	799.6	8.7	0.0	79 996.4

Predicted CPUE or non-zero catch probability for these models is shown in Figure 9. This model, like the Ghost-Whales one, predicts high catch rates for fishing in the 1997–98 fishing year. Very low (under 0.4 t/n.mile) values are predicted for 1996–97 and the final two years and moderate values for the 1994–95 and 1995–96 years. The probability of a non-zero catch decreases gradually up until

1998–99 then jumps back to the level of the earliest years in 1999–2000. Catch rates are highly variable between vessels, as is the probability of a non-zero catch. The model predicts steadily decreasing CPUE over the first four weeks of winter but becomes very erratic after this with no clear pattern through July and August. Hill N2 shows about twice the probability of a non-zero catch predicted for hill N1. The model predicts decreasing catch rate with increasing speed, particularly through the range of the most common trawling speeds (2–4 knots), and increasing probability of a non-zero catch with depth, to a maximum at about 1000 m.

The year indices from each model and the combined index (linear index*binomial index) are given in Table 11. The relatively low value for 1997–98 in the binomial model reduced slightly the influence of the large value in the linear model for this year, but the final indices fail to form a pattern of declining value over time as might be expected if CPUE was tracking the expected decline in abundance. This set of indices is an improvement over that from Ghost-Whales, however, with high values also shown for 1994–95 and 1995–96 and low values in later years excluding 1997–98.

Table 11: Year indices for North hills from the log-linear, binomial, and combined models.

Year	Log-linear index	Binomial index	Combined index
1994–95	2.204	0.802	1.768
1995–96	2.056	0.762	1.567
1996–97	0.327	0.670	0.219
1997–98	3.802	0.620	2.356
1998–99	0.249	0.502	0.125
1999–00	0.262	0.762	0.199

(c) East hills

The log-linear regression selected four predictors: *(year)*, *vessel*, *week*, and *latitude*. No interaction terms were accepted into the model. The *year* predictor explained only 5% of the deviance but *vessel* (25%) and *week* (10.9%) had a very strong influence in the model with *latitude* having a small effect. The model overall explained a large amount of the total deviance (42.7%) (Table 12).

Table 12: Final model fits for the log-linear regression for East hills. DoF, degrees of freedom; AIC, Akaike Information Criteria.

	DoF	Deviance	Residual DoF	Residual deviance	Percentage deviance explained	Additional % deviance explained	AIC
Year	5	128.2	367	2 241.1	5.4	5.4	680.9
Vessel	9	595.4	358	1 645.7	30.5	25.1	583.7
Week	12	258.4	346	1 387.3	41.4	10.9	543.9
Latitude	1	29.0	345	1 358.3	42.7	1.2	538.1

Three predictors were selected for the binomial model for the East hills data: *(year)*, *vessel*, and the cubic polynomial of *depth*. Only *vessel* is shown to have a strong influence on non-zero catch probability, explaining an additional 9% deviance out of a model total of 12.5% (Table 13).

Table 13: Final model fits for the binomial regression for East hills. DoF, degrees of freedom; AIC, Akaike Information Criteria.

	DoF	Deviance	Residual DoF	Residual deviance	Percentage deviance explained	Additional % deviance explained	AIC
Year	5	13.2	595	784.6	1.7	1.7	796.6
Vessel	9	71.5	586	713.1	10.6	9.0	743.1
Depth	1	9.7	585	703.4	11.8	1.2	735.4
$Depth^2$	1	3.3	584	700.2	12.2	0.4	734.2
$Depth^3$	1	2.2	583	698.0	12.5	0.3	734.0

Predicted CPUE or non-zero catch probability for the East hills models is shown in Figure 10. The linear model predicts high catch rates for the 1997–98 fishing year compared with all other years and shows a similar pattern of catch rate over time to the other two areas examined. Slightly higher catch rates are predicted for 1994–95 and 1996–97 than for the remaining three years. The probability of a non-zero catch is variable in the first few years, but generally shows an increase over time with the highest values in 1996–97 and 1999–2000. Catch rates vary little between eight of the ten vessels, but one vessel has a predicted catch rate of about twice that of the other vessels and another a rate about five times greater. The probability of a non-zero catch is quite variable between vessels, with a range of about 0.3 to 0.9. The model predicts a rapid increase in catch rate early in the period to a peak in week 3. The catch rate drops rapidly again in weeks 4 and 5 then gradually over the remaining weeks. The highest catch rates are predicted for the tows that are more in the southern regions of these hills and it is notable that the model selected latitude ahead of the categorical *hill* variable. The model predicts the probability of a non-zero catch to be at a maximum in quite shallow depths, somewhere less than 700 m, although more than 95% of tows in the data were deeper than 700 m.

The year indices from each model and the combined index (linear index*binomial index) are given in Table 14. The binomial model has the greatest influence on the 1995–96 index, as the very low probability of a non-zero catch in that year reduces greatly the relative value from the linear model. The 1997–98 year stands out again in this set of indices with by far the highest value, and the values for the other years are all relatively low and show little pattern.

Table 14: Year indices for East hills from the log-linear, binomial, and combined models.

Year	Log-linear index	Binomial index	Combined index
1994–95	0.799	0.43	0.34
1995–96	0.382	0.11	0.04
1996–97	0.753	0.77	0.58
1997–98	2.664	0.53	1.43
1998–99	0.272	0.56	0.15
1999–00	0.285	0.69	0.20

3.2.3 Sensitivities

The pattern of CPUE over time shown in each of these models does not appear to track the decline in abundance expected with intensive fishing and the known landings in the Louisville Ridge over this period, mainly due in each case to a very high index for the 1997–98 fishing year. A closer examination of the tow by tow data for 1997–98 showed that, for each area, several trawls recorded very high catch per nautical mile due to high catches from very short tows and also that one vessel was responsible for a high percentage of the higher catch rate records. To test the effect of these two factors in the linear models, each was rerun, first without the high catch rate vessel, then with t/tow in place of t/n.mile as the dependant variable. Only the variables selected from the initial model were offered to the model, except that for the t/tow model *distance* was also included as a variable. These sensitivities were not tested in the binomial models as these models had a much smaller influence on the final index.

The results of these sensitivities are shown in Figure 11. In the Ghost-Whales models the effects of excluding the high catch rate vessel and of using t/tow as the dependent variable are very similar. In both cases the sharp increase in the index in 1997–98 is much reduced and the indices for most other years remain almost unchanged. In addition, the index for the 1999–2000 year from the alternative models is much smaller than for the base case. For the North hills area the effect on the indices of using t/tow as the dependent variable is slight and does not reduce the relative value of the 1997–98 index. Excluding the high catch rate vessel, however, has a pronounced effect on the 1997–98 index, bringing it to a level more in line with the other values. For this model alone a general pattern of declining CPUE over time is produced. The alternative models had no useful influence on the East hills area, with the exclusion of the high catch rate vessel having almost no effect and substituting t/tow as the dependent variable only making the 1997–98 index greater relative to the other years.

4. STOCK ASSESSMENT

A deterministic stock reduction technique (after Francis 1990) was used to attempt to estimate virgin biomass (B_0) and current biomass (B_{curr}) for the Louisville orange roughy stock(s). The model was fitted to standardised CPUE indices (without interaction effects) using maximum likelihood, assuming normal errors, and an assumed c.v. for the CPUE indices of 0.3. In common with other orange roughy assessments, the maximum exploitation rate was set at 0.67. The model treats sexes separately, and assumes a Beverton-Holt stock-recruit relationship.

Biological parameters were assumed the same as those applied for the Chatham Rise stock (see Annala et al. 1999). Catch history information is incomplete for early years of the fishery when several foreign vessels were known to have fished the Ridge. There is no known record of their catches. Therefore, the assumed catch history is that derived from New Zealand and Australian catch records. Overrun of reported catch (e.g., burst bags, inappropriate conversion factors) was assumed to be zero, as even if there was some, it is likely that it was similar between years.

The model was not able to estimate virgin biomass within reasonable bounds for any of the three seamount groups. The stock reduction analysis uses the impact of catch on CPUE to estimate virgin biomass. Because there was little contrast or overall trend in standardised CPUE, the model could not determine an upper bound for the seamount populations. Even for the linear indices from the sensitivity analyses where one major vessel was removed, virgin biomass could be estimated for only one seamount group (Table 15).

Table 15: Estimates of B_0 and B_{min} for the full dataset, and for the dataset with one high performing vessel removed, for the three seamount groups. NA, could not be estimated.

	B_0		
Seamount group	Full data	Less one vessel	B_{min}
Ghost-Whales	NA	NA	3 900 t
North	NA	5 800 t	4 400 t
East	NA	NA	2 300 t

5. DISCUSSION

The indices derived from both unstandardised and standardised analyses of catch and effort data do not appear to perform well in tracking abundance. The winter series show little contrast over time, which was noted by Clark (2000) in comparison with data from the full fishing year. The latter, however, is of limited use in recent years when most fishing has occurred during the winter months. In general, CPUE in winter has been variable, high in 1998, but low in other years. It seems unlikely that true abundance would change so much between years. The large increase in 1998 may to an extent be due to relatively low effort that year, which could have reduced the effect of heavy fishing pressure disrupting aggregations, and therefore increasing CPUE. The high CPUE in 1998 was caused in part by a single very successful vessel, but even when that vessel was removed the trend was the same, although less pronounced. It is possible that on some seamount features the distribution of aggregations is variable and dynamic, which makes the fishery more "hit-or-miss", and limits the usefulness of CPUE as a measure of abundance.

Although biomass and yield cannot be estimated for the seamount groups examined here, decreasing catches over time, and generally low values of CPUE, suggest that stock sizes are small. Seamount fisheries typically show a pattern of decreasing catch rates over time (Clark 1999b), and careful management is required to avoid localised depletion of the fish stocks. However, the Louisville Ridge fishery is unregulated, and although there has been discussion between New Zealand and Australian officials on joint management of deepwater fisheries in the general Australasian region, this has not to date dealt with the Louisville Ridge. The fishing grounds are distant from New Zealand, and with declining catches, the number of vessels fishing there has decreased from the numbers in 1994–95 and 1995–96. However, this in itself does not guarantee a self-regulating fishery. Once vessels are committed to going to the Ridge, even if catch rates are low, they will tend to stay and fish what is there quite hard to make the trip pay.

The change in scale of the analysis tried this year, from large regions to smaller groups of seamounts, has not provided clearer answers. Nevertheless, with a fishery that has changed its distribution over time, examination of catch and effort data over smaller areas is appropriate. Monitoring of the fishery should continue, as levels of effort and catch can be variable, seamount fisheries can be vulnerable to rapid overexploitation, and the changes observed to date do not suggest there is a large stock/s on the Ridge.

6. ACKNOWLEDGMENTS

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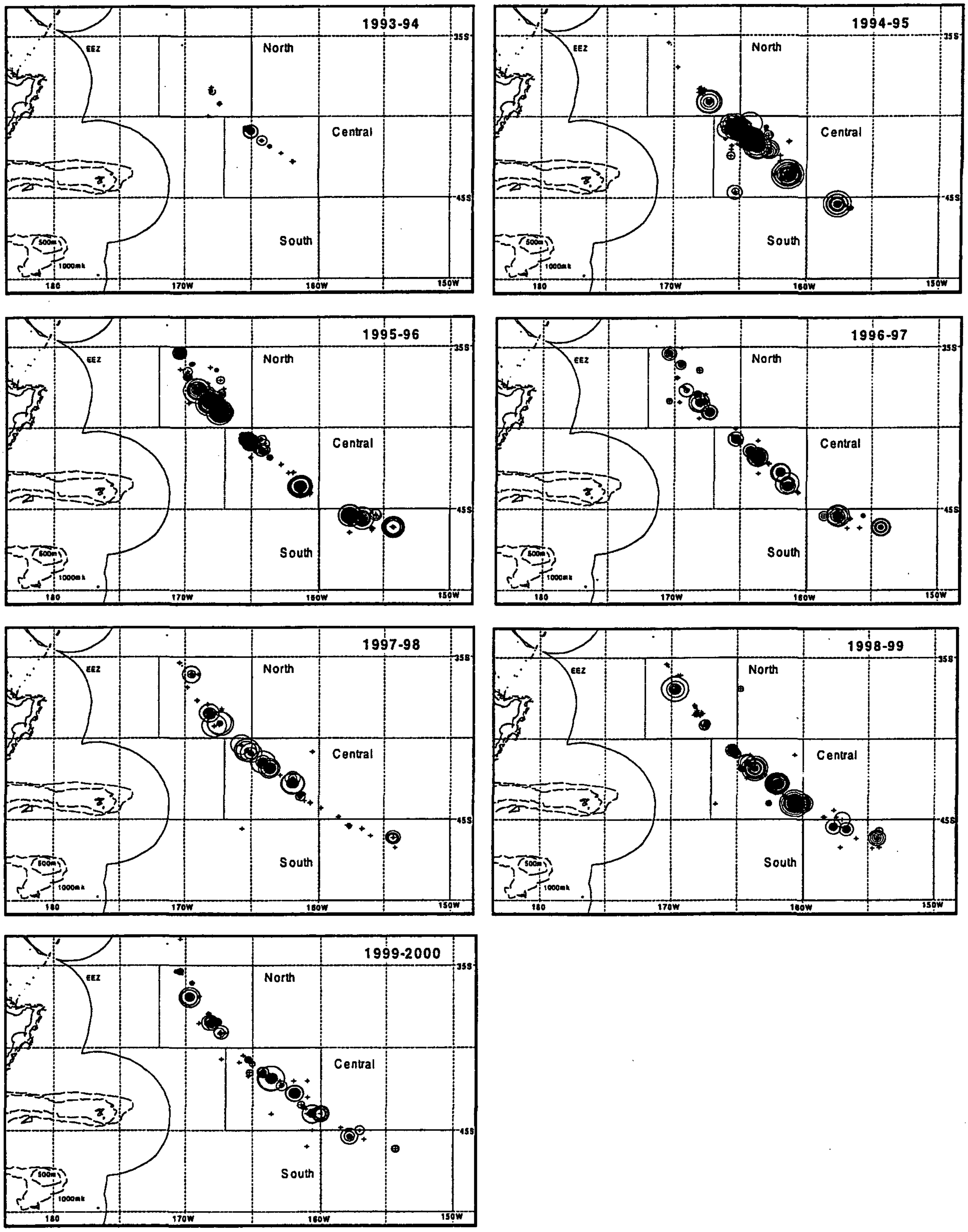

Figure 1: Distribution of catch rate of orange roughy (catch per trawl) on the Louisville Ridge, 1993-94 to 1999-2000 fishing years (circle size proportional to catch, maximum = 80 t).

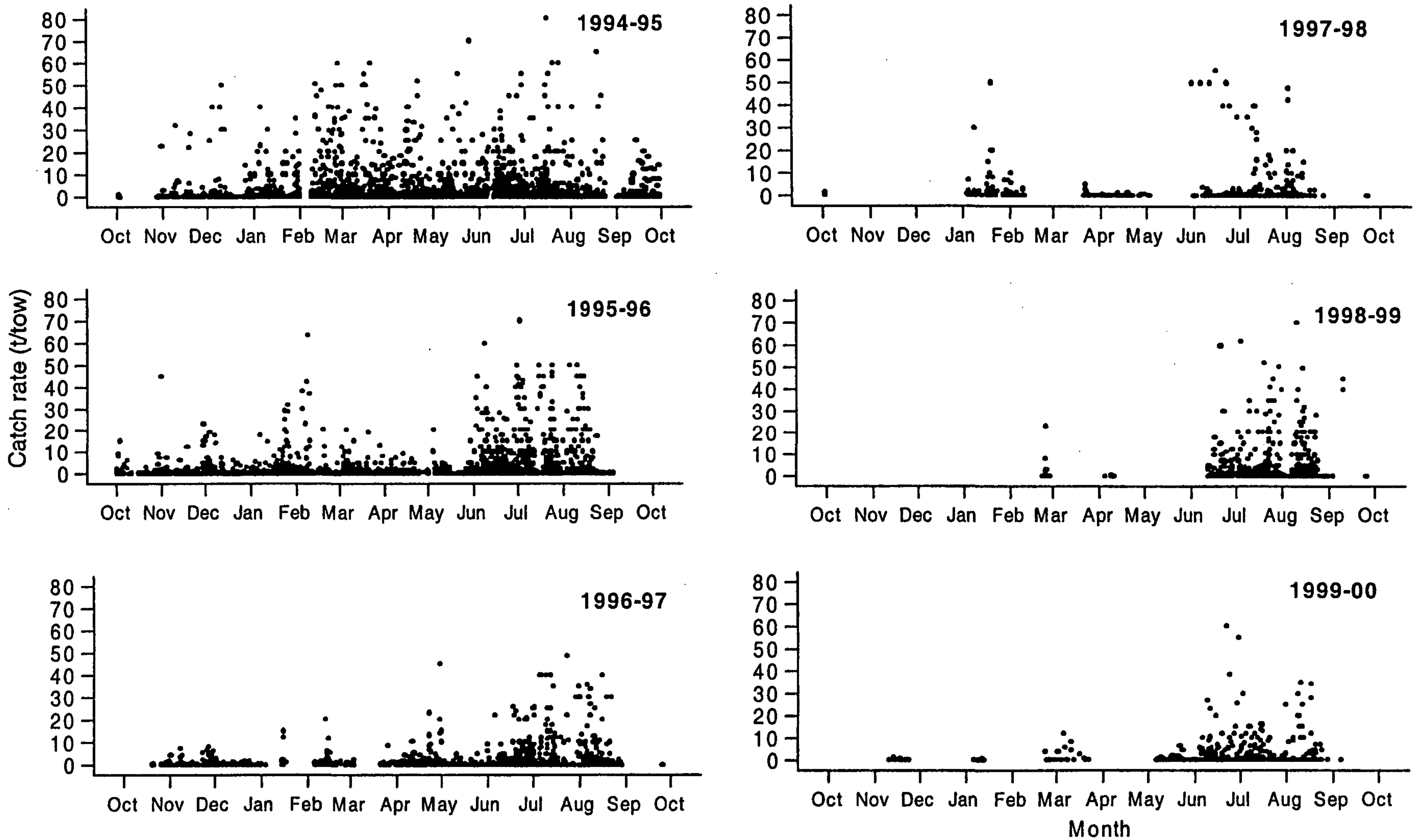

Figure 2: Catch rate profiles (t/tow for individual trawls) of orange roughy on the Louisville Ridge by fishing year.

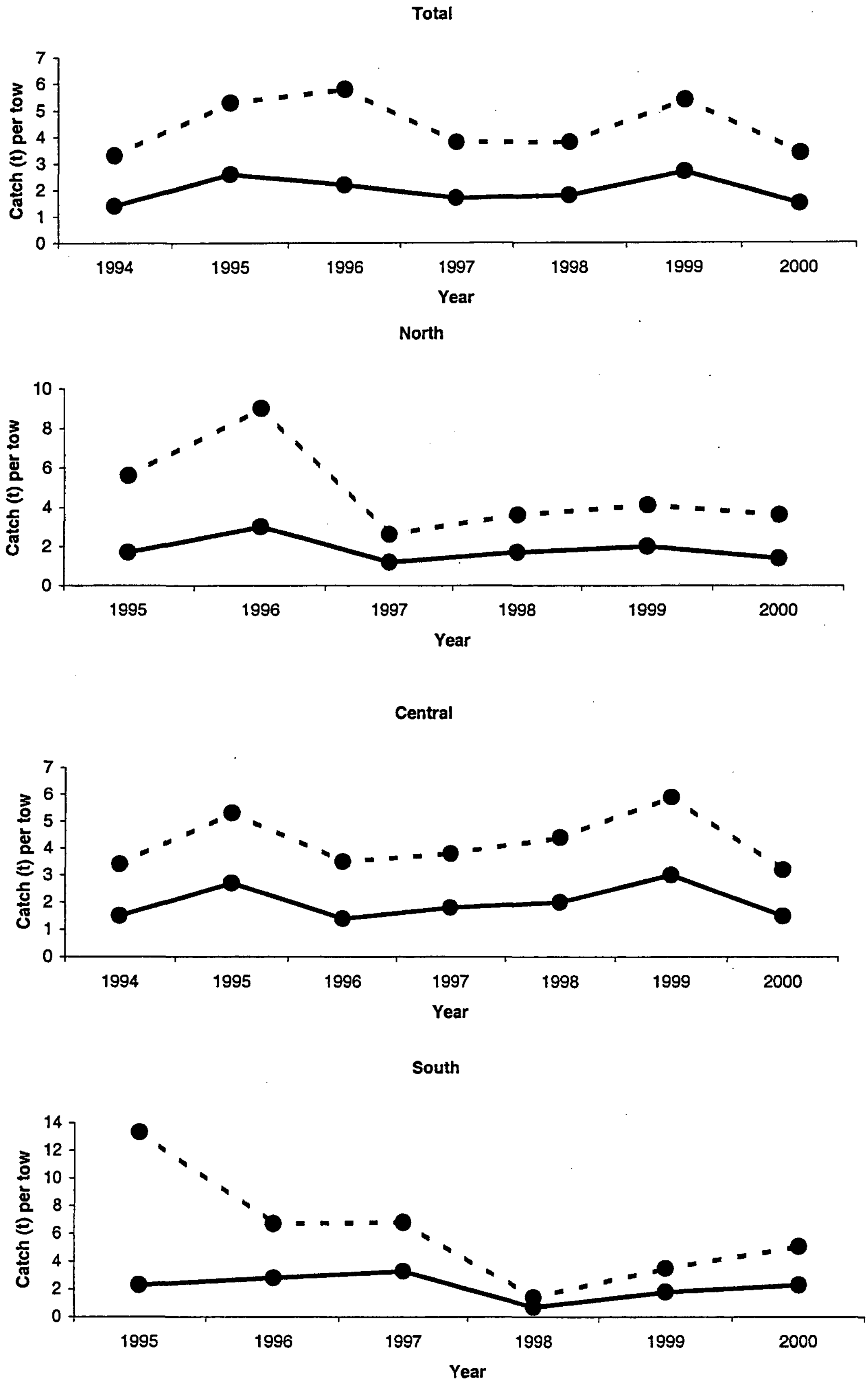

Figure 3: Unstandardised CPUE (t/tow) by area by year for all months (solid line) and for the winter period (dashed line).

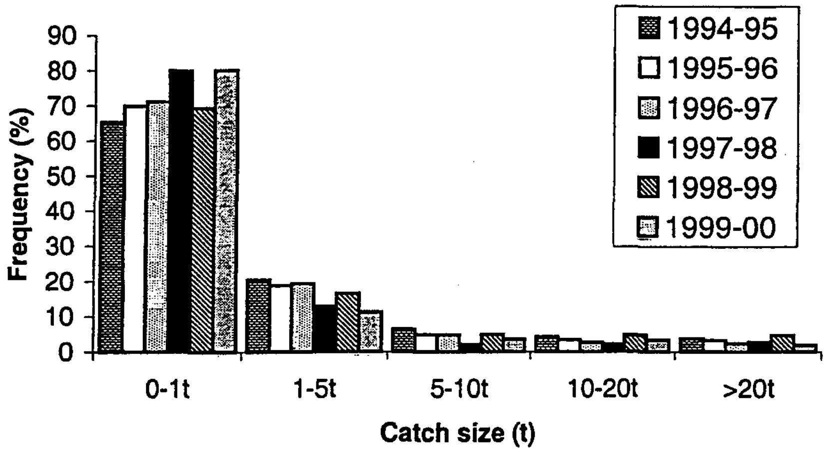

Figure 4: Plot of catch size frequency per tow of orange roughy by New Zealand vessels for five catch levels during the recent years of fishing.

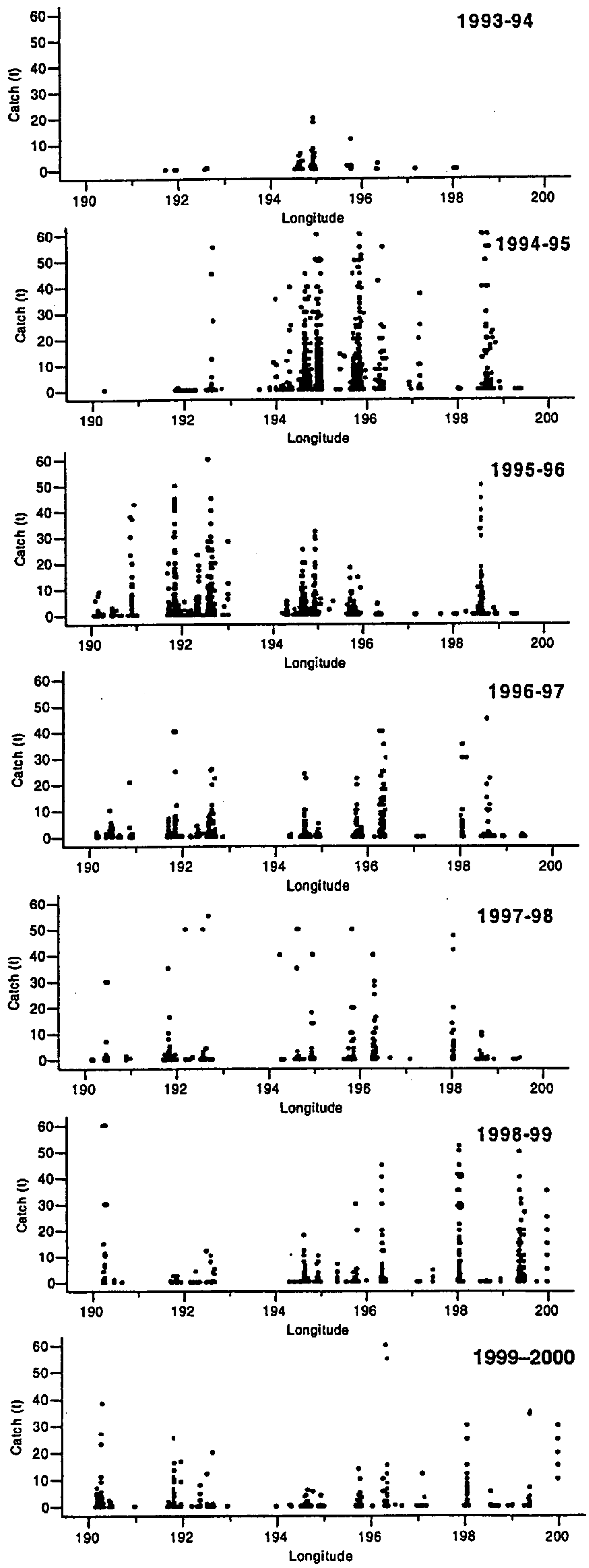

Figure 5: Catch rates (t/tow) of orange roughy by fishing year by longitude for the area of main fishing grounds on the Louisville Ridge.

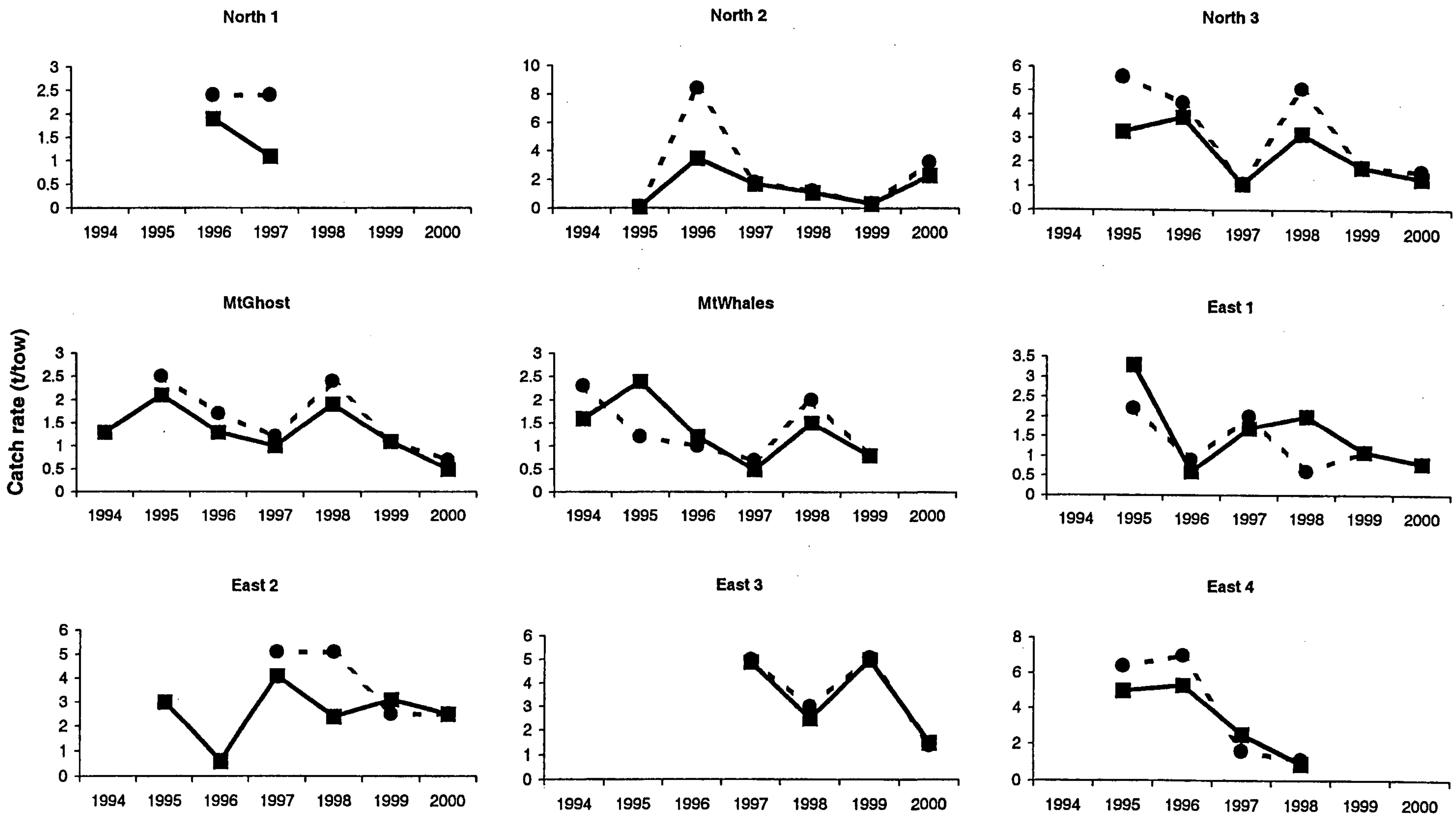

Figure 6: Changes in catch rate (t/tow) of orange roughy for the total year (solid line) and winter months (dashed line) for seamounts on the Louisville Ridge.

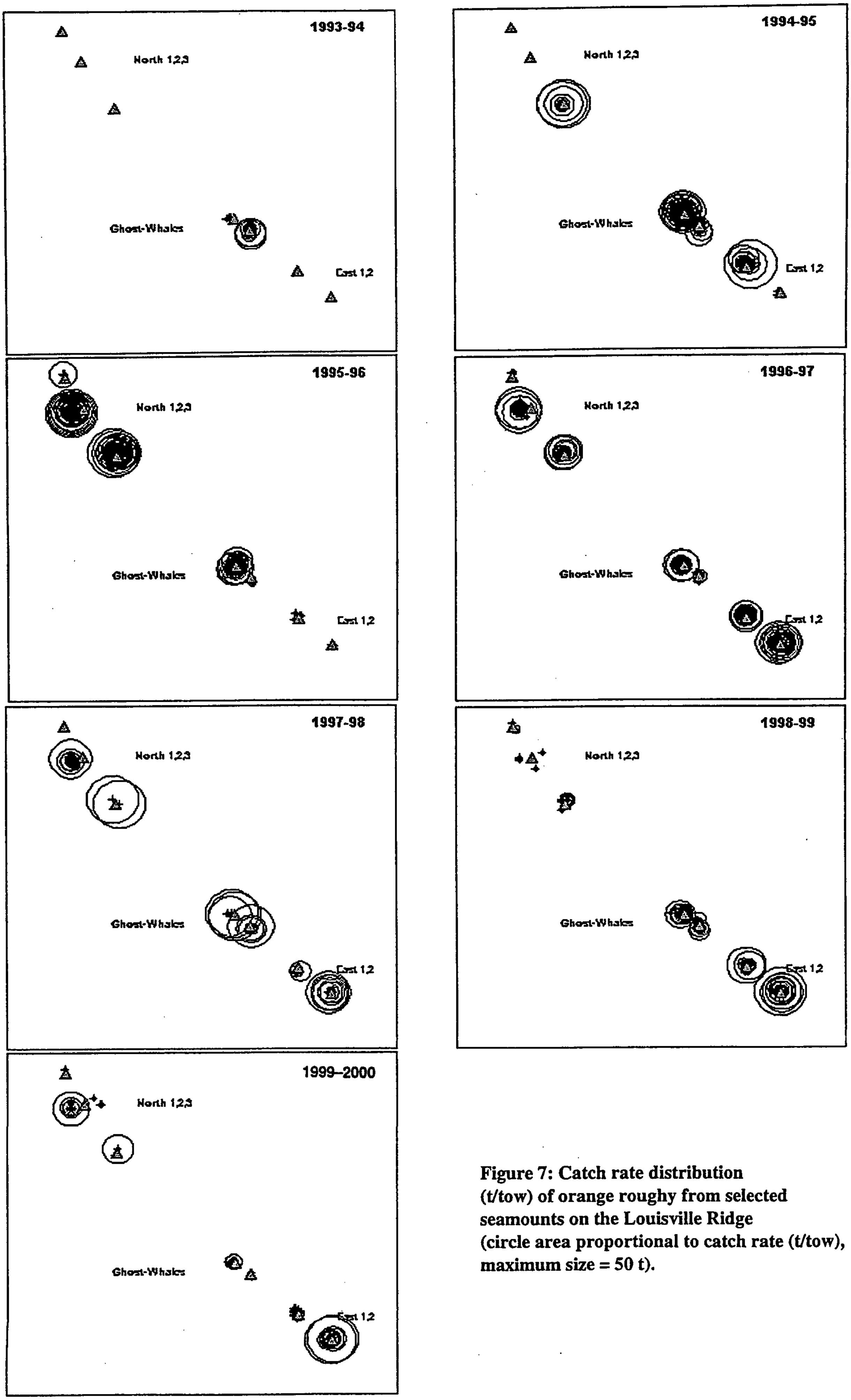

Figure 7: Catch rate distribution (t/tow) of orange roughy from selected seamounts on the Louisville Ridge (circle area proportional to catch rate (t/tow), maximum size = 50 t).

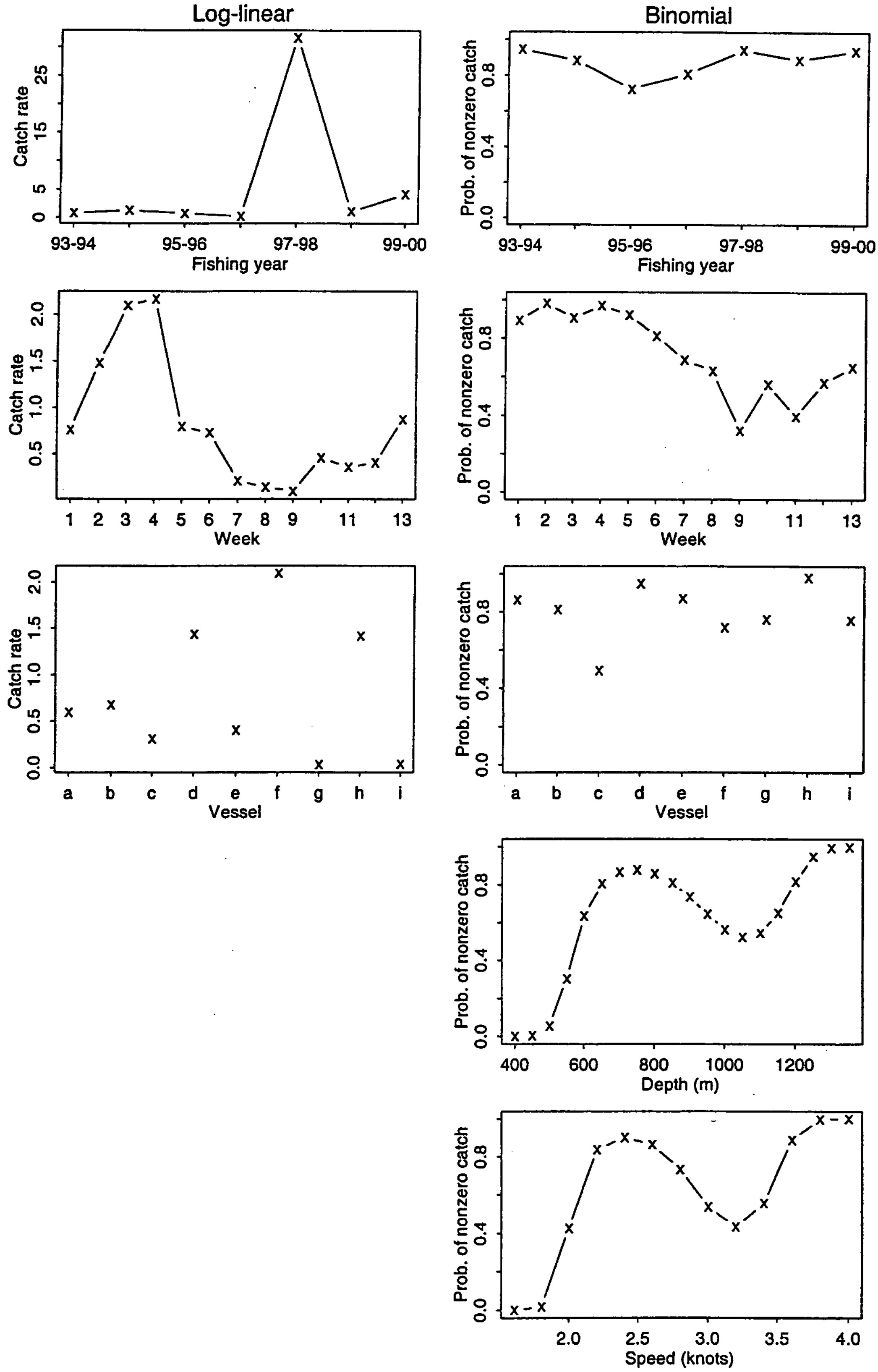

Figure 8: Ghost-Whales model predictions. Catch rates (left panel, t/n.mile) from the log/linear model by fishing year, week, and vessel. Non-zero catch probabilities (right panel) from the binomial model for the same predictors plus depth and speed. Predictions are based on mean weighted coefficient values for each model variable.

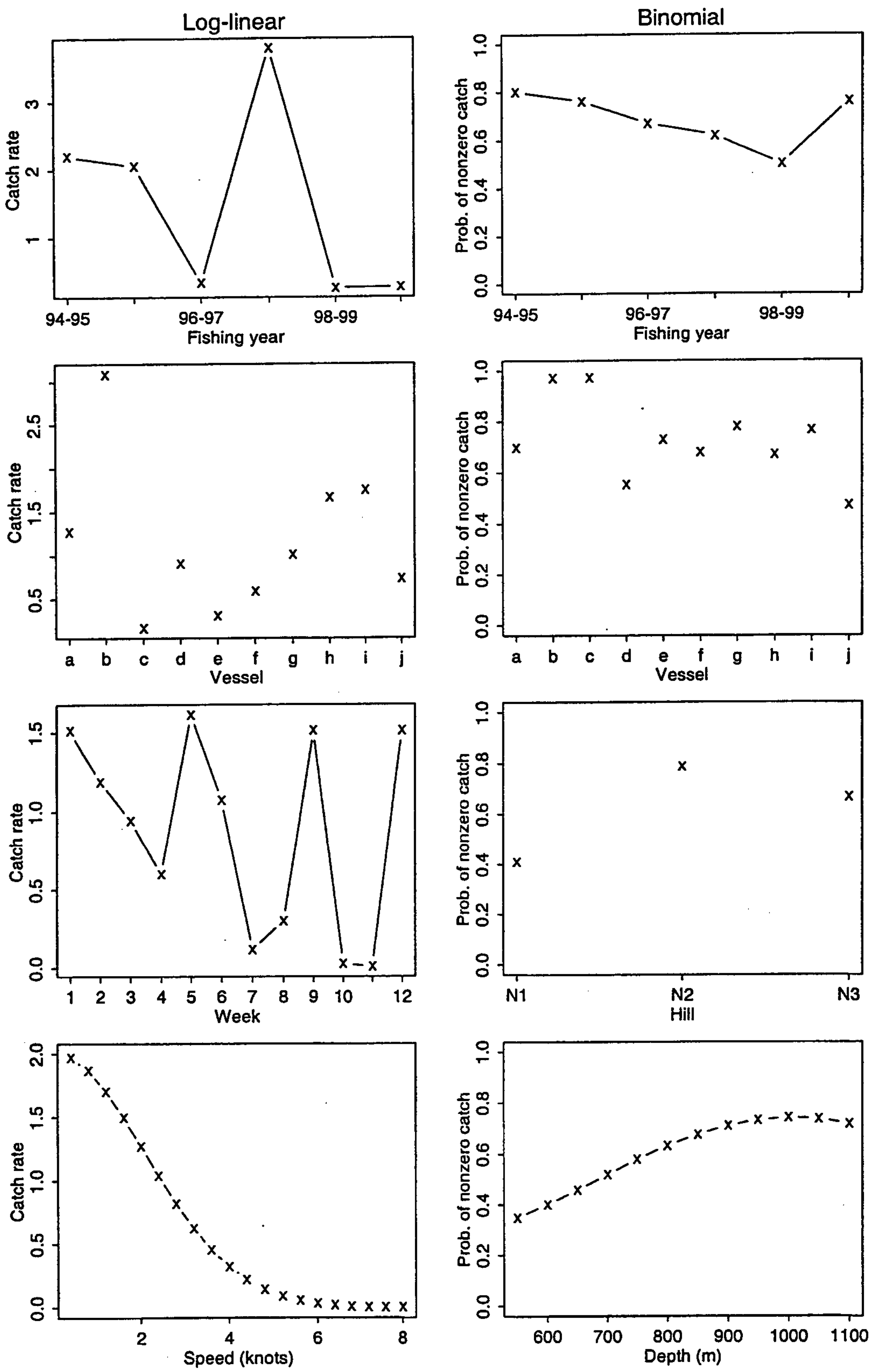

Figure 9: North hills model predictions. Catch rates (left panel, t/n.mile) from the log/linear model by fishing year, vessel, week, and speed. Non-zero catch probabilities (right panel) from the binomial model for fishing year, vessel, hill, and depth. Predictions are based on mean weighted coefficient values for each model variable.

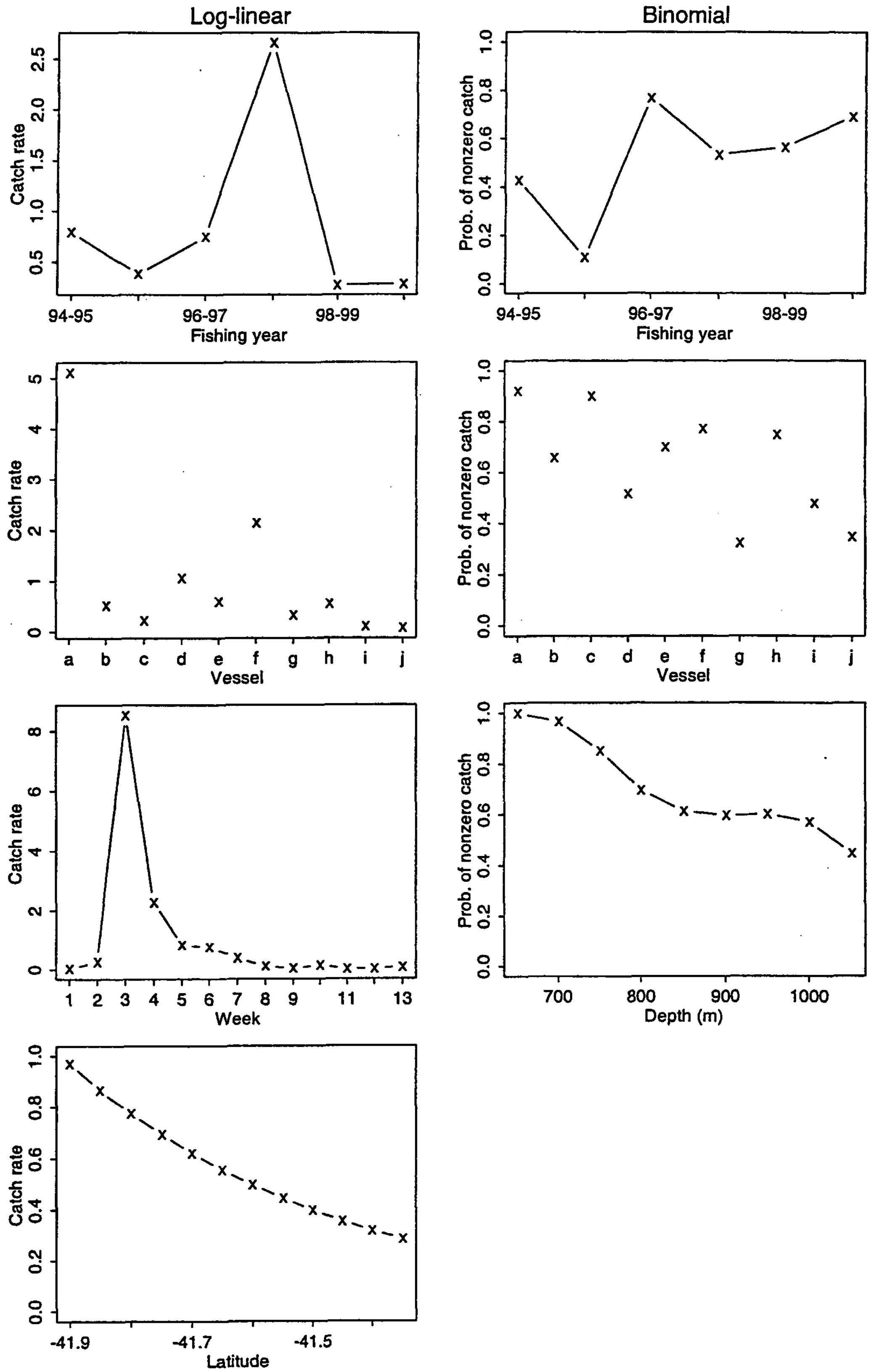

Figure 10: East hills model predictions. Catch rates (left panel, t/n.mile) from the log/linear model by fishing year, vessel, week, and latitude. Non-zero catch probabilities (right panel) from the binomial model for fishing year, vessel, and depth. Predictions are based on mean weighted coefficient values for each model variable.

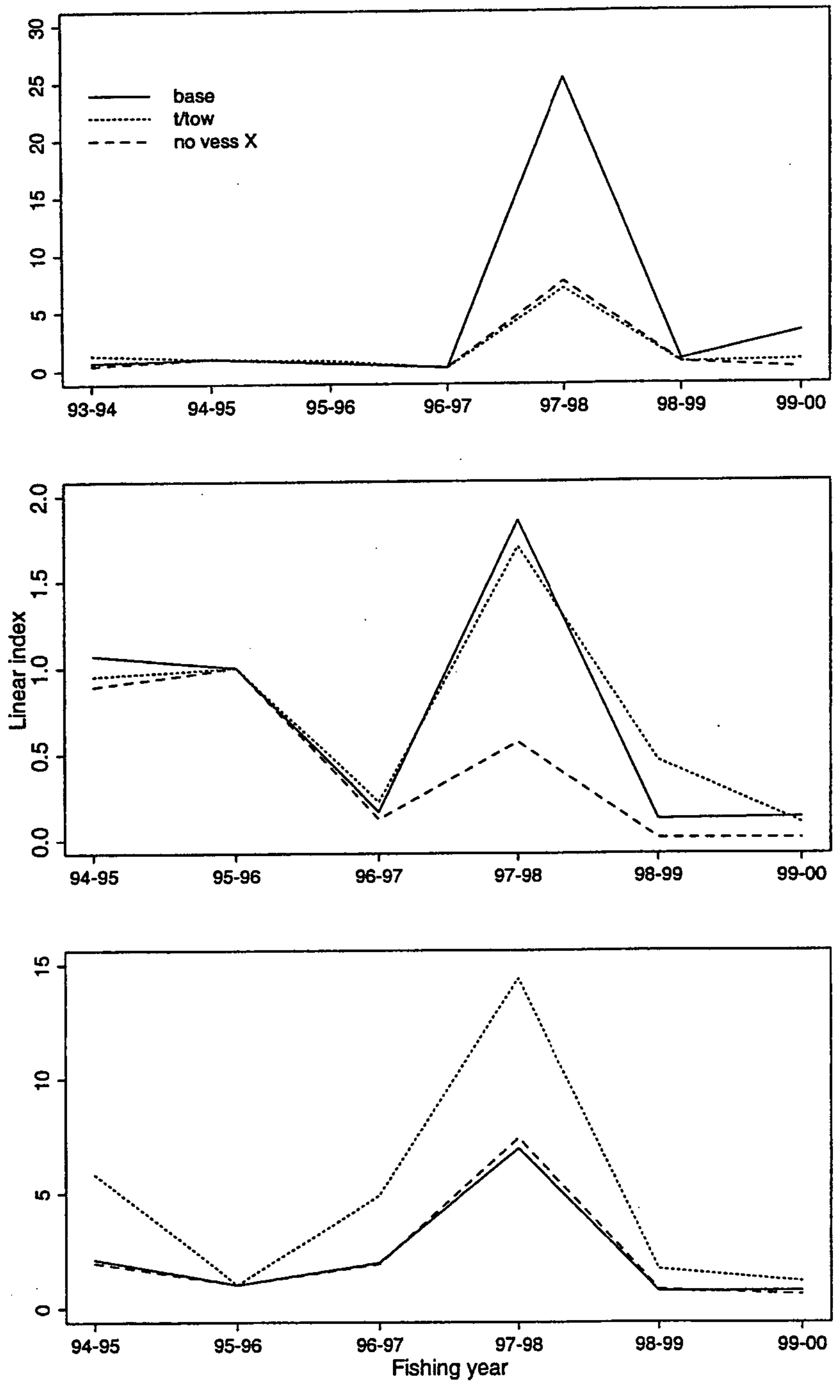

Figure 11: Linear model year indices for the base case model, for a model with t/tow as the dependent variable, and for a model excluding a high catch rate vessel (no vess X), for Ghost-Whales (top), North hills (middle), and East hills (bottom). Indices are scaled to the base year (1994–95).