NOAA Technical Memorandum NMFS-NE-128

Essential Fish Habitat Source Document:

Haddock, *Melanogrammus aeglefinus*, Life History and Habitat Characteristics

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

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Essential Fish Habitat Source Document:

Haddock, *Melanogrammus aeglefinus*, Life History and Habitat Characteristics

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

Editorial Production

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

Special Acknowledgments

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

Internet Availability

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

Information Updating

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

Species Names

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

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

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

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

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

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

FOREWORD

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

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

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

NMFS Strategic Plan for Fisheries Research (February 1998)

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

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

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

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

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

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

JAMES J. HOWARD MARINE SCIENCES LABORATORY
HIGHLANDS, NEW JERSEY
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NORTHEAST FISHERIES SCIENCE CENTER

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INTRODUCTION

The haddock, *Melanogrammus aeglefinus*, is a demersal gadoid species found on both sides of the North Atlantic (Figure 1). In the western Atlantic, haddock are distributed from Greenland to Cape Hatteras, North Carolina. Five haddock stocks have been identified in the northwest Atlantic from Newfoundland to Georges Bank (Cushing 1986). Haddock are managed under the New England Fishery Management Council's Northeast Multispecies Fishery Management Plan (NEFMC 1993), which recognizes two principal haddock stocks, Georges Bank and the Gulf of Maine, partially or wholly in U.S. waters. There is evidence, however, that larvae from Browns Bank, which is in Canadian waters, drift inshore as far south as Cape Cod (Colton and Temple 1961) and spend at least a portion of their lives in U.S. coastal waters.

This Essential Fish Habitat Source Document provides information on the life history and habitat requirements of the three haddock stocks inhabiting U.S. waters in the Gulf of Maine area: (1) Gulf of Maine, (2) Georges Bank, and (3) Browns Bank.

LIFE HISTORY

A brief synopsis of the life history characteristics of haddock is provided in Amendment 5 to the Northeast Multispecies Fishery Management Plan (NEFMC 1993). More detailed information is provided here and in reviews by Bigelow and Schroeder (1953), Blacker (1971), Hardy (1978), Chenoweth *et al.* (1986), and Collette and Klein-MacPhee (in prep.).

EGGS

Haddock spawn over pebble gravel substrate, avoiding ledges, rocks, kelp and soft mud (Bigelow and Schroeder 1953). The eggs are spawned at the bottom but become buoyant after fertilization, rising into the water column where subsequent development occurs (Hardy 1978; Page *et al.* 1989). Depending on water temperature, eggs hatch in 9-32 days after spawning (Laurence and Rogers 1976; Hardy 1978).

LARVAE

Larvae range in size from 2.0-4.99 mm in length. Size varies geographically, and the mean for Georges Bank-Gulf of Maine fish is 4.08 mm (Collette and Klein-MacPhee, in prep.).

JUVENILES

Larvae metamorphose into juveniles in 30-42 days (Laurence 1978) and at a length of 2-3 cm (Fahay 1983). Juveniles initially remain in the upper part of the water column, but at 3-5 months and 3-10 cm [or 3-4 cm (Hardy 1978), 4-6 cm (Lough and Bolz 1989), 6-8 cm (Fahay 1983), 7-8 cm (Perry and Neilson 1988), 9-10 cm (Mahon and Neilson 1987)] they descend toward the bottom and adopt a demersal lifestyle (Bigelow and Schroeder 1953).

ADULTS

Adult haddock can reach sizes exceeding 110 cm and 16 kg, although commercially caught haddock average 35.5-58.5 cm and 0.5-2 kg. The maximum age documented from Northeast Fisheries Science Center (NEFSC) surveys from 1970-1988 is 14 years (Penttila *et al.* 1989), but ages greater than 9 years are uncommon.

REPRODUCTION

Size and age at first maturity vary considerably among haddock stocks (Table 1), although several trends are obvious. First, females mature at a larger size and older age than males, and second, Georges Bank haddock mature at a much smaller size and younger age than haddock from Browns Bank and the Gulf of Maine (also see Clark 1959). There is evidence that the age and size at maturity of Georges Bank haddock have declined in recent years (O'Brien *et al.* 1993; Trippel *et al.* 1997). For example, the median length of maturity during 1977 to 1983 was 37 cm for males and 40 cm for females, compared to 26.8 cm and 29.7 cm in recent years (O'Brien *et al.* 1993). Since age and size at maturity in haddock have been shown to be density-dependent (Waiwood and Buzeta 1989; Ross and Nelson 1992), declines in the abundance of the Georges Bank stock (see Status of Stocks below) may explain these declines in age and size at maturity.

Georges Bank and Browns Bank are the principal spawning areas in the Gulf of Maine area. Generally, the greatest production is from Georges Bank. Limited spawning also occurs on Nantucket Shoals (Smith and Morse 1985) and along the South Channel and the New England coast (Colton and Temple 1961). Jeffreys Ledge and Stellwagen Bank are two major spawning sites along the coast of New England (Colton 1972). Ames (1997) reports many small, relatively isolated spawning areas in inshore Gulf of Maine waters. Based on interviews with retired commercial fishers from Maine and New Hampshire, 100 haddock spawning sites were identified, covering a total of 499 square miles, from Ipswich Bay to Grand Manan Channel. It is unclear which of these spawning areas are historical versus current.

The timing of spawning varies among sites; the general pattern is for spawning to occur later as one moves north (Page and Frank 1989). Presumably, this is due to decreasing water temperatures with increasing latitude. There is considerable inter-annual variation in spawning time within sites. On Georges Bank, spawning occurs from January to June (Smith and Morse 1985), usually peaking in late-March to early-April (Smith and Morse 1985; Lough and Bolz 1989; Page and Frank 1989; Brander and Hurley 1992). On Browns Bank, spawning occurs from early March to June (Campana 1989), usually peaking in late-April to early-May (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). The inter-annual variation in the onset and peak of spawning can be explained, at least in part, by environmental conditions, more specifically the severity (in terms of temperature and duration) of the preceding autumn and winter (Smith *et al.* 1981).

FOOD HABITS

Haddock initially inhabit the upper reaches of the water column, feeding on pelagic prey (zooplankton). Larvae and early stage (pelagic) juveniles are passive foragers on less motile prey such as invertebrate eggs, copepods and phytoplankton (Kane 1984). Juveniles undergo a transformation at age 3 to 5 months, after which they are closely associated with the bottom and feed on benthic prey. Juveniles show a distinct transition from planktonic to benthic feeding (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. Amphipods remain relatively important through the first year, but there is a shift from planktonic to benthic species. Benthic juveniles and adults are indiscriminant consumers of invertebrates, feeding primarily on crustaceans, polychaetes, mollusks, echinoderms and some fish (Bowman and Michaels 1984; Mahon and Neilson 1987; Collette and Klein-MacPhee, in prep.).

The 1973-1990 Northeast Fisheries Science Center (NEFSC) bottom trawl survey data on food habits [see Reid *et al.* (1999) for details] for juveniles and adults combined (1973-1980: 8-87 cm; 1981-1990: 10-88 cm) reveal that crustaceans, echinoderms, polychaetes and mollusks are the most important prey items of haddock (Figure 2). Crustaceans make up the major part of the diet of juveniles; amphipods are the most abundant crustacean, followed by decapods, euphausiids, and mysids. However, crustaceans are less important (although still the most common prey type) in the adult diet, while echinoderms (particularly Ophiuroidea, *Ophiopholis aculeata*, and *Ophiura sarsi*) and polychaetes increase in importance. This trend is evident during both sampling periods. Mollusks are less abundant in the haddock diet, but are present in all size classes, as are low numbers of fish

LARVAL RETENTION

A factor that may be critical to the survival of the egg and larval stages, and thus to the determination of haddock year-class strength, is the degree of larval retention on or near the spawning grounds. For example, there is a southerly flow of surface water from the area of haddock spawning on Georges Bank. Colton and Temple (1961) concluded that eggs and larvae in the surface layers would therefore be carried either into the slope water zone or the coastal waters southwest of the Bank. Any larvae drifting into the slope water zone would be carried in a northeasterly direction away from Georges Bank and the continental shelf and would be lost to the fishery. Thus, strong year-classes may arise in years when circulation results in retention of larvae on the Bank (Smith and Morse 1985) or in nursery grounds to the southwest of the Bank (Colton and Temple 1961; Polacheck *et al.* 1992). 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. Ames (1997) suggests that eggs and larvae in the coastal Gulf of Maine are retained over critical habitat by tidal currents, and that this serves to enhance survival.

HABITAT CHARACTERISTICS

Detailed information on the life history and habitat characteristics of haddock is summarized in Table 2. This information is limited to stocks inhabiting U.S. waters (including Browns Bank, see Introduction); information from other stocks, e.g., Canadian and European, was not considered.

EGGS AND LARVAE

The egg and larval stages occur in the water column at depths of 10-50 m below the surface (Marak 1960; Colton and Temple 1961; Miller *et al.* 1963; Hardy 1978). Temperatures of 4-10^{o}C (Laurence and Rogers 1976; Laurence 1978) and high salinities, 34-36 ppt (Laurence and Rogers 1976), are preferred.

Most of the haddock eggs taken during Marine Resources Monitoring, Assessment and Prediction (MARMAP) surveys (see Geographical Distribution below) were at temperatures of 4-10^{o}C and depths of 50-

130 m. Most larvae were taken at 4-14°C and 30-90 m.

JUVENILES AND ADULTS

After transformation, haddock are almost exclusively a groundfish, closely associated with pebble gravel bottom (Bigelow and Schroeder 1953; Lough *et al.* 1989). Benthic juveniles and adults are generally found at depths of 40-150 m (Bigelow and Schroeder 1953; Murawski and Finn 1988; Perry and Neilson 1988); 50-100 m is the preferred depth range (Scott 1982; Waiwood and Buzeta 1989) However, they but can be found as shallow as 10 m (Blacker 1971) and as deep as 200+ m (Colton 1972; Hardy 1978), although few are found deeper than 183 m (Bigelow and Schroeder 1953).

Juveniles are most abundant at temperatures of 4.5-10°C (Murawski and Finn 1988). Adults are found at temperatures of 0-13°C (Hardy 1978), but are most common at 2-9°C (Bigelow and Schroeder 1953; Colton 1972; Waiwood and Buzeta 1989), and salinities of 31-35 ppt, although 32 ppt is optimal (Bigelow and Schroeder 1953; Scott 1982; Waiwood and Buzeta 1989).

Most of the juvenile haddock taken during NEFSC trawl surveys (see Geographical Distribution below) were at temperatures of 4-12°C (4-9°C in spring and 7-12°C in autumn) and depths of 25-125 m. Most adults were taken at 4-12°C (4-8°C in spring and 7-12°C in autumn) and 50-100 m. Most juveniles taken during Massachusetts trawl surveys (see Geographical Distribution below) were at 5-10°C (5-8°C in spring and 8-10°C in autumn) and 30-50 m. Most adults were taken at 5-12°C and 25-60 m.

SUBSTRATE

The distribution of substrate sediments in the Gulf of Maine area is presented in Figure 3. There seems to be considerable amounts of suitable substrate for haddock (i.e., gravelly sand and gravel) throughout southwestern Nova Scotia and in patches on Georges Bank; there is relatively very little in the Gulf of Maine. Consequently, haddock are most abundant on Browns and Georges Banks (see Section 4 below).

The primary haddock spawning sites, the northeast part of Georges Bank and Browns Bank (Colton and Temple 1961, Lough and Bolz 1989), are in areas containing large amount of suitable substrate. There is relatively little suitable substrate and spawning in the Gulf of Maine, however, two areas where haddock spawning has been reported, Stellwagen Bank and Jeffreys Ledge (Colton 1972), contain gravelly sand substrate. As well, all haddock spawning sites identified by Ames (1997) occurred in areas of gravel or sandy substrate. A more rigorous analysis overlaying groundfish distribution onto substrate sediment distribution is currently being performed.

GEOGRAPHICAL DISTRIBUTION

Haddock in the northwest Atlantic were distributed from Cape Charles, Virginia to Labrador, Canada during 1975-1994 (Figure 4). Areas of highest abundance include Georges Bank, the Scotian Shelf (including Browns Bank), and the southern Grand Bank.

EGGS

The 1978-1987 MARMAP ichthyoplankton surveys [see Reid *et al.* (1999) for details] found eggs from New Jersey to southwest Nova Scotia (Figure 5). The highest densities were over southwest Nova Scotia and Georges Bank, which is expected since Georges and Browns Banks are the principal haddock spawning areas (Colton and Temple 1961; Laurence and Rogers 1976; Brander and Hurley 1992). Eggs were collected from January through August, with the highest abundance collected in April, followed by March and May. This corresponds with observations that peak spawning occurs from March to May (Bigelow and Schroeder 1953; Page and Frank 1989; Brander and Hurley 1992). The highest mean density of eggs occurred in April (77.3 eggs/10 m^2), followed by March (21.1 eggs/10 m^2), with high concentrations spreading to the Gulf of Maine. By July and August, mean densities had decreased considerably (< 0.1 eggs/10 m^2).

All eggs were collected within a narrow range of temperatures, 2-10°C; the vast majority occurred within 4-10°C (Figure 6), which is the temperature range at which egg survival is highest (Hardy 1978). In January, the highest abundance of eggs was found at 6-7°C, while in February, March and April highest abundance was at 4-6°C. Colton (1972) and Hardy (1978) have 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, and during July and August almost all eggs were found at 8-10°C.

Eggs were collected at depths in the water column ranging from 10-450 m, however the majority were found at 50-130 m (Figure 6). From January to May the highest abundance 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

The 1977-1987 MARMAP ichthyoplankton surveys [see Reid *et al.* (1999) for details] found larvae from the

Delmarva Peninsula to southwest Nova Scotia, and from inshore waters to the seaward limits of the surveys (Figure 7). Larvae were collected from January through July, with the highest average mean density occurring in May (8.3 larvae/10 m^2) and April (8.1 larvae/10 m^2). High concentrations of larvae were found off southwest Nova Scotia and Georges Bank spreading southward. Mean densities were very low in January and February, and had declined drastically by July (< 0.1 larvae/10 m^2). These data concur with previous studies that indicate that hatching begins in earnest in March and peaks in April and May (Smith and Morse 1985; Campana 1989).

Larvae were collected within a wider range of temperatures than eggs, 2-15^{o}C, with the majority occurring at 4-14^{o}C (Figure 8). In January, the majority of larvae were found at 9-10^{o}C, during February to April, most larvae were at 4-7^{o}C, during May to June at 6-9^{o}C, and in July the majority of larvae were found at 9-11^{o}C and 14^{o}C.

Larvae were collected at depths in the water column ranging from 10-325 m, however the majority were found at 30-90 m (Figure 8). The majority of larvae tend to inhabit the upper 50 m of the water column (Marak 1960; Hardy 1978). From January to June, the majority of 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.

JUVENILES AND ADULTS

NEFSC Bottom Trawl Surveys

Catches from the 1963-1997 NEFSC bottom trawl surveys [see Reid *et al.* (1999) for details] indicate that the distribution of juvenile and adult haddock are similar (Figure 9), although juveniles tend to be distributed further to the south in summer and autumn. Juveniles and adults were caught in all seasons from throughout the Gulf of Maine, Scotian Shelf and Georges Bank. More large catches were made in autumn than spring, presumably because adults migrate offshore to winter pre-spawning aggregations (Halliday and McCraken 1970). The greatest abundance occurs on Georges and Browns Banks, followed by the Scotian Shelf off southwest Nova Scotia, Nantucket Shoals, and Stellwagen Bank. In the spring, juveniles and adults were most abundant on Georges Bank and the Scotian Shelf, particularly Browns Bank. Winter and summer distributions are presented as presence/absence, thus precluding a discussion of abundances (Reid *et al.* 1999).

Haddock were caught at a wide range of temperatures (3-16^{o}C; Figure 10). The temperature distributions of juveniles and adults were similar. There was a definite seasonal effect on the temperature preferences of both juveniles and adults, with higher temperatures preferred in autumn. In spring, juveniles were found at 3-13^{o}C, with the majority at 4-9^{o}C, and the highest abundance at 6^{o}C, while in autumn, juveniles were found at 4-15^{o}C, with the majority at 7-12^{o}C, and the highest abundance at 9^{o}C. In spring, adults were found at 3-13^{o}C, with the highest abundance at 5-6^{o}C and the majority at 4-8^{o}C, while in autumn, adults were found at 4-16^{o}C, with the highest abundance at 8^{o}C and most at 7-12^{o}C. Bigelow and Schroeder (1953) and Hardy (1978) state that adults are found between 0-13^{o}C, and rarely < 2^{o}C.

Haddock were caught at depths ranging from 15-350 m (Figure 10). The depth distributions of adults and juveniles are very similar, and there is no appreciable seasonal effect other than a slightly wider range of depths inhabited in autumn. Overall, the majority of haddock were caught between 50-100 m, and the greatest abundance of both life stages during both autumn and spring was at 75 m. In spring, juveniles were found at 25-200 m, with the majority at 50-125 m, and at 15-250 m, with the majority at 25-100 m, during autumn. Adults were found at 25-225 m with the majority at 50-100 m in spring, and at 15-350 m with the majority at 50-100 m in autumn. Adults in the Gulf of Maine have previously been reported to inhabit depths of 46-137 m (Bigelow and Schroeder 1953).

Massachusetts Inshore Trawl Surveys

Juveniles were far more abundant in coastal Massachusetts waters than adults (Figure 11). Juveniles were more abundant in autumn than spring. 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 the spring, juveniles were still most abundant north of Cape Ann, in northeastern Massachusetts Bay, and in two aggregations off eastern Cape Cod, but were no longer widespread in Cape Cod Bay. A fairly large aggregation was also found northwest of Provincetown, Cape Cod.

Adults were more abundant in spring than in autumn. This corresponds to adult migrations with offshore winter pre-spawning and spawning aggregations (Halliday and McCraken 1970). In autumn, they were virtually non-existent from inshore Massachusetts waters; in spring, adults were most abundant in northeast Massachusetts Bay, and were also found northeast of Cape Ann.

Juveniles and adults were found at temperatures ranging from 4-14^{o}C (Figure 12) and were found at warmer temperatures in autumn than spring. Juveniles were most abundant at 5-8^{o}C in spring and 8-10^{o}C in autumn. Adults were most abundant at 5-9^{o}C in spring, and the few found in autumn were at 11-12^{o}C. Juveniles and adults were found at depths of 15-80 m (Figure 12).

Juveniles were most abundant at 35-50 m in spring and 30-45 m in autumn. Adults were most abundant at 25-50 m in spring, and the few found in autumn were at 50-60 m.

OFFSHORE VS. INSHORE

No inshore distribution data are available for eggs and larvae, but the NOAA Estuarine Living Marine Resources (ELMR) program lists haddock eggs and larvae as ‘not present’ in the majority of bays and estuaries in New England and the Mid-Atlantic Bight. In the few inshore areas where they have been reported (Great Bay, Massachusetts Bay, Cape Cod Bay, Buzzards Bay, Narragansett Bay), they are listed as ‘rare’ (Jury *et al.* 1994; Stone *et al.* 1994).

Juveniles were more abundant inshore in autumn than spring. They occurred in shallower water and at lower temperatures inshore than offshore. Adults were far more abundant offshore than inshore. They were more abundant inshore in spring than autumn, and conversely, more abundant offshore in autumn than spring. This most likely reflects the offshore migration to pre-spawning and spawning aggregations (Halliday and McCraken 1970). They occurred at warmer temperatures and shallower depths inshore than offshore.

STATUS OF THE STOCKS

The total landings (U.S. and Canada) in 1996 from the Georges Bank and Gulf of Maine haddock stocks were 4226 metric tons (mt), 71% higher than 1995, 54% higher than 1994, but 8% lower than 1993 and 34% lower than 1992 (Mayo 1995; Brown 1998).

In the Gulf of Maine, commercial landings declined from a high of about 5000 mt in the mid-1960s to less than 1000 mt in 1973 (Figure 13). Total annual landings increased sharply between 1974 and 1980 and averaged 7000 mt from 1980 to 1983. Since 1983, catches have declined to record lows. The NEFSC autumn survey biomass index has declined steadily since 1978 and reached a record low of 0.09 in 1992 (less than 1% of the peak 1963 survey). Abundance remains at an all time low and recruitment has been insufficient to support landings, resulting in recruitment overfishing and continued stock depletion (Mayo 1995).

On Georges Bank, total commercial landings increased from about 50,000 mt annually prior to 1965 to nearly triple that in 1965 and 1966 (Figure 13). Landings declined through 1976, but catches increased between 1977 and 1980 reaching 28000 mt. Catches declined after 1980 to 4500 mt in 1989 and since 1989 catches have ranged between 2300 and 6900 mt (Northeast Fisheries Science Center 1997). The NEFSC spring and autumn bottom trawl surveys indicate that the biomass has declined markedly since the late 1970s (Mayo 1995). The 1995 and 1996 autumn survey indices are higher than recent years, but are still extremely low relative to historic levels (Figure 13; Brown 1998). The stock remains in a state of collapse: total stock size declined from 133 million in 1979 to 14 million in 1991 (Mayo 1995). Total stock has increased somewhat in 1995 and 1996 (Figure 13). Spawning stock biomass reached a record low of 11,000 mt in 1993, but has since rebounded to over 32,000 mt in 1996 (Northeast Fisheries Science Center 1997). This is a sharp increase, but is still far below historical average levels.

The September 1997 ‘Status of Fisheries of the United States’ (National Marine Fisheries Service 1997) reports that the Georges Bank haddock stock is presently not being overfished, nor is it approaching an overfished condition. However, the 24th Stock Assessment Workshop concludes that the Georges Bank stock is at a low biomass level and is in an over-exploited state (Northeast Fisheries Science Center 1997). The status of the Gulf of Maine stock is listed as unknown (National Marine Fisheries Service 1997).

Data from the NEFSC bottom trawl surveys is presented in Figure 14 to contrast the distribution of haddock from recent periods of low abundance (1992-1996) with periods of high abundance (1963-1967). The pattern is similar for juveniles and adults, with the exception that juveniles are distributed further south in years of low abundance, while adults were not. In years of low abundance, juveniles and adults were rare on Georges Bank (the apparent absence of haddock on Browns Bank during this period is due to the absence of sampling effort in this area after 1987). In years of high abundance, they were far more abundant on Georges Bank, Nantucket Shoals, and Stellwagen Bank.

RESEARCH NEEDS

The biology of northwest Atlantic haddock is quite well-known, as evidenced by the completeness of the habitat matrix presented in this report (Table 2). However, there is a need for more detailed information in certain areas:

- More information on the genetic structure of haddock stocks is needed. 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) identified 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. They recommend that additional sampling effort is 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 needed. 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 spawning is needed; our literature search uncovered very few spawning details, other than the fact that spawning occurs at the bottom over gravel substrate.
- Information on growth and survival rates by habitat type (i.e., Level 4 EFH information) is needed to accurately designate Essential Fish Habitat for haddock.

The October 1997 report of the 24th Stock Assessment Workshop (Northeast Fisheries Science Center 1997) lists research recommendations for improving haddock stock assessments:

- Improve biological sampling of commercial landings and discards.
- Examine effects of large tows on overall and age-specific abundance indices for haddock, specifically with reference to closed areas.
- Examine effects of abrupt changes in mean weight at age during the 1990s, specifically with respect to the 1989-1991 year-classes in the eastern part of Georges Bank.
- Investigate factors associated with apparent recent improvements in survival rations (R/SSB).

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Table 1. Size and age at maturity of haddock, *Melanogrammus aeglefinus*.

Stock	Time Period	A_{50} (years) *male*	A_{50} (years) *female*	L_{50} (cm) *Male*	L_{50} (cm) *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
Browns Bank	1970-1985	-	-	36.4	42.6	Waiwood and Buzeta 1989
	1979-1985	2.8-3.3	2.8-3.6	33-35	34-38	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, *Melanogrammus aeglefinus*. Information that could not be distinguished as either juvenile or adult 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 pebble gravel bottom. 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).
Larvae [2]	Size at hatch ranges from 2 - 5 mm (mean = 4 mm).	Generally pelagic. Maximum depth approximately 150 m. Majority found at depths of 10-50 m.		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.
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 & Hudson Canyon. Occur on same grounds as adults.	Pebble gravel bottom.	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 Browns Bank: 42.5/36.5 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 & 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)
[2] Marak (1960), Colton and Temple (1961), Miller et al. (1963), Laurence (1974, 1978), Hardy (1978), Kane (1984), Lough and Bolz (1989)
[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)
[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. NW flow of water off Browns Bank to western Nova Scotia, New Brunswick and New England as far south as Cape Cod.	
Larvae [2]		Larvae drift with surface currents. Georges Bank larvae may be swept off the Bank to the SW (@ 0.65 cm/s), otherwise are retained; on Browns Bank some larvae retained due to the Browns Bank gyre, others dispersed inshore due to the Nova Scotia coastal current.	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 & 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.

[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)
[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)

Table 2. cont'd.

Life Stage	Predators	Spawning	Notes
Eggs [1]	Preyed upon by a wide range of pelagic predators.	Georges and Browns Banks are the principle spawning areas (GB > BB). Limited spawning along South Channel and New England coast. Spawning occurs over all of Georges, but main spawning center is in NE part of the bank. 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 late-March-April; Browns Bank: early March-June, peaks late April-early May.	Egg duration on Georges Bank varied from 10-20 days over 34 year period; mean egg duration during peak spawning was 15.5 days. Egg duration on Browns Bank varied from 10-30 days over the same 34 years; mean egg duration during peak spawning was 18.6 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 & 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 temp. 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 & summer; coincides with the inshore fishery. Offshore fishery occurs during the winter and early spring. Distribution influenced more by restrictive spawning area & 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 (1950), 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)

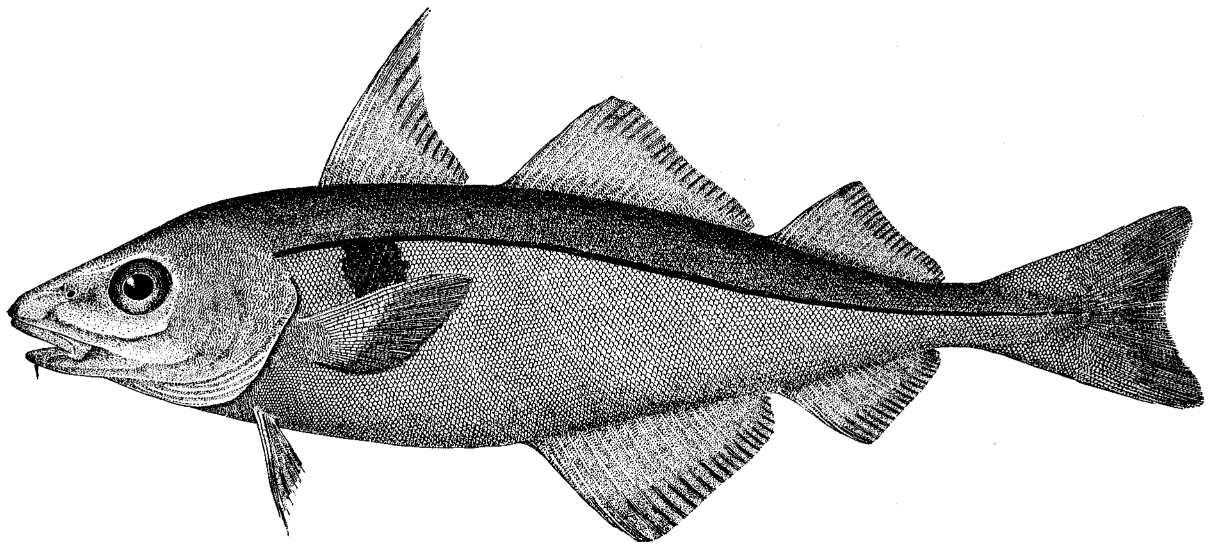


Figure 1. The haddock, M*elanogrammus aeglefinus* (from Goode 1884).

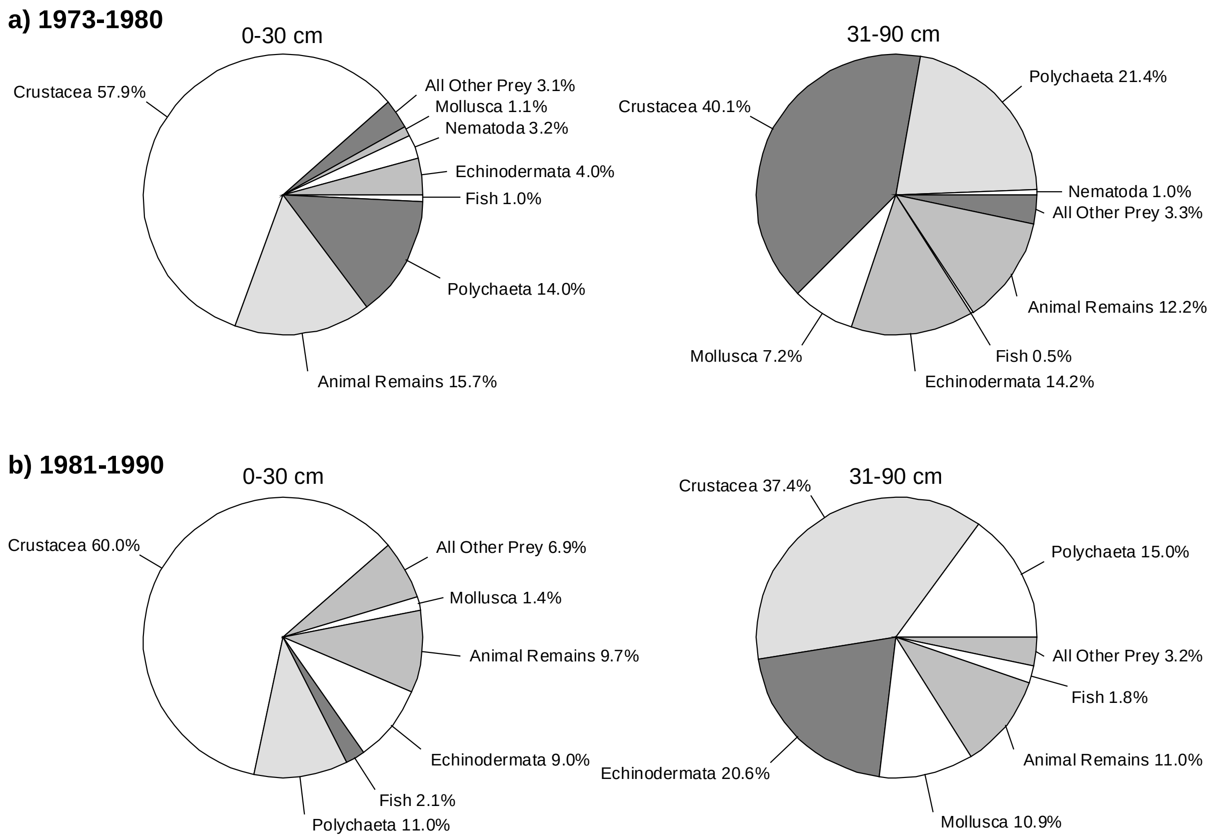


Figure 2. Abundance (% occurrence) of the major prey items of haddock collected during NEFSC bottom trawl surveys from 1973-1980 and 1981-1990. Methods for sampling, processing, and analysis of samples differed between the time periods [see Reid *et al.* (1999) for details]. (a) 1973-1980, 0-30 cm: n=532, 31-90 cm: n=1356; (b) 1981-1990, 0-30 cm: n=98, 31-90 cm: n=930. The 0-30 cm size category corresponds, at least roughly, to the juvenile life stage, and the 31-90 cm size class corresponds to adults. The category "animal remains" refers to unidentifiable animal matter.

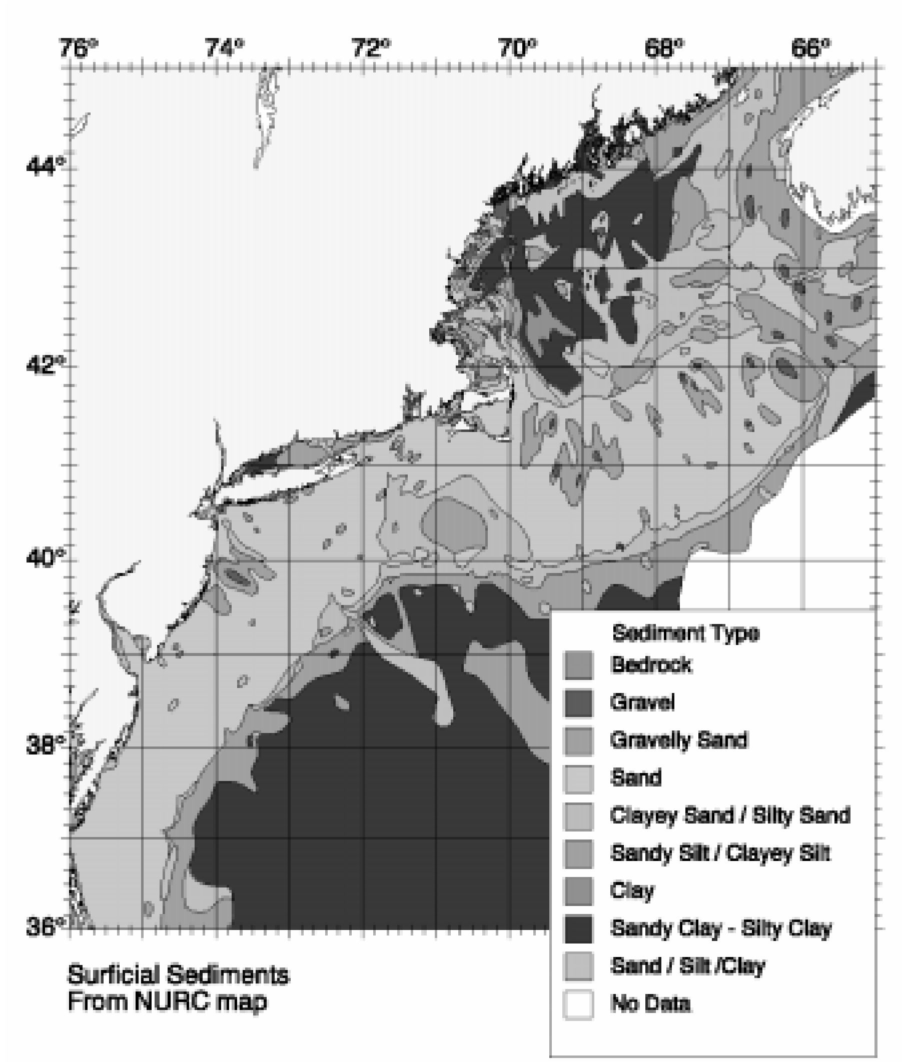
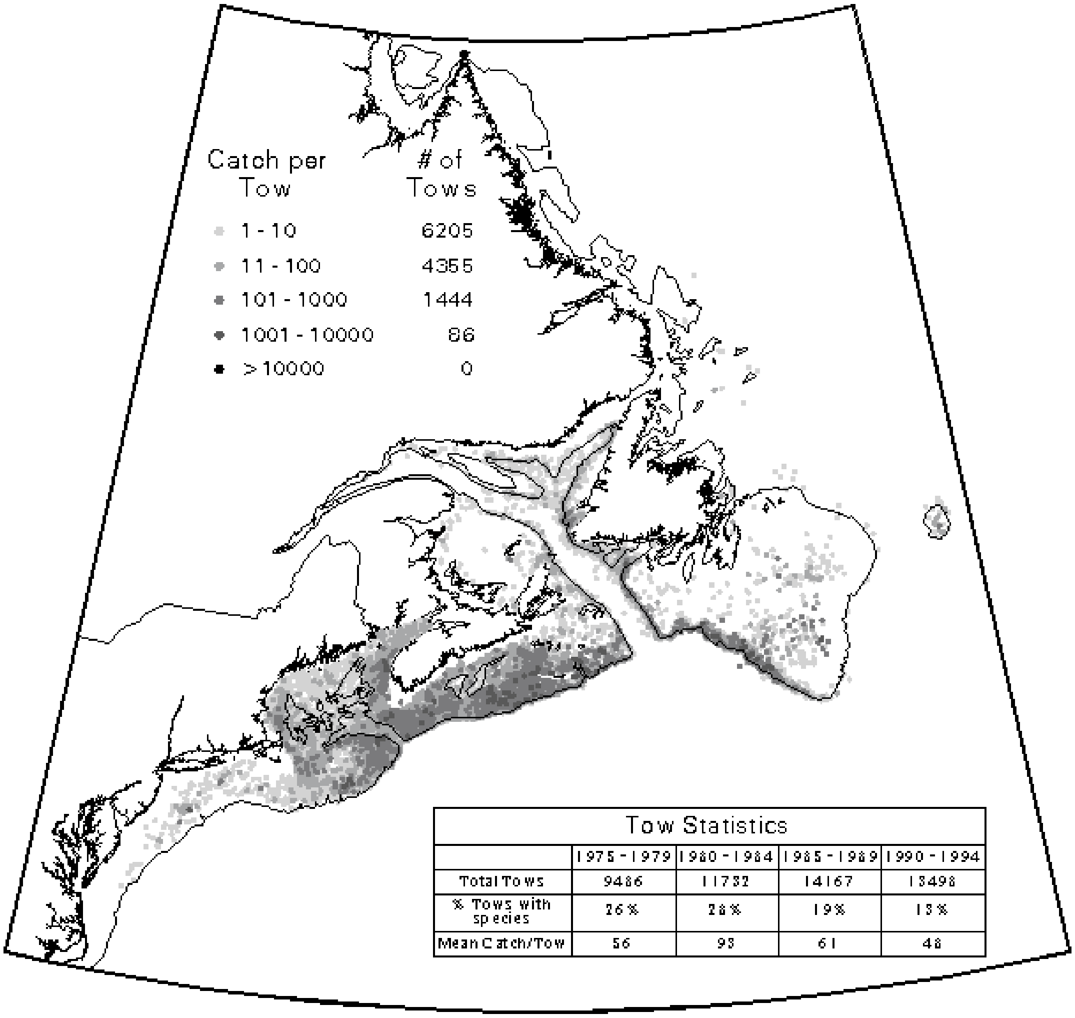


Figure 3. Distribution of surficial sediments along the northeast coast of the United States. Data are from the United States Geological Survey and NOAA.



	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 4. Distribution and abundance of haddock from Newfoundland to Cape Hatteras during 1975-1994. Data are from the U.S. NOAA/Canada DFO East Coast of North America Strategic Assessment Project (http://www-orca.nos.noaa.gov/projects/ecnasap/ecnasap_table1.html).

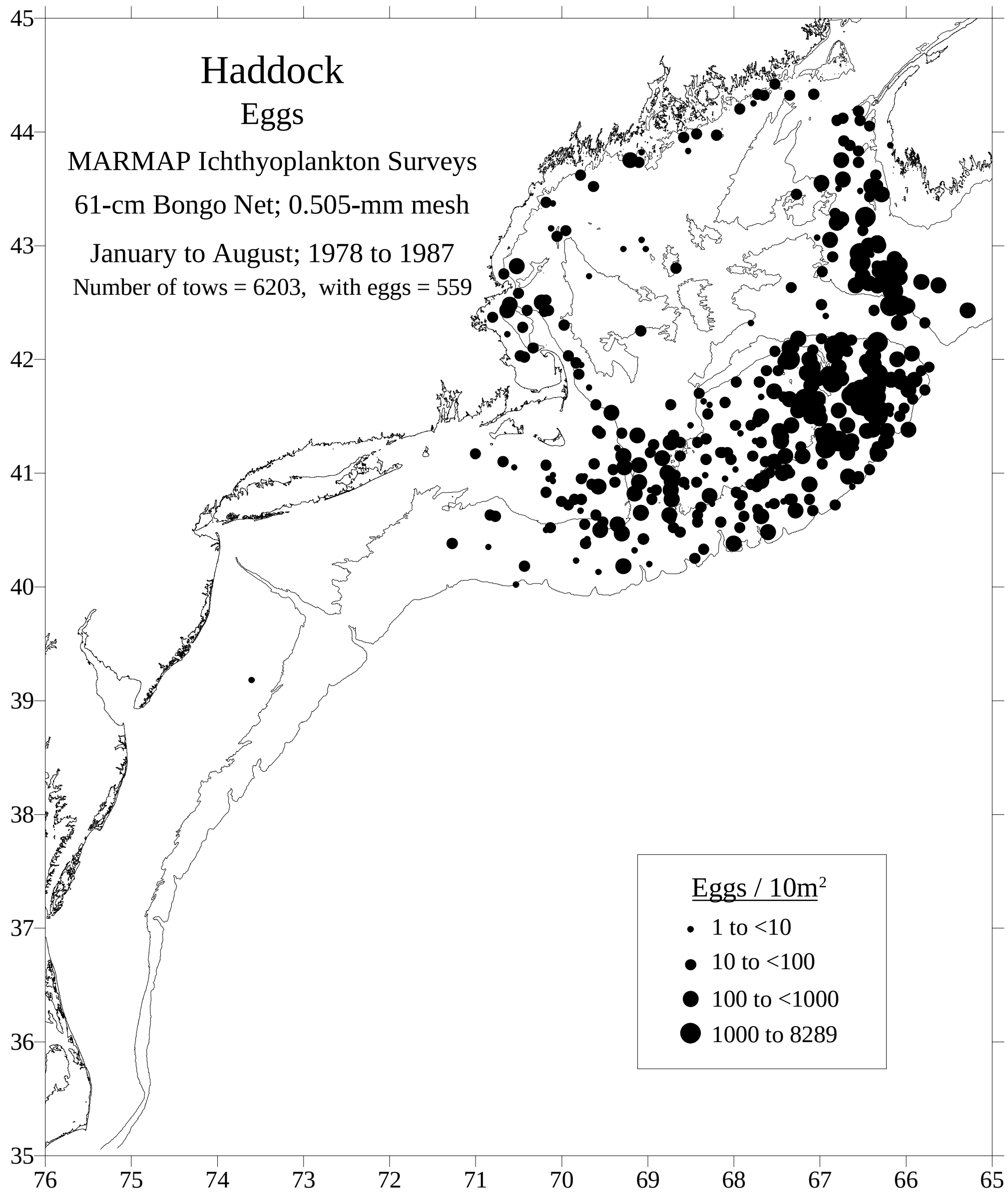
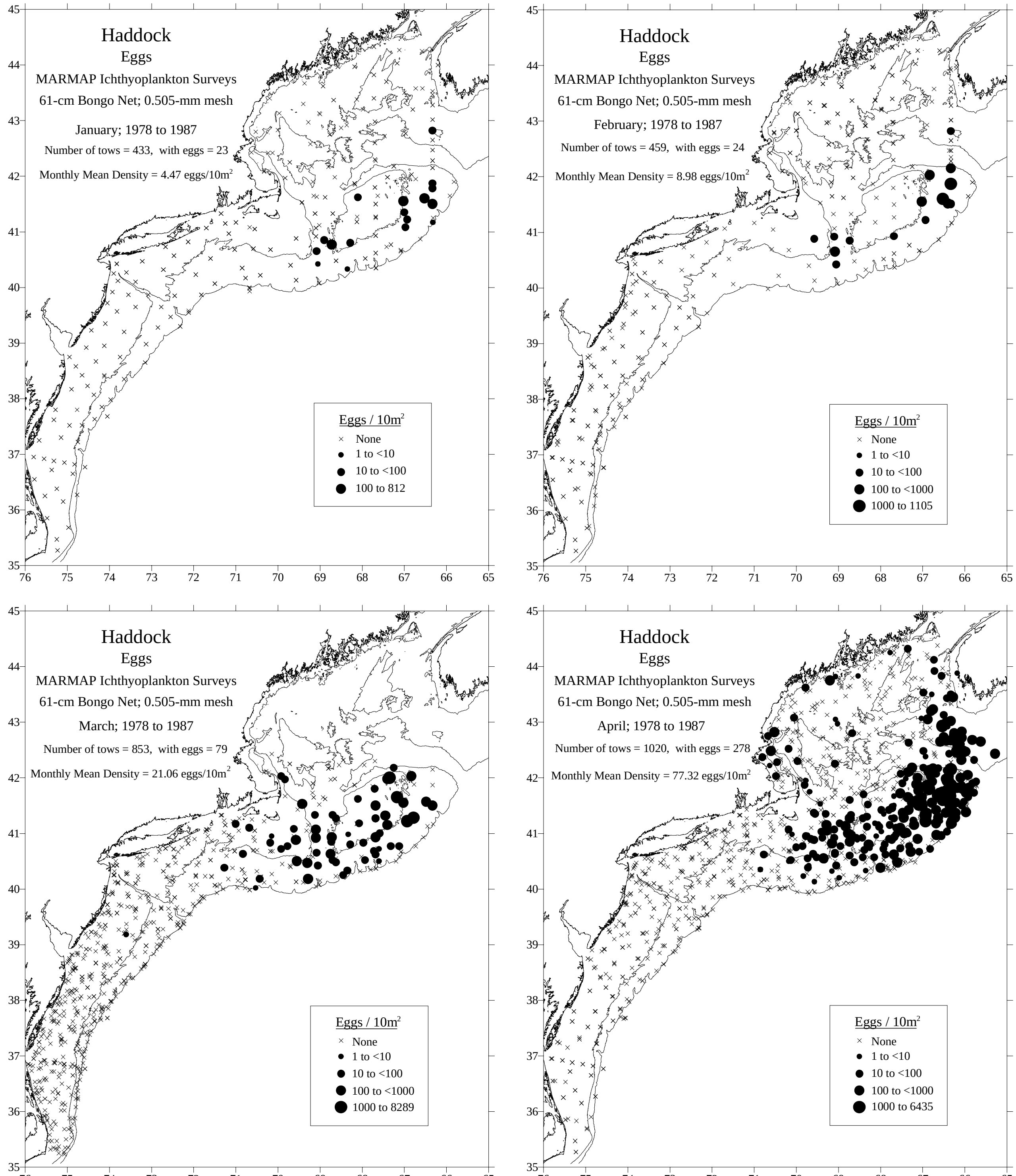


Figure 5. Distribution of haddock eggs collected during NEFSC MARMAP offshore ichthyoplankton surveys (January to August, 1978-1987). Egg densities are represented by dot size [see Reid *et al.* (1999) for details].



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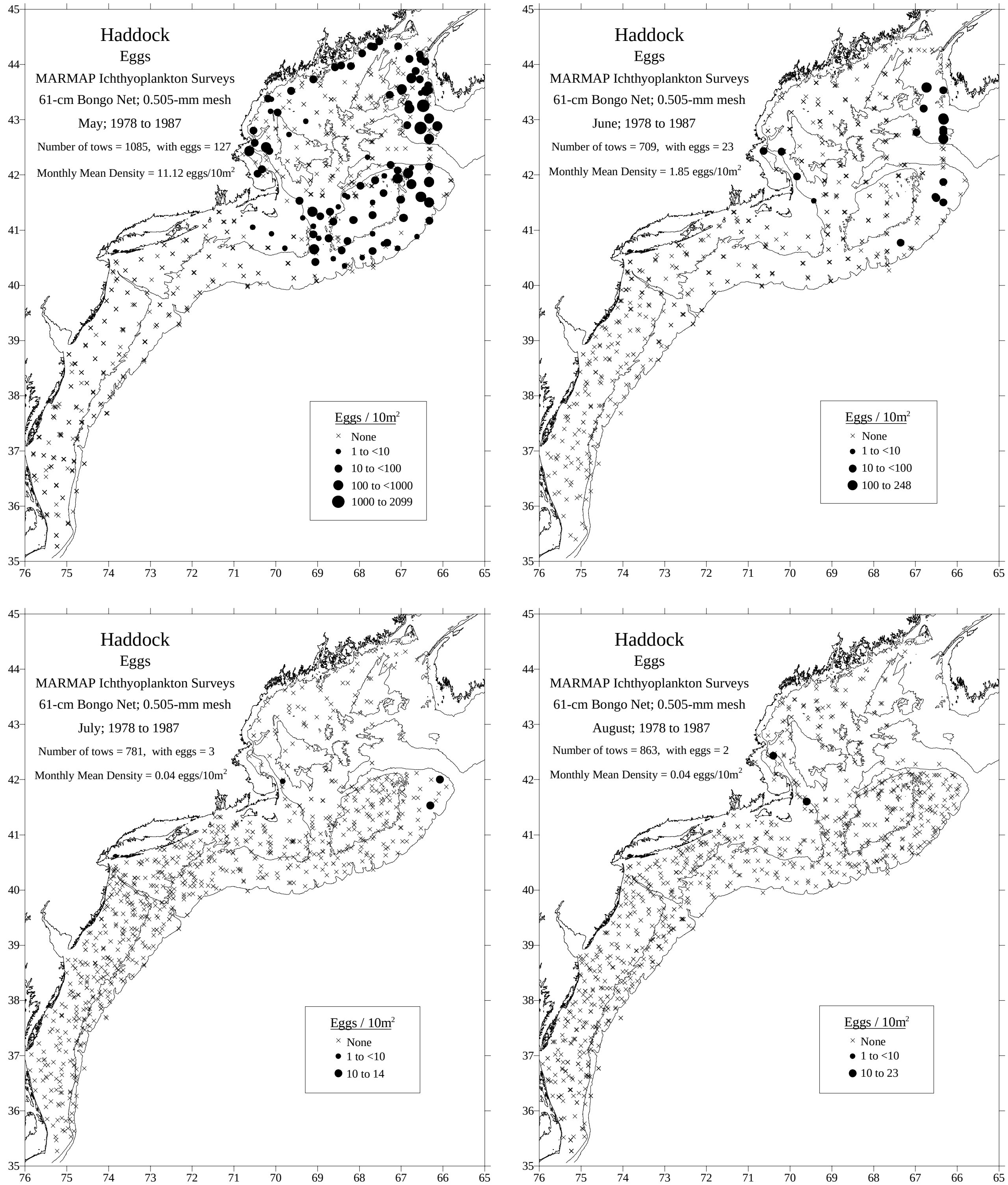

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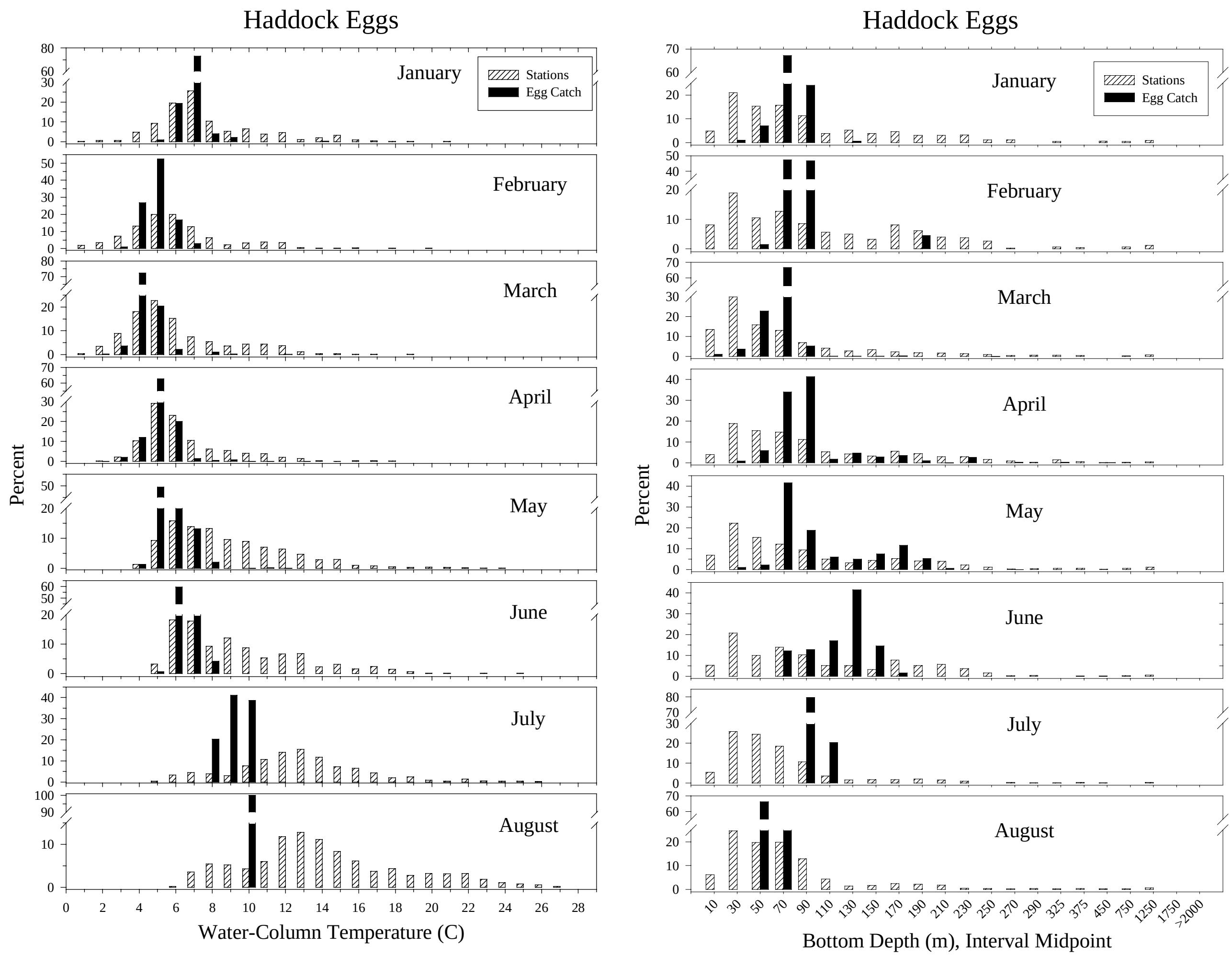


Figure 6. Monthly abundance of haddock eggs relative to water column temperature (to a maximum of 200 m) and bottom depth based on NEFSC MARMAP ichthyoplankton surveys, all years combined (January to August, 1978-1987). Open bars represent the proportion of all stations which were surveyed; solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

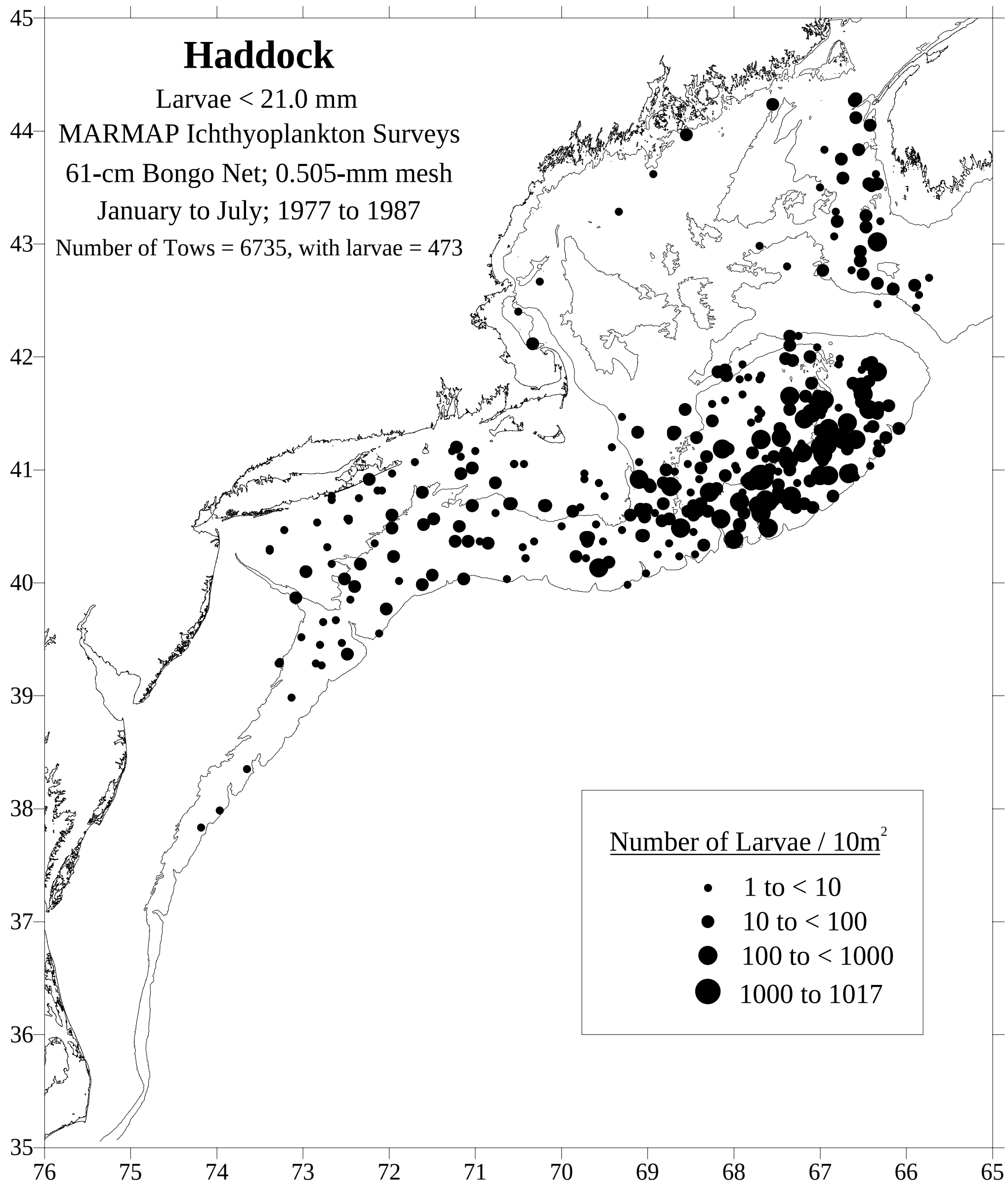
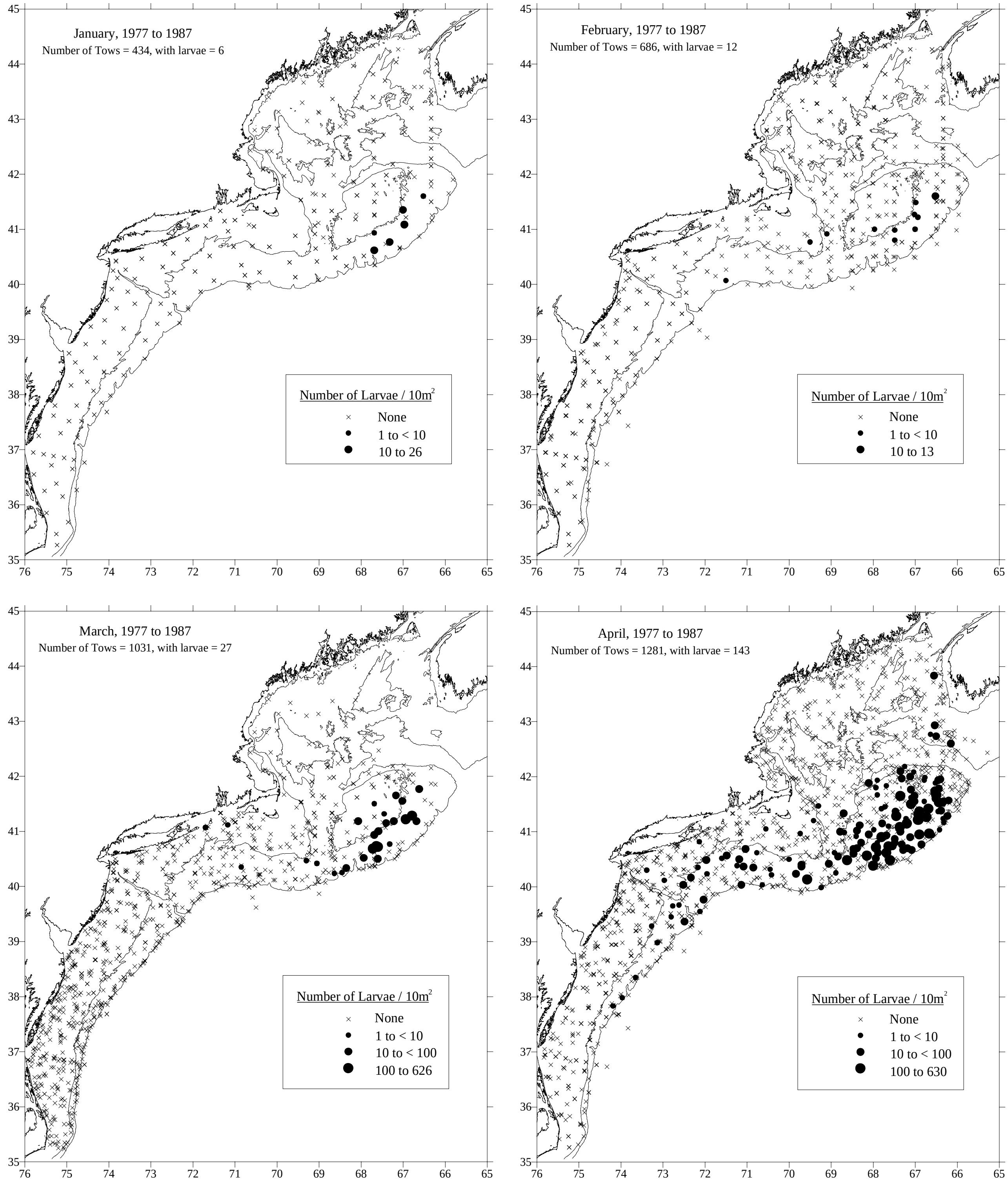


Figure 7. Distribution of haddock larvae collected during NEFSC MARMAP offshore ichthyoplankton surveys (January to July, 1977-1987). Larval densities are represented by dot size [see Reid *et al.* (1999) for details].



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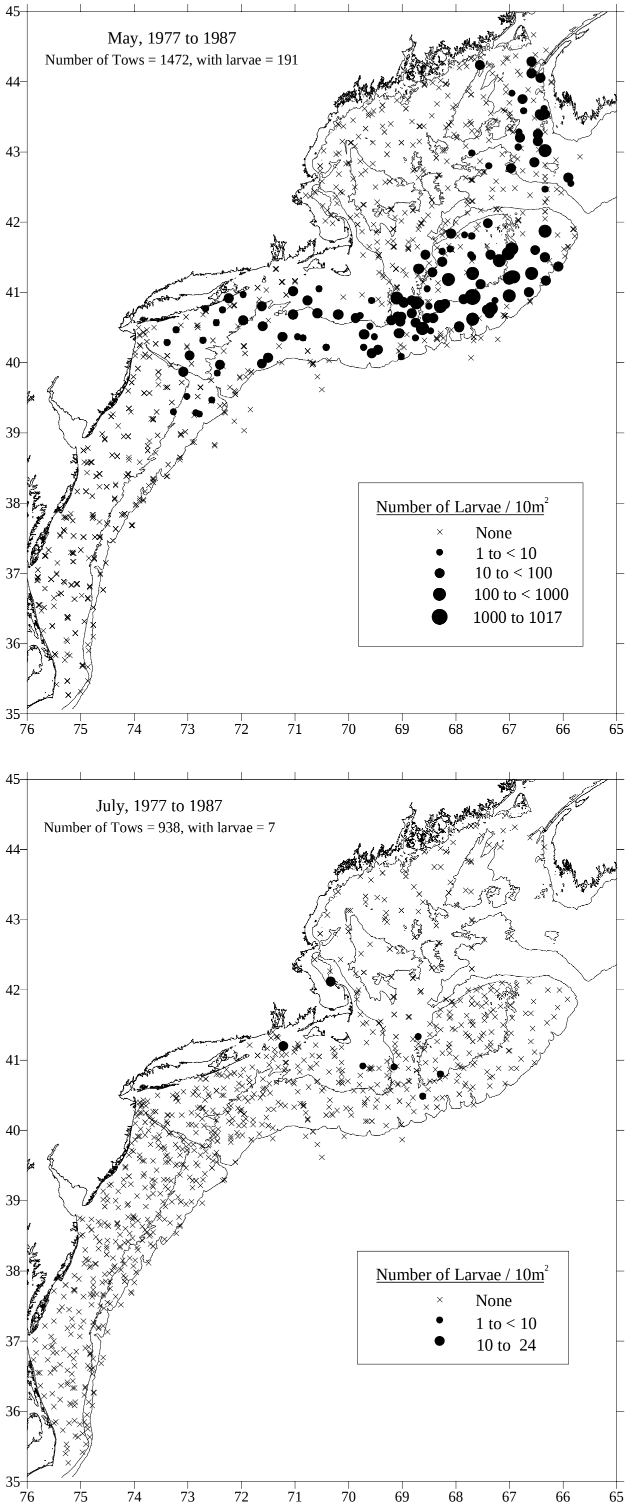

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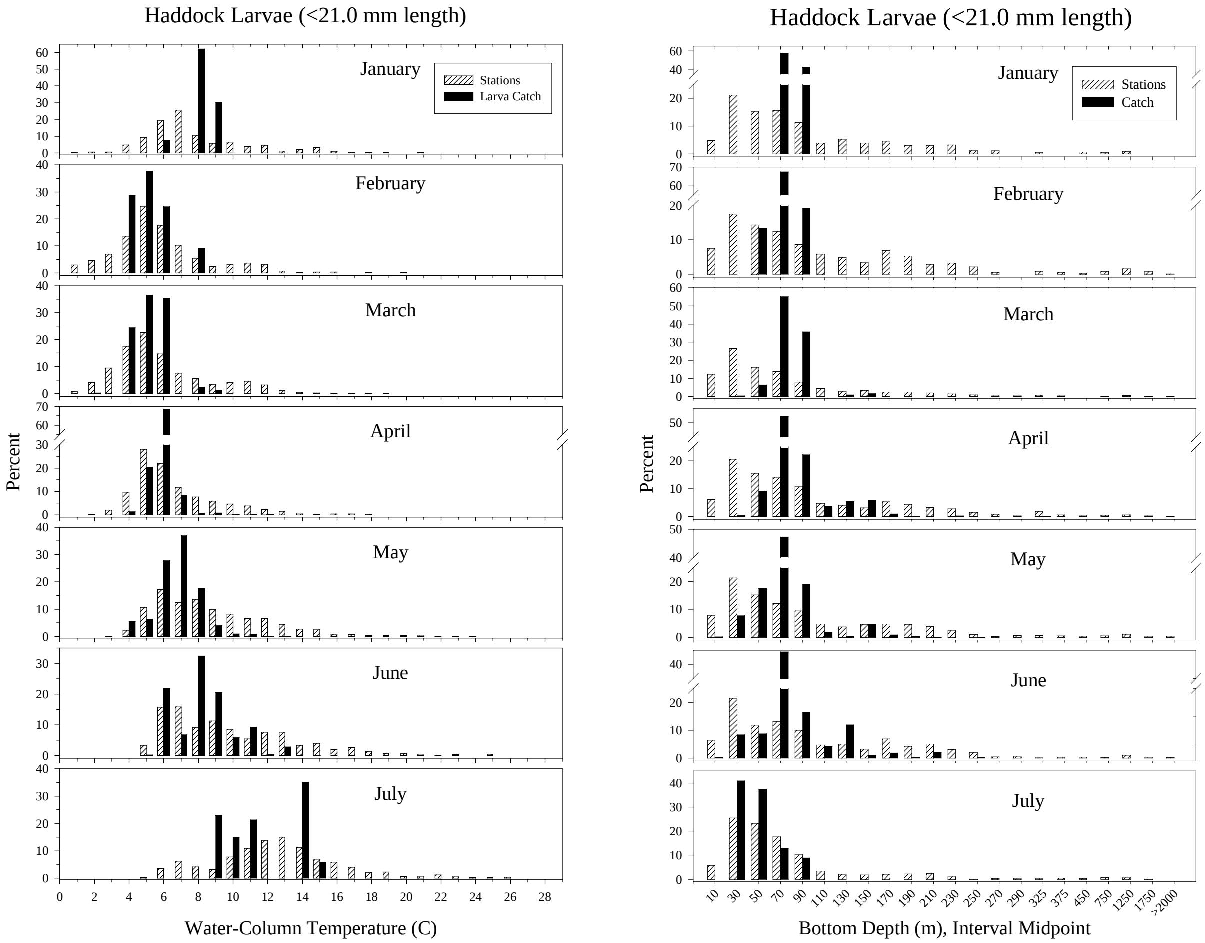


Figure 8. Monthly abundance of haddock larvae relative to water column temperature (to a maximum of 200 m) and bottom depth from NEFSC MARMAP ichthyoplankton surveys, all years combined (January to July, 1977-1987). Open bars represent the proportion of all stations which were surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

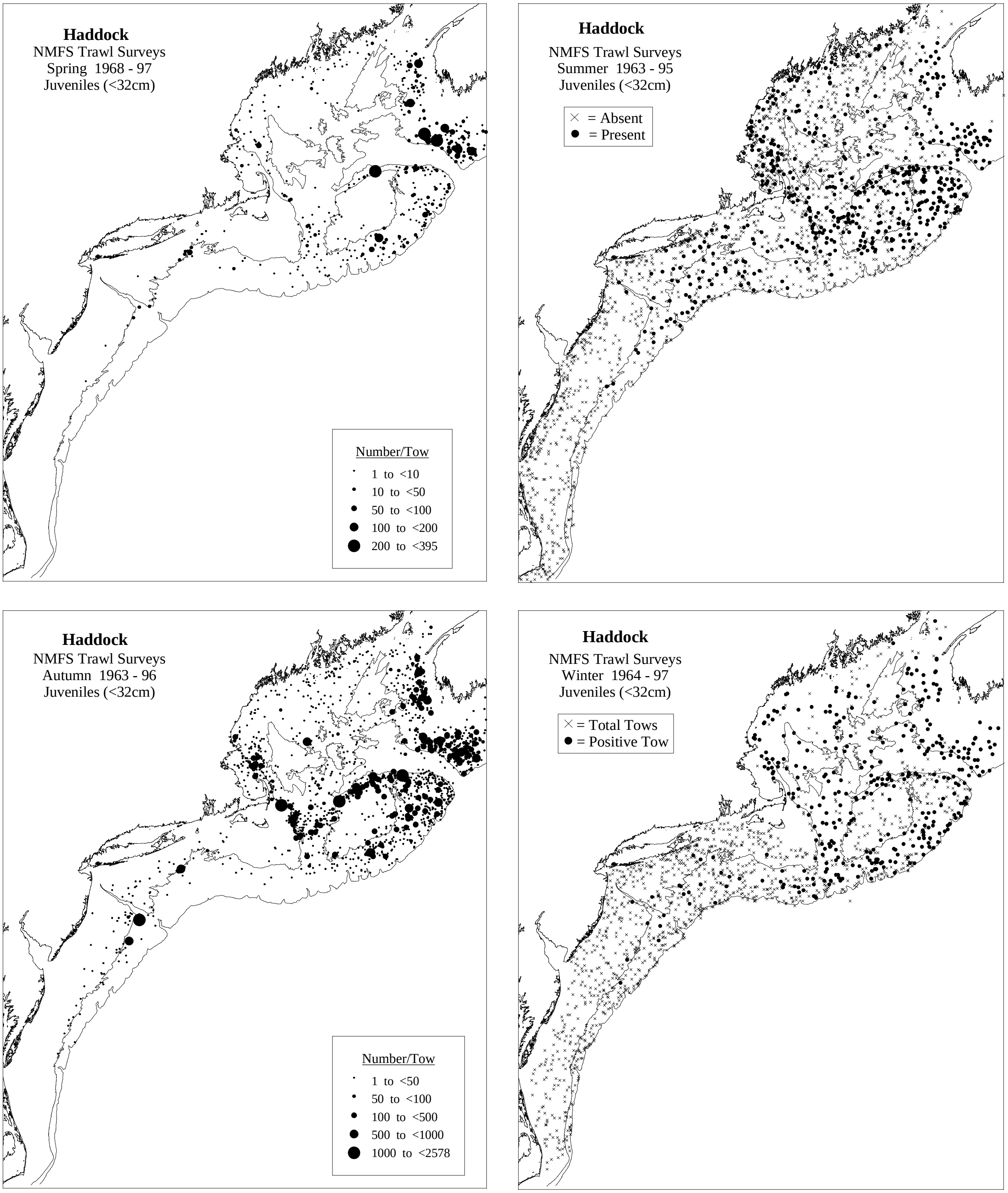
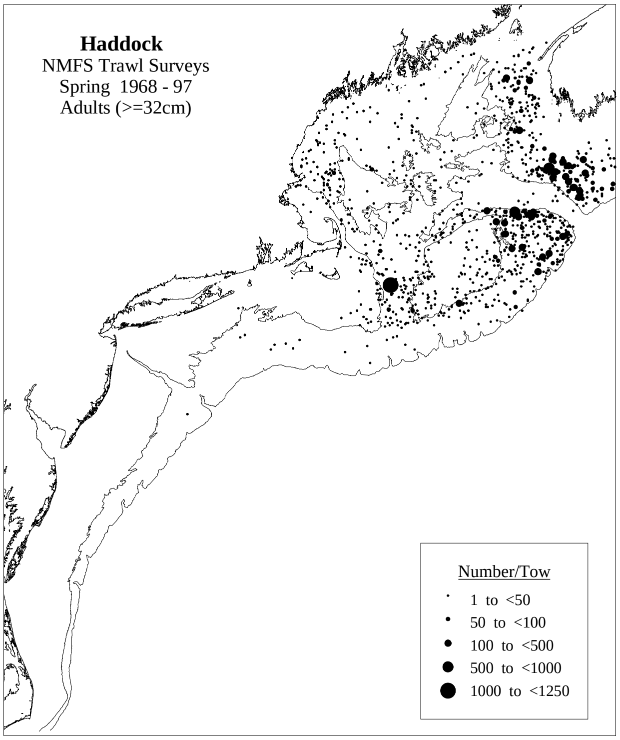
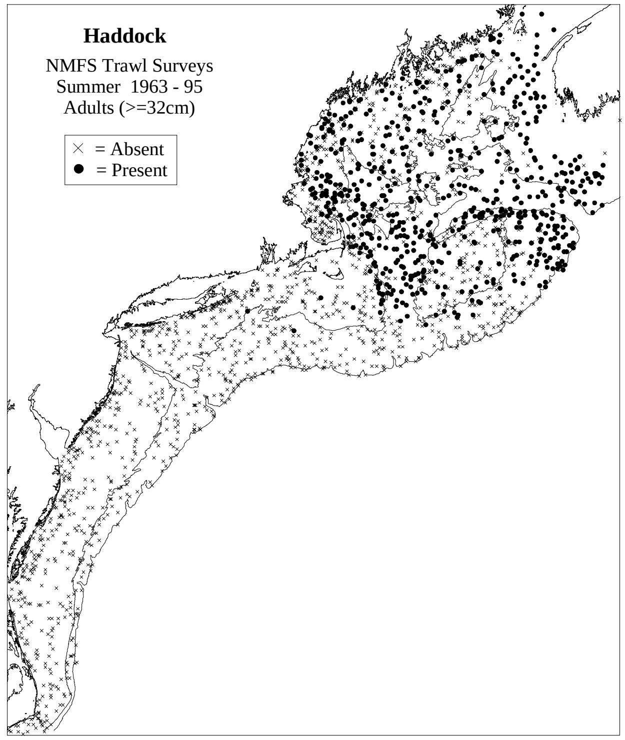
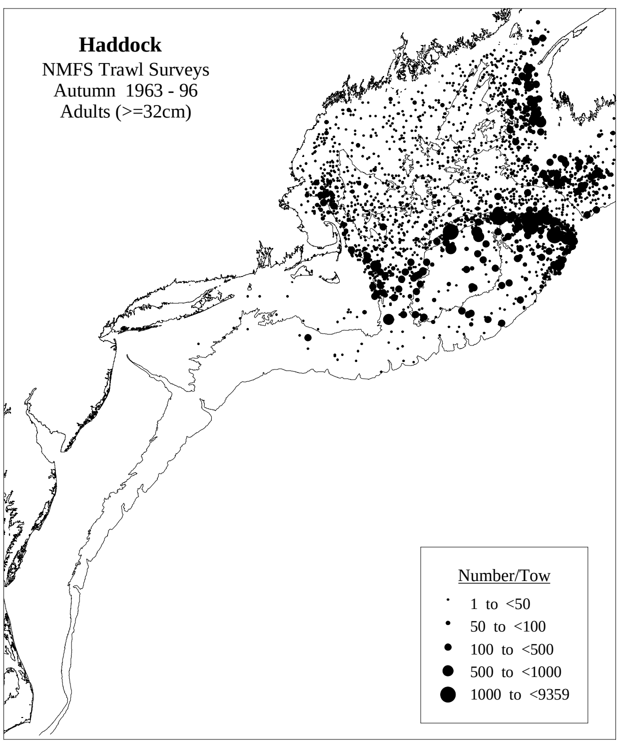
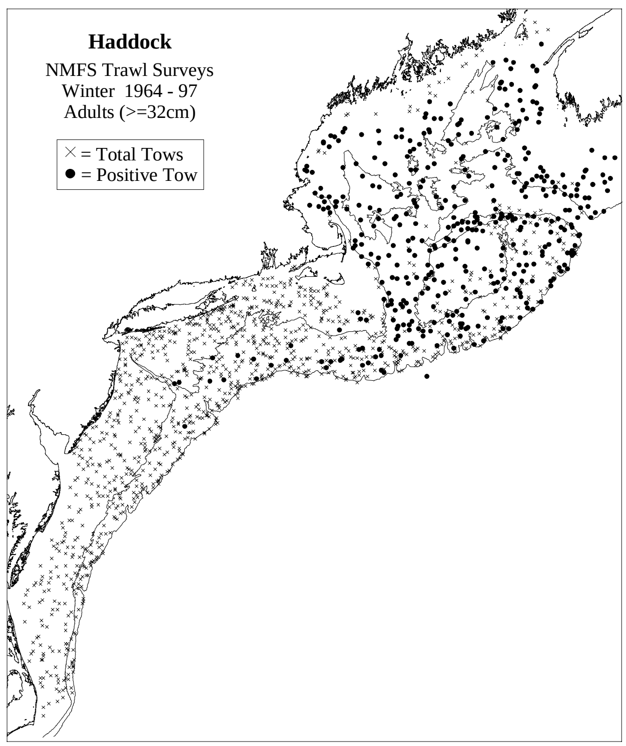


Figure 9. Distribution of juvenile and adult haddock collected during NEFSC bottom trawl surveys, (spring, summer, autumn and winter, 1963-1997). Densities are represented by dot size in spring and autumn plots, while only presence and absence is represented in summer and winter plots [see Reid *et al.* (1999) for details].









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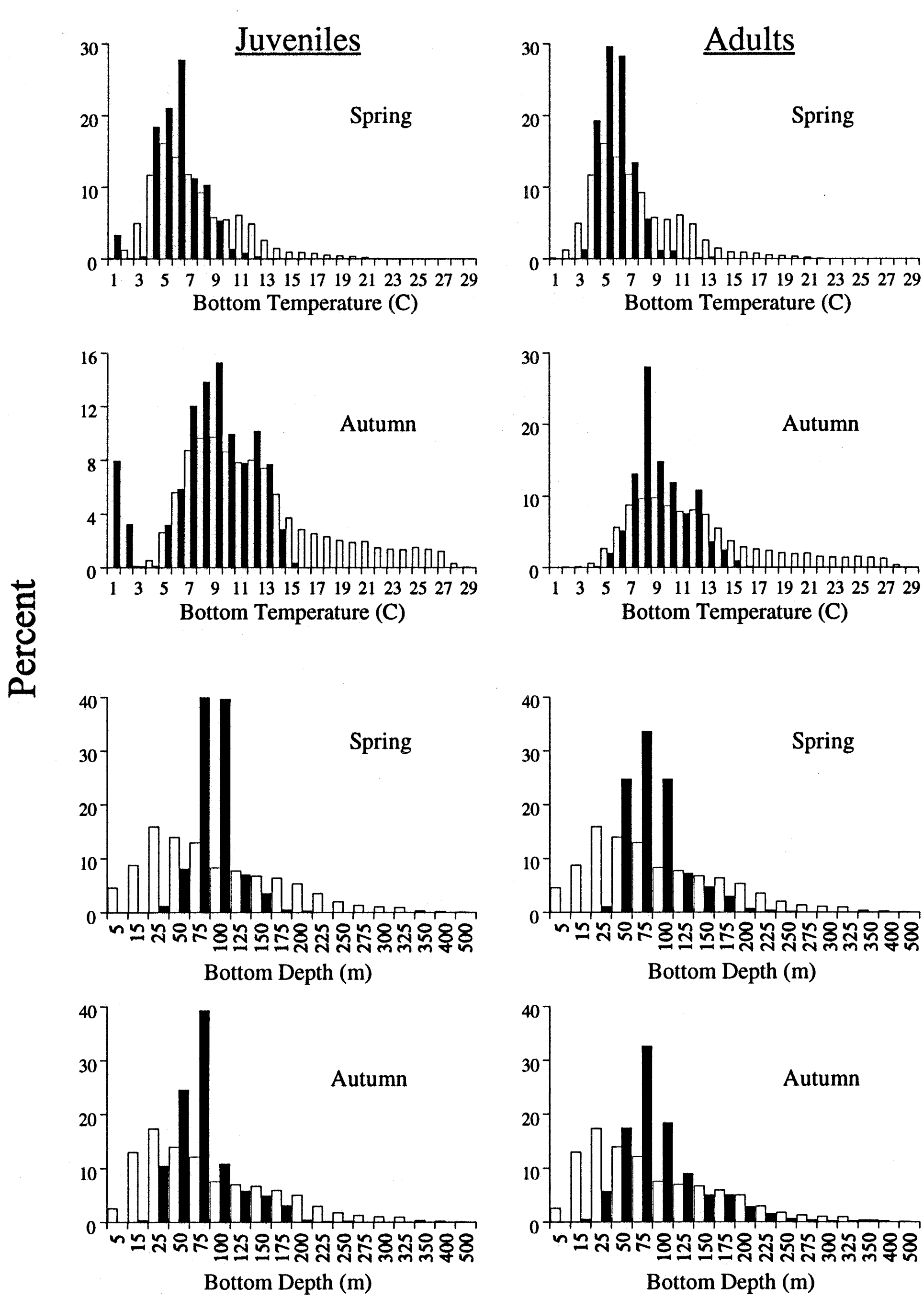


Figure 10. Abundance of juvenile and adult haddock relative to bottom water temperature and depth based on spring and autumn NEFSC trawl surveys, all years combined (1963-1997). Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized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

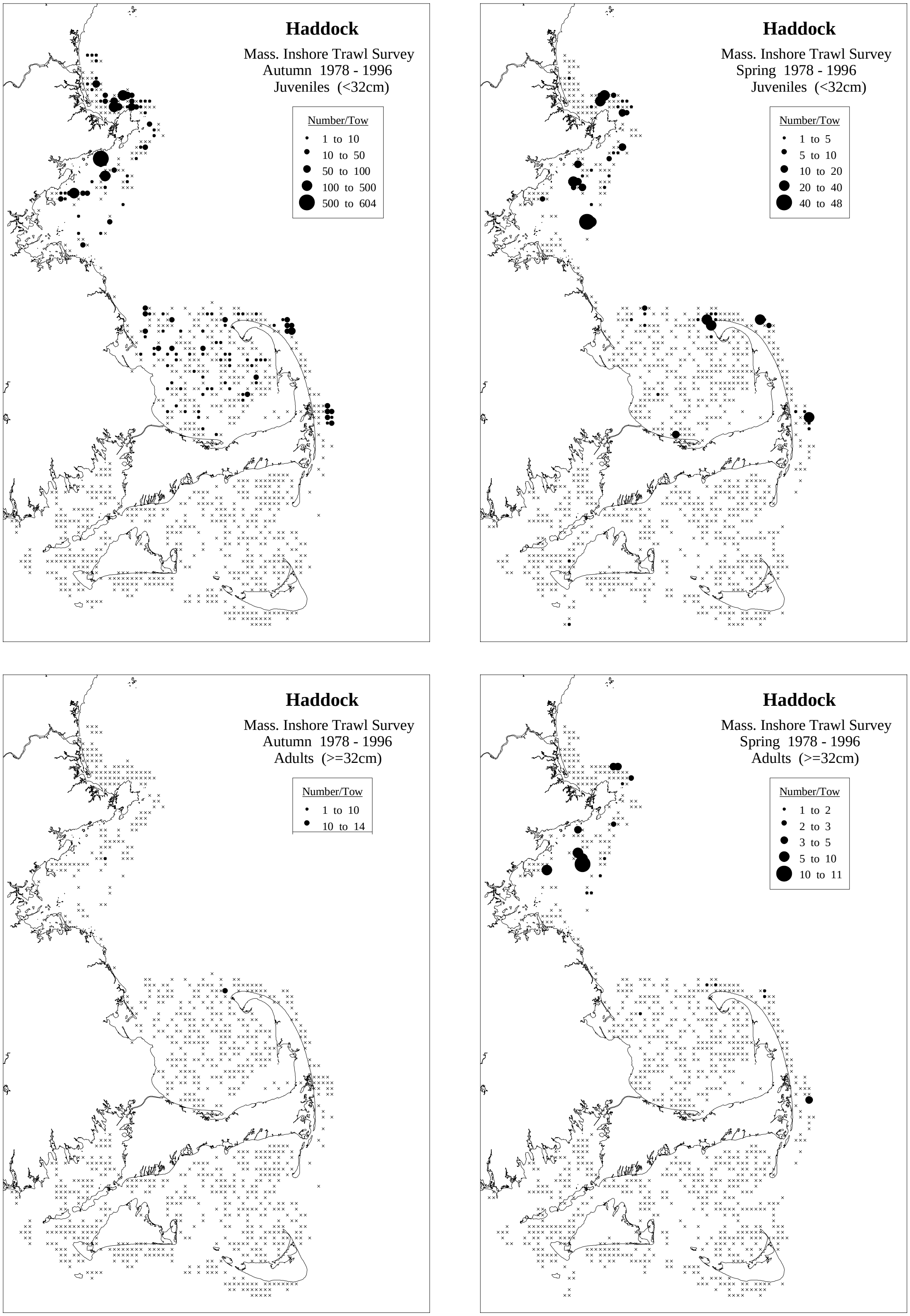


Figure 11. Distribution of juvenile and adult haddock collected in coastal waters of Massachusetts during Massachusetts inshore trawl surveys (autumn and spring, 1978-1996) [see Reid *et al.* (1999) for details].

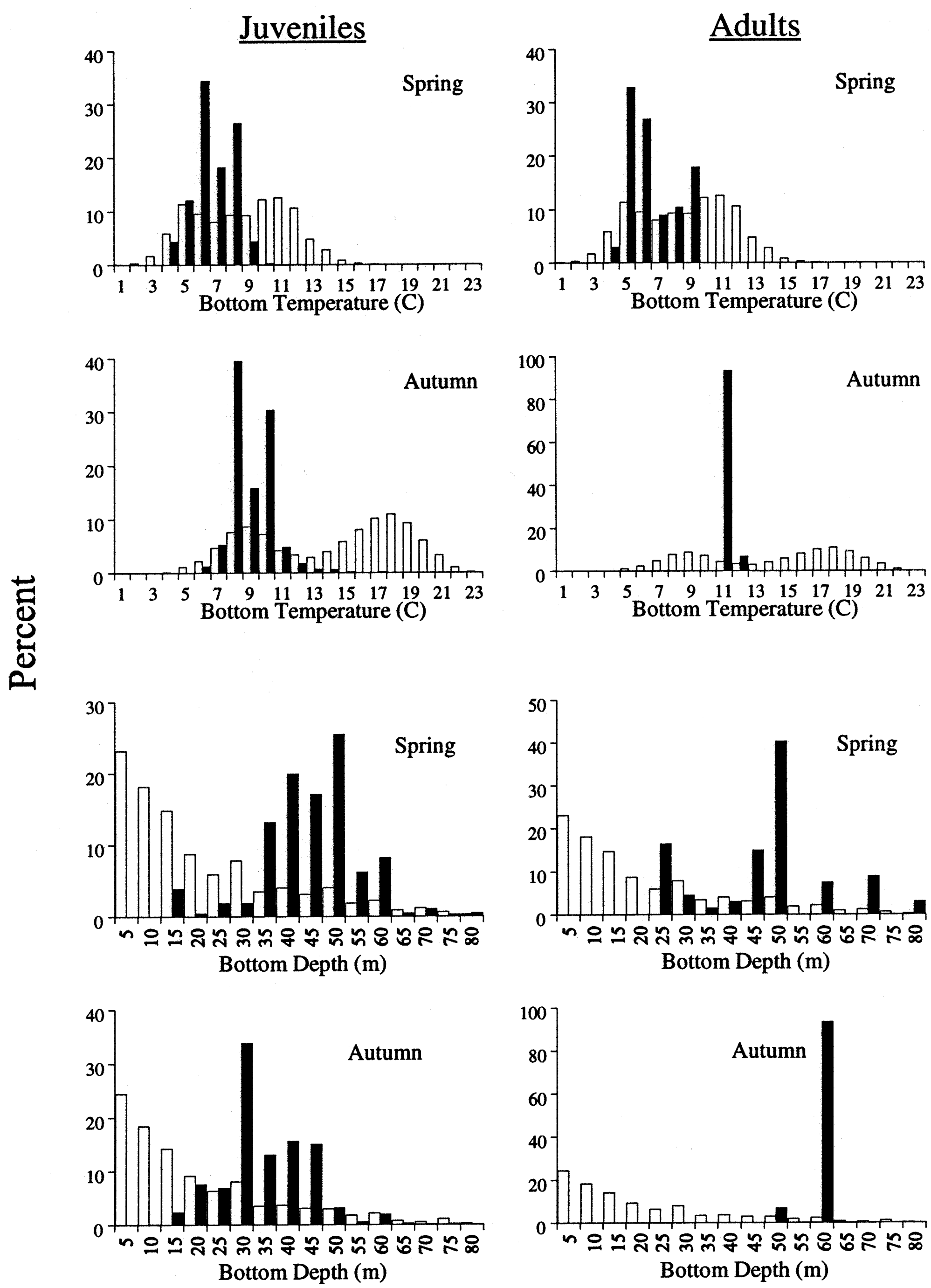
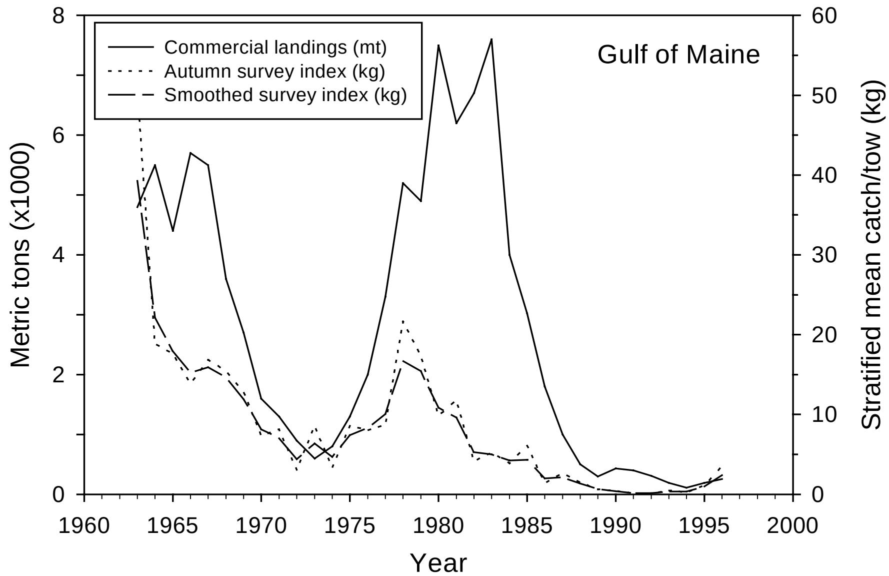


Figure 12. Abundance of juvenile and adult haddock relative to bottom water temperature and depth based on Massachusetts inshore trawl surveys for all years combined (spring and autumn, 1978-1996). Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).



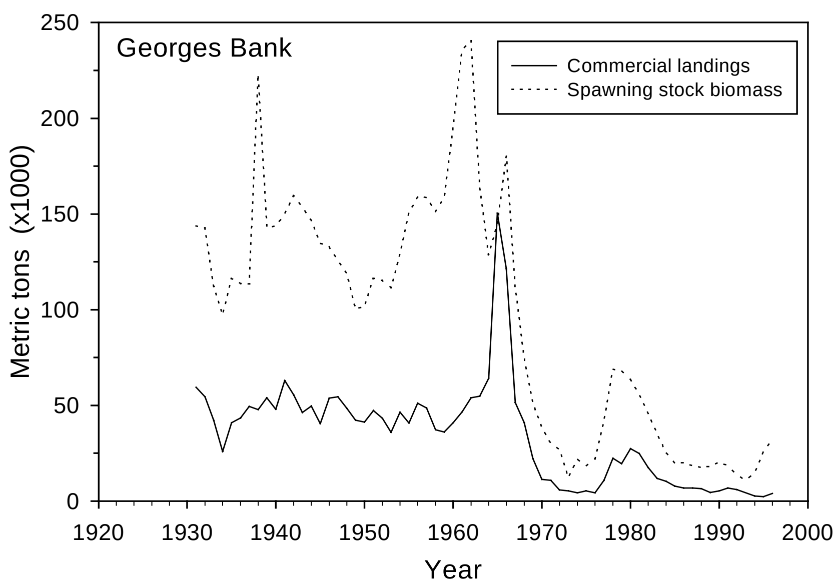


Figure 13. Commercial landings and survey indices (from the NEFSC bottom trawl surveys) of haddock from the Gulf of Maine, 1963-1996 (top) and commercial landings and spawning stock biomass (from the NEFSC bottom trawl surveys) of haddock from Georges Bank, 1930-1996 (bottom).

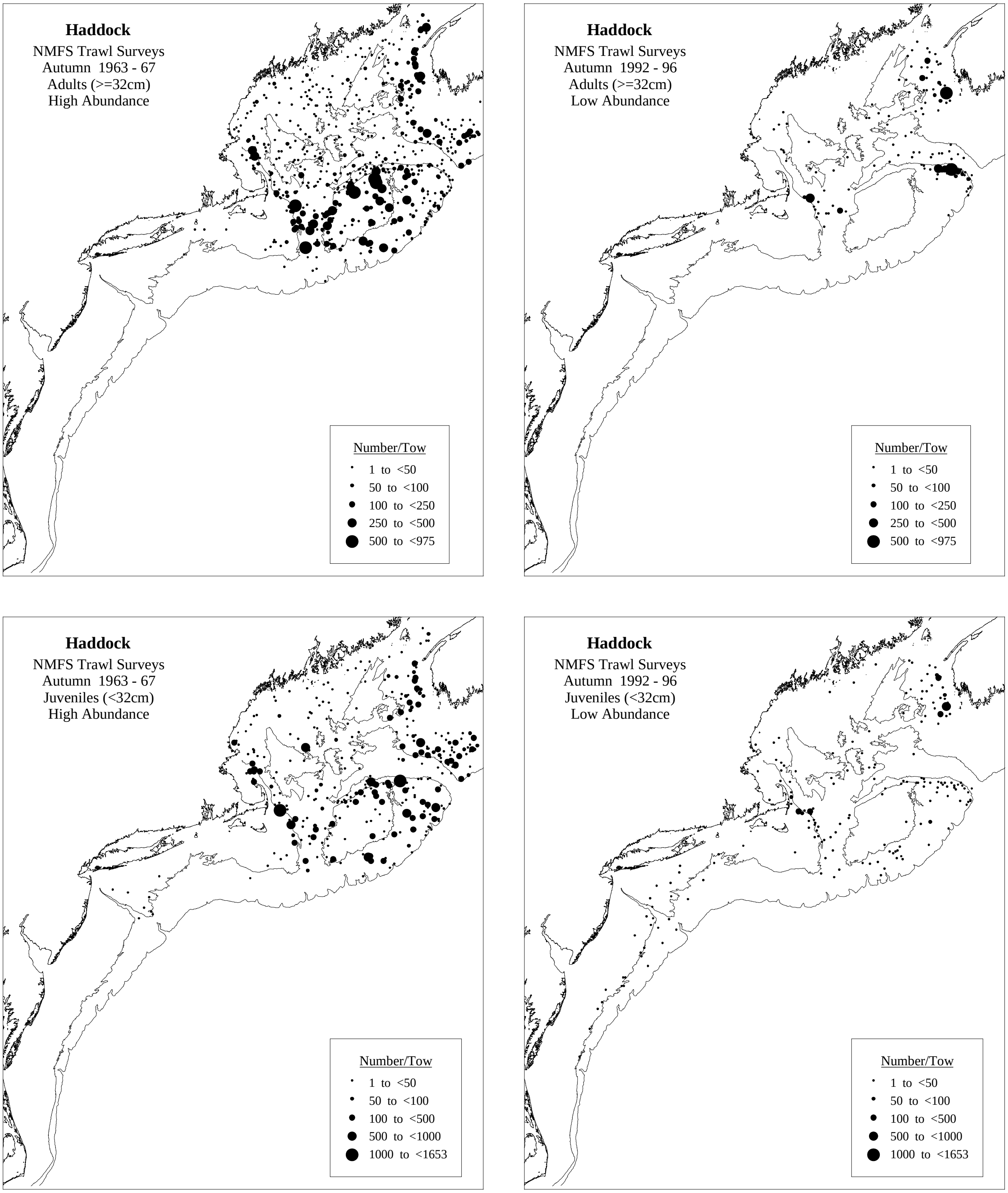


Figure 14. Distribution of juvenile and adult haddock during years of high abundance (1963-1967) and years of low abundance (1992-1996) from autumn NEFSC bottom trawl surveys.

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