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THE DISTRIBUTION, ABUNDANCE AND PRODUCTION OF ATLANTIC COD AND HADDOCK LARVAE OFF NORTHEASTERN UNITED STATES IN 1978-79 AND 1979-80

by

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ABSTRACT

Temporal and spatial patterns of distribution and abundance, along with production estimates of Atlantic cod, *Gadus morhua*, and haddock, *Melanogrammus aeglefinus*, larvae are described from broadscale MARMAP surveys as part of a continuing program to monitor annual spawning cycles of the principal species off northeastern United States. Areal patterns of distribution for both species resemble those for the 5-year period between 1973-74 and 1977-78 in that major concentrations of larvae were centered over the eastern half of Georges Bank with lesser concentrations in the Gulf of Maine and off southern New England. The period of peak spawning by Atlantic cod and the onset of haddock spawning seem to be related to environmental conditions. In 1978-79, the third in a succession of three severe winters, spawning by both species peaked in spring, a pattern that held during the record cold autumn-winter period of 1976-77 and 1977-78. In 1979-80, a moderate autumn-winter accompanied by warmer water temperatures than the previous three years, larvae of Atlantic cod were most abundant during the winter and, for the first time since 1976, haddock larvae occurred on Georges Bank during the winter survey. Estimates of larval production on Georges Bank were substantially greater for haddock than cod during both years. The estimate for cod in 1980 nearly doubled the 1979 estimate while estimates for haddock for the 2-year period were similar.

INTRODUCTION

A comprehensive fishery ecosystems study known as MARMAP (Marine Resources Monitoring and Prediction) has been a focal point of research at the Northeast Fisheries Center (NEFC) for nearly a decade. MARMAP is designed around a time series of broadscale trawl and plankton surveys which monitor shifts in the distribution, abundance and production of marine organisms from different trophic levels, as well as fine scale process oriented field and laboratory studies. It is made up of conceptually related scientific disciplines which function as a unit to collect the kinds of biological and environmental data needed to piece together the course of events that transpire within marine ecosystems to influence the size of fish populations. Estimates of egg and larval populations and adult spawning biomass of principal fish species are derived from the surveys. By crosswalking results of the various MARMAP research activities and incorporating information from other investigations, biologists at NEFC are working toward a level of understanding of biological and environmental interactions that will allow them to predict the size of incoming year classes (Sherman 1980). This report summarizes the distribution, abundance and production of Atlantic cod and haddock larvae as determined from MARMAP surveys between late autumn and spring of 1978-79 and 1979-80. It updates information presented by Smith et al. (1979) and thus provides a continuous 7-year data base for larvae of these two important species which dates back to the 1973-74 spawning season.

MARMAP plankton surveys are conducted in shelf and slope waters from Cape Hatteras to Nova Scotia. Sampling intensity increased from two to six or more surveys/year in the autumn of 1976 when the program took on international dimensions through joint participation of ships and scientific personnel from Poland, USSR, FRG, GDR, Canada, France and the United States. Survey collections and measurements since 1977 include: ichthyoplankton (Berrien et al. in press; Berrien 1981; Sherman et al. 1981; Smith et al. 1978, 1979, 1980a, b; Sullivan 1980); zooplankton (Sherman et al. 1977, 1979; Sherman and Jones 1980); phytoplankton identification and cell counts (Esser et al. 1980; Marshall and Cohn unpubl. ms); nutrients (Draxler et al. 1979); chlorophyll *a* measurements (Evans et al. 1979); twice-daily primary productivity measurements (O'Reilly and Busch 1979); dissolved oxygen; and temperature and salinity (Pawlowski et al. 1978; Nickerson and Wright 1980).

METHODS

Plankton stations are arranged to form transects at seven locations within the 260,000 km^2 survey area which includes shelf and slope waters from Cape Hatteras, North Carolina to Nova Scotia, Canada. Other stations were chosen from a stratified random design used for NEFC trawl surveys (see Grosslein 1969; Clark and Wood 1978) to provide "even" coverage. We currently occupy 175 stations, spaced at 25 to 35-km intervals. The survey area is sectioned into four subareas for analytical purposes (Figure 1).

Methods used to collect ichthyoplankton are described in detail by Smith and Richardson (1977). Double oblique tows are made with 61-cm bongos fitted with 0.505 and 0.333-mm mesh nets. The bongos are lowered to within a few meters of bottom at 50 m/min and retrieved at 20 m/min. Ship speed is variable at less than 3 kts to maintain a 45° wire angle. The 0.505-mm mesh samples are used for ichthyoplankton studies; the 0.333-mm mesh samples for zooplankton. Water temperatures included in this report are means of surface and bottom temperatures.

Initial processing of MARMAP ichthyoplankton samples is completed at the Morski Instytut Rybacki, Szczecin, Poland. Within three to six months of delivery to the Institute, larvae are sorted, identified and measured then returned to NEFC's Sandy Hook Laboratory, along with appropriate logs and eggs. At Sandy Hook, the ichthyoplankton information is keypunched for entry into the MARMAP Information System (MIS) and eggs are identified and staged to map spawning areas and derive estimates of spawning stock biomass.

We calculated larval production for cod and haddock spawned on Georges Bank, the principal spawning grounds within the survey area, using the formula:

$$L_0 = Ln \left(\frac{1}{1+m}\right)^n$$

where L_0 is the number of larvae produced, or hatched; Ln is the number hatched at age n; n is age of larvae in days; and m is the mortality rate.

Larvae were measured to the nearest 0.1 mm, grouped into 0.5-mm size intervals and transformed into estimates of abundance using the method described by Berrien et al. (in press). A review of length-frequency plots indicated that cod and haddock larvae >10 mm were not represented in our catches in proportion to their true abundance. Thus we based production on larvae <10.1 mm (SL). With consideration given to water temperature (mean of surface and bottom for positive stations), ages in days for each 0.5-mm size interval were taken from growth curves constructed from growth rates (dry weight) at temperature (Laurence 1978) and length-weight regressions (Laurence 1979). To arrive at estimates of production, the midpoint of each 0.5-mm length interval was used to calculate age. We assumed a daily mortality rate of 7.1% for haddock, based on estimates of 4.8 to 10.7% for larvae collected near the Faroe Islands (Saville 1956) and 6.5 to 7.7% for larvae from Georges Bank (Laurence 1974). Lacking empirical data, we arbitrarily assumed the same daily mortality rate (7.1%) for cod larvae. The onset of hatching was estimated from the size (age) of the largest larvae taken on the first cruise of the season or from information on the timing of initial occurrences on past surveys. The close of hatching was estimated from the size (age) of the smallest larvae or the presence/absence of eggs on the final cruise of the spawning season.

DISTRIBUTION, ABUNDANCE AND PRODUCTION OF LARVAE

ATLANTIC COD - The spawning season of Atlantic cod within the MARMAP survey area begins in autumn and continues into spring. Eggs occur in our samples from mid-November through May. The principal spawning grounds are centered over the eastern half of Georges Bank.

Even though the late autumn 1978 survey missed the important spawning area on eastern Georges Bank, the absence of cod larvae on all but three stations indicated very limited spawning (Figure 2). Normally at this time cod larvae are broadly distributed and most abundant off southern New England, within the area surveyed during the abbreviated cruise in 1978 (see Smith et al. 1979). Based on the isolated distribution and meager catches (see Table 1) we concluded that late autumn spawning in 1978 was limited in scope and intensity.

An equally serious sampling shortfall occurred on our winter (February-March) survey. With the exception of 10 stations in the Gulf of Maine and four on Georges Bank, coverage was limited to the southern New England and Middle Atlantic subareas where larvae were scattered in low density concentrations as far south of the offings of Chesapeake Bay (Figure 2). Abundance estimates for the Middle Atlantic subarea are low but fall within the range of estimates for the 1973-77 period. Off southern New England they are significantly less than those of 1974 and 1975 surveys but similar to our observations during the anomalous winters of 1976 to 1978.

From April through early May both the areal distribution and abundance of larvae increased dramatically, with most of the young cod centered over the eastern half of Georges Bank where the mean water temperature was 4.8°C (Figure 2). Despite the surge in spawning activity, with the exception of 1976, estimates of larval abundance are 19 to 73% below those observed in early spring during the previous 5-year period (Table 1). Towards the end of May the larval population remained centered over the eastern half of Georges Bank. Mean water temperature had warmed to 7.8°C. With the exception of some evidence of westward transport along the southern part of the Bank, both the distribution and abundance of larvae remained much as they were during the previous survey (see Figure 2 and Table 1).

Our subsequent survey began in late June off Cape Hatteras. It was well into July when we reached the Georges Bank area. Despite the occurrence of cod eggs in samples collected through the end of May on our previous survey, cod larvae did not occur in our June-July ichthyoplankton samples which did not include the eastern third of Georges Bank and most of the Gulf of Maine.

Production estimates for both cod and haddock larvae on Georges Bank in 1978-79 are based on only two surveys, both in the spring of 1979. Thus there was a large time lapse between the onset of spawning and our initial surveys, especially for cod. We chose November 15 (1978) to represent the beginning of hatching, a date that approximated the initial occurrence of cod larvae in past years and again in 1979. Based on the occurrence of both eggs and recently hatched larvae in our May 1979 samples, we estimated that hatching ended no earlier than June 15. With the limited information at hand, we derived a production estimate for the Georges Bank subarea of 39.172×10^{12} larvae. Hatching peaked between March 13 and March 30. Using incubation rates from Laurence and Rogers (1976) and temperature observations from our surveys, we concluded that spawning peaked between late February and mid-March.

In the fall of 1979 the distribution of Atlantic cod larvae resembled early season patterns observed during previous surveys. Most of the young fish were located off southern New England, around Nantucket Shoals, rather than over Georges Bank where spawning is most intense later in the season (Figure 3). The abundance of larvae around Nantucket Shoals during the November-December survey was more than double that on Georges Bank and nearly an order of magnitude greater than that observed off southern New England during the autumn 1978 survey (Table 1).

By winter the center of distribution shifted to eastern Georges Bank where mean water temperature was 4.4°C at those stations where we caught cod larvae (Figure 3). Abundance estimates were the highest of the season, marking the first time in the 7-year data set that larval abundance peaked during winter (Table 1). Our abundance estimates for this winter survey are five times greater than the previous winter high for the MARMAP time series.

In early spring the principal concentration of cod larvae remained centered on Georges Bank with lesser concentrations along the eastern part of the Gulf of Maine. Mean water temperatures were: 5.6°C in Gulf of Maine; 6.2°C on Georges Bank; and 7.2°C off southern New England, or >1°C warmer than those observed at about the same time in 1979. Just as in 1979, changes in configuration of the distributional pattern from the previous survey suggest a westward movement of larvae along the southern part of Georges Bank. There is no indication that larvae were being transported off the shelf except, perhaps, at the extreme western end of the distribution south of Cape Cod (Figure 3). By late spring spawning had apparently ended. Most of the remaining planktonic larvae were situated along the western part of the Gulf of Maine with lesser concentrations off southern New England (Figure 3). Mean water temperatures in the two subareas were 8.8 and 10.7°C, respectively. Abundance estimates dropped sharply from early spring levels which is normal for this time of year, but we did not sample the eastern parts of Georges Bank and the Gulf of Maine where most larvae occurred on our earlier surveys (Table 1).

December 2 marked the mid-date of sampling on Georges Bank on our late autumn (1979) survey. We estimated the oldest larvae in our samples at 16 days and assigned November 15 as the date that hatching began. Given mean water temperatures at the time (9.8°C) and information in Laurence and Rogers (1976), we surmised that spawning began during the first week of November. We established June 5 as the termination date for hatching, based on the age of the smallest larvae in our late spring survey which had a sampling mid-date of June 17. Larval production for the year was computed to be 64.313×10^{12}, a figure 39% greater than the 1978-79 estimate. Peak hatching occurred between December 9 and January 29, or two to three months earlier than the late March peak in 1979.

HADDOCK - Haddock traditionally begin spawning later than Atlantic cod off northeastern United States. Eggs occur from February through May; larvae from February into June. Like cod, haddock larvae reach peak levels of abundance during the late April-early May time period.

Just as with Atlantic cod larvae, the sampling shortfalls on our winter 1979 survey detracted from our results. We caught one haddock larva at one station off southern New England, the area which approximates the southern limit of their distribution (Figure 2). Given the similarity of environmental conditions to those of 1977 and 1978 when haddock did not occur during the winter surveys, it seems unlikely they occurred on Georges Bank in significant numbers, if at all, at the time of this cruise.

By early spring larvae were widely distributed over the eastern part of Georges Bank and northward into the Gulf of Maine where mean temperatures were 4.7 and 4.3°C, respectively (Figure 2). Despite the apparent increase in spawning activity, abundance estimates shown in Table 2 were generally below those encountered during the same time period on 1974 to 1978 surveys (see Smith et al. 1979).

The distribution of haddock larvae continued to expand in May, covering the eastern part of the Gulf of Maine where the mean water temperature was 7.7°C; most of Georges Bank where water temperature increased to 8°C; and a large part of the southern New England subarea east of Montauk Point, Long Island, where the mean temperature was 8.3°C. The majority of the larval population (76%) occurred on Georges Bank where a large, moderately abundant concentration stretched across the entire length of the Bank. As with cod larvae, it appears when comparing the distribution patterns from the two spring surveys that haddock larvae were being transported to the west along the southern part of Georges Bank (Figure 2). Although larval abundance estimates peaked for the season on this spring survey, and eggs were widespread over the same general area as larvae, we caught no young haddock on the following survey in June-July.

We estimated from the oldest larvae in our early spring survey that haddock eggs began to hatch on February 20. Because of the widespread occurrence of eggs through May, we projected that hatching ended on June 15. With the above dates and information from two spring surveys, we derived a production estimate for haddock larvae on Georges Bank of 102.888×10^{12}, an estimate more than two times greater than that for cod in 1979. Peak production occurred during the last week in March which corresponds with the period of peak production for cod. Given incubation rates in Laurence and Rogers (1976) and the mean water temperature where we caught haddock larvae on the early spring survey, the time of peak spawning was about a week after that of cod, or during the third quarter of March.

Haddock larvae occurred on Georges Bank during the 1980 winter survey, their first winter occurrence since 1976, and their highest winter abundance level since the surveys began in 1973 (see Figure 3 and Table 2). The mean water temperature where we caught young haddock was 5.2°C, or 0.5°C warmer than early spring temperatures in 1979.

By early spring their distribution continued to broaden and their abundance expand. Water temperatures were similar to those of the winter survey. We found haddock larvae continuously distributed across Georges Bank and northward along the eastern part of the Gulf of Maine to Nova Scotia. As with past surveys, the areal distributions and centers of abundance for both cod and haddock larvae were similar (Figure 3). Despite their expanded distribution into Gulf of Maine and southern New England waters, most (90%) of the young haddock remained on Georges Bank. The abundance of haddock larvae peaked for the season on this early spring survey, or about a month before the 1979 peak (Table 2).

By late spring the center of distribution shifted to the western part of Georges Bank where the mean water temperature was 9.4°C. Larvae occurred in the Gulf of Maine to the eastern limit of our coverage, and two low density concentrations were situated off southern New England. If haddock larvae occurred over the eastern part of Georges Bank where we did not sample, they were isolated from those larvae on the western part of the Bank (Figure 3). Abundance levels declined sharply from the previous survey and small, recently hatched larvae were not taken. Spawning apparently began and ended earlier than in 1979 (Table 2).

The estimated age of young haddock in our February-March samples and incubation rates in Laurence and Rogers (1976) place the onset of spawning on or about January 1, or nearly two months earlier than in 1979. Based on the age of the youngest larvae in our late spring samples, we established June 6 as the last day of hatching. Peak spawning occurred from about February 10 through the end of March, also earlier than in 1979. The time frame for peak hatching was offset from these dates by about 11 days. We computed larval production to be 110.466×10^{12} which is nearly twice that for cod in 1980 and similar to the 1979 estimate for haddock. For comparison purposes the production estimates for both cod and haddock larvae are listed below.

	1978-79	1979-80
Atlantic cod	39.172×10^{12}	64.313×10^{12}
Haddock	102.888×10^{12}	110.466×10^{12}

DISCUSSION

In their analysis of the 1973-74 to 1977-78 MARMAP data set, Smith et al. (1979) observed an apparent correlation between the severity of winter (i.e., temperature) and the seasonal spawning cycles of cod and haddock on Georges Bank. They described a seasonal pattern of occurrence for cod larvae that shifted from intermediate levels in late autumn to low in winter and high in spring. During the abnormally cold autumn-winter period of 1976-77 cod larvae were at relatively low levels of abundance in late autumn and absent in mid-winter. In 1978, another anomalous winter, they did not catch cod larvae on the Bank until spring. Haddock began spawning later than cod, their larvae first occurring on mid-winter surveys during moderate winters but not until spring in 1977 and 1978. The above pattern seemed to hold for both species during the first of the two spawning seasons covered in this report but not for cod during the 1979-80 season. Although sampling shortfalls detracted from our results, cod larvae seemed to be at depressed levels of abundance during the late autumn and winter surveys of 1978-79, the third of three successive record-cold winters in the survey area (Ingham and Haynes 1980). Their distribution and abundance expanded with the coming of spring but not to levels observed in other years. We caught only one haddock larva on the winter survey and that was in the southern New England subarea. They too reached peak abundance on Georges Bank in spring. In 1980, when winter weather conditions moderated, the spawning habits of both species changed dramatically from those observed during the three colder winters. The winter survey of 1980 marked the first time since the MARMAP surveys began that the abundance of Atlantic cod larvae was at peak levels during the winter. At the same time, the winter abundance estimates for haddock were the highest of the 7-year data set, and it appears that spawning began early in January.

Despite the above patterns, changing winter weather conditions do not seem to hold much promise for describing cause and effect mechanisms which determine year class success. Both species have produced two relatively strong year classes since the MARMAP surveys began in 1973; both during the same years, 1974-75 and 1977-78. The others were average to weak (Serchuk and Wood 1981; Clark et al. 1981). The former (1974-75) was a year of moderate winter weather. Cod and haddock larvae occurred at a relatively high level of abundance during winter but at relatively low levels during spring. In 1978 larvae of both species were absent on Georges Bank during the abnormally bitter winter months but at relatively high levels of abundance during spring (Smith et al. 1979). Thus the above-average year classes were produced during years of contrasting winter weather conditions which seemed to influence the temporal spawning patterns of cod and haddock but not their year class success.

Mean circulation on Georges Bank is described as a clockwise gyre (Bumpus 1973), a feature that would tend to retain planktonic organisms such as fish eggs and larvae on the Bank. Residual drift is to the west and southwest along the southern part of the Bank, thus explaining the changing configuration in the patterns of distribution of cod and haddock larvae during our spring surveys. Although the gyre is believed to be fairly constant, mounting evidence suggests that episodic anomalies frequently disrupt the gyral pattern. Two sources of disruption which could strongly influence the destiny of cod and haddock larvae are the on/off movement of the shelf water/slope water front (see Hilland and Armstrong unpubl. ms) and warm core rings which spin off the Gulf Stream and move westward along the Bank's southern flank (Celone and Chamberlain 1980). Circumstantial evidence from field and laboratory studies suggests that starvation is a principal source of larval mortality, and, consequently, one of the major sources of variability in year class success (see May 1974). But with measurements of primary production on Georges Bank ranking among the highest in the world (Cohen et al. 1978; O'Reilly and Busch 1979) anomalous advective processes might play a larger role than inadequate food supplies during larval development in establishing year class success for fishes spawned on Georges Bank.

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Table 1. Density (k = larvae/10m^2) and abundance estimates (no. x 10^9) for Atlantic cod larvae, based on collections in four subareas of the western North Atlantic from Cape Hatteras, North Carolina to the Gulf of Maine, 1978-80. ND = no data (not sampled).

Year	Cruise	Date	Subarea	# of Sta.	Positive Sta.	Mean Abundance (k)[1]	Standard Error ($S\bar{x}$)	Abundance (no. x 10^9)
1978-79	BEL 78-04	Dec	GOM	39	1	0.914	0.914	0.896
			GB	18[2]	0	0	0	0
			SNE	21	2	0.791	1.811	0.474
			MA	ND	ND	ND	ND	ND
	DEL 79-03	Feb-Mar	GOM	10[2]	0	0	0	0
			GB	4[2]	0	0	0	0
			SNE	48	10	1.233	0.566	7.387
			MA	40	9	1.071	0.836	6.247
	ALB 79-03	Apr-May	GOM	42	6	2.551	0.627	25.004
	DEL 79-04		GB	32	18	23.890	1.312	99.882
			SNE	27	2	0.611	0.826	3.659
			MA	2[2]	0	0	0	0
	DEL 79-05	May	GOM	50	8	2.642	1.011	25.897
			GB	27	15	26.313	1.165	110.013
			SNE	44	11	1.951	0.787	11.688
			MA	49	1[3]	0.031	0.031	0.179
	ALB 79-06	Jun-Jul	GOM	11[2]	0	0	0	0
			GB	19	0	0	0	0
			SNE	44	0	0	0	0
			MA	49	0	0	0	0
1979-80	ALB 79-13	Dec	GOM	48	2	0.469	0.558	4.597
	WI 79-03		GB	27	4	1.084	0.435	4.533
			SNE	29	6	1.904	0.654	11.404
			MA	ND	ND	ND	ND	ND
	ALB 80-02	Feb-Apr	GOM	50	3	1.087	0.700	10.656
	WI 80-02		GB	26	13	94.613	2.002	395.568
			SNE	46	9	1.417	0.770	8.491
			MA	50	1[3]	0.043	0.043	0.248
	EV 80-01	Apr-May	GOM	52	10	1.574	0.756	15.429
	ALB 80-03		GB	29	17	55.818	1.206	233.371
	DEL 80-02		SNE	44	3	0.887	0.739	5.315
			MA	50	1[3]	0.084	0.084	0.490
	DEL 80-03	May-Jun	GOM	36	3	4.526	1.374	44.366
	EV 80-04		GB	20	3	0.988	0.418	4.131
			SNE	43	4	0.873	0.605	5.227
			MA	50	0	0	0	0

[1] k = mean number of larvae/10m^2 surface area. Refer to Berrien et al. (in press) for discussion of rationale procedures for use of Δ-distribution which appears to describe these data. Abundance is expansion of k to reflect subarea size.

[2] Incomplete coverage

[3] When n_1-1, the mean is estimated by x/n, and its variance by x^2/n^2, where x is the single non-zero value; both are unbiased estimators (Berrien et al. in press).

Table 2. Density (k = larvae/10m^2) and abundance estimates (no. x 10^9) for haddock larvae, based on collections in four subareas of the western North Atlantic from Cape Hatteras, North Carolina to the Gulf of Maine, 1978-80. ND = no data (not sampled).

Year	Cruise	Date	Subarea	# of Sta.	Positive Sta.	Mean Abundance (k)[1]	Standard Error ($S\bar{x}$)	Abundance (no. x 10^9)
1978-79	BEL 78-04	Dec	GOM	39	0	0	0	0
			GB	18[2]	0	0	0	0
			SNE	21	0	0	0	0
			MA	ND	ND	ND	ND	ND
	DEL 79-03	Feb-Mar	GOM	10[2]	0	0	0	0
			GB	4[2]	0	0	0	0
			SNE	48	1[3]	0.115	0.115	0.690
			MA	40	0	0	0	0
	ALB 79-03 DEL 79-04	Apr-May	GOM	42	4	1.165	0.701	11.431
			GB	32	16	6.565	0.818	27.447
			SNE	27	0	0	0	0
			MA	2[2]	0	0	0	0
	DEL 79-05	May	GOM	50	8	9.745	1.602	95.526
			GB	27	15	112.197	1.422	469.084
			SNE	44	9	9.430	1.184	56.490
			MA	49	0	0	0	0
	ALB 79-06	Jun-Jul	GOM	11[2]	0	0	0	0
			GB	19	0	0	0	0
			SNE	44	0	0	0	0
			MA	49	0	0	0	0
1979-80	ALB 79-13 WI 79-03	Dec	GOM	48	0	0	0	0
			GB	27	0	0	0	0
			SNE	29	0	0	0	0
			MA	ND	ND	ND	ND	ND
	ALB 80-02 WI 80-02	Feb-Apr	GOM	50	0	0	0	0
			GB	26	6	21.698	1.148	90.718
			SNE	46	0	0	0	0
			MA	50	0	0	0	0
	EV 80-01 ALB 80-03 DEL 80-02	Apr-May	GOM	52	5	3.042	0.850	29.816
			GB	29	16	135.088	1.835	564.788
			SNE	44	5	5.765	1.273	34.536
			MA	50	0	0	0	0
	DEL 80-03 EV 80-04	May-Jun	GOM	36	3	1.612	0.364	15.800
			GB	20	6	5.706	0.831	23.858
			SNE	43	11	2.160	0.438	12.939
			MA	50	0	0	0	0

[1] k = mean number of larvae/10m^2 surface area. Refer to Berrien et al. (in press) for discussion of rationale and and procedures for use of Δ-distribution which appears to describe these data. Abundance is expansion of k to reflect subarea size.

[2] Incomplete coverage

[3] When n_1=1, the mean is estimated by x/n, and its variance by x^2/n^2, where x is the single non-zero value; both are unbiased estimators (Berrien et al. in press).

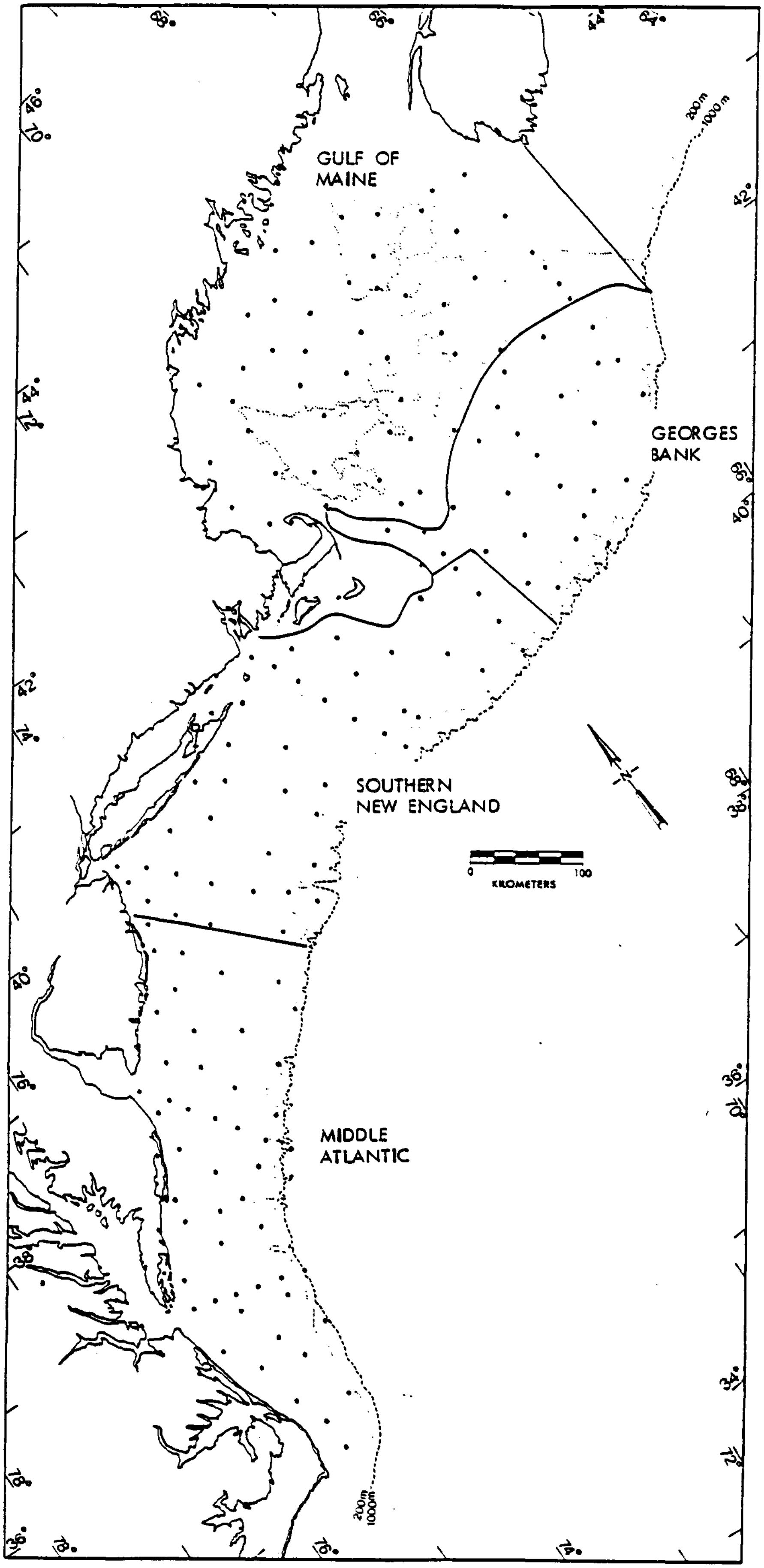

Figure 1. MARMAP survey area off northeastern United States showing station plan and four analytical subareas.

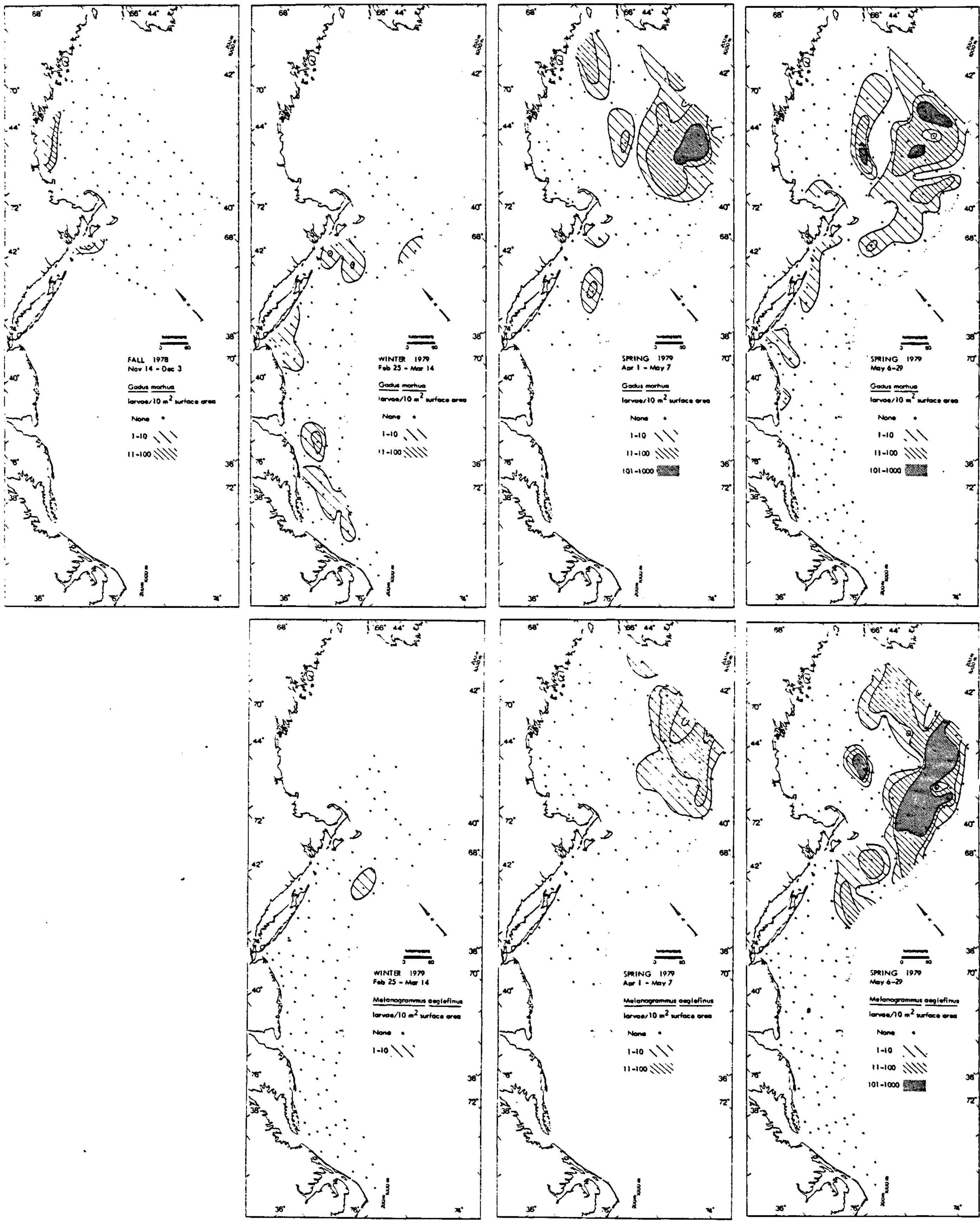

Figure 2. Distribution and abundance of Atlantic cod (top) and haddock (bottom) larvae off northeastern United States during 1978-79 spawning season.

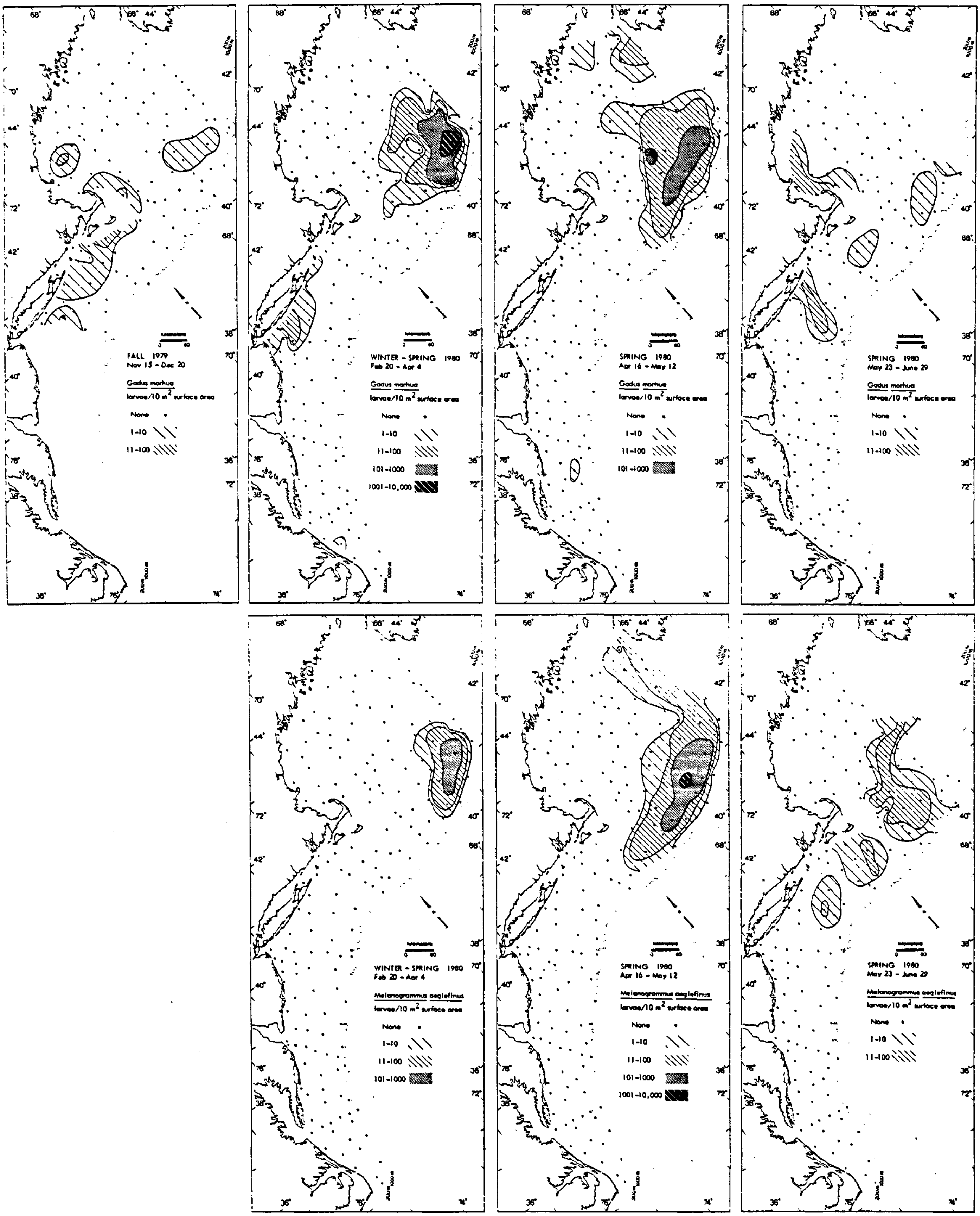

Figure 3. Distribution and abundance of Atlantic cod (top) and haddock (bottom) larvae off northeastern United States during 1979-80 spawning season.