NOAA Technical Memorandum NMFS-NE-193

Essential Fish Habitat Source Document:

Longfin Inshore Squid, *Loligo pealeii*, Life History and Habitat Characteristics

Second Edition

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

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NOAA Technical Memorandum NMFS-NE-193

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Essential Fish Habitat Source Document:

Longfin Inshore Squid, *Loligo pealeii*, Life History and Habitat Characteristics

Second Edition

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Editorial Notes on "Essential Fish Habitat Source Documents" Issued in the *NOAA Technical Memorandum NMFS-NE* Series

Editorial Production

For "Essential Fish Habitat Source Documents" issued in the *NOAA Technical Memorandum NMFS-NE* series, staff of the Northeast Fisheries Science Center's (NEFSC's) Ecosystems Processes Division largely assume 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 is performed by, and all credit for such production rightfully belongs to, the staff of the Ecosystems Processes Division.

Internet Availability and Information Updating

Each original issue of an "Essential Fish Habitat Source Document" is published both as a paper copy and as a Web posting. The Web posting, which is in "PDF" format, is available at: *http://www.nefsc.noaa.gov/nefsc/habitat/efh*.

Each issue is updated at least every five years. The updated edition will be published as a Web posting only; the replaced edition(s) will be maintained in an online archive for reference purposes.

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.*, Nelson *et al*. 2004[a]; Robins *et al.* 1991[b]), mollusks (*i.e.*, Turgeon *et al.* 1998[c]), and decapod crustaceans (*i.e.*, Williams *et al.* 1989[d]), and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals (*i.e.*, Rice 1998[e]). Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species.

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[a]Nelson, J.S.; Crossman, E.J.; Espinosa-Pérez, H.; Findley, L.T.; Gilbert, C.R.; Lea, R.N.; Williams, J.D. 2004. Common and scientific names of fishes from the United States, Canada, and Mexico. 6th ed. *Amer. Fish. Soc. Spec. Publ.* 29; 386 p.

[b]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991. World fishes important to North Americans. *Amer. Fish. Soc. Spec. Publ.* 21; 243 p.

[c]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.

[d]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.

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

PREFACE TO SECOND EDITION

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 NOAA Fisheries to assist the regional fishery management councils in the implementation of EFH in their respective fishery management plans.

NOAA Fisheries 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 a series of EFH species reports (plus one consolidated methods report). The EFH species reports are a survey of the important literature as well as original analyses of fishery-independent data sets from NOAA Fisheries 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 understandably are referred to as the "EFH source documents."

NOAA Fisheries 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.

The initial series of EFH species source documents were published in 1999 in the *NOAA Technical Memorandum NMFS-NE* series. Updating and review of the EFH components of the councils' Fishery Management Plans is required at least every 5 years by the NOAA Fisheries Guidelines for meeting the Sustainable Fisheries Act/EFH Final Rule. The second editions of these species source documents were written to provide the updated information needed to meet these requirements. The second editions provide new information on life history, geographic distribution, and habitat requirements via recent literature, research, and fishery surveys, and incorporate updated and revised maps and graphs. This second edition of the longfin inshore squid EFH source document is based on the original by Luca M. Cargnelli, Sara J. Griesbach, Cathy McBride, Christine A. Zetlin, and Wallace W. Morse, with a foreword by Jeffrey N. Cross (Cargnelli *et al*. 1999).

Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NOAA Fisheries, 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.

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INTRODUCTION

The longfin inshore squid, *Loligo pealeii*, is a schooling species of the molluscan family Loliginidae (Figure 1). It is distributed in continental shelf and slope waters from Newfoundland to the Gulf of Venezuela, and occurs in commercial abundance from southern Georges Bank to Cape Hatteras. The fishery for longfin inshore squid is managed by the Mid-Atlantic Fishery Management Council under the Atlantic Mackerel, Squid and Butterfish Fishery Management Plan, Amendment 8 (MAFMC 1998). Within the range of commercial exploitation, the population is considered to be a single stock unit. This Essential Fish Habitat Source Document provides information on the life history and habitat characteristics of longfin inshore squid inhabiting the Gulf of Maine, Georges Bank, and the Middle Atlantic Bight.

LIFE HISTORY

See Brodziak (1995) for a brief synopsis of life history. More detailed information is provided here.

EGGS AND LARVAE

The 1 mm x 1.6 mm eggs are encased in a gelatinous capsule as they pass through the female oviduct during mating. Each capsule contains 150-200 eggs (Arnold *et al.* 1974; Gosner 1978; MAFMC 1998) and is about 50-80 mm long and 1 cm in diameter (Gosner 1978; Lange 1982; MAFMC 1998). During spawning, the male cements bundles of spermatophores into the mantle cavity of the female. The jelly is penetrated by sperm as the egg capsules pass through the oviduct (Black *et al.* 1987). The egg capsules are laid on the bottom in clusters 50-60 cm wide composed of hundreds of capsules (Gosner 1978; Griswold and Prezioso 1981). Each female lays 20-30 capsules (Lange 1982). The number of eggs spawned per female has been reported as 950-8,500 (Haefner 1959), 3,500-6,000 (Summers 1971), 2,500-15,900 (Vovk 1972b), and 3,000-6,000 (MAFMC 1998). Development time varies from 257 to 642 hrs depending on water temperature; 26.7 days to hatching at 12-18^{o}C, 18.5 days at 15.5-21.3^{o}C, and 10.7 days at 15.5-23.0^{o}C (Summers 1971).

Larvae of the longfin inshore squid are referred to as paralarvae (Young and Harman 1988). Little is known about them because they are planktonic, being found in the water column near the surface (McMahon and Summers 1971), and require special sampling techniques. Larvae 2-4 mm in length have been caught in the Gulf of Maine (Bigelow 1924).

JUVENILES AND SUBADULTS

There are two juvenile stages. ‘Juvenile’ is the stage after the paralarval stage and before the ‘subadult’ stage. The subadult stage is before maturity, when morphological characteristics of adults are attained (Young and Harman 1988). The shift from inhabiting surface waters to a demersal lifestyle occurs at 45 mm (Vecchione 1981). Off Martha’s Vineyard, the juvenile life stage lasts about 1 month. Subadults migrate by November to the outer shelf areas where they remain until March (Summers 1968a, b). Subadults are thought to overwinter in deeper waters along the edge of the continental shelf (Black *et al.* 1987). Young-of-the-year (subadults) are found with adults in mid-summer bottom trawl catches (Summers 1968a, b). Juveniles and subadults grow quickly, with growth rates dependent on temperature (Hatfield *et al*. 2001).

Sexual maturity is first reached at about 8-12 cm (Macy 1980; Brodziak and Hendrickson 1999). The length at which 50% of individuals are sexually mature (L_{50}) is 16-20 cm, depending on season and location (Brodziak 1995; Macy and Brodziak 2001; Hatfield and Cadrin 2002).

ADULTS

Historically, the lifespan of longfin inshore squid was believed to be 1-2 years (Summers 1971; Lange 1982). However, Brodziak and Macy (1996), using statolith aging, demonstrated exponential growth and a lifespan of less than 1 year.

Longfin inshore squid reach sizes greater than 40-50 cm mantle length (ML), although most are less than 30 cm (Vecchione *et al.* 1989; Brodziak 1995). They are sexually dimorphic – males grow more rapidly and reach larger size at age than females (Brodziak 1995). Growth depends on temperature (Hatfield *et al*. 2001) and is highest for individuals hatched during winter (Macy and Brodziak 2001). Longfin inshore squid migrate offshore during late autumn and overwinter in warmer waters along the edge of the continental shelf; they return inshore during the spring and early summer (MAFMC 1998). Mature individuals enter inshore waters before immature ones (Macy 1982). Off Massachusetts, larger individuals migrate inshore in April-May while smaller individuals move inshore in the summer (Lange 1982). Longfin inshore squid form large schools based on size prior to feeding (Macy 1980) and make diurnal vertical migrations up into the water column at night (MAFMC 1998). This movement may be associated with the pursuit of food organisms such as euphausiids.

REPRODUCTION

Brodziak and Macy (1996), Macy and Brodziak (2001), and Hatfield and Cadrin (2002) show that longfin inshore squid spawn year round with seasonal and geographic peaks that vary among years and geographic areas (Lange and Sissenwine 1980). Most eggs are spawned in May and hatching occurs in July (Summers 1971). Spawning has been reported from August to September in the Bay of Fundy (Stevenson 1934), from May to August in New England waters (Summers 1971; Macy 1980), and from late spring to early summer in the Middle Atlantic (Lange and Sissenwine 1983; Black *et al.* 1987). Mesnil (1977) reported that spawning on the Scotian Shelf and Georges Bank occurs during early spring and late summer. Spawning south of Cape Hatteras may also be important (Hatfield and Cadrin 2002).

Spawning has been reported in the Gulf of Maine in Cobequid Bay and Massachusetts Bay (Bigelow 1924), the Bay of Fundy (Stevenson 1934), Minas Basin (Cohen 1976), along the eastern coast of Nova Scotia in St. Margaret's and Terrence bays (Dawe *et al.* 1990), on Georges Bank (Mesnil 1977), and in the Middle Atlantic in Narragansett and Delaware bays (Haefner 1959; Griswold and Prezioso 1981).

Based on recent research, reproductive biology and behavior is complicated for longfin inshore squid. Visual and chemical cues regulate competition among males for females on spawning grounds (Buresch *et al*. 2003). Females may lay multiple clutches over periods of up to several weeks (Maxwell and Hanlon 2000; King *et al*. 2003). Eggs in the same capsule from a single female may have multiple fathers from multiple spawning events and females appear to store sperm from spawning events for later use (Buresch *et al*. 2001).

FOOD HABITS

The diet of the longfin inshore squid changes with size; small immature individuals feed on planktonic organisms (Vovk 1972b; Tibbetts 1977) while larger individuals feed on crustaceans and small fish (Vinogradov and Noskov 1979). Cannibalism is observed in individuals larger than 5 cm (Whitacker 1978). Studies by Vovk and Khvichiya (1980) and Vovk (1985) showed that juveniles 4.1-6 cm long fed on euphausiids and arrow worms, while those 6.1-10 cm fed mostly on small crabs, but also on polychaetes and shrimp. Adults 12.1-16 cm long fed on fish (clupeids, myctophids) and squid larvae/juveniles, and those > 16 cm fed on fish and squid (Vovk and Khvichiya 1980; Vovk 1985). Fish species preyed on by longfin inshore squid include silver hake, mackerel, herring, menhaden (Langton and Bowman 1977), sand lance, bay anchovy, menhaden, weakfish, and silversides (Kier 1982). Maurer and Bowman (1985) demonstrated the following seasonal and inshore/offshore differences in diet: in offshore waters in the spring, the diet is composed of crustaceans (mainly euphausiids) and fish; in inshore waters in the fall, the diet is composed almost exclusively of fish; and in offshore waters in the fall, the diet is composed of fish and squid.

PREDATION

Many pelagic and demersal fish species, as well as marine mammals and diving birds, prey upon juvenile and adult longfin inshore squid (Lange and Sissenwine 1980; Vovk and Khvichiya 1980; Summers 1983). Marine mammal predators include longfin pilot whale, *Globicephala melas*, and common dolphin, *Delphinus delphis* (Waring *et al.* 1990; Overholtz and Waring 1991; Gannon *et al.* 1997). Fish predators include bluefish, sea bass, mackerel, cod, haddock, pollock, silver hake, red hake, sea raven, spiny dogfish, angel shark, goosefish, dogfish, and flounder (Maurer 1975; Langton and Bowman 1977; Gosner 1978; Lange 1980).

GEOGRAPHICAL DISTRIBUTION

Longfin inshore squid occur from Newfoundland to the Gulf of Venezuela, however, the principal concentrations exploited in the United States occur from Georges Bank to Cape Hatteras (Brodziak 1995). Longfin inshore squid are generally found at water temperatures of at least 9^{o}C (Lange and Sissenwine 1980). The population makes seasonal migrations that appear to be related to bottom water temperatures; they move offshore during late autumn to overwinter along the edge of the continental shelf and return inshore during the spring and early summer (MAFMC 1998). When inshore waters are coldest during winter and early spring, the population concentrates along the outer edge of the continental shelf. The inshore movement to the shelf areas takes place when water temperatures are rising (Black *et al.* 1987) and begins in the south and proceeds north along the coast (MAFMC 1998). A northerly extension of the range has been noted in summer (Black *et al.* 1987).

The terms 'pre-recruit' (unexploited sizes) and 'recruit' (exploited sizes) are often used in reference to longfin inshore squid. Exploitation begins at a minimum mantle length of about 9 cm. Thus, pre-recruits are ≤ 8 cm and recruits are ≥ 9 cm.

EGGS AND LARVAE

The egg and larval stages of longfin inshore squid were not sampled by the Northeast Fisheries Science Center (NEFSC) Marine Resources Monitoring, Assessment and Prediction program (MARMAP) offshore ichthyoplankton surveys.

PRE-RECRUITS

The NEFSC bottom trawl surveys [see Reid *et al.* (1999) for details] captured longfin inshore squid pre-recruits during all seasons (Figure 2; note that winter and summer distributions are presented as presence only data, precluding a discussion of abundances.). In winter, pre-recruits were captured from Cape Hatteras to Nantucket Shoals, although most were found south of Long Island. They were generally found offshore and concentrated toward the 200 m isobath. They were distributed a little farther inshore in the southern part of the range, presumably due to warmer water temperatures. In the spring, the distribution extended farther to the south, with high concentrations south of Cape Hatteras, and farther to the north, with high numbers in southern New England and some catches on Georges Bank and the Scotian Shelf. Higher concentrations were found near the 200 m isobath. In summer, they were concentrated nearshore, with a few found on central Georges Bank. In autumn, longfin inshore squid were distributed along the coast of Maine, in Massachusetts Bay, and from Georges Bank to south of Cape Hatteras from nearshore to the 200 m isobath, with some of the highest concentrations found nearshore. This presumably indicates the beginning of the offshore migration.

The spring and fall distributions and abundances of pre-recruits around coastal Massachusetts, based on Massachusetts inshore bottom trawl surveys [see Reid et al. (1999) for details], are shown in Figure 3. In the spring, high concentrations occurred south of Cape Cod and around Martha's Vineyard and Nantucket Island. Low numbers were found in and around Cape Cod Bay, and none were captured north of Cape Cod. Much higher numbers of pre-recruits were found in the fall. High concentrations were found in Buzzards Bay, around Martha's Vineyard and Nantucket Island, throughout Cape Cod Bay, in Massachusetts Bay, and north and south of Cape Ann. The lower numbers of pre-recruits in inshore waters in the spring was most likely due to the survey occurring prior to the main part of the inshore migration.

The seasonal distributions and abundances of prerecruits in Narragansett Bay, based upon the 1990-1996 Rhode Island bottom trawl surveys, are shown in Figure 4. In winter, very few were caught, and they were only found at one station near the entrance to the Bay. Catches increased slightly in spring, and were highest during summer and autumn. This pattern corresponds to inshore migrations beginning in early spring.

The distributions and abundances of both pre-recruit and recruit longfin inshore squid in Long Island Sound from April to November 1986-1994, based on the Connecticut Fisheries Division bottom trawl surveys, are shown in Figure 5, Figure 6, and Figure 7. The following description of their distributions relative to depth and bottom type is taken almost verbatim from Gottschall *et al*. (2000).

Longfin inshore squid taken in the survey ranged from 2-40 cm mantle length (Figure 5), with the largest squid present in May and June. Squid were rarely observed in April (4% occurrence), but from May through November they were commonly taken throughout the Sound. The percent occurrence varied little during these months, ranging from 63% in July to 81% in September (Figure 6D). Abundance remained stable through late spring and summer (Figure 6A), and then increased dramatically in fall when squid ranging in size from 2-12 cm recruited to the trawl.

Although squid were commonly encountered throughout Long Island Sound in late spring, they were most abundant east of Stratford Shoal, particularly in depths > 18 m on the transitional and sand bottom (Figure 6B and C) of the Mattituck Sill and the adjacent portion of the Central Basin (Figure 7). In addition, they were concentrated in Niantic Bay. In contrast, longfin inshore squid appeared to be more dispersed in summer. In fall, when small squid were abundant, they were distributed throughout the Sound, but were more abundant in the Central and Western Basins. During the fall generally, abundance tended to increase with depth and was highest over mud bottom, with abundance over transitional and sand bottoms ranking second and third respectively. Although the abundance of squid was very low in November, they were still commonly encountered throughout the Sound (65% occurrence). Abundance was similar over all bottom types but, as in the fall period, abundance tended to increase with depth (Gottschall *et al*. 2000).

Longfin inshore squid pre-recruits were captured in the Hudson-Raritan estuary during spring, summer, and fall (Figure 8). They were found almost exclusively in the eastern portion of the bay and were collected in the highest numbers in the summer and autumn.

RECRUITS

NEFSC bottom trawl surveys captured longfin inshore squid recruits during all seasons (Figure 9; again note that winter and summer distributions are presented as presence data, precluding a discussion of abundances.). Their seasonal distributions are nearly identical to that of pre-recruits and illustrate the spring and summer inshore and the autumn offshore migrations.

The distribution of longfin inshore squid recruits in waters off Massachusetts was almost identical to that of pre-recruits, although the overall number of recruits was much lower (Figure 10).

Recruits were caught during all seasons in Narragansett Bay (Figure 11). Catches were low in winter, increased somewhat in spring, and were highest during summer and autumn. This pattern corresponds to inshore migrations beginning in spring.

The distributions and abundances of both pre-recruits and recruits in Long Island Sound were discussed previously.

Longfin inshore squid recruits were captured in the Hudson-Raritan estuary during spring, summer, and fall (Figure 12). They were found mostly in the eastern portion of the bay; the highest catches occurred in summer and autumn.

The 1988-1999 Virginia Institute of Marine Science (VIMS) trawl surveys of Chesapeake Bay suggests that recruit longfin inshore squid (> 12 cm) appeared in their catches primarily in April, with a few in May, and most likely were limited to sites around the Bay mouth and eastward (Geer 2002).

HABITAT CHARACTERISTICS

Information on the habitat characteristics and preferences of the longfin inshore squid are summarized in Table 1.

EGGS AND LARVAE

Egg masses are commonly found attached to rocks and small boulders on sandy/muddy bottom and on aquatic vegetation, such as *Fucus* sp., *Ulva lactuca*, *Laminaria* sp. and *Porphyra* sp. (Arnold *et al.* 1974; Griswold and Prezioso, 1981; Summers 1983). The eggs are demersal, are generally laid in waters < 50 m deep (Bigelow 1924; Griswold and Prezioso 1981; Lange 1982), and are found at temperatures of 10-23^{o}C (McMahon and Summers 1971) and salinities of 30-32 ppt (McMahon and Summers 1971).

The larvae are pelagic near the surface (McMahon and Summers 1971; McConathy *et al.* 1980) and occur at temperatures of 10-26^{o}C and salinities of 31.5-34.0 ppt (Vecchione 1981). Surface waters are important to hatchlings and larvae and individuals move deeper as they grow older (Vecchione 1981). Longfin inshore squid larvae were common in ichthyoplankton samples across a wide range of depths and areas (Vecchione *et al*. 2001).

PRE-RECRUITS

Juveniles inhabit the upper 10 m of the water column over water 50-150 m deep (Mercer 1969; Vovk and Khvichiya 1980; Brodziak and Hendrickson 1999). They are found at surface water temperatures of 10-26^{o}C (Vecchione 1981; Brodziak and Hendrickson 1999) and salinities of 31.5-34.0 ppt (Vecchione 1981). Longfin inshore squid move up (nighttime) and down (daytime) in the water column on a daily (diel) basis (Hatfield and Cadrin 2002) but the importance of off-bottom habitat is unknown because sampling has been primarily with bottom trawls. Diel migration patterns depend on squid size and season (Hatfield and Cadrin 2002).

Distributions of pre-recruits relative to bottom water temperature, depth, and salinity based on spring and fall NEFSC bottom trawl surveys are shown in Figure 13. During the spring surveys, pre-recruits were found in a temperature range of 4-21ºC, with the majority at about 8-14ºC. They were found over a depth range of 1-400 m, and a salinity range of 31-36, with most found at 34-36 ppt. During the fall the pre-recruits were found over a wider temperature range of 6-28ºC, with peaks in abundance between roughly 10-19ºC. Their depth range during that season was between 1-400 m, with the majority found above about 60 m. Their salinity range was between 29-36 ppt, with the majority at 32-33 ppt.

The spring and autumn distributions of pre-recruits in Massachusetts coastal waters relative to bottom water temperature and depth based on Massachusetts inshore bottom trawl surveys are shown in Figure 14. In the spring, the pre-recruits were found at a temperature range of 5-17ºC, with most at 10-14ºC. Their depth range was from 6 m to a depth of approximately 65 m; the majority were found between 6-25 m. In the fall they were found over a wider temperature range of 5-22ºC, with bimodal peaks at about 8-10ºC and a larger one 16-20ºC. Their depth range during fall was between 1-85 m, with the majority found between about 6-35 m.

In the Narragansett Bay bottom trawl survey, pre-recruits were found at depths ranging from 10-110 feet (3-367 m) (Figure 15). In winter the few pre-recruits caught were taken at 90 feet (27 m), in summer and spring most were caught at 20-40 feet (6-12 m) and

100-110 feet (30-34 m), and in autumn most were caught at 100 feet (30 m). Pre-recruits were collected at temperatures ranging from 9-25°C. They were collected at temperatures of 10°C in winter, from 9-16°C in spring, from 11-25°C with most at 19°C in summer, and from 13-23°C with most at 20°C in autumn.

In the Hudson-Raritan estuary, pre-recruits were collected at temperatures ranging from 11-24°C, but most were taken at 16-21°C. They were also collected at depths of 15-75 ft (~5-23 m), with most at 30 ft (9 m) and 45-50 ft (14-15 m), and salinities of 20-33 ppt, with the highest catch at 30 ppt. They were found at dissolved oxygen levels of 5-10 mg/L, with most at 7-8 mg/L (Figure 16). Longfin inshore squid require oxygen concentrations greater than 4 mg/L (Howell and Simpson 1994).

The distributions and abundances of both pre-recruit and recruit squid in Long Island Sound relative to depth and bottom type, based on surveys by Gottschall *et al*. (2000), were discussed previously in Geographic Distribution: Pre-recruits.

RECRUITS

Adult longfin inshore squid inhabit the continental shelf and upper continental slope to depths of 400 m (Vecchione *et al.* 1989), but depth varies seasonally. In spring they occur at depths of 110-200 m (Serchuk and Rathjen 1974; Lange and Sissenwine 1980), in summer and autumn they inhabit inshore waters as shallow as 6-28 m (Summers 1968a, b; Serchuk and Rathjen 1974; Gosner 1978; Howell and Simpson 1994), and in winter they inhabit offshore waters to depths of 365 m (Lange 1982). They are found on mud or sand/mud substrate (Howell and Simpson 1994), at surface temperatures ranging from 9-21°C, and bottom temperatures ranging from 8-16°C (Summers 1969; Lux *et al.* 1974; Serchuck and Rathjen 1974; Lange and Sissenwine 1980; Macy 1980; Brodziak and Hendrickson 1999). Adults, like juveniles, migrate up and down in the water column in response to light conditions and the importance of off-bottom habitat is unknown.

Distributions of recruits relative to bottom water temperature, depth, and salinity based on spring and fall NEFSC bottom trawl surveys are shown in Figure 17. During the spring, recruits were found in a temperature range of 4-21ºC, with the majority at about 7-13ºC. They were found over a depth range of 1-400 m, and a salinity range of about 30-36, with most found at 34-35 ppt. During the fall the pre-recruits were found over a wider temperature range of 6-28ºC, with a peak between about 10-15ºC. Their depth range during that season was between 1-400 m, with the majority found above about 70 m. Their salinity range was between 30-37 ppt, with most at 32-33 ppt.

Around Massachusetts in the spring, the recruits were found at a temperature range of 6-17ºC, with most at 10-13ºC (Figure 18). Their depth range was from about 1 m to approximately 50 m, with the majority found between 6-20 m. As with the pre-recruits, the recruits in the fall were found over a wider temperature range of 5-22ºC, with bimodal peaks at about 8-10ºC and a larger one 16-20ºC. Their depth distribution during fall was similar to that of the pre-recruits (range of 1-85 m, with the majority found between about 6-35 m).

In Narragansett Bay, recruits were found at depths ranging from 10 to 120 ft (3-37 m) (Figure 19). In winter the few recruits caught were taken at 90-100 ft (27-30 m). In summer and spring they were taken at depths ranging from 10-120 ft (3-37 m). In spring, about 40% were caught at 100-110 feet (30-34 m), with another 20% found at 70 ft (21 m), while in summer, the majority were caught at 100-110 ft. In autumn, most were caught at 90-100 feet (27-30 m). Recruits were taken at temperatures ranging from 7-25°C (Figure 19). Seasonally they were collected at 7-10°C in winter, with almost all caught at 10°C; at 9-16°C in spring, with most at 9-13°C; at 9-25°C in summer, with most at 18-21°C; and at 11-23°C in autumn, with a peak at 15°C.

In the Hudson-Raritan estuary, recruits were collected at temperatures ranging from 9-24°C, but most were at 16-17°C (Figure 20). They were also collected at depths of 10-75 ft (~5-23 m), with most at 50 and 60 ft (~15-18 m), and salinities of 20-33 ppt, with the highest catch at 30 ppt. They were found at dissolved oxygen levels of 5-11 mg/L, with most at 7-8 mg/L. Longfin inshore squid require oxygen concentrations greater than 4 mg/L (Howell and Simpson 1994).

RESEARCH NEEDS

- Human impacts may be significant on sandy bottom habitats used by inshore longfin squid for their eggs. However, little information is available on egg habitat locations, seasonal occurrence, sediment characteristics, and depth or water chemistry. This type of information might be useful for designating marine reserves, seasonal closed areas, and other measures.
- Additional information about use of off-bottom habitat and vertical distribution of inshore longfin squid in the water column is needed for stock assessment and management. This is because a substantial portion of the inshore longfin squid stock may be unavailable to bottom trawl surveys that are used to track abundance.
- Information about distribution of inshore longfin squid in deepwater off the continental shelf and south of Cape Hatteras would be useful because

bottom trawl surveys do not reach these areas and an unknown portion of the stock is resident there (NEFSC 2002).

- More information on growth rates and maturity are needed from geographically and temporally diverse studies.
- The commercially exploited population from Cape Hatteras to Georges Bank, inshore and offshore and in all seasons, is considered a single stock unit. More information is needed on stock structure, including gene flow and levels of genetic differentiation among geographic areas.

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Table 1. Summary of life history and habitat characteristics for longfin inshore squid, based on the pertinent literature. This table is essentially the same as that used in the first longfin inshore squid EFH source document (Cargnelli *et al*. 1999); more recent studies have not been added.

Life Stage	Size and Growth	Habitat	Substrate	Temperature	Salinity
Eggs [1]	Incubation time varies with temperature: 26.7 d at 12-18°C, 18.5 d at 15.5-21.3°C, and 10.7 d at 15.5-23.0°C.	Eggs generally in shallow waters, < 50 m and near shore.	Egg masses are commonly found on sandy/mud bottom; usually attached to rocks/boulders, pilings, or algae such as *Fucus*, *Ulva lactuca*, *Laminaria* and *Porphyra* sp.	Eggs found in waters 10-23°C; usually > 8°C. Optimal development at 12°C.	Found at 30-32 ppt.
Larvae [2]	Paralarvae range in size from 1.4-15 mm ML (mantle length). Growth rates slower for winter-hatched animals than spring-hatched.	Found in coastal, surface waters in spring, summer, and fall. Hatchlings found in surface waters day and night. Move deeper in water column as they grow larger.		Found at 10-26°C (at lower temperatures found at higher salinities).	Found at 31.5-34.0 ppt.
Juveniles [3]	Size ranges from approximately 15 mm - 8 cm. At 6-8 cm sexual size dimorphism is evident, before offshore migrations occur. Growth rates of young-of-the-year are 12-38 mm/month.	Inhabit upper 10 m at depths of 50-100 m on continental shelf. Found in coastal inshore waters in spring/fall, offshore in winter. Migrate to surface at night. Ontogenetic descent: at 45 mm, chromatophores are concentrated on dorsal rather than ventral surface, indicating a change from inhabiting surface waters to demersal lifestyle.		Found at 10-26°C (at lower temperatures found at higher salinities). Juveniles prefer warmer bottom temperatures and shallower depths in fall than adults.	Found at 31.5-34.0 ppt.
Adults [4]	Smallest size at maturity 8 cm ML; most are > 10 cm ML. Males grow faster than females and attain larger sizes; larger sizes at higher latitudes. Growth is rapid, faster in warm months (1.5-2.0 cm/month) than in cold months (0.4-0.6 cm/month). Life span is < 1 year. Maximum size and age are ~50 cm ML, 3 yrs.	Range from Newfoundland south to Cape Hatteras, on continental shelf and upper slope. Most abundant from Gulf of Maine to Hatteras. March-October: inshore, shallow waters up to 180 m. Winter: offshore deeper waters, up to 400 m on shelf edge. Most abundant at bottom during the day; move upwards at night. Generally found at greater depths and cooler bottom temperatures in the fall than juveniles. Importance of off-bottom habitat poorly understood.	Mud or sandy mud.	Found at surface temperatures ranging from 9-21°C and bottom temperatures ranging from 8-16°C.	

[1] Bigelow (1924); McMahon and Summers (1971); Arnold *et al.* (1974); Griswold and Prezioso (1981); Lange (1982); Summers (1983); Dawe *et al.* (1990).

[2] McMahon and Summers (1971); McConathy *et al.* (1980); Vecchione (1981); Nesis (1982); Vovk (1983); Young and Harman (1988).

[3] Summers (1968a, b); Mercer (1969); Macy (1980); Vovk and Khvichiya (1980); Vecchione (1981); Young and Harman (1988); Brodziak and Henderson (1999).

[4] Haefner (1964); Summers (1968a, b, 1969, 1971, 1983); Rathjen (1973); Lux *et al.* (1974); Serchuk and Rathjen (1974); Cohen (1976); Mesnil (1977); Gosner (1978); Sissenwine and Bowman (1978); Lange (1980, 1982); Lange and Sissenwine (1980); Macy (1980); Nesis (1982); Vecchione *et al.* (1989); Dawe *et al*. (1990); Howell and Simpson (1994); Brodziak and Macy (1996); Brodziak and Henderson (1999).

Table 1. Cont'd.

Life Stage	Prey	Predators	Spawning	Notes
Eggs [1]	N/A		Most eggs are spawned in May, hatching occurs in July. Fecundity ranges from 950-15,900 eggs per female.	Eggs are demersal. Enclosed in a gelatinous capsule containing up to 200 eggs. Each female lays 20-30 capsules. Laid in masses made up of hundreds of egg capsules from different females.
Larvae [2]	Primary prey are copepods.			"Paralarvae" defined as stage after hatching when cephalopods are pelagic. Tentacles are non-functional at ≤ 15 mm.
Juveniles [3]	Primary prey varies with size: < 4.0 cm: plankton, copepods; 4.1-6.0 cm: euphausiids, arrow worms; 6.1-10.0 cm: crabs, polychaetes, shrimp. Cannibalism observed in specimens larger than 5 cm ML (small *Illex illecebrosus* were found in 49 of 322 *Loligo* stomachs).	Many pelagic and demersal fish species as well as marine mammals and birds.		Changes in habitat as the squid grows are indicated by changes in the diet.
Adults [4]	Fish prey includes silver hake, mackerel, herring, menhaden, sand lance, bay anchovy, menhaden, weakfish, and silversides. Invertebrate prey includes crustaceans (*Crangon, Palaeomonetes* sp.) and squid. 15 cm adults can eat fish up to half their mantle length. At 16-25 cm, consume more fish and less crustaceans as growth increases; > 25 cm, more squid than fish eaten; and > 30 cm, almost exclusively squid.	Predators include many fishes (bluefish, sea bass, mackerel, cod, haddock, pollock, hakes, sea raven, goosefish, flounder, dogfish, angel sharks, skates), pilot whale (*Globicephala melas*) and common dolphin (*Delphinus delphis*), and diving birds.	Spawning occurs on Scotian Shelf, Georges Bank, Gulf of Maine, and from Nantucket Shoals to Cape Hatteras in shallow waters, 10-90 m, from April-November (New England: May-August; Bay of Fundy: Aug-September). Georges Bank: two broods - early spring and late summer. Spring spawn: hatch in June, mature over winter. Summer spawn: hatch in fall, mature in 2nd winter. Mating occurs during inshore migration in spring. Mortality occurs after first spawning.	*Loligo* form schools according to size class prior to feeding. Oxygen requirement > 4 ml/l. Larger individuals migrate earlier (April-May) than smaller ones.

[1] Haefner (1959); Summers (1971); Vovk (1972b), Arnold *et al.* (1974); Gosner (1978); Griswold and Prezioso (1981); Lange (1982); Nesis (1982); Lange and Sissenwine (1983).
[2] Vecchione (1981); Vovk (1983); Young and Harman (1988).
[3] Vovk (1972b, 1985); Tibbetts (1977); Whitaker (1978); Vinogradov and Noskov (1979); Vovk and Khvichiya (1980); Vecchione (1981).
[4] Stevenson (1934); Summers (1969, 1971); Vovk (1972a, 1985); Rathjen (1973); Maurer (1975); Cohen (1976); Langton and Bowman (1977); Mesnil (1977); Tibbetts (1977); Gosner (1978); Vinogradov and Noskov (1979); Lange (1980, 1982); Lange and Sissenwine (1980, 1983); Macy (1980); Griswold and Prezioso (1981); Kier (1982); Summers (1983); Maurer and Bowman (1985); Dawe *et al.* (1990); Waring *et al.* (1990); Overholtz and Waring (1991); Howell and Simpson (1994); Brodziak and Macy (1996); Gannon *et al.* (1997).

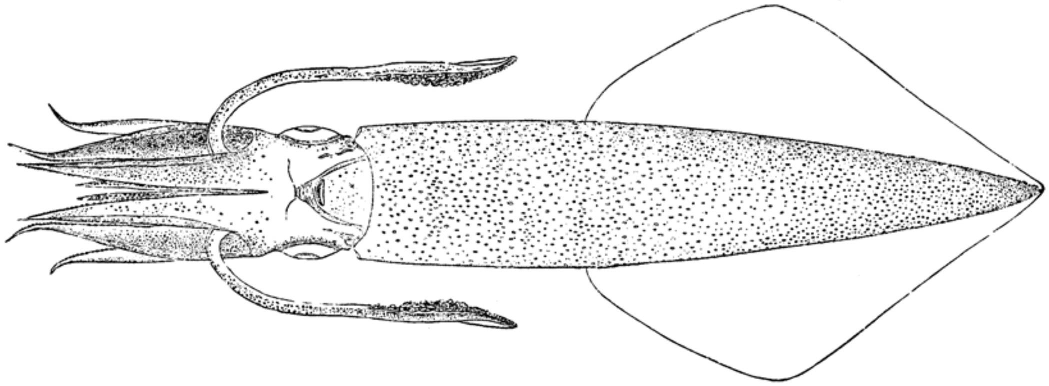

Figure 1. The longfin inshore squid, *Loligo pealeii* (from Goode 1884).

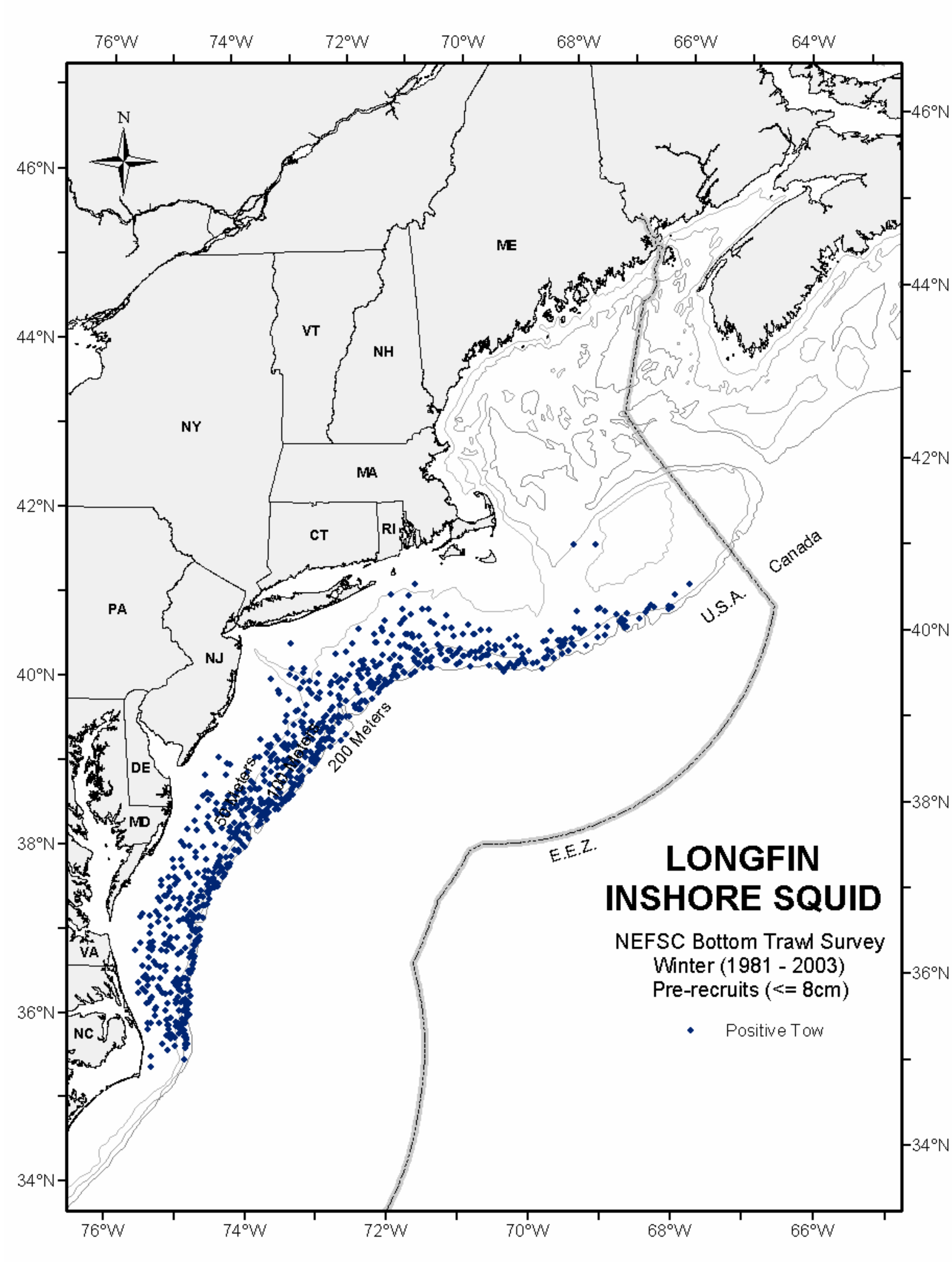

Figure 2. Seasonal distributions and abundances of pre-recruit longfin inshore squid collected during NEFSC bottom trawl surveys.
Based on NEFSC winter bottom trawl surveys (1981-2003, all years combined). Distributions are displayed as presence only.

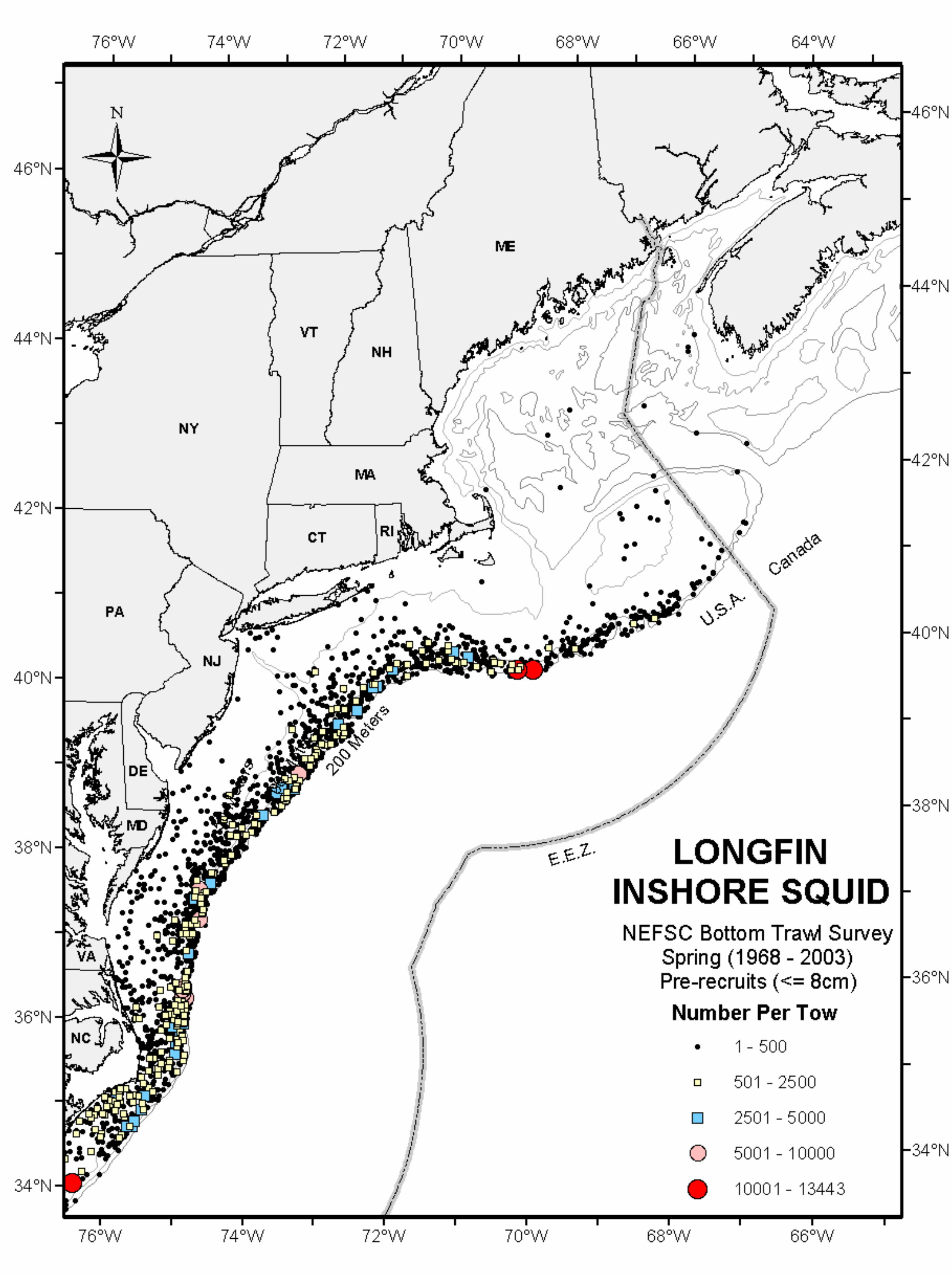

Figure 2. Cont'd.
Based on NEFSC spring bottom trawl surveys (1968-2003, all years combined). Survey stations where pre-recruits were not found are not shown.

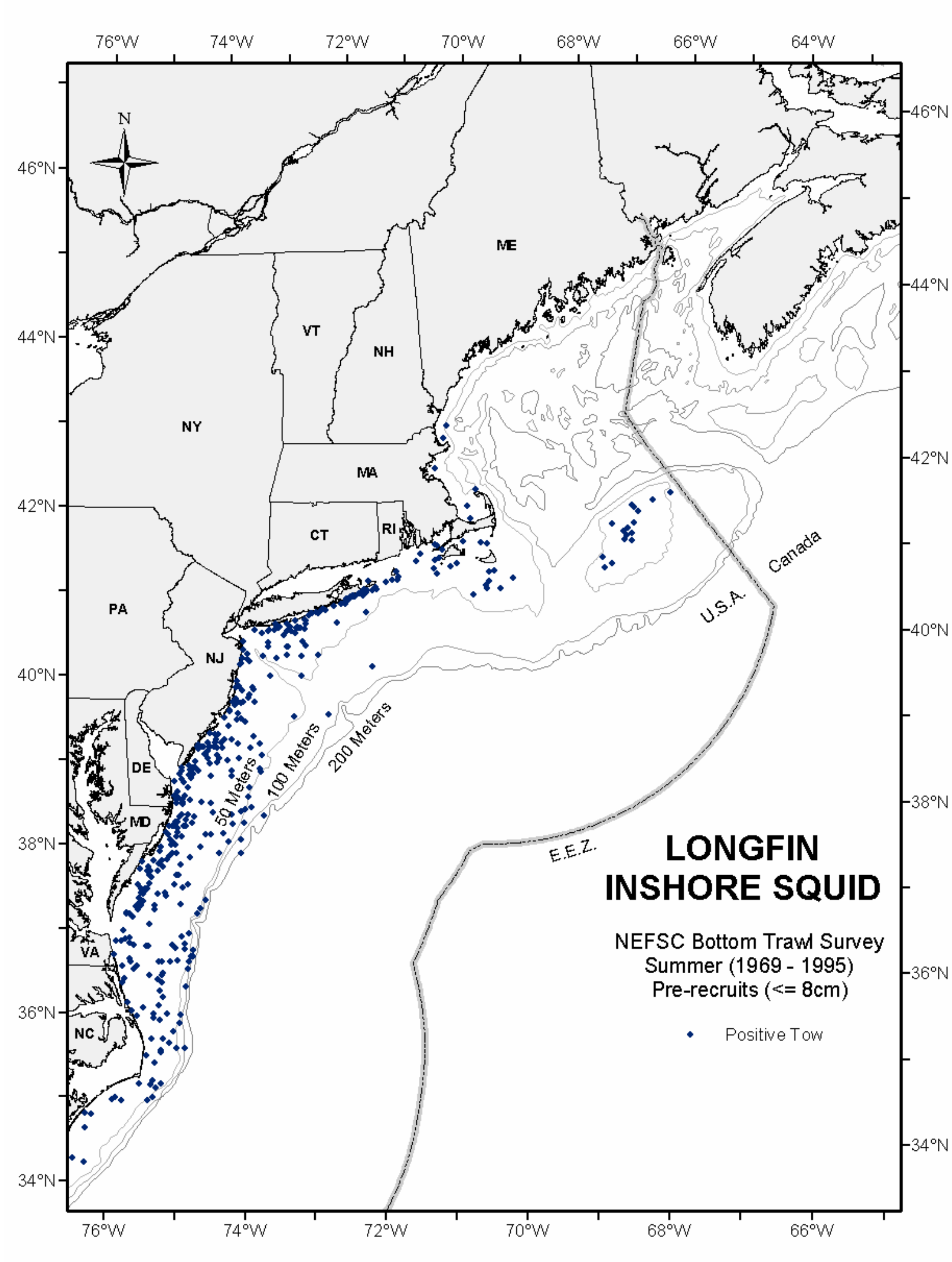

Figure 2. Cont'd.
Based on NEFSC summer bottom trawl surveys (1969-1995, all years combined). Distributions are displayed as presence only.

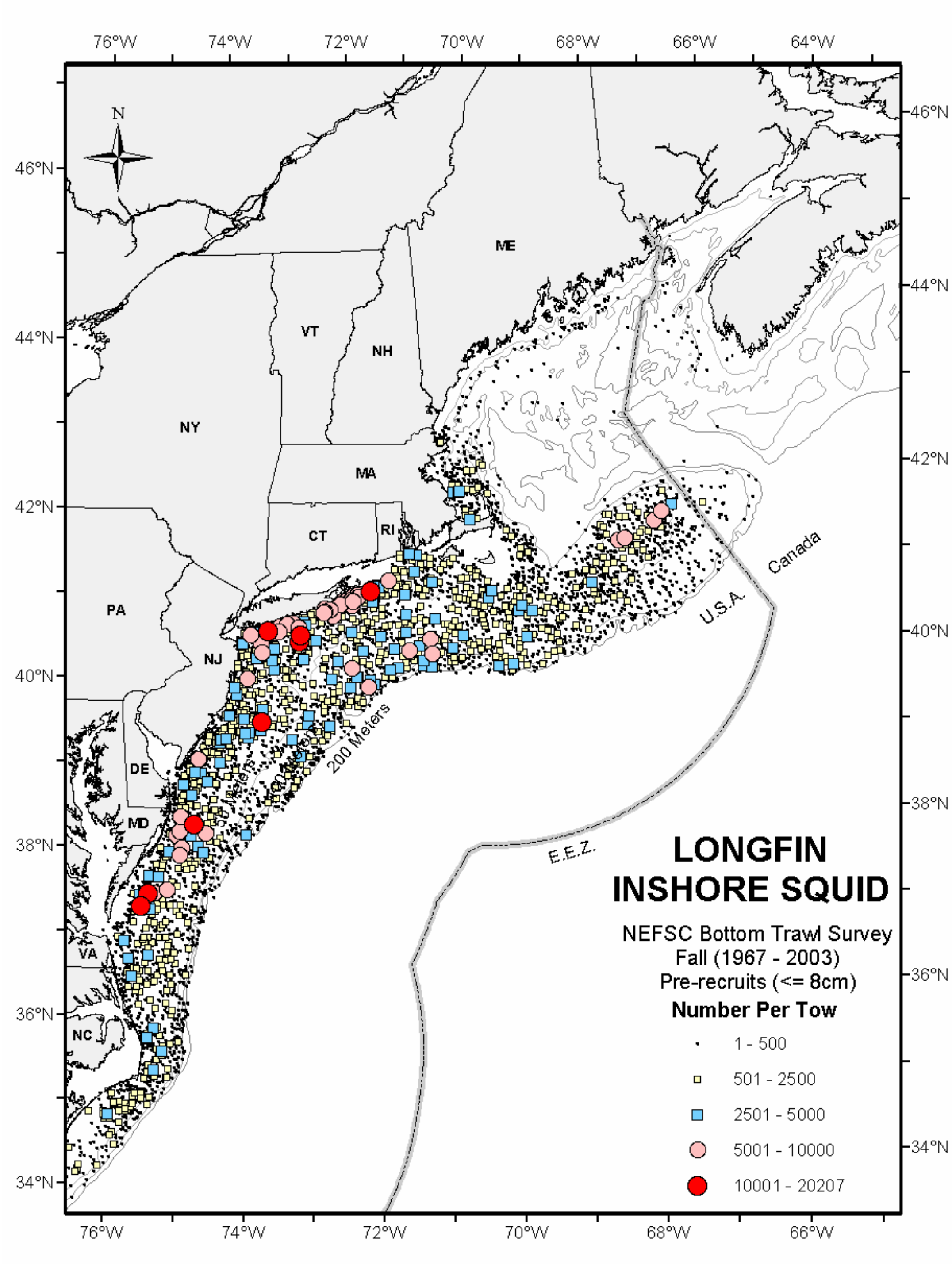

Figure 2. Cont'd.
Based on NEFSC fall bottom trawl surveys (1967-2003, all years combined). Survey stations where pre-recruits were not found are not shown.

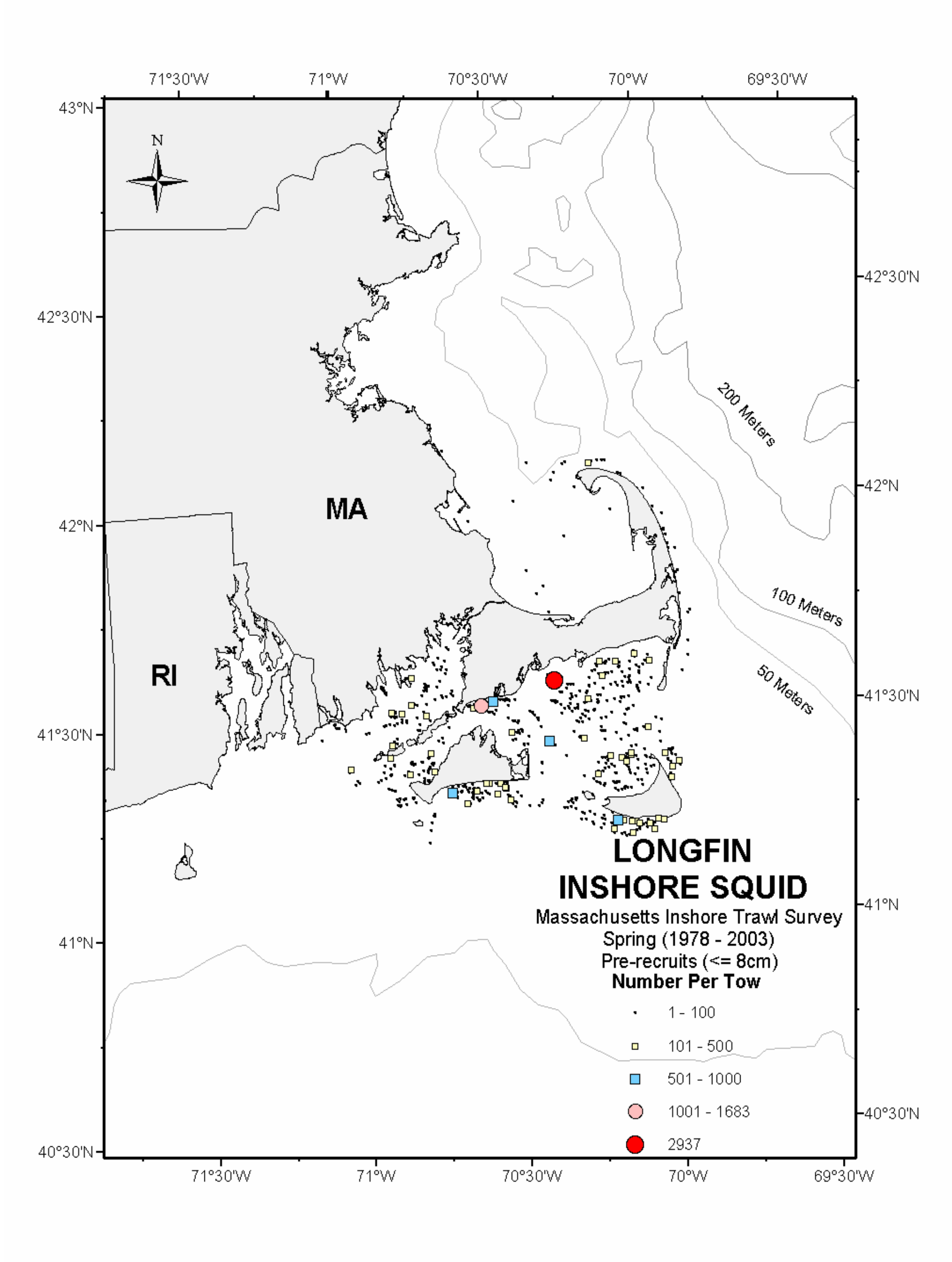

Figure 3. Distribution and abundance of pre-recruit longfin inshore squid in Massachusetts coastal waters. Based on spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where pre-recruits were not found are not shown.

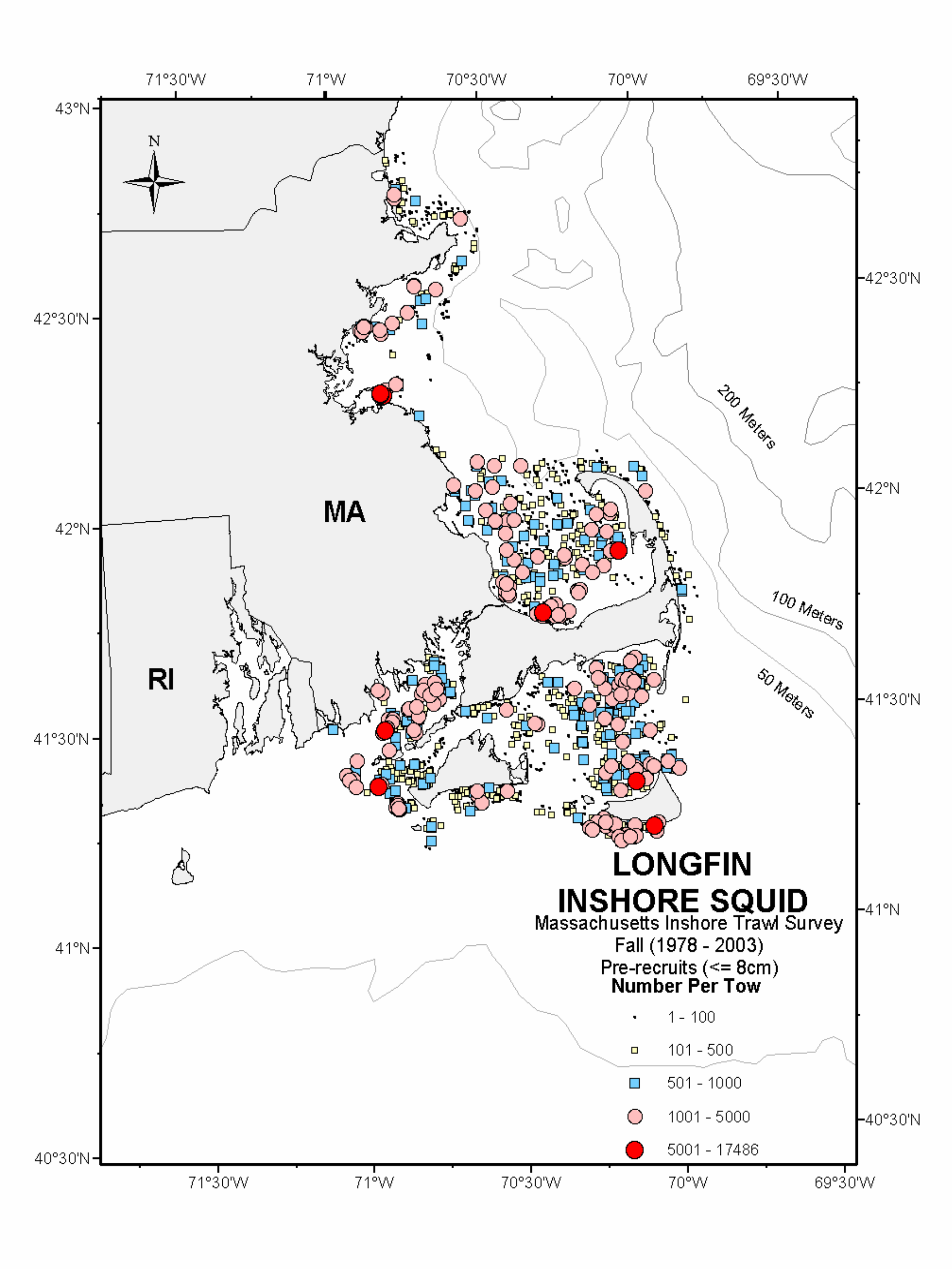

Figure 3. Cont'd.
Based on fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where pre-recruits were not found are not shown.

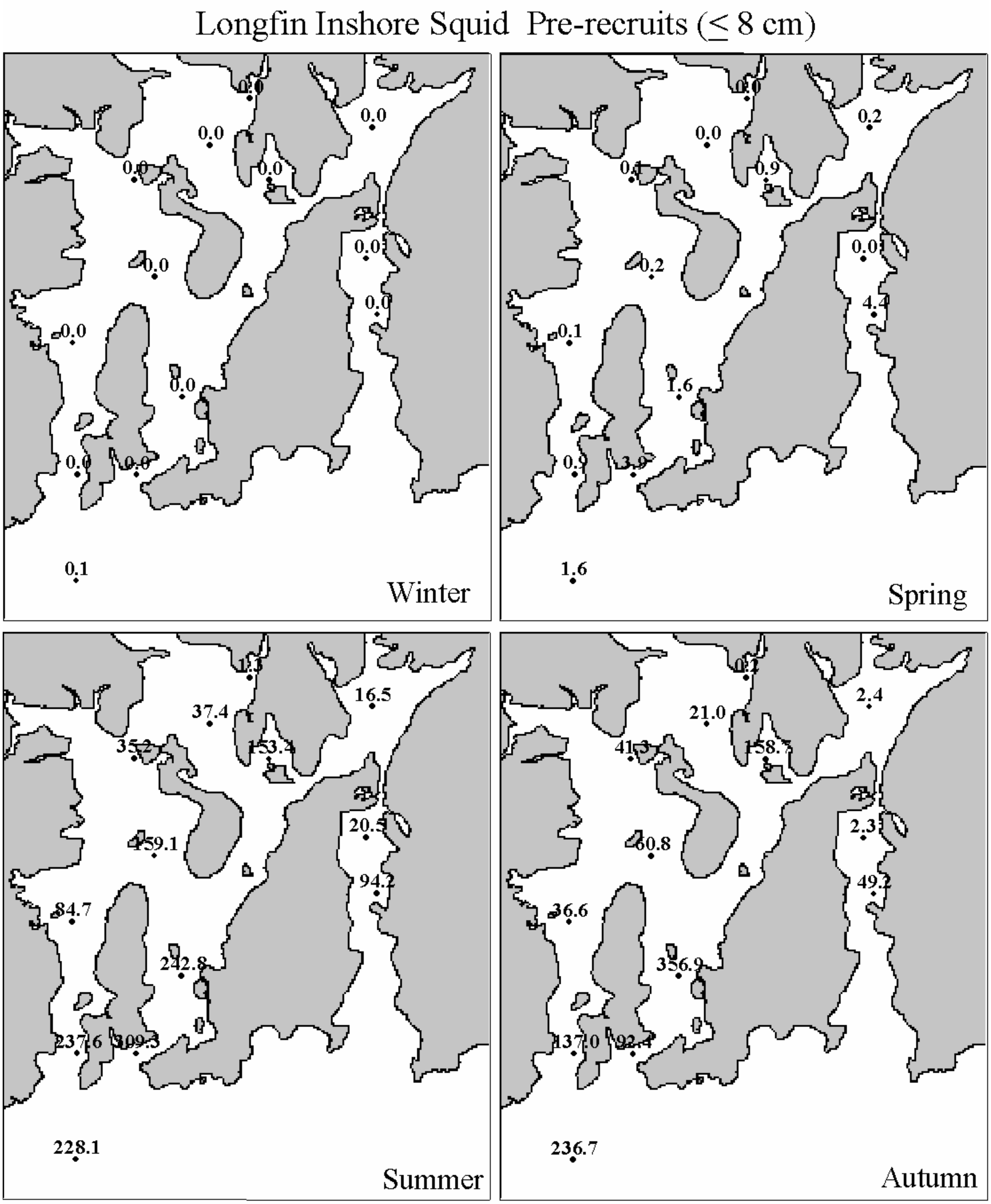

Figure 4. Seasonal distribution and abundance of longfin inshore squid pre-recruits in Narragansett Bay. Based upon the 1990-1996 Rhode Island bottom trawl surveys. The numbers shown at each station are the average catch per tow rounded to one decimal place [see Reid *et al.* (1999) for details].

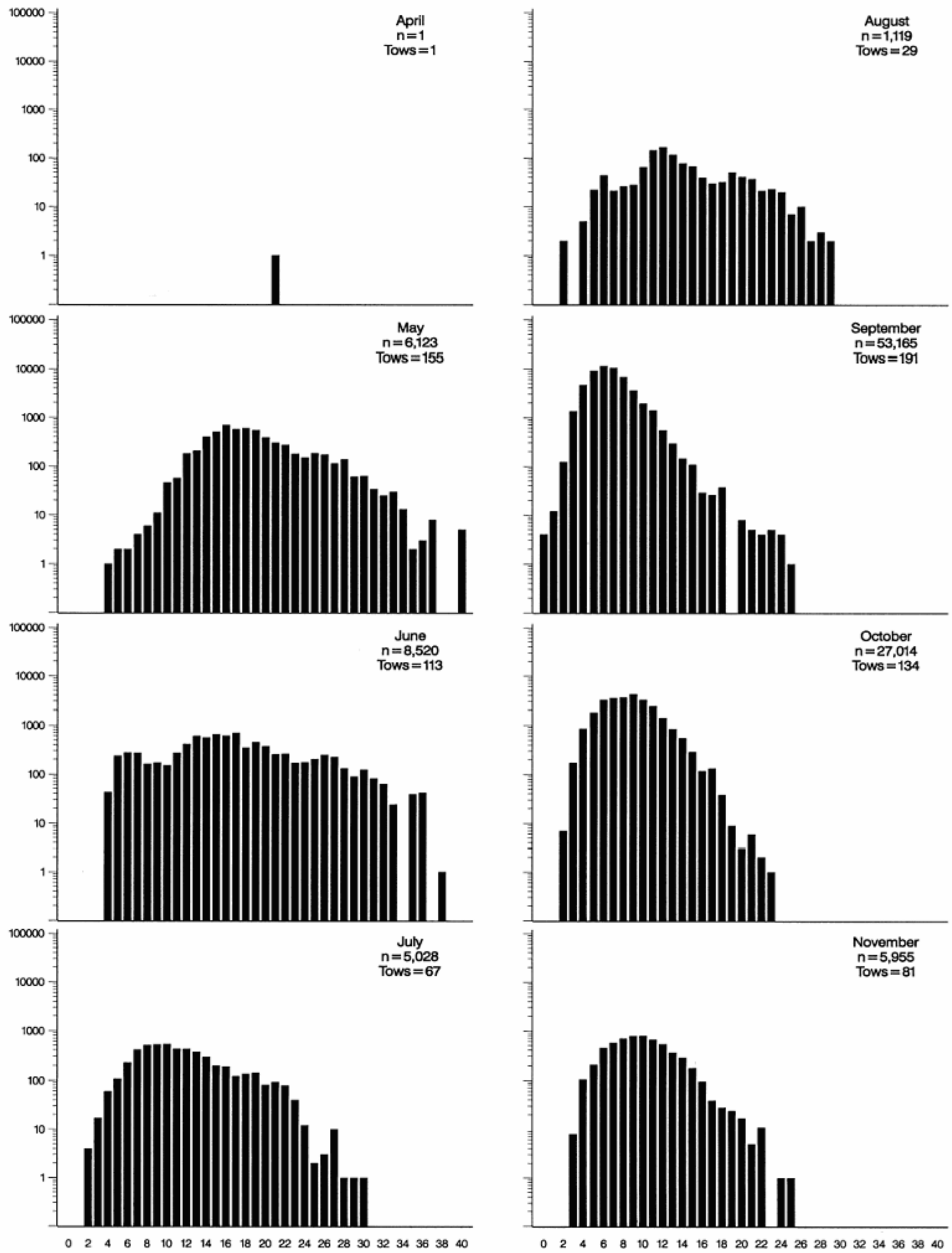

Figure 5. Monthly $\log_{10}$ length frequencies (cm) of longfin inshore squid collected in Long Island Sound, based on 106,925 squid taken in 771 tows between 1987 and 1994. Source: Gottschall *et al.* (2000).

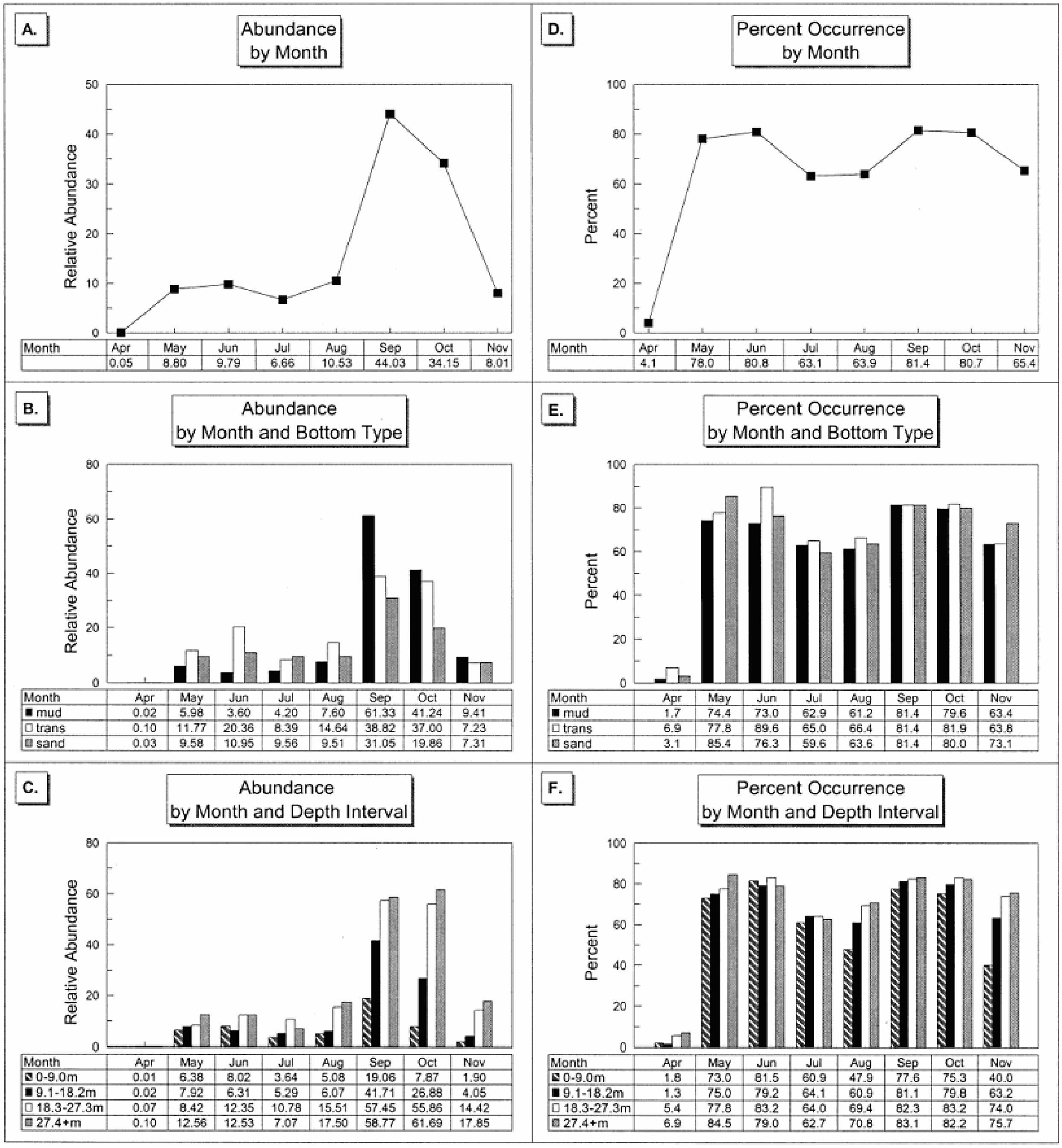

Figure 6. Relative abundance (geometric mean catch/tow) catch/tow and percent occurrence (proportion of samples in which at least one individual was observed) for longfin inshore squid in Long Island Sound, by month, month and bottom type, and month and depth interval. Source: Gottschall *et al.* (2000).

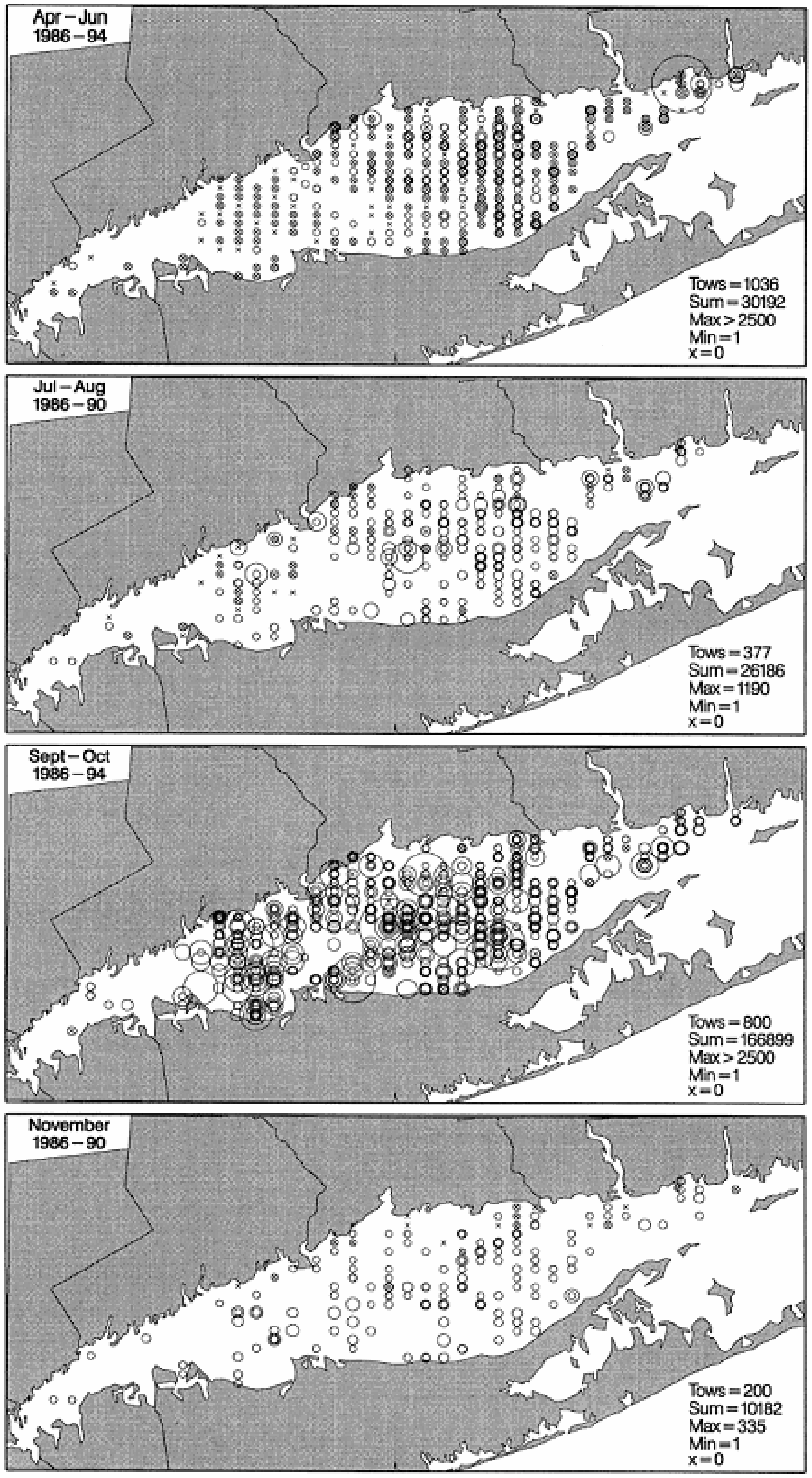

Figure 7. Distribution and abundances of longfin inshore squid in Long Island Sound, based on the finfish surveys of the Connecticut Fisheries Division, 1986-1994. Source: Gottschall *et al.* (2000). Circle diameter is proportional to the number of squid caught, and is scaled to the maximum catch (indicated by "max=" or "max>"); the largest circle represents a tow with a catch of > 2,500 squid. Collections were made with a 14 m otter trawl at about 40 stations chosen by stratified random design.

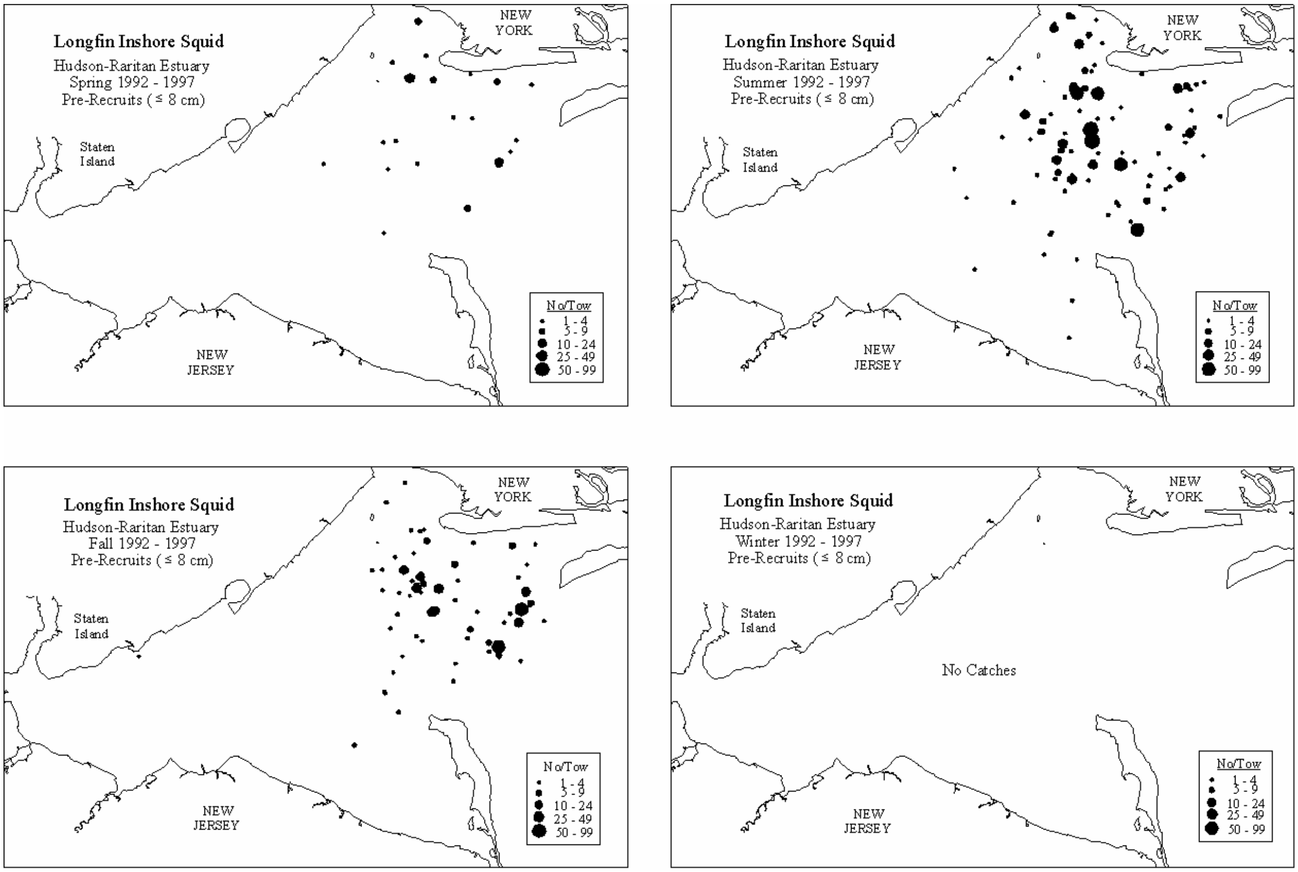

Figure 8. Seasonal distribution and abundance of longfin inshore squid pre-recruits collected in the Hudson-Raritan estuary.
Based on NEFSC Hudson-Raritan trawl surveys, January 1992 – June 1997 [see Reid *et al.* (1999) for details].

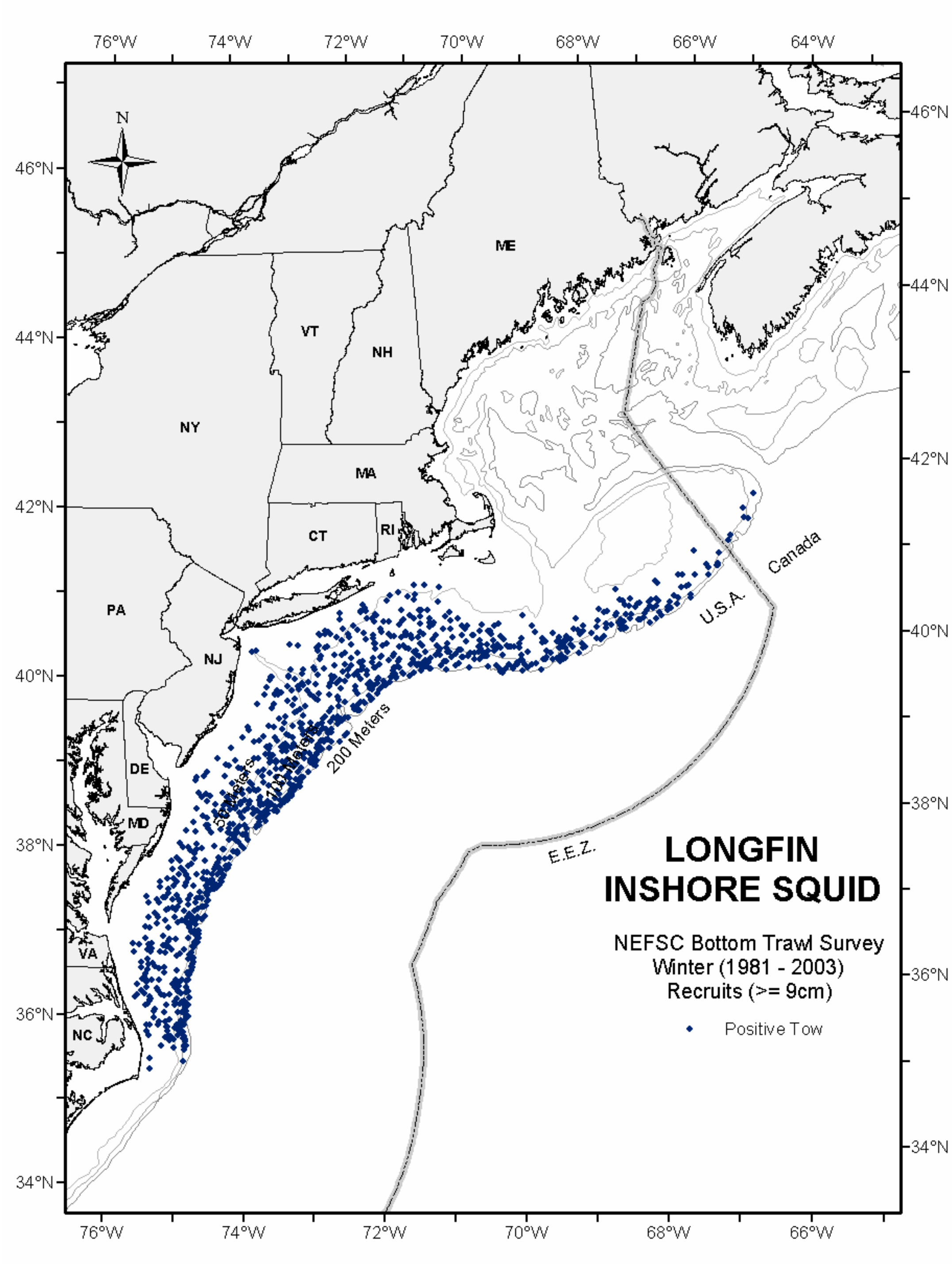

Figure 9. Seasonal distributions and abundances of recruit longfin inshore squid collected during NEFSC bottom trawl surveys.
Based on NEFSC winter bottom trawl surveys (1981-2003, all years combined). Distributions are displayed as presence only.

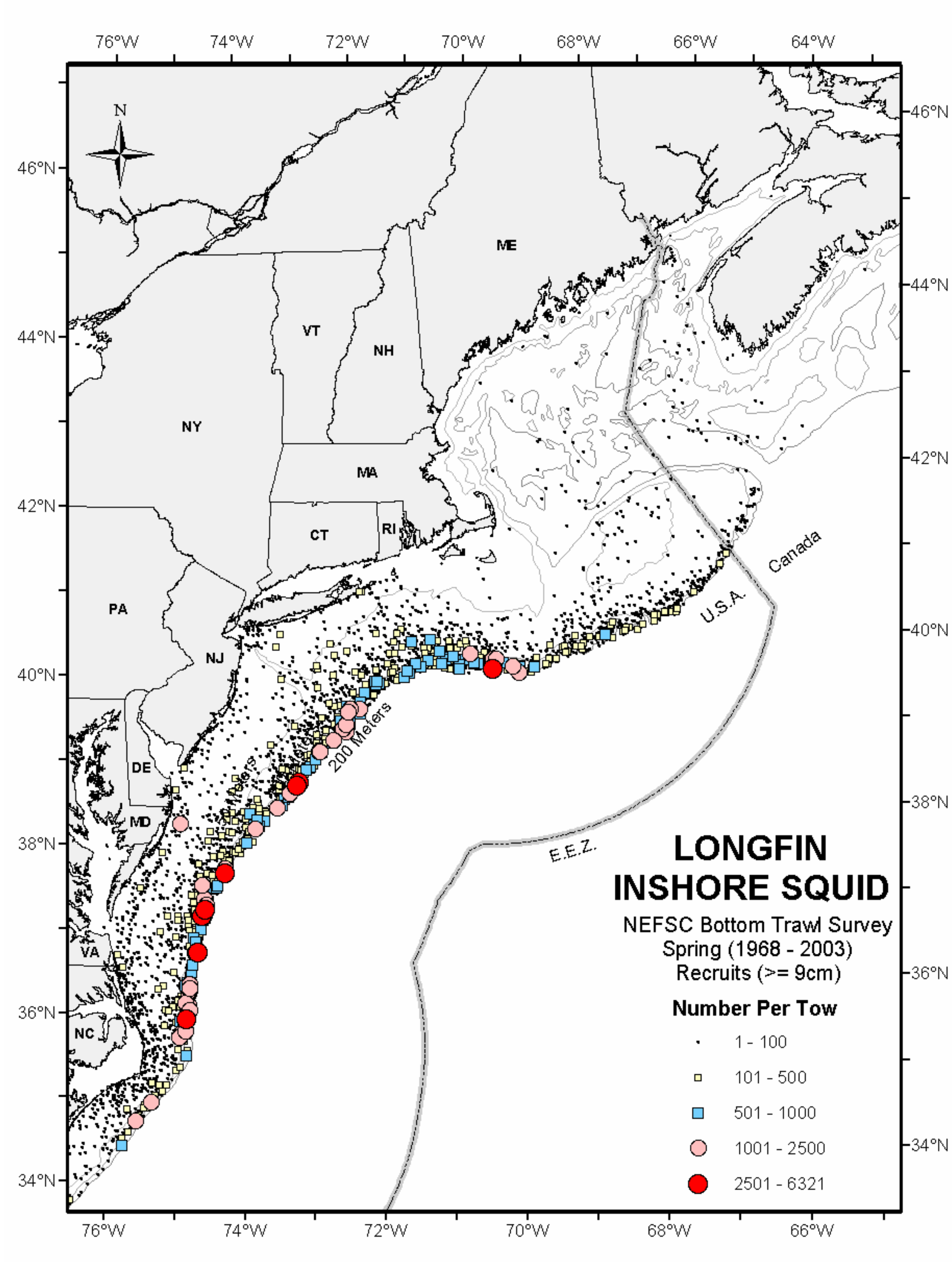

Figure . Cont'd.
Based on NEFSC spring bottom trawl surveys (1968-2003, all years combined). Survey stations where recruits were not found are not shown.

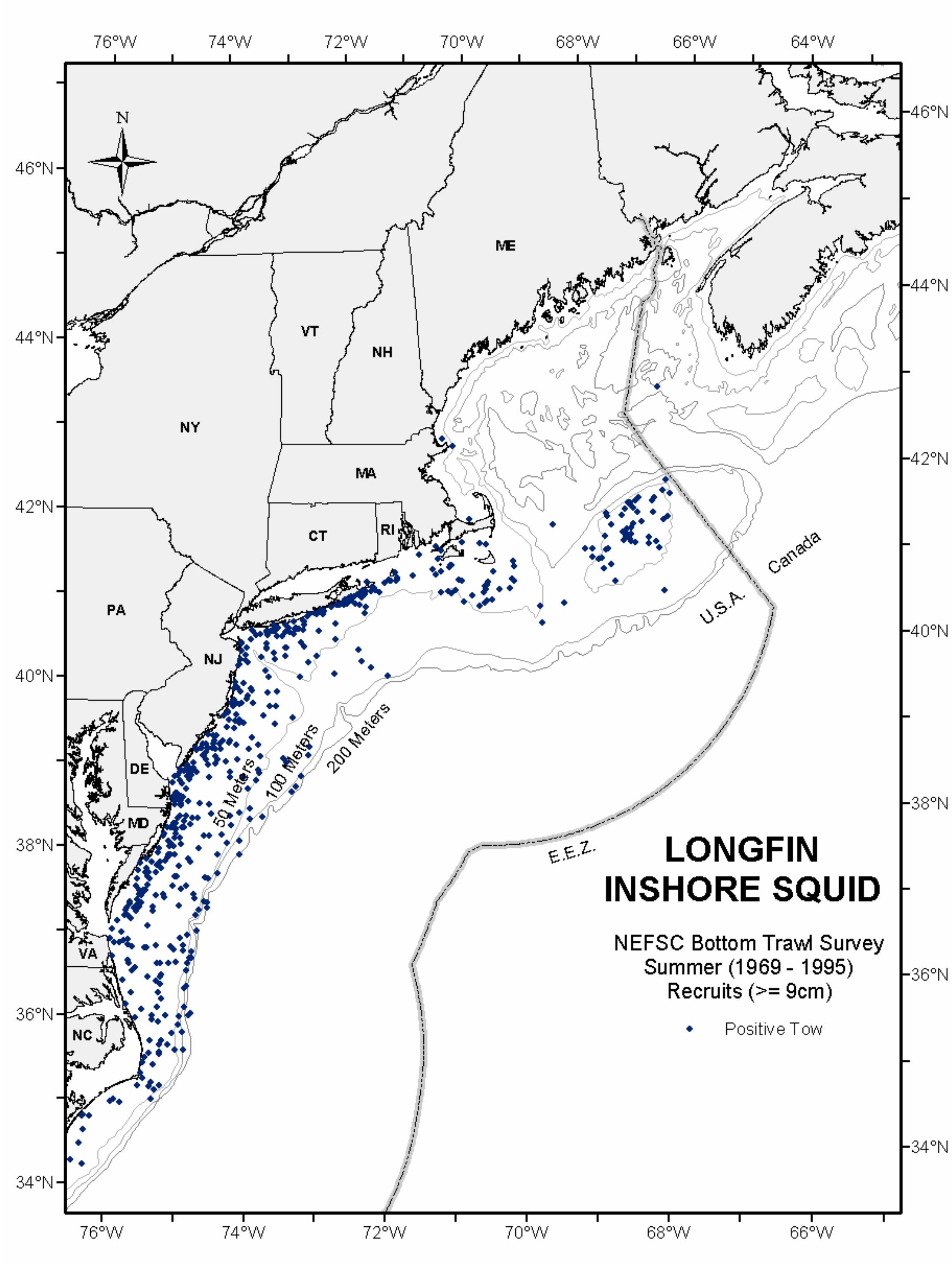

Figure 9. Cont'd.
Based on NEFSC summer bottom trawl surveys (1969-1995, all years combined). Distributions are displayed as presence only.

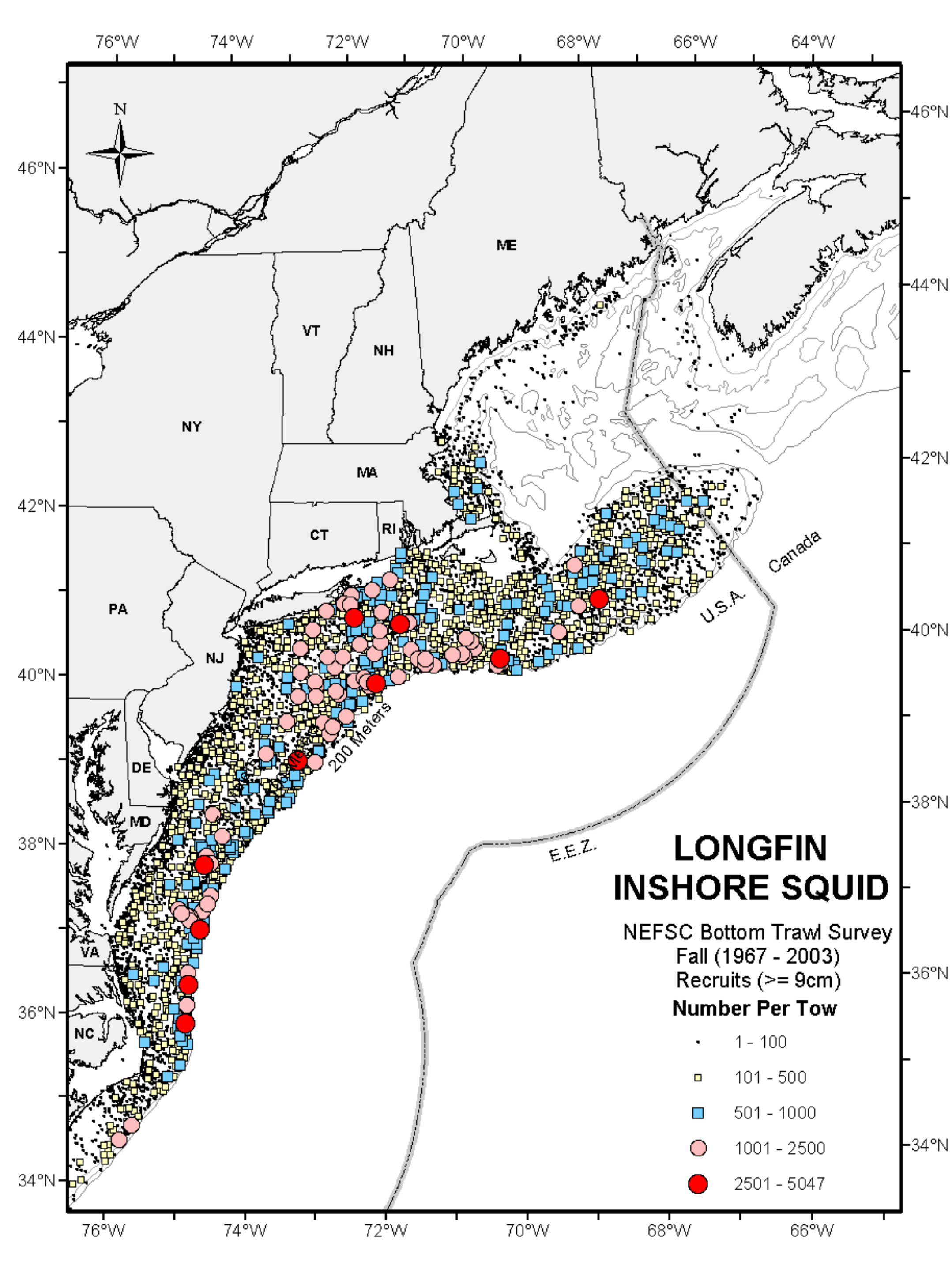

Figure 9. Cont'd.
Based on NEFSC fall bottom trawl surveys (1967-2003, all years combined). Survey stations where recruits were not found are not shown.

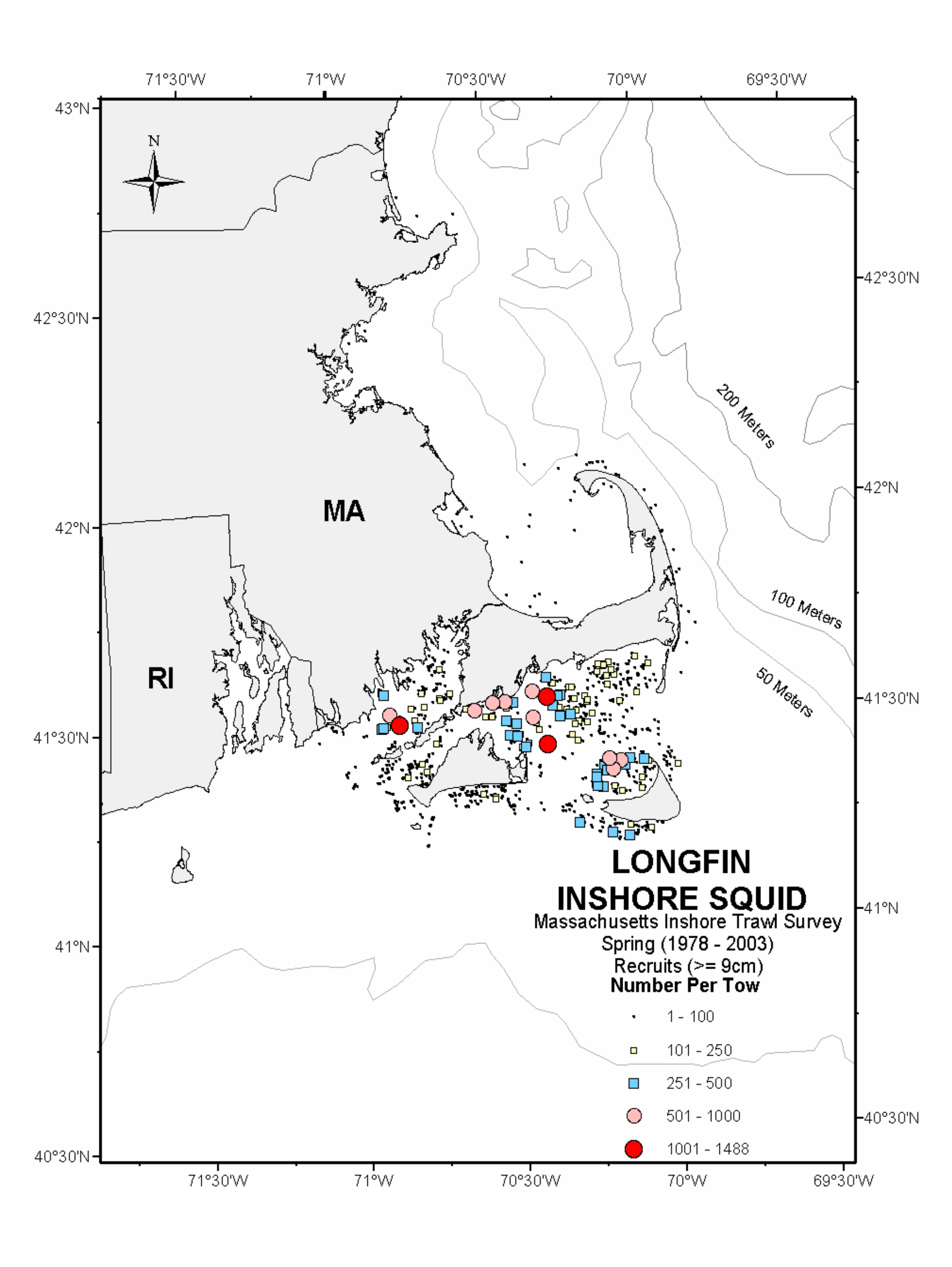

Figure 10. Seasonal distributions and abundances of recruit longfin inshore squid in Massachusetts coastal waters. Based spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where recruits were not found are not shown.

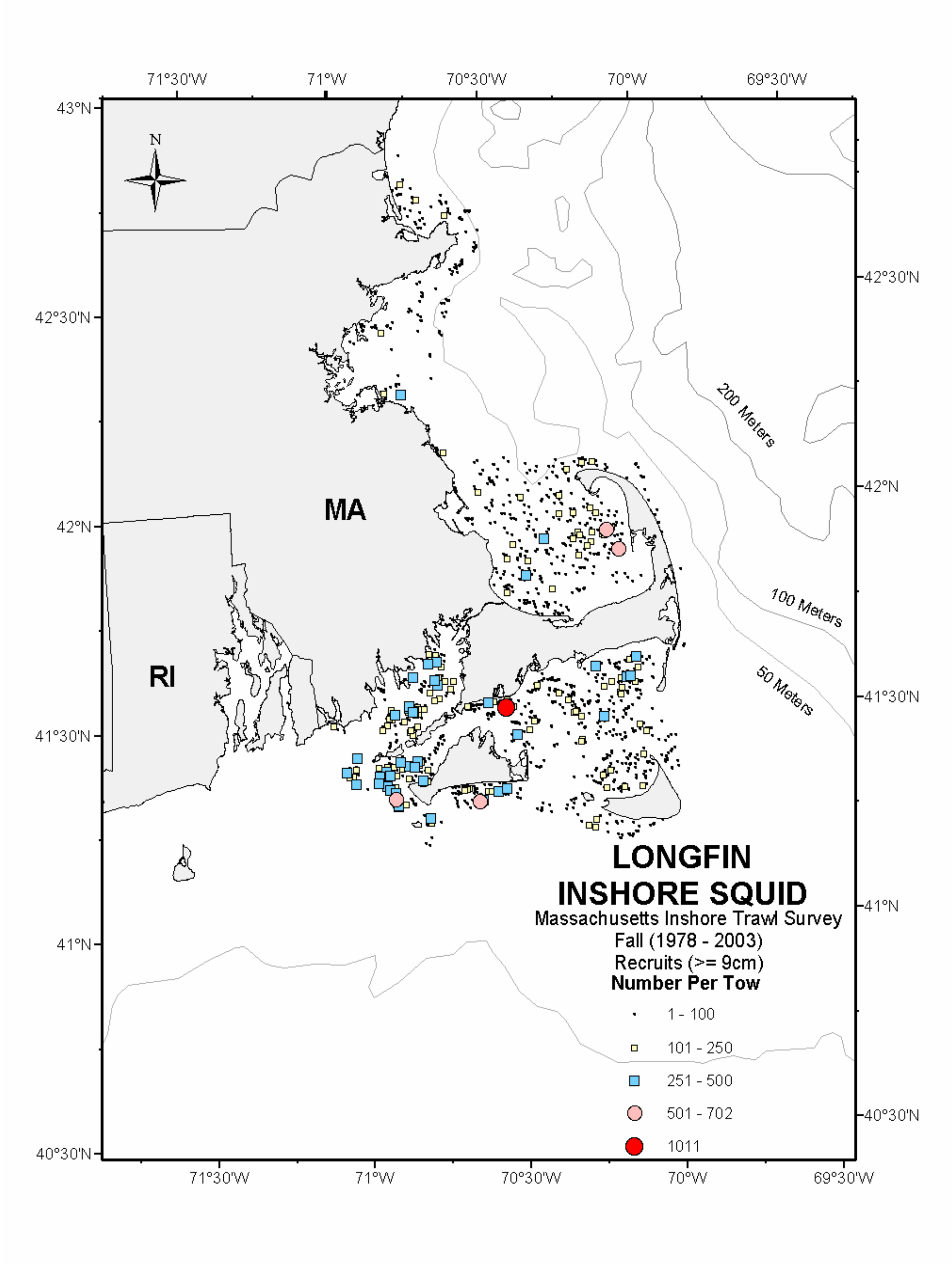

Figure 10. Cont'd.
Based on fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where recruits were not found are not shown.

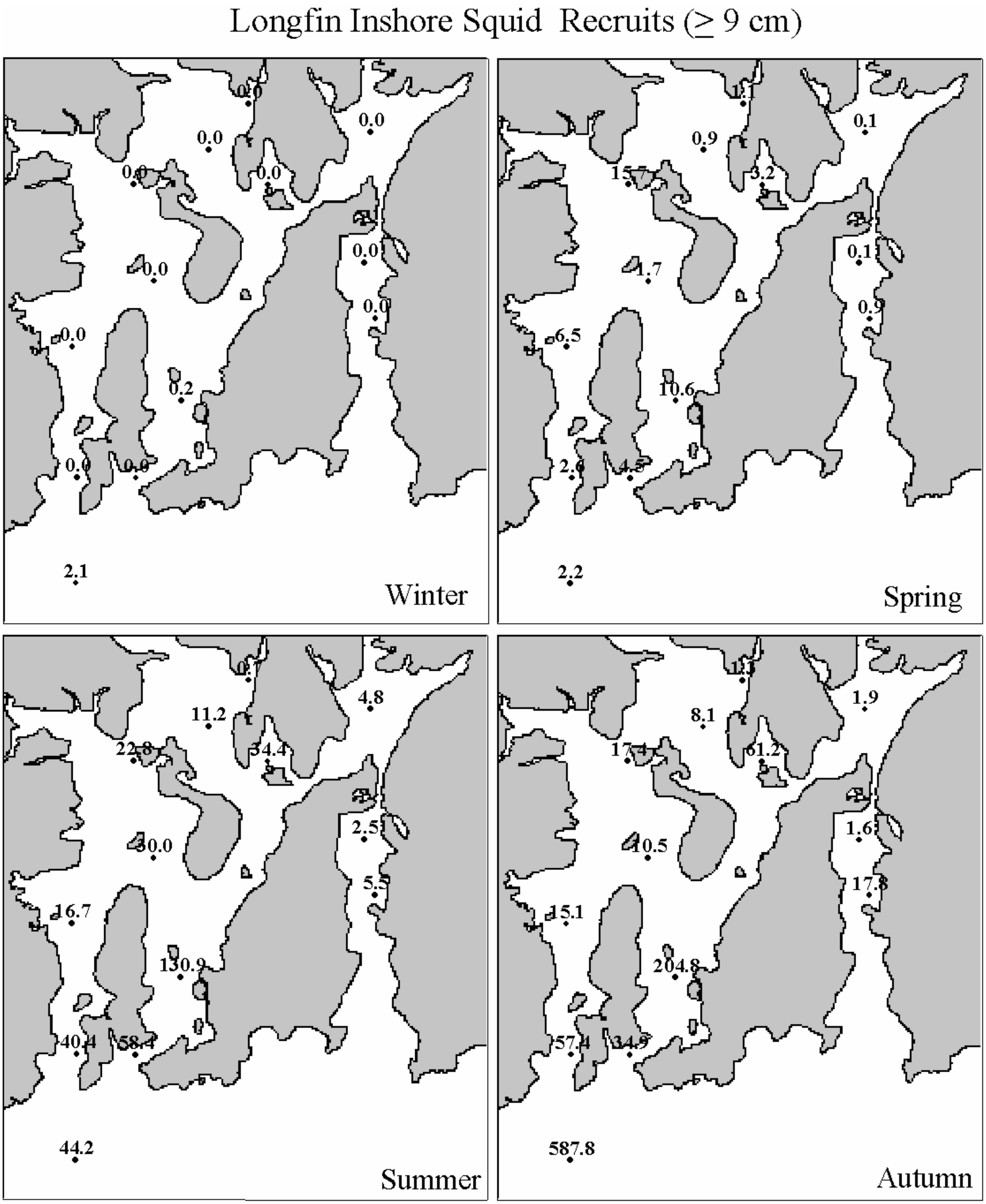

Figure 11. Seasonal distribution and abundance of longfin inshore squid recruits in Narragansett Bay. Based upon the 1990-1996 Rhode Island bottom trawl surveys. The numbers shown at each station are the average catch per tow rounded to one decimal place.

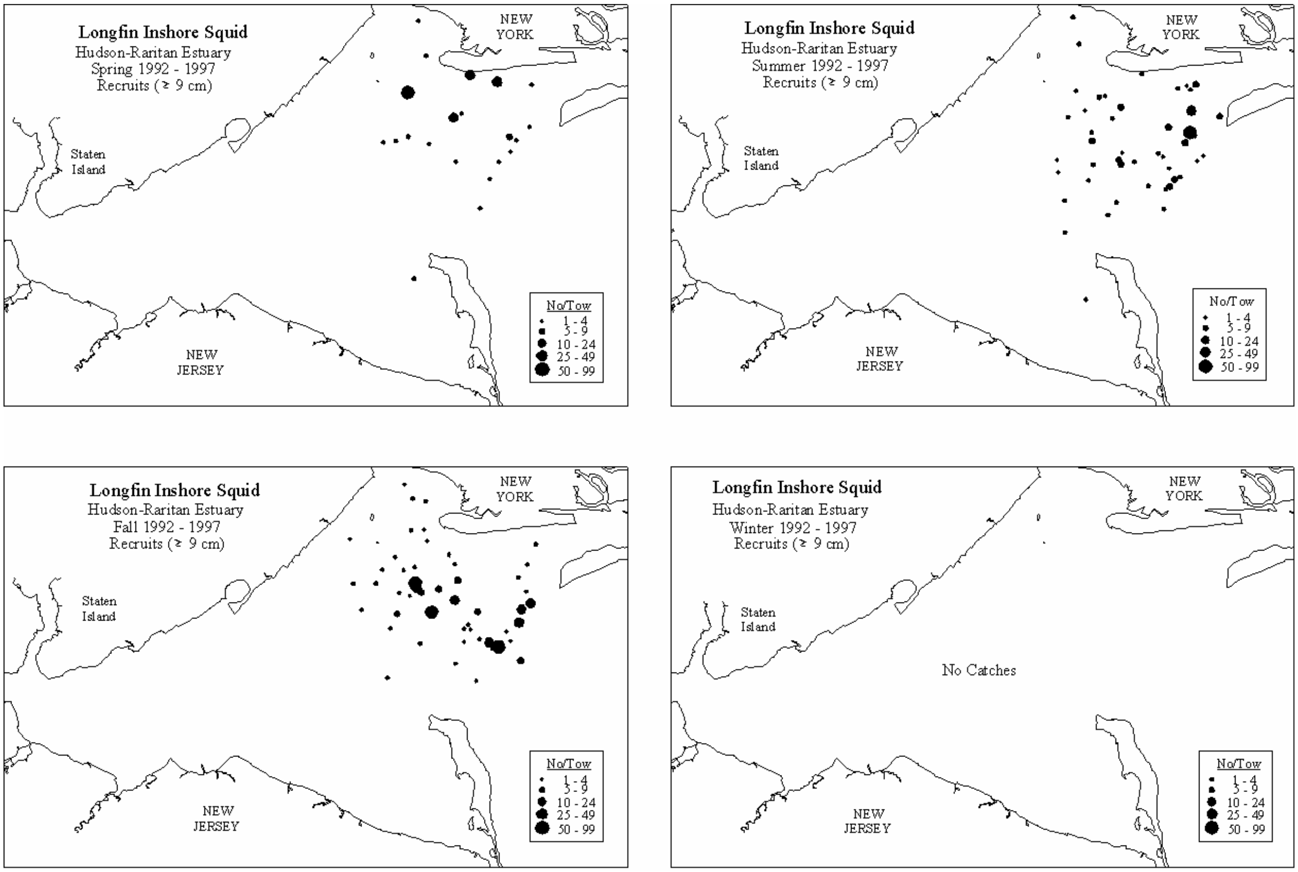

Figure 12. Seasonal distribution and abundance of longfin inshore squid recruits collected in the Hudson-Raritan estuary.
Based on NEFSC Hudson-Raritan trawl surveys, January 1992 – June 1997.

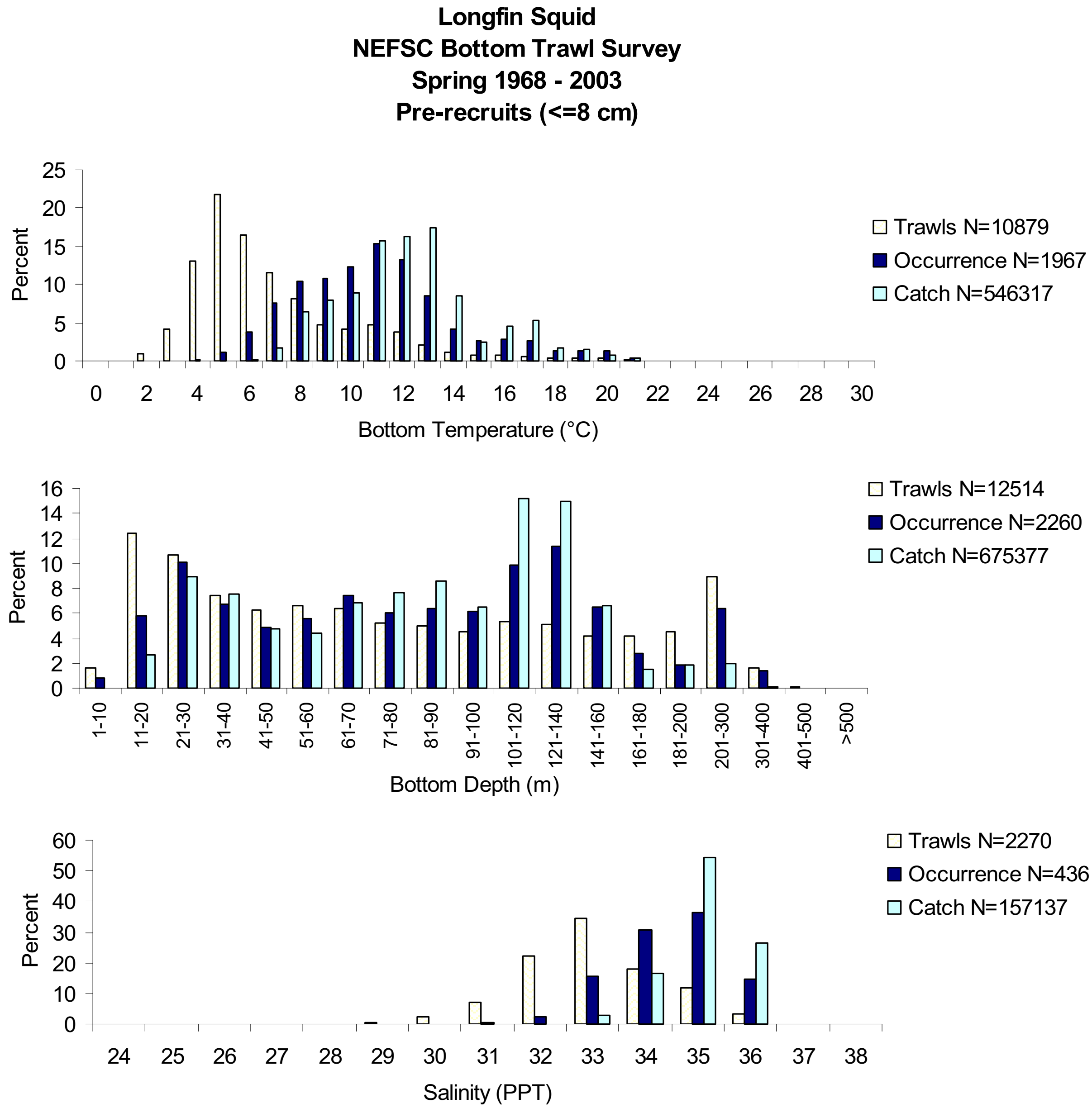

Figure 13. Distributions of pre-recruit longfin inshore squid and trawls from NEFSC bottom trawl surveys relative to bottom water temperature, depth, and salinity.
Based on NEFSC spring bottom trawl surveys (temperature and depth: 1968-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which longfin inshore squid occurred and medium bars show, within each interval, the percentage of the total number of longfin inshore squid caught. Note that the bottom depth interval changes with increasing depth.

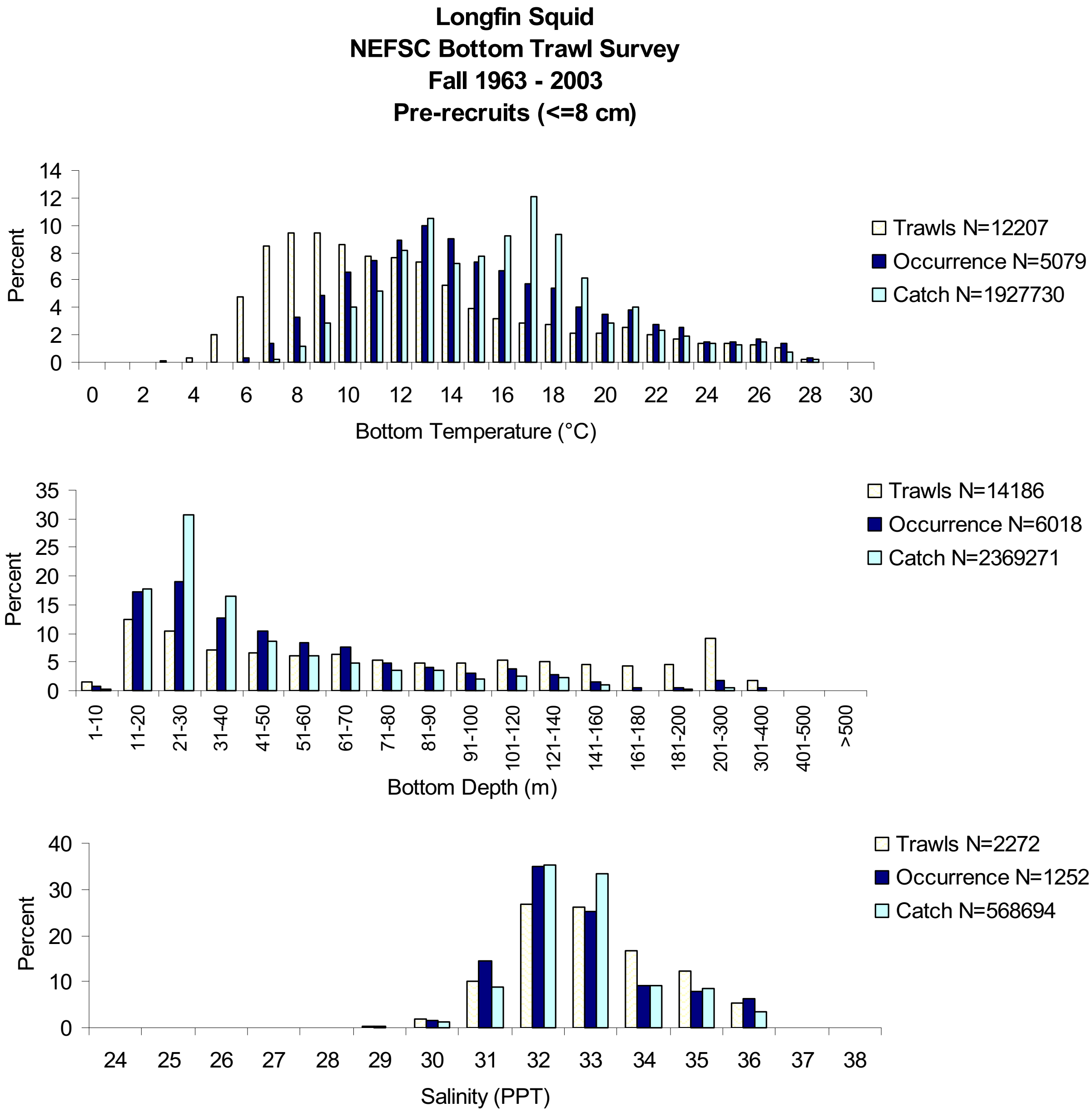

Figure 13. Cont'd.
Based on NEFSC fall bottom trawl surveys (temperature and depth: 1967-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which longfin inshore squid occurred and medium bars show, within each interval, the percentage of the total number of longfin inshore squid caught. Note that the bottom depth interval changes with increasing depth.

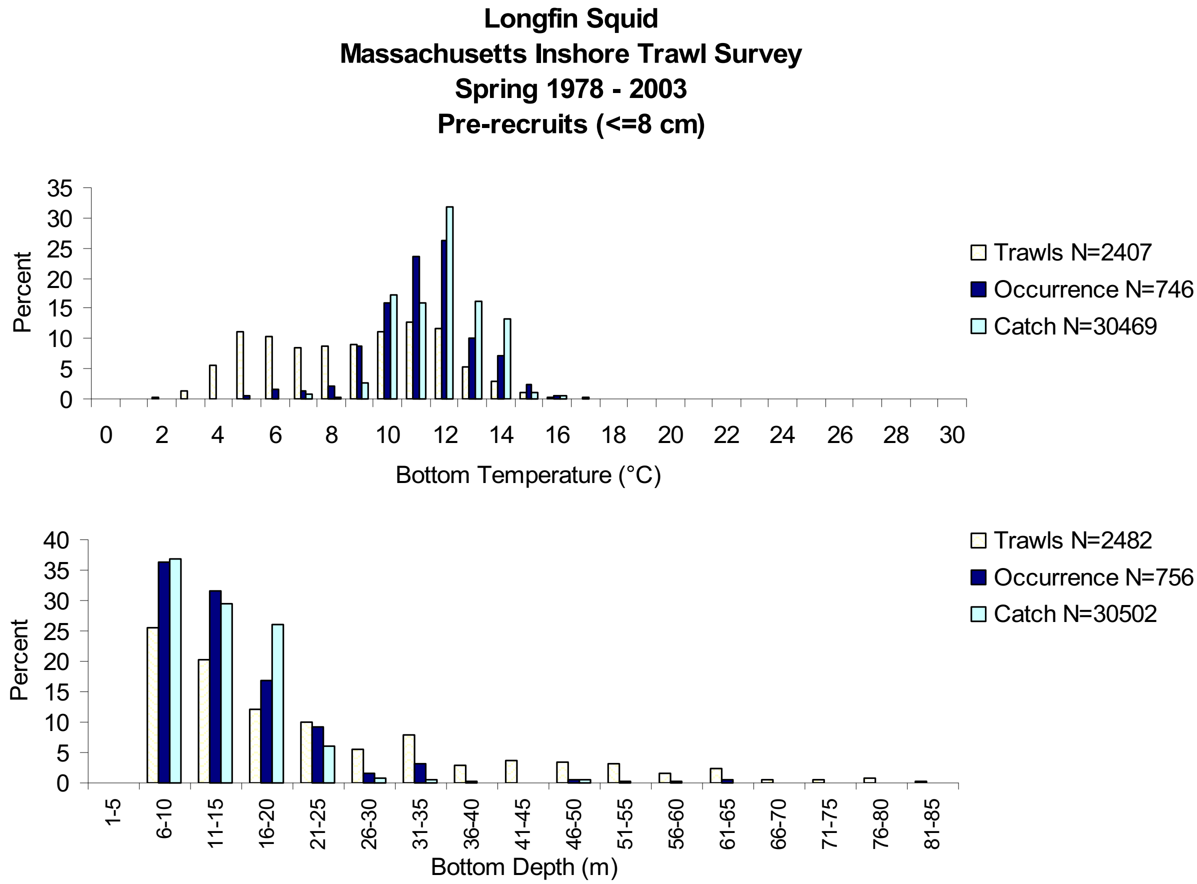

Figure 14. Distributions of pre-recruit longfin inshore squid and trawls in Massachusetts coastal waters relative to bottom water temperature and depth.

Based on spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which longfin inshore squid occurred and medium bars show, within each interval, the percentage of the total number of longfin inshore squid caught.

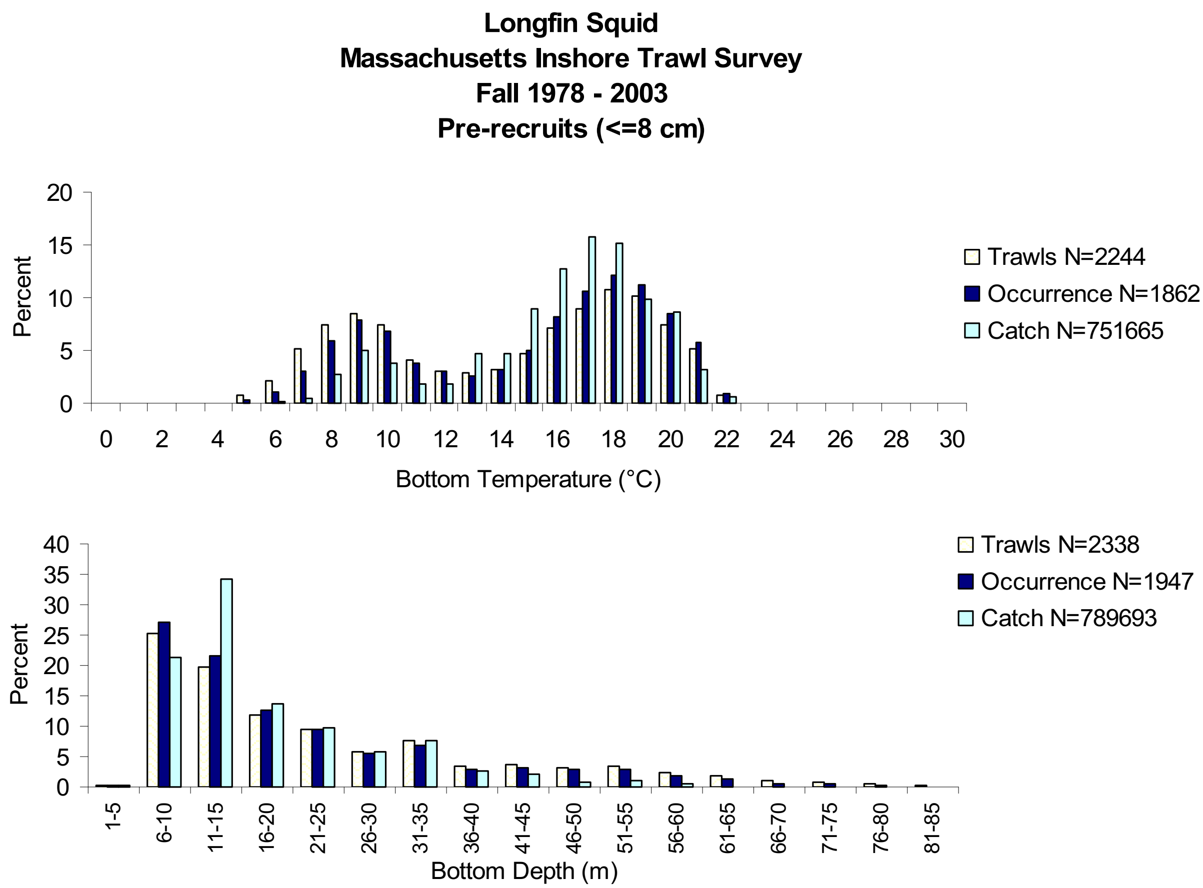

Figure 14. Cont'd.
Based on fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which longfin inshore squid occurred and medium bars show, within each interval, the percentage of the total number of longfin inshore squid caught.

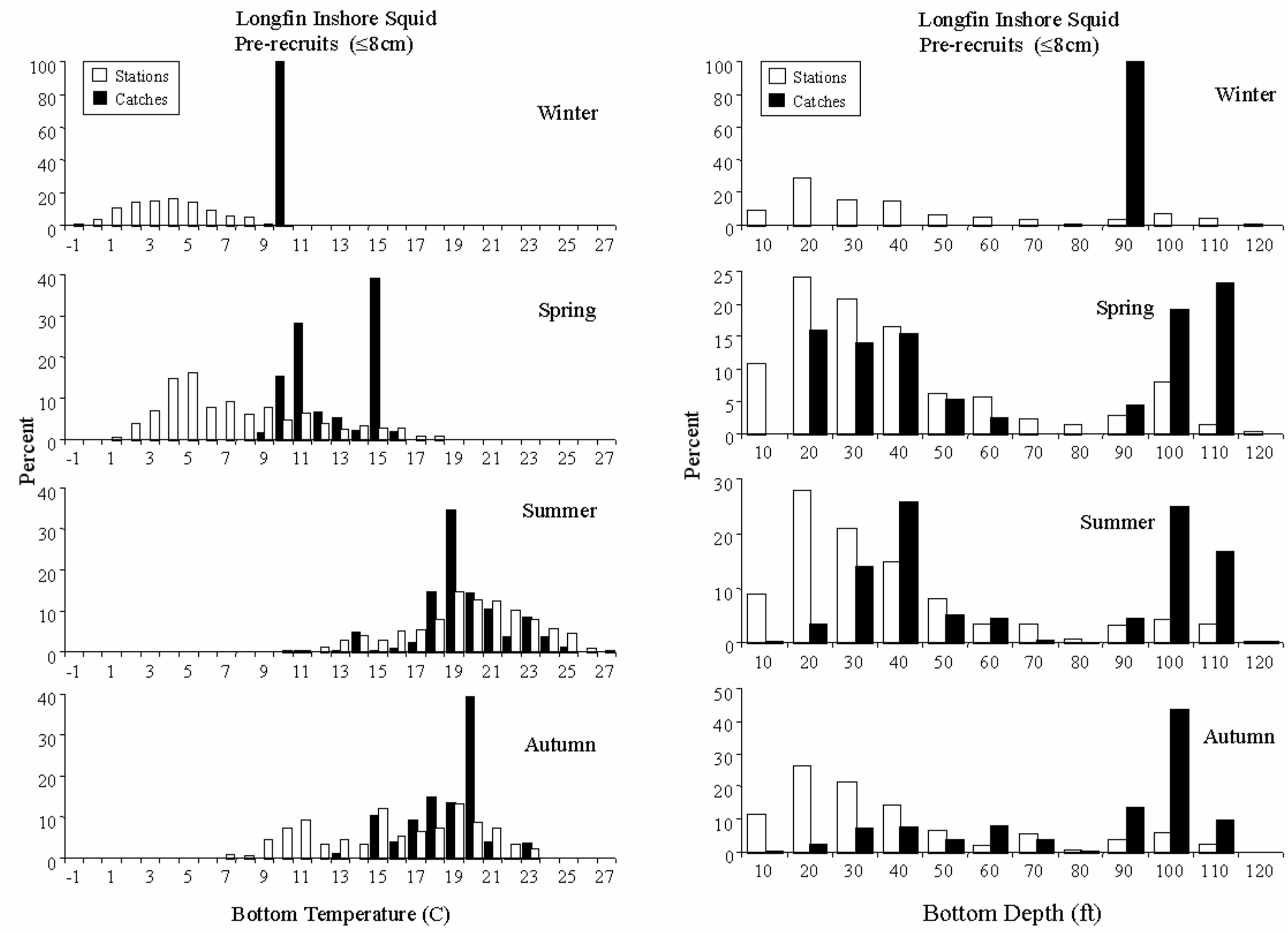

Figure 15. Distributions of longfin inshore squid pre-recruits in Narragansett Bay relative to mean bottom water temperature and bottom depth.
Based on Rhode Island trawl surveys, 1990-1996. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all catches.

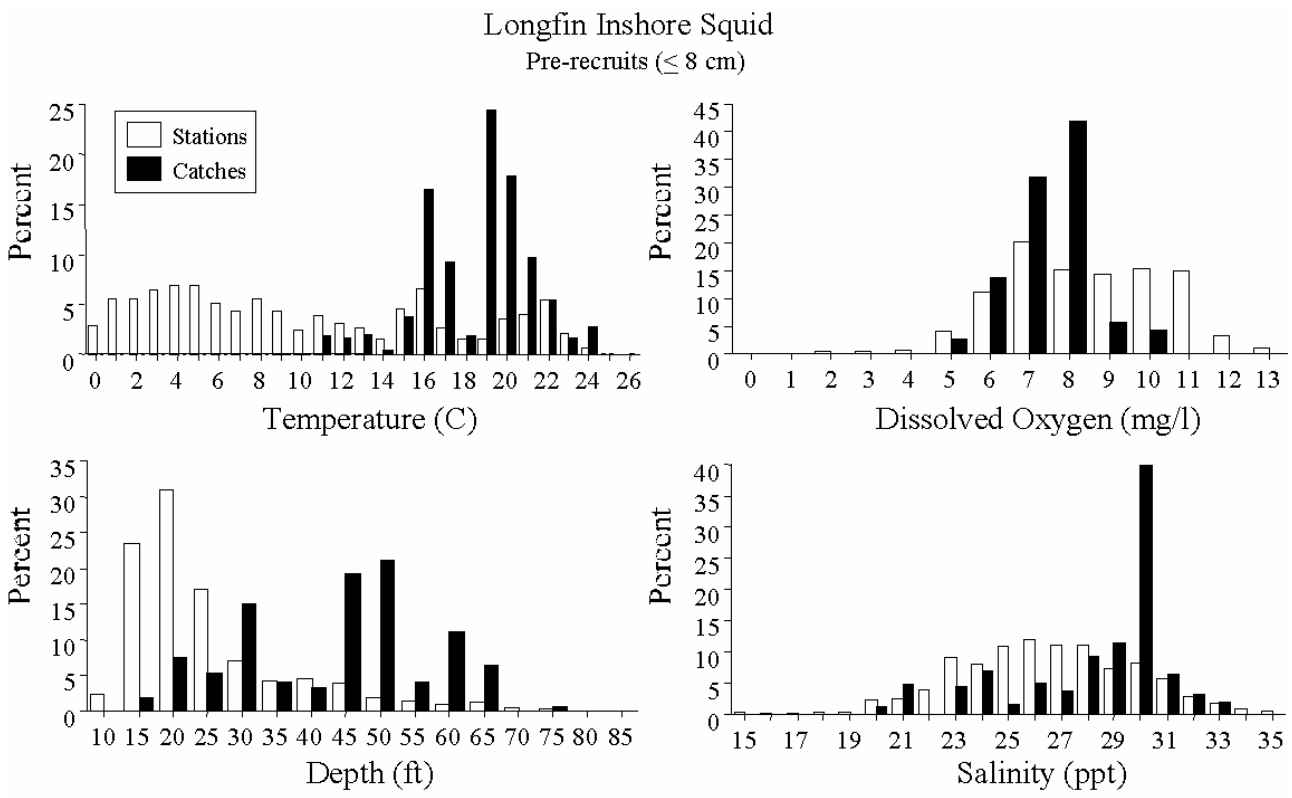

Figure 16. Distributions of longfin inshore squid pre-recruits in the Hudson-Raritan estuary relative to bottom water temperature, depth, dissolved oxygen, and salinity.
Based on NEFSC Hudson-Raritan estuary trawl surveys, 1992-1997, all seasons and years combined. Open bars represent the proportion of all stations surveyed, solid bars represent the proportion of the sum of all standardized catches.

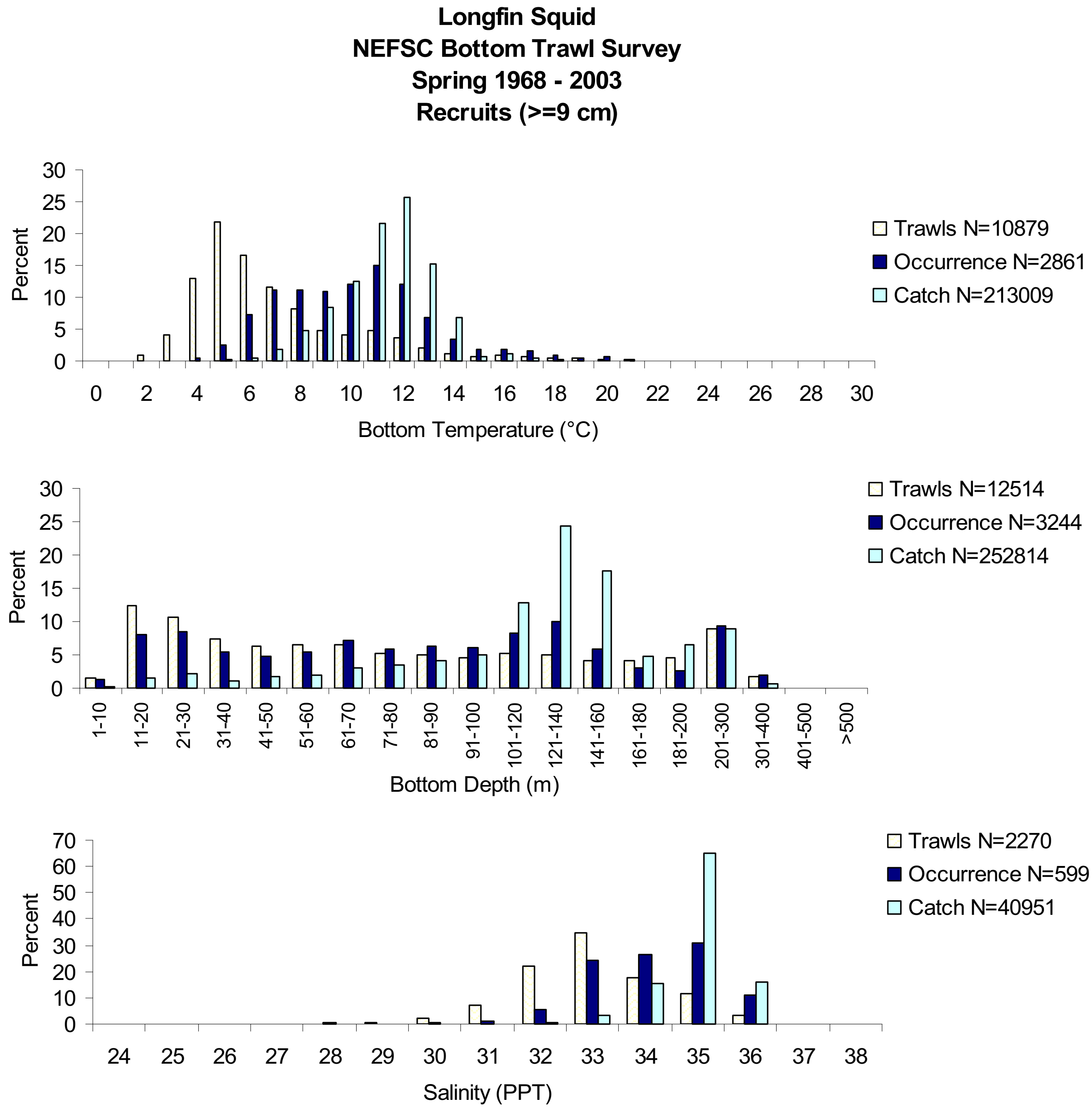

Figure 17. Distributions of recruit longfin inshore squid and trawls from NEFSC bottom trawl surveys relative to bottom water temperature, depth, and salinity.
Based on NEFSC spring bottom trawl surveys (temperature and depth: 1968-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which longfin inshore squid occurred and medium bars show, within each interval, the percentage of the total number of longfin inshore squid caught. Note that the bottom depth interval changes with increasing depth.

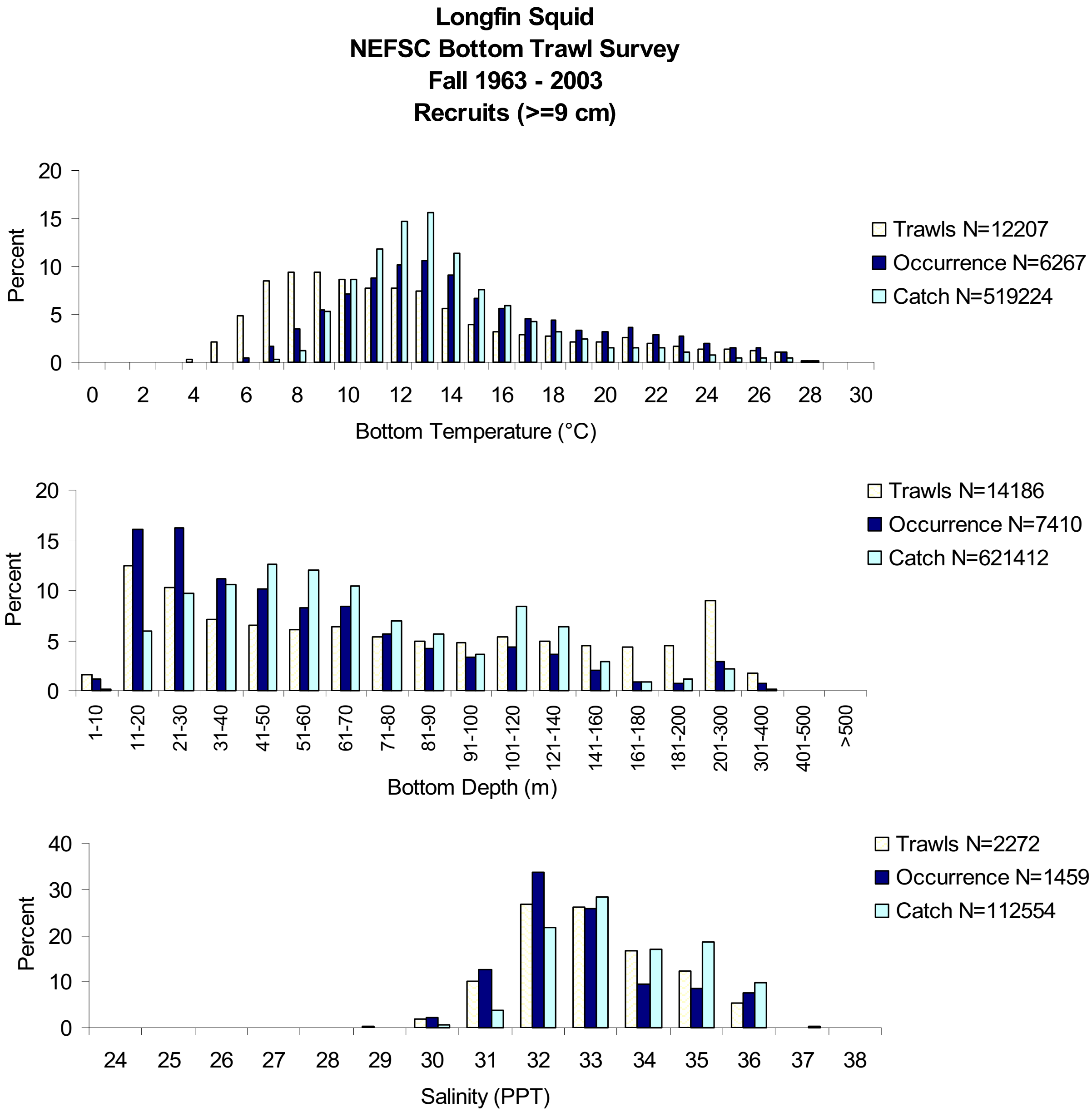

Figure 17. Cont'd.
Based on NEFSC fall bottom trawl surveys (temperature and depth: 1967-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which longfin inshore squid occurred and medium bars show, within each interval, the percentage of the total number of longfin inshore squid caught. Note that the bottom depth interval changes with increasing depth.

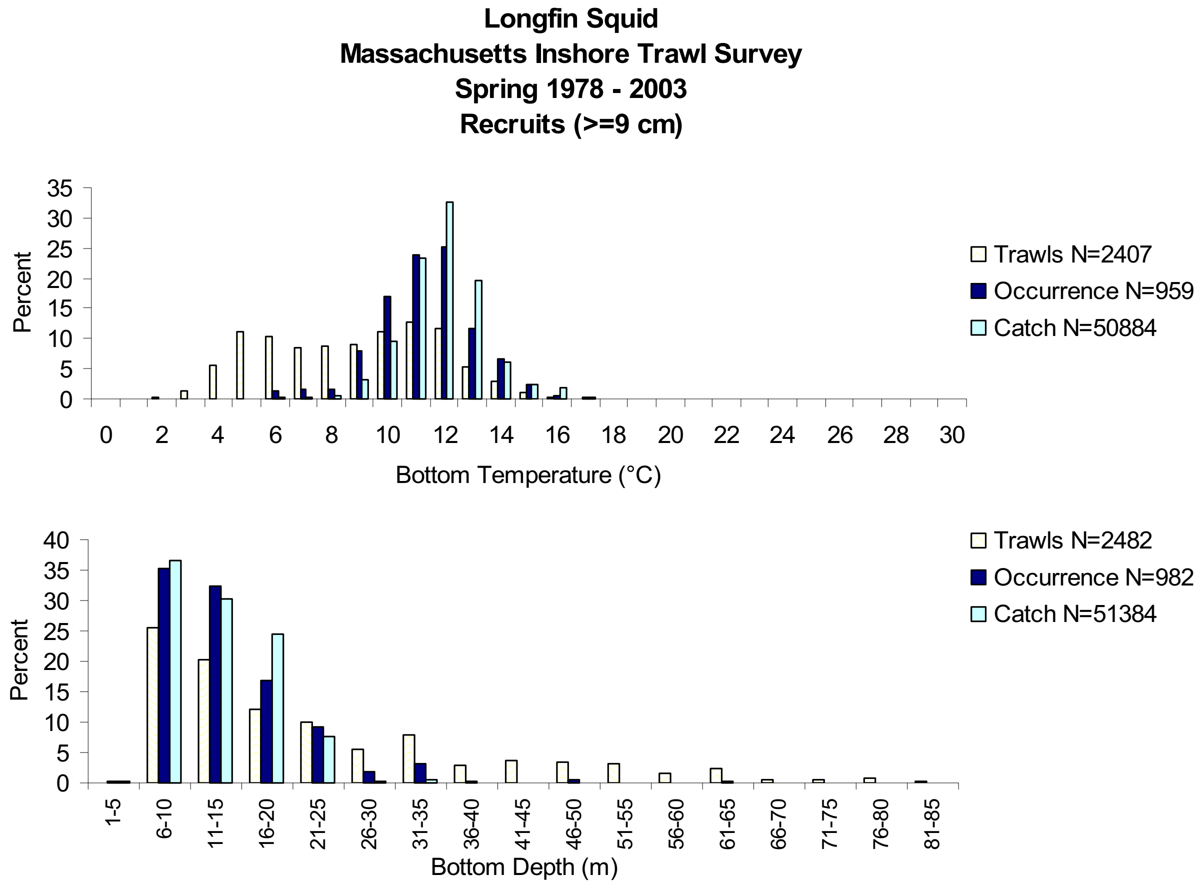

Figure 18. Distributions of recruit longfin inshore squid and trawls in Massachusetts coastal waters relative to bottom water temperature and depth.
Based on spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which longfin inshore squid occurred and medium bars show, within each interval, the percentage of the total number of longfin inshore squid caught.

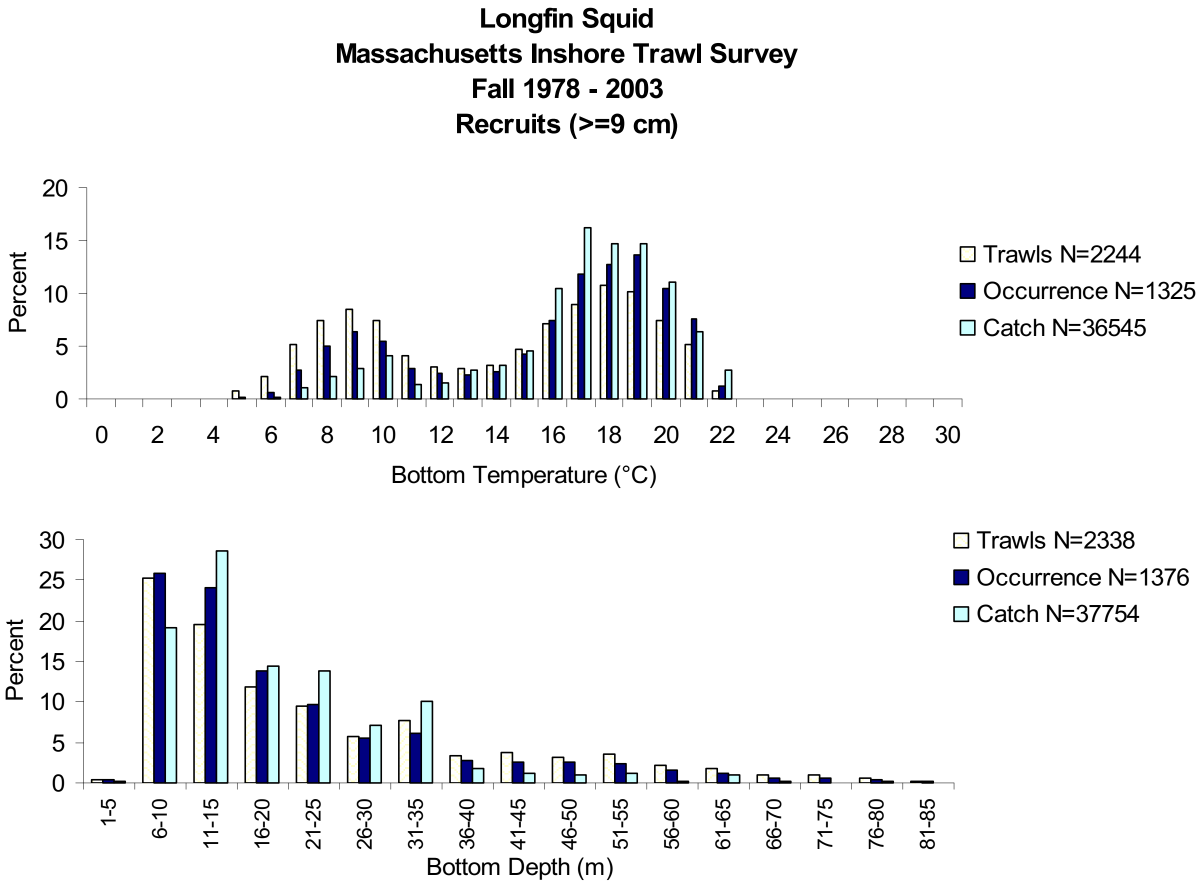

Figure 18. Cont'd.
Based on fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which longfin inshore squid occurred and medium bars show, within each interval, the percentage of the total number of longfin inshore squid caught.

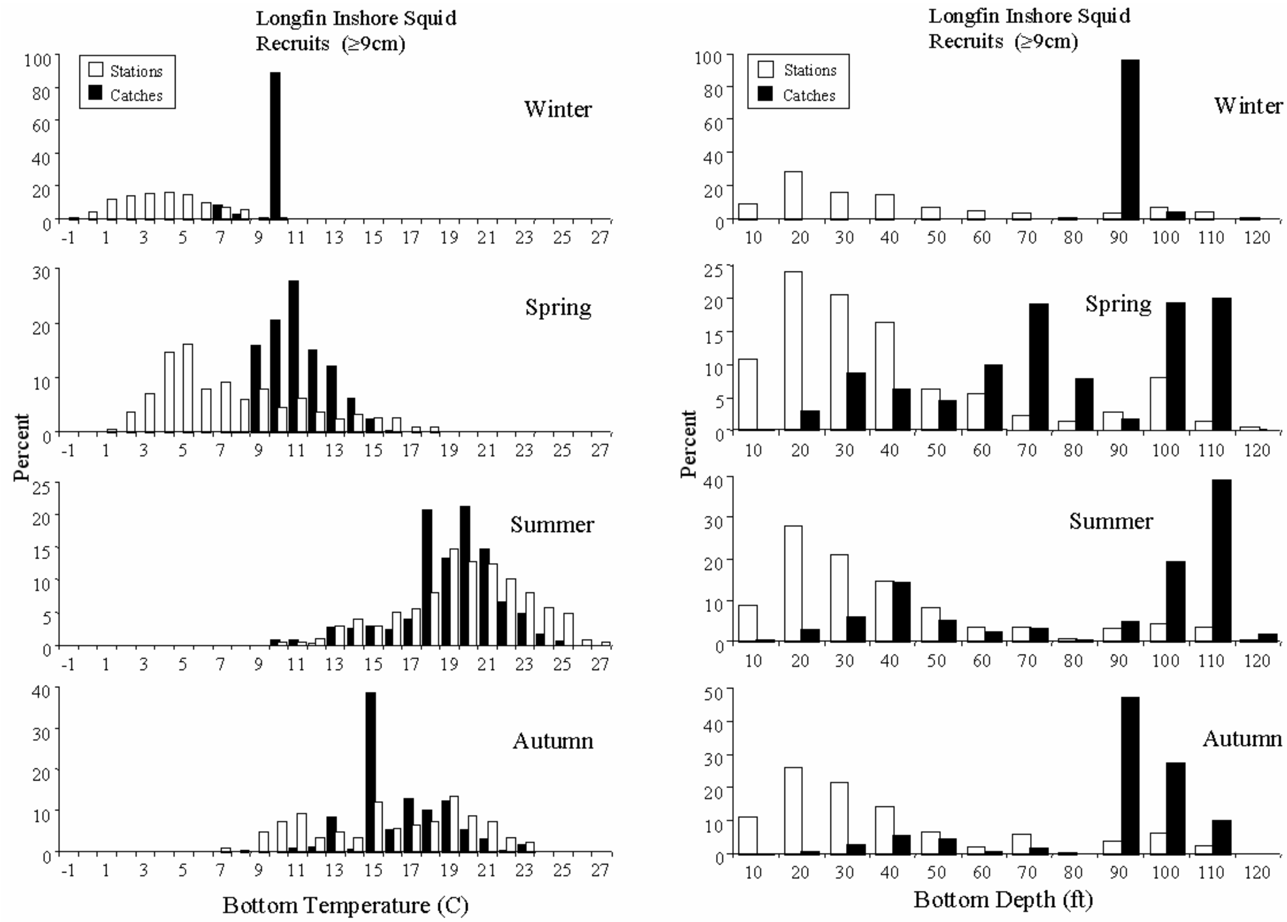

Figure 19. Distributions of longfin inshore squid recruits in Narragansett Bay relative to mean bottom water temperature and bottom depth.
Based on Rhode Island trawl surveys, 1990-1996. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all catches.

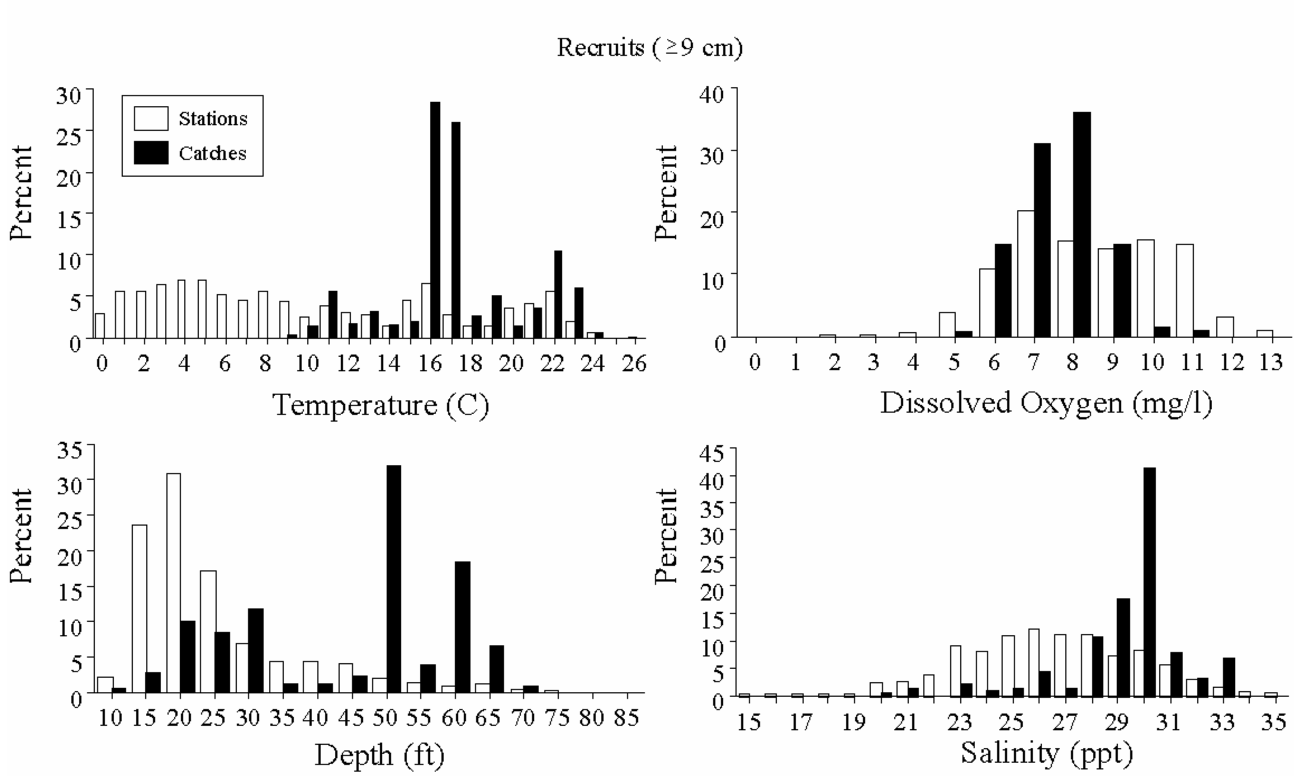

Figure 20. Distributions of longfin inshore squid recruits in the Hudson-Raritan estuary relative to bottom water temperature, depth, dissolved oxygen, and salinity.
Based on NEFSC Hudson-Raritan estuary trawl surveys, 1992-1997, all seasons and years combined. Open bars represent the proportion of all stations surveyed, solid bars represent the proportion of the sum of all standardized catches.

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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 "conducting ecosystem-based research and assessments of living marine resources, with a focus on the Northeast Shelf, to promote the recovery and long-term sustainability of these resources and to generate social and economic opportunities and benefits from their use." 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. Currently, there are three such media:

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