NOAA Technical Memorandum NMFS-NE-139

Essential Fish Habitat Source Document:

Witch Flounder, *Glyptocephalus cynoglossus*,
Life History and Habitat Characteristics

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

September 1999

Recent Issues

105. **Review of American Lobster (*Homarus americanus*) Habitat Requirements and Responses to Contaminant Exposures.** By Renee Mercaldo-Allen and Catherine A. Kuropat. July 1994. v + 52 p., 29 tables. NTIS Access. No. PB96-115555.

106. **Selected Living Resources, Habitat Conditions, and Human Perturbations of the Gulf of Maine: Environmental and Ecological Considerations for Fishery Management.** By Richard W. Langton, John B. Pearce, and Jon A. Gibson, eds. August 1994. iv + 70 p., 2 figs., 6 tables. NTIS Access. No. PB95-270906.

107. **Invertebrate Neoplasia: Initiation and Promotion Mechanisms -- Proceedings of an International Workshop, 23 June 1992, Washington, D.C.** By A. Rosenfield, F.G. Kern, and B.J. Keller, comps. & eds. September 1994. v + 31 p., 8 figs., 3 tables. NTIS Access. No. PB96-164801.

108. **Status of Fishery Resources off the Northeastern United States for 1994.** By Conservation and Utilization Division, Northeast Fisheries Science Center. January 1995. iv + 140 p., 71 figs., 75 tables. NTIS Access. No. PB95-263414.

109. **Proceedings of the Symposium on the Potential for Development of Aquaculture in Massachusetts: 15-17 February 1995, Chatham/Edgartown/Dartmouth, Massachusetts.** By Carlos A. Castro and Scott J. Soares, comps. & eds. January 1996. v + 26 p., 1 fig., 2 tables. NTIS Access. No. PB97-103782.

110. **Length-Length and Length-Weight Relationships for 13 Shark Species from the Western North Atlantic.** By Nancy E. Kohler, John G. Casey, Patricia A. Turner. May 1996. iv + 22 p., 4 figs., 15 tables. NTIS Access. No. PB97-135032.

111. **Review and Evaluation of the 1994 Experimental Fishery in Closed Area II on Georges Bank.** By Patricia A. Gerrior, Fredric M. Serchuk, Kathleen C. Mays, John F. Kenney, and Peter D. Colosi. October 1996. v + 52 p., 24 figs., 20 tables. NTIS Access. No. PB98-119159.

112. **Data Description and Statistical Summary of the 1983-92 Cost-Earnings Data Base for Northeast U.S. Commercial Fishing Vessels: A Guide to Understanding and Use of the Data Base.** By Amy B. Gautam and Andrew W. Kitts. December 1996. v + 21 p., 11 figs., 14 tables. NTIS Access. No. PB97-169320.

113. **Individual Vessel Behavior in the Northeast Otter Trawl Fleet during 1982-92.** By Barbara Pollard Rountree. August 1997. v + 50 p., 1 fig., 40 tables. NTIS Access. No. PB99-169997.

114. **U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments -- 1996.** By Gordon T. Waring, Debra L. Palka, Keith D. Mullin, James H.W. Hain, Larry J. Hansen, and Kathryn D. Bisack. October 1997. viii + 250 p., 42 figs., 47 tables. NTIS Access. No. PB98-112345.

115. **Status of Fishery Resources off the Northeastern United States for 1998.** By Stephen H. Clark, ed. September 1998. vi + 149 p., 70 figs., 80 tables. NTIS Access. No. PB99-129694.

116. **U.S. Atlantic Marine Mammal Stock Assessments -- 1998.** By Gordon T. Waring, Debra L. Palka, Phillip J. Clapham, Steven Swartz, Marjorie C. Rossman, Timothy V.N. Cole, Kathryn D. Bisack, and Larry J. Hansen. February 1999. vii + 182 p., 16 figs., 56 tables. NTIS Access. No. PB99-134140.

117. **Review of Distribution of the Long-finned Pilot Whale (*Globicephala melas*) in the North Atlantic and Mediterranean.** By Alan A. Abend and Tim D. Smith. April 1999. vi + 22 p., 14 figs., 3 tables. NTIS Access. No. PB99-165029.

118. **Tautog (*Tautoga onitis*) Life History and Habitat Requirements.** By Frank W. Steimle and Patricia A. Shaheen. May 1999. vi + 23 p., 1 fig., 1 table. NTIS Access. No. PB99-165011.

119. **Data Needs for Economic Analysis of Fishery Management Regulations.** By Andrew W. Kitts and Scott R. Steinback. August 1999. iv + 48 p., 10 figs., 22 tables. NTIS Access. No. PB99-171456.

120. **Marine Mammal Research Program of the Northeast Fisheries Science Center during 1990-95.** By Janeen M. Quintal and Tim D. Smith. September 1999. v + 28 p., 4 tables, 4 app. NTIS Access. No. PB2000-100809.

NOAA Technical Memorandum NMFS-NE-139

This series represents a secondary level of scientifiic publishing. All issues employ thorough internal scientific review; some issues employ external scientific review. Reviews are -- by design -- transparent collegial reviews, not anonymous peer reviews. All issues may be cited in formal scientific communications.

Essential Fish Habitat Source Document:

Witch Flounder, *Glyptocephalus cynoglossus*, Life History and Habitat Characteristics

Luca M. Cargnelli, Sara J. Griesbach, David B. Packer,
Peter L. Berrien, Wallace W. Morse, and Donna L. Johnson

National Marine Fisheries Serv., James J. Howard Marine Sciences Lab., 74 Magruder Rd., Highlands, NJ 07732

U. S. DEPARTMENT OF COMMERCE
William Daley, Secretary
National Oceanic and Atmospheric Administration
D. James Baker, Administrator
National Marine Fisheries Service
Penelope D. Dalton, Assistant Administrator for Fisheries
Northeast Region
Northeast Fisheries Science Center
Woods Hole, Massachusetts

September 1999

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

Editorial Production

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

Special Acknowledgments

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

Internet Availability

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

Information Updating

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

Species Names

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

---

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

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

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

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

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

FOREWORD

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

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

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

NMFS Strategic Plan for Fisheries
Research (February 1998)

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

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

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

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

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

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

JAMES J. HOWARD MARINE SCIENCES LABORATORY
HIGHLANDS, NEW JERSEY
SEPTEMBER 1999

JEFFREY N. CROSS, CHIEF
ECOSYSTEMS PROCESSES DIVISION
NORTHEAST FISHERIES SCIENCE CENTER

Contents

Tables

Figures

INTRODUCTION

The witch flounder, *Glyptocephalus cynoglossus*, is a right-eyed, small-mouthed flounder of the family Pleuronectidae (Figure 1) which occurs on both sides of the Atlantic Ocean. In U.S. waters, it is common throughout the Gulf of Maine and occurs in deeper areas on and adjacent to Georges Bank and along the continental shelf edge as far south as Cape Hatteras, North Carolina. Witch flounder are managed under the New England Fishery Management Council's Northeast Multispecies Fishery Management Plan (NEFMC 1993). This Essential Fish Habitat source document provides information on the life history and habitat requirements of witch flounder inhabiting U.S. waters.

LIFE HISTORY

A brief synopsis of the life history characteristics of witch flounder is provided in Amendment #5 to the Northeast Multispecies Fishery Management Plan (NEFMC 1993). More detailed information is provided here and in reviews by Bigelow and Schroeder (1953), Burnett and Clark (1983), and Collette and Klein-MacPhee (in prep.).

EGGS

Spawning occurs at or near the bottom, however the buoyant eggs rise into the water column where subsequent egg and larval development occurs. Eggs range in diameter from 0.7 to 1.45 mm and average 1.27 mm (Bigelow and Schroeder 1953; Evseenko and Nevinsky 1975; Burnett *et al.* 1992). Hatching occurs 7 to 8 days after spawning at 7.8 to 9.4^{o}C (Bigelow and Schroeder 1953).

LARVAE

The resulting larvae measure 3.5 to 5.6 mm in length (Colton and Marak 1969; Fahay 1983) and possess a larger yolk sac than other flatfish larvae (Bigelow and Schroeder 1953).

JUVENILES

The pelagic stage of witch flounder is the longest among the species of the family Pleuronectidae (Evseenko and Nevinsky 1975). Descent to the bottom occurs when metamorphosis is complete, at 4 to 12 months of age (Bigelow and Schroeder 1953; Evseenko and Nevinsky 1975). Size at metamorphosis reported in the literature varies considerably, from 20-68 mm (see Table 1).

There are no obvious geographic or temporal trends in these data. Changes in size at metamorphosis over time (similar to recent changes in size at maturity, see Reproduction below) could be masking any latitudinal gradients. Alternatively, the huge amount of variation in size at metamorphosis could be due to 'sampling error'. For example, it is unclear whether these data represent size at metamorphosis or settlement (which may not occur simultaneously; see Research Needs). At the Atlantic Reference Centre in New Brunswick, witch flounder specimens in the late stages of metamorphosis range from 36.9 to 50.8 mm. Metamorphosing specimens of 36.3 mm were still pelagic, but metamorphosed specimens of 59.7 mm were demersal (Lou van Guelpen, Atlantic Reference Centre, Huntsman Marine Science Centre, St. Andrews, NB, personal communication), indicating that settlement may in fact occur after metamorphosis is complete. These data show much less variation than those presented in Table 1.

ADULTS

Adults can reach a maximum length of 78 cm. Bigelow and Schroeder (1953) reported the maximum size in the Gulf of Maine to be 63.5 cm, with an average size of 30.5-51 cm.

REPRODUCTION

The available data show considerable variation in the size (L_{50}) and age (A_{50}) at maturity of witch flounder in U.S. waters. However, the trend that females mature at a later age and larger size than males is consistent (Table 2). There has been a decrease in both the age and size of sexual maturity in recent years (O'Brien *et al.* 1993). In many fish, growth rates are density dependent, with increased growth at lower densities. Thus, decreases in A_{50} and L_{50} may be the result of declining witch flounder stock densities. Alternatively, selective overfishing could result in such decreases. In general, maturation of Gulf of Maine-Georges Bank witch flounder occurs at a similar size, but an earlier age, than slower-growing witch flounder in colder Canadian waters: Nova Scotia, female L_{50}=33.0-34.3 cm, A_{50}=7.2-8.8 years, male L_{50}=29.2-33.0 cm, A_{50}=5.1-9.2 years (Beacham 1983).

Witch flounder spawn from March to November, with peak spawning occurring in summer. The general trend is for spawning to occur progressively later from south to north (Martin and Drewry 1978; Brander and Hurley 1992). In the Gulf of Maine-Georges Bank region, spawning occurs from April to November, and peaks from May to August (Bigelow and Schroeder 1953; Evseenko and Nevinsky 1975; Burnett *et al.* 1992; O'Brien *et al.* 1993). The western and northern areas of the Gulf of Maine tend to be the most active spawning sites (Burnett *et al.* 1992). In the Middle Atlantic Bight, spawning occurs from April to August, peaking in May or June (Smith *et al.* 1975; Martin and Drewry 1978), and the most important spawning grounds are off Long Island (Smith *et al.* 1975). Spawning occurs in dense aggregations which are associated with areas of cold water (Burnett *et al.* 1992). Witch flounder spawn at 0-10^{o}C (Bigelow and Schroeder 1953).

FOOD HABITS

The main food items in the witch flounder diet are polychaetes and crustaceans, although mollusks and echinoderms are also important. Overall, polychaetes were by far the most important food item, accounting for greater than 70% of the diet (Maurer and Bowman 1975; Collette and Klein-MacPhee, in prep.). However, there is a distinct ontogenetic shift in diet, with polychaetes increasing in importance and crustaceans decreasing in importance with age. By sexual maturity, polychaetes dominate the diet considerably, while crustaceans are far less important. The top food items of smaller juveniles (< 20 cm) were crustaceans (74% of the diet), while polychaetes accounted for only 19%. However, larger juveniles (21-30 cm) fed primarily on polychaetes (45-65%) followed by crustaceans (15-37%). Mollusks and echinoderms were consumed in smaller quantities (0-5%) (Bowman and Michaels 1984). Adults 31-60 cm fed primarily on polychaetes (60-66%) and echinoderms (6-18%), with crustaceans, mollusks, and coelenterates accounting for a smaller part of the diet. Adults > 60 cm fed almost exclusively on polychaetes (98%) (Bowman and Michaels 1984). There is little variation in diet with geographic area. An exception is southern New England, where squid can be almost as important a food source as polychaetes (Collette and Klein-MacPhee, in prep.).

The 1973-1990 Northeast Fisheries Science Center (NEFSC) trawl survey data on food habits [see Reid *et al.* (1999) for details] verify that polychaetes are the most important food source of witch flounder (Figure 2). During 1973-1980, small (5-30 cm) witch flounder fed primarily on polychaetes (37%) and crustaceans (27%) (Figure 2a). Polychaetes remained the most important food source among larger (> 30 cm) individuals, however, crustaceans declined in importance, replaced in the diet by mollusks and echinoderms. The 1981-1990 data also show that polychaetes dominate the witch flounder diet (Figure 2b). Once again, an ontogenetic shift in diet is evident, although this shift contrasts those described above: crustaceans increase in importance while polychaetes decrease in importance in larger fish.

NICHE SEPARATION

Powles and Kohler (1970) suggested that witch flounder occupy three largely discrete ecological niches, resulting in the different life stages being geographically separated from each other. The pelagic egg and larval stages are spent in the water column over deep water. The juvenile stage occurs in very deep water when metamorphosed fish settle to the bottom. Juveniles remain separated from the adult population, occupying deeper areas until the onset of sexual maturity. Other studies, for example, Markle (1975) who suggested that the continental slope off Virginia serves as a nursery area for 1 to 4 year old juveniles, supported this niche separation hypothesis. However, others have demonstrated that these results may have been gear-biased and that although a large percentage of adult witch flounder inhabit shallower waters than juveniles, some are also found in deeper waters (Walsh 1987). Thus, although juvenile and adult witch flounder are indeed distributed differently, a discrete separation of adults and juveniles as proposed by Powles and Kohler (1970) does not exist (see Geographical Distribution below).

HABITAT CHARACTERISTICS

Information on the habitat requirements and preferences of witch flounder is presented here and summarized in Table 3. This information concentrates primarily on stocks inhabiting U.S. waters; with some exceptions, information from Canadian and European stocks were not considered.

EGGS AND LARVAE

The witch flounder is a deep water fish inhabiting depths down to approximately 1500 m. The egg and larval stages are pelagic, generally over deep water, at temperatures ranging from about 4 to 13^{o}C (Bigelow and Schroeder 1953). Most of the witch flounder eggs taken during NEFSC Marine Resources Monitoring, Assessment and Prediction (MARMAP) ichthyoplankton surveys (see Geographical Distribution) were at temperatures of 4-12^{o}C and depths of 30-150 m (but taken as deep as 1250 m) (Figure 5). Most larvae were taken at 4-13^{o}C and 10-210 m (Figure 7).

JUVENILES AND ADULTS

When metamorphosis is complete, juveniles settle to the bottom. Juveniles and adults are found at temperatures ranging from about 0 to 15^{o}C (Markle 1975; MacDonald *et al.* 1984; Collette and Klein-MacPhee, in prep.), although most are at 2 to 9^{o}C (Lange and Lux 1978; Scott 1982a), and salinities of 31 to 36 ppt (Markle 1975; Martin and Drewry 1978; Scott 1982a; MacDonald *et al.* 1984). They are found over mud, clay, silt, or muddy sand substrates (Powles and Kohler 1970; Martin and Drewry 1978; MacDonald *et al.* 1984), at depths ranging from 20 to 1565 m (Bigelow and Schroeder 1953; Markle 1975; Lange and Lux 1978), although the majority are found at 90-300 m (Martin and Drewry 1978; Collette and Klein-MacPhee, in prep.). Juveniles tend to inhabit deeper water than adults.

Most of the juvenile witch flounder taken during NEFSC trawl surveys (see Geographical Distribution) were at temperatures of 4-10°C (4-6°C in spring and 7-10°C in autumn) and depths of 75-200 m (but taken as deep as 450 m). Most adults were taken at 4-11°C and 50-200 m (but taken as deep as 400 m) (Figure 9). Most juveniles taken during Massachusetts trawl surveys (see Geographical Distribution) were at 5-10°C (5-6°C in spring and 8-10°C in autumn) and 65-80 m. Most adults were taken at 5-9°C and 40-70 m (Figure 11).

Substrate preference is an important habitat consideration for groundfish. The witch flounder is very closely tied to mud/silt, muddy-sand, and clay substrate (Powles and Kohler 1970; Martin and Drewry 1978; Scott 1982b; MacDonald *et al.* 1984) and rarely occurs on any other bottom type. This close association with soft substrate may be the result of their preference for polychaete prey (Susan Wigley, NEFSC, Woods Hole Laboratory, personal communication). Auster *et al.* (1991) showed small scale habitat associations of witch flounder with depressions in mud bottom. This association could possibly serve as a means of evading strong currents.

GEOGRAPHICAL DISTRIBUTION

Witch flounder were distributed from Cape Hatteras, North Carolina to Labrador, Canada during 1975-1994 (Figure 3). The areas of highest abundance were the Gulf of St. Lawrence, the southwestern edge of the Grand Bank, and deep waters directly north of the Grand Bank. In U.S waters, witch flounder were most common in the Gulf of Maine off Cape Ann, Massachusetts. The distribution of witch flounder in the Gulf of Maine is governed by depth (Bigelow and Schroeder 1953). They tend to be found in the deeper areas of the Gulf.

EGGS

The 1978-1987 NEFSC MARMAP offshore ichthyoplankton surveys [see Reid *et al.* (1999) for details] collected eggs from Cape Hatteras to southwest Nova Scotia (Figure 4). Eggs were found earlier in the Middle Atlantic Bight than in New England, where eggs were not found until May. This agrees with studies suggesting that spawning occurs later to the north (Martin and Drewry 1978; Brander and Hurley 1992). The highest egg densities appear to be in the Gulf of Maine and Massachusetts Bay in May and June. High densities of eggs occurred in May (monthly mean 5.7 eggs/10 m^2) in Massachusetts Bay, along the south flank of Georges Bank and throughout the Middle Atlantic Bight. The highest abundances occurred in June (monthly mean 8.0 eggs/10 m^2) off New England, particularly in the Gulf of Maine and Georges Bank. This concurs with reports that spawning peaks in May and June (Smith *et al.* 1975; Martin and Drewry 1978; Neilson *et al.* 1988).

Eggs were collected within a wide temperature range, 4-17°C, however, the majority occurred at 4-12°C (Figure 5). Egg incubation is said to proceed normally at 7-13°C (Bigelow and Schroeder 1953). From February-April, eggs were found mostly at 4-9°C, while from May-July, eggs were found at temperatures as warm as 17°C, although the majority were found at 6-9°C. From August-October, most eggs were found at 9-13°C.

Eggs were collected at depths ranging from about 10-1250 m (Figure 5). From February-April, eggs were generally collected at depths of 30-70 m, while from May-September, they were found mostly at 50-90 m. In October, the majority of eggs were collected at depths of 110 and 150 m.

LARVAE

The 1977-1987 NEFSC MARMAP offshore ichthyoplankton surveys [see Reid *et al.* (1999) for details] found larvae evenly distributed from Cape Hatteras to southwest Nova Scotia, with the exception of the central Gulf of Maine (Figure 6). The highest densities appear to be in Massachusetts Bay. Highest mean densities occurred in June (monthly mean 2.4 larvae/10 m^2), followed by July (monthly mean 1.0 larvae/10 m^2).

Larvae were collected within a temperature range of 4-20°C (Figure 7). In March and April, larvae were found primarily at temperatures of 4-6°C, while in May and June larvae were found mostly at 6-11°C. In July and August, greater than 50% of the larvae were found at temperatures of 10-13°C. In September, 50% of the larvae were collected at 11°C, in October, the majority were found at 8-11°C, and in November larvae were found mostly at 10°C.

Larvae were collected at depths ranging from 10-210 m (Figure 7). In March and April, greater than 70% of the larvae were collected at depths of 70 m. In May to September, the majority of larvae were found from 50-70 m, and in October and November, the larvae were found over a wider range of depths, from 30-210 m.

JUVENILES

NEFSC Bottom Trawl Survey

NEFSC bottom trawl surveys [see Reid *et al.* (1999) for details] captured juvenile witch flounder year-round (Figure 8). In winter, juveniles were found along the edge of the continental shelf along the 200 m contour as far south as Virginia and throughout the Gulf of Maine. In spring, juveniles were distributed throughout the Gulf of Maine and along the 200 m depth contour from Georges Bank south to Cape Hatteras, with greatest abundances around Cape Ann (Jeffreys Ledge) and Massachusetts Bay (Stellwagen Bank). In summer, they were mostly concentrated in the Gulf of Maine, but nearer the coast than in winter. Autumn distributions were similar to spring, with highest densities in Massachusetts Bay and in the vicinity of Jeffreys Ledge in the Gulf of Maine; south of Georges Bank, distribution patterns persist along the 200 m depth contour, but at lower densities than in the spring.

There appears to be a seasonal difference in juvenile occurrence with bottom temperature. In the spring, greater than 50% of witch flounder juveniles occurred at temperatures around 4-6^{o}C, while in the fall, greater than 50% occurred at temperatures between 7 and 10^{o}C (Figure 9). Juvenile witch flounder off Virginia have been shown to inhabit significantly colder waters in November (mean 5.5^{o}C) than in June (mean 7.3^{o}C) (Markle 1975).

In the spring and autumn, witch flounder were caught at depths ranging from 50-450 m, with the majority occurring between 75-200 m (Figure 9). There is no observed seasonal difference in occurrence relative to depth. However, Markle (1975) claims that juveniles off Virginia inhabited significantly deeper waters in November (mean depth 670 m) than in June (mean depth 492 m).

Massachusetts Inshore Trawl Survey

The 1978-1996 Massachusetts inshore surveys [see Reid *et al.* (1999) for details] show high concentrations of juveniles in the vicinity of Cape Ann, Massachusetts and equal abundances in spring and autumn. (Figure 10). There is a seasonal difference in juvenile occurrence relative to bottom water temperature. In the spring, juveniles occurred from 2-7^{o}C, with about 90% at temperatures of 5-6^{o}C, while in autumn they occurred at 7-11^{o}C, with about 90% at 8-10^{o}C (Figure 11). There does not appear to be a major seasonal difference in juvenile occurrence with depth. Juveniles were caught at depths ranging from about 40-80 m, with the majority occurring between 65-80 m (Figure 11). Since juvenile witch flounder are essentially sedentary, inhabiting constant depths throughout the year, seasonal difference in temperature of occurrence is likely the result of seasonal changes in bottom temperature, and not active choice for preferred temperatures.

ADULTS

NEFSC Bottom Trawl Survey

NEFSC bottom trawl surveys [see Reid *et al.* (1999) for details] captured witch flounder adults during all seasons (Figure 8). In winter, adults were found along the edge of the continental shelf as far south as the Delmarva Peninsula, along the southern flank of Georges Bank, as well as in the Gulf of Maine. In spring, witch flounder were spread along the continental shelf from Georges Bank south to Cape Hatteras, as well as the Gulf of Maine, with greatest abundances around Cape Ann, Massachusetts Bay, and nearshore in the Gulf of Maine. In summer, they were mostly concentrated in the Gulf of Maine, with smaller concentrations on the shelf as far south as New Jersey. In the autumn, adults were concentrated in the Gulf of Maine with highest densities in Massachusetts Bay and the northern edge of Georges Bank, and with lower densities along the shelf as far south as Maryland.

There does not appear to be a major seasonal difference in occurrence relative to bottom temperature. Adult witch flounder occurred at temperatures between 2-15^{o}C, with the majority found between 4-8^{o}C in spring and 5-11^{o}C in autumn (Figure 9).

There also does not appear to be a major seasonal difference in adult occurrence relative to depth. Adults were caught at depths ranging from about 15-400 m, with most occurring between 50-200 m (Figure 9). However, Powles and Kohler (1970) reported that adults on the Scotian Shelf inhabited shallower depths in summer than in winter.

Massachusetts Inshore Trawl Survey

The 1978-1996 Massachusetts inshore trawl surveys [see Reid *et al.* (1999) for details] show high concentrations of adults north and south of Cape Ann, with lower numbers in Cape Cod Bay (Figure 10). Similar to juveniles, adult witch flounder are present in equal numbers in spring and autumn. There is a slight seasonal difference in adult occurrence relative to bottom water temperature. In the spring they were found at 2-13^{o}C, with about 60% found at temperatures of 5-7^{o}C, while in autumn they were at 5-12^{o}C, with about 65% at warmer temperatures of 8-9^{o}C (Figure 11). Adults were caught at depths ranging from 20-80 m (Figure 11). In the spring, the majority occurred at 40-50 m. In autumn, adults were distributed bimodally with peaks at 40-50 m and 65-70 m.

JUVENILE VS. ADULT

Based on NEFSC bottom trawl survey data in the Middle Atlantic Bight, juveniles and adults were similarly distributed along the edge of the continental shelf. However, the adult distribution ranged further inshore (on the continental shelf) than that of juveniles which were found almost exclusively on the continental slope. This is reflected in the histograms in Figure 9, where a greater proportion of juveniles relative to adults were caught in deeper waters. This result supports the conclusion of Walsh (1987) that although a large percentage of adult witch flounder are found shallower than juveniles, a discrete separation of adults and juveniles does not exist, as had been proposed by Powles and Kohler (1970).

STATUS OF THE STOCKS

The total landings from the Georges Bank and Gulf of Maine witch flounder stocks in 1996 were 2,100 metric tons (mt), a 5% decrease from 1995 (2,210 mt), and a 21% decrease from 1994 (2,670 mt) (Wigley 1998; Figure 12). In recent years most of the U.S. catch has come from the Gulf of Maine. The witch flounder autumn survey index has declined considerably from an average of 3.6 kg per tow in 1966-1970, to an historical low of 0.2 kg/tow in 1992 (Wigley 1995). Although survey indices have increased since 1992, reaching 1.02 kg/tow in 1996 (Wigley 1998; Figure 12), witch flounder biomass remains at a low level. Since the mid-1980's the age structure of the stock has become severely truncated, with a striking decline in the number of older (> 11 years) fish (Wigley and Mayo 1996). Spawning stock biomass has declined sharply from 26,000 mt in 1982 to about 6,300 mt in 1990 and has fluctuated at about 7,000 mt through 1993 (Wigley and Mayo 1996). The September 1997 report 'Status of Fisheries of the United States' (National Marine Fisheries Service 1997) reports that the U.S. witch flounder stock is presently in an overfished condition.

Data from the NEFSC bottom trawl surveys is presented in Figure 13 to contrast the distribution of witch flounder during a recent period of low abundance (1989-1992) with a period of high abundance (1983-1986). The distribution of adults was not different among high and low abundance periods, but there are higher densities within the Gulf of Maine during the period of high abundance. There is no apparent difference in distribution or density of juvenile witch flounder among low and high abundance periods. Strong year-classes during the low abundance period and weak year-classes during the high abundance period could be masking any difference (Susan Wigley, NEFSC, Woods Hole Laboratory, personal communication).

RESEARCH NEEDS

The status of existing knowledge of the biology of U.S. witch flounder stocks is best summed up in the following quote: "The biology of the witch flounder has been well studied in the east Atlantic and Canada, but little work has been reported from the Gulf of Maine-Georges Bank region" (Burnett *et al.* 1992).

Little is known about predation on this species (Burnett and Clark 1983), as well as interactions with other species in general. There are also no details in the existing literature on the specific nature of witch flounder spawning. Are eggs spawned directly on the bottom? Information on growth and survival rates by habitat type is lacking, as are data to support theories of habitat use by the different life stages. Such information is important to an accurate designation of Essential Fish Habitat for witch flounder.

The size at metamorphosis and timing of metamorphosis and settlement need to be investigated more thoroughly. A wide range of sizes is presented in the literature (see Table 1), which may be a result of inconsistency in field methods. For example, some studies may actually be reporting size at settlement, or different studies may be measuring different stages of metamorphosis. It is unclear whether settlement occurs during (and if so at what stage?) or after metamorphosis. Laboratory-based experiments would allow this to be investigated, along with the factors affecting and resulting in variation in the size at metamorphosis and timing of metamorphosis.

Finally, research into the structure of U.S. witch flounder stocks is required. Amendment #5 of the Northeast Multispecies Plan (NEFMC 1993) states that "research vessel data suggest that the Gulf of Maine population may be relatively discrete from populations in other areas." However, there are currently no genetic data to support such claims. In Newfoundland, genetic analysis revealed a total of six genetic stocks within three management areas (Fairbairn 1981). Each genetic stock differed in population structure, time of spawning, individual growth rate, and temperature and depth of capture.

ACKNOWLEDGMENTS

The literature review was greatly aided by the draft update to the Bigelow and Schroeder (1953) section on witch flounder provided by Bruce Collette. Joseph Vitaliano provided gut contents data from the food habits database. The authors also wish to thank Claire Steimle, Judy Berrien, and Rande Ramsey-Cross for help with the literature reviews. Susan Wigley provided excellent comments that improved this document.

REFERENCES CITED

Auster, P.J., R.J. Malatesta, and S.C. Larosa. 1991. Microhabitat use by continental slope megafauna. Am. Zool. 31: 127A.

Beacham, T.D. 1983. Variability in size and age at sexual maturity of witch flounder, *Glyptocephalus cynoglossus*, in the Canadian Maritimes region of the northwest Atlantic Ocean. Can. Field Nat. 97: 409-422.

Bigelow, H.B. and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. U.S. Fish Wildl. Serv., Fish. Bull. 53. 577 p.

Bowman, R.E. and W.L. Michaels. 1984. Food of seventeen species of northwest Atlantic fish. NOAA Tech. Mem. NMFS-F/NEC-28. 183 p.

Brander, K. and P.C.F. Hurley. 1992. Distribution of early-stage Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), and witch flounder (*Glyptocephalus cynoglossus*) eggs on the Scotian Shelf: a reappraisal of evidence on the coupling of cod spawning and plankton production. Can. J. Fish. Aquat. Sci. 49: 238-251.

Burnett, J. and S.H. Clark. 1983. Status of witch flounder in the Gulf of Maine - 1983. U.S. Natl. Mar. Fish. Serv., Northeast Fish. Center, Woods Hole Lab., Ref. Doc. No. 83-36. 31 p.

Burnett, J., M.R. Ross, and S.H. Clark. 1992. Several biological aspects of the witch flounder (*Glyptocephalus cynoglossus* (L.)) in the Gulf of Maine-Georges Bank region. J. Northwest Atl. Fish. Sci. 12: 15-25.

Collette, B.B. and G. Klein-MacPhee. In preparation. Witch flounder, *Glyptocephalus cynoglossus* (Linnaeus 1758). *In* B.B. Collette and G. Klein-MacPhee eds. Bigelow and Schroeder's fishes of the Gulf of Maine. Smithsonian Institution Press, Washington, DC.

Colton, J.B., Jr. and R. Marak. 1969. Guide for identifying the common planktonic fish eggs and larvae of continental shelf waters, Cape Sable to Block Island. U.S. Bur. Comm. Fish. Biol. Lab., Woods Hole, Lab. Ref. No. 69-9. 43 p.

Evseenko, S.A. and M.M. Nevinsky. 1975. Spawning and development of witch flounder, *Glyptocephalus cynoglossus* L., in the northwest Atlantic. Int. Comm. Northwest Atl. Fish (ICNAF) Res. Bull. No. 11: 111-123.

Fahay, M.P. 1983. Guide to the early stages of marine fishes occurring in the western North Atlantic Ocean, Cape Hatteras to the southern Scotian Shelf. J. Northwest Atl. Fish. Sci. 4: 1-423.

Fairbairn, D.J. 1981. Which witch is which? A study of the stock structure of witch flounder (*Glyptocephalus cynoglossus*) in the Newfoundland region. Can J. Fish. Aquat. Sci. 38: 782-794.

Frank, K.T., J.W. Loder, J.E. Carscadden, W.C. Leggett and C.T. Taggart. 1992. Larval flatfish distributions and drift on the southern Grand Bank. Can. J. Fish. Aquat. Sci. 49: 467-483.

Goode, G.B. 1884. The fisheries and fishery industries of the United States. Section I: Natural history of useful aquatic animals. Govt. Print. Office, Washington, DC. Plates.

Lange, A.M.T. and F.E. Lux. 1978. Review of the other flounder stocks (winter flounder, American plaice, witch flounder and windowpane flounder) off the northeast United States, August 1978. U.S. Natl. Mar. Fish. Serv., Northeast Fish. Cent., Woods Hole Lab. Ref. Doc. No. 78-44. 19 p. + appendices.

MacDonald, J.S., M.J. Dadswell, R.G. Appy, G.D. Melvin, and D.A. Methven. 1984. Fishes, fish assemblages, and their seasonal movements in the lower Bay of Fundy and Passamaquoddy Bay, Canada. Fish. Bull. (U.S.) 82: 121-140.

Markle, D.F. 1975. Young witch flounder, *Glyptocephalus cynoglossus*, on the slope off Virginia. J. Fish. Res. Board Can. 32: 1447-1450.

Markle, D.F. and J.A. Musick. 1974. Benthic-slope fishes found at 900 m depth along a transect in the western N. Atlantic Ocean. Mar. Biol. 26: 225-233.

Martin, F.D. and G.E. Drewry. 1978. Development of fishes of the Mid-Atlantic Bight: An atlas of egg, larval and juvenile stages. Vol. 6: Stromateidae through Ogcocephalidae. U.S. Fish Wildl. Serv. Biol. Serv. Prog. FWS/OBS 78/12. 416 p.

Maurer, R.O., Jr. and R.E. Bowman. 1975. Food habits of marine fishes of the northwest Atlantic – data report. U.S. Natl. Mar. Fish. Serv., Northeast Fish. Cent., Woods Hole Lab. Ref. Doc. 75-3. 90 p.

Morse, W.W. 1979. An analysis of maturity observations of 12 groundfish species collected from Cape Hatteras, North Carolina to Nova Scotia in 1977. U.S. Natl. Mar. Fish. Serv., Northeast Fish. Cent., Sandy Hook Lab. Rep. 79-32. 20 p.

National Marine Fisheries Service. 1997. Report to Congress. Status of fisheries of the United States: Report on the status of fisheries of the United States. September 1997. [Homepage of the National Marine Fisheries Service]. [Online]. Available: http://www.nmfs.gov/sfa/Fstatus.html.

[NEFMC] New England Fishery Management Council. 1993. Final amendment #5 to the Northeast Multispecies Fishery Management Plan incorporating the supplemental environmental impact statement. Vol. I. September 1993. NEFMC. [Saugus, MA.]

Neilson, J.D., E.M. DeBlois, and P.C.F. Hurley. 1988. Stock structure of Scotian shelf flatfish as inferred from ichthyoplankton survey data and the geographic distribution of mature females. Can. J. Fish. Aquat. Sci. 45: 1674-1685.

O'Brien, L.O., J. Burnett, and R.K. Mayo. 1993. Maturation of nineteen species of finfish off the northeast coast of the United States, 1985-1990. NOAA Tech. Rep. NMFS 113. 66 p.

Powles, P.M. and A.C. Kohler. 1970. Depth distribution of various stages of witch flounder, *Glyptocephalus cynoglossus* off Nova Scotia and in the Gulf of St. Lawrence. J. Fish. Res. Board Can. 27: 2053-2062.

Reid, R., F. Almeida, and C. Zetlin. 1999. Essential fish habitat source document: Fishery independent surveys, data sources, and methods. NOAA Tech. Mem. NMFS-NE-122. 39 p.

Scott, J.S. 1982a. Depth, temperature and salinity preferences of common fishes of the Scotian Shelf. J. Northwest Atl. Fish. Sci. 3: 29-39.

Scott, J.S. 1982b. Selection of bottom type by groundfishes of the Scotian Shelf. Can. J. Fish. Aquat. Sci. 39: 943-947.

Smith, W.G., J.D. Sibunka, and A. Wells. 1975. Seasonal distributions of larval flatfishes (*Pleuronectiformes*) on the continental shelf between Cape Cod, Massachusetts and Cape Lookout, North Carolina, 1965-66. NOAA Tech. Rep. NMFS SSRF-691. 68 p.

Walsh, S.J. 1987. Habitat partitioning in witch flounder *Glyptocephalus cynoglossus*: a re-evaluation with additional data and adjustment for gear selectivity. Fish. Bull. (U.S.) 88: 147-153.

Wigley, S. 1995. Witch flounder. *In* Conservation and Utilization Division, Northeast Fisheries Science Center eds. Status of the fishery resources of the northeastern United States for 1994. p. 73-74. NOAA Tech. Mem. NMFS-NE-108.

Wigley, S. 1998. Witch flounder. *In* S.H. Clark ed. Status of the fishery resources off the northeastern United States for 1998. p. 79-80. NOAA Tech. Mem. NMFS-NE-115.

Wigley, S.E. and R.K. Mayo. 1996. Assessment of the Gulf of Maine-Georges Bank witch flounder stock for 1994. U.S. Natl. Mar. Fish. Serv., Northeast Fish. Sci. Cent. Ref. Doc. 94-17. 86 p.

Table 1. Size at metamorphosis for witch flounder, *Glyptocephalus cynoglossus*, from various locations.

Location	**Size (mm)**	**Reference**
Georges Bank	20	Evseenko and Nevinsky (1975)
Cape Hatteras to Nova Scotia	22-35	Fahay (1983)
Gulf of Maine	35	Colton and Marak (1969)
Nova Scotia	38	Powles and Kohler (1970)
Grand Bank	50	Frank *et al.* (1992)
Gulf of Maine	40-50	Bigelow and Schroeder (1953)
Gulf of Maine	68	Kelly and Marak*

**cited as a personal communication by Powles and Kohler (1970)*

Table 2. Age and size at maturity of witch flounder, *Glyptocephalus cynoglossus*, from various locations.

Location	**Time**	**Age at Maturity (years)**		**Size at Maturity (cm)**		**Reference**
		male	*female*	*male*	*female*	
Gulf of Maine	1986-1990	3.6	4.4	25.3	30.4	O'Brien *et al.* (1993)
Gulf of Maine/ Georges Bank	1977-1984	4.5	6.0	27.6	33.5	Burnett *et al.* (1992)
Middle Atlantic Bight	-	6	6-7	30	36	Martin and Drewry (1978)
Cape Hatteras - Nova Scotia	1977	-	-	33.0	34.9	Morse (1979)

Table 3. Summary of life history and habitat parameters for witch flounder, *Glyptocephalus cynoglossus*. ‘MARMAP’ and ‘NEFSC’ refer to data discussed in the Geographical Distribution section of the text. Note: information that was not specifically separated into juvenile and adult is presented under the heading “Juveniles/Adults”.

Life Stage	Size and Growth	Habitat	Substrate	Temperature
Eggs [1]	Mean egg diameter is 1.18 mm, range = 0.67-1.45 mm. Yolk diameter ranges from 0.95-1.05 mm.	Pelagic, over deep water. On the SE part of Georges Bank, eggs have been captured over shallower waters, 50-85 m, but in Canadian waters, south of the Grand Bank over up to more than 5000 m. MARMAP: found at 10-170 m, most at 50-150 m.		Incubation is 7-8 days at 8-9^{o}C. Incubation proceeds normally between 7.2-12.8^{o}C. Eggs are buoyant, and thus may experience warmer temperatures than those at which they are spawned (typically spawned at 4-9^{o}C, but found in surface waters as high as 10-12.8^{o}C). MARMAP: found at 4-17^{o}C, most at 4-12^{o}C.
Larvae [2]	Size at hatch ranges from 3.5-6.0 mm, mean is 4.8 mm. Size at metamorphosis ranges from 20-50 mm (but can be delayed to larger sizes). Descent to bottom occurs after eye migration is complete.	Caught at depths of 0-250 m; primarily 10-90 m. One study showed the center of witch flounder abundance south of Cape Cod to be off Long Island, over 75 m of water and at a bottom temperature of 5^{o}C. MARMAP: found at 30-210 m.	N/A	MARMAP: found at 4-16^{o}C, most at 4-13^{o}C.
Juveniles [3]	Up to approximately ≥ 30 cm (2-5 yrs); size at maturity varies considerably.	Off Virginia: dominant at about 900 m; the upper continental slope is a nursery area. Caught in significantly deeper waters in Nov. (mean = 670 m) than in June (mean = 492m). Off Nova Scotia: caught mainly at 180-288 m. NEFSC: found at 50-450 m, most at 75-200 m.		Off Virginia are caught at bottom temperatures of 4.1-11.3^{o}C. Caught at significantly colder temperatures in November (mean = 5.5^{o}C) than in June (mean = 7.3^{o}C). NEFSC: most found at 4-10^{o}C.
Juveniles/ Adults [4]		Deepwater species. Gulf of Maine distribution is governed by water depth; generally occur deeper than 20-36 m (where substrate is suitable), primarily between 90-300 m; have been found as deep as 1565 m. Juveniles inhabit greater depths than adults. Found at around 80 m in Bay of Fundy.	Found over discrete microhabitat types; fine muddy sand, clay or mud.	Gulf of Maine: found at -1.0-14.5^{o}C, (but tend to avoid > 10^{o}C); in winter-early spring found at 2-3^{o}C; in late summer-early fall found at 7-9^{o}C. Spawn at 0-10^{o}C. Bay of Fundy: found at 1-12^{o}C.
Adults [5]	Females attain a larger maximum size (~62 cm) than males (~58 cm). Median age and length at maturity (A_{50}/L_{50}): Nova Scotia, 1964-1966, female =10 yrs/44 cm, male = 7/37; Mid-Atlantic Bight, 1970s, female = 6-7/36, male = 6/30; Hatteras to Nova Scotia, 1977, female = -/34.9, male = -/33.0; Gulf of Maine/Georges, 1977-1984, female = 6/33.5, male = 5/29.6; 1982-1984, male = 4/24.3; 1986-1990, female = 4.4/30.4, male = 3.6/25.3	Range from Labrador-Cape Hatteras, but not commercially abundant south of Cape Cod. In US waters are common throughout the Gulf of Maine and deeper areas of Georges Bank. Newfoundland to Hatteras: most common in deep water, 90-275 m. Gulf of Maine/Georges Bank: mean depth of adults = 147 m; juveniles are shallower in winter/spring (112 m) than in summer/fall (198 m). Nova Scotia: adults in summer at 36-270 m and in winter at 90-432 m. Bay of Fundy: preferred depth range 30-89 m, mean 52 m. NEFSC: 15-400 m, most at 50-200 m.	Middle Atlantic Bight: found over mud, clay, mud or clay mixed with sand, smooth ground between rocky patches, rarely on sand. Scotian Shelf: concentrated on silty, mud & clay bottoms; rare on sands & gravel.	Newfoundland to Hatteras, NC in winter: -0.6-4^{o}C; in summer: 7-10^{o}C. Spawning fish were found at bottom temperatures of 2.9-8.9^{o}C. Bay of Fundy: preferred temperature range 7-8^{o}C, mean 7.4^{o}C. Association between spawning activity and areas of cold water may explain formation of dense pre-spawning aggregations. NEFSC: found at 2-16^{o}C, most at 4-11^{o}C.

[1] Bigelow and Schroeder (1953), Colton and Marak (1969), Evseenko and Nevinsky (1975), Neilson *et al.* (1988), Burnett *et al.* (1992)
[2] Bigelow and Schroeder (1953), Colton and Marak (1969), Powles and Kohler (1970), Evseenko and Nevinsky (1975), Smith *et al.* (1975), Fahay (1983)
[3] Powles and Kohler (1970), Markle and Musick (1974), Markle (1975), Burnett *et al.* (1992), Collette and Klein-MacPhee (in prep.)
[4] Bigelow and Schroeder (1953), MacDonald *et al.* (1984), Auster *et al.* (1991), Collette and Klein-MacPhee (in prep.)
[5] Powles and Kohler (1970), Lange and Lux (1978), Martin and Drewry (1978), Morse (1979), Scott (1982a,b), Burnett *et al.* (1992), O’Brien *et al.* (1993)

Table 3. cont'd.

Life Stage	Salinity	Currents	Prey	Predators	Spawning	Notes
Eggs [1]	High salinities.	General drift to south and southwest.	N/A	Preyed upon by a wide range of pelagic predators.	Spawning occurs from March to October; occurs progressively later to the north and east. NC to MA: spawning peaks in May/June. Gulf of Maine and Georges Bank: spawning from May - Sept, peaks in July/Aug. More northerly banks (off northeast Nova Scotia): peak in August/Sept. Most important spawning grounds in the Middle Atlantic Bight are off Long Island and southern New England.	Mixing of spawning groups seems likely, due to fact that eggs and larvae are pelagic, and the extended duration of the larval pelagic stage (up to 1 year). Eggs are pelagic, spherical and transparent. Not found in the Bay of Fundy.
Larvae [2]	High salinities.	Shelf currents transport some larvae to SSW.		Preyed upon by a wide range of pelagic predators.	N/A	Yolk sac is absorbed 10 days after hatching. Smaller larvae are found nearer the surface than larger larvae. Lengthy pelagic larval stage lasts from 4-6 months - 1 year.
Juveniles [3]	Off Virginia: caught at bottom salinities of 34.9-35.7 ppt.		< 20 cm: fed primarily on crustaceans (74%)(70% is the euphausiid *Meganyctophanes norvegica*) and polychaetes (19%). 21-30 cm: fed on polychaetes (45-65%), crustaceans (15-37%), mollusks (0.5-2%), and echinoderms (0-4.8%).		N/A	The slope off Virginia may serve as a nursery for 1 to 3 or 4 year old witch flounder; juveniles are discrete from the adult stock. Larger juveniles (up to 37 cm for males and 44 cm for females), may join the adult aggregation just prior to maturation.
Juveniles/ Adults [4]	Found at 31-32.5 ppt in Bay of Fundy.		Primary prey are invertebrates. Diet is composed of: 71.9% polychaetes (16.3% Neridiforms), 9.5% echinoderms (5.2% Thyone), 5.3% crustaceans (2.8% amphipods), 3.7% mollusks (2.8% *Loligo*), 1.5% coelenterates, 0.8% fish. In southern New England, squid are almost equal in importance to polychaetes as the primary prey item.	Primary predators in the Gulf of Maine are goosefish & harp seals. Other predators include spiny dogfish, halibut and large cod.		Gulf of Maine: no evidence of seasonal movements; stationary year round. Bay of Fundy juveniles are caught from November to May only; adults are caught from June to October only; this suggests seasonal movements.
Adults [5]	Middle Atlantic Bight: found within 33-35.2 ppt. Bay of Fundy: preferred range 32-33 ppt, mean 32.4 ppt.		Mid-Atlantic to Scotian Shelf: 31-60 cm length fish fed on polychaetes (60-66%), echinoderms (6-18%), crustaceans (1.2%-10.8%), mollusks (0.8-2.6%), and coelenterates (0-5.9%); > 60 cm fish fed primarily on polychaetes (98%).		Spawning occurs earliest in southern waters. Most active spawning sites in the Gulf of Maine, primarily northwest of Cape Cod. Gulf of Maine/Georges Bank; spawning ranges from April-Nov; peaks May-Aug at depths of 24-360 m, (mean depth 129 m, mean temp. of 4.9°C). Middle Atlantic Bight: spawning ranges from April-Aug; peaks May-June (earliest in more southerly waters). Locations: from shore to slope waters in localized areas, depths range from 70-260 m, primarily at 100-160 m.	No evidence of seasonal movements in Gulf of Maine. But, on the Scotian Shelf, adults tend to inhabit shallower depths in summer (spawning season) than in winter. Sex ratios were approx. 1:1 (range from 46.3-54.1% male). Females grow faster and larger than males; growth slower at greater depths.

[1] Bigelow and Schroeder (1953), Colton and Marak (1969), Evseenko and Nevinsky (1975), Smith *et al.* (1975), Martin and Drewry (1978), Fahay (1983), Neilson *et al.* (1988), Brander and Hurley (1992), Burnett *et al.* (1992), O'Brien *et al.* (1993)

[2] Bigelow and Schroeder (1953), Colton and Marak (1969), Evseenko and Nevinsky (1975)

[3] Bigelow and Schroeder (1953), Powles and Kohler (1970), Markle (1975), Maurer and Bowman (1975), Bowman and Michaels (1984), Collette and Klein-MacPhee (in prep.)

[4] Bigelow and Schroeder (1953), Maurer and Bowman (1975), MacDonald *et al.* (1984), Collette and Klein-MacPhee (in prep.)

[5] Bigelow and Schroeder (1953), Powles and Kohler (1970), Martin and Drewry (1978), Scott (1982a), Bowman and Michaels (1984), Burnett *et al.* (1992), O'Brien *et al.* (1993)

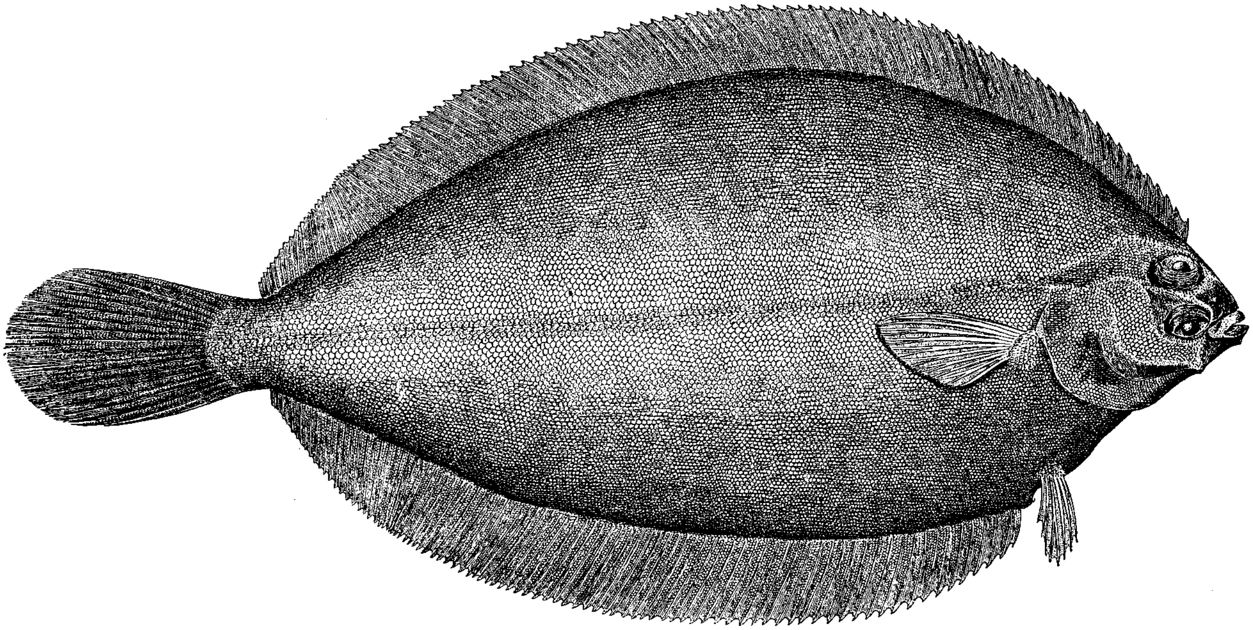


Figure 1. The witch flounder, *Glyptocephalus cynoglossus* (from Goode 1884).

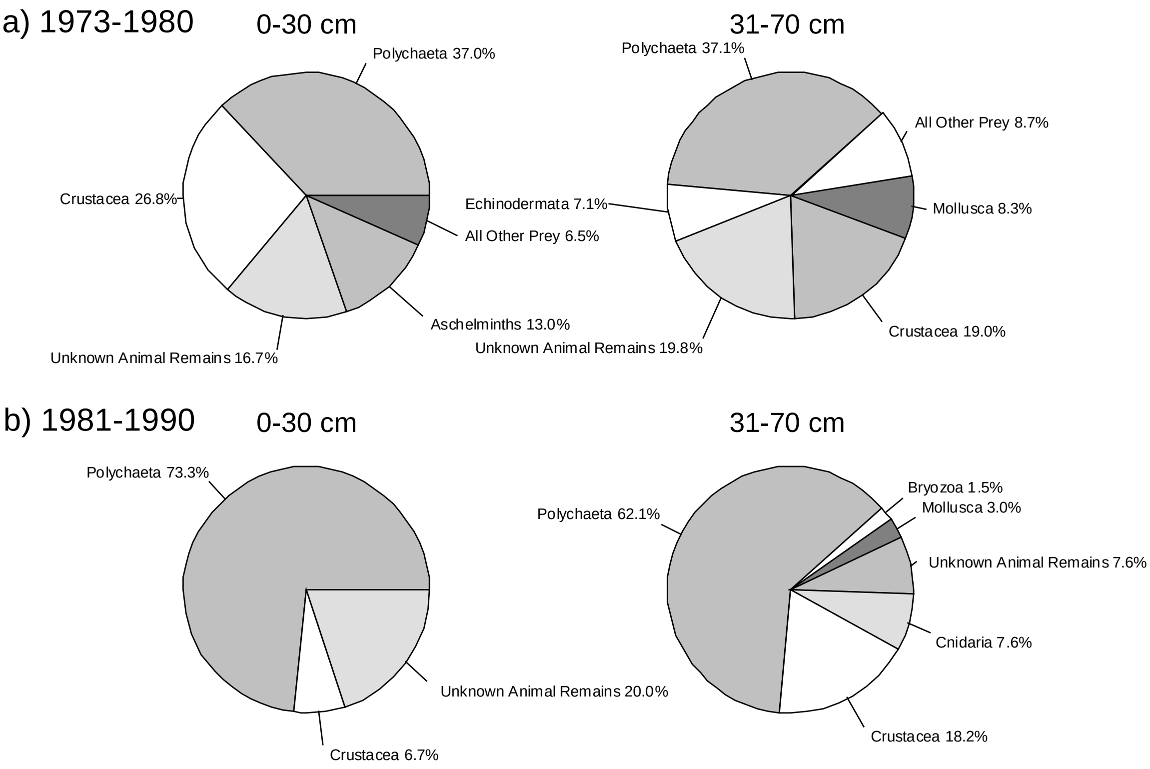
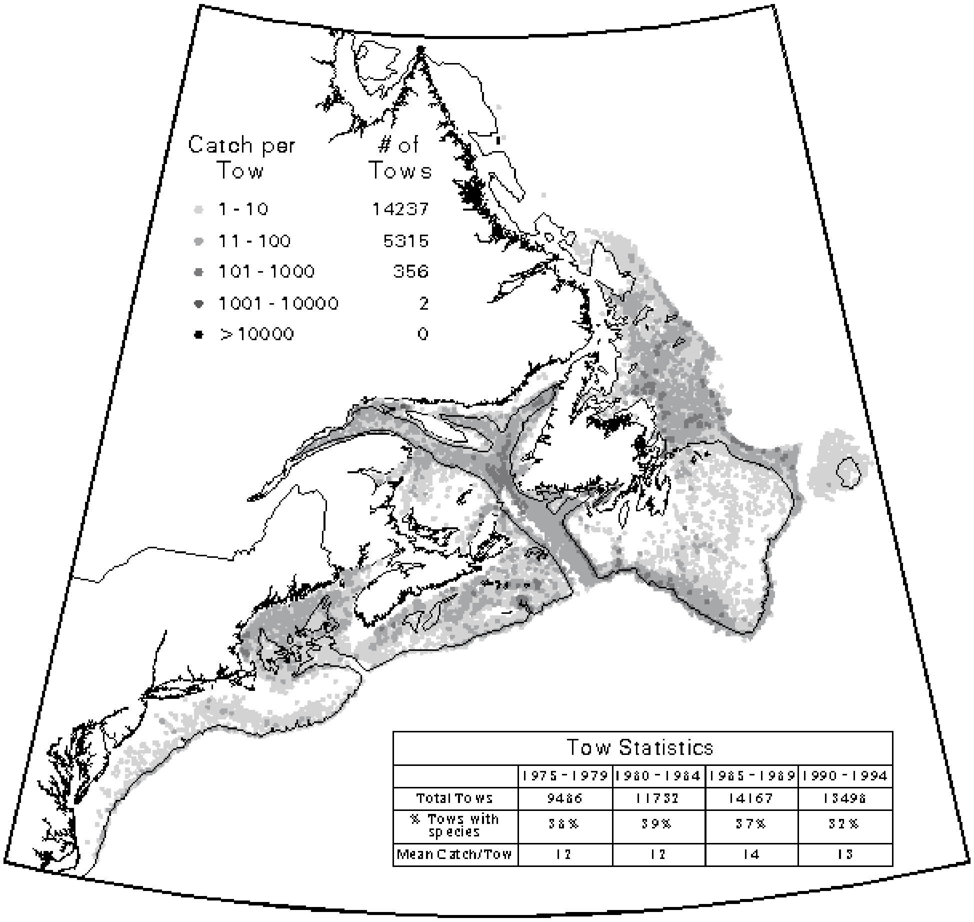


Figure 2. Abundance (% occurrence) of the major prey items of witch flounder collected during NEFSC bottom trawl surveys from 1973-1980 and 1981-1990. The 0-30 cm size category corresponds, at least roughly, to the juvenile life stage, and the 31-70 cm size category corresponds to adults. “Unknown Animal Remains” refers to unidentifiable animal matter. Methods for sampling, processing, and analysis of samples differed between the time periods [see Reid *et al.* (1999) for details]. (a) 1973-1980, 0-30 cm: n = 60; 31-70 cm: n = 583), (b) 1981-1990, 0-30 cm: n = 15; 31-70 cm: n = 62).



Catch per Tow	# of Tows
● 1 - 10	14237
● 11 - 100	5315
● 101 - 1000	356
● 1001 - 10000	2
● >10000	0

Tow Statistics

	1975 - 1979	1980 - 1984	1985 - 1989	1990 - 1994
Total Tows	9486	11732	14167	13498
% Tows with species	38%	39%	37%	32%
Mean Catch/Tow	12	12	14	13

Figure 3. Distribution and abundance of witch flounder from Newfoundland to Cape Hatteras during 1975-1994. Data are from the U.S. NOAA/Canada DFO East Coast of North America Strategic Assessment Project (http://www-orca.nos.noaa.gov/ projects/ecnasap/ecnasap_table1.html).

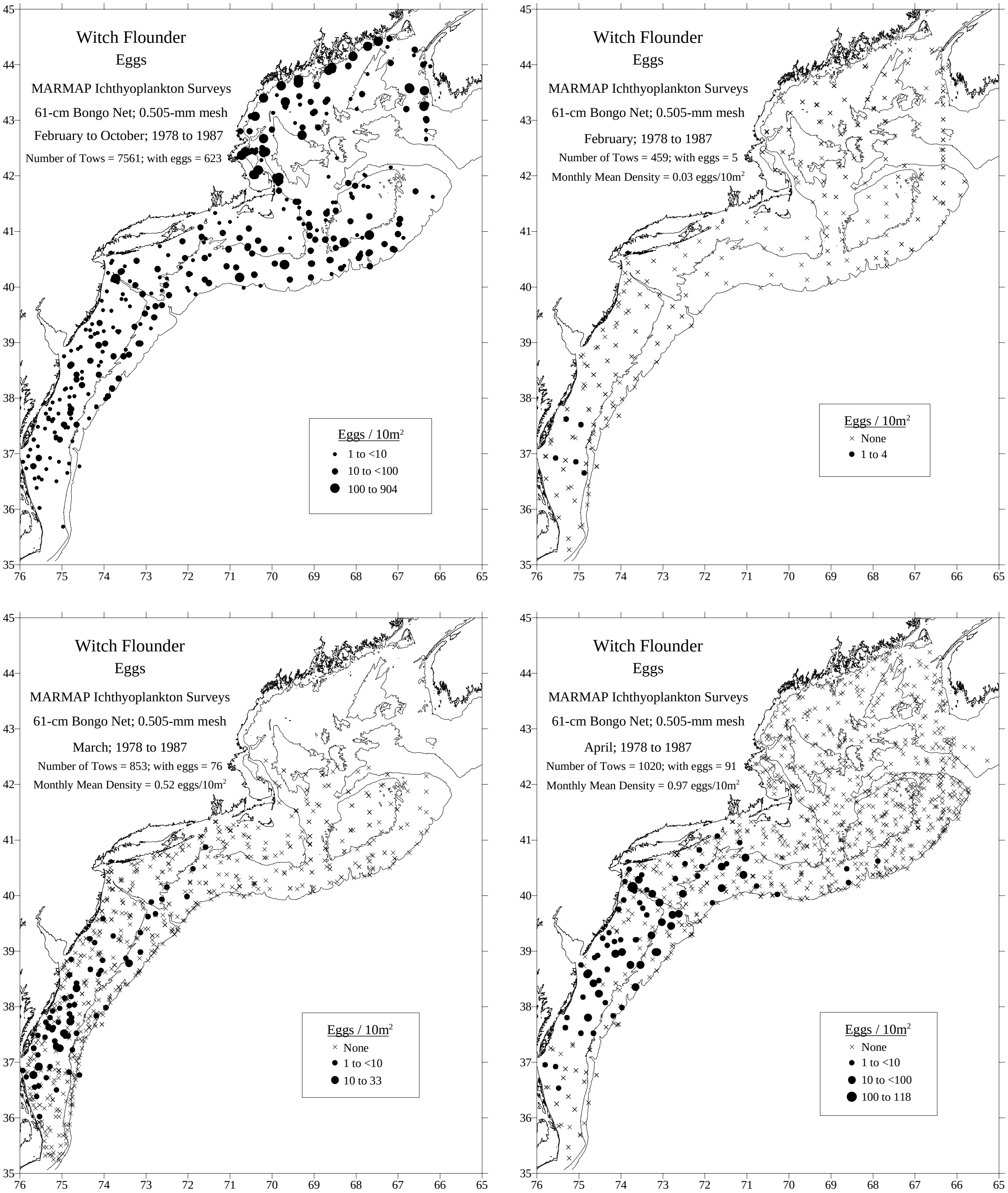


Figure 4. Distribution of witch flounder eggs collected during NEFSC MARMAP offshore ichthyoplankton surveys, February to October, 1978-1987 [see Reid *et al.* (1999) for details].

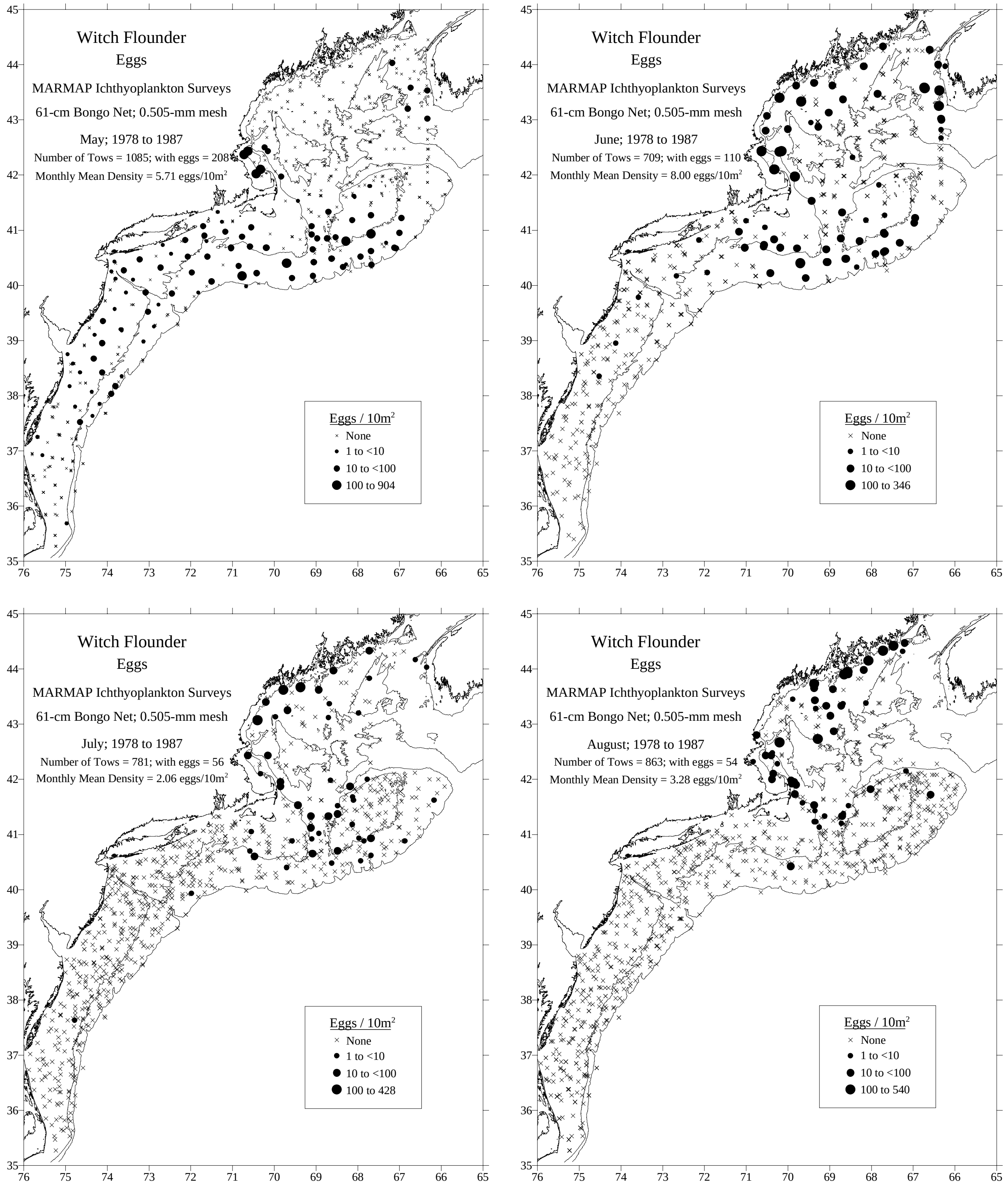


Figure 4. cont'd.

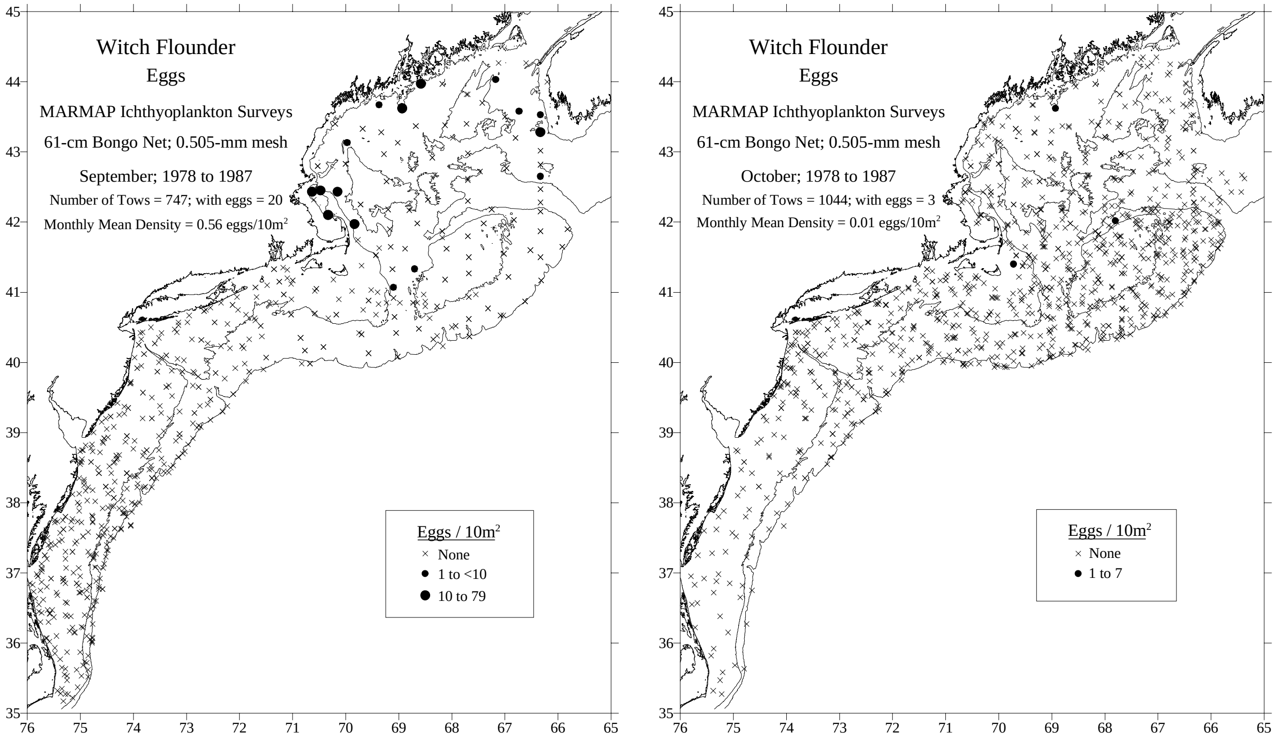


Figure 4. cont’d.

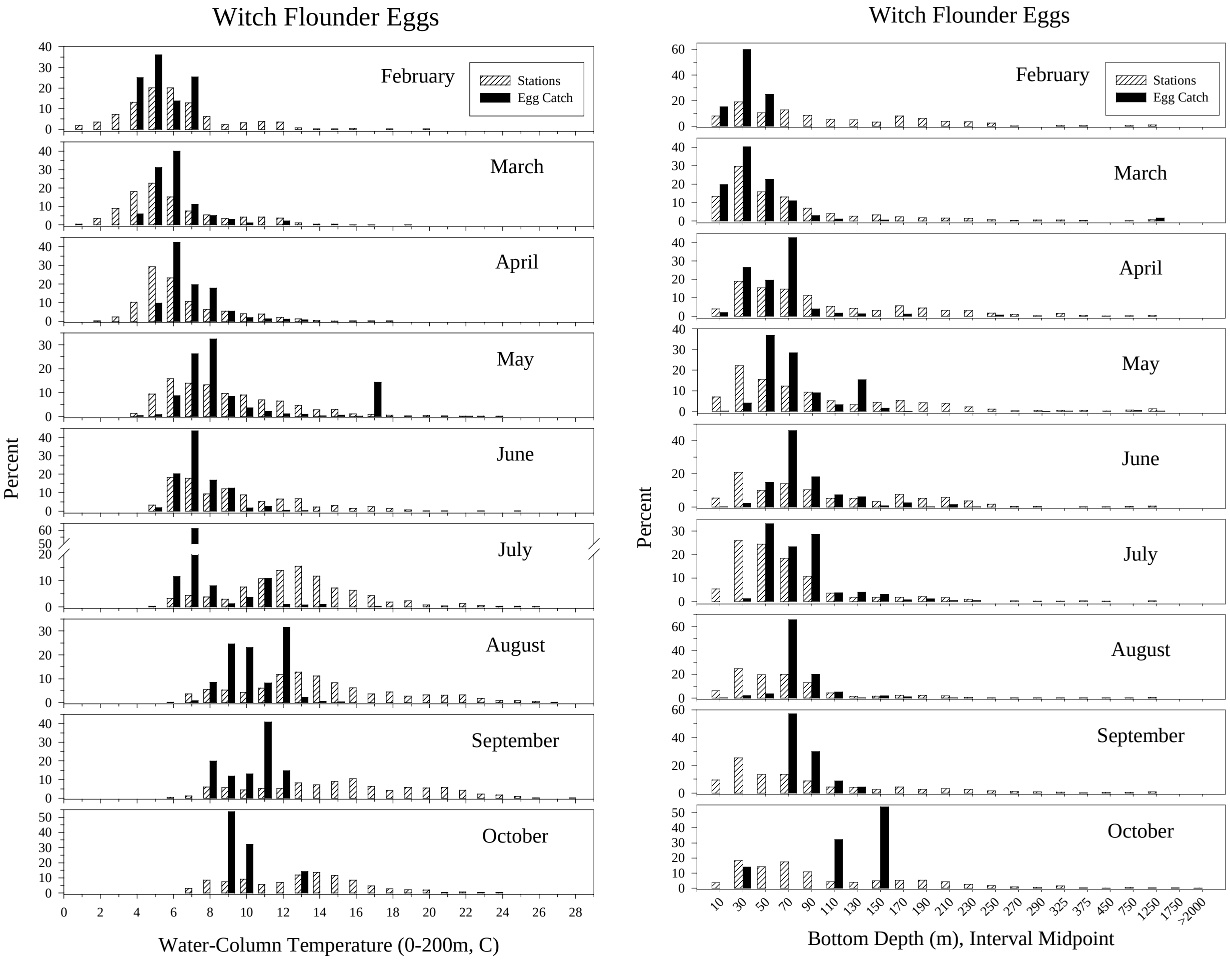


Figure 5. Abundance of witch flounder eggs relative to water column temperature (^{o}C, to a maximum of 200 m) and bottom depth (m) based on NEFSC MARMAP ichthyoplankton surveys, February to October, 1978-1987 (all years combined). Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number of eggs/10 m^2).

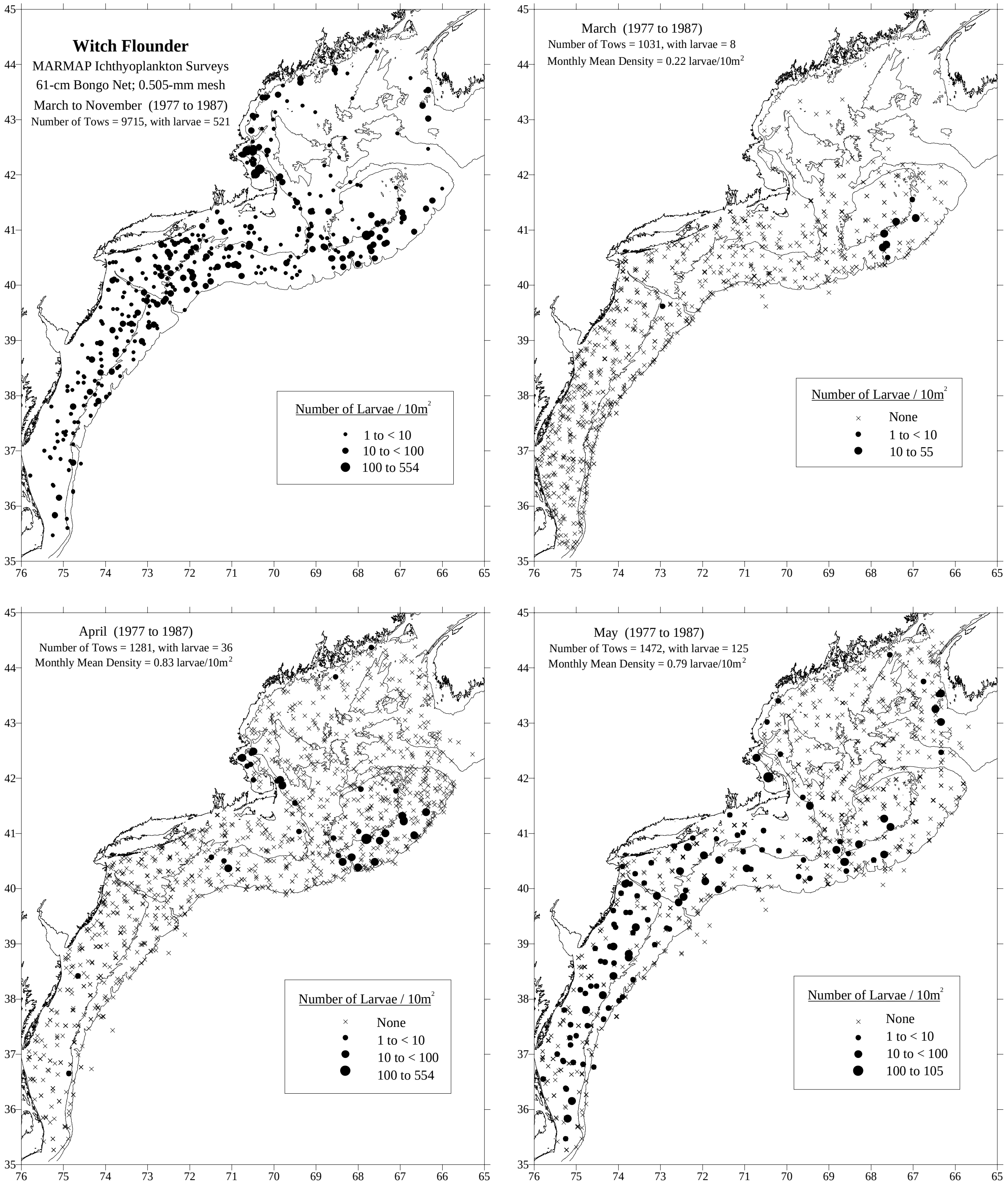


Figure 6. Distribution of witch flounder larvae collected during NEFSC MARMAP offshore ichthyoplankton surveys, March to November, 1977-1987 [see Reid *et al.* (1999) for details]. All larval sizes are included (up to a maximum of 54 mm). Larval densities are represented by dot size.

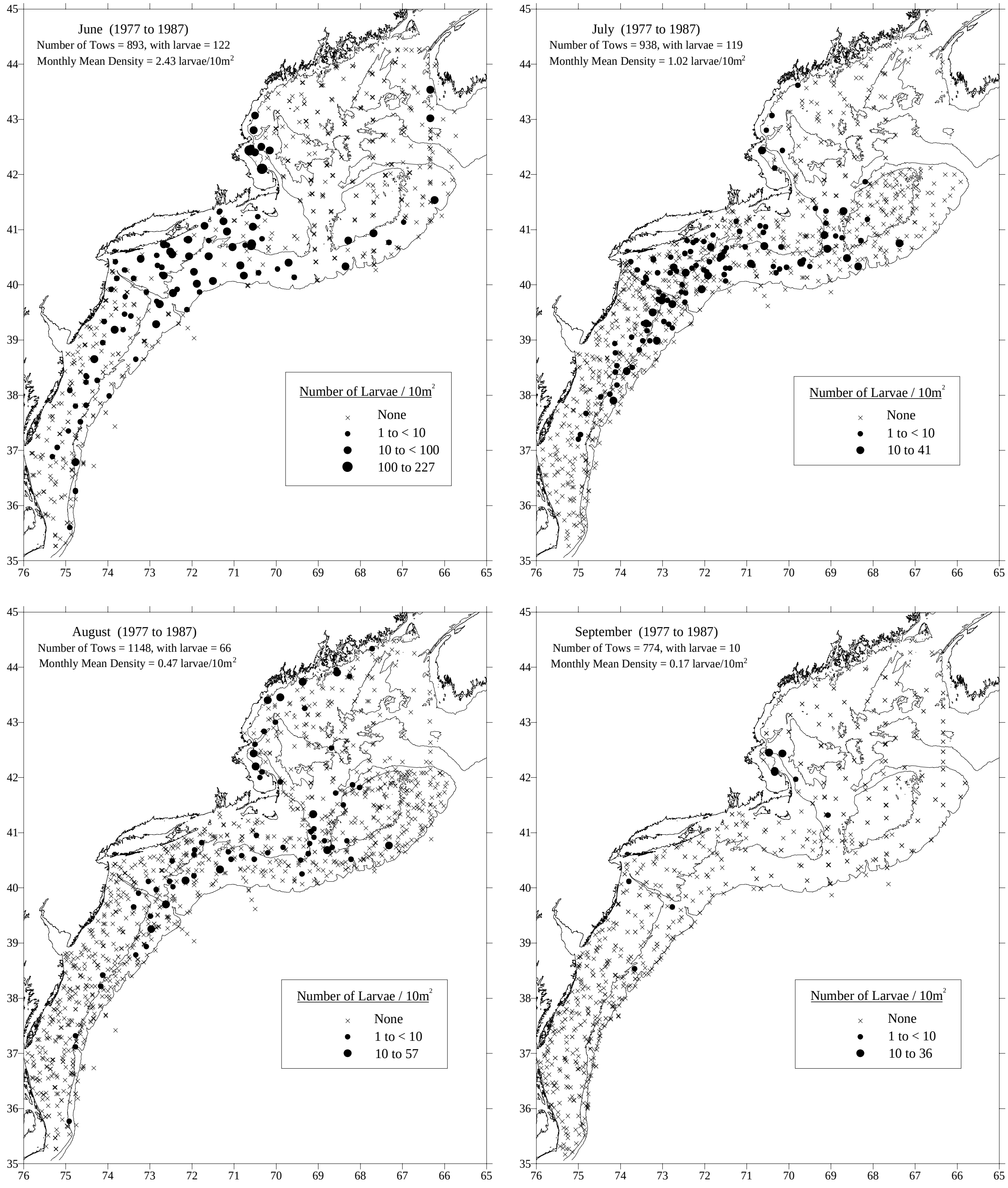


Figure 6. cont'd.

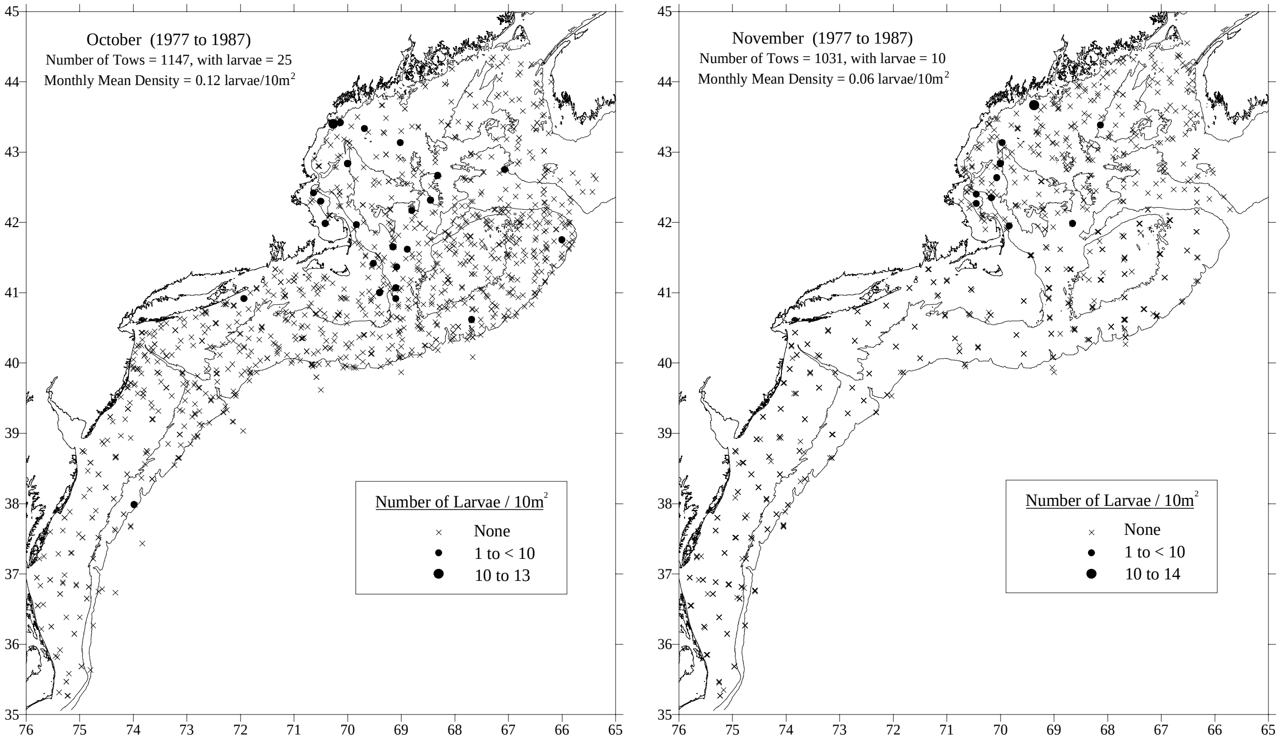


Figure 6. cont’d.

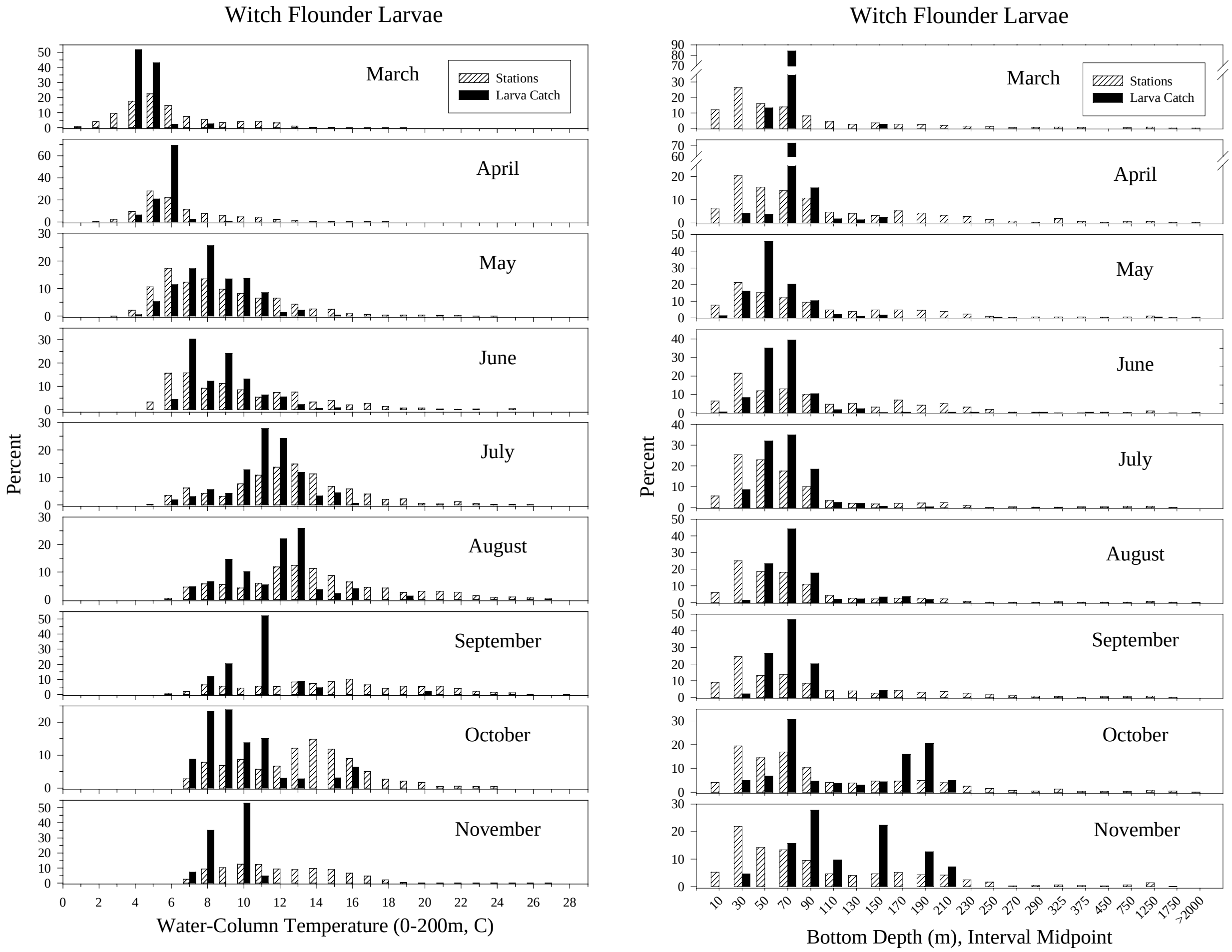


Figure 7. Abundance of witch flounder larvae relative to water column temperature (^{o}C, to a maximum of 200 m) and bottom depth (m) based on NEFSC MARMAP ichthyoplankton surveys, March to November, 1977-1987 (all years combined). All larval sizes are included (up to a maximum of 54 mm). Open bars represent the proportion of all stations surveyed, while sold bars represent the proportion of the sum of all standardized catches (number of eggs/10 m^{2}).

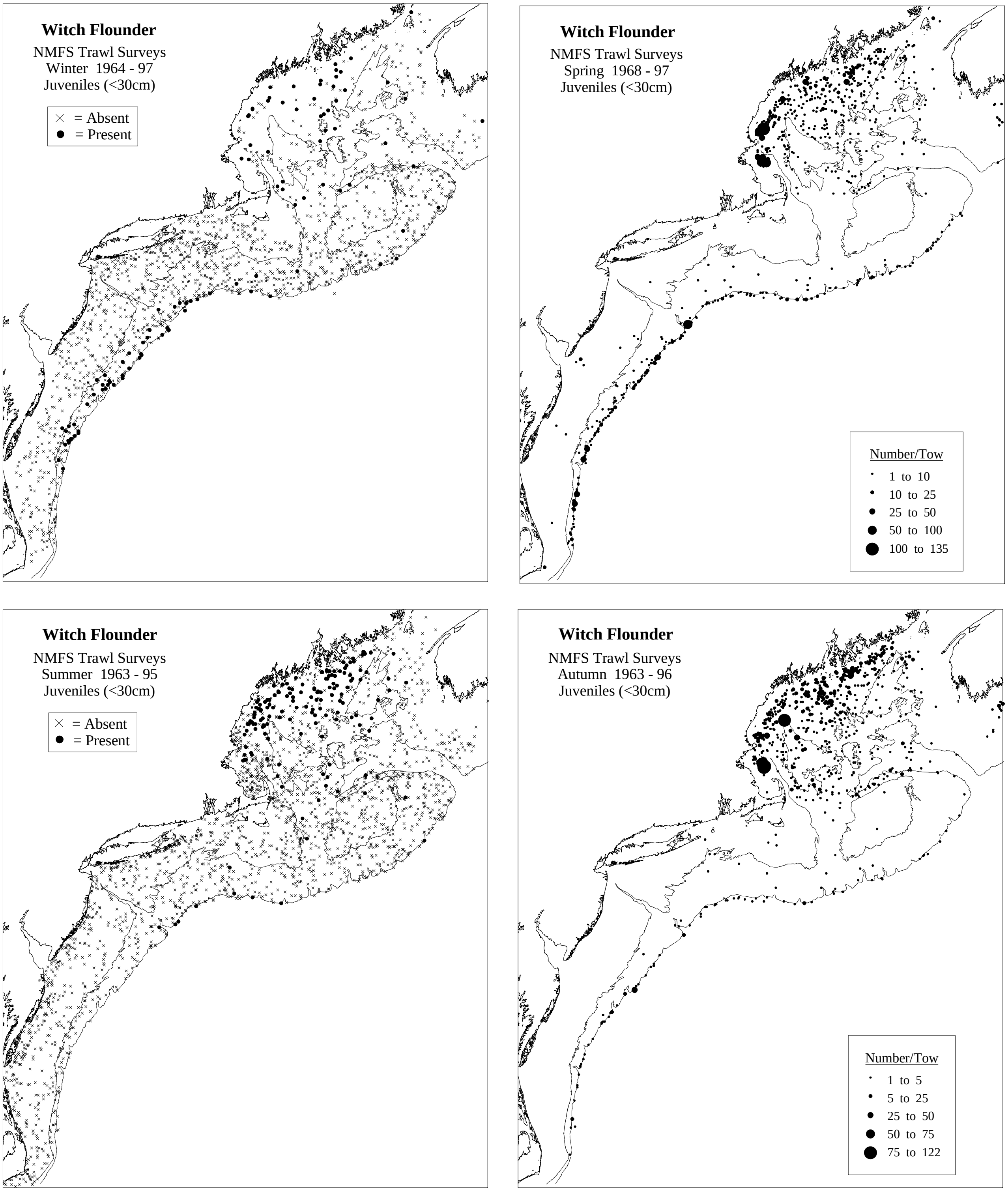


Figure 8. Distribution of juvenile and adult witch flounder collected during NEFSC bottom trawl surveys (winter, spring, summer, and autumn, 1963-1997). Densities (number per tow) are represented by dot size in spring and autumn plots, while only presence and absence are represented in winter and summer plots [see Reid *et al.* (1999) for details].

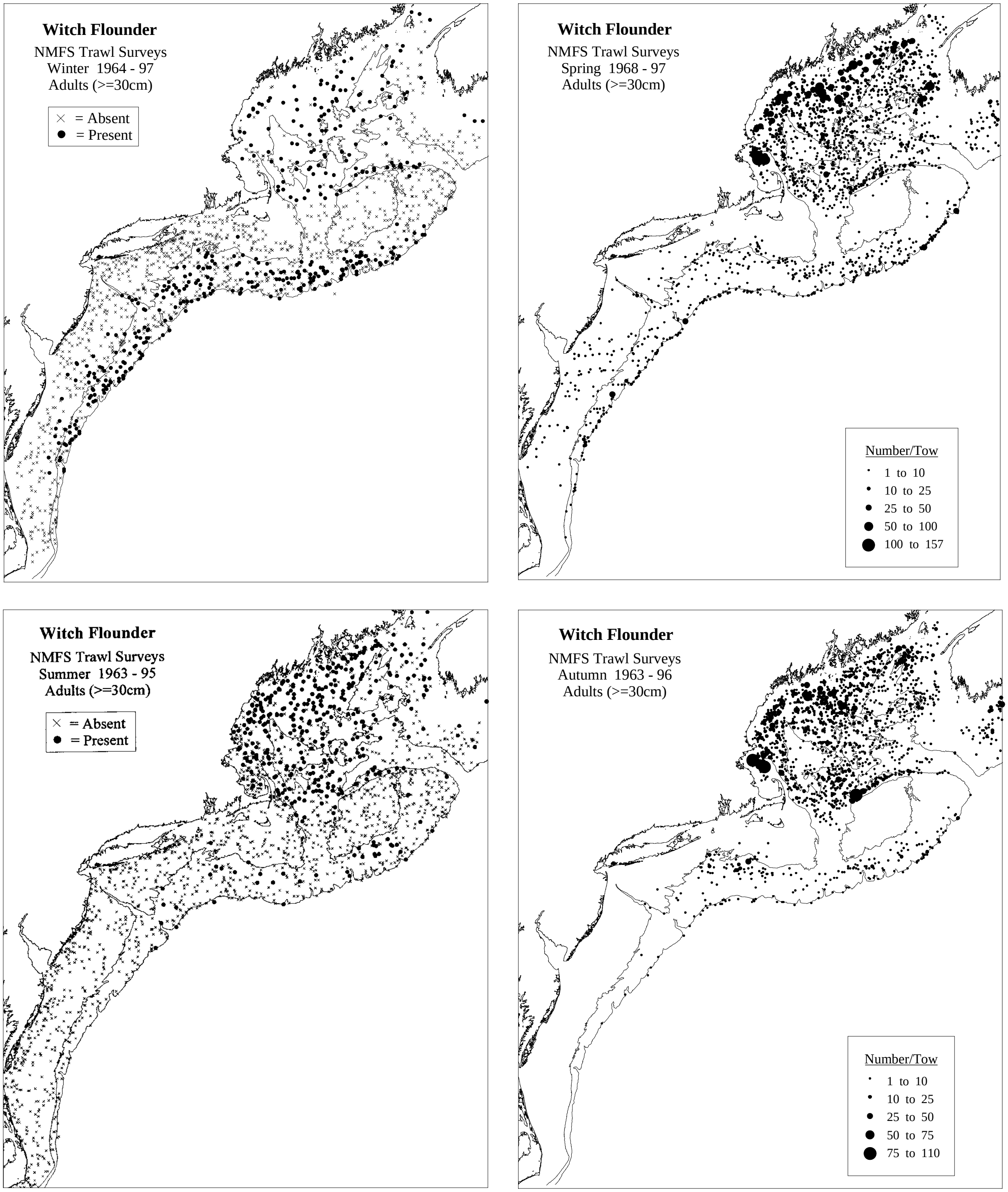


Figure 8. cont'd.

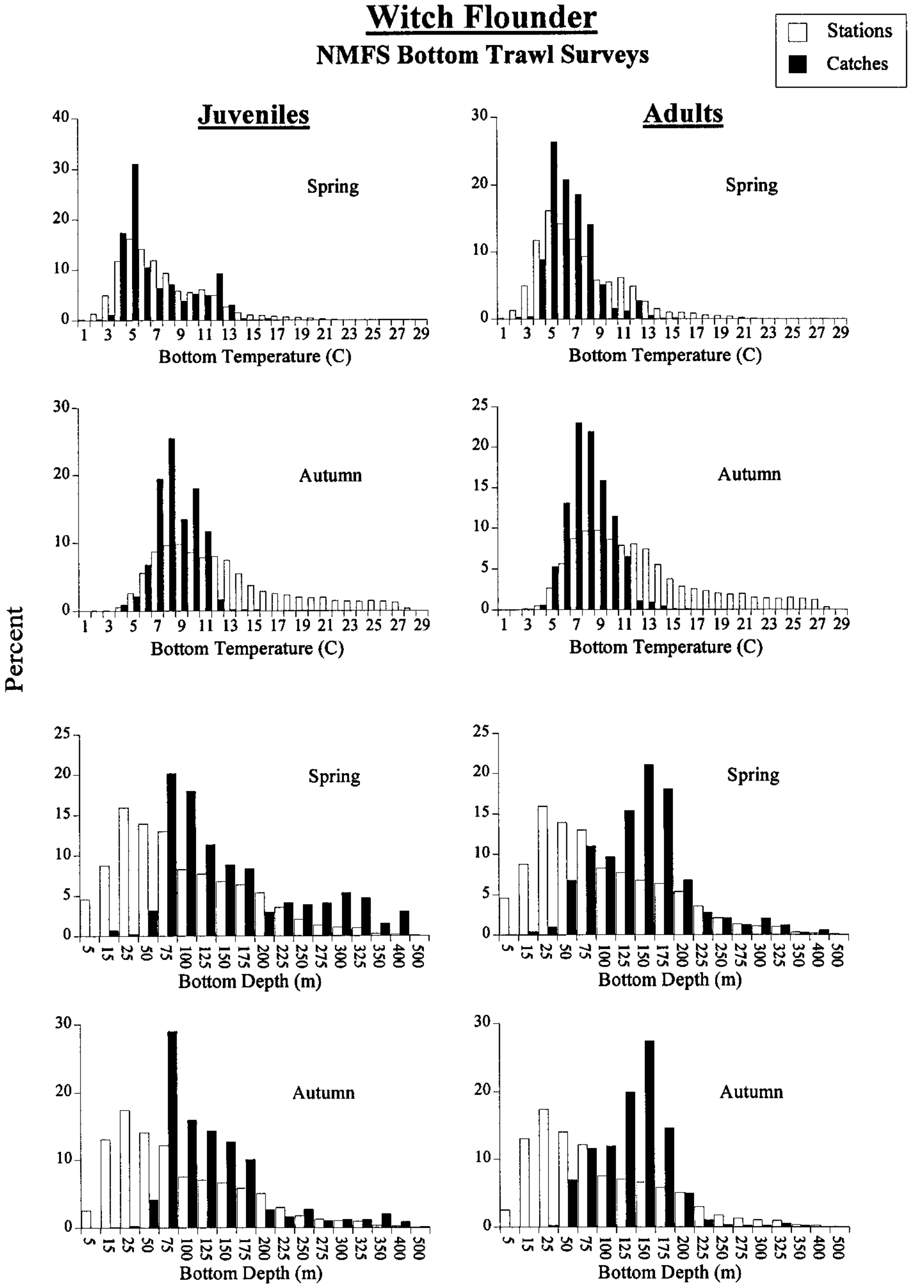


Figure 9. Abundance of juvenile and adult witch flounder relative to bottom water temperature (°C) and depth (m) based on NEFSC bottom trawl surveys (spring and autumn, 1963-1997). Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

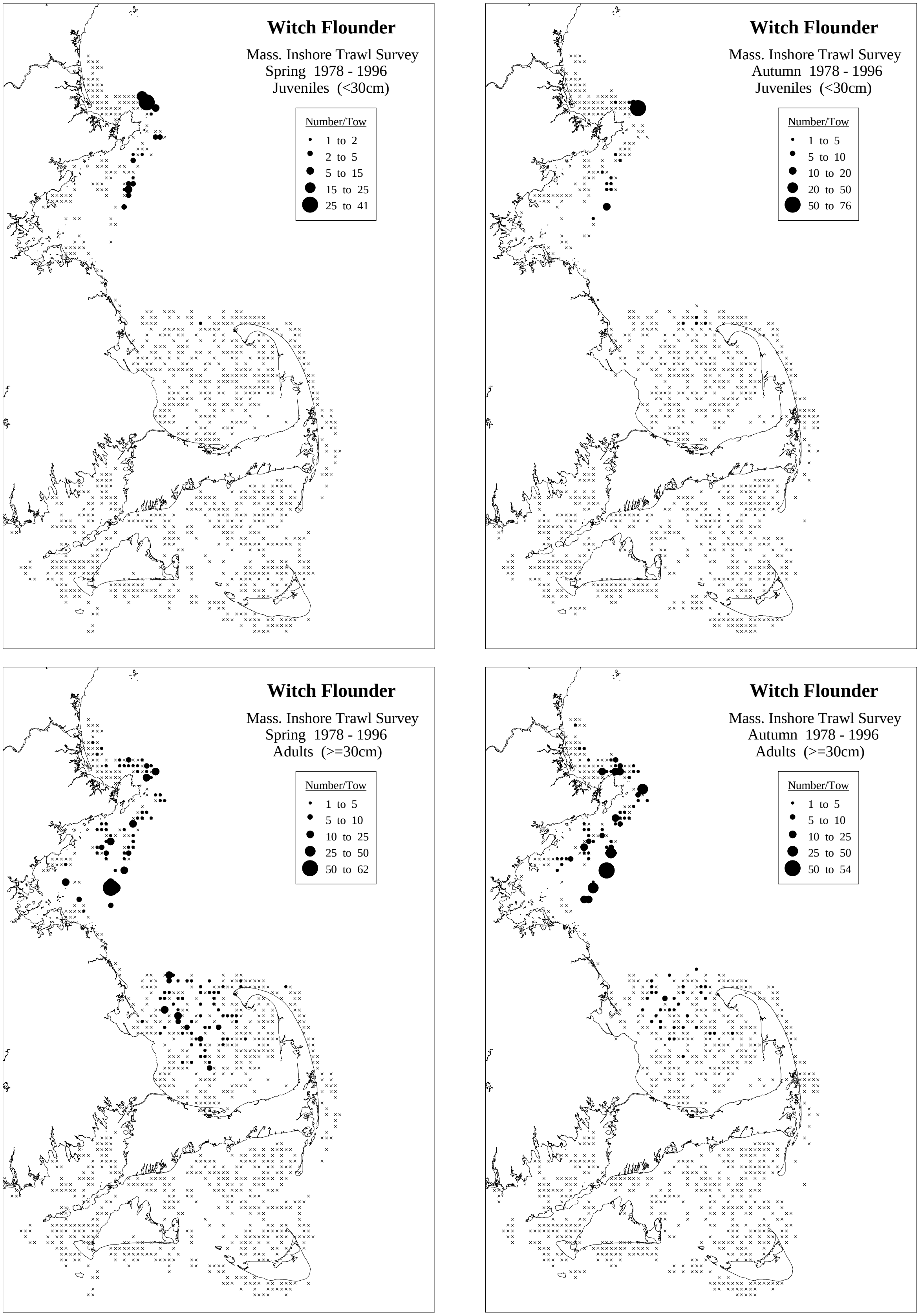


Figure 10. Distribution of juvenile and adult witch flounder collected in inshore waters of Massachusetts during spring and autumn Massachusetts inshore trawl surveys, 1978-1996 [see Reid *et al.* (1999) for details].

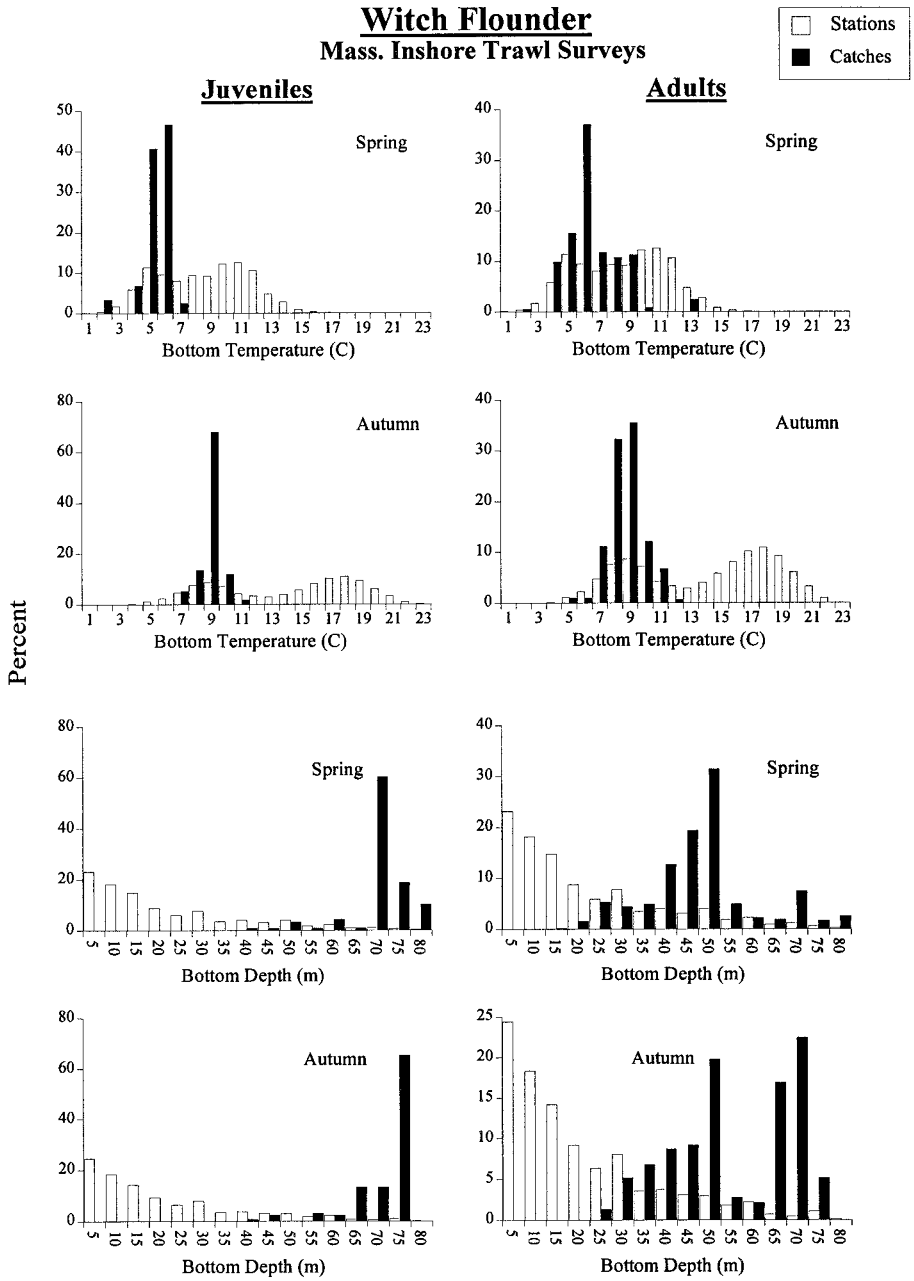


Figure 11. Abundance of juvenile and adult witch flounder relative to bottom water temperature (^{o}C) and depth (m) based on Massachusetts inshore bottom trawl surveys (spring and autumn, 1978-1996, all years combined). Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

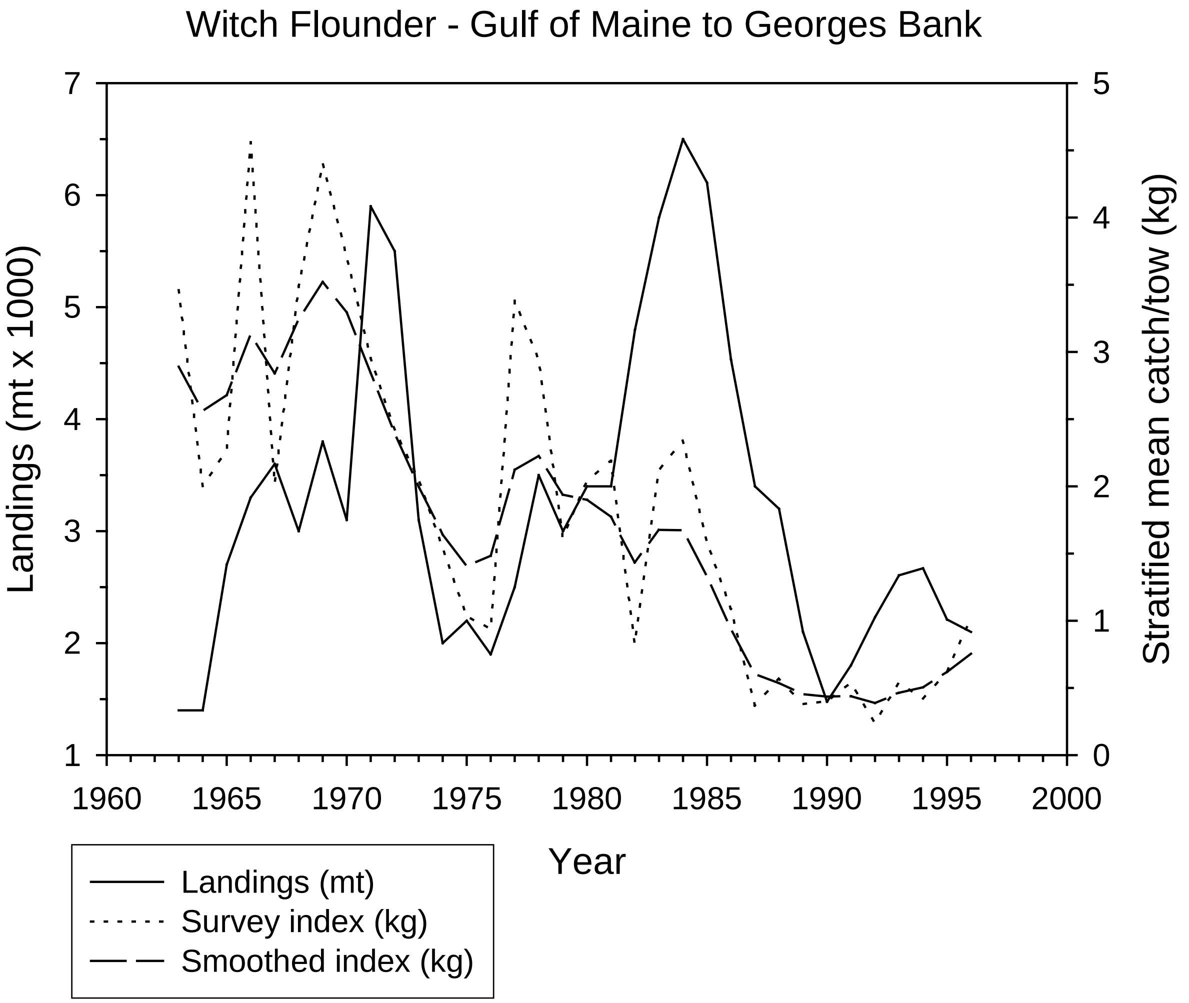


Figure 12. Commercial landings and NEFSC autumn bottom trawl survey indices (stratified mean weight per tow) for witch flounder in the Gulf of Maine and Georges Bank, 1963-1996.

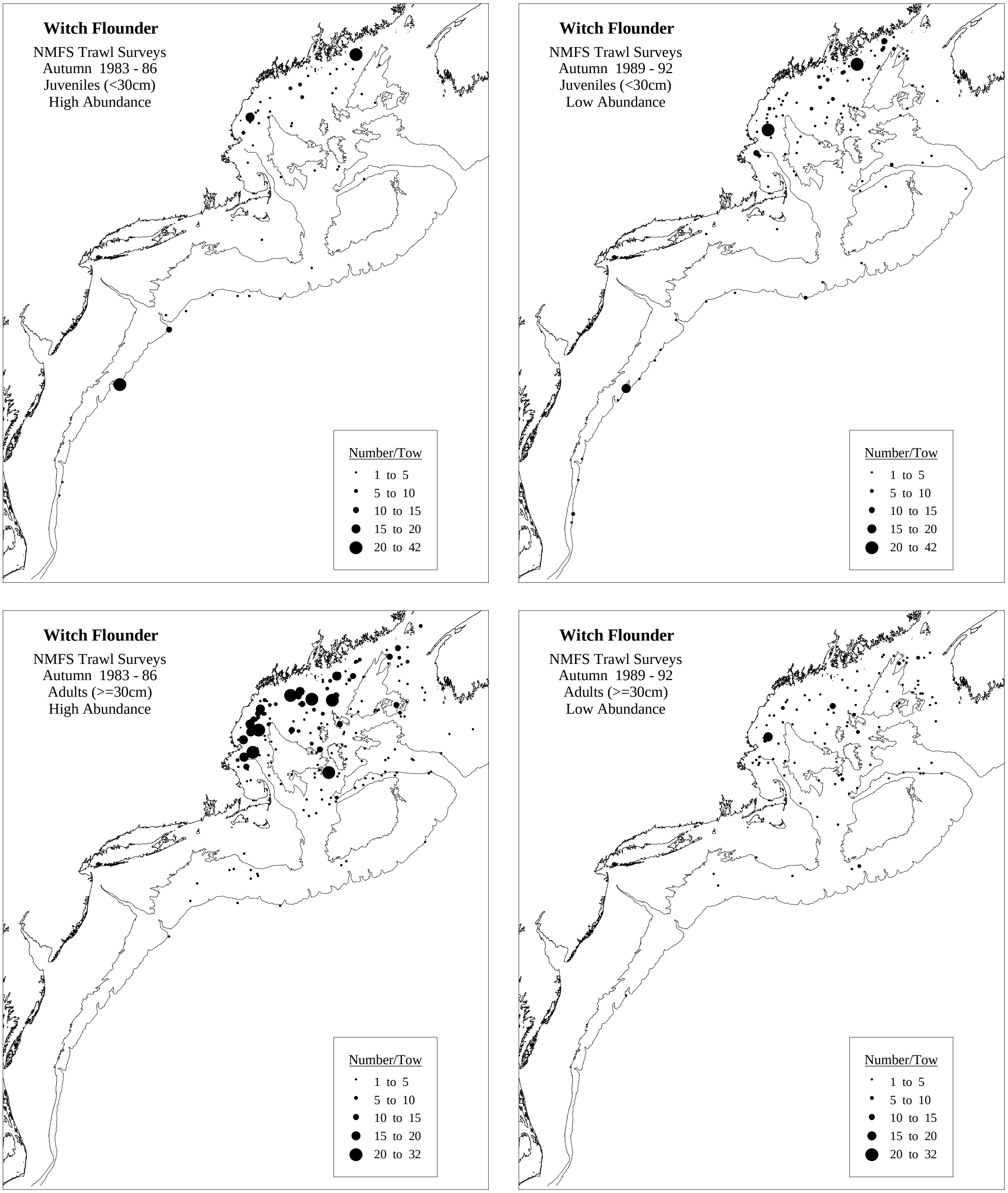


Figure 13. Distribution of juvenile and adult witch flounder during a period of relatively high abundance (1983-1986) and a period of relatively low abundance (1989-1992) based on autumn NEFSC bottom trawl surveys.

Publishing in *NOAA Technical Memorandum NMFS-NE*

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.

Manuscripts by Northeast Fisheries Science Center (NEFSC) authors will be published in this series upon approval by the NEFSC's Deputy Science & Research Director. Manuscripts by non-NEFSC authors may be published in this series if: 1) the manuscript serves the NEFSC's mission; 2) the manuscript meets the Deputy Science & Research Director's approval; and 3) the author arranges for the printing and binding funds to be transferred to the NEFSC's Research Communications Unit account from another federal account. For all manuscripts submitted by non-NEFSC authors and published in this series, the NEFSC will disavow all responsibility for the manuscripts' contents; authors must accept such responsibility.

The ethics of scientific research and scientific publishing are a serious matter. All manuscripts submitted to this series are expected to adhere -- at a minimum -- to the ethical guidelines contained in Chapter 1 ("Ethical Conduct in Authorship and Publication") of the *CBE Style Manual*, fifth edition (Chicago, IL: Council of Biology Editors). Copies of the manual are available at virtually all scientific libraries.

Manuscript Preparation

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."

Style: All NEFSC publication and report series are obligated to conform to the style contained in the most recent edition of the *United States Government Printing Office Style Manual*. That style manual is silent on many aspects of scientific manuscripts. NEFSC publication and report series rely more on the *CBE Style Manual,* fifth edition.

For in-text citations, use the name-date system. A special effort should be made to ensure that the list of cited works contains all necessary bibliographic information. For abbreviating serial titles in such lists, use the most recent edition of the *Serial Sources for the BIOSIS Previews Database* (Philadelphia, PA: Biosciences Information Service). Personal communications must include date of contact and full name and mailing address of source.

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).

Typing text, tables, and figure captions: Text, including tables and figure captions, must be converted to, or able to be coverted to, WordPerfect. In general, keep text simple (*e.g.*, don't switch fonts, don't use hard returns within paragraphs, don't indent except to begin paragraphs). Especially, don't use WordPerfect graphics for embedding tables and figures in text. If the automatic footnoting function is used, also save a list of footnotes as a separate WordPerfect file. When the final draft is ready for review, save the text, tables, figure captions, footnotes, and front matter as separate document files.

Tables should be prepared using all tabs or all spaces between columnar data, but not a combination of the two. Figures must be original (even if oversized) and on paper; they cannot be photocopies (*e.g.,* Xerox) unless that is all that is available, nor be on disk. 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 magnetic copy on a disk, 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
Northeast Fisheries Science Center
National Marine Fisheries Service
166 Water Street
Woods Hole, MA 02543-1026 USA

NORTHEAST FISHERIES SCIENCE CENTER
Dr. Michael P. Sissenwine, Science & Research Director
CAPT John T. Moakley, Operations, Management & Information Services Staff Chief
Teri L. Frady, Research Communications Unit Chief
Jon A. Gibson, Biological Sciences Editor & Laura S. Garner, Editorial Assistant

Research Communications Unit
Northeast Fisheries Science Center
National Marine Fisheries Service, NOAA
166 Water St.
Woods Hole, MA 02543-1026

STANDARD
MAIL A

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 "planning, developing, and managing multidisciplinary programs of basic and applied research to: 1) better understand the living marine resources (including marine mammals) of the Northwest Atlantic, and the environmental quality essential for their existence and continued productivity; and 2) describe and provide to management, industry, and the public, options for the utilization and conservation of living marine resources and maintenance of environmental quality which are consistent with national and regional goals and needs, and with international commitments." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific journals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Those media are in three categories:

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

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

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

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