Recovery of the Gulf of Maine–Georges Bank Atlantic herring (*Clupea harengus*) complex: perspectives based on bottom trawl survey data

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Abstract–NMFS bottom trawl survey data were used to describe changes in distribution, abundance, and rates of population change occurring in the Gulf of Maine–Georges Bank herring (*Clupea harengus*) complex during 1963–98. Herring in the region have fully recovered following severe overfishing during the 1960s and 1970s. Three distinct, but seasonally intermingling components from the Gulf of Maine, Nantucket Shoals (Great South Channel area), and Georges Bank appear to compose the herring resource in the region. Distribution ranges contracted as herring biomass declined in the late 1970s and then the range expanded in the 1990s as herring increased. Analysis of research survey data suggest that herring are currently at high levels of abundance and biomass. All three components of the stock complex, including the Georges Bank component, have recovered to pre-1960s abundance. Survey data support the theory that herring recolonized the Georges Bank region in stages from adjacent components during the late 1980s, most likely from herring spawning in the Gulf of Maine.

Manuscript accepted 13 February 2002.
Fish. Bull. 100:593–608 (2002).

The Atlantic herring (*Clupea harengus*) resource in the Northwest Atlantic has been an important source of food and commerce for nearly four centuries (Anthony and Waring, 1980). Simple wier fisheries with relatively low landings began in the 1600s in both the United States and Canada but evolved into much larger operations, and landings increased. The most important early fishery for herring in the United States developed in the late 1800s, resulting in the building of numerous sardine canning plants, with annual landings eventually ranging from 60,000 metric tons (t) to 100,000 t by the early to mid 1900s (Anthony and Waring, 1980). An important weir fishery developed in New Brunswick during the 1950s and provided fish for canning operations in the region. Both the U.S. and Canadian fisheries initially focused on juvenile fish; fisheries for adults developed only when the abundance of juveniles (available to fixed gear) declined in the early 1960s (Anthony and Waring, 1980).

In the early 1960s Atlantic herring on Georges Bank became the focus of a major fishery by gill-net vessels from the former Soviet Union (Hennemuth and Rockwell, 1987). By the mid 1960s distant-water herring fisheries had developed in the Gulf of St Lawrence, on the Scotian Shelf, on Georges Bank, and on Jeffreys Ledge (Fig. 1) (Anthony and Waring, 1980). Landings of herring from the Gulf of St Lawrence to Georges Bank peaked at over 900,000 t in 1968, declining steadily thereafter (Anthony and Waring, 1980).

The Georges Bank herring fishery (combined Nantucket Shoals and Georges Bank region) began in 1961 and increased rapidly to a peak of 373,000 t in 1968 (Figs. 1 and 2). During the early 1970s, landings steadily declined and in 1977 the herring fishery on Georges Bank collapsed (low landings and abundance) (Fig. 2) (Anthony and Waring, 1980; Tupper et al.[1]). During the same period, landings in the Gulf of Maine fishery ranged from 35,000 to 82,000 t (Fig. 2).

Stock assessments prepared by the International Commission for Northwest Atlantic Fisheries (ICNAF) for Georges Bank herring (combined Nantucket Shoals and Georges Bank) began in the late 1960s, and annual total allowable catch quotas (TAC) were established in 1972. Annual assessments were conducted by using virtual population analysis (VPA) and results from these assessments revealed that the Georges Bank component peaked in abundance in 1967 and rapidly declined thereafter (Anthony and Waring, 1980). These findings were confirmed by larval herring surveys conducted during the 1970s and 1980s, where a general decline in larval abundance in the region was noted during 1975–78 and the complete absence of herring larvae in the Georges Bank-Nantucket

[1] Tupper, M. H., V. C. Anthony, S. B. Chenoweth, and H. A. MacCluen. 1998. Biology and assessment of Gulf of Maine herring stocks, 104 p. Gulf of Maine Aquarium, PO Box 7549, Portland, ME 04112.

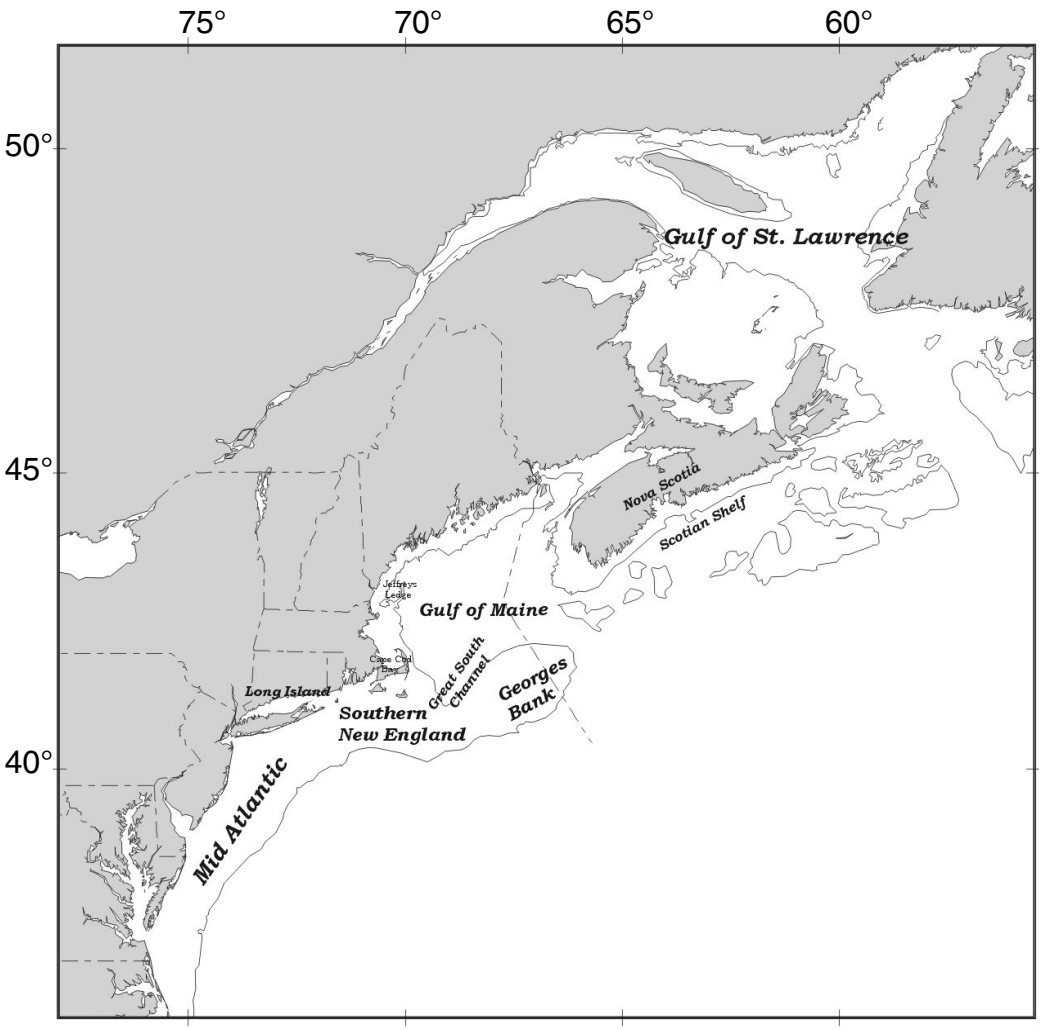


Figure 1

Regional map of the Mid-Atlantic, New England, and Canada area showing states, the providence of Nova Scotia, offshore place names, and the 100-m depth contour.

Shoals region during 1979–84 (Lough et al., 1985; Smith and Morse, 1993).

Presently pelagic fishes such as Atlantic herring and mackerel (*Scomber scombrus*) have recovered to historic high abundances (Clark, 1998). Atlantic herring have recovered to pre-1960s biomass and abundance and are now becoming the subject of renewed interest by fleets from the United States and Canada (Clark, 1998; NEFSC[2]). During a recent survey (spring 1999), herring were caught in 47% of the standardized tows and represented one of the top five species in terms of abundance and biomass (NEFSC[3]).

The presence and increase of spawning fish and larvae in historically important areas of Nantucket Shoals (Great South Channel area), Georges Bank, and along the coast of Maine have been documented ((Zinkevich, 1967; Stephenson and Kornfield, 1990; Smith and Morse, 1993; Stevenson[4]).

The purpose of this paper is to describe the magnitude of the decline and recovery of the herring complex in the Gulf of Maine–Georges Bank region and the chronology of

[2] NEFSC (Northeast Fisheries Science Center). 1998. Atlantic herring: report of the 27th Northeast regional stock assessment workshop (27th SAW). Stock Assessment Review Committee (SARC) consensus summary of assessments, 27 p. Northeast Fisheries Science Center, Woods Hole, MA 02543.

[3] NEFSC (Northeast Fisheries Science Center). 1999. Fisherman's report: bottom trawl survey. Woods Hole Laboratory, National Marine Fisheries Service, March 1–April 22, 1999, 20 p. Northeast Fisheries Science Center, Woods Hole, MA 02543.

[4] Stevensen, D. K. 1989. Spawning locations and times for Atlantic herring on the Maine Coast. Maine Department of Marine Resources Research Reference Document 89/5, 24 p. Maine Department of Marine Resources, Boothbay Harbor, ME 04575.

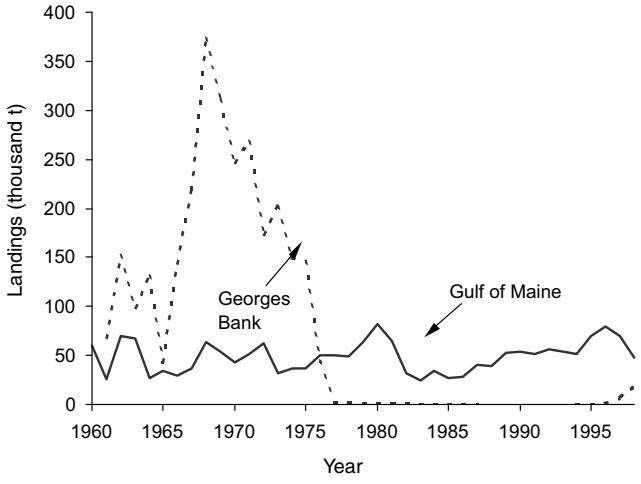


Figure 2

Landings of Atlantic herring (thousands of t) from the Gulf of Maine and Georges Bank, 1960–98.

the differential recovery by area by using NEFSC bottom trawl data from 1963 to 1998. We also wanted to examine two theories regarding the recovery of Georges Bank herring: 1) that it was due to a resurgence of extant spawners (Stephenson and Kornfield, 1990) or 2) that is was due to recolonization from adjacent components of the complex (Smith and Morse, 1993).

Methods

Details of the statistical design, areal coverage, standardization methods, gear type, and species catchability in the NEFSC bottom trawl surveys are provided in Grosslein (1969); Azarovitz (1981); Byrne et al. (1981), and a NEFSC report (NEFSC, 1988). Briefly, the surveys are based on a stratified random research design that covers the region from Cape Hatteras to the Scotian Shelf at depths between 27 and 200 m (15 to >100 fathoms), each spring and autumn.

We used data from spring (1968–98) and autumn (1963–98) bottom trawl surveys to produce indices of abundance, and plot distribution patterns for the Gulf of Maine–Georges Bank Atlantic herring complex. For spring, we used the same strata set (strata 1–30, 33–40, and 61–76) (Fig. 3) as used in the assessment of the herring complex (NEFSC[2]). We produced indices of total abundance (swept area numbers [millions]) to follow changes in the stock complex over time, assuming that a standardized survey tow covers 0.1 nmi and that all herring are available to the gear.

For autumn we used a smaller strata set (1–30, 33–40) (Fig. 3) to generate indices of abundance (area-swept numbers) because herring are seldom found south and west of Long Island during this season (NEFSC[2]). Changes in abundance by subregion (reflecting abundance trends by spawning components) were assessed by using indices for the Gulf of Maine (strata 26–28, 37–40), Nantucket Shoals (Great South Channel area) (strata 9–11, 23–25), and Georges Bank (strata 13–14, 16–17, 19–22, 29–30) (Fig. 3).

We produced box plots that represent the median survey catch location aggregated over a latitudinal gradient (35–45°N latitude) collapsed over the entire east-west longitude of the region. We repeated the same procedure for the longitudinal gradient (64–76°W longitude). These plots show the median, inter quartiles (25% and 75%), whiskers (1.5 times the absolute value of the interquartile range) and outliers of the data. We also constructed maps of spring survey catch locations for 1970, 1975, 1980, 1985, 1990, and 1995 to show trends in herring distribution and abundance over the time period. Changes in distribution and abundance during autumn 1963–98 are depicted in plots of Atlantic herring catch locations for 1965, 1970, 1975, 1980, 1985, 1990, and 1995.

We also produced box plots of bottom temperature for the sites where herring were captured during both seasons. For spring and autumn, we also plotted the proportion of survey tows with catches of Atlantic herring as a measure of how often surveys encountered Atlantic herring over the time series. We used LOWESS (locally weighted regression smoothing) (Cleveland, 1979) to make the temporal trends in both of these time series easier to follow.

Results

Atlantic herring abundance indices from spring surveys changed markedly during 1968–98 (Fig. 4A). A period of relatively high abundance (area swept, millions of fish), in

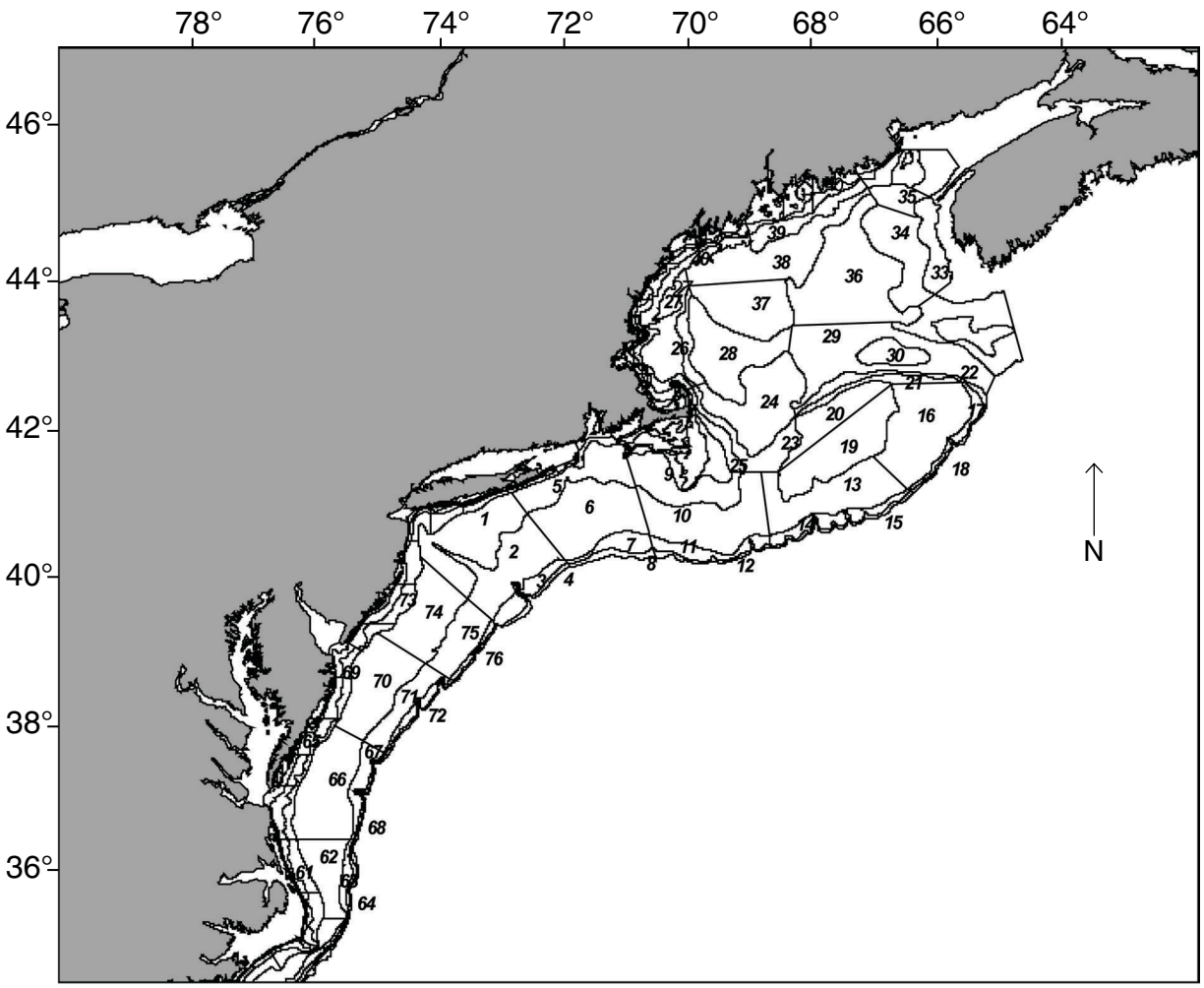


Figure 3

Survey strata used in the Northeast Fisheries Science Center research bottom trawl surveys for the region from Cape Hatteras, NC, to Nova Scotia, Canada.

the late 1960s was followed by a low abundance from 1971 to 1985. After 1985, abundance indices increased steadily to values that were 2–3 times larger (1993, 1996–98) than those at the beginning of the time series (Fig. 4A). Atlantic herring abundance was six times higher during 1992–98 than during 1968–75.

Herring spawn between mid-September and mid-October, and the timing is dependent on location and year. The NEFSC autumn research survey is usually conducted just after the spawning season for Atlantic herring, but this survey is a useful indicator of the abundance of spawners in the various component areas. Herring abundance in the autumn surveys was low (range 2.5–17.7 million fish) during 1963–67, very low from 1968–1986 (range 0.0–4.4 million fish), and much higher since 1987 (range 45.6–604.2 million fish) (Fig. 4B).

The herring complex occupied a consistently wider latitudinal range in the spring during the late 1980s and 1990s than in prior years. The complex was centered between 39°–41°N latitude during 1968–70 and then gradually shifted northwards (Fig. 5A). During 1982–84, the median latitude of the complex had moved north to 42° (north of Cape Cod); by 1984, the distribution of the stock complex was confined between 40°30′–44°10′N latitude, about a 50% decrease in latitudinal range as compared to 1968 (Fig. 5A). As abundance increased in the late 1980s, the center of the spring distribution of Atlantic herring moved southwards and the range extended; since 1989 the medial latitudinal position of the complex has remained at 41°N (Fig. 5A)

Major shifts in the longitudinal position of the complex have also occurred. During 1968–70, herring were generally west of 70°W longitude (Fig. 5B). Subsequently (through 1986) the complex shifted farther to the east. As abundance increased, in the late 1980s, the longitudinal center of the complex moved westward remaining at about 70°W longitude during 1989–98. During this time period, the east-west extent of the complex expanded greatly (Fig. 5B).

The median, interquartile range, and overall range in latitude of the herring complex in autumn is character-

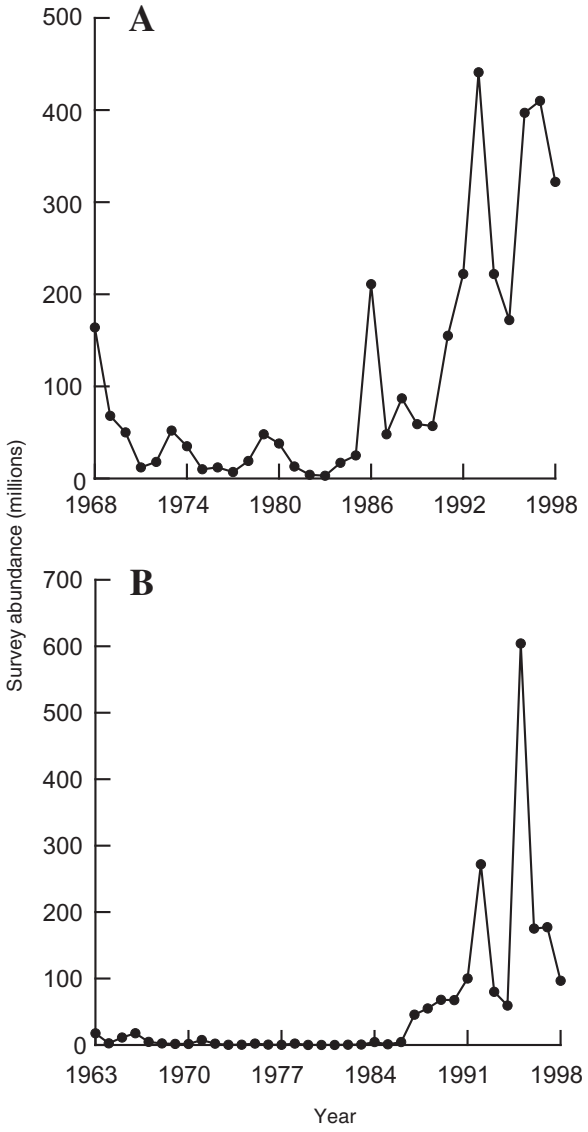


Figure 4

Abundance indices (swept area, millions of fish) of Atlantic herring from (**A**) spring bottom trawl surveys during 1968–98 and (**B**) autumn bottom trawl surveys during 1963–98.

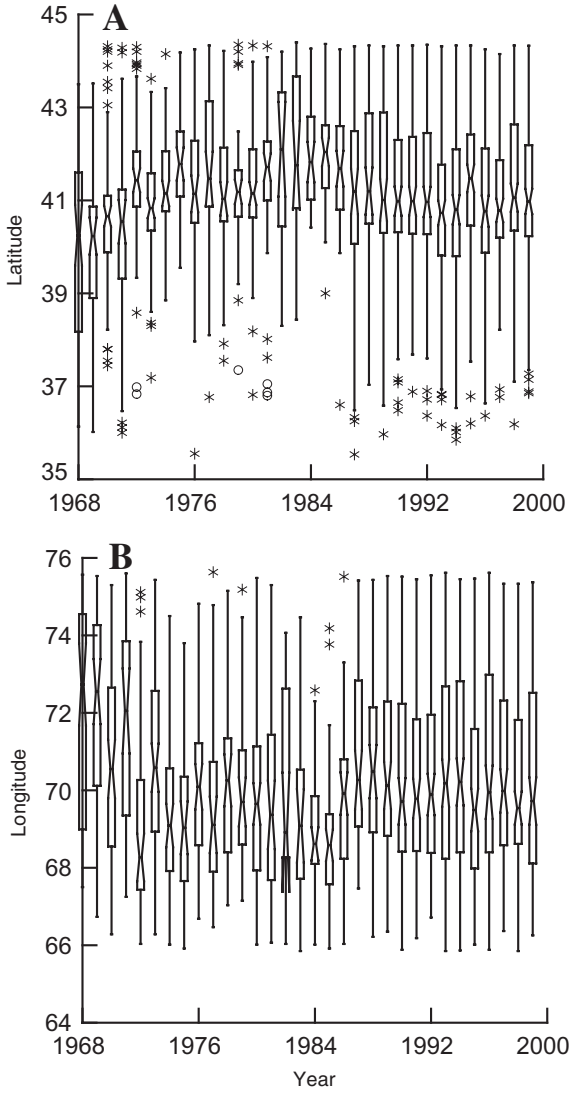


Figure 5

Median (notch), interquartile range, whiskers (±1.5 times the absolute value of the interquartile range), values outside the whiskers (*), and far outside the whiskers (o) of the (**A**) latitude and (**B**) longitude of positive catches of Atlantic herring from the spring NEFSC bottom trawl survey during 1968–98.

ized by rapid changes and a general movement to the north during 1963–75 (Fig. 6A). During 1963–64, the stock complex was centered around 42°, moved a full degree to the south by 1967, and then shifted north to almost 43° by 1975. Survey abundance was so low during 1976–81 that any trends in median latitude were obscured (Fig. 6A). As the stock recovered, median latitude became stable, ranging between about 42°00′ and 42°30′.

The median longitude of the complex hovered around 68°15′–68°45′ during 1963–72, then shifted to the west of 69° during 1973–86 (Fig. 6B). When recovery began, the median longitude of the complex moved slightly to the east of 69°, stabilized between 69°30′ and 69°50′ during 1991–95, and moved farther east during 1996–98 to about 68°35′ (Fig. 6B).

Since 1968, median bottom water temperatures for the entire continental shelf during spring have fluctuated between 5° and 7.5°C, with individual bottom locations ranging between 1° and 14°C and a few values falling outside this range (NMFS[5]). Herring maintained their pref-

[5] NMFS (National Marine Fisheries Service). 2001. Unpubl. data. Northeast Fisheries Science Center, Woods Hole, MA 02543.

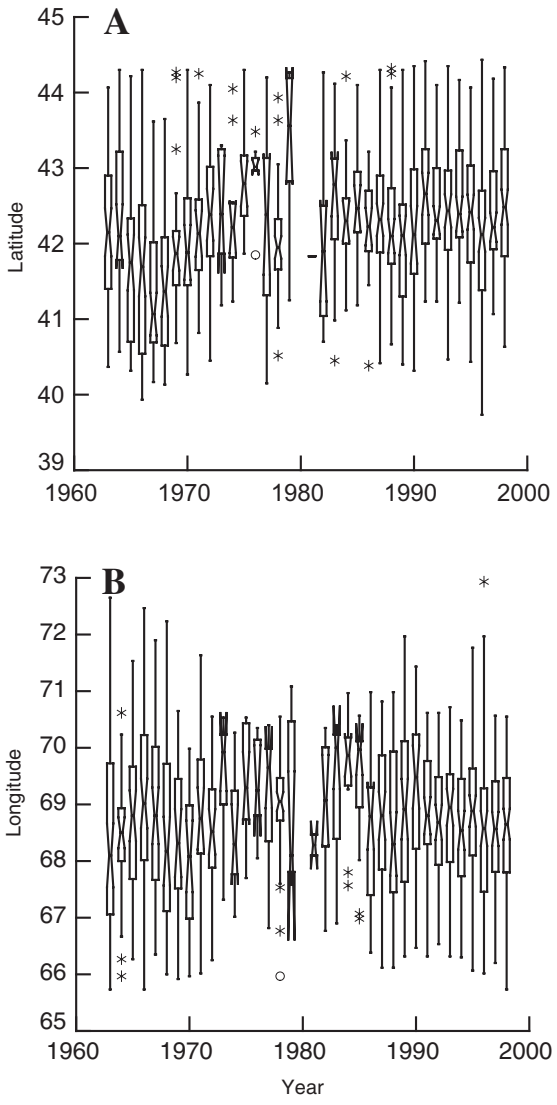


Figure 6

Median (notch), interquartile range, whiskers (±1.5 times the absolute value of the interquartile range), values outside the whiskers (*), and far outside the whiskers (o) of the (**A**) latitude and (**B**) longitude of positive catches of Atlantic herring from the autumn NEFSC bottom trawl survey during 1963–98.

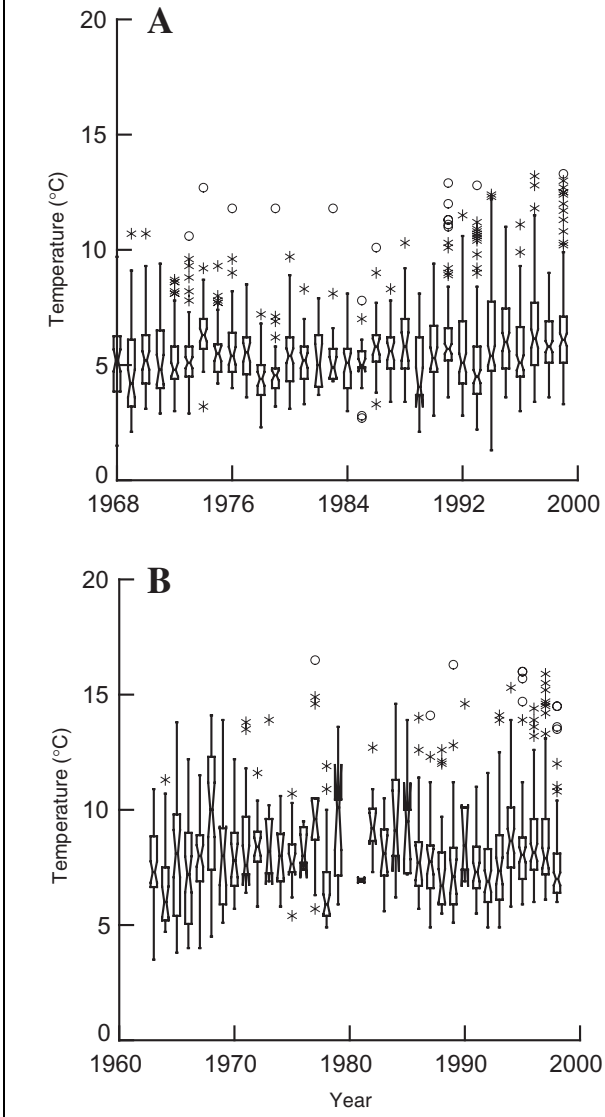


Figure 7

Median (notch), interquartile range, whiskers (±1.5 times the absolute value of the interquartile range), values outside the whiskers (*), and far outside the whiskers (o), of the bottom temperature of positive catches of Atlantic herring from the (**A**) spring NEFSC bottom trawl survey during 1968–98 and (**B**) autumn NEFSC bottom trawl survey during 1963–98.

erence for water temperatures that were cooler than the annual shelf-wide ranges; most herring were caught at bottom temperatures around 5°C during 1968–94 and at about 6°C thereafter (Fig. 7A). During 1972–91, the interquartile range in capture temperature was very narrow, about 1–2°C, expanding afterwards to 2–3°C (Fig. 7A). The overall range in capture temperatures increased greatly in the 1990s.

The median bottom water temperature for the continental shelf during autumn 1963–98 fluctuated between 8° and 12°C, and ranged between 3° and 25°C with a few higher observations (NMFS[5]). Herring were generally captured in the autumn surveys at bottom water temperatures around 8°C during 1963–76 and at about 7–8°C from 1983 to 1998 (Fig. 7B). The interquartile range in capture temperature was about 2–4°C (Fig. 7B), again much cooler than the shelf-wide ranges.

The proportional number of locations where Atlantic herring were captured during spring surveys declined

from 0.30 in 1968 to 0.09 in 1982 (Fig. 8A). During 1983–93, herring were captured in an increasing proportion of survey hauls; by the 1990s, the herring proportion in all survey tows was over 0.60 (Fig. 8A). Autumn surveys during the 1960s and 1970s also showed a declining trend in the proportion of stations containing herring. This decline was even more pronounced than in spring, with the proportion of herring at less than 0.05 of the sample sites during 1979–81 (Fig. 8B). This trend began to change in 1982 and by the 1990s the proportion of tows with herring was well over 0.40 (Fig. 8B).

Spring distribution maps from selected years (1970–95) show that significant changes in herring distribution occurred during 1968–98. In 1970 herring were encountered at 74 sites in the central Gulf of Maine (GOM), on southern Georges Bank (GB), and across the continental shelf from south of Nantucket to Chesapeake Bay (Fig. 9). During 1975, fewer sampling locations (39 sites) had herring and the distribution was constricted. The complex was confined to a few areas in the central GOM, on southern GB, south of Cape Cod, and off of Long Island (Fig. 9). In 1980, fish were encountered (89 sites) along eastern GB and found across western-southern GB to south of Long Island. During 1985, the spring distribution (48 sites) was more restricted than in 1980. By 1990 Atlantic herring were found at 101 sites throughout the GOM, western and southern GB, and across the shelf from Cape Cod to Chesapeake Bay. In 1995, herring were even more widely dispersed (108 sites) across the continental shelf.

Abundance of herring from these selected spring research survey years reflect the general decline in the stock in the late 1970s and recovery to much higher levels in the late 1990s (Fig. 9). In 1970, herring were abundant over the entire continental shelf from Nantucket to Chesapeake Bay with the highest abundance off Long Island and New Jersey (Fig. 9). During the late 1970s, through the mid 1980s, herring were less abundant and the largest catches (101–500 fish per station) were generally taken south of Cape Cod (Fig. 9). By the 1990s, herring were abundant over a wider area and catches in the 101–500 fish-per-tow range were common.

Maps of autumn survey catch locations depict significant spatial changes in herring distribution during the past 30 years (Fig. 10). In 1965 postspawning fish were located (47 sites) in the central GOM, on Jeffreys Ledge, Nantucket Shoals, and the shelf-slope break along western to northern GB (Fig. 10). In 1970 herring were caught at 25 sites (mostly in the GOM and on eastern GB), in 1975 at only 18 sites, and in 1980 at only one location (along the coast of Maine). The number of capture sites increased in 1985 (17) when herring were found primarily in the Stellwagen Bank-Jeffreys Ledge region, and at a few sites on Georges Bank (Fig. 10). In 1990, herring were widely dispersed (31 sites) along the coast of Maine, Jeffreys Ledge, and Nantucket shoals, and in 1995 herring were dispersed throughout the entire region (75 sites) (Fig. 10).

In the early part of the autumn survey time series, herring were widely dispersed, but not very abundant. In 1965, only a few tows had catches greater than 50 fish (Fig. 10). During 1970–85 very few herring were taken and most tows represented only single fish (Fig. 10). By 1990 a general recovery was apparent and catches of 50+ fish per station were common. Atlantic herring were again abundant along the coast of Maine, on Jeffreys Ledge, and in the Great South Channel area (Fig.10). In 1995, herring were abundant over the entire Gulf of Maine–Georges Bank region.

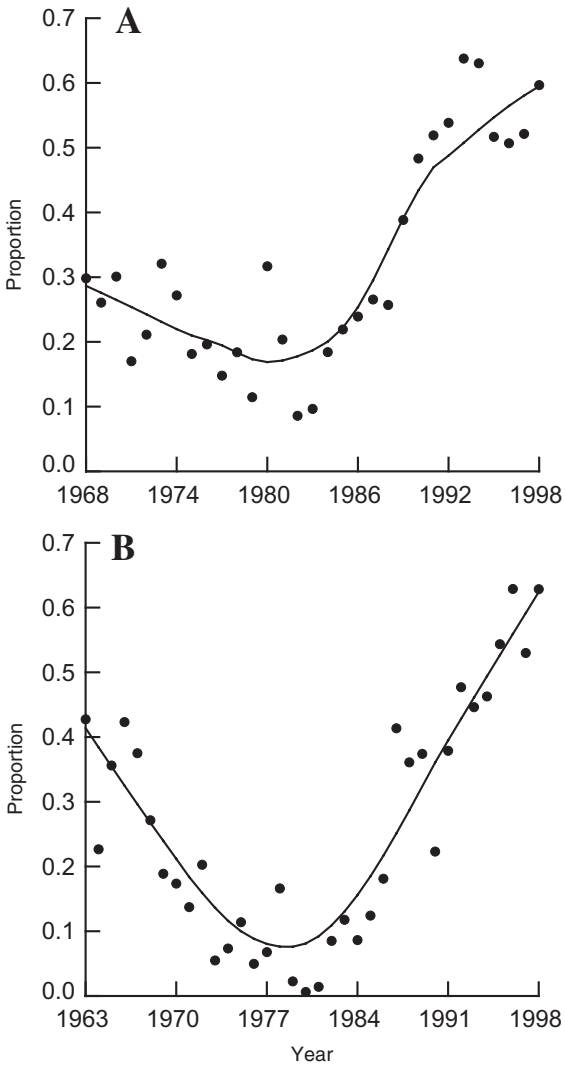


Figure 8

Proportion of survey tows with positive occurrences of Atlantic herring with a LOWESS curve for the data from (**A**) spring bottom trawl surveys during 1968–98 and (**B**) autumn bottom trawl surveys during 1963–98.

Survey abundance indices of herring in the Gulf of Maine, on Nantucket Shoals, and on Georges Bank, increased greatly since the mid 1980s, but at different rates (Fig.11). Increases in the GOM (range 2.8–85.9 million fish, 1987–98) and GB (range 2.1–120 million fish, 1991–98) regions appeared to be about equal in magnitude although the recovery in the GOM began earlier than on GB (Fig.

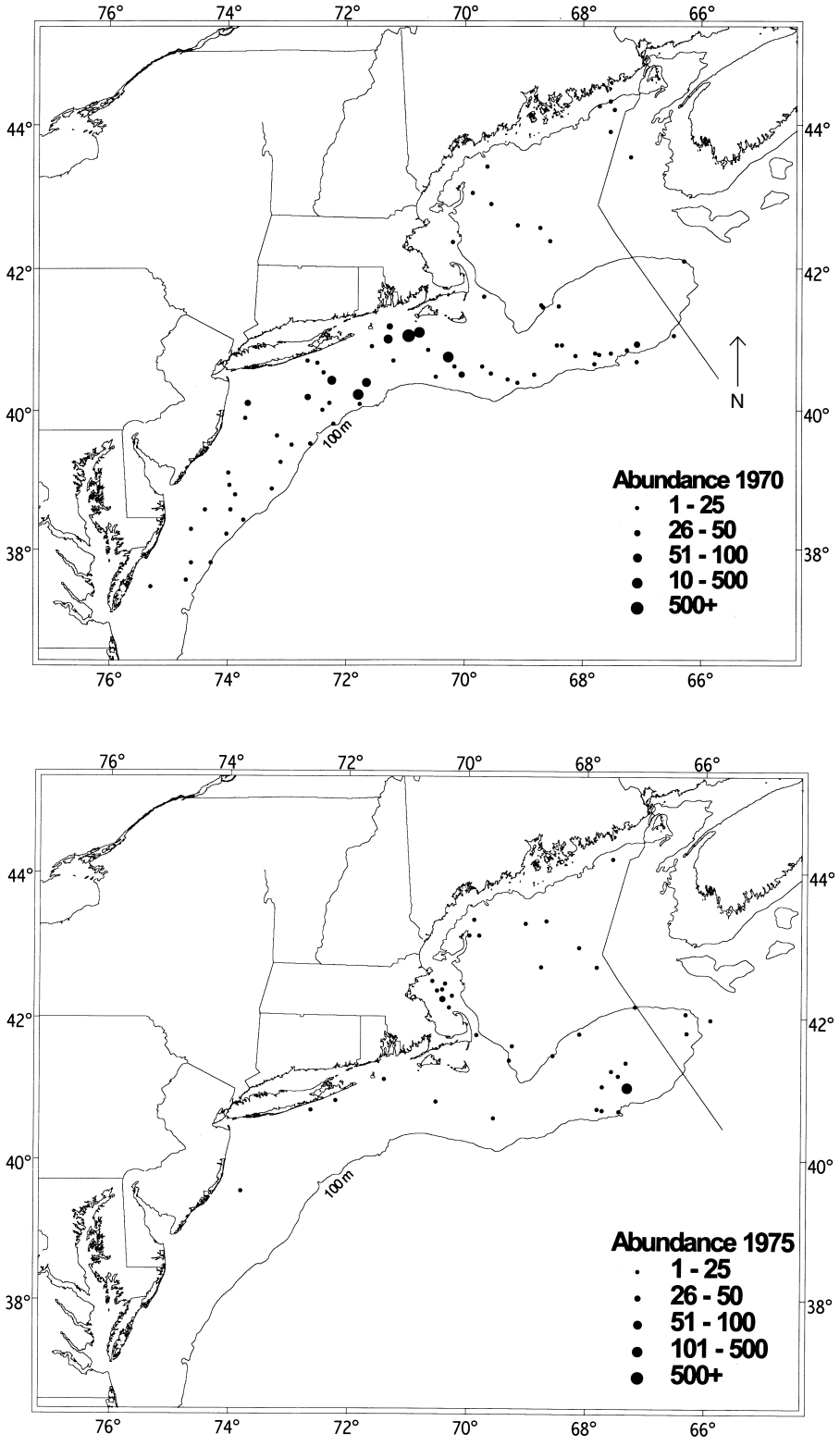
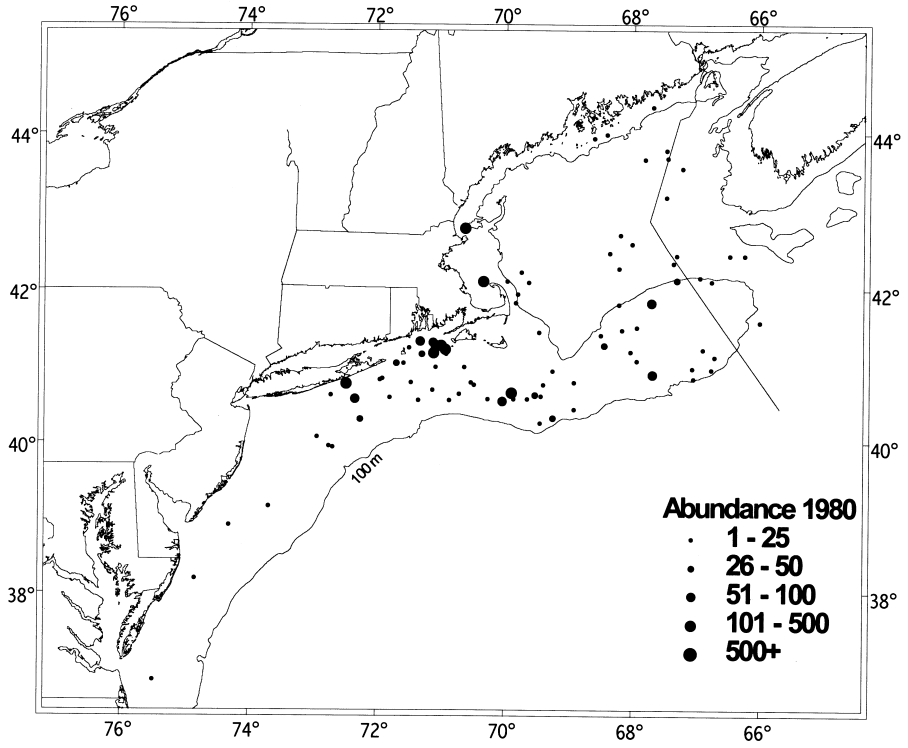
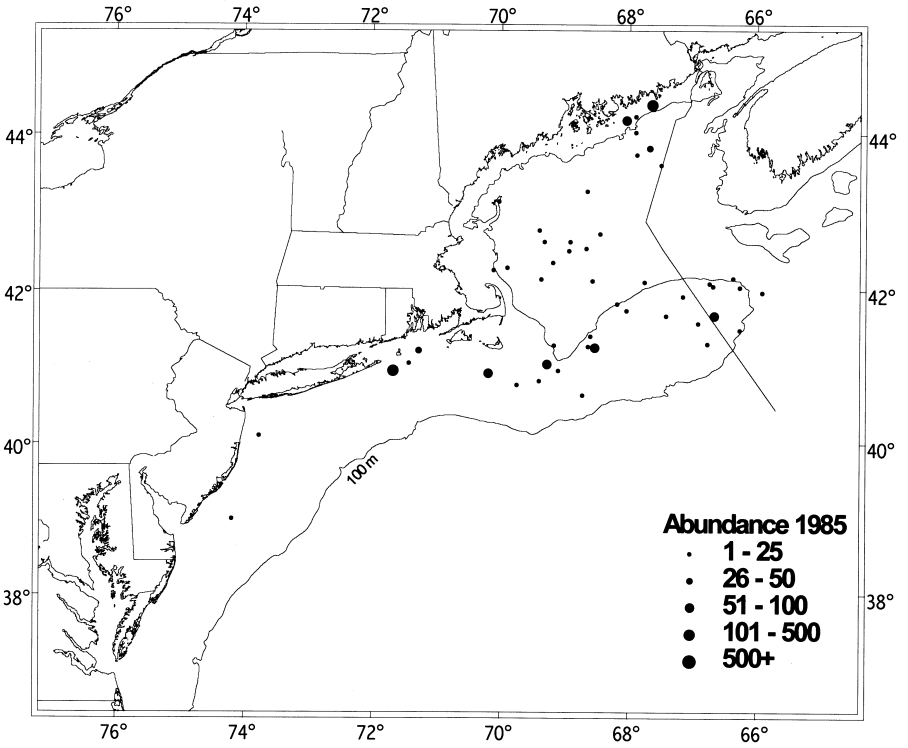


Figure 9

Catch locations and abundance (number of fish per station) for Atlantic herring for selected years (1970, 1975, 1980, 1985, 1990, 1995) from spring bottom trawl surveys conducted during 1968–98.





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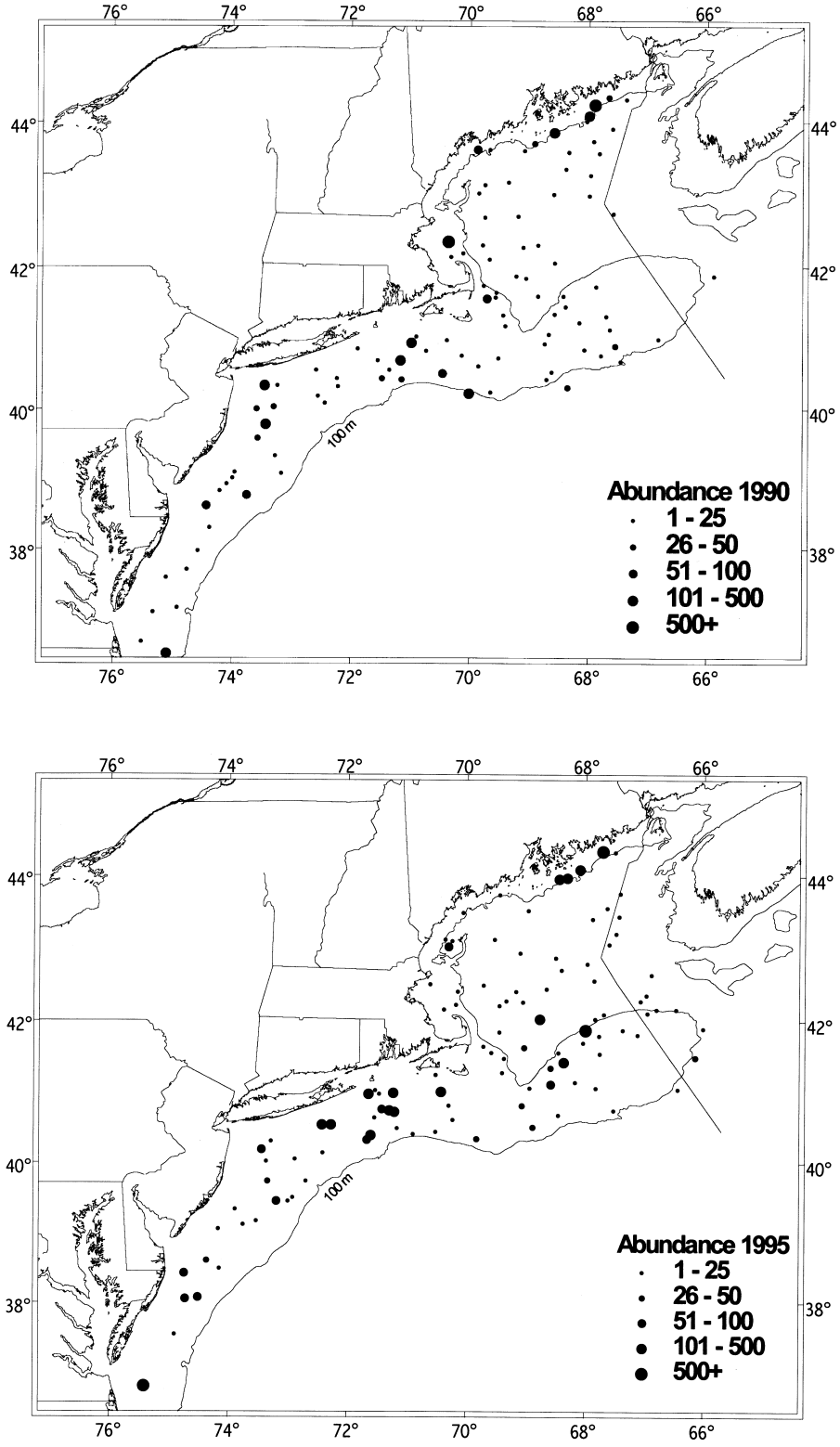

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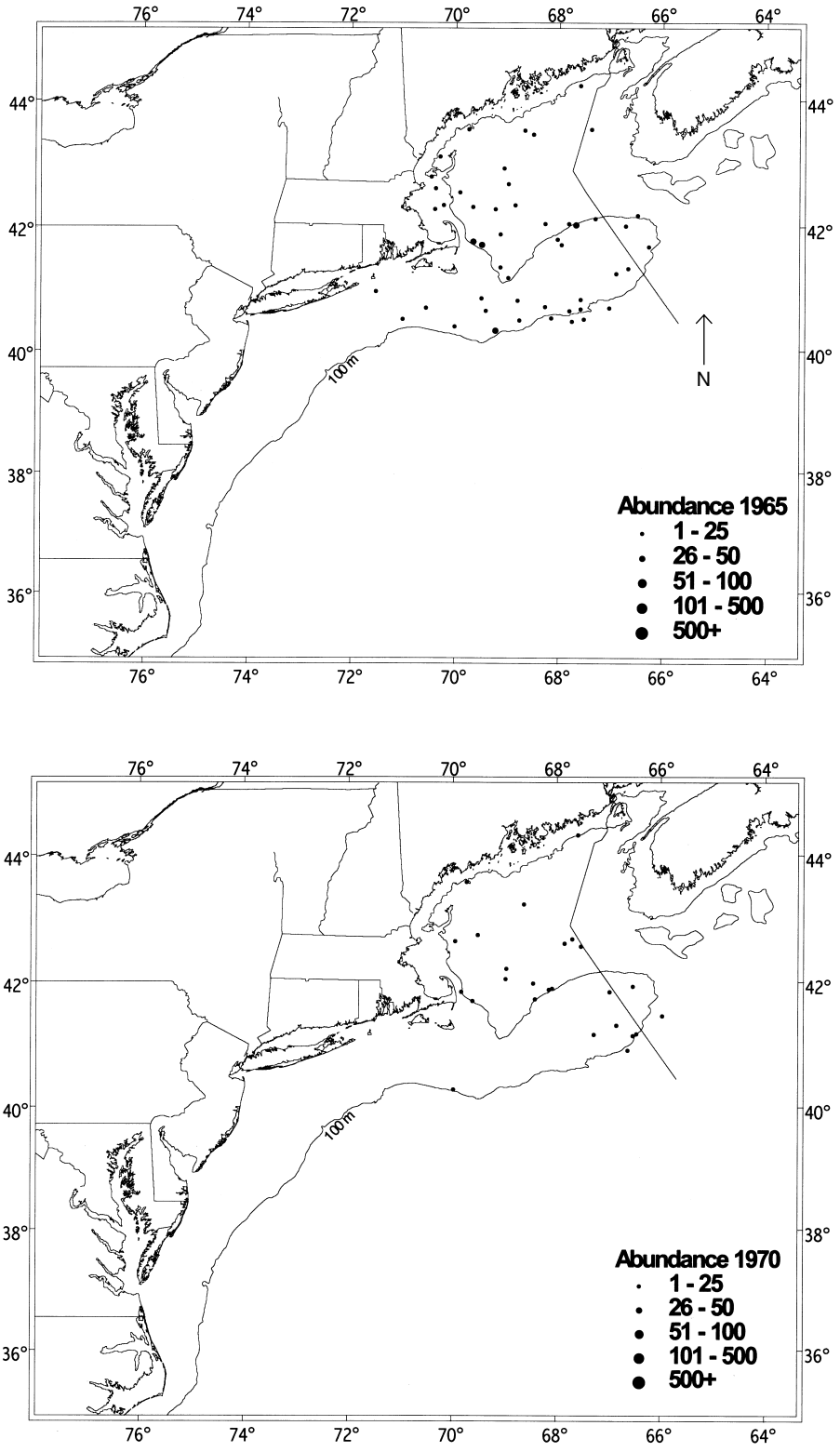
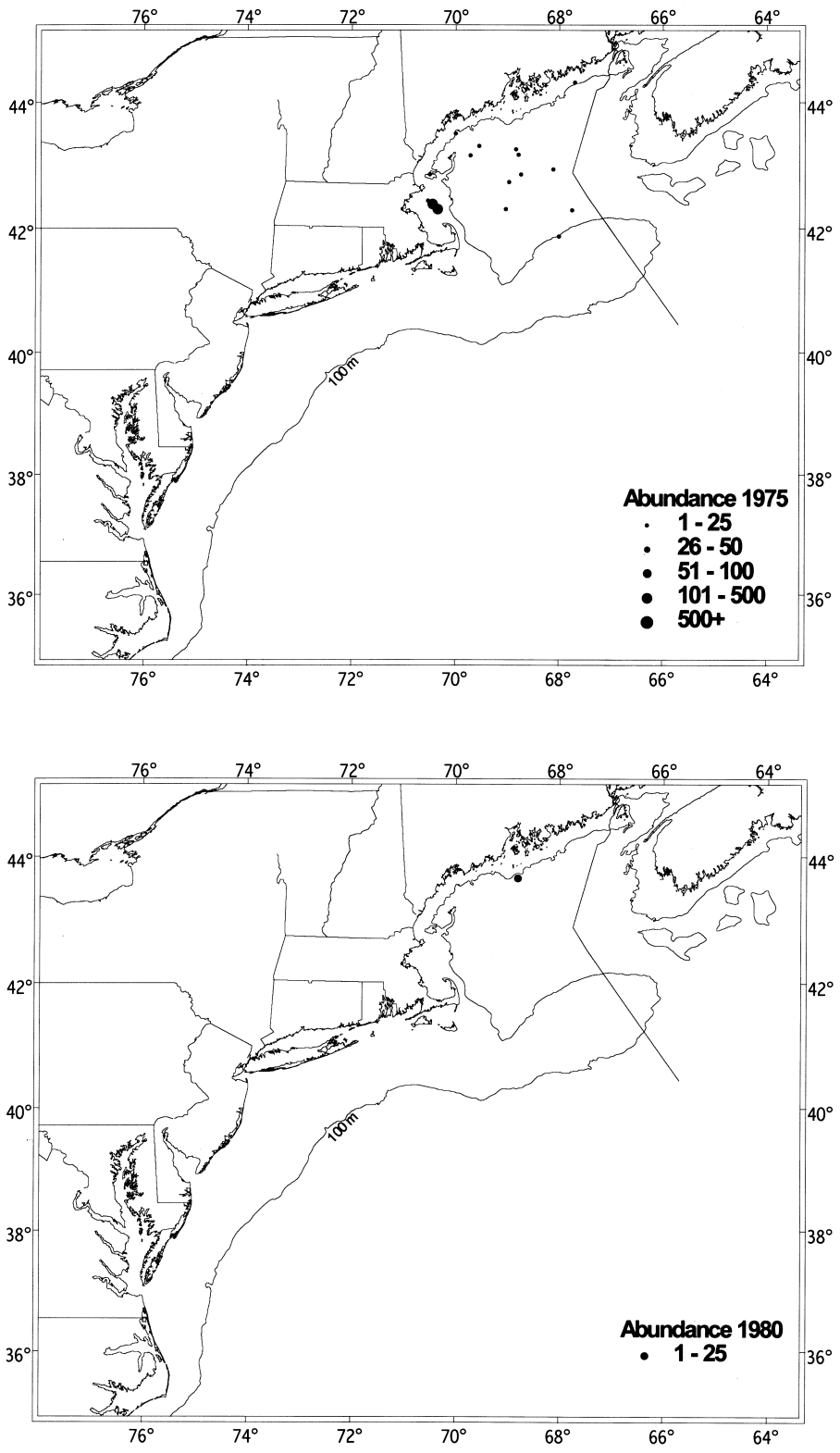


Figure 10

Catch locations and abundance (number of fish per station) for Atlantic herring for selected years (1965, 1970, 1975, 1980, 1985, 1990, 1995) from autumn bottom trawl surveys conducted during 1963–98.



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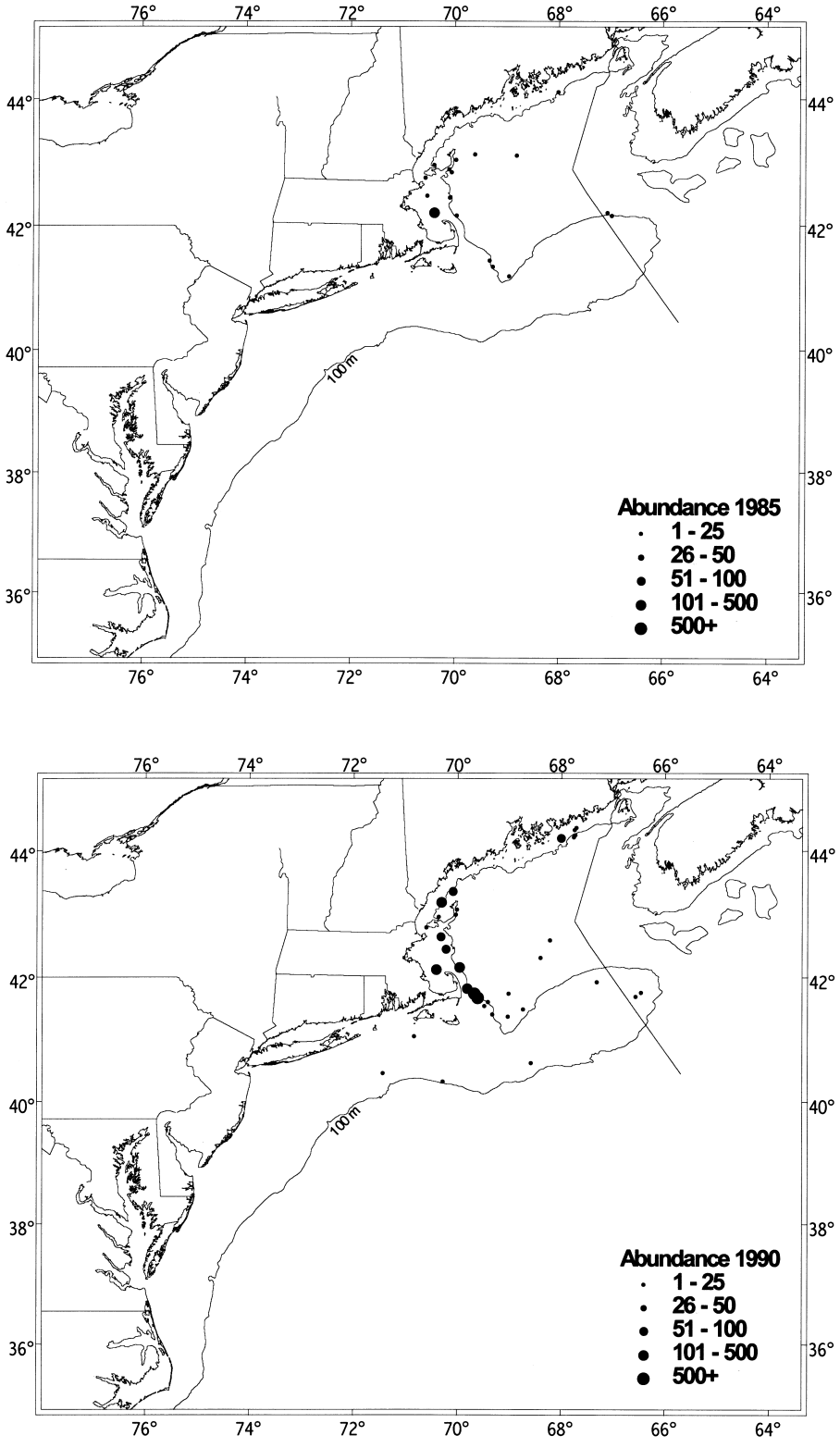

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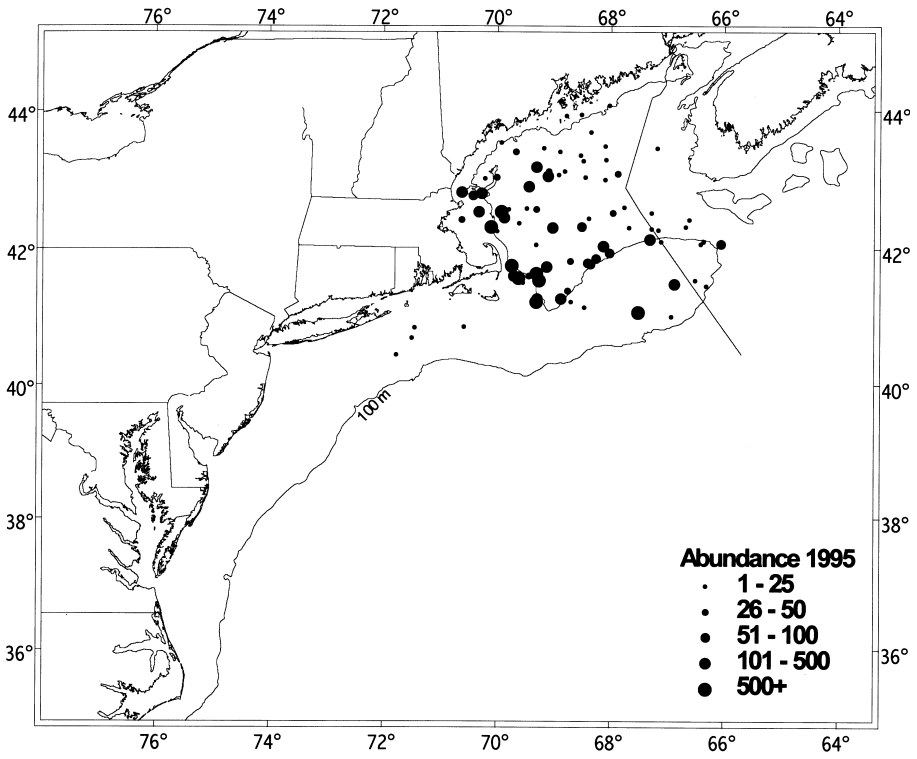

Figure 10 (continued)

11). The recovery in the Gulf of Maine started in 1984 and continued through to 1998 (Fig. 11A). The largest overall increase in abundance has occurred in the Nantucket Shoals region (range 28.8–398.3 million fish) (Fig. 11B). Similarly, after a long hiatus from 1963–1986, this stock component increased considerably during 1987–98. The Georges Bank component was the last to recover, with significant increases in abundance beginning in 1992 (Fig. 11C).

Discussion

Atlantic herring are currently abundant in the Gulf of Maine–Georges Bank region as evidenced by research survey results and recent stock assessments (NEFSC[2]). This resource was heavily exploited during 1961–76 by distant-water fishing vessels with catches that were not sustainable, resulting in the collapse of the Georges Bank component in 1977. The causes of this collapse have been ascribed to excessive fishing mortality and concentration of effort on spawning areas (Anthony and Waring, 1980). ICNAF routinely set total allowable catches (TACs) in excess of scientific recommendations and these TACs were often exceeded (Anthony and Waring, 1980). Spawning concentrations were heavily fished, and egg and larval production declined steadily, followed by the complete absence of larvae on Georges Bank for an entire decade (Anthony and Waring, 1980; Lough et al., 1985; Smith and Morse, 1993).

Full recovery of the Atlantic herring resource has required almost two decades (NEFSC[2]). Spawning area closures and restrictions in the Gulf of Maine beginning in the 1980s may have been influential, but the relative impact of these indirect measures cannot be assessed (Stevenson[4]). During 1978–94 there were almost no offshore landings and abundance and biomass for the GB component improved steadily (NEFSC[2]).

The distribution range of the herring complex was greatly reduced after each of the three stock components were heavily fished; the extent of the spring distribution was much reduced by the early 1980s and autumn spawning activity was confined to the western Gulf of Maine. The relative encounter rate in both research surveys, as measured by the proportion of tows with herring, also declined during this period. As the complex began to recover, its range extended and the proportion of survey tows with herring increased dramatically. The complex was more widely dispersed by the mid 1990s with the recovery of all three components to, or above, historic abundance and biomass (NEFSC[2]).

Murawski (1993) found that temperature is a very important factor in determining the distribution of pelagic fishes, particularly Atlantic herring. Herring appear to have maintained a preferred thermal regime despite elevated and variable overall shelf temperatures in spring and autumn, and large changes in abundance. The ±5°C median spring temperature for 1968–94 from our study is in agreement with the average of 4.8°C from Murawski (1993). After the complex recovered, the median spring bottom temperature increased slightly to about 6°, probably indicative of the much broader range of the complex. Murawski (1993) calculated an autumn average of 8.5° for Atlantic herring and the median from the current study was 7–8°. This autumn preference reflects the distribu-

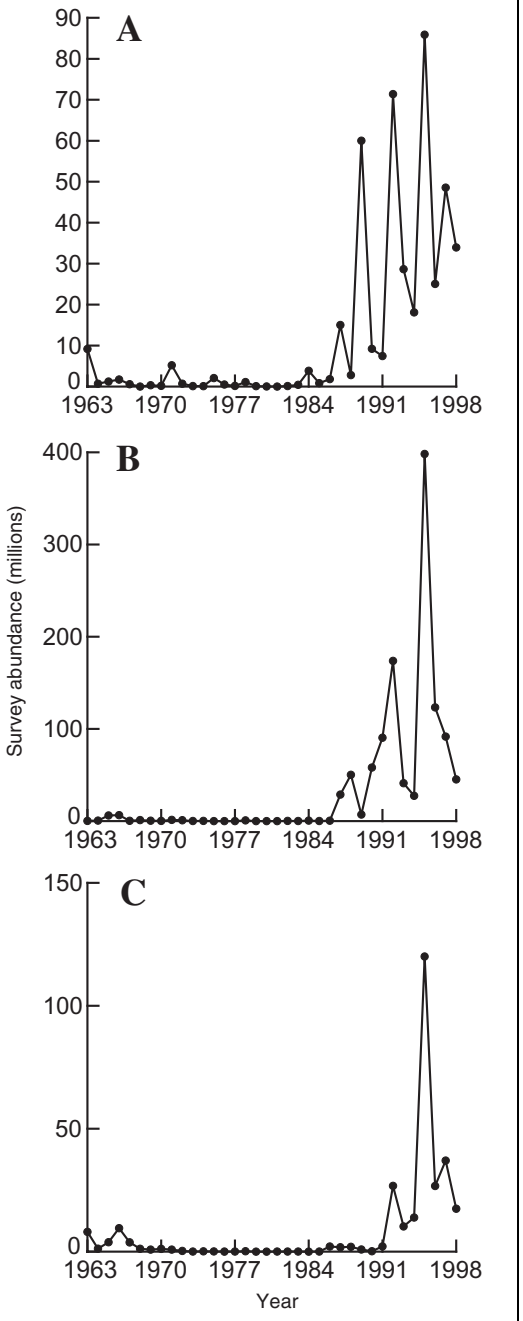

Figure 11

Abundance (swept area, millions of fish) of Atlantic herring from (**A**) the Gulf of Maine, (**B**) Nantucket Shoals, and (**C**) Georges Bank from autumn bottom trawl surveys during 1963–98.

tion of postspawning fish in the cooler waters of the Gulf of Maine and Northern Georges Bank. Although thermal conditions play a major role in the zoogeography of fishes, the influence of abundance was probably overwhelming in producing the recovery of the historic range in distribution observed in the Atlantic herring complex.

Several independent sources of information suggest that the recovery of this stock occurred in a stepwise manner with the Gulf of Maine component recovering first, followed by the Nantucket Shoals component, and finally the Georges Bank component. The autumn bottom trawl survey data showed an improved trend in the Gulf of Maine in 1984, the Nantucket Shoals component in 1987, and Georges Bank in 1992. Larval surveys conducted during 1971–90 showed a progression of larval abundance from the Cape Cod Bay-Stellwagen Bank area in 1976–84, to Nantucket Shoals in 1985–87, and on Georges Bank in 1988–90 (Smith and Morse, 1993). Larval distribution data suggested that larvae from Jeffreys Ledge spawners were probably transported to Nantucket Shoals and that in subsequent years larvae from these areas were transported or adults moved to western Georges Bank and finally eastern Georges Bank (Smith and Morse, 1993). The general pattern of water circulation in the region (McGillicuddy et. al., 1988) also favors this hypothesis for the recovery.

Smith and Morse (1993) suggested that the larval survey data support the hypothesis that a recolonization of Atlantic herring occurred on Nantucket Shoals and Georges Bank. The data from their study showed a chronological pattern in larval abundance and distribution, beginning in the Gulf of Maine and progressing toward the Nantucket shoals region and finally to Georges Bank. In contrast, Stephenson and Kornfield (1990) asserted that the reappearance of herring on Georges Bank was more related to a resurgence of low numbers of stock-specific endemic fish. The autumn NMFS bottom trawl survey data tend to support the conclusions of Smith and Morse (1993) in both direction and timing. Survey indices show a progressive recovery in herring abundance from the Gulf of Maine to Nantucket Shoals, and finally to Georges Bank.

Significant changes in stock distribution, shifts in centers of primary abundance, and regional declines or disappearance of historically important spawning contingents are evident from the data. Autumn indices show that the stock component in the Gulf of Maine reached very low abundances during 1973–83 and that the Nantucket Shoals and Georges Bank components were nearly, if not actually, extirpated. Recovery times for these two components of the stock were relatively long—on the order of 10–15 years. Without a local supply of larvae, recovery was delayed considerably. Recovery was probably contingent on a supply of larval herring from the Gulf of Maine that eventually recolonized the offshore areas. Spawning restrictions along the coast of Maine and on Jeffreys Ledge in the 1980s may also have contributed to the recovery of Gulf of Maine component, thereby setting in motion the recovery of the entire stock complex.

Acknowledgments

We thank the dedicated personnel from the Northeast Fisheries Science Center and the many volunteers who worked tirelessly to collect the bottom trawl survey data during 1963–98.

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