NOAA Technical Memorandum NMFS-NE-196

Essential Fish Habitat Source Document:

Haddock, *Melanogrammus aeglefinus*, 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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Second Edition

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Woods Hole, Massachusetts

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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 Haddock EFH source document is based on the original by Luca M. Cargnelli, Sara J. Griesbach, Peter L. Berrien, Wallace W. Morse, and Donna L. Johnson, 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 haddock, *Melanogrammus aeglefinus*, is a demersal gadid found on both sides of the North Atlantic (Figure 1). In the northwest Atlantic, haddock are distributed from Cape May, New Jersey to the Strait of Belle Isle, Newfoundland (Klein-MacPhee 2002). Six haddock stocks have been identified in the northwest Atlantic from Newfoundland to Georges Bank (Begg 1998). There are two haddock stocks in U.S. waters: Georges Bank and Gulf of Maine. U.S. haddock fisheries are managed by the New England Fishery Management Council under the Northeast Multispecies Fishery Management Plan (NEFMC 1993). The Georges Bank haddock stock is also a transboundary resource, which is co-managed with Canada.

This Essential Fish Habitat Source Document provides up-to-date information on the life history characteristics and habitat requirements of the Georges Bank and Gulf of Maine haddock stocks.

LIFE HISTORY

The life history characteristics of Georges Bank and Gulf of Maine haddock are described in detail by Bigelow and Schroeder (1953) and Klein-MacPhee (2002). Some additional information on early life history stages may be found in Hardy (1978) and Chenoweth *et al.* (1986). Characteristics of egg, larval, juvenile, and adult haddock life history stages are described below.

EGGS

Haddock spawn over various substrates including rocks, gravel, smooth sand, and mud (Klein-MacPhee 2002). Eggs are broadcast and fertilized near the bottom. Fertilized eggs are buoyant and remain in the water column where subsequent development occurs (Hardy 1978; Page *et al.* 1989). Egg size ranges from 1.32-1.60 mm. Incubation time varies with temperature (Laurence and Rogers 1976; Hardy 1978) and can range from 6-42 days (Klein-MacPhee 2002). In temperature-controlled laboratory experiments, haddock eggs averaged about 17-21 days to hatch (Hardy 1978). At water temperatures typical of Georges Bank, haddock eggs hatch in about 15 days (Page and Frank 1989).

LARVAE

Newly-hatched haddock larvae range from 2.0-5.0 mm in length (Klein-MacPhee 2002). Average size at hatch is 4.1 mm for Georges Bank and Gulf of Maine haddock. Length at hatch tends to decrease as the spawning season progresses (Colton and Marak 1969). Larvae absorb their yolk sack within roughly 5 days (Page *et al*. 1999).

Larval survival and growth is influenced by hatching date and oceanographic conditions. Larvae hatched earlier in the spawning season appear to have a survival advantage over those hatched later in the season (Lapolla and Buckley 2005). On Georges Bank, stratified conditions appear to enhance larval survival and growth (Buckley and Lough 1987). Larvae may be advected long distances by ocean currents. In some years, wind-driven currents transport haddock larvae from Georges Bank to the Mid-Atlantic Bight (Polacheck *et al*. 1992). Larval growth appears to be positively correlated with temperatures of about 7-9°C, but may be suppressed at 4 °C (Laurence 1974, 1978). In general, increased temperature has a positive effect on both larval size at age (Green *et al*. 2004) and growth rates (Caldarone 2005). Larval growth generally exceeds 0.2 mm d^{-1} and appears to peak at about 0.5 mm d^{-1} in June (Green *et al*. 2004).

JUVENILES

Larvae metamorphose into juveniles in roughly 30-42 days (Laurence 1978) at lengths of 2-3 cm (Fahay 1983). Small juveniles initially live and feed in the epipelagic zone. Juveniles remain in the upper part of the water column for 3-5 months. After reaching lengths of 3-10 cm (Hardy 1978; Fahay 1983; Mahon and Neilson 1987; Perry and Neilson 1988; Lough and Bolz 1989), juveniles visit the ocean bottom in search of food. Once suitable bottom habitat is located, juveniles settle into a demersal existence (Klein-MacPhee 2002).

ADULTS

Adult haddock are demersal benthivores ranging in size from roughly 30 cm to up to 1 meter. Haddock do not make extensive seasonal migrations. In winter, they prefer deeper waters and tend to move shoreward in summer. When summer water temperatures reach 10-11°C, haddock move to colder, deeper waters. The largest haddock reported from American waters was a 13.6 kg fish (Klein-MacPhee 2002). The oldest haddock documented from Northeast Fisheries Science

Center (NEFSC) surveys during 1963-2002 was a 17 year old fish captured in 1980. Most commercially-caught haddock weigh from 1-3 kg.

REPRODUCTION

Haddock are highly fecund broadcast spawners (Klein-MacPhee 2002). Depending upon their size, adult females produce on the order of hundreds of thousands to millions of eggs per year. Eggs are released near the ocean bottom in batches and fertilized by a courting male. After fertilization, haddock eggs become buoyant and rise to the surface water layer.

Median age and size of maturity differ slightly between the Georges Bank and Gulf of Maine haddock stocks (Table 1). During the late-1980s, Georges Bank haddock matured at younger ages and smaller sizes than Gulf of Maine haddock (O'Brien *et al*. 1993, see also Clark 1959). On Georges Bank, males matured at younger ages and smaller sizes than females. In the Gulf of Maine, median age of maturity for males was greater than for females while male and female sizes at maturity were similar. Size at maturity of Georges Bank haddock has declined in recent years (O'Brien *et al*. 1993; Trippel *et al.* 1997). For example, female median length of maturity was about 40 cm during 1977-1983 but declined to about 34-36 cm in the early-1990s. Density-dependence may explain the apparent decline in median size of maturity since haddock appear to mature at smaller sizes when population density is low (Waiwood and Buzeta 1989; Ross and Nelson 1992).

Georges Bank is the principal haddock spawning area in the northeast U.S. continental shelf ecosystem. Haddock spawning is concentrated on the northeast peak of Georges Bank. The western edge of Georges Bank also supports a smaller spawning concentration (Walford 1938). The two spawning components are persistent and exhibit phenotypic differences in otolith morphometrics (Begg *et al*. 2000). Although the vast majority of reproductive output originates from Georges Bank, some limited spawning activity occurs on Nantucket Shoals (Smith and Morse 1985) and along the South Channel (Colton and Temple 1961). In the Gulf of Maine, Jeffreys Ledge and Stellwagen Bank are the two primary spawning sites (Colton 1972). In addition, Ames (1997) also reported numerous small, isolated spawning areas in inshore Gulf of Maine waters. Based on interviews with retired commercial fishers from Maine and New Hampshire, Ames (1997) identified 100 haddock spawning sites, covering roughly 500 square miles, from Ipswich Bay to Grand Manan Channel.

The timing of haddock spawning activity varies among areas. In general, spawning occurs later in more northerly regions (Page and Frank 1989; Lapolla and Buckley 2005). There is also inter-annual variation in the onset and peak of spawning activity. On Georges Bank, spawning occurs from January to June (Smith and Morse 1985), usually peaking from February to early-April (Smith and Morse 1985; Lough and Bolz 1989; Page and Frank 1989; Brander and Hurley 1992; Lapolla and Buckley 2005) but the timing can vary by a month or more depending upon water temperature (Marak and Livingstone 1970; Page and Frank 1989). In the Gulf of Maine, spawning occurs from early February to May, usually peaking in February to April (Bigelow and Schroeder 1953). Overall, cooler water temperatures tend to delay haddock spawning and may contract the duration of spawning activity (Marak and Livingstone 1970; Page and Frank 1989).

FOOD HABITS

Haddock diet changes with life history stage. Pelagic larvae and small juvenile haddock feed on phytoplankton, copepods, and invertebrate eggs in the upper part of the water column (Kane 1984). Juvenile haddock eat small crustaceans, primarily copepods and euphausiids, as well as polychaetes and small fishes. Juveniles make a transition from pelagic to demersal habitat at ages from 3 to 5 months. During this transition, juvenile diet changes to primarily benthic prey (Mahon and Neilson 1987). Planktonic prey such as copepods and pteropods decrease in importance after juveniles become demersal, while ophiuroids and polychaetes increase in importance. When juveniles reach 8 cm in length, they feed primarily on echinoderms, small decapods, and other benthic prey (Bowman *et al*. 1987). Benthic juveniles above 30 cm and adults feed primarily on crustaceans, polychaetes, mollusks, echinoderms, and some fish (Bowman and Michaels 1984; Mahon and Neilson 1987; Klein-MacPhee 2002). Regional variation in haddock food habits also exists (Bowman *et al*. 2000). Echinoderms are more common prey items in the Gulf of Maine than on Georges Bank. In contrast, polychaetes are more common prey on Georges Bank than in the Gulf of Maine.

Food habits data collected during Northeast Fisheries Science Center (NEFSC) bottom trawl surveys [see Reid *et al.* (1999) and Link and Almeida (2000)] reveal that the species composition of haddock prey varies by haddock size class (Figure 2). Unidentified fish (> 40%), amphipods (> 30%), and well-digested prey (WDP, > 10%) were the most common prey items by weight for small haddock less than 20 cm in length. The diet of haddock between 20 and 50 cm in length was more varied and included WDP (> 20%), amphipods (> 15%), ophiuroids (> 10%), and polychaetes (> 10%). Ophiuroids (> 15%), amphipods (> 10%), WDP (> 10%), and polychaetes (> 10%) were the most common prey items of large haddock with lengths between 50 and 80 cm. Extra-large haddock over 80 cm in length fed primarily upon clupeids (> 25%), ophiuroids (> 20%), amphipods (> 10%), and scombrids (> 10%). There was more sampling variation in the diet of extra-large haddock due to low sample size. Overall, the NEFSC food habits data show that haddock diet includes more ophiuroids and becomes more varied as fish increase in size. It also shows that amphipods are an important prey item for all demersal life history stages and that fish are an important component of the diet of very large haddock.

LARVAL RETENTION

The retention of haddock larvae in suitable nursery areas is an important factor in determining year class strength of Georges Bank haddock. The clockwise gyre around the main portion of Georges Bank provides a physical mechanism to retain haddock larvae on the Bank. Larvae associated with the interior of the gyre tend to remain on Georges Bank (Smith and Morse 1985) while those associated with the outside of the gyre tend to be transported southwest by prevailing currents towards Nantucket Shoals. Strong year-classes may arise in years when circulation results in either retention of larvae on the Bank (Smith and Morse 1985) or in transport of larvae to nursery grounds to the southwest of the Bank (Colton and Temple 1961; Polacheck *et al.* 1992). Comparisons of water residence times on Georges Bank and spawning locations suggest that haddock select areas and times of the year that enhance the probability of larval retention on the Bank (Page *et al*. 1999).

Lough and Bolz (1989) found that the southerly drift of larvae may be slowed, and retention on the shoals of Georges Bank enhanced, by larvae residing nearer to the bottom in waters shallower than 70 m. In some years, differences in wind stress and associated geostrophic currents alter the pattern of larval retention on the Bank. Wind-driven southwesterly surface currents can alter the pattern of larval retention and transport haddock larvae over hundreds of kilometers into the Mid-Atlantic Bight (Polacheck *et al*. 1992). In contrast, strong episodes of southeastward wind stress are associated with high egg and larval mortalities in some years (Mountain *et al*. 2003). There is limited information on retention of larval haddock in the Gulf of Maine. Ames (1997) suggests that haddock eggs and larvae in coastal Gulf of Maine waters may be retained in suitable habitats by tidal currents.

GEOGRAPHICAL DISTRIBUTION

In the northwest Atlantic, haddock are distributed from Cape Charles, Virginia to Labrador, Canada (Figure 3). Georges Bank, the Scotian Shelf, and the southern Grand Bank have the highest densities of haddock. The distributions of haddock egg, larval, and juvenile and adult stages on Georges Bank and the Gulf of Maine are described below.

EGGS

The distribution of haddock eggs was determined using monthly NEFSC Marine Resources Monitoring, Assessment and Prediction (MARMAP) survey data. During 1978-1987, MARMAP ichthyoplankton surveys caught haddock eggs from New Jersey to southwest Nova Scotia (Figure 4). The highest densities were found on Georges Bank and Browns Bank, which are important haddock spawning areas (Colton and Temple 1961; Laurence and Rogers 1976; Brander and Hurley 1992). Eggs were collected from January through August. The highest concentrations occurred in April, followed by March and May. This pattern is consistent with the timing of peak spawning from March to May (Bigelow and Schroeder 1953; Page and Frank 1989; Brander and Hurley 1992). In particular, the highest mean densities of eggs occurred in April (77.3 eggs/10 m^2) and March (21.1 eggs/10 m^2). By July and August, mean densities had decreased substantially (< 0.1 eggs/10 m^2).

Data from the more recent U.S. GLOBEC Georges Bank surveys (February-July, 1995; January-June, 1996-1999) showed the highest concentration of eggs to be on the eastern, Canadian side of Georges Bank, with peaks occurring during February-March and into April (Figure 5).

LARVAE

The distribution of haddock larvae was determined using monthly MARMAP survey data. The 1977-1987 MARMAP ichthyoplankton surveys captured haddock larvae from the Delmarva Peninsula to southwest Nova Scotia (Figure 6). Larvae were collected from January through July. The highest mean densities occurred in May (8.3 larvae/10 m^2) and April (8.1 larvae/10 m^2). High densities of larvae were found off southwest Nova Scotia and Georges Bank, spreading southward. Mean densities were low in January and February. Larval densities were highest in April through June and declined substantially by July (< 0.1 larvae/10 m^2). These findings are consistent with the seasonal pattern of haddock spawning (Smith and Morse 1985; Campana 1989).

Data from the more recent U.S. GLOBEC Georges Bank surveys showed the highest numbers of larvae were in March and April and mostly in southern areas of the Bank between the 50-100m isobath (Figure 7).

JUVENILES AND ADULTS

Seasonal catches of juvenile (≤ 31 cm) and adult haddock (> 31 cm) in NEFSC bottom trawl surveys [see Reid *et al*. (1999) for details] during 1963-2003 show that the distributions of juvenile and adult haddock are generally similar (Figure 8 and Figure 10; note that winter and summer distributions are presented as presence data only, precluding a discussion of abundances). During winter and summer, juveniles and adults (Figure 8 and Figure 10) are found on Georges Bank, throughout the Gulf of Maine, in southern New England, and in the northern section of the Mid-Atlantic (the latter is not true for adults in the summer). During spring, adults are generally found near spawning areas (Figure 10). Dense concentrations of adults are found on the northeast peak of Georges Bank, in the Great South Channel and in coastal waters of the Gulf of Maine. Juvenile distribution during spring is similar to that of adults although more juveniles occur on the southern flank of Georges Bank (Figure 8). In autumn, adults are found throughout the Gulf of Maine, the Great South Channel, and the northern flank and northeast peak of Georges Bank (Figure 10). Juvenile distribution during autumn is generally shallower than adults and in some years, extends south into the Mid-Atlantic Bight, with large numbers around Hudson Canyon (Figure 8).

Information on the inshore distribution of juvenile and adult haddock was collected from Massachusetts inshore bottom trawl surveys during 1978-2003 [see Reid *et al*. (1999) for details]. Juveniles were more abundant in coastal Massachusetts waters than adults (Figure 9 and Figure 11), and were more abundant in autumn than spring. In the spring, juveniles were most abundant north of Cape Ann, in northeastern Massachusetts Bay, and in two aggregations off eastern Cape Cod, but were not widespread in Cape Cod Bay. Another aggregation was found northwest of Provincetown, Cape Cod. Adults were more abundant in spring than in autumn. In spring, adults were most abundant in northeast Massachusetts Bay, and were also found northeast of Cape Ann and around Provincetown. In autumn, juveniles were most abundant directly north and northeast of Cape Ann and in northeastern Massachusetts Bay. They were also found in two aggregations off the east coast of Cape Cod, and in low numbers throughout Cape Cod Bay. In autumn, adults were mostly absent from inshore Massachusetts waters.

The distributions and abundances of juvenile and adult haddock along the coasts of Maine and New Hampshire, based on spring and fall 2000-2004 Maine-New Hampshire inshore groundfish surveys (Sherman *et al*. 2005), are shown in Figure 12. The majority were juveniles, particularly in the fall, with higher numbers of adults seen in the spring (Figure 13). Haddock CPUE along the Maine-New Hampshire coast by region and season/year is shown in Figure 14.

HABITAT CHARACTERISTICS

Detailed information on life history and habitat parameters for Georges Bank and Gulf of Maine haddock were summarized from the literature (Table 2). The habitat characteristics of egg and larval stages as well as juvenile and adult stages are described below.

EGGS AND LARVAE

Haddock egg and larval stages are pelagic. They are usually found at depths of 10-50 m below the surface (Marak 1960; Colton and Temple 1961; Miller *et al.* 1963; Hardy 1978), and in water temperatures of 4-10°C (Laurence and Rogers 1976; Laurence 1978) and salinities of 34-36 ppt (Laurence and Rogers 1976). During the MARMAP surveys, most haddock eggs were collected at temperatures of 4-10°C and depths of 50-130 m while most larvae were collected at 4-14°C and 30-90 m (Figure 15 and Figure 18).

Haddock eggs were sampled at temperatures ranging from 2-10°C. The vast majority were found at 4-10°C (Figure 15), the temperature range at which egg survival is highest (Hardy 1978). In January, the highest densities of eggs were found at 6-7°C , while in February, March, and April, the highest densities occurred at 4-6°C. This is consistent with Colton (1972) and Hardy (1978) who reported that the optimum spawning temperature for haddock is 2-7°C. In May and June, the highest abundance of eggs was at 5-7°C. During July and August almost all eggs were found at 8-10°C. Thus, eggs were found at higher temperatures as the spawning season progressed.

Eggs were sampled at water column depths ranging from 10 m to 450 m. However, the majority were found at 50-130 m (Figure 15). From January to May the highest density of eggs occurred at depths of 70-90 m, while in June the majority of eggs were deeper, at 110-150 m. In July, all eggs were found between 90-110 m, and in August all eggs were found at 50-70 m.

Larvae were captured at temperatures of 2-15°C, a wider range than for eggs. The majority of larvae occurred at 4-14°C (Figure 18). There was monthly variation in the temperatures where larvae were caught.

In January, the majority of larvae were found at temperatures of 8-9°C. During February to April, larvae were at a cooler range of 4-6°C. In May and June, most larvae were caught at 6-9°C. In July, a few larvae were found at 9-11°C and 14°C.

Larvae were captured at water column depths ranging from 10 m to 325 m. However the majority occurred at 30-90 m (Figure 18). From January to June, most larvae were found at 70-90 m, and during July all larvae were found at 30-90 m, with the highest abundance at 30-50 m.

During the more recent GLOBEC Georges Bank survey from January to July 1995-1999, the majority of eggs were found in a narrow temperature range of about 3-4°C in January, and from about 1-3°C from February to May, and at temperatures of 3-6°C in June (Figure 13). Their depth range on Georges Bank during that same period was centered on 61-100 m (Figure 14). Larvae were found at temperatures of 6-7°C in January, mostly from 5-6°C in February and April, and from 4-5°C in March (Figure 16). In May, the majority were found at the lower temperature of 2°C, while in June they were spread over a temperature range of 6-12°C. In July, larvae were caught at 8°C and 10°C. Most were found at depths of 61-100 m from January to April, from 61-80 in May and June, and from 81-120 m in July (Figure 17).

JUVENILES AND ADULTS

Juvenile and adult haddock are demersal. Juveniles and adults are usually found at depths between 40-150 m (Bigelow and Schroeder 1953; Murawski and Finn 1988; Perry and Neilson 1988). Their preferred depth range is from 50-100 m (Scott 1982; Waiwood and Buzeta 1989), but they can sometimes be found as shallow as 10 m (Blacker 1971) or as deep as 200+ m (Colton 1972; Hardy 1978).

Juveniles are commonly found at water temperatures of 4.5-10°C (Murawski and Finn 1988). Adults can be found at a wider range of 0-13°C (Hardy 1978), but prefer temperatures of 2-9°C (Bigelow and Schroeder 1953; Colton 1972; Waiwood and Buzeta 1989). Juvenile and adult haddock are commonly associated with salinities of 31-35 ppt, although 32 ppt is optimal (Bigelow and Schroeder 1953; Scott 1982; Waiwood and Buzeta 1989).

During spring and fall NEFSC trawl surveys (Figure 21 and Figure 23), both juveniles and adults were caught at depths of 21-400 m and temperatures of 2-16°C. During spring and fall Massachusetts inshore trawl surveys (Figure 22 and Figure 24), juveniles were caught at depths of 6-85 m and temperatures of 3-16°C, while adults were caught at 26-85 m and 4-12°C.

During spring NEFSC surveys, most juveniles and adults were captured at temperatures of 4-7°C with peaks at 5-6°C (Figure 21 and Figure 23). The preferred juvenile depth range in spring was 71-140 m while the preferred salinity range was 33 ppt. The preferred adult depth range in spring was 51-120 m while the preferred salinity was 33 ppt. During autumn, the preferred juvenile temperature range was about 6-13°C with a peak at 8°C (Figure 21). Most juveniles were captured at depths of 41-120 m and at salinities of 32-34 ppt. The preferred adult temperature range during autumn was 6-10°C, and with a peak at 7°C (Figure 23). Most adults were found at depths greater than 81 m, with a preferred salinity of 33-34 ppt.

During the Massachusetts spring inshore trawl surveys, juveniles were primarily found at temperatures of 4-8°C and at depths of 31-65 m (Figure 22). Most adults occurred at temperatures of 4-8°C and depths of 46-55 m (Figure 24). In the autumn, juveniles were primarily found at temperatures of 7-10°C and at depths of 31-50 m (Figure 22). Adults were generally absent from inshore waters during autumn (Figure 24); the few that were present occurred at temperatures of 8°C, 10°C, and 12°C and at depths of 61-65 m.

SUBSTRATE

Preferred bottom types include gravel, pebbles, clay, and smooth hard sand, particularly smooth areas between rocky patches (Klein-MacPhee 2002). Juvenile and adult haddock do not frequent ledges, rocks, kelp, or soft oozy mud. The distribution of substrate sediments on Georges Bank and in the Gulf of Maine area show regional differences (Figure 25). Substantial areas of suitable substrate for haddock (i.e., sand, gravelly sand, and gravel) are found on Georges Bank. In contrast, fewer areas of suitable substrate exist in the Gulf of Maine. Consequently, haddock are more abundant on Georges Bank than in the Gulf of Maine. In particular, the principal haddock spawning area on the northeast peak of Georges Bank (Colton and Temple 1961; Lough and Bolz 1989) contains large areas of suitable substrate. Similarly, the two principal spawning areas in the Gulf of Maine, Stellwagen Bank and Jeffreys Ledge (Colton 1972), also contain gravelly sand substrate.

STATUS OF THE STOCKS

The U.S. Sustainable Fisheries Act of 1996 (DOC 1996) requires that fishery conservation and management measures prevent overfishing and rebuild depleted stocks to biomasses consistent with producing maximum sustainable yield (MSY). Overfishing occurs whenever fishing mortality exceeds a threshold that jeopardizes the reproductive capacity of a stock to produce maximum sustainable yield. Guidelines to the Act also specify that a depleted resource is one that has been reduced below a minimum stock size threshold. For Georges Bank and Gulf of Maine haddock, the minimum stock size threshold is one-half the biomass needed to produce MSY (B_{MSY}). It is possible for a stock to be classified as overfished (due to previous overharvesting) even though the annual harvest rate is below the overfishing threshold. This has been the case for haddock, which have been rebuilding in recent years.

For Georges Bank haddock, spawning biomass and the proxy fishing mortality (F_{MSY}) to produce MSY are B_{MSY} = 250,300 mt and F_{MSY} = 0.26, respectively (Northeast Fisheries Science Center 2002). The overfished threshold for Georges Bank haddock is $B_{THRESHOLD}$ = 125,200 mt. The overfishing threshold for Georges Bank haddock is $F_{THRESHOLD}$ = 0.26. In the last formal assessment of Georges Bank haddock in 2004 (Brodziak *et al*. 2005), spawning biomass was 116,800 mt (93% of $B_{THRESHOLD}$ and 47% of B_{MSY}). Therefore, the Georges Bank haddock stock was overfished in 2004. In 2004, the fishing mortality was 0.24 (92% of $F_{THRESHOLD}$). Therefore, overfishing was not occurring on the Georges Bank haddock stock in 2004.

For Gulf of Maine haddock, the stock biomass index and the proxy exploitation rate index to produce MSY are B_{MSY} = 22.2 kg/tow and F_{MSY} = 0.23 (Northeast Fisheries Science Center 2002). The overfished threshold for Gulf of Maine haddock is $B_{THRESHOLD}$ = 11.1 kg/tow. The overfishing threshold for Gulf of Maine haddock is $F_{THRESHOLD}$ = 0.23. In the last formal assessment of the Gulf of Maine haddock stock in 2004 (Brodziak and Traver 2005), the stock biomass index was 5.8 kg/tow (52% of $B_{THRESHOLD}$ and 26% of B_{MSY}) with a standard error of 1.1 kg/tow. Based on the point estimate of the biomass index, the Gulf of Maine haddock stock was overfished in 2004. In 2004, the exploitation rate index was 0.18 (78% of $F_{THRESHOLD}$). Therefore, overfishing was not occurring on the Gulf of Maine haddock stock in 2004.

Prior to mid-1990s, Georges Bank haddock had been overfished for decades (Brodziak and Link 2002). The stock had experienced long-term declines in spawning biomass and recruitment (Brodziak *et al*. 2001) and was considered by some to have been near collapse in the early 1990s. It was around this time that fishery management actions to recover Georges Bank haddock and other groundfish stocks were initiated.

Fishery management measures implemented since 1994 have decreased fishing mortality (Figure 26a). These measures have included large year-round closed areas, restrictions on fishing effort, increases in trawl mesh size, and other conservation measures (Fogarty and Murawski 1998). Fishing mortality on Georges Bank haddock averaged F=0.35 per year during 1980-1993, or about 36% higher than the current overfishing limit (F_{MSY} =0.26) for this stock. Since 1994, annual fishing mortality for Georges Bank haddock has averaged about F=0.17, about 30% below F_{MSY}.

Stock response to reductions in fishing mortality during the 1990s was dramatic (Figure 26b). Under persistent overfishing in the 1980s, Georges Bank haddock spawning biomass declined from 67,400 mt in 1980 to only 14,600 mt in 1993. Since 1994, spawning biomass has increased substantially as fishing mortality decreased. By 2003, spawning biomass had increased to 131,900 mt, the highest abundance of adult spawners since 1966 and over a 9-fold increase since 1993. Nonetheless, the Georges Bank haddock stock is presently considered to be overfished since spawning biomass is still less than half of the rebuilding target.

Recruitment of Georges Bank haddock has displayed a similar positive response as spawning biomass to reduced fishing mortality (Figure 26c). Recruitment averaged only 8 million age-1 recruits per year during 1980-1993. Since 1994, average recruitment has increased over 10-fold to about 87 million fish. Further, prospects remain positive for continued high recruitment. When Georges Bank haddock spawning stock biomass (SSB) exceeds its 1931-1998 median value of about 82,000 mt, the likelihood of above-average recruitment increases over 20-fold (Brodziak *et al*. 2001). Similarly, the expected magnitude of recruitment increases over 3-fold when SSB exceeds 82,000 mt. Recent U.S. and Canadian assessments and research survey data suggest that the 2003 year class is exceptionally abundant (Figure 26c).

Recruits per spawner data shows that survival ratios for Georges Bank haddock were relatively low from the late-1960s to early-1990s in comparison to historic ratios during the 1930s-1960s (Figure 26d). The impact of the large-scale area closures, reductions in fishing effort, and trawl mesh size increases during the 1990s have had a positive effect on recruits per spawning stock biomass (R/SSB). During 1980-1993, R/SSB averaged about 0.33 recruits per kg. Since 1994, average R/SSB, excluding the exceptional 2003 year class, has increased to 0.46 recruits per kg. Further increases in R/SSB may still occur since, at least historically, the expected value of R/SSB was higher. Overall, the recent increases in R/SSB indicate that survival ratios are approaching the historical average of about 0.76 recruits per kg observed during 1931-1960. If the recent increase in productivity can be sustained, it is possible that historic yields on the order of 50,000 mt per year may be achieved.

The formal rebuilding plan for Georges Bank haddock adopted in Amendment 13 calls for fishing at the overfishing threshold F_{MSY}=0.26 during 2004-2008 (NEFMC 2003). In 2009, the fishing mortality would be reduced marginally to $F_{REBUILD}$=0.245, a value projected to produce at least a 50% chance that spawning biomass will meet or exceed B_{MSY}=250,300 mt in 2014. This rebuilding strategy is subject to change in 2008 if observed progress towards rebuilding spawning biomass or reducing fishing mortality is not consistent with the projected rebuilding trajectory.

In May, 2004, a formal quota sharing agreement between Canada and the U.S. was implemented to share the harvest of the transboundary eastern Georges Bank haddock management unit (Figure 27). This agreement includes total allowable catch quotas for each country as well as in-season monitoring of the catch of haddock on eastern Georges Bank.

RESEARCH NEEDS

The biology of northwest Atlantic haddock is reasonably well known and the habitat matrix is relatively complete (Table 2). However, more detailed information is needed in certain areas:

- More information is needed on the population genetic structure of haddock stocks. The present stock definitions are based on tagging studies, meristic data, age composition, and growth data (Northeast Fisheries Science Center 1997). Few studies of genetic structure currently exist. Purcell *et al.* (1996) detected significant temporal variation in gene frequencies on Georges Bank, and suggested that spawning on the Bank may not be genetically discrete. However, Zwanenburg *et al.* (1992) found that gene flow among spawning aggregations on five banks in the northwestern Atlantic, including Georges Bank, was restricted and that deep channels can be significant barriers to gene flow. Zwanenburg *et al.* (1992) indicated that additional sampling effort was needed to provide a clearer understanding of haddock population structure.
- A better understanding of the factors affecting recruitment and year-class strength is also needed. Research into obvious factors such as the effects of water temperatures, food levels, and predation on the survival of the early life stages is required. Also, the role of other factors such as hydrographic effects (e.g., tidal and non-tidal currents) which affect the retention and transport of eggs and larvae should be investigated more thoroughly.
- Interactions with other closely related species (e.g., cod) are probably important, and need to be better understood.
- Detailed information on fecundity and spawning behavior is needed. There is limited field data on haddock reproductive biology for either the Georges Bank or the Gulf of Maine stocks.

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Table 1. Median size and age at maturity of haddock.

Stock	Time Period	A_{50} (years) *male*	*female*	L_{50} (cm) *Male*	*female*	Reference
Georges Bank	1985-1989	1.3	1.5	26.8	29.7	O'Brien *et al.* 1993
	1986-1989	1.1-1.9	1.8-2.6	24-34	33-41	Trippel *et al.* 1997
	1989-1995	1.1-1.4	1.6-2.0	23-30	34-36	Trippel *et al.* 1997
Gulf of Maine	1985-1989	2.1	1.8	35.0	34.5	O'Brien *et al.* 1993

Table 2. Summary of life history and habitat parameters for haddock.
Based on the pertinent literature. Information that applies to both juveniles and adults is listed under 'Juveniles/Adults.'

Life Stage	Size and Growth	Habitat	Substrate	Temperature
Eggs [1]	Mean size at hatch is 3.33 mm. Largest size at hatch occurs at approximately 8°C; decrease in size at lower and higher temperatures.	Early stage eggs concentrated near the surface; later stages are distributed more uniformly over depth or have a sub-surface maximum. One study shows that stage I, II and III eggs were within the top 20 m, while the center of mass of stage IV eggs was 31 m.	Eggs are spawned over rocks, gravel, smooth sand, and mud. After spawning, eggs become buoyant, rise and float near the surface where subsequent development occurs.	Peak spawning occurs when mean surface temperature is 2-10°C. Incubation duration varies with temperature: 20-32 days at 2°C, 11-23 days at 4°C, 11-17 days at 6°C, 9-13 days at 8°C, and 6-8 days at 11°C. Highest survival rate occurs at 4-10°C (mean 6°C). In temperature-controlled lab, eggs averaged about 17-21 days to hatch.
Larvae [2]	Size at hatch ranges from 2 - 5 mm (mean = 4 mm). Larval growth generally exceeds 0.2 mm d^{-1} and appears to peak at about 0.5 mm d^{-1} in June.	Generally pelagic. Maximum depth approximately 150 m. Majority found at depths of 10-50 m.		Larval growth positively correlated with temperatures of about 7-9°C , but may be suppressed at 4°C. Upper lethal = 10°C; lower lethal = 4°C. Time to metamorphosis: at 9°C = 30 days after hatching; at 4°C = 36-42 days. Growth rates: at 4°C = 3.68 %/day, at 7°C = 5.53, at 9°C = 13.36. On Georges Bank, hatching occurs in 2-3 weeks at normal spring temperatures. Increased temperature has a positive effect on both larval size at age and growth rates.
Juveniles [3]	Metamorphosis of larvae occurs at approximately 3 cm.	Small juveniles found near the surface (10-40 m), more or less stationary in the open sea. Descent to bottom (35-100 m) occurs at age 3-5 months and length 5-10 cm (after metamorphosis). YOY found in nursery area between Nantucket Shoals and Hudson Canyon. Occur on same grounds as adults.	Pebble gravel bottom. See adults also.	Occur at 4.5-11.0°C. Occur at colder temperatures in winter/spring than summer/fall.
Adults [4]	Mean size at maturity (female/male, cm): Georges Bank: 29.7/26.8 Gulf of Maine: 34.5/35.0 Size at maturity positively density dependent.	Occur throughout the Gulf and offshore banks; greatest concentration on Georges Bank. More exclusively a groundfish than cod. Generally below 10 m, most in 40-150 m, few deeper than 200 m. No extreme migrations, only short inshore/offshore movements.	Selective as to type of substrate: chiefly broken ground, gravel, pebbles, smooth hard sand and smooth areas between rocky patches. Avoid ledges, rocks, kelp, or soft mud.	Occur at 0-13°C, but are most abundant at 2-9°C and prefer 4-7°C; mortality at < 1°C; avoid > 10°C. Spawn at 2-7°C, optimum is 4-6°C.
Juveniles/ Adults [5]	Average size at age: 1 - 17.5 cm, 2 - 33.8 cm, 3 - 45.5 cm, 4 - 54.0 cm, 5 - 60.1 cm, 6 - 64.5 cm, 7 - 67.6 cm, 8 - 69.9 cm, 9 - 71.5 cm, 10 - 72.7 cm, 11 - 73. 6cm, 12 - 74.2 cm, 13 - 74.6 cm, 14 - 75.0 cm, 15 - 75.2 cm.			

[1] Bigelow and Schroeder (1953); Miller *et al.* (1963); Laurence and Rogers (1976); Hardy (1978); Lough *et al.* (1989); Page and Frank (1989); Page *et al.* (1989); Waiwood and Buzeta (1989); Klein-MacPhee (2002).

[2] Marak (1960); Colton and Temple (1961); Miller *et al*. (1963); Laurence (1974, 1978); Hardy (1978); Kane (1984); Lough and Bolz (1989); Green *et al*. (2004); Caldarone (2005).

[3] Bigelow and Schroeder (1953); Colton and Temple (1961); Blacker (1971); Colton (1972); Hardy (1978); Mahon and Neilson (1987); Murawski and Finn (1988); Perry and Neilson (1988); Lough and Bolz (1989); Lough *et al.* (1989).

[4] Bigelow and Schroeder (1953); Marak and Livingstone (1970); Colton (1972); Hardy (1978); Scott (1982); Waiwood and Buzeta (1989); O'Brien *et al.* (1993); Klein-MacPhee (2002).

[5] Penttila *et al.* (1989).

Table 2. Cont'd.

Life Stage	Salinity	Currents	Prey
Eggs [1]	Highest egg survival occurs at 34-36 ppt. Egg mortality below 25 ppt; mortality decreases with increasing salinity (26-36 ppt).	SW flow of water off Georges Bank results in a southerly flow of eggs and larvae from the NE spawning center.	
Larvae [2]		Larvae drift with surface currents. Georges Bank larvae may be swept off the Bank to the SW (at 0.65 cm/s), otherwise are retained. Southerly drift of larvae may be slowed, and retention on shoals of Georges Bank enhanced, by larvae residing nearer to the bottom in waters < 70 m. In contrast, strong episodes of southeastward wind stress are associated with high egg and larval mortalities in some years. Eggs and larvae in coastal Gulf of Maine waters may be retained in suitable habitats by tidal currents.	Passive foragers on less motile prey: invertebrate eggs, copepods and phytoplankton. In general, ate most abundant species but restricted to prey of a certain size; for example larvae 4-18 mm fed on larval copepods, > 18 mm fed on adult copepods. Feeding peaks shortly before sunset. Larvae may need prey concentrations of 0.5 - 3.0 plankters/ml for suitable growth.
Juveniles [3]		Tidal current weaker near bottom, for example at Georges Bank, current = 1-5 cm/s at 10 cm above bottom, and 7-24 cm/s at 1 m above bottom.	Indiscriminate consumers of invertebrates. Distinct transition from planktonic to benthic feeding. Planktonic prey declines after becoming demersal: copepods and pteropods decreased, while ophiuroids & polychaetes increased. Major benthic prey items (proportion of diet by weight) are crustaceans (56.5%), polychaetes (15.1%), and fish (1.4%).
Adults [4]	Generally found within 31.5 - 35 ppt; Spawn at 31.5 - 34 ppt.		Indiscriminate consumers of sedentary or slow moving invertebrates: crustaceans, annelids, polychaetes, mollusks and echinoderms. Fish make up small part of diet. Heaviest feeding in June; distinct seasonal changes in diet composition.
Juveniles/ Adults [5]			Omnivorous and highly opportunistic. Prey almost exclusively on benthic invertebrates. Order of importance (proportion of diet by weight): echinoderms, 29.9%; polychaetes, 17.6%; crustaceans, 16.2%; fish eggs, 14.6%; other polychaetes, 12.7%. Prey items by area (Gulf of Maine/ Georges Bank/Scotian Shelf) (% by weight): fish-2.2/28.4/3.8, polychaetes-14.7/23.5/11.8, crustacean-15.2/16.0/14.4, mollusks-1.6/3.8/3.0, echinoderms-51.9/7.8/49.0. Echinoderms more common prey in Gulf of Maine than on Georges Bank; polychaetes more common prey on Georges Bank than in Gulf of Maine. Overall, diet includes more ophiuroids and becomes more varied as fish increase in size; amphipods an important prey item for all demersal life history stages, with other fish an important component of the diet of very large haddock.

[1] Colton and Temple (1961); Laurence and Rogers (1976); Smith and Morse (1985); Page *et al.* (1989).
[2] Marak (1960); Laurence (1974); Hardy (1978); Kane (1984); Smith and Morse (1985); Campana *et al.* (1989); Lough and Bolz (1989); Polacheck *et al*. (1992); Ames (1997); Mountain *et a*l. (2003).
[3] Bigelow and Schroeder (1953); Blacker (1971); Bowman and Michaels (1984); Mahon and Neilson (1987); Perry and Neilson (1988); Lough *et al.* (1989).
[4] Bigelow and Schroeder (1953); Wigley and Theroux (1965); Tyler (1972); Hardy (1978); Scott (1982); Bowman and Michaels (1984); Waiwood and Buzeta (1989)
[5] Langton and Bowman (1980); Bowman and Michaels (1984); Bowman *et a*l. (2000); NEFSC food habits database.

Table 2. Cont'd.

Life Stage	Predators	Spawning	Notes
Eggs [1]	Preyed upon by a wide range of pelagic predators.	Northeast peak of Georges Bank and the Great South Channel are the principle spawning areas. Limited spawning along New England coast. Spawning occurs over all of Georges, but largest concentration is on the northeast peak. Spawning occurs from January to July; delay in peak spawning time as one moves north. Gulf of Maine: Feb.-May, peak varies Feb.-April; Georges Bank: Jan.-June, peak lFeb.-early April.	Egg duration on Georges Bank varied from 10-20 days over 34 year period; mean egg duration during peak spawning was 15.5 days. Haddock embryos less tolerant of temperature and salinity extremes than cod embryos.
Larvae [2]	Preyed upon by a wide range of pelagic predators.	Nursery grounds lie (a) between Georges Bank and Nova Scotia and (b) to the east of Cape Cod.	Young tend to drift under bells of jellyfish (*Cyanea*). Lab results imply that the first weeks after hatching are a critical period for larvae. One study estimated daily mortality rate at 7.1%.
Juveniles [3]	0+ and 1+ fish primarily preyed on by cod, pollock, and silver hake.		1-2 yr old fish particularly abundant on Georges Bank. Vertical migrations may depend on diel light cycle, thermal structure, interspecific competition, prey availability and tidal current speed.
Adults [4]	Preyed upon by seals.	Onset of spawning related to environmental conditions; earlier in years with moderate autumn-winter temperatures than in years with cold autumn/winter. Eggs released at intervals over a 3 week period. Fecundity ranges from 12,000-3,000,000 eggs; varies with size; year to year variation may be correlated with temperature. Median age at maturity (female/male, years): Georges Bank: 1.5/1.3; Gulf of Maine: 1.8/2.1. Evidence that median length at maturity on Georges Bank has decreased (during 1977-1983 was 40/37).	Move into shallower water in spring and summer; coincides with the inshore fishery. Offshore fishery occurs during the winter and early spring. Distribution influenced more by restrictive spawning area and bottom type conditions than by temperature variation.
Juveniles/ Adults [5]			Stock abundance clearly influenced growth rates: higher correlations occurred during time periods of highest stock abundance than at times when stocks were depleted. Stock size was significantly correlated with juvenile growth but not young adult growth.

[1] Walford (1938); Colton and Temple (1961); Marak and Livingstone (1970); Laurence and Rogers (1976); Hardy (1978); Smith and Morse (1985); Perry and Neilson (1988); Campana (1989); Lough and Bolz (1989); Page and Frank (1989).
[2] Laurence (1974); Hardy (1978); Smith *et al.* (1981); Cushing (1986).
[3] Bigelow and Schroeder (1953); Miller *et al.* (1963); Blacker (1971); Murawski and Finn (1988); Perry and Neilson (1988).
[4] Bigelow and Schroeder (1953); Colton (1972); Hardy (1978); Smith *et al.* (1981); O'Brien *et al.* (1993).
[5] Ross and Nelson (1992).

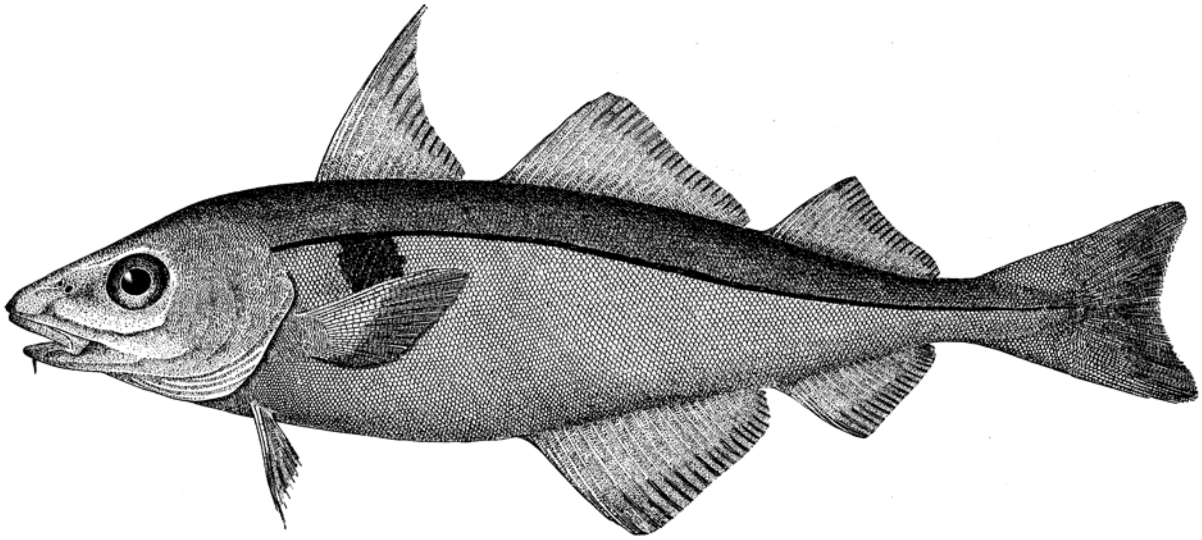


Figure 1. The haddock, *Melanogrammus aeglefinus* (from Goode 1884).

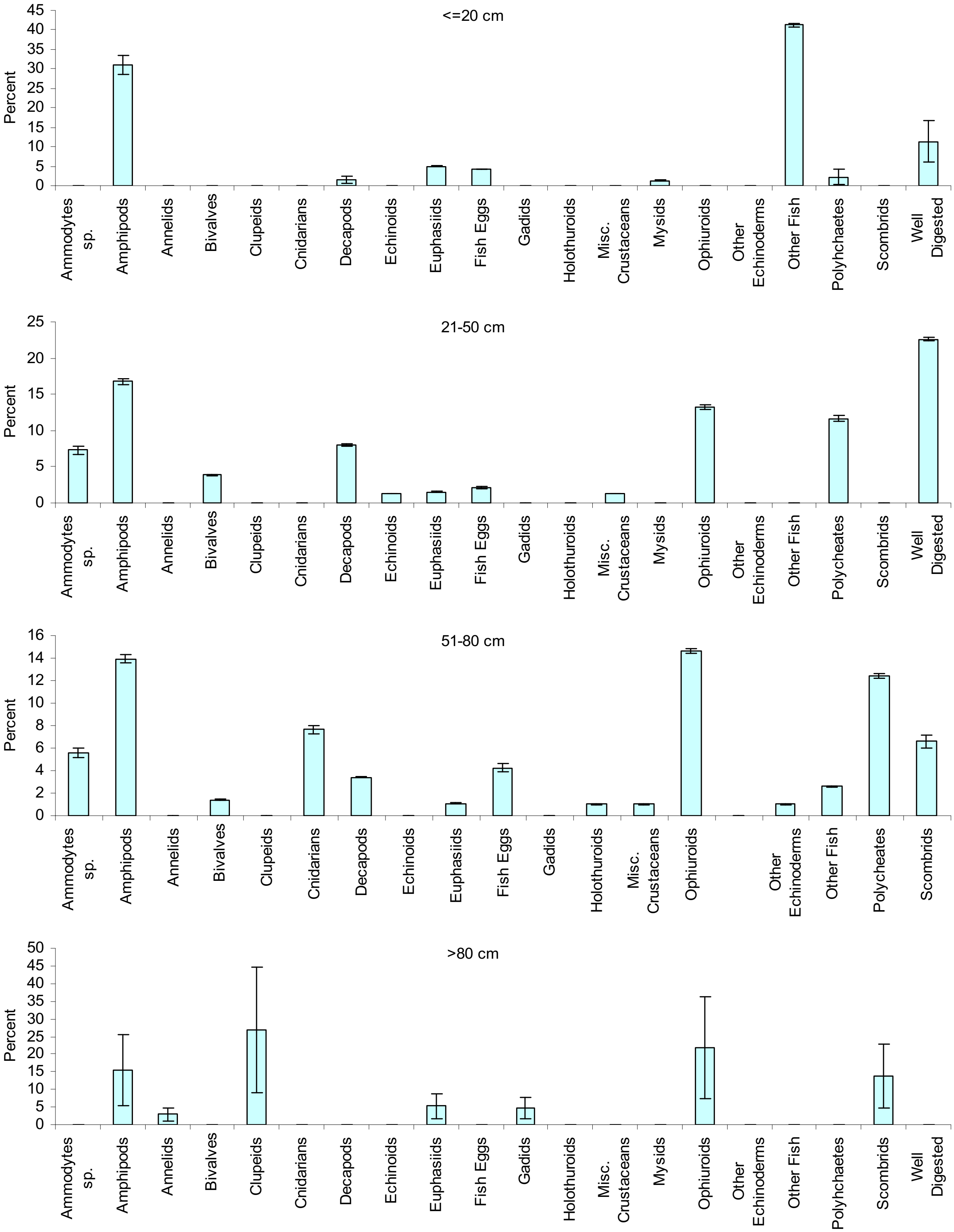
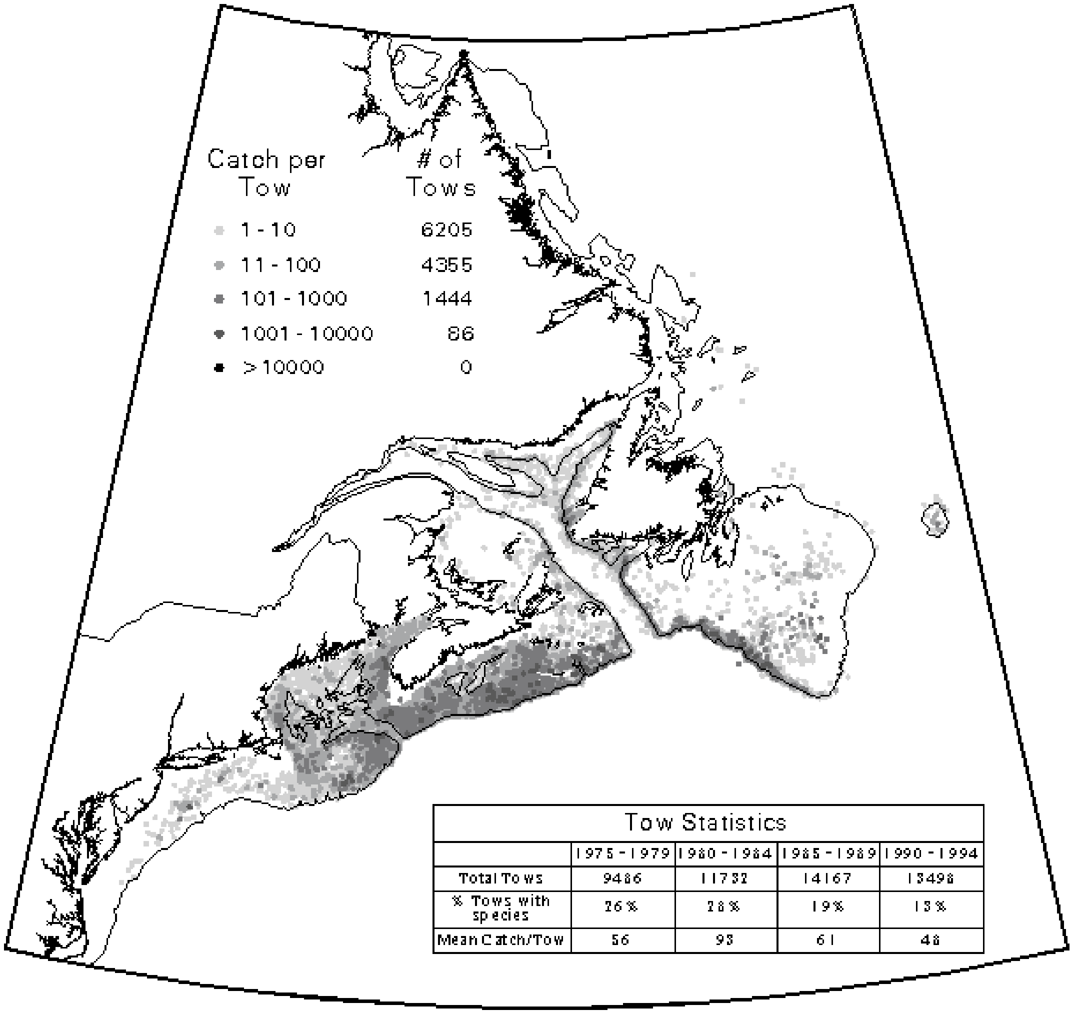


Figure 2. Percent by weight of the major prey items in the diet of four size categories of haddock. Specimens were collected during NEFSC bottom trawl surveys from 1973-2001 (all seasons). For details on NEFSC diet analysis, see Link and Almeida (2000).



Tow Statistics

	1975 - 1979	1980 - 1984	1985 - 1989	1990 - 1994
Total Tows	9486	11732	14167	13498
% Tows with species	26%	28%	19%	13%
Mean Catch/Tow	56	93	61	48

Figure 3. Overall distribution and abundance of haddock in the northwest Atlantic Ocean.
Based on research trawl surveys conducted by Canada (DFO) and the United States (NMFS) from 1975-1994 (http://www-orca.nos.noaa.gov/projects/ecnasap/ecnasap_table1.html).

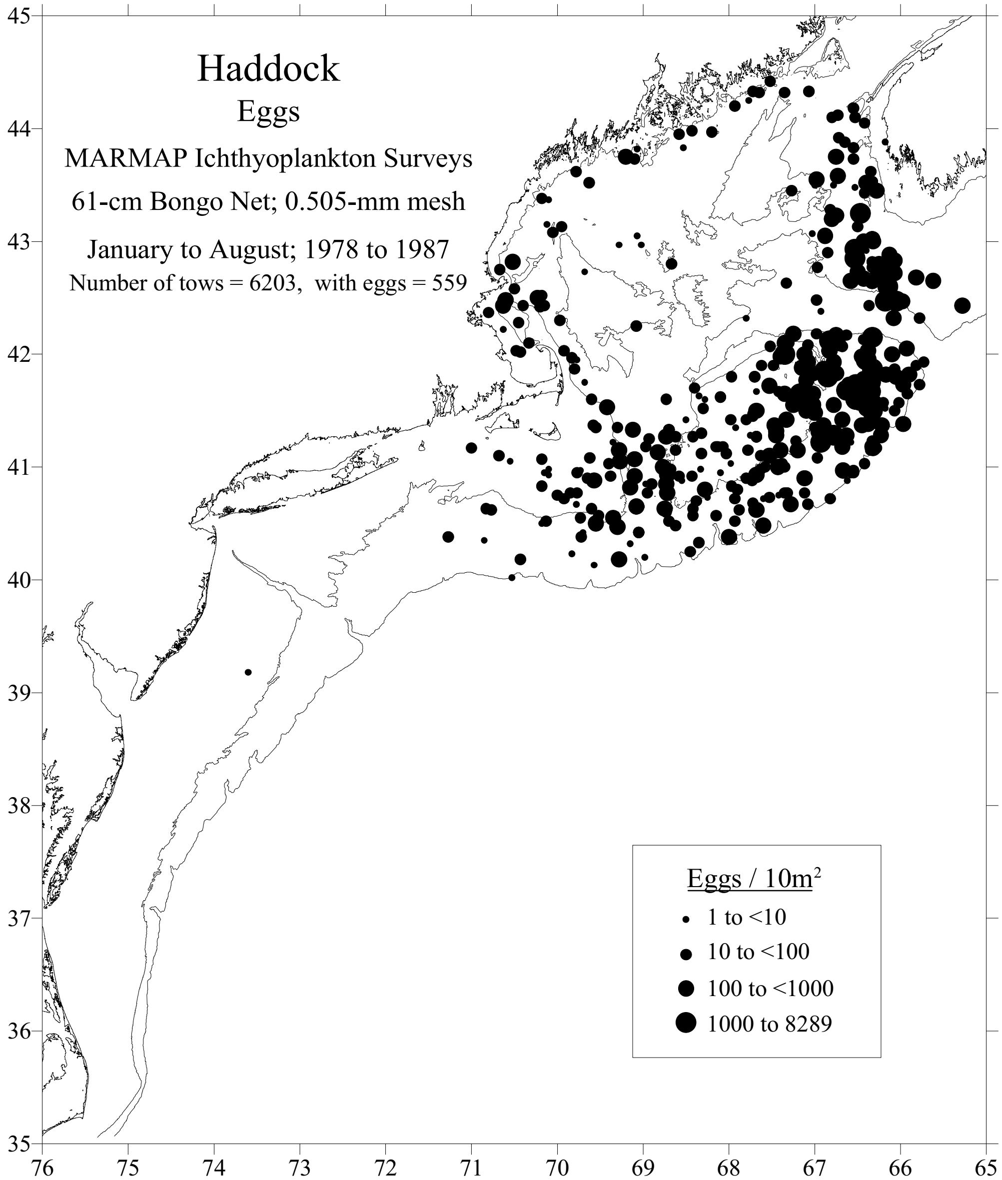


Figure 4. Distributions and abundances of haddock eggs collected during NEFSC MARMAP ichthyoplankton surveys. For all available months and years from 1978 to 1987 combined.

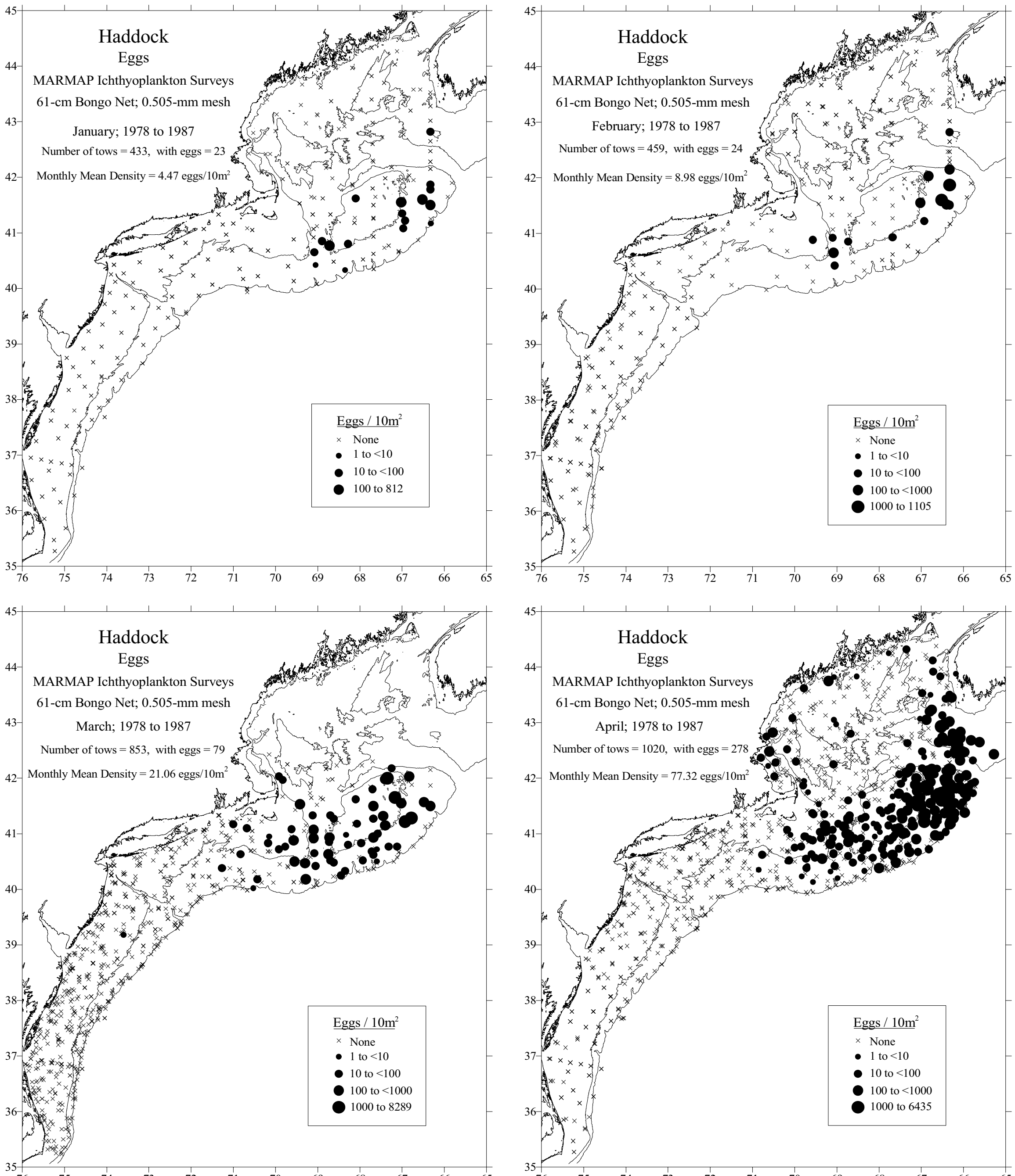


Figure 4. Cont'd.
From MARMAP ichthyoplankton surveys, January through April, 1978-1987.

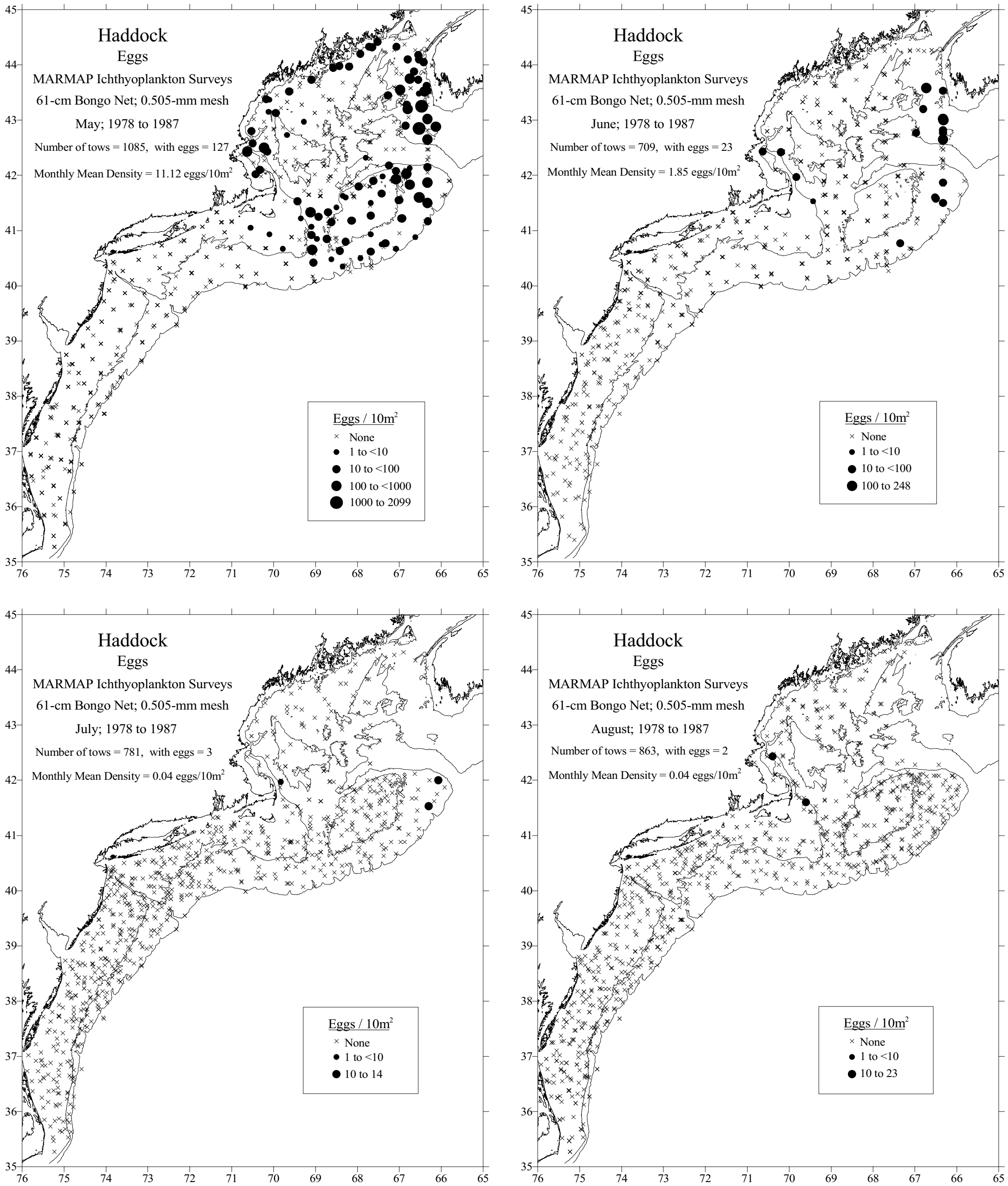


Figure 4. Cont'd.
From MARMAP ichthyoplankton surveys, May through August, 1978-1987.

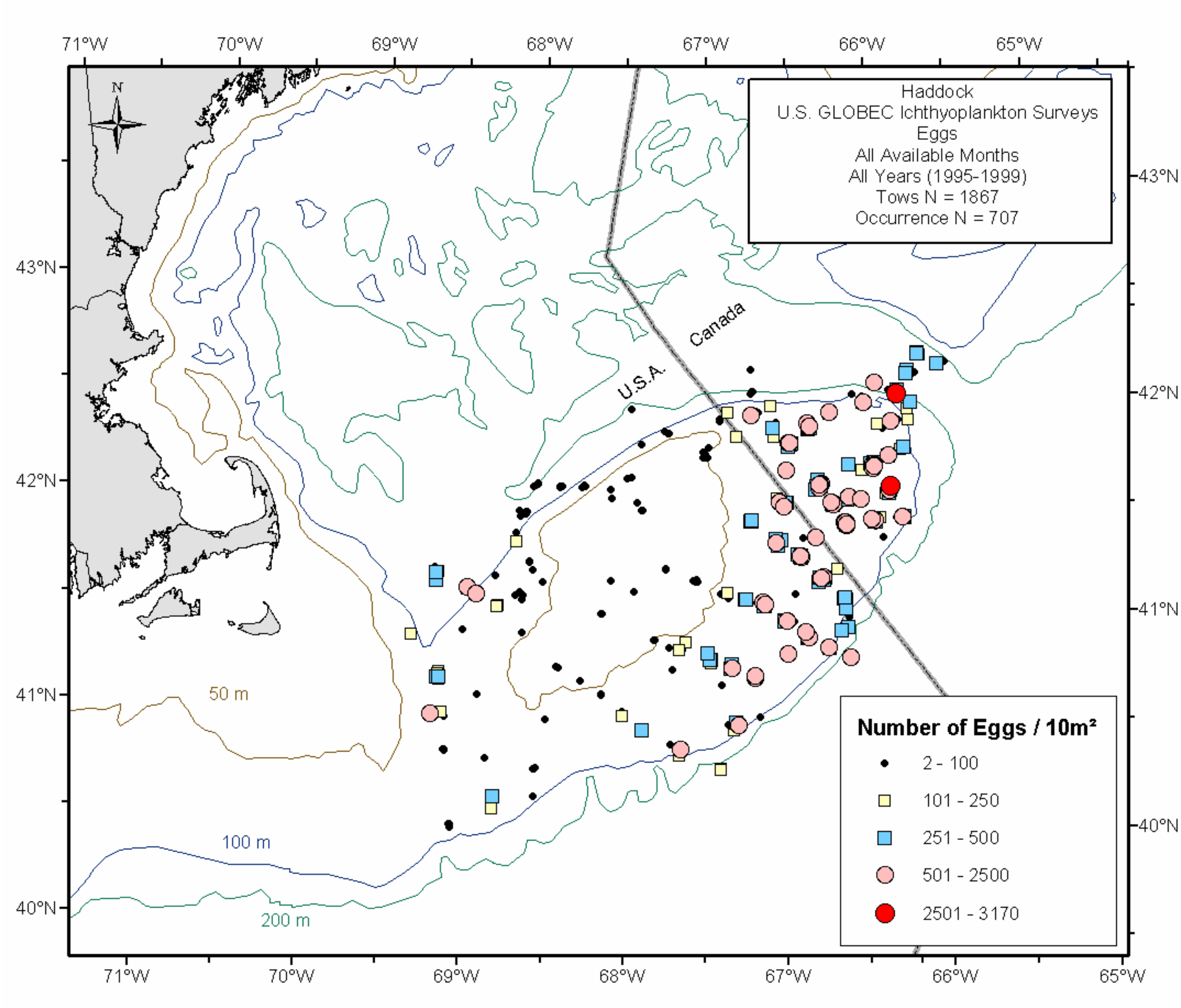
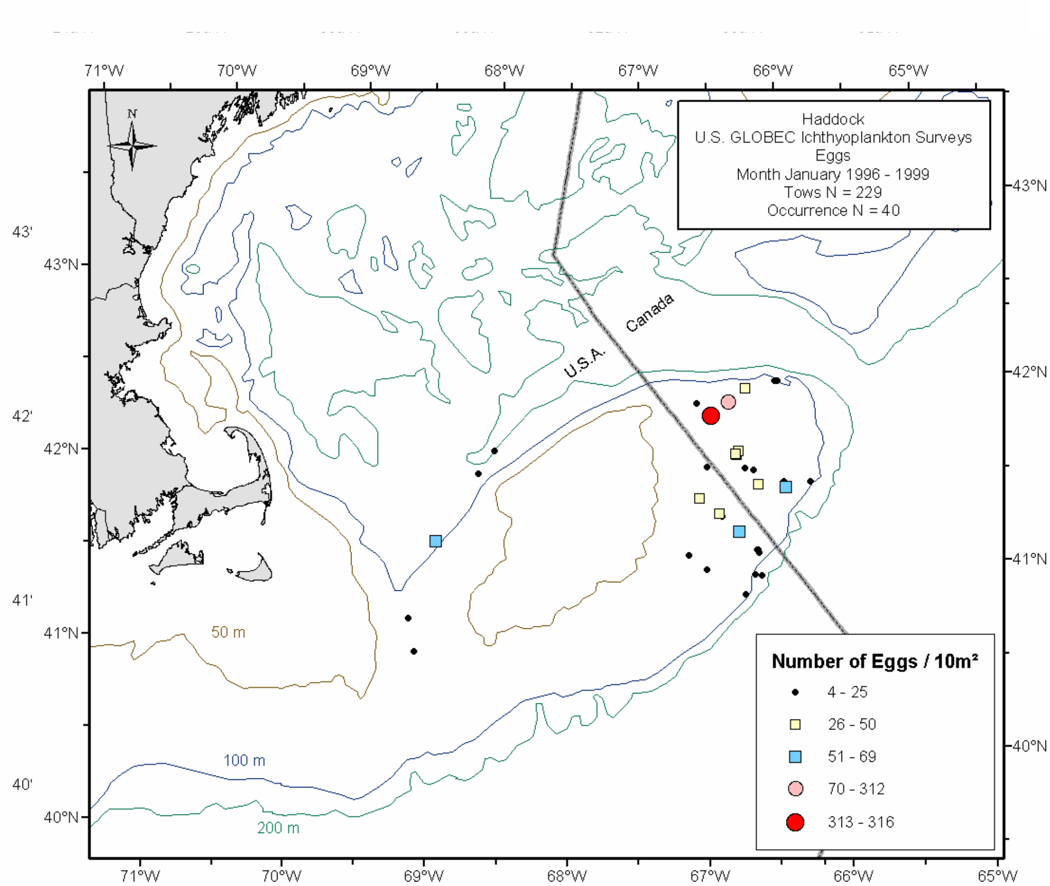


Figure 5. Distributions and abundances of haddock eggs collected during GLOBEC Georges Bank ichthyoplankton surveys.
For all available years (February-July, 1995; January-June, 1996-1999) combined.



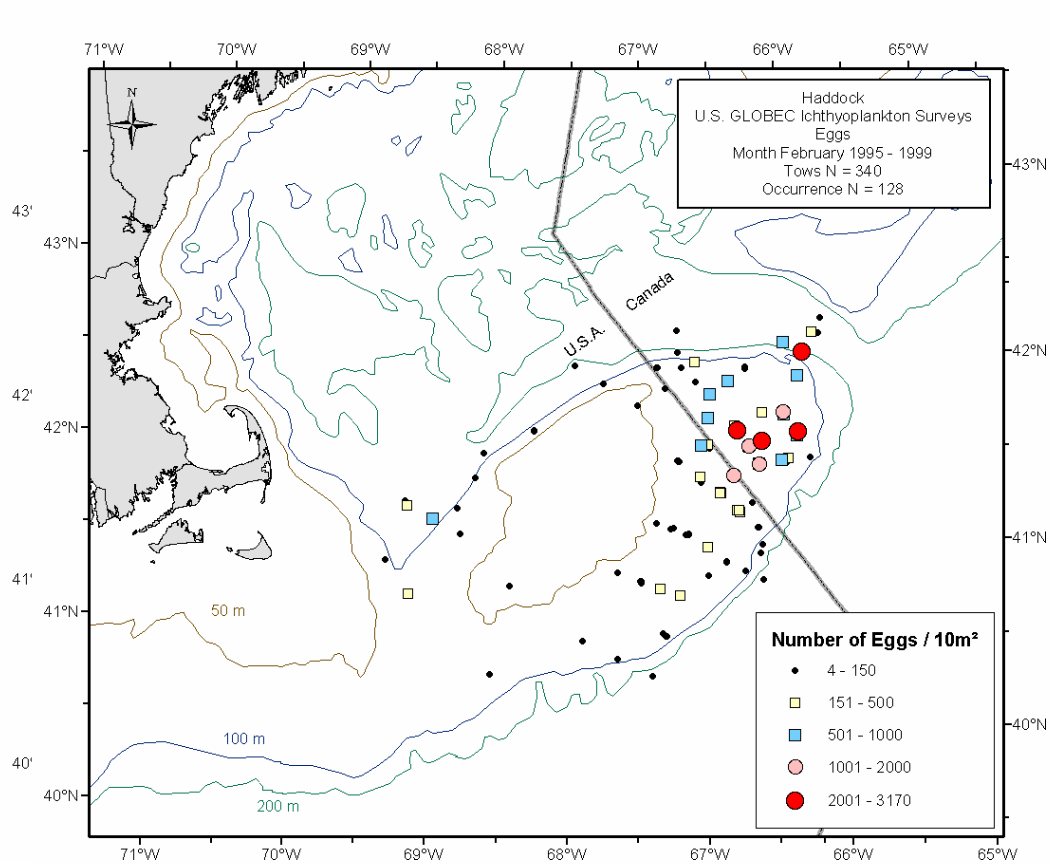
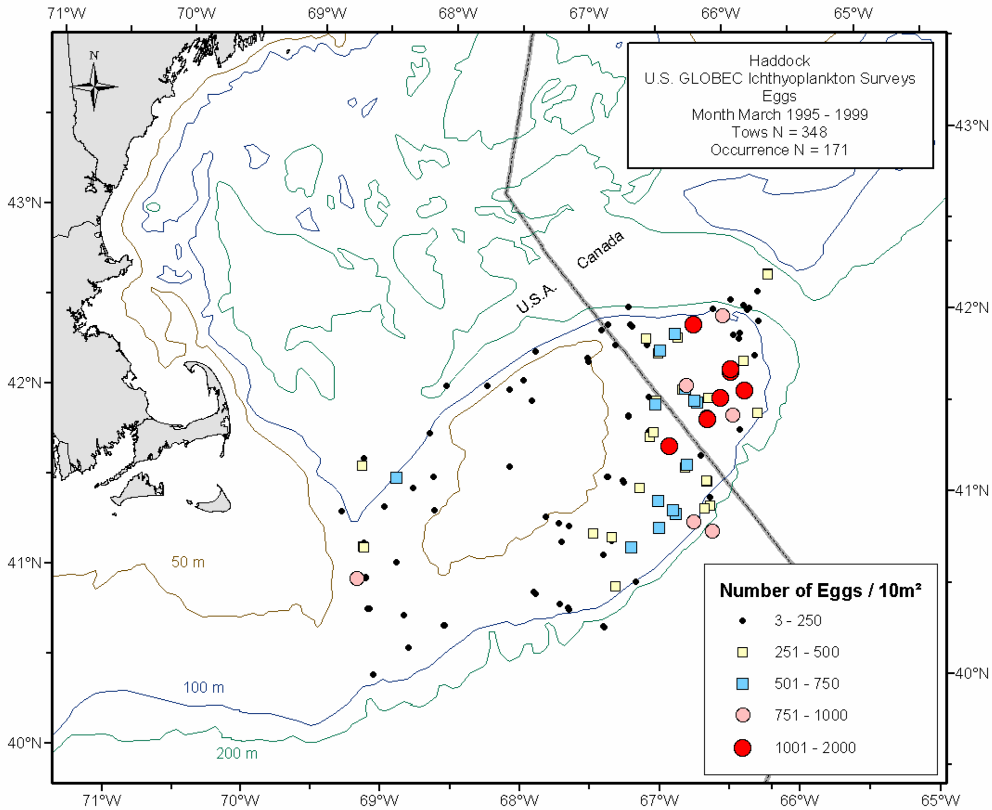


Figure 5. Con
From GLOBEC ichthyoplankton surveys, January and February, for all available years combined.



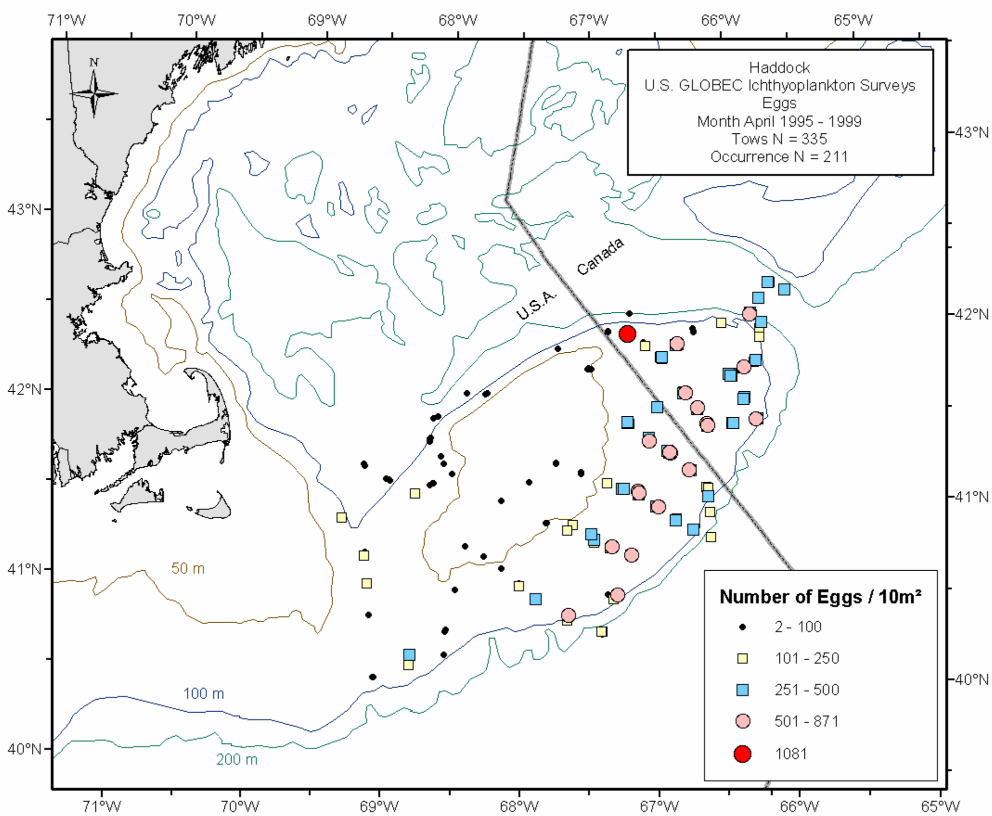


Figure 5. Cont'd.
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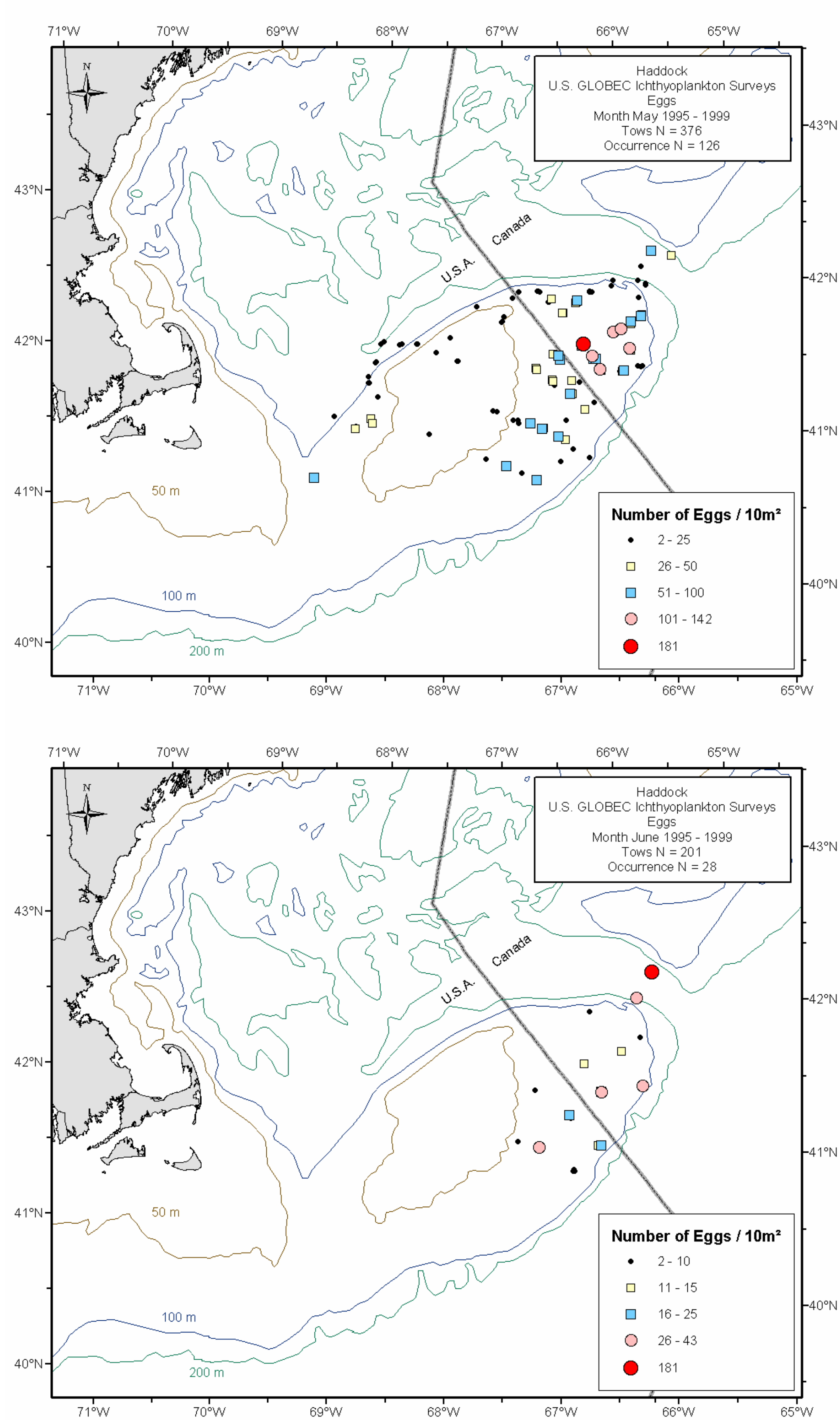

Figure 5. Cont'd.
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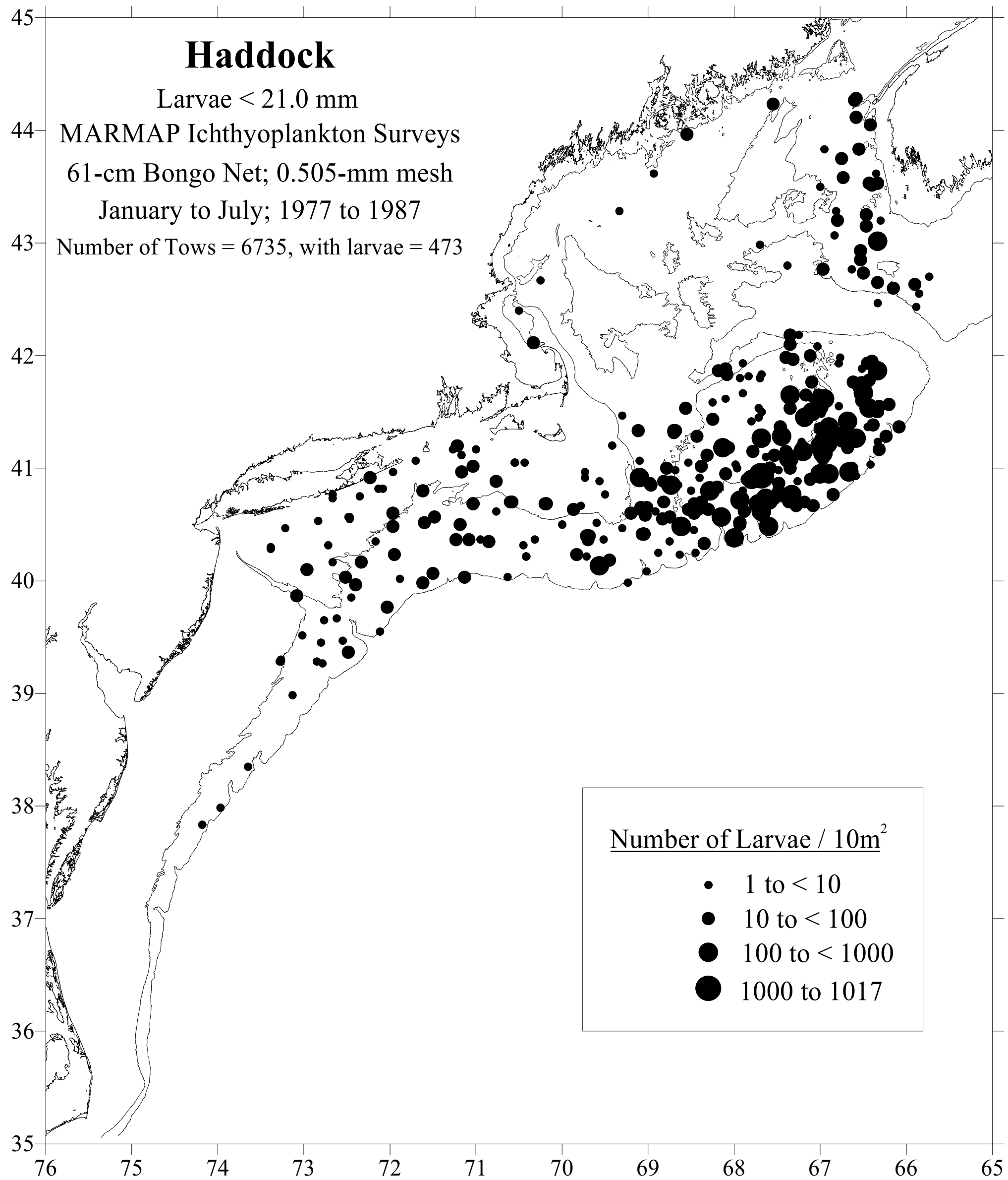
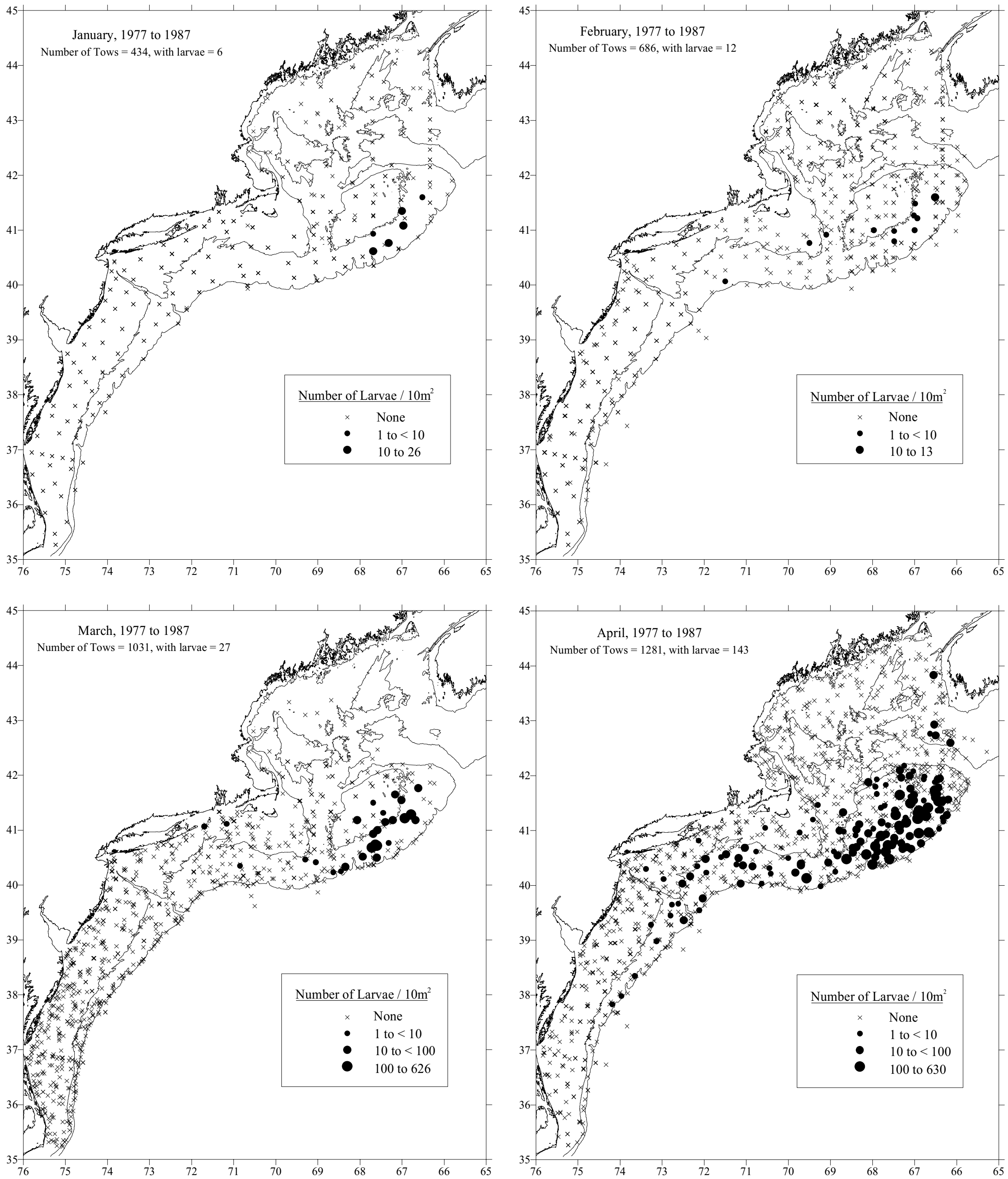


Figure 6. Distributions and abundances of haddock larvae collected during NEFSC MARMAP ichthyoplankton surveys.
For all available months and years from 1977 to 1987 combined.



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From MARMAP ichthyoplankton surveys, January through April, 1977-1987.

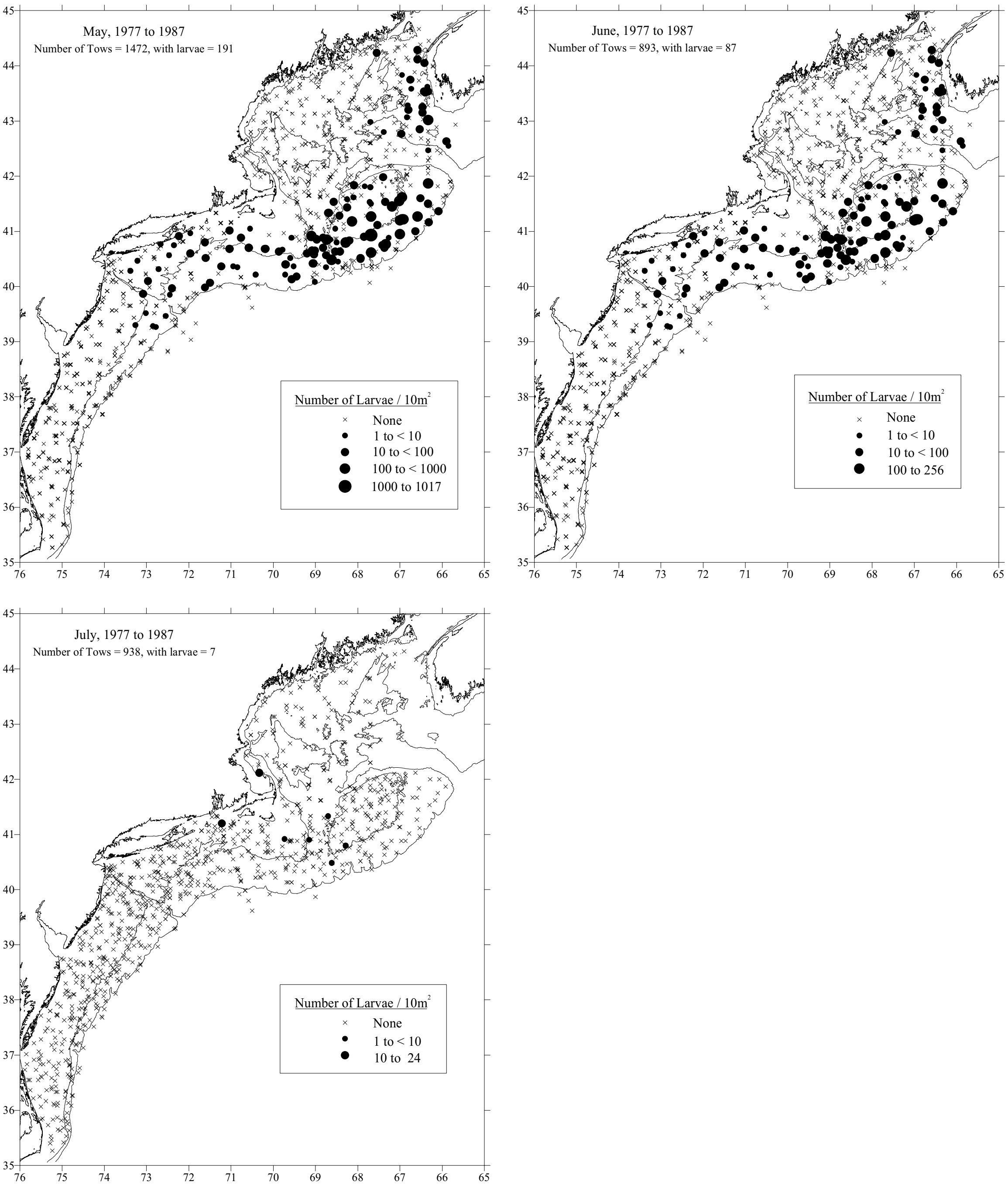


Figure 6. Cont'd.
From MARMAP ichthyoplankton surveys, May through July, 1977-1987.

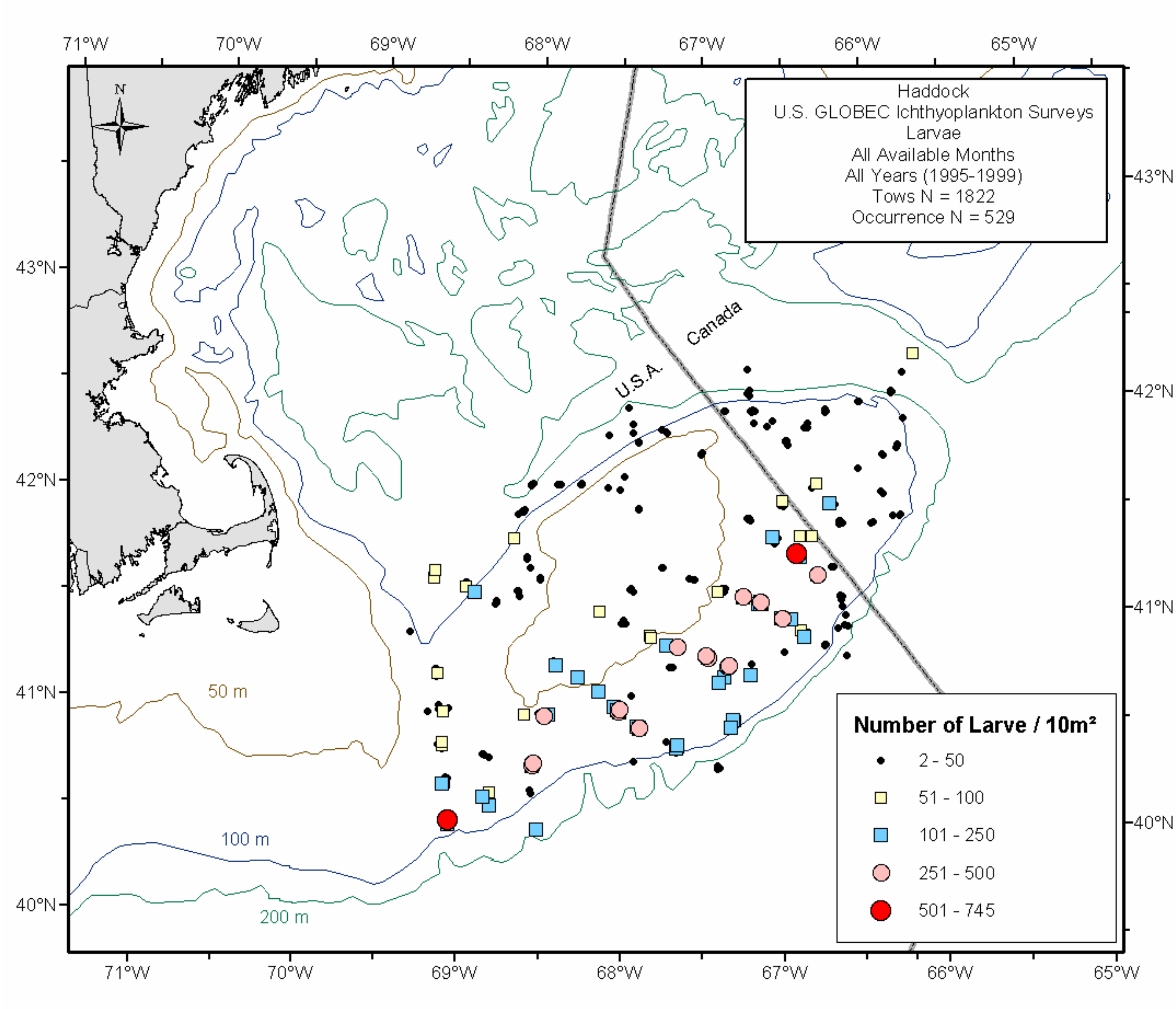
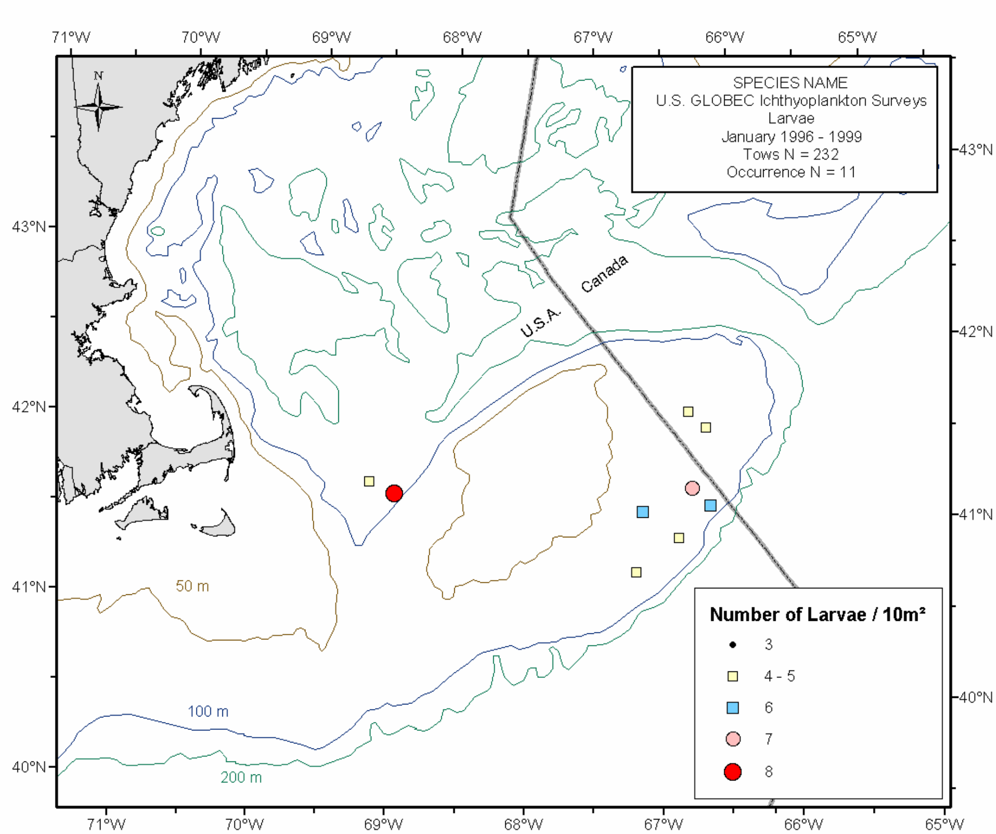


Figure 7. Distributions and abundances of haddock larvae collected during GLOBEC Georges Bank ichthyoplankton surveys.
For all available years (February-July, 1995; January-June, 1996-1999) combined.



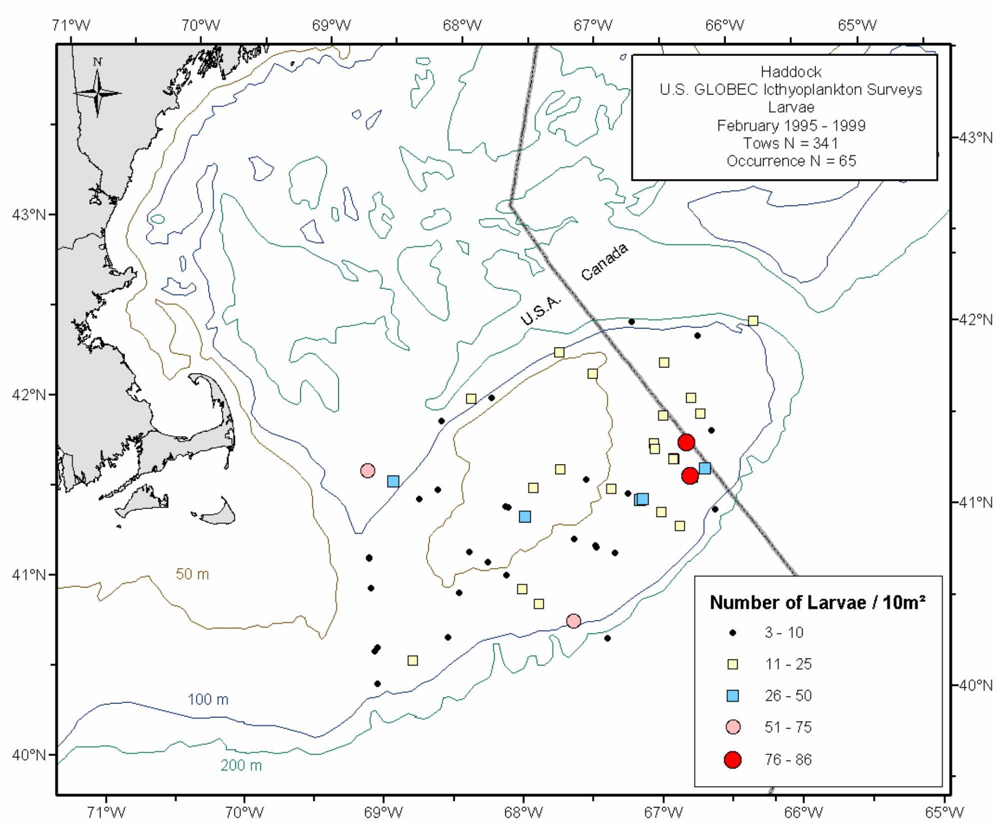
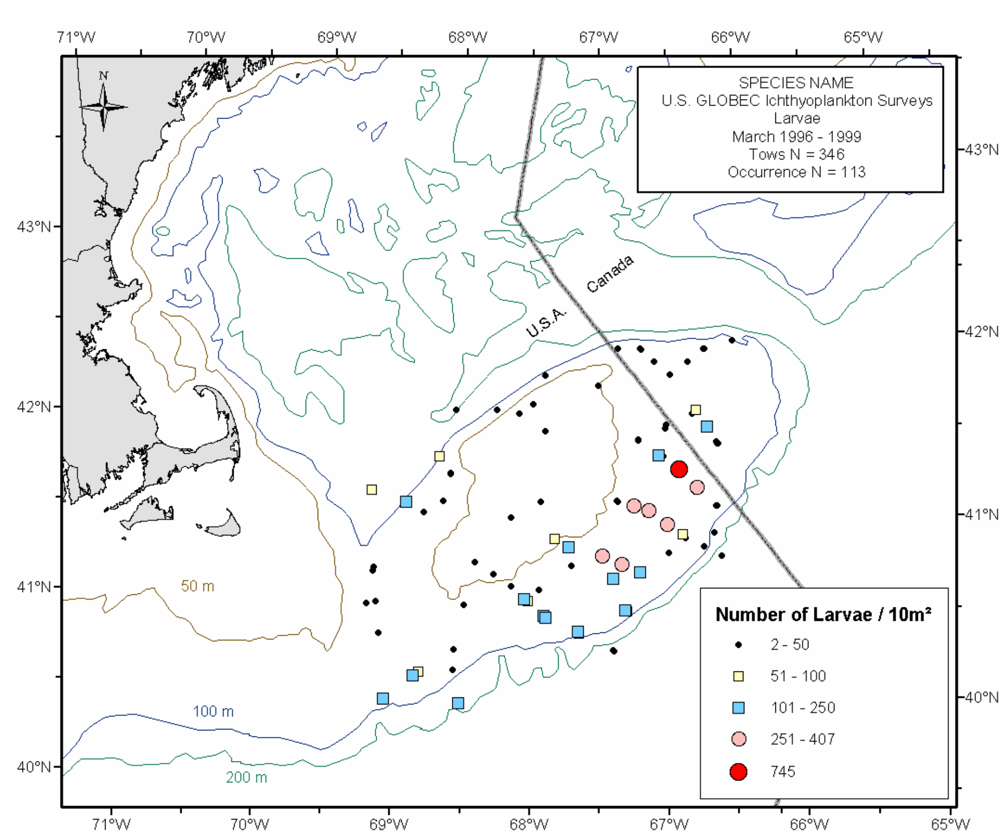


Figure 6. Cont'd.
From GLOBEC ichthyoplankton surveys, January and February, for all available years combined.



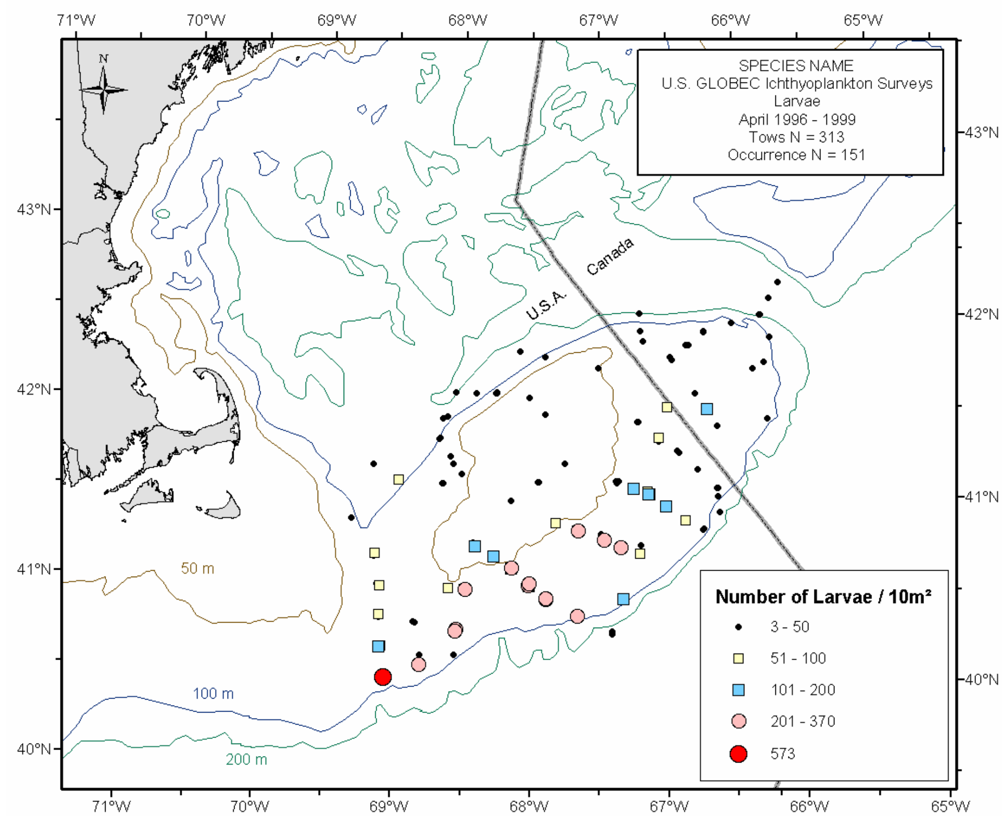


Figure 6. Cont'd.
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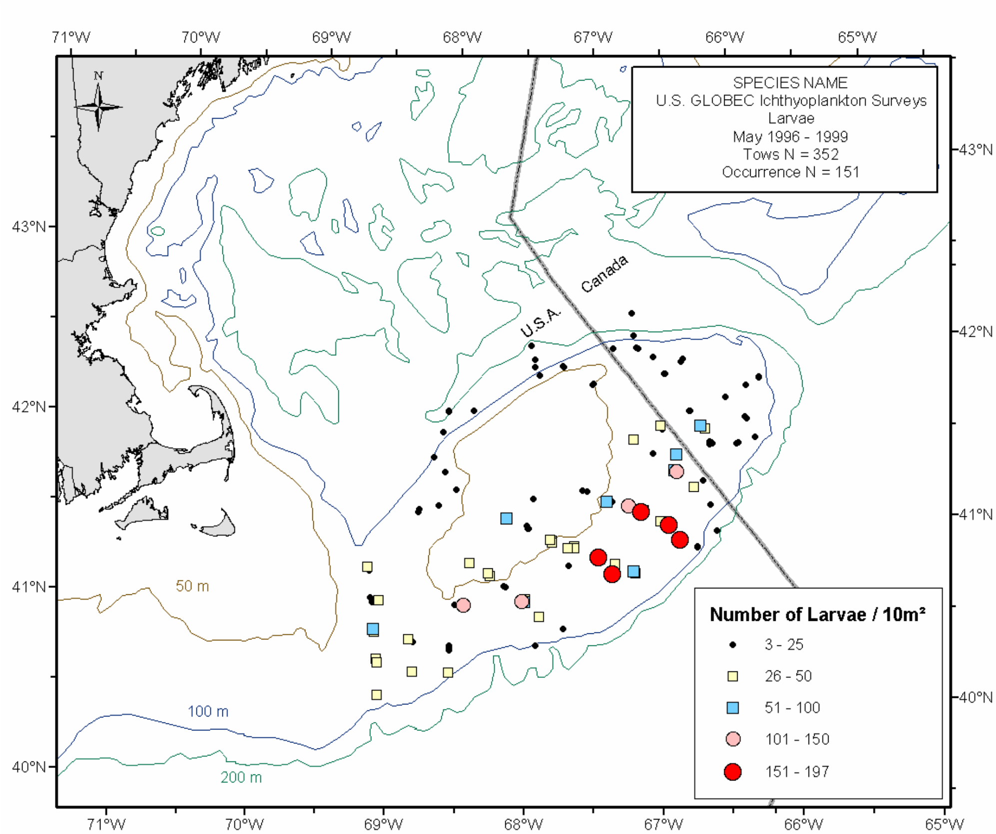

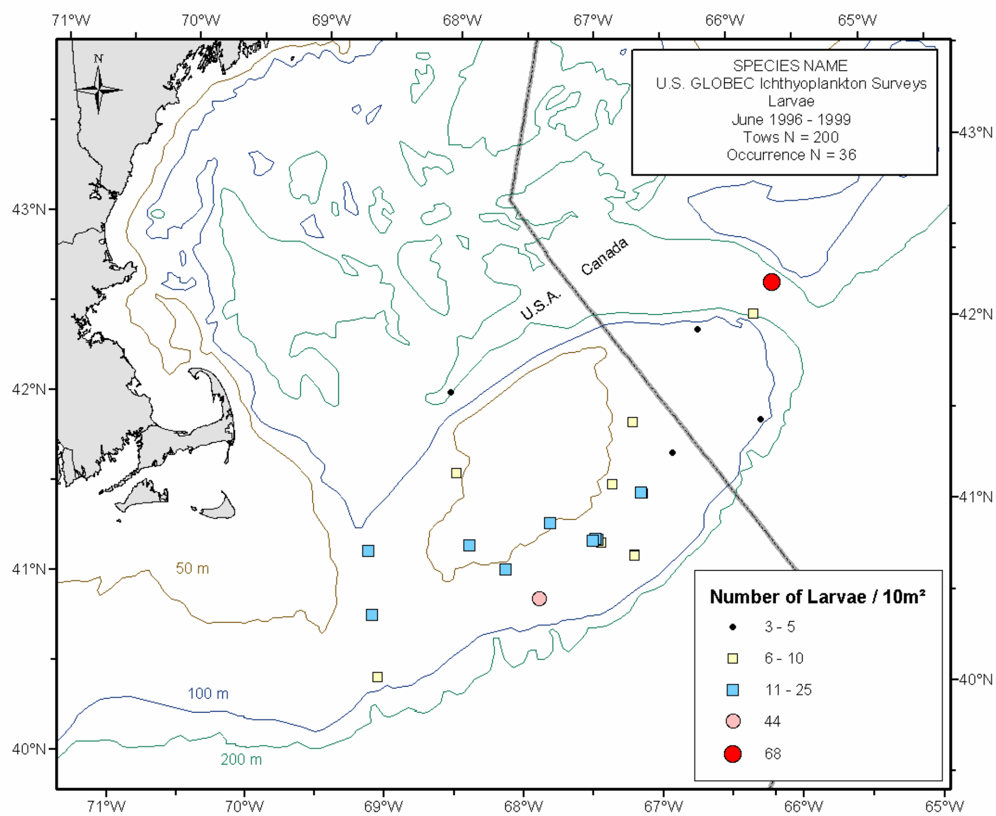

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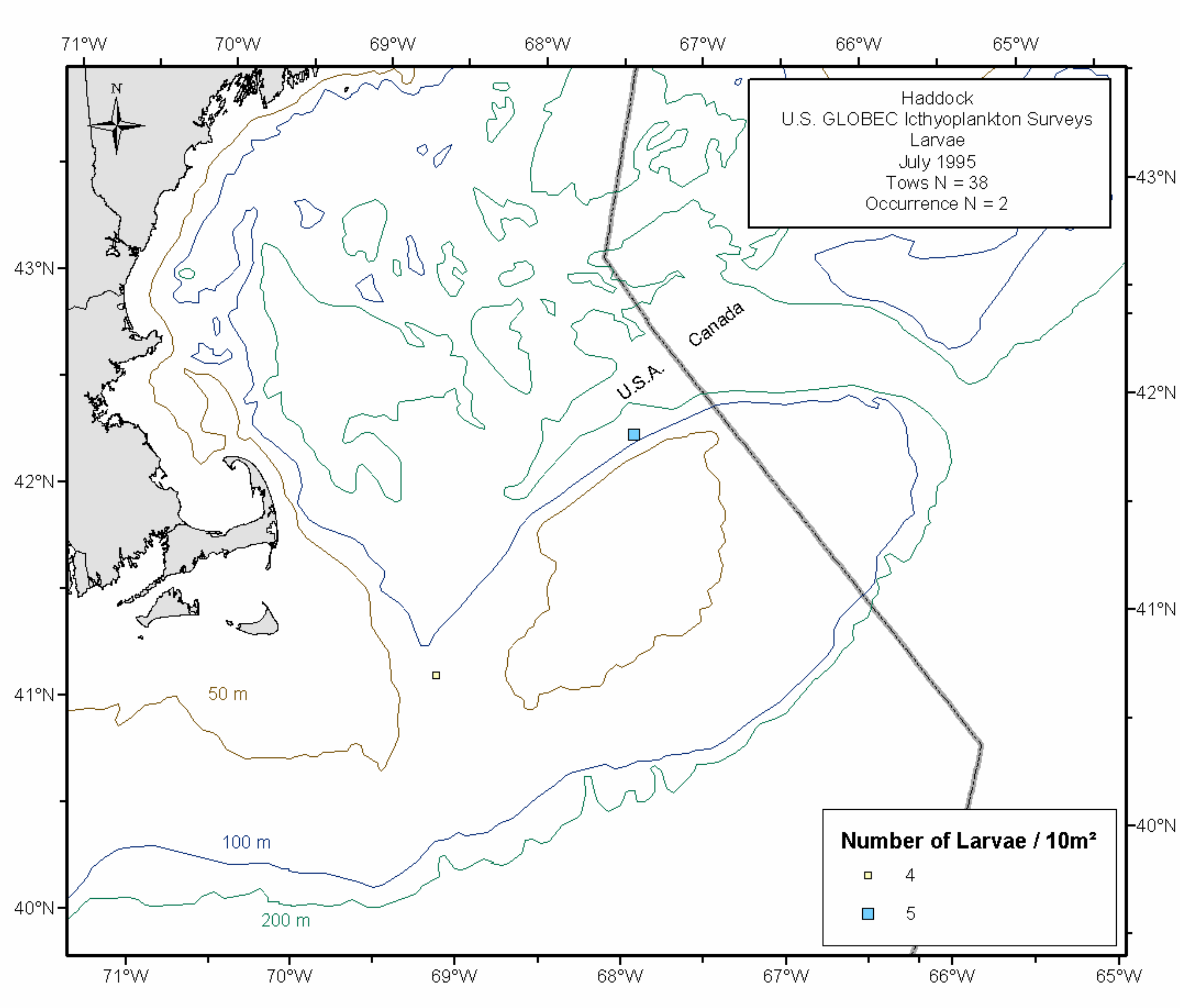

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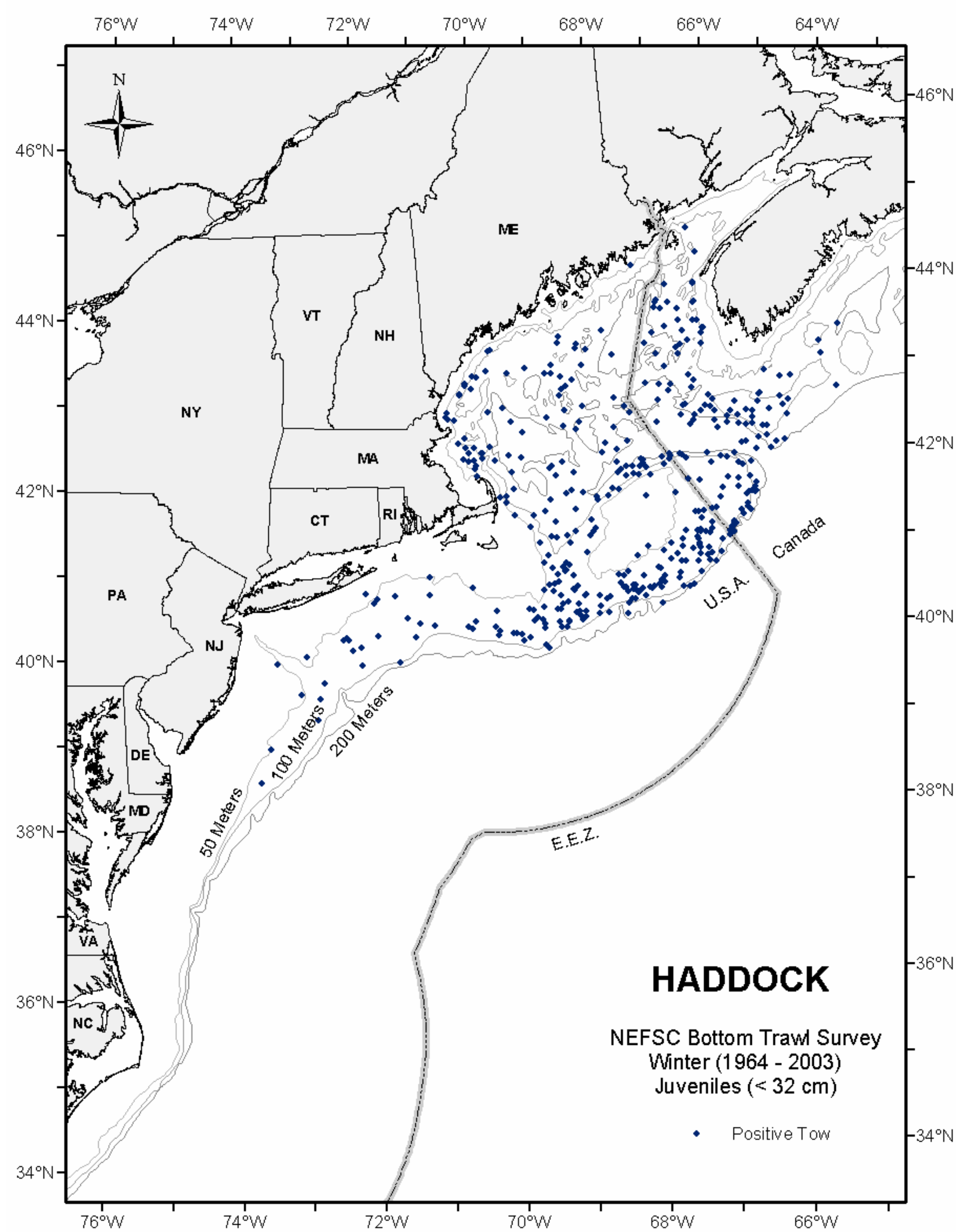


Figure 8. Seasonal distributions and abundances of juvenile haddock collected during NEFSC bottom trawl surveys. From NEFSC winter bottom trawl surveys (1964-2003, all years combined). Distributions are displayed as presence only.

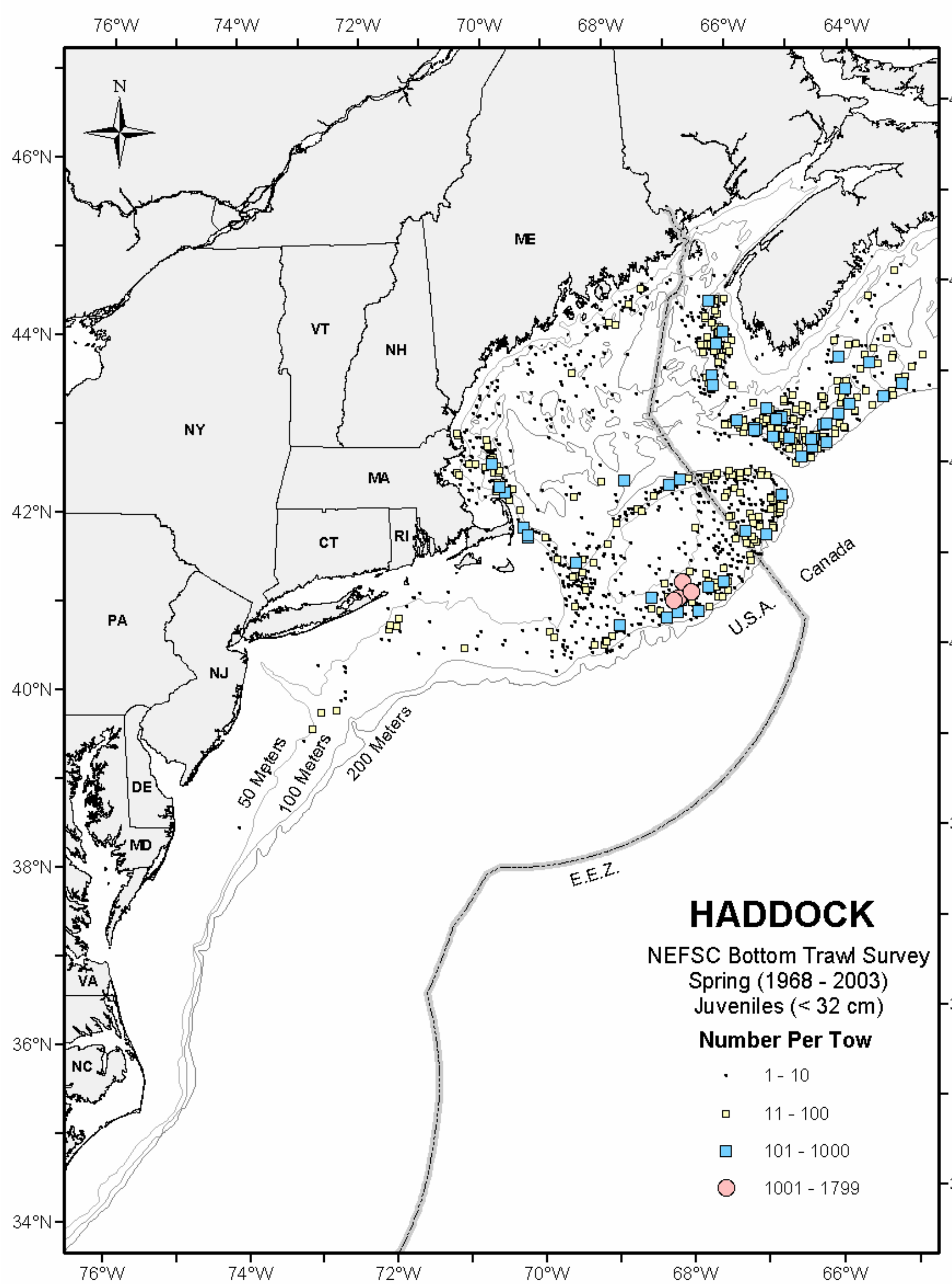


Figure 8. Cont'd.
From NEFSC spring bottom trawl surveys (1968-2003, all years combined). Survey stations where juveniles were not found are not shown.

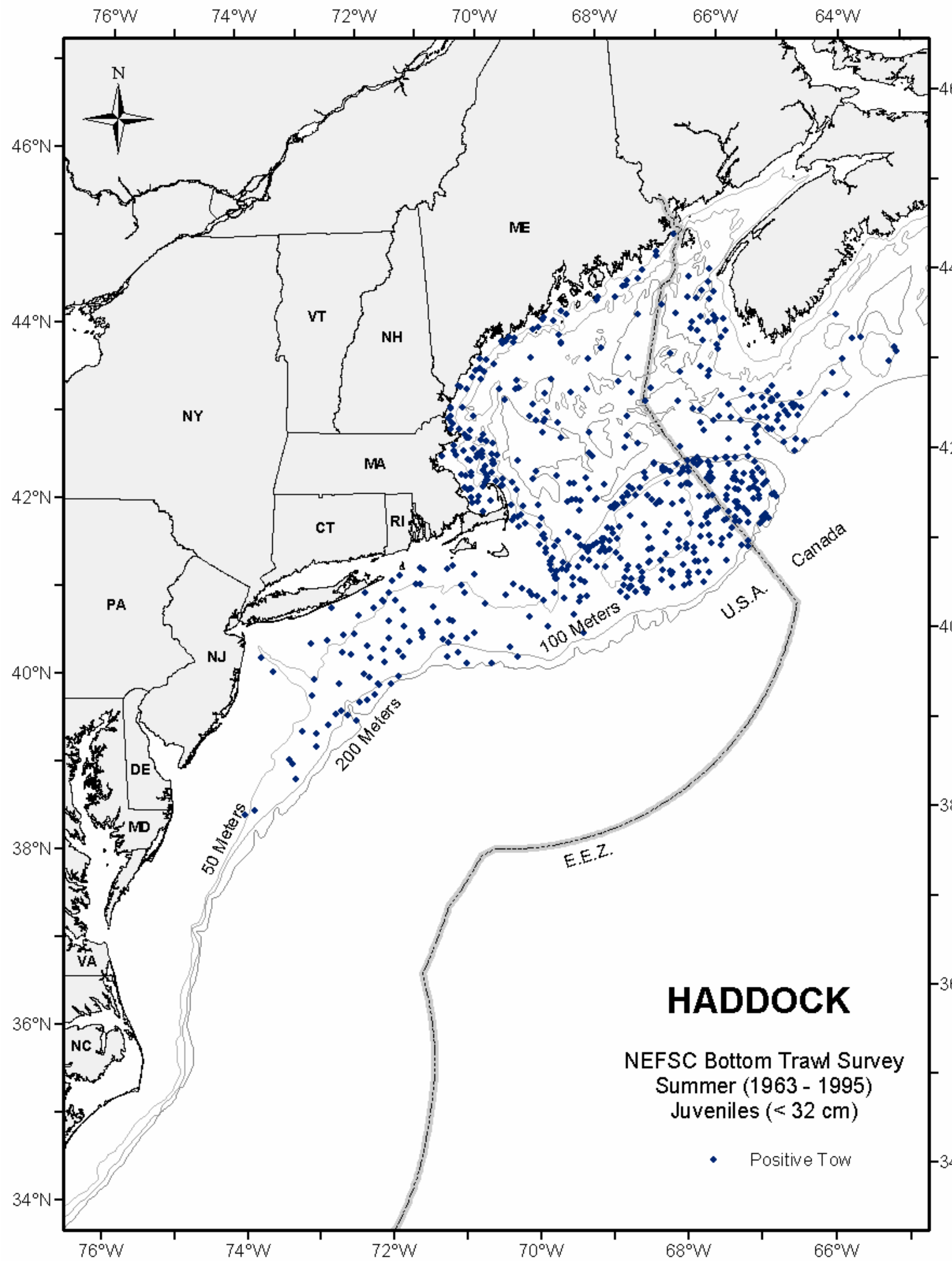
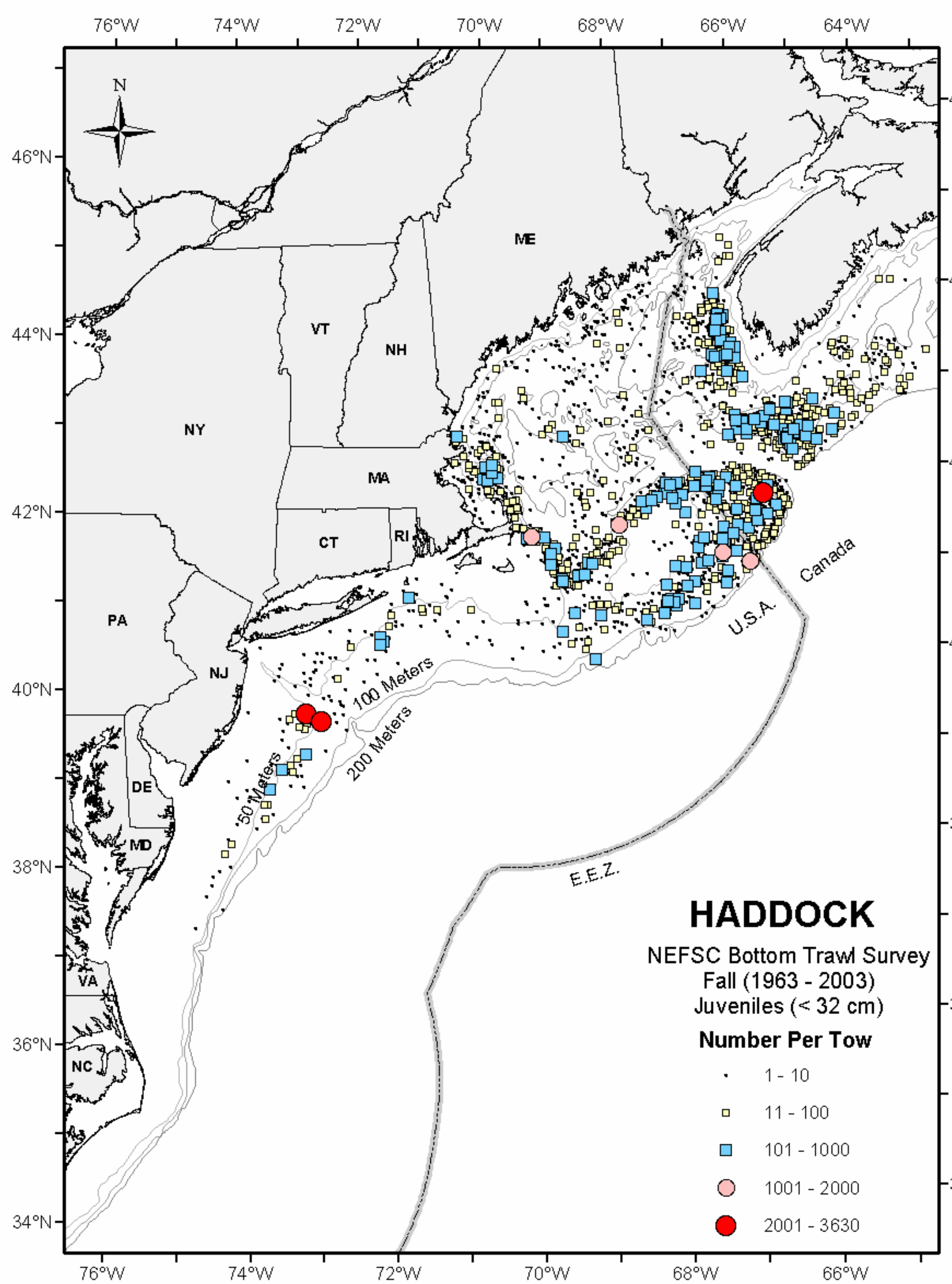


Figure 8. Cont'd.
From NEFSC summer bottom trawl surveys (1963-1995, all years combined). Distributions are displayed as presence only.



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From NEFSC fall bottom trawl surveys (1963-2003, all years combined). Survey stations where juveniles were not found are not shown.

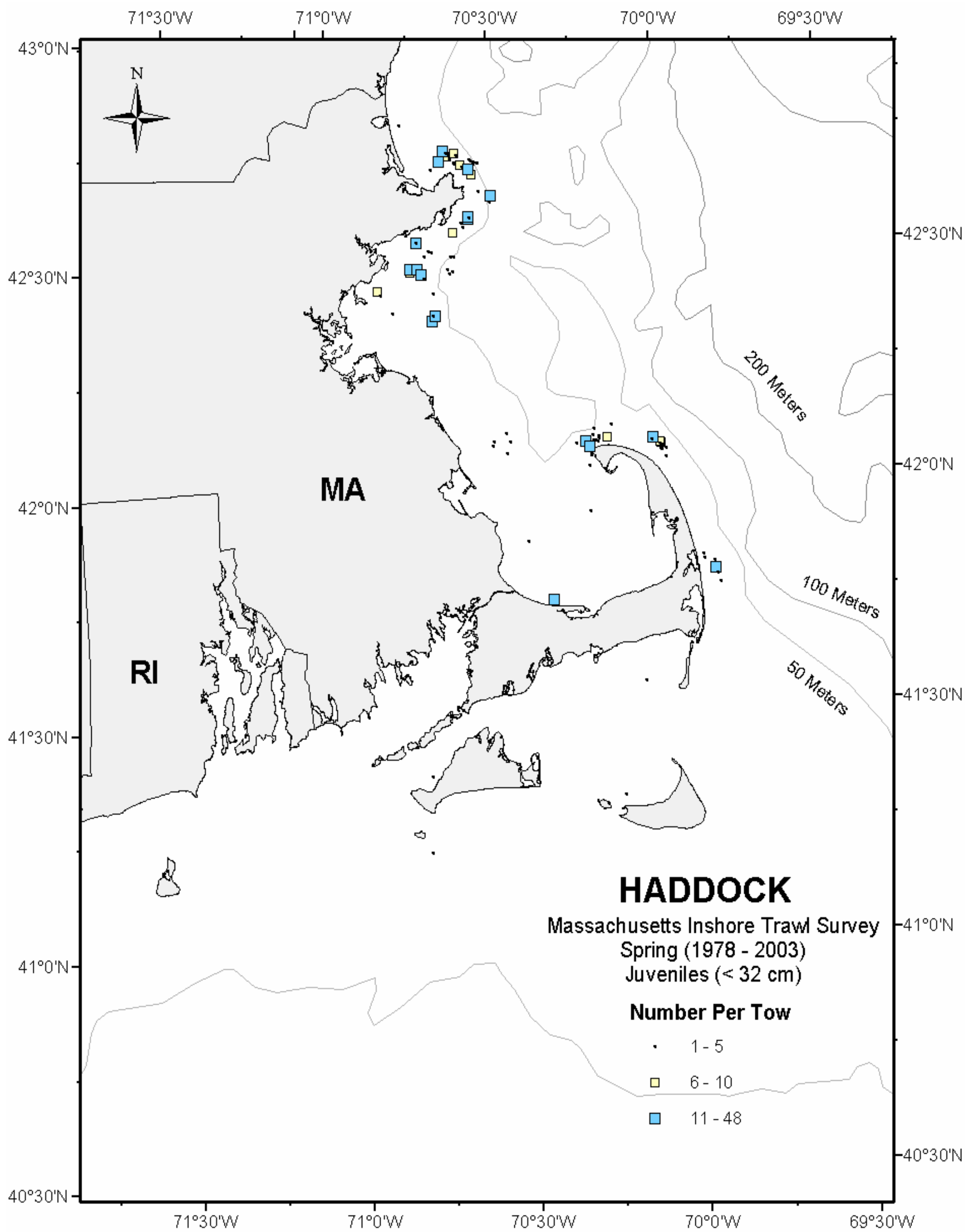


Figure 9. Seasonal distributions and abundances of juvenile haddock in Massachusetts coastal waters. From spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where juveniles were not found are not shown.

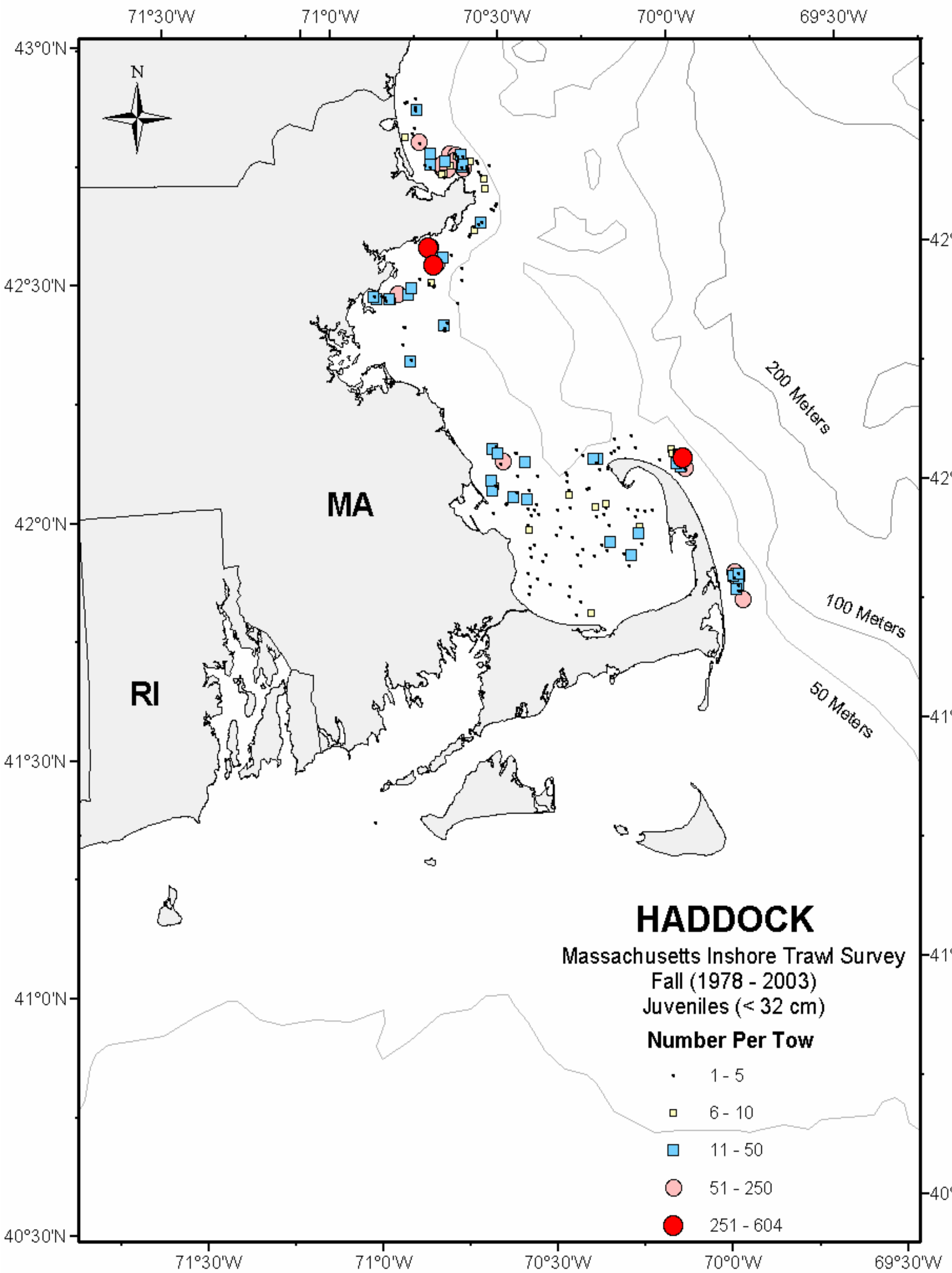


Figure 9. Cont'd.
From fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where juveniles were not found are not shown.

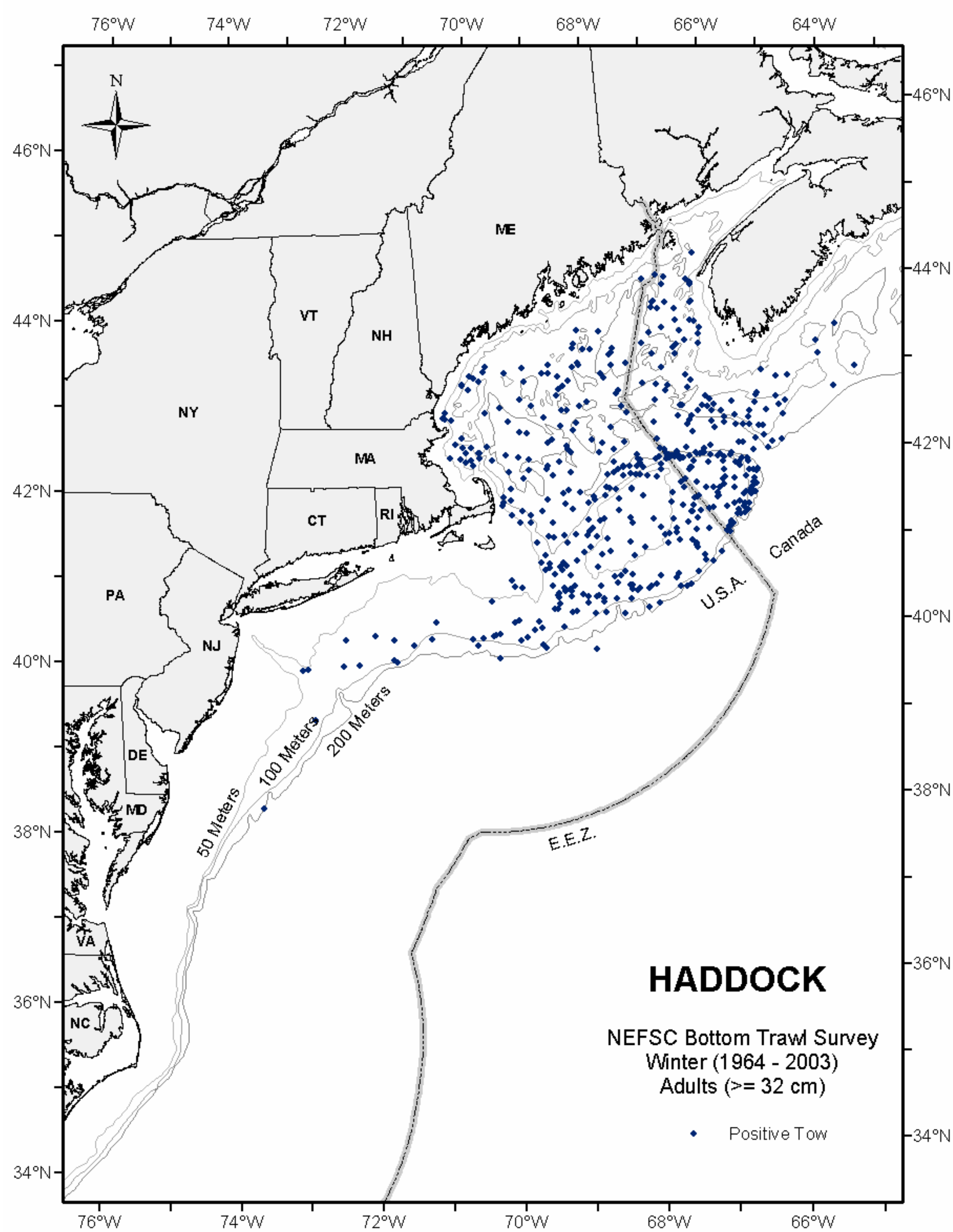


Figure 10. Seasonal distributions and abundances of adult haddock collected during NEFSC bottom trawl surveys. From NEFSC winter bottom trawl surveys (1964-2003, all years combined). Distributions are displayed as presence only.

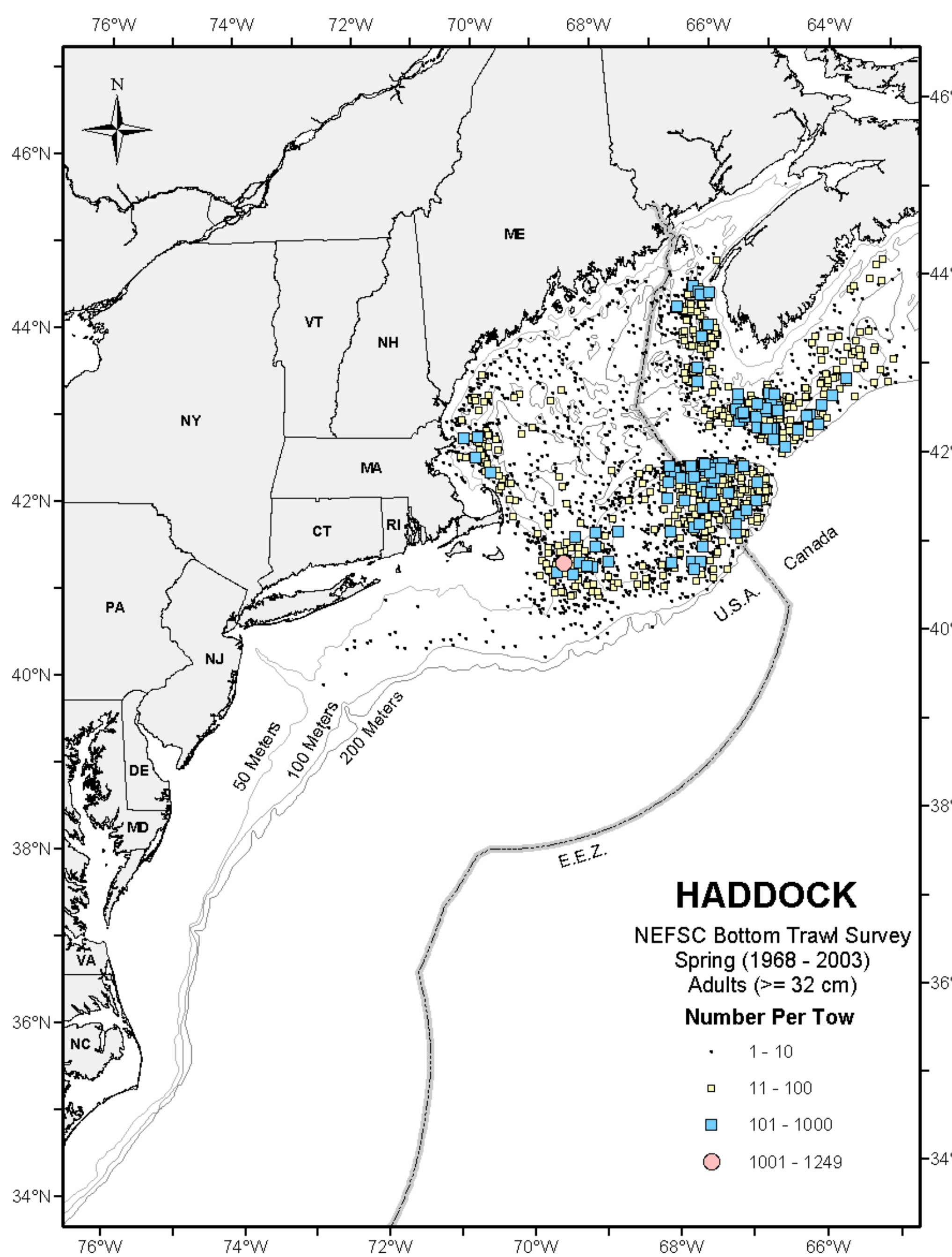
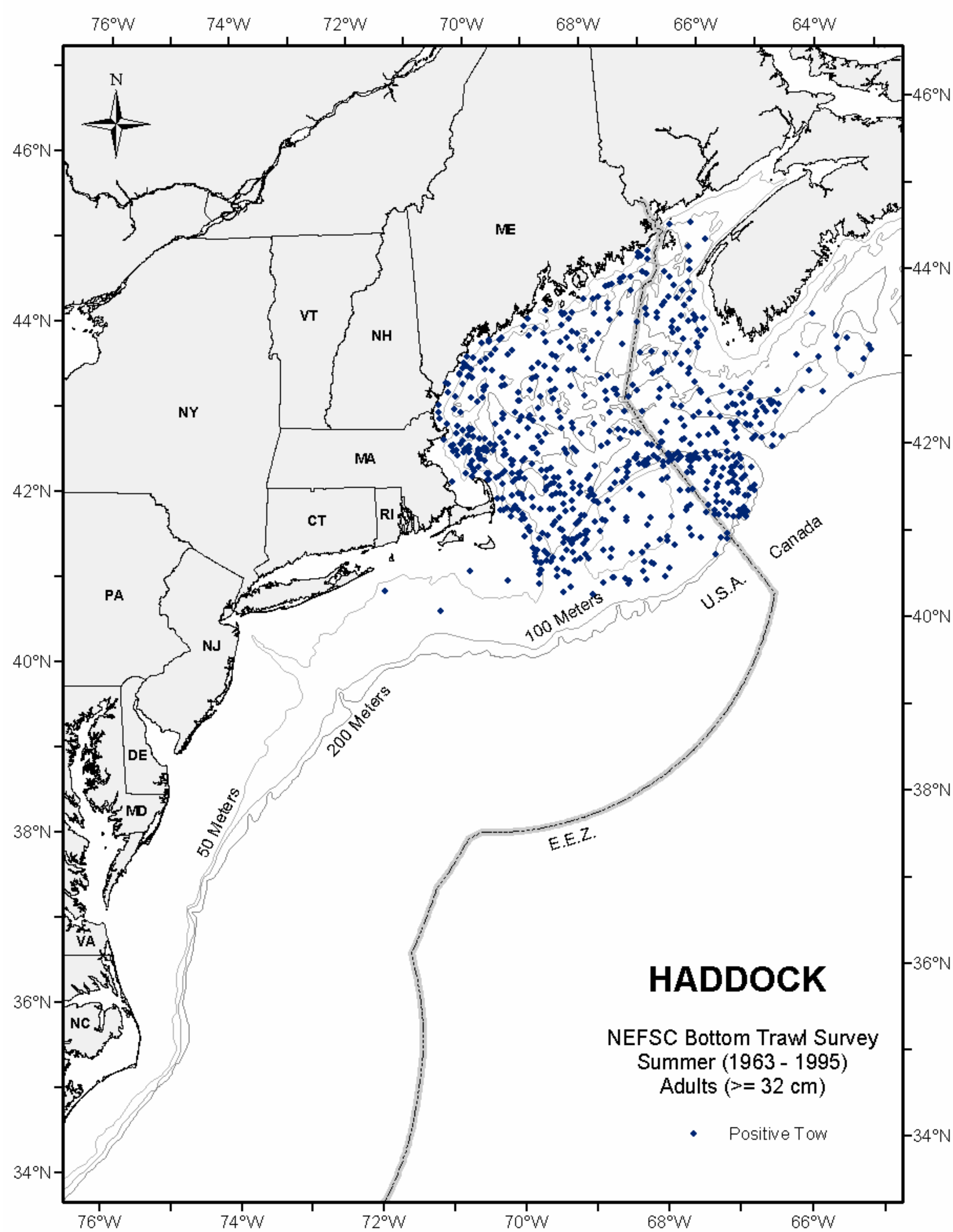


Figure 10. Cont'd.
From NEFSC spring bottom trawl surveys (1968-2003, all years combined). Survey stations where adults were not found are not shown.



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From NEFSC summer bottom trawl surveys (1963-1995, all years combined). Distributions are displayed as presence only.

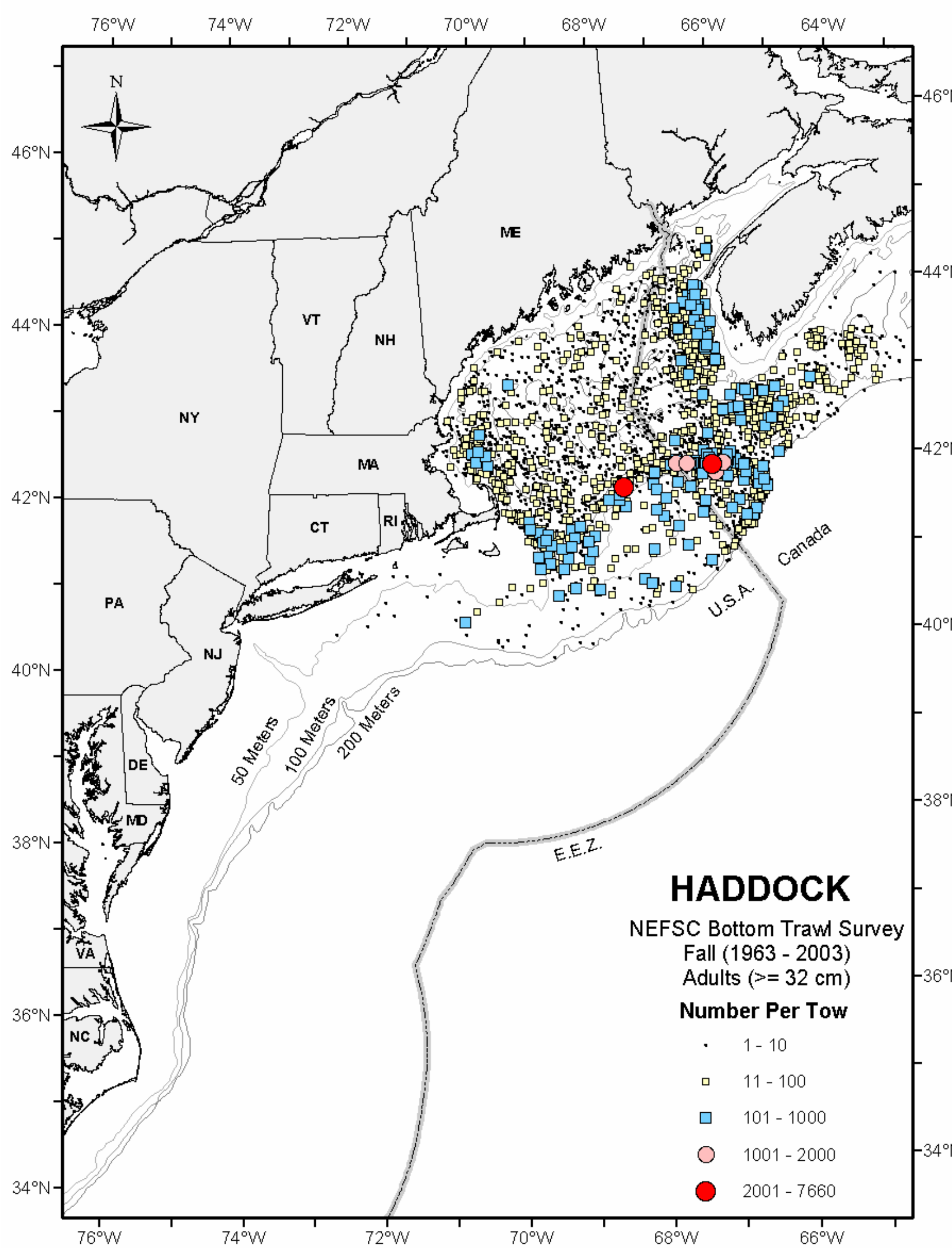


Figure 10. Cont'd.
From NEFSC fall bottom trawl surveys (1963-2003, all years combined). Survey stations where adults were not found are not shown.

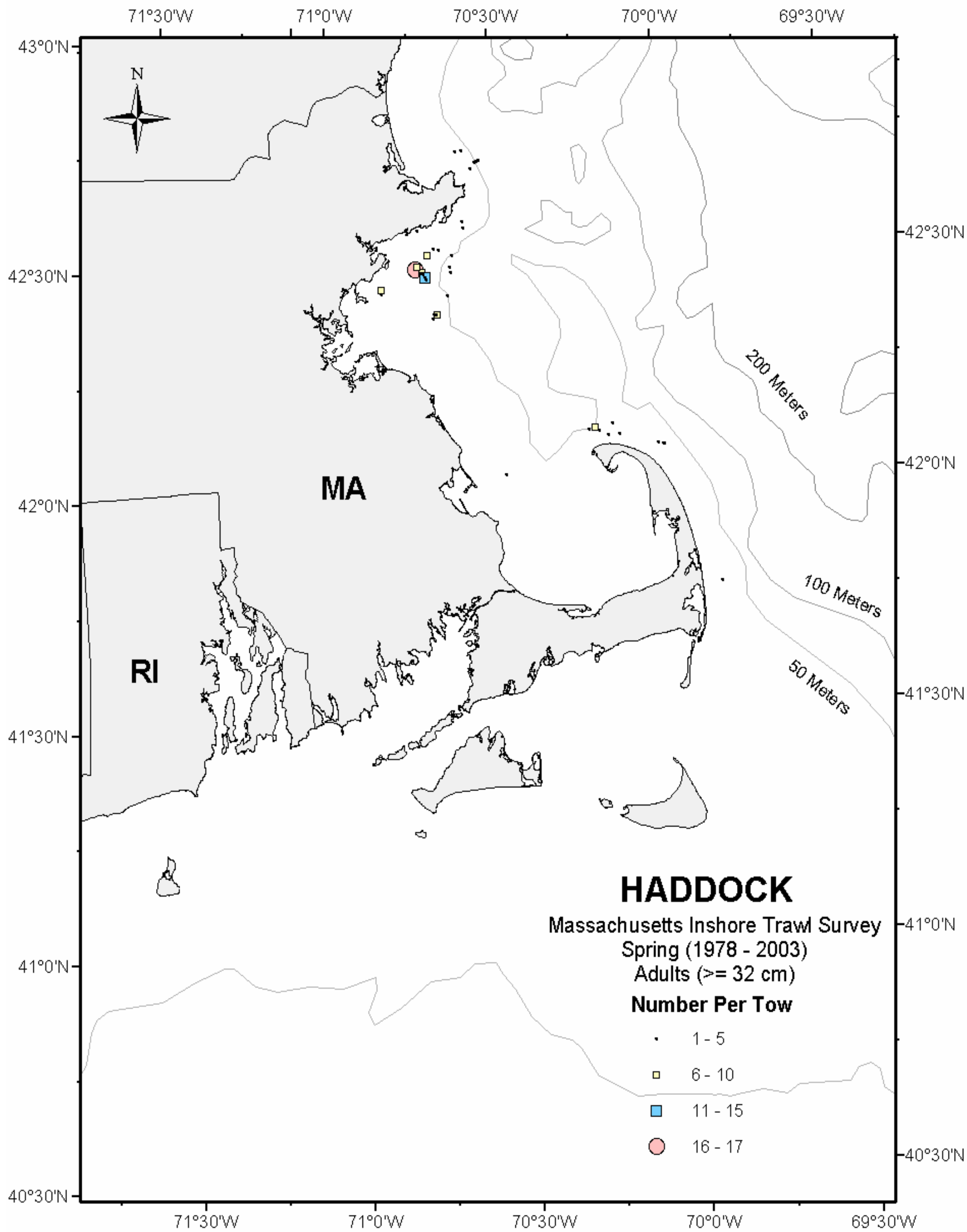


Figure 11. Seasonal distributions and abundances of adult haddock in Massachusetts coastal waters. From spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where adults were not found are not shown.

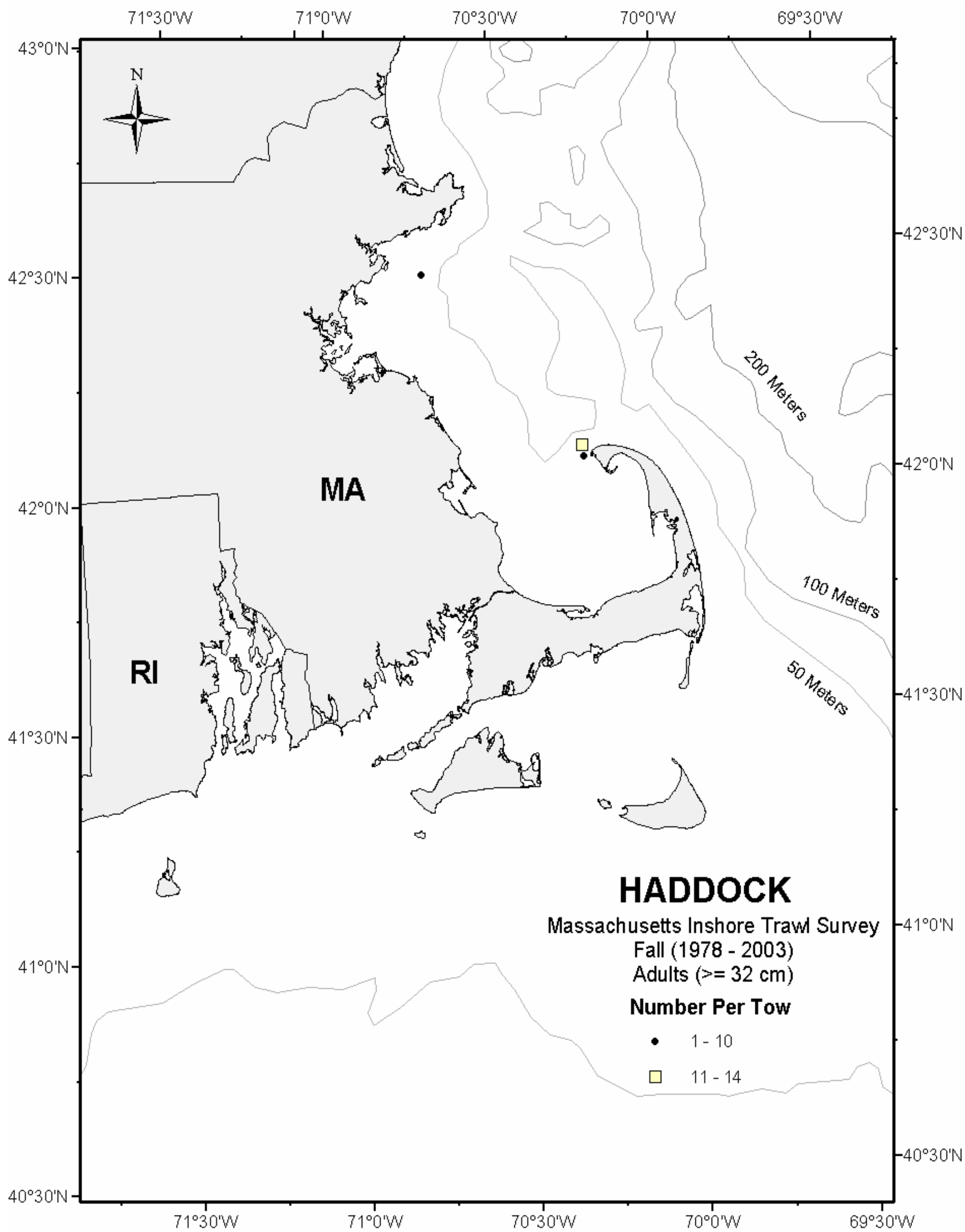
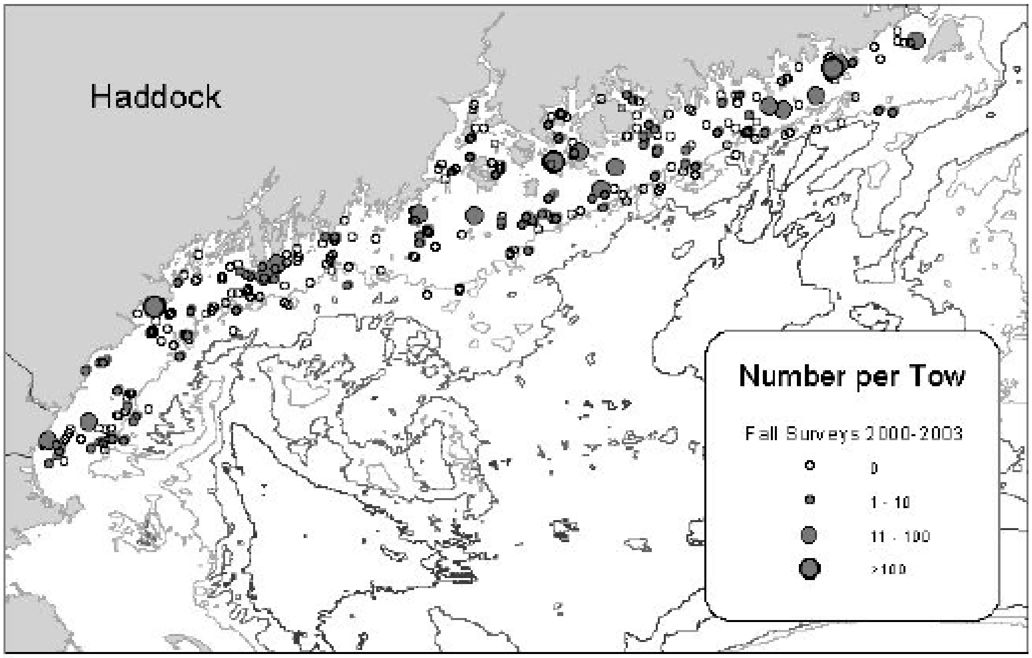


Figure 11. Cont'd.
From fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where adults were not found are not shown.



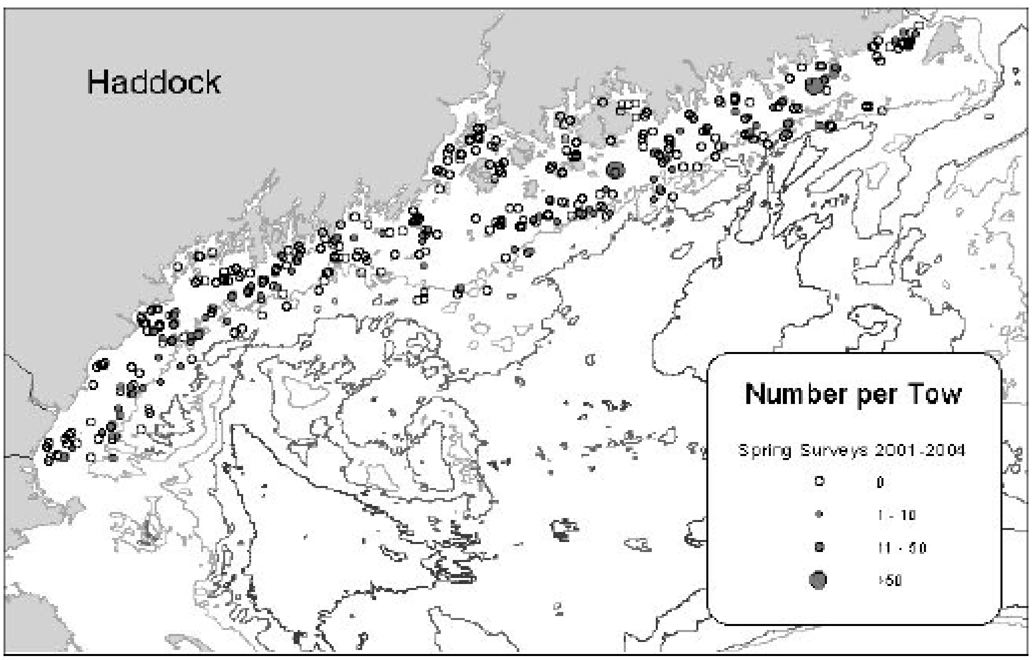
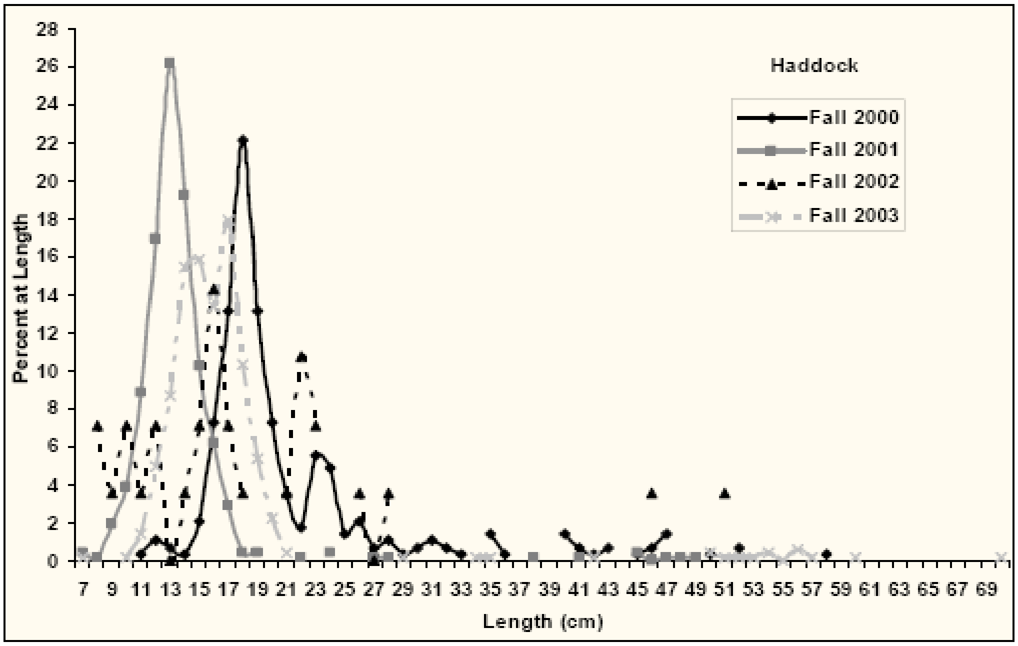


Figure 12. Distribution and abundance of haddock along the coasts of Maine and New Hampshire. From the Maine – New Hampshire spring 2001-2004 and fall 2000-2003 inshore groundfish trawl surveys. For details on the survey, see Sherman *et al*. (2005).



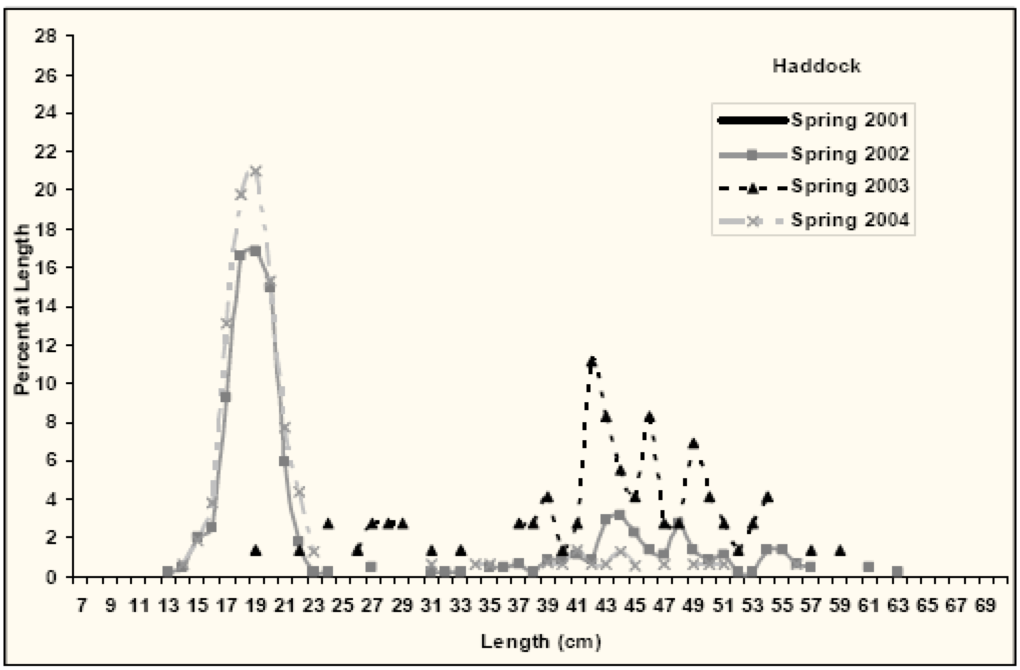


Figure 13. Length frequency plots for haddock caught along the Maine and New Hampshire coasts, by season/year. Based on the Maine – New Hampshire inshore groundfish trawl survey for spring 2001-2004 and fall 2000-2003. Source: Sherman *et al*. (2005).

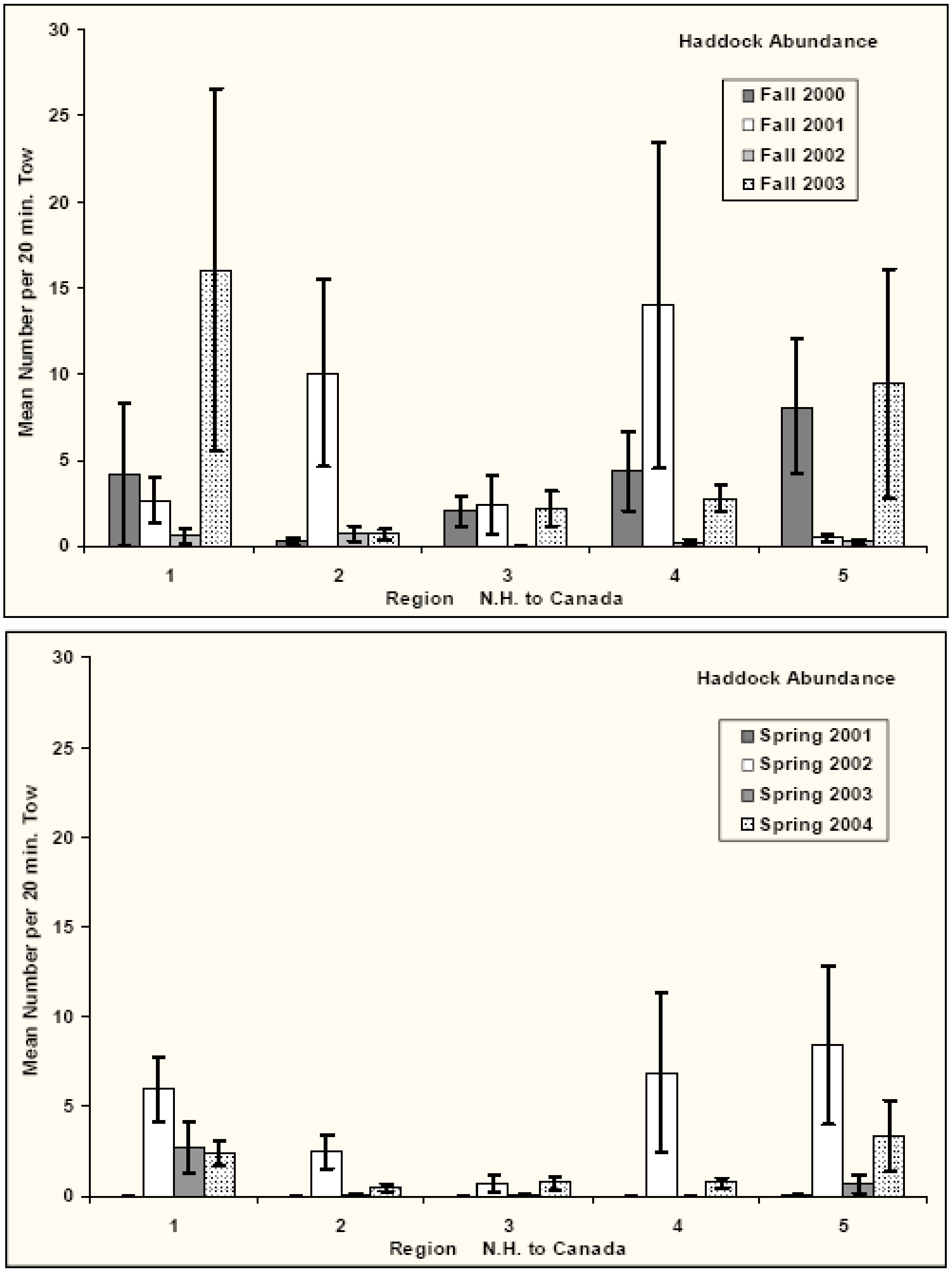


Figure 14. Regional catch-per-unit-effort of haddock caught along the Maine and New Hampshire coasts, by season/year.
Based on the Maine – New Hampshire inshore groundfish trawl survey for spring 2001-2004 and fall 2000-2003. Region 1 = NH–Southern ME; Region 2 = Casco Bay–Midcoast ME; Region 3 = Penobscot Bay, ME; Region 4 = Jerico–Frenchmens Bay, ME; Region 5 = Downeast ME. Source: Sherman *et al*. (2005).

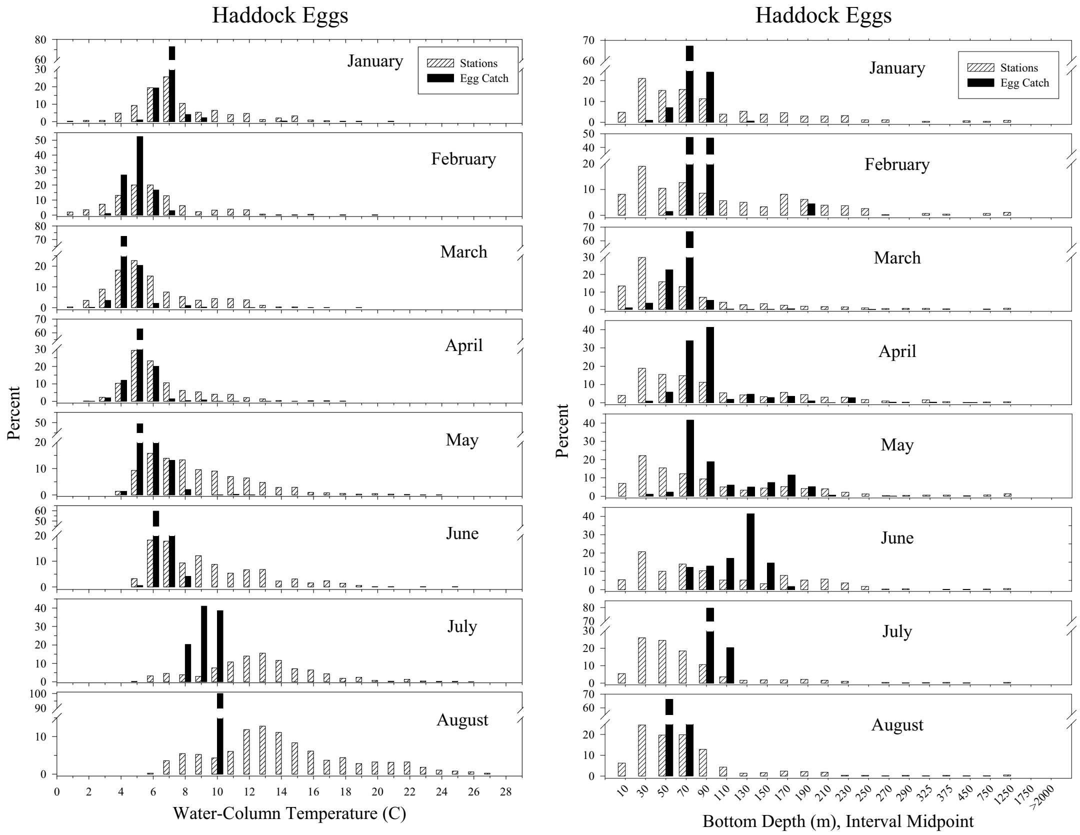


Figure 15. Distributions of haddock eggs collected during NEFSC MARMAP ichthyoplankton surveys relative to water column temperature and bottom depth.
For all available months and years from 1978-1987 combined. Open bars represent the proportion of all stations which were surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2). Note that the bottom depth interval changes with increasing depth.

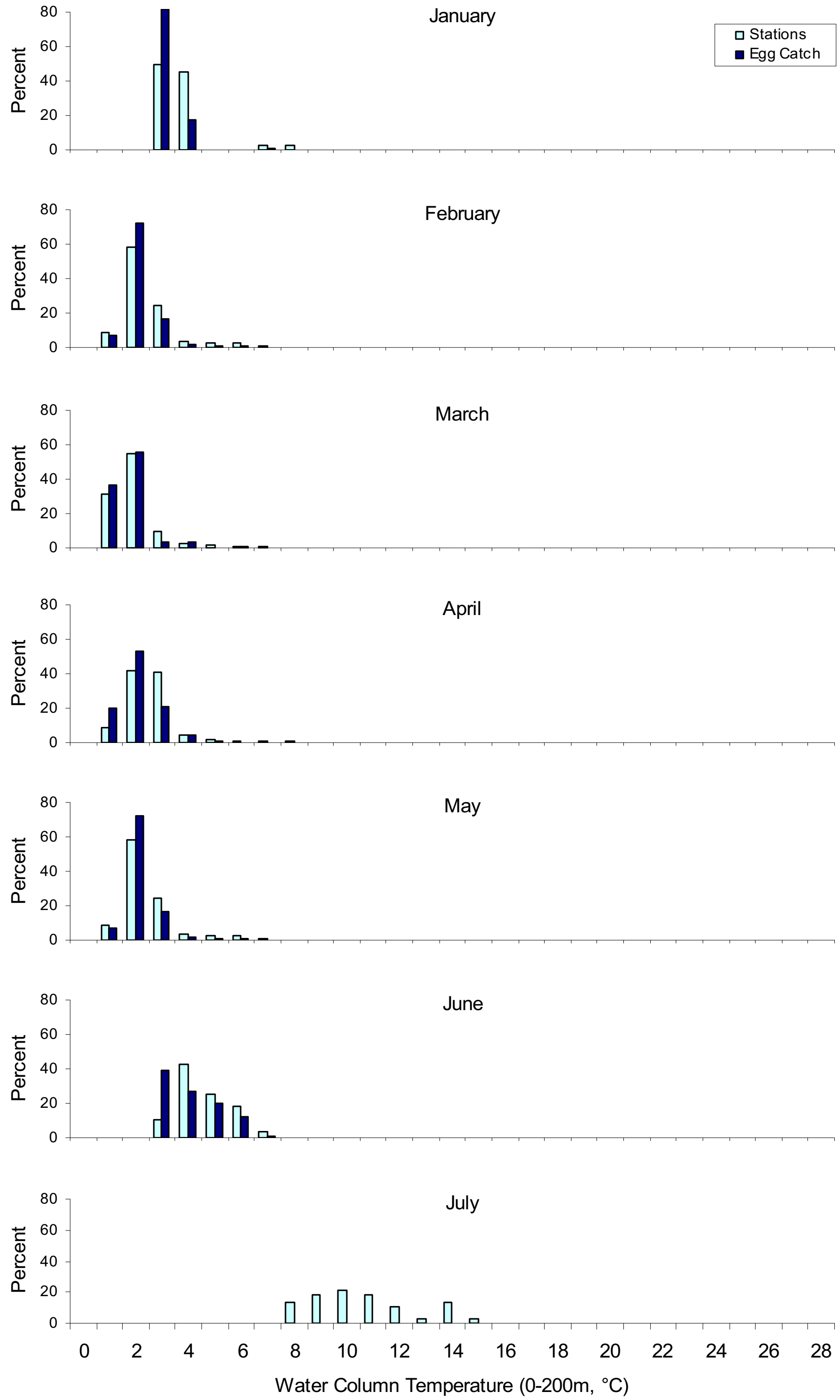


Figure 16. Distributions of haddock eggs collected during GLOBEC ichthyoplankton surveys relative to water column temperature.
From GLOBEC Georges Bank surveys (February-July, 1995; January-June, 1996-1999) by month for all available years combined. Light bars represent the proportion of all stations surveyed, while dark bars represent the proportion of the sum of all standardized catches (number/10m^2).

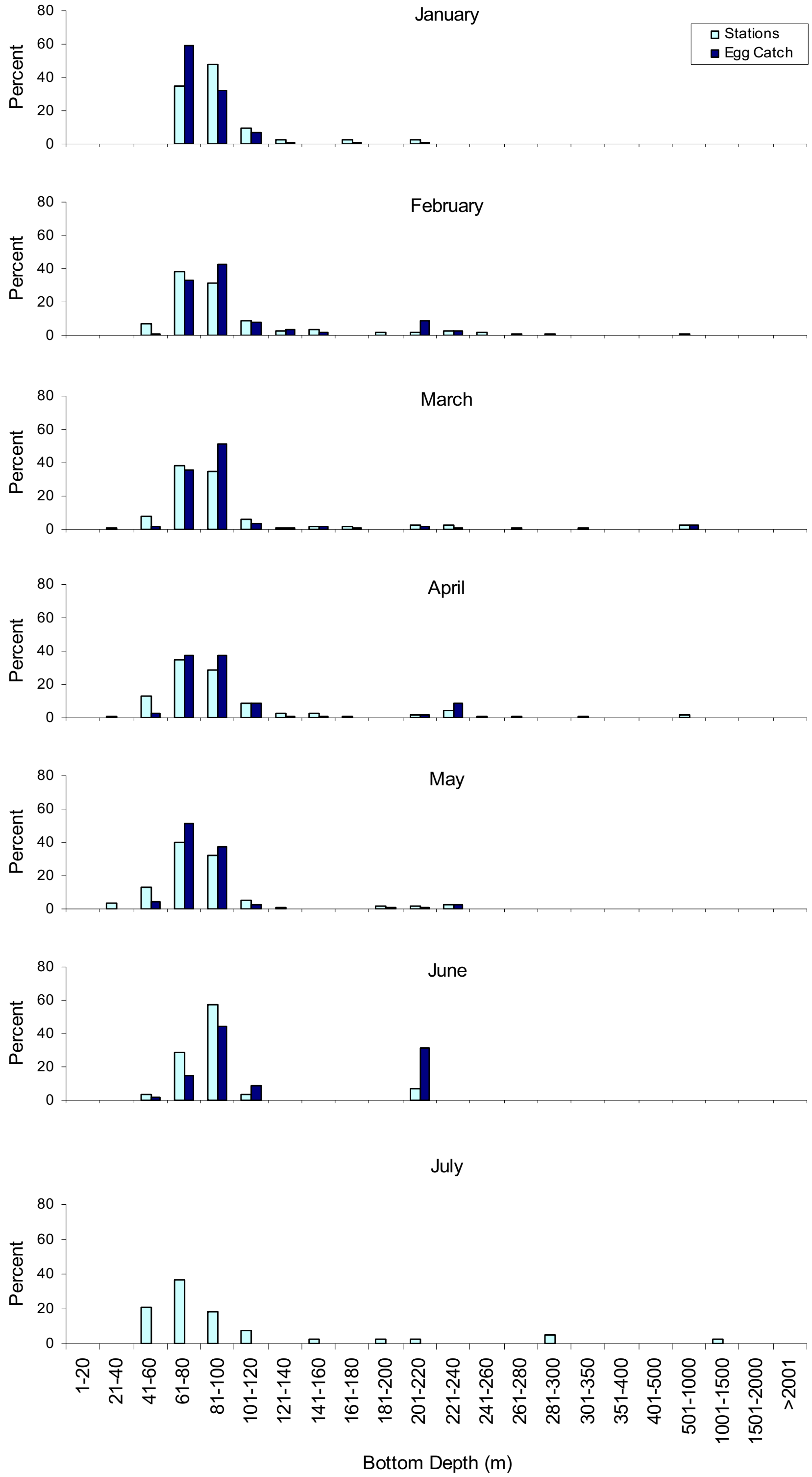


Figure 17. Distributions of haddock eggs collected during GLOBEC ichthyoplankton surveys relative to bottom depth. From GLOBEC Georges Bank surveys (February-July, 1995; January-June, 1996-1999) by month for all available years combined. Light bars represent the proportion of all stations surveyed, while dark bars represent the proportion of the sum of all standardized catches (number/10m^2). Note that the bottom depth intervals change with depth.

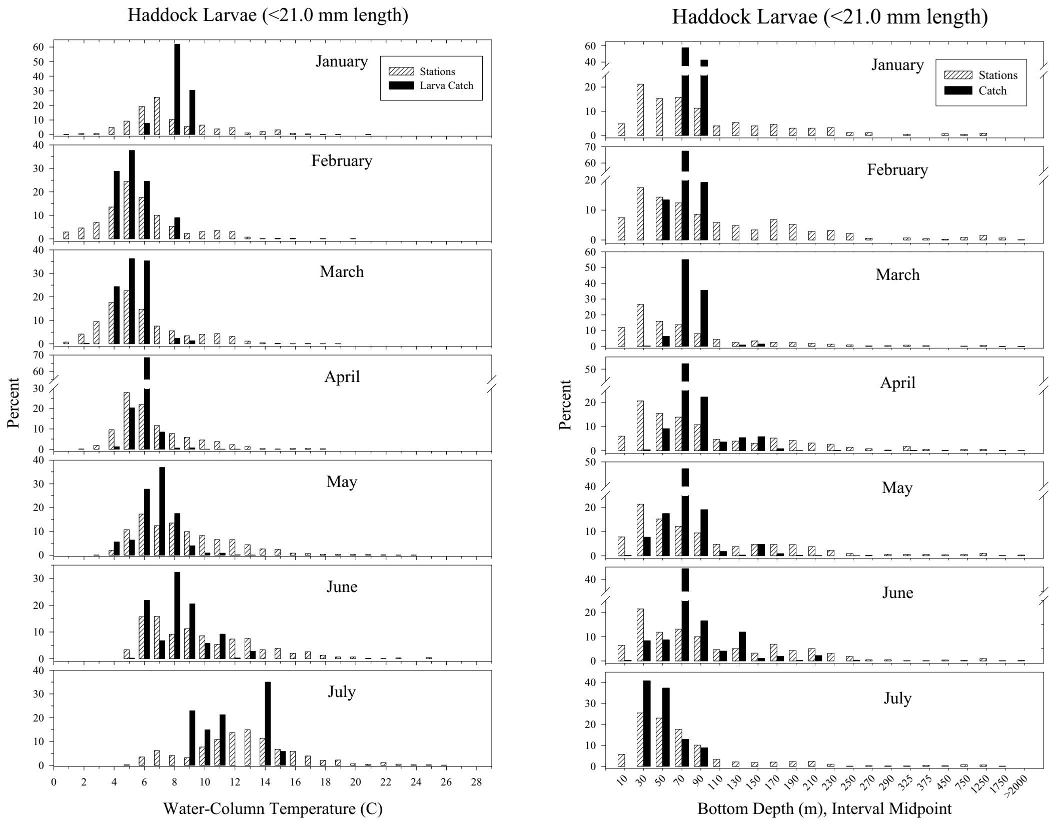


Figure 18. Monthly distributions of haddock larvae collected during NEFSC MARMAP ichthyoplankton surveys relative to water column temperature and bottom depth.
For all available months and years from 1977-1987 combined. Open bars represent the proportion of all stations which were surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2). Note that the bottom depth interval changes with increasing depth.

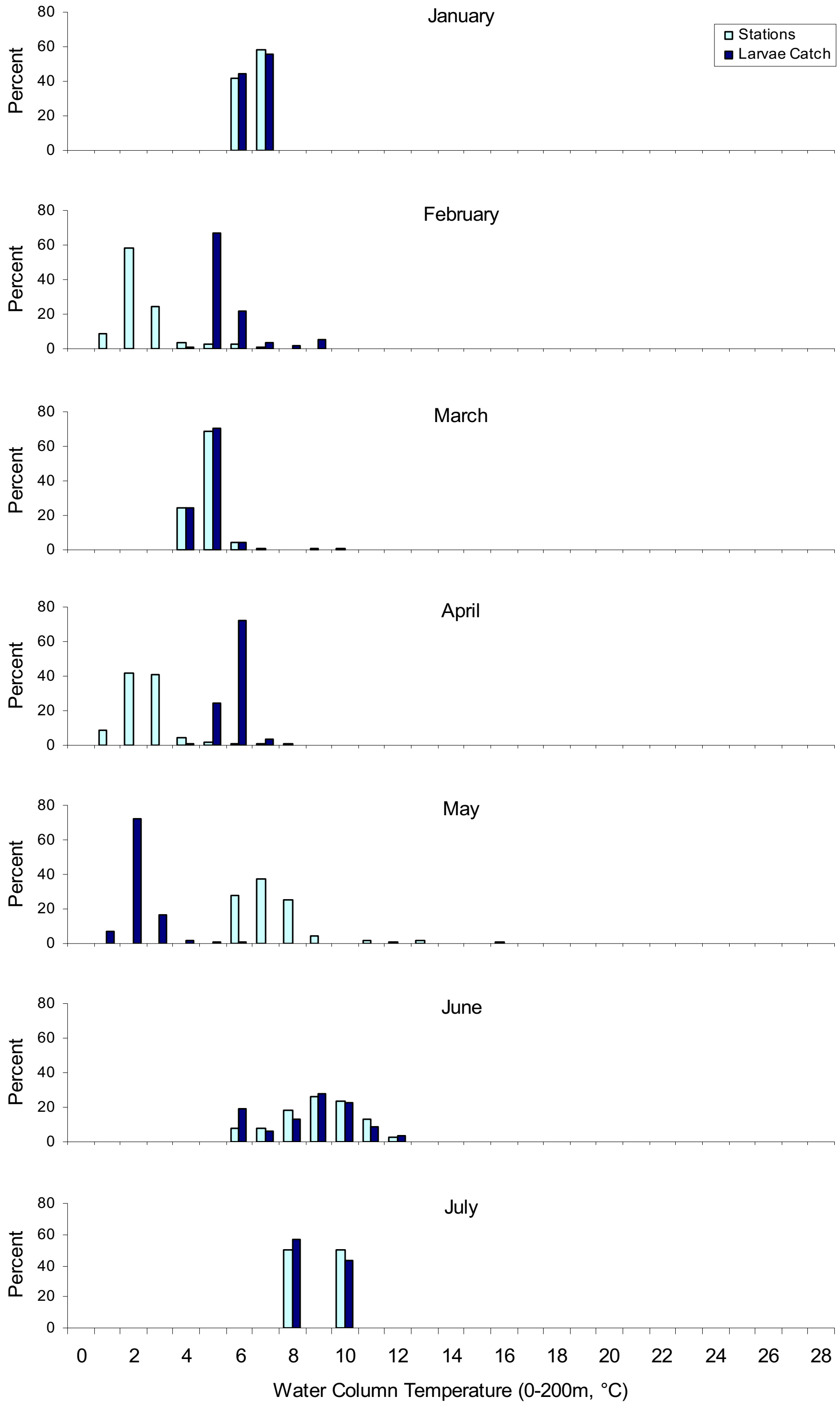


Figure 19. Distributions of haddock larvae collected during GLOBEC ichthyoplankton surveys relative to water column temperature.
From GLOBEC Georges Bank surveys (February-July, 1995, January-June, 1996-1999) by month for all available years combined. Light bars represent the proportion of all stations surveyed, while dark bars represent the proportion of the sum of all standardized catches (number/10m^2).

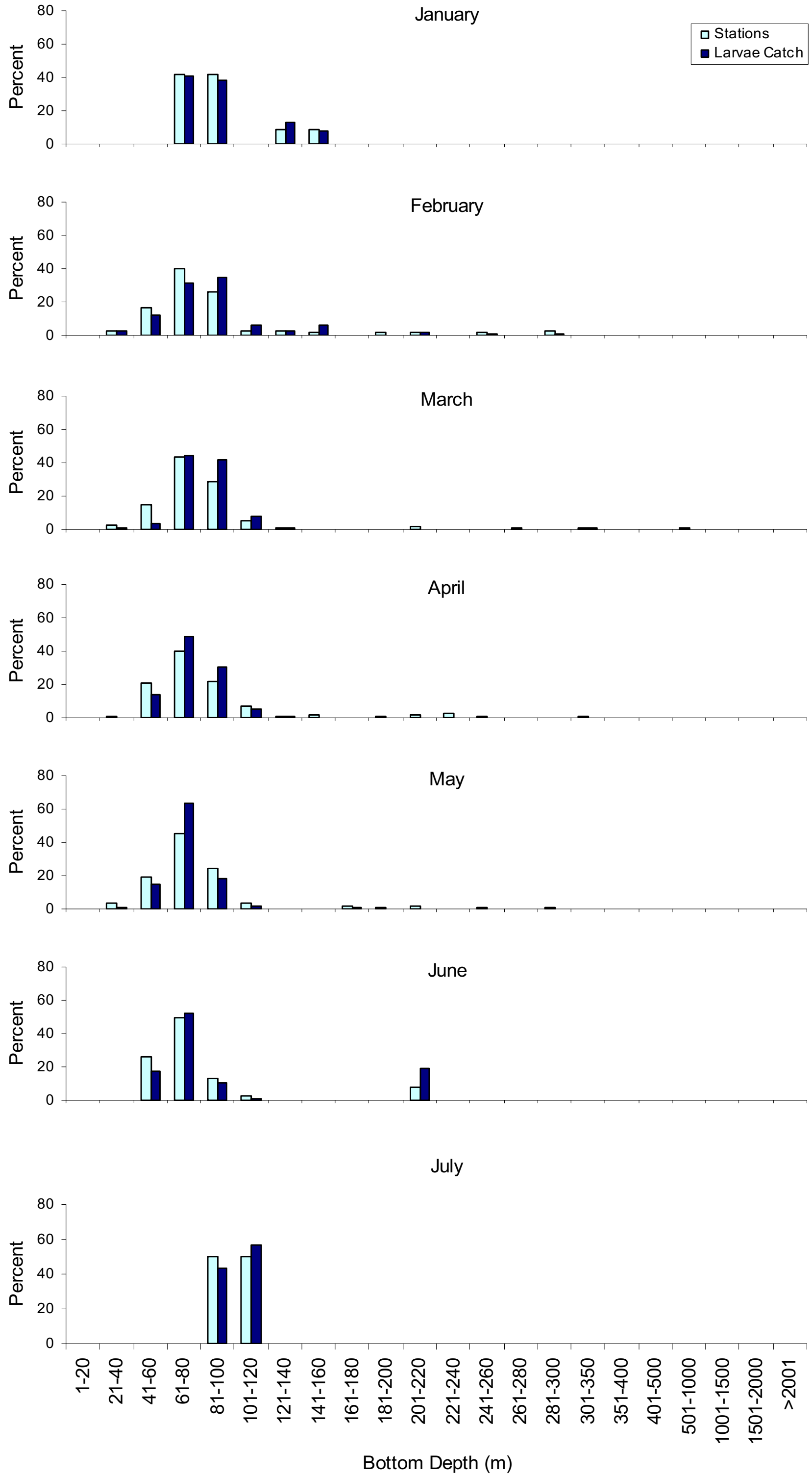


Figure 20. Distributions of haddock larvae collected during GLOBEC ichthyoplankton surveys relative to bottom depth. From GLOBEC Georges Bank surveys (February-July, 1995; January-June, 1996-1999) by month for all available years combined. Light bars represent the proportion of all stations surveyed, while dark bars represent the proportion of the sum of all standardized catches (number/$10m^2$). Note that the bottom depth intervals change with depth.

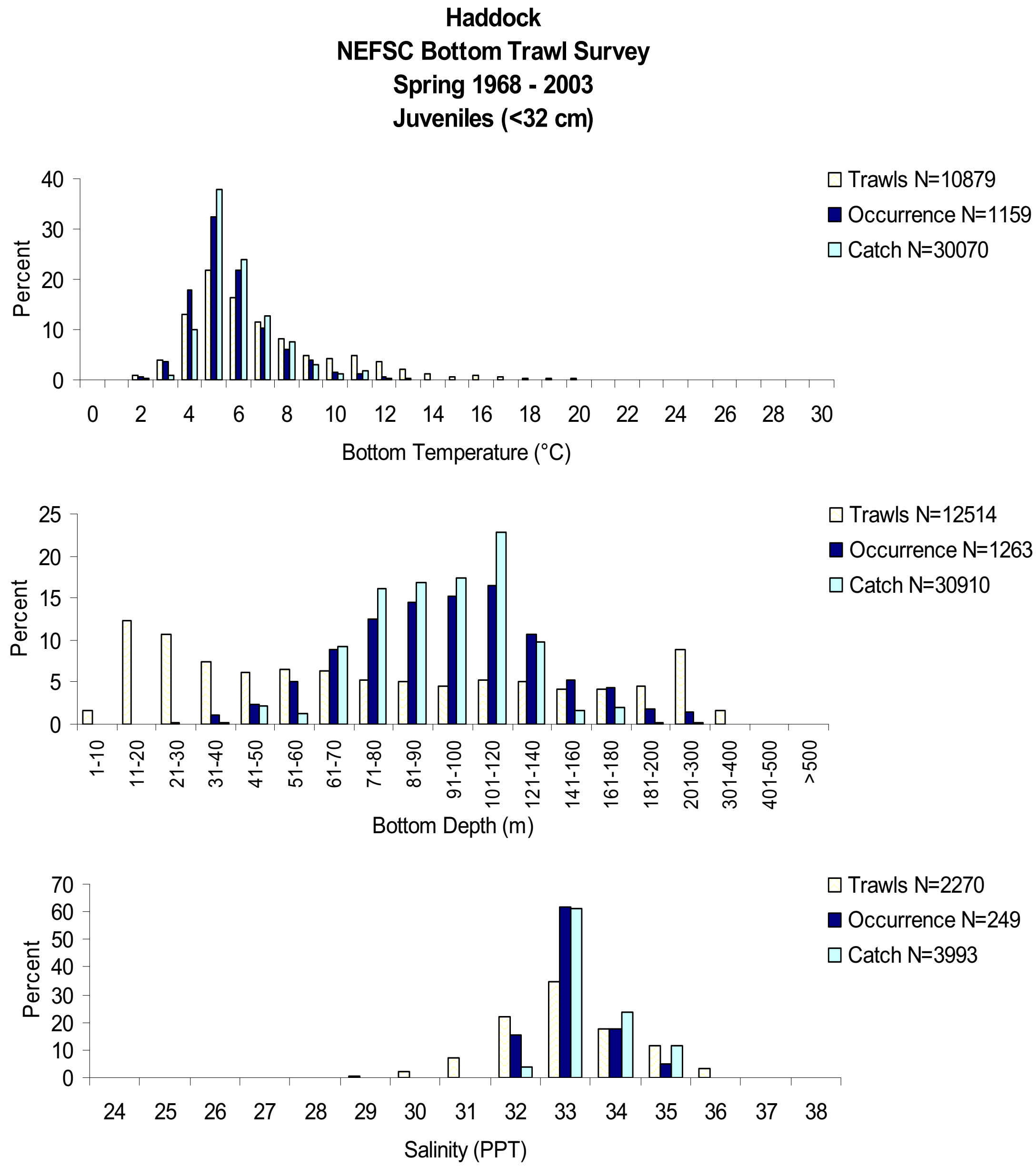


Figure 21. Distributions of juvenile haddock and trawls from NEFSC bottom trawl surveys relative to bottom water temperature, depth, and salinity.

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 haddock occurred and medium bars show, within each interval, the percentage of the total number of haddock caught. Note that the bottom depth interval changes with increasing depth.

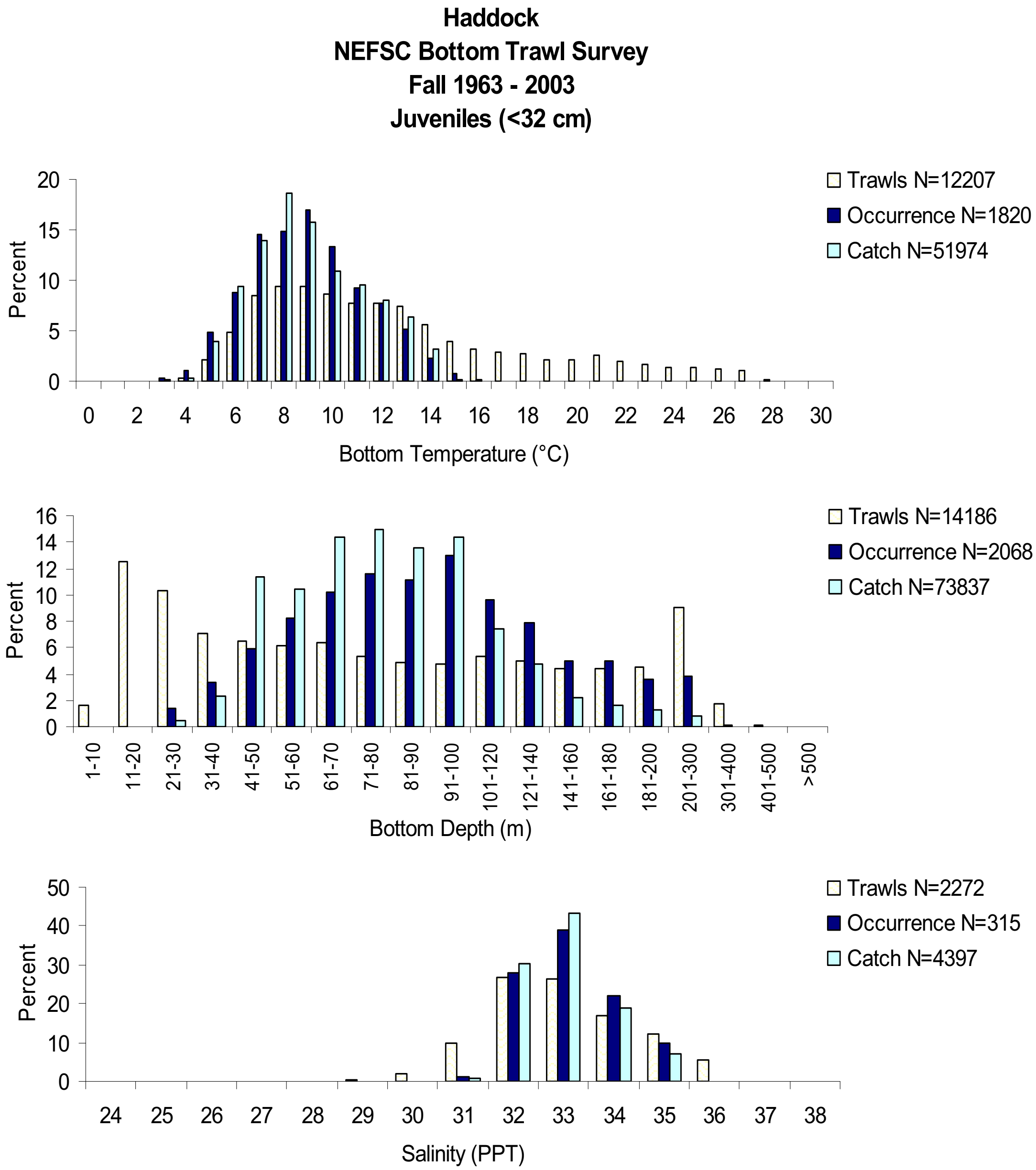


Figure 21. Cont'd.
Based on NEFSC fall bottom trawl surveys (temperature and depth: 1963-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which haddock occurred and medium bars show, within each interval, the percentage of the total number of haddock caught. Note that the bottom depth interval changes with increasing depth.

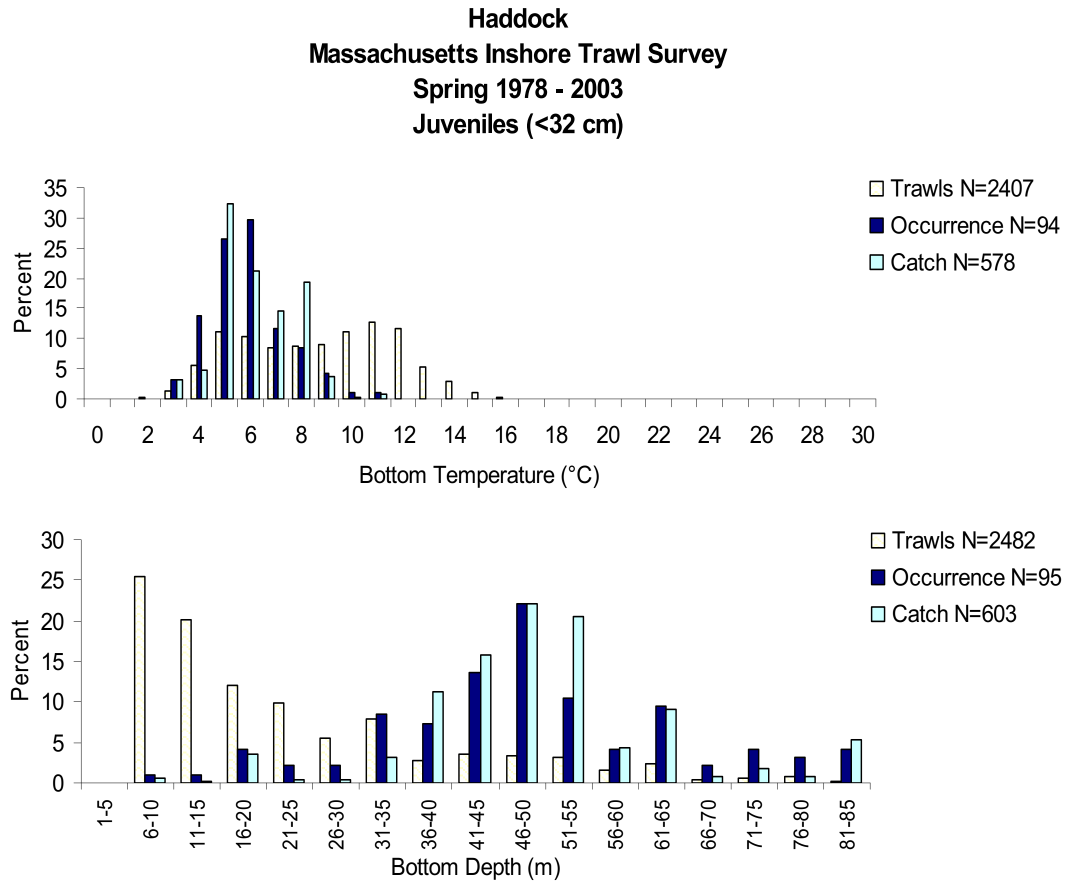


Figure 22. Distributions of juvenile haddock and trawls in Massachusetts coastal waters relative to bottom water temperature and depth.
Based on spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which haddock occurred and medium bars show, within each interval, the percentage of the total number of haddock caught.

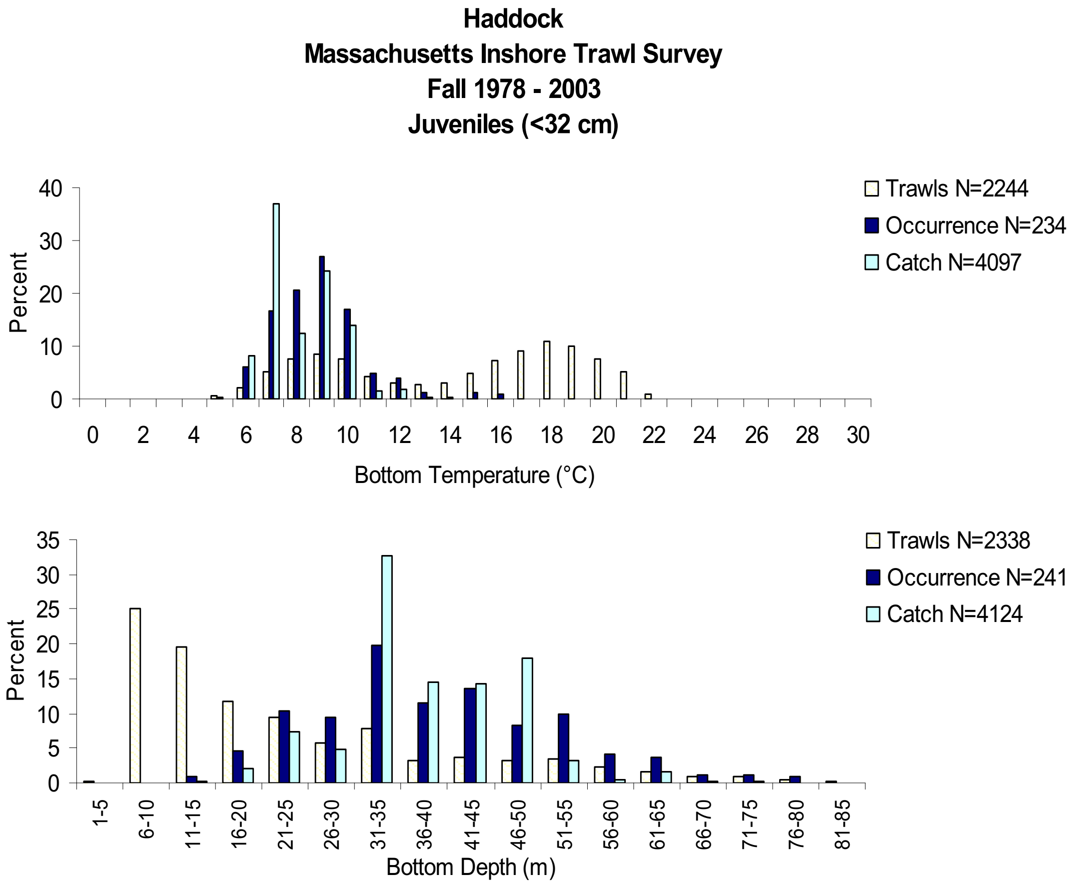


Figure 22. Cont'd.
Based on fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which haddock occurred and medium bars show, within each interval, the percentage of the total number of haddock caught.

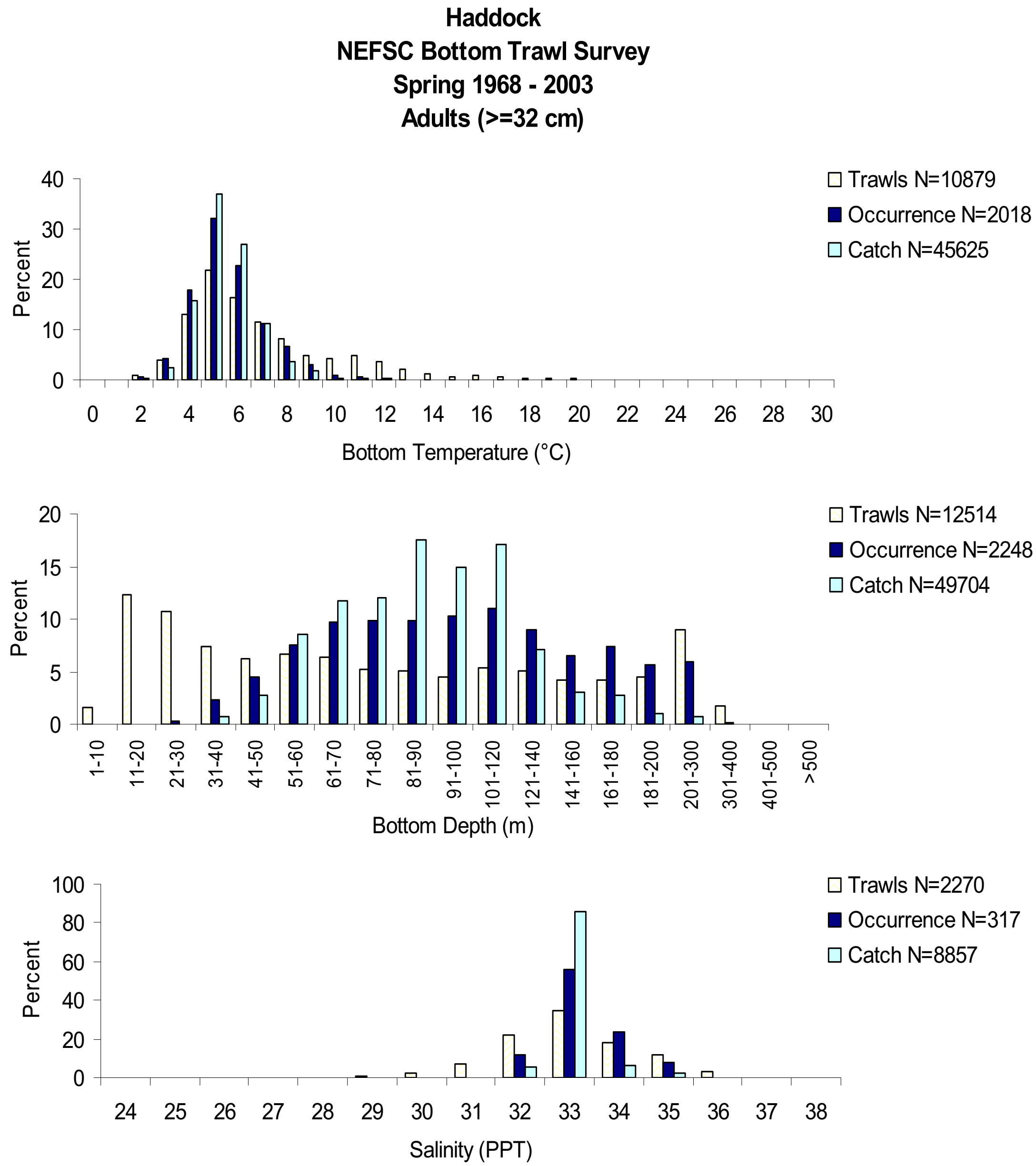


Figure 23. Distributions of adult haddock and trawls from NEFSC bottom trawl surveys relative to bottom water temperature, depth, and salinity.
Based on NEFSC spring bottom trawl surveys (temperature and depth: 1968-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which haddock occurred and medium bars show, within each interval, the percentage of the total number of haddock caught. Note that the bottom depth interval changes with increasing depth.

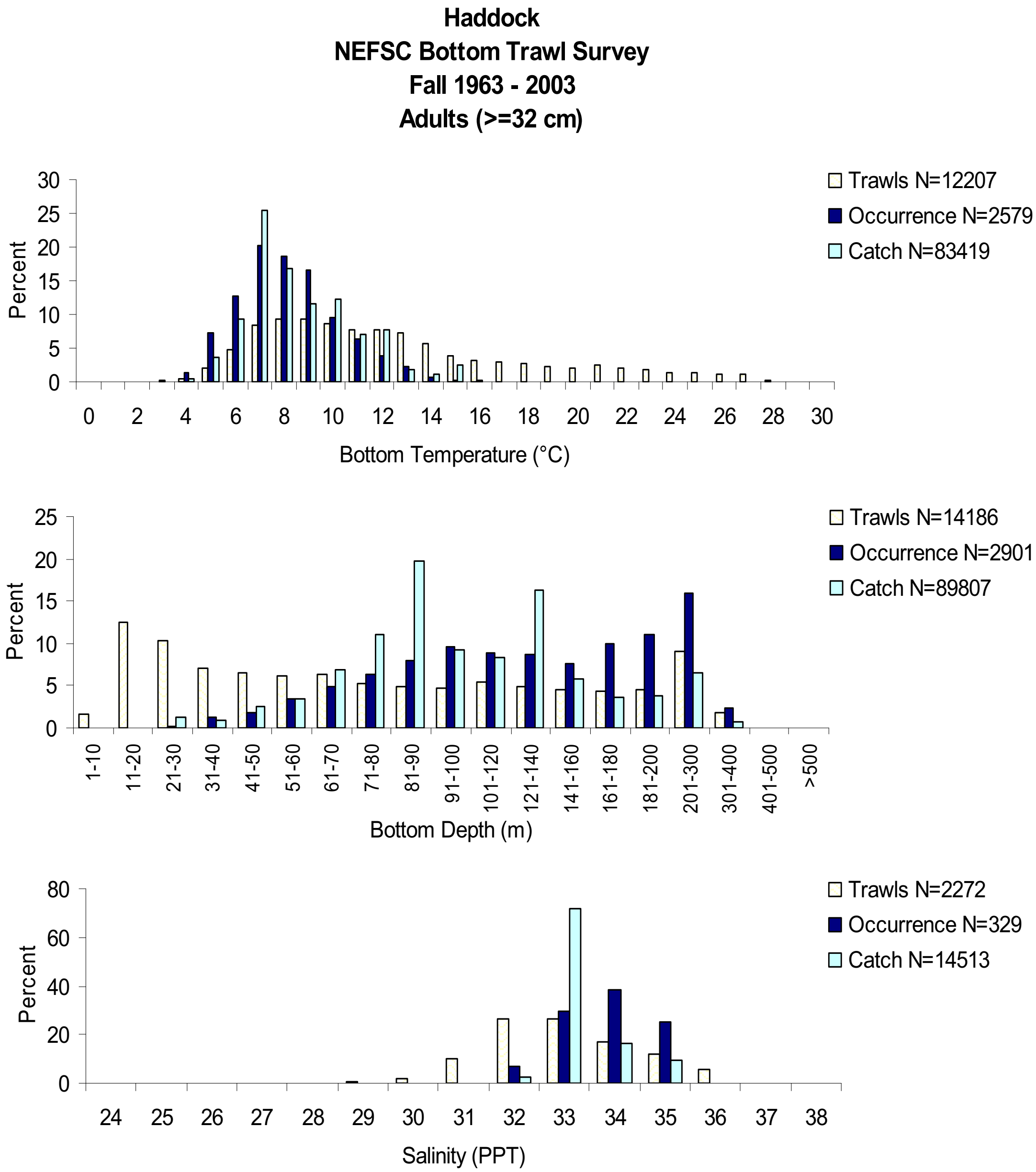


Figure 23. Cont'd.
Based on NEFSC fall bottom trawl surveys (temperature and depth: 1963-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which haddock occurred and medium bars show, within each interval, the percentage of the total number of haddock caught. Note that the bottom depth interval changes with increasing depth.

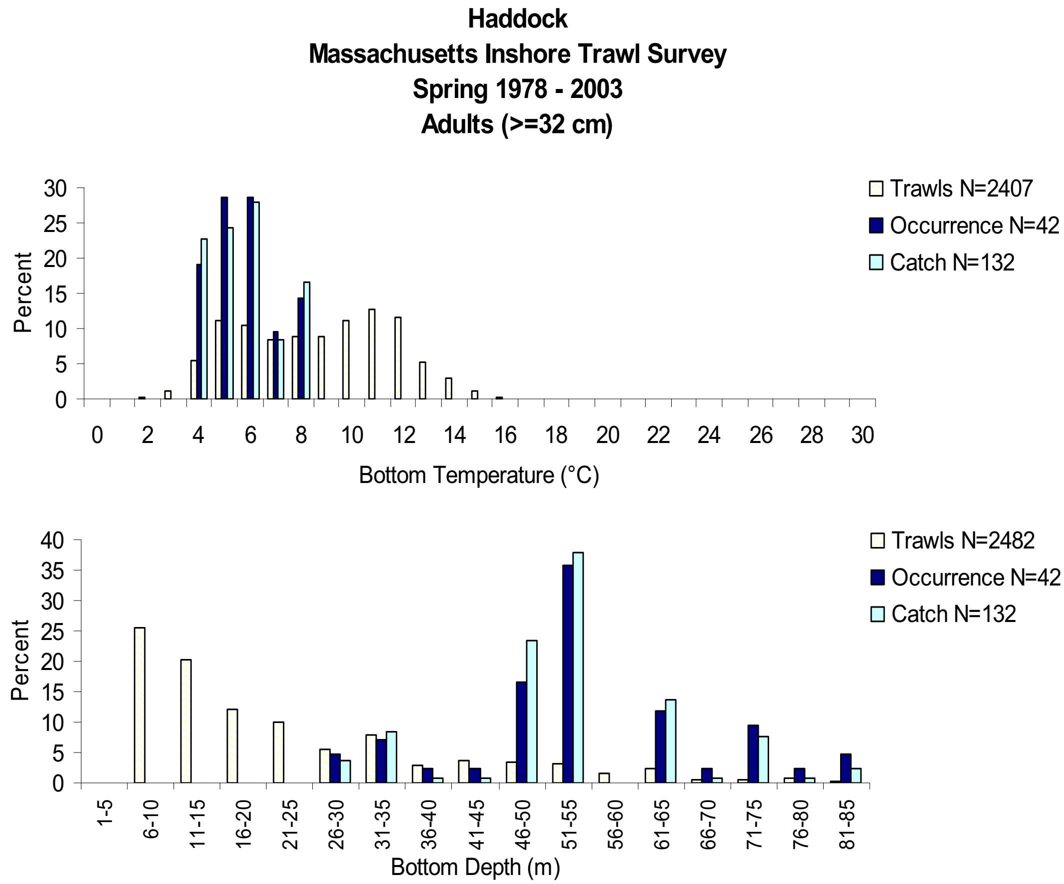
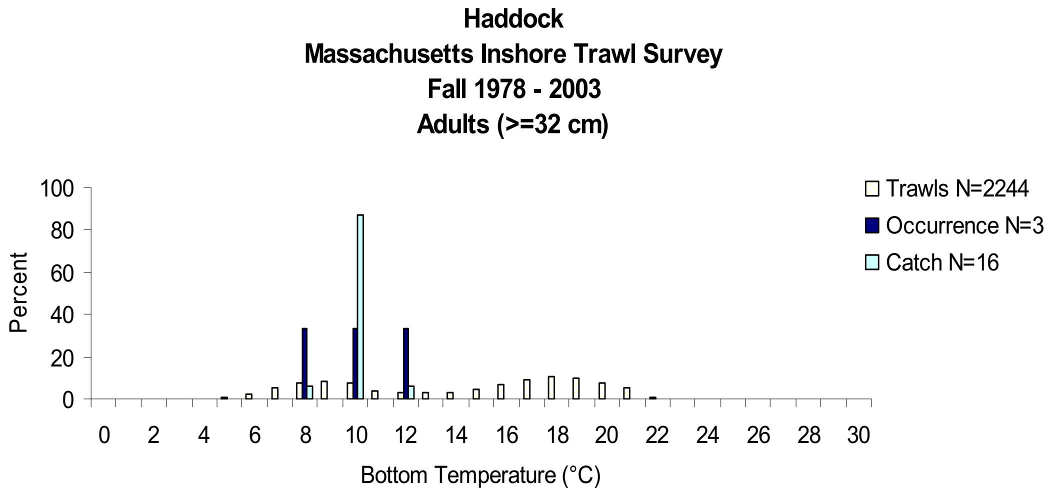


Figure 24. Distributions of adult haddock and trawls in Massachusetts coastal waters relative to bottom water temperature and depth.
Based on spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which haddock occurred and medium bars show, within each interval, the percentage of the total number of haddock caught.



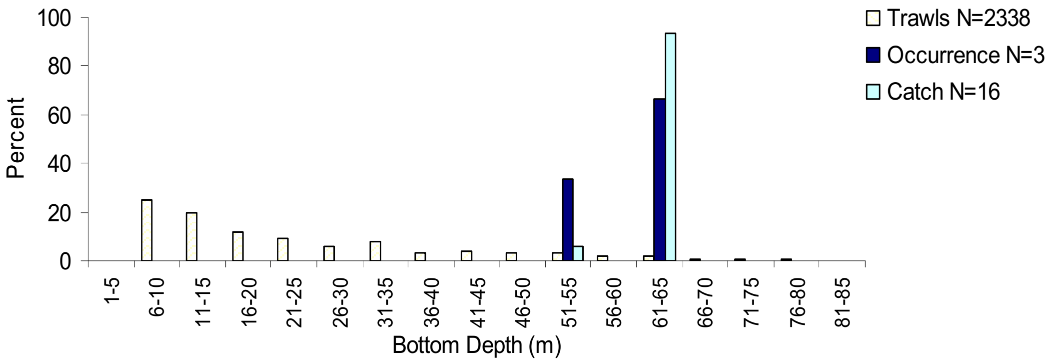


Figure 24. Cont'd.
Based on fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which haddock occurred and medium bars show, within each interval, the percentage of the total number of haddock caught.

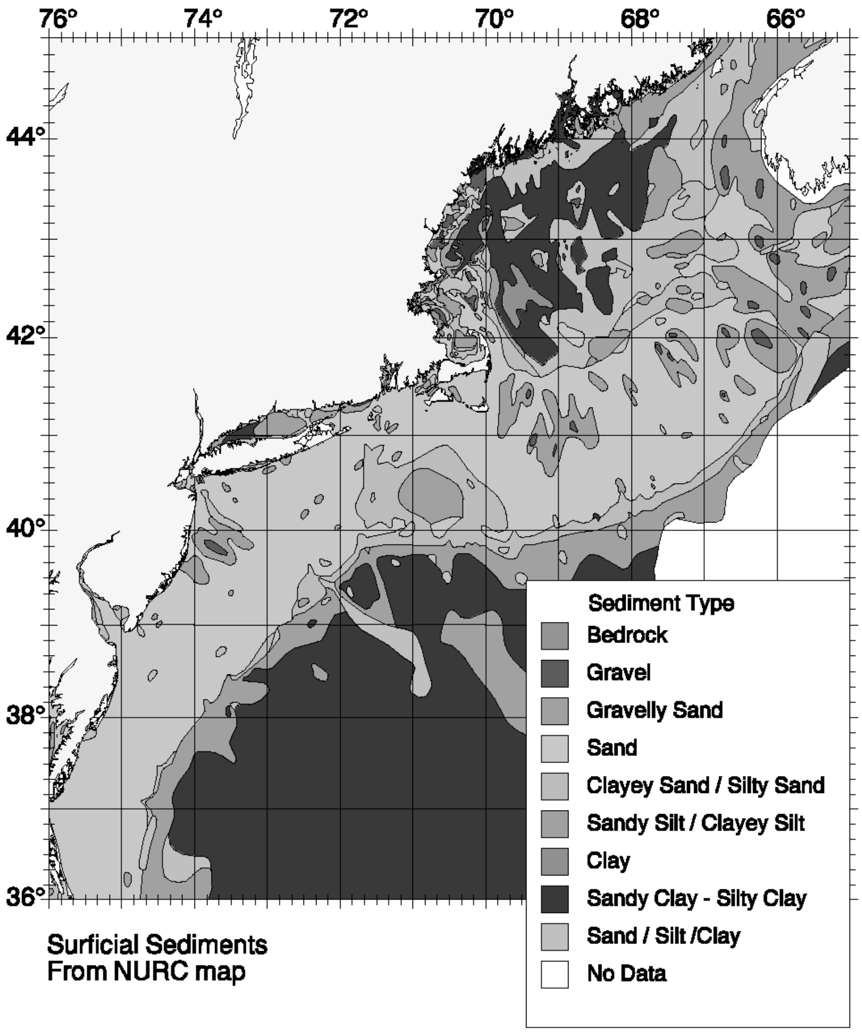


Figure 25. Distribution of surficial sediments along the northeast coast of the United States. Data are from the United States Geological Survey and NOAA.

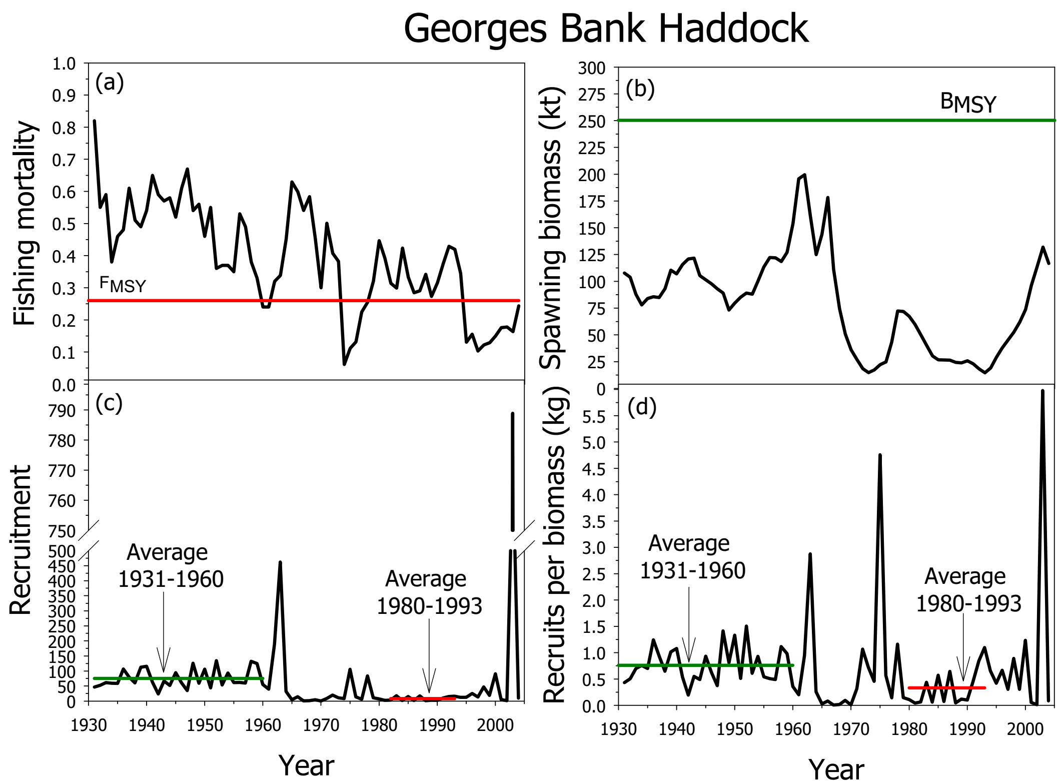


Figure 26. Fishing mortality (a), spawning biomass (b), recruitment (c), and recruits per spawning biomass (d) of Georges Bank haddock during 1931-2004, from Brodziak *et al*. (2005).

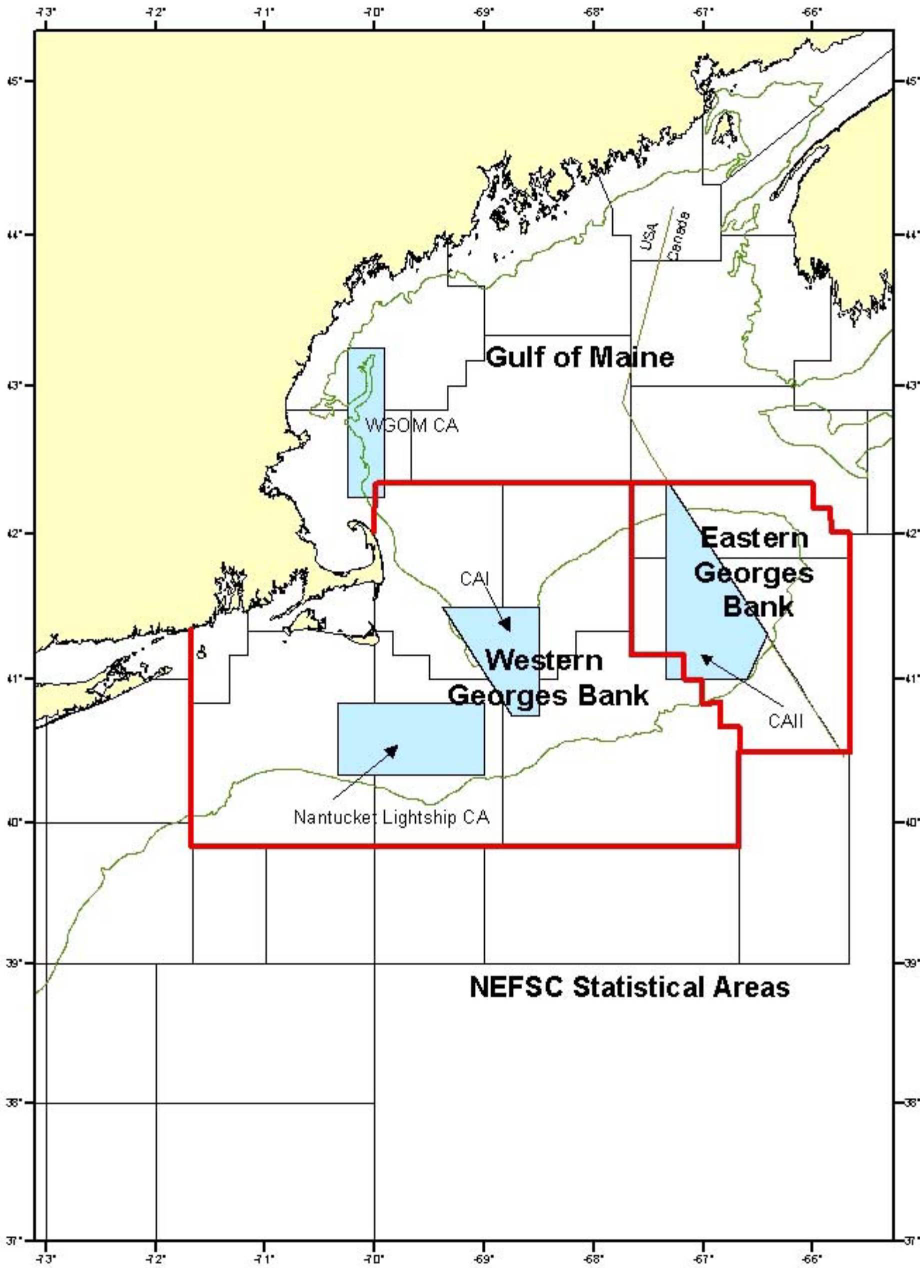


Figure 27. Spatial definition of haddock management units in the Gulf of Maine and Georges Bank region along with locations of the western Gulf of Maine closed area (WGOM CA), Closed Area I (CA I), Closed Area II (CA II), and the Nantucket Lightship closed area (Nantucket Lightship CA).

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