Spatial and temporal distribution of juvenile Atlantic cod *Gadus morhua* in the Georges Bank-Southern New England region

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Abstract.–Commercial landings data and research-vessel survey data collected by the Northeast Fisheries Science Center during 1982–86 were analyzed to identify spatial and temporal patterns as well as possible mechanisms associated with juvenile cod *Gadus morhua* distribution. Analysis of survey data indicated that cod ages 1–2, age 3, and age 4+ were distributed at different depths during the spring; however, during the autumn, age-3 fish co-occurred with age 1–2 fish.

Analysis of commercial landings data revealed the following patterns of distribution for age-2 cod: In quarter 1, concentrations appeared in the Nantucket Shoals region and the central portion of Georges Bank; in quarter 2, the concentration was northeast of Nantucket Shoals and also remained on Georges Bank; in quarter 3, both aggregations moved northeastward into deeper waters, along the 100 m contour of the Great South Channel and the Northern Edge, respectively; and in quarter 4, the Nantucket Shoals concentration had moved southwestward to shallower water, resuming locations identified in quarter 1, while the Georges Bank concentration remained as in quarter 3.

While intraseasonal spatial distributions did not appear to be defined by temperature, seasonal shifts in concentration of juvenile cod were most likely associated with temperature.

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The Atlantic cod *Gadus morhua* has accounted for more catch, by weight, than any other species in the U.S. Atlantic coast groundfish fishery during the past two decades (Serchuk and Wigley In press). Recent declines in annual landings of cod from the Georges Bank–Southern New England region (N. Atl. Fish. Org. Div. 5Z) have generated concern for the fishery. Total nominal catches (U.S. and Canadian commercial landings, plus U.S. recreational catch) from this area dropped from a high of 64,000 metric tons (t) live weight in 1982, to 27,900 t in 1986. Although catches increased to 33,700 t in 1987, 64% of the catch in numbers and 36% in weight consisted of age-2 fish from the strong 1985 year-class (NEFSC 1988). Of the various commercial market categories of cod, 'scrod' generally represents the smallest size grouping of cod landed. Scrod landings paralleled the general decline of Georges Bank cod landings, decreasing from 8100 t in 1982 to 3400 t in 1986. In addition, Northeast Fisheries Science Center (NEFSC) research-vessel survey abundance indices for spring and autumn 1987 were among the lowest observed for cod in the 25-year survey time-series (Serchuk and Wigley In press).

During the period December 1986–March 1987, anomalously high discard rates of juvenile cod below the legal minimum landed size of 19 inches (48.3 cm) TL were associated with commercial trawling operations using small mesh in the Nantucket Shoals area. This high discard level led to an emergency action extending large mesh regulation (5.5-inch mesh in codend) to this region during 23 February–31 March 1988 to "reduce fishing effort and mortality on juvenile Atlantic cod stocks found in high concentrations in this area at this time" (Federal Register, 50 CFR Part 651, 26 Feb. 1988). Large mesh regulation was permanently extended to the Nantucket Shoals area in January 1989 (Federal Register, 50 CFR Part 651, 31 Jan. 1989) (Fig. 1). In addition, the "Nantucket Shoals scrod slaughter" may have prompted the development and implementation of the Flexible Area Action System (FAAS) by the New England Fishery Management Council (NEFMC) and the National Marine Fisheries Service (NMFS). Under this plan, the Regional Director, NMFS Northeast Region, could close an area to fishing, impose mesh size restrictions, or establish catch limits for a period of 3 weeks to 6 months to minimize discards of juvenile fish. This represents a significant departure from the traditional uses of seasonal or areal closures, such as protection of adult haddock *Melanogrammus aeglefinus* during spawning (Halliday 1987).

For such a plan to be effective, knowledge of fish distribution pat-

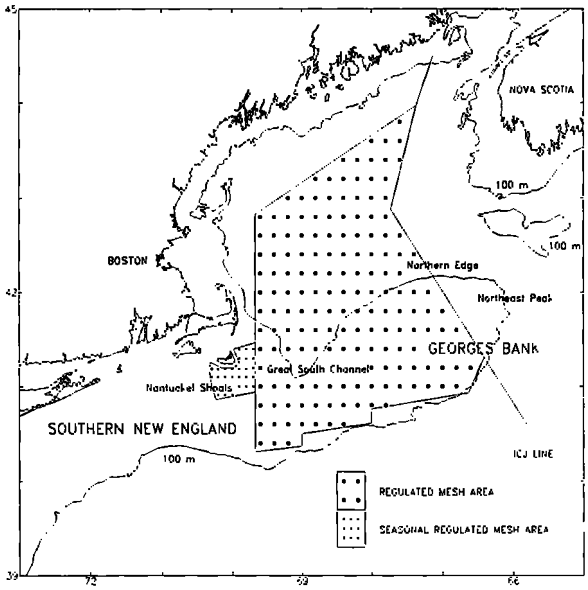

Figure 1
Georges Bank–Southern New England region of the Northwest Atlantic Ocean, showing geographic features and regulated mesh (5.5-inch) areas under the Northeast Multispecies Fishery Management Plan of the New England Fishery Management Council.

terns is necessary. In addition to documenting geographic, seasonal, and age-specific aspects of distribution, studies must examine mechanisms (such as temperature, depth, spawning, or feeding behavior) underlying these observed patterns. Numerous tagging studies have been conducted for Atlantic cod in the Northwest Atlantic: McKenzie (1934, 1956) and McCracken (1956) described cod movements in Canadian waters based on tagging experiments, and Smith (1902), Schroeder (1928, 1930), and Wise (1958, 1962) tagged cod from Woods Hole, Nantucket Shoals, and Nova Scotia to New Jersey, respectively. More recently, cod distributions delineated by bottom-trawl survey data from research vessels have been presented by Scott (1988) for Canadian waters and Grosslein and Azarovitz (1982) and Almeida et al. (1984) for U.S. waters. None of these studies considered fish size in the analyses. Overholtz (1984) found age-specific patterns of distribution for another gadoid species, haddock, in the Georges Bank region. Wigley and Gabriel (1991) and Bowman et al. (1987) examined distributions of several juvenile fishes, including cod, using NEFSC bottom-trawl survey data collected from Cape Hatteras, NC to Nova Scotia, Canada.

In our study, NEFSC commercial landings data and research-vessel survey data collected during 1982–86 were analyzed to identify spatial and temporal patterns as well as possible mechanisms associated with distributions of juvenile cod. The study period corresponds roughly to the duration of the NEFMC's Interim Fishery Management Plan for Atlantic Groundfish (31 March 1982 to 18 September 1986; NEFSC 1987). During this period, fishing practices were reasonably unchanged, although (1) an increase in minimum mesh size for the Georges Bank region from 5.125 inches (130 mm) to 5.5 inches (140 mm) was implemented on 1 April 1983, and (2) the International Court of Justice (ICJ) line dividing Georges Bank into U.S. and Canadian portions (Fig. 1) was established in October 1984. The study period also encompasses years of both strong and weak recruitment as well as a 50% reduction in spawning-stock biomass, events that allow evaluation of resulting distributions over varying year-class strengths and stock sizes.

Materials and methods

Distribution by temperature and depth

Temperature and depth analyses were based upon data collected for Atlantic cod during NEFSC spring and autumn bottom-trawl surveys during 1982–86 in the Georges Bank–Southern New England region in depths of 9–366 m. The stratified-random survey design and the standardization of survey gear and methodology are described in detail by Grosslein (1969) and Azarovitz (1981). Water-column temperature profiles, including bottom temperature (recorded to 0.1°C), were obtained on approximately half the survey stations via expendable bathythermographs; depths (m) were recorded using research-vessel electronic depth-sounding equipment. All cod were measured (FL to nearest cm) and a subset sampled for age, growth, and maturity information. Otoliths were processed and age determinations obtained according to procedures described by Penttila (1988); maturity staging was performed using classification criteria outlined by Burnett et al. (1989).

Estimates of mean temperature and depth (weighted by number of fish in each tow), and associated standard errors and ranges, were calculated by age for each season and tested for age-specific effects. Based upon results from analyses of individual age-groups, ages 1 and 2 were combined as well as fish age 4 or greater. These age-groups, as well as age-3 fish, were then retested for age-group specific effects. Assumptions of data normality were complicated by two factors. The first is the inherent nature of survey catch data as described by Pennington and Grosslein (1978), who found that the two most likely models for the distribution of fish (i.e., heterogeneous Poisson and randomlydistributed clumps) both generated a negative binomial distribution. The second factor is that cod are not fully recruited to the survey sampling gear until age 3 or 4 (Serchuk and Wigley 1986). For these reasons, a distribution-free analysis of variance (Kruskal and Wallis 1952) was employed for statistical comparisons of temperature and depth distributions by age groups.

Spatial and temporal distribution

Commercial landings data (see Burns et al. [1983] for a detailed explanation of the commercial catch sampling program in the northeastern United States) for scrod cod collected by NEFSC during 1982–86 from the Georges Bank–Southern New England region (NEFSC Statistical Areas 521–526 and 537–539) were examined for spatial and temporal aspects of juvenile cod occurrences. Biases associated with the use of landings data were assumed to be negligible for this highly-directed fishery. Otter trawl catches account for 86–90% of the annual total cod landings (Serchuk and Wigley 1986); hence other gear types were excluded from subsequent analysis.

Table 1

Mean lengths-at-age, sample sizes, standard errors (SE), and range of observed values for age 0–10 cod *Gadus morhua* collected during NEFSC spring and autumn bottom-trawl surveys, 1982–86, in the Georges Bank–Southern New England region.

			Length (cm)		
Season	Age	*N*	$\bar{x}$	SE	Range
Spring	1	106	24.2	0.565	13.0–46.0
	2	458	43.8	0.253	26.0–58.0
	3	349	59.5	0.398	34.0–75.0
	4	212	69.0	0.570	46.0–89.0
	5	170	77.1	0.666	51.0–96.0
	6	69	84.7	1.013	64.0–108.0
	7	41	93.2	1.338	76.0–110.0
	8	24	102.5	2.235	79.0–124.0
	9	15	104.9	2.439	92.0–127.0
	10	5	102.8	5.678	87.0–119.0
Autumn	0	99	11.7	0.400	6.0–25.0
	1	279	36.9	0.308	23.0–51.0
	2	306	53.7	0.313	32.0–71.0
	3	145	68.0	0.557	42.0–83.0
	4	37	74.3	1.373	49.0–89.0
	5	16	85.4	2.432	60.0–99.0
	6	7	90.3	3.227	80.0–102.0
	7	6	98.8	2.613	94.0–110.0
	8	4	96.3	4.608	86.0–105.0
	9	3	105.0	5.196	96.0–114.0
	10	1	118.0	—	—

Fish in the scrod market category weigh 0.7–1.4 kg, measure 40–60 cm TL, and are 1–3 yr of age according to the growth function developed by Penttila and Gifford (1976).

Geographic resolution within Statistical Areas (SAR) was obtained by assigning the landings within each SAR to 10-min squares of latitude and longitude (~100 nm^2) based upon information from interviewed (i.e., dockside interviews of captains in which precise catch-location information was obtained) trips landing scrod cod. Scrod landings associated with interviewed trips were prorated upward for each 10-min square by the ratio, derived for each SAR, of total monthly landings to monthly interviewed landings. Prorated scrod landings were summarized quarterly for each year for each 10-min square.

Scrod cod landings were partitioned into age-groups 1, 2, 3 and 4+ by constructing a catch-at-age matrix using a technique described by Serchuk and Wigley (1986). In this method, quarterly mean weights for scrod cod were calculated by applying a length-weight equation to quarterly scrod length-frequency data; these means, in turn, were divided into scrod landings for the corresponding quarter to generate numbers landed. Age compositions for scrod landings were derived by applying quarterly age/length keys to numbers at length landed; resulting proportions at age were then applied to prorated scrod landings for each 10-min square to obtain estimates of landings by weight for each age-group.

Results

Temperature and depth distribution

Analyses of survey data were based upon 1455 and 904 cod collected during spring and autumn bottom-trawl surveys, respectively, during 1982–86. Mean lengths-at-age and associated statistics for cod ages 0–10 are presented in Table 1. Geographically, juvenile cod (defined as fish <37 cm, the minimum size at first maturity; Morse 1979) exhibited seasonal patterns of distribution. In spring, juveniles are dispersed throughout the Georges Bank–Southern New England region (Fig. 2A), while in autumn they are concentrated along the 100 m contour west of the Great South Channel and the Northern Edge and Northeast Peak of Georges Bank (Fig. 2B).

Differences in distribution with respect to both mean temperature and depth were noted for all age-groups of cod (Table 2). Mean temperatures were approximately 5.3°C in spring and 9.2°C in autumn for all age-groups, despite the fact that there was considerable overlap in the temperatures for the two seasons (Table 2). However, within seasons, differences in mean temperature observed between age-groups were within 0.5°C, except for age-0 cod in the autumn (Table 2). In general, distribution patterns were delineated more by differences in depth than temperature.

No age-0 cod were captured during spring surveys due to their pelagic larval existence at this time (early April–early May). Age-1 and age-2 cod were found at significantly shallower mean depths than age-3 and age 4+ cod (57.0 and 58.0 m vs. 68.4 and 86.3 m, respectively; Table 2). The difference between mean depths of age-3 and age 4+ cod was also significant (Kruskal-Wallis ANOVA, $p<0.01$; Table 3). In the autumn surveys (corresponding to late September–late October), age-3 cod were observed at a mean depth similar to those for ages 1–2 (85.8 m vs. 86.8 and 85.2 m, respectively; Table 2) and significantly different (Kruskal-Wallis ANOVA, $p<0.01$; Table 3) from that for age 4+ cod (116.0 m; Table 2). Additionally, age-0 cod were captured in the autumn and observed to be distinct from all other age-groups with respect to both temperature and depth (Table 2).

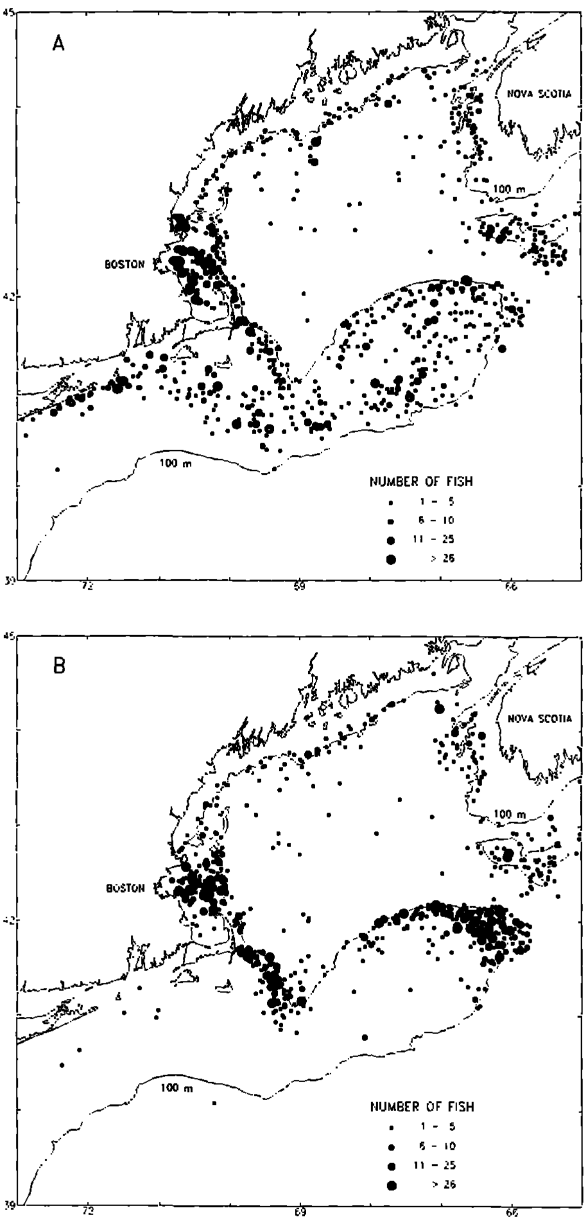

Figure 2
Geographic distribution (number/tow) of juvenile cod *Gadus morhua* <37 cm in length collected during NEFSC spring (A) and autumn (B) bottom-trawl surveys, 1968–86, in the Georges Bank–Southern New England region.

Spatial and temporal distribution

Statistical Area 521 accounted for 49% of total prorated scrod landings during the sampling period 1982–86, from a high of 57% in 1983 to a low of 29% in 1986, while SAR 523 and 522 contributed 14% and 13%, respectively; landings from Southern New England (SAR 537–539) accounted for only about 2% of total scrod landings (Table 4). Interviewed coverage was obtained for a high percentage of scrod landings

Table 2
Mean temperatures and depths, sample sizes, standard errors (SE), and range of observed values for age-groups 0, 1, 2, 3, and 4+ of cod *Gadus morhua* collected during NEFSC spring and autumn bottom-trawl surveys, 1982–86, in the Georges Bank–Southern New England region.

Season	Age	N	$\bar{x}$	SE	Range
			Temperature (°C)		
Spring	1	106	5.18	0.124	2.8–9.0
	2	458	5.03	0.050	3.3–12.1
	3	349	5.51	0.064	2.8–9.4
	4+	542	5.42	0.051	3.0–12.1
Autumn	0	99	10.02	0.233	5.8–14.3
	1	279	8.75	0.123	5.4–14.3
	2	306	9.02	0.108	5.4–14.3
	3	145	9.33	0.195	5.2–19.2
	4+	75	9.33	0.292	5.1–15.3
			Depth (m)		
Spring	1	106	56.98	2.001	25–122
	2	458	57.97	1.307	24–237
	3	349	68.36	1.966	24–210
	4+	542	86.34	2.346	25–307
Autumn	0	99	68.77	2.934	28–153
	1	279	86.80	2.185	28–230
	2	306	85.19	2.618	28–230
	3	145	85.80	3.945	31–205
	4+	75	116.00	7.793	26–328

Table 3

Results of Kruskal-Wallis analyses of variance of age-specific cod *Gadus morhua* distribution by temperature and depth by season, based on data for cod collected during NEFSC bottom-trawl surveys, 1982–86, in the Georges Bank–Southern New England region. NS = not significant, $p>0.05$; **highly significant, $p<0.01$.

Season	Age-group	Temp.	Depth
Spring	3 vs. 4+	NS	**
	1–2 vs. 3	**	**
	1–2 vs. 4+	**	**
Autumn	3 vs. 4+	NS	**
	1–2 vs. 3	NS	NS
	1–2 vs. 4+	NS	**

Table 4

Scrod cod *Gadus morhua* landings (t, live weight) by Statistical Area and year, 1982–86, in the Georges Bank–Southern New England region. Percentages of NEFSC commercial scrod landings for which interviewed coverage was obtained are given in parentheses. (Statistical Areas are shown in Figs. 3A–3D.)

Area	1982	1983	1984	1985	1986
521	4564(76)	4350(76)	1396(81)	3033(93)	1022(87)
522	1025(71)	978(73)	415(75)	855(93)	476(84)
523	1215(83)	958(95)	766(91)	939(87)	365(96)
524	554(68)	411(92)	517(92)	568(92)	757(84)
525	240(66)	109(80)	150(77)	204(91)	118(83)
526	466(92)	665(76)	413(90)	743(95)	579(84)
537	76(68)	135(73)	103(76)	60(74)	168(50)
538	4(30)	7(59)	3(61)	5(20)	5(60)
539	10(28)	3(22)	1(30)	<1(27)	<1(14)
Total	8154(76)	7616(79)	3764(84)	6407(92)	3490(84)

(76–92% annually during the period; Table 4), suggesting that the proration procedure employed in this study accurately depicts the patterns of landings.

Age-2 cod dominated commercial landings of scrod in all years except 1984 and 1986, when age-3 fish comprised the majority (Table 5); this exception is due to weak 1982 and 1984 year-classes (Serchuk and Wigley In press). Age-1 fish are too small to be caught by the commercial gear until quarters 3 and 4; conversely, age 4+ fish grow out of the scrod market category and into the next market category after quarter 2 (Table 5). Based upon these observations, and the observation above from analysis of survey data that age-3 cod are seasonally segregated from ages 1–2, analysis of juvenile cod distribution from commercial data was confined to age-2 fish.

Table 5

Age composition by weight (t, live weight) of scrod cod *Gadus morhua* landings by quarter, 1982–86, in the Georges Bank–Southern New England region.

		Quarter				
Year	Age-group	1	2	3	4	Scrod total
1982	1	0	0	4	230	234
	2	417	1140	3141	1836	6534
	3	190	469	203	31	893
	4+	198	240	56	0	494
	Total	805	1849	3404	2097	8155
1983	1	0	0	16	61	77
	2	199	976	1554	1260	3989
	3	437	1170	965	502	3074
	4+	212	156	93	15	476
	Total	848	2302	2628	1838	7616
1984	1	0	0	1	78	79
	2	73	381	395	418	1266
	3	611	672	395	102	1780
	4+	236	182	185	33	636
	Total	920	1235	976	631	3762
1985	1	0	0	10	101	111
	2	304	1002	1813	1826	4945
	3	192	510	335	123	1160
	4+	96	46	43	6	191
	Total	592	1558	2201	2056	6407
1986	1	0	0	0	120	120
	2	162	467	193	249	1071
	3	948	850	289	52	2139
	4+	148	4	8	0	160
	Total	1258	1321	490	421	3490

The following patterns of age-2 juvenile cod distribution emerged. In quarter 1, juvenile cod were concentrated in the Nantucket Shoals region (south of the stepped portion of the boundary between SAR 521 and 526) as well as being dispersed generally across the shallower central portions of Georges Bank, primarily in SAR 522 and 524 (Fig. 3A). By quarter 2, the area concentration was north of Nantucket Shoals (in SAR 521), while on Georges Bank there continued to be a dispersed distribution as in quarter 1 (Fig. 3B). In quarter 3, the Nantucket Shoals concentration had moved northeastward within SAR 521 to deeper water along the 100 m contour of the west slope of the Great South Channel; similarly, juveniles on Georges Bank had formed concentrations along the 100 m contour in SAR 522 (the east slope of the Great South Channel) and 523 (the Northern Edge and Northeast Peak areas; Fig. 3C). By quarter 4, the Nantucket Shoals concentration had

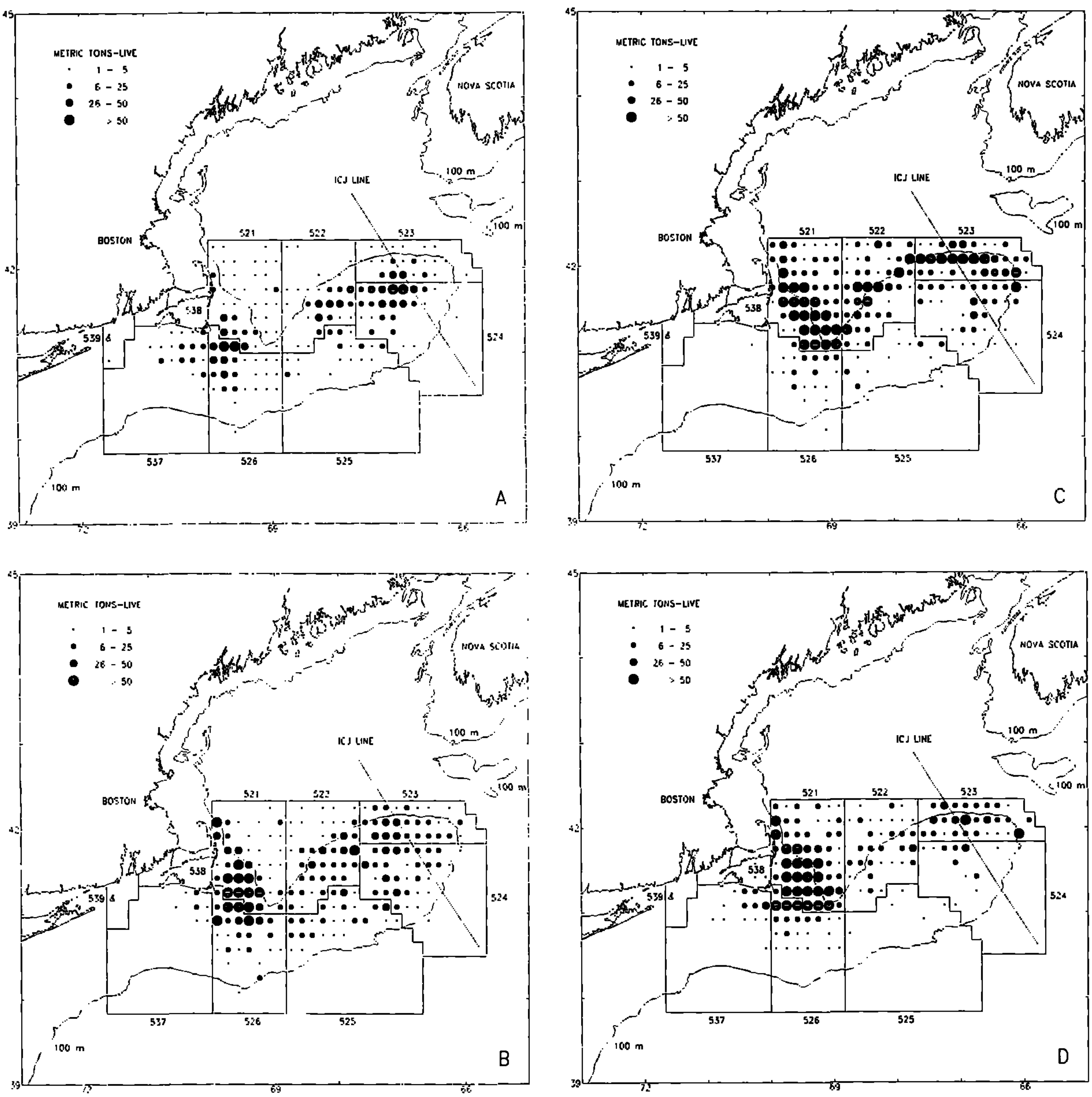

Figure 3
Distribution of age-2 cod *Gadus morhua* by 10-min squares of latitude and longitude from NEFSC scrod landings data (t, live weight), 1982–86, for quarters 1 (A), 2 (B), 3 (C), and 4 (D) in the Georges Bank–Southern New England region.

shifted south and southwestward within SAR 521 to shallower water and into SAR 526, resuming locations identified in quarter 1; however, the concentration on Georges Bank in SAR 523 was still present (Fig. 3D).

Visual inspection of quarterly distribution plots for each year suggested that these patterns of juvenile cod concentrations persisted over varying year-class strengths and stock sizes; however, in the interest of space, only aggregate plots are presented (Figs. 3A–3D). Age-2 cod from strong 1980 and 1983 year-classes (Serchuk and Wigley In press) exhibited the same seasonal movements described above, as did age-2 fish from the relatively weak 1982 and 1984 year-classes. Similarly, no changes in observed annual patterns were evident from 1982 to 1986, during which time spawning-stock biomass diminished from over 80,000 t to about 33,000 t (Serchuk and Wigley In press).

Discussion

The observed seasonal variation in distribution of age-3 cod relative to age groups 1–2 and 4+ may be associated with a transitional period involving both maturation and feeding habits. Age 3 encompasses a period in which there is a mismatch in size-at-first-maturity and the attainment of the adult diet. Median size and age at sexual maturity for cod is about 50 cm and 2.5 yr, respectively (Livingstone and Dery 1976), and during spring some age-3 fish recruit to the spawning population. Autumnal co-occurrence of age-3 fish with ages 1–2 may be related to diet. Bowman and Michaels (1984) presented data which indicate that cod <66–70 cm have not assumed the adult diet dominated by fish; the mean length of age-3 cod in autumn is 68.0 cm (Table 1).

In a mathematical evaluation of spatial distributions of several North Sea species, Houghton (1987) suggested that cod distributions were more complex and less persistent than those observed for haddock or flatfish. In this study, however, the spatial and temporal patterns observed for juvenile Atlantic cod from landings data were remarkably uniform over the study period, and did not seem to vary according to stock size or year-class strength. The use of commercial data in this study is somewhat constrained by management regulations, fishing practices, and the distribution of fishing effort, yet results from analysis of survey data in this study seem to corroborate these conclusions.

The use of mean values in this study to define patterns of temperature and depth distribution may better reflect general tendencies rather than absolute preferences; in actuality, cod of all ages except age 0 were found at virtually all available temperatures and depths. Yet the patterns that emerged in this study are, for the most part, consistent with those identified in other studies. Both Schroeder (1930) and Wise (1962) noted the tendency for older cod to move into greater depths. Scott (1988) found that cod in colder Canadian waters were distributed at temperatures of 2–10°C, with largest catches occurring at 4–6°C. The apparent contradiction posed by the movement of cod to deeper, warmer water in winter–spring observed by Scott (1988), and the observations in this study of movement to shallower water on Nantucket Shoals and Georges Bank during this period, is an artifact of the different temperature regimes for the two regions; in each case, cod are changing depth locations to maintain preferred temperatures. Schroeder (1930) reported cod occurrences within an annual range of 0–17°C in the region from Nantucket Shoals to North Carolina, and attributed the triggering of the autumn migration of Nantucket Shoals adult cod westward to New Jersey for winter spawning to falling bottom temperatures in October. Similarly, movements of juvenile cod from Nantucket Shoals to deeper water off Chatham and the Great South Channel in summer–early autumn were thought to be in response to locally-available, cooler temperatures (Schroeder 1930). Wise (1958, 1962) determined from tagging studies that a resident population of cod inhabited the Nantucket Shoals–Great South Channel area year-round, but that Nantucket Shoals also represented the summer residence for the population of cod that wintered off the coast of New Jersey. Thus, the distribution patterns observed in this study within SAR 521 and 526 would most likely reflect seasonal movements of resident cod, although the migratory population may partially contribute to landings for quarters 2 and 3 in SAR 526.

Scott (1982) concluded from an analysis of fish distribution by bottom type that, although generally associated with sand-gravel sediments, cod occurred over all substrates and that observed patterns of distribution were more likely due to the bottom-type preferences of major prey items (e.g., *Cancer* crabs, sand lance, *Ammodytes* sp., etc). Although no quantitative analysis of distribution by bottom sediment was undertaken here, the seasonal shifts in concentration identified in this study do not suggest any major change in substrate preference of cod. However, the Great South Channel and the Northern Edge–Northeast Peak regions, where concentrations of scrod cod occur in quarters 3 and 4, are characterized by coarser sediment types than those generally found elsewhere on Georges Bank (Wigley 1961, Schlee 1973).

Based on the above analyses, there is evidence for well-defined seasonal and geographic shifts in concentration for juvenile Atlantic cod in the Georges Bank–Southern New England region. Moreover, these patterns of concentration appear to be associated primarily with temperature. The high level of spatial and temporal resolution possible, i.e., 10-min squares of latitude and longitude and quarters, suggest that this type of study may be useful in assisting fisheries managers with decisions regarding seasonal and areal closures under the Flexible Area Action System.

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