Northwest Atlantic Fisheries Organization

Serial No. N2238

NAFO SCR Doc. 93/55

SCIENTIFIC COUNCIL MEETING - JUNE 1993

The Food of Cod in Divisions 2J, 3K and 3L During the Autumns of 1978-1992

by

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Introduction

The cod stock in Divisions 2J3KL has experienced a reduction in biomass and a restriction in distribution in recent years (Baird et al. MS 1992). During the same period, estimates of capelin abundance from Canadian hydroacoustic surveys in autumn in Divisions 2J3K declined abruptly and unexpectedly from 1,744 thousand t in 1989 (Miller MS 1990) to 96 thousand t in 1990 (Miller and Lilly MS 1991), and continued to decline to 34 thousand t in 1992 (D. S. Miller, Department of Fisheries and Oceans, St. John's, Newfoundland, pers. comm.). An analysis of cod stomach content data collected in Divisions 2J3K in 1978 and 1980-1986 demonstrated that the quantity of capelin in the stomachs of the cod increased with capelin abundance, and that at times of low capelin abundance, cod did not compensate by feeding more intensively on other prey (Lilly 1991). There is concern, therefore, that the apparent reduction in capelin biomass has caused an energetic stress in cod, and that this might be related to the decline in cod biomass.

The purpose of this paper is to examine certain aspects of the interaction between cod and capelin, with emphasis on the years 1989-1992. I first describe the average distribution of cod catches during bottom-trawl surveys, and the geographic pattern of occurrence of capelin in the stomachs of cod caught during those surveys, in Divisions 2J3KL during the autumns of 1980-1989. I then examine in more detail the distributions of cod and the occurrence of capelin in cod stomachs in 1989-1992. A preliminary examination of annual variability in feeding success is accomplished by visual comparisons of the average quantities of food in the stomachs of the cod at the time of the surveys in 1978 and 1980-1992. This analysis is done by Division to permit easy comparison with descriptions of changes in cod biomass (Baird et al. MS 1992).

Materials and Methods

Bottom-trawl surveys

Cod were caught during bottom-trawl surveys conducted from southern Labrador to the central Grand Bank (Divisions 2J3KL) during October-December 1978-1992 (Table 1).

All surveys in Division 2J3K were conducted with the 74 m stern trawler R.V. 'Gadus Atlantica'. The survey pattern changed several times. In 1978, a single trip surveyed depths from 100 m to 400 m in Div. 2J and 200 to 400 m in Div. 3K. In both 1979 and 1980, the area was surveyed twice, the first trip fishing depths 200-1500 m and the second fishing 100-400 m in Div. 2J and 200-400 m in Div. 3K. The first trip in each of these years was earlier than trips in other years, and is not used in among-year comparisons. The fishing pattern became more standardized in 1981, with two or three consecutive non-overlapping trips fishing depths of 100-1000 m in Div. 2J and 200-1000 m in Div. 3K. Depths between 100 and 200 m in northwestern Div. 3K (St. Anthony Shelf and Grey Islands Shelf) were added in 1984 and subsequent years, but this depth range has not been surveyed in southern Div. 3K (Baie Verte Shelf and Fogo Shelf).

Surveys in Division 3L were conducted with the 51 m side trawler R.V. 'A. T. Cameron' (1981, 1982) and the sister 50 m stern trawlers R.V. 'Wilfred Templeman' (1983, 1985, 1987-1992) and R.V. 'Alfred Needler' (1986) (Table 1). There was no survey in autumn 1984. In each year the area was surveyed in one or two non-overlapping trips, except in 1985, when three trips conducted essentially two complete passes through the Division as part of a special programme of quarterly sampling.

The 'Gadus Atlantica', 'Wilfred Templeman' and 'Alfred Needler' deployed an Engel-145 trawl, whereas the 'A. T. Cameron' deployed a Yankee 41-5 trawl. In all instances, a 29 mm mesh liner was inserted in the codend. Tows were made at 3.5 knots for 30 min at each fishing station, and catches from the few stations of duration other than 30 min were appropriately adjusted. No adjustments were made for possible between-vessel differences in catching efficiency. Fishing in all Divisions and years was conducted on a 24-h basis.

Fishing stations were allocated randomly within depth strata, with a new station selection being conducted each year. That is, stations were not repeated across years. Doubleday (1981) provides illustrations of the strata and information on their areas and depth-ranges. Prior to 1989, the number of stations allocated to each stratum was roughly proportional to the size of the stratum, with the constraint that each stratum be allocated no fewer than 2 stations. (There were instances in which the sampling objectives were not realized.) A 2-phase survey design was adopted for 1989 and 1990. In the first phase, stations were allocated on a stratified-random basis as above. In the second phase, additional stations were allocated randomly to strata where variation in cod catch was high during the first phase. In 1991 and 1992, the number of stations assigned to each stratum was selected so as to minimize variance as observed during surveys in earlier years. Thus, the number of stations per unit area varied considerably among strata. The constraint that each stratum be allocated no fewer than 2 stations still applied.

Stomach collections

Stomachs were collected from cod caught in all surveys from 1978 onward, with the exception of the second survey in 1979. The sampling request in 1978 called for stomachs to be collected from up to 5 randomly selected cod per 10-cm length-group per station. The sample size was reduced to 3 per 10-cm length group for 1979-1982, and changed to 3 per 9-cm length group in 1983-1992.

The sampling objectives were not always attained. In some instances, one or more fish were caught in a station/length-group, but no stomach was collected. (This occurred for various reasons, including allocation of the fish to other purposes and insufficient time to conduct stomach sampling.) In other instances, one or more stomachs were collected, but either they were not examined or they were examined and the records were not kept. (This occurred, for example, when stomachs were not well preserved, accidentally cut or misplaced, or when there was confusion in the records. The only major gap in the data occurred in 1981, when stomachs from 25 fishing stations in northern Div. 3K were lost because they were not well preserved.)

Stomachs were not collected from fish which showed signs of regurgitation, such as food in the mouth or a flaccid stomach. Stomachs were individually tagged and excised, and fixed and preserved in 4% formaldehyde solution in seawater prior to examination of their contents in the laboratory.

Stomach analysis

Examination involved separation of food items into taxonomic categories. Fish and decapod crustacea were identified to species, but most other groups were assigned to higher order taxa. Items in each taxon were placed briefly on absorbent paper to remove excess liquid, and then counted and weighed to the nearest 0.1 g.

Data analysis

The quantity of a specific prey in the stomachs of the cod from a specified sample was expressed as a mean partial fullness index:

$$PFI_i = \frac{1}{n} \sum_{j=1}^{n} \frac{W_{ij}}{L_j^3} * 10^4$$

where W_{ij} is the weight of prey i in fish j, L_j is the length of fish j, and n is the number of fish in the sample. Mean total fullness index was calculated as:

$$TFI = \sum_{i=1}^{m} PFI_i$$

where m is the number of prey categories.

The present analysis was restricted to cod within the 36-71 cm length range, because cod smaller than about 30-35 cm cannot feed on the largest capelin and cod larger than about 70 cm tend to feed to an increasing extent on groundfish and crabs (Lilly 1991).

The geographic distributions of cod catches and food in cod stomachs are presented in expanding symbol plots, as opposed to contour plots generated from modelling of the catches and stomach fullness values, in order to provide visual information on the spatial distribution of fishing stations, the relationship between distribution and bathymetry, and the variability among stations. This presentation also permits station-by-station comparison of cod catch and the quantity of capelin in cod stomachs. To investigate the long term distribution of cod and the geographic pattern in stomach fullness, the arithmetic mean catch per tow, mean partial fullness index for capelin (PFI_c), and mean total fullness index (TFI) were calculated from all stations occurring in areas of 10′ latitude and 20′ longitude during the period 1980-1989. To illustrate the distribution of cod catches and the quantity of capelin in cod stomachs (PFI_c) in 1989-1992, the cod catch and mean PFI_c were plotted for each year and individual station.

Results

Distributions of cod, capelin and total prey, 1980-1989

In the plot of mean catches of cod during the period 1980-1989 (Fig. 1), relatively large mean catches occur in several areas: the northern and eastern slopes of Hamilton Bank; west of Belle Isle Bank; the outer trough between Belle Isle Bank and Funk Island Bank; the outer trough between Funk Island Bank and Grand Bank, and the adjacent northeastern slope of Grand Bank; and the plateau of Grand Bank. The plot of mean stomach fullness indices for capelin (PFI_c) during the period 1980-1989 (Fig. 2) reveals a fairly distinct break between moderate to high fullness indices in northern and western Division 2J3K (Hamilton Bank, western Belle Isle Bank, and west of Funk Island Deep) and fullness indices of similar magnitude in northern Division 3L (northern and northeastern slopes of Grand Bank). Plots for individual years (Lilly, 1991; Lilly and Davis, in prep.) reveal that the capelin tend to be either on Hamilton Bank and along the coastal shelf off southern Labrador and northeastern Newfoundland, or more aggregated on the central Northeast Newfoundland Shelf, as was the case in 1986 and 1987. The cod concentrations on Hamilton Bank and west of Belle Isle Bank, and along the northeast slope of Grand Bank, coincide with areas of moderate to high PFI_c values. Cod concentrations in the outer trough between Belle Isle Bank and Funk Island Bank, and in the outer trough between Funk Island Bank and Grand Bank (near the 2J3K boundary), experienced low PFI_c values.

The geographic pattern of total fullness index (TFI) (Fig. 3) generally reflects the pattern of capelin in stomachs (PFI_c) (Fig. 2). The major exception is southern and western Division 3L, where the major prey are shrimp (Avalon Channel) and sand lance (plateau of Grand Bank). Low TFI values were prevalent on the eastern and southern Northeast Newfoundland Shelf, including the areas of cod concentration in the outer troughs between Belle Isle Bank and Funk Island Bank, and between Funk Island Bank and Grand Bank.

Distribution of cod and capelin, 1989-1992

The geographic plots for individual years 1989-1992 (Fig. 4-7) illustrate the dramatic decline in cod catch and change in cod distribution. In 1989 (Fig. 4) few cod were caught in northwestern Division 2J, but large catches were secured in most of the areas where relatively large catches had been obtained in the 1980's (Fig. 1). In 1990 (Fig. 5) moderate and large catches were confined to the outer shelf in Divisions 2J3K and the plateau of Grand Bank. In 1991 (Fig. 6) there were no large catches on Hamilton Bank and the plateau of Grand Bank. By 1991 (Fig. 7) good catches were secured only in a small area near the shelf break in northern Division 3L. The capelin experienced a pronounced shift from northern and western Divisions 2J3K to southern and eastern Division 3K during this period (Fig. 4-7). Lilly and Davis (MS 1993) provide additional details regarding this change in capelin distribution.

A visual comparison of the plots of cod catch and the quantity of capelin in cod stomachs reveals that in 1989 cod preyed intensively on capelin over most of Hamilton Bank, the Northeast Newfoundland Shelf, and the northeastern slope of Grand Bank (Fig. 4). The area of intensive feeding contracted in 1990 and 1991 (Fig. 5,6). However, on a broad scale the area of intensive feeding contracted into the area into which the cod contracted, so that in each year most cod were not far from where they could successfully prey on capelin.

Nevertheless, examination of distributions on a finer scale reveals that there was little overlap on a station-by-station basis. For example, the cod in the large catches on northeastern Funk Island Bank in 1991 were either not feeding on capelin or had very little capelin in their stomachs, whereas those cod from very small catches a short distance to the southeast had much capelin in their stomachs (Fig. 6). Similarly, the cod taken in several large catches at approximately 49° N in 1992 had very little capelin in their stomachs, even though the cod from smaller catches at similar depths to the north and south were feeding well on capelin (Fig. 7).

Stomach fullness by Division, 1978-1992

To examine the possibility that a decline in the abundance of capelin had caused a decline in the feeding intensity of cod, the mean stomach fullness of cod (36-71 cm only) was calculated for each year and Division (Fig. 8). As reported by Lilly (1991), most of the year-to-year variability in stomach fullness in Divisions 2J3K is caused by changes in capelin abundance and capelin distribution. In both Division 2J and Division 3K there was an overall increase in feeding on capelin from the period of very low capelin abundance in 1978 to the period of relatively high abundance in 1985-1989. The higher PFI_c values in Division 2J relative to Division 3K in 1980-1985 and 1988 reflect the northwesterly distribution of capelin in those years (Lilly and Davis MS 1993). The higher values in Division 3K in 1986 and 1987 reflect the southerly distribution of capelin at the time of the bottom-trawl surveys in those years. The high values in both Divisions in 1989 reflect the broad distribution of intensive feeding by cod on capelin. The intensive feeding by cod on capelin in 1990 is surprising, given the low biomass estimate from the Canadian hydroacoustic survey that year. The high value for Division 2J in 1990 is somewhat misleading, because it obscures the fact that predation by cod on capelin was very low on Hamilton Bank and very high on Belle Isle Bank. In 1991 and 1992, the few cod remaining in Division 2J found very few capelin, whereas those in Division 3K were feeding intensively.

In Division 3L, the importance of capelin increased over time. This may reflect an increase in the abundance of capelin, but in 1991 it also reflects a decrease in sampling outside the northern and northeastern areas where capelin were the major prey throughout the time-series. A value cannot be provided for Division 3L in 1992, because analysis of stomach contents has not been completed. However, the value is likely to be relatively high, because most cod were caught in the north and northeast, and feeding on capelin was moderately intensive in these areas (Fig. 7).

Discussion

During the period 1989-1992 there was a severe reduction in the catch of cod during reasearch bottom-trawl surveys in Divisions 2J3KL, and a dramatic change in cod distribution. Certain areas where large catches had been taken in the 1980's (Fig. 1) no longer yielded large catches. Other areas continued to yield good catches, but by 1991 only the troughs between Belle Isle Bank and Funk Island Bank and between Funk Island Bank and Grand Bank yielded cod, and by 1992 only the latter remained. It is interesting that these two areas were not sites where the cod historically found good foraging. Indeed, these were areas of poor feeding (Fig. 2,3).

The opportunity for feeding did not remain poor in these areas. Capelin moved into the southeastern Northeast Newfoundland Shelf from their historic distributions to the north and west (Lilly and Davis MS 1993). Many cod experienced good feeding on capelin in 1990-1992. However, for the most part, the high stomach fullness indices were confined to cod taken from small catches. It may be that the capelin were preyed upon by cod at the periphery of the large cod concentrations, and few capelin survived toward the centre of these concentrations. It is also possible that the capelin avoided the large cod concentrations. It is notable, for instance, that the area of high PFI_c values ended at the edge of the cod concentrations on northeastern Funk Island Bank in 1991 (Fig. 6), but that the high PFIc values extended to the shelf break when the cod were absent in 1992 (Fig. 7).

There is little evidence from the analysis presented here that the cod were finding less prey in recent years than they had in the past. Only in Division 2J did the stomach fullness decline in recent years, and even there the level was no lower than it had been in 1978. However, as noted above, cod taken in most large catches were feeding poorly. Perhaps the fullness indices should be weighted by the catch in individual stations or in strata. The influence of weighting will be examined in a subsequent paper.

Stomach content data collected from surveys in the autumn can provide only limited information on factors affecting well-being of cod. They can provide information on the relationship between capelin abundance and the intensity of feeding by cod on capelin, and reveal whether cod tend to feed to an increasing extent on other prey at times of low cod abundance. However, information on feeding at other times of the year is not available. For example, the stomach content data shows that cod on Hamilton Bank were not feeding on capelin at the time of the surveys in 1990-1992. However, it is known from the distribution of commercial fishing that there were concentations of capelin on Hamilton Bank in the late summer and early autumn of 1990, and the cod there may have been feeding well on capelin at that time. In addition, there is no monitoring of the quantity of cod coming inshore each year, the duration of their stay in shallow water, and the duration and intensity of their feeding on capelin.

Acknowledgements

I wish to thank the many individuals who participated in the trawl surveys and helped to collect the cod stomachs. The stomachs were examined by LGL Limited, Fundy Isles Marine Enterprises Ltd., and S. Fudge and Associates Ltd. B. Moriarity and M. Wheaton helped compile the data, and D. Davis helped plot the distributions. This research was funded in part by the Government of Canada's Atlantic Fisheries Adjustment Program (Northern Cod Science Program).

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Table 1. Selected data for bottom-trawl surveys in Divisions 2J3KL in the autumns of 1977-1992. AN = ALFRED NEEDLER, ATC = A. T. CAMERON, GA = GADUS ATLANTICA, WT = WILFRED TEMPLEMAN.

Year	Div.	Ship/Trip	Sampling dates (d/mo.-d/mo.)	Number of stations occupied		Phase 1 stations with cod		Phase 1 stations with capelin	
				Phase 1	Phase 2	No.	%	No.	%
1977	2J3K	GA 3	11/11-02/12	127		96	76	7	6
1978	2J3K	GA 15	04/11-27/11	125		122	98	2	2
1979	2J3K	GA 29	15/11-04/12	124		121	98	42	34
1980	2J3K	GA 44	22/11-08/12	134		129	96	25	19
1981	2J3K	GA 58,59	14/11-13/12	224		182	81	53	24
	3L	ATC 323,325	03/10-18/11	97		87	90	13	13
1982	2J3K	GA 71,72	30/10-08/12	303		251	83	97	32
	3L	ATC 333,334	30/10-06/12	121		113	93	43	36
1983	2J3K	GA 86-88	28/10-07/12	255		220	86	57	22
	3L	WT 7-9	13/10-14/11	126		122	97	44	35
1984	2J3K	GA 101-103	27/10-05/12	262		219	84	67	26
1985	2J3K	GA 116-118	23/10-02/12	311		251	81	127	41
	3L	WT 37-39	09/10-18/11	232		189	82	80	35
1986	2J3K	GA 131-133	03/11-11/12	215		185	86	52	24
	3L	AN 72	13/11-30/11	142		119	84	38	27
1987	2J3K	GA 145-147	29/10-08/12	288		252	88	94	33
	3L	WT 65	15/10-01/11	165		149	90	38	23
1988	2J3K	GA 159-161	04/11-13/12	239		209	87	84	35
	3L	WT 78	26/10-13/11	189		167	88	85	45
1989	2J3K	GA 174-176	02/11-19/12	276	48	228	83	134	49
	3L	WT 87	12/10-31/10	174	21	134	77	72	41
1990	2J3K	GA 190-192	03/11-19/12	243	68	178	73	83	34
	3L	WT 101	18/10-18/11	161	27	140	87	31	19
1991	2J3K	GA 208-210	06/11-17/12	313		229	73	117	37
	3L	WT 114,115	08/11-02/12	219		168	77	45	21
1992	2J3K	GA 224-226	29/10-09/12	319		209	66	153	48
	3L	WT 129,130	05/11-29/11	215		146	68	80	37

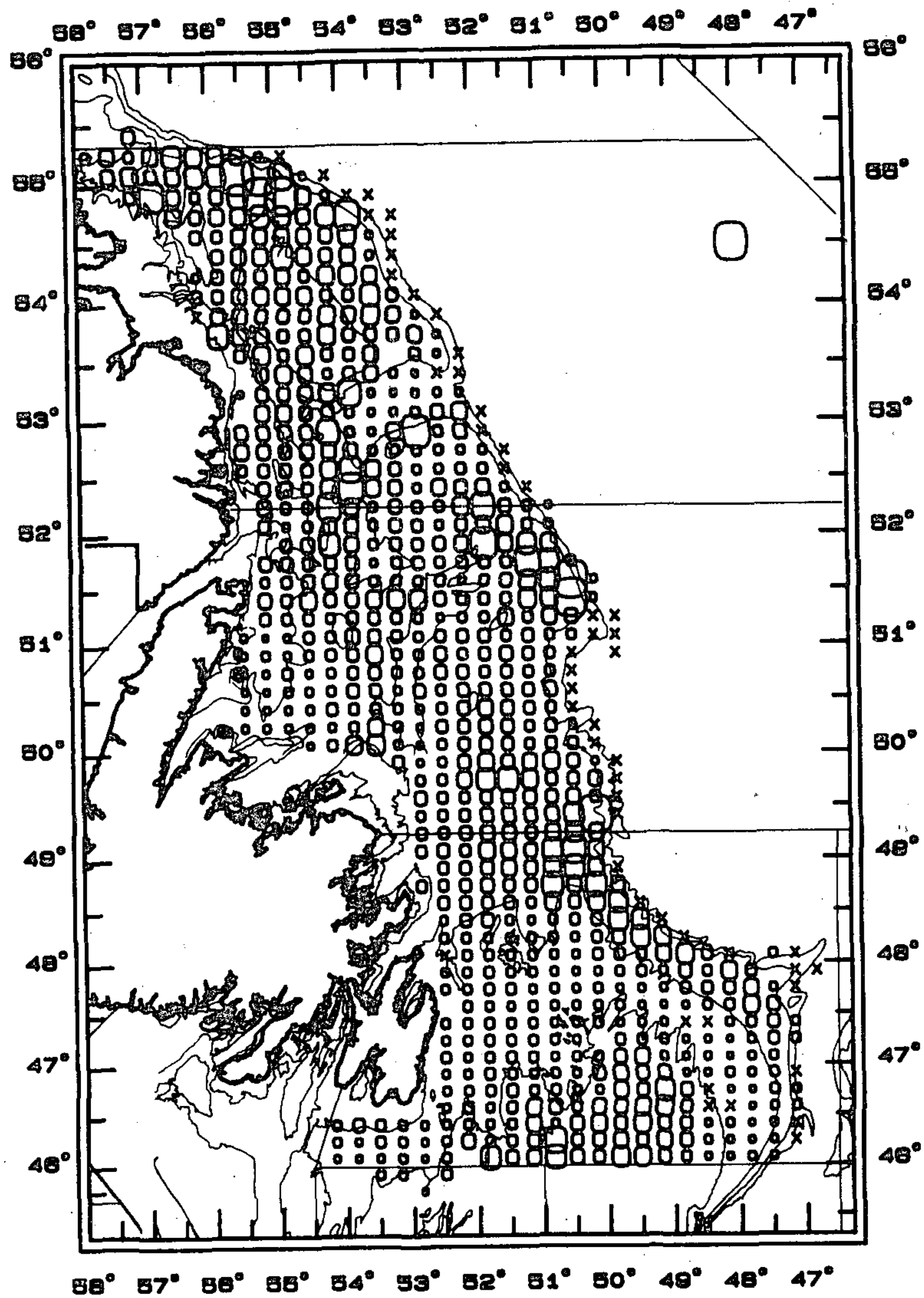

Fig. 1. Geographic variation in mean catch of cod in the autumns of 1980-1989 in areas of 10′ latitude and 20′ longitude. A symbol for 1000 kg/30 min tow is shown in top right. Symbol area is proportional to the mean catch. x shows where tows were made but no capelin were caught.

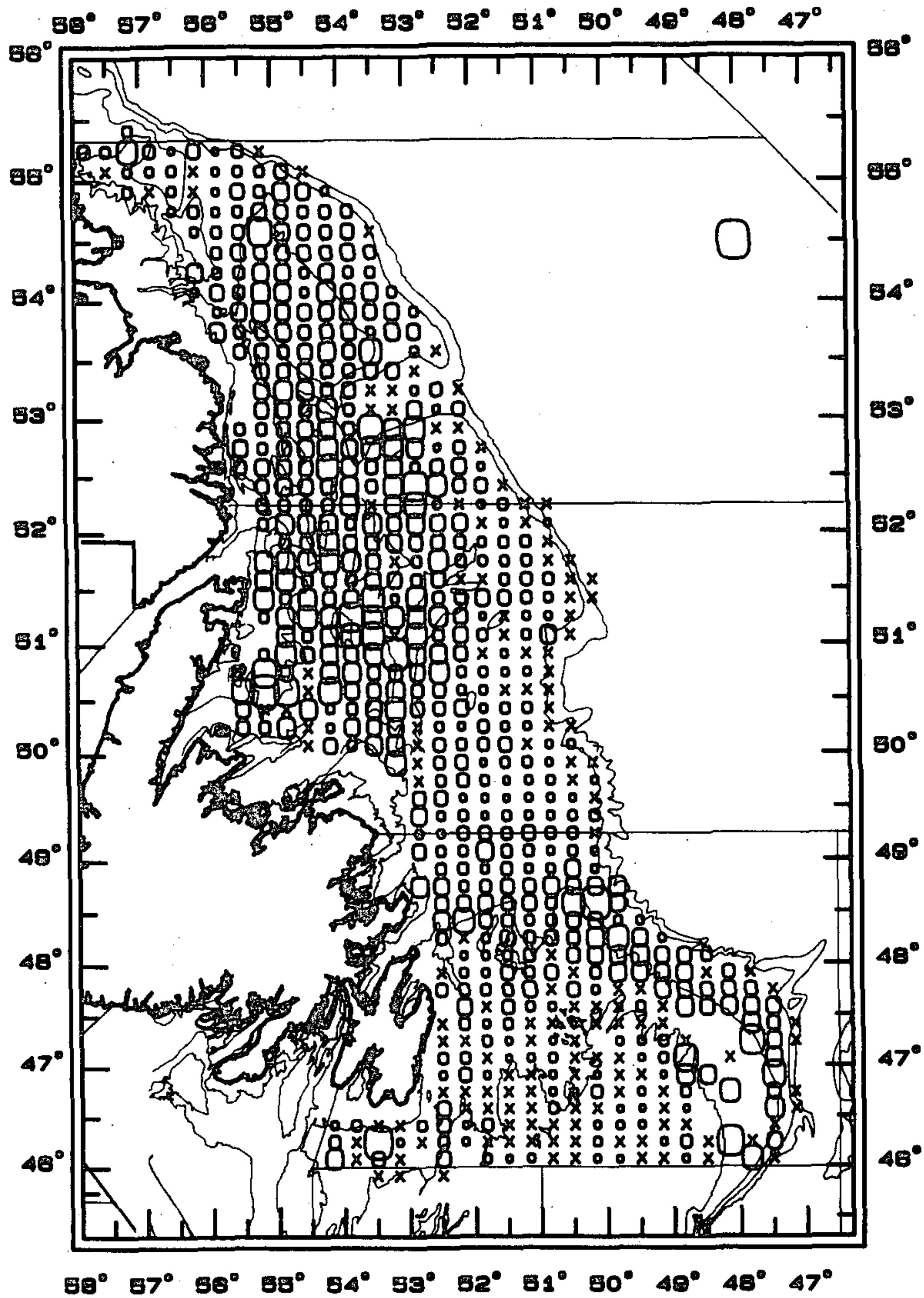

Fig. 2. Geographic variation in mean partial fullness index for capelin occurring in stomachs of cod in the autumns of 1980-1989. All stomachs collected from cod (36-71 cm only) caught in areas of 10′ latitude and 20′ longitude were combined. A symbol for PFI_c=10 is shown in top right. Symbol area is proportional to PFI_c. x shows where stomachs were collected but no capelin were found.

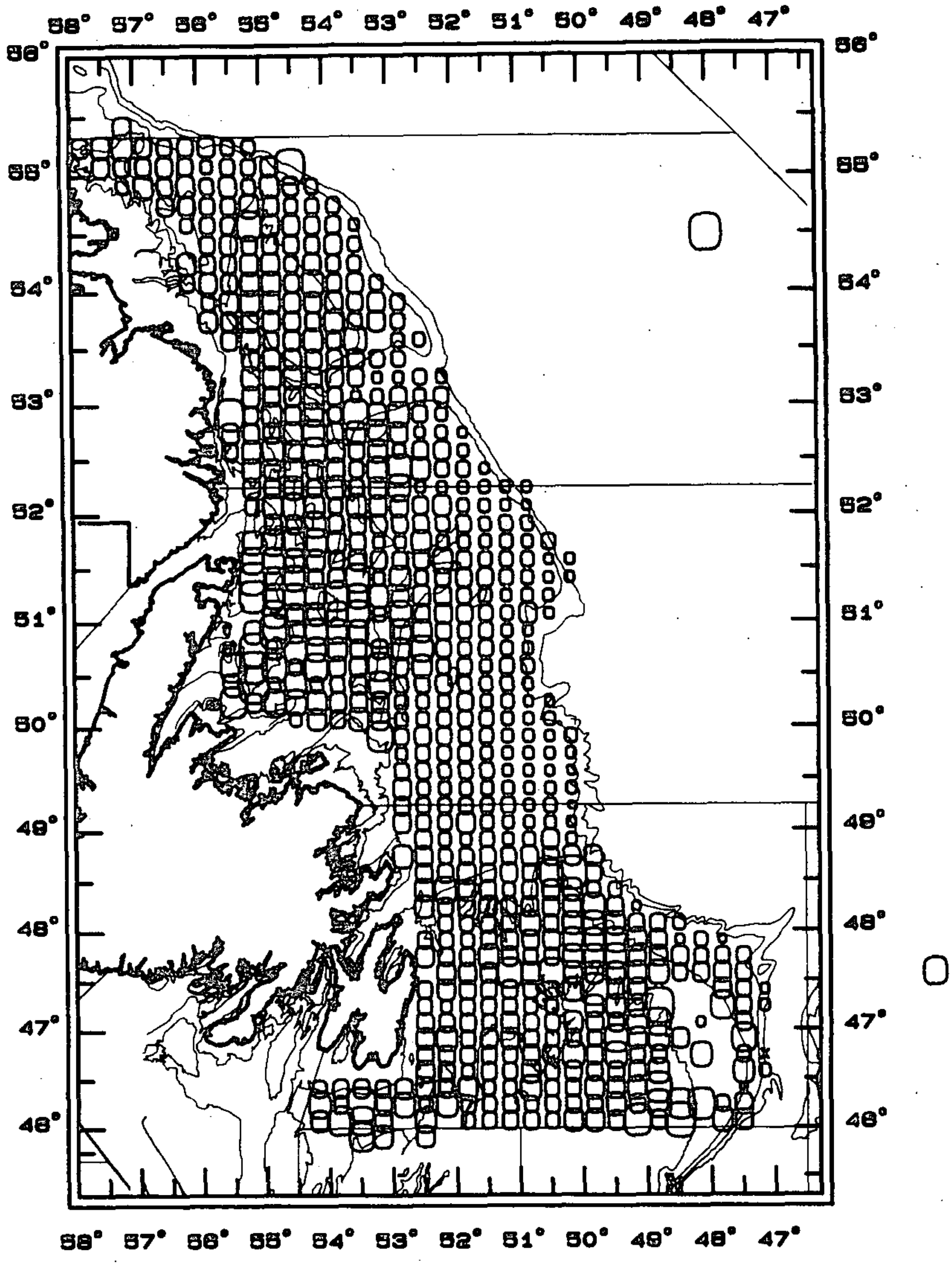

Fig. 3. Geographic variation in total fullness index (all prey combined) in the autumns of 1980-1989. All stomachs collected from cod (36-71 cm only) caught in areas of 10′ latitude and 20′ longitude were combined. A symbol for TFI=10 is shown in top right. Symbol area is proportional to TFI. x shows where stomachs were collected but no capelin were found.

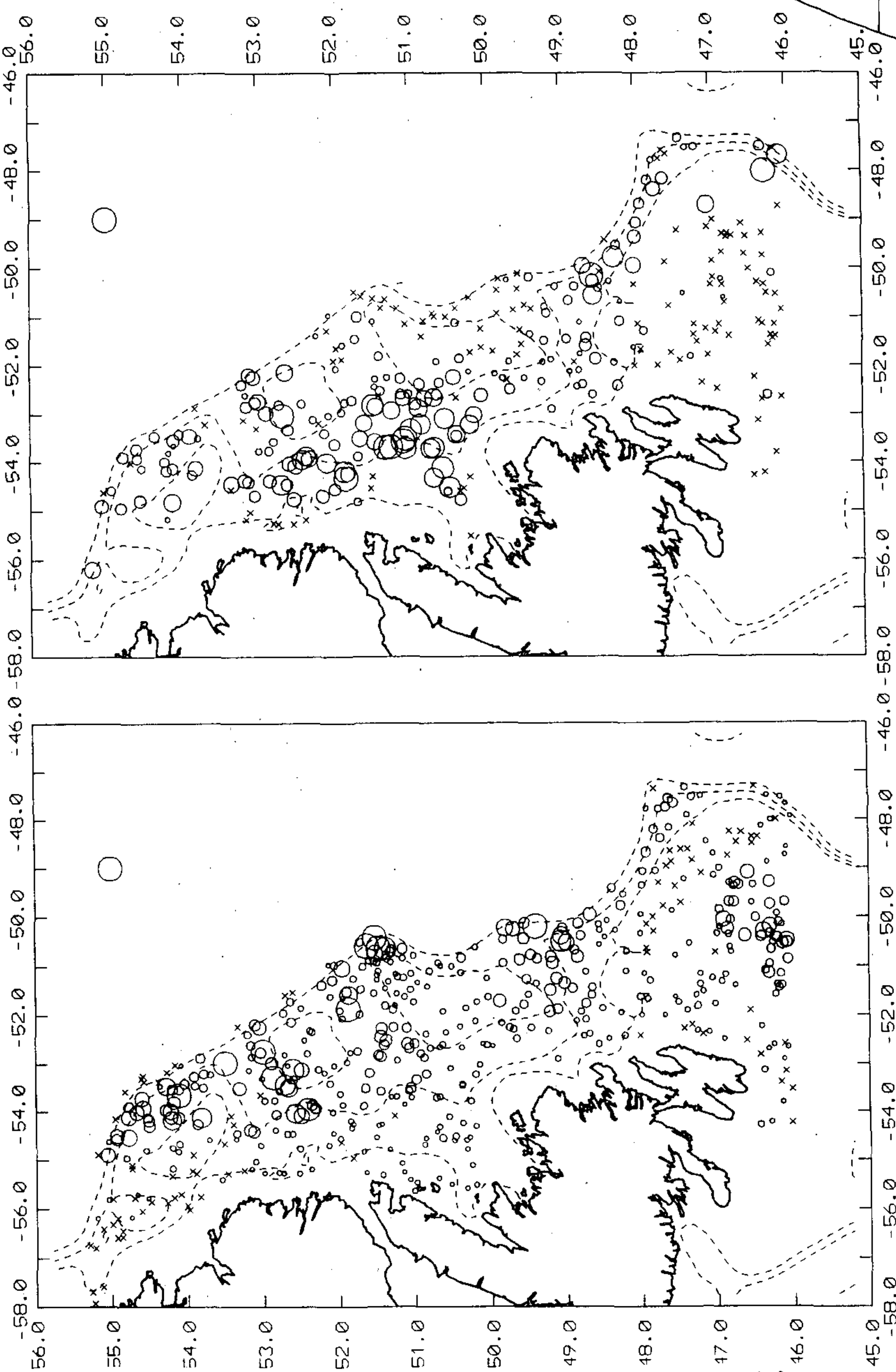

Fig. 4. Cod catches (left panel) and mean partial fullness indices (PFI_c) for capelin in cod stomachs (right panel) in 1989. Catches are from survey phases 1 and 2, but stomach data are from phase 1 only. Values were set to a maximum of 10 before plotting. A symbol for 1000 kg/30 min tow and PFI_c = 10 is shown at the top right of the respective panels. Symbol area is proportional to the value. x shows where there was no cod catch (left panel) or where stomachs were collected but no capelin were found (right panel).

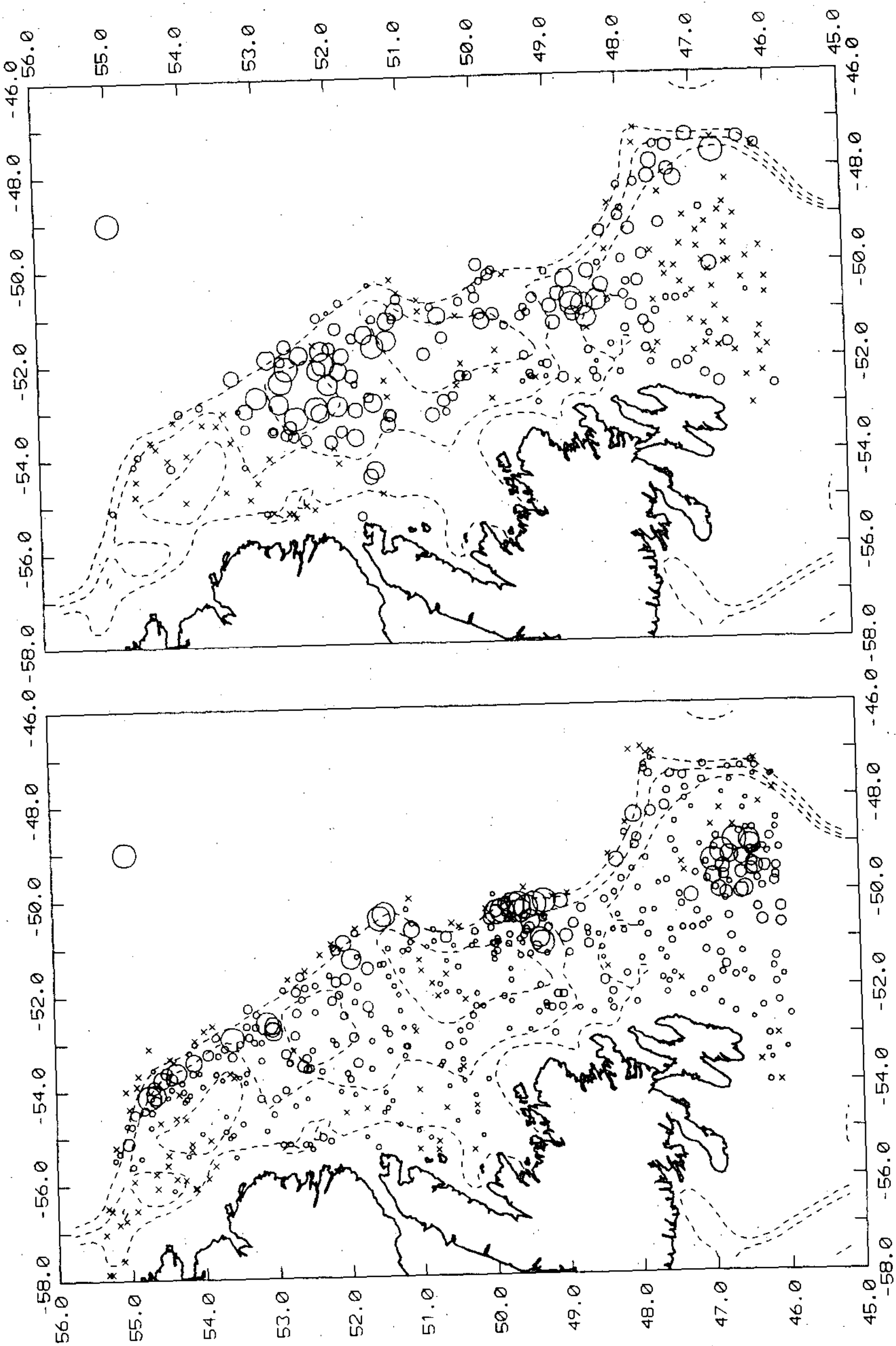

Fig. 5. Cod catches (left panel) and mean partial fullness indices (PFI_c) for capelin in cod stomachs (right panel) in 1990. Catches are from survey phases 1 and 2, but stomach data are from phase 1 only. Symbols as in Fig. 4.

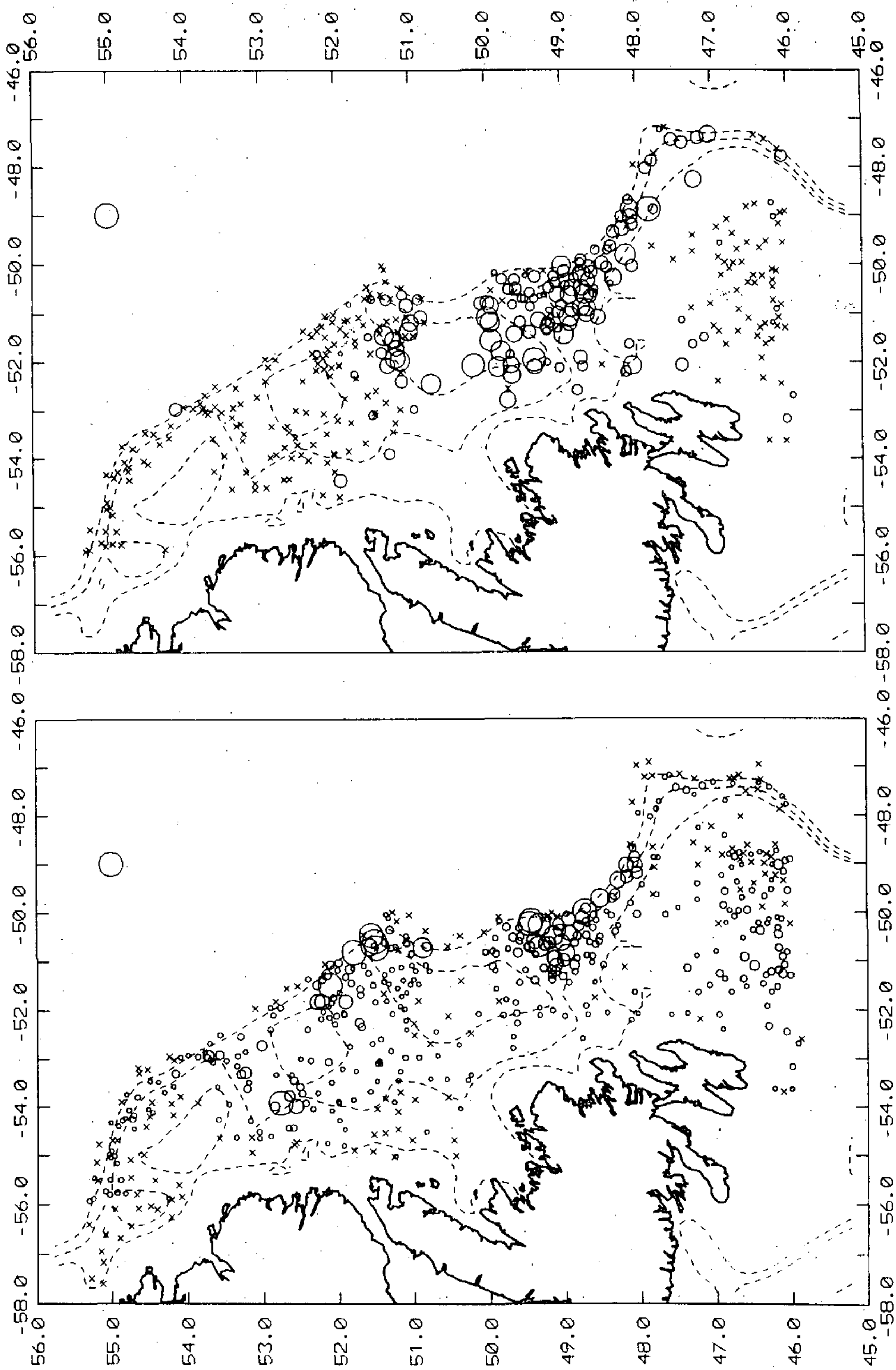

Fig. 6. Cod catches (left panel) and mean partial fullness indices (PFI_c) for capelin in cod stomachs (right panel) in 1991. Symbols as in Fig. 4.

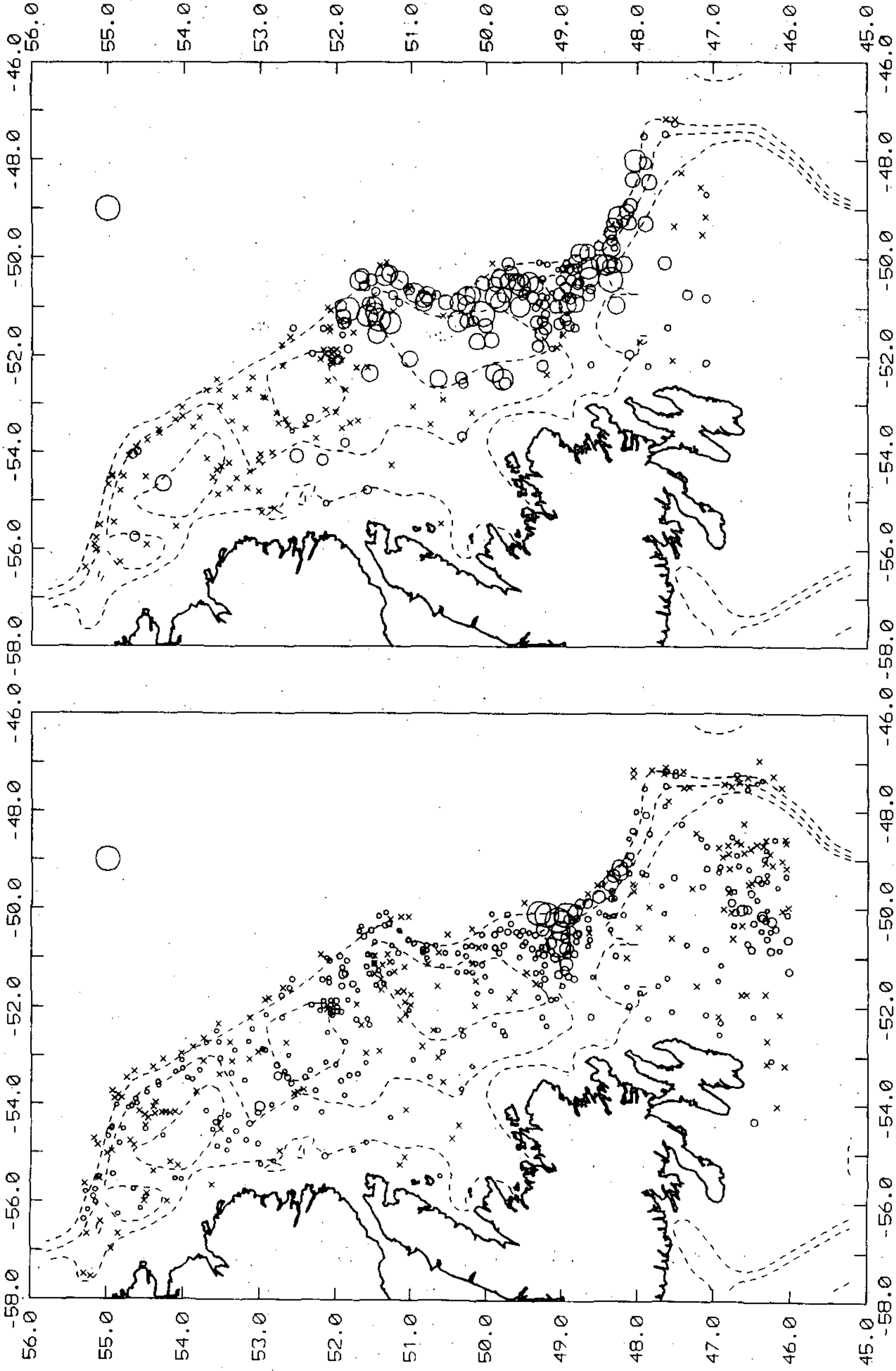

Fig. 7. Cod catches (left panel) and mean partial fullness indices (PFI_c) for capelin in cod stomachs (right panel) in 1991. Stomachs collected from cod caught at some stations in southern Division 3L have not been examined. Symbols as in Fig. 4.

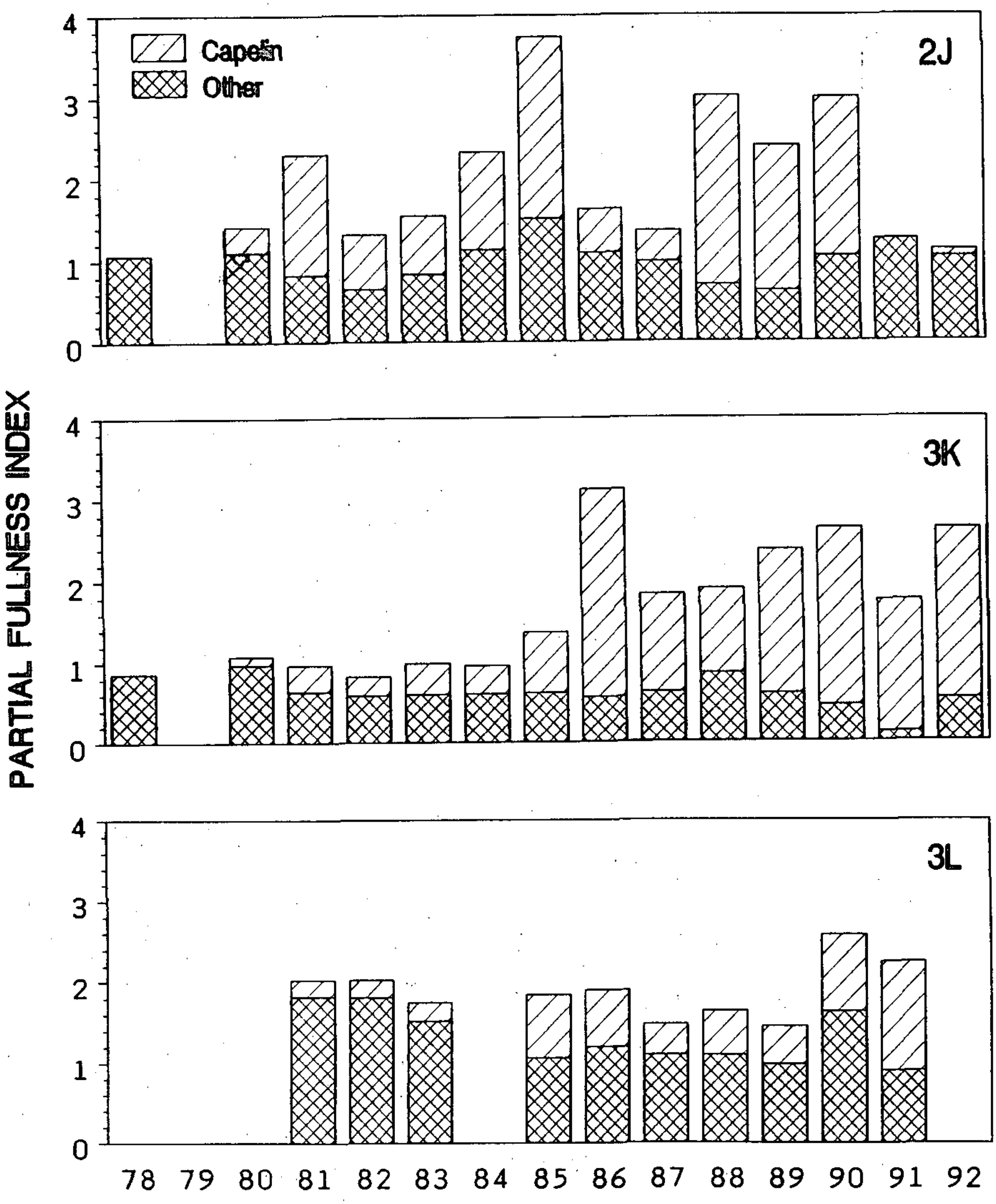

Fig. 8. Mean stomach fullness by Division and year. The total fullness index is divided into partial fullness indices for capelin and all other prey combined.