DFO Atlantic Fisheries
Research Document 95/ 74

MPO Pêches de l'Atlantique
Document de recherche 95/ 74

# Did the feeding level of the cod off southern Labrador and eastern Newfoundland decline in the 1990s?

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## Abstract

The distributions of cod and capelin, and the average quantity of food in the stomachs of the cod, were monitored in the offshore area of NAFO Divisions 2J3KL during the autumns of 1978-1994. In the 1990s, the distribution of cod gradually became limited to a diminishing number of specific areas on the outer shelf. No concentrations were encountered in 1994. During the same period, the capelin in Divisions 2J and 3K moved from a northwesterly distribution to a southeasterly distribution. The average quantity of food in the stomachs of cod in Division 2J declined from high levels in 1988-1991 to low levels in 1991-1994. This decline was caused by a very low abundance of capelin in Division 2J at the time of the surveys. A similar decline in cod stomach fullness occurred in Division 3K in 1994. No decline was observed in Division 3L. The declines in the abundance of cod in Divisions 2J and 3K preceded the declines in stomach fullness. Interpretation of annual variability in cod feeding success is confounded by variability in timing of the surveys and within-season variability in the timing of cod and capelin migrations.



## Résumé

On a étudié la distribution de la morue et du capelan ainsi que la quantité moyenne de nourriture dans l'estomac des morues des eaux du grand large des divisions 2J3KL de l'OPANO en automne, durant la période 1978-1994. Dans les années 1990, la distribution de la morue s'est limitée progressivement à un nombre décroissant de secteurs situés sur la partie externe de la plate-forme. Aucune concentration n'a été décelée en 1994. Au cours de la même période, le capelan des divisions 2J et 3K s'est redistribué, passant du nord-ouest au sud-est. La quantité moyenne de nourriture dans l'estomac des morues de 2J, qui était élevée durant la période 1988-1991, a chuté au cours de la période 1991-1994. Cette baisse est imputable à une très faible abondance du capelan dans la division 2J lors des relevés. Une diminution comparable du contenu de l'estomac des morues s'est produite en 1994 dans la division 3K. Aucune baisse de cette sorte n'a été observée dans la division 3L. La baisse de l'abondance de la morue dans les divisions 2J et 3K a précédé celle du contenu stomacal. L'interprétation de la variabilité annuelle de l'apport trophique est détanurée par la variabilité dans la période des relevés et la variabilité intersaisonnière dans la période de migration de la morue et du capelan.

# Introduction

Many hypotheses have been advanced to explain the decline in the stock of cod which occupies the southern Labrador Shelf, the Northeast Newfoundland Shelf and the northern Grand Bank (NAFO Divisions 2J+3KL) (Fig. 1). Among these hypotheses is the idea that many cod succumbed to stress occasioned by inadequate feeding, the latter being caused by a decline in prey resources or a reduction in prey availability (Atkinson and Bennett 1994). Greatest concern rests with capelin, the major prey of cod in this area (Lilly 1987, 1991). Capelin biomass estimates from acoustic surveys conducted in both spring and autumn by both Canada and Russia declined dramatically in the early 1990s and have remained very low (Bakanev 1992; Miller 1992, 1994). In contrast, indices of capelin abundance in the inshore area of eastern Newfoundland have not shown corresponding declines, leading to uncertainty regarding stock status (Carscadden 1994). The possibility of a decline in capelin abundance is of concern because such declines have been correlated with reductions in growth rate of cod in waters around Iceland (Steinarsson and Stefánsson 1991) and in the Barents Sea (Mehl and Sunnanå 1991; Jørgensen 1992), and with a reduction in somatic condition of cod in the Barents Sea (Jørgensen 1992).

Variations in the level of prey resources are not easy to determine in the Labrador/Newfoundland region, because the cod undergo extensive seasonal migrations and feed on a wide variety of prey (Lilly 1987). The kind and quantity of prey in cod stomachs varies greatly over time and space and also varies with predator size. Of all the prey being consumed by cod, the only one which is monitored directly with research surveys is capelin (Anon 1994a). Trends in the populations of some other prey may be determined from by-catches in bottom-trawl surveys (eg. Arctic cod; Lilly et al. 1994), catch rates in commercial fisheries (eg. northern shrimp; Anon 1994b), or total catches in commercial fisheries (eg. short-finned squid; Beck et al. 1994). However, there is virtually no information on trends in other taxa, such as macrozooplankton (hyperiid amphipods, euphausiids, mysids), shrimp other than northern shrimp, juvenile snow crabs, toad crabs, gammarid amphipods, polychaetes, and bank clams.

One test of whether the prey resources have been adequate to meet the cod's requirements is to determine if there has been a decline in the quantity of prey occurring in the stomachs of cod caught during the annual bottom-trawl resource assessment surveys. The geographic pattern of feeding by cod on capelin during the autumns of 1980-1988, and changes in 1989-1992, were described by Lilly (1994), and the average quantity of prey in cod stomachs, by Division (2J, 3K and 3L) and year, were reported by Lilly (1993) and Taggart et al. (1994). The following summary is extracted with minor changes from Lilly (1994).

> During the period 1980-1988, relatively large catches of cod occurred in several areas: (1) from the northern limit of the survey to the coastal shelf off northern Newfoundland, especially the northern tip of Hamilton Bank and near the isthmus leading

to Belle Isle Bank; (2) the outer trough between Belle Isle Bank and Funk Island Bank; (3) the outer trough between Funk Island Bank and Grand Bank, and from there southeastward along the northeastern slope of Grand Bank; and (4) the plateau of Grand Bank (Fig. 2). This pattern, with some variations, was apparent in both cold years (eg. 1984, 1985; Fig. 3,4) and warm years (eg. 1986) (Fig. 5). During the period 1980-1988, the average quantity of capelin found in cod stomachs, expressed as a fullness index ($PFI_c$), was moderate to high in two broad regions: (1) northern and western Divisions 2J3K (Hamilton Bank, western Belle Isle Bank, and the inner shelf off northeastern Newfoundland) and (2) northern Division 3L (northern and northeastern slopes of Grand Bank) (Fig. 2). In many years, such as 1984 and 1985 (Fig. 3,4), the capelin in Divisions 2J3K were primarily on Hamilton Bank and along the coastal shelf off southern Labrador and northeastern Newfoundland, whereas in some other years, notably 1986 and 1987 (Fig. 5,6), they were more aggregated on the central Northeast Newfoundland Shelf. In some years, such as 1988 (Fig. 7), they were more evenly distributed between the two Divisions. The average distributions (Fig. 2) reveal that the area of cod concentration from Hamilton Bank to the coastal shelf off northern Newfoundland, and the area along the northeast slope of Grand Bank, both broadly coincide with regions of moderate to high $PFI_c$ values. In contrast, 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 (especially within Division 3K), experienced low $PFI_c$ values. The cod on the plateau of Grand Bank also fed very little on capelin at this time of year, but they did prey intensively on other species, most notably sand lance (Ammodytes dubius) (unpubl. data).

Geographic plots for the years 1989-1992 (Fig. 8-11) illustrate the recent decline in cod catch and change in cod distribution. In 1989 few cod were caught toward the coast in Divisions 2J and 3K. By 1991 there were no large catches on Hamilton Bank and the plateau of Grand Bank, and by 1992 good catches were secured only in a small area near the shelf break just south of the Division 3K,3L boundary. The capelin in Divisions 2J3K experienced a pronounced shift from the northwest to the southeast during this period. The apparent distinction between a Division 2J3K group and a Division 3L group (Fig. 2) was less clear in 1990 and absent in 1991 and 1992.

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. 2.) The area of intensive feeding contracted in 1990 and contracted further in 1991 and 1992. It may be inferred from these observations and from the geographic pattern of capelin by-catches during the bottom-trawl surveys (Lilly and Davis 1993) that the capelin not only occupied a smaller area but also moved into that region in which the remaining cod were found, so that in each year most cod were not far from where they could successfully prey on capelin.

The average quantity of food in the cod stomachs, expressed as a fullness index, has been presented by Division and year (Lilly 1993; Taggart et al. 1994) to permit visual comparison with plots of the somatic condition and liver index of the cod (Bishop et al. 1994; Taggart et al. 1994). In Divisions 2J and 3K, the level of feeding on capelin (Fig. 12) reflects both an increase in capelin abundance from the late 1970s to the mid- and late 1980s (Carscadden 1994) and annual variability in the distribution of capelin at the time of the surveys (Lilly 1994). From 1980 to 1985, the partial fullness index for capelin ($PFI_c$) was higher in Division 2J than in Division 3K, but in 1986 and 1987 the

$PFI_c$ values were higher in Division 3K, reflecting the southerly distribution of capelin at the time of the surveys in those years. In 1988 the $PFI_c$ value was again higher in Division 2J. In 1989 and 1990, the $PFI_c$ values were approximately equal in the two Divisions. This is somewhat misleading for 1990 because in that year there was very little capelin in stomachs of cod caught on Hamilton Bank and large quantities in cod caught on Belle Isle Bank (Fig. 9). In 1991 and 1992, there was very little capelin in stomachs of cod in Division 2J but large quantities in cod in Division 3K. In Division 3L, the average level of stomach fullness declined somewhat in the 1980s but was relatively high in 1990-1992. The tentative conclusion that the overall feeding level of cod in the autumn did not decline in 1990-1992, except for the very few cod remaining in Division 2J, is supported by analyses of the condition (somatic and liver indices) of cod collected during the autumn surveys. Only in Division 2J in 1991 and 1992 did average condition of medium size cod (45-71 cm or ages 6-8) drop below levels recorded in the late 1970s and early 1980s (Taggart et al. 1994).

The first purpose of this paper is to supplement the presentations of cod catch and quantity of capelin in cod stomachs (Lilly 1994) with plots illustrating capelin catch and total quantity of food in cod stomachs, for each year since the mid-1980s. The second purpose is to provide similar information for 1993 and 1994.

## Materials and methods

Cod and capelin were caught during random depth-stratified bottom-trawl surveys conducted during October-December in Divisions 2J3K (1978-1994) and Division 3L (1981-1994, excluding 1984). All surveys in Divisions 2J and 3K were conducted with the 74 m stern trawler R.V. 'Gadus Atlantica'. Surveys in Division 3L were conducted with the 51 m side trawler R.V. 'A. T. Cameron' and the sister 50 m stern trawlers R.V. 'Wilfred Templeman' and R.V. 'Alfred Needler'. There were no autumn surveys in Division 3L in 1978-1980 and 1984. 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 meshliner was inserted in the codend. Tows were made at 3.5 knots for 30 min at each fishing station, and catches from the few tows of duration other than 30 min were appropriately adjusted. No adjustments were made for possible between-vessel differences in catching efficiency. Details regarding areas and locations of strata and changes in survey pattern are provided by Bishop et al. (1994), Lilly and Davis (1993) and Bishop (1994). The most notable change in survey coverage was the addition of depths between 100 and 200 m in northwestern Division 3K (St. Anthony Shelf and Grey Islands Shelf) in 1984 and subsequent years. Fishing in all Divisions and years was conducted on a 24-h basis.

Stomachs were collected from up to 3 randomly selected cod per 10-cm length-group per station in 1980-1982 and 3 per 9-cm length group in 1983-1994. 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. In 1978-1993, the stomachs were fixed and preserved in 4% formaldehyde solution in seawater prior to examination of their contents in the laboratory. In 1994, the stomachs were frozen prior to examination.

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.

The quantity of capelin in the stomachs of the cod from a specified sample was expressed as a mean partial fullness index (Fahrig et al., 1993):

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

where $W_{cj}$ is the weight (g) of capelin in fish j, $L_j$ is the length (cm) of fish j, and n is the number of fish in the sample. This index is based on the assumption that stomach capacity is a power function of length, and is analogous to Fulton's condition factor (body weight/length$^3$). Mean total fullness index was calculated as

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

where $W_{tj}$ is the total weight of prey in fish j.

For simplicity, the present analysis was restricted to cod within the 36-71 cm length range, and all cod within this range were pooled. 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, capelin catches, average relative quantity of food in cod stomachs (TFI) and average relative quantity of capelin in the stomachs ($PFI_c$) are presented in expanding symbol plots in order to provide visual information on annual changes in the spatial distribution of fishing stations, the among-station variability in catch and stomach fullness, and the relationship between fish distribution and bathymetry. This presentation also permits station-by-station comparisons among the four variables.

# Results

## Observations in 1993

In 1993, the geographic patterns in cod catch, capelin catch and feeding by cod on capelin (Fig. 13) were similar to the patterns seen in 1992 (Fig. 11). Moderate to large catches of cod were obtained only near the shelf edge in Division 3L just south of the 3K/3L boundary. Largest catches of capelin occurred on the slopes of St. Anthony Basin and Funk Island Deep in Division 3K and from there southeastward along the northeastern slope of Grand Bank. The geographic pattern of feeding by cod on capelin was similar to the pattern in capelin catches.

Mean stomach fullness indices in 1993 were almost identical to those recorded in 1992 (Fig. 12). The low value (TFI=1.10) in Division 2J may be attributed to a low abundance of capelin in this area. The major prey for the medium-sized cod (36-71 cm) were northern shrimp (PFI=0.47) and Arctic cod (PFI=0.14). The relatively high total fullness index (TFI=2.73) in Division 3K was dominated by capelin (PFI=2.16). Minor prey included northern shrimp (PFI=0.22) and striped pink shrimp (PFI=0.12). The relatively high total fullness index (TFI=2.60) in Division 3L was dominated by capelin (PFI=1.73). Minor prey included sand lance (TFI=0.27), hyperiid amphipods (PFI=0.11) and northern shrimp (PFI=0.11). The high TFI values on the plateau of Grand Bank (south-central Division 3L) (Fig. 13) represent feeding on sand lance. Very few cod were caught in this area.

## Observations in 1994

In 1994, cod occurred only in small numbers in a small proportion of the stations (Fig. 14). Capelin were caught in small quantities in Division 2J and western Division 3K, but in much larger quantities in central and southern Division 3K. Largest catches were on the eastern flank of Funk Island Deep, on western Funk Island Bank, and south of Funk Island Bank. Small to moderate catches of capelin were taken in northern and northeastern Division 3L and in the Avalon Channel. In general, capelin distribution in 1994 was similar to that observed in 1991-1993. The geographic pattern of feeding by cod on capelin was similar to the pattern in capelin catches, except that the highest quantities of capelin in cod stomachs occurred in Division 3L rather than in Division 3K. The reason for the relatively low quantity of capelin in stomachs of cod caught in southeastern Division 3K is not known.

Mean stomach fullness indices in 1994 were generally lower than those recorded in recent years (Fig. 12). In Division 2J, no capelin were found in the stomachs, and the total fullness index was the lowest in the time-series (TFI=0.60). The major prey was northern shrimp (PFI=0.38) In Division 3K, only a small quantity of capelin was found in the stomachs, and the total fullness index was the lowest in the time-series (TFI=0.72). Capelin (PFI=0.26) and northern shrimp (PFI=0.29) contributed equally to

the stomach contents. Only in Division 3L were the partial fullness index for capelin (PFI=1.58) and the total fullness index (TFI=2.42) similar to values in recent years. The second most important prey was Arctic cod (PFI=0.24).

## Discussion

The pattern of annual change in the stomach contents of cod varied among Divisions. In Division 2J, the stomach fullness in 1993 continued at the low level observed since 1991. In 1994, it declined further to the lowest level in the time-series. In Division 3K, the fullness index declined precipitously in 1994 from relatively high levels through the late 1980s and early 1990s. The decline was caused by a great reduction in feeding on capelin. In Division 3L, there was no change from the relatively high level seen through the 1990s.

The conclusion that the overall level of feeding did not decline in 1991-1992, except for the very few cod remaining in Division 2J (Lilly 1994), must be considered preliminary and tentative. In the early 1990s many of the cod were taken in a few large catches, and individual cod taken in these large catches tended to have little food in their stomachs (Lilly 1994). The stomach content data will be re-analyzed using the method of Warren et al. (1994) to take into consideration the size of the catch. A more refined estimation of the rate of energy intake must also employ a model of feeding rate, measures of caloric density for major prey taxa, and an estimate of the efficiency (in caloric terms) with which the cod digest and absorb each major prey taxon.

It has also been stated (Lilly 1994) that the absence of a decline in feeding, except in Division 2J, is supported by analyses of the condition (somatic and liver indices) of cod collected during the autumn surveys. Only in Division 2J in 1991 and 1992 did average condition of medium size cod drop below levels recorded in the late 1970s and early 1980s. This assertion is based solely on visual inspection of independent plots of each data series. A statistical analysis to determine if a significant amount of the variability in cod growth and condition can be predicted from stomach content data has yet to be conducted.

There are uncertainties associated with the use of stomach content data obtained from cod caught during the annual bottom-trawl surveys. The initial hope was that the intensity of feeding by cod on capelin and other prey at the time of the surveys would reflect the overall annual availability of prey to the cod. However, during the late autumn, when the surveys have been conducted, many of the cod are thought to be migrating across the shelf from summer feeding grounds in shallow coastal waters to overwintering areas on the outer shelf and upper slope, and capelin migrate southward from the Hamilton Bank area into central Division 3K. There may be annual variability in the timing of both events. In addition, the surveys have varied in time (Carscadden et al. 1989). A consequence of variability in the timing of migrations and surveys is that an

attempt to discern annual variability may be confounded by within-season variability. There is evidence that this has happened. For example, in some years the cod on Hamilton Bank had much capelin in their stomachs at the time of the survey. In other years, there was very little. For some of those years when very little capelin was found in cod on Hamilton Bank, there is evidence from acoustic surveys and the distribution of the capelin fishing fleet that there had been a large quantity of capelin on Hamilton Bank before the bottom-trawl survey entered the area. It is thus likely that cod which had been on Hamilton Bank earlier in the autumn may have been feeding intensively on capelin. In such instances, the quantity of food in the stomachs at the time of the survey would not be a good measure of the average autumn feeding level.

The problem of within-season variability discussed above is one example of the large problem of estimating the degree and duration of geographical overlap between cod and its prey, especially capelin. There is also the difficulty caused by the fact that, in Divisions 2J and 3K, observations are available on an annual basis only from autumn surveys. The problem is reduced somewhat in Division 3L by the availability of stomach content data from both spring and autumn. In all three Divisions there is the additional difficulty of determining the proportion of the stock coming inshore each year, the duration of their inshore residence, their success in finding capelin, and the temperatures which they experience.

In summary, there is no evidence in the preliminary analysis conducted to date to indicate that average stomach fullness of cod declined before or in parallel with the decline in cod biomass recorded by the autumn bottom-trawl surveys. There was a dramatic decline in stomach fullness in Division 2J from a high level in 1988-1990 to a low level in 1991-1994. This decline in stomach fullness is attributed to the very low abundance of capelin in Division 2J at the time of the surveys. The biomass of cod in Division 2J declined to a very low level by 1990 (Bishop et al. 1994). Thus, the decline of cod in Division 2J preceded the decline in stomach fullness. In Division 3K and Division 3L there were substantial declines in cod biomass in the early 1990s but no decline in average stomach fullness until the reduction in Division 3K in 1994. One must be cautious in interpreting these results for the various reasons discussed above and because the sample sizes have become increasingly small in the 1990s.

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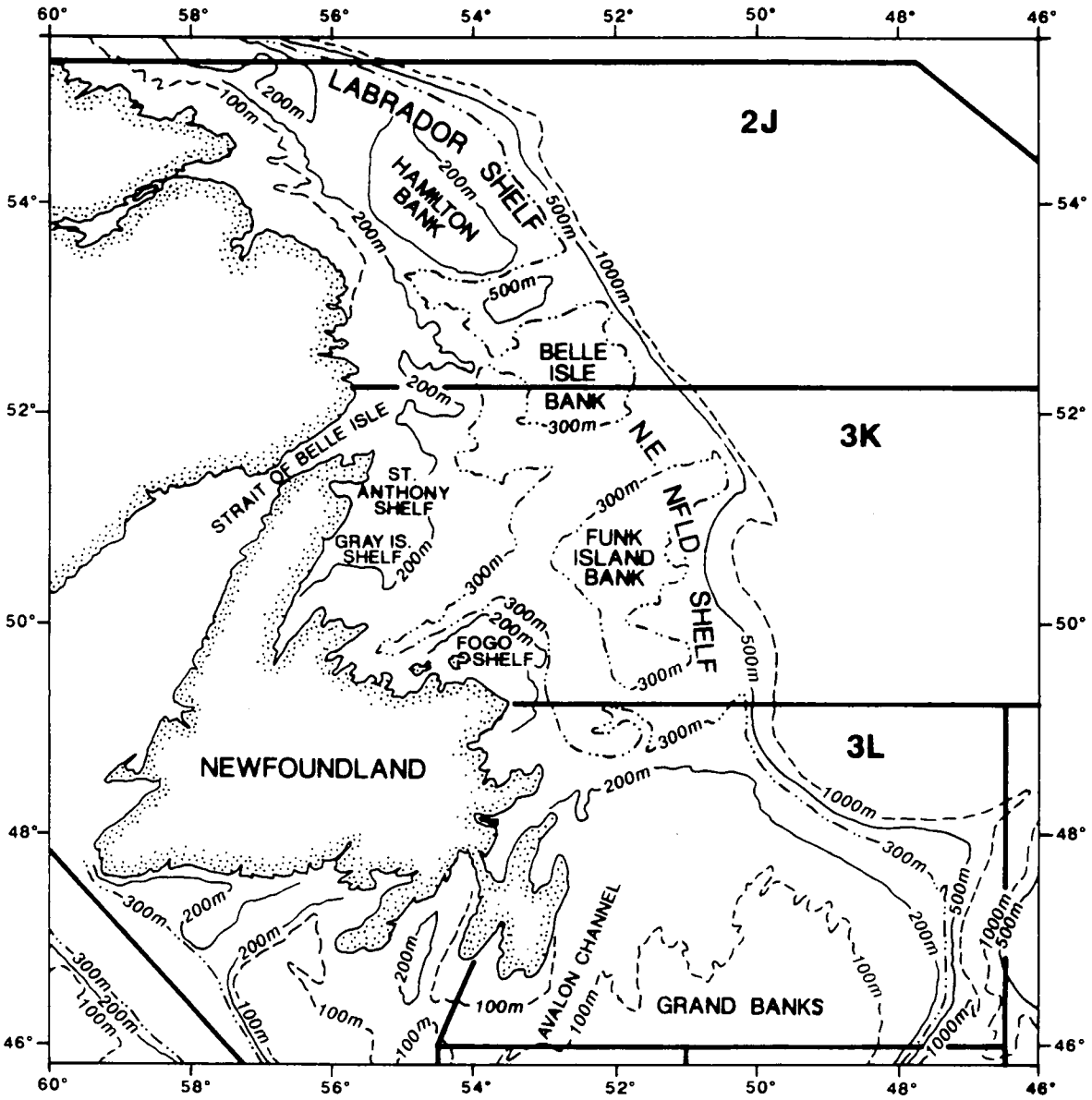


Fig. 1. Map of the study area, showing major physiographic features and NAFO Divisions.

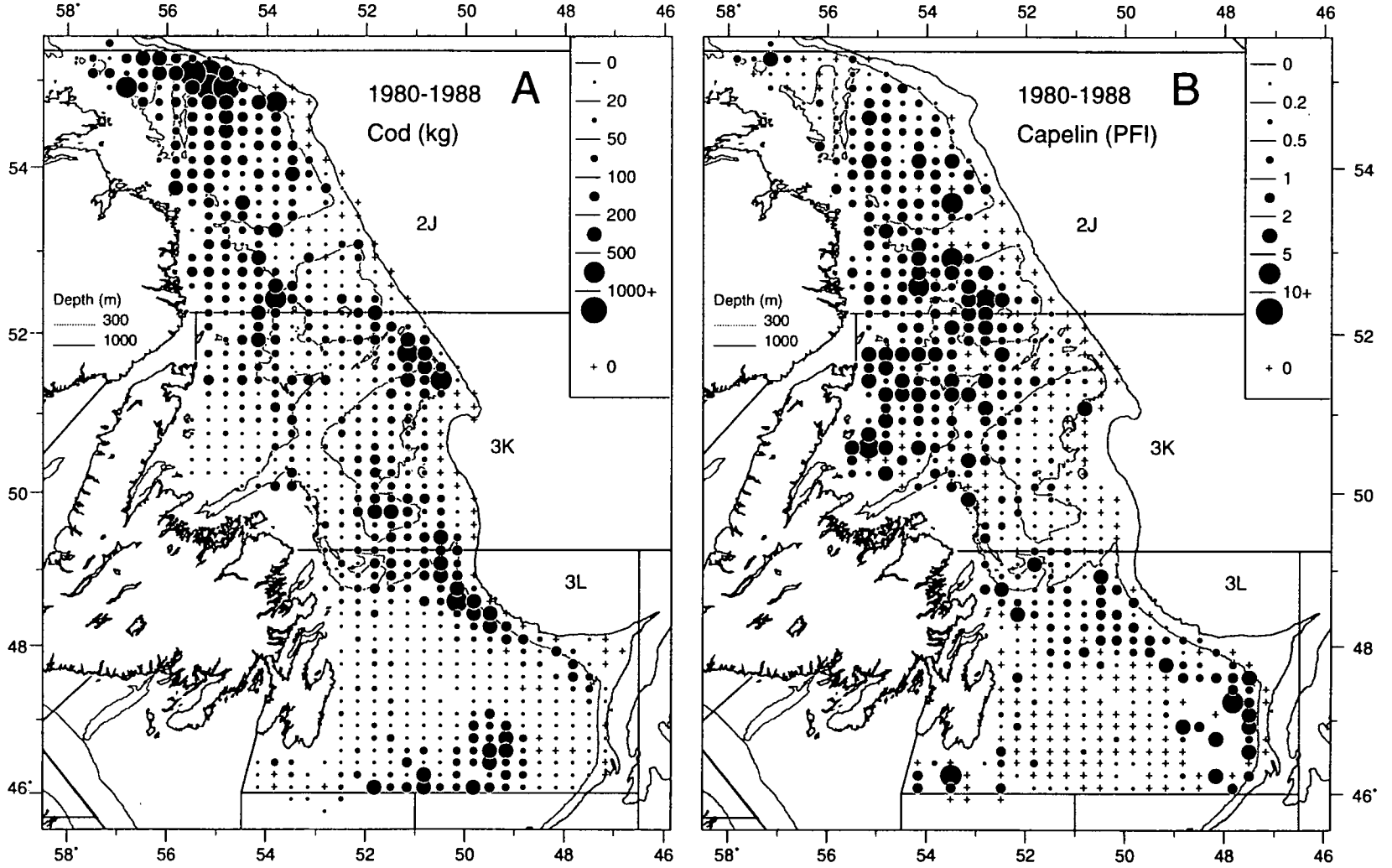


Fig. 2. (A) Mean catch of cod (kg/30 min tow) and (B) mean partial fullness index for capelin in cod stomachs, in 1980-1988. The data from all tows in areas of 10′ latitude and 20′ longitude were combined. From Lilly (1994).

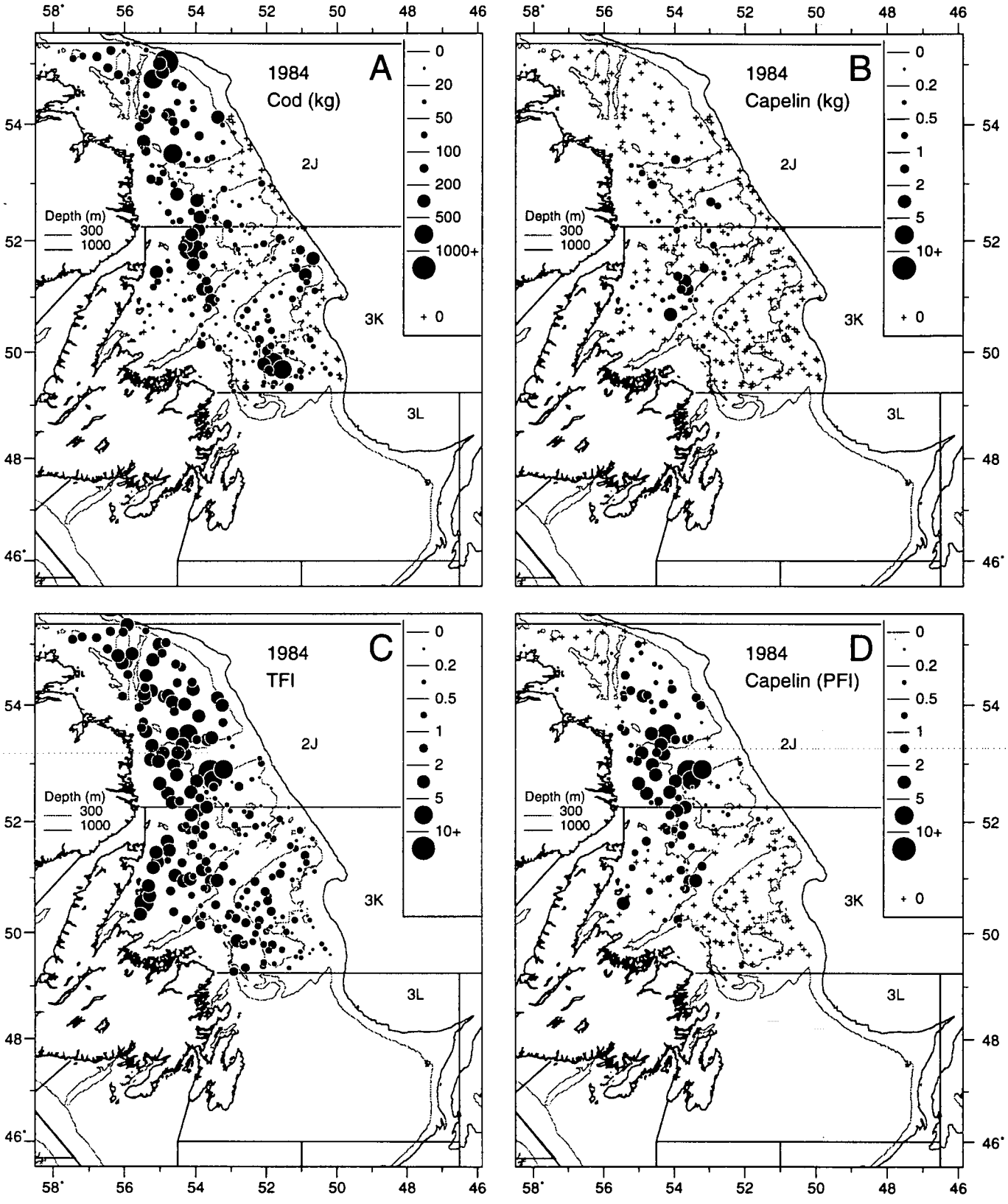


Fig. 3. (A) Cod catch (kg/30 min tow), (B) capelin catch (kg/30 min tow), (C) average total stomach fullness index (TFI), and (D) average partial stomach fullness index for capelin ($PFI_c$), for each fishing station in 1984. There was no survey in Division 3L.

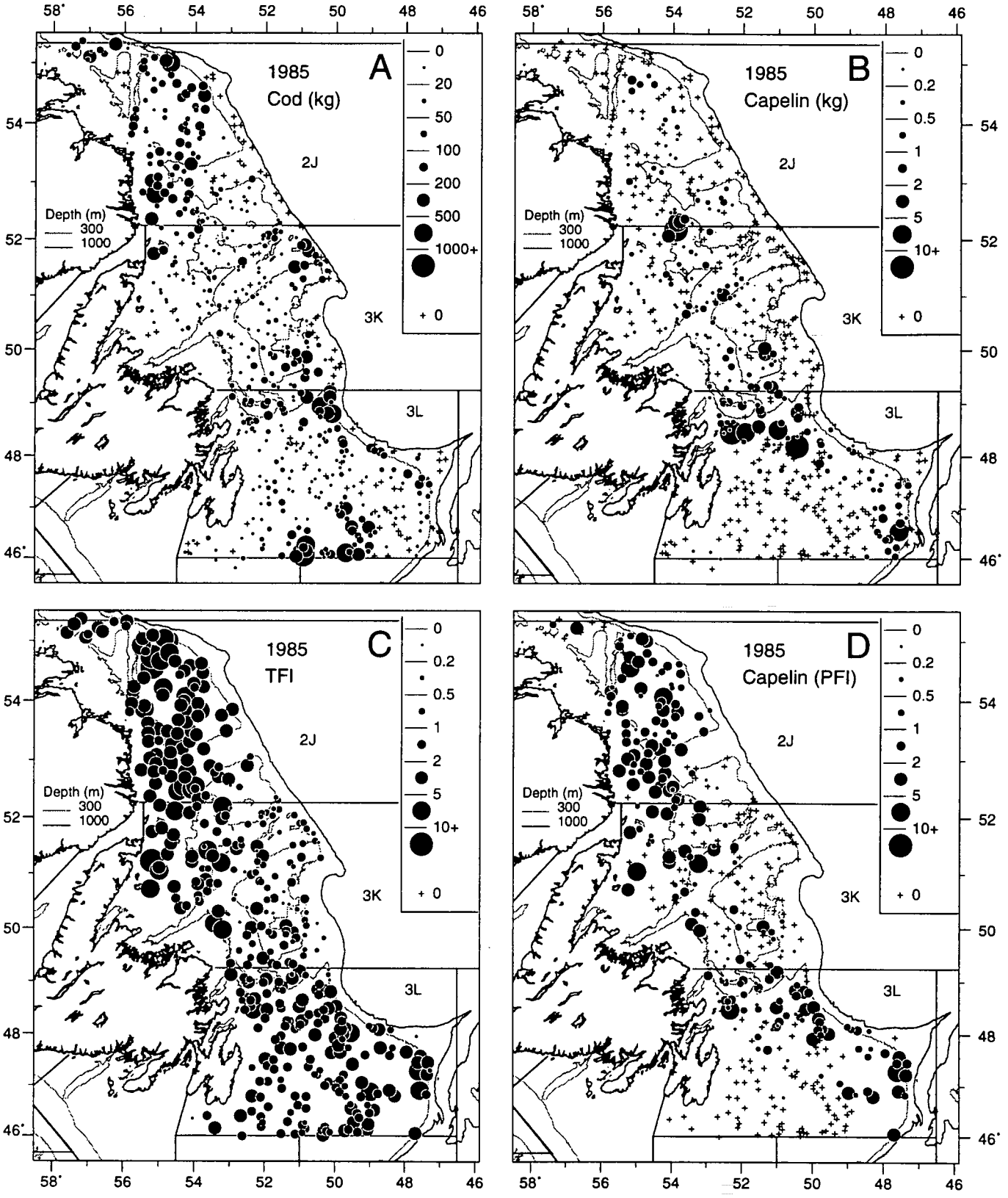


Fig. 4. (A) Cod catch (kg/30 min tow), (B) capelin catch (kg/30 min tow), (C) average total stomach fullness index (TFI), and (D) average partial stomach fullness index for capelin ($PFI_c$), for each fishing station in 1985.

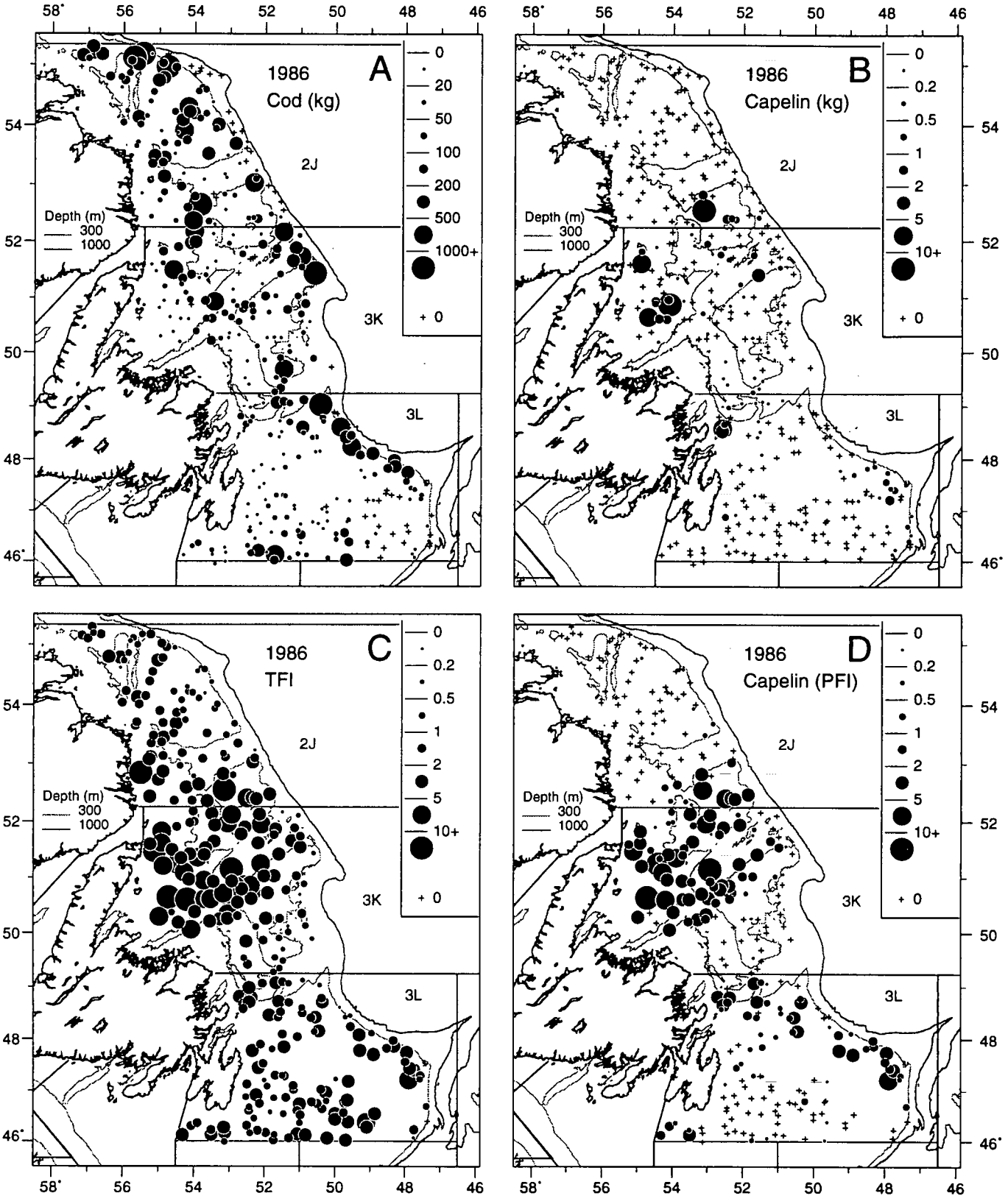


Fig. 5. (A) Cod catch (kg/30 min tow), (B) capelin catch (kg/30 min tow), (C) average total stomach fullness index (TFI), and (D) average partial stomach fullness index for capelin ($PFI_c$), for each fishing station in 1986.

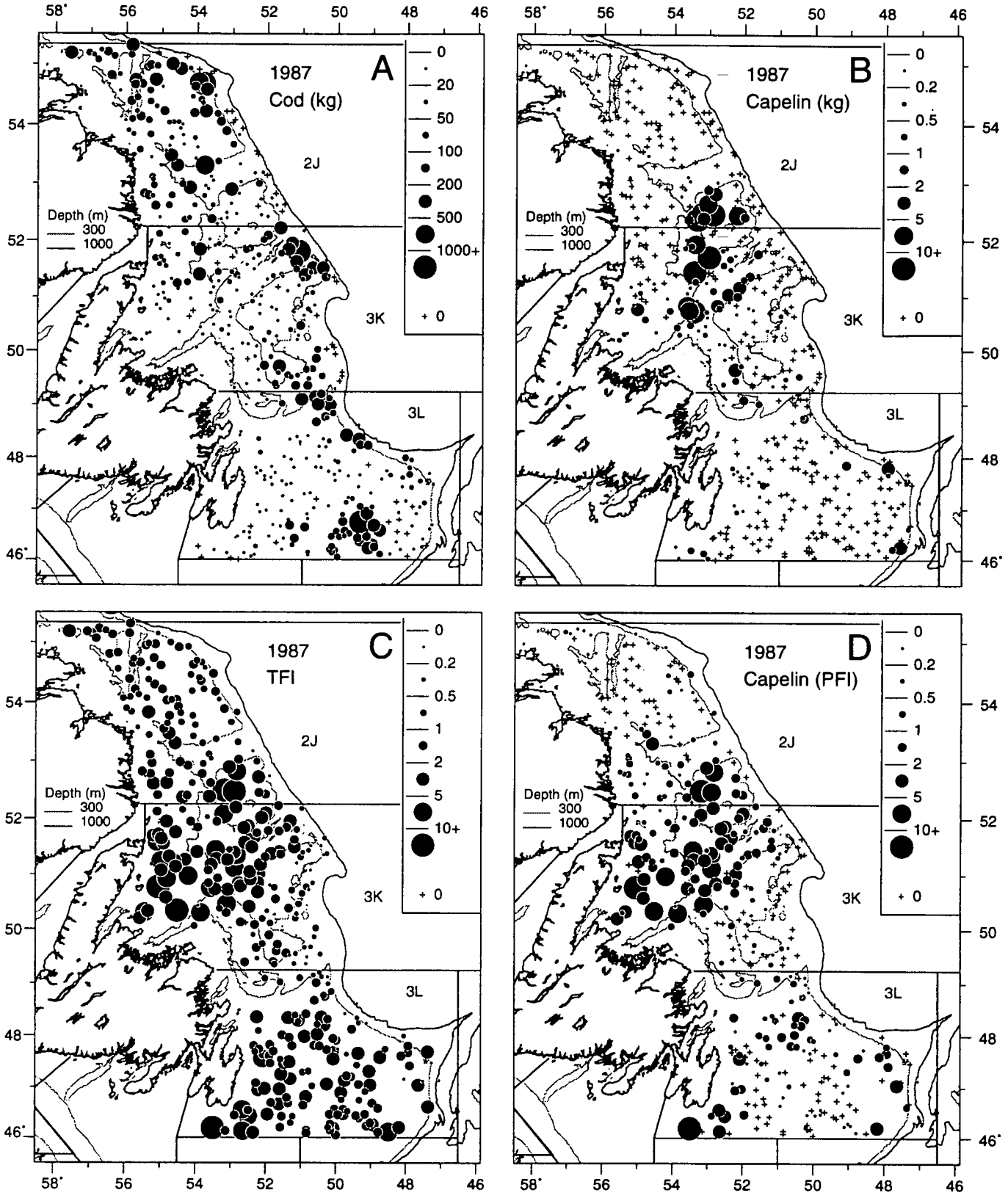


Fig. 6. (A) Cod catch (kg/30 min tow), (B) capelin catch (kg/30 min tow), (C) average total stomach fullness index (TFI), and (D) average partial stomach fullness index for capelin ($PFI_c$), for each fishing station in 1987.

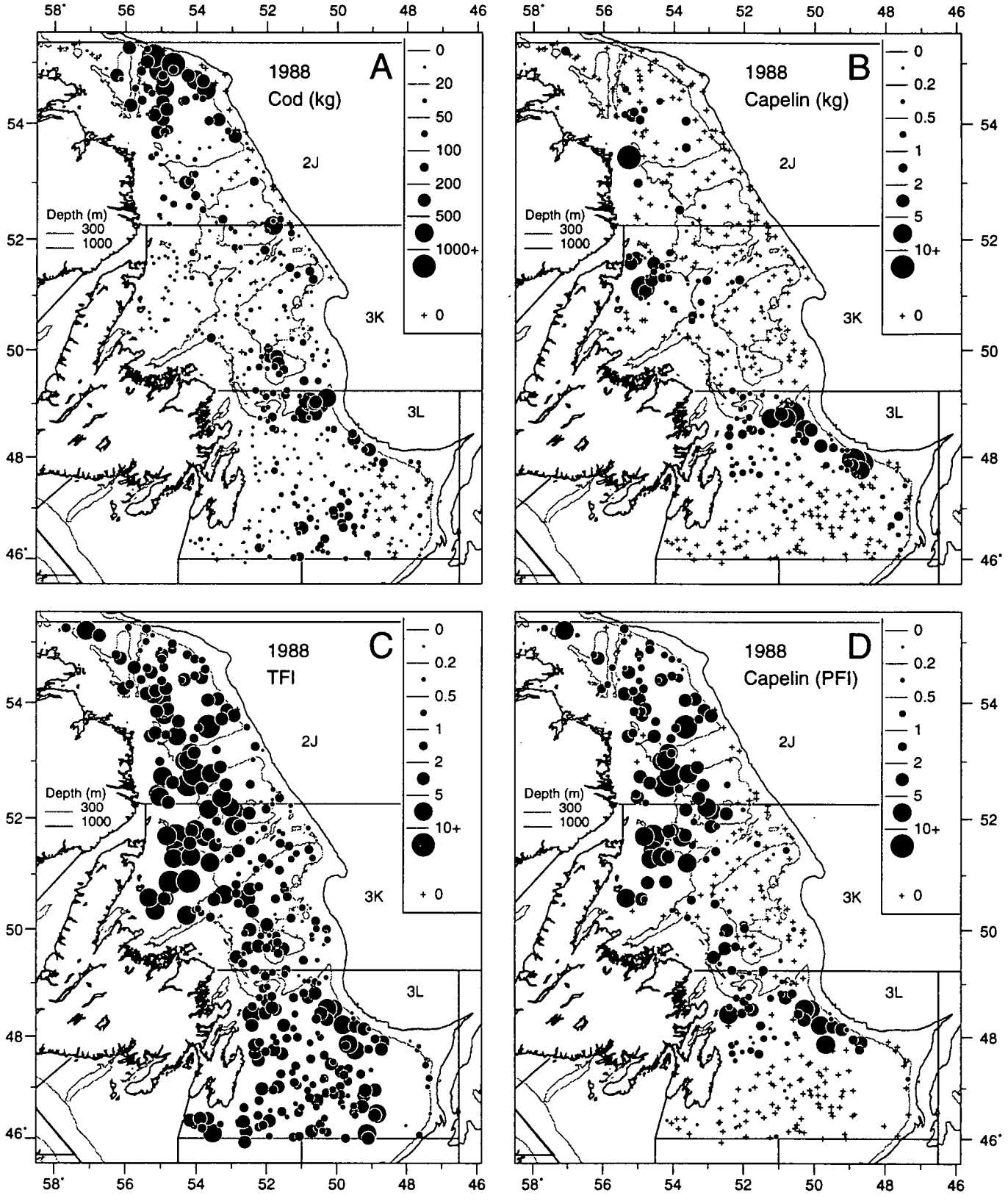


Fig. 7. (A) Cod catch (kg/30 min tow), (B) capelin catch (kg/30 min tow), (C) average total stomach fullness index (TFI), and (D) average partial stomach fullness index for capelin ($PFI_c$), for each fishing station in 1988.

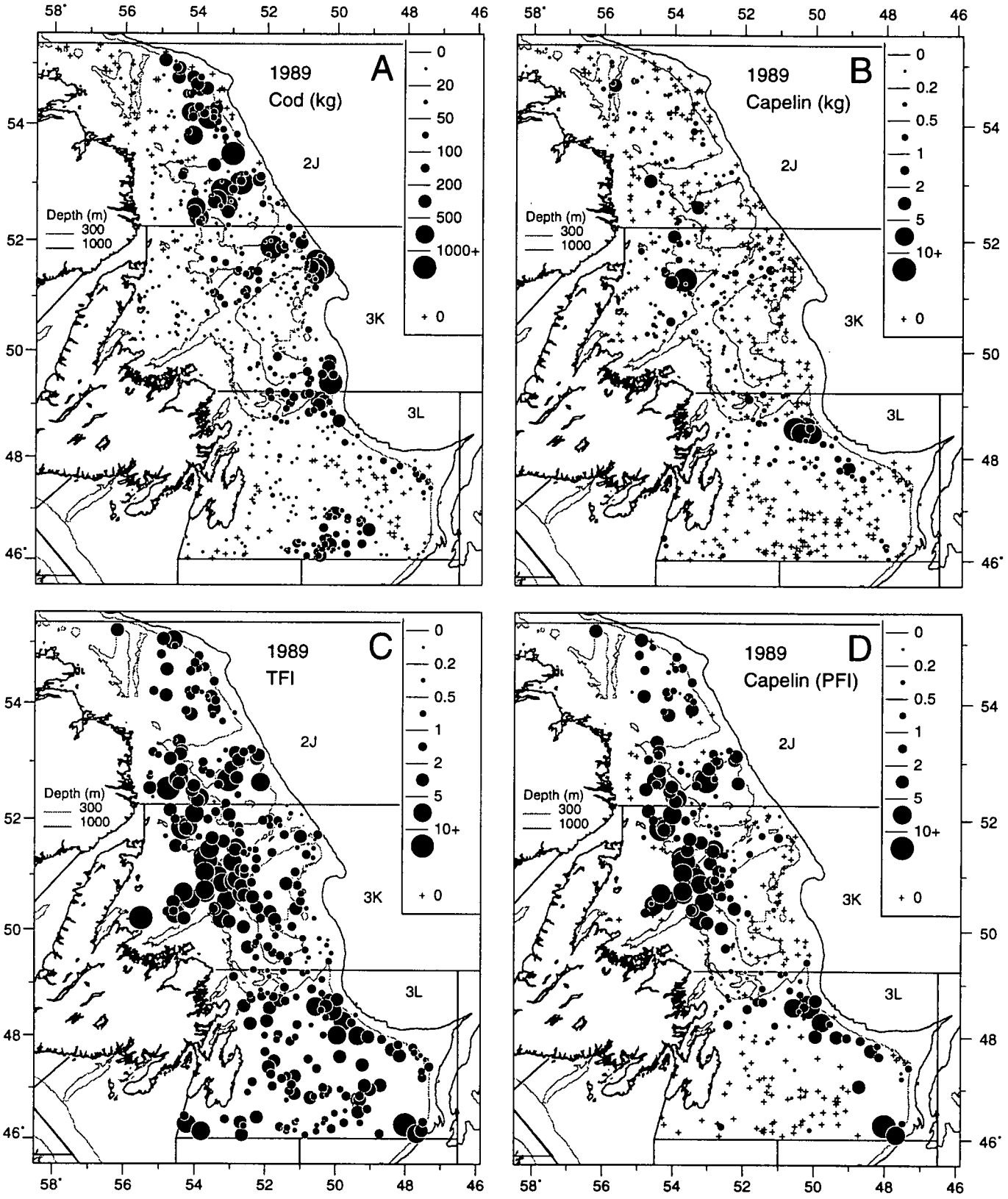


Fig. 8. (A) Cod catch (kg/30 min tow), (B) capelin catch (kg/30 min tow), (C) average total stomach fullness index (TFI), and (D) average partial stomach fullness index for capelin ($PFI_c$), for each fishing station in 1989.

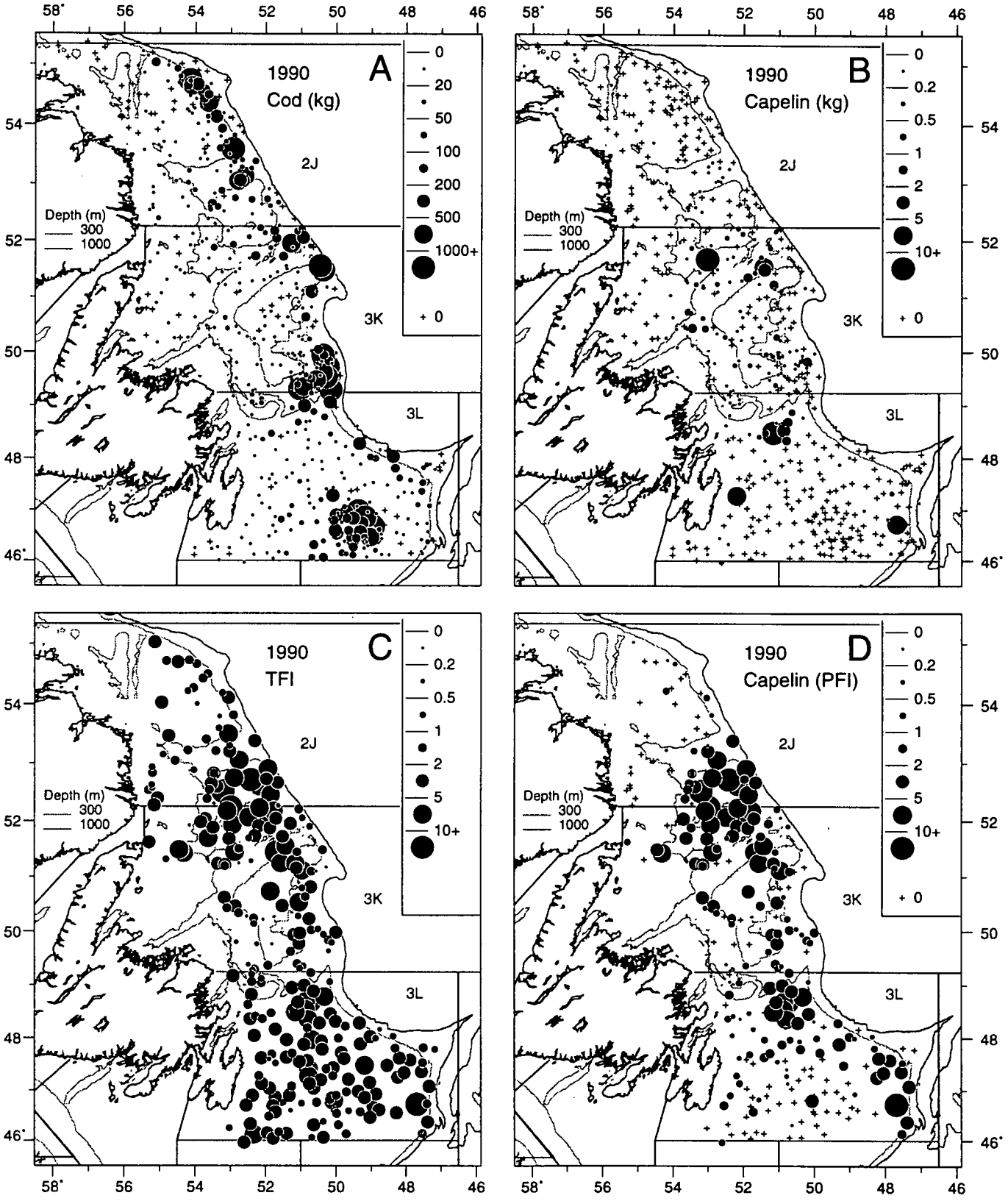


Fig. 9. (A) Cod catch (kg/30 min tow), (B) capelin catch (kg/30 min tow), (C) average total stomach fullness index (TFI), and (D) average partial stomach fullness index for capelin ($PFI_c$), for each fishing station in 1990.

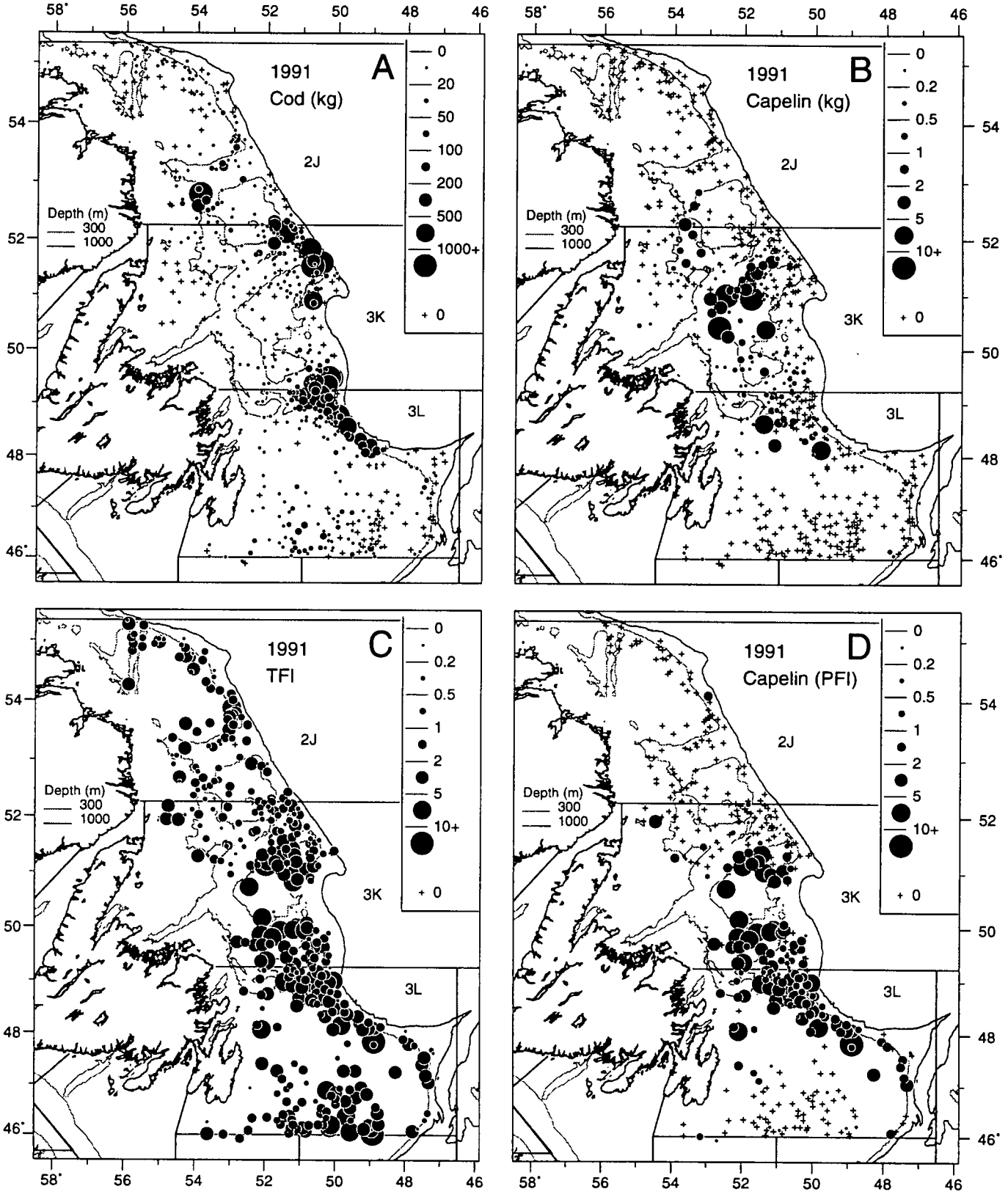


Fig. 10. (A) Cod catch (kg/30 min tow), (B) capelin catch (kg/30 min tow), (C) average total stomach fullness index (TFI), and (D) average partial stomach fullness index for capelin ($PFI_c$), for each fishing station in 1991.

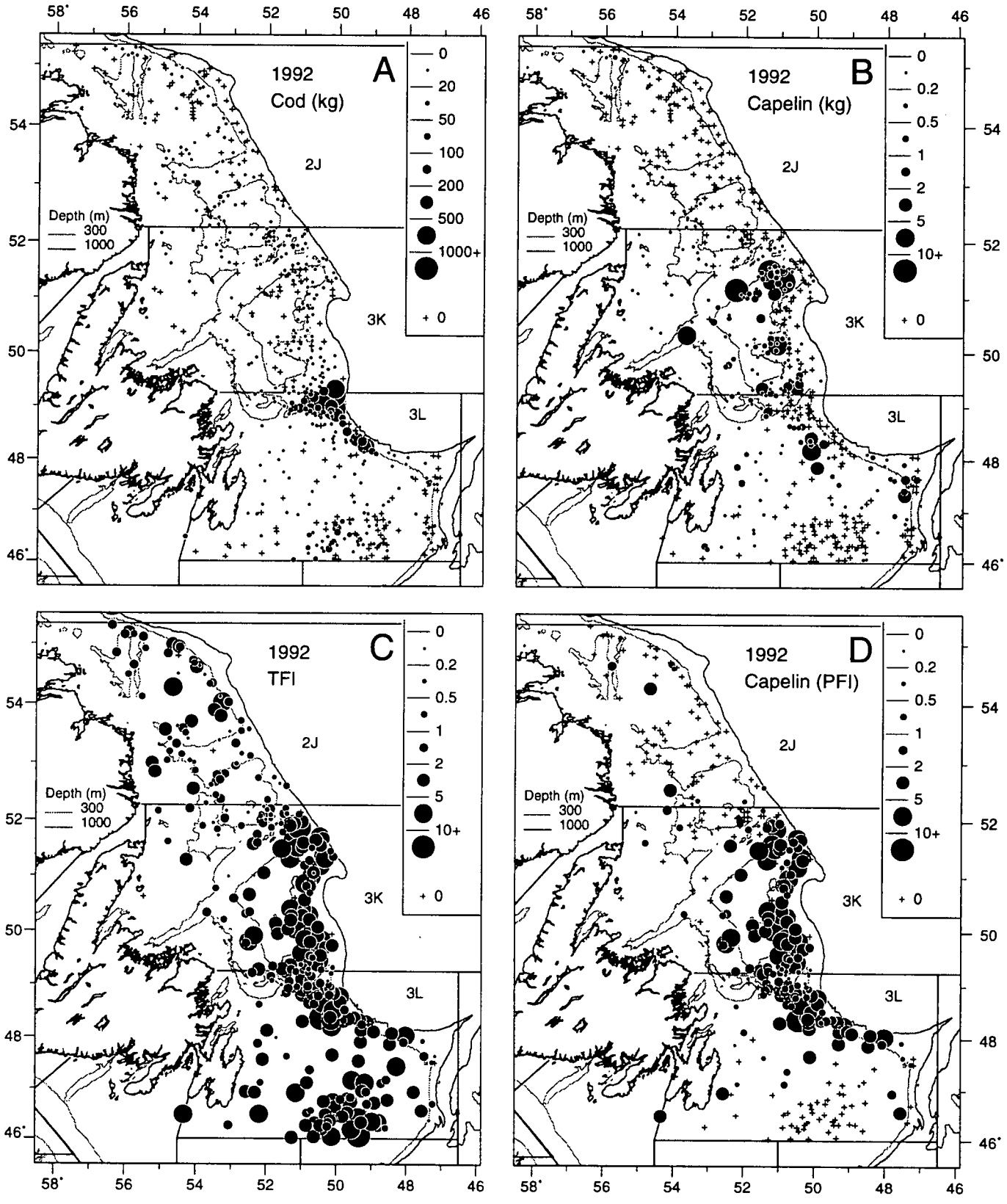


Fig. 11. (A) Cod catch (kg/30 min tow), (B) capelin catch (kg/30 min tow), (C) average total stomach fullness index (TFI), and (D) average partial stomach fullness index for capelin ($PFI_c$), for each fishing station in 1992.

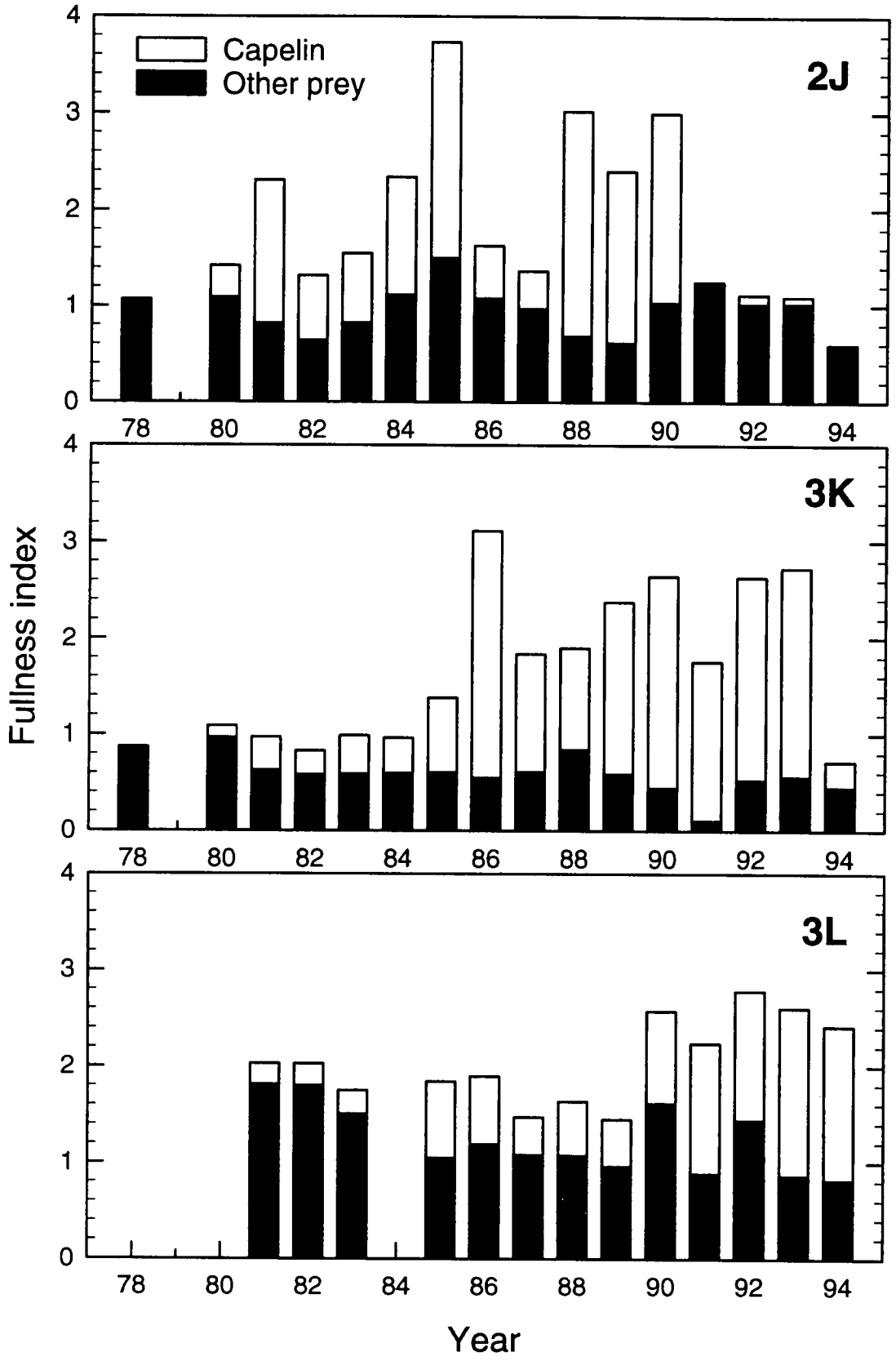


Fig. 12. Mean stomach fullness index of cod (36-71 cm only) by Division and year. The fullness index is partitioned into capelin and all other prey combined. Stomachs from cod caught in depths less than 200m on the St. Anthony and Grey Islands shelves (strata 618 and 619) are excluded. Updated from Lilly (1993) and Taggart et al. (1994).

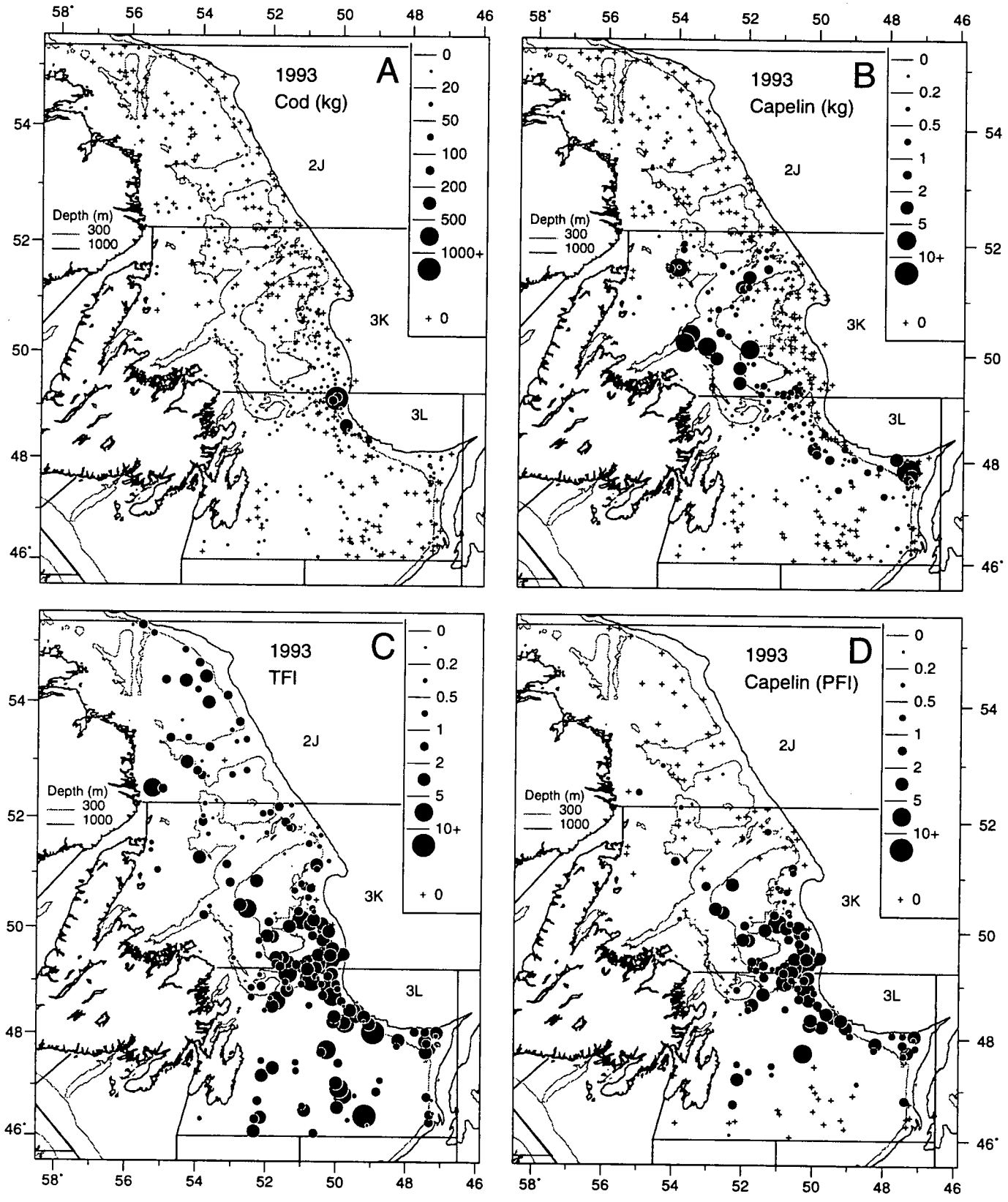


Fig. 13. (A) Cod catch (kg/30 min tow), (B) capelin catch (kg/30 min tow), (C) average total stomach fullness index (TFI), and (D) average partial stomach fullness index for capelin ($PFI_c$), for each fishing station in 1993.

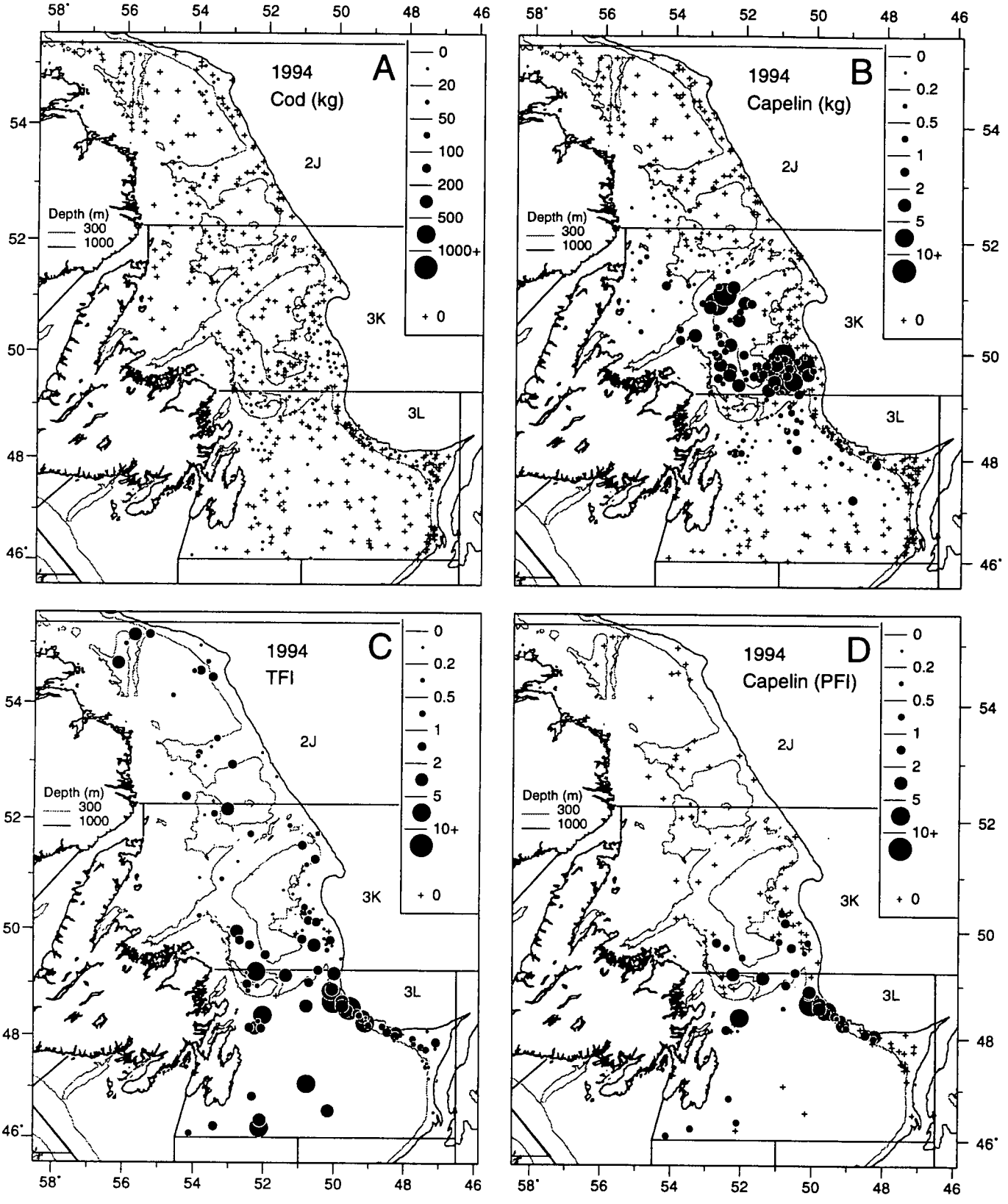


Fig. 14. (A) Cod catch (kg/30 min tow), (B) capelin catch (kg/30 min tow), (C) average total stomach fullness index (TFI), and (D) average partial stomach fullness index for capelin ($PFI_c$), for each fishing station in 1994.