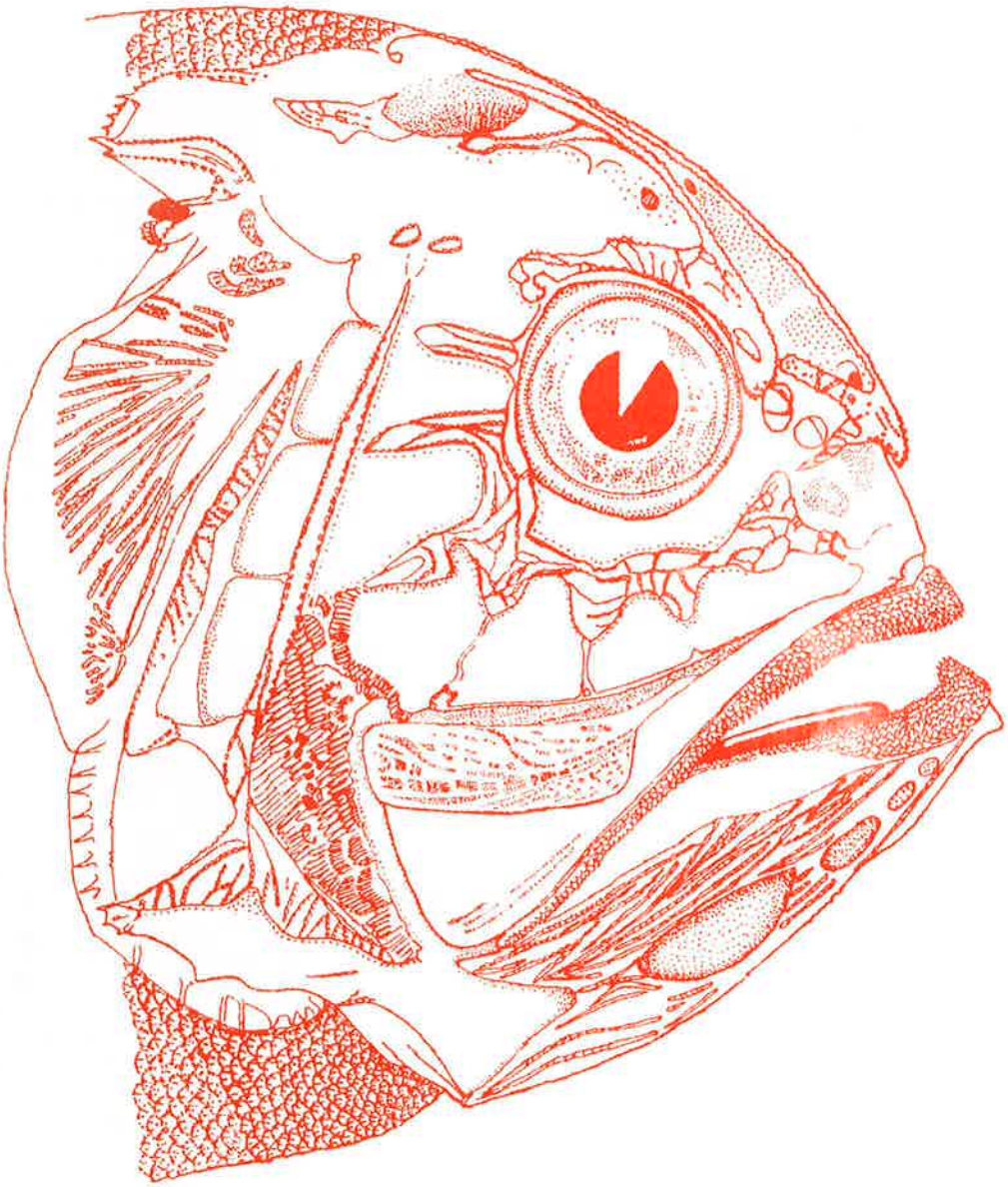
Orange roughy on the northeast Chatham Rise: a description of the commercial fishery, 1979–88



R. P. Coburn
I. J. Doonan

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Inquiries to:
The Editor, MAF Fisheries Greta Point,
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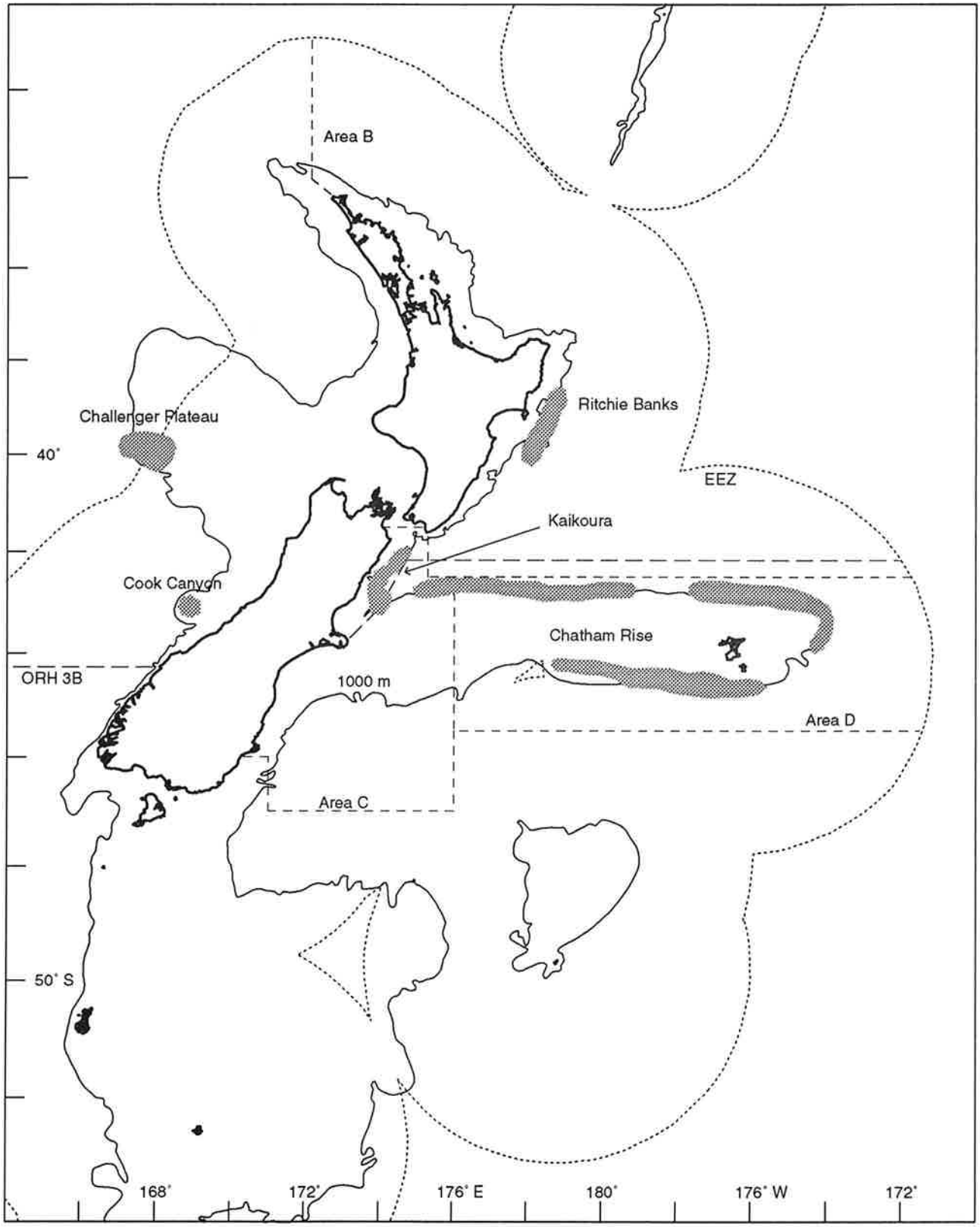

Figure 1: The main orange roughy fishing grounds in 1988 and fisheries management areas.

Abstract

Coburn, R. P. & Doonan, I. J. 1994: Orange roughy on the northeast Chatham Rise: a description of the commercial fishery, 1979–88. *N.Z. Fisheries Technical Report No. 38.* 49 p.

Tow by tow catch records of the first 10 years (1979–88) of commercial fishing of orange roughy (*Hoplostethus atlanticus*) on the northeast Chatham Rise were examined to provide a description of the fishery in 1988 and its development to that point. The fishery has marked seasonal patterns in the position, depth, and catch per kilometre that correspond to the spawning period (7–31 July); predictable major concentrations of fish at the focus of fishing activity (177° 55' W, 42° 48' S, at depths of 800–950 m); and a predictable time of peak catch per kilometre at this focus (31 July). Most fish are caught there before they have spawned and as catch per kilometre there is increasing. Catch per kilometre data suggest a migration into and away from the focus, and over the decade fishing strategy has evolved to exploit this migration. Catch per vessel day and catch per tow show no trend. Catch per kilometre has fallen to one-half the 1979 level, though during the spawning period it has remained the same. High median catch per kilometre (over 1.35 $t.km^{-1}$) fishing at the focus has occurred progressively later over the years.

A model has been developed to explain the changes in the fishing pattern over the 10 year period. It supports the MAF Fisheries stock assessment work and suggests an improvement to it, and it shows why CPUE analysis does not work for this fishery.

Introduction

Catch data from commercial vessels were used to describe the orange roughy fishery on the northeast Chatham Rise for 1979–88.

MAF Fisheries has collected tow by tow data from deepwater trawlers fishing New Zealand's 200 n. mile Exclusive Economic Zone (EEZ) since 1978. These data have been used to describe the development of the fishery since 1979 and its state in 1988. The data are sufficient to show trends, and they support the MAF Fisheries stock assessments, which apparently contradicted the impressions of many industry personnel.

This work was done at the same time as a formal standardised catch per unit effort (CPUE) study of the fishery (*see* Doonan 1991), which was intended to provide an index of abundance.

The Chatham Rise

Orange roughy has been an important commercial species since 1979. It is a major earner of export dollars in the fishing sector and has been instrumental in the development of a domestic deepwater fleet. Orange roughy exports were worth NZ$141 million free on board for the year ended 31 March 1988 (Anon. 1989). The fishery for orange roughy first developed on the Chatham Rise, and, though orange roughy are now fished widely around New Zealand (Figure 1), the largest catch still comes from the Chatham Rise. For example, in the 1987–88 fishing year 53% of the total reported orange roughy catch from the EEZ (45 000 t) was taken from the Chatham Rise.

Although it is thought that orange roughy were taken from the Chatham Rise before 1979, substantial catches were not reported until 1979. Thus, the fishery can be examined as it developed from a near-virgin state.

The Chatham Rise is a ridge-like eastern part of the New Zealand Plateau which extends from the middle of the South Island to beyond the Chatham Islands. Orange roughy are fished around the sides of the rise in depths of 700–1500 m. Three distinct areas are fished: the northwest, northeast, and south (Figure 2). The northeast area is fished mainly in winter, whereas the other areas are fished throughout the year (Figure 3). Over the study period, 1979–88, the northeast was the most important area (Appendix 1); for example, in 1987

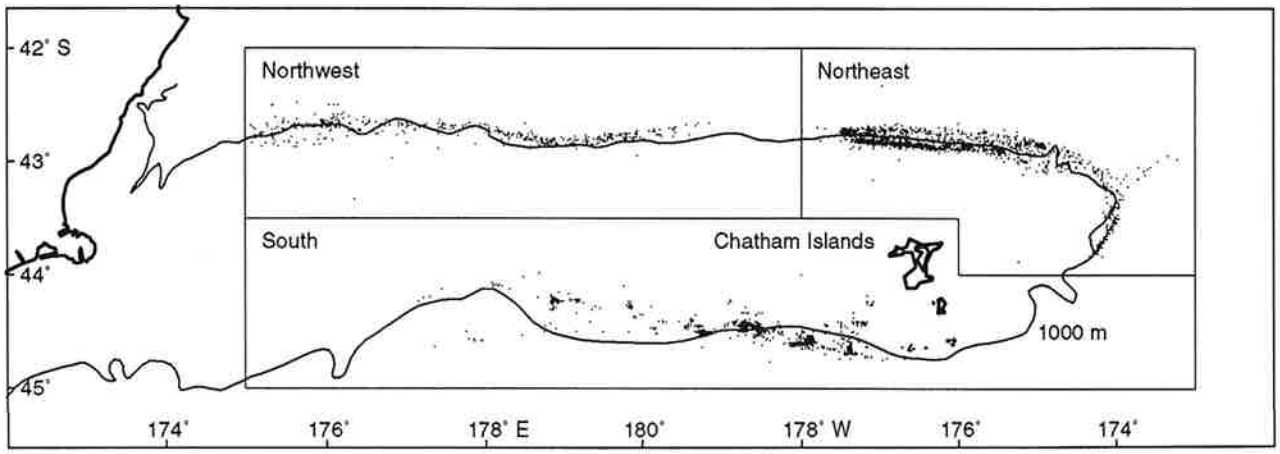

Figure 2: Start position of tows that caught or targeted orange roughy in the three areas on the Chatham Rise in 1987.

it accounted for about 70% of the total Chatham Rise catch.

The northeast area is mainly flat ground and is fished by "ground trawling". (In recent years there has been a shift to some pinnacle fishing in the northeast.) The southern fishery is based on pinnacles and "drop-offs", and fishing is usually done by flying the net near the bottom and/or landing it on the bottom for a short time. The northwest area is a mixture of smooth and rough bottom, and it is the area least fished. Orange roughy is the only target species on the northeast grounds, and there is no major bycatch. In the other areas, particularly the south, catches are often a mixture of orange roughy and oreos (mainly smooth oreo (*Pseudocyttus maculatus*) and black oreo (*Allocyttus niger*)). However, the most important difference between the areas is that the northeast fishery is a spawning fishery.

The spawning period

Orange roughy spawn on the northeast Chatham Rise during July (Pankhurst 1988). Fish in a spawning condition have been reported from the other areas, but never in large concentrations, and this analysis has been restricted to the northeast fishery. Fishing in the northeast starts in May and finishes in September. Most of the catch is taken before the fish spawn; however, the catch during spawning is also substantial, and there is a smaller fishery after spawning (*see* Figure 3).

The spawning period has been defined as 7–31 July (J. M. Fenaughty, MAF Fisheries, pers. comm.) and 18–31 July (Pankhurst 1988). Fenaughty defined the spawning period as the time between that when 50% of females are running ripe and 50% are spent. This is also the time when MAF Fisheries

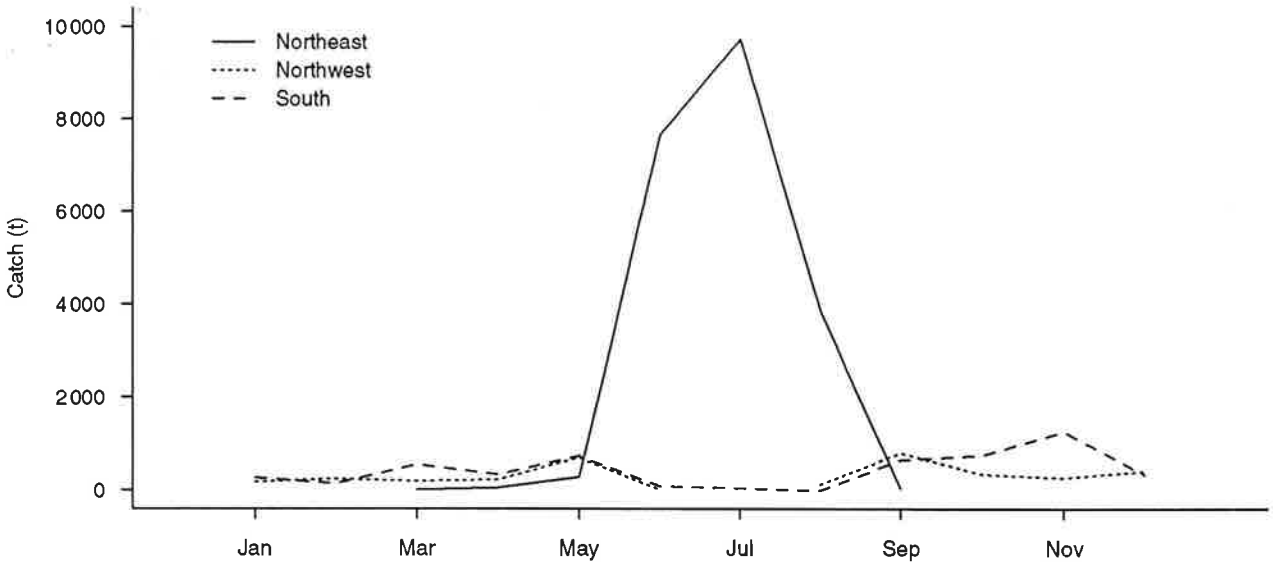

Figure 3: Monthly catch of orange roughy from the northwest, northeast, and south Chatham Rise in 1987.

surveys this stock. Pankhurst defined the start of the spawning period as the time of the first appearance of spent fish, and the end of the period as the time when 75% of fish were spent — 12–15 days after the start. This gives the same end date as Fenaughty defined. Our analysis uses 7–31 July as the spawning period because that includes the period when most fish spawn, though it appears that spawning activity is concentrated in the second half of the period.

Pankhurst (1988) studied the fishery during 1984–86, and he found that the onset of spawning and duration of spawning were the same each year. Fenaughty has surveyed the area since 1984 and has also seen no change in the spawning period (J. M. Fenaughty, MAF Fisheries, pers. comm.).

Data and analysis

The data are from catch records of commercial fishing vessels. All commercial vessels fishing in New Zealand waters are required to fill out catch records, and these have been collected since the introduction of the EEZ in 1978. The Chatham Rise is fished by large vessels which record details of each tow. We extracted the data for tows that either targeted or caught orange roughy.

For each tow the following data were normally recorded: vessel, target species, date, start time, start position, depth, speed, end time, estimated catch of orange roughy, and names of other species caught. Most records were complete.

Vessels were supposed to record the processed catch for each tow, but most recorded it only once a day. Processed fish is packed and frozen at sea in blocks of a known weight, so the processed weight is reasonably accurate, more so than catch per tow estimated by eye. However, it is difficult to assign the processed catch back to the individual tows, because the allocation depends on the tow estimate. Thus, because we wanted to examine the fishery by individual tow, we used the catch per tow estimated by eye.

There were only slight differences between processed catch back-calculated by a conversion factor and estimated catch in most years (Table 1). The main difference occurred in 1979–80, which may have been because of the recent introduction of the reporting system. The differences in 1980–81 and 1981–82 almost balance each other out. Differences in the April-September 1983 period were because the processed catch figures were not available for some of the smaller vessels. From 1983–84 on, the differences were small.

The closeness of the match between the processed and estimated catches is partly due to fishers balancing the estimated catches to match the factory production; that is, the figures are not independent, they came off the same form. In addition, some catches may not have been recorded (Francis & Robertson 1991, page 4).

The statistical package "New S" was used to examine the data and to produce tables and plots. All available data were used where possible; for example, all tows were plotted in Figure 2 when both latitude and longitude were recorded, but tows were not plotted when either or both of these details were missing.

Catch per kilometre trawled was calculated for each tow from the estimated catch, the speed of fishing, and the difference between the start and end times of the tow. If any of these details were missing, catch per kilometre could not be calculated and was recorded as "unknown". However, if there was a nil catch, catch per kilometre was recorded as zero, even if there were other details missing. "High" catches per kilometre are those of 1.35 $t.km^{-1}$ or greater. This level corresponds to the upper quartile of all tows during 1979–88.

Table 1: Reported catch (t) of orange roughy from the Chatham Rise (area D, see Figure 1) for the fishing years 1978–88

Fishing year*	Estimated catch†	Processed catch‡	Difference (%)
1978–79	59	–	–
1979–80	10 160	12 234	–18.0
1980–81	25 727	23 217	11.0
1981–82	19 960	21 644	–8.0
1982–83	20 909	21 159	–1.0
1983	14 431	12 772	13.0
1983–84	23 580	23 842	–1.0
1984–85	26 073	25 791	1.0
1985–86	26 900	27 008	–0.4
1986–87	28 545	28 884	–1.0
1987–88	23 576	23 632	–0.2

* 1978–79 to 1982–83 were 1 Apr–31 Mar, 1983 was 1 Apr–30 Sep, 1983–84 to 1987–88 were 1 Oct–30 Sep.
† Estimated catch from reported catch for each tow.
‡ Back-calculated from processed catch figures by using a conversion factor of 1.92 from headed and gutted weights. Figures include iceboats and factory vessels except for 1983, when no iceboat catches were recorded.

Catch per kilometre for groups of tows is the total catch for the group divided by the total distance towed by the group. If either catch or distance towed data were missing for an individual tow, that tow was excluded from the calculation.

The actual times recorded as start or end of tow may vary between vessels; some record start time as the time the trawl warps are locked, others record it as the time the net is on the bottom and fishing, as seen on a net monitor. In addition, start and end times are typically recorded to the nearest 5 or 10 min. These factors affect the accuracy of the calculated catch per kilometre, particularly for short tows, which tend to have high catches.

Suspect data have not been removed or corrected, and there are obvious examples, such as the tows recorded in water close to the Chatham Islands which is too shallow for orange roughy. These positions may have been incorrectly recorded at sea or may have occurred during data entry. However, data were checked by the Fisheries Statistics Unit (FSU) at Greta Point (*see* King *et al.* 1987), and most errors would have been fixed. We have focused on the main trends, which should transcend any random errors left in the data.

Catch and effort history

Catch history

Total annual reported catch from the northeast Chatham Rise has been fairly constant, usually about 15 000–20 000 t (Table 2). Catches from the whole Chatham Rise have been restricted by quotas and closed seasons (Table 3), and catches from the northeast fishery reflect changes in these restrictions and not necessarily the availability of fish.

The national mix of the fleet has changed over the years. In 1979–81 Soviet vessels took most of the catch (initially as foreign licensed vessels, then either as joint venture partners with New Zealand companies or under charter to New Zealand companies), but their proportion has decreased. The Soviet vessels were the only ones fishing under foreign licences; all other fishing was done by joint venture with New Zealand companies, under charter to New Zealand companies, or by domestic (New Zealand owned) vessels. The Japanese were first involved in 1980, and they took a substantial part of the catch from 1981 onwards. Domestic vessels began fishing in 1982, and since 1984 they have taken the largest catch, except in 1987. Korean vessels first fished in 1980, and their portion of the catch has continued to increase. Polish and West German vessels fished in the first few years, but they did not become an established part of the fleet.

The number of vessels and the number of tows by year and nation are given in Appendix 2.

Catch per unit effort

A detailed analysis of catch per unit effort (CPUE) for this fishery was made by Doonan (1991). He used a linear model that effectively standardised CPUE with respect to the important variables. Doonan used catch per kilometre as the index of CPUE because it gave more precise (i.e., lower variance) estimates of the resulting indices of abundance than other indices. However, he concluded that CPUE was not a good indicator of biomass in this fishery because the behaviour of the

Table 2: Catch (t) of orange roughy from the northeast Chatham Rise by nation for calendar years 1979–88

	West Germany	Poland	U.S.S.R.*	U.S.S.R.	Korea	Japan	New Zealand	Total
1979	1 192		8 932					10 124
1980	5 220		2 213	9 117	494	730		17 776
1981		2 321		9 019	1 141	3 425		15 909
1982				1 226		3 588	3 586	8 401
1983				60	1 022	4 360	3 520	8 964
1984				2 483	2 424	4 261	6 375	15 555
1985				1 650	2 797	4 088	9 250	17 827
1986				1 559	3 750	6 469	7 673	19 453
1987				29	3 939	9 914	7 698	21 581
1988				519	4 615	3 425	7 226	15 787
Total	6 412	2 321	11 145	25 662	20 182	40 260	45 328	151 377

* Foreign licensed vessels.

Table 3: Orange roughy quota by fishing year for the Chatham Rise, 1981–82 to 1987–88

Fishing year*	Quota (statistical area†)		Comment
1981–82	19 790	(D)	Quota first set (13 Aug 1981)
1982–83	19 750	(D)	Closed season (1 Aug-30 Sep and 1 Mar-30 Apr)
1983	14 000	(D)	Change of fishing year, 1 Mar-30 Apr closed season removed
1983–84	29 750	(B, C, D)	Allocation of quota to companies and conversion factors set, 1 Aug-30 Sep closed season removed
1984–85	29 750	(C, D)	
1985–86	29 800	(C, D)	Companies to process 35% of total quota onshore (in N.Z.) past the headed and gutted stage
1986–87	38 000	(3B)	New area (3B) now includes the southern ocean areas
1987–88	38 000	(3B)	

* 1981–82 to 1982–83 years were 1 Apr–31 Mar, 1983 was 1 Apr–30 Sep, 1983–84 to 1987–88 was 1 Oct–30 Sep.
† See Figure 1.

resultant biomass index could not be reconciled with known growth characteristics of orange roughy and the catch history of the fishery.

We analysed CPUE in an unstandardised manner to further identify characteristics of the fishery, not as an indicator of biomass. We examined three measures of effort: number of vessel-days (one vessel-day is recorded each time a vessel does at least one tow in any given day), number of tows, and distance towed. The CPUE indicators were: mean catch per vessel-day, mean catch per tow, and catch per kilometre trawled. Mean catch per tow has been used to provide an index of abundance (*see* Clark 1991).

The size of vessels in the fishery did not change much over the 10 years, particularly after 1983 (Appendix 3). Vessels ranged from 76 to 3085 gross registered tonnage (GRT) and about half the vessels in any year were over 2000 GRT. Doonan (1991) found that neither vessel size nor horsepower were important in explaining changes in CPUE.

Mean catch per vessel-day was fairly stable over the 10 years (typically about 30–40 t), as was mean catch per tow (about 10 t) (Figure 4). Therefore, vessels usually towed three to four times a day, and this did not change over the period. In contrast, catch per kilometre has decreased (from about 1.0 t

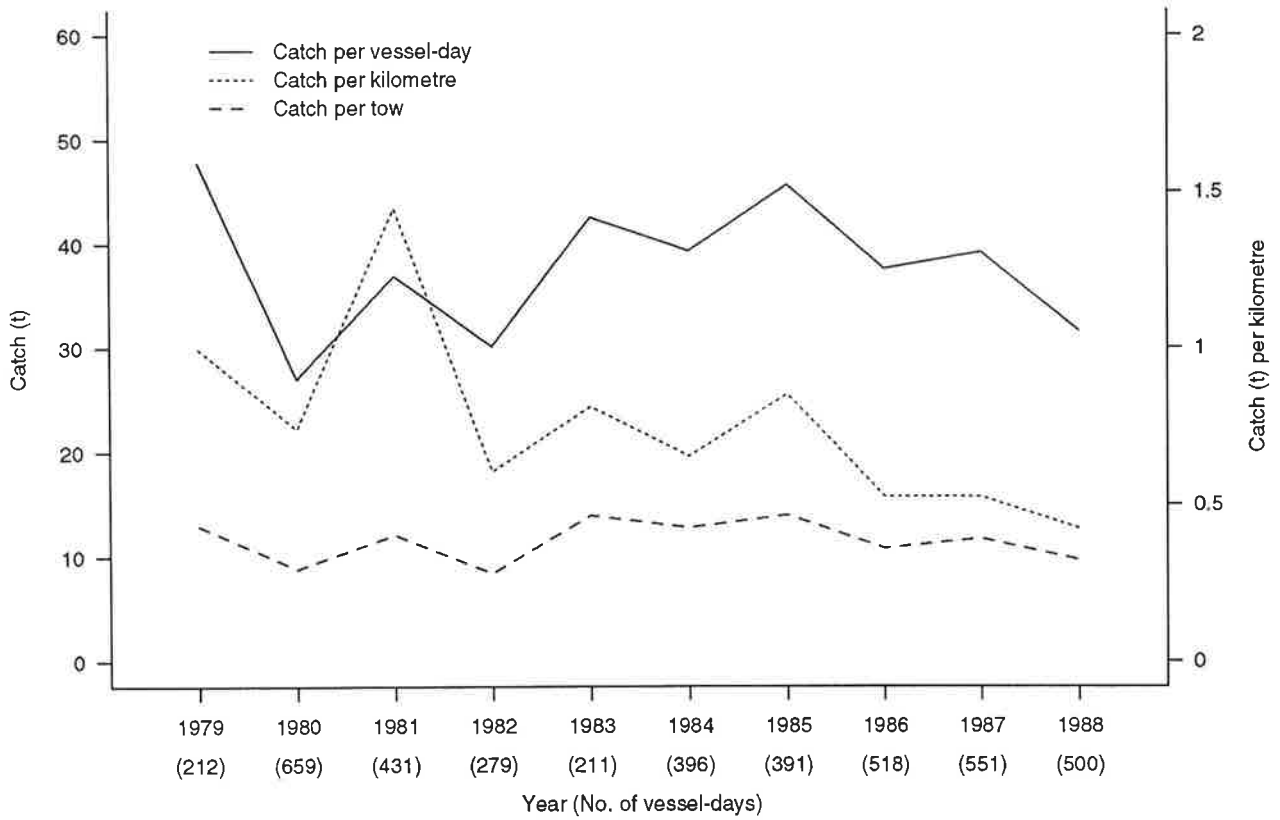

Figure 4: Catch per unit effort for each full season in calendar years 1979–88. (1978–79 to 1982–83 were 1 Apr–31 Mar, 1983 was 1 Apr–30 Sep, 1983–84 on were 1 Oct–30 Sep).

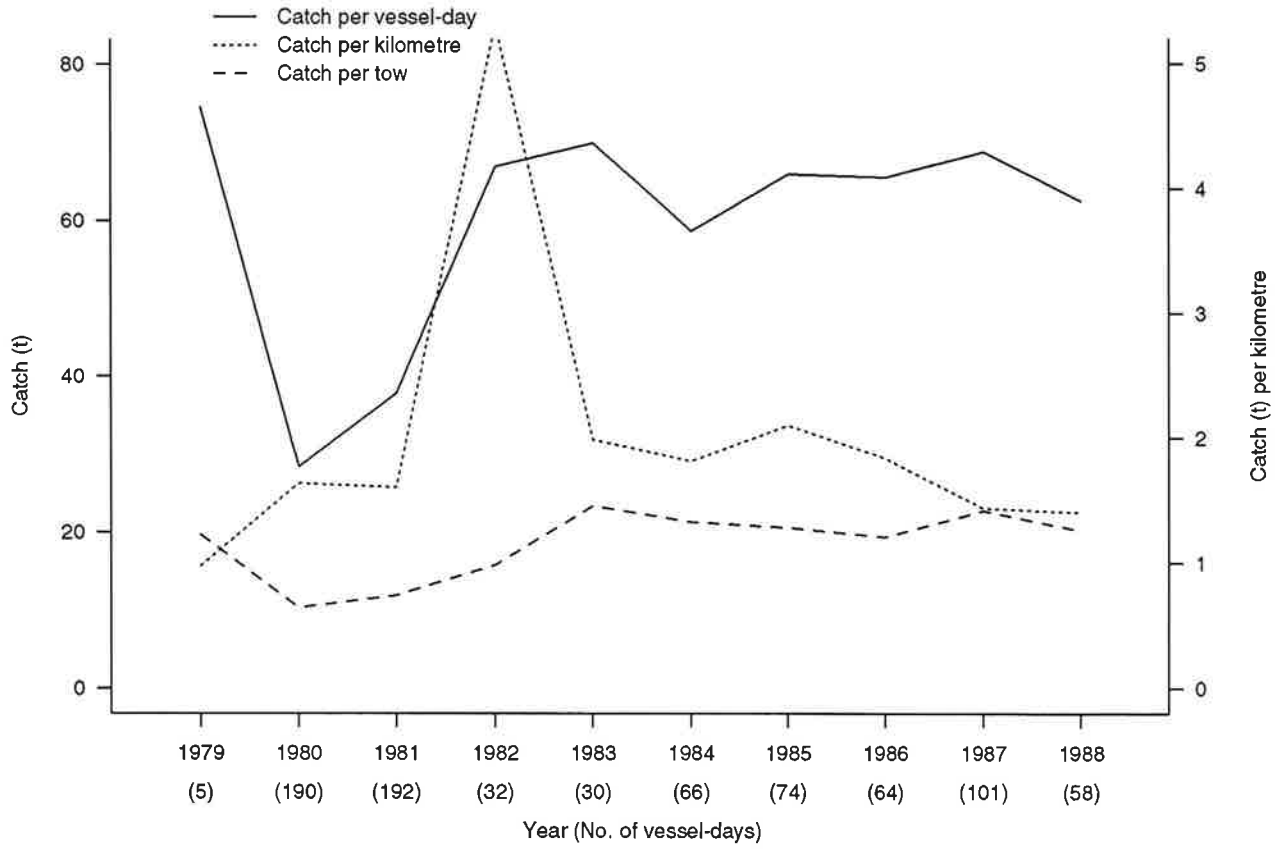

Figure 5: Catch per unit effort for the main spawning period (7–31 July inclusive), 1979–88.

to about 0.5 t). Doonan (1991) also found that standardised catch per kilometre fell over the period, and that the largest change occurred in the earlier years.

Catch per unit effort is shown for the main spawning period (7–31 July) for 1979–88 in Figure 5. The 1979 figures are based on only 5 vessel-days, and those for 1982 and 1983 are based on less than half the vessel-days typical in other years. Mean catch per vessel-day during spawning increased to about 60 t in 1982 and has since remained constant. Mean catch per tow followed a similar pattern; increasing in the early years (to about 20 t in 1983), and remaining constant since then. Therefore, during the main spawning period vessels typically towed about three times per day, and this practice continued during 1983–88. Catch per kilometre has been fairly steady at about 1.5 $t.km^{-1}$, except in 1982, when it was much higher, perhaps because two new vessels entered the fishery and were the only vessels fishing during the spawning period.

Thus, CPUE was stable for at least the last 7 years of 1979–88, except for catch per kilometre for the whole fishery, which dropped steadily. Generally, CPUE fluctuated more in the early years and then stabilised. Catch per kilometre declined over the whole season, but not during the spawning period. In addition, because catch per kilometre dropped for the whole fishery, whereas mean catch per tow did not, tows were mostly getting longer (i.e., vessels were towing over more ground to get the same catch).

The distribution of catch per kilometre was similar in each year (Figure 6). Most tows caught less than 2.0 $t.km^{-1}$, but many caught at least 2–4 times as much. The skewed distribution has continued, but the mode has shown a downward trend.

High catches can saturate the processing capacity of a vessel, and when taken repeatedly the vessel must stop trawling and clear the backlog of fish. This occurred during the 1985 season when a commercial vessel achieved saturation catches during and after the spawning season (Figure 7). This saturation was common in late July and early August, particularly in the middle years (1983–85). However, it was less common in later years (1986–88).

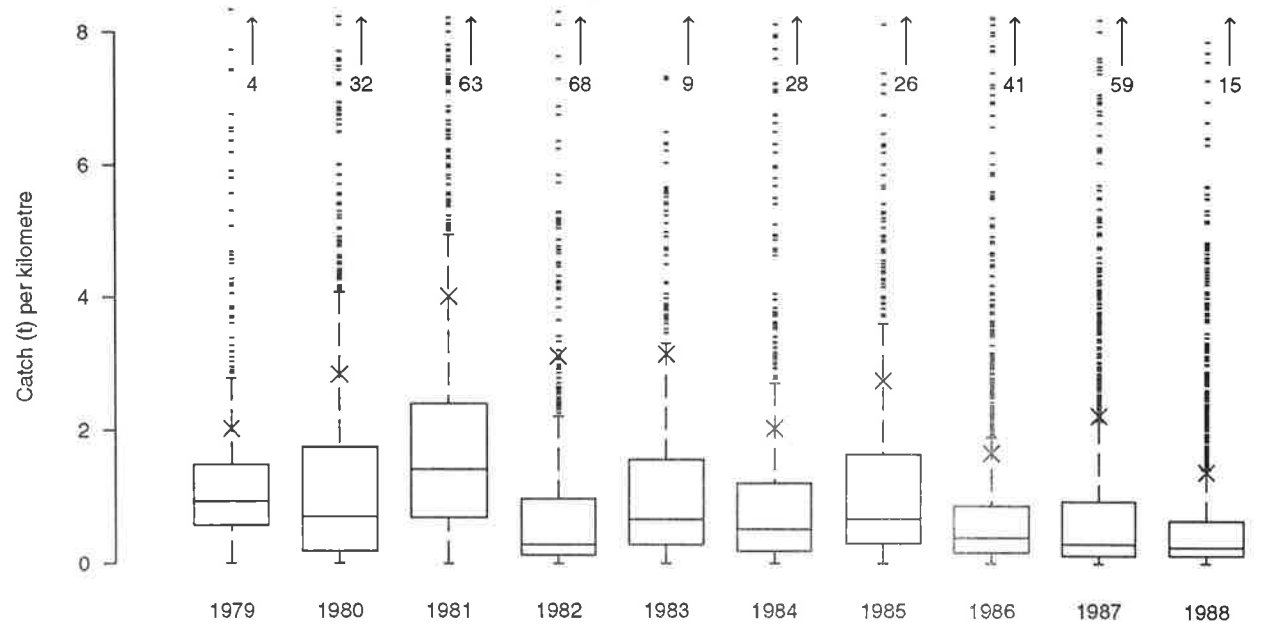

Figure 6: Catch per kilometre distribution of individual tows for each season, 1979–88. (The boxplots show the median (centre line of box), the lower quartile (bottom of box), and the upper quartile (top of box). The upper eighth is shown with a cross. The vertical lines outside the box extend to within 1.5x (inter-quartile range), and the dashes show individual tows with rates outside that range. The number under the arrows is the number of tows where catch rate exceeded 8 t.km^{-1}.)

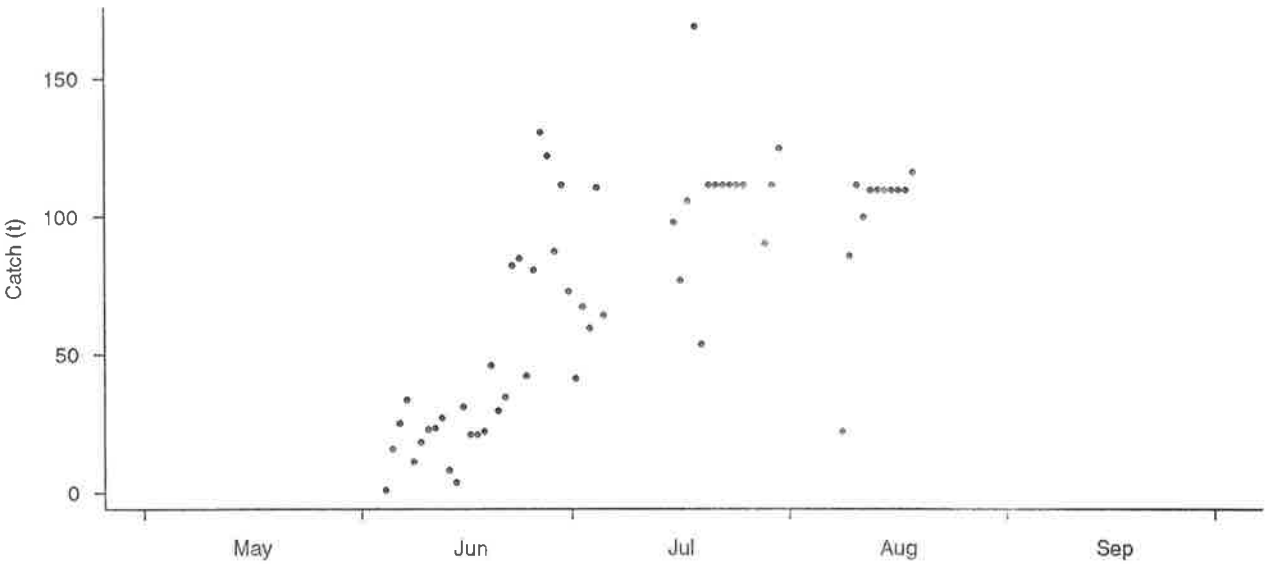

Figure 7: Daily catches of a commercial vessel during the 1985 season.

Pattern of fishing in 1988

Introduction

The fishery in 1988 had a definite seasonal pattern, typical of those in the previous few years. Catch per kilometre started low, rose to a peak, then fell back again. There were pronounced seasonal patterns to the size of fleet, fishing position, and depth fished. The seasonal pattern was divided into three phases: prespawning, spawning, and postspawning.

The fleet was largest before the spawning period. Vessels fished widely over the northeast Chatham Rise, mostly getting low catches per kilometre. A few tows recorded high catches per kilometre, mostly in deep water west and east of the main fishing area. Nearer the spawning period high catches per kilometre were recorded in the main fishing area, and vessels focused on that area. The fleet was much smaller during the spawning period, and vessels fished the main fishing area in 800–950 m and recorded high catches per kilometre towed. After the spawning period the few remaining vessels moved eastward, away from the main area. Initially, catches per kilometre were high, but after about 10 days they dropped to a low level.

Area fished

Fishing occurred on the northeastern quarter of the Chatham Rise along a band of sea bed that roughly follows the 1000 m depth contour (*see* Figure 2). This band is about 350 km long and 10 km wide, and about 750 km^2 of it was swept by nets (assuming a typical net width of 20 m).

Tow position here is defined by position along the fished band (axis position) rather than by latitude and longitude coordinates. The axis position for a tow is the distance (in kilometres) measured from 178° W along the axis line to a point on the axis line that is nearest the tow (Figure 8).

An area north and west of the Chatham Islands was fished much more intensively than the rest of the fishing grounds (Figures 8 and 9). This main area is where orange roughy spawn, and it is known by fishers as the "hot spot", because high catch per kilometre tows are common during the spawning period. Fishing is about five times as heavy in this area than in the rest of the ground. The centre of the area corresponds to a feature on the sea bed at 176° 55' W (axis position 85 km). This feature has been described as a canyon (Pankhurst 1988, page

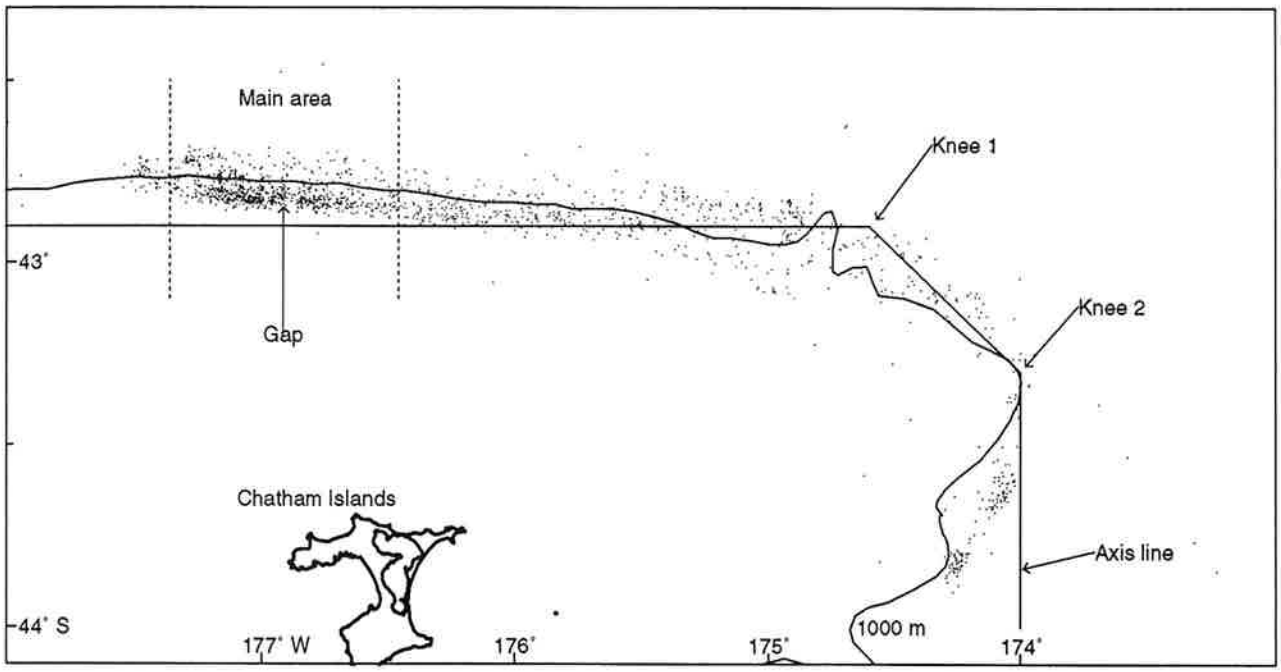

Figure 8: The start position of tows that caught or targeted orange roughy on the northeast Chatham Rise in 1988 (knee 1 is at 42.8° S, 174.6° W, knee 2 is at 43.3° S, 174.0° W).

105), a gully with a hill along its eastern margin (D. A. Robertson, MAF Fisheries, pers. comm.), and a volcanic plug (J. M. Fenaughty, MAF Fisheries, pers. comm.), and it is often referred to by fishers as the "gap". The main area extends about 35 km either side of the gap.

Tows typically approach the gap from either side, but fishers avoid towing through it, and the net is usually hauled before it reaches the gap (which is shown by the dip in the main area peak in Figure 9). In early years of the fishery some attempts were made to fish on the gap, but gear was lost (J. M. Fenaughty, MAF Fisheries, pers. comm.). However, similar features are fished on in other spawning orange roughy fisheries (e.g., Challenger Plateau, Ritchie Banks).

Season

The number of vessels in the fishing fleet varied over the May to September season (Figure 10). The northeast Chatham Rise was not fished for orange roughy outside this season. Vessels began to arrive in mid May, and there was a quick build-up to a maximum of about 15 vessels in early to mid June. By early July most vessels had left, and only a few remained after July. Thus, effort was concentrated before the spawning season.

Only the domestic New Zealand vessels fished the full season. The charter fleet (Korean, Soviet, and Japanese vessels) fished the early season and then mostly left to fish for hoki (*Macruronus novaezelandiae*) on the west coast of the South Island.

Catch per kilometre

There was a strong seasonal pattern in catch per kilometre that corresponded to the spawning period. Catch per kilometre was low until late June, increased during July, as spawning began, and peaked in late July (Figure 11). By mid August catch per kilometre had returned to low levels. The period of high catch per kilometre was during spawning and about 10 days after spawning.

Fleet movement

There was a strong seasonal pattern to the position of fishing that corresponded to the spawning period (Figure 12). Before spawning, the fleet was spread widely over the northeast corner of the Chatham Rise. By the onset of spawning, nearly

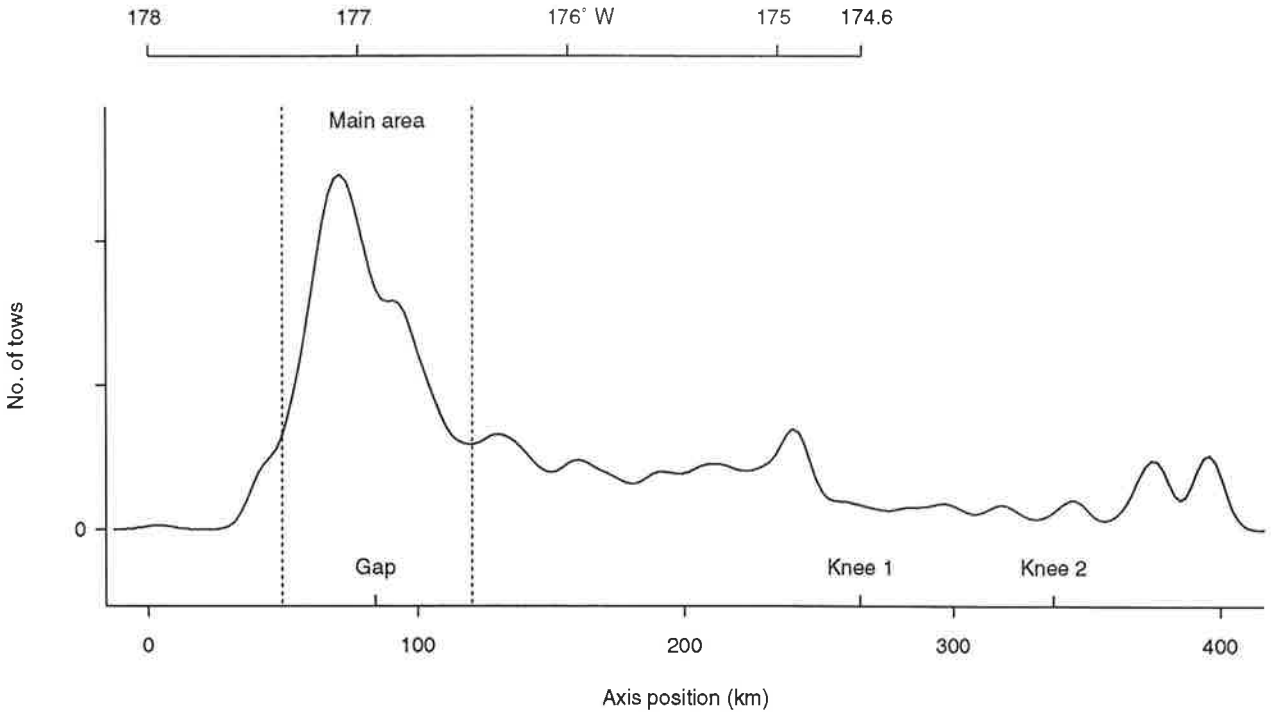

Figure 9: Number of tows along the axis line (*see* Figure 8). (The line is a smoothed density trace, and smoothing is by a method known as "4(3RSR)2H twice" (Tukey 1977, Chapters 7 and 16).

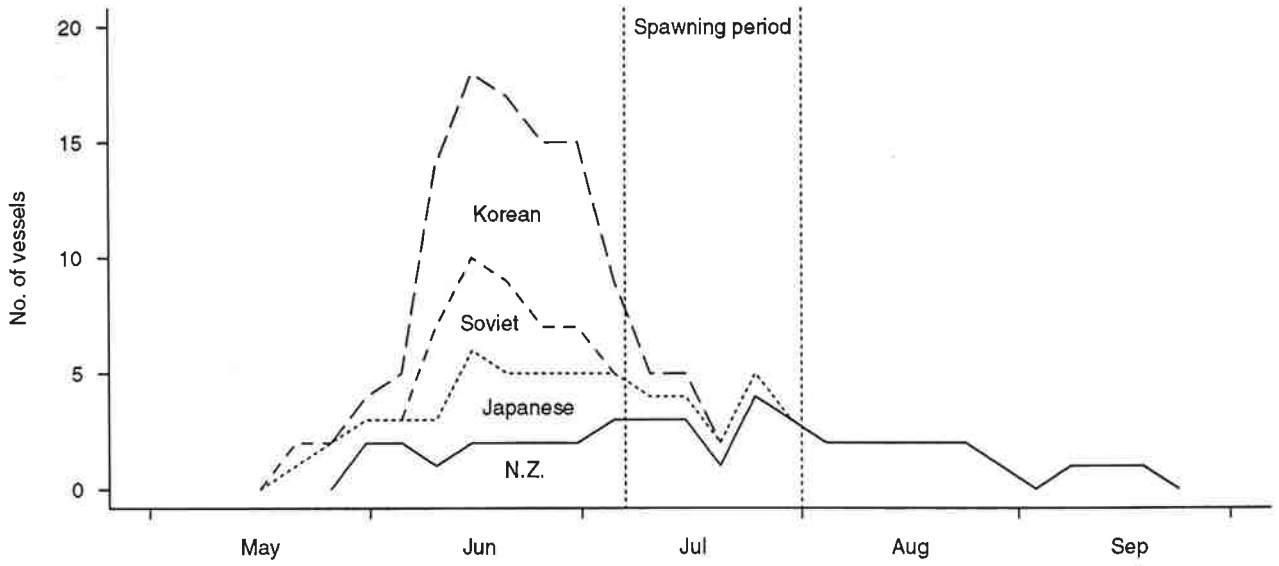

Figure 10: Number of vessels and their nationality for the northeast Chatham Rise, 1988. (Counted by 5 day periods, in which a vessel must have done at least one tow to be counted.)

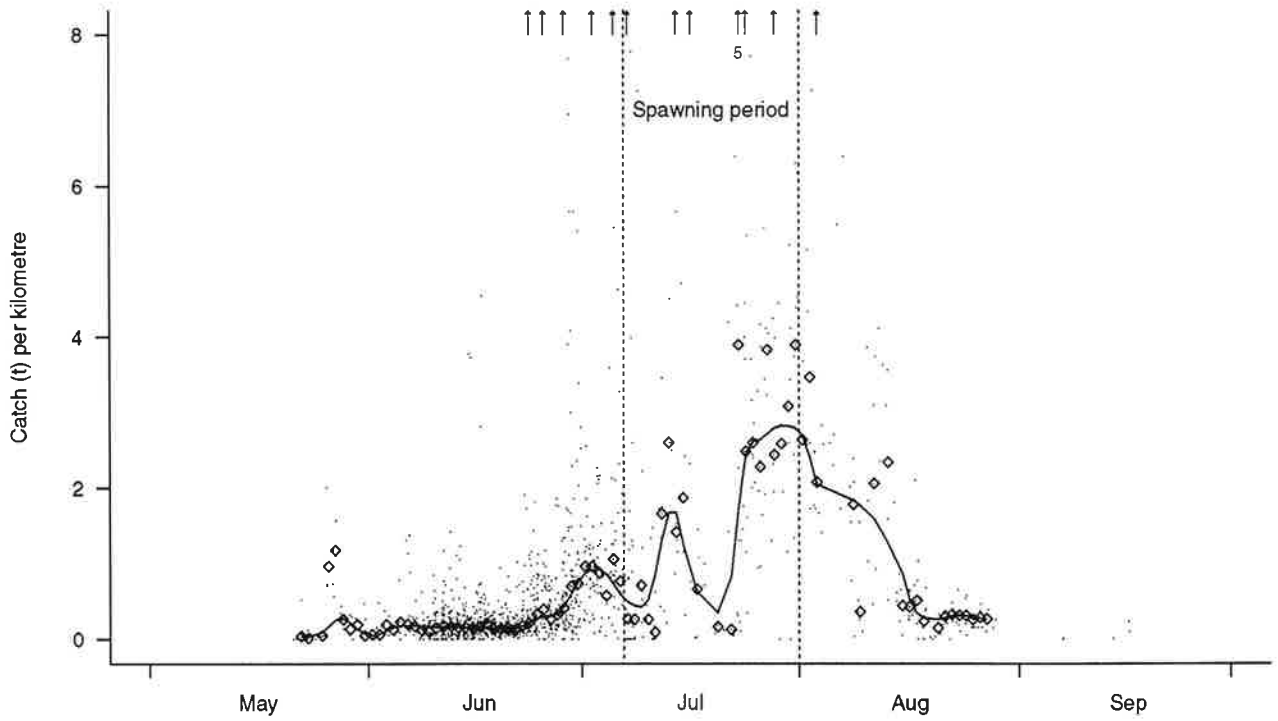

Figure 11: Catch per kilometre during the 1988 season. (The diamonds show daily median catch when at least four tows were done that day. A smooth line is drawn through daily median catch rates by use of a method known as "4(3RSR)2H twice" (Tukey 1977, Chapters 7 and 16). Arrows and numbers under them show a tow(s) with catches over 8 t.km^{-1}.)

all vessels had either left the fishery or moved into the main area. The main area was almost the only area fished during spawning. After spawning, vessels moved steadily east away from the main area.

Only 12% of tows had high catch per kilometre (over 1.35 t.km^{-1}). Most high catch per kilometre tows were in the main area during or immediately before the spawning period. High catch per kilometre tows were occasionally taken before spawning at the western edge of the fishing area (about 177° 30' W, axis position 39 km) and also east of the main area at about 174° 50' W (axis position 250 km). After spawning, high catch per kilometre tows were common for about 10 days as the vessels moved east.

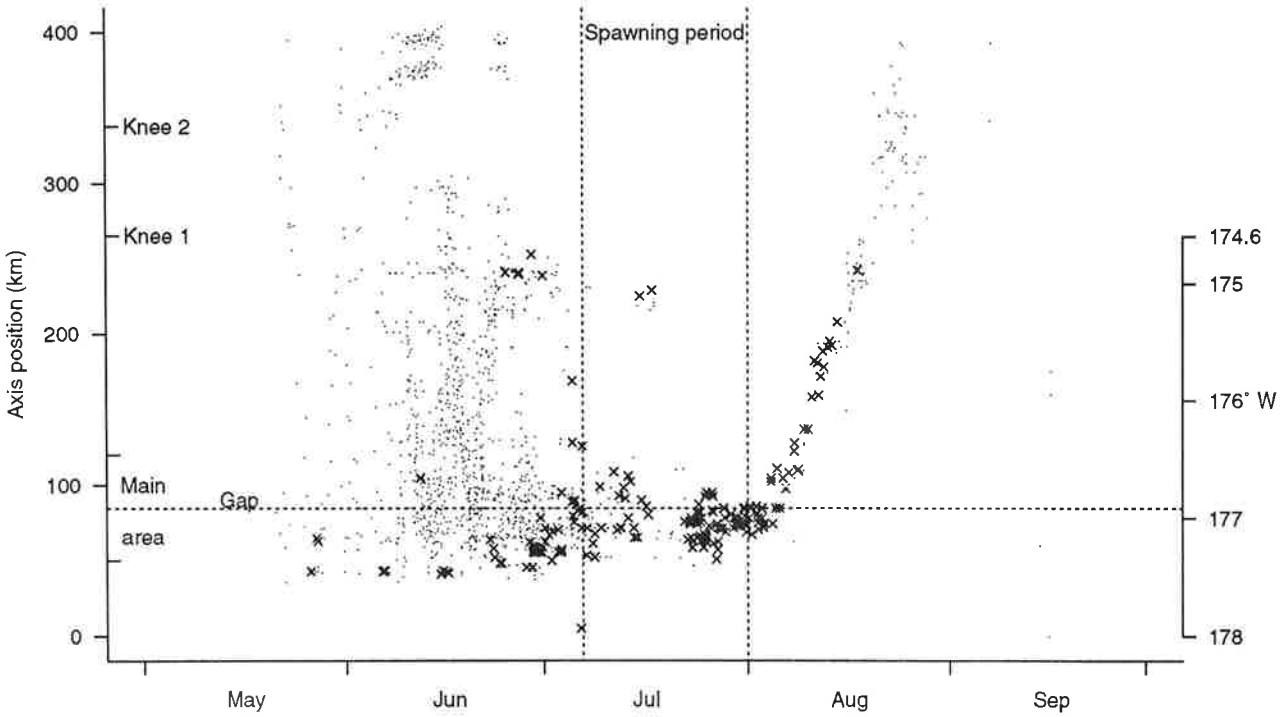

Figure 12: Tow positions during the 1988 season. (Tow positions are axis position — *see* p. 12. Catch rates over 1.35 t.km^{-1} are shown by "x".)

Depth of fishing

There was also a strong seasonal pattern to depth of fishing (Figure 13). During the prespawning period the fleet fished over a wide depth range (800–1250 m). This range was reduced to 800–950 m during spawning, but about 2 weeks after spawning deeper waters were again fished. The pattern of fishing shown by depth of water fished was similar to that shown by tow position, though increases in the latter occurred about 1 week earlier (*see* Figure 12).

Most high catch per kilometre tows were taken in 800–950 m during spawning. However, some high catch per kilometre tows were taken in deep water (about 1200 m) and some in intermediate depths (about 1000 m) just before spawning. After spawning, high catch per kilometre tows were taken in 800–950 m as vessels moved east.

Position and depth

The season showed a pattern of three phases that related to the spawning period (Figure 14). Before spawning the vessels fished over a wide range of positions and depths. By the onset of the main spawning period vessels had either left the fishery or moved into the main area (50–120 km axis position) and a narrow depth zone (800–950 m). During spawning the fleet was fairly stationary. After spawning, the remaining vessels moved east from the main area, at spawning depths, up to the 250 km axis position, then gradually moved into deeper water as fishing continued eastward.

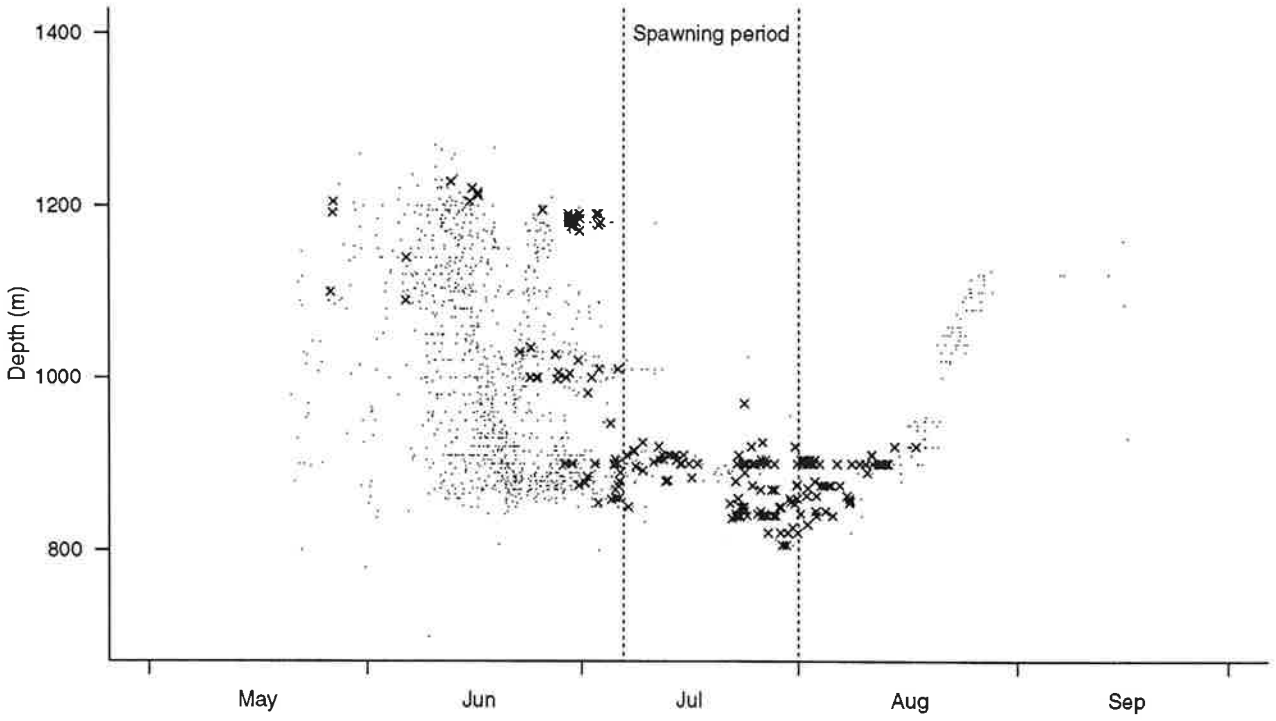

Figure 13: Depth of fishing for tows during the 1988 season. (Catch rates over 1.35 t.km^{-1} are shown by "x".)

Development of fishing, 1979–88

Introduction

There were substantial differences between the fishing patterns in the early years, but the pattern had stabilised by 1986–88.

The major changes took place outside the spawning period. As the fishery developed, prespawning fishing moved further from the main area and into deeper water, and after spawning a regular fleet movement eastward developed. Catch per kilometre continued to decline, mainly before spawning, and there was a contraction of the period of high catch per kilometre.

Area fished

The area fished increased substantially over the 10 years. The main area was fished every year, but additional ground was fished in each successive year (Figure 15).

The area fished expanded towards the east and south, and this expansion occurred in two general steps: the first was in 1982, when the fleet fished out to the corner (where the 1000 m contour turns south); the second was in 1986, when fishing extended south past this corner. The 1980 season was an exception because there was a lot of fishing to the east.

Season

The timing of fishing changed substantially in the early years. However, by 1985 a pattern had been established and subsequent annual changes were minor (Figure 16).

The presence of a substantial fleet of Soviet vessels in 1979 (*see* Appendix 2) suggested that these vessels had fished there before; however, it is thought that the fishing was minor before 1979.

The 1980 season was an exception, mainly because of the high activity late in the season.

In 1981–83 the fishery was closed on 31 July (the end of spawning) as a management measure. However, FV *Kaltan*, under charter for research, did both commercial and research fishing during August 1982 (*see* Robertson *et al.* 1984). This

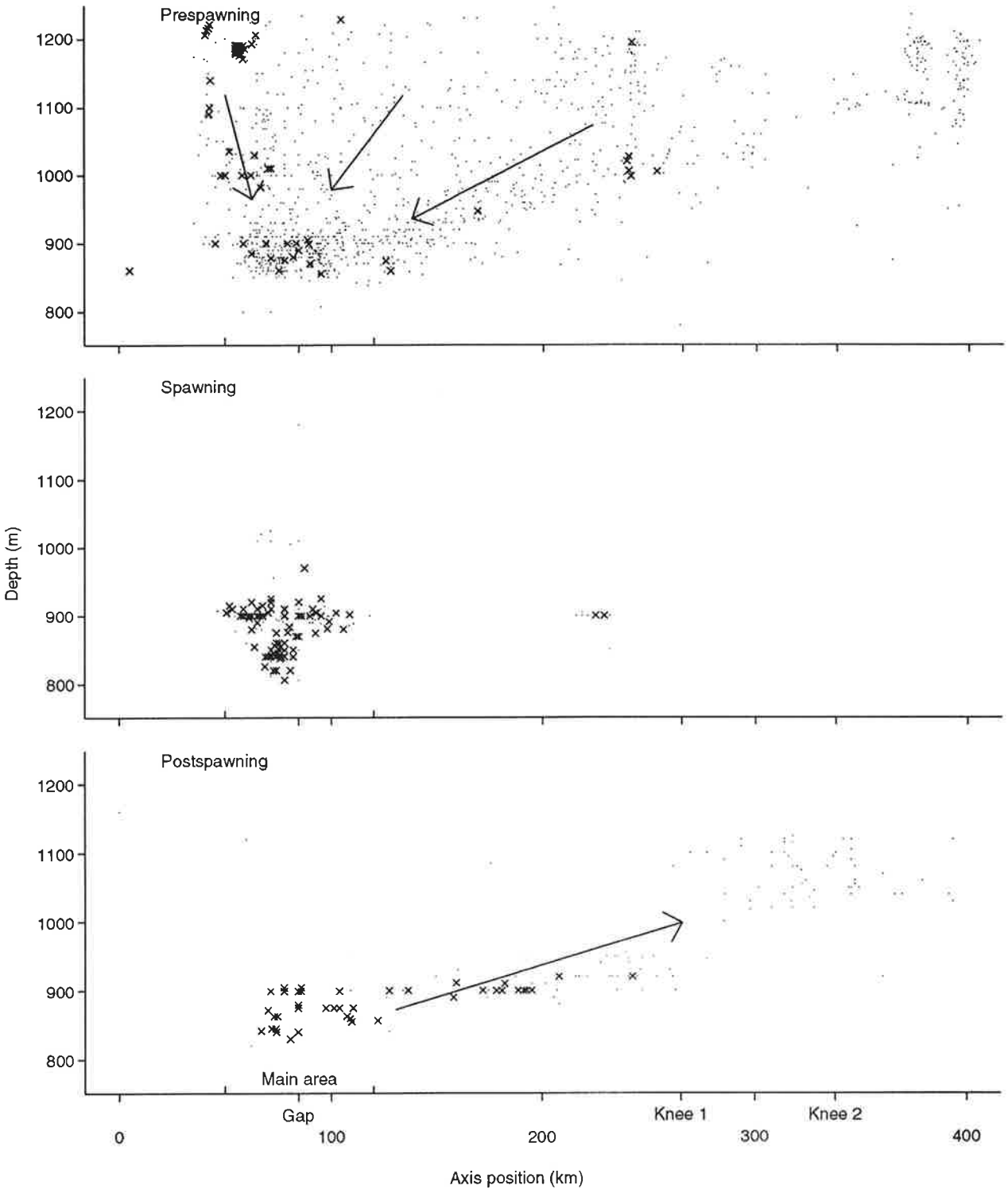

Figure 14: The three phases of the 1988 fishing season by tow position (axis position — *see* p. 12) and depth. (Catch rates over 1.35 t.km^{-1} are shown by "x", and gross fleet movement is shown by the arrows.)

measure was removed in 1984, and the postspawning period became an established part of the fishery.

In 1982–84 fishing began in early May, but by 1988 there was little fishing until mid May. From 1985 a steady pattern appeared to be established. The fleet was largest before spawning, about one-third of the vessels remained to fish during the spawning period, and only a few vessels fished after spawning.

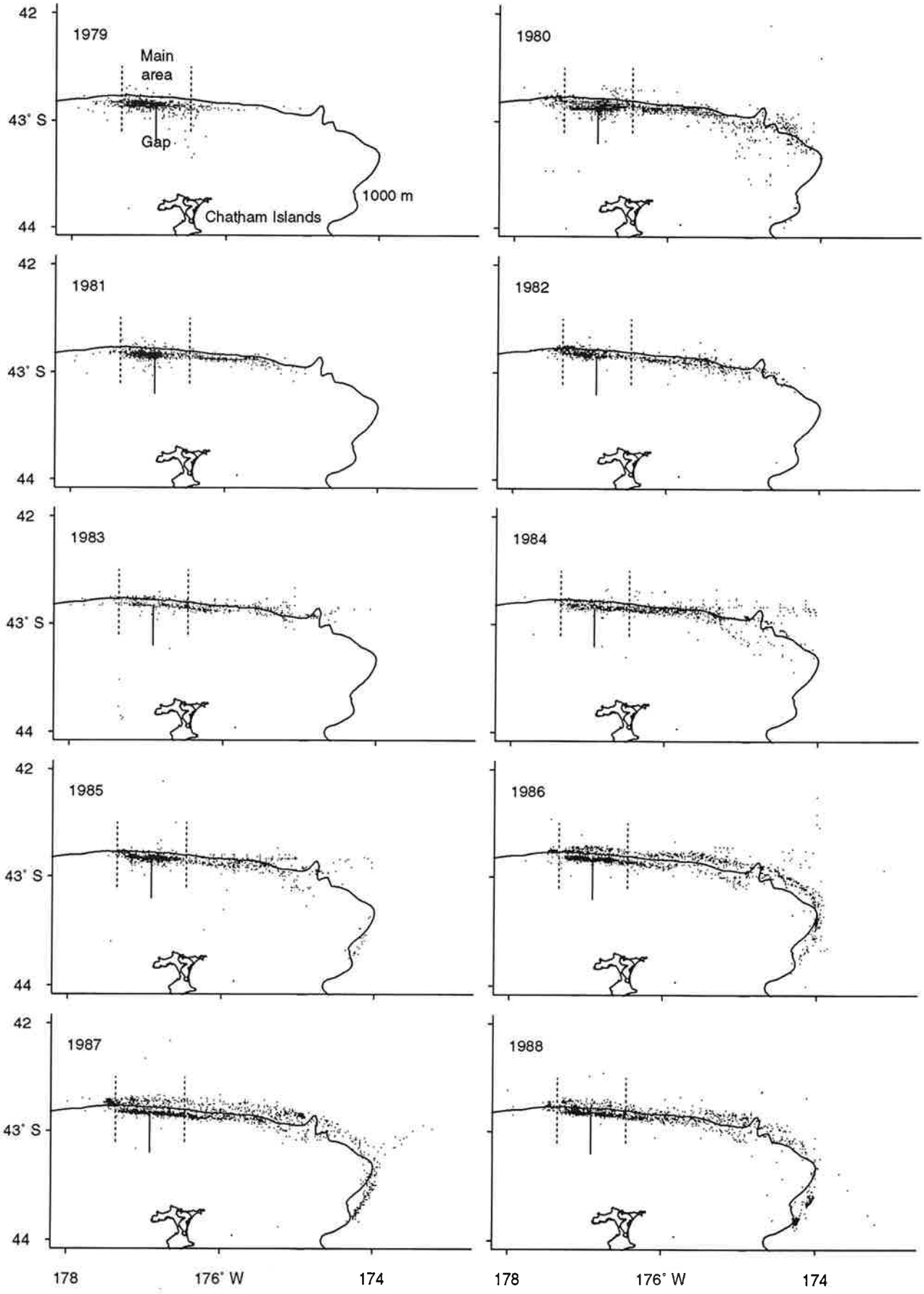

Figure 15: Start position of tows that caught or targeted orange roughy for each season, 1 May–30 Sep, 1979–88.

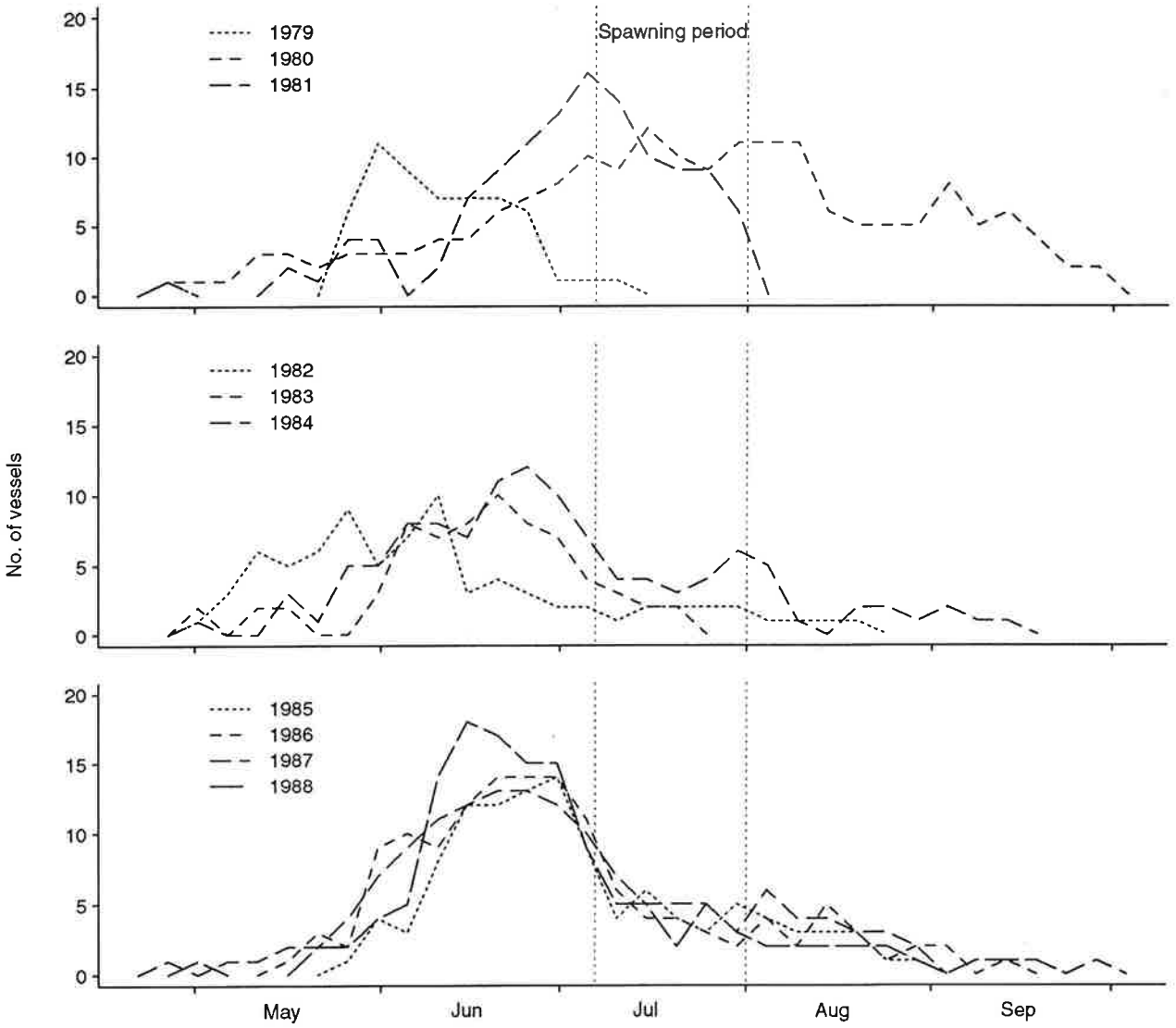

Figure 16: Number of vessels in the fishery during 1979–88. (Each vessel must have done at least one tow in a 5 day period.)

Median catch per kilometre

There has been a major reduction in median catch per kilometre before spawning, particularly in the early years, but by 1986 it had stabilised (Figure 17 and Appendix 4).

The spawning period was fished sporadically in the early years and there was no obvious pattern. However, it was fished consistently from 1984, though there has been a reduction in median catch per kilometre.

There has also been a gradual decline in median catch per kilometre after spawning. However, the time when catch rates drop to low levels (about mid August) has not changed.

Fluctuations in daily median catch per kilometre during and immediately before spawning appeared regular in some years (especially 1986 and 1988).

We found no correlation between median catch per kilometre and phase of the moon; however, it is possible that correlations are hidden in this complex multivariate data set. Pankhurst (1988, page 104) found no correlation between gonad stages and lunar cycle. Bad weather has been suggested as the cause of the fluctuations (D. A. Robertson, MAF Fisheries, pers. comm.).

In summary, the seasonal pattern has generally been a rise in median catch per kilometre during prespawning and spawning to a peak in late July, followed by a fall to a low level in mid August. However, there has been a continuing overall decline. High median catches per kilometre now start later, but finish at the same time as they did earlier in the development of the fishery, so the period of high median catch per kilometre is shorter.

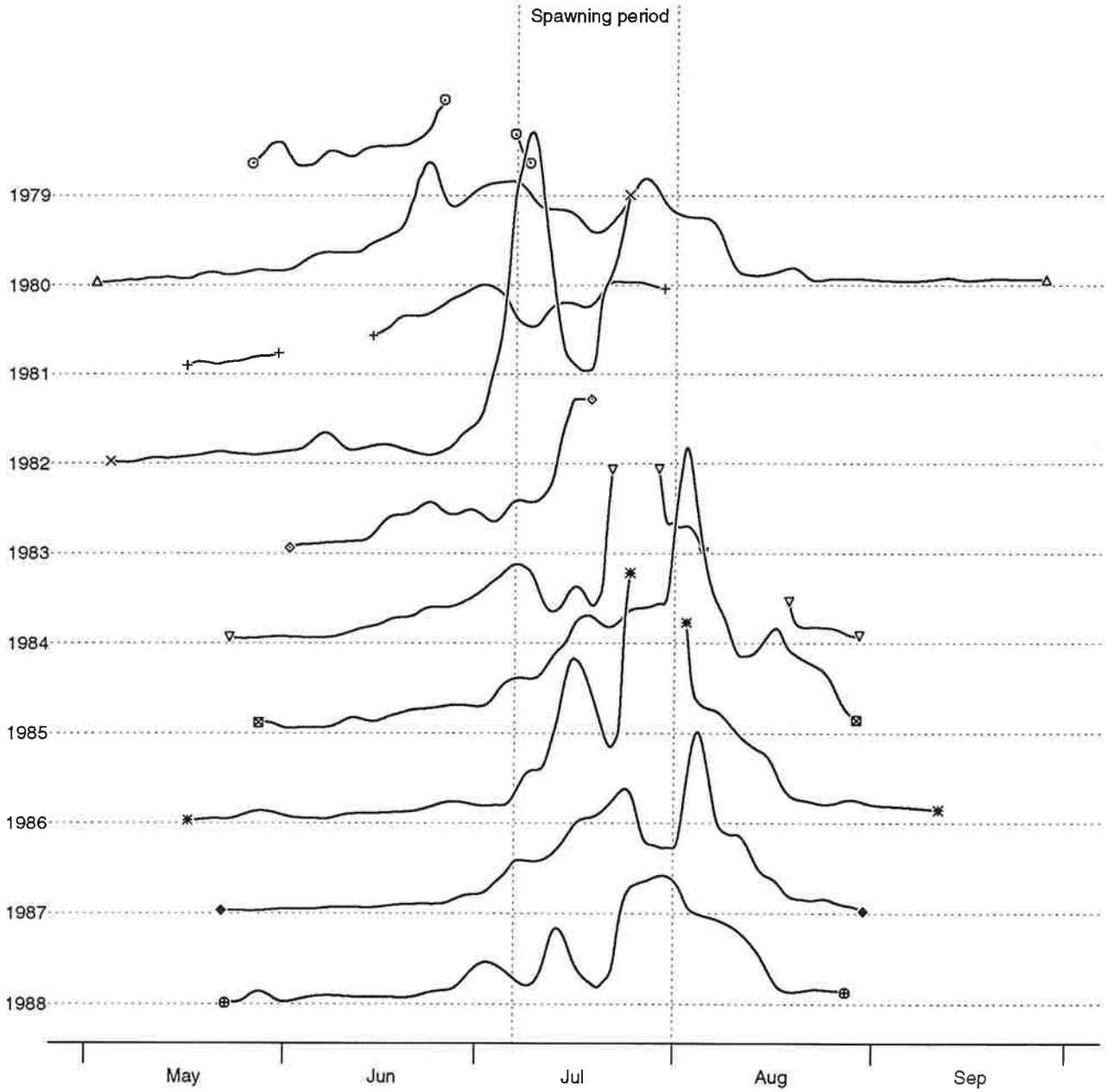

Figure 17: Median catch per kilometre for 1979–88. (A smooth line is drawn through daily median catch rates by use of a method known as "4(3RSR)2H twice" (Tukey 1977, Chapters 7 and 16). The scale is 2 t.km^{-1} between seasons. The data were derived from Appendix 4.)

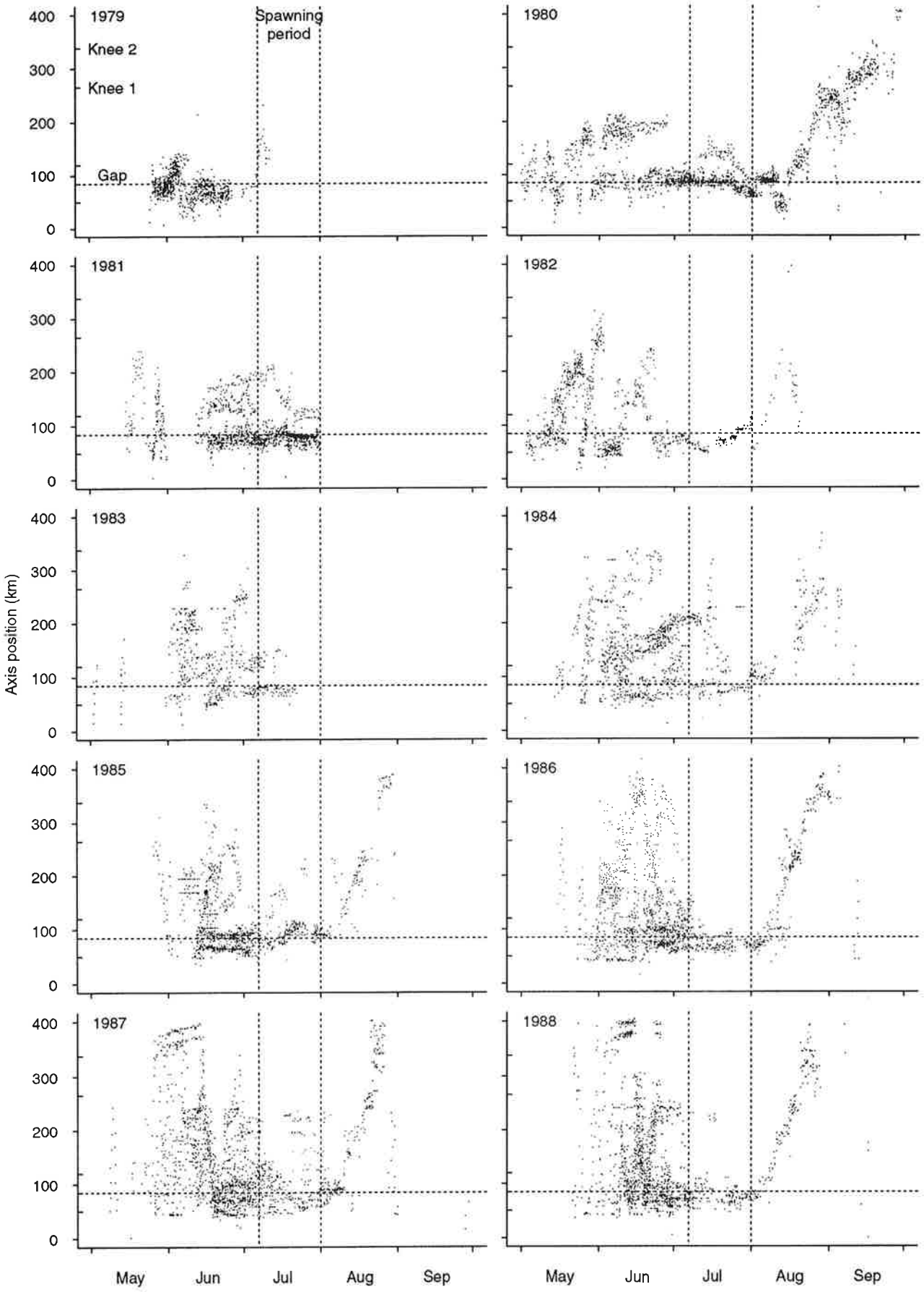

Figure 18: Tow positions for 1979–88. (Tow positions are axis positions — *see* p. 12.)

Fleet movement

A regular pattern of fleet movement has evolved in the fishery (Figure 18 and Appendix 5). In 1979 fishing was in or near the main area. However, in subsequent years there was a steady increase in the eastward range of vessels targeting prespawning fish. Fishing during spawning has always been mostly in the main area. Postspawning fishing was irregular until 1985, by which time a steady eastward movement had developed, and this was repeated in the following years.

Depth of fishing

There has been a major extension to the depth of fishing over the development of the fishery (*see* Appendix 5). Since 1979 the proportion of fishing in deeper water has increased each year, and this change has occurred mainly in the prespawning phase (Figure 19). The 800–950 m depth zone was always fished, but it became less important in the prespawning fishery as vessels fished deeper waters. This movement into deeper water took place in two distinct steps; in 1982 and in 1986.

In summary, a regular seasonal pattern of fishing depth has emerged. By 1988 vessels fished over a wide depth range (800–1300 m) in the prespawning fishery, concentrated mainly on the 800–950 m depth zone in the main area during spawning, and, followed the eastward movement after spawning, gradually moving into deeper water (down to about 1200 m) (Figure 20).

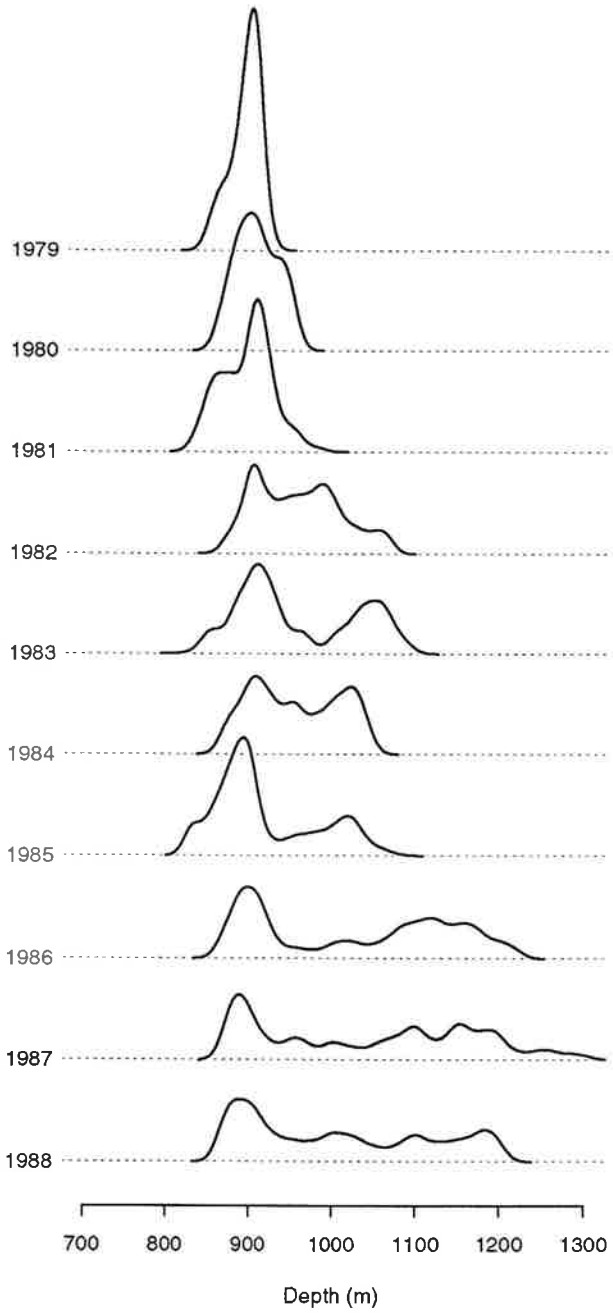

Figure 19: Relative distribution of fishing effort (number of tows) at depth for prespawning fishing (before 7 July). (The line is a smoothed density trace, and smoothing is by a method known as "4(3RSR)2H twice" (Tukey 1977, Chapters 7 and 16).)

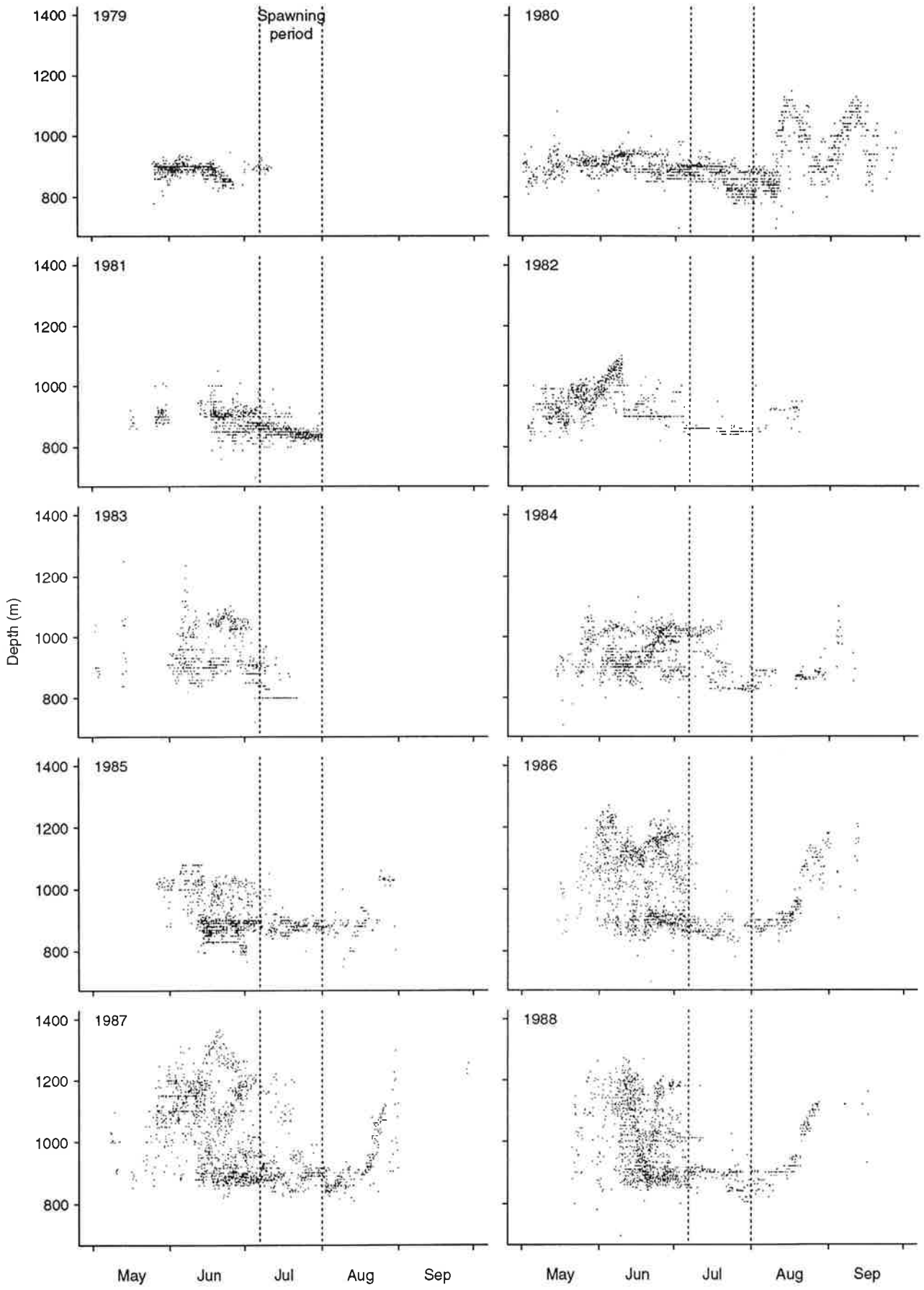

Figure 20: Depth of tows by month for 1979–88.

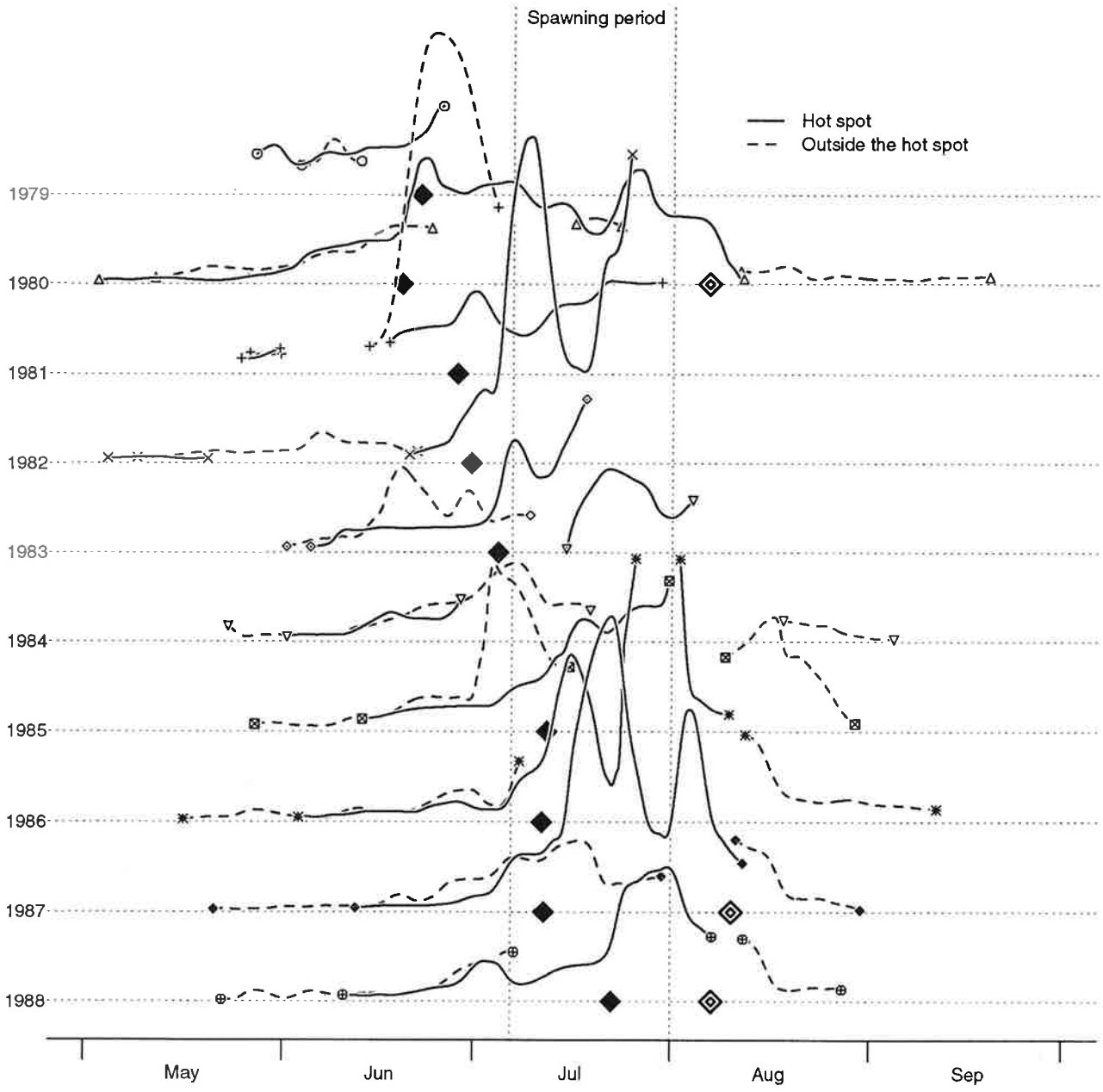

Figure 21: Median catch per kilometre from the hot spot and from outside the hot spot. Lines are daily medians smoothed by use of a method known as "4(3RSR)2H twice" (Tukey 1977, Chapters 7 and 16) and are shown only when there were at least four tows per day. The start and finish of high median catches per kilometre (> 1.35 t.km^{-1}) from the hot spot are shown by the solid diamonds and double diamonds respectively (the finish was known only in 1980, 1987, and 1988).)

The "hot spot"

The area where high catches per kilometre are taken during spawning is called the hot spot by fishers. The hot spot is defined here as between 177° 21.5' and 176° 27.7' W (axis position 50–120 km) at depths of 800–950 m. These ranges contain the high catch per kilometre fishing that occurred during, and about 1 week either side of, spawning (Appendices 5 and 6). Apart from the depth restriction, the hot spot is the same area as the main fishing area (*see* Figure 8).

Pankhurst (1988) identified a main spawning area (177° 00' to 176° 30' W, 800–950 m), mainly on the basis of gonadal condition of fish caught on research surveys. This was a similar area to that of the hot spot, because this is where orange roughy aggregate to spawn, and fishing on spawning aggregations will produce high catches per kilometre.

To examine the effects of the fleet fishing further from the hot spot and in deeper water, we compared fishing inside and outside the hot spot. Median catches per kilometre are higher outside the hot spot until shortly before spawning (Figure 21). The time of onset of high median catches per kilometre in the hot spot has shifted later over the 10 years, whereas the time that median catch per kilometre declines appears to have stayed the same. Therefore, the period of high catch per kilometre fishing in the hot spot has become progressively shorter.

It is not known whether the boundaries of the hot spot have changed over the period, because vessels concentrate effort in the area, and the boundaries were not explored.

There were no obvious daily patterns in the data from either during or outside the spawning period. Pankhurst (1988, page 101) similarly found no evidence of any diel rhythm to spawning activity.

In summary, the hot spot has stayed in the same place over the years of this study, and peak catches per kilometre are taken at the same time (late July). However, the date of onset of high median catches per kilometre there has become progressively later, though the period of high catches appears to have finished at the same time over the last few years (*see* below).

Postspawning migration

The fleet movement and catch per kilometre after spawning suggest a migration of fish eastward away from the hot spot. This migration was not exploited in the early years of the fishery, but since 1985 it has been fished regularly.

After spawning, high catches per kilometre are taken along a narrow band (Figure 22). This was not discovered by the fleet until 1985 (Figure 23). However, in 1982 FV *Kaltan*, a commercial vessel under charter for research, doing random tows for a biomass survey as well as some commercial tows, did fish along this band (*see* Robertson *et al.* 1984). The late discovery of this band may be because the postspawning period was fished in only 3 of the first 6 years, and because fishing the band means leaving the hot spot while catch per kilometre is still high.

The decrease in prespawning median catch per kilometre, and the extension in time of postspawning median catch per kilometre, suggests that in the more recent years the season had been about the same length, but had merely started later. However, the fishery on the postspawning band of high catch per kilometre (which extends eastwards from the hot spot) started at about the same time each year. In addition, spawning has occurred at the same time each year. These contradict the theory of a later start to the season.

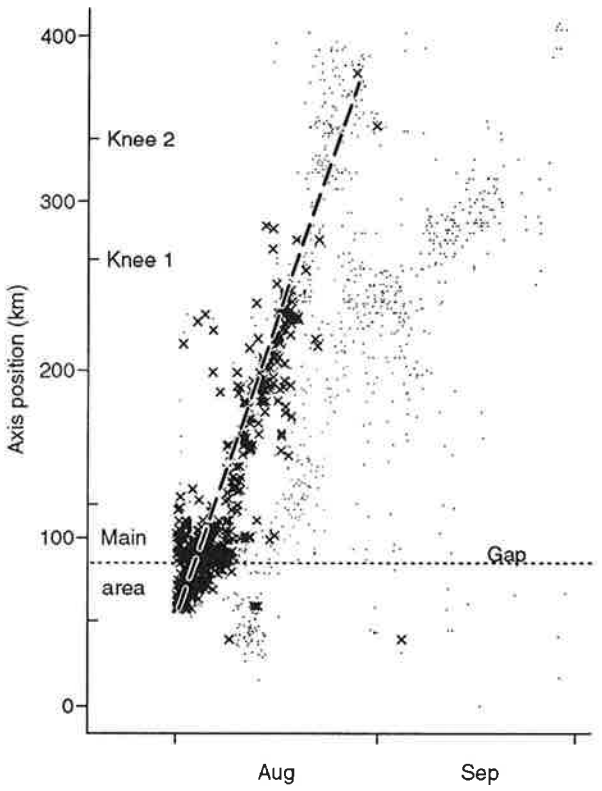

Figure 22: Tow position during the postspawning period (Aug–Sep) for 1979–88. (Tow positions are axis positions — *see* p. 12. Catch rates over 1.35 t.km^{-1} are shown by "x", and the solid line has been fitted by eye through these high catch rates.)

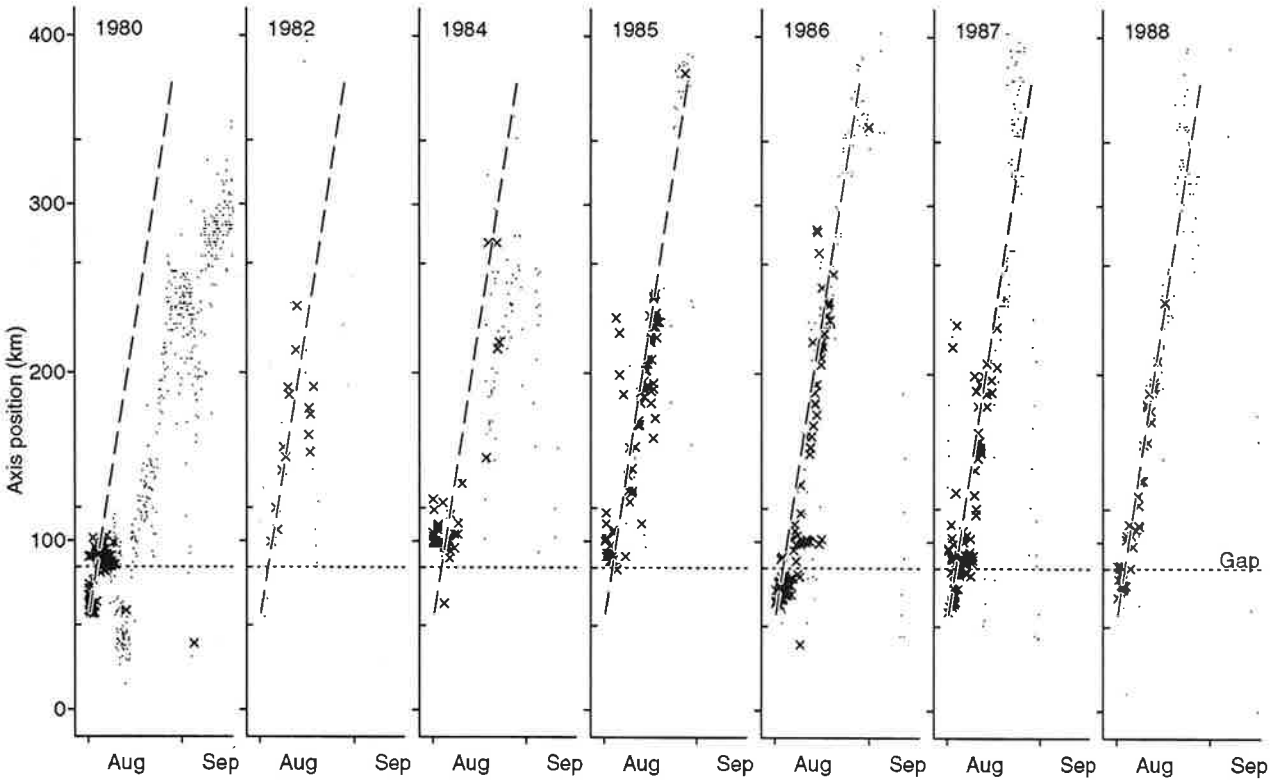

Figure 23: Tow position during the postspawning period (Aug–Sep) for each year during 1979–88. (Tow positions are axis positions — *see* p. 12. Catch rates over 1.35 t.km^{-1} are shown by "x", and the solid line has been fitted by eye through these high catch rates. There was no postspawning fishing in 1979, 1981, and 1983.)

The high catches taken along the band when catches outside the band are low, and the observed vessel movements, both suggest that the fish are migrating en masse away from the hot spot after spawning.

Research data from MAF Fisheries trawl surveys show that catches per kilometre east of the hot spot are low immediately before the high catches are taken there, which supports the migration interpretation (Figure 24). (There are no data from commercial vessels because they do not fish in this area at this time.)

The rate of the supposed migration, taken from a line fitted by eye through high catch per kilometre tows in the postspawning period (*see* Figure 22), is 10 km per day, or 0.3 fish lengths per second. Orange roughy in the area have a modal length of 35 cm (Robertson *et al.* 1984), and Harden Jones (1968) states that, as a rule of thumb, fish have a maximum sustainable speed of three fish lengths per second. Orange roughy are physiologically likely to be slow swimmers (they have no red muscle, a deep body, and a thick caudal peduncle), so this rate of movement is reasonable.

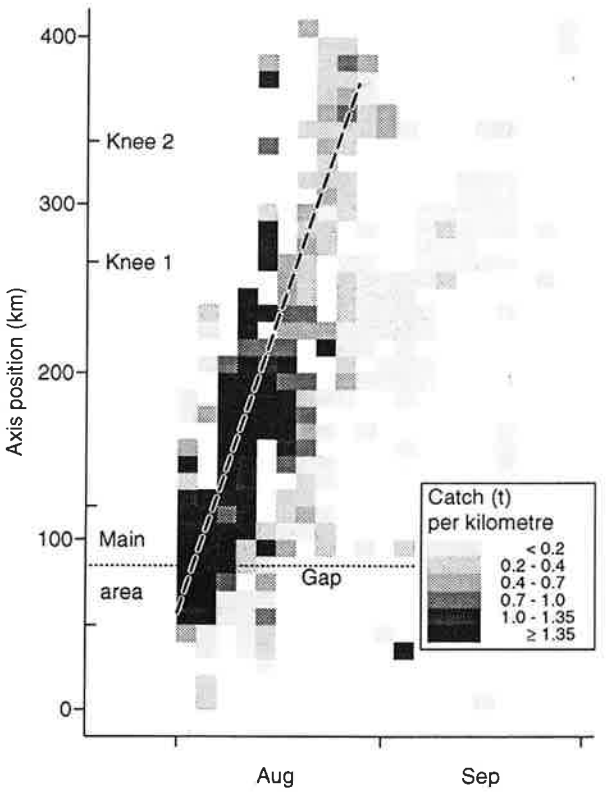

Figure 24: Median catch per kilometre during the postspawning period (Aug–Sep) for all commercial and research tows during 1979–88. (Median catch per kilometre is calculated and shown by cells of 10 km axis position and 3 days. Cells are shown if there were at least two tows. Tow positions are axis positions — *see* p. 12.)

Spatial and temporal distribution of median catch per kilometre

The distributions discussed here are based on data (commercial and research) from the 1986–88 seasons, when the fishing pattern appeared to have stabilised.

Distribution by area

Before spawning median catches per kilometre are highest east and west of the main area (Figure 25). The western area is bounded by foul ground, and the high median catches per kilometre there suggest the fish are being caught as they move out of the foul ground.

In the east the highest median catches per kilometre are taken along a broad band that leads from the east toward the hot spot. The timing of the catches suggests a prolonged migration of fish into the main area. The migration appears to have a similar rate of movement to that of the postspawning band, but without the concentration of high median catches per kilometre. The wider spread suggests a more diffuse migration to the spawning area.

Shortly after spawning begins median catches per kilometre are mostly low outside the main area, which suggests that the inward migration has waned and that most fish are inside the main area. However, there is an exception at about axis position 220 km, where high median catches per kilometre are taken during the spawning period, which suggests it may be a secondary spawning area, though commercial fishing there is patchy, and vessels always leave it to fish the main area.

Commercial fishing is concentrated in the main area immediately before spawning, but it appears that catch per kilometre before spawning could be increased if effort increased along the western boundary and the eastern band.

Distribution by depth

Before spawning begins the highest median catches per kilometre are taken in deeper water (Figure 26). As spawning begins, most high median catches per kilometre are recorded in the spawning depths (800–950 m). However, some high median catches per kilometre are still taken in deeper water, whereas they are low in depths less than 800 m.

Immediately after spawning the minimum depth at which high median catches per kilometre occur increases, and they become far more frequent in deeper water than they were during spawning. This suggests that fish return to deeper water after spawning.

The distribution of commercial tows by depth generally reflects the catch per kilometre distribution (i.e., most tows are at depths which give the highest catches per kilometre). However, high median catches per kilometre were recorded by research tows in depths of about 1000–1100 m immediately after spawning ends, and these depths were not fished commercially at that time.

Discussion

Examination of the catch records of commercial vessels fishing for orange roughy on the northeast Chatham Rise has led to a simple model of fish movement and behaviour during winter.

The model explains changes in the fishing pattern over the 10 year period. It supports the MAF Fisheries stock assessment work and suggests an improvement to it. It shows why CPUE analysis has been of limited use for this fishery.

The model of fish movement and behaviour

The model for the northeast Chatham Rise fishery consists of the prespawning migration into the area, the spawning period (7–31 July), and the postspawning migration.

From October to April there are few orange roughy on flat bottom in the northeast Chatham

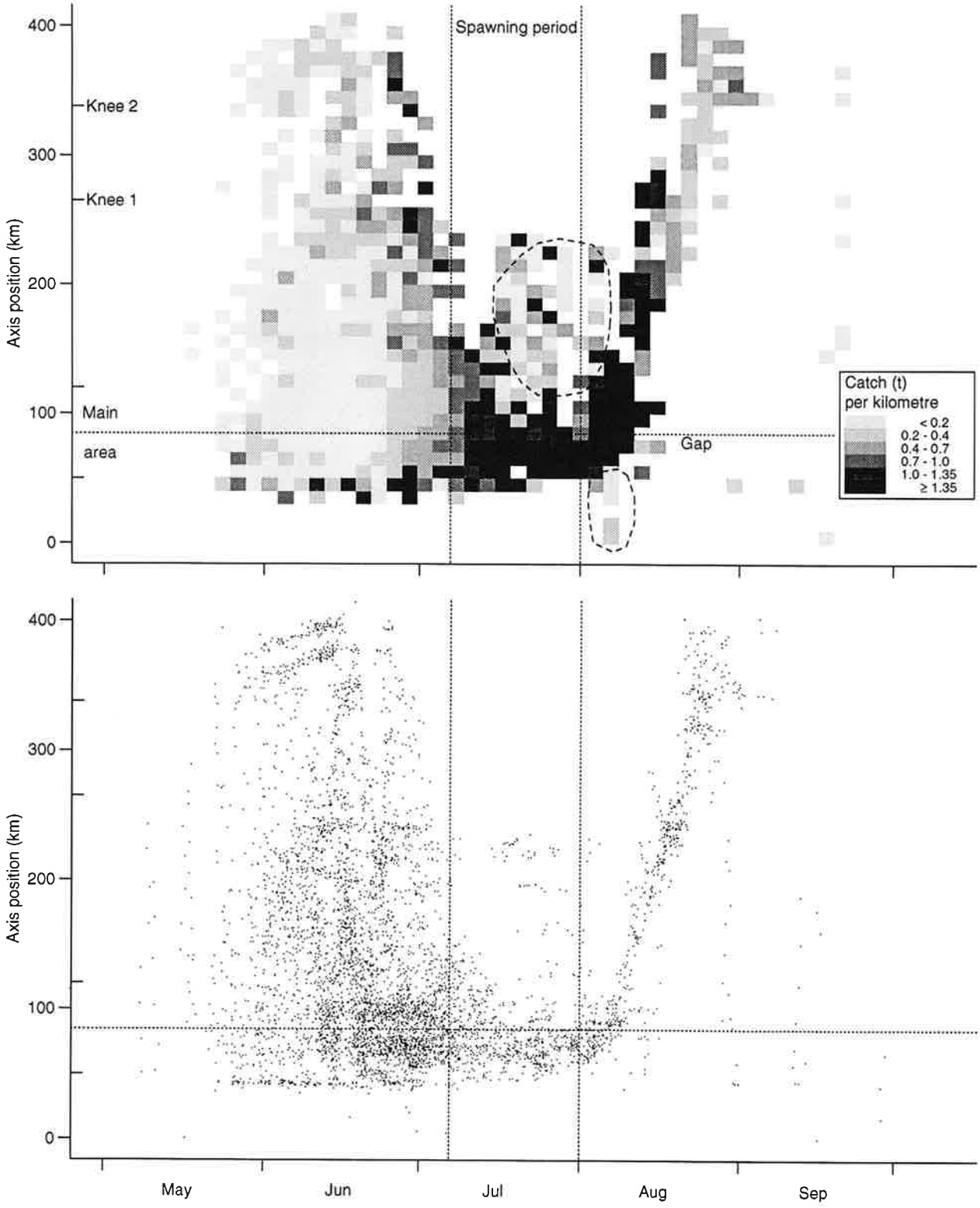

Figure 25: ***Top.*** **Median catch per kilometre by axis position for commercial and research tows during 1986–88. (Median catch per kilometre is calculated and shown by cells of 10 km axis position and 3 days. Cells are shown if there were at least two tows. Data inside the two ringed areas are mainly from research tows. Tow positions are axis positions — *see* p. 12.)** ***Bottom.*** **The distribution of commercial tows during 1986–88.**

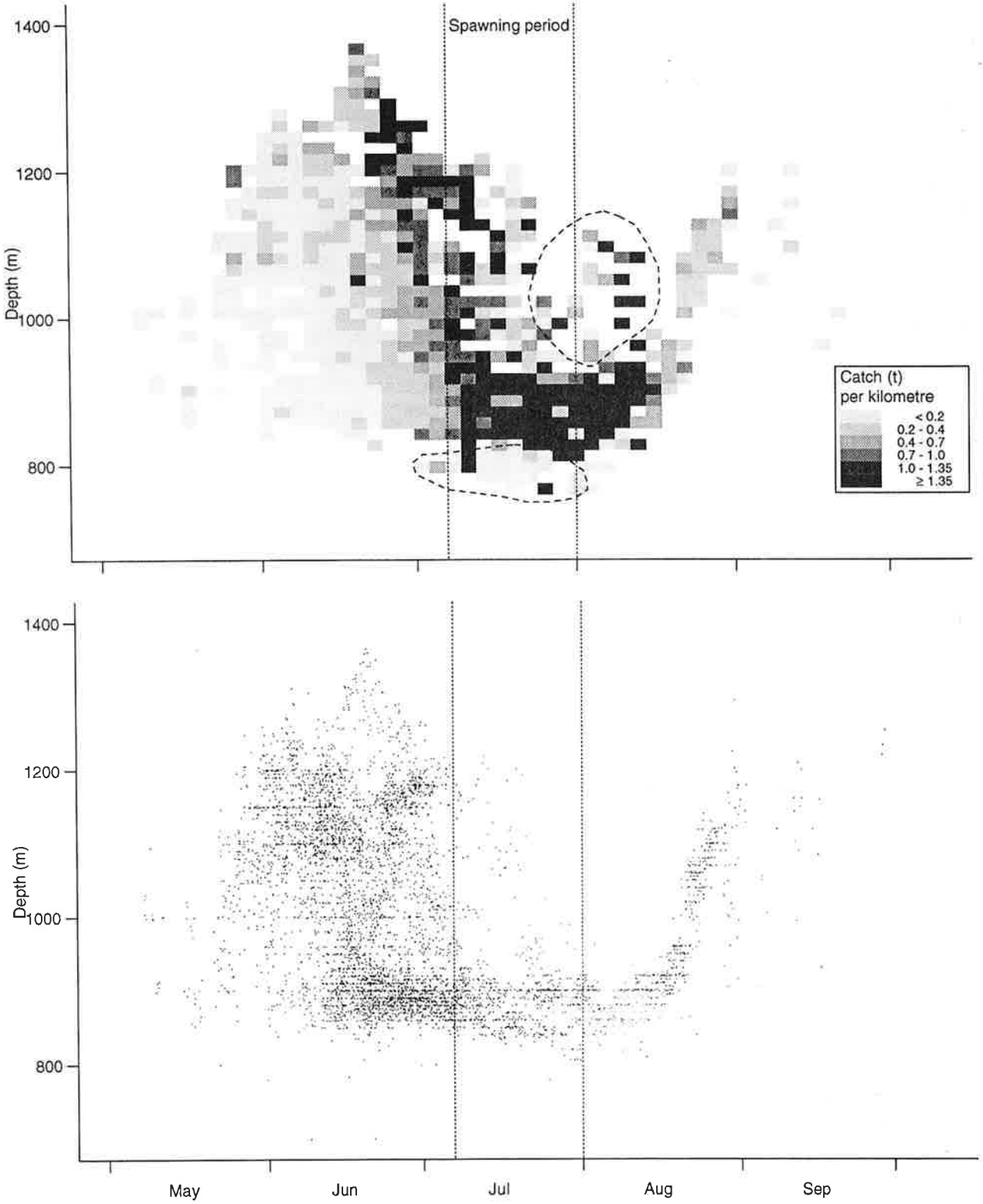

Figure 26: ***Top.*** **Median catch per kilometre by depth for commercial and research tows during 1986–88. (Median catch per kilometre is calculated and shown by cells of 15 m depth and 3 days. Cells are shown if there were at least two tows. Data inside the two ringed areas are mainly from research tows.)** ***Bottom.*** **The distribution of commercial tows during 1986–88.**

Rise, and the area was not fished commercially during 1979–88. Research trips during this time caught a maximum of about 35 kg of orange roughy per tow (mean catches per kilometre are 0.008 $t.km^{-1}$) (MAF Fisheries unpublished data). In contrast, the northwest and south Chatham Rise are fished commercially.

During the prespawning period orange roughy migrate towards an area about 70 km long centred over a canyon on the sea bed at 176° 55' W and between depths of 800 and 950 m (the hot spot). The inward migration is from both east and west of this focus, and concurrently from deeper water to the shallower spawning depths.

By mid July the inward movement has ended, and spawning has started at the hot spot. Fish that have not reached the hot spot at this stage will soon spawn anyway. Surveys conducted each year since 1984 have shown that there are spawning fish over a wide area of the northeast Chatham Rise each year within 2 days of 18 July (J. M. Fenaughty, MAF Fisheries, pers. comm.).

During spawning the fish form dense aggregations which are targeted by commercial fishers and can yield very high catch rates (over 4 $t.km^{-1}$).

Spawning is completed by the end of July, and fish then leave the northeast Chatham Rise.

The postspawning or outward migration differs from the inward migration. After spawning, a mass of fish appears to move out of the area at the same time, whereas the prespawning migration is more like a prolonged flow of fish into the area. Our data show outward movement only to the east. However, fish may also move to the west, but any such movement has not been identified because vessels generally do not fish there.

By the end of August fish have mostly left the northeast Chatham Rise, and catch rates are again low there.

The pattern of fishing

In the early years of the fishery (1979–81), fishing was at or near the hot spot in the early part of the season and catches per kilometre were good. However, in later years catches per kilometre there at this time were lower, and vessels searched wider and deeper and intercepted fish on their way to the hot spot. This increase in range and depth of fishing occurred mainly in two steps, in 1982 and 1986.

The fishing pattern during the spawning period has not changed over the 10 years. Vessels fish at the hot spot and get high catches per kilometre. However, towards the end of the decade there were more vessels exploiting this phase.

The postspawning migration was first exploited in 1985, and so the fishery was then exploiting most of the migration pathway. However, most fishing still occurs at the hot spot when catches per kilometre there are rising.

The fishery was extended in time in 1984 (when the whole season (May to September inclusive) was fished), in depth in 1986 (when fishing went down to 1300 m), and in range in 1986 (with the eastward extension to axis positions at about 350 km).

Stock assessment

The information summarised in this study has been an important part of the assessments of the Chatham Rise orange roughy fishery. Some of the linkages are outlined below.

A major part of the fisheries research effort on the northeast Chatham Rise orange roughy has been the stock size assessment for input to management decisions. The assessment has been by random trawl surveys and a stock reduction model (*see* Francis & Robertson 1991). This study has shown that the current survey design is generally good. In particular, it supports the exclusion of the *Kaltan* survey result from the survey time series.

In 1982 the first assessment survey was made with FV *Kaltan* (*see* Robertson *et al.* 1984); however, this survey was not considered directly comparable with later surveys and it has been excluded from recent assessments (*see* Robertson *et al.* 1988). This study shows that *Kaltan* was surveying fish during their postspawning migration, and because the survey inadvertently followed the postspawning migration, it was likely to produce an overestimation of biomass. The *Kaltan* survey estimate of relative abundance was much higher than that from later surveys (386 000 t versus 210 600 t respectively, *see* Robertson (1986)).

This study supports the design of the 1984–90 surveys because they cover the right area at the right time to survey most of the fish targeted on the northeast Chatham Rise. The design was based on a 7–31 July period and a standard area, the "survey box" between 177° 30' and 175° 00' W and in depths of 750–1250 m. The migration scenario outlined here suggests that the survey box was large enough to contain the major spawning aggregations and that most fish that enter the survey box would be there during the survey period.

However, fish movement within the survey box during the survey may be a problem. The survey analysis assumes that there is no significant fish movement during the survey. This is probably true for most of the survey (about 14–31 July), but in the early part (about 7–14 July) fish appear to be still migrating to the hot spot. A shorter survey (14–31 July) would lessen the impact of fish movement, though it would allow fewer stations to be occupied. The survey period could not be delayed further because of the postspawning migration.

Catch per unit effort analysis

Stock assessments show that the stock size in 1988 (120 000 t) was less than one-third that of 1979 (375 000 t) and that the decline was linear.

Neither unstandardised CPUE (this study) nor fully standardised CPUE (*see* Doonan 1991) analysis of this fishery indexes abundance.

Three simple CPUE measures were examined: mean catch per vessel-day, mean catch per tow, and catch per kilometre towed. Trends were evident only in catch per kilometre, which halved over the period. However, even catch per kilometre showed no trend if the data were restricted to the main spawning period.

The expectation that CPUE will index abundance is based on a simple model in which fish are evenly distributed within a fishery and take up the same area, but at lower density, as abundance falls. However, these assumptions are not met in this fishery because of the migration and aggregation.

Fishers have an economic incentive to maintain or improve catch rates in general, and catch per vessel-day in particular. They have been successful in doing this in this fishery, even though stock assessments show that abundance has declined dramatically (Francis & Robertson 1991). This success has been achieved because of improved knowledge of the fishery, improved fishing gear, and other operational factors.

Catch rates have been maintained by better exploiting the migration pathway (for example, the postspawning migration, though it only accounts for a small amount of the total catch) and by changing the timing of effort towards the peak of the season. The 1988 data suggest that catch rates could be maintained for at least the next season, particularly by increasing effort in the peak of the season.

Improvements in fishing gear (navigational equipment and depth sounders in particular) have also been important in the maintenance of catch rates. These improvements would probably have most effect during the spawning period, when fish are aggregated and the ability to find fish on the sounder and to accurately tow on them, and to repeat successful tows, is more critical than during the less aggregated phases. Other gear improvements, such as net and trawl efficiency, would also have had a positive effect on catch rates.

Other operational factors can also influence CPUE measures. For example, catch per tow has been maintained, despite falling catch per kilometre, by an increase in tow duration (speed of tow has not changed). Through experience and the use of net sounders, some fishers under some conditions can regulate the size of catch. Saturation of processing capacity can also influence CPUE measures, in particular catch per vessel-day. Operational factors can both raise or lower CPUE measures in ways that tell little about abundance. For example, fishers might attempt to land smaller catches to obtain a less damaged, higher value product, or for ease of handling. Alternatively, they might increase the processing capacity by installing bigger freezers, or decrease it by switching to a fillet only operation.

Limitations of the data

The main problems with the data are that they were collected for a specific purpose and there was no experimental design. This limits options for their analysis. For example, there are other interpretations of fish behaviour that could account for the changes in the catch data. One possibility is that orange roughy have responded to the presence of fishing vessels at the hot spot by staying in the deeper water and only moving up to spawning depths just in time to spawn. However, there are no catch per kilometre data from deeper water in the early years of the fishery (1979–81), which would provide one test of this hypothesis.

Another illustration of the limitations of the data is the non-random nature of the fishing. It was not possible to determine whether the area of high catches per kilometre during spawning changed with changes in the abundance of fish. Commercial vessels concentrate their effort in the area of high catch rates, so their catch rate data cannot be used to determine the boundary between high and low catch rates.

Conclusions

This study has shown the value of collecting and analysing tow by tow records of commercial fishing. Analysis has helped describe the development of an important fishery and interpret the likely pattern of fish behaviour.

However, the use of such data alone in stock assessment work (based on analysis of CPUE) is potentially misleading, and fishery independent assessments are necessary.

Acknowledgments

We acknowledge the fishers who filled out the catch effort logbooks, and we thank all members of the former FSU for checking and computer storage of the data. Special thanks to Jack Fenaughty for his experienced comments, and thanks to Don Robertson and Ian West for their critical review and many helpful suggestions. Thanks to Geoff Baird for extensive revision and editing.

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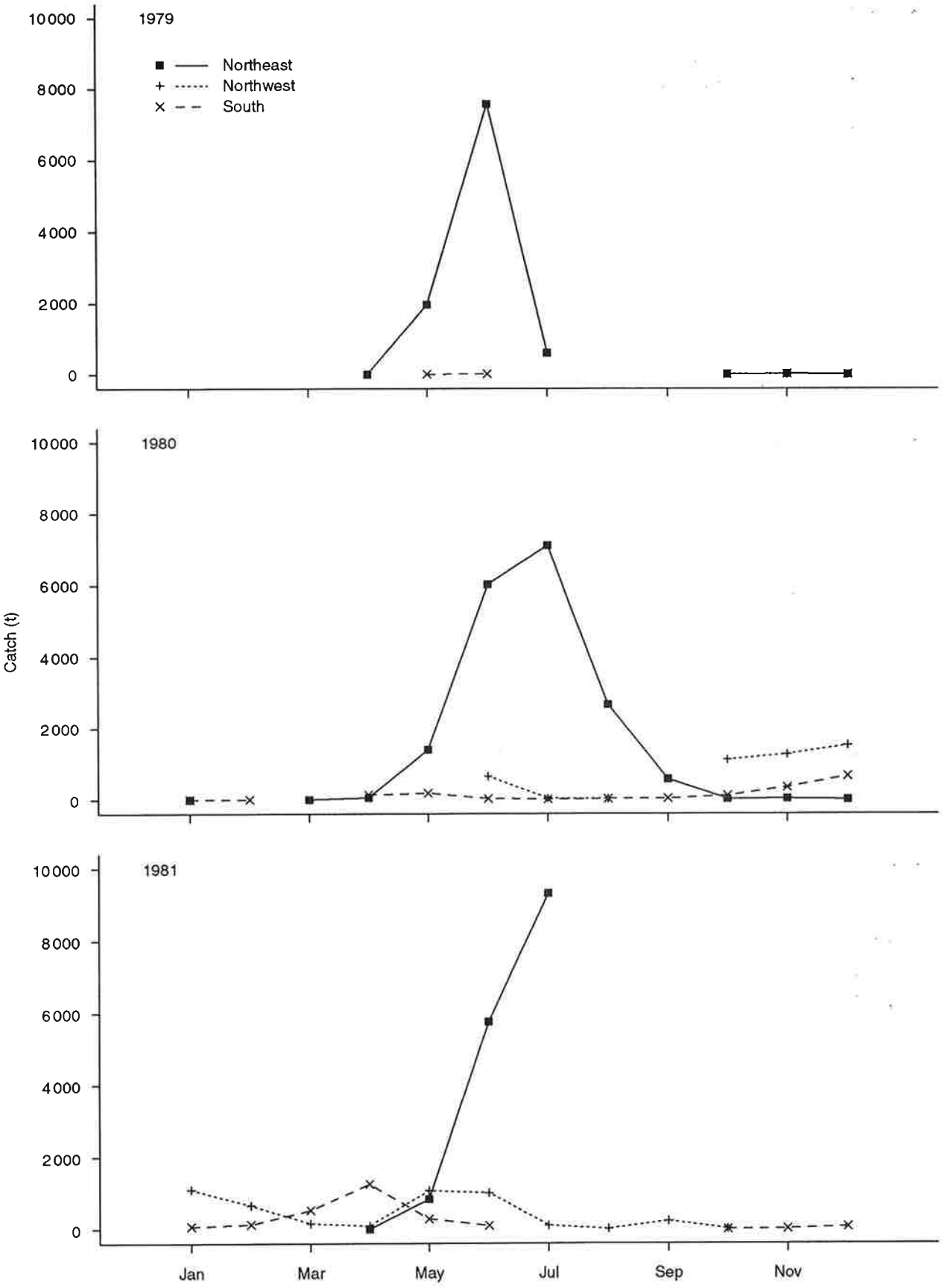
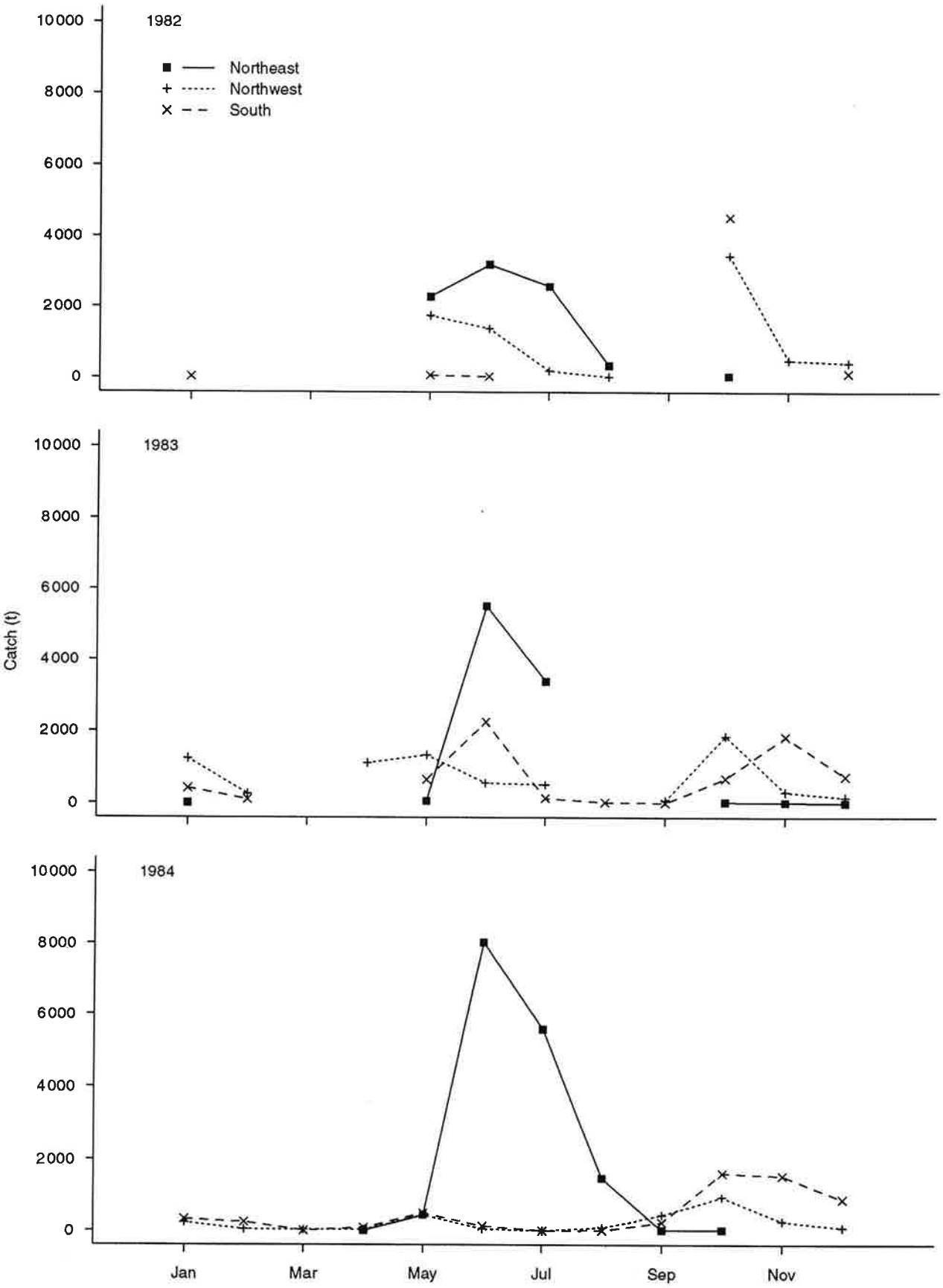
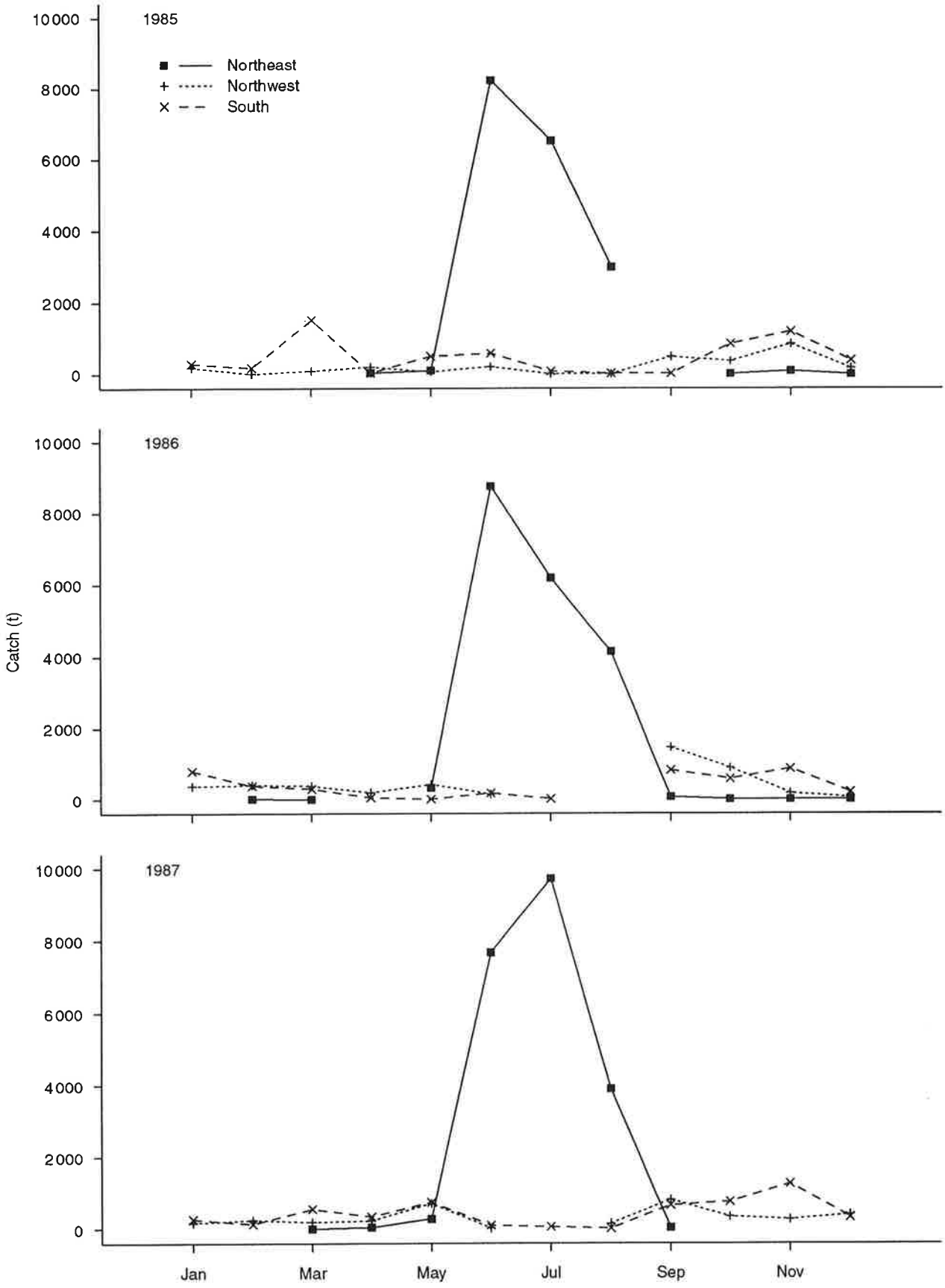
Appendix 1: Monthly catches from the three areas on the Chatham Rise (*see* Figure 2).



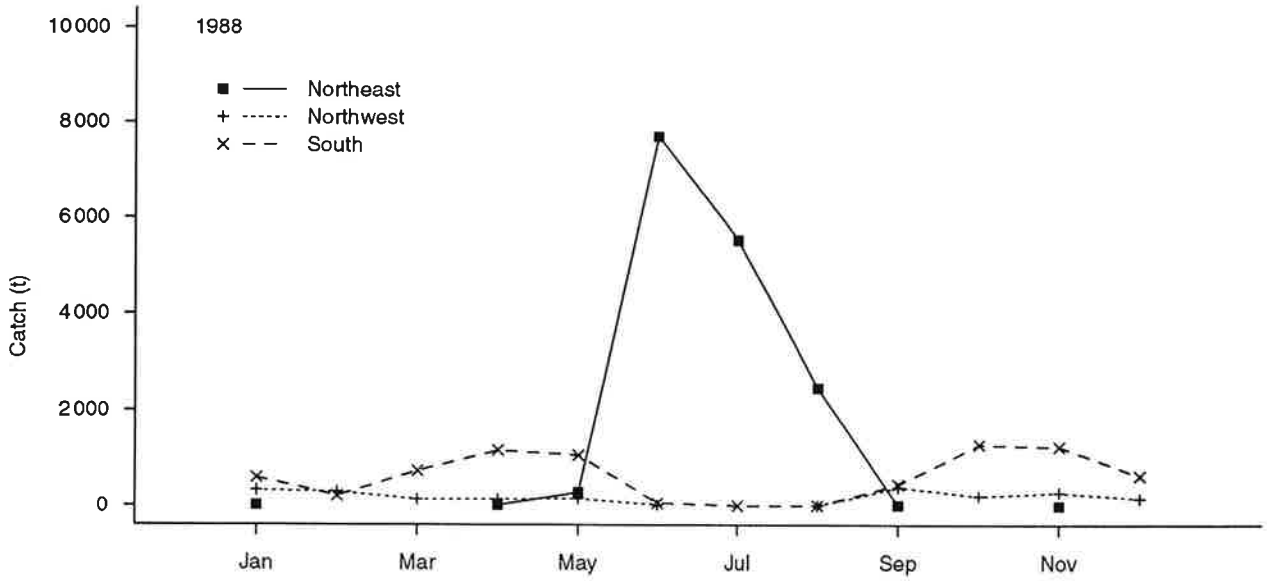
Appendix 1 — *continued*



Appendix 1 — *continued*



Appendix 1 — *continued*

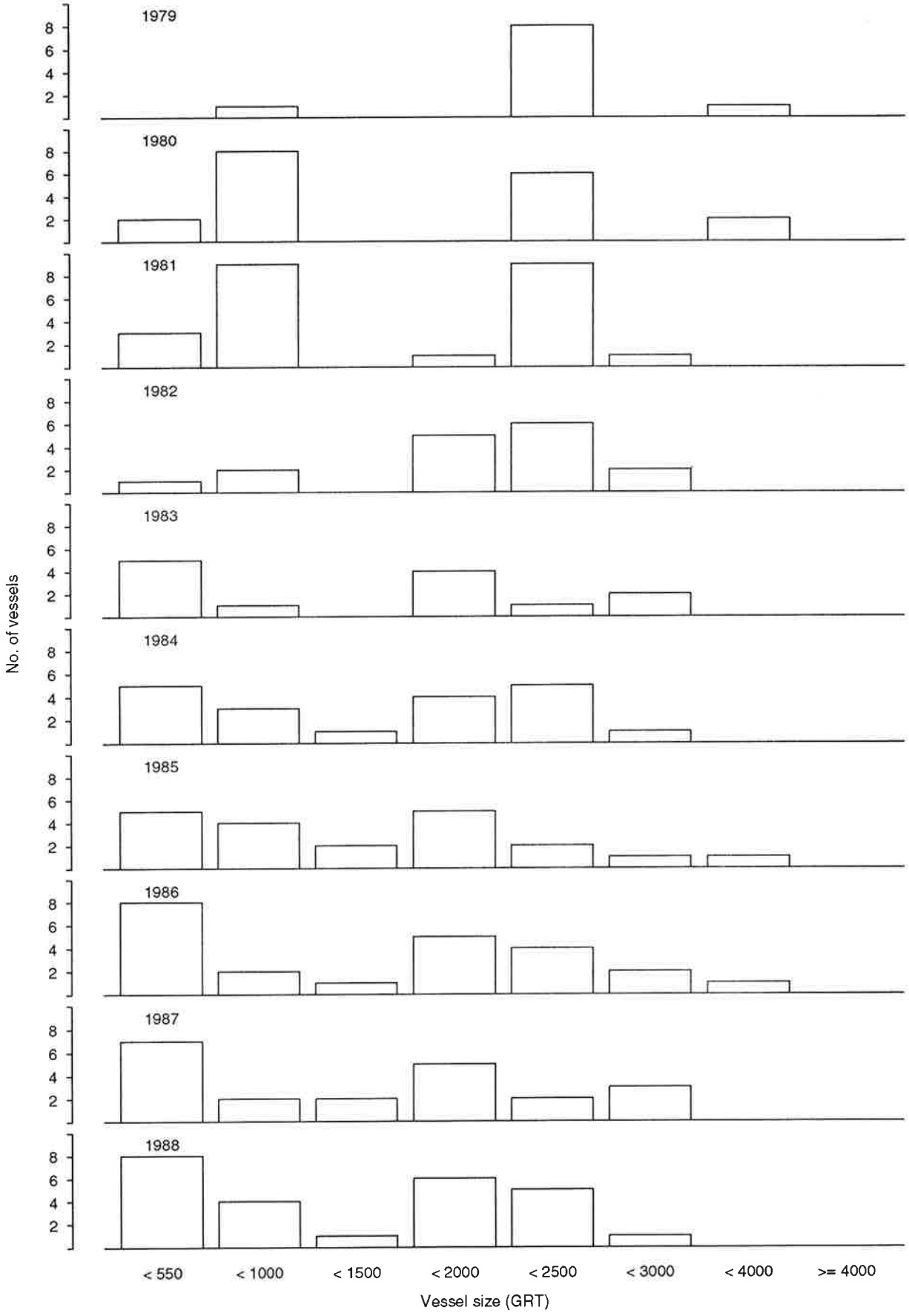


Appendix 2: Number of vessels (and tows) by nation and calendar year, 1979–88

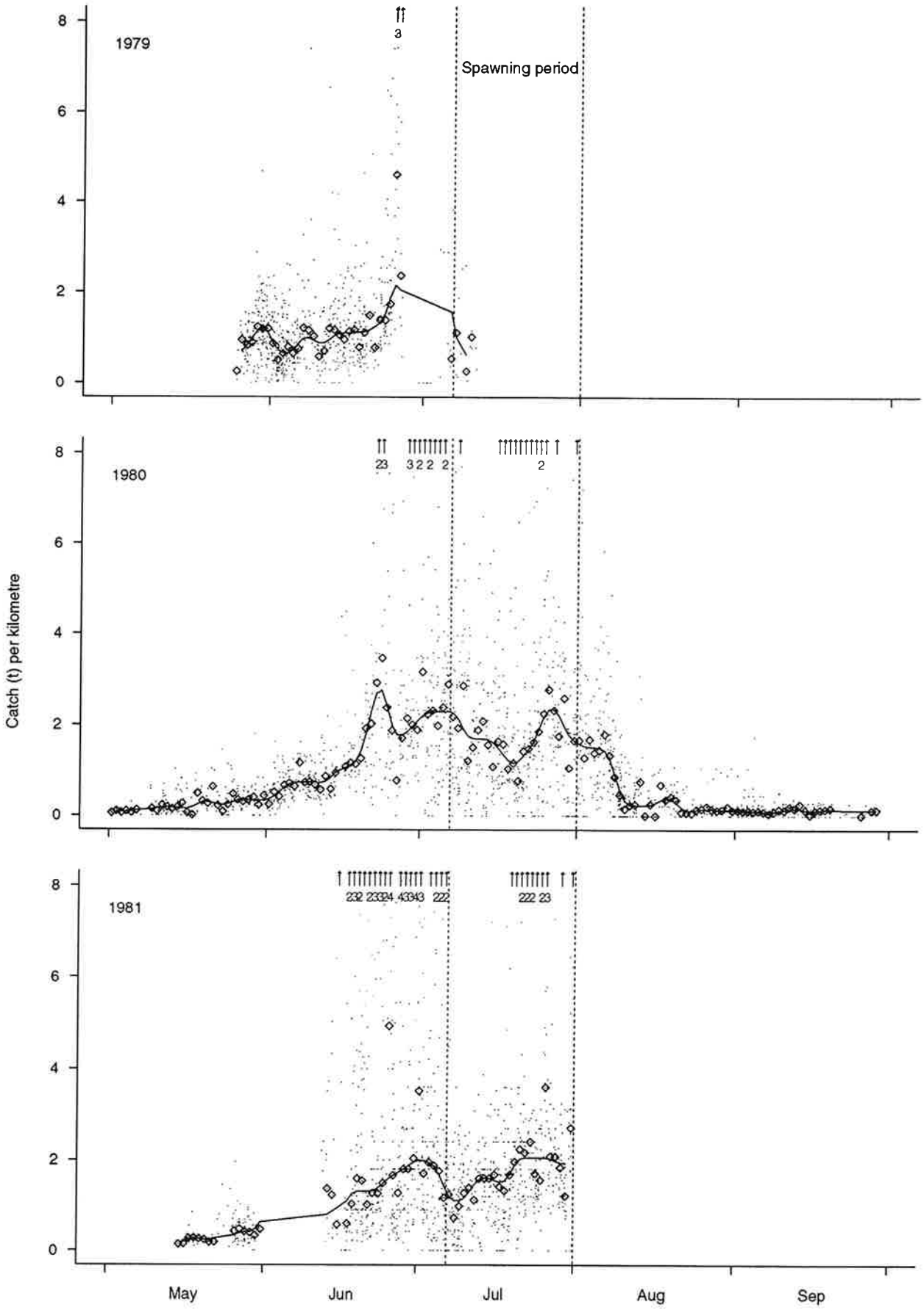
	West Germany	Poland	U.S.S.R.*	U.S.S.R.	Korea	Japan	New Zealand	Total
1979	1	0	10	0	0	0	0	11
	(74)		(711)					(785)
1980	1	0	1	15	2	1	0	20
	(353)		(224)	(1 384)	(38)	(24)		(2 023)
1981	0	1	0	18	2	3	0	24
		(203)		(884)	(90)	(142)		(1 319)
1982	0	0	0	8	0	6	2	16
				(306)		(375)	(323)	(1 004)
1983	0	0	0	1	3	4	5	13
				(7)	(122)	(255)	(260)	(644)
1984	0	0	0	6	4	4	4	19
				(179)	(283)	(253)	(495)	(1 220)
1985	0	0	0	3	5	6	5	20
				(149)	(280)	(286)	(560)	(1 277)
1986	0	0	0	4	6	6	7	23
				(182)	(402)	(581)	(643)	(1 808)
1987	0	0	0	2	6	7	6	21
				(9)	(471)	(757)	(611)	(1 848)
1988	0	0	0	5	9	4	7	25
				(208)	(549)	(385)	(521)	(1 663)
Total	2	1	11	62	37	41	36	192
	(427)	(203)	(935)	(3 308)	(2 235)	(3 058)	(3 413)	(13 591)

* Foreign licensed vessels.

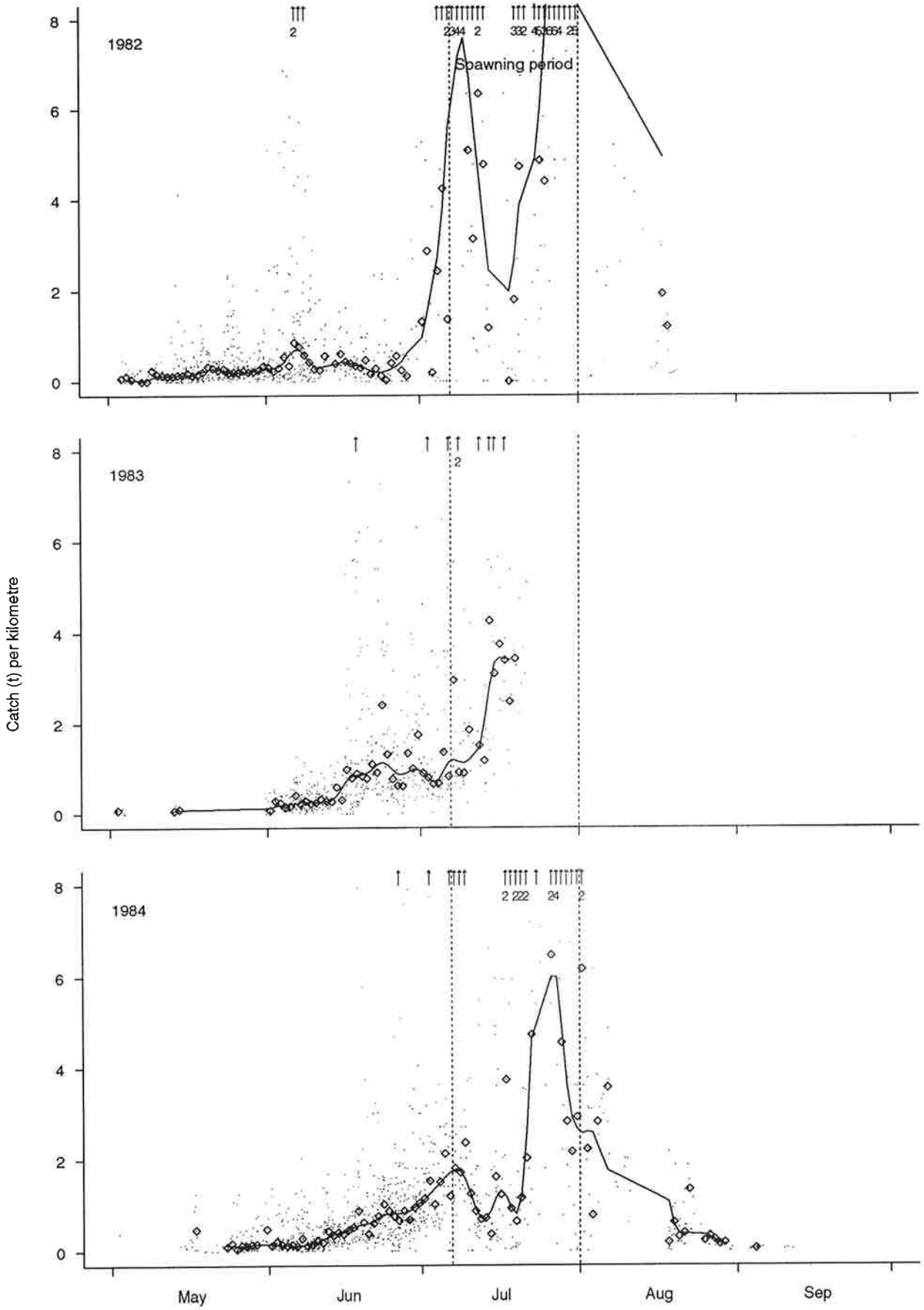
Appendix 3: Number of vessels fishing for orange roughy on the northeast Chatham Rise, 1979–88, by gross registered tonnage (GRT).



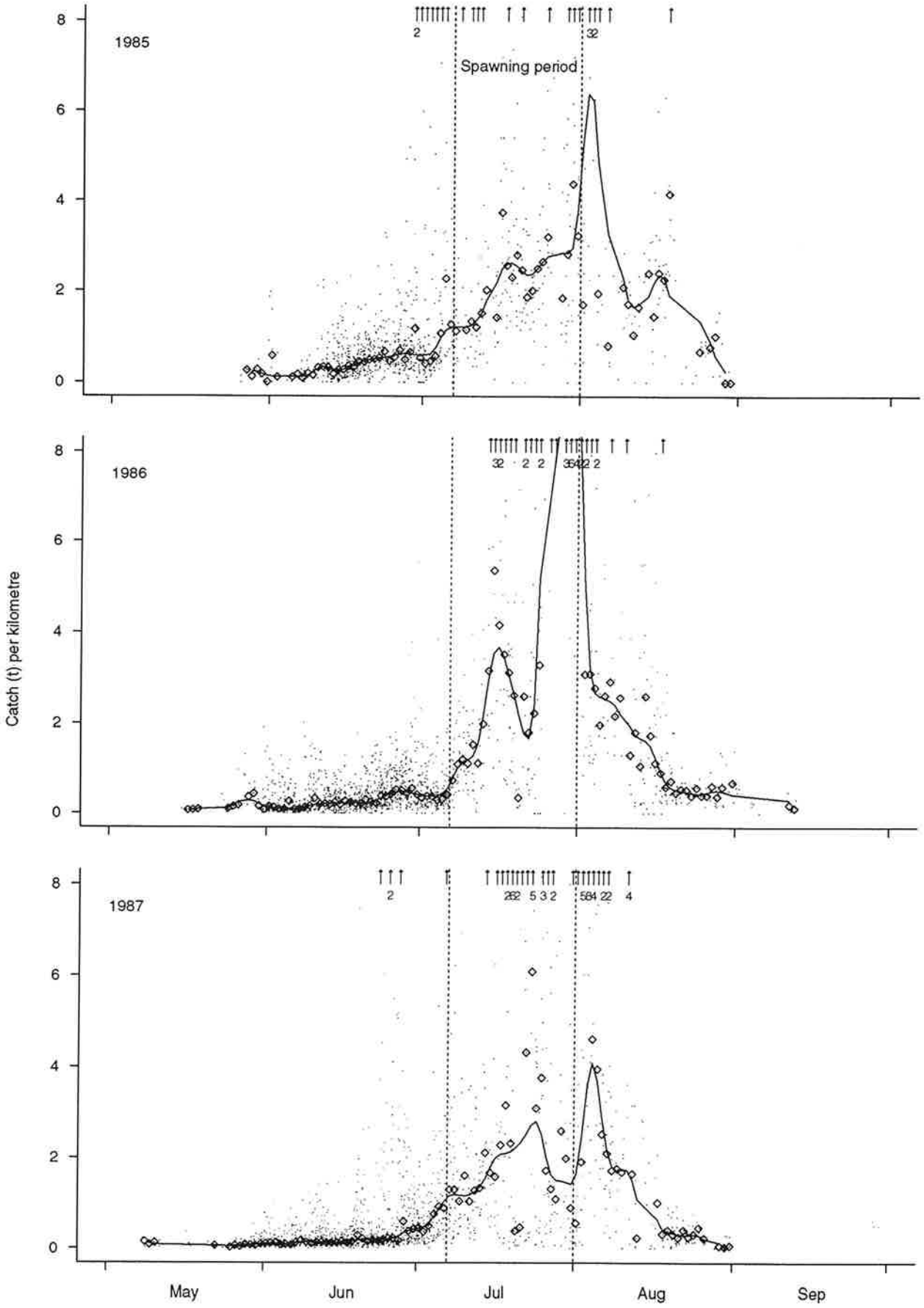
Appendix 4: Catch rates for 1979–88. (Daily median catch rates are shown with a diamond when at least four tows were done that day. A smooth line is drawn through the medians by use of a method known as "4(3RSR)2H twice" (Tukey 1977, Chapters 7 and 16). Arrows and numbers under them show tows with catches over 8 t.km^{-1}).



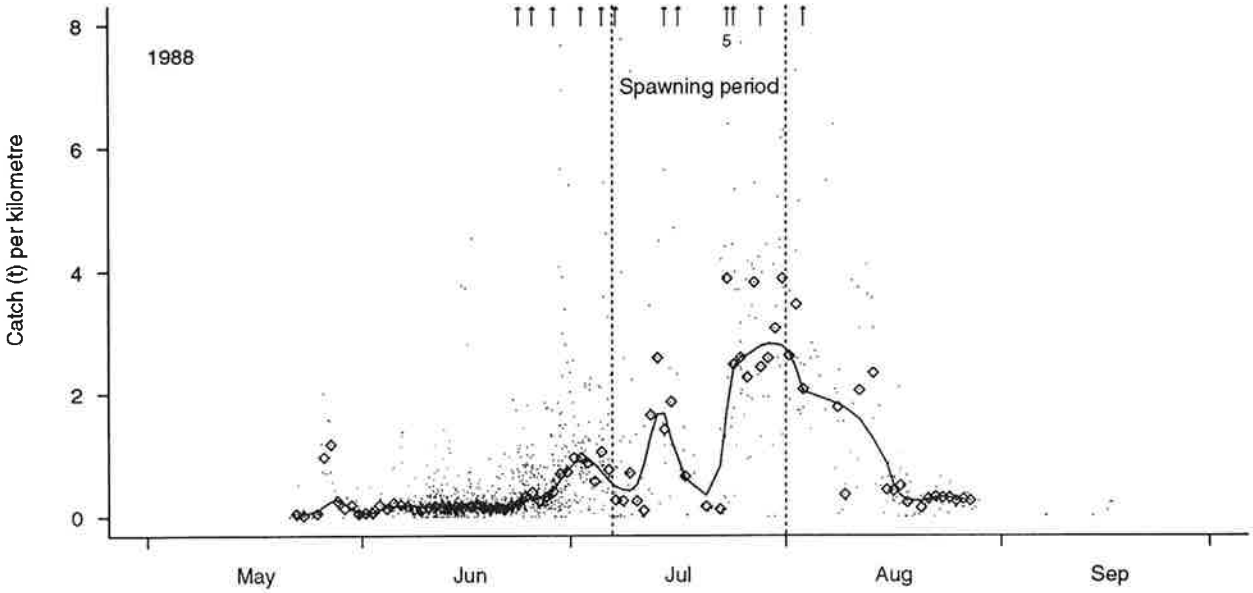
Appendix 4 — *continued*



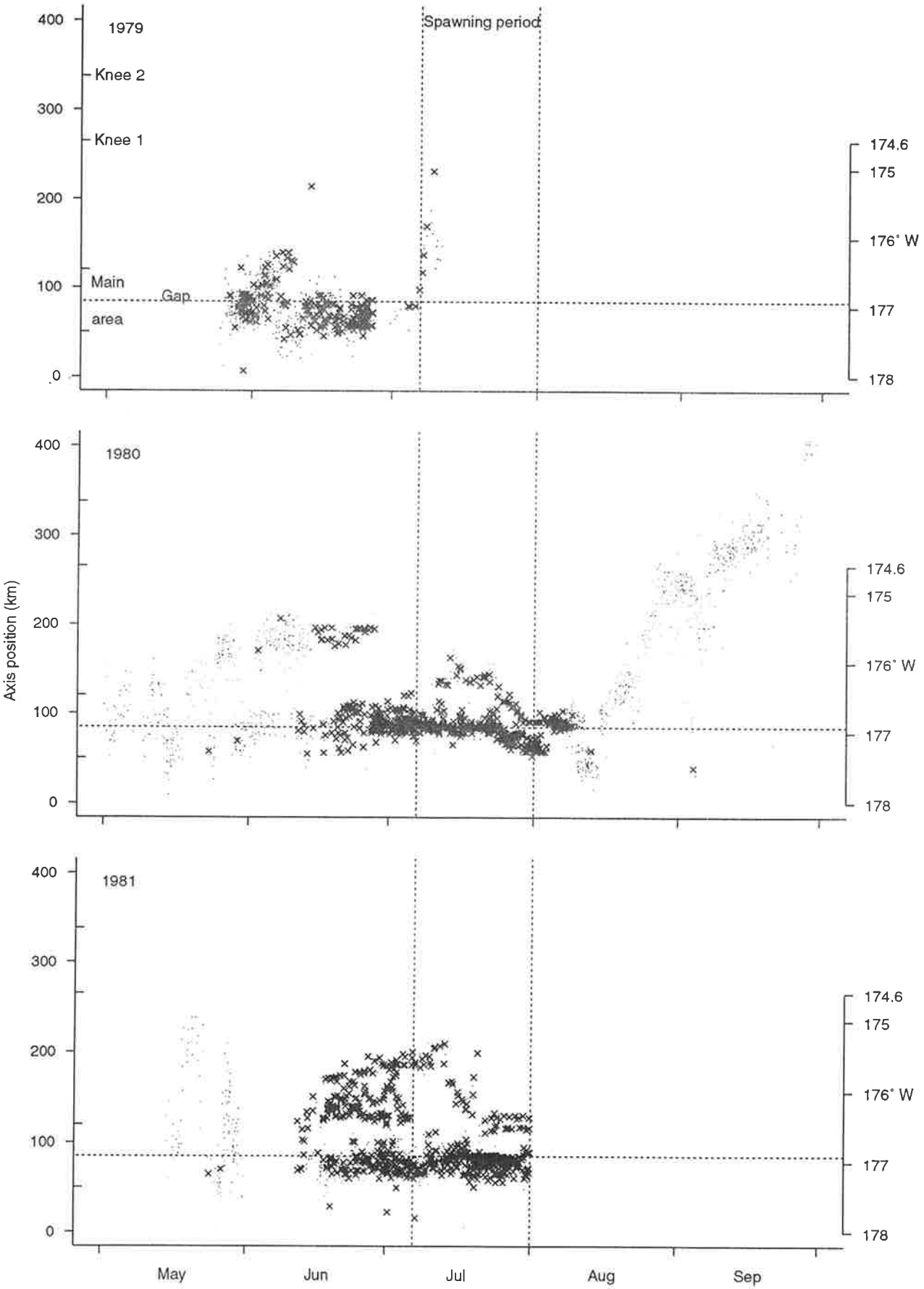
Appendix 4 — *continued*



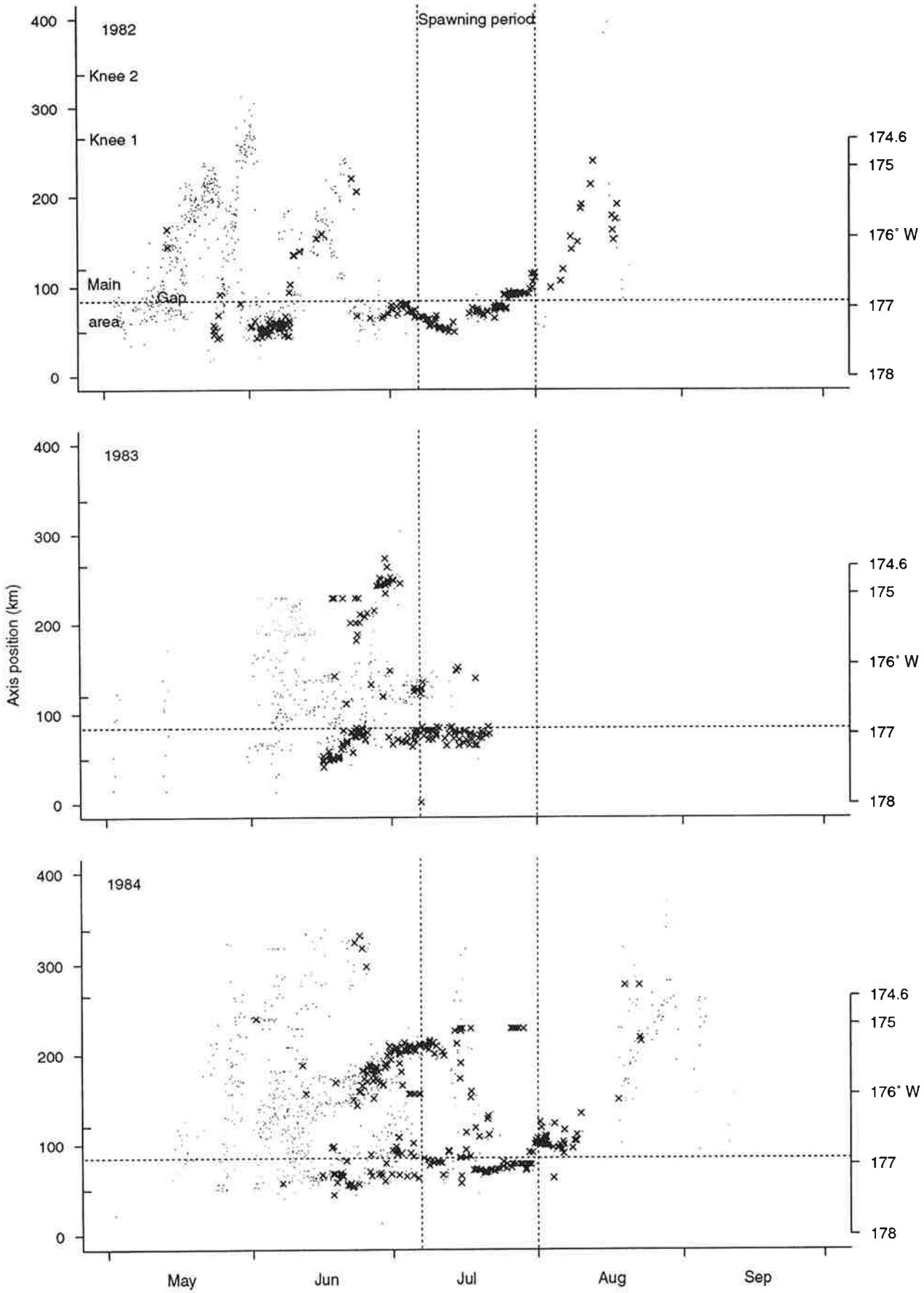
Appendix 4 — *continued*



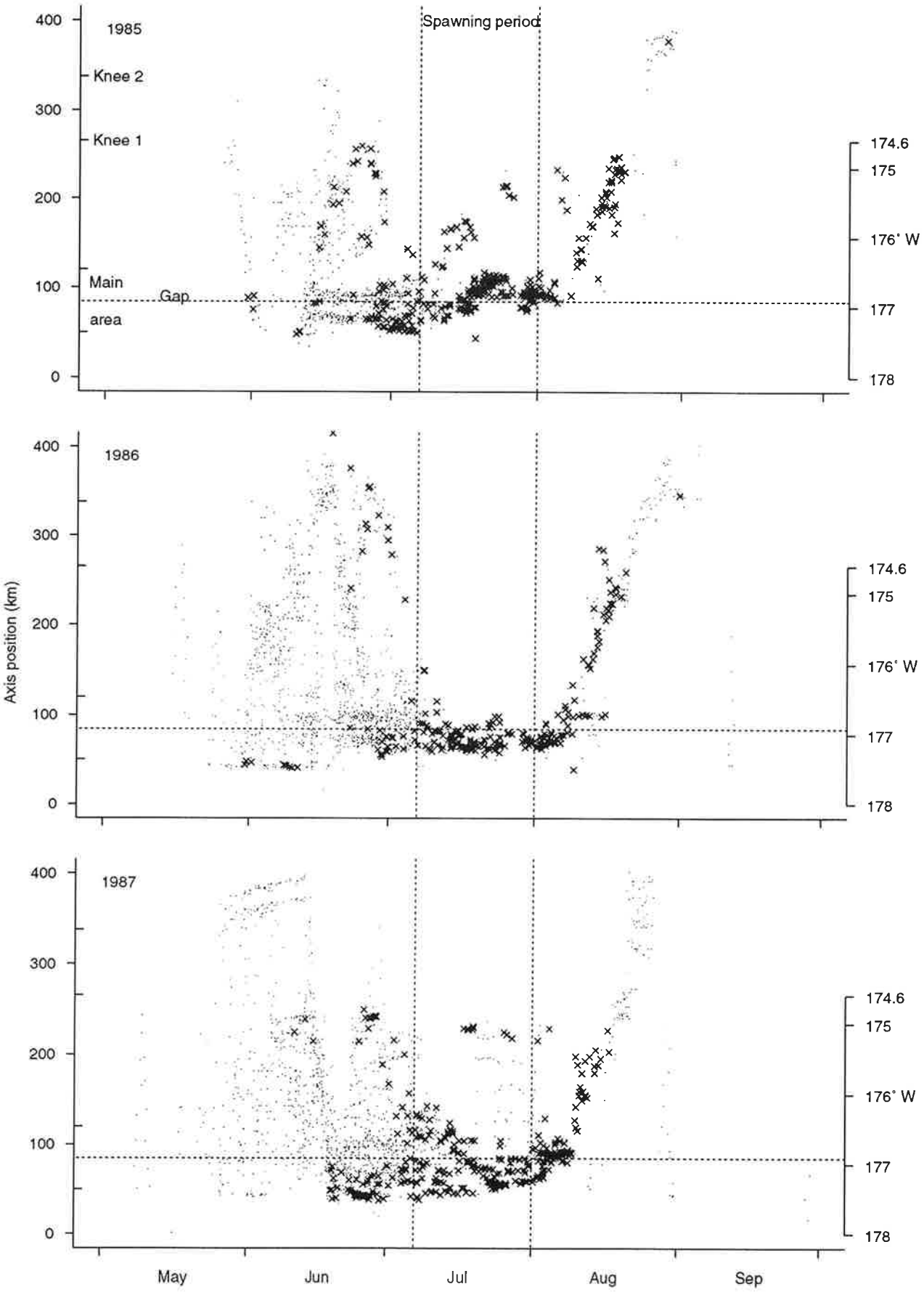
Appendix 5: Catch rate and tow position for 1979–88. (Catch rates over 1.35 t.km^{-1} are shown by "x".)



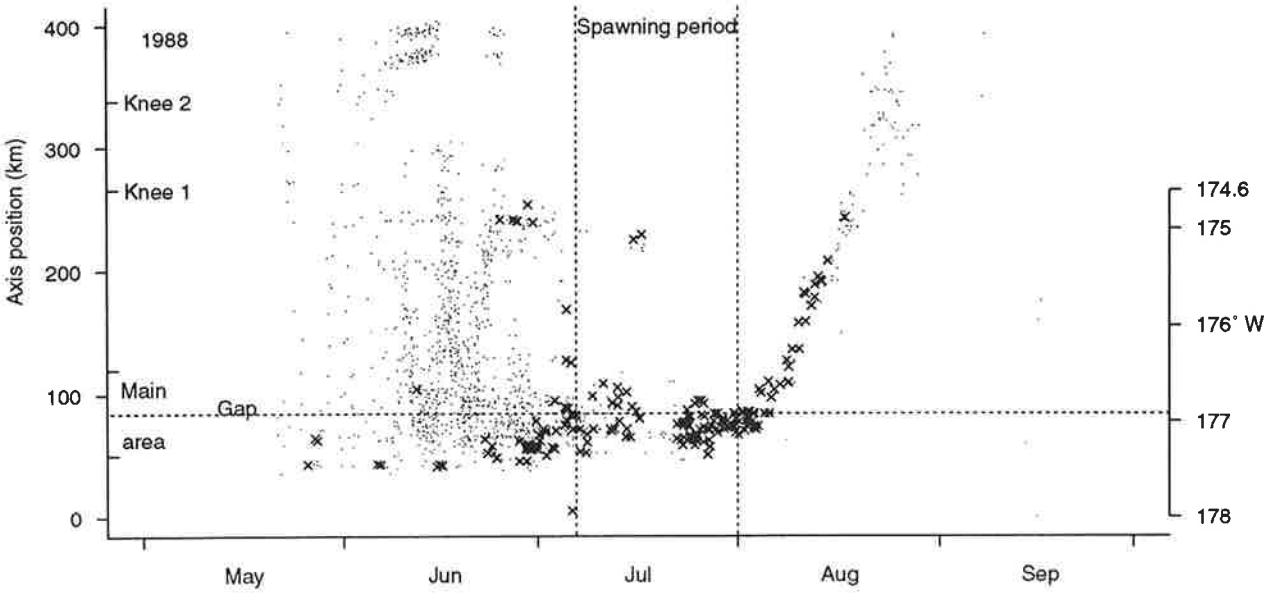
Appendix 5 — *continued*



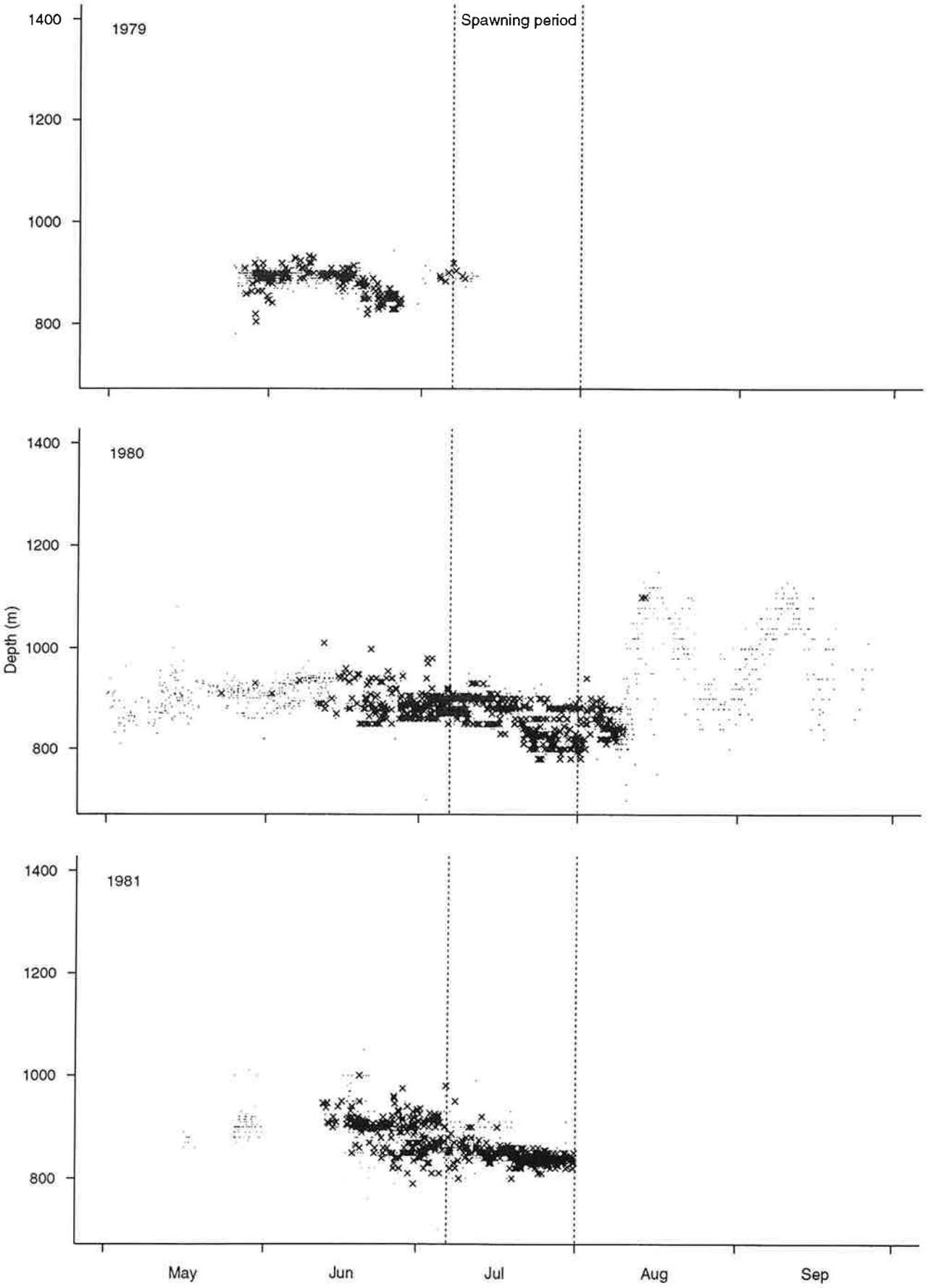
Appendix 5 — *continued*



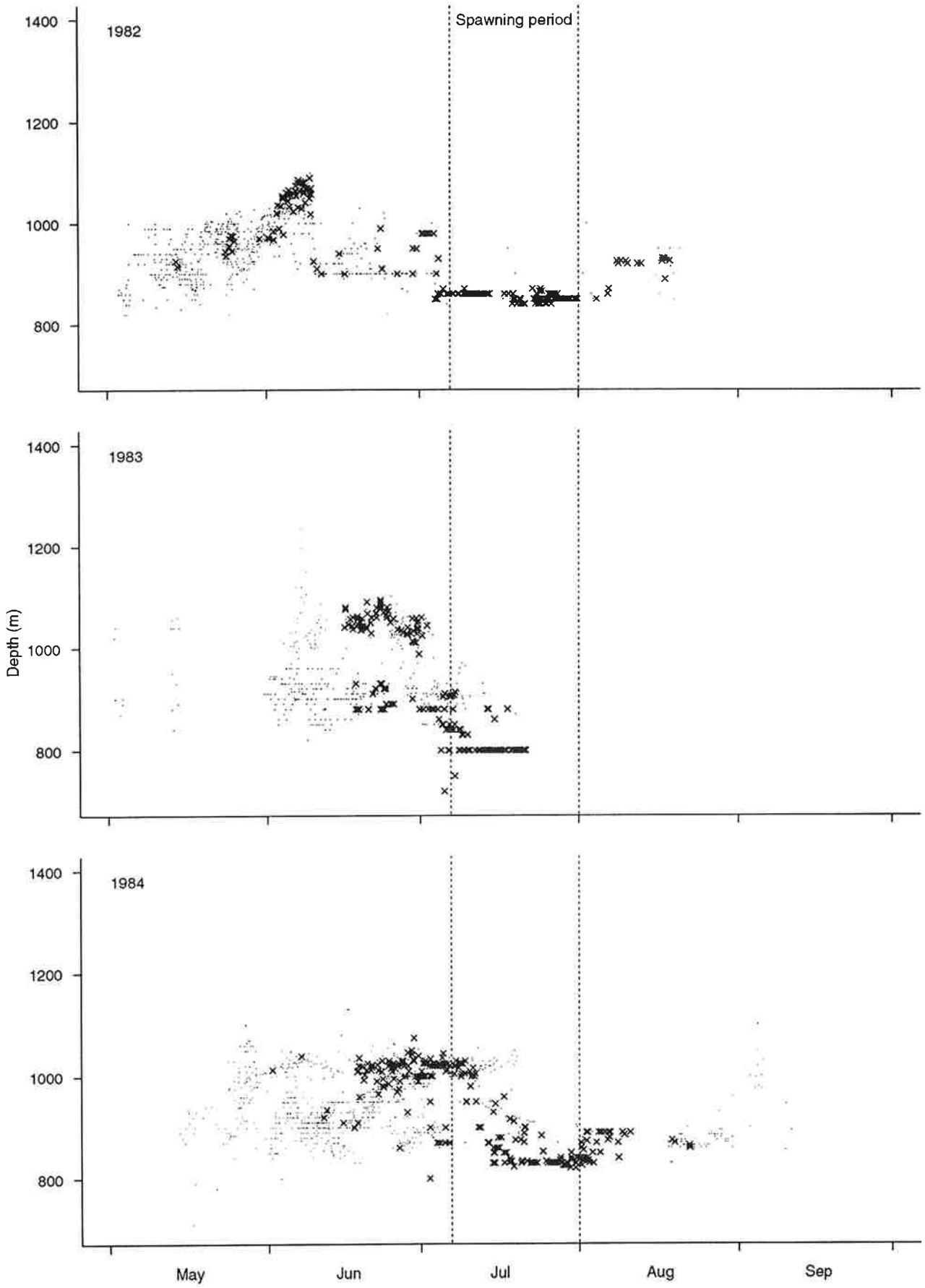
Appendix 5 — *continued*



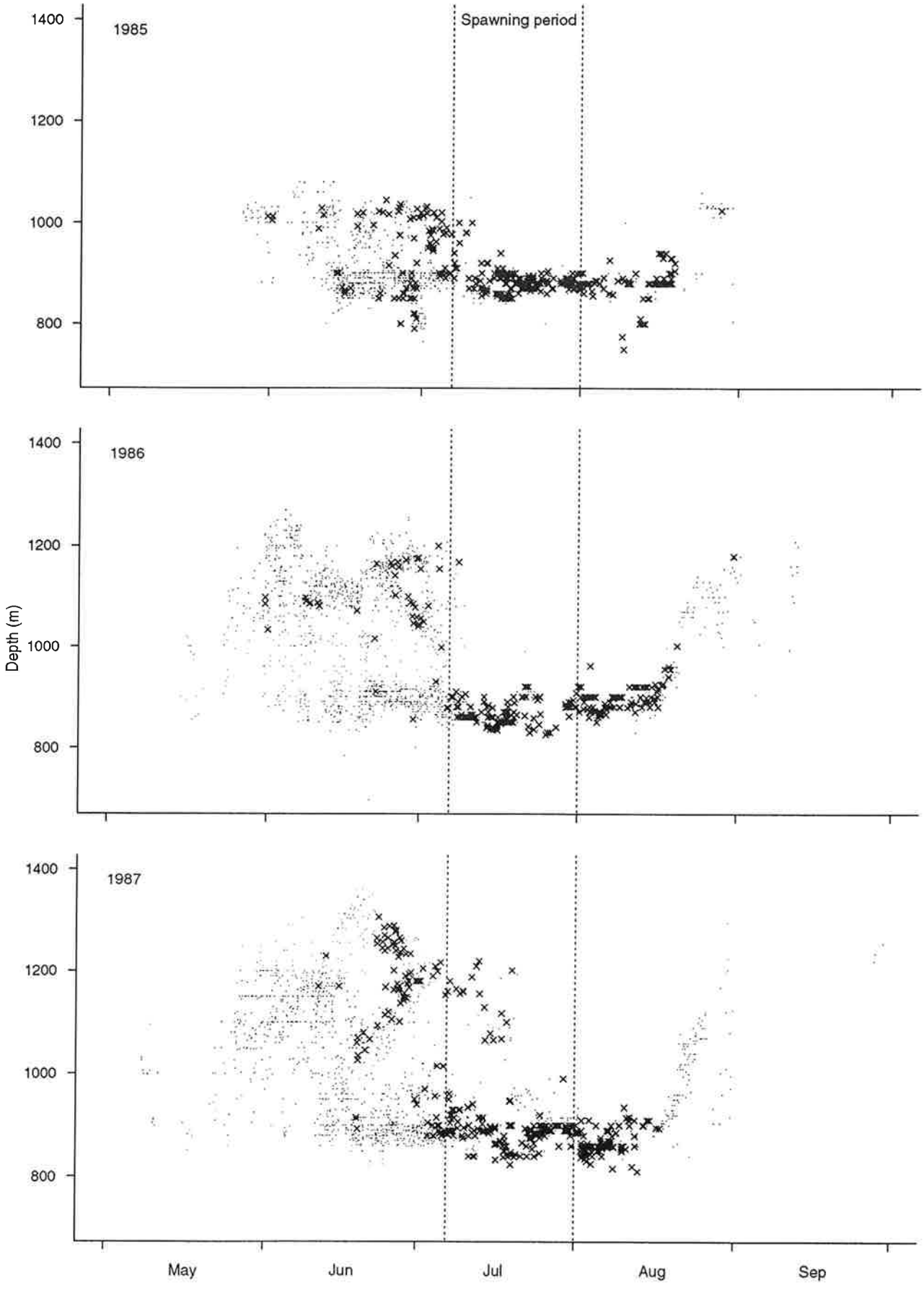
Appendix 6: Catch rate and tow depth for 1979–88. (Catch rates over 1.35 t.km^{-1} are shown by "x".)



Appendix 6 — *continued*



Appendix 6 — *continued*



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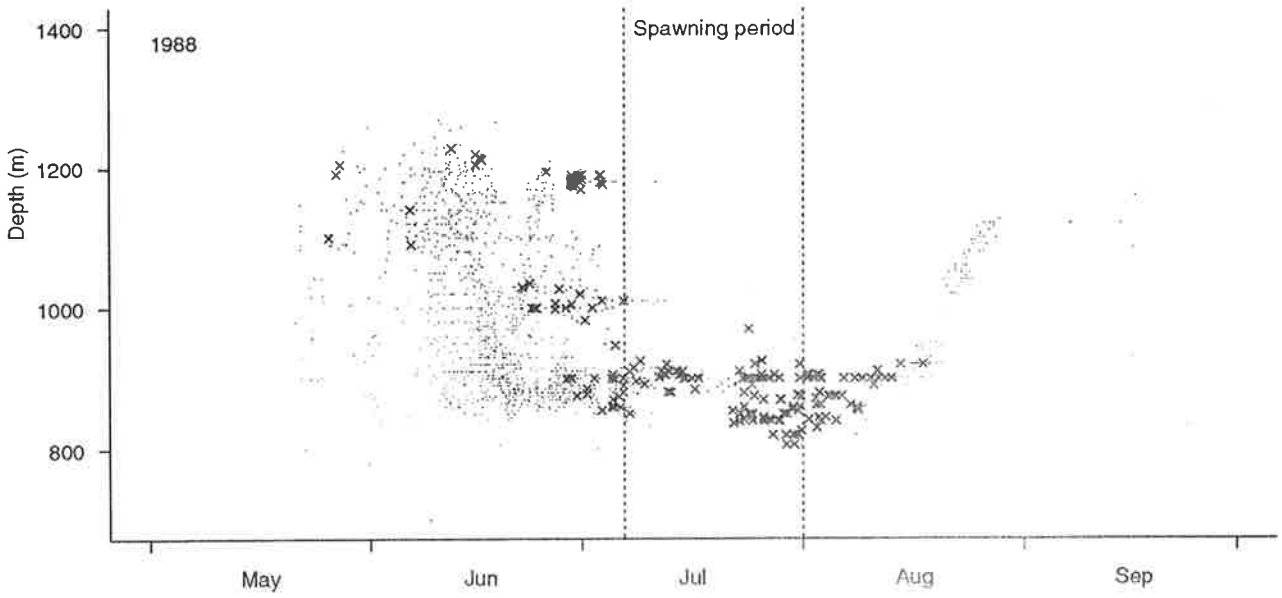

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