



**Massachusetts Division of Marine Fisheries
Technical Report TR-12**

Technical Report

Spatial Distribution of Ages 0 and 1 Atlantic Cod (*Gadus morhua*) off the Eastern Massachusetts Coast, 1978- 1999, Relative to 'Habitat Area of Special Concern'

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Department of Fisheries, Wildlife, and Environmental Law Enforcement
Executive Office of Environmental Affairs
Commonwealth of Massachusetts**

June 2002

Massachusetts Division of Marine Fisheries Technical Report Series

Managing Editor: Michael P. Armstrong

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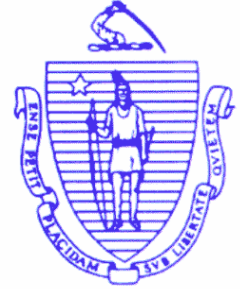
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Spatial Distribution of Ages 0 and 1 Atlantic Cod (*Gadus morhua*) off the Eastern Massachusetts Coast, 1978- 1999, in Support of 'Habitat Area of Special Concern'

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June 2002

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Abstract: Twenty-two years of semi-annual inshore research-trawl survey data provided empirical evidence that eastern Massachusetts coastal embayments annually serve as a settlement area for pelagic juvenile Atlantic cod (*Gadus morhua*); at least two influxes of newly-settled demersal juveniles were evident in most years. Analyses of mean catch per tow, mean length, and frequency of occurrence for age 0 and age 1 cod revealed striking and stable patterns of spatial distribution by depth. In spring, newly-settled age 0 cod preferred depths <90' while age 1 occupancy was centered within 61-180'. In autumn, age 0 cod were widely distributed from 31-180' but were principally concentrated at 91-180' and age 1 showed strong preference for the 121-180' stratum. Analyses of frequency of occurrence and mean length of age 0 and age 1 indicated that depth is an important factor governing distribution. Smaller, younger cod occupied shallower depths and moved to deeper water as they grew in size and age. Except for slightly broader depth occupancy by age 0, results were generally consistent with published research on the functional role of coastal and offshore bank settlement habitats and postsettlement processes. Inshore cod settlement habitats and ontogenetic movements are historically and geographically similar with the pattern of cod distribution reviewed for waters off Atlantic Canada and in the Gulf of Maine. Survey abundance indices and analyses coupled with these reviews constitute strong evidence for a coastal 'Habitat Area of Particular Concern' designation for the Gulf of Maine Atlantic cod stock.

Introduction

The Essential Fish Habitat (EFH) mandate of the Magnuson-Stevens Act requires that Fishery Management Plans identify Habitat Areas of Particular Concern (HAPC) within designated EFH for managed species (DOC 1996). One economically important species managed by the New England Fisheries Management Council (NEFMC) is Gulf of Maine Atlantic cod (*Gadus morhua*), a stock whose status remains critically low despite management measures imposed to forestall collapse (NEFMC's MSMC 1999).

Scientific studies undertaken mainly in Atlantic Canada highlight the functional dependence of early post-settlement cod on certain habitat types within the subtidal benthic community. Because the results of this research justify the ecological function and sensitivity to anthropogenic stress criteria for an HAPC, they were summarized as part of a proposal to designate the entire perimeter of the Gulf of Maine from mean low water (MLW) to a depth of 30' below MLW as an HAPC (NEFMC 1999). This measure would enable a higher standard of awareness, protection, and consultation between federal and state agencies to minimize impacts to "critical" habitat thus improving juvenile survivorship and perhaps enhancing recruitment to the fishery.

Researchers have described the problems of assessing abundance and distribution of post-larval pelagic and demersal juvenile cod, age-groups 0 and 1 (Suthers and Frank 1989; Dalley and Anderson 1997). Fluctuations in success of cod spawning and oceanographic conditions influence survival rate of pre-settlement young, location of settlement areas, and interannual catch variation of post-settlement fish. Because of temporal changes in habitat availability and utilization, documenting and evaluating habitats of disproportionate importance to demersal age 0 distribution is very much related to choosing the appropriate spatial and temporal scales of sampling (Schneider et al. 1999).

Measuring relative abundance of age 0 and 1 gadids has been problematic owing to difficulties in sampling appropriate post-larval habitat (Keats 1990; Keats and Steele 1992), low daytime catchability (Colton 1965; Methven and Bajdik 1994; Gibson et al. 1996), and size selectivity of capture gear (Methven and Schneider 1998). Methven and Schneider (1998) compared catches among a variety of active and passive sampling gears and found that bottom otter trawls took some of the highest catches of young cod; however, 92% were taken at night, supporting Keat's (1990) observations and opinion that "routine surveys to estimate abundance inshore will have to be conducted at night."

Research-vessel multispecies trawl surveys have important operational limitations and biases. Hardbottom areas cannot be effectively sampled. When bobbins and rockhoppers are added to a trawl's sweep to minimize gear damage, catchability of cod early age-groups decreases (Engas and Gode 1986). Inshore waters are often only partly accessible to large research trawlers required for synoptic wide-ranging offshore coverage, thus some species' juvenile stages may be unavailable to national surveys. Inshore trawling after dusk may be dangerous and problematic because of navigation hazards and difficulty avoiding passive fishing gear thus jeopardizing both the survey trawl and fixed gear. Furthermore, trawl sampling in the Massachusetts' sector of the Gulf of Maine is often hampered by extensive seasonal gill net and lobster trap concentrations that preclude access to some areas and bottom habitats.

Notwithstanding sampling difficulties, the Massachusetts Division of Marine Fisheries (MDMF) long-term research trawl survey catch records were used to link cod productivity and nearshore habitats in the southwest Gulf of Maine. We analyzed 22 years (1978-99) of young juvenile cod data collected from eastern Massachusetts' territorial waters. We postulate that the distribution of moderate to high age 0 densities indicates areas of higher cod productivity and suggests preferred habitat. Results are integrated with published ecological information describing how habitat mediates post-settlement processes, i.e., predation, competition, growth, and habitat selection. A review of age 0 distribution information in coastal and offshore waters of Atlantic Canada provides a biological and historical perspective to that of the Gulf of Maine proper and the northern New England coast in particular.

Methods

Data Collection. Spring and autumn trawl surveys of Massachusetts territorial waters have been conducted during daylight hours every May and September, over approximately the same dates, since 1978. The survey uses a stratified random sampling design with strata defined by region and depth. This study concerns two of the survey's five regions: region 4 (Cape Cod Bay, Provincetown to the North River) and region 5 (Massachusetts Bay, North River to the MA/NH border). Regions are stratified into depth strata: $\leq 30'$, 31-60', 61-90', 91-120', 121-180', and $>180'$. Sampling sites are

allocated according to proportion of stratum area to total survey area. Selected sites are occasionally relocated due to untowable, rough bottom or concentrations of fixed gear and sometimes deleted when no alternative tow sites can be located within a stratum.

A 20-minute tow is made at each station with a two seam 3/4 Whiting trawl: 39' headrope/ 51' footrope, with 3.25" nylon stretch mesh in the wings and square, and 2.5" mesh in the body and codend. The codend contains a 0.25"-mesh liner. The net is rigged with a 3.5" rubber disc-covered chain sweep, 62.0' chain bottom legs, 60.0' wire top legs, and 5.0 X 3.25', 325 lb. wooden trawl doors. The gear is fished with a 3:1 ratio of towing cable length to depth and at a vessel speed of 2.5 knots. At each station, a marine hydrographic instrument is used to record bottom water temperature. Standard survey techniques are followed in processing the catches, i.e., species are sorted, weighed (nearest 0.1 kg), and length-frequency (nearest cm) recorded. Sample collections are also routinely made including removal of otoliths of cod for assessment-related application. In Massachusetts' territorial waters, the average number of spring stations completed by region and stratum (shallowest to deepest) were: region 4 - 3.0, 4.6, 4.6, 4.7, 4.9, 2.0 (total 23.8); region 5 - 2.8, 2.7, 3.0, 2.7, 4.5, 2.8 (total 18.5). Autumn station averages and totals were: region 4 - 2.5, 4.3, 4.8, 4.7, 5.2, 2.0 (total 23.5); region 5 - 2.3, 1.9, 2.8, 2.3, 4.6, 3.1 (total 17.0). For purposes of analysis, the stratified mean number per tow and coefficient of variation of the mean (a standard measurement of precision) of age 0 and age 1 cod have been calculated for each of the six comparable depth strata in region 4 and 5. For purposes of clarity, these statistics for combined strata will be termed a depth stratum, i.e., the stratified statistics for strata 25 and 31 (strata $\leq 30'$ in regions 4 and 5) will be called the $\leq 30'$ stratum, and the tabulated within year mean of stratum means will be called a yearly mean. Sampling intensity within the combined regions of the study area has been one station per 21 and 22 mi^2 . in spring and autumn, respectively.

Statistical Analyses. For this analysis, cod length groups corresponding to age 0 - 1-10 cm, spring; 1-15 cm, autumn - and age 1 - 11-29 cm, spring; 16-33 cm, autumn - were established based on MDMF and National Marine Fisheries Service (NMFS)/ Northeast Fisheries Science Center

(NEFSC) age-length keys (J. Burnett, NEFSC, personal communication) and applied to the MDMF length-frequency distribution of catches.

Year and stratum effects were tested using two-way analysis of variance (ANOVA) without replication for age 0 and age 1 for spring and autumn surveys. We applied Tukey's honestly significant difference test for a posteriori multiple comparisons among strata means and to identify homogeneous subsets (Zar 1984).

In order to determine depth preferences, within year strata means were standardized to Z scores using unweighted within year means for all strata to remove year-class effects. Mean Z scores were calculated for each strata for the spring and autumn time series for ages 0 and 1. A zero mean Z score represents average catch rates, positive mean Z score in a stratum represents above average catch rates, and negative mean Z scores represent below average catch rates over the time series. The time series of annual stratum Z scores with mean stratum Z lines are plotted and significance of the slope of the trend lines were tested using linear regression.

Year and stratum effects were tested using the Kruskal-Wallis test, the non-parametric equivalent of single factor ANOVA for ranked data. The non-parametric method does not rely on assumptions about distribution of the data. Depth preferences were also examined by ranking strata within a year, with the highest stratum catch per tow ranked 2.5 and lesser rankings decremented in units of 1.0, the stratum with the lowest catch per tow assigned a rank of -2.5. Rankings above zero indicate the stratum catch rate in a year was above the mean rank, rankings below zero were below the mean rank. Mean stratum ranks were calculated for the entire time series.

The frequency of occurrence (number of tows) containing age 0 and age 1 cod was tested for independence from strata with a chi-square test. The null hypothesis was that the frequency of occurrence of age 0 and age 1 is independent of depth stratum. For spring data, all years were pooled. For autumn data, age 1 were not captured in the $\leq 30'$ stratum, so strata $\leq 30'$ and $30-60'$ were pooled as were all years.

We also tested whether the frequency of co-occurrence of age 0 and age 1 was independent of the frequency of capture of the two age-groups with a chi-square analysis. Six strata and all years were pooled for the spring series, and five strata (no age 1 cod caught in $\leq 30'$, autumn) and all years were

pooled for the autumn series. We calculated the expected frequency of co-occurrence by multiplying the number of stations in the stratum by the product of the probability of the occurrence of age 0 and probability of occurrence of age 1 (i.e., frequency of occurrence/ total stations for each age-group). The null hypothesis was that frequency of co-occurrence within a depth stratum is a random event whose probability is the product of the probability of capture for age 0 and age 1 within that stratum. If age 0 and age 1 display avoidance behavior, the frequency of co-occurrence would be less than expected; similarly, if attraction occurs, then frequency of co-occurrence would be more than expected.

Stratum and year effects on mean length (age 0 and age 1 combined) of cod were tested with a two-way ANOVA for the spring and autumn surveys. Twenty-one years were used in the spring analysis (spring 1978 had a missing value in the $>180'$ stratum). Eight years and six depth strata were used for the autumn dataset. In order to include more years in the analysis, the $\leq 30'$ and $31-60'$ strata were pooled. This increased the number of years in the analysis to 17.

Stratum and year effects on mean length of age 0 and age 1 cod were tested with two-way ANOVA for the spring and autumn surveys. Six years where mean length values were available in all six strata were used in the spring analysis. Eight years and six depth strata were used for the autumn analysis.

Catch weighted average bottom water temperature and average depth was determined for ages 0 and 1 catches over the time series. Catch weighted average temperature was calculated by summing the product of temperature and cod catch in number at each station and dividing by the sum of the cod catch at all stations.

$$\bar{T} = \frac{1}{\sum_{i=1}^L C_i} \sum_{i=1}^L C_i T_i$$

Where: C_i = catch at station i

T_i = temperature at station i

L = number of stations in strata 25

through 36

Catch weighted mean seasonal depth was calculated for these age-groups by summing the product of mean depth and cod catch in number at

each station and dividing by the sum of the catch at all stations. Mean depth was estimated as the average of starting depth and ending depth for a tow. Ending depth was not recorded for 1978-1980 surveys so starting depth was used as a proxy for mean depth.

$$\bar{D} = \frac{1}{\sum_{i=1}^L C_i} \sum_{i=1}^L C_i D_i$$

Where: D_i = mean depth at station i

T_i = temperature at station i

L = number of stations in strata 25 through 36

Results

Over the 22 year time series, 42,698 age 0 and 14,377 age 1 juvenile Atlantic cod were caught in Massachusetts' territorial waters of the southwest portion of Gulf of Maine (Table 1). Inclusive depth ranges of age 0 and age 1 cod were 18-264' and 20-266', respectively. In the $\leq 30'$ stratum, the minimum and mean towed depth was 16' and 27', respectively. For the $>180'$ stratum, the maximum and mean towed depth was 277' and 216', respectively.

Young juvenile cod catch rates by depth stratum and season, and associated thermal regimes are described for each sampling season with tabulated information. For example, in the $\leq 30'$ depth stratum, the spring time series mean number of age 0 cod was 31 fish per tow with the annual stratified mean number per tow ranging from 0 to 376 (Table 3). Age 0 cod were captured at 75 (59%) of 128 stations sampled in $\leq 30'$ (Table 12). Time series mean spring bottom water temperature in the $\leq 30'$ stratum was 8.3°C, the annual means for all years varied from 6.3-11.3°C (Table 2). Examination of Tables 3-6 shows variation in yearly means (up to 3 orders of magnitude) which may be related to year class strength as a result of interannual variation in settlement or survival rates. Considerable variation clearly exists among strata means within year.

ANOVA for Year and Strata Effects on Catch per Tow. The two way ANOVA found highly significant ($P < 0.001$) year effects for spring age 0, autumn age 0, and spring age 1. Year effects were not significant for autumn age 1 ($P = 0.34$). Strata

effects were highly significant ($P < 0.01$) for spring age 0, spring age 1, and autumn age 1. Strata effects were not significant for autumn age 0 ($P = 0.172$).

For the season/age-group combinations with significant strata effects, Tukey's honestly significant difference test identified homogeneous groups of stratum means. For spring age 0 strata means, two homogeneous groups were detected (Table 7): Group A - strata sets $\leq 30'$, 31-60', and 61-90' ($P = 0.128$); and Group B - strata sets $\leq 30'$, 61-90', 91-120', 121-180', and $>180'$ ($P = 0.363$). Overlapping sets of similarities exists: both the $\leq 30'$ and 61-90' strata were common to both homogeneous groups. The test did not have the statistical power to distinguish the group to which these strata belonged. Clearly, the differences between the groups is driven by significant differences between the 31-60' stratum and the $>90'$ strata set. The probabilities in Table 7 clearly show that the stratum mean for $\leq 30'$ is closer in affinity to strata $<90'$ than strata $>90'$. Our biological interpretation of these data is that depths $<60'$ are the preferred settlement depths for age 0 cod in spring and settlement declines as depth increases.

For spring age 1 strata means, two homogeneous groups of means were detected (Table 8): Group A - strata sets $\leq 30'$, 31-60', and $>180'$ ($P = 0.939$); and Group B - 61-90', 91-120', and 121-180' ($P = 0.948$). Spring age 1 appear to prefer the intermediate depth strata 60-180'. For autumn age 1 strata means, two homogeneous groups were detected (Table 9): Group A - stratum 121-180' ($P = 1.000$); and Group B - strata set $\leq 30'$, 31-60', 61-90', 91-121', and $>180'$ ($P = 0.511$). Autumn age 1 show a high preference for the 121-180 depth zone.

Z Scores. Z score transformation of within year stratum means provides a method to graphically detect patterns of depth preferences by removing year effects. Mean stratum Z scores are good indicators of general depth preferences for the time series, and plots of stratum Z scores provide information on the stability of these patterns across time.

Time series mean strata Z scores show striking patterns of depth preferences over season and age. Spring age 0 mean stratum Z scores were above average for $\leq 30'$, 31-60', near average for 61-90' depth strata, and well below average for the three strata $>90'$ (Fig. 1A, Table 10).

Table 1. Summary of age 0 and age 1 Atlantic cod catches in MDMF Inshore Trawl Surveys with associated catch-weighted mean depth and bottom temperatures, 1978-1999.

	Age 0		Age 1	
	Spring	Autumn	Spring	Autumn
Total Number of Stations	933	850	933	850
Number of Stations With Catch	358	456	385	122
Number of Fish	17,319	25,379	11,861	2,516
Catch-Weighted Mean Depth (ft.)	53	110	115	167
Catch-Weighted Mean Bottom Water Temperature (°C)	7.3	8.4	5.3	8.7

Table 2. Mean bottom water temperatures (°C) by depth stratum for MDMF spring and autumn surveys undertaken in SW portion of the Gulf of Maine (MA territorial waters), 1978-1999.

Year	≤ 30'		31 - 60'		61 - 90'		91 - 120'		121 - 180'		> 180'		Stratified Mean	
	SPRING	AUTUMN	SPRING	AUTUMN	SPRING	AUTUMN	SPRING	AUTUMN	SPRING	AUTUMN	SPRING	AUTUMN	SPRING	AUTUMN
1978	11.3	14.8	9.3	13.3	7.2	10.1	7.5	9.5	7.6	8.1	11.5	6.8	8.5	10.1
1979	8.9	11.5	8.1	11.3	6.6	8.6	4.7	8.9	4.2	8.2	3.7	8.5	5.9	9.3
1980	7.3	15.5	8.2	12.4	6.5	10.2	7.6	9.2	6.1	8.9	5.4	8.6	6.8	10.4
1981	8.3	14.3	8.0	11.3	6.0	12.9	6.0	12.6	5.9	11.8	5.3	9.7	6.4	12.5
1982	7.0	14.9	5.9	12.4	5.4	9.2	4.8	7.7	4.5	7.6	4.3	7.4	5.2	9.4
1983	6.6	15.0	8.0	14.9	6.7	10.8	6.0	9.2	6.3	9.0	5.0	8.3	6.5	11.1
1984	7.5	12.7	7.5	11.7	5.0	9.3	4.7	8.4	4.5	7.2	4.6	7.0	5.4	9.0
1985	8.9	16.3	8.3	15.0	7.2	13.7	6.4	11.2	5.2	9.5	4.7	8.1	6.6	11.9
1986	8.9	14.9	8.1	13.1	6.9	10.5	6.9	9.7	6.0	9.0	5.3	8.0	6.9	10.4
1987	8.3	12.7	7.7	8.1	7.0	6.4	6.6	5.6	5.7	5.2	5.6	5.0	6.7	6.4
1988	8.6	15.1	7.7	10.9	6.6	9.7	5.7	8.2	4.7	6.9	4.2	6.2	6.0	8.8
1989	6.7	12.1	5.1	9.8	4.2	8.6	3.8	7.9	2.8	7.3	2.2	6.2	4.0	8.5
1990	7.7	16.5	7.5	14.4	7.1	12.8	4.6	10.3	3.9	9.1	3.0	7.5	5.4	11.5
1991	9.7	16.5	10.2	16.2	8.2	13.3	7.7	11.5	6.0	9.7	4.8	8.7	7.6	12.1
1992	8.6	12.9	8.1	11.0	7.6	9.0	6.4	7.8	5.2	6.7	4.4	6.2	6.4	8.6
1993	8.4	13.1	7.1	12.0	5.5	8.9	5.0	8.4	4.4	8.6	3.7	6.9	5.4	9.2
1994	8.9	16.0	8.3	16.0	7.6	14.6	6.2	14.0	4.8	10.4	4.5	9.7	6.3	13.2
1995	8.5	14.0	8.5	12.5	7.5	10.3	7.3	9.6	5.4	8.7	4.5	8.8	6.7	10.2
1996	6.6	16.5	7.0	15.7	5.3	13.3	4.9	12.1	4.3	8.8	4.0	8.3	5.2	12.0
1997	6.3	17.0	7.0	16.1	6.1	12.1	5.8	9.4	5.1	8.7	5.0	8.2	5.8	11.4
1998	9.0	14.1	8.0	10.7	6.7	9.1	6.2	8.4	4.9	6.6	4.6	5.7	6.3	8.8
1999	10.3		8.7		7.5		5.9		4.9		4.5		6.6	
MEAN	8.3	14.6	7.8	12.8	6.6	10.6	5.9	9.5	5.1	8.4	4.8	7.6	6.2	10.2

Spring age 1 mean stratum Z scores are above average for 61-90', 91-120', and 121-180' strata and below average for ≤30', 31-60, and >180' (Fig. 1B, Table 10). A comparison of the spring age 1 and spring age 0 mean stratum Z scores suggest strong but partial segregation of the two age-groups.

Autumn age 0 mean stratum Z scores were above average for 91-120' and 121-180' depth strata; near average for 31-60' and 61-90'; and, below average for ≤30' and >180' (Fig. 1C, Table 10). The variance of mean stratum Z scores was the lowest in the four data sets, implying that age 0 cod are more eurybathic in the autumn than in the spring

(Table 10).

Autumn age 1 mean stratum Z scores were well above average for 121-180', average for >180', and below average for the four strata <120' (Fig. 1D, Table 10). Seasonally lower time series mean catch rates (Table 6), lower frequency occurrence across all strata (Table 12), a seasonal catch-weighted depth shift (115' to 167'; Table 1), and the absence of a significant year effect for autumn age 1 suggests that a large proportion of yearlings either moved out of the study area or were less vulnerable to our sampling gear in autumn.

Table 3. Catch rate of age 0 demersal Atlantic cod (stratified mean no. per 20 min. tow) and coefficient of variation of stratified means by depth strata for MDMF Inshore Spring Trawl Surveys, 1978-1999.

Year	≤ 30'		31 - 60'		61 - 90'		91 - 120'		121 - 180'		> 180'		Yearly Mean
	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	
1978	25.47	39.5	34.51	58.0	48.26	35.9	7.38	30.8	0.00	4.0	0.00	0.0	19.27
1979	30.56	67.8	215.65	72.5	91.57	84.3	8.26	93.2	2.23	25.0	0.93	84.2	58.20
1980	0.97	77.5	13.72	77.3	22.62	33.7	6.08	15.0	1.90	58.3	0.00	0.0	7.55
1981	0.00	0.0	22.74	88.9	73.75	58.2	10.41	86.7	0.39	83.1	1.48	100.0	18.13
1982	1.42	71.3	5.61	93.2	1.17	91.1	0.63	46.8	0.40	44.7	0.00	0.0	1.54
1983	0.85	73.1	1.24	88.1	0.76	52.9	0.00	0.0	0.07	100.0	0.00	0.0	0.49
1984	1.30	65.2	0.00	0.0	0.30	50.0	0.10	100.0	0.00	0.0	0.00	0.0	0.28
1985	0.18	100.0	3.79	47.6	0.15	100.0	0.14	100.0	0.19	57.7	0.42	71.9	0.81
1986	2.58	33.5	3.80	32.7	0.00	0.0	0.18	100.0	0.15	61.2	0.00	0.0	1.12
1987	2.94	79.5	0.56	54.1	0.91	100.0	0.10	100.0	0.25	100.0	0.00	0.0	0.79
1988	3.67	54.0	5.33	38.7	0.73	42.1	0.10	100.0	0.68	40.3	0.59	51.1	1.85
1989	0.49	73.3	0.12	100.0	0.33	66.7	0.39	100.0	0.07	100.0	0.00	0.0	0.23
1990	6.52	53.6	18.80	72.2	0.48	55.5	0.72	56.7	0.31	100.0	2.95	100.0	4.96
1991	1.09	79.5	0.98	78.3	0.11	100.0	0.00	0.0	0.00	0.0	0.49	100.0	0.45
1992	2.67	72.1	5.21	41.7	0.82	84.9	0.00	0.0	0.21	100.0	0.00	0.0	1.49
1993	78.27	12.3	266.77	75.9	93.97	75.7	4.13	52.7	0.46	71.0	0.00	0.0	73.93
1994	7.23	51.8	19.99	69.4	0.00	0.0	0.14	100.0	0.00	0.0	0.25	100.0	4.60
1995	27.77	59.5	37.17	58.9	4.46	44.3	1.33	62.7	0.42	76.3	0.00	0.0	11.86
1996	51.54	40.0	5.98	52.5	0.77	62.3	0.43	100.0	0.07	100.0	0.00	0.0	9.80
1997	45.73	67.6	25.79	46.4	8.58	57.4	0.24	72.0	0.00	0.0	0.00	0.0	13.39
1998	18.59	81.0	104.18	42.4	11.20	68.8	1.07	43.0	0.09	100.0	1.72	71.4	22.81
1999	375.78	79.3	458.79	63.7	26.45	52.8	6.25	88.9	0.53	73.8	0.25	100.0	144.68
Timeseries Mean	31.16		56.85		17.61		2.19		0.38		0.41	Grand Mean = 18.10	
25th percentile	1.09		3.79		0.33		0.10		0.07		0.00		0.81
50th percentile	2.94		5.98		0.82		0.39		0.21		0.00		4.60
75th percentile	27.77		25.79		11.20		1.33		0.42		0.49		13.39

Table 4. Catch rate of age 1 demersal Atlantic cod (stratified mean no. per 20 min. tow) and coefficient of variation of stratified means by depth strata for MDMF Inshore Spring Trawl Surveys, 1978-1999.

Year	≤ 30'		31 - 60'		61 - 90'		91 - 120'		121 - 180'		> 180'		Yearly Mean
	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	
1978	4.03	98.4	1.90	71.5	20.78	77.4	42.88	48.5	10.60	46.3	0.00	0.0	13.37
1979	0.18	100.0	12.65	34.9	23.20	40.3	16.32	76.1	85.21	59.3	15.22	90.1	25.46
1980	0.23	100.0	2.40	85.4	66.34	34.1	98.57	26.3	75.30	42.3	0.75	50.8	40.60
1981	11.68	97.7	32.06	85.9	22.84	55.6	55.71	68.5	19.00	27.3	10.59	100.0	25.31
1982	0.00	0.0	3.19	96.1	32.53	85.8	14.24	45.3	23.11	40.5	2.15	66.6	12.54
1983	0.31	100.0	18.91	72.7	68.70	6.3	52.49	73.2	28.08	41.0	10.32	100.0	29.80
1984	0.00	0.0	1.44	100.0	3.59	60.9	4.35	70.7	5.85	43.3	0.37	74.2	2.60
1985	0.00	0.0	0.12	100.0	3.43	95.7	2.77	39.8	5.06	46.6	0.17	100.0	1.93
1986	0.00	0.0	0.00	0.0	84.12	100.0	3.87	52.4	3.93	52.4	0.51	57.7	15.41
1987	0.18	100.0	4.44	59.0	15.31	56.6	15.50	73.6	8.54	36.1	10.59	97.6	9.09
1988	0.00	0.0	0.49	78.3	25.70	54.0	11.25	63.9	32.14	31.0	1.60	71.0	11.86
1989	0.98	73.3	8.38	47.6	40.62	76.0	48.13	67.5	46.09	40.8	7.20	32.2	25.23
1990	0.00	0.0	0.38	100.0	8.47	66.1	17.31	54.9	12.34	92.5	0.34	50.0	6.47
1991	0.00	0.0	10.81	100.0	0.57	100.0	9.96	91.3	12.31	73.5	0.41	25.0	5.68
1992	0.00	0.0	0.24	100.0	5.58	86.6	4.35	55.0	17.75	72.4	1.68	10.1	4.93
1993	0.18	100.0	5.44	68.7	8.35	97.8	1.71	42.7	10.51	35.3	3.95	24.6	5.02
1994	0.00	0.0	6.29	97.5	0.41	63.8	12.71	81.5	16.19	49.3	14.92	63.5	8.42
1995	0.00	0.0	0.36	57.7	25.51	99.6	4.44	54.7	4.90	27.9	0.25	100.0	5.91
1996	0.00	0.0	0.37	73.9	0.55	100.0	0.29	0.0	4.29	76.0	0.25	100.0	0.96
1997	0.00	0.0	0.60	100.0	1.51	100.0	6.71	47.4	7.60	38.3	0.25	100.0	2.78
1998	0.00	0.0	0.00	0.0	0.86	70.8	0.29	100.0	11.43	35.8	0.00	0.0	2.10
1999	0.00	0.0	0.00	0.0	54.87	100.0	0.99	70.0	10.92	34.7	0.17	100.0	11.16
Timeseries Mean	0.81		5.02		23.36		19.31		20.51		3.71	Grand Mean = 12.12	
25th percentile	0.00		0.36		3.43		3.87		7.60		0.25		4.93
50th percentile	0.00		1.44		15.31		9.96		12.31		0.75		8.42
75th percentile	0.18		6.29		32.53		16.32		23.11		7.20		15.41

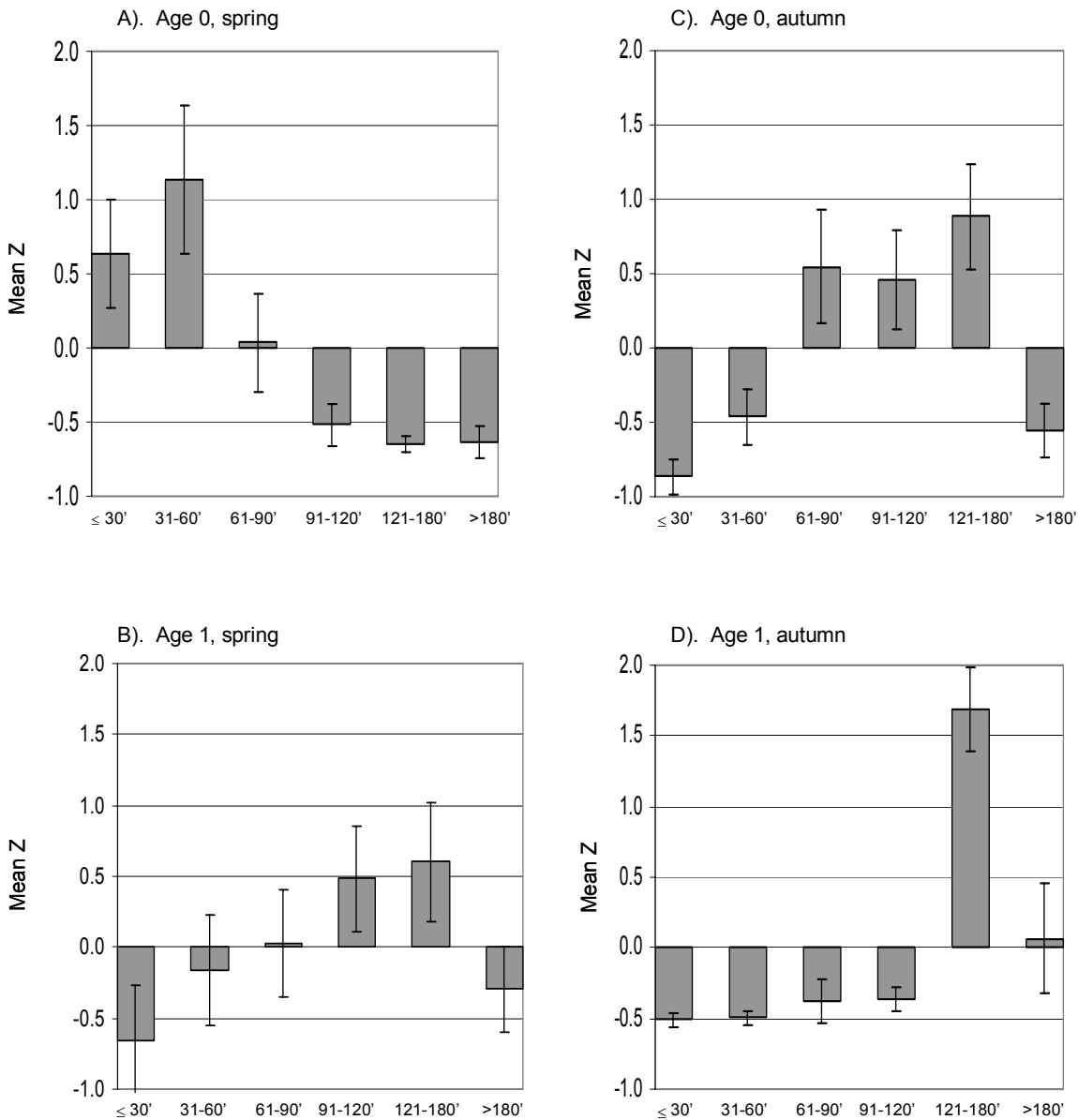
Table 5. Catch rate of age 0 demersal Atlantic cod (stratified mean no. per 20 min. tow) and coefficient of variation of stratified means by depth strata for MDMF Inshore Autumn Trawl Surveys, 1978-1999.

Year	≤ 30'		31 - 60'		61 - 90'		91 - 120'		121 - 180'		> 180'		Yearly Mean
	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	
1978	0.93	100.00	5.95	56.60	26.14	83.00	568.82	55.70	181.56	34.70	22.80	24.70	134.37
1979	0.00	0.00	0.88	65.10	15.18	49.40	7.63	54.50	1.69	41.40	1.40	88.70	4.46
1980	0.00	0.00	0.00	0.00	4.55	60.50	17.42	71.20	6.58	33.60	0.74	100.00	4.88
1981	0.80	100.00	0.00	0.00	0.00	0.00	2.61	66.70	2.26	47.00	0.42	71.90	1.02
1982	15.61	100.00	4.84	75.30	9.63	68.60	1.01	52.30	0.78	35.00	0.13	100.00	5.33
1983	0.00	0.00	0.16	100.00	0.15	100.00	0.29	100.00	3.38	47.60	0.91	32.90	0.82
1984	4.19	100.00	5.35	81.60	2.32	49.10	8.31	45.30	22.31	53.60	29.57	34.30	12.01
1985	0.00	0.00	0.00	0.00	0.26	71.60	1.92	46.80	6.60	42.00	2.76	34.00	1.92
1986	0.00	0.00	1.38	51.90	1.77	68.50	0.72	72.30	5.48	23.10	2.92	25.00	2.05
1987	1.00	100.00	488.13	13.40	388.04	53.90	307.56	39.70	389.10	80.40	5.18	39.20	263.17
1988	0.00	0.00	8.66	83.80	3.19	54.50	6.02	35.00	8.52	34.50	0.25	100.00	4.44
1989	0.50	70.90	0.00	0.00	0.82	100.00	3.10	87.10	7.01	24.20	0.75	57.70	2.03
1990	0.00	0.00	0.00	0.00	4.99	100.00	13.80	87.40	17.55	33.30	9.45	30.60	7.63
1991	0.16	100.00	0.50	100.00	0.11	100.00	6.80	65.90	8.57	12.50	7.19	9.60	3.89
1992	21.16	71.70	51.35	49.50	13.53	60.70	20.75	41.90	9.47	29.70	2.51	44.20	19.80
1993	0.00	0.00	12.91	51.50	115.04	59.60	105.08	41.30	25.73	84.60	2.61	52.40	43.56
1994	18.84	91.80	179.99	97.30	0.74	49.40	1.14	44.30	5.54	52.20	34.60	37.60	40.14
1995	0.00	0.00	2.20	74.40	4.50	78.10	6.39	72.40	1.37	30.60	1.24	44.70	2.62
1996	0.53	100.00	4.47	49.20	14.20	91.90	5.28	22.90	8.06	30.70	7.07	5.00	6.60
1997	0.00	0.00	0.26	61.20	1.14	87.70	1.74	92.20	4.62	27.60	0.25	100.00	1.34
1998	0.00	0.00	3.12	70.50	3.68	58.40	7.39	57.10	1.15	49.80	0.00	0.00	2.56
Timeseries Mean	3.03		36.67		29.05		52.08		34.16		6.32		Grand Mean = 26.89
25th percentile	0.00		0.16		0.82		1.92		3.38		0.74		2.05
50th percentile	0.00		2.20		3.68		6.39		6.60		2.51		4.46
75th percentile	0.93		5.95		13.53		13.80		9.47		7.07		12.01

Table 6. Catch rate of age 1 demersal Atlantic cod (stratified mean no. per 20 min. tow) and coefficient of variation of stratified means by depth strata for MDMF Inshore Autumn Trawl Surveys, 1978-1999.

Year	≤ 30'		31 - 60'		61 - 90'		91 - 120'		121 - 180'		> 180'		Yearly Mean
	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	
1978	0.00	0.00	0.54	100.00	0.27	100.00	0.58	100.00	5.76	34.10	0.25	100.00	1.23
1979	0.00	0.00	0.00	0.00	4.26	65.30	1.21	24.30	3.93	64.70	10.28	93.50	3.28
1980	0.00	0.00	0.00	0.00	0.11	100.00	0.58	50.00	17.15	65.40	40.29	78.30	9.69
1981	0.00	0.00	0.00	0.00	0.15	100.00	1.02	14.30	17.34	64.00	20.43	97.60	6.49
1982	0.00	0.00	0.00	0.00	0.00	0.00	0.10	100.00	7.85	97.40	0.00	0.00	1.33
1983	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.04	65.70	0.00	0.00	0.34
1984	0.00	0.00	0.00	0.00	0.00	0.00	0.29	100.00	0.94	79.30	0.00	0.00	0.21
1985	0.00	0.00	0.00	0.00	0.00	0.00	0.19	100.00	1.73	100.00	0.25	100.00	0.36
1986	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.24	97.60	0.13	100.00	0.90
1987	0.00	0.00	0.00	0.00	0.00	0.00	0.44	100.00	5.34	100.00	0.49	100.00	1.05
1988	0.00	0.00	1.76	76.20	0.33	100.00	1.89	38.50	56.27	80.90	1.62	31.40	10.31
1989	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.30	100.00	0.37	74.20	1.61
1990	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	33.44	61.40	0.25	100.00	5.62
1991	0.00	0.00	0.00	0.00	0.00	0.00	0.87	83.90	14.13	100.00	0.00	0.00	2.50
1992	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.50	78.80	2.71	100.00	1.37
1993	0.00	0.00	0.00	0.00	0.00	0.00	1.45	100.00	12.56	77.80	0.89	48.80	2.48
1994	0.00	0.00	0.00	0.00	0.00	0.00	0.58	50.00	58.11	95.70	0.74	33.30	9.91
1995	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.26	100.00	9.85	100.00	1.85
1996	0.00	0.00	0.00	0.00	0.33	100.00	0.00	0.00	0.45	100.00	0.00	0.00	0.13
1997	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	100.00	0.00	0.00	0.01
1998	0.00	0.00	0.00	0.00	0.00	0.00	0.77	82.00	3.27	95.30	0.00	0.00	0.67
Timeseries Mean	0.00		0.11		0.26		0.47		12.46		4.22		Grand Mean = 2.92
25th percentile	0.00		0.00		0.00		0.00		2.04		0.00		0.67
50th percentile	0.00		0.00		0.00		0.29		5.50		0.25		1.37
75th percentile	0.00		0.00		0.11		0.77		14.13		1.62		3.28

Figure 1. Time series of mean strata Z scores and two standard errors for Atlantic cod, MDMF surveys: A) Age 0, spring; B) Age 1, spring; C) Age 0, autumn; D) Age 1, autumn, 1978-1999.



Examination of trends in stratum Z scores signifies that the pattern of depth occupancy appears to be stable over the 22 year time series (Figs. 2-5). Of the 24 regressions, only spring age 0, $\leq 30'$ and spring age 0, 61-90' had significant slopes ($P=0.05$) but the regressions were weak ($R^2=0.18$ and 0.43 , respectively) (Fig. 2). Over the time series, Z scores increased for the $\leq 30'$ stratum (slope = 3.22) and decreased in the 61-90' stratum (slope = -5.52) implying greater and diminishing occupancy, respectively. Both reg-

ressions appear to be influenced by the first four survey years and are insignificant if these years are excluded. Although the first four years of surveys were conducted on a different vessel than the rest of the time series, we cannot offer a plausible explanation for changing catchabilities in the two depth strata for spring surveys in these years.

Kruskal-Wallis Test for year and stratum effects on catch per tow. The Kruskal-Wallis tests found significant year effects for spring age 0

($P=0.023$), autumn age 0 ($P<0.001$), and spring age 1 ($P=0.014$). Year effect was not significant for autumn age 1 ($P=0.52$). Strata effects were highly significant ($P<0.001$) for spring age 0, spring age 1, autumn age 0 and autumn age 1. These results are consistent with results from the two-way ANOVA with exception that the Kruskal-Wallis test found a significant stratum effect for autumn age 0.

Mean Stratum Rankings. Ranking of within year stratum means also provides a method to visually detect patterns of depth preferences by removing year effects similar to the Z score analysis, but disregards the magnitude of difference among strata means. This is analogous to the difference between parametric ANOVA and non-parametric Kruskal-Wallis statistical methods. Mean stratum ranks should provide information on the general patterns of depth preference over the entire time series.

The distribution of mean stratum ranks was similar to distribution of mean stratum Z scores (Fig. 6, Table 11). Spring age 0 mean stratum rank were above the mean for strata 31-60', $\leq 30'$, and 61-90', and below average for three strata $>90'$ (Fig. 6A). Spring age 1 mean stratum ranks were above the mean for the three strata 60-180', and below the mean for two strata $<60'$ and the $>180'$ stratum (Fig. 6B).

Autumn age 0 mean stratum ranks were above the mean for strata 121-180', 91-120', and 61-90' (Fig. 6C). The variance of mean stratum ranks was the lowest in the four data sets, once again suggesting that the autumn age 0 cod are more evenly distributed among strata than for other season-age combinations examined (Table 11). Autumn age 1 mean stratum ranks are well above average for 121-180', above average for 91-120' and $>180'$ strata, and below average for the three strata $<90'$ (Fig. 6D). Age 1 cod show a high preference for stratum 121-180: this stratum ranked 1st for 17 of 21 surveys and 2nd three times (Table 6).

Frequency of Occurrence and Co-occurrence. Frequencies of occurrence of age 0 and age 1 pooled by depth strata within season are presented in Table 12. The chi-square statistic was highly significant for stratum effects in both spring ($P<0.0001$) and autumn ($P<0.0001$) time series. Frequency of occurrence of age 0 and age 1 cod is significantly dependent on depth stratum. This result is consistent with previous analyses showing significant strata effects for age 0 and age 1 mean

number per tow.

Observed and expected frequencies of co-occurrence of age 0 and age 1 in seasonal surveys are shown in Table 13. The chi-square statistic was insignificant for both spring ($P=0.51$) and autumn ($P=0.16$) time series. We conclude that the frequency of co-occurrence of age 0 and age 1 is random within a depth stratum. During daylight hours, spatial segregation of age 0 and age 1 occurs through differences in depth preference among the two age-groups rather than differential habitat preference within a depth zone.

Stratum and Year Effects on Mean Length of Age 0 and 1 Combined. A two way ANOVA of spring mean length data found significant year ($P<0.001$) and stratum ($P<0.001$) effects. Mean length from shallowest ($\leq 30'$) to deepest stratum ($>180'$) was 6.6, 9.9, 15.6, 16.9, 20.8, and 18.7 cm.

A two-way ANOVA using eight years and six strata for the autumn dataset yielded significant year ($P<0.05$) and stratum ($P<0.001$) effects. A two way ANOVA using 17 years and five strata sets (strata $\leq 30'$ and 31-60' were pooled) found significant year ($P<0.001$) and stratum ($P<0.001$) effects. Mean lengths from shallowest ($< 60'$) to deepest stratum were 7.4, 8.1, 7.7, 14.7, and 12.3 cm. Results were consistent with the previous analysis of distribution of age 0 and age 1 by depth strata. Smaller, presumably younger cod are found in the two shallowest strata ($<60'$). Annual variation in timing of spawning and settlement, prey availability, water temperature, along with density-dependent growth are possible mechanisms for year effects on mean length.

Age 0 Length-frequencies. In all 22 years, spring length-frequency data shows one modal class suggesting an annual April or early May settlement pulse (Fig. 7). The mode occurs at various lengths from 3 to 7 cm TL, but most frequently at 5 cm. A very small number of 9 or 10 cm individuals were taken in some years. These individuals may represent young cod from either an early winter spawning - early spring hatch, fast growing fish from the first settlement pulse (e.g., in 1978), or slow-growing individuals from a previous year-class (i.e., mis-keyed).

Autumn length-frequency data was either unimodal or bimodal - at about 4 and 13 cm TL - indicating one or two settlement pulses (Fig. 8). Mid-year settlement resulting from a probable late spring adult cod spawning was evident in at least 18

Table 7. Results of Tukey's HSD test for significant differences in catch rates between strata for spring age 0 Atlantic cod. Bold indicates $p < 0.05$.

Strata	≤ 30'	31-60'	61-90'	91-120'	121-180	>180'
≤ 30'	X	0.568	0.953	0.432	0.363	0.364
31-60'		X	0.128	0.008	0.001	0.006
61-90'			X	0.920	0.878	0.879
91-120'				X	1.000	1.000
121-180					X	1.000
>180'						X
Group A ($p = 0.128$)	A	A	A			
Group B ($p = 0.363$)	B		B	B	B	B

Table 8. Results of Tukey's HSD test for significant differences in catch rates between strata for spring age 1 Atlantic cod. Bold indicates $p < 0.05$.

Strata	≤ 30'	31-60'	61-90'	91-120'	121-180	>180'
≤ 30'	X	0.939	0.000	0.001	0.000	0.988
31-60'		X	0.001	0.026	0.012	1.000
61-90'			X	0.948	0.989	0.001
91-120'				X	1.000	0.011
121-180					X	0.005
>180'						X
Group A ($p = 0.939$)	A	A				A
Group B ($p = 0.948$)			B	B	B	

Table 9. Results of Tukey's HSD test for significant differences in catch rates between strata for autumn age 0 Atlantic cod. Bold indicates $p < 0.05$.

Strata	≤ 30'	31-60'	61-90'	91-120'	121-180	>180'
≤ 30'	X	1.000	1.000	1.000	0.000	0.511
31-60'		X	1.000	1.000	0.000	0.540
61-90'			X	1.000	0.000	0.581
91-120'				X	0.000	0.638
121-180					X	0.012
>180'						X
Group A ($p = 1.000$)					A	
Group B ($p = 0.511$)	B	B	B	B		B

Table 10. Time series means of within-year stratum Z scores and variance of mean stratum mean Z scores of age 0 and age 1 Atlantic cod, MDMF spring and autumn trawl survey catches, 1978-1999.

	Stratum						Mean	Variance
	≤30'	31-60'	61-90'	91-120'	121-180'	>180'		
Age 0 spring	0.63	1.13	0.04	-0.52	-0.65	-0.64	0.00	0.56
Age 0 autumn	-0.66	-0.16	0.03	0.48	0.60	-0.29	0.00	0.23
Age 1 spring	-0.87	-0.47	0.55	0.46	0.88	-0.56	0.00	0.52
Age 1 autumn	-0.51	-0.50	-0.38	-0.36	1.68	0.06	0.00	0.72

Table 11. Time series means of within-year stratum rank and variance of mean stratum rank of age 0 and age 1 Atlantic cod, MDMF spring and autumn trawl survey catches, 1978-1999.

	Stratum						Mean	Variance
	≤30'	31-60'	61-90'	91-120'	121-180'	>180'		
Age 0 spring	1.23	1.82	0.50	-0.70	-1.32	-1.52	0.00	1.92
Age 0 autumn	-1.55	-0.31	0.10	0.88	1.17	-0.29	0.00	0.95
Age 1 spring	-2.27	-0.68	1.18	1.05	1.73	-1.00	0.00	2.42
Age 1 autumn	-1.33	-1.05	-0.76	0.26	2.26	0.62	0.00	1.80

of 21 autumn surveys. All age 0 cod ≤4 cm were considered to be post-settled demersal juveniles since no attempt was made aboard ship to differentiate demersal (pigmentation on unpaired fins) from pelagic juveniles; however, the length at transition from pelagic to juvenile demersal stage is variable - ~2.5-4.0 cm in New England coastal water (Bigelow and Schroeder 1953).

Stratum and Year Effects on Mean Length of Age 0. Previous analyses suggest that by autumn, age 0 cod's preference shifts to deeper strata (61-180'). However, reduced variance among strata implies depth is not as strong a factor as in the spring (Tables 10 and 11). We suspect that this may be a function of larger 0-group cod beginning to move into deeper water (61-180') while smaller cod, and more newly-settled cod continue to prefer shallower water.

The ANOVA for the spring age 0 mean length did not have significant year (P=0.37) or stratum effects (P=0.11). Mean lengths from shallowest to deepest strata were 4.7, 4.7, 5.2, 5.1, 5.3, and 5.5 cm. The ANOVA for the autumn age 0 had a significant year effect (P<0.001) but strata effects (P=0.20) were insignificant. Autumn age 0 mean lengths from shallowest to deepest strata were 5.4, 7.4, 7.2, 6.8, 6.9, and 6.0 cm. Although strata effects were insignificant in both seasons at 5%

probability, low sample sizes (spring=6 years, autumn=8 years) and relatively high probability of strata effects (spring, P=0.11; autumn, P=0.20) suggests that the results may reflect low statistical power due to low sample size. Examination of seasonal strata mean length information is indicative of age 0 moving into deeper water with somatic growth.

Distribution Plots. The geographic distribution (and relative abundance) of age 0 and age 1 cod juveniles collected during MDMF spring and autumn inshore trawl surveys, 1978-99, are shown in Figs. 9-12. During spring surveys, age 0 densities were highest in Ipswich Bay, and along the shoreline of Massachusetts Bay and Cape Cod Bay (Fig. 9). Spring age 1 densities were highest in Ipswich Bay, throughout Massachusetts Bay, and the northern portion of Cape Cod Bay (Fig. 10). During autumn surveys, highest age 0 densities were observed north of Cape Ann, along the shore of Massachusetts Bay from Gloucester to Hull and throughout Cape Cod Bay (Fig. 11). Autumn age 0 cod were more widely distributed than spring age 0. Autumn age 1 densities were highest along the territorial water line north of Cape Ann and in central region of Massachusetts Bay. In Cape Cod Bay, only moderate densities of age 1 occurred in the northernmost portion of the Bay (Fig. 12).

Table 12. Frequency of occurrence (number of tows) with age 0, age 1, and both age groups of Atlantic cod by stratum in 1978-1999 MDMF spring and autumn trawl surveys, all years pooled.

		Stratum					
		≤30'	31-60'	61-90'	91-120'	121-180'	>180'
Spring	Age 0	75	109	67	48	45	14
	Age 1	11	43	66	84	129	52
	Both age groups	5	25	33	31	28	6
	Total # of stations	128	162	168	163	206	106
Autumn	Age 0	14	56	76	93	149	68
	Age 1	0	4	10	22	58	27
	Both age groups	0	3	9	18	47	16
	Total # of stations	101	131	159	147	205	107

Table 13. Observed and expected frequency of co-occurrence of age 0 and age 1 Atlantic cod in spring and autumn MDMF trawl surveys, 1978-1999 (all years pooled). Chi-squared statistic was insignificant for spring ($p=0.51$) and autumn ($p=0.016$).

		Stratum					
		≤30'	31-60'	61-90'	91-120'	121-180'	>180'
Spring observed		5.0	25.0	33.0	31.0	28.0	6.0
Spring expected		6.4	28.9	26.3	24.7	28.2	6.9
Autumn observed			3.0	9.0	18.0	47.0	16.0
Autumn expected			1.7	4.8	13.9	42.2	17.2

Figure 2. Annual mean stratum Z scores for age 0 Atlantic cod, spring, with time series means, 1978 - 1999. Bold line represents mean stratum Z score.

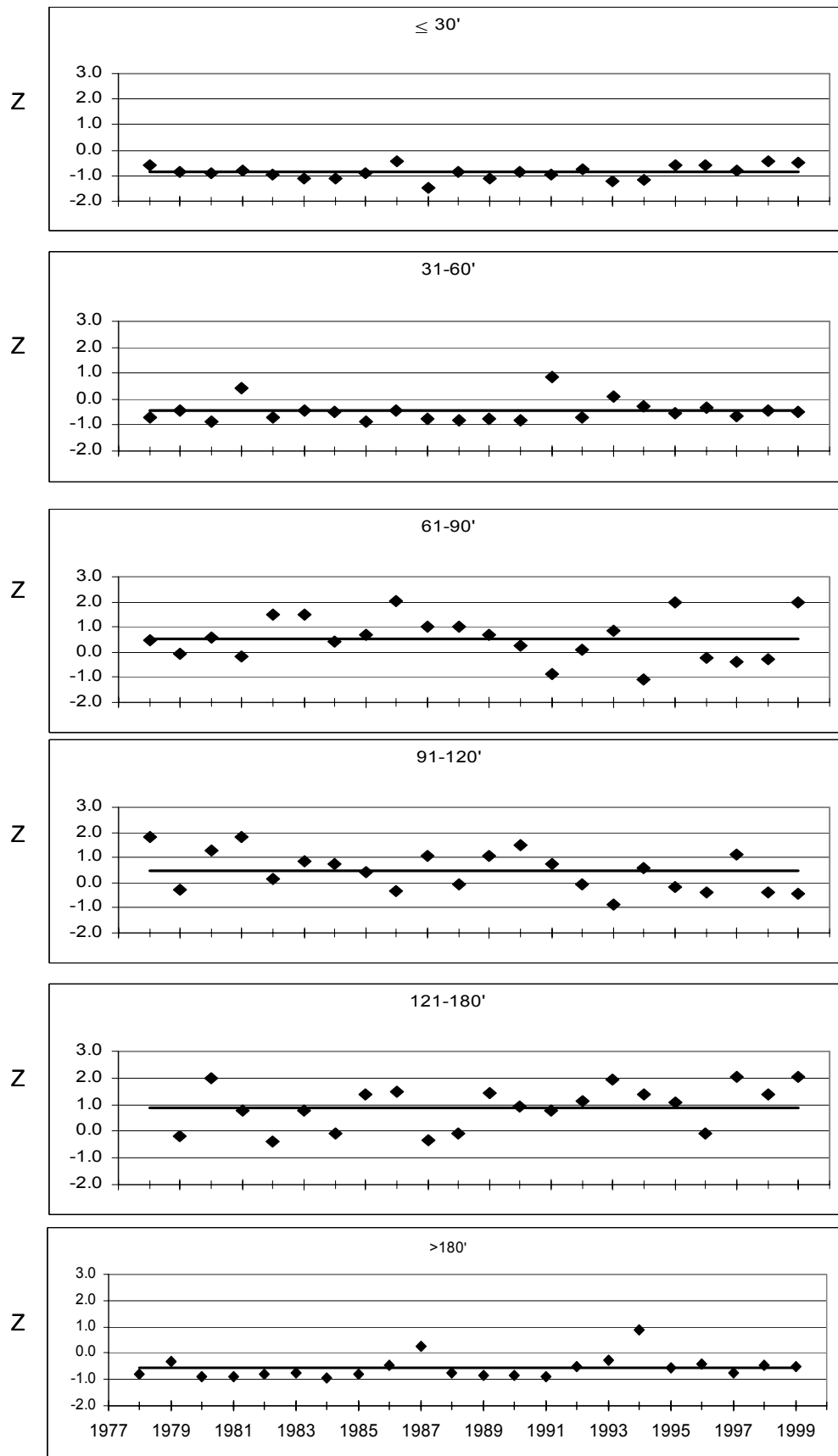


Figure 3. Annual mean stratum Z scores for age 1 Atlantic cod, spring, with time series means, 1978 - 1999. Bold line represents mean stratum Z score.

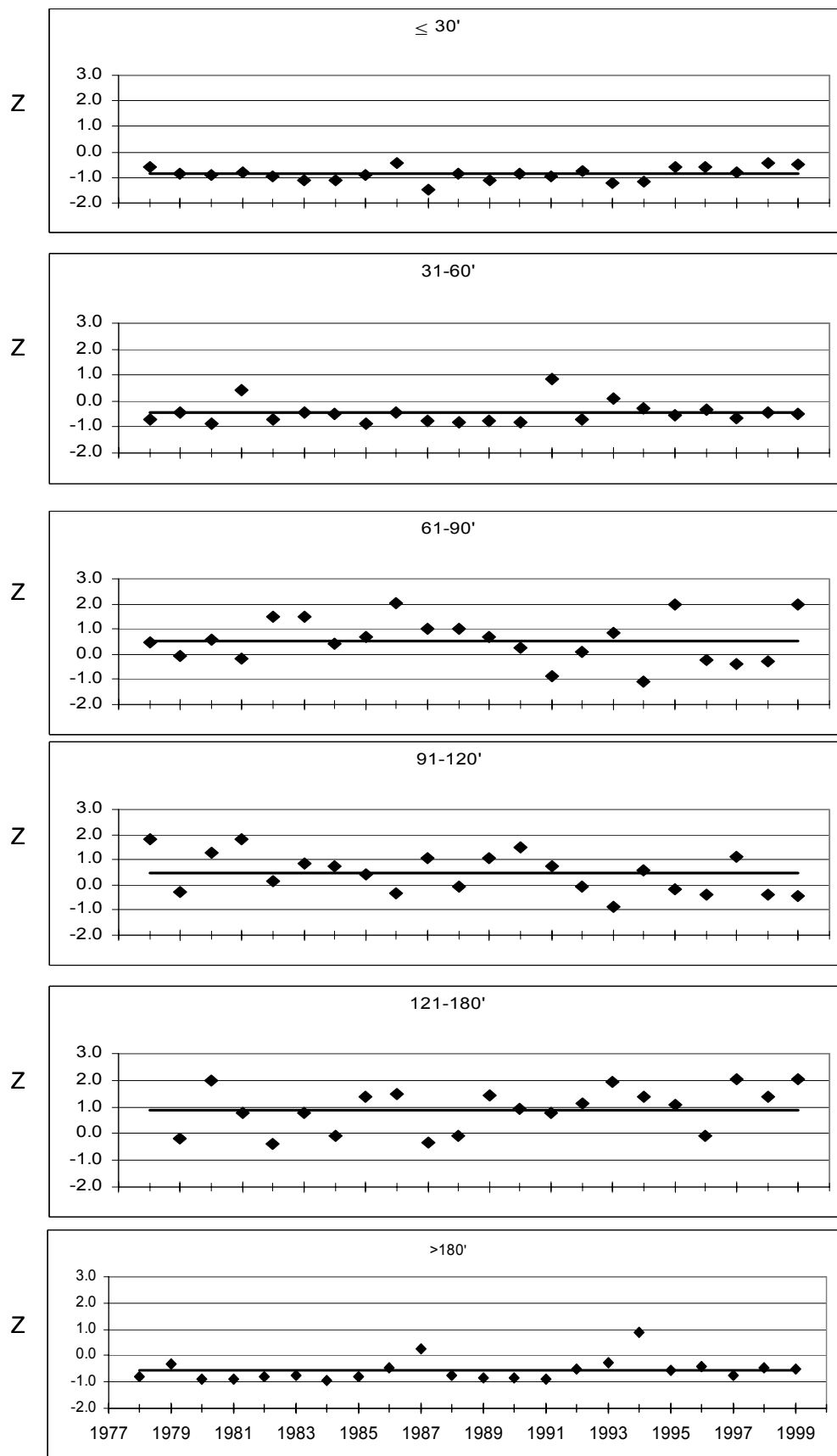


Figure 4. Annual mean stratum Z scores for age 0 Atlantic cod, autumn, with time series means, 1978 - 1999. Bold line represents mean stratum Z score.

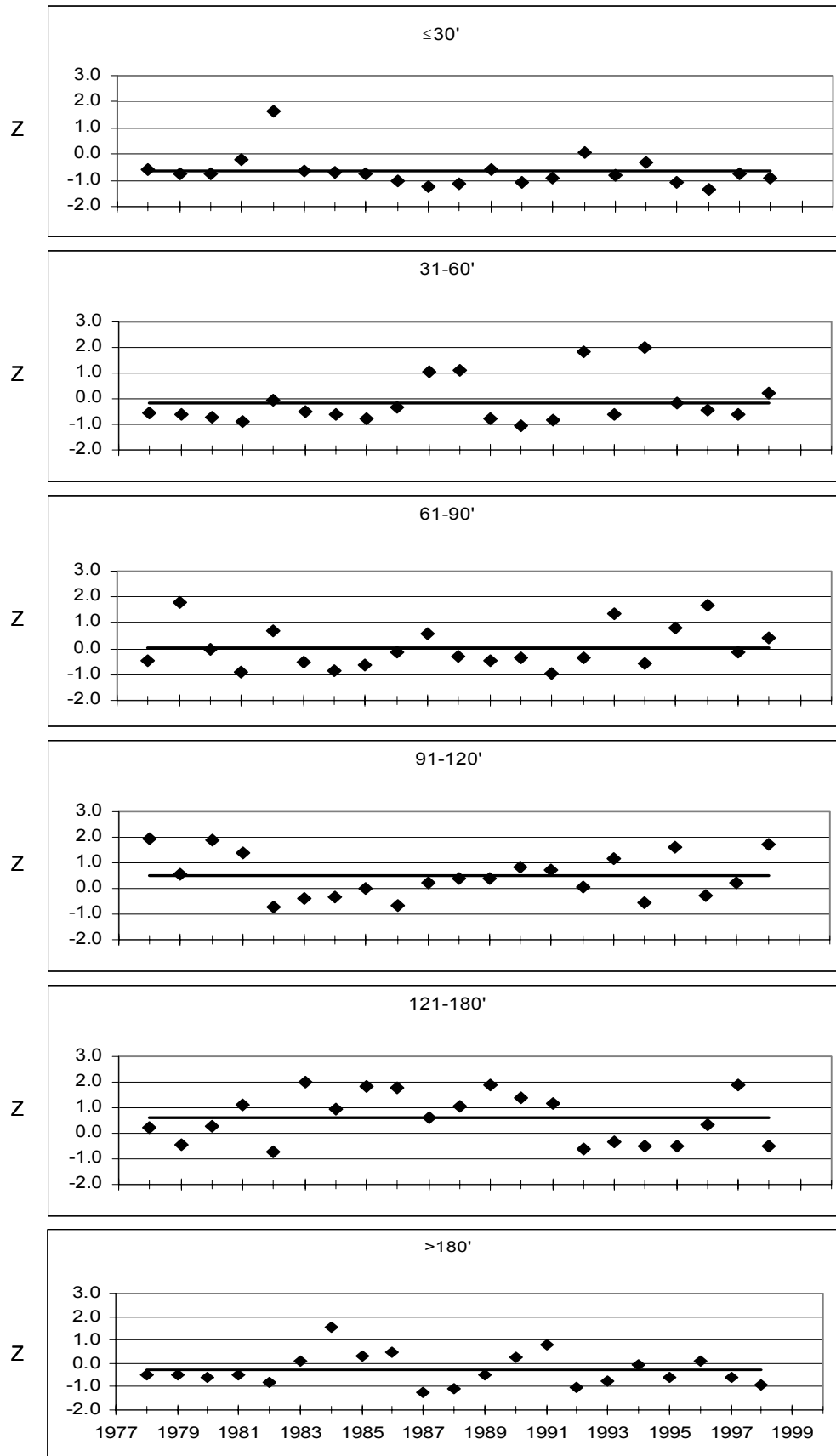


Figure 5. Annual mean stratum Z scores for age 1 Atlantic cod, autumn, with time series means, 1978 - 1999. Bold line represents mean stratum Z score.

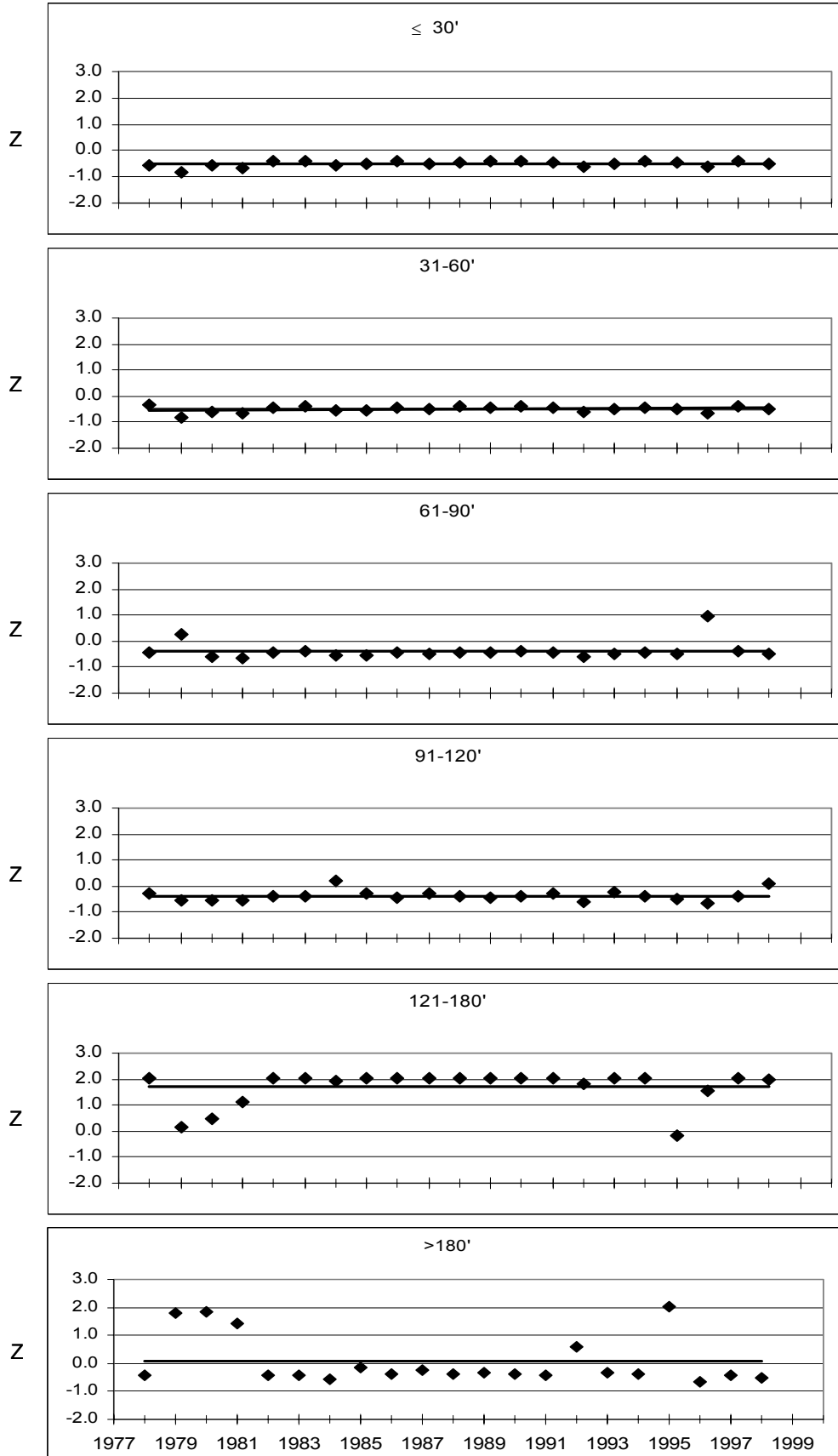


Figure 6. Time series mean stratum rankings for Atlantic cod: A) Age 0, spring; B) Age 1, spring; C) Age 0, autumn; D) Age 1, autumn, from the MDMF trawl survey, 1978-1999.

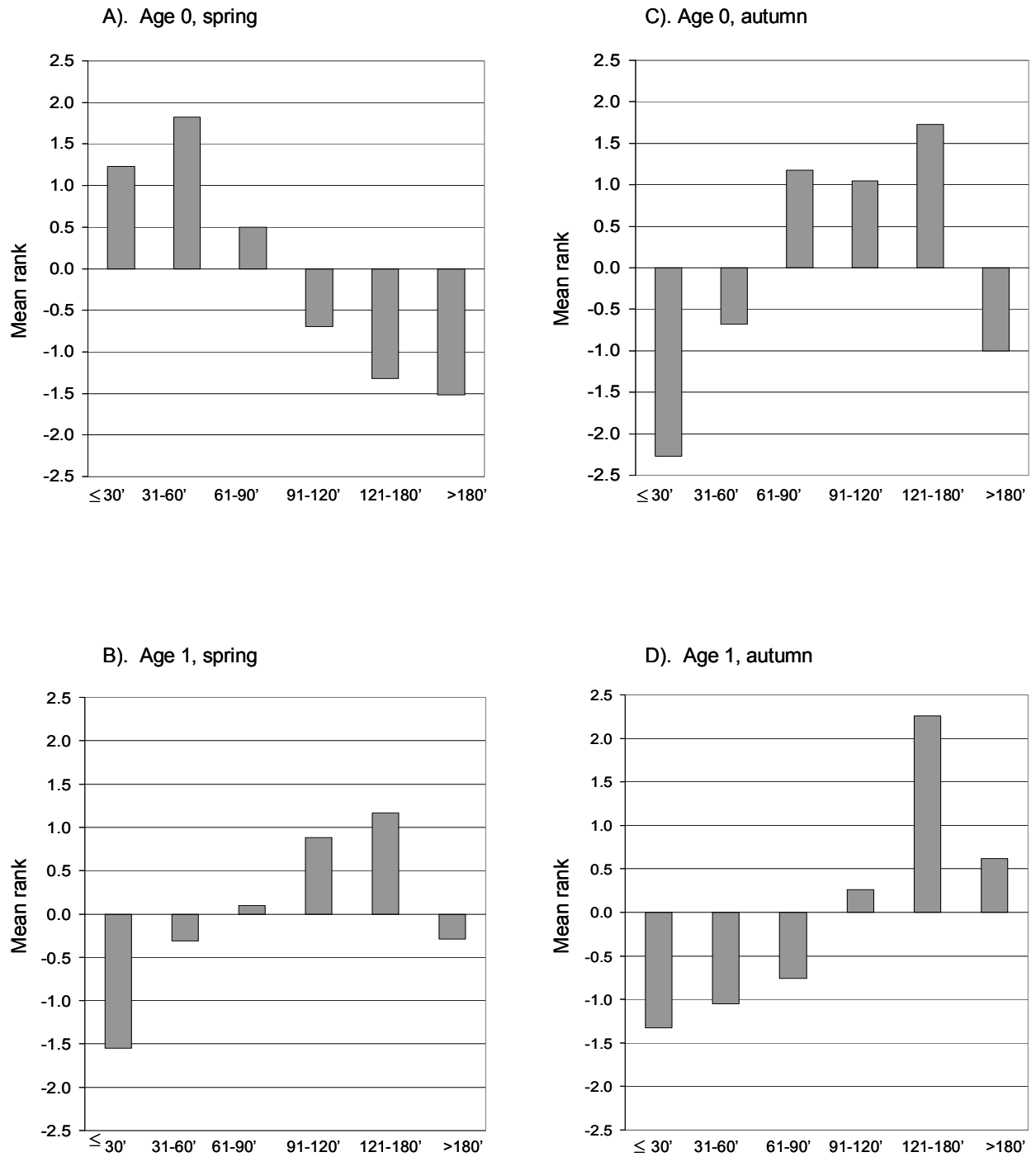


Figure 7. Length frequency distributions of age 0 Atlantic cod from MDMF spring trawl surveys undertaken in SW portion of Gulf of Maine (MA territorial waters), 1978 - 1999.

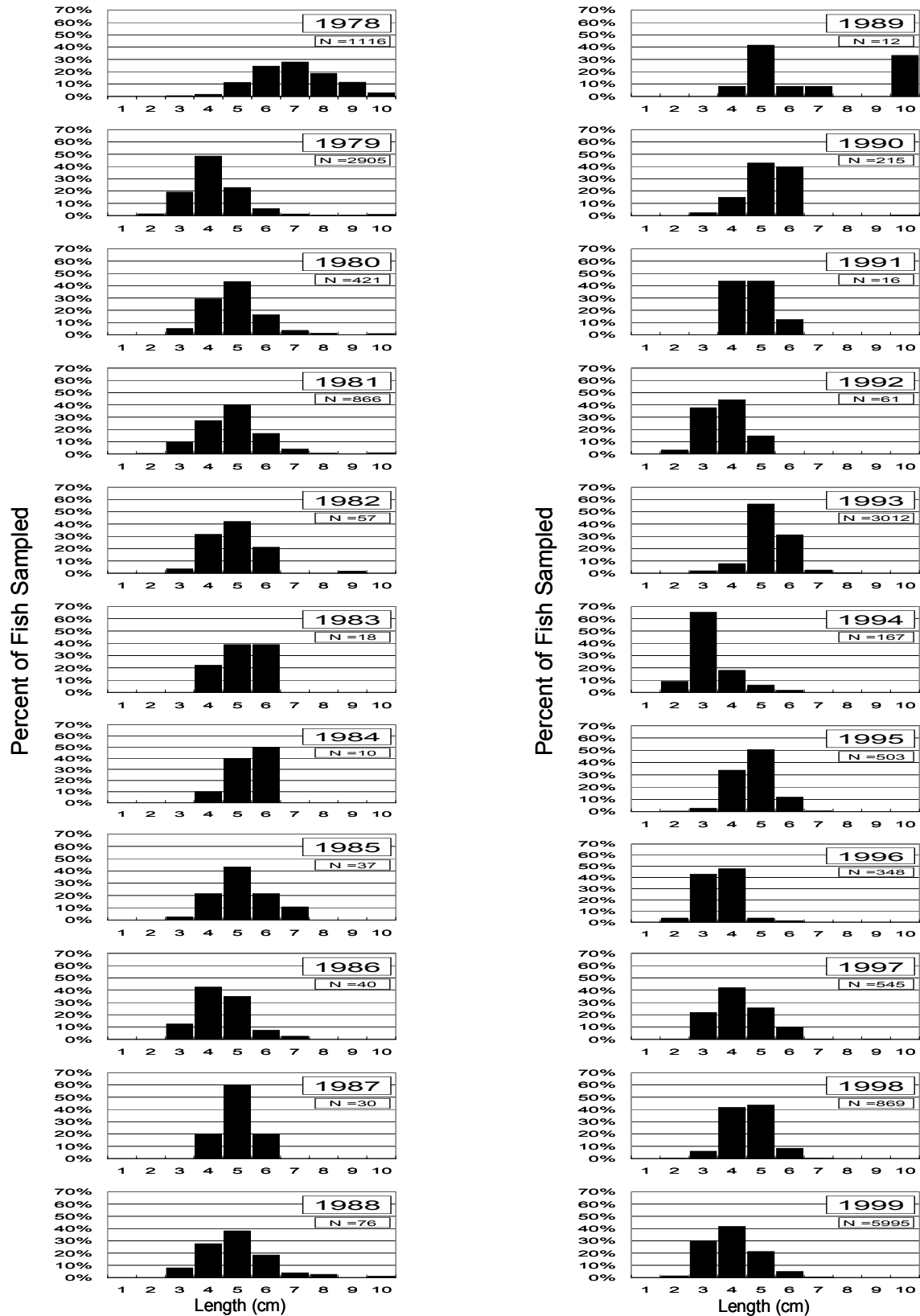
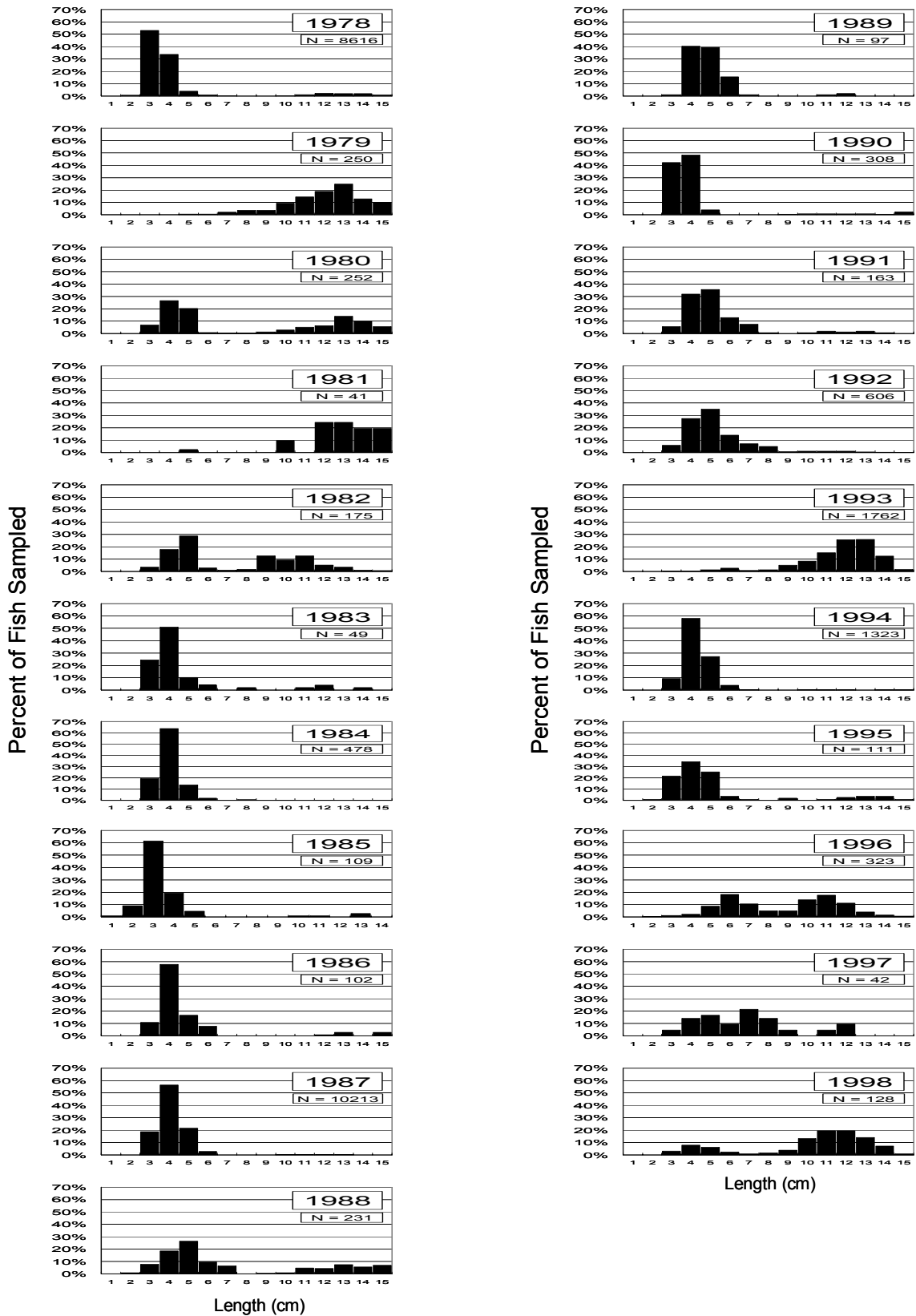
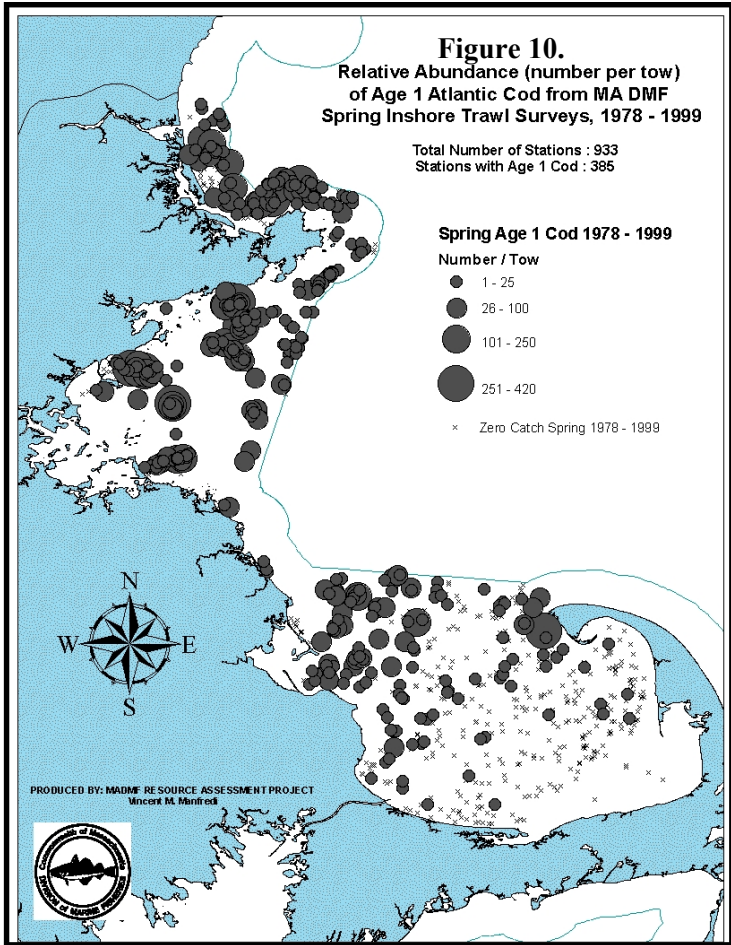
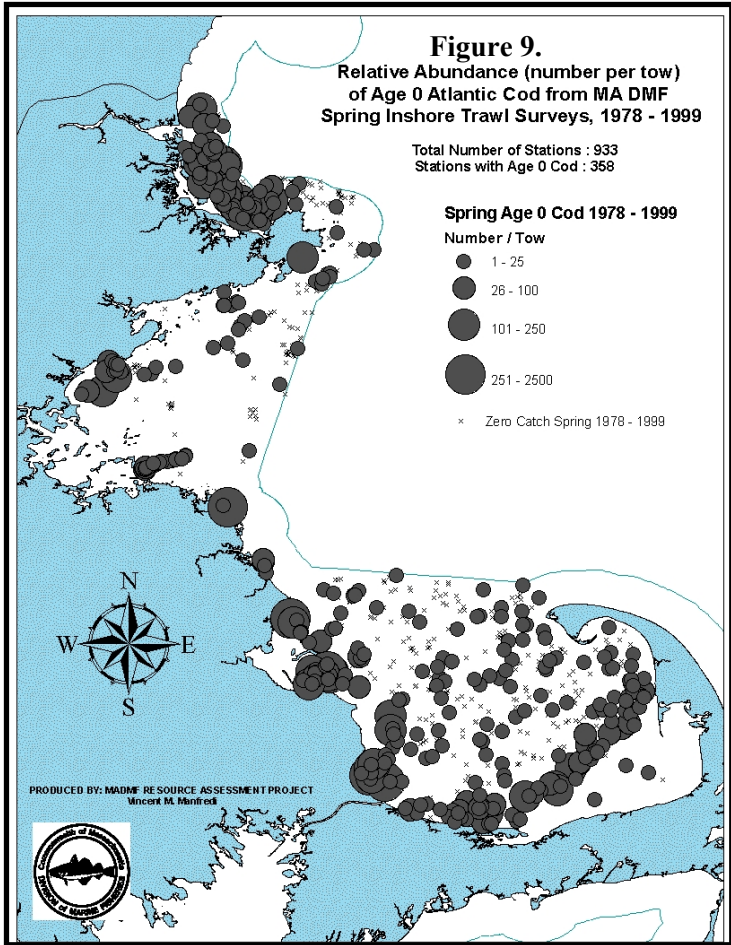
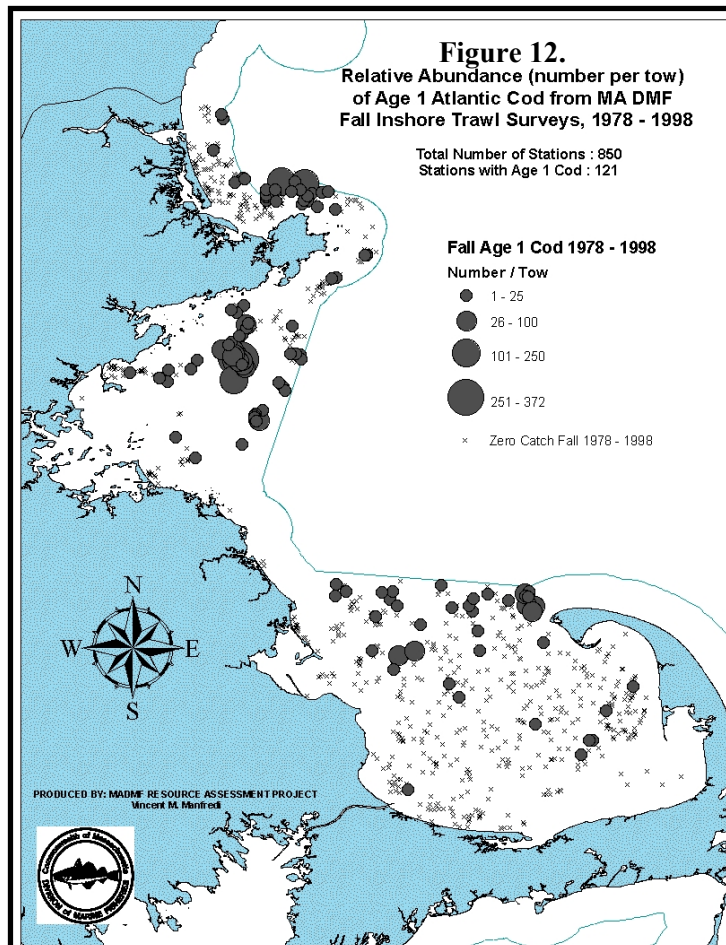
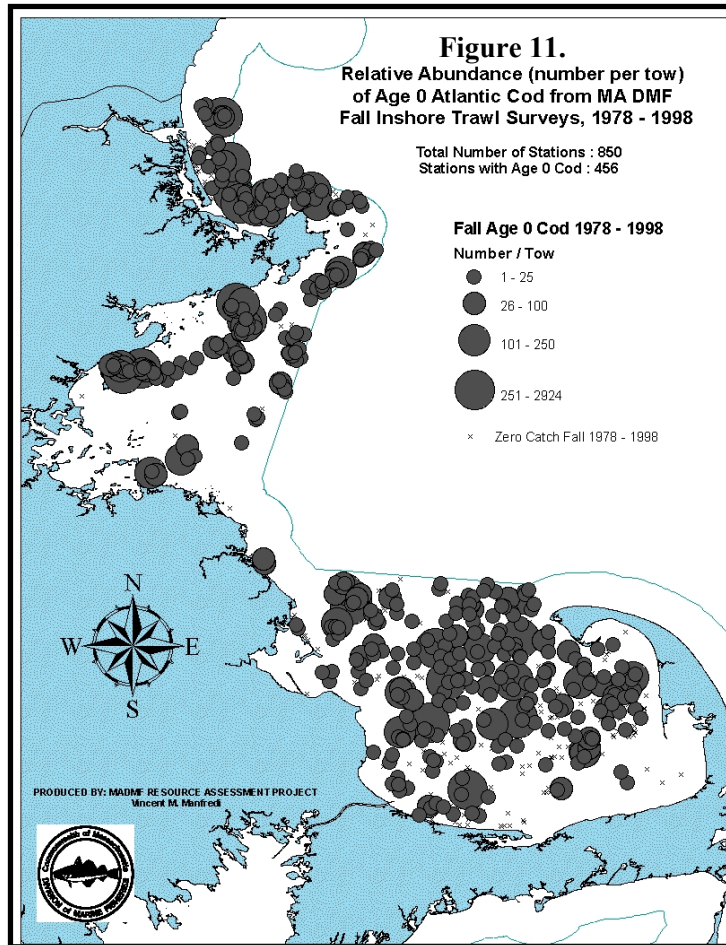


Figure 8. Length frequency distributions of age 0 Atlantic cod from MDMF autumn trawl surveys undertaken in SW portion of Gulf of Maine (MA territorial waters), 1978 - 1999.







Discussion

The MDMF trawl survey catch record indicates that the eastern Massachusetts coastal region annually serves as a settlement area or "sink" for pelagic juvenile cod. In all 22 spring sampling periods, depths <90' inside the coastal headlands of major embayments - Ipswich Bay, Massachusetts Bay, and Cape Cod Bay - offered suitable habitat for successful settlement.

In 13 of 22 years, highest spring densities were recorded in 31-60'; however, there are several reasons why the shoaler $\leq 30'$ stratum may be more seasonally important for settlement. According to recent studies in coastal Nova Scotia and Newfoundland, post-settlement survival and age 0 abundance is highest in complex bottom types - seagrass beds, cobble/ gravel areas, and biogenic covered rock reef (Tupper and Boutilier 1995b; Grant and Brown 1998b). All these bottom types are common in shallow waters of our study area although hardbottom habitats are also widespread in the Gulf of Maine.

A continuum of untrawlable hardbottom features exists along the Massachusetts coastline $\leq 30'$ from the Annisquam River outlet on Ipswich Bay, around Cape Ann and westward along the North Shore of Massachusetts Bay to Swampscott, as well as along the South Shore of Massachusetts Bay from Hull to Marshfield. Despite extensive searching for towable bottom in this depth zone, only a few sites have been successfully trawled. These two sections of the nearshore depth stratum (estimated to be 20% of stratum area) are poorly sampled.

The MDMF trawl survey samples only the deepest portion of the $\leq 30'$ stratum because conducting operations in depths shoaler than 20' in most wind and sea conditions is imprudent due to the research vessel's 10' draft; accordingly, the minimum and mean sampling depth in this stratum was 16' and 27', respectively. Whether or not the $\leq 30'$ stratum plays a more significant role for settlement than our depth-limited shallow water sampling indicates, the fact remains that no significant difference exists between $\leq 30'$ and 31-60' stratum means.

The 1987 cohort was assessed as the largest Gulf of Maine year-class in the last two decades (Mayo et al. 1998). In autumn 1987, we recorded the highest age 0 densities of the time series in three strata (31-60', 61-90', 121-180'), and the second highest in one stratum (91-120'). Subsequent strong

recruitment of this year-class signifies that depths from 31-180' afford important settlement habitat. Whether densities of this magnitude resulted in over-crowding of demersal habitats is unknown. However, sufficient habitat was available in 1987 to sustain a cohort of this size. This suggests that cohort strength is not currently constrained by habitat availability.

Diminished seasonal occupancy in <60' in autumn surveys does not negate the importance of the <60' for settlement. The preference of newly settled cod for 0-60' may reflect selection of habitat that reduces post-settlement mortality. Although pelagic juveniles exhibit no preference for shallow-water substrate type at settlement, subsequent spatial patterns are "completely altered by habitat-specific post-settlement mortality" (Tupper and Boutilier 1995b). Predation rates vary among habitat types, but are lowest in structurally complex types such as cobble substrate and eelgrass (*Zostera marina*) (Gotceitus and Brown 1993; Gotceitus et al. 1995; Tupper and Boutilier 1995a; Grant and Brown 1998b) and highest on unvegetated sand where age 0 densities may decline to zero within weeks of settlement (Tupper and Boutilier 1995b). The shift in depth preference in the autumn may simply reflect an ontogenetic shift in preference to deeper water.

Spring strata mean lengths suggest that the larger/older age 0 cod (i.e. early settlers) appear to be dispersing seaward, perhaps having already outgrown or lost site fidelity on certain shallow habitats. This movement occurred by late June in eelgrass beds in St. Margaret's Bay, Nova Scotia (Tupper and Boutilier 1995b). Also, young cod could have been reacting to pressure from predators and shifting habitats (Fraser et al. 1996).

Similarly, larger/older age 0 cod inhabiting depths <60' in spring may have responded to environmental cues, such as rising water temperature, and relocated to deeper, more favorable regimes by autumn as suggested by eight years of autumn mean length data. This is also reflected in the seasonal shift in catch-weighted mean depth of age 0 (53 to 110') compared to the change in catch-weighted bottom temperature from 7.3 to 8.4C. The mean temperature for the shallower strata (0-90') are 14.6, 12.8, and 10.6°C, respectively. Maintaining optimum temperature may be an important factor in the movement to deeper water in the autumn. Larval and juvenile cod growth is positively correlated with temperature

from 4-14°C in high latitude Northeast Atlantic cod stocks and faster growth might be expected at the higher temperatures experienced by low-latitude populations (Otterlei et al. 1999) such as the Gulf of Maine cod stock.

Spatial distribution of autumn age 0 might be related to thermocline dynamics and the distribution of zooplankton. An annual summer thermocline develops in the study area with vernal warming and persists into October (Davis 1984). Daily bottom temperature data from a series of MDMF temperature monitors deployed at various depths (40', 60', 90', 120') in Massachusetts and Cape Cod Bays over the last decade (Estrella and Glenn 1999) indicates that the vertical temperature gradient occurs in the 60-90' depth range from May-September. Distribution in cooler, sub-thermocline waters may convey energetic benefits for young juveniles as it apparently does for three-year-old cod (Clark and Green 1990 and 1991).

On Georges Bank off the New England coast, pelagic juvenile cod are found throughout the water column in well-mixed waters in early spring, but they become increasingly concentrated in the developing thermocline as it increases in steepness (Lough and Potter 1993), coinciding with the distribution of the zooplankton prey (Buckley and Lough 1987). Neilson and Perry (1990) suspected that feeding migrations of post-larval juvenile gadids might be limited by the thermocline and suggested that the combined influence of temperature gradients and prey distribution may play a role in where settlement occurs.

We would expect pelagic juvenile and newly-settled epibenthic cod to be concentrated near their critical food resource. The Massachusetts coastal region supports high zooplankton productivity year round (Durbin 1996; Lemieux et al. 1998), especially the smaller zooplankton species favored by young cod in coastal regions (Grant and Brown 1998a). During the flooding tide, internal waves generated along Stellwagen Bank in outer Massachusetts Bay cause vertical oscillations of the thermocline with six to eight minute periodicity resulting in significant plankton movement or concentration (Davis 1984). Grant and Brown (1998a) postulated that high densities of newly settled cod are associated with just such physical forcing phenomena that aggregate zooplankton.

Considering the depths occupied by newly settled cod off eastern Massachusetts coupled with

the preponderance of less-complex silt-clay sediments generally > 66' or 20 m (Young and Rhoads 1971), we might expect that daytime foraging at these depths would be disadvantageous to survival, i.e., newly settled cod would have to break off feeding (energy gain) more frequently while confronting possibly greater predation risk. Age 0's consistent autumn usage of the 121-180' stratum (highest mean stratum Z score, highest mean stratum rank, and second highest mean catch per tow) suggests that deeper inshore habitats off eastern Massachusetts provide ample shelter to sustain concentrations of age 0 cod. We suspect a variety of epifaunal organisms (e.g., sulphur sponge, *Cliona*; and sand dollars, *Echinarachnius*), possibly associated with cones and depressions, formed by feeding activities of the dominant burrowing holothurian, *Molpadia oolitica*, could offer sufficient structural complexity to be important on silt-clay sediments within the study area (Young and Rhoads 1971).

The significantly higher mean number per tow of age 1 cod in 121-180 stratum compared to other strata in autumn suggests that yearlings preferred a deeper, colder water environment. Daytime bi-weekly July to December SCUBA surveys of transect perpendicular to shore and to depths of 74' in Trinity Bay, Newfoundland, noted that age 1 cod were observed only at depths below a thermocline at ~49' (Goceitas et al. 1997).

Although survey catch data shows age 0 and age 1 cod co-occur in inshore waters during spring and autumn sampling seasons, statistical analyses (ANOVA, Tukey's, Kruskal-Wallis tests) substantiates reports of ecological segregation between these age-groups during daylight hours (Tupper and Boutilier 1995a; Fraser et al. 1996; Goceitas et al. 1997; Grant and Brown 1998a). However, spatial separation of age 0 and age 1 appears to be driven by different depth preferences rather than different habitat preferences (frequency of co-occurrence is random within depth strata).

Our inability to detect avoidance response within a depth stratum appears inconsistent with reports in the literature suggesting differential habitat selectivity for age 0 and age 1 cod. In laboratory experiments, age 0 cod avoided substrate occupied by age 1 cod to minimize contact (Fraser et al. 1996). Age 1 are reported to prefer hardbottom areas in all seasons except winter (Keats et al. 1987; Keats 1990; Goceitas et al. 1997). Similarly, observations from a deep sea submersible during

winter corroborate laboratory and shallow water studies indicating substrate selection by age 1 is age specific (and different from older juveniles); age 1 were usually found over gravel substrate relying on cryptic coloration to remain undetected by predators (Gregory and Anderson 1997). The observed depth range of age 1 in inshore waters of Newfoundland during winter was 59-492' and they were most abundant from 97-394' (Gregory et al. 1997).

We recognize that habitat may be spatially heterogeneous within a single tow and catches may often represent the integration of young cod captured over different habitats. Although aspects of the MDMF survey help show that habitat of critical importance occurs in state waters, a multispecies survey cannot by itself identify small-scale habitats. Preferred microhabitat features can only be determined by *in situ* observations and delimited by specialized and expensive surveys. However, inferring larger scale dynamics from small-scale *in situ* observations may also lead to erroneous conclusions about the importance of small-scale dynamics to broader population dynamics. The scaling of spatially and temporally limited data to larger scale questions remains problematic.

Review of Settlement Habitats and Post-settlement Processes. The depth range we noted for epibenthic juvenile cod off eastern Massachusetts is generally consistent with numerous historical observations (summarized in Hardy 1978) of ~2.5-5.0 cm cod noted from the Mid-Atlantic Bight to coastal regions and seas off high-latitude countries of the Northeast Atlantic. Off Newfoundland, age 0 distribution is centered at 13-23' MLW in autumn (Methven and Schneider 1998) and a sharp drop-off in abundance occurs at 66' (20 m) (Schneider et al. 1997).

Methven and Schneider (1998) proposed a theory to explain concentrated settlement nearshore (as well as on offshore banks) and it would seem to partially account for the spatial distribution noted in the southwest Gulf of Maine. In the pelagic drifting phase, developing cod larvae undertake progressively greater vertical migrations in the water column to maintain diel contact with zooplankton. When encountering substrate on a daytime descent, they may be "trapped", initiating transition to a demersal habit. A steeply sloped subtidal region, such as off Newfoundland, would serve to concentrate pre-settlement juveniles very close to shore, whereas off eastern Massachusetts, a

more gradual sloping nearshore shelf, in conjunction with diel movements and tidal cycles, might broaden the settlement zone. Water column stratification and vertical turbulence associated with the slope of the shelf as well as other factors could also influence vertical distribution during the pre-settlement period (Werner et al. 1993).

For coastal populations in Nova Scotia and Newfoundland, shallow depths ($\leq 16'$ or 5 m) appear to be most conducive for growth and survival. Shallow depths and use of habitat ecologically segregates the 0-group fish from yearling cod, particularly during daylight (Tupper and Boutilier 1995a; Fraser et al. 1996; Gotceitas et al. 1997; Grant and Brown 1998b). In contrast to 0-group cod, one-year-olds are inactive and generally in slightly deeper water until after dusk when they undertake shoreward movement (Keats 1990; Keats and Steele 1992), and begin foraging (Methven and Bajdik 1994; Grant and Brown 1998a), sometimes cannibalizing age 0 cod (Bogstad et al. 1994). Older juvenile cod also undertake these shoreward movements and prey on young cod (Gotceitas et al. 1997; Grant and Brown 1998a; Cote et al. 1998).

Newly settled age 0 juveniles remain highly localized for at least several weeks after settlement, consistent with acquiring food, growing rapidly, and avoiding predators (Tupper and Boutilier 1995a and 1995b; Grant and Brown 1998b). In order to fulfill these needs, newly settled cod observe a strict diurnal cycle, feeding in intracohort shoals in a tidally-influenced manner (Grant and Brown 1998a) during the day while remaining "site attached" to bottom features (Tupper and Boutilier 1995a) that afford protective cover (Gotceitas and Brown 1993; Gotceitas et al. 1995; Tupper and Boutilier 1995a; Grant and Brown 1998b). Age 0 appear to disperse to this shelter at night, cease feeding, and are less active to reduce confrontation with predators (Grant and Brown 1998a and 1998b).

On Georges Bank, vertical movements and activity of newly settled juvenile cod correspond to the light-dark cycle adhered to by pelagic juveniles (Perry and Neilson 1988; Lough and Potter 1993). Epibenthic juveniles remain near the sea-bed by day and move off-bottom 10-16' (3-5 m) at night to feed on demersal zooplankton that swarm into the water column after sunset (Lough et al. 1989; Lough and Potter 1993). Perry and Neilson (1988) documented that recently-settled cod fed mainly in late afternoon and early evening at both isothermal and thermally stratified sites ($> 200'$ in depth) on

both holozooplankton and demersal zooplankton. In subtidal coastal environments, the transition (~6-10 cm) from feeding on small pelagic prey by day to benthic invertebrates at night (Grant and Brown 1998a) is coincident with a developed mouth gape (Lomond et al. 1998).

The competitive advantage for shelter and food accrues to individuals that settle on coarse substrate (gravel, cobble, rock reef) or in beds of aquatic vegetation especially eelgrass (Tupper and Boutilier 1995a; Gotceitas, et al. 1995; Fraser et al. 1996; Gotceitas et al. 1997; Grant and Brown 1998a and 1998b) macrophytes (Keats et al. 1987). Favored by such refuge and abundant food resources in these habitats, the largest and earliest epibenthic individuals, in particular, defend a larger territory than smaller/ later settlers do (Tupper and Boutilier 1995a). Grant and Brown (1998b) suggested that the formation of localized feeding aggregations, which they observed in eelgrass beds and on unvegetated substrate, is a behavioral adaptation to enhance foraging success and detection of predators.

The threat of predation, the presence of older cod, and bottom substrate type prompts shifts in habitat use to avoid detrimental interactions in laboratory experiments (Fraser et al. 1996). Age-groups 0 and 1 prefer sand substrate in the absence of predators, but when in presence of an older conspecific, young-of-the-year and yearlings either change substratum type to avoid the predator or hide in cobble-gravel, kelp, dense imitation eelgrass, or increasingly dense sponge mimics, all of which increase age 0 survivorship (Gotceitas and Brown 1993; Gotceitas et al. 1995; Fraser et al. 1996; Gotceitas et al. 1997; Lindholm et al. 1999).

On Georges Bank, epibenthic juveniles are transported by the prevailing current gyre when off bottom. For the first two months after settling, age 0 survival is predicated on descending to the large pebble-gravel deposits located on northeastern Georges Bank where their cryptic coloration patterns reduces predation risk; 0-group cod are "poorly represented" on the more widespread sedimentary substrates (Lough et al. 1989).

In shallow coastal areas, growth appears to be temperature dependent (Tupper and Boutilier 1995a) and differs among habitat types. Growth is fastest in eelgrass beds and slowest on sand bottom (Tupper and Boutilier 1995b). Fast growth increases cod survival (Tupper and Boutilier 1995a;

Campana 1996). Otolith size-at-age and length-at-age (days) of pelagic juveniles on Georges Bank was significantly correlated with year-class strength and maximized at lengths corresponding to the approximate size at transition to an epibenthic existence (Campana 1996).

Because otolith check rings were not found upon microstructure examination of daily growth rings of newly settled (50-100 day old) cod from Georges Bank, Bolz and Lough (1988) believed there was no "abrupt metabolic disturbance" associated with settlement, as might be expected if diet or behavior had changed. This suggested that while pelagic juveniles are physiologically capable of settling, they remain in a drifting state, subject to vagaries of dispersal and jeopardy of predation, and this period may last 1-2 months for individual cod (Bolz and Lough 1988).

Perspective on Distribution of Age 0 Cod, Northwest Atlantic. Atlantic Canada. The northern Atlantic cod stock complex underwent a dramatic decline in biomass during the late 1980's resulting in the collapse of the famous Grand Bank fishery in 1992. From 1946-92, Canadian Department of Fisheries and Oceans (DFO) research trawl data indicated adult cod spawning throughout the continental shelf and slope of Labrador and Newfoundland, as well as on all banks and the Flemish Cap. Inshore spawning also occurred in southeastern Labrador and at "high concentrations" in large bays of southeastern Newfoundland (Hutchings et al. 1993). The authors' review suggested "historical shifts in the perceived importance of various spawning locations and that the predominant view of the past 30 years - offshore spawning being more important than inshore spawning.....lacks empirical support."

Cod ichthyoplankton distribution studies intensified in the last decade. An annual, shelf-wide north-to-south pattern of spawning and offshore-to-inshore progression of more developed (older) larvae was observed and coupled to spawning locations and availability of suitable settlement habitats (Pepin and Helbig 1997). A simultaneous drift simulation study projected highly variable transport and distribution of eggs and larvae with a "dynamic interchange of material" between mid-shelf and coastal regions such that "eggs and larvae may be transported from the shelf into coastal nursery areas, eggs can be spawned in the bays and later move out onto the shelf, or eggs and (or) larvae may drift into the bays and be

retained there for some time before drifting back out onto the shelf." The dual production and nursery role of the inshore region for inshore and offshore spawned fish seemed to confirm Hutchings et al.'s (1993) suggestion that coastal areas may have provided a larger contribution to cod recruitment than was previously believed (Pepin and Helbig 1997).

Following the 1992 stock collapse, much of the remaining spawning stock biomass was located in the inshore regions of northeast Newfoundland and spawning aggregations were located or re-discovered in various locations within large Newfoundland bays (Neis, et al. 1999). Subsequent pelagic juvenile surveys in autumn, 1992-1994, found pre-settlement juveniles throughout the inshore area in all three years; however, pelagic juveniles were infrequent offshore until 1994, when a large concentration was observed on the Northeast Newfoundland Shelf (Anderson and Dalley 1997).

Dalley and Anderson (1997) reported results from a bottom trawl survey directed at young juvenile cod. Multiple transects extended from the coast, beginning at a depth of about 197' (60 m) and to hundreds of kilometers offshore in early winter, 1992-1994. The catch rates of age 0 were inversely related to bottom depth in all three years, and inshore densities of age 0 were "several orders of magnitude greater than offshore". Age 0 "were almost exclusively restricted to the inshore areas"; highest single catches each year were taken within major northeast coastal bays. Older juveniles, including age 1, were widely distributed inshore and offshore.

Dalley and Anderson (1997) provided the following perspective as part of their report. When stock biomass was robust (viz. early 1960's), age 0 juveniles occurred on the offshore shelf in "low numbers" during winter; however, "data from offshore areas were limited by sampling trawls that had low catchabilities for young cod, Most importantly, these surveys did not sample the inner shelves or within any of the large northeast Newfoundland bays."

The bays along the eastern coast of Newfoundland are where young cod were commonly observed more than several decades earlier and now serve as the only substantial source of recruits to the adult stock (Ings, et al. 1997). In some of these shallow, subtidal habitats, scientists have documented high catch number per (seine)

haul of age 0 cod in the course of ecological studies. Age 0 cod are concentrated nearshore beginning in April or May coinciding with the first settlement pulse and these influxes may occur periodically until December (Methven and Bajdik 1994).

For offshore waters over the eastern Scotian Shelf, mean cod catch rates at age by depth interval were calculated from DFO stratified random trawl surveys conducted in summer, 1970-1989 (Sinclair 1992). The time series mean number per (30-minute) tow for age 0 in the < 164' (50 m) depth zone, corresponding to shallow areas of Middle, Sable Island, Banquereau Banks, etc. was 0.053 (148 tows) and for the 165-328' (50-100 m) zone was 0.134 (649 tows). The time series age 1 catch per tow for the same shallow and deeper zone was 13.644 and 1.428, respectively.

DFO trawl surveys off Newfoundland and Nova Scotia operate seaward of the 656' (200-m) isobath and the 300' isobath (91-m), respectively. As a consequence, little quantitative age 0 distribution information appears in published literature from inshore regions with the exception of the special investigations noted above.

Gulf of Maine. The distribution of spawning fish is a very important factor in determining dispersal of pre-settlement juveniles (via prevailing currents) to potential nursery areas (Pepin and Helbig 1997). Off southwestern Nova Scotia, inter-annual differences in larval and pelagic juvenile cod catch densities were documented as well as distribution shifts between offshore and nearshore waters (Suthers and Frank 1989). These observations were related to variable circulation features on Browns Bank, an offshore cod spawning ground, thus suggesting that the inshore areas in the northeast section of the Gulf of Maine served as nursery area for cod originating from Browns Bank (Suthers and Frank 1989). Research-trawl catches of juvenile cod have been noted within Annapolis Basin, St. Mary's Bay, and along (< 65' or 20 m) exposed coastline (i.e., Trinity Ledge), as well as in other bays and harbors of Southwest Nova Scotia (Horne and Campana 1989).

In the early part of the twentieth century, many cod spawning grounds were noted along the length of the Maine coast, over half within state jurisdiction (Ames 1998). Retired fishermen described over-exploitation gradually extirpating these spawning aggregations/ resident subpopulations (or pollution rendering spawning

habitat uninhabitable) beginning in the 1930's when annual total commercial landings began fluctuating sharply before declining to a 1952-1963 low period. Thereafter, landings began a twenty-year upswing. Even though areas nearby known spawning grounds sometimes held cod, many spawning areas were reported to have remained barren (Ames 1998).

During the late 1970's, spawning cod aggregations still occurred along the Maine coast as suggested by light to moderate egg concentrations taken annually from October through July, 1977-87, in standardized monthly or bimonthly NEFSC ichthyoplankton sampling cruises, known as MARMAP (Marine Resource Monitoring Assessment and Prediction) surveys (Berrien and Sibunka 1999). A downward trend in egg abundance was observed over this period, however. Ames (1998) reported an hypothesis that restrictive multiple current gyres have effectively insulated coastal waters east of Penobscot Bay from eggs and larvae, thereby preventing cod from recolonizing Maine's inshore waters.

If spawning still occurs off the Maine mid-coast area, onshore currents associated with the Jeffries Bank eddy in the western Gulf of Maine (Brooks 1985) might be expected to advect early life stages inshore at least from mid-coast south. Two Maine Division of Marine Resources (MDMR) scientists has expressed doubt to the NEFMC whether age 0 cod are currently populating Maine's nearshore habitats. The Gulf of Maine cod stock's occupied range has contracted in recent years (NEFMC's MSMC 1998) suggesting loss of spawning aggregations; however, concluding that 0-group cod are not occupying nearshore habitats is premature without undertaking directed sampling efforts (particularly at night) in absence of coastwide, systematic surveys. For example, following an inquiry by a member of NEFMC's Habitat Technical Committee, Dr. Mark Tupper, an ecologist, responded (R. Langton, MDMR; personal communication):

"Regarding intertidal cod, I caught them with a beach seine at low tide, in a seagrass bed right beside the Darling Center dock (Damariscotta River estuary, Walpole, Maine). The catch of gadids was mixed, with a high proportion of pollock and tomcod in addition to *G. morhua*. I believe it was the last week of August, and it was around mid-day (late morning or early afternoon)."

Moreover, reports exist of juvenile cod being taken in seine and gill net catches (1976-81) from Passamaquoddy Bay, Bay of Fundy (MacDonald et al. 1984); as regularly present in monthly trawl tows (1978-79) in Johns Bay, ME (Hacunda 1981); in experimental gill net catches (1985-86) off Pemaquid Point, ME (Ojeda and Dearborn 1991); and, cod (presumed juveniles), taken in fyke net collections (1993) in a shallow salt pond at Kennebec Point, Maine (Lazzari et al. 1999). Additionally, qualitative reports note juvenile cod as common or abundant in 11 Maine bays and rivers from Passamaquoddy Bay south to Saco Bay (Jury, et al. 1994). A sufficient number of contemporary positive reports from the nearshore marine environment north of Massachusetts exist to support the designation of an HAPC within EFH.

The documented use of the inshore zone on the Nova Scotia side of the Gulf, anecdotal observations from the Maine coast, together with our study results strongly suggest a Gulf-wide pattern of utilization. Certainly, information to conclude that cod behave differently in Maine from cod in Massachusetts and Canadian Maritimes is lacking.

In the southwestern Gulf of Maine, two historical cod spawning grounds (Ipswich Bay and Plymouth) straddle the Massachusetts territorial limit and are still annually occupied by breeding adults. Fifty-one standardized ichthyoplankton MARMAP cruises were conducted monthly or bimonthly by the NEFSC within and adjoining the eastern Massachusetts' seaward boundary as part of a broadscale ecosystem study off the northeastern United States (Berrien and Sibunka 1999). Moderate to high densities of cod eggs were encountered from November-June on virtually every survey of the Massachusetts portion of their study area, 1977-87. In addition, larval concentrations were observed during all months and densities were highest (100 to < 1000/ m³) from May-July (Morse et al. 1987).

The prevailing southwestward-flowing coastal current as well as summer upwelling-favorable winds (Graham 1970) off eastern Massachusetts would advect eggs and larvae shoreward. The bottom drift next to the coast tends to flow directly onshore (Bumpus 1973), and along with tidal currents (Bumpus 1974), would move pelagic juveniles into Massachusetts coastal embayments.

MDMF's seasonal trawl catches of settled 0-group juveniles substantiates shoreward transport

and settling of pelagic juvenile cod. In the first half of the twentieth century, scientific sentiment was contrary to our results, i.e., cod spawning areas off Massachusetts (as well as spawning grounds along the Maine coast) were believed to be more important in supplying eggs to replenish offshore grounds via passive drift and settlement (see Schroeder 1930). The origin of this belief appears to be Bigelow's (1927) classic studies on circulation in the Gulf of Maine that commenced in 1912 coupled with Fish's (1925) study in Massachusetts Bay.

Using largely qualitative ichthyoplankton sampling techniques and inferences from surface drift bottle results, Fish (1925) found "thousands" of cod eggs in surface tows in western Massachusetts Bay and only late embryos in the eastern part, but catching no cod larvae in vertical plankton hauls with a meter net containing No. 2 fine silk bolting cloth (equivalent to 390-mm mesh), he concluded that the anticlockwise drift transported eggs out of the bay before they hatched. Another half century passed before bottom water circulation in the Gulf of Maine was described (Bumpus 1973) and standardized ichthyoplankton sampling was initiated (Lux and Kelly 1981; Scherer 1984), including the broadscale MARMAP surveys. The MARMAP studies utilize quantitative techniques with 505-mm mesh net and double vertical oblique tows (from surface to within 5 m of the bottom and return to surface) for sampling ichthyoplankton. The positive pre-settlement cod catches in the contemporary studies are supportive of our observations. We suspect that Fish's (1925) sampling net and methodology elicited avoidance behavior from larval and pelagic juvenile cod.

We do not know the source of newly-settled cod found off eastern Massachusetts. The obvious presumption would be the nearby spawning grounds since fish species are believed to spawn where circulation features promote retention and transport of planktonic stages to nursery areas (Sinclair 1988).

At locations shoalward of MDMF trawl survey stations, 2-9 cm cod have been captured along the Plymouth shoreline in generally low numbers during small otter trawl daytime sampling from March-October, 1982-93 (B. Lawton, MDMF, unpublished data). Similarly, in Salem Sound, cod of an identical length range were also taken in small trawl and seine collections from February-September, 1997 (Chase et al. 2002). In both

surveys, sampling was year-round and age-1 length juveniles were rare.

Our seasonal age-related differences in catch-weighted mean depth reflect a progressive ontogenetic movement from an inshore region of cod settlement to deeper water habitats and seaward fishing areas. The addition of age 1 and older juveniles to the vulnerable population offshore is consistent with distribution of sexually immature juveniles (< 37 cm) taken in NEFSC trawl surveys. Pre-reproductive cod are generally distributed at depths < 328' (100 m) along the Maine coast and seasonally concentrated between Jeffrey's Ledge and Cape Cod, and particularly in Massachusetts Bay in autumn (Wigley and Gabriel 1991).

Age 0 cod are rarely caught in the NEFSC spring offshore survey of the Gulf of Maine (> 89' or 27 m, strata 26-30 and 36-40) due to their pelagic existence when surveys are conducted in early spring. Both 0- and 1-group cod are more common in autumn. Over the autumn 1963-1997 time series, standardized catch per tow indices for age 0 and 1 have never been higher than 1.3 and 5.6, respectively (Mayo et al. 1998).

Catch rates between the DFO, NEFSC, and MDMF surveys are not directly comparable due to differences in survey catchability. Catchability differences between surveys are a result of different area swept, different gear efficiency, daytime sampling versus around-the-clock sampling, different timing of the surveys, sampling a portion of the stock's range versus more synoptic areal coverage, and DFO and NEFSC trawl's ability to sample harder bottom. As an example, the DFO and NEFSC's overall catchability averages diel differences in catchability, while the MDMF only samples in daylight. Catchability may also vary between seasons within surveys.

Trawl Efficiency. Since trawl efficiency is less than 100%, survey indices measure relative abundance not absolute abundance. Inability to sample hardbottom, due to gear limitations may introduce bias if the proportion of cod on trawlable and untrawlable bottom changes with stock size. Sources of measurement error, i.e., the difference between relative abundance adjusted for catchability and true population size, include sampling error and "annual effects" or seasonal changes in species availability. Changes in availability can occur when fish respond to environmental effects by altering the timing of

seasonal distributional shifts relative to the timing of the survey. This may be more problematical for the MDMF surveys, which only samples a portion of a stock's range than for the more synoptic NEFSC surveys. Differences in catchability among age-groups also exist.

The MDMF stratified sampling design was implemented to increase precision of the mean by reducing among strata variation for multispecies and was not designed specifically for cod. Comparison of stratum catch rates provides insight into distribution of ages 0 and 1 cod within inshore Massachusetts's waters. Inability to access hardbottom areas may introduce bias in among strata comparisons if the proportion of untrawlable bottom varies among strata and cod are differentially distributed on towable and untowable bottom.

Summary

MDMF resource survey data documents that a cod nursery is located off the eastern Massachusetts coastline and within state territorial water jurisdiction. Results correspond to first-hand accounts of juvenile grounds being close to shore in the Gulf of Maine as noted by fishermen and naturalists from the latter half of the 19th century, and summarized by Bigelow and Schroeder (1953):

"During the first year after the young cod take to bottom many of them live in very shoal water, even along the littoral zone, and many young fry have been taken at Gloucester and elsewhere along the shores of New England, while many small cod are caught about the rocks only a fathom or two deep even in summer. . . . it is certain that many cod fry take to bottom on the offshore banks also, for we have trawled young fry at many localities between Nantucket Shoals and Browns Bank.....But they usually are more plentiful on the rough inshore bottoms than on the smoother offshore banks. A reasonable explanation is that if young cod take to the bottom on rough, rocky grounds, or among algae, they have a fair chance of escaping their various enemies, but that they find no hiding places on the smooth bottom that characterize extensive areas on Georges Bank and on Nantucket Shoals, hence, are soon decimated."

The often-insightful observations of an earlier time in New England waters have also proven to be similar to contemporary research findings off Atlantic Canada, and on Georges Bank.

Off the eastern Massachusetts coast, age 0 cod occurred at 50% (889 of 1,783 stations) of all stations successfully trawled. Newly settled cod were concentrated (mean $Z > 0$) at depths $< 90'$ in May and between 60-180' in September. Since the breadth of the region encompassing the 180' (55 m) isobath off New Hampshire and Maine is about the same as Massachusetts', our results would suggest that 0-group cod, if present there now, are probably utilizing similar depths throughout the region.

For a number of cod stocks, variability in year class strength is usually determined in the larval stage and attenuated by post-settlement density-dependent juvenile mortality (Myers and Cadigan 1993). Many of the behavioral ecology studies cited above describe how certain habitats mediate post-settlement processes leading to significant decreases in predator-induced mortality, and likely physiological stress. If suitable habitat is either limited by its availability (e.g., eelgrass) and (or) occupied by competitors, such as age 1 cod, when settlement occurs, a carrying capacity bottleneck might ensue that could ultimately limit cod recruitment. For example, when local settlement strength was high and eelgrass beds were fully occupied by age 0 cod in Trinity Bay, Newfoundland, a significant increase in abundance was noted in less suitable no-eelgrass habitat where they might have been subject to higher mortality (Grant and Brown 1998b). Similarly, laboratory experiments suggest that if age 1 cod, or other predators, occupy preferred habitats, pelagic juveniles would be expected to delay settlement (Fraser et al. 1996) possibly incurring increased mortality in the drifting state, again resulting in an upper limit to the number of survivors.

The extent to which such behavioral responses and known preferences effect habitat utilization by 0-group cod off the eastern Massachusetts coast is unknown; however, the manifestation of such events are reflected in interannual and interseasonal variation in depth zone occupancy we recorded. We may never know all the critical processes, but the volume of recent research devoted to ecology of young cod in the North Atlantic coupled with our field observations is sufficient to identify a recruitment nursery. Based on our results, the

subtidal coastal waters extending to 180' (55 m) in the Gulf of Maine is an important nursery ground for cod during their first year of life.

Consistent with protocols for designating an HAPC, substratum types within the 180' isobath that are most threatened by human-induced alteration and disturbance (Wilbur and Pentony 1999), as well as specific fishing practices which reduce habitat complexity (Auster and Langton 1999), should fall under the aegis of HAPC. Eelgrass is an important nursery habitat type for age 0 in countries bordering the Northwest and Northeast Atlantic Ocean (Gotceitas et al. 1997) and is in jeopardy particularly in U.S. coastal regions. Eelgrass is subject to multiple stresses and disturbances contributing to loss of acreage (Short and Burdick 1996), decreased food web structure (McClelland and Valiela 1998), and foregone predator (benthic fish, lobster, and large shellfish) biomass (Heck et al. 1995). Protecting eelgrass habitat should be a high priority. In addition to the well-documented, largely shallow-water habitat types, our study infers that perhaps other unidentified structural components on deeper, fine-grained sediments may be very important and should be identified.

An HAPC for the Gulf of Maine cod stock would encompass critically dependent structural component(s) of the sea floor that enhance survivorship of young juveniles. Ultimately, if HAPCs are to fulfill expectations, managers and fishermen must embrace an ecosystem-based philosophy where exploitation would be balanced against the need to maintain long-term sustainability of renewable resources and other goals. Minimizing impacts on critical benthic niches will have positive effects on cod productivity, benthic habitats, and biodiversity. At the same time, resource users are demanding more balanced approaches than simply closing areally expansive areas to all bottom-fishing methods. Presented with harsh economic alternatives, they will help develop fishing technologies less destructive of bottom habitat. Low impact harvesting methods can lead to greater habitat complexity and correspondingly greater settlement and survival of newly-settled cod. Of course, affording more protection to nursery habitats alone does not assure enhanced recruitment since New England's coastal regions depend on replenishment from adult spawning aggregations elsewhere.

Acknowledgements

We thank Daniel A. Arnold, a longtime draggerman and early NEFMC member, who had the foresight, experience, and patience to help establish this program in 1978. Individuals who were once, and for various periods, members of the four person staff responsible for undertaking all aspects of these surveys, except vessel operations, deserve special credit: James Buckley, Steve Cadrin, Bruce Estrella, Frank Germano, Brian Kelly, Donald MacIsaac, Brian O'Gorman, Sherry Sass, and David Witherell. Each helped sustain requisite standards in aspects of survey work and database management thus enhancing the value of the data set. Similarly, we are very grateful for: the dedication and effort expended by every crew member of the F/V FRANCES ELIZABETH (1978-81) and the NOAA R/V GLORIA MICHELLE (1982-99); for the help of hundreds of state, federal, and university biologists who voluntarily shared on-board processing tasks with us; and, the labor, skill, and advice from David Arnold and Dennis Bruce on gear maintenance. We are grateful for the steadfast support of former and current Division Directors, Allen Peterson and Philip Coates, and administrative oversight from W. Leigh Bridges and Paul Diodati. From the initiation of this program to the present, there has been generous and timely assistance from the NMFS/NEFSC and many individuals at the Woods Hole Laboratory, particularly Tom Azarovitz, Jay Burnett, Linda Despres, Paul Kostovich, William Kramer, Mary Laird, Jack Moakley, Jacqueline Riley, as well as Allen Blott and Anne Studholme of the Narragansett and J.J. Howard Laboratories, respectively. This study was conducted under the auspices of the U.S. Fish and Wildlife Service Federal Aid to Sport Fish Restoration Act, project F-56-R. An earlier version of the manuscript benefited from helpful suggestions of Steve Cadrin. We also acknowledge the timely assistance with GIS plotting and statistical expertise from Dorothy Graaskamp (DFWELE) and Robert Glenn (MDMF), respectively.

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