NOAA Technical Memorandum NMFS-NE-135

Essential Fish Habitat Source Document:

Silver Hake, *Merluccius bilinearis*, Life History and Habitat Characteristics

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Region
Northeast Fisheries Science Center
Woods Hole, Massachusetts

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Essential Fish Habitat Source Document:

Silver Hake, *Merluccius bilinearis*, Life History and Habitat Characteristics

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Editorial Notes on Issues 122-152 in the *NOAA Technical Memorandum NMFS-NE* Series

Editorial Production

For Issues 122-152, staff of the Northeast Fisheries Science Center's (NEFSC's) Ecosystems Processes Division have largely assumed the role of staff of the NEFSC's Editorial Office for technical and copy editing, type composition, and page layout. Other than the four covers (inside and outside, front and back) and first two preliminary pages, all preprinting editorial production has been performed by, and all credit for such production rightfully belongs to, the authors and acknowledgees of each issue, as well as those noted below in "Special Acknowledgments."

Special Acknowledgments

David B. Packer, Sara J. Griesbach, and Luca M. Cargnelli coordinated virtually all aspects of the preprinting editorial production, as well as performed virtually all technical and copy editing, type composition, and page layout, of Issues 122-152. Rande R. Cross, Claire L. Steimle, and Judy D. Berrien conducted the literature searching, citation checking, and bibliographic styling for Issues 122-152. Joseph J. Vitaliano produced all of the food habits figures in Issues 122-152.

Internet Availability

Issues 122-152 are being copublished, *i.e.*, both as paper copies and as web postings. All web postings are, or will soon be, available at: *www.nefsc.nmfs.gov/nefsc/habitat/efh*. Also, all web postings will be in "PDF" format.

Information Updating

By federal regulation, all information specific to Issues 122-152 must be updated at least every five years. All official updates will appear in the web postings. Paper copies will be reissued only when and if new information associated with Issues 122-152 is significant enough to warrant a reprinting of a given issue. All updated and/or reprinted issues will retain the original issue number, but bear a "Revised (Month Year)" label.

Species Names

The NMFS Northeast Region's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes (*i.e.*, Robins *et al.* 1991[a]), mollusks (*i.e.*, Turgeon *et al.* 1998[b]), and decapod crustaceans (*i.e.*, Williams *et al.* 1989[c]), and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals (*i.e.*, Rice 1998[d]). Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species (*e.g.*, Cooper and Chapleau 1998[e]).

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[a]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991. Common and scientific names of fishes from the United States and Canada. 5th ed. *Amer. Fish. Soc. Spec. Publ.* 20; 183 p.

[b]Turgeon, D.D. (chair); Quinn, J.F., Jr.; Bogan, A.E.; Coan, E.V.; Hochberg, F.G.; Lyons, W.G.; Mikkelsen, P.M.; Neves, R.J.; Roper, C.F.E.; Rosenberg, G.; Roth, B.; Scheltema, A.; Thompson, F.G.; Vecchione, M.; Williams, J.D. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. 2nd ed. *Amer. Fish. Soc. Spec. Publ.* 26; 526 p.

[c]Williams, A.B. (chair); Abele, L.G.; Felder, D.L.; Hobbs, H.H., Jr.; Manning, R.B.; McLaughlin, P.A.; Pérez Farfante, I. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. *Amer. Fish. Soc. Spec. Publ.* 17; 77 p.

[d]Rice, D.W. 1998. Marine mammals of the world: systematics and distribution. *Soc. Mar. Mammal. Spec. Publ.* 4; 231 p.

[e]Cooper, J.A.; Chapleau, F. 1998. Monophyly and interrelationships of the family Pleuronectidae (Pleuronectiformes), with a revised classification. *Fish. Bull. (U.S.)* 96:686-726.

FOREWORD

One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats.

Magnuson-Stevens Fishery Conservation and Management Act (October 11, 1996)

The long-term viability of living marine resources depends on protection of their habitat.

NMFS Strategic Plan for Fisheries Research (February 1998)

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), which was reauthorized and amended by the Sustainable Fisheries Act (1996), requires the eight regional fishery management councils to describe and identify essential fish habitat (EFH) in their respective regions, to specify actions to conserve and enhance that EFH, and to minimize the adverse effects of fishing on EFH. Congress defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The MSFCMA requires NMFS to assist the regional fishery management councils in the implementation of EFH in their respective fishery management plans.

NMFS has taken a broad view of habitat as the area used by fish throughout their life cycle. Fish use habitat for spawning, feeding, nursery, migration, and shelter, but most habitats provide only a subset of these functions. Fish may change habitats with changes in life history stage, seasonal and geographic distributions, abundance, and interactions with other species. The type of habitat, as well as its attributes and functions, are important for sustaining the production of managed species.

The Northeast Fisheries Science Center compiled the available information on the distribution, abundance, and habitat requirements for each of the species managed by the New England and Mid-Atlantic Fishery Management Councils. That information is presented in this series of 30 EFH species reports (plus one consolidated methods report). The EFH species reports comprise a survey of the important literature as well as original analyses of fishery-independent data sets from NMFS and several coastal states. The species reports are also the source for the current EFH designations by the New England and Mid-Atlantic Fishery Management Councils, and have understandably begun to be referred to as the "EFH source documents."

NMFS provided guidance to the regional fishery management councils for identifying and describing EFH of their managed species. Consistent with this guidance, the species reports present information on current and historic stock sizes, geographic range, and the period and location of major life history stages. The habitats of managed species are described by the physical, chemical, and biological components of the ecosystem where the species occur. Information on the habitat requirements is provided for each life history stage, and it includes, where available, habitat and environmental variables that control or limit distribution, abundance, growth, reproduction, mortality, and productivity.

Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NMFS, the regional fishery management councils, fishing participants, Federal and state agencies, and other organizations will have to cooperate to achieve the habitat goals established by the MSFCMA.

A historical note: the EFH species reports effectively recommence a series of reports published by the NMFS Sandy Hook (New Jersey) Laboratory (now formally known as the James J. Howard Marine Sciences Laboratory) from 1977 to 1982. These reports, which were formally labeled as *Sandy Hook Laboratory Technical Series Reports*, but informally known as "Sandy Hook Bluebooks," summarized biological and fisheries data for 18 economically important species. The fact that the bluebooks continue to be used two decades after their publication persuaded us to make their successors – the 30 EFH source documents – available to the public through publication in the *NOAA Technical Memorandum NMFS-NE* series.

JAMES J. HOWARD MARINE SCIENCES LABORATORY
HIGHLANDS, NEW JERSEY
SEPTEMBER 1999

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NORTHEAST FISHERIES SCIENCE CENTER

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INTRODUCTION

Silver hake, *Merluccius bilinearis* (Figure 1), are distributed on the continental shelf of the northwest Atlantic Ocean from Cape Fear, North Carolina (Karnella 1973) to the Gulf of St. Lawrence and the southern edge of the Grand Banks, Newfoundland, Canada (Leim and Scott 1966). An early report of their southern range as being deep waters off the Bahamas (Norman 1939) was probably a misidentification of *Merluccius albidus*, the offshore hake. Silver hake are most abundant from Nova Scotia to New Jersey.

Silver hake are slender, fast swimming gadids that are often found in dense schools associated with specific hydrographic conditions, prey concentrations, and spawning requirements. Analyses of bottom trawl catches in U.S waters show that adult silver hake are found throughout the survey area (Cape Hatteras, North Carolina to Cape Sable, Nova Scotia) in winter and spring, but are concentrated in deep basins in the Gulf of Maine and along the continental slope from Nova Scotia to Cape Hatteras (Almeida 1987; Helser *et al.* 1995; Helser 1996).

In U.S. waters, two stocks of silver hake have been identified based on morphometric differences. One stock occurs in the Gulf of Maine to northern Georges Bank while the other stock ranges from southern Georges Bank to Cape Hatteras. Juveniles and adults migrate to deeper waters of the continental shelf as water temperatures decline in the autumn and return to shallow waters in spring and summer to spawn. Major spawning areas are coastal Gulf of Maine, southern Georges Bank, and waters south of Rhode Island. Silver hake are relatively fast growing, reach sexual maturity at 2-3 years of age (20-30 cm), and live a maximum of 15 years, although in recent years few fish older than 6 years are caught.

LIFE HISTORY

EGGS

The eggs are pelagic, 0.88-0.95 mm in diameter, drift with the prevailing currents, and hatch in about two days at 20^{o}C.

LARVAE

Newly hatch larvae are pelagic and are about 2.6-3.5 mm long. Pelagic life lasts about 2 months and at about 17-20 mm long the larvae descend to the bottom as juveniles.

JUVENILES AND ADULTS

Studies of age and growth of silver hake in U.S. waters began with Schaefer (1960). Nichy (1969) aged juvenile fish and conducted an age validation study. In an investigation of the effect of stock size on growth of various age classes in the northern Georges Bank-Gulf of Maine stock, Ross and Almeida (1986) found that mean weight-at-age (2-5 years) was significantly inversely correlated with three measures of stock density during 1962-1979. Almeida (1978) and Penntila *et al.* (1989) used von Bertalanffy growth functions to describe growth of the northern and southern stocks. Almeida (1978) found faster growth and greater size in the northern stock compared to the southern stock.

Helser (1996) made a detailed analysis of the growth of silver hake in four areas of the U.S. continental shelf during 1975-1980, 1982-1987, 1988-1992. He found significant differences in growth between the Middle Atlantic and southern Georges Bank in all three periods, between northern Georges Bank and the Gulf of Maine during 1975-1980 and 1982-1987, and between northern and southern Georges Bank during 1982-1987. Growth in the Gulf of Maine, on average, was slow, but the fish attained the large asymptotic length (k = 0.33, L_∞ = 47 cm) compared to the Middle Atlantic Bight (k = 0.51, L_∞ = 43 cm); growth on Georges Bank was intermediate.

Females grow faster and live longer than males. Reported maximum lengths and ages are 34 cm and 6 years for males and 60-64 cm and 12 years for females (Bigelow and Schroeder 1953; Nichy 1969). Interestingly, maximum lengths of silver hake collected during the NMFS Northeast Fisheries Science Center (NEFSC) bottom trawl survey are 78 cm in spring and 76 cm in autumn. Table 1 lists mean lengths at age to indicate relative size-at-age for Gulf of Maine, Middle Atlantic, northern Georges Bank, and southern Georges Bank for 1988-1992.

Helser and Almeida (1997) performed a detailed analysis of the possible effects of stock abundance, growth, spring water temperatures, and depths on the proportion of silver hake that are mature at age 2 and 3. Population abundance accounted for most of the variation in sexual maturity and growth in the southern stock accounted for some additional variation. Both catch-weighted water temperature and catch-weighted bottom depth had no statistically significant effect on the proportion mature at age 2 or 3 for the northern stock, or at age 2 for the southern stock. A slight effect was found for the proportion mature at age 3 for the southern stock.

REPRODUCTION

Female silver hake are asynchronous spawners that produce and release several batches of eggs during the spawning season (Sauskan and Serebryakov 1968).

Silver hake eggs and larvae have been collected in all months on the continental shelf in U.S. waters, although the onset of spawning varies regionally (Bigelow and Schroeder 1953; Marak and Colton 1961; Sauskan and Serebryakov 1968; Fahay 1974; Morse *et al.* 1987; Waldron 1988; Berrien and Sibunka 1999). Silver hake spawn over a wide range of temperatures and depths. In the Middle Atlantic Bight, newly spawned eggs were collected at surface water temperatures between 13^{o}C and 22^{o}C (Fahay 1974). In the Gulf of Maine, Bigelow and Schroeder (1953) reported that spawning temperatures ranged from 5^{o}C to 13^{o}C.

Spawning begins in January along the shelf and slope in the Middle Atlantic Bight and proceeds north and east to Georges Bank into May. By June spawning has spread into the Gulf of Maine and continues to be centered on Georges Bank through summer. In October, spawning is centered in southern New England and by December spawning is observed again along the shelf and slope in the Middle Atlantic Bight. Over the U.S. continental shelf, significant numbers of eggs are produced beginning in May, numbers increase through August, and then decline rapidly during September and October (Berrien and Sibunka 1999).

The primary spawning grounds probably coincide with concentrations of ripe adults and newly spawned eggs. These grounds occur between Cape Cod, Massachusetts, and Montauk Point, New York (Fahay 1974), on the southern and southeastern slope of Georges Bank (Sauskan 1964) and the area north of Cape Cod to Cape Ann, Massachusetts (Bigelow and Schroeder 1953).

Silver hake median length at maturity (i.e., 50% mature) has declined in recent years. Table 2 lists observations of silver hake age and length at maturity.

FOOD HABITS

The diet of silver hake consists primarily of fish, crustaceans, and squids, depending on the size, age, and sex of the silver hake (Schaefer 1960; Domanevsky and Nozdrin 1963; Dexter 1969; Edwards and Bowman 1979; Bowman 1984; Waldron 1993; Helser *et al.* 1995). Young fish (< 20 cm) eat mainly crustaceans, such as euphausiids and shrimps. As silver hake grow they consume a larger proportion of fish and individuals > 35 cm feed almost exclusively on fish (Bowman 1984).

MIGRATION

During spring and summer, silver hake move into nearshore waters in the Gulf of Maine, to the northern edge of Georges Bank, and northward in the Middle Atlantic Bight. By autumn, they return again to the deeper basins in the Gulf and along the continental slope. The pattern for juveniles is similar to adults in general distribution and movements, except that the centers of juvenile abundance occur in shallower waters. Juveniles are abundant inshore along the Middle Atlantic and on the shoals of Georges Bank.

STOCK STRUCTURE

Silver hake occurring on the U.S. continental shelf have been divided into at least two stocks. Numerous studies using a variety of methods, including morphometrics (Conover *et. al.* 1961; Almeida 1987), growth patterns on otoliths (Nichy 1969), serological analyses (Konstantinov and Noskov 1969; Schenk 1981), seasonal distribution patterns (Anderson 1974; Almeida 1987), and growth (Helser 1996), indicate that fish in the Middle Atlantic Bight are distinct from fish in the Gulf of Maine. The line dividing these two stocks occurs somewhere between Nantucket Shoals and the northern edge of Georges Bank. However, the results of these studies are inconclusive and additional work is needed to confirm the existence of biologically separate stocks (e.g., Helser 1996).

HABITAT CHARACTERISTICS

EGGS

Data from the NEFSC Marine Resources Monitoring, Assessment and Prediction (MARMAP) ichthyoplankton survey was used to determine the relationships between bottom depth and water temperature in the upper 15 m and silver hake egg abundances (Figure 2). Eggs occurred in relatively deeper waters than the stations sampled. The bottom depths where eggs were captured ranged from 10-1250 m, but most eggs were collected between 50-150 m. A shift to shallower shelf waters during late spring is evident (Figure 2); the average depth of egg occurrences declined from about 100 m in spring to about 60 m in summer.

The percent frequencies of stations sampled show the expected annual cycle in water temperatures (Figure 2) and the occurrences of eggs show a similar cycle. During the months of coldest temperatures (March and April) silver hake eggs occurred in the coldest temperatures of the year (5-12^{o}C). As the water warmed in the spring, the occurrences of eggs shifted to warmer waters until summer, when eggs were found mostly between 13 and 20^{o}C. During autumn the waters began to cool and egg occurrences shifted to cooler waters (10-15^{o}C). Peak abundance of eggs occurred from June to September and during these months most eggs were found in temperatures 11-17^{o}C. The large bar in June at 21^{o}C reflects an unusually large catch of eggs (18,908 eggs/10 m^2).

The results presented for the NEFSC MARMAP survey agree with published observations of depth and temperature occurrences of silver hake eggs (Bigelow and Schroeder 1953; Fahay 1974; Waldron 1988).

LARVAE

The relationships of bottom depth and water temperature in the upper 15 m of water to the abundance of silver hake larvae from the NEFSC MARMAP survey are shown in Figure 3. Larvae occurred in relatively deeper water than the overall depths of stations sampled although generally shallower than eggs. The bottom depths where larvae were captured ranged from 10 to 1250 m, but most occurred between 50-130 m. The depths of larvae occurrence remained stable throughout most of the year but a shift to slightly deeper waters occurred during May and June.

The occurrences of larvae in relation to water temperature in the top 15 m showed a shift in preferred temperatures that followed the annual warming and cooling cycle **(**Figure 3). During the months of coldest temperatures (February and March) silver hake larvae were found in the coldest water of the year (5-12^{o}C). As the water warmed in the spring, the occurrences of larvae shifted to warmer waters until summer when they were found mostly between 10 and 16^{o}C. During autumn, the waters began to cool, but larvae remained in warmer waters (10-16^{o}C). Peak abundance of larvae occurred from July to October and during these months most were found in temperatures 11-16^{o}C.

JUVENILES

Based on the NEFSC bottom trawl survey, the relationships of bottom temperature and depth to catches of juvenile silver hake in spring and autumn are shown in Figure 4. In spring, silver hake were captured at temperatures of 3-17^{o}C and bottom depths of 5-350 m. Their preferred temperatures and depths were 6-9^{o}C and 150-275 m. In autumn, they occurred in temperatures and depths of 5-22^{o}C and 5-350 m and their preferred ranges were 10-17^{o}C and 25-75 m.

The relationships of bottom temperature and depth to catches of juvenile silver hake in spring and autumn from the Massachusetts trawl survey are shown in Figure 5. Juveniles were caught at all depths and temperatures during both seasons. No clear temperature preference was detected in spring, but in autumn, 7-11^{o}C was preferred. During both seasons, the shallowest depths (< 20 m) had the smallest catches of juveniles.

Analyses of the Hudson-Raritan estuary trawl study data on the relationships of bottom temperature, dissolved oxygen, salinity, and depth to catches of juvenile silver hake in spring and autumn are shown in Figure 6. Silver hake occurred at temperatures from 1-17^{o}C and preferred temperatures from 9-14^{o}C. The preferred levels of dissolved oxygen were 7-9 mg/l. They occurred at all depths sampled except 10 m and showed preference for depths of 10-20 m. Juveniles avoided salinities less than 20 ppt and showed preferences for salinities above 28 ppt.

In the Rhode Island trawl surveys, juvenile hakes were relatively abundant in Narragansett Bay at depths near 30 m during winter, spring and summer and at 10 m in autumn (Figure 7). They occurred at most bottom temperatures but preferred 9^{o}C temperatures in summer.

ADULTS

Silver hake adults and juveniles are found over wide temperature and depth ranges in U.S. continental shelf waters (Table 3). The relationships of bottom temperature and depth to catches of adult silver hake in spring and autumn from the NEFSC bottom trawl survey are shown in Figure 4. In spring, adult silver hake were captured at temperatures of 3-19^{o}C and bottom depths of 5–400 m. Their preferred temperature and depths in spring were 7-13^{o}C and 125–325 m. In autumn, they occurred in temperatures and depths of 4-22^{o}C and 5–500 m and their preferred ranges were 7-11^{o}C and 150–225 m.

Based on the Massachusetts trawl survey, the relationships of bottom temperature and depth to catches of adult silver hake in spring and autumn are shown in Figure 5. They occurred at all temperatures in spring and no clear temperature preference could be detected. In autumn, they occurred in temperatures from 5-17^{o}C but preferred temperature from 7-11^{o}C. They were caught at depths > 5 m in spring and > 15 m in autumn. During both seasons, the lowest numbers of adults were caught in the shallower depths (< 20 m).

The Hudson-Raritan estuary trawl surveys caught a total of just one adult silver hake in January 1995. In Narragansett Bay, adult hakes were relatively abundant at depths > 20 m in all seasons (Figure 8) and showed a preference for bottom temperatures between 7 and 16^{o}C.

In Long Island Sound, silver hake were found at all temperatures sampled, except at 23^{o}C in autumn, and they showed no particular preference for temperature in either spring or autumn. Hakes were captured at most depths sampled and showed no preference for particular depths in spring or autumn. Silver hake were captured throughout the range of salinities observed in the sound. No clear salinity preference was evident in spring, but in autumn, hakes were captured at higher than average salinities.

Scott (1982) reports that silver hake on the Scotian Shelf prefer salinities between 33 and 34 ppt, but were captured in waters with salinity from 31 to 34 ppt. In a large-scale analysis of research bottom trawl surveys on the Scotian Shelf, Scott (1982) found silver hake occurred on all bottom types from gravel to fine silt and clay, but were mainly associated with silts and clays. The areal trends in bottom type on the Scotian Shelf shows that coarse sand and gravel are associated with shallow water and finer grain deposits with deeper water and that the proportion of gravel increases from east to west. Thus, the areal trends in grain size and bottom water temperatures, as well as prey distributions, confound our ability to determine which factors contribute to distribution patterns of silver hake on the Scotian Shelf.

On the extremely fine-scale, Auster *et al.* (1997) found that silver hake (1.5-5 cm) were more abundant on silt-sand bottoms containing amphipod tubes at 55 m deep in the Middle Atlantic Bight. Silver hake (12.6-27.6 cm) were found on flat sand, sand-wave crests, shell and biogenic depressions, but were most often found on flat sand at one site in the Middle Atlantic Bight (Auster *et al.* 1991).

A summary of the ranges and preferences of various environmental parameters of the life stages of silver hake are presented in Table 4.

GEOGRAPHICAL DISTRIBUTION

The overall distribution of silver hake is from the Gulf of St. Lawrence to Cape Hatteras (Figure 9). The areas of highest abundance are the southern edge of the Grand Bank, the Scotian Shelf, the Gulf of Maine, Georges Bank, and the Middle Atlantic Bight off Long Island.

EGGS

Silver hake eggs were found throughout the area surveyed during NEFSC MARMAP ichthyoplankton surveys (Figure 10). They were most abundant in the deeper parts of Georges Bank (> 60 m) and the shelf off southern New England. Eggs were captured in all months of the year. From January to March, eggs occurred in small numbers in the deep waters of the Middle Atlantic Bight. By April, the occurrence of eggs extended eastward along the southern edge of Georges Bank and the total number of eggs increased slightly. During May and June the catches of eggs extended onto the shelf and into nearshore waters in the Middle Atlantic Bight and southern New England areas. Some eggs were captured in the western part of the Gulf of Maine. By July and August the center of abundance had shifted east onto Georges Bank with southern New England and the Gulf of Maine continuing to show some catches of eggs. In September and October the occurrences of eggs began to decline with centers of abundance still on Georges Bank and into southern New England. Few eggs were captured in November or December but most occurred again in deeper waters of the Middle Atlantic Bight.

LARVAE

The individual survey distributions of silver hake larvae from Cape Hatteras, North Carolina to Nova Scotia, based on 50 ichthyoplankton surveys in the NEFSC MARMAP series (1977-1984), reveal considerable year-to-year differences in the temporal and spatial patterns of abundance. Centers of abundance in July - September occurred on Georges Bank and in southern New England in 1977, 1978, 1982, and 1983. In 1981 few larvae were found anywhere in the survey area. Only in 1979 and 1980 were significant numbers of larvae encountered in the Gulf of Maine (Morse *et al.* 1987).

The cumulative distribution and abundance of silver hake larvae from all NEFSC MARMAP surveys is shown in Figure 11. The overall pattern of distribution is similar to the distribution of eggs, wherein the center of abundance is on Georges Bank and a secondary center is in the southern New England area. Few larvae were captured from January through March, none in April, and most occurred in the Middle Atlantic Bight (Figure 11). The low catches reflect the relatively low egg production of silver hake during the early months of the year. During May and June larvae were abundant from off Virginia to the southwestern part of Georges Bank in depths from 60-130 m. The peak months of larval abundance were July-September and the centers of abundance were now in southern New England and on Georges Bank. Distribution of larvae during October to December had shifted to the west from Georges Bank to southern New England and the Middle Atlantic Bight and abundance had dropped following the decrease in egg production during the late autumn and early winter. Table 5 lists the published reports of the nearshore and estuarine occurrences of silver hake eggs and larvae south of Cape Cod.

JUVENILES

Based on the NEFSC bottom trawl survey, juvenile silver hake occurred across the shelf in the Middle Atlantic Bight and southern New England areas, along the southern and northern edges of Georges Bank, and scattered throughout the Gulf of Maine in the winter (Figure 12). In the spring, they occurred throughout the survey area but tended to avoid the shallowest part of Georges Bank. Concentrations occurred in relatively shallow waters in southern New England and in most of the southern and western parts of the Gulf of Maine. Positive catches during summer surveys show a distribution similar to that in the spring. By autumn, the distribution of juveniles again covered the shelf with small catches in the southern part of the Middle Atlantic Bight and in the center of the Gulf of Maine. Centers of abundance occurred in nearshore waters off New Jersey and Long Island, south of Rhode Island, on Georges Bank, and along the coast of Massachusetts and Maine.

Silver hake juveniles were caught throughout the Massachusetts trawl survey area in spring and autumn and were concentrated off Cape Ann, in Cape Cod Bay and south of Martha's Vineyard. Light catches were made in Vineyard Sound and Buzzards Bay (Figure 13).

Juvenile silver hake were collected throughout most of the Hudson-Raritan estuary survey area but were concentrated in areas near the ocean (Figure 14). The highest catches occurred in autumn (Oct.-Dec.) and no juveniles were captured in summer (July-Aug.).

Juvenile silver hake were captured throughout Narragansett Bay in all seasons with the highest average catches of juveniles (~3 hake/tow) occurring in summer (Table 6; Figure 15). In general, low numbers of hake occurred throughout the Bay and the highest average catches were at the ocean station 1. Seasonal length frequencies indicate that juveniles and adults occurred in similar proportions during all seasons except summer when juveniles dominated the catches.

The catches of silver hake in Long Island Sound were dominated by fish < 23 cm long in both seasons and occurred throughout the bay (Figure 16).

ADULTS

Based on the NEFSC bottom trawl survey, silver hake were distributed across the shelf in the northern Middle Atlantic Bight and southern New England areas, along the southern and northern edges of Georges Bank, and scattered throughout the Gulf of Maine in the winter (Figure 12). In the spring, they occurred throughout the survey area but tended to avoid the shallowest parts of the Middle Atlantic Bight and Georges Bank. Concentrations occurred in relatively deep waters of the Middle Atlantic, southern New England, along the southern and northern edges of Georges Bank, and in the western part of the Gulf of Maine. Positive catches during summer surveys showed a distribution similar to that in the spring. By autumn, the distribution of adults again covered the shelf except for the southwestern part of the Middle Atlantic Bight and in the center of Georges Bank. Centers of abundance occurred in south of Rhode Island, on the northern edge of Georges Bank, and most of the Gulf of Maine.

Based on the Massachusetts trawl survey, silver hake adults were caught throughout the survey area in spring and north of Cape Cod in autumn. They were concentrated south of Martha's Vineyard and Nantucket in spring and off Cape Ann and in Cape Cod Bay in autumn. Small catches were made in Vineyard Sound and Buzzards Bay in both seasons (Figure 13).

The Hudson-Raritan estuary trawl survey caught a total of just one adult silver hake in January 1995. Results of the Rhode Island trawl survey showed that, in general, low numbers of hake occurred throughout Narragansett Bay and the highest average catches were at the ocean station 1. Adult hakes occurred throughout the bay in small numbers in all seasons (Figure 15). Seasonal length frequencies indicate that juveniles and adults occurred in similar proportions during all seasons except summer when juveniles dominated the catches (Figure 15).

The catches of silver hake in Long Island Sound showed a high incidence of adults (> 22 cm) in spring. Based on the wide distribution of silver hake adults, it appears that they occur in all areas of the sound (Figure 16).

Jury *et al.* (1994) compiled summaries of the occurrence and relative abundance of eggs, larvae, juveniles, and adults in estuaries north of Cape Cod and Stone *et al.* (1994) compiled similar data for Cape Cod to Cape Hatteras (Table 7).

STATUS OF THE STOCKS

According to the Report to Congress on the Status of Fisheries of the United States (National Marine Fisheries Service 1997), the Gulf of Maine/northern Georges Bank stock (GBGM) of silver hake is not overfished while the southern Georges Bank/Middle Atlantic stock (SGBMA) is overfished. The GBGM silver hake stock biomass accounts for, on average, about 80% of the NEFSC autumn survey stratified mean catch-per-tow (in kilograms). The NEFSC autumn survey mean catch-per-tow for the two stocks is used herein to indicate inter-annual changes in stock size (Figure 17).

GULF OF MAINE/NORTHERN GEORGES BANK STOCK

The autumn research bottom trawl catches declined in the mid- to late 1960s to the lowest catches on record when there was a period of heavy exploitation by distant water fleets. Strong year classes in 1973 and 1974 helped to increase stock biomass during the mid-1970s, but stock size again declined until the early 1980s. Since that time biomass indices have increased significantly but with wide annual fluctuations. From the low biomass estimates in the 1960s when catch-per-tows were 2-3 kg, the stock size has increased to about 10 kg/tow during the last 10 years. Contrary to the bottom trawl catches, results from virtual population analysis showed a significant decline through 1986 in stock biomass from the pre-1975 period (Helser

1995).

SOUTHERN GEORGES BANK/MIDDLE ATLANTIC STOCK

Similar to the GBGM stock, the SGBMA stock apparently declined during the 1960s and early 1970s based on a significant decline in the autumn stratified mean catch-per-tow. Stock size increased somewhat until about 1985, but has declined to historically low levels in recent years. Research bottom trawl catches have ranged from about 3-4 kg/tow in the 1960s to about 0.5-0.8 kg/tow in the mid-1990s.

Periods of high (1989-1993) and low abundance (1967-1971) (see Figure 17) were analyzed for the distribution and relative abundance of juveniles and adults in autumn (Figure 18). The overall distribution of juveniles and adults appears about the same regardless of stock size. The relative abundance is quite different between the two time periods. Much higher catches of juveniles and adults occurred on Georges Bank and particularly in the Gulf of Maine during the period of high abundance.

RESEARCH NEEDS

- Questions remain about the definition of silver hake stocks. Research is needed to define the biological basis of the two (or more) stocks. Seasonal distributions indicate considerable movement of fish across the current stock boundary line on Georges Bank, which raises the question of the degree of intermixing between the stocks.
- The habitat parameters used in this report are location, depth, temperature, and, for Long Island Sound, salinity. A critical parameter is bottom type, which needs to be included in future habitat considerations.
- Little is known about the effects of the prey field on the distribution in space and time of silver hake. Additional food habits analysis is needed to determine the possible relationships of predator-prey and distribution and abundance.
- There are indications that fine scale (less than shelf wide) habitat characteristics may be important at various times in the life of silver hake. Examples are food and predator abundance during the larval stage, fine-scale bottom structure for small juveniles, and the contribution of estuaries to the success of year classes.

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Table 1. Mean length (cm) at age (years) in silver hake, *Merluccius bilinearis*, for Gulf of Maine (GM), Middle Atlantic (MA), northern Georges Bank (NGB), and southern Georges Bank (SGB) from samples collected during 1988-1992; based on Helser (1996).

	Area			
Age	**GM**	**MA**	**NGB**	**SGB**
1	12.3	9.1	12.1	11.7
2	22.0	21.2	22.1	21.4
3	28.8	28.7	28.8	27.8
4	33.6	33.5	33.3	31.9
5	37.0	36.4	36.3	34.6
6	39.3	38.2	38.3	36.4
7	41.0	39.4	39.7	37.5
8	42.1	40.1	40.6	38.3
9	43.0	40.5	41.2	38.8
10	43.5	40.8	41.6	39.1
11	43.9	41.0	41.9	39.3
12	44.2	41.1	42.1	39.4

Table 2. Observations of silver hake, *Merluccius bilinearis*, age and length at maturity.

Author	**Years**	**Area**	**Age (years)**	**Length (cm)**
Bigelow and Schroeder 1953	1950s	Gulf of Maine	~ 2	
Sauskan 1964	1962-1964	Georges Bank	2-3	29-33
Morse 1979	1977	US Shelf		24-26
Beacham 1983	1960s-1970s	Scotian Shelf	1-2	31 females 1960s; 26 females 1970s
O'Brien *et al.* 1993	1985-1989	US Shelf	1.6-1.7	22.3-22.7 males 23.1-23.2 females
Helser and Almeida 1997	1973-1990	US Shelf	2 - 20% mature in 1973 2 - 80% mature in 1990	

Table 3. Published observations about silver hake, *Merluccius bilinearis*: bottom water temperature, depth distributions, and preferences.

Author	Area	Temperature (°C)		Depth (m)	
		Range	Preference	Range	Preference
Bigelow and Schroeder 1953	Gulf of Maine	4-18	> 6	tide line - > 700	
Domanevsky and Nozdrin 1963	Southeast Georges Bank		9-11		90-110
Sauskan 1964	Georges Bank; 1962-1963	6-12	10-12: ripe adults, 6-10: post spawn		85-200 spring 40-110 summer
Fritz 1965	Continental Shelf, NJ to Nova Scotia; Autumn, 1955-1961	3.9-19.4	6-12	30-410	70-210
Sarnits and Sauskan 1967	Georges Bank 1964		7-8		140-230
Edwards 1965	Southern New England		> 9		
Scott 1982	Eastern Gulf of Maine	1-13	7-10	15 - > 200 fathoms	80-89 fathoms
Almeida 1987	U.S Continental Shelf			Adults: inshore - 400	
Murawski and Finn 1988	Georges Bank		Winter: 5.97 Spring: 8.45 Summer: 8.95 Autumn: 8.42		Winter: 208 Spring: 186 Summer: 97 Autumn: 163
Murawski 1993	U.S Continental Shelf		Spring: 6.76 Summer: 8.03 Autumn: 10.00		Spring: 186 Summer: 97 Autumn: 163
Helser and Almeida 1997	U.S Continental Shelf	5.5-10.5 most	> 8.0 southern Stock	50-150 most	> 80 southern Stock

Table 4. Summary of habitat parameters for silver hake, *Merluccius bilinearis*.

Life Stage	**Temperature Range (^oC)**	**Temperature Preference (^oC)**	**Depth Range (m)**	**Depth Preference (m)**	**Salinity Preference (ppt)**	**Dissolved Oxygen (mg/l)**	**Bottom Type**
Eggs	5-20	11-17	10-1250	50-150			
Larvae	7-20	10-16	10-1250	50-130			
Juveniles	3-17 Spring, 5-22 Autumn	6-9 Spring, 10-17 Autumn	5-350 Spring, 5-350 Autumn	150-270 Spring, 25-75 Autumn	Hudson-Raritan: > 18, Long Island Sound: 28-30	Hudson-Raritan: 5-7	Silt-sand in Mid-Atlantic Bight. All types on Scotian Shelf
Adults	3-9 Spring, 4-22 Autumn	7-13 Spring, 7-11 Autumn	5-400 Spring, 5-500 Autumn	125-325 Spring, 150-225 Autumn			All types on Scotian Shelf

Table 5. Published reports of the nearshore and estuarine occurrences of silver hake, *Merluccius bilinearis*, eggs and larvae from the area south of Cape Cod.

Study	**Area and Dates**	**Eggs**	**Larvae**
Herman 1963	Narragansett Bay March 1957 - March 1958, weekly sampling	6 eggs July - October. Temperatures 14.8 - 21.4°C	33 larvae July - October Temperatures 12.0 - 22.4°C
Bourne and Govoni 1988	Narragansett Bay, RI June 1972 - August 1973	Listed as present in low numbers	Listed as present in low numbers
Perlmutter 1939	Salt waters of Long Island, NY 1938	Small numbers off Montauk Point in June & July	37 Larvae (2.6-6.0 mm) from June to September, most in June in Block Island Sound
Merriman and Sclar 1952	Block Island Sound, RI 1943 - 1946	None	16 larvae (4.0 - 9.0mm) July and November
Wheatland 1956	Long Island Sound March 1952 - March 1954	None	None
Richards 1959	Long Island Sound 1954 - 1955	None	None
Monteleone 1992	Great South Bay, NY April 1985 - December 1986	None	None
Dovel 1981	Hudson River March - December 1972	None	None
Virginia Institute of Marine Science Fisheries Laboratory 1961	Lower Chesapeake Bay and nearshore ocean December 1959 - December 1960	None	31 larvae (4-21mm) caught only in the ocean. December - April, June

Table 6. Average number of silver hake, *Merluccius bilinearis,* in Narragansett Bay, per tow by season. From the Rhode Island Division of Fish and Wildlife bottom trawl surveys of Narragansett Bay, 1990 - 1996.

Species	**Juveniles**				**Adults**			
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Silver Hake	2.353	0.286	3.031	1.425	1.495	0.449	0.179	0.187

Table 7. Summary of the distribution and abundance of silver hake, *Merluccius bilinearis,* in North Atlantic and Mid-Atlantic estuaries based on Jury *et al.* (1994) and Stone *et al.* (1994).

Estuary	Adults T	Adults M	Adults S	Sp Adults T	Sp Adults M	Sp Adults S	Juveniles T	Juveniles M	Juveniles S	Larvae T	Larvae M	Larvae S	Eggs T	Eggs M	Eggs S
Passamaquoddy Bay		**c**	**a**			r		**c**	**a**	*	*	r	*	*	r
Englishman/Machias Bays		c	a			r		c	a	*	*	r	*	*	r
Narragaugus Bay		c	a			r		c	a	*	*	r	*	*	r
Blue Hill Bay		c	a			r		c	a	*	*	r	*	*	r
Penobscot Bay		**c**	**a**			**r**		**c**	**a**	*****	*****	**r**	*****	*****	**r**
Muscongus Bay		**c**	**c**			**r**		**c**	**c**	*****	*****	**r**	*****	*****	**r**
Damariscotta Bay		**c**	**c**			**r**		**c**	**c**	*****	*****	**r**	*****	*****	**r**
Sheepscot Bay		**c**	**a**			**r**		**c**	**c**	*****	*****	**r**	*****	*****	**r**
Kennebec/Androscoggin Rivers		**c**	**c**			n		**c**	**c**	*	*	n	*	*	n
Casco Bay		c	c			r		c	c	*	r	c		r	c
Saco Bay		c	c			r		c	c		r	r		r	r
Wells Harbor	nz		r	nz	*		nz		r	nz		r	nz		r
Great Bay			r						r			**r**			**r**
Merrimack River		r	nz			nz		r	nz		r	nz		**r**	nz
Massachusetts Bay	nz	nz	**c**	nz	nz	**c**	nz	nz	**c**	nz	nz	**c**	nz	nz	**c**
Boston Harbor	nz	c	c	nz			nz	c	c	nz	r	c	nz	r	c
Cape Cod Bay	nz	c	c	nz		c	nz	c	c	nz	r	c	nz	r	c
Waquoit Bay	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Buzzards Bay	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Narragansett Bay	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Connecticut River	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Gardiners Bay	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Long Island Sound	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Great South Bay	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Hudson River/Raritan Bay	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Barnegat Bay	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
New Jersey Inland Bays	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Delaware Bay	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Delaware Inland Bays	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Chincoteague Bay	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Chesapeake Bay mainstream	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Chester River	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Choptank River	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Patuxent River	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Potomac River	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Tangier/Pocomoke Sounds	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Rappahannock River	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
York River	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
James River	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n

Relative Abundance
h = Highly abundant, a = abundant,
c = common, r = rare, blank = not present,
n = no data presented, * = no data available,
nz = particular zone not present

Data Reliability for Life Stages
Highly Certain = Bold and Underlined Text
Moderately Certain = Bold Text
Reasonable Inference = Normal Text

Tidal Zones
T = Tidal Fresh 0.0-0.5 ppt
M= Mixing Zone 0.5-25 ppt
S = Seawater Zone > 25 ppt

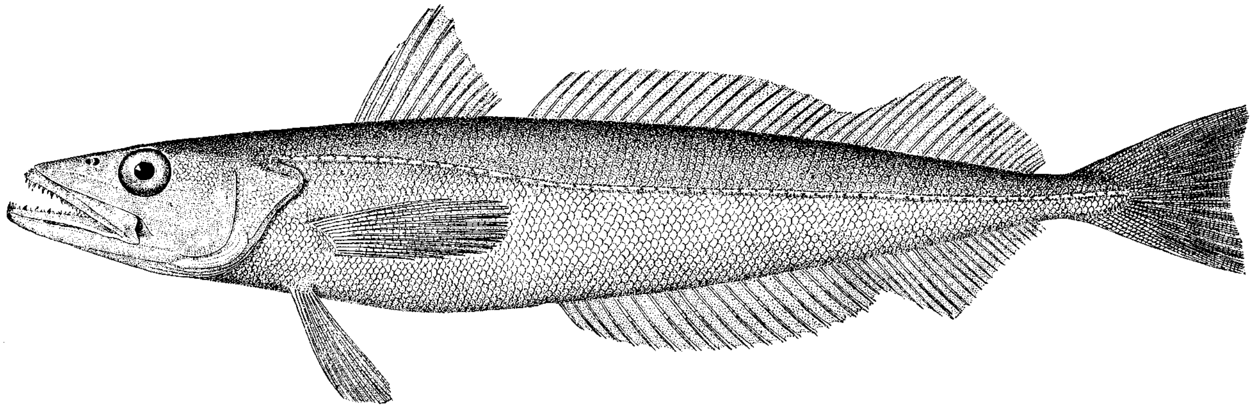


Figure 1. The silver hake, *Merluccius bilinearis* (Mitchell) (from Goode 1884).

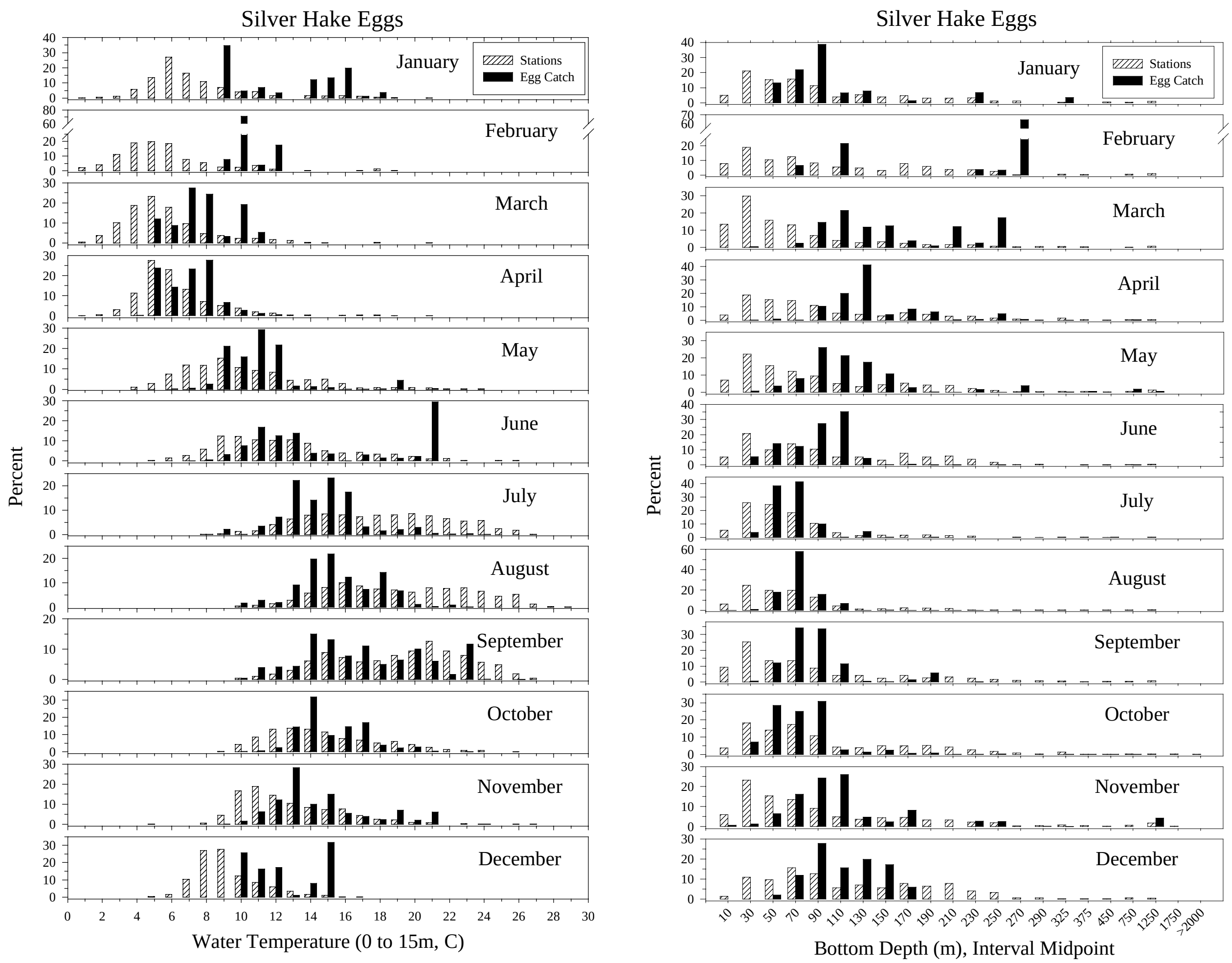


Figure 2. Abundance of silver hake eggs relative to water column temperature and bottom depth from NEFSC MARMAP ichthyoplankton surveys (1978-1987) by month for all years combined. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

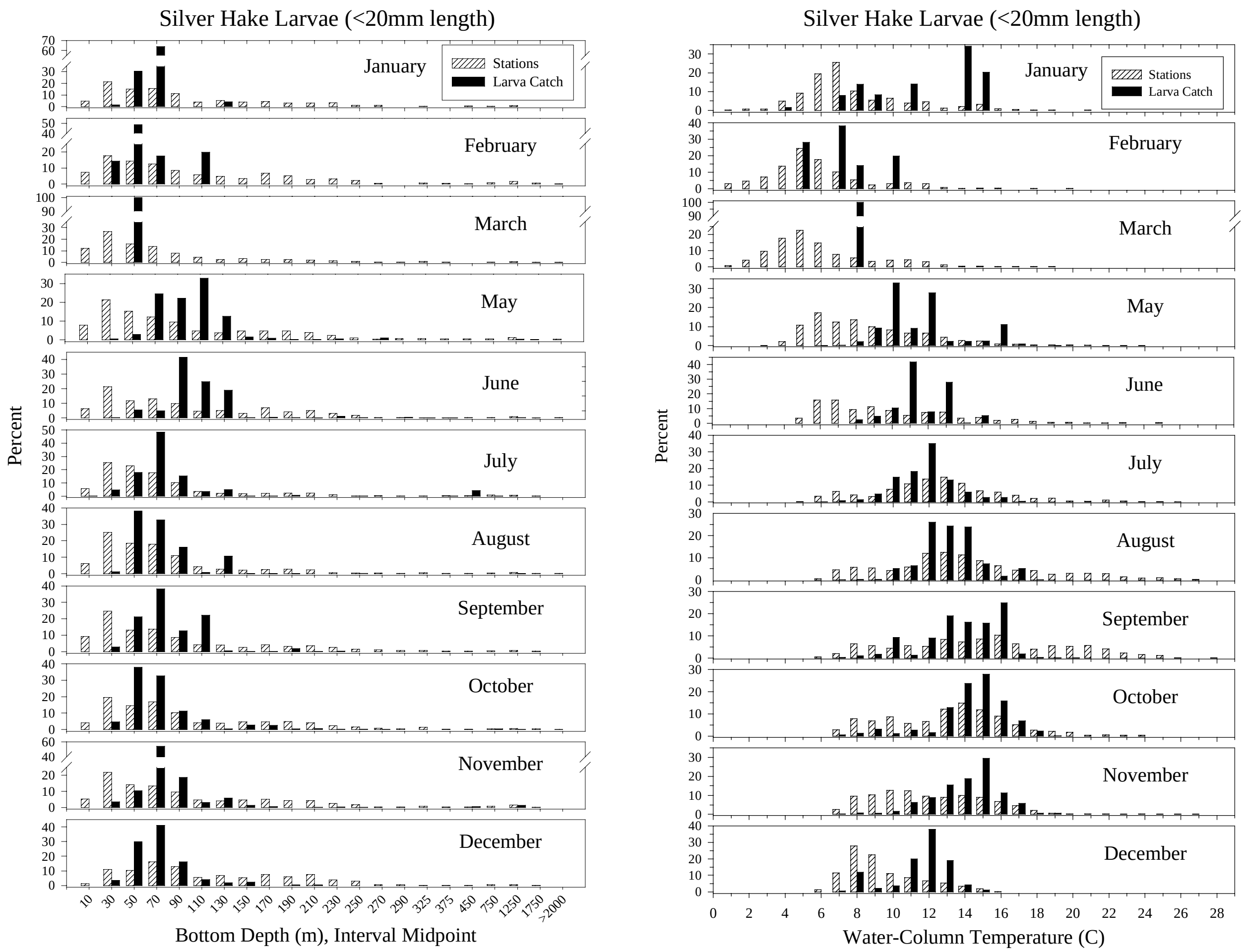


Figure 3. Abundance of silver hake larvae relative to water column temperature and bottom depth from NEFSC MARMAP ichthyoplankton surveys (1977-1987) by month for all years combined. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

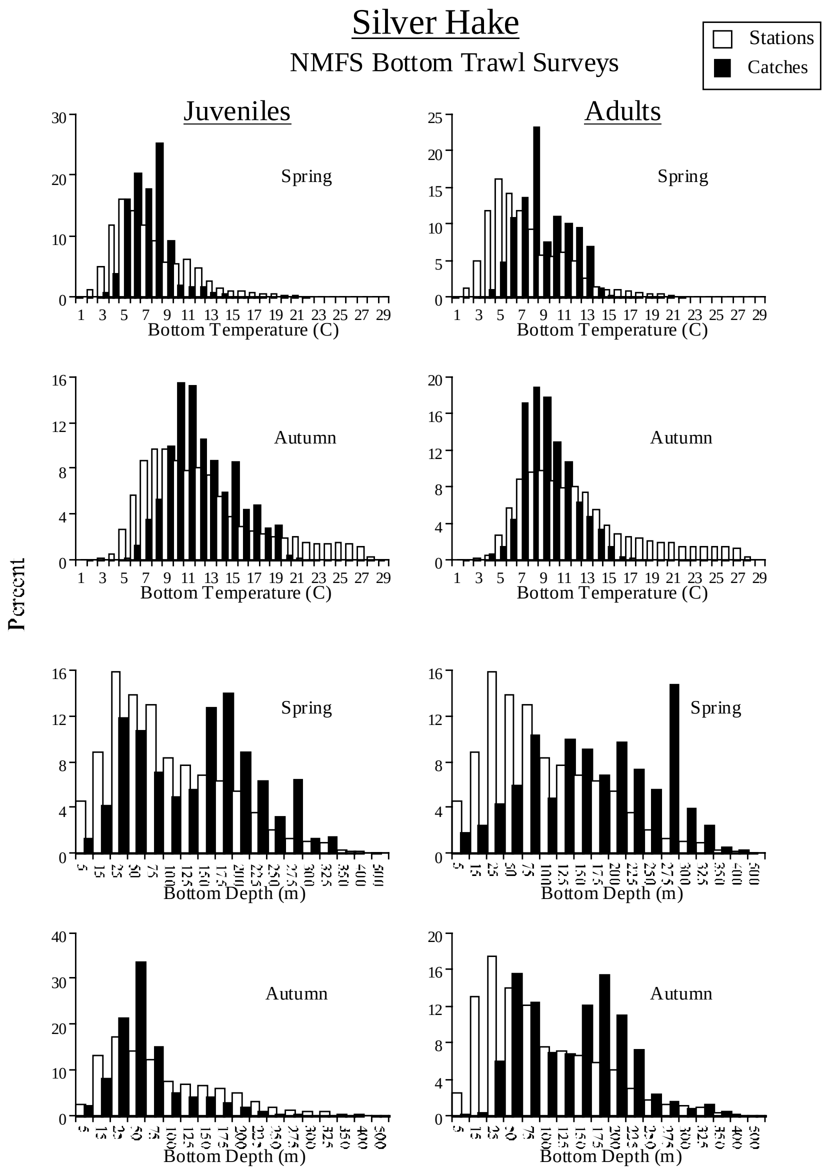


Figure 4. Abundance of juvenile and adult silver hake relative to bottom water temperature and depth based on NEFSC bottom trawl surveys for spring (1968-1997) and autumn (1963-1996), all years combined. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

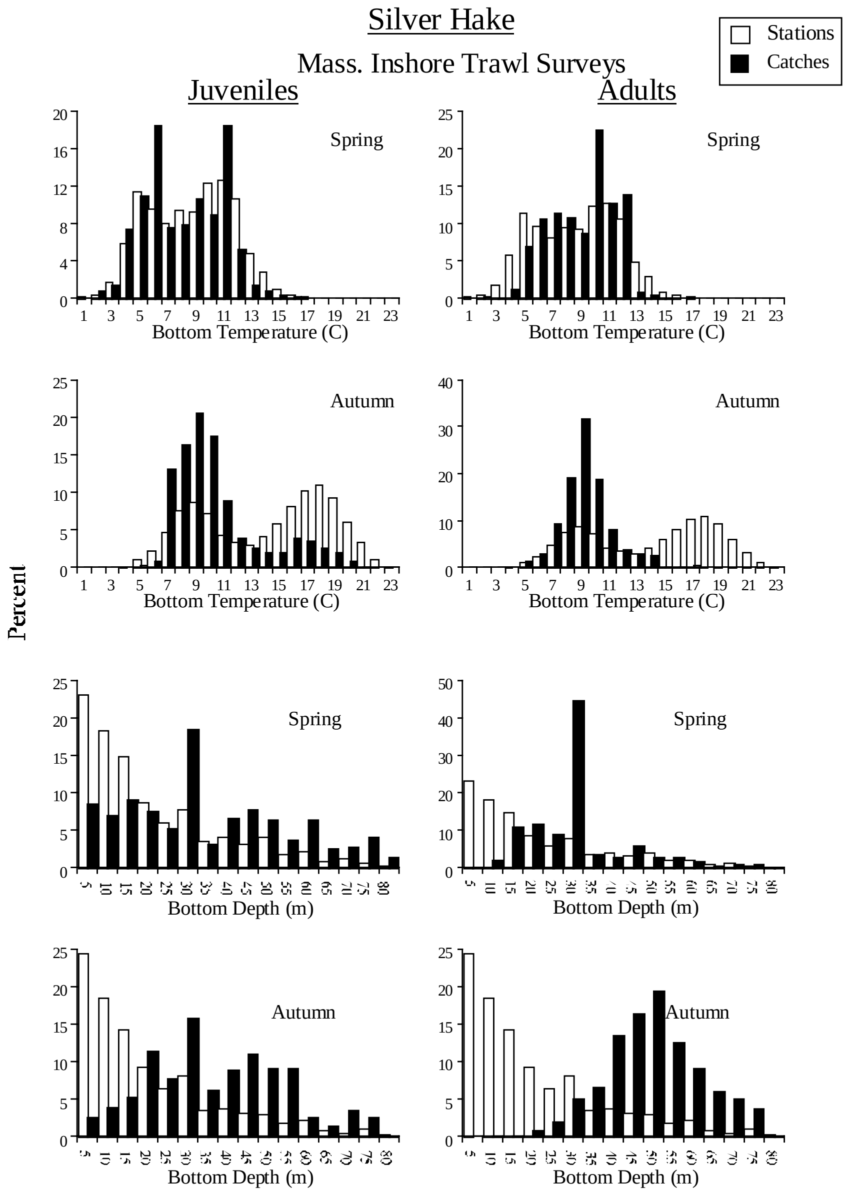


Figure 5. Abundance of juvenile and adult silver hake relative to bottom water temperature and depth based on Massachusetts inshore bottom trawl surveys (spring and autumn 1978-1996) for all years combined. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

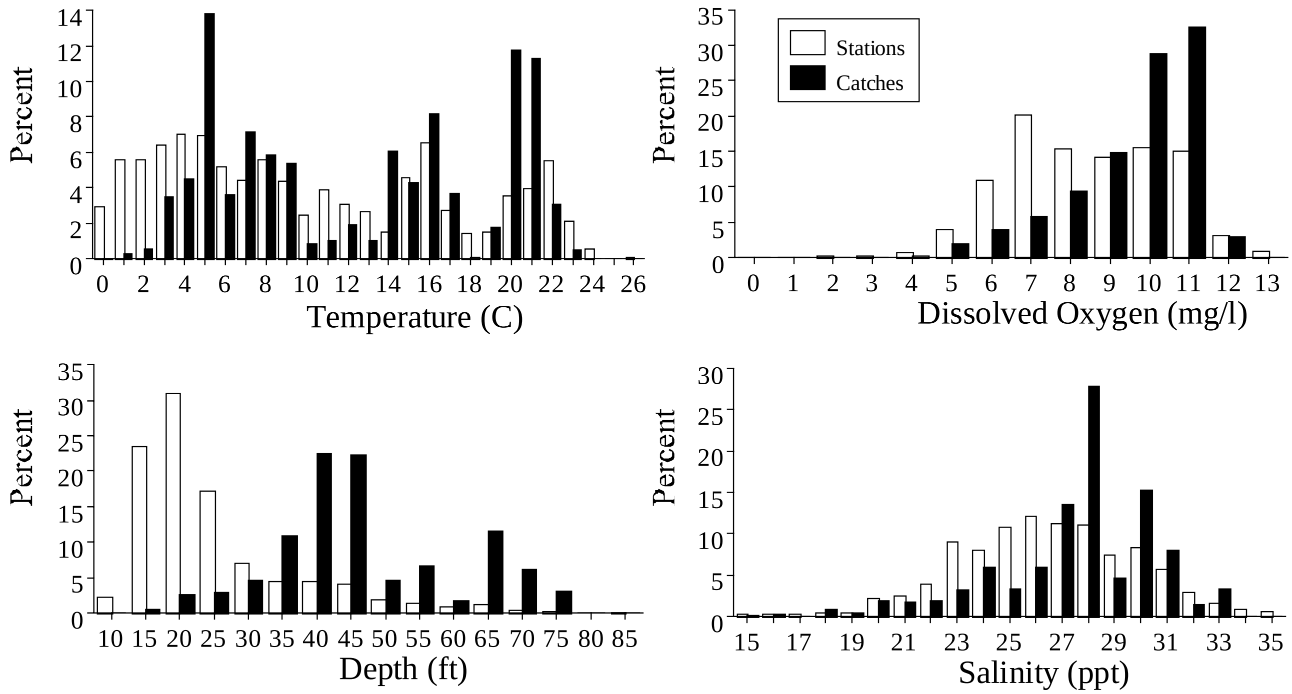


Figure 6. Abundance of juvenile silver hake (< 23 cm) relative to bottom water temperature, dissolved oxygen, depth, and salinity from Hudson-Raritan estuary trawl surveys (January 1992 - June 1997, all years combined).

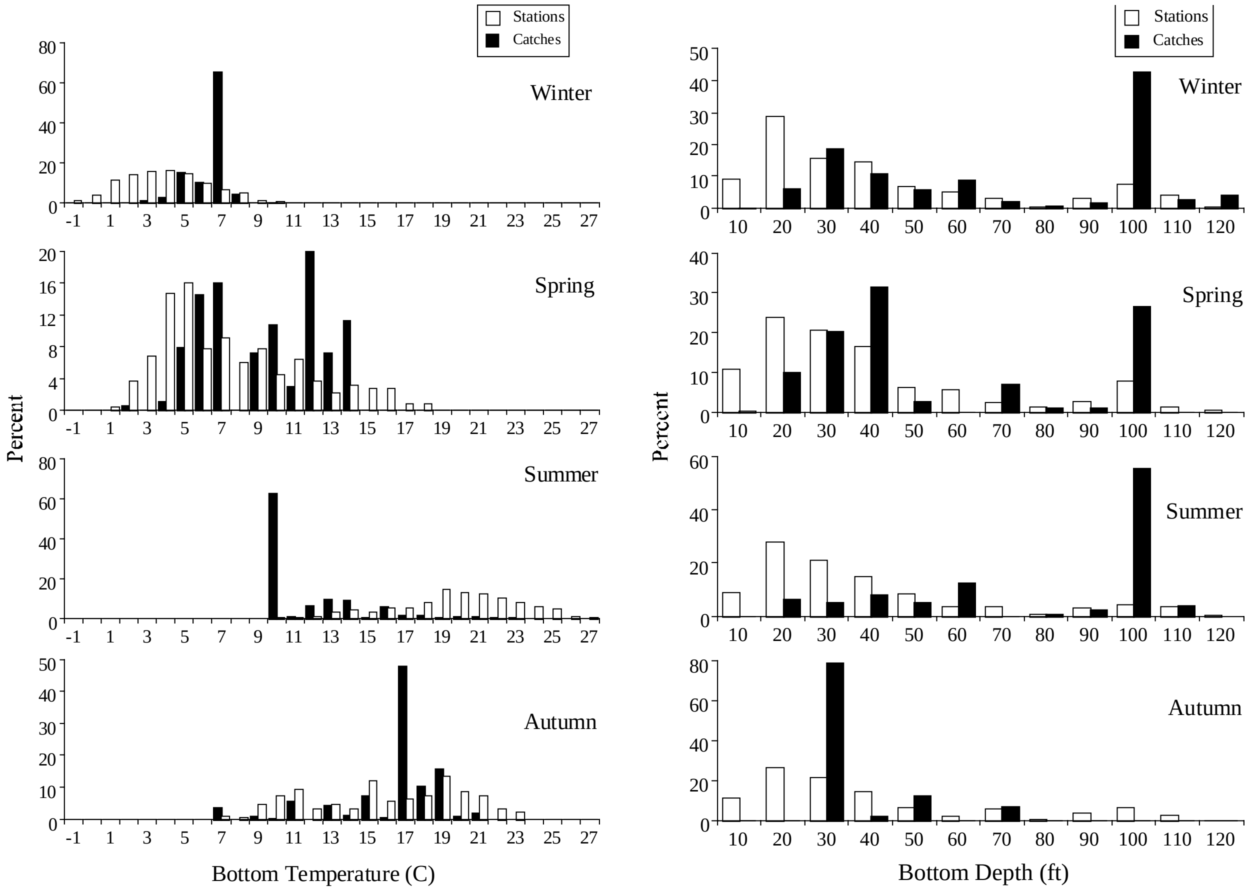


Figure 7. Seasonal abundance of silver hake juveniles (< 23 cm) relative to mean bottom water temperature and bottom depth from Rhode Island Narragansett Bay trawl surveys, 1990-1996. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all catches.

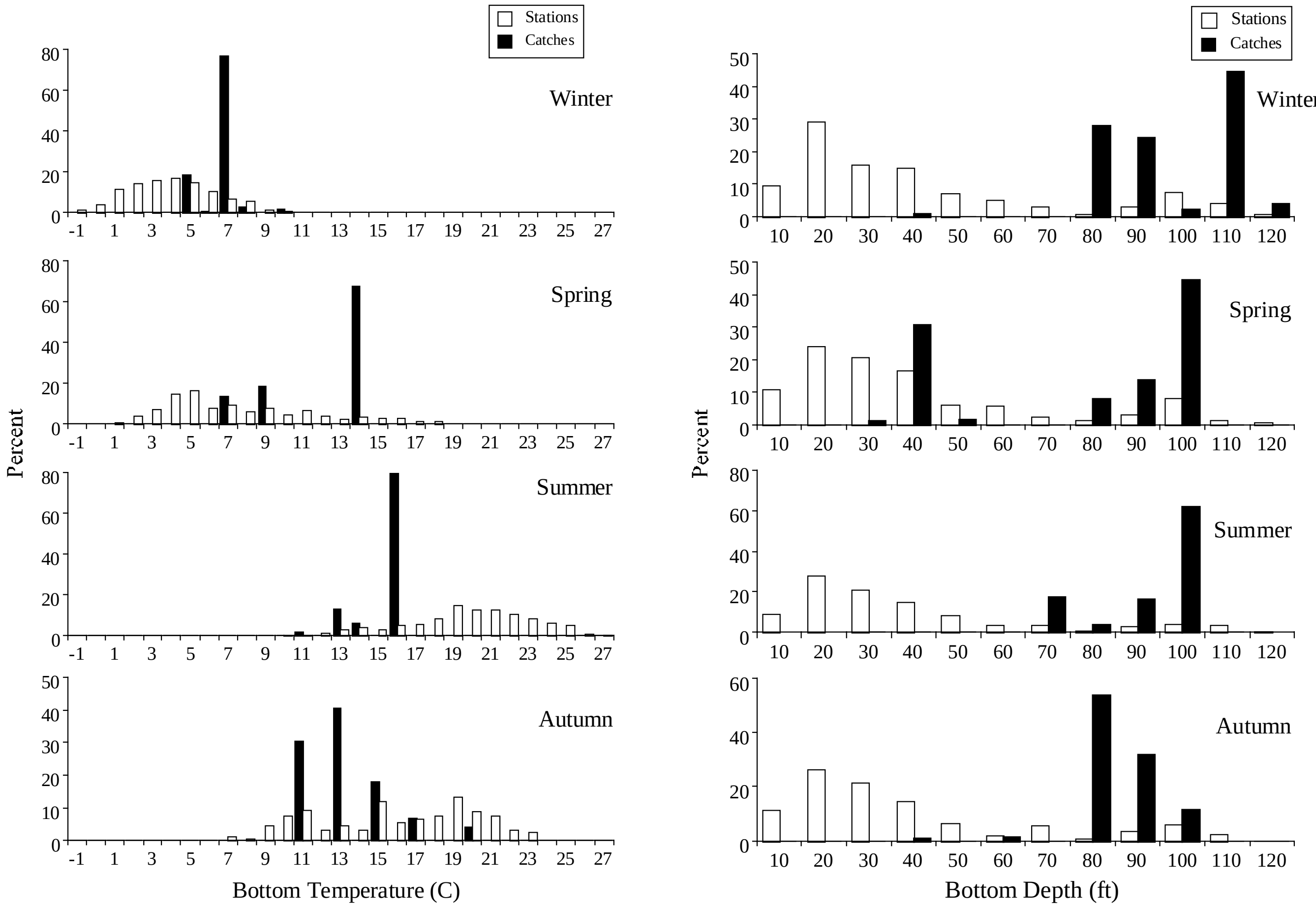


Figure 8. Seasonal abundance silver hake adults (≥ 23 cm) relative to mean bottom water temperature and bottom depth from Rhode Island Narragansett Bay trawl surveys, 1990-1996. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all catches.

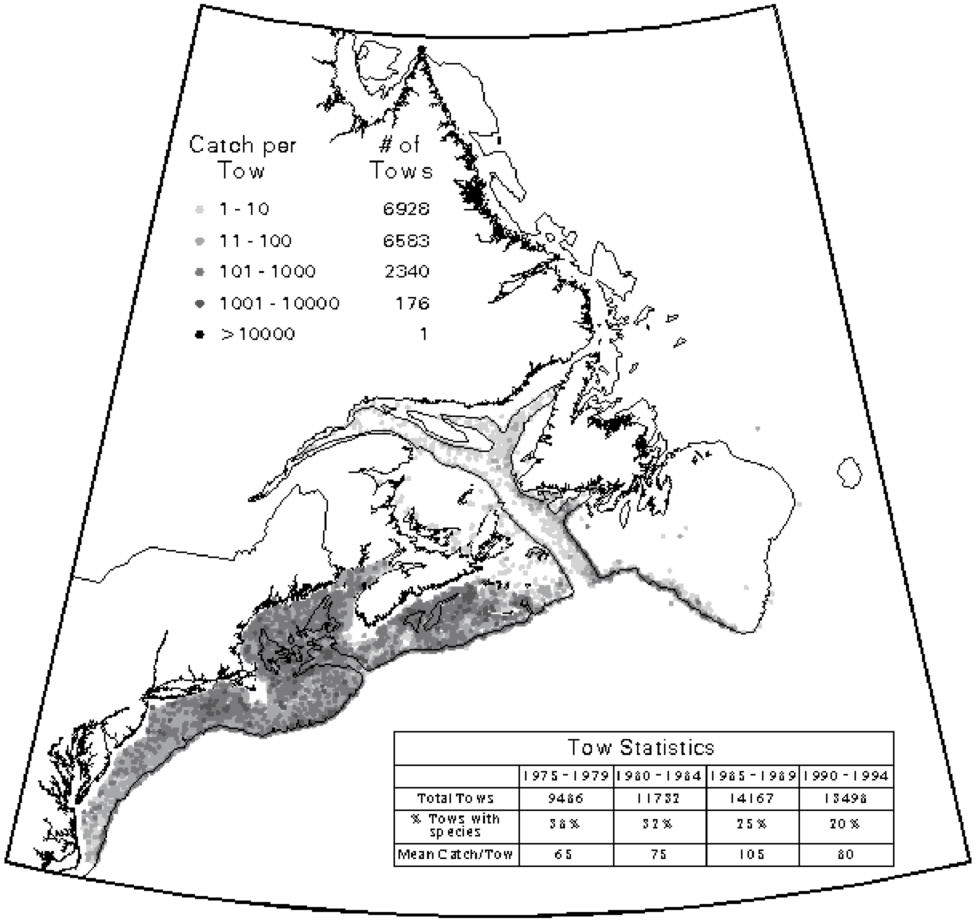


Figure 9. Overall distribution of silver hake in the northwest Atlantic Ocean during 1975-1994. Data are from the U.S. NOAA/Canada DFO East Coast of North America Strategic Assessment Project (http://www-orca.nos.noaa.gov/projects/ecnasap/ecnasap_table1.html).

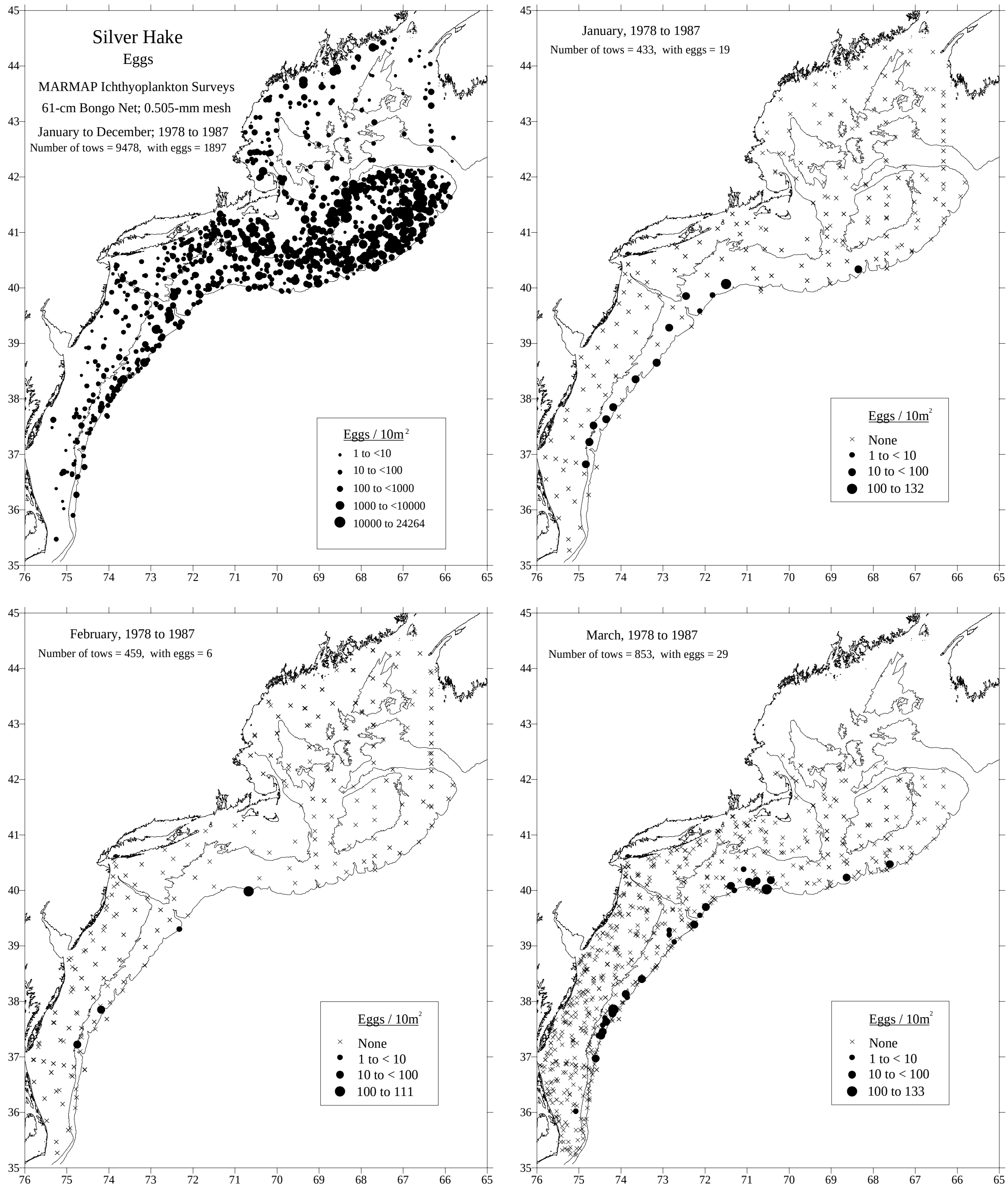


Figure 10. Distribution and abundance of silver hake eggs collected during NEFSC MARMAP ichthyoplankton surveys, January to December, 1978-1987 [see Reid *et al.* (1999) for details].

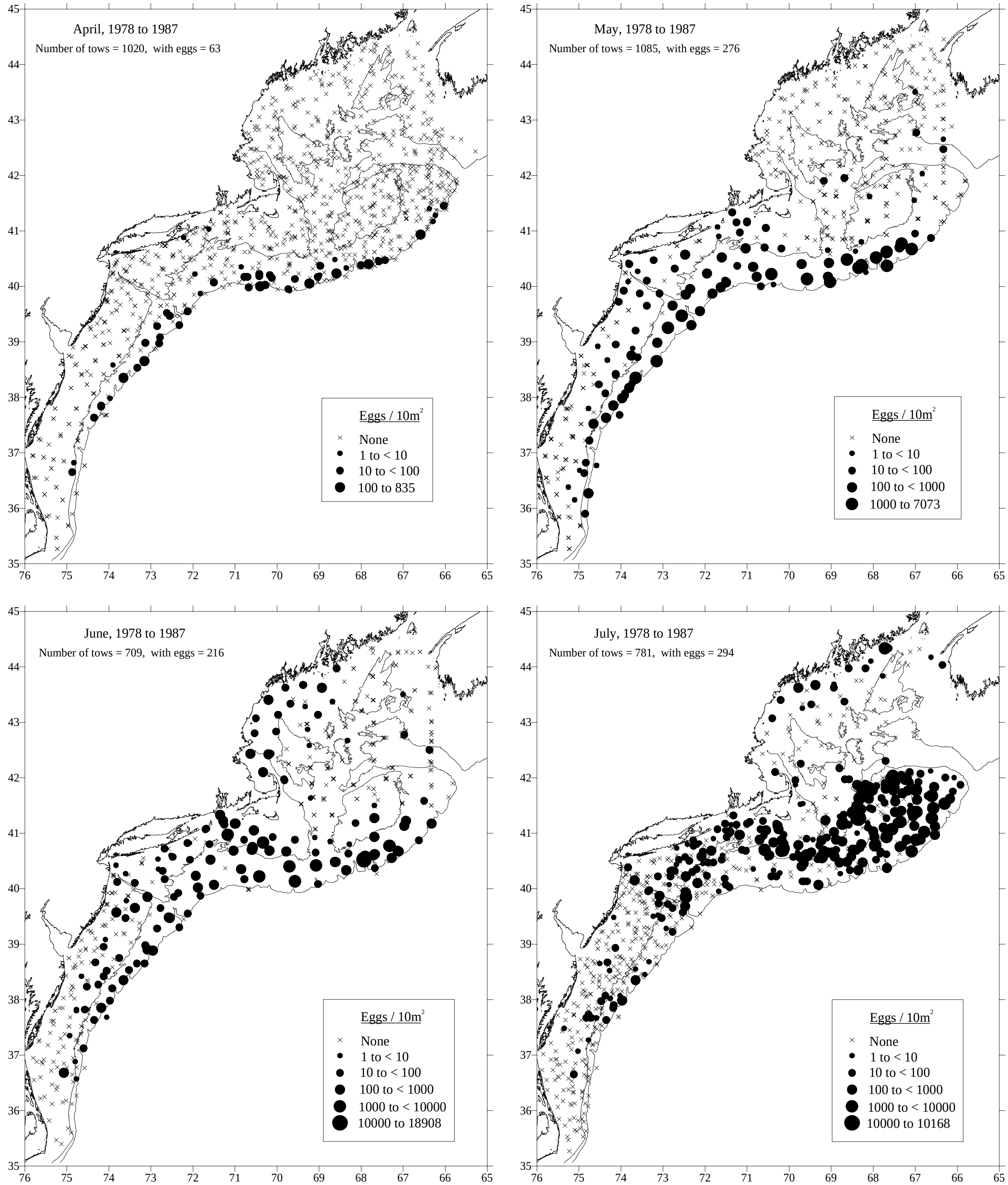
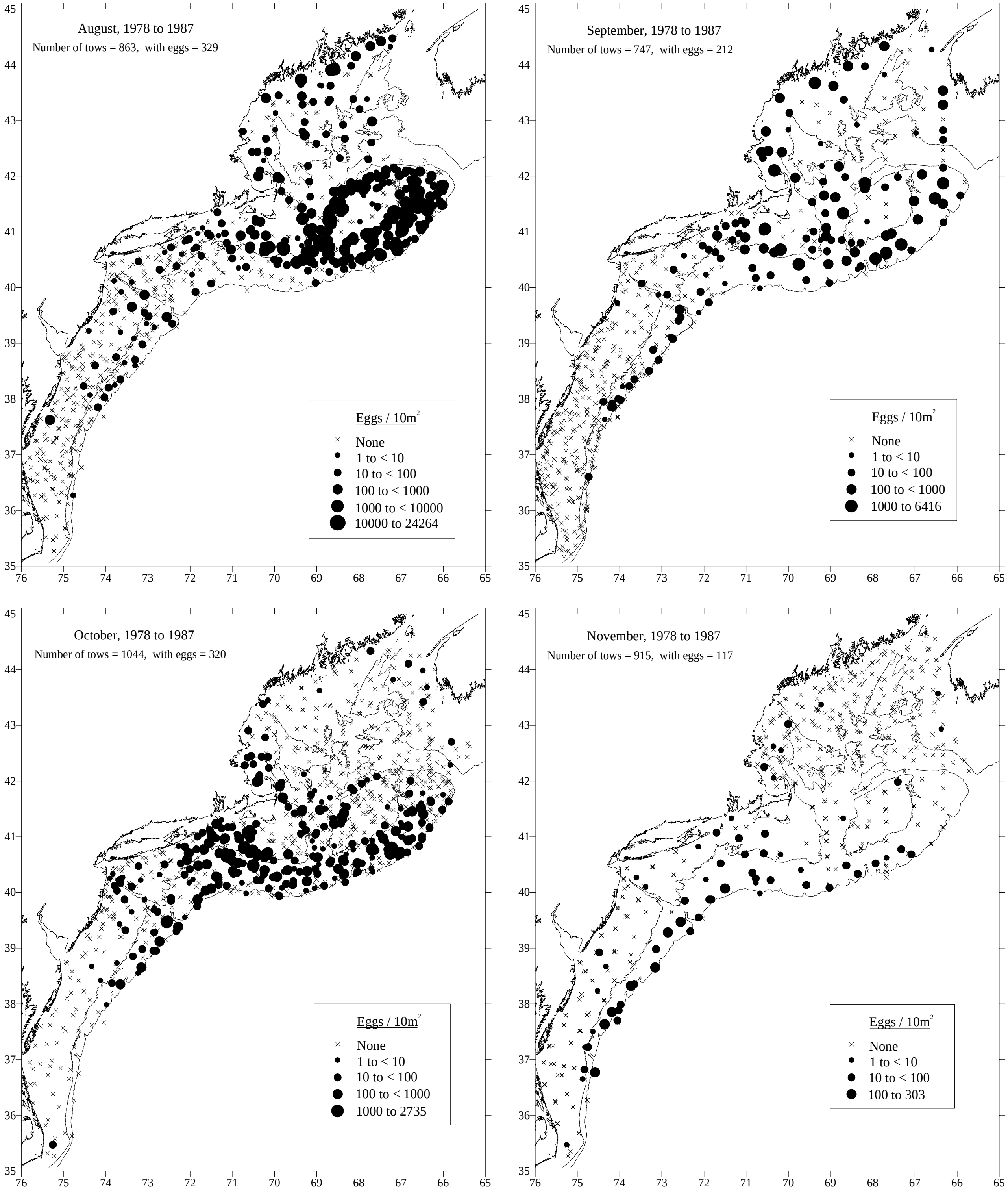


Figure 10. cont’d.



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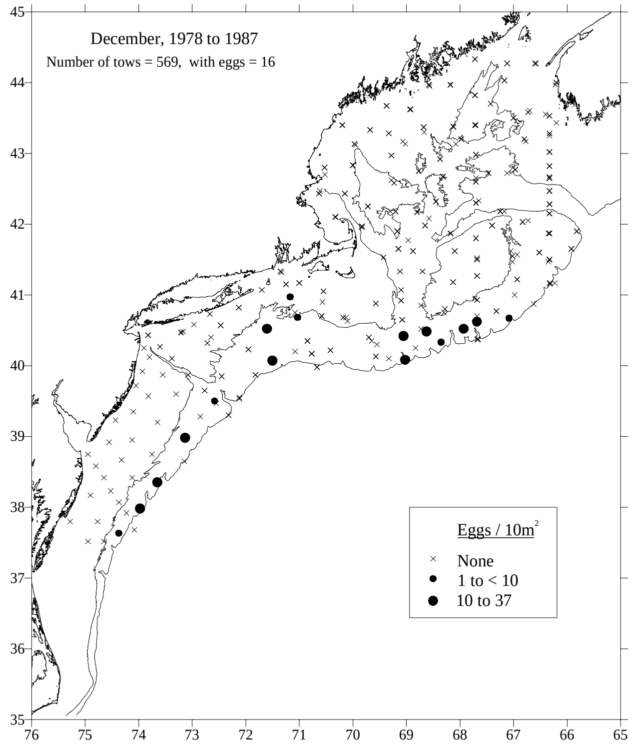

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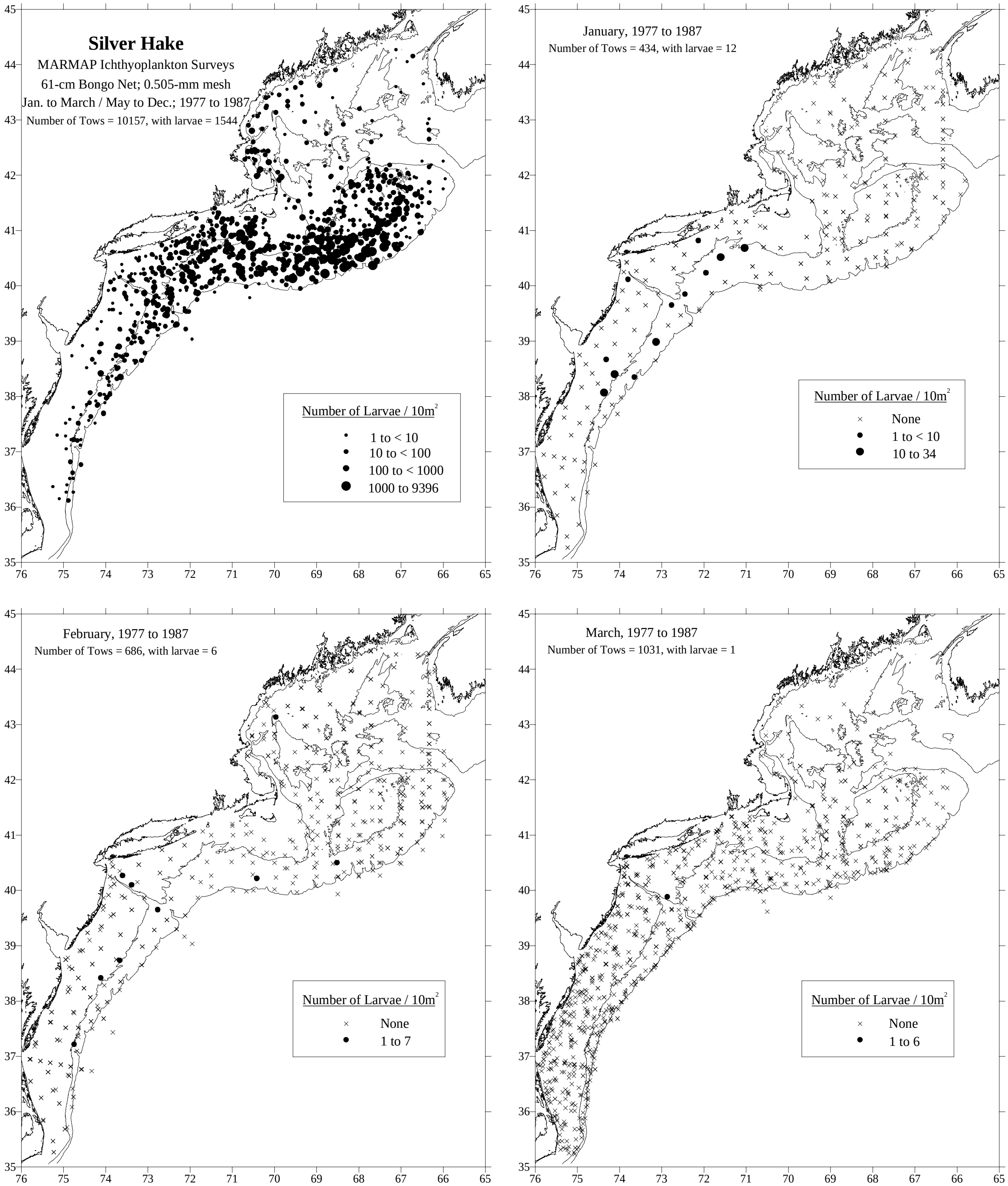


Figure 11. Distribution and abundance of silver hake larvae collected during NEFSC MARMAP ichthyoplankton surveys, 1977-1987 [see Reid *et al.* (1999) for details].

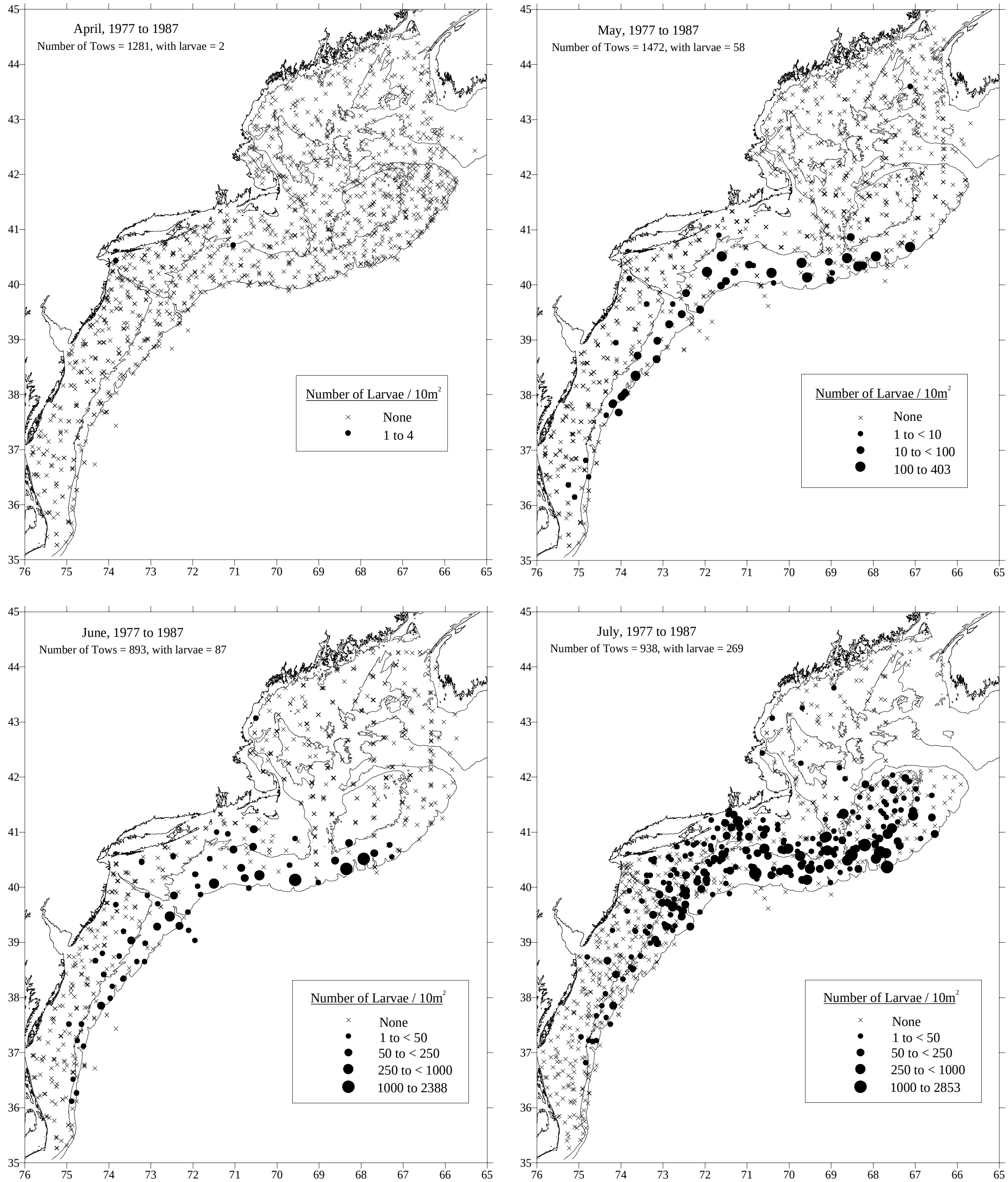
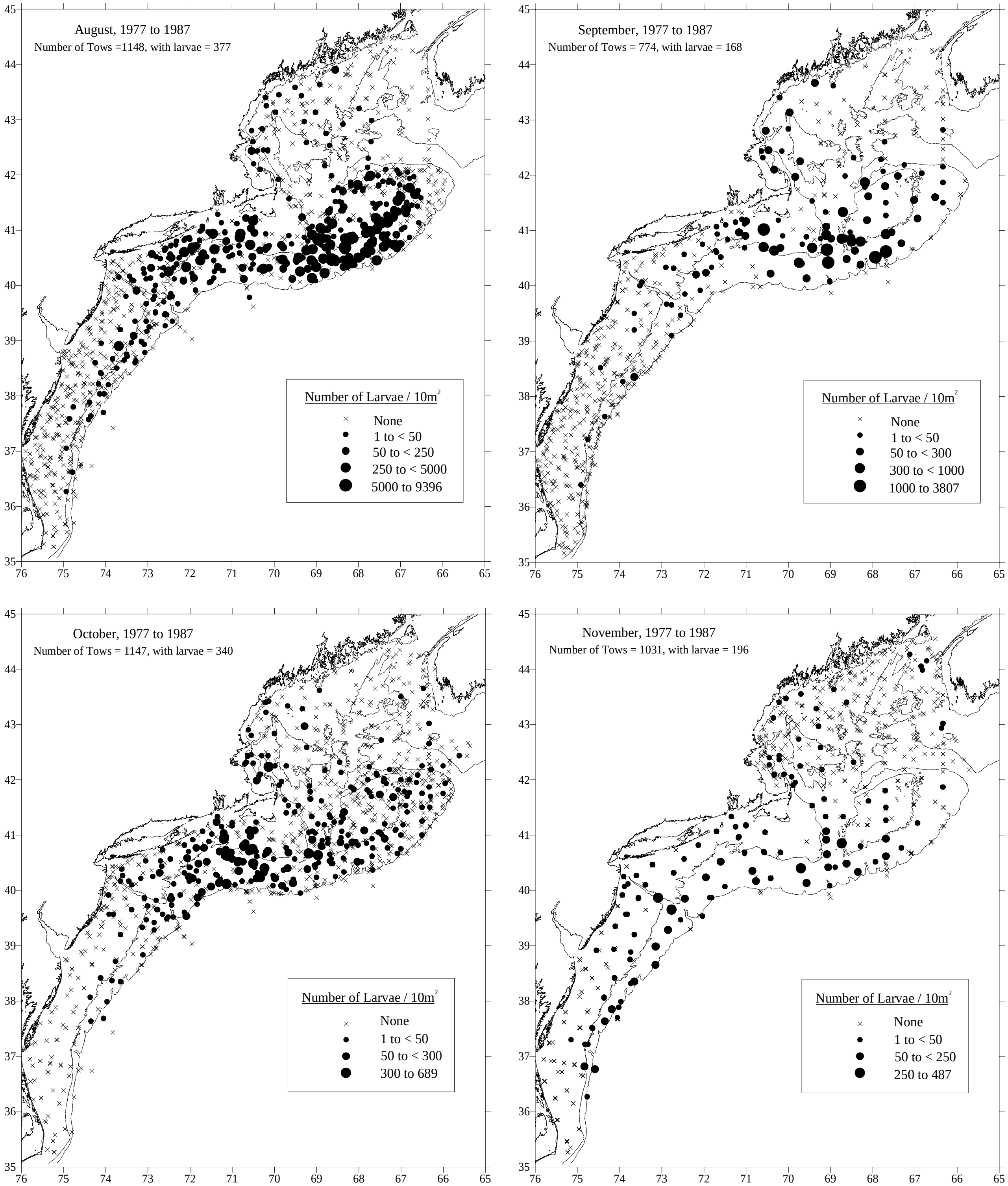


Figure 11. cont'd.



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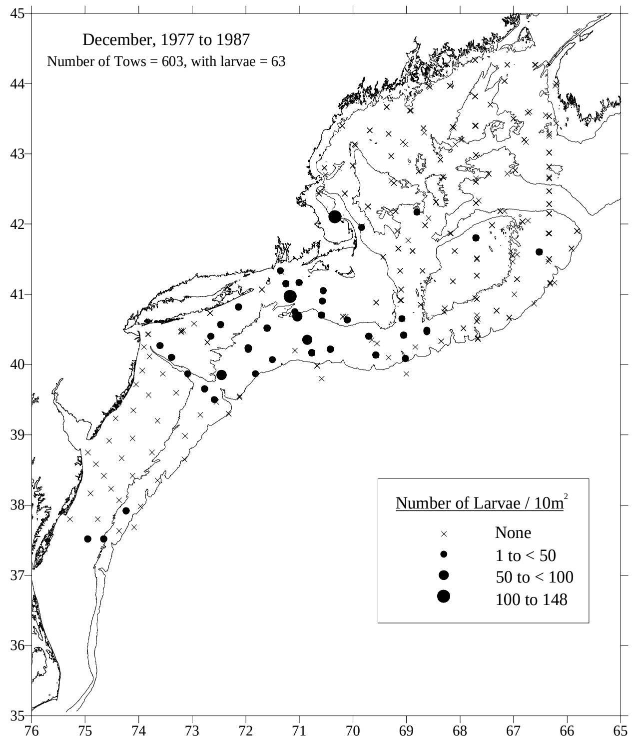

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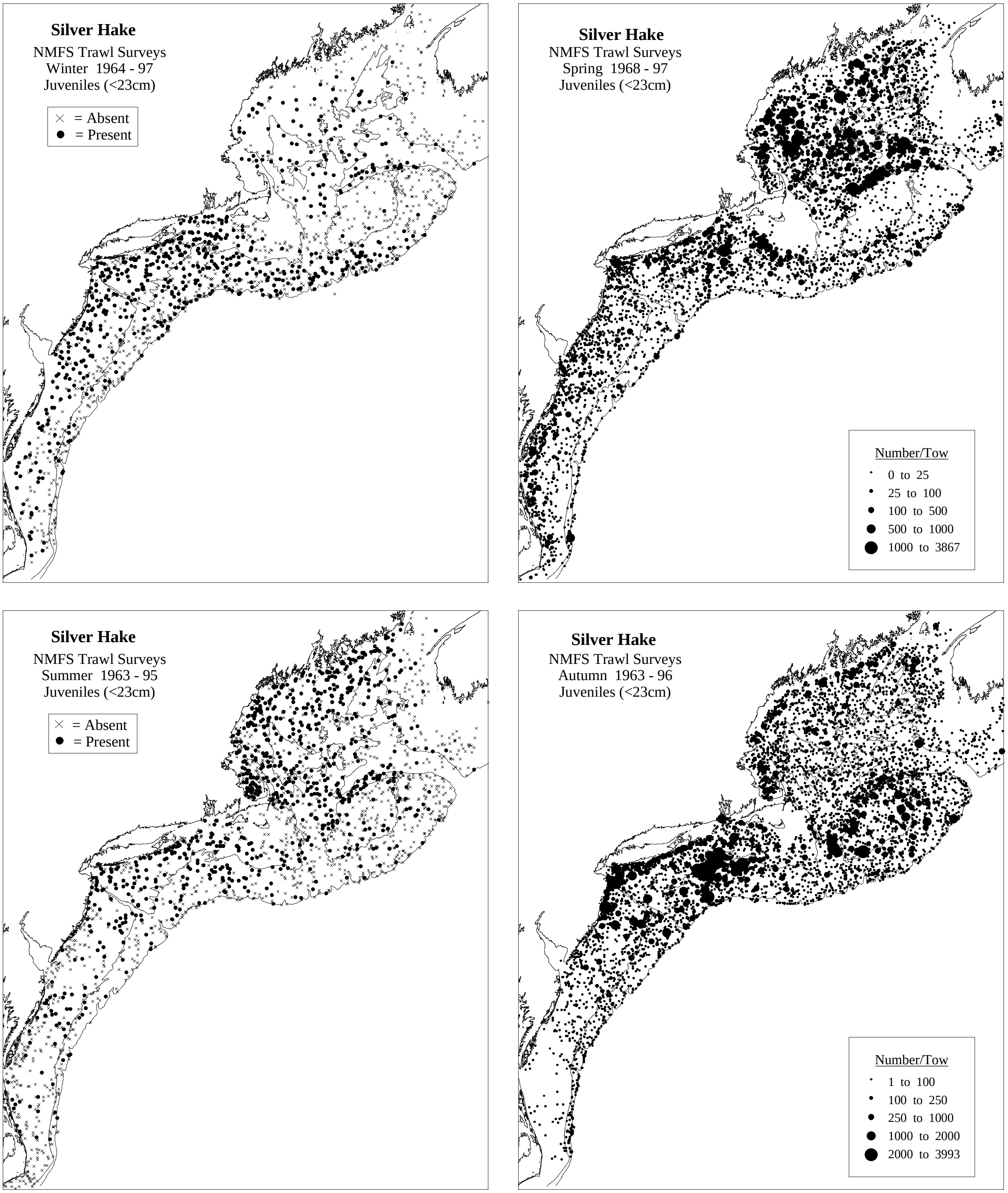
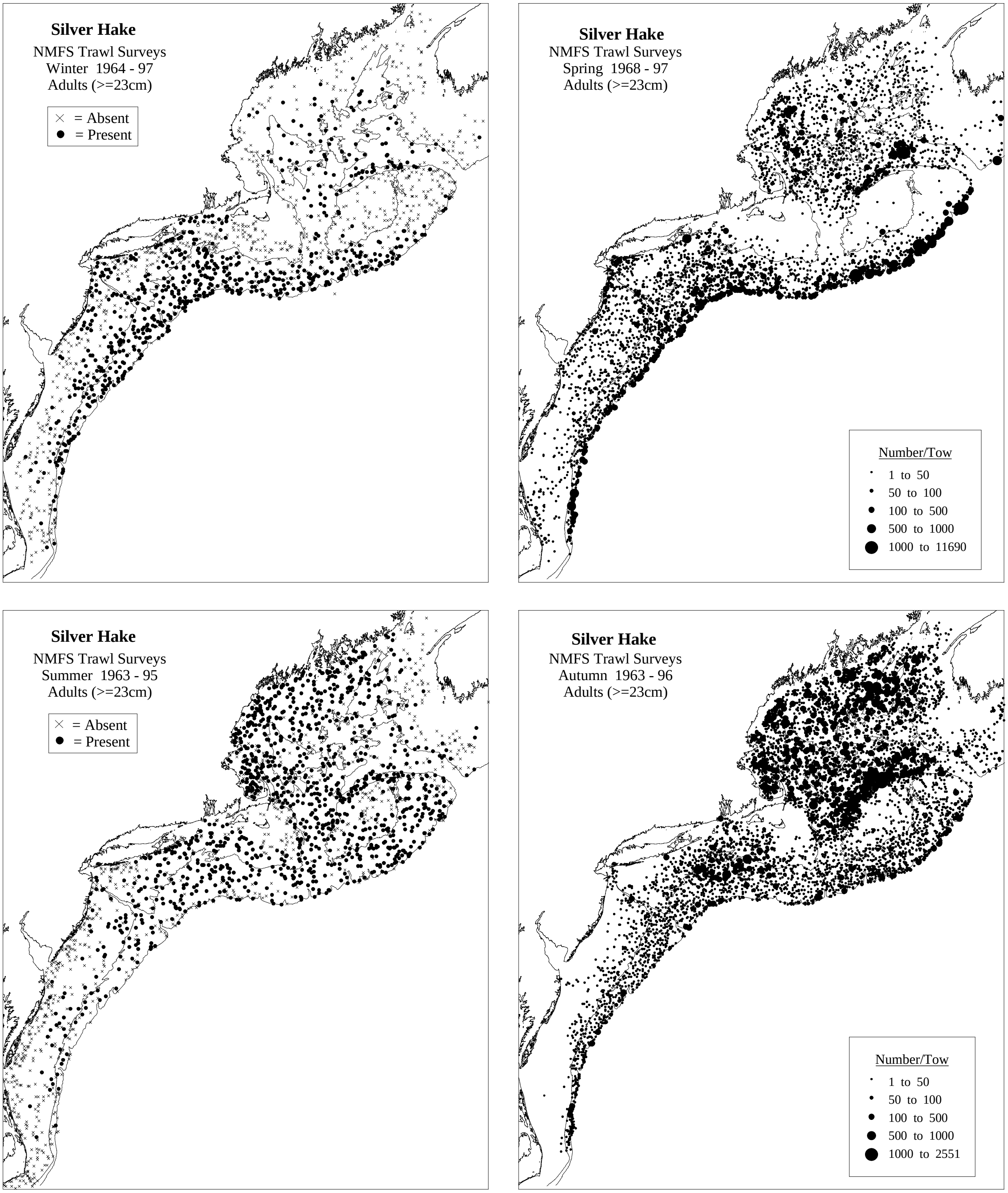


Figure 12. Distribution of juvenile and adult silver hake collected during NEFSC bottom trawl surveys during winter (1964-1997), spring (1968-1997), summer (1963-1995), and autumn (1963-1996). Densities are represented by dot size in spring and fall plots, while only presence and absence are represented in winter and summer plots [see Reid *et al.* (1999) for details].



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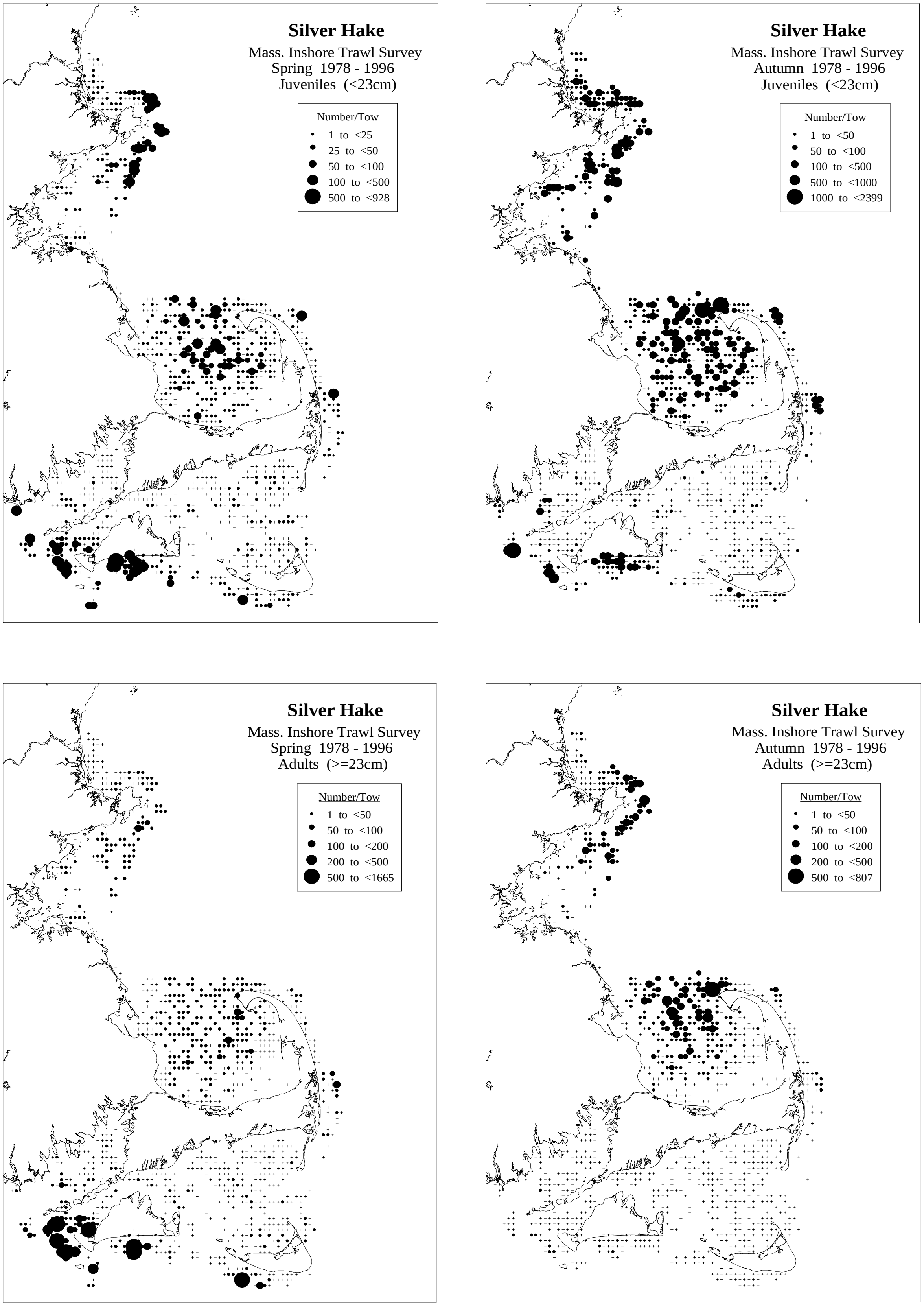


Figure 13. Distribution and abundance of juvenile and adult silver hake in Massachusetts coastal waters collected during spring and autumn Massachusetts inshore bottom trawl surveys, 1978-1996 [see Reid *et al.* (1999) for details]. Stations where no fish were taken are denoted by '+'.

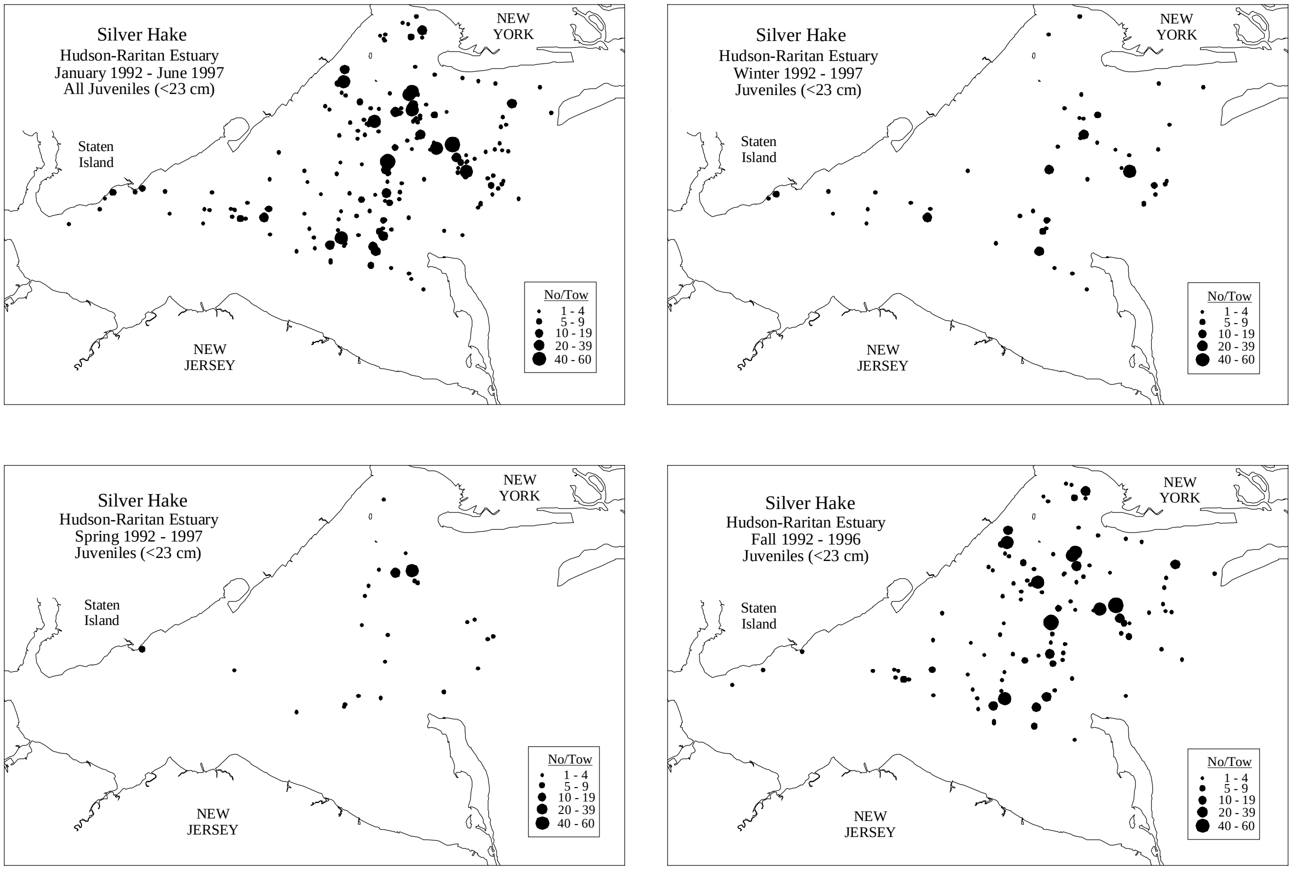


Figure 14. Distribution and abundance of juvenile silver hake collected in the Hudson-Raritan estuary from January 1992 - June 1997, based on Hudson-Raritan trawl surveys [see Reid *et al.* (1999) for details].

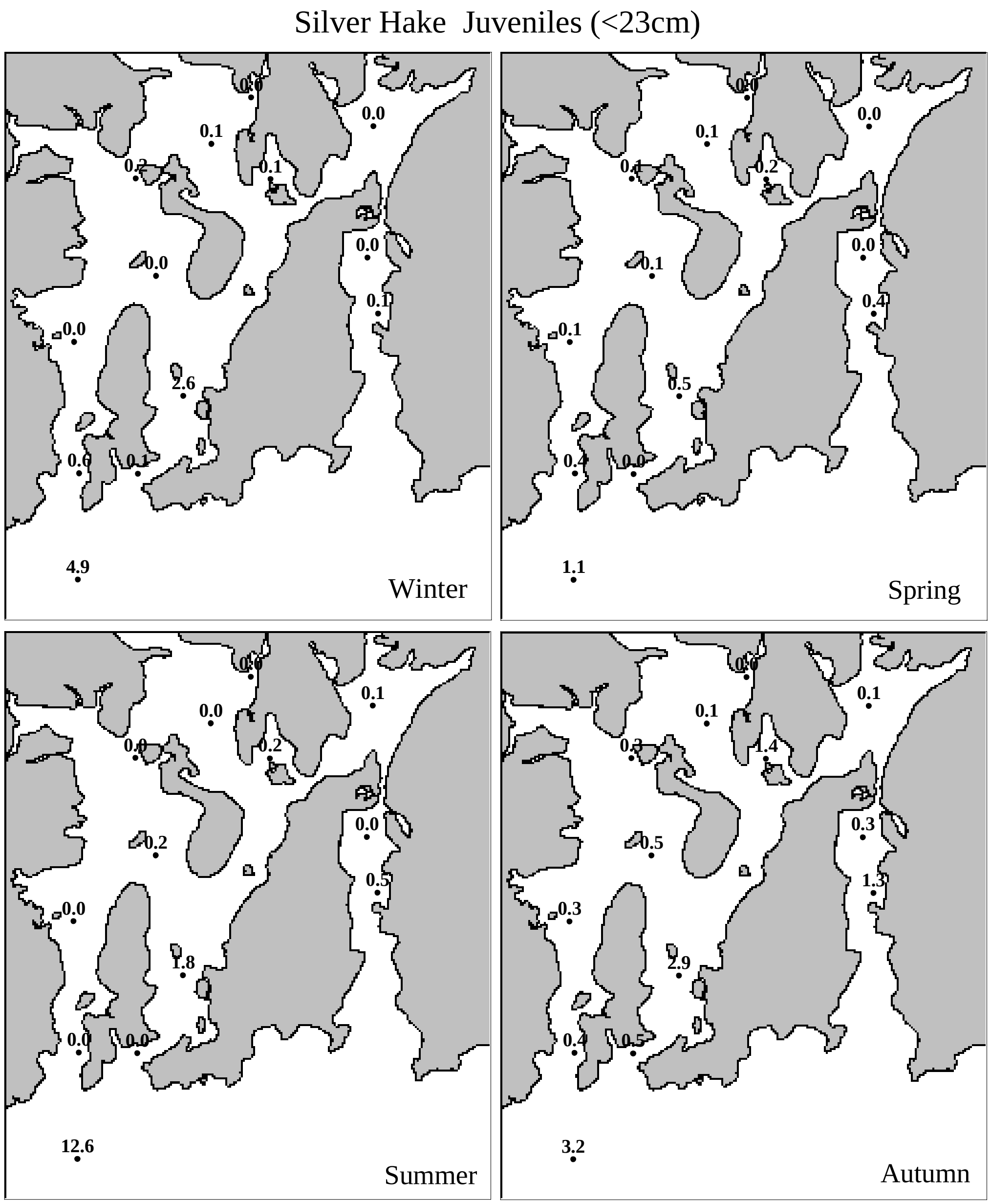
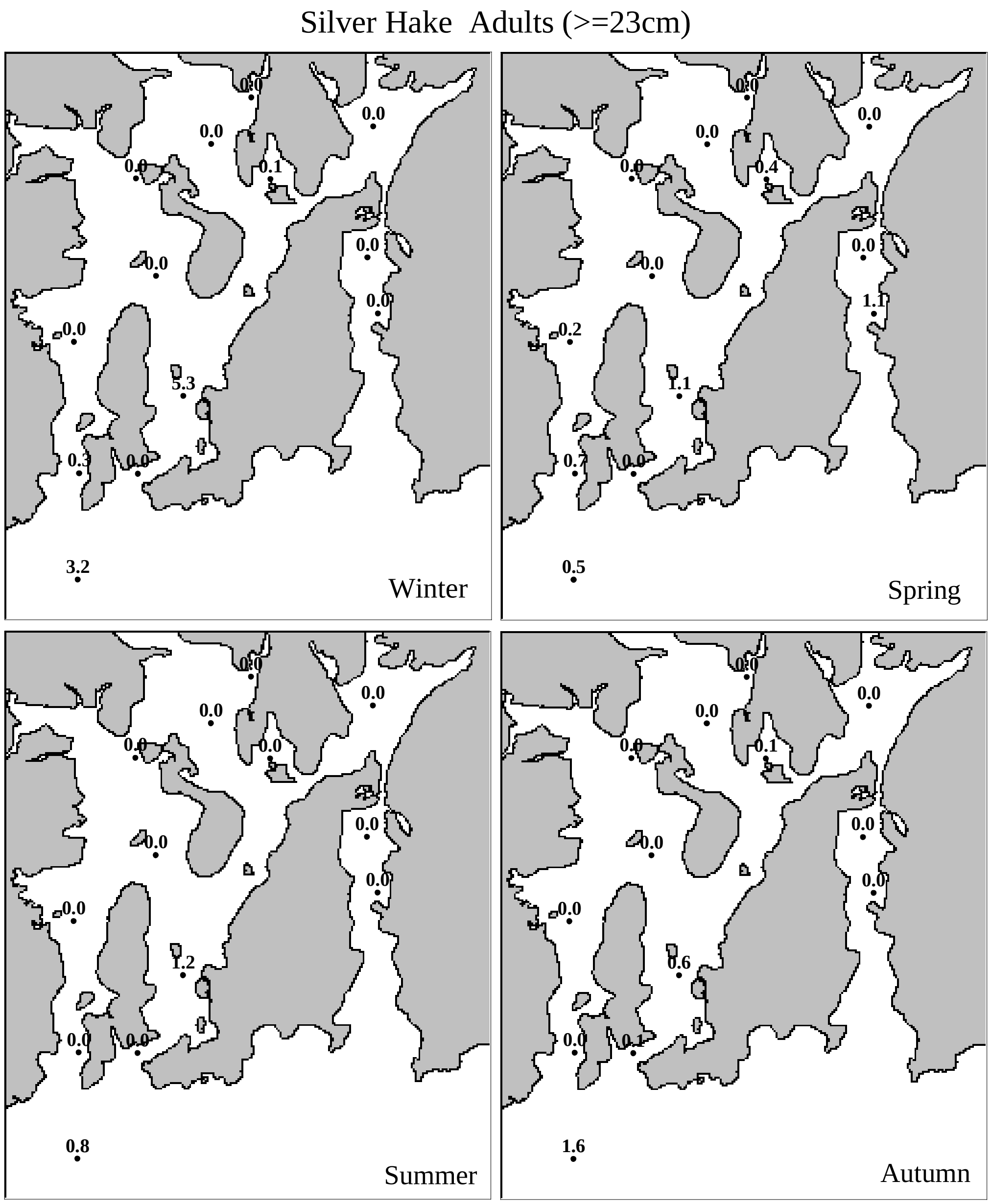


Figure 15. Distribution, abundance and length frequencies of juvenile and adult silver hake collected during each season in Narragansett Bay during 1990-1996 Rhode Island bottom trawl surveys. The numbers shown at each station are the average catch per tow rounded to one decimal place [see Reid *et al.* (1999) for details].



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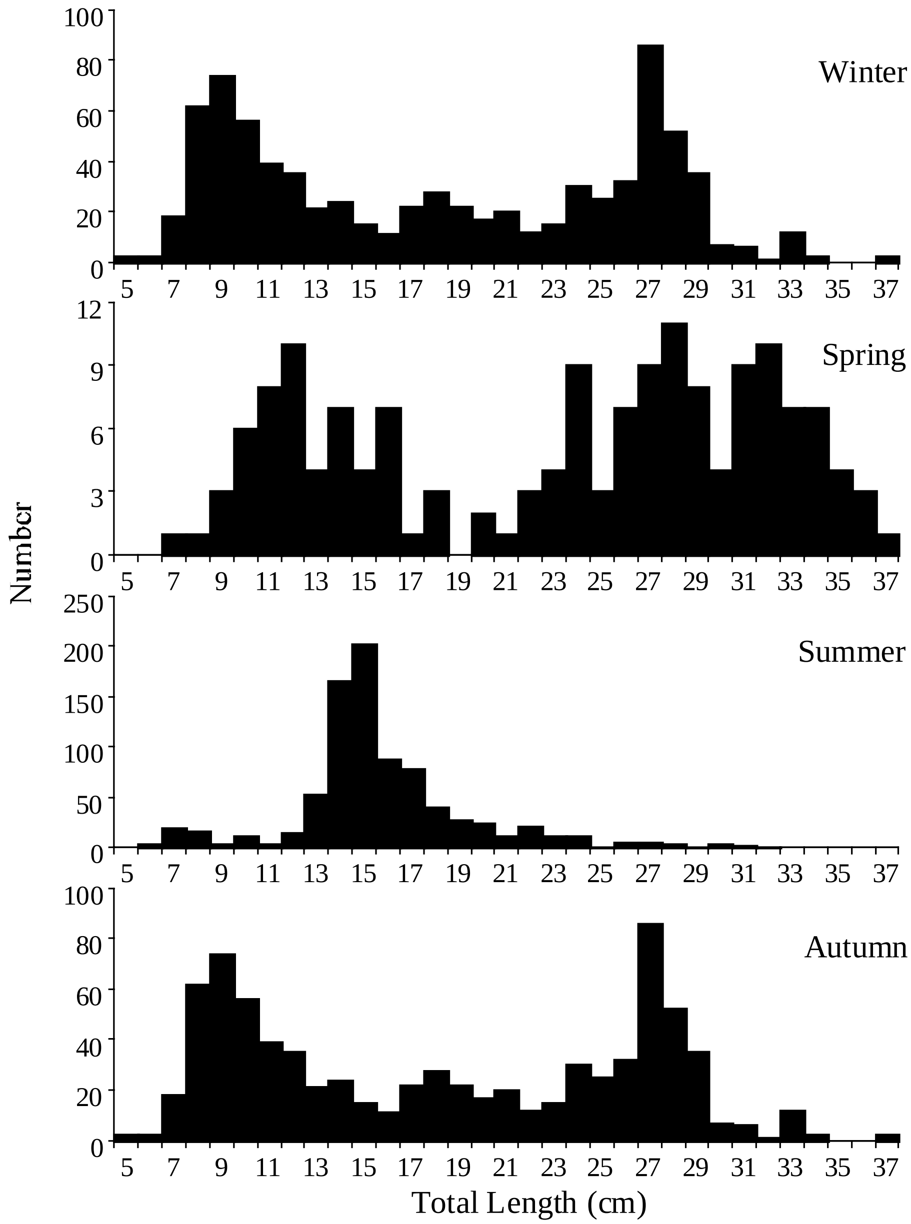

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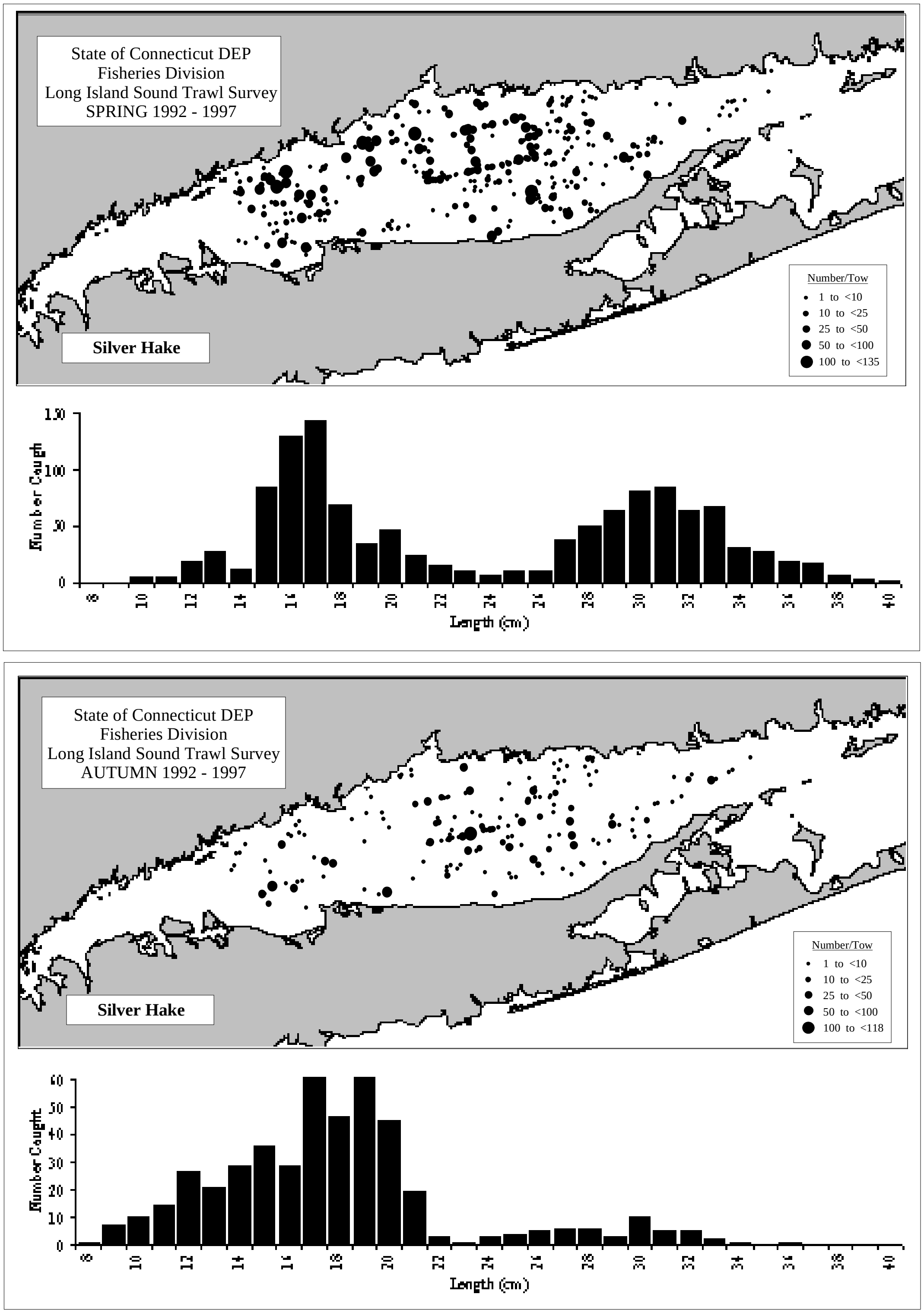

Figure 16. Distribution, abundance, and length frequencies of juvenile and adult silver hake collected during spring and autumn in Long Island Sound, from the Connecticut bottom trawl surveys, 1992-1997 [see Reid *et al.* (1999) for details].

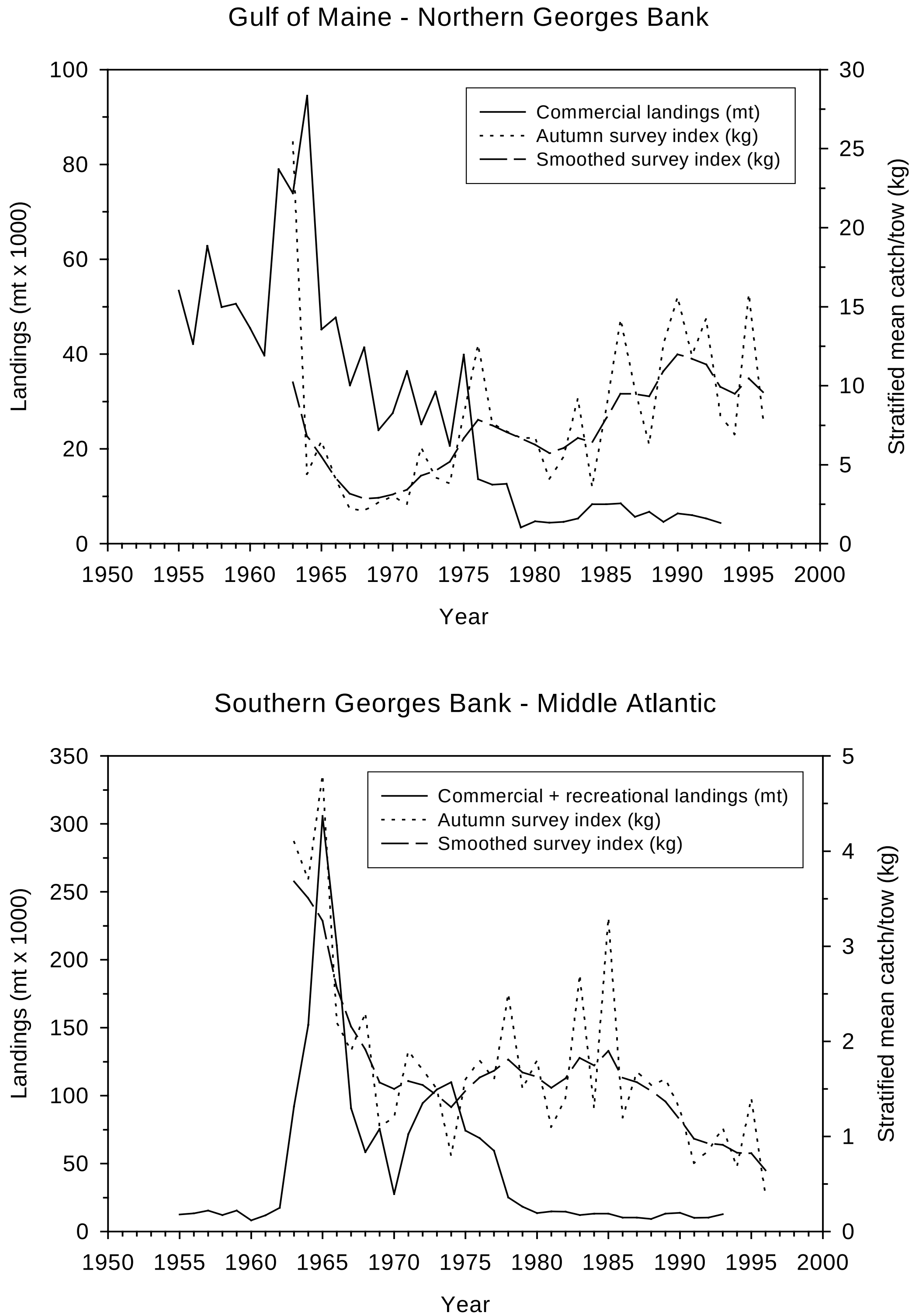

Figure 17. Commercial landings and abundance indices (from the NEFSC bottom trawl surveys) for the Gulf of Maine-Georges Bank and southern Georges Bank-Middle Atlantic stocks of silver hake.

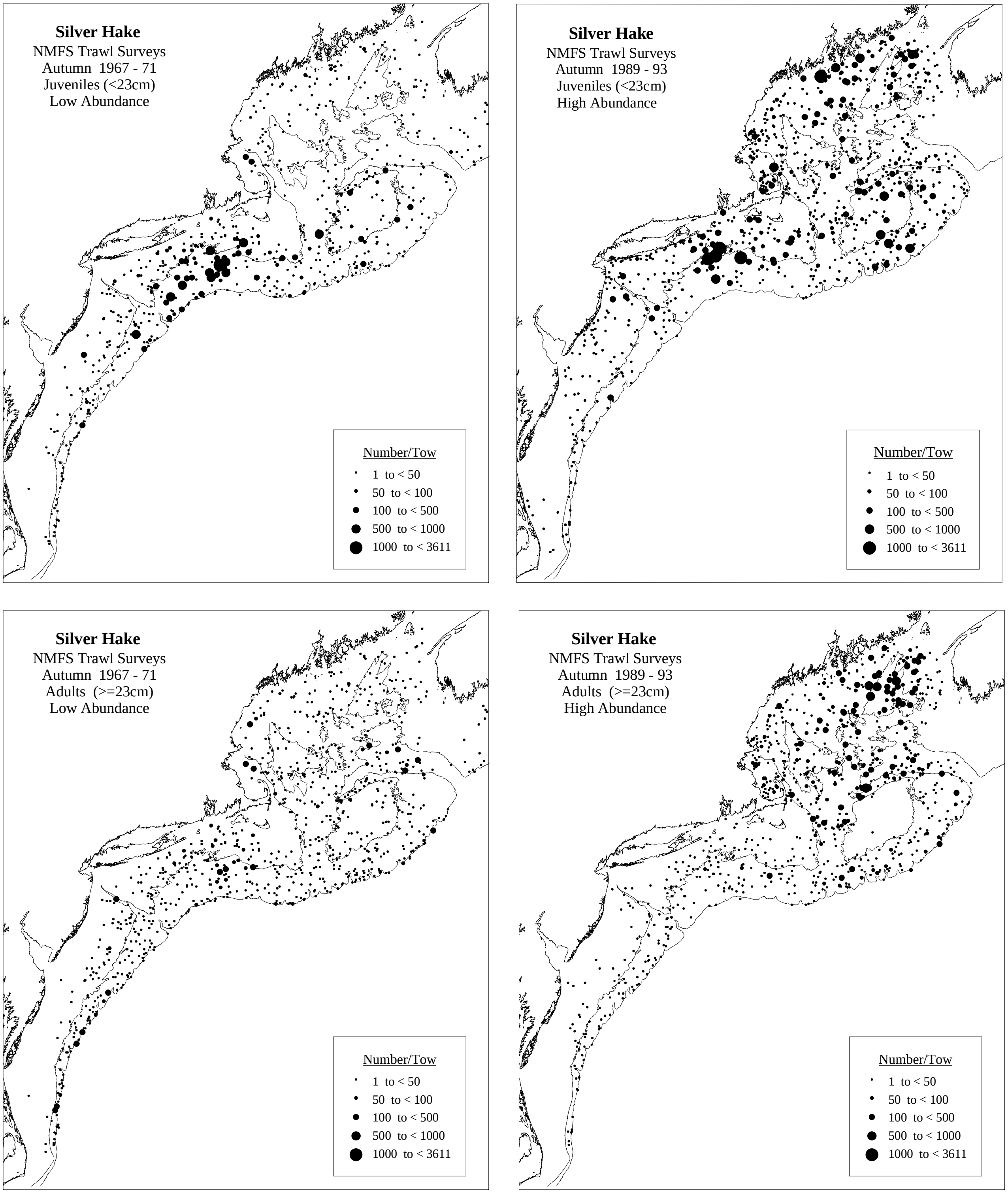

Figure 18. Distribution and abundance of juvenile and adult silver hake from NEFSC autumn bottom trawl surveys during a period of relatively low abundance (autumn 1967-1971) and a period of relatively high abundance (autumn 1989-1993).

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