NOAA Technical Memorandum NMFS-NE-187

Essential Fish Habitat Source Document:

American Plaice, *Hippoglossoides platessoides*, 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

August 2004

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Second Edition

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

Editorial Production

For "Essential Fish Habitat Source Documents" issued in the *NOAA Technical Memorandum NMFS-NE* series, staff of the Northeast Fisheries Science Center's (NEFSC's) Ecosystems Processes Division largely assume the role of staff of the NEFSC's Editorial Office for technical and copy editing, type composition, and page layout. Other than the four covers (inside and outside, front and back) and first two preliminary pages, all preprinting editorial production is performed by, and all credit for such production rightfully belongs to, the staff of the Ecosystems Processes Division.

Internet Availability and Information Updating

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

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

Species Names

The NMFS Northeast Region's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes (*i.e.*, Robins *et al.* 1991a[a], b[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 (*e.g.*, Cooper and Chapleau 1998[f]; McEachran and Dunn 1998[g]).

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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. 1991a. Common and scientific names of fishes from the United States and Canada. 5th ed. *Amer. Fish. Soc. Spec. Publ.* 20; 183 p.

[b]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991b. 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.

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

[g]McEachran, J.D.; Dunn, K.A. 1998. Phylogenetic analysis of skates, a morphologically conservative clade of elasmobranchs (Chondrichthyes: Rajidae). *Copeia* 1998(2):271-290.

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ERRATA

Page 23
In Table 5. Con't., footnote 2, change:

[2] Bigelow and Schroeder (1953); Howell and Caldwell (1984); Scherer (1984); Neilson et al. (1988); DFO (1989); Berrien and Sibunka (1999); Hebert and Wearing-Wilde 2002.

to:

[2] Bigelow and Schroeder (1953); Bowman and Michaels (1984); Howell and Caldwell (1984); Scherer (1984); Neilson et al. (1988); DFO (1989); Berrien and Sibunka (1999); Hebert and Wearing-Wilde (2002); Link and Almeida (2000); Link et al. (2002); Packer and Langton (unpubl. manuscript).

In Table 5. Con't., eliminate footnote 4:

[4] Bigelow and Schroeder (1953); Bowman and Michaels (1984); Link and Almeida (2000); Link et al. (2002); Packer and Langton (unpubl. manuscript).

In Table 5. Con't., line 1 of footnote 5, change:

[5] Huntsman (1918); Bigelow and Schroeder (1953); Backus (1957); Powles (1965); Colton (1972); Pitt (1973); Dow

to:

[4] Huntsman (1918); Bigelow and Schroeder (1953); Backus (1957); Powles (1965); Colton (1972); Pitt (1973); Dow

Page 25

In Table 5. Con't., footnote 2, change:

[2] Powles (1965); Bowman and Michaels (1984); Ross and Hokenson (1997).

to:

[2] Powles (1965); Bowman and Michaels (1984)

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 American plaice EFH source document is based on the original by Donna L. Johnson, Peter L. Berrien, Wallace W. Morse, and Joseph J. Vitaliano, with a foreword by Jeffrey N. Cross (Johnson *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 American plaice, *Hippoglossoides platessoides* (Figure 1), is an arctic-boreal to temperate-marine pleuronectid (righteye) flounder that inhabits both sides of the North Atlantic on the continental shelves of northeastern North America and northern Europe (Scott and Scott 1988; Sparholt 1990; Langton and Bowman 1981). In Europe, it is known as the long rough dab and occurs from Iceland and Spitzbergen south to the North Sea, the western Baltic, and as far south as the English Channel. In the western Atlantic, it is common from the outer coast of Labrador, south from Hamilton Inlet, Newfoundland, on the Grand Banks, in the Gulf of St. Lawrence, west and south to Cape Cod, Bigelow and Schroeder 1953; Smith et al. 1975). It occurs as far south as Montauk Point, NY. The spawning seasons are geographically connected with latitude, where spawning occurs in the southern limits first, followed by the northern region (Howell and Caldwell 1984).

It is considered to be the most abundant flatfish species in the western Atlantic Ocean (Bowering and Brodie 1991; Nagler *et al.* 1999) and to have historic importance in the offshore fishery of North America (Walsh 1994). In the early 1980s through 1990s, American plaice populations in the western Atlantic declined dramatically for undetermined causes (Beacham 1983; Bowering *et al.* 1997; Nagler *et al.* 1999), environmental changes, such as temperature (Morgan 1992) and pollution (Nagler and Cyr 1997), may be responsible. An overwhelming contributing factor to the decline in some stocks is believed to be overfishing (Nagler *et al.* 1999). Northeast stock assessment reports through 2001 classify American plaice as ‘overfished’ and that overfishing is occurring in the Gulf of Maine-Georges Bank region (O’Brien *et al*. 2002).

In Canadian waters, American plaice have been exploited since the start of the otter trawl fishery in 1947. It is one of four major species contributing to the Newfoundland and Labrador fisheries (Bowering and Brodie 1991). Notable increases in abundance of plaice were found inside the closed fishing grounds of Emerald Bank/Western Bank (Frank *et al.* 2000). In U.S. waters, the fishery for American plaice started to develop around 1975 in the Gulf of Maine as the abundance of other commercially desirable flatfish, such as yellowtail flounder, winter flounder, and summer flounder, began to decrease (Sullivan 1981). Prior to 1973, the primary use of American plaice caught on Georges Bank was for bait (Lange and Lux 1978).

LIFE HISTORY

EGGS

American plaice spawn buoyant eggs, which lack oil globules. The eggs have a characteristically large, transparent perivitelline space, which is formed from water entering between the egg and its membrane (Bigelow and Schroeder 1953). The perivitelline width is approximately 37% of the reference diameter (Russell 1976); this large sac allows the egg to float near the surface for about 2 weeks, and thus can be transported far from where it was shed (Hebert and Wearing-Wilde 2002). The eggs are smooth, non-sticky, and spherical in shape. The average diameter of an egg is 2.5 mm (range 1.38-3.2 mm). The yolk is unsegmented and unpigmented. During development, the embryo is covered with a scattered pigment and there are no pigments on the primordial fin (Russell 1976).

LARVAE

American plaice larvae hatch at 2.4 mm SL (Fahay 1983) and development of five clusters or groups of pigment begins at 4-6 mm (Klein-MacPhee 2002). Yolk absorption is complete about 5 days after hatching when the larva is 6.2-7.5 mm long. Transformation of the larva and migration of the left eye begins when the larva is approximately 20 mm. Although the duration of the transformation process varies with temperature, it is usually complete when the larva is 30-40 mm (Colton and Marak 1969).

JUVENILES

Dramatic physiological transformations occur during the juvenile stage. The body shape continues to change, flattening and increasing in depth from side to side. As the migration of the left eye across the top of the head to the right side reaches completion, descent towards the bottom begins (Huntsman 1918). Pigment patterns become more abundant and develop on the right side of the body while the left side remains unpigmented. Growth during the first year is greater in warmer, southern climates. Juveniles can reach a length of 7.6 cm by winter.

ADULTS

The adult plaice has a slender, broad body, rough scales, a small head with a sharp nose, a wide gaping mouth, and a slightly protruding lower jaw. The upper and lower jaws are lined with many small conical-shaped teeth (Hebert and Wearing-Wilde 2002). Both the anal and dorsal fins are soft rayed and extend the length of the body. The pelvic fins are smaller than the rounded pectoral fins. The dorsal fin starts above the left eye (Muus and Nielsen 1999). On the dorsal side, where both eyes reside, it is reddish brown, while the ventral side is blind and white. Adults obtain average lengths from 27-66 cm TL. As with most flatfish species, the sexes differ in size at age, with females reaching larger sizes than males (Bowering and Brodie 1991; Swain and Morgan 2001). It is the only Gulf of Maine flounder that is right-handed with a large mouth, round tail, and straight lateral line with a slight arch over the pectoral fin (Bigelow and Schroeder 1953). In many locations it is characterized as a sedentary, slow growing flatfish (Bigelow and Schroeder 1953).

REPRODUCTION

Identification of egg quality and reproduction capabilities are important for predicting fecundity and recruitment variability in marine populations of American plaice (Nagler *et al.* 1999). Measurements of fecundity have been used for determining recruitment in marine fish populations as have the counting of viable egg numbers and larval production measurements. Nagler *et al.* (1999) studied patterns of egg production, fecundity, egg quality, and hatch success of spawning female American plaice under laboratory conditions. They found no direct correlation between absolute fecundity and size of American plaice females; therefore size could not be used to predict their actual fecundity. This differs from previous studies by Pitt (1964) who showed a positive correlation between absolute fecundity and body size.

American plaice have been categorized as batch spawners. Eggs are released in batches every few days over the spawning period (Nagler *et al.* 1999). Adults spawn and fertilize their eggs at or near the bottom. Eggs drift into the upper water column after they are released (Colton and Temple 1961). Plaice produce large quantities of eggs. For example, a 40 cm plaice is capable of producing between 250,000 and 300,000 eggs, and a 65 - 70 cm plaice can produce approximately 1,500,000 eggs. Eggs float and hatch at the surface (DFO 1989; Hebert and Wearing-Wilde 2002) and the amount of time between fertilization and hatching varies with water temperature. A large amount of time could pass before young fish finally settle to the bottom (DFO 1989).

In the northern part of its range, plaice spawn in the summer (Hebert and Wearing-Wilde 2002). In the southern part of its range in the Gulf of Maine, the spawning season extends from March through the middle of June, with peak spawning activity in April and May (Bigelow and Schroeder 1953; Colton *et al.* 1979; Smith *et al.* 1975). Nursery areas are found in coastal waters of the Gulf of Maine (Bigelow and Schroeder 1953). Spawning occurs at depths < 90 m and spawning adults migrate from deeper depths into shallower grounds before spawning (Bigelow and Schroeder 1953).

MATURITY

American plaice exhibit dimorphic growth and maturation rates. Males tend to mature at an earlier age and at a smaller size (O'Brien *et al.* 1993). In northern regions there is much variation in maturity of American plaice at age and size (Pitt 1975; Bowering and Brodie 1991; Morgan and Colbourne 1999). Results from a back-calculated growth study by Fossen *et al.* (1999) indicated that sexually mature American plaice tended to be larger than immature individuals at the same age. Their study revealed a correlation between slow growth, delayed maturation, and expected maximum age. Their findings suggest that rapid growth leads to early maturation and that maturity may lead to size-selected mortality, for example, mature individuals are exposed to higher mortality rates.

In Canadian waters, maturation was determined to be density dependent. American plaice stocks would mature earlier when population levels were lower than the average population size. In addition, cohorts settling at warm temperatures with higher growth rates over their juvenile period tended to mature earlier and at a smaller size range (Morgan and Colbourne 1999).

Species in the Gulf of Maine and Georges Bank area can reach lengths of 70 cm and can attain ages > 20 years. At age 3, they are approximately 22 to 28 cm in length, between 90-190 g in weight and most are sexually mature by age 4 (O'Brien 1998). On Georges Bank, maturity studies from 1992-1996 revealed that males matured at 21.3 cm TL, and females at 29.8 cm TL and during the years 1987-1991, females matured at 28.2 cm TL (Wigley *et al.* 1998) (Table 1). In the Gulf of Maine during 1986-1990, males matured in 3 years at 22.1 cm TL and females in 3.6 years at 26.8 cm TL (O'Brien *et al.* 1993). Growth rates are higher and maturity is reached earlier in the southern areas (Scotian Shelf, Gulf of Maine) than in the north. The lowest growth rates occurred in St. Mary's Bay while the fastest growth rates occurred in the Gulf of Maine (Table 1). Powles (1965) noted that slower growth rates were observed in deeper waters. Differences also occurred between genders and after four years of age, females grew faster than males (Sullivan 1981).

Huntsman (1918) noted that the age at maturity of plaice varied as much as 11 years and depended on water temperatures. In areas of highest temperature; e.g., 10°C, in Passamaquoddy Bay and the Cape Cod region, plaice had the shortest development time to maturity (3-5 years). The lowest temperature recorded was 0°C for Newfoundland (Bay of Islands) and there, plaice had the longest development time (10-13 years) (Huntsman 1918; Bigelow and Schroeder 1953).

In Canadian waters, temperature controls spawning of American plaice, resulting in spatial and temporal variations in spawning (Bowering and Brodie 1991). Normally, American plaice are captured within wide ranges of temperatures from -1.5 to 13°C, and are most numerous within -0.5 to 2.5°C. However, during peak spawning periods bottom temperature preferences vary (Pitt 1966), ranging from 3.5°C on the Flemish Cap to -1.3°C on the northern part of the Grand Bank (Bowering and Brodie 1991).

Areas of maximum spawning occur in the western Gulf of Maine and over southeastern Georges Bank; optimum spawning temperatures range between 3-6°C. These bottom water temperatures exist throughout much of the spawning period within the 100 m isobath from Cape Cod to New Jersey (Colton 1972). Outside this southern boundary, temperatures are too high for survival rather than too high for reproduction (Colton 1972).

FOOD HABITS

American plaice larvae show a gradual shift in size-selective preference when maxilla length ranges change from 100-200 μm to 200 - ≥ 500 μm (Pepin and Penney 1997). Larvae feed on plankton, diatoms, and copepods found in the upper water layers. Prior to settling, juveniles feed on small crustaceans, polychaetes, and cumaceans (Bigelow and Schroeder 1953). When they do settle on the ocean floor, their diet gradually changes as fish grow and the size of their mouth gape increases to accept wider sized prey (DFO 1989). Feeding competition exists between young plaice and cod (Powles 1965).

Adult plaice are opportunistic feeders, flexible in their dietary habits, and will take whatever is most abundant or accessible (Langton and Bowman 1981; Macdonald and Green 1986; Langton and Watling 1990; Keats 1991; Zamarro 1992; Klemetsen 1993; Ntiba and Harding 1993; Martell and McClelland 1994; Packer *et al*. 1994; Berestovskiy 1995). Although their normal habitat is at or near the ocean floor, and they are considered benthic feeders, they frequently migrate off the bottom at night in pursuit of prey (DFO 1989). They are categorized as a predator whose diet composition consists of a combination of small benthic crustaceans, echinoderms, cnidarians, and polychaetes (Bowman *et al.* 2000; Table 2 and Table 3). Diets of adults are primarily echinoderms, chiefly sand dollars, sea urchins, and brittle stars (Huntsman 1918; Pitt 1973; Sullivan 1981; Keats 1991). The brittle star, *Ophiura sarsi*, makes up 65% of the plaice diet at some locations in the Gulf of Maine (Klein-MacPhee 2002). The diets of plaice collected during 1973-2001 Northeast Fisheries Science Center (NEFSC) bottom trawl surveys were also dominated by echinoderms; arthropods, annelids, and mollusks were also eaten (Figure 2). The stomach contents of plaice from western Nova Scotia, Gulf of Maine, Georges Bank, and Southern New England are generally similar (Powles 1965; Minet 1973; Pitt 1973; Langton and Bowman 1981) although the specific prey consumed can vary geographically.

Off the coastal bank of Norway, American plaice feeding habits are distinctly different from other flatfish species. They feed more on benthic and epibenthic organisms such as ophiuroids and crustaceans. In the North Sea they feed on more fish (particularly sandlance), as well as polychaetes, crustaceans and ophiuroids (Ntiba and Harding 1993; Høines and Bergstad 2002). In Passamaquoddy Bay, Canada, amphipods, mysids, euphausiids, polychaetes, bivalve mollusks and Atlantic herring are the major prey of plaice (Tyler 1971, 1972; Macdonald and Green 1986; Macdonald and Waiwood, 1987). In Sheepscot Bay, Maine, polychaetes, mysids, amphipods, sand shrimp (*Crangon septemspinosa*), and Atlantic herring are important prey (Langton and Watling 1990; Packer and Langton, unpublished manuscript.). Offshore in the Gulf of Maine, the brittle star *Ophiura sarsi* is one of the dominant epifaunal taxa (Watling *et al*. 1988) and is the primary prey of plaice; crustaceans (euphausiids and pandalid shrimp), bivalve mollusks (*Yoldia* spp., *Chlamys islandica*, *Cerastoderma pinnulatum*), and tube-dwelling polychaetes are of secondary importance (Langton and Bowman 1981; Bowman and Michaels 1984; Packer *et al*. 1994). Using NEFSC data from 1977-1980, Bowman *et al*. (2000) found that on Georges Bank, they ate almost exclusively echinoderms, making up 92% of the total stomach content by weight. In the Gulf of Maine they consumed mostly echinoderms (47% by weight) and bivalve mollusks (26% by weight). Mollusks accounted for over 60% of the diet (by weight) on the Scotian Shelf. Inshore north of Cape Hatteras the preferred prey consisted of echinoderms (47% by weight) and crustaceans (18% by weight) (Table 3). In southern New England, plaice consume large quantities of amphipods, shrimp (*Crangon*), polychaetes, and bivalves (Klein-MacPhee 2002).

The 1973-2001 NEFSC food habits database for American plaice (Figure 2) shows that diet composition did not change significantly over time, with echinoderms and ophiuroids remaining the dominant prey types (Link *et al.* 2002). Previous studies suggest there are ontogenetic shifts in diet, with American plaice consuming fewer polychaetes as their body size increased. Smaller (< 16-30 cm) individuals fed predominately on polychaetes, crustaceans, and small brittle stars. As they grew larger (> 30 cm) they fed primarily on bivalve mollusks, brittle stars and other echinoderms, decapods, and fish (Huntsman 1918; Powles 1965; Pitt 1973; Langton and Bowman 1981; Bowman and Michaels 1984; Martell and McClelland 1994). A detailed listing of prey-type (by percent weight) by size-class of plaice, from Bowman *et al.* (2000), is shown in Table 2. Bowman and Michaels (1984) reported that polychaetes were especially important prey of plaice < 20 cm and noted that the largest fish fed mostly on echinoderms. In Sheepscot Bay, Maine, mysids generally decreased in importance with increasing predator size while polychaetes appeared to increase (Packer and Langton, unpublished manuscript).

Seasonal shifts occurred as well. Echinoderms and other invertebrates were heavily consumed in the spring, then bivalves, pandalids and polychaetes in summer, followed by ophiuroids and fish eggs in autumn (Link *et al.* 2002). There is little or no feeding during January and February. This is followed by a rapid increase in feeding in May, which continues through September (Powles 1965). The highest feeding rates occur during the summer, enabling high-energy production for metabolic use and gonad maturation (MacKinnon 1972).

PREDATION AND MORTALITY

American plaice larvae are commonly consumed by redfish (Klein-MacPhee 2002). Larger plaice ≤ 35 cm are frequently preyed on by cod and other bottom feeding species (Powles 1965; Bowman and Michaels 1984). Adults are consumed by Greenland sharks, cod, halibut, goosefish, and spiny dogfish (Bigelow and Schroeder 1953; Hebert and Wearing-Wilde 2002). Along the Scotian Shelf and in the Gulf of St. Lawrence, grey seals are the primary predators of plaice (Benoit and Bowen 1990). Harbour seals in Sable Island, Nova Scotia exhaust minimal foraging energy and secure high capture rates while preying upon American plaice and other flounders (Bowen *et al.* 2002).

In the Newfoundland-Labrador fishery it was determined that fishing contributed more to mortality at a much greater rate than predation, discarding, disease, starvation, temperature or environmental changes (Bundy 2001). The northern shrimp trawl fishery operates December through May from the Stellwagen Bank area off Massachusetts to the central Maine coast (McInnes 1986; Ross and Hokenson 1997). Worldwide, this industry accounts for 35% of the discarded bycatch (Alverson *et al.* 1994; Ross and Hokenson 1997). In New England, mortalities of American plaice were positively correlated with on-deck sorting time. Also seabird (e.g., great black-backed gulls and herring gulls) predation was relatively high for American plaice. Consumption by seabirds was found to be directly proportional to the amount of time the fish were on deck (Ross and Hokenson 1997).

MIGRATION

In U.S. and Canadian waters, American plaice is regarded as a sedentary species migrating only for spawning and feeding (Pitt 1969; Colton 1972; Bowering and Brodie 1991). Results from tagging studies have indicated only minor distances in migration. Most recaptured plaice were less than 30 miles from the tagging site and approximately 7-8 years after tagging (DFO 1989).

In Canadian waters, American plaice tend to occupy a wide depth range, often migrating to deeper offshore locations in the winter and returning to shallower water by spring (Hebert and Wearing-Wilde 2002). They have been captured at depths of 700 m; typically, the largest commercial catches occur between 100 - 200 meters at a temperature < 1.0°C (Hebert and Wearing-Wilde 2002).

GEOGRAPHICAL DISTRIBUTION

American plaice occur on both sides of the North Atlantic. On the western side of the Atlantic, it is common from the outer coast of Labrador, Newfoundland, the Grand Banks, and the Gulf of St. Lawrence west and south to Cape Cod; its southern limit is Montauk Point, NY (Bigelow and Schroeder 1953; Smith *et al.* 1975). It also occurs in North Atlantic estuaries and rivers where it ranges from highly abundant to rare (Jury *et al.* 1994; Table 4). Plaice are also found in inshore areas north of Cape Hatteras, NC (Bowman *et al.* 2000).

EGGS

Ichthyoplankton collections made in Cape Cod Bay revealed that plaice eggs were present from January through July, and larvae were present from January through August (Scherer 1984). Early stage eggs were collected on the northern perimeter of the Bay suggesting that it was a spawning site. The southern distribution of late-stage eggs suggested displacement by counter-clockwise drift patterns in the Bay. It is believed that the American plaice eggs may have been spawned outside of Cape Cod Bay and carried into the Bay by prevailing currents. The eggs could have drifted as much as 49.0 km from their original spawning location (Scherer 1984). Smith *et al.* (1975) determined from the low larval occurrence and the prevailing circulation patterns off southern New England that spawning had occurred along the southern edge of Georges Bank and that currents flowing into the Middle Atlantic Bight subsequently transported the larvae.

The NEFSC Marine Resources Monitoring, Assessment and Prediction (MARMAP) ichthyoplankton surveys (1978-1987; see Reid *et al.* [1999] for details) captured eggs throughout the year (Figure 3). During February and March, eggs were collected on Stellwagen Bank, off Cape Ann, on Jeffreys Ledge, along coastal Maine, and on Georges Bank. During April and May, the highest egg concentrations occurred along the eastern edge of Georges Bank and along the coastal areas off eastern Massachusetts, the Gulf of Maine, southwest Nova Scotia, and Browns Bank. From June through December, eggs were collected almost exclusively along the coastal areas in the Gulf of Maine; some eggs were collected on Georges Bank and the Scotian Shelf.

The cumulative distribution and abundance of American plaice eggs for all Georges Bank U.S. Global Ocean Ecosystems Dynamics (GLOBEC) ichthyoplankton surveys during 1995-1999 are shown in Figure 4. American plaice eggs were generally restricted to locations within depth zones $\geq$ 56 m. They were most abundant at greater depths on Georges Bank (56-110 m); along the Great South Channel, the central and eastern part of the southern flank and the northern part of the Northeast Channel where depths are > 185 m. Very few eggs were captured during January. Catches increased tenfold by February along the eastern part of the Northeast Peak reaching peak numbers by March. The occurrence of eggs extended eastward along the southern flank of Georges Bank and into the eastern section of Georges Basin. By April, the high concentrations shifted toward the western part of the southern flank. In May and June catches of eggs declined dramatically, with centers of abundance still along the southern flank of Georges Bank.

LARVAE

Sullivan (1981) found that larval plaice were transported by currents southwest along the coast; some were retained in the Gulf of Maine while others were transported to Georges Bank. Changes in circulation patterns also lead to large numbers of pelagic larvae being transported off Georges Bank (Colton and Temple 1961; Sullivan 1981). Larval plaice that drift into the slope water zone along the southern edge of Georges Bank are susceptible to transport in a northeasterly direction away from Georges Bank and the continental shelf. Differences in temperature between the coastal and slope water zones could affect the transported larvae by subjecting them to thermal stress. Plaice larvae were found in relatively shallow waters on Georges Bank, in Massachusetts Bay, and along coastal Maine (Smith *et al.* 1975).

Larvae were first captured in the NEFSC MARMAP ichthyoplankton surveys (1977-1987) in small numbers during March on the southeastern flank of Georges Bank (Figure 5). By April, numbers increased throughout Georges Bank and larval distributions spread towards the Great South Channel and onto Nantucket Shoals. Peak abundance occurred during May from Georges Bank as far south as Delaware. The highest May abundance occurred around Cape Cod Bay and along the 60 m contour on Georges Bank. Larval abundance decreased dramatically in June and continued to decline in August.

The cumulative distribution and abundance of American plaice larvae for all GLOBEC Georges Bank surveys is shown in Figure 6. As with the distribution of eggs, the overall pattern was retained within the deeper water zones. Centers of abundance were also located in areas of the Great South Channel and along the southern flank. Few larvae were collected during February. During March and April, larvae were abundant from the central part of the southern flank westward to the Great South Channel at depths ranging between 56-110 m. In May, areas of higher abundance appeared along the northern part of the Great South Channel. By June, abundance levels dropped at all areas across Georges Bank.

JUVENILES

NEFSC bottom trawl surveys [see Reid *et al.* (1999) for details] captured juvenile ($\leq$ 26 cm TL) American plaice year-round, mostly in the Gulf of Maine and Georges Bank (Figure 7; note that winter and summer distributions are presented as presence data only, precluding a discussion of abundances). In winter, they were mostly scattered throughout the Gulf of Maine and the Great South Channel; some occurred on Georges Bank, especially along the northern edge, and in southern New England. In spring, plaice were found in the same areas, but the highest densities were in the western Gulf of Maine, especially near the coast and off Cape Cod, including Massachusetts and Cape Cod Bays. They also appear to be concentrated in the western Gulf of Maine in the summer. Fall distributions are similar to those in the spring, with many also in the Great South Channel and on the northern edge of Georges Bank.

The distributions and abundances of both juvenile and adult American plaice 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 8. They were most abundant in the southwestern Gulf of Maine in the spring (Figure 8 and Figure 9). Spring catches showed a larger size range (Figure 10), while fall catches were made up of more juveniles (Sherman *et al*. 2005).

Both the spring and fall 1978-2003 Massachusetts inshore trawl surveys [Figure 11; see Reid *et al*. (1999) for details] show that juvenile American plaice were abundant around Cape Ann, Massachusetts Bay, and in Cape Cod Bay.

ADULTS

NEFSC bottom trawl surveys [see Reid *et al*. (1999) for details] captured adult American plaice (> 26 cm TL) in the same areas as the juveniles, but generally in lower numbers in spring and fall (Figure 12; again, winter and summer distributions are presented as presence data only, precluding a discussion of abundances). In winter, they were scattered throughout the Gulf of Maine and Georges Bank, with a few in southern New England. In spring, they were found in the same areas, with the highest densities in the western Gulf of Maine, especially near the coast, off Cape Cod, and near the Great South Channel, as well as on the northern edge of Georges Bank and central Georges Bank. Adults also appear to be heavily concentrated in the western Gulf of Maine in the summer. Fall distributions are somewhat similar to those in the spring, but the adults are even more abundant in the western Gulf of Maine and near the Great South Channel, with lower numbers throughout Georges Bank.

The distributions and abundances of both juvenile and adult American plaice along the coasts of Maine and New Hampshire, based on spring and fall 2000-2004 Maine-New Hampshire inshore groundfish surveys, was discussed previously (Sherman *et al*. 2005).

The distributions of the adults in both the spring and fall 1978-2003 Massachusetts inshore trawl surveys (Figure 13) are similar to those of the juveniles, but in lower overall numbers. Again, they were abundant around Cape Ann, Massachusetts Bay, and in Cape Cod Bay.

HABITAT CHARACTERISTICS

Information on the habitat requirements and preferences of American plaice (based on both the pertinent literature and the most recent NEFSC and state surveys) are presented here and summarized in Table 5 and Table 6.

EGGS

In the northwest Atlantic, plaice eggs have been collected during all months of the year (Berrien and Sibunka 1999). In the Gulf of Maine and on the Scotian Shelf, egg abundance peaked in early April and May (Smith *et al.* 1975; Neilson *et al.* 1988).

Data from the NEFSC MARMAP ichthyoplankton surveys (Figure 14) and the GLOBEC Georges Bank survey (Figure 15 and Figure 16) were used to determine the relationships between bottom depth and water column temperature and American plaice egg abundances. Eggs from the MARMAP survey were found over depths ranging from 10 m to approximately 325 m, with the majority occurring between about 50-90 m. Eggs from the GLOBEC Georges Bank survey occurred as deep as 501-1000 m; however, the majority were found between 41-100 m.

Plaice eggs were collected at temperatures ranging from about 1-12°C during the MARMAP survey. During February through April, most eggs were collected between 3-6°C. During May to July the majority of eggs were found at 5-8°C. From August to December, eggs were found at higher temperatures, with most eggs found at approximately 9-11°C. During the seven-month period of the GLOBEC Georges Bank survey, eggs remained within a narrow range of about 4-8°C.

Bigelow and Schroeder (1953) reported that eggs incubate from 11 to 14 days at 3.9°C. Howell and Caldwell (1984) reared embryos and yolk-sac larvae at temperature regimes of 2, 6, 10, and 14°C. For all temperatures ≤ 10°C, a positive correlation resulted between temperature and the development rate; growth of those reared at 10°C was the fastest. Mortality resulted for all embryos reared at the upper thermal limit of 14°C. The laboratory controlled embryos and larvae were smaller in size at yolk-sac absorption than their wild reared counterparts and would be more susceptible to predation and starvation. However, those reared between 2-6°C were larger and developed a greater probability of surviving and first feeding.

LARVAE

Shepherd *et al.* (2000) reared yolk-sac larvae at two controlled temperatures of 5° and 10°C during the developmental period to test swimming capabilities and escape responses. They found a significant relationship between temperature and development of finfold area and yolk-sac size at age. Larvae reared at 10°C had larger fin fold area and used up their yolk-sac reserves earlier. Therefore in many cases the development rate was altered by the temperature and affected swimming performance, but there was no effect on escape response. American plaice larvae with low development rates do appear to have an advantage when food is scarce.

Larvae from the NEFSC MARMAP ichthyoplankton surveys (Figure 17) were found over depths ranging from 30-210 m, with most occurring at 50-90 m except for August, where about 45% also occurred at 130 m. Larvae occurred from February through June during the GLOBEC Georges Bank surveys (Figure 18 and Figure 19). The bottom depths where larvae were captured ranged from 41 m to between 301-350 m, with the majority between 41-120 m. The depth at which larvae occurred remained constant from February to May, changing to deeper waters in June.

Plaice larvae were captured at temperatures ranging from 4-14°C during the NEFSC MARMAP surveys. Larvae were most abundant at 5-8°C from March through June and 10-12°C during July and August. During the GLOBEC Georges Bank survey, larvae were found in the coldest temperatures (4-6°C) from February to April. In May and June the larvae were found from 6-11°C.

JUVENILES

The spring and fall distributions of juvenile American plaice (≤ 26 cm TL) relative to bottom water temperature, depth, and salinity based on 1963-2003 NEFSC bottom trawl surveys from the Gulf of Maine to Cape Hatteras are shown in Figure 20. In the spring, juveniles were found between 2-10°C, with most between 4-6°C. During autumn, they were found between 4-16°C, with the majority between about 5-11°C. They occurred at depths ranging from 11-400 m in both the spring and autumn. They were caught in a salinity range of 31-35 ppt, with the majority found at 33 ppt during both seasons.

The spring and autumn distributions of juvenile American plaice in Massachusetts coastal waters relative to bottom water temperature and depth based on 1978-2003 Massachusetts inshore trawl surveys are shown in Figure 21. Juvenile plaice were collected at temperatures ranging from 1-12°C during the spring, and 4°C to about 17°C during the autumn. They were most abundant at 4-6°C in the spring and 7-10°C in the autumn. In the spring, they were found over depths ranging from 6-85 m, with the majority occurring between about 46-65 m. During autumn they were also found from 6-85 m, with the majority again occurring between approximately 46-65 m.

ADULTS

The geographic boundaries of American plaice distribution appear to be defined by warm summer and fall temperatures. Since the early 1940s, coastal warming and cooling trends have been observed in waters between Cape Sable and Long Island (Colton 1972). These trends are related to changes of subsurface water. Cold years are defined as years when coastal water from Labrador displaces slope water. Warm years occur when there is a low ratio of coastal to central Atlantic water and slope water borders the 200 m isobath.

The spring and fall distributions of adult American plaice in the Gulf of Maine and on Georges Bank relative to bottom water temperature, depth, and salinity based on NEFSC bottom trawl surveys are shown in Figure 22. Adults in the spring appeared to have similar temperature preferences to juveniles with most found at temperatures from 4-6°C with an overall range of 1-12°C. In autumn, plaice were found in a temperature range of 3-15°C, with most at about 6-9°C. Their depth range in spring was from 11-400 m and in fall the range was from 21-400 m. They were caught in a salinity range of 31-35 ppt, with the majority found at 33 ppt in the spring and 33-34 ppt in the autumn.

The spring and autumn distributions of adult American plaice in Massachusetts coastal waters relative to bottom water temperature and depth are shown in Figure 23. Adults had similar temperature preferences to the juveniles. Adult plaice were collected at temperatures from 1-12°C during the spring and 4-14°C during the autumn. The majority was found between 4-6°C in the spring and 7-9°C in the autumn. Adults were found at depths ranging from 6-85 m in the spring and 16-85 m during the autumn.

American plaice display great contrasts in seasonal habitat association in different geographic regions. Generally, American plaice from southern Labrador to Rhode Island are found in deep water from 90-180 m and do not normally occur in water less than 25-35 m (O'Brien 2000; Dery 1998). In Canadian waters they occur in temperatures ranging from approximately –1.5°C to temperatures above 5°C and from depth locations inshore down to 700 m. Preferences in temperature are 0-1.5°C and depths 90-250 m (DFO 1989). Generally, plaice encountered in the deeper depth ranges are at higher temperatures (DFO 1989). Scott (1982a) reported that on the Scotian Shelf, American plaice ranged between depths of 27-366 m, with preferences between 55-128 m, while their temperature range was between 0-13°C, with preferences between 1-4°C. However, in other locations such as on the Grand Bank's Division 3L, they have been captured at depths > 800 m (Iglesias *et al.* 1996). Other surveys in the U.S. and commercial catch statistics generally confirm similar movement and depth preferences in the Gulf of Maine (Colton 1972). Gulf of Maine plaice normally occur in waters 25-180 m deep, but are also found in shoal waters when temperatures are severely cold (Bigelow and Schroeder 1953). With the exception of witch flounder, plaice is considered the most abundant of all flatfish in the Gulf of Maine at depths between 54-90 m (Klein-MacPhee 2002). They are also widespread on Georges Bank along the 90-180 m zone of its northern edge (Bigelow and Schroeder 1953).

Dow (1977) found that water temperatures influence the abundance of American plaice in a study of climatic effects on relative abundance and availability. There were significant positive correlations between the annual catch of fish off the Maine coast and mean annual surface temperatures. These results imply that temperature is a limiting factor in the abundance of American plaice.

Temperature is a chief determinant of habitat quality for fish (Fry 1971; Reynolds and Casterlin 1979; Swain and Morgan 2001). The relationship between the amount of food available and temperature ultimately affect growth rates in fish, because prey are often more readily abundant at certain depth ranges. For plaice, this is more pronounced in some areas than others, such as in the southern Gulf of St. Lawrence and off Newfoundland. It has been observed that female plaice seek warmer temperatures during feeding (Swain *et al.* 1998). It is believed that these warmer locations also provide optimal conditions for growth during the summer. Temperature-mediated differences in metabolic rate have been used to explain relationships in different latitudinal locations and maximum body length as well as other features of American plaice (Walsh 1994; Walsh 1996). Stratoudakis *et al.* (1997) found differences in life history features by comparing length frequency and age of plaice from two geographically different areas. Behavior, such as swimming mobility, can also be effected by extreme temperatures. Laboratory studies of swimming speeds of American plaice when herded by trawl gear also revealed swimming efficiency to be temperature and size dependent (Winger *et al.* 1999).

Swain *et al.* (1998) found significant differences in habitat selection by plaice for both the winter (January) and summer (September) seasons. Both genders were found to occupy deeper, warmer water during the winter time period. Females were found to occupy significantly warmer water in September during the feeding season in the southern Gulf of St. Lawrence and exhibited a faster growing rate than males. In this location, plaice were found at depths of 58-67 m and temperatures of –0.1 to 0.3°C in September, and at depths of 374-426 m and temperatures of 5.2-5.4°C in January. Minimal feeding occurs during the overwintering period in some northwest Atlantic groundfish populations (Powles 1965; Swain *et al.* 1998).

Murawski (1993) used data from NEFSC bottom trawl surveys and principal component analyses to classify American plaice as a deep-cold water sedentary species. In comparison to the entire shelf, the Gulf of Maine has a narrow temperature range with increasing depth (Holzwarth and Mountain 1990; Murawski 1993). Thus, in the deep waters of the Gulf, American plaice are not subjected to the as much temperature variability as shallow water inhabitants.

American plaice occur at mean salinities of 20-22 ppt in Hamilton Inlet, Labrador (Backus 1957), 30 ppt or lower in Baltic areas, 32.8 ppt in the Gulf of Maine, and 34 ppt in offshore Atlantic waters (Bigelow and Schroeder 1953).

During a study of fishes of the Scotian Shelf, Scott (1982a) found American plaice had salinity preferences between 31-34 ppt; highest abundance occurred at 33 ppt. Of the 31 species studied by Scott (1982a), American plaice displayed the widest salinity, depth, and temperature ranges.

American plaice prefer a soft bottom substrate (Sparholt 1990; Langton and Bowman 1981) and they are frequently found on fine sand or gravel bottoms (Scott and Scott 1988; Bowering and Brodie 1991). Under laboratory conditions, Morgan (2000) found that American plaice demonstrated a clear preference for finer gravelly sand particles over courser gravel substrate. When temperature and substrate were tested together, plaice would continue to prefer sand even if the temperature fell below zero degrees. On the Scotian Shelf, plaice were most abundant on sand and gravel substrates (Scott 1982b). They were found in lesser numbers on sand, silt, and clay and were rare on Scotian Shelf drift (a mixed substrate). In eastern Newfoundland, plaice were frequently collected where sandy substrates bordered areas of bedrock. It is believed that they occur near bedrock because bedrock is the preferred habitat of an important prey species, green sea urchins (*Strongylocentrotus droebachiensis*) (Keats 1991). In some areas, their distribution has been correlated with mud substrates (Walsh 1996; Packer and Langton, unpublished manuscript).

RESEARCH NEEDS

- Determination of how depth, temperature, and bottom type control the spatial and temporal distribution of plaice; this is especially important for U.S. populations where little research has been conducted.

- Confirmation of vertical migration and seasonal distribution patterns of early life stages.
- Age and growth determination based on otolith microstructure for early life stages.
- The strength of habitat dependency and/or interaction for juveniles and adults.
- Determination of adult migration patterns (i.e., tagging studies).

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"Food and feeding of 5,592 individuals of American plaice (*Hippogolossoides platessoides*, Fabricius) was examined from Grand Bank (NAFO Divisions 3NO), Flemish Cap (NAFO Div. 3M) and Svalbard Area (ICES Div. IIb). Differences in diet composition were observed by areas. Feeding intensity was higher on Flemish Cap (77.6%) and lower in the Svalbard (4.7%). There was significant seasonal feeding variation in the Svalbard, with higher feeding intensity in summer. The main groups of prey were Pisces (46%), Echinodermata (20%), Crustacea (16%) and Mollusca (10%). The prey spectrum was larger in the south of the Grand Bank, the main prey being Pisces (64%), while both on Flemish Cap and in Svalbard the main prey was Ophiuroidea (39%). Feeding pattern indicated that American plaice is a daytime feeder, and no marked differences were noted over a 24 hour period. Low cannibalism intensity was observed on Grand Bank. A greater similitude was present between the diets on Flemish Cap and in Svalbard. Composition and overlapping diet, by length classes, were also analyzed."

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"American plaice from off New England (ICNAF Subarea 5) grow faster than in western north Atlantic waters farther to the north. Von Bertalanffy growth equations were $l_t = 450\left[1 - e^{-0.27(t-0.41)}\right]$ for males and $l_t = 675\left[1 - e^{-0.15(t-0.10)}\right]$ for females."

Morgan, M.J. 2001. Time and location of spawning of American plaice in NAFO divisions 3LNO. J. Northwest Atl. Fish. Sci. 29: 41-49.

"Spawning times and spawning locations of American plaice (*Hipploglossoides platessoides*) on the Grand Bank (NAFO Divisions 3LNO) were examined from 1971 to 1999. No specific spawning locations were identified; rather, spawning was widespread throughout the Grand Bank. Spawning occurred over a broad seasonal period; spawning females were found in all months from February through August, with the highest proportion of spawners occurring in April through June. Significant annual variability occurred in the time of spawning, with a trend towards later spawning in the early-1990s. Spawning time was positively correlated with temperature and depth, and negatively correlated with the weighted mean age of the spawning stock biomass."

Morgan, M.J. 2003. A preliminary examination of variability in condition of American plaice in NAFO divisions 3LNO. Sci. Counc. Res. Doc. NAFO. 03/11. 14 p.

"Spatial and temporal changes in condition were examined for American plaice (*Hippoglossoides platessoides*) in NAFO Div. 3L, 3N and 3O. Data were available from spring and fall Canadian research vessel surveys from 1993 to 2002 (2001 for fall). Data were available for males and females for both total body and liver weight. There was a clear seasonal difference in condition of American plaice with condition being higher in the fall. Relative body condition tended to be highest in Div. 3N in both spring and fall. Relative liver condition was highest in Div. 3L and lowest in Div. 3O in both seasons. There were no significant correlations between condition and abundance in a NAFO Division. There was significant annual variability in condition but no consistent pattern over time."

Morgan, M.J. 2003. Variation with age in the timing and duration of spawning in American plaice. J. Fish. Biol. 62: 464-473.

"Spawning time of female American plaice *Hippoglossoides platessoides* varied significantly with age. This effect, however, was not consistent across years. Generally, younger fish spawned earlier than older fish, but in the 1990s they spawned later than older fish. Spawning duration also varied with age, with younger fish generally having a longer spawning period than older fish. Changes in depth distribution were

related to changes in both spawning time and duration. As depth increased, spawning time became later and duration became shorter. Fish < 11 years old showed the largest change in both spawning time and depth distribution."

Morgan, M.J., W.B. Brodie, and D.W. Kulka. 2002. Was over-exploitation the cause of the decline of the American plaice stock off Labrador and northeast Newfloundland? Fish. Res. 57: 39-49.

"The population of American plaice in the waters off Labrador and on the northeast Newfoundland shelf declined substantially during the mid to late 1980s, early 1990s at a time when reported catches were very low. An earlier study examined the overlap in distribution between American plaice and cod in research vessel survey data and concluded that unreported bycatch in the cod fishery could explain the decline of the Div. 2J portion of the Subarea 2+ Div. 3K stock of American plaice. We evaluate the method proposed in that study and use reported and observer estimates of catch to investigate potential catch levels relative to survey estimates of population biomass. This method does not appear to be a good predictor of American plaice bycatch in the cod fishery as most of the regressions were not significant and it requires extrapolation well beyond the range of the data used to build the regressions. Furthermore, there was a little overlap between the extent of the commercial cod fishing grounds and the distribution of American plaice in the autumn surveys. For this stock, catch to survey biomass ratios were low regardless of the source of information used to estimate catch and suggest an exploitation rate that should be well below sustainable levels. These analyses support the conclusion that fishing was not the cause of the decline in this population of American plaice."

Nevinsky, M.M. and V.P. Serebryakov. 1973. American plaice, *Hippoglossoides platessoides* Fabr., spawning in the Northwest Atlantic area. Int. Comm. Northwest Atl. Fish. (ICNAF) Res. Bull. 10: 23-26.

"The temporal and spatial distribution of American plaice spawning in Subareas 2, 3, and 4 are based on ichthyoplankton collections at 3,127 stations during 1959-70 and the maturity condition of the gonads of 9,000 adult specimens taken from commercial catches during 1954-70. American plaice seem to spawn in most parts of the area in depths of 50 to 250 m. The main spawning areas are on the northern shallows of the Grand Bank, off southern Newfoundland, on St. Pierre and Green Banks, off Cape Breton and on Banquereau Bank. The temperatures of the near-bottom and the surface water layers over the spawning grounds were from 0° to 6°C and 6° to 18°C respectively. The most intensive spawning was observed in April, May, and June with near-bottom temperatures from 0° to 2.5°C. The spawning grounds are situated in the areas of action of branches of the Labrador Current or in those of cold water from the Gulf of St. Lawrence. Larvae at different stages of development were found in the same general areas as the eggs, i.e. mostly over the spawning grounds. The low current velocities over the spawning areas and the peculiarities of larvae distribution indicate that the passive migration period of the American plaice is not long during their early stage of development."

Ollerhead, L.M.N., M.J. Morgan, D.A. Scruton, and B. Marrie. 2004. Mapping spawning times and locations for 10 commercially important fish species found on the Grand Banks of Newfloundland. Can. Tech. Rep. Fish. Aquat. Sci. 2522. 49 p.

"Using data collected on Department of Fisheries and Oceans (DFO) research vessel surveys, a Geographic Information System (GIS) was used to create maps that illustrated locations and timing of higher intensity spawning for ten commercially important fish species found on the Grand Banks. The maps showed that within the coverage of the Grand Banks surveys, peak spawning occurred for many species in spring and early summer with the location of the spawning peak often varying from month to month. Marked areas of higher intensity spawning were found for most species, with other, lesser amounts occurring simultaneously in other regions of the survey. During peak season in the spring and early summer, considerable spawning activity was observed on much of the Grand Banks. Historical versus recent spawning trends were also mapped to illustrate how the locations of the higher intensity spawning areas behaved over a longer time frame. These maps showed, for some species, that the spawning areas were static while others were dynamic. This project studied American plaice (*Hippoglossoides platessoides*), Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), redfish (*Sebastes* spp.), witch flounder (*Glyptocephalus cynoglossus*), yellowtail flounder (*Limanda ferruginea*), northern shrimp (*Pandalus borealis*), Iceland scallop *(Chlamys islandica*), sea scallop (*Placopectin magellanicus*) and surf clam (*Spisula solidissima*)."

Walsh, S.J., M. Simpson, M.J. Morgan, K.S. Dwyer, and D. Stansbury. 2001. Distribution of juvenile yellowtail flounder, American plaice and Atlantic cod on the southern Grand Bank: A discussion of nursery areas and marine protected areas. Sci. Counc. Res. Doc. NAFO. 01/78. 49 p.

"The annual Canadian fall bottom trawl survey data from the southern Grand Bank, NAFO Div. 3NO were examined for the period 1985-1999 for the location of possible nursery areas for yellowtail flounder, American plaice and cod. Only the juvenile yellowtail flounder nursery area remained geographically localized throughout the time series with minimum temporal and spatial shifts. There was a large shift in the temporal and spatial pattern of juvenile plaice nursery areas in the southern Grand Bank, which may be related to a reduced overall stock size. This was also evident in the northern nursery area of Div. 3L. The temporal and spatial pattern of juvenile cod was also quite variable which may be related to changes in population size and bottom temperatures. The main nursery area for yellowtail flounder occupied the area of the southern portion of the Southeast Shoal together with area immediately to the west, i.e. in the NAFO Regulatory Area outside Canada's 360 km economic zone. This nursery is the only area for which a physical boundary can be defined in the context of establishing a Marine Protected Area. Two areas, a small and large box, were suggested that encompass, on average, 62% (small box) and 83% (large box) of all the juvenile yellowtail flounder on the southern Grand Bank. On average, 14% and 32% of all juvenile American plaice, respectively, and 13% and 44% of all juvenile cod, respectively, on the southern Grand Bank were found in these two boxes."

Wigley, S.E. and W.L. Gabriel. 1991. Distribution of sexually immature components of 10 northwest Atlantic groundfish species based on Northeast Fisheries Center bottom trawl surveys, 1968-86. NOAA Tech. Mem. NMFS-F/NEC-80. 17 p.

"Analyses of data obtained from research vessel survey cruises over a 19-year period reveal distinctive patterns in the geographic occurrence of immature fish. These occurrences provide qualitative evidence for potentially significant fishing mortality of the sexually immature components of 10 species in the Gulf of Maine-Georges Bank-Southern New England region, where substantial overlap exists between unregulated mesh/exempted fishing areas and the distributions of these immature fish."

Table 1. The age and length at maturity of female American plaice in the northwest Atlantic.

Area	**A_{50}** (yrs)	**L_{50}** (cm)	**Year**	**Source**
Labrador	8.11	45.84	1978-1988	Bowering and Brodie (1991)
Northern Grand Bank	13.98	42.14	1961-1965	Pitt (1975)
Northern Grand Bank	10.57	40.36	1969-1972	Pitt (1975)
St. Mary's Bay, Newfoundland	15.20	54.00	1964	Pitt (1966)
Flemish Cap	7.80	40.00	1964	Pitt (1966)
Southeastern Grand Bank	8.79	41.45	1971	Pitt (1975)
St. Pierre Bank	9.48	48.26	1978-1988	Bowering and Brodie (1991)
Scotian Shelf	6.00	31.00	1970-1974	Beacham (1983)
Scotian Shelf	4.70	30.80	1975-1979	Beacham (1983)
Nova Scotia to Cape Hatteras	- -	33.60	1979	Morse (1979)
Atl. Coast of N. Am. (77' - 42')	8.00	30.00	1991	Miller *et al.* (1991)
Gulf of Maine	3.80	29.70	1980	Sullivan (1981)
Gulf of Maine	3.60	26.80	1986-1990	O'Brien *et al.* (1993)
Georges Bank	- -	28.20	1987-1991	Wigley *et al.* (1998)
Georges Bank	- -	29.80	1992-1996	Wigley *et al.* (1998)

(A_{50}) Age at which 50% of females are mature
(L_{50}) Length at which 50% of females are mature

Table 2. Diet composition of American plaice by fish length category.
Values are the percent of stomach content by weight, from Bowman *et al*. (2000).

	Length Category (cm)									
Stomach Contents	<16	16-20	21-25	26-30	31-35	36-40	41-45	46-50	>50	Total
Anthozoa	**-**	**-**	**-**	**1.8**	**4.3**	**-**	**-**	**-**	**-**	**0.7**
Nematoda	**1.8**	**2.5**	**11.1**	**<0.1**	**<0.1**	**<0.1**	**-**	**-**	**-**	**0.5**
Mollusca	**-**	**-**	**0.2**	**<0.1**	**34.6**	**24.3**	**12.2**	**29.8**	**16.8**	**20.3**
Bivalvia	-	-	0.2	<0.1	34.6	24.3	12.2	24.4	11.9	17.7
Chlamys islandica	-	-	-	-	-	-	-	-	7.6	2.5
Arctica islandica	-	-	-	-	0.4	-	-	-	4.3	1.4
Cyclocardia borealis	-	-	-	-	-	-	11.2	-	-	1.3
Bivalvia unid.	-	-	0.2	<0.1	34.2	24.3	1.0	24.4	<0.1	12.5
Mollusca unid.	-	-	-	-	-	-	-	5.4	4.9	2.6
Polychaeta	**5.2**	**8.1**	**2.5**	**5.0**	**1.4**	**4.3**	**3.3**	**-**	**5.8**	**2.2**
Lumbrineridae	<0.1	0.9	-	<0.1	-	-	-	-	-	<0.1
Nephtys sp.	-	-	-	0.7	0.4	-	-	-	-	0.1
Nephtyidae	3.4	-	2.4	-	-	-	-	-	-	0.2
Spionidae	0.4	0.8	<0.1	1.7	<0.1	0.9	0.4	-	0.3	0.4
Terebellidae	-	-	-	-	-	0.4	-	-	-	<0.1
Polychaeta unid.	1.4	6.4	0.1	2.6	1.0	3.0	2.9	-	5.5	1.5
Crustacea	**0.4**	**2.1**	**14.7**	**8.3**	**17.1**	**13.0**	**3.0**	**0.7**	**0.2**	**5.2**
Isopoda	-	-	-	0.1	-	-	-	-	-	<0.1
Chiridotea sp.	-	-	-	0.1	-	-	-	-	-	<0.1
Amphipoda	0.2	0.2	-	1.8	0.9	0.5	-	0.7	-	0.5
Unicola irrorata	0.2	-	-	-	-	-	-	-	-	<0.1
Monoculodes intermedius	-	0.2	-	-	-	-	-	-	-	<0.1
Leptocheirus pinguis	-	-	-	1.8	0.9	-	-	0.7	-	0.4
Gammaridea	<0.1	-	-	-	<0.1	0.5	-	<0.1	-	0.1
Euphausiacea	-	-	-	-	-	7.9	-	-	-	0.7
Decapoda	0.2	-	14.7	6.4	16.2	4.6	3.0	-	0.2	4.0
Dichelopandalus leptocerus	-	-	-	2.8	-	-	3.0	-	-	0.6
Pandalidae	-	-	-	-	16.2	4.6	-	-	-	2.5
Crangon septemspinosa	-	-	13.6	3.6	-	-	-	-	-	0.8
Crangonidae	0.2	-	-	-	-	-	-	-	-	<0.1
Decapoda unid.	-	-	1.1	-	-	-	-	-	0.2	0.1
Crustacea unid.	-	1.9	-	-	<0.1	-	<0.1	-	-	<0.1
Echinodermata	**4.1**	**3.2**	**0.7**	**26.4**	**26.3**	**41.8**	**64.9**	**68.3**	**62.0**	**49.8**
Echinoidea	-	-	-	1.8	3.2	1.1	0.5	17.2	1.6	4.5
Echinarachnius parma	-	-	-	-	-	-	-	16.5	-	3.1
Echinoidea unid.	-	-	-	1.8	3.2	1.1	0.5	0.7	1.6	1.4
Opiuroidea	4.1	2.4	0.7	24.6	23.1	40.7	64.4	20.3	60.4	39.5
Ophiura robusta	-	-	-	-	3.8	-	-	-	-	0.5
Ophiura sarsi	-	1.9	-	18.3	3.4	8.7	56.7	17.4	6.4	14.5
Ophiuroidea unid.	4.1	0.5	0.7	6.3	15.9	32.0	7.7	2.9	54.0	24.5
Echinodermata unid.	-	0.8	-	-	-	-	-	30.8	-	5.8
Animal Remains and Misc.	**88.5**	**25.6**	**64.1**	**34.7**	**16.3**	**16.3**	**16.6**	**1.2**	**7.3**	**15.9**
Sand and Rock	**-**	**58.5**	**6.7**	**23.8**	**-**	**0.3**	**-**	**-**	**7.9**	**5.4**
Number Sampled	**30**	**22**	**35**	**51**	**53**	**34**	**33**	**19**	**23**	**300**
Number Empty	**12**	**9**	**19**	**27**	**24**	**18**	**21**	**10**	**7**	**147**
Mean Stomach Content (g)	**0.153**	**0.077**	**0.157**	**0.250**	**0.366**	**0.418**	**0.530**	**1.546**	**2.187**	**0.518**
Mean Fish Length (cm)	**12**	**18**	**23**	**28**	**32**	**37**	**42**	**47**	**55**	**32**

Table 3. Diet composition of American plaice by geographical area.
Values are the percent of stomach content by weight, from Bowman *et al*. (2000).

Stomach Contents	Geographical area			
	Georges Bank	Gulf of Maine	Scotian Shelf	Inshore North of Cape Hatteras
Anthozoa	**0.8**	**-**	**-**	**2.9**
Nematoda	**-**	**0.1**	**-**	**2.3**
Mollusca	**0.4**	**26.4**	**61.2**	**<0.1**
Bivalvia	0.4	24.6	37.3	<0.1
Chlamys islandica	-	-	37.3	-
Arctica islandica	0.3	2.5	-	-
Cyclocardia borealis	-	2.2	-	-
Bivalvia unid.	0.1	19.9	-	<0.1
Mollusca unid.	-	1.8	23.9	-
Polychaeta	**0.5**	**1.0**	**-**	**7.9**
Lumbrineridae	-	<0.1	-	<0.1
Nephtys sp.	-	<0.1	-	0.3
Nephtyidae	-	-	-	1.0
Spionidae	-	<0.1	-	1.9
Terebellidae	-	-	-	0.2
Polychaeta unid.	0.5	1.0	-	4.5
Crustacea	**2.3**	**2.3**	**-**	**17.6**
Isopoda	<0.1	-	-	-
Chiridotea sp.	<0.1	-	-	-
Amphipoda	2.2	<0.1	-	0.2
Unicola irrorata	<0.1	-	-	-
Monoculodes intermedius	-	-	-	<0.1
Leptocheirus pinguis	2.2	-	-	-
Gammaridea	<0.1	<0.1	-	0.2
Euphausiacea	-	1.3	-	-
Decapoda	0.1	1.0	-	17.4
Dichelopandalus leptocerus	-	1.0	-	-
Pandalidae	-	-	-	13.2
Crangon septemspinosa	0.1	-	-	4.0
Decapoda unid.	-	<0.1	-	0.2
Crustacea unid.	-	<0.1	-	-
Echinodermata	**92.3**	**42.4**	**-**	**47.5**
Echinoidea	16.9	2.4	-	-
Echinarachnius parma	16.9	-	-	-
Echinoidea unid.	-	2.4	-	-
Opiuroidea	75.4	40.0	-	16.0
Ophiura robusta	-	-	-	2.5
Ophiura sarsi	-	24.2	-	4.6
Ophiuroidea unid.	75.4	15.8	-	8.9
Echinodermata unid.	-	<0.1	-	31.5
Animal Remains and Misc.	**3.6**	**25.3**	**-**	**14.3**
Sand and Rock	**0.1**	**2.5**	**38.8**	**7.5**
Number Sampled	17	186	6	91
Number Empty	4	92	5	46
Mean Stomach Content (g)	1.689	0.471	1.717	0.315
Mean Fish Length (cm)	27	33	40	30

Table 4. Distribution and relative abundance of American plaice in North Atlantic estuaries and rivers by life history stage.
Source: Jury *et al.* (1994).

Estuaries and Rivers	Life Stage	Distribution and Relative Abundance		Months of Occurrence	Data Reliability
		Mixing	Seawater		
Passamaquoddy Bay	Adults (A)		Common	March - Nov	**
	Spawning adults (S)		Common	March - May	**
	Juveniles (J)	Common	Common	March - Nov	*
	Larvae (L)		Common	April - June	**
	Eggs (E)		Common	March - May	**
Englishman / Machias Bay	**A**		Common	March - Nov	*
	S		Common	March - May	*
	J	Common	Common	March - Nov	*
	L		Common	April - June	*
	E		Common	March - May	*
Narraguagus Bay	**A**		Common	March - Nov	*
	S		Common	March - May	*
	J	Common	Common	March - Nov	*
	L		Common	April - June	*
	E		Common	March - May	*
Blue Hill Bay	**A**		Common	March - Nov	*
	S		Common	March - May	*
	J	Common	Common	March - Nov	*
	L		Common	April - June	*
	E		Common	March - May	*
Penobscot Bay	**A**		Common	March - Nov	**
	S		Common	March - May	**
	J	Common	Common	March - Nov	**
	L		Common	April - June	**
	E		Common	March - May	**
Muscongus Bay	**A**		Abundant	March - Nov	**
	S		Common	March - May	*
	J	Common	Highly Abundant	March - Nov	*
	L	Rare	Common	April - June	*
	E		Common	March - May	*
Damariscotta River	**A**		Abundant	March - Nov	**
	S		Common	March - May	**
	J	Common	Highly Abundant	March - Nov	*
	L	Rare	Common	April - June	*
	E		Common	March - May	**
Sheepscot River	**A**		Abundant	March - Nov	***
	S		Common	March - May	***
	J	Common	Highly Abundant	March - Nov	***
	L	Rare	Common	April - June	***
	E		Common	March - May	**
Kennebec / Androscoggin Rivers	**A**		Abundant	March - Nov	**
	S		Common	March - May	*
	J	Common	Highly Abundant	March - Nov	*
	L	Rare	Common	April - June	*
	E		Common	March - May	*
Casco Bay	**A**		Abundant	March - Nov	*
	S		Common	March - May	*
	J	Common	Highly Abundant	March - Nov	*
	L	Rare	Common	April - June	*
	E		Common	March - May	*

(*** = Highly Certain; ** = Moderately Certain; * = Reasonable Inference)

Table 4. Cont'd.

Estuaries and Rivers	Life Stage	Distribution and Relative Abundance		Months of Occurrence	Data Reliability
		Mixing	Seawater		
Saco Bay	**A**		Abundant	March. - Nov.	*
	S		Common	March - May	*
	J	Common	Highly Abundant	March. - Nov.	*
	L	Rare	Common	April - June	*
	E		Common	March - May	*
Wells Harbor	**A**				*
	S				**
	J		Rare	June - Oct.	*
	L		Rare	April - June	*
	E		Rare	March - May	*
Great Bay	**A**		Rare	March - Nov.	*
	S				**
	J		Rare	March - Nov.	*
	L		Rare	April - July	*
	E		Rare	March - June	*
Merrimack River	**A**				*
	S				**
	J	Rare		March - Sept.	*
	L	Rare		April - July	*
	E	Rare		March - June	*
Massachusetts Bay	**A**		Highly Abundant	Jan. - Dec.	***
	S		Highly Abundant	Feb. - June	**
	J		Highly Abundant	Jan. - Dec.	***
	L		Abundant	March - July	*
	E		Abundant	Feb. - June	*
Boston Harbor	**A**		Abundant	Jan. - Dec.	**
	S		Common	Feb. - June	*
	J		Abundant	Jan. - Dec.	*
	L	Rare	Common	March - July	*
	E	Rare	Common	Feb. - June	*
Cape Cod Bay	**A**		Abundant	Jan. - Dec.	**
	S		Highly Abundant	Feb. - May	**
	J		Highly Abundant	Jan. - Dec.	**
	L	Rare	Highly Abundant	March - July	**
	E	Rare	Highly Abundant	Feb. - July	**

(*** = Highly Certain; ** = Moderately Certain; * = Reasonable Inference)

Table 5. Summary of habitat parameters for American plaice, based on the pertinent literature.

Life Stage	Depth	Substrate	Salinity	Temperature/Season
Spawning Adults [1]	Adults spawn and fertilize their eggs at or near the bottom, eggs drift into the upper water column after they are released. Coastal waters of the Gulf of Maine are nursery areas. Spawning occurs at depths < 90 m and spawning adults migrate from deeper depths into shoaler grounds before spawning.			In the Gulf of Maine the spawning season extends from March through the middle of June, with peak spawning activity in April and May. Water temperatures control spawning of American plaice resulting in varied times and locations of spawning in the northwest Atlantic. Normally, American plaice are captured within wide ranges of temperatures from -1.5 to 13°C, and are most numerous within -0.5° to 2.5°C. However, during peak spawning periods, bottom temperature preferences vary. Areas of maximum spawning occur in the western Gulf of Maine and over southeastern Georges Bank; optimum spawning temperatures range between 3-6°C. These bottom water temperatures exist throughout much of the spawning period within the 100 m isobath from Cape Cod to New Jersey. Outside this southern boundary, temperatures are too high for survival.
Eggs [2]	Eggs float and hatch at the surface and the amount time between fertilization and hatching of eggs varies depending on water temperature.			Eggs incubate from 11 to 14 days at 3.9°C. In the Gulf of Maine and on the Scotian Shelf, egg abundance peaks in early April and May. In Cape Cod Bay plaice eggs were present from January through July Lab reared eggs between 2-6°C were larger and developed a greater probability of surviving and first feeding, growth of those reared as 10°C was the fastest.

Table 5. Cont'd.

Life Stage	Depth	Substrate	Salinity	Temperature/Season
Larvae [3]	Plaice larvae were found in relatively shallow waters on Georges Bank, in Massachusetts Bay, and along coastal Maine. Larval plaice that drift into the slope water zone along the southern edge of Georges Bank are susceptible to transport in a northeasterly direction away from Georges Bank and the continental shelf. Larval plaice found in the upper water levels can be transported by currents southwest along the coast; some were retained in the Gulf of Maine while others can be transported to Georges Bank.			In Cape Cod Bay larvae were present from January through August. Larval transformation process varies with temperature, it is usually complete when the larva is 30-40 mm Larvae reared at 10°C had larger fin fold area and used up their yolk-sac reserves earlier. Therefore in many cases the development rate was altered by the temperature and affected swimming performance, but no affect on escape response.
Juveniles [4]				

Table 5. Cont'd.

Life Stage	Depth	Substrate	Salinity	Temperature/Season
Adults [5]	Their normal habitat is at or near the ocean floor; however, they frequently migrate off the bottom at night in pursuit of prey. Plaice are found in shoal waters when temperatures are severely cold, they normally occur in waters 25-180 m deep. In southern Labrador to Rhode Island are generally found in deep water from 90-180 m and are not normally found in water < 25-35m. In Canadian waters it occurs at preferred depths of 90-250 m. On the Scotian Shelf American plaice range between 27-366 m, with preferences between 55-128 m. Gulf of Maine plaice normally occur in waters 25-180 m deep, but are also found in shoal waters when temperatures are severely cold. With the exception of witch flounder, plaice is considered most abundant of all flatfish in Gulf of Maine at depths between 54-90 m. Widespread on Georges Bank along the 90-180 m zone of its northern edge.	They prefer a soft bottom substrate. Laboratory experiments show a preference for the finer gravelly sand. On the Scotian Shelf, plaice were most abundant on sand and gravel substrates. In eastern Newfoundland, plaice were frequently collected where sandy substrates bordered areas of bedrock. In some areas, their distribution has been correlated with mud substrates.	American plaice occur at mean salinities of 20-22 ppt in Hamilton Inlet, Labrador 30 ppt or lower in Baltic areas, 32.8 ppt in the Gulf of Maine, 34 ppt in offshore Atlantic waters. On Scotian Shelf, had salinity preferences between 31-34 ppt; highest abundances occurred at 33 ppt.	They can thrive in temperatures ranging from -0.5 to 13.0°C. In Canadian waters it occurs in temperatures ranging from approximately -1.5°C to temperatures above 5°C, with a preferred temperature range of 0-1.5°C. The warmer temperature sought by females during feeding also provide optimal conditions for growth during the summer. The maturity of plaice varied as much as 11 years and depended on water temperatures. The highest temperature, 10°C, for Passamaquoddy Bay and the Cape Cod region had the shortest time of development to maturity (3-5 years). The lowest temperature recorded was 0°C for Newfoundland (Bay of Islands) and plaice had the longest development time (10-13 years) On the Scotian Shelf, American plaice ranged between 0-13°C with preferences between 1-4°C Significant positive correlations exist between the annual catch of fish off the Maine coast and mean annual surface temperatures, meaning that temperature is a limiting factor in the abundance of plaice.

[1] Bigelow and Schroeder (1953); Colton and Temple (1961); Colton (1972); Smith *et al.* (1975); Colton *et al.* (1979); Bowering and Brodie (1991).
[2] Bigelow and Schroeder (1953); Howell and Caldwell (1984); Scherer (1984); Neilson *et al.* (1988); DFO (1989); Berrien and Sibunka (1999); Hebert and Wearing-Wilde 2002.
[3] Colton and Marak (1969); Smith *et al.* (1975); Sullivan (1981); Scherer (1984); Shepherd *et al.* (2000).
[4] Bigelow and Schroeder (1953); Bowman and Michaels (1984); Link and Almeida (2000); Link *et al.* (2002); Packer and Langton (unpubl. manuscript).
[5] Huntsman (1918); Bigelow and Schroeder (1953); Backus (1957); Powles (1965); Colton (1972); Pitt (1973); Dow (1977); Langton and Bowman (1981); Scott (1982a); Scott(1982b); Bowman and Michaels (1984); Scott and Scott (1988); Holzwarth and Mountain (1990); Langton and Watling (1990); Sparholt (1990); Bowering and Brodie (1991); Murawski (1993); Iglesias *et al.* (1996); Walsh (1996); Dery (1998); Morgan (2000); Klein-MacPhee (2002); Packer and Langton (unpubl. manuscript).

Table 5. Cont'd.

Life Stage	Prey	Predators / Species Associations
Eggs	N/A	
Larvae[1]	American plaice larvae show a gradual size-selectivity preference when maxilla length ranges change from 100-200 μm to 200 - $\geq$ 500 μm. Larvae feed on plankton, diatoms, and copepods that exist in the upper water layers.	Redfish consumes larvae.
Juveniles[2]	Prior to settling, juveniles feed on small crustaceans, polychaetes, and cumaceans. When they settle their diet gradually changes as they grow and the size of their mouth gape increases to accept wider-sized prey. They consume mostly ophiuroids. Smaller (< 25-30 cm) individuals feed predominately on mysids, amphipods, polychaetes, small brittle stars, and some mollusks. In Sheepscot Bay, Maine, mysids generally decreased in importance with increasing predator size and polychaetes appeared to increase.	Feeding competition exists between young plaice and cod. Cod and other bottom feeding species prey upon them.

Table 5. Cont'd.

Life Stage	Prey	Predators / Species Associations
Adults[3]	Consumed ophiuroids, echinoderms, chiefly sand dollars, sea urchins, and brittle stars. Larger individuals (> 30 cm) feed primarily on fish, brittle stars and other echinoderms, and bivalve mollusks. The brittle star, *Ophiura sarsi*, makes up 65% of the plaice diet at some locations in the Gulf of Maine. Diets of plaice collected during 1973-2001 NEFSC bottom trawl surveys were also dominated by echinoderms; arthropods, annelids, and mollusks were also eaten. Off the coastal bank of Norway, American plaice feeding habits are distinctly different from other flatfish species, they feed more on benthic and epibenthic organisms such as ophiuroids and crustaceans. In the North Sea they feed on more fish (particularly sandlance), as well as polychaetes, crustaceans and ophiuroids. In Passamaquoddy Bay, Canada, they feed on amphipods, mysids, euphausiids, polychaetes, bivalve mollusks, and Atlantic herring. In Sheepscot Bay, Maine, they eat polychaetes, mysids, amphipods, sand shrimp. Offshore in the Gulf of Maine, the brittle star *Ophiura sarsi* is the primary prey; crustaceans (euphausiids and pandalid shrimp), bivalve mollusks (*Yoldia* spp., *Chlamys islandica*, *Cerastoderma pinnulatum*), and tube-dwelling polychaetes are of secondary importance. On Georges Bank, they ate almost exclusively echinoderms. In Southern New England, plaice consume large quantities of amphipods, shrimp (*Crangon*), polychaetes, and bivalves. In the spring echinoderms and other invertebrates were heavily consumed. In summer (highest feeding rates): bivalves, pandalids and polychaetes. In autumn: ophiuroids and fish eggs. There is little or no feeding in January and February and a rapid increase of feeding in May through September.	Eaten by Greenland sharks, cod, halibut, goosefish, and spiny dogfish. Along the Scotian Shelf and in the Gulf of St. Lawrence, grey seals are the primary predators Seabird consumption on landed fish aboard boats; consumption was found to be directly proportional to the amount of time the fish was on deck.

[1] Pepin and Penney (2000); Klein-MacPhee (2002).
[2] Powles (1965); Bowman and Michaels (1984); Ross and Hokenson (1997).
[3] Huntsman (1918); Bigelow and Schroeder (1953); Powles (1965); Tyler (1971); Tyler (1972); Pitt (1973); Langton and Bowman (1981); Sullivan (1981); Bowman and Michaels (1984); Macdonald and Green (1986); Macdonald and Waiwood (1987); Watling *et al.* (1988); DFO (1989); Benoit and Bowen (1990); Langton and Watling (1990); Keats (1991); Zamarro (1992); Klemetsen (1993); Ntiba and Harding (1993); Alverson *et al.* (1994); Martell and McClelland (1994); Packer *et al.* (1994); Ross and Hokenson (1997); Link and Almeida (2000); Bowen *et al.* (2002); Hebert and Wearing-Wilde 2002; Klein-MacPhee (2002); Link *et al*. (2002); Packer and Langton (unpubl. manuscript).

Table 6. Summary of habitat parameters for American plaice, based on available surveys.

Life Stage	Survey	Temperature	Depth	Salinity
Eggs	1978-1987 MARMAP ichthyoplankton surveys from Nova Scotia to Cape Hatteras.	Range: 1-12°C, overall range 4-8°C; Feb.-Apr. 3-6°C, May-July 5-8°C, Aug.-Dec. 9-11°C.	Range: approximately 10-325 m, majority occurring between 50-90 m.	n/a
	1995-1999 GLOBEC surveys on Georges Bank.	Range: from Jan.-June remained in a narrow range of about 4-8°C.	Range: most occurred between 41-100 m.	n/a
Larvae	1977-1987 MARMAP ichthyoplankton surveys from Nova Scotia to Cape Hatteras.	Range: 4-14°C. During Mar.-Jun. most occurred between 5-8°C, during July-Aug. between 10-12°C.	Range: 30-210 m. Most occurred at 50-90 m, except Aug. where the majority were found at 130 m.	n/a
	1995-1999 GLOBEC surveys on Georges Bank.	Range: 4-6°C from Feb.-Apr., 6-11°C from May-June.	Range: 41 m to between 301-350 m, majority between 41-120 m. Depth at which larvae occurred remained constant from Feb.-May, changing to deeper waters in June.	n/a
Juveniles	1963-2003 Spring and Fall NEFSC trawl surveys from Gulf of Maine to Cape Hatteras.	*Spring*: range of 2-10°C, most between 4-6°C. *Fall*: range of 4-16°C, majority between 5-11°C.	*Spring*: range of 11-400 m. *Fall*: range of 11-400 m.	*Spring*: range of 31-35 ppt, majority found at 33 ppt. *Fall*: range of 31-35 ppt, majority found at 33 ppt.
	1978-2003 Massachusetts inshore trawl surveys.	*Spring*: range of 1-12°C, with most between 4-6°C. *Fall*: range of 4-17°C, majority between 7-10°C.	*Spring*: range of 6-85 m, majority between 46-65 m. *Fall*: range of 6-85 m, majority between 46-65 m.	n/a
Adults	1963-2003 Spring and Fall NEFSC trawl surveys from Gulf of Maine to Cape Hatteras.	*Spring*: range of 1-12°C, most between 4-6°C. *Fall*: range of 3-15°C, peaks between about 6-9°C.	*Spring*: range between 11-400 m. *Fall*: range of 21-400 m.	*Spring*: range of 31-35 ppt, majority at 33 ppt. *Fall*: range of 31-35 ppt, majority at 33-34 ppt.
	1978-2003 Massachusetts inshore trawl surveys.	*Spring*: range of 1-12°C, majority between 4-6°C. *Fall*: range of 4-14°C, most between 7-9°C.	*Spring*: range of 6-85 m. *Fall*: range of 16-85 m.	n/a

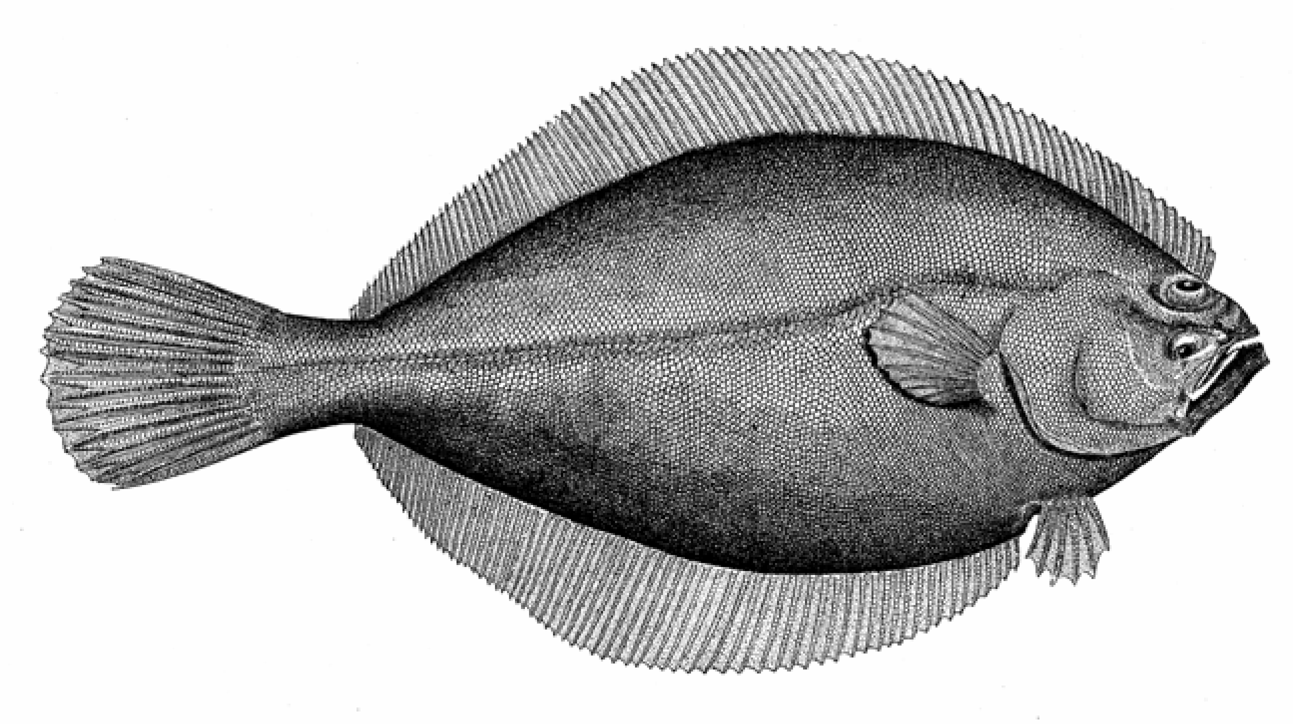


Figure 1. The American plaice, *Hippoglossoides platessoides* (Fabricius 1780) (from Goode 1884).

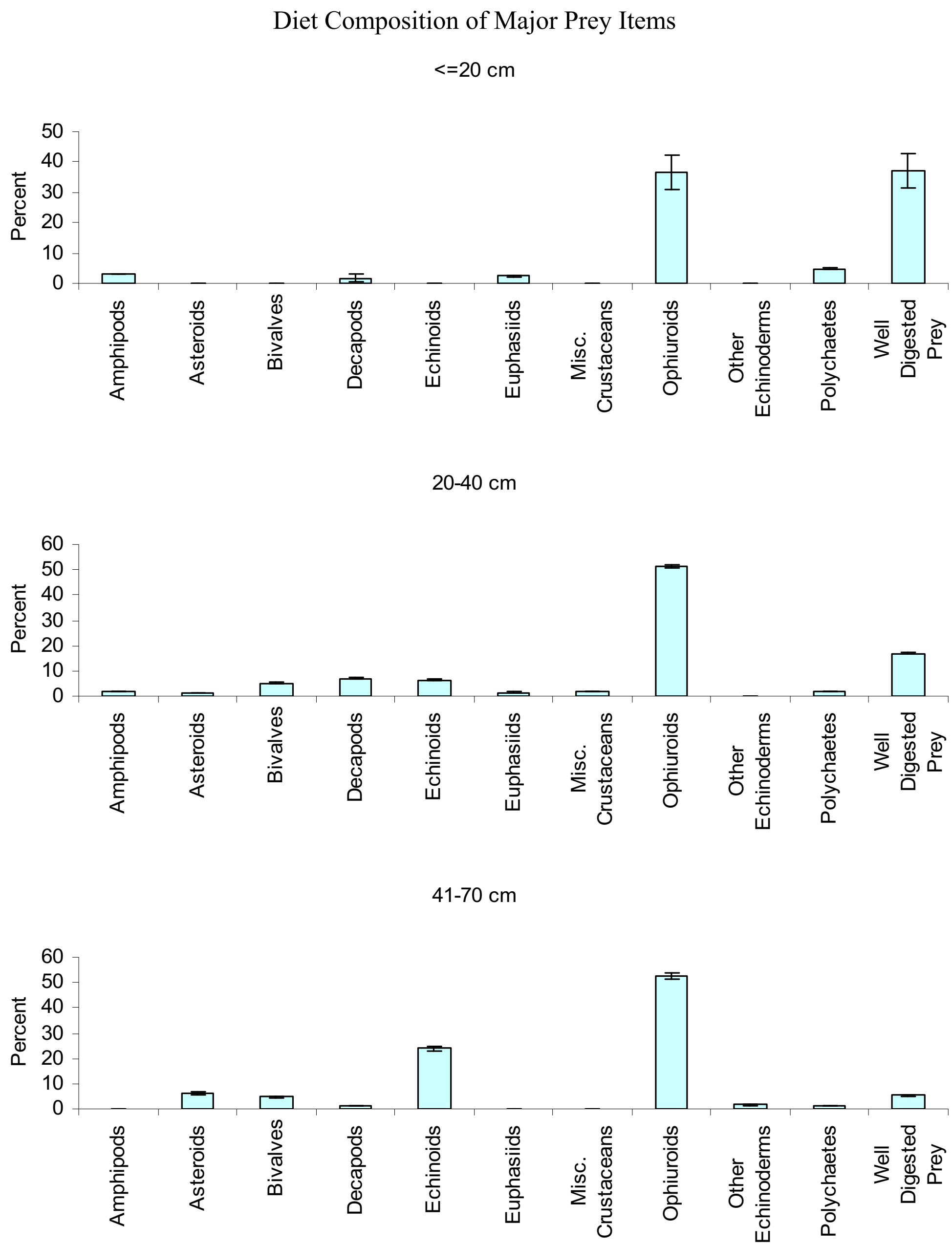


Figure 2. Percent by weight of the major prey items in the diet of three size categories of American plaice. From specimens collected during NEFSC bottom trawl surveys from 1973-2001 (all seasons). For details on NEFSC diet analysis, see Link and Almeida (2000).

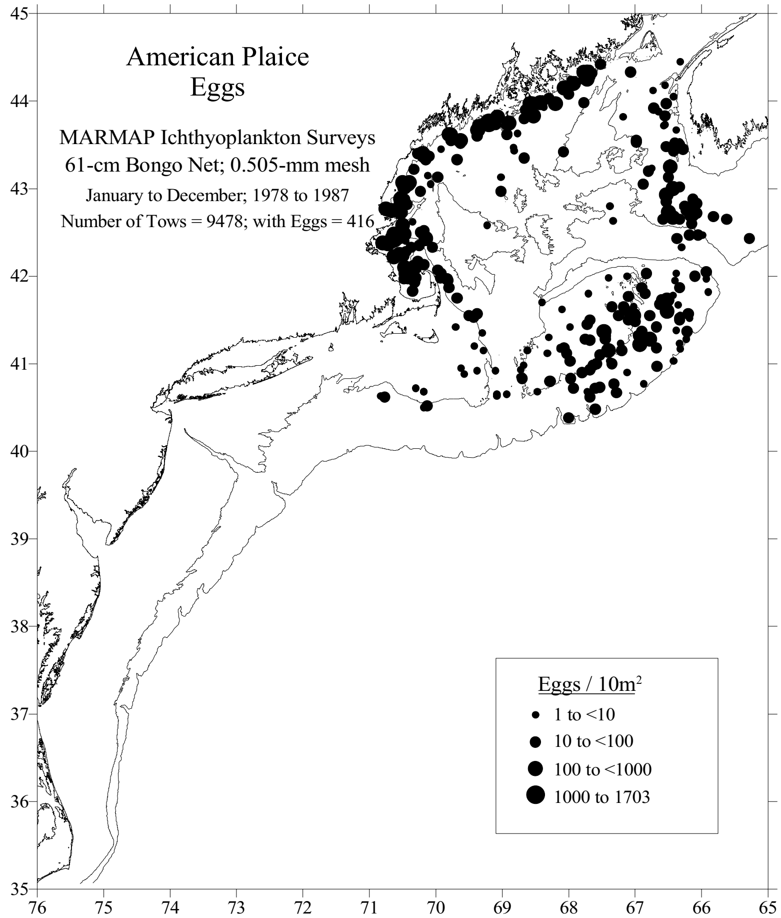


Figure 3. Distributions and abundances of American plaice eggs collected during NEFSC MARMAP ichthyoplankton surveys.
For all available months and years from 1978-1987 combined.

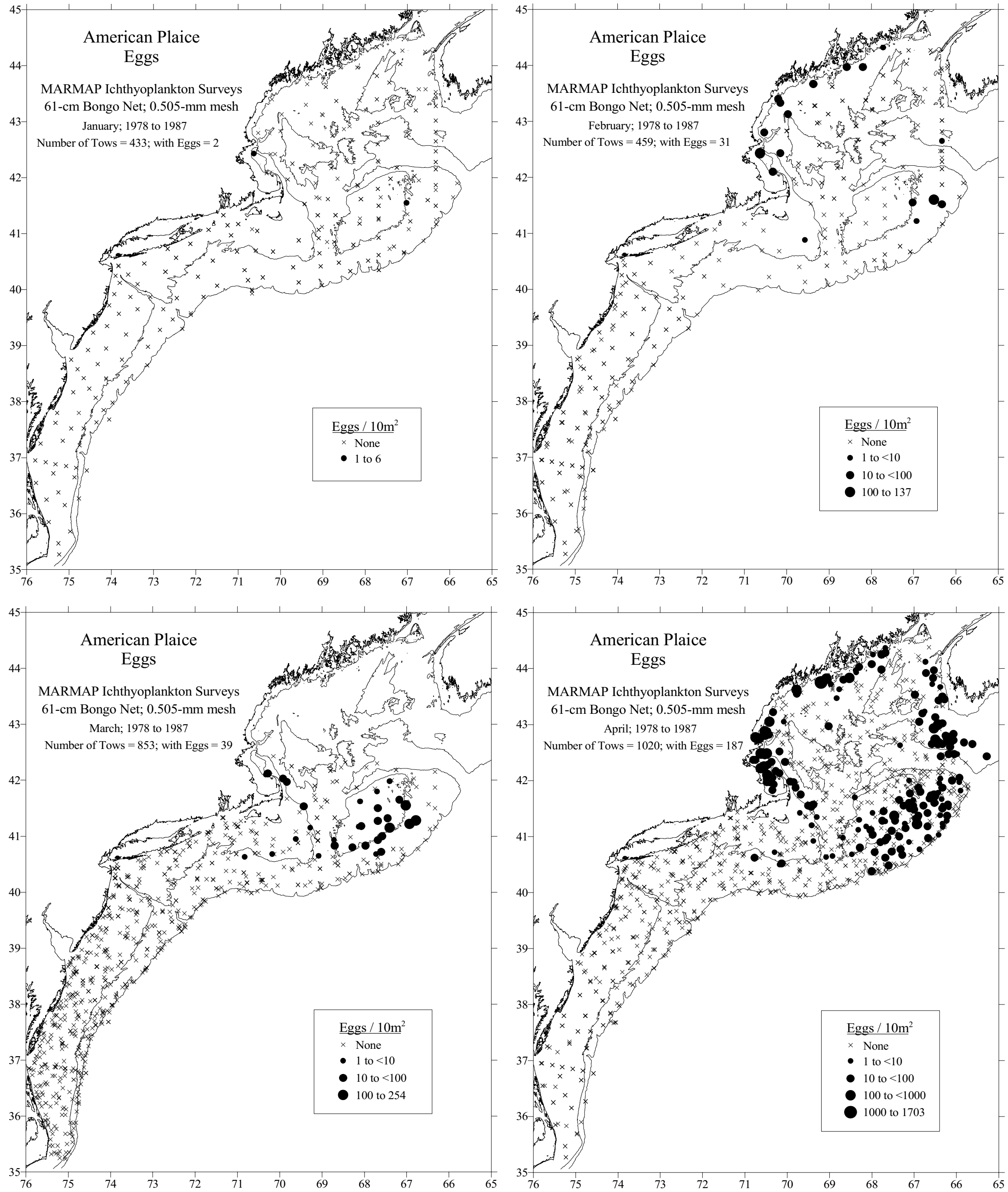


Figure 3. Cont'd.
From MARMAP ichthyoplankton surveys, January through April, 1978-1987.

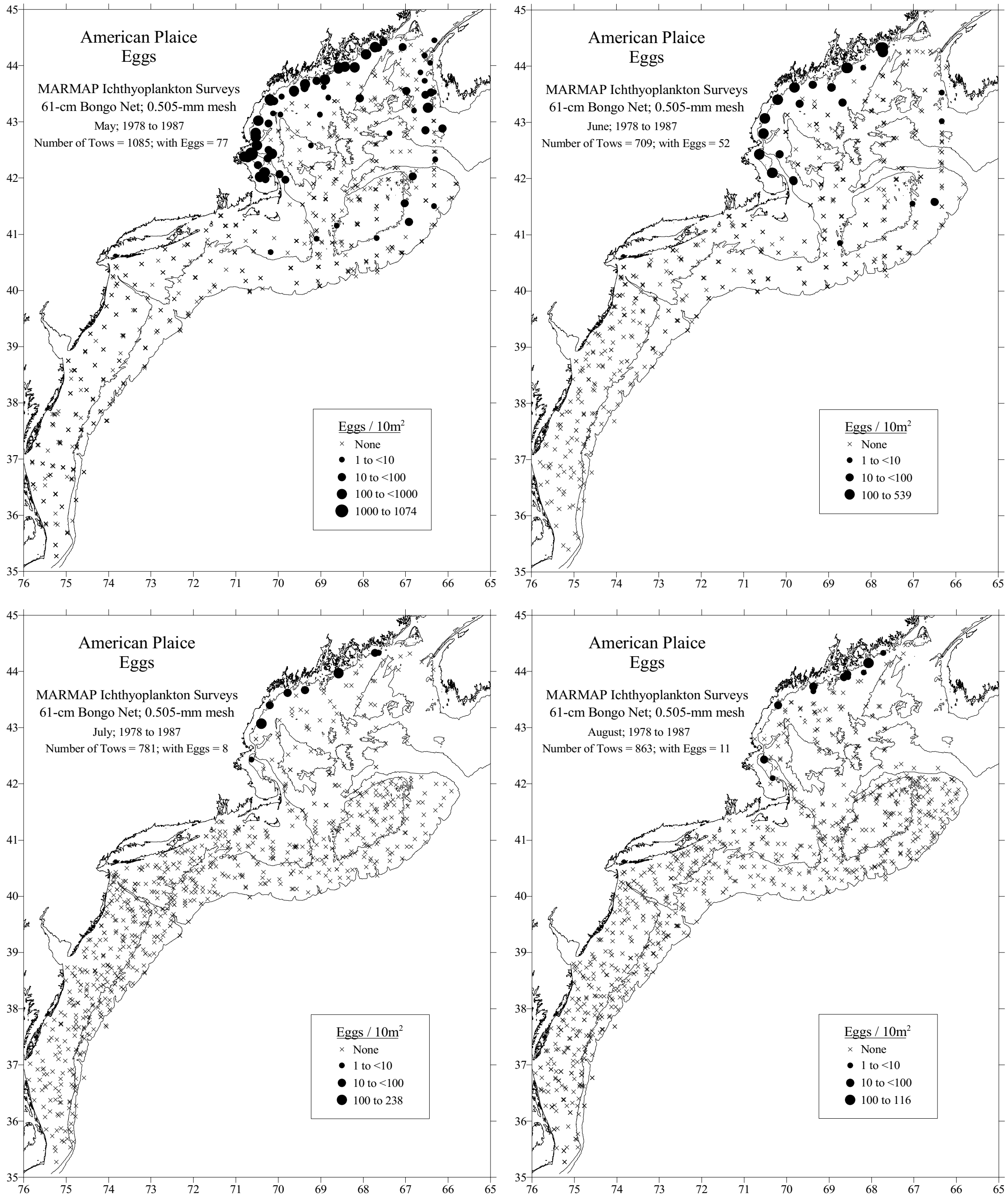
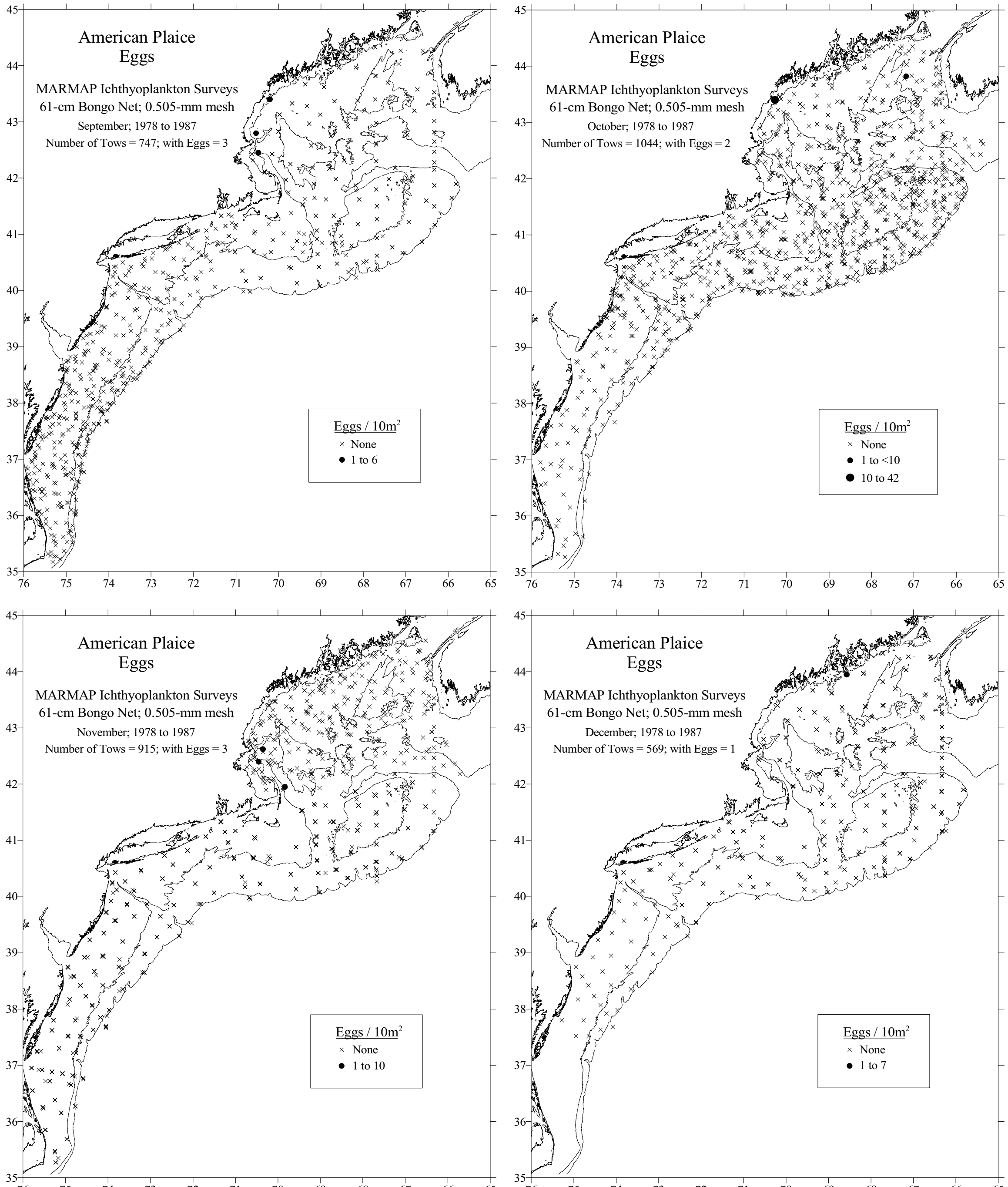


Figure 3. Cont'd.
From MARMAP ichthyoplankton surveys, May through August, 1978-1987.



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From MARMAP ichthyoplankton surveys, September through December, 1978-1987.

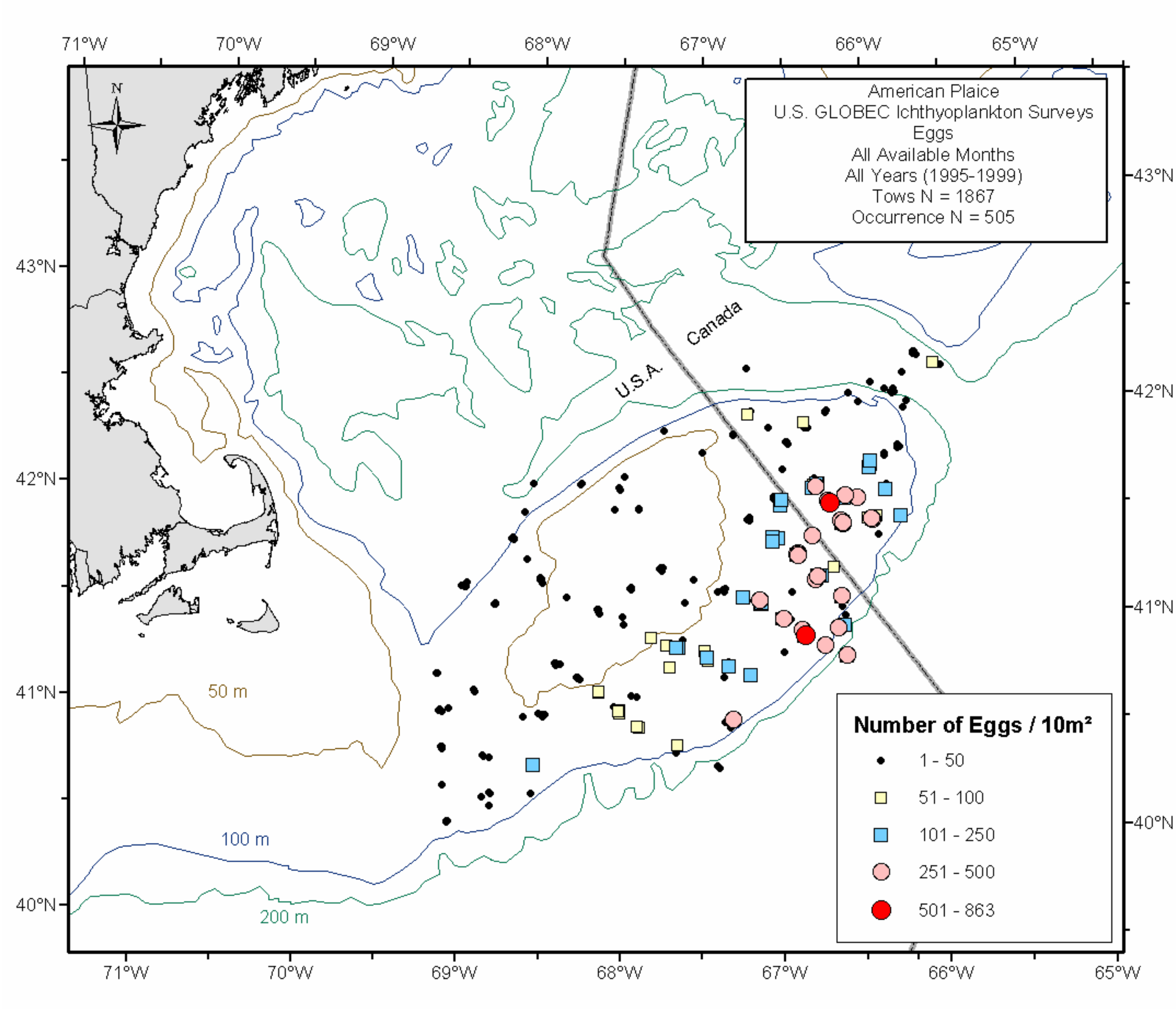
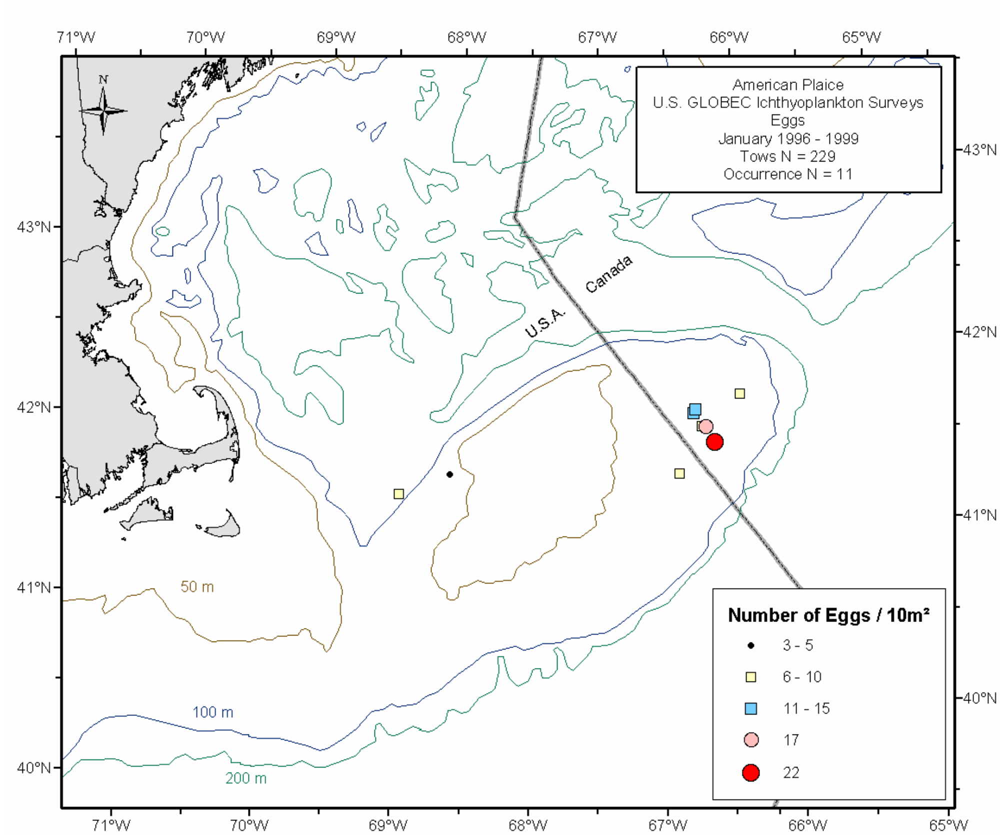


Figure 4. Distributions and abundances of American plaice eggs collected during GLOBEC Georges Bank ichthyoplankton surveys.
For all available years (February-July, 1995; January-June, 1996-1999) combined.



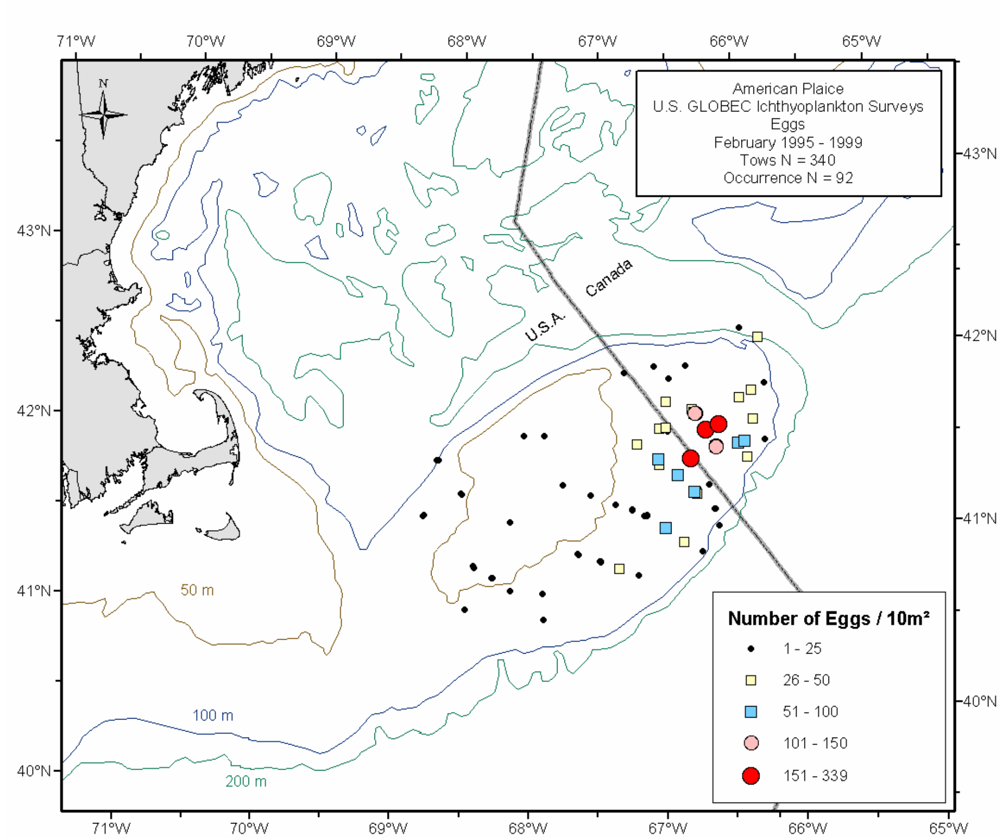
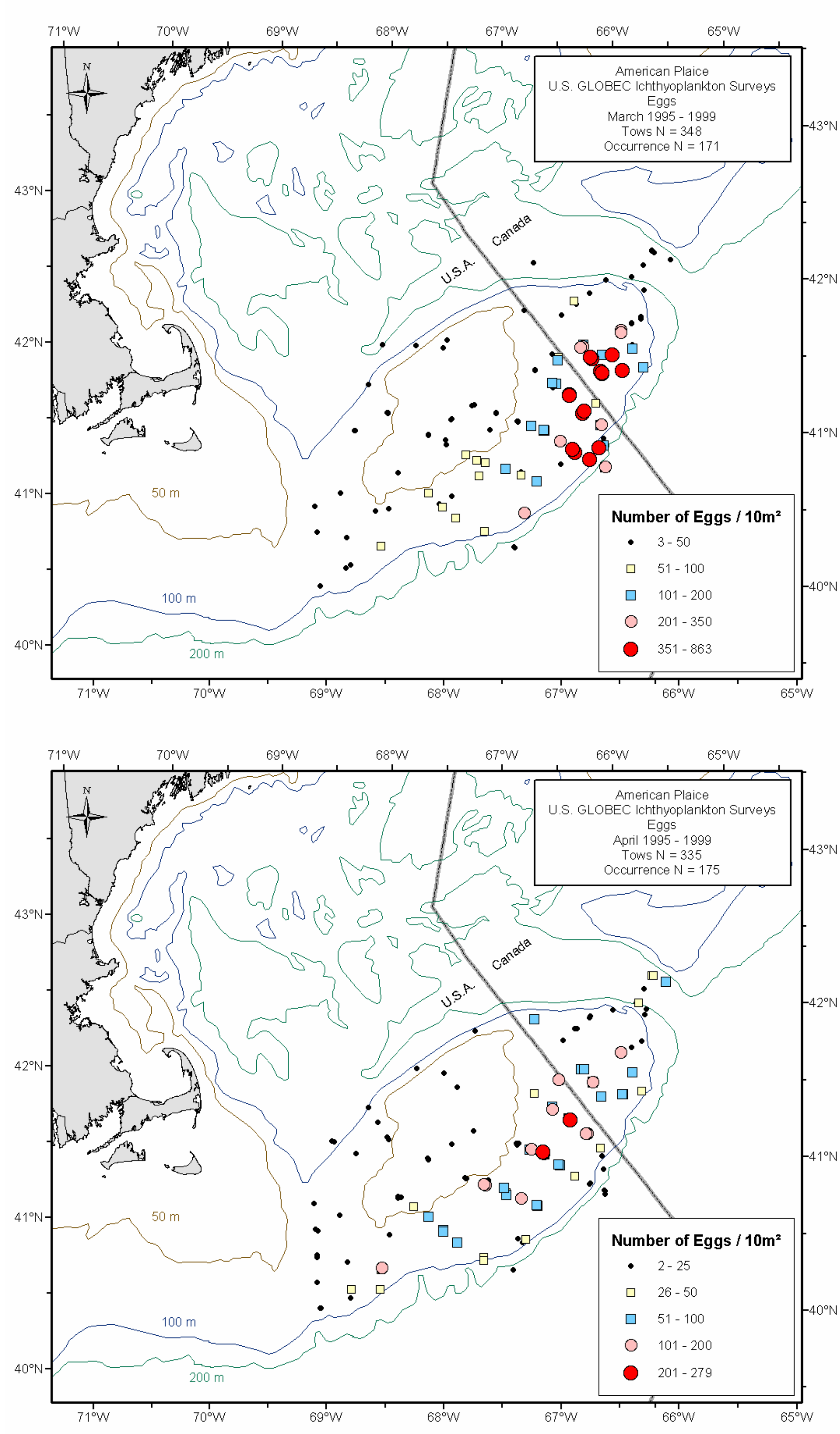


Figure 4. Cont'd.
From GLOBEC ichthyoplankton surveys, January and February, for all available years combined.



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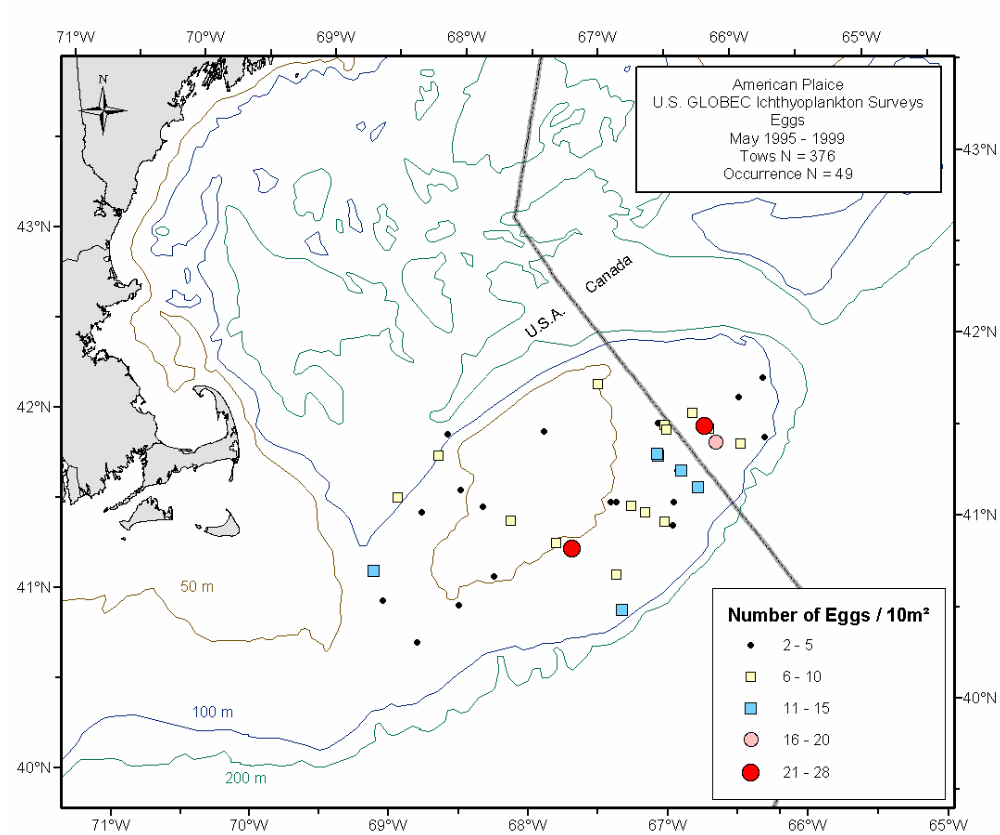
From GLOBEC ichthyoplankton surveys, March and April, for all available years combined.



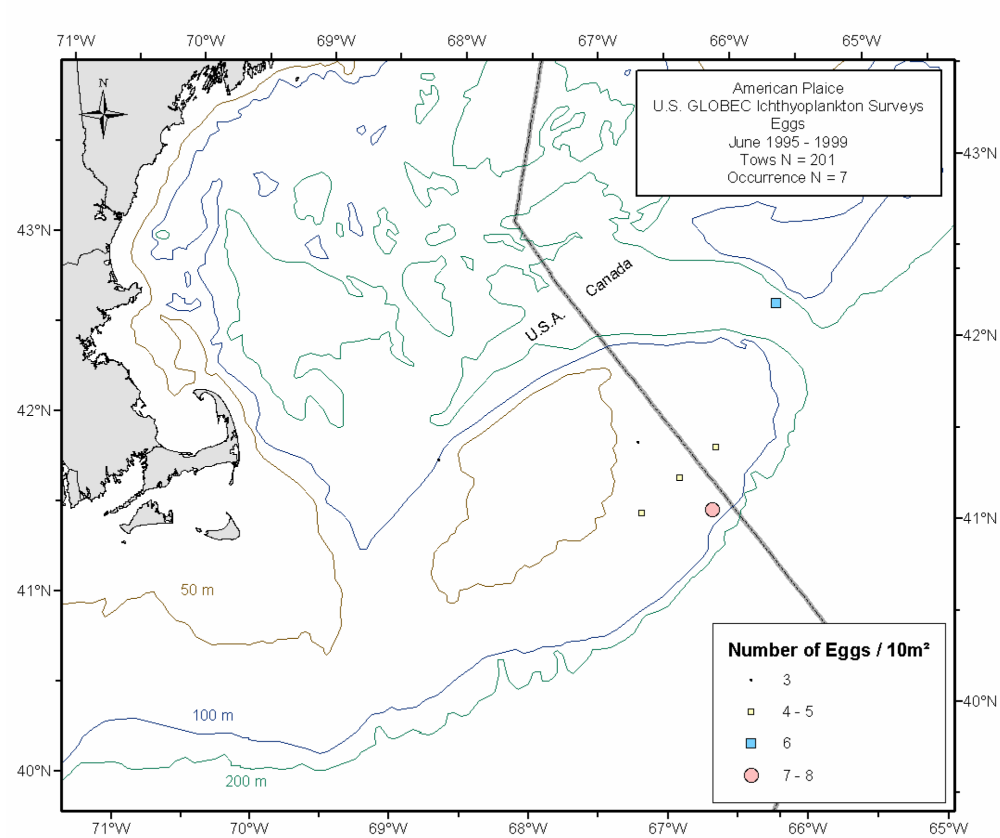


Figure 4. Cont'd.
From GLOBEC ichthyoplankton surveys, May and June, for all available years combined.

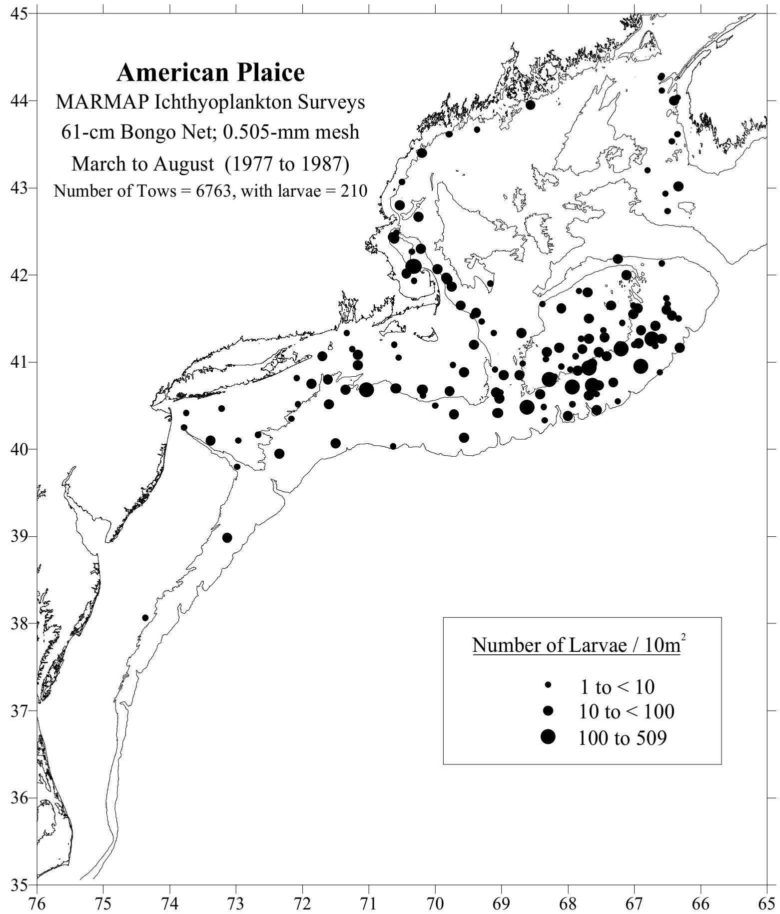


Figure 5. Distributions and abundances of American plaice larvae collected during NEFSC MARMAP ichthyoplankton surveys.
For all available months and years from 1977-1987 combined.

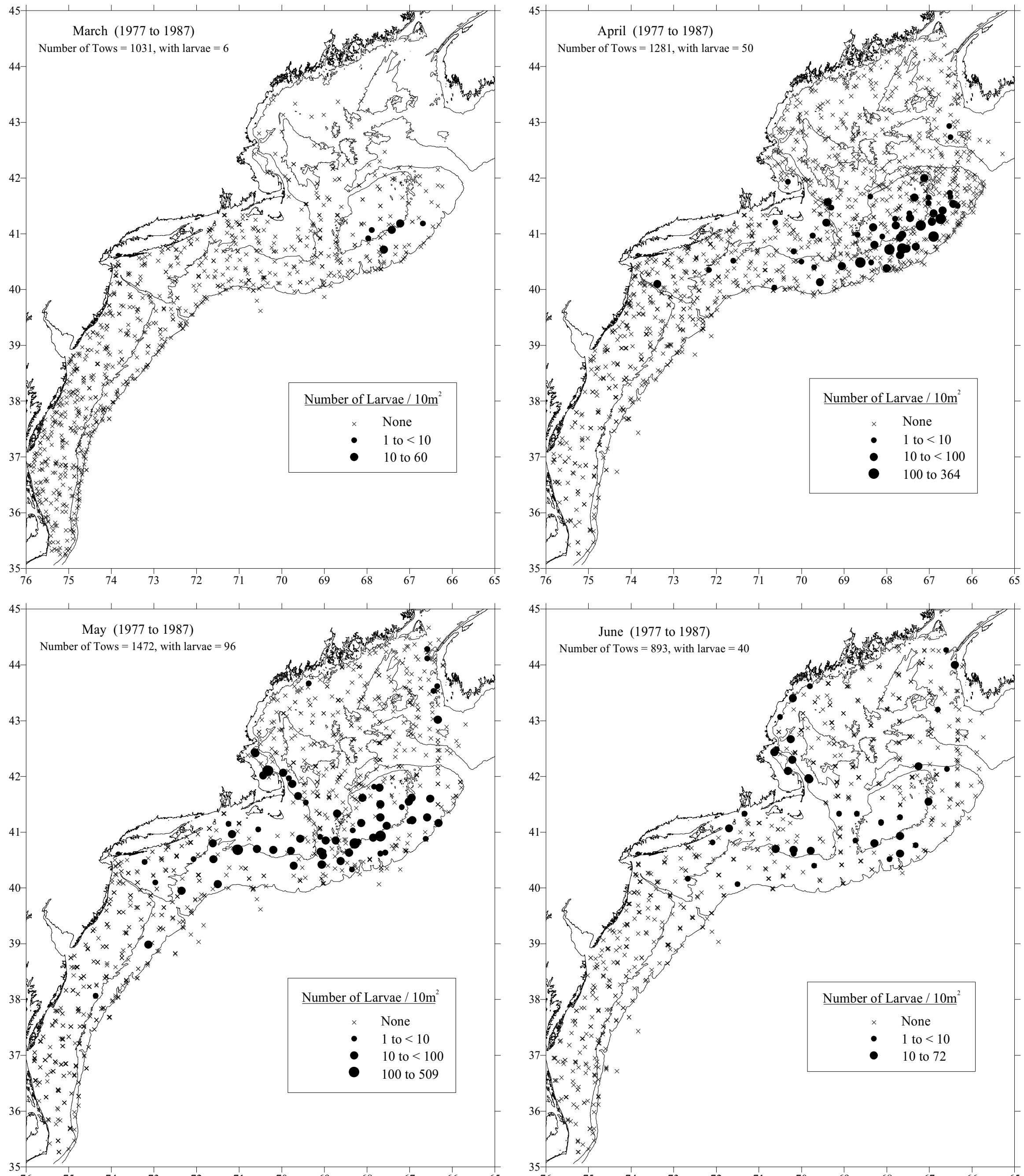
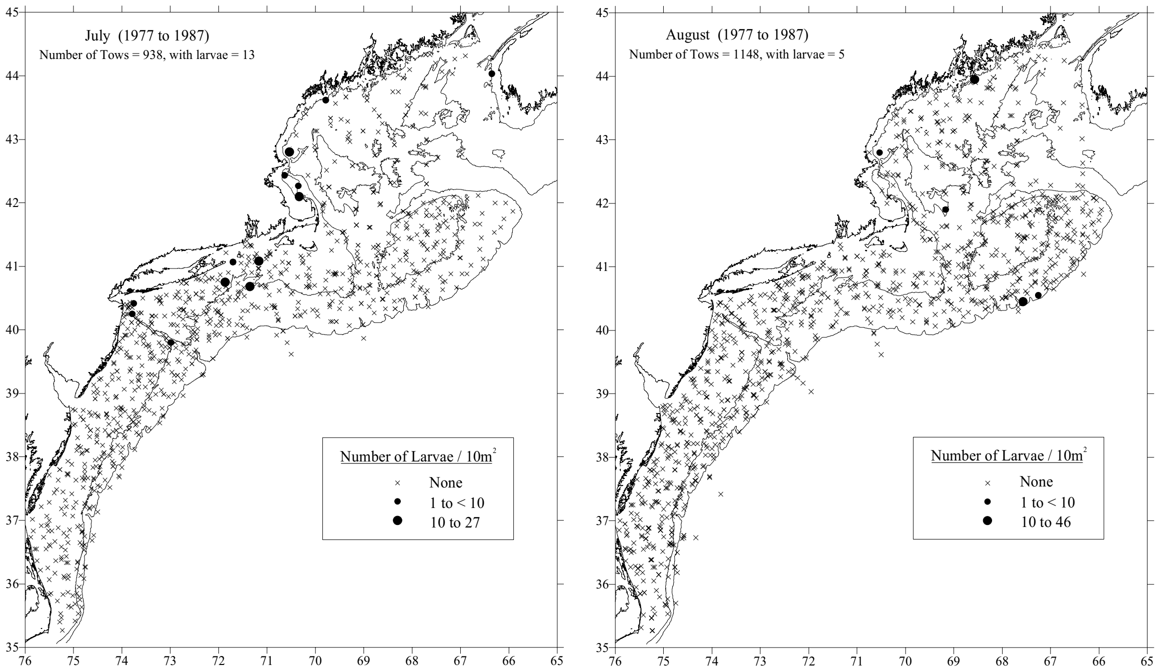


Figure 5. Cont'd.
From MARMAP ichthyoplankton surveys, March through June, 1977-1987.



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From MARMAP ichthyoplankton surveys, July and August, 1977-1987.

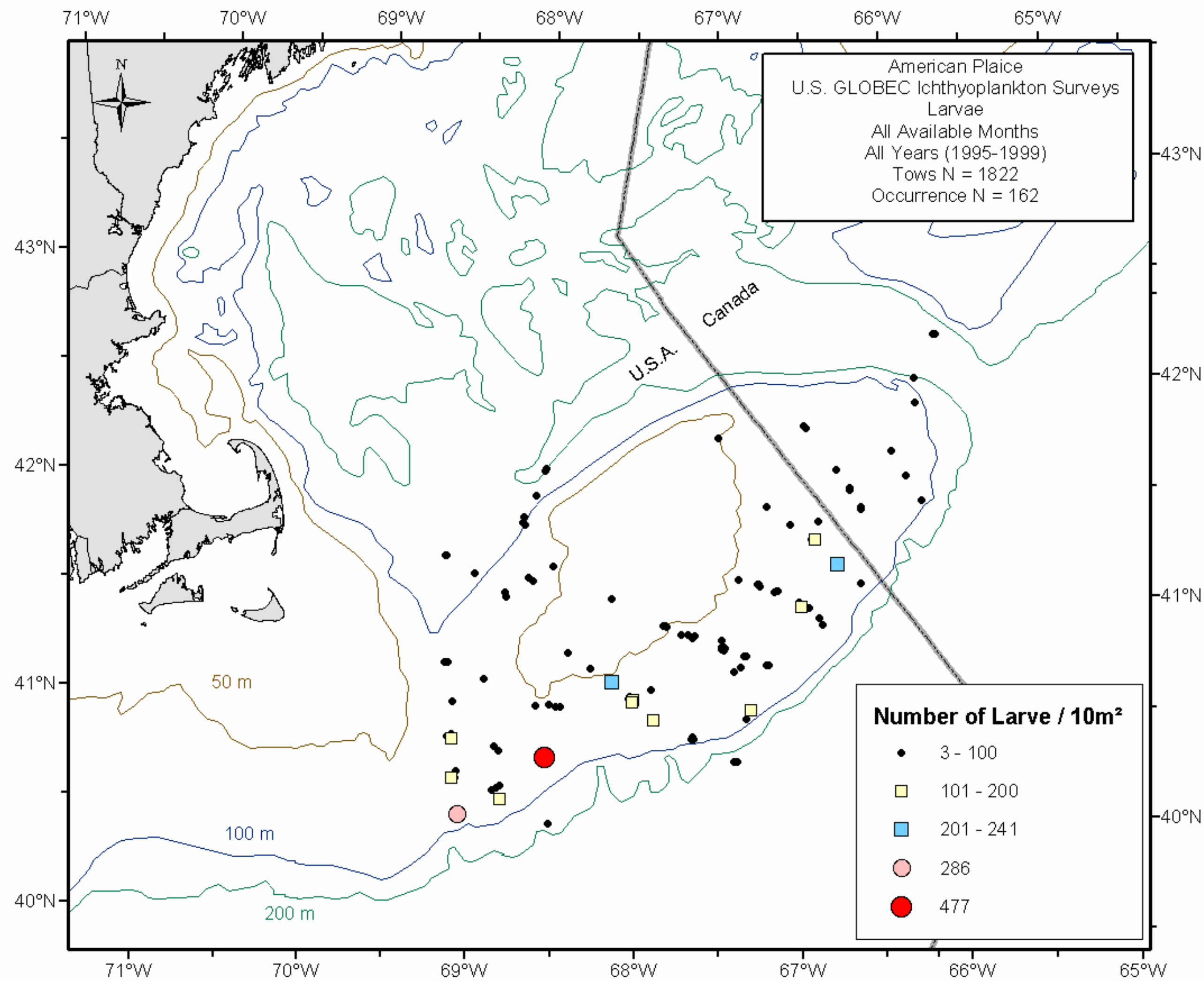
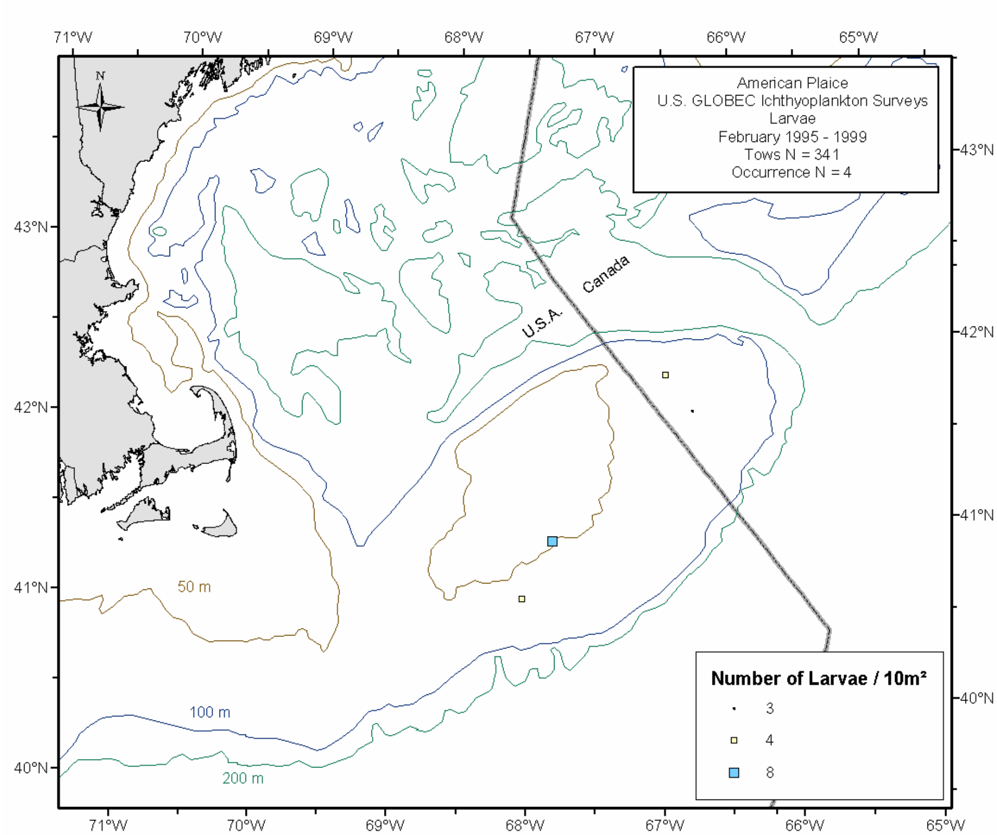


Figure 6. Distributions and abundances of American plaice larvae collected during GLOBEC Georges Bank ichthyoplankton surveys.
For all available years (February-July, 1995; January-June, 1996-1999) combined.



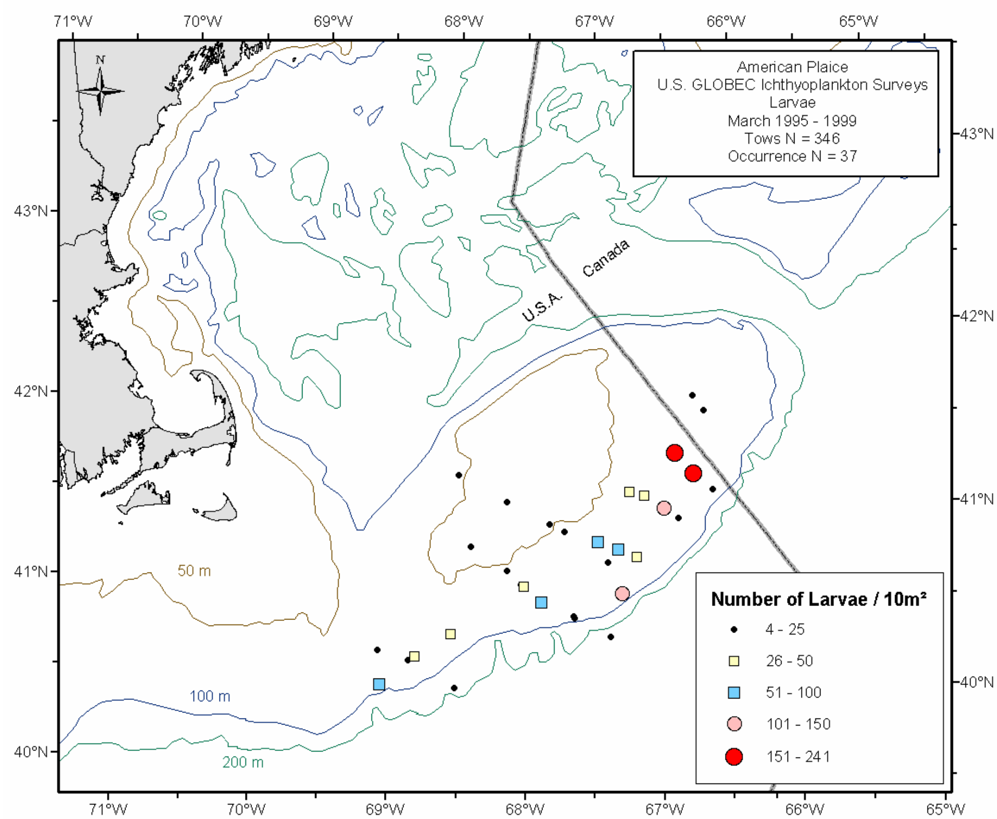
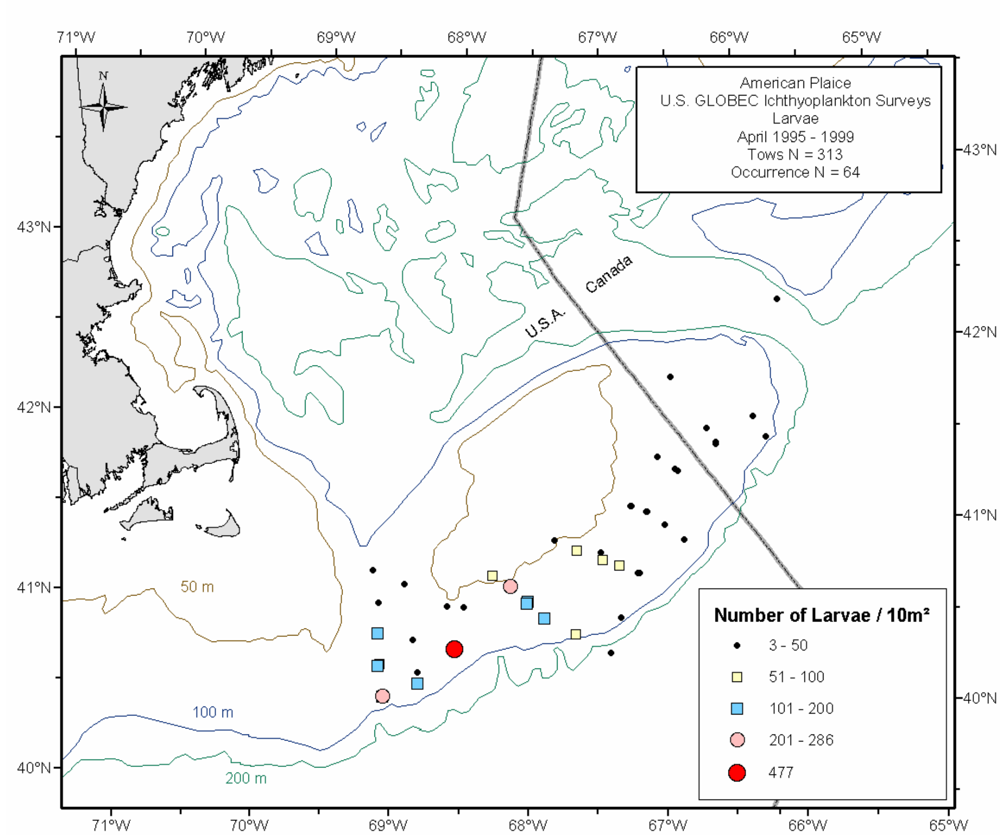


Figure 5. Cont'd.
From GLOBEC ichthyoplankton surveys, February and March, for all available years combined.



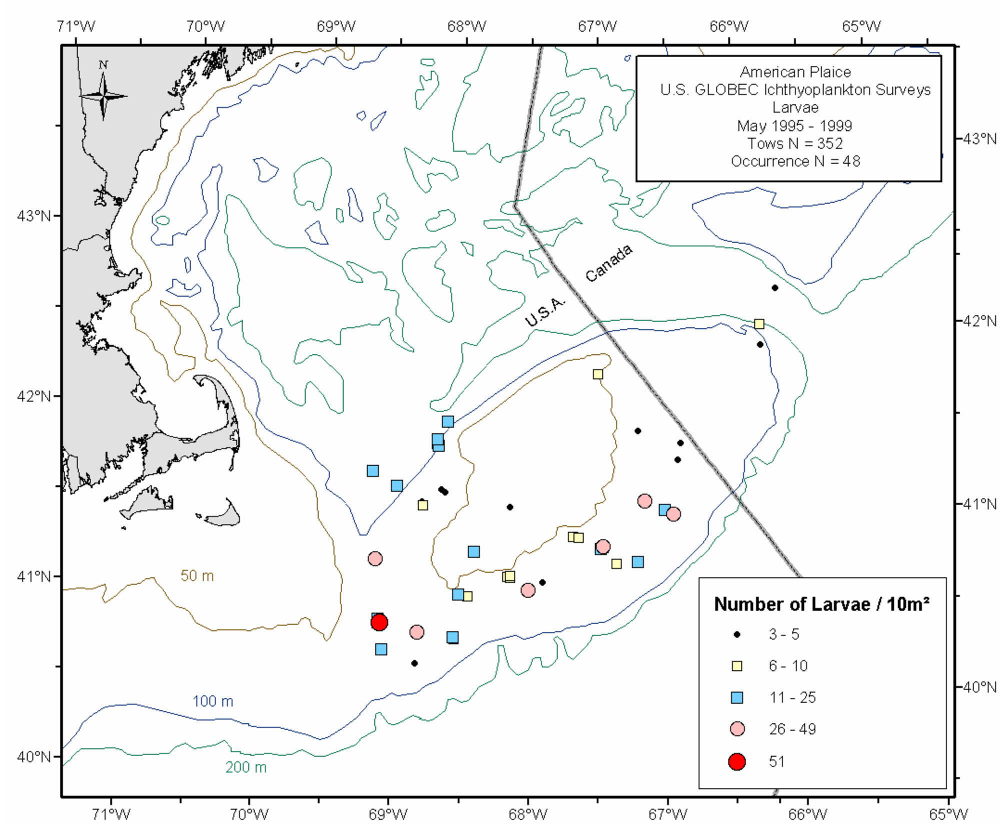


Figure 5. Cont'd.
From GLOBEC ichthyoplankton surveys, April and May, for all available years combined.

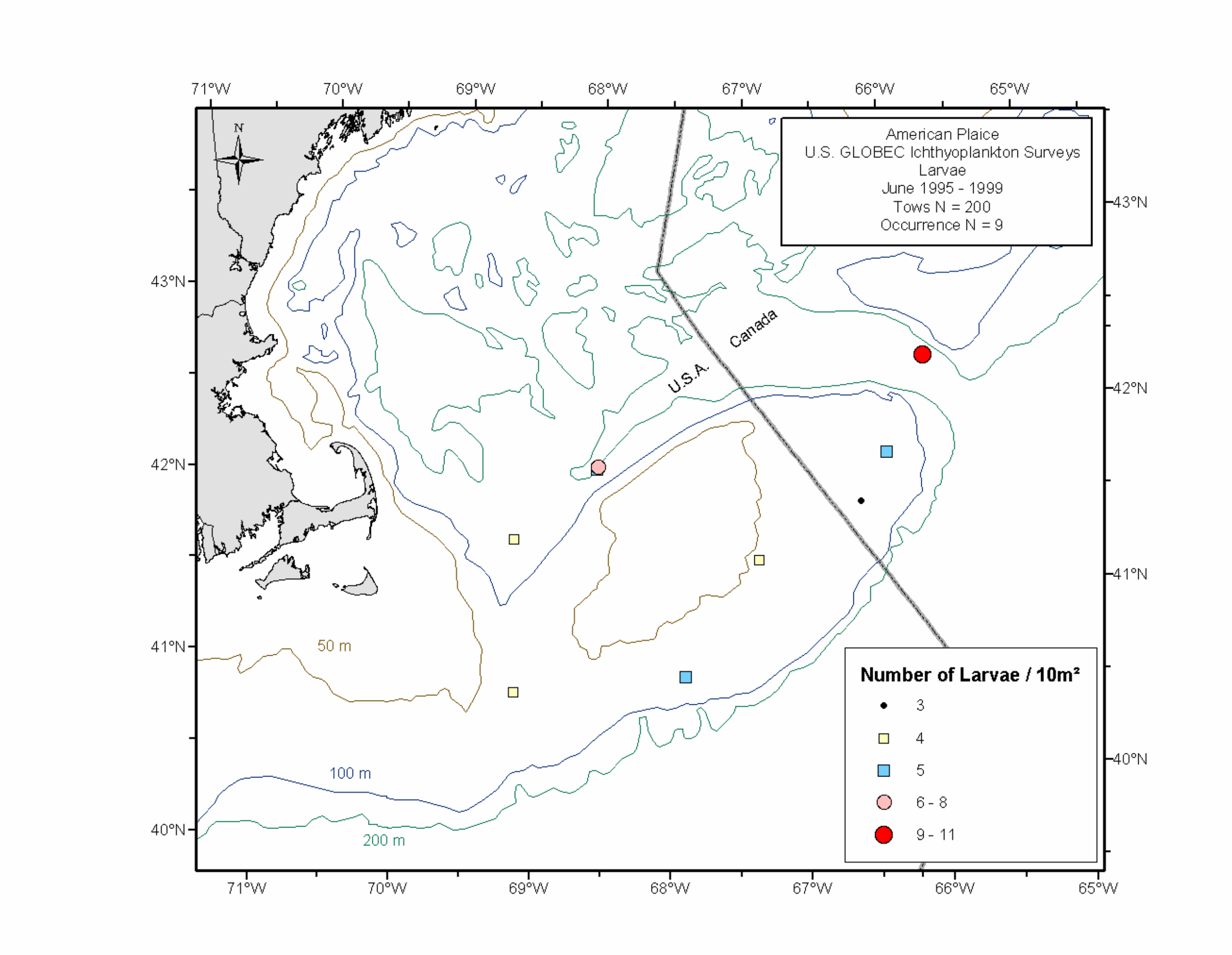


Figure 5. Cont'd.
From GLOBEC ichthyoplankton surveys, June, for all available years combined.

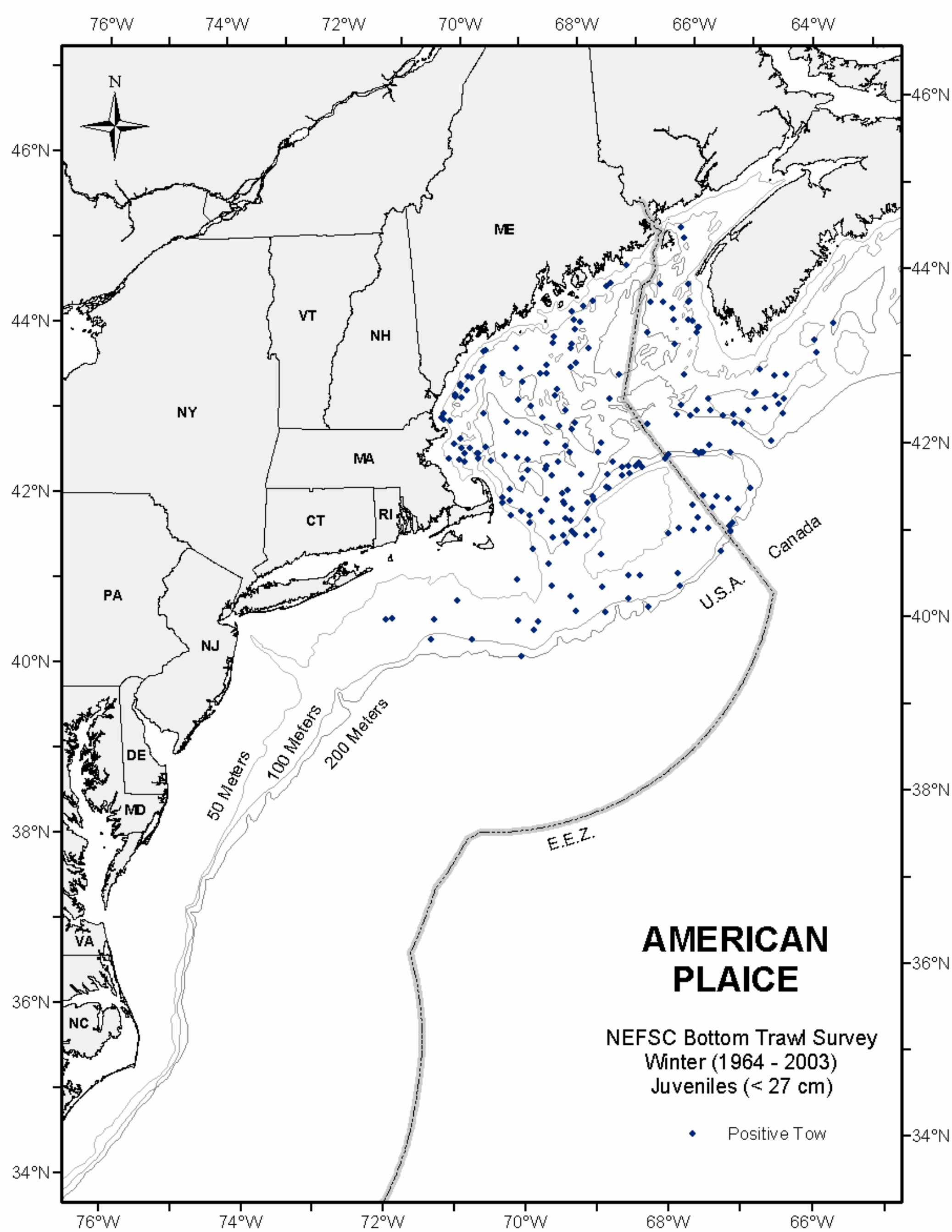


Figure 7. Seasonal distributions and abundances of juvenile American plaice collected during NEFSC bottom trawl surveys.
Based on NEFSC winter bottom trawl surveys (1964-2003, all years combined). Distributions are displayed as presence only.

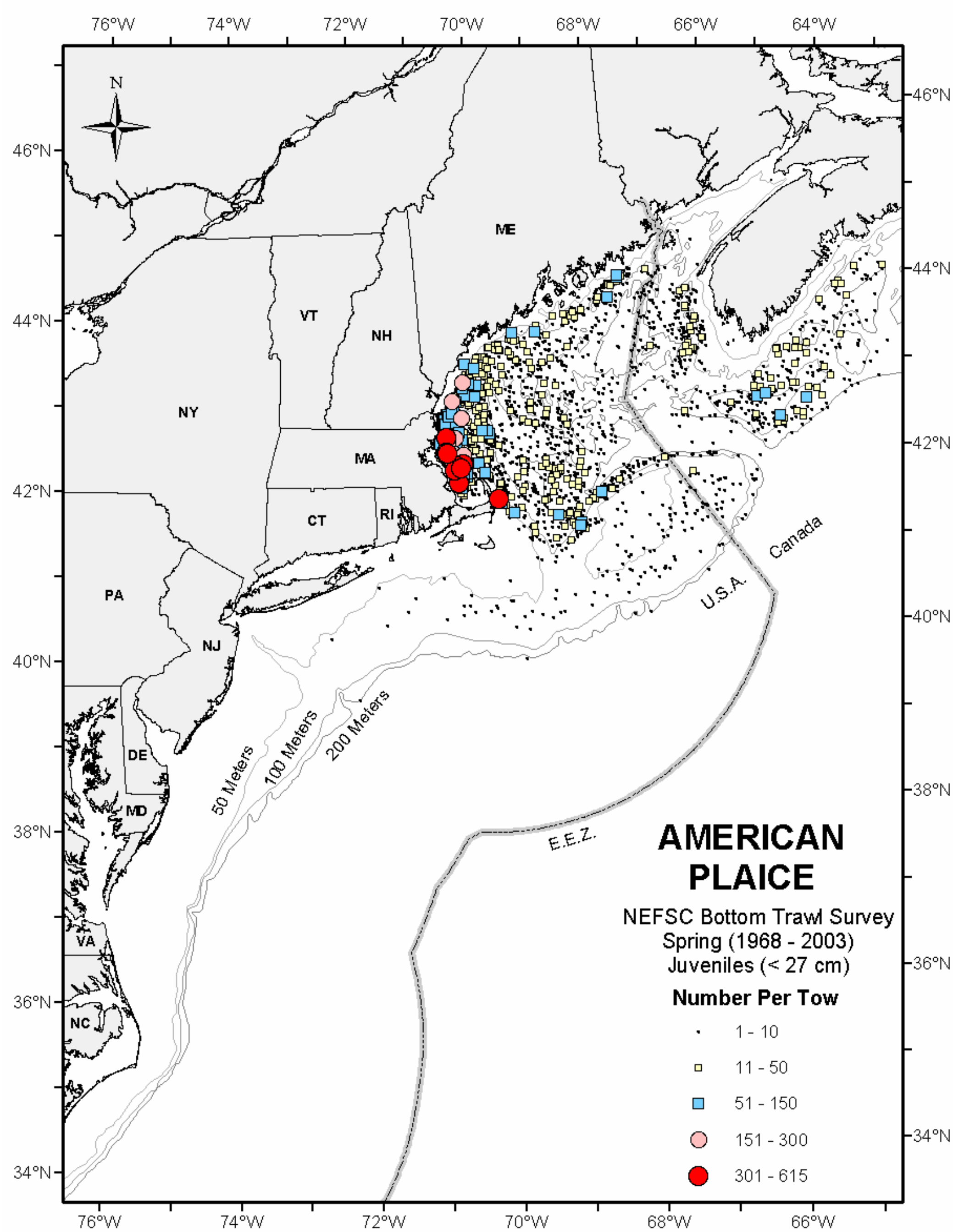


Figure 7. Cont'd.
Based on NEFSC spring bottom trawl surveys (1968-2003, all years combined). Survey stations where juveniles were not found are not shown.

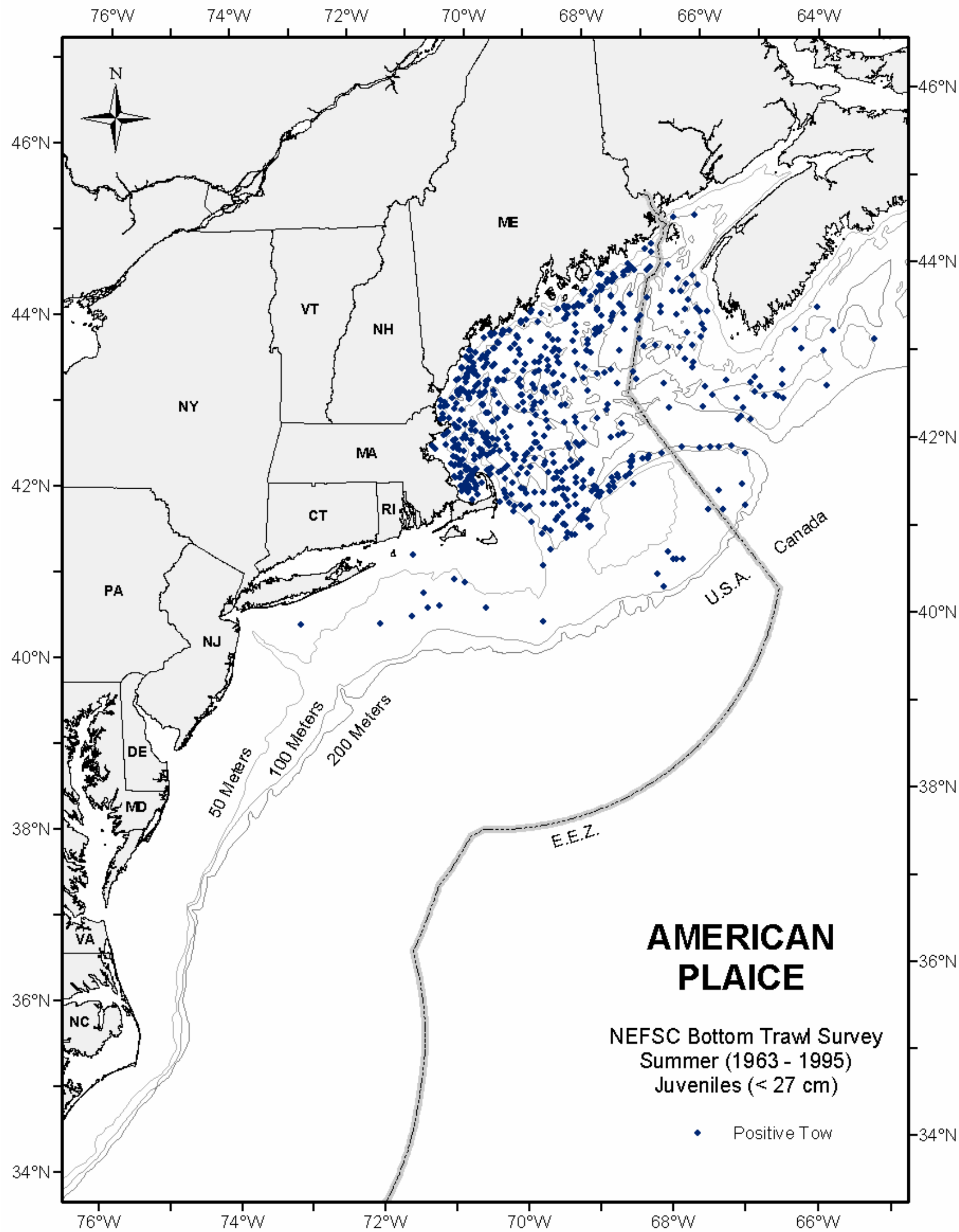


Figure 7. Cont'd.
Based on NEFSC summer bottom trawl surveys (1963-1995, all years combined). Distributions are displayed as presence only.

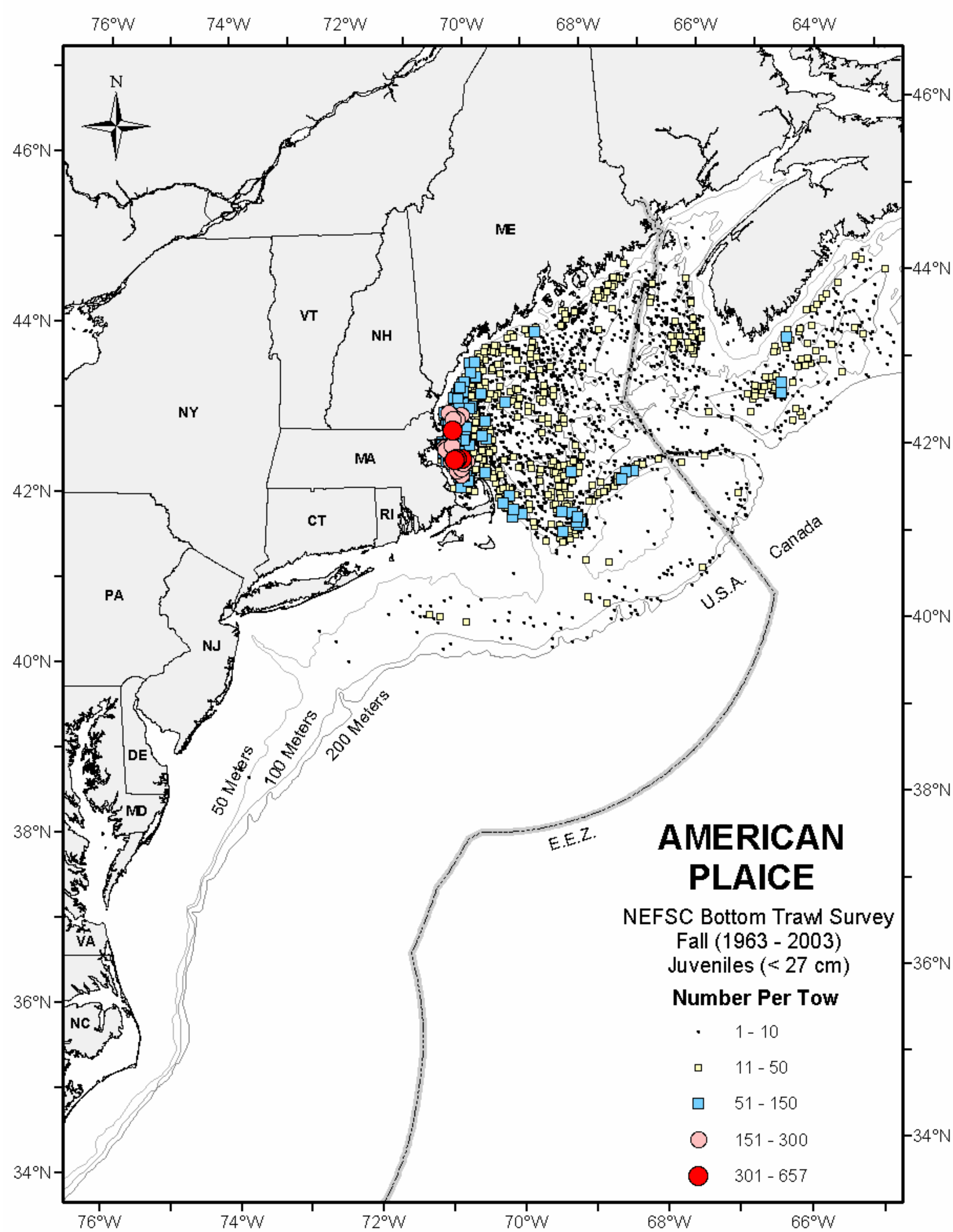


Figure 7. Cont'd.
Based on NEFSC fall bottom trawl surveys (1963-2003, all years combined). Survey stations where juveniles were not found are not shown.

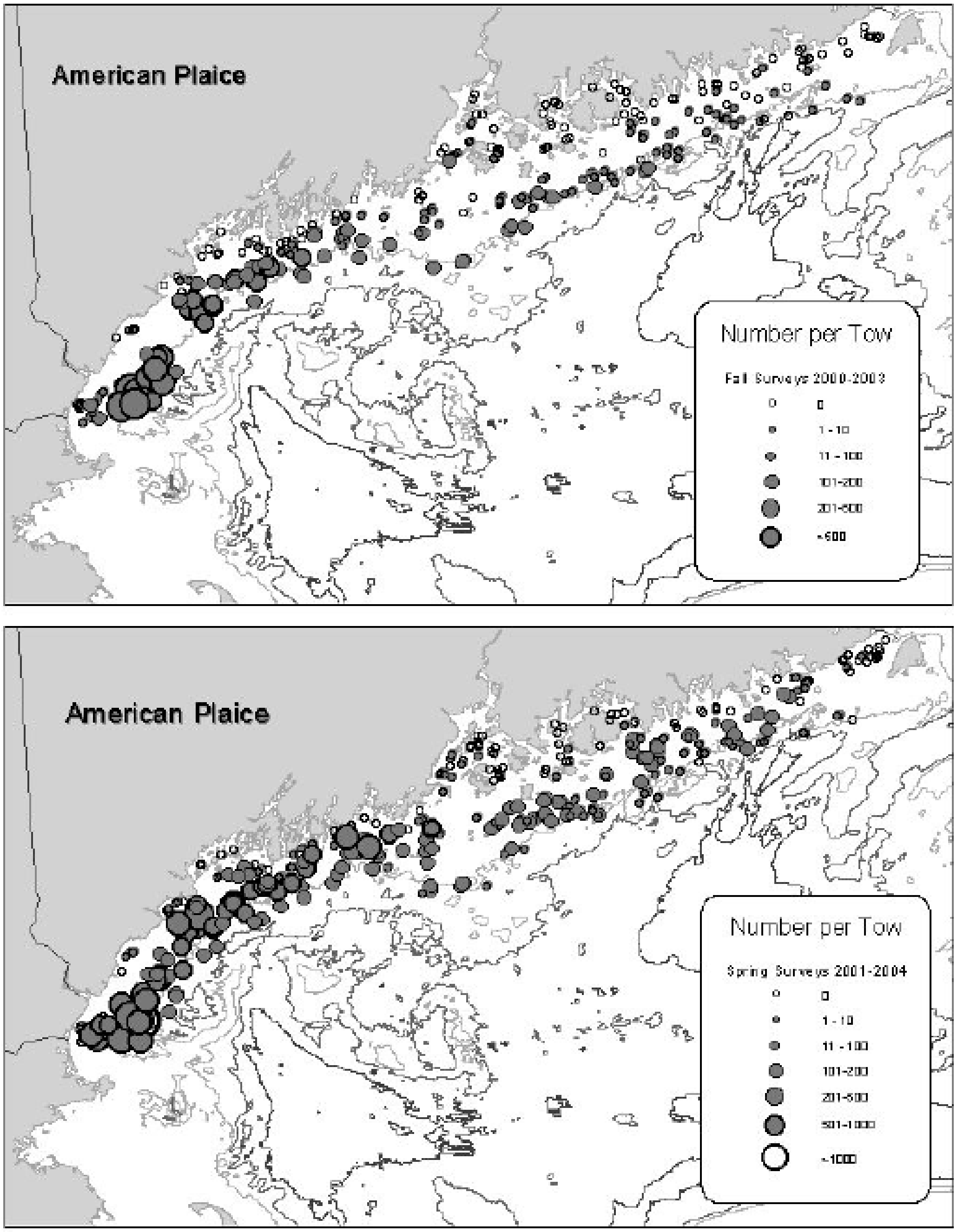
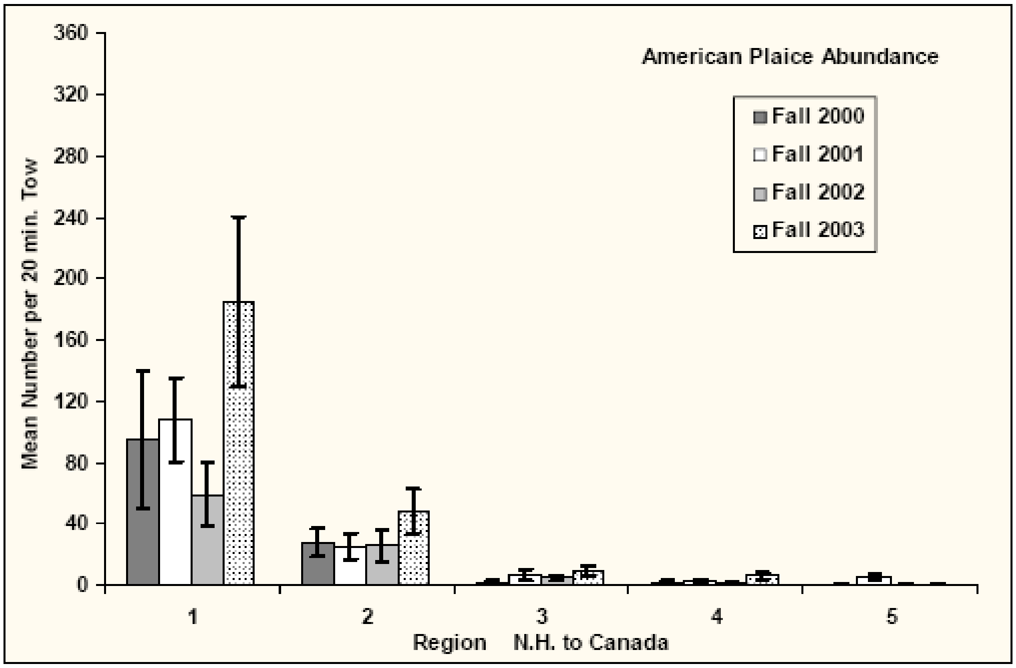


Figure 8. Distribution and abundance of American plaice along the coasts of Maine and New Hampshire. Based on the Maine – New Hampshire spring 2001-2004 and fall 2000-2003 inshore groundfish trawl surveys. For details on the survey, see Sherman *et al*. (2005).



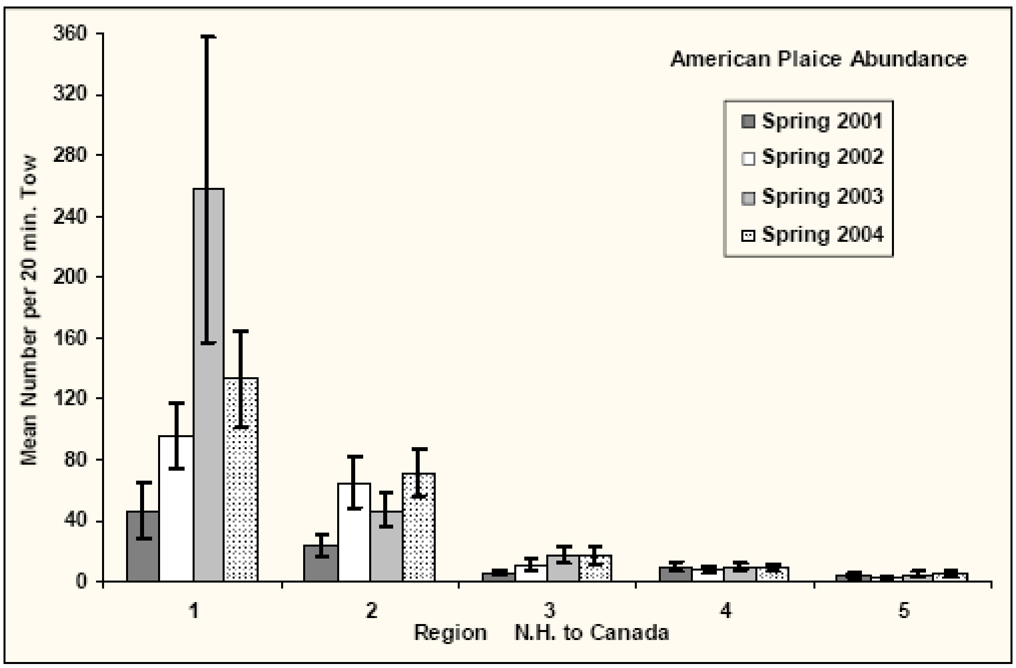


Figure 9. Regional catch-per-unit-effort of American plaice caught along the Maine and New Hampshire coasts, by season/year.
Based on the Maine – New Hampshire inshore groundfish trawl survey for spring 2001-2004 and fall 2000-2003. Region 1 = NH–Southern ME; Region 2 = Casco Bay–Midcoast ME; Region 3 = Penobscot Bay, ME; Region 4 = Jerico–Frenchmens Bay, ME; Region 5 = Downeast ME. Source: Sherman *et al*. (2005).

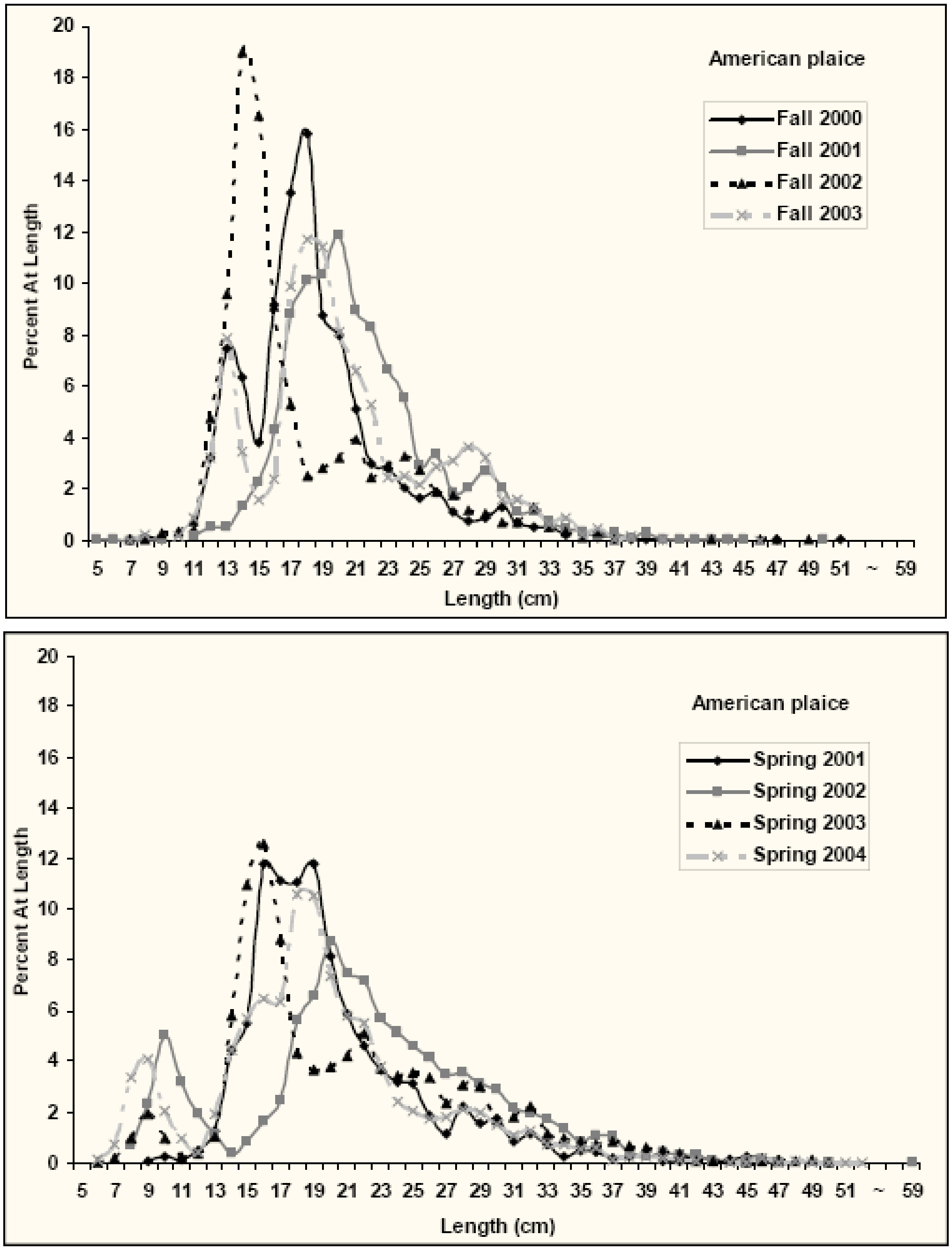


Figure 10. Length frequency plots for American plaice caught along the Maine and New Hampshire coasts, by season and year.
Based on the Maine – New Hampshire inshore groundfish trawl survey for spring 2001-2004 and fall 2000-2003.
Source: Sherman *et al*. (2005).

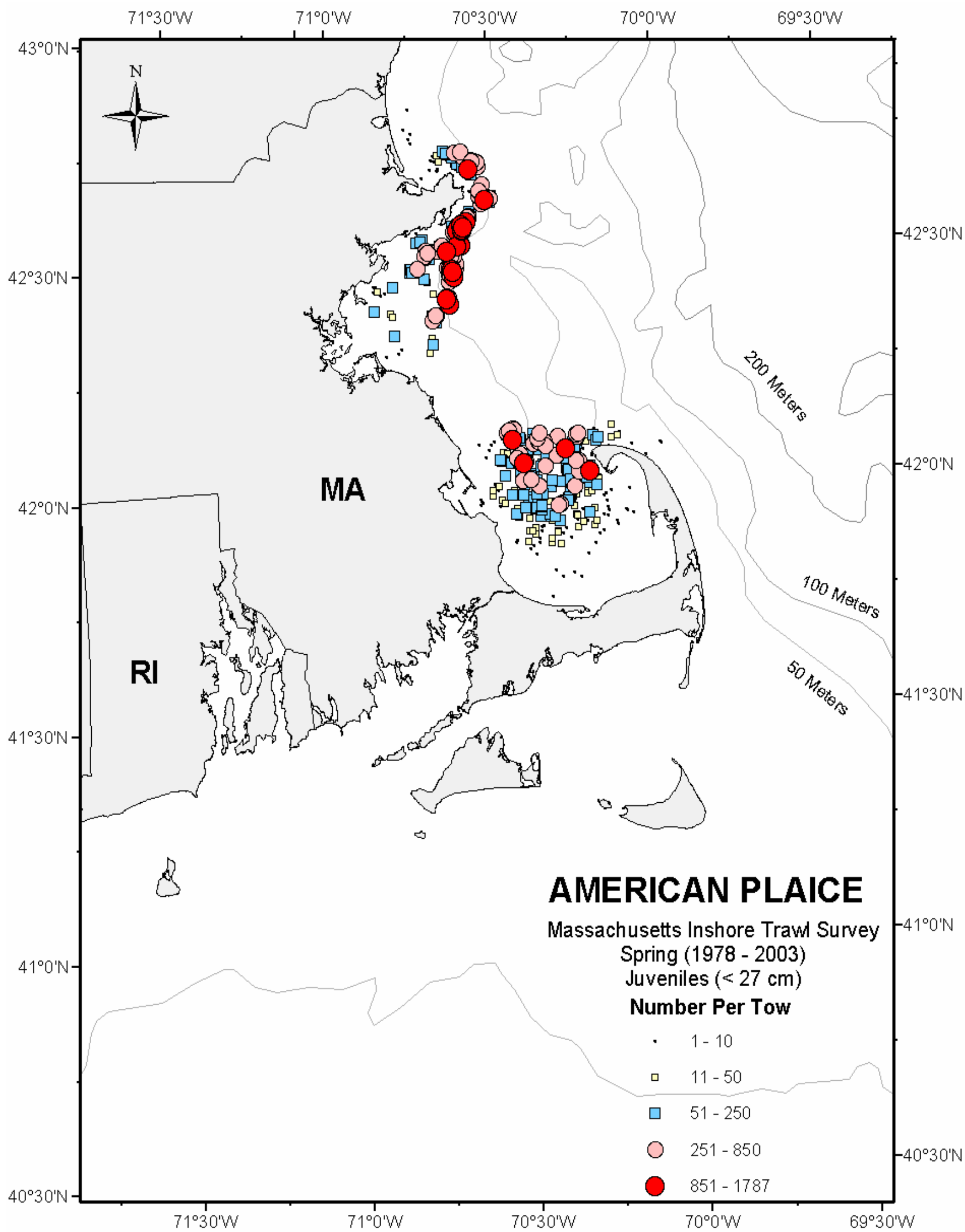


Figure 11. Seasonal distributions and abundances of juvenile American plaice in Massachusetts coastal waters. Based on spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where juveniles were not found are not shown.

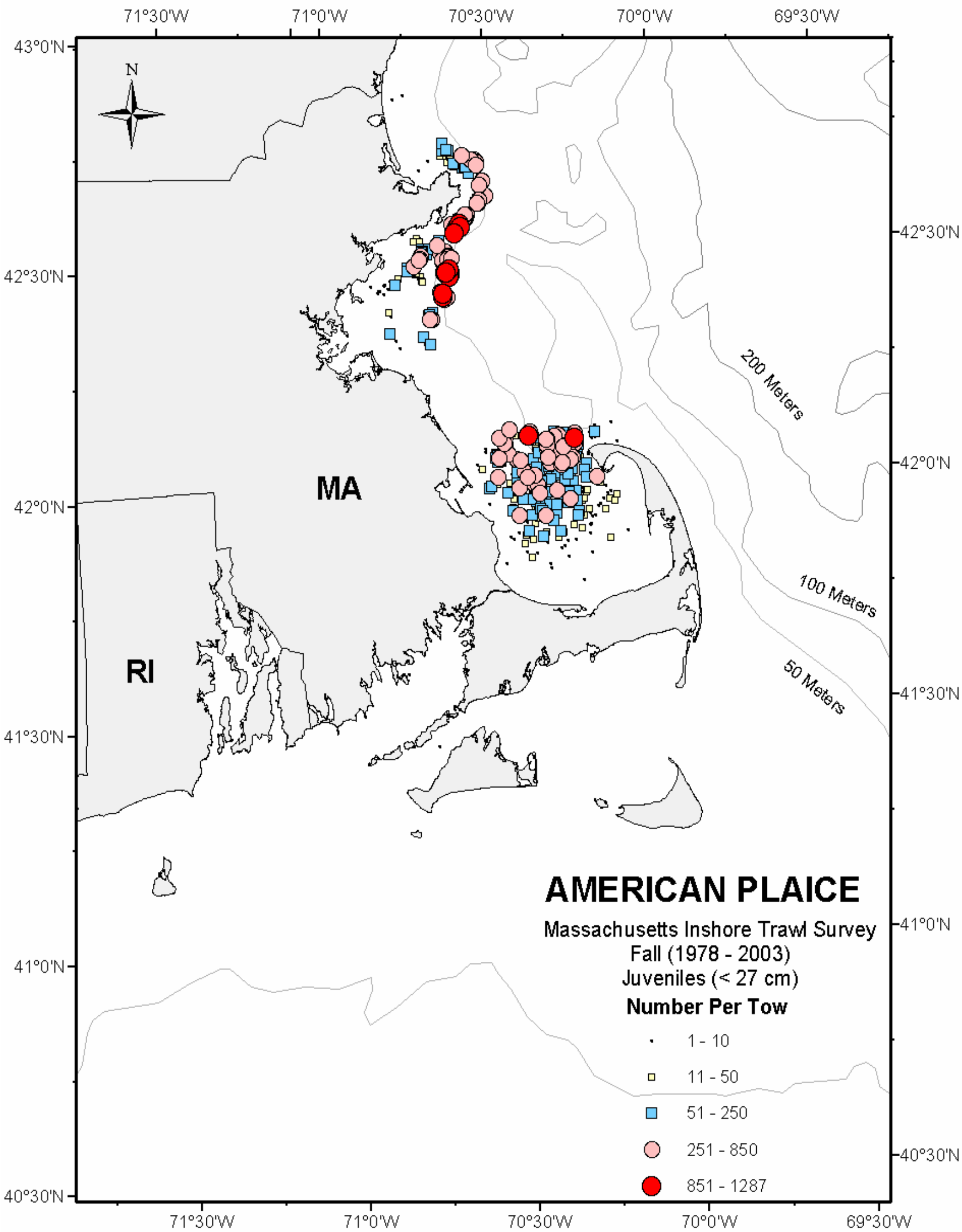


Figure 11. Cont'd.
Based on fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where juveniles were not found are not shown.

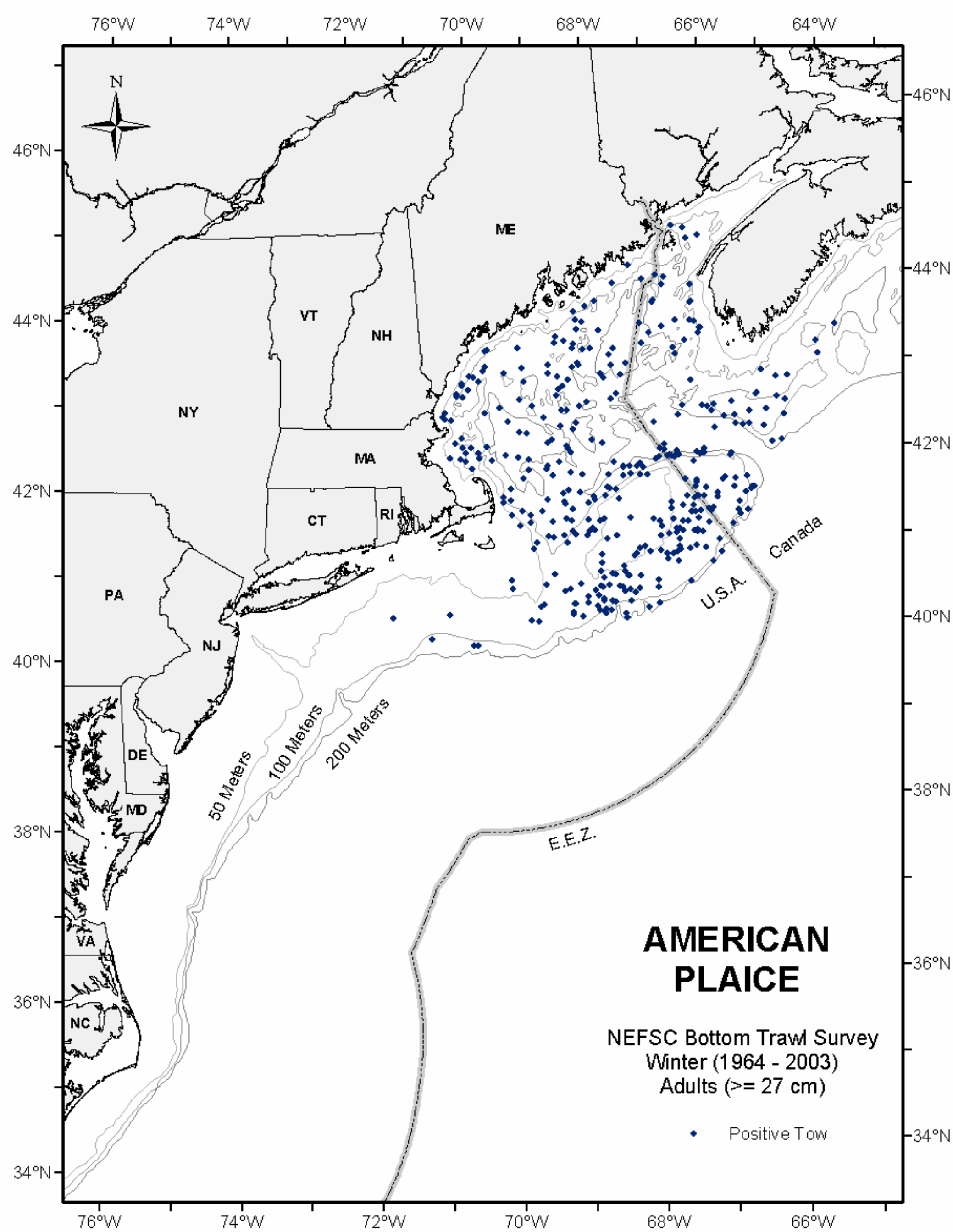


Figure 12. Seasonal distributions and abundances of adult American plaice collected during NEFSC bottom trawl surveys.
Based on NEFSC winter bottom trawl surveys (1964-2003, all years combined). Distributions are displayed as presence only.

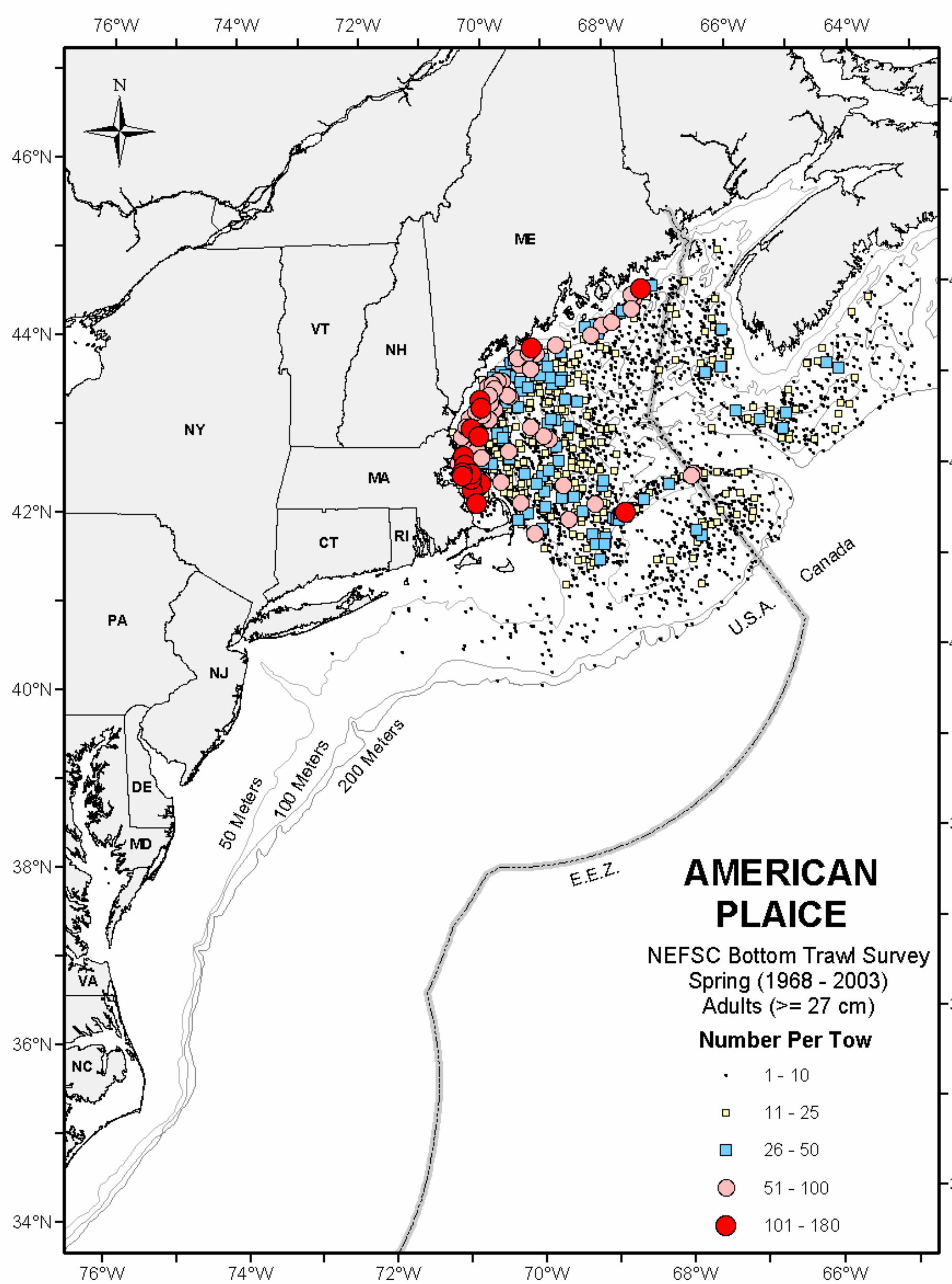


Figure 12. Cont'd.
Based on NEFSC spring bottom trawl surveys (1968-2003, all years combined). Survey stations where adults were not found are not shown.

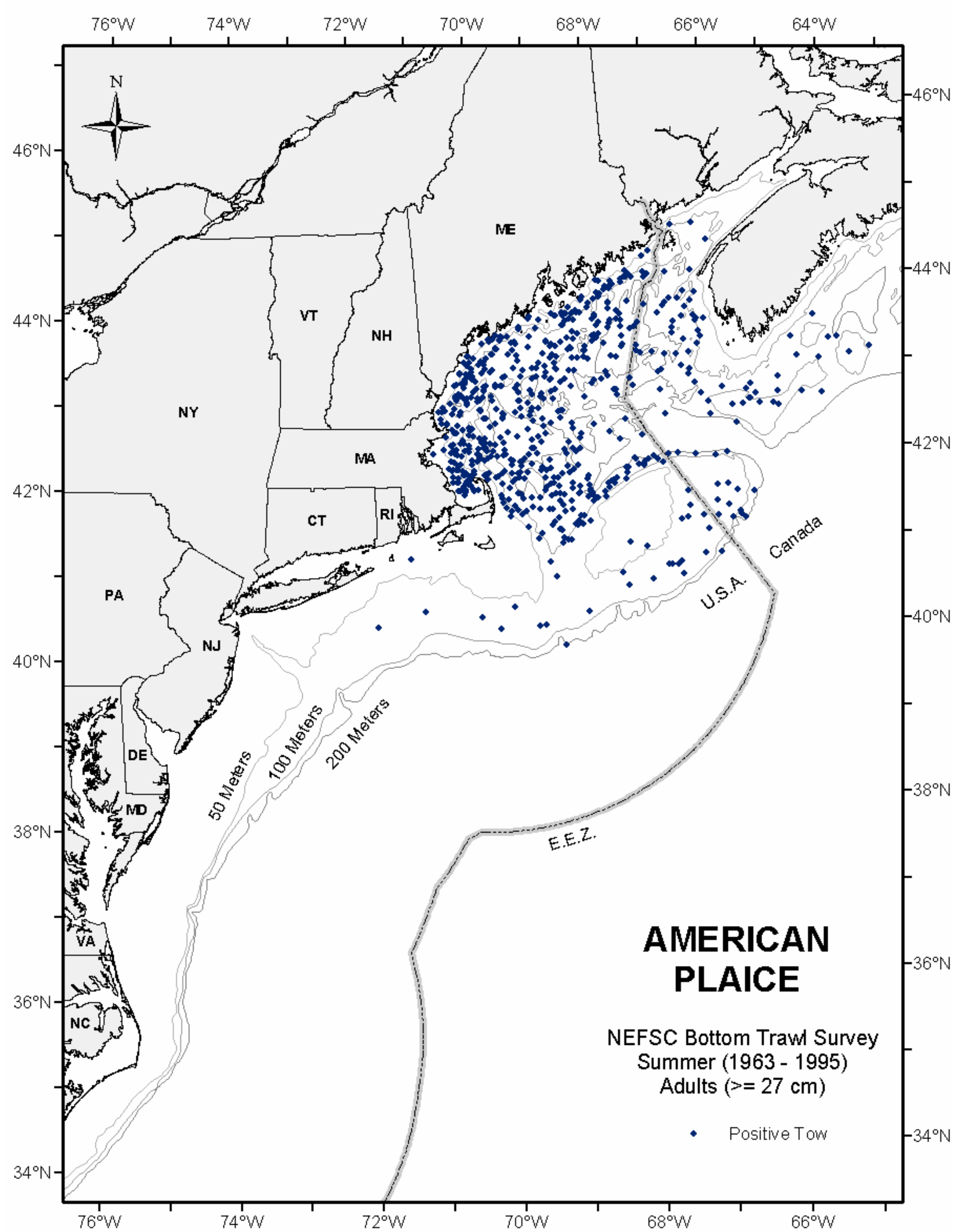


Figure 12. Cont'd.
Based on NEFSC summer bottom trawl surveys (1963-1995, all years combined). Distributions are displayed as presence only.

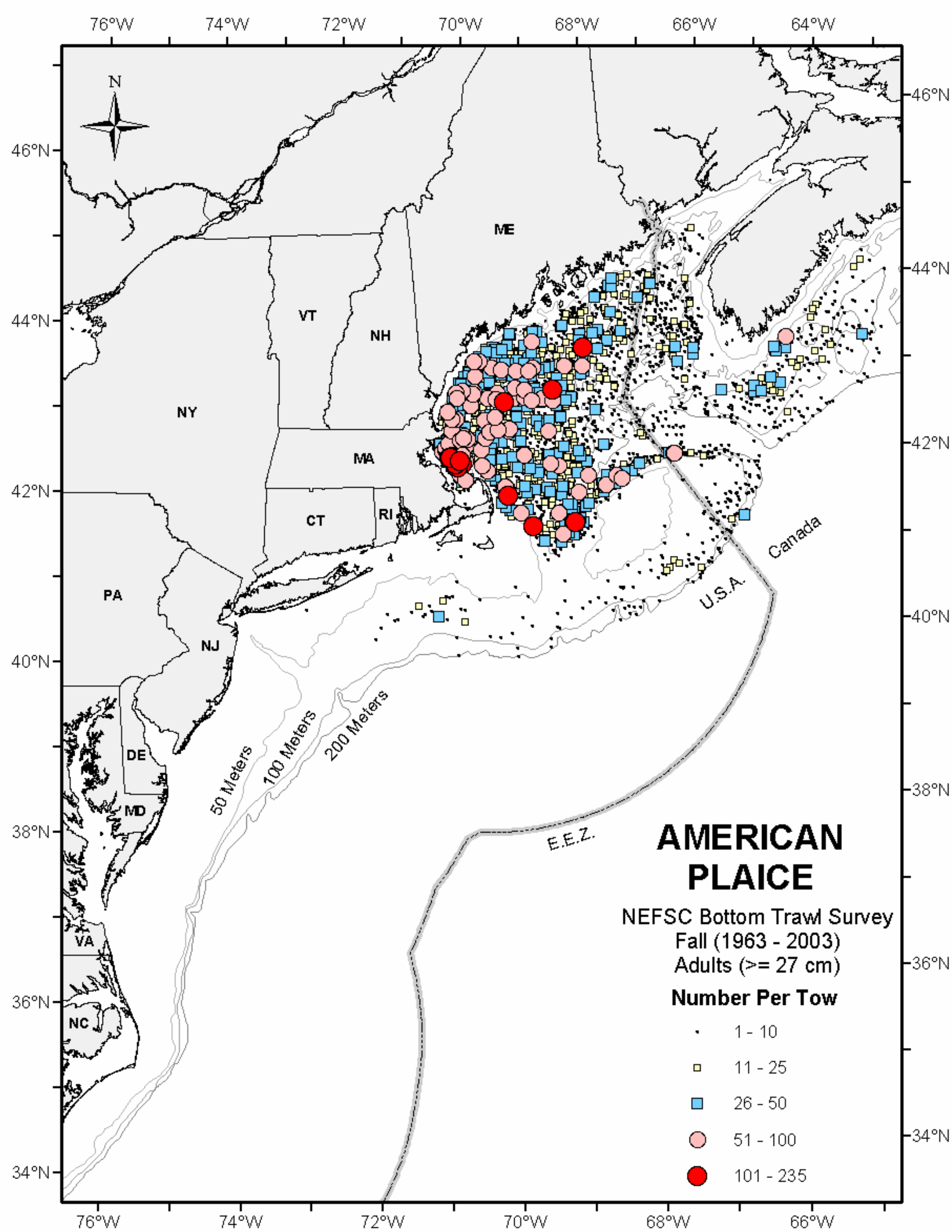


Figure 12. Cont'd.
Based on NEFSC fall bottom trawl surveys (1963-2003, all years combined). Survey stations where adults were not found are not shown.

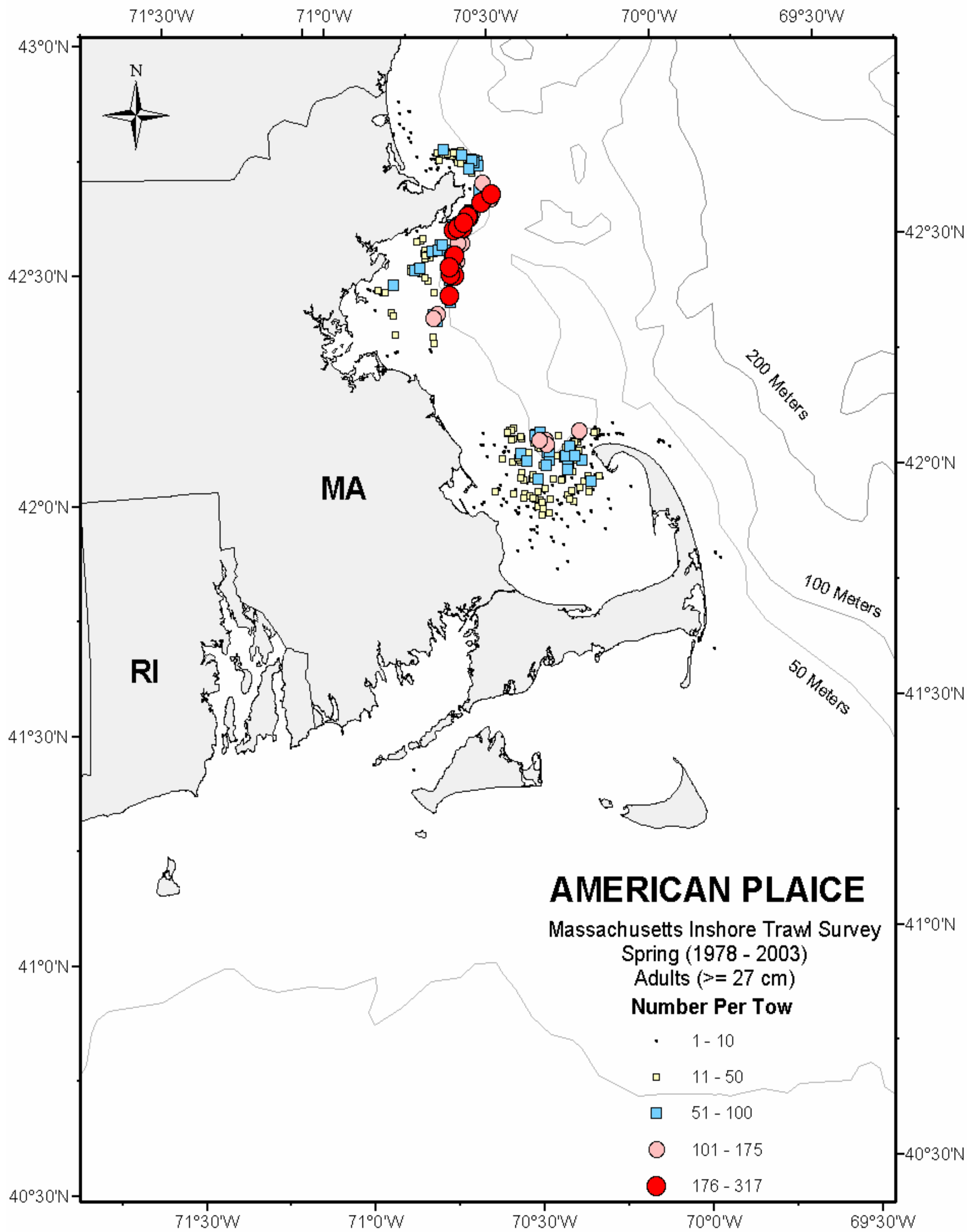


Figure 13. Seasonal distributions and abundances of adult American plaice**Error! Reference source not found.** in Massachusetts coastal waters.
Based on spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where adults were not found are not shown.

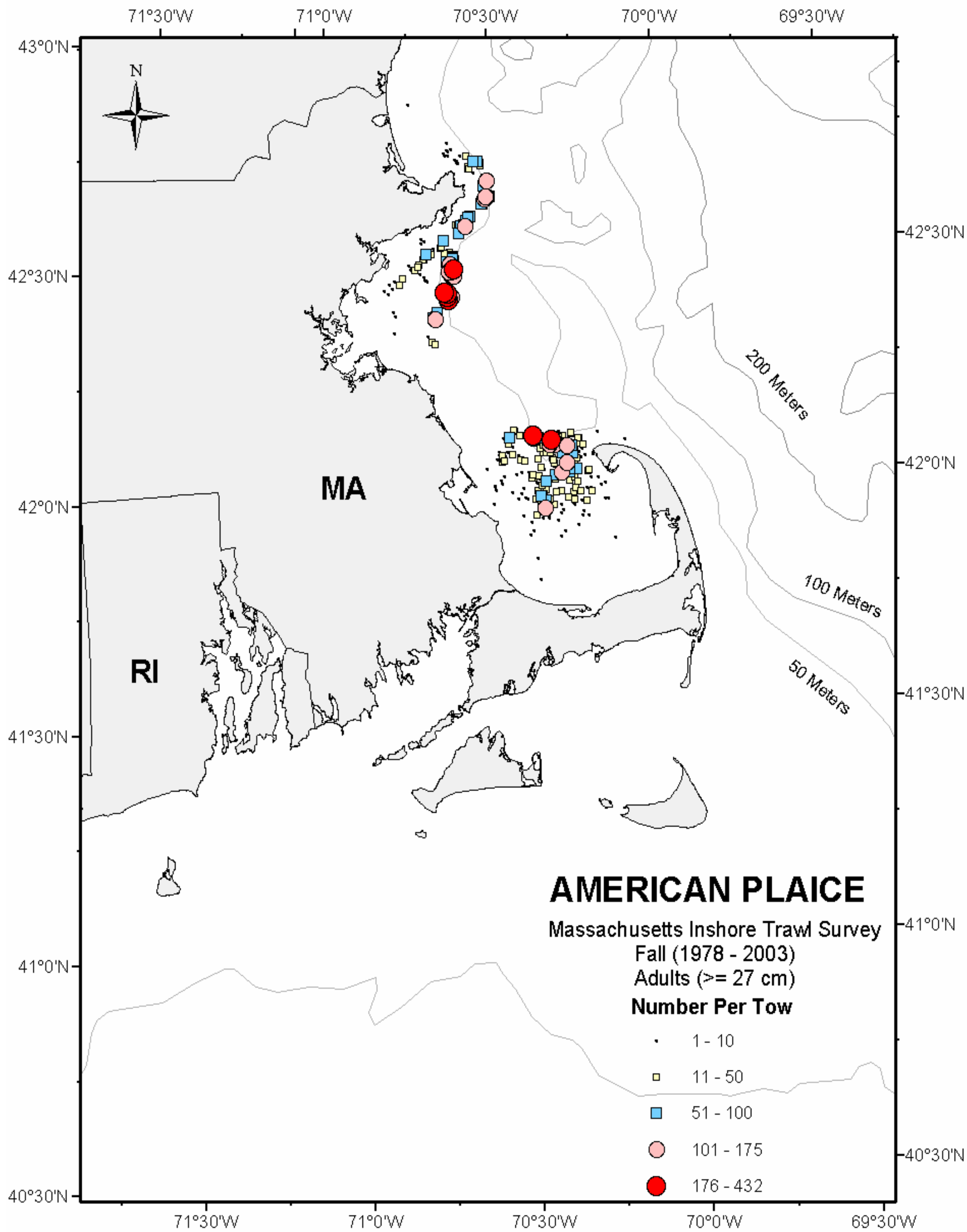


Figure 13. Cont'd.
Based on fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where adults were not found are not shown.

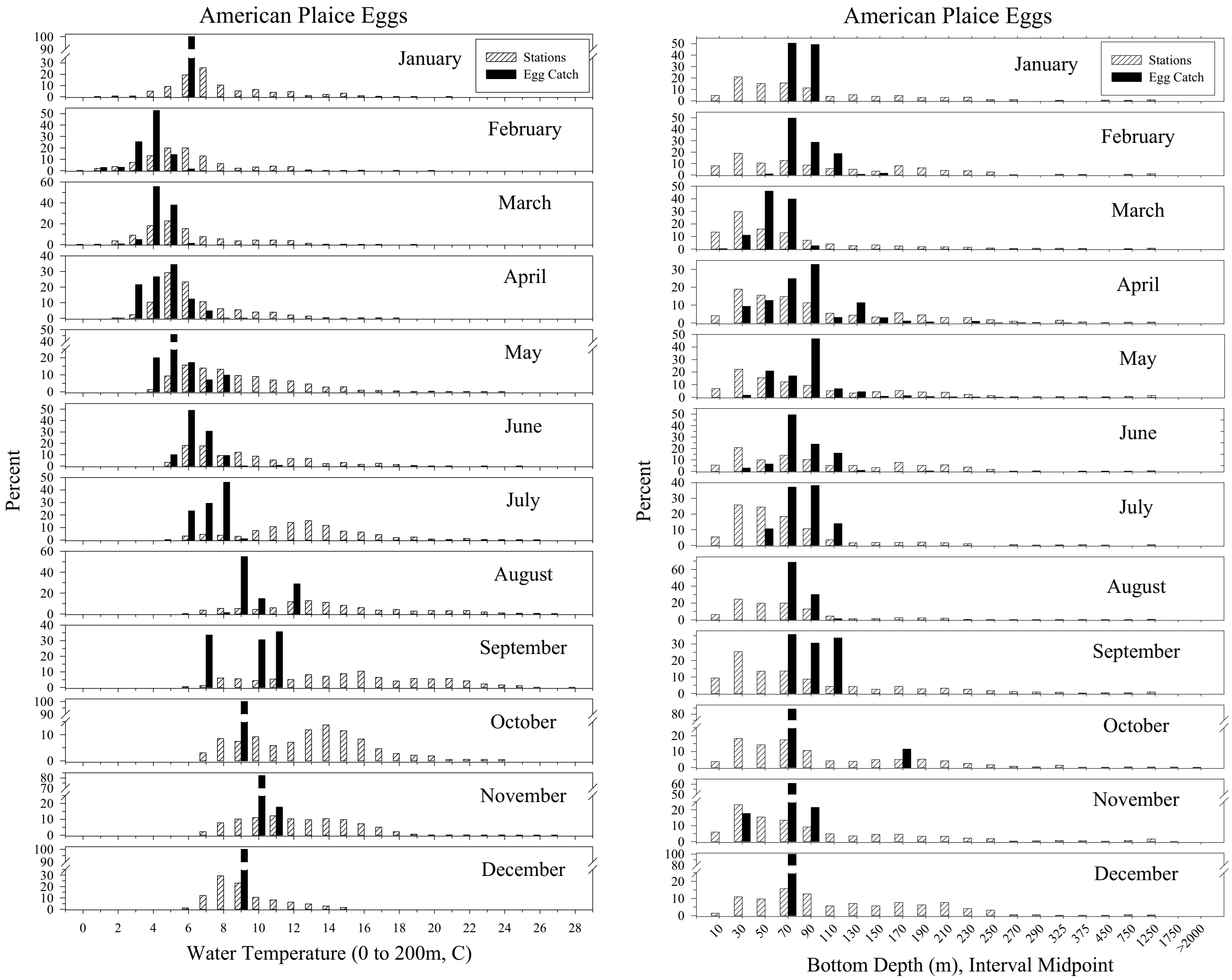


Figure 14. Monthly distributions of American plaice eggs collected during NEFSC MARMAP ichthyoplankton surveys relative to water column temperature and bottom depth.
For all available months and years from 1978-1987, combined. Open bars represent the proportion of all stations which were surveyed, while 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.

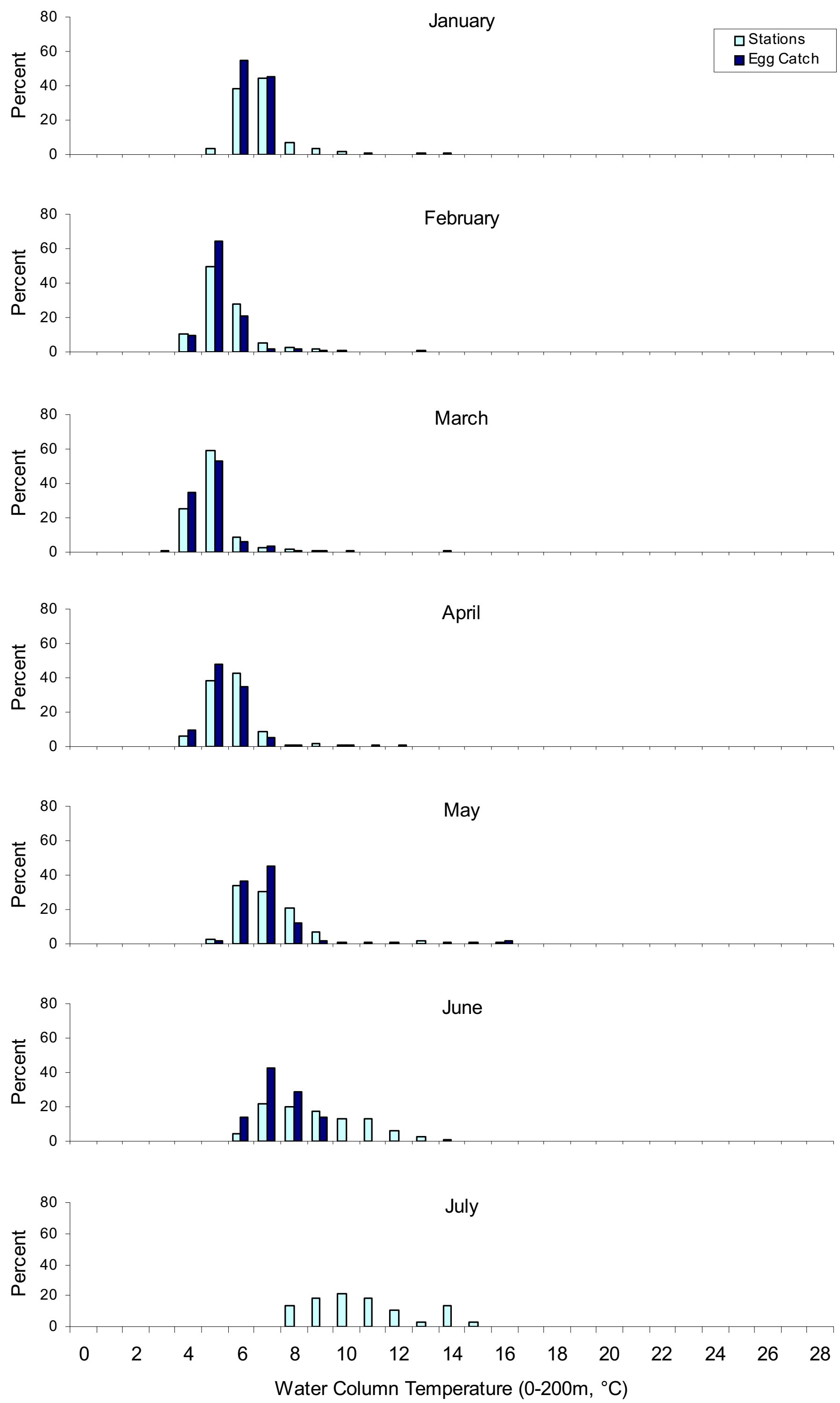


Figure 15. Distributions of American plaice**Error! Reference source not found.** eggs collected during GLOBEC ichthyoplankton surveys relative to water column temperature.
Based on GLOBEC Georges Bank surveys (February-July, 1995; January-June, 1996-1999) by month for all available years combined. Light bars represent the proportion of all stations surveyed, while dark bars represent the proportion of the sum of all standardized catches (number/10 m^2).

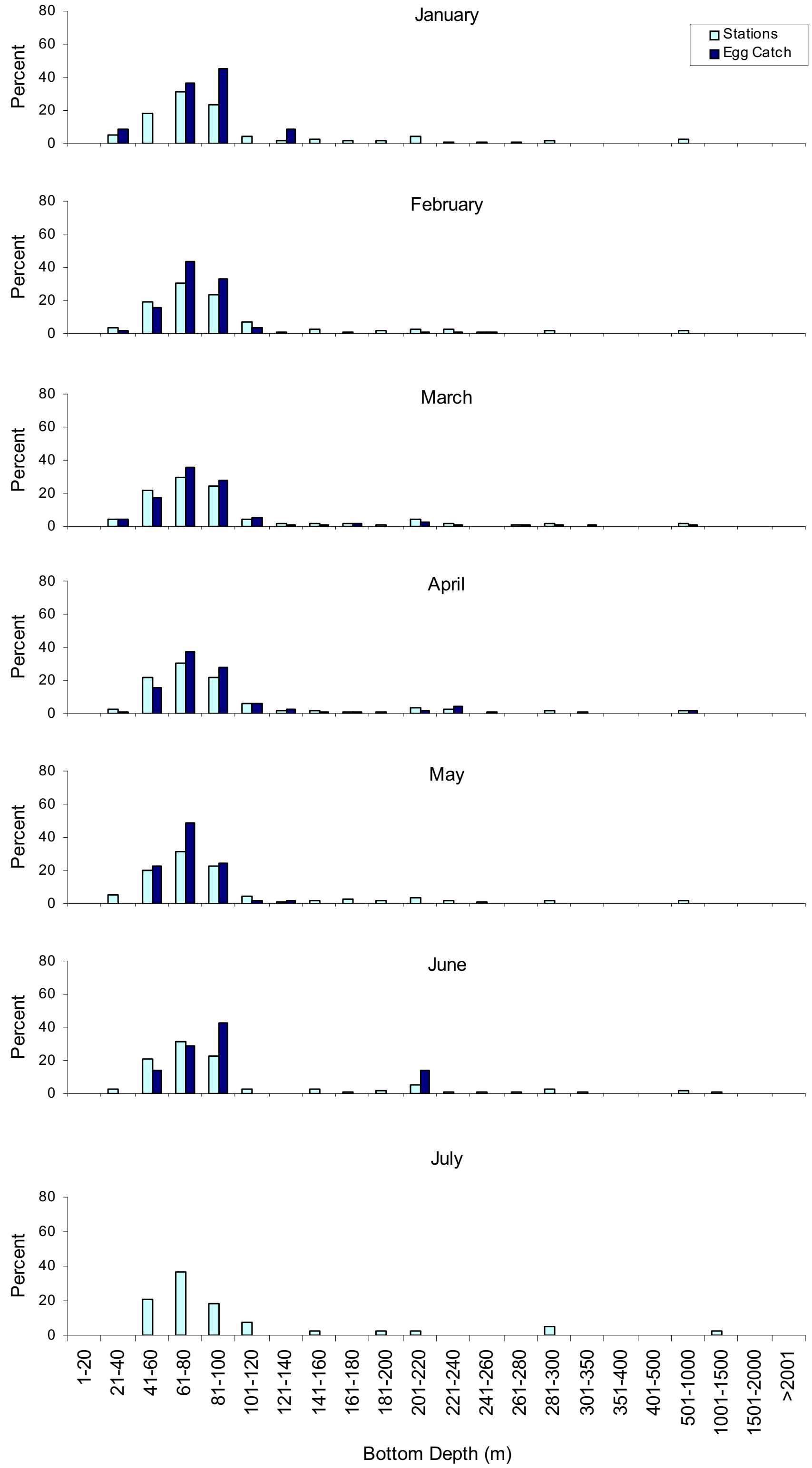


Figure 16. Distributions of American plaice eggs collected during GLOBEC ichthyoplankton surveys relative to bottom depth.
Based on GLOBEC Georges Bank surveys (February-July, 1995; January-June, 1996-1999) by month for all available years combined. Light bars represent the proportion of all stations surveyed, while dark bars represent the proportion of the sum of all standardized catches (number/10 m^2). Note that the bottom depth intervals change with depth.

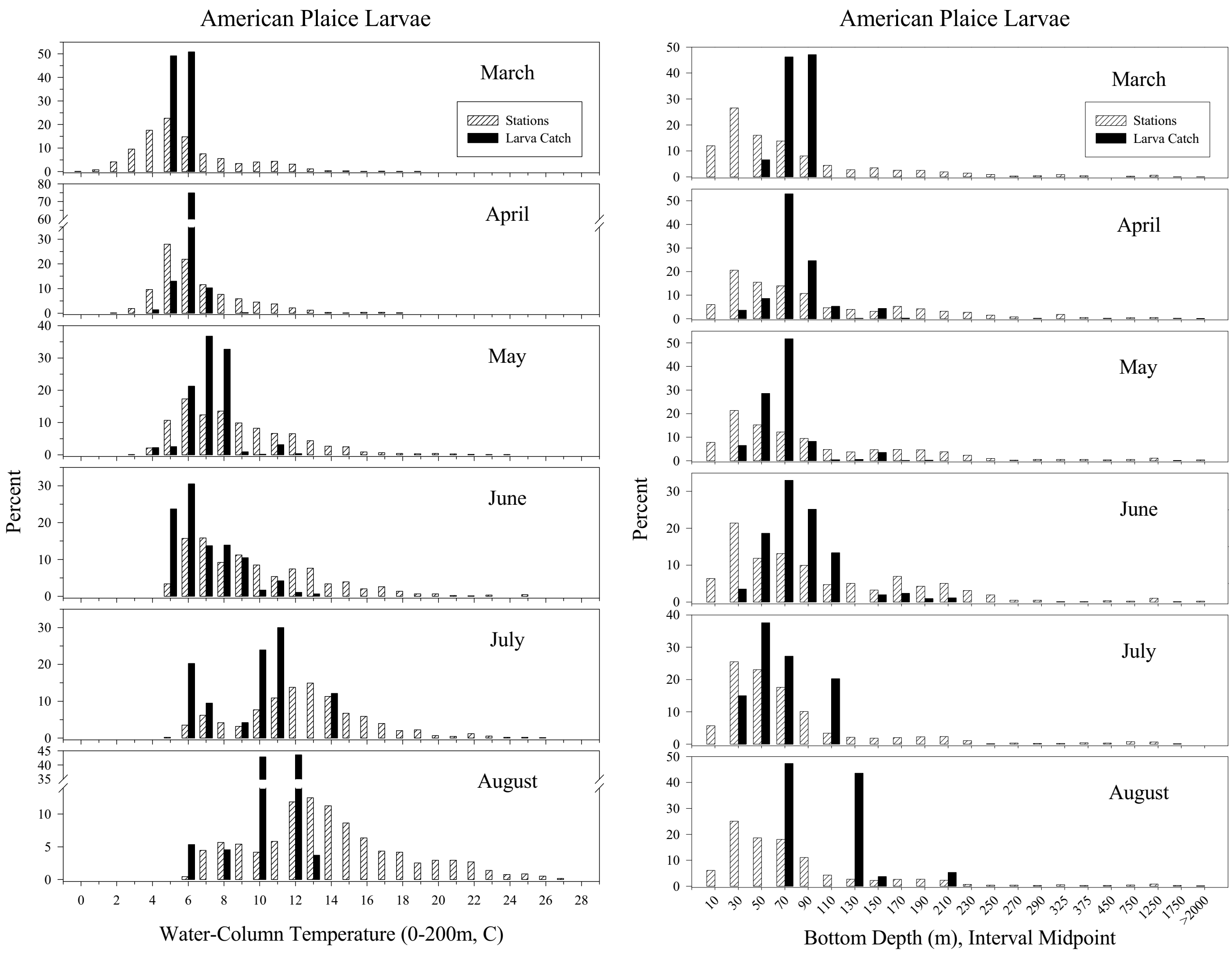


Figure 17. Monthly distributions of American plaice larvae collected during NEFSC MARMAP ichthyoplankton surveys relative to water column temperature and bottom depth.
For all available months and years from 1977-1987, combined. Open bars represent the proportion of all stations which were surveyed, 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.

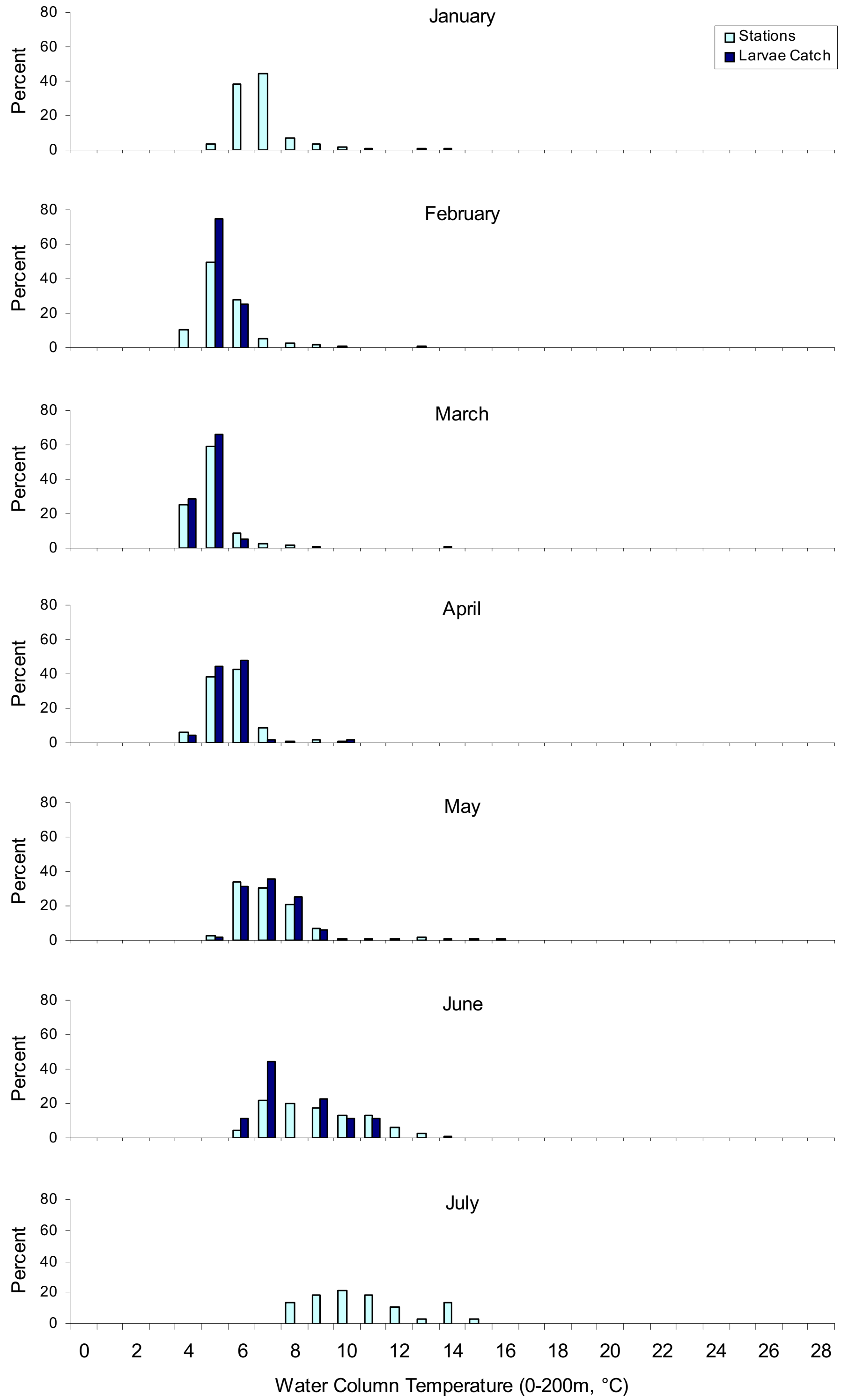


Figure 18. Distributions of American plaice larvae collected during GLOBEC ichthyoplankton surveys relative to water column temperature.
Based on GLOBEC Georges Bank surveys (February-July, 1995; January-June, 1996-1999) by month for all available years combined. Light bars represent the proportion of all stations surveyed, while dark bars represent the proportion of the sum of all standardized catches (number/10 m^2).

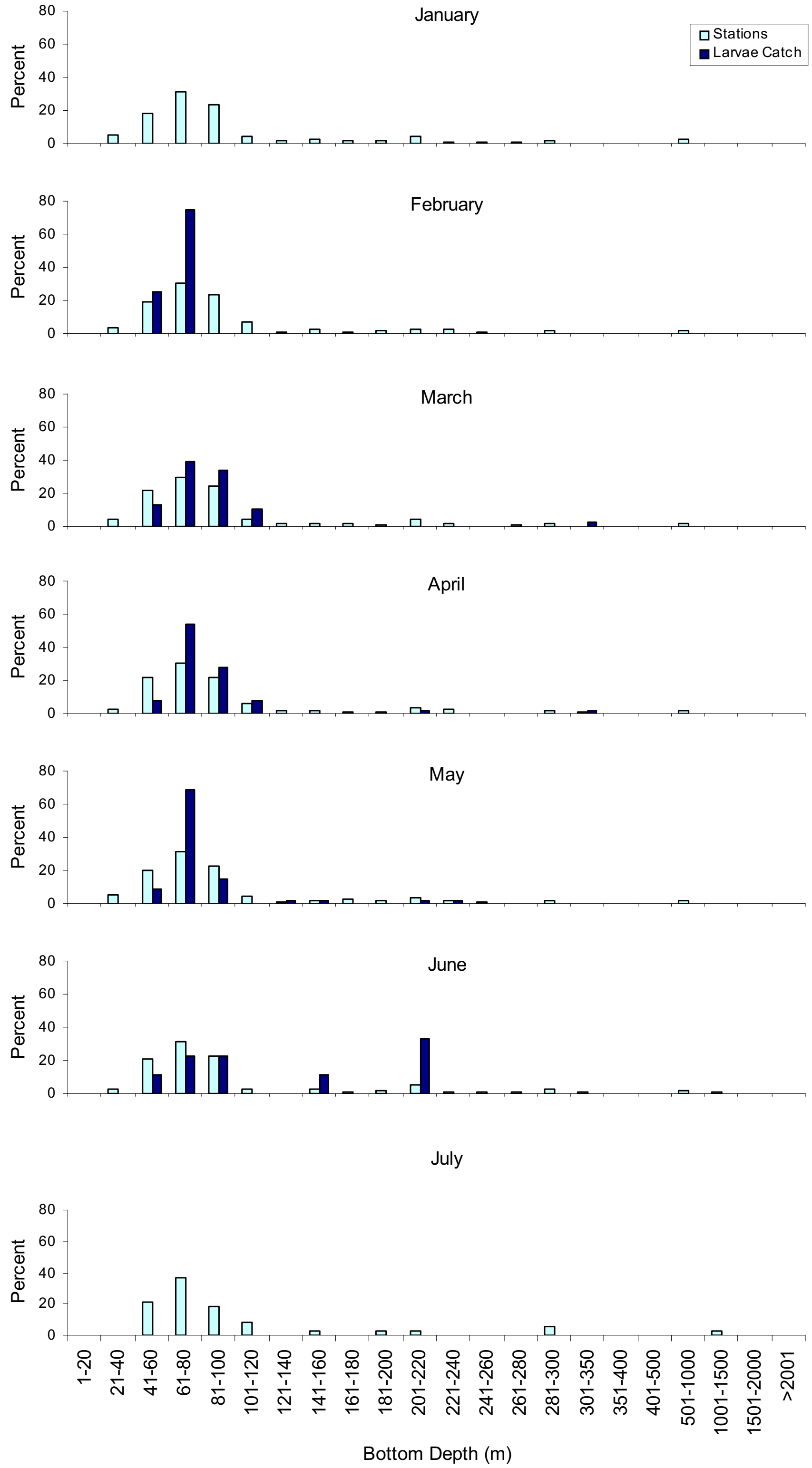


Figure 19. Distributions of American plaice larvae collected during GLOBEC ichthyoplankton surveys relative to bottom depth.
Based on GLOBEC Georges Bank surveys (February-July, 1995; January-June, 1996-1999) by month for all available years combined. Light bars represent the proportion of all stations surveyed, while dark bars represent the proportion of the sum of all standardized catches (number/10 m^2). Note that the bottom depth intervals change with depth.

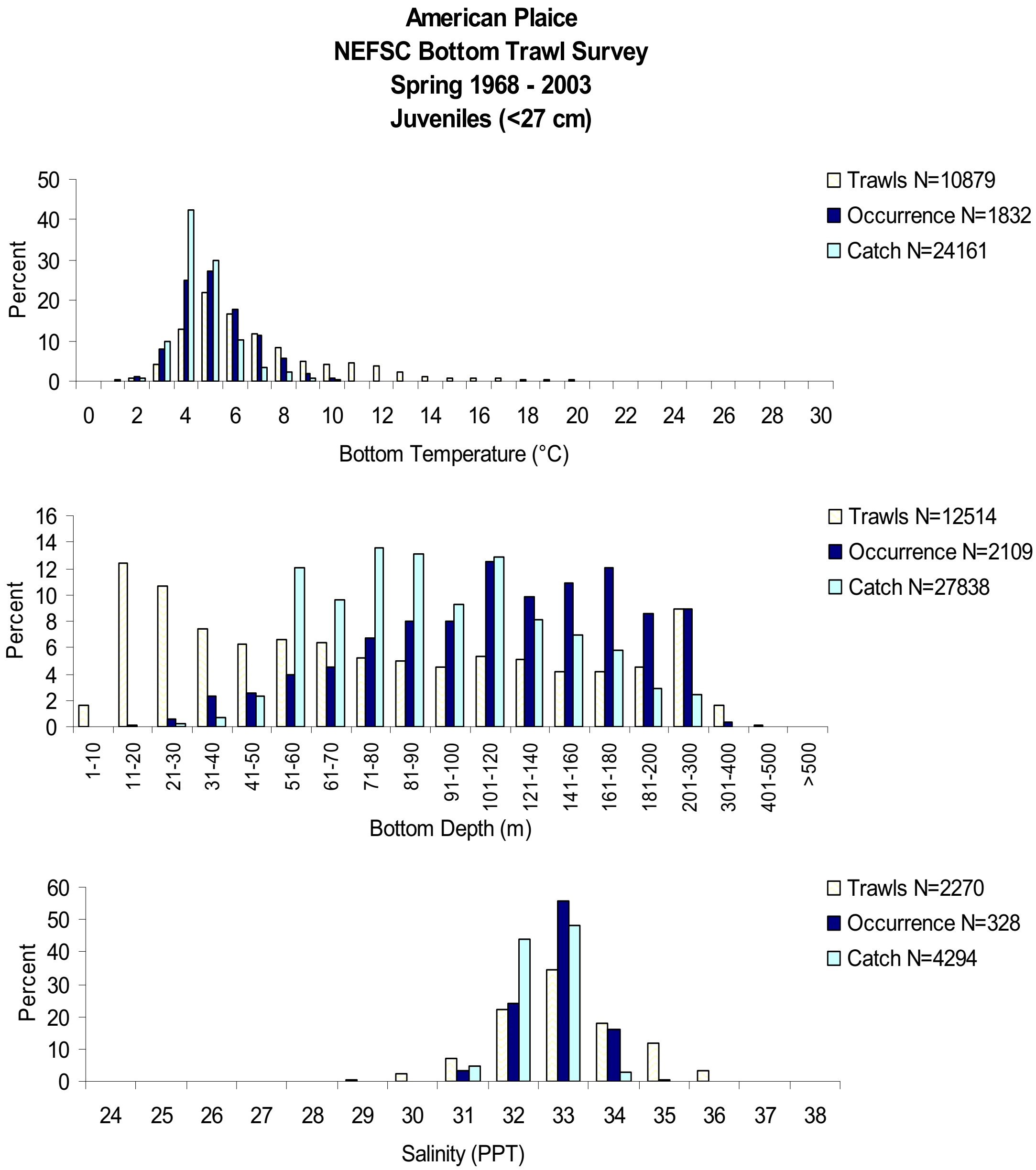


Figure 20. Distributions of juvenile American plaice and trawls from NEFSC bottom trawl surveys relative to bottom water temperature, depth, and salinity.
Based on NEFSC spring bottom trawl surveys (temperature and depth: 1968-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which American plaice occurred and medium bars show, within each interval, the percentage of the total number of American plaice caught. Note that the bottom depth interval changes with increasing depth.

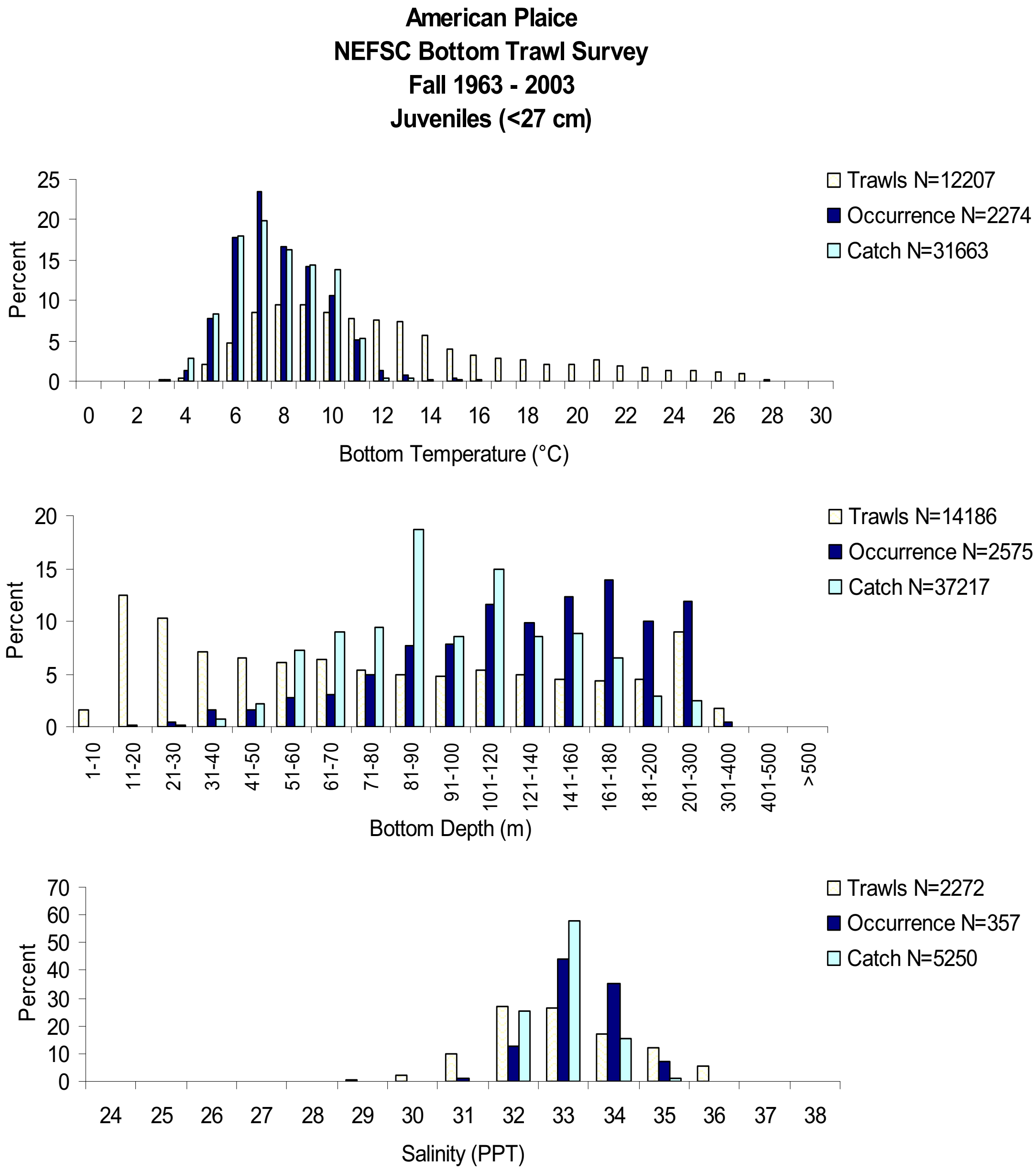


Figure 20. Cont'd.
Based on NEFSC fall bottom trawl surveys (temperature and depth: 1963-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which American plaice occurred and medium bars show, within each interval, the percentage of the total number of American plaice caught. Note that the bottom depth interval changes with increasing depth.

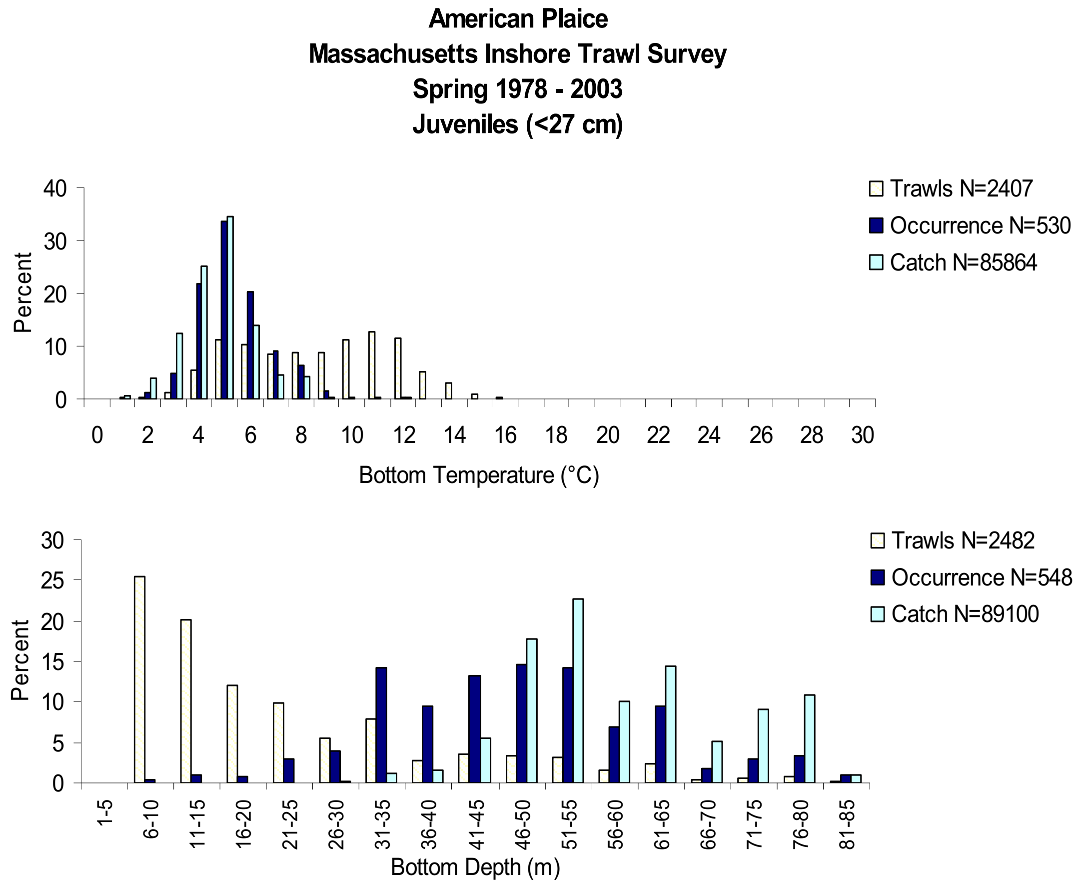


Figure 21. Distributions of juvenile American plaice and trawls in Massachusetts coastal waters relative to bottom water temperature and depth.
Based on spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which American plaice occurred and medium bars show, within each interval, the percentage of the total number of American plaice caught.

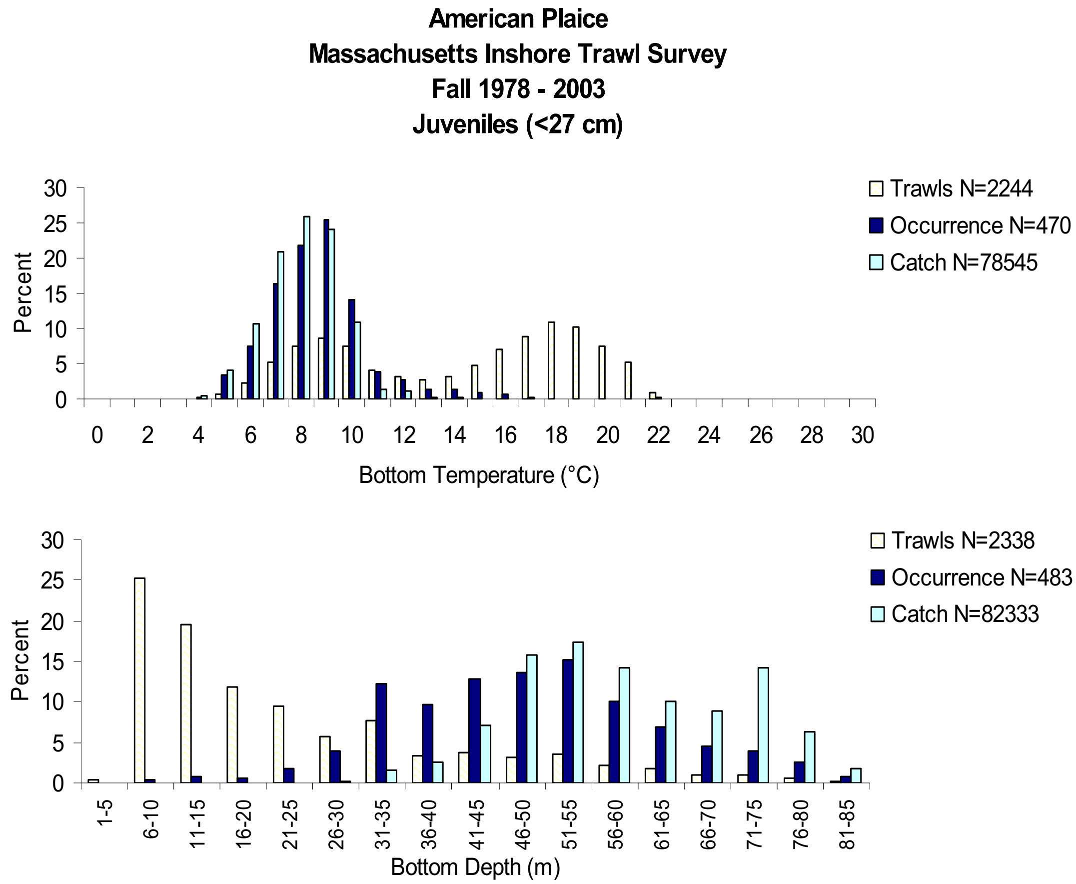


Figure 21. Cont'd.
Based on fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which American plaice occurred and medium bars show, within each interval, the percentage of the total number of American plaice caught.

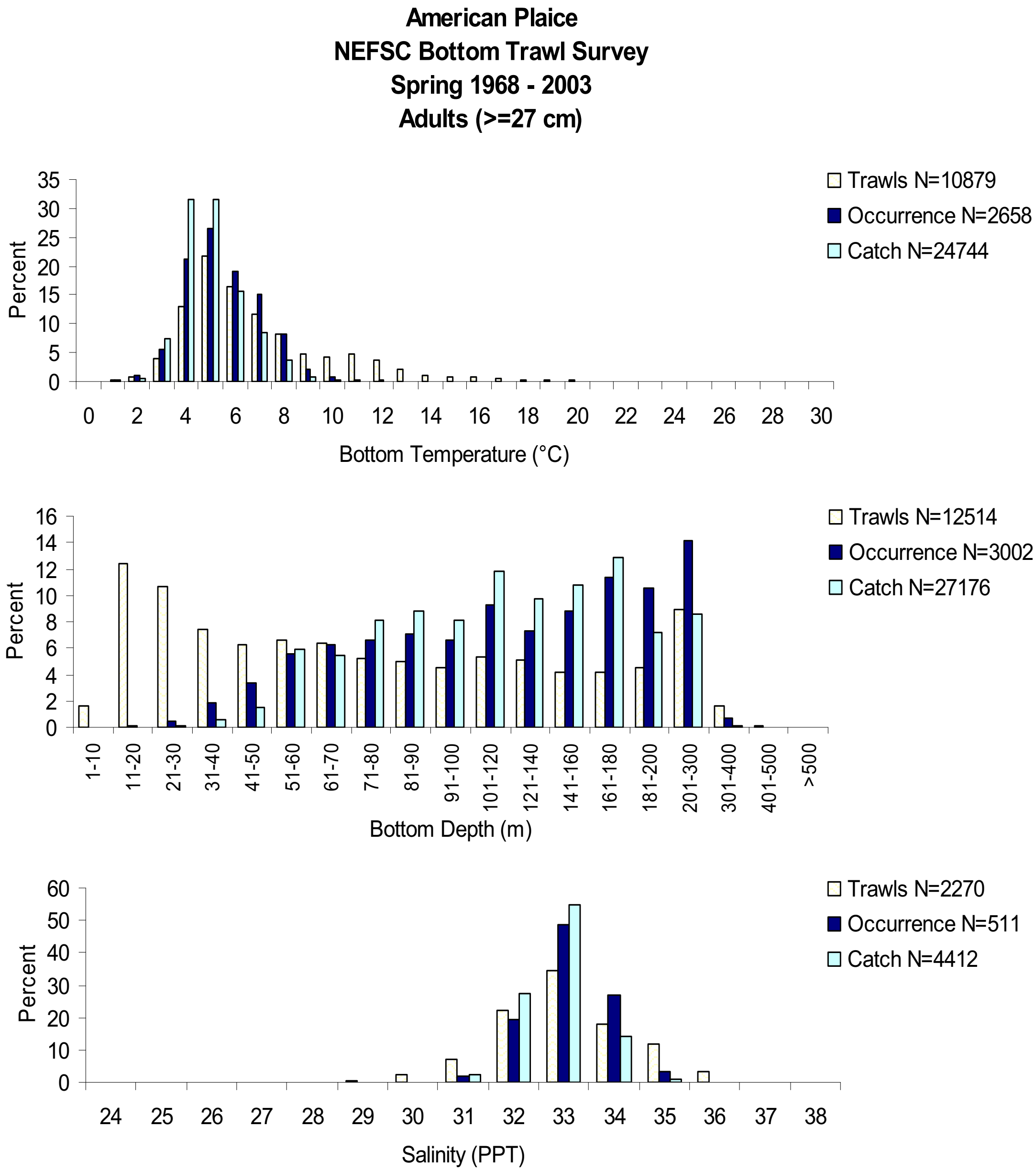


Figure 22. Distributions of adult American plaice and trawls from NEFSC bottom trawl surveys relative to bottom water temperature, depth, and salinity.
Based on NEFSC spring bottom trawl surveys (temperature and depth: 1968-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which American plaice occurred and medium bars show, within each interval, the percentage of the total number of American plaice caught. Note that the bottom depth interval changes with increasing depth.

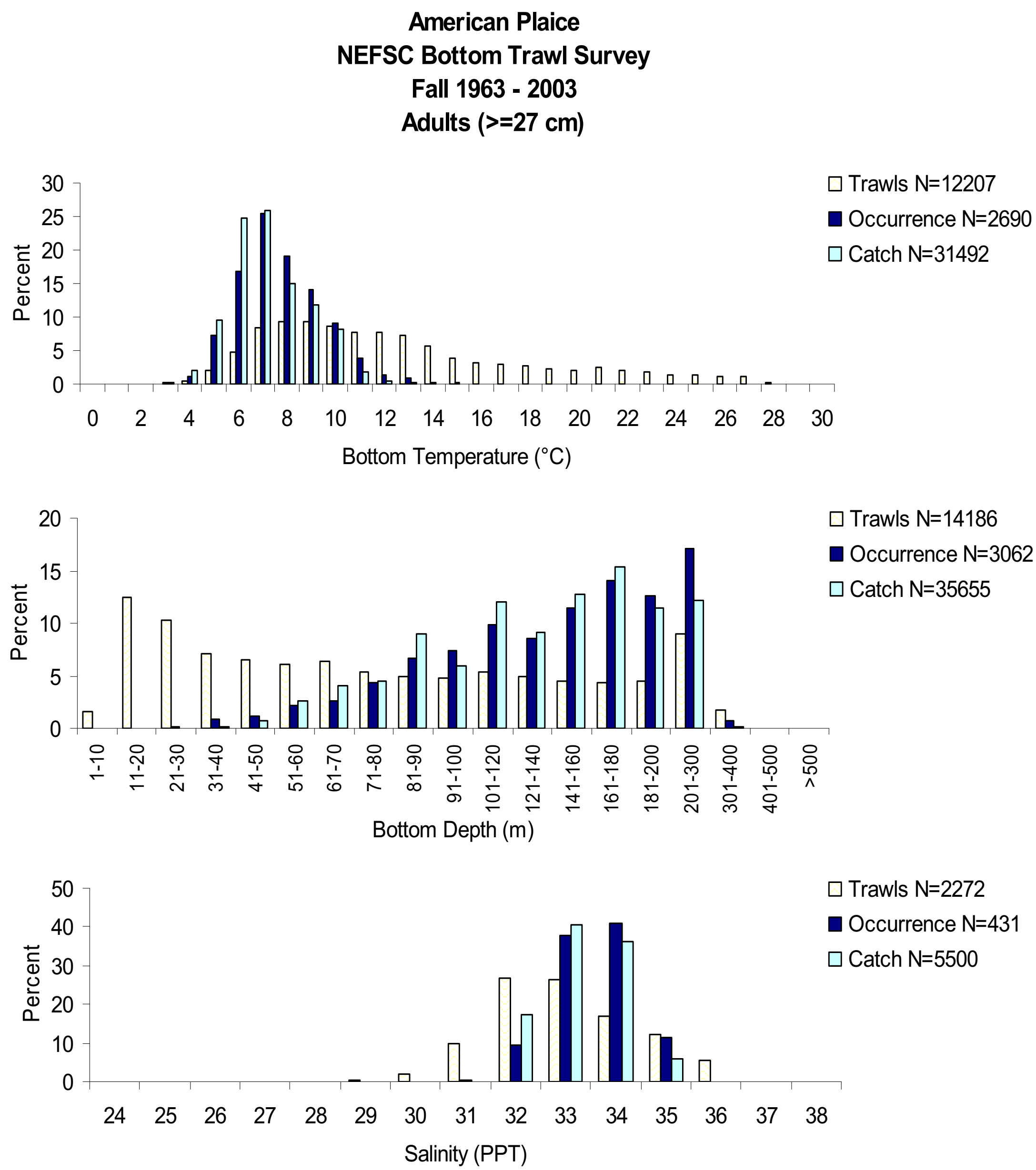


Figure 22. Cont'd.
Based on NEFSC fall bottom trawl surveys (temperature and depth: 1963-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which American plaice occurred and medium bars show, within each interval, the percentage of the total number of American plaice caught. Note that the bottom depth interval changes with increasing depth.

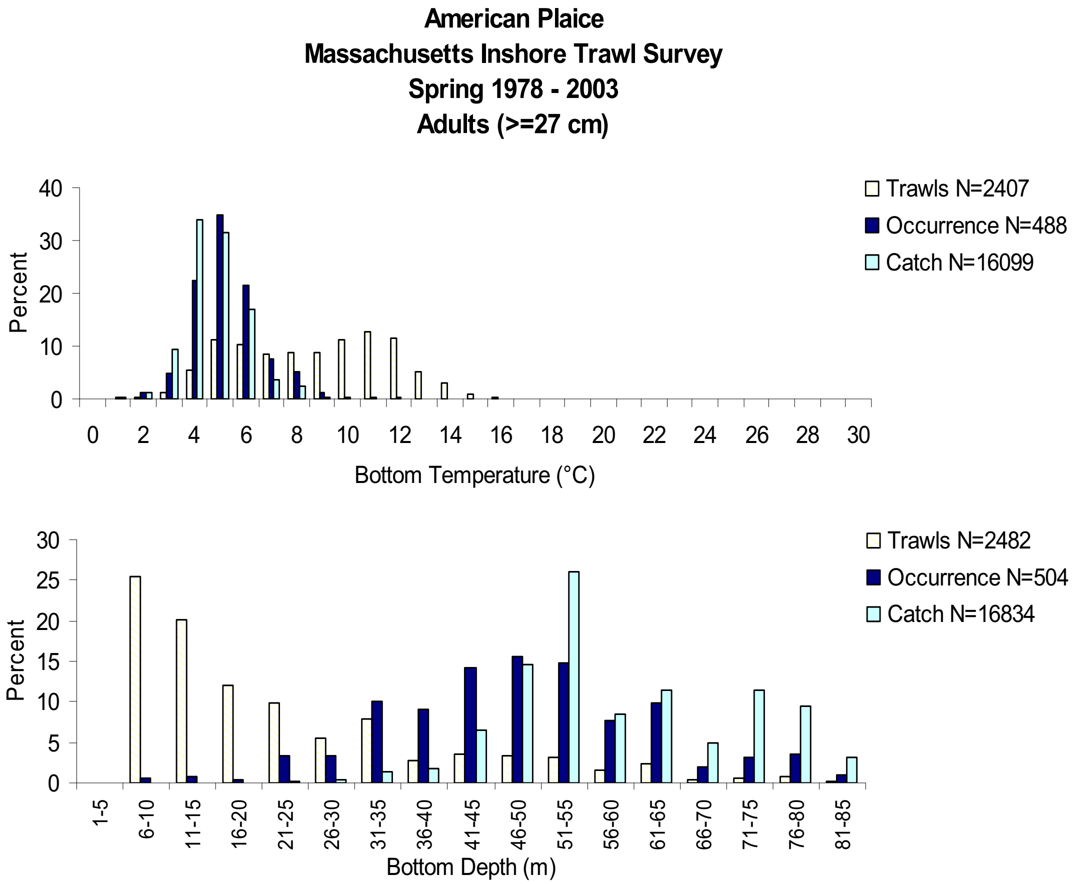


Figure 23. Distributions of adult American plaice and trawls in Massachusetts coastal waters relative to bottom water temperature and depth.
Based on spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which American plaice occurred and medium bars show, within each interval, the percentage of the total number of American plaice caught.

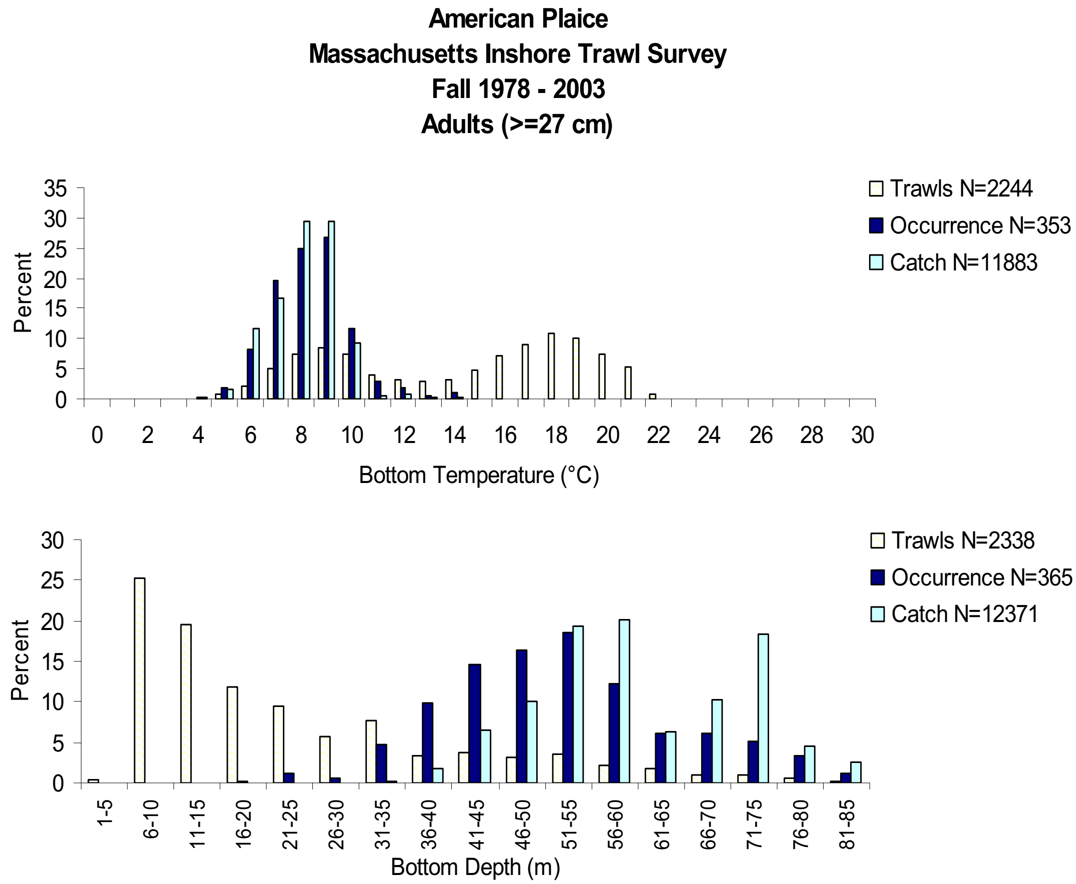


Figure 23. Cont'd.
Based on fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which American plaice occurred and medium bars show, within each interval, the percentage of the total number of American plaice caught.

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Manuscript Qualification

This series represents a secondary level of scientific publishing in the National Marine Fisheries Service (NMFS). For all issues, the series employs thorough internal scientific review, but not necessarily external scientific review. For most issues, the series employs rigorous technical and copy editing. Manuscripts that may warrant a primary level of scientific publishing should be initially submitted to one of NMFS's primary series (*i.e., Fishery Bulletin, NOAA Technical Report NMFS,* or *Marine Fisheries Review*).

Identical, or fundamentally identical, manuscripts should not be concurrently submitted to this and any other publication series. Manuscripts which have been rejected by any primary series strictly because of geographic or temporal limitations may be submitted to this series.

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Organization: Manuscripts must have an abstract, table of contents, and -- if applicable -- lists of tables, figures, and acronyms. As much as possible, use traditional scientific manuscript organization for sections: "Introduction," "Study Area," "Methods & Materials," "Results," "Discussion" and/or "Conclusions," "Acknowledgments," and "References Cited."

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For spelling of scientific and common names of fishes, mollusks, and decapod crustaceans from the United States and Canada, use *Special Publications* No. 20 (fishes), 26 (mollusks), and 17 (decapod crustaceans) of the American Fisheries Society (Bethesda, MD). For spelling of scientific and common names of marine mammals, use *Special Publication* No. 4 of the Society for Marine Mammalogy (Lawrence, KS). For spelling in general, use the most recent edition of *Webster's Third New International Dictionary of the English Language Unabridged* (Springfield, MA: G.&C. Merriam).

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Tables should be prepared with a table formatting function. Each figure should be supplied both on paper and on disk, unless there is no digital file of a given figure. Except under extraordinary circumstances, color will not be used in illustrations.

Manuscript Submission

Authors must submit one paper copy of the double-spaced manuscript, one disk copy, and original figures (if applicable). NEFSC authors must include a completely signed-off "NEFSC Manuscript/Abstract/Webpage Review Form." Non-NEFSC authors who are not federal employees will be required to sign a "Release of Copyright" form.

Send all materials and address all correspondence to: Jon A. Gibson (Biological Sciences Editor), NMFS Northeast Fisheries Science Center, 166 Water Street, Woods Hole, MA 02543-1026.

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Publications and Reports of the Northeast Fisheries Science Center

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "conducting ecosystem-based research and assessments of living marine resources, with a focus on the Northeast Shelf, to promote the recovery and long-term sustainability of these resources and to generate social and economic opportunities and benefits from their use." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific journals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Currently, there are three such media:

NOAA Technical Memorandum NMFS-NE -- This series is issued irregularly. The series typically includes: data reports of long-term field or lab studies of important species or habitats; synthesis reports for important species or habitats; annual reports of overall assessment or monitoring programs; manuals describing program-wide surveying or experimental techniques; literature surveys of important species or habitat topics; proceedings and collected papers of scientific meetings; and indexed and/or annotated bibliographies. All issues receive internal scientific review and most issues receive technical and copy editing.

Northeast Fisheries Science Center Reference Document -- This series is issued irregularly. The series typically includes: data reports on field and lab studies; progress reports on experiments, monitoring, and assessments; background papers for, collected abstracts of, and/or summary reports of scientific meetings; and simple bibliographies. Issues receive internal scientific review, but no technical or copy editing.

Resource Survey Report (formerly *Fishermen's Report*) -- This information report is a quick-turnaround report on the distribution and relative abundance of selected living marine resources as derived from each of the NEFSC's periodic research vessel surveys of the Northeast's continental shelf. There is no scientific review, nor any technical or copy editing, of this report.

OBTAINING A COPY: To obtain a copy of a *NOAA Technical Memorandum NMFS-NE* or a *Northeast Fisheries Science Center Reference Document*, or to subscribe to the *Resource Survey Report*, either contact the NEFSC Editorial Office (166 Water St., Woods Hole, MA 02543-1026; 508-495-2228) or consult the NEFSC webpage on "Reports and Publications" (*http://www.nefsc.noaa.gov/nefsc/publications/*).