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Distribution of northern shrimp (Pandalus borealis) in Divisions 2J3KL as inferred from stomach contents of cod (Gadus morhua)

by

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Abstract

The northern shrimp (Pandalus borealis) is not a large component of the stomach contents of cod (Gadus morhua) caught during the autumn on the shelf off southern Labrador and eastern Newfoundland, but it does occur in the cod stomachs in sufficient numbers to permit inferences regarding its size composition and distribution. Because cod are size-selective predators, the size of the cod was considered in all analyses. The degree of misidentification of prey was considered to be low, because the inferred distribution of northern shrimp differed from that of its congener, the striped pink shrimp (P. montagui). The former was found in greatest quantities in cod caught in deep areas of the shelf, whereas the latter was found in greatest quantities in shallower waters. Ontogenetic changes in the areal distribution of northern shrimp were inferred from the distribution of specific length-groups of shrimp found in the cod stomachs. The smallest shrimp, assumed to be age-0, were found primarily in deep water on the shelf off northeastern Newfoundland. Older juveniles were found primarily in shallow water. With increasing size, the shrimp moved deeper and onto the commercial fishing grounds. There is evidence of recruitment in the south and subsequent movement to fishing grounds to the north.

Resumé

La crevette nordique (*Pandalus borealis*) n'est pas une importante composante du contenu stomacal de la morue (*Gadus morhua*) capturée à l'automne sur le plateau continental au large du sud du Labrador et de l'est de Terre-Neuve, mais on la trouve dans un nombre suffisamment élevé de morues pour qu'il soit possible de faire quelques déductions au sujet de sa répartition par taille et de sa distribution. Comme la morue est un prédateur qui choisit ses proies en fonction de la taille, on a tenu compte de la taille de la morue dans toutes les analyses. Le niveau d'erreur d'identification des proies était jugé relativement faible parce que la distribution présumée de la crevette nordique diffère de celle de sa congénère, la crevette ésope (*P. montagui*). La première se trouve en grande quantité dans les morues capturées en eau profonde sur la plate-forme continentale, tandis que la seconde est la plus abondante sur les petits fonds. La répartition de groupes de longueur précis trouvés dans l'estomac des morues a permis de conclure à l'existence de changements ontogénétiques dans la répartition géographique de la crevette nordique. Les plus petites crevettes, que l'on suppose d'âge 0, ont été observées surtout dans les morues des eaux profondes de la plate-forme, au large du nord-est de Terre-Neuve. Les juvéniles plus âgées se trouvaient surtout sur les petits fonds. Plus la taille augmente, plus la crevette se déplace vers les eaux profondes et les zones de pêche commerciale. On observe un certain recrutement au sud et un mouvement subséquent vers les zones de pêche du nord.

Introduction

Predators may be viewed as sampling devices. Examination of the stomach contents of cod (Gadus morhua) caught on the southern Labrador Shelf and Northeast Newfoundland Shelf (NAFO Divisions 2J and 3K) has revealed that cod find shrimp (Pandalus borealis) throughout much of the area (Lilly 1984; Lilly and Parsons 1991; Lilly 1992). The distribution revealed by cod stomach examinations links many of the shrimp grounds fished commercially, and has supported the aggregation of several of these areas into larger management units (Anon. 1994).

Cod prey on a wide size range of shrimp (Lilly 1984). The finding of prominent modes at 3-5 mm and 8-11 mm carapace length (CL) in autumn has helped interpretation of shrimp length at age (Parsons et al. 1986; Parsons et al. 1989).

This paper will examine in more detail the size and inferred geographic distribution of shrimp found in cod stomachs and will extend the range of the study to Division 3L. The first objective is to explore some of the characteristics of cod as a sampling tool. This includes investigation of the possibility of misidentification of prey and determination of relationships between the size of the cod and the size and number of shrimp in their stomachs. The second objective is to study ontogenetic changes in shrimp distribution.

Methods

Study area

The study area in NAFO Divisions 2J, 3K and 3L encompasses the southern Labrador Shelf, the Northeast Newfoundland Shelf, the northern Grand Bank, and the adjacent continental slope to a depth of 1000 m (Fig. 1). The continental shelf has several deep areas, most notably Cartwright Channel on the Labrador Shelf and Hawke Channel, St. Anthony Basin and Funk Island Deep on the Northeast Newfoundland Shelf. The Labrador Current flows southeastward along the shelf and keeps temperatures low (Smith et al. 1937). The cold intermediate layer of the current is deepest and coldest toward the coast, and temperatures below 0^0 C are found to depths of about 200 m in many years (Petrie et al. 1988). Maximum bottom temperatures in the survey area are usually about 4^0C.

Stomach collections and examination

Cod were caught during random-stratified bottom trawl surveys designed to assess the abundance of demersal fish during October-December in Divisions 2J3K (1980-1989) and Division 3L (1981-1989, excluding 1984) (Table 1). Data

(1980-1989) and Division 3L (1981-1989, excluding 1984) (Table 1). Data collected during surveys in more recent years are not included because the cod declined severely in abundance and became increasingly aggregated toward the edge of the shelf (Bishop et al. 1994; Lilly 1994). This resulted in a very uneven distribution of stomach sampling, with relatively high sampling intensity toward the shelf break and very low sampling intensity on the inner part of the shelf. 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'. Details regarding ships and gear employed, sampling dates and changes in survey pattern are provided by Lilly and Davis (1993) and Bishop et al. (1994). Stratum areas and locations are provided by Doubleday (1981) and Bishop (1994). 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 1983-1989. 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.

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. Pandalid shrimp which were not identified to species are not considered in this paper. 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. Whenever digestive condition permitted, the carapace length (CL) of shrimp was measured to the nearest mm from the posterior edge of the eye socket to the posterior mid-dorsal margin of the carapace. All stomach content examinations were performed by commercial companies under contract.

Data analysis and presentation

To study the geographical distribution of shrimp, it was assumed that the average quantity of shrimp in the stomachs of cod collected at a specific locality reflected the relative abundance of shrimp at that locality (Fahrig et al. 1993). The average quantity of shrimp of species s in the stomachs of the cod in a specified sample was expressed as a mean partial fullness index:

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

where W_{sj} is the weight (g) of shrimp species s in fish j, L_j is the length (cm) of fish j, and n is the number of fish in the sample.
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.

The geographic distribution of shrimp was determined from visual inspection of expanding symbol plots of spatial variation in (1) PFI values and (2) the average number of shrimp found in cod stomachs.

Results

Northern shrimp was not a large component of the stomach contents of cod collected in autumn in the area from the southern Labrador Shelf to the northern Grand Bank (Table 1). The average quantity of shrimp in the cod stomachs, expressed relative to cod size (PFI_{pb}), was in all years less than 0.1 in Divisions 2J3K and less than 0.03 in Division 3L. This represents only 3-7% of the total fullness index (TFI) in Divisions 2J3K and < 2% in Division 3L. Nevertheless, many northern shrimp were found. The frequency of occurrence of northern shrimp in the stomachs examined each year was 17-26% (median=21.8%) in Divisions 2J3K and 4-15% (median=7.3%) in Division 3L. A total of 16,512 shrimp were identified as P. borealis, and 8132 (49%) of these were in sufficiently good shape to be measured.

Cod-shrimp size relationships

The influence of the size of the cod on the size and number of shrimp in their stomachs was explored with cod caught in depths greater than 200 m in Division 3K and Division 2J south of 53°45'N. This area corresponds to the Hawke Channel - Division 3K management area (Anon. 1994), excluding that portion on the outer slope of Hamilton Bank (ie. east of 55°00'W and between 53°45'N and 54°45'N).

The length-frequency of shrimp found in cod stomachs was dominated in most years by prominent modes at approximately 3-5 mm, 8-10 mm and 14-15 mm CL (Fig. 2). The frequency from 1983 is dissimilar from the others, the most notable difference being the absence of a trough at approximately 11-13 mm CL. While this may represent the true frequency distribution of P. borealis consumed by cod in 1983, there is a possibility of misidentification of prey or inaccurate length measurement. The stomachs collected in 1983 were among those examined by a company which experienced difficulties with prey identification. Data from 1983 are therefore excluded from further analysis. The length-frequency in 1984 does not appear as dissimilar as the frequency in 1983, but the stomachs were examined by the same company, and are also excluded as a precautionary measure.

The maximum size of shrimp consumed by cod increased with cod length (Fig. 3). A cod would have to be at least 45-50 cm in length to prey on a shrimp of 29 mm CL, which is the largest shrimp found in stomachs in this area. With increasing cod length, there was a gradual change from feeding entirely on small shrimp to feeding mainly on medium and large shrimp (Fig. 4).

Despite the change in shrimp size composition with increasing predator length, the average weight of shrimp in cod stomachs, expressed relative to cod size (PFI_{pb}), was relatively constant for cod in the length range 18-89 cm (Fig. 5). Investigations of spatial variability in PFI_{pb} will be restricted to cod in this length range.

Geographic distribution of P. borealis and P. montagui

Consistency in patterns of geographic distribution provide a further test of the reliability of shrimp identification. Although many species of shrimp have been identified in the stomach contents of cod caught in this area, errors in identification of P. borealis are most likely to occur with its congener, the striped pink shrimp (P. montagui). The striped pink shrimp was less important than the northern shrimp to the diet of cod in Divisions 2J3K, but more important in Division 3L (Table 1). The overall distribution of the two species was determined from plots of spatial variation in PFI values (Fig. 6). P. borealis were found in largest quantities in stomachs of cod collected in the Cartwright and Hawke Channels in Division 2J and in much of the deeper shelf water of Division 3K. In contrast, P. montagui were found widely distributed in the shallower water of Divisions 2J and 3K. Largest quantities were found in stomachs of cod caught in the western and southern Avalon Channel in Division 3L. These patterns are in broad-scale agreement with those deduced from catches during trawl surveys (Squires 1965, 1990). The spatial consistency in the distribution pattern of each species (Fig. 6) and the low degree of overlap between high PFI_{pb} values and high PFI_{pm} values (Fig.

7) support the contention that few shrimp were assigned to the wrong species of Pandalus.

Distribution of P. borealis by size-group

To study ontogenetic changes in shrimp distribution, the shrimp were divided into 4 length groups: 2-6, 7-11, 12-19 and >19 mm CL. The first two modes represent ages 0 and 1 respectively (Parsons et al. 1986). By comparison with lengths at age deduced by Parsons et al. (1989), it may be inferred that the third mode represents males of ages 2, 3, and 4. The fourth group would be composed of older males and females.

The relationship between the mean number of shrimp of a given size group found in the cod stomachs and the size of the cod is complex (Fig. 8). As shrimp size increases, the minimum size of cod which can ingest it also increases. The number of shrimp of a given size which could be contained within a stomach increases rapidly with cod length because of rapidly increasing stomach capacity. However, large cod tend not to feed on small shrimp, possibly because of decreasing energetic return. The curves in Fig. 8 might also reflect variability in the degree of geographic overlap between the 4 size-groups of shrimp and the 11 size-groups of cod. Subsequent analysis of the geographic distribution of shrimp length groups 1-4 above will use data from cod of length-ranges 9-80, 27-98, 36-98 and 54-98 cm respectively.

The distribution of shrimp changed with increasing shrimp size (Fig. 9). Age-0 shrimp (2-6 mm CL) were found in highest numbers in cod caught on the flanks of St. Anthony Basin and Funk Island Deep, and in the saddles between Belle Isle Bank and Funk Island Bank and between Funk Island Bank and Grand Bank. Very few were found in Division 2J.

Age-1 shrimp (7-11 mm CL) were found in highest numbers in cod caught in shallower water than where the age-0 shrimp were found. Highest numbers occurred to the west of Funk Island Deep and St. Anthony Basin. Moderate numbers were found in Cartwright Channel, west of Hawke Channel, on northern and western Funk Island Bank, and southward from Funk Island Bank to the northern edge of Grand Bank. Densities in Hawke Channel were low.

The 12-19 mm CL group was broadly distributed. Relatively high densities were found in cod caught in the Cartwright Channel, the southern Hawke Channel, and on the slope of the coastal shelf to the west of Hawke Channel, St. Anthony Basin and Funk Island Deep. There were also relatively large numbers at some sites off the Fogo Shelf and on the northern edge of Grand Bank.

Large shrimp (>19 mm CL) were not as broadly distributed as the 7-11 and 12-19 mm groupings. Highest numbers tended to be found in cod caught in those areas where the commercial fishery has operated, viz. in Cartwright Channel, in northwestern and southern Hawke Channel, on the flanks of St. Anthony Basin and Funk Island Deep, and in the saddle between Belle Isle Bank and Funk Island Bank (compare Fig. 2 of Lilly and Parsons, 1991). The strong similarity between the distribution of large shrimp in cod stomachs and the distribution of commercial fishing effort supports the notion that measures of the quantity or number of shrimp in cod stomachs can provide a useful index of shrimp density.

Influence of cod size on perception of shrimp distribution

There exists the possibility that the perceived geographic distribution of a specific size group of shrimp may be influenced by the length group of cod chosen for calculation of the mean number of shrimp per stomach. As a simple test, the broad (9-80 cm) length range of cod employed for investigating the distribution of 0-group shrimp was subdivided into four groups: 9-26, 27-44, 45-62, and 63-80 cm. Visual inspection of geographic plots derived from these four data sets (Fig. 10) revealed that they were similar to one another and to the distribution based on all these cod combined (Fig. 9).

Discussion

Cod as a sampling device for shrimp

The use of a predator such as cod as a sampling device for shrimp has several advantages. The cod stomachs provide a source of information on distribution and length-at-age of shrimp which is independent of that provided by the commercial fishery and research surveys dedicated to shrimp. In addition, the examination of cod stomachs yields individuals of smaller size than are taken by other collection methods, and provides information at times and places not covered by species-specific surveys. Finally, the method is relatively inexpensive if the catching of predators is already conducted as part of an ongoing program (eg. annual groundfish surveys).

There are several potential problems to consider when using predators as sampling tools.

(1) Digestion processes may render prey susceptible to misidentification. Misidentification is very likely to have occurred in this study, but consistency in the patterns of distribution of *P. borealis* and its congener *P. montagui*, and the low level of geographic overlap between them, support the contention that misidentification was not a serious problem.

(2) The number of individuals collected may be small compared to other collection methods. This is certainly true in the present study, where the number of shrimp identified as P. borealis was on average fewer than 0.7 per stomach in Division 2J3K and fewer than 0.2 per stomach in Division 3L. Nevertheless, the intensive stomach sampling program for cod during the period 1980-1989 yielded a total of 16,512 P. borealis, of which 8132 were measured.
(3) The predator distribution may not completely overlap the prey distribution. This was not a problem during the period covered by this study, but the usefulness of cod as a sampling tool for shrimp declined in the 1990s as the cod distribution became reduced. In addition, the relatively small number of surveys on the Labrador Shelf north of Division 2J, and the small catches of cod during those surveys, limits the possibilities for exploring the distribution of juvenile shrimp in these more northern areas.
(4) The prey may have been ingested at a location other than where the predator was captured. This could clearly be a problem on small spatial scales, but should not be a problem on the spatial scales studied here.
(5) The number of prey of a specific size range present in the stomach of a predator at the time of capture varies with the size of the predator. In the present study, predator size-groups which contained few individuals of a particular prey size-group were excluded from calculation of the mean number of prey per stomach. However, there was no attempt to adjust for the observation that the mean number of prey per stomach was not constant within the predator length range employed for the calculation.

The perceived geographic distribution of a specific size group of shrimp may not be greatly dependent on the choice of length range of cod. As a simple test, the distribution of 0-group shrimp was investigated based on their occurrence in 4 cod length groups: 9-26, 27-44, 45-62, and 63-80 cm. Visual inspection of geographic plots derived from these four data sets revealed that they were similar to one another and to the distribution based on all these cod combined.
(6) The rate of consumption of the prey in question may be affected by the availability of other prey. The possibility that the level of predation by cod on shrimp may vary with the availability of other prey (such as capelin) remains to be tested. This question is of concern if one wishes to examine annual variability in the intensity of predation on shrimp, but is less important if one is looking at long-term (decadal) patterns in distribution.

Distribution of northern shrimp

Cod consume northern shrimp over much of the southern Labrador Shelf and the Northeast Newfoundland Shelf in Divisions 2J3KL. The distribution of these shrimp changes with size. The smallest shrimp (2-6 mm CL) were found primarily in deep water on the Northeast Newfoundland Shelf within Division 3K. This result is somewhat surprising, because previous studies (eg. Fréchette and Parsons

1983) reported that juvenile shrimp occur in shallower water than adult shrimp. If the absence of these age-0 shrimp from stomachs of cod caught in shallow water accurately reflects their distribution, then they must move to shallower water before the next autumn. The broad distribution of older juveniles in shallow water, and their gradual movement with age into deeper water and onto the commercial fishing grounds, supports the contention that shrimp on the various fishing grounds do not represent separate populations. This observation has been cited as support for combining many of the fishing grounds into larger assessment and management units (Anon. 1994).

The small numbers of age-0 shrimp in Division 2J, and the possibility of movement of age-1 and older shrimp into Division 2J from Division 3K, has not previously been recognized. Additional studies are required to determine if shrimp caught in northern areas are derived from recruitment in Division 3K. This is particularly important for the shrimp in Cartwright Channel, which may spend their early years in the Hawke Channel - Division 3K management unit and their later years in the Hopedale and Cartwright channels management unit.

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References

Anon. 1994. Report on the status of the shrimp resource in the Northwest Atlantic in areas off Newfoundland and Labrador, in the Gulf of St. Lawrence, and on the Scotian Shelf. DFO Atl. Fish. Stock Status Report 94/6: 35 p.

Bishop, C. A. 1994. Revisions and additions to stratification schemes used during research vessel surveys in NAFO Subareas 2 and 3. NAFO SCR Doc. 94/43, Serial No. N2413: 23 p.

Bishop, C. A., J. Anderson, E. Dalley, M. B. Davis, E. F. Murphy, G. A. Rose, D. E. Stansbury, C. Taggart, and G. Winters. 1994. An assessment of the cod stock in NAFO Divisions 2J+3KL. NAFO SCR Doc. 94/40, Serial No. N2410: 50 p.

Doubleday, W. G. [ed.] 1981. Manual on groundfish surveys in the Northwest Atlantic. NAFO Sci. Coun. Studies 2: 7-55.

Fahrig, L., G. R. Lilly, and D. S. Miller. 1993. Predator stomachs as sampling tools for prey distribution: Atlantic cod (Gadus morhua) and capelin (Mallotus villosus). Can. J. Fish. Aquat. Sci. 50: 1541-1547.

Fréchette, J., and D. G. Parsons. 1983. Report of shrimp ageing workshop held at Ste. Foy, Quebec, in May and at Dartmouth, Nova Scotia, in November 1981. NAFO Sci. Coun. Studies 6: 79-100.

Lilly, G. R. 1984. Predation by Atlantic cod on shrimp and crabs off northeastern Newfoundland in autumn of 1977-82. ICES C.M. 1984/G:53: 25 p.

Lilly, G. R. 1992. Distribution of juvenile shrimp (Pandalus borealis) off southern Labrador and eastern Newfoundland as inferred from stomach contents of cod (Gadus morhua), p. 114-117. In Y. de Lafontaine, T. Lambert, G. R. Lilly, W. D. McKone, and R. J. Miller [ed.] Juvenile stages: the missing link in fisheries research. Report of a workshop. Can. Tech. Rep. Fish. Aquat. Sci. 1890: 139 p.

Lilly, G. R. 1994. Predation by Atlantic cod on capelin on the southern Labrador and Northeast Newfoundland shelves during a period of changing spatial distributions. ICES mar. Sci. Symp. 198: 600-611.

Lilly, G. R., and D. J. Davis. 1993. Changes in the distribution of capelin in Divisions 2J, 3K and 3L in the autumns of recent years, as inferred from bottom-trawl by-catches and cod stomach examinations. NAFO SCR Doc. 93/54, Serial No. N2237: 14 p.

Lilly, G. R., and D. G. Parsons. 1991. Distributional patterns of the northern shrimp (Pandalus borealis) in the northwest Atlantic as inferred from stomach contents of cod (Gadus morhua). ICES C.M. 1991/K:41: 15 p.

Parsons, D. G., G. R. Lilly, and G. J. Chaput. 1986. Age and growth of northern shrimp Pandalus borealis off northeastern Newfoundland and southern Labrador. Trans. Amer. Fish. Soc. 115: 872-881.

Parsons, D. G., V. L. Mercer, and P. J. Veitch. 1989. Comparison of the growth of northern shrimp (Pandalus borealis) from four regions of the Northwest Atlantic. J. Northw. Atl. Fish. Sci. 9: 123-131.

Petrie, B., S. Akenhead, J. Lazier, and J. Loder. 1988. The cold intermediate layer on the Labrador and Northeast Newfoundland Shelves, 1978-86. NAFO Sci. Coun. Studies 12: 57-69.

Smith, E. H., F. M. Soule, and O. Mosby. 1937. The Marion and General Greene expeditions to Davis Strait and Labrador Sea, 1928-1935. Scientific results, part 2: Physical oceanography. U.S. Treasury Dept., Coast Guard Bull. 19: 1-259.

Squires, H. J. 1965. Decapod crustaceans of Newfoundland, Labrador and the Canadian eastern Arctic. Fish. Res. Board Can., Manuscript Report Series (Biol.) 810: 212 p.

Squires, H. J. 1990. Decapod crustacea of the Atlantic coast of Canada. Can. Bull. Fish. Aquat. Sci. 221: 532 p.

Table 1. Number of stomachs collected from cod caught each year during autumn bottom-trawl surveys in Divisions 2J3K and 3L, and number and quantity of shrimp (*Pandalus borealis* and *P. montagui*) found in those stomachs.

Year	No. of Stomachs	Occurrence (%)	No. of *P. borealis* Found	Measured	PFI_{pb}	PFI_{pm}	TFI
2J3K							
1980	1795	23.7	1231	713	0.071	0.009	1.311
1981	1403	20.8	932	465	0.069	0.021	1.806
1982	3075	24.4	2066	1255	0.075	0.008	1.266
1983	2760	25.0	2260	913	0.091	0.029	1.296
1984	2733	25.7	2866	1217	0.095	0.025	1.708
1985	2435	18.2	1274	780	0.065	0.021	2.555
1986	2121	19.7	935	481	0.067	0.027	2.307
1987	2162	20.8	1256	624	0.056	0.028	1.709
1988	1832	22.8	1159	573	0.078	0.017	2.303
1989	2073	17.4	978	297	0.074	0.011	2.114
Total 2J3K	22389		14957	7318			
3L							
1981	684	3.5	28	13	0.004	0.157	1.991
1982	869	15.0	289	128	0.025	0.044	2.028
1983	1149	8.4	213	99	0.017	0.112	1.720
1984							
1985	1946	6.0	269	173	0.015	0.052	1.879
1986	1195	6.2	198	131	0.009	0.081	1.798
1987	1273	4.5	105	58	0.006	0.041	1.407
1988	1464	8.6	278	121	0.015	0.075	1.739
1989	1035	9.2	175	91	0.026	0.102	1.546
Total 3L	9615		1555	814			
Total 2J3KL	32004		16512	8132			

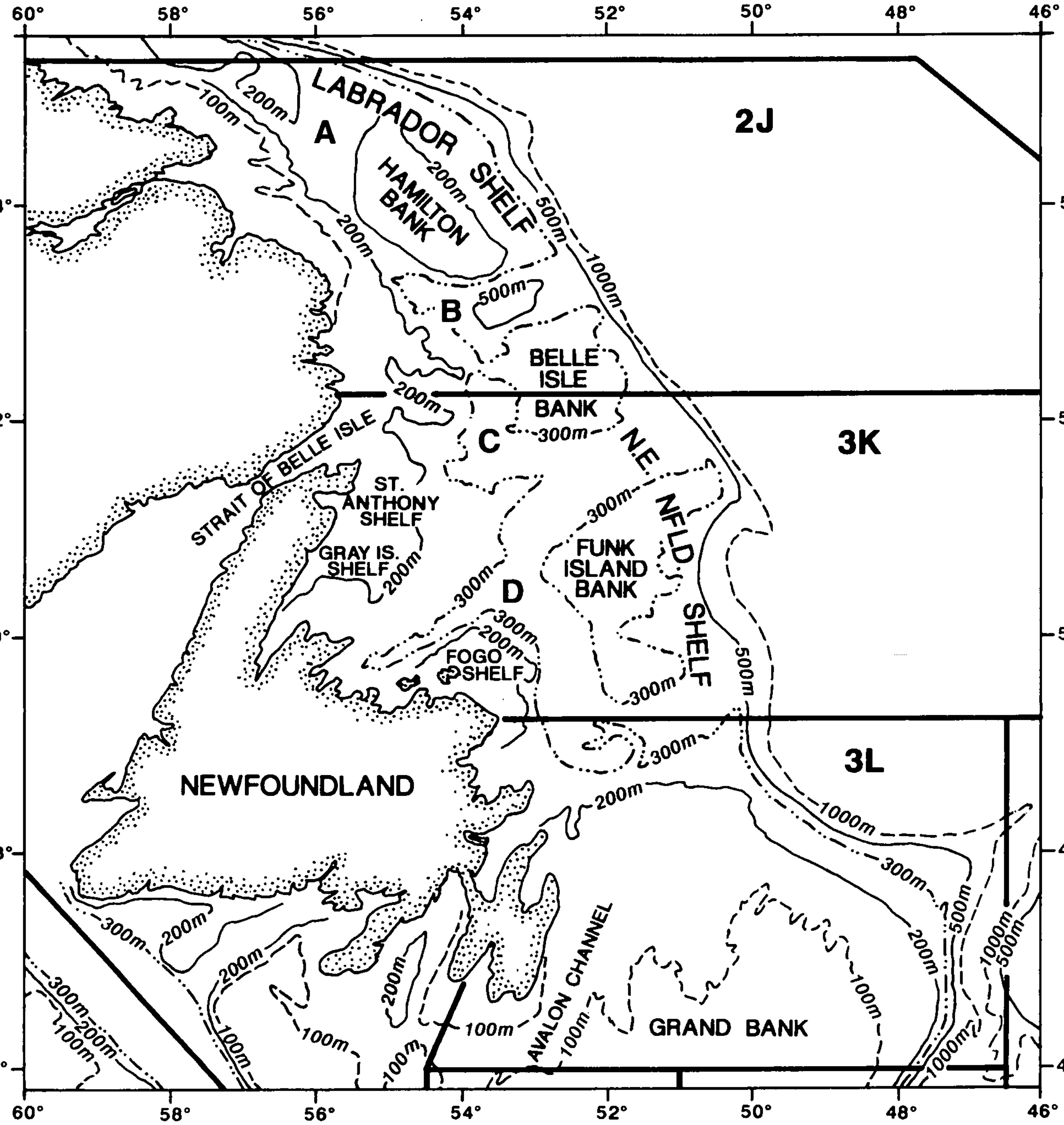

Fig. 1. Map of the study area, showing major physiographic features and NAFO Divisions. The letters A-D indicate Cartwright Channel, Hawke Channel, St. Anthony Basin and Funk Island Deep, respectively.

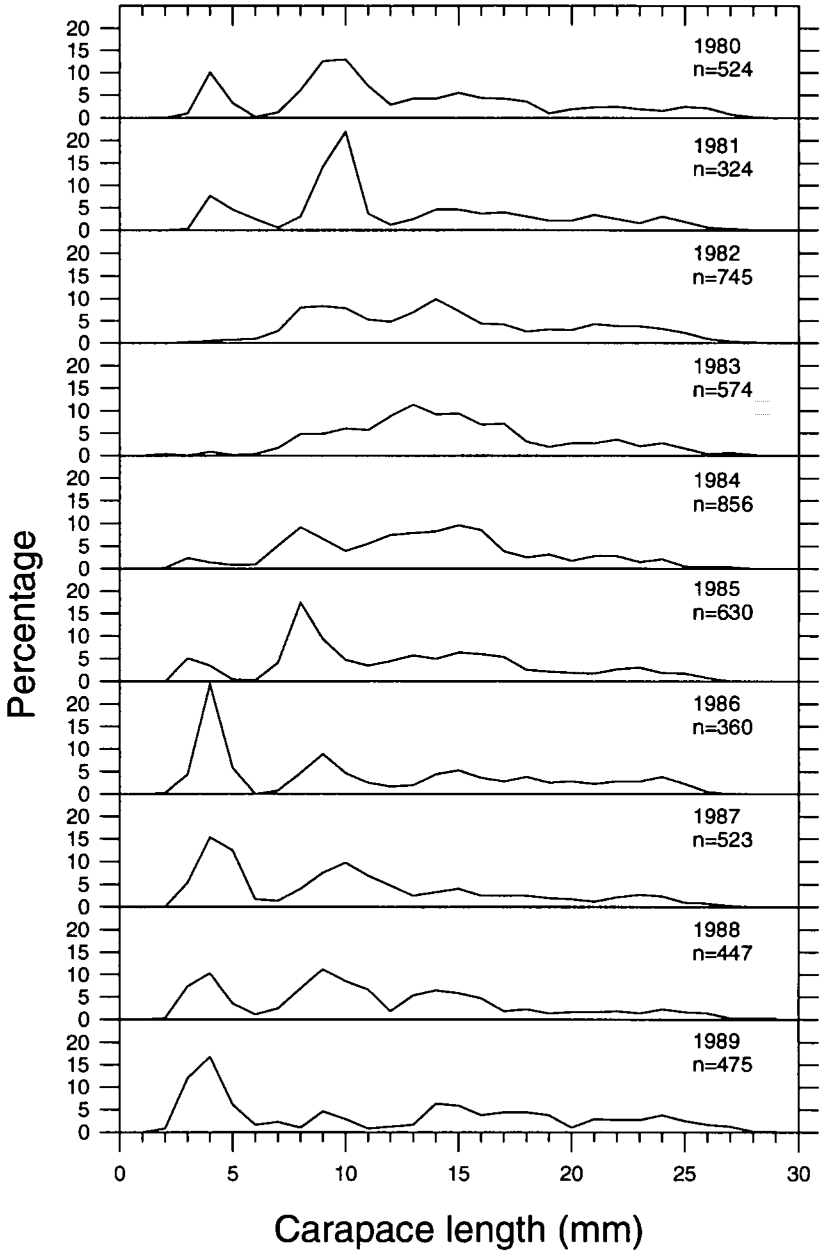

Fig. 2. Length frequency of all measured <u>Pandalus borealis</u> found in the stomachs of cod of all sizes collected in Division 3K and Division 2J south of 53°45'N at depths greater than 200 m, by year. n is the number of shrimp measured.

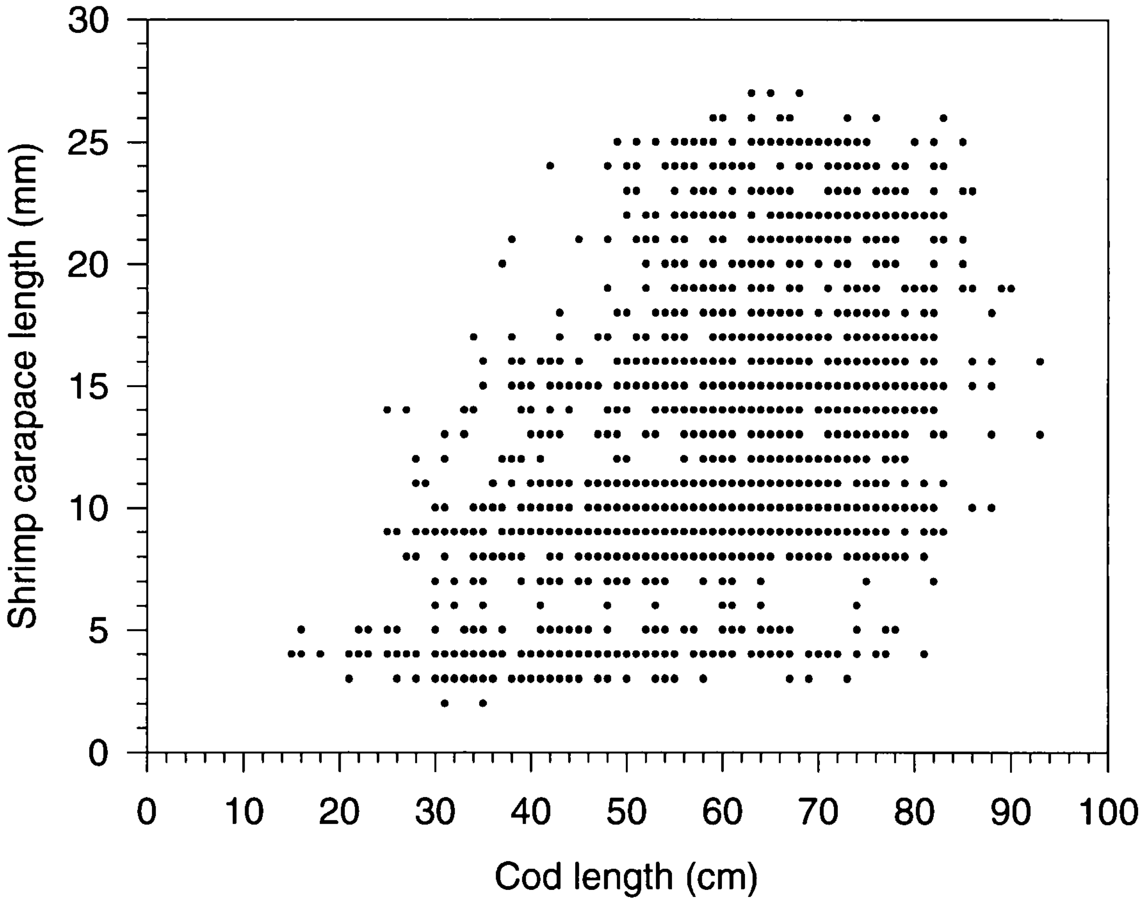

Fig. 3. Relationship between length of cod and the carapace length of _Pandalus borealis_ found in the stomach. Only points represented by 2 or more occurrences are plotted.

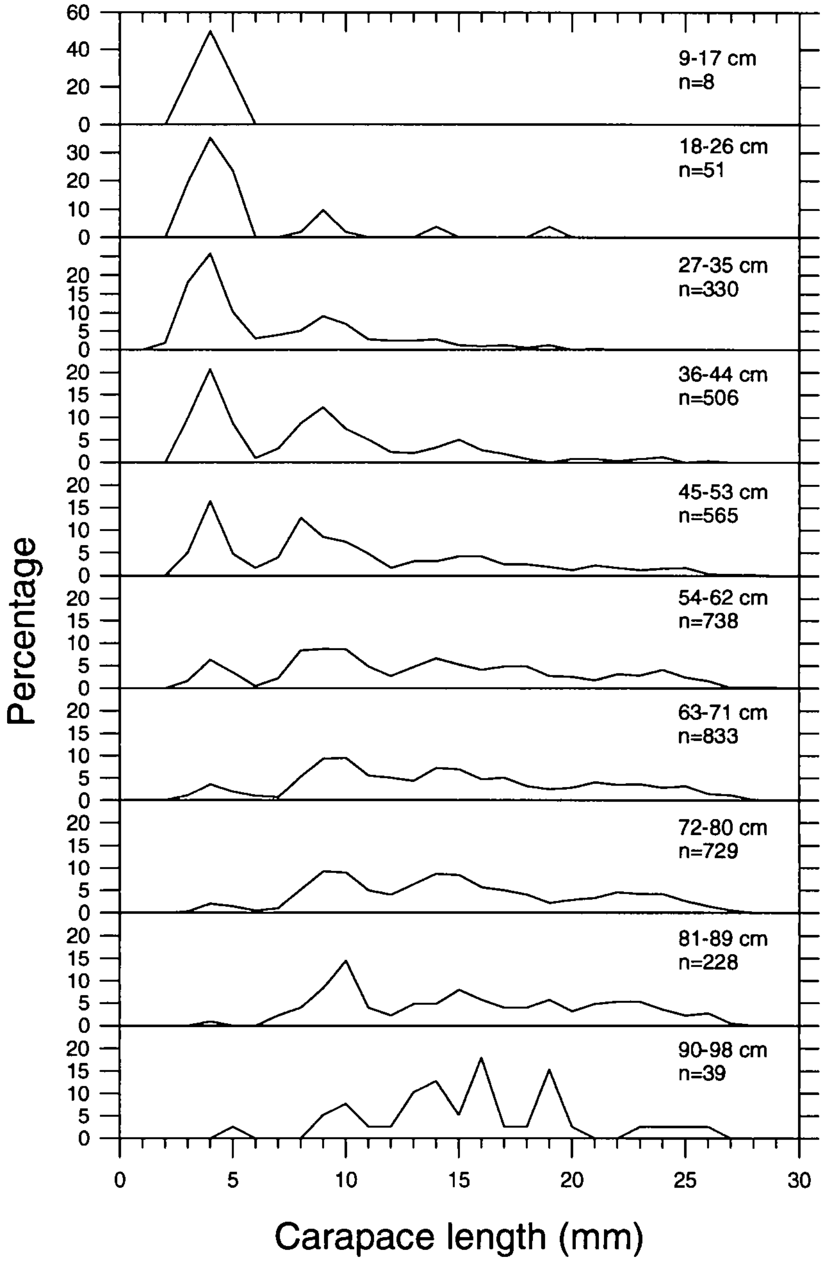

Fig. 4. Length frequency of Pandalus borealis found in the stomachs of cod collected in Division 3K and Division 2J south of 53°45'N at depths greater than 200 m, by cod length. Data from 1980-1982 and 1985-1989 are combined. n is the number of shrimp measured.

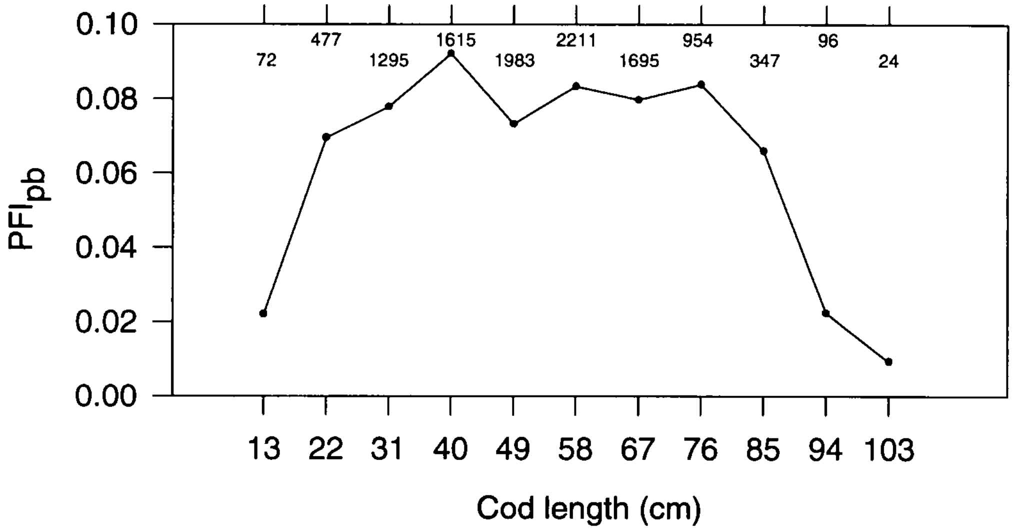

Fig. 5. Relationship between the partial fullness index for Pandalus borealis occurring in cod stomachs and cod length in 9-cm groupings. Data from stomachs of cod collected in Division 3K and Division 2J south of 53°45'N at depths greater than 200 m in 1980-1982 and 1985-1989 are combined. The numbers at the top are the number of stomachs available from each cod length group.

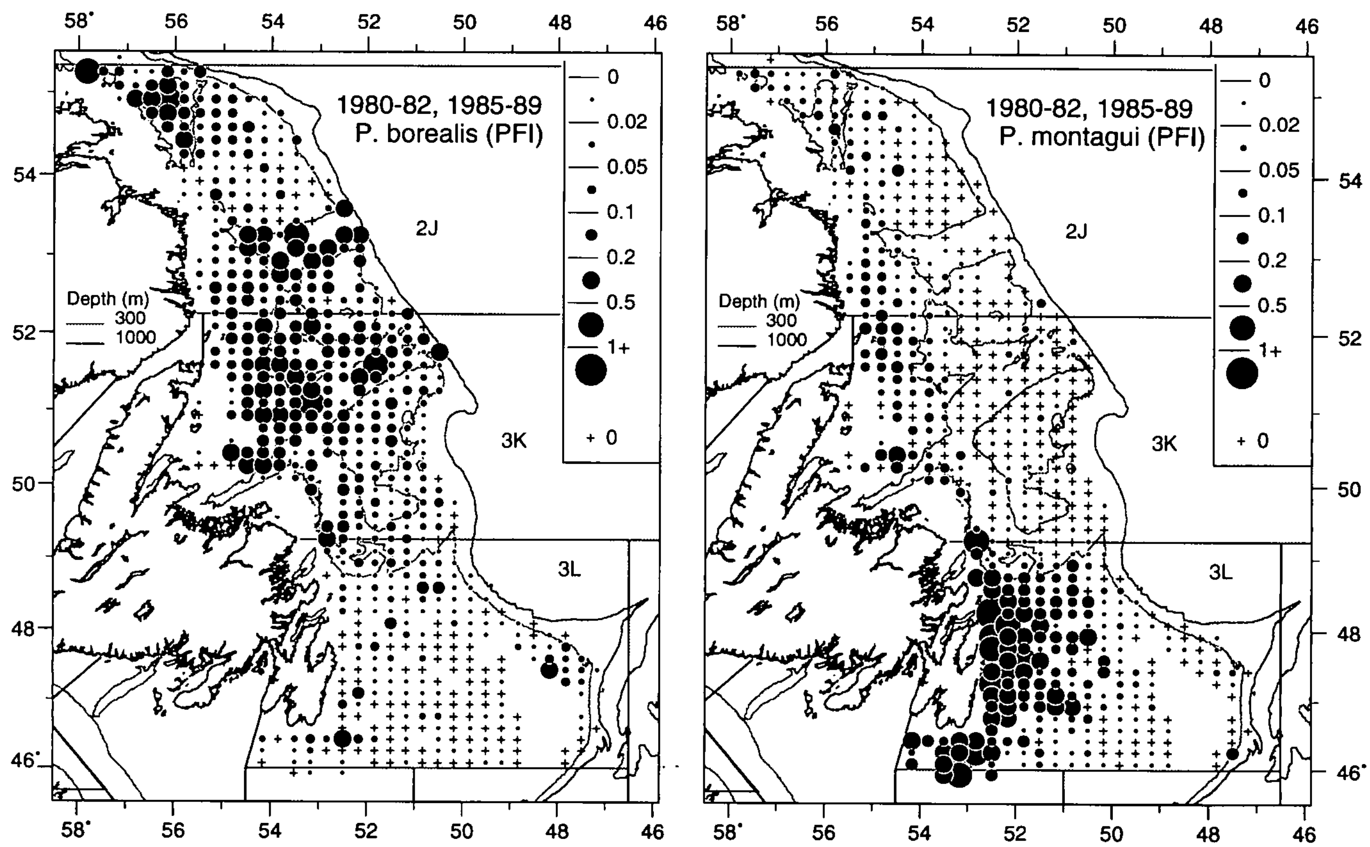

Fig. 6. Geographic variation in mean partial fullness index (PFI) for Pandalus borealis and P. montagui occurring in stomachs of cod (18-89 cm only) in 1980-1982 and 1985-1989. The data from all stomachs collected in areas of 10' latitude and 20' longitude are combined. Areas represented by fewer than 6 stomachs are not plotted.

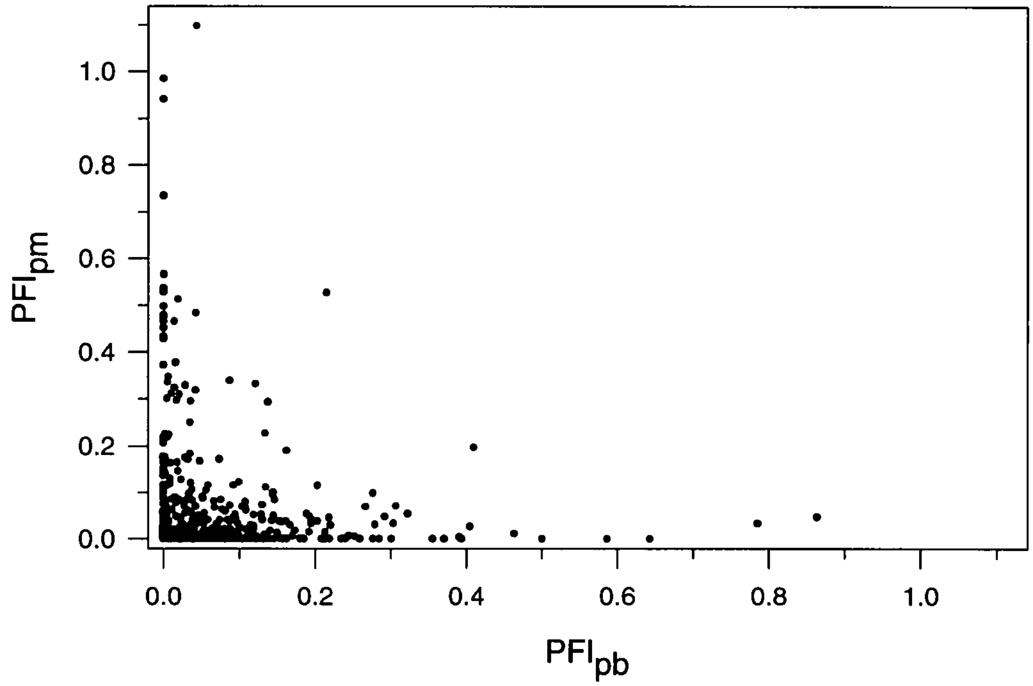

Fig. 7. Relationship between the mean partial fullness for Pandalus borealis (PFI_{pb}) and the mean partial fullness index for P. montagui (PFI_{pm}) for the 618 grid points illustrated in Fig. 6. Many points are hidden.

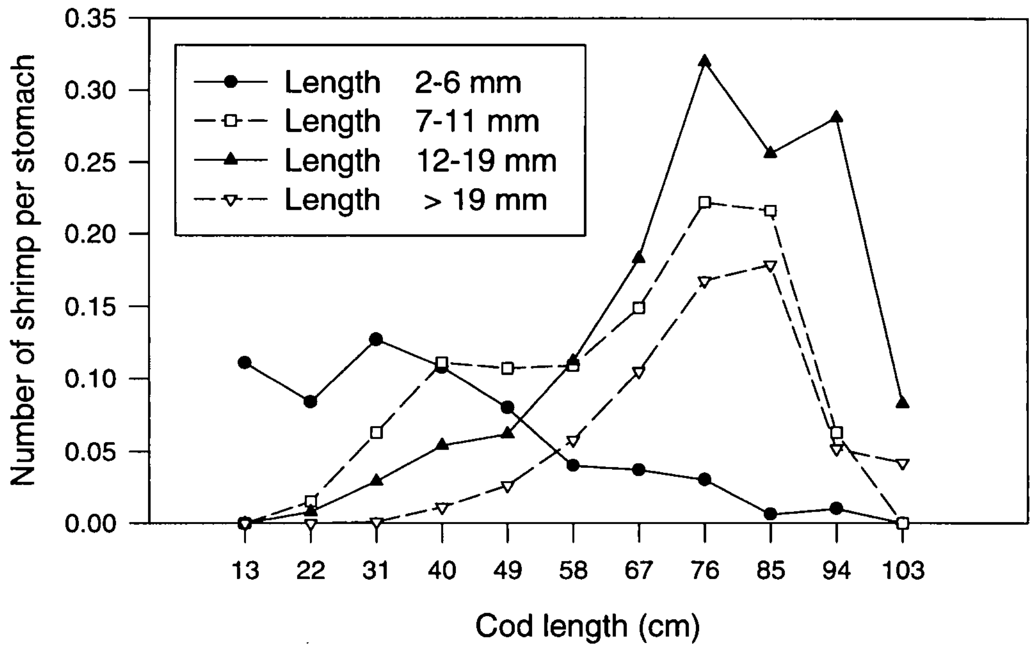

Fig. 8. Relationship between the mean number of Pandalus borealis per stomach and cod length, where the shrimp are aggregated into 4 modal groups and the cod into 9-cm groups. Data from stomachs of cod collected in Division 3K and Division 2J south of 53°45'N at depths greater than 200 m in 1980-1982 and 1985-1989 are combined.

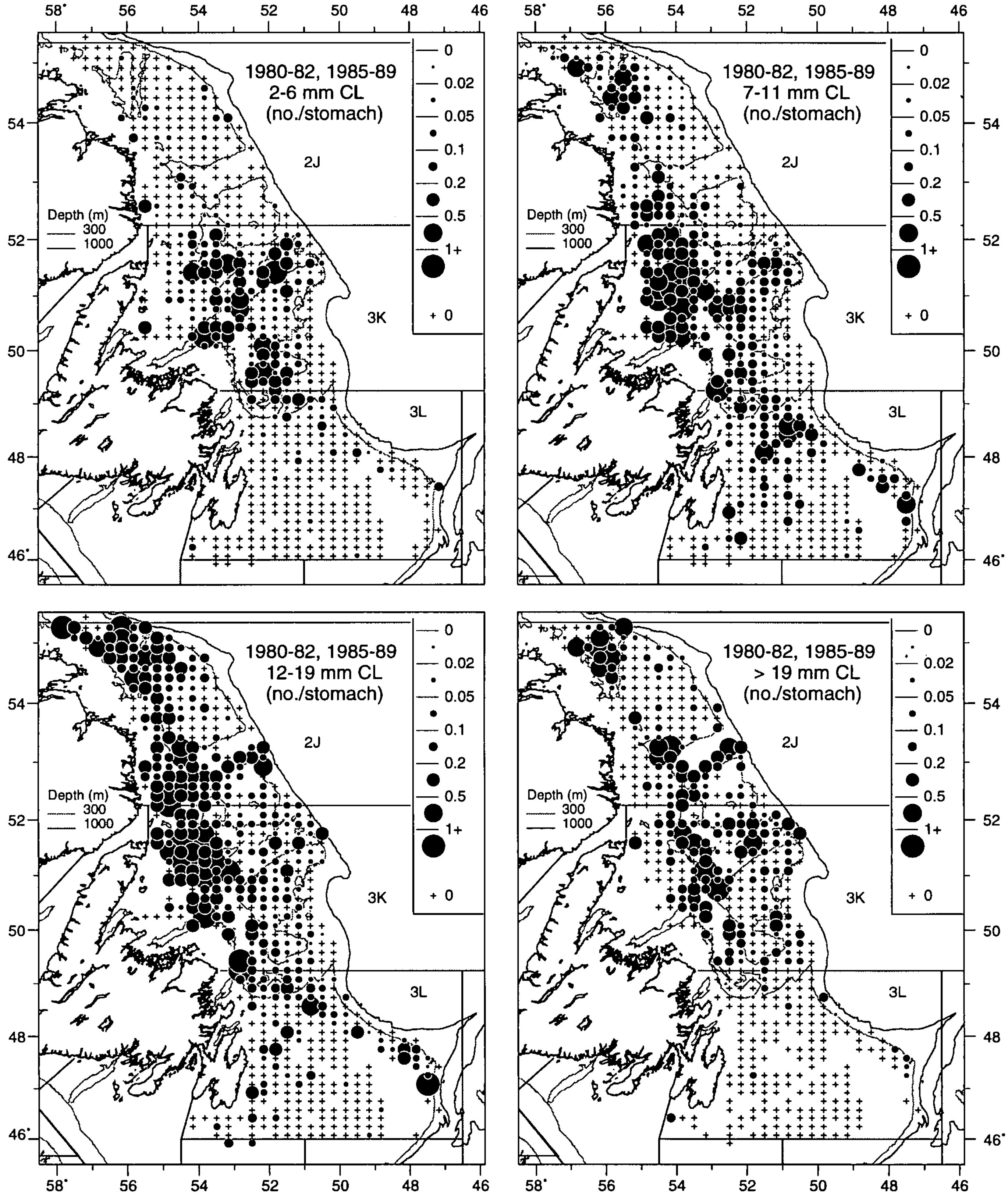

Fig. 9. Geographic variation in mean number of <u>Pandalus borealis</u> occurring in stomachs of cod in 1980-1982 and 1985-1989. The shrimp are aggregated into 4 size-groups. For each group, the data from stomachs of all cod of a specified length range (see text), collected in areas of 10′ latitude and 20′ longitude, are combined. Areas represented by fewer than 6 stomachs are not plotted.

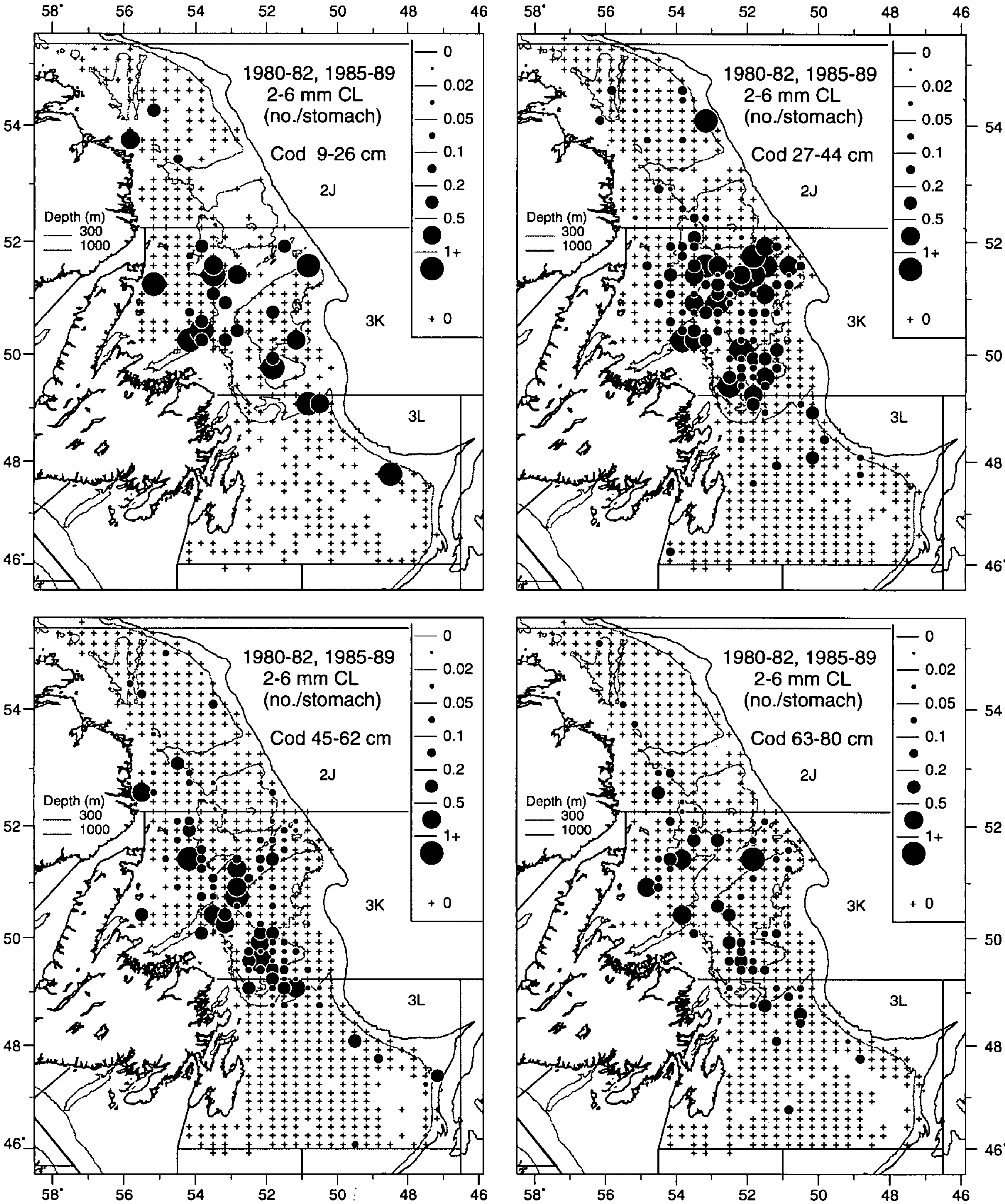

Fig. 10. Geographic variation in mean number of 0-group (2-6 mm CL) Pandalus borealis occurring in stomachs of cod in 1980-1982 and 1985-1989. Each panel shows the distribution as revealed from occurrences in the stomachs of a different length group of cod. The data from stomachs of all cod of a specified length range, collected in areas of 10′ latitude and 20′ longitude, are combined. Data are displayed for all grid points; that is, grid points represented by fewer than 6 stomachs are not deleted as they are in Figs. 6 and 9.