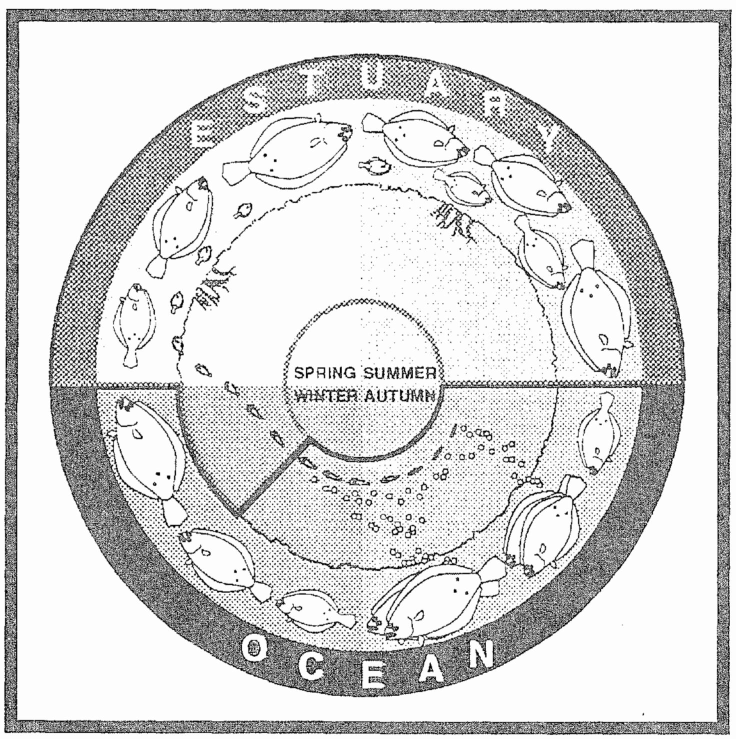
Science for Solutions

NOAA COASTAL OCEAN PROGRAM
Decision Analysis Series No. 1

SYNTHESIS OF SUMMER FLOUNDER HABITAT PARAMETERS

Kenneth W. Able
Susan C. Kaiser

May 1994



U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Coastal Ocean Office

The Decision Analysis Series has been established by NOAA's Coastal Ocean Program (COP) to present documents for coastal resource decision makers which contain analytical treatments of major issues or topics. The issues, topics, and principal investigators have been selected through an extensive peer review process. To learn more about the COP or the Decision Analysis Series, please write:

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Cover illustration: Life History of Summer Flounder
(larger view explained in detail on inside back cover)

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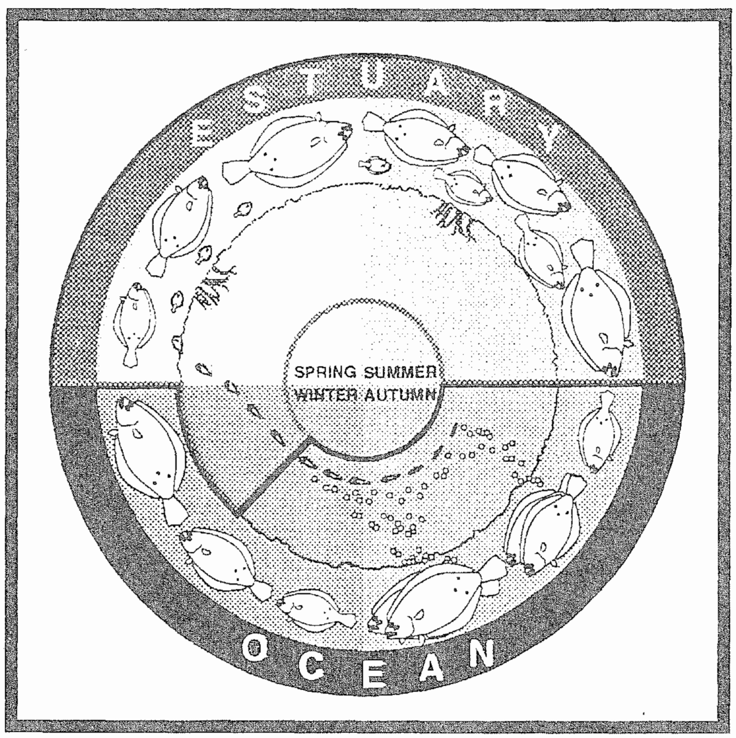

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Note to Readers

The NOAA Coastal Ocean Program (COP) provides a focal point through which the agency, together with other organizations with responsibilities for the coastal environment and its resources, can make significant strides toward finding solutions to critical problems. By working together toward these solutions, we can ensure the sustainability of these coastal resources and allow for compatible economic development that will enhance the well-being of the Nation now and in future generations. The goals of the program parallel those of the NOAA Strategic Plan for 1995-2005.

A specific objective of COP is to provide the highest quality scientific information to coastal managers in time for critical decision making and in a format useful for these decisions. To help achieve this, COP inaugurated a program of developing documents that would synthesize information on issues that were of high priority to coastal managers. To develop such documents, a three-step process was used: 1) to compile a list of critical topics in the coastal ocean through a survey of coastal resource managers and to prioritze and select those suitable for the document series through the use of a panel of multidisciplinary technical experts; 2) to solicit proposals to do research on these topics and select principal investigators through a rigorous peer-review process; and 3) to develop peer-reviewed documents based on the winning proposals.

Seven topics and associated principal investigators were selected in the initial round. This volume, *Synthesis of Summer Flounder Habitat Parameters* by Kenneth W. Able and Susan C. Kaiser of Rutgers University, is the first document in this Decision Analysis Series to be published. Other volumes will be published over the next two years on the following topics: seagrass restoration technology, salt marsh restoration, coastal watershed restoration, restoring streams and anadromous fish habitat affected by logging, eutrophication and phytoplankton blooms, and management of cumulative coastal environmental impacts.

As with all of its products, COP is very interested in ascertaining the utility of the Decision Analysis Series particularly in regard to its application to the management decision process. Therefore, we encourage you to write, fax, call, or Internet us with your comments. Please be assured that we will appreciate these comments, either positive or negative, and that they will help us direct our future efforts. Our address and telephone and fax numbers are on the inside front cover. My Internet address is DSCAVIA@HQ.NOAA.GOV.

Donald Scavia
Director
NOAA Coastal Ocean Program

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Executive Summary

The summer flounder, Paralichthys dentatus, is overexploited and is currently at very low levels of abundance. This is reflected in the compressed age structure of the population and the low catches in both commercial and recreational fisheries. Declining habitat quantity and quality may be contributing to these declines, however we lack a thorough understanding of the role of habitats in the population dynamics of this species. Stock structure is unresolved and current interpretations, depending on the technique and study area, suggest that there may be two or three spawning populations. If so, these stocks may have differing habitat requirements. In response to this lack of knowledge, this document summarizes and synthesizes the available information on summer flounder habitat in all life history stages (eggs, larvae, juveniles and adults) and identifies areas where further research is needed.

Several levels of investigation were conducted in order to produce this document. First, an extensive search for summer flounder habitat information was made, which included both the primary and gray literature as well as unanalyzed data. Second, state and federal fisheries biologists and resource managers in all states within the primary range of summer flounder (Massachusetts to Florida) were interviewed along with a number of fish ecologists and summer flounder experts from the academic and private sectors. Finally, information from all sources was analyzed and synthesized to form a coherent overview.

This document first presents an overview of the economic importance and current status of summer flounder (Chapter 1). It then summarizes our present state of knowledge of summer flounder distribution, life history patterns and stock identification (Chapter 2). This is followed by a synopsis of habitat requirements during each life history stage. For convenience, this is presented by general habitat as offshore eggs (Chapter 3), offshore larvae (Chapter 4), estuarine larvae (Chapter 5), estuarine juveniles (Chapter 6), offshore juveniles (Chapter 7) and estuarine and offshore adults (Chapter 8). In several instances, previously undigested data sets are analyzed to provide more detailed information, especially for estuarine juveniles. The information is then discussed in terms of its relevance to resource managers (Chapter 9).

A comprehensive bibliography on all aspects of the distribution, biology, and ecology of summer flounder (Appendix A) is provided with both an author index and a subject index for easy reference. This bibliography also serves as the primary reference for literature cited in the text. Finally, a list of researchers who are considered experts on summer flounder (Appendix B) and a list of potential user groups of this document (Appendix C) are included.

Summer flounder occur in continental shelf and estuarine waters of the western north Atlantic from Nova Scotia (Canada) to Florida (United States). The center of abundance lies in the Middle Atlantic Bight, and due to the extensive fishery and research emphasis, our understanding of life history patterns is most complete for this portion of the range. In the Middle Atlantic Bight, temporal and spatial distribution in estuarine and offshore habitats is determined largely by temperature and salinity. Generally, adult summer flounder and older juveniles migrate seasonally in response to temperature changes, spending winters on the middle and outer continental shelf and summers on the inner continental shelf and in estuaries. Adults spawn while moving offshore in autumn and early winter. Eggs rise to near surface waters and the newly hatched larvae are planktonic and symmetrical in shape. While over the continental shelf, larvae begin transformation, the process by which the right eye migrates to the left side of the head. This is accompanied by other morphological and physiological changes as larvae prepare for settlement. During winter to early spring, transforming larvae move into estuaries where eye migration is completed and settlement to the bottom marks the beginning of the juvenile stage. In spring, many fishes that have overwintered on the continental shelf join these juveniles in estuaries. During their summer residencies, juveniles and adults are most abundant in higher salinity waters of estuaries. As winter approaches, most juveniles move offshore with adults, however some may overwinter in the deep waters of larger estuarine systems. In the South Atlantic Bight, summer flounder life history patterns have not been as thoroughly studied. In general, adults spawn on the continental shelf in autumn and winter, and transforming larvae enter estuarine nursery habitats in the spring where they settle. However, adults may predominantly use inner continental shelf waters as summer forage grounds rather than estuaries.

This synthesis indicates that temperature and dissolved oxygen are the habitat parameters of primary importance to summer flounder. Low winter temperatures are likely a source of natural mortality to transforming larvae as they enter estuaries, especially in the northern portion of their range. Low spring temperatures decrease growth rates for transforming larvae and early juveniles, and by delaying or slowing growth, may make these individuals more vulnerable to predation for longer periods of time, thus reducing survival. The presumed preference for higher salinity explains the greater abundance in the lower portions of estuaries. Low dissolved oxygen on the continental shelf and in estuaries can affect distribution and survivorship. Episodes of hypoxia or anoxia can cause habitat use patterns to change as individuals attempt to migrate away from feeding areas. These movements may concentrate individuals in a small area, making them more susceptible to fishing mortality. If migration is not possible, natural mortality can result, which together with fishing losses can have a significant impact on local populations.

In summary, despite the economic importance of summer flounder in fisheries along the east coast of the U.S., we still lack a clear understanding of habitat requirements and this is especially true for the eggs and larvae. We know somewhat more for the juveniles and adults, although the depth of understanding varies from region to region. Due to the highly migratory nature of this species, summer flounder exploit a variety of habitats from shallow estuaries to the deep edge of the continental shelf. However, the habitats that are perhaps the most critical, estuarine nurseries, are the habitats that are most severely impacted by human activity.

As a result, we recommend that estuarine juveniles should be the focus of researchers and resource managers because: 1) juvenile growth and survival in estuarine nurseries may be especially critical to subsequent year–class strength; and 2) estuarine habitats are especially vulnerable to alteration and negative impacts that could influence habitat quantity and quality. Habitat–specific data is generally limited. Of those habitats examined, high–salinity subtidal salt marsh creeks and shallow portions of bays appear to be most important as nurseries, especially for the early juvenile stages. We therefore suggest that resource managers pay particular attention to these habitats and their maintenance in order to improve the status of summer flounder populations.

Chapter 1
Introduction

BACKGROUND AND OVERVIEW

The summer flounder, (Paralichthys dentatus), an important species in commercial and recreational fisheries on the east coast of the United States, is currently overexploited (Mid–Atlantic Fishery Management Council 1990, 1991a,b). Since implementation of the summer flounder management plan (Mid–Atlantic Fishery Management Council 1990, 1991a,b), the status has shown some improvement with about a 70% and 50% increase in commercial and recreational landings, respectively, between 1990 and 1992. However, the total reported commercial landings in 1992 (7,300 metric tons) were only about 40% of the total landings in 1979 when this fishery peaked (17,945 metric tons) and 1992 recreational landings were only about 25% of the 1983 peak for this fishery (Terceiro 1993). In addition, the most recent National Marine Fisheries Service/Northeast Fisheries Science Center fishery–independent groundfish survey indices for spring are about one–fifth of those for the mid–to–late–1970s (Mid–Atlantic Fishery Management Council 1990, 1991a,b). Along with reduced abundance, the age structure of the population is severely compressed with relatively few individuals older than three years of age (Terceiro 1993). As a result, the spawning individuals are younger, presumably less fecund than older, larger individuals, and have fewer seasons to reproduce before being harvested.

Despite the importance of summer flounder, there are significant gaps in our knowledge of the population dynamics of this species. For instance, several years of exceptionally poor recruitment throughout much of the range (Mid–Atlantic Fishery Management Council 1990, 1991a,b) suggest other factors besides fishing pressure affect summer flounder abundance, but these are poorly understood. Two major reasons why the patterns of recruitment are inadequately understood is that our knowledge of young–of–the–year habitats is poor, which may result in extremely variable young–of–the–year assessments. In addition, recent habitat–oriented studies have suggested that low temperatures encountered by juveniles in estuarine nurseries during the winter may impact both survival and subsequent year–class strength (Malloy and Targett 1991; Szedlmayer et al. 1992). These kinds of results need to be summarized so that resource managers can effectively protect or enhance important nursery habitats. Thus, the purpose of this document is: 1) to synthesize the available literature (both primary and gray) on habitat parameters and habitat use patterns of all life history stages (egg, larval, juvenile, adult) of summer flounder throughout its range; 2) to incorporate unpublished data from federal, state and academic institutions into the synthesis; and 3) to provide a complete bibliography for all aspects of summer flounder biology.

SCOPE

For purposes of this synthesis, we define habitat as where an animal lives (Odum 1971[1]). We interpret this broadly to include general distribution of all life history stages, as well as movements and selected aspects of the biology, such as those that appear related to habitat use or impacts on habitats (anthropogenic effects). We have cautiously interpreted prior generalizations regarding summer flounder habitat, and are particularly careful not to extrapolate from general statements concerning other closely related flounders (Paralichthys spp.). Because pertinent life history information is frequently lacking, we include a brief summary of our current understanding of the salient aspects. Since different stocks or populations may have different habitat requirements or patterns of habitat use, we also briefly summarize what is known about distribution and stock identification. We recognize that we still lack important information about the habitat of summer flounder during all life history stages.

[1] Odum, E.P. 1971. Fundamentals of Ecology. W.B. Saunders Co., Philadelphia, PA

Chapter 2

Distribution and Life History Patterns

GEOGRAPHICAL DISTRIBUTION

Summer flounder occur in continental shelf and estuarine waters of the western North Atlantic (Fig. 2.1) from Nova Scotia, Canada (Bigelow and Schroeder 1953; Scott and Scott 1988), to Florida, United States (Ginsburg 1952; Gutherz 1967; Gilbert 1986; Grimes et al. 1989). They are most abundant from Cape Cod, Massachusetts, to North Carolina (Grosslein and Azarovitz 1982). In the north, commercial and recreational catches drop in the vicinity of Rhode Island, and occurrence north of Cape Cod Bay is described as extremely rare (Bigelow and Schroeder 1953). Distribution in the southernmost part of the range is not clear partly because summer flounder are not identified to species in the commercial fisheries, which treat them largely as by-catch. Gilmore et al. (1981) list them as abundant in the Indian River Lagoon on the east coast of Florida, and Gilbert (1986) considers them to extend as far south as Sebastian Inlet, Florida.

GENERAL LIFE HISTORY

Summer flounder reproduce in the fall and perhaps into the winter. Detailed observations of the timing and location of spawning are available only for Georges Bank and the Middle Atlantic Bight (Morse 1981; Able et al. 1990; Fig. 2.1). There are no records of eggs from estuaries, but based on collections of planktonic eggs during the period from 1975 to 1985, spawning occurs during the seasonal offshore migration and is fairly equally distributed over the entire continental shelf (Fig. 2.2). Peak spawning occurs in October and November throughout the Middle Atlantic Bight and Georges Bank, although December collections are lacking from some areas (Fig. 2.3). Spawning occurs over the continental shelf in the South Atlantic Bight as well, however data are largely lacking in the existing literature (Powles and Stender 1976).

The planktonic larvae are reported over the Middle Atlantic Bight shelf but are not very abundant over Georges Bank (Fig. 2.4, 2.5). The earliest spawning and subsequent larval development occurs off eastern Long Island and on Georges Bank as early as September. By October, the larvae are primarily found on the inner continental shelf

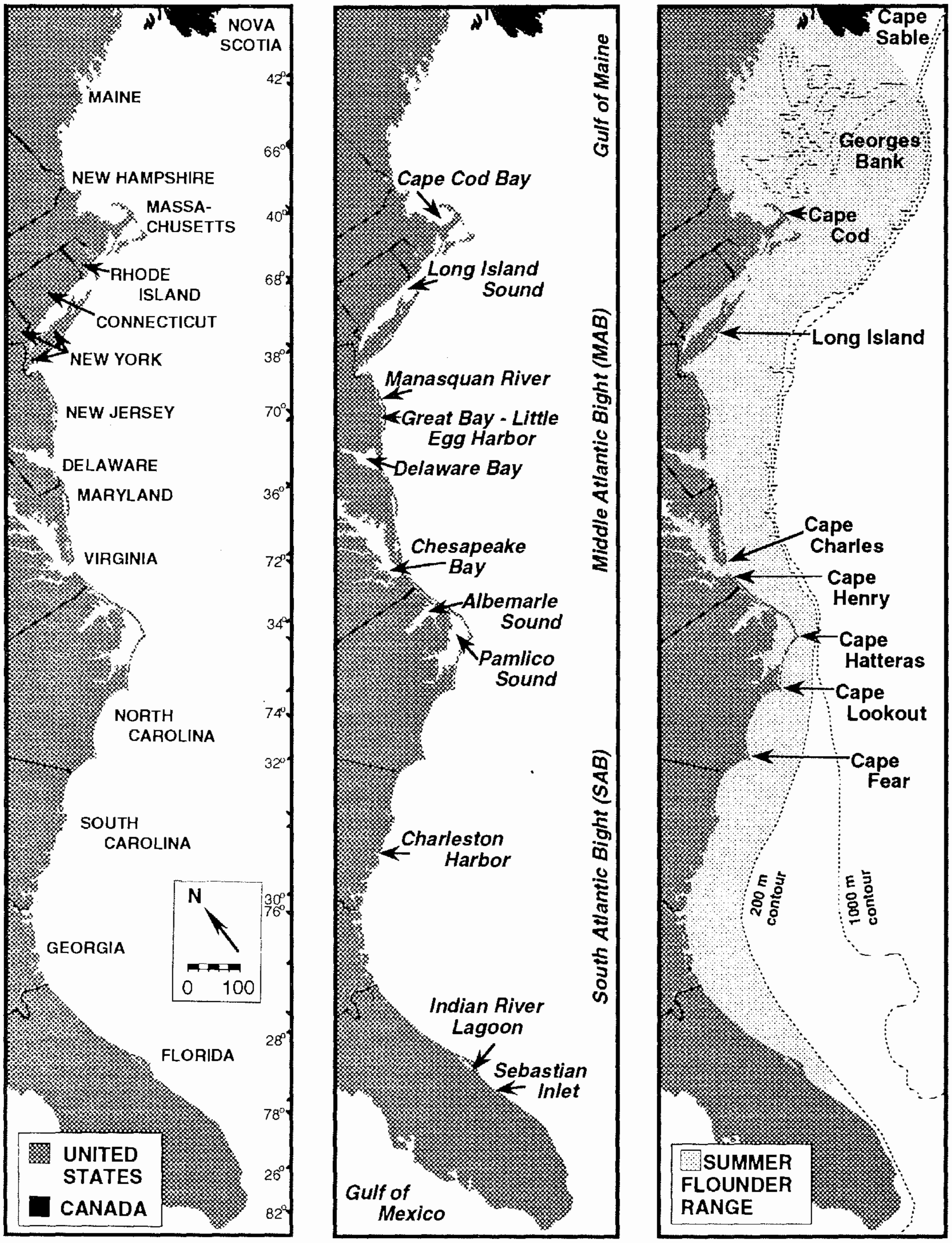


Figure 2.1. East coast of the United States and Canada with features mentioned in the text.

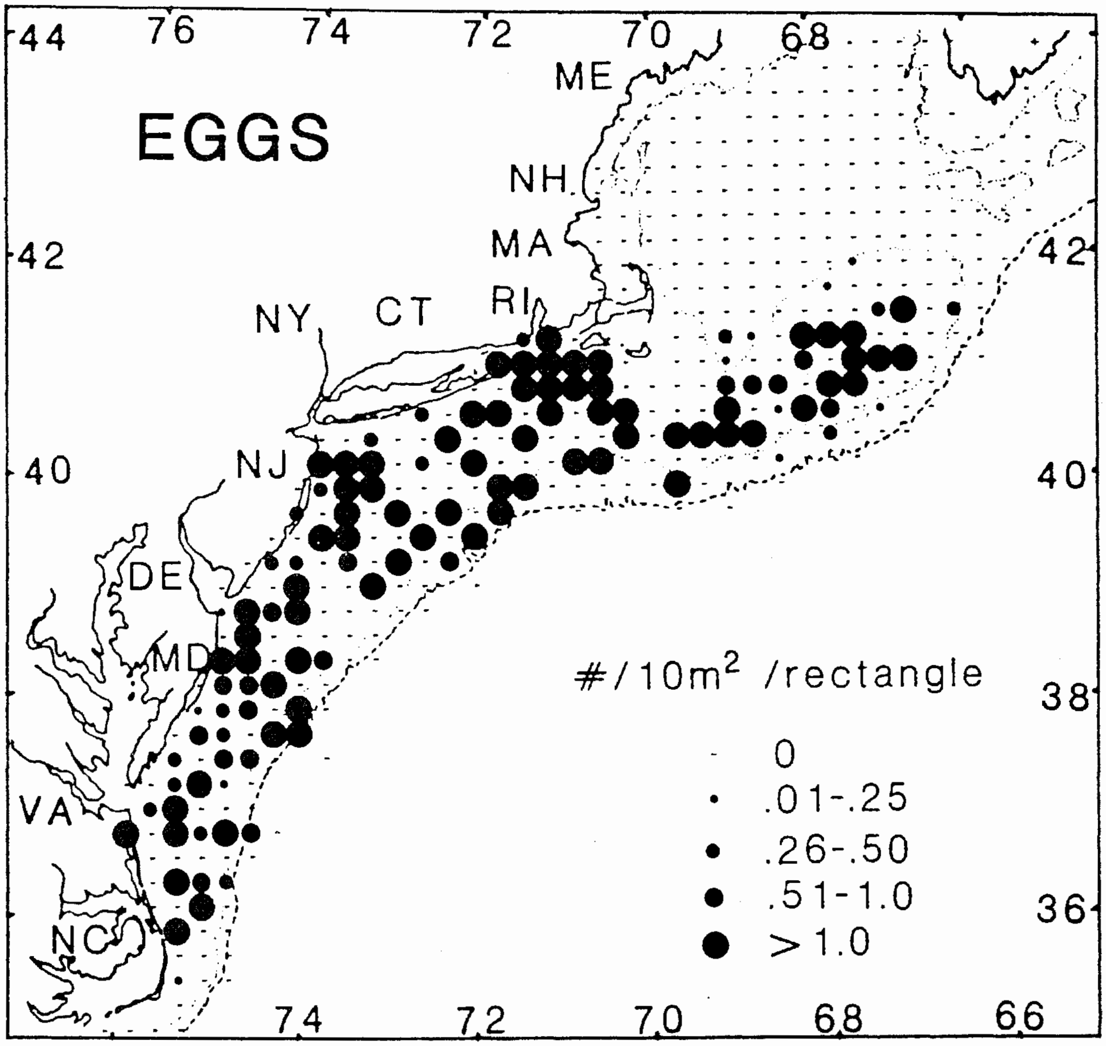


Figure 2.2. Cumulative distribution and mean abundance of summer flounder eggs from National Marine Fisheries Service (NMFS), Marine Resources Monitoring, Assessment and Prediction (MARMAP) offshore surveys during 1977-1984 (Sherman 1980, 1986). Monthly to bimonthly plankton samples were collected from Cape Sable to Cape Hatteras (Fig. 2.1) using 61 cm bongo frames (Sibunka and Silverman 1984; Morse et al. 1987). The 200 m and 1000 m contours are shown. (Figure from Able et al. 1990).

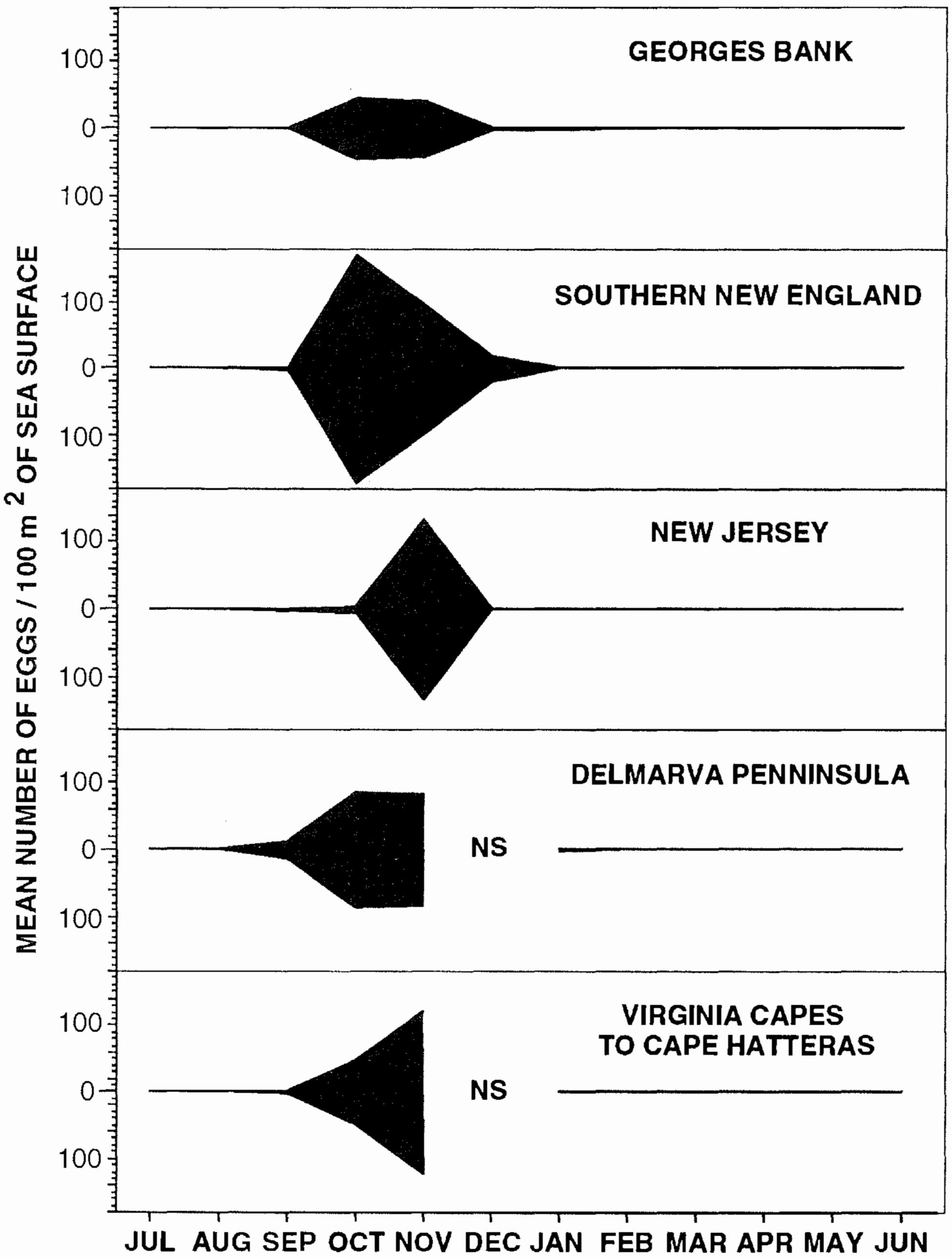


Figure 2.3. Monthly abundance of summer flounder eggs by region from National Marine Fisheries Service (NMFS), Marine Resources Monitoring, Assessment and Prediction (MARMAP), offshore surveys during 1979-81, 1984, and 1985. Monthly to bimonthly plankton samples were collected from Cape Sable to Cape Hatteras (Fig. 2.1) using 61 cm bongo frames (Sherman 1980, 1986; Sibunka and Silverman 1984; Morse et al. 1987). Southern New England is the offshore region between southeastern Cape Cod and northern coastal New Jersey. Delmarva is the peninsula between Delaware and Chesapeake bays that is part of Delaware, Maryland and Virginia. NS = no samples.

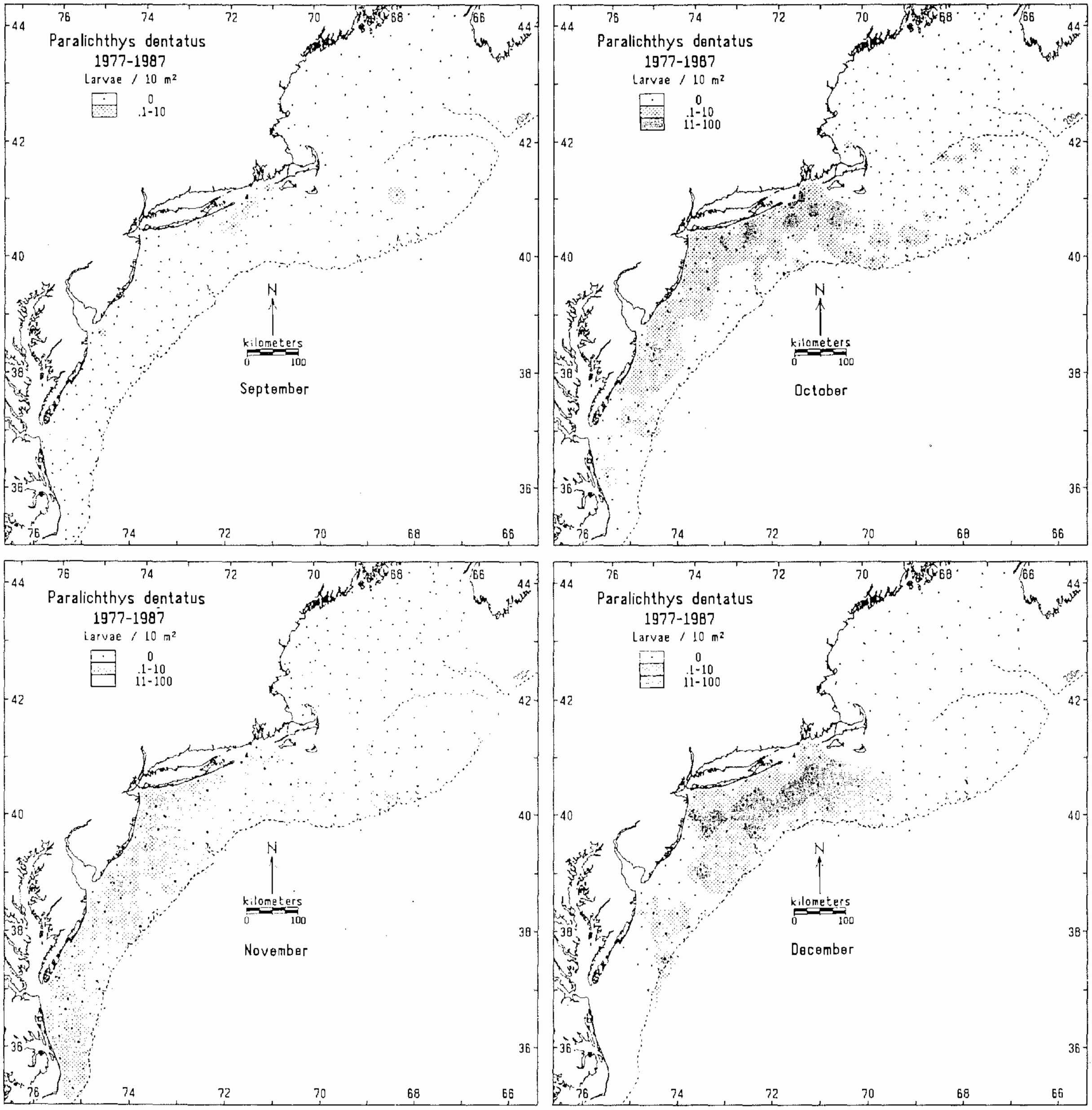


Figure 2.4. Monthly distribution and mean abundance of summer flounder larvae from National Marine Fisheries Service (NMFS), Marine Resources Monitoring, Assessment and Prediction (MARMAP) offshore surveys during 1977-1987. Monthly to bimonthly plankton samples were collected from Cape Sable to Cape Hatteras (Fig. 2.1) using 61 cm bongo frames (Sibunka and Silverman 1984; Morse et al. 1987). The 200 m contour is shown. (Figure by M.P. Fahay, National Marine Fisheries Service, Sandy Hook, New Jersey).

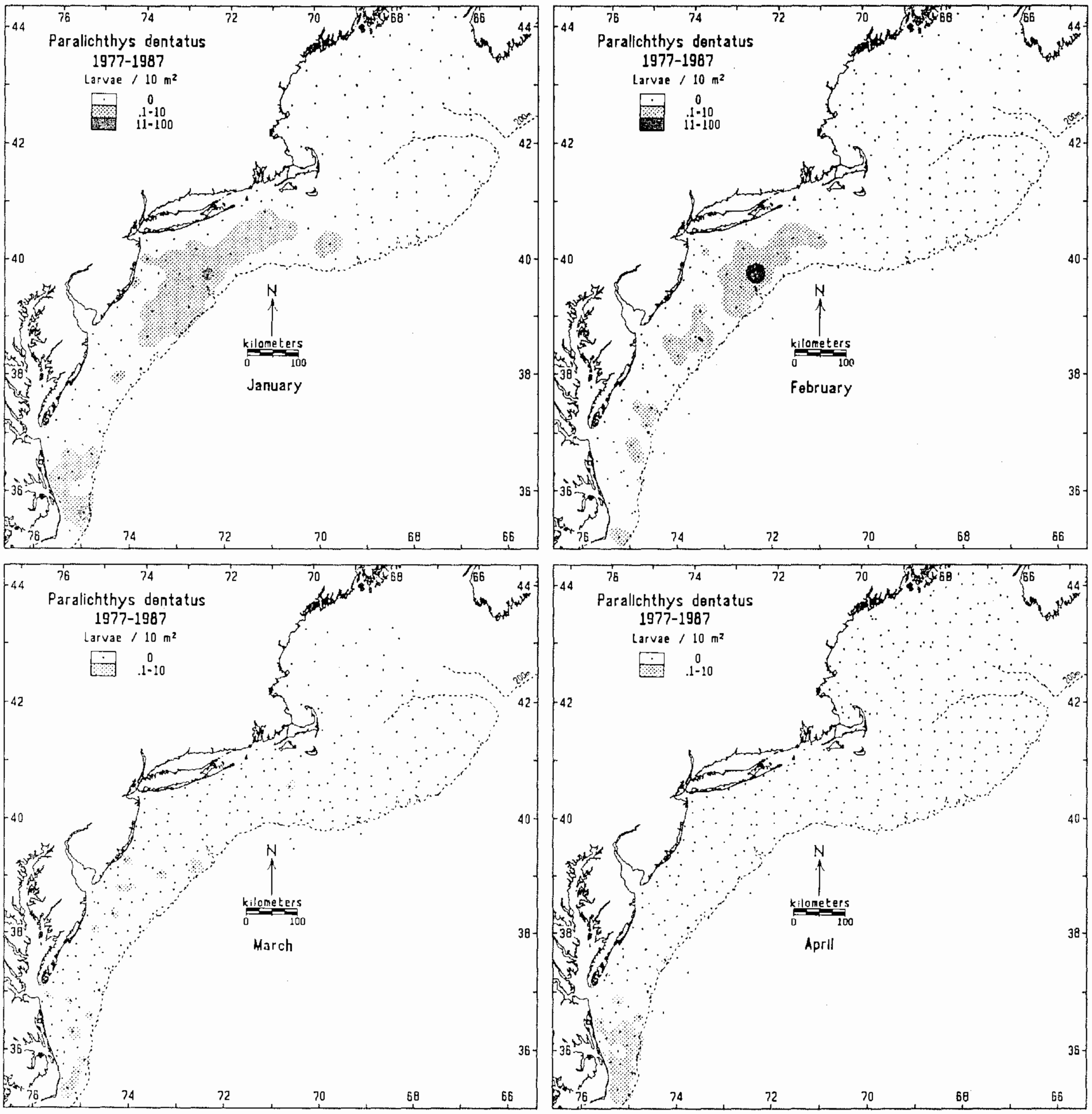


Figure 2.4 (continued).

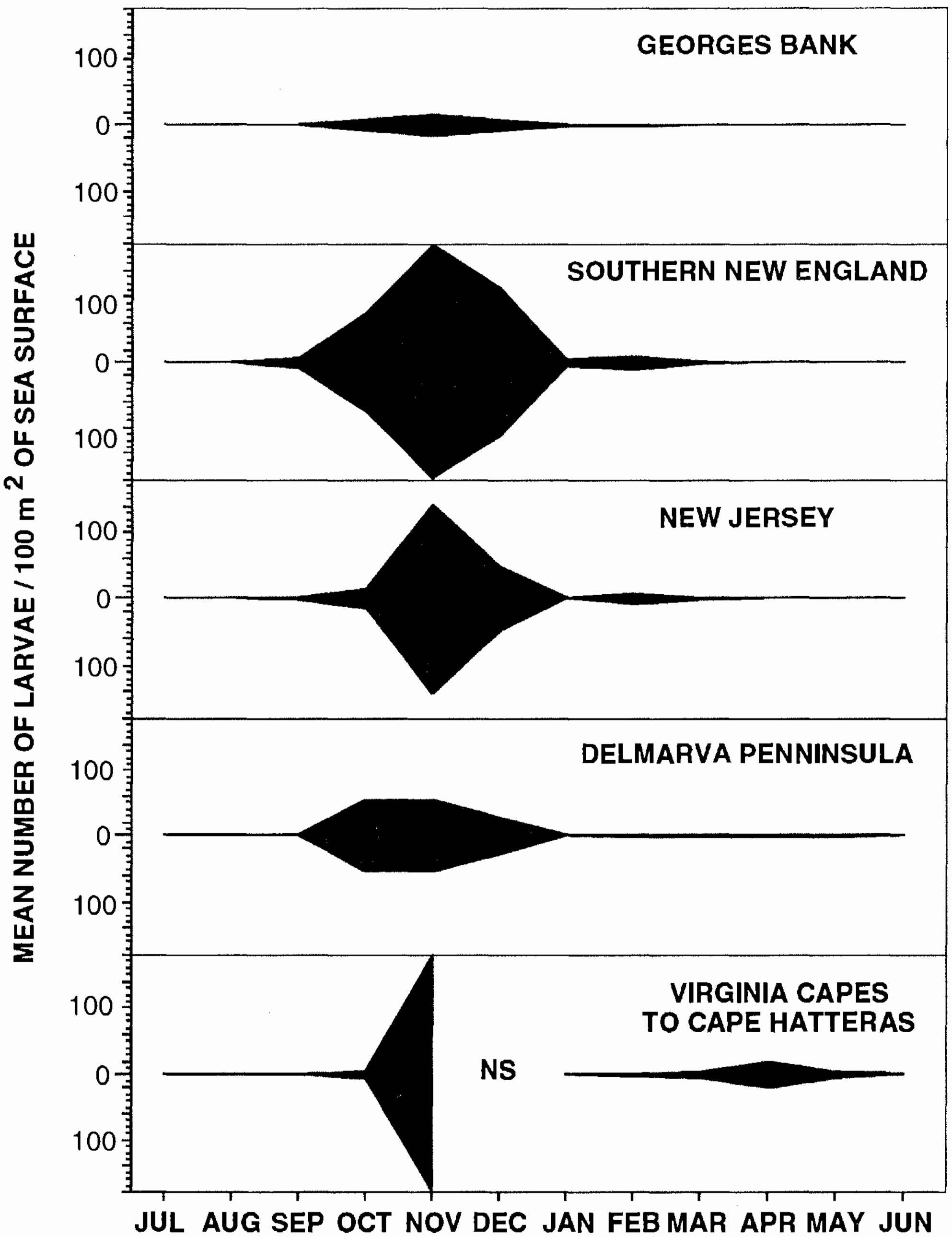


Figure 2.5. Monthly abundance of summer flounder larvae by region from National Marine Fisheries Service (NMFS), Marine Resources Monitoring, Assessment and Prediction (MARMAP), offshore surveys during 1979-81, 1984, and 1985. Monthly to bimonthly plankton samples were collected from Cape Sable to Cape Hatteras (Fig. 2.1) using 61 cm bongo frames (Sherman 1980, 1986; Sibunka and Silverman 1984; Morse et al. 1987). Southern New England is the offshore region between southeastern Cape Cod and northern coastal New Jersey. Delmarva is the peninsula between Delaware and Chesapeake bays that is part of Delaware, Maryland and Virginia. NS = no samples.

between Chesapeake Bay and Georges Bank. During November and December, when the larvae are most abundant in every region, they are fairly evenly distributed over both the inner and outer portions of the shelf. By January and February, the remaining larvae are primarily found on the middle and outer portions of the shelf. In April, the remaining larvae are concentrated off North Carolina.

As the larvae undergo eye migration during transformation (Fig. 2.6), they enter estuarine nursery areas (Burke et al. 1991; Keefe and Able 1993). Based on data from the Great Bay–Little Egg Harbor estuarine system in southern New Jersey (Fig. 2.7a), this occurs just as the right eye is migrating across the top of the head (transformation stage G through H+) at sizes of 8 – 16 mm SL [standard length] (Fig. 2.8). They then leave the water column and settle to the bottom where they begin to bury in the substrate and complete development to the juvenile stage (Keefe and Able 1994). The morphological transition from larva to juvenile lasts beyond initial settlement, making the distinction between late larva and early juvenile somewhat arbitrary. We suggest that summer flounder be considered juveniles when they have reach the I stage (Fig. 2.6), when the pectoral fin resembles that of adults, and when the scales are formed. Further, we suggest that those individuals that have not completed eye migration, pectoral fin and scale formation be referred to as transforming larvae, as Burke (1991) has done. If larvae enter the estuary when water temperatures are low, mortality can occur (Szedlmayer et al. 1992) or transformation and growth can be delayed for weeks (Keefe and Able 1994) until warmer temperatures allow continued growth and development. The ability to delay transformation may help explain the seeming disparity between a peak of spawning in October and November and the occurrence of transforming larvae in estuaries over a protracted period from October through April.

Recently settled juveniles can be found in a variety of habitats, but by summer many are found in salt marsh creeks (Szedlmayer et al. 1992; Wenner et al. 1990; Burke et al. 1991; Rountree and Able 1992a,b; Rountree and Able 1993). Growth during the summer is exceptionally fast, and at least in some estuaries can average 1.9 mm per day (Szedlmayer et al. 1992). By September or October, the individuals that were spawned the previous fall have reached 230 to 300 mm TL [total length] (Able et al. 1990; Szedlmayer et al. 1992; Fig. 2.9). These fast growth rates appear to be common to most estuarine nurseries (Almeida et al. 1992). At this time and size, many of these juveniles begin to move out of the estuaries and onto the continental shelf (Able et al. 1990; Szedlmayer and Able 1993). The adults follow a similar pattern (Fig. 2.10, 2.11), migrating in the fall to spawn over the continental shelf. They overwinter near the edge of the shelf and then migrate back into inner continental shelf and estuarine areas the following spring.

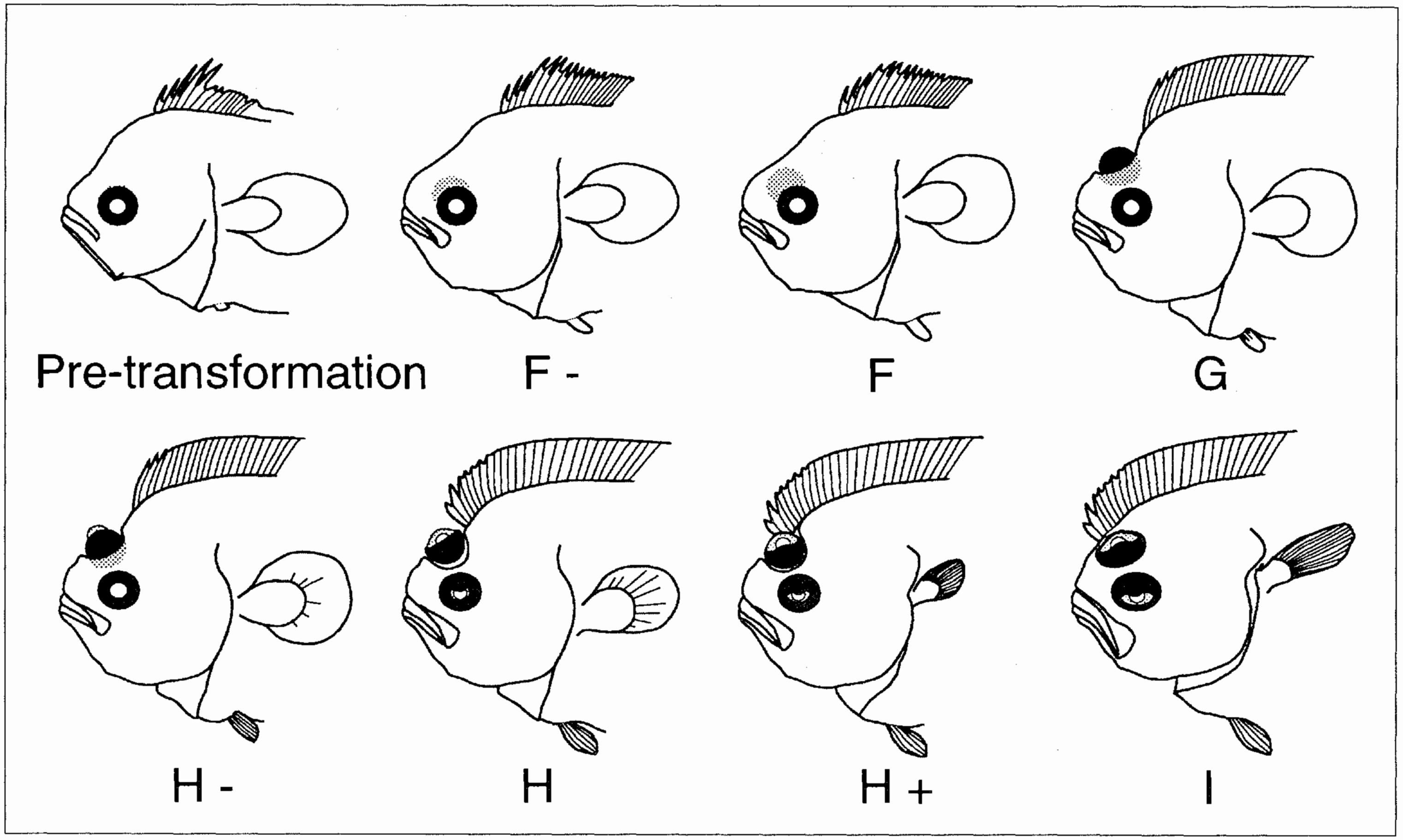
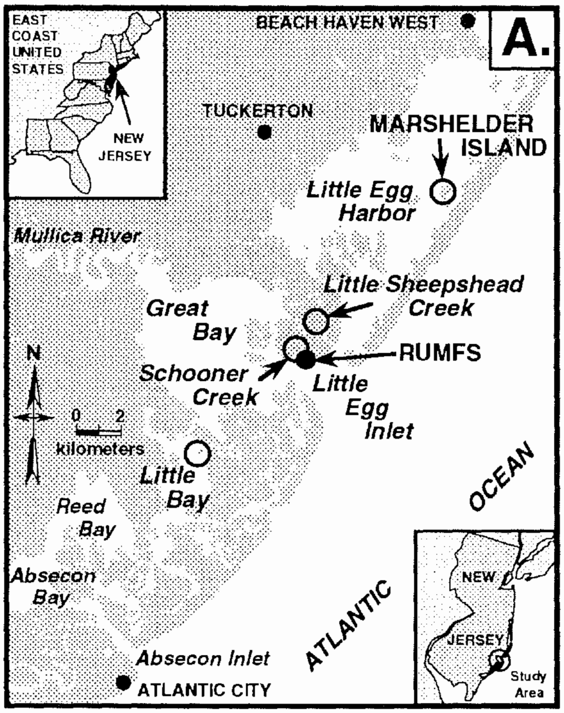
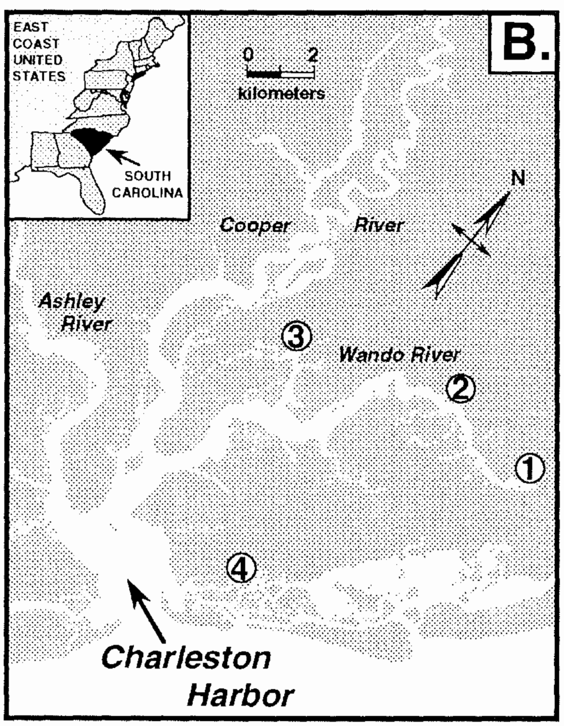
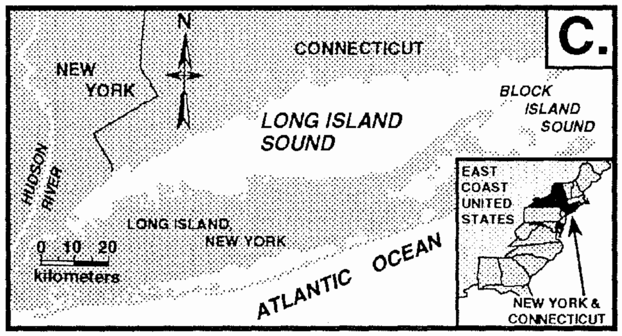


Figure 2.6. Classification of transformation stages for summer flounder based on degree of eye migration (adapted from Keefe and Able 1993). The right and left eyes are bilateral and symmetrical in pre-transformation individuals. At the first stage of transformation, F -, the eyes are bilateral but asymmetrical with the right eye just dorsal to the left eye. By Stage G, the right eye is visible from the left side of the fish. Stage H - differs from G in that the cornea of the eye is visible from the left side of the fish. At Stage H, the right eye has reached the dorsal midline. By Stage H +, the right eye has reached the left side of the head but has not yet reached its final resting place. At Stage I , the eye is set in the socket and the dorsal canal has closed.







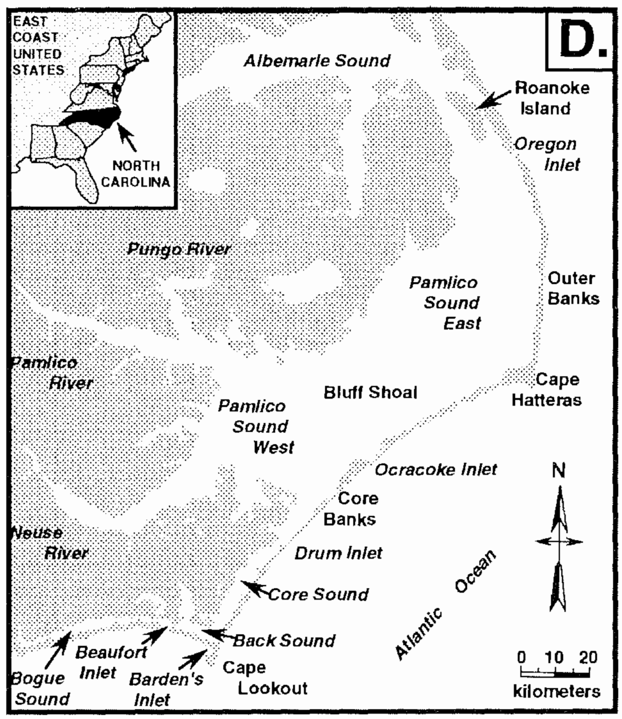


Figure 2.7. A. Great Bay - Little Egg Harbor estuarine system in southern New Jersey with the location of Rutgers University Marine Field Station (RUMFS) indicated. Study sites referred to in the text are indicated by a circle: B. Charleston Harbor estuarine system in South Carolina. Study creeks mentioned in the text are indicated by circled numbers and are as follows; 1) Pita Creek, 2) Lachicotte Creek, 3) Beresford Creek, and 4) Inlet Creek: C. Long Island Sound system bordered by New York and Connecticut: D. Pamlico-Albemarle sounds estuarine system in North Carolina.

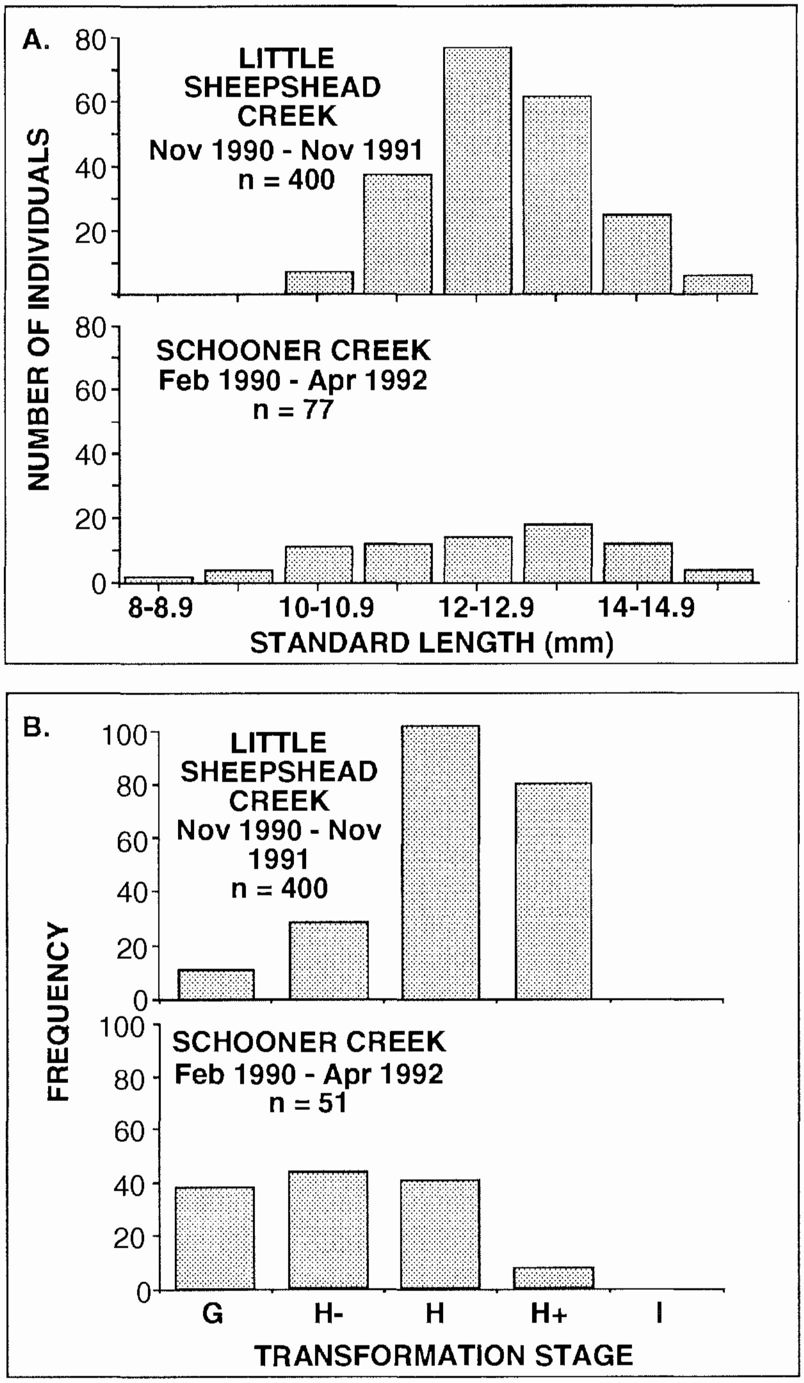


Figure 2.8. A. Length-frequency, and, B. stage-frequency distributions for transforming summer flounder larvae collected during Rutgers University Marine Field Station ichthyoplankton surveys in two Great Bay-Little Egg Harbor estuarine system marsh creeks (Fig. 2.7A). Sampling was conducted with 1.0 m and 0.5 m plankton nets with 1 mm mesh. See Fig. 2.6 for transformation stage descriptions.

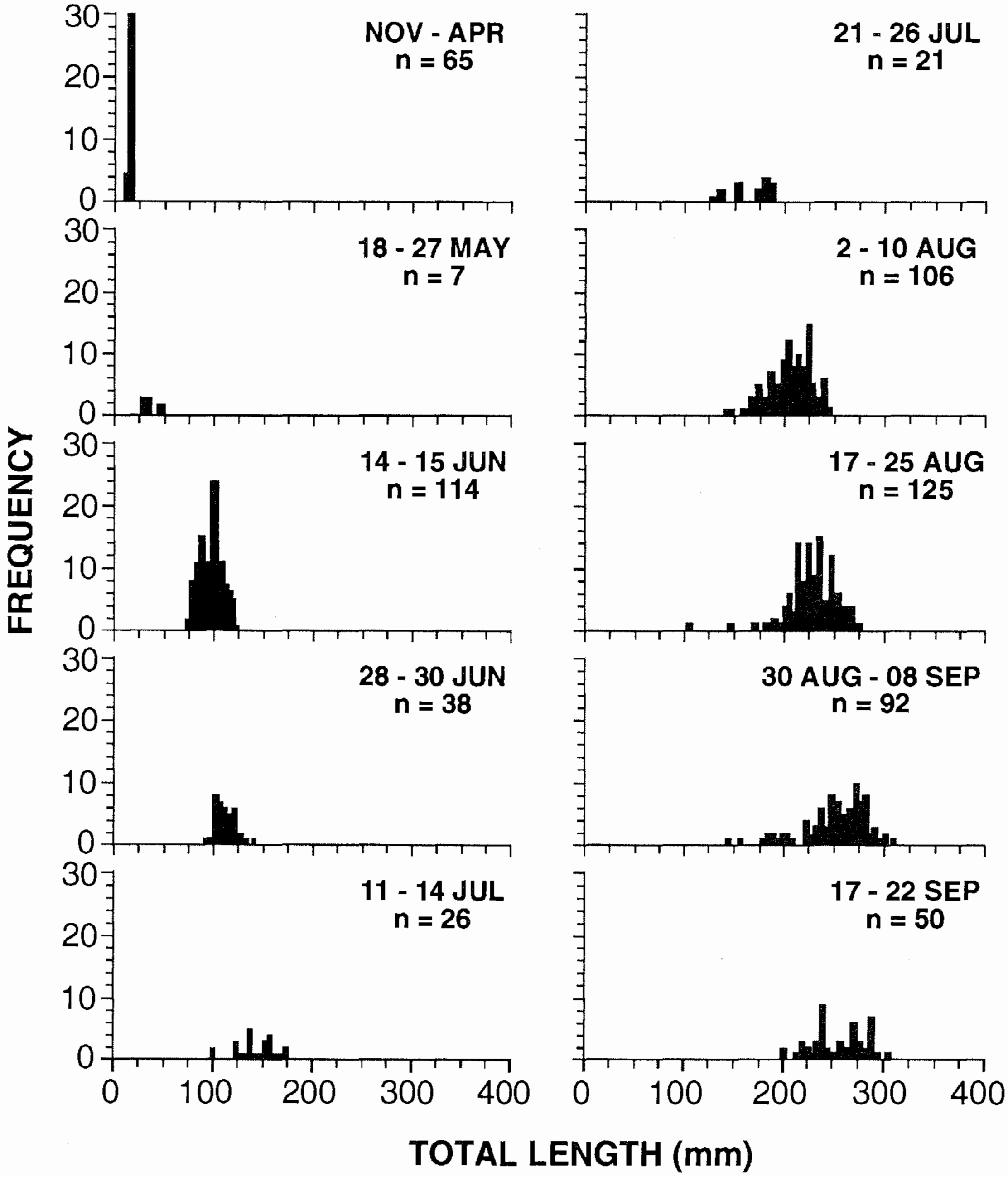


Figure 2.9. Length-frequency distributions for young-of-the-year summer flounder collected during 1988-1989 sampling in the Great Bay-Little Egg Harbor estuarine system (Fig. 2.7A; adapted from Szedlmayer et al. 1992).

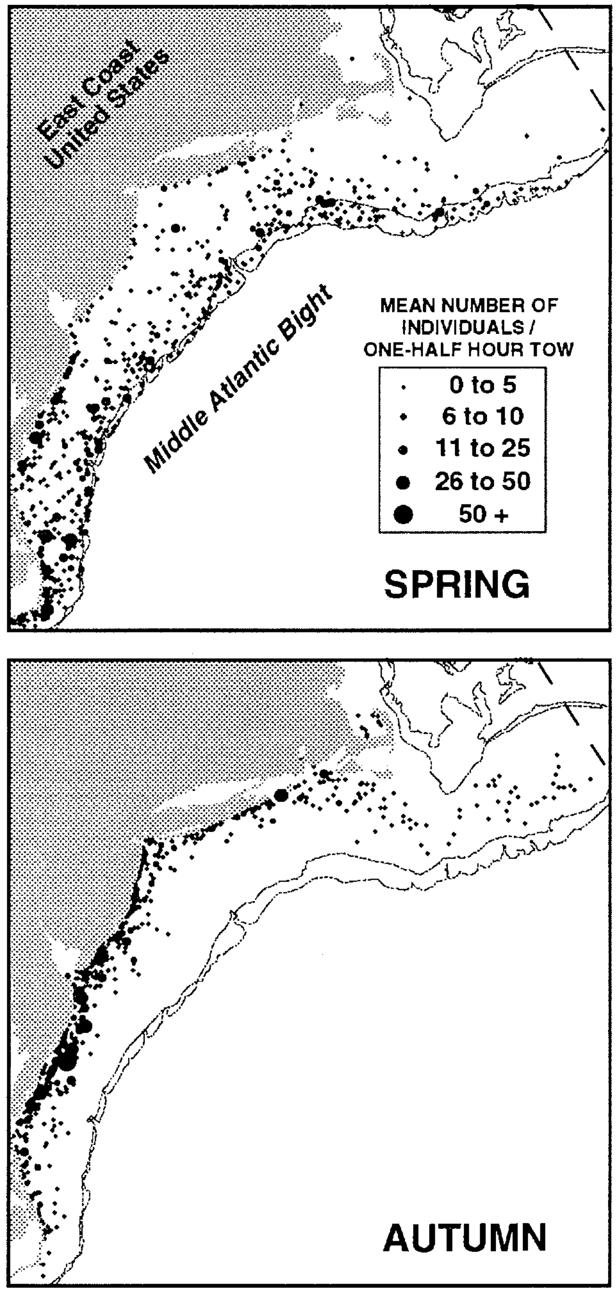


Fig. 2.10. Seasonal distribution and abundance of summer flounder from National Marine Fisheries Service (NMFS), Northeast Fisheries Science Center (NEFSC) groundfish surveys for spring (1982-1990) and autumn (1981-1990). Sampling was conducted by stratified random design in the Gulf of Maine to Nova Scotia, on Georges Bank, and in the Middle Atlantic Bight (Fig. 2.1) using 0.5 hour tows of a #36 Yankee trawl with a 12.7 mm mesh liner in the codend . The 200 m and 1000 m contours are shown. (Adapted from maps provided by T. Azarovitz and B. O'Gorman, National Marine Fisheries Service, Woods Hole Laboratory, Massachusetts).

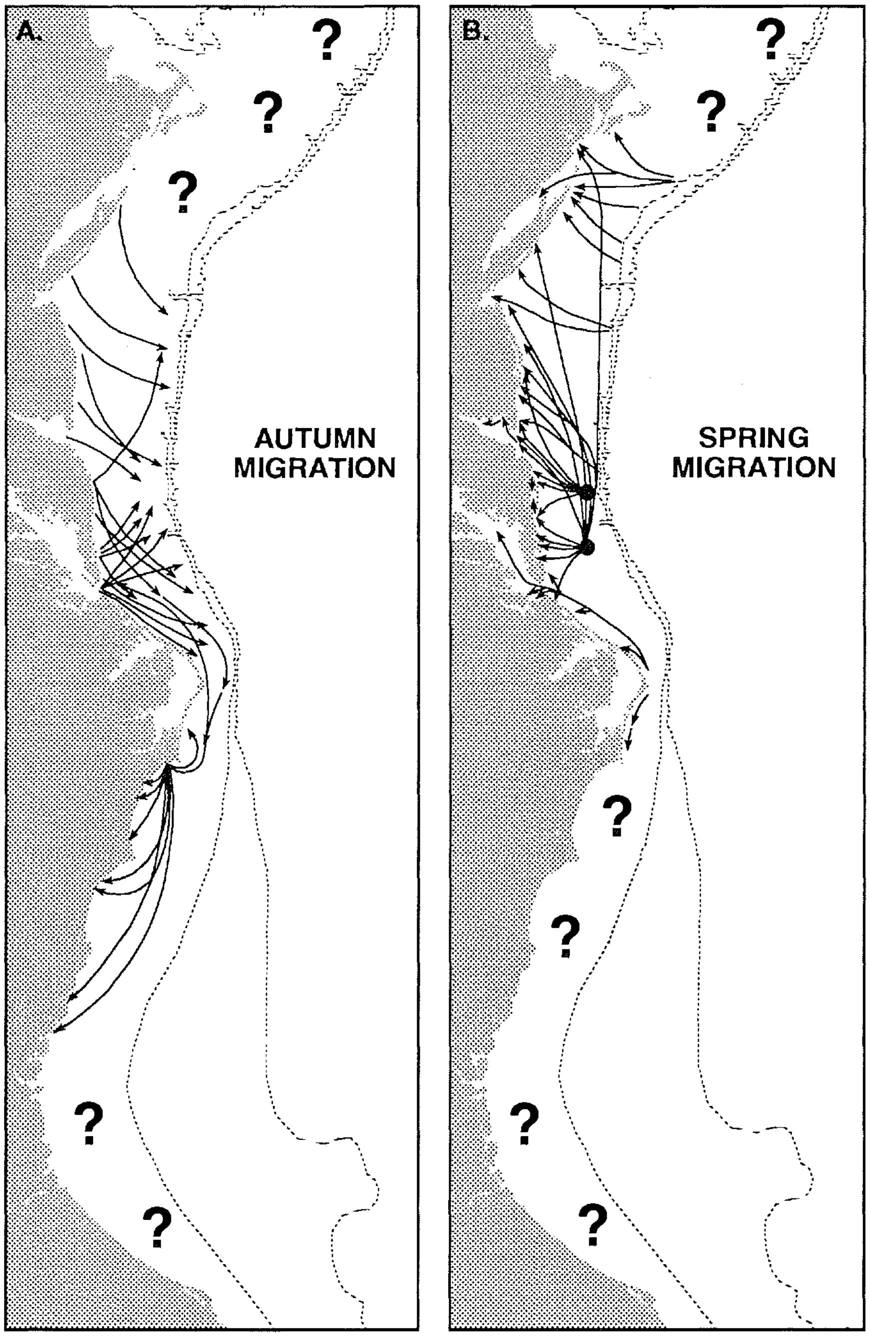


Figure 2.11. Synopsis of results of tagging studies on adult summer flounder depicting, A. offshore movement from summer feeding grounds and, B. inshore movement from overwintering grounds. ● indicates exact overwinter location was unknown; i.e., fish were tagged in an estuary in spring and were recaptured in an estuary the following spring. **?** indicates no data available. Data are drawn from the following sources: Westman and Neville (1946); Hamer and Lux (1962); Poole (1962); Murawski (1970a); Scarlett (1984); Mercer et al. (1987); Desfosse et al. (1990); Jesien and Hocutt (1991).

STOCK IDENTIFICATION

There have been, and continue to be, a number of attempts to resolve the identity of summer flounder stocks with a variety of techniques. To date, there have been three basic interpretations. First, the results of some studies have suggested that there are two major stocks, one in the Middle Atlantic Bight and another in the South Atlantic Bight. Many of these studies, beginning with Ginsburg (1952), have used meristic and morphometric techniques (Smith and Daiber 1977; Wilk et al. 1980; Fogarty 1981). However, other investigators (R. Jesien and C. Hocutt, pers. comm.) have been concerned with allometric effects on the analyses by both Wilk et al. (1980) and Fogarty (1981) because northern and southern study populations were of different sizes.

A second interpretation identifies two Middle Atlantic Bight–based stocks. One stock appears to make a consistent offshore migration in the winter and return to estuaries and inner continental shelf waters in the summer. The second population appears to spend the summer in estuaries and inner continental shelf areas from Virginia to Maryland but overwinters near Cape Hatteras. This latter population has been referred to by some as the trans–Hatteras stock. This interpretation can be derived from electrophoretic (Van Housen 1984), meristic and morphometric (Delaney 1986) analyses and tagging studies (Holland 1991). Both of these potential stocks occur in Chesapeake Bay and along the eastern shore of Virginia and perhaps Maryland in the summer (J. Desfosse, J. Musick, R. Jesien, C. Hocutt, pers. comm.). A third interpretation is a combination of the previous two in that it recognizes three stocks, one from the Middle Atlantic Bight, one from the South Atlantic Bight, and the trans–Hatteras stock. Evidence to support the distinction in local populations north and south of Cape Hatteras is based on the tagging studies by the North Carolina Division of Marine Fisheries (Mercer et al. 1987; Monaghan 1992).

The resolution of these different interpretations will probably not be immediate, but because of the poor status of summer flounder populations (Mid–Atlantic Fishery Management Council 1990, 1991a,b), there is considerable focus on this problem. Current emphasis is on tagging studies in Maryland, Virginia and North Carolina. Whether or not continued study eventually resolves stock identity, two results from the tagging studies are of interest. First, studies in which fish have been tagged in estuarine areas show that there are a large number of returns to the same estuary the subsequent summer (Westman and Neville 1946; Poole 1962; Hamer and Lux 1962; Murawski 1970a; Desfosse et al. 1990; Holland 1991; Jesien and Hocutt 1991; Jesien et al. 1992; Monaghan 1992). Most of these studies are from the Middle Atlantic Bight where these fish presumably overwinter along the edge of the continental shelf or closer to shore in the south. Second, there is a trend for some fish to be found to the north and east of the original capture sites.

Chapter 3

Eggs

INTRODUCTION

Summer flounder eggs are buoyant (Smith 1973a,b), and ascend from the benthic spawning habitat on the continental shelf to upper ocean waters. Their distribution is a useful means of defining general limits of spawning.

SPATIAL AND TEMPORAL DISTRIBUTION

Summer flounder eggs have been collected over adult spawning grounds from inner to outer continental shelf waters as early as September in northern regions (Smith 1973a,b; Able et al. 1990) and as late as January (Able et al. 1990) and February (Smith 1973a,b) in southern regions (Figure 2.2, 2.3). From Georges Bank to Cape Lookout, peak concentrations occur primarily in October and November (Able et al. 1990), however Smith (1973a,b) reported a December peak off Cape Hatteras in 1965. In this region, stratified sampling to 33 m depth collected most eggs in the upper 15 m of the water column (Smith 1973a,b). Information on egg distribution south of Cape Lookout is not available.

TEMPERATURE

Vertical movement of the eggs from the bottom after spawning may expose them to as much as a 15°C change in water temperature, but the available data suggest that they can tolerate such a range. Between Cape Cod and Cape Lookout, eggs were collected in temperatures from 9.1 – 22.9°C, with most occurring in water temperatures of 13 – 17.9°C (Smith 1973a,b). Laboratory studies have shown that egg incubation time and water temperature are positively correlated between 5 – 21°C, and that in this range, normal development and hatching occurred from two to nine days (Smith and Fahay 1970; Smigielski 1975; Johns and Howell 1980; Johns et al. 1981). Further information is available from a study on the potential effects of entrainment in once–through cooling systems of power plants (Smith et al. 1979). Late embryo stage eggs were exposed to sudden increases in temperature (pre–experiment acclimation = 16°C; experimental shock exposures = 23, 26, 29, 32, and 35°C) for time periods ranging from 3 – 180 minutes at each shock level, and survivorship was high. One hundred percent mortality occurred only at 35°C for exposure times at and above 90 minutes.

Chapter 4
Offshore Larvae

INTRODUCTION

After hatching over the continental shelf, larvae are planktonic, symmetrical in form, and dependent on their yolk sacs for nutrition. Under usual temperature and salinity conditions, the yolk sac is fully absorbed within four days and feeding begins (Smigielski 1975; Johns et al. 1981). Larval development in the Middle Atlantic Bight occurs during the autumn breakdown of the thermocline and the resultant plankton bloom (Morse 1981). Transformation (Fig. 2.6) begins offshore and may be accompanied by behavioral changes that aid movement into estuaries (Burke 1991) where permanent settlement occurs.

SPATIAL AND TEMPORAL DISTRIBUTION

Offshore larval distribution (Fig. 2.4) is similar to that for eggs (Fig. 2.2). Between Georges Bank and Cape Lookout (Fig. 2.1), larvae have been collected as early as September in the northern regions (off Cape Cod) and as late as May in the south (off North Carolina) (Smith 1973a,b; Smith et al. 1975; Bolz et al. 1981; Able et al. 1990). Data on larval occurrences south of Cape Lookout are scarce, partly because identification is complicated by the presence of the larvae of two and sometimes three other species of Paralichthys (Powles and Stender 1976).

TEMPERATURE

Larvae have been collected over a wide range of water temperatures (0 – 23.1°C) between Cape Cod and Cape Lookout, with most occurring at temperatures of 9.0 – 17.9°C (Smith 1973a,b). In the laboratory, yolk sac larvae died at temperatures below 11°C, but those held above 11°C developed normally (Johns and Howell 1980; Johns et al. 1981). Studies on the potential effects of power plant cooling systems to summer flounder larvae provide further information. The ability of newly hatched yolk sac larvae to avoid predation was actually enhanced after a +10°C thermal shock (base 15.1°C; Deacutis 1978), however mortality resulted from shock exposure to 32°C (Hoss et al. 1974).

SUBSTRATE

Planktonic larvae may begin making excursions to the bottom before entering estuaries (K.W. Able, unpubl. data). Small numbers of transforming larvae have been collected with a small-mesh beam trawl during autumn 1991 from an inner continental shelf site (15 m depth) off New Jersey. These larvae were in early transformation (pre-transforming to stage H, 11.4 – 15.4 mm SL; Fig. 2.6) and had coloration typical of larvae that occurred in the plankton except some of the melanophores were stellate (expanded), which made them appear more pigmented than normal. We suspect that these larvae had settled on the substrate intermittently on their way into the adjacent estuary (Fig. 2.8) because larger, later-stage summer flounder larvae were seldom found at this site, even though large numbers of other recently settled flatfishes (Etropus, Scophthalmus) were often collected (K.W. Able, unpubl. data). There is no evidence that permanent settlement occurs on the continental shelf (Able et al. 1990), although benthic sampling with the appropriate small-mesh gear has been infrequent.

Chapter 5
Estuarine Larvae

INTRODUCTION

Summer flounder larvae entering estuaries are undergoing morphological transformation and are probably changing physiologically as well in order to cope with fluctuations of salinity in the estuary. Movement into the estuary may involve intermittent settling to test the substrate and larvae may take advantage of tidal stream transport prior to permanent settlement in the estuary. Because of the lack of developmental (stage) information in much of the literature, here we refer to all pelagic individuals as larvae and to all benthic individuals that have not achieved sexual maturity as juveniles.

SPATIAL AND TEMPORAL DISTRIBUTION

Summer flounder larvae move from offshore to shallow estuarine habitats to complete transformation and permanently settle (Keefe and Able 1993). In Middle Atlantic Bight estuaries from Long Island Sound to as far south as Chesapeake Bay, movement of larvae into estuaries has been reported to occur from October through April (Merriman and Sclar 1952; Olney 1983; Olney and Boehlert 1988; Able et al. 1990; Szedlmayer et al. 1992). The only published report of the larvae in an estuary in summer (Herman 1963) is questionable (Smith 1973a,b; Able et al. 1990). In the Great Bay–Little Egg Harbor estuarine system (Fig. 2.7a), larvae have been sampled in two marsh creeks near Little Egg Inlet, Little Sheepshead and Schooner creeks, during a five–year period (Figs. 5.1, 5.2). At Little Sheepshead Creek, temporal occurrence of larvae was sporadic within and between years. In the winters of 1989–1990, 1990–1991 and 1992–1993, most larvae occurred in January through March while few, if any, occurred in the fall. However, in the winter of 1991–1992, they were clearly more abundant in October through January. In Schooner creek, larvae were most abundant during December through March, although fall sampling did not occur in some years (Fig. 5.2). There seems to be some very general correspondence in abundance between these sites with the peaks in February 1990, February 1991, and December 1991 – February 1992 co–occurring at each creek. Earlier sampling (1962–1972) in nearby Manasquan Inlet collected all larvae during October through December (Able et al. 1990). In the South Atlantic Bight, movement into the estuary occurred from January through April with abundance peaks in February and March in North Carolina and South Carolina (Weinstein 1979; Bozeman and Dean 1980; McGovern 1986; Hettler and Chester 1990;

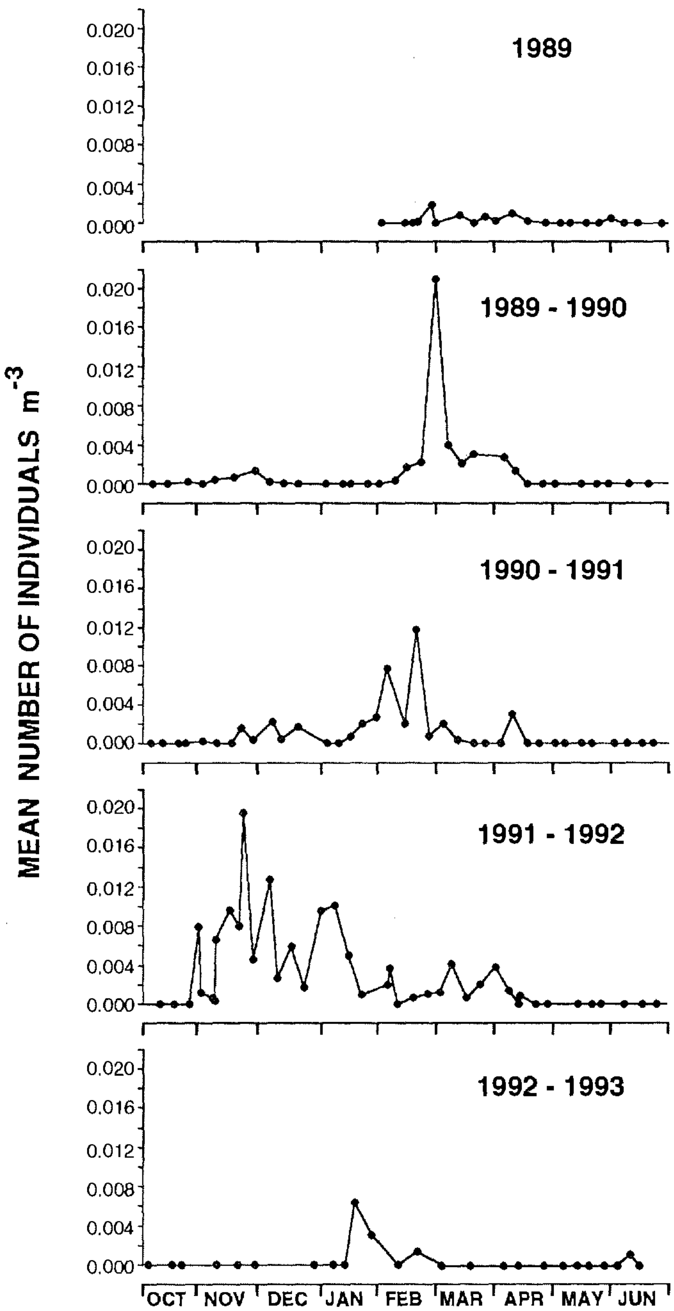


Figure 5.1. Catch per unit effort for summer flounder larvae moving into an estuary based on Rutgers University Marine Field Station ichthyoplankton survey at Little Sheepshead Creek (Fig. 2.7A) from February 1989 through May 1993. The sampling site is a broad creek that cuts through the salt marsh peninsula between Great Bay and Little Egg Harbor and recieves Atlantic Ocean water on flood tides. Two plankton nets (1 meter diameter hoop, 1 mm mesh) were deployed once a week during the night flood tide for 3 to 5 consecutive 0.5 hour sets. Volume of water strained was determined using flow meters. July, August and September were sampled but are omitted because no summer flounder were collected in these months in any year.

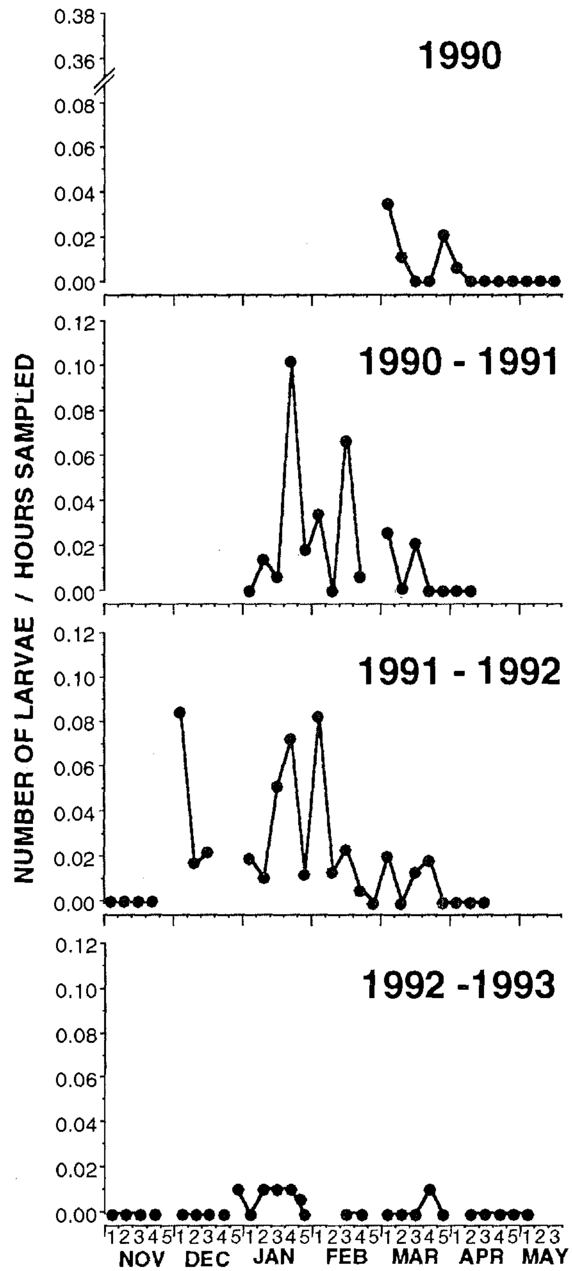


Figure 5.2. Catch per unit effort for summer flounder larvae moving into an estuary based on Rutgers University Marine Field Station ichthyoplankton survey at Schooner Creek (Fig. 2.7A) from late-February 1990 through mid-May 1993. The sampling site is a small (1 km) polyhaline marsh creek that terminates in high marsh. A stationary plankton net (0.5 m diameter hoop, 3.0 mm mesh) was fished in the lower main creek continuously (day and night) for 1 to 7, 24 hour periods each week. Data are summarized for 5 sample periods during each month where the first four periods represent 7 days and the fifth period includes the 2 or 3 days remaining in that month. Months not represented were not sampled except for several days in late October 1992 during which time no summer flounder were collected. Unconnected points indicate breaks in sampling.

McGovern and Wenner 1990; Warlen and Burke 1990; Burke et al. 1991). The consistency in transformation stages and sizes at which larvae enter Middle Atlantic Bight and South Atlantic Bight estuaries (Burke et al. 1991; Keefe and Able 1993) suggests that transforming larvae develop behaviors that first allow transport into the estuaries from offshore during early stages (Burke 1991) and then, during later stages, aid up–estuary movement to settlement habitats, perhaps by tidal stream transport as for Paralichthys spp. (Weinstein et al. 1980a). This is discussed further below (see Substrate and Behavior).

TEMPERATURE AND SALINITY

Temperature appears to be the most significant environmental factor controlling duration of transformation and thus, perhaps, timing of larval movement into estuaries. Late–development larvae have been collected in water temperatures ranging from 0 – 13°C in Middle Atlantic Bight estuaries (Olney and Boehlert 1988; Wyanski 1990; Szedlmayer et al. 1992), from 8.4 – 23.4°C in South Carolina (McGovern and Wenner 1990) and from 2 – 22°C in North Carolina (Williams and Deubler 1968a). Larvae collected in Little Sheepshead Creek (Figs. 2.7, 5.1) typically occurred at temperatures of 0 – 12.0°C. In Schooner Creek (Figs. 2.7, 5.2), larvae were collected at –2.0 – 14°C. In the laboratory, however, water temperatures less than 2°C killed transforming larvae (Szedlmayer et al. 1992). In another laboratory study of the same population, mortality of mid–transformation larvae held at 4°C was significantly greater than those held at 10°C (Keefe and Able 1993). Thus, estuarine larvae suffer increased mortality based on both the severity and duration of cold water temperatures. Further, duration of transformation was dependent on ambient water temperatures, ranging from 25 days at average temperatures of 17°C to 93 days at average temperatures of 6.6°C. Data for a South Carolina estuary suggest that a milder winter may mean earlier movement into the estuary (Cain and Dean 1976; Bozeman and Dean 1980).

Larvae moving into estuaries are reported from a wide range of salinities. In the two New Jersey marsh creeks (Figs. 5.1, 5.2), larvae occurred at salinities ranging from 20 – 33 ppt. In North Carolina, larvae were collected throughout the estuary at salinities ranging from 0.02 – 35.0 ppt (Williams and Deubler 1968a). In a South Carolina study, larvae occurred from 0 – 24.7 ppt (McGovern and Wenner 1990).

SUBSTRATE AND BEHAVIOR

The estuarine movements of transforming larvae may be accomplished by vertical migrations between pelagic and benthic habitats (Weinstein et al. 1980a,b). In North Carolina, summer flounder and other species of Paralichthys responded to diel and tidal cycles by migrating to surface waters on night flood tides (Weinstein et al. 1980a). Many others have described increased catches of transforming larvae during night flood tides (Deubler 1958; Williams and Deubler 1968a,b; Olney and Boehlert 1988; Hettler and Chester 1990) and very high catches during new moon periods (Williams and Deubler 1968a,b; Hettler and Chester 1990). Weinstein et al. (1980a,b) suggested that this behavior allows larvae to enter shallow habitats in marsh creeks and shoals where they are retained by an ebb–tide response of seeking the substrate. More recent behavioral data support these observations and indicate that transforming larvae may test the substrate before permanent settlement. Larvae observed in the laboratory, in the absence of tidal currents, swam in the water column more often at night (Keefe and Able 1994). These larvae swam with their bodies held vertically, sank with their bodies held horizontally, and were capable of periodically resting on the substrate on their right sides even before completing eye migration (Keefe and Able 1994). Many were capable of partial burial at early stages (stages G to H–, Fig. 2.6), but were not able to bury completely until late transformation (H+). Burke (1991) suggests that these behaviors may begin to develop during transformation offshore.

Chapter 6
Estuarine Juveniles

INTRODUCTION

Permanent settlement and subsequent fast growth of juveniles occurs in estuarine nursery grounds, and recent evaluation of age data has determined that juveniles may become sexually mature as early as the end of their first summers (Able et al. 1990; Szedlmayer et al. 1992; Almeida et al. 1992). The temporal occurrence of juveniles in estuaries varies with location. In the northern part of their range, they leave during the winter and return the next spring with the adults. In the southern part of their range, they enter estuaries in the winter and may stay until the following winter.

SPATIAL AND TEMPORAL DISTRIBUTION

The best available information indicates that juveniles occur most frequently in shallow subtidal and intertidal areas in the lower portions of estuaries (Tagatz and Dudley 1961; Keup and Bayless 1964; Dahlberg 1972; Powell and Schwartz 1977), but the habitats may change with increasing size. In the South Atlantic Bight, recently settled individuals (< 25 mm TL) occur on tidal flats and in marsh creeks (Powell and Schwartz 1977; Weinstein and Brooks 1983; Burke et al. 1991). In Charleston Harbor (Fig. 2.7b), recently settled juveniles (< 25 mm TL) occurred in a number of estuarine creeks (Fig. 6.1) in the winter (January/March), which is consistent with the winter occurrence of larvae in this region (McGovern and Wenner 1990; Warlen and Burke 1990). Less is known for the Middle Atlantic Bight. In New Jersey, juveniles less than 50 mm TL are not frequently collected even though larvae are common (Able et al. 1990; Szedlmayer et al. 1992; Keefe and Able 1992). The juveniles that have been collected were in many habitats including salt marsh creeks, shallow coves and shallow portions of bays (K.W. Able, unpubl. data). In Virginia, recently settled juveniles have been collected in shallow marsh habitats on the western shore of Chesapeake Bay and the Atlantic Ocean side of Virginia's eastern shore (Wyanski 1990).

Larger juveniles (> 50 mm TL) have been collected in estuaries all along the east coast. This has been documented for New Jersey (Szedlmayer et al. 1992; Rountree and Able 1992a,b), Delaware (Smith and Daiber 1977; Malloy 1990), Maryland (Schwartz 1961a,b), Chesapeake Bay and Virginia's eastern shore (Horwitz 1978; Geer et al. 1990; Bonzek et al. 1991; Wyanski 1991; Bonzek et al. 1992), North Carolina

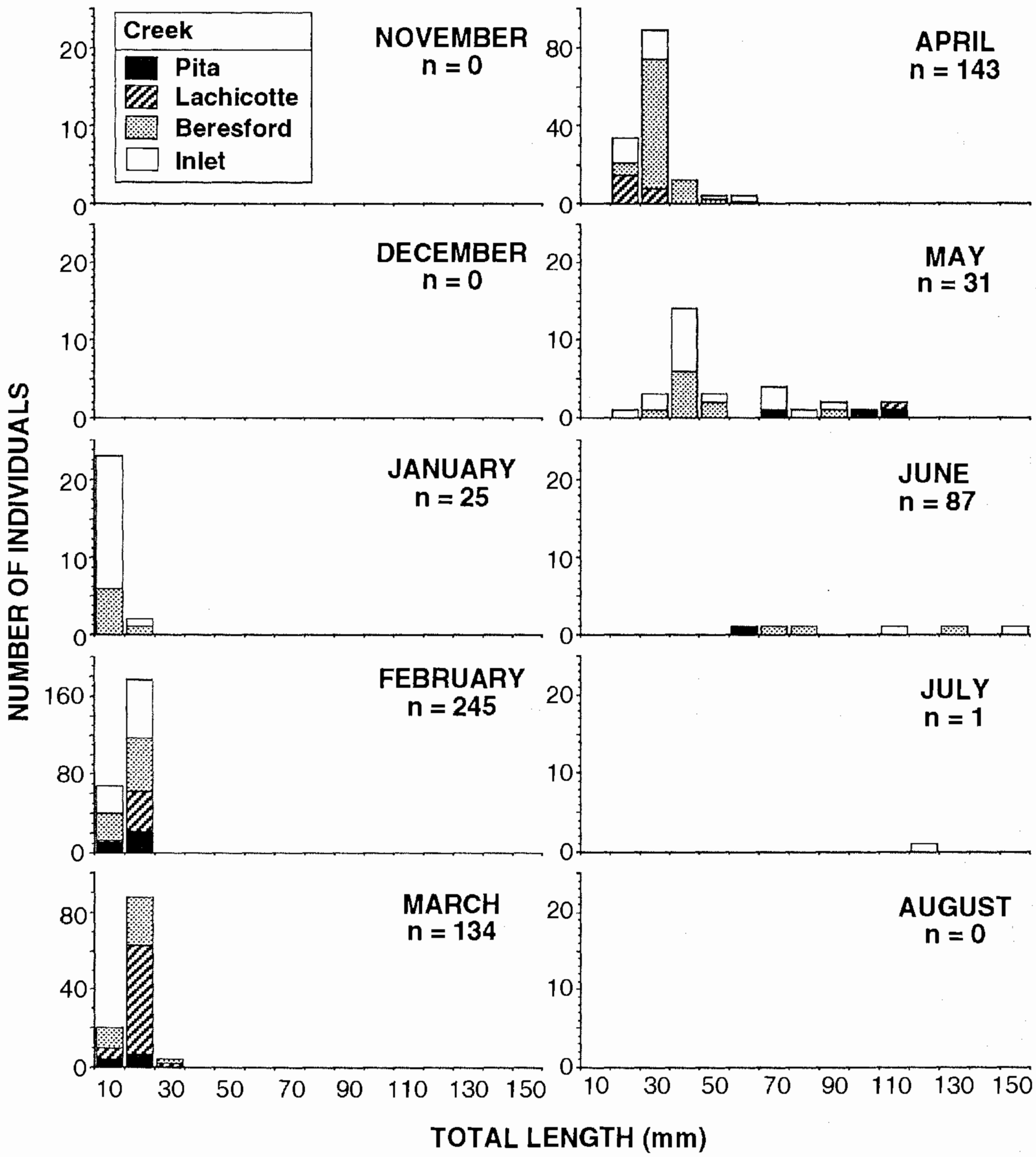


Figure 6.1. Length-frequency distributions for juvenile summer flounder collected during 1986 (November, December) -1987 from four Charleston Harbor estuarine system marsh creeks (Fig. 2.7B) using a rotenone/block net method (Wenner et al. 1990).

(Burke et al. 1991), South Carolina (Wenner et al. 1990) and Georgia (Reichert and van der Veer 1991). Additional details are available from Long Island Sound (Fig. 2.7c) where juveniles and adults, approximately 200 – 400 mm TL (Fig. 6.2), were collected throughout much of the sound (Fig. 6.3).

The temporal pattern of estuarine use by these larger juveniles varies with latitude and presumably winter water temperatures. In Long Island Sound, they appear most abundant in spring and fall, and are less abundant in mid–summer (Fig. 6.2, 6.3), when they may have moved into subestuaries of the sound. By late fall/early winter (November), they have moved offshore into the Atlantic Ocean. In Great Bay, young–of–the–year spend the summer in the estuary and begin leaving as early as August (Able et al. 1990; Rountree and Able 1992a; Szedlmayer and Able 1992; Szedlmayer et al. 1992) and this continues until November or December, when very few individuals remain. In Delaware Bay, most individuals were collected from May through September but a few were taken in every winter month in the deeper parts of the estuary (Smith and Daiber 1977). In Virginia waters of Chesapeake Bay, most collections are dominated by young–of–the–year, at least in most years (Horwitz 1978; Geer et al. 1990; Bonzek et al. 1991; Wyanski 1990; Bonzek et al. 1992). These individuals tend to be closer to the ocean in March and are more abundant farther up the bay during the summer and fall. Typically, all juveniles and adults move offshore for the winter (Hildebrand and Schroeder 1928; Musick 1972), although this pattern may vary between years. In a warm year (1991) in Chesapeake Bay, some individuals were captured during January while in other years (1989, 1990) they were absent (Horwitz 1978; Geer et al. 1990; Wyanski 1990; Bonzek et al. 1991, 1992).

For Pamlico Sound and the adjacent subestuaries in North Carolina (Fig. 2.7d), juveniles are most abundant in the summer but are collected as late as December (Fig. 6.4) and reportedly remain in the estuaries for the first 18 to 20 months of life (Powell and Schwartz 1977). The earliest collections available (March; Fig. 6.4) potentially represent individuals that overwintered. By May, the year class that entered as larvae in the winter (see above) is evident at sizes of 20 – 100 mm TL in shallow beach and marsh fringe habitats (Fig. 6.5). This same cohort is evident in trawl collections from the deeper portions of Pamlico Sound in seasonal collections from June through December (Fig. 6.4). These individuals are most abundant in the central portion of Pamlico Sound and are seldom found in the larger subestuaries (Pamlico and Neuse rivers) in the system, regardless of whether it is a year of relatively large (1987) or small (1990) abundance (Fig. 6.5). A seasonal pattern is evident with low abundance in the spring (March) and winter, and greatest abundance in summer (June and September) (Fig. 6.6). In Charleston Harbor (Fig. 2.7b), larger juveniles are evident in the harbor channels during bimonthly sampling (Fig. 6.7), thus at this latitude, a portion of the population overwinters in the estuary. In Georgia, juveniles have been collected from March through July and are most abundant in April and May (Mahood et al. 1974a,b,c,d); Shipman 1983; Music and Pafford 1984).

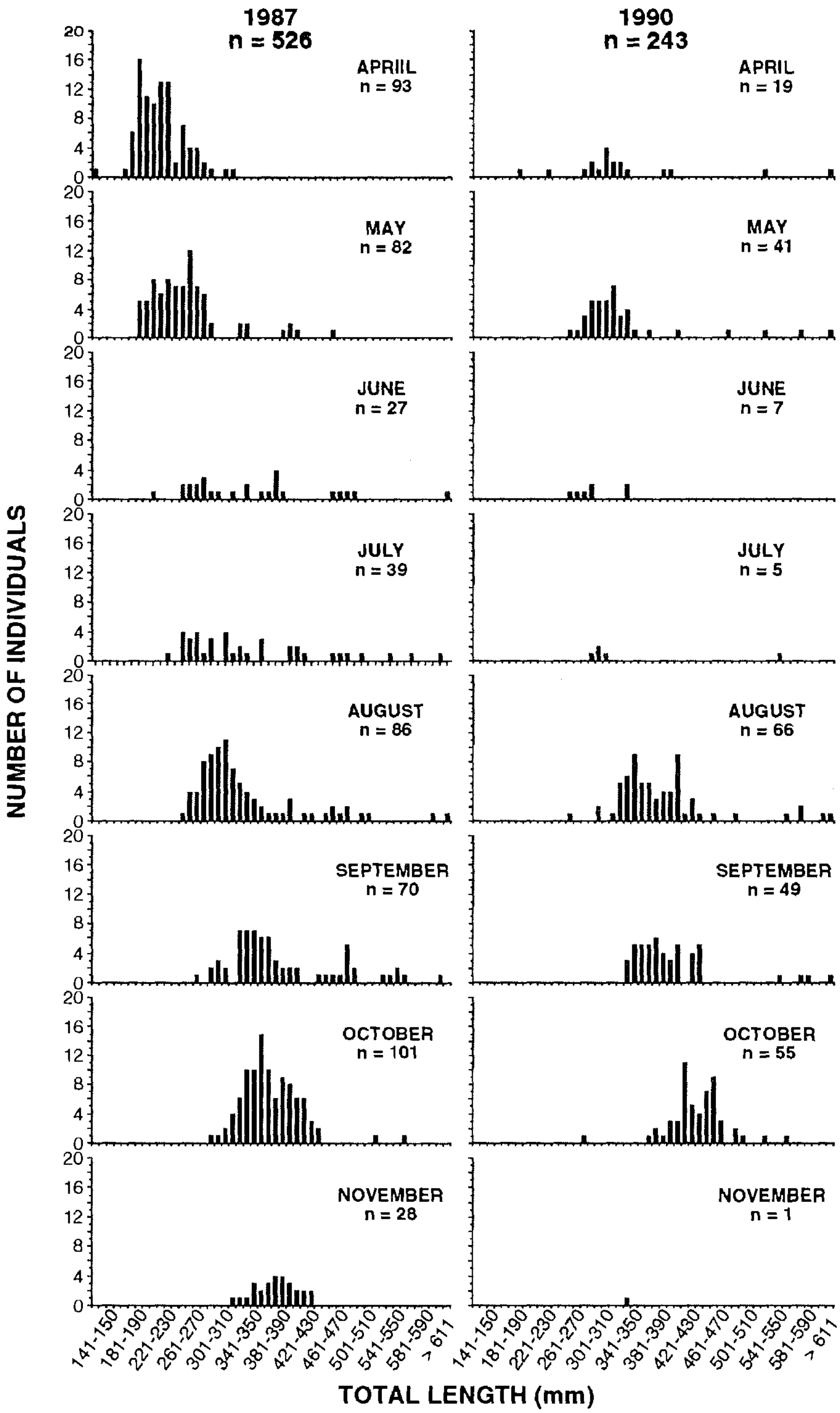


Figure 6.2. Monthly length-frequency distributions for juvenile and adult summer flounder in Long Island Sound (Fig. 2.7C) during years of high (1987) and low (1990) abundance. Collections were made with 0.5 hour tows of a 14 m otter trawl at, typically, 40 stations that were chosen by stratified random design. Data are based on the finfish surveys of the Connecticut Division of Marine Fisheries (1990a, 1990 and 1992).

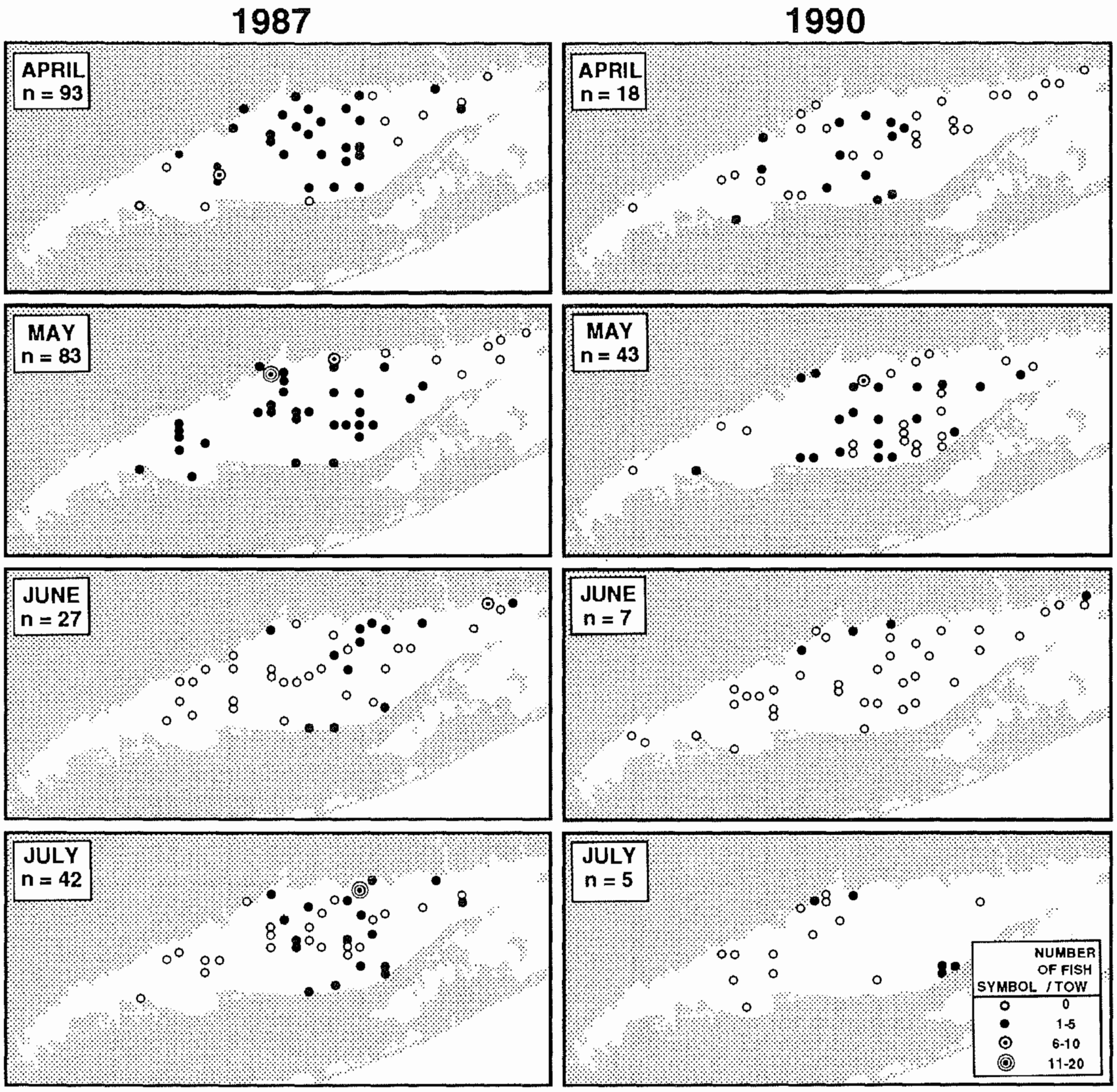
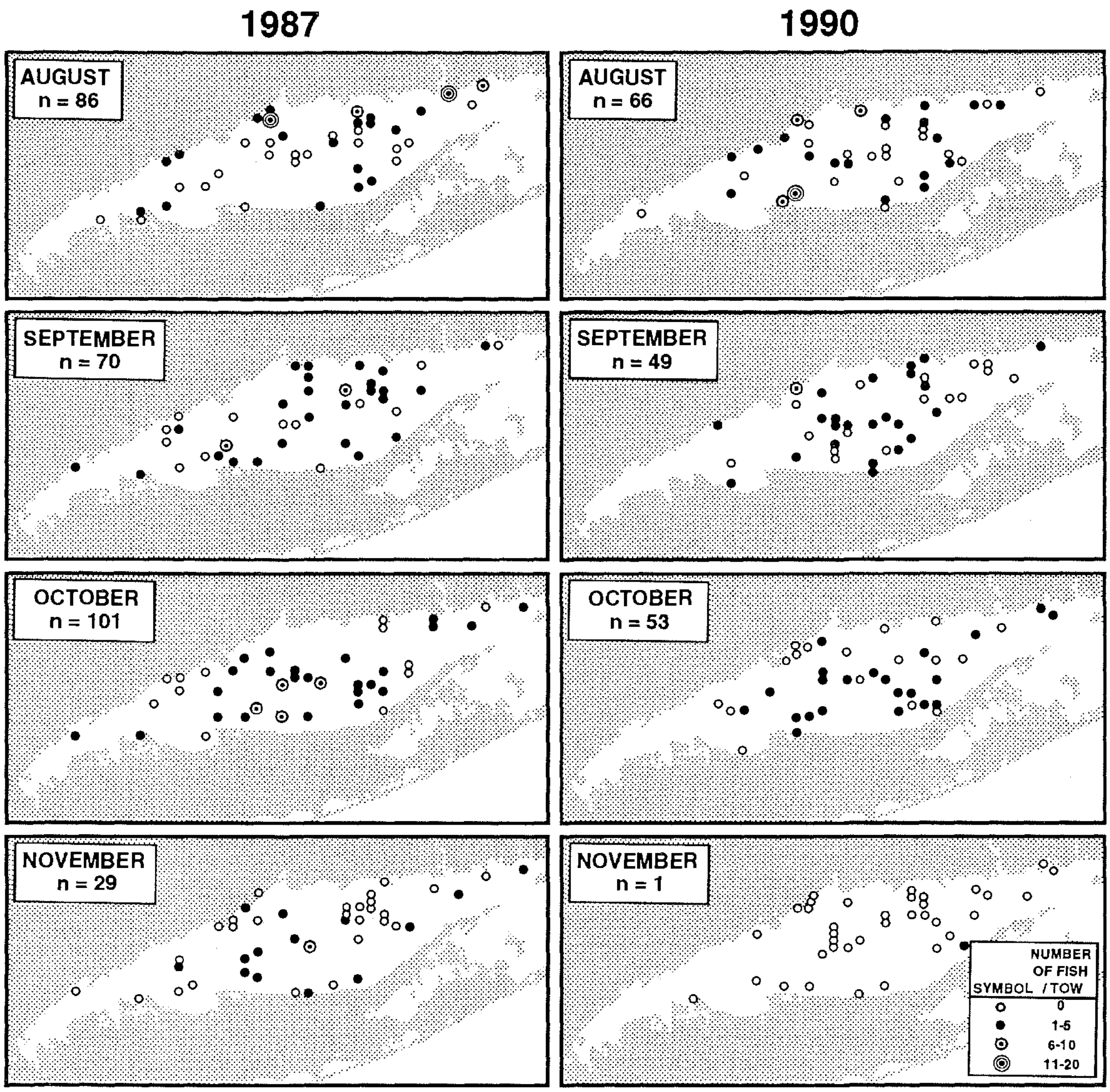


Figure 6.3. Distribution and abundance of juvenile and adult summer flounder in Long Island Sound (Fig. 2.7C) during years of high (1987) and low (1990) abundance. Collections were made with 0.5 hour tows of a 14 m otter trawl at, typically, 40 stations that were chosen by stratified random design. Data based on the finfish surveys of the Connecticut Division of Marine Fisheries (1990a, 1990b and 1992).



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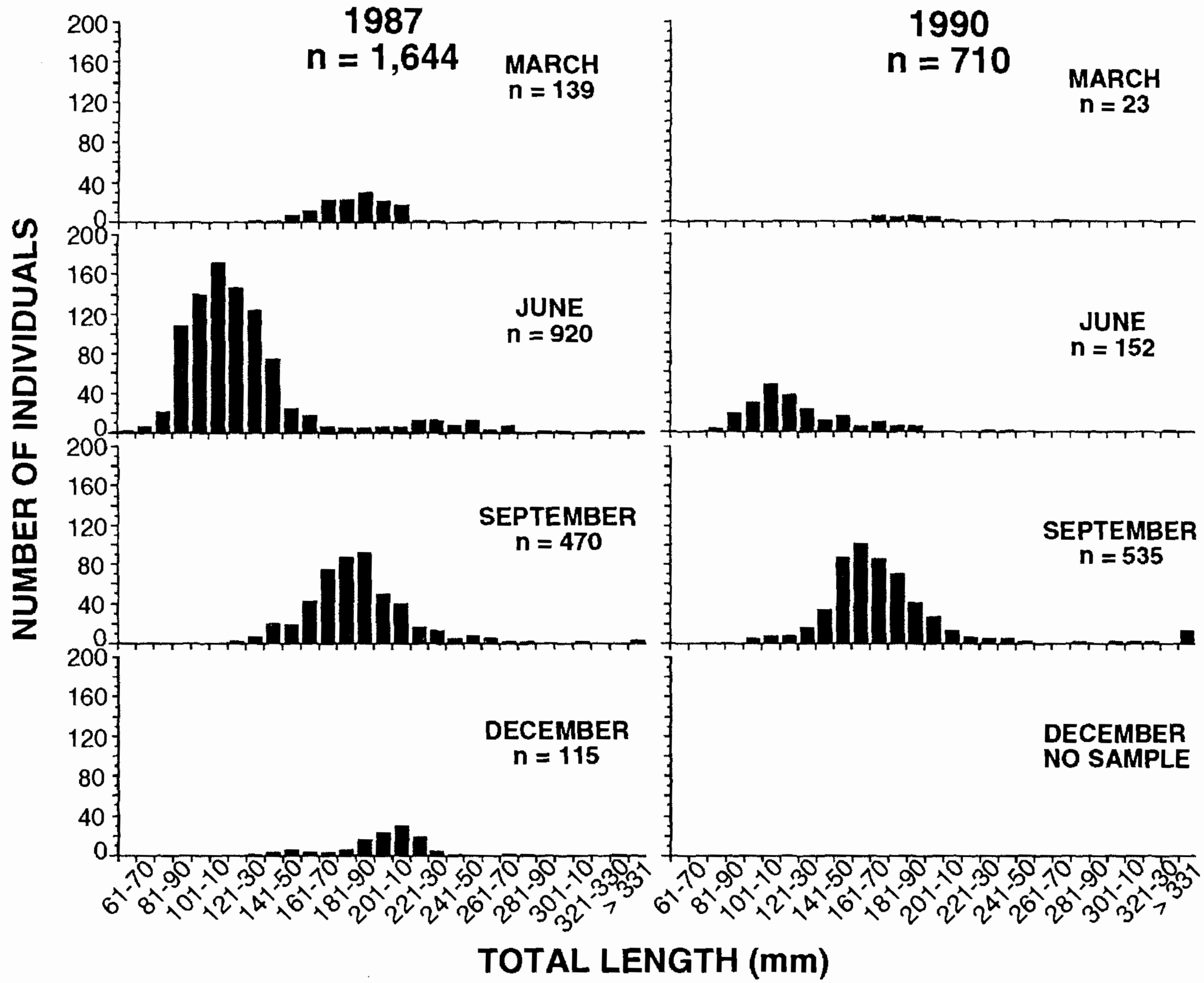

Figure 6.4. Length-frequency distributions for juvenile and adult summer flounder in the Pamlico-Albemarle sounds estuarine system (Fig. 2.7D) during years of high (1987) and low (1990) abundance. A stratified random design was used to choose sites throughout Pamlico Sound, the lower reaches of Albemarle Sound and three subestuaries (Pamlico, Neuse and Pungo rivers) for sampling by 20 minute tows of a Mongoose trawl during four months in 1987 and 3 months in 1990. Data are based on the North Carolina Division of Marine Fisheries (1987-1991) trawl survey.

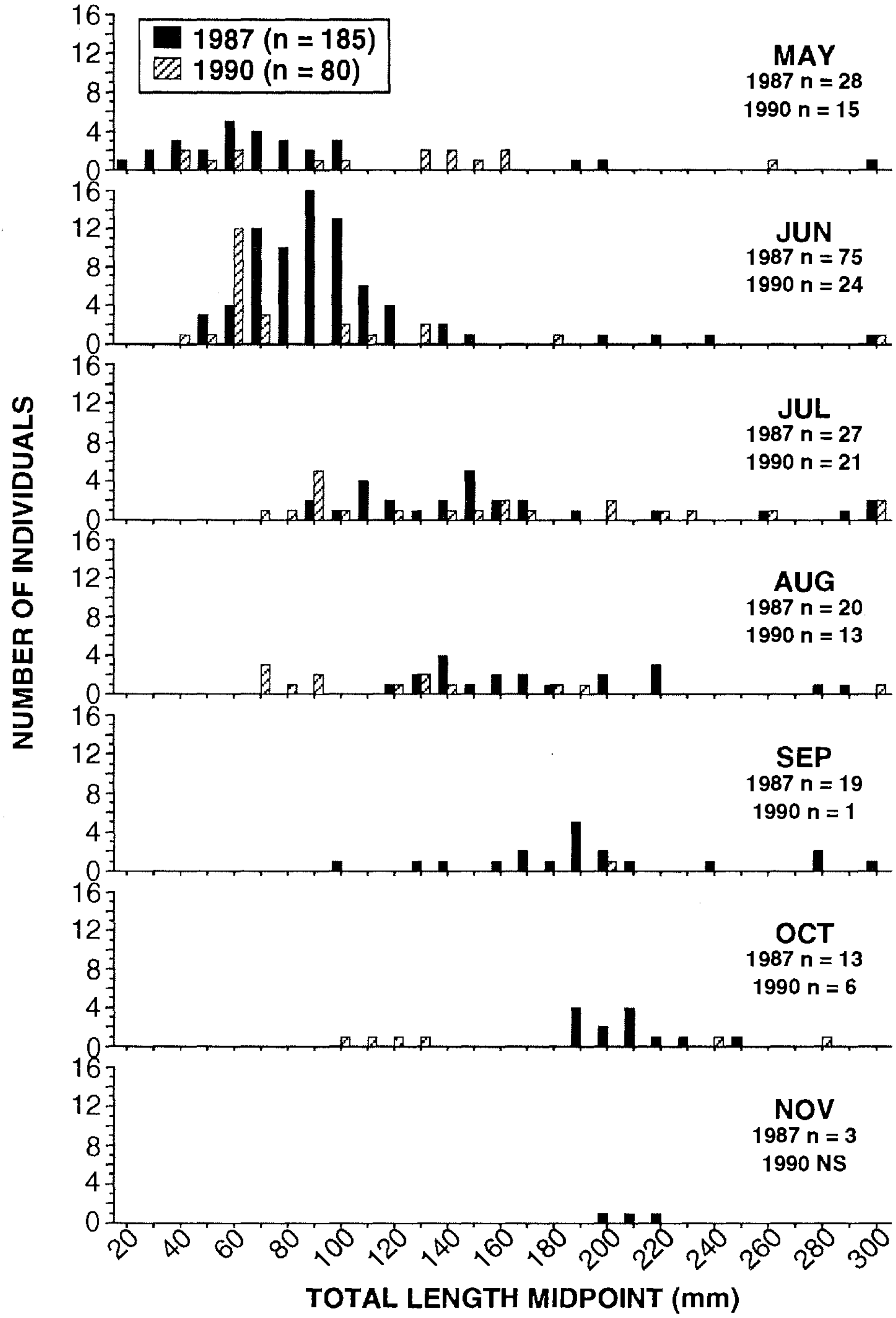

Figure 6.5. Monthly length-frequency distributions of juvenile summer flounder in shallow beach and marsh fringe habitats in the Pamlico-Albemarle sounds estuarine system (Fig. 2.7D) during years of high (1987) and low (1990) abundance. Sampling was conducted from May through November by the North Carolina Division of Marine Fisheries with 10.5 and 20 m seines. Data from Noble and Monroe (1991).

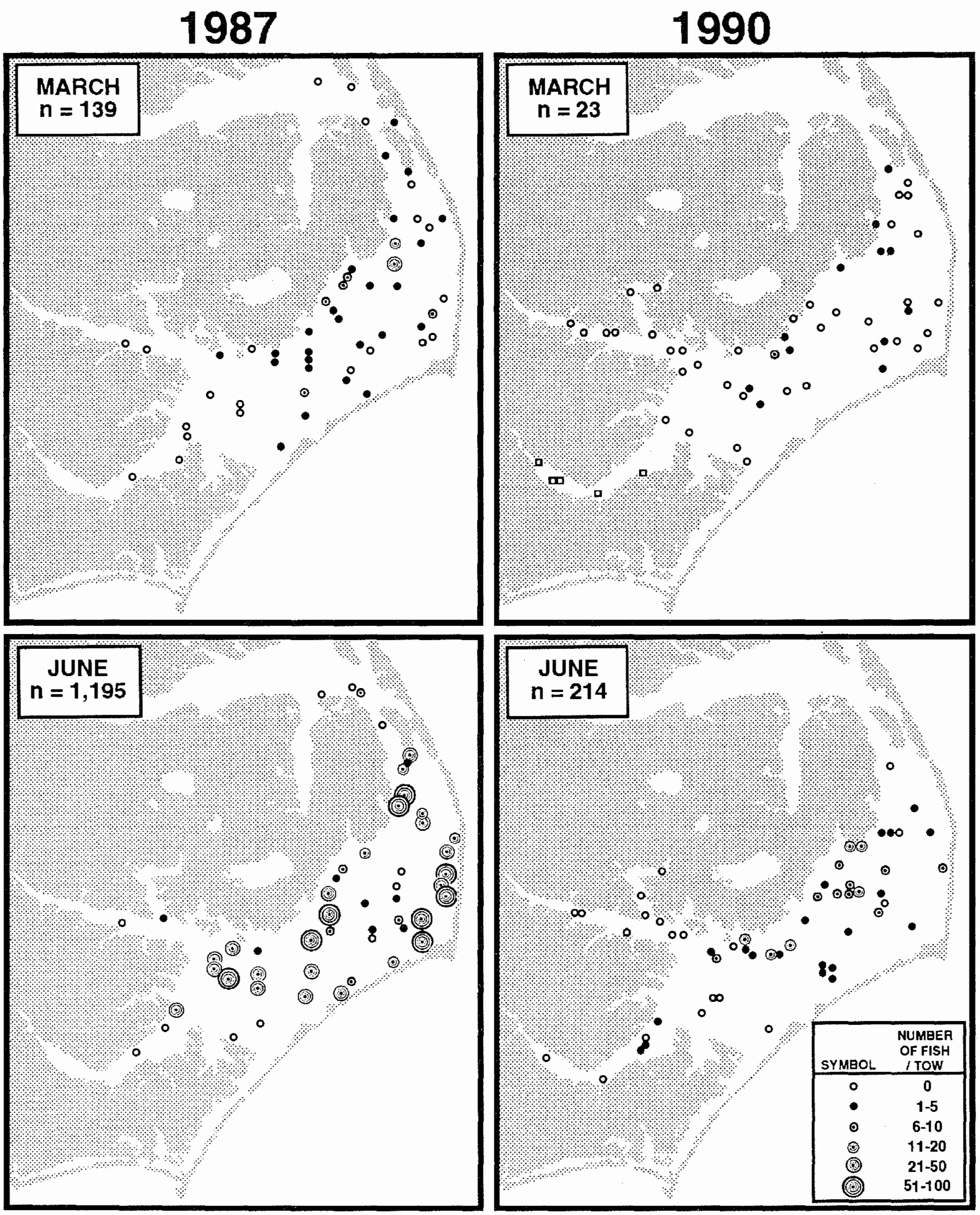

Figure 6.6. Distribution and abundance of juvenile and adult summer flounder in the Pamlico-Albemarle sounds estuarine system (Fig. 2.7D) during years of high (1987) and low (1990) abundance. A stratified random design was used to choose sites throughout Pamlico Sound, the lower reaches of Albemarle Sound and three subestuaries (Pamlico, Neuse and Pungo rivers) for sampling by 20 minute tows a Mongoose trawl during four months in 1987 and 3 months in 1990. Data are based on the North Carolina Division of Marine Fisheries (1987-1991) trawl survey.

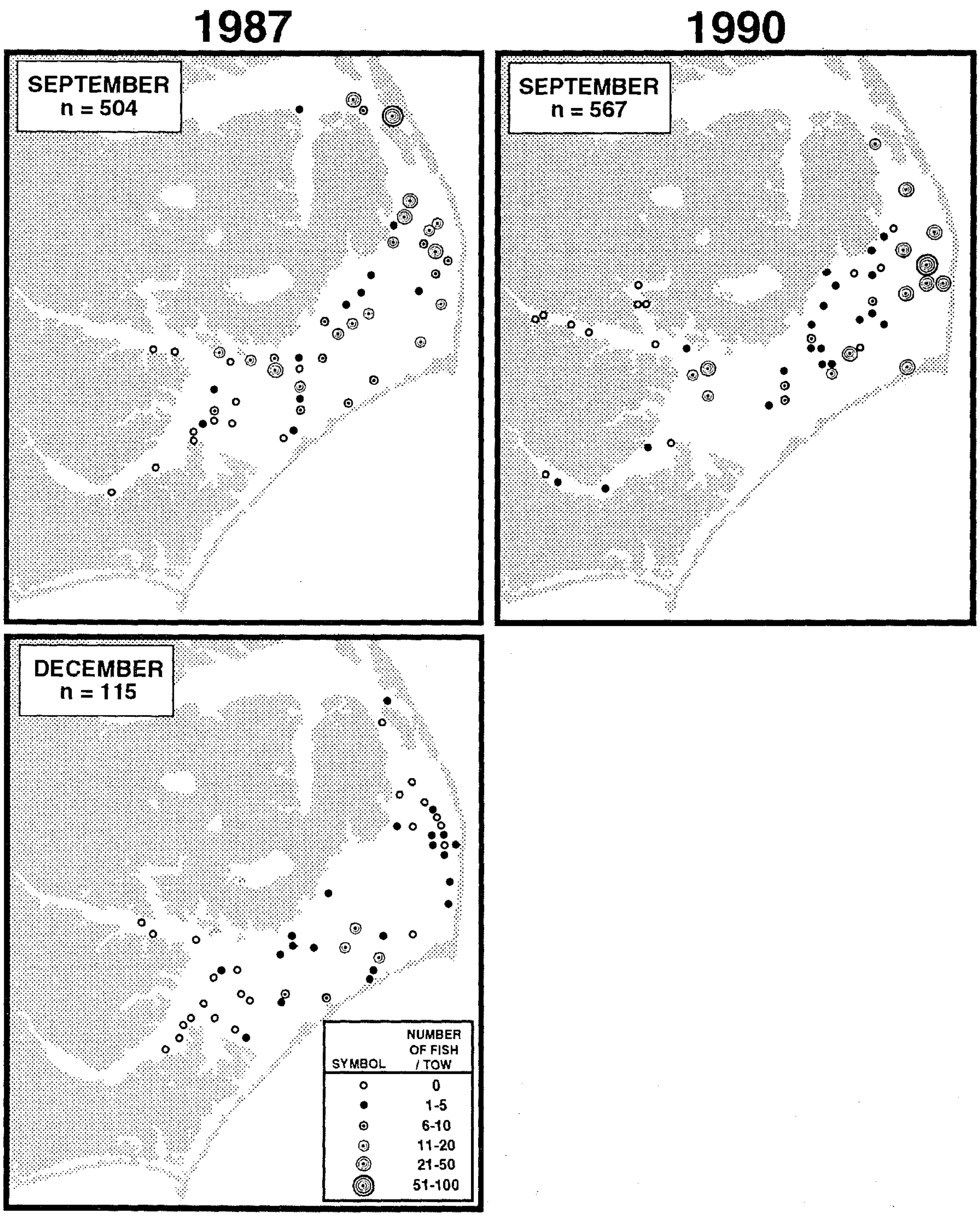

Figure 6.6 (continued).

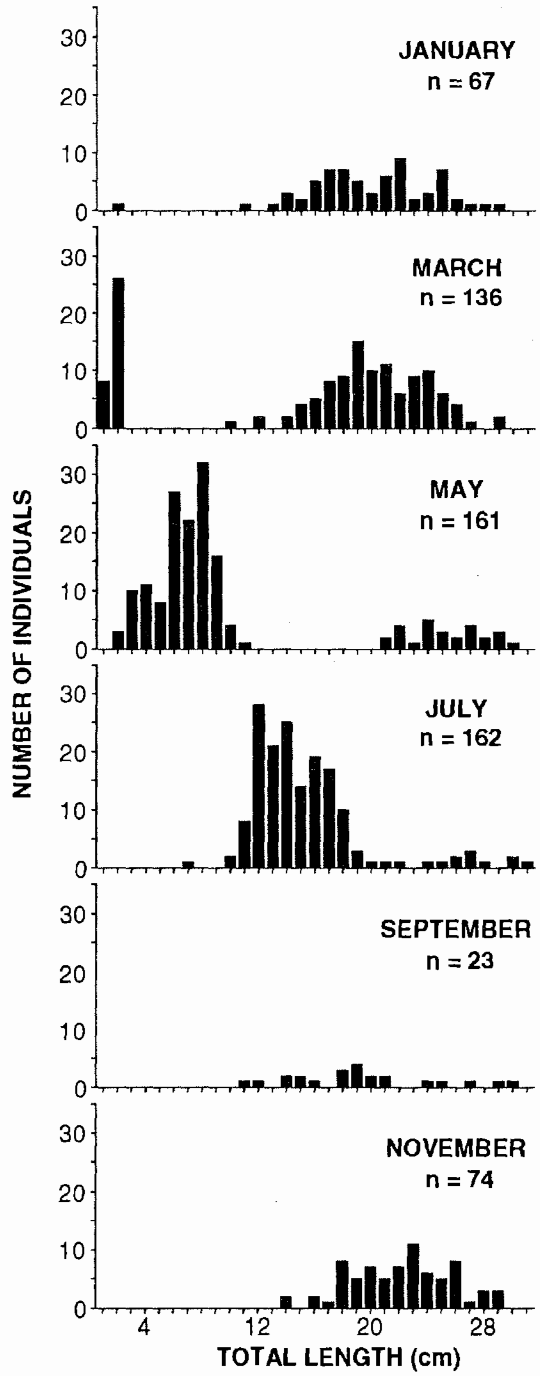

Figure 6.7. Length-frequency distributions for juvenile summer flounder in channels in the Charleston Harbor estuarine system (Fig. 2.7B) during 1985-1988. Bimonthly sampling was conducted using 4.9 and 7.6 semiballoon shrimp trawls with 3.2 - 32 mm mesh liners in the codends. Data based on a survey conducted by the South Carolina Marine Resources Center (C. Wenner, pers. comm.)

TEMPERATURE, SALINITY AND DISSOLVED OXYGEN

Estuarine juveniles can be found in a wide range of naturally occurring physical conditions. Most laboratory and field studies are in agreement regarding the preference for higher salinity, at least at larger sizes. In the winter, collections of recently settled individuals (< 50 cm TL) in the Charleston Harbor estuary (Fig. 2.7b; Table 6.1) occurred at very low as well as high salinities (February – March; Fig. 6.8). However, by May, when most individuals ranged from 20 – 110 mm TL, they were found at higher salinities (> 10 ppt). Thus in this system, as they disperse into the estuary, they may move up into nearly fresh water, but as they grow they are most abundant in the higher salinities that occur lower in the estuaries. In lower Chesapeake Bay, young-of-the-year were common in creeks that had salinities over 15 ppt and were most abundant at the highest salinities but were absent in a creek where values were 3 – 11 ppt (Table 6.2). In North Carolina, young-of-the-year have been found at salinities from 3 – 35 ppt, but were most abundant when salinities were greater than 12 ppt (Powell and Schwartz 1977). In more recent data from Pamlico Sound (Fig. 2.7d), almost all individuals were collected in the sound while few were found in the adjacent lower-salinity subestuaries such as the Pamlico and Neuse rivers (Fig. 6.6). This pattern was similar in years with both high and low abundance.

A number of laboratory studies indicate that juveniles grow best in moderate temperatures and higher salinities. For example, feeding rate is positively correlated with temperature but interacts with salinity so that higher salinities result in faster feeding rates (Peters and Kjelson 1975). These studies found that weight gain and salinity were positively correlated between 10 – 30 ppt but reduced at 40 ppt. Other studies (Malloy and Targett 1991) found little effect of salinities (10, 20 and 30 ppt) on feeding rate, assimilation efficiency and growth rate. Studies designed to test the effects of temperature on condition, growth and survival of juveniles from estuaries north (Delaware) and south of Cape Hatteras (North Carolina) indicate that differences in late winter/early spring water temperatures have significant effects on growth (Malloy 1990; Malloy and Targett 1991; Malloy and Targett 1994; Malloy and Targett in press). Southern juveniles generally experience warmer temperatures in the field and showed increased vulnerability (reduced growth and increased mortality) to cold water conditions in the laboratory compared with northern juveniles.

Low growth rates have been observed at low temperatures (< 12 – 14°C) in the laboratory (Malloy 1990; Malloy and Targett 1991; Malloy and Targett 1994; Malloy and Targett in press) and have been confirmed in caging experiments in New Jersey (Fig. 6.9). During the autumn, the average growth rate was negligible (–0.6 and 0.01 mm/day). Under these same conditions there was little change in developmental

Table 6.1. Physical characteristics of four marsh creek study sites in the Charleston Harbor estuary (Fig. 6.1) sampled monthly for 13 months from June 1986 - August 1987 (Hoffman 1991). Fishes were collected by setting paired block nets upstream and downstream of the sites, releasing rotenone upstream, and then dip-netting and seining. See Fig. 2.7B for station locations; 1 = Pita Creek; 2 = Lachicotte Creek; 3 = Beresford Creek ; 4 = Inlet Creek. (mlw = mean low water.)

(SITE NO.) LOCATION	TEMPER-ATURE (°C)	SALINITY (ppt)	DISSOLVED OXYGEN (ppm)	DEPTH (m)	SUBSTRATE	TOTAL NO. SUMMER FLOUNDER
(1) 35.6 km from mouth of Charleston Harbor	7.6-32	0.8-24.5	4.2-10.2	0.6 - 1.1 at mlw	shell hash and sand	50
(2) 30.7 km from mouth of Charleston Harbor	7.3-30.9	7.1-25.2	1.6-11.2	0.7 - 1.8 at mlw	sand and shell hash with some mud downstream	133
(3) 20.7 km from mouth of Charleston Harbor	9.6-31.5	13.0-23.7	2.0-11.7	0.4 at mlw	mud upstream, sand and some shell downstream	223
(4) 8.3 km NE of mouth of Charleston Harbor in a creek off the intracoastal waterway	7.2-32.0	27.4-36.2	0.8-10.7	0.7 at mlw	shell hash with very little mud, 2 small oyster bars in upper 1/2 partially exposed at low tide	201

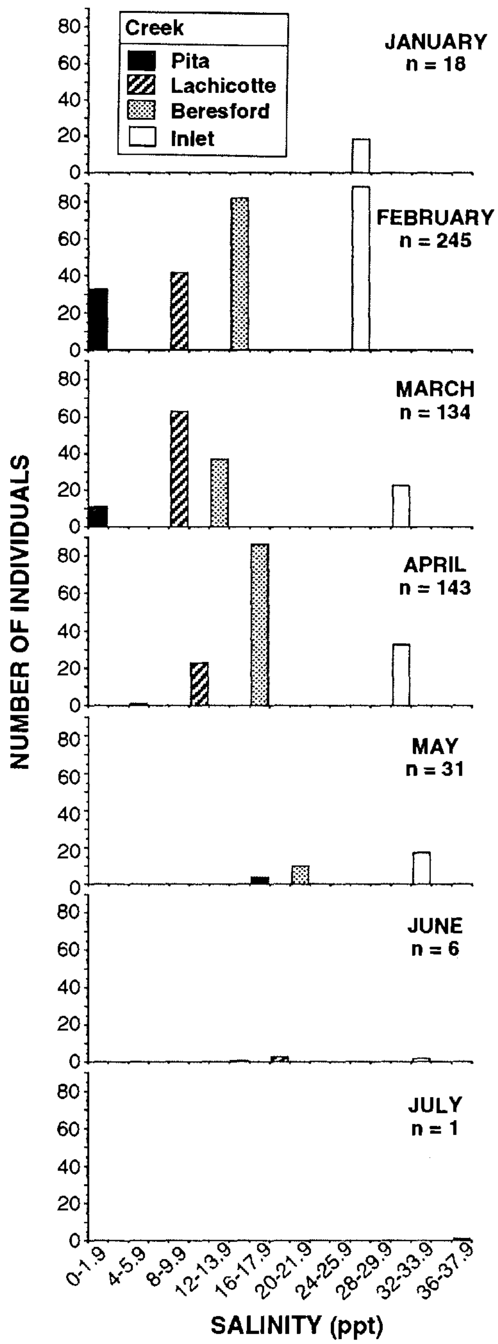

Figure 6.8. Abundance of juvenile summer flounder relative to salinity in four Charleston Harbor estuarine system marsh creeks (Fig. 2.7B) collected by a rotenone / block net method during 1987 by the South Carolina Marine Resources Center. Data based on Wenner et al. (1990).

Table 6.2. Physical characteristics of four marsh creek study sites in lower Chesapeake Bay and the ocean side of the eastern shore of Virginia (Fig. 2.1) sampled monthly from June - November in 1989 and May - November in 1990 (Daniel in prep). Fishes were collected by setting paired block nets upstream and downstream of the sites, releasing rotenone upstream, and then dip-netting and seining.

(SITE NO.) LOCATION	TEMPER-ATURE (°C)	SALNITY (ppt)	MEAN LOW WATER (m)	SUBSTRATE	VEGETATION	TOTAL NO. SUMMER FLOUNDER
(1) small tributary of the Poropotank River; ~3.1-6.1 m wide, ~30.5 m long	15-31	3-11	0.3-0.5	shell hash and very muddy	off _Spartina_ marsh, some _Juncus_	0
(2) in Goodwin Islands at mouth of York River; ~9.1 m wide, ~30.5 m long	16-30	15-24	0.9	hard-packed mud and shell hash in center, very muddy sides	off _Spartina_ marsh; _Spartina_ island in center	26
(3) creek off main channel entering town of Wach-apreague; ~6.1 m wide, ~30.5 m long	15-30	26-29	0.8-0.9 (hole= 1.1-1.2)	shell hash in cen-ter and steep muddy sides	none	59
(4) behind Parramore Island, close to mouth of Little Machipongo Inlet; ~6.1 m wide, ~30.5 m long	17-28	28-33	0.15-0.2 (hole=1.2)	sandy mud	off _Spartina_ marsh	68

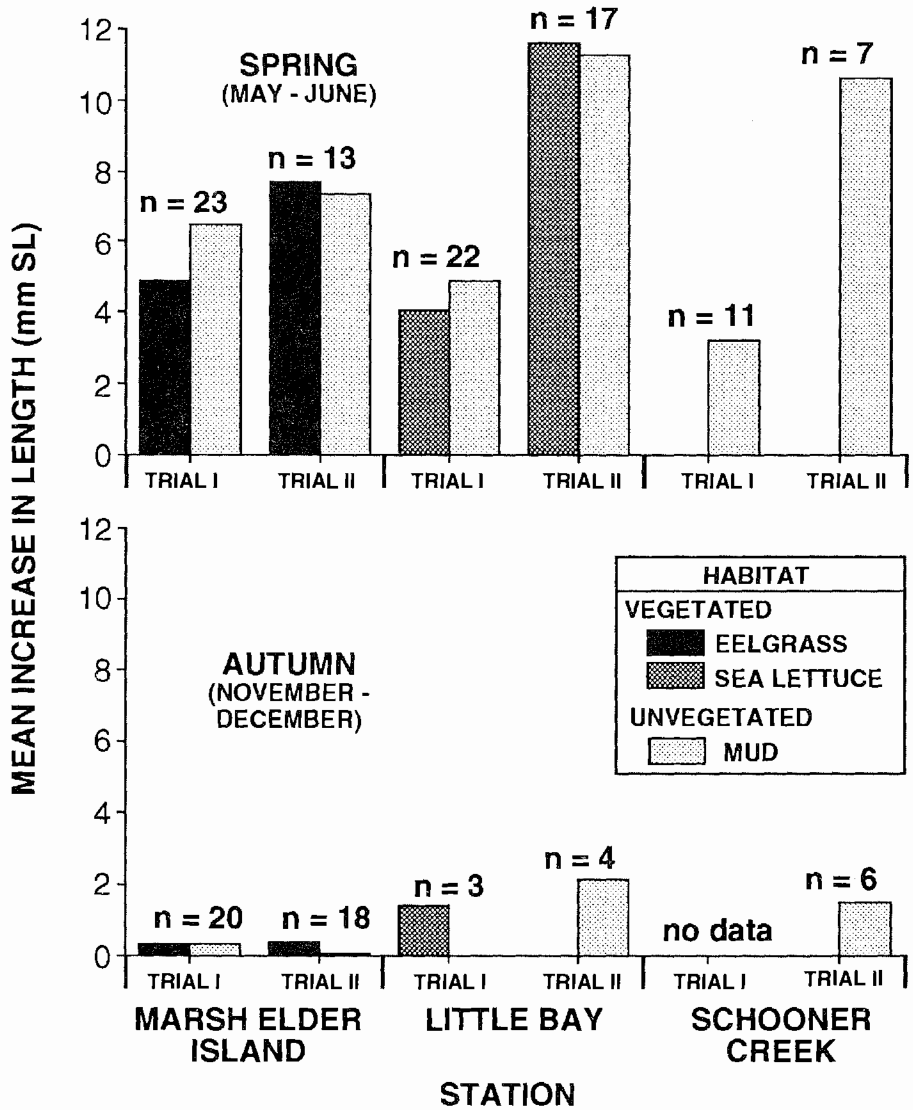

Figure 6.9. Habitat-specific growth of juvenile summer flounder held in cages (6 mm mesh) at three sites in the Great Bay-Little Egg Harbor estuarine system (Fig. 2.7A) during spring and autumn 1991. Two trials of 10 - 11 days duration were conducted at each station during each season. For each trial, four cages containing juvenile summer flounder (n = number of individuals used in each trial) of 12 - 41 mm SL were deployed: two on vegetated substrate (eelgrass = Zostera marina; sea lettuce = Ulva lactuca) and two on adjacent unvegetated substrate (mud). Adapted from Keefe and Able (1992).

stage as had been observed in laboratory experiments (Keefe and Able 1994). At temperatures below 2 – 3°C, significant mortality has been reported in laboratory experiments (Malloy 1990; Malloy and Targett 1991; Szedlmayer et al. 1992; Malloy and Targett 1994; Malloy and Targett in press) and this may be an important source of mortality affecting subsequent year–class strength. The impact of low temperatures may vary between years depending on the severity of winter. During spring and summer, growth rates have varied from approximately 0.5 – > 1.0 mm/day for recently settled individuals (Keefe and Able 1992) to a range of 1.5 – 1.9 mm/day for young–of–the–year juveniles (Szedlmayer et al. 1992; Rountree and Able 1992a). Estuarine juveniles with ultrasonic tags that were tracked for 1 – 33 days in Schooner Creek in Great Bay (Fig. 2.7a) were observed over a wide range of temperatures (16.0 – 28.0°C), salinities (22 – 35 ppt) and oxygen levels (2.4 – 8.9 ppm), but they generally stayed within narrow limits for these parameters (Szedlmayer and Able 1993). The mean values for each fish were much more restricted for temperature (22.3 – 24.9°C), salinity (27 – 31 ppt) and dissolved oxygen (5.9 – 6.8 ppm).

SUBSTRATE

Recently settled individuals have been collected in estuaries on the eastern shore of Virginia in depths typically less than 2 m where the substrate was composed of more than 50% very fine sand, silt and clay (Wyanski 1990). In North Carolina estuaries, similar–sized individuals were abundant in shallow (< 1 m) areas but were also found in slightly deeper areas (1.5 – 3 m). They were most abundant over sandy substrates (Burke et al. 1991). In laboratory experiments with the same population, juveniles (14.7 mm ± 1.2 mm SL) preferred sand substrate (< 5% silt–clay) over mud substrate (> 95% silt–clay) regardless of availability of prey (Burke 1991). This same preference for sand was observed for similar stages in the laboratory for a New Jersey population (Keefe and Able 1992). In marsh creeks in Charleston Harbor (Fig. 2.7b), similar–sized individuals were abundant over substrates that ranged from mud to sand and shell hash with occasional oyster bars (Table 6.1).

Larger young–of–the–year in North Carolina have been most abundantly collected where sand sediments or a transition from fine sand to silt and clay occurred and less abundantly where silt and clay predominated (Turner and Johnson 1973; Powell and Schwartz 1977). They also occurred abundantly in marsh creeks with soft mud bottoms and some shell hash in southern New Jersey (Szedlmayer et al. 1992; Rountree and Able 1992a), Virginia (Table 6.2) and South Carolina (Table 6.1). In Virginia, these larger individuals occurred over shallow sand, deep sand and deep fine sediments (Wyanski 1990) as well as in eelgrass beds (Orth and Heck 1980; Lascara 1981; Weinstein and Brooks 1983).

Habitat quality, as measured by relative growth, was evaluated with caging experiments in Great Bay–Little Egg Harbor (Fig. 2.7a; Fig. 6.9). Growth of recently settled and small juveniles (17 – 41 mm SL) based on caging experiments was variable in spring (range 0.18 – 0.89 mm/day). Growth did not appear to be strictly related to the habitats tested (eelgrass and adjacent unvegetated substrate, sea lettuce and adjacent unvegetated substrate and marsh creek). The fastest growth occurred in shallow bays and marsh creeks.

BEHAVIOR

Tagging studies in Long Island (Poole 1962), New Jersey (Hamer and Lux 1962; Murawski 1970a) and Maryland (Jesien et al. 1992) estuaries indicate that a large proportion of juveniles tagged in estuaries in the summer return to the same system during the following summer. Diel movements of estuarine juveniles have been studied in two habitat types, marsh creeks and eelgrass habitats, and in the laboratory with sand and mud substrates. In the laboratory, recently settled juveniles exhibited a diel pattern of burying behavior that was influenced by several other variables as well, including substrate type, water temperature, tide and the presence and type of predator (fish or shrimp; Keefe and Able 1994). These individuals buried more during the day, especially at the time of high tide. In Great Bay, ultrasonically tagged individuals followed a regular diel cycle of movements in the 1–km–long Schooner Creek (Fig 2.7a; Szedlmayer and Able 1993). These young–of–the–year individuals (210 – 254 mm TL) spent most of the time at the mouth of the creek during the July–September study period. Movements up the creek typically occurred on night flood tides followed by a return down the creek on the following ebb tide. These tide–mediated movements were for feeding on resident marsh creek fishes and crustaceans (Rountree and Able 1992a) and may have been influenced by low dissolved oxygen conditions in the upper portion of the creek, especially on night low tides (Szedlmayer and Able 1993). In North Carolina, some individuals move onto the surface of regularly flooded salt marshes during flood tides (Hettler 1989). In both field observations in Chesapeake Bay and laboratory experiments (Lascara 1981), juveniles fed in and at the edge of patchy seagrasses (Zostera marina and Ruppia maritima) while displaying an ambush predator strategy. In these habitats most feeding occurred in the morning.

Seasonal movements of larger juveniles from estuaries occur as temperatures are dropping in autumn but this pattern may vary with latitude, water depth of the estuary and temperature. In Great Bay (Fig. 2.7a), juveniles migrated out of marsh systems in the late summer and early fall. In one instance, a single individual was tracked from Schooner creek, through Little Egg Inlet and into the ocean, a distance of about 1.5 km (Szedlmayer and Able 1993). In North Carolina, it has been assumed that juveniles overwinter in the estuaries (Powell and Schwartz 1977). However movement offshore, especially of larger individuals, may occur in late summer (A. Powell, pers. comm.), which may account for the smaller sizes reported for young–of–the–year at the end of the year (Powell 1982) relative to more northern populations. A similar migration offshore with increasing size has also been suggested for Georgia populations (Music and Pafford 1984).

Chapter 7
Offshore Juveniles

INTRODUCTION

Juveniles join adults in an offshore migration, but details are lacking. Some juveniles that spend the first summer in estuaries move onto the continental shelf as temperatures decline in the fall or as they reach larger sizes. After overwintering on the shelf, many move back into estuaries for the second summer. Details of their habitats and other aspects of the biology are not well-known because they are not frequently differentiated from adults. For purposes of this treatment, offshore juveniles are less than 320 mm in the fall, winter and spring.

SPATIAL AND TEMPORAL DISTRIBUTION

Juveniles appear to make seasonal migrations similar to those of the adults. They leave the estuaries during the summer or early autumn throughout much of their range. In the Middle Atlantic Bight, young-of-the-year have been found exclusively on the inner continental shelf in fall surveys (Able et al. 1990) and this pattern was evident in more recent surveys as well (Fig. 7.1). In the northern Middle Atlantic Bight, most collections were very close to shore while farther south they were found farther out on the shelf. In the winter, this year class was distributed off the middle and outer continental shelf from Long Island to Cape Hatteras. By spring, portions of this same year class were still found near the edge of the continental shelf but some individuals had already moved back inshore.

In the South Atlantic Bight (Fig. 7.2), the pattern of movement from the estuaries onto the continental shelf may differ in timing. South Atlantic Bight trawl surveys in depths of less than 10 m (Beatty et al. 1989; Wenner and Sedberry 1989) indicate that small juveniles (100 – 200 mm TL) could be found as early as June and that their numbers increased through July and August, when the modal size was approximately 200 mm TL. They were especially abundant at sample locations adjacent to major inlets (Beatty et al. 1989; Fig. 7.3). By September through November they were collected

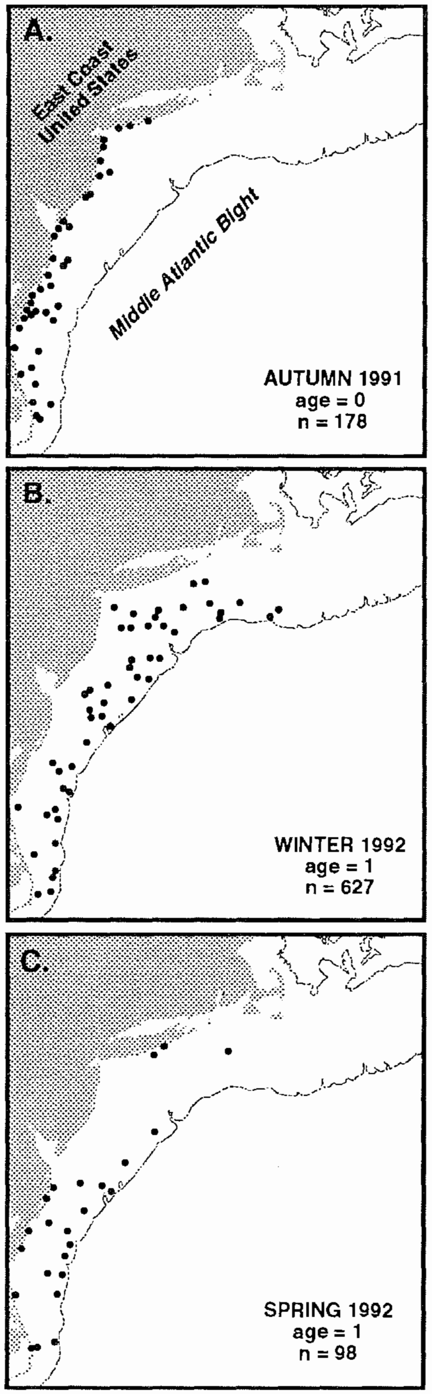

Figure 7.1. Distribution of summer flounder juveniles (< 320 mm TL; 0 - 1 year of age) from National Marine Fisheries Service (NMFS), Northeast Fisheries Science Center (NEFSC) groundfish surveys for A. autumn, B. winter, and C. spring, 1991 - 1992. Sampling was conducted by stratified random design in the Gulf of Maine to Nova Scotia, on Georges Bank, and in the Middle Atlantic Bight (Fig. 2.1) using 0.5 hour tows of a #36 Yankee trawl with a 12.7 mm mesh liner in the codend . The 1000 m contour is shown. Collections where no juveniles were caught are omitted. (Adapted from maps provided by G. Shepherd, National Marine Fisheries Service, Woods Hole Laboratory, Massachusetts).

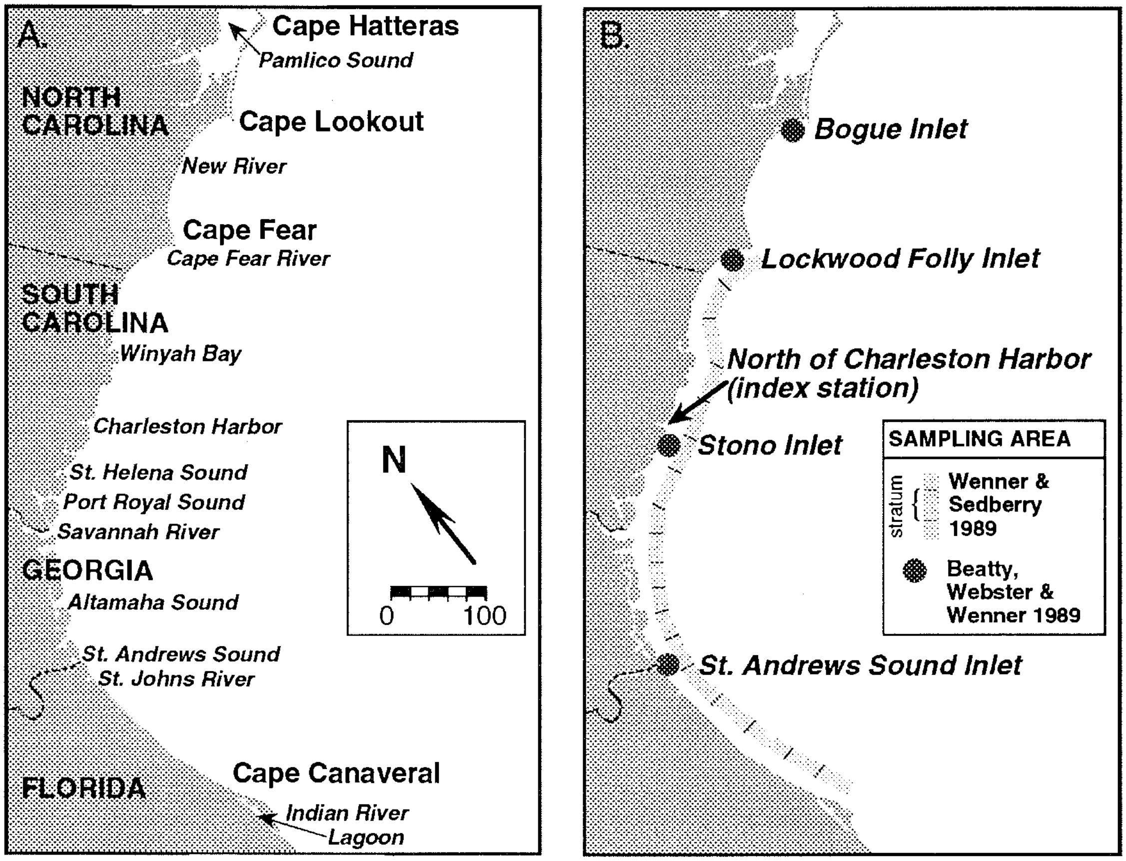

Figure 7.2. A. South Atlantic Bight (region between Cape Hatteras, North Carolina, and Cape Canaveral, Florida) with major capes, bays and rivers indicated, and B. sample areas for two South Atlantic Bight inner continental shelf (< 10 m) trawl surveys. Wenner and Sedberry (1989) sampled at randomly chosen sites within each stratum during 1980, 1981 and 1982. Beatty et al. (1989) sampled four inlet locations and an index station during 1987 and 1988. Three sites were sampled at each location; a within inlet site, a beach site and an off-beach site.

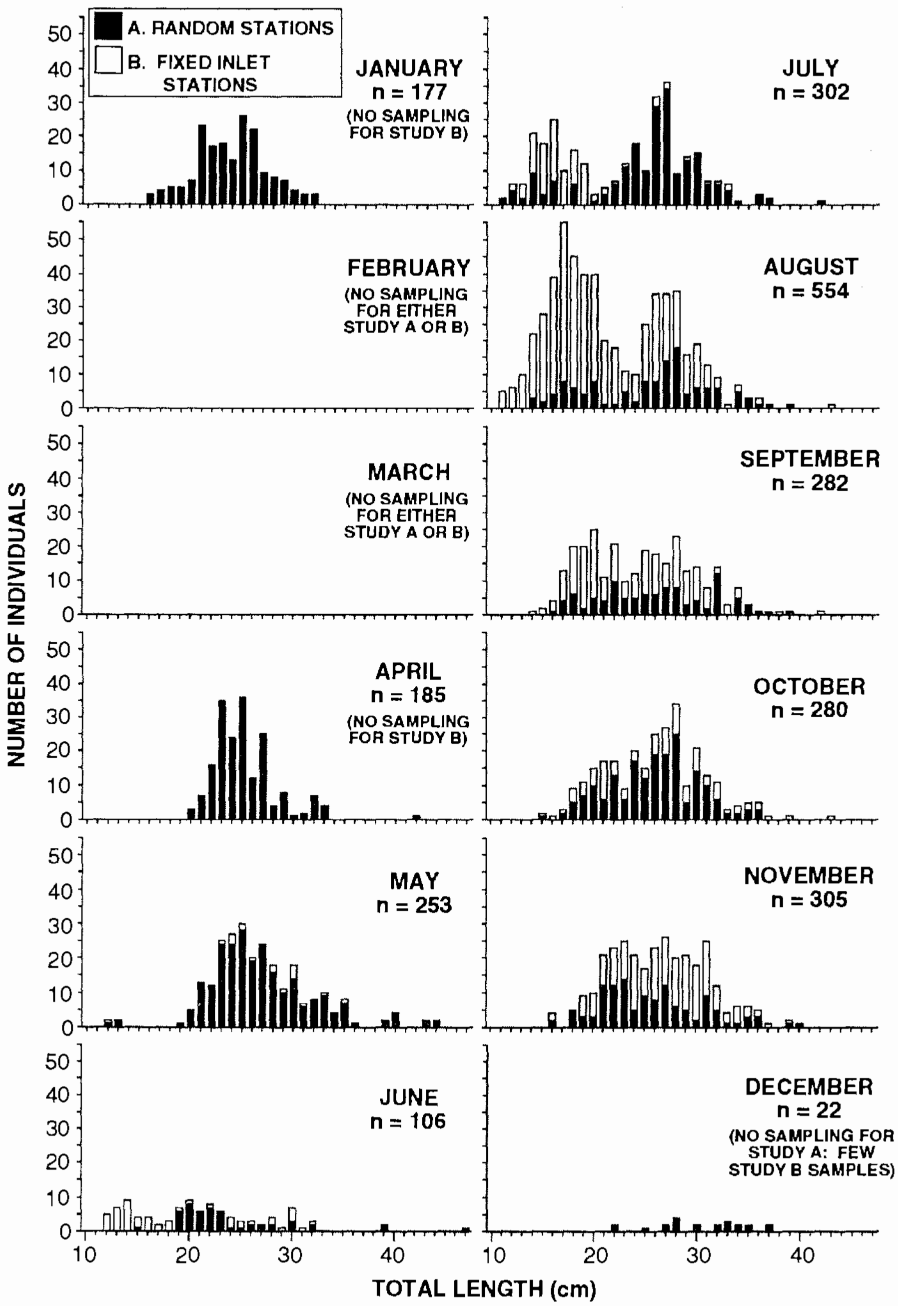

Figure 7.3. Monthly length-frequency distributions for juvenile and adult summer flounder from two trawl surveys conducted in nearshore waters (< 10 m) on the South Atlantic Bight inner continental shelf (Fig. 7.2): A. random stations sampled between Cape Fear and Cape Canaveral during 1980 - 1982 (Wenner and Sedberry 1989), and B. fixed stations sampled outside four major inlets between Cape Fear and Georgia during 1987 - 1988 (Beatty, Webster and Wenner 1989).

both near the shore and at inlets. During the winter, sampling was less frequent in both these programs, but juveniles were abundant near the shore in January. This same year class is well represented at these areas in April and May through July and August, which indicates that a portion spend the summer on the shallow inner continental shelf.

TEMPERATURE

In the Middle Atlantic Bight collections during 1970–1979, juveniles were most abundant at bottom temperatures greater than 15°C (Sissenwine et al. 1979), but nothing else is known primarily because juveniles and adults are not differentiated.

Chapter 8
Estuarine and Offshore Adults

INTRODUCTION

The adult life history stage of summer flounder begins when individuals reach sexual maturity. Based on aging and maturation studies (Poole 1961; Eldridge 1962; Smith 1969; Powell 1974; Smith and Daiber 1977; Morse 1981; Smith et al. 1981; Gillikin and Holland unpublished), the majority become sexually mature at sizes as small as 240 – 270 mm TL for males and 300 – 350 mm TL for females (Morse 1981). The habitats occupied by adults are largely determined by their extensive migratory patterns (Figs. 2.10, 2.11). Details of their seasonal distribution are limited to large–scale trawl surveys. These have been more intensive and extensive in the Middle Atlantic Bight than in the South Atlantic Bight and this is reflected in the following account in which we combine the treatment of adults in estuarine and continental shelf habitats.

SPATIAL AND TEMPORAL DISTRIBUTION

In the Middle Atlantic Bight and northern South Atlantic Bight, adults overwinter on the outer continental shelf (70 – 155 m depth; Grosslein and Azarovitz 1982), migrate inshore to shallow inner continental shelf and estuarine waters in spring, and begin offshore migration back to the outer continental shelf in autumn (Figs. 2.10, 2.11; Hildebrand and Schroeder 1928; Bigelow and Schroeder 1953; Grosslein and Bowman 1973; Smith 1973a,b; Rogers and Van Den Avyle 1983; Able et al. 1990) or as early as August in some cases (Schwartz 1961a,b). Gonad maturation may begin as early as late–summer in Middle Atlantic Bight estuaries (Schwartz 1961a,b; Smith 1969; Smith and Daiber 1977), and spawning occurs during offshore migration (Eldridge 1962; Smith 1973a,b; Murawski and Festa 1976; Able et al. 1990). There is some evidence to suggest that the largest, older individuals eventually remain over the continental shelf all year (Festa 1977). However due to current fishing pressure, the majority of adults are only three years of age or younger (Terceiro 1993), and those individuals largely utilize estuarine and inner continental shelf waters in summer.

The seasonal patterns of distribution and abundance of adults in the Middle Atlantic Bight are largely reflected in the pattern of catches from the commercial fishery (Fig. 8.1), although these must be cautiously interpreted because the patterns may reflect the fisher's behavior rather than that of summer flounder. In January–March when water temperatures are coldest, they are clearly most abundant at the edge of the

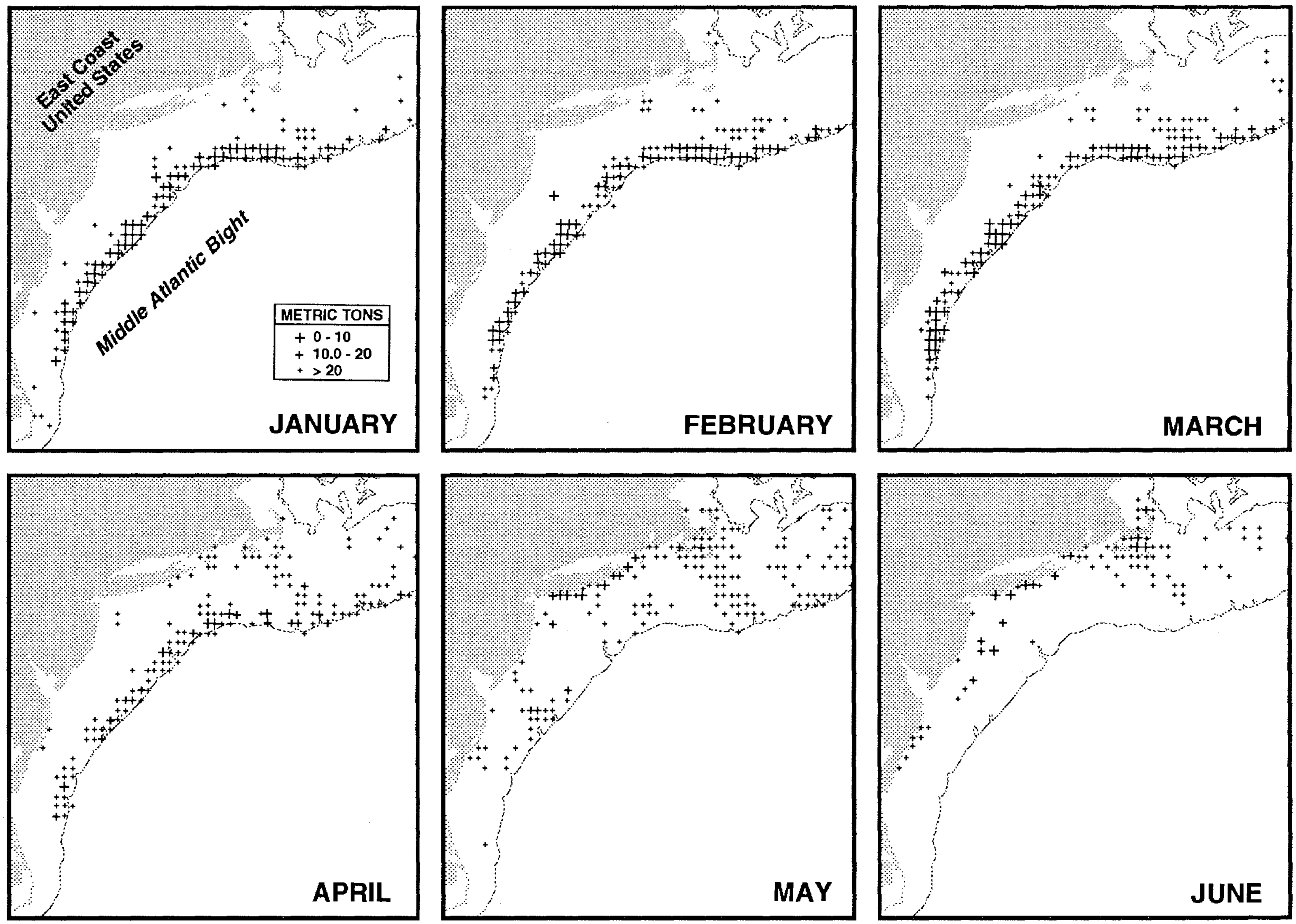

Figure 8.1. Average annual landings (metric tons per ten minutes square of latitude and longitude) of summer flounder captured in the United States commercial fishery during 1987-1989 from the Gulf of Maine to off Cape Hatteras (Fig. 2.1) by month. The 200 m contour is shown. (Adapted from maps provided by G. Shepherd, National Marine Fisheries Service, Woods Hole Laboratory, Massachusetts.)

Adults

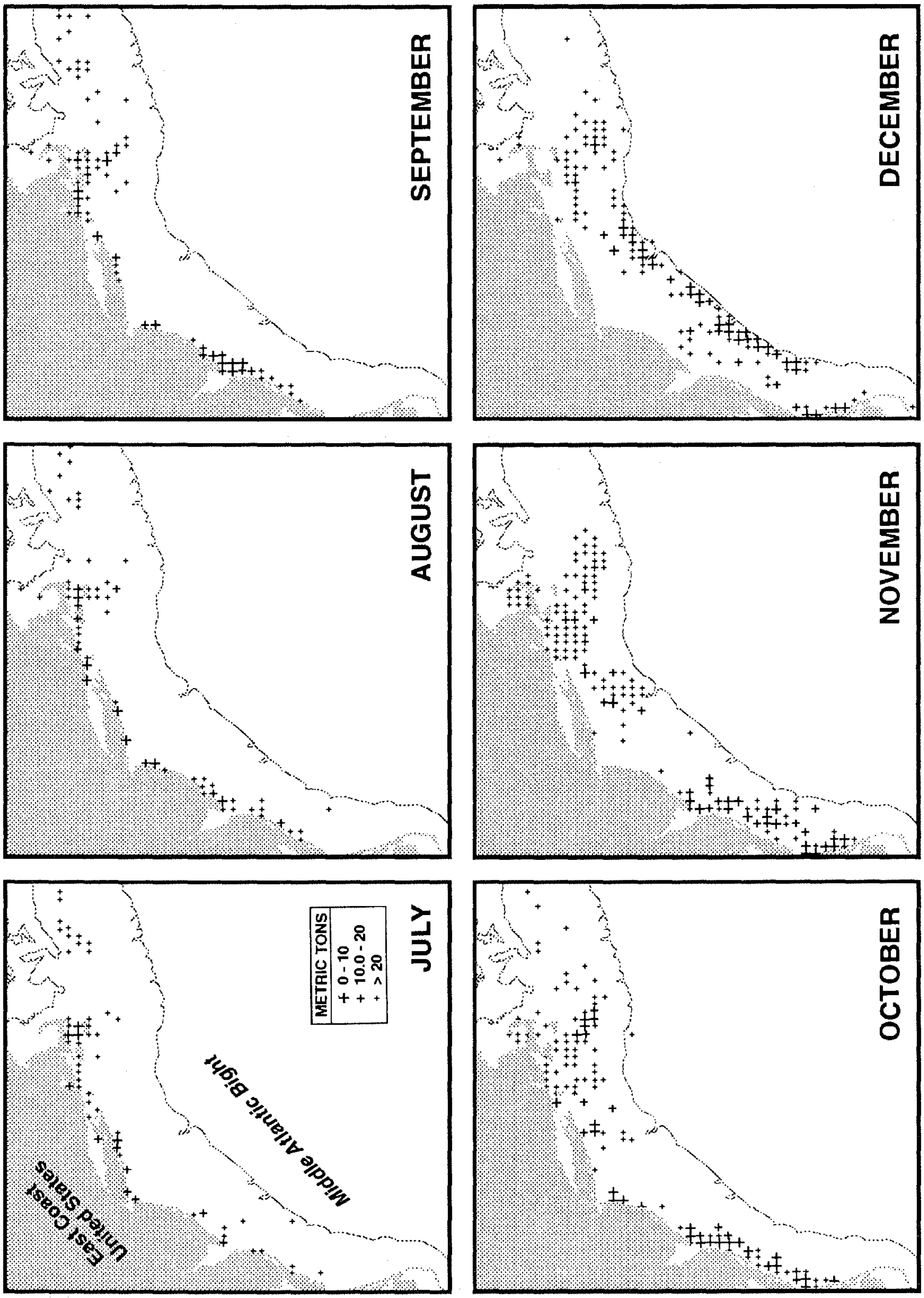

Figure 8.1 (continued).

continental shelf from the westernmost edge of Georges Bank to just south of Chesapeake Bay. By April, some catches are reported in shallower waters from off Long Island, the south shore of Massachusetts and on to Georges Bank. By May, this pattern is more pronounced with catches from inner continental shelf waters from Georges Bank south to Maryland. At this time there are much lower catches at the edge of the shelf. Catches decline on the shelf through June and July, but they begin to increase in August through September. By August, the first reports of catches north of Cape Cod occur and these continue through December. Most of the increased catches occur off southern Massachusetts and in the vicinity of Delaware Bay. By October, this trend continues while spreading over most of the Middle Atlantic Bight. In November, catches increase on the middle portions of the shelf, but none are reported from Georges Bank. By December, catches at the edge of the shelf have increased and the pattern begins to resemble that for January.

This pattern is supported by the fishery independent data from the long time series of trawl surveys conducted by the National Marine Fisheries Service in the Middle Atlantic Bight (Fig. 2.10). During the spring survey (February – March) they were most abundant at the edge of the shelf from Georges Bank south to the North Carolina – Virginia border. This center of abundance is typically in depths of 70 – 150 m (Azarovitz and Grosslein 1987). At the same time, smaller numbers were collected over middle to inner shelf waters. More fish were collected in inner shelf waters from Delaware Bay and south to Cape Hatteras. In autumn (September – November), fish were most abundant from Nantucket Shoals and shallower waters from Long Island to the mouth of Chesapeake Bay. Small collections were also made on the mid-shelf portions of Georges Bank. Earlier studies, based on trawl surveys prior to 1979 (Sissenwine et al. 1979), demonstrated a similar pattern with individuals widely distributed over the continental shelf in depths from 0 – 360 m during the spring. During summer and autumn, they occurred primarily in depths less than 100 m but in winter they were not found in water shallower than 70 m.

The occurrence of adults in estuaries in the Middle Atlantic Bight corresponds in time with their inshore movements on the continental shelf. This is evident from several systems. In Long Island Sound, individuals that are presumably age 1+ and older (Fig. 6.2) are present in April and May collections, become less abundant in June and July, and more abundant in August through October (Fig. 6.3). Fewer individuals are present in November, presumably because of the migration offshore. These are distributed throughout Long Island Sound although they are most abundant in the central portion. In Great Bay (Fig. 2.7a), based on an extensive creel survey from 1967 to 1976, adults (> 320 mm TL) are well represented in the catches, particularly from 1967 to 1972. Subsequently, the average size of fish landed was smaller during 1975 to 1976 (Fig. 8.2). In Maryland, adults are present in the estuary as early as April and through the summer (Jesien and Hocutt 1991). On the eastern shore of Virginia they occur from April – November (Richards and Castagna 1970). In Pamlico Sound

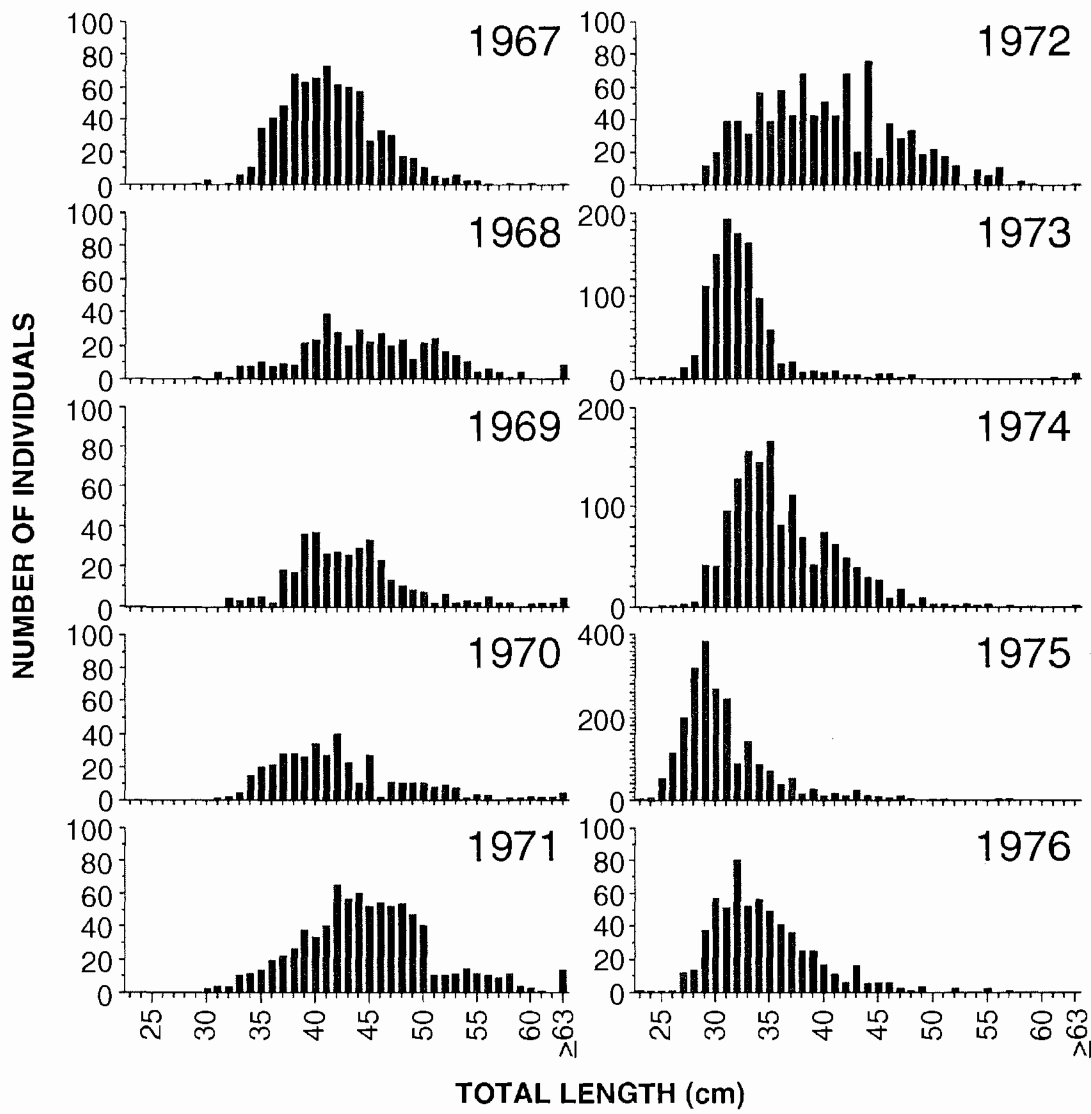

Figure 8.2. Length-frequency distributions of summer flounder in Great Bay (Fig. 2.7A) from the recreational fishery creel survey conducted by the New Jersey Department of Environmental Protection and Energy for the month of July over a ten year period (Murawski and Festa 1979).

(Fig. 2.7d), adults are notable by their absence (Fig. 6.7) and a similar situation also occurs in South Carolina (Wenner et al. 1990; Fig. 6.10) and Georgia (Dahlberg 1972; Music and Pafford 1984).

Information on offshore adults in the southern South Atlantic Bight is limited in part because summer flounder are not a major component of the commercial fisheries and also because the various species of Paralichthys are not differentiated. There are only a few adults (> 300 mm TL) captured during any month in South Atlantic Bight trawl survey programs on the inner continental shelf (< 11 m; Beatty et al. 1989; Wenner and Sedberry 1989). Prior surveys have captured few adults as well (Struhsaker 1969). Adults have been reported on ocean beaches and artificial reef habitats in spring and summer in Georgia and Florida (Miller and Jorgenson 1969; Gilmore et al. 1981) and on the outer continental shelf in the winter (Pearson 1932).

TEMPERATURE, SALINITY AND OXYGEN

Seasonal fluctuations in water temperature may be one of the primary factors controlling the timing of spring and winter migrations and spawning for summer flounder adults (Nesbit and Neville 1935; Ginsburg 1952; Edwards 1964). Spawning adults are found primarily in bottom water temperatures of 12 – 19°C (Smith 1973a,b; Festa 1974b) on the continental shelf habitat from Cape Cod to Cape Lookout. The cold bottom water present in the Middle Atlantic Bight in early autumn may limit the seaward extent of migration (Smith 1973a,b), and thus spawning habitat, during part of this time. In southern South Atlantic Bight waters, high temperatures may explain the absence of adults in estuarine habitats during spring and summer when young–of–the–year are present. Most adults occur in the high–salinity (> 28 ppt) portions of estuaries (Richards and Castagna 1970; Powell and Schwartz 1977; Mid–Atlantic Fishery Management Council 1990; 1991a,b; Burke 1991; Hoffman 1991; Noble and Monroe 1991; Szedlmayer et al. 1992).

Summer flounder oxygen requirements have not been well studied, however some reports indicate that episodes of hypoxia (low dissolved oxygen, ~< 3 ppm) or anoxia (absence of dissolved oxygen, 0 ppm) may be a common feature of the offshore habitat and may significantly impact local distribution and survival. One of the best–studied episodes of hypoxia to affect summer flounder occurred on the Middle Atlantic Bight continental shelf off New Jersey in midsummer to late–autumn 1976 (Swanson and Sinderman 1979). Reports of dramatically increased catch rates of adults in the ocean beach and estuarine recreational fishery indicate that these fishes were avoiding hypoxic areas offshore by moving into Great Bay (Murawski and Festa 1977). During this event, summer flounder were caught only in ocean areas free of hypoxic water, and divers observed dead adults on the ocean floor (Freeman and Turner 1977). Adult summer flounder were also reported among the victims of a fish kill washed onto Jones Beach, New York, in September 1951 during a period of offshore hypoxia similar to the 1976 episode (Perlmutter 1959). Other fish kills reported for 1968, 1971 and 1974 suggest that mortality due to hypoxia is not uncommon (Freeman and Turner 1977).

SUBSTRATE

Adult summer flounder are typically described as preferring hard, sandy substrate in which they can easily bury (Bigelow and Schroeder 1953; Schwartz 1964; Smith 1969). During their stay in Middle Atlantic and northern South Atlantic estuaries, however, adults exploit a broad range of lower and mid–estuary habitats including salt marsh creeks (Dahlberg 1972; Rountree and Able 1992a) and seagrass beds (Bigelow and Schroeder 1953; Orth and Heck 1980), which frequently have muddy or silty substrates, as well as sand flats (Dahlberg 1972; Gilmore et al. 1981). Adults with normal pigment can take on camouflaging patterns that resemble nearly any bottom substrate (Mast 1916).

Chapter 9
Implications for Resource Managers

Despite the importance of summer flounder to commercial and recreational fisheries, we lack a clear understanding of habitat requirements for all life history stages, particularly for the eggs and larvae. For instance, we know nothing about the role of transport processes on the behavior that influences the movement of transforming larvae into estuaries. We know somewhat more for the juveniles and adults, although the degree of understanding varies from region to region and is made more difficult because this species is highly migratory. In general, our understanding of habitat requirements for most life history stages is better for Middle Atlantic Bight than for South Atlantic Bight populations.

Of those habitat parameters for which information is available, it appears that temperature and dissolved oxygen have the strongest influence on habitat use and quality. Temperature affects the seasonal occurrence in estuarine habitats especially in autumn when declining water temperatures result in offshore migration. This is evident in the Middle Atlantic and South Atlantic bights where the difference in seasonal temperatures in estuaries is great. In the former, most individuals leave the estuary for the winter; in the latter, some portion of the population overwinters in the estuary. This pattern may vary with the severity of the winter.

Naturally varying temperatures may also influence survival during the first year and thus impact subsequent year–class strength. Low temperatures (2 – 3°C) cause mortality in transforming larvae and small juveniles. As a result, long and cold winters may cause increased mortality, especially in the northern portion of the range. Low temperatures also cause reduced growth and potentially increased predation rates because transforming larvae and juveniles may remain at smaller, more vulnerable sizes for longer periods.

Dissolved oxygen influences habitat–use patterns during episodes of hypoxia ($\sim < 3$ ppm) or anoxia (0 ppm). During the 1976 hypoxia/anoxia event off New Jersey, migration away from this stress caused fish to concentrate in nearby estuaries and resulted in increased fishing mortality. If migration is not possible, natural mortality can result with subsequent loss of a significant portion of the local population.

It is clear that estuaries are critical nursery areas throughout the range. High salinity, subtidal salt marsh creeks are the most important estuarine habitats because they provide optimal conditions for growth of juveniles, especially during the spring and early summer of the first year. Natural or anthropogenic impacts on these creeks (ditching, bulkheading, etc.) probably reduce the quantity and quality of summer flounder nursery habitat and eventually reduce the growth and survival of populations anywhere this occurs. The same may be said of high–salinity bays because these habitats are also used by older juveniles and adults during the summer growing season.

In the future, habitat research should focus on the transforming larvae and early juveniles because there is increasing evidence that year–class strength may be determined at this time. In addition, the fact that summer flounder are estuarine–dependent is critical because estuaries are the most likely to be affected by present and future human activities. This is especially relevant given the increasing human population levels expected on estuarine shores throughout the range of summer flounder.

Resource managers who can influence habitat decisions should begin to recognize that habitat loss and degradation has as an important effect on fisheries as overfishing, which has received disproportionately more attention. In addition, the habitat problem affects all fisheries, both commercial and recreational. Further, because of the highly migratory nature of summer flounder populations, habitat loss and degradation in one local area can easily influence fish abundance elsewhere. Lastly, habitat research and management for summer flounder can not operate in a vacuum and requires complementary information on stocks, life history, migrations, food habits, etc., as well as a broader understanding of habitat changes on geographical and decadal scales.

Glossary

Adult: Fish that is fully developed in morphology and meristic characteristics and has also attained sexual maturity.

Allometric: Growth of a part of an organism in relation to the growth of the whole organism or some other part of it.

Ambient temperature: The natural temperature of the water.

Anoxia: Absence of dissolved oxygen in water; 0 ppm.

Anthropogenic effects: Human impacts on the natural environment and wildlife.

Assimilation efficiency: The rate at which an animal converts food into body weight.

Benthic: On or pertaining to the bottom substrate (the benthos) in an aquatic habitat.

Buoyant: Tendency to float or rise in water.

C (°C): Temperature in degrees Celsius. To convert to Fahrenheit, use equation $°F = (9/5 \times °C) + 32$.

Clay: Sediments with grain size < 0.004 mm in diameter based on the Wentworth scale.

Cohort: All the individuals resulting from the same spawning event in a population.

Continental shelf: The edge of the continent that is submerged in relatively shallow ocean water.

Creel survey: A survey of the recreational fishery that quantifies the fish landings at public piers and docks. A "creel" is the traditional satchel in which anglers pack their catch during fishing, but a creel survey is not restricted to fish packed in creels.

Crustacean: Aquatic arthropods that typically have a body covered with a hard shell, including lobsters, shrimps, crabs, etc.

Diel: Occurring on a daily basis. For instance, patterns of faunal movement that are correlated with the cycles of light and dark are diel patterns.

Dissolved oxygen: Oxygen that is in solution with water, and is available for plant and animal respiration.

Ebb tide: Tidal stage at which ocean water flows in an offshore direction and estuarine waters flow toward the ocean.

Glossary

Egg: A reproductive cell produced by a female organism; an ovum. May refer to both fertilized and unfertilized state.

Electrophoresis: A means of detecting genetic differences among populations of a species by sampling proteins from members of the populations and analyzing the movement of these protein particles in a medium through which an electrical charge is passed.

Entrainment: The intake of relatively immobile, free–floating organisms with water drawn into an industrial, municipal or electric utility power plant.

Estuary (estuarine): Transitional environments between fresh water and salt water.

Etropus microstomus: Scientific name for the flatfish with the common name smallmouth flounder. This is a lefteye flounder in the same family (Bothidae) as summer flounder.

Fauna: All of the animal life in a given region or period of time.

Flora: All of the plant life in a given region or period of time.

Flood tide: The tidal stage at which ocean water flows in an inshore direction and into estuarine systems.

Family: In scientific classifications, an assemblage of genera possessing certain characters in common by which they are distinguished. Subordinate to phylum, class and order and superordinate to genus and species.

Genus: In scientific classifications, an assemblage of species possessing certain characters in common, by which they are distinguished (plural = genera). Subordinate to phylum, class, order and family and superordinate to species.

Gonad (gonadal): A reproductive organ or sex gland (ovary, testis) in which the gametes (ova, sperm) are produced.

Georges Bank: A large, shallow (< 5 m in some areas) bank on the continental shelf in the northern Middle Atlantic Bight that is an important fishery region (see Fig. 2.1).

Groundfish: Fishes that primarily inhabit the benthic environment, such as flatfish.

Habitat: The native environment or usual dwelling place of an animal or group of animals.

High tide: The period during which water depth is highest during a given tidal cycle. This occurs as the terminus of flood tide, prior to the beginning of ebb tide.

Hypoxia: Low levels of dissolved oxygen in water (~< 3 ppm) that are extremely stressful to most aquatic life.

Ichthyoplankton: Very small fishes that drift in the water column as plankton and are typically larvae.

Inshore: Refers primarily to estuaries behind the shoreline of the coast, however may also refer to continental shelf areas close to the shore. Inshore movement is toward the shoreline and/or beyond into estuaries.

Intertidal: Shallow areas along the shore and in estuaries that are alternately exposed and covered by the tides.

Juncus: Genus name of upper estuarine plants that are generally named rushes.

Juvenile: Young fish after attaining full adult morphology and meristic characteristics, but before sexual maturation.

Larva: Young fish between time of hatching and the juvenile stage. Includes period of yolk sac absorption and morphological and physiological transformation.

Low tide: The period during which water depth is lowest during a given tidal cycle. This occurs as the terminus of the ebb tide, prior to the beginning of the flood tide.

MARMAP: Marine Resources Monitoring, Assessment and Prediction. National Marine Fisheries Service long-term offshore plankton survey.

Mean low water (MLW): The average of all the low tide depths for a given region relative to a set datum (reference point) in the region.

Melanophore: Black and brown pigmented cells (chromatophores) in the epidermis (skin) of a fish that are capable of changing size, shape and color by expansion and contraction.

Meristic: Numerical characteristics of the skeleton and musculature of an animal that can be used to identify species or races within species, such as the number of caudal (tail) fin rays.

Middle Atlantic Bight: Zoogeographic marine region of the Atlantic Ocean that includes the estuarine and the continental shelf waters between Cape Cod, Massachusetts (including the northern extension of Georges Bank) and Cape Hatteras, North Carolina (see Fig. 2.1).

Migration: 1. Movement of fauna from one region to another. Usually refers to regularly observed patterns of movement based on season and/or life history stage of a migratory animal, however, the term may also refer to a localized, anomalous movement as well. 2. Movement of a subset within a larger system, e.g., eye migration of transforming summer flounder larvae entails the movement of the right eye to the left side of the head.

Morphology (morphological): The form and structure of an organism considered as a whole.

Morphometric: The size relationships of various morphological characteristics of an animal. For instance, the width vs. the depth, or the snout to eye length vs. the snout to caudal (tail) length. These relationships can be used to identify species or races within species.

Mud: Sediments with grain sizes within both the clay and silt ranges of < 0.0063 mm in diameter.

NEFSC: Northeast Fisheries Science Center.

NMFS: National Marine Fisheries Service.

NOAA: National Oceanic and Atmospheric Administration.

Offshore: Refers largely to the expanse of submerged continental shelf on the ocean side of the shoreline but may also refer to areas nearer the ocean edge of the shelf. Offshore movement is away from the shoreline.

Osmoregulation: The biological strategy employed by fish to regulate and maintain their internal water and salt concentrations against the water and salt concentrations in their surrounding environment; i.e., saltwater or freshwater.

Overwinter: To spend the winter, usually in a particular location or state of physiology.

Paralichthys dentatus: Scientific name for the fish with the common name summer flounder in the family Bothidae (lefteye flounders).

Pectoral fin: Paired fins located behind the head of a fish that articulate with the pectoral girdle (musculature).

Pelagic: In or pertaining to the water column as distinct from the benthic region.

Pigmentation: Coloration of tissues or cells.

Planktonic: Pertaining to the aggregate of passively floating or drifting organisms in a body of water.

Plankton bloom: An event where conditions are conducive to rapid reproduction of planktonic organisms in the ocean or other body of water.

Population: A group of individuals of any one species that are capable of interbreeding. Uses of the term vary from including all individuals throughout the range to including only those individuals in a specified region.

Ppm: Parts per million; units used to measure dissolved oxygen in water.

Ppt: Parts per thousand; units to measure the salinity of water.

Recruitment: Addition of new individuals to a life history stage by growth and survival (e.g., from larvae to juveniles), to a specified region by movement (e.g., from offshore to estuaries), or to a fishery by survival or based on capture gear (e.g., mesh size).

Ruppia maritima: Scientific name for the plant with the common name widgeon grass. Species of submerged angiosperm common to estuaries in the western Atlantic. A thin, flat-bladed grass that is anchored to the bottom by a root-rhizome system and produces stalk-like reproductive bodies.

Salinity: Salt content of water. The combined weight of certain salts dissolved in 1 kg of sea water, usually expressed as parts of salt per thousand parts of water (ppt).

South Atlantic Bight: Zoogeographic marine region of the Atlantic Ocean that includes the estuarine and continental shelf waters between Cape Hatteras, North Carolina and the southern tip of Florida (see Fig. 2.1).

Scophthalmus aquosus: Scientific name for the fish with the common name windowpane flounder, a lefteye flounder in the same family (Bothidae) as summer flounder.

Sand: Sediments with grain size ranging from 1.0 – 2.0 mm diameter (very coarse) to 0.062–0.125 mm in diameter (very fine) based on the Wentworth scale.

Silt: Sediments with grain size 0.004 – 0.062 mm in diameter based on the Wentworth scale.

Spawning: Fish reproduction process characterized by females and males depositing eggs and sperm into the water simultaneously or in succession so as to fertilize the eggs.

Spartina: The genus name of salt marsh grasses generally named cordgrasses. These are the common tall– and short–form grasses fringing the higher–salinity portions of sandy estuarine systems of the western Atlantic with the Middle Atlantic being their primary range.

Species: In scientific classifications, a group of individuals that share essential features, interbreed and produce similar progeny and possess the same scientific name. This name is typically two parts, consisting of the genus of that group (e.g., Paralichthys) followed by the "specific" name (e.g., dentatus). This name is unique among all life within that kingdom and is subordinate to phylum, class, order, family and genus.

Stellate: Descriptive term for melanophores that appear roughly star–shaped when expanded.

Stock: 1. A separate breeding population of a species. 2. Term used to identify a management unit of fishery species.

Standard length (SL): A method of measuring fish length from the anterior part of the head to the posterior margin of the hypural plates.

Stratified sampling: A study design whereby replicate sampling is conducted in predetermined subsets of a region, e.g., conducting the same standardized trawling program at surface, midwater and bottom in the water column, or at the same depth but within equal–sized blocks of an area.

Subestuary: Smaller system within a larger estuary such as a branching subtidal marsh creek with intertidal tributaries.

Substrate: General term for any benthic habitat.

Subtidal: The shallow water zone, often only a few feet deep, which is influenced by tides but never completely drained at low tide.

Thermocline: A steep, vertical temperature gradient resulting in stratification of the water column.

Tidal stream transport: A mechanism by which some marine life passively move into estuarine systems by entering the water column during flood tides and moving to the bottom during ebb tides, resulting in net up–estuary movement.

Total length (TL): A method of measuring fish length from the most anterior part of the head to the furthest extension of the caudal (tail) fin.

Transformation: Period of transition from the larval stage to the juvenile form characterized by both morphological and physiological changes.

Trophic: Feeding or feeding relationships between animals.

Ultrasonic tag: A fish–marking tag that emits a distinct radio frequency, allowing researchers to track fish movements with a receiver.

Ulva lactuca: Scientific name for the macroalga with the common name sea lettuce. Common to estuaries, it grows in broad, translucent, bright green sheets that are lobed or ruffled at the edges. Initially attaches to the substrate with a short stalk and later drifts free.

Year-class: The fish spawned and hatched in a given year. Distinct from cohort in that some species may have several spawning events in a given year resulting in several cohorts but one year–class.

Yolk sac: A bag–like ventral extension of the gut containing nutritive materials that first appears in the fish embryo and is later absorbed by the larva during the stage after hatching and before feeding.

Young-of-the-Year: Age–0 fish, or those animals born within the past year, which have not yet reached one year of age.

Zostera marina: The scientific name for the plant with the common name eelgrass. Species of submerged angiosperm common to estuaries in the western Atlantic. A broad, flat–bladed grass that is anchored to the bottom by a root–rhizome system and produces stalk–like reproductive bodies.

Appendix A
Comprehensive Summer Flounder Bibliography

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Author index to the Bibliography

Note: Numbers correspond to citations listed in Appendix A

Subject index to the Bibliography

Note: Numbers correspond to citations listed in Appendix A

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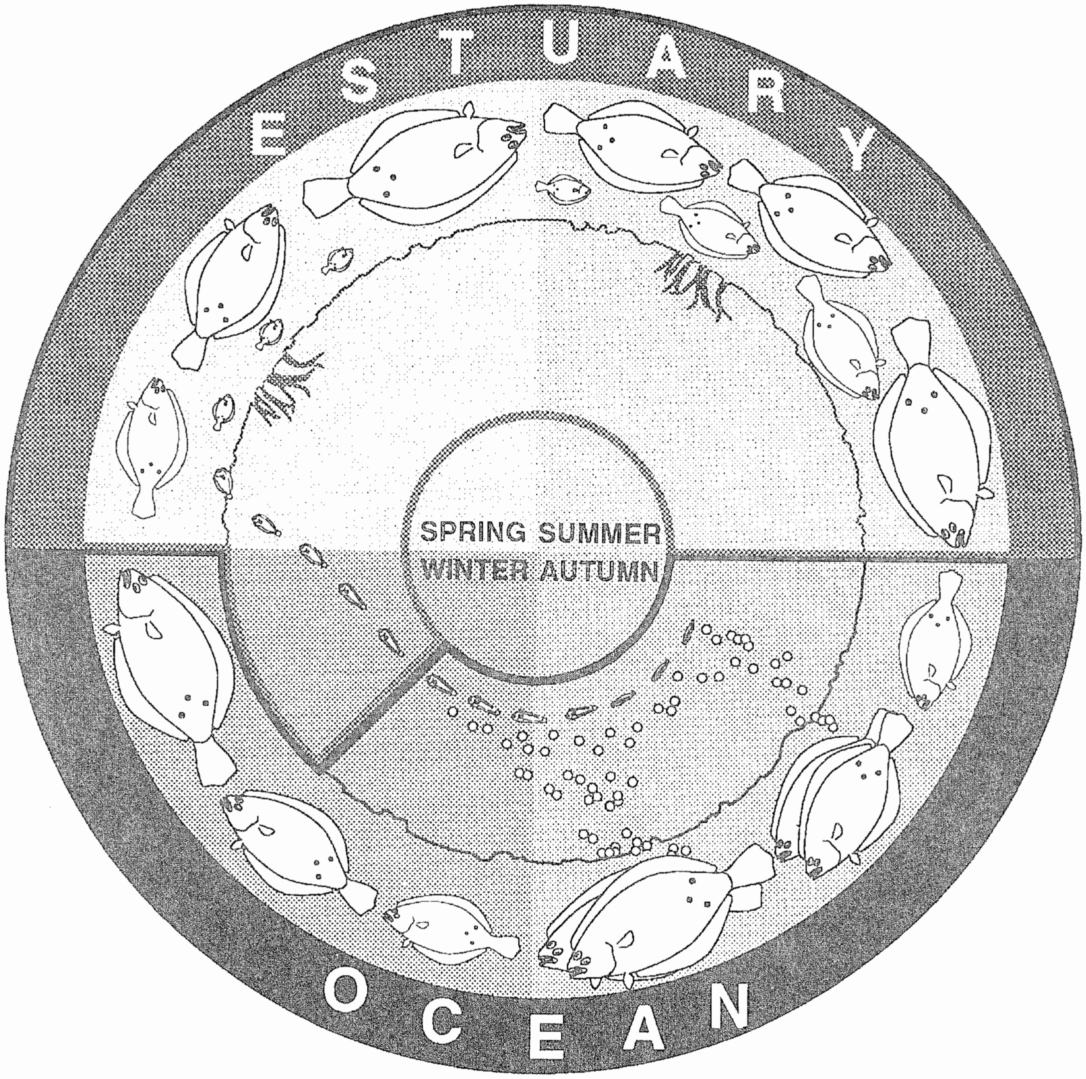

Life History of Summer Flounder. Adults generally spend summer in estuaries and on the shallow continental shelf, migrate offshore in autumn, spend winter in the ocean, and migrate back inshore in spring. Adults spawn in the ocean during autumn and winter. Eggs rise to near-surface waters and larvae hatch. Larvae are pelagic and begin development in the ocean but they enter estuaries during winter and spring to complete development and settle. Juveniles grow rapidly during the summer and join adults in offshore migration in autumn, returning to estuaries the following year.