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EXECUTIVE SUMMARY

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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 2000–01 fishing year. Catch and effort summaries have been compiled using data from the Quota Management System (QMS), based on individual tow records from TCEPR and HSCER 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 for the last two years, although this may be incomplete for 2000–01. The level of effort in the fishery (both number of vessels and number of trawls) has varied over time in a similar pattern to that of the overall catch.

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 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.

A more detailed examination of CPUE has been carried out for 11 seamounts or seamount groups in an attempt to improve the description for a fishery where changes in fishing patterns on small spatial scales can confound broader regional analyses. Standardised CPUE indices were calculated for three seamount groups. A linear 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 able to estimate virgin biomass within reasonable bounds for only one of the three groups. 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 southeast for over 4000 km from the Kermadec Ridge. 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, and by Clark & Anderson (2001).

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 ORH2001/03 ("Orange roughy fisheries outside the EEZ") for the 2001–02 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 2000–01 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 & Langley (2002).

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) or High Seas Catch-Effort-Returns (HS-CERs). 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. There are no other deepwater bottom trawl fisheries on the Ridge, so these criteria should capture all the relevant data.

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). Historically a large number of tows had misrecorded 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, including reallocation of data from other areas to the Louisville Ridge, were corrected before analysis (Table 1).

Table 1: Summary of data corrections for the Louisville Ridge fishery data.

Fishing year	No. tows corrected	Total no. tows
1993–94	28	134
1994–95	313	4294
1995–96	249	4024
1996–97	41	1849
1997–98	74	787
1998–99	76	1093
1999–2000	30	918
2000–01	13	711

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 by Clark & Anderson (2001).

Information on previous 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. No data were available for other countries that have fished the area at times (e.g., China, Russia) and there are no estimates of the level of catch or effort.

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)(see Figure 1):

- 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. Effort in the south dropped further in 1999–2000. Several good catches were taken in the southern region during 2000–01, but most effort and catch was spread over central and north areas.

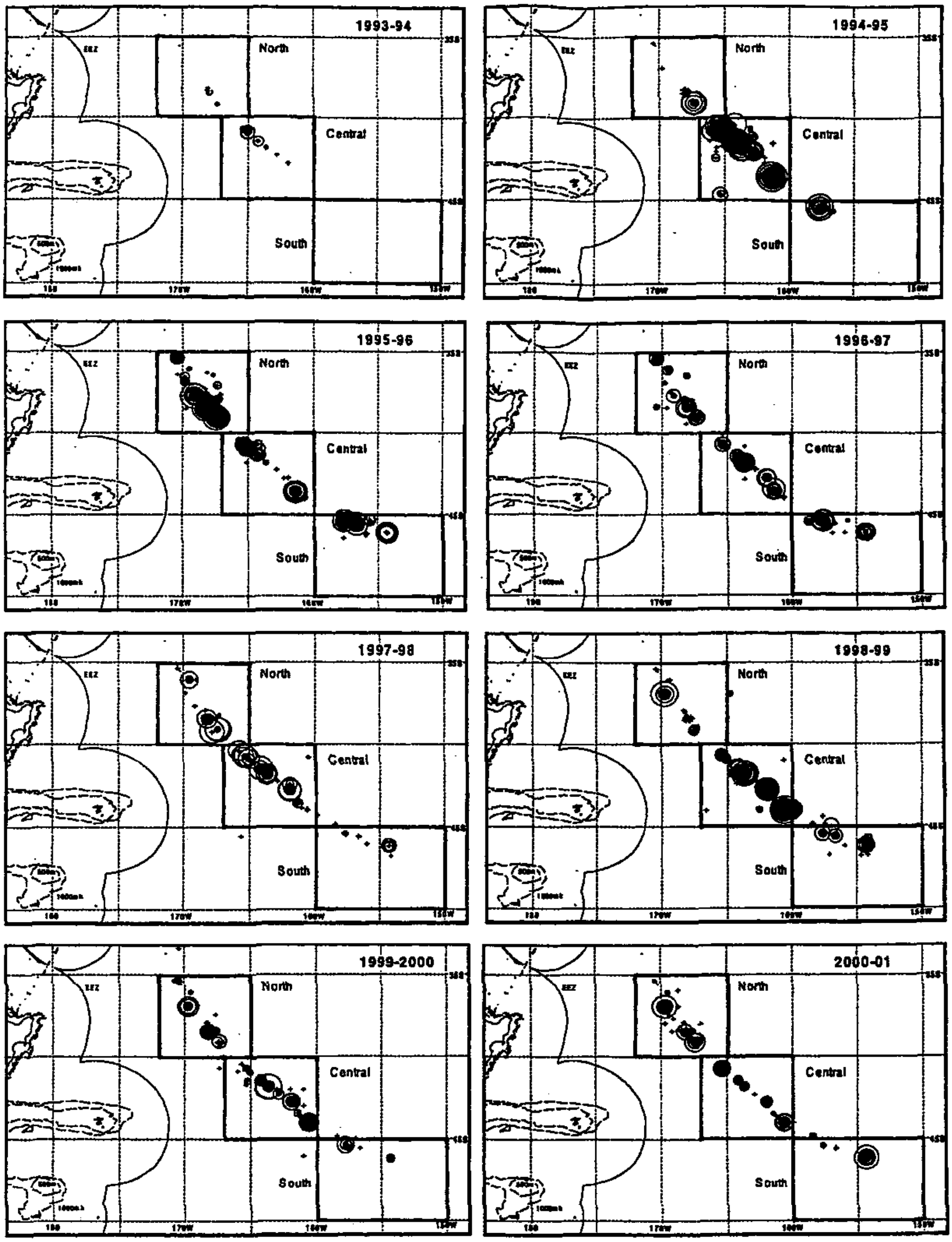

Figure 1: Distribution of catch rate of orange roughy (catch per trawl) on the Louisville Ridge, 1993–94 to 2000–01 fishing years (circle size proportional to catch, maximum = 80 t).

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 2). 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.

Table 2: 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	138	50
North		230		0	<1
Central		2580		117	6
South		214		20	44
1999–2000					
Total	0	1 369	1369	66	6
North		450		<1	<1
Central		819		60	4
South		100		6	2
2000–01					
Total	0	1363	>1363	107	10
North		667		1	1
Central		511		106	9
South		185		<1	<1

The distribution of New Zealand catch has varied between years. The fishery developed in the central region in 1994–95, but catches there decreased in 1995–96 as other grounds developed in the northern region of the Ridge, with southern seamounts also yielding good catch rates (Figure 1). Catches from northern and central regions have fluctuated in recent years, and are still much lower than in the mid 1990s. Catches in the south have continued to be low.

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). Oreo catches now comprise more smooth oreo, mainly from the central area.

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 3, covering number of vessels, tows, catch, and averages for catch per tow, depth of trawl, distance towed, and vessel tonnage.

Table 3: Summary of orange roughy catch and effort data for New Zealand vessels in the Louisville Ridge fishery, 1993–94 to 1999–2000 (number of vessels with ≥ 10 tows in parentheses; No, number).

Fishing year	1993–94	1994–95	1995–96	1996–97	1997–98	1998–99	1999–2000	2000–01
No. tows	134	4294	4024	1849	787	1093	918	711
No. vessels	7(3)	31(29)	26(24)	16(15)	13(10)	17(15)	12(11)	11(10)
No. tows ORH target	134	4280	3920	1845	779	1089	903	707
No. tows zero catch	54	1475	1522	666	423	474	342	247
% zero catch	40	34	38	36	54	43	37	35
ORH catch (t)	189	11 340	8 764	3 209	1 404	3 025	1 369	1 363
Mean catch ORH (t/tow)	1.4	2.6	2.2	1.7	1.8	2.7	1.5	1.9
Mean depth (m)	810	843	851	862	850	810	899	870
Mean distance (n.mile)	3.2	1.6	1.5	1.6	1.2	1.6	1.1	1.4
Mean vessel tonnage	1 157	953	1 269	1 468	1 063	712	818	514

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 a 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%. Mean catch over the entire year has varied between 1.4 and 2.7 t/tow. The mean depth fished, and duration of trawls, has varied slightly between years. The size of vessels, as indicated by their gross tonnage, decreased markedly in 1998–99, and dropped again for 2000–01.

Data on levels of catch and effort (represented by number of trawls) by month for the three regions are presented in Table 4. The northern area developed in 1995–96 with large catches in the winter and high levels of effort 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 from 1997–98 onwards the period of fishing contracted, with most large catches in the June–August months.

Table 4: 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			2000–01		
	t	Nt	CPUE	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			0	
Nov		0			0		64.0	24	2.7	118.6	89	1.3		0			0		0.2	6			0	
Dec		0		0	1		123.8	107	1.2	29.9	83	0.4		0			0			0			0	
Jan		0		0.1	14	*	22.9	82	0.3		0		58.0	34	1.7		0		0.3	7			0	
Feb		0		0	1		400.8	147	2.7	81.5	59	1.4	0.4	4			0		5.2	7		23.5	32	0.7
Mar		0		0.5	6		328.0	183	1.8	20.9	37	0.6	0	6			0		15.9	5			0	
Apr	0.1	2		0.1	5		88.0	164	0.5	76.0	69	1.1	5.9	31	0.2		0			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		31.2	101	0.3	13.1	12	1.1
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	244.2	148	1.6	524.1	195	2.7
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	153.0	43	3.6	106.2	94	1.1
Aug		0		0.4	2		3.4	9			0			0		0	2			0			0	
Sep	1.0	3		3.5	9		0.5	3			0			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			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		0	
Dec		0		338.8	141	2.4	48.4	87	0.6	5.0	29	0.2		0			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			0	
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		57.2	35	1.6
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			0	
Apr		0		980.6	322	3.0	26.6	58	0.4	227.3	73	3.1	3.9	53	0.1	*	3			0			0	
May		0		992.5	455	2.2	98.0	132	0.7	37.0	69	0.5		0			0		2.9	9			0	
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	255.2	79	3.2	121.0	83	1.5
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	257.8	316	0.8	106.0	117	0.9
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	268.5	89	3.0	227.0	42	5.4
Sep	72.3	67	1.1	295.8	173	1.7		0			0			0		85.0	4		0.3	13	*		0	
South																								
Oct		0			0		69.2	38	1.8		0			0			0			0			0	
Nov		0			0		32.1	71	0.4	1.5	12	0.1		0			0		0.6	7			0	
Dec		0			0		13.9	36	0.4		0			0			0			0			0	
Jan		0			0		8.0	74	0.1		0		0.1	2			0			0			0	
Feb		0			0		0.2	9			0			0		42.0	10	4.2		0			0	
Mar		0			0		0	1			0			0			0			0			0	
Apr		0			0			0			0			0		0.3	6			0			0	
May		0			0			0		0	3			0			0			0			0	
Jun		0			0		0	1			0			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	0.9	1	
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	184.0	100	1.8
Sep		0		77.8	121			0			0			0		0	1			0			0	

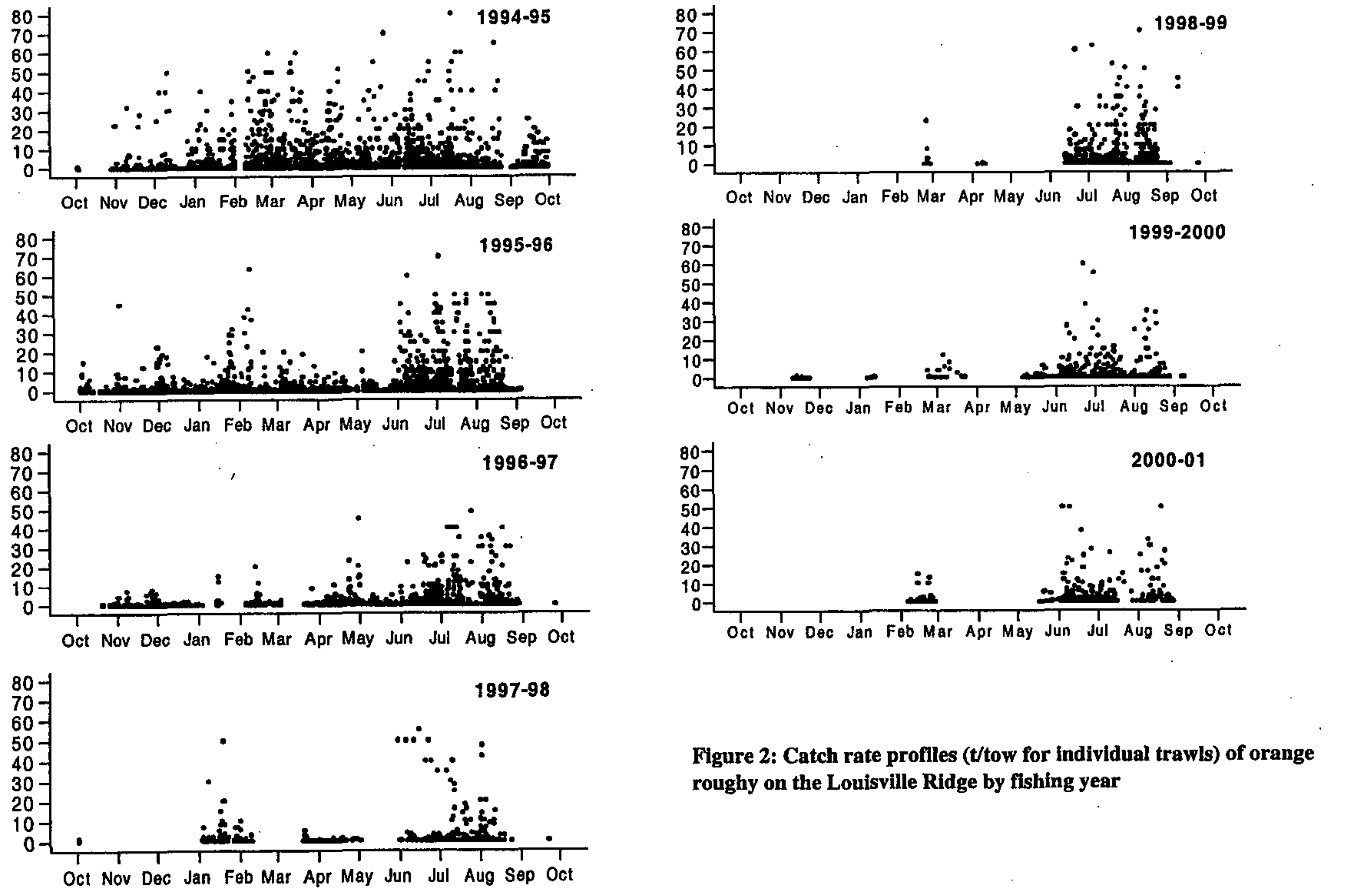

Figure 2: Catch rate profiles (t/tow for individual trawls) of orange roughy on the Louisville Ridge by fishing year

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 5. The progressive contraction in distribution of effort and catch towards the winter months means unstandardised CPUE is also presented for the June to August period which has 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 increased in all areas in 1998–99, and declined in North and Central regions in 1999–2000, and in the South in 2000–01. The magnitude of these catch rates is, however, much lower than experienced in the first few years of the main New Zealand orange roughy fisheries on the Chatham Rise, Challenger Plateau, and Ritchie Banks.

Table 5: Average catch rate (t per tow) of orange roughy by New Zealand vessels from the Louisville Ridge, 1993–94 to 2000–01, and by sub-area. The top line is for the entire year, the second line is for June-August.

Area	1993–94	94–95	95–96	96–97	97–98	98–99	99–2000	2000–01
Total	1.4	2.6	2.2	1.7	1.8	2.7	1.5	1.9
	1.9	2.7	3.6	2.1	2.0	2.7	1.8	2.0
North	–	1.7	3.0	1.2	1.7	2.0	1.4	2.0
		3.9	6.0	1.4	1.9	2.1	2.1	2.2
Central	1.5	2.7	1.4	1.8	2.0	3.0	1.5	1.8
	1.9	2.6	2.1	2.0	2.4	2.9	1.6	1.9
South	–	2.3	2.8	3.3	0.7	1.8	2.3	1.8
		11.0	3.9	3.5	0.7	1.7	2.8	1.8

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, as the fishery has occurred predominantly in winter.

The frequency of catches by size has been examined over the last six years of the fishery. 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 4) shows the location of the main seamounts that have been fished over time. Nine seamounts were chosen by Clark & Anderson (2001) to examine changes in catch and effort on the scale of an individual seamount. These account for the main peaks in catch per tow in Figure 5, with the addition of two further seamounts ("Far North" and "Far East") this year where more data are available (Table 6).

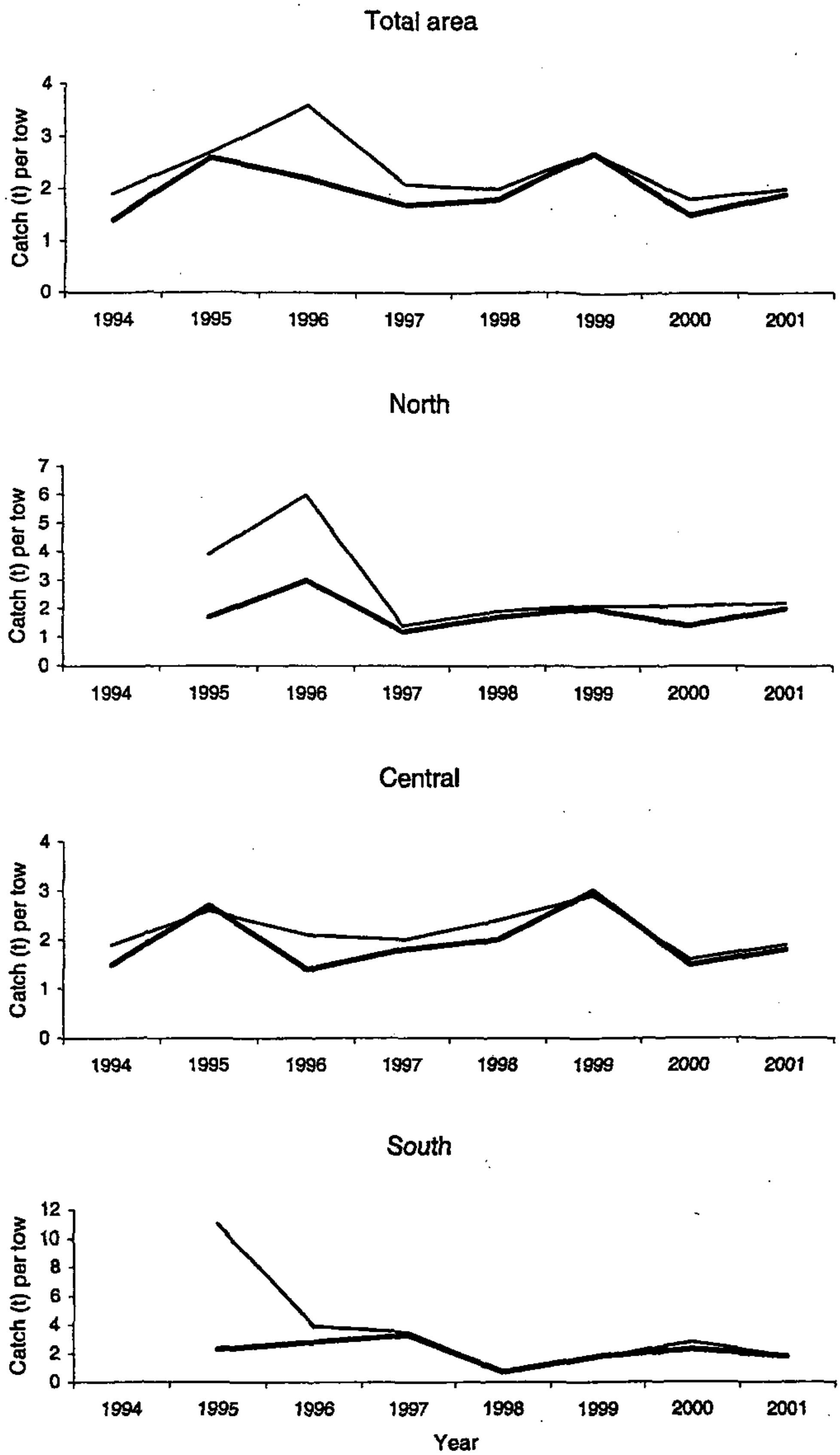

Figure 3: Unstandardised CPUE (t/tow) by area by year for all months (heavy line) and for the winter period (thin line).

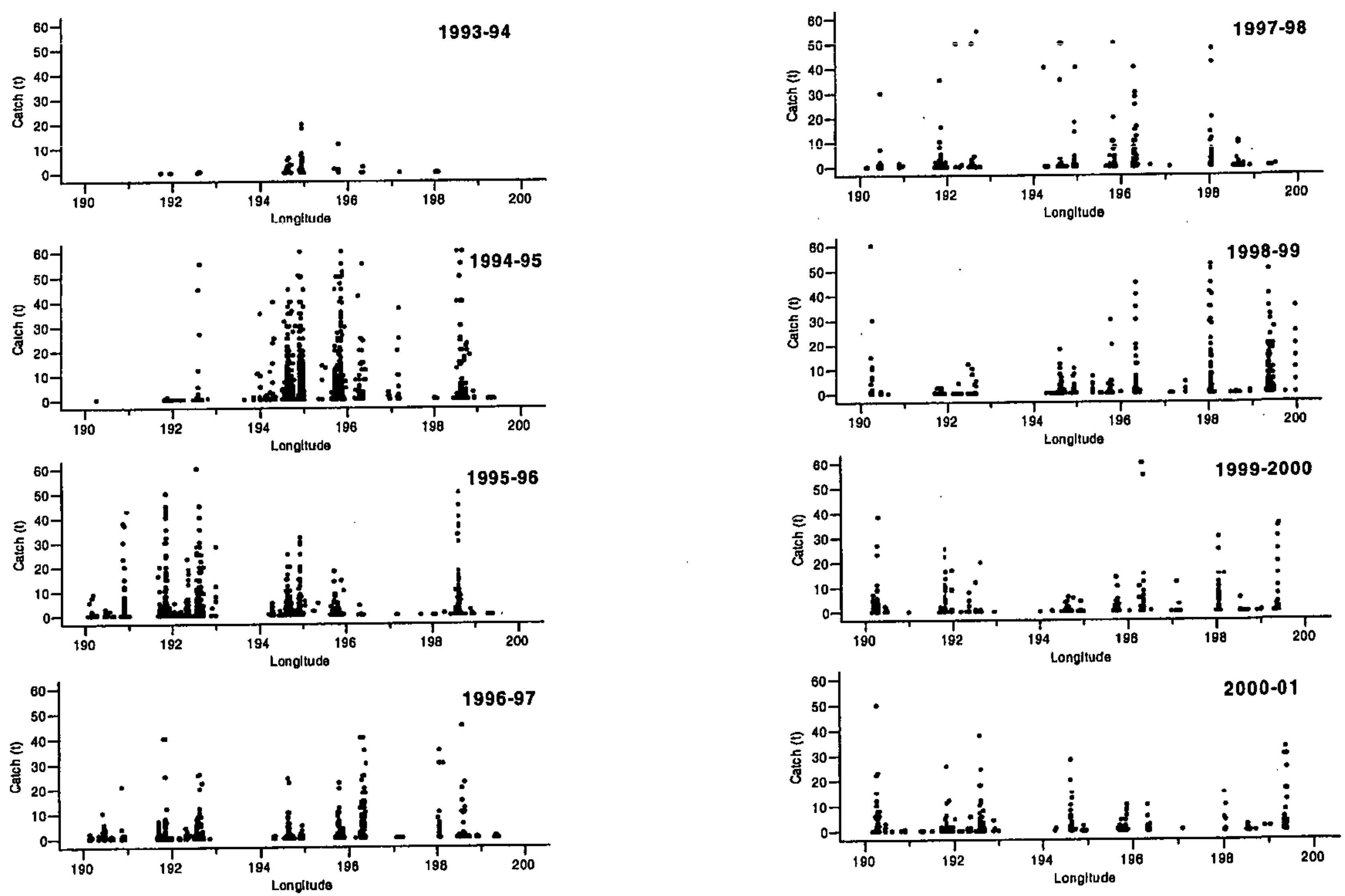

Figure 4: Catch rates (t/tow) of orange roughy by fishing year by longitude for the main fishing region of the Louisville Ridge.

Table 6: Position and depth at peak for the selected seamounts.

Seamount "name"	Latitude (S)	Longitude (W)	Depth at peak (m)
Far North	36.9	190.3	955
North 1	38.0	191.7	~1000
North 2	38.2	192.2	250
North 3	39.2	192.5	878
Mt Ghost	40.7	194.6	720
Mt Whales	40.9	195.0	662
East 1	41.4	195.7	784
East 2	41.9	196.3	918
East 3	42.8	198.1	810
East 4	43.5	198.6	690
Far East	44.0	199.4	740

Over the duration of the fishery, these 11 features have accounted for 81% of the tows by New Zealand vessels, and 80% of the orange roughy catch.

All the seamounts have experienced a general decrease in catch rates over time (Figure 5), 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, and the major central seamounts of Mts Ghost and Whales a more gradual and consistent decline to 2000–01 when high catch rates occurred on Mt Ghost. Those further east are more variable, although East 2, 3, and 4 catch rates have dropped markedly in recent fishing years.

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. Far North is 100 n.miles northwest of North 1.
- **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. Far East is a further 100 n.miles to the southeast.

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. Far North and North 1 were also dropped because of few years of data.

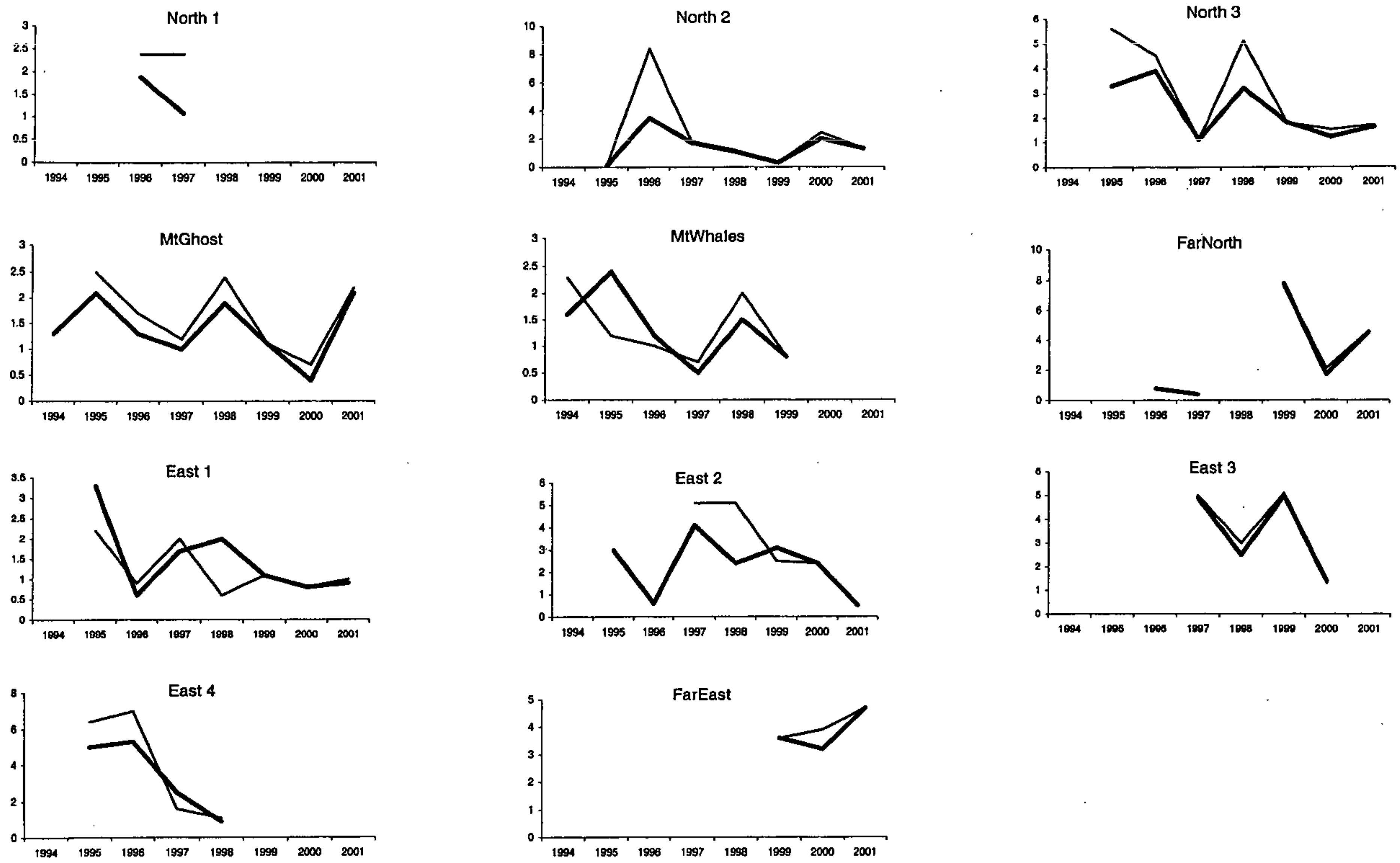

Figure 5: Changes in catch rate (t/tow) of orange roughy for the total year (heavy line) and winter months (thin line) for selected seamount groups.

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), and following the general procedures employed in the previous examination of CPUE in this fishery by Clark & Anderson (2001). Separate analyses were run for each of the three pairs of seamounts; North 2 and North 3, Mt Ghost and Mt Whales, and East 1 and East 2.

Catch per distance towed was used as the unit of CPUE. Although catch per tow is often used in this type of fishery assessment (e.g., Field 1992), in this fishery there is a wide variation of trawl lengths with many long trawls along the tops and down the sides of larger seamounts, and it was felt appropriate to use a more meaningful estimate of catch rate. The bases of the seamounts extend to several thousand metres, beyond the depths of orange roughy fishing, and so there is no confusion with tows on the flat. Distance towed was derived from tow duration and speed, as recorded tow positions were not sufficiently accurate to be meaningful with short tows. An arbitrary value of 0.01 n.mile was assigned to derived tow lengths of zero distance. Only tows that reported orange roughy as the target species were used.

A simple linear regression was used with the year variable forced into each model and each regression was run using a forward stepwise procedure. In the previous assessment (Clark & Anderson 2001) a combined log-linear/binomial model was used, but the binomial models showed little trend in the year effects and had no real influence on the final model indices. Tows with no catch of orange roughy were accounted for in the model by assigning them a catch of 1 kg, as it is unlikely that a tow catches absolutely no orange roughy. However, it is realised that the value of the constant applied can be important. The value of 1 kg represents one fish.

The criterion used for determining which predictor variable to add to the model at each stage was the maximum increase in the value of R^2, and we required an increase in R^2 of more than 0.5 for a variable to be included in the model.

The year effect indices were calculated directly from the model coefficients, and standard errors were calculated from the canonical form of the CPUE indices (in which there is no reference year) following the methods of Francis (1999).

Data from winter months only are considered, as the fishery in recent years has operated almost exclusively in June and July. Data from August has been used previously (Clark & Anderson 2001) but with no tows from that month present in the groomed dataset for the areas concerned in the last two years, they were left out of this analysis.

The number of vessels operating in the Louisville Ridge fishery has fluctuated over time, and the fleet composition has also varied considerably. Although 50 different vessels have fished the area, few have consistently remained in the fishery. To remove the effect of vessels with less experience, which may be expected to have more variable fishing success and have little value in linking data between years, only vessels which fished the area in four or more years and carried out more than 100 tows overall have been considered (Table 7). These criteria were applied to the combined data from the six seamounts being examined, and effort is often lower and more variable on the groups of seamounts examined separately. Twelve vessels met the criteria.

The response variable in the regression was log(tonnes/n.mile) and the set of predictor variables shown in Table 8 was tested in each model. No interaction terms were tested. The log transformation is necessary to provide approximately normally distributed errors.

Table 7: Number of trawls by vessel and fishing year for those vessels making 100 or more trawls over at least four fishing years.

Vessel	1993–94	1994–95	1995–96	1996–97	1997–98	1998–99	1999–00	2000–01
1		484	97			4		62
2	49	217	125	234	16			
3	3	293	42	98	17	29		
4		171	34	1	15	35	71	115
5		224	29	4	68	13		
6	4	118		44		12	126	
7	5	154	13	93	19	7	2	
8			59	114	8	12	29	2
9		74	21	32	12	3	41	
10		43	44		17	35		26
11		4	94	16		19		
12			67	16		11	18	4

The two month winter period was split into nine *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 five days long.

Table 8: Summary of independent variables tested, number of categories in parenthesis (North, Ghost-Whales, East).

Variable	Type	Description
Year	Categorical (7,8,7)	Fishing year
Vessel	Categorical (12,9,12)	Vessel identification no.
Hill	Categorical (2, 2, 2)	Seamount on which tow occurred
Week	Categorical (9)	Week 1–9 for winter month period
Month	Categorical (2)	Month of tow
Longitude	Continuous	Decimal longitude at start of tow
Latitude	Continuous	Decimal latitude at end of tow
Speed	Polynomial *3	Speed (kts) of vessel at start of tow
Depth	Polynomial *3	Depth (m) of groundrope at start of tow
Nation	Categorical (2)	Nation of vessel registration
Vessel tonnage	Polynomial *3	Gross tonnage of vessel
Vessel power	Polynomial *3	Vessel power (kW)

3.2.2 Results

(a) Ghost-Whales

The model was based on a dataset comprising 942 records. The stepwise process led to a model with four predictors:

CPUE (log(t/tow)) = (*year*) + *vessel* + *week* + poly(*speed*)^3 + error

Variable	Additional R^2	Total R^2
+ fishing year	6.20	6.20
+ vessel	14.43	20.63
+ week	5.87	26.50
+ speed^3	0.74	27.24

The predictor *year* explained 6.2% of the variability in CPUE and *vessel* provided the most explanatory power, increasing R^2 by 14.4%. A moderate amount of the total variance (27%) is explained by the three predictors selected.

Predicted CPUE for the selected model variables is shown in Figure 6. The predicted catch rate (tonnes/n.mile) is shown for a range of values (or category level) of each predictor, with the other factors held fixed at median values. The model predicts generally very low catch rates, the result of a high proportion of zero catches in the data (25%). The *year* predictor show a very irregular pattern of CPUE over time with low, downward trending values in the first four years followed by a large increase in 1997–98 and fluctuating values in the last few years. There is a wide range of catch rates among the nine vessels selected for the model, which explains why *vessel* is the most powerful of the predictors. There is a logical pattern in CPUE over time during the winter period examined, with increasing CPUE in the first weeks of July peaking in week "d" (22–28 June), followed by a sharp drop and a decreasing level of CPUE through to the end of the period. Catch rates are maximised at a trawling speed of about 2.4 knots, and are very low at speeds greater than 2.8 knots.

(b) North hills (N2, N3)

This model, based on 818 records, is similar to the Ghost-Whales model.

CPUE (log(t/tow)) = (*year*) + *vessel* + *week* + poly(*depth*)^3 + error

Variable	Additional R^2	Total R^2
+ fishing year	6.23	6.23
+ vessel	6.42	12.65
+ week	1.22	13.87
+ depth^3	0.61	14.48

The predictor *year* explained 6.2% of the variability in the data, and *vessel* again provided the most explanatory power. The model explains only 14.5% of the total variability in the data.

Predicted CPUE for the selected model variables is shown in Figure 7. The model depicts declining CPUE over time, with the highest catch rates in the first two years and much lower, but erratic, values subsequently. Three vessels stand out from the other nine with catch rates many times that of several of the poorer performing vessels. The very low CPUE predicted by the model overall can again be linked to the high fraction of tows with no orange roughy catch (33%), demonstrating the sensitivity of the model to the value of the constant chosen. The model predicts a general decline in CPUE over the nine weeks of June and July, although there is a sharp rise in week "e" (28 June to 4 July), and increasing CPUE with trawl depth up to a maximum at about 900 to 1000 m.

(c) East hills (E1, E2)

The model, based on 672 records, selected five predictors:

CPUE (log(t/tow)) = (*year*) + *vessel* + *week* + poly(*depth*)^3 + poly(*speed*)^3 + error

Variable	Additional R^2	Total R^2
+ fishing year	3.07	3.07
+ vessel	16.90	19.97
+ week	3.90	23.87
+ depth^3	1.77	25.64
+ speed^3	0.96	26.60

The *year* effect is not strong in this model, explaining only 3.1% of the variability in CPUE. The *vessel* predictor, as in the previous two models, has the most explanatory power in the model, adding a further 16.9% R^2. The third predictor chosen is again *week* and the continuous variables *depth* and *speed* are in this case both selected in polynomial form. The model overall has a moderate explanatory power (26.6% R^2).

Model predictions are shown in Figure 8. A high fraction of zero catches (38%) leads again to predictions of low values of CPUE overall. The *year* predictor indicates low values of CPUE in the first two years followed by an increase to a peak in 1997–98, then a decline in the last three years. The *vessel* effect is driven largely by the influence of a single vessel with average catch rates of more than ten times that of any other vessel. Variation in catch rates among the other vessels is evident, but is overshadowed by the high performing vessel. A pattern of increasing and then decreasing CPUE over the nine *week* periods matches the expected pattern of CPUE through the spawning period of orange roughy. The peak in week "d" corresponds to the period 22–28 June. The model predicts high catch rates only at 750 m or shallower. The model predicts CPUE will be maximised at a trawling speed of about 2.4 to 2.5 knots.

CPUE indices

The model indices (scaled to the reference year) for each seamount complex are given in Table 9 and Figure 9. Standard errors and c.v.s were in each case calculated from the canonical form of the indices, i.e., they are independent of the reference year. The reference year is the first year in each series with sufficient data to input to the model. For Ghost-Whales this was 1993–94 but for the North hills and East hills there were insufficient data available from 1993–94, and so the reference year in those models is 1994–95.

For the Ghost-Whales and East hills models 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. In each case there is a sharp rise in the index in the 1997–98 fishing year, but even ignoring this anomaly, which was also apparent in the previous analysis (Clark & Anderson 2001), there is no clear trend (either down or up) in either series. In contrast, the North hills year indices do show a declining trend over time. The highest values are in the earliest two years and although the subsequent indices are somewhat erratic, with a rise in 1997–98 as in the other models, the overall trend is downwards.

Table 9: Year indices for each model, with c.v.s calculated from the canonical form of the CPUE indices.

	Ghost-Whales		North hills		East hills	
Year	CPUE index	c.v.	CPUE index	c.v.	CPUE index	c.v.
1993–94	1.00	1.08	—	—	—	—
1994–95	0.58	0.39	1.00	0.88	1.00	0.51
1995–96	0.30	0.48	1.00	0.38	0.78	0.96
1996–97	0.08	0.54	0.15	0.38	4.27	3.44
1997–98	7.54	0.65	0.59	0.69	25.31	14.74
1998–99	0.47	0.43	0.03	0.69	7.82	3.53
1999–00	4.45	1.45	0.23	0.66	10.51	6.91
2000–01	1.14	0.80	0.34	0.67	2.43	1.53

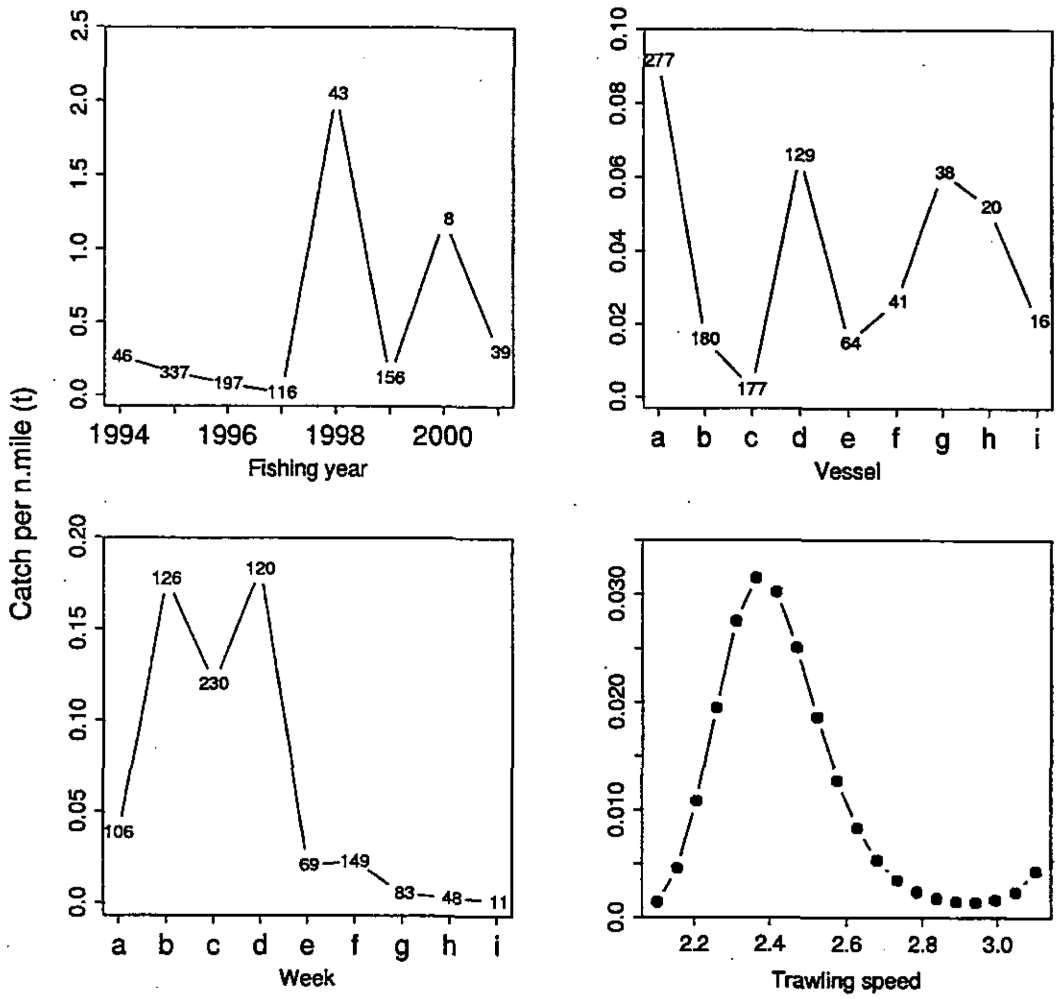

Figure 6: Model fits for Ghost-Whales data. In each figure the values of the predictors not being examined are held fixed at median values. The numbers on the plots represent the number of records associated with each predicted value. For the plot of catch rate by vessel (top right) vessels are ordered by decreasing number of records.

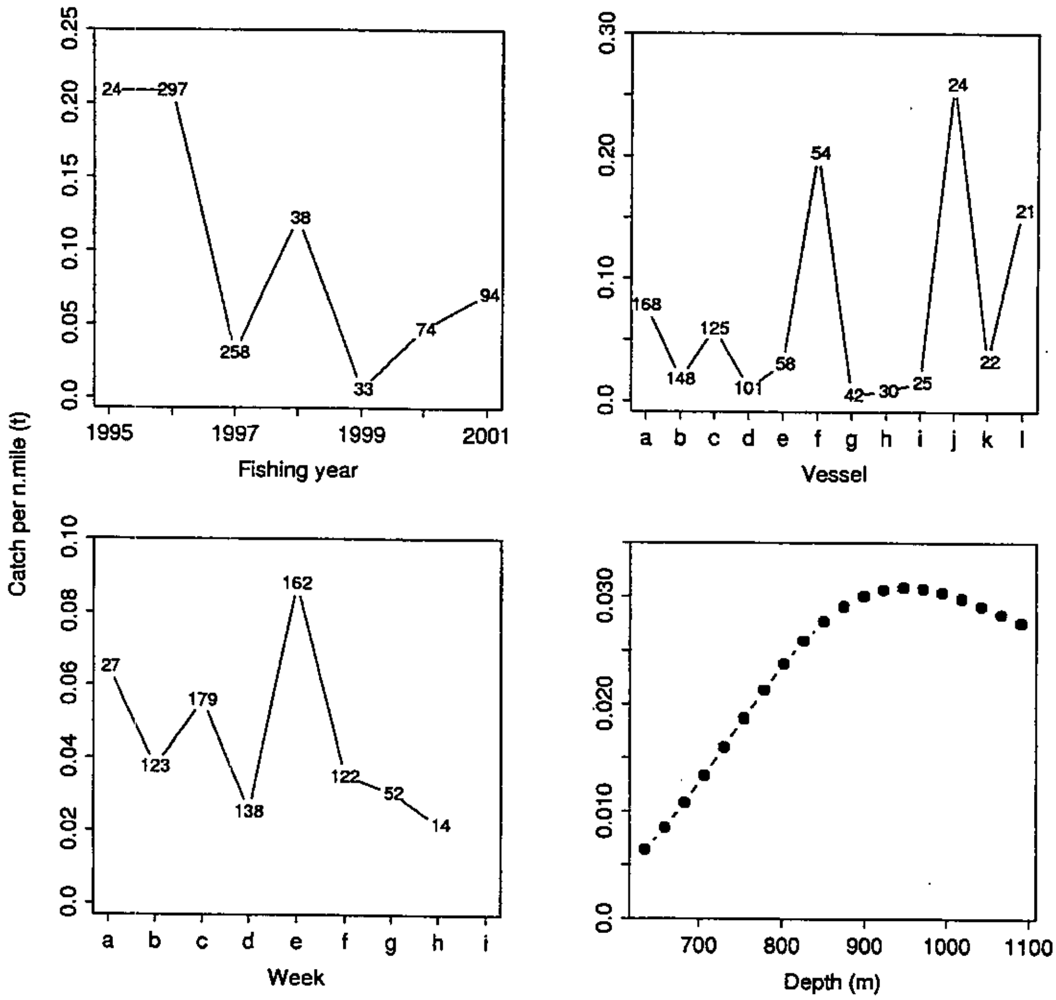

Figure 7: Model fits for North hills data. In each figure the values of the predictors not being examined are held fixed at median values. The numbers on the plots represent the number of records associated with each predicted value. For the plot of catch rate by vessel (top right) vessels are ordered by decreasing number of records.

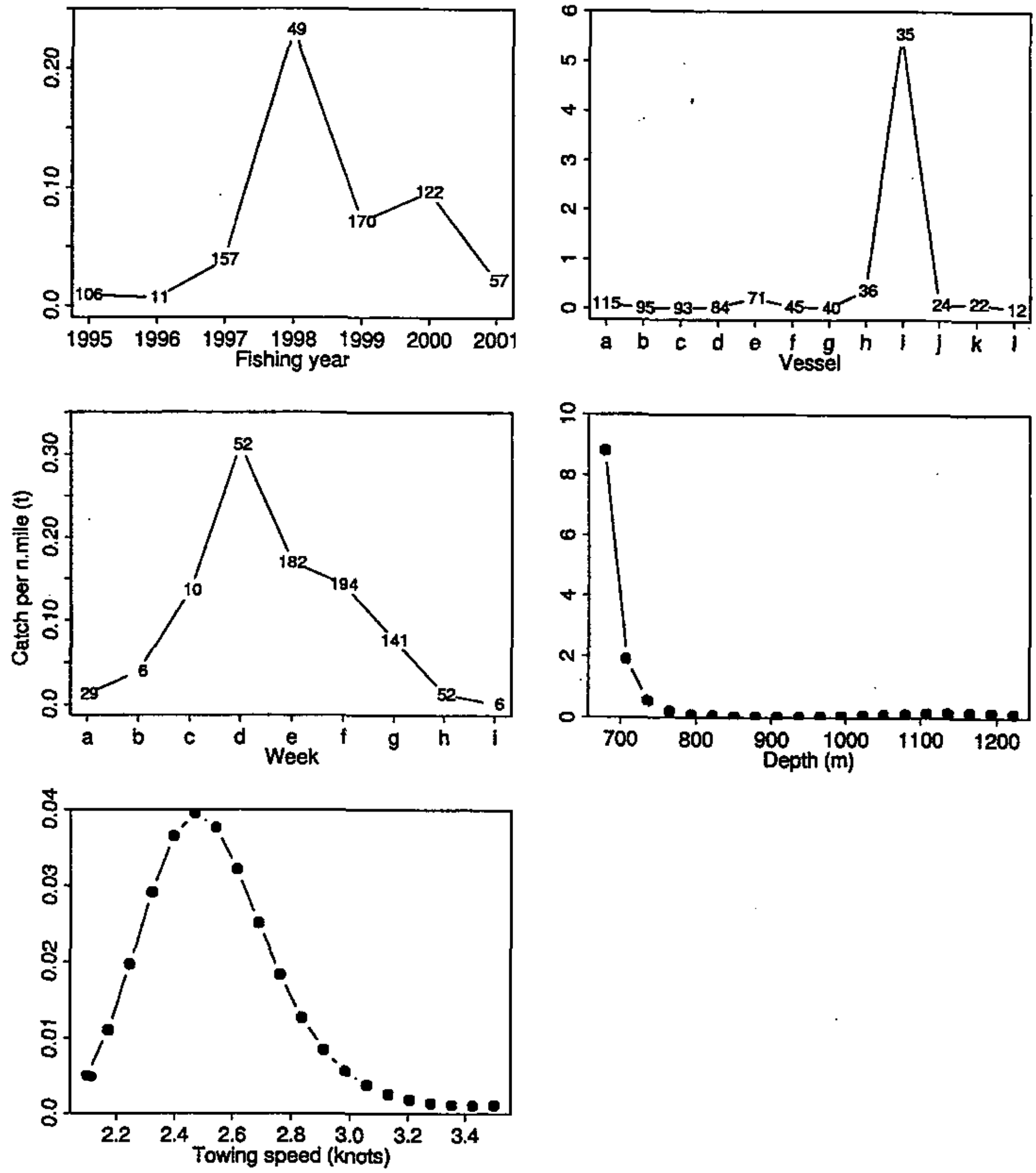

Figure 8: Model fits for East hills (E1 and E2) data. In each figure the values of the predictors not being examined are held fixed at median values. The numbers on the plots represent the number of records associated with each predicted value. For the plot of catch rate by vessel (top right) vessels are ordered by decreasing number of records.

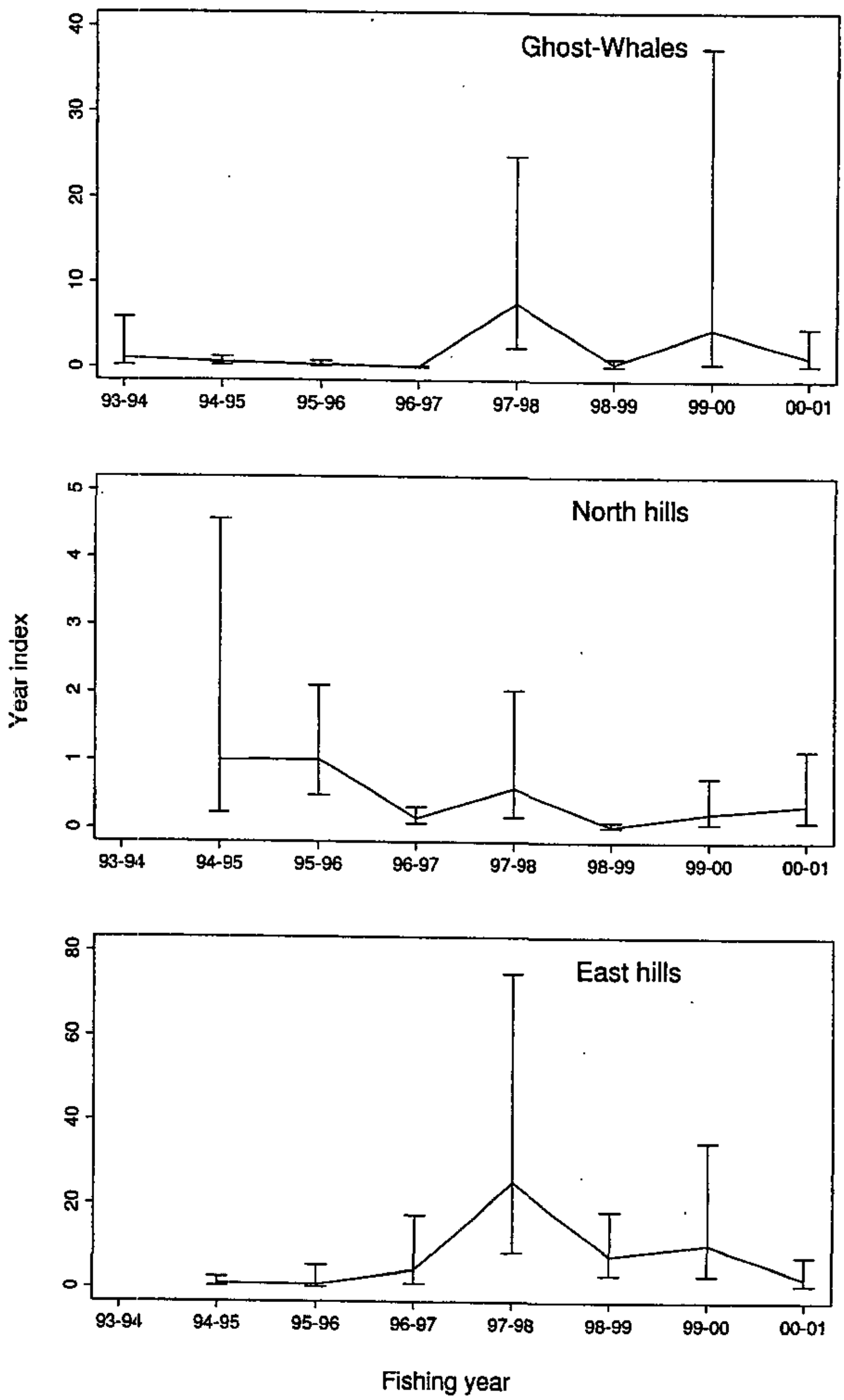

Figure 9: Model indices (± 2s.e.) for each fishery subset. Errors are estimated from the canonical form of the indices and are independent of the reference year.

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 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. 2001). The assumed catch history is that derived from New Zealand and Australian catch records, although it is acknowledged as incomplete. 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 the Ghost-Whales seamount group. 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. The c.v. value of 0.3 was increased to 1.0 in order to examine if freeing the CPUE index values (more in line with the calculated c.v. from the GLM) would help the model fit. However, this was still unsuccessful. The analysis was successful with the North 2–3 seamounts, where B_0 was estimated at 4900 t (Table 10). The model also computed a biomass estimate for East 1–2 seamounts. However, this was regarded as unreliable, because the CPUE series (a dome pattern over time) appears inconsistent with the model. If the model assumptions (including CPUE being proportional to biomass) were correct it would be very unlikely the observed CPUE indices would occur. Distribution of the residuals was poor, and the fit of the model for a wide range of biomass values was similar.

Table 10: Estimates of B_0 and B_{min} for the three seamount groups. NA, could not be estimated. Values in parentheses are thought unreliable.

Seamount group	B_0	B_{min}	$B_{2000-01}$	$B_{2000-01}/B_0$
Ghost-Whales	NA	3 900 t	NA	NA
North	4 900 t	4 400 t	1 470 t	0.3
East	(2 300 t)	2 300 t	(230 t)	(0.1)

The stock size trajectory, and fit of the CPUE indices to it, are shown in Figure 10 for North 1–2 seamounts.

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. In general, CPUE in winter has been variable, and 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 (Clark & Anderson 2001), 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. It appears that further standardised CPUE work is of limited value, and should not proceed at this stage. Development work could be carried out on either the datasets, variables considered, or the model structure to try and improve the usefulness of CPUE. Alternatively, the results of the seamounts "meta-analysis" (Clark et al. 2001) could be applied to estimate the likely minimum stock size based on physical characteristics of the Louisville seamounts.

Although biomass and yield cannot be considered well-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. 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, because of the steaming distance, once vessels are committed to going to the Ridge it is likely they will stay there and fish hard even if catch rates are low.

The change in scale of the analysis tried this year and last, 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.

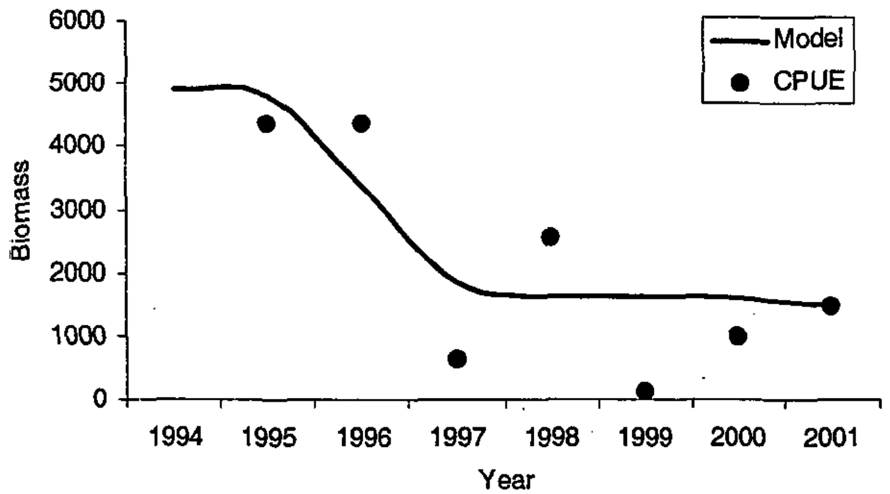

Figure 10: Plot of stock size trajectory estimated from the stock assessment model and trends in the CPUE indices scaled to biomass for the North seamounts.

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