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Distribution and abundance of polar cod (Boreogadus saida) off southern Labrador and eastern Newfoundland

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Abstract

Polar cod (Boreogadus saida) were caught frequently during bottom-trawl surveys in the autumns of 1978-1993 on the continental shelf off southern Labrador and eastern Newfoundland. An analysis of length compositions revealed that the majority of these polar cod were of ages 1 and 2. The minimum trawlable biomass was low in 1978-1984 but higher on average and more variable in 1985-1993. During 1978-1990 most of the polar cod were caught on Hamilton Bank and the coastal shelf off southern Labrador and northeastern Newfoundland, with smaller numbers on western Funk Island Bank and southward to the Avalon Channel. An eastward shift in 1991-1993 is discussed in relation to the possible influence of changes in abundance and distribution of a potential competitor (capelin) and two predators (Atlantic cod and harp seals), and a decline in water temperature.

Introduction

The polar cod (Boreogadus saida), a small circumpolar gadid known as the Arctic cod in North America, is important in the transfer of energy from zooplankton (and under-ice biota) to a variety of fish, seabirds and marine mammals in the Arctic Ocean and cold regions of adjacent seas (Frost and Lowry, 1981; Bradstreet, et al., 1986; Welch et al., 1992). In the western Atlantic it occurs as far south as the southern Gulf of St. Lawrence and the southern Grand Bank (Scott and Scott, 1988). It is common off southern Labrador and eastern Newfoundland, where it is eaten by Atlantic cod, Gadus morhua (Lilly, 1991), Greenland halibut, Reinhardtius hippoglossoides (Bowering and Lilly, 1992), seabirds, including murres, Uria lomvia (Elliot, et al., 1990) , and seals, particularly harp seals, Phoca groenlandica (Sergeant, 1973; Lawson, et al., 1993).

There has been no directed fishery for polar cod in the northwest Atlantic, although a small bycatch was reported in the Romanian capelin fishery in 1979 (Maxim, 1980). There have been no attempts to obtain reliable measures of polar cod abundance, but information on distribution and relative abundance is available from bottom-trawl surveys conducted from northern Labrador to the southern Grand Bank. Lear (1979) reported very large schools on Saglek Bank (northern Labrador Shelf) in 1978, but such large schools were not found in subsequent years (Lear and Bowering, 1985). Polar cod also occur on the plateaus of other banks along the Labrador Shelf, toward the coast on the Northeast Newfoundland Shelf, and on the northern Grand Bank. Most fish are caught in areas where cold water extends to bottom. Relative abundance and average size of individuals decrease from north to south (Lear, 1979).

Estimates of biomass have been derived from the bycatches in trawl surveys conducted in 1978-1981 off northern and central Labrador (Lear and Bowering, 1985) and in 1977-1984 off southern Labrador and eastern Newfoundland (Lear and Baird, 1985). These estimates are considered minimal because the semi-pelagic behaviour of polar cod may reduce their vulnerability to bottom trawls and their small size may allow them to pass through the mesh.

The purposes of this paper are to extend the biomass estimates to 1993, to determine if annual variability in biomass is caused by variability in year-class strength, and to examine the distribution of polar cod in greater detail than in previous studies.

Methods

Study area

The trawl survey area in Northwest Atlantic Fisheries Organization (NAFO) Divisions 2J, 3K and 3L (Fig. 1) covers the southern Labrador Shelf, the Northeast Newfoundland Shelf, the northern Grand Bank, and the adjacent continental slope to a maximum depth of 1000 m. The continental shelf in this area is broad and much of it is deep. Hamilton Bank at the southern end of the Labrador Shelf has an extensive plateau less than 200 m in depth, whereas Belle Isle Bank and Funk Island Bank on the Northeast Newfoundland Shelf have only small areas shallower than 200 m. Grand Bank in the south has an extensive area between 100 and 200 m. Depths greater than 400 m occur in the saddles northwest of Hamilton Bank and between Hamilton Bank and Belle Isle Bank, and in basins landward of Belle Isle Bank and Funk Island Bank.

A prominent oceanographic feature of the shelf is the presence in summer of a Cold Intermediate Layer (CIL) with temperatures of less than 0^0 C extending to about 200 m (Petrie, et al., 1988). This CIL, which is deepest and coldest toward the coast, decreases in volume and increases in temperature during the autumn. Nevertheless, bottom temperatures below 0^0 C were found in depths of about 100-200 m during the autumn trawl surveys in many years, especially on Grand Bank (Colbourne, 1993). Maximum bottom temperatures in the survey area are usually about 4^0 C.

Surveys

Polar cod were caught during random-stratified bottom trawl surveys designed to assess the biomass of demersal fish during October-December 1978-1993 (Table 1). 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. Additional details regarding areas and locations of strata and changes in survey pattern are provided by Bishop et al. (1993), 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.

Assignment of ages

Polar cod were measured to the nearest 1 cm fork length. The combined catch at length within each year generally revealed two dominant modes at approximately 11-13 cm and 16-18 cm (Fig. 2). Assignment of ages 1 and 2 to these modes is consistent with lengths at age determined by counting annuli in otoliths (Wells, 1980) and with the progression of modes in length-frequencies of catches taken at various times of the year (Lear, 1979). A mode at 7-8 cm, which was prominent only in 1979, was assumed to represent age-0, and fish longer than the age-2 mode were combined into a fourth group (ages 3+). Modal groups were usually easier to distinguish in catches from individual sets than in the combined catch (Fig. 2). Therefore, individual fish were assigned to ages 0, 1, 2 and 3+ on the basis of visual inspection of the length composition of the catch from each individual tow. Minimum values, between adjacent modes, were divided equally between age groups.

In some years, there were a few hauls in which the number of polar cod caught was recorded but not their lengths. In such instances, it was assumed that the age composition of the unmeasured catch was identical to the age composition of the combined catches of other hauls in the same stratum or adjacent strata. Lengths were not available for 195 polar cod from 26 hauls in Division 3L in 1992. In this case, the age composition of each catch was assumed to be identical to the age composition of the combined catches from all other hauls in Division 3L in 1992.

Estimation of biomass and numbers at age

The biomass of polar cod in each stratum was estimated as

$$W_h = \frac{A_h \sum_{i=1}^{n_h} W_{hi}}{a n_h}$$

where W_{hi} is the weight (kg) of polar cod in set i (i = 1, 2, ..., n_h) in stratum h, A_h is the area of stratum h, and a is the area sampled by a standard tow (estimated to be 4.58 x 10^4 m^2). The biomass in each Division was obtained by summing over strata. Numbers at age were estimated in the same way.

Distributions

The geographic distributions of polar cod catches are presented in expanding symbol plots in order to provide visual information on annual changes in spatial distribution of fishing stations, among-station variability in catch of polar cod, and the relationship between fish distribution and bathymetry.

Results

During the period 1978-1993, polar cod were caught in 40% of the 4010 sets in Divisions 2J3K and 28% of the 2042 sets in Division 3L (Table 1). The percentage occurrence varied from 12% to 60% in Divisions 2J3K and from 12% to 50% in Division 3L. Catches were usually small. The median catch, in hauls where polar cod were recorded, was less than 1 kg in every year, and the 95th percentile exceeded 10 kg only in 2 years in Divisions 2J3K. The maximum catch was 100 kg.

The minimum trawlable biomass varied from 225 t to almost 6000 t (Fig. 3). It was relatively low (<2000 t) in 1978-1984, but fluctuated considerably in 1985-1993, with 3 years (1985, 1989, and 1993) in excess of 4000 t. In some years (eg. 1981, 1985) most of the biomass was found in Division 2J, whereas in other years (eg. 1988, 1989) most was in Division 3K. The biomass in Division 3L was less than 300 t in 1981-1991, but increased to 740 t in 1992 and 1290 t in 1993.

Most of the polar cod caught during these surveys were age-1 or age-2 (Fig. 4). Age-0 polar cod were found in abundance only in 1979, when four large catches were obtained on central Hamilton Bank. The abundance of age-1 polar cod was about 50 million or less in all years except 1985, 1988, and 1991-1993. The abundance of age 2 fish was about 40 million or less in all years except 1985 and 1989, and the abundance of ages 3+ was about 4 million or less in all years except 1984. It is difficult to determine the relative strength of year-classes, because age-0 fish were seldom caught in the bottom trawl and ages could not be distinguished beyond age-2. However, it appears that the 1981, 1983, 1984, 1987 and 1990-1992 year-classes may have been strong, with 1987 being the strongest. Determination of relative year-class strength may be further hampered by annual variability in catchability or distribution. For example, ages 1, 2 and 3+ were all relatively strong in 1985.

The distribution of polar cod in Divisions 2J, 3K and 3L is illustrated with the catches at ages 1 and 2 in selected years (Fig. 5). In years prior to 1991, most polar cod were caught on Hamilton Bank and the coastal shelf off southern Labrador and northeastern Newfoundland. Age-1 fish were often caught in large numbers in the channel just west of Funk Island Bank and on the western side of the bank, but age-2 fish were much less abundant in this area. Polar cod were also found in Division 3L, particulary in the northwest and in the Avalon Channel. Polar cod were seldom caught on southeastern Hamilton Bank, on Belle Isle Bank, and on northern and eastern Funk Island Bank. In 1991-1993 the distribution expanded further to the east, with larger and more frequent catches occurring on southeastern Hamilton Bank, Belle Isle Bank, northeastern Funk Island Bank, and the northern and northeastern slopes of Grand Bank. Catches were small in the relatively few hauls conducted close to the coast off northeastern Newfoundland.

Discussion

The stock structure of polar cod in the northwest Atlantic is not known. Most of the individuals captured during the bottom-trawl surveys off southern Labrador and northeastern Newfoundland were of ages 1 or 2. Large catches of age-0 polar cod were obtained only in 1979. However, large numbers of age-0 polar cod have been found, at least during some years, during acoustic surveys designed to estimate the biomass of capelin, <u>Mallotus</u> <u>villosus</u> (Miller, 1979). Catches of older cod (ages 3+) in the bottom-trawl surveys were small. As reported by Lear (1979) and Wells (1980), larger and older polar cod were very abundant and dominated catches on the northern Labrador Shelf in the late 1970s. Most of the adult stock may reside in this area or even further north. Spawning may also occur primarily in the north, although spawning sites have not been positively identified. Early life history stages may be advected southward in the Labrador Current to the southern Labrador and Northeast Newfoundland Shelves, where the young cod may live for 1 or 2 years before returning north. On the other hand, there may be local spawning at various sites along the coast of Labrador and eastern Newfoundland. Most information on spawning of polar cod relates to Russian waters (eg. Barenkova, et al., 1966; Rass, 1968), and additional study is required to identify times and locations of spawning and to elucidate stock structure in the northwest Atlantic.

The biomass and abundance of polar cod in the study area was low during the late 1970s and early 1980s, but became higher on average and more variable from the mid-1980s to the early 1990s. This pattern is not in agreement with the scenario posed by Vesin, et al. (1981), who postulated that the decline in capelin biomass in the late 1970s should have made large quantities of zooplankton available to other planktivores, such as polar cod, and improved their growth and/or recruitment. As evidence, they cited the unusual occurrence of small polar cod in the capelin fishery (Maxim, 1980) and the observations of large concentrations of polar cod during capelin acoustic surveys conducted by Russia in 1978 (Seliverstov and Serebrov, 1979) and by Canada in 1978 and

1979 (Miller, 1979; Carscadden and Miller, 1980). However, the catches during bottom trawl surveys did not reach high levels until 1985 and 1988-1989, by which time the capelin had recovered to a relatively high level (Lilly, 1994a; Miller, 1994). There is thus no clear evidence of a reciprocal relationship between capelin abundance and polar cod abundance. Lilly (1991) drew the same conclusion based on the quantities of polar cod found in Atlantic cod stomachs. It is possible that the high abundance of juvenile polar cod observed off southern Labrador and northeastern Newfoundland in the late 1970s was related to the very large numbers of adult polar cod found on the northern Labrador Shelf at the same time.

The relatively high abundance of polar cod in many years since the mid-1980s may be related to the cold water temperatures which have prevailed since the early 1980s (Colbourne, et al., 1994). Cold water temperatures may enhance survival of young fish in the study area and may encourage the southward movement of polar cod from north of the study area. The potential influence of water temperature on abundance of polar cod requires additional study.

Polar cod were found further to the east in 1991-1993 than in previous years. Because catches near the coast in Division 3K were small, it is possible that there was an eastward shift in distribution, rather than simply an expansion to the east. This change in distribution may be related to changes in distribution and abundance of potential competitors (notably capelin) and predators (especially Atlantic cod and harp seals).

The abundance of capelin, as estimated during acoustic surveys on the shelf environment of Divisions 2J3K, declined to very low levels in the 1990s (Miller, 1994), and their distribution within Divisions 2J3K shifted from the north and west to the southeast (Lilly, 1994a,b; Miller, 1994). Although a detailed comparison of the distributions of capelin and polar cod in the 1980s has not been conducted, it is clear from distribution plots presented in this paper and in Lilly (1994a) that polar cod and capelin overlap considerably, with polar cod being more confined to western Hamilton Bank and the coastal shelf off southern Labrador and eastern Newfoundland. It is possible that polar cod compete with capelin for food, and moved to the east as competition from capelin was relaxed. There is no information on annual variability in the abundance and distribution of the calanoid copepods, hyperiid amphipods, and other pelagic invertebrates which are prey for both capelin (Chan and Carscadden, 1976) and polar cod (Lilly, 1980) in this area.

The abundance of Atlantic cod declined dramatically in the late 1980s and 1990s (Bishop, et al., 1993; Taggart, et al., 1994), and their distribution at the time of the surveys became reduced to the outer shelf (Bishop, et al., 1993; Lilly, 1994). Because Atlantic cod is a predator on polar cod (Lilly, 1991), a second possible explanation for the eastward shift in polar cod distribution is reduced predation pressure from Atlantic cod.

Polar cod was the major prey of harp seals on the coastal side of the shelf off southern Labrador and northeastern Newfoundland in the 1990s (Lawson et al., 1993). There are anecdotal reports that in recent years the seals have been arriving in these waters earlier than in the past (G. Stenson, Dept. of Fisheries and Oceans, St. John's, Canada, pers. comm.). Thus, a third possibility is that the polar cod moved eastward to avoid the seals, although it is known that the seals also occur on the middle and outer shelf.

The change in polar cod distribution may also be related directly to changes in physical factors rather than to changes in the biotic environment. For example, Monstad and Gjosaeter (1987) reported that polar cod in the Barents Sea were distributed further to the west when water temperatures were low. The temperature of water on the shelf off southern Labrador and eastern Newfoundland was below the long-term mean during most years since the early 1980s and was far below normal in 1990-1993 (Colbourne, et al., 1994). Perhaps the eastward shift in polar cod distribution was related to an easterly extension of cold water. However, an eastward shift was not observed during an earlier cold period in 1984-1985.

Additional study is required to clarify the complex influence or multiple effects of capelin, cod, seals, and water temperature on the increase in polar cod abundance since the mid-1980s and the change in polar cod distribution in the 1990s.

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Table 1. Selected data for bottom-trawl surveys in Divisions 2J3K and 3L in the autumns of 1978-1993. 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	Stations with polar cod		Percentiles of[a] polar cod catches			
					No.	%	50	75	95	Max.
1978	2J3K	GA 15	04/11-27/11	125	15	12	0.34	0.9	3	3
1979	2J3K	GA 29	15/11-04/12	124	53	43	0.09	0.3	3	6
1980	2J3K	GA 44	22/11-08/12	134	28	21	0.10	0.7	9	10
1981	2J3K	GA 58,59	14/11-13/12	224	61	27	0.40	1.2	4	15
	3L	ATC 323,325	03/10-18/11	97	21	22	0.02	0.2	1	1
1982	2J3K	GA 71,72	30/10-08/12	303	123	41	0.20	0.6	3	6
	3L	ATC 333,334	30/10-06/12	121	22	18	0.05	0.1	< 1	< 1
1983	2J3K	GA 86-88	28/10-07/12	255	77	30	0.20	1.3	5	20
	3L	WT 7-9	13/10-14/11	126	33	26	0.10	0.4	2	4
1984	2J3K	GA 101-103	27/10-05/12	262	77	29	0.50	1.6	5	6
1985	2J3K	GA 116-118	23/10-02/12	311	149	48	0.30	1.6	11	100
	3L	WT 37-39	09/10-18/11	232	70	30	0.10	0.3	1	2
1986	2J3K	GA 131-133	03/11-11/12	215	75	35	0.30	1.0	4	13
	3L	AN 72	13/11-30/11	142	63	44	0.10	0.2	1	2
1987	2J3K	GA 145-147	29/10-08/12	288	97	34	0.10	0.4	4	12
	3L	WT 65	15/10-01/11	165	16	10	0.09	0.3	4	4
1988	2J3K	GA 159-161	04/11-13/12	239	120	50	0.25	1.2	9	36
	3L	WT 78	26/10-13/11	189	54	29	0.10	0.2	1	1
1989[b]	2J3K	GA 174-176	02/11-19/12	324	131	40	0.82	2.5	14	22
	3L	WT 87	12/10-31/10	195	44	23	0.15	0.3	1	2
1990[b]	2J3K	GA 190-192	03/11-19/12	311	99	32	0.24	0.7	4	7
	3L	WT 101	18/10-18/11	188	23	12	0.09	0.2	1	1

Table 1. (Cont'd.)

Year	Div.	Ship/Trip	Sampling dates (d/mo.-d/mo.)	Number of stations occupied	Stations with polar cod		Percentiles of[a] polar cod catches			
					No.	%	50	75	95	Max.
1991[b]	2J3K	GA 208-210	06/11-17/12	313	158	50	0.30	0.8	3	9
	3L	WT 114,115	08/11-02/12	219	49	22	0.05	0.1	< 1	< 1
1992[b]	2J3K	GA 224-226	29/10-09/12	319	191	60	0.35	1.0	3	6
	3L	WT 129,130	05/11-29/11	215	94	44	0.15	0.4	2	4
1993[b]	2J3K	GA 236-238	30/10-06/12	263	150	57	0.56	1.3	4	8
	3L	WT 145,146	12/11-04/12	153	76	50	0.32	0.9	3	4
1978-1993	2J3K			4010	1604	40	0.30	1.0	5	100
	3L			2042	565	28	0.10	0.3	1	4

[a] Percentiles are calculated for those stations in which polar cod were recorded in the catch.
[b] Not directly comparable to 1978-88. In the earlier years, the number of stations allocated to each stratum was roughly proportional to stratum area, whereas in 1989-1993 a few strata were allocated a relatively high number of stations.

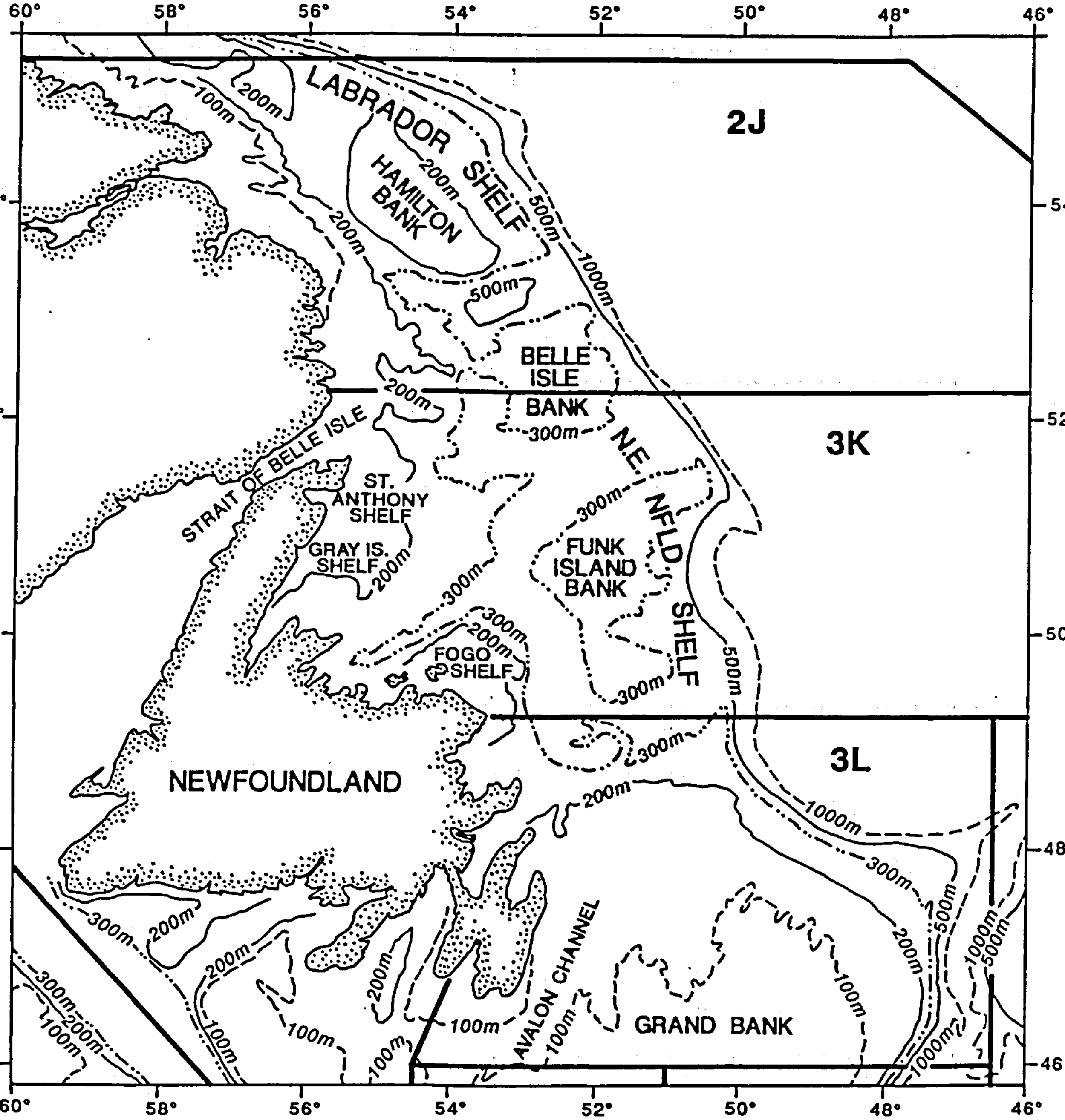

Figure 1. Map of the study area, showing major physiographic features and NAFO Divisions.

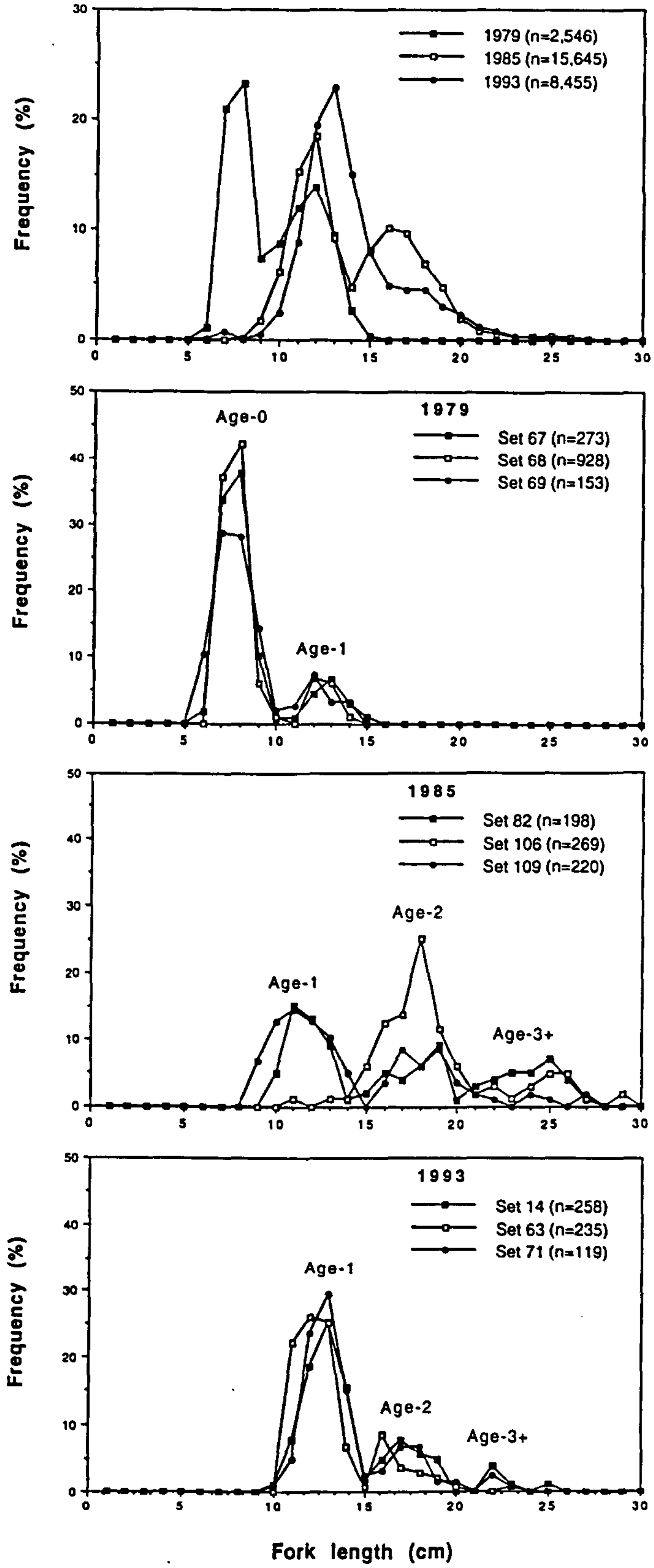

Figure 2. Length frequency distributions of polar cod from three years: 1979, 1985, and 1993. The upper panel shows the total for all sets, and the other panels show three selected sets in each year. Age-groups are indicated for the different modes.

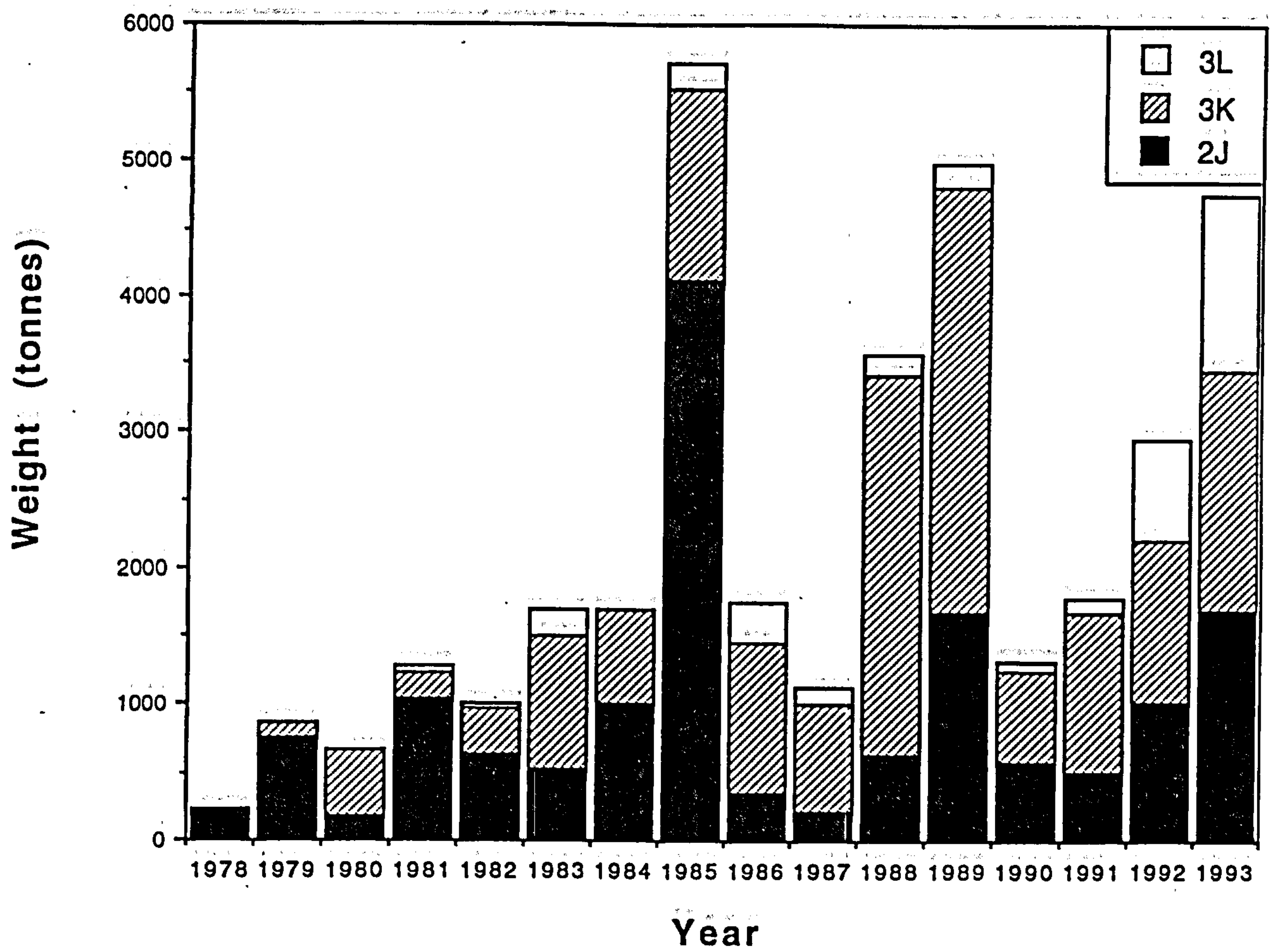

Figure 3. Biomass (tonnes) of polar cod by year and Division, estimated from areal expansion of mean catch per tow. Division 3L was not surveyed in 1978-1980 and 1984.

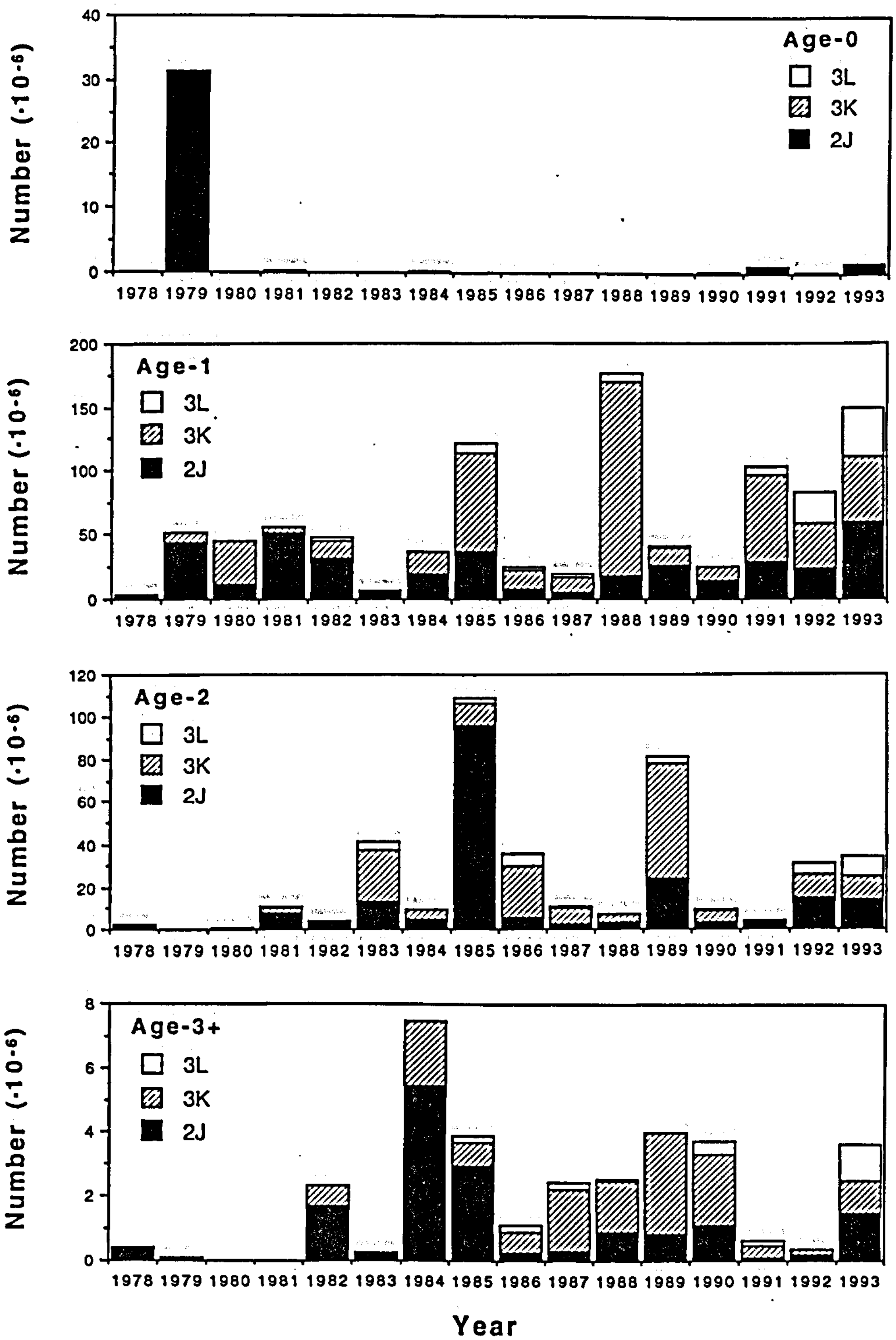

Figure 4. Abundance (millions) of polar cod by age, year and Division, estimated from areal expansion of mean catch at age per tow. Catch at ages 0, 1, 2, and older (3+) was determined by visual inspection of 1-cm length frequency distributions from individual sets.

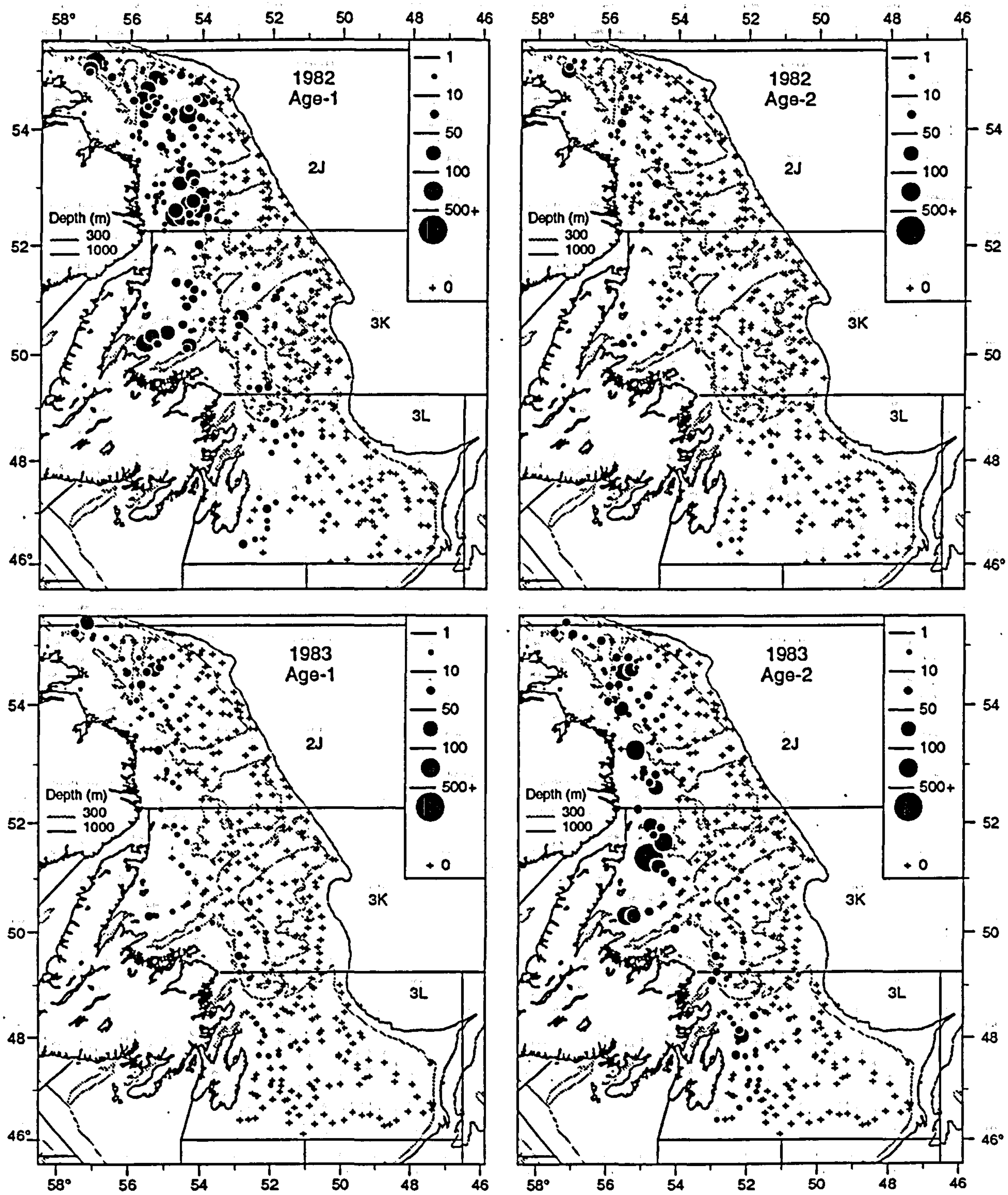

Figure 5. Catches (numbers/30 min tow) of polar cod of age-groups 1 and 2 at each station in selected years; 1982-1983, 1985-1986, and 1988-1993.

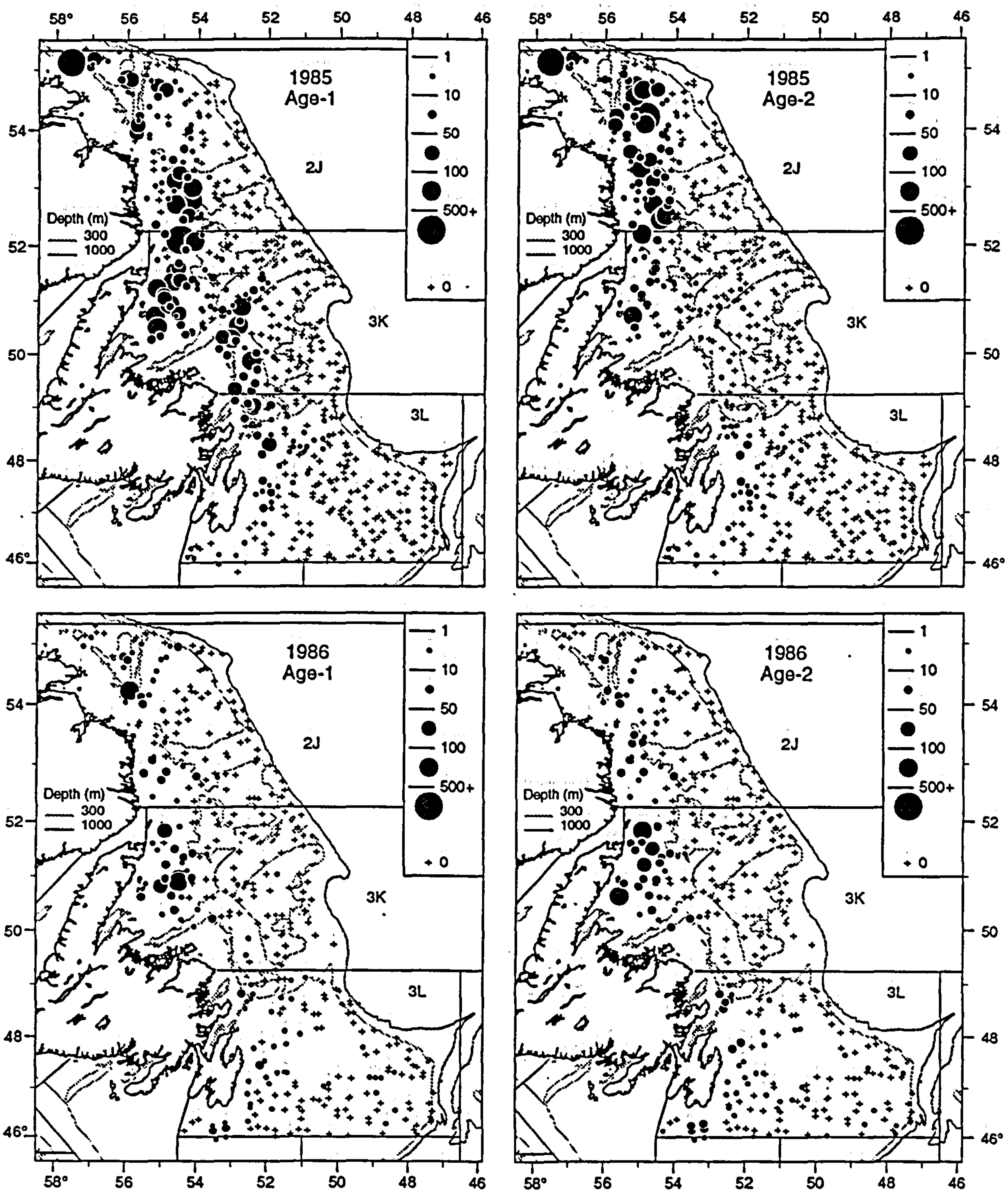

Figure 5. (continued).

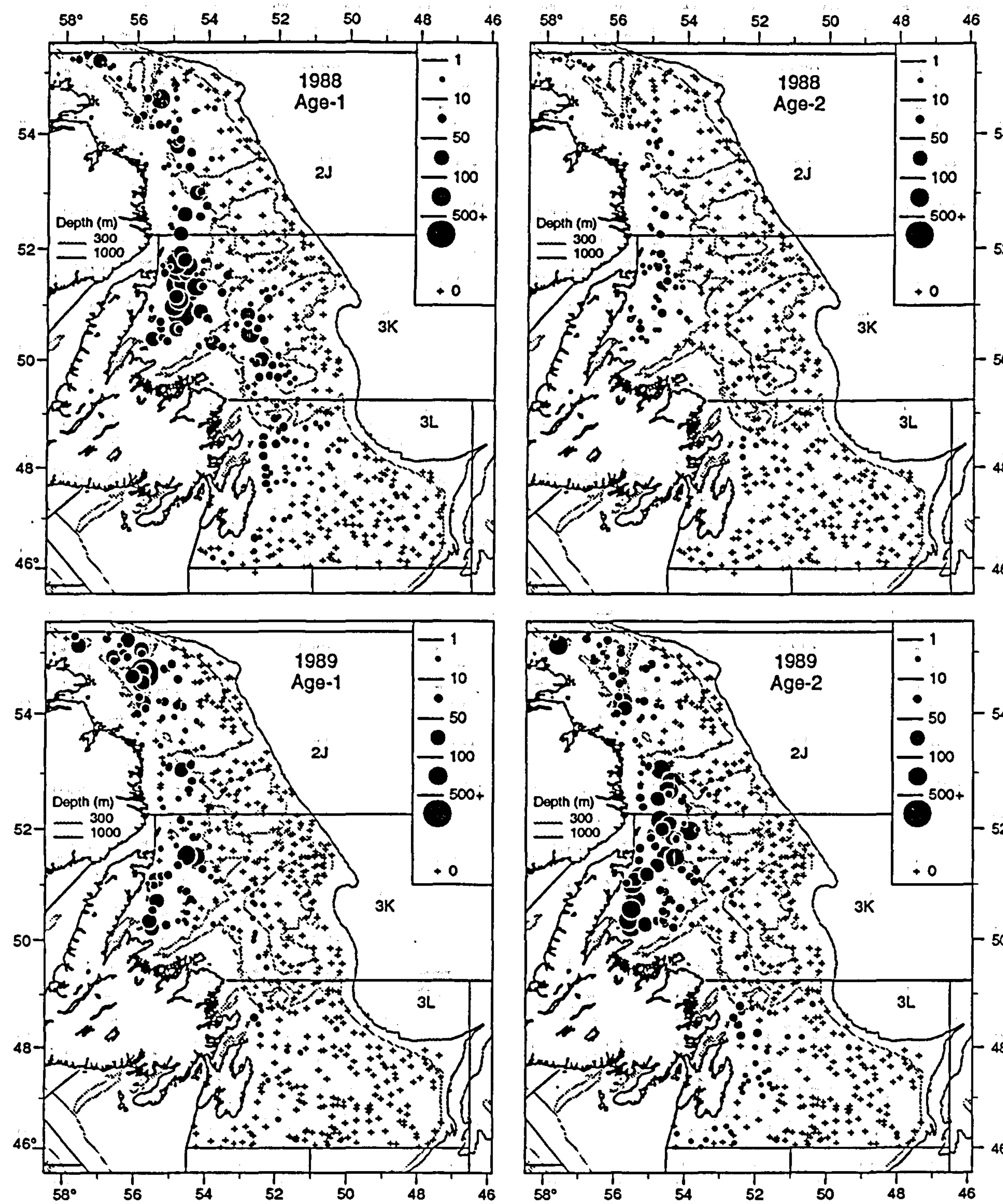

Figure 5. (continued).

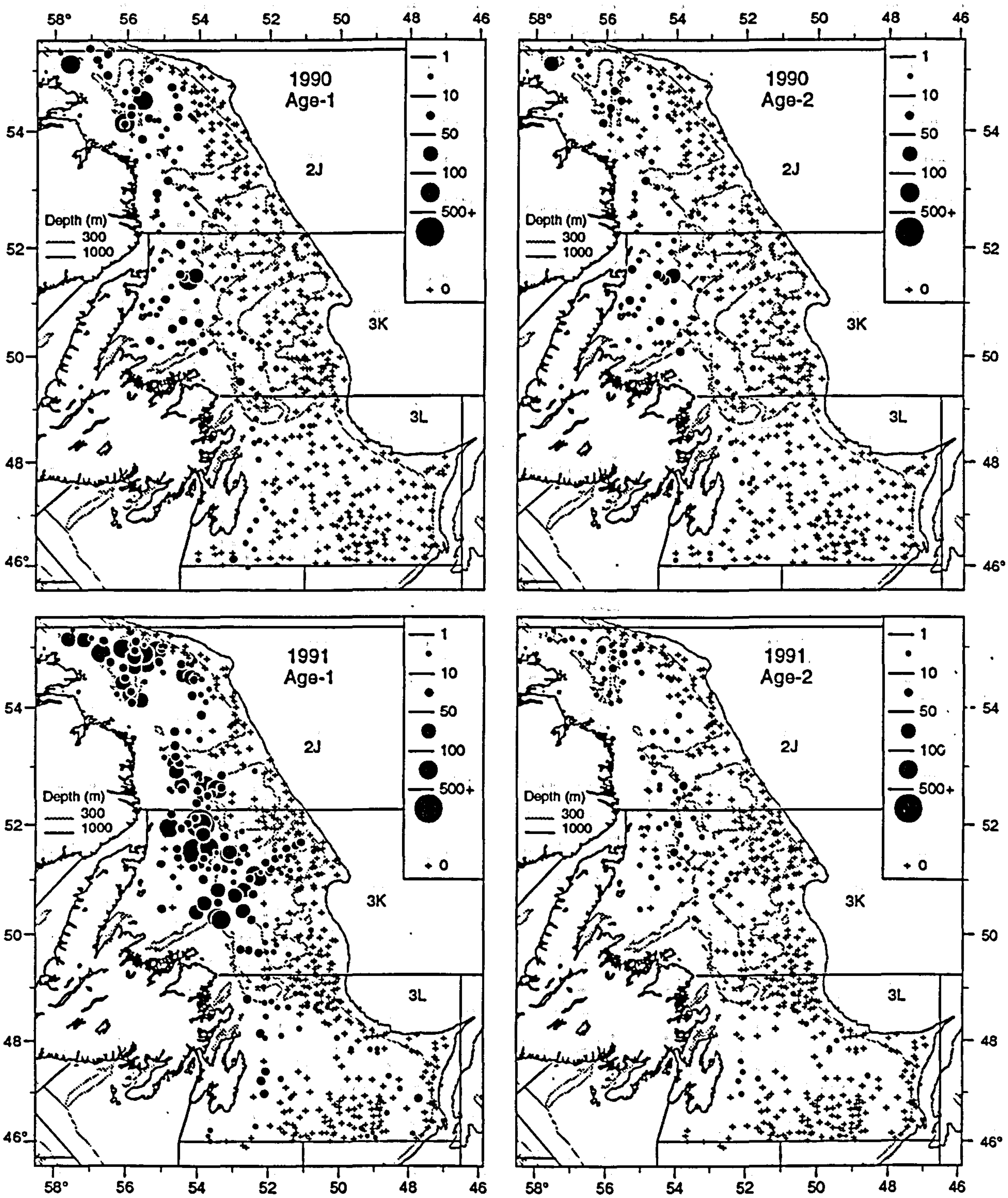

Figure 5. (continued).

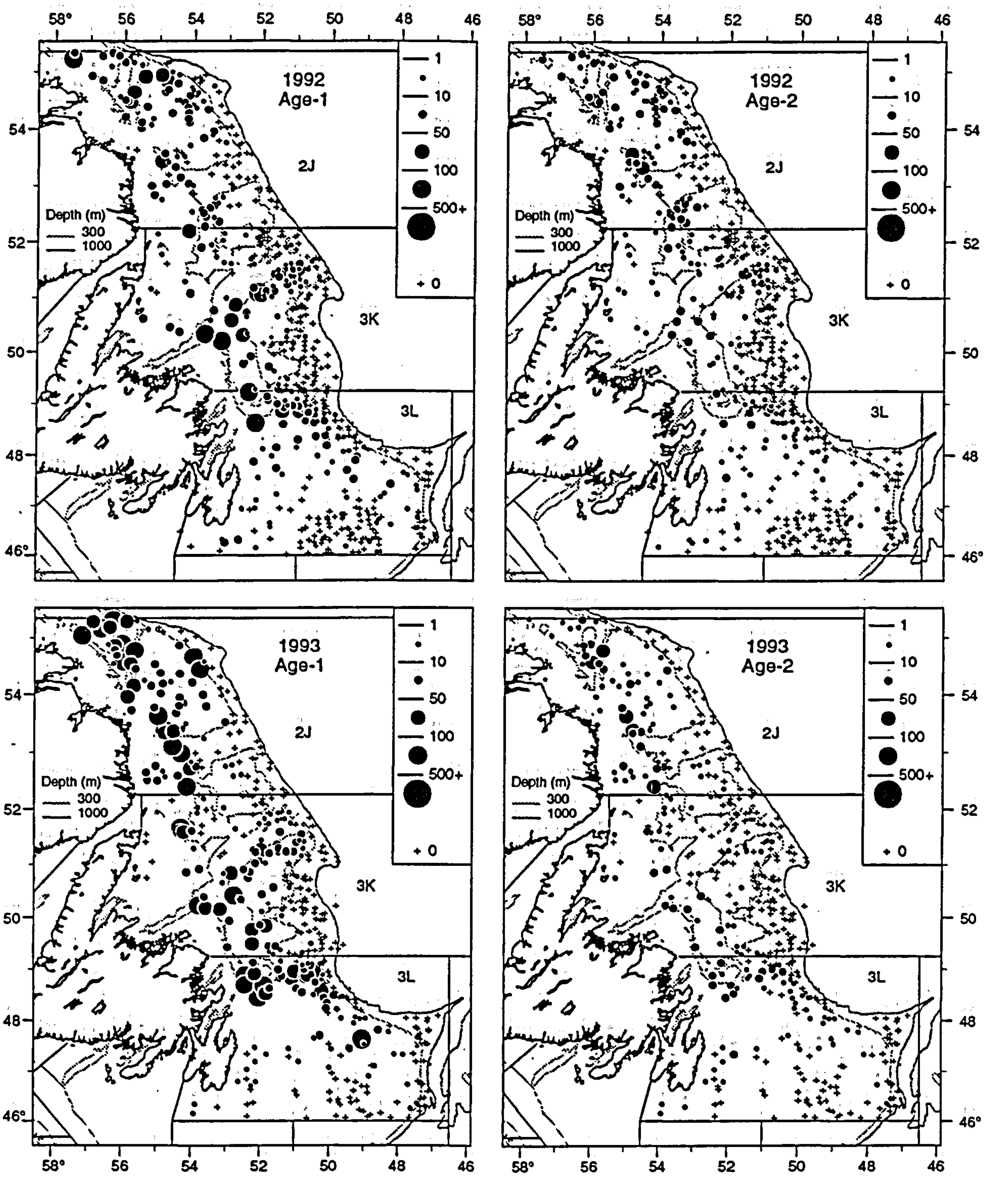

Figure 5. (continued).