NOAA Technical Memorandum NMFS-NE-144

Essential Fish Habitat Source Document:

Bluefish, *Pomatomus saltatrix*, 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

September 1999

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NOAA Technical Memorandum NMFS-NE-144

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Essential Fish Habitat Source Document:

Bluefish, *Pomatomus saltatrix*, Life History and Habitat Characteristics

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September 1999

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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INTRODUCTION

The bluefish, *Pomatomus saltatrix* (Figure 1), ranges in the western North Atlantic from Nova Scotia and Bermuda to Argentina, but it is rare between southern Florida and northern South America (Robins *et al*. 1986). They travel in schools of like-sized individuals and undertake seasonal migrations, moving into the Middle Atlantic Bight (MAB) during spring and south or farther offshore during fall. Within the MAB they occur in large bays and estuaries as well as across the entire continental shelf. Juvenile stages have been recorded from all estuaries surveyed within the MAB, but eggs and larvae occur in oceanic waters (Able and Fahay 1998). Bluefish growth rates are fast and they may reach a length of 1.1 m (3.5 ft) and a weight of 12.3 kg (27 lbs) (Bigelow and Schroeder 1953). They may live to age 12.

A bimodal size distribution of young-of-the-year (YOY) bluefish during the summer in the New York Bight suggests that there are two spawning events along the east coast. Recent studies suggest that spawning is a single, continuous event, but that young are lost from the middle portion resulting in the appearance of a split season. As a result of the bimodal size distribution of juveniles, young are referred to as the *spring-spawned cohort* or *summer-spawned cohort* in the habitat discussion and distribution maps presented below.

LIFE HISTORY

EGGS

Eggs from the MAB are pelagic and spherical with a diameter of 0.95-1.00 mm. They have a smooth, transparent shell and a homogeneous yolk. The single oil globule is 0.26-0.29 mm in diameter and the perivitelline space is narrow (Fahay 1983). Incubation times depend on temperature. At 18.0-22.2^{o}C, hatching occurs after 46-48 h (Deuel *et al.* 1966). Eggs from the South Atlantic Bight (SAB) have not been described.

LARVAE AND PELAGIC-JUVENILES

Larvae are 2.0-2.4 mm long when they hatch; the eyes are unpigmented and the mouth parts are undeveloped. Characteristic pigment includes parallel lines of melanophores along the dorsal fin base, body midline, and anal fin base. Teeth are well developed at 4.3 mm and fin rays are complete at a size of about 13-14 mm (Fahay 1983). Larvae rarely occur deeper in the water column than 15 m; most are concentrated at a depth of about 4 m during the day, but they are about equally distributed between that depth and the surface at night (Kendall and Naplin 1981). The bluefish transforms from a larva to a "pelagic-juvenile" stage that is specially adapted for an oceanic, near-surface existence after completion of fin ray development (Figure 2). This specialized stage is characterized by a silvery, laterally compressed body, with dark blue counter-coloration on the dorsum. This transition occurs at an age of 18-25 d and at a size of 10-12 mm SL (Hare and Cowen 1994). Scales begin to form at about 12 mm on the posterior part of the lateral line region, then proceed forward, until the head is completely scaled at about 37 mm (Silverman 1975). Swimming ability in many fish species dramatically improves during this transformation (e.g. Hunter 1981; Stobutzki and Bellwood 1994; Leis *et al.* 1996) and this improvement presumably applies to bluefish as well. It is during this stage that bluefish arrive at nursery areas in the central part of the MAB, after advection via the Gulf Stream from spawning areas in the SAB and after crossing the Slope Sea (Hare and Cowen 1996; Hare *et al*., in prep.) and the continental shelf (Cowen *et al.* 1993). This transport (active or passive) is crucial to the recruitment of these progeny to vital estuarine nursery areas, and therefore this life history stage might be considered a critical bottleneck.

JUVENILES (INCLUDING YOUNG-OF-THE-YEAR)

Juveniles have a usual fish shape without unusual features. The caudal fin is forked and the body is somewhat laterally compressed, with a silvery, unpatterned color. The mouth is large and oblique and all fin spines are strong. Two distinct dorsal fins touch at their bases; the second dorsal fin is about the same length as the anal fin base (Able and Fahay 1998). The *spring-spawned cohort* is 60-76 d old with a mean size of 60 mm when they recruit to estuarine habitats in the MAB in late May to mid-June (McBride and Conover 1991; Cowen *et al.* 1993). The *summer-spawned cohort* either remains in coastal nursery areas (Kendall and Walford 1979; Able and Fahay 1998) or enters estuarine nurseries in mid- to late August when they are 33-47 d old with a mean length of 46 mm (McBride and Conover 1991). Juveniles of both cohorts depart MAB estuaries and coastal areas in October and migrate to waters south of Cape Hatteras, North Carolina. At this time, members of both cohorts range from 4 to 24 cm long (Able and Fahay 1998). During most years, the *spring-spawned cohort* dominates in the emigrating young-of-the-year.

ADULTS

Adult bluefish are blue-green above, silvery below, moderately stout-bodied, and armed with stout teeth along both jaws. The snout is pointed and the mouth is large and oblique. The caudal fin is large and forked. The fin ray formulae are first dorsal: 7-9 spines; second dorsal: 1

spine and 23-26 rays; anal: 2-3 spines and 25-28 rays. Vertebrae number 26. The maximum length is about 115 cm and maximum weights are 4.5-6.8 kg, although an occasional heavier fish has been taken. The maximum age is 12 years. The sex ratio is 1:1 for all age groups (Boreman 1982), although Lassiter (1962) reported a ratio of two females per male in North Carolina and Hamer (1959) found a ratio of three females to two males in New Jersey.

REPRODUCTION

A seminal study, based largely on the distribution of eggs and larvae, concluded that there were two discrete spawning events in western Atlantic bluefish. The first occurs during March-May near the edge of the continental shelf of the SAB. The second occurs between June and August in the MAB (Kendall and Walford 1979). Recent studies have re-examined this conclusion and refined our knowledge of a complex reproductive pattern, and support the concept of a single, migratory spawning stock (Hare and Cowen 1993; Smith *et al.* 1994).

Sexual maturity and gonad ripening occur in early spring off Florida, early summer off North Carolina, and late summer off New York (Hare and Cowen 1993). In the New York Bight, gonadosomatic studies indicate that both sexes are ripe or ripening between June and September with a strong peak in July (Chiarella and Conover 1990). Larvae re-occur in the SAB in the fall (Collins and Stender 1987) and there are also indications that gonads reach a second peak in ripeness in fishes off Florida in September. Most bluefish are mature by age 2 (Deuel 1964). It is not known whether individuals spawn serially or what the contributions of individuals are to observed spawning patterns of the population. In South Africa, individuals may spawn repeatedly over a period of 5-6 months (Van der Elst 1976), but there is no comparable information for the U.S. population.

FOOD HABITS

During their oceanic larval stage, bluefish primarily consume copepods. Fishes begin to be included in their diet at sizes of 30 mm, and by 40 mm, fishes are the major diet item. Soon after this shift in diet, juveniles migrate inshore to occupy estuarine habitats (Marks and Conover 1993).

The results of several studies suggest that bluefish juveniles and adults eat whatever taxa are locally abundant (Table 1). The components of young-of-the-year bluefish diet in Sandy Hook Bay, New Jersey and the effects of those components on condition were studied over a three-year period (Friedland *et al.* 1988). Fishes dominated the diet during 1981, while crustaceans and polychaetes were more important during 1983 and 1984. Weight-length relationships indicated that weight at length was significantly greater in 1981 than in the other two years. Thus, not only does the quality of diet differ between estuaries, but the method of foraging may also differ; more benthic foraging was evident in bluefish from Sandy Hook Bay than in bluefish sampled in estuaries in Delaware (Grant 1962) and North Carolina (Lassiter 1962). Depending on age class, diets might change through a season. In Chesapeake Bay, diets of three age classes differed through the summer (Table 1), but all three concentrated on *Brevoortia tyrannus* in the fall (Hartman and Brandt 1995a, b).

PREDATION

Sharks, tunas, and billfishes are the only predators large and fast enough to prey on adult bluefish. They are a major component in the diet of shortfin mako shark, composing 77.5% of the diet by volume (Stillwell and Kohler 1982). This study estimated that this shark may consume between 4.3 and 14.5% of the bluefish resource between Georges Bank and Cape Hatteras. Bluefish also ranked fourth in number and occurrence and third in volume in swordfish diets, especially off the Carolinas (Stillwell and Kohler 1985). Blue sharks and sandbar sharks also prey on bluefish (Kohler 1988; Medved *et al.* 1985). Young-of-the-year are preyed upon by four oceanic bird species, the Atlantic puffin, Arctic tern, common tern, and roseate tern (Creaser and Perkins 1994; Safina *et al.* 1990). Cannibalism has only rarely been reported, but occurs in age 1 and older year classes in North Carolina (Lassiter 1962), and bluefish compose a minor component of the diet of larger bluefish collected during Northeast Fisheries Science Center (NEFSC) bottom trawl surveys on the continental shelf (NEFSC, unpublished data).

MIGRATIONS

Bluefish are warm water migrants and do not occur in MAB waters at temperatures < 14-16°C (Bigelow and Schroeder 1953). They generally move north in spring-summer to centers of abundance in the New York Bight and southern New England and south in autumn-winter to the waters in the SAB as far as southeastern Florida. There is a trend for larger individuals to occur farther north during the summer (Wilk 1977). Anecdotal reports suggest that larger adults truncate their southward migration and spend the winter on the outer part of the continental shelf of the MAB. One report witnessed a single fish landed from about 100 m deep off Martha's Vineyard during mid-January 1950 and several hauls of 80-640 kg from the vicinity of Hudson Canyon during early February of the same year (Bigelow and Schroeder 1953). Another study simply reported "boats engaged in the winter trawl fishery for fluke and scup along the outer margin of the continental shelf often bring in a few bluefish" (Hamer 1959). These reports have been perpetuated since (Lund 1961; Miller 1969; Lund and Maltezos 1970; Hardy 1978). However, recent winter trawl surveys do not indicate, nor are fisheries or other data available to support, the presence of bluefish in the MAB during winter, except for a few occurrences near the shelf edge off Cape Hatteras (see Geographical Distribution).

STOCK STRUCTURE

The bluefish is presently managed as a single stock (MAFMC 1997). Although there is evidence of separate spawning events (see Reproduction), fish from these spawning groups mix extensively during their lives, and recent conclusions have ascertained that bluefish year classes are composed of seasonal cohorts (Chiarella and Conover 1990). Recent studies have re-examined this conclusion and refined our knowledge of a complex reproductive pattern, supporting the concept of a single, migratory spawning stock (Hare and Cowen 1993; Smith *et al.* 1994). A mitochondrial DNA study of *spring*- and *summer-spawned* bluefish also concluded that bluefish along the east coast of the United States comprise a single genetic stock (Graves *et al.* 1992).

HABITAT CHARACTERISTICS

The habitat characteristics for eggs, larvae, pelagic-juveniles, juveniles, and adults based on results of this compendium and pertinent published reports are presented in Table 2. Included are observations of habitat use by young-of-the-year in estuaries. When studies of juvenile abundance have been related to environmental variables, such as eelgrass presence/absence or a substrate type, they have usually been conducted with seines where catch-per-unit-of-effort is difficult to establish. Comparing the results of these studies between locations is usually not possible, and further details of essential habitats are therefore not yet available. Appendix 1 contains more complete data from various studies reported in the literature.

EGGS

In the MAB, bluefish eggs are found in the open ocean at temperatures 18-22^{o}C and salinities > 31.0 ppt. Peak spawning occurs in the evening (Norcross *et al.* 1974). Eggs in the southern part of the MAB may be advected south and offshore (Norcross *et al.* 1974).

LARVAE AND PELAGIC-JUVENILES

Larvae in the MAB occur in open oceanic waters, near the edge of the continental shelf in the southern Bight and over mid-shelf depths farther north (Norcross *et al.* 1974; Kendall and Walford 1979). Most larvae occur in temperatures of 18-24^{o}C and salinities of 30-32 ppt. They migrate vertically in the water column, occurring near the surface at night, but centered at about 4 m during daylight (Kendall and Naplin 1981). Larvae spawned in the SAB (*spring-spawned cohort*) are subject to advection north via the Gulf Stream (Hare and Cowen 1996; Kendall and Walford 1979), but some recruit successfully to estuaries in the SAB (Collins and Stender 1987; McBride *et al.* 1993).

The transport of pelagic-juveniles was outlined by Kendall and Walford (1979) and elaborated by Hare and Cowen (1996). Many are found in the vicinity of Cape Hatteras as early as April. In May, several have been collected on the shelf in the SAB (Fahay 1975; Kendall and Walford 1979). By June, they occur in the MAB between the shore and the shelf/slope front, actively crossing the shelf (Hare and Cowen 1996). In both the SAB and MAB, there is a strong negative correlation between fish size and depth indicating an offshore origin and onshore migration with growth.

JUVENILES (INCLUDING YOUNG-OF-THE-YEAR)

Juveniles occur in estuaries, bays, and the coastal ocean of the MAB and SAB, where they are less common. They occur in many habitats, but do not use the marsh surface. The range of physical and structural conditions in which they are found is summarized in Table 2. Juveniles begin to depart MAB estuaries in October and migrate south to spend the winter months south of Cape Hatteras.

ADULTS

Adult bluefish occur in the open ocean, large embayments, and most estuarine systems within their range. Although they occur in a wide range of hydrographic conditions, they prefer warmer temperatures and are not found in the MAB when temperatures decline below 14-16^{o}C. See Table 2 for a summary of habitat requirements of adult bluefish.

GEOGRAPHICAL DISTRIBUTION

EGGS

Spring-spawned cohort: The spring spawning occurs near the edge of the continental shelf in the SAB.

However, bluefish eggs have not been collected or identified from this region.

Summer-spawned cohort: Eggs were collected from May to August over the MAB continental shelf during the NEFSC Marine Resources Monitoring, Assessment and Prediction (MARMAP) program surveys [see Reid *et al.* (1999) for methods]. Bluefish eggs were most abundant in July (Figure 3). Eggs were distributed near Cape Hatteras in May and their occurrences expanded rapidly northward during the summer. In July, eggs were distributed as far as southern New England waters with a center of abundance off Delaware Bay and New Jersey (Berrien and Sibunka 1999). Eggs were not collected after August. Bluefish eggs do not occur in estuarine waters. During the NEFSC MARMAP surveys, eggs occurred across the entire shelf, but were most concentrated in mid-shelf depths (Berrien and Sibunka 1999). In another study, most (80%) eggs collected off the Chesapeake Bay mouth were > 55 km from shore (Norcross *et al.* 1974). Most eggs were collected at surface temperatures between 17 and 23^{o}C, and over depths of 30 to 70 m (Figure 4).

LARVAE

The distribution of all larvae collected in the MAB and SAB is shown in Figure 5. There has been a critical lack of sampling in the area immediately south of Cape Hatteras.

Spring-spawned cohort: Our understanding of the distribution of larvae in the SAB (corresponding to the *spring-spawned cohort*) is limited. The NEFSC MARMAP ichthyoplankton program sampled there from 1973 through 1980; bluefish larvae generally were collected in low densities, both in water column sampling with bongo nets (Figure 6) or Isaacs-Kidd midwater trawls (Table 3), and at the surface with two types of neuston net (Figure 7). Most larvae occurred near the 200 m depth contour, placing them close to the Gulf Stream and presumably enhancing their chances of advection to the north as proposed by Kendall and Walford (1979), Powles (1981), and Hare and Cowen (1993, 1996). The collection of bluefish eggs in April and May is consistent with back-calculated birth dates determined from estuarine recruits in the New York Bight (NYB) (see Juveniles). The densest concentrations of larvae in NEFSC MARMAP cruises in the SAB occurred over the outer half of the continental shelf during April and May. Currents there flow toward the northeast and are affected by the Gulf Stream (Lee and Atkinson 1983), while on the inner shelf, wind-driven currents are important in affecting the drift of larvae (Powles 1981; Lee and Atkinson 1983). A secondary concentration of larvae was detected during late summer/early fall of one year (1976) and may indicate the existence of an isolated spawning event (Figure 6). During 1979, all sampling was done by Isaacs-Kidd midwater trawl and was restricted to the shelf area near Charleston, South Carolina between February and August (Table 3). Larvae were collected with this gear in low densities between February and mid-May; two tows in April yielded somewhat higher densities.

Summer-spawned cohort: The distribution of larvae in the MAB is similar to that of the eggs (Figure 8). Larvae < 11 mm (the size when they become pelagic-juveniles) first occur near Cape Hatteras and along the shelf edge in the Wilmington Canyon area during May, and are present through the summer in increasing numbers throughout the southern and central parts of the MAB. Although larvae are only rarely collected in estuarine waters, they have been reported from a few large systems in the MAB, including one larva, one occurrence in Narragansett Bay (Herman 1963) and several estuaries in New York/New Jersey (Table 4). During June, peak larval abundance occurs between Cape Hatteras and Chesapeake Bay and off New Jersey. Larvae are most dense in the central part of the MAB in July and remain dense during August. Few larvae occur in the MAB during September. Larvae rarely occur deeper in the water column than 15 m and most are concentrated at a depth of about 4 m during the day, but are about equally distributed between that depth and the surface at night. Neuston sampling, therefore, is likely to drastically undersample bluefish when done during the day. In NEFSC MARMAP sampling, larvae occurred across the entire shelf but were most concentrated in mid-shelf depths. Most larvae were collected at surface temperatures between 17° and 26°C and over water depths of 30 to 70 m (Figure 9).

PELAGIC-JUVENILES (LARVAL TO JUVENILE TRANSITION)

There are no available data that adequately describe the distribution of this transformation stage in bluefish life history, however, limited observations have been made in the NYB (Shima 1989; Hare and Cowen 1996). These observations support the view that temperatures below 13-15^{o}C impede the progress of this stage into MAB estuaries. In early June, these pelagic-juveniles mass at the shelf-slope temperature front, and resume their inshore migration when that front dissipates (Hare and Cowen 1996).

JUVENILES

It is presently unknown if bluefish are "estuarine dependant" since the distribution of juveniles over the continental shelf has not been described. The distribution and relative abundance of juveniles has been documented for estuaries along the east coast of the United States (Table 4) and for estuaries in Maine (Table 5).

A survey of juvenile bluefish published in the early 1970s (Clark 1973) noted that their distribution differed from historical observations (Figure 10). Bluefish were not observed south of Daytona Beach through the 1970s, although juveniles were reported from estuaries as far south as Palm Beach, Florida in the early part of the century (Evermann and Bean 1898; Nichols 1913). This author also suggested that the apparent high densities of juveniles in certain regions (e.g., New Jersey and South Carolina) were due to greater sampling effort. Remaining enigmatic occurrences include those in the freshwaters of the upper Chesapeake Bay (Mansueti 1955; Lund 1961), although the Chesapeake and Delaware Canal may play a role in their presence there.

Several young-of-the-year surveys (or surveys that adequately sample young stages) are conducted within MAB states (Figure 11). Several caveats pertaining to these results prevent these state data from being compared directly. Some surveys are conducted throughout the year, while others are limited in their seasonal extent, and the resultant densities are therefore unequal. Although all results are expressed as "number per tow," tow lengths and gear characteristics vary between states, and thus the basis for this number can be unequal. Finally, the definition of "juvenile" can vary between states; in some cases, it is based solely on length frequency distributions, in some cases it is based on an arbitrary length cutoff. In most states, all fish < 30 cm are considered juveniles, although in the Chesapeake Bay region, some of these could be age 1+ if they were collected early in the year (Munch 1997).

Despite these caveats, certain trends are evident in the data. There are signs of strong year classes in each state data set, but these do not necessarily match temporally. In general, abundances are greater in states between Rhode Island and New Jersey, and considerably lower in states in the southern part of the MAB, further emphasizing the importance of the former.

Massachusetts Trawl Survey

Juvenile bluefish are collected in twice-yearly otter trawl sampling in nearshore waters of Massachusetts [see Reid *et al.* (1999) for details]. Juveniles are not found during spring, but are more abundant during fall (Figure 12); most positive collections occur in embayments south of Cape Cod. In the fall, juveniles occur in the warmest bottom water temperatures and occur most commonly at the shallowest stations (Figure 13).

Rhode Island Trawl Survey, Narragansett Bay

Juveniles were collected during summer and autumn in a survey of Narragansett Bay (Figures 14, 15) [see Reid *et al.* (1999) for details]. Most were collected in depths of 6-15 m and at bottom water temperatures of 17-22^{o}C (Figure 16).

Connecticut Trawl Survey, Long Island Sound

Young-of-the-year appear during June and by mid-August, they compose 93% of the bluefish catches in Long Island Sound (Figure 17) [see Reid *et al.* (1999) for details]. Abundance is highest during mid-summer on the Connecticut side of the sound in depths < 18 m, but adults are more widespread than juveniles (Figure 18). Peak abundance is reached during September when bluefish (94% juveniles) are found throughout the sound. Juvenile abundance is highest in depths of 9-27 m over mud bottoms in three areas: 1) the Connecticut side from New Haven to Norwalk; 2) across the Western Basin into Smithtown Bay; and 3) across the Central Basin from New Haven to Mattituck. Abundance decreases rapidly after September and juveniles appear to depart before adults.

NEFSC Hudson-Raritan Trawl Survey

Most bluefish collected in the Hudson-Raritan estuary and Sandy Hook Bay trawl survey are juveniles (< 35 cm) [see Reid *et al.* (1999) for details]. There are no occurrences during winter and only a few adults are collected during spring (Figure 19). During summer and fall, juveniles occur throughout the area in all depths sampled, at bottom temperatures between 12 and 24^{o}C (Figure 20). The largest collections were made near navigation channels or in a basin near Graves End Bay.

SEAMAP Trawl Survey, South Atlantic Bight

The Southeast Area Monitoring and Assessment Program (SEAMAP) surveys sampled the coastal region between Cape Hatteras, North Carolina and Cape Canaveral, Florida [see Reid *et al.* (1999) for details]. After an initial several years when gear and methods were not standardized, methodology became synoptic and standardized between 1990 and 1996 (Beatty and Boylan 1997; Boylan *et al.* 1998). Bluefish collected during the latter survey period are shown in Figure 21. Length frequencies of these collections indicate most were young-of-the-year or age 1 (Figure 22). Information on distributions over the offshore portions of the SAB shelf are lacking for any size class. Monthly occurrences of these bluefish are shown in Figure 23. Occurrences decrease during spring, are at low levels during summer, and increase during October beginning in the northern part of the bight, which suggests an influx of migrating young-of-the-year from the MAB.

ADULTS

Massachusetts Trawl Survey

Adult bluefish are collected in twice-yearly otter trawl sampling in nearshore waters of Massachusetts. During spring, a few large adults are sometimes found in the vicinity of Nantucket and Vineyard sounds, when juveniles are not found (Figure 12). Both juveniles and adults are more abundant during fall when most collections occurred in embayments south of Cape Cod (Figure 12). Adults in spring and fall occur over the warmest bottom water temperatures and most commonly in the shallowest stations (Figure 13).

Rhode Island Trawl Survey, Narragansett Bay

Adults were rarely collected during summer and autumn in a survey of Narragansett Bay (Figures 14, 15). Most were collected in depths of 6-21 m (summer) and 9-43 m (autumn) and at bottom water temperatures of 15-26^{o}C (summer) and 17-21^{o}C (autumn) (Figure 16).

Connecticut Trawl Survey, Long Island Sound

Bluefish adults begin to appear in Long Island Sound during May (Figure 17) when temperature preferences are 9-18^{o}C (Figure 18). Abundance is highest during mid-summer on the Connecticut side of the sound in depths < 18 m and adults are more widespread than juveniles. Peak abundance is reached during September when bluefish (94% juveniles) are found throughout the sound. Abundance decreases rapidly after September and juveniles appear to depart before adults.

NEFSC Hudson-Raritan Trawl Survey

Most bluefish collected in Hudson-Raritan estuary and Sandy Hook Bay are juveniles (< 35 cm). There are no occurrences during winter and only a few adults are collected during spring (Figure 19). Their collections relative to bottom temperature, depth, dissolved oxygen, and salinity are shown in Figure 20.

JUVENILES AND ADULTS

NEFSC Trawl Surveys

Bluefish are migratory and their distribution varies seasonally and according to age and size of individuals composing schools. Length frequencies of trawl-collected bluefish were examined to determine age and size composition of catches in the NEFSC bottom trawl survey (Figure 24). Modes were separable into spawning cohorts and year classes based on published studies and are the bases for the distribution maps (Figures 25-32).

The distribution of all lengths during all seasons (Figure 25) indicates that bluefish occur most densely along the coast of the MAB and through the central part of Georges Bank, although these results may reflect the increased efficiency of the trawl in shallower waters. Winter occurrences are limited to the outer continental shelf near Cape Hatteras and these few occurrences are larger fish (Figures 26, 27). Spring collections include *spring-spawned* young-of-the-year off North Carolina, *spring-spawned* age 1 restricted to coastal areas south of Cape Hatteras, age 2 individuals along the continental shelf edge off North Carolina, and older year classes distributed between Cape Hatteras and the offing of the Delmarva Peninsula (Figure 28). The distributions of < 30 cm and > 30 cm bluefish relative to depths and temperatures sampled during these spring surveys are shown in Figure 29.

Summer surveys collected several age classes, including *summer-spawned* young-of-the-year in the New York Bight; *spring-spawned* young-of-the-year widely distributed along the coast between New York and Cape Hatteras; age 1 fish, especially off North Carolina, but also in the Chesapeake Bay region; and older year classes, mostly over Georges Bank (Figure 30).

Fall surveys are most important for measuring relative year-class strength. Young-of-the-year of both *spring-* and *summer-spawned cohorts* and age 1 individuals are abundant along the coast between Long Island and Cape Hatteras. Older year-classes are more abundant in southern New England and Georges Bank waters (Figure 31). When all lengths are considered, there is a trend for bluefish to occur on the warmest stations sampled (Figure 32). However, this trend is most pronounced for young-of-the-year when they are separated from older year classes. The relative occurrences of all year classes by bottom depths closely mirror the distribution of depths sampled (Figure 32).

All age classes, in combined spring and fall surveys, were collected mostly over depths < 20 m. They were collected at warmer temperatures during spring surveys, but showed little preference for temperatures during fall surveys.

STATUS OF THE STOCK

Population fluctuations have been common in the western Atlantic bluefish population since colonial times. Wide swings in abundance occurred between the 1600s and the 1950s (Bigelow and Schroeder 1953). In recent years, the total catch of bluefish (commercial landings plus recreational catches) peaked in the late 1970s and early 1980s and has declined since (Figure 33). Commercial landings decreased about 22% between 1994 and 1995. During 1982-1996, age 1 fishing mortality increased approximately fourfold, recruitment has declined from an estimated 75 million fish at age 0 to about 14 million fish, and estimates of the spawning stock biomass have decreased from about 300,000 mt to 100+ mt (Stock Assessment Review Committee, Coastal Pelagic Subcommittee 1996).

There is little difference in the distribution of adults between a period of relatively high population abundance (1980-1982) and a period of low abundance (1994-1996) (Figure 34). However, the same comparison of the distribution of young-of-the-year indicates a decline in abundance in the southern part of the MAB. Whether this is due to year-class failure in estuaries of that region, or reflects a lack of pelagic-juvenile recruitment to those estuaries, is unknown.

RESEARCH NEEDS

LIFE HISTORY AND BIOLOGY

We lack information on the reproductive biology of bluefish. Observed patterns of spawning may be based on the population level rather than on information on individual reproductive traits. We presently do not know whether individuals spawn serially, and if so, how many times they are capable of spawning in a year. We also do not know if these reproductive characteristics vary with age. It is apparent that more study of the distribution of older stages needs to be correlated with spawning events. Since bluefish school in like-sized (and supposedly like-aged) groups, we need to know what groups are where and when, and how those aggregations are associated with the observed densities of eggs. Simply describing how many spawning events are occurring can not solve the issue of the number of manageable stocks.

Our understanding of the "pelagic-juvenile" stage is limited despite its obvious importance. We need to better understand the details of transport mechanisms that provide progeny of reproduction in the SAB to nurseries in the MAB. Increased sampling of the neuston or near-surface layers of the ocean between production areas and estuarine nursery areas, associated with appropriate oceanographic observations, would provide much-needed insight into factors affecting transport and estuarine recruitment.

There has been a tight correlation between population size and the contribution of the *spring-spawned cohort* to fall trawl collections in the last three decades. Yet our knowledge of reproduction in the SAB is limited to a brief, under-sampled period in the 1970s when the population was at a relatively low level of abundance. Furthermore, larvae produced in June in the southern part of the MAB appear not to survive [unless recruits to Maine estuaries result from this output, see Creaser and Perkins (1994)], the fate of the remaining MAB summer offspring remains enigmatic, and the relative contribution of this *summer-spawned cohort* to year-class success would seem to be negligible.

There is some evidence for spawning during the fall in the Cape Canaveral region of Florida that appears to be discrete, rather than a continuation of spawning in the MAB. This evidence has been demonstrated in this document with larval occurrences and a disjunct autumn distribution of fishes between 26 and 40 cm. Hare and Cowen (1993) present gonadosomatic data that suggest the same thing. Admittedly, some of this evidence is weak and based on incomplete sampling, and should be improved to determine the origin of these spawning fish, the magnitude of spawning, and the fate of any progeny.

HABITAT REQUIREMENTS

It is obvious from a review of the literature that we lack data to address the habitat issue at Tier 3 (habitat-specific growth, reproduction, and survival rates). Assessing how characteristics of habitat might affect the quality of young-of-the-year is therefore not feasible. Results of biological sampling, in estuaries or continental shelf waters, only rarely report specific characteristics of sampling sites. Therefore, data accruing from these studies are likely to be limited to “presence/absence” value only. According to Miller (1984): “We need a reasonable schema of estuaries, emphasizing the factors that have the most significance to the fish. Unfortunately, the necessary physical data are often lacking for an accurate characterization. Many are also temporally unstable. Not even our attempts to classify estuaries recognize their dynamic nature…we need more complete descriptions of how biologically relevant abiotic factors within estuaries affect biologically relevant scales of time and space. Without this, we cannot hope to untangle the biological processes or to compare results from different estuaries. Biologists need to involve more physical oceanographers and meteorologists in our research.” Clearly, in the future, more attention to details of collecting sites needs to be paid, and habitat research supported, such that the linkages between habitat quality and year class success can be made.

There are lingering conclusions that the *summer-spawned cohort* in the MAB uses nearshore coastal zones as nurseries, more so than estuaries. To some extent, this view may be based on the relative paucity of this cohort compared to the *spring-spawned cohort* in estuaries. Increased sampling of the near-coastal environment with appropriate gear should be encouraged to assess the relative value of this region.

ACKNOWLEDGMENTS

The author thanks L. Cargnelli and S. Griesbach for transforming the drafts into publication format.

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Table 1. Dietary items of bluefish from several study areas.

Source	**Life History Stage and Study Location**	**Diet Items (in order of importance)**
Texas Instruments Incorporated 1976	Young-of-the-year, Hudson River (tidal)	*Anchoa mitchilli* (dominated diet through summer), Clupeidae, *Microgadus tomcod*, *Alosa sapidissima*, *Notropis hudsonius*, Cyprinodontidae
Festa 1979	11-20 cm, Little Egg Harbor estuary, NJ	*Fundulus* spp., Atherinidae, *Anchoa* spp., *Callinectes sapidus*, *Brevoortia tyrannus*, *Crangon septemspinosa*
Friedland *et al.* 1988	Juvenile, Sandy Hook, NJ	1981: Teleosts, Crustacea, Polychaeta 1982: Crustacea, Teleostei, Polychaeta 1983: Crustacea, Teleostei, Polychaeta (weight at length significantly greater in 1981)
Hartman and Brandt 1995a, b	Age 0, Age 1, and Age 2, Chesapeake Bay (Diets of all age classes changed through season)	Age 0: *Anchoa mitchilli*, *Menidia menidia*, *Brevoortia tyrannus* Age 1: *Leiostomus xanthurus*, *A. mitchilli*, *M. menidia*, *B. tyrannus* Age 2: *Micropogonias undulatus*, *A. mitchilli*, *B. tyrannus* (*B. tyrannus* becomes important in diets of all age classes in Sep-Oct.)
Buckel and Conover 1997	Young-of-the-year, Hudson River estuary	Unidentified fish, *Anchoa mitchilli*, *Alosa* spp., *Morone saxatilis*, *Morone americana*
NEFSC, Trawl Survey Diet Data	All ages (mean size 35.6 mm FL), continental shelf, Georges Bank and Middle Atlantic Bight	1973-1980: Unidentified fishes, *Illex* spp., *Etrumeus teres*, *Loligo* spp., *Peprilus triacanthus*, Cephalopoda 1981-1990: Unidentified fishes, *Ammodytes dubius*, *Peprilus triacanthus*, *Loligo* spp., *Clupea harengus*

Table 2. Summary of life history and habitat characteristics for bluefish, *Pomatomus saltatrix*. See Appendix 1 for a more complete listing of habitat variables.

Life History Stage	Habitat (Spatial and Temporal)	Temperature	Salinity	Light/Vertical Distribution	Currents/ Circulation	Prey	Estuarine Use
Eggs [1]	*spring cohort*: unknown. *summer cohort*: occurs across continental shelf, southern New England to Cape Hatteras. Most in mid-shelf waters.	*spring cohort*: unknown. *summer cohort*: most in 18-22°C.	*spring cohort*: unknown. *summer cohort*: 31.0 ppt or more (minimum 26.0 ppt).	*spring cohort*: unknown. *summer cohort*: peak spawning in the evening (1900-2100 hrs).	*spring cohort*: unknown. *summer cohort*: in southern MAB, surface currents transport eggs south and offshore.	--	None
Larvae [2]	*spring cohort*: near edge of continental shelf, Cape Hatteras-Cape Canaveral, FL. Peak April-May. *summer cohort*: most 30-70 m depths, May-Sept, peak in July.	*spring cohort*: smallest larvae in > 24°C. *summer cohort*: near Cape Hatteras 22.1-22.4°C; in MAB 18-26°C.	*spring cohort*: smallest larvae in > 35 ppt. *summer cohort*: in MAB in 30-32 ppt.	*spring cohort*: > 4 mm strongly associate with surface. *summer cohort*: near surface at night, mostly at about 4 m during day.	*spring cohort*: subject to northward advection by Gulf Stream. Some retained in SAB by southerly counter-current. *summer cohort*: southwest winds in MAB may facilitate cross-shelf transport.	*summer cohort*: mostly copepod life history stages. Guts full during day.	None
Pelagic Juveniles [3]	*spring cohort*: smallest near 180 m contour; larger near shore. April-May. *summer cohort*: cross MAB shelf from Slope Sea to shore, early- to mid-June.	*spring cohort*: 19.0-24.0°C (or higher well offshore). *summer cohort*: in MAB 15.0-20.0°C (most > 18.0°C). As low as 13.0°C when cross shelf.	*spring cohort*: Near 180 m contour, > 35.0 ppt. *summer cohort*: During June, range 36.0-31.0 ppt.	*both cohorts*: strongly associated with the surface.	*spring cohort*: shoreward movement with growth unless advected north. *summer cohort*: move shoreward with growth. Currents important, but active swimming indicated.	--	*both cohorts*: enter estuarine nurseries during this stage
Juveniles [4] ***(summer cohort only)***	Several estuarine study areas between Narragansett Bay, RI and Delaware Bay and Delaware River.	In most studies, arrive > 20°C, remain in temperatures up to 30°C, emigrate when declines to 15°C. Can not survive below 10°C or above 34°C. Fall migration in 18-22°C on inner continental shelf.	Usually 23.0-33.0 ppt but can intrude to as low as 3.0 ppt.	Day: usually near shorelines or in tidal creeks. Night: usually in open bay or channel waters.	Can occur in surf zone or clear to turbid back-estuarine zones.	Atlantic silversides, clupeids, striped bass, bay anchovy, others.	Mostly sand, but some mud, silt, clay. Also uses *Ulva*, *Zostera* beds, and *Spartina* or *Fucus*.
Adults [5]	Generally oceanic, nearshore to well offshore over continental shelf.	Warm water, usually > 14-16°C. Can tolerate 11.8-30.4°C but are stressed at either extreme.	Oceanic salinities.	--	--	Sight feeders, prey on other fishes almost exclusively.	Not uncommon in bays, larger estuaries, as well as coastal waters.

[1] Norcross *et al.* 1974; Berrien and Sibunka 1999; Data from present report
[2] Norcross *et al.* 1974; Kendall and Walford 1979; Kendall and Naplin 1981; Powles 1981; Collins and Stender 1987; Hare and Cowen 1996; Data from present report
[3] Fahay 1975; Kendall and Walford 1979; Powles 1981; Collins and Stender 1987; Hare and Cowen 1996
[4] Lund and Maltezos 1970; Olla *et al*. 1975; Milstein *et al.* 1977; Nyman and Conover 1988; Rountree and Able 1992a, b; McBride *et al.* 1995; Able *et al.* 1996; Buckel and Conover 1997
[5] Bigelow and Schroeder 1953; Olla and Studholme 1971

Table 3. Sampling in 1979 ("Southern MARMAP") for bluefish larvae in the Charleston Bump area (32°37' N - 32°80' N x 78°42' W - 79°00' W). Isaacs Kidd MWT only.

Date	Sampling Depth	Sampling Duration	Volume Sampled	Bluefish No./10m^2
February 9	15	5	308	
"	37	27	641	
"	84	33	816	
February 28	31	26	693	0.89
"	54	25	1085	
"	110	35	1052	
March 13	30	22	580	
"	74	29	995	
March 17	114	38	1258	0.91
March 18	28	20	700	
March 27	18	20	742	1.16
"	58	27	1002	0.78
"	98	34	1261	
March 28	30	26	965	
April 6	32	25	875	0.71
"	62	25	875	41.48
"	132	40	1400	0.38
April 18	27	20	700	
"	38	21	735	2.22
"	128	33	1155	
April 19	42	22	770	1.45
April 30	28	22	770	36.99
May 1	76	27	945	21.16
"	134	38	1330	
"	50	25	875	3.97
May 16	34	22	770	2.65
"	58	25	875	9.55
"	130	35	1225	0.36
June 5	28	22	770	
"	58	31	1085	
June 30	37	26	910	
July 1	58	29	1015	
"	124	47	1645	
August 12	42	24	890	
August 13	127	31	1150	
"	50	22	816	
"	22	20	742	

Table 4. Distribution of early life history stages of bluefish, *Pomatomus saltatrix*, in estuaries from Maine to Florida. Occurrences are not quantitative and may be based on one or very few specimens. Estimates of relative abundance after Nelson and Monaco (1994), Jury *et al*. (1994), Stone *et al*. (1994). Some Middle Atlantic Bight estuaries after Able and Fahay (1998).

Estuary	**Eggs**	**Larvae**	**Juveniles**
Passamaquoddy Bay, ME	None	None	Rare
Englishman/Machias Bay, ME	None	None	Rare
Narraguagus Bay, ME	None	None	Rare
Blue Hill Bay, ME	None	None	Rare
Penobscot Bay, ME	None	None	Common
Muscongus Bay, ME	None	None	Common
Damariscotta River, ME	None	None	Common
Sheepscot River, ME	None	None	Common
Kennebec/Androscoggin Rivers, ME	None	None	Common
Casco Bay, ME	None	None	Common
Saco Bay, ME	None	None	Common
Wells Harbor, ME	None	None	Common
Great Bay, ME/NH	None	None	Common
Merrimack River, NH	None	None	Rare
Massachusetts Bay, MA	None	None	Common
Boston Harbor, MA	None	None	Common
Cape Cod Bay, MA	None	None	Common
Nauset Marsh, MA	None	None	None
Buzzards Bay, MA	None	Rare	Abundant
Narragansett Bay, RI	None	Rare/common	Abundant
Connecticut River, CT	None	None	Abundant
Long Island Sound, NY	None	None	Abundant
Gardiners Bay, NY	Rare	Rare	Abundant
Great South Bay, NY	None	None	Abundant
Hudson River, Raritan/Sandy Hook Bays, NY/NJ	Rare	Rare	Abundant
Barnegat Bay, NJ	None	Rare	Abundant
Great Bay, NJ	None	Rare	Common
Southern Inland bays, NJ	None	Rare	Abundant
Delaware Bay, NJ/DE	None	rare	Abundant
Delaware Inland bays, DE	None	None	Common
Eastern Shore, MD/VA	None	Rare	Common
Chesapeake Bay mainstem, MD/VA	None	None	Abundant
Chester River, MD	None	None	Common
Choptank River, MD	None	None	Common

Table 4. cont'd.

Estuary	Eggs	Larvae	Juveniles
Patuxent River, MD	None	None	Common
Potomac River, MD/VA	None	None	Abundant
Tangier/Pocomoke Sound, VA	None	None	Abundant
Rappahannock River, VA	None	None	Abundant
York River, VA	None	None	Abundant
James River, VA	None	None	Abundant
Albemarle Sound, NC	None	None	Common
Pamlico Sound, NC	None	None	Abundant
Pungo River, NC	None	None	Common
Neuse River, NC	None	None	Common
Bogue Sound, NC	None	None	Common
New River, NC	None	None	Common
Cape Fear River, NC	None	None	Abundant
Winyah Bay, SC	None	None	Common
Santee Rivers (N&S), SC	None	None	Common
Charleston Harbor, SC	None	None	Common
St. Helena Sound, SC	None	None	Common
Broad River, SC	None	None	Common
Savannah River, SC/GA	None	None	Common
Ossabow Sound, GA	None	None	Common
Sapelo Sound/ St. Catherine, GA	None	None	Common
Altamaha River, GA	None	None	Common
St. Andrew/St. Simon Sound, GA	None	None	Common
St. Johns River, FL	None	None	Common
Indian River, FL	None	None	Rare
Biscayne Bay, FL	None	None	Rare

Table 5. Unpublished records of juvenile bluefish in waters of coastal Maine. Collection locations are ordered from north to south (after Creaser and Perkins 1994).

Location	Date of Collection	O/E[1]	Number Collected	Size (mm TL)	Method[2]
Marston Pt.	August 25, 1983	O	3	100-130	HW
Seal Island	July 1991	O	1	50	AT
Matinicus Rock	July 24-30, 1991	O	4	50-60	RT
"	July 9-17, 1991	O	14	40-50	AT
"	Mid-July 1990	O	2	30-40	AT
"	July 5, 1989	O	2	85-90	AP
"	July 18, 1986	O	1	77	AP
Foot Bridge (Boothbay Harbor)	Summer 1970-1974	O	---	Juveniles (2 modes)	HS
DMR Dock	July 4, 1984	O	3	40-50	HL
"	August 25, 1978	O	1	86	DN
"	September 14, 1971	O	5	95-105	---
Townsend Gut	September 5, 1985	O	1	Juvenile	HL
Lobster Cove	August 11, 1991	O	4	162-192	HL
"	August 30, 1990	O	1	145	HL
Sheepscot River	August 2, 1989	E	1	140	HL
Sheepscot Falls	August 1967	E	---	150-200	HL
Marsh River	July 17-Sept 17, 1991	E	60	101-217	GN
"	August 1-Sept 26, 1990	E	149	89-218	GN
"	August 8-28, 1989	E	102	92-194	GN
"	August 26, 1987	E	6	129-163	GN
"	August 14, 1986	E	28	93-121	GN
The Eddy	July 9, 1991	E	3	80-85	HS
Cross River	August 8, 1991	E	1	115	HS
Berry Island	September 8, 1974	E	4	125-140	HS
"	August 29, 1973	E	2	132-141	HS
"	August 30, 1972	E	1	112	HS
Kennebec Pt.	August 10-22, 1990	O	29	39-70	HS

Table 5. cont'd.

Location	Date of Collection	O/E[1]	Number Collected	Size (mm TL)	Method[2]
Mouth of Abagadasset River	July 18, 1991	E	2	84-94	HS
"	July 3, 1991	E	6	112-115	HS
"	August 3, 1989	E	8	52-76	HS
"	September 11, 1987	E	2	142-150	HS
"	July 17, 1986	E	5	70-77	HS
Mouth of Androscoggin River	August 5, 1983	E	2	82-86	HS
Bath Bridge	Summer 1982	E	90	< 100	OT
Winnegance Bay	Summer 1988-1990	E	---	50-150	HL
Atkins Bay	Summer 1981	E	---	80-90	HS
Howard Point	August 1988	E	3	70-130	FK
Jenny Island	July 16, 1991	E	1	40	CT
Merepoint Bay	September 26, 1991	E	97	150-174	GN
Royal River	Summer 1988	E	---	Juvenile	---
SMVTI Dock	September 1986	O	---	130-150	HL
Union Wharf	September 1984	O	6	150-200	HL
Dunston, Libby, Nonesuch Rivers (confluence)	Summer 1987	E	---	Juvenile	HL
1 mi. off amusement pier, Old Orchard Beach	Summer 1961-1964	O	---	Juvenile	HL
Wells Harbor	August 1991	E	1	68	FN

[1] O = oceanic; E = estuarine
[2] Collection methods: OT = otter trawl; FN = fyke net; HL = hook and line; HS = haul seine; AP = Atlantic puffin; GN = gill net; AT = Arctic tern; DN = dip net; CT = common tern; HW = herring weir; RT = roseate tern

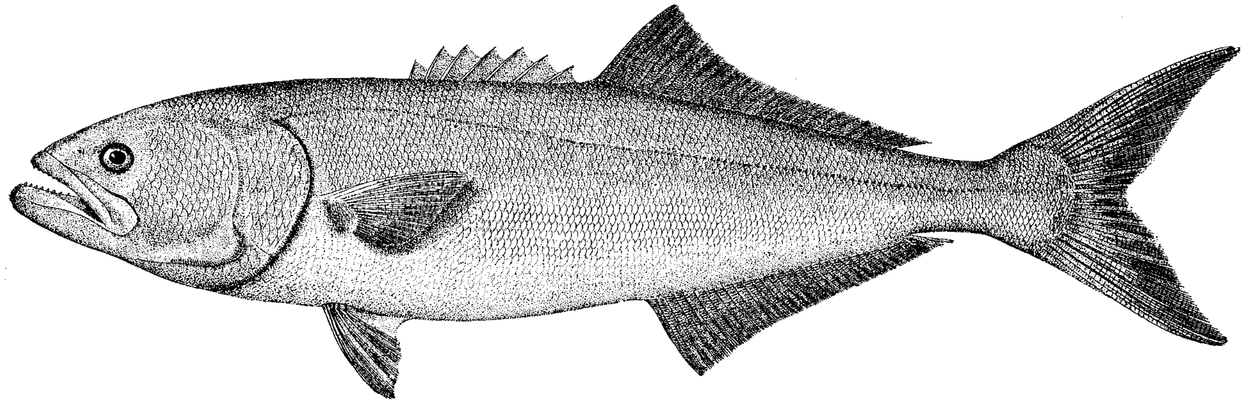


Figure 1. The adult bluefish, *Pomatomus saltatrix* (from Goode 1884).

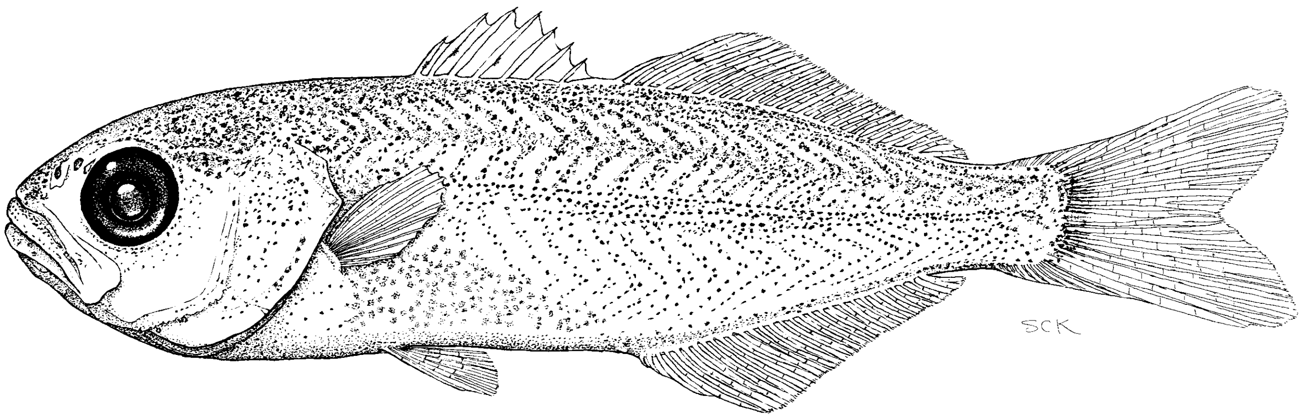


Figure 2. The pelagic juvenile bluefish, 24.3 mm SL (from Able and Fahay 1998).

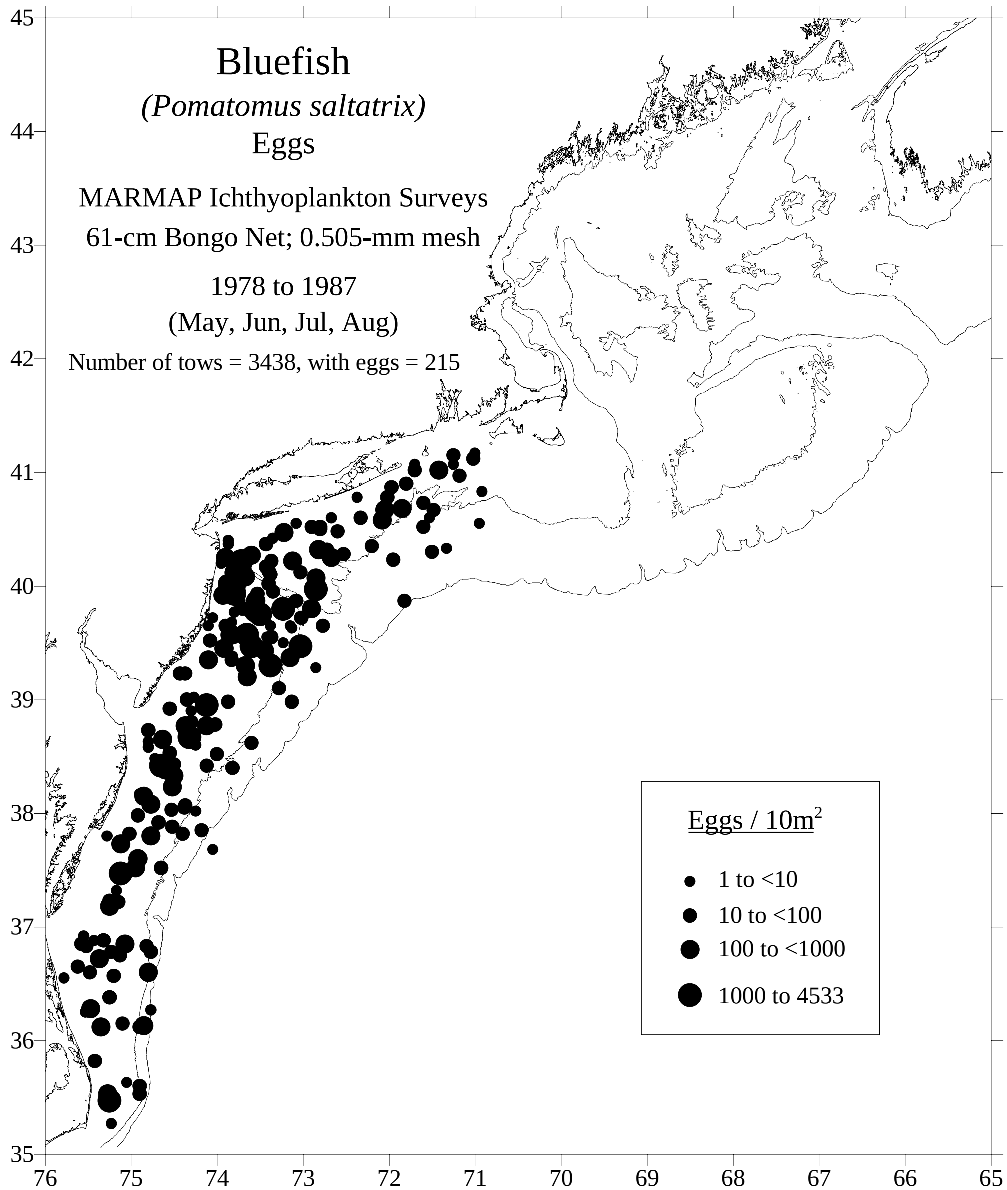


Figure 3. Distribution and abundance of bluefish eggs collected during NEFSC MARMAP ichthyoplankton surveys in the Mid-Atlantic Bight from 1978-1987 [survey also covered the Gulf of Maine and Georges Bank; see Reid *et al.* (1999) for details].

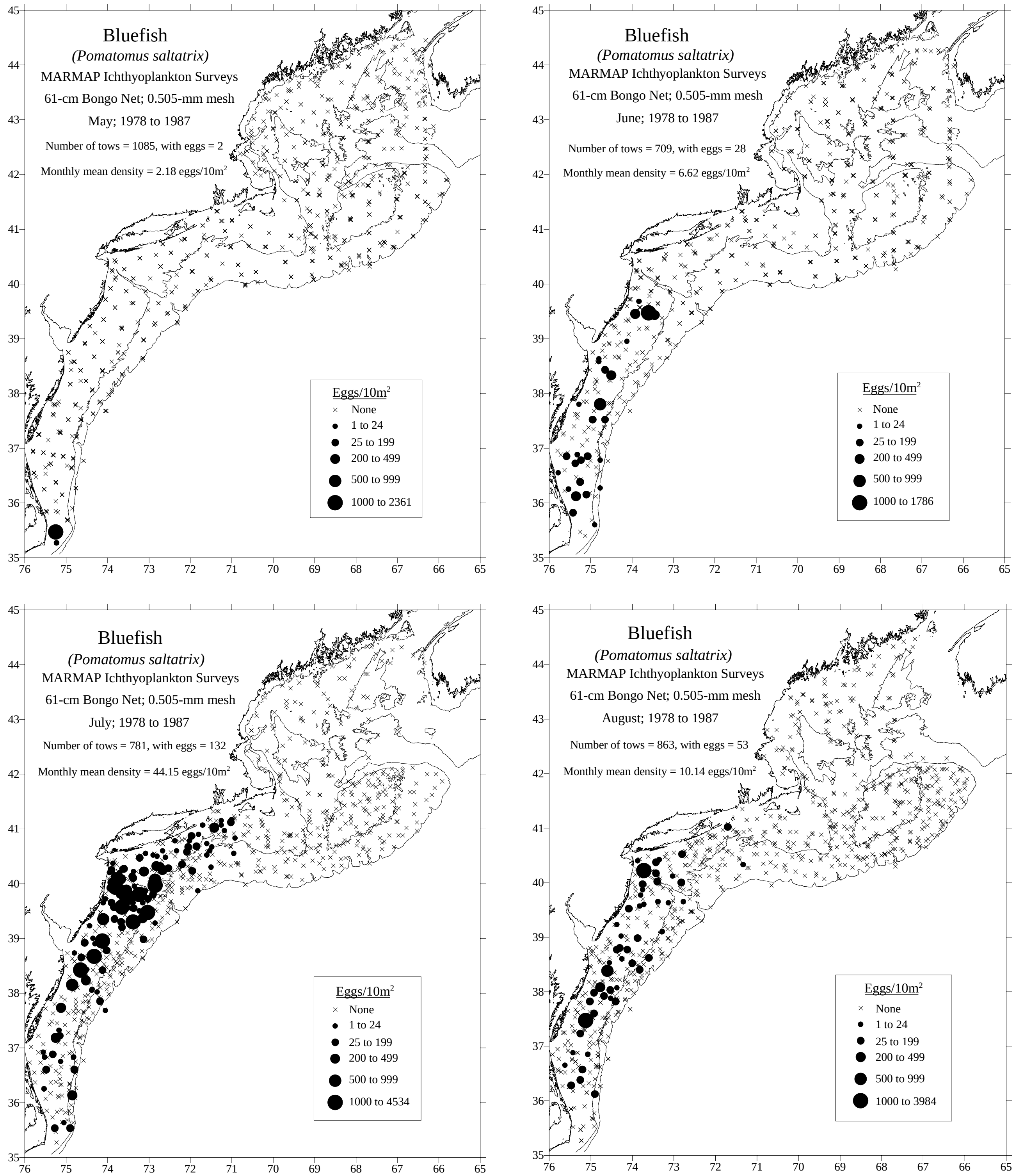


Figure 3. cont'd.

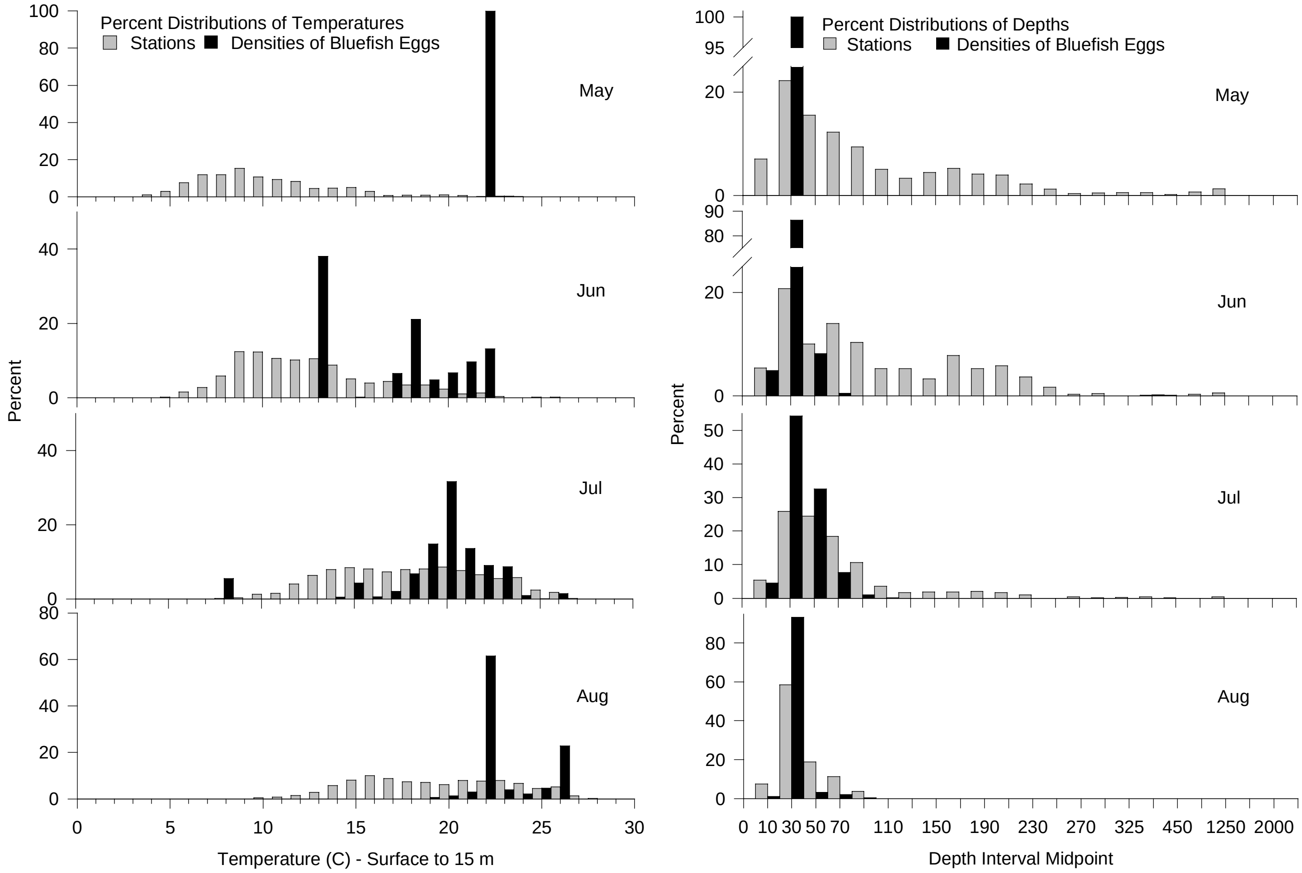


Figure 4. Abundance of bluefish eggs relative to near-surface water column temperature and depth based on NEFSC MARMAP ichthyoplankton surveys in the Mid-Atlantic Bight (May- August 1978-1987, all years combined).

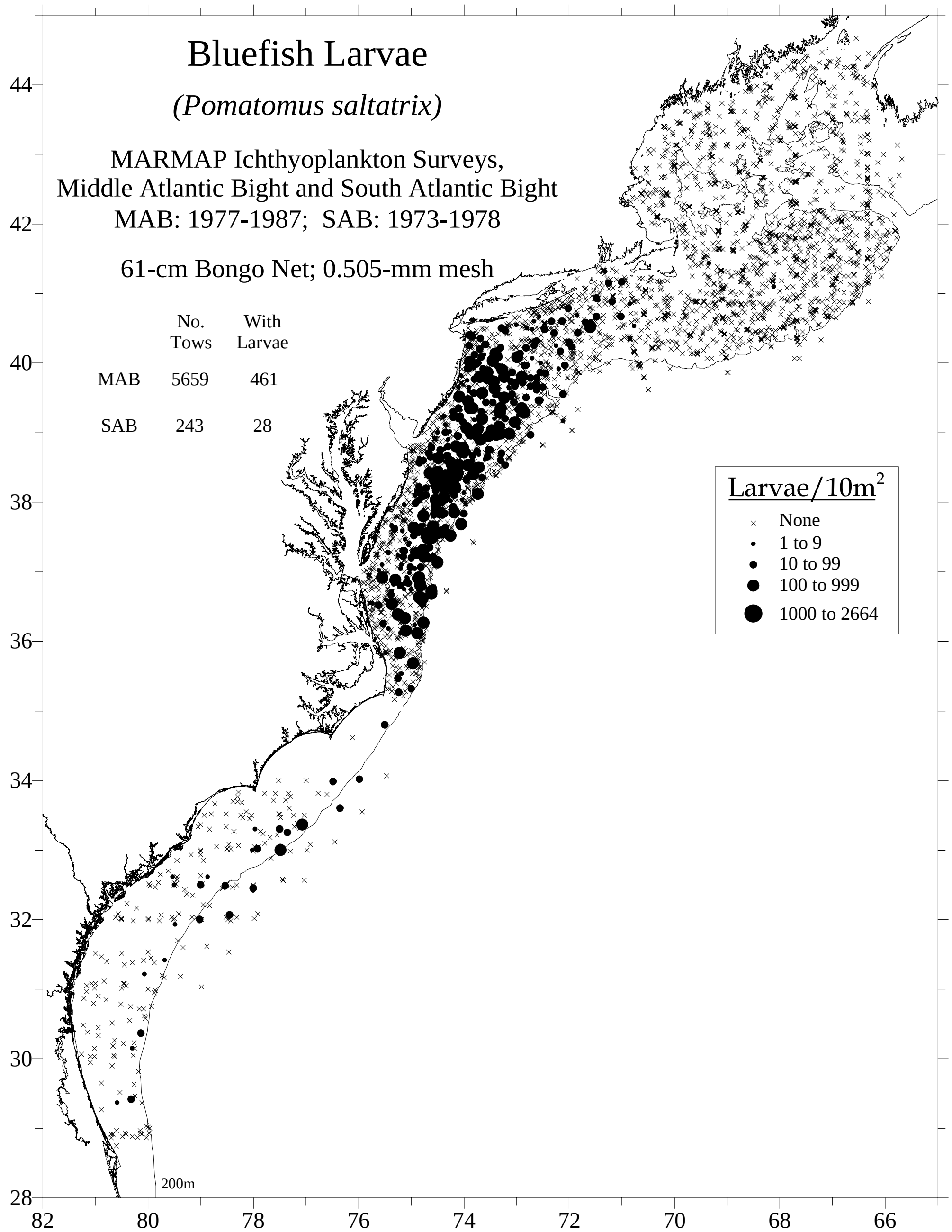


Figure 5. Distribution and abundance of bluefish larvae collected during NEFSC MARMAP ichthyoplankton surveys of both the Mid-Atlantic Bight (1977-1987) and South Atlantic Bight (1973-1978) [survey also covered the Gulf of Maine and Georges Bank; see Reid *et al.* (1999) for details].

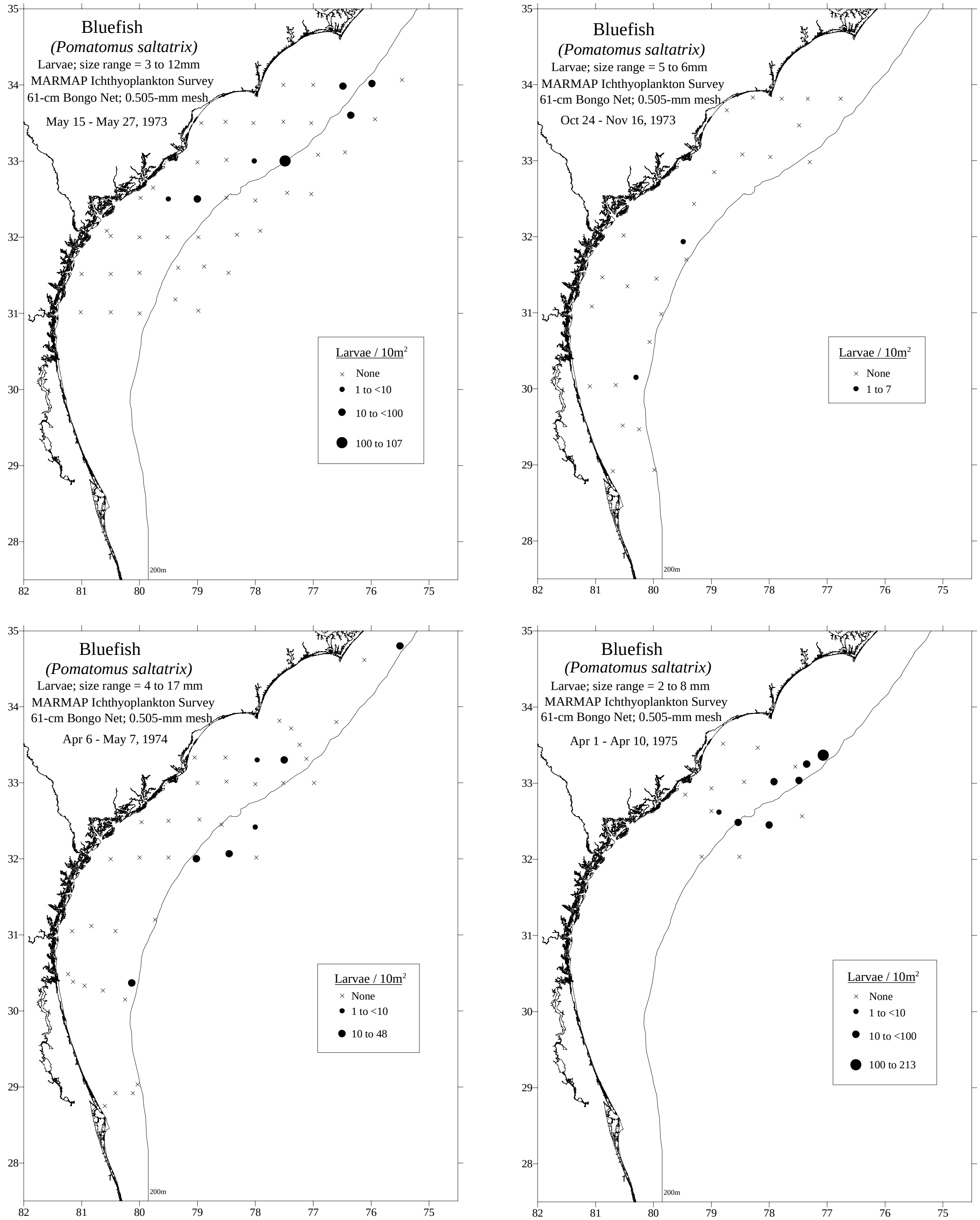
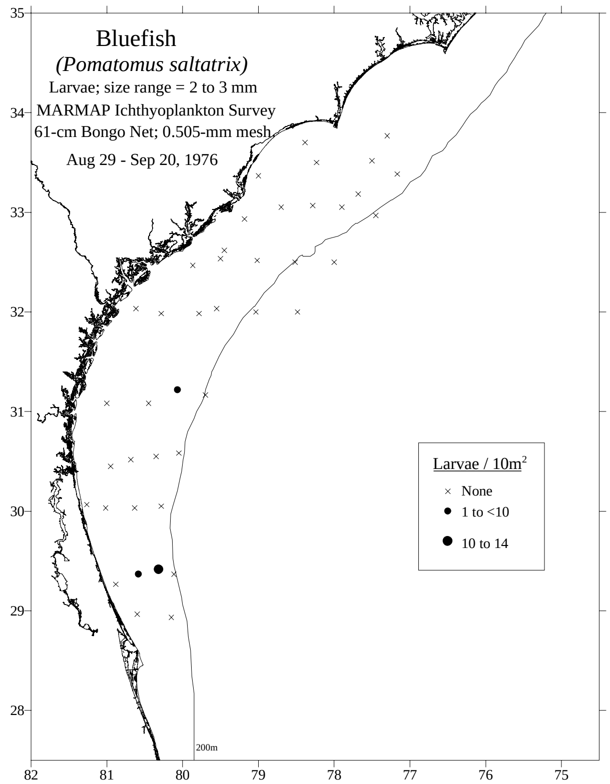
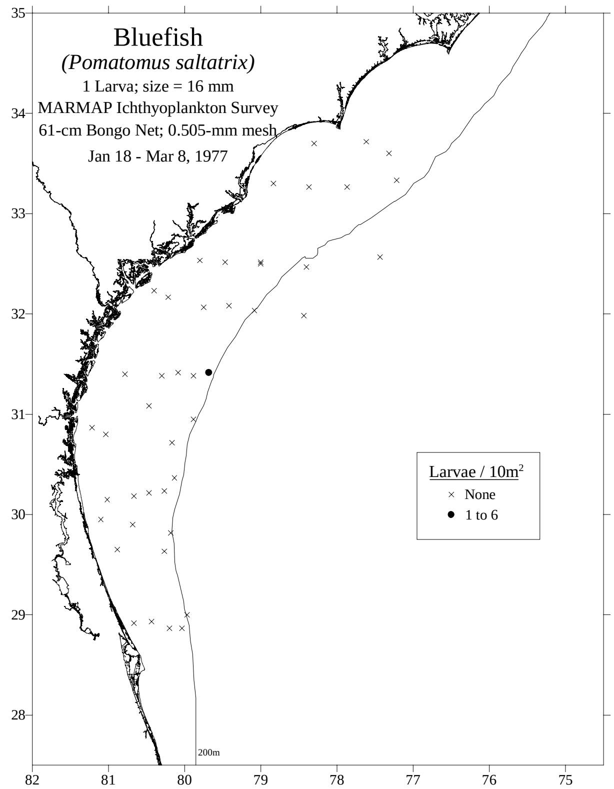


Figure 6. Distribution and abundance of bluefish larvae collected with a bongo net in the South Atlantic Bight during NEFSC MARMAP ichthyoplankton surveys [see Reid *et al.* (1999) for details].





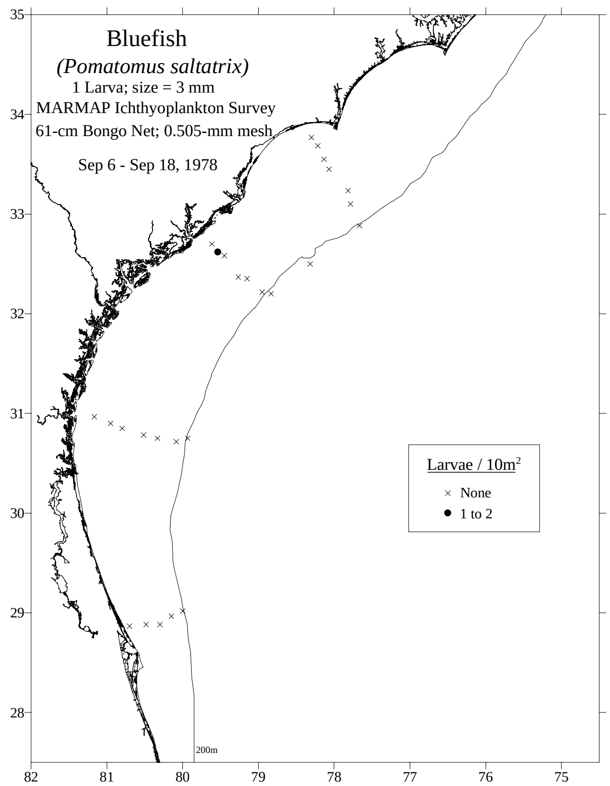


Figure 6. cont'd.

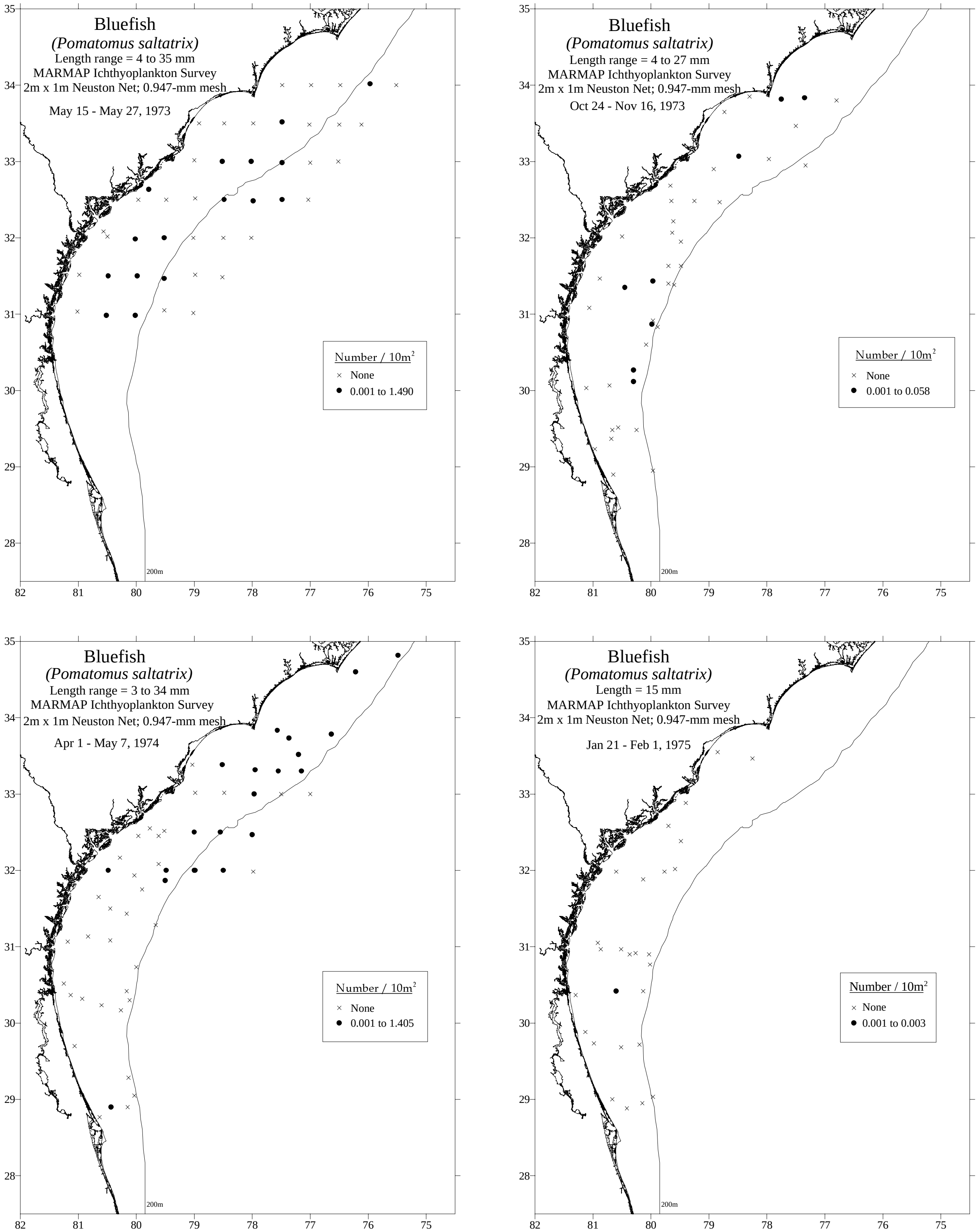


Figure 7. Distribution and abundance of bluefish larvae collected in a neuston net in the South Atlantic Bight during NEFSC MARMAP ichthyoplankton surveys [see Reid *et al.* (1999) for details].

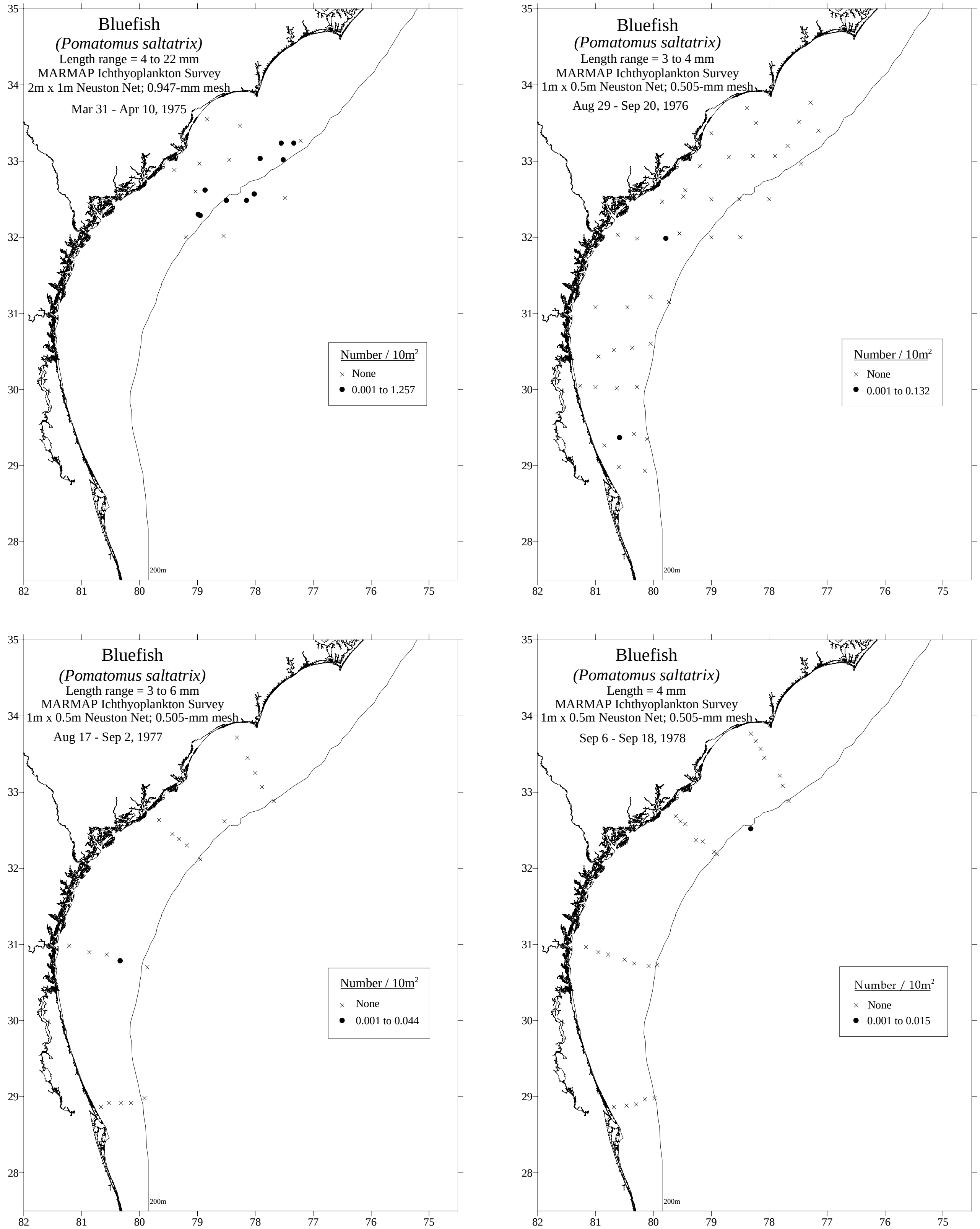


Figure 7. cont'd.

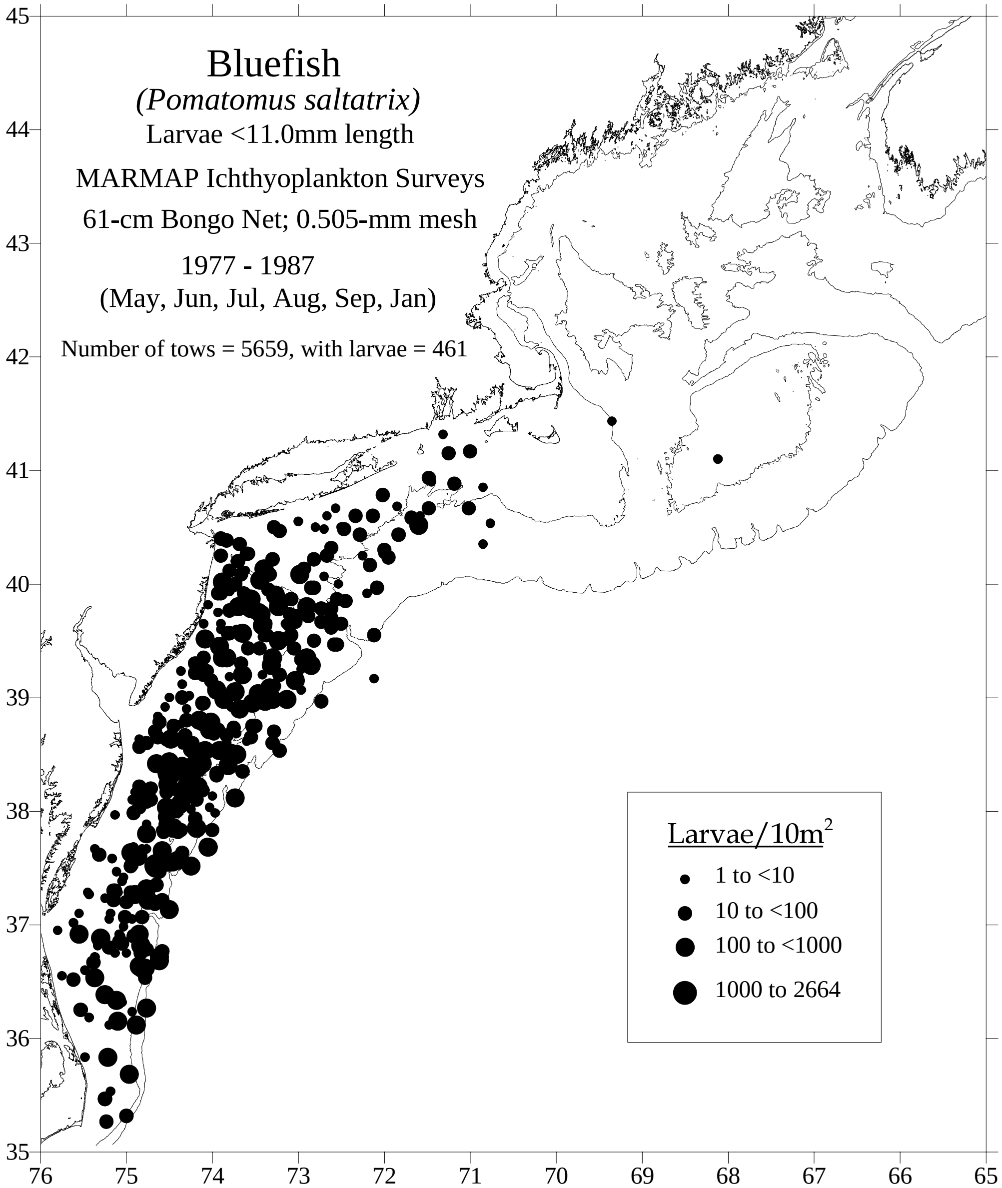
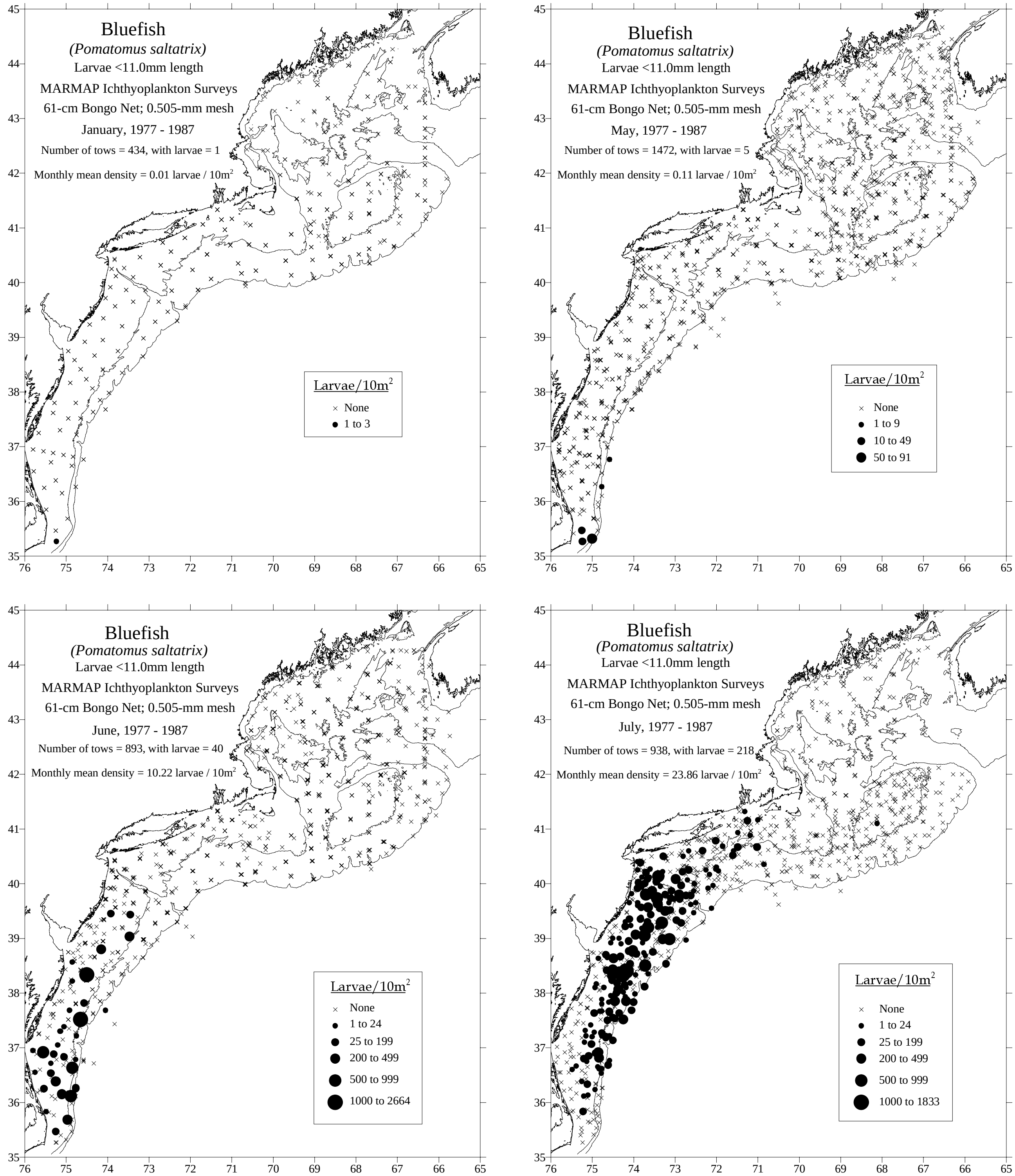


Figure 8. Distribution and abundance of bluefish larvae collected during NEFSC MARMAP ichthyoplankton surveys in the Mid-Atlantic Bight from 1977-1987 [survey also covered the Gulf of Maine and Georges Bank; see Reid *et al.* (1999) for details].



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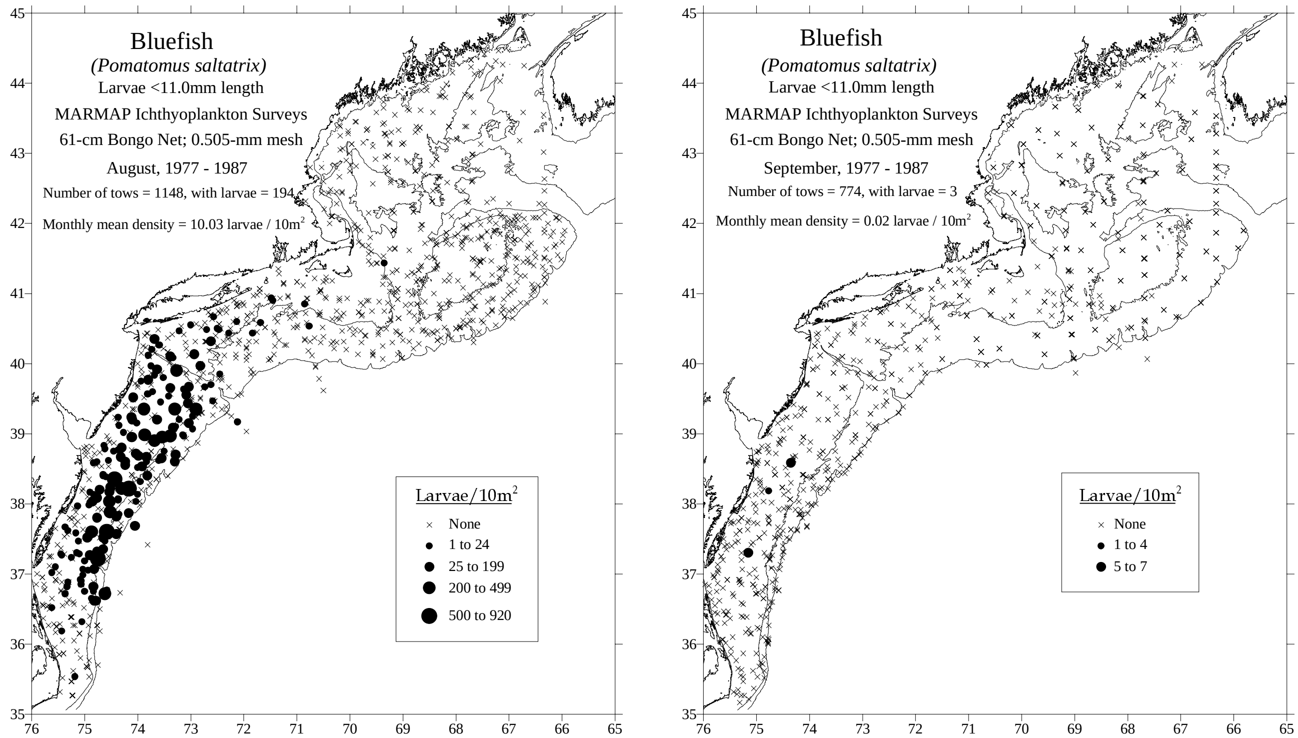

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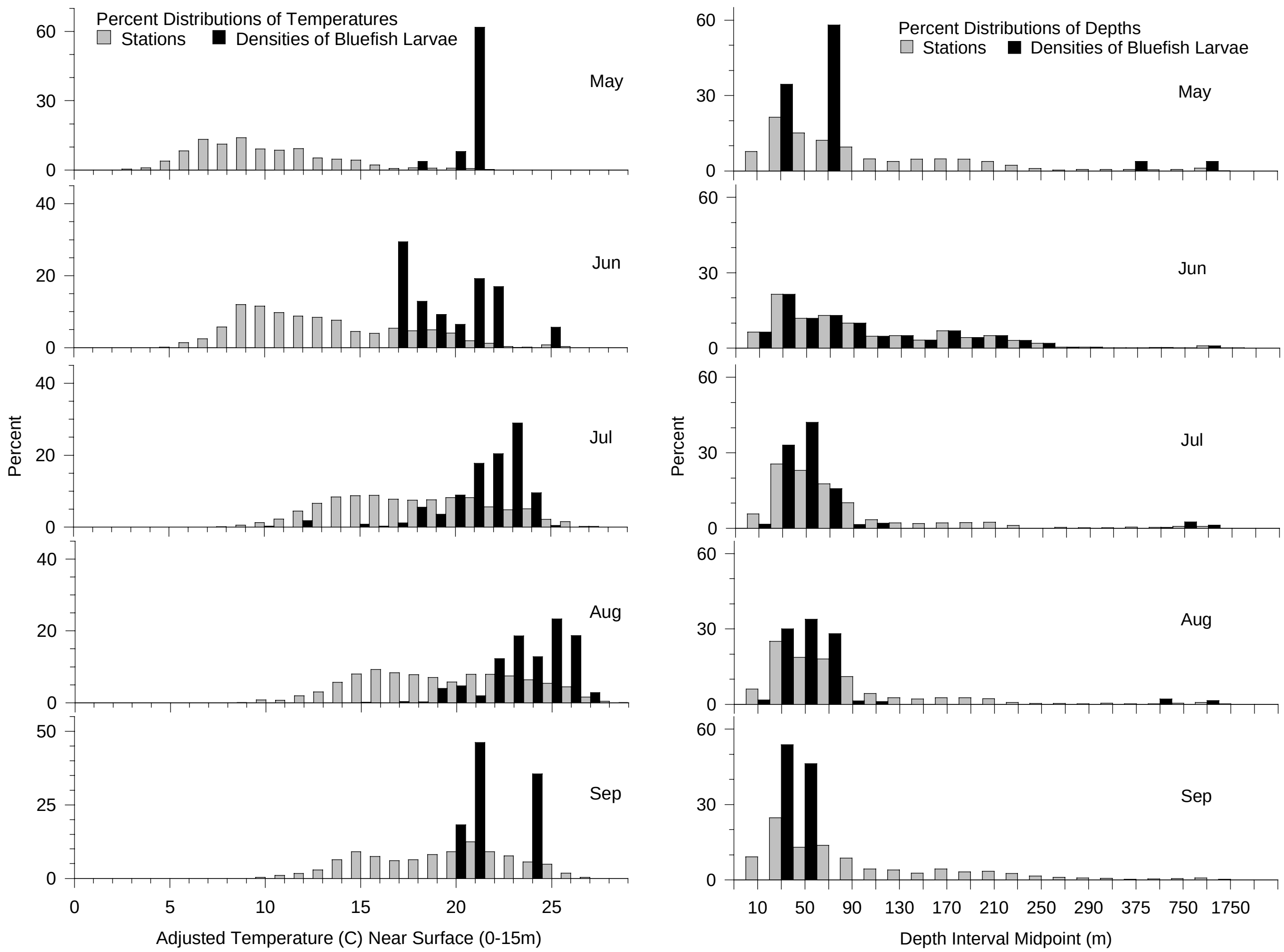


Figure 9. Abundance of bluefish larvae relative to near-surface water column temperature and depth based on NEFSC MARMAP ichthyoplankton surveys in the Mid-Atlantic Bight (May-September 1977-1987, all years combined).

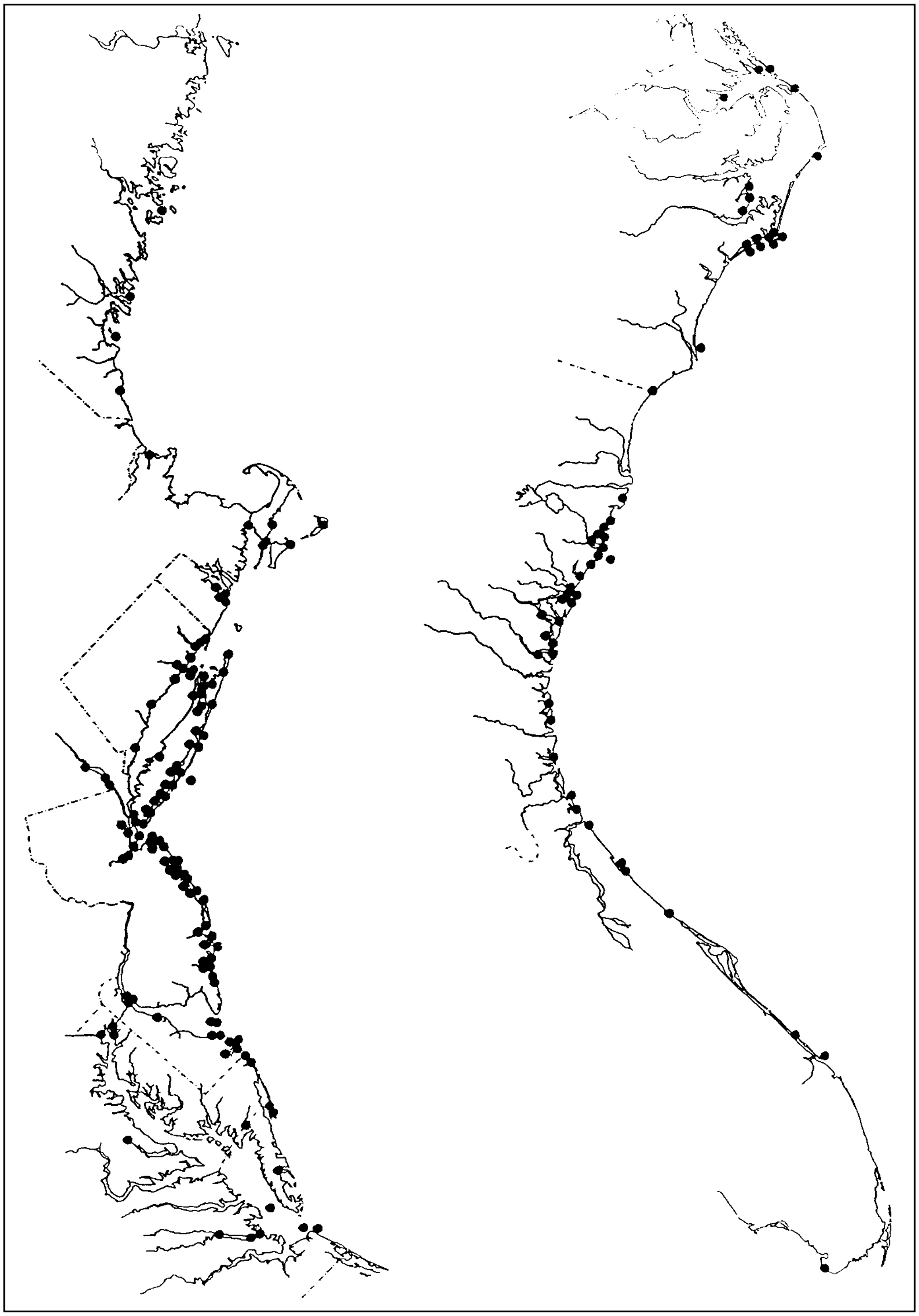


Figure 10. Reported occurrences of juvenile bluefish along the east coast of the United States (Clark 1973).

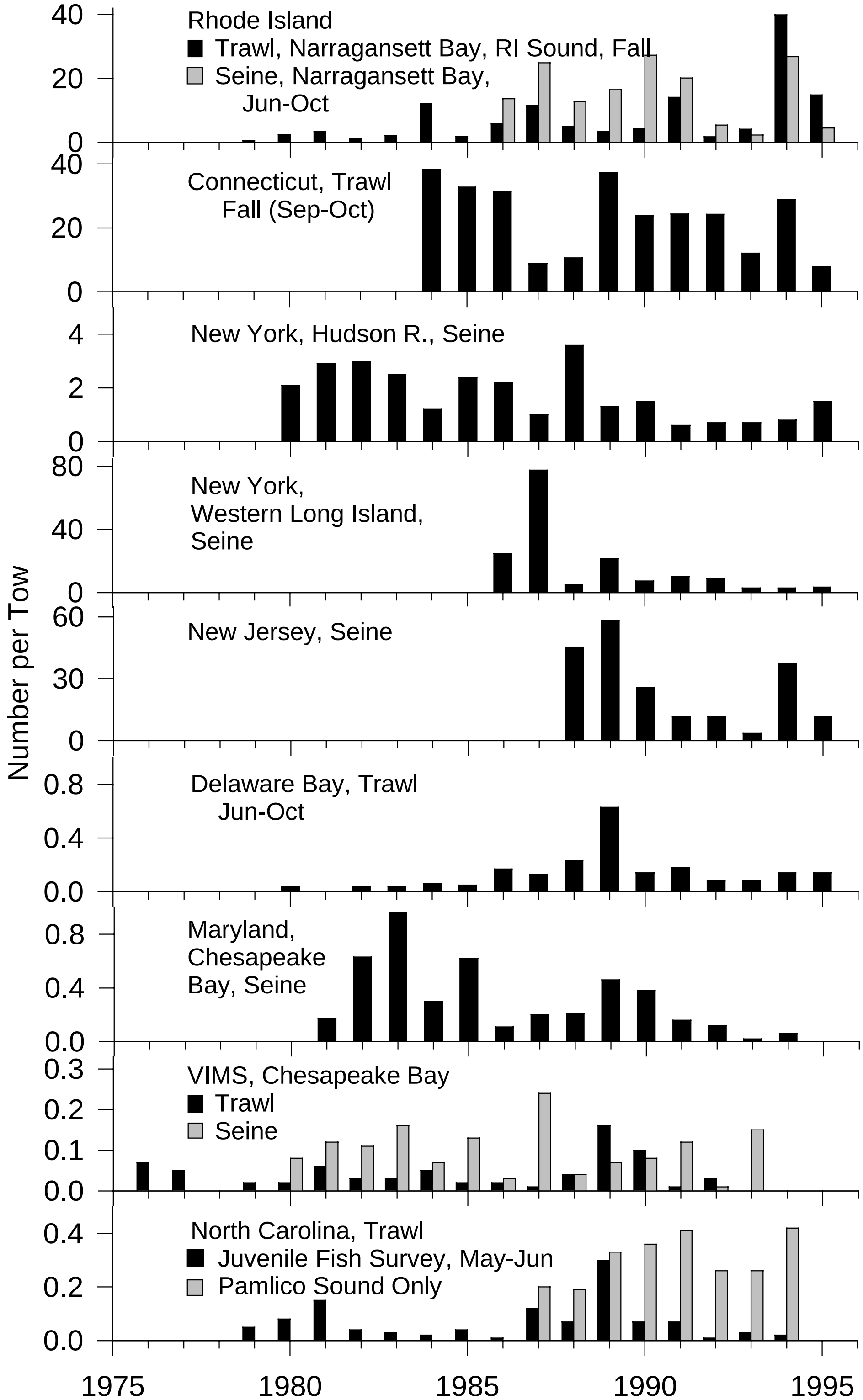


Figure 11. Abundance (number/tow) of young-of-the-year bluefish in seine and trawl surveys by state and by year.

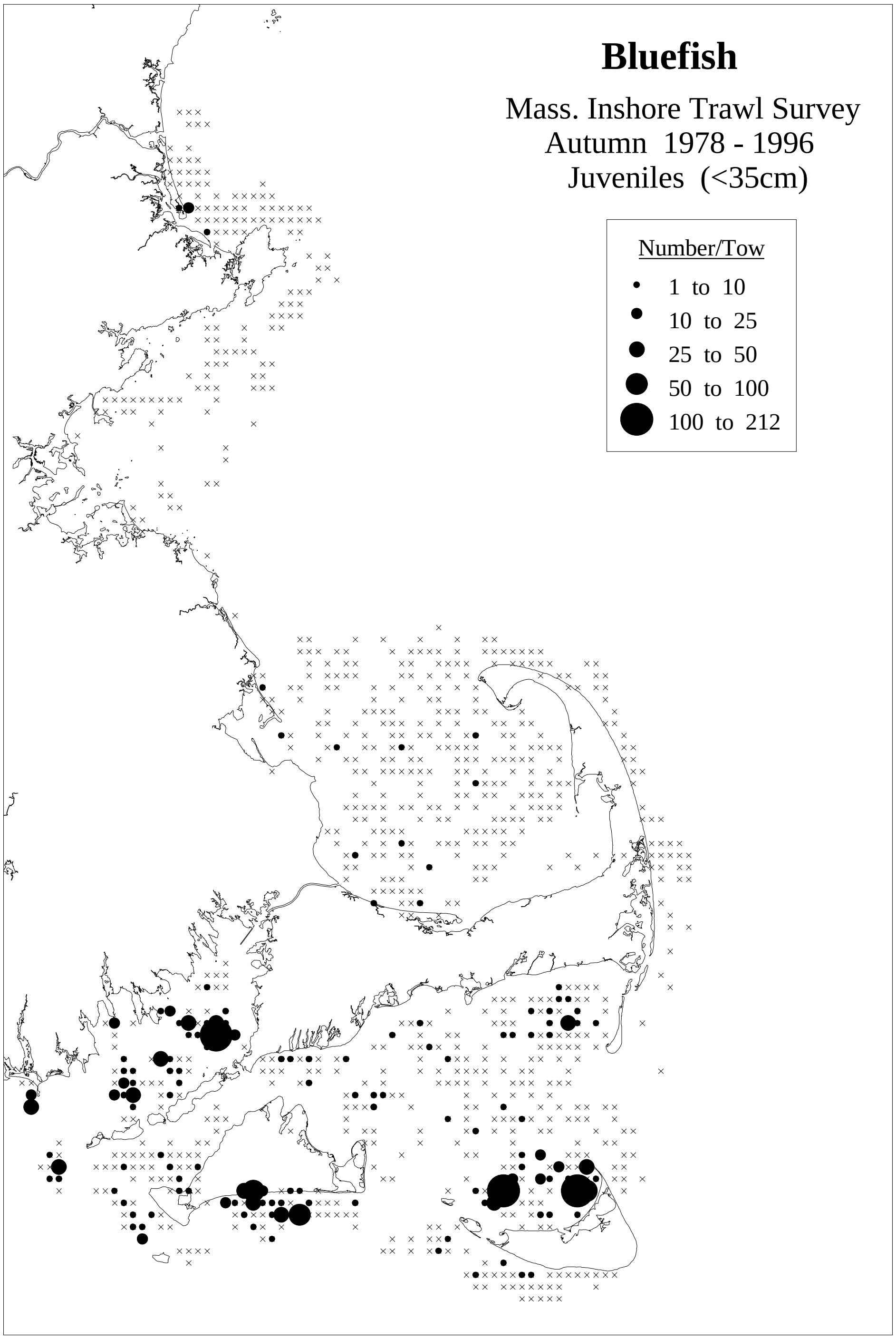
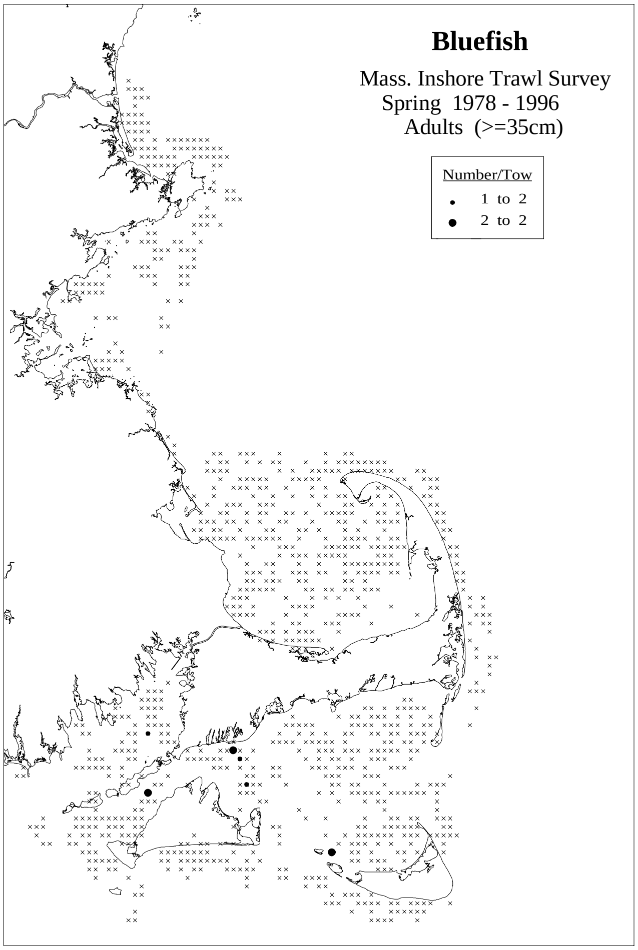


Figure 12. Distribution and abundance of juvenile and adult bluefish collected in Massachusetts coastal waters during spring (adults only) and autumn (both juveniles and adults) Massachusetts inshore trawl surveys [1978-1996, all years combined; see Reid *et al.* (1999) for details].



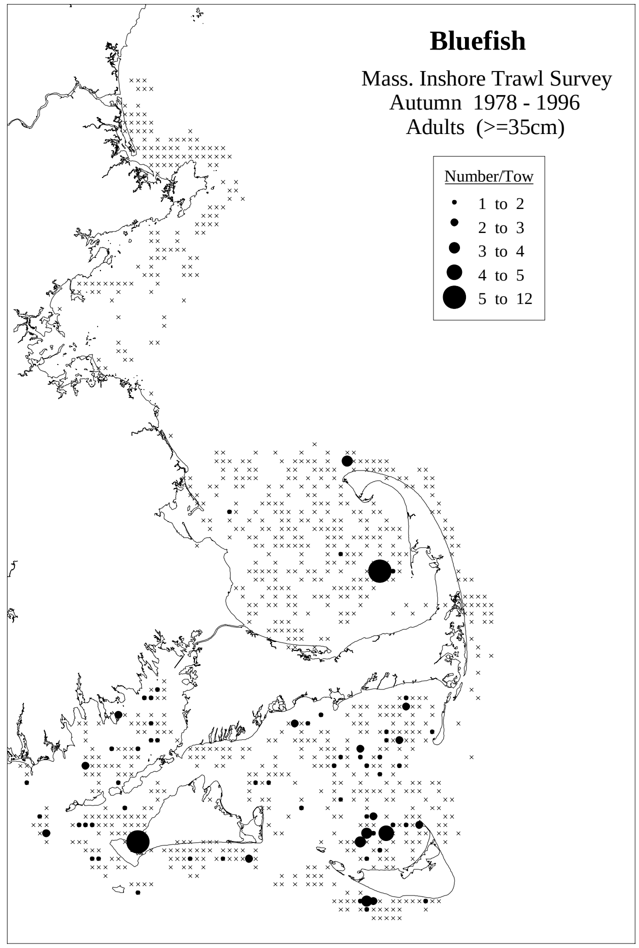


Figure 12. cont'd.

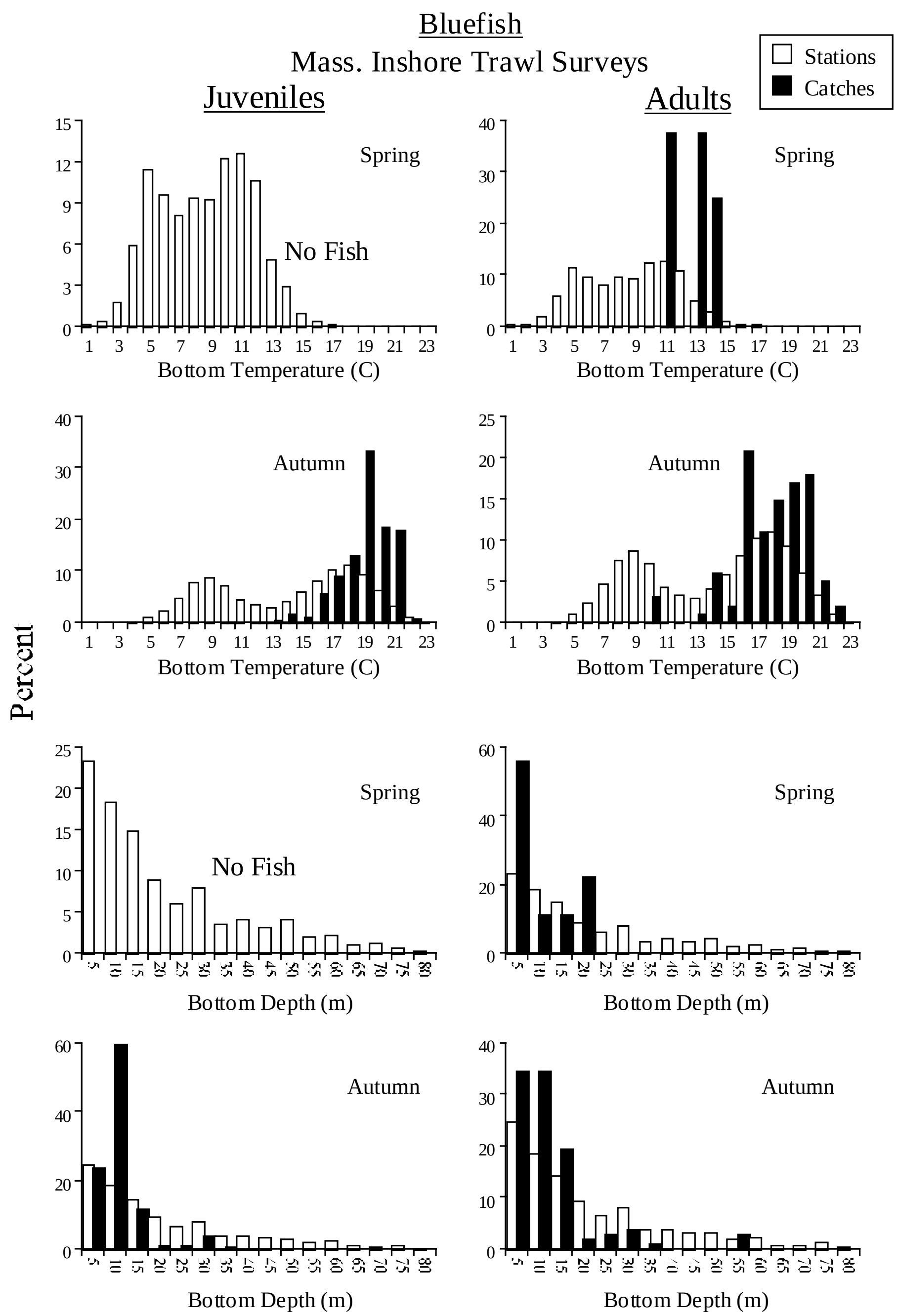


Figure 13. Abundance of juvenile and adult bluefish relative to bottom water temperature and depth based on Massachusetts inshore bottom trawl surveys (spring and autumn 1978-1996, all years combined).

Bluefish Juveniles (< 35 cm)

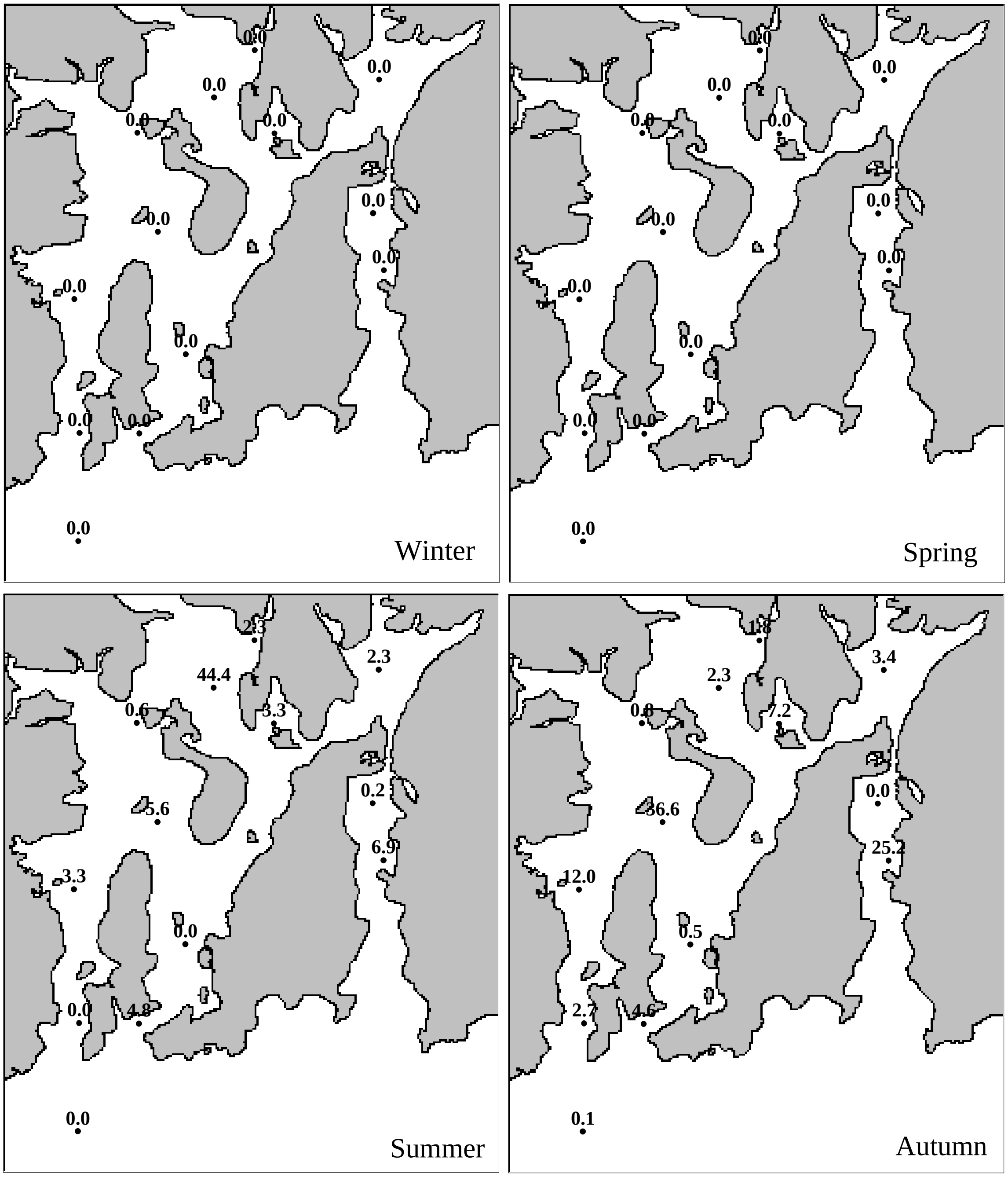


Figure 14. Distribution and abundance of juvenile and adult bluefish collected in Narragansett Bay during 1990-1996 Rhode Island bottom trawl surveys. The numbers shown at each station are the average catch per tow rounded to one decimal place [see Reid *et al.* (1999) for details].

Bluefish Adults (>= 35 cm)

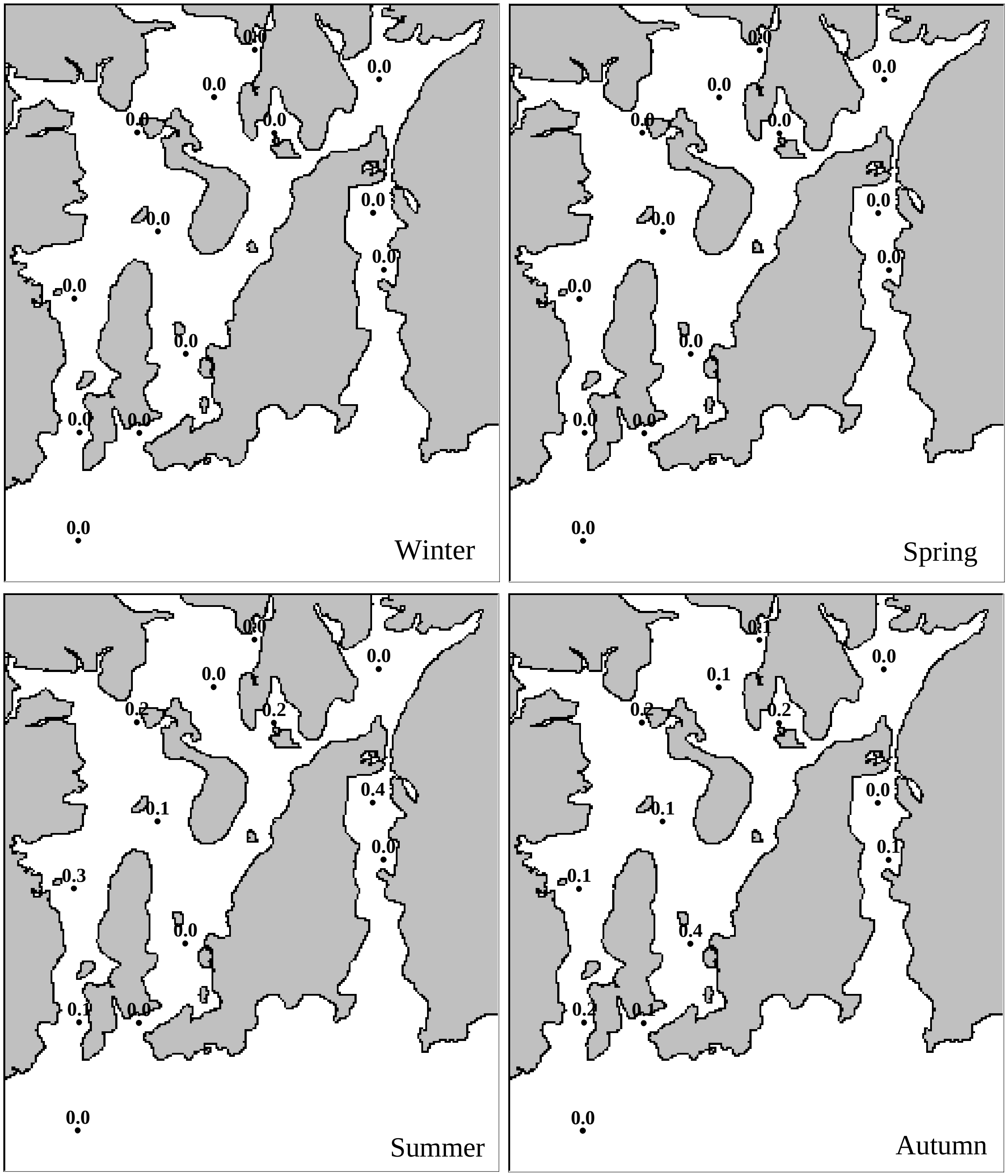


Figure 14. cont'd.

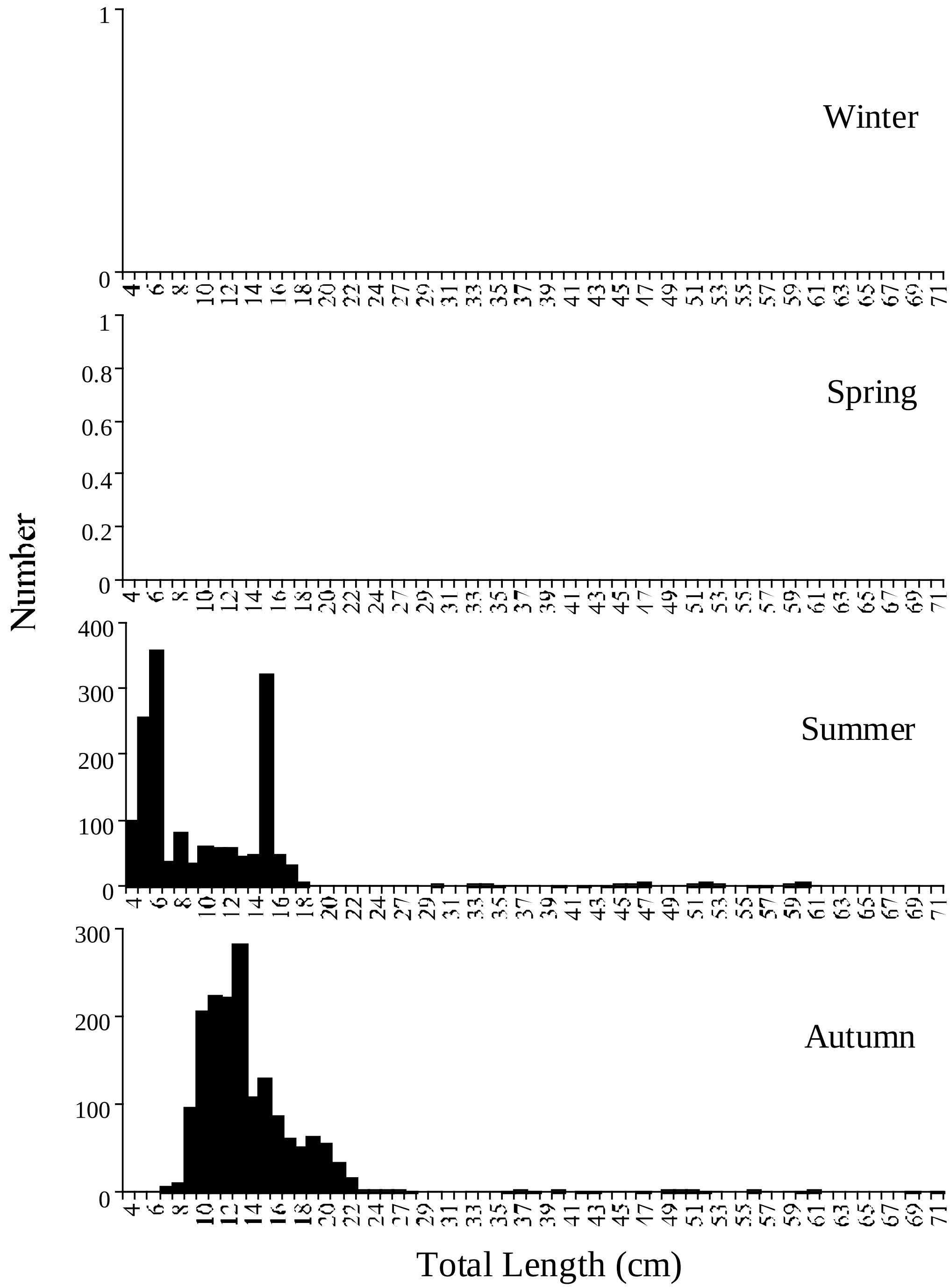


Figure 15. Seasonal length frequency distributions of bluefish collected in Narragansett Bay during 1990-1996 Rhode Island bottom trawl surveys [all years combined; see Reid *et al.* (1999) for details].

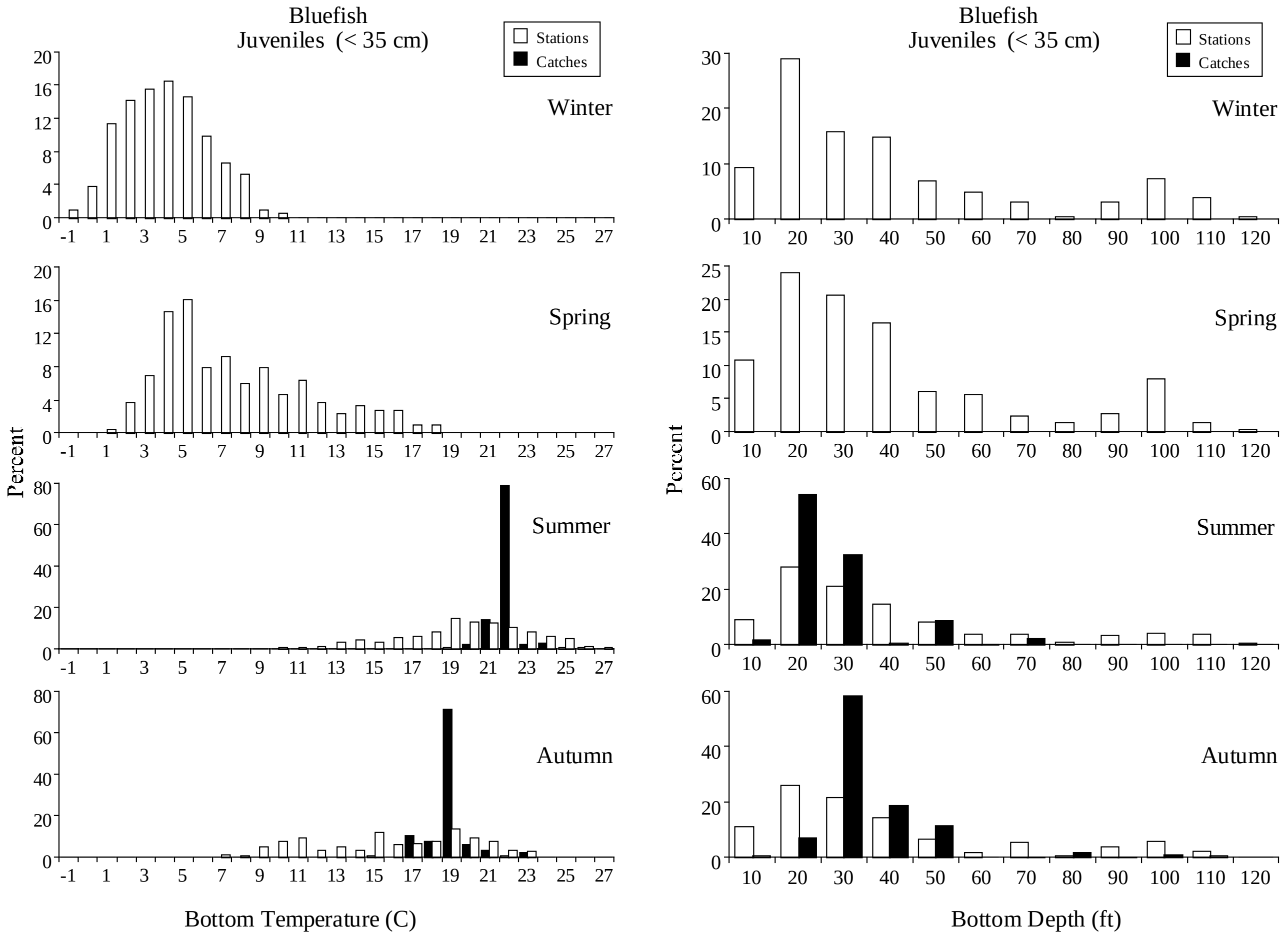


Figure 16. Seasonal abundance of juvenile and adult bluefish relative to bottom water temperature and depth based on Rhode Island Narragansett Bay trawl surveys (1990-1996, all years combined).

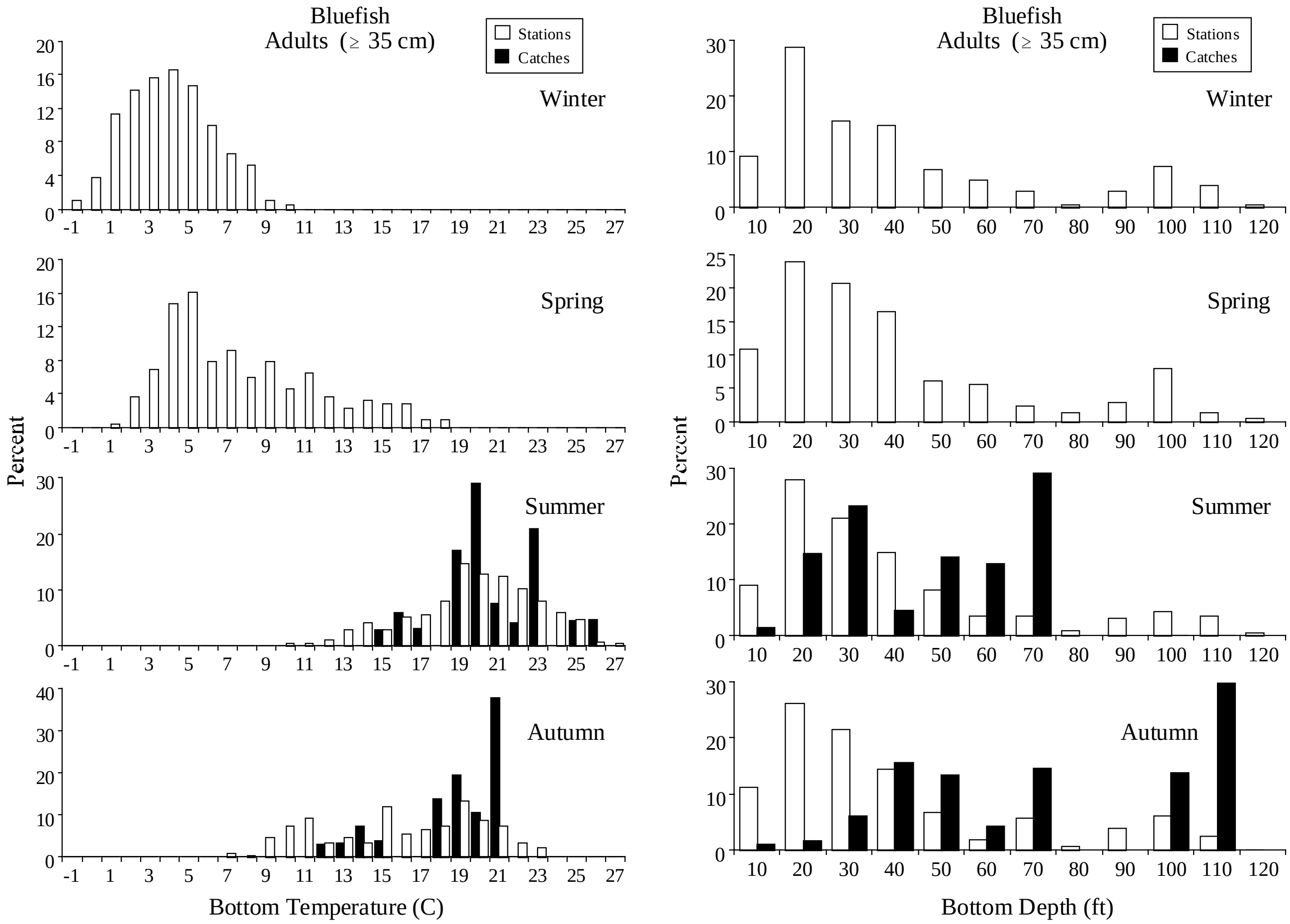


Figure 16. cont'd.

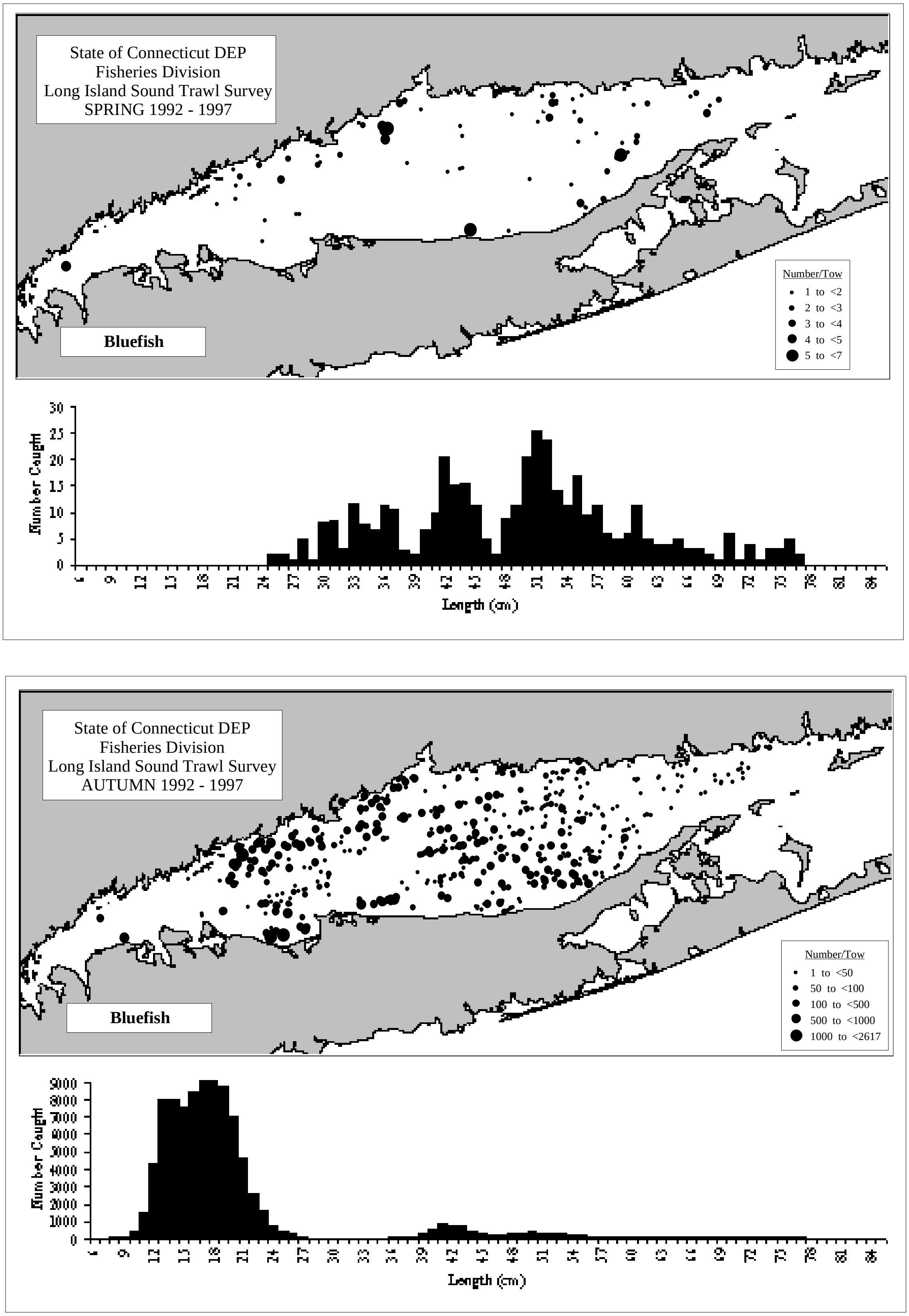
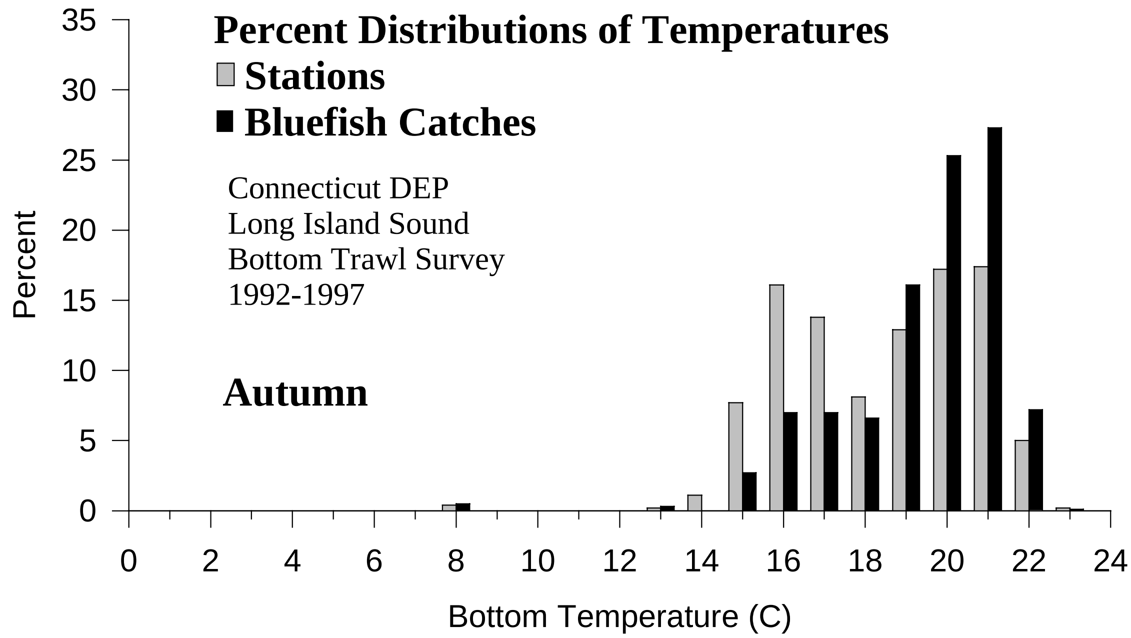


Figure 17. Distribution, abundance, and length frequency distributions of bluefish in Long Island Sound collected during spring and autumn Connecticut bottom trawl surveys [1992-1997, all years combined; see Reid *et al.* (1999) for details].



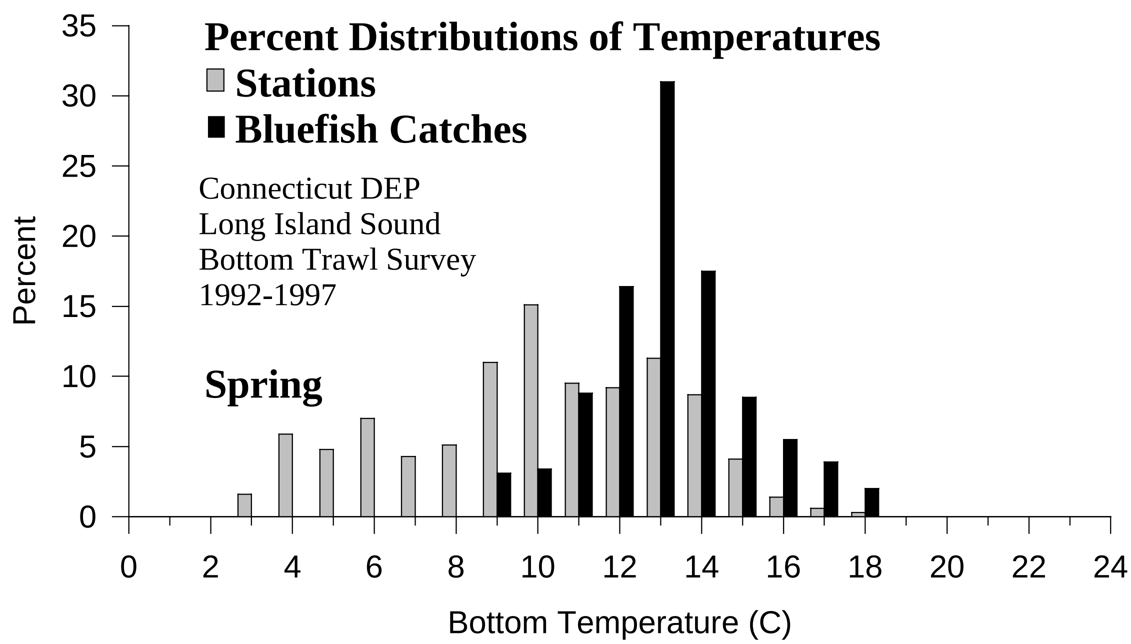


Figure 18. Abundance of bluefish relative to bottom water temperature based on spring and autumn Connecticut bottom trawl surveys in Long Island Sound (1992-1997, all years combined).

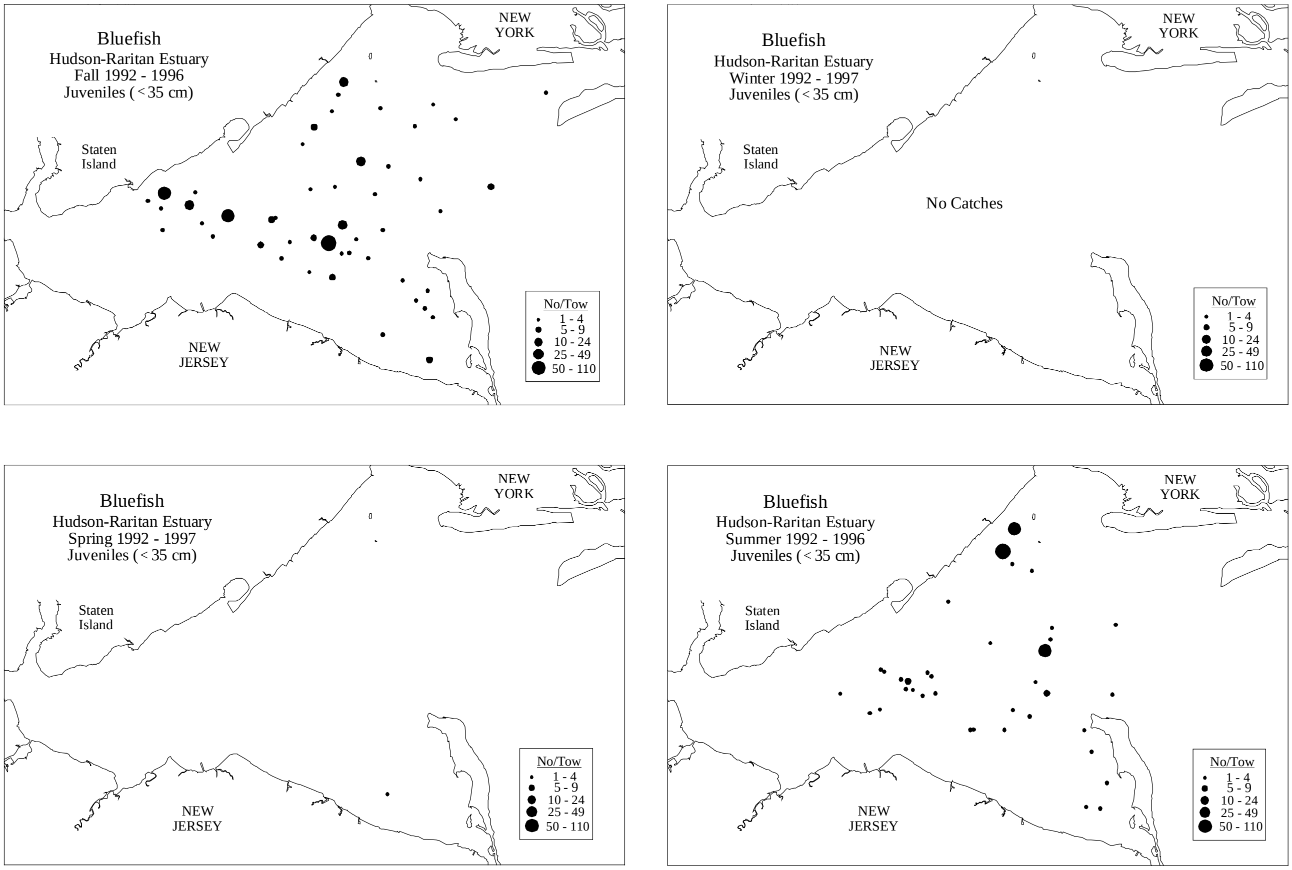


Figure 19. Seasonal distribution and abundance of juvenile and adult bluefish collected in the Hudson-Raritan estuary during Hudson-Raritan trawl surveys [1992-1997, all years combined; see Reid *et al.* (1999) for details].

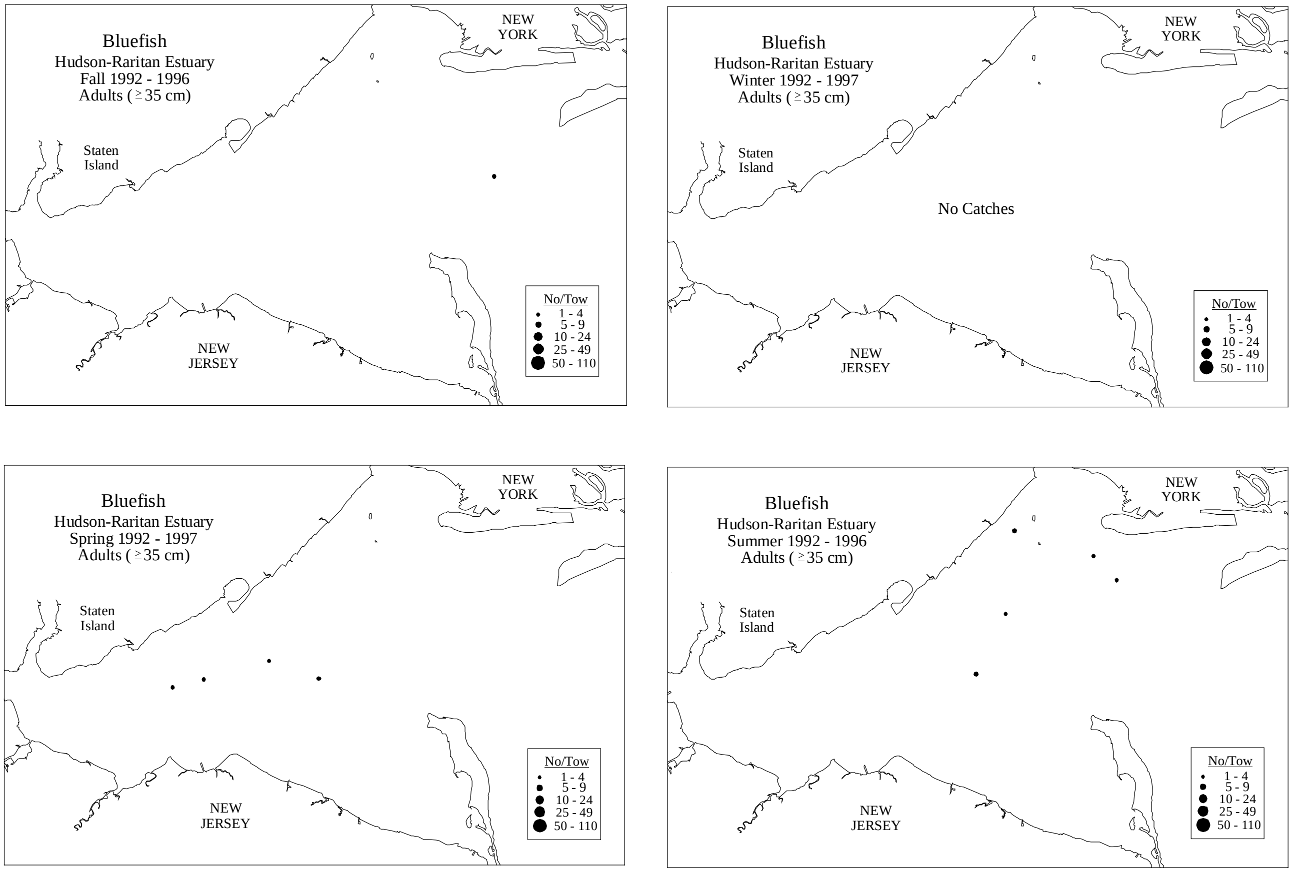


Figure 19. cont'd.

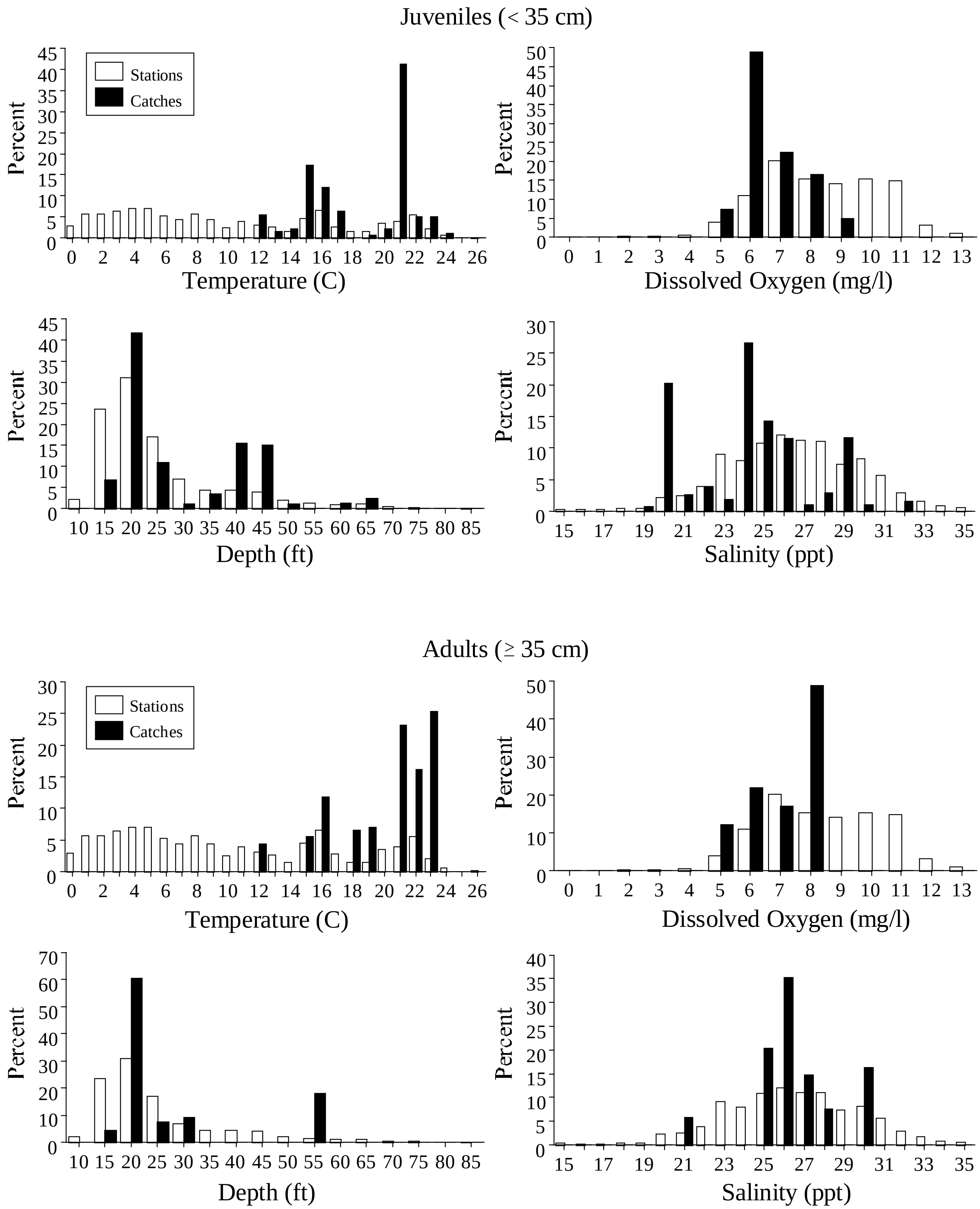


Figure 20. Abundance of juvenile and adult bluefish relative to bottom water temperature, depth, dissolved oxygen, and salinity based on Hudson-Raritan estuary trawl surveys (1992-1997, all years combined).

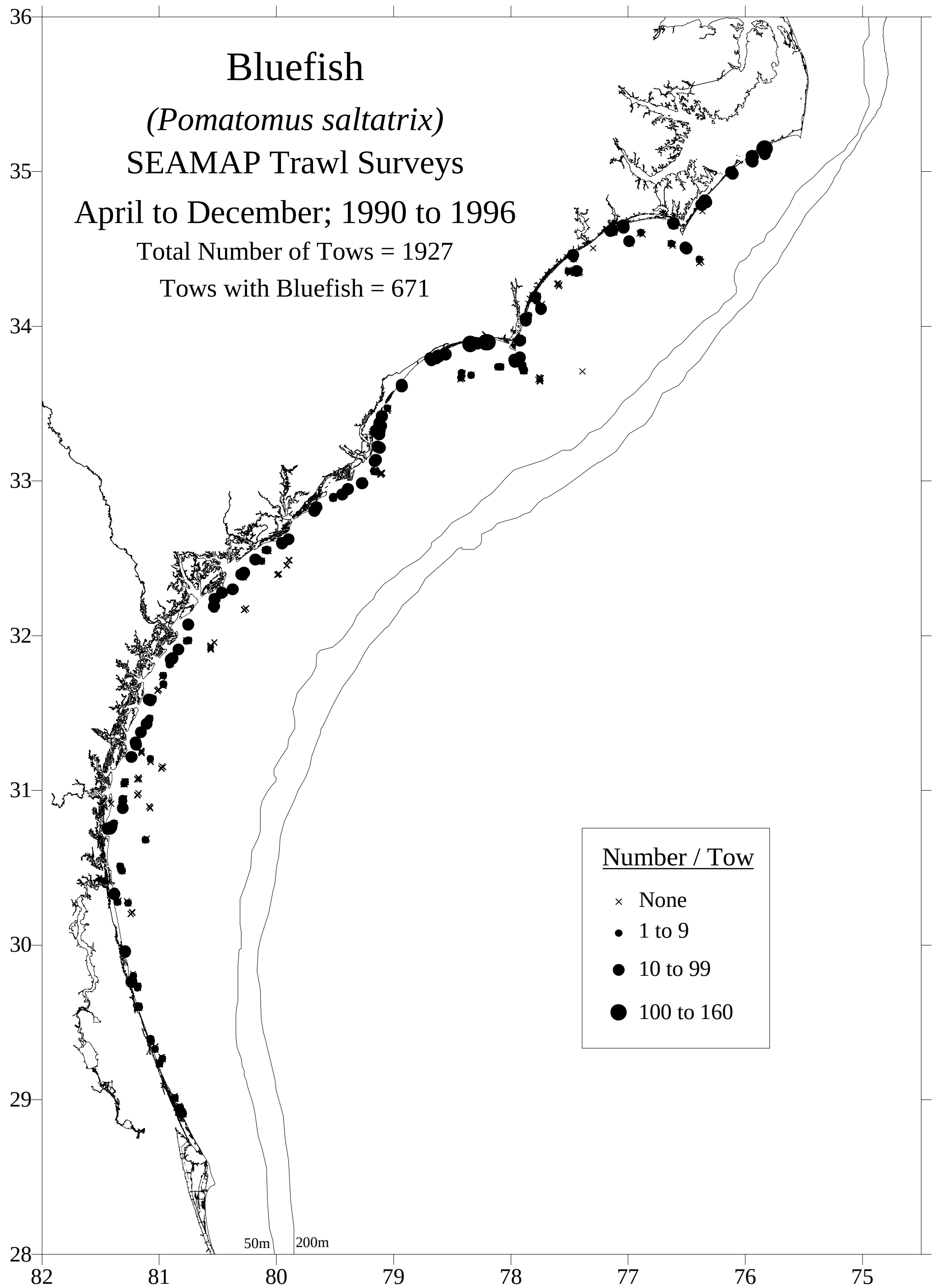


Figure 21. Distribution and abundance of bluefish in the South Atlantic Bight collected during SEAMAP bottom trawl surveys [1990-1996, all years combined; see Reid *et al.* (1999) for details].

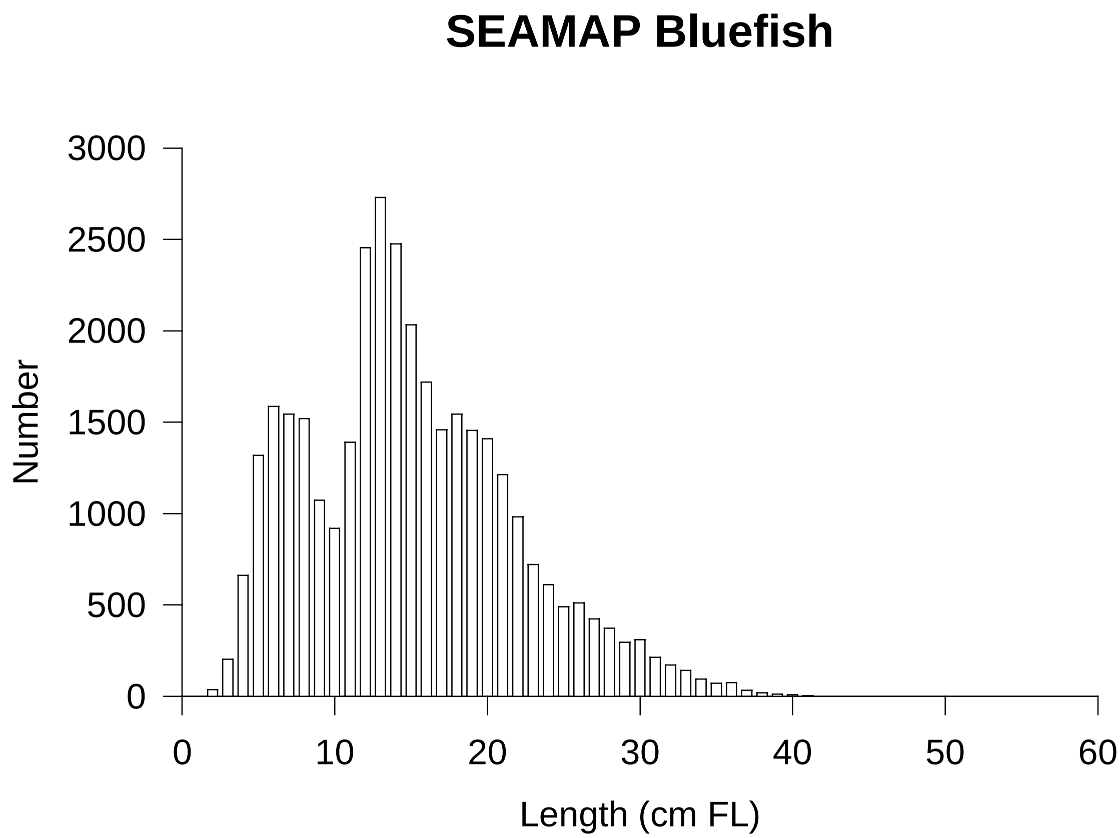


Figure 22. Length frequency distribution of bluefish in the South Atlantic Bight collected during SEAMAP bottom trawl surveys (1990-1996, all years combined).

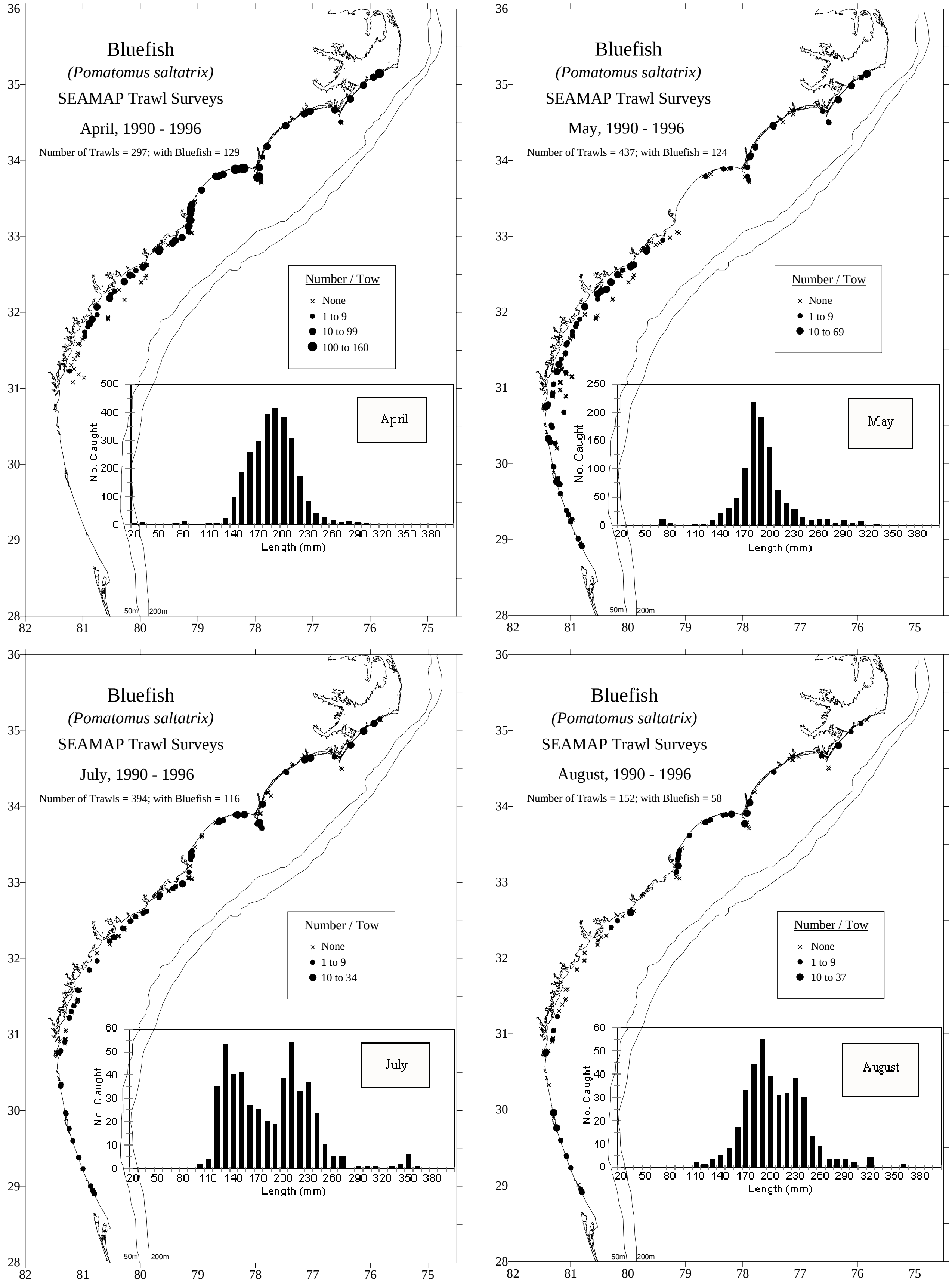
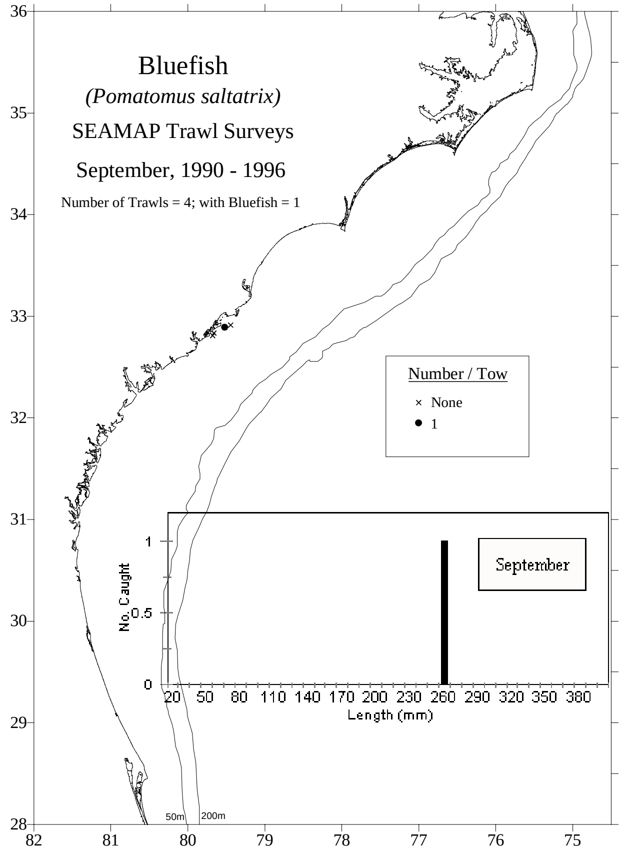
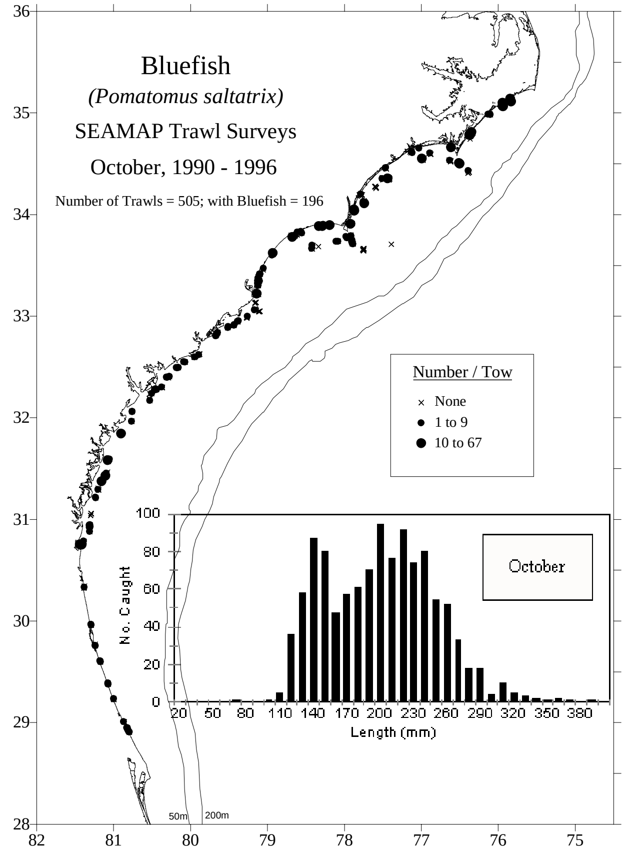


Figure 23. Monthly distribution, abundance, and length frequency distribution of bluefish in the South Atlantic Bight collected during SEAMAP bottom trawl surveys (1990-1996, all years combined).





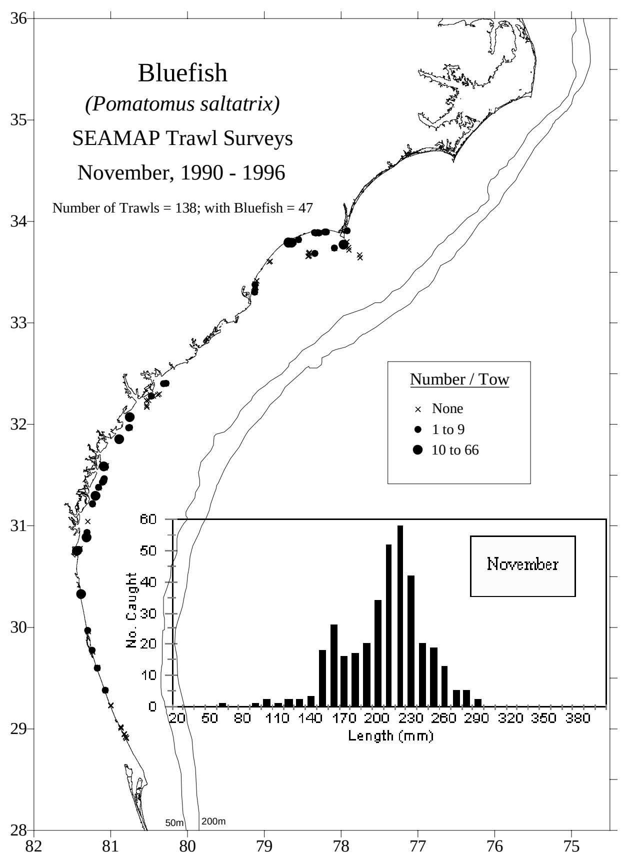


Figure 23. cont'd.

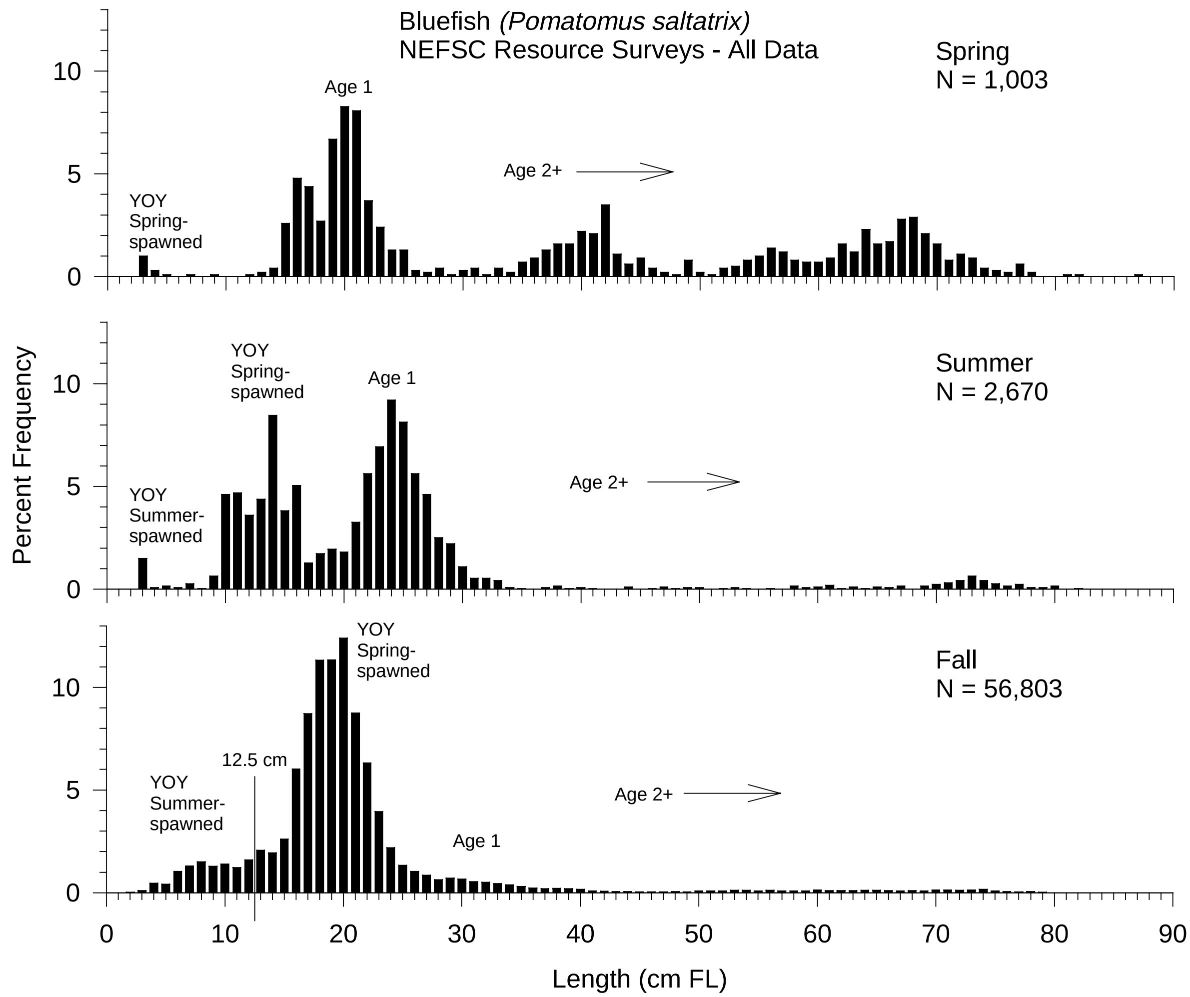


Figure 24. Seasonal length frequency distributions used to determine bluefish size and age cutoffs in NEFSC bottom trawl surveys.

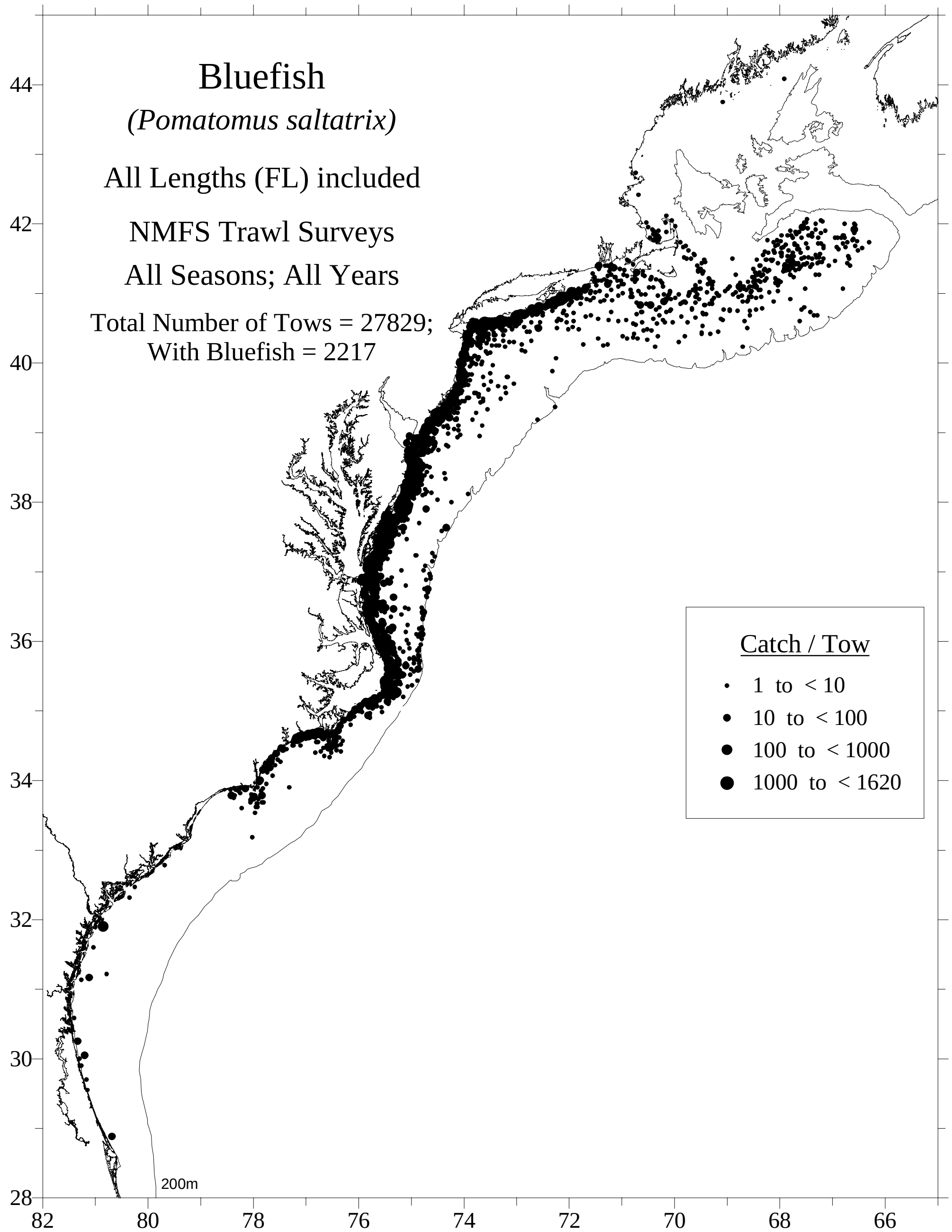


Figure 25. Distribution and abundance of bluefish (all sizes combined) collected off the east coast of the United States during NEFSC bottom trawl surveys [all years and seasons combined; see Reid *et al.* (1999) for details].

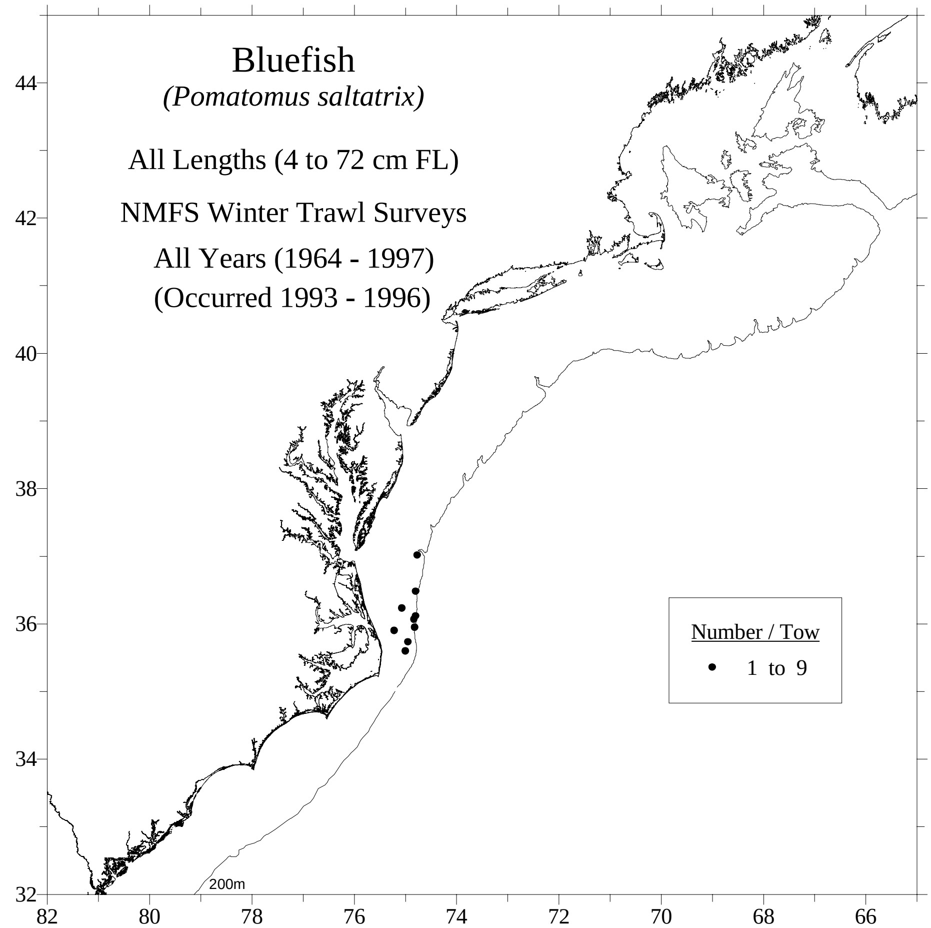


Figure 26. Distribution and abundance of bluefish (all lengths combined) collected off the east coast of the United States during winter NEFSC bottom trawl surveys [1964-1997, all years combined; see Reid *et al.* (1999) for details].

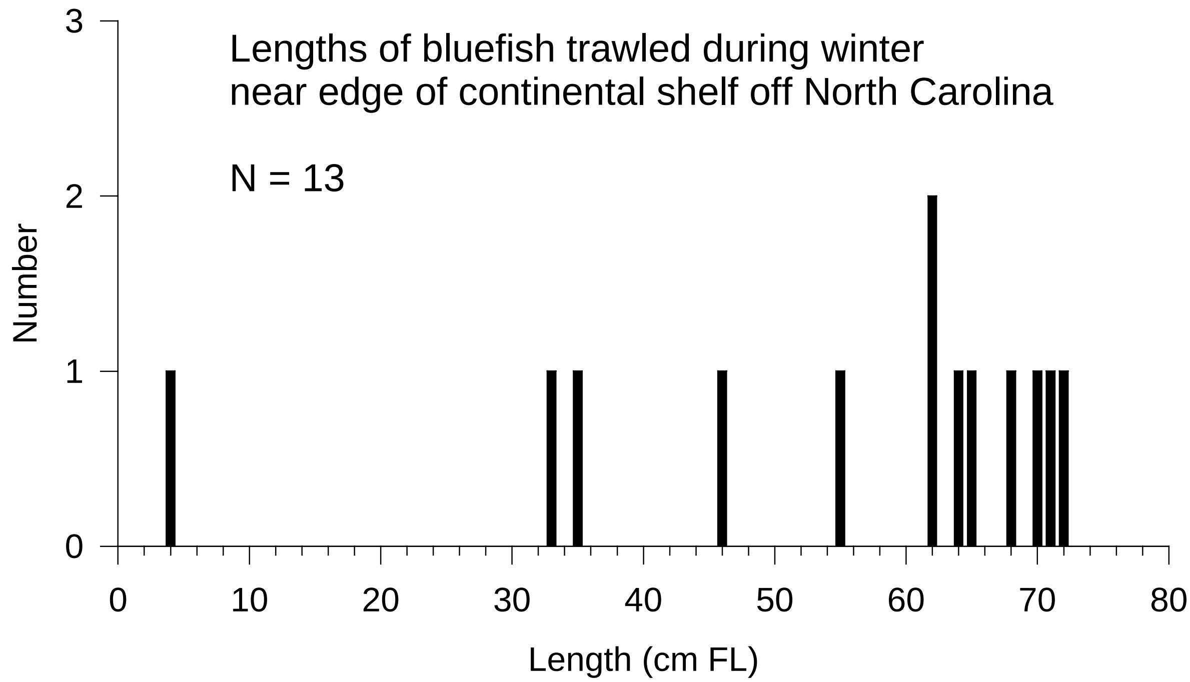


Figure 27. Length frequency distribution of bluefish caught in the winter off North Carolina during winter NEFSC bottom trawl surveys.

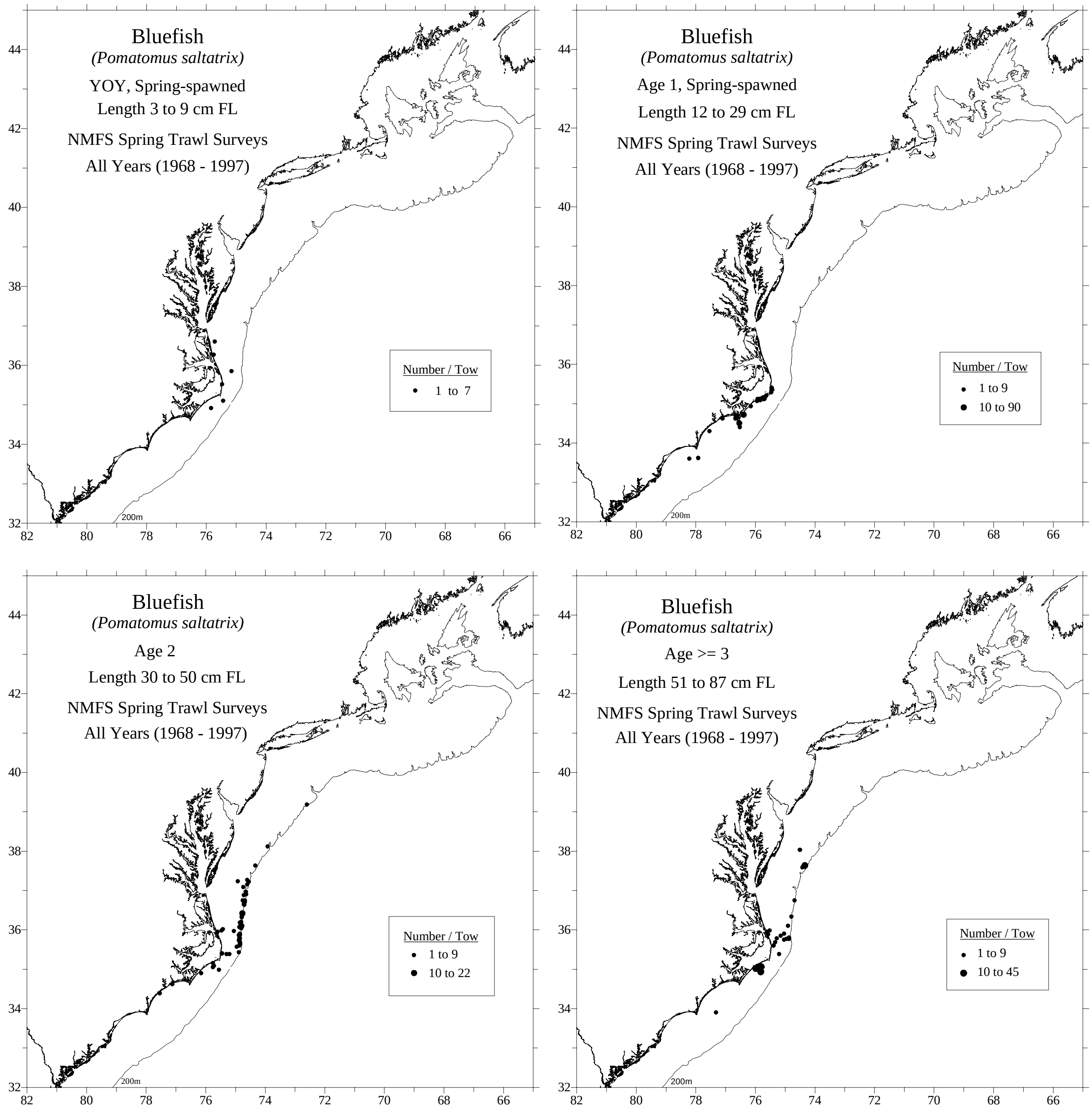


Figure 28. Distribution and abundance of four size classes of bluefish collected off the east coast of the United States during spring NEFSC bottom trawl surveys [1968-1997, all years combined; see Reid *et al.* (1999) for details].

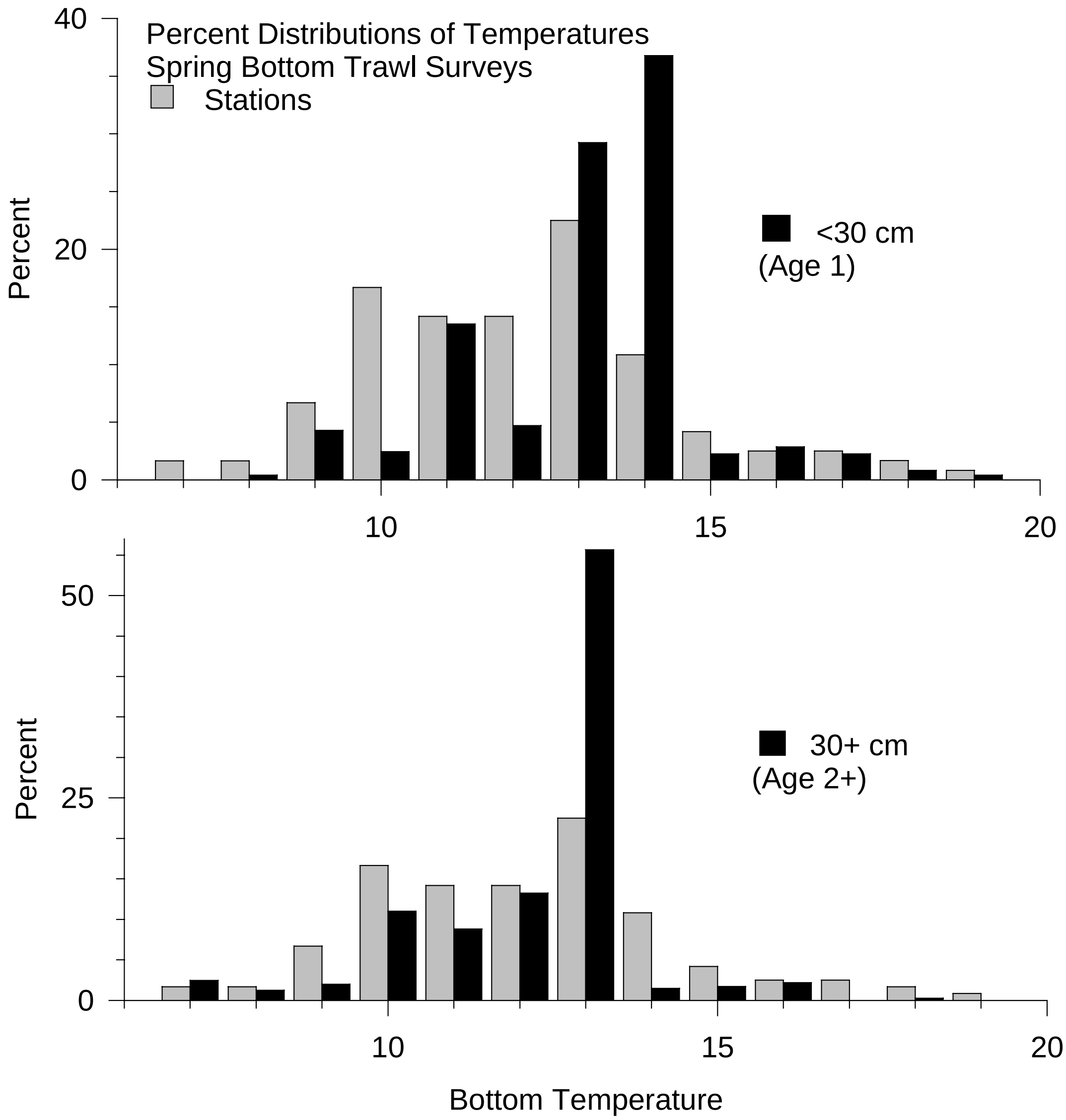


Figure 29. Abundance of large (> 30 cm) and small (< 30 cm) bluefish relative to bottom water temperature and depth based on spring east coast NEFSC bottom trawl surveys.

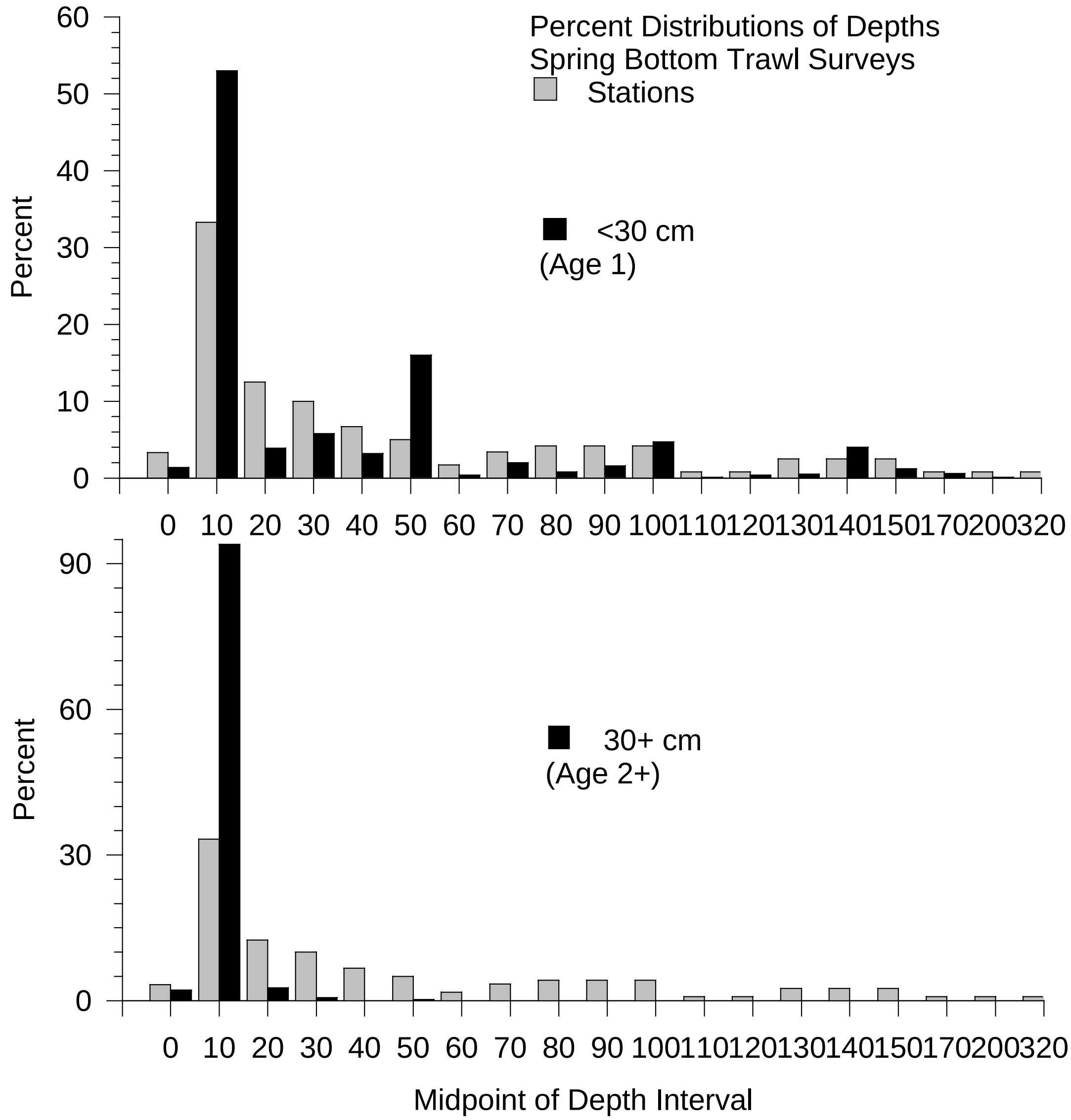


Figure 29. cont’d.

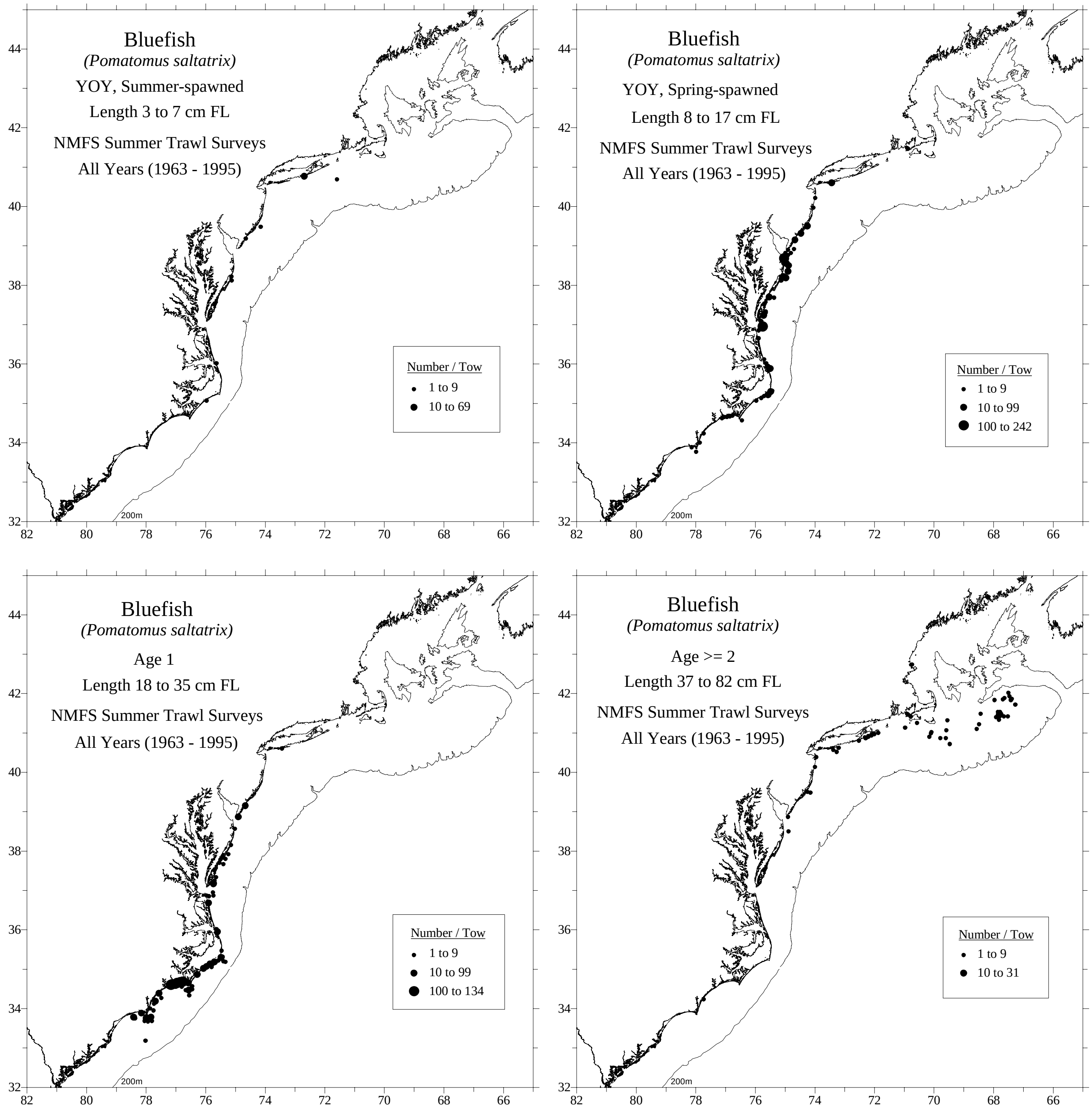


Figure 30. Distribution and abundance of four size classes of bluefish collected off the east coast of the United States during summer NEFSC bottom trawl surveys [1963-1995, all years combined; see Reid *et al.* (1999) for details].

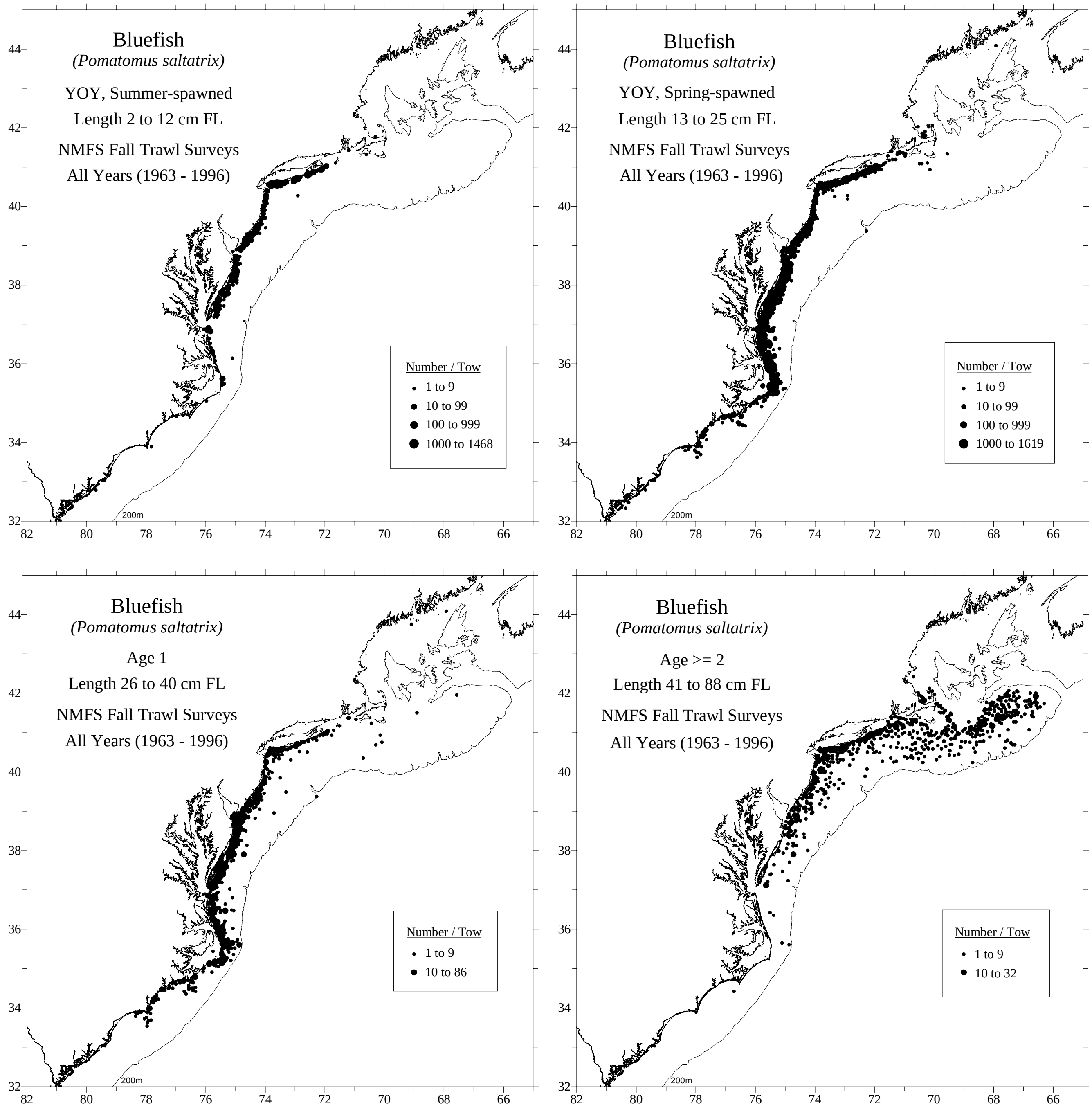


Figure 31. Distribution and abundance of four size classes of bluefish collected off the east coast of the United States during fall NEFSC bottom trawl surveys [1963-1996, all years combined; see Reid *et al.* (1999) for details].

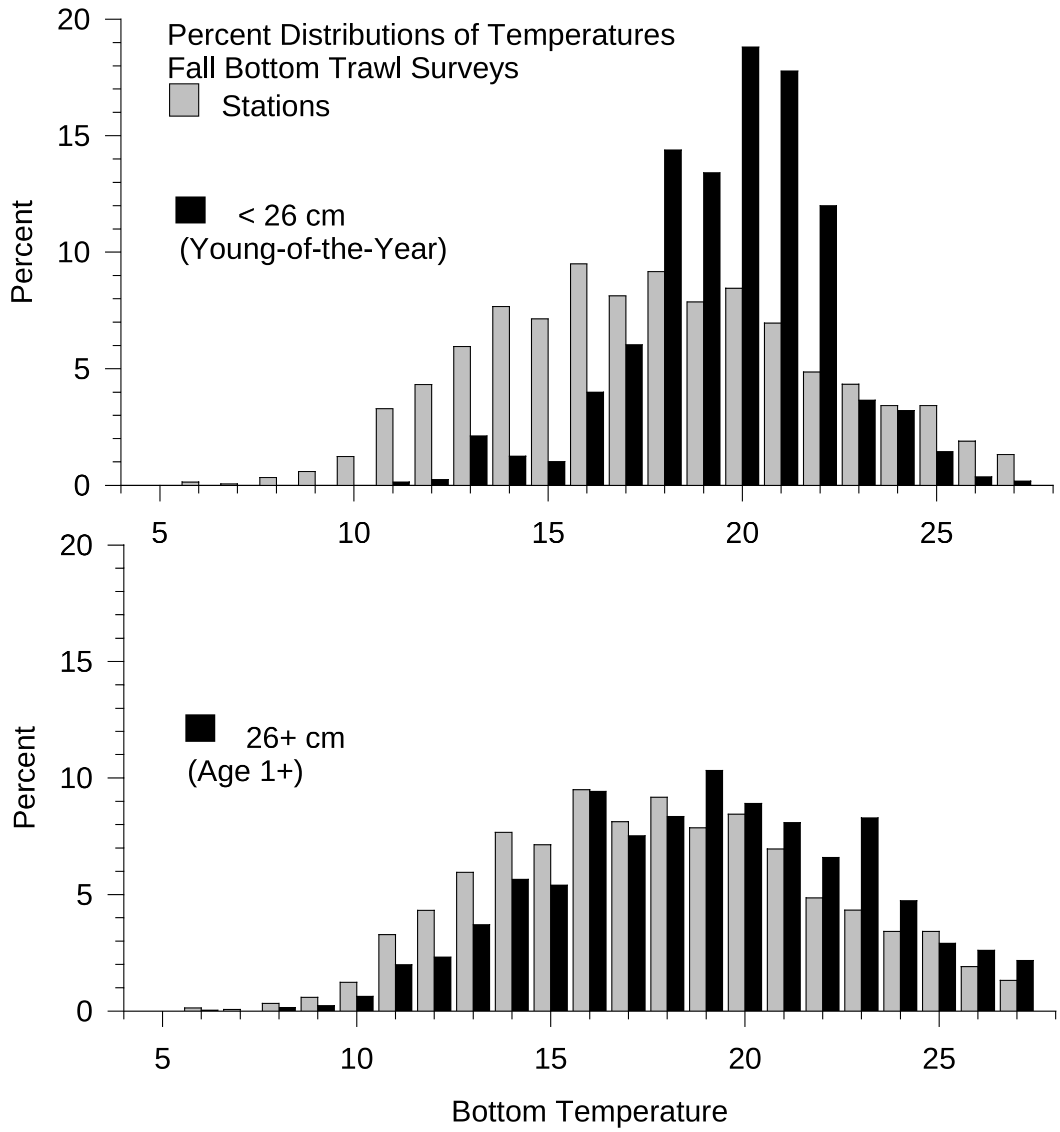


Figure 32. Abundance of young-of-the-year (YOY, < 26 cm) and age 1+ (> 26 cm) bluefish relative to bottom water temperature and depth based on fall east coast NEFSC bottom trawl surveys.

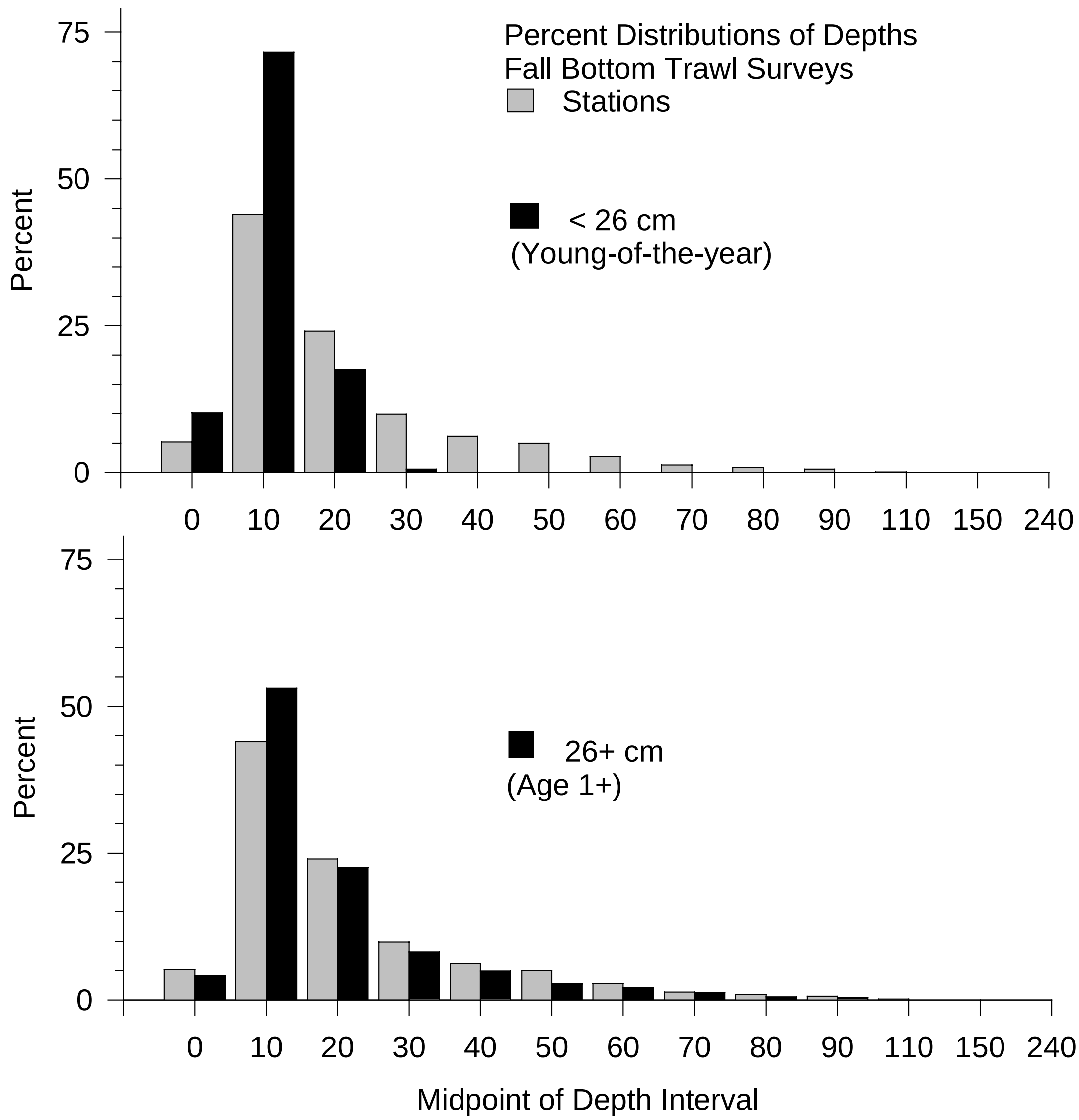


Figure 32. cont’d.

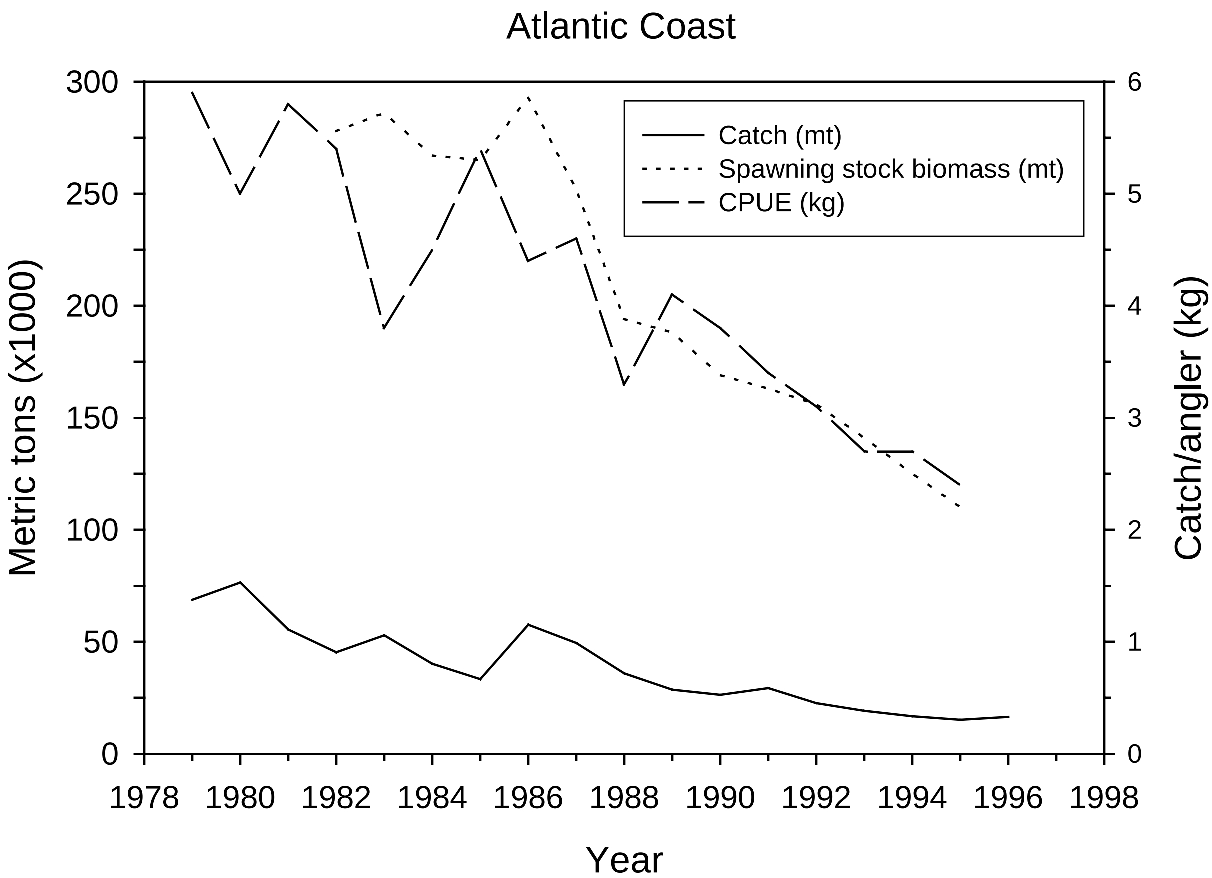


Figure 33. Commercial landings, spawning stock biomass, and catch per unit effort (CPUE) for bluefish along the east coast of the United States (NEFSC, unpublished data).

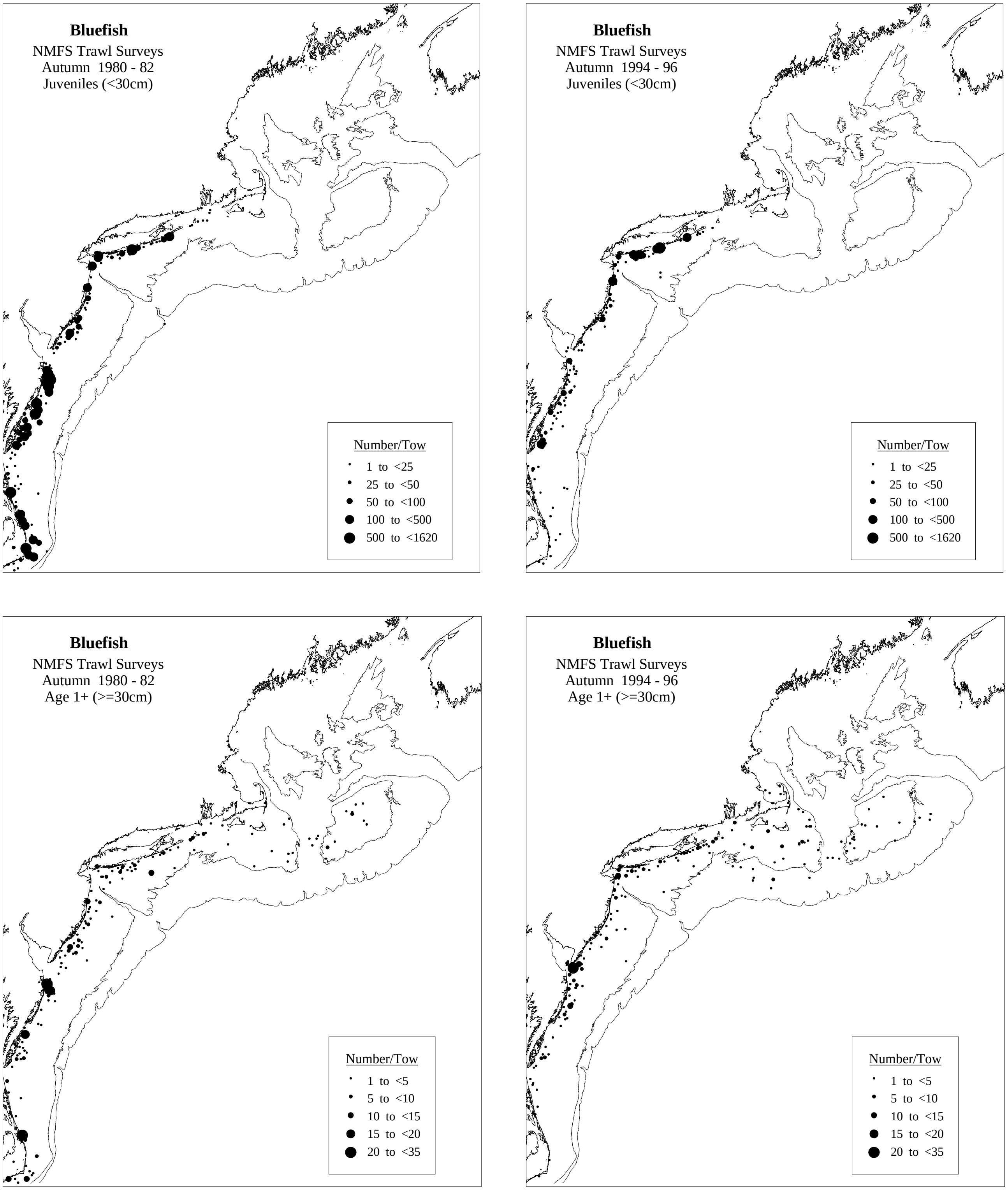


Figure 34. Distribution and abundance of juvenile (< 30 cm) and adult (≥ 30 cm) bluefish during a period of high abundance (1980-1982) and during a period of low abundance (1994-1996) based on autumn NEFSC bottom trawl surveys.

Appendix 1. Bluefish habitat characteristics. MAB = Middle Atlantic Bight; SAB = South Atlantic Bight.

Eggs

Authors	Study Period and Area	Habitat (Spatial and Temporal)	Temperature	Salinity	Dissolved Oxygen	Currents	Light	Prey
Berrien and Sibunka 1999	1977-1987, Continental Shelf waters, Gulf of Maine to Cape Hatteras	Occur southern New England to Cape Hatteras across entire shelf. Most in mid-shelf waters of MAB, especially off New Jersey and Delaware Bay. May-August.	---	---	---	---	---	---
Present Study	1973-1980, SAB; 1977-1987, MAB	SAB: No data; MAB: most found over depths of 20-40 m, May-August, peak in July.	SAB: No data; MAB: Most in 18-22°C	---	---	---	---	---
Norcross *et al.* 1974	1960-1962, Continental Shelf waters off Virginia	Across shelf, from nearshore to shelf edge, but most in outer half of shelf. June through August, peak July.	22°C or more. (Minimum 18°C)	31 ppt or more. (Minimum 26.6 ppt)	---	Prevailing surface currents transport eggs south and offshore.	Peak spawning evening (1900-2100 hrs.)	---

Appendix 1. cont'd.

Larvae

Authors	Study Period and Area	Habitat (Spatial and Temporal)	Temperature	Salinity	Dissolved Oxygen	Currents	Light/Vertical Distribution	Prey
Norcross *et al.* 1974	1960-1962, Continental Shelf waters off Virginia	Surface waters, most near edge of shelf.	---	---	---	---	---	---
Kendall and Walford 1979	1965-1967, Continental Shelf waters between Cape Cod and Palm Beach, Florida	Late April: in and near Gulf Stream off Cape Hatteras; May: near edge of shelf off Carolinas; August: mid-shelf depths off New Jersey; September: few in New York Bight; October: concentration near shelf edge off Georgia.	C. Hatteras: 22.1-22.4°C; MAB: 18-26°C SAB: 20-26°C	MAB: 30-32 ppt SAB: 35-38 ppt	---	Larvae from spring spawn advected north via Gulf Stream.	---	---
Kendall and Naplin 1981	July 1974, outer Continental Shelf off Delaware Bay	Vertical distribution study. Most larvae within 4 m of surface.	Surface 23°C	Surface 33 ppt	---	---	Near surface at night; mostly at 4 m during daylight.	Mostly copepod life history stages. Guts full during day; empty during night.
Collins and Stender 1987	1973-1980, Cape Hatteras to Cape Canaveral, Florida.	Mostly in waters > 40 m, primarily in spring, secondarily in late summer.	---	---	---	Southerly counter-current retains larvae in SAB.	> 4 mm strongly associated with surface.	---
Powles 1981	1973-1976, Cape Fear, North Carolina to Cape Canaveral, Florida	Peaked April-May; smallest near edge of shelf; larger closer to shore or advected north.	Smallest larvae > 24°C	Smallest larvae > 35 ppt	---	Ekman drift would impede inshore migration.	Predominately neustonic.	---
Present Study	SAB: 1973-1980; MAB: 1977-1987	SAB: Most April-May near edge of shelf; MAB: May-September, peak July, mostly between depths of 30-70 m.	SAB: No data MAB: Most 18-24°C	---	---	SAB: subject to northward advection by Gulf Stream.	---	---
Hare and Cowen 1996	March 1990, 1991; April 1989; June 1991; Water masses off Cape Hatteras	Larvae occurred March through June; different sizes occurred in different water masses.	March: 20-25°C; April: 18-25°C; June: 21-25°C	March: 36+ ppt; April: 34.5-36.5 ppt; June: 31-36 ppt	---	SW winds in MAB may facilitate cross-shelf transport of larvae.	---	---

Appendix 1. cont'd.

Pelagic-Juveniles

Authors	Study Period and Area	Habitat (Spatial and Temporal)	Temperature	Salinity	Dissolved Oxygen	Currents	Light/Vertical Distribution	Prey
Hare and Cowen 1996	1988, MAB shelf edge	Cross shelf from Slope Sea to shore early to mid-June.	13.0-15.0°C	---	---	Wind-driven flow may be important, but active swimming probably more important.	Surface oriented	---
Kendall and Walford 1979	1965-1972, East Coast U.S. (MAB and SAB Continental Shelf into Slope Sea)	April (late): many near Cape Hatteras; May: shelf in SAB, largest nearshore; June: MAB between shore and shelf/slope front; Fall: few between Delaware Bay and Cape Hatteras; Winter: few between St. Johns River and Cape Canaveral.	April-May: 22.1-24.0°C Jun: 15.0-20.0°C (most > 18.0°C) Fall: 15.0-18.0°C Winter: 13.0-15.0°C	---	---	Migrate across shelf from shelf/slope front to shore as shelf waters warm.	All collected in near-surface samplers.	---
Collins and Stender 1987	1973-1980, SAB Cape Fear-Cape Canaveral	Seaward of 40 m isobath, mostly spring, some fall occurrences.	---	---	---	Strong negative correlation of size and depth during spring, indicates shoreward movement with growth.	Strongly associated with the surface.	---
Fahay 1975	Seasonal, May 1967-Feb. 1968. SAB Continental Shelf	14 collected between North Carolina and Cape Canaveral, various depths between nearshore and shelf edge. All during May.	19.0-24.0°C	---	---	---	---	---
Powles 1981	1973-1976; SAB Cape fear-Cape Canaveral	Smallest collected near 180 m contour; larger near shore.	180 m contour: > 24.0°C	180 m contour: > 35.0 ppt	---	Weak association of size with proximity to coast. Most probably advected north.	Strongly associated with the surface.	---

Appendix 1. cont'd.

Juveniles and Older

Authors	Study Period and Area	Habitat (Spatial and Temporal)	Temperature	Salinity	Dissolved Oxygen	Currents/ Tide	Substrate/ Vegetation	Light/ Diel	Prey
Nyman and Conover 1988	1985-1986, both shores of Long Island, New York	Occur in embayments, between late May and October.	Arrive > 20°C; emigrate ca. 15°C	---	---	---	---	---	---
Rountree and Able 1992a, b	1988-1989, Great South Bay, New Jersey	Occur in polyhaline subtidal marsh creeks during summer.	> 20.0°C	23.0-30.0 ppt	---	---	---	Day: tidal creeks Night: open bay	*Menidia menidia*
Able *et al.* 1996	Great Bay, New Jersey	Most bluefish in subtidal creeks.	19.0-28.0°C	25.0-33.0 ppt	---	---	0.3-1.2 m depth; *Ulva lactuca*	---	---
Milstein *et al.* 1977	1972-1974, Great Bay, New Jersey	Several distinct habitats studied; bluefish most abundant in mud-sand, high salinity sites; also sandy beaches.	---	---	---	Slow to moderate, swept by waves.	Mostly sand, some gravel, silt, clay; *Ulva lactuca*, *Spartina alterniflora*, *Fucus* (sometimes).	---	---
Smith 1971	1969-1970, four low-salinity creeks, upper Delaware Bay	Six YOY occurred in two of the creeks, June and July.	24.5-30.0°C	0-5.2 ppt	4.5-7.3	Ebb/flood	Sand/gravel	Day	---
Pristas and Trent 1977	1972, St. Andrews Bay, Florida	Range of depths sampled with gill nets, 24 hrs. Bluefish most dense in shallowest zone (0.7-1.1 m).	11.4-27.0°C	25.3-34.6 ppt	---	---	> 80% sand; vegetation most dense in shallow zone.	Bluefish most abundant at night in shallowest zone.	---
McBride *et al.* 1995	Narragansett Bay, Rhode Island	June-October, shallow beaches.	18.0-28.0°C	25.0-34.0 ppt	---	---	Cobble, gravel, shell, sand; *Ulva* and some *Zostera*	Day sampling only.	---
de Sylva *et al.* 1962	1958-1960, Delaware Bay and River	July and August, mostly in shore zone of lower estuary.	---	usually high, but as low as 3.0 ppt	---	Surf zone, clear to turbid.	Sand	---	Collected with small clupeids and anchovies
Buckel and Conover 1997	1992-1993, Hudson River estuary	Mid-channel and nearshore day-night occurrence and feeding study.	---	---	---	---	---	Most abundant nearshore during daylight; mid-channel at night and twilight.	Gut fullness highest twilight and day, usually low at night. Prey: striped bass, bay anchovy, clupeids.
Present Study	1964-1997, Continental shelf MAB, south to Cape Fear, Cape Canaveral	Inner shelf (over depths < 20 m) during summer and fall.	Most 18-22°C	---	---	---	---	---	

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The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "planning, developing, and managing multidisciplinary programs of basic and applied research to: 1) better understand the living marine resources (including marine mammals) of the Northwest Atlantic, and the environmental quality essential for their existence and continued productivity; and 2) describe and provide to management, industry, and the public, options for the utilization and conservation of living marine resources and maintenance of environmental quality which are consistent with national and regional goals and needs, and with international commitments." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific journals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Those media are in three categories:

NOAA Technical Memorandum NMFS-NE -- This series is issued irregularly. The series includes: data reports of long-term or large area studies; synthesis reports for major resources or habitats; annual reports of assessment or monitoring programs; documentary reports of oceanographic conditions or phenomena; manuals describing field and lab techniques; literature surveys of major resource or habitat topics; findings of task forces or working groups; summary reports of scientific or technical workshops; and indexed and/or annotated bibliographies. All issues receive internal scientific review and most issues receive technical and copy editing. Limited free copies are available from authors or the NEFSC. Issues are also available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, VA 22161.

Northeast Fisheries Science Center Reference Document -- This series is issued irregularly. The series includes: data reports on field and lab observations or experiments; progress reports on continuing experiments, monitoring, and assessments; background papers for scientific or technical workshops; and simple bibliographies. Issues receive internal scientific review but no technical or copy editing. No subscriptions. Free distribution of single copies.

Fishermen's Report* and *The Shark Tagger -- The ***Fishermen's Report*** (FR) is a quick-turnaround report on the distribution and relative abundance of commercial fisheries resources as derived from each of the NEFSC's periodic research vessel surveys of the Northeast's continental shelf. There is no scientific review, nor any technical or copy editing, of the FR; copies are available through free subscription. ***The Shark Tagger*** (TST) is an annual summary of tagging and recapture data on large pelagic sharks as derived from the NMFS's Cooperative Shark Tagging Program; it also presents information on the biology (movement, growth, reproduction, etc.) of these sharks as subsequently derived from the tagging and recapture data. There is internal scientific review, but no technical or copy editing, of the TST; copies are available only to participants in the tagging program.

To obtain a copy of a technical memorandum or a reference document, or to subscribe to the fishermen's report, write: Research Communications Unit, Northeast Fisheries Science Center, 166 Water St., Woods Hole, MA 02543-1026. An annual list of NEFSC publications and reports is available upon request at the above address. Any use of trade names in any NEFSC publication or report does not imply endorsement.