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Changes of Time and Sites of Herring (*Clupea harengus* L.) Spawning vs. Bottom Temperature Over the Spawning Beds in the Georges Bank-Nantucket Shoals Area, 1971-1977 Seasons

by

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ABSTRACT

The distribution of newly hatched larval herring has been examined for 30 ICNAF Larval Herring Surveys covering the period from September to December of 1971 - 1977. Sampling on these cruises was conducted on standard grids of bongo-net stations at 3-4 week intervals throughout the autumn. Concentrated abundances of small larvae $\leq$ 8 mm SL have been used to delineate spawning areas and compared with station bottom temperatures to describe thermal spawning and hatching conditions. Delay of spawning on Georges Bank after 1973 was found to be associated with the warming trend observed by Davis (1978) particularly since 1971. Large volumes of very warm (>14, 15°C) water on the top of Georges Bank during autumn surveys observed since 1971 could have affected herring spawning and/or egg and larval survival. The decline in abundance of Georges Bank stock and virtual disappearance of signs of spawning on the traditional grounds after 1976 are discussed in conjunction with the continued spawning in the Nantucket Shoals area where the mean bottom temperatures were much lower than those on Georges Bank.

INTRODUCTION

With the development of the offshore herring fishery in the 1960's, Georges Bank became an area of major interest to distant water fleets. The herring catch on Georges Bank increased

dramatically until 1968 and then declined to virtually zero in 1977 in spite of the strong 1970 year class (Anthony and Waring, 1980). Although heavy fishing undoubtedly was a principal factor in the decline, it is possible that environmental factors may also have played a part. In particular, it was observed that during the period 1968 to 1977, there was a general warming trend in the region and that in 1973, 1974, 1976 and 1977, temperatures on the order of 14-15°C occurred on Georges Bank during the herring spawning season, and these were considerably higher than those believed to be optimum. Cooper et al. (1975) suggested that 9.5°C was the optimum temperature for herring spawning based on studies in the western Gulf of Maine. The onset of herring spawning on Georges Bank was delayed in 1973 and thereafter, and the length of the spawning season was shortened after 1975. Herring spawning virtually ceased on northeastern Georges Bank after 1976 whereas it continued on Nantucket Shoals where water temperatures never reached the high levels observed on Georges Bank.

These changes in the timing and location of herring spawning in the Georges Bank region were documented by intensive larval herring surveys conducted by the International Commission for the Northwest Atlantic Fisheries (ICNAF) and have been summarized by Lough et al. (1979). However, the observed changes were not studied in detail in relation to temperature. The aim of this study is to examine the location and timing of spawning and hatching success, in relation to temperature on the spawning grounds, by using the distribution of newly hatched herring larvae as a spawning site indicator. The study covers the 1971-1977 spawning seasons in the Georges Bank-Nantucket Shoals region, and utilizes the ICNAF data base described in Lough et al. (1979).

It is possible to use early stage herring larvae as spawning site indicators since herring spawn at discrete locations on the sea bed and each stock of herring in the Northwest Atlantic has its own unique spawning time and place (Sindermann, 1978). The fact that the Georges Bank stock is discrete from stocks in the

Gulf of Maine and western Nova Scotia has been clearly demonstrated. Boyar et al. (1973) summarized the seasonal distribution of larval herring in the Georges Bank-Gulf of Maine region from 1962 to 1970 and concluded that larvae originating from the three major spawning areas (Georges Bank, western Gulf of Maine and southwestern Scotian Shelf) remained discrete throughout the larval period due to restrictive circulation patterns. The ICNAF surveys from 1971-1977 confirmed that there is a low degree of larval mixing between the Georges Bank stock and western Gulf of Maine and southwest Nova Scotian stocks (Lough et al., 1979). Nantucket Shoals larvae intermix with those from Georges Bank and in the studies of Lough et al. (1979, 1980), larvae from the two areas are pooled and treated as originating from one spawning stock. However, there are persistent differences in the period of spawning and environmental conditions between these two areas. These differences plus the fact that spawning continued in the Nantucket Shoals area after the virtual disappearance of herring from Georges Bank after 1976, suggest that there is some discreteness between the groups of herring associated with these two spawning sites. In any case, the distribution of newly hatched larvae can be used to delimit herring spawning sites and the precise timing of spawning.

In this paper larvae $\leq$ 8 mm SL are used as spawning indicators and these are believed to be a maximum of one week old. Newly hatched larvae on Georges Bank are estimated to be 5.7 mm and after five days are about 7 mm long (Lough et al., 1980b).

METHODS

Vessels and cruise dates are listed in chronological order in Table 4 for the 30 surveys included in this study from 1971 to 1977. Cruise tracks and station positions for each of the surveys can be found in Lough and Bolz (1979a). A 3.5 knot double-oblique haul was made at each station using a 61-cm bongo net sampler (0.505 and 0.333-mm mesh). A Braincon V-fin

depressor (122 cm) was used to achieve the desired wire angle of 45° for the relatively high towing speed, and a Bendix or Benthos time depth recorder was attached to the wire near the bongo for a permanent trace of the haul profile. General Oceanics flowmeters were tied in the mouths of each bongo net to calibrate the amount of water strained. The bongo gear was deployed at 50 m/min to a maximum depth of 100 m or to within 5 m of the bottom in shoaler areas and the rate of retrieval was at 10 m/min. The standard bongo haul filtered between 100 and 1000 m^3 of water for each side of the net, depending on the maximum depth of the tow.

Standardized larval herring data in the form of various computer summaries and plots from 0.505- and 0.333-mm mesh, 61 cm bongo samples representing 30 cruises of the 1971-1977 seasons were processed through the MARMAP Biostatistical Unit, NEFC, Narragansett, RI. Data from both the 0.505- and 0.333-mm nets were used interchangeably since randomized paired comparison tests (Box et al., 19) did not show significant differences in the catchability of the two nets.

The study area was divided into two subareas, Nantucket Shoals and Georges Bank according to Schlitz (1976). Stations were chosen where small larvae $\leq$ 8 mm SL occurred. Larval concentration areas were defined by plotting all positive stations where the ratio of small larvae ($\leq$ 8 mm SL) to the total number of larvae was greater than .25, and where abundance of all larvae was greater than 10/10 m^2 (Figures 2-5, shaded areas). Areas where small larvae occurred but the ratio of small to large larvae fell below .25 and abundance of total larvae fell below 10/10 m^2, were identified as dispersal areas.

Preliminary bottom temperature plots have been obtained from Dr. W. Redwood Wright, Fishery Oceanography Investigation, NEFC, Woods Hole, MA. Bottom temperature values were marked at all stations where small larvae occurred and mean bottom temperatures and their standard deviations were calculated for both concentration and dispersal areas (Table 4).

RESULTS

Time and Place of Spawning

The standarized grid of sampling stations, 15-20 miles apart, cover the entire Georges Bank-Nantucket Shoals area (Figure 1) including the main herring spawning grounds of these regions. Spawning on Georges Bank occurred progressively later in the season from east to west. The northeastern part of Georges Bank is the major spawning area where newly hatched larvae appeared in the 1971-1973 seasons in September and attained maximum abundance by mid-to-late October. In 1974 and 1975, hatching of larvae occurred later in the season beginning in the first half of October and peaking in abundance in November.

The Nantucket Shoals larvae hatched later than those on Georges Bank in 1972 and 1973, and the peak in abundance and distribution of newly hatched larvae occurred in late October-early November. In 1971, no concentrations of small larvae were found in September and October but some dispersed larvae were observed in November and December which suggests that spawning on Nantucket Shoals was much weaker and occurred earlier in that year.

Hatching of larvae lasted for the longest period in 1973 on Georges Bank which coincided with recruitment of the very strong 1970 year-class, the strongest in the last decade (Anthony and Waring, 1980). This strong year-class is also evident in intensive spawning of the 1974 season and the prolonged 1975 season. On Nantucket Shoals the period of hatching became progressively longer from 1972 to 1975, with the longest period in 1975. In the 1976 season, spawning on Georges Bank was delayed further until as late as mid-October and lasted for the shortest period in the time series. After 1976 herring spawning was observed only in the Nantucket Shoals region (Figure 2).

Location of herring spawning grounds on Georges Bank did not differ during the years 1971-1975. The area of concentrated abundance of newly hatched larvae (in Figures 3-6 shaded area) first occurred on the Northern Edge in September (for the 1971-

1973 seasons), extended their range to the east and south in October, and contracted their area in November and disappeared in December. The highest concentrations of newly hatched larvae were observed in October 1972 and 1974, with areas of concentration covering approximately 4,500 km^2 in 1972 and about 10,000 km^2 in 1974. The largest area of mass occurrence of small larvae was recorded in the 1973 and 1974 seasons.

The area around the four sampling stations (83, 84, 89 and 90) may be the approximate center of the historical spawning ground on Georges Bank, since this is where the maximum frequency of occurrence of high abundance of newly hatched larvae was observed for the 1971-1975 seasons (Table 1). The depth at these stations ranged from 58 to 82 m.

Distribution of dispersed small larvae clearly shows the spread of larvae from spawning areas, first to the southeast and thereafter turning to the southwest, generally coinciding with the anticyclonic circulation on Georges Bank. The bulk of the larval population is found throughout the season within the 100 m contour. However, there is some indication from the time series to suggest the loss of larvae particularly in 1973, 1974 and 1975 when patches of newly hatched larvae were widely distributed to the east in the vicinity of Northeast Channel and to the north toward the Gulf of Maine.

A smaller herring spawning ground was observed in the western portion of Georges Bank within the area of station 51, where except for the 1971 season, larvae normally appear later between the latter half of October and the first part of November. No patches of small larvae were found on the Southern Slope of the Bank, suggesting that spawning did not occur in this area.

The coastal spawning in the Nantucket Shoals area inside the grid of stations might be the cause of underestimated abundance of larvae in remaining years of our time series. In the 1972-1976 seasons patches of newly hatched larvae occurred most often at stations 26, 27 and 30 southeast of Cape Cod from the first part of October to mid-November and even to mid-Dcember in 1973

and 1975. In the Nantucket Shoals region, dense concentrations of small larvae were found over a relatively small area compared to Georges Bank, with the exception of the 1973 season when the distribution of newly hatched larvae extended to the southeast.

The main spawning occurred on Georges Bank in 1971, 1973 and 1974, and in the Nantucket Shoals area in 1972 and 1975-1977 (Lough et al., 1980). In the following years up to 1981 only a few individual herring larvae were found on Georges Bank (Smith et al., 1980; R/V WIECZNO Cruise Reports 1980, 1981).

In Figures 9 and 10 the length frequencies of herring larvae caught in the 1971-1976 seasons shows a fairly typical unimodal distribution with dominance of small larvae during the first cruise, and polymodal distributions during later cruises within each season. Dominance of newly hatched larvae through the whole spawning season from September to November was observed in 1973 and 1974 on Georges Bank and in the 1972-1974 seasons on Nantucket Shoals which indicates very intensive and prolonged spawning

Thermal Conditions

North-south hydrographic sections in Figure 11 made during the peak of larval occurrence clearly shows the existence of warm Bank water (12-15°C) well-mixed to the depth of 50 m and separated from the stratified water of the Gulf of Maine to the north and Slope Water to the south. Except in 1975, the mean bottom temperature associated with recently hatched herring larvae (Table 3) as well as minimum and maximum temperatures on Northern Edge spawning grounds (Figure 3-7) were much higher than the optimum temperature (9.5°C) for herring spawning cited by Cooper et al. (1975). The highest mean bottom temperature, 15°C, was found in September 1971 (13.2-17°C) and the maximum of 19.1°C in September 1974, whereas the lowest was 8.1°C in 1975 with the range 7.8-8.4°C.

It should be noticed that herring spawning grounds on the Northern Edge of Georges Bank are in the immediate vicinity of a sharp temperature front which is not stationary but is advected

back and forth by tides so that some portions of the Bank are subjected to twice daily temperature fluctuations of 6-7°C (Wright and Lough, 1979). However, there was no evidence in our time series of the presence of such cold water over the spawning grounds.

The Nantucket Shoals region (Figure 12) water was much more variable and concentrations of newly hatched larvae have occurred over the area where bottom temperatures differed between cruises and stations. In 1971, 1976 and 1977 when concentrations of newly hatched larvae were not found in the Nantucket Shoals area, mean bottom temperatures were calculated for historical spawning areas. In 1971, extremely low temperatures ranging from 6.1° to 7.9°C were observed over the Nantucket Shoals historical spawning grounds, an average of 6.4°C lower than those on Georges Bank. Mean bottom temperatures were also much lower in the remaining seasons on the Nantucket Shoals spawning grounds compared to those on Georges Bank. This might be the result of a much smaller volume of well-mixed water over the spawning ground and of the fact that the front often crossed the area of occurrence of concentrations of larvae $\leq$ 8 mm.

DISCUSSION

The knowledge of exact spawning sites an provide information on time and conditions of spawning useful for fishery science. The locality and onset of herring spawning on Georges Bank have been studied by several different methods (Noskov and Zinkevich, 1970; Caddy and Iles, 1973; Graham and Chenoweth, 1973; Drapeau, 1973; Pankratov and Sigajev, 1973; Boyar et al., 1973; and others). Herring spawn on Georges Bank on very specific substrate type, on a flat surface of fairly well sorted rounded gravel, 2-10 mm in diameter, in waters characterized by strong mixing processes (Caddy and Iles, 1973; Drapeau, 1973) at a mean depth of 70 m (ranging from 42-92 m). This is in contrast to Jeffreys Ledge (Cooper et al., 1975) and shallow water grounds observed in the Gulf of St. Lawrence by Tibbo et al. (1963), where red algae form the spawning substrate, and to those off

Southwest Nova Scotia where sand and red algae form the spawning substrate.

Hatching of larvae has been observed in the field by scuba divers (Cooper et al., 1975) to occur 8-9 days after spawning at a temperature of ca. 10°C, whereas Pankratov and Sigajev (1973) investigating Georges Bank spawning beds have found eggs laid in several layers with a maximum density of eggs (24.4 km/m^2) in a center of spawning bed. The eggs were developing at 13-14°C. Recently hatched yolk-sac larvae may be retained for one to several days in clusters of algae if egg deposition is in an area of vegetation (Cooper et al., 1975) or they may stay close to the sea floor within 1 m of the bottom (Caddy and Iles, 1973) for 1-3 days after hatching. Also, there are scuba and submersible observations of dense aggregations of yolk-sac larvae being carried by currents near the bottom adjacent to areas of egg deposition (Graham and Chenoweth, 1973).

Herring larvae of 4-8 mm are about 1 week old and are initially concentrated in the upper water column immediately over spawning areas, but are then dispersed by surface and near surface water currents to the southwest across Georges Bank at the rate of 1-8 miles per day (Lough et al., 1980). Larvae begin feeding before the yolk-sac is resorbed within 7 days of hatching (Lett, 1976), however, Lough et al. (1980b) have observed in laboratory conditions resorption of the yolk-sac after 4.5 days. One can, therefore, fairly precisely delineate the major spawning sites using cruise abundance and distribution of larvae $\leq$ 8 mm SL to represent the recently-hatched larvae. Herring spawning grounds are extended in a wide belt along the Northern Edge of Georges Bank in the area ca. 10,000 km^2 recognized as potential herring spawning grounds, within which Pankratov and Sigajev (1973) have found small egg beds from 0.3 to 1.1 km^2.

On the basis of available information, Drapeau (1973) has concluded that the grounds most favorable for herring spawning on eastern Georges Bank would be included within a 50 x 100 km area between the latitude, 41°34′N and 42°08′N and the longitude,

66°30′W and 67°45′W, which is contained within the area delineated in this study. Size and extent of spawning grounds on Georges Bank fluctuated in particular years depending on intensity of spawning and biomass of spawning stock.

Quantitative surveys of herring spawning beds in the 1960′s showed a progressive contraction in the spawning area and total number of eggs laid, from which a corresponding reduction in adult stock was deduced (Noskov and Zinkevich, 1970). During the 1970′s, herring spawning reached it′s greatest extent during the 1973-1975 seasons, as a result of the strong 1970 year-class.

Boyar et al. (1973) have recorded, besides spawning grounds on the northern part of Georges Bank, several smaller herring spawning sites along the Southern Slope at depths from 50 to 200 m. Spawning in these southern areas was not confirmed in this study, probably due to different methods. Boyar et al. (1973) determined the localities of spawning grounds on the basis of distribution of ripe and running herring (gonadal Stage VI) which were migrating toward the Northern Edge. Lack of spawning on southern Georges Bank in the 1970′s may also be due to the above mentioned contraction of spawning grounds as a result of reduction of spawning biomass.

Draganik and Dlugosz (1969 and 1971) stated that for years 1966-1969, adult herring stock caught by the fishery fleet from June to September migrated along the Southern Slope in a wide belt at a depth of 90 m, reaching the Northern Edge in September when the onset of spawning began. In October, the fishery was concentrated in the western part of the Bank and on Nantucket Shoals. According to information available from FRG research vessels for 1968-1969, herring were on southern Georges Bank in gonadal Stage V during September, while Stage VI were found in September and October on the Northern part of the Bank and on Nantucket Shoals (Dornheim, unpublished data).

Within a given season, larval abundance shows a systematic progression from low to high to low numbers during the September-December period which is consistent with a concentrated spawning

in one time and place (Lough et al., 1980). Their data reproduced here as Table 3 gives estimated seasonal hatching dates for the 1971-1978 seasons, Georges Bank and Nantucket Shoals areas combined. Spawning began in early September in 1971-1973, and delayed apparently until the end of September in 1974 and 1975, and delayed further until as late as mid-October in 1976-1978. However, the estimation of seasonal hatching dates was confounded due to combining data for both areas since Nantucket Shoals spawning normally begins later than on Georges Bank.

In 1970 Pankratov and Sigajev (1973) estimated beginning of spawning on 16-17 September on the eastern part of the Bank, and noted prolonged duration of spawning which lasted for about 2 months. In the years 1972 to 1974, Paciorkowski and Giedz (1975) determined that peak spawning periods on Georges Bank were 24-26 September for 1972-1973 and 2 October in 1974, based on 1972-1974 Polish catch per tow data for maturity Stages VI and VII. It should be noticed that the production of larvae was extremely low in 1976 and for 1977-1978 seasons and thereafter herring spawning has been limited to Nantucket Shoals where traditionally, herring spawning has taken place 2 weeks later than on Georges Bank. Smith et al (1980) found only a few specimens of herring larvae on Georges Bank in 1978 and 1979. Similar negative results were obtained by the Polish R/V WIECZNO in the 1980 and 1981 seasons. It seems that the strong year-class 1970 was the last one which recruited to the Georges Bank spawning stock and spawned there until 1976. In contrast, herring spawning has continued uninterrupted in the Nantucket Shoals area throughout the period of study.

At this point arises the question as to what extent abiotic conditions have contributed to poor recruitment after the 1970 year-class, and to the delay of spawning and shift of spawning activity to the west. Davis (1978) has indicated a general warming trend of 2-3°C during autumn on Georges Bank during the period 1969-1977; autumn bottom temperatures attained high values in 1973, 1974 and 1976-1977 seasons. Furtak and Majewciz (1982) found a thermal anomaly of +2°C on the Northern Edge of Georges

Bank for the month of October in the years 1972-1978. Also, the 8-year mean (1971-1978) temperature for Georges Bank of 11.6°C and 9.5°C for Nantucket Shoals was about 0.6°C and 0.7°C warmer, respectively, than the 1940-1966 long-term mean reported by Colton and Stoddard (1973).

Long-term changes may cause periodic northward and/or southward displacements of spawning and fishing grounds (Simpson, 1953). Grainger (1978), who worked on herring off the Irish west coast, concluded that reduction in abundance coincidental with a period of warming is what would be expected of a "cold water" species on the southern end of its range, probably due to a reduction in stock size or a northward shift in its distribution to colder waters. Since herring have continued to spawn on the northeastern part of Nantucket Shoals after the collapse on Georges Bank, it seems very likely that higher temperatures may have altered the migrating patterns of adult herring thus causing a westward shift away from traditional spawning grounds. The northeast corner of Nantucket Shoals is in an area of upwelling of cold Gulf of Maine water and thus would be less affected by a general warming trend than Georges Bank.

In the case of Georges Bank, the spawning beds placed within the relatively large and well-mixed area makes it more likely that temperature effects would appear here than anywhere else in the Gulf of Maine. Looking at the large volume of very warm (>14-15°C) water on the top of Georges Bank during autumn surveys since 1971, it is difficult to see how herring spawning would be unaffected if temperatures above 14.5°C are in any way detrimental (Blaxter, 1956). The proximity of the cold temperature front along the northern edge of Georges Bank did not affect spawning beds on Georges Bank as was suggested by Wright and Lough (1979). In contrast, on Nantucket Shoals, cold water upwells directly on spawning beds.

In the area of larval concentration on Georges Bank, bottom temperature data for 1971-1977 do not show water colder than the mean bottom temperature, 11.7°C (range, 9.5°-13.4°C), except for the cold year 1975, when the mean dropped to 8.1°C (7.8°-8.4°C).

The optimum temperature for herring spawning in the Gulf of Maine region is stated as 9.5°C, which coincides with the bottom temeprature observed (9.5°-10°C) over 6 year on Jeffreys Ledge (McCarthy et al., 1979). A review of the literature, however, shows that herring spawn over a wide range from 0° to 12°C in the spring and from 8° to 15°C in the autumn. Laevastu and Hela (1970) summarized different studies and indicate that the mean herring spawning temperature for spring is 7.4°C and for autumn 10.7°C.

The development of eggs and larvae is undoubtedly the most critical period in the life history of fish when they are most strongly influenced, directly and indirectly, by physical conditions. Lewis (1965) conducted experiments on the effect of mimimum temperature on survival of larval Atlantic Menhaden and found that larvae acclimated at 7.0° and 10.0°C survived over twice as long as those acclimated at 12.5° or 15.0°C. Pankratov and Sigajev (1973) have hatched herring larvae onboard ship in jars from eggs taken on eastern Georges Bank at 16.4°C, and the larvae survived for about 1 hour. High environmental temperatures may result in abnormal jaw development hence impairment of feeding performance of larvae (Alderdice and Velsen, 1971). In our time series, extremely high temperatures, >16°C (maximum 19.1°C in 1974 and 17.1°C in 1971), were recorded at the beginning of spawning seasons in years 1971-1974, and these high temperatues may have affected the egg development and larval survival. It is of interest to note that the lowest larval mortality found by Lough et al. (1980) was during 1975, the coldest season in the time series.

Blaxter (1956) has indicated that the relation between year-class strength and spawning temperature is fitted by a dome-shaped curve with optimum conditions around 12°C ranging from 5.5 to 14.5°C . Successful hatching falls below 20% when the incubation temperature exceeds 15°C. Postuma (1971) also found a significant relationship between year-class strength and temperature conditions on the spawning grounds of autumn spawning North Sea herring which he believed may operate through differential egg mortality at different temperatures.

It is unlikely that a simple linear relationship between temperature and spawning success exists, but temperature trends of the magnitude encountered during the past decade undoubtedly influenced certain biological phenomena including changes in spawning time, growth rates, and distributional characteristics of several species (Davis, 1978). Some observable changes in this latest warming trend in the Gulf of Maine, include increased population of green crabs along the Maine coast, northerly extended seasonal distribution of Atlantic mackerel, general shift of juvenile silver hake since 1971 from Cape Cod and westward to Georges Bank and into the Gulf of Maine. Anthony and Waring (1980) indicate increased growth rates, faster maturity and higher fecundity at length for herring in the 1970's; however, they attribute these changes to the decline in stock size.

Another factor to consider is the possible disruptive effects of a fishery on spawning aggregations. The very act of fishing on the spawning concentrations may directly reduce effectiveness of spawning in a manner not reflected by catch rates (Anthony and Warming 1980). This would pertain especially to the period when bottom trawling gear was widely used in the Georges Bank fishery. Nantucket Shoals spawning grounds were partly protected from fishing directly on spawning beds due to their much shallower distribution.

The relationships between herring stocks of Gulf of Maine and Georges Bank is not quite clear but is likely that unexploited adult stocks in late 1950's, due to good recruitment and the interest of the American fishery directed to juveniles only, extended their distribution to offshore areas. The stock of herring on Georges Bank increased to a tremendous size during the early 1960's as a result of two very good year classes. By the mid-1960's, recruitment dropped off while fishing effort increased and the stock declined to a low level by 1972. Since then the stock has been supported by the recruitment of a single year-class (1970 year-class) which by 1977 had been pretty much fished out on Georges Bank. The reduction of herring stock

biomass combined with unfavorable thermal conditions caused the "withdrawal" of Georges Bank stock to the coastal Gulf of Maine.

The fact that during nearly two decades of Georges Bank fishery only three good year-classes have appeared, suggests that the conditions were unfavorable in most of those years for spawning, hatching and larval survival. In most of the years (1971-1977), however, there appear to have been sufficient numbers of larvae produced on Georges Bank and Nantucket shoals combined to result in a strong year-class if conditions had been favorable (Lough et al., 1980). Thus, the size of herring year-classes on Georges Bank appear to be determined by environmental factors operating during the first months of life following hatching.

SUMMARY

1. Distribution and abundance of newly hatched larval herring less than 8 mm SL from 30 ICNAF surveys covering the Georges Bank-Nantucket Shoals area over 7 spawning seasons, 1971-1977, were used to delineate spawning areas and compared with station bottom temperatures to describe thermal conditions at spawning and hatching.

2. Spawning occurred in the northern part of Georges Bank from September through November or December in the 1971-1973 seasons, and was delayed until October in the 1974-1976 seasons. In the Nantucket Shoals area, spawning occurred usually from October through December, except in 1971 when no concentration of newly hatched larvae was observed indicating lack of spawning on historic egg bed sites. After 1975, the onset of spawning was delayed and shortened in both areas. Hatching of larvae lasted for the longest period in 1973 and 1975 on Georges Bank and in 1972-1975 in the Nantucket Shoals area.

3. The spawning area derived from the occurrence of dense concentrations of newly hatched larvae varied in particular

seasons, ranging from 4,500 km^2 in 1972 to about 10,000 km^2 in 1974 on Georges Bank and about 3,500 km^2 in the Nantucket Shoals. However, in the latter area the lack of sampling in shoaler waters (<25 m) might be the source of underestimation of larval abundance and their distribution. The depth of spawning grounds ranged from 58 to 82 m on Georges Bank and from 30 to 75 m on Nantucket Shoals.

4. The dispersal of newly hatched larvae illustrated by distribution of larval concentrations lower than 10 larvae per 10 m^2 shows a general southwest drift on Georges Bank coinciding with the circulation pattern which insures the retention of larvae on the Bank; however, there is some evidence from the time series which suggests the loss of larvae particularly toward the Gulf of Maine and Northeast Channel. On Nantucket Shoals larvae drifted southwest and toward shallow coastal waters.

5. A general warming trend of 2-3°C was observed during the autumn by Davis (1978) for the Gulf of Maine-Georges Bank area, and it was particularly evident on herring spawning grounds in the northeastern part of Georges Bank after 1971 and reached highest temperatures in 1973, 1974, 1976 and 1977. The mean bottom temperatures over delineated spawning grounds ranged from 12° to 15°C during the first month of spawning in 1971-1974 and the 1976, 1977 seasons, while the maximum bottom temperature of 19.1°C was observed in 1974 at station 89 within this area. It is likely that the large volume of very warm (>14, 15°C) and well-mixed water over Georges Bank spawning beds could affect spawning success, if temperature above 14.5°C is in any way detrimental (Blaxter, 1956).

6. On the Nantucket Shoals spawning grounds the mean bottom temperatures were much lower, compared to those on Georges Bank, ranging from 6.1° to 13.3°C. The lack of spawning in 1971 on historical spawning beds on Nantucket Shoals seems to

be the result of extremely low temperatures observed in that year on the Shoals. The continuation of herring spawning on Nantucket Shoals in recent years may be related to the fact that temperature ranges found there (about 9° to 13°C) are closer to the optimum range than those on Georges Bank.

7. Continued poor recruitment following a large 1970 year-class coupled with heavy fishing in the early 1970's resulted in serious stock depletion by 1977. Thus it seems likely that although temperature may have had a negative effect on spawning and larval survival, it was masked by overfishing which reduced Georges Bank stock size to a level below that necessary to rebuild the stock.

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REFERENCES

Alderdice, D. F., and F. P. J. Velsen. 1971. Some effects of salinity and temperature on early development of Pacific herring (Clupea pallasi). J. Fish. Res. Board Can. 28: 1545-1562.

Anthony, V. C., and G. T. Waring. 1980. Estimates of herring spawning stock biomass and egg production for the Georges Bank-Gulf of Maine region. NAFO SCR Doc. 80/IX/135, 38 pp.

Blaxter, J. H. S. 1956. Herring Rearing - 2. The effect of temperature and other factors on development. Scottish Home Dept., Mar. Res., 1956(5) Edinburgh.

Box, G. E. P., W. G. Hunter, and J. S. Hunter. 19 . Statistics for experimenters. An Introduction to design, data analysis, and model building. John Wiley and Sons

Boyar, H. C., R. R. Marak, F. E. Perkins, and R. A. Clifford. 1973. Seasonal distribution and growth of larval (Clupea harengus L.) in the Georges Bank-Gulf of Maine area from 1962 to 1970. J. Cons. int. Explor. Mer. 35: 36-51.

Caddy, J. F., and T. D. Iles. 1973. Underwater observations on herring spawning grounds on Georges Bank. ICNAF Res. Bull. No. 10: 131-139.

Cooper, R. A., J. R. Uzmann, R. A. Clifford, and K. J. Pecci. 1975. Direct observations of herring (Clupea harengus L.) egg beds on Jeffreys Ledge, Gulf of Maine in 1974. ICNAF Res. Doc. 75/93. 6 pp.

Davis, C. W. 1978. Seasonal bottom-water temperature trends in the Gulf of Maine and on Georges Bank, 1963-75. NOAA Tech. Rept. NMFS, SSRF-725, 17 pp.

Dornheim, H. 1977. Letter communication. Bundersforschungsanstalt für Fischerei, Institut für Seefischerei, 2 Hamburg, Germany Federal Republic.

Draganik, B., and R. Długosz. 1969. Stado śledzia Ławicy George'a jako baza surowcowa dla rybołówstwa. Studia i Materiały MIR Seria B, 18, 62 pp.

Draganik, B., R. Długosz. 1971. Charakterystyka eksploatacyjna łowisk śledziowych północno-zachodniego Atlantyku. Studia i Materiały MIR Ser. B, 24, 50 pp.

Drapeau, E. 1973. Sedimentology of herring spawning grounds on Georges Bank. ICNAF Res. Bull. No. 10: 151-162.

Furtak, A., and A. Majewicz. 1981. Analiza zmienności warunków hydrologicznych jesienia w rejonie Georges Bank i Nantucket Shoals w okresie 1971-1978. Unpublished manuscript. 30 pp.

Graham, J. J., and S. B. Chenoweth. 1973. Distribution and abundance of larval herring, Clupea harengus Linnaeus, over egg beds on Georges Bank. ICNAF Res. Bull. No. 10: 141-149.

Grainger, R. J. R. 1978. Herring abundance off the west of Ireland in relation to oceanographic variation. J. Cons. int. Explor. Mer 32(2): 180-188.

Grimm, S. K., W. Maslo, and M. Pastuszak. 1975. Report on larval herring distribution in the Gulf of Maine and on Georges Bank, 27 September - 18 October 1974, ICNAF Res. Doc. 75/109, 17 pp.

Lough, R. G., and G. R. Bolz. 1979. A description of the sampling methods, and larval herring (Clupea harengus L.) data report for surveys conducted from 1968-1978 in the Georges Bank and Gulf of Maine areas. NOAA-NMFS, Northeast Fisheries Center, Woods Hole Lab. Ref. Doc. No. 79-60. 230 pp.

Lough, R. G., G. R. Bolz, M. D. Grosslein, and D. C. Potter. 1979. Abundance and survival of sea herring (Clupea harengus L.) larvae in relation to environmental factors, spawning stock size, and recruitment for the Georges Bank area, 1968-1977 seasons, ICNAF Res. Doc. 79/VI/112. 47 pp.

Lough, R. G., G. R. Bolz, M. R. Pennington, and M. D. Grosslein. 1980. Abundance and mortality estimates of sea herring (Clupea harengus L.) larvae spawned in the Georges Bank-Nantucket Shoals area 1971-1978 seasons, in relation to spawning stock and recruitment. NAFO SCR Doc. 80/IX/129, 59 pp.

Lough, R. G., M. R. Pennington, G. R. Bolz, and A. A. Rosenberg. 1980. A growth model for larval sea herring (Clupea harengus L.) in the Georges Bank-Gulf of Maine area based on otolth growth increments NAFO SCR Doc. 80/IX/131.

Lett, P. F., and A. C. Kohler. 1976. Recruitment: a problem of multispecies interaction and environmental perturbation, with special reference to Gulf of St. Lawrence herring (Clupea harengus L.). J. Fish. Res. Bd. Can. 33: 1353-1371.

Lewis, R. M. 1965. The effect of minimum temperature on the survival of larval Atlantic Menhaden, Brevoortia tyrrannus. Trans. Am. Fish. Soc., Vol. 94(4): 409-412.

Laevastu, T., and I. Hela. 1970. Fisheries Oceanography. Fishing News. (Books) Ltd.

McCarthy, K., C. Gross, R. Cooper, R. Langton, K. Pecci, and J. Uzmann. 1979. Biology and geology of Jeffreys Ledge and adjacent basins: an unpolluted inshore fishing area, Gulf of Maine, NW Atlantic. ICES C.M. 1979/E:44. 12 pp.

Paciorkowski, A., and M. Giedz. 1975. Polish observations on the course of Georges Bank hering spawning in relation to catch per tow, 1972-1974, ICNAF Res. Doc. 75/37 5 pp.

Pankratov, A. M., and I. K. Sigajev. 1973. Studies on Georges Bank herring spawning. 1970. ICNAF Res. Bull. No. 10: 125-129.

Postuma, K. H. 1971. The effect of temperature in the spawning and nursery areas on recruitment of autumn-spawning herring in the North Sea. Rapp. P.-v. Réun. Cons. Int. Explor. Mer 160: 175-183.

Schlitz, R. 1975. A preliminary summary of hydrographic data collected on ICNAF larval herring surveys, 1971-1973. ICNAF Res. Doc. 75/111. 29 pp.

Simpson, A. C. 1973. Some observations on the mortality of fish and the distribution of plankton in the southern North Sea during the cold winter 1946-1947. Journ. Cons. ICES, 19, 150-177.

Smith, W. G., D. G. McMillan, and A. Wells. 1980. The distribution and abundance of Atlantic herring larvae in the Gulf of Maine region as determined from MARMAP surveys 1977-1980. NAFO SCR Doc. 80/IX/146.

Sindermann, C. J. 1979. Status of Northwest Atlantic herring stocks of concern to the United States. Technical Series Report No. 23, 446 pp.

Tibbo, S. N., D. J. Scarrat, and P. W. G. McMullon. 1963. An investigation of herring (Clupea harengus L.) spawning using free-diving techniques. J. Fish. Bd. Canada, 20: 1067-1079.

"WIECZNO" Cruise Report 1980, MIR - Gdynia.

"WIECZNO" Cruise Report 1981, MIR - Gdynia.

Wright, W. R., R. G. Lough. 1979. The Georges Bank larval herring patch study of 1978. A preliminary report. ICES 1979/L:36. 13 pp.

Table 1. Ranked comparison of the Georges Bank stations at which high abundance of small larvae (<8 mm SL) occurred with maximum frequency in the 1971-1975 seasons.

Stations Number	SEASONS					Combined Seasons 1971-1975	Depth m
	1971	1972	1973	1974	1975		
84	1	2	2	4	2	1	64
90	3-4	1	3	1	5	2	64
83	5	3	1	3	3-4	3	58
89	6	7	4	5	1	4	82
91	3-4	5	4	2	-	5	88
96	-	-	10	6	6	6	97
82	9	-	5	11-12	-	7	64
72	-	3	7	-	-	8	42
85	-	-	-	11-12	3-4	9	208
51	8	-	9	9	-	10	92

Table 2. Ranked comparison of the Nantucket Shoals stations at which high abundance of small larvae (<8 mm SL) occurred in the 1971-1977 seasons.

Station Number	SEASONS							Total 1971-1977	Depth m
	1971	1972	1973	1974	1975	1976	1977		
26	2	1	1	1	3	-	3	1	56
27	1	2	2	2	1	1-2	2	2	45
30	4	5	5	3	2	1-2	1	3	56
23	3	-	3	8	-	-	-	4	40
22	-	3	-	4	5	-	-	5	30
24	-	6	6	7	-	-	-	6	75

Table 3. Estimated seasonal hatching dates and spawning grounds of Atlantic sea herring for the 1971-1978 seasons, Georges Bank and Nantucket Shoals area. Spawning season and area based on abundance estimates for the occurrence of recently-hatched larvae less than 10 mm SL (Lough et al., 1980).

Season	Hatching Dates Combined Area	Weighted Middate	Length of Season (Days)	Spawning Area[1]	
				Georges Bank	Nantucket Shoals
1971	10 Sep-26 Dec	15 Oct	107	96	4
1972	16 Sep-28 Dec	22 Oct	103	14	86
1973	9 Sep-29 Dec	25 Oct	111	56	44
1974	28 Sep-22 Dec	2 Nov	85	86	14
1975	20 Sep-27 Dec	30 Oct	98	34	66
1976	10 Oct- 8 Nov	24 Oct	29	3	97
1977	1 Oct-14 Nov	24 Oct	74	1	99
1978	16 Oct-19 Dec	8 Nov	64	1	99

[1]Percentage of small larvae (10 mm SL) originating in each area.

TABLE 4

Mean bottom-water temperature associated with recently hatched herring larvae (Clupea harengus L.) collected on 30 ICNAF surveys covering the Nantucket Shoals and Georges Bank spawning areas, 1971-1977 seasons. Mean bottom temperatures and their standard deviations were calculated for (1) all positive stations where the ratio of small larvae, less than 8 mm SL, to total was greater than .25 and, (2) only for those stations where a high abundance of small larvae, greater than 10/10 m^2, occurred. Herring larvae were collected by a standard ICNAF double-oblique 61 cm bongo-net haul at each station. ~~Only~~ The 333 mesh larval herring data ~~is~~ represented here.
and 505 are

			NANTUCKET SHOALS							GEORGES BANK						
				MEAN BOTTOM TEMPERATURE							MEAN BOTTOM TEMPERATURE					
				Stations with high abundance of small larvae			All positive stations with small larvae				Stations with high abundance of small larvae			All positive stations with small larvae		
VESSELS & CRUISE NUMBERS		CRUISE DATES	Cruise Middate	N	°C	1 SD	N	°C	1 SD	Cruise Middate	N	°C	1 SD	N	°C	1 SD
CRYOS	71-01	9-24 Sep 1971	-	8*	6.9	1.93				14 Sep	4	15.0	1.48	8	13.9	2.27
DELAWARE II	71-04	21 Sep-4 Oct	-	6*	7.7	2.16				26 Sep	5	12.4	.20	11	12.2	2.55
VIANDRA	71-01	9-25 Oct	23 Oct	3*	6.1	.3				15 Oct	6	13.8	.75	10	12.7	2.3
W. HERWIG	71-01	29 Oct-12 Nov	11 Nov	6*	7.7	2.3	11	11.1	3.34	5 Nov	3	13.0	.76	10	11.5	2.4
ALBATROSS IV	71-07	2-17 Dec	14 Dec	6*	7.9	.4	3	8.8	.45	8 Dec						
ARGUS	72-01	22-30 Sep 1972								25 Sep	2	13.0	1.20	3	13.5	1.24
WIECZNO	72-01	2-28 Oct	4 Oct	2	13.3		9	12.6	2.78	16 Oct	3	11.7	1.60	7	11.4	1.90
ARGUS	72-02	12-28 Oct	14 Oct	5	7.9	2.97	8	8.7	3.30	21 Oct	-	-	-	11	10.8	2.34
A. DOHRN	72-01	31 Oct-12 Nov	2 Nov	3	9.7	1.79	10	9.5	2.96	7 Nov	2	11.3	*.8	9	10.9	1.01
ALBATROSS IV	72-09	28 Nov-15 Dec	30 Nov	3	8.2	.3	-	-	-	9 Dec	-	-	-	-	-	-
CRYOS	73-01	16-28 Sep 1973		-	-	-	-	-	-	22 Sep	3	13.9	1.3	7	11.0	2.8
WIECZNO	73-40	29 Sep-21 Oct	4 Oct	3	11.9	3.30	-	-	-	12 Oct	6	12.5	2.3	13	12.2	2.3
BELOGORSK	73-01**	15 Oct-1 Nov	17 Oct							26 Oct						
W. HERWIG	73-43	28 Oct-8 Nov	30 Oct	8	12.9	1.92	14	10.7	3.3	4 Nov	6	12.8	1.7	11	11.7	2.3
ALBATROSS IV	73-09	4-20 Dec	5 Dec	3	12.7	1.3	14	10.9	2.5	14 Dec	11	11.8	.1	7	10.9	.7
WIECZNO	74-01	27 Sep-18 Oct 1974	30 Sep	4	10.4	3.4	-			6 Oct	6	12.5	1.9	11	11.8	2.3
PROGNOZ	74-01	18-30 Oct	26 Oct	5	11.1	1.6	7	11.8	1.8	20 Oct	9	12.1	1.15	13	12.1	1.0
A. DOHRN	74-01**	16-23 Nov	17 Nov							20 Nov						
ALBATROSS IV	74-13	4-19 Dec	6 Dec				12	12.3	2.4	14 Dec						
BELOGORSK	75-02	25 Sep-9 Oct 1975	28 Sep	1	9.6					4 Oct	2	8.1	.3	5	9.0	.9
BELOGORSK	75-03	16-30 Oct	27 Oct	6	10.4	1.4	8	10.2	2.12	20 Oct	7	10.1	1.9	21	10.5	2.45
A. DOHRN	75-187	1-18 Nov	13 Nov				11	7.4		6 Nov	6	11.3	.7	23	11.8	1.7
ALBATROSS IV	75-14	2-17 Dec	15 Dec							9 Dec	1	9.7	-	5	9.7	.46
BELOGORSK	76-03	4-11 Oct 1976		9*	10.1	2.8					6*	14.3	1.47			
WIECZNO	76-03	14 Oct-3 Nov	18 Oct	9*	11.6	2.5				27 Oct	9*	13.1	.71			
A. DOHRN	76-02	15-29 Nov	16 Nov	9*	8.7	1.3				23 Nov	7*	9.6	.4			
RESEARCHER	76-01	27 Nov-11 Dec	29 Nov							5 Dec						
WIECZNO	77-06	4-24 Oct 1977	20 Oct	6*	9.2	2.2					6*	13.0	1.8			
A. DOHRN	77-03	9-19 Nov		13*	9.1	2.3					12*	11.6	1.4			
DELAWARE II	77-13	8-20 Dec		8*	7.8	.3										

*For 1971, 1976, and 1977 seasons mean bottom temperatures were calculated for historical herring spawning areas on Georges Bank-Nantucket Shoals

**No temperature data available.

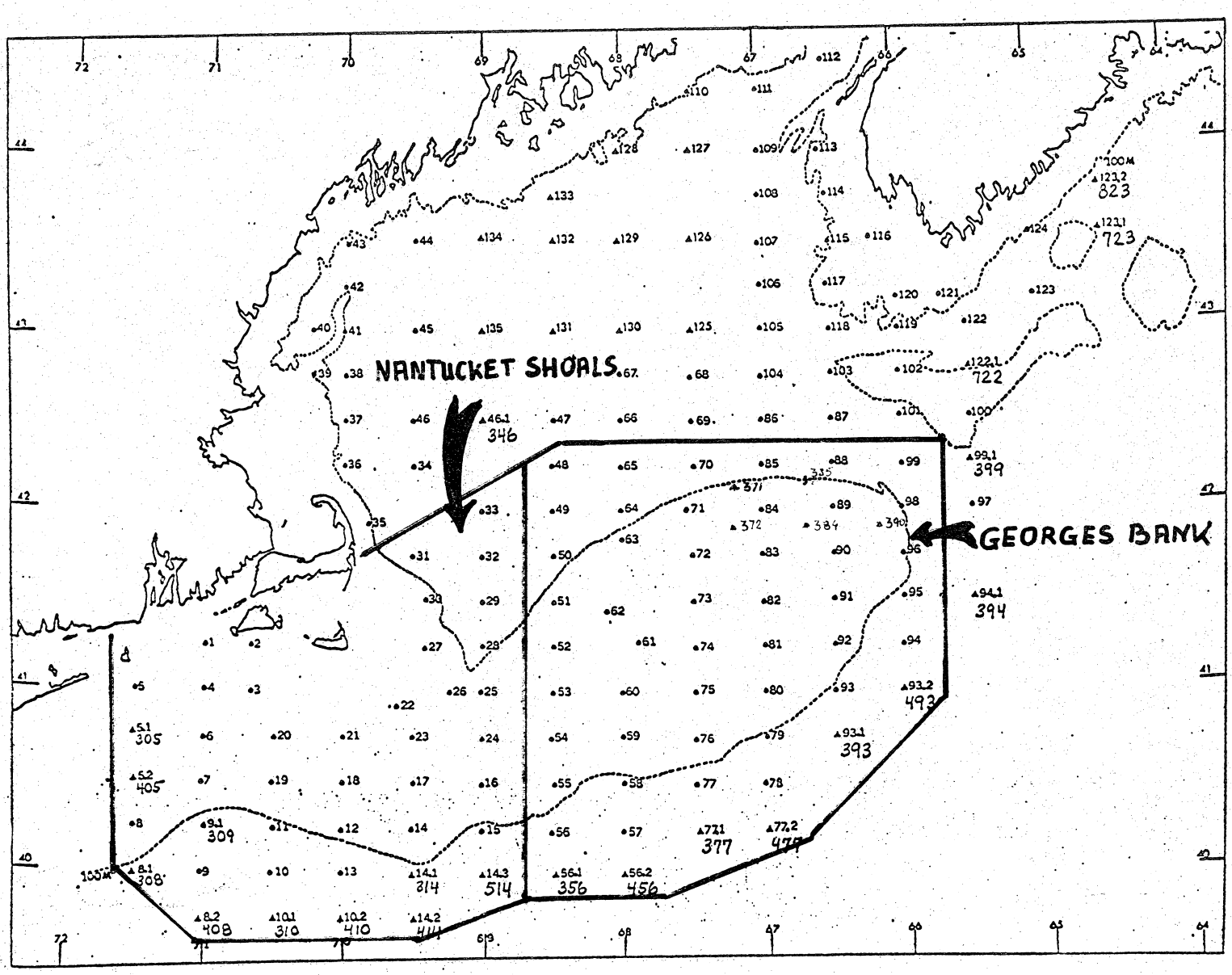


Fig. 1. Station plot for ICNAF larval herring surveys. Stations 1-33 represent the Nantucket Sholas area, and Stations 48-99 represent the Georges Bank area. The paper concerns the enicircled area, only.

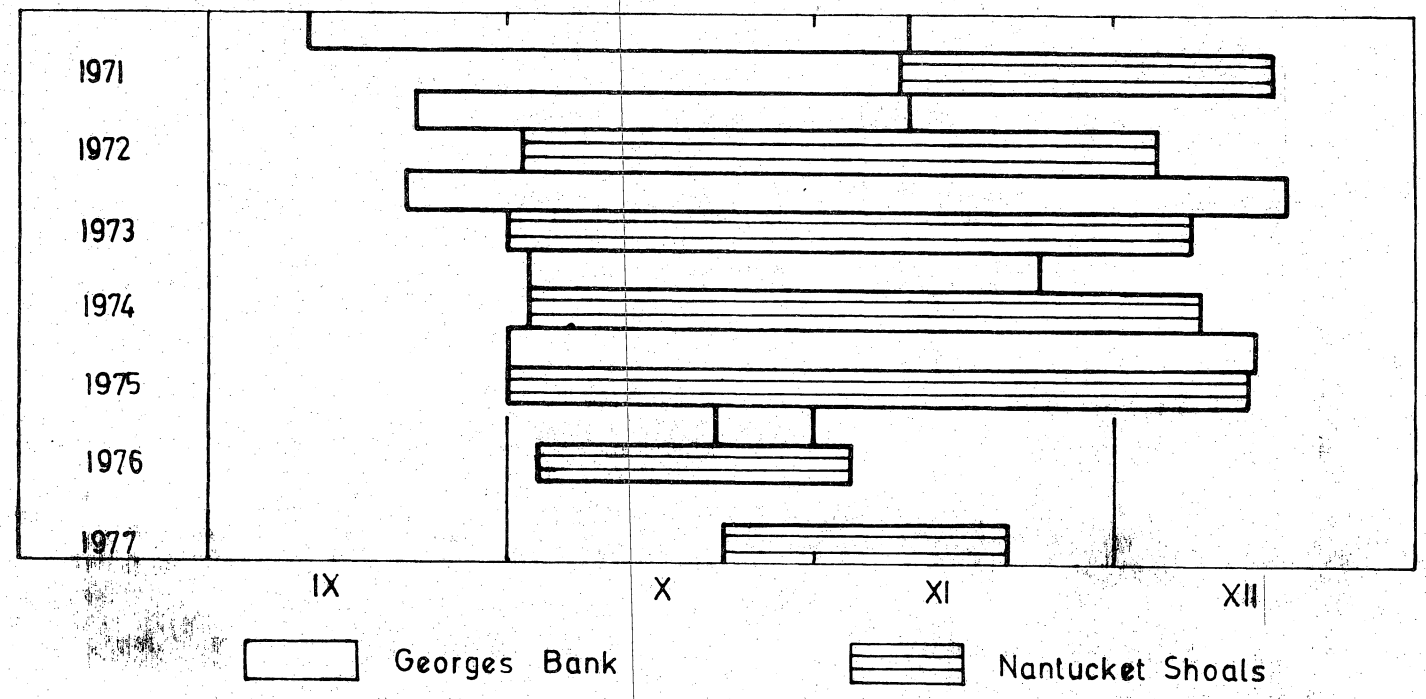


Fig 2. Estmated seasonal hatching dates of Atlantic herring Clupea harengus L. on Georges Bank and Nantucket Shoals spawning grounds for the 1971-1977 seasons. Spawning season and area based on occurence and abundance of recently hatched larvae less than 8 mm SL.

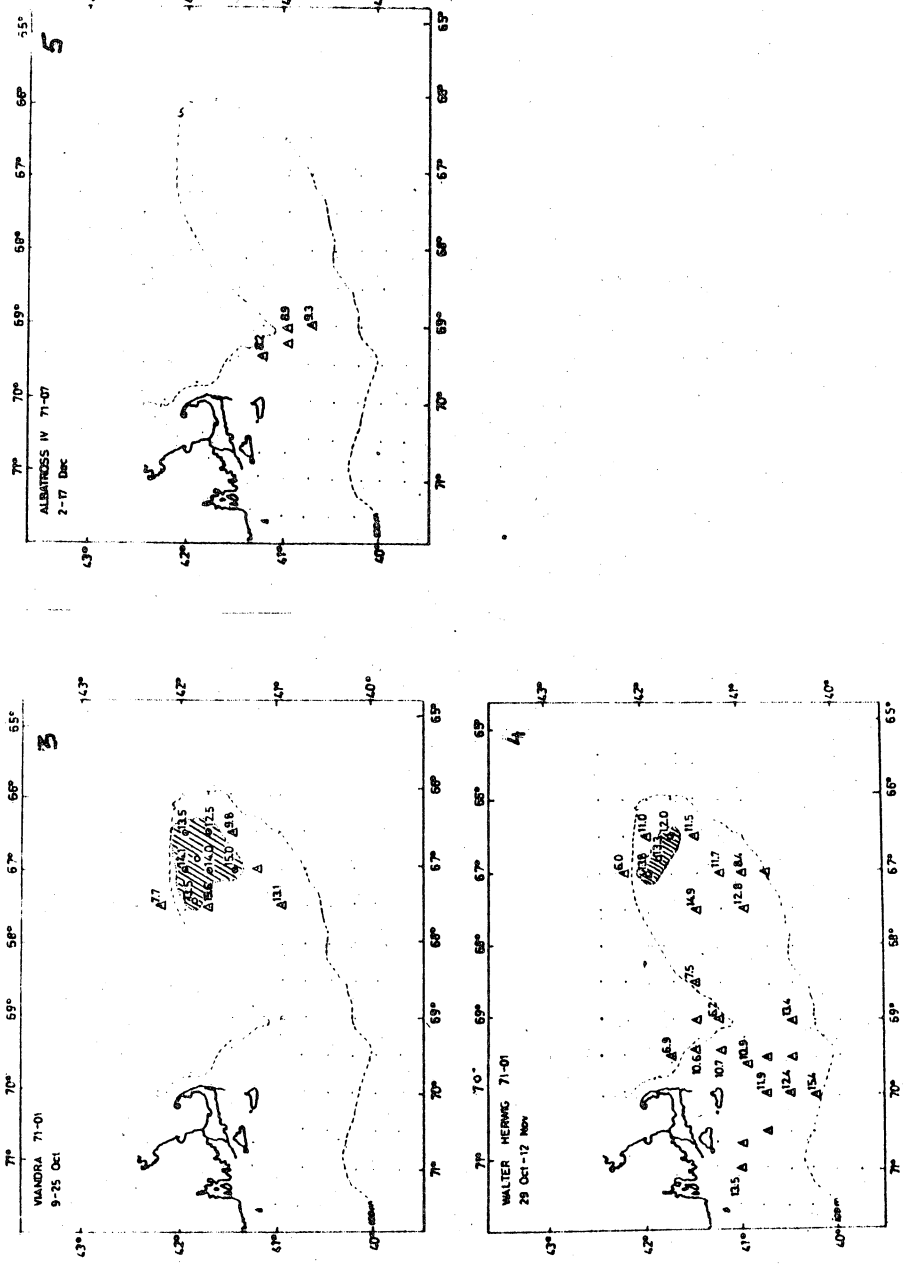


Fig 3. The 1971 season's distribution of dense concentrations /> 10/10m^2/ of recently hatched herring larvae less than 8 mm SL /hachured area/ between succesive cruises. Triangels represent dispersed small larvae and numbers represent station bottom temperatures.

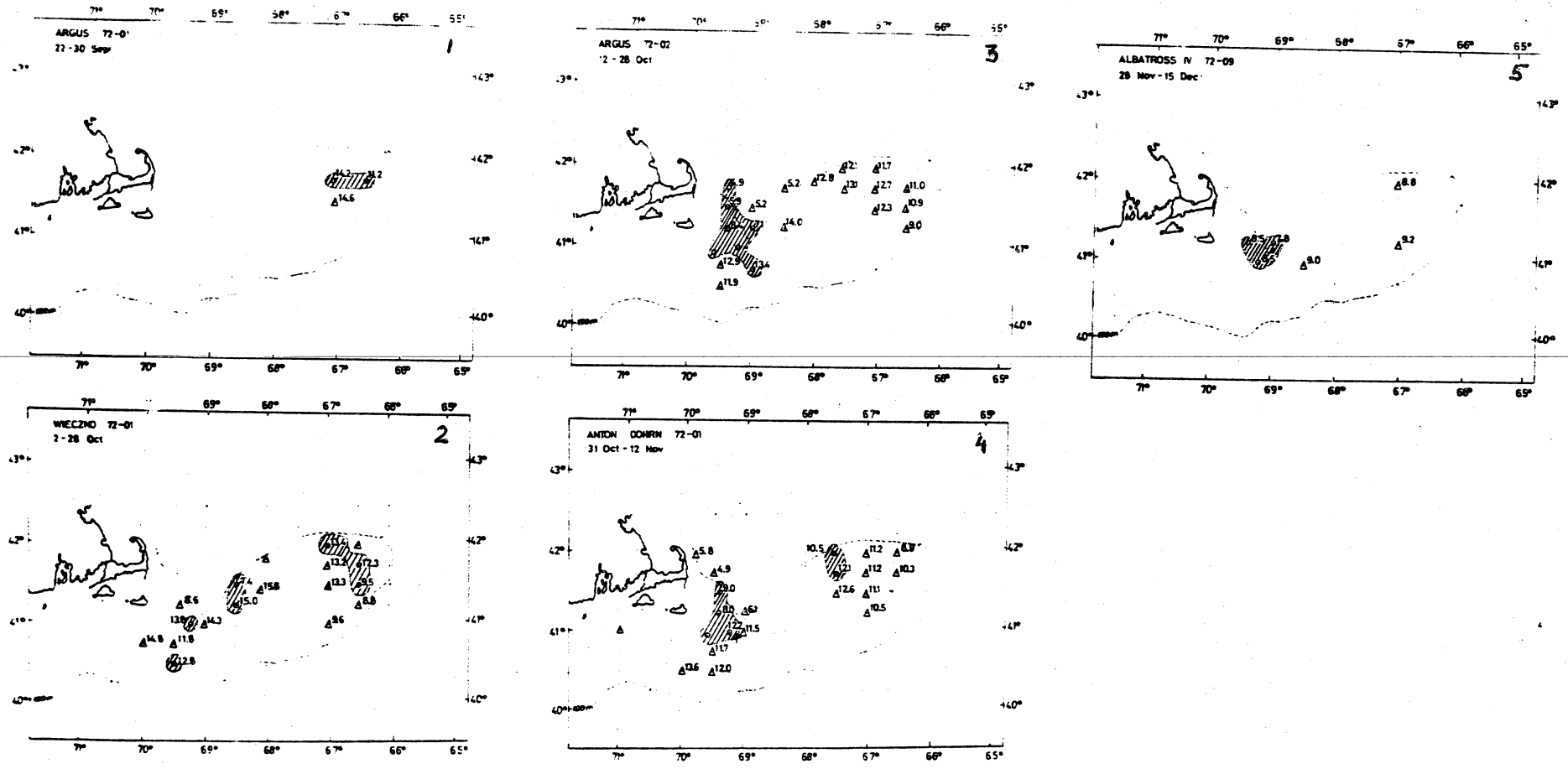


Fig. 4. The 1972 season's distribution of dense concentrations />10/10 m^2/ of recently hatched herring larvae less than 8 mm SL /hachured area/ between succesive cruises. Triangels represent dispersed small larvae and numbers represent station bottom temperatures.

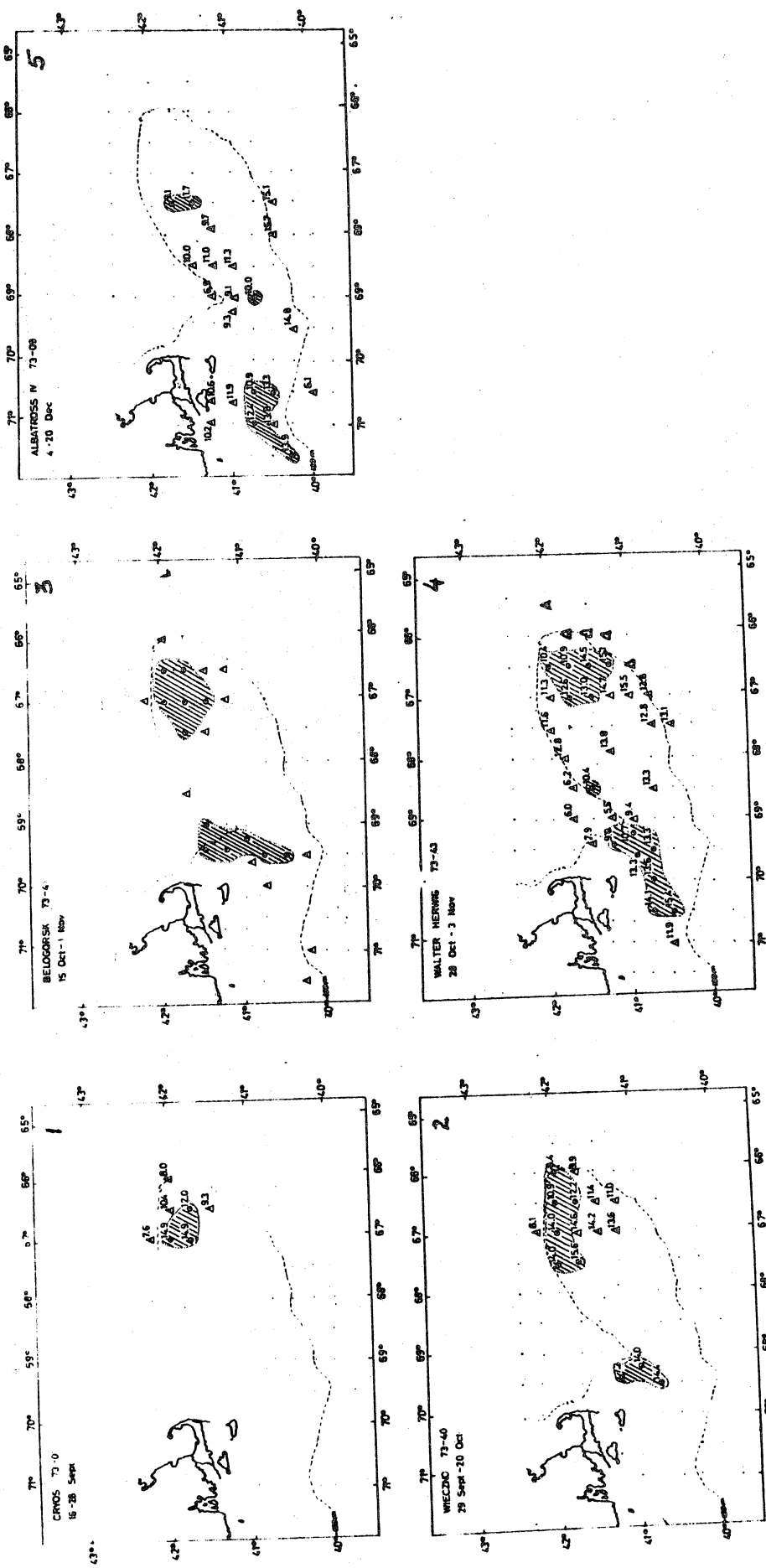


Fig. 5 The 1973 season's distribution of dense concentrations /> 10/10 m^2/ of recently hatched herring larvae less than 8 mm SL /hatchured area/ between succesive cruises. Triangels represent dispersed small larvae and numbers represent station bottom temperatures.

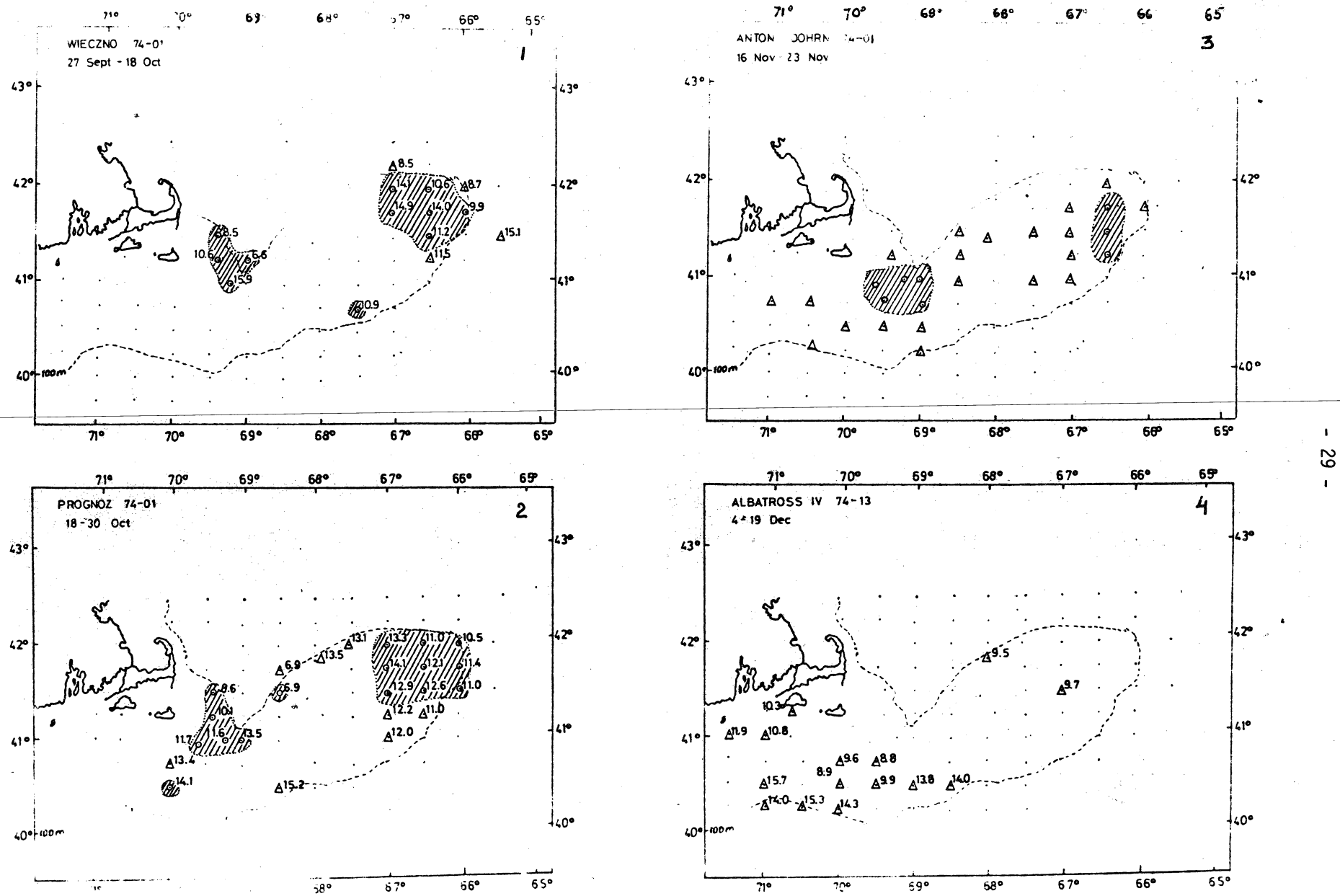


Fig..6. The 1974 season's distribution of dense concentrations / 10/10 m^2/ of recently hatched herring larvae less than 8 mm SL /hachured area/ between succesive cruises. Triangels represent dispersed small larvae and numbers represent station bottom temperatures.

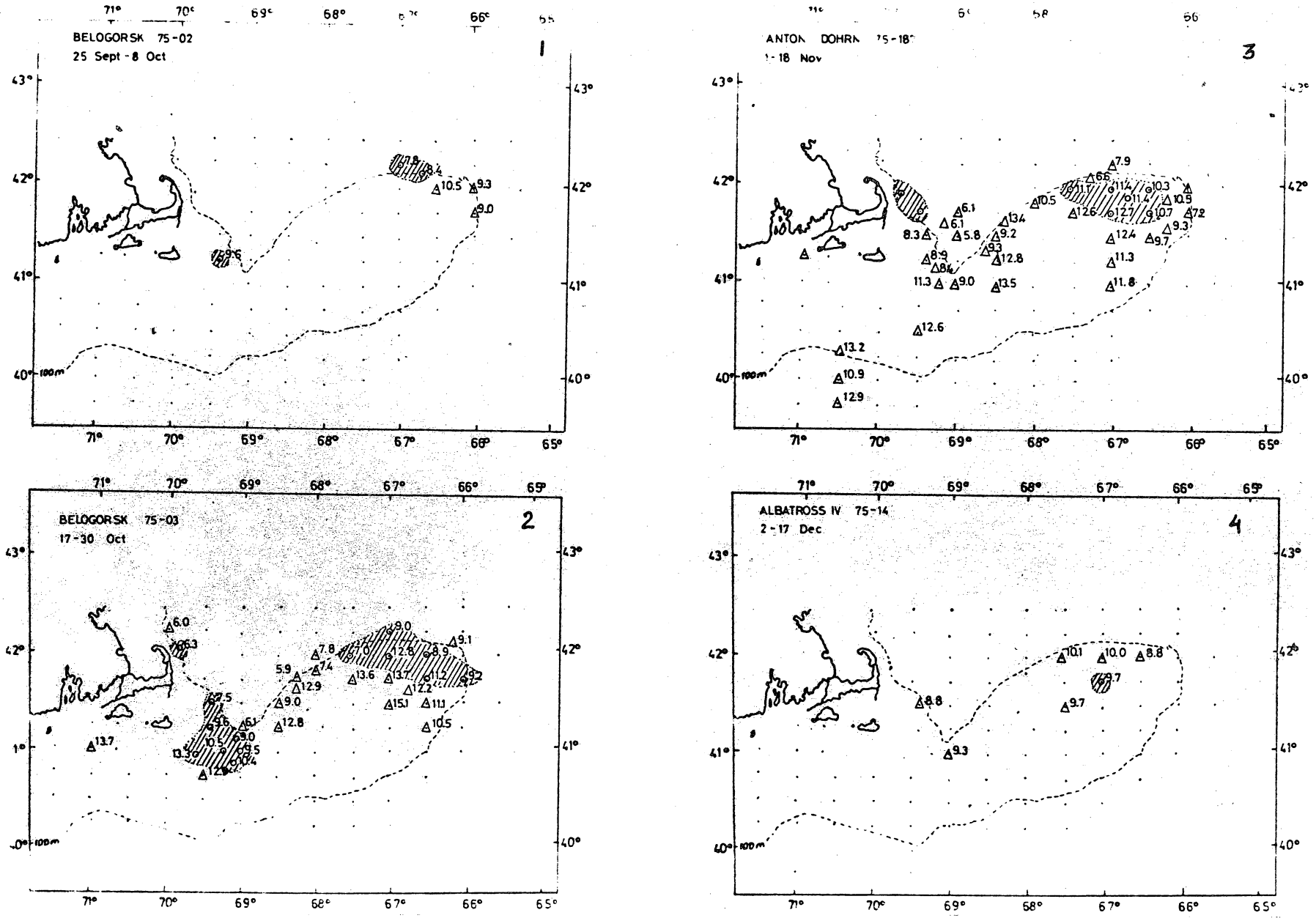


Fig. 7 The 1975 season's distribution of dense concentrations /> 10/10 m^2/ of recently hatched herring larvae less than 8 mm SL /hachured area/ between succesive cruises. Triangels represent dispersed small larvae and numbers represent station bottom temperatures.

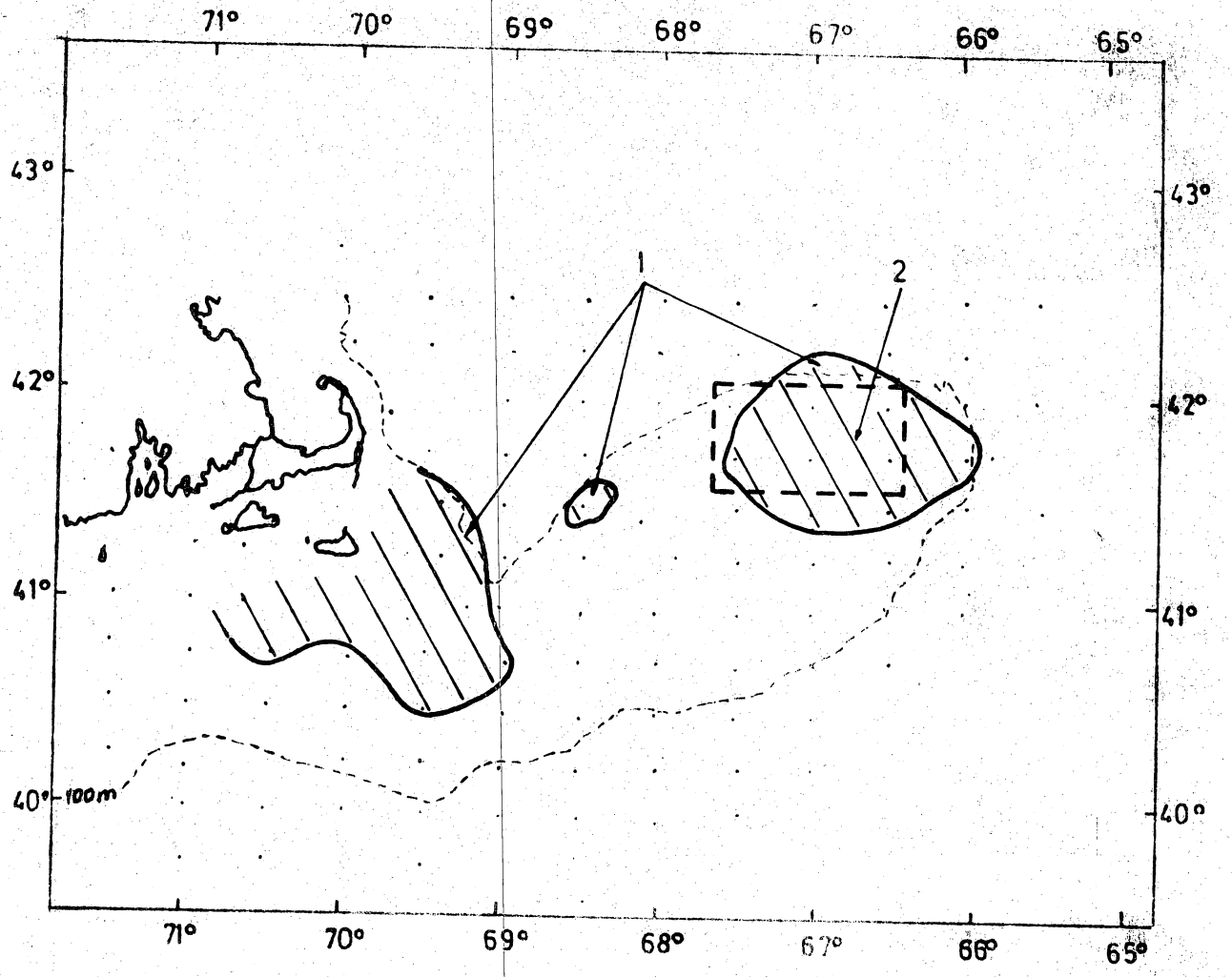


Fig. 8. /1/ Estimated potential spawning grounds derrived from occurence of dense concentrations of recently hatched larvae less than 8 mm Sl for the 1971-1977 seasons. /2/ Drapeau's /1973/ most suitable area for herring spawning on Georges Bank as concerned the bathymetry, geology and oceanography.

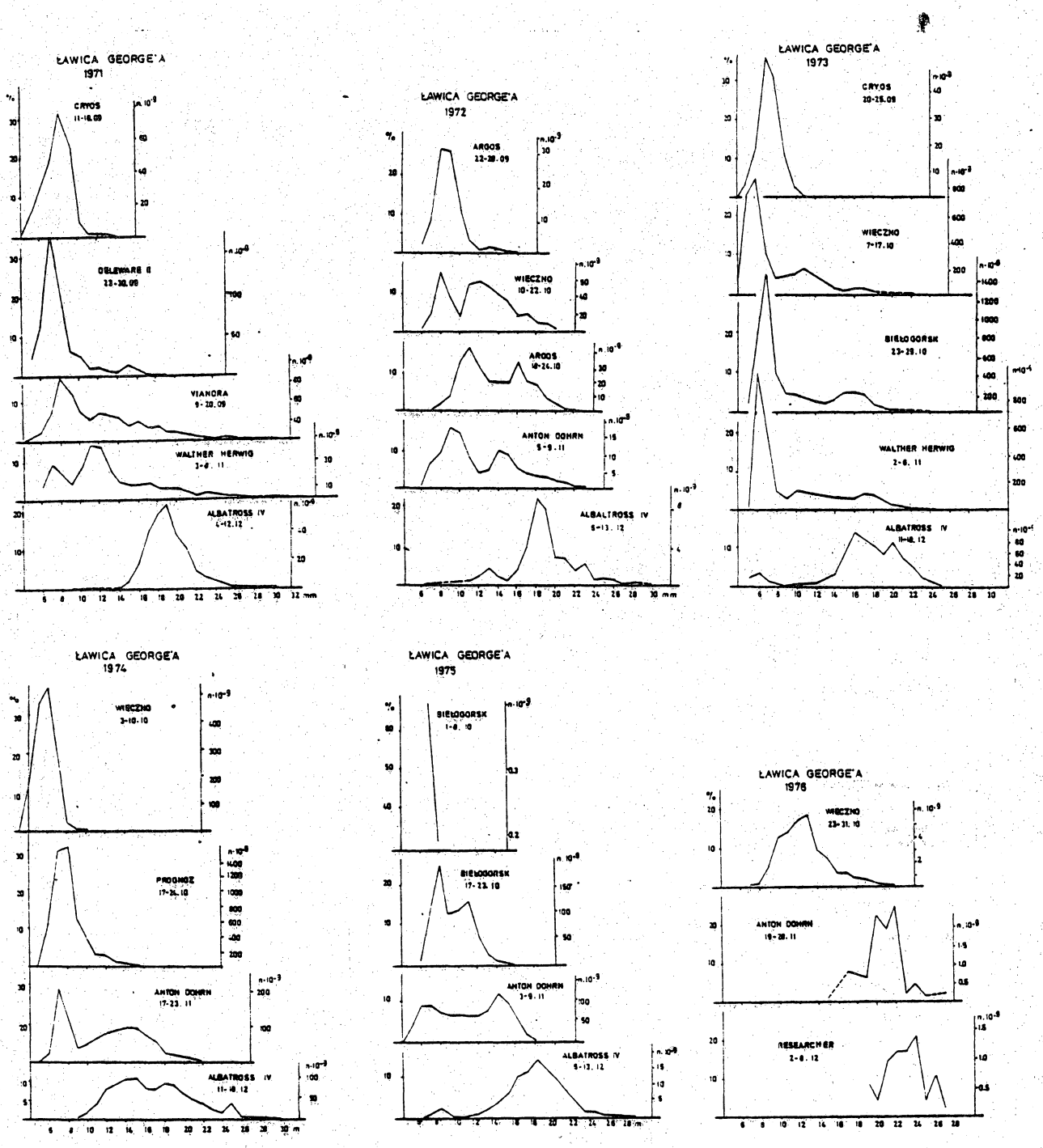


Fig. 9. Length frequency distribution on the Georges Bank, 1971-1976 seasons

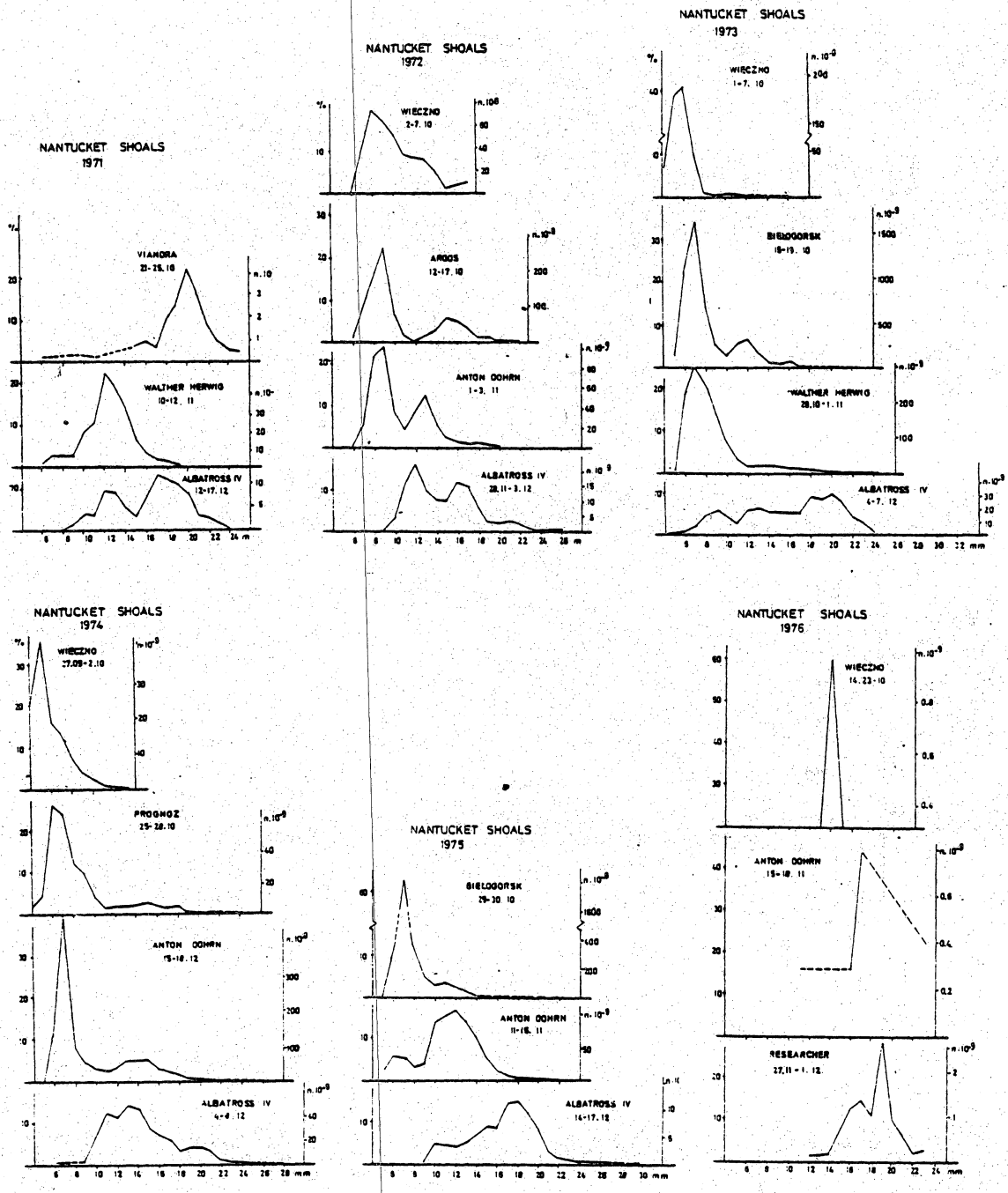
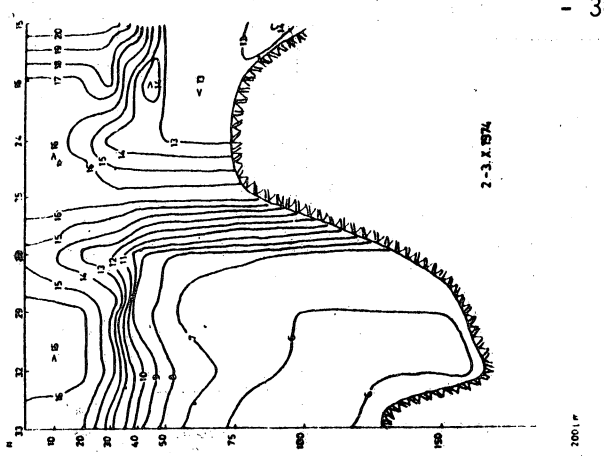
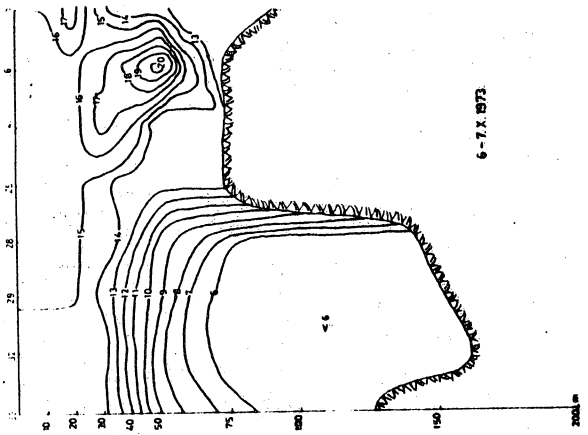
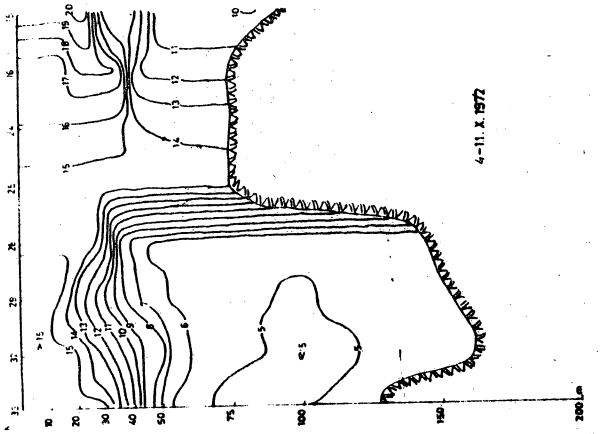
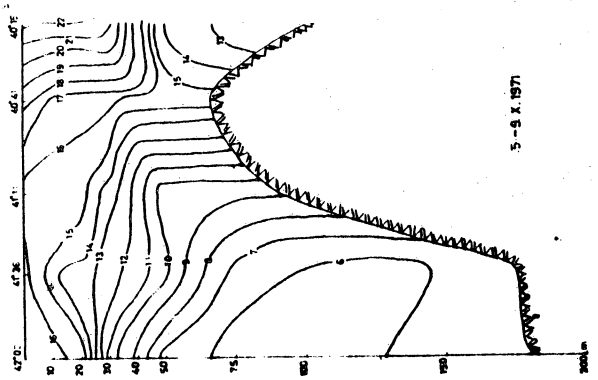


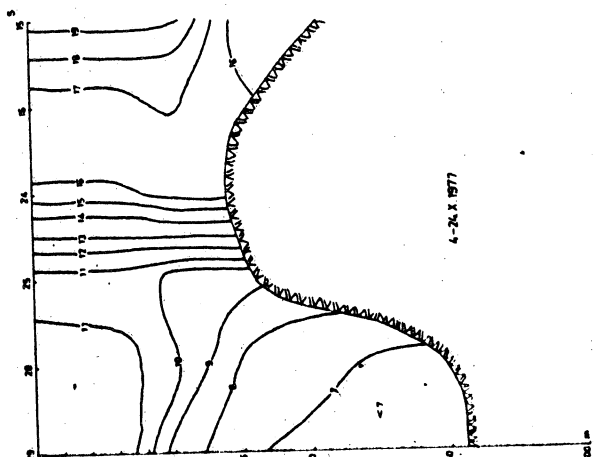
Fig. 10. Length frequency distribution in the Nantucket Shoals area, 1971-1976 seasons

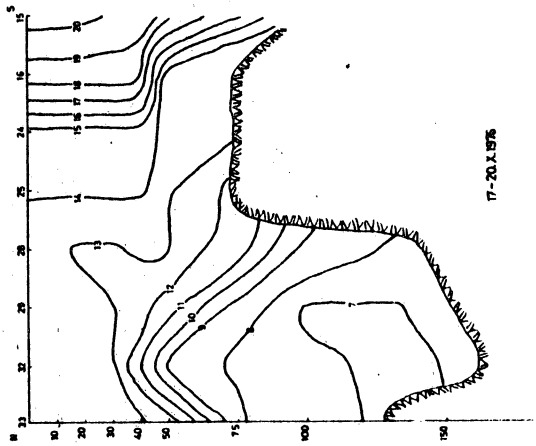












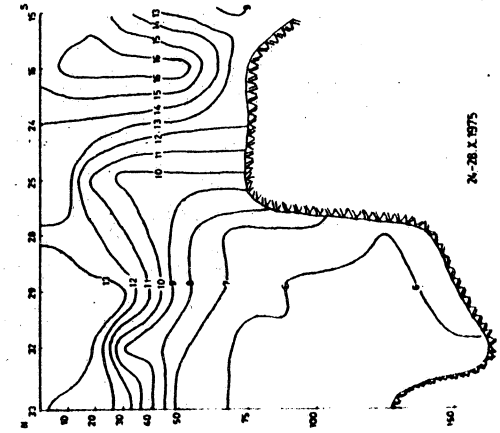


Fig. 11. Temperature sections across Georges Bank /67°W/, October 1971-1977

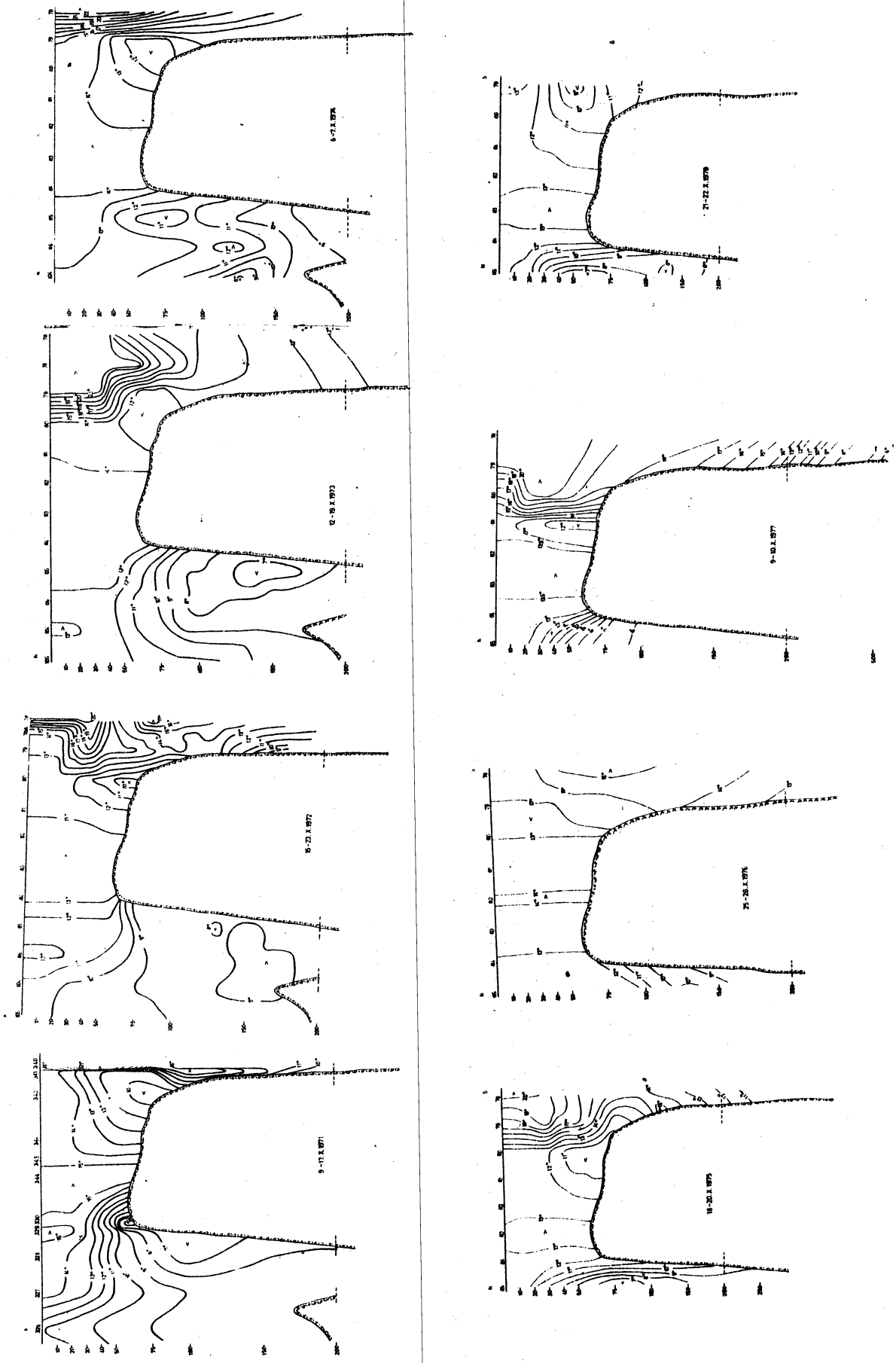


Fig. 12. Temperature sections across Nantucket Shoals /69°W/, October 1971-1978