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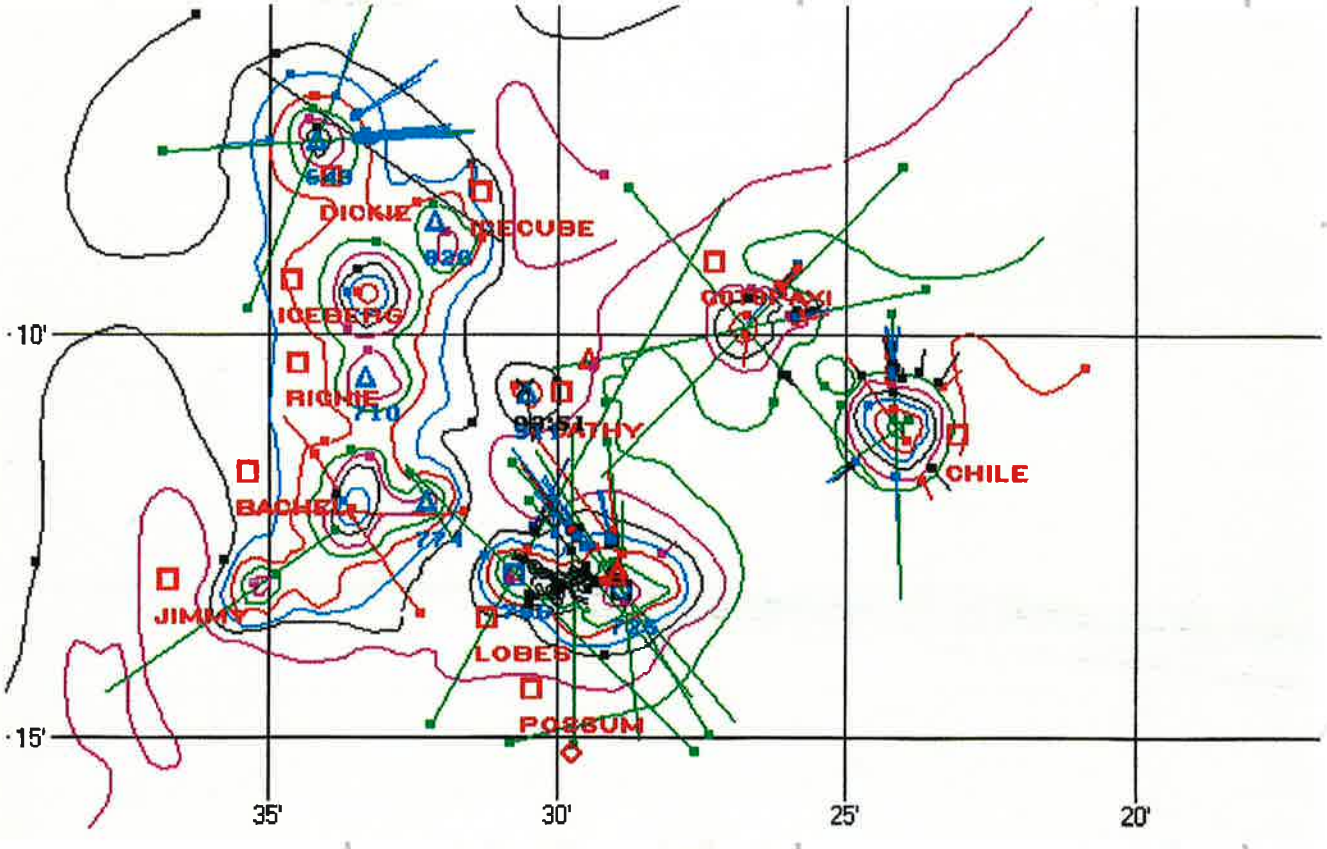
The fishery for orange roughy on the northeast Chatham Rise, 1988–89 to 1993–94

R. P. Coburn and I. J. Doonan



New Zealand Fisheries Technical Report No. 48
ISSN 0113-2180
1997

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Published by NIWA
Wellington
1997

ISBN 0-478-08421-8

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Publication Services, NIWA
PO Box 14 901, Wellington, New Zealand

The *New Zealand Fisheries Technical Report* series in part continues the *Fisheries Research Division Occasional Publication* series. The *New Zealand Fisheries Occasional Publication* series contains mainly conference proceedings and bibliographies.

Edited by M. F. Beardsell
Set in 10 on 11 Times Roman
Printed by Madison Printing Company Limited

Cover illustration: fisher's chart of the Andes complex, east Chatham Rise, courtesy of Sealord Group Ltd.

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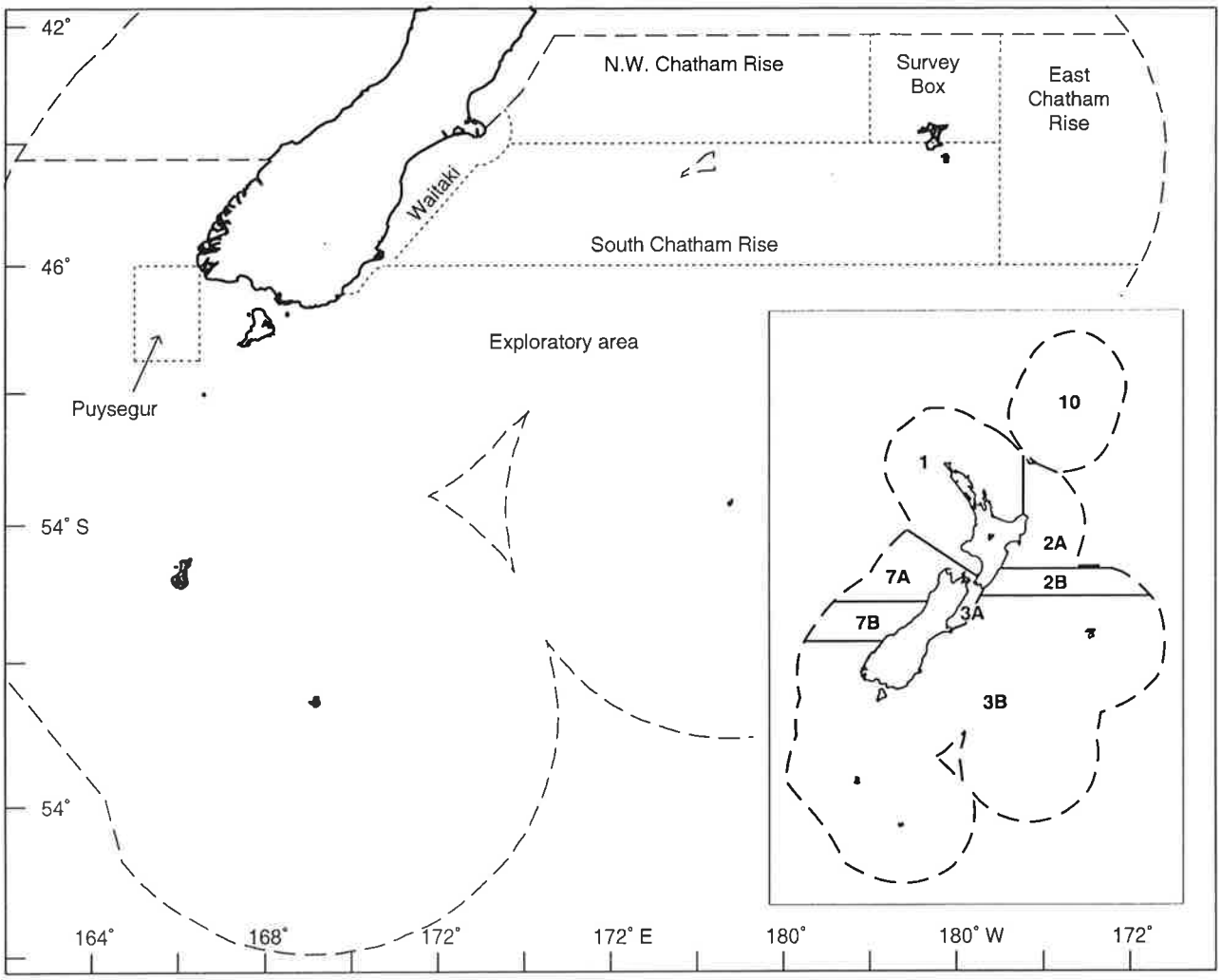

Figure 1: Quota management area ORH 3B for orange roughy showing subareas. Insert: orange roughy quota management areas.

Abstract

Coburn, R. P. & Doonan, I. J. 1997: The fishery for orange roughy on the northeast Chatham Rise, 1988–89 to 1993–94. ***New Zealand Fisheries Technical Report No. 48.*** **28 p.**

Tow by tow data show the fishing patterns for orange roughy on the northeast Chatham Rise for the fishing years 1988–89 to 1993–94. Over this period the following changes occurred: there was a switch from trawling flat bottom during winter spawning to year round on hills; the main fishing ground was closed; the quota was divided between subareas and reduced; and the foreign charter fleet was supplanted by domestic vessels. While abundance (as determined by relative trawl survey indices) fell to less than a half, yearly catch per vessel day and catch per tow changed little, showing that superficial analysis of catch data for tracking abundance can be deceptive. Fishing on the areas of flat seabed had a similar pattern to that established in the first 10 years of the fishery, but both the period and area in which high catch rates were common (i.e., at the main spawning site) have declined. For hills, the largest catch (and effort) was in the first year of exploitation. In subsequent years, catch rates declined on the main hills.

Introduction

The first recorded fishery for orange roughy (*Hoplostethus atlanticus*) was in 1979 on the north Chatham Rise (Survey Box, Figure 1) and in the following decade the fishery expanded on to the rest of the Chatham Rise. Initially, foreign licensed vessels fished there, but by 1981 they were under charter to New Zealand companies. After 1981, New Zealand operators began acquiring their own deepsea vessels, and by the mid 1980s these accounted for about one third of the annual catch. By 1991–92 the foreign charters were all but displaced. Until 1990 this fishery supplied over half the New Zealand catch of orange roughy and it is still the largest in New Zealand (Table 1. *See* Annala (1995) for more detail). The Chatham Rise fishery is in quota management area (QMA) ORH 3B, which also includes separate fisheries in the southern ocean which started in mid 1991.

A stock assessment in 1991 showed that the sustainable yield was far lower than the quota for ORH 3B (Francis & Robertson 1991), which at the time consisted only of the Chatham Rise fishery. This created considerable interest in its management from industry, environmental groups, and the public. Initially, this led to a redistribution of quota into subareas defined by the Minister of Fisheries (*see* Figure 1 for sub areas in 1992–93), and later to a reduction of the ORH 3B quota (Table 2) allocated to the Chatham Rise.

These subareas have evolved a little, but those we are concerned with are the "Box" and "East" areas which define the northeast Chatham Rise (*see* Figure 1). These subareas correspond closely to the boundaries used in a previous study (Coburn & Doonan 1994) which covered the first 10 years of the northeast fishery, 1979–88, and which this study continues for 1989–94. Restricting the study to the northeast Chatham Rise does not presuppose a separate stock there. Currently, stock boundaries cannot be clearly drawn on the Chatham Rise and one stock has been assumed for stock assessments (Francis *et al.* 1995). Historically, most catch has come from the northeast, but this has declined recently (Table 3).

Until the 1990s, the northeast fishery differed from that on the rest of the Chatham Rise in timing and nature. Up to 1988–89, the northeast fishery occurred in winter on spawning fish over a wide area of the northeast Chatham Rise. Coburn & Doonan (1994) showed that fish may migrate into a main spawning site (centred at 176° 55' W, 42° 48' S, in depths from 800 to 950 m) from deeper water and from east and west, followed by a return migration. The time and location of peak catch rates (t/km, cpkm) were the same each year, but catch rates declined over the years, particularly in the pre-spawning phase of fishing. Fishing was on mainly flat ground using bottom trawling. In other parts of the Chatham Rise fishing was directed at aggregations that formed around pinnacles and drop-offs most of the year. The trawling technique was different and required greater precision to "fly" the net and land it on the top of the pinnacle and run it down the sides. Now, fishing in the northeast is mostly on hills and can occur throughout the year.

Like Coburn & Doonan (1994), this report uses catch data from commercial vessels to describe the patterns of orange roughy fishing on the northeast Chatham Rise. Because hill fishing is so different from that on flat ground, we have analysed the hill data separately.

Table 1: Reported catch (to nearest 100 t) of orange roughy from New Zealand QMA areas (*see* Figure 1 for areas: source Annala (1995)). ORH 3B has been divided into the Chatham Rise and a southern part (south of 46° S)

Fishing year	Chatham Rise	ORH 3B Southern	Challenger (7A)	East coast (2A, 2B, 3A)	West coast (7B)
1984–85	29 300	–	5 100	8 400	300
1985–86	30 100	–	7 800	8 000	1 800
1986–87	30 100	–	11 500	8 700	1 400
1987–88	24 200	–	12 200	9 700	1 400
1988–89	32 800	–	10 200	9 500	1 700
1989–90	31 500	200	4 300	10 500	1 700
1990–91	20 600	900	1 400	10 000	1 700
1991–92	15 500	7 800	1 900	10 100	1 600
1992–93	13 700	6 300	2 100	9 100	1 100
1993–94	14 000	3 100	1 700	9 900	700

Table 2: Orange roughy quota (TACC, total allowable commercial catch) for ORH 3B and subareas by fishing year

Fishing year	TACC(t)	Chatham Rise
1987–88	38 065	
1988–89	38 300	
1989–90	32 787	
1990–91	23 787	
1991–92	23 787	18 787[a]
1992–93	21 300	14 000[b]
1993–94	21 300	14 000[c]

a Industry to catch 5000 t south of 46° S.
Lesser of 9000 t or reported catch from "box" in 1990–91 to be taken from "box".

b ORH 3B subdivided into 7 subareas (*see* Figure 1)

subarea	Quota (t)
Northwest Chatham Rise	3 500
Box	0
East Chatham Rise	4 500
South Chatham Rise	6 000
Waitaki	300
Puysegur	5 000
Exploratory	2 000

c In June 1994, 1000 t of exploratory quota shifted to the Arrow plateau (*see* Figure 2).

Table 3: Orange roughy catch (nearest 100 t) from the Chatham Rise apportioned between the Box and East subareas (*see* Figure 1) (percentages given to nearest whole percent)

Fishing year	Chatham Rise	Box + East		Box		East	
	t	t	%	t	%	t	%
1988–89	32 700	19 800	61	16 900	52	2 900	9
1989–90	31 500	17 100	54	16 400	52	700	2
1990–91	20 600	12 200	59	6 200	30	6 000	29
1991–92	15 500	12 900	83	1 000	6	11 900	77
1992–93	14 000	4 700	34	100	1	4 600	33
1993–94	14 100	5 300	38	0	0	5 300	38

Data and analysis

The Chatham Rise is fished by large trawlers which provide the Ministry of Fisheries (MFish) with a record of each tow. Information recorded includes the date, target species, start and finish times and locations, depth, speed of trawl, and species caught. We have the engine power and tonnage of each vessel. (A check was run for any small vessels which fill a simpler log-book; none was found in the study area.) The data are stored in the MFish quota monitoring system which took over from the previous system in 1988–89.

The best source of total catch for the whole of ORH 3B is from the reported landings declared against quota which are recorded on a landed catch form. The tow by tow records capture most of the reported landings, typically about 90%, although rather less in the first 2 years of the new system (Table 4). Thus, the tow by tow records should characterise the fishery. Subtotals of catches by area from the tow records were adjusted up by the ratio for ORH 3B of the reported landings to the total catch in the tow records. Catch rates were not adjusted because they enter as a ratio. All figures should be viewed as "best estimates" and not as impeccable statements of fact.

We allocated a tow to a hill if it was within a radius of 5 km from the mid point of the hill. The exception was the Andes hill complex (44° 21' S to 44° 4' S, 174° 38' W to 174° 19' W) where we used a box to allocate tows to it (Figure 2). Any tow not allocated to a hill was taken to be on the flat.

Start and end positions were recorded to the nearest minute of longitude or latitude. For plotting, we jittered the position by ± 0.5' to reduce over plotting. Where we plot tow tracks (*see* Figure 22 and Appendix 1), in addition to jittering start and end positions we excluded tows where calculated length was greater than 50 km or where tow length was greater than four times the length expected from the recorded tow duration and trawl speed. This prevents plotting of tows which we believe have an incorrect end of tow position recorded. Jittering was also used where necessary to better illustrate the data, for example, in Figure 11 the date is jittered ± 0.5 day to reduce over plotting.

Table 4: Total catch fromtow by towrecordsintonne(nearest 100 t) and as a percentage (nearest whole percent) of total reported catch of ORH 3B by fishing year

Fishing year	Declared (t)	Tow by tow (t)	%
1988–89	32 785	26 800	82
1989–90	31 669	22 900	72
1990–91	21 521	20 000	93
1991–92	23 269	22 100	95
1992–93	20 048	18 300	91
1993–94	17 136	15 300	89

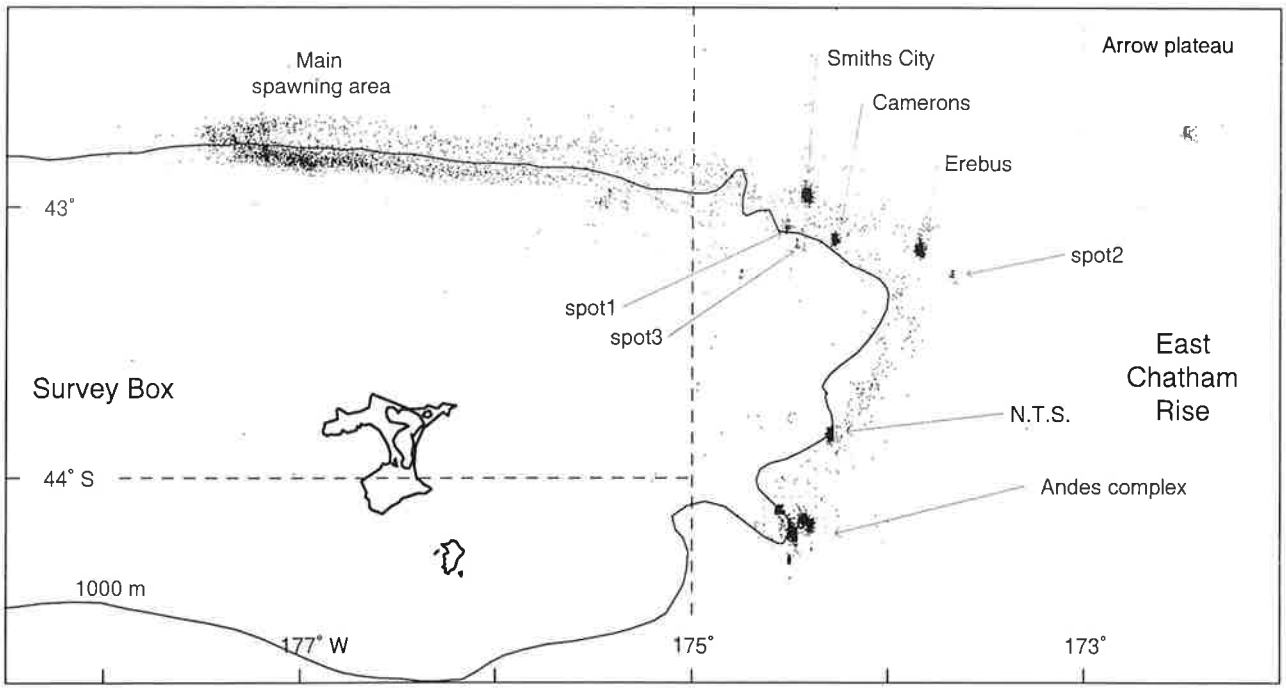

Figure 2: Start positions of tows that targeted orange roughy between 1988–89 and 1993–94. The depth range of the main spawning site is not shown.

We also used data from the MAF random trawl surveys to describe gonad development. We used only female data because males are more difficult to stage macroscopically. Data from before 1985 was excluded because some staging was done differently. These data are held in NIWA's "Trawl" database (Anderson & Fenaughty 1996).

Data cleaning

In our analysis we focused on main trends which should be resistant to outliers and random variations because of the large amount of data. Hence, only the obvious errors in the data were removed.

We extracted all tows that targeted or caught orange roughy within subareas Box and East (*see* Figure 1) from 1 October 1988 to 30 September 1994.

The following data were then excluded.

(1) Tows not targeting orange roughy; there was only a handful of these in any year.

(2) Tows where the east/west part of the start of tow longitude had clearly been recorded wrongly.

(3) Tows in any year from vessels that had fewer than five tows. This excludes some further tows that are likely to have had the wrong position recorded.

(4) The tows from the *Cordella* research trawl surveys in 1989 and 1990. Other research surveys were not recorded in the MFish catch and effort database.

(5) Sixty-one tows by one vessel between 24 July 1989 and 7 August 1989 had recorded catches that were clearly anomalous. The vessel was an experienced orange roughy vessel and recorded very low catches (13–56 kg). This never occurred in other years. These data have been excluded from Figures 11, 15, and 23 and Appendix 2. They do not have a material effect on any other results.

Fleet composition and catch per unit effort

Historically, the northeast Chatham Rise was fished mainly by foreign vessels under charter to New Zealand quota holders. From the mid 1980s, the domestic deepwater fleet grew and gradually came to supplant the charter vessels (Figure 3). Since 1988–89 there has been a decrease in the number of vessels in this fishery and the largest vessels have departed (Figure 4).

Yearly medians of catch per vessel day and catch per tow showed a slight decline (Figures 5 and 6). However, catch per kilometre showed a marked increase in 1990–91 when the median jumped from 0.36 to 1.1 t/km (Figure 7), corresponding to the start of hill fishing.

Figure 3: Proportion of catch from the northeast Chatham Rise by nationality for each fishing year (DOM, New Zealand; KOR, Korean; JAP, Japanese; SOV, Soviet/Russian; NOR, Norwegian).

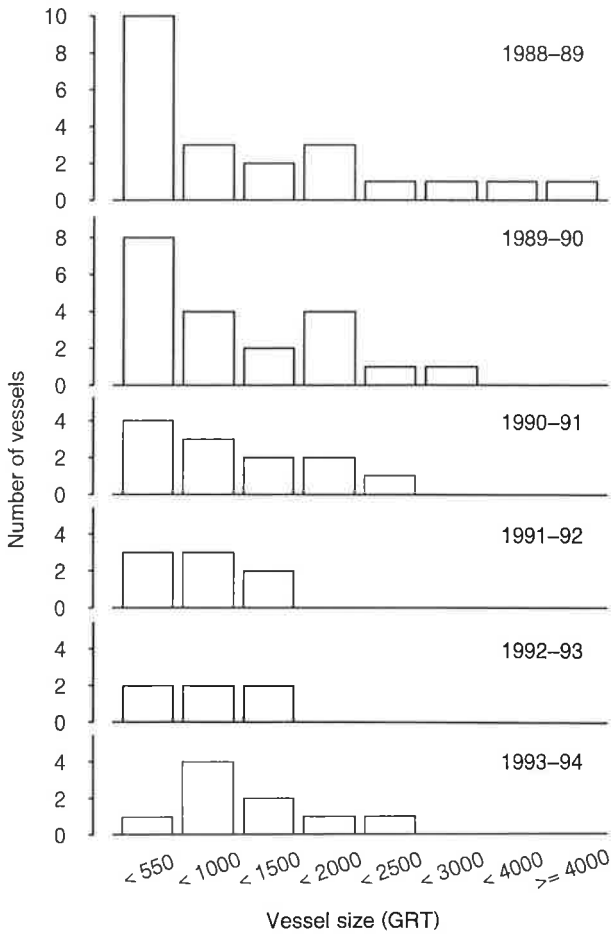

Figure 4: Vessel size (GRT, gross registered tonnage) distribution by fishing year.

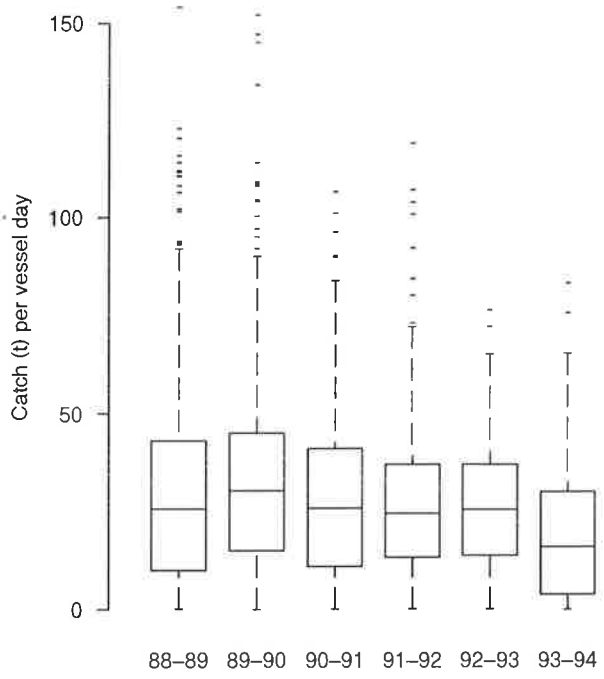

Figure 5: Distribution of catch per vessel day by fishing year, showing the median (centre line of box), upper and lower quartiles (box), 1.5 times the interquartile range (dashes), and individual values outside the latter range.

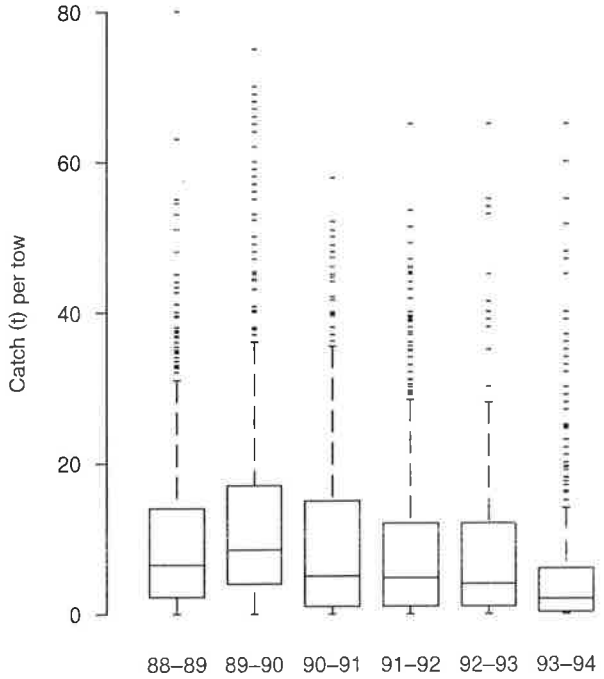

Figure 6: Distribution of catch per tow by fishing year (*see* Figure 5 for interpretation).

The spawning period

The pattern of fishing on the flat is driven by the spawning migration, so knowing when spawning occurs helps to interpret the patterns seen. We used the same spawning period (7–31 July) as Coburn & Doonan (1994): this period also matches gonad development. Female gonad development can be macroscopically staged into immature or resting, maturing (will spawn this season), ripe (clear eggs visible and so ready to spawn), running ripe (eggs freely flowing, spawning, or about to spawn), and spent (finished spawning) (Pankhurst *et al.* 1987). By combining the data from the 1985 to 1994 surveys at the main spawning site (176° 27'–177° 21' W, 800–950 m) we built a composite profile of the fraction of fish at each stage except immature over spawning (Figure 8). This shows that the onset of ripe females is between 1 and 5 July and of running ripe females between 7 and 10 July, so spawning can be considered to start on 7 July. For the finish of spawning we choose 31 July because the pattern of fish movement detailed by Coburn & Doonan suggests that most fish are moving away from the main spawning site by then and are presumably spent. Remaining fish continue to spawn in the first week of August, but we feel 7–31 July covers the period of spawning for most fish. A research survey in 1995 using trawl and acoustics also observed the movement of fish out of the main spawning site at the end of July (Tracey *et al.* 1997).

We also examined the timing of peak spawning (maximum percentage running ripe) by year and found that it varied by only about a week. Pankhurst (1988) described orange roughy spawning dynamics in this and other New Zealand fisheries.

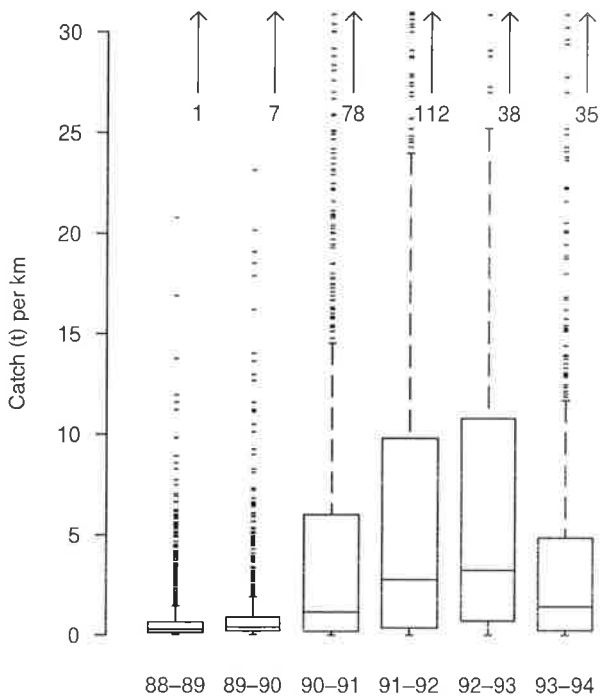

Figure 7: Distribution of catch per kilometre (t) by fishing year (*see* Figure 5 for interpretation). The numbers under the arrows are the number of tows where the catch rate exceeded 30 t/km.

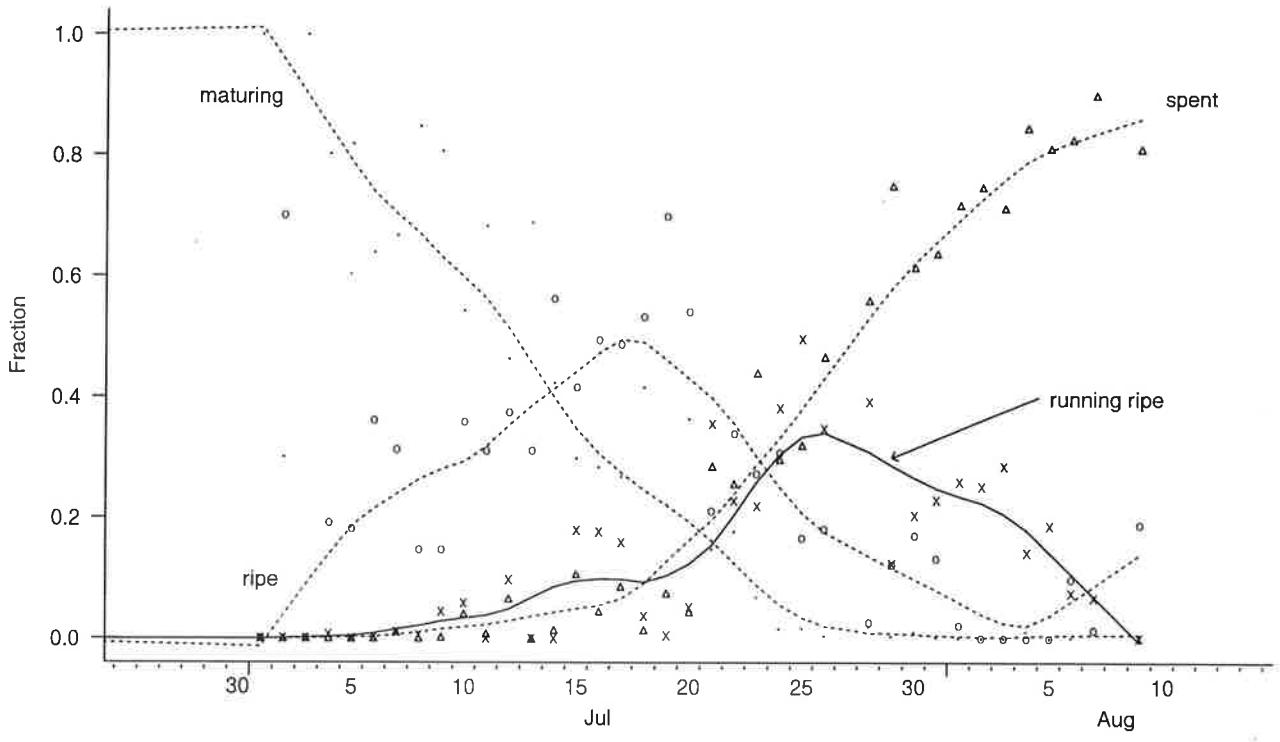

Figure 8: Daily fractions of gonad stages for female orange roughy over the spawning period in the main spawning site (800–950 m, 176° 27′–177° 21′ W). Data are from all winter orange roughy surveys on the Chatham Rise since 1985. Lowess lines are drawn through daily fractions that were weighted by catch. Gonad stages are: maturing, dot; ripe, circle; running ripe, cross; spent, triangle.

Fishing on flat ground

By 1988 a predictable fishing pattern had emerged (*see* Coburn & Doonan 1994) which was repeated in 1988–89 with some incremental changes, the main one being the continuation of a trend toward placing effort closer to the high catch rate period in late July. Maximum effort was in late June and sustained effort continued through to mid August (Figure 9). The maximum fleet size was somewhat less than in earlier years (*see* Coburn & Doonan (1994), figure 16) and effort was more concentrated on the high catch rate period in late July than in any previous season.

The area fished (Figure 10) was similar to that in the previous three seasons (*see* Coburn & Doonan (1994), figure 15). Effort was distributed over a wide area with a concentration at the main spawning site.

Catch rates (median catch per kilometre, Figure 11) followed a similar pattern to those of earlier years (*see* Coburn & Doonan (1994), figure 17 and appendix 4), increasing through June to peak in July and trailing off in August. However, median catchrates (for a given time) are typically less than in earlier years, a continuation of the trend noted by Coburn & Doonan (1994).

The areal distribution of the fleet over the season (Figure 12) was similar to that of earlier seasons. During pre-spawning, vessels fished widely over the northeast Chatham Rise then moved into the main spawning area. Post spawning, vessels followed a migration "tail" eastward away from the main spawning site (described by Coburn & Doonan 1994) (*see* 'x's post July in Figure 12)

The seasonal pattern of depth fished was similar to that of earlier seasons: vessels fished over a wider depth range pre-spawning, moved shallower during spawning, and then back into deeper water afterwards (Figure 13). The number of tows deeper than 950 m during spawning was much increased on earlier years and provided some good catch rates.

The 1989 pattern can be seen again in 1990 and 1991 (Figures 14–17 and Appendices 2–4), but effort became less year by year (Figure 14) and by 1992 only three vessels fished for little more than a week. Seasonal features are no longer noticeable over this short period. We believe the data for 1991 have some tows from hill fishing mixed in and, therefore, may not be directly comparable with the other years' figures.

The "Hot Spot"

The term "hot spot" is used by fishers for the area where large catches can be made at the main spawning site, that is, it has a limited season. The hot spot has shrunk in both area and duration. The decrease in duration happens because the onset of high catch rates was later, but the end still occurred at about the same time. This onset

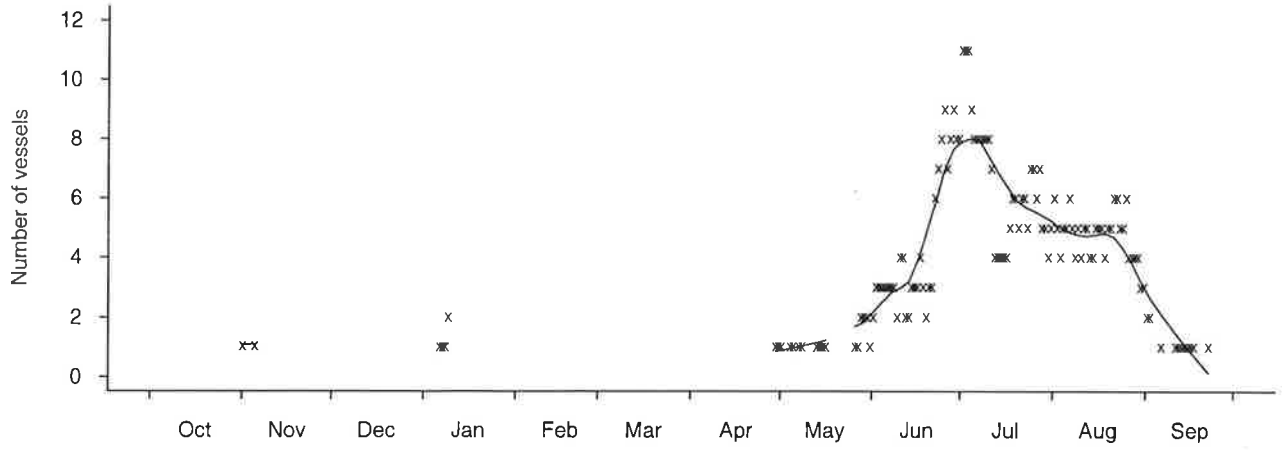

Figure 9: Daily fleet size over the 1988–89 fishing year. Crosses show the number of vessels recording at least one trawl on each day. The smooth line was drawn using a local regression technique (Cleveland 1979) and is broken where gaps of more than 4 days occur.

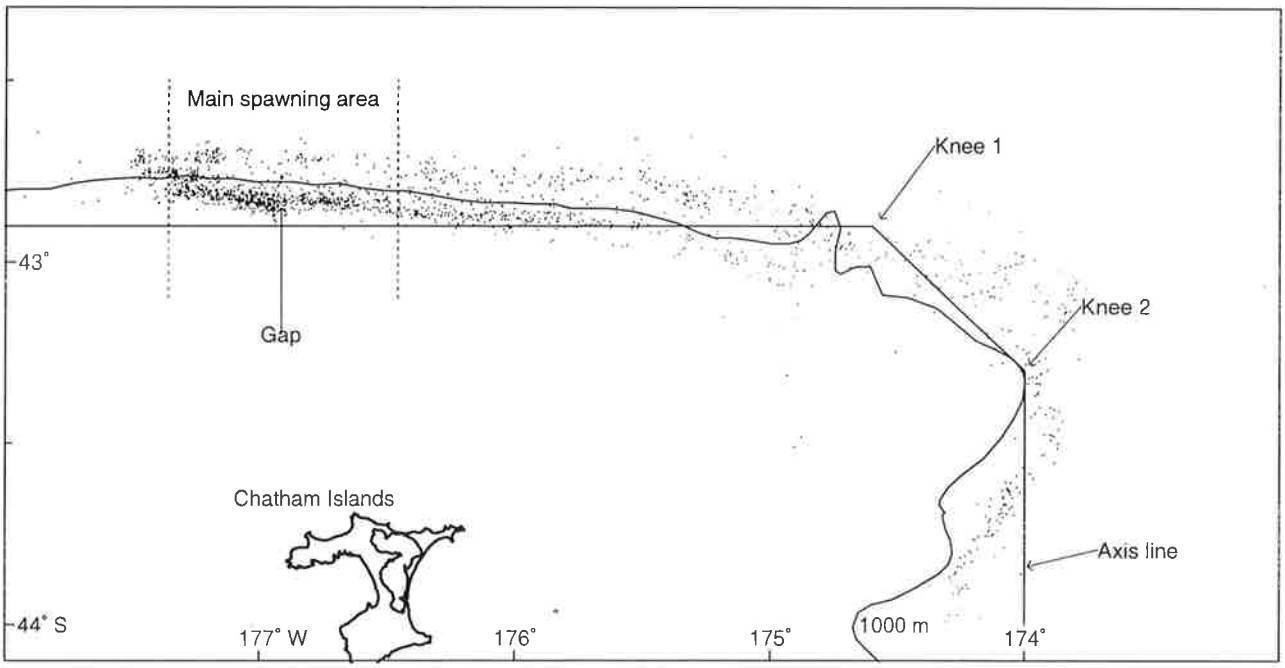

Figure 10: Start positions of tows in the 1988–89 fishing year. Also shown is the axis line used to define axis position (*see* Coburn & Doonan (1994), p. 12 for details). The depth range of the main spawning site is not shown.

(defined as a median catch rate of over 1.35 t/km) has progressively shifted to a later time, and by the late 1980s it was around 20 July (Figure 18), i.e., just after the peak in ripe females (*see* Figure 8). In 1991, median catch rates of 1.35 t/km were not reached. By restricting the data to the main spawning site (176° 27'–177° 21' W, 800–950 m) we have avoided the problem of hill tows being incorrectly included and believe the profiles shown in Figure 18 are comparable.

The size of the hot spot is hard to define because vessels do not fish the margins where catch rates are low. However, MAF survey data show a progressive shrinkage of the area in which good survey catch rates (over 1 t/n.mile) commonly occur (*see* Francis *et al.* 1995, figure 7 or Clark 1995). The survey data do not reveal the shortening of the hot spot because the surveys have not covered it for long enough over enough years (R.I.C.C. Francis, NIWA, Wellington, pers. comm.).

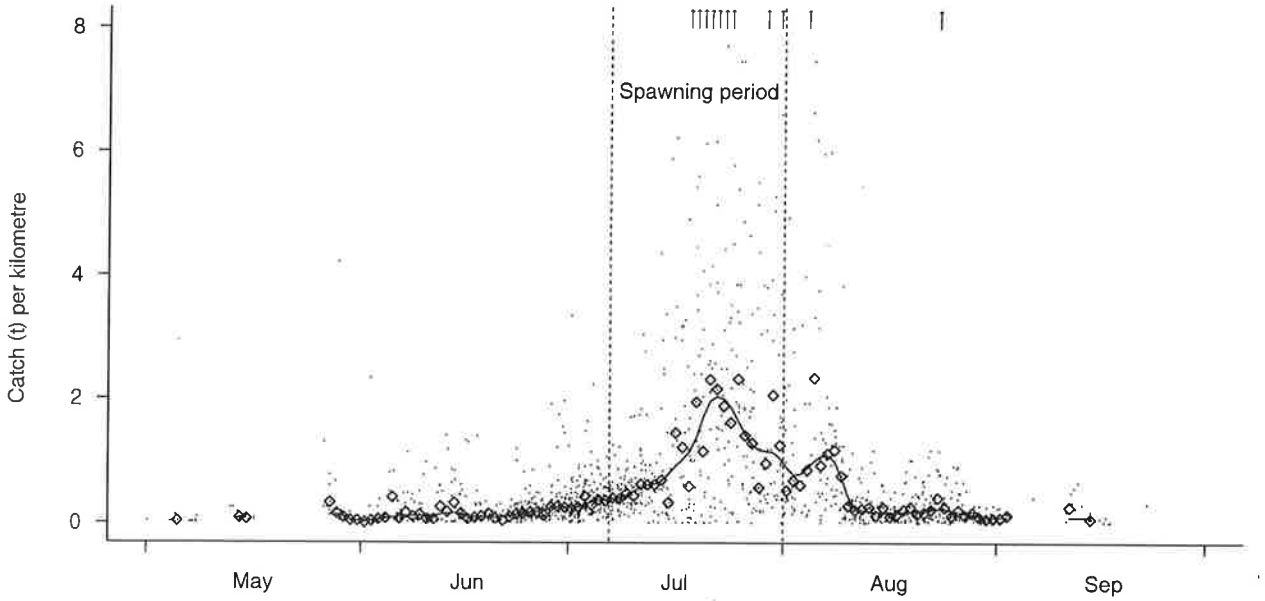

Figure 11: Catch per kilometre over the 1989 season. A smooth line is drawn through daily medians (diamonds) for days on which there were at least four tows (".") . This line is broken where gaps of more than 4 days occur. Arrows indicate tows taking more than 8 t/km.

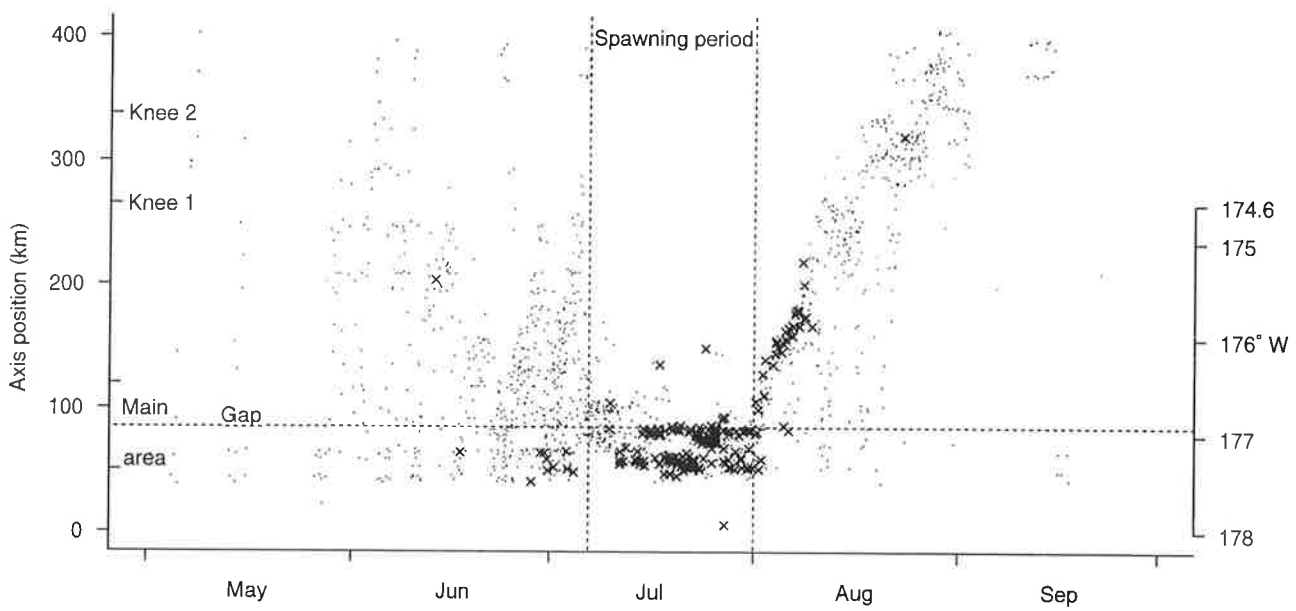

Figure 12: Axis position of tows over the 1989 season. Axis position is measured from 178° W along the axis line (*see* Figure 10). Catch rates over 1.35 t/km are shown by "x".

Hill fishing

Fishing on hills is more difficult than fishing on flat ground and there is a greater risk of damage to gear and less control over catch size. Hills on the northeast Chatham Rise protrude from flat or gently sloping ground in single cones or as a group, that is, they are isolated features (*see* Figure 2). An example is the Andes, a group with the nearest other fished hill 38 km away.

The steepness of some of the hill sides relative to the size of the trawl gear means that to fish them the gear should land on the top (otherwise it may come fast on the hill) and be towed down the side while warp is paid out. The narrower the top and the steeper the sides, the more difficult the hill is to fish. Furthermore, some directions down any hill may be too rough to trawl on and so often

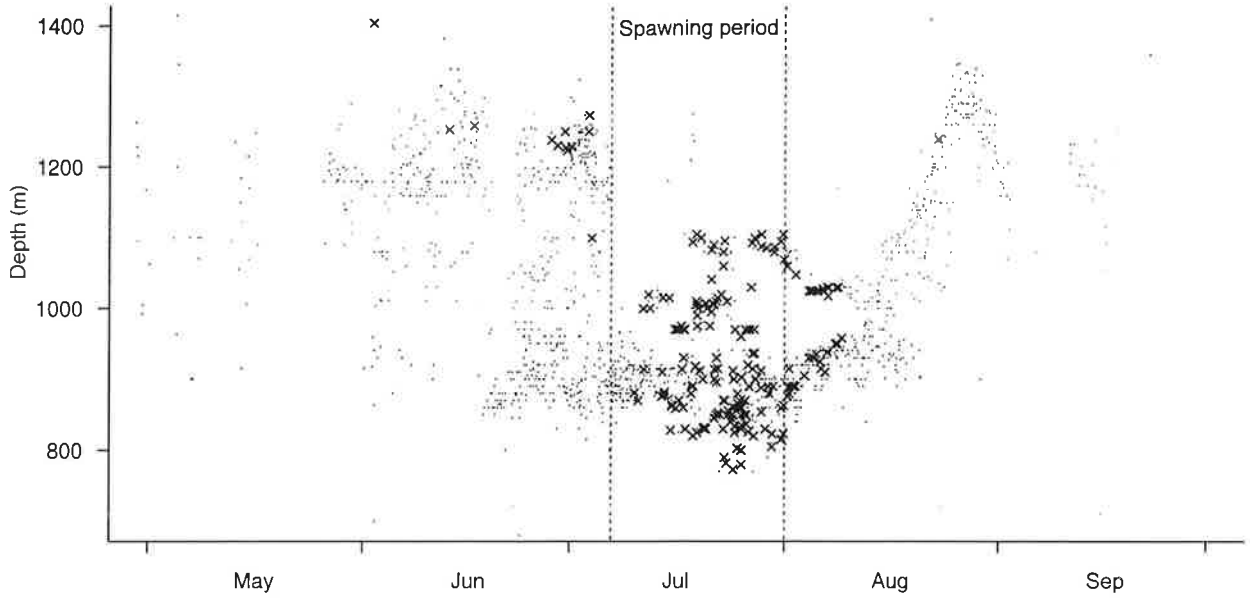

Figure 13: Depth of fishing for tows during the 1989 season (catch rates over 1.35 t/km are shown by "x").

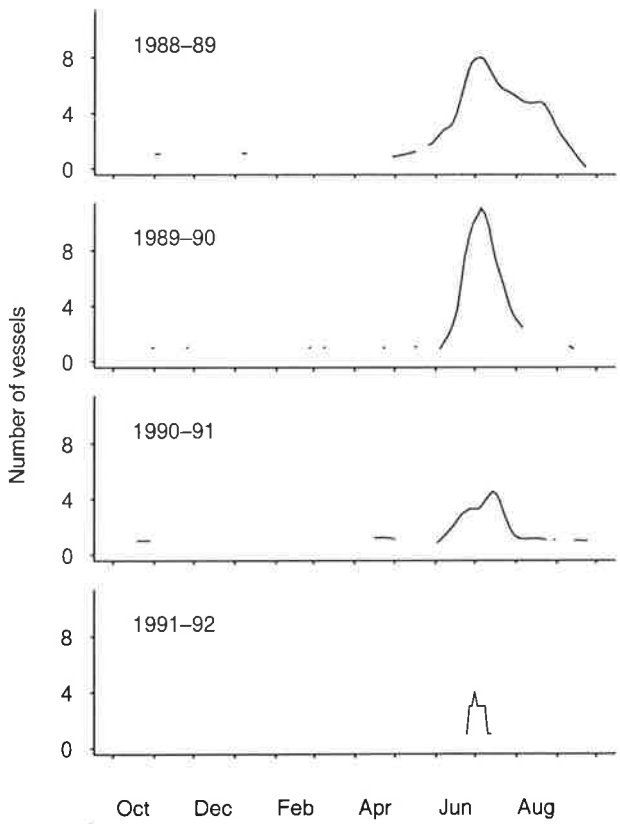

Figure 14: Fleet size on flat ground in fishing years 1988–89 to 1991–92. The line is a local regression fit (*see* Figure 9).

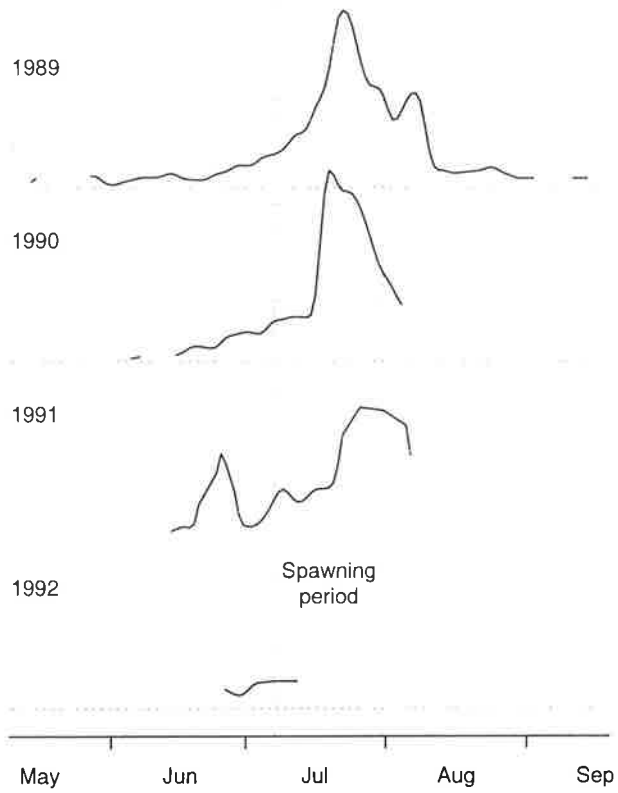

Figure 15: Catch per kilometre profiles for fishing on the flat, 1988–89 to 1991–92. The profiles are smooth median lines (*see* Figure 11).

only a part of the hill is fished. Navigation is all important, requiring GPS and other sophisticated fishing gear to allow vessels to return to a precise location and repeat tows almost exactly. Before 1988 GPS was installed on just one New Zealand vessel with only 8 h coverage a day. In 1988, GPS was on three vessels and had 12 h coverage, and by late 1992 there was 24 h coverage and all vessels had GPS. Hill fishing seems to be the preserve of New Zealand skippers who have the most experience; most of the flat tows in 1991–93 were by the charter fleet. However, weather can be a factor and skippers who would normally fish hills may fish the flat in poor conditions (M. R. Clark, NIWA, Wellington, pers. comm.).

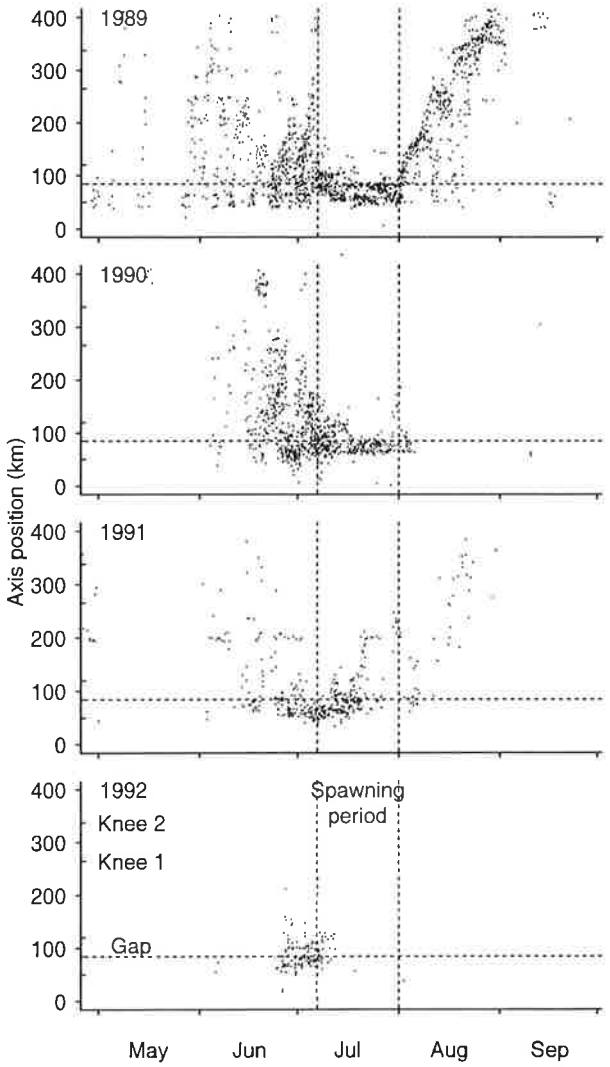

Figure 16: Axis position (*see* Figure 12) of fishing on flat ground, 1988–89 to 1991–92.

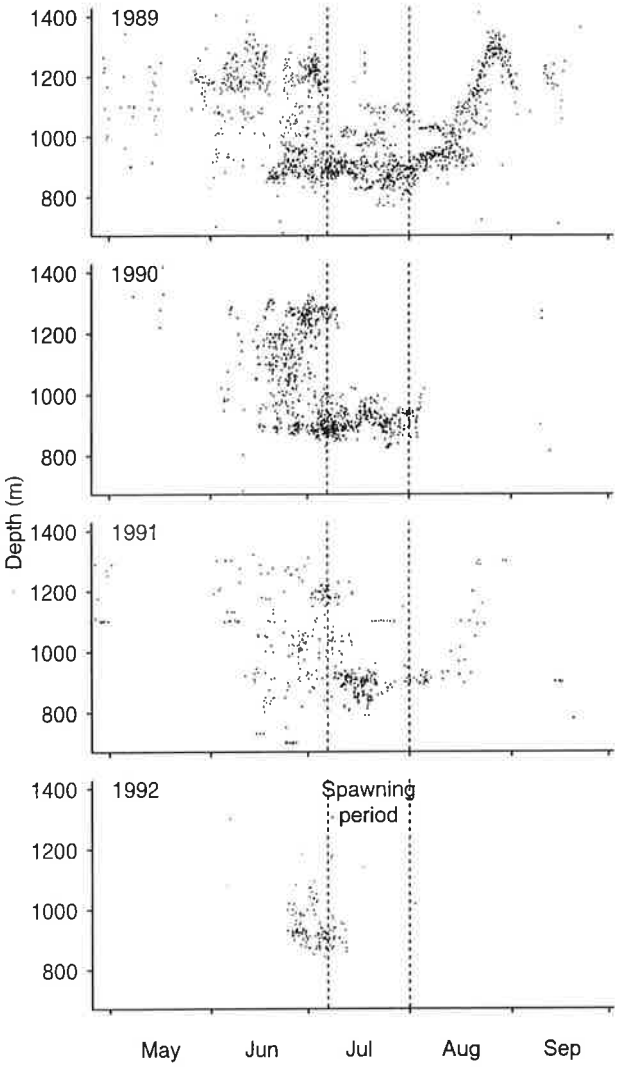

Figure 17: Depth of fishing on flat bottom, 1988–89 to 1991–92.

Catch rate was expressed as tonnes per tow (cpt) because tow duration (used to calculate cpkm) is not recorded accurately enough for the short tows that are made on hills.

Most hill fishing has been on Smiths City, Camerons, and Erebus, first exploited in 1991, and the Andes complex, which was first exploited in 1992 (*see* Appendix 1). Smiths City, Camerons, and Erebus appear to be seasonal and are almost free of oreo bycatch: the Andes complex is akin to south Chatham Rise hills with significant oreo bycatch and no clear seasonality.

Smiths City, Camerons, and Erebus

The total catch of orange roughy and the number of tows decreased over the years (Table 5). Mean catch per tow has a downward trend on Smiths City, shows no trend on Camerons, and has increased on Erebus (but on very low effort). There is a small bycatch of oreo with no trend. Combining these data (Figure 19) shows that after the first year's fishing, effort (number of tows) and catch rate (median cpt) were seasonal with little effort outside an extended winter period (April–September), which had poor catch rates. The oreo bycatch was not seasonal. One interpretation of these data is that after a "resident" population of fish was removed in the first year, fish become readily available again only during the spawning migration (outlined by Coburn & Doonan 1994) which passes through these hills.

The Andes

The Andes is a particularly rugged group of hills which was found several years before it was first fished substantially in 1991–92 (*see* Appendix 1). The total catch of orange roughy halved in subsequent years (Table 6), with oreo bycatch being about a quarter of the total catch. Mean cpt for orange roughy declined by 45% between 1991–92 and 1993–94. There was no clear seasonality of catch or catch rate on these hills for orange roughy or oreos.

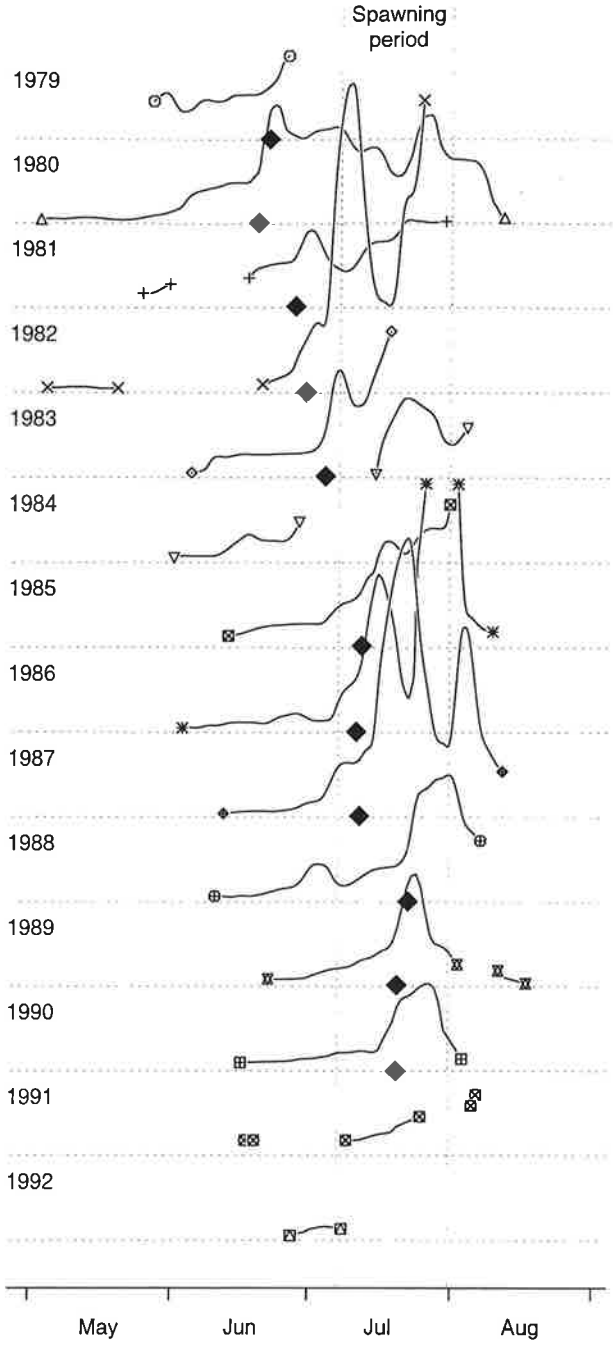

Figure 18: Catch per kilometre profiles from the main spawning site (800–950 m, 176° 27′–177° 21′ W) for each season, 1979 to 1992. The profiles are smooth median lines as in Figure 11. The diamonds show when the profiles first exceed 1.35 t/km.

The Andes provide a case study of how hills are exploited. Along with pioneering safe tow paths, some fishers use GPS, sounders, and computer mapping tools to build up highly detailed personal bathymetric charts of hills. An example is given in Figure 20, which also shows one fisher's tows. This compares well with similar data from MAF Fisheries surveys (*see* Wood 1995). Pioneering new tow paths is risky, but the catches at the beginning of exploitation are usually the best. Initially, some skippers consider these tow positions too valuable to record in logbooks and apply an offset or use a nominal position (Figure 21). However, most do record positions accurately.

Exploitation was mainly on Possum, Cotopaxi, and Chile in the first year, when catch rates were highest. Catch rate was maintained for the next year, but the number of tows and catch was reduced to below half that of the previous year. In the third year, most activity was on Possum and the mean catch rate fell significantly. Some effort shifted on to a previously unfished hill, Iceberg. A similar pattern of serial exploitation of hills has occurred on the south Chatham Rise, but on a much wider geographic scale (Francis & Robertson 1991).

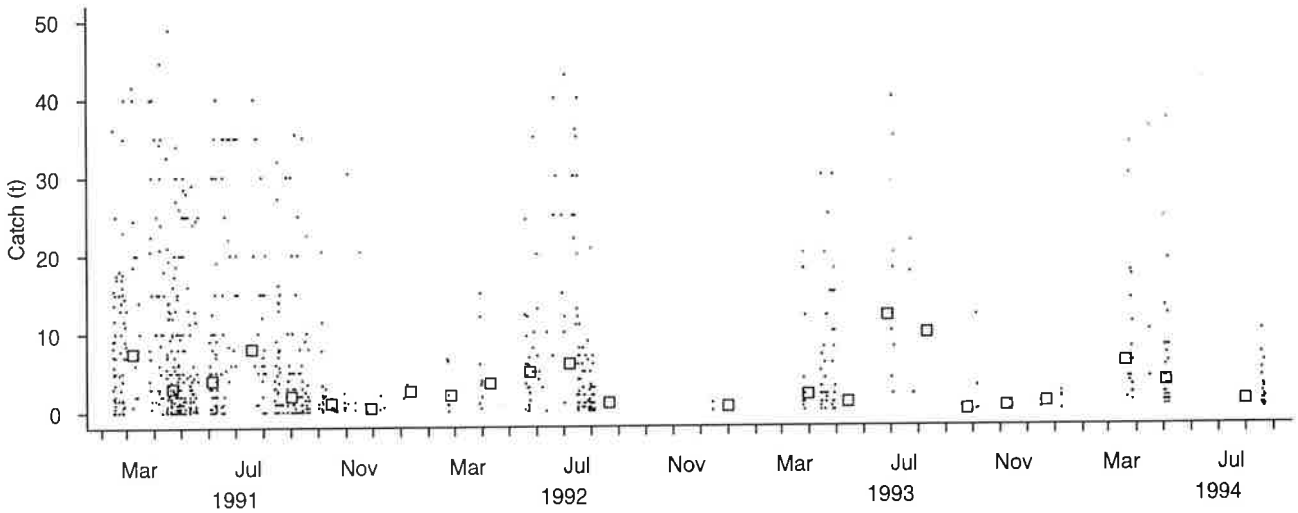

Figure 19: Catch per tow over time from Smiths City, Camerons, and Erebus combined. Each tow ('.') is jittered by ± 0.5 day. Squares mark the median catch in each of 30 time periods of equal duration spanning the data.

Table 5: For 1990–91 to 1993–94, number of tows (n), catch (to nearest 10 t) of orange roughy and oreo (smooth oreo plus black oreo), and mean catch per tow of orange roughy for the hills Smiths City, Camerons, and Erebus

		Catch		Catch rate
Fishing year	n	orange roughy	oreo	(cpt)
Smiths City				
1990–91	352	3 640	260	9.6
1991–92	159	1 120	70	6.7
1992–93	36	250	20	6.3
1993–94	48	270	60	5.2
Camerons				
1990–91	60	430	80	6.6
1991–92	20	30	10	1.3
1992–93	28	280	10	9.1
1993–94	40	170	10	4.0
Erebus				
1990–91	204	1 140	500	5.2
1991–92	38	190	30	4.7
1992–93	14	120	30	7.8
1993–94	9	100	40	9.8

Table 6: Catch statistics for the Andes complex, 1991–92 to 1993–94. Number of tows (n), catch (to nearest 10 t) of orange roughy (ORH) and oreo (smooth oreo plus black oreo), mean catch per tow of orange roughy and oreo bycatch (% of orange roughy plus oreo catch)

		Catch (t)			Catch rate
Fishing year	n	orange roughy	oreo	mean cpt (ORH)	bycatch (%)
1991–92	819	8 560	3 110	9.9	26
1992–93	335	3 190	920	8.7	22
1993–94	577	3 450	1 220	5.5	26

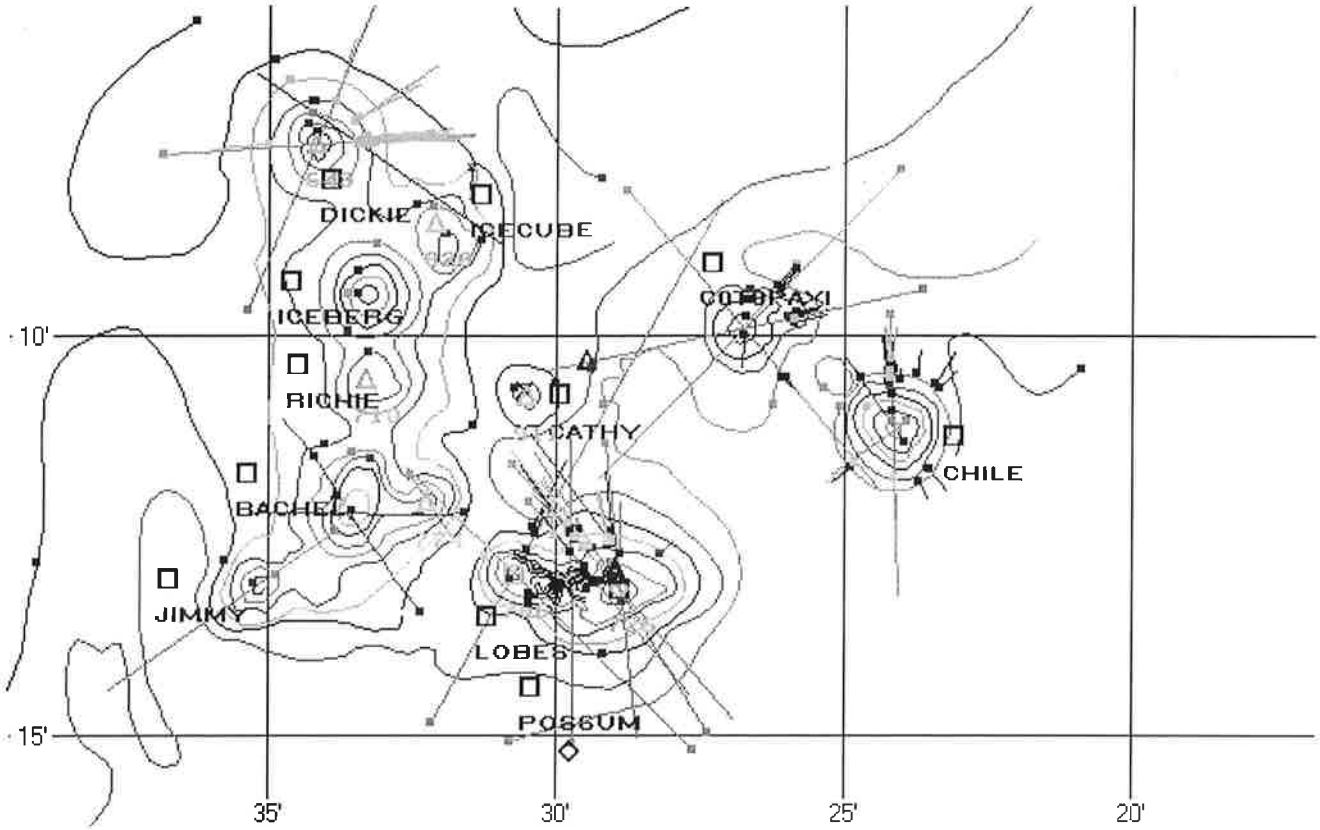

Figure 20: One fisher's chart of the Andes complex showing topography and some tow paths.

Discussion

Position and catch provide valuable background material for managing fisheries. For the orange roughy fishery on the Chatham Rise these data showed the significance of new hills (Francis & Robertson 1991), the influence of oreo bycatch on the change of fishing pattern (Francis *et al.* 1993), and the concentration of fishing into small areas (Francis *et al.* 1995). However, these data are open to interpretation and can be misleading if used selectively. In particular, unchecked aggregations of data are potentially misleading and detailed analysis is required to reveal what is happening, for example, the mean catch per vessel day over the area by year shows a steady rate, indicating little trouble in the fishery, whereas detailed stock assessments showed a major decline in stock size.

Coburn & Doonan (1994) suggested that fish migrate into the main spawning site for spawning and migrate back afterwards. The 4 more years of fishing on the flat examined here do not contradict this suggestion. However, the successful fishing at Smiths City, Camerons, and Erebus (which are on the migration pathway) during July suggests that not all orange roughy migrate to the main spawning site and raises the possibility that there may be separate stocks of orange roughy on the northeast Chatham Rise.

The shrinkage of the hot spot seems likely to be a manifestation of declining abundance, as estimated in stock assessments (Francis *et al.* 1995). Over the years the period during which median catch rates exceed the threshold of 1.35 t/km has shortened and peak median catch rates have reduced (*see* Figure 18). The Ritchie Hill fishery at spawning time has shown a similar reduction as biomass declined (Field *et al.* 1994, figure 1). Spawning makes orange roughy vulnerable to heavy exploitation because vessels can target spawning aggregations to maintain catch rates even if the number of aggregations or their size diminishes. The orange roughy fishery on the Challenger Plateau collapsed (Clark & Tracey 1994) after 8 years when the main spawning aggregations failed to form and quotas for the whole Challenger Plateau (QMA ORH 7A) were cut to less than 2000 t.

When the orange roughy fishery developed on the Puysegur Bank (which is in the same management area as the Chatham Rise, ORH 3B) quota holders agreed to reduced the Chatham Rise catch by 5000 t in 1991–92. The Chatham Rise quota was again reduced in 1992–93 to 14 000 t, a little over half the historical annual catch, and reduced again in 1994–95 to 8000 t (excluding the

Arrow plateau). The last quota is close to the long term yields estimated from the stock assessment (Francis *et al.* 1995). We might, therefore, expect an equilibrium between the removal of fish by fishing and natural mortality and increases from productivity. Some new but minor hills may be pioneered, but it seems unlikely that there are any major reservoirs of orange roughy left on the Chatham Rise as the area has been extensively explored. One possibility is fishing deeper, but orange roughy appear to become less abundant below 1200 m (Grimes 1994, table 5). Thus, with no new reservoirs of orange roughy and a constant stock size, we may see a stabilisation of fishing practice and catch rates in coming years provided the quota is held constant.

Should the current hills be depleted of orange roughy we expect the main spawning area in the Spawning Box during winter will be the last place where orange roughy can be caught in large amounts on the Chatham Rise. (The Box was reopened for the 1995–96 season.)

Summary of the fishery, 1979 to 1994

The fishery expanded from 1979 to 1987. Annual catch grew to over 20 000 t and vessels fished over a wider area, deeper and longer through the season, and skippers learnt to exploit the fish migration pathway. Since 1987 the fishery has contracted. Annual catch dropped to 5000 t, the main historical fishing area was closed, and since 1992 most fish have been caught on hills in the east of the region.

Although the fishery has been dynamic, the timing and location of spawning fish has been the same each year and mean catch per vessel day has changed little. However, the size and period of the hot spot has shrunk and independently assessed abundance has fallen.

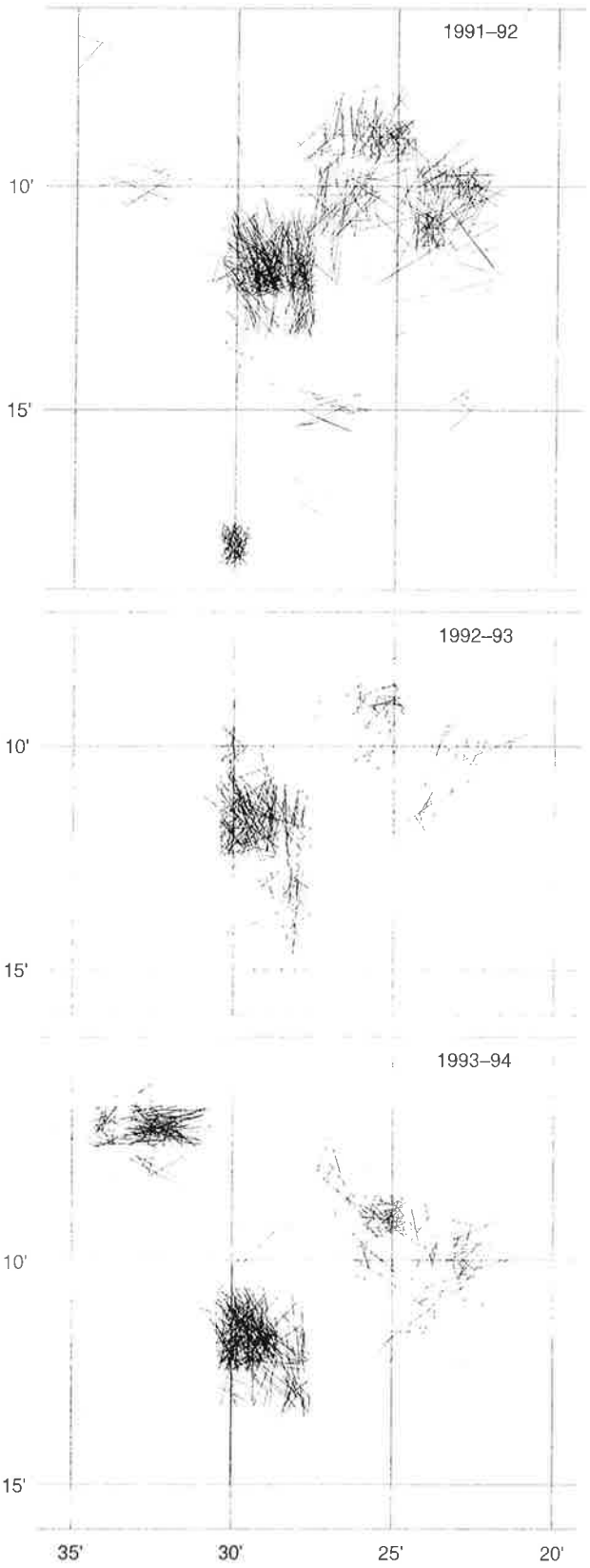

Figure 21: Tow tracks on the Andes complex (around 44° S, 174° W *see* Figure 2), 1991–92 to 1993–94 (start and end positions are jittered ± 0.5'). Also shown is a block which had positions recorded with an offset in 1991–92 (lower left). No hill exists there.

Acknowledgments

We acknowledge the fishers who filled out the catch effort logbooks and thank members of the Ministry of Fisheries who made the data available. Thanks to Sealord Group Limited, Mike Baker, and Dick Harris for allowing us to use Figure 20, which also appears on the cover. Thanks to Trevor McDonald of Pacific Microsystems for information on GPS coverage. Thanks to Malcolm Clark and Karen Field for their review and many useful suggestions.

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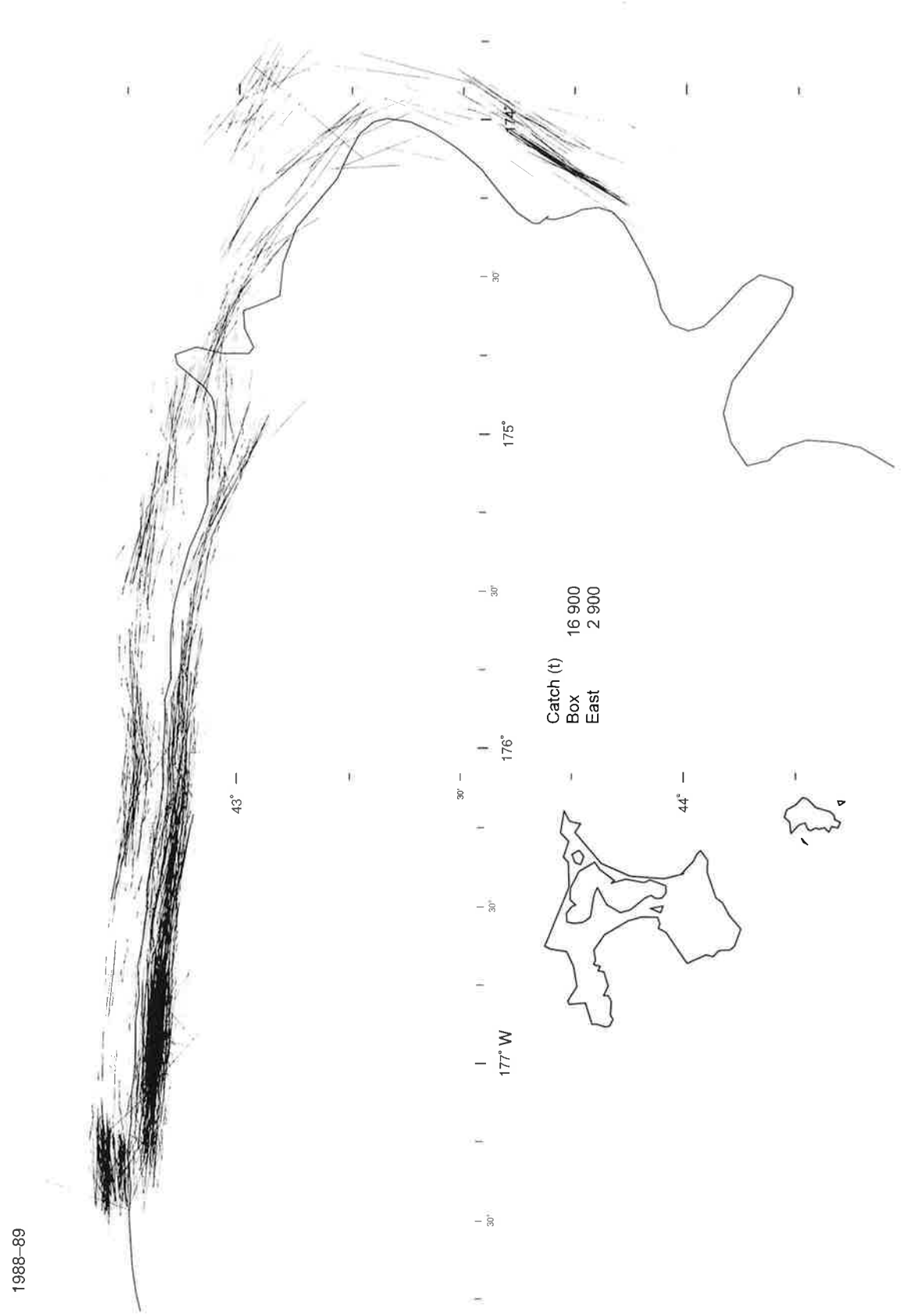
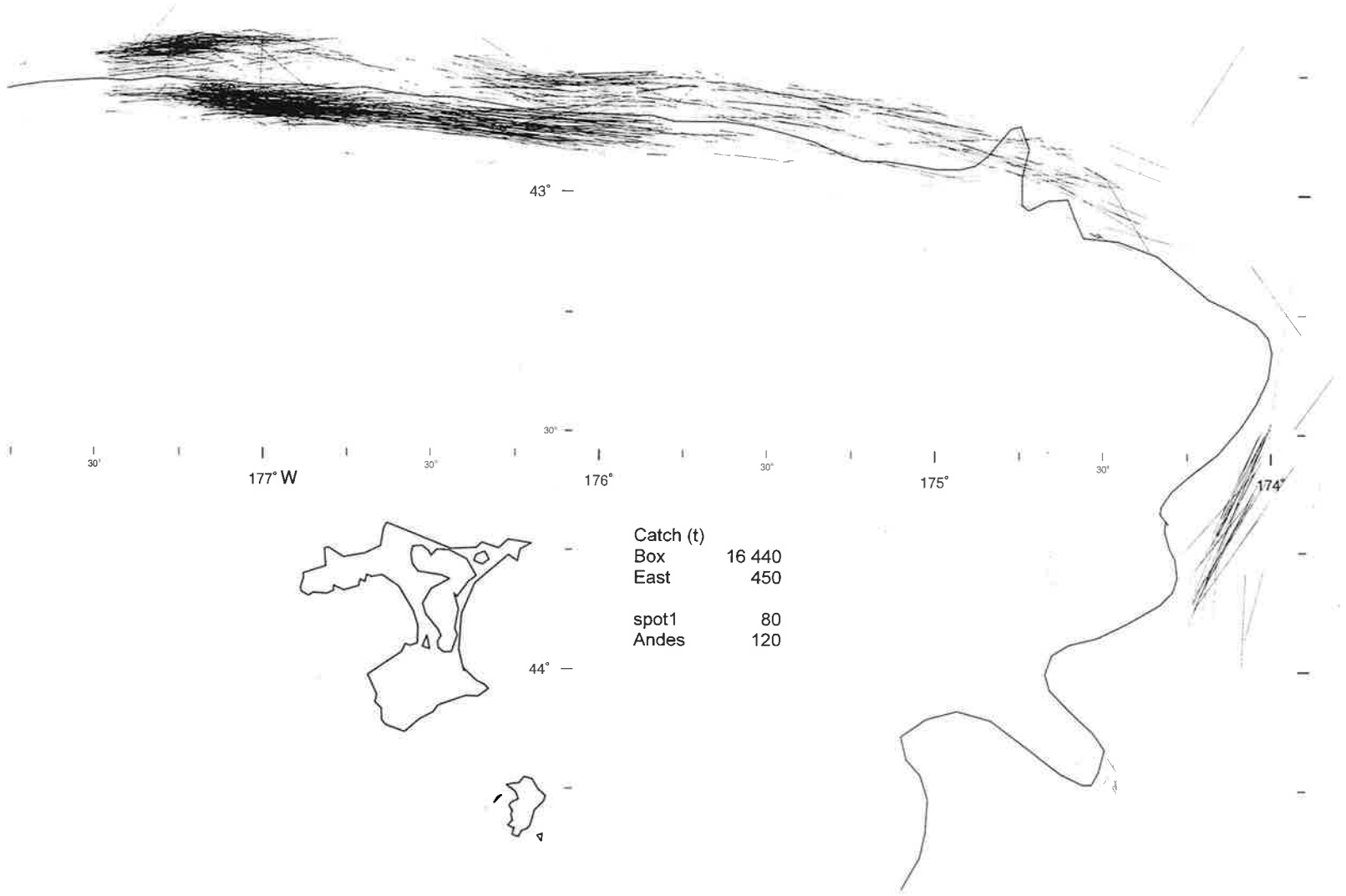
Appendix 1: Tow tracks and approximate catches on the northeast Chatham Rise, 1988–89 to 1993–94

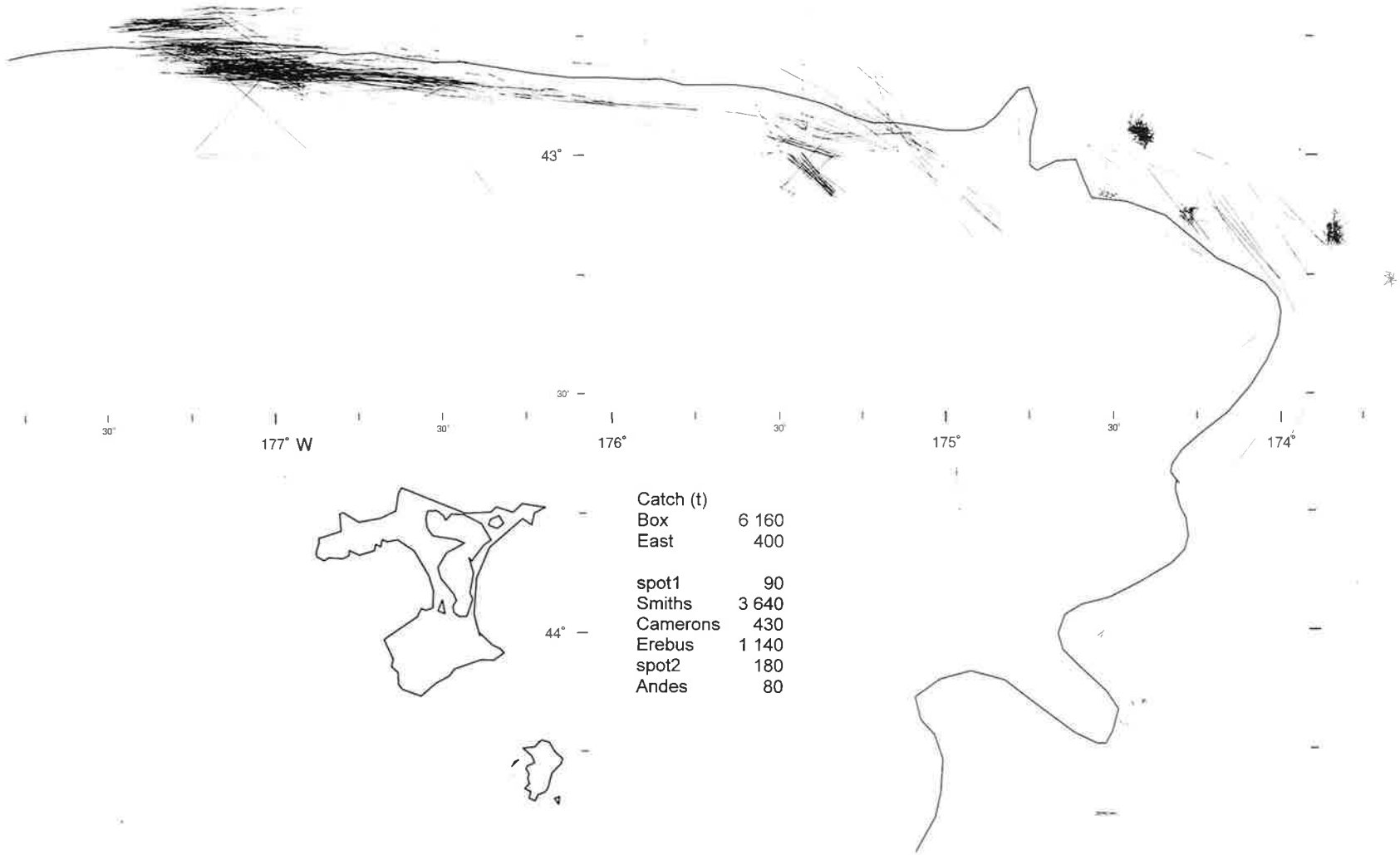
Start and end positions are jittered +/- 0.5'. Catches are broken down into fishing on flat bottom and by named features.



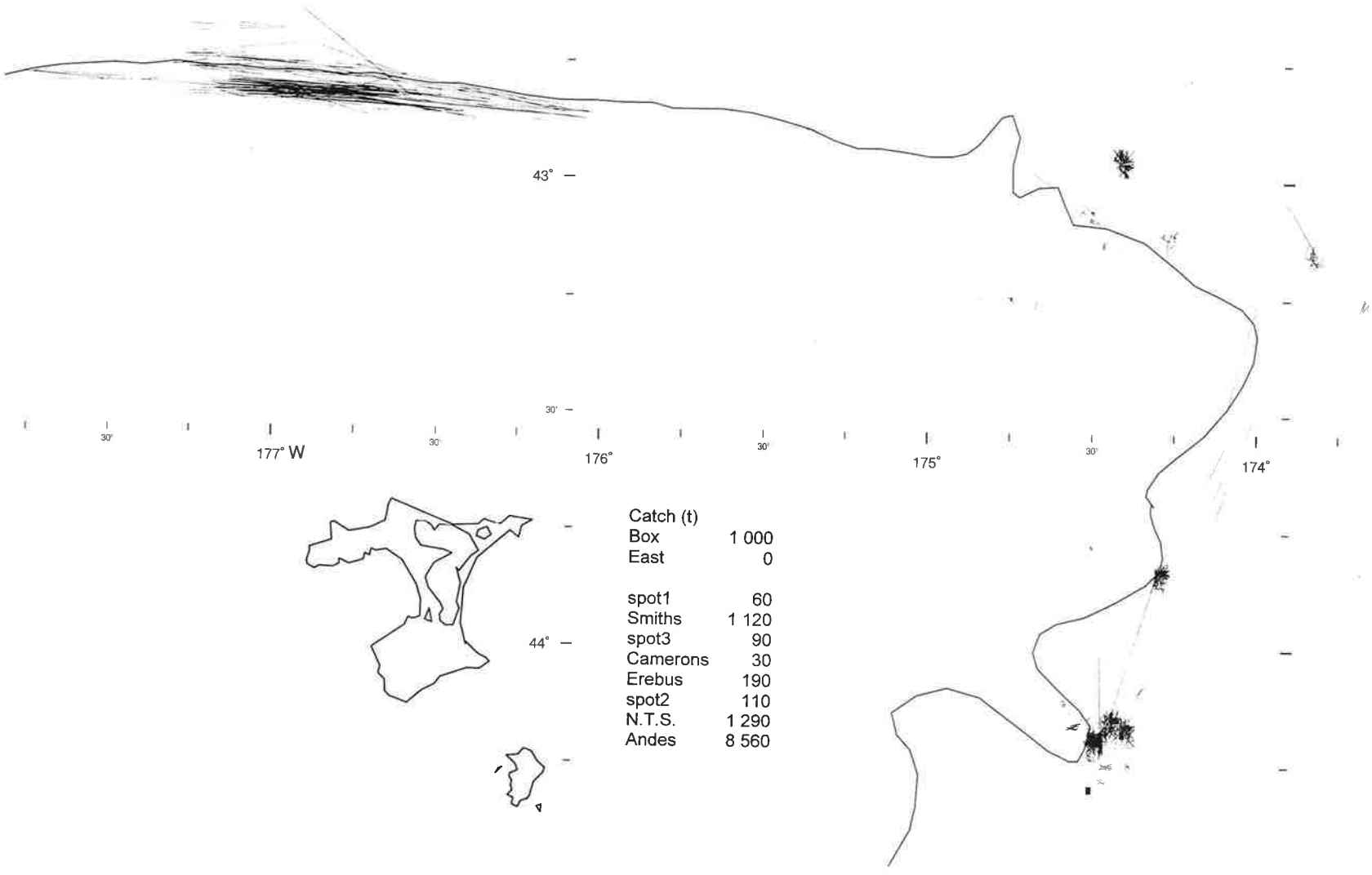
1989–90


43°
30°
30'
177° W
30'
176°
30'
175°
30'
174°
44°
Catch (t)
Box 16 440
East 450
spot1 80
Andes 120

1990–91

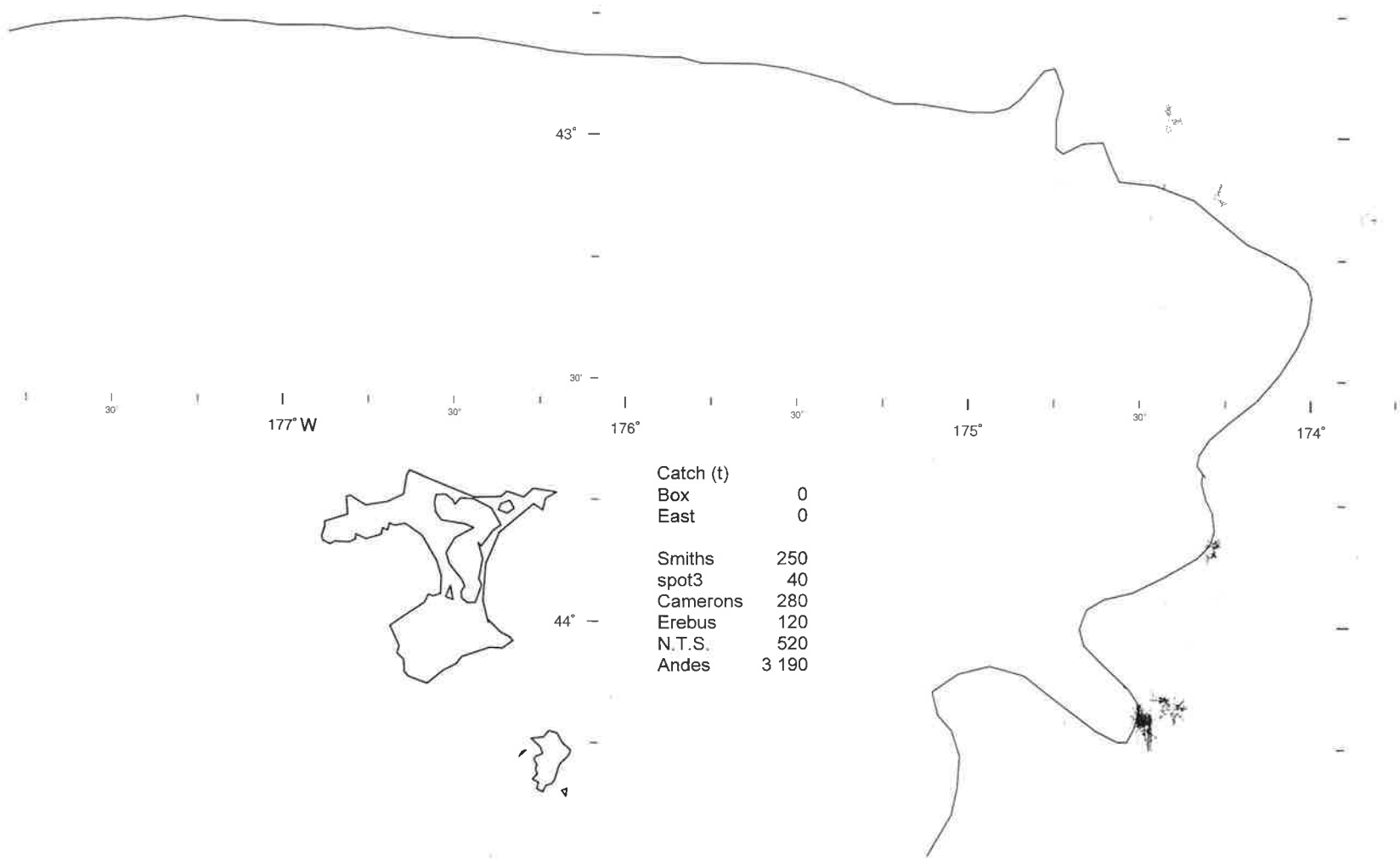

43°
30'
30'
30'
30'
30'
177° W
176°
175°
174°
44°
Catch (t)
Box 6 160
East 400
spot1 90
Smiths 3 640
Camerons 430
Erebus 1 140
spot2 180
Andes 80

1991–92



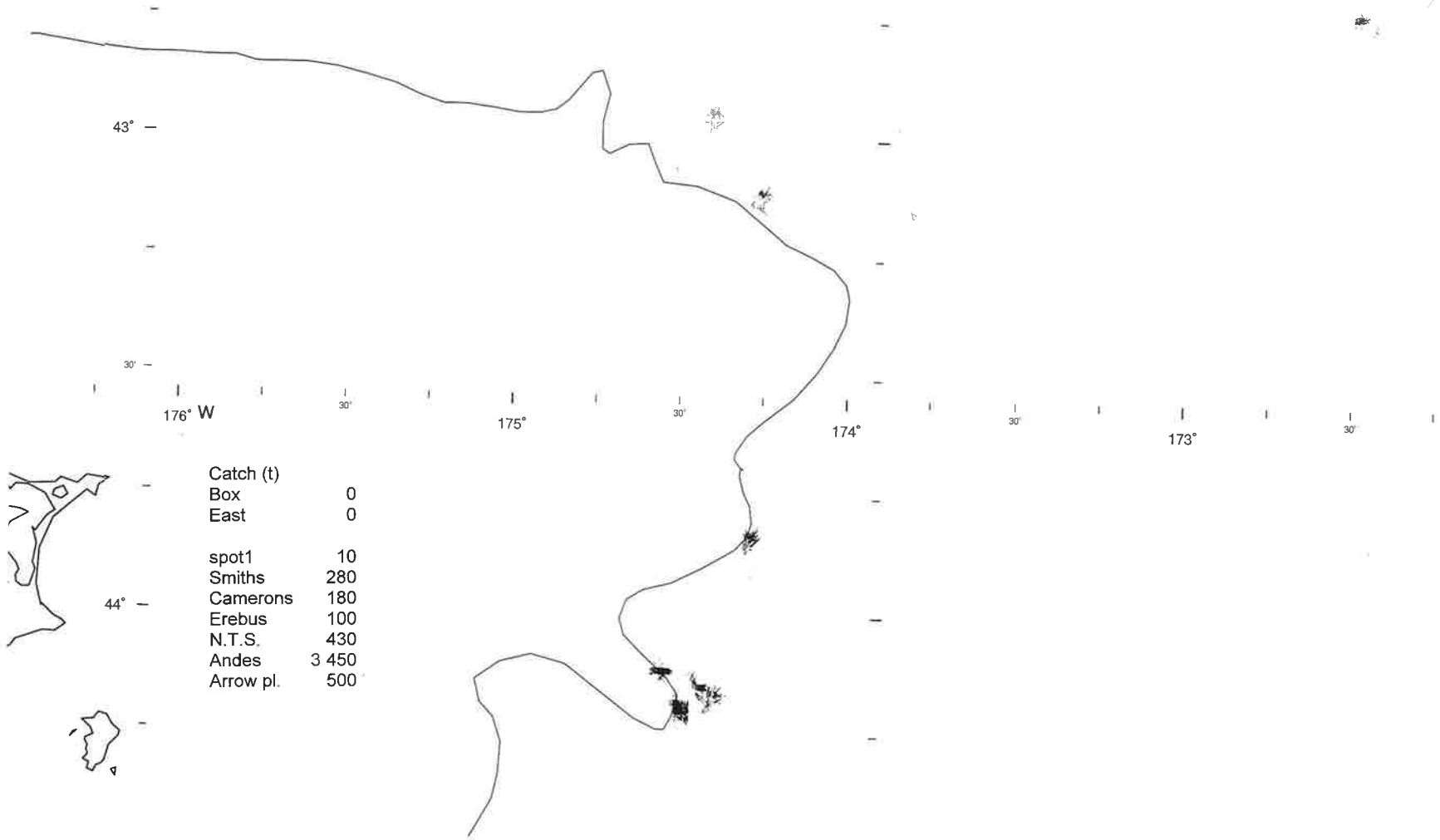
Catch (t)	
Box	1 000
East	0
spot1	60
Smiths	1 120
spot3	90
Camerons	30
Erebus	190
spot2	110
N.T.S.	1 290
Andes	8 560

1992–93



Catch (t)	
Box	0
East	0
Smiths	250
spot3	40
Camerons	280
Erebus	120
N.T.S.	520
Andes	3 190

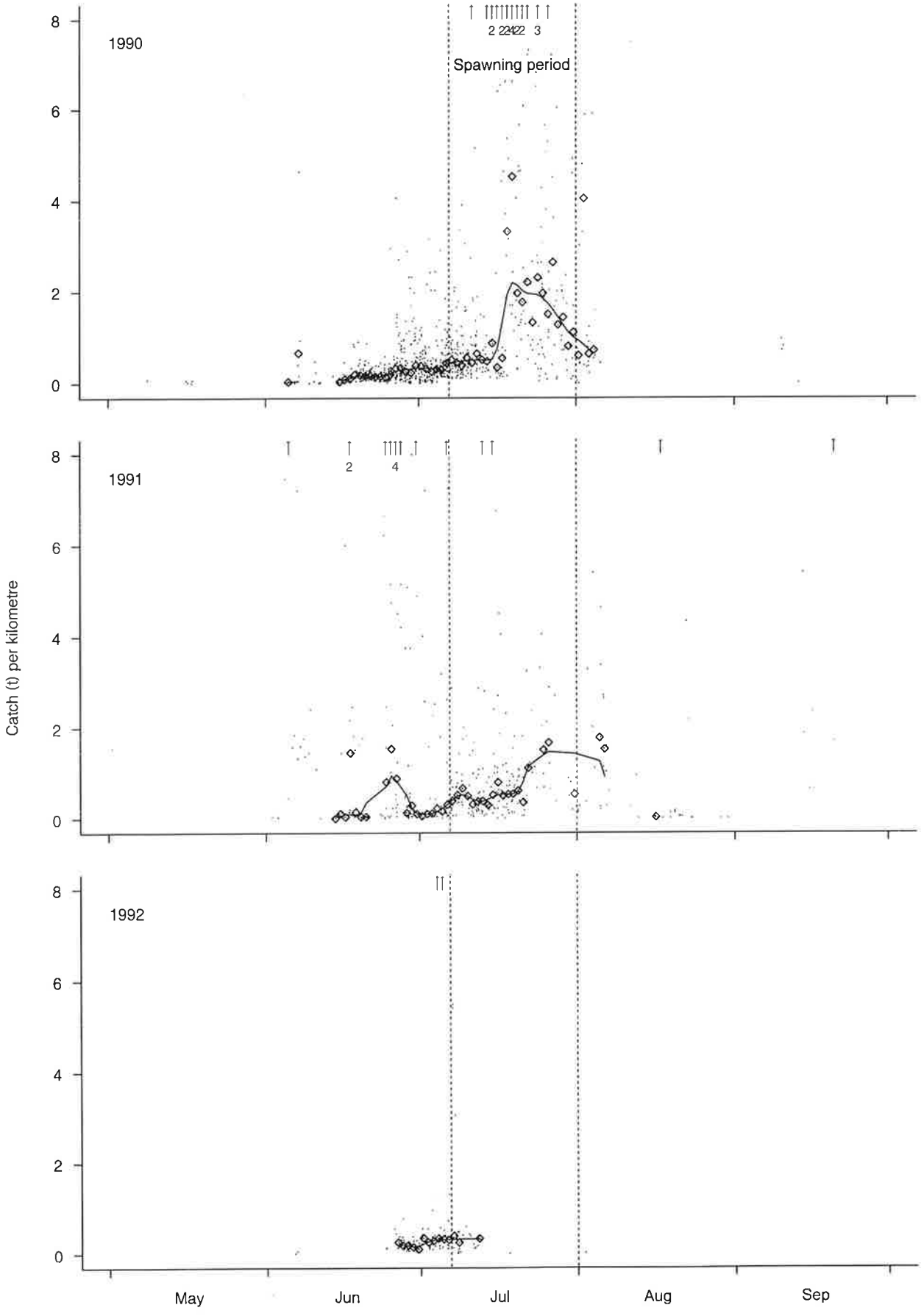
1993–94



Catch (t)	
Box	0
East	0
spot1	10
Smiths	280
Camerons	180
Erebus	100
N.T.S.	430
Andes	3 450
Arrow pl.	500

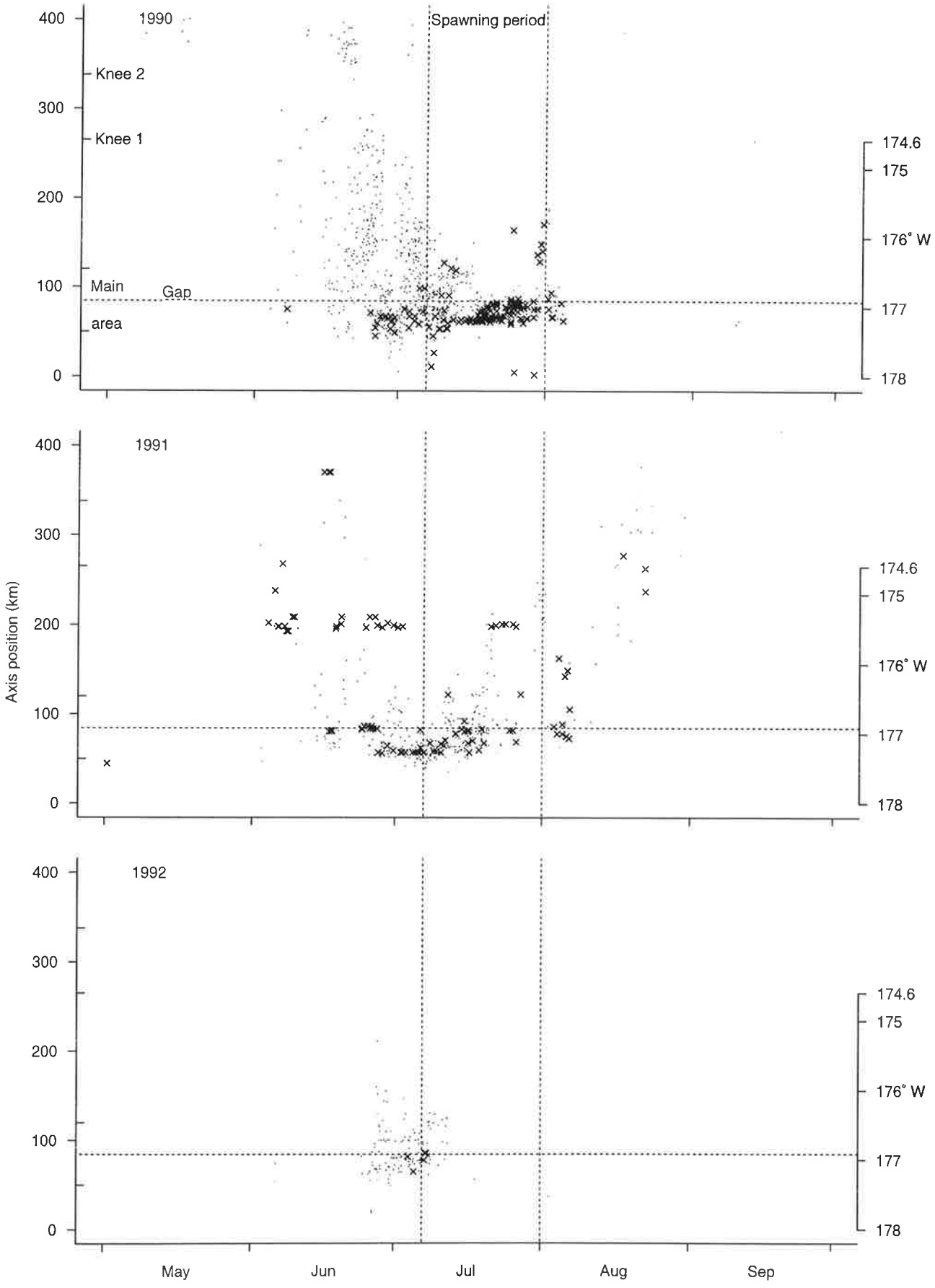
Appendix 2: Catch per kilometre over the season, 1990 to 1992

A smooth line is drawn through daily medians ("x") that have at least four tows (".") in the given day. This line is broken where gaps of more than 4 days occur in the data. Arrows indicate tows with catch rates over 8 t/km.



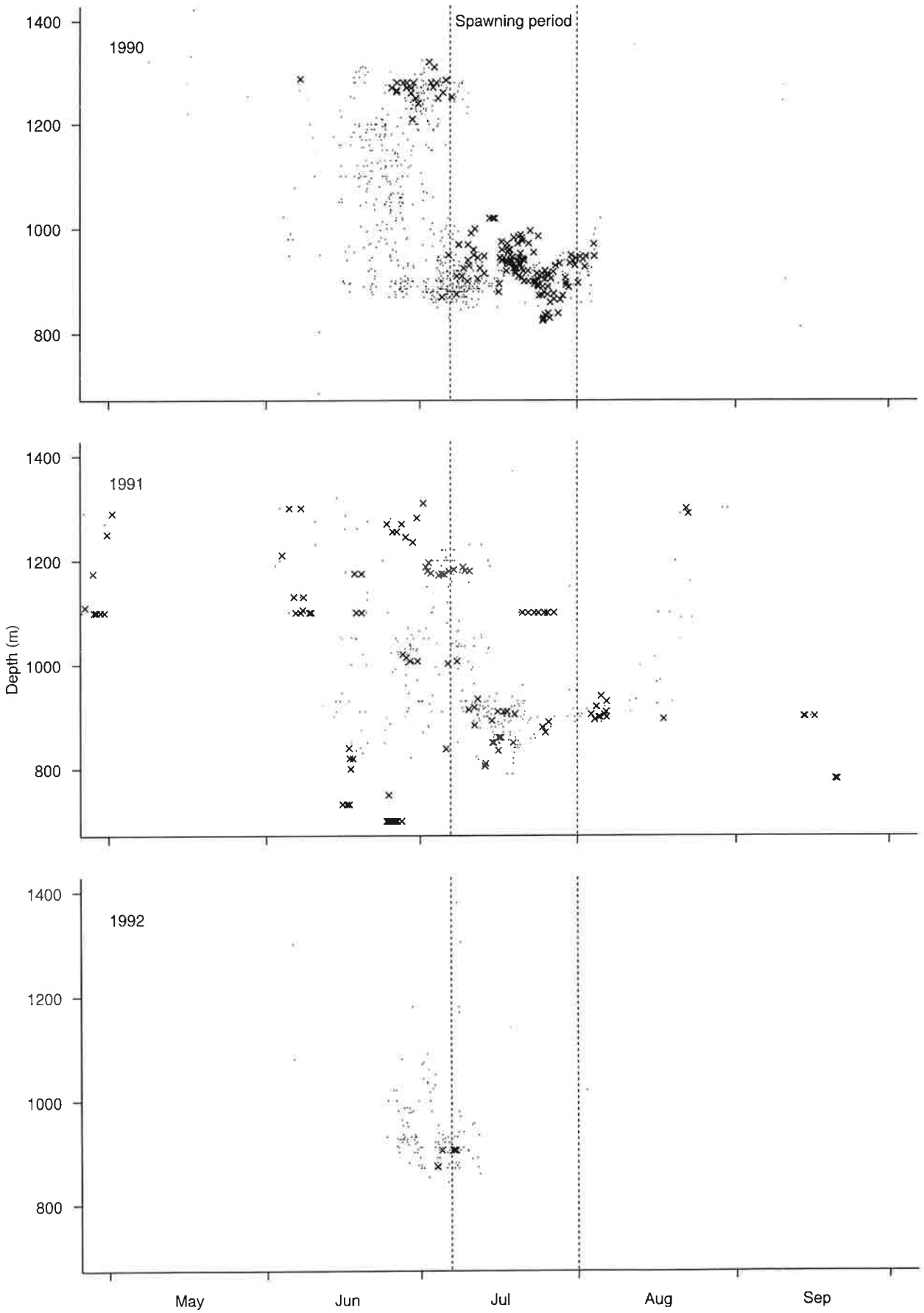
Appendix 3: Axis position of tows over the season, 1990 to 1992

Axis position is measured from 178° W along the axis line (*see* Figure 10). High catch rate (over 1.35 t/km) tows are shown by 'x'.



Appendix 4: Depth of fishing over the season 1990 to 1992

High catch rate (over 1.35 t/km) tows are shown by 'x'.



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