Fish Distribution

Marvin D. Grosslein
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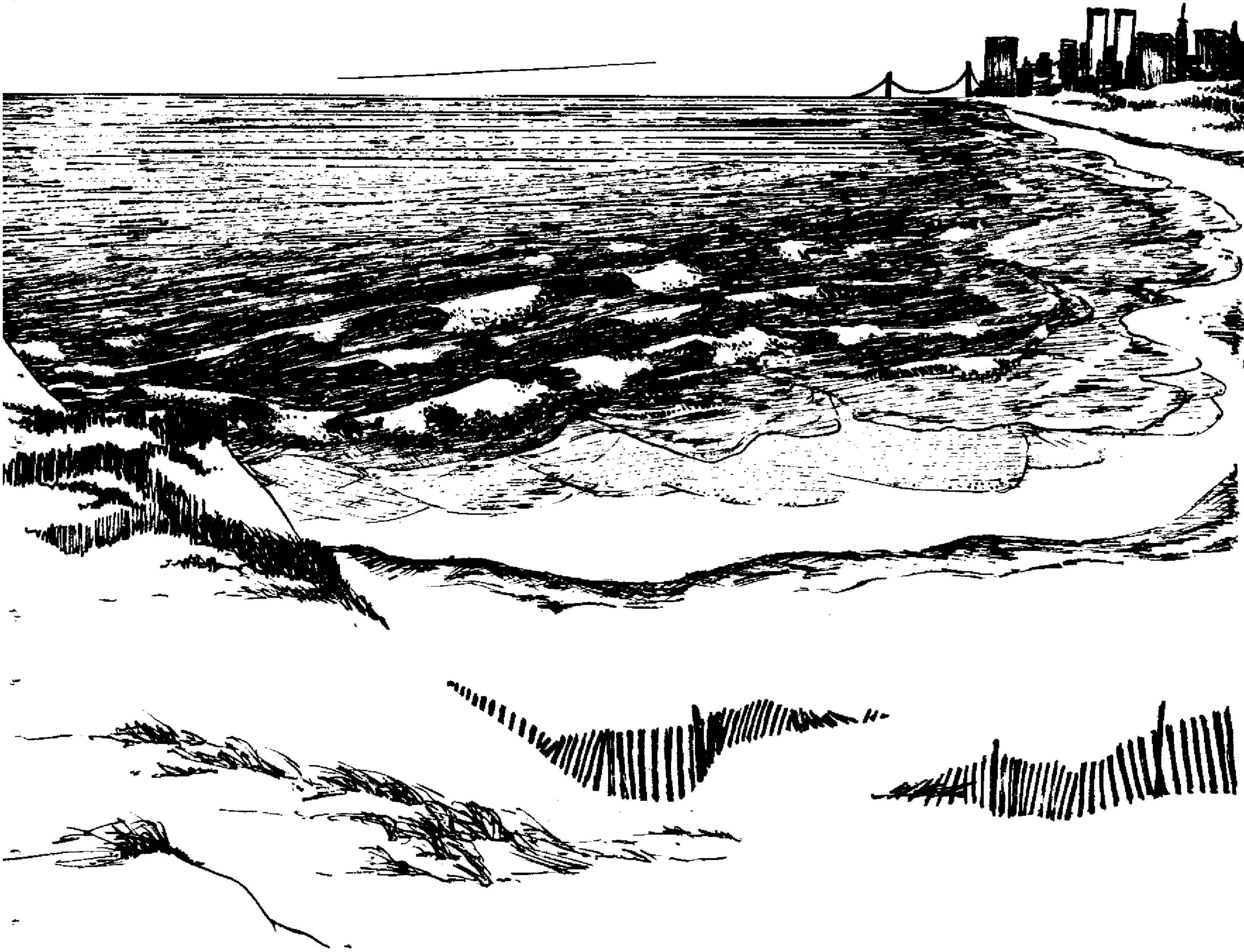

MESA NEW YORK BIGHT ATLAS MONOGRAPH 15

The offshore water in the bend of the Atlantic coastline from Long Island on one side to New Jersey on the other is known as New York Bight. This 15,000 square miles of the Atlantic coastal ocean reaches seaward to the edge of the continental shelf, 80 to 120 miles offshore. It's the front doorstep of New York City, one of the world's most intensively used coastal areas—for recreation, shipping, fishing and shellfishing, and for dumping sewage sludge, construction rubble, and industrial wastes. Its potential is being closely eyed for resources like sand and gravel—and oil and gas.

This is one of a series of technical monographs on the Bight, summarizing what is known and identifying what is unknown. Those making critical management decisions affecting the Bight region are acutely aware that they need more data than are now available on the complex interplay among processes in the Bight, and about the human impact on those processes. The monographs provide a jumping-off place for further research.

The series is a cooperative effort between the National Oceanic and Atmospheric Administration (NOAA) and the New York Sea Grant Institute. NOAA's Marine EcoSystems Analysis (MESA) program is responsible for identifying and measuring the impact of man on the marine environment and its resources. The Sea Grant Institute (of State University of New York and Cornell University, and an affiliate of NOAA's Sea Grant program) conducts a variety of research and educational activities on the sea and Great Lakes. Together, Sea Grant and MESA are preparing an atlas of New York Bight that will supply urgently needed environmental information to policy-makers, industries, educational institutions, and to interested people.

ATLAS MONOGRAPH 15 characterizes the fish fauna of the Middle Atlantic Bight and summarizes the ecology of 43 species of fish and shellfish, with emphasis on those aspects of life history considered most important in controlling their distribution and abundance. An attempt is made to assess the total impact of man's activities on fish populations, particularly the effects of fishing and pollution, and to distinguish between these effects and natural environmental factors. Much unpublished information of the National Marine Fisheries Service (NMFS) is included on the distribution of fishes and on the fluctuations in fish biomass in relation to fishing. Changes in populations are also examined in relation to seasonal and long-term temperature trends, and on pollution effects.

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MESA New York Bight Project

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CONTENTS

MAPS

TABLES

FIGURES

Acknowledgments

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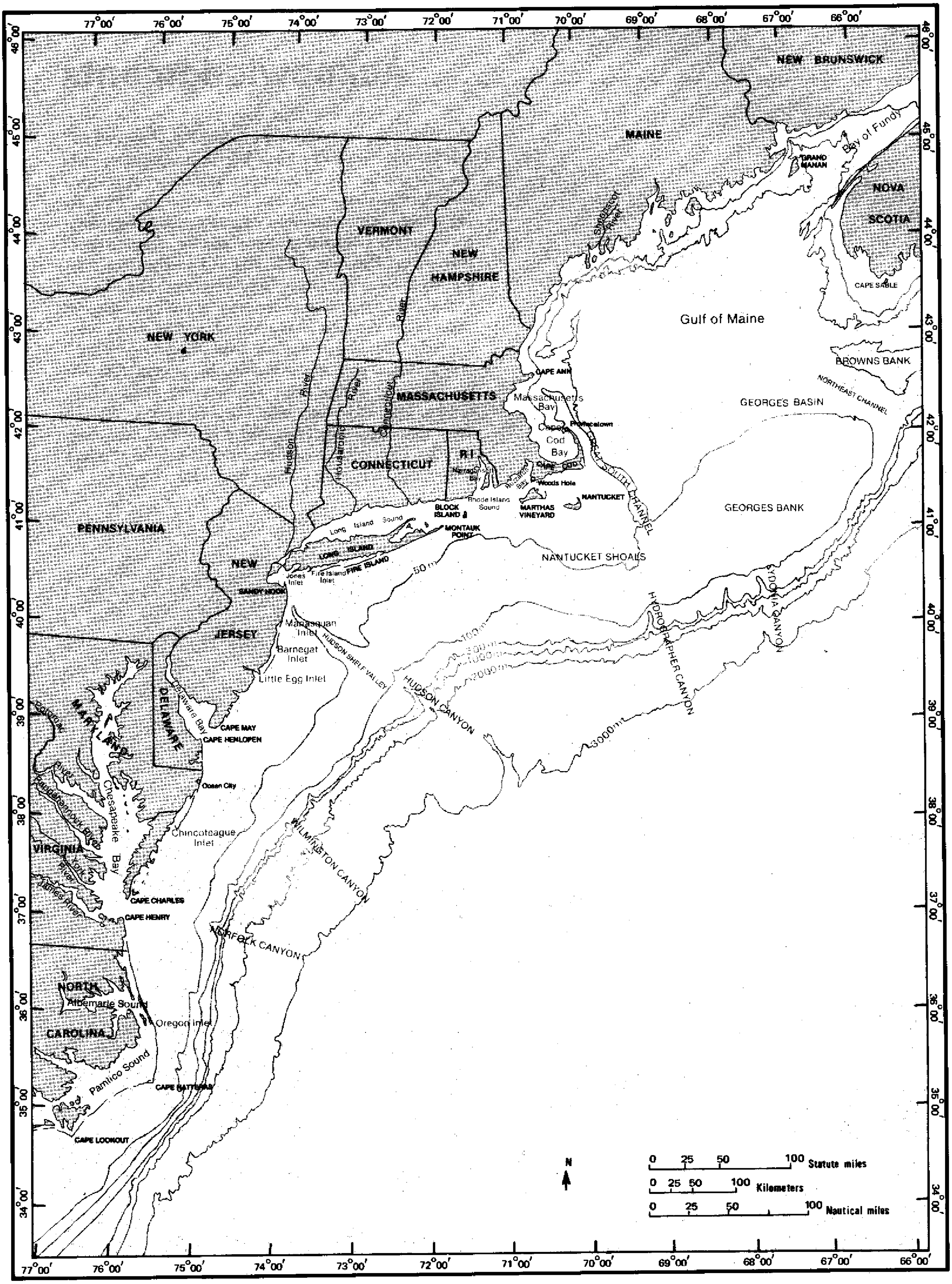
Map 1. General Locator



Abstract

The Middle Atlantic Bight is a complex ecosystem characterized by rapid latitudinal change in water temperatures and associated fauna. Subtropical and boreal fish fauna overlap in the region from Cape Hatteras to Georges Bank, resulting in a highly diverse fish community with large seasonal fluctuations in distribution. The general ecology of 43 important species of fish and shellfish in the Middle Atlantic Bight is summarized in terms of 1) distribution and seasonal movements, 2) population size and fisheries, 3) reproduction-growth-life span, 4) feeding interrelationships, and 5) environmental sensitivity to pollutants and natural environmental factors. Most species found in the Bight also spawn there; thus environmental conditions and water quality in the Bight control the reproductive success of the populations occurring there. The geographic and seasonal distribution of spawning in the Bight is described for major species through the distribution of their larvae, the life stage believed to be most vulnerable to natural environmental changes and pollution.

The monograph concludes with an examination of the relative importance of natural environmental factors versus man's impacts in controlling fish abundance. Population declines and reduced productivity due to pollution have been demonstrated for both shellfish and fishes although chiefly in inshore waters; as yet there is no clear evidence of major impact of pollution on populations in offshore waters but there is concern about possible undetected impacts and potential future effects because of growing pressures for substantially increased ocean dumping. Declines in biomass of many populations clearly have been related to excessive fishing pressure in recent years, and there will be a continuing need for some control over fishing mortality rates if we are to achieve optimum yields from our fishery resources. However, so far it appears that natural mortality factors operating in the first year of life exert the greatest control over annual fluctuations in fish populations.

Introduction

Evaluating the total impact of man's activities on fish and shellfish populations in the Middle Atlantic Bight is a difficult task. It requires that we distinguish between natural environmental effects and man-induced effects, although we have not yet gained an adequate understanding of the natural biological and physical processes controlling fish distribution and production.

This region and New York Bight in particular present difficult problems for researchers with respect to distribution of fishes because of environmental extremes encountered each year. Estuaries frozen in winter reach tropical temperatures in summer. Few resident fish occur, and most species are seasonal migrants resulting in distinctly different summer and winter populations.

From the standpoint of total population size, variability in survival of egg and larval stages is thought to be responsible for most of the large natural fluctuations frequently observed in fish populations, but we have not yet identified the actual mechanisms controlling survival at these early life stages. Physical environmental factors, predators, and larval food supply interact in complex ways in the natural environment, therefore, for example, it would be difficult to infer the impact of pollution on larval survival without a better understanding of the factors controlling growth and predation in these highly vulnerable early life stages.

After reaching the juvenile and adult stages, many species are subjected to heavy fishing pressure. For example, total biomass estimates for all finfish and squid from Cape Hatteras to the Gulf of Maine showed an overall decline of about 50% during the 1964-75 decade (Clark and Brown 1977). This decline was obviously related to the very large increase in foreign commerical fishing during that period. However, the changes in finfish biomass, particularly the rapid decline during the early 1970s, was heavily influenced by the extraordinary abundance of the 1967 year class of mackerel, which was followed by relatively weak mackerel year classes. The impact of this large year class of mackerel on other species may have been substantial as a source of food and as a competitor or predator (on larvae), but with our present knowledge we can only speculate. To understand the total effects of fishing, we need a much better understanding of the complex food web and the biological interactions among many species affecting growth, natural mortality, and reproduction.

In short, we are dealing with a large-scale and enormously complex ecosystem involving not only fishes and their physical environment but a vast array of other species and life forms upon which fish production depends. In order to put protection of environmental quality and management of living marine resources on a firm foundation, we need a much better understanding of this ecosystem than is presently available. Intensive research over a long period of time is necessary. In the meantime, decisions should be based on an appreciation of the complexity of the ecosystem, in particular, the interrelatedness of the various components, and on a thorough appraisal of the available life history information for important species, particularly those aspects most likely to be affected by environmental change relevant to exploitation and management by man. Such aspects include seasonal migrations, areas and times of spawning, ecology of egg and larval stages, growth rates and age at maturity, feeding interrelationships, and general sensitivity to environmental factors.

This monograph summarizes up-to-date information on these and other aspects of life history for 43 species of economically important fish and shellfish species of the Middle Atlantic Bight, and it provides a brief overview of the problems faced assessing production potential and man's influence on these components of the marine ecosystem.

In the past decade a number of atlases or inventories have appeared that describe the living marine resources of the US east coast. These studies were done largely in response to the need for baseline information and environmental impact analyses of impending offshore oil and gas production. They vary widely in scope, but all summarize significant information on major fish and shellfish populations and fisheries in the Middle Atlantic Bight region; some also consider marine mammals and birds as well as plankton and benthos. These serve as descriptive supplements to this monograph:

(1) *Coastal and Offshore Environmental Inventory—Cape Hatteras to Nantucket Shoals* (Saila and Pratt 1973), treats oceanography and the zoogeography and ecology of major biota (birds, mammals, fish, benthos, phytoplankton, zooplankton) in the region, and describes the nature of commercial and recreational fisheries including maps of the principal fishing areas.

(2) An extensive inventory of coastal resources, published in 1974 by The Research Institute of the Gulf of Maine, Public Affairs Research Center (1974). This is a three-volume compilation of data on socio-economic and environmental characteristics of the coastal zone and continental shelf waters from Sandy Hook, NJ, to the Bay of Fundy.

(3) An atlas published in 1976 by the Shell Oil Company (Gusey 1976) focuses on the fish and wildlife resources of the Middle Atlantic Bight with particular emphasis on estuarine habitats and coastal wetlands in relation to migratory waterfowl. It includes material on marine mammals and characteristics and recent trends in commercial and sport fisheries of the Bight.

(4) A comprehensive literature review on common marine fishes of the Massachusetts coastal zone was published in 1976 by the University of Massachusetts (Clayton et al 1976). Brief synopses are given for 57 species of coastal fishes with emphasis on range and distribution, population characteristics, reproduction, feeding and predators, and environmental disturbances.

(5) An atlas published by the University of Miami (Heald 1968) of principal commercial fish and shellfish resources on the continental shelf from Florida to New York shows general seasonal and geographic locations of the fisheries. This includes a brief indication of the landings (mainly 1965 data or earlier) in the South Atlantic as well as the Middle Atlantic Bight.

(6) A much more complete description of the mid-Atlantic fisheries is provided in the MESA New York Bight Atlas Monograph 16 (McHugh and Ginter 1978), which presents a history of the development of recreational and commercial fisheries (including foreign fishing) for all major fish and shellfish stocks of the mid-Atlantic, including annual landing statistics for the 1960-75 period and a discussion of the recent changes in population abundance in relation to environmental effects and management of the fisheries.

(7) A six-volume atlas involving the early life stages of the fishes of the Middle Atlantic Bight was prepared by the University of Maryland (Jones, Martin, and Hardy 1978). This atlas provides descriptions of egg, larval, and juvenile stages of more than 300 species of fish from the Bight and includes identification keys. Also, brief life history descriptions are given for all life stages including distribution, range, spawning migrations, and other movements.

(8) Wigley and Theroux (1981) published a quantitative inventory of the distribution, abundance, and species composition of the macrobenthic invertebrates from Cape Hatteras to Cape Cod. This census is based on an intensive series of standard quantitative bottom grab samples from the shore to the edge of the continental shelf, and distribution maps of the major taxonomic groups are related to depth, bottom temperatures, and geographic locations.

(9) MESA New York Bight Atlas Monograph 14 (Pearce and Radosh 1981) on benthos in New York Bight emphasizes distribution and abundance in relation to effects of environmental factors including pollution.

This monograph presents quantitative species distribution data based on unpublished records of the National Oceanic and Atmospheric Administration, National Marine Fisheries Service (NOAA/NMFS). For example, maps of the geographic and seasonal distribution of 28 species of marine fishes are based largely on unpublished trawl catch records from intensive and standardized research vessel surveys by the Northeast Fisheries Center (NEFC). The maps illustrate the relative density distribution of the whole population for most species, often encompassing the entire range of the species, and they represent part of a long and continuing time series of the standardized surveys that will permit comparisons with either past or future data on a quantitative basis. The principal focus of this monograph is on the Middle Atlantic Bight (Cape Hatteras to Cape Cod), but the surveys also include Georges Bank and the Gulf of Maine, and, therefore, the entire region (Map 1) is included in the species distribution maps. A total list of species caught on the 1973-74 trawl surveys is included in a brief section of zoogeography of the mid-Atlantic, and although the list is not a complete faunal list, it is particularly useful because of the standardized time series of sampling, especially for outer shelf fishes that have not been adequately covered in previous zoogeographic analyses. Another unique feature is a series of maps illustrating the distribution of larval stages of 27 species in the Bight. Such quantitative information is becoming more and more important as we are faced with the problems of evaluating site-specific environmental impacts.

The major part of the monograph consists of synopses of 43 species representing the most important fish and shellfish populations of the Bight. These synopses were prepared by NMFS fishery biologists, some of whom have conducted studies of certain species, incorporating the latest published and unpublished information on population biomass, distribution and migrations, feeding interrelationships, basic features of reproduction and growth, and documented sensitivity to environmental factors. Very brief descriptions of the principal commercial and recreational fisheries are also presented, and these generally complement or augment the descriptions given by McHugh and Ginter (1978). Inevitably, there would be some overlap with the earlier studies noted above, but the present monograph includes a unique quantitative data base representing a major addition to the knowledge needed for evaluating changes in marine fish populations.

Finally, the monograph includes a summary of pollution and its effects on marine fishes in the Bight, and a brief outline of major problems in obtaining the understanding needed for managing and protecting the Bight area ecosystem.*

Survey Methods

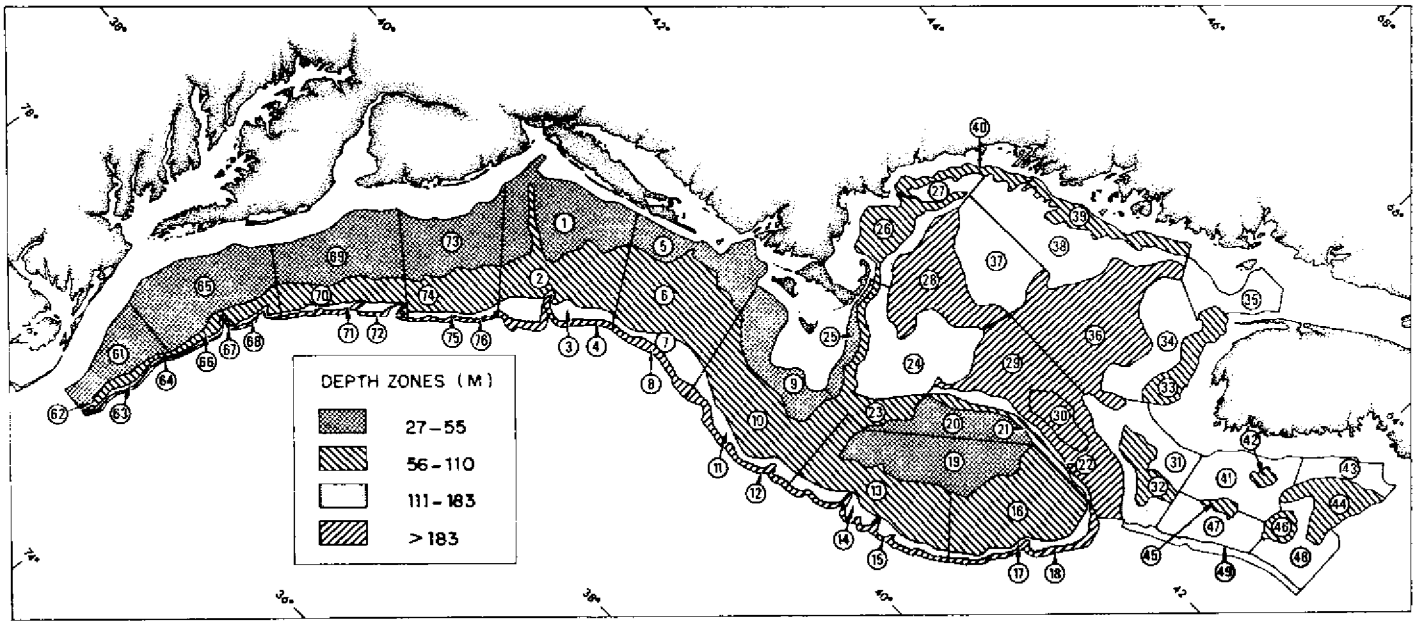
Distribution of most of the finfishes discussed in this monograph are based on bottom trawl surveys by NMFS research vessels. Since 1967, continental shelf waters more than 27 m (88.6 ft) deep from Nova Scotia to Cape Hatteras have been surveyed at least twice each year in spring and autumn. Coastal waters less than 27 m (88.6 ft) deep between Block Island and Cape Hatteras have been similarly surveyed since autumn 1972. Trawl catch data from these respective offshore and inshore surveys represent the most detailed source of information available on finfish distribution in the mid-Atlantic region as a whole.

The survey area was divided into smaller sampling areas called strata, whose size and shape are determined by geographic and hydrographic factors related to fish distribution (Map 2).** Seasonal movements of fishes are associated with seasonal changes in water temperature, and water temperature patterns are closely associated with depth; therefore, depth was the primary factor in selecting stratum boundaries. Other factors, such as bottom types and proximity to major estuaries, were also considered.

On each survey, trawl stations were randomly selected in each stratum, with approximately one station for every 1,000 km² (300 nmi²) offshore and every 500 km² (150 nmi²) inshore. This method assured representative sampling at all depths and a fairly uniform distribution of stations over the survey area. Further details on the rationale of this sampling design are presented by Grosslein (1969).

Nets used on the trawl surveys were modified commercial otter trawls designed for fishing on the bottom.

Map 2. Sampling strata used on NMFS bottom trawl surveys



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* Throughout this monograph the term "Bight" refers to the entire Middle Atlantic Bight. Subregions such as the New York Bight and Chesapeake Bight (Delaware Bay to Cape Hatteras) are so designated.

** Inshore Sampling Strata (not shown) were used for surveys in depths less than 27 m in the Bight.

Table 1. Trawls used in 1973 and 1974 surveys

Trawl	Survey series	Approximate Dimensions of Trawl Opening While Fishing: Horizontal Sweep (Wingspread)	Vertical Opening (Headrope)
#41 Yankee	spring offshore	11.8 m (38.7 ft)	4.6 m (15.0 ft)
#36 Yankee	autumn offshore	10.4 m (34.1 ft)	3.2 m (10.5 ft)
¾ size #36 Yankee	spring and autumn inshore	8.6 m (28.2 ft)	1.4 m (4.6 ft)

Trawls used in the 1973 and 1974 surveys selected for this monograph are described in Table 1.

Exact specifications and riggings of the #36 and #41 trawls are summarized by Grosslein (1974); specifications for the ¾ Yankee are on file at the NMFS Laboratory in Woods Hole, MA. All trawl hauls in the series were 30 minutes long at a speed of 3.5 knots (4 mph); the cod ends of all nets were lined with 1.3 cm (0.5 in) stretch mesh liner to retain small (juvenile) as well as large fish. The weight and length frequency of each species of fish and shellfish was recorded for each catch, and a variety of other biological samples or observations was obtained for selected species (scales and otoliths for determining age, maturity stages of gonads, stomach contents, for example).

Density distributions of all species represented by the trawl series are based on plots of actual catches (in pounds) for each standard haul. The reader must keep in mind that these are original catch data unadjusted for estimates of trawl efficiency. That is, when a trawl sweeps over a certain path on the bottom, only a portion of the fish in that path is actually captured. Some fishes are above the trawl, some escape laterally, some wriggle under the groundrope, and some swim back out of the trawl after going into it. The actual catchability or availability coefficients vary widely among species, and for different life stages of the same species with time of day, depth, and season—even for a given life stage of a single species. Finally, each type of trawl has its own catchability coefficient for any given species. We do not yet have accurate measures of these coefficients for any species for any one trawl, nor do we yet have accurate measures of the relative fishing power differentials among the three trawls. Proper adjustments to convert the catch per haul data for each trawl to a scale of absolute abundance would be a massive computing job, and at the present stage of our knowledge would result only in first approximations at best for most species. Since the relative abundance scale is sufficient for illustrating population density distribution, we have chosen to work with raw, unadjusted catch data. The main consequence is that the trawl catches of a species do not necessarily reflect its true abundance; hence we cannot use the unadjusted catch data to compare abundance of different species.

Further, the spring and autumn offshore survey abundance indices for any species cannot be compared directly, mainly because a larger trawl was used on spring surveys to improve catches of pelagic species such as mackerel and herring. The inshore surveys are not strictly comparable with the offshore surveys because a smaller trawl was used inside 27 m (88.6 ft); however, preliminary fishing power studies suggest that the differential between inshore and offshore trawls may not be very large.

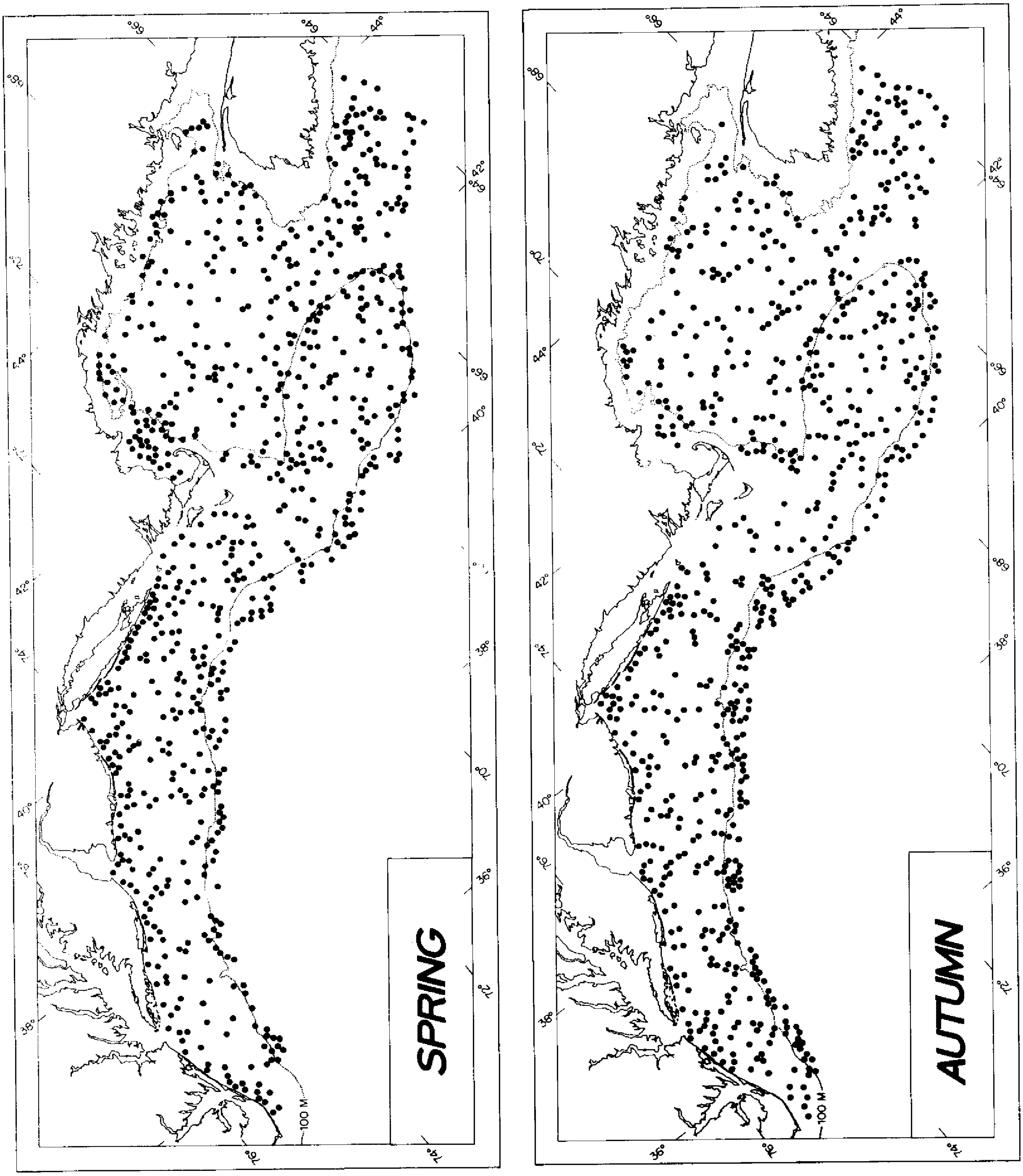
To provide a more generalized picture of density distribution for autumn and spring, the 1973 and 1974 offshore surveys were combined on a single plot. Autumn surveys were done in October and spring surveys in April for both years; and temperature conditions were comparable for both years. Only 1974 data were plotted for inshore surveys because inshore surveys were best synchronized with offshore surveys in 1974 and because the sampling intensity (number of stations per unit area) of the inshore surveys is about twice that of the offshore surveys. By pooling the offshore plots for 1973 and 1974, and combining with the 1974 inshore plot, we get a single plot for each season fairly representative of the *relative* population density distribution of each species. The timing of the cruises is given in Table 2 and the distribution of stations is shown in Map 3.

Distribution Data From Sources Other Than Trawl Surveys. Some species are either not available to bottom trawls or are caught in such small numbers that other sources of data must be used. For example, surf clam distribution is based on NMFS dredge surveys, and sea scallop, oyster, and blue crab distribution is based on commercial catch records. The specific source and characteristics of distributional data are described in the synopses for individual species. Larval fish distribution maps are based on a special series of plankton cruises, and methods are described in the section on larval fish.

Table 2. Cruise dates for map series

	Middle Atlantic Bight		Georges Bank	Gulf of Maine
	Offshore	Inshore	Offshore	Offshore
Spring 1973	16-30 March	—	9-24 April	2-15 May
1974	12 March-2 April	1-25 April	3-22 April	16 April-4 May
Autumn 1973	26 September-8 October	—	9-26 October	30 October-20 November
1974	23 September-9 October	23 September-4 October	10-20 October	21 October-14 November

Map 3. Cumulative plot of NMFS trawl stations for 1973 and 1974 offshore surveys combined, and for 1974 inshore surveys



Fish Fauna of the Middle Atlantic Bight

Cape Hatteras and Cape Cod have long been recognized as important zoogeographic barriers. There is, however, disagreement in the biogeographical literature as to the proper classification of this region of the shelf between the capes called the Middle Atlantic Bight (Map 1) in terms of a faunal province or the associated climatic zone. The classification seems to depend in large part on the type of organisms studied and their habitat (for example, benthos vs. fish, inshore vs. offshore). Terms like "boreal" and "arctic" are used to designate both climatic zones and faunal provinces, and a variety of such terms are also used to describe basically the same temperature conditions.

In this section, we present: (1) a brief summary of the major conclusions from a few recent zoogeographic studies, and (2) a summary of the seasonal and geographic variations in species composition of research vessel survey catches in terms of the occurrence of southern and northern forms. Our main purpose is to describe the fish fauna of the Bight relevant to the problems of interpreting changes in abundance and estimating impacts of environmental changes. We make no attempt to deal with the problem of zoogeographic classification in a formal way but the data presented here can contribute to a more accurate classification with respect to fishes. Both the formal zoogeographic studies and our surveys serve to illustrate the major point we wish to make here—a large proportion of the fish species found in the Bight is not endemic to the area; many species are seasonal migrants whose population centers of abundance lie either to the north or the south of the Bight.

Hazel (1970) presented a very useful description of the historical development of the concept of faunal provinces of the Atlantic coasts of North America and Europe. He outlined various biogeographic schemes developed for this region from the 1800s to the 1960s, including the latitudinal and temperature limits associated with each faunal province, and he compared the faunal provinces with the corresponding marine climatic zones identified by various authors.

Among four recent studies reviewed by Hazel (1970), two put the Bight region in the Virginian Province with southern and northern boundaries represented by Cape Hatteras and Cape Cod respectively. In the other two studies, the Bight was characterized as boreal or as an overlap area between the cold temperate fauna characteristic of Cape Cod and the warm termperate fauna south of Cape Hatteras. In these latter two studies the lack of a unique or endemic fauna was the basis for not recognizing the Bight as a separate province.

In a more recent review of marine zoogeography, Briggs (1974) concluded that on the basis of the distribution of shore fishes, mollusks, and decapod crustaceans, and particularly the very low number of endemic fish species, the Bight is best represented as the southern limit of a cold temperate (boreal) faunal province that extends north of Cape Cod. Briggs noted that of 250 species of shore fish recorded from the Bight, 190 species (about 75%) are tropical or warm-temperate forms that range north of Cape Hatteras only during summer months. Presumably, most of the studies referred to by Briggs were conducted near shore in the warm part of the year. His analysis highlights the fact that a significant proportion of the fish species in the Bight during summer is seasonal migrants. In comparison with Briggs' data, the relative importance of northern (cold-temperate) species in terms of occurrence and absolute abundance is significantly greater in our trawl and ichthyoplankton surveys that include both offshore and inshore areas and cold as well as warm periods.

The proportion of a population that spawns in an area is particularly important from the standpoint of environmental assessment since larvae represent the most vulnerable stage of the entire life cycle.

Table 3 lists 180 fish species taken on the 1974 NMFS spring and autumn bottom trawl surveys. Only offshore stations (generally 27 m or 88.6 ft or deeper) were occupied east and north of Martha's Vineyard, except for a few inshore stations near Martha's Vineyard in spring 1974. Both inshore and offshore stations, covering the depth range of 6 to 366 m (18 to 1,200 ft) were occupied from Martha's Vineyard to Cape Hatteras. The percent occurrence of each species in each season is recorded separately for inshore and offshore stations and for four areas corresponding to certain strata sets (see Map 2 for sampling strata) as follows:

1) Cape Hatteras to Delaware Bay (offshore strata 61-72 and adjacent inshore strata);
2) Delaware Bay to Martha's Vineyard (offshore strata 1-8, 73-76, and adjacent inshore strata);
3) Martha's Vineyard to and including Georges Bank (offshore strata 9-23, 25, and one inshore stratum, south of Martha's Vineyard);
4) Gulf of Maine and western Nova Scotia (offshore strata 24, 26-49).

Major shifts in spring and autumn distributions for any given species can be seen by reference to changes in the percent occurrences among these areas.

We have also classified each species according to one of three faunal categories:

1) Principal abundance north and/or east of Cape Cod—Georges Bank (N);
2) Principal abundance south of Cape Hatteras (S);
3) Principal abundance in the mid-Atlantic* (MA).

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* For purposes of faunal classification, we have included the area from Cape Hatteras to and including the whole of Georges Bank as part of the mid-Atlantic region because Georges Bank is an extension of the shelf which in summer is suitable habitat for many warm temperate species. Although this

These classifications are based on the zoogeographical literature and partly on our survey results. The category N corresponds to the generally accepted cold-temperate or boreal faunal group, and S corresponds to the warm-temperate or tropical fauna. The category MA may be considered as principal residents or even endemic to the mid-Atlantic. For convenience, the terms "northern" and "southern" refer to the categories N and S respectively. These faunal categories are shown in Table 3 in the first column after the scientific names. The classifications are uncertain for some species, and in the case of both the northern and southern species, there is considerable variability in the proportions of the populations that overlap into or out of the mid-Atlantic (ranging from a few stragglers to significant components of the whole population on a seasonal basis).

In the next column to the right of the faunal category in Table 3, we have indicated those species which also appeared on the checklist of fishes by Struhsaker (1969) based on extensive trawling south of Cape Hatteras. Three levels of frequency of occurrence are shown for demersal fish: (1) less than 10%, (2) 10 to 50%, and (3) greater than 50%. Struhsaker used a separate classification for pelagic fish that we have converted to: (a) occasional, (b) common, and (c) frequent. The validity of our faunal classifications for southern species tends to be confirmed by the frequency of co-occurrence of southern species with Struhsaker's records.

In the third column after the scientific name in Table 3, we have indicated those species also reported as larvae north of Cape Hatteras (transects A-K, corresponding to Martha's Vineyard to Currituck Beach shown in Map 6) in the plankton cruises of the R/V DOLPHIN in 1965-66 (Berrien et al 1978). Nine species of invertebrates routinely recorded in bottom trawl catches are shown at the end of Table 3.

Of the total 180 fish species shown in Table 3 only 10 were considered to be category MA—principal residents in the mid-Atlantic region (Cape Hatteras to Georges Bank). These are dusky shark, snake eel, blueback herring, lined seahorse, striped bass, tilefish, scup, blackbelly rosefish, summer flounder, and windowpane. One of the nine invertebrate species, longfin squid, was also classified MA (Table 3). The vast majority of the species is either northern or southern forms, and the data from Table 3 indicate a higher proportion of northern forms in the Bight than suggested by Briggs. Seasonal and geographic shifts in species composition of the mid-Atlantic in terms of faunal groups were summarized as follows. First, considering only autumn catches and only the area from Cape Hatteras to Georges Bank, 88 species (61%) were put in category S, 50 (34%) in category N, and 7 (5%) in category MA (Table 4). If we look at spring catches only, there are 29 fewer southern species, 7 more northern species, and 3 additional mid-Atlantic species (Table 4). If we look separately at the two areas from Martha's Vineyard to Delaware Bay and from Delaware Bay to Cape Hatteras, and also distinguish inshore from offshore strata, we see that in the autumn (when the larger representation of southern species occurs) the highest number of southern species is found south of Delaware Bay and near shore (Table 5).

Thus, on the basis of spring and autumn distribution of fishes from near shore to the edge of the shelf, it is clear that while so-called warm-temperate (Carolinian) forms are predominant when water temperature is relatively warm, there is a substantially larger proportion of cold-temperate (boreal) fish species than indicated by Briggs (1974). Also, there are a few species whose principal abundance clearly occurs in the Bight, namely longfin squid, windowpane flounder, and blueback herring. One species, scup, appears to be truly endemic.

The greater relative importance of northern fish species is also illustrated by the occurrence of larval stages of the species listed in Table 3, during the 1965-66 plankton surveys to be described in the next section. Of the 33 species represented as larvae in Table 3, 16 were northern, 16 were southern, and 1 was classified as mid-Atlantic. In terms of absolute numbers of larvae for the more abundant species in the ichthyoplankton, it is clear from Berrien's analysis in the next section (see Table 6) that the northern species are by far the most abundant in winter and spring, and that the southern and northern forms are about equally abundant during summer and autumn.

The important point here is the fact that the fish fauna of the Bight is characterized by an extremely high proportion of migratory species. This occurs because the Bight is characterized by unusually large seasonal changes in temperature (Parr 1933). For example, in the New York Bight apex, there is a range of about 25 °C (45 °F) between summer and winter surface temperatures in nearshore areas (from 1° to 26 °C or 34° to 79 °F), and inshore bottom temperatures range from a maximum of about 21 °C (70 °F) in summer to less than 1 °C (34 °F) in winter (Bowman and Wunderlich 1977). The range of temperature maxima and minima decreases with depth, and near the edge of the shelf at 150 to 200 m (492 to 656 ft), the extreme range is only from 7° to 13 °C (44° to 55 °F). Bottom water temperatures during the 1973-74 spring and autumn surveys are shown in Maps 4 and 5. The large temperature fluctuations in shoal waters serve as strong ecological stimuli and force migration of fishes. When water temperatures rise in spring and summer there is a large influx of warm water forms (for example, drums, bluefish, jacks) from the south; and a number of cold water forms (for example, cod, Atlantic herring, alewives, mackerel, spiny dogfish, and shad) migrate out of the region to the

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region corresponds to the first three geographic areas shown in Table 3, the faunal classifications were not based solely on occurrence in these areas in 1974, but included knowledge of fish distribution gained from the entire time series of NMFS trawl surveys going back to 1963, as well as information from the literature.

north. When water temperatures begin to drop significantly in autumn, the warm water species in the Bight migrate offshore toward deeper and warmer waters and they move southward toward Cape Hatteras or beyond where winter temperatures on the shelf are much higher (these include such species as summer flounder, butterfish, longfin squid, hakes, sea bass); then the cold water species move south into the Bight again in winter.

The Bight is perhaps best described as a transitional faunal province where significant overlap of cold temperate and warm temperate species occurs, and above all where the fauna exhibit dramatic seasonal shifts with the large temperature changes. This has important implications for studies that purport to measure effects of natural environmental fluctuations or man's impacts in terms of changes in the abundance of fishes in the mid-Atlantic.

Table 3. Frequency (%) of occurrence of fish and shellfish species[1] taken on 1974 spring and autumn bottom trawl surveys from Cape Hatteras to Nova Scotia

					AUTUMN 1974						SPRING 1974						
					South of Delaware Bay		Delaware Bay to Martha's Vineyard		Martha's Vineyard to Georges Bank	Gulf of Maine and western Nova Scotia	South of Delaware Bay		Delaware Bay to Martha's Vineyard		Martha's Vineyard to Georges Bank		Gulf of Maine and western Nova Scotia
Common Name	Scientific Name	Faunal group	Occurrence south of Hatteras[2]	Larval occurrence north of Hatteras[3]	I(46)	O(37)	I(33)	O(52)	O(87)	O(117)	I(50)	O(25)	I(59)	O(50)	I(7)	O(78)	O(98)
Hagfishes	*Myxinidae*																
Atlantic Hagfish	*Myxine glutinosa*	N			0	0	0	8	1	8	0	4	0	16	0	9	17
Lampreys	*Petromyzontidae*																
Sea Lamprey	*Petromyzon marinus*	N			0	0	0	0	0	1	0	4	0	0	0	0	0
Sand Tigers	*Odontaspididae*																
Sand Tiger	*Odontaspis taurus*	S	2		7	0	0	0	0	0	2	4	0	0	0	0	0
Cat Sharks	*Scyliorhinidae*																
Chain Dogfish	*Scyliorhinus retifer*	S	1		0	3	0	0	0	0	0	0	0	4	0	0	0
Requiem Sharks	*Carcharhinidae*																
Blacktip Shark	*Carcharhinus limbatus*	S			2	0	0	0	0	0	0	0	0	0	0	0	0
Sandbar Shark	*Carcharhinus milberti*	S	1		13	0	0	2	0	0	0	0	0	0	0	0	0
Dusky Shark	*Carcharhinus obscurus*	MA			7	0	0	0	0	0	4	0	0	0	0	0	0
Smooth Dogfish	*Mustelus canis*	S			43	3	64	23	6	0	60	24	8	0	0	0	0
Atlantic Sharpnose Shark	*Rhizoprionodon terraenovae*	S			4	3	0	0	0	0	0	0	0	0	0	0	0
Dogfish Sharks	*Squalidae*																
Black Dogfish	*Centroscyllium fabricii*	N			0	3	0	0	0	0	0	12	0	0	0	0	0
Spiny Dogfish	*Squalus acanthias*	N	2		2	0	0	15	38	49	46	72	49	78	100	69	44
Angel Sharks	*Squatinidae*																
Atlantic Angel Shark	*Squatina dumerili*	S	2		22	19	0	0	0	0	10	0	0	0	0	0	0
Electric Rays	*Torpedinidae*																
Atlantic Torpedo	*Torpedo nobiliana*	S			0	0	0	2	0	0	0	0	0	0	0	0	0
Skates	*Rajidae*																
Clearnose Skate	*Raja eglanteria*	S	3		28	8	9	0	0	0	46	4	0	2	0	4	4
Little Skate	*Raja erinacea*	N			2	8	12	31	54	9	52	36	88	60	100	71	14
Rosette Skate	*Raja garmani*	S	3		0	8	0	4	0	0	0	0	0	2	0	0	0
Barndoor Skate	*Raja laevis*	N			0	0	0	0	0	0	0	0	0	0	0	4	0
Winter Skate	*Raja ocellata*	N			0	0	0	4	44	0	0	12	34	12	100	42	9
Thorny Skate	*Raja radiata*	N			0	0	0	0	25	61	0	0	0	0	0	31	76
Smooth Skate	*Raja senta*	N			0	0	0	0	7	8	0	0	0	0	0	5	42
Stingrays	*Dasyatidae*																
Roughtail Stingray	*Dasyatis centroura*	S			13	3	3	0	0	0	16	0	0	0	0	0	0
Bluntnose Stingray	*Dasyatis sayi*	S	2		30	3	0	0	0	0	12	0	0	0	0	0	0
Spiny Butterfly Ray	*Gymnura altavela*	S	2		24	3	0	0	0	0	2	0	0	0	0	0	0
Smooth Butterfly Ray	*Gymnura micrura*	S	1		0	0	0	0	0	0	2	0	0	0	0	0	0
Eagle Rays	*Myliobatidae*																
Bullnose Ray	*Myliobatis freminvillei*	S	2		39	3	3	0	0	0	4	0	0	0	0	0	0
Cownose Ray	*Rhinoptera bonasus*	S	2		13	0	0	0	0	0	0	0	0	0	0	0	0
Sturgeons	*Acipenseridae*																
Atlantic Sturgeon	*Acipenser oxyrhynchus*	N	1		0	0	0	0	0	0	2	0	0	0	0	0	0
Conger Eels	*Congridae*																
Conger Eel	*Conger oceanicus*	S	1		7	3	3	4	3	0	0	8	2	4	14	0	0
Snake Eels	*Ophichthidae*																
Snake Eel	*Ophichthus cruentifer*	MA			0	0	0	0	0	0	0	0	0	4	0	3	0
Snipe Eels	*Nemichthyidae*																
Slender Snipe Eel	*Nemichthys scolopaceus*	S			0	0	0	0	0	0	0	16	0	0	0	3	3
Herrings	*Clupeidae*																
Blueback Herring	*Alosa aestivalis*	MA			0	0	0	0	1	0	6	8	7	14	0	0	0
Hickory Shad	*Alosa mediocris*	S			0	0	0	0	0	0	0	0	0	4	0	1	0
Alewife	*Alosa pseudoharengus*	N			0	3	0	0	0	13	14	8	34	46	29	27	19
American Shad	*Alosa sapidissima*	N	b		0	0	0	2	1	0	6	0	14	18	0	8	7
Atlantic Menhaden	*Brevoortia tyrannus*	S	b	+	13	0	0	0	0	0	0	0	0	0	0	0	0
Atlantic Herring	*Clupea harengus harengus*	N	b	+	0	0	0	0	5	8	2	4	8	26	14	41	29
Round Herring	*Etrumeus teres*	S	b		15	0	27	6	6	0	8	4	0	4	0	0	0
Atlantic Thread Herring	*Opisthonema oglinum*	S	b		9	3	0	0	0	0	0	0	0	0	0	0	0
Spanish Sardine	*Sardinella anchovia*	S			13	0	0	0	0	0	0	0	0	0	0	0	0

Table 3. continued

Common Name	Scientific Name	Faunal group	Occurrence south of Hatteras[2]	Larval occurrence north of Hatteras[3]	AUTUMN 1974						SPRING 1974						
					South of Delaware Bay		Delaware Bay to Martha's Vineyard		Martha's Vineyard to Georges Bank	Gulf of Maine and western Nova Scotia	South of Delaware Bay		Delaware Bay to Martha's Vineyard		Martha's Vineyard to Georges Bank		Gulf of Maine and western Nova Scotia
					I(46)	O(37)	I(33)	O(52)	O(87)	O(117)	I(50)	O(25)	I(59)	O(50)	I(7)	O(78)	O(98)
Anchovies	*Engraulidae*																
Striped Anchovy	*Anchoa hepsetus*	S	b	+	43	5	9	0	0	0	8	0	0	2	0	0	0
Bay Anchovy	*Anchoa mitchilli*	S	b	+	17	0	9	0	1	0	14	0	5	0	0	0	0
Smelts	*Osmeridae*																
Rainbow Smelt	*Osmerus mordax*	N			0	0	0	0	0	0	0	0	2	0	0	0	0
Argentines	*Argentinidae*																
Atlantic Argentine	*Argentina silus*	N			0	0	0	2	0	8	0	4	0	2	0	3	13
Lightfishes	*Gonostomatidae*																
Longtooth Anglemouth[4]	*Gonostoma elongatum*	N			0	0	0	4	0	0	0	4	0	0	0	0	0
Viperfishes	*Chauliodontidae*																
Viperfish[4]	*Chauliodus sloani*	S			0	0	0	0	0	0	0	8	0	0	0	0	0
Lizardfishes	*Synodontidae*			+													
Inshore Lizardfish	*Synodus foetens*	S	3		17	0	3	0	1	0	0	0	0	0	0	0	0
Snakefish	*Trachinocephalus myops*	S	3		2	0	0	0	0	0	0	0	0	0	0	0	0
Stomiatidae[4]	*Stomiatidae*																
Stomias affinis	*Stomias affinis*	S			0	3	0	0	0	0	0	0	0	0	0	0	0
Maurolicidae[4]	*Maurolicidae*																
Pearlsides	*Maurolicus muelleri*	N			0	0	0	6	5	12	0	12	0	6	0	4	9
Paralepididae[2]	*Paralepididae*																
Paralepis borealis	*Paralepis borealis*	N			0	3	0	0	0	0	0	0	0	0	0	0	0
Greeneyes	*Chlorophthalmidae*																
Shortnose Greeneye	*Chlorophthalmus agassizi*[5]	S	1		0	0	0	0	5	4	0	16	0	18	0	12	0
	Chlorophthalmus chalybeius	S			0	19	0	8	0	0	0	0	0	0	0	0	0
Lanternfishes	*Myctophidae*																
Horned Lanternfish[4]	*Ceratoscopelus maderensis*	N			0	0	0	0	1	0	0	16	0	4	0	0	0
Sternoptichidae[4]	*Sternoptichidae*																
Silver Hatchetfish	*Argyropelecus aculeatus*	N			0	11	0	2	0	0	0	8	0	2	0	0	0
Hatchetfish	*Polyipnus asteroides*	N			0	0	0	4	2	1	0	8	0	0	0	0	0
Trachichthyidae[4]	*Trachichthyidae*																
Hoplostethus mediterraneus	*Hoplostethus mediterraneus*	S			0	3	0	2	0	0	0	3	0	2	0	0	0
Goosefishes	*Lophiidae*																
Goosefish	*Lophius americanus*	N	2	+	0	16	3	19	18	25	36	60	34	70	0	35	48
Frogfishes	*Antennariidae*																
Singlespot Frogfish	*Antennarius radiosus*	S	2		0	0	0	0	0	0	0	4	0	0	0	0	0
Batfishes	*Ogcocephalidae*																
Roughback Batfish	*Ogcocephalus parvus*	S			0	0	0	0	0	0	4	0	0	0	0	0	0
Longnose Batfish	*Ogcocephalus vespertilio*	S			0	0	0	0	0	0	0	0	0	8	0	0	0
Codfishes	*Gadidae*																
Blue Hake[4]	*Antimora rostrata*	N			0	0	0	2	0	0	0	0	0	0	0	0	0
Cusk	*Brosme brosme*	N			0	0	0	0	1	15	0	0	0	2	0	3	34
Fourbeard Rockling	*Enchelyopus cimbrius*	N		+	0	0	0	2	0	6	0	0	2	2	0	5	19
Atlantic Cod	*Gadus morhua*	N		+	0	0	0	2	24	56	0	8	37	18	71	63	59
Haddock	*Melanogrammus aeglefinus*	N		+	0	0	0	0	29	59	0	0	0	0	0	45	47
Offshore Hake	*Merluccius albidus*	N			0	5	0	10	9	2	0	20	0	18	0	6	0
Silver Hake	*Merluccius bilinearis*	N		+	4	46	42	69	82	79	34	68	92	94	86	67	86
Hakeling[4]	*Physiculus fulvus*	S			0	0	0	2	0	0	0	0	0	0	0	0	0
Longfin Hake	*Phycis chesteri*	N	2		0	3	0	6	3	7	0	4	0	2	0	8	5
Pollock	*Pollachius virens*	N		+	0	0	0	0	7	27	0	0	0	0	0	29	49
Red Hake	*Urophycis chuss*	N		+	0	5	3	29	60	27	26	28	76	72	43	54	52
Spotted Hake	*Urophycis regius*	S	3		9	68	6	44	6	0	70	28	8	10	0	3	0
White Hake	*Urophycis tenuis*	N			0	0	0	0	28	65	0	12	0	20	0	17	65
Cusk-Eels and Brotulas	*Ophidiidae*																
Fawn Cusk-Eel	*Lepophidium cervinum*	S	2		9	0	0	10	7	1	2	24	0	22	0	14	0
Mottled Cusk-Eel	*Lepophidium jeannae*	S	2		0	0	0	0	0	0	2	0	0	0	0	0	0
Bank Cusk-Eel	*Ophidion holbrooki*	S	3		0	0	0	0	0	0	2	0	0	0	0	0	0
Crested Cusk-Eel	*Ophidion welshi*	S			0	0	0	0	0	0	6	0	0	0	0	0	0
Polka-Dot Cusk-Eel	*Otophidium omostigmum*	S	1		0	0	0	0	0	0	0	0	0	2	0	0	0
Striped Cusk-Eel	*Rissola marginata*	S	2		7	0	0	0	0	0	4	0	2	0	0	0	0

Table 3. continued

					AUTUMN 1974						SPRING 1974						
					South of Delaware Bay		Delaware Bay to Martha's Vineyard		Martha's Vineyard to Georges Bank	Gulf of Maine and western Nova Scotia	South of Delaware Bay		Delaware Bay to Martha's Vineyard		Martha's Vineyard to Georges Bank		Gulf of Maine and western Nova Scotia
Common Name	Scientific Name	Faunal group	Occurrence south of Hatteras[2]	Larval occurrence north of Hatteras[3]	I(46)	O(37)	I(33)	O(52)	O(87)	O(117)	I(50)	O(25)	I(59)	O(50)	I(7)	O(78)	O(98)
Eelpouts	*Zoarcidae*																
Wolf Eelpout	*Lycenchelys verrilli*	N			0	0	0	0	0	0	0	0	0	0	0	4	29
Ocean Pout	*Macrozoarces americanus*	N			0	0	0	4	6	6	2	12	68	48	43	36	31
Grenadiers	*Macrouridae*																
Marlin-Spike	*Nezumia bairdi*	S			0	0	0	0	1	0	0	0	0	2	0	5	6
Roughhead Grenadier[4]	*Macrourus berglax*	N			0	0	0	0	0	0	0	0	0	2	0	0	0
Longnose Grenadier	*Coelorhynchus carminatus*	S			0	0	0	0	0	0	0	0	2	0	0	0	0
American Straptail Grenadier[4]	*Malacocephalus occidentalis*	S			0	0	0	0	0	0	0	8	0	6	0	0	0
Flyingfishes and Halfbeaks	*Exocoetidae*																
Halfbeak	*Hyporhamphus unifasciatus*	S			2	0	0	0	0	3	0	0	0	0	0	0	0
Sauries	*Scomberesocidae*																
Atlantic Saury	*Scomberesox saurus*	N			0	0	0	0	6	0	0	0	0	0	0	0	0
Silversides	*Atherinidae*																
Atlantic Silverside	*Menidia menidia*	N	1		0	0	0	0	0	0	2	0	0	0	0	1	0
Beardfishes	*Polymyxiidae*																
Beardfish[4]	*Polymixia lowei*	S			0	0	0	0	0	0	0	0	0	0	0	3	0
Dories	*Zeidae*																
American John Dory	*Zenopsis ocellata*	N	2		0	0	0	5	0	0	0	0	0	0	0	0	0
Boarfishes	*Caproidae*																
Deepbody Boarfish	*Antigonia capros*	S	2		0	0	0	2	2	0	0	0	0	0	0	0	0
Sticklebacks	*Gasterosteidae*																
Threespine Stickleback	*Gasterosteus aculeatus*	N			0	0	0	0	0	2	0	0	0	0	0	0	0
Snipefishes	*Centriscidae*																
Longspine Snipefish	*Macrorhamphosus scolopax*	S	2		0	3	0	4	0	0	0	0	0	0	0	0	0
Pipefishes and Seahorses	*Syngnathidae*																
Lined Seahorse	*Hippocampus erectus*	MA	2		0	0	0	0	0	0	0	0	5	0	0	0	0
Northern Pipefish	*Syngnathus fuscus*	N	1		2	0	0	0	0	0	0	0	7	0	0	1	0
Temperate Basses	*Percichthyidae*																
Striped Bass	*Morone saxatilis*	MA			0	0	0	0	0	0	4	0	5	0	0	0	0
Sea Basses	*Serranidae*																
Rock Sea Bass	*Centropristis philadelphica*	S			2	0	0	0	0	0	2	0	0	0	0	0	0
Black Sea Bass	*Centropristis striata*	S	3	+	43	24	27	10	1	0	36	44	24	6	14	0	0
Tilefishes	*Branchiostegidae*																
Tilefish	*Lopholatilus chamaeleonticeps*	MA			0	2	0	0	0	0	0	0	0	6	0	0	0
Bluefishes	*Pomatomidae*																
Bluefish	*Pomatomus saltatrix*	S	2	+	70	19	27	10	14	0	6	16	0	0	0	0	0
Cobias	*Rachycentridae*																
Cobia	*Rachycentron canadum*	S	2		2	3	0	0	0	0	0	0	0	0	0	0	0
Remoras	*Echeneidae*																
Remora	*Remora remora*	S			2	3	0	0	0	0	0	0	0	0	0	0	0
Jacks and Pompanos	*Carangidae*																
African Pompano	*Alectis crinitus*	S	1		2	0	0	0	0	0	0	0	0	0	0	0	0
Blue Runner	*Caranx crysos*	S			30	3	3	0	0	0	0	0	0	0	0	0	0
Crevalle Jack	*Caranx hippos*	S			4	0	6	0	0	0	0	0	0	0	0	0	0
Mackerel Scad	*Decapterus macarellus*	S			7	0	24	0	0	0	0	0	0	0	0	0	0
Round Scad	*Decapterus punctatus*	S	2		9	3	3	0	0	0	0	0	0	0	0	0	0
Bigeye Scad	*Selar crumenophthalmus*	S	1		13	0	6	0	0	0	0	0	0	0	0	0	0
Lookdown	*Selene vomer*	S	3		2	0	0	0	0	1	0	0	0	0	0	0	0
Greater Amberjack	*Seriola dumerili*	S	2		4	0	0	0	0	0	0	0	0	0	0	0	0
Banded Rudderfish	*Seriola zonata*	S	1		0	3	0	0	0	0	0	0	0	0	0	0	0
Rough Scad	*Trachurus lathami*	S	2		35	8	3	0	1	0	0	8	0	2	0	0	0
Atlantic Moonfish	*Vomer setapinnis*	S	2		4	0	3	0	0	0	0	0	0	0	0	0	0
Dolphins	*Coryphaenidae*			+													
Pompano Dolphin	*Coryphaena equisetis*	S			2	0	0	0	0	0	0	0	0	0	0	0	0
Grunts	*Pomadasyidae*																
Pigfish	*Orthopristis chrysoptera*	S	2		9	0	0	0	0	0	0	0	0	0	0	0	0

Table 3. continued

					AUTUMN 1974							SPRING 1974						
Common Name	Scientific Name	Faunal group	Occurrence south of Hatteras²	Larval occurrence north of Hatteras³	South of Delaware Bay I(46)	South of Delaware Bay O(37)	Delaware Bay to Martha's Vineyard I(33)	Delaware Bay to Martha's Vineyard O(52)	Martha's Vineyard to Georges Bank O(87)	Gulf of Maine and western Nova Scotia O(117)	South of Delaware Bay I(50)	South of Delaware Bay O(25)	Delaware Bay to Martha's Vineyard I(59)	Delaware Bay to Martha's Vineyard O(50)	Martha's Vineyard to Georges Bank I(7)	Martha's Vineyard to Georges Bank O(78)	Gulf of Maine and western Nova Scotia O(98)
Porgies	*Sparidae*																
Sheepshead	*Archosargus probatocephalus*	S	2		2	0	0	0	0	0	0	0	0	0	0	0	0
Pinfish	*Lagodon rhomboides*	S	3		2	0	0	0	0	0	0	0	0	0	0	0	0
Longspine Porgy	*Stenotomus caprinus*	S			24	0	0	0	0	0	0	0	0	0	0	0	0
Scup	*Stenotomus chrysops*	MA	3		57	24	36	25	6	2	24	40	37	22	14	1	0
Drums	*Sciaenidae*																
Silver Seatrout	*Cynoscion nothus*	S	3		2	0	0	0	0	0	0	0	0	0	0	0	0
Weakfish	*Cynoscion regalis*	S	3		48	3	21	0	0	0	14	0	0	0	0	0	0
Banded Drum	*Larimus fasciatus*	S	3	+	4	0	0	0	0	0	2	0	0	0	0	0	0
Spot	*Leiostomus xanthurus*	S	3	+	78	11	0	0	0	0	8	0	0	0	0	0	0
Southern Kingfish	*Menticirrhus americanus*	S	3		11	0	0	0	0	0	8	0	0	0	0	0	0
Northern Kingfish	*Menticirrhus saxatilis*	S	2		20	0	3	0	0	0	0	0	0	0	0	0	0
Atlantic Croaker	*Micropogon undulatus*	S	3	+	65	14	0	0	0	1	6	8	0	0	0	0	0
Star Drum	*Stellifer lanceolatus*	S	3		0	0	0	0	0	0	2	0	0	0	0	0	0
Goatfishes	*Mullidae*																
Red Goatfish	*Mullus auratus*	S	3		0	0	3	0	0	0	0	0	0	0	0	0	0
Wrasses	*Labridae*																
Tautog	*Tautoga onitis*	N	1	+	0	0	0	0	0	0	0	4	0	0	0	0	0
Cunner	*Tautogolabrus adspersus*	N		+	0	0	6	0	5	1	0	0	14	2	0	5	0
Mullets	*Mugilidae*																
Striped Mullet	*Mugil cephalus*	S			0	0	3	0	0	0	0	0	0	0	0	0	0
Barracudas	*Sphyraenidae*																
Northern Sennet	*Sphyraena borealis*	S	2		7	3	9	0	0	0	0	0	0	0	0	0	0
Pricklebacks	*Stichaeidae*																
Snake Blenny	*Lumpenus lumpretaeformis*	N			0	0	0	0	0	1	0	0	0	0	0	0	2
Daubed Shanny	*Lumpenus maculatus*	N			0	0	0	0	0	3	0	0	0	0	0	1	21
Radiated Shanny	*Ulvaria subbifurcata*	N			0	0	0	0	0	0	0	0	0	0	0	3	4
Gunnels	*Pholidae*																
Rock Gunnel	*Pholis gunnellus*	N			0	0	0	2	0	1	0	0	0	0	0	3	3
Wolffishes	*Anarhichadidae*																
Atlantic Wolffish	*Anarhichas lupus*	N			0	0	0	2	0	13	0	0	0	0	0	15	38
Wrymouths	*Cryptacanthodidae*																
Wrymouth	*Cryptacanthodes maculatus*	N			0	0	0	2	0	0	0	0	0	2	0	1	2
Sand Lances	*Ammodytidae*																
American Sand Lance⁶	*Ammodytes americanus*	N			0	5	3	2	1	0	4	8	7	12	0	14	0
Pteropsaridae⁴	*Pteropsaridae*																
Hypsicometes gobioides	*Hypsicometes gobioides*	S			0	0	0	2	0	0	0	0	0	0	0	0	0
Snake Mackerels	*Gempylidae*																
Conejo⁴	*Promethichthys prometheus*	S			0	3	0	0	0	0	0	0	0	0	0	0	0
Cutlassfishes	*Trichiuridae*																
Atlantic Cutlassfish	*Trichiurus lepturus*	S	2		13	3	0	2	0	0	6	0	0	0	0	0	0
Benthodesmus atlanticus	*Benthodesmus atlanticus*	N			0	3	0	2	0	0	0	0	0	0	0	0	0
Mackerels and Tunas	*Scombridae*																
Atlantic Mackerel	*Scomber scombrus*	N		+	2	0	0	2	8	11	0	12	2	50	0	37	2
King Mackerel	*Scomberomorus cavalla*	S	a	+	4	0	0	0	0	0	0	0	0	0	0	0	0
Spanish Mackerel	*Scomberomorus maculatus*	S	c		15	3	0	0	0	0	0	0	0	0	0	0	0
Butterfishes	*Stromateidae*																
Harvestfish	*Peprilus alepidotus*	S	2		2	0	0	0	0	0	2	0	0	0	0	0	0
Butterfish	*Peprilus triacanthus*	S	3	+	89	51	67	63	31	3	50	40	25	46	14	9	0
Scorpionfishes	*Scorpaenidae*																
Blackbelly Rosefish	*Helicolenus dactylopterus*	MA			0	24	0	19	15	2	0	12	0	10	0	12	0
Redfish or Ocean Perch	*Sebastes marinus*	N			0	0	0	2	9	84	0	0	0	4	0	8	71
Searobins	*Triglidae*																
Armored Searobin	*Peristedion miniatum*	S			0	16	0	2	0	0	0	8	0	14	0	1	0
Northern Searobin	*Prionotus carolinus*	S	3	+	61	41	36	17	2	0	30	48	25	24	100	3	0
Striped Searobin	*Prionotus evolans*	S	2	+	52	3	30	0	0	0	36	16	19	6	0	0	0

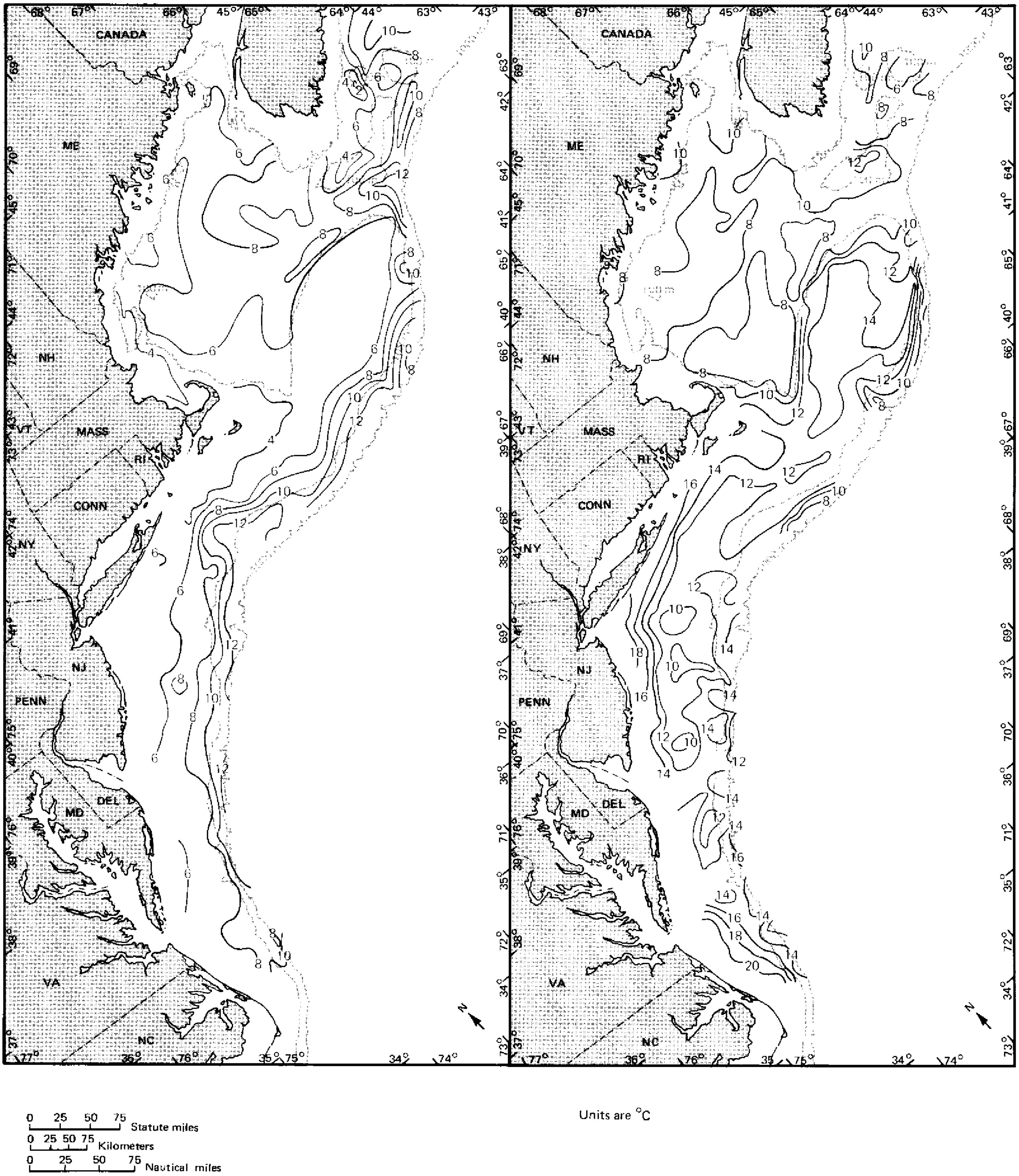
Table 3. continued

					AUTUMN 1974						SPRING 1974							
					South of Delaware Bay		Delaware Bay to Martha's Vineyard		Martha's Vineyard to Georges Bank	Gulf of Maine and western Nova Scotia	South of Delaware Bay		Delaware Bay to Martha's Vineyard		Martha's Vineyard to Georges Bank		Gulf of Maine and western Nova Scotia
Common Name	Scientific Name	Faunal group	Occurrence south of Hatteras[2]	Larval occurrence north of Hatteras[3]	I(46)	O(37)	I(33)	O(52)	O(87)	O(117)	I(50)	O(25)	I(59)	O(50)	I(7)	O(78)	O(98)
Sculpins	*Cottidae*																
Sea Raven	*Hemitripterus americanus*	N			0	0	0	2	18	6	0	0	7	14	0	41	13
Grubby	*Myoxocephalus aenaeus*	N			0	0	0	0	2	0	0	0	0	0	0	0	1
Longhorn Sculpin	*Myoxocephalus octodecemspinosus*	N			0	0	0	8	40	15	0	0	56	20	100	65	28
Shorthorn Sculpin	*Myoxocephalus scorpius*	N			0	0	0	0	0	0	0	0	0	0	0	6	0
Moustache Sculpin	*Triglops murrayi*	N			0	0	0	0	2	20	0	0	0	0	0	4	19
Poachers	*Agonidae*																
Alligatorfish	*Aspidophoroides monopterygius*	N			0	0	0	0	3	3	0	0	0	0	0	10	23
Lumpfishes and Snailfishes	*Cyclopteridae*																
Lumpfish	*Cyclopterus lumpus*	N			0	0	0	0	0	4	0	0	0	0	0	0	0
Seasnail	*Liparis atlanticus*	N		+	0	0	0	2	1	1	0	0	0	0	0	4	2
Striped Seasnail	*Liparis liparis*	N			0	0	0	0	0	0	0	0	0	0	0	1	0
Lefteye Flounders	*Bothidae*																
Gulf Stream Flounder	*Citharichthys arctifrons*	S	2	+	0	8	0	10	24	2	0	44	0	38	0	27	0
Smallmouth Flounder	*Etropus microstomus*	S	2	+	0	0	0	0	0	0	0	0	5	0	0	0	0
Summer Flounder	*Paralichthys dentatus*	MA	3	+	85	27	58	23	10	0	74	48	47	26	29	8	0
Fourspot Flounder	*Paralichthys oblongus*	S			0	24	6	40	37	2	4	44	27	74	14	28	2
Windowpane	*Scophthalmus aquosus*	MA	2		22	24	45	29	33	2	76	16	97	32	100	41	4
Righteye Flounders	*Pleuronectidae*																
Witch Flounder	*Glyptocephalus cynoglossus*	N		+	0	3	0	4	8	42	2	24	0	22	0	18	74
American Plaice	*Hippoglossoides platessoides*	N		+	0	0	0	0	10	69	0	0	0	2	0	22	83
Atlantic Halibut	*Hippoglossus hippoglossus*	N			0	0	0	0	0	7	0	0	0	0	0	8	13
Yellowtail Flounder	*Limanda ferruginea*	N		+	0	0	3	15	41	9	0	8	63	50	86	59	18
Winter Flounder	*Pseudopleuronectes americanus*	N		+	0	0	3	17	32	12	30	0	95	18	86	38	16
Soles	*Soleidae*																
Hogchoker	*Trinectes maculatus*	S	3		7	0	0	0	0	0	6	0	0	0	0	0	0
Tonguefishes	*Cynoglossidae*																
Blackcheek Tonguefish	*Symphurus plagiusa*	S	3		2	0	0	0	0	0	6	0	0	0	0	0	0
Triggerfishes and Filefishes	*Balistidae*																
Orange Filefish	*Aluterus schoepfi*	S	3		2	5	0	0	0	0	2	0	0	0	0	0	0
Gray Triggerfish	*Balistes capriscus*	S	3		9	3	0	0	0	0	0	0	0	0	0	0	0
Planehead Filefish	*Monacanthus hispidus*	S	3		46	35	27	17	7	0	0	0	0	0	0	0	0
Puffers	*Tetraodontidae*																
Smooth Puffer	*Lagocephalus laevigatus*	S	2		2	0	0	0	0	0	0	4	0	0	0	0	0
Northern Puffer	*Sphoeroides maculatus*	S	3		11	3	9	0	0	0	14	4	0	0	0	0	0
Porcupinefishes	*Diodontidae*																
Striped Burrfish	*Chilomycterus schoepfi*	S	3		2	0	0	0	0	0	0	0	0	0	0	0	0
INVERTEBRATES																	
American Lobster	*Homarus americanus*	N			0	19	6	29	36	23	0	24	12	34	0	28	24
Red Crab	*Geryon quinquidens*	N			0	3	0	4	1	1	0	4	0	4	0	5	8
Jonah Crab	*Cancer borealis*	N			0	3	6	6	5	0	0	32	0	46	0	28	4
Rock Crab	*Cancer irroratus*	N			2	24	3	10	5	1	0	44	0	24	0	6	0
Blue Crab	*Callinectes sapidus*	S			4	0	0	0	0	0	0	0	0	0	0	0	0
Sea Scallop	*Placopecten magellanicus*	N			0	24	0	38	22	5	0	32	0	48	0	35	9
Shortfin Squid	*Illex illecebrosus*	N			0	43	0	37	51	44	0	28	0	30	0	14	1
Longfin Squid	*Loligo pealei*	MA			87	100	52	90	57	9	66	80	31	68	43	23	0
Brief Squid	*Lolliguncula brevis*	S			0	0	0	0	0	0	6	0	0	0	0	0	0

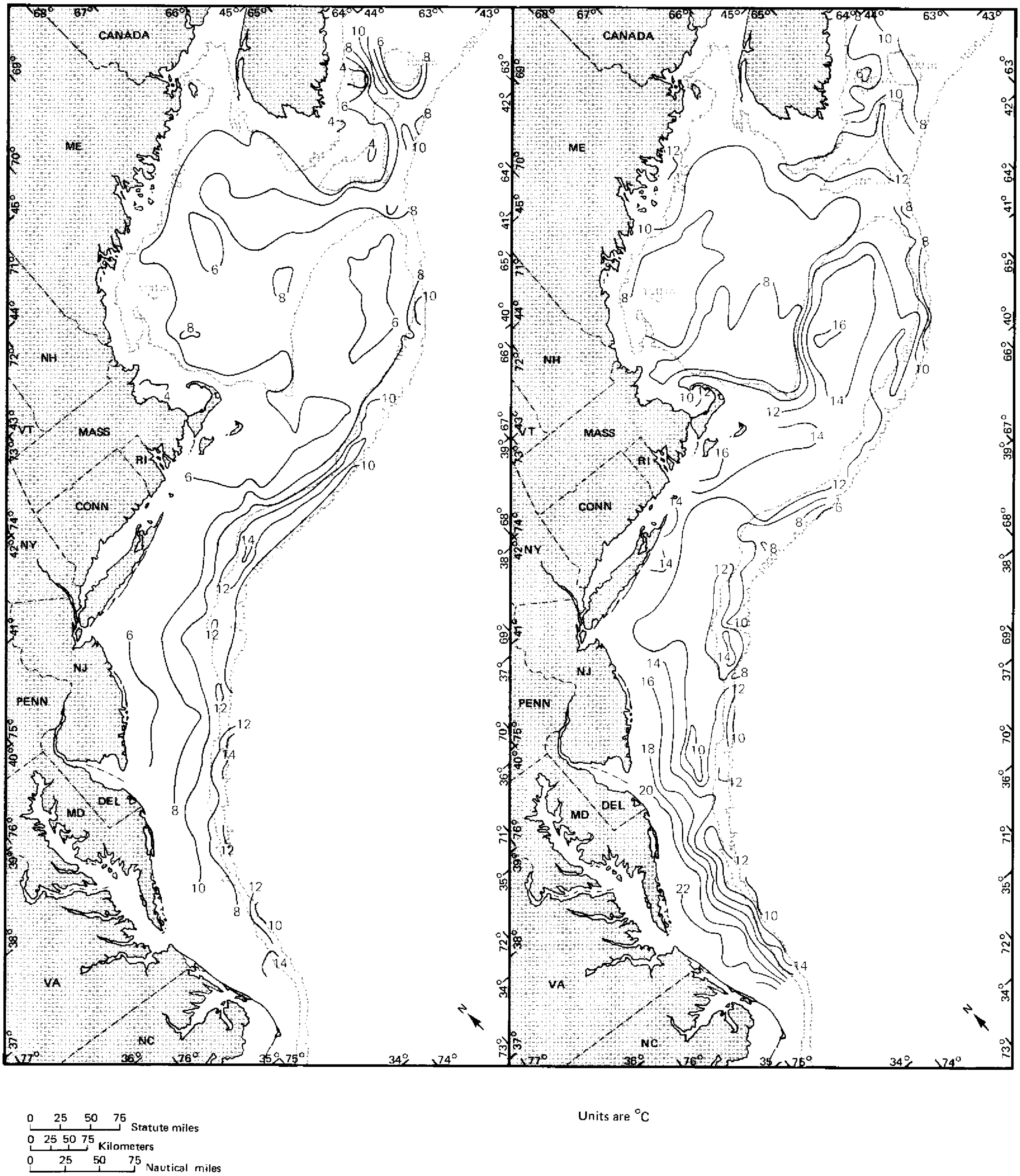
[1] Common and scientific names are according to Bailey et al (1970).
[2] Occurrence south of Cape Hatteras (Struhsaker 1969) — see text for definition of abundance scales.
[3] From Berrien et al (1978). Occurrence of larvae north of Cape Hatteras shown as +. See text for details.
[4] From Jordan et al (1930).
[5] Should be considered subspecies of *C. agassizi* until more specimens studied.
[6] There may be two species of sand lance in this area.

NOTE: Survey region subdivided into four geographic zones and two depth zones (Inshore = I, Offshore = O; and numbers of hauls shown in parentheses). Additional information is given in the three columns after the scientific name as follows: faunal group, occurrence in bottom trawl catches south of Cape Hatteras, and occurrence as larvae north of Cape Hatteras.

Map 4. Bottom temperatures, 1973 trawl surveys (spring-left, autumn-right)



Map 5. Bottom temperatures, 1974 trawl surveys (spring-left, autumn-right)



Map 6. Station transects for 1965-66 series plankton cruises (basis for larval fish distribution plots)

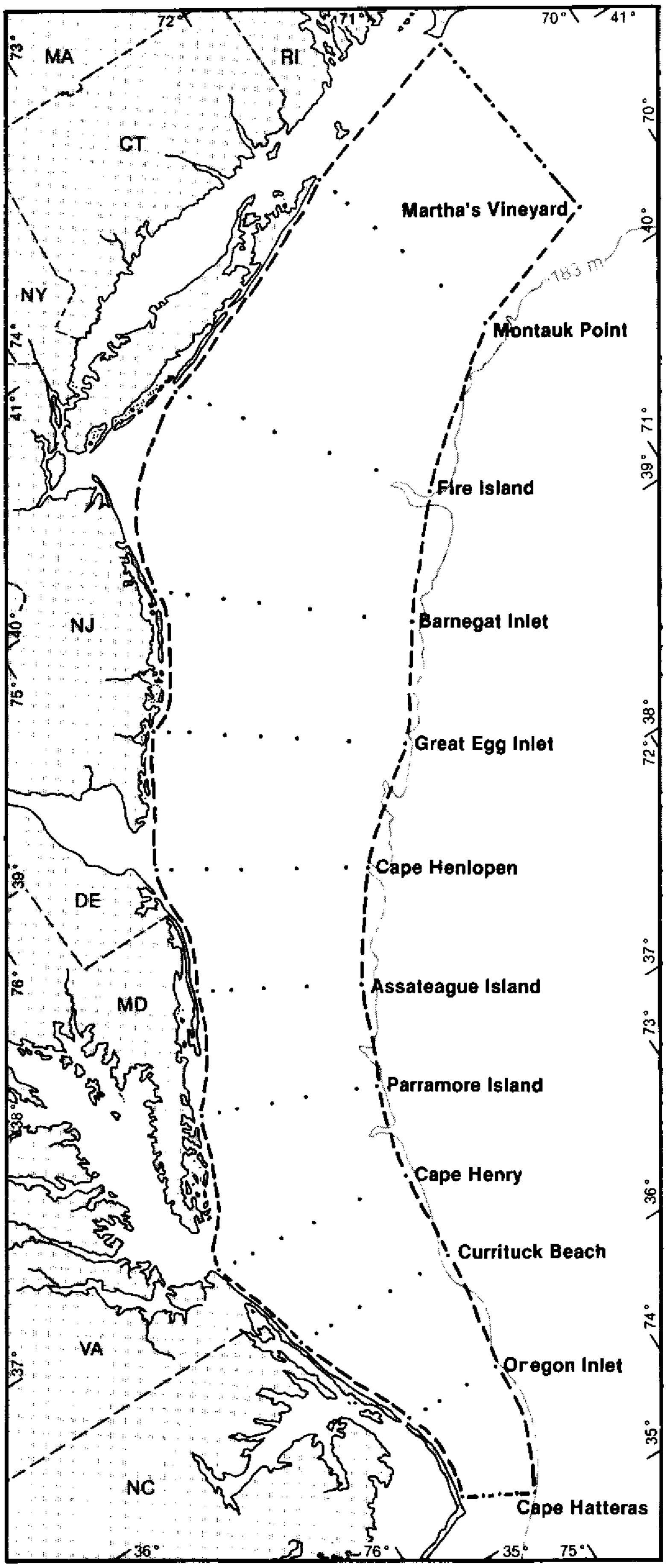


Table 4. Numbers of fish species caught in 1974 autumn and spring bottom trawl surveys from Cape Hatteras to Georges Bank, classified into three faunal categories

Faunal category	Autumn No. of species (%)	Spring No. of species (%)
Northern (N)	50 (34)	57(45)
Southern (S)	88 (61)	59 (47)
Mid-Atlantic (MA)	7 (5)	10 (8)
Total	145	126

Note: Data from Table 3.

Table 5. Numbers of fish species caught in 1974 autumn bottom trawl surveys from Cape Hatteras to Martha's Vineyard, classified into three faunal categories

Faunal category	South of Delaware Bay (Strata 61-67) inshore	offshore	Delaware Bay to Martha's Vineyard (Strata 1-9) inshore	offshore
Northern (N)	6	18	11	38
Southern (S)	69	44	30	24
Mid-Atlantic (MA)	4	5	3	4
Total	79	67	44	66

Note: Data from Table 3.

Larval Fish Distribution in the Middle Atlantic Bight

Peter Berrien

Introduction

Natural fluctuations in fish populations may be due largely to factors controlling survival of egg and larval stages. This is because these early life stages have limited mobility and are particularly vulnerable to changes in their immediate environment. For example, temperature, food, predators, parasitism, transport, and pollution all can be critical mortality factors, but larvae have virtually no ability to move out of an area to reduce the impact of one or more of these factors. Thus, distribution of larvae in time and space relative to these mortality factors is a critical element in assessing environmental impacts on fish populations.

Although the Bight does not have a large endemic fauna, it is nevertheless an important nursery area for the eggs and/or larvae of a number of major recreational and commercial fish populations. Significant quantities of fish larvae may be found in all areas of the Bight just about any time of year. However, each species has its own distributional pattern and it requires a very large logistic effort to describe that pattern quantitatively for the whole population of eggs and larvae. This is because their development is rapid (two days to a few weeks from fertilization to hatching) and because for many species spawning takes place over a period of several months and throughout the entire Bight. Even in cases where species spawn in more restricted areas, planktonic eggs and larvae are rapidly dispersed with currents. It would be necessary to monitor this dispersal at least monthly throughout the Bight in order to relate it even to average currents, or, for example, to evaluate possible impacts of pollution from known sites or plumes. Direct estimates of egg development, larval growth, feeding conditions, and survival require still more intensive sampling within representative "patches" of the eggs and larvae throughout their development cycles. No investigations of this scope and magnitude have been attempted so far, although, a series of eight cruises was conducted in the Bight from December 1965 to December 1966, providing a fairly comprehensive picture of the geographic and seasonal distribution of ichthyoplankton (Clark et al 1969; Berrien et al 1978). A total of 87 species were identified from the cruises and the larval stages of 27 of these species were selected to illustrate the patterns of spawning in the Bight. These 27 species represent the bulk of the larval catches and also many of the finfish of commercial and recreational importance. Fish eggs were not used to delineate spawning patterns because relatively few eggs have been identified from these collections.

It should be noted that the distribution patterns of larvae from the 1965-66 cruises are only approximate because (1) distance between transects was fairly large and there were gaps of more than a month between some cruises, and (2) distribution patterns for any one species may vary significantly from year to year depending upon environmental conditions and population size. For example, it is possible that during summer 1966 the larvae were distributed further north than usual because the drought conditions of the mid-1960s may have caused reversals in the normal southward drift in the Bight (Bumpus 1969). Nevertheless, the 1965-66 cruise data are believed to be broadly representative of the temporal and spatial distribution of eggs and larvae in the Bight. Larvae of anadromous species and those that spawn in estuaries are not represented in this series.

The locations and names of the transects sampled on each cruise are shown in Map 6. The period of each cruise and the period of larval occurrence for each species is indicated in Table 6. For many species, spawning has a pronounced geographic shift throughout the spawning period; in such cases the period for any spawning location in the Bight will be substantially shorter than that shown in Table 6. A ninth cruise was conducted September 1966 on the four northernmost transects only; larval catches on this cruise are not included in any of the distribution plots given here, but results were incorporated into comments in the text.

Generally, two Gulf V plankton nets were towed at each station, one net from surface to 15 m (49 ft), and the other from 15 to 33 m (49 to 108 ft). The standard profile was step-oblique with 5 minute steps at each 3 m (10 ft) depth interval. Catch data were adjusted to compensate for contamination of the deeper net, and to standardize the catches when the tow profiles were altered. Further details of the towing procedures and data adjustments are described by Fahay (1974).

Seasonal Changes in Larval Fish Communities

The broad geographic and seasonal distribution of spawning is presented first by combining cruises to represent the four seasons. The distribution charts for spring, summer, and autumn are each based on pooled catches of two cruises; only one cruise (January–February 1966) is included for the winter season, therefore, larval catches were doubled for that cruise to make them roughly comparable to the other seasons. To maintain seasonal comparability the December 1965 cruise was not included in this seasonal summary.

Larval catches for all 27 species combined are summarized as numbers of species and total numbers of larvae (Table 7, Maps 7-10). The frequency of occurrence and percentage species composition of larval catches by season are summarized in Table 8.

Winter. Thirteen species were taken on the January–February cruise at an average of 1.9 species per station, the least number for any of the four seasons (Map 7, Table 7). The two species with the greatest frequency of occurrence were sand lance, caught at 71% of the stations and cod at 38% (Table 8). Sand lance alone accounted for 83% of the total catch of larvae and the relatively high densities found off Martha's Vineyard and from Cape Henlopen to Parramore Island (Map 7) were largely caused by catches of sand lance. The total larval abundance of all species in winter was the lowest for any season (Table 7). Thus, as shown from both numbers of species and total number of larvae, winter is the time of minimum spawning activity in the Bight.

Spring. During the April–May cruises there were increases in catches, both in the number of species and numbers of larvae. Of the 27 species, 24 were caught during spring at an average of 3.8 per station, twice the rate for winter (Table 7). The five most frequently occurring species (Table 8) were yellowtail flounder (at 87% of the stations), sand lance (61%), cod (44%), windowpane (43%), and winter flounder (41%). For all species combined there were about 5.5 times as many larvae per station as in winter (Table 7). Within the areas of greatest abundance off New Jersey and Delaware Bay (Map 8), the major contributors were winter flounder inshore, and yellowtail flounder in mid-shelf waters. These two species comprised 97% of the larvae caught on the three transects from Barnegat Inlet to Cape Henlopen. Over the entire area, from Martha's Vineyard to Cape Hatteras, four species constituted 92% of the larvae taken in spring; these four in decreasing order of abundance were yellowtail flounder, winter flounder, Atlantic mackerel, and windowpane.

Summer. During the June–August cruises, 23 of the 27 species were caught at an average of 7.8 species per station, the highest number of species per station for any season and more than double the rate for spring (Table 7). Distribution of species caught in summer tended to be more widespread than the ones taken in spring, causing the extensive areas of diverse catches shown on Map 9. Those species occurring over the widest area were: butterfish (at 87% of the stations), fourspot flounder (73%), hakes (65%), yellowtail flounder (62%), goosefish (54%), silver anchovy and northern searobin (each 50%), Atlantic mackerel and frigate mackerel (each 45%), and silver hake (44%). Thirteen less common species were also taken in summer (Table 8).

The abundance of larvae in summer increased to almost twice that in spring (Table 7). The areas of high abundance (more than 500 larvae per station) were more widespread than in spring, occurring across the breadth of the shelf off Martha's Vineyard and Montauk Point, and in three aggregations in mid-shelf waters from Barnegat Inlet to Cape Hatteras (Map 9). The majority of low density areas was inshore, from Barnegat Inlet to Cape Hatteras. The most abundant larvae were yellowtail flounder (20% of the total season catch) and hakes, silver anchovy, and Atlantic mackerel (each 12% of the total). Each of all other species taken during summer made up less than 10% of the catch (Table 8).

Autumn. Average values of species per station and larval abundance during the September–October and November–December cruises in 1966 were comparable to values for summer. Twenty species were taken during autumn, at an average of 7.0 species per station, only slightly below the average for summer (Table 7). A broad band of high species diversity extended from Martha's Vineyard to Assateague Island with areas of low diversity found on offshore extremes of transects and inshore from Great Egg Inlet (Map 10). Species showing the widest distribution and hence the highest frequency of occurrence were: hakes (92% of the stations), summer flounder (79%), northern searobin (68%), windowpane (67%), menhaden (66%), and silver hake (60%).

The average abundance of larvae (333/station) in autumn was the highest of all seasons (Table 7). Over the entire area, from Martha's Vineyard to Cape Hatteras, three species made up 77% of the total larvae caught: hakes (32%), northern searobin (27%), and menhaden (18%). Among the other 17 species, each accounted for less than 10% of the total (Table 8).

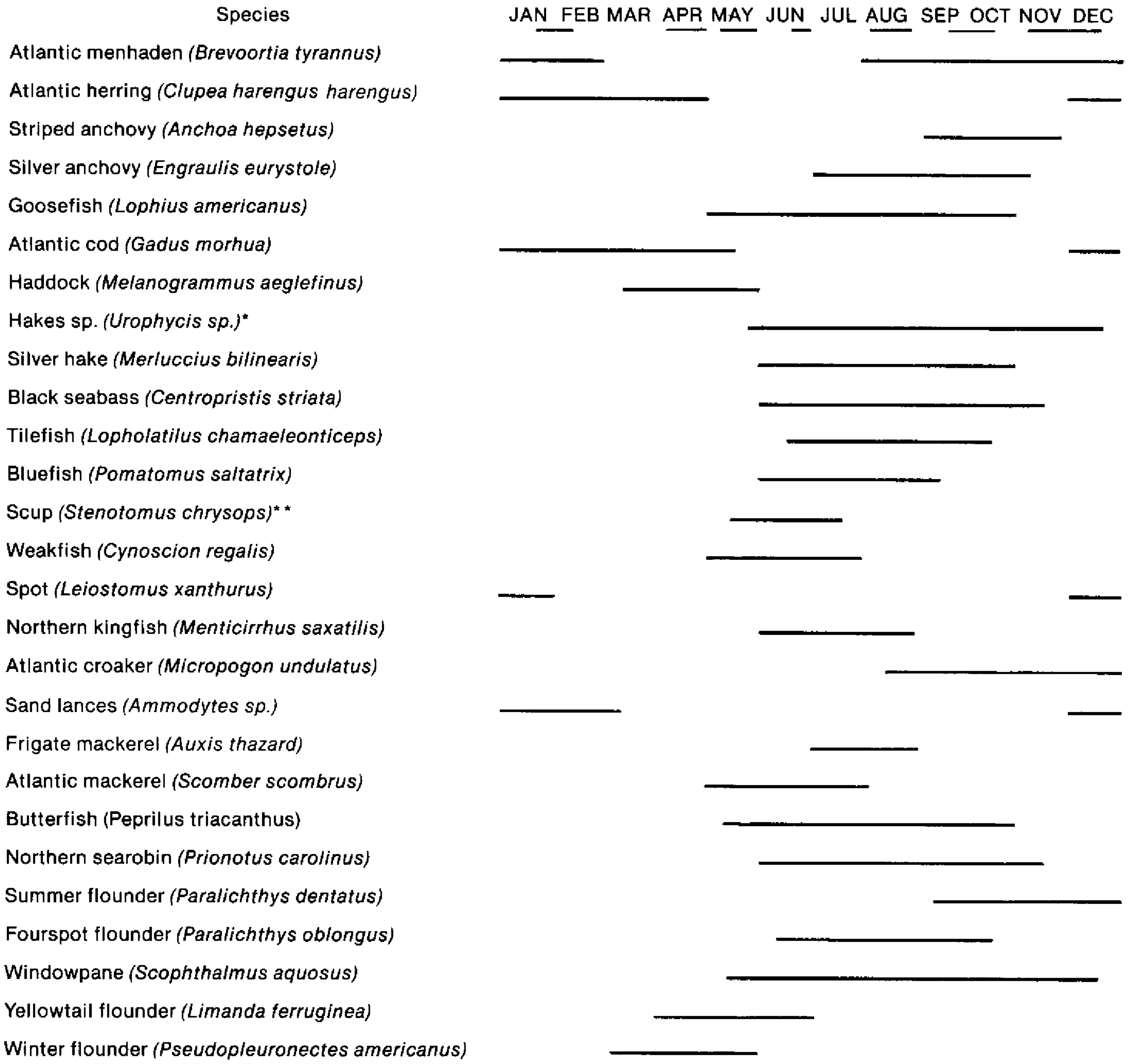
There were two areas of high larval abundance in autumn (Map 10). In the larger of these two areas, between Fire Island and Assateague Island, four species constituted 91% of the total—menhaden, hakes, northern searobin, and windowpane. A second small area of high larval abundance, located off Oregon Inlet and Cape Hatteras, was dominated by catches of striped anchovy and Atlantic croaker. Both of these species apparently spawn extensively to the south, and this high density area represented the northern extent of spawning and probably was a result of Gulf Stream transport of spawning products. The lowest density areas during autumn generally occurred inshore over most of the length of the survey area, across the shelf at Currituck Beach, and on a few scattered stations at the shelf edge (Map 10).

Larval Distributions of Individual Species

Of the 27 species listed in Table 8, 18 are discussed here, and the larval distribution of each of these is shown with a single chart of all cruises pooled together (Maps 11–19). Where significant spawning occurs outside the survey area it is generally noted.

The spawning times and locations inferred here for the 18 species are based on the distribution of recently hatched larvae, and in nearly every case the highest concentrations of larvae represent these youngest, most abundant stages. Larval measurements of herrings, anchovies, and sand lances were total length (TL—tip of snout to posterior edge of caudal fin); all other species were measured in standard length (SL—tip of snout to posterior edge of hypural plate, or to the end of the notocord if the hypural plate had not yet formed).

Table 6. Larval occurrences of various species within the Middle Atlantic Bight as indicated by 1965-66 ichthyoplankton collections (survey period shown by lines directly beneath month names).



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* *Urophycis* sp. refers primarily to red hake (*U.* chuss) and some white hake (*U.* tenuis) with spotted hake (*U.* regius) larvae taken during later months of the indicated season and into winter (M.P. Fahay personal communication).

** *Stenotomus chrysops* (scup) spawning information primarily from Nichols and Breder (1927), Perlmutter (1939), Bigelow and Schroeder (1953), and Finkelstein (1969^{a,b}).

Table 7. Catch summary for larvae of 27 fish species taken during the 1965-66 ichthyoplankton survey in the Middle Atlantic Bight

	Number of Species			Number of Larvae		
	Total	Average Per Station	Range Per Station	Total	Average Per Station	Range Per Station
Winter	13	1.9	0 to 5	2264	29.8	0 to 486
Spring	24	3.8	1 to 8	13267	161.8	1 to 661
Summer	23	7.8	0 to 13	23955	292.1	0 to 2194
Autumn	20	7.0	1 to 12	27312	333.1	2 to 5934

Table 8. Occurrence (%) and total catch (%) for 27 species of fish larvae by station

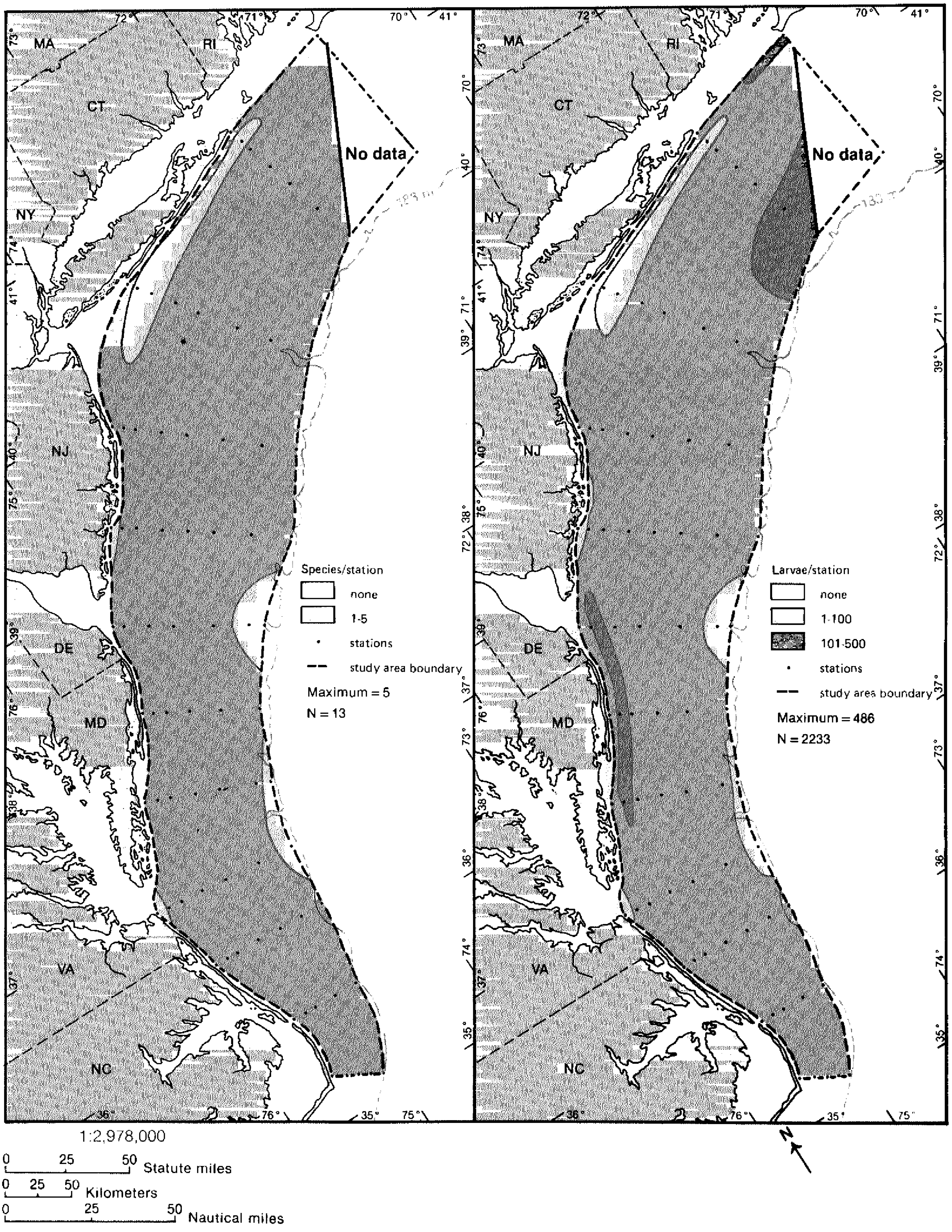
	Winter		Spring		Summer		Autumn	
	% Occurrence on Stations	% of Total Catch	% Occurrence on Stations	% of Total Catch	% Occurrence on Stations	% of Total Catch	% Occurrence on Stations	% of Total Catch
Atlantic menhaden *(Brevoortia tyrannus)**	18.4	2.8	6.1	0.1	9.8	0.1	65.9	17.8
Atlantic herring *(Clupea harengus harengus)**	27.5	2.5	11.0	0.4			26.8	1.0
Striped anchovy *(Anchoa hepsetus)*			3.7	0.7	11.0	0.6	24.4	2.8
Silver anchovy *(Engraulis eurystole)**	3.9	0.4	2.4	0.3	50.0	11.9	40.2	1.4
Goosefish *(Lophius americanus)*			6.1	0.1	53.7	0.6	18.3	0.1
Atlantic cod *(Gadus morhua)**	38.2	6.4	43.9	0.9	17.1	0.1	24.4	0.3
Haddock *(Melanogrammus aeglefinus)*	2.6	0.3	15.9	0.8	8.5	0.1		
Hakes *(Urophycis* sp.*)**	6.6	1.0	8.6	0.1	64.6	12.0	91.5	32.1
Silver hake *(Merluccius bilinearis)**			2.4	0.1	43.9	5.8	59.8	3.3
Black seabass *(Centropristis striata)**					15.9	0.4	12.2	0.1
Tilefish *(Lopholatilus chamaeleonticeps)*					6.1	0.3	2.4	0.1
Bluefish *(Pomatomus saltatrix)**			2.4	0.1	31.7	6.4	1.2	0.1
Scup *(Stenotomus chrysops)*			2.4	0.1	4.9	0.1	3.7	0.1
Weakfish *(Cynoscion regalis)*			1.2	0.1	15.9	0.4		
Spot *(Leiostomus xanthurus)*	7.9	1.7	3.7	0.1			1.2	0.1
Northern kingfish *(Menticirrhus saxatilis)*			1.2	0.1	25.6	0.3		
Atlantic croaker *(Micropogon undulatus)**	3.9	0.4			17.1	1.1	20.7	1.1
Sand lances *(Ammodytes* sp.*)**	71.1	82.8	61.0	3.1				
Frigate mackerel *(Auxis thazard)*			2.4	0.1	45.1	7.5	4.9	0.1
Atlantic mackerel *(Scomber scombrus)**			17.1	9.3	45.1	11.7		

Table 8. continued

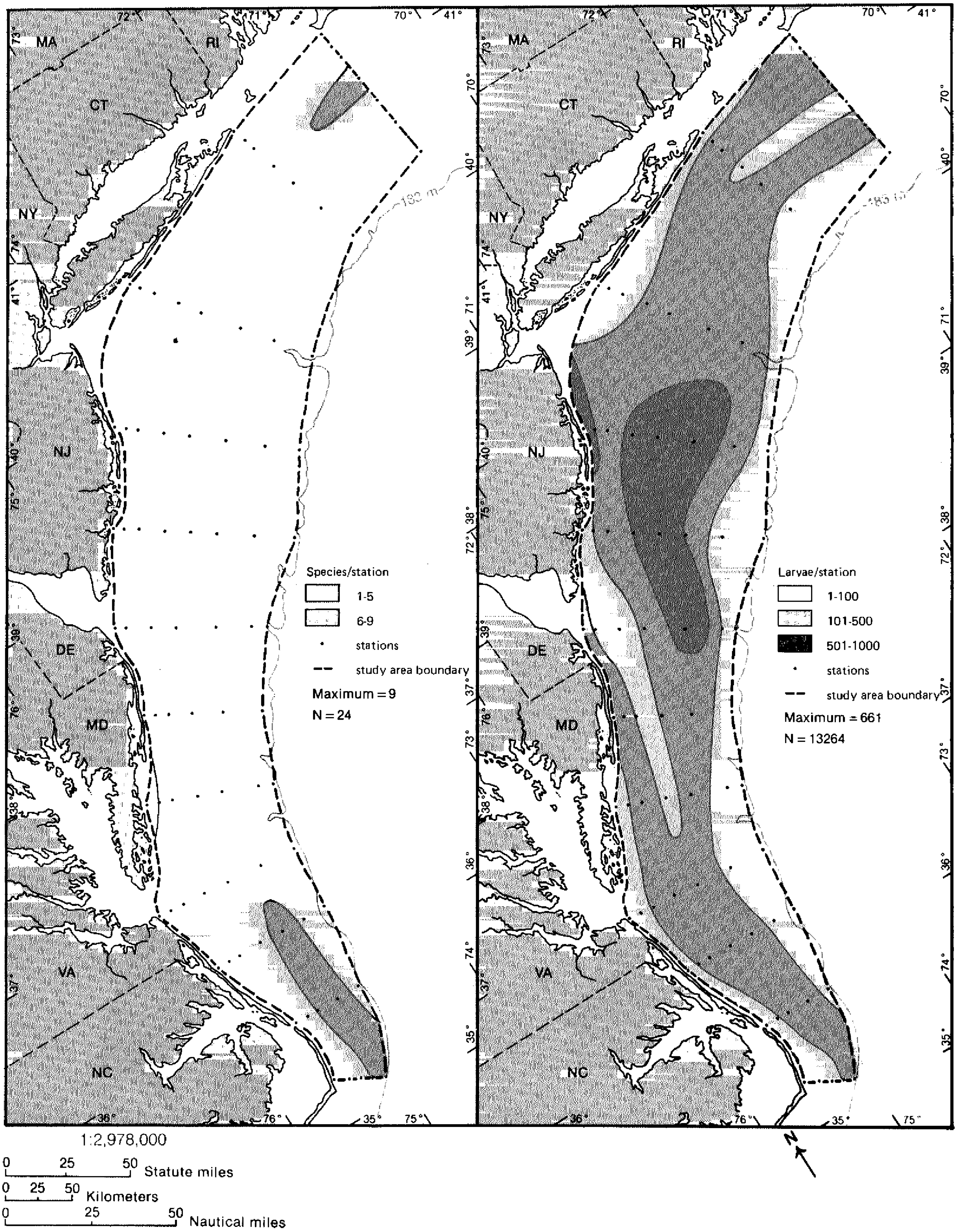
	Winter		Spring		Summer		Autumn	
	% Occurrence on Stations	% of Total Catch	% Occurrence on Stations	% of Total Catch	% Occurrence on Stations	% of Total Catch	% Occurrence on Stations	% of Total Catch
Butterfish *(Peprilus triacanthus)**			12.2	0.7	86.6	9.4	40.2	0.4
Northern searobin *(Prionotus carolinus)**	2.6	0.2	3.7	0.1	50.0	4.4	68.3	27.1
Summer flounder *(Paralichthys dentatus)**	17.1	1.1	4.9	0.1			79.3	3.8
Fourspot flounder *(Paralichthys oblongus)**			1.2	0.1	73.2	4.9	42.7	1.4
Windowpane *(Scophthalmus aquosus)**	3.9	0.4	42.7	8.6	29.3	1.0	67.1	7.5
Yellowtail flounder *(Limanda ferruginea)**	1.3	0.1	86.6	56.4	62.2	19.8		
Winter flounder *(Pseudopleuronectes americanus)**			41.5	17.8	8.5	1.4		

*Larval distribution plots shown for these species individually (Maps 11-19)

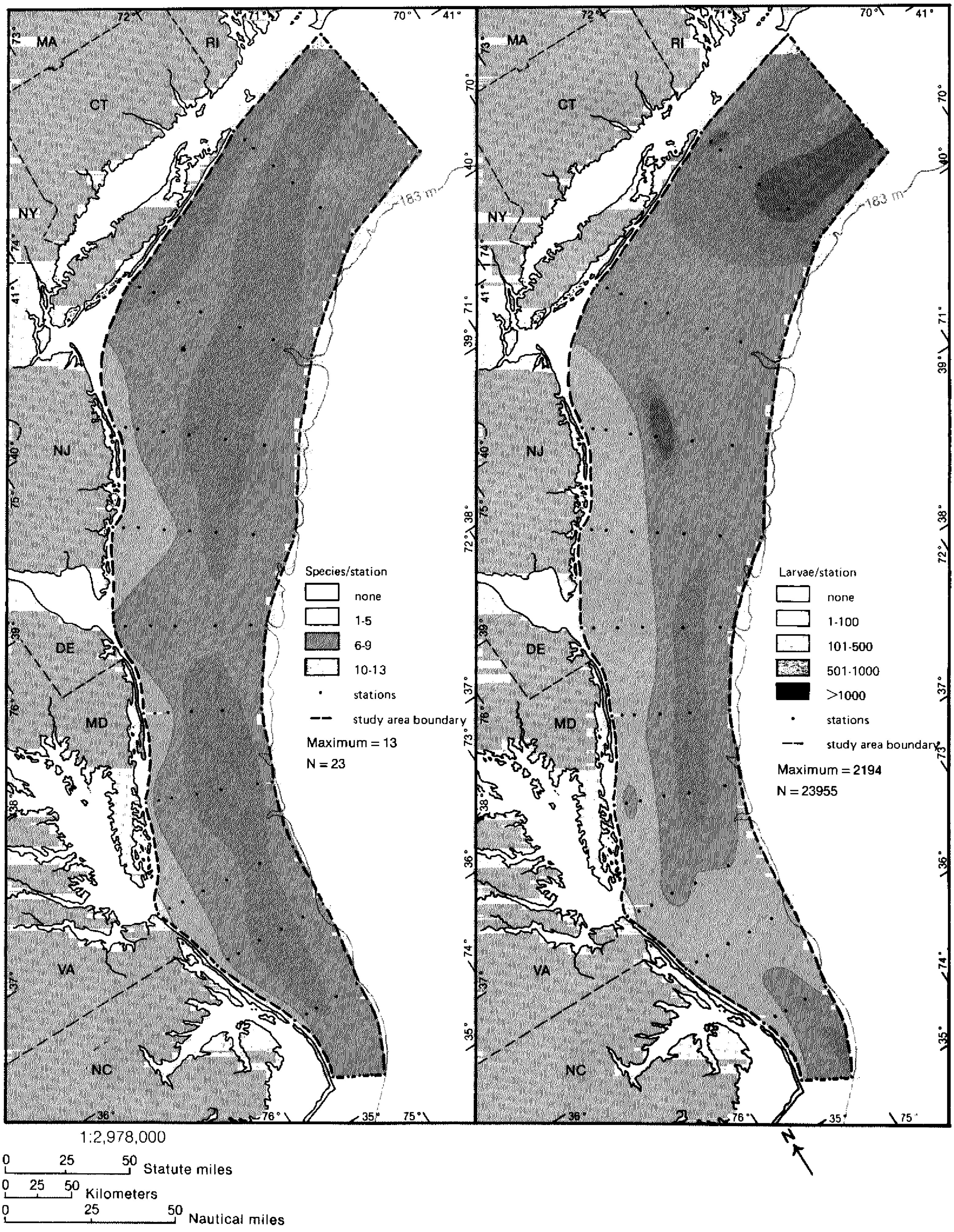
Map 7. Winter distribution of larval fish



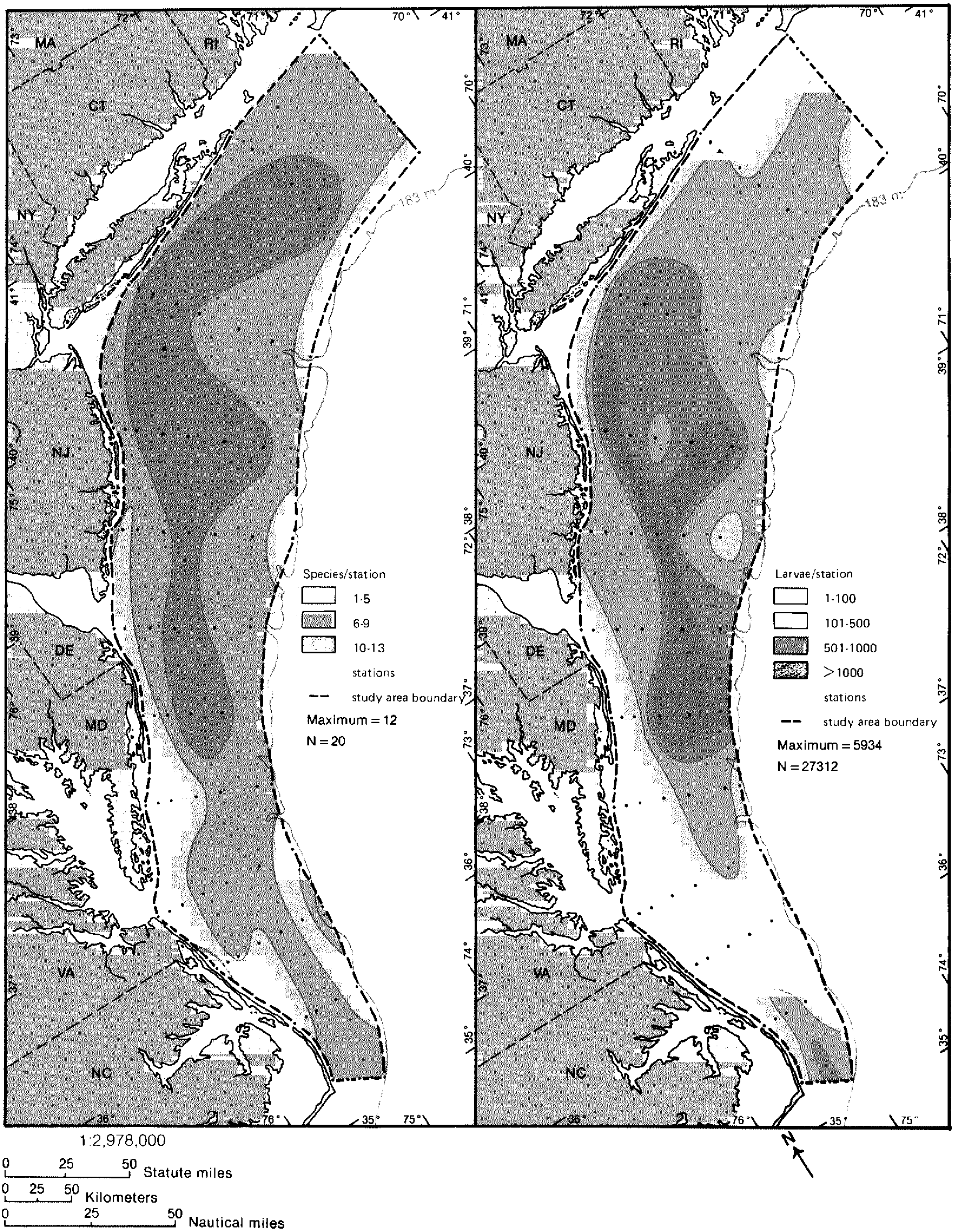
Map 8. Spring distribution of larval fish



Map 9. Summer distribution of larval fish



Map 10. Autumn distribution of larval fish



Sand lances, *Ammodytes* sp. (Map 11). Sand lance larvae were taken primarily during winter and spring cruises. During early December only a few were caught, occurring off Martha's Vineyard and Long Island. They were recently spawned, less than 7 mm (0.3 in) long (Richards and Kendall 1973). During the January–February survey, larvae were abundant, occurring from Martha's Vineyard to Cape Hatteras with concentrations off Montauk Point, Delaware Bay, and the MD–VA eastern shore. The modal length was 10 mm (0.4 in). In early April they were found from Martha's Vineyard to Cape Hatteras, but were less abundant than in winter. Although average size was larger in April (mode, 19 mm or 0.7 in) than in winter, there still were larvae in the 5 mm (0.2 in) length interval, indicating spawning in late March. By May only a few larger larvae (►11 mm or ►0.43 in) were taken; they occurred from Martha's Vineyard to Great Egg Inlet, NJ, and were widely dispersed.

Throughout the spawning season, late November to late March, recently hatched sand lance occurred both inshore and offshore.

Atlantic cod, *Gadus morhua* (Map 11). Atlantic cod larvae were taken during six cruises between November and June. They were distributed from Martha's Vineyard to the VA eastern shore, with a few larvae off Oregon Inlet and Cape Hatteras. The greatest concentrations were found from Martha's Vineyard to Cape Henlopen, occupying the full breadth of the shelf in the north and midshelf waters off New Jersey and Delaware. These data represent only the southern limit of the total larval distribution for this species. Extensive spawning of the species occurs farther north, from Nantucket and Georges Bank, through the Gulf of Maine and the Gulf of St. Lawrence, and off Nova Scotia and Labrador (Bigelow and Schroeder 1953; Leim and Scott 1966).

Cod larvae were caught in all months from December through June, but numbers were low in June. Small larvae, 3 to 5 mm (0.1 to 0.2 in) long, occurred on all six cruises, indicating some spawning within the survey area from November to May.

Atlantic mackerel, *Scomber scombrus* (Map 12). Atlantic mackerel is primarily a spring spawner in the Bight. It is a highly migratory pelagic species spawning progressively from south to north. Spawning is apparently determined by the northward advance of warming in surface waters. The south to north progression of spawning is illustrated by the larval distribution and sizes. During May, larvae occurred only from Cape Henry to Oregon Inlet; they had a modal length of 3.5 mm (0.1 in) SL* and were apparently spawned near the first of May. During June they occurred over a much greater area and farther north, extending from Parramore Island to Martha's Vineyard, and there was a decrease in modal size from 35.0 mm (1.4 in) in the south to 3.5 mm (0.1 in) in the north, reflecting the progression of spawning northward. By August only a few larvae were found off Martha's Vineyard and Montauk Point, with a modal length of 3.5 mm (0.1 in).

Yellowtail flounder, *Limanda ferruginea* (Map 12). Yellowtail flounder larvae were the most abundant of all flatfish larvae in the survey and they were taken during cruises in April, May, June, and August, 1966, from Martha's Vineyard to Oregon Inlet (Smith, Sibunka, and Wells 1975). Larval abundance was highest in May and June, and the distribution of larvae less than 4 mm (0.16 in) indicated that most spawning within the survey area occurred from Martha's Vineyard to Cape Henry during May and June, with lesser spawning intensity as early as March and as late as August. During May the majority of small larvae (◄4 mm or ◄0.16 in) occurred off New Jersey and Delaware, and in June they were off Long Island and Martha's Vineyard (Smith et al 1975). Although the adults do not migrate extensively, this seasonal progression of small larvae is consistent with an eastward movement of adults along Long Island and southern New England, reported by Royce, Buller, and Premetz (1959).

The Bight represents the southern limit of the range for yellowtail flounder, and total abundance of yellowtail is generally greater on Georges Bank than in the southern New England area.

Winter flounder, *Pseudopleuronectes americanus* (Map 13). Adult winter flounder over-winter in bays and estuaries, move only a few miles offshore in summer, and return inshore in autumn. Spawning occurs in estuaries from late winter through spring. Larvae were caught in April, May, and June, 1966, and were most abundant in April. Most larvae occurred near shore after having been flushed out of the estuaries (Smith et al 1975).

During April, larvae that were spawned toward the end of march occurred from Martha's Vineyard to Cape Henry with concentrations occurring off the northern NJ coast and off Delaware Bay and Maryland (Smith et al 1975). In May, larvae were found from Martha's Vineyard to Parramore Island on the VA eastern shore, but were abundant only off Martha's Vineyard. In June, larvae were taken off Martha's Vineyard and Long Island.

The northward and eastward shift in larval abundance between cruises reflects the progression of spawning influenced by the southwest to northeast trend in warming of near shore waters in spring. The larvae sampled by the offshore surveys represented fish which probably did not survive, because juveniles apparently require estuaries as nursery areas (Smith et al 1975).

Butterfish, *Peprilus triacanthus* (Map 13). Butterfish spawning in the Bight begins in the south in early spring,

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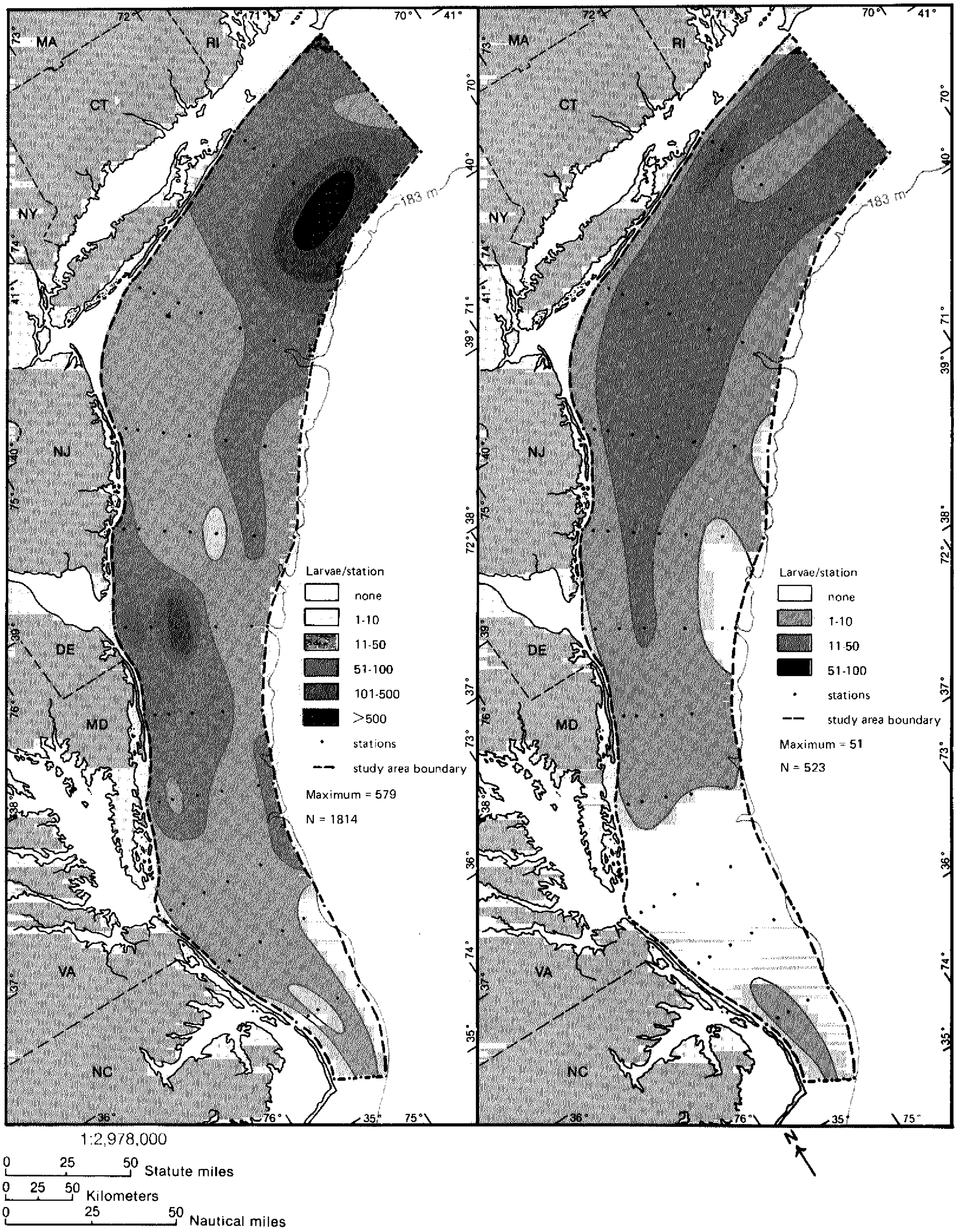
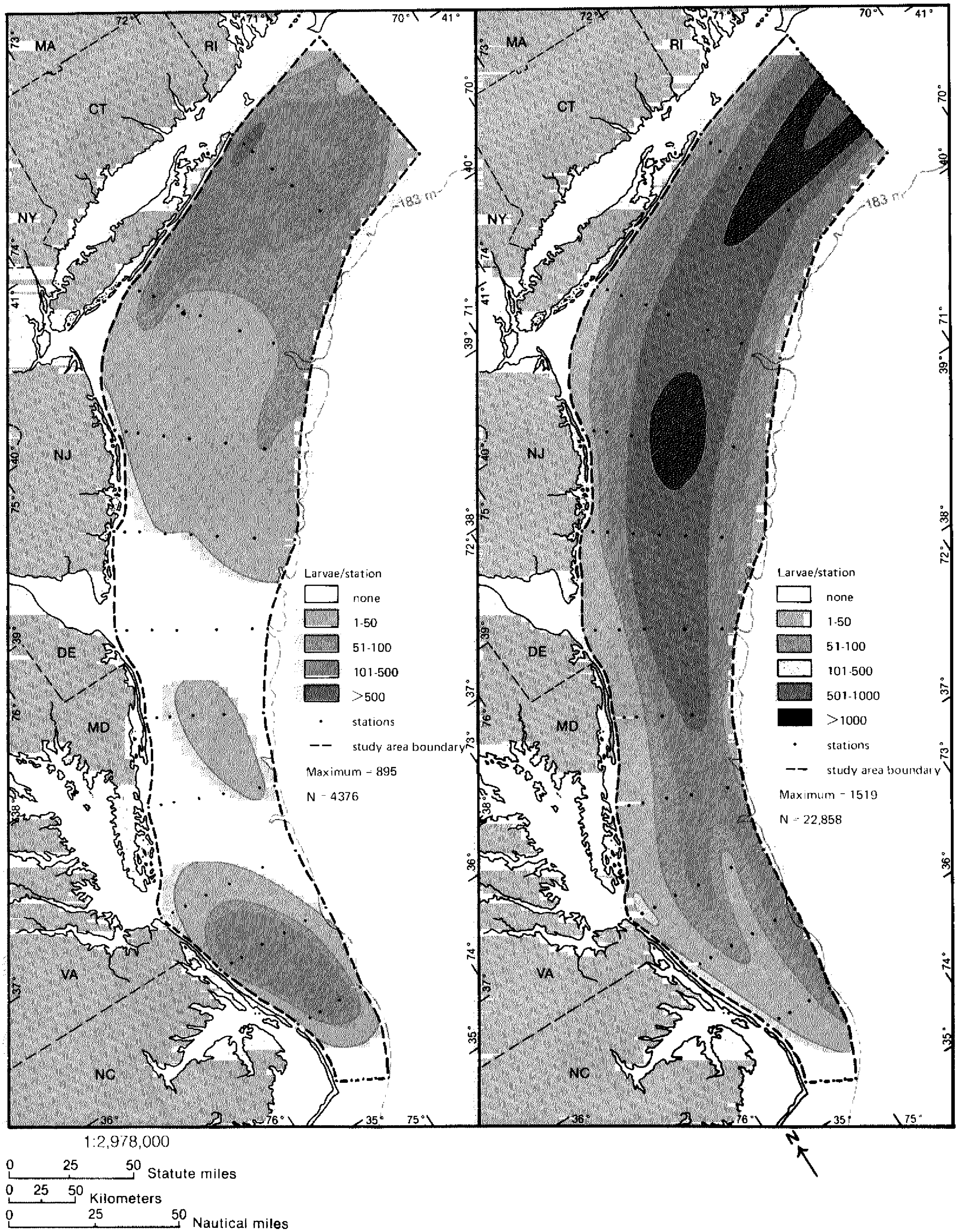
*SL - Standard Length, a measurement from the tip of the head to the end of the last vertebra.

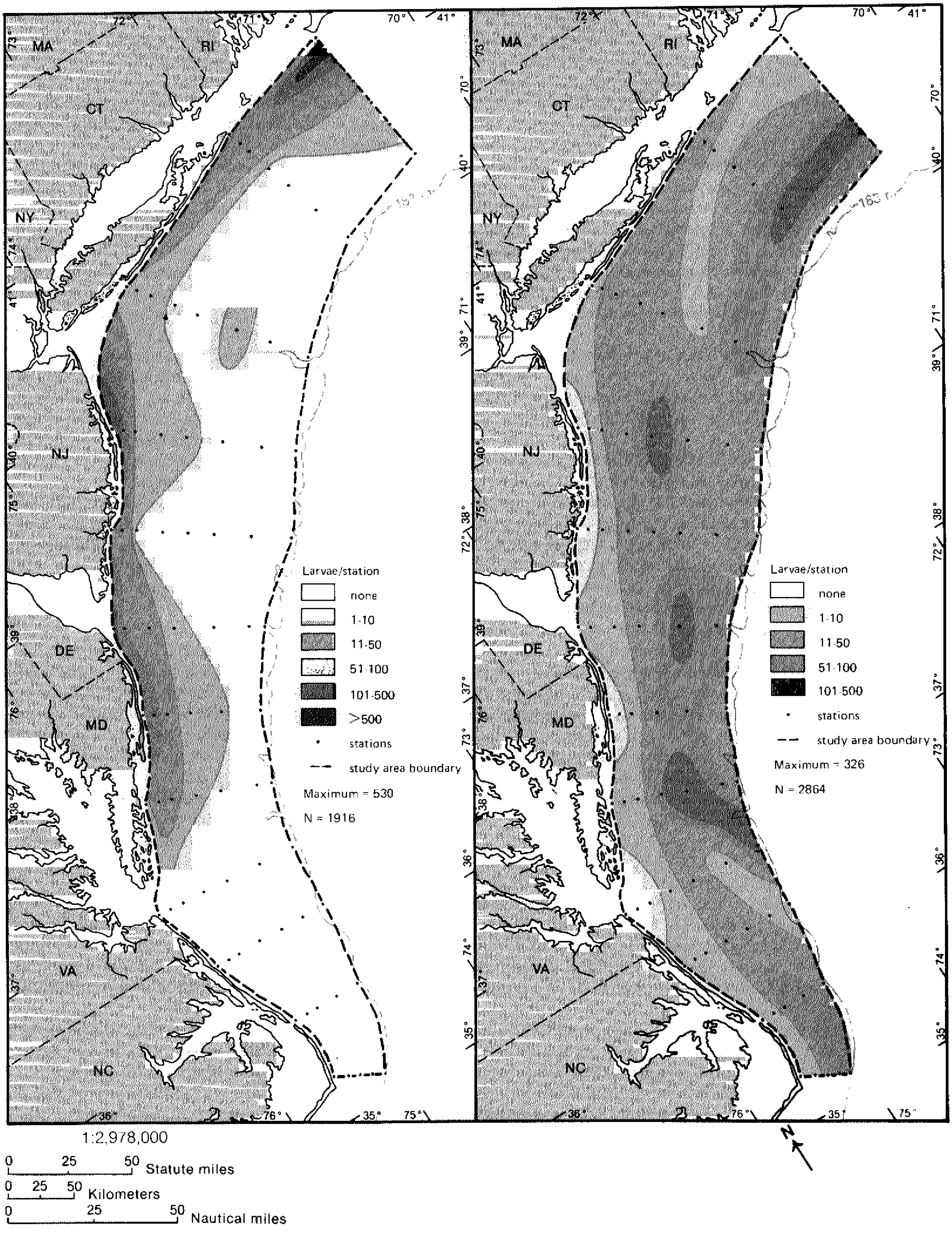
Map 11. Annual composite distribution of American sand lance (left) and Atlantic cod (right) larvae



Map 12. Annual composite distribution of Atlantic mackerel (left) and yellowtail flounder (right) larvae



Map 13. Annual composite distribution of winter flounder (left) and butterfish (right) larvae



spreads north to Chesapeake Bay through spring, occurs over the entire area in summer and early autumn, then ceases by November. Butterfish larvae were caught on seven of the eight cruises, between April and December, and occurred on all transects at some time during this period. Small larvae 3 to 4 mm (0.12 to 0.16 in) were found off Cape Hatteras in April and May, from Cape Hatteras to Cape Henry in June, over the entire area from Cape Hatteras to Martha's Vineyard in large numbers during August, and from Cape Hatteras to Barnegat Inlet in much smaller numbers in September–October. No small larvae were caught in November–December. Large larvae (greater than 15 mm or 0.6 in) were found scattered over the Bight in August, September–October, and November–December.

The areas of high abundance plotted on the composite distribution map are due to catches in August, except for the high abundance off Oregon Inlet and Cape Hatteras which represents larvae taken April, May, and June.

Silver hake, *Merluccius bilinearis* (Map 14). Silver hake larvae were caught on six cruises from May to December, between Martha's Vineyard and Cape Hatteras, and the highest abundance was observed August and September–October from Martha's Vineyard to Cape Henlopen. In addition, large catches of larvae not plotted on Map 14 were made during a September abbreviated cruise that occupied only the four northernmost transects.

Small larvae (2 to 4 mm or 0.08 to 0.16 in) tended to be found inshore and near the surface, whereas larger larvae tended to be offshore and deeper, apparently seeking the bottom in deep water as they grow. Small larvae also tended to be restricted to the northeast portion of the survey area while this was not true for larger larvae. This indicated drift toward the southwest, away from a spawning area near the northeast edge of the survey area (Fahay 1974). Similar to cod, major spawning of silver hake occurs on Georges Bank, in the Gulf of Maine, and off Nova Scotia.

Hakes, *Urophycis* sp. (Map 14). Hake larvae were caught during all cruises of the series, and are thought to be predominantly red hake, *U. chuss.* However, because of identification problems, two other species are likely to be present in the samples; these are white hake, *U. tenuis,* and spotted hake, *U. regius* (M.P. Fahay, personal communication).

In winter and spring only a few small larvae were taken south of Chesapeake Bay (2 to 4 mm or 0.08 to 0.16 in). Small larvae occurred off Martha's Vineyard and Montauk in June; and were abundant from Martha's Vineyard to Barnegat Inlet in August, and from Fire Island to Currituck September–October. By November–December these small larvae were still found over the entire length of the survey area, but were abundant only off Parramore Island and Cape Hatteras. In December very few small larvae were found and they were offshore and scattered; apparently most hake spawning had diminished by this time.

It is probable that spotted hake comprised a significant portion of the small larvae south of Chesapeake Bay in winter and that the rest of the larvae spawned progressively southward over the survey area throughout summer and autumn were mostly red hake and some white hake. Significant spawning of both the latter two species occurs to the north and east of the Bight.

Silver anchovy, *Engraulis eurystole* (Map 15). Silver anchovy larvae were caught on all cruises of the series, but small larvae (3 to 5 mm or 0.12 to 0.2 in) were caught only from May to December. These small larvae were taken off Cape Hatteras in May and June, from Fire Island to Cape Hatteras in August, off Fire Island and Barnegat Inlet in September (during the cruise that extended south only to Barnegat Inlet), off Great Egg Inlet and Cape Hatteras in October, and off Cape Hatteras in December. Therefore, although spawning is indicated from May to November or December near Cape Hatteras, it occurs only from August to October farther north, to Long Island.

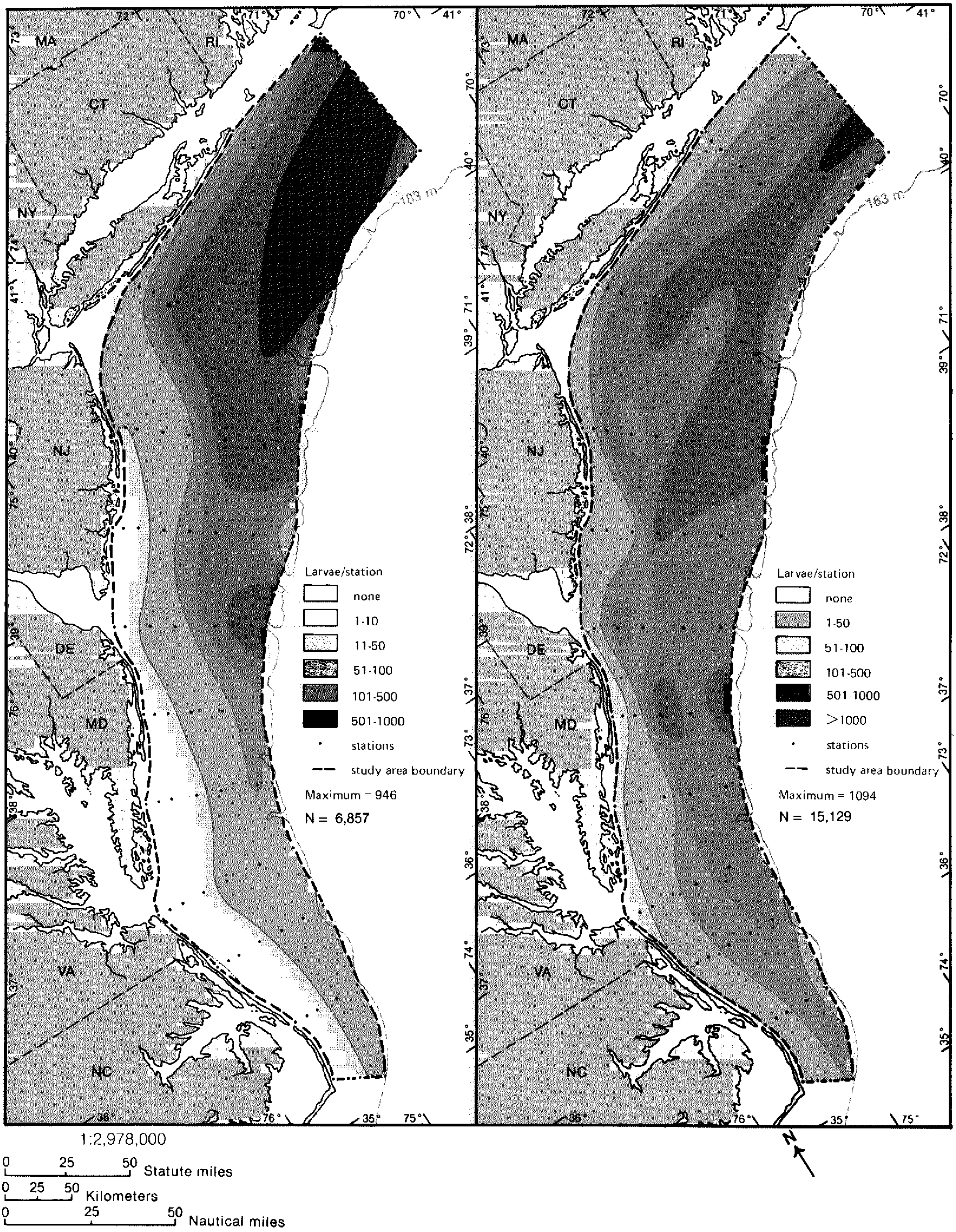
The areas of high abundance off Long Island and Cape Henlopen to Parramore Island represent larvae (all sizes) caught in August, whereas the high catches in the area off Oregon Inlet and Cape Hatteras were taken mostly May to November, and some December, January, and April.

Bluefish, *Pomatomus saltatrix* (Map 15). Bluefish is primarily a summer spawner within the Bight. Larvae were caught from May to October, but substantial catches were made only in August, when 99% of all bluefish larvae were caught. In all months, most of the larvae caught were small and therefore indicated some recent spawning. In May, larvae were taken only off Cape Hatteras, but in August they occurred from Montauk Point to Currituck. During the abbreviated September cruise and again in October a few larvae were caught off Barnegat Inlet.

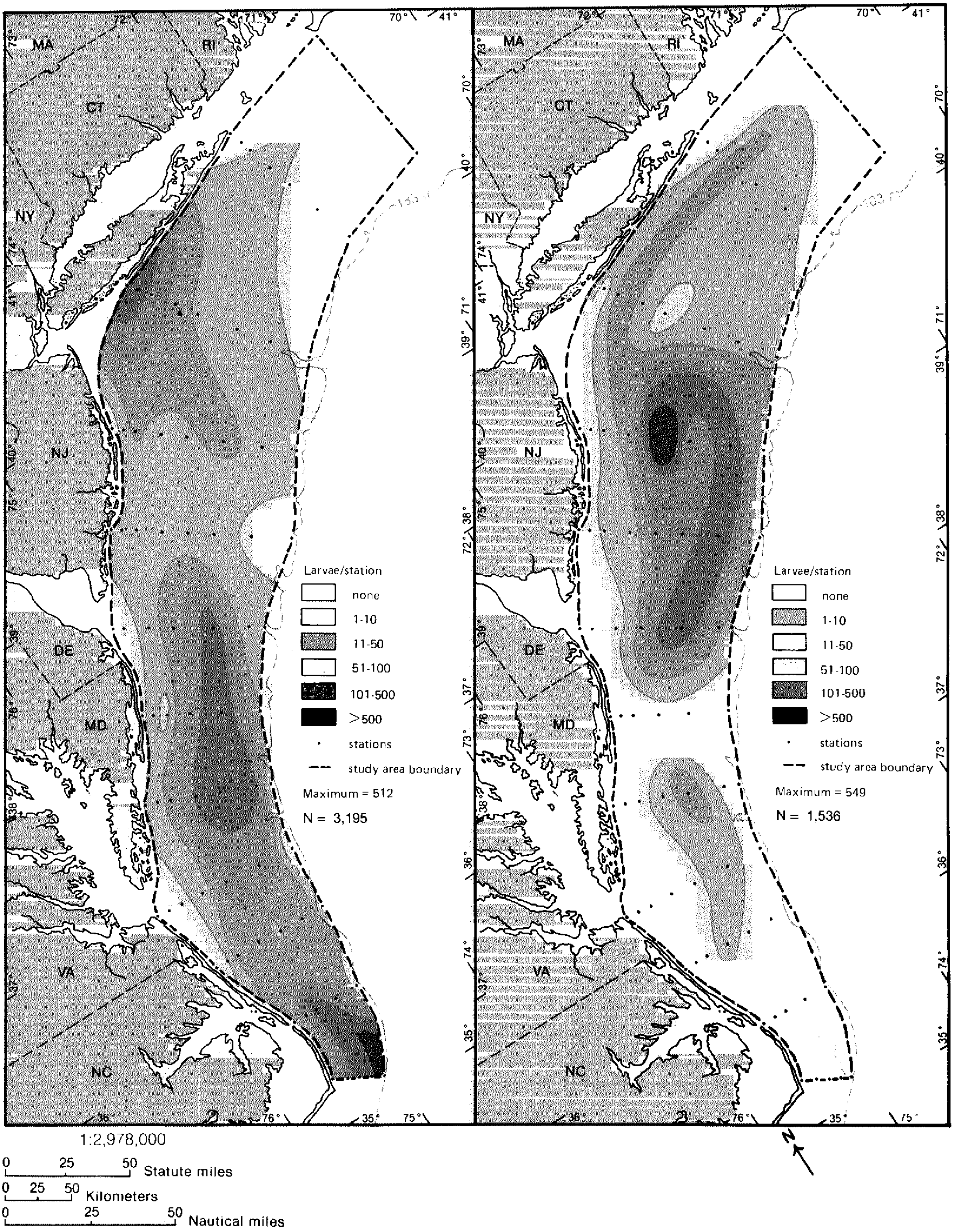
Black sea bass, *Centropristis striata* (Map 16). Black sea bass larvae were caught from June to November, but inferences on spawning are tentative because so few larvae were taken. Small larvae (3 to 5 mm or 0.12 to 0.2 in) were taken on all these cruises but larvae caught in August comprised 85% of the total plotted on Map 16.

A northerly progression of spawning, as indicated by these larvae, was noted by Kendall (1972). In June, larvae were caught off Parramore Island and Oregon Inlet, in August they were found from Cape Henlopen to Oregon Inlet, and during the abbreviated cruise in September, they were caught off Barnegat Inlet, the northernmost point of capture. In October they occurred from Barnegat Inlet to Currituck, and in November were off Cape Henlopen and Parramore Island.

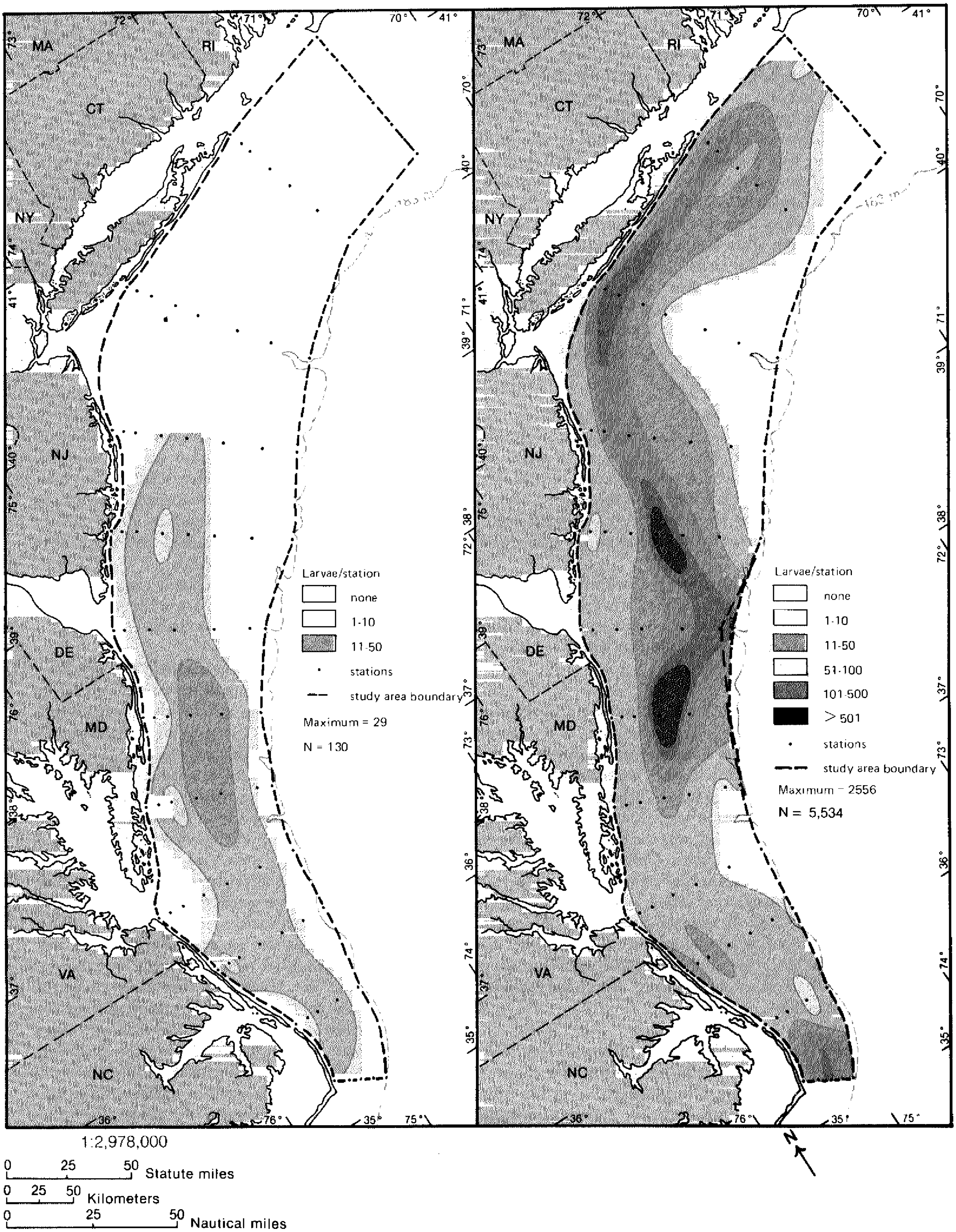
Map 14. Annual composite distribution of silver hake (left) and hake, *Urophycis* sp. (right), larvae



Map 15. Annual composite distribution of silver anchovy (left) and bluefish (right) larvae



Map 16. Annual composite distribution of black sea bass (left) and menhaden (right) larvae



Atlantic menhaden, *Brevoortia tyrannus* (Map 16). Although larval menhaden were caught during all of the survey cruises, the occurrences of small (◀8 mm or ◀0.3 in) larvae indicate spawning extended from late spring through summer and autumn and into winter. There was a seasonal shift in spawning area as shown by catches of small larvae during various cruises (Kendall and Reintjes 1975). In June and August small larvae occurred inshore between Montauk Point and Cape Henlopen. In September–October they were more widespread and were found over the breadth of the shelf between Martha's Vineyard and Currituck Beach; also the bulk of the larval catches north of Chesapeake Bay were taken during this cruise. During November and December cruises, small larvae were caught south of Delaware Bay, and in the January–February cruises larvae were taken south of Chesapeake Bay.

Atlantic herring, *Clupea harengus harengus* (Map 17). Atlantic herring larvae were caught during five cruises between December and May. All were taken north of Chesapeake Bay and all but a few were north of Delaware Bay. The largest catches occurred on the three northernmost transects during December. Very few larvae taken were less than 10 mm (0.4 in) and these occurred in December.

The lack of small larvae is consistent with the fact that the Bight is not a regular spawning area for Atlantic herring. It may, however, serve as a nursery area for some herring larvae derived from Nantucket Shoals or Georges Bank.

Northern searobin, *Prionotus carolinus* (Map 17). Northern searobin larvae were caught during all of the survey cruises. However, there was considerable variation in the areas of occurrence and abundance, particularly among the 2 to 5 mm (0.08 to 0.2 in) larvae. These small larvae were found off Cape Hatteras in May, from Great Egg Inlet to Oregon Inlet in June, and over the entire survey area in August. During the September–October cruise they again occurred over the entire survey area and in much greater abundance than any other cruise; catches on this cruise comprised 89% of all searobin larvae taken during all cruises. In November and December, only a few small larvae were caught; these were scattered between Fire Island and Cape Hatteras, indicating that spawning had ended by early November.

Summer flounder, *Paralichthys dentatus* (Map 18). Spawning of summer flounder extends from late summer to midwinter and occurs throughout the survey area from Martha's Vineyard to Cape Hatteras. There is a southerly shift in egg and larval distribution as the season progresses. Spawning occurred from September to December north of Chesapeake Bay and south from November to February (Smith 1973*a*). Most spawning occurred where bottom temperatures were 12° to 19°C (54° to 66°F). During October large catches of larvae were taken between Massachusetts and Virginia.

Fourspot flounder, *Paralichthys oblongus* (Map 18). Fourspot flounder larvae were caught from May to October within the Bight survey area. May and June they were found south of Cape Henlopen and were small (all were ◀8 mm or ◀0.3 in). They occurred over the inner half of the shelf, except off Oregon Inlet where they extended to the outer edge of the shelf. By August, larvae occurred from Martha's Vineyard to Oregon Inlet. Aggregations of larvae shown in Map 18, off Martha's Vineyard and New Jersey represent catches of very small larvae (◀4 mm or ◀0.15 in) in August. This August catch constituted 71% of all fourspot larvae taken during the series of survey cruises. Larger larvae (8 to 12 mm or 0.3 to 0.5 in) were caught mostly between Great Egg Inlet and Currituck, reflecting earlier spawning in the southern half of the survey area (Smith et al 1975). Small fourspot larvae were abundant in September on the four transects sampled, Martha's Vineyard to Barnegat Inlet, although they were not as abundant as during August in the same area. During October, larvae occurred from Montauk Point to Cape Henry and were most abundant in mid-shelf waters from Great Egg Inlet to Assateague Island.

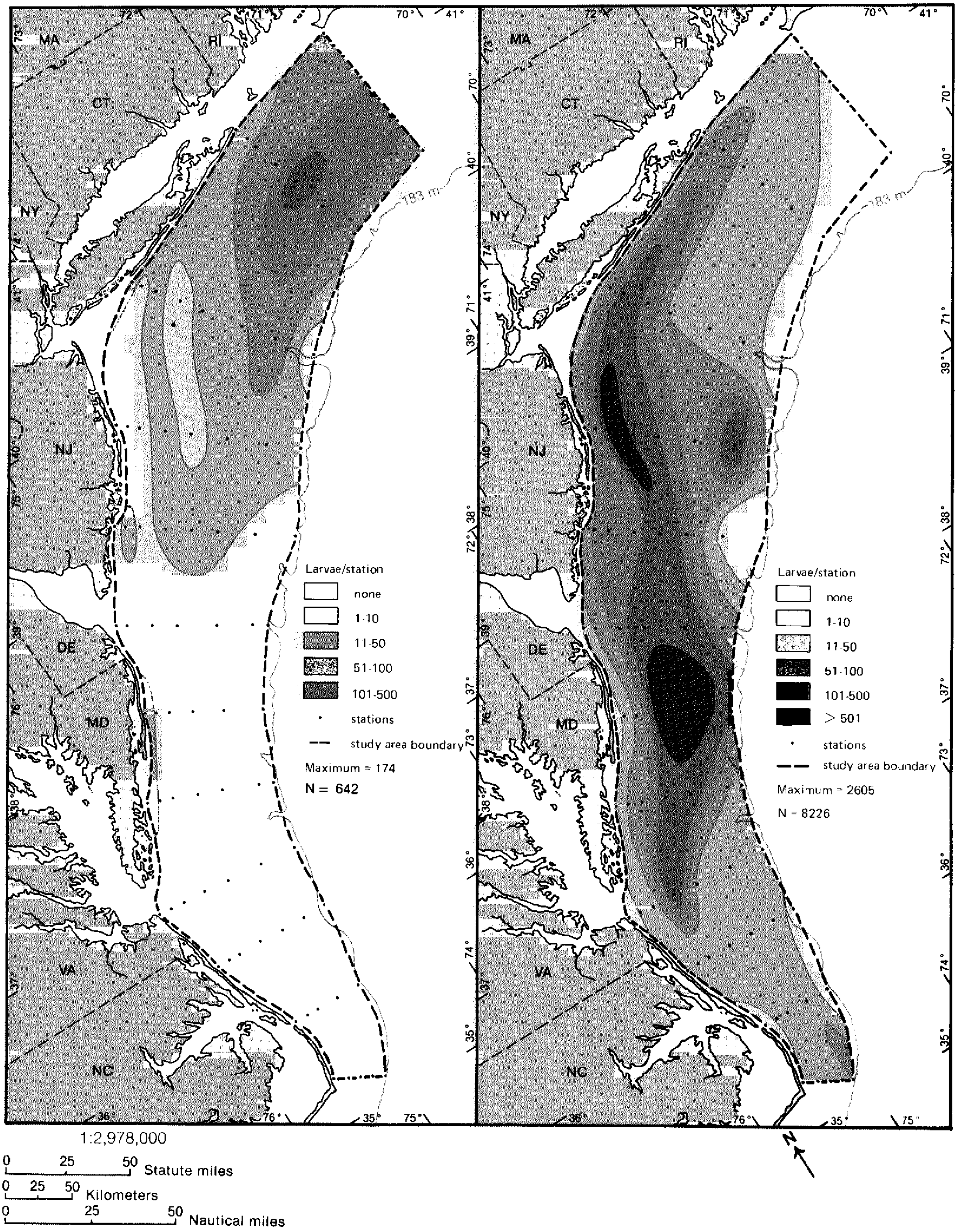
Judging from catches of small larvae, fourspot flounder spawn within the Bight from May to late September or early October with a peak in June (Smith et al 1975).

Windowpane *Scophthalmus aquosus* (Map 19). Windowpane larvae were caught during all cruises. This species apparently spawns almost year-round within the Bight, but there are seasonal shifts in spawning area as indicated by larval distributions during different cruises.

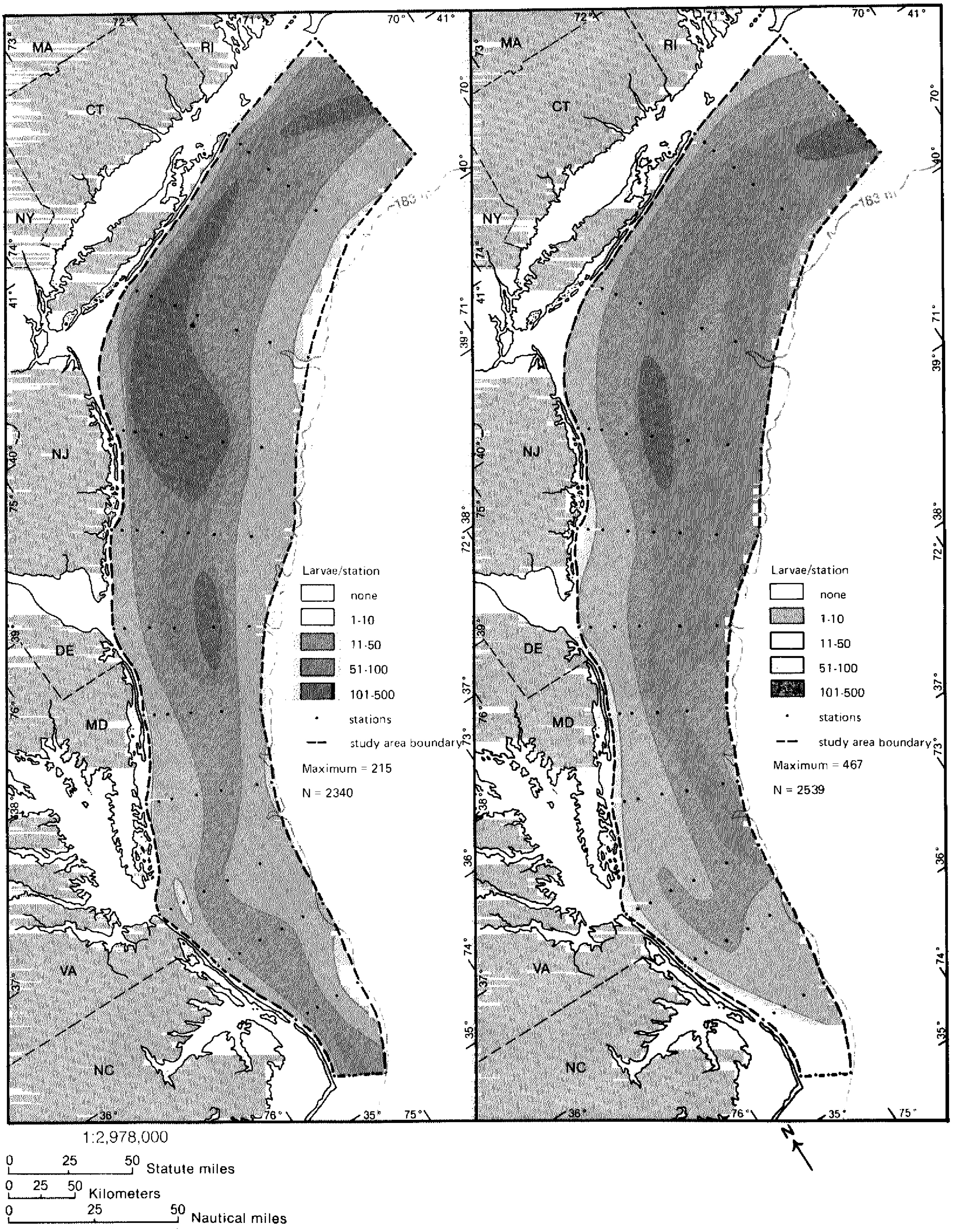
In April, a few small larvae were caught off Cape Henry to Cape Hatteras; in May their distribution had shifted northward to extend from Martha's Vineyard to Assateague Island. In August they were centered still farther north, between Martha's Vineyard and Fire Island. During the September abbreviated cruise they were taken over the inner half of shelf waters, from Martha's Vineyard to Barnegat Inlet. Small larvae were very abundant in September–October when they occurred from Martha's Vineyard to Assateague Island and were most abundant off Long Island and New Jersey. The November–December distribution was similar to that of the preceding cruise but extended farther south to Oregon Inlet and they were again abundant off New Jersey. During the December cruise they were abundant and extended from Fire Island to Cape Hatteras; they were most concentrated from Barnegat Inlet to Cape Henlopen. By January–February spawning had stopped; very few larvae were taken and these were relatively large (4 to 10 mm or 0.16 to 0.4 in) and widely scattered.

Smith and associates (1975) reported a correlation be-

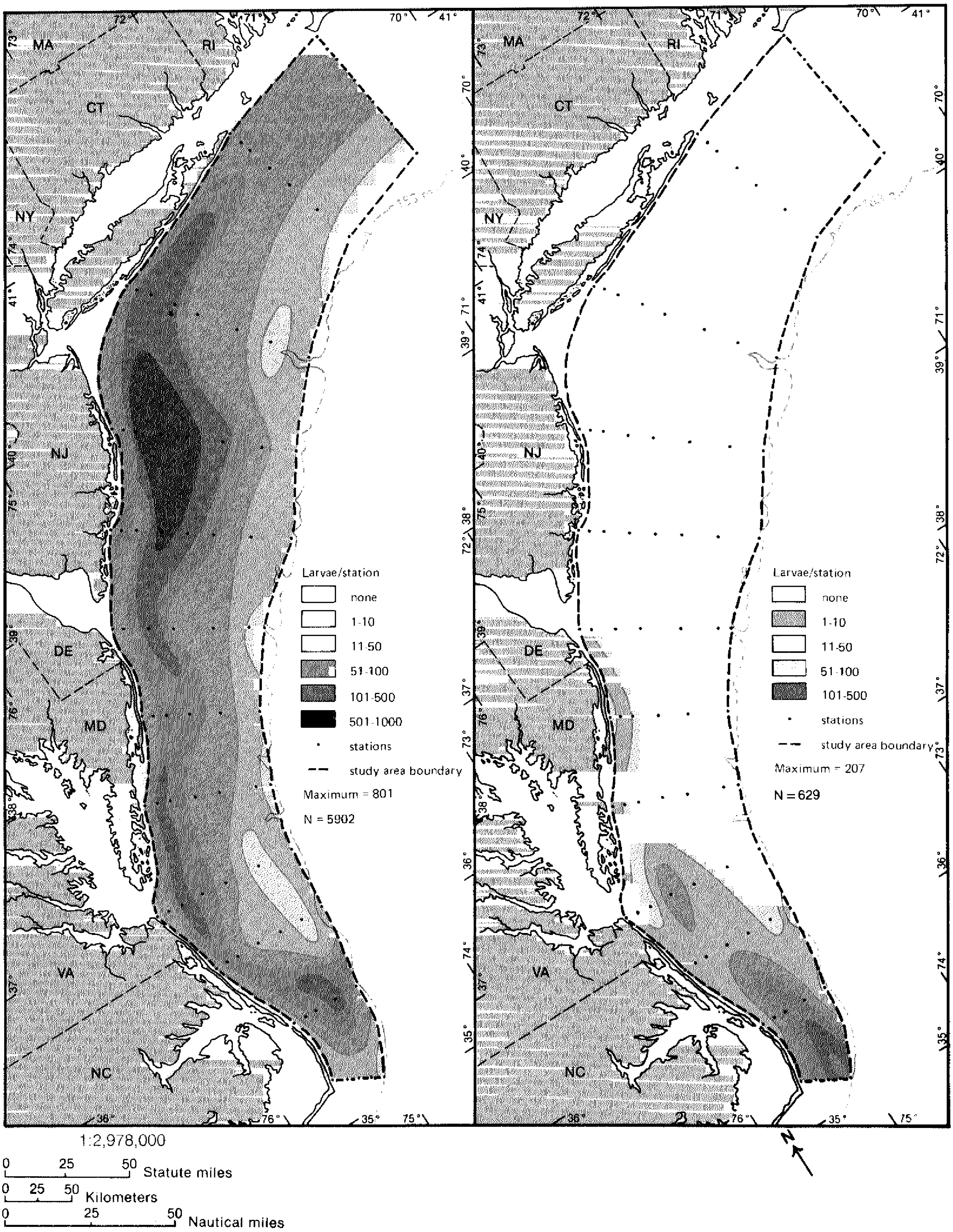
Map 17. Annual composite distribution of Atlantic herring (left) and northern searobin (right) larvae



Map 18. Annual composite distribution of summer flounder (left) and fourspot flounder (right) larvae



Map 19. Annual composite distribution of windowpane (left) and Atlantic croaker (right) larvae



Note: Density around the shoreward station on the Barnegat Inlet transect = 1 to 10 Atlantic croaker larvae per station tween bottom temperature and occurrence of small larvae; 98% of the 2 to 4 mm (0.08 to 0.16 in) larvae were caught where the temperature was between 6° and 17°C (43° to 63°F). At temperatures above 17°C (63°F) in the south during summer, and below 6°C (43°F) during winter, small larvae were not found and no spawning was indicated.

Atlantic croaker, *Micropogon undulatus* (Map 19). Small Atlantic croaker larvae (3 to 5 mm or 0.12 to 0.2 in) were caught during the August, September–October, November–December, and December cruises; they occurred south of Chesapeake Bay. A few larger larvae (6 to 48 mm or 0.24 to 1.9 in) were caught during November–December, and January–February cruises, generally inshore except at Cape Hatteras, and as far north as Barnegat Inlet.

Spawning within the Bight occurred from August to December. Only the northern extent of the larval distribution was sampled, and spawning probably occurred later to the south.

Species Synopses

Introduction

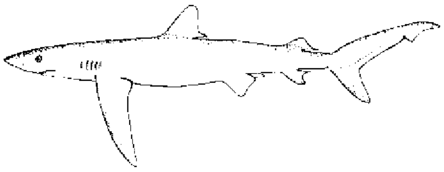
Life history synopses of 43 species of fish and shellfish of the Bight are presented in this section. The information for each fish is organized into five categories: Distribution and Seasonal Movements; Population Size and Fisheries; Reproduction, Growth, Life Span; Feeding Interrelationships; and Environmental Sensitivity (if known). Information on environmental sensitivity appears only in those synopses citing experimental studies of specific environmental effects, or where unique environmental sensitivity could be inferred which clearly would be important in assessing known environmental impacts (such as temperature tolerance for species likely to encounter hot water plumes from power plants). General life history of Bight fishes relevant to environmental impact studies is briefly reviewed in the summary section on environmental effects.

Synopses are arranged in phylogenetic order consistent with that of Table 3. Species maps usually show general distribution in blue shading and spawning areas in brown; arrows are sometimes used to clarify complex migratory patterns. Maps also contain notes where species distribution extend beyond map boundaries.

The synopses are by design only a brief summary of the topics indicated. They include only the material and references considered most important, and do not represent the complete literature on each species. It should be noted that because of the large differences in amount of information available on different species, there is a wide range in the scope and completeness of the various synopses.

Blue Shark *Prionace glauca*

John G. Casey



Distribution and Seasonal Movements. Forty-seven species of sharks have been reported from coastal and oceanic waters from Cape Hatteras, NC, to Cape Sable, Nova Scotia (Bigelow and Schroeder 1948, 1953; Casey 1964; Schwartz and Burgess 1975). All these species can be expected to occur in the Middle Atlantic Bight but the list includes rare, deep water forms, stray individuals whose principal ranges are north or south of the Bight, small dogfish sharks, and larger species that may be common in some years and absent in others. About a dozen shark species that grow to a length of over 1.8 m (6 ft) are common to the Bight, in the sense that some are caught or seen by fishermen every year. All of the larger sharks are seasonal migrants, most abundant May through September.

The most abundant species of large shark in New York Bight, and the most commonly caught by sport fishermen, is the blue shark. Other common species of large sharks include the sandbar, dusky, mako, and hammerhead sharks. The sandbar shark is mostly restricted to the continental shelf; the blue, dusky, and mako sharks occur both inshore and far offshore. Both the dusky and sandbar sharks use the Bight as nursery grounds; the blue shark, and presumably also the mako, have offshore nursery grounds. The sandbar and dusky sharks occur later in the season in the Bight than the blue and mako sharks, reducing possible competition between the two groups. Interactions between the blue shark and the mako are not well understood.

The blue shark is found in all major ocean basins and is widely distributed throughout the North Atlantic. Tagging studies have shown that some blue sharks travel distances greater than 4,827 km (3,000 mi) and a number of transAtlantic crossings have been recorded (Casey and Hoenig 1977). East to west movements have also been recorded (Stevens 1976). Despite these records, the migration patterns and degree of intermixing between shark populations of the eastern and western Atlantic are not well understood.

In the western North Atlantic the blue shark has a complicated pattern of distribution based on age, sex, and season of the year. During the warm months of the year some segments of the population are found on the continental shelf, and from May through October the blue shark is caught by sport and commercial fishermen from Cape Hatteras to the Grand Banks off Newfoundland. In the Middle Atlantic Bight region these sharks are commonly found in shoal waters 30 to 40 m (98 to 131 ft) off Long Island and southern New England in the spring and summer; every year some are caught in Block Island Sound and the lower reaches of Narragansett Bay. For unknown reasons, blue sharks are taken only occasionally inshore on the continental shelf between the Virginia capes and western Long Island, but they are found everywhere offshore from the outer edge of the continental shelf to the Gulf Stream and beyond (Map 20). There is considerable local movement of blue sharks in New York Bight during the warm part of the year with individuals moving along the shelf and others moving onshore and offshore (Casey and Hoenig 1977). Among the small blue sharks (less than

180 cm or 5.9 ft fork length) taken on the shelf, the sex ratio is very nearly equal to one, but the catch of large blue sharks is heavily dominated by males (Pratt 1979).

In late summer and autumn most of the blue sharks leave the Bight although there are some sharks associated with the Gulf Stream all year. The exact migration routes are poorly understood, but many sharks follow a southerly route along the outer edge of the shelf to the vicinity of Cape Hatteras and the margin of the Gulf Stream (Casey and Hoenig 1977). Some blue sharks can be found off Cape Hatteras at all times of the year, while others travel as far south as Bermuda, the Caribbean Sea, and South America. The long distance movements are particularly difficult to interpret since sharks tagged in the Bight have been recovered off South America during all seasons of the year.

Blue sharks have been reported over a broad range of temperatures (8° to 27°C or 46° to 81°F), but they are most common when temperatures range between 13° and 18°C (55° and 64°F). Sciarrotta and Nelson (1977) used telemetry to show that blue sharks off Catalina, CA, were restricted to temperatures of 8.5° to 17.5°C (47.3° to 63.5°F) and spent 73% of the time in water from 14° to 16°C (52° to 61°F). At one time the blue shark was thought to be extremely rare in the Caribbean Sea (Anonymous 1945) but with the development of deep water commerical long-line fising operations, blue sharks were reported regularly there (Guitart Manday 1975). Thus, in tropical areas the blue shark undergoes a submergence and stays in cooler subsurface waters. In New York Bight when annual June surface water temperatures are below 18°C (64°F) the catch in the sport fishery for large sharks is almost exclusively blue sharks. As the water temperatures rise above 18°C, the species composition changes and sandbar, dusky, mako, tiger, and hammerhead sharks are taken in addition to blue sharks (Casey 1977).

Population Size and Fisheries. Blue sharks are extremely abundant, but the total population size is unknown. This lack of information is due largely to the absence of a commercial fishery for the blue sharks. The hides are thin-skinned and many are unsuitable for tanning because of severe bite marks inflicted on females during mating. The jaws are not spectacular as curios and although the meat is edible it is not very firm in texture. The fins are currently the most commercially valuable part of the blue shark. The fins are used for shark fin soup and are taken by foreign fishermen as a by-product of high seas fisheries for tunas and billfishes for sale primarily in oriental markets.

One indication of the abundance of the blue shark is a comparison of blue shark catch rates with that of other, better known large predatory species such as tuna and swordfish. Records from exploratory long-line research cruises and some commercial swordfish logbooks for the Bight reveal that the catch of blue shark per hundred hooks varied from 0.55 to 3.26 (Casey and Hoenig 1977). Blue sharks comprise from 15.9 to 50.3% of these long-line catches and it was not unusual for commercial swordfish long-liners to catch several hundred blue sharks on a single set of 1,000 hooks.

In the last few years, sport fishing for sharks has become increasingly popular. A 1970 survey estimated that anglers caught nearly a half million sharks weighing 2.7 million kg (6 million lb) in the area north of Cape Hatteras, NC (Deuel 1973). These estimates do not include dogfish sharks. Unfortunately, it is not known which of the larger species are represented in the catch, although in New York Bight catches are heavily dominated by blue sharks and sandbar sharks.

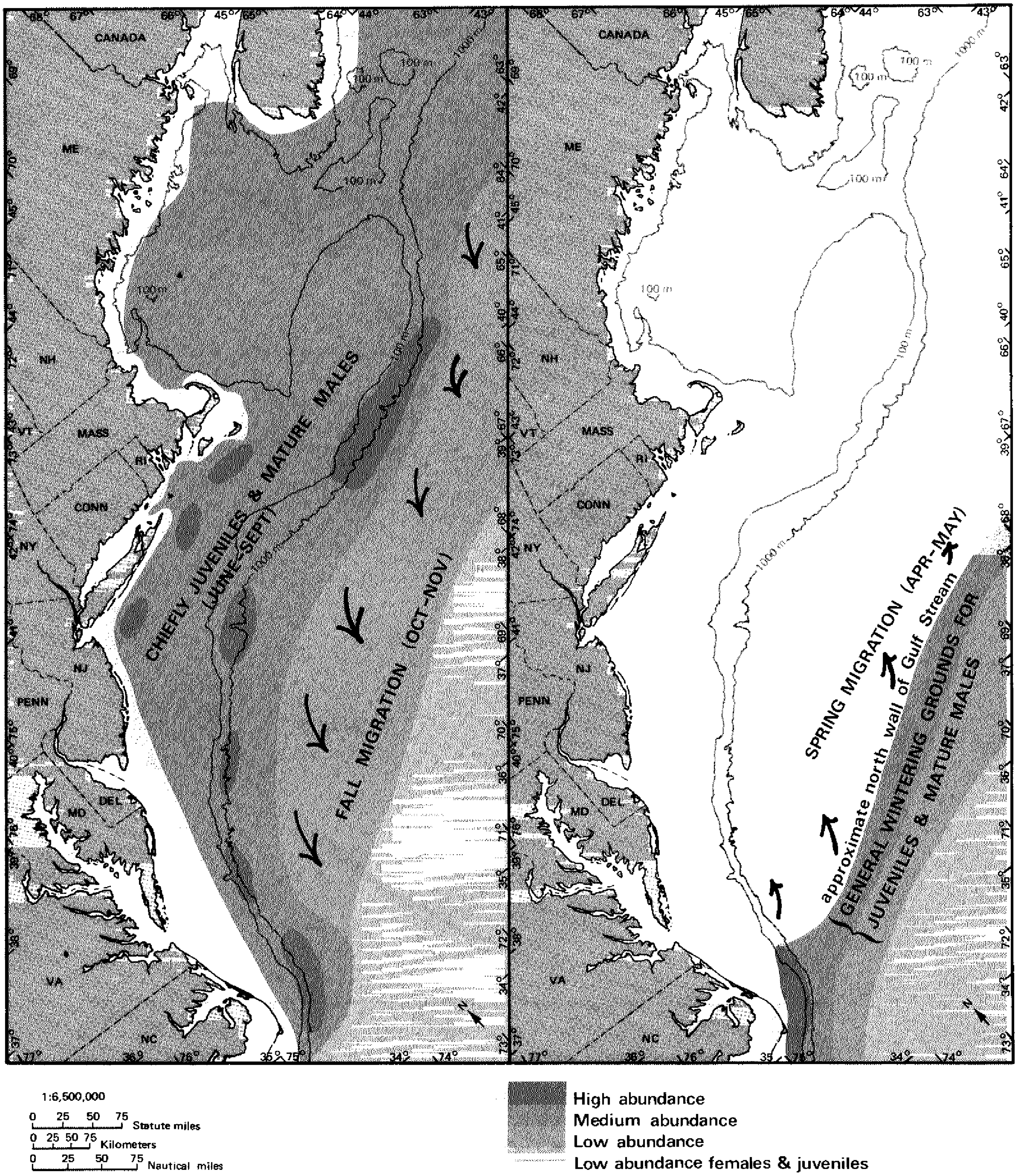
Results of monitoring a June shark fishing tournament on Long Island from 1965 through 1979 show that 150 boats landed between 77 and 1,200 blue sharks in two days of fishing. The average annual catch rate varied from 0.8 to a little over 8 blue sharks per boat (Casey 1977). As the summer progresses, the nearshore sport catches of blue sharks tend to decline. The sharks may move farther to the north and east (Georges Bank, the Gulf of Maine, and Nova Scotia). Catches of sharks increase again off Long Island in September and October suggesting a return migration, but they are much lower than in the early spring.

Reproduction, Growth, Life Span. Blue sharks mature at about six years old (approximately 180 cm or 5.9 ft FL). They are viviparous and the females apparently have an annual reproduction cycle whereas the males are sexually active throughout the year. The mature females are largely absent from the shelf, slope, and Gulf Stream areas, with only a few full-term gravid or post-partum females reported inshore anywhere within the Bight. It is not known where most of the mature and gravid females reside except that adult females have been most commonly reported from tropical waters of the Gulf Stream, Sargasso Sea, and eastern Atlantic (Aasen 1966). Although most females on the shelf are still immature, nearly all females taken off Long Island during summer show fresh bite marks, characteristic of mating activity, which takes place on the shelf after the spring migration. There is evidence that sperm is stored for extended periods in the larger of these females, believed to produce young at a later time. The period of gestation is about 12 months and the young are typically born far offshore beyond the Gulf Stream (Map 20). Up to 80 young are produced in a litter, although the average litter is probably much smaller (Pratt 1979).

The growth of blue sharks is shown in Figure 1. Young are born at approximately 45 cm (18 in) TL in the spring and attain a size of 85, 120, and 155 cm (33, 47, and 61 in) after one, two, and three years, respectively. From tagging studies and examination of growth rings on vertebrae, it appears that blue sharks do not live past 13 years.

The relationship between the fork length of the fish and the round (whole) weight is shown graphically in Figure 2.

Map 20. Blue shark — distribution and pupping areas



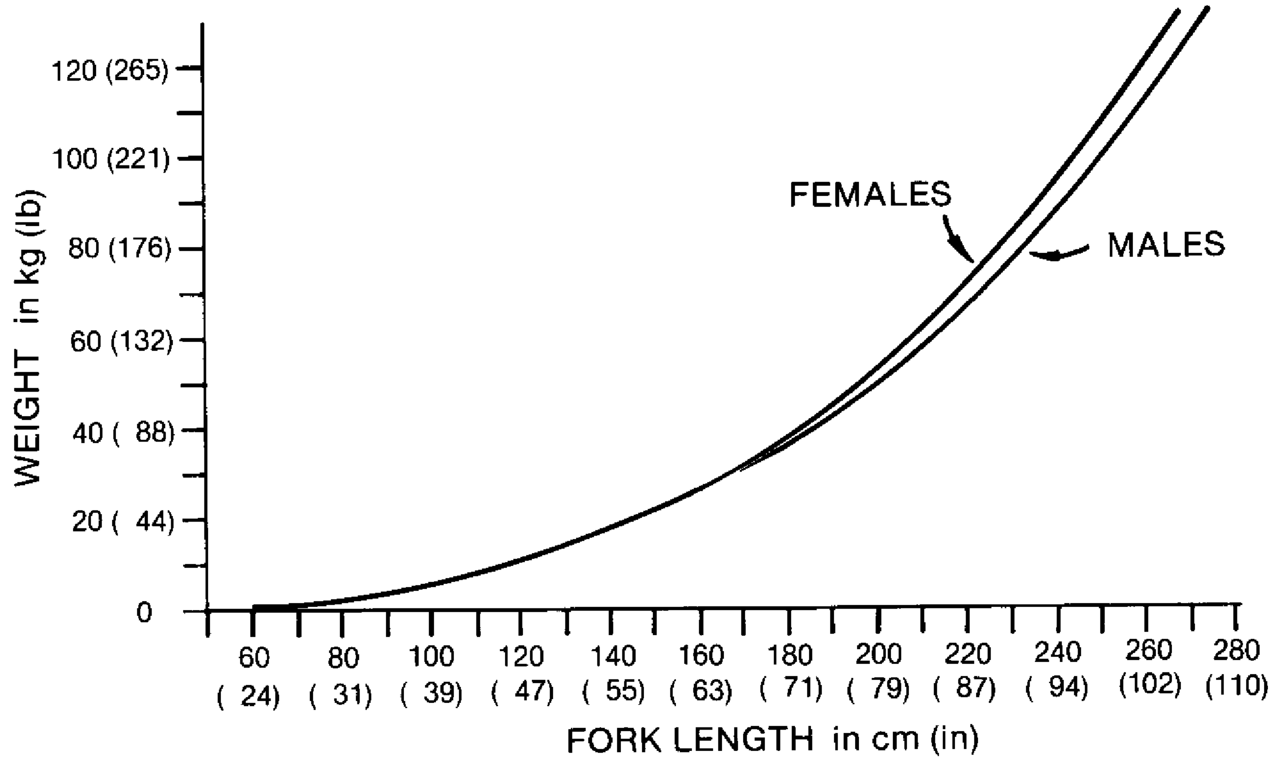
Feeding Interrelationships. The food of the blue shark consists mostly of fish and cephalopods. They have been reported to feed on the bottom in depths of around 70 m (230 ft), to eat groundfish on Georges Bank, and to eat midwater squids (Bigelow and Schroeder 1953; Stevens 1973). They are also frequently seen and caught at the surface by fishermen who use menhaden, mackerel, and a variety of other bait.

Blue sharks taken by anglers near shore in New York Bight seem to have a different diet than those taken over the continental slope (Casey and Hoenig 1977). Offshore, squid seem to be of major importance, whereas near shore the bulk of the food is teleost fish such as hakes, flatfishes, and bluefish.

Environmental Sensitivity. As with other species of apex predators, blue sharks are known to concentrate heavy metals in their muscle tissues (Stevens and Brown 1974). Greig and Wenzloff (1977) found mercury levels as high as 2.0 ppm in blue shark muscle. This concentration far exceeds the present FDA safety guidelines for human consumption and presents an obstacle to the development of commercial fisheries for the species.

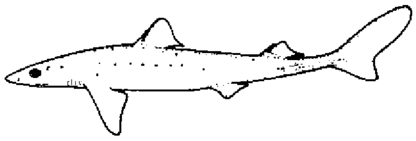
Figure 1. Growth curve for blue shark

Figure 2. Length-weight relationship for blue shark
Source: from Stevens 1975



Spiny dogfish *Squalus acanthias*

Edward Cohen



Distribution and Seasonal Movements. In the Northwest Atlantic spiny dogfish are found from Labrador to Florida, although they are most abundant from Nova Scotia to Cape Hatteras. They migrate extensively along the east coast (Jensen 1965, 1969; Shafer 1970) and are transients in a large part of their range. Spiny dogfish generally range as far south as Florida in winter, and are found chiefly north of Cape Cod in summer (Bigelow and Schroeder 1953; Davis, Musick, and Joseph 1971). Normally, they begin their southward migration in October, and begin returning north in late spring.

NMFS trawl surveys show that in autumn (October) the population is found almost entirely north of Long Island, whereas in spring a significant part of the population has migrated at least as far south as Cape Hatteras (Map 21). Some dogfish remain in the Gulf of Maine year around.

Jensen (1965) and Shafer (1970) considered spiny dogfish to be restricted to the outer edge of the shelf during their spring migration but the 1973-74 groundfish surveys do not bear this out. Map 21 shows that during spring spiny dogfish were found all over the shelf, not just at the shelf's edge.

In the mid-Atlantic and New England areas spiny dogfish inhabit waters with bottom temperatures ranging from 4° to 18°C (39° to 64°F), but their preferred temperature range seems to be between 7.2° and 12.8°C or 45° and 55°F (Jensen 1965).

Population Size and Fisheries. The total biomass of dogfish in the New England area has been estimated to range from about 150,000 metric tons (MT) to about 225,000 MT (Edwards 1968; S. Clark, Northeast Fisheries Center, personal communication). The fishery for spiny dogfish in the Northwest Atlantic is very limited, with about 20,000 MT reported per year since 1972. Very few dogfish are landed by US fishermen since there is virtually no demand in the country for dogfish, either for industrial or market purposes. Until recently, it was uneconomical for US fishermen to take spiny dogfish for sale to European nations (Holmsen 1968). A small export market of about 2,000 MT of dogfish fillets has started in the last few years.

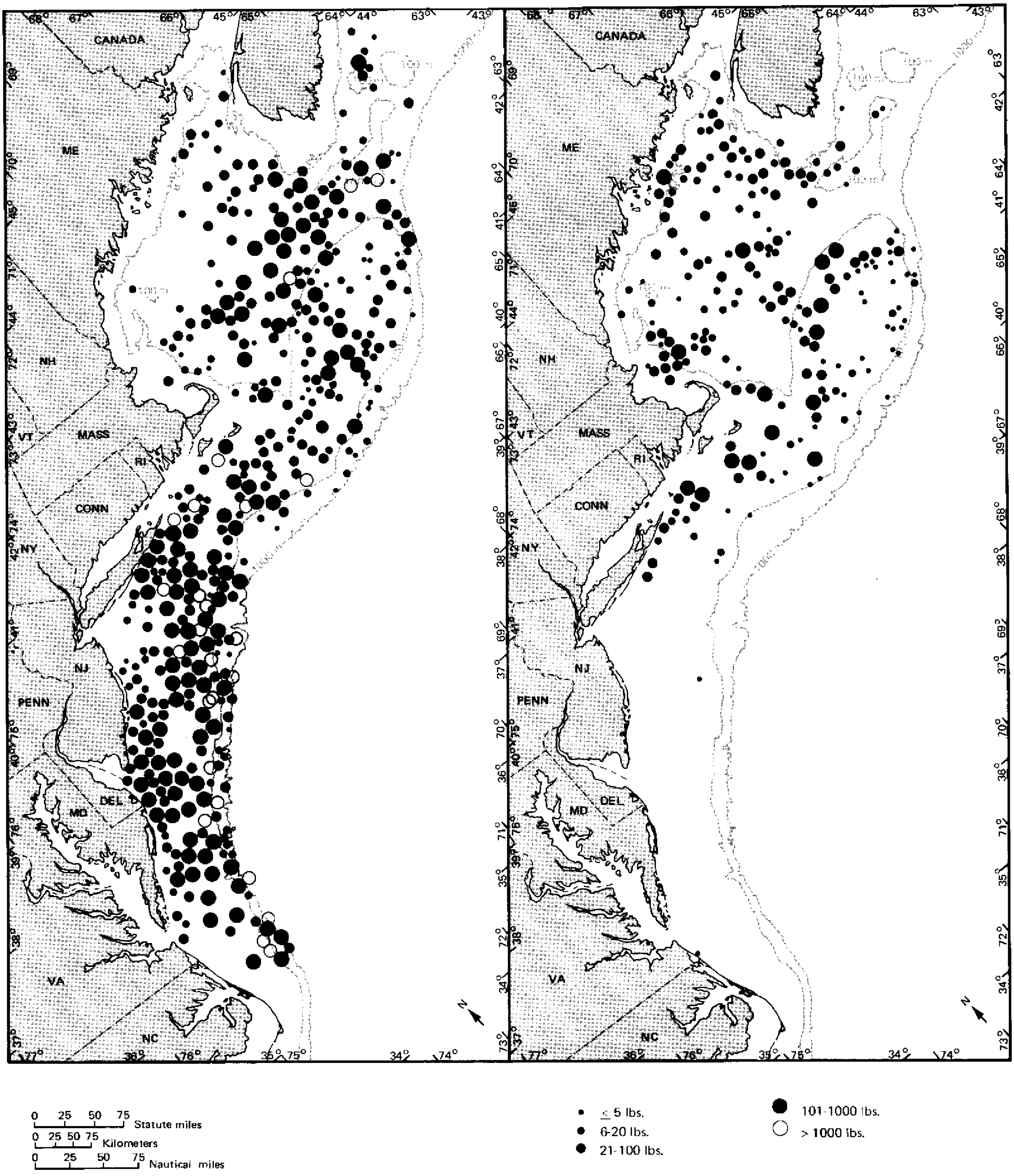
Low fishing pressure may be all that the species can sustain over a long period because of the low reproductive potential. In the North Sea and Norwegian Sea it has been estimated that no more than 20% of the stock, and probably less, can be harvested annually to achieve maximum sustainable yield (Holden 1968).

Reproduction, Growth, Life Span. Bigelow and Schroeder (1953) reported that spiny dogfish spawn offshore in winter. This is confirmed by bottom trawl surveys that show that young are released in the Bight region during spring (Map 21). Spiny dogfish bear live young, called pups, but there is no placental attachment during gestation. The gestation period of about two years is one of the longest in the animal kingdom (Jensen 1965). The number of pups varies from 2 to 29, but the average for the northwestern Atlantic is 4 to 6 (Bigelow and Schroeder 1953; Ketchen 1972). At birth the pups are about 25 to 30 cm (10 to 12 in) long (Jensen 1965).

Spiny dogfish school by size until sexual maturity, after which they school by sex (Bigelow and Schroeder 1953; Shafer 1970). They reach sexual maturity at about 60 cm (24 in) in length for the males and at about 75 cm (30 in) for the females, at an age of nine years or older (Jensen 1965). The growth rate of spiny dogfish is about 3.2 cm per year based on length frequency analysis, and on spine readings (Jensen 1965). At this rate of growth, a female would be about 14 years old at first maturity. Spiny dogfish in the northeast Pacific are about 20 years old at first maturity (Ketchen 1975). Thus, the life span of spiny dogfish may be 25 to 30 years, with adult females attaining lengths of 100 to 124 cm (39 to 49 in) and weights of 7.3 to 9.8 kg or 20 to 26 lb (Jensen 1965).

Feeding Interrelationships. Spiny dogfish are voracious, opportunistic feeders; they eat most species of fish smaller than themselves, primarily mackerel, herring, scup, and flatfish, but also cod and haddock (Maurer and Bowman 1975). They also feed on shrimp, crabs, squid, siphonophores, and sipunculid worms and are one of the few species that will eat ctenophores (Bigelow and Schroeder 1953; Jensen 1965; Maurer and Bowman 1975). Spiny dogfish have few natural enemies although they are preyed upon to some degree by other sharks.

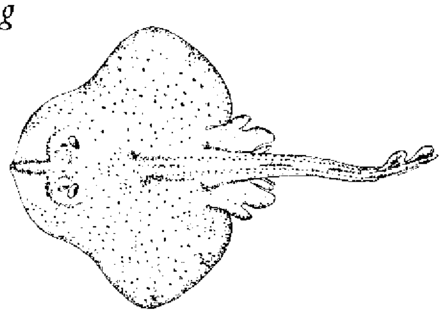
Map 21. Spiny dogfish — distribution of NMFS 1973-74 research vessel trawl catches (dots) (spring-left, autumn-right)



Note: young abundant in brown shaded area

Big and Little Skates *Raja ocellata* and *R. erinacea**

Gordon T. Waring



Distribution and Seasonal Movements. Big *(Raja ocellata)* and little *(Raja erinacea)* skates generally range from northern North Carolina to the southern side of the Gulf of St. Lawrence (Bigelow and Schroeder 1953). Both species are frequently captured in waters shallower than 111 m (364 ft) and within a temperature range of 1.2° to 21°C (34.2° to 70°F) for big skate and 1.2° to 19°C (34.2° to 66°F) for little skate (McEachran and Musick 1975).

These two skates are nearly identical in physical appearance, and separating them is difficult, particularly for small specimens. Identification on trawl surveys is based on physical characteristics described by McEachran (1973), but 100% accuracy in identification is not feasible on these routine surveys.

NMFS autumn surveys indicate that big skates are primarily caught on Georges Bank in summer and autumn. Spring catches indicate some big skates may aggregate inshore along the eastern end of Long Island during winter and spring (Map 22). Little skates were caught from Georges Bank to Chesapeake Bay, and they also appear to aggregate off eastern Long Island during spring (Map 23).

Skates generally appear to be less vulnerable to the trawl in summer and autumn than in spring; this is especially pronounced in the case of little skates from Cape Cod southward (Map 23). These seasonal changes probably reflect mostly behavioral responses to temperature rather than migration.

Hickey (1974) noted that little skates appeared inshore along northern Long Island April-May and October-November. They were most abundant mid-May and November when water temperatures were 12°C (54°F). McEachran and Musick (1975) noted that little skates were most abundant on the shelf off Chesapeake Bay during winter and those that remained there during summer moved into deeper waters. Fritz and Daiber (1963) noted that little skates are the dominant skates in Delaware Bay during winter and spring when water temperatures fall below 15°C (59°F).

Population Size and Fisheries. Spring surveys provide the best abundance estimates of big and little skates in the Bight since the fish are in shoal waters and more available to the trawl. From 1968 to 1978, minimum biomass estimates of big and little skates averaged about 23,000 and 88,000 MT respectively from Cape Hatteras to Georges Bank.

The US commercial fishery for big and little skates involves two components. In the first the wings are the only portion of the fish sold by the fishermen. Species identification is thus not available and accurate landing weights are only recorded for mixed species. The second is the industrial trawl fishery in which skates, along with other fish, are landed whole to be processed into fish meal. Edwards and Lux (1958) analyzed the catch composition of the 1956-58 New England industrial trawl fishery. In southern New England during this period, big skates comprised approximately 4% of the total average landings of 56,731 MT and little skates accounted for approximately 6% of this total. In the Gloucester, MA, industrial fishery, big skates accounted for 2.5% of the average total landings of 10,587 MT, while little skates accounted for 2% of the total.

Industrial fishery catch data by species are not available for 1958-68. However, from 1969 to 1978 big skate and little skate annual landings averaged 217 MT and 953 MT respectively in the southern New England industrial trawl fishery. During this period skates represented from 6.5% to 17% of the total industrial landings in southern New England.

Reproduction, Growth, Life Span. Little skates spawn throughout the year; pregnancy periods peak November-January and June-July, with lows March-April and August-October in southern New England waters (Richards, Merriman, and Calhoun 1963) and in Delaware Bay (Fritz and Daiber 1963). Although this cyclic reproductive behavior has not been reported for big skates, pregnant females have been taken December-January off southern New England (Bigelow and Schroeder 1953). Spawning presumably occurs along the mid-Atlantic coast and on Georges Bank since newly laid egg cases have been taken throughout this area (Map 22).

All true skates lay eggs, and fertilization is internal via the male's clasper organ (Friedman 1935; Richards et al 1963). Little skates prefer a relatively hard bottom substrate for egg laying. Skate egg development takes place in a leathery case, commonly called the mermaid's purse. The egg cases are formed two at a time, usually one egg per case. The cases have sticky filaments that adhere to sand and pebbles, increasing their weight and holding them to the substrate (Richards et al 1963; Fritz and Daiber 1963).

Six months may be the minimum time required for hatching and it may take as long as nine months. Newly hatched little skates have a whip-like extension on the tail; this extension disappears as they become older. Length at

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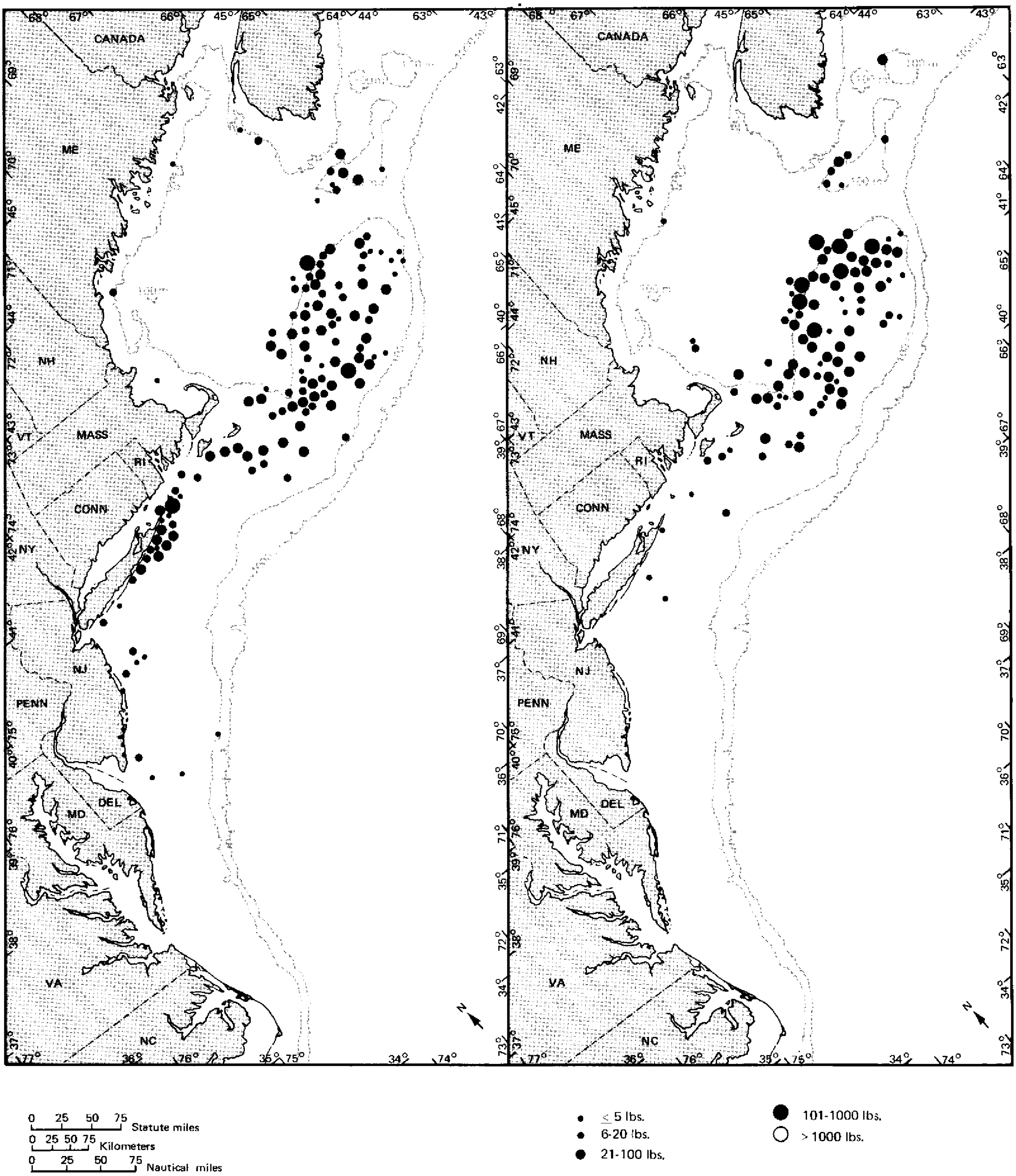
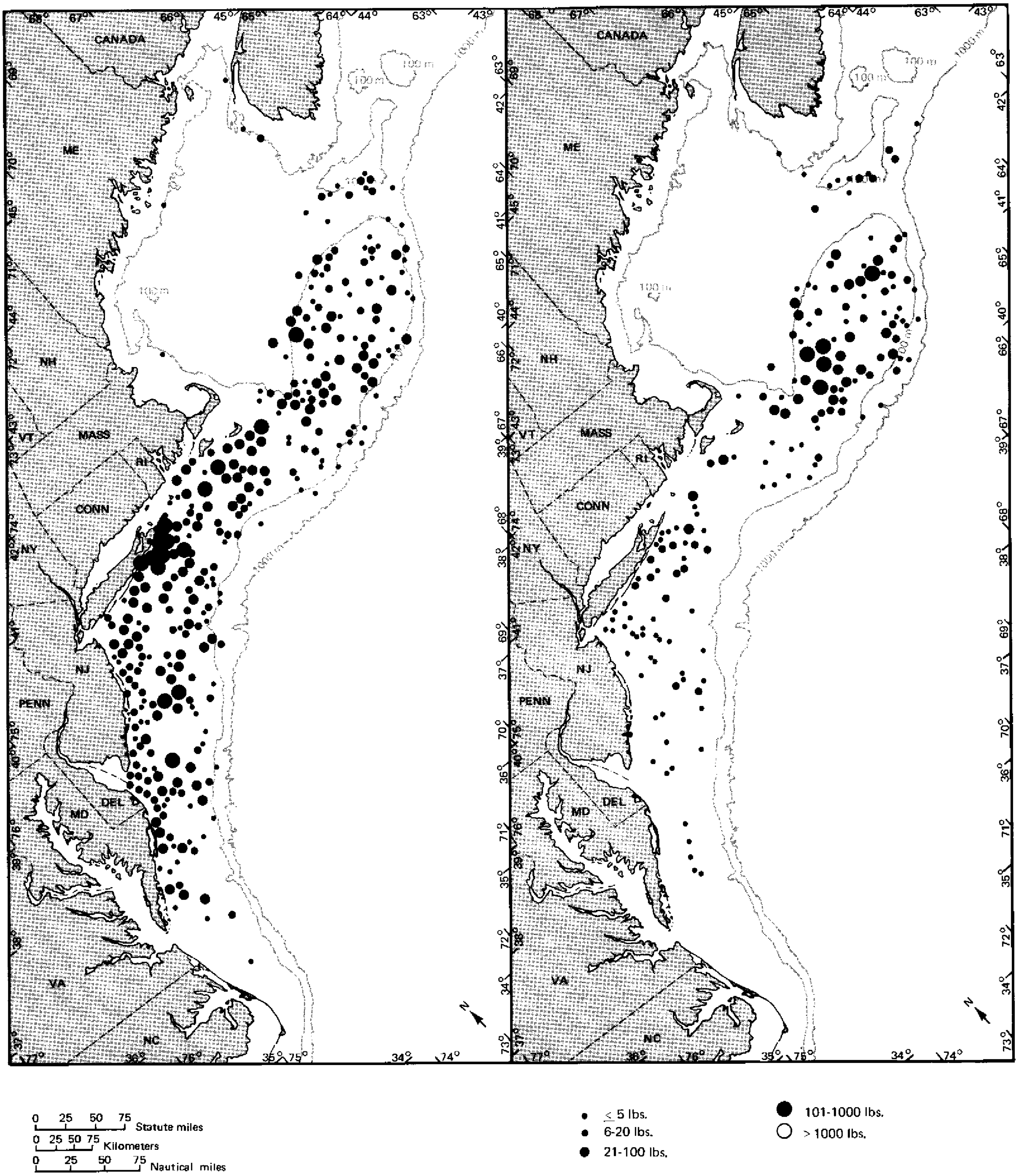
*Big skates grow larger than little skates, hence the name. However, the accepted common name for *R. ocellata* is now winter skate (Bailey *et al* 1970).

Map 22. Big skate — distribution of NMFS 1973-74 research vessel trawl catches (dots) (spring-left, autumn-right)



Map 23. Little skate — distribution of NMFS 1973-74 research vessel trawl catches (dots) (spring-left, autumn-right)



hatching is between 9 and 10 cm (3.5 and 3.9 in). Big skate egg cases are 1.7 to 2.7 times larger than those of little skates, not counting the horns. Fecundity estimates of big and little skates are not yet available, but a reasonable assumption is that 60 to 150 eggs are produced per year, based on studies of other species (Libby and Gilbert 1960; Holden, Rout, and Humphreys 1971; DuBuit 1976).

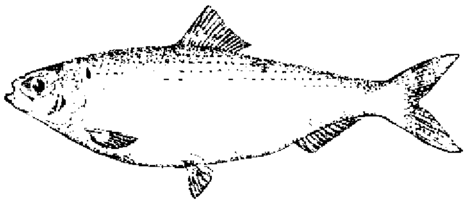
Age determinations in skates present a problem since skates lack hard parts such as scales and otoliths, which lend themselves readily to age analysis. Richards and associates (1963) studied aging in little skates by reading densely calcified bands in the centrum and comparing these to length-frequency data. They found young-of-the-year skates are 11 to 16 cm (4 to 6 in); one-year-olds, 16 to 26 cm (6 to 10 in); two-year-olds, 22 to 35 cm (9 to 14 in); three-year-olds, 28 to 40 cm (11 to 16 in). Merriman and associates (1953) stated that growth was probably 8 to 10 cm (3 to 4 in) a year for the first three years. After age five, length increased only 2 to 3 cm (0.8 to 1 in) in a year. Little skates greater than 50 cm (20 in) are rare, and eight is probably the maximum age ever attained. Sexual maturity is reached at three to four years. Information on age and growth of big skates is lacking.

Feeding Interrelationships. Both big and little skates eat a variety of benthic invertebrates. The predominant prey species are from the following taxonomic groups: decapods, amphipods, isopods, polychaetes, molluscs, and fishes (McEachran 1973; Maurer and Bowman 1975). Fritz and Daiber (1963) and Smith (1950) found little skates to be very dependent upon a single prey species—sand shrimp *(Crangon septemspinosus)* in Delaware Bay and a digger amphipod *(Leptocheirus pinguis)* in Block Island Sound.

Big skates are prey for goosefish; such information on little skates is lacking but they are also presumably preyed upon by goosefish and probably other large fish predators.

Blueback Herring *Alosa aestivalis*

Ralph K. Mayo



Distribution and Seasonal Movements. Blueback herring, closely related to the alewife, occurs from Nova Scotia to Florida but is most abundant in waters south of New England. The species is anadromous and spawns in late April in the Chesapeake Bay region and in June in Nova Scotia (Hildebrand 1963; Leim and Scott 1966).

In spring, blueback herring appear to be concentrated on the continental shelf between southern New England and Cape May, whereas in autumn they are found in the Georges Bank-Gulf of Maine area (Map 24). In general, the timing and nature of their seasonal movements appear similar to those of the alewife.

Population Size and Fisheries. Blueback appear to be less abundant than alewives in the Bight, as indicated by smaller survey catches in both spring and autumn. However, precise population estimates are not available since the two species are treated as one in the fishery.

Reproduction, Growth, Life Span. In the Connecticut River, most males first spawn at ages three and four and most blueback females, at ages four and five (Marcy 1969; Scherer 1972). In the Altamaha River, GA, however, blueback matured as early as age two (Street and Adams 1969). Evidence of repeat spawning up to five times has been reported throughout the geographical range of blueback herring (Joseph and Davis 1965; Scherer 1972).

Blueback herring first enter fresh water and brackish spawning grounds from early April in Virginia to June in Nova Scotia. Although early studies indicated that these fish proceed only a very short distance upstream or spawn directly in upper estuaries (Hildebrand 1963), data of Loesch and Lund (1977) and Scherer (1972) for the Connecticut River and by Street (1970) for the Altamaha River, showed that blueback herring migrate some distance upstream. Unlike the alewife, however, blueback herring spawn in swift-flowing streams over rocky or gravel bottom (Loesch and Lund 1977).

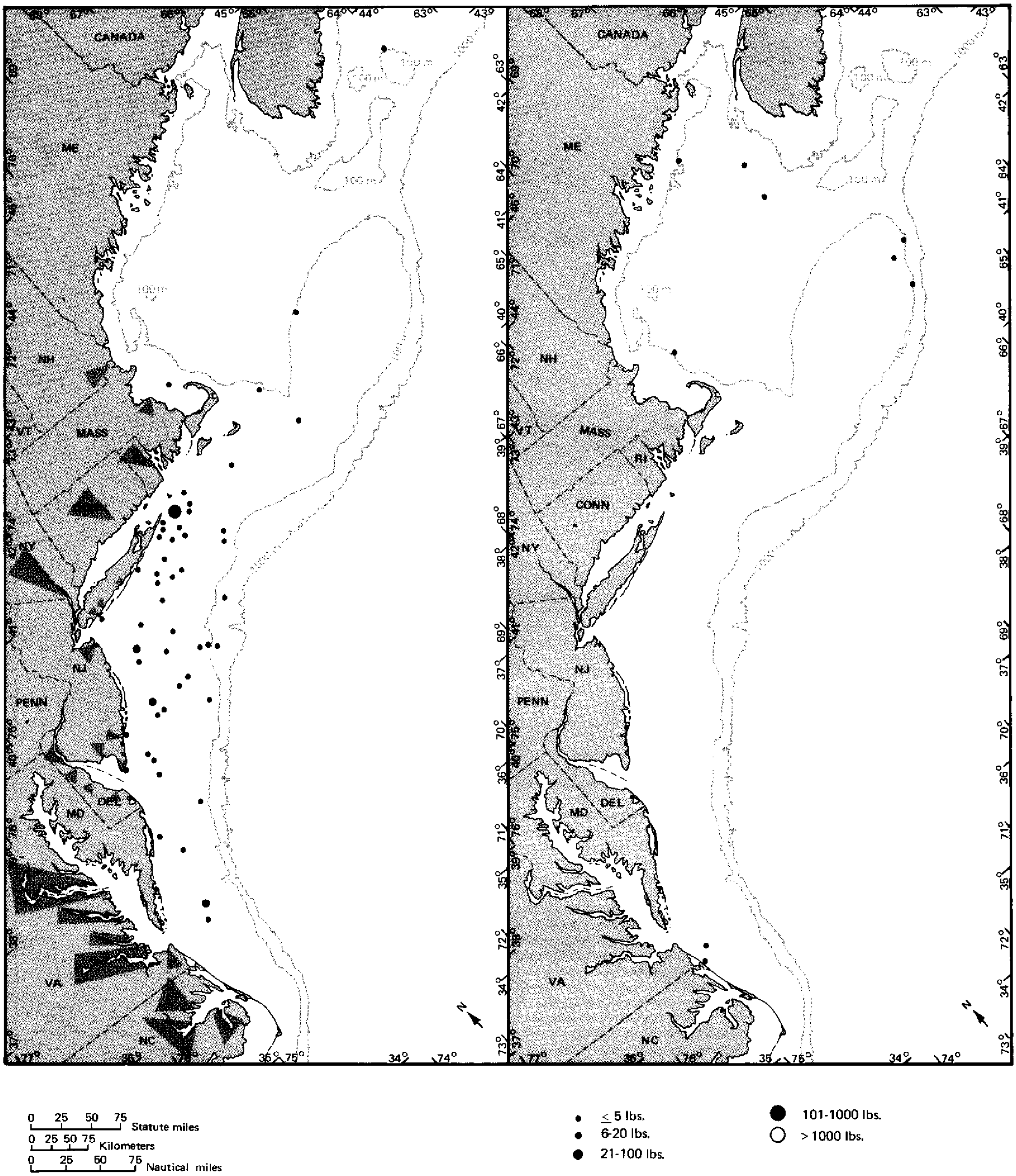
Spawning by blueback herring has been noted at water temperature as low as 14°C (57°F) in the Connecticut River (Loesch and Lund 1977). Optimal temperatures range from 21° to 24°C (70° to 75°F), considerably higher than those for alewives (Mansueti and Hardy 1967). Loesch (1968) also noted that a temperature of 27°C (81°F) inhibited spawning in tributaries of the Connecticut River.

Fertilized eggs are demersal, somewhat adhesive, and semitransparent. The average diameter is approximately 1 mm (0.04 in). Incubation requires approximately 50 hours at 22°C (72°F). At hatching, larvae are 3.5 mm (0.14 in) long (Mansueti and Hardy 1967). Maximum fecundity estimates reported for Connecticut River blueback herring are 349,700 eggs (Loesch and Lund 1977) and 354,270 eggs (Scherer 1972). Street (1970) reported a maximum fecundity estimate of 399,735 eggs for blueback herring collected in the Altamaha River.

As for alewives, the downstream movement of blueback juveniles begins in late summer; juveniles were observed moving downstream from September to early November in the Connecticut River (Scherer 1972).

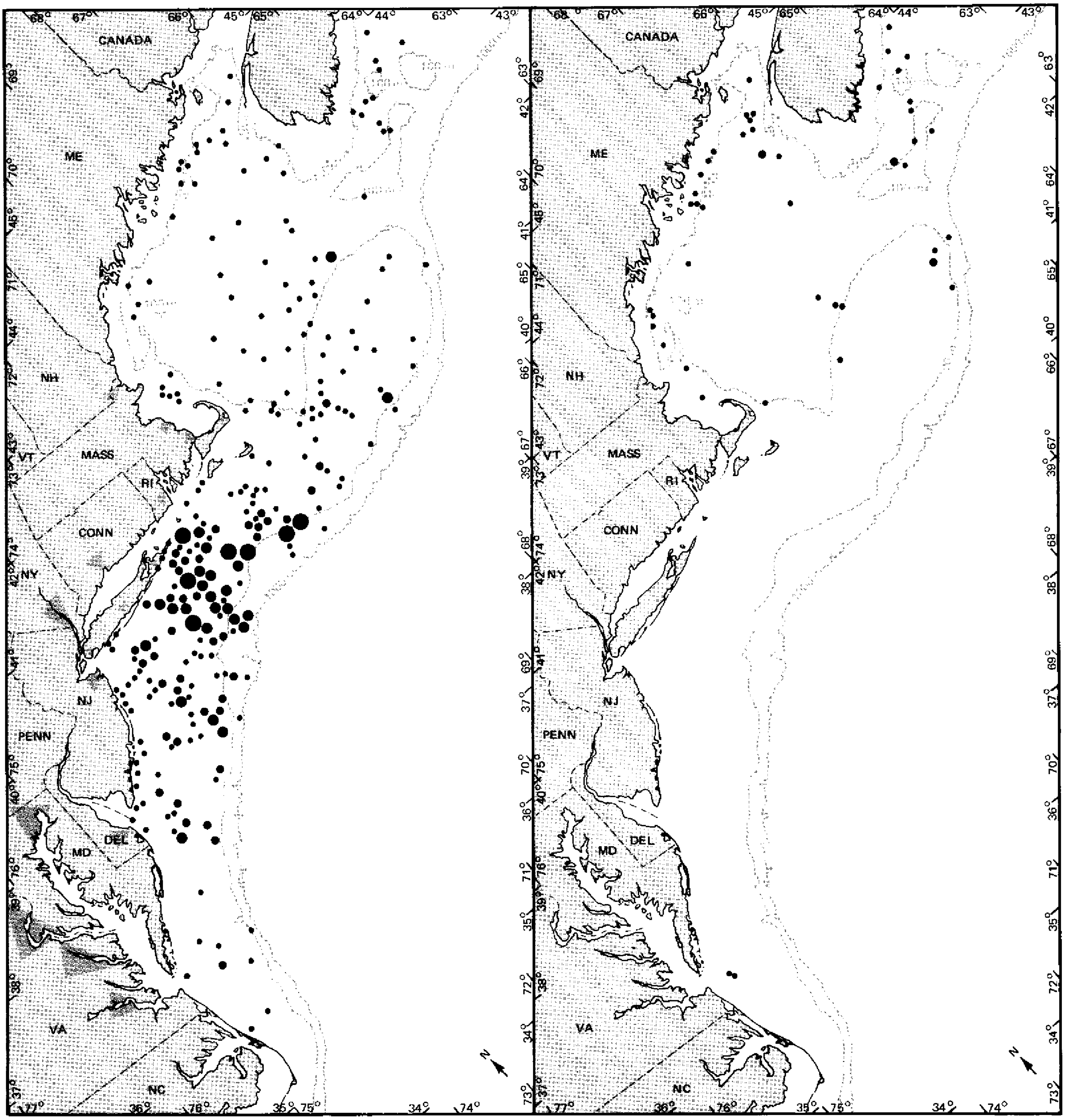
Samples taken from spawning runs of blueback herring revealed a 2:1 ratio of males to females (Loesch 1968;

Map 24. Blueback herring — distribution of NMFS 1973-74 research vessel trawl catches (dots) and spawning areas (shading) (spring-left, autumn-right)



Note: shading on land shows spawning areas: triangle size proportionate to size of spawning area

Map 25. Alewife — distribution of NMFS 1973-74 research vessel trawl catches (dots) and spawning areas (shading) (spring-left, autumn-right)



0 25 50 75 Statute miles

0 25 50 75 Kilometers

0 25 50 75 Nautical miles

• ≤ 5 lbs.

● 6-20 lbs.

● 21-100 lbs.

● 101-1000 lbs.

Note: shading on land shows spawning areas: triangle size proportionate to size of spawning area

Scherer 1972). The sex ratio shifted during the course of the spawning migration: like alewives, blueback males dominated early in the run, females dominated later. Holland, Johnson, and Street (1975) found an overall 1:1 sex ratio in studies conducted off the NC coast. The apparent discrepancy between the 2:1 sex ratio during spawning migrations and the 1:1 ratio in offshore samples may be explained by the earlier maturation of males and their subsequent appearance at the beginning of the spawning runs.

Blueback herring have been reported to live a maximum of six to eight years (Netzel and Stanek 1966; Marcy 1969; Street and Adams 1969; Scherer 1972). The maximum size observed by Marcy was 330 mm (13 in) TL for females and 312 mm (12 in) TL for males. The maximum number of spawning seasons per fish varied from three to five seasons (Street and Adams 1969; Scherer 1972).

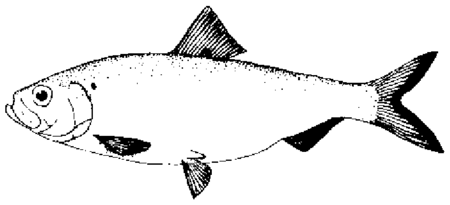
Feeding Interrelationships. Stomach contents of juvenile blueback herring collected from nursery grounds in the James, Pamunkey, and Mattaponi rivers of Virginia have been reported to consist chiefly of juvenile copepods and the cladocerans *Bosmina coregoni* and *Diaphanosoma branchyurum* (Hoagman et al 1974). Unlike alewives, juvenile blueback herring appear to be random filter feeders, exhibiting little or no selectivity for particular food organisms. Burbridge (1974), however, reported strong selectivity by young-of-the-year blueback herring for adult copepods, and moderate-to-weak selectivity for copepodites and *Bosmina* sp. Feeding was also reported to have only taken place during daylight. The dominant food items in juvenile blueback herring collected in the Connecticut River were tendipedid larvae and cladocerans (Scherer 1972). In stomachs of adult blueback herring collected on NMFS bottom trawl surveys between Nantucket Shoals and Cape Hatteras, the principal food items were Cirrepedia and the copepods *Calanus finmarchicus, Metridia lucens,* and *Pseudocalanus minutus* (R. Maurer and J. Murphy, personal communication).

Environmental Sensitivity. The effect of entrainment on survival of juvenile and larval blueback herring is available in a study of young fish in a nuclear power plant cooling system (Marcy 1973). Although much of the mortality was caused by mechanical damage, when the cooling water discharged temperature was between 28° and 29°C (82° and 84°F), only 7.5% of the fish survived on one day and none survived on another day. Further, Schubel, Smith, and Koo (1977) demonstrated that exposure of larval blueback herring to increases in water temperature of 7° to 8°C (44° to 46°F) above ambient levels for periods of 4 to 40 minutes resulted in significant larval mortality when measured 24 hours after the initial exposure.

Tolerance of juvenile blueback herring to changes in salinity appears to be quite high (Chittenden 1972). All but 1 of 38 fish placed in an experimental tank survived a rise in salinity from 5 ‰ to 28 ‰ over six days.

Alewife *Alosa pseudoharengus*

Ralph K. Mayo



Distribution and Seasonal Movements. The alewife, an anadromous member of the family Clupeidae, is found from Newfoundland to North Carolina, apparently centering between the Gulf of Maine and Chesapeake Bay (Winters, Moores, and Chaulk 1973; Tyus 1974). In spring, alewives are aggregated on the continental shelf between Block Island and Cape May, NJ, preparatory to the inshore spawning migration (Map 25); they then enter coastal rivers to spawn in fresh water. In autumn, alewives are found in the northern part of their range and are conspicuously absent from the Bight (Map 25). Presumably, adult alewives, having returned from the freshwater spawning grounds in late spring and throughout summer, migrate in autumn northeasterly toward the Gulf of Maine or proceed directly offshore to overwinter on the outer edge of the continental shelf, beyond the 366 m (1,200 ft) depth limit of the survey area.

Trawl surveys indicate that except during the actual spawning migration, adult alewives should be concentrated in the Bight from early spring through late summer. Differences in the magnitude of the Bight catches between spring and autumn are caused partly by a northeast shift in distribution and partly by the tendency, displayed by most pelagic species encountered, to remain in the upper water column in autumn.

Population Size and Fisheries. A commercial fishery for alewife and blueback has existed since colonial times. The annual spring migration into coastal streams provided early settlers with a substantial food source. Today the fishery is conducted from Nova Scotia to North Carolina. The major US fishery centers in the Chesapeake Bay region. In most areas, the fishery for alewife and blueback herring —together called river herring—is mixed because the migratory patterns of both species tend to overlap.

The US catch of river herring from New York to North Carolina increased from 16,000 MT in 1964 to a maximum of 24,000 MT in 1969, then declined to 4,900 MT in 1977. Hoagman and associates (1974) estimated that river herring stocks in this region could support an annual maximum sustainable yield between 23,000 and 28,000 MT. Beginning in 1967, exploitation of these stocks by offshore international fishing fleets brought a sharp increase in the total river herring catch which reached approximately 35,000 MT in 1969. Since then, the foreign catch declined to about 100 MT in 1977.

The reported commercial catch represents a minimum estimate, since alewives are also harvested domestically for personal consumption in virtually all rivers and streams along the coast. The magnitude of the catch derived from these locally administered fisheries is unknown.

In recent years, the average age of alewives in the inshore VA and NC catches has declined (Street and Davis 1976). These fisheries are becoming more dependent on a single year-class with virgin fish comprising a greater proportion of the population. NMFS survey data show a decline in stock abundance since 1969, and Street and Davis (1976) stated that catch per unit of effort in the inshore VA and NC fisheries has also declined.

Reproduction, Growth, Life Span. Alewives become sexually mature between three and five years old, when they first appear in upstream spawning migrations. Most males mature at three and four, and most females at four and five. Mean size at maturity can vary from 265 to 278 mm (10 to 11 in) for males and from 284 to 308 mm (11 to 12 in) for females (Marcy 1969; Mayo 1974). The average size of all mature adults may vary between 250 and 350 mm (10 and 14 in) depending on age, sex, and location. Evidence of repeat spawning of adult alewives has been reported throughout the entire range of their distribution (Havey 1961; Marcy 1969; Holland et al 1975).

Spawning runs commence in March and early April in the Chesapeake Bay area (Tyus 1974), and in mid-April or early May along Long Island and Cape Cod (Rounsefell and Stringer 1943). Alewives migrate up coastal river systems to spawn in shallow, quiet areas of tributary streams and ponds of large rivers and small coastal streams (Collins 1952; Kissel 1969). Most researchers found water temperature to be a major factor governing the initiation of alewife spawning migrations (Richkus 1974; Beltz 1975). The fish enter fresh water when the river temperature rises above 10°C (50°F); spawning begins at temperatures between 13° and 15°C or 55° and 59°F (Kissel 1969; Mayo 1974). The randomly broadcast eggs are adhesive immediately after extrusion but lose this property within a few hours after spawning (Cooper 1961).

Sex ratios of spawning populations may vary between years; however, most researchers report a predominance of males in the young age groups. Cooper (1961) noted a 2:1 male to female ratio on spawning grounds; he attributed this to earlier maturing of males. Older age groups tend to be dominated by females. The shift in the sex ratio with age may indicate high mortality in the earlier maturing males. Recruitment of a strong year-class into the adult spawning populaton initially results in a high male to female sex ratio, but as the year-class ages, the sex ratio shifts toward females. In a study of alewives collected on Georges Bank, Netzel and Stanek (1966) reported a predominance of females in samples taken July and October. Dominant age groups in both samples were four, five, and six.

Early studies showed alewife fecundity between 60,000 and 100,000 eggs (Smith 1907); however, recent studies indicate fecundity on the order of 100,000 to 300,000 eggs (Kissel 1974; Mayo 1974). In general, the diameter of unfertilized alewife eggs varies between 0.80 and 0.95 mm (0.03 and 0.04 in); fertilized eggs vary between 0.94 and 1.25 mm (0.04 and 0.05 in) in diameter and require three to five days at 20°C (68°F), six days at 15.6°C (60.1°F) for incubation (Mansueti and Hardy 1967). Hatching occurs between 6.9° and 29.4°C (44.4° and 84.9°F), with optimum survival at 17.8°C or 64°F (Edsall 1970). Larval length at hatching has been reported between 3.5 and 5 mm (0.1 and 0.2 in) with yolk sac absorption occurring within four or five days after hatching.

Since alewives spawn in fresh water, egg and larval stages are not components of the biomass in the New York Bight area. Alewives use many of the rivers discharging into the Bight as spawning grounds, and juveniles use the estuaries as nurseries. Young-of-the-year alewives remain in fresh water until summer when downstream migration occurs. Increases in juvenile emigration appear to correspond to increased river discharge and declines in water temperature associated with periods of high precipitation (Richkus 1975; Huber 1978). Juvenile alewives may overwinter in estuarine nursery grounds or proceed directly to the open ocean.

Alewives have been reported to live up to eight or nine years, reaching a maximum length between 350 and 360 mm (13.7 and 14 in) for males and from 351 to 356 mm (13.7 to 13.9 in) for females (Havey 1961; Mayo 1974). Mature adults are represented in spawning populations from age three to nine; repeat spawning occurs up to six years in succession. However, most alewives spawn for only three or four years after the initial migration. In general, most alewives that spawn for the first time at age three do not live beyond age six; most of the older fish (age seven to nine) do not spawn until age four or five (Rideout 1974).

Tyus (1974) reported a total annual mortality of 85% between ages three and four in North Carolina, while Havey (1961) estimated an annual mortality of 75% between ages six and seven in Long Pond, ME. However, Tsimenides (1970) estimated that the total annual mortality of Rappahannock and Potomac River alewives collected between 1965 and 1969 varied between 50% and 60%. An even lower total annual mortality rate of 39% was estimated for alewives taken offshore in the Bight (Puzhakov 1975). It is apparent that the annual mortality varies with location and probably depends on the degree of exploitation.

Feeding Interrelationships. Alewives are considered to be chiefly planktivorous. In fresh water, adult alewives were reported to be both species- and size-selective in their choice of prey organisms (Brooks and Dodson 1965; Hutchinson 1971). The principal food items in alewife stomachs studied by Hutchinson were cyclopoid copepods and the cladocerans *Bosmina longirostris* and *Holopedium gib-*

berum. Janssen (1976) has suggested that alewives also exhibit nonselective feeding behavior patterns. In the marine environment, alewives feed chiefly on euphausiids (*Meganyctiphanes norvegica*), mysids (*Neomysis americana*), mollusks (*Limacema retroversa*), and chaetognaths (Maurer and Bowman 1975). In stomachs of alewives from the Bight, the principal food items were *L. retroversa* and chaetognaths (R. Maurer, personal communication).

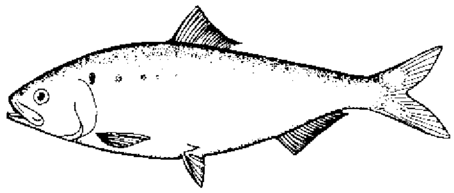
Young fish, upon leaving the freshwater portion of the rivers, fall prey to larger marine predators such as bluefish and striped bass (Bigelow and Schroeder 1953). Adults may also be utilized by these voracious predators whose presence in the inshore waters coincides with the downstream migration of alewives in June, July, and August.

Environmental Sensitivity. Exposure of alewife eggs to increases in water temperature from 6° to 10°C (43° to 50°F) above ambient, resulted in no significant reduction in hatching success (Schubel 1974; Schubel et al 1977). Deformities in alewife larvae resulted when eggs were exposed to nonlethal temperature increases as low as 10°C (50°F) even though egg survival was unaffected (Koo and Johnston 1978). Larval stages of the closely related blueback herring exhibited severe disorientation at 15°C (59°F) above ambient, and both egg and larval stages underwent total mortality at 20°C (68°F) above ambient. In a laboratory study of the effect of temperature and salinity on salt balance in alewives, Stanley and Colby (1971) concluded that tolerance of alewives to temperature stress was about equal in fresh and salt water.

Thunberg (1971) found evidence of home stream selection based on laboratory studies of alewives taken from spawning runs in Rhode Island. This theory is supported indirectly by the correlation between the number of juveniles emigrating and number of adults immigrating four years later in a Maine lake (Havey 1973). Experimental studies on alewives and blueback in the Cape Cod Canal suggest that selection of alternative channels during upstream spawning migrations may be affected by relatively small differences in the level of free CO_2 in the water (Collins 1952). Thus, seemingly minor alterations of home stream environmental conditions may have significant effects on upstream movement, spawning, and subsequent development of eggs and larvae.

American Shad, *Alosa sapidissima*

Anthony L. Pacheco and Linda Despres-Patanjo



Distribution and Seasonal Movements. American shad is an anadromous species, spawning in virtually all principal watersheds ranging along the Atlantic coast from the St. Lawrence River, Canada, to the St. John's River, FL. Shad live in continental shelf waters most of the year (summer, autumn, and winter) and move into coastal rivers to spawn in the spring. While they are offshore it is believed that fish from various spawning rivers of a wide region are all mixed together. During early spring it is speculated that these different spawning stocks segregate out again and the schools move inshore and each ascends to its home stream to spawn (Talbot and Sykes 1958). Offshore distribution of shad in the NMFS survey area is based on cumulative catch records from 1963-1976 offshore spring and autumn trawl surveys (Map 26). On spring surveys shad were distributed in offshore water throughout the region; however in autumn they were found primarily east of Hudson Canyon (Neves and Despres 1979). Spring and autumn catches of shad on NMFS bottom trawl surveys illustrate the offshore distribution of the species in the survey area (Map 26). Most of the spring catches in the Bight were made in March, about the time the mature fish would be expected to begin their inshore movement to the spawning rivers.

Population Size and Fisheries. The commercial shad catch in the Bight declined drastically from levels taken prior to the turn of the century and in particular rivers has been characterized by considerable fluctuation. On the Hudson, a major spawning river, there was a period of high production from 1880 to 1901 which included the highest recorded landing of 1,950 MT in 1889. This was followed by a period of low catches through the mid 1930s and then an increase again from 1936 to 1946, to a level about half that observed in the late 1800s (McHugh and Ginter 1978). Thereafter, both landings and effort steadily declined. The combined commercial catch from New York, New Jersey, and Delaware dropped from about 450 MT in the early 1960s to 135 MT in the early 1970s, and continued to decline through 1975. The early decline probably resulted from industrial pollution; the most recent decline has been attributed to economic conditions rather than a lack of fish (McHugh and Ginter 1978). In the NY-NJ area, gill nets are the principal commercial gear, followed by pound nets. Some shad are also taken commercially by seines and other miscellaneous gear.

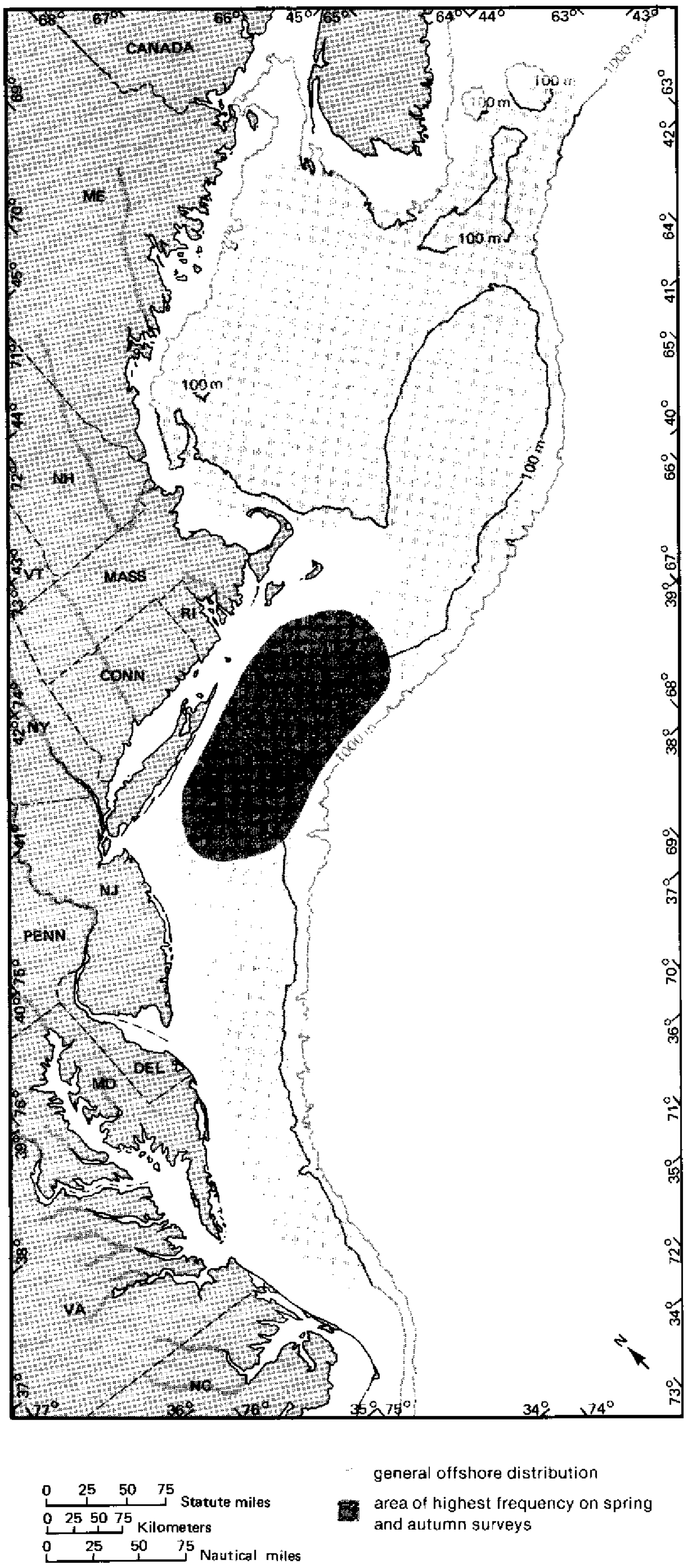
A sport fishery by trolling, drifting, and casting lures in rivers has grown in popularity and the 1970 recreational harvest in the North Atlantic (New York to Maine) and mid-Atlantic (Cape Hatteras to New York) regions was estimated at 280 and 1,900 MT respectively (Deuel 1973). In recent years the recreational catch has been about the same level as the commercial catch (McHugh and Ginter 1978).

Reproduction, Growth, Life Span. American shad spawn mostly in freshwater portions of tidal rivers, frequently near mouths of creeks and other river sections with extensive flats. In the New York Bight region the peak of the spawning run occurs in April. A female may deposit from 100,000 to 600,000 eggs depending on her size, with most spawning activity occurring in early evening between water temperatures of 12° to 20°C (54° to 68°F).

The eggs are released near the surface and then sink and roll along the bottom with currents. Massmann (1952) found that eggs in the Pamunkey River were not taken in abundance until water temperatures reached 12°C (54°F), with a median spawning temperature of 16° to 17°C (61° to 63°F). Eggs normally hatch in 3 to 8 days (6 days at 17°C or 63°F). Larvae are 7 to 10 mm (0.28 to 0.39 in) at hatching and absorb the yolk in 4 to 5 days at 17°C (63°F). The larval stage lasts 21 to 28 days. Larvae occur in fresh to brackish waters and their movements are generally downstream. Juveniles gradually move out of estuarine waters during the first summer and typically are in the ocean by autumn. They move downstream when water temperature falls below about 16°C (61°F) and a few remain in estuaries for the first winter. Females reach maturity at lengths of 38 to 48 cm (15 to 19 in); males which normally mature a year earlier than females first spawn at lengths of 30 to 44 cm (12 to 17 in). Some shad may live 10 years, but most reach a maximum age of 8. Walburg and Nichols (1967) and Holland and Yelverton (1973) have summarized growth data by sexes from various rivers. At comparable ages, females are consistently larger than males.

Feeding Interrelationships. Levesque and Reed (1972) found that small larvae of the Connecticut River fed mostly on crustaceans (57%) and immature dipterans (37%); larger larvae (to 28 mm or 1.1 in) ate a smaller portion of cyclopoid copepods, but more chironomids including smaller shad larvae. Juvenile shad from the Hudson River contained ostracods and insects (Walburg 1957), while shad from the Connecticut River fed on chironomid pupae and crustaceans (Levesque and Reed 1972). In salt water, adult shad feed on zooplankton which includes large copepods, mysids, and euphausiids (Bigelow and Schroeder 1953; Hildebrand 1963; Leim and Scott 1966; Walburg and Nichols 1967). Little or no food has been found in stomachs of adult shad taken in fresh water during their spawning migration; available plankton may be too small for retention by gill rakers. Few creatures other than man have been reported as direct predators on adults, however,

Map 26. American Shad — distribution and spawning areas from historical fishery records



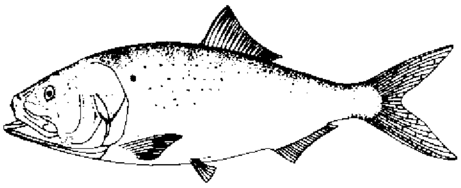
Note: brown shading along rivers shows spawning areas carnivorous species such as striped bass and bluefish must take their toll of emigrating juveniles.

Environmental Sensitivity. Loss of spawning sites and interference with upstream passage by dams or pollution impair or preclude the restoration of runs. Walburg and Nichols (1967) discussed the extent of shad runs in 1896 and subsequent dimunition of their range. By 1960 shad runs were reduced by 80 km (50 mi) in the Susquehanna River because of the Conowingo Dam, and they were completely blocked in the Housatonic River. Pollution of the Hudson River is considered partly responsible for a loss of 55 km (34 mi) in upstream movement. Marcy (1972) found no shad eggs from the Connecticut River in dissolved oxygen concentrations below 5 ppm.

Increasing construction of power plants in New York Bight may impact directly on shad in the spawning rivers. Specifically, entrainment in cooling systems and thermal blocks are a potential threat to survival of young shad. However, natural factors such as competition for food among early life stages, temperature, and volume of flow in spawning streams appear to play the major role in controlling shad populations (Leggett 1977).

Atlantic Menhaden *Brevoortia tyrannus*

John W. Reintjes



Distribution and Seasonal Movements. The Atlantic menhaden, also known as mossbunker, bunker, or pogy, migrates seasonally along the Atlantic coast of the United States, from Maine to Florida, and is one of the more abundant fishes in the Bight. The whereabouts of the major portion of the population from December to March is not accurately known. Surface schools of menhaden are last seen migrating southward in the vicinity of Cape Lookout and Cape Fear, NC, in mid-December. In March, large adults first appear off the coast of New Jersey but surface schools are not abundant until late May or early June. There is a continual movement through the Bight of larger and older fish that apparently move northward to Cape Cod and the Gulf of Maine, usually until late July or early August (Nicholson 1971, 1972, 1978). In September, with the first autumnal cooling, a southward movement begins that is usually complete by late November when only a few stragglers are left in New York Bight.

From May to October, both yearling and adult menhaden are found in surface schools in the Bight. About 90% of the adult population is within 5 to 8 km (3 to 5 mi) of the coast (Map 27), usually inside 20 m (66 ft), according to fishing logbooks and aerial spotting. Density of schools drops off rapidly in waters deeper than 20 m, but a few schools have been observed as far out as the 55 m (180 ft) contour. Juveniles are generally restricted to streams, bays, and sounds associated with major estuaries.

Population Size and Fisheries. Menhaden, a member of the herring family, is a bony, oily fish used almost exclusively for fish meal and condensed fish solubles for poultry and animal rations and oil for various uses (June and Reintjes 1976). About 98% is caught with purse seines and taken to reduction plants. The remainder, caught in pound nets, gillnets, and haul seines, is used for bait. From 1940 to 1963 nearly half of the Atlantic menhaden landed were caught from Montauk Point, NY, to Ocean City, MD, including Long Island Sound and Delaware Bay (Reintjes 1969). In 1953, the catch from this area amounted to more than 363,000 MT. Reduction plants were located at Amagansett, NY; Port Monmouth, Tuckerton, and Wildwood, NJ; and Lewes, DE. Logbooks kept by fishermen show that menhaden fishing occurred in the Bight from May to October, with peak fishing during June, July, and August (Roithmayr 1963).

As menhaden abundance began to decline in the mid-1960s, reduction plants closed and the number of vessels decreased (Schaaf and Huntsman 1972). Changes in catch per unit of effective effort, an index of stock abundance, indicate a five-fold decrease of total stock through 1965. After 1964 only small landings were made in the New York Bight area, and by 1969, five of the six plants were closed. The population recovered somewhat since the low of 1969 and this is probably due, in part, to a 54% reduction in the observed fishing effort in New York Bight (Schaaf 1975).

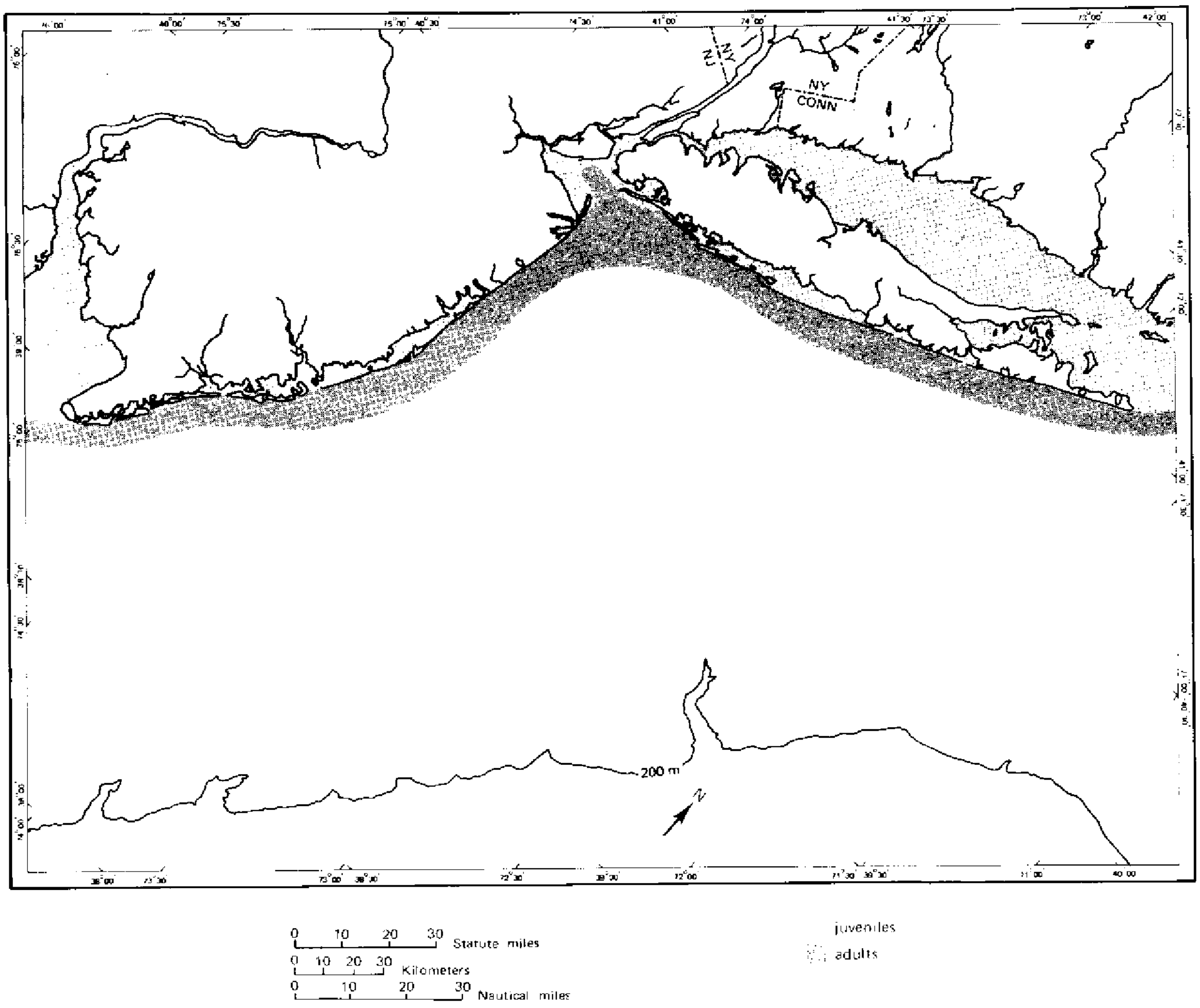
The menhaden population decline was most apparent in the New York Bight area where the fishery depended on the older age groups. From 1955 to 1963, menhaden age three and older contributed about 50% of the catch by weight; from 1964 to 1974 these fish contributed less than 20%. In Chesapeake Bay, fishing effort and landings increased after 1963 despite the decline in the total population; but the fishery was dependent on one- and two-year-old fish. The increased Chesapeake landings resulted from more vessels and spotter aircraft, and also from a longer season that permitted autumn fishing on southward migrating fish. Recovery of the New York Bight fishery seems questionable in view of the heavy fishery in Virginia (McHugh and Ginter 1978).

Reproduction, Growth, Life Span. Atlantic menhaden mature sexually at about two years old, and spawn annually in the middle of the continental shelf and in the larger, more saline bays and sounds. Females produce 60,000 to 600,000 eggs each year, depending on size and age (Higham and Nicholson 1964; Dietrich 1979). Spawning occurs somewhere along the Atlantic coast every month. The principal spawning apparently occurs during late autumn and winter off the coasts of Virginia and the Carolinas. There is no information on the proportion of the total population that spawns in New York Bight, where spawning occurs from April to October (Map 27). Larvae are transported to the inshore areas by ocean currents or by swimming (Nelson, Ingham, and Schaaf 1977). After passing into the estuaries, they move into the upper, lower salinity zones and metamorphose into juveniles. Apparently, metamorphosis occurs only in estuaries since no metamorphic larvae or prejuveniles have been collected at sea (Kendall and Reintjes 1975). Juveniles gradually move down the estuary to more saline areas, where they remain until autumn, at which time they move into the ocean. Juveniles from the Bight migrate southward and winter south of Cape Hatteras. The following summer they occur in the fishery from Florida to Chesapeake Bay. Although some stragglers overwinter in estuaries in some years, the autumn exodus from New York Bight is generally complete.

Growth of menhaden has been estimated from mean lengths of fish in successive age groups and has been verified by annular rings on scales (June and Roithmayr 1960). One-year-old fish are approximately 135 mm (5.5 in); two-year-olds, 215 mm (8.5 in); three-year-olds, 250 mm (10 in); five-year-olds, 270 mm (11 in); and five- to seven-year olds, 300 to 350 mm (12 to 15 in). The lengths are from the tip of the snout along the midline to the fork of the tail. The longest menhaden on record was 8 years old, 418 mm (16 in), and the oldest was 12, according to annular marks on its scales.

Surveys to estimate juvenile menhaden abundance in Atlantic estuaries were conducted annually from 1961 to 1978. These estimates of relative abundance are based on brief surveys that show great variability from site to site and five-fold differences between some years. So far these juvenile abundance indices have not provided reliable predictions of year-class strength (Schaaf, Sykes, and Chapoton 1975; D.W. Ahrenholz, personal communication).

Map 27. Atlantic menhaden — distribution and spawning based on historical commercial fishery records



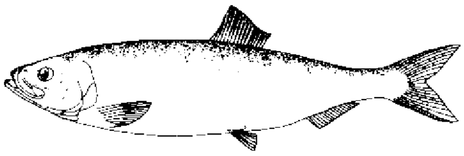
Feeding Interrelationships. Larval menhaden eat individual planktonic animals, mainly crustaceans, whereas juveniles and adults filter plankton through a sievelike gill and branchial apparatus. Menhaden are carnivorous as larvae and become omnivorous after metamorphosis into juveniles (June and Carlson 1971). Following metamorphosis, menhaden subsist mainly on one-cell plants and their digestive system is characteristic of herbivores, with a muscular gizzard-like cardiac stomach, low peptase content, and a long coiled intestine.

Menhaden are preyed upon by nearly all of the larger marine carnivores. Sharks, porpoises, bluefish, weakfish, pollock, striped bass, red drum, swordfish, and tunas are the predators most commonly reported. Bluefish are considered the principal predator of menhaden in New York Bight.

Environmental Sensitivity. Dredging and filling, domestic and industrial wastes, and the effects of urbanization have reduced the estuarine nursery areas for menhaden in New York Bight. In the 1954-68 period the loss of coastal marshes that serve as menhaden nurseries was estimated at 22% in Connecticut, 29% in New York, and 10% in New Jersey (Spinner 1969).

Atlantic Herring *Clupea harengus harengus*

Vaughn C. Anthony



Distribution and Seasonal Movements. The Atlantic herring ranges north to the edge of the polar ice in Greenland and Labrador and as far south as Cape Hatteras. Herring spawns on Georges Bank September-October and then migrates to the New York Bight area to overwinter from December through April. The spring migration back to Georges Bank is apparently timed to coincide with the mid-May peak in zooplankton production there (Riley 1947). The herring on Georges Bank are large, generally age three and older, although some juveniles are also found. The herring that move through the Bight are mostly mature fish, age four and older. Herring that overwinter close to the RI coast may be from Georges Bank or the Gulf of Maine. Tagging studies indicate that some herring spend their summers as far north as the Bay of Fundy (Stobo, Scott, and Hunt 1975; Stobo 1976*a*; Almeida and Burns 1978).

Autumn survey catches of herring are sparse because at this time of year herring form tight schools on the spawning grounds, and the random stations on the survey are likely to miss them. In spring, herring are more randomly distributed and thus more available to the survey (Map 28). Atlantic herring distribution differs by size and age. In 1964-66 winter survey cruises and 1968-75 spring cruises no juveniles were found south of Hudson Canyon (Anthony et al 1975). The southernmost limit of their distribution seems to be around Long Island; to the east and north of this area they are found on Georges Bank, off southern Nova Scotia, and throughout the Gulf of Maine. In southern New England, juveniles are generally found inside the 60 m (197 ft) depth contour and usually inside 80 m (262 ft) on Georges Bank.

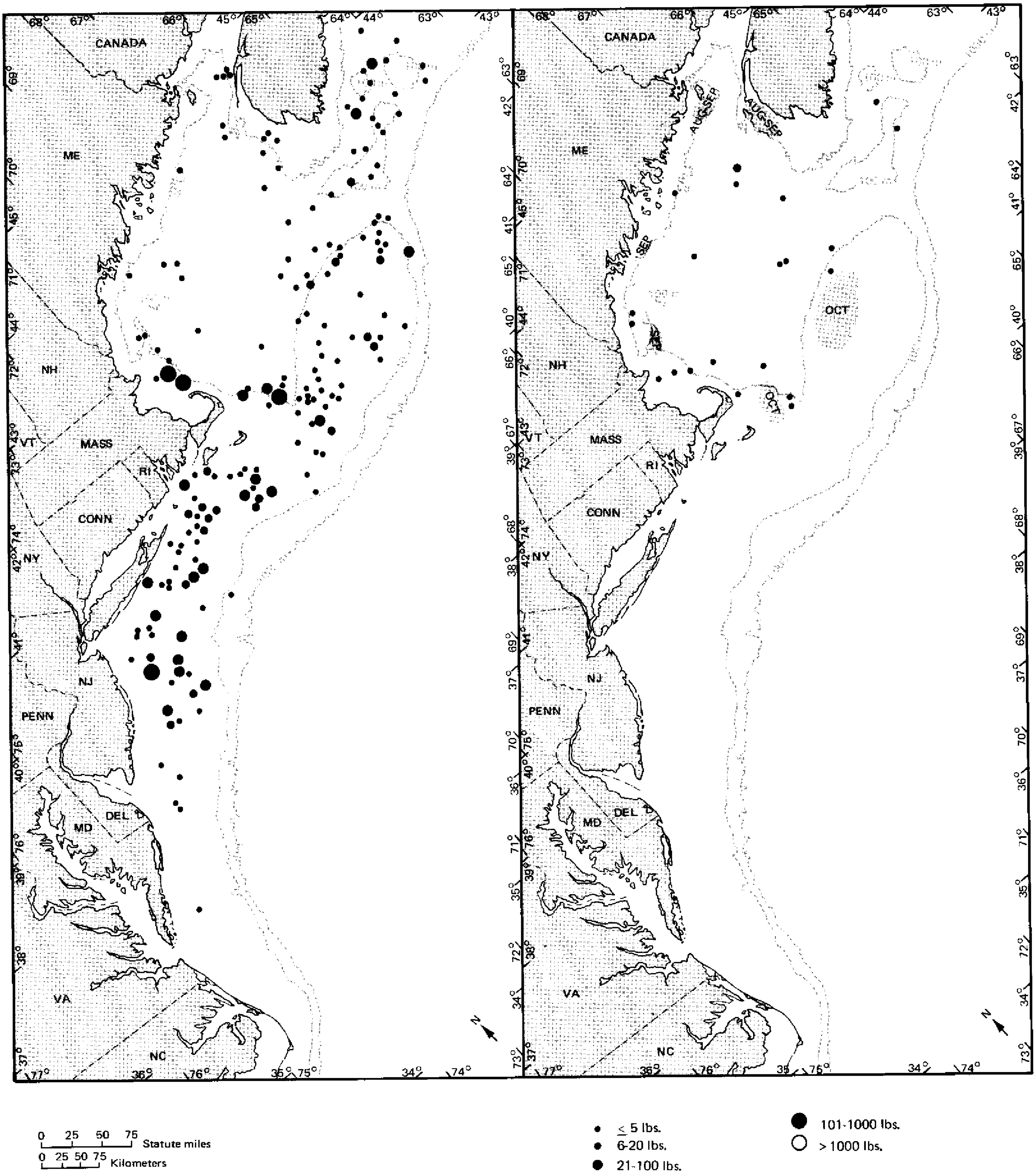
Population Size and Fisheries. The size of the Georges Bank spawning stock (age four and older) increased in the early 1960s to a peak of 1.4 million MT in 1967 from two very strong year-classes in 1960 and 1961. By 1973 the stock size had decreased to about one-tenth the 1967 level, largely because of heavy fishing and only average or poor recruitment to the adult spawning stock. The stock size more than doubled in 1974, from the low 1973 level, as a result of very good recruitment from the 1970 year-class. However, this level declined rapidly and the stock collapsed in 1977 as evidenced from commercial catch and research vessel data.

Although herring were caught on Georges Bank as early as the seventeenth century (for bait in cod fisheries), intensive fishing of this stock did not begin until the early 1960s. The Soviet Union began fishing for herring in 1961; Poland joined the fishery in 1966, and other countries in 1967 (Anthony 1972). Herring fishing effort increased rapidly after 1965 and reached a peak in 1972 when it was about 10 times the level of the mid-1960s.

The total catch from the Georges Bank stock increased steadily from 1965, reaching a peak of 374,000 MT by 1968, and then declined steadily thereafter. Catch limitations were imposed by the International Commission for the Northwest Atlantic Fisheries (ICNAF) in 1972 after which the stock biomass showed a slight recovery, but remained far below the desired level. The proportion of the total catch from the Georges Bank stock that is taken from the Middle Atlantic Bight has varied with the extent of the winter fishery; it reached a peak 1969-71 when total catches west and south of Block Island were about 40,000 MT. After implementation of the ICNAF catch restrictions in 1972 most countries took their quotas in September-October from Georges Bank. Seasonal shifts in the foreign fleets depended to a large extent on migrations of herring, mackerel, and hake (McHugh and Ginter 1978).

With the enactment of the Fishery Conservation and Management Act (FCMA), March 1977, the foreign catch allocation was reduced from 60,000 MT in 1976 to 33,000 MT in 1977 and set at 0 for the 1978-80 period (New England Regional Fishery Management Council 1978). The 1977 foreign fishery was restricted to a small area or "herring window" on Georges Bank during September–October. The total US catch from the Georges Bank stock

Map 28. Atlantic herring — distribution of NMFS 1973-74 research vessel trawl catches (dots) and spawning areas (shading) (spring-left, autumn-right)



Note: brown shading shows major spawning areas: size proportionate to average population except no spawning on Georges Bank since 1976.

has been small, averaging only 2,600 MT since 1968, with a high of 4,600 MT in 1973.

Reproduction, Growth, Life Span. Atlantic herring in southern New England generally mature at age four, although since 1971 a significant proportion of age three herring on Georges Bank has matured, apparently due to increased growth rate. Herring fecundity varies with length from about 18,000 eggs at 25 cm (10 in) long to approximately 140,000 eggs at 33 cm (13 in) long (Perkins and Anthony 1969).

Spawning occurs from August through October from Nantucket Shoals to Newfoundland over rocky or gravel bottoms in 4 to 55 m (13 to 180 ft) of water (Bigelow and Schroeder 1953). Spawning does not occur in New York Bight proper (Map 28). Some spawning areas are large and have generated major fisheries, but many small spawning sites also exist along the Maine and Nova Scotia coasts. The significance of these various spawning areas in providing recruitment to the herring fisheries is not yet known.

Herring eggs are demersal and stick to gravel or algae on the ocean floor. The eggs are 1 to 1.4 mm (0.04 to 0.05 in) in diameter and hatch in 10 to 15 days, depending on temperature (Bigelow and Schroeder 1953). Larval size at hatching is about 5 to 7 mm (0.2 to 0.3 in) with growth of 0.18 to 0.25 mm (0.007 to 0.010 in) per day immediately after hatching (Graham and Chenoweth 1973).

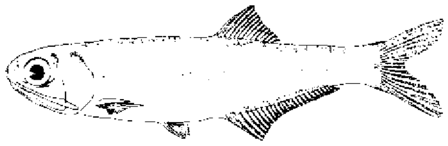
Surveys conducted from September to March indicated that herring larvae from Georges Bank disperse westward at least as far as eastern Long Island (R.G. Lough, personal communication). After metamorphosis occurs at 40 mm (1.6 in) in April, the juveniles apparently school and move into shallow waters. Graham and Davis (1971) reported that herring began to move into the Sheepscot estuary of Maine as early as late September and continued until late November. A second group of herring was observed entering the estuary April–May; Graham and Davis assumed that these herring overwintered in offshore areas.

Herring of the Georges Bank-mid-Atlantic area grow to 14 cm (6 in) by the end of their first year and reach 35 cm (14 in) at their maximum life span of about 14 to 15 years (Anthony 1972). Weight gain is rapid during the first two years of life. Along western Maine, herring born September–October still weigh less than 1 g (0.04 oz) by June but grow to 20 g (0.7 oz) by October when they are just one year old. By October of their second year they weigh 62 g (2 oz), and 92 g (3 oz) in October of the next year. At younger ages, herring are larger in the offshore waters of Georges Bank. In August-September, herring age two, three, four, five, and six weigh 87, 155, 180, 220, and 240 g (3, 5, 6, 7.7, and 8.4 oz), respectively. These data describe herring growth during the 1960s. There has been some indication that the growth rate beginning with the 1968 year-class has increased, but an updated growth curve has not been calculated.

Feeding Interrelationships. Food studies of herring in the Bight are limited. Larval herring along the ME coast eat copepods, crustacean eggs, and nauplii, cirriped larvae, and tintinnids (Sherman and Honey 1968). According to Maurer (1975), adult herring of the Georges Bank area feed mainly on chaetognaths (43% by weight), euphausiids (34%), and pteropods (6.2%). Atlantic mackerel, a potential competitor of herring, feeds mainly on calanoid copepods (32.7%) and pteropods (33.5%). A comparison of genera from the stomachs of both herring and mackerel indicates that 16 of the 29 food items identified were shared by both species (Maurer 1976).

Anchovy

Charles J. Byrne



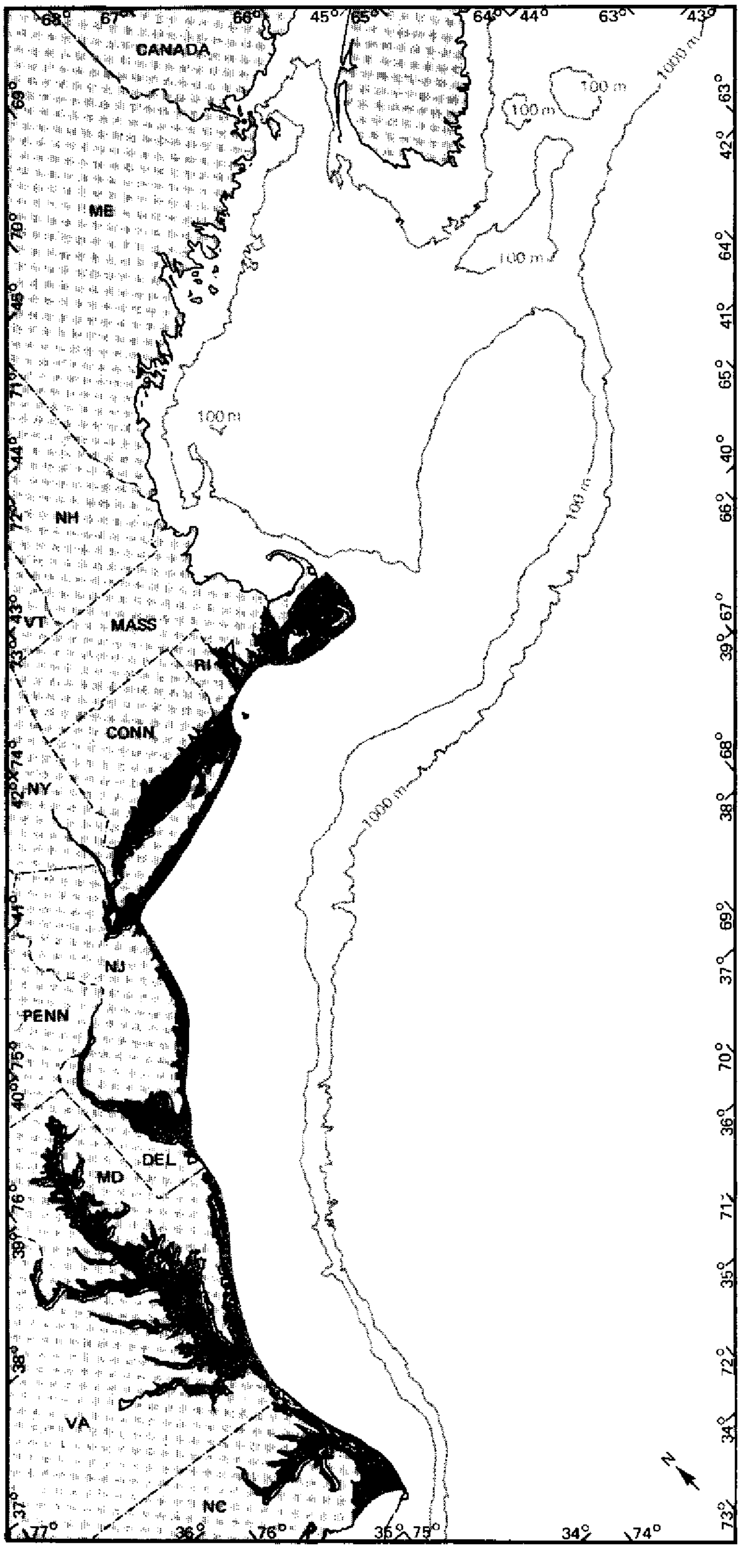
Distribution and Seasonal Movements. Anchovies (order Clupeiformes, family Engraulidae) are small, schooling, herring-like fishes. Anchovies differ from herring in that they have proportionally larger mouths located on the underside of the head rather than at the end of the snout as in the case of herrings.

Anchovies are generally more southerly in their distribution, but at least three species have been taken on bottom trawl surveys conducted in the Bight, these are: bay anchovy, *Anchoa mitchilli,* striped anchovy, *Anchoa hepsetus,* and silver anchovy, *Engraulis eurystole* (Map 29). It also appears that there may be up to four other species found occassionally as far north as the Bight: dusky anchovy, *Anchoa lyolepis,* flat anchovy, *Anchoviella perfasciata,* longnose anchovy, *Anchoa nasuta,* and New Jersey anchovy, *Anchoa duodecim* (Nichols and Breder 1927; Briggs 1958; Hildebrand 1963; Daly 1970).

The range of the bay anchovy extends from Cape Cod to the Yucatan Peninsula in Mexico, with occasional sightings as far north as Maine (Hildebrand 1943, 1963; Bigelow and Schroeder 1953). The striped anchovy is common from Cape Cod to Argentina, but is most numerous from the Virginia capes to the West Indies (Hildebrand 1943, 1963; Bigelow and Schroeder 1953). The striped anchovy rarely strays into the Gulf of Maine (Bigelow and Schroeder 1953), but has been reported as far north as Halifax, Nova Scotia, (Vladykov 1935). The silver anchovy is found from Cape Cod to Beaufort, NC (Hildebrand 1943, 1963). However, Daly (1970) has tentatively identified a few specimens taken off Miami as silver anchovies, which would extend their range.

Bay and striped anchovies are nearshore and estuarine in their distribution. On NMFS trawl surveys in the

Map 29. Anchovies — distribution and spawning areas based on historical fishery records



0 25 50 75 Statute miles
0 25 50 75 Kilometers
0 25 50 75 Nautical miles

Note: blue shading shows general distribution and spawning areas

Bight, bay anchovies were seldom found in waters greater than 25 m (82 ft), while striped anchovies were found somewhat deeper. Similar depth ranges were reported by Hildebrand (1963). Inshore, bay anchovies may be found in fresh water while striped anchovies do not leave brackish or salt water. Silver anchovies generally are found further offshore than either the bay or striped anchovy and are absent from estuaries, but on occasion are observed near sandy beaches.

Bay and striped anchovies are able to withstand a wide range of salinity and temperature conditions. Bay anchovies have been found in fresh water as far as 64 km (40 mi) from brackish water (Massman 1954) and in the extremely saline waters of the Laguna Madre, TX (75 to 80 ‰), although a salinity of less than 50 ‰ is preferred (Simmons 1957). Salinity in New York Bight rarely, if ever, exceeds 35 ‰. Striped anchovies have been found in salinities ranging from 1.8 ‰ to 48 ‰ (Roessler 1970). Temperature ranges for bay and striped anchovy are reported as 3.8° to 35°C (39° to 95°F) and 8.1° to 32°C (14° to 90°F) respectively (Roessler 1970).

Bay and striped anchovies show some seasonal movements that vary with age. In Delaware Bay, Stevenson (1958) found that small anchovies tended to congregate near shore. In spring, yearlings and older anchovies were distributed both in shallow and deep waters. By midsummer, most of the yearlings had moved to deeper waters as the young of the year began to appear. By winter all sizes of anchovies vacated the shallower waters in favor of nearshore areas and deeper bay areas and were not observed in shallow areas again until the subsequent spring.

Hildebrand and Schroeder (1928) found that striped anchovies withdrew from Chesapeake Bay during the cold months while a substantial number of bay anchovies remained in the deeper waters of the bay. There appears to be no significant northward or southward movement exhibited by these species.

Population Size and Fisheries. There is no fishery for anchovies in the Bight but the population may be of considerable size. It has been estimated that the annual sustainable production potential of anchovies from Cape Hatteras to Georges Bank may be on the order of 10,000 MT (Edwards 1968).

Based on the NMFS trawl surveys, and other studies by Hildebrand and Cable (1930) and Stevenson (1958), the bay anchovy is by far the most abundant of the anchovies found in the Bight. Smith (1971) found the bay anchovy to be the second most abundant adult species taken in the Delaware River estuary; Dovel (1970) found it to be the third most abundant species (in larval stages) in upper Chesapeake Bay. Near Beaufort, NC, Tagatz and Dudley (1961) found that at the less saline sampling sites, adult bay anchovies were the most numerous species and composed up to half of the total catch for the autumn months. This same study found that striped anchovy was the second most abundant species at the most saline (15.8 to 35.7 ‰)

sampling site, and in the autumn composed up to 70% of the total catch.

Reproduction, Growth, Life Span. Stevenson (1958) found that bay anchovies become sexually mature at approximately 30 to 40 mm (1.2 to 1.6 in), and Hildebrand and Cable (1930) observed that the striped anchovy frequently is sexually mature at a length of 75 mm (3 in). There is evidence that both species of anchovy spawn more than once each season and in the case of the bay anchovy, the earlier hatched individuals are able to spawn that same season (only 2.5 to 3 months to first maturity).

The spawning season for the bay anchovy in the Bight runs from late April through late September (Nichols and Breder 1927; Hildebrand and Cable 1930; Richards 1959; Dovel 1971). Hildebrand and Cable (1930) found that near Beaufort the striped anchovy spawned from mid-April through July with the peak of activity in late May and early June. The silver anchovy has been observed to spawn during July and August (Kuntz and Radcliffe 1918; Nichols and Breder 1927), but the occurrence of early stage larvae from May to December 1966, indicates a much broader period of spawning. Bay anchovies spawn throughout the entire salinity gradient in the estuaries but in Chesapeake Bay they seem to prefer salinities of 13 to 15 ‰ (Dovel 1971). In Long Island Sound (with salinity 24 to 30 ‰), bay anchovies spawned in waters less than 20 m (66 ft) deep (Riley 1956; Richards 1959). Stevenson (1958) reported that striped anchovies spawned in the lower estuarine (higher salinity) waters. Hildebrand and Cable (1930) stated that the striped anchovy spawned in waters less than 22 m (72 ft) deep and no farther than 16 km (10 mi) offshore, and that both bay and striped anchovies spawned within the harbor, sounds, and along the outer shores of the banks as well as in the estuaries near Beaufort.

All three anchovy species apparently spawn early in the evening (Kuntz and Radcliffe 1918; Hildebrand and Cable 1930). Striped and bay anchovies spawn free floating eggs which vary in size according to salinity (Dovel 1971). Higher salinities result in smaller eggs. Fertilized eggs possess no oil globules and occur throughout the water column (Dovel 1971). The incubation period for bay anchovy has been reported as approximately 24 hours at 27.2° to 27.8°C or 81° to 82°F (Kuntz 1915), and approximately 48 hours at 18.9° to 21.1°C (66° to 70°F) for striped anchovy (Hildebrand and Cable 1930). The incubation period for silver anchovy eggs is unknown.

In Chesapeake Bay, after hatching, bay anchovy larvae move upstream to low salinity (◀12 ‰) areas (Dovel 1970) and toward shallower and near surface waters until winter approaches (Stevenson 1958; Dovel 1971). In autumn when the temperature drops to about 11°C (52°F), they move into deeper and warmer waters of higher salinity.

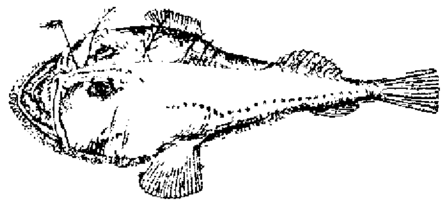
The maximum size of the striped anchovy is approximately 15.3 cm (6 in) and that of the bay anchovy approximately 11.4 cm or 4.5 in (Hildebrand and Cable 1930). The age at which these fish reach maximum length is not known since there are no satisfactory aging techniques, but analysis of length frequencies suggests that the largest striped anchovies are probably two to three years old (Stevenson 1958). Dovel (1971) felt that the bay anchovy has a short life span in Chesapeake estuaries.

Feeding Interrelationships. Anchovies are zooplankton feeders and both the bay and striped anchovies select larger food items as they grow (Hildebrand and Cable 1930; Stevenson 1958). The striped anchovy's diet consists largely of copepods, supplemented by small gastropods, ostracods, annelids, some minute bivalve molluscs, and, occasionally, mysids (Hildebrand and Cable 1930; Stevenson 1958). Anchovies feed in currents at night, and during the day form large schools in protected areas to escape predation.

Smith (1971) felt that the bay anchovy played an important role as a forage species, and Merriner (1975) listed anchovies as a major prey species for weakfish. Some of the other important species that utilize anchovies include striped bass, bluefish, and summer flounder (Bigelow and Schroeder 1953; Poole 1964; Wilk 1977). Any piscivorous fish species whose range overlaps with that of anchovies probably includes anchovies in its diet.

Goosefish *Lophius americanus*

Paul W. Wood, Jr.

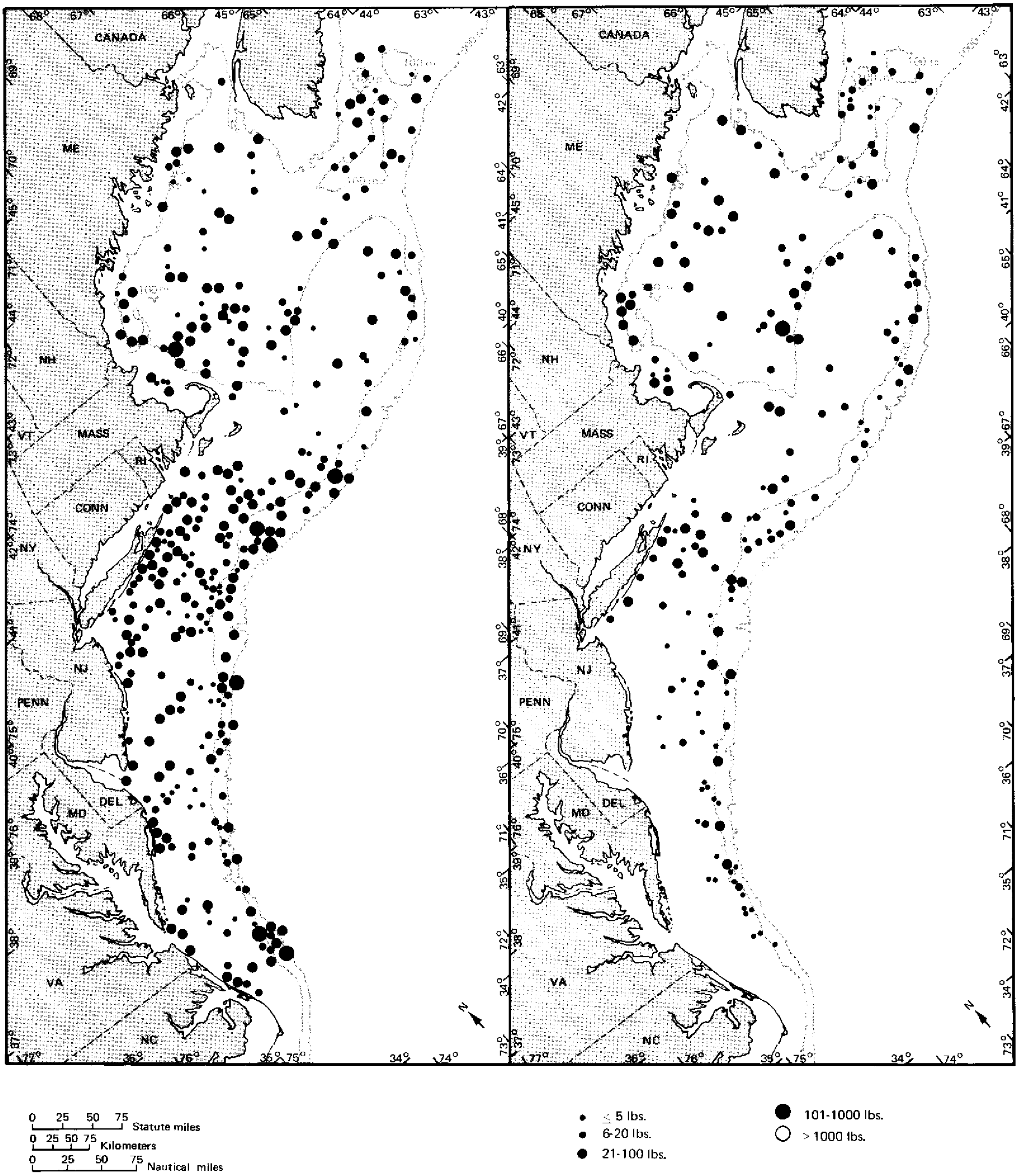


Distribution and Seasonal Movements. The goosefish, also known as monkfish or angler, is found from the Grand Banks of Newfoundland and the Gulf of St. Lawrence southward to North Carolina (Bigelow and Schroeder 1953). Its depth range is from the tide line down to at least 668 m (3,190 ft) and quite likely deeper.

The species has been taken in water temperatures ranging from 0° to 24°C (32° to 75°F). In the Southwest Ground near Block Island, the abundance was found to be greatest when the temperature was about 9°C or 48°F (Edwards 1965). Along the Canadian Atlantic mainland the largest concentrations occur at about 3° to 6°C (37° to 42°F) in winter and about 5° to 9°C (41° to 48°F) in summer (Jean 1965).

Seasonal movements of goosefish appear minimal on Nantucket Shoals, Georges Bank, the Gulf of Maine, and

Map 30. Goosefish — distribution of NMFS 1973-74 research vessel trawl catches (dots) (spring-left, autumn-right)



the Nova Scotian Shelf, but west of Nantucket Shoals and southward along the continental shelf there is a definite seasonal change in distribution as indicated by bottom trawl surveys. In spring they are found over the whole of the shelf from inshore out to at least 366 m (1,200 ft); but south of Nantucket Shoals in summer and autumn, goosefish move out of shoal waters except just off Long Island where they still occur fairly close inshore (Map 30). They may be avoiding the warm waters (►15°C or ►59°F) nearshore, and this may also explain their absence on the Georges Bank shoals in autumn. Their occurrence inshore near Long Island may be partly related to the presence of the so-called "cold bubble" or cool pool normally found in New York Bight in summer and early autumn (Bowman and Wunderlich 1977). Food availability may also be a factor since a number of prey species tend to aggregate off Long Island in summer and early autumn, for example, skates, silver hake, red hake, yellowtail, butterfish, squid, scup, and summer flounder. Bigelow and Schroeder (1953) reported that the goosefish population normally found inshore off Rhode Island seeks deeper waters in July to avoid the extreme summer temperatures, then returns inshore in October after autumn cooling. The reverse seasonal movements have been reported in Nova Scotian waters, where goosefish invade shallow waters in summer and migrate back to deep waters in winter (Jean 1965). However, summer and autumn water temperatures are very much cooler off Nova Scotia than in the mid-Atlantic, therefore, the same seasonal distribution pattern is unlikely.

Population Size and Fisheries. An estimate of the goosefish biomass was made from 1968-74 autumn trawl survey data from Browns Bank, Nova Scotia, to Cape Hatteras. It was assumed that goosefish catchability and distribution were similar to that of "other flounder," as described by Clark and Brown (1977); areal expansion of the goosefish survey catches yielded a standing crop estimate of about 18,000 MT. Approximately 10% of this standing crop resides in the New York Bight area.

The goosefish is an underutilized species in the United States. Landings for both human consumption and industrial use are low. Since 1966, US landings have averaged less than 4% per year of the goosefish caught from Cape Hatteras to the eastern end of the Nova Scotian Shelf. The Soviet Union has taken most of the remainder. Data on uses of the Soviet catch are not available, but some portion probably went for human consumption.

The percentage of the total US catch utilized for food has varied, but landings for food increased since 1966. Prior to 1966, reported US landings of goosefish for food exceeded 75 MT only once, in 1944. From 1967 to 1974 only one year had a landing as low as 75 MT. In 1972 almost 150 MT were landed, in 1973 over 250 MT, and in 1974 almost 400 MT.

Landings for food from the New York Bight area for the period 1973-78 are given in Table 9. The goosefish contribution to industrial landings is estimated at less than 1%.

Table 9. Domestic goosefish landings from New York Bight area

Year	Landings (MT)
1973	21
1974	22
1975	37
1976	37
1977	69
1978	209

The future of the goosefish as a food source may be growing for two reasons. First, on its own merits it may become recognized as a palatable and enjoyable addition to American table fare, since it is regarded as a delicacy in some European countries (Connolly 1920). Second, it may be recognized by default, as the more desired species decrease in availability and increase in price.

Reproduction, Growth, Life Span. Goosefish spawn in spring, summer, and early autumn, according to latitude, and through a long season (Bigelow and Schroeder 1953). Eggs have been found inshore as well as offshore, indicating no particular preference for spawning area (Connolly 1920). The planktonic eggs are contained in a single layer of mucus veil up to 11 m (36 ft) long and 0.9 m (3 ft) wide, containing over a million eggs (Bigelow and Schroeder 1953). Incubation may vary from as few as 7 days to as many as 22 days. Young goosefish have fairly well ceased their pelagic existence by the time they are 8 cm (3 in) long and several months old (Dahlgren 1928).

Goosefish appear to grow about 10 cm (4 in) per year as shown in Table 10. Fulton (1903) indicated maturity is reached by males at four years of age and females at five years of age. Adults range to 122 cm (4 ft) in length and 23 kg (50 lb) in weight (Bigelow and Schroeder 1953).

Feeding Interrelationships. Adult goosefish have few enemies, but small ones are undoubtedly preyed upon by various fishes. The larval stages are eaten by many invertebrates, including ctenophores, copepods, and hydroids; goosefish larvae in turn feed upon copepods, crustacean larvae, and arrow worms. The adult has a remarkable appetite, eating any fishes it can catch, several invertebrate species including lobster, crabs, and squid, and sea birds as well (Bigelow and Schroeder 1953). Maurer (1975) reported the goosefish diet in the North Atlantic to be 12% squid and 85% fish by weight. The relative importance of the various species in the goosefish's diet varies on different fishing grounds, depending on food availability (Bigelow and Schroeder 1953).

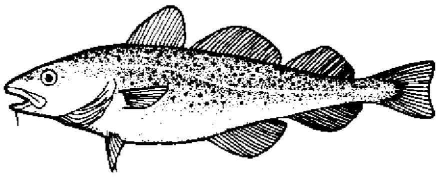
Table 10. Length at age for Goosefish

Age	Length in cm (in)
1	11 (4)
4	46 (18)
8	74 (29)
9	79 (31)
10	94 (37)
12	102 (40)

Source: Connolly 1920

Atlantic Cod *Gadus morhua*

Eugene G. Heyerdahl and *Robert Livingstone, Jr.*



Distribution and Seasonal Movements. One of the most widely known fishes inhabiting the North Atlantic is the Atlantic cod. Its range extends to the northern Barents Sea, Bay of Biscay, and coastal European waters including the Baltic, and it can be found around Iceland, southern Greenland, and from Baffin Island to North Carolina. Throughout its range the cod can be divided into subpopulations or stocks associated with geographically separated habitats. Off the New England coast three to four stocks are hypothesized: (1) Georges Bank, east of the 68th meridian; (2) Gulf of Maine, north of Provincetown, MA; (3) southern New England, south and west of Nantucket Shoals; and (4) mid-Atlantic coast, a stock that spends part of the year mingled with the southern New England stock (Wise 1958, 1962). The separation or extent of the mixing between these last two stocks has not been clearly defined.

Favoring water temperatures between 0° and 10°C (32° and 50°F), the mid-Atlantic stock migrates north and east in summer and autumn, reaching Nantucket Shoals when the shoaler waters of New York Bight exceed 20°C (68°F); it then ranges back southwestward to coastal New York, New Jersey, and Chesapeake Bay during winter and spring where some spawning is believed to occur. This seasonal movement can be partially seen in the distribution of catches in spring and autumn surveys (Map 31). Throughout their range of habitats cod can be found from depths exceeding 366 m (1,200 ft) to nearshore surf areas.

Population Size and Fisheries. A first approximation of the cod biomass from Cape Hatteras to Maine is about 130,000 MT (S. Clark, personal communication). Cod biomass increases considerably in the fish communities off Canada and Greenland, as seen in reported commercial landings. In 1973 about 97% of the cod harvested in the northwest Atlantic came from waters east and north of New England.

Cod are fished both commercially and for recreation throughout their range, with populations off the US coast most numerous north and east of Cape Cod (Jensen 1972). In the Middle Atlantic Bight the commercial fishery has been seasonal with peak catches taken from December through February. At one time an active fishery existed as far south as the Chesapeake Bay region, with pound nets, long-lines, and trawls, but catches were never large compared to those from northerly stocks. In the New York Bight area, peak catches approached 5,000 MT (1930), but commercial landings in 1970 approximated only 260 MT. The Chesapeake Bay region yielded a maximum catch of only 390 MT (1961). Cod landings from New England waters, on the other hand, exceeded 50,000 MT several times since 1900, and current estimates of maximum sustained yield from this area range around 40,000 to 45,000 MT.

With the increasing number of saltwater anglers and the growing popularity of winter sportfishing, the cod has taken on a new importance, particularly in the Bight (McHugh and Ginter 1978). The 1970 US marine recreational survey estimated that over 16,000 MT of cod were taken by recreational fisheries from New York to Maine waters; the majority of these fish were probably landed from New York Bight. By comparison, the US commercial landings of cod in 1970 for New York to Maine was only 24,000 MT. South of New York Bight the recreational fisheries catch exceeded the commercial landings by 11% (100 MT compared to 89 MT).

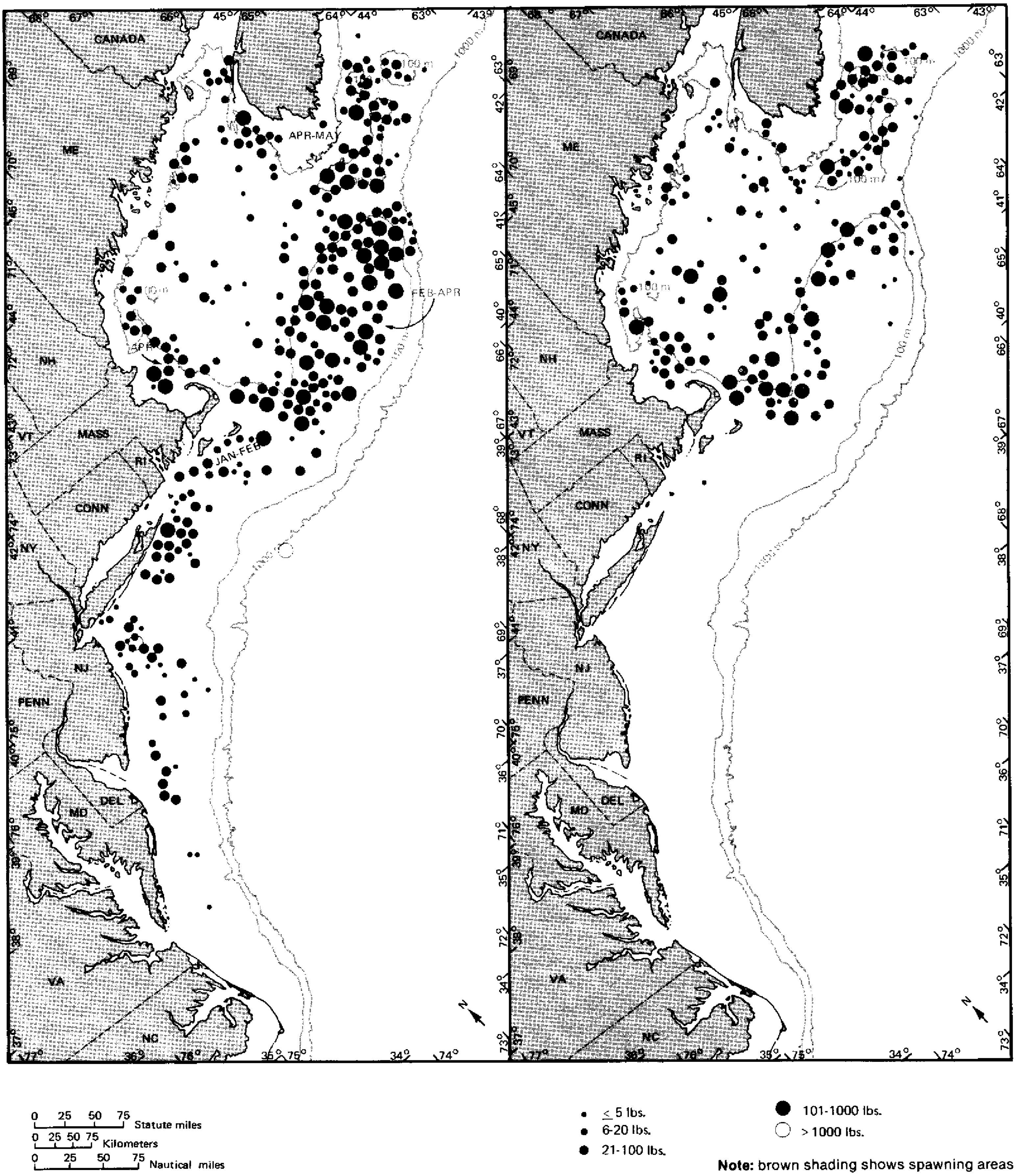
Reproduction, Growth, Life Span. Cod prefer shoal areas for spawning; several major spawning grounds are known (Map 31). Though no specific areas have been documented, both eggs and larvae have been observed from Block Island to Cape Hatteras (see Map 11), indicating that some spawning occurs in the Bight region.

Optimal spawning and hatching temperatures for cod range from 5° to 7°C (41° to 45°F), and peak spawning in the Bight occurs during December and January. Spawning takes place near the bottom, but the eggs and larvae are pelagic and may be greatly affected by hydrographic conditions (Wise 1961). Hatching occurs within two to four weeks, and larvae grow to a length of 40 mm (2 in) in 120 days. Cod are extremely fecund; a single female produces anywhere from 3 million to more than 9 million eggs (Wise 1961).

Growth occurs in steady increments to ages over 15 years (Penttila and Gifford 1975), and individuals may weigh more than 90 kg (241 lb); however, an average-sized fish would be between 5 and 10 kg (12 and 27 lb).

Feeding Interrelationships. The feeding habits of cod

Map 31. Atlantic cod — distribution of NMFS 1973-74 research vessel trawl catches (dots) and spawning areas (shading) (spring-left, autumn-right)

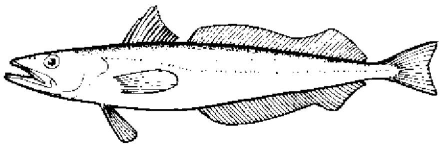


are extremely variable, depending upon their age, the time of year, and their geographic distribution. The pelagic larvae feed entirely on plankton, but as they reach a size of 7 to 10 cm (3 to 4 in) they actively seek a bottom habitat where their diet gradually switches to invertebrates (clams, crabs, mussels, molluscs) and fishes (Wise 1961; Bowman 1975). Adult cod may change their patterns of distribution in relation to food availability. At times, fishes may provide the major food source, but cod frequently feed on benthic invertebrates (Maurer 1975).

The most serious predators of adult cod are large sharks, spiny dogfish, and larger adult cod; juveniles fall prey to a host of predatory fish species such as pollock.

Silver Hake *Merluccius bilinearis*

E.D. Anderson



Distribution and Seasonal Movements. Silver hake are found along the continental shelf between South Carolina and the Grand Banks and are most abundant between Cape Sable, Nova Scotia, and New York (Bigelow and Schroeder 1953). In New York Bight, they have the largest biomass of any demersal species (Edwards 1968). Silver hake migrate seasonally, generally inhabiting shoal waters less than 90 m (295 ft) during summer and autumn and deeper offshore waters in winter and spring (Map 32).

Several stocks of silver hake apparently exist between the Gulf of Maine and Cape Hatteras. Conover, Fritz, and Vieira (1961) reported two separate stocks, one in the Gulf of Maine and one south of Cape Cod, based on differences in body measurements. Tagging and growth studies similarly indicated separate stocks in these two areas (Fritz 1959, 1962, 1963; Nichy 1969). Konstantinov and Noskov (1969) reported two stocks, one on Georges Bank and another between Cape Cod and Cape Hatteras, with some apparent mixing in the Nantucket Shoals area. Some evidence suggests the Gulf of Maine and northern Georges Bank silver hake may comprise the same stock.

Water temperature is apparently the chief environmental factor governing distribution and the timing of annual migrations. Bigelow and Schroeder (1953) reported a temperature tolerance range of 4° to 18°C (39° to 64°F). Domanevsky and Nozdrin (1963) observed that silver hake on the southeastern part of Georges Bank July-August 1962 were most abundant at a depth of 90 to 110 m (295 to 361 ft), with bottom temperatures of 9° to 11°C (48° to 52°F). Sauskan (1964) and Sarnits and Sauskan (1967) noted that spawning and maturing silver hake were concentrated on the southeastern slope of Georges Bank April-June 1962-63 at depths of 85 to 200 m (279 to 656 ft), with bottom temperatures of 10° to 12°C (50° to 54°F), and that post-spawning feeding concentrations along northern Georges Bank occur at depths of 40 to 110 m (131 to 361 ft) and bottom temperatures of 6° to 10°C (43° to 50°F). Edwards (1965) indicated that in winter silver hake generally do not occur where temperatures are much below 9°C (48°F), except for the young-of-the-year, and that silver hake prefer progressively warmer waters as they increase in size.

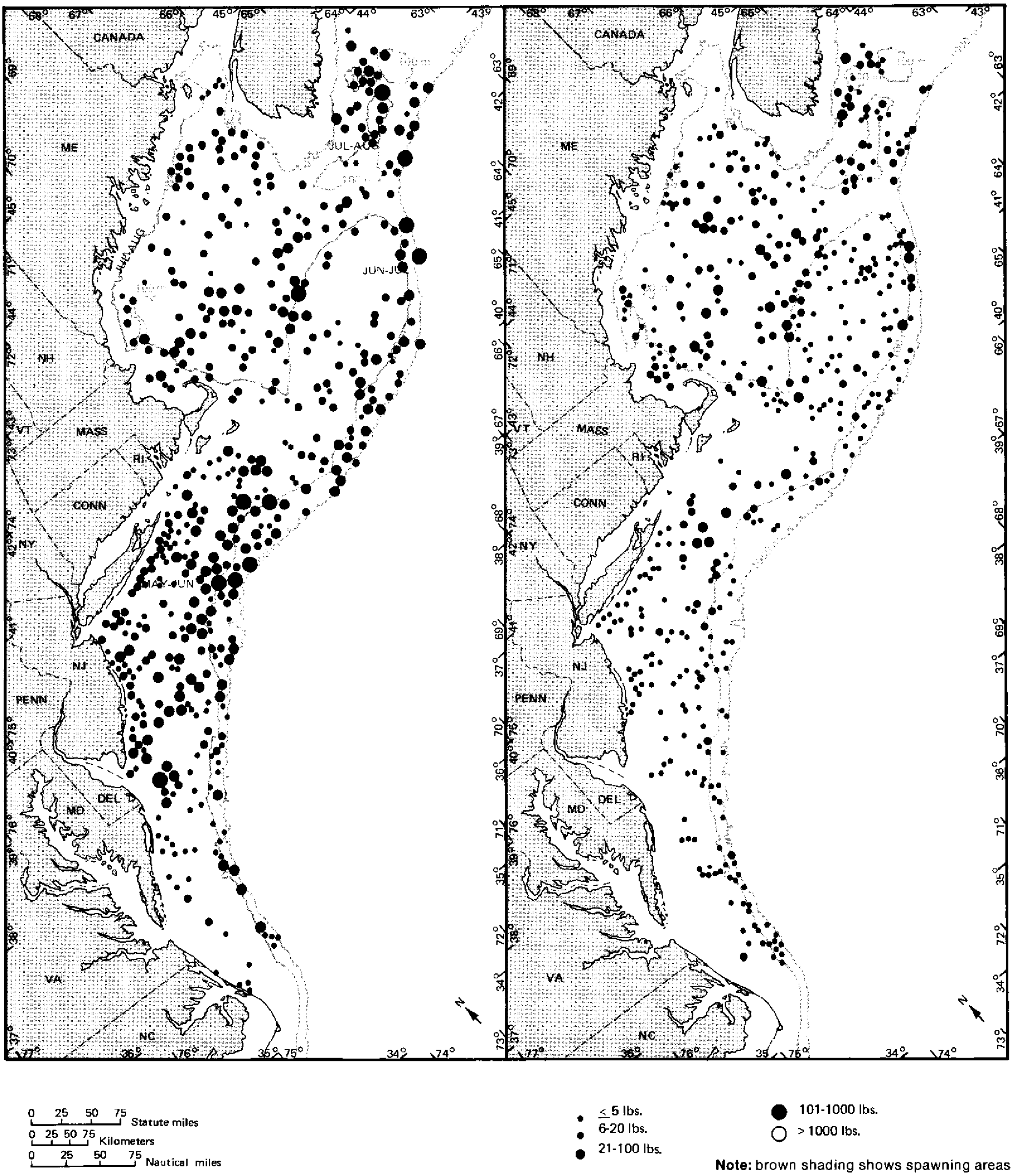
Population Size and Fisheries. The size of silver hake stocks has fluctuated greatly since the 1950s. Intensive fishing by the Soviet Union in the mid-1960s (Anderson 1975*b*) reduced the biomass considerably to a total of about 280,000 MT in 1970 compared to a peak of 1,330,000 MT in 1963-64 (Almeida and Anderson 1978*a,b,c*). The estimated biomass between the Gulf of Maine and Cape Hatteras averaged about 500,000 MT in 1973-75 (Anderson 1975*a,b*); the stock between Cape Cod and Cape Hatteras averaged about 175,000 MT, or 35% of the total. Total catches have declined steadily since 1973 and the stocks have increased due to improved recruitment. In 1978 the total biomass was about 700,000 MT or about 50% of the level in 1963-64 (Almeida and Anderson 1978*a,b,c*). The stock between Cape Cod and Cape Hatteras increased to about 390,000 MT in 1978, 86% of its previous high in 1965. Year-class strength during the past 25 years has varied greatly.

Reproduction, Growth, Life Span. Bigelow and Schroeder (1953) indicated that Gulf of Maine silver hake probably matured at age two. Sauskan (1964) reported that first-time spawners on Georges Bank in 1962-63 were 29 to 33 cm (11 to 13 in) long and two to three years old. Doubleday and Halliday (1975) stated that for silver hake on the Nova Scotian Shelf from 1971 to 1974, all males greater than 25 cm or 10 in (age two and older) and all females greater than 30 cm (12 in) were sexually mature. Silver hake in the Bight are assumed to mature also at about age two. Sauskan and Serebryakov (1968) reported that fecundity averaged 343,000 eggs in females 25 to 30 cm (10 to 12 in) long and 391,700 eggs in females 30 to 35 cm (12 to 14 in) long.

In spring silver hake migrate in dense concentrations from deep-water overwintering grounds to shoaler regions along the continental shelf and in the Gulf of Maine. Spawning in the Gulf of Maine takes place along the coast from Cape Cod to Grand Manan Island and particularly along the eastern side of Cape Cod north to Cape Ann (Bigelow and Schroeder 1953). The major spawning grounds on the continental shelf are along the southeastern and southern slopes of Georges Bank (Sauskan and Serebryakov 1968), around Nantucket Shoals, and south of Martha's Vineyard, MA (Fahay 1974). Some spawning occurs as far south as Cape Hatteras (Map 32).

Egg and larval collections show that spawning lasts

Map 32. Silver hake — distribution of NMFS 1973-74 research vessel trawl catches (dots) and spawning areas (shading) (spring-left, autumn-right)



Note: brown shading shows spawning areas

from May to November (Bigelow and Schroeder 1953; Marak and Colton 1961; Marak, Colton, and Foster 1962; Sauskan and Serebryakov 1968; Colton and St. Onge 1974; Fahay 1974). Since water temperature regulates the onset of spawning, the period of peak activity varies annually as well as areally but generally occurs July-August in the Gulf of Maine and June-July on the continental shelf. Bigelow and Schroeder (1953) reported that 5°C (41°F) was the lowest temperature limit for spawning, with most eggs produced at 8° to 13°C (46° to 55°F).

During surveys conducted in 1966 between Martha's Vineyard and Cape Lookout (Fahay 1974), 88% of the silver hake eggs collected were taken between Martha's Vineyard and Montauk Point; approximately half these eggs were collected in June. Larvae were found to be most densely concentrated between Nantucket Shoals and Hudson Shelf Valley; 91% of the total catch was taken August-October (see Map 41). These results suggest that New York Bight is a principal spawning and nursery area for silver hake.

Individual females generally release three batches of eggs during a season—half the annual production in the first batch and the remainder divided between the second and third batches (Sauskan and Serebryakov 1968; Fahay 1974). Spawning presumably occurs near the bottom, but the eggs are pelagic (Sauskan 1964). Incubation is most successful between 13° and 16°C (55° and 61°F), with minimum and maximum extremes of 10° and 20°C or 50° and 63°F (Bigelow and Schroeder 1953). Kuntz and Radcliffe (1918) assumed an incubation period of 48 hours but did not report the water temperature. They reported that larvae were about 2.8 mm (0.1 in) long at hatching.

Eggs and larvae drift with prevailing currents as far southwest as 77 to 111 km (48 to 69 mi) from the spawning site (Sauskan and Serebryakov 1968; Fahay 1974). Pelagic life continues for approximately two months, after which the larvae, measuring about 17 to 20 mm (0.7 to 0.8 in) SL descend to the bottom (Fahay 1974). According to Bigelow and Schroeder (1953), juvenile silver hake remain in deep waters during the following year before migrating inshore as mature fish.

Growth is fairly rapid for the first several years of life; females grow faster and live longer than males (Schaefer 1960; Nichy 1969). Silver hake aged by Nichy (1969) showed a maximum length of 34 cm (13 in) for males and 60 cm (24 in) for females, a maximum age of 6 years for males and 12 years for females. Bigelow and Schroeder (1953) reported maximum length and weight to be about 64 cm (25 in) and 2.3 kg (6.2 lb) respectively.

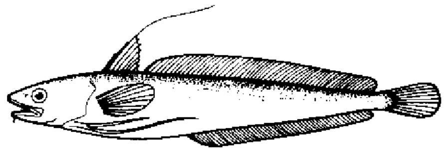
Feeding Interrelationships. Silver hake are vigorous and predacious, have numerous sharp teeth, and wander extensively both vertically and areally in search of prey. Diet consists primarily of fish, crustaceans, and squid (Bigelow and Schroeder 1953; Jensen and Fritz 1960; Schaefer 1960; Domanevsky and Nozdrin 1963; Vinogradov 1972). Young hake eat mainly euphausiids and shrimp; older hake eat mostly squid and fish, including commercially important species such as herring and mackerel as well as young silver hake. From the standpoint of total food consumption (and particularly fish), silver hake represent one of the most important predators in the Bight and adjacent waters (Grosslein, Langton, and Sissenwine 1980).

According to Vinogradov (1972), silver hake feed intensively during spring and summer prior to spawning and during autumn following spawning. Feeding diminishes during winter, although fish wintering in the Hudson Canyon area apparently feed intensively at that time.

Silver hake are preyed upon by various species including other silver hake, pollock, flounders, cod, and mackerel (Maurer 1975).

Red Hake *Urophycis chuss*

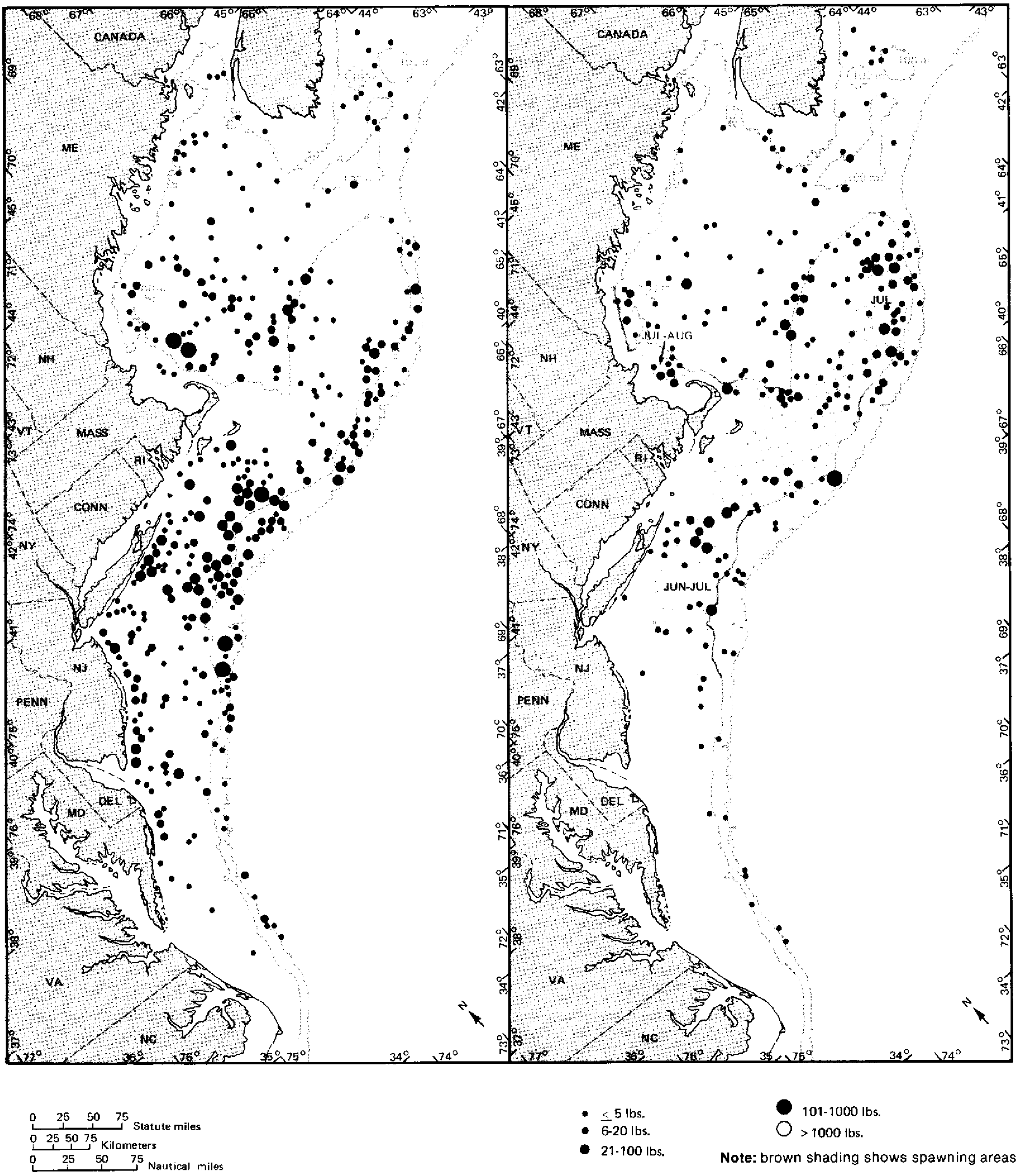
E.D. Anderson



Distribution and Seasonal Movements. Red hake are distributed along the continental shelf from southern Nova Scotia to North Carolina and may stray as far north as the Gulf of St. Lawrence (Musick 1974). They are most heavily concentrated from the southwestern part of Georges Bank to Hudson Shelf Valley. Rikhter (1970) reported two stocks of red hake, one inhabiting the southern and southwestern parts of Georges Bank and the second extending southwest from Cape Cod. A separate but much smaller stock probably exists in the Gulf of Maine (Anderson 1974).

Red hake is demersal and found over a sand or mud bottom (Fritz 1965; Musick 1974); adult fish prefer a water temperature range of 5° to 12°C or 41° to 54°F (Musick 1969). The species moves inshore or offshore with seasonal temperature changes. During autumn, adult fish are generally dispersed both inshore and offshore, but in winter and early spring they aggregate in deeper offshore areas (Map 33). Edwards, Livingstone, and Hamer (1962) found red hake to be most abundant in waters between 183 and 457 m (600 and 1,500 ft) deep off southern New England in winter, where water temperatures at the bottom were 8° to 10°C (46° to 50°F). In late spring, mature fish (►28 cm or ►11 in) migrate inshore; in southern New England they then move offshore again in summer to spawn (Musick 1974). During summer, areas of highest concentration are generally in waters less than 110 m (360 ft) deep between Martha's Vineyard and Long Island and on southwestern Georges Bank. According to Edwards (1965) red hake moved into deeper waters in early

Map 33. Red hake — distribution of NMFS 1973-74 research vessel trawl catches (dots) and spawning areas (shading) (spring-left, autumn-right)



Note: brown shading shows spawning areas

summer when the bottom temperature reached 10°C (50°F). In the Gulf of Maine, adult fish remained closer inshore (◀55 m or ◀180 ft) in summer where water temperatures (5° to 10°C or 41° to 50°F) are comparable to those of southern New England in summer (Musick 1974).

Population Size and Fisheries. Red hake population size has fluctuated considerably since the early 1960s, as shown in international commercial landings and US trawl surveys (Anderson 1974). Total landings from Cape Hatteras to Nantucket Shoals increased rapidly from a level of 4,500 MT in 1960 to a peak of 61,000 MT in 1966, then declined to about 10,000 MT in 1970, rose again to 42,000 MT in 1973, and declined again down to 5,400 MT in 1978. Annual landings of red hake from 1963 to 1975, with separate statistics for the two stocks from 1969 on, are given by McHugh and Ginter (1978). These changes stemmed from intensive fishing and variable year-class strength. Estimates of the overall biomass of red hake from Georges Bank to Cape Hatteras totaled approximately 300,000 MT in the mid-1960s (Edwards 1968; Anderson 1974); about 75% of that was contributed by the southern New England mid-Atlantic stock. Biomass levels have since declined and in 1978 were estimated to be about 60,000 MT in each of the two stocks (Almeida, Anderson, and Herring 1978, 1979).

Reproduction, Growth, Life Span. Red hake reach sexual maturity at about 29 cm (11 in) long and two years old (Musick 1969). Spawning begins in May off southern New England and in June in the Gulf of Maine. Domanevsky and Nozdrin (1963) reported that the 1962 spawning peak on Georges Bank occurred in mid-July in waters 110 to 120 m (361 to 394 ft) deep. According to Perlmutter (1939), spawning off Long Island took place from May to September, with the peak from the end of June through July. Thus far it has been impossible to distinguish red hake eggs from white hake (*Urophycis tenuis*) eggs. Presumably, New York Bight is an important spawning and nursery area for red hake (see Map 14). Eggs are pelagic and average 0.74 mm (0.03 in) in diameter (Hildebrand and Cable 1938). Incubation under laboratory conditions has been reported as 90 hours at 15.6°C or 60.1°F (Hildebrand and Cable 1938), 36 hours at 21.1°C or 69.9°F (Miller and Marak 1959), and for red hake-white hake or *U. chuss-U. tenuis* hybrid 95 hours at 14.3°C or 57.7°F (Musick 1969). At hatching, larvae measured 1.83 to 1.98 mm or 0.07 to 0.08 in (Hildebrand and Cable 1938) and 1.76 to 2.29 mm (0.07 to 0.08 in) or an average of 2.04 mm or 0.08 in (Miller and Marak 1959). Both pelagic eggs and larvae drift southwest with prevailing currents. Larvae become demersal when they are between 35 and 40 mm (1.4 and 1.6 in) long.

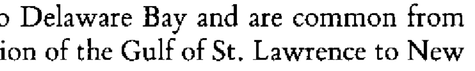
During their first year juveniles enter and live within the mantle cavity of the sea scallop (*Placopecten magellanicus*) apparently to escape predators (Musick 1969). They remain there until they outgrow their hosts or are killed or forced to leave when water temperatures drop below about 4°C (39°F). The largest red hake found inside sea scallops were 130 to 140 mm (5.1 to 5.5 in) long (Musick 1974). Musick (1969) suggested that as the number and average size of sea scallops decrease from heavy fishing, red hake populations may be affected. The distribution of juvenile red hake (◀15 cm or ◀0.6 in) coincides with that of the sea scallop. In all seasons they are generally found in waters shoaler than 110 m (360 ft) and appear to avoid waters colder than 4°C or 39°F (Musick 1974). Immature red hake (15 to 28 cm or 6 to 11 in) remain near the scallop beds, temperature permitting, until their second autumn when they move inshore to within 55 m (180 ft) until water temperatures drop to about 4°C (39°F), then they migrate offshore to overwinter (Musick 1974).

Red hake normally grow to a maximum of 55 cm (22 in) long and weigh about 2 kg or 5 lb (Musick 1967). Maximum age may be as high as 12 years, although red hake older than about 6 years are not very common in commercial catches (Rikhter 1974).

Feeding Interrelationships. Red hake feed on a variety of invertebrates and fishes; amphipods are the most common prey, followed by fishes, squid, shrimp, and assorted invertebrates (Vinogradov 1972). Immature fish feed mainly on amphipods, whereas older red hake consume more fishes, squid, shrimp, and assorted decapods. Feeding intensity increases in spring, ceases during spawning, peaks in October, and diminishes considerably during winter.

Ocean Pout *Macrozoarces americanus*

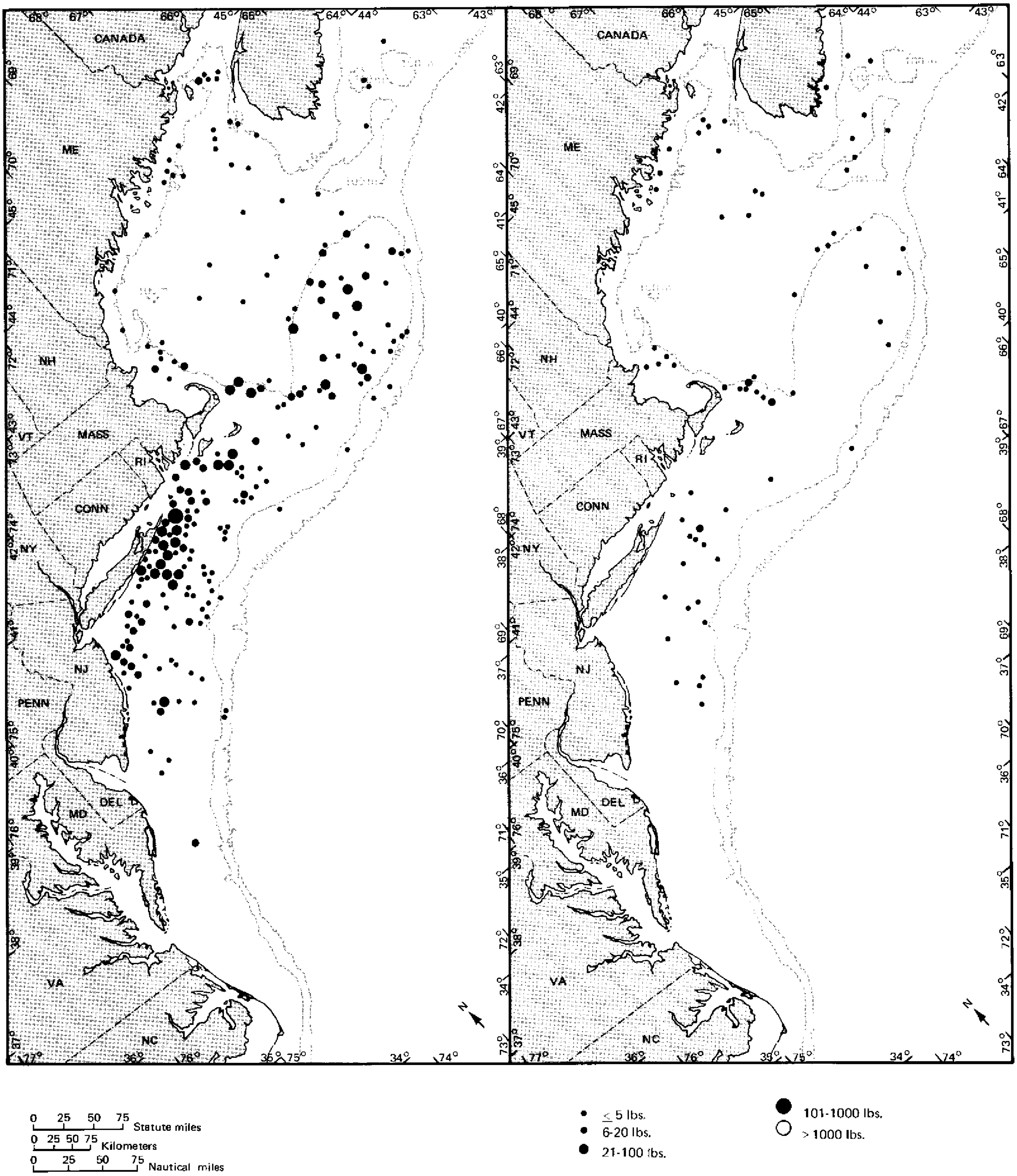
Stephen H. Clark and *Robert Livingstone, Jr.*



Distribution and Seasonal Movements. The ocean pout (known also as eelpout, yellow eel, conger eel, rock eel, muttonfish, and ling) is a soft, slimy eel-like fish, mottled reddish brown to yellow. Ocean pout occur from Labrador south to Delaware Bay and are common from the southern portion of the Gulf of St. Lawrence to New Jersey (Leim and Scott 1966). Along the US coast, commercial and research vessel survey data indicate that abundance tends to be highest off Long Island in winter and spring (Map 34); major areas of concentration have not been found during summer.

The species is demersal; its behavior in captivity sug-

Map 34. Ocean pout — distribution of NMFS 1973-74 research vessel trawl catches (dots) (spring-left, autumn-right)



gests it is secretive, hiding among rocks and vegetation. Ocean pout are normally slow-moving and sluggish but can swim actively for brief periods when disturbed. Ocean pout occur over a variety of bottom types and are normally taken in waters from 15 to 80 m (49 to 262 ft) deep. Young ocean pout are common in the intertidal zone in the Bay of Fundy; adults have been taken at depths exceeding 180 m or 590 ft (Bigelow and Schroeder 1953). Ocean pout prefer continental shelf areas less than 110 m (361 ft) deep, sand and gravel substrates, and relatively low temperatures of 6° to 7°C or 43° to 45°F (Orach-Meza 1975). High bottom temperatures during summer in the Bight probably limit southward distribution of ocean pout.

No evidence has been found to indicate that ocean pout migrate to any significant degree. Sheehy and associates (1977) observed very little movement during tagging studies at Block Island; of 106 tagged fish that had been at large for approximately a year or more, 90% were captured within 4 km (2.5 mi) of the tagging location and none were recovered more than 12.8 km (8 mi) away. On the other hand, seasonal changes in local distribution do occur. In Rhode Island Sound and adjacent waters, ocean pout are abundant in winter and early spring, yet virtually disappear from these areas during summer (Edwards 1965; Jeffries and Johnson 1974). It is currently believed that this species remains in the same general area throughout its life and that these seasonal changes in distribution merely reflect localized movements associated with temperature changes and spawning behavior, to and from areas unavailable to trawling gear. In the southern New England-Georges Bank area, ocean pout cease feeding and move into cooler rocky areas in summer, returning in late autumn as temperatures decline (Orach-Meza 1975). Evidence exists for a similar temperature-induced movement out of inshore areas in the Gulf of Maine later on in summer (Bigelow and Schroeder 1953; Tyler 1971*b*) although in that area the species does not reappear until the following spring.

Vertebral count data show the existence of at least two genetically distinct stocks, one in the Bay of Fundy region and one from Cape Cod south; also, more localized populations appear to exist from Cape Cod to Long Island Sound (Olsen and Merriman 1946). More recent meristic and morphometric studies also suggest the existence of distinct unit stocks with little apparent mixing (Orach-Meza 1975).

Population Size and Fisheries. Little is known about historical trends in ocean pout abundance, although Clark and Brown (1975) reported declines in research vessel survey abundance indices of 80% for the southern New England area and 83% for Georges Bank from 1963 to 1974. From 1973-74 surveys, overall standing crop from Cape Hatteras to Nova Scotia was estimated to be about 99,000 MT, of which 68,123 MT (69% of the total) occurred from Cape Hatteras to Nantucket Shoals (Orach-Meza 1975).

In the New England area, commercial landings were negligible up to and during the 1930s; most of the catch was discarded. US commercial landings fluctuated between 21 and 52 MT from 1935 to 1942. In 1943, attempts to promote the species as a food fish resulted in a dramatic increase in landings to over 4,500 MT. However, infections by a protozoan parasite (*Plistophora macrozoarcides*), which causes large lesions, together with price ceilings, soon made ocean pout unattractive commercially (Olsen and Merriman 1946). By the early 1950s, New England landings returned to prewar levels. Parasitic lesions have evidently been a continual or at least recurring problem; Olsen and Merriman (1946) reported rates of lesion occurrence as high as 52% depending upon area, while Sheehy, Sissenwine, and Saila (1974) observed a 29% rate; however, they later observed a rate of only 6%. Differences may reflect variation in filleting, processing, and candling techniques as well as differences in seasons and areas fished (Sheehy et al 1977).

During the 1950s and the 1960s US landings were used almost entirely for industrial purposes and the species has contributed significantly to total industrial landings in some years (for example, 30% of the southern New England-mid-Atlantic total from 1970 to 1974). Total US landings increased from 2,100 MT in 1964 to an annual average of 7,700 MT from 1966 to 1968 before declining to only 274 MT in 1975. From 1966 to 1969 significant quantities of ocean pout were also taken in New England and mid-Atlantic waters by Soviet vessels. Total international landings peaked at 27,000 MT in 1969 but subsequently declined sharply to an annual average of 5,600 MT from 1970 to 1974. Essentially all of the landings since 1974 have been taken by US vessels. Recent marketing efforts which concentrated on a fresh fillet product have met with considerable success and food landings and sales volume have increased significantly since 1975 (Sheehy et al 1977). In 1977 total US landings were 1,060 MT, more than 50% of which was marketed for human consumption.

Reproduction, Growth, Life Span. In the southern New England area, ocean pout males mature between two and four years of age at lengths ranging from 25 to 39 cm (10 to 15 in); females mature between five and nine years old at lengths from 45 to 65 cm or 18 to 26 in (Olsen and Merriman 1946). Fecundity is size-dependent, ranging from 1,300 to over 4,100 eggs in the specimens examined to date.

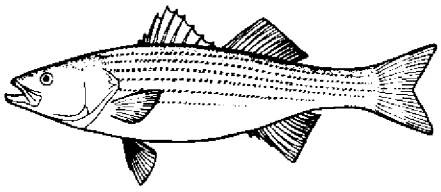
Spawning occurs in September and October, generally at depths of 50 m (164 ft) or less, at temperatures of approximately 10°C (50°F). Adults congregate in rocky areas where the females deposit masses of eggs encased in a gelatinous matrix in rocky depressions or crevices. The eggs are apparently guarded by one or both parents during the incubation period, which requires from 2.5 months in southern New England waters to 3.5 months in more northerly areas (Olsen and Merriman 1946).

Ocean pout larvae are about 3 cm (1 in) long at hatching and closely resemble adults (White 1939). Larvae and juveniles, like adults, appear to be demersal, as they do not occur in plankton (Colton, personal communication). In the southern New England area, juvenile ocean pout attain lengths of 11 to 15 cm (4 to 6 in) in their first year of life, 25 cm (10 in) by the end of their second year, and 31 cm (12 in) at the end of their third year; lengths of up to 81 cm (32 in) may be reached in 10 years (Olsen and Merriman 1946). Sheehy and associates (1974) estimated a slower rate of growth for this area—67.8 cm (26.7 in) at 12 years. Growth is slower in northerly areas, where 60 cm (24 in) fish may be as old as 13 years (Clemens and Clemens 1921). The majority of mature fish in the southern New England area range in length from 40 to 70 cm (16 to 28 in), with an average weight of 1.5 kg (4 lb). Few individuals appear to survive beyond the age of 16 (Olsen and Merriman 1946). To date, the largest specimen on record was a 98 cm (39 in) fish weighing 5.3 kg (14.2 lb).

Feeding Interrelationships. Ocean pout feed primarily on invertebrates: mussels (*Mytilus* and *Modiolus*), other bivalves (*Yoldia* and *Pecten*), whelks (*Buccinum*), periwinkles (*Littorina*), brittle stars, sea urchins, sand dollars (*Echinarachnius*), crabs (*Cancer*), and other crustaceans (Bigelow and Schroeder 1953). Occasionally they also feed on fishes and fish eggs, although these are minor in their diet. Some regional variation in food habits is evident. Northern pout prefer shelled molluscs (Clemens and Clemens 1921), whereas southern New England pout feed primarily on sand dollars and crustaceans (Olsen and Merriman 1946). Ocean pout are undoubtedly preyed on by other fishes, notably, predatory species such as pollock and hake, although there is little specific data on this subject.

Striped Bass *Morone saxatilis*

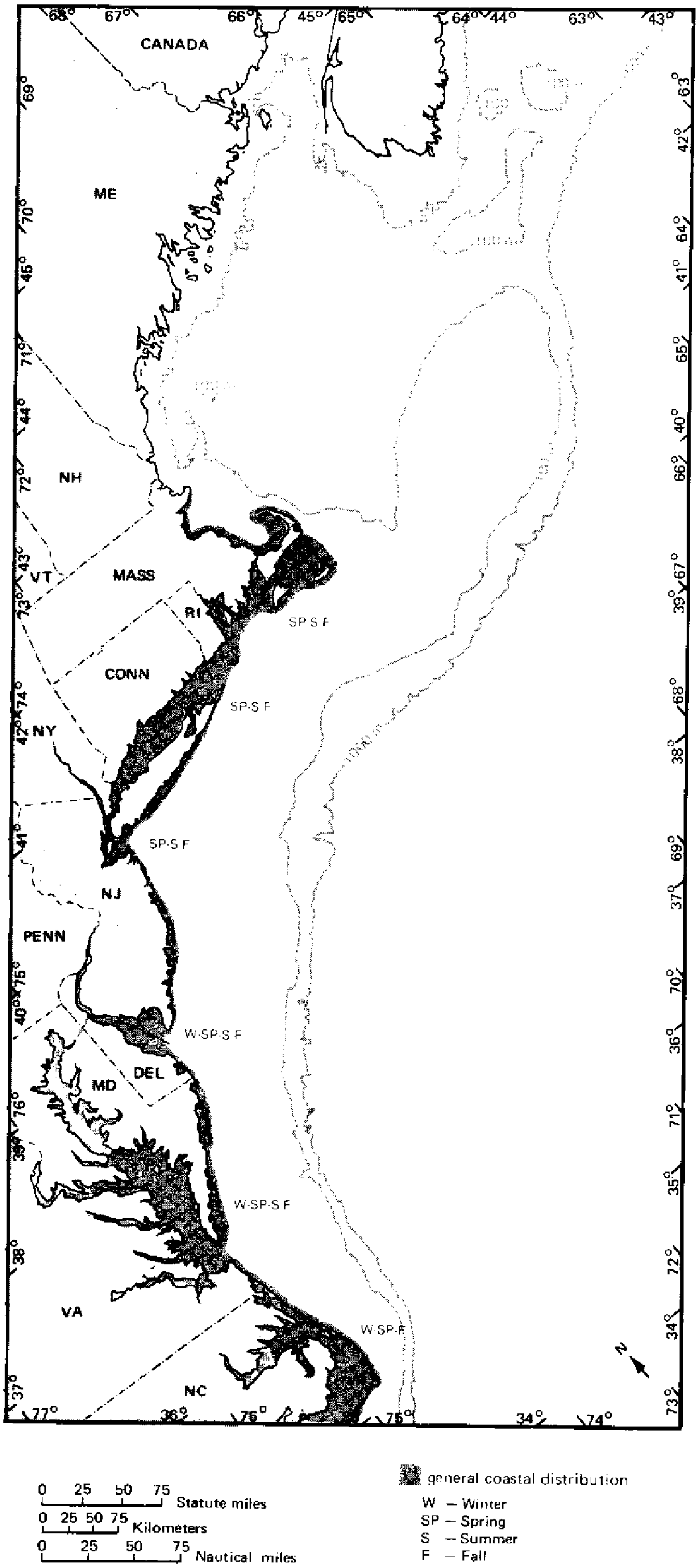
W.G. Smith



Distribution and Seasonal Movements. Striped bass occur naturally from Canada to northern Florida and in some rivers along the Gulf coast from western Florida to Louisiana. Their center of abundance lies between Cape Cod and Cape Hatteras. In addition to their natural range, striped bass occur along the Pacific coast from southern California to Washington, as a result of a stocking program during the late 1800s; limited success has been achieved in establishing naturally reproducing stocks in freshwater rivers, lakes, and reservoirs.

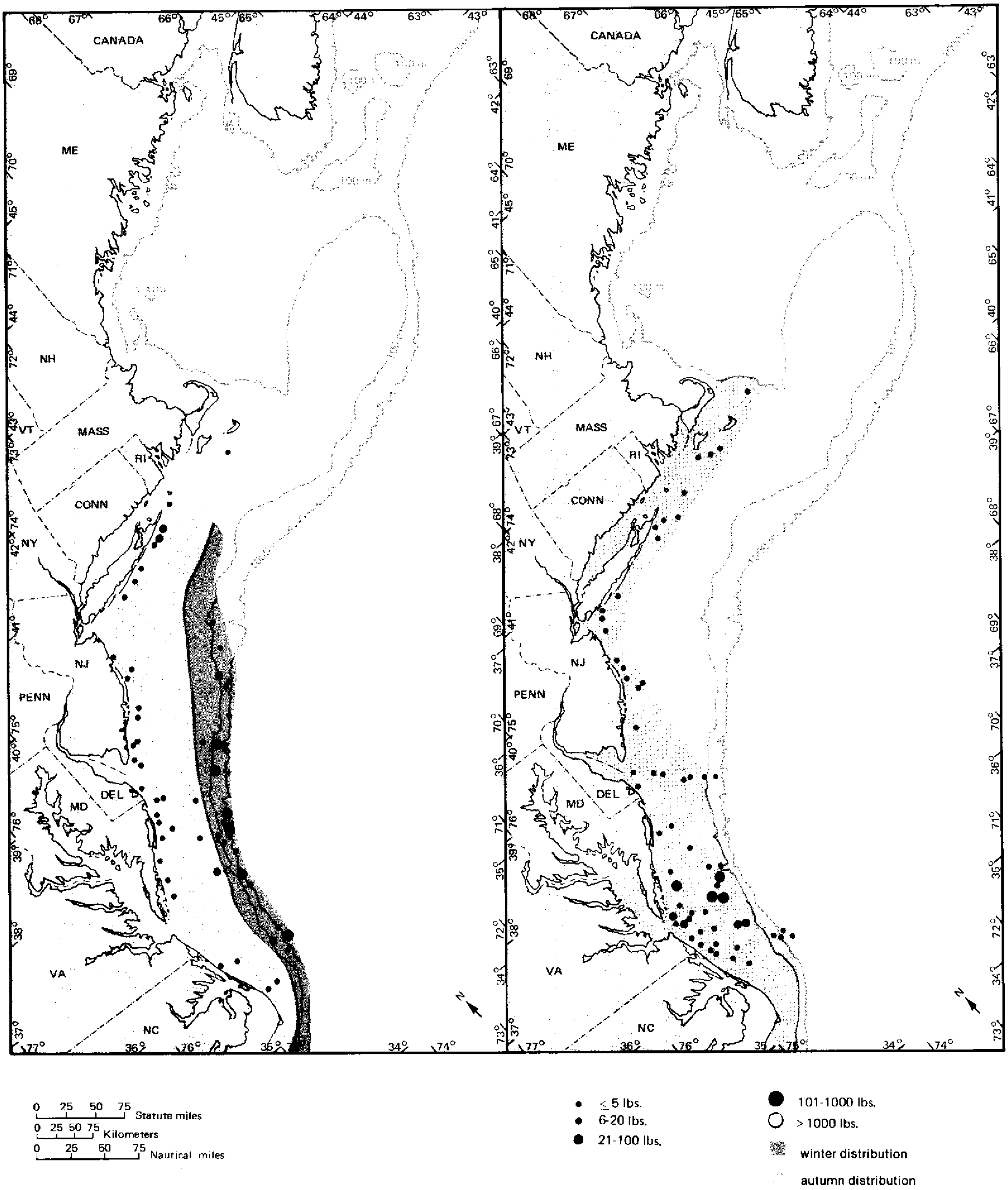
The migratory habits of striped bass vary from local

Map 35. Striped bass — distribution and spawning areas based on historical fishery records



Note: brown shading shows spawning areas

Map 36. Black sea bass — distribution of NMFS 1973-74 research vessel trawl catches (dots) and spawning areas (shading) (spring-left), autumn-right)



Note: brown shading shows spawning areas

seasonal movements within a home river system to extensive coastal migrations of several hundred miles. For example, in Canadian waters striped bass move only between bays and rivers emptying into the Gulf of St. Lawrence. South of Cape Hatteras and in the Gulf of Mexico bass remain in the home river for their entire life cycle. They move upstream in late winter and spring to spawn; in mid- to late summer they return downstream, where they remain until the next spawning season.

Along the mid-Atlantic and New England states the population structure of striped bass is more complex because there is some mixing of fish from the various spawning rivers during their seasonal migrations along the coast. Evidence indicates that part of the population of fish two or more years old leave the rivers in spring; others, and all of those less than two years old, remain in or near their home rivers. Those that leave, migrate northward where they spend the summer feeding along the ocean front and in adjacent bays and sounds from New Jersey to Maine. From mid-September through December they return southward; some pass the winter in their home river system, others in a different river or estuary, and still others in coastal waters from southern New Jersey to North Carolina (Map 35). Regardless of the extent of their coastal migrations, striped bass are seldom caught more than 7 to 9 km (4 to 5 mi) from shore.

Population Size and Fisheries. Striped bass were in short supply along the mid-Atlantic coast from about 1900 until 1933. In 1934 a large year-class turned the population decline around, and large year-classes have been observed at about six-year intervals since 1934 (Koo 1970). Their abundance has fluctuated since the late 1930s, but the supply has been adequate to support a significant commercial fishery and in recent years a very much larger recreational fishery (McHugh and Ginter 1978). Recreational fishermen from Maine to North Carolina caught an estimated 17,000 MT of bass in 1960 (Clark 1962), 25,700 MT in 1965 (Deuel and Clark 1968), and 33,200 MT in 1970 (Deuel 1973). In contrast, commercial landings were on the order of 5,000 MT from 1967 to 1973 (McHugh and Ginter 1978). Commercial landings in 1977 and 1978 were only about 2,400 and 1,800 MT respectively.

Reproduction, Growth, Life Span. Striped bass are anadromous. Their upriver spawning run varies from a few to more than 160 km (100 mi), depending on the river. Spawning grounds vary from sandy bottom, estuarine rivers to rocky, freshwater streams. Tributaries of Chesapeake Bay—the Potomac, James, and York rivers and several smaller rivers on the eastern shore of Maryland —are collectively considered major spawning grounds of striped bass. However, significant spawning occurs in tributaries of Albemarle Sound, the Chesapeake-Delaware Canal, the Hudson River, and occasionally in small rivers (Bigelow and Schroeder 1953; Merriman 1941; Freeman, personal communication). No spawning occurs in New York Bight oceanic waters.

Spawning takes place from January to June, depending on latitude, and is governed largely by water temperature. Between Cape Cod and Cape Hatteras spawning begins in March or April and continues through June when water temperatures are between 10° and 20°C (50° and 68°F). Peak spawning activity is at about 18°C (64°F). Eggs are nonadhesive and slightly heavier than fresh water. Successful spawning requires enough current to prevent the eggs from settling to bottom where they may be silted over and smothered.

The spawning population of the mid-Atlantic states is made up of males two years or older and 30 cm (12 in) and females four years or older and 45 cm (18 in). The number of mature ova in females varies by age, weight, and length; estimates range from 62,000 to 112,000 eggs per pound of body weight (Jackson and Tiller 1952). Older fish produce more eggs than younger fish. Striped bass eggs range in diameter from 2.4 to 3.9 mm (0.09 to 0.15 in), the average being 3.5 mm or 0.14 in (Mansueti 1958). They are spherical, with a single large oil globule. Eggs hatch in about 70 to 74 hours at 14° to 15°C (57° to 59°F). Newly hatched larvae are about 2.5 mm (0.09 in) long. They remain in fresh or slightly brackish water until they are about 12 to 15 mm or 0.5 to 0.6 in long (Bigelow and Schroeder 1953). At that time they move in small schools toward shallow, protected shorelines, where they remain until autumn. The young fish acquire the body shape of adults and their fins are fully developed when about 36 mm (1.4 in) long, but the characteristic longitudinal stripes do not appear until later (Pearson 1938).

In winter, young striped bass congregate in deep parts of their home river. During their second summer, or when a year old and about 13 cm (5 in) long, the young bass move from their parent stream to nursery gounds in low-salinity parts (◄3.2 ‰) of bays or sounds. Striped bass live mostly in small groups until they are two years old. Thereafter, and until they reach about 5 kg (10 lb), they often congregate in large schools. Bass up to 9 kg (20 lb) may also school, but large fish over 14 kg (30 lb) are usually found alone or in small groups, except when mating (Bigelow and Schroeder 1953).

Striped bass grow to great size and live 15 years or more. Several fish more than 45 kg (100 lb), and estimated to have been at least 1.8 m (6 ft) long, have been caught in North Carolina and Massachusetts. Both sexes grow at the same rate until three years old; thereafter the females grow faster and larger. Most bass over 14 kg (30 lb) are females (Mansueti 1961*a*).

Feeding Interrelationships. Bass are voracious feeders and consume a wide variety of fishes and invertebrates. Shad, river herring, and menhaden seem to be the most preferred prey fishes; crabs, shrimp, squid, clams, and other invertebrates are often included in the striper's diet

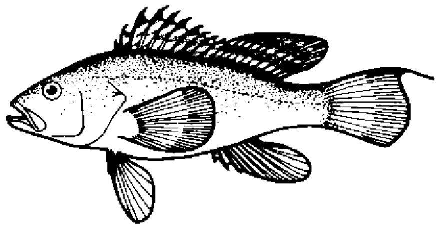
(Pearson 1938). When feeding on any particular prey, however, bass usually ignore other sorts of food (Bigelow and Schroeder 1953).

Environmental Sensitivity. Striped bass are hardy, adaptable fish, able to make the transition from saltwater to freshwater. Mansueti (1961*b*) suggested that their increased numbers during the 1940s and 1950s were related to man-induced organic enrichment. Although bass populations and civilization seem compatible, they are strongly dependent on estuaries, many of which show the heavy impact of man's activities. Dam construction has effectively eliminated a number of rivers as spawning grounds; particularly the Susquehanna (Koo 1970). In many coastal areas more than 50% of the original marshland and other shallow areas important to striped bass have been altered or destroyed through dredging, filling, or polluting (Clark 1967). Recently, the effects of egg and larval entrainment at nuclear power plants constructed near known spawning sites have become a major concern to those interested in the future of striped bass (Jensen 1970).

There are numerous studies on specific effects of heat and mechanical damage as well as effects of various pollutants on fish eggs and larvae including striped bass and there have been specific estimates of striped bass mortality at power plants (Campbell et al 1977; Koo and Johnston 1978). However, there is no specific evidence of widespread damage to the total striped bass population (or to any other anadromous species) which so far can be attributed directly to pollution (Sindermann 1976) or to power plants (Van Winkel 1977).

Black Sea Bass *Centropristis striata*

Arthur W. Kendall, Jr., and *Linda P. Mercer*



Distribution and Seasonal Movements. The black sea bass is the only resident member of the family Serranidae in New York Bight. Another member of this family, the rock sea bass, does occur in the southern part of the Middle Atlantic Bight (see Table 3). Within its range from Cape Cod to Cape Canaveral, FL (Miller 1959), there appear to be two populations of black sea bass, one north and one south of Cape Hatteras.

North of Cape Hatteras, black sea bass migrate seasonally, inshore and north in spring, offshore and south in autumn (Nichols and Breder 1927; Pearson 1932; Nesbit and Neville 1935; Lavenda 1949; June and Reintjes 1957; Frame and Pearce 1973). In the spring migration, adults move to their coastal spawning areas and juveniles to estuarine nursery areas. Spring and autumn trawl surveys in 1973 and 1974 showed that the major portion of the northern population lies south of Delaware Bay even in early autumn while water temperatures are still high (Map 36); this is consistent with the fact that since about 1965 the abundance of sea bass has been low in the Bight (McHugh and Ginter 1978). Spring surveys (March) show winter aggregations along the continental shelf edge (Map 36). Autumn surveys show a more inshore distribution, particularly north of Delaware Bay; however, the trawl surveys may not give an accurate representation of density distribution of the population because the research vessel avoids precisely the areas where sea bass tend to aggregate, namely, wrecks and rough bottom. Older and larger black sea bass (►20 cm or ►8 in) move offshore sooner than do young-of-the-year, and winter in deeper waters (73 to 165 m or 239 to 541 ft). Small black sea bass (8 to 12 cm or 3 to 5 in) winter in shallower areas of 56 to 110 m or 184 to 361 ft (Pearson 1932; Musick and Mercer 1975). Black sea bass may tolerate temperatures as low at 6°C (43°F) but are more abundant in waters 9°C (48°F) and above (Nesbit and Neville 1935; Musick and Mercer 1975).

South of Cape Hatteras black sea bass are resident in given areas year round (Moe 1966; Beaumarriage 1969; Cupka, Dias, and Tucker 1973). Lack of seasonal movements in the southern population is attributed to the temperature regime along the Carolina and Florida coasts. Water temperatures are usually no lower than 10°C (50°F) at any time during the year, except in shallow estuaries. In their southern range, black sea bass are generally associated with rough bottom, wrecks, and reefs.

Population Size and Fisheries. The size of the northern population in New York Bight, as reflected by commercial catch statistics, declined rather steadily from its peak levels in the early 1950s to its all time low levels in the early 1970s (McHugh and Ginter 1978). Commercial black sea bass landings for the entire Bight dropped sharply from about 4,000 MT per year in the early 1960s to less than 1,000 MT in 1971 and 1972. In the Bight, catch per unit effort in both the winter trawl fishery and the summer "pot" (baited traps on bottom) fishery, dropped drastically after 1965. However, the pot fishery south of Cape Hatteras showed an increase in catch per unit effort; total catch also increased because of recent development of the pot fishery off the Carolinas (Rivers 1966; Cupka et al 1973).

The recreational harvest is now thought to be larger than the commercial catch (McHugh and Ginter 1978). Increased sport fishing and foreign trawling probably contributed to higher sea bass mortality in recent years, and sea bass may be overharvested especially in the northern part of their range where fewer large and medium size fish were landed in the early 1970s. The relative importance of exploitation rate *vs* natural factors in controlling population size is not known. However, because most of the exploited black sea bass are males, heavy fishing pressure may cause the sex ratio of the population to so favor females that the number of remaining males may not be sufficient to sustain adequate reproduction.

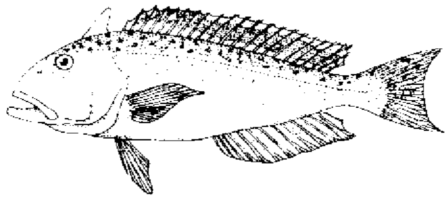
Reproduction, Growth, Life Span. Black sea bass begin life as females and transform into males but the sex of individuals remains functionally distinct at all times (Lavenda 1949). This is substantiated by the presence of regressing ovarian tissue in mature testes and developing testicular elements within the ovaries of functional females. The size range and age over which sex reversal takes place are highly variable. Only part of the population reverses sex during a given time interval. Females as large as 35 mm (1.4 in) SL and identifiable males as small as 13 cm (0.5 in) SL have been found. Most black sea bass undergo sex reversal in the size range from 15 to 24 cm (6 to 9 in) SL — an age range of two to five years. Sex reversal takes place in autumn after spawning. Females are more abundant than males because they predominate in small size and young age classes (◄24 cm or ◄9 in SL); males predominate in the range from 26 to 35 cm (10 to 14 in) SL and five to eight years (Dias 1971; Cupka et al 1973). Black sea bass mature between one and four years of age. Cupka and associates (1973) found that the smallest mature male examined measured 139 mm (5 in) SL, and the smallest mature female, 160 mm (6 in) SL. Mature males and females in each age group are larger than immature specimens in the same age group.

The northern population of black sea bass spawns during summer primarily between Chesapeake Bay and Montauk in waters 18 to 45 m (59 to 148 ft) deep (Musick and Mercer 1975). Spawning off Virginia and Maryland probably begins in June and peaks in July; to the north it begins and peaks progressively later (Perlmutter 1939; Pearson 1941; Herman 1963; Kendall 1972). Black sea bass eggs have not been identified in field samples, although laboratory studies show them to be planktonic (Hoff 1970). The planktonic larval stage is quite short. Young sea bass become demersal between 13 and 24 mm (0.5 and 0.9 in) TL and use saline areas of estuaries from Florida to Massachusetts as nursery grounds (Kendall 1972).

Feeding Interrelationships. Black sea bass are generalized predators, feeding on crustaceans, fish, and molluscs (Hildebrand and Schroeder 1928; Miller 1959; Cupka et al 1973). According to Hildebrand and Schroeder (1928), adults feed on crabs and fishes; young fish feed on shrimp, isopods, and amphipods. Young sea bass less than 14.6 cm (5.8 in) are bottom feeders in the shallows, and eat very few fish (Kimmel 1973). More than half the food of younger fish (25 to 100 mm or 1 to 4 in) consisted of mysids, whereas larger fish (100 to 150 mm or 4 to 6 in) fed mostly on crabs. Some grazing activity is indicated since sea bass stomachs contain barnacles and other attached organisms such as colonial tunicates. This type of feeding appears to be far more prevalent in adult than in juvenile fish (Cupka et al 1973). Feeding apparently decreases in autumn and during the spawning season (Hoff 1970; Cupka et al 1973).

Tilefish *Lopholatilus chamaeleonticeps*

Bruce L. Freeman and *Stephen C. Turner*



Distribution and Seasonal Movements. The tilefish, a large bottom-dwelling fish, occurs along the outer part of the continental shelf and the upper part of the continental slope from Nova Scotia south to Florida, along the Gulf of Mexico to Campeche Bank, and off Venezuela, Guyana, and Surinam in South America (Bigelow and Schroeder 1953; Leim and Scott 1966; Wolf and Rathjen 1974; Wolf 1974; Dooley 1978; Freeman and Walford 1974, 1976; Freeman and Turner 1977). Tilefish is restricted to a relatively narrow band of the shelf, in most places less than 32 km (17 nmi) wide, that ranges in depth from about 75 to 460 m (245 to 1,500 ft). In both the northern and southern extremes of its range it occurs mostly in depths of 140 to 310 m (460 to 1,015 ft), and in the Middle Atlantic Bight it is concentrated in depths of approximately 110 to 240 m or 360 to 790 ft (see Map 37) where the annual temperature range is only from 9.4° to 14.4°C or 49° to 58°F (Freeman and Turner 1977; Bowman and Wunderlich 1977).

Tilefish do not appear to migrate extensively. The location of fishing grounds remains consistent throughout the year and from year to year. Several fish inadvertently "tagged" when hooks and short lengths of line that had broken off fishermen's gear were recaptured several months later. The tagged fish remained in the same area or moved only a few miles away from the original site (Freeman and Turner 1977). Also, the fact that the species was slow to reappear in New York Bight after a catastrophic fish kill in the late 1800s suggests that repopulation of the area was almost entirely by local reproduction and not by migration from other areas (Bigelow and Schroeder 1953).

Observations from submarines indicate that tilefish are closely associated with holes in the bottom and appear to be especially abundant in the vicinity of submarine canyons. They usually occur in clusters, occupying holes or burrows in the clay walls of steep canyon sides, or among boulders near the heads of canyons (Uzmann et al 1977*b*). Other fish and invertebrates also occupy and compete for various size burrows in the canyon walls and this community has been described as similar to the Pueblo Indian villages (Cooper and Uzmann 1977; Warme, Cooper, and Slater 1978; see Figure 3).

Population Size and Fisheries. Based on fishing accounts in the early 1900s, it is estimated that there was a potential sustainable catch of 900 to 1,400 MT a year off southern New England, New York, and New Jersey (Bigelow and Schroeder 1953). Accurate estimates of the size of the tilefish populations have not yet been made, but an examination of the landings from 1915 to 1977 reveals that catches of 450 MT or more were maintained 34 of the last 63 years (Freeman and Turner 1977).

Since its beginning in 1915 the commercial fishery has fluctuated widely in relation to market conditions, and it was very low during both major war periods. Landings reached their all time high of 4,500 MT in 1916, just one year after the fishery was first initiated after a massive governmental publicity campaign (Freeman and Turner 1977). However, landings dropped to only 5 MT by 1920, then increased abruptly to 523 MT in 1921, and from 1922 to 1933 fluctuated between 500 to 1,000 MT except for 1929 and 1930 when 2,095 and 1,858 MT respectively were reported (Freeman and Tarner 1976). Landings then declined drastically again to a low of 8 MT in 1943, followed by a rapid return to nearly 500 MT in 1948 and reaching 1,600 MT in 1954 and 1955, the peak levels during the otter trawl fishery. By 1968 landings had declined again to only 32 MT and then began another steady increase reaching the 1,000 MT level by 1976 (Freeman and Turner 1976), and just over 2,000 MT in 1977 (Turner, personal communication). This recent increase is due largely to a rejuvenation of longlining out of NJ ports.

Since 1969 there has been a steadily increasing rod and reel recreational fishery for tilefish by large party and charter boats (Freeman and Turner 1977). However, the recreational catch is still small (10 to 340 MT) relative to the commercial catch. A brief summary of the tilefish fishery since 1960 in the states bordering New York Bight is presented by McHugh and Ginter (1978).

Reproduction, Growth, Life Span. Females are believed to reach first maturity at about age eight, at a length of about 70 cm (28 in) and a weight of 5 kg (11 lb). Females of this size generally produce from 2.5 to 5 million eggs (Morse, personal communication). A 9 kg (20 lb) female measuring 84 cm (33 in) produces from 4.5 to 9 million eggs; one of 14 kg (30 lb) measuring 95 cm (37 in), 7 to 14 million; and a large female of 16 kg (35 lb) measuring 100 cm (39 in), 8 to 16 million eggs.

From 1972 to 1974 running ripe females were observed March to September, indicating a prolonged spawning season (Freeman and Turner 1977). During 1966 tilefish larvae were found between June and October; eggs probably were in the 1966 collections but have not been identified (see Table 6). An individual female probably spawns several times during each spawning season, as indicated by several sizes of developing eggs in the ovary (Morse, personal communication). The spherical egg is about 1.2 mm (0.05 in) in diameter, with a single oil globule; it is nonadhesive, positively buoyant, and pelagic. The incubation period of the eggs probably depends on water temperature as is true for other fishes. Hatching occurred in 40 hours at about 23.4°C (74.1°F) in the only known case of successful artificial fertilization (Fahay, personal communication).

Estimates of tilefish growth rate are preliminary because an accurate aging procedure has not yet been established. Length of fish for any given year-class varies widely, probably because of the prolonged spawning season. One-year-old tilefish average about 10 cm (4 in) long (Bigelow and Schroeder 1953). At age eight they are believed to reach an average length of approximately 70 cm (28 in). The largest tilefish on record was 125 cm (4 ft) and 27 kg (59 lb), and may have been more than 20 years old (Freeman and Turner 1977).

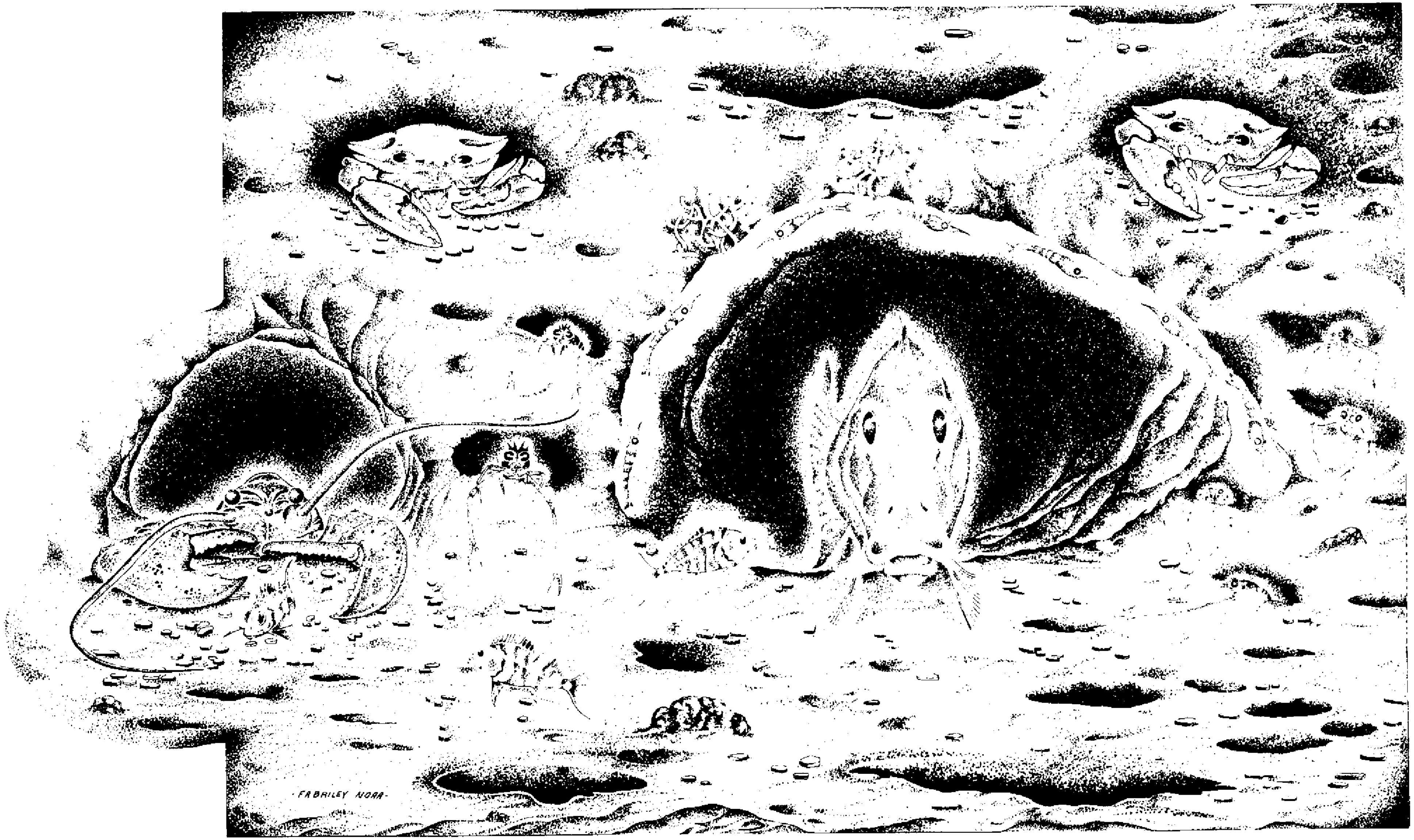
Feeding Interrelationships. Tilefish are equipped with strong, sharp, tearing teeth as well as several sets of crushing teeth, making them capable of seizing and devouring a variety of prey. They feed mostly on crustaceans but also on a great variety of other invertebrates and fishes that occur on or near the bottom. Among food items that have been identified are squat lobster (Galatheid crabs), other crabs, bivalve molluscs, echinoderms, annelid worms, sea cucumbers, anemones, tunicates, sea urchins, American lobster, shrimps, squids, and fishes (Collins 1884; Linton 1901*a,b*; Bigelow and Schroeder 1953). The occurrence of Atlantic mackerel, sea herring, and offshore hake (some as large as 1 kg or 2.2 lb) in the stomachs of tilefish indicates that they are quite capable of chasing and catching actively swimming fishes (Freeman and Turner 1977). Judging from hook and line catches, tilefish are daytime feeders, and most of the feeding is close to the bottom.

Small tilefish are sometimes preyed upon by spiny dogfish and conger eels, and have been observed in stomachs of larger tilefish (Freeman and Turner 1977). It is possible that large sharks may prey upon free swimming tilefish since sharks often attack tilefish that have been hooked on longlines set along the bottom (Bigelow and Schroeder 1953; Freeman and Turner 1977).

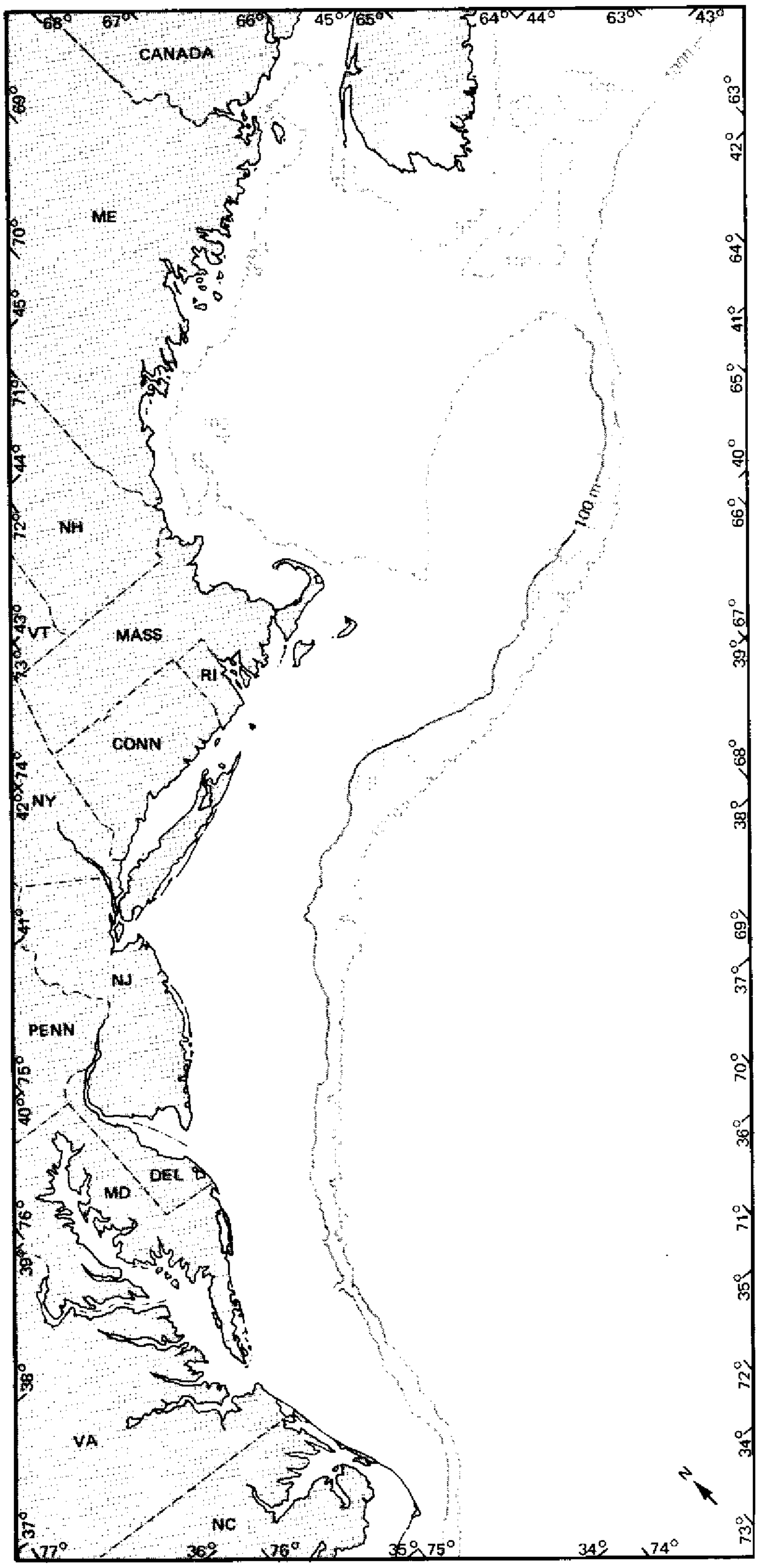
Environmental Sensitivity. In early spring, 1882, several vessels sailing offshore reported seeing great numbers of dead or dying fish floating at the surface of the sea between the latitudes of Cape May and Montauk Point. Many of the fish were tilefish, an estimated 500 million of them (Collins 1884). The mass mortality of tilefish of the Middle Atlantic Bight was so complete that exploratory fishing trips over the succeeding five years failed to catch a single specimen, and scientists considered the tilefish to have become extinct (Lucas 1891). But 11 years after the disaster, several specimens were caught, and within 16 years tilefish were once again becoming abundant (Bumpus 1899).

It is believed that this mass mortality of tilefish, as

Figure 3. Pueblo Village community, Veatch Canyon, at 200 m.



Map 37. Tilefish — distribution and spawning areas based on historical fishery records

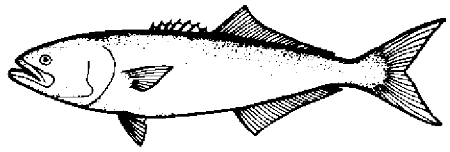


Note: blue shading shows distribution and spawning areas

well as other species of fishes and invertebrates, was due to a displacement of the narrow band of warm water lying along the edge of the continental shelf by unusually cold water. The warm water band is bordered not only on its inshore edge by cold water but on its offshore edge as well. The cold bottom waters probably shifted from inshore to the edge of the shelf and beyond causing a sudden lowering of the temperature within the warm band, trapping the fishes living there and killing them (Verrill 1882*b*). Although temperatures were not recorded during the mass mortality, those taken the following summer showed the bottom waters to be considerably colder than in previous years, and the rich warm water fauna which normally lived there was absent. It had been partially replaced by some cold-water forms (Verrill 1882*b*). Had the cold, shelf water only destroyed the invertebrates living along the sea floor during 1882, eventually it still might have resulted in a very large mortality of tilefish, for they feed mostly on species occurring within the warm band of water.

Bluefish *Pomatomus saltatrix*

Stuart J. Wilk

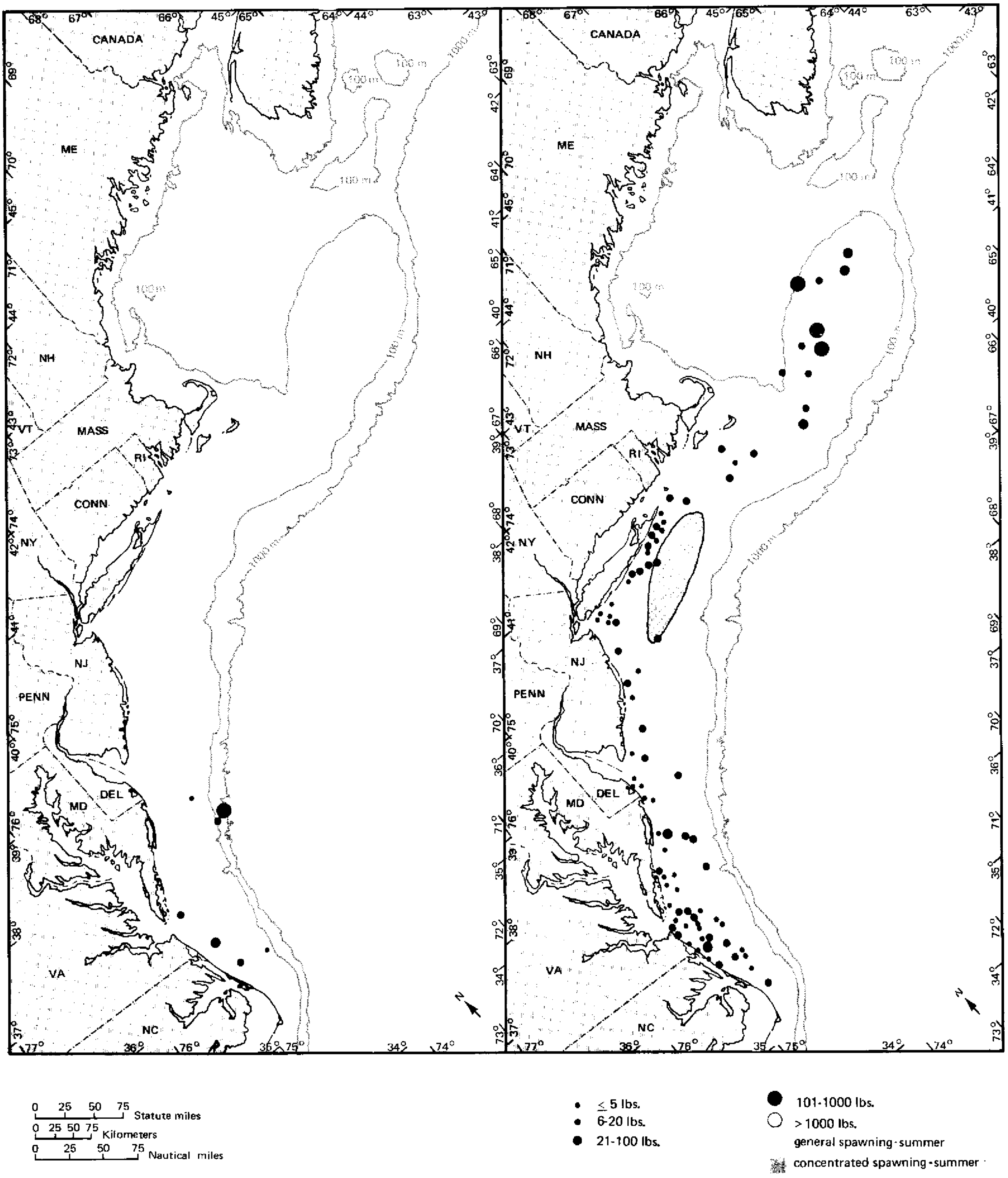


Distribution and Seasonal Movements. Bluefish of the world are generally referred to as a single species. It is the only member of its family, Pomatomidae, closely related to the family Carangidae that contains the jacks and pompanos (Jordan and Evermann 1896-1900; Bigelow and Schroeder 1953).

The bluefish occurs worldwide in temperate and warm temperate zones, generally in continental shelf waters, and it has been recorded from the Atlantic, Indian, and Pacific oceans (Briggs 1960). Our knowledge of bluefish distribution along the Atlantic coast depends almost entirely on nearshore commercial and recreational catches supplemented by bottom trawl catches by research vessels, collections taken in beach seines, and distribution of young stages taken in plankton nets and midwater trawls. Most of our knowledge is limited to that part of their lives spent in coastal and estuarine waters. However, their distribution is evidently much wider and extends farther out on the continental shelf, as indicated by the absence of both small and large individuals during winter in south Atlantic waters, and by sporadic catches made by offshore otter trawlers. Since the mid-1970s research vessels have caught unusual numbers in offshore waters of the mid-Atlantic and Georges Bank areas.

The bluefish is a migratory pelagic species, generally traveling in groups of like-size fish, the groups are loosely associated in much larger aggregations that may extend over tens of square kilometers along the coast. Aggrega-

Map 38. Bluefish — distribution of NMFS 1973-74 research vessel trawl catches (dots) and spawning areas (shading) (spring-left, autumn-right)



tions travel seasonally, generally north in spring and summer, south in autumn and winter. This is illustrated by NMFS spring and autumn trawl surveys (Map 38). Their movements are probably directed by several features of environment, of which temperature and photoperiod are the most important (Olla and Studholme 1971, 1972). On the Atlantic coast bluefish visit some sections of the coast a few weeks at most, enroute to the summering or wintering grounds. These grounds center, during summer, in New York Bight and southern New England, and in the northern section of North Carolina, and during winter, in the southeastern portion of Florida.

Population Size and Fisheries. Commercial fishermen in New York Bight take bluefish with gill nets, haul seines, pound nets, hook and lines, otter trawls, and purse seines; in past years they also took them with fyke and hoop nets. From 1950 to 1970, commercial catches in New York Bight (New York and New Jersey) ranged between 90 and 1,220 MT per year with an average of 635 MT per year. Commercial landings increased to over 2,000 MT 1973-75 (McHugh and Ginter 1978).

Bluefish is one of the most important recreational species in the Bight and the sport catch far exceeds the commercial catch. It provides both sport and food for people fishing the bays and sounds, along ocean beaches, and as far over the continental shelf as they care to go. Anglers take bluefish from boats while trolling, casting, live-bait fishing, jigging, and chumming. It is unlikely that any other species could completely replace it were it to disappear (Freeman and Walford 1974).

Although bluefish have been important to anglers for the last century and a half, only during the last decade or so have catch estimates been made. During 1960 the mid-Atlantic anglers' catch reached an estimated 11,000 MT and ranked sixth in weight among all species caught in the United States (Clark 1962). During 1965 it dropped to 6,800 MT, but bluefish ranked second in weight among all species (Deuel and Clark 1968). According to Deuel (1973) about 23,000 MT were taken in 1970 by anglers in the Bight, and bluefish was the number one recreational species caught in the United States (54,000 MT).

Reproduction, Growth, Life Span. Bluefish first become sexually mature at age two. Lassiter (1962) found that a bluefish 53 cm (21 in) long contained about 900,000 maturing eggs; one 58 cm (23 in) long contained about 1.1 million eggs.

Fertilized bluefish eggs are spherical, 0.9 to 1.2 mm (0.03 to 0.05 in) in diameter and contain an oil globule which ranges from 0.22 to 0.30 mm or 0.008 to 0.01 in (Deuel, Clark, and Mansueti 1966). The egg capsule is transparent, colorless, with a thin but tough membrane, a pale amber yolk and a deep amber, single large oil globule. Incubation takes approximately 48 hours at 20° to 21°C (68° to 70°F). Bluefish larvae are between 2.0 and 2.2 mm (0.08 and 0.09 in) at hatching and metamorphose at 20 to 25 mm (0.79 to 0.98 in).

The early life history of bluefish, derived from systematic collections over the Atlantic shelf, as well as from literature, presents a complex pattern (Kendall, personal communication). There appear to be two major areas and seasons of spawning along the US east coast: one offshore near the inner edge of the Gulf Stream from southern Florida to North Carolina in the spring, chiefly in April and May; the other in the Middle Atlantic Bight in summer, chiefly June through August (Maps 38 and 15). Spawning of both groups probably proceeds in waves (Kendall, personal communication).

Young bluefish spawned in spring spend their first summer in estuaries of the Bight, mostly between Cape May and eastern Long Island. Bluefish spawned in summer apparently remain at sea and migrate south of Cape Hatteras in early autumn when they are about 50 to 75 mm (2 to 3 in) long, and spend the winter offshore, appearing in spring mostly in North Carolina sounds.

Growth of young fish in the two principal nursery areas — Middle Atlantic Bight and North Carolina sounds — is indicated by progression of average lengths of fish sampled from early summer through autumn. The fish of the smallest size class arriving in the Bight in early summer (average length about 25 to 30 mm or 0.9 to 1.1 in) grow to be about 200 mm (8 in) long by the time they disappear in autumn. During this time no age mark develops on their scales. These are fish spawned in southern waters in the spring. Fish of the dominant size class arriving in the North Carolina sounds in the spring (modal fork length about 230 mm or 9 in) form an age mark on their scales in May; they remain in the sounds through summer and at the time they disappear in autumn, they average about 290 to 300 mm (11 to 12 in). These are fish that had been spawned in the summer of the previous year in northern waters. Some of the spring spawned fish also enter the North Carolina sounds in summer. These do not form the first age mark on their scales until the following spring.

The average fork lengths for bluefish of age groups one through eight based on over 15,000 age determinations from scale readings of samples collected from Rhode Island to Florida between 1963 and 1968, are presented in Table 11.

Feeding Interrelationships. Bluefish feed throughout the water column on a large variety of fishes and invertebrates. Among the fishes most frequently observed in the stomachs of specimens examined from New York Bight are butterfish, round herring, sand lance, menhaden, silverside, mackerel, and anchovy. Among the invertebrates are shrimp, squids, crabs, mysids, and annelid worms.

Feeding studies have shown that although bluefish are responsive to olfactory stimuli, they rely primarily on vision to locate and capture prey. The size of prey is an im-

Table 11. Length at age for Bluefish

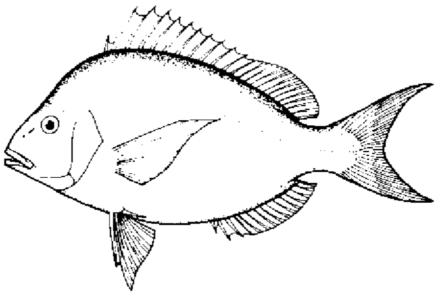
Age	Length in cm (in)
1	22 (9)
2	35 (14)
3	46 (18)
4	55 (22)
5	62 (24)
6	68 (27)
7	72 (28)
8	76 (30)

portant factor in feeding motivation. Bluefish, apparently satiated on small baitfish, can be stimulated to resume feeding when they are offered larger ones of the same species (Olla, Katz, and Studholme 1970).

Only the higher predators, pelagic sharks, tunas, and billfishes pose a predatory threat to the fast-swimming bluefish (Wilk 1977).

Scup *Stenotomus chrysops*

W. Morse



Distribution and Seasonal Movements. Scup (also called porgy) is a continental shelf species occurring primarily in the area from Cape Hatteras to Cape Cod. Extensive seasonal migrations are made from inshore summer grounds to offshore winter grounds (Map 39). In April scup arrive off Chesapeake Bay and by early May, off southern New England, New York, and New Jersey. Large fish (0.7 to 1.5 kg or 2 to 4 lb) often appear first, followed by smaller fish about a week later. During summer, fish about four years old and older tend to stay in nearshore ocean waters or near the mouths of large bays. Younger fish are found within bays and sounds and tend to inhabit the more saline waters of these estuaries.

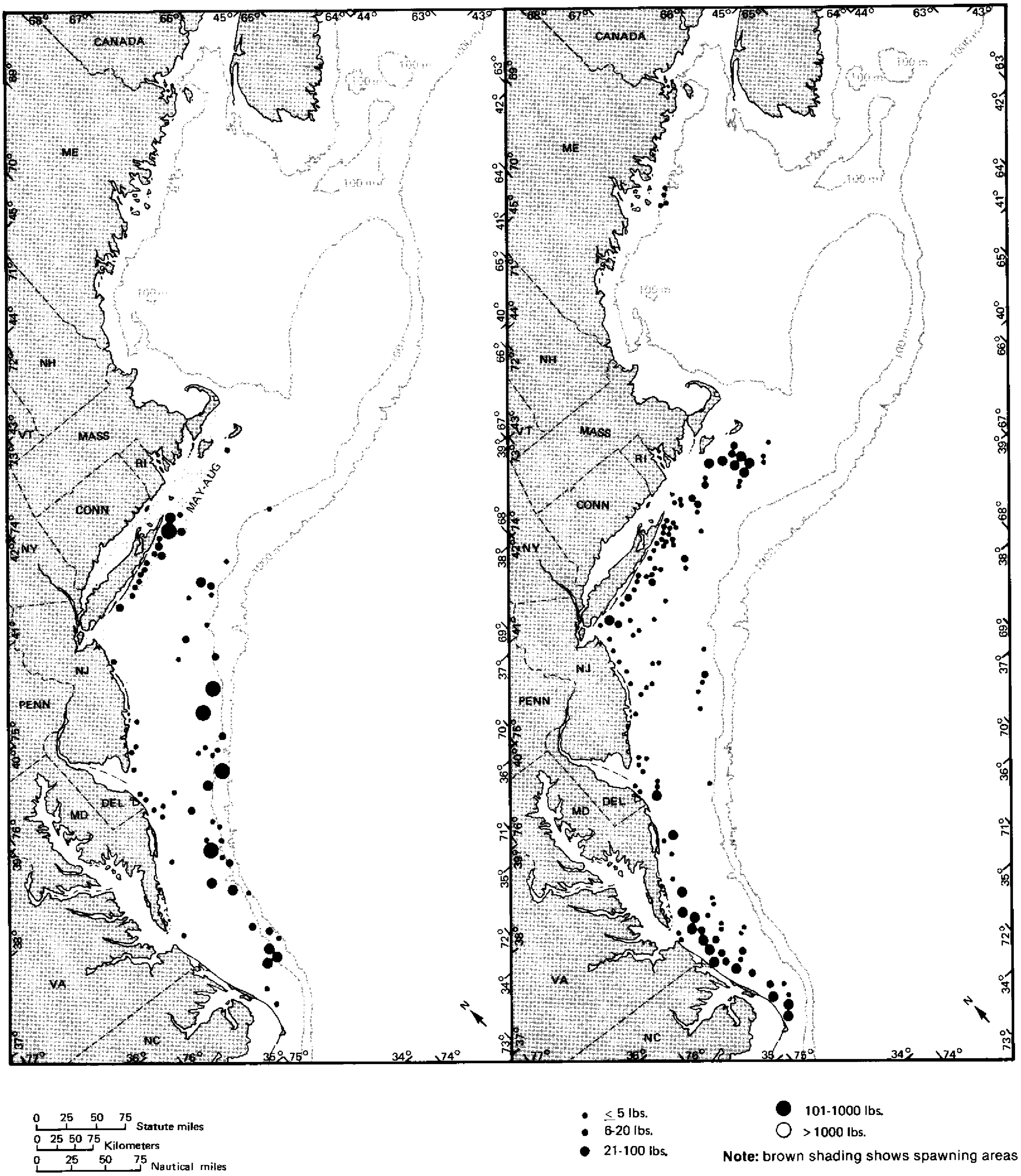
At the time of the autumn 1973-74 mid-Atlantic trawl surveys (late September-early October) scup were still largely inshore (Map 39). Later in October and November they migrated offshore to winter grounds and by the end of November they were absent from inshore waters. A few stragglers may be found near shore in November in some years even as far north as the Gulf of Maine. Winter distribution is generally from about New Jersey to Cape Hatteras in waters 37 to 146 m (120 to 480 ft) deep. Year-to-year differences in winter distribution are primarily determined by the location and extent of bottom water temperatures warmer than 7°C (45°F), the lower limit of temperature tolerance for scup (Neville and Talbot 1964). Offshore trawl surveys March 1973 and 1974 found scup still in fairly deep waters, but some were found close to shore in the April 1974 inshore survey. As waters warm in April and May, the inshore migration to the summer spawning and feeding grounds begins. It is not yet clear whether there is one homogeneous population of scup in the mid-Atlantic or whether there are separate stocks. From tagging and finray count studies (meristic) north of Delaware Bay, Hamer (1970) suggested there may be distinct subpopulations occupying the southern New England and New Jersey areas in summer. In summer and autumn the scup found off Chesapeake are largely immature.

Population Size and Fisheries. Commercial landings statistics show historical fluctuations in scup population size. In 1947 about 8,626 MT of scup were landed in the United States and by 1960, 22,246 MT, but in just 10 years (1970), the US landings dropped to 1,816 MT. In the past, population instability was caused by environmental and biological factors resulting in comparatively low reproduction (Neville and Talbot 1964). Both poor spawning success and fishing pressure, including foreign and domestic harvesting of marketable fish (McHugh and Ginter 1978), and the destruction of unmarketable size fish, probably contributed to the dramatic reduction of the scup resource from the early 1960s to the early 1970s (Neville and Talbot 1964). An increase in landings since 1970 indicates resurgence of scup, but it has not reached its former abundance as an important food fish in New York Bight (McHugh and Ginter 1978).

Tagging and meristic studies on scup found north of Delaware Bay indicate there may be at least two subpopulations of scup: one centering during summer in southern New England, the other in New Jersey (Hamer 1970). Results of the tagging show that the migratory patterns of the southern New England stock and New Jersey stock are similar but that the southern New England stock winters north of the New Jersey stock. NMFS spring trawl surveys suggest there may be some intermingling of the two stocks on the offshore winter grounds (Map 39).

Reproduction, Growth, Life Span. Scup spawn from about May through August; peak spawning is during June, which coincides with arrival inshore in spring of migrating fish. The principal spawning areas are LI and NJ estuaries, including Sandy Hook, lower New York bays, and eastern Long Island bays (Nichols and Breder 1927; Perlmutter 1939; Finkelstein 1969*a*). Spawning also oc-

Map 39. Scup — distribution of NMFS 1973-74 research vessel trawl catches (dots) and spawning areas (shading) (spring-left, autumn-right)



curs in nearshore ocean waters, Long Island Sound, and Narragansett Bay (Wheatland 1956). Since scup eggs and larvae are not reported south of New Jersey it is unlikely spawning in that area contributes significantly to the population.

Scup eggs are buoyant, spherical, and contain a single oil globule. The rather small egg (0.85 to 1.15 mm or 0.03 to 0.04 in diameter) hatches in about 40 hours at 22°C (72°F). Newly hatched larvae are pelagic and approximately 2 mm (0.08 in) long. In three days the yolk is absorbed, and at a length of 10 mm (0.4 in) pigmentation appears and fins are differentiated in the larvae. At a length of 25 mm (1 in) diagnostic characters of the species are evident and shortly afterward the larvae abandon the pelagic phase and become bottom dwelling. They assume the adult's basic shape at about 40 to 60 mm or 1.6 to 2.3 in (Kuntz and Radcliffe 1918).

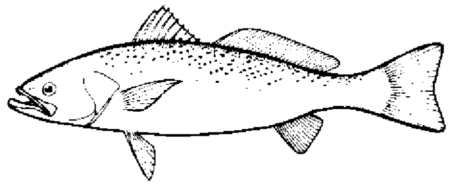
Juveniles from 50 to 80 mm (2 to 3 in) are common during September; by November they are 60 to 100 mm (2 to 4 in) long. Growth is slow during winter; fish have reached only 100 to 115 mm (4 to 5 in) in length by spring. During the first three years, however, scup will grow to about 60% of their expected maximum size. At age one they average 106 mm (4 in) long, at two, 160 mm (6 in) long, and at three, 204 mm (8 in) long. Scup may live 15 years and reach a length of about 37 cm (15 in) and weigh 1.5 kg or 4 lb (Finkelstein 1969*b*).

Scup females and males reach sexual maturity at age two. Eggs taken from ripe fish are from 0.66 to 0.95 mm (0.03 to 0.04 in) in diameter, the same as fertilized eggs collected in plankton (Finkelstein 1969*b*).

Feeding Interrelationships. Scup are bottom feeders, consuming small crustaceans, worms, molluscs, and quantities of vegetable debris (Bigelow and Schroeder 1953). Maurer and Bowman (1975) gave the following breakdown of stomach contents on a percentage weight basis: coelenterates (21%), polychaetes (32%), crustaceans (9%), molluscs (8%), unidentified animal remains (27%), miscellaneous (2%). Scup are eaten by piscivorous fishes throughout their range, and man is probably the principal predator of adult fish.

Weakfish *Cynoscion regalis*

Stuart J. Wilk



Distribution and Seasonal Movements. The weakfish is one of more than 20 members of the family Sciaenidae found along the US Atlantic and Gulf coasts. This group is commonly known as drum fishes because most species produce drumming or croaking sounds by vibrating their swim bladders with specialized muscles.

Weakfish occur along the US east coast from southern Florida to Massachusetts Bay, straying northward occasionally to Nova Scotia (Bigelow and Schroeder 1953; Leim and Scott 1966). Although most of our knowledge is limited to that part of their lives spent in coastal and estuarine waters, weakfish distribution is probably much wider and extends farther out on the continental shelf than has been generally believed (Pearson 1932; Bigelow and Schroeder 1953). Occasional catches have been made in offshore waters on NMFS spring trawl surveys (Map 40).

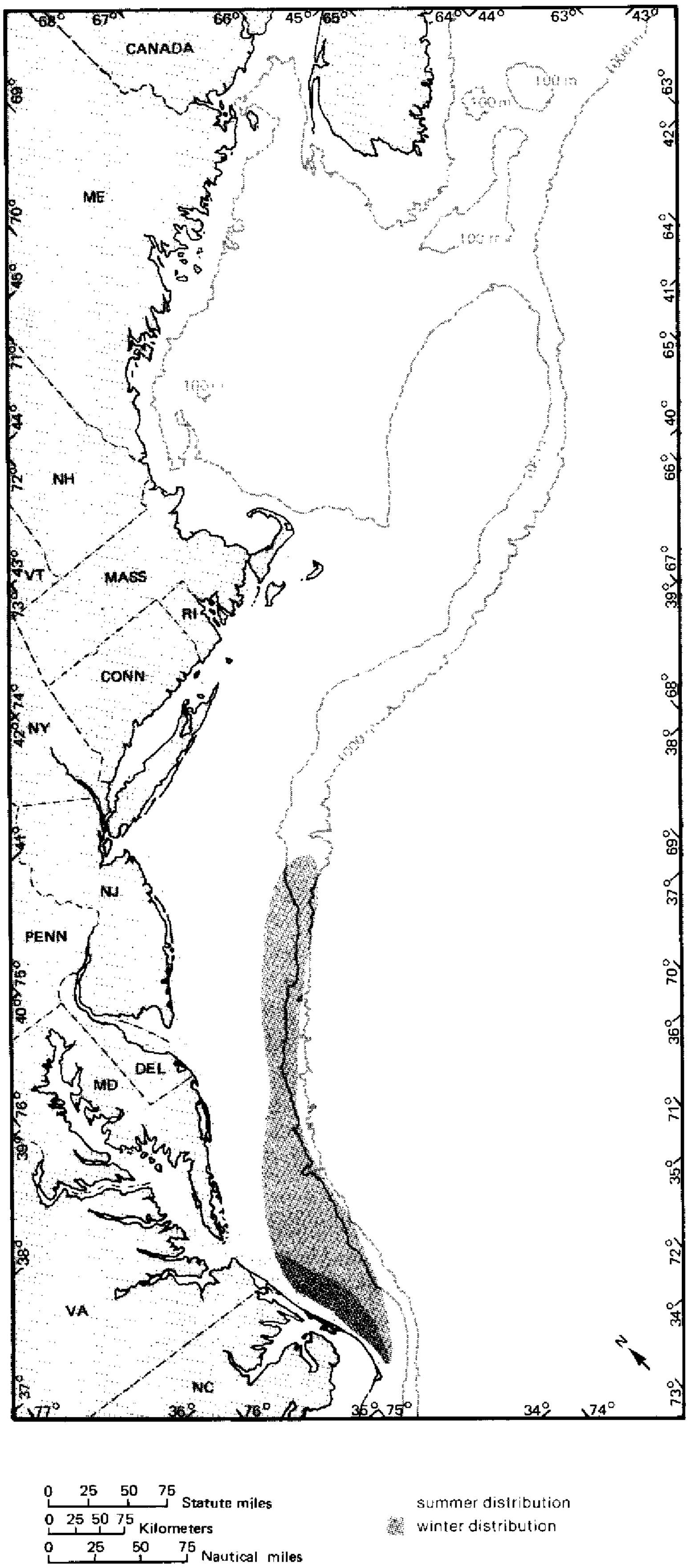
Weakfish younger than age four migrate south along the coast in autumn and winter, some as far as Florida, and north in spring and summer (Wilk 1976; Wilk and Silverman 1976). Fish older than age four move offshore and south in autumn, probably no farther than North Carolina, then return to their inshore northern grounds with the advent of spring warming. Larger fish, some over 5 kg (12 lb), move fastest and travel farthest; they tend to congregate in the northern part of their range.

Population Size and Fisheries. The possibility of two or even three distinct populations of weakfish has been postulated, but evidence is only suggestive. Statistical studies of ova diameters, scale peculiarities, counts of gill rakers, fin rays, and vertebrae; and various measurements along the body are highly suggestive but only marginally significant (Welsh and Breder 1923; Hildebrand and Cable 1934; Perlmutter 1939; Nesbit 1954; Daiber 1954; Perlmutter, Miller, and Poole 1956; and Sequin 1959). Limited tagging studies by the US Fish and Wildlife Service from 1931 to 1938 demonstrated that mixing occurs and that it is variable through time, but there was no clear delineation of subpopulations (Nesbit 1954).

Very little is known of factors affecting population size, recruitment, and mortality of the weakfish. Historical commercial catch records indicate considerable fluctuations in abundance which are probably due to natural variations in recruitment of young fish to the adult stock. However, there has been a general decline in abundance from about 1910 to the late 1960s when it reached an all time low; since 1970 abundance has begun to increase again (McHugh and Ginter 1978).

Commercial fishermen take weakfish with gill nets, haul seines, pound nets, hook and line, otter trawls, and trammel nets; they used to take them with fyke and hoop nets also. Anglers take weakfish from boats and shore by trolling, chumming, casting, live-bait fishing, jigging, still fishing, and drift fishing. In 1970 over 500,000 anglers caught 10 million fish weighing nearly 7,000 MT in the Bight area — New Jersey to North Carolina (Deuel 1973). The 1970 commercial catch from the same area was approximately 3,000 MT but increased to more than 7,000 MT by 1975 (McHugh and Ginter 1978). Comparison of

Map 40. Weakfish — general distribution from NMFS research vessel surveys



1960, 1965, and 1970 commercial and sport catch estimates suggests that recreational and commercial catches are about equal (McHugh and Ginter 1978).

Reproduction, Growth, Life Span. Both male and female weakfish become sexually mature between one and two years of age, the majority at age one (Merriner 1973). The number of eggs produced is a function of size. A weakfish 280 mm (11 in) long contained approximately 286,000 mature eggs; one 546 mm (21 in) long contained approximately 1.7 million eggs.

Spawning occurs in nearshore and estuarine zones along the coast from May to October and peaks during May and June for most fish (Welsh and Breder 1923; Bigelow and Schroeder 1953). The eggs are spherical, buoyant, about 0.87 to 0.99 mm (0.03 to 0.04 in) in diameter, with one or more oil globules; they hatch in 48 hours or less at 20° to 21°C (68° to 70°F). Newly hatched larvae are 1.75 mm (0.07 in) long, growing to about 2.2 mm (0.09 in) in 24 hours. The young attain a length of about 30 mm (1 in) in their first month of life and as much as 180 mm (7 in) by their fifth month (Welsh and Breder 1923; Hildebrand and Schroeder 1928; Hildebrand and Cable 1934; Pearson 1941; Bigelow and Schroeder 1953; Harmic 1958; Sequin 1959).

Many investigators during the last 75 years have estimated age composition and rate of growth from annual rings on scales, otoliths, and vertebrae, and also from length frequencies. These estimates vary considerably not only from one investigator to another, but from season to season, year to year, and area to area. Table 12 contains the age/length ranges and averages (Wilk 1976).

TABLE 12. Length at age for weakfish

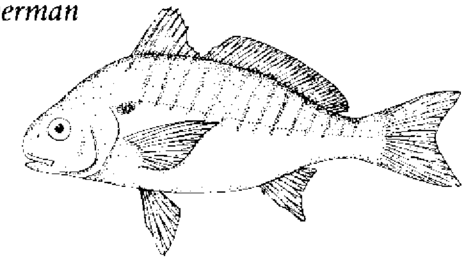
	Length in mm (in)	
Age	Range	Average
1	130-315	191 (7.5)
2	221-361	264 (10.4)
3	240-400	310 (12.2)
4	260-480	375 (14.8)
5	340-555	435 (17.1)
6	419-645	480 (18.9)
7-8	427-686	495 (19.5)

Variations may result from the existence of several distinct groups, which have different growth rates and which mix in variable proportions during their migration.

Feeding Interrelationships. Weakfish feed throughout the water column. The size of the individual dictates the size of the prey: young fish depend on invertebrates and small fishes; older fish depend primarily on other fishes. Among the prey fishes most frequently observed are butterfish, herrings, sand lance, silversides, anchovies, young weakfish, Atlantic croaker, spot, scup, and killifishes; among the invertebrates are shrimps, squids, crabs, worms, and clams (Peck 1896; Eigenmann 1901; Linton 1904; Tracy 1910; Welsh and Breder 1923; Nichols and Breder 1927; Hildebrand and Schroeder 1928; Bigelow and Schroeder 1953; Thomas 1971; Merriner 1975).

Spot *Leiostomus xanthurus*

Malcolm J. Silverman



Distribution and Seasonal Movements. Spot has many common names including Lafayette, Cape May goody, goody, and Norfolk spot. It is a schooling fish and a member of the croaker family, but only the males are capable of a faint drumming sound similar to that of the Atlantic croaker (Hildebrand and Schroeder 1928). The species ranges from Massachusetts to Mexico, but its greatest abundance on the Atlantic coast is from Chesapeake Bay to the Carolinas. Spot occur from Cape Hatteras to Delaware Bay from late spring until late autumn; during summer months they inhabit sounds, bays, and estuaries, and then in autumn migrate south and offshore toward winter spawning grounds (Map 41). During late winter most spot are found south of Cape Hatteras.

Population Size and Fisheries. Abundance of spot has varied widely in the Bight. In 1925 spot were so abundant off New York that the Brooklyn Edison Company had to shut down its generators so work crews could remove spot from the condenser pumps (Nichols and Breder 1927). However, abundance declined drastically in New York Bight since the 1940s, with NY and NJ commercial landings dropping from a peak of nearly 800 MT in 1943 to an annual average of only 1.4 MT in the decade 1965-74 (McHugh and Ginter 1978). Spot began to return to New York Bight in the 1970s, and by 1975 and 1976 landings again reached levels comparable to those of the 1950s.

Commercial fisheries for spot are centered in the Chesapeake Bay area where they are caught during spring and autumn migrations with haul seines, pond nets, and gill nets in the sounds and along beaches. The major fishery in Chesapeake Bay occurs in the autumn. Off the Carolinas, otter trawls also take a large number of spot during the autumn migration and in winter on the offshore wintering grounds (Pearson 1932; Struhsaker 1969). Many juvenile spot are destroyed in the various inshore fisheries from Chesapeake Bay southward, including pound nets, otter trawls, and shrimp trawls during late spring and summer; the juveniles are either discarded or are landed as scrap (Pacheco 1962*a*; Brown and McCoy 1969).

Spot are an important recreational species and the sport catch is apparently much larger than the commercial catch (McHugh and Ginter 1978). In 1970 an estimated 33 million spot were caught by anglers from New Jersey to Cape Hatteras (Deuel 1973).

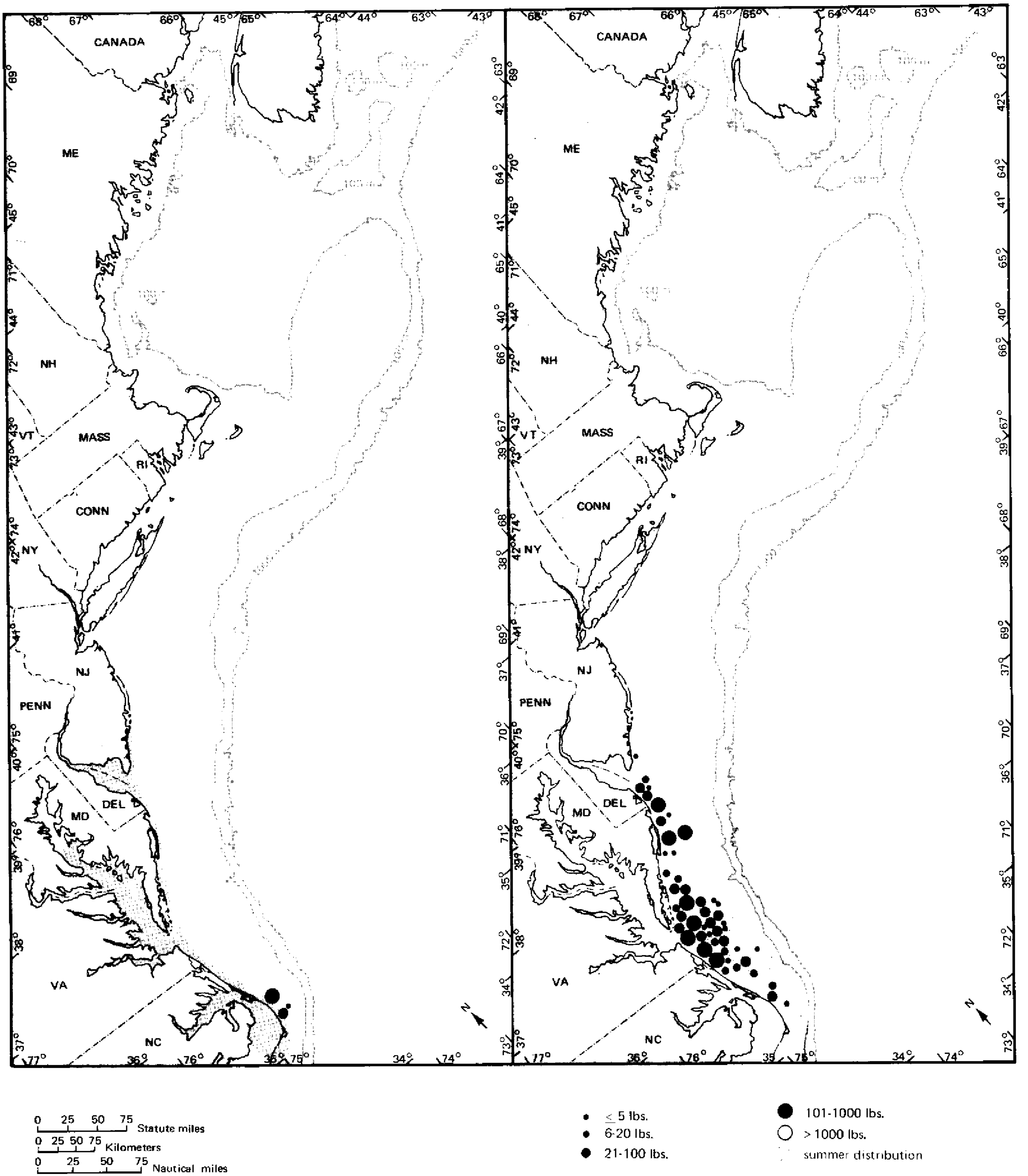
Reproduction, Growth, Life Span. Spot become sexually mature by the end of their second year or beginning of the third year at a size of about 20 cm or 7.9 in (Dawson 1958). Adult spot begin to leave New York Bight in late September, and migrate southward toward offshore winter spawning grounds south of Chesapeake Bay (Pearson 1932; Pacheco 1962*a,b*; Chao and Musick 1977). Spawning occurs from October to March and peaks in December and January. Little is known of egg and larval development, but eggs are small and probably have a short incubation period (Hildebrand and Cable 1930; Johnson 1978). Young-of-the-year spot 15 to 20 mm (0.6 to 0.8 in) enter lower Chesapeake Bay in April and by late spring occupy the uppermost limits of the bay, entering fresh water. Adults return to the estuaries in late April and May but do not range as far into the estuaries as juveniles (Pacheco 1962*a*).

Spot sampled from NJ waters reached a total length of 8 to 10 cm (3.1 to 3.9 in) at the end of the first year, 17 to 22 cm (6.7 to 8.7 in) at age two, and 24 to 29 cm (9.4 to 11.4 in) at age three (Welsh and Breder 1923). However, the average size and rate of growth varies throughout their range (Sundararaj 1960). Spot is a relatively small fish reaching a maximum size of about 34 cm (13.4 in) and a weight of less than 0.7 kg or 1.5 lb (Hildebrand and Cable 1930). Few spot exceed 25 cm (9.8 in) and they seldom live longer than three years.

Feeding Interrelationships. Spot have a small inferior mouth, identifying them as bottom feeders. They feed on small crustaceans, annelids, small fish, molluscs, and vegetable matter (Hildebrand and Cable 1930). Hollis (1952) reported that spot is an important part of the diet of striped bass.

Environmental Sensitivity. It has been hypothesized that degradation of estuaries from industrial and residential development and pollution may have had a deleterious effect on survival of juvenile spot (Joseph 1972). Temperature is another factor affecting spot in estuaries; they are occasionally killed in large numbers during cold winters. For example, in January 1976 more than 10 million spot were believed killed by a cold spell which covered upper Chesapeake Bay with 5 to 20 cm (2 to 8 in) of ice and lowered bottom water temperatures to near freezing; the spot apparently had stayed in the bay longer than usual

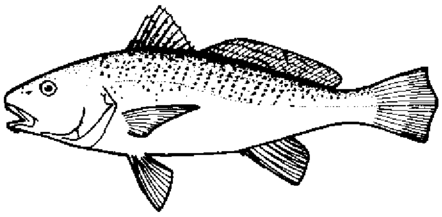
Map 41. Spot — general distribution and spawning areas (shading) and distribution of NMFS 1973-74 trawl catches (dots) (spring-left, autumn-right)



Note: brown shading shows fall and winter spawning areas because of abnormally high autumn temperatures and were trapped by the sudden cold (Anonymous 1976).

Atlantic croaker *Micropogon undulatus*

Malcolm J. Silverman



Distribution and Seasonal Movements. The Atlantic croaker is known also as hardhead, crocus, roncodina, and corvina; both sexes produce the characteristic croaking noise (Hildebrand and Schroeder 1928). The species ranges from Gulf of Maine to Argentina, but is seldom caught north of New Jersey (Chao and Musick 1977). It is most abundant along the US east coast from Chesapeake Bay to the Carolinas where it inhabits bays, sounds, and estuaries; some croakers also go up into brackish and fresh water. Distribution and seasonal movements of Atlantic croaker from Cape Hatteras northward is very similar to that of spot (see Map 42). They are found inshore and in estuaries during late spring and summer, and then migrate south and offshore toward winter spawning grounds largely south of Chesapeake Bay (Hildebrand and Schroeder 1928; Hildebrand and Cable 1930; Haven 1959; Bearden 1964).

Population Size and Fisheries. Atlantic croaker populations were low at the beginning of the century but increased to relatively high levels in the 1940s (Joseph 1972). More than 29,000 MT were landed in 1945 during the peak of the commercial fishery; at that time Atlantic croaker represented one of the most important food fishes on the US east coast (McHugh and Ginter 1978). The population then declined to very low levels north of Cape Hatteras until the mid-1970s when it again increased; however, the recovery may have been slowed due to possible high mortality of croakers during the cold 1976-77 winter (McHugh and Ginter 1978).

The commercial fisheries for croaker are centered in the Chesapeake Bay area where they are caught in pound nets, haul seines, and gill nets during spring and autumn migrations and to a lesser extent during summer. A large number of croaker are taken by otter trawl during spring migration and in winter on the offshore wintering grounds. The croaker was an important mainstay of the pound net fishery in the Chesapeake region for a number of years and also an important part of the NJ pound net fishery (Perlmutter 1959). Young croaker, like spot, are caught in great numbers in inshore waters by pound nets and otter and shrimp trawls, and become part of the scrap landings or are discarded (Brown and McCoy 1969).

Croaker is an important recreational species, and in recent years the sport catch apparently has exceeded the commercial catch (McHugh and Ginter 1978). In 1970 anglers took an estimated 5 million croakers from New Jersey to Cape Hatteras (Deuel 1973).

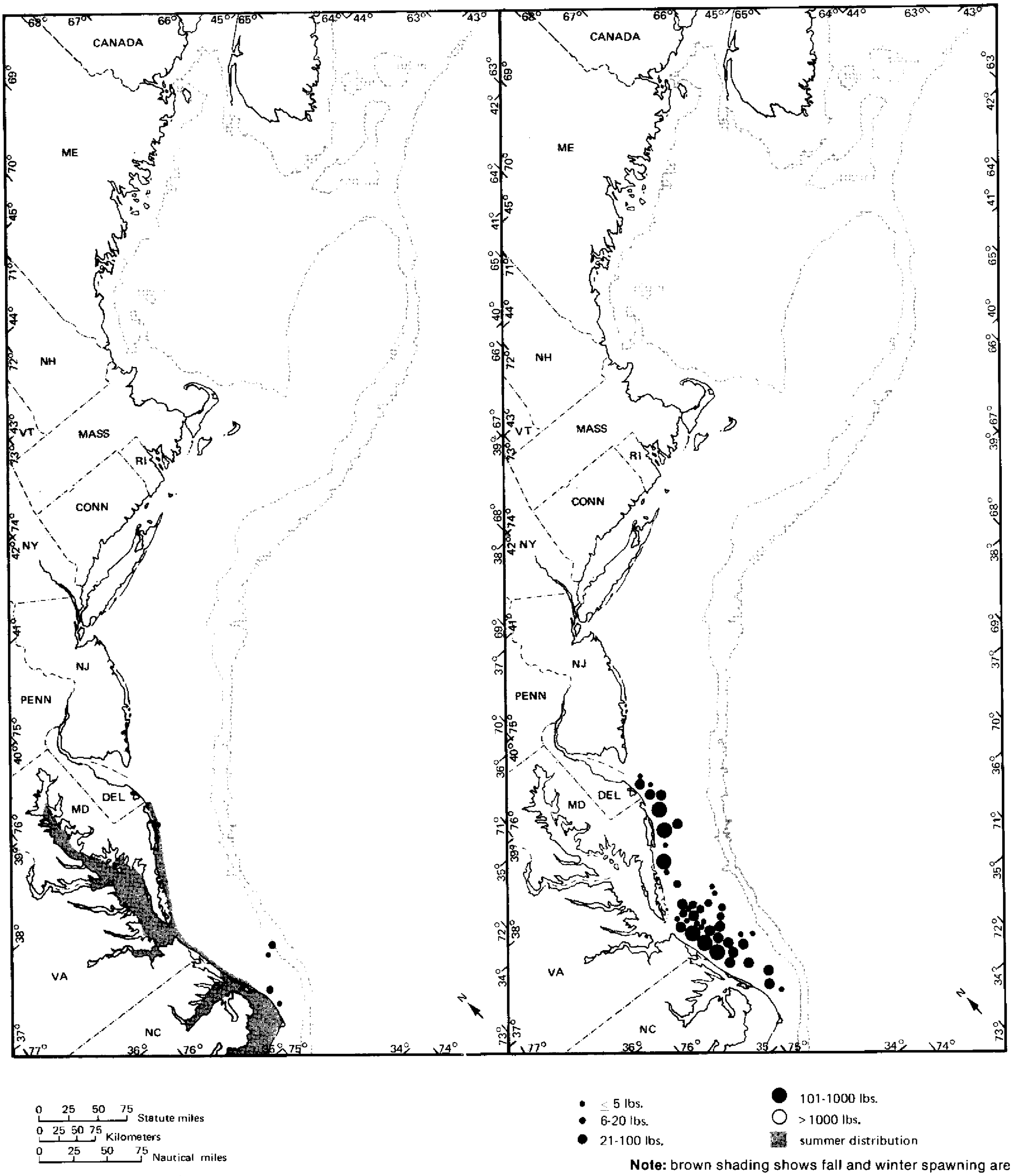
Reproduction, Growth, Life Span. North of Cape Hatteras croaker spawn from August to December with peak spawning in October (Hildebrand and Schroeder 1928). Adult croaker begin to leave the estuaries in late summer, moving southward along the shore and then offshore to spawn and overwinter. South of Hatteras spawning occurs September to March with an October peak (White and Chittenden 1977; Johnson 1978). Little is known of croaker spawning behavior or egg development. Small croaker larvae have been taken in the Bight south of Chesapeake Bay August through December (Map 19).

The age and size of sexually mature croaker vary with locality. Those north of Cape Hatteras mature at age two while those south mature at age one (White and Chittenden 1977). In New Jersey they reach 4 cm (1.6 in) by the first winter, 15 cm (5.9 in) by the second, 22 cm (8.7 in) the third, and 26 cm (10.2 in) the fourth winter (Welsh and Breder 1923). The croaker is a relatively small fish averaging 20 to 22 cm (8 to 9 in); it seldom exceeds a length of 50 cm (19.7 in) and a weight of 1.8 kg (4 lb), and rarely lives more than four years. An unusually large croaker that measured 67 cm (26 in) and weighed 3.6 kg (8 lb) gutted, was reported by Rivas and Roithmayr (1970).

Feeding Interrelationships. Croakers are bottom feeders that eat small crustaceans, annelids, molluscs, ascidians, ophiurans, and fish (Hildebrand and Schroeder 1928). Dovel (1968) reported that striped bass feed heavily on croaker and that their predation during winter may have an influence on croaker populations.

Environmental Sensitivity. Joseph (1972) concluded that temperature is a dominant factor in controlling the abundance of Atlantic croaker. Sea water temperatures were rising over the first half of this century, which may have brought about the increased abundance of croaker during that period. During the 1960s, winters were generally colder and croaker populations in the Bight were at very low levels, especially compared with the 1940s. Increased abundance of juvenile croakers in 1973 and 1974 was attributed to warmer winters in those years, and mass mortalities of young-of-the-year croakers were observed during very cold winters (Chao and Musick 1977). It is likely that the exceptionally cold 1976-77 winter caused heavy mortality of juvenile croakers.

Map 42. Atlantic croaker — general distribution and spawning areas (shading) and distribution of NMFS 1973-74 trawl catches (dots) (spring-left, autumn-right)



Note: brown shading shows fall and winter spawning areas

American Sand Lance *Ammodytes americanus*

Charles J. Byrne

Distribution and Seasonal Movements. The American sand lance is a very slender, small eel-like fish which has a unique habit of burrowing rapidly into the sand. Other common names are sand eel, launce, or lant. There is controversy over the number of *Ammodytes* species in the Northwest Atlantic due to wide variations in the meristic counts (numbers of vertebrae, and dorsal and ventral fin rays). Several researchers recognized two species of sand lances: an inshore species with lower counts, *A. americanus* or *A. hexapterus*, and an offshore species, *A. dubius* (Leim and Scott 1966; Richards, Perlmutter, and McAneny 1963; Scott 1968). However, after further study Scott (1972*b*) concluded that inshore and offshore sand lances could not be separated on a species basis and further speculated that these forms may be the same as the European *A. marinus*. The sand lances off the eastern coast of North America are identified here as *A. americanus*.

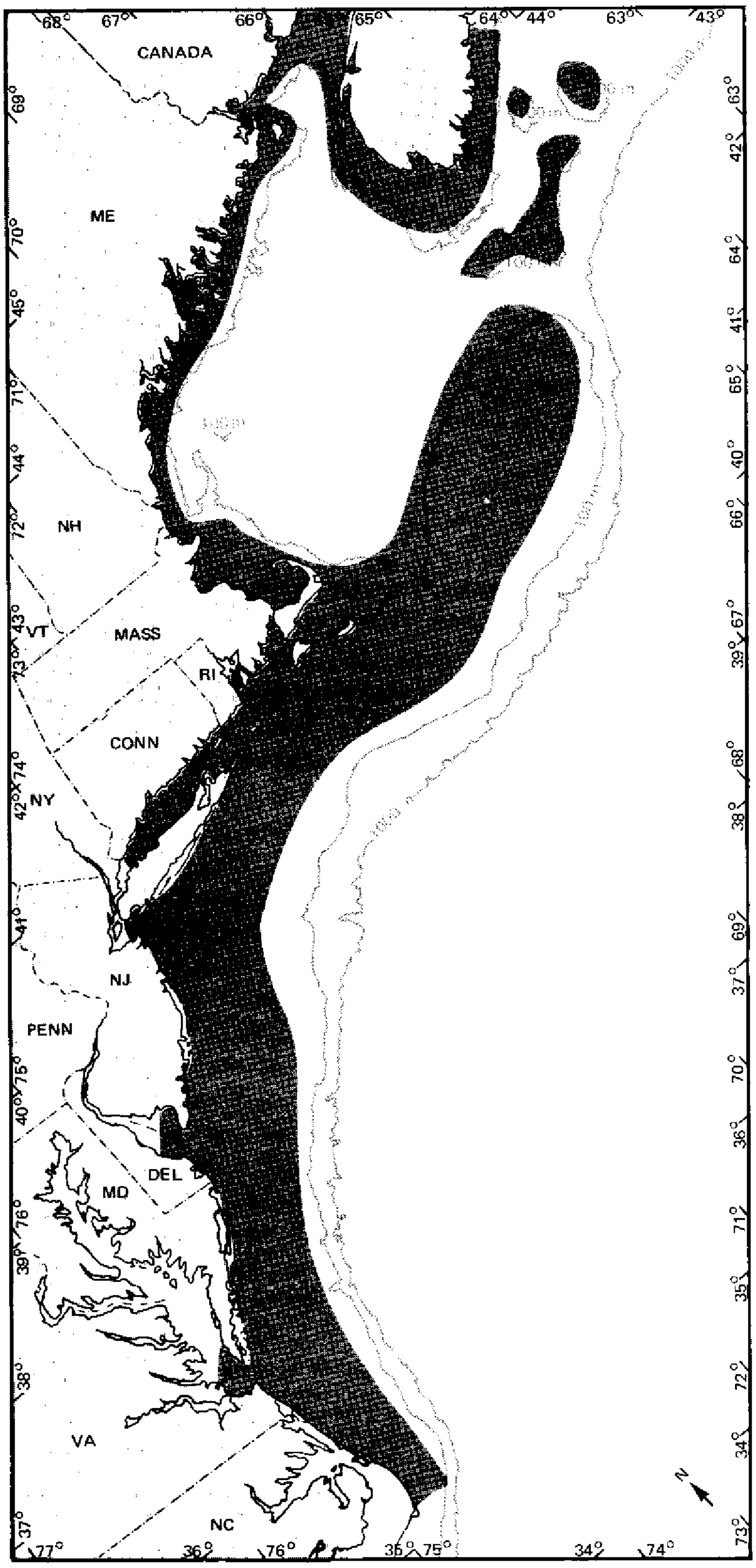
The American sand lance is found from Cape Hatteras to Hudson Bay and Greenland, and from upper estuaries to the edge of the continental shelf (Norcross, Massmann, and Joseph 1961; Scott 1968). However, the species is most abundant near the inner half of the continental shelf, over sand and fine gravel bottoms into which it frequently burrows (Bigelow and Schroeder 1953). It is rarely seen off the rocky sections of the coastline.

Scott (1968) indicated little seasonal movement of sand lance stocks on the Nova Scotian banks and observed that they tolerate a wide range of temperature. A tagging experiment in the southern North Sea showed that sand lance (*A. marinus*) do not move out of restricted areas (Popp Madsen 1963). NMFS trawl surveys in the Bight have shown that sand lance occur in separate localized aggregations, and it is probable that these populations are not migratory. Although the general occurrence of sand lance in the NMFS survey area is illustrated in Map 43, such distribution is not consistent.

Population Size and Fisheries. In northern Europe there is a large commercial (fish meal) fishery for sand lance, and in 1974, 532,129 MT were landed (International Council for the Exploration of the Sea 1977). So far the utilization of this resource along the US east coast and in New York Bight has been limited to the baitfish industry. From 1965 to 1973 reported US landings ranged from 0 to 73 MT; 565 tons were reported by Japan in 1972, the only record of any foreign landings of sand lance during this period (International Commission for the Northwest Atlantic Fisheries 1975).

Direct estimates of the size of the North American population are not available, but it is assumed large con-

Map 43. Sand lance
— distribution and spawning areas
based on historical fishery records



Note: blue shading shows distribution and spawning areas sidering the important role the sand lance plays in the food web and the large numbers of sand lance larvae in the ichthyoplankton. There is evidence that the sand lance population has been increasing markedly since about 1974, based on NMFS trawl and plankton surveys (Smith and Sullivan 1978; Grosslein, Langton, and Sissenwine, 1980).

Reproduction, Growth, Life Span. The American sand lance matures in its second year (Westin et al 1979). Males mature a few months ahead of the females but there is no observable difference in growth rate between the sexes (Scott 1968). Apparently, each adult female spawns only once during a given year and up to 45% of the female body weight is gonadal tissue (Westin et al 1979). The length-fecundity relationship for American sand lance taken in the Merrimac River was determined by Westin and associates (1979) as follows:

$F = 0.328\ L^{3.857}$,
where F = number of eggs
L = fork length (cm)

Using this formula, American sand lance of 18 cm (7.1 in) would produce about 23,000 eggs.

In the Bight, spawning occurs November to March and is restricted to the inner half of the continental shelf, although no eggs have been found in upper estuaries (Richards and Kendall 1973). The eggs are demersal and adhere to the bottom; they contain a single oil globule, and are approximately 0.825 mm (0.03 in) in diameter after extrusion into the water (Williams, Richards, and Farnsworth 1964; Scott 1972*a*). They are thought to be deposited either within or on the sand or gravel bottom (Ehrenbaum 1904; Williams et al 1964). Hatching does not occur until the bottom temperature drops to 9°C (48°F) or lower (Wheatland 1956; Norcross et al 1961). Hatching in New York Bight occurs late November through May, but the greatest numbers of larvae are observed January to March (Wheatland 1956; Richards and Kendall 1973). Larvae are found from upper estuaries to the edge of the continental shelf (Map 11; Norcross et al 1961; Richards and Kendall 1973). However, in one study larvae increased in size as the sampling moved offshore, suggesting that they may be able to direct their movements across the shelf (Norcross et al 1961).

Table 13. Length at age for sand lance

Age	Fork Length in cm (in)
1	7.3-12.4 (2.9-4.9)
2	9.0-15.4 (3.5-6.1)
3	11.9-20.8 (4.7-8.2)
4	12.3-21.8 (4.8-8.6)
5	15.9-23.8 (6.2-9.4)

When larvae emerge from the egg they are approximately 3 to 4 mm (0.1 to 0.2 in) long and become planktonic. By the time they reach about 35 mm (1.4 in) they return to the bottom (Scott 1973*a*). Norcross and associates (1961) estimated that *A. americanus* larvae off the Virginia capes grew approximately 11.7 mm (0.5 in) per month during February and March. Thus, the planktonic stage may last two to three months.

Length at age for female sand lance collected from Block Island Sound and the Merrimac River are presented in Table 13 (Westin et al 1979).

Length at age data for sand lance from the Nova Scotian shelf (Scott 1968) indicate that growth rate there is higher than in the Bight. The oldest known American sand lances from the Nova Scotian Shelf were nine years old and 37 cm (14.6 in) long, however, the one-to-three year old groups dominate the population (Reay 1970).

Feeding Interrelationships. The adult sand lance is both a filter feeder for small prey and a selective feeder for larger prey (Scott 1973*b*). Sand lance have been observed near the surface at night off Nova Scotia (Scott 1973*b*) and at all levels of the water column during daylight hours off Cape Cod (Meyer, Cooper, and Langton 1979). The adult prefers larger zooplankton up to a maximum size of 1.5 cm (0.6 in). On the Scotian Shelf, the most frequent prey in order of importance were copepods, crustacean larvae, invertebrate eggs, polychaete larvae, larvaceans, fish eggs, pteropods, and cirripede larvae (Scott 1973*b*). Copepods were by far the most important item comprising approximately 65% by volume of all the stomach contents of the adults. Off Cape Cod the diet of sand lance consisted chiefly of copepods and chaetognaths, 41% and 40% respectively (Meyer et al 1979).

TABLE 14. Percent by weight of *Ammodytes* sp. in stomach contents of fishes caught from Cape Hatteras to Nova Scotia

			Area		
Species	Mid-Atlantic	Southern New England	Georges Bank	Gulf of Maine	Western Nova Scotia
Cod	- (0)	0 (79)	0.1 (817)	0 (364)	11.2 (439)
Pollock	0 (7)	- (0)	0 (197)	0 (181)	9.6 (203)
White Hake	- (0)	0 (79)	0 (128)	0 (312)	5.4 (91)
Longhorn Sculpin	0 (38)	0 (453)	0.5 (287)	0 (50)	0 (80)

Note: Numbers of stomachs examined in parenthesis.

Source: Bowman et al 1976

In Long Island Sound, sand lance larvae feed during daylight hours based upon diel (daily) variations in stomach fullness; gut contents of larvae approximately 4 mm (0.16 in) in length, included phytoplankton, copepod nauplii, invertebrate eggs, and peridinians (Covill 1959). As the larvae increased in size to 13 mm (0.51 in), phytoplankton and peridinians decreased in importance while copepod nauplii increased. By the time the larvae were approximately 21 mm (0.83 in) long, adult copepods were the major prey.

The sand lance itself is an important food item in the diets of other fish. Scott (1968) noted that eggs and larvae of sand lance are vital factors in sustaining the stocks of many of the Nova Scotia fishes at their present levels. In the mid-Atlantic area sand lance larvae have been found in stomachs of Atlantic herring and Atlantic mackerel (Maurer 1976).

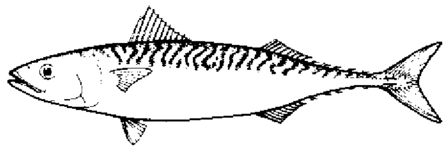
Adult and juvenile sand lance are preyed upon by many demersal and pelagic fish species, as well as finback whales and porpoises (Bigelow and Schroeder 1953). Extensive food habits studies by NMFS have confirmed the occurrence of *Ammodytes* in the diet of certain groundfish species, particularly cod, and it appears that the importance of *Ammodytes* as prey increases from south to north. During 1969-72 more than 18,000 stomachs representing 29 species of fish were collected on NMFS trawl surveys from Cape Hatteras to Nova Scotia. Adult or juvenile *Ammodytes* were positively identified in four groundfish species, namely cod, white hake, pollock, and longhorn sculpin; and except for longhorn sculpin, virtually all the occurrences were in the western Nova Scotia area (Bowman, Maurer, and Murphy 1976). The relative importance of *Ammodytes* in the total food content ranged from a low of 0.5% by weight for longhorn sculpin to 11.3% for cod (Table 14). The data in Table 14 represent minimum occurrences since most of the fish found in stomachs are unidentified.

During the 1958-63 period, groundfish stomach contents were examined on Canadian trawl surveys of the entire Nova Scotian Shelf, and sand lance made up as much as 75% by weight of the prey of large cod (►50 cm or ►20 in) in the Sable Island area (Scott 1968). For the entire cod population, and over the Scotian Shelf, and presumably on an annual basis, Scott suggested that sand lance may have contributed up to 50% of the total volume of food for cod at that time.

The importance of sand lance as prey in the mid-Atlantic probably has increased in recent years along with the increase in the sand lance population. This is supported by the fact that during NMFS spring surveys from 1976 to 1978, a large percentage of cod stomachs containing sand lance was observed in New York Bight, whereas in the 1969-72 studies noted above, no sand lance were recorded in cod from the Bight.

Atlantic Mackerel *Scomber scombrus*

Peter Berrien



Distribution and Seasonal Movements. Atlantic mackerel occur in the western North Atlantic from Black Island, Labrador, to Beaufort, NC (Sette 1950; Parsons 1970). They normally sustain fisheries from the Gulf of St. Lawrence and Nova Scotia to the Cape Hatteras area (Sette 1950; Bigelow and Schroeder 1953).

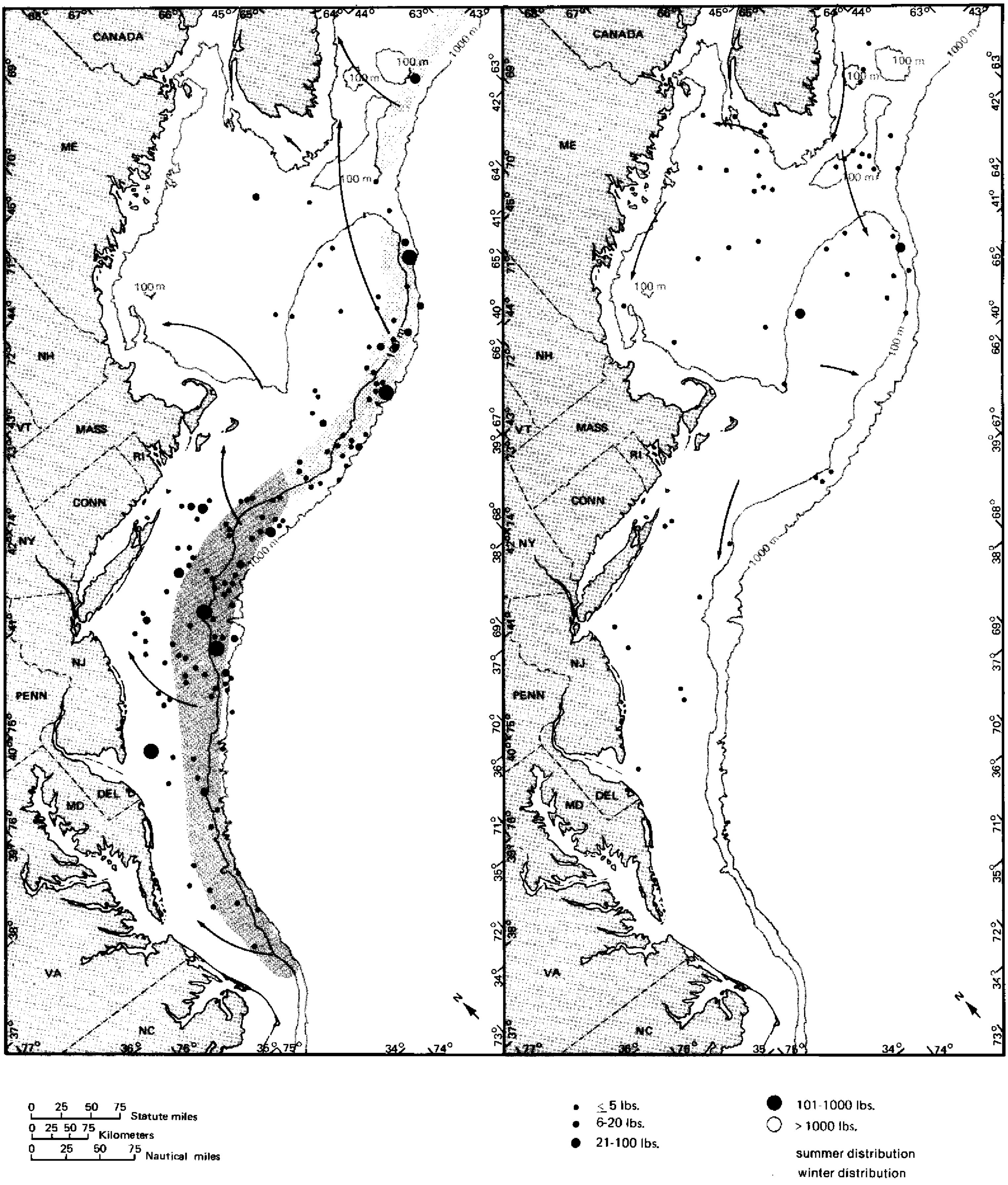
Based on the separation of spawning areas, on tagging studies, and on the size composition of commercial catches, Sette (1950) described northern and southern population contingents with different spring and autumn migration patterns and summer distributions. Because of apparent mixing of the two contingents during migrations, Sette suggested that they may not be genetically distinct. More recent studies including meristics and enzyme types also showed no significant differences between the two groups (MacKay 1967; MacKay and Garside 1969).

Atlantic mackerel apparently overwinter in deep water near the edge of the continental shelf from Sable Island Bank to the Chesapeake Bay region (Sette 1950; Leim and Scott 1966; MacKay 1967; Isakov 1973). In spring there is a general inshore, then northeastward migration, and in autumn the pattern is reversed (Map 44).

The southern contingent begins the spring spawning migration by moving inshore between Delaware Bay and Cape Hatteras, usually between mid-March and mid-April. They then move northeast along the coast, continually joined by schools from the northern contingent also moving inshore. The overwintering area and timing of spring migration varies from year to year, probably due to differences in water temperature and rate of warming. Maximum spawning takes place off New Jersey and Long Island in late April and May. By early June the schools are off southern Massachusetts and in June and July have moved to the western side of the Gulf of Maine where they remain during summer. The southern contingent leaves the Gulf of Maine in October and returns to deep water to overwinter, apparently near the shelf edge where the bottom temperature is above 7°C (45°F), probably between Long Island and Chesapeake Bay (Sette 1950; Bigelow and Schroeder 1953; Hoy and Clark 1967; MacKay 1967; Anderson 1975*c*; Anderson and Almeida 1977).

The northern contingent begins to move inshore off southern New England usually in late May, mixing temporarily with part of the southern contingent. The northern fish then migrate eastward along the coast of Nova Scotia, are joined by other mackerel schools from offshore, and move into the Gulf of St. Lawrence where they spawn in June and July and spend the rest of the summer. Small

Map 44. Atlantic mackerel — general distribution and spawning areas (shading) and distribution of NMFS 1973-74 trawl catches (dots) (spring-left, autumn-right)



Note: brown shading shows spring spawning areas fish (◀30 cm or ◀12 in) tend to lag behind large fish during the spring migration and spawn later (MacKay 1967; Stobo and Hunt 1974; Moores, Winters, and Parsons 1975). Some northern fish separate from the main body and remain along the coasts of Maine, Nova Scotia, and Cape Breton Island for the summer. The main body of northern fish leaves the Gulf of St. Lawrence in September and October via Cabot Strait, moves west along Nova Scotia, and passes through the Gulf of Maine from October to December, where the northern and southern contingents again temporarily mix. The northern fish leave the Gulf of Maine near Cape Cod in December and are assumed to overwinter in deep water over the outer shelf between Sable Island Bank and Long Island; and further mixing probably occurs then (Sette 1950; Bigelow and Schroeder 1953; MacKay 1967; Parsons and Moores 1974; Stobo and Hunt 1974; Anderson 1975*c*; Moores et al 1975).

Tagging experiments on Atlantic mackerel demonstrate extensive movements (Sette 1950; Leim and Scott 1966; Moores et al 1975; Stobo 1976*b*). Tagged fish have moved from Newfoundland to southern New England, New York Bight, and Maryland. Mackerel tagged in the Gulf of St. Lawrence in October were recaptured on Georges Bank and off New Jersey and Delaware in winter. Mackerel tagged off Nova Scotia were recaptured off New England, off Sable Island and Delaware in winter, and off New Jersey. One Atlantic mackerel tagged near Woods Hole in June was recaptured in Nova Scotian waters. These studies confirm probable mixing during winter.

Population Size and Fisheries. Commercial catches of Atlantic mackerel in the Northwest Atlantic have varied greatly over the years due to economic conditions, changing fishing methods and areas, and fluctuations in abundance (Hoy and Clark 1967; Anderson and Paciorkowski 1980).

In the mid-1960s an extensive offshore otter trawl fishery began in the Northwest Atlantic by distant water fleets chiefly from Europe. They began fishing on mackerel, partly because of its high abundance and partly because of declining herring stocks. The total mackerel biomass (age one and older) in the Northwest Atlantic increased from about 600,000 MT in the early 1960s to a peak of 2.4 million MT in 1969, and then declined rapidly to less than 500,000 MT in 1978 (Anderson and Paciorkowski 1980). The large rise and fall in abundance was due chiefly to the recruitment of four consecutive strong year-classes in 1966-69, and particularly the extraordinary 1967 year-class, followed by a series of relatively small year-classes from 1970 to 1977, generally less than half the strength of the 1966, 1968, and 1969 year-classes and less than a quarter the size of the 1967 year-class (Anderson and Paciorkowski 1980). Total commercial landings from this stock increased from only 7,300 MT in 1960 to a peak of 419,000 MT in 1973, and then declined rapidly to 77,000 MT in 1977, the first year of management under extended jurisdiction in both US and Canadian waters inside the 200 mile zone. The bulk of this harvest came from the area between Georges Bank and Cape Hatteras (for example, 90% during the peak 1970-74 period). For the same period, about 60% came from the Middle Atlantic Bight alone. In 1978 the commercial catch from the Bight dropped to about 1,000 MT, most of which were taken by US fishermen.

The US recreational catch of Atlantic mackerel is substantially greater than the US commercial catch, averaging 13,700 MT per year (1960-77) compared to only 2,200 MT for the commercial fishery (Anderson and Paciorkowski 1980). The estimated sport catch has also followed the major trends in mackerel abundance, rising from 5,000 MT in 1960 to a peak of 33,000 MT in 1969, then declining to the lowest estimated catch of 550 MT in 1977. Sport catches increased sharply in 1978 to 6,500 MT (Christensen et al 1979; Anderson and Overholtz 1979).

The fluctuations in mackerel year-classes are believed to be due to variations in larval survival (Sette 1943; Bigelow and Schroeder 1953; Hoy and Clark 1967). Factors influencing mortality of larvae may include water temperature, zooplankton abundance, wind driven surface currents, epizootics, and the abundance of mackerel larvae relative to their prey (Sette 1943; Taylor, Bigelow, and Graham 1957; Sindermann 1958; MacKay 1967; Lett, Kohler, and Fitzgerald 1975; Winters 1976; Anderson and McBride 1976). Average recruitment levels may be reduced when the spawning stock drops below some critical level. There was concern that the heavy fishing coupled with poor recruitment in the 1970s would drive the spawning stock down below such a level, and catch restrictions have been imposed since 1976 to promote rebuilding of the stock (Anderson and Paciorkowski 1980). Stock size was expected to increase significantly in 1979 as a result of a fairly strong 1978 year-class, the largest since 1969 (Anderson and Overholtz 1979).

Reproduction, Growth, Life Span. Spawning of Atlantic mackerel in the Northwest Atlantic occurs during spring and summer and progresses from south to north as surface waters warm and the fish migrate. The southern contingent spawns from mid-April to June in the Middle Atlantic Bight and the Gulf of Maine (Map 44), and the northern contingent spawns in the southern Gulf of St. Lawrence from the end of May to mid-August (Morse 1978*a*). Most spawn in the shoreward half of continental shelf waters, although some spawning extends to the shelf edge and beyond (Map 12). Spawning occurs in surface water temperatures of 7° to 14°C (45° to 57°F), with a peak around 10° to 12°C or 50° to 54°F (Sette 1943; Bigelow and Schroeder 1953).

In their third year of growth about half the Atlantic mackerel reach maturity, and all are mature in their fifth year. Size at maturity averages 27 to 28 cm (10.6 to 11 in)

FL in the Bight (Isakov 1976; Moores 1976).

Fecundity estimates ranged from 285,000 to 1.98 million eggs for southern contingent mackerel between 31 and 44 cm (12 and 17 in) FL (Morse 1978*a*). Analysis of egg diameter frequencies indicated that mackerel spawn between five and seven batches of eggs per year (Morse 1978*a*). The eggs are 1 to 1.3 mm (0.04 to 0.05 in) in diameter, have one 0.3 mm (0.1 in) oil globule, and generally float in the surface water layer above the thermocline or in the upper 10 or 15 m or 33 or 49 ft (Sette 1943; Bigelow and Schroeder 1953; MacKay 1967; Berrien 1975). Incubation depends primarily on temperature; it takes 7.5 days at 11°C (52°F), 5.5 days at 13°C (55°F), and 4 days at 16°C or 61°F (Worley 1933).

Atlantic mackerel are 3 mm (0.1 in) long at hatching, grow to about 50 mm (2 in) in two months, and reach a length of 20 cm (8 in) in December, near the end of their first year of growth. Possible larval mortality mechanisms are noted in the previous section. During their second year of growth they reach about 26 cm (10 in) in December, and by the end of their fifth year they grow to an average length of 33 cm (13 in) FL (Anderson 1973; Isakov 1973; Stobo and Hunt 1974). Fish that are 10 to 13 years old reach a length of 39 to 40 cm or 15 to 16 in (Stobo and Hunt 1974; Isakov 1976).

MacKay (1967) studied growth in several year-classes of Atlantic mackerel in Canada and theorized that growth is population density dependent, that is, abundant year-classes grow more slowly than less abundant year-classes. Moores and associates (1975) did not find this relationship for the same year-classes of Newfoundland fish.

Feeding Interrelationships. Atlantic mackerel are opportunistic feeders that swallow their food whole. Food consists primarily of zooplankters captured by active pursuit of individual animals or by passive filtering (Bigelow and Schroeder 1953; Leim and Scott 1966; Hoy and Clark 1967; MacKay 1967; Moores et al 1975). Immature mackerel feed and fatten from spring onward; older fish feed until ripening of the gonads, stop feeding until spent, then resume feeding (Bigelow and Schroeder 1953). Studies by Maurer (1975) showed mackerel feeding largely on calanoid copepods and pteropods; a comparison of stomach contents from both herring and mackerel indicated that 16 of 29 prey genera were shared by both species (Maurer 1976).

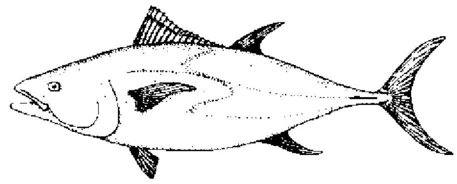
Predators of Atlantic mackerel include whales, dolphins, mackerel and thresher sharks, dogfish, tunas, bonito, bluefish, striped bass, codfish, squid, and seabirds. They are hosts for parasitic nematodes and trematodes (Bigelow and Schroeder 1953; Hoy and Clark 1967). Considering the total food web involving mackerel, their impact on the ecosystem must be substantial in years when they are extremely abundant.

Environmental Sensitivity. The usual temperature range associated with Atlantic mackerel is 7° to 20°C or 41° to 68°F (Sette 1950; Bigelow and Schroeder 1953). Their sensitivity to temperature is shown by (1) their withdrawal from coastal waters as the temperature falls; (2) their usual avoidance of the cool waters in the Bay of Fundy, which is within their geographic range (Leim and Scott 1966); (3) absence from Newfoundland waters except since 1940, which is coincident with warming trends there (Templeman and Fleming 1953; Moores et al 1975); (4) the positive correlation of increased mackerel catches in New England with long-term warming trends (Taylor et al 1957); and (5) a northeasterly shift in overwintering area concurrent with a recent warming trend (Anderson and Almeida 1977). MacKay (1967) suggested that survival of young Atlantic mackerel may be adversely affected by wind-generated mixing which caused sudden temperature drops in surface waters. Lower ambient temperature would decrease the growth rate, lengthen the planktonic stage, and increase time of vulnerability to predators.

Frequencies of chromosome abnormalities were studied in mackerel eggs collected in New York Bight, and although background aberration rates are not known for mackerel, the average proportion of abnormal chromosomes observed was sufficiently above background levels reported for other species to suspect that pollutants in the Bight might be high enough to be causing damage to mackerel embryos (Longwell 1976).

Bluefin Tuna *Thunnus thynnus*

H.A. Schuck



Distribution and Seasonal Movements. The bluefin tuna is a highly migratory species that utilizes the Middle Atlantic Bight during critical periods of its life cycle. This tuna occurs from Argentina to above the Arctic Circle and on both sides of the Atlantic.

Giant bluefin (over 123 kg or 270 lb) annually pass northward through the Straits of Florida in May and June during or just after spawning. They follow the Gulf Stream northward and usually appear in coastal waters off New Jersey and Long Island, and Cape Cod Bay about June or July and off the Maine coast, Nova Scotia, Prince Edward Island, and Newfoundland shortly thereafter. Medium sizes (32 to 123 kg or 70 to 270 lb) normally move into the Bight area in June and then move inshore. Juveniles or school tuna (3 to 32 kg or 5 to 70 lb) typically appear in early July first off Virginia, Delaware, and Maryland, next off New Jersey, then off Long Island, and finally south of Cape Cod. In some years, late season concentrations of bluefin of various sizes have occurred off New York Bight.

The overall summer distribution of bluefin tuna in the Northwest Atlantic is shown in Map 45. All sizes have historically left these inshore feeding areas with the coming of autumn storms. In winter, bluefin generally are taken only by longline fisheries over wide areas of the North and South Atlantic.

Morphometric differences, times and areas of spawning, and tag returns show essentially two bluefin tuna populations—one on each side of the Atlantic, with some intermixing. Tagging studies indicate that in certain years giant bluefin from the Straits of Florida cross the North Atlantic to Norway. The time record for movement from Bimini to Norway is less than 50 days at 204 km/day or 84 nmi/day (Mather 1962). The distance record is over 16,035 km (6,600 mi), for a fish tagged off Cat Cay, Bahamas, and recaptured off Argentina. School tuna tagged in the New York Bight area have occasionally crossed the Atlantic to the Bay of Biscay, France; a few fish tagged near the Bay of Biscay have been recaptured in New York Bight (Mather 1967). Some evidence suggests that giants tend to cross the Atlantic during summer but that juveniles tend to cross during winter. TransAtlantic migrations apparently do not occur every year, nor include the total population.

Population Size and Fisheries. After the second world war, commercial and sport fishing efforts for bluefin tuna increased on both sides of the Atlantic; new markets developed, more efficient fishing methods were introduced, smaller sizes were more actively sought, and the total fishing pressure on all sizes increased dramatically. The increased effort led to peak landings in 1955 from all the fisheries combined of about 32,000 MT, declining thereafter to about 10,000 MT by 1970, and 7,000 MT by 1973. Declines first became obvious in European waters; by 1973 landings of some fisheries had dropped by 99%, and several fisheries had gone out of business due to lack of fish.

In the Northwest Atlantic, US demand for bluefin tuna was low prior to the mid-1950s. Giants were taken in modest numbers from New York Bight to Newfoundland by harpoon, handline, rod and reel, and shore traps. Medium-sized tuna were taken along with the giants (except at Bimini) and with school fish in the Bight. Also, a few young-of-the-year were being caught in the New York Bight area by sport fishermen. Catches of all sizes in the Western Atlantic were modest, and the stock appeared stable. However, three developments rapidly changed the situation:

1. Longlining for bluefin was introduced into the Atlantic by the Japanese in 1956, and they (with other nations) began heavy fishing in mid-ocean throughout the North and South Atlantic.

2. US purse-seining for bluefin tuna was introduced into New York Bight in 1962—a method to which the bluefin proved extremely vulnerable. School tuna (ages one to four) were the main targets.

3. The Japanese learned that giant tuna taken in late summer off New England and Canada had the ideal fat content for their raw fish delicacy—*sashimi*. Their offering to buy giants at up to $1.45/lb (instead of the previous two to five cents/lb) in autumn 1972 greatly increased US fishing pressure on giants, particularly by rod and reel fishermen.

As a result of these changes, fishing mortality rates increased substantially in the Northwest Atlantic particularly on immature tuna found in the New York Bight area. Fewer juveniles survived to maturity, and with a declining spawning stock the status of the stock was considered serious (Mather 1972, 1973, 1974). Since 1974, measures have been taken by the International Commission for the Conservation of Atlantic Tunas (ICCAT) to prevent any further increase in fishing mortality.

Reproduction, Growth, Life Span. First maturity in bluefin tuna appears to occur at about age six. Only negligible signs of maturity have been observed in three-year-old bluefin tuna in the Western Atlantic and only slight signs in four- and five-year-old fish. Egg productions estimated by Rodriguez-Roda (1967) range from 5.2 million eggs for a 130 cm (63 in) fish to 32 million for a 230 cm (91 in) fish. Eggs are buoyant and drift with the currents.

Giant bluefin spawn in late April, May, and most of June in the northern Caribbean, the Gulf of Mexico, the Atlantic east and north of the Bahamas, and in the Straits of Florida. Evidence that medium-sized fish spawn slightly later off the Bight area includes:

1. finding ripe females and spent fish in the area;

2. occurrence of larvae in plankton tows in these areas;

3. observations of juveniles 20 to 120 mm (0.8 to 4.7 in) regurgitated by terns (Potthof and Richards 1970); and

4. records of young-of-the-year as early as June from Maryland to Cape Cod and through the following winter off the Carolinas (Mather et al, in press).

These observations suggest that the mid-Atlantic may be an important nursery ground for the bluefin. From a collection of 26 fish now known to be young-of-the-year (Mather and Schuck 1960) it can be estimated that fry hatched about May grow nearly 7.6 cm (3 in) per month, and attain 0.9 kg (2 lb) by September.

Westman and Gilbert (1941) and Westman and Neville (1942) aged juveniles in the New York Bight area, and Mather and Schuck (1960) expanded the aging to older fish throughout the Western Atlantic and validated age determinations to age 14. Based on these studies the probable growth rate of bluefin tuna in the Western Atlantic is shown in Table 15.

The world record rod and reel catch is 560 kg or 1,235 lb (International Game Fish Association 1979), and fish over 631 kg (1,500 lb) have reportedly been captured by other methods. Such giants are probably more than 20 years old.

Map 45. Bluefin tuna — distribution and spawning areas based on historical fishery records

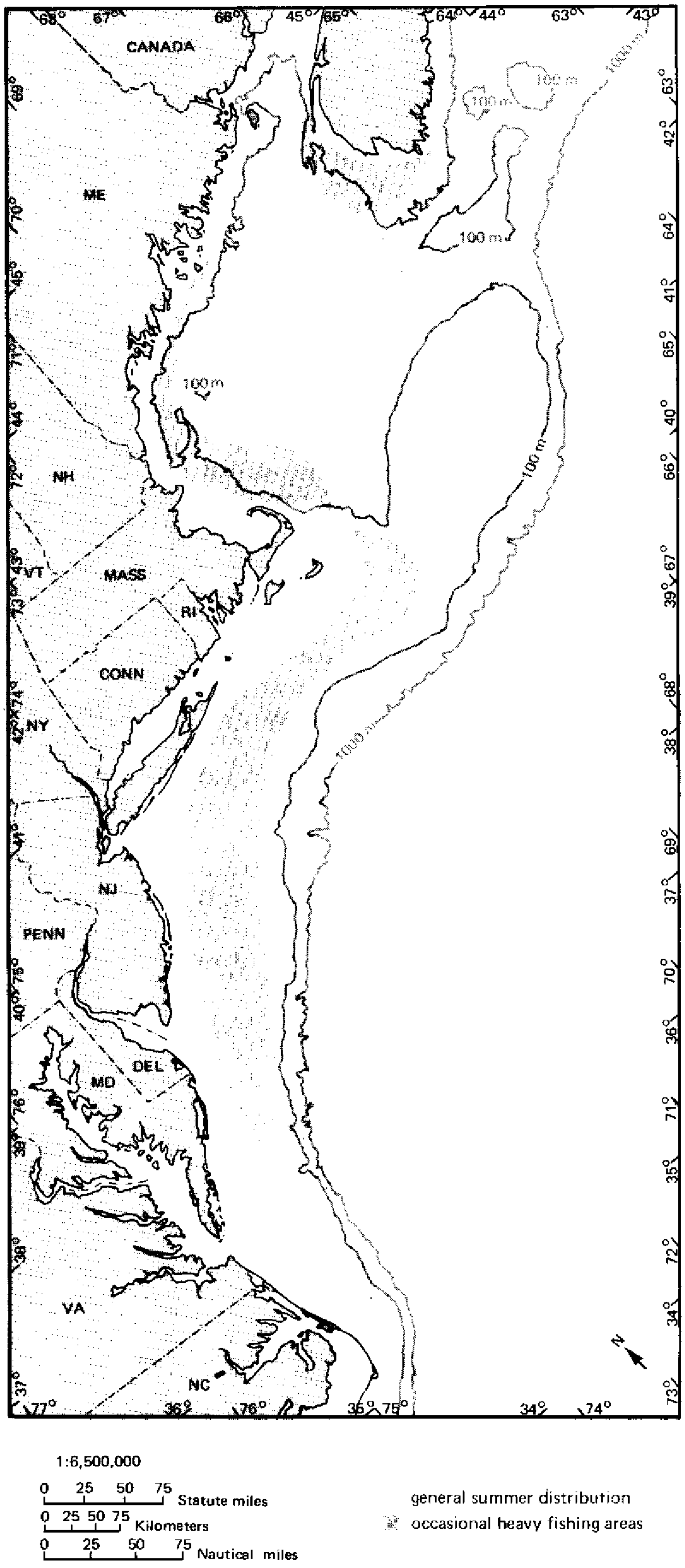


Table 15. Average weight at age of bluefin tuna taken in midsummer.

Age	Weight in kg (lb)	
0	1	(2.2)
1	4	(8.8)
2	10	(22)
3	18	(40)
4	31	(68)
5	45	(99)
6	67	(148)
7	85	(187)
8	110	(242)
9	130	(286)
10	150	(330)
11	170	(374)
12	200	(440)
13	235	(517)
14	290	(638)

NOTE: By midsummer each age group is about four months older than the even years shown.

Feeding Interrelationships. The bluefin feeds heavily on other fishes and decapods, especially schooling species, like herring, mackerel, silver hake, and squid (Bigelow and Schroeder 1953). In summer, tuna are seen feeding or traveling on the surface in coastal waters, but stomach contents indicate that they also feed on the bottom. In winter, bluefin are often in less productive oceanic areas and may depend on large zooplankton as well as fishes for sustenance. During the spawning season the majority of bluefin caught have empty stomachs.

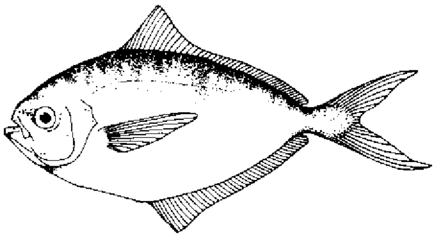
Other than man, the chief predators of large bluefin appear to be medium-sized cetaceans. Wulff (1943) and Mayo (personal communication) reported occasional attacks on schools of giant tuna by killer whales, *Orcinus orca*, off Newfoundland and Massachusetts. Similar attacks on schools of giant tuna in the Straits of Florida and in several other areas have been attributed to blackfish, *Globicephala melaena*, but in fact they were probably false killer whales, *Pseudorca crassidens.*

Environmental Sensitivity. The bluefin tolerates wide ranges of temperature and salinity—it is found from mid-ocean to shallow coastal waters and occasionally in harbors and rivers, particularly in Canada. This species is not truly cold-blooded and can actually maintain body temperatures as high as 8°C (18°F) above that of the ambient water (Carey and Teal 1969). This explains its remarkable ability to migrate rapidly over extremely long distances and through great variations of water temperature, such as from 30°C (86°F) at the Bahamas to 6°C (43°F) off Norway. Bigelow and Schroeder (1953) set the minimum surface temperatures at which the species occurs at about 16°C (61°F) for small sizes and 10°C (50°F) for giants.

European researchers indicated that during the spawning season the species is more sensitive to its environment than during the rest of the year (Roule 1917; de Buen 1927; Sella 1929; Scorida 1938). Temperature and salinity are believed to influence the exact location and timing of spawning in European waters, but there have been no similar studies in the western Atlantic.

Butterfish *Peprilus triacanthus*

Gordon Waring and *Steven Murawski*



Distribution and Seasonal Movements. The butterfish occurs from Newfoundland to Florida, but it is most abundant between southern New England and Cape Hatteras (Hildebrand and Schroeder 1928). Meristic and morphometric studies by Caldwell (1961) and Horn (1970) have suggested that two populations of butterfish exist in the Atlantic. One population appears to be restricted to shoal waters (less than about 20 m or 66 ft) south of Cape Hatteras, and another population occurs chiefly north of Cape Hatteras but possibly with some segments extending south of Hatteras in deeper waters of the shelf. There is some evidence that the inshore population described by Horn may have been a Gulf of Mexico species, *P. burti* (Perschbacher, Sulak, and Schwartz 1979).

Whatever the population structure in summer and autumn, butterfish are found over the entire mid-Atlantic shelf, inshore to offshore (Map 46). In late autumn butterfish move offshore in response to seasonal cooling and aggregate along the edge of the shelf where water temperatures remain relatively warm; the offshore movement is not so extensive south of Delaware Bay where winter cooling is less severe. Also, there is apparently some movement to the south, at least in shoaler waters. Butterfish have a minimum survival temperature of about 10°C or 50°F (Colton 1972). Inshore migrations of butterfish begin in April, and a return northerly movement also occurs in the spring.

Population Size and Fisheries. Prior to 1963 butterfish were harvested exclusively by US fishermen. From 1920 to 1963 total US butterfish landings averaged 3,500 MT and no significant trends were observed in the fishery as a whole which was conducted chiefly in the Middle Atlantic Bight (Waring 1975). However, there were some opposing trends by individual states from about 1940 to the early 1960s; NY and NJ landings declined (McHugh and Ginter 1978) whereas those in Rhode Island and Massachusetts increased (Waring 1975). Therefore, no significant trend for the Bight as a whole results. Since 1963, when foreign fleets first began catching butterfish, US landings steadily declined, reaching a 40-year low of about 800 MT in 1972 (Murawski and Waring 1979).

Autumn trawl surveys in the Bight indicated a 24% decline in abundance of butterfish from 1967 to 1974 (Clark and Brown 1977). Increased foreign fishing and lower than average recruitment to the stock contributed to the decline (Waring 1975).

Total landings of all countries rose to 17,500 MT in 1969 (mostly Soviet catches) then declined to 6,500 MT in 1972; landings were 19,500 MT in 1973 and declined to 11,400 MT in 1976. Since 1969 the foreign catch has been taken chiefly by Japanese vessels as a by-catch in their fishery for long-finned squid (*Loligo*).

Minimum biomass estimates from NMFS offshore trawl surveys averaged 61,000 MT from 1969-73 (Waring 1975). Stock size in early 1976 as determined from virtual population analysis was 32,000 MT, the lowest observed for the period 1968-76 (Murawski and Waring 1979).

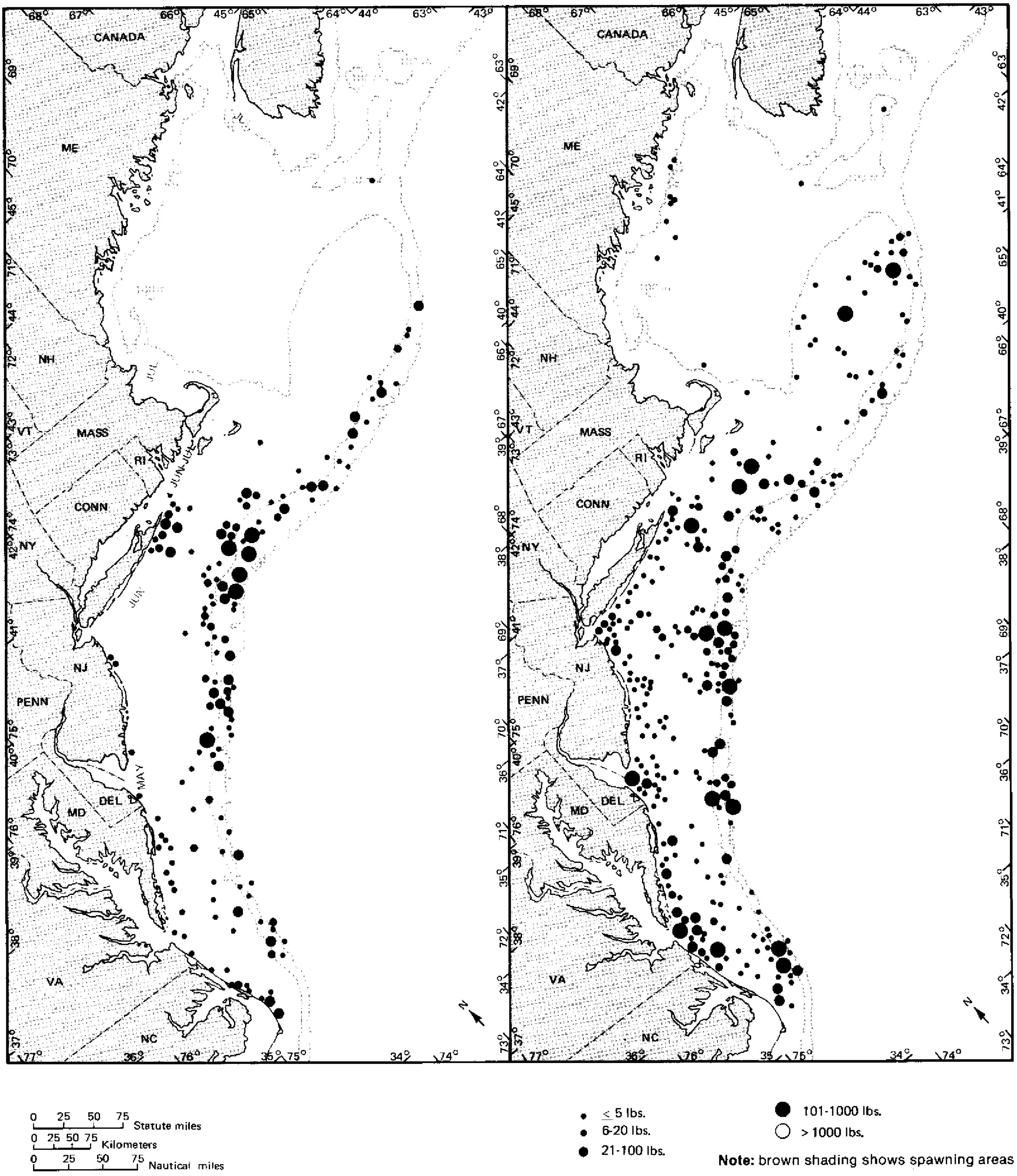
Reproduction, Growth, Life Span. Butterfish spawning takes place chiefly during summer (June-August) in inshore waters generally less than 30 m (98 ft) deep (Bigelow and Schroeder 1953; Livingstone, personal communication). The times and duration of spawning are closely associated with changes in surface water temperature. Colton (1972) suggested that the minimum spawning temperature is approximately 15°C (59°F).

Peak egg production occurs in Chesapeake Bay in June and July (Hildebrand and Schroeder 1928; Lessard 1974), off Long Island and Block Island in late June and early July (Perlmutter 1939; Austin 1973; Austin and Tollefson 1973), in Narragansett Bay in June and July (Herman 1963; Marine Research, Inc. 1974), and in Massachusetts Bay June to August (Bigelow and Schroeder 1953). However, Austin (personal communication) found eggs in the Bight in September 1971.

Butterfish eggs and larvae have been described by Kuntz and Radcliffe (1918) and Colton and Honey (1963). The eggs, 0.7 to 0.8 mm (0.027 to 0.031 in) in diameter, are pelagic, transparent, spherical, and contain a single oil globule. The egg membrane is thin and horny. Incubation at 18°C (65°F) takes less than 48 hours. Newly hatched larvae are 2 mm (0.08 in) long and like most fish larvae are longer than they are deep. At 6 mm (0.2 in) larval body depth has increased substantially in proportion to length, and at 15 mm (0.6 in) the fins are well differentiated and the young fish takes on the general appearance of the adult. Larvae are found at the surface or in the shelter of the tentacles of large jellyfish (Bigelow and Schroeder 1953; Thomas and Milstein 1973).

Butterfish eggs are found throughout the Bight and on Georges Bank, and they occur in the Gulf of Maine, but larvae appear to be relatively scarce east and north of Nan-

Map 46. Butterfish — distribution of NMFS 1973-74 research vessel trawl catches (dots) and spawning areas (shading) (spring-left, autumn-right)



Note: brown shading shows spawning areas

tucket Shoals (Bigelow and Schroeder 1953; Colton and St. Onge 1974). In 1966, larvae were caught from Cape Hatteras to Martha's Vineyard from April to December, but were most abundant in August (Map 13). In 1973, from mid-June to early September, larvae were common in the plankton off Shoreham, LI (Lessard 1974). Post-larvae and juveniles were common in plankton net samples taken in August in the vicinity of Little Egg Inlet, NJ (Thomas and Milstein 1973). Juveniles 76 to 101 mm (3 to 4 in) long have been taken in Rhode Island waters in late October (Tracy 1910).

Growth is fastest during the first year and decreases each year thereafter. Young-of-the-year butterfish collected in October trawl surveys (at about 4 months old) average 12.2 cm (4.8 in) long. Fish about 16 months old are 16.8 cm (6.6 in), at about 28 months old fish are 17.3 cm (6.8 in), and at 40 months old they are 19.8 cm (7.8 in). Draganik and Zukowski (1966) reported the maximum age as six. More recent studies showed that the population was composed of four age groups ranging from young-of-the-year to over age three (DuPaul and McEachran 1969; Waring 1975; Kawahara 1977).

Some butterfish are sexually mature at age one, but all are sexually mature by age two (DuPaul and McEachran 1969).

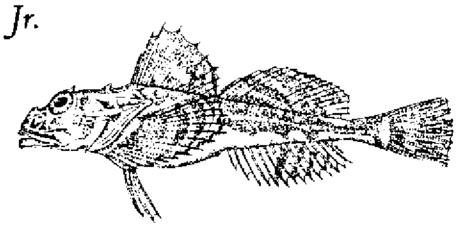
Feeding Interrelationships. The butterfish is primarily a planktivore and feeds on copepods, small fish, polychaetes, small jellyfish (*cnidaria*), and gammarid amphipods (Bigelow and Schroeder 1953; Lang 1974). Stomach contents of butterfish collected during autumn off Shoreham, LI, showed that 50% of their diet was *cnidaria* (Lang 1974). In Narragansett Bay juvenile butterfish were the single greatest predator on ctenophores (Kramer, personal communication). This could be of major significance to recruitment of other fishes because ctenophores are implicated as major predators of small fish larvae.

Analysis of food habits of marine fish in the Bight indicate butterfish are prey for silver hake, bluefish, goosefish, and common hammerhead sharks (Maurer and Bowman 1975). Butterfish are also preyed upon by squid and may be a significant part of their food source since seasonal distribution patterns of longfin squid, *Loligo pealei,* are similar to butterfish (Tibbetts 1977).

Longhorn Sculpin

Myoxocephalus octodecemspinosus

Paul W. Wood, Jr.



Distribution and Seasonal Movements. The longhorn sculpin is found from eastern Newfoundland to New Jersey, with occasional sightings off Virginia (Bigelow and Schroeder 1953). Throughout most of its range the longhorn sculpin is inshore during autumn and winter and offshore during late spring and summer, with no appreciable north-south migration (Map 47). While inshore it may be present on shoals, in harbors, and on the flats at high tide. It is common in Block Island Sound November through April and off New York September to May (Bigelow and Schroeder 1953). Morrow (1951) thought seasonal movements may be caused by an endocrine cycle rather than by temperature. Sculpins are found in temperatures ranging from 0° to 19°C (32° to 66°F). They are caught in considerable numbers down to 91 m (298 ft) and have been taken as deep as 192 m or 630 ft (The Research Institute of the Gulf of Maine, Public Affairs Research Center 1974).

Population Size and Fisheries. In the United States, longhorn sculpin are landed only in the industrial trawl fisheries and along with many other so-called industrial species are utilized for fish meal and fertilizer. The mean estimated annual catch of sculpin was approximately 1,500 MT between 1970 and 1974 in the area from Cape Hatteras to western Nova Scotia. The mean catch by the Soviet Union over the same years was about 3,600 MT. It seems likely that the total population biomass must be at least on the order of 10,000 to 15,000 MT for this region.

NMFS trawl survey data indicate that only about 2.5% of the longhorn sculpin found from Nova Scotia to Cape Hatteras are located in the New York Bight area.

Reproduction, Growth, Life Span. Spawning takes place throughout the longhorn sculpin's range November through January and large fish spawn later than small ones (Morrow 1951). The female produces about 8,000 demersal, adhesive eggs per year (Bigelow and Schroeder 1953); these hatch in three months or less. Sculpin reach maturity during the third year when the length is about 21 cm (8 in) and have been aged to 11 years (Morrow 1951).

Average growth rate appears to be slow after maturation by length-at-age data reported in The Research Institute of the Gulf of Maine, Public Affairs Research Center (1974) and shown in Table 16.

Map 47. Longhorn sculpin — distribution of NMFS 1973-74 research vessel trawl catches (dots) (spring-left, autumn-right)

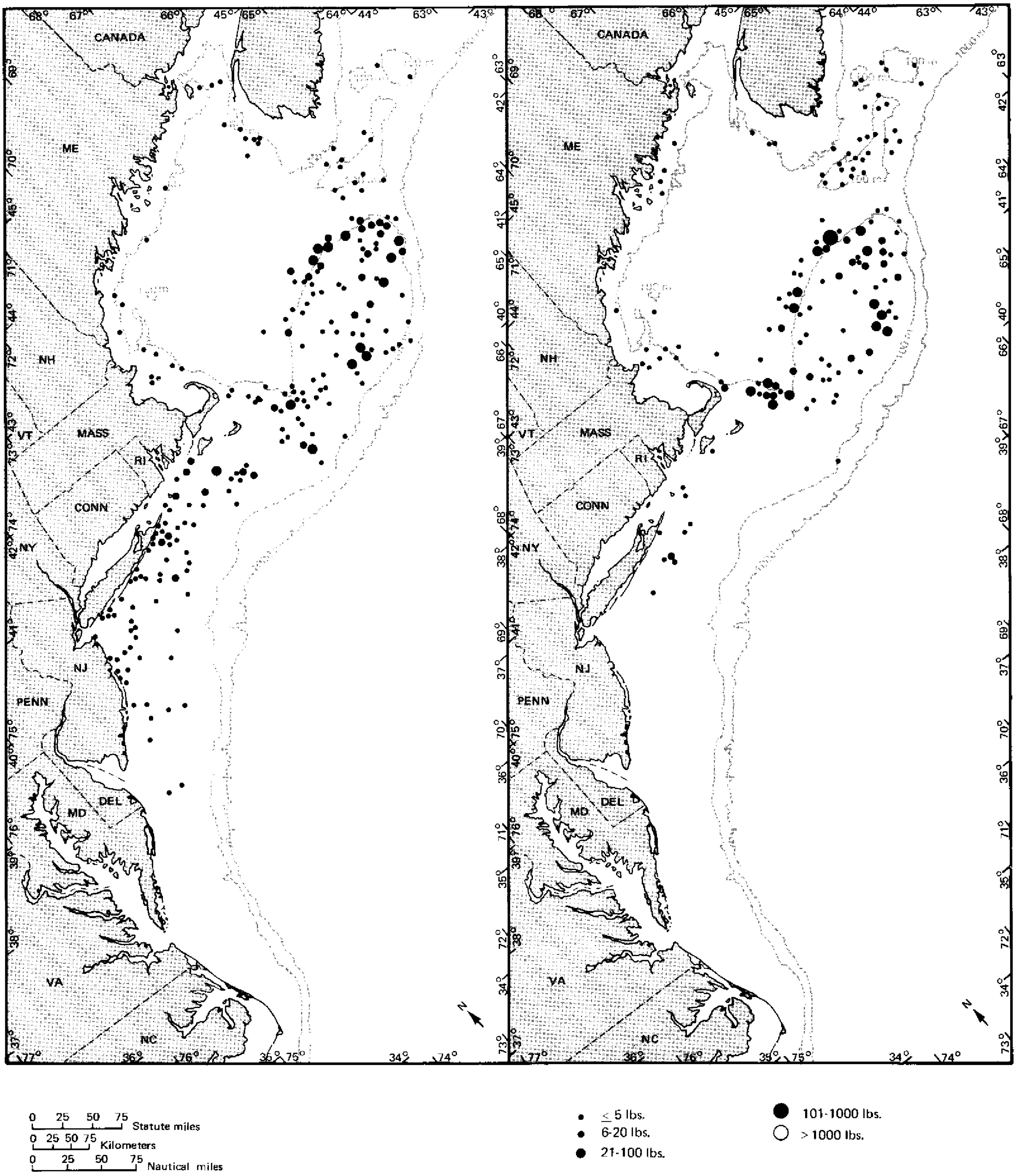


Table 16. Length at age for Longhorn sculpin.

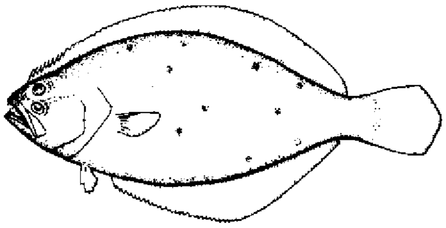
Age	Length in cm (in)
1	5.6 (2.2)
2	18.2 (7.1)
3	24.3 (9.6)
4	26.3 (10.4)
5	27.4 (10.8)
6	28.6 (11.3)
7	29.2 (11.5)
8	29.8 (11.7)
9	30.2 (11.9)

Feeding Interrelationships. Longhorn sculpin feed primarily on crustacea and particularly *Cancer* crabs (Maurer and Bowman 1975). Fish including other sculpins form a much smaller part (8%) of their diet (Maurer and Bowman 1975), but fish fry (very young) eaten include alewives, cunners, eels, mummichogs, herring, mackerel, menhaden, puffers, sand lance, scup, silversides, smelt, tomcod, silver hake, and sculpin (Bigelow and Schroeder 1953). Longhorn sculpin also eat fish eggs and are suspected of being significant herring egg predators because of their abundance near herring egg beds on Georges Bank (Caddy et al 1971).

Fishes feeding on longhorn sculpin include barndoor skate, smooth skate, goosefish, cod, wolffish, and sea raven (Maurer and Bowman 1975).

Summer Flounder *Paralichthys dentatus*

Charles J. Byrne and *Thomas R. Azarovitz*



Distribution and Seasonal Movements. The summer flounder is one of the lefteye flounders in the family *Bothidae* and is one of the larger and more predaceous flatfish. The range of the summer flounder, or fluke as they are sometimes called, extends from Nova Scotia (Vladykov and McKenzie 1935; Leim and Scott 1966) to Florida (Norman 1934). Briggs (1958) has given their range as extending into the northern Gulf of Mexico. However, occurrences north of Cape Cod are uncommon, and south of Cape Hatteras their numbers dwindle rapidly. South of the Virginia capes two other closely related species, the southern flounder (*Paralichthys lethostigma*) and the gulf flounder (*Paralichthys albigutta*) enter the recreational and commercial fisheries and often are not distinguished from summer flounder.

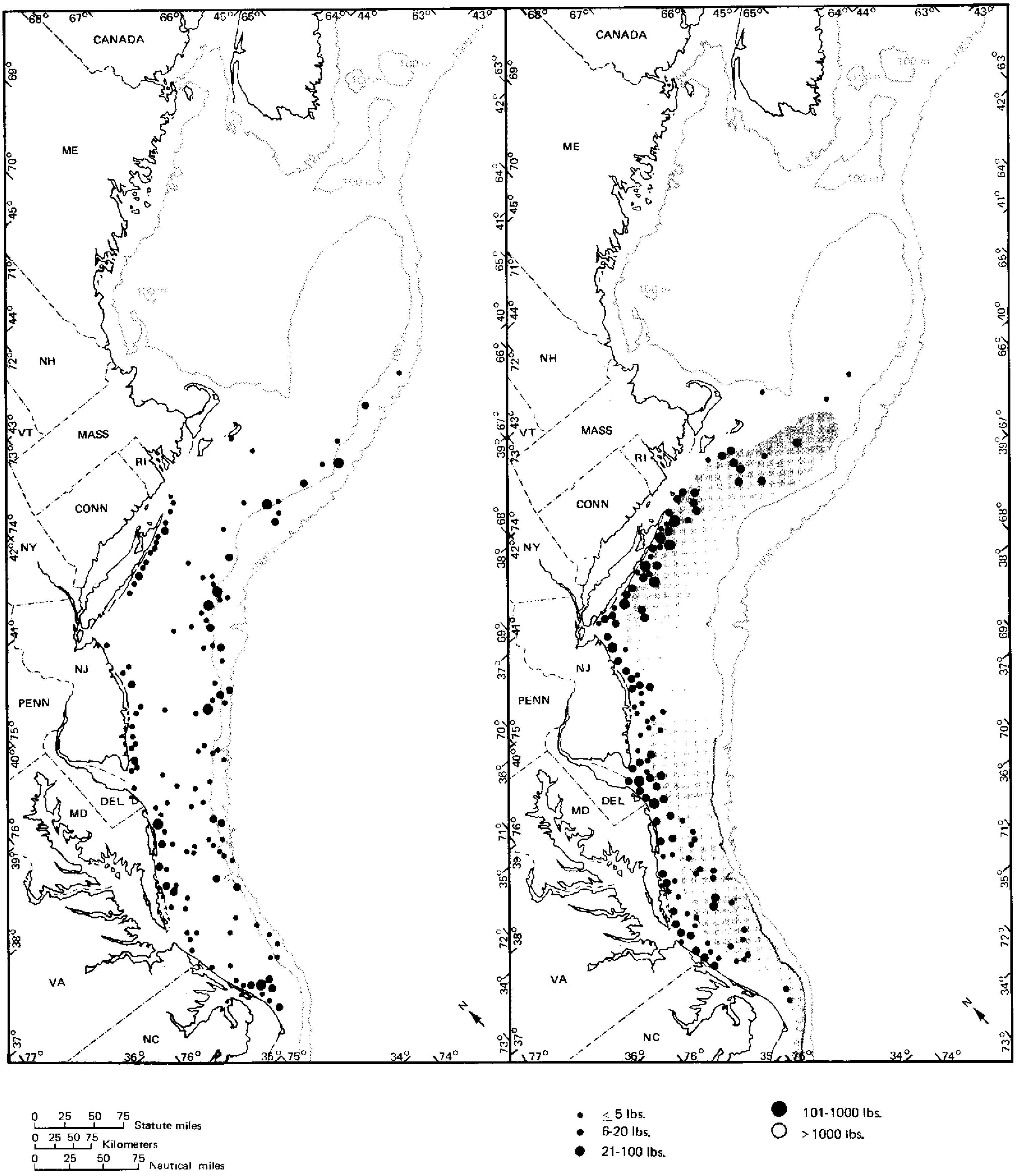
In the Middle Atlantic Bight summer flounder can be found from the outer portion of the continental shelf to shallow inshore waters, and they exhibit seasonal inshore-offshore migrations as shown by NMFS trawl surveys (Map 48). During the summer months, summer flounder are distributed in shallow coastal waters, bays, and estuaries. In the winter and early spring, they are found offshore, principally in depths ranging from about 70 to 155 m (230 to 509 ft).

In the inshore waters of New York Bight, summer flounder usually first appear in April, continue to move inshore May and June, and reach their peak abundance July or August. Recreational creel surveys show that angler catches reach a peak in early July but then drop off sharply in August (Poole 1962; Murawski and Festa 1977). Possible explanations for the sudden drop in August recreational catches include: (1) start of the offshore migration at this time; (2) effects of intense and localized recreational fishing pressure; and (3) changes in feeding behavior which may relate either to the impending offshore migration or subsequent spawning. Special monthly NMFS trawl surveys, from June 1974 to June 1975 in the New York Bight apex, seem to show that the maximum inshore movement of summer flounder occurred in August in that year, and that the offshore migration was well under way by the third week in September (Wilk et al 1977).

Hamer and Lux (1962) conducted a tagging experiment on both inshore and offshore grounds. Summer flounder that were tagged in NJ inshore waters, scattered over the entire Middle Atlantic Bight during their offshore migration. Since spawning occurs in autumn (Smith 1973*a*), this pattern suggests that the summer flounder population of the Bight is homogeneous. Other results of the study showed: (1) summer flounder tagged on offshore grounds to the east of Hudson Canyon were recaptured between Lower New York Bay and Cape Cod and rarely strayed south or west of Hudson Canyon; (2) fish released in the inshore waters of New Jersey could be found from Veatch Canyon to below the Virginia capes; and (3) there was a tendency for summer flounder to spend their second summer (after tagging) north or east of where they were released. Hamer and Lux (1962) found general movement of adults northward along the NJ coast and eastward along the LI coast toward the vicinity of Martha's Vineyard. This pattern of movement is consistent with the fact that one- and two-year old summer flounder are not taken in offshore NMFS trawl surveys between Nantucket Shoals and George Bank. That is, in the absence of these younger fish, there would have to be a steady movement eastward to maintain a population in these offshore areas.

Juveniles spend the summer months in the inshore estuarine areas. During the late 1960s greater numbers of post-larvae and juveniles were found in the bays and sounds south of the Virginia capes than to the north. It was hypothesized that this was due to the prevailing southwesterly drift which carried eggs and larvae away

Map 48. Summer flounder — distribution of NMFS 1973-74 research vessel trawl catches (dots) and spawning areas (shading) (spring-left, autumn-right)



Note: brown shading shows spawning areas (October-December) from the northern spawning areas, and that the southern areas were the primary nursery grounds for the species. Most of these conclusions were based on information obtained when the summer flounder population in the mid-Atlantic and especially New York Bight was very low. However, historical records show that when the summer flounder population was at higher levels, significant numbers of juveniles were also found in northern estuaries (Poole 1961; Smith 1973*a*). Juveniles in southern waters overwinter in the bays and sounds whereas in the north there is some movement offshore, although many larval and juvenile summer flounder still remain inshore through the winter months (Smith 1973*b*; Wilk et al 1977). Data are not adequate to determine the relative importance of the two areas accurately, but it is clear that summer flounder use the northern estuaries to a significant extent.

Population Size and Fisheries. In a historical summary of the flounder fisheries of New York Bight, McHugh (1977*a*) noted that the summer flounder, which is the principal species in NJ flounder landings, had reached peak levels in the 1950s and then declined drastically in the 1960s. Although population estimates are not available for this period it is apparent that abundance must have declined significantly, particularly in the northern part of the Bight. For example, landings in Massachusetts showed a precipitous drop, from 5,240 MT in 1961 to only 41 MT in 1970 (Chang and Pacheco 1976). The first estimates of actual population size were made by Chang and Pacheco (1976) who estimated that from 1967 to 1974 the summer flounder population north of Cape Hatteras ranged from 36,000 to 74,000 MT. They also estimated that the maximum annual catch that could be safely removed on a long-term average basis was about 20,000 MT.

During the winter, the summer flounder fishery is entirely an offshore trawl fishery, whereas in summer the fishery is concentrated in coastal waters, bays and estuaries, and has both recreational and commercial components. The summer commercial fishery utilizes the otter trawl (which accounts for approximately 90% of total commercial landings), and also pound nets, hand lines, haul seines, floating traps, gill nets, weirs, other types of fish traps and pots, and spears (Wheeland 1973). Almost the entire recreational fishery is made up of anglers; however, in the more southern states some summer flounder are taken with spears. Deuel (1973) found that from Long Island northward approximately 63% of the recreational catch was in sounds, bays, and rivers with the remainder coming from the ocean; south of Long Island 59% were taken from sounds, bays, and rivers.

Deuel (1973) estimated that during 1970, recreational fishermen landed approximately 8,800 MT of summer flounder between Cape Hatteras and Maine. During the same year, approximately 2,600 MT were landed by US commercial fishermen and approximately 36 MT were reported by foreign fishermen (Wheeland 1973; International Commission for the Northwest Atlantic Fisheries 1975). The recreational fishery probably accounts for more than half of the total catch. Hamer and Lux (1962) found that from inshore releases, approximately 54% of the tags were recovered through the commercial fishery, while the remaining 46% were recovered from the recreational fishery. More accurate estimates of recreational catch are needed for clarification.

Reproduction, Growth, Life Span. Summer flounder spawn as they are migrating offshore during the autumn. Smith (1973*a*) found that spawning starts mid-September between southern New England and New Jersey. As the season progresses spawning moves southward, and by October spawning takes place nearly as far south as Chesapeake Bay. In late October spawning ends off New York and southern New England, and by mid-December most spawning ceases in the Middle Atlantic Bight. South of Cape Hatteras spawning begins as early as November on the outer banks of North Carolina and a few eggs may be found until February.

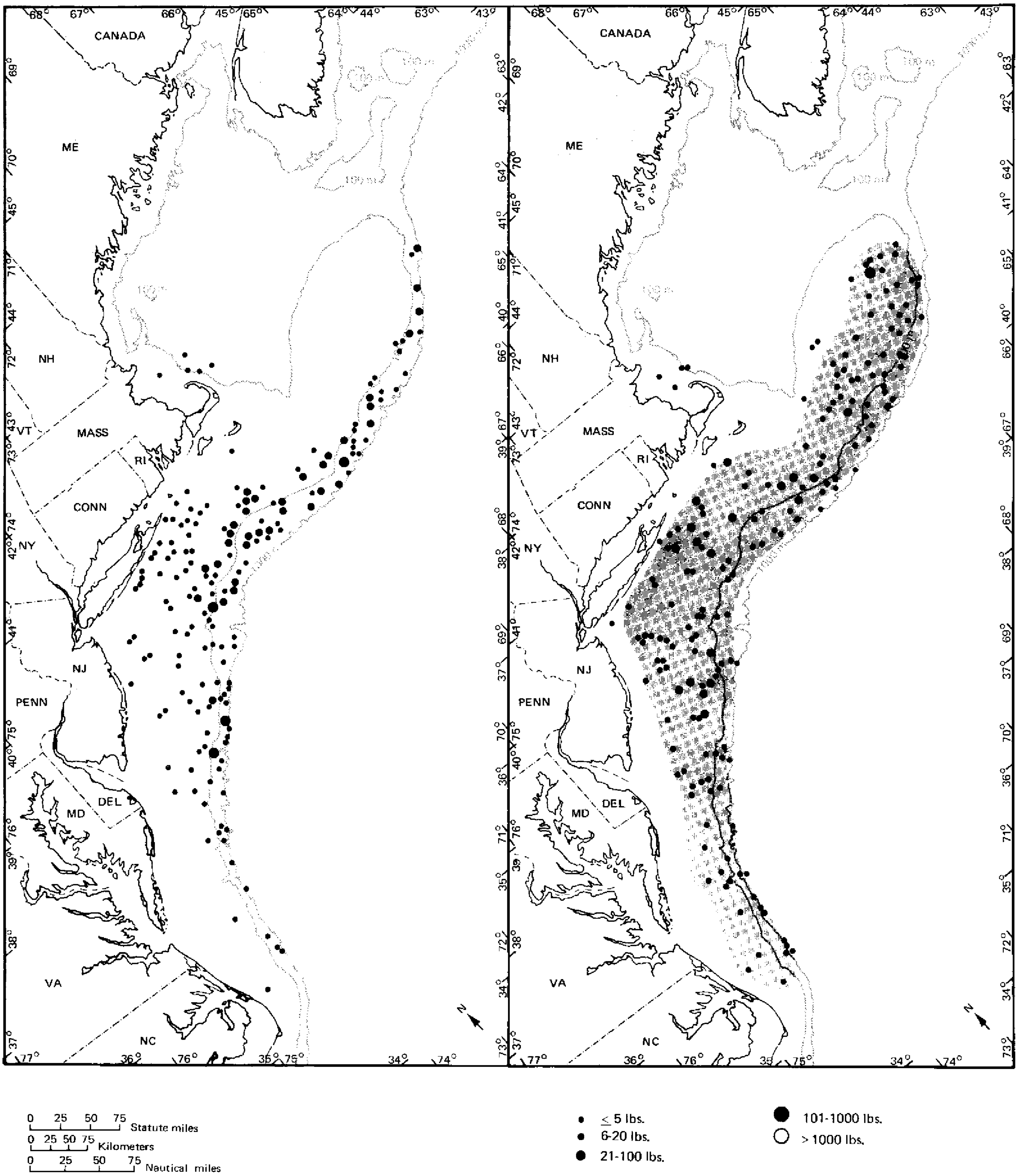
Summer flounder first spawn at the end of their third year when they reach about 37 cm (15 in) in length (Eldridge 1962). The number of eggs produced varies from about 0.5 million in a 40 cm (16 in) long fish to over 3.5 million in a fish over 65 cm or 26 in (Morse 1978*b*). Fertilized eggs are buoyant, spherical with a transparent rigid shell of about 0.9 to 1.1 mm (0.035 to 0.047 in), and have one spherical oil globule at the vegetal pole during development (Smith and Fahay 1970). The perivitelline space occupies about 6% of the egg radius. As the embryo develops the yolk becomes centrally located.

Smith (1973*a*) discussed the geographical distribution of eggs and larvae in 1966 in detail. The heaviest concentrations of eggs and larvae were found between Long Island and Cape Hatteras; the greatest number of eggs was taken within 46 km (28.6 mi) of shore and larvae were most abundant 22 to 83 km (13.7 to 51.6 mi) from shore. Larvae were found in the northern part of the Bight from September to February, and in the southern part from November to May (Smith 1973*a*). A composite pattern of larval distribution for all cruises in 1966 is shown in Map 18.

Smith found that eggs were most abundant (approximately 77% of the total) in the water column where bottom temperatures ranged from 12° to 19°C (53° to 66°F). However, eggs were found in temperatures as cold as 9.1°C and as warm as 22.9°C (48° and 73°F). Larvae have been found in temperatures ranging from 0° to 23.1°C (32° to 73.6°F) but are most abundant between 9.0° and 17.9°C (48.4° and 64.2°F). The incubation period from fertilization to hatching is estimated to vary with temperature as follows: about 142 hours at 9.1°C (48.4°F); 72 to 75 hours at 17.5°C (63.5°F); and 56 hours at 22.9°C or 73.2°F (Smith 1973*a*).

After the pelagic summer flounder larvae metamorphosize, they are capable swimmers and become demersal. They then migrate toward shore and enter the estuaries.

Map 49. Fourspot flounder — distribution of NMFS 1973-74 research vessel trawl catches (dots) and spawning areas (shading) (spring-left, autumn-right)



Note: brown shading shows spawning areas (autumn)

Juvenile summer flounder are well adapted for estuarine life; they are able to withstand a wide range of temperatures and salinites (Duebler and White 1962). Juveniles apparently remain in the estuaries (or just outside the estuaries in the north) until they are of sufficient size to join an offshore migration with the adult summer flounder population.

Several authors have investigated length-at-age relationships for summer flounder (Poole 1961; Eldridge 1962; Smith and Daiber 1977; Richards 1970). Although Poole's results show faster growth than the others, all studies showed that females grow faster than males and are consistently larger than their male counterparts at any given age except for the first few months after hatching.

The length-weight relationship for summer flounder from southern New England waters has been calculated by Lux and Porter (1966). Their results showed that there are both seasonal and sexual differences in this relationship. Males weighed slightly more than females at a given length, but the males were also older due to their slower rate of growth. This difference between the sexes was also noted by Smith and Daiber (1977) and Eldridge (1962).

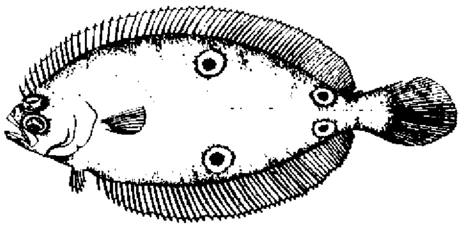
Richards (1970) estimated the maximum lengths for summer flounder to be about 61 cm (24 in) for males and 94 cm (37 in) for females, and corresponding maximum weights were 2.6 kg (5.7 lb) for males and 13.4 kg (29.5 lb) for females. These values are comparable with those reported by Bigelow and Schroeder (1953).

Feeding Interrelationships. Summer flounder are active,voracious feeders, and fish make up a very significant part of their diet. They are most active during daylight hours and may be found well up in the water column as well as on the bottom (Olla, Samet, and Studholme 1972). Included in their diet are: winter flounder, northern pipefish, Atlantic menhaden, bay anchovy, red hake, Atlantic silverside, American sand lance, bluefish, weakfish, mummichog, rock crabs, squids, shrimps, small bivalve molluscs, small crustaceans and snails, marine worms, and sand dollars (Verrill and Smith 1873; Bigelow and Schroeder 1953; Poole 1964).

Natural predators of adult summer flounder are unknown but larger predators such as large sharks, rays, and goosefish probably include summer flounder in their diets. Results of the extensive 1969-72 food habits studies by NMFS showed that flatfishes occurred in the stomachs of a number of fish-eating species taken in the mid-Atlantic; these included spiny dogfish, goosefish, cod, silver hake, red hake, spotted hake, sea raven, longhorn sculpin, and fourspot flounder (Bowman et al 1976). These data do not indicate the proportion of summer flounder among the flatfish prey but it is likely they are represented.

Fourspot Flounder *Paralichthys oblongus*

Daniel Ralph



Distribution and Seasonal Movements. The fourspot flounder is a lefthanded flatfish in the family *Bothidae*, which resembles the summer flounder in appearance and habits, but is smaller and generally not found inshore except in southern New England. The fourspot is characterized by four prominent "eye" spots on its back. It ranges from Georges Bank to Tortugas, FL, but the center of abundance is between Nantucket Shoals and Delaware Bay (Bigelow and Schroeder 1953; Gutherz 1967). NMFS trawl survey records and larval collections indicate occurrence to be rare south of Cape Hatteras (Smith et al 1975; Wilk and Silverman 1976). A few catches have been made as far north as the Massachusetts Bay area.

In the northern mid-Atlantic fourspot occur over much of the shelf, including inshore waters, whereas in the southern mid-Atlantic they are found chiefly offshore (Gutherz 1967). Spring and autumn trawl surveys indicate that north of Delaware Bay there is some seasonal movement into deeper waters in winter, particularly on Georges Bank, and a return to shoaler waters in summer (Map 49).

In New York Bight the fourspot flounder is a yearlong resident, although monthly trawl surveys indicate the greatest concentrations occur there from September through November (Wilk et al 1975). Seasonal movements are believed to be related to changes in bottom temperature.

Population Size and Fisheries. Historically, there has been no directed fishery for the fourspot flounder, either commercial or recreational. Records of landings have been combined with those of other miscellaneous flatfishes and listed as "unclassified flounders." Catches on trawl surveys have provided the primary source for baseline biological data on the species. At present, there is no analysis available on the population structure.

Reproduction, Growth, Life Span. The spawning season of the fourspot flounder is May to October, peaking in June and July (Wilk et al 1975). Spawning commences in the south and advances north in response to increasing water temperatures. Larvae appear first nearshore off Virginia and North Carolina and occur farther seaward as offshore waters warm (Bigelow and Schroeder 1953; Smith et al 1975). Larval distribution (Map 18) indicates most spawning occurs along the northern half of the Middle Atlantic Bight in temperatures between 6° and 9°C (43° and 48°F) in waters 35 to 80 m (115 to 262 ft) deep (Smith et al 1975).

Fourspot flounder eggs are buoyant, nonadhesive, contain a single oil globule, and have an average diameter of 1 mm or 0.04 in (Miller and Marak 1962). Eggs hatch in approximately eight days at a temperature of 11.7°C or 53.1°F (Nichols and Breder 1927). Artificially spawned eggs hatched in 54 hours at 21°C or 70°F (Miller and Marak 1962). Larval length at hatching ranges from 2.7 to 3.2 mm (0.11 to 0.12 in). Metamorphosis begins at about 10 to 11 mm (5.34 to 5.43 in) SL with migration of the right eye. As the body shape becomes more flounderlike at 12 mm (0.47 in) dorsal eye migration has advanced further, scale formation has begun, and fin formation is complete (Leonard 1971). Metamorphosis is not complete at this stage but larvae may already be settling to the bottom since Smith and associates (1975) reported seldom catching pelagic larvae larger than 8 mm (0.31 in), which they attributed to a change from pelagic to a demersal type behavior. Young-of-the-year fish have been found in New York Bight in July and their greatest abundance observed in October (Wilk et al 1975; Smith et al 1975).

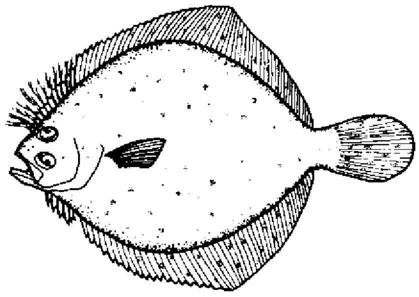
Adults average 25 to 30 cm (9.8 to 11.8 in) TL, with an approximate maximum of 45 cm (18 in), but females weigh more than males at a given length (Wilk et al 1975). No information is presently available on age composition of the population, rates of growth, and fecundity. However, sex ratio has been observed to vary throughout the year with respect to the annual spawning cycles (Wilk et al 1975).

Feeding Interrelationships. The fourspot flounder's diet is similar to that of summer flounder and consists of small fishes and squid, crabs, shrimp, other crustaceans, molluscs, and annelids (Bigelow and Schroeder 1953). Maurer and Bowman (1975) analyzed stomach contents of fourspot flounder and grouped the food items into five categories: crustaceans, 32% by weight; molluscs, 21%; fishes, 32%; animal remains, 13%; and miscellaneous, 1%. Silver hake alone comprised 27% of the total diet and squid contributed 21%.

Environmental Sensitivity. Preliminary investigation of fin erosion in fourspot flounder (Ziskowski and Murchelano 1975) suggests that this disease may be associated with pollution in the Bight.

Windowpane *Scophthalmus aquosus*

Louise Dery and *Robert Livingstone, Jr.*

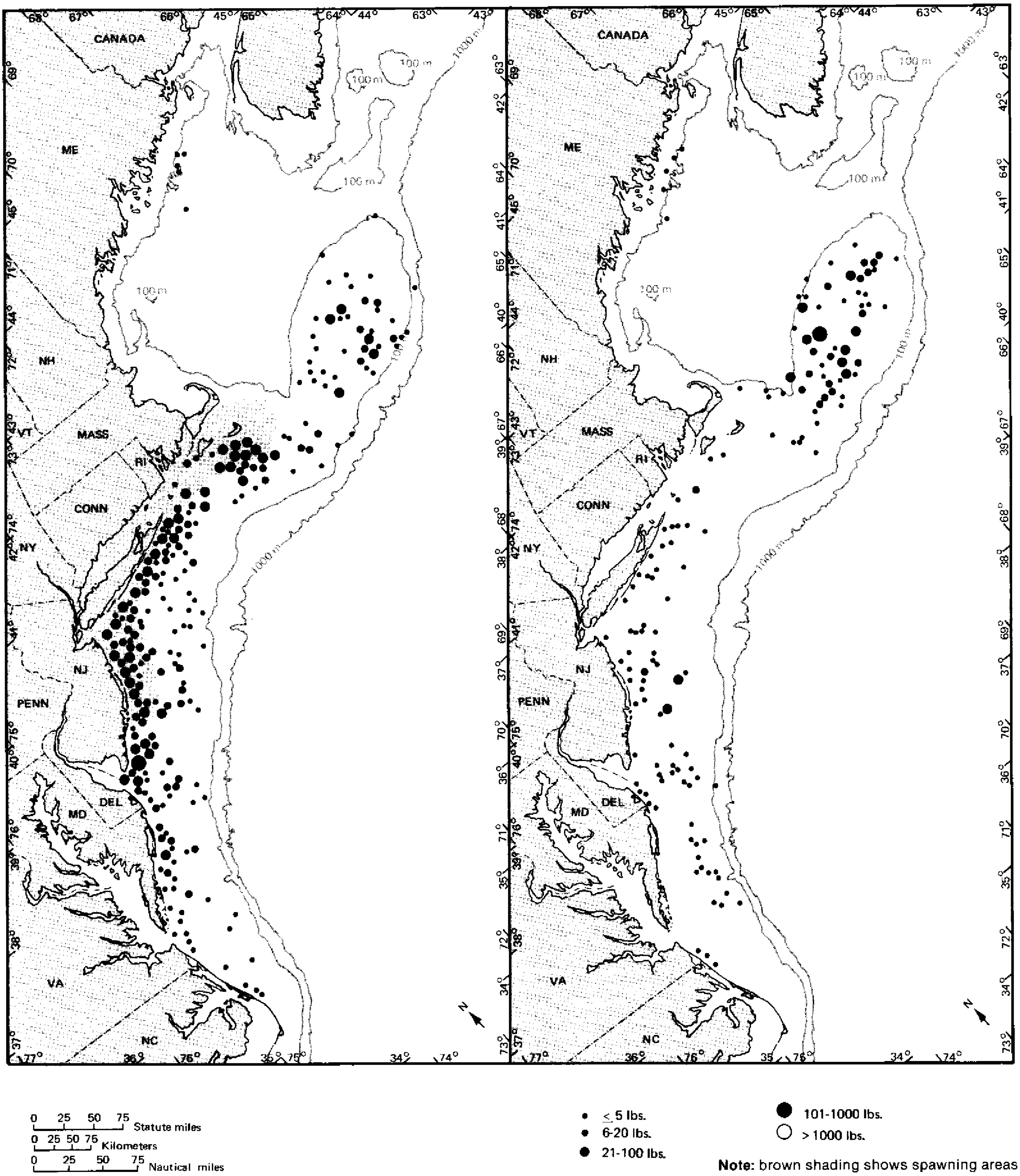


Distribution and Seasonal Movements. The windowpane or sand flounder is a lefthanded flatfish of the family *Bothidae.* Its name derives from the fact that it has such a thin body that it appears translucent when held up against a light. It occurs from the Gulf of St. Lawrence to South Carolina, but is most abundant from Georges Bank to the Chesapeake Bay area, with maximum abundance in New York Bight. North of Cape Cod this species is found only in scattered locations, perhaps limited by temperature. The windowpane is generally found on sandy bottoms in waters less than about 80 m (262 ft), and according to Bigelow and Schroeder (1953), close inshore and in estuaries to just below mean low water mark. Tagging studies showed that windowpane tend to move along the coast but provided no evidence that they undergo major seasonal migrations (Moore 1947). However, NMFS trawl surveys (Map 50) indicate that they are aggregated in shoal waters in the summer and early autumn (when bottom water temperatures are still warm) and move offshore during winter and early spring months when temperatures are near minimum (Lange and Lux 1978).

Population Size and Fisheries. The windowpane has been largely ignored as a food fish until recently (mid-1970s), because it is a small, thin-bodied fish compared to other flounders. Before 1975 the only significant landings occurred in New York, where a short-lived market developed toward the end of the second world war with landings of about 1,600 MT in 1944 and 1945. After the war the market quickly declined (Moore 1947). Foodfish landings of windowpane began again in 1975 particularly in New Bedford, MA, probably due in part to regulations imposed on the declining yellowtail fishery and possibly due to increased abundance of windowpane since 1972 (Lange and Lux 1978). Total New England foodfish landings for the species have ranged from about 1,700 to 2,000 MT between 1975 and 1978. Much of this catch came from Georges Bank where the largest individuals are found (Lange and Lux 1978). An estimate of total population size is not yet available for windowpane.

Windowpane has also been landed in the United States as an industrial "trash" species (reduced to fish

Map 50. Windowpane — distribution of NMFS 1973-74 research vessel trawl catches (dots) and spawning areas (shading) (spring-left, autumn-right)



Note: brown shading shows spawning areas

meal) since the late 1940s and landings ranged from 66 to 399 MT during the 1969-78 period (Table 17).

Reproduction, Growth, Life Span. Although windowpane spawn primarily from Cape Cod to Chesapeake Bay in depths less than 40 m or 131 ft (Colton and St. Onge 1974; Smith et al 1975), some spawning takes place north of Cape Cod — larvae have been collected along the Maine Coast and Scotian Shelf (Shih, Figueria, and Grainger 1971). Major spawning occurs inshore and in the estuaries of New York Bight; in and around Massachusetts Bay (Bigelow and Schroeder 1953); Block Island Sound (Moore 1947); Narragansett Bay (Herman 1963; Marine Research, Inc. 1974); Long Island (Austin 1973, 1976; Amish 1974; Bloom 1974); and Little Egg Inlet and vicinity (Thomas and Millstein 1973). Estuarine spawning is not important south of New York Bight (Scotton et al 1973).

Windowpane apparently spawn somewhere in the Bight from April to December; geographic and seasonal shifts in spawning activity depend on temperature. During 1966, spawning began in April south of Chesapeake Bay, reached its peak in May and ended by June; it advanced northward to New Jersey and New York during the summer, reaching a peak there in autumn, and at the same time spawning resumed off Virginia and North Carolina (Smith et al 1975). Throughout the Bight 70% of the spawning in 1966 occurred in the range of 8.5° to 13.5°C (47° to 56°F) in bottom water temperatures. Spawning was interrupted during the summer of that year south of Chesapeake Bay when bottom temperatures exceeded 15°C (59°F) and resumed in autumn when they dropped below 14°C or 58°F (Smith et al 1975).

Windowpane eggs are pelagic, spherical, transparent, and buoyant, 1.00 to 1.20 mm (0.04 to 0.05 in) in diameter, with a single colorless to lemon-colored oil globule 0.16 to 0.28 mm (0.006 to 0.01 in), possessing faint irregular surface markings. Incubation occurs in eight days at temperatures between 10.6° and 14.4°C (51° and 58°F). The newly hatched prolarva, about 5.5 mm (0.22 in) long, have pigment and an eye on either side of the body and swim upright. Postlarval metamorphosis is rapid; by 8.5 mm (0.33 in) fin ray formation is nearly completed. Migration of the right-hand eye to the left side is complete by 10 mm (0.39 in) and juveniles are now ready to move to the bottom of their inshore habitats (Moore 1947; Bigelow and Schroeder 1953). Windowpane pass through their larval stages in about one to two months, which is rapid relative to other flounders. With growth and maturity young windowpane tend to move offshore into deeper waters.

TABLE 17. US industrial landings (MT) of windowpane, 1969-78.

Year	Nantucket Shoals to Block Island	Block Island to Delaware Bay	Total (MT)
1969	200	112	312
1970	107	57	164
1971	38	28	66
1972	Not listed by species		—
1973	385	14	399
1974	369	10	379
1975	181	60	241
1976	113	30	143
1977	119	16	135
1978	220	26	246

TABLE 18. Length at age for windowpane.

Age	Length in cm (in) Male	Length in cm (in) Female
1	◄ 18 (7.1)	◄ 18 (7.1)
2	20-29 (7.9-11.4)	20-29 (7.9-11.4)
3	28 (11)	28 (11)
4	29.5 (11.6)	31.5 (12.4)
5	31 (12.2)	33 (13)
6	31.5 (12.4)	34.5 (13.6)
7	—	36 (14.2)

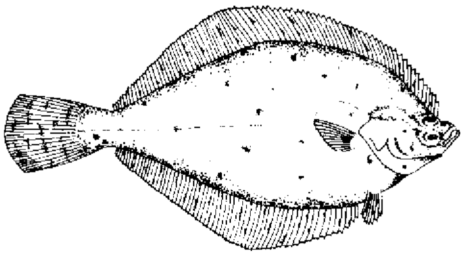
Moore (1947) reported Block Island Sound males and females reaching sexual maturity at age three to four. Recent observations indicate that many males are mature by age two. No mature males have been observed less than 20 cm (7.9 in), and no mature females less than 23 cm (9 in). No data are available on the fecundity of the windowpane.

Length-at-age data from 1975 late winter and early spring samples in southern New England are presented in Table 18. Females evidently outgrow males after age three and reach lengths greater than 40 cm (15.7 in). No males were encountered greater than 35 cm (13.8 in). These data indicate larger fish at given ages than reported by Moore (1947).

Feeding Interrelationships. Mysid shrimp, *Neomysis*, are the predominant prey of windowpane in New York Bight (Moore 1947, Long Island Sound; Maurer, personal communication, NMFS, Woods Hole, general New York Bight area). Other crustaceans were of secondary importance, particularly caridian shrimps, amphipods, and crabs. Other invertebrates such as molluscs, squid, ascidians, annelids, echinoids (Georges Bank), and holothurians have been found in their stomachs. Small fish, such as herring, sand lance, silversides, and fish larvae also occur, but Moore (1947) and Maurer (1975) consider the fish diet to be of minor importance.

Yellowtail Flounder *Limanda ferruginea*

F.E. Lux and *Robert Livingstone, Jr.*



Distribution and Seasonal Movements. Yellowtail flounder ranges from the south coast of Labrador to Chesapeake Bay and is abundant in New York Bight, off New England to Georges Bank, off the south shore of Nova Scotia in the vicinity of Sable Island, and on Grand Bank since about 1965 (Bigelow and Schroeder 1953; Pitt 1970; International Commission for the Northwest Atlantic Fisheries 1978). It is found in waters from about 10 to 100 m (33 to 330 ft) deep, although most of the US catch is taken in depths of 27 to 64 m (90 to 210 ft). The yellowtail occurs over bottoms of coarse, medium, and fine sands and mixtures of sand and mud; it tends to avoid soft mud and rocky bottoms, at least in late juvenile and adult stages. Off New England it is found in waters as cold as 1°C (34°F) in winter and as warm as 18°C (64°F) in summer.

New England tagging studies show that yellowtail travel as far as 425 km (264 mi) from the release point (Royce et al 1959; Lux 1963). Fish tagged off Block Island made a regular annual migration eastward in spring and summer to the vicinity of southern Nantucket Shoals, and about 3% of them moved as far east as Georges Bank. The fish returned westward in autumn and winter. On Georges Bank the pattern was similar, with about 5% of the fish moving westward off the bank to southern New England waters in the winter and back to the bank in summer. Fish tagged off the eastern end of Cape Cod, on the other hand, showed little evidence of seasonal movement. No tagging studies have been conducted in the Bight.

The 1973-74 otter trawl surveys in spring and autumn illustrate that the major part of the yellowtail biomass is found between New York Bight and Georges Bank (Map 51). Yellowtail are found as far south as Delaware Bay in the spring.

Population Size and Fisheries. The yellowtail catch from Georges Bank to New York Bight is taken mostly by US commercial fishermen using otter trawls. Total catches have fluctuated widely during the past 50 years, chiefly due to variations in recruitment; changes in fishing effort also contributed to these fluctuations (Lux 1969). The fishery began in the 1930s and catches rose rapidly until 1943 when a severe decline began. In the late 1950s catches again rose and were between 30,000 to 45,000 MT through the 1960s and early 1970s except for a peak of 56,000 MT in 1969 caused by unusually heavy fishing by foreign fleets in that one year. Generally good year-classes from the late 1950s until the late 1960s sustained the fishery until the early 1970s. Since 1969 recruitment has declined drastically, particularly in the southern New England area, and catches from Georges Bank to New York Bight combined dropped steadily from 41,000 MT in 1972 to 12,000 MT in 1978 (McBride and Sissenwine 1979). Landings in the Bight have also been restricted by quotas imposed on the southern New England stock (from about Block Island to 69°W longitude) in 1971, and the mid-Atlantic stock (west of Block Island) in 1975.

The proportion of the total catch coming from New York Bight (corresponding to the mid-Atlantic stock) has always been relatively small, usually less than 10%. Reported catches from New York Bight ranged from 2,000 to 9,000 MT from 1970 to 1974, and then dropped to less than 1,000 MT from 1975 to 1978. Yellowtail spawning stock biomass in the Bight is now at a very low level and although the entire fishery is now under a catch quota, the population will not increase significantly until there is a substantial improvement in recruitment.

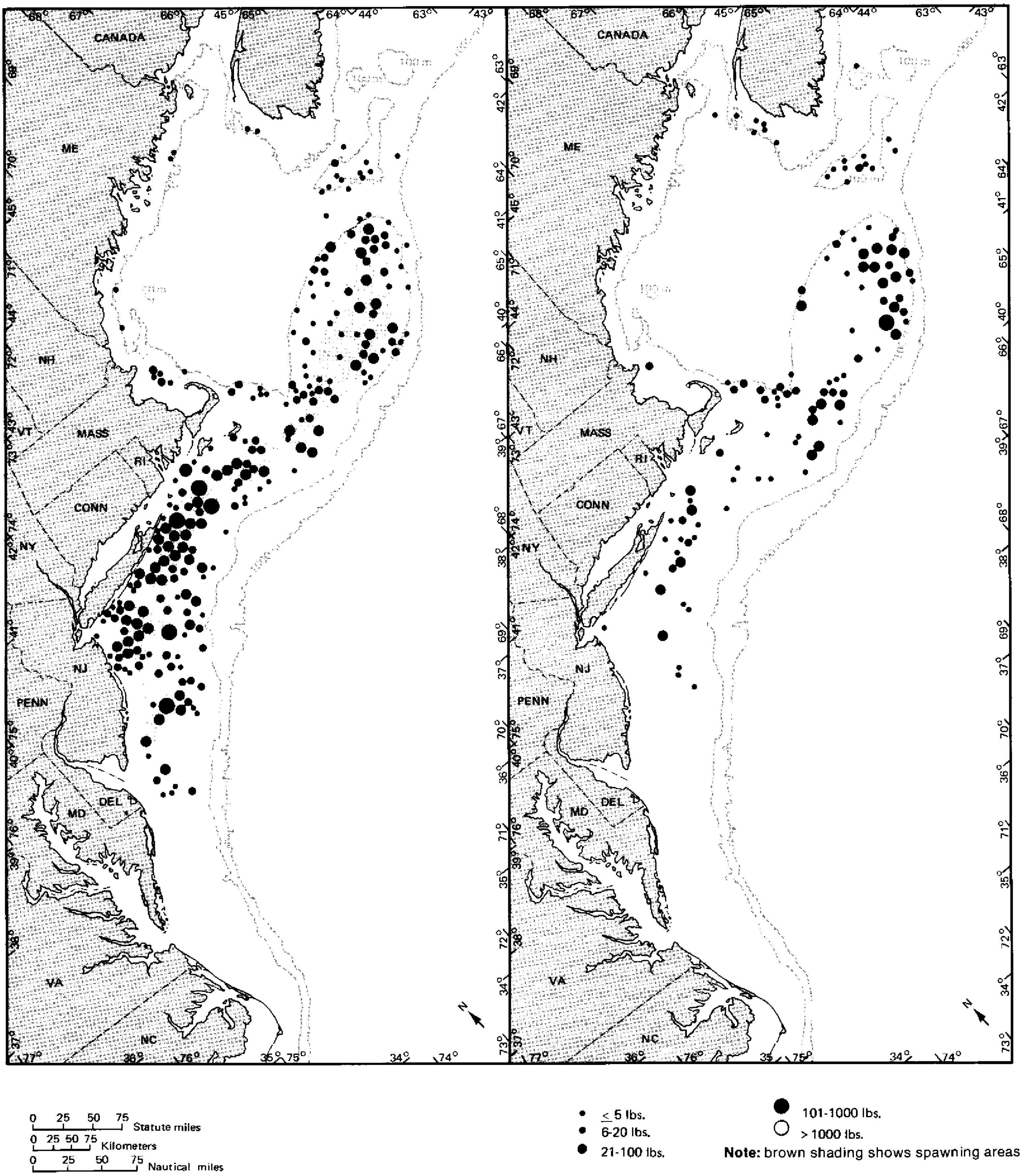
Reproduction, Growth, Life Span. Yellowtail from New England waters usually spawn for the first time when they are three years old and about 30 to 35 cm (12 to 14 in) long (Royce et al 1959); they then spawn in each successive year. Spawning occurs primarily from March to July, peaking about mid-May. An individual fish apparently spawns over a period of time because all eggs of a given female do not mature simultaneously (Bigelow and Schroeder 1953). Fecundity varies from about 1.2 million eggs for a 38 cm (15 in) female to about 3.5 million eggs for one 50 cm (20 in). Spawning takes place over all areas where adult yellowtail are present (Map 51).

Fertilized eggs are buoyant, remaining suspended near the water surface until hatching, which takes place in five days at a temperature of 10° to 11°C or 50° to 52°F (Bigelow and Schroeder 1953). The newly hatched larvae, about 3 mm (0.1 in) long, are pelagic; they drift with surface currents, subsisting on the yolk sac for the few days it takes for development of the mouth. They then begin feeding on copepods and other plankton. At 10 mm (0.4 in) the larvae are still symmetrical, but thereafter metamorphosis proceeds rapidly, ending at about 14 mm (0.6 in). Adult pigmentation is nearly complete at this length, which usually is reached by late summer, and the young fish go to the bottom. Pelagic phases last three to four months, depending on water temperature.

The pelagic stages are commonly caught from Georges Bank to Long Island, and in some years eggs and larvae are taken as far south as Chesapeake Bay (Smith et al 1975; Map 12). Pelagic stages are regularly found in spring plankton in coastal Gulf of Maine waters, though they are not abundant there (Colton and St. Onge 1974).

Nursery areas are poorly defined for young fish in the

Map 51. Yellowtail flounder — distribution of NMFS 1973-74 research vessel trawl catches (dots) and spawning areas (shading) (spring-left, autumn-right)



• ≤ 5 lbs.	● 101-1000 lbs.
• 6-20 lbs.	○ > 1000 lbs.
● 21-100 lbs.	

Note: brown shading shows spawning areas

TABLE 19. Length at age for yellowtail flounder.

Age	Total length in cm (in)	
	Male	Female
1	5 (2)	5 (2)
2	25 (10)	25 (10)
3	32 (13)	33 (13)
5	35 (14)	40 (16)
7	39 (15)	45 (18)

first year after they reach the bottom since only small numbers are caught in research trawl surveys. Possibly, to avoid predation, the young seek the shelter of rough bottom where sampling is less effective. Following this first year, however, they are caught in increasing numbers with adult yellowtail.

Growth in length of yellowtail off southern New England is rapid in the first three years and then slows down (Lux and Nichy 1969). Beginning in the third year females grow faster than males. Average lengths-at-age for males and females from southern New England are presented in Table 19.

Beyond age seven, length increases slowly with age for both sexes. A few fish grow to a much larger size, reaching lengths of 47 cm (19 in) at about 10 to 12 years of age for males and 64 cm (25 in) at about 13 to 15 years of age for females (Lux and Nichy 1969).

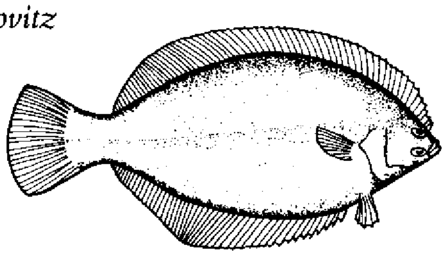
Feeding Interrelationships. Yellowtail feed on invertebrate animals that are closely associated with sandy bottoms. Their principal foods consist of small crustaceans, particularly amphipods, polychaete worms, and a few small molluscs. Small fishes have been reported in their diet but apparently are of little importance for they have been rarely observed in the contents of hundreds of yellowtail stomachs examined by NMFS.

There is some predation on yellowtail by larger fish, such as cod on Georges Bank and bluefish off Long Island, but this does not appear to be a major source of mortality.

Environmental Sensitivity. Some evidence indicates that cooler water temperatures promote the production of strong year-classes. Large year-classes of the late 1950s and 1960s were spawned during a cooling trend (Lux 1964; Sissenwine 1977). Water temperatures are now higher in the Bight than in the 1960s which may be related to the poor recruitment since that time (Davis, personal communication).

Winter Flounder *Pseudopleuronectes americanus*

Thomas R. Azarovitz



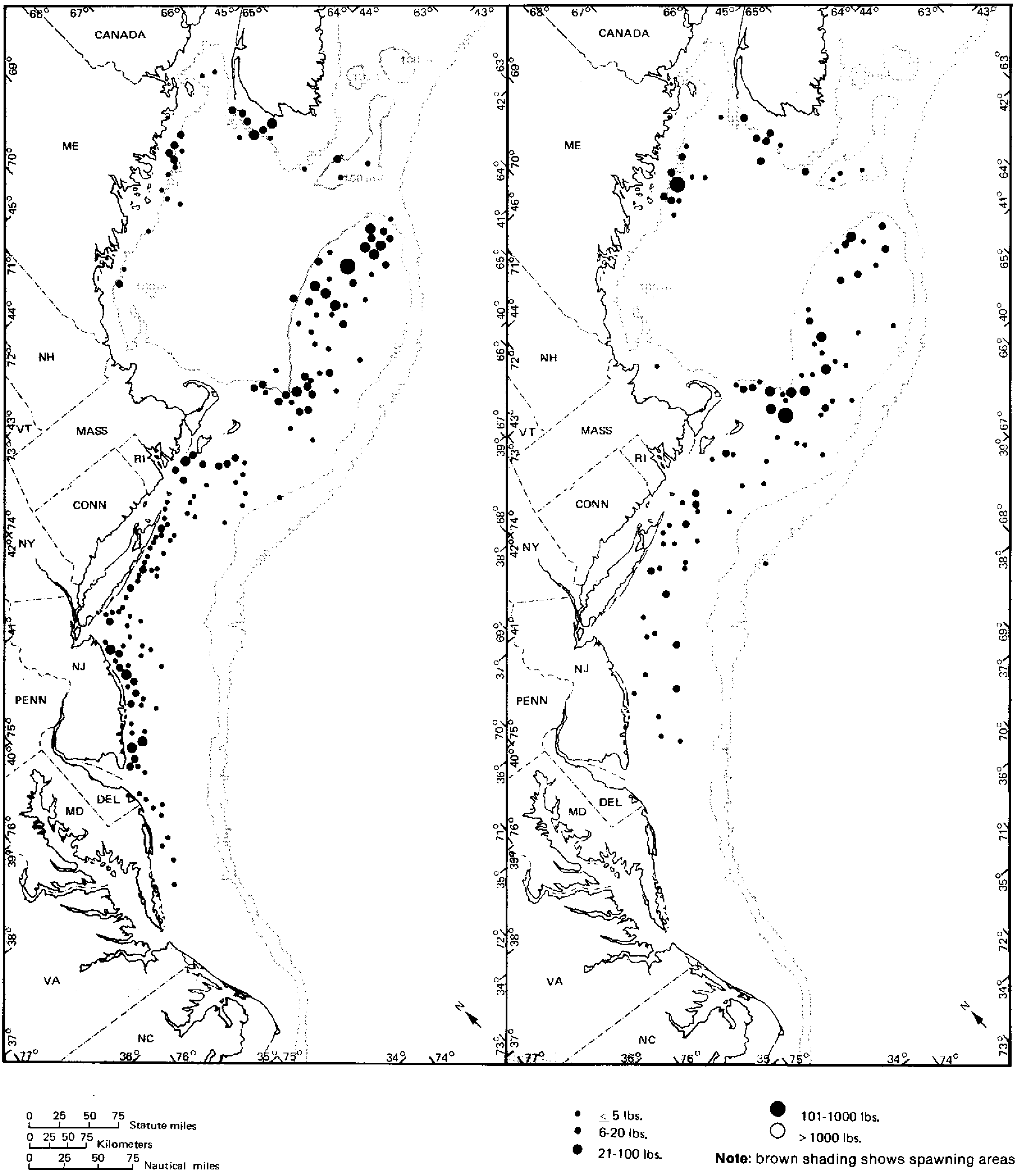
Distribution and Seasonal Movements. Winter flounder or blackback is a small-mouthed right-eye species of the family *Pleuronectidae* and is found between Labrador and Georgia. The fish generally inhabit the soft mud, clay, sandy, or pebbly bottoms of bays, estuaries, and shallow coastal waters (Bigelow and Schroeder 1953). In New York Bight they are not commonly found in waters deeper than 55 m or 180 ft (Wilk 1977), but in offshore waters of Georges Bank, the winter flounder has been taken in waters as deep as 128 m or 420 ft (Bigelow and Schroeder 1953).

The winter flounder on Georges Bank was once considered a separate species (*Pseudopleuronectes dignabilis*) because of its larger size and higher fin ray counts (Kendall 1912; Perlmutter 1947). It is now considered a single species although Lux, Peterson, and Hutton (1970) confirmed the higher fin ray counts on Georges Bank as compared with fish from inshore areas. The population on Georges Bank is, however, considered separate from the populations inshore. In inshore waters, winter flounders are further grouped into small subpopulations or stocks that have local seasonal and spawning migrations (Lobell 1939; Perlmutter 1947; Pearcy 1962; Pierce and Howe 1977). There is some evidence of interarea migration but only for a small percentage of the local stocks (Howe and Coates 1975). These discrete local stocks result from females laying demersal, nondispersive eggs. Larvae and juveniles remain in the spawning estuaries, and the adults do not mix with other stocks (Perlmutter 1947).

Spring and autumn distributions of the total complex of stocks from Cape Hatteras to Nova Scotia are illustrated in Map 52. Because the rocky coast from Cape Cod Bay through the Gulf of Maine is generally untrawlable, the distribution pattern derived from the NMFS surveys is incomplete. Winter flounder actually occur in significant numbers along this coastal region.

Winter flounder south of Cape Cod migrate from bays and estuaries offshore to cooler coastal waters as water temperatures warm in late spring. North of Cape Cod where summer water temperatures are colder they remain in the bays and harbors, moving into deep holes and channels during the warmest weather. Large fish are apparently less tolerant of warm waters and move to cooler waters earlier than young fish (Pearcy 1962; McCracken 1963; Howe and Coates 1975). When autumnal cooling begins in the Bight the fish move inshore; the greatest con-

Map 52. Winter flounder — distribution of NMFS 1973-74 research vessel trawl catches (dots) and spawning areas (shading) (spring-left, autumn-right)



Note: brown shading shows spawning areas centration occurs in the estuaries between December and March, although a few winter flounder remain offshore during winter (Wilk et al 1977). In waters far to the north, when bays become completely clogged with ice, the fish move from the shallows to the deeper, warmer channels and coastal waters (McCracken 1963).

McCracken (1963) concluded that winter flounder prefer temperatures below 15°C (58°F) in northern regions. A comparison of the winter flounder distribution and recorded bottom temperatures from the NMFS surveys (Map 52 and Maps 4, 5) indicates a preference for cooler waters (◄15°C or ◄59°F) in the Bight and also on Georges Bank. However, Olla, Wicklund, and Wilk (1969) found that some winter flounder remained in Great South Bay during the summer when water temperatures were between 17.2° and 24.0°C (63° and 75°F). They observed the flounders while diving, and the fish were under no apparent behavioral stress in temperatures as high as 22.5°C (72.5°F); but when temperatures reached 23°C (73°F), activity ceased and the flounders buried themselves in the cooler bottom sediments. From a summary of experimental and field studies of temperature effects in a comprehensive synopsis on winter flounder (Klein-MacPhee 1978), it appears that these fish experience significant stress above 25°C (77°F) and that temperatures of 28° to 29°C (about 85°F) are lethal. Mass mortalities on the south shore of Long Island have been attributed to warm water (Nichols 1918).

Population Size and Fisheries. The US commercial catch of winter flounder is taken chiefly by otter trawlers in spring and autumn. Winter flounder are usually marketed as "flounder" fillets but larger specimens have traditionally been called "lemon sole" by fishermen. Since 1937, when winter flounder landings were first recorded separately from other flounders, the total US commercial catch has fluctuated between 6,000 and 14,000 MT (Lange and Lux 1978). On the average, less than 15% of this total comes from New York Bight (New York, New Jersey, and Delaware); the bulk of the catch comes from Georges Bank and is landed in New England ports. Since 1965 the US commercial catch has comprised about 90% of the total commercial harvest including foreign catches.

US commercial landings of winter flounder generally declined from 16,600 MT in 1965 to 7,500 MT in 1974; this may reflect a decrease in abundance because commercial and research vessel catch per unit effort indices have both declined during that same period (Lange and Lux 1978). It is difficult to construct accurate pooled estimates of abundance for the entire population complex of winter flounder because there are so many separate stocks and unique components of the otter trawl fleet (Berry, Saila, and Horton 1965; Howe and Coates 1975). Nevertheless, abundance trends based on the commercial catch and effort data and NMFS trawl surveys are broadly similar. US commercial landings increased again in 1975, and reached 12,000 MT in 1978 which is 20% above the average level of 10,000 MT for the period 1965-77 (Lange and Lux 1978). The commercial landings for the Middle Atlantic Bight region alone also increased from about 400 to nearly 800 MT from 1976 to 1978. However, population abundance does not appear to have increased this much since commercial and research abundance indices have not increased proportionately. Instead, fishing effort has probably increased for winter flounder as a result of low abundance of summer flounder and yellowtail in the Bight.

In New England (Maine to New York) the 1970 US commercial catch of 11,000 MT was surpassed by the recreational catch of over 11,113 MT (Deuel 1973). In the Middle Atlantic Bight (New Jersey to Cape Hatteras) Deuel (1973) estimated the 1970 recreational catch at 5,860 MT, whereas the US commercial catch was only 136 MT. Although recreational catch data are not available for the NY-NJ area, it is reasonable to assume that the sportfish catch in the Bight exceeds the commercial catch. Winter flounders are available to sport fishermen during the coldest winter and early spring months, a time when few other fish can be caught.

Reproduction, Growth, Life Span. Winter flounders spawn in the Bight from mid-winter through early spring. Smith and associates (1975) suggested that peak spawning progresses northward, triggered by warming spring waters. Winter flounders spawn in waters from 2 to 6 m (7 to 20 ft) deep principally in the upper estuaries (Bigelow and Schroeder 1953; Pearcy 1962). It is not known whether the flounder that remain offshore in the Bight during the winter spawn. Smith and associates (1975) found eggs and larvae offshore but surmised they were flushed from estuaries. Reproductive success is believed to be primarily dependent on the spawning in the upper estuaries since larval and juvenile mortalities are much lower in the upper as compared with lower parts of estuaries (Pearcy 1962).

Females mature in the Bight when they are two to three years old (Perlmutter 1947), whereas in the northern limits of their range they mature when five to seven years old (Kennedy and Steele 1971; Saila and Pratt 1973). Eggs are demersal, adherent, and small, ranging from 0.7 to 0.9 mm (0.027 to 0.035 in). They initially have no oil globule but develop one during incubation (Bigelow and Schroeder 1953). Both temperature and salinity can affect hatching success but salinity is more important (Rogers 1976).

Larvae are 3 to 3.5 mm (0.12 to 0.14 in) long at hatching and the yolk is absorbed in 12 to 14 days at 5 mm (0.2 in) under laboratory conditions. Metamorphosis is complete in two and a half to three and a half months when larvae are 8 to 9 mm (0.31 to 0.35 in) long (Bigelow and Schroeder 1953). Early larval stages are most abundant in the upper estuary and gradually move into the lower estuary as they grow and can resist the currents encountered there (Pearcy 1962). The juveniles eventually leave the estuary to follow the adults.

Since the winter flounder populations consist of discrete stocks, typical population growth analyses are not feasible (Berry et al 1965; Howe and Coates 1975). Poole (1966) found that growth varied between small local populations within Long Island Sound. Howe and Coates (1975) estimated that winter flounder south of Cape Cod averaged from 270 mm (11 in) at age 3 to 450 mm (18 in) at age 10. Males were smaller than females by 40 to 50 mm (1.6 to 1.9 in) at maturity. Male winter flounders as old as 11 years and females estimated at 12 years were found on Georges Bank by Lux (1973).

Feeding Interrelationships. Winter flounder are small-mouthed fish that feed on a wide variety of small invertebrates including coelenterates, nemerteans, polychaetes, crustaceans, molluscs, and ascidians (Maurer and Bowman 1975). Wells and Steele (1973) found as much as 40% (by weight) of stomach contents to be plant material. Since winter flounder apparently depend on sight to locate prey, they feed only during the day (Pearcy 1962; Olla et al 1969).

Pearcy (1962) studied the feeding habits of larval and juvenile winter flounder in Connecticut's Mystic River estuary. He found that post-larval winter flounder fed primarily on crustaceans, polychaetes, and small protozoan-like animals. Copepods were the most important food of small juveniles. Large juveniles fed mostly on amphipods and polychaetes. He also found that adult winter flounder remained in the estuary, feeding primarily on the polychaete *Neanthes* and, therefore, may be in direct competition with juvenile winter flounder.

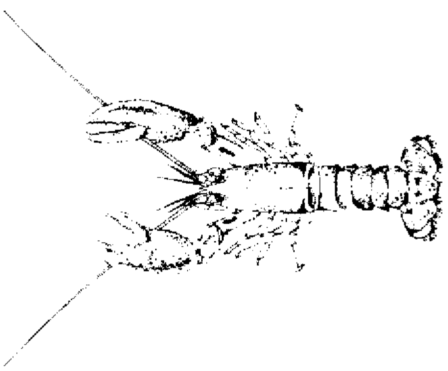
Adult winter flounder are eaten by large estuarine and coastal predators such as striped bass and goosefish. Predation is the major cause of larval and juvenile winter flounder mortality (Pearcy 1962). Larvae were particularly vulnerable to the small hydromedusa, *Sarsia tubulosa,* whose distribution and abundance were correlated with flounder larvae. Juvenile winter flounder were found in stomachs of toadfish and summer flounder. Cormorants, blue herons, and ospreys probably feed on young flounder (Pearcy 1962; Tyler 1971*a*).

Environmental Sensitivity. Since winter flounder are critically dependent on estuarine conditions, they are particularly vulnerable to environmental degradation in estuaries. For example, the demersal and adhesive eggs are susceptible to toxic wastes that accumulate in sediments. These same wastes could affect larvae and older stages; Tyler (1971*a*) showed that winter flounder are dependent to some degree on the fauna of the intertidal zone for food. Therefore, dredging, bulkheading, and filling of the shores of estuaries could detrimentally affect flounder production, as could artificially raising water temperatures. Sublethal high temperatures dramatically affect the feeding and overall behavior of winter flounder (Olla et al 1969).

There is circumstantial evidence of the effects of pollution in the literature. Fewer larvae and juveniles survived in a polluted estuary (Pearcy 1962). Also, it was noted that winter flounder were entirely absent from polluted sections of Long Island Sound (Greely 1939). Fin erosion in winter flounder occurs more frequently in polluted than nonpolluted areas of New York Bight (Ziskowski and Murchelano 1975). Many other specific environmental effects in local areas were implied in a comprehensive review of the biology of winter flounder by Klein-MacPhee (1978). However, there is no estimate of the extent to which degradation of estuaries has impacted the whole population complex of winter flounder.

Northern Lobster *Homarus americanus*

Thurston S. Burns

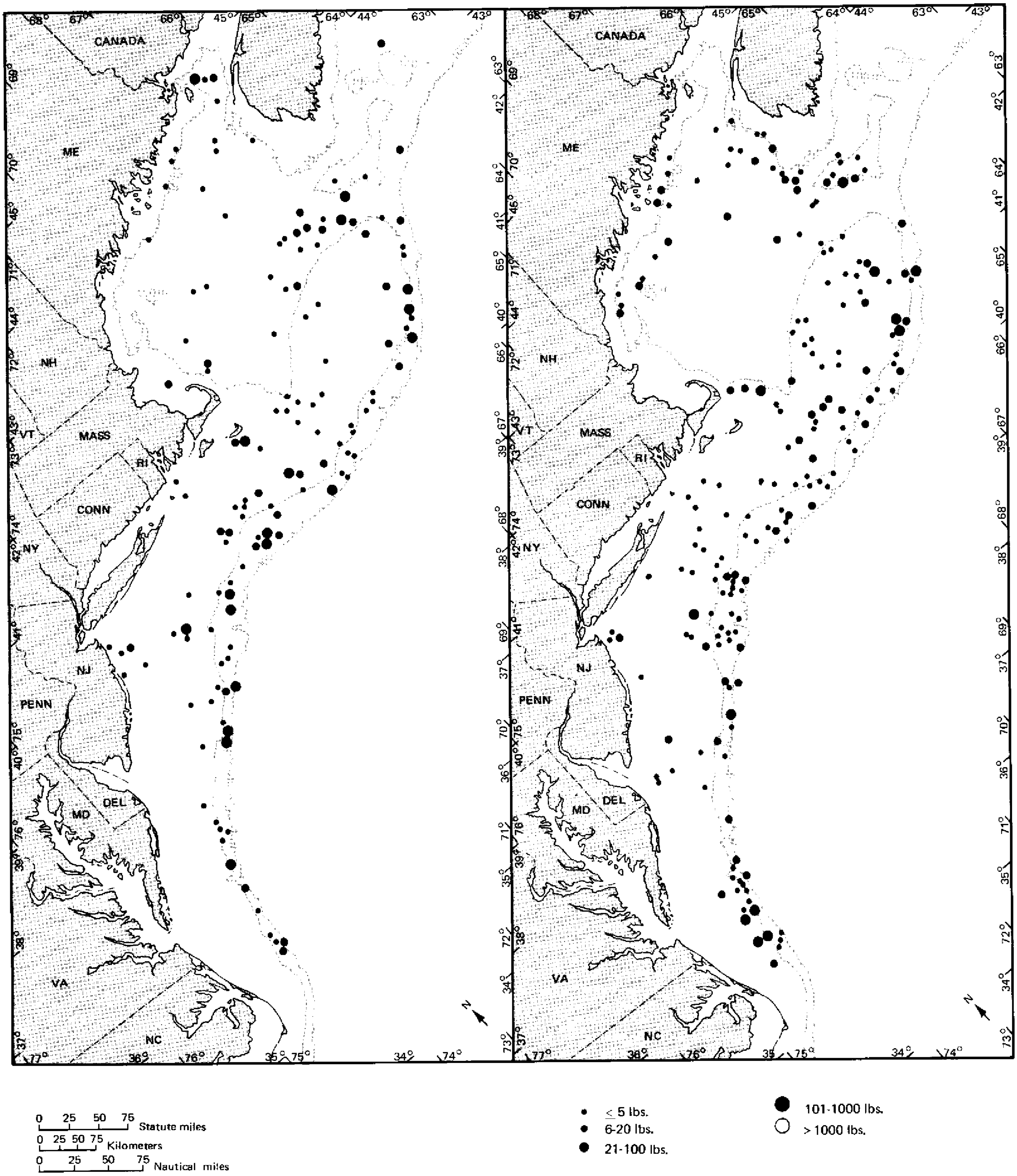


Distribution and Seasonal Movements. The northern lobster is limited to waters off the east coast of North America where its range extends from the coastal surf to slope waters 700 m (2,300 ft) deep, and from Henley Harbor, Labrador, to Cape Hatteras (Whiteaves 1901; Herrick 1909).

US coast lobsters can generally be divided into inshore and offshore groups, based on fishing methods and population characteristics, although overlap exists in both cases (Skud 1970). Biochemical, parasitological, morphometric, and tagging studies were conducted in an effort to resolve the problem of stock identification. Results of these studies suggested that inshore and offshore lobsters may form separate populations, with some intermingling from Cape Cod to southern Long Island during summer when offshore lobsters move to shoaler waters (Saila and Flowers 1968; Barlow and Ridgway 1969, 1971; Uzmann 1970; Cooper and Uzmann 1971; Tracey et al 1975; Uzmann, Cooper, and Pecci 1977*a*). To date, lobster stocks have not been accurately defined and additional research is necessary to delineate stock boundaries.

Several studies indicate that movements of lobsters in coastal areas of New Brunswick, Nova Scotia, Prince Edward Island, and the Gulf of Maine are limited in extent and generally nonmigratory (Wilder 1960; Cooper 1970).

Map 53. Northern lobster — distribution of NMFS 1973-74 research vessel trawl catches (dots) (spring-left, autumn-right)



However, lobsters tagged in the western Gulf of Maine suggest a general southwesterly movement (particularly large lobsters) into waters of New Hampshire and Massachusetts (Dow 1974). Tagging results in Long Island Sound and off Block Island, RI, indicated nonmigratory movements in western Long Island Sound, extensive migrations of some lobsters in eastern Long Island Sound to the continental shelf edge, and a mixture of migratory and nonmigratory lobsters off Block Island (Lund, Stewart, and Rathbun 1973).

Lobsters of the outer shelf migrate laterally along the shelf edge as well as to shoaler waters in spring and summer, returning to deeper waters in autumn and winter (Cooper and Uzmann 1971; Uzmann et al 1977*a*). They move from offshore canyon areas (Hudson, Block, Atlantis, Veatch) into inshore fishing grounds southwest of Cape Cod (no intrusions into the Gulf of Maine have been reported), where offshore migrants are taken in the coastal trap fishery of Long Island during spring and summer. South of Hudson Shelf Valley little is known of lobster movements.

Autumn trawl surveys by NMFS indicate that when bottom temperatures are relatively warm in shoal waters, lobsters occur over a wide depth range extending from the shelf edge shoreward (Map 53, and Maps 4, 5). In spring, before lobsters move to shoaler waters, catches tend to be larger and more concentrated near the shelf edge.

Population Size and Fisheries. Accurate estimates are not yet available for the lobster population from Maine to North Carolina. Total reported US landings of lobsters increased steadily from about 10,000 MT in the mid-1940s to 13,000 MT in 1959, and have fluctuated around 14,000 MT since then; landings in excess of 15,000 MT were recorded in 1969-71 and again in 1978. All of the catch is taken by US fishermen (no foreign fishery is allowed), and the bulk of the catch is taken by the inshore fishery principally off Maine and Massachusetts.

The inshore commercial and recreational fishery for lobsters is primarily fished by small boats with one or two men using single pots or strings of 5 to 10 traps. Since the mid-1950s these traditional methods have been augmented by recreational skin and SCUBA divers who land small quantities of lobsters in southern New England; it is illegal to take lobsters while diving in Maine and New Hampshire. Inshore landings have fluctuated around 10,000 to 12,000 MT for the last 30 years, and have generally accounted for 80% to 90% of the total US lobster catch.

In the 1950s a directed trawl fishery for lobsters was established in the offshore canyon areas off southern New England. Landings increased from 157 MT in 1952 to over 3,000 MT in 1969, and as the fishery developed it expanded southward to Norfolk Canyon and eastward to Corsair Canyon on Georges Bank (Burns et al 1979). Trawl landings reached a peak of 3,197 MT in 1970 and declined sharply thereafter as the offshore fishery converted primarily to trap gear fished in strings of about 40 to 100 or more traps. The total 1978 offshore catch of lobsters for trawls and traps combined was 2,700 MT, about 17% of total US catch.

Generally less than 10% of the total lobster catch is taken from New York and southward, and most of that is landed in New York and New Jersey. NY and NJ landings generally increased from less than 300 MT in 1950 to 1,559 MT in 1970, and then declined to 677 MT in 1978. The increased landings of New York Bight observed from 1950 to 1970 may have been due to a southward shift in the center of abundance of lobsters because of the cooling trend in water temperatures (McHugh and Ginter 1978). The temperature trend was reversed in the late 1960s and since then it has been warming generally on Georges Bank and in the Bight (Davis 1976, personal communication). Lobster abundance indices based on catch per haul in NMFS autumn surveys in offshore areas of southern New England began to decline in the mid-1960s before an intensive offshore fishery developed; since 1975 abundance indices on Georges Bank and in the deep parts of the Gulf of Maine have shown increases (Burns et al 1979). Thus, a return shift northward of the center of abundance may be in progress.

Reproduction, Growth, Life Span. Lobster spawning areas off the US coast have not been located, and little information is available on abundance and distribution of larval lobsters south of Canada. Lund and Stewart (1970) attempted to identify areas of larval concentrations and distribution in offshore waters of southern New England. However, they found no concentrations and concluded that larvae appeared to be present in surface waters out to the shelf edge in July and August.

Cooper and Uzmann (1971) stated that with few exceptions recaptured lobsters were distributed in a temperature range of 10° to 17.5°C (50° to 63.5°F) and hypothesized that slope waters lack sufficiently high temperatures during summer for egg extrusion, hatching, molting, and subsequent mating. Thus, inshore migrations to warmer waters may be necessary for spawning. Saila and Flowers (1968) found that offshore egg carrying females displaced to inshore waters did not appear to move offshore until the eggs had been shed.

Fecundity of lobsters varies from a few thousand to 75,000 eggs, depending on the size of the individual. Eggs are attached to the swimmerets of the tail and are carried by the female for 10 to 12 months before being hatched and released as larvae. After releasing the larvae the female molts and mates.

Growth rates of lobsters vary according to location and sex. Growth occurs through molting, when the exoskeleton is cast off, and depends on two variables: molting frequency and carapace increment per molt. The length of the intermolt period varies greatly according to the lobster's age, the water temperature, and the relative food abundance. Observations indicate that lobsters molt an average of 10 times during the first season, that is, from date of hatching in summer to the end of the calendar year (Hughes and Matthiessen 1962). Thereafter, molting frequencies decline, and one molt per year is considered average for commercial size lobsters 80 to 100 mm (3 to 4 in) carapace length, except that mature females molt approximately every two years. Very large lobsters molt less frequently but frequencies have not been determined.

For inshore lobsters of the Gulf of Maine the carapace increment in length is about 14% per molt (Thomas 1973) and lobsters attain minimum legal size, approximately 81 mm (3 in) in five to seven years. Offshore lobsters grow substantially faster (Cooper and Uzmann 1977); males reach 81 mm (3 in) in four years and females in six years. Since lobsters shed all hard parts in molting, age determination is not possible with standard aging techniques. Estimates place the maximum age at about 40 years, but life expectancy may be much greater in offshore waters.

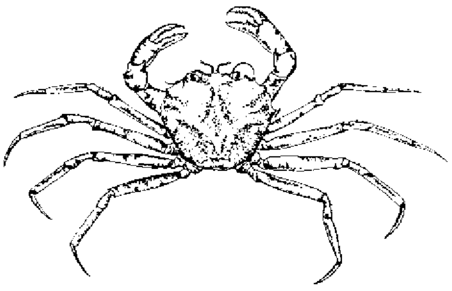
Feeding Interrelationships. During the larval stages (first 20 to 30 days) lobsters are planktonic and are undoubtedly preyed upon by a variety of fishes. Scant information exists on feeding of or predation on juveniles in the early benthic phase.

Large lobsters consume a variety of marine invertebrates, fishes (living and dead), and small amounts of marine plants. Predators of lobsters on the bottom include demersal fishes such as cod, skates, dogfish, and wolffish, but the magnitude of predation by these species is unknown.

Environmental Sensitivity. Limited information is available on sensitivity of lobsters to changes in the environment. A survey by Scarratt (1969) indicated that paper mill effluents had no immediate or direct effects on distribution and abundance of lobster larvae near Pictou, Nova Scotia. In an experimental study, Wilder (1952) found that heavy metals such as copper, monel metal, zinc, and lead were toxic to lobsters. Pearce (1971) studied New York Bight benthic communities and found that lobsters that migrated into waste disposal areas were debilitated and diseased. Pathological development of the disease included fouling of the gills and branchial cavities followed by severe lesions of the exoskeleton (Young and Pearce 1975). The studies also showed that sediments in the dumping zones were characterized by very high concentrations of heavy metals, including copper and lead, which are known to be toxic to lobsters.

Deep-Sea Red Crab, *Geryon quinquedens*

Fredric M. Serchuk and *Roland L. Wigley*



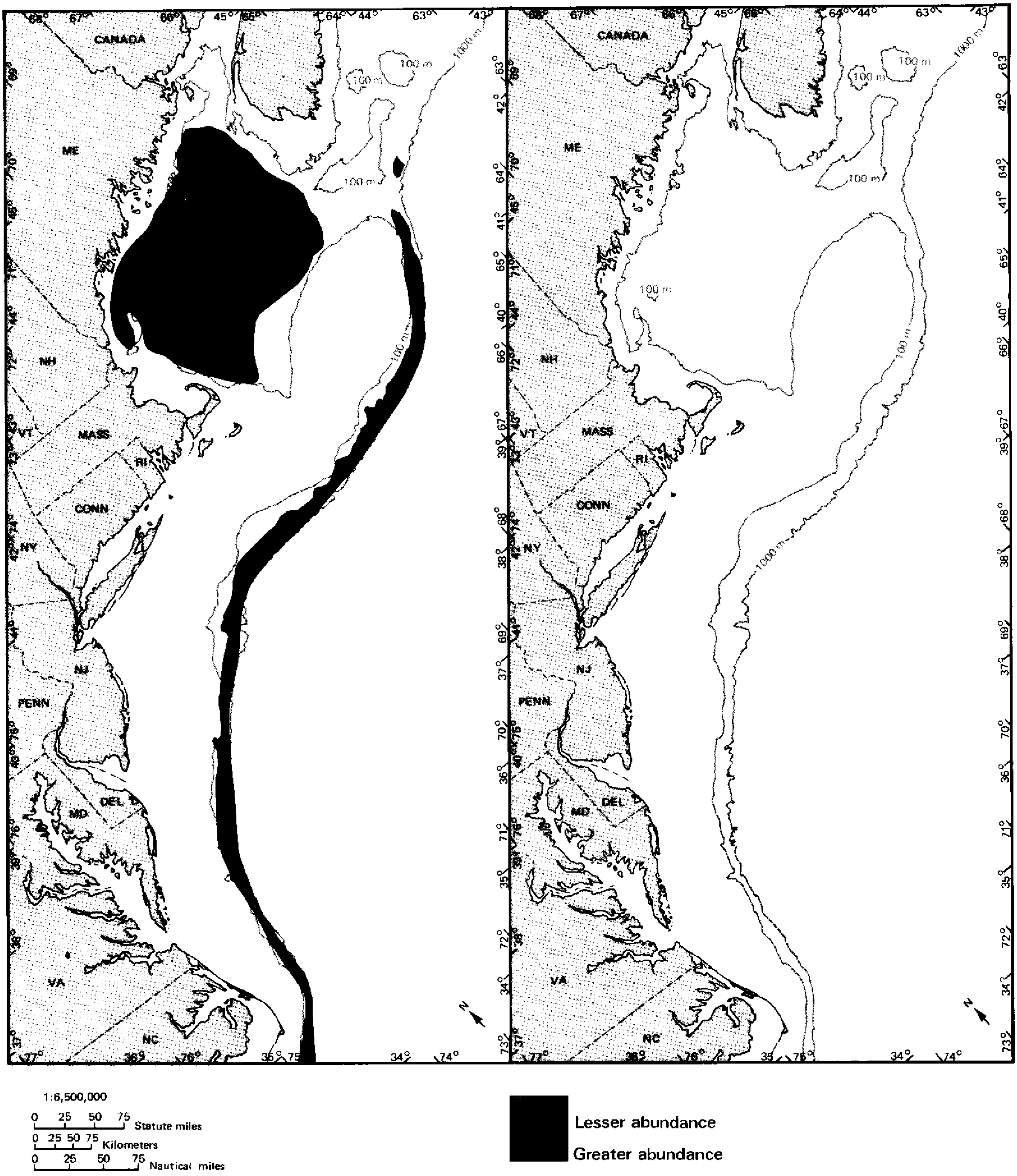
Distribution and Seasonal Movements. The deep-sea red crab occurs at depths of 40 to 2,155 m (130 to 7,000 ft) in the western Atlantic Ocean from Nova Scotia and the northern Gulf of Maine to Mar del Plata, Argentina (Rathbun 1937; Williams and Wigley 1977). In waters off Maine to Cape Hatteras red crabs are found in depths from 110 to 1,460 m or 360 to 4,790 ft (McRae 1961), with the principal biomass occurring between 320 to 640 m (1,050 to 2,100 ft) at water temperatures from 5° to 8°C or 41° to 46°F (Gray 1970; Meade and Gray 1973; Haefner and Musick 1974; Wigley, Theroux, and Murray 1975). In the Gulf of Maine, red crabs may be found at depths shallower than 210 m (690 ft); along the continental slope, the crab is generally restricted to the bathyal zone, ►200 m or 656 ft (Map 54). They occur in and near submarine canyons as well as on the relatively undisturbed parts of the slope. Aggregations occur on both hard and mud bottom, with silty clay the preferred substrate (Schroeder 1959; Williams and Wigley 1977).

The densest aggregations (Map 54) exist off the southern New England coast at depths ranging from 320 to 412 m or 1,050 to 1,350 ft (Wigley et al 1975), and east-southeast of Ocean City in waters between 366 and 549 m or 1,200 and 1,800 ft (McRae 1961; Haefner and Musick 1974; Haefner 1978). In southern New England, commercial fishing is concentrated in the continental slope region from Hydrographer to Hudson canyons. Farther south, fishing activity is localized in the vicinity of the Norfolk Canyon.

Trawl and trap survey investigations indicate that red crabs are, to some degree, bathymetrically segregated by sex (Haefner and Musick 1974; Murray 1974; Wigley et al 1975; Ganz and Herrmann 1975). Females are common only from about 320 to 500 m (1,050 to 1,640 ft); males are sparse in shallow water (less than 320 m) but rather uniformly abundant from 320 to 1,280 m (1,050 to 4,200 ft). Young crabs are restricted to the deeper waters (►640 m or 3,100 ft). An inverse relationship exists between water depth and temperature and crab size suggesting a size-related long-term up-slope migration pattern, with recruitment occurring from the deep waters.

The red crab is not a swimming crab and hence lacks the large muscle located at the fifth pereiopod base (lump meat). Tagging studies indicate that movements are rela-

Map 54. Deep-sea red crab — distribution and spawning areas based on historical fishery records



tively minor for adult crabs, although some individuals, at large for as much as three years, have been recovered up to 75 km (47 mi) from their release location (Ganz and Herrman 1975; Lux and Rathjen, personal communication). Seasonal variations in movement and distribution patterns have yet to be investigated.

In waters south of Virginia, the red crab is found together with *Geryon affinis*, a closely related deep-water crab found in Northwest Atlantic waters from Chesapeake Bay to the Florida straits (Chace 1940; Schroeder 1959).

Population Size and Fisheries. Directed commercial exploitation of the red crab began in 1973 off New England in response to declines in the offshore lobster fishery (Rathjen 1974, 1977). The potential for a commercial fishery had long been realized, but prior to the early 1970s red crabs were considered a nuisance since they were commonly taken as incidental catch in offshore lobster gear (Schroeder 1959; McRae 1961; New England Marine Resources Information Program 1974).

Annual New England red crab landings ranged from 112 MT in 1973 to 1,245 MT in 1977; almost 80% of these landings were from the vicinities of the offshore southern New England canyon areas (Veatch, Atlantis, and Block). Massachusetts vessels accounted for over 90% of these harvests. Landings in 1977 in New England doubled from 1976 (638 MT), and were the highest in the short history of the directed fishery.

Development of a mid-Atlantic fishery began in 1977 and 1978 in response to dwindling supplies of surf clams, local publicity about red crab stocks, and variabilities associated with blue crab harvests. The bulk of the catches have come from the Norfolk Canyon area, and have been landed in MD and VA ports.

Normally, landings in New England consist only of male crabs possessing a minimum carapace width of 114 mm (4.5 in), the minimum size accepted by processors (Holmsen and McAllister 1974; Wigley et al 1975). Females and small male crabs are culled from the catch at sea. Harvested males are either brought back to port alive, or butchered and iced in sections aboard ship, and delivered to shore for further processing (Ganz and Herrmann 1975). Similar practices occur in the mid-Atlantic, although a small live "basket" trade exists in Maryland.

Population estimates of commercial-size (▶114 mm or 4.5 in carapace width) red crabs between offshore Maryland and eastern Georges Bank, were derived from a 1974 NMFS survey using otter trawl and photo-sled sampling techniques; about 43 million crabs of harvestable size, with a biomass of 26,700 MT, existed within the surveyed areas. Greatest concentrations of crabs were present off southern New England (46% of the total) and off Georges Bank (31%).

Annual maximum sustained (average) yield for populations between Georges Bank and offshore Maryland has been estimated at about 2,700 MT (Serchuk 1977). Red crab populations in the Gulf of Maine are not expected to contribute significantly to the commercial fishery since research surveys indicated an absence of large crabs (▶114 mm or 4.5 in) in these waters (Herrmann 1974).

Reproduction, Growth, Life Span. Female red crabs become sexually mature at about 80 to 91 mm (3.1 to 3.6 in) carapace width; the size at onset of sexual maturity in males is unknown but may be as small as 51 mm (2 in) carapace width (Haefner 1977). Estimates of fecundity range from 35,500 to 211,500 fertilized eggs per female (Gray 1970; Caddy, Chandler, and Wilder 1974). Extruded eggs are attached to the pleopods and change from light red or orange to deep brown or black as development proceeds.

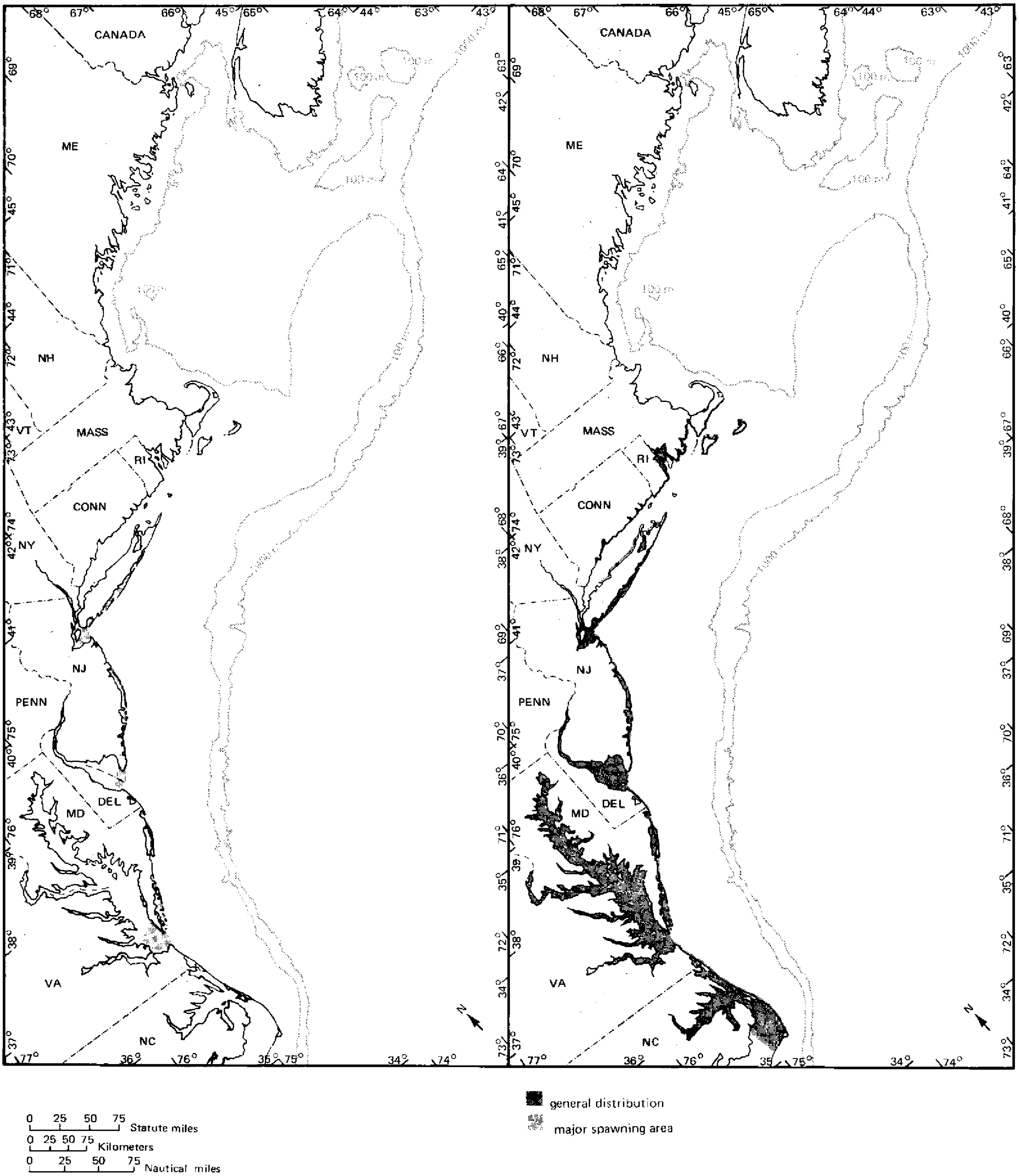
The temporal occurrence of egg-bearing females in research and commercial catches suggests a prolonged spawning season from at least September through early summer, possibly influenced by water temperature and/or water depth (Haefner 1978). Hatching occurred in April, May, and June for crabs held in the laboratory (Gray 1970; Perkins 1973). Larvae taken in neuston (surface) samples at sea in June suggest a similar hatching period in nature (Grant, Olney, and Smyth 1978). Larvae are planktonic and pass through six developmental stages (Perkins 1973). Development to first crab stage lasted an average of 39 days at 18° to 21°C (64° to 70°F) and 30‰ to 31‰ salinity. Undoubtedly, molting progresses much more slowly at environmental temperatures characteristic of the cold water red crab habitat. The occurrence of young crabs only in deep water implies that red crab larvae settle out of the plankton and survive at depths in excess of 740 m or 2,427 ft (Wigley et al 1975).

Male red crabs are generally larger and heavier than female crabs. Males may reach a maximum width of 178 mm (7 in) and a weight of about 1.36 kg (3 lb), while females rarely exceed 135 mm (5.3 in) carapace width and 0.57 kg or 1.25 lb (Caddy et al 1974; Holmsen and McAllister 1974; Ganz and Herrmann 1975). Tagging and recapture studies suggest that the growth rate of adult crabs is slow; molting may not occur for two or three years (Lux and Rathjen, personal communication). The possibility exists that after reaching sexual maturity, female red crabs cease molting or, at least, molt infrequently.

Laboratory molting experiments with five female red crabs 74 to 93 mm (2.9 to 3.7 in) carapace width indicated a 7% increase in carapace width following molting (Gray 1970). Similar female red crab experiments conducted in 1976 yielded an average percentage width increase of 11.6% and an average body weight increase of 33.5% (J. Farlow, personal communication).

The life span of the red crab is not known. Maximum age may be as high as 15 years, based on preliminary laboratory growth data and field molting frequencies.

Map 55. Blue crab — distribution and spawning areas based on historical fishery records (spring-left, autumn-right)

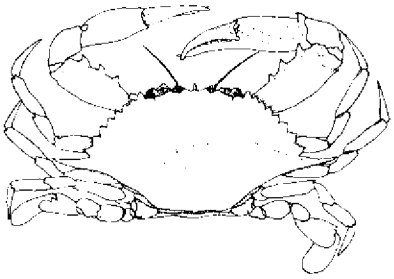


Feeding Interrelationships. No data are available on the feeding habits of red crab in nature, but its habitat and morphology suggest that it is a scavenger and bottom feeder. Under laboratory conditions, adult red crabs have eaten sea anemones, hard clams, and fish, with sea anemones a preferred food item (Gray 1970; Ganz and Herrmann 1974). Red crabs have been commercially taken using pots and traps baited with menhaden, redfish, flounder, and other species (Ganz and Herrmann 1974).

Environmental Sensitivity. Red crab, like many other deep water crustaceans, cannot withstand sudden changes in its habitat. At water temperatures above 10°C (50°F), adult red crabs in laboratory experiments exhibited visible signs of stress, becoming sluggish and regurgitating food materials; crabs placed in waters above 21°C (70°F) became motionless and were unable to right themselves when overturned (Ganz and Herrmann 1974). Stress reactions at temperatures higher than 10°C (50°F) suggest a reason why red crabs are seldom found in areas where bottom water temperatures exceed this level (Gray 1970).

Blue Crab *Callinectes sapidus*

Robert L. Lippson



Distribution and Seasonal Movements. The blue crab has a known range from the Gulf of Maine to Uruguay, but is generally distributed from Long Island to the Gulf of Mexico (Williams 1965). It is most abundant in Chesapeake Bay but is found in commercial quantities in New York Bight, particularly off New Jersey and Delaware (Map 55). There are occasional periods of relatively high abundance off Long Island and as far north as Vineyard Sound, MA. The species is confined mostly to coastal estuaries and lagoons but may be found in nearshore waters of the Bight.

The blue crab is a highly mobile animal, able to swim with its modified, paddle-like rear legs. It performs a complex seasonal migration pattern up and down estuaries in relation to its reproduction cycle, generally moving into shoaler waters in spring and back into deeper waters in autumn where it becomes torpid and remains throughout winter and early spring (Miller, Sulken, and Lippson 1975). Individual blue crabs probably do not migrate north and south along the coast on a seasonal basis.

Population Size and Fisheries. Annual commercial blue crab landings from New York to North Carolina have ranged from 30,000 to 50,000 MT since 1960 (McHugh 1977*a*). The bulk of these landings were from Chesapeake Bay, and less than 10% came from New York Bight. Except for the peak year of 1939, landings from New York, New Jersey, and Delaware have generally been less than 1,000 MT (McHugh and Ginter 1978). Landings declined in New York Bight during the 1960s, reaching a low of less than 200 MT in 1968, and then began increasing again, reaching a level of about 1,400 MT in 1975. From 1976 to 1978, the commercial catch averaged 1,300 MT per year in New York Bight; during the same period landings for the entire Middle Atlantic Bight average about 32,000 MT.

Blue crabs are harvested commercially with crab pots, trotlines (a modified longline), and crab dredges and crab scrapes. In Maryland, crab pots account for approximately 49% of the catch while trotlines account for 44%. In Virginia, approximately 65% of the crabs harvested are taken with crab pots, 27% by dredge, with the remaining 8% taken mostly by scrapes and trotlines (Lippson 1973).

Blue crabs are a highly valued recreational species and are easily caught with dipnets, traps, and trotlines. No data are available on the numbers landed, but the recreational harvest is estimated to be about half the commercial harvest.

Reproduction, Growth, Life Span. Blue crab mating occurs during summer and early autumn (May-October); the greatest activity takes place in mid-estuarine waters where salinities range from 10‰ to 20‰. The male seeks out a female about to molt, grasps her until she begins to molt, and then releases her. Immediately after the female has molted and while she is still soft, the male again grasps her and insemination takes place. Fertilization takes place later after the females migrate down the estuary to higher salinity and deeper waters where they spend the winter. Most males remain in the upper estuary where the salinity ranges from 10‰ to 18‰, and probably bury themselves in the mud during winter.

The female releases between 750,000 and 2 million fertilized eggs onto the hair fringes of the abdominal pleopods. The creamy-orange eggs gradually darken until the egg mass is black just prior to hatching. Approximately two weeks are required for the eggs to hatch; the exact length of time is influenced by temperature, salinity, and other environmental factors.

The newly hatched larval crab, termed a zoea, begins swimming immediately and is planktonic. It molts rapidly, and during each successive molt the legs and pleopods become more fully developed. After approximately six weeks and six or seven molts, it reaches a second-stage larval form called the megalops, which is more crab-like than the zoea. The megalops has five recognizable pairs of legs and the first pair becomes claws. Although able to swim, the megalops tends to move along the bottom. After about two weeks, it molts into the first true crab stage.

Easily recognizable as a miniature blue crab, the young crab, 3 to 5 mm wide (0.11 to 0.19 in), possesses five pairs of walking legs, the first and fifth modified as claws and paddles, respectively. Young crabs are active swimmers and with the aid of tides and currents soon spread throughout the estuarine and nearshore ocean areas. Juvenile crabs molt frequently but as they grow in size, the period between molts increases. The crab continues molting until it reaches maturity. The exact number of molts is not known, but is thought to exceed 15. Crabs derived from eggs spawned in June mature at a width of approximately 125 mm (5 in) in 14 to 16 months, but those from eggs spawned in late summer and early autumn usually require 18 to 20 months to attain full size and maturity. Individual crabs probably do not live more than three years.

Feeding Interrelationships. Blue crabs are omnivorous and feed on a wide variety of plants and animals. Their animal prey includes small fishes, soft clams, and young hard clams, and they are one of the chief predators of juvenile blue crabs during the soft intermolt stages.

Inshore fishes are the principal predators of blue crabs (again during the soft stage) and include striped bass, summer flounder, white perch, and spot.

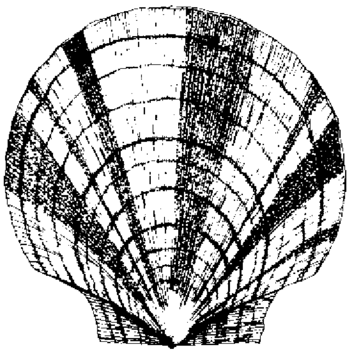
Environmental Sensitivity. The effects of environmental factors on blue crabs are poorly known, but it is believed that the early life stages may be particularly vulnerable to pollutants in estuarine waters. It has been suggested that the increased abundance of blue crabs in the New York Bight area since 1968 might possibly be related to the ban on DDT spraying (McHugh 1977*b*).

A more direct link exists between the introduction of a toxic chemical, Kepone, and the subsequent decline in the blue crabs in the James River, VA. Kepone is believed to have been released into the James River during the late 1960s or early 1970s at Hopewell, VA, about 97 km (60 mi) upstream from the mouth of the river (Lippson and Gardner 1977). The commercial crab catch from the James River dropped from an annual average of 900 MT in the 1968-72 period to less than 15 MT by 1975, a decline of more than 90% in three years; at the same time there was no downward trend in landings from the nearby Rappahannock River. Since 1976 harvest restrictions have been imposed on the James River to prevent public health risk.

Toxicity of Kepone in blue crabs has been demonstrated. Crabs fed on oysters containing 0.15 mg/g of Kepone showed significantly higher mortality and had fewer molts than did crabs fed on uncontaminated oysters (Schimmel et al 1979). In a Kepone-free environment, there was no measurable loss of the toxic chemical from body tissue in crabs held 28 days; some loss occurred after 28 days but it was still detectable in crabs held for 90 days. The impact of Kepone in the James River is expected to persist for some time and may spread downstream because the chemical has been incorporated in the sediments. A gradual sediment transport downstream can spread the contamination closer to the mouth of the river and may eventually impact the major spawning areas in the Chesapeake.

Sea Scallop *Placopecten magellanicus*

J.A. Posgay



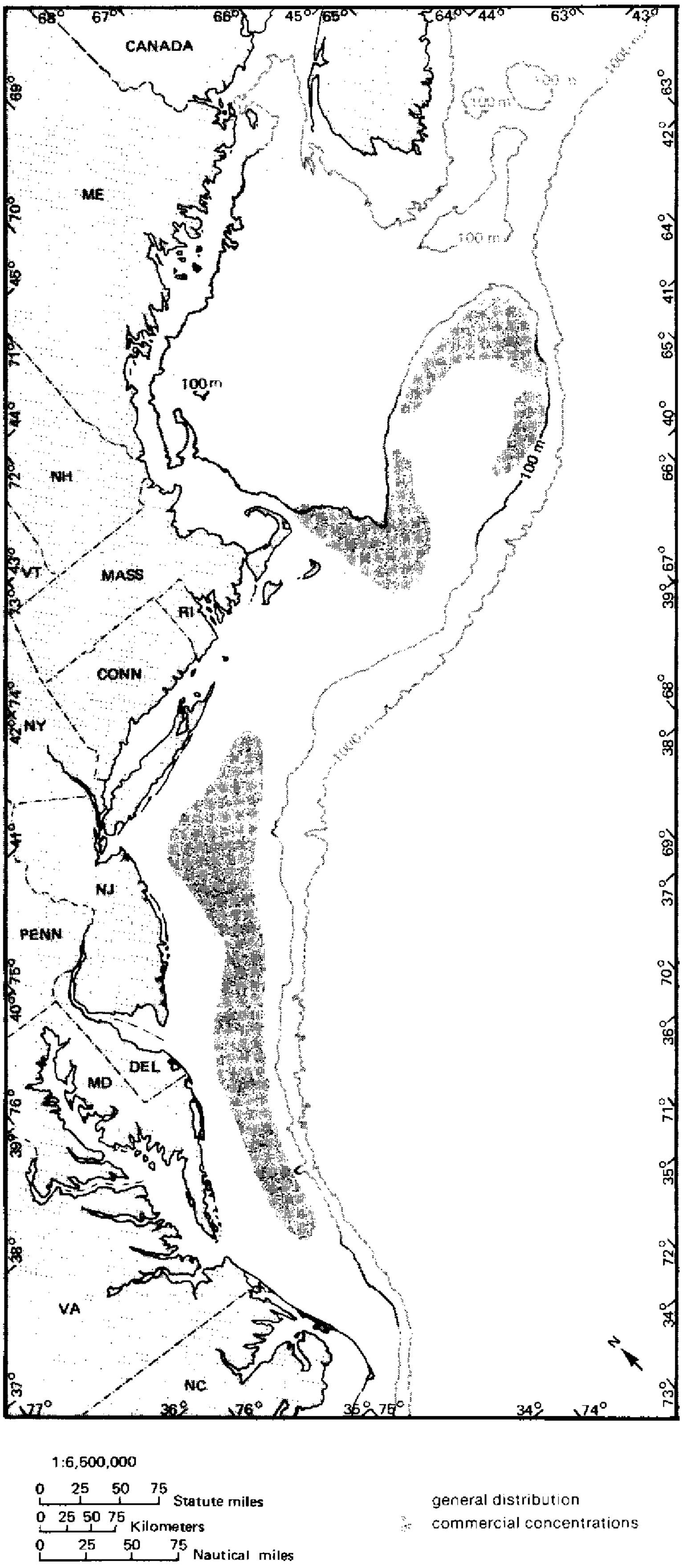
Distribution and Seasonal Movements. The sea scallop occurs only in the Northwest Atlantic from the Straits of Belle Isle to the Virginia capes (Posgay 1957). North of Cape Cod it is frequently found just below the low tide mark, but in the Middle Atlantic Bight it is restricted to the deeper waters where the summer temperature does not exceed 20°C (68°F). Aggregations sufficiently dense to support a fishery are usually found at depths between 40 and 100 m (130 and 328 ft) with some records to 200 m (656 ft) and only rare occurrences in deeper water. Although sea scallops are vigorous swimmers and individuals may frequently move about, concentrations of adults remain fixed (Posgay 1963). There is no evidence for directed movements or seasonal migrations. The greatest concentrations, as deduced from the fishery and research vessel investigations, occur on eastern Georges Bank. Within the Bight, the best fishing is usually found in the vicinity of Hudson, Baltimore, and Norfolk canyons (Map 56).

Population Size and Fisheries. The sea scallop fishery in the Bight has exhibited considerable variability. From 1952 to 1964 annual landings from these grounds averaged about 10,400 MT live weight with a range of 5,000 to 21,000 MT. Landings rose dramatically to 65,000 MT in 1965 and then reached 75,000 MT in 1966. There was a gradual decline to a more normal level of about 9,000 MT for the years 1970-74. The years 1975-78, showed another large increase in annual landings (Figure 4). The preliminary data for 1978 show about 72,000 MT, just below the previous record year of 1966.

Both periods of greatly increased landings were the direct result of the recruitment of two unusually successful year classes, 1961 and 1972, which attracted increased fishing effort from other grounds and other fisheries. Shell samples collected from the commercial fleet operating in the Bight have always shown that a large fraction of the landings, usually over 90%, was made up of the newly recruited year-class (four to five years old). There has always been enough fishing effort in the area to locate the centers of abundance and enough vessel capacity to harvest the crop as soon as the scallops reached an attractive size. Most of the greatly expanded effort in 1965-66 was diverted from Georges Bank which was then suffering from declining catch rates after the bumper years of 1961-63. Some of the increased effort in 1976-77 came from other areas and other fisheries but a large fraction of it was the result of newly built vessels. When the grounds revert to average patterns of recruitment, there will be a problem of what to do with all this increased capacity.

Map 56 illustrates the general distribution and commercial concentrations of scallops. The United States and Canadian fleets fished all grounds in the Bight very heavily in the middle 1960s and the records of catch effort, and area of capture are excellent. The value to the fishing boats (ex-vessel) of these landings was about $10 million per year.

Map 56. Sea scallop — distribution and spawning areas based on historical commercial fishery records

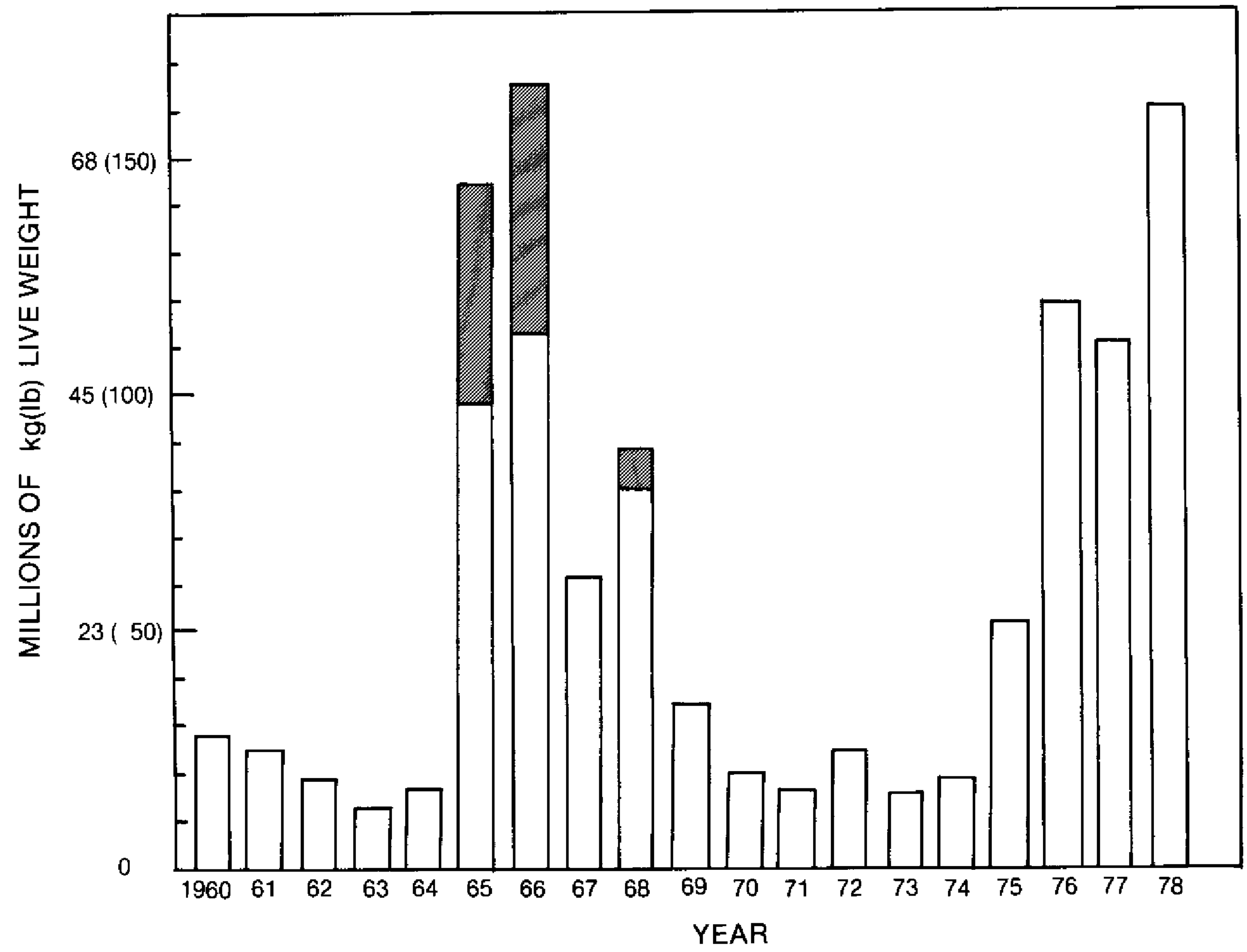


Reproduction, Growth, Life Span. Unlike the bay scallop, *Aequipecten irradians,* the sexes are separate in the sea scallop. The single gonad is a large, tongue-shaped organ that occupies most of the mantle cavity ventral to the foot. Sea scallops are normally ripe from late winter to early autumn during which time the gonads are full and plump. Male gonads are a creamy white and female gonads are a bright coral red. Hermaphrodites are not unknown but are extremely rare (Merrill and Burch 1960).

Most sea scallops become sexually mature during the spring that they lay down their third annual ring (over three years old) at about 75 mm (2.9 in). There is some evidence that sea scallops found off the coast of North Carolina and Virginia may spawn as early as July but for those further north spawning does not occur until late September or early October (Posgay and Norman 1958; MacKenzie, Merrill, and Serchuk 1978). The gonads of the four year olds spawning for the first time are so small that they contribute very little to total egg production. Fecundity in five year old and older females reaches the hundreds of thousands and even millions of eggs and it is these year-classes that constitute the main body of the spawning stock. All of the scallops in the same general area spawn at the same time, perhaps stimulating one another, over a short time span. Females extrude their eggs, males extrude their sperm and fertilization takes place outside the mantle cavity. The trigger mechanism that sets off the mass spawning is not known.

The eggs and larvae are planktonic and follow the usual molluscan developmental stages (Merrill 1961). The

Figure 4. Total annual landings of sea scallops from the Middle Atlantic Bight (ICNAF Statistical Area 6) 1960-78 (Shading indicates Canadian landings.)



duration of the planktonic phase in the wild is not known and has only recently been determined in culture to be about 35 days at 15°C or 59°F (Culliney 1974). Very little is known of the first two years of the sea scallop's life history. Small scallops are rare in the usual types of benthic samplers, and the larvae have never been clearly identified in plankton collections.

During the month or more that the eggs and larvae are planktonic, they are transported long distances in the prevailing surface currents. No local aggregation can be self-reproducing with the possible exception of Georges Bank where a semipersistent gyre may retain the spawning products long enough for them to complete development and settle out. Nevertheless, the same general areas tend to be the most productive year after year throughout the range (Map 56). Spat-fall off the Chesapeake Bay is probably the result of spawning off Delaware Bay, and these beds are populated from spawning off the Hudson River. The Hudson Shelf Valley beds are probably derived from sea scallop larvae which were entrained in water escaping from the Georges Bank gyre and being carried to the west. Very little is known about the rate of transport of the coastal waters between Cape Cod and Cape Hatteras but Bowman and Wunderlich (1977) reported that Gulf Stream eddies, pinched off and transported to the southwest over the continental slope, move about 5 to 10 cm/sec (= 6.5 km/day). In a month, this amounts to about 200 km (124 mi), just about the distance between major scallop concentrations in the Bight (Map 56).

The sea scallop grows rapidly during its first few years of life (Merrill, Posgay, and Nichy 1966). The rate varies between grounds but a reasonable average for the Bight is shown in Table 20. The weight shown in Table 20

TABLE 20. Average growth of sea scallops.

Age	Length mm (in)	Weight g (oz)
3	66 (2.6)	5.2 (0.2)
4	88 (3.5)	12.6 (0.4)
5	104 (4.1)	21.3 (0.7)
6	117 (4.6)	29.9 (1.0)
7	126 (5.0)	37.6 (1.2)
8	133 (5.2)	44.1 (1.4)
9	138 (5.4)	49.3 (1.6)
10	141 (5.6)	53.5 (1.9)

is that of the adductor muscle, which represents the commercial crop; to convert to approximate live weight, multiply by 8.3. Natural mortality is fairly low, about 10% per year, and in the absence of heavy fishing pressure the life span might reach 20 years.

Yield per recruit calculations predict that the large 1965-66 harvests would have been still larger if age at first capture had been postponed for a few years. The rate of removal was more than 60%per year, which gives a maximum yield with an age at first capture at about eight. Postponing capture for three years, from 4.5 to 7.5 years of age, would have increased the yield by about 35%.

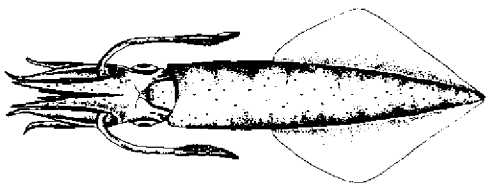
Feeding Interrelationships. The sea scallop, like most bivalves, is a filter feeder, straining particles from water passing through its mantle cavity. The contents of the gut and stomach are usually quite green and it is reasonable to assume that it subsists on phytoplankton, mostly diatoms, with perhaps some contribution from organic detritus. One of the characteristics of scallops found in waters deeper than 100 m (328 ft) is a slow growth rate which may be caused by lack of living phytoplankton.

Adult sea scallops do not seem to have any major predators except man. Evidently their agility and their hard shells with sharp edges make them unattractive or unattainable. The shells of juveniles (<25 mm or <0.98 in) have been found in the stomachs of eel pouts (Bigelow and Schroeder 1953). Medcof and Bourne (1964) also reported them in cod, American plaice, and wolffish. Undoubtedly, the eggs and larvae are eaten by anything big enough to catch and swallow them.

Environmental Sensitivity. The sea scallop cannot stand sudden drastic changes in its habitat. Mass mortalities observed in the Gulf of St. Lawrence have been shown to be caused by internal waves in the thermocline forcing warm water to the bottom and killing the scallops (Dickie and Medcof 1963). Increased turbidity has been shown to increase stress, depress feeding, and cause weight loss in sea scallops (Stone 1975).

Long-Finned Squid *Loligo pealei*

Anne M.T. Lange



Distribution and Seasonal Movements. The common American or long-finned squid is found on the continental shelf, primarily from Cape Hatteras to Georges Bank, though it has been reported as far north as New Brunswick, Canada, and south to Georgia. It ranges from shallow coastal waters 3 m (10 ft) or less in spring and summer to at least 365 m (1,200 ft) along the continental shelf edge in winter (Map 57). Squid migrate inshore each spring to spawn and offshore in winter to avoid cold waters. They prefer water temperatures generally greater than 8°C or 46°F (Serchuk and Rathjen 1974).

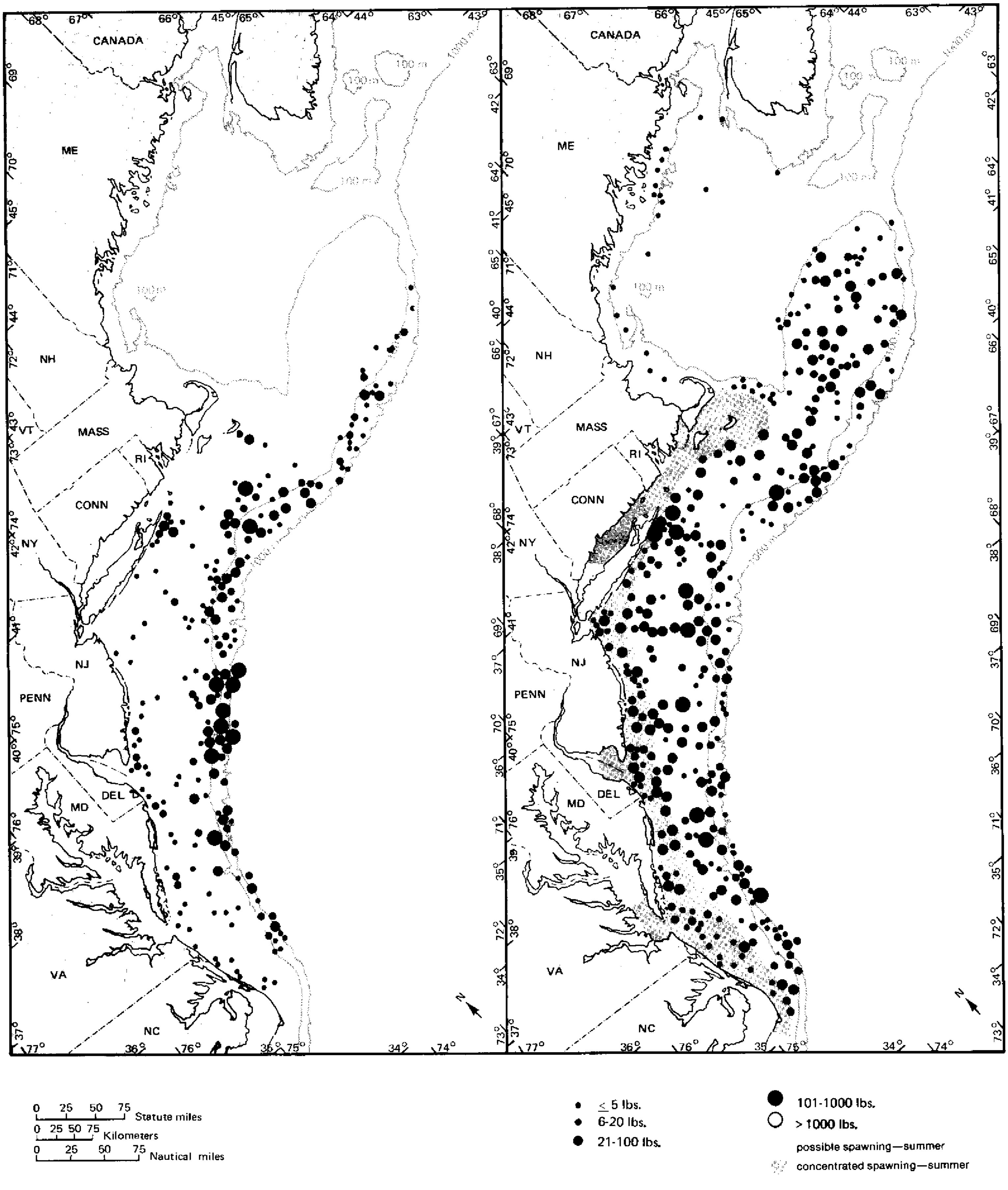
Inshore migrations begin with large individuals (greater than 18 cm or 7 in dorsal mantle length) in April off Delaware Bay and in early May off New York and Cape Cod. These squid begin spawning in late April to mid-May in shallow waters in the Woods Hole, MA area. Actual spawning was observed at a depth of 3 to 5 m or 10 to 16 ft (Lawday, personal communication). As the season progresses and water temperatures rise, smaller specimens (between 8 and 10 cm or 3 and 7 in) arrive to spawn and continue to appear until late September, and some of these may not actually spawn until the following year. In October and November, as temperatures decrease inshore, squid move offshore to the edge of the continental shelf.

Population Size and Fisheries. Reported landings of squid by US fishermen, in waters from Maine to Virginia, have fluctuated between 1,000 and 2,000 MT since first recorded in the late 1800s. With entry of foreign fleets to the squid fishery in 1964, and especially after Japanese and Spanish fisheries began in 1967 and 1970 respectively, landings increased to about 57,000 MT in 1973. Virtually all of these landings consist of two species of squid, *Loligo pealei* and *Illex illecebrosus* (short-finned squid) which until 1978 were not completely separated in the landings statistics submitted to ICNAF (International Commission for the Northwest Atlantic Fisheries 1978). The rapid increase in landings and uncertainty as to the total population size of squid led ICNAF to place a 44,000 MT limit on total allowable catch (TAC) of *Loligo* for all countries in 1976, and this same TAC has been in effect each year since then, under extended jurisdiction. However, the TAC has not been reached in any year partly because of restrictions (area, season, and by-catch) on foreign fleets.

Total landings of *Loligo* increased from less than 1,000 MT in 1966 to a peak of 37,600 MT in 1973 and then declined to 10,800 MT in 1978 (International Commission for the Northwest Atlantic Fisheries 1978). The bulk of the *Loligo* catch was taken by other nations; US landings ranged only from 653 MT to 3,600 MT during the 1970-78 period, and represented only 6% of the cumulative total *Loligo* landings for this period. Most of the US *Loligo* catch is taken nearshore in spring when the *Loligo* come inshore to spawn.

Autumn trawl surveys by NMFS from 1967 to 1976 indicated a general increase in relative abundance of *Loligo* but the trend has been downward since then (Lange 1979). Accurate estimates of total *Loligo* biomass are not yet available, but standing crops are obviously much larger than the annual landings which ranged from 10,800 to 37,600 MT from 1970 to 1978. The reduction in *Loligo*

Map 57. Long-finned squid — distribution of NMFS 1973-74 research vessel trawl catches (dots) and spawning areas (shading) (spring-left, autumn-right)



landings since 1973 is due partly to the decline in abundance, and since 1977 to restrictions on foreign fishing.

Reproduction, Growth, Life Span. Squid lack the hard body parts normally used in aging techniques; they do not survive long in captivity and are too fragile for tagging. Consequently, age and growth studies are based on length frequency distributions and biological observations. On the average, they survive 12 to 24 months and grow to 18 to 28 cm (7 to 11 in) dorsal mantle length, although some males survive about 36 months and reach more than 40 cm or 16 in (Summers 1971).

Mesnil (1977) has suggested a complicated crossover life cycle for this species, related to its extended spawning season (April to September). This proposed cycle suggests that there are two overlapping reproduction cycles for *Loligo,* with maturation occurring over the winter and spawning taking place in April-May or August-September. Those squid spawned in spring would hatch in June and mature during their first winter. Most will spawn during late summer of the following year (at about 14 months, 18 to 22 cm or 7 to 9 in) and it is assumed that they suffer high mortality after spawning; observations on squid mating in tanks indicate significant damage to females (Summers 1971). A few may survive to the following spring and it is presumed that these did not spawn yet. The squid spawned in late summer hatch in September and are too young to mature over their first winter and therefore spend the next spring and summer feeding and growing. Maturation for this group occurs during their second winter and they spawn early in the spring at about 20 months old (about 20 cm or 8 in).

Eggs are collected in gelatinous capsules as they pass through the female's oviduct during mating (Summers, Arnold, and Gilbert 1974). Each capsule is about 8 cm (3 in) long and 1 cm (0.4 in) in diameter. Summers and associates (1974) noted that mating activity among captive *Loligo* was initiated when clusters of newly spawned egg capsules were placed in the tank. During spawning the male cements bundles of spermatophores into the mantle cavity of the female, and as the capsule of eggs passes out through the oviduct its jelly is penetrated by the sperm. The female then removes the egg capsule and attaches it to a preexisting cluster of newly spawned eggs. The female lays between 20 and 30 of these capsules, each containing 150 to 200 large (about 1.2 mm or 0.05 in), oval eggs, for a total of 3,000 to 6,000 eggs. These clusters of demersal eggs, with as many as 175 capsules per cluster, are found in shallow waters 3 to 30 m (10 to 100 ft) and may often be found washed ashore on beaches.

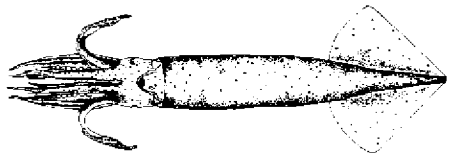
McMahon and Summers (1971) observed that *Loligo* eggs in captivity develop in 11 to 27 days at temperatures ranging from 23° to 12°C (73° to 54°F); in nature, they may develop over a 20°C (68°F) span of seawater temperature, beginning at 8°C (46°F). Little is known about the larval stages of *Loligo*; larvae are about 3 mm (0.1 in) at hatching. They are not often found in the spawning areas and are assumed to be washed away by currents. A few 2 cm (0.8 in) and many 3 to 4 cm (1 to 2 in) juveniles appear in autumn research vessel catches in shallow waters. Significant numbers of these juveniles have also been found around Hudson Shelf Valley in late winter when adults are mostly found offshore. These are presumably October-spawned individuals just beginning to move offshore.

Feeding Interrelationships. *Loligo* are active predators of crustaceans (euphausiid shrimp), small fishes such as butterfish and young silver hake, and other *Loligo,* particularly during the squid spawning season when they are in high concentrations.

Squid are preyed upon by at least 48 different species of fishes and by marine mammals (Tibbetts 1977). Maurer (1975) found that squid made up a substantial part of the diet of bluefish (30.5%), sea raven (19.9%), fourspot flounder (17.7%), spiny dogfish (12.6%), and goosefish (12.2%). They were also found to make up 2.1% of the diet of silver hake.

Short-Finned Squid *Illex illecebrosus*

Roland L. Wigley

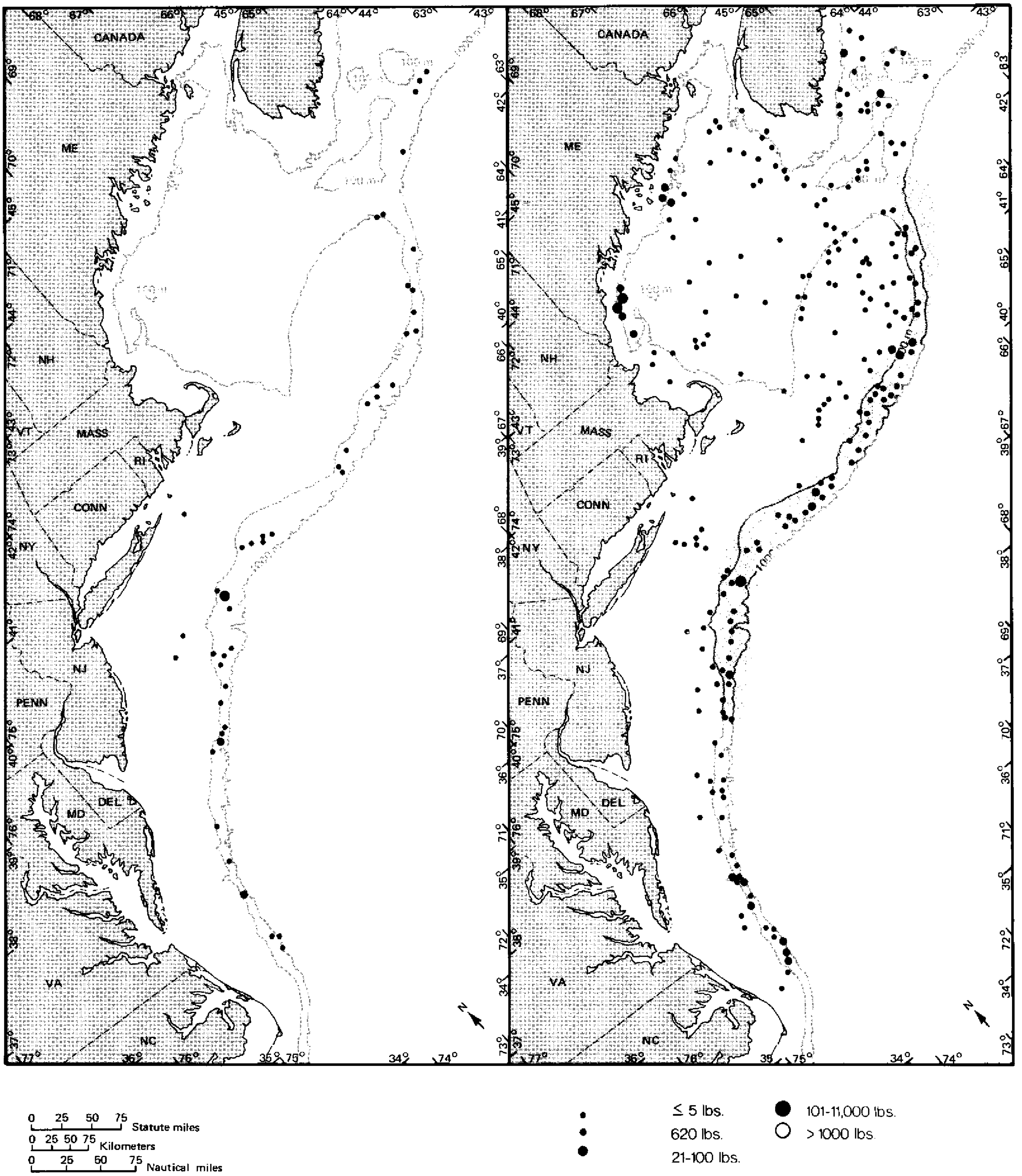


Distribution and Seasonal Movements. Short-finned squid, sometimes referred to as summer squid, short-tail squid, or red squid, is the larger of two commercially important squid species occurring off the northeastern United States. It is a member of the family Ommastrephidae, which are oceanic squids, as opposed to Loliginidae (*Loligo*), which are primarily continental shelf species.

The short-finned squid is rather widely distributed in both eastern and western North Atlantic waters (Verrill 1882*a*; Mercer 1965; Nesis 1968; Tibbetts 1977). In the eastern Atlantic it ranges from Scandinavia southward to the Bristol Channel (southwest England) and westward to the Faroe Islands and Iceland. In Western Atlantic waters it ranges from Greenland, Labrador, and Newfoundland southward to Florida. It is most abundant in the Newfoundland region and moderately abundant between Newfoundland and New Jersey (Mercer 1965; Nesis 1968; Noskov and Rikhter 1971).

Short-finned squid migrate between offshore waters and coastal areas (Mercer 1965; Murray and Wigley 1968; Vovk 1969; Paulmier and Mesnil 1975; Tibbetts 1977). They spend winters (January-March) in dense aggregations along the outer continental shelf and upper slope where the water temperatures are relatively warm, 8° to

Map 58. Short-finned squid — distribution of NMFS 1973-74 research vessel trawl catches (dots) and spawning areas (shading) (spring-left, autumn-right)



Note: brown shading shows probable spawning areas

14°C (46° to 57°F). In the spring (April-May) when shelf waters begin warming, they migrate shoreward, and move into the Gulf of Maine and even into coastal bays, sounds, and harbors. During summer and autumn short-finned squid are widespread throughout the entire New England-mid-Atlantic continental shelf (Map 58). In November-December they begin moving to deeper, warmer, offshore waters. This seaward shift is very pronounced by January-February when they have migrated to the upper slope or to waters deeper than 100 m (328 ft) in the Georges Basin area and Northeast Channel where relatively warm, high-salinity waters enter the Gulf of Maine. The squid remain in deep waters (►80 m or ►262 ft) offshore along the outer margin of the shelf throughout the rest of the winter and early spring and repeat the migratory cycle the following spring.

Over the continental shelf and the upper slope depth, short-finned squid range throughout the water column from surface to bottom; in deep oceanic waters they may remain in the upper levels. Their range is from 0 to at least 681 m or 2,234 ft (Verrill 1882*a*). During the day they occur near the bottom and sometimes rest on the seabed (Bradbury and Aldrich 1969). At night they rise to the surface and will congregate around vessels and other sources of light.

Population Size and Fisheries. As is the case for *Loligo,* there are no accurate estimates of *Illex* biomass in the area from Cape Hatteras to the Gulf of Maine. Prior to 1976 the relative abundance of *Illex* in this area appeared to be considerably less than that of *Loligo* based on catch per haul data from NMFS autumn trawl surveys. It is possible that *Illex* may be less vulnerable than *Loligo* to the NMFS research trawls, but commercial landings of *Illex* were also generally less than *Loligo* (Lange 1979). Abundance of *Illex* increased substantially in 1976 as indicated by commercial catch/effort statistics and NMFS trawl surveys, and minimum biomass estimates of *Illex* derived from the surveys were about the same order of magnitude during 1976-78 as for *Loligo* (Lange 1979).

Reported total landings of *Illex* generally were less than 3,000 MT prior to 1970, and then increased rapidly reaching peak levels of about 25,000 MT in 1976 and 1977, and dropping back to less than 18,000 MT in 1978. There were unusually large numbers of young *Illex* in 1978 surveys, suggesting that the stock may be increasing.

US *Illex* landings ranged from approximately 100 to 1,000 MT from 1970 to 1978, representing only 1% of the cumulative catch of *Illex* for this period. Quotas (TAC) on *Illex* were 30,000 MT in 1976, 35,000 MT in 1977, and 30,000 MT in 1978; as for *Loligo* the TAC was not reached in any year.

Reproduction, Growth, Life Span. Little is known about the reproduction of short-finned squid. Sperm are stored in elongate, bat-shaped spermatophores. During copulation the male places spermatophores in the female's mantle cavity, attaching them to the mantle wall near the oviduct opening. It is believed that the eggs are spawned one by one, in batches, and fertilized within the mantle cavity. Fertilized eggs are assumed to float free in the water. However, to date, no short-finned squid eggs have been identified in the many plankton samples taken in western North Atlantic waters.

The spawning season for this squid is not well documented. In Newfoundland waters spawning is believed to take place between January and June (Squires 1967). Off the northeastern United States, first indications of gonad ripening become apparent in late July when water temperatures are at least 10° to 12°C (50° to 54°F). Large males (over 18 cm or 7 in mantle length) are first to show evidence of imminent spawning activity. About the same time, ovaries become greatly enlarged. In the more advanced stage of spawning the females contain a multitude of spermatophores acquired from the males. Usually, large females mature early in the season. Thus, off the northeastern United States spawning apparently begins in August and probably extends through winter, depending upon geographic location and water temperature. Earliest spawning occurs on the outer shelf about 150 to 200 km (93 to 124 mi) east of northern New Jersey, in the vicinity of Husdon Shelf Valley in waters 175 m (574 ft) and deeper (Map 58). Spawning is also believed to occur during the latter part of August and early September in shelf waters 75 to 200 m (246 to 656 ft) deep from New Jersey (and perhaps farther south) northeastward to eastern Georges Bank. Whether spawning takes place in the Gulf of Maine is not known.

Although the age and growth phase of this squid's life history is not well understood, there is evidence that its lifespan is only about 1.5 years (Mercer 1965; Squires 1967; Tibbetts 1977). The largest (greater than 40 cm or 16 in mantle length) and oldest individuals live to be approximately two years old. During early life, monthly increase in weight averages about 50 g (2 oz). In older individuals the weight increment is only one-half to one-third that of the young. The growth of males and females is nearly identical at sizes less than 20 cm (8 in) mantle length. In larger individuals the males are slightly heavier at a given length than females. In spring and summer short-finned squid commonly average 15 to 18 cm (6 to 7 in) mantle length and weigh 70 to 125 g (2 to 4 oz). By late summer and early autumn they have increased to an average of about 18 to 25 cm (7 to 10 in) long and weigh 125 to 325 g (4 to 11 oz).

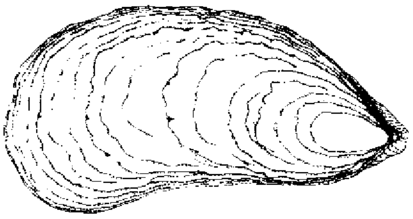
Feeding Interrelationships. Principal foods of short-finned squid off the northeastern United States are crustaceans (mainly euphausiids, with small quantities of hyperiid amphipods) and fishes (Atlantic sea herring and Atlantic mackerel). Cannibalism is common and larger specimens in particular are known to prey heavily on fellow members of their species (Wigley, personal communication).

Short-finned squid constitute a major source of food for large carnivorous marine animals. Adults are heavily preyed upon by porpoises and other whales and by numerous pelagic fishes (tuna and swordfish, for example). Bottom-dwelling fishes also prey upon this species. Although unverified, young stages of this squid are believed to be an important food for smaller fishes and invertebrate animals.

When annoyed or alarmed, this squid discharges a cloud of dark, inky fluid, reputed to be distasteful to its pursuer or antagonist.

American Oyster *Crassostrea virginica*

Clyde L. MacKenzie, Jr.



Distribution and Seasonal Movements. The American oyster ranges from northern New Brunswick to Mexico and is most abundant in the Middle Atlantic Bight and the Gulf of Mexico (Galtsoff 1964). The oyster population in the Bight represents about 55% of the total US stock and that in the Gulf of Mexico accounts for the remainder. The bulk of the mid-Atlantic population occurs in Chesapeake Bay (Map 59). The oyster lives in estuaries in salinities from 5‰ to 30‰, and has a depth range from the intertidal zone to 40 m or 130 ft (Merrill and Boss 1966), but most grow in depths from 1 to 5 m (3 to 16 ft). It is dormant in winter and does not feed or grow in temperatures below 6° to 7°C (43° to 46°F). The oyster requires a hard substrate such as shells or stones and cannot survive if covered with sand or mud.

Population Size and Fisheries. The oyster fisheries of Long Island Sound, Delaware Bay, and Chesapeake Bay are very old, dating from precolonial times, and oyster fishermen often come from families who have been oystering for several generations, gathering the oysters with tongs and dredges. However, the oyster resources of the Bight have been declining for the past 100 years. Commercial landings of oyster meats declined from about 65,000 MT in the late 1800s to only 10,000 MT in the 1960s (Lyles 1969). In New York Bight alone, landings of meats dropped from an average of 12,000 MT in the late 1800s to about 1,000 MT in the 1960s (McHugh and Ginter 1978). The decline resulted primarily from loss of suitable habitat due to siltation and dredging, and the direct and indirect effects of industrial and domestic pollution. Natural factors such as disease have also been important in some areas. For example, in the late 1950s and early 1960s, oyster populations in Delaware Bay and lower Chesapeake Bay were decimated by disease, caused by a microscopic organism *Minchinia nelsoni* (Andrews and Hewatt 1957; Haskin, Stauber, and MacKin 1966; Andrews and Wood 1967; Farley 1968; Sindermann 1970). These populations have not yet fully recovered. In Long Island Sound the oyster industry was virtually eliminated in the 1950s after a severe storm buried most oysters with silt; this was followed by an invasion of starfish — major oyster predators (MacKenzie 1970*a*). Subsequently, the industry recovered somewhat with improved cultivation methods.

Since 1960, total oyster production in the Bight has remained fairly steady at about 10,000 to 12,000 MT of oyster meats, and it averaged 11,000 MT from 1976 to 1978. Presently, the total oyster population probably consists of about 45 million bushels (including shells). Most oysters originate as seed in public beds under state management; production could be substantially increased by applying cultivation techniques to improve the condition of setting beds and control predators of larvae and spat (young oysters). For example, improvements in cultivation increased production in New York from 46 MT in 1967 to 956 MT in 1975 (McHugh and Ginter 1978).

Reproduction, Growth, Life Span. Oysters first reach maturity in their second year of life and over a length range of 2.5 to 4.7 cm (1.0 to 1.8 in); males mature at smaller sizes than females (Galtsoff 1964). Spawning occurs from June through August, and sperm and eggs are cast into the waters where fertilization occurs. The fertilized eggs develop into pelagic shelled larvae and drift about with tidal currents for about two weeks. When about 0.3 mm (0.01 in) long, the larvae set on oysters, clean shells and stones, and begin to grow. The annual production of spat varies widely. Sets of commercial magnitude are less frequent in the northern than in the southern part of the Bight, probably because lower temperatures result in a shorter spawning period and thus fewer chances for a set. For instance, the average annual setting frequency in Long Island Sound is about 50%, in Delaware Bay, 75%, and in Chesapeake Bay, nearly 100% (MacKenzie 1977*a*; Kunkle, personal communication). However, setting has been irregular even in Maryland since 1972, possibly due to lower salinities in estuaries as a result of the 1972 tropical storm Agnes and above normal runoff since then.

Growth rates are slower in the north because of lower temperatures. Oysters take four to five years to attain the market length of 7.5 to 10 cm (3 to 4 in) in the north as compared to about three years in the south.

Feeding Interrelationships. Oysters of all ages, including larvae, juveniles, and adults, feed on phytoplankton and zooplankton (Galtsoff 1964). Planktonic particles become trapped on the mucus covering of the oysters' gills and are then ingested or rejected.

Predators can eliminate oyster populations if not controlled, and predation is highest on oyster spat (MacKenzie 1970*a,b*). Oyster predators and competitors are much more numerous in higher salinity areas such as Long Island Sound (average salinity about 27 ‰) than in areas of low salinity (◄15 ‰) such as upper Delaware Bay and much of Chesapeake Bay. In Long Island Sound, major predators are the starfish and oyster drills, and competitors include barnacles and slipper shells (the latter compete with and kill spat by either using attachment surfaces or growing over them). Farther south, oyster drills are the most serious predators of attached oysters. Another predator is the bay anemone which preys on oyster larvae in Chesapeake Bay (MacKenzie 1977*b*; Steinberg and Kennedy 1979). In addition, some oyster pests, particularly mud blister worms and boring sponges, discolor and encrust oyster shells, thereby reducing their palatability and market value (Galtsoff 1964).

Fish and invertebrates are much more abundant on oyster beds than in adjacent areas without oysters, because the oysters provide attachment surfaces and hiding places for the invertebrates and shelter for small fish (Arve 1960).

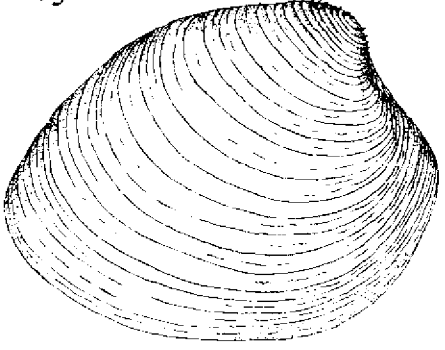
Environmental Sensitivity. The adult oyster is extremely hardy, growing and even reproducing (although perhaps not effectively) in heavily polluted sections of estuaries where many other invertebrate species cannot exist. The greatest effect of pollution has been to gradually eliminate traditional oyster producing areas, because the oysters become contaminated with bacteria and viruses from domestic sewage, and are unsafe for human consumption. For example, Raritan Bay, formerly a large supplier of oysters and hard clams for the New York City area, is now so badly polluted that it is closed to commercial oystering over its entire area for public health reasons. However, oysters continue to reproduce and grow in its most polluted sections.

Many former oyster bottoms have been destroyed by dredging to form harbors and channels, and other areas have been severely degraded through siltation from normal runoff as well as the filling and dredging (Moore and Trent 1971). These effects together with the loss of oyster production areas from sewage contamination account for the major portion of the long-term declines in oyster production.

In spite of the hardiness of adult oysters, however, sublethal effects of heavy metals, pesticides, and petroleum residues have been demonstrated on them. For example, silver in concentrations as low as 0.1 ppm altered 0_2 consumption (Thurberg, Calabrese, and Dawson 1974). Even more important are effects of pollutants on eggs and larvae. Petroleum contaminants reduce fertilization of oyster eggs (Renzoni 1973), and oyster larvae are extremely sensitive to pollutants such as detergents, pesticides, weedicides, and heavy metals (Davis 1961; Calabrese and Davis 1967; Calabrese et al 1977). In laboratory experiments, DDT killed 90% of larvae at a concentration of only 0.05 ppm, and mercury, silver, and copper killed 95% of larvae at 0.02, 0.04, and 0.06 ppm, respectively, in 12 to 14 days. Finally, pollutants also inhibit growth of the oyster's food (Ukeles 1965, 1968).

Hard Clam *Mercenaria mercenaria*

Clyde L. MacKenzie, Jr.



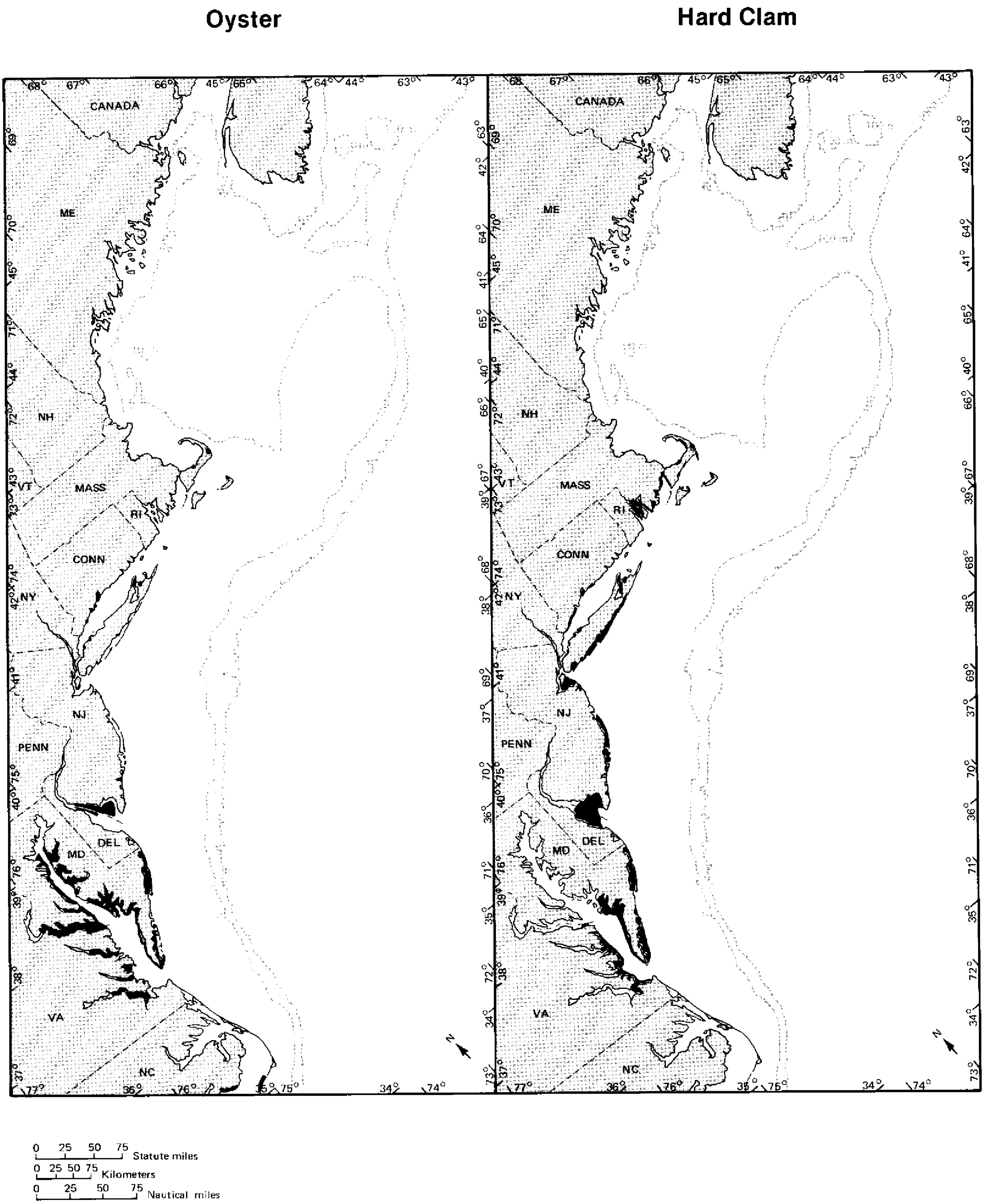
Distribution and Seasonal Movements. The hard clam, hard-shell clam, or northern quahog ranges along the Atlantic coast from the Gulf of St. Lawrence to Florida where it inhabits the sections of bays and estuaries with salinities of 15‰ to 32‰ and also a few coastal areas (Abbott 1974). Its depth range extends from the low tide mark to at least 7 m (23 ft), and it remains burrowed in the location of the original set. Most of the hard clam population occurs within the Middle Atlantic Bight (Map 59). Another closely related species, *Mercenaria campechiensis,* is also found in the Bight but only in deeper waters of the southern part (Merrill and Ropes 1967; Abbott 1974).

Population Size and Fisheries. The total hard clam population consists of many millions of bushels. Greatest abundance occurs in southern Massachusetts, around Long Island and along the NJ coast, where densities reach as high as 100 bushels per acre.

The hard clam fishery is one of the oldest in the country. Hard clams are harvested in a variety of ways, from hand rakes and tongs to hydraulic and nonhydraulic dredges (Tiller, Glude, and Stringer 1952). Most small clams, termed little necks and cherrystones, are consumed raw on-the-half-shell; the larger ones are made into chowders and stuffed clams.

US peak production of hard clams was about 9,500 MT in the late 1940s and early 1950s, and then declined to just under 6,000 MT by 1965 where it has remained to the present time (Ritchie 1977). In New York Bight alone landings increased from about 2,700 MT in the late 1950s to a peak of over 5,000 MT in 1971, probably due to increased abundance (McHugh and Ginter 1978). Landings appear to be declining somewhat since 1975, with NY and NJ landings alone dropping from 4,800 MT in 1976 to 4,000 MT in 1978.

Map 59. Oyster and hard clam — distribution and spawning areas based on historical fishery records



Oyster

Hard Clam

Historically, management has involved conserving stocks and spreading out employment by restricting clam size, harvesting gear, and daily landings. Failure to adequately police the fishermen's harvest of undersized clams can lead to rapid population depletion. For example, in Northport Bay, LI, during the 1960s, a dense bed of clams covering several hundred acres was depleted within three years because fishermen retained and sold all seed clams they took with the adults. Under good management, this bed might have lasted for more than 10 years. It is probably feasible to increase clam abundance through enhancing spat sets and reducing predators (MacKenzie 1977*c*).

Reproduction, Growth, Life Span. Hard clams mature at least by age two and at lengths of 3.2 to 3.8 cm or 1.2 to 1.5 in (Belding 1912). Spawning occurs June through August, and sperm and eggs are released into the water where fertilization occurs. The planktonic larval period lasts about eight days (Loosanoff and Davis 1963). Upon setting the young clam, 0.2 mm (0.008 in) long, attaches itself to sand grains. As it grows, the clam burrows into the sediment (Belding 1912; Carriker 1961). Setting densities of juvenile clams of 125/m² have been reported, with an extreme as high as 2,000/m² (Carriker 1961; Landers, personal communication). At the end of their first summer, juveniles are about 7 mm (0.28 in) long. Spat sets occur nearly every year but predation is high on juveniles, especially at lengths below 15 to 20 mm or 0.6 to 0.8 in (MacKenzie 1977*c*).

Clams grow to little neck size, 5 to 6 cm (2 in), in about 5 or 6 years, and reach a maximum length of about 15 cm (6 in) at an estimated age of 20 years.

Feeding Interrelationships. Hard clams of all ages, including larvae, juveniles, and adults feed on phytoplankton and zooplankton. Planktonic particles become trapped on mucus coating the clams' gills and are then ingested.

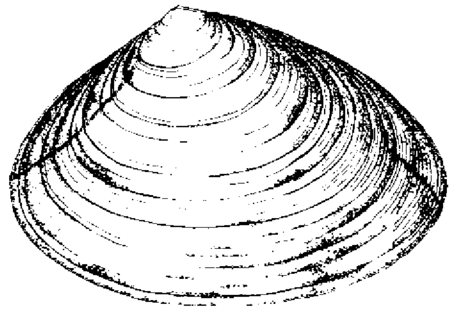
Clams are preyed upon by gastropods, crabs, starfish, and perhaps fish (Carriker 1961; MacKenzie 1977*c*). Reduction of predators by use of poisons led to a 7- to 8-fold increase in hard clam abundance on two beds, totaling 4.5 hectares (11 acres) in LI bays during the 1960s (MacKenzie 1977*c*). In laboratory trays, various predators consume juvenile clams rapidly. Average predation rates for selected individual predators were as follows: oyster drill (juvenile), 0.4 clams/hr; mud crab (Xanthidae), 14 clams/hr; and rock crab, 30 clams/hr (Carriker 1957; MacKenzie 1977*c*).

Environmental Sensitivity. Like the oyster, the hard clam is a hardy species growing and reproducing in grossly polluted habitats. However, domestic pollution has resulted in closure of many clam beds because the clams are unsafe for human consumption. For example, Raritan Bay over its entire area and substantial portions of Great South Bay have been closed to commercial harvesting, cutting off a supply of perhaps a few million bushels of clams. The dredging of harbors and channels for navigation has destroyed many formerly productive clam beds in New York Bight, and the areas open for commercial clamming appear to be getting smaller each year.

In laboratory containers of sea water, hard clam larvae are killed by various pesticides, weedicides, detergents, and heavy metals which sometimes contaminate estuaries. For example, Sevin, at a concentration of 5.0 ppm, killed 100% of clam larvae before they could metamorphose and set (Davis 1961). In general, hard clam eggs are more sensitive to pesticides and heavy metals than larvae, but substantial mortality can occur in both stages at low concentrations of such pollutants (Davis and Hidu 1969; Calabrese and Nelson 1974). Pollutants also inhibit growth of algae utilized as food by the clams (Ukeles 1965, 1968).

Atlantic Surf Clam *Spisula solidissima*

John W. Ropes, Steven A. Murawski, and *Fredric M. Serchuk*



Distribution and Seasonal Movements. The Atlantic surf clam, one of the largest bivalves living on the continental shelf of eastern North America, is distributed in predominantly sandy sediments from the Gulf of St. Lawrence to Cape Hatteras (Merrill and Ropes 1969). It is most abundant off the mid-Atlantic coast where the largest fishery occurs (Map 60). It varies in size throughout its geographic range and can reach a maximum shell length of 226 mm or 8.9 in (Ropes and Ward 1977). Mean sizes of 127 to 186 mm (5.0 to 7.3 in) were reported for NJ fishing areas from 1965 to 1974. A smaller species, *S. raveneli,* found south of Cape Hatteras rarely exceeds 75 mm (3 in); *S. polynyma,* a boreal species, inhabits deep water locations north of Long Island and attains a shell length of 150 mm (6.7 in). These latter species are generally not found mixed with *S. solidissima* in the Bight.

Extensive NMFS surveys on ocean clams have been conducted in the Bight since 1965 (Ropes 1979*a*). Most of the surf clams caught during these surveys were shallower than 43 m (141 ft), although some occurred as deep as 66 m (215 ft). A few live specimens have been reported at 128 m (420 ft). Surf clams in commercial concentrations occur from shore to 18 m (60 ft) off Long Island and to 37 m (120 ft) off New Jersey. Off the Delmarva Peninsula and VA-

NC coasts, surf clams are concentrated in 18 to 37 m (60 to 120 ft) depths.

High temperatures and low salinities probably influence distribution. Castagna and Chanley (1973) gave minimum salinities of 12.5 ‰ and 16.0 ‰ for adult and larval surf clam survival respectively. Savage (1976) included 30°C (86°F) as a critical maximum temperature for *S. solidissima,* a value equal to the limit reported for a related European species, *S. solida,* by Schlieper, Flugel, and Theede (1967).

Surf clams exhibit no seasonal movements or directed migrations. However, the juveniles and adults are active burrowers and have been seen leaping from the bottom (Ropes and Merrill 1966, 1973).

Population Size and Fisheries. Commerical exploitation of surf clams began on Cape Cod during the late 1870s as a bait fishery for the handline cod fleet (Yancey and Welch 1968). Annual landings remained at a relatively low level until the introduction of power dredge harvesting techniques in the developing NY and NJ inshore fisheries during the 1930s (Ritchie 1977). The modern food fishery began off Long Island in the mid-1940s; commercial landings increased fourfold between 1944 and 1945 (546 to 2,168 MT of meats) and reached an annual average of about 6,400 MT during the 1950s. The discovery of extensive offshore surf clam beds in the Delmarva region and off Virginia in the late 1960s and early 1970s further accelerated fishery development and resulted in peak total commercial landings of 43,580 MT in 1974. Rapid depletion of the Virginia beds quickly led to marked declines in annual landings, and catches averaged only 22,700 MT in 1976 and 1977.

In recent years the NMFS survey indices (mean number per tow) for the offshore NJ and VA-NC surf clam populations have been much lower than during the late 1960s, implying marked declines in resource abundance (Serchuk et al 1979). Annual landings patterns from these regions have generally paralleled the survey results. The offshore Delmarva surf clam populations have had the most stable survey abundance indices of any of the offshore populations.

A Fishery Management Plan was implemented November 1977 to rebuild the declining surf clam populations to allow eventual harvesting (of offshore stocks) approaching the 50 million pound (22,700 MT) level (National Marine Fisheries Service 1977). This plan restricts the annual offshore surf clam landings to 1.8 million bushels (about 13,600 MT), and regulates quarterly harvests and fishing efforts (fishing time per vessel per week). The plan also established a moratorium prohibiting the entry of additional vessels into the surf clam fishery. Given the present level of surf clam landings established in the Fishery Management Plan and the maintenance of average recruitment, population levels in all offshore surf clam areas should stabilize in the future.

Reproduction, Growth, Life Span. Studies on the 1964 year-class of surf clams at Chincoteague Inlet showed that most clams produced gametes and spawned at age one, and full sexual maturity was attained in their second year in specimens as small as 45 mm or 1.8 in (Ropes 1979*b*). Off New Jersey, large clams (►125 mm or ►4.9 in) can spawn twice each year (Ropes 1968*b*). A major spawning in mid-summer was followed by a minor spawning in late autumn during three of the four years sampled (Ropes 1968*b*). In the fourth year, spawning was apparently delayed by cold bottom temperatures until late summer and a second spawning did not occur that year. The sexes are separate, with the ratio of males to females about equal in the beds, and hermaphroditism is an anomalous condition (Ropes 1968*a*).

Egg and larval development in nature probably follows that seen in the laboratory. Larvae developed and metamorphosed after 19 days at 22°C (72°F); slower growth and higher mortalities were observed at higher and lower temperatures (Loosanoff and Davis 1963). The larvae develop from a fertilized egg (about 0.053 mm or 0.002 in in diameter) through larval (trochophore and veliger) stages typical for bivalves before an active, ciliated foot forms and they settle to the bottom as juveniles measuring 0.230 to 0.250 mm (0.009 to 0.010 in). The larvae are capable of swimming but it is mainly the ocean currents that disperse them and that concentrate juveniles in beds, often near shore. Such accumulations along the NJ shore are sources of significant landings and are sometimes washed ashore in large numbers during storms (Yancey and Welch 1968). The fate of larval and juvenile clams in the natural environment is largely unknown, but the selection of settlement sites, availability of food, and predation are some natural factors limiting survival (Coe 1953, 1956; Thorson 1966).

Surf clams grow to a length of about 50 mm (2 in) by the time they are fully mature at age two, and growth continues at a fairly rapid rate to about 150 mm (6 in) at age seven, which is the average commercial size (Ropes 1979*a*). Growth rate diminishes thereafter but surf clams continue to increase in size to about 185 mm or 7.4 in (Figure 5). A maximum age of 30 years was reported by Jones, Thompson, and Ambrose (1978).

Feeding Interrelationships. Surf clams feed by a complex filtering mechanism, which includes trapping particles on the mucus-covered gills and soft body (Kellogg 1915). The process may be selective for the kinds and sizes of foods ingested and assimilated, but in general the food requirements are poorly known. Leidy (1878) observed several different genera and species of diatoms in the digestive tract of surf clams from a NJ beach; Loosanoff and Davis (1950, 1963) used mixed plankton cultures to feed larval surf clams.

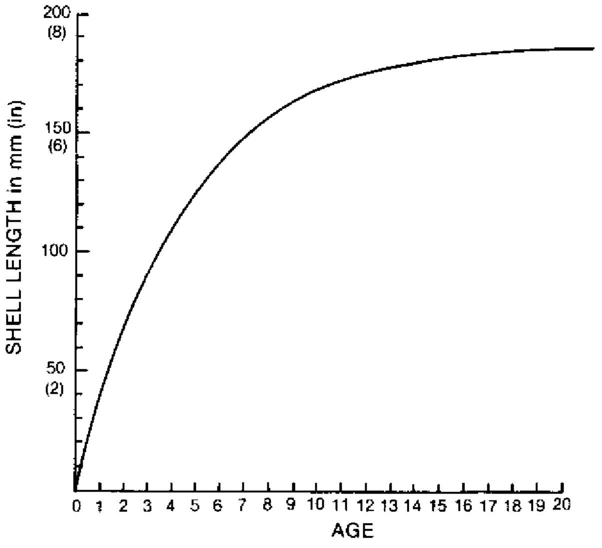
Known predation on surf clams is limited to a few snail and fish species, although other marine organisms may actively utilize them for food. Moon snails, *Lunatia heros* and *Polinices duplicatus*, bore countersunk holes in the shells to gain entry and feed on the soft body (Leidy 1878; Belding 1910). Ropes, Chamberlin, and Merrill (1969) found that 50% of the small dead surf clams in windrows on Wallops Island Beach, VA, were bored; Franz (1977) found that *Lunatia* selected surf clams less than 80 mm (3.1 in) in shell length.

Surf clam shells have been found in the stomachs of haddock and cod (Clapp 1912; Bigelow and Schroeder 1953; Clarke 1954). Other fish and crabs probably prey on surf clams, as well as seagulls and other birds near shore (Ropes et al 1969).

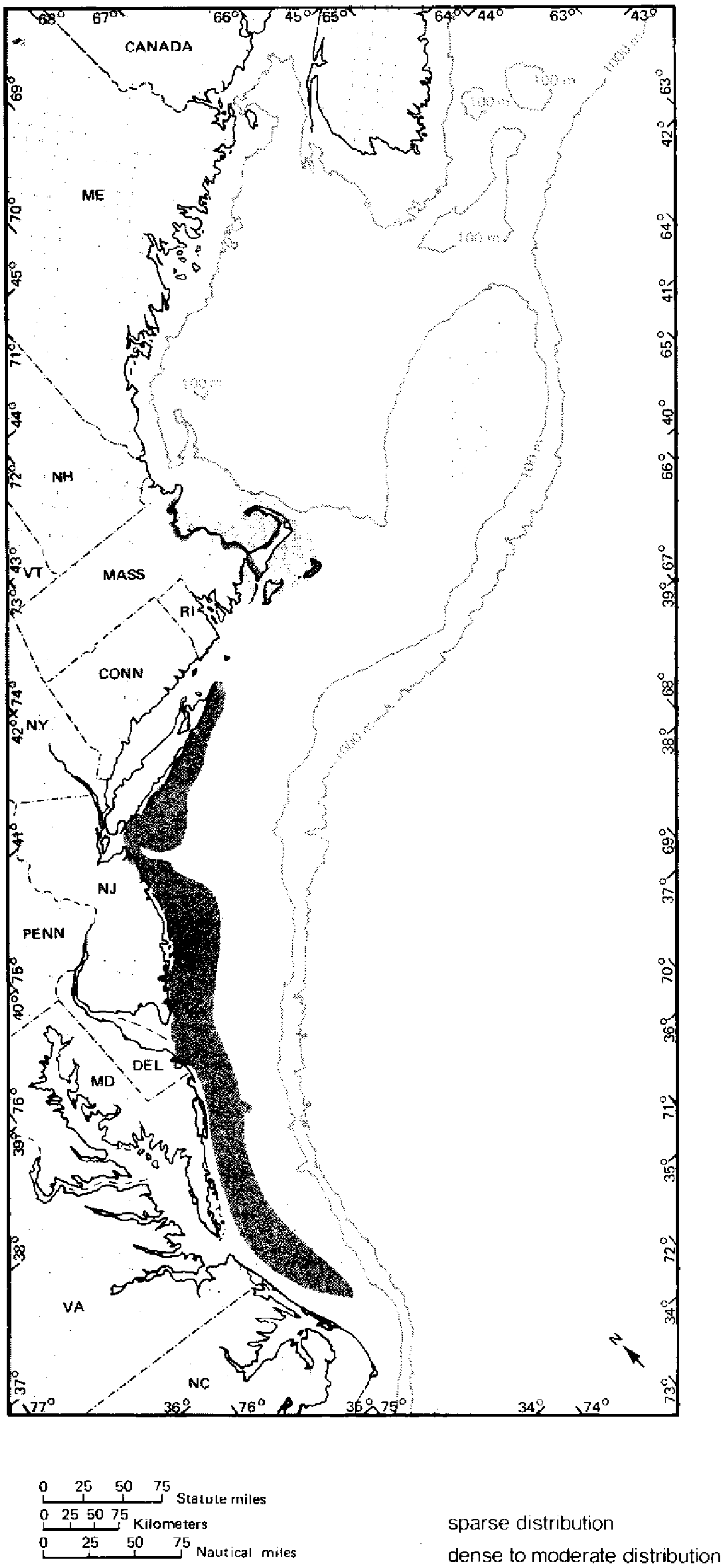
Competition with other species has not been documented but may occur in the very dense concentrations of clams in nearshore beds. Growth is slower in surf clams taken inshore and these clams often exhibit shell irregularities which suggest that normal growth was interrupted, perhaps by food shortage or effects of storms or low oxygen.

Environmental Sensitivity. Bivalve molluscs, in general, have been found to accumulate industrial, domestic, and agricultural pollutants. These can have detrimental effects on their reproduction (especially survival of eggs and larvae) and growth, and may produce significant public health risks for man (Vernberg and Vernberg 1974; Scarpelli and Rosenfield 1976; Sindermann 1976; Calabrese, Thurberg, and Gould 1977). With respect to surf clams, in particular, there are no quantitative estimates of the possible loss in production due to pollution. However, Buelow (1968) found concentrations of bacteria (associated with sewage) at such high levels in clams taken near dump sites in New York Bight, that in 1970 an area 386 km² (240 mi²) in the vicinity of these dumpsites had to be closed to shellfishing (Verber 1976).

Figure 5. General Age and growth relationship for surf clams
Source: from Ropes 1979

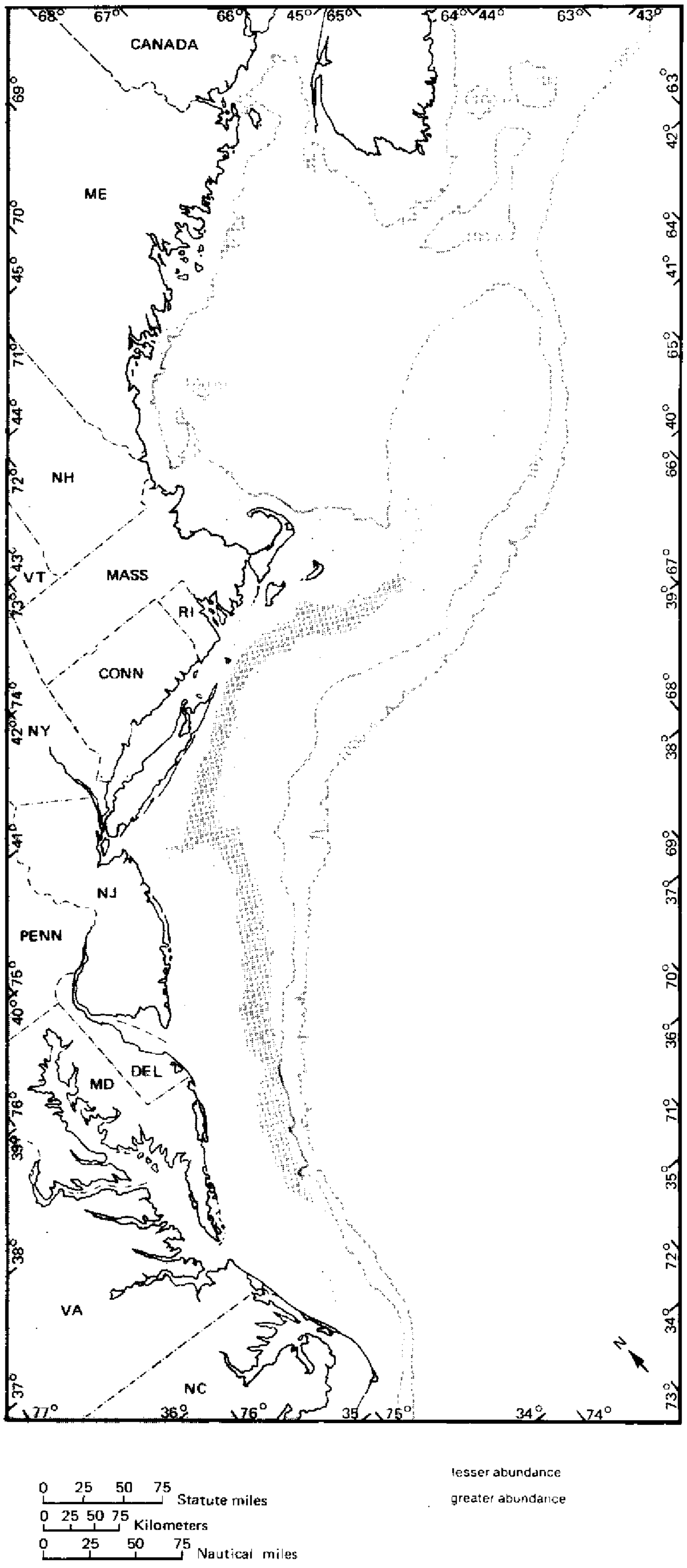


Map 60. Atlantic surf clam — general distribution from NMFS research vessel surveys



Note: Georges Bank abundance unknown

Map 61. Ocean quahog — general distribution from NMFS research vessel surveys

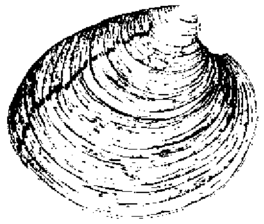


Thus, pollution indirectly affects surf clam production through closure of shellfishing areas. It may also directly affect patterns and levels of potential recruitment to the surf clam population in the Bight area. For example, the heavily polluted New York Bight apex may be a significant source of larvae (carried by southward currents) for the productive clam beds off New Jersey and further south (Franz 1976). Specific effects of contaminants on survival of the highly vulnerable larval stages might therefore impact on overall production in the Bight.

Natural environmental factors occasionally cause catastrophic mortality in adult clams. In 1968 Ogren and Chess (1969) associated surf clam mortality with low dissolved oxygen levels on wrecks and reefs off New Jersey. In 1976, unusually early spring warming and stratification of the water column, followed by a very heavy phytoplankton bloom, eventually led to widespread anoxic conditions off New Jersey (Sindermann and Swanson 1979) These conditions affected a 6,750 km² (4,194 mi²) area of the surf clam resource, and resulted in an estimated loss of 62% of the biomass in that area, and a 31% decline in the 1976 NJ landings (Ropes et al 1979).

Ocean Quahog *Arctica islandica*

Fredric M. Serchuk, Steven A. Murawski,
and *John W. Ropes*



Distribution and Seasonal Movements. The ocean quahog, the only extant species of the family Articidae, is a boreal pelecypod occurring on both sides of the North Atlantic (Nicol 1951; Zatsepin and Filatova 1961). In the Northwest Atlantic, ocean quahogs are distributed on the continental shelf from Newfoundland to Cape Hatteras (Map 61). Commercial concentrations in the Middle Atlantic Bight are found at depths between 25 and 60 m (80 and 200 ft); large inshore aggregations are found in the Gulf of Maine, the cost of the Maritime Provinces, and off Cape Cod (Hiltz 1977; Ropes 1979*a*). The species inhabits a variety of substrata but is most abundant in soft sandy-mud and silty-sand (Parker and McRae 1970). It is generally restricted to cooler waters where bottom temperatures seldom exceed 20°C or 68°F (Golikov and Scarlato 1973). Seasonal movements or directed migrations of adult quahogs do not occur (The Research Institute of the Gulf of Maine, Public Affairs Research Center 1974).

Population Size and Fisheries. Commercial exploitation of the ocean quahog began during the second world war in response to the US war food production program (Arcisz and Neville 1945). Landings increased from 301 MT (meats) in 1944 to 685 MT in 1946, but sharply declined afterward; annual landings averaged only 107 MT from 1947 through 1969 (Ropes 1979*a*). Prior to 1976, virtually all domestic production was derived from the traditional Rhode Island and Block Island Sound fisheries. During the 1970s industrial interest and expansion in harvesting and marketing of ocean quahogs increased (Rathjen 1977) with annual landings averaging 658 MT 1970-75. The development of the NJ fishery in 1976 and the Delmarva Peninsula fishery in 1977 resulted in marked increases in annual catches. Total US landings in 1977 were 8,074 MT, a 221% gain from 1976, and 12-fold greater than the 1970-75 average; 84% of the 1977 catch was taken by the NJ and Delmarva fisheries.

Significant fishing effort was transferred from the mid-Atlantic surf clam fishery to the ocean quahog resource in 1976 and 1977 because of the relatively depressed status of offshore surf clam populations, landings restrictions enacted in the surf clam fishery, and accelerated technological advances in the utilization of ocean quahog meats. To prevent overfishing of ocean quahogs, a Fishery Management Plan regulating quahog harvests was implemented in November 1977 for a two-year period. The plan restricts the annual ocean quahog catch to 3 million bushels (about 13,600 MT).

Distribution and relative abundance of ocean quahog populations in the Bight have been monitored through federal exploratory and shellfish research survey assessment cruises conducted since 1965 (Parker and McRae 1970; Ropes 1979*a*; Murawski and Serchuk 1979). Although an earlier standing crop estimate derived from a single shellfish assessment cruise (National Marine Fisheries Service 1976) suggested 2.5 million MT (meats) of ocean quahogs existed from Long Island south to Virginia, more recent analyses of combined data from the 1965-77 shellfish assessment surveys (6 cruises used) indicated a minimum population biomass of quahogs of 1.5 million MT (Murawski and Serchuk 1979). Abundance declined south of Long Island, but highest concentrations were found in all regions (Long Island, New Jersey, and Delmarva) between 40 and 60 m (130 and 197 ft).

Detailed information on growth and mortality rates of ocean quahogs do not exist, and catch/effort data from the fishery are available for only three years. Thus, an accurate assessment of maximum sustainable yield is not possible.

Reproduction, Growth, Life Span. The spawning season of ocean quahogs begins in early summer when water temperatures initially reach 13.5°C (56°F), is at a maximum in August, and ceases in early October (Loosanoff 1953). The annual gonadal cycle is continuous; well-defined sex cells are present in the follicles throughout the year. Sexes are separate and hermaphroditism rarely, if ever, occurs. Preliminary observations indicated sexual maturity in individuals as small as 26 mm (1 in) shell length, although this condition may be delayed until a 47 mm (1.8 in) shell length is attained (Thompson, personal communication).

Eggs and larvae are planktonic and undergo typical molluscan development from trochophore through veliger stages to metamorphosis (Landers 1976). A 60-day larval period has been determined in laboratory culture at 10° and 12°C or 50° and 54°F (Landers 1972). Due to the long larval life, larvae are probably widely dispersed in the field by water currents. Little is known of the juvenile life but predation is probably high in smaller individuals due to their size and inability to burrow deeply (Ropes 1979*a*). Empty shells exhibiting gastropod drill holes are often taken in dredge samples suggesting that boring snails may be important invertebrate predators (Merrill, Chamberlin, and Ropes 1969).

The growth rate of ocean quahogs is poorly documented. Loosanoff (1953) indicated the 90 to 102 mm (3.5 to 4.0 in) individuals were several years old but did not provide aging technique details. Canadian scientists interpreted external shell "rings" as growth indicators but these results remain unpublished (Meagher and Medcof, personal communication). Growth studies of notched individuals by the same investigators indicated a relatively slow growth rate; quahogs 15 to 20 mm (0.6 to 0.8 in) long grew only 3.5 mm (0.1 in) from June 4 to August 21, with larger individuals displaying less growth (Hiltz 1977). Age analysis of ocean quahogs collected off Iceland revealed that 90 mm (3.5 in) individuals were as old as 18 years (Skuladottir 1967), but aging methodology was not given. Recent examination of the cut edge of sectioned ocean quahog shell showed many individuals possessing over 100 internal shell "rings" (Thompson, personal communication). If these markings correspond to annual marks, the ocean quahog would be one of the longest lived and slowest growing molluscs known.

Feeding Interrelationships. Ocean quahogs are suspension, filter-feeders. The natural diet has not been studied, but under laboratory conditions, individuals have been maintained on cultured unicellular algae (Winter 1970; Landers 1976). Filtration rates increased with quahog body size and temperature from 4° to 20°C or 39° to 68°F (Winter 1969).

Boring snails may be important predators of quahogs (Merrill et al 1969). Also, bottom feeding fish, particularly cod, often contain large numbers of quahog shells in their stomachs (Gould and Binney 1870; Arntz 1978).

Environmental Sensitivity. The effects of environmental factors on ocean quahog survival, particularly the larval and juvenile stages, are poorly known. The sedentary nature of the species suggests, however, that it would be vulnerable to sudden changes in its habitat caused by temperature or oxygen flux. Mortalities associated with anoxic bottom waters in the Bight during the summer of 1976 were noted in field survey assessments (Ropes et al 1979), although biomass loss was relatively low compared to other bivalves. The ability of ocean quahogs to burrow beneath the surface and respire anaerobically for periods as long as seven days may allow individuals to withstand short-term periods of stress (Taylor 1976). Ocean quahogs accumulate the toxin for paralytic shellfish poisoning but usually eliminate this poison quickly when the causative organism (*Gonyaulax tamerensis*) is no longer in the plankton (Prakash, Medcof, and Tennant 1971). Accumulation of heavy metals by quahogs in their natural habitat has been documented by Buelow (1968). Laboratory experiments indicate that ocean quahogs can accumulate yellow phosphorus from seawater containing this element (Fletcher 1971).

Environmental Effects vs. Man's Impact — An Overview

A fundamental problem in establishing a scientific basis for the management of fish populations has been the separation of natural environmental effects from the impacts by man — fishing and alteration of the environment. The accumulated, circumstantial evidence around the world, based on many years of fishery statistics and biological studies, indicates that with the exception of a few anadromous species it is the natural environment that plays the major role in controlling abundance and distribution of marine fishes, both in the sense of short-term localized fluctuations and long-term population trends. However, in recent years the effects of man's activities have become more evident and some are deleterious.

A massive buildup of foreign fleets in the Northwest Atlantic in the 1960s and associated heavy fishing resulted in a substantial reduction in the total finfish biomass in the Bight. This level of exploitation probably exceeded the finfish productive capacity of the region. Concern over this situation contributed to the establishment of a 200-mile limit by the United States. At the same time, concern was rapidly increasing over the possible effects of pollution in the marine environment, including the offshore waters of the continental shelves, particularly in the New York Bight area. The destruction and fouling of estuarine habitats by local oil spills raised fears of much larger impacts from offshore oil and gas production; and accumulating evidence of contamination of fish and shellfish with heavy metals, pesticides, petroleum hydrocarbons, and human pathogens, to name a few, resulted in mounting concern over the possible reduction in productive capacity of the environment as well as increased human health risks.

Following is a brief overview of the status of knowledge in assessing environmental effects and man's impact on the fishes and shellfishes of the Middle Atlantic Bight.

Fishing

Until the advent of annual large-scale bottom trawl surveys on the east coast by the Bureau of Commercial Fisheries (now NMFS) in the 1960s, the only regular source of information on abundance of marine fishes was the commercial fishery statistics. These statistics date to the late 1800s on the east coast but have been recorded annually only since about 1930. The quality and completeness of statistics improved substantially in the 1950s after formation of the International Commission for the Northwest Atlantic Fisheries (ICNAF), organized to promote the conservation and wise management of fishery resources in the area. Landings statistics are often not good measures of fish abundance because the areas fished and the amount of effective effort expended by fishermen can change rapidly with market conditions and new technology (trawl design, for example) as well as with availability of fish. Detailed statistics on effort and areas fished were lacking for all but a few fisheries in the Bight as were data on growth and mortality rates required for assessment of production potential and effects of fishing. Nevertheless, qualitative evaluations are possible.

1930-1960. In two comprehensive reviews of the Middle Atlantic Bight fisheries, the weight of evidence suggests that from 1930 to the early 1960s fluctuations in commercial finfish landings were largely a result of natural variations in abundance and/or market conditions rather than the direct effect of fishing (McHugh 1977*b*; McHugh and Ginter 1978). During this period, landings of some food finfishes increased and some declined; the group as a whole showed a decline. The decline in landings of several species (notably, butterfish, cod, and haddock) was caused by a drop or shift in fishing effort by mid-Atlantic trawlers into other fisheries (McHugh and Ginter 1978). On the other hand, declines in hard clam production in Rhode Island during the late 1950s may have been prevented if fishing had been controlled (McHugh 1977*a*). Also, higher yields of a number of finfish stocks (butterfish, spot, croaker, bluefish, sea trout, for example) may have been achieved if large numbers of juveniles had not been destroyed in pound net and shrimp fisheries (McHugh 1959). However, except for localized and relatively short-term effects on some stocks, the fisheries of this era probably did not exceed the productive capacity of the finfish and shellfish resources of the Bight as a whole, except in the case of oysters where the productive capacity of the environment was steadily declining as a result of loss of habitat due to dredging, siltation, and other indirect causes of pollution.

From Cape Hatteras to the Gulf of Maine, annual landings of finfish averaged less than 500,000 MT during the 1950s, and the total resource was relatively stable with many large stocks (for example, hake, Atlantic herring, Atlantic mackerel, squid) virtually unexploited (McBride and Brown 1979).

Post 1960. The situation changed in the 1960s with the advent of foreign fishing off the US east coast. Foreign vessels first arrived in the early 1960s and rapidly expanded their fleets over the entire area from Cape Hatteras to Georges Bank (Brown et al 1976; Hennemuth 1976). Total commercial fishing effort increased nearly sixfold from 1961 to 1973, and the commercial catch of finfish* in ICNAF Subarea 5 and Statistical Area 6 (Cape Hatteras to Gulf of Maine) increased rapidly from 336,000 MT in 1960

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*In this discussion finfish excludes menhaden, white perch, American eel, tunas, swordfish, and large sharks.

to more than 1 million MT in 1971 (Brown et al 1976; Hennemuth 1976). The increase in commercial fishing effort was due almost entirely to foreign fleets; effort by US vessels actually declined slightly from 1965 to 1973 (Hennemuth 1976). At the same time, recreational catches of finfish were estimated to be on the order of 200,000 MT (Deuel 1973).

The drastic increase in rate of commercial harvests caused dramatic declines in abundance of certain stocks by the early 1970s, resulting in the reduction of about 65% in the total finfish biomass from 1963 to 1974. Fishing effort was exceeding that which would produce maximum sustainable yield (MSY), estimated to be on the order of 900,000 MT (Brown et al 1976; Clark and Brown 1977). MSY refers to the maximum *average* level of annual catch that could be sustained over a long period. In an attempt to reverse the effects of the overfishing, reductions in commercial harvests were achieved by ICNAF quotas on individual species, starting with haddock in 1970, yellowtail flounder in 1971, and Atlantic herring in 1972, and extending to most other major species by 1973 (Brown 1976). In 1974 a total finfish quota on all finfish combined was set at a level lower than the sum of all individual species quotas to prevent any further decline in finfish biomass (International Commission for the Northwest Atlantic Fisheries 1974). Progressively lower ICNAF quotas were imposed in 1975 and 1976 to begin recovery (Brown 1976). In 1977 both the United States and Canada extended their jurisdiction to cover the area previously under ICNAF management, and further substantial reductions in foreign fishing occurred in 1977 and 1978. Although US effort increased on a few species after the 200-mile limit went into effect, the fishing intensity on the finfish biomass as a whole dropped to only a fraction of what it had been a few years earlier.

The low point of the finfish biomass for the region was reached in 1975; since then nearly all species have shown evidence of recovery. By 1979 the total biomass was approaching the level that existed prior to entry of the foreign fleets. The total finfish biomass dropped from about 7 million MT in 1966-68 to less than 2 million MT in 1975 (Clark and Brown 1979), then increased to about 3 million MT in 1976-78. A preliminary estimate for 1979 showed the biomass returning to levels possibly as high as in the early 1960s (Northeast Fisheries Center 1979). This latest increase is due chiefly to significant increases in stocks of Atlantic mackerel and short-finned squid, and Atlantic herring in the Gulf of Maine.

Precise estimates of change in finfish biomass are not reported for the Bight area alone, but catch per haul indices from NMFS trawl surveys show that the largest declines on an individual species basis occurred from Cape Hatteras to Cape Cod. During the period of heaviest fishing in the Bight, from 1967 to 1974, many species (including flounders, cod, haddock, red and silver hake, ocean pout, white hake, spiny dogfish, sea robins, and miscellaneous groundfish) showed declines in research vessel indices of 50% or more; the average decline in actual catch per haul for all finfish and squid was 52% in the area from Nantucket Shoals to Hudson Shelf Valley, and 74% from Hudson Shelf Valley to Cape Hatteras (Clark and Brown 1977). However, by 1978, just four years after the first total finfish quota was imposed, there were significant increases in abundance of most of these species, and US landings also increased for some of them (McBride and Brown 1979).

The only commercially valuable finfish species subjected to heavy fishing, both domestic and foreign, in recent years that have not yet recovered in the Bight area, at least to pre-1968 levels, are yellowtail flounder, red hake, Atlantic herring, and river herring. Poor recruitment of yellowtail flounder during most of the 1970s in southern New England may be related to environmental factors associated with the warmer temperatures (Sissenwine 1977). However, there is some concern that the Georges Bank spawning stock of Atlantic herring, and perhaps also the spawning stocks of river herring and yellowtail in the Bight, have been driven so low that probability of successful reproduction may be reduced except for extremely favorable environmental conditions.

The rapidly growing sport fisheries must also be taken into account. Included are several important species, such as striped bass and bluefish, that are taken almost entirely by US fishermen and exploited only lightly or not at all by foreign fleets. The first national sport fishery survey was conducted in 1960, and since then rough estimates of the sport harvest have been made about every five years. Sport fishing has been increasing rapidly in the Bight and recreational catches are estimated to be about as large or larger than domestic commercial catches for many species, for example, striped bass, bluefish, weakfish, summer flounder, winter flounder, black sea bass, cod, mackerel, and croaker (McHugh and Ginter 1978). Over the entire area the total recreational harvest of all species of finfish was estimated to be about 233,000 MT in 1970; numbers of anglers have increased substantially since then (Deuel 1973; Northeast Fisheries Center 1979).

A rough idea of the importance of this sport harvest can be obtained from the estimate of MSY for the "other finfish" category used in assessments by NMFS. This category includes about 60 species of finfish usually taken incidentally or in mixed industrial catches of commercial fisheries, and it also includes major recreational species such as striped bass, bluefish, weakfish, croaker, and scup. The MSY for this entire group is estimated at 275,000 MT. Since 1969 the total catch, recreational and commercial combined, of "other finfish" has been well below this level, with estimated catches in 1977-78 averaging about 200,000 MT (Northeast Fisheries Center 1979). Although the recreational catch estimates are imprecise, they clearly represent a major proportion of the "other finfish" catch and a significant proportion of the total commercial harvest of finfish. While there is no evidence that the "other finfish" category as a whole is declining under current catch levels, present harvest rates of bluefish are at or above the MSY level of about 88,000 MT and, if maintained, bluefish abundance probably will decline (Anderson and Almeida 1979). Striped bass abundance and catches had been generally increasing since the 1930s, but since 1974 abundance seems to have declined (McHugh and Ginter 1978); if recruitment declines or levels off, the striped bass sport harvest may exceed the productive capacity of the stock.

NMFS surveys show strong year-classes in the 1970s for weakfish. The stock probably will be maintained at current levels of fishing effort, although greater yield could be obtained by delaying age-at-first capture (Murawski 1977).

Abundance of scup also increased in the 1970s as indicated by NMFS surveys and catch-per-day indices of southern New England trawlers. The 1978 harvest of approximately 13,000 MT, commercial plus recreational catches, is below the estimated minimum MSY level of 15,000 MT (Northeast Fisheries Center 1979; McBride and Brown 1979).

The menhaden population of the Bight, entirely a domestic fishery, increased dramatically in the late 1950s and early 1960s with recruitment of the unusually abundant year-classes of 1955, 1956, and 1958. These three year-classes contributed the bulk of the peak landings during this period; the population then declined markedly during the mid-1960s and reached a low point about 1969 (Schaaf 1975). The virtual collapse in the mid-1960s of the menhaden fishery in New York Bight, which is dependent on adult fish migrating northward from Virginia, was coincident with this abundance decline. It followed the onset in 1960 of an extremely heavy fishery on younger fish in Virginia (McHugh and Ginter 1978). Natural factors are undoubtedly involved since abundance declined off Virginia in the mid-1960s as well as in New York Bight, and then increased again in both areas in the early 1970s. However, it seems likely that fishing intensity may now be so great that it affects distribution as well as total productive potential of the stock in the Bight as a whole. Fishing on young menhaden will need to be reduced in order to achieve maximum yield per recruit (Schaaf 1975).

Shellfish resources of the Bight have been exploited exclusively by US fishermen, except for some Canadian scallop catches prior to 1977. In the surf clam fisheries, substantial declines in abundance and production potential occurred after 1968 off New York and New Jersey as a direct result of heavy fishing. Management programs are now underway to rebuild surf clam stocks to more productive levels (McHugh and Ginter 1978; Mid-Atlantic Fishery Management Council 1979). Sea scallop and lobster are two other species for which the fishing rate is too high in the Bight (Northeast Fisheries Center 1979). Another major shellfish species, the ocean quahog, is in better shape since a significant fishery for it did not begin until 1978; it is already under a management plan (Mid-Atlantic Fishery Management Council 1979).

Fishing is a very significant factor controlling abundance of many fishes in the Bight. We now have a first approximation of the level of fishing that the finfish resource can sustain and it is encouraging to see such a rapid recovery following reduction in fishing. However, with rising food prices and a rapidly expanding recreational fishery, continuing controls will be necessary on preferred species in the foreseeable future if we wish to avoid problems of excessive fishing effort. The task of determining the optimum level of catch and effort and then achieving that level is very complex, involving social, economic, and political considerations as well as the production potential of the exploited fish populations.

Environmental Degradation

Ever since colonial times, our population growth and industrial development have had a detrimental effect on the quality of coastal waters along the US east coast. A variety of coastal zone activities, including industry, agriculture, shipping, port development, and residential and recreational developments, have degraded the physical and chemical characteristics of coastal waters for fish and shellfish through siltation, wetlands destruction, dams, dredging, chemical and thermal discharges, and dumping, oil contamination, and sewage (Zoellner 1977). Dams have resulted in the most obvious physical effects, illustrated by the loss of spawning rivers for species such as striped bass and American shad. Similarly, harbor dredging and filling have resulted in the loss of shellfish producing areas. Siltation has also eliminated many former oyster-producing areas. Although there are no accurate measures of the magnitude of these changes, the physical space in the Bight and its adjacent estuaries is less than it used to be, decreasing productive potential for the species.

Chemical degradation of coastal waters has resulted from a wide variety of pollutants. Their direct and indirect effects may be more widespread than the effects of habitat loss. Pollution is of particular concern in the mid-Atlantic because of the heavy concentration of population and industry in the region. This concentration puts the maximum potential pollution load into the same area where there is maximum demand for the benefits of a clean and productive marine ecosystem. Estimating the impacts of pollution on the living marine resources is extremely difficult because we have inadequate knowledge of the natural biotic and abiotic mechanisms controlling marine populations and because effects of pollutants and natural environmental factors are often manifested in similar ways, ranging from subtle effects on food supplies, reproduction, and behavioral modifications to large-scale mortality of eggs, larvae, juveniles, and even adults (Waldichuck 1974; Johnston 1976).

Following is a brief outline of the principal biological and physical mechanisms by which pollutants generate their effects, and the problems in evaluating effects on organisms. Also following is a brief summary of the major types of pollution in the mid-Atlantic and their observed or inferred effects.

Evaluating Effects of Pollutants on Marine Animals. Major factors that must be considered in evaluating biological impacts of pollution include: (1) the distribution, concentration, and chemical forms of pollutants in the sea in relation to the distribution of populations of organisms, and (2) modes of uptake and specific effects of pollutants on marine organisms at their various life stages including cycling and bioaccumulation of materials through complex food webs.

Recently, we have learned a great deal through research on the effects of specific pollutants on fishes in laboratory studies and restricted in-situ observations. By far the largest proportion of this work has involved freshwater fishes and, therefore, we are not as far along in our understanding of specific effects in marine species nor do we have as much baseline information on levels of pollutants in marine waters. Much has yet to be learned about the basic chemistry of various pollutants in sea water and about their cycling through the ecosystem. Most experimental studies on specific effects of pollutants have been done in the laboratory at concentrations far above those normally encountered in the sea. But the most important and the most difficult aspect is the measurement of sublethal or chronic (long-term) effects on organisms in the natural (if polluted) environment. Here we are dealing with an enormously complex multi-variable system that cannot be duplicated in the laboratory. For example, factors influencing the toxicity of heavy metals in solution (after Bryan 1976) include:

—form of the metal in water (inorganic vs organic; soluble or particulate, ionic structure if soluble; colloidal, precipitated, or adsorbed if particulate);

—presence of other pollutants (possible synergism);

—environmental factors affecting physiology of organisms and possibly the form of the metal in water (temperature, pH, dissolved oxygen, light, salinity);

—condition of the organism (exact stages in life history during exposure to pollutant, activity, past history in relation to nutrition or exposure or adaptation to pollutant);

—behavioral response (which may change susceptibility or exposure to chemical).

The chief mechanism involved in the chronic effects of major contaminants such as heavy metals, halogenated hydrocarbons like pesticides, and petroleum residues is inhibition of respiration and enzyme activity that can lead to reduced oxygen consumption and slower growth, for example. Other effects include changes in amino acid balance, ionic-osmotic regulation impairment, and lesions in various body parts (for example, olfactory organs in fishes, important for sensory orientation in the sea including location of food). Larval stages are especially sensitive and significant mortality can occur at very low concentrations of toxic materials. There can be wide differences in tolerance even among the various stages of embryonic development of the same organism. In general, pollutants reduce the capacity of individuals to perform normal life functions, thereby reducing their ability to survive normal environmental stresses.

Even when specific sublethal effects of a pollutant on a given life stage of a species are known from laboratory studies, it is extremely difficult to extrapolate to an estimate of the total impact on the whole population of the species. This is because the actual mortality in the natural environment is caused by complex interactions involving many other species and life stages — the prey and predators of the given species — that also may be affected by the same pollutant. Understanding pollution effects on one animal involves understanding the impact on a whole community of animals in terms of a change in production potential and composition. Ecologists have a long way to go to understand the dynamics of whole communities, and evaluating effects of pollution is made still more difficult by a general lack of baseline data for levels of pollutants as well as conditions of the marine resources prior to the introduction of pollutants. Finally, the huge scale of the marine ecosystem makes it extremely difficult to obtain quantitative measures of whole populations or communities.

Types of Pollution and Observed Effects in the Mid-Atlantic. The mid-Atlantic, particularly New York Bight, is subject to virtually all of the major sources of pollution generated by man, including gaseous and particulate pollutants in the atmosphere, wastes of all kinds entering the rivers flowing into the Bight, and wastes discarded at various dumpsites in the Bight including sewage sludge, dredge spoils, and industrial wastes containing toxic chemicals (Gross 1976*a*, *b*; Mueller and Anderson 1978). The major input of contaminants to New York Bight originates from the NY metropolitan area and the Hudson River drainage basin, chiefly from wastewater, runoff, and materials discharged from barges (Mueller, Johnson, and Jeris 1976). Among the contaminants directly toxic to marine animals are heavy metals, organochlorine pesticides (particularly DDT) and polychlorinated biphenyls (PCBs), and petroleum hydrocarbons. In addition, domestic sewage and runoff from agricultural areas provide increased levels of organic nutrients that indirectly may lead to deleterious effects through reduced levels of oxygen. This sewage or runoff may even lead to toxic conditions resulting from enhanced phytoplankton blooms, and increases or changes in bacterial populations that have been associated with increases in the incidence of disease and tumors in marine organisms. Evidence for specific effects of pollution on fish and fisheries of the mid-

Atlantic Bight has been summarized by Sindermann (1976, 1979). Some examples follow:

— high mortality of winter flounder larvae in a Massachusetts estuary due to pesticides;

— deleterious effects (such as growth cessation and high mortality rates) on hard-shell clam beds in Rhode Island due to petroleum pollution;

— decline in value of fish and shellfish tainted with petroleum waste from estuaries;

— closure and reduced production from shellfish beds in Long Island Sound, New York Bight, and in many estuaries due to high levels of coliform bacteria from sewage;

— significantly greater incidence of fish and shellfish diseases (such as fin rot and shell and gill disease) in the New York Bight apex, where the maximum pollutant load occurs;

— drastic reductions in striped bass populations, and to a lesser extent shad populations, in the Delaware River due to extremely low dissolved oxygen levels stopping or reducing spawning runs.

Studies of fin rot disease in two species of flounders in New York Bight showed significantly higher incidence of the disease in sewage sludge disposal areas or nearby degraded areas of the Bight apex than in cleaner adjacent waters (Murchelano and Ziskowski 1976). Frequency of occurrence of fin rot disease in winter flounder ranged from 2.9% in areas of low carbon deposits to 5.1% in areas of high carbon deposits in Bight apex areas, whereas incidence dropped to 0.7% outside the apex. In summer flounder, incidence of fin rot was 0.6% from the apex, 3.0% from Sandy Hook - Raritan Bay, and 0 in Great Bay, outside the apex. Winter flounder kept in cages in the sewage sludge disposal area developed fin rot disease, with severity proportional to time in the cage. In contrast, winter flounder held in a cage at a (clean) control site did not develop fin rot. Caged winter flounder in the disposal areas had substantially lower survival rates than those in the control cage.

The "black gill" condition in rock crabs, believed to be the accumulation of black sludge sediment in the gills, was found to be more prevalent in crabs from sewage disposal sites than from clean areas (Sawyer, 1982). In addition to the debris, the rock crabs taken from these sites also showed excessive fouling of the gills by bacteria, amoeba, diatoms, copepods, and stalked ciliates. Although this condition could not be related to specific evidence of stress or mortality, it is quite likely that there are deleterious effects.

Pelagic fish eggs that float at or near the surface may be particularly vulnerable to pollution since the surface film of the ocean may contain high concentrations of contaminants (MacIntyre 1974). Experimental studies have shown that a number of chemical contaminants including heavy metals, pesticides, and petroleum hydrocarbons can cause damage to egg cells leading to severe chromosomal damage and death of embryos during early developmental stages (Sindermann 1979). High frequencies of chromosomal abnormalities were observed in May 1974 in pelagic Atlantic mackerel eggs and embryos in New York Bight (Longwell 1976). Indices of egg viability based on cell state, chromosome irregularities, and anomalies at the gastrulation stage, were significantly higher in areas further from the coast and dumping grounds (Longwell and Hughes 1980). Similar studies were conducted in May 1977 that also included measures of heavy metals in surface and subsurface waters, and analyses of 65 toxic aromatic and chlorinated hydrocarbons in plankton. Statistically significant associations were found between measures of mackerel egg health (in terms of chromosomal - cell - embryo anomalies) and the levels of heavy metals and hydrocarbons (Longwell and Hughes 1980). Application of such cytologic and cytogenetic techniques appears to hold considerable promise for direct measurement of sublethal effects of pollution in ocean waters.

For shellfish, the closure of oyster and inshore clam-producing areas for public health reasons is a significant indirect effect of pollution. Fortunately, the rate at which shellfish beds are being closed has been decreasing in recent years, but the absolute decrease in potential mollusc production has continued (Zoellner 1977). Water quality improvements alone from full implementation of standards in the Federal Water Pollution Control Act Amendments of 1972 could increase production of oysters and clams on the order of 85% by 1985 (Zoellner 1977).

Other indirect effects include unmarketability of tainted shellfish from oil spill areas, and bans on sale or use of swordfish because of high mercury levels, or estuarine fishes because of high PCB levels (Sindermann 1976).

There is concern about the potential long-term effects of increasing the average water temperature in semi-enclosed areas such as Long Island Sound as a result of a proliferation of nuclear power plants that require very large amounts of water for cooling. The effects of oxygen depletion in summer might become much more severe under higher average water temperatures since fish require more oxygen at higher temperatures. There may be some beneficial effects, such as the retention of migratory fish in the vicinity of warm water plumes during winter in places like Barnegat Bay, NJ, and Long Island Sound, where winter recreational fisheries did not exist before for species such as bluefish, striped bass, and white perch (McHugh 1977*b*). However, the same fish could conceivably suffer mortality if a plant suddenly shut down during winter.

There is also considerable circumstantial evidence of possible direct and indirect effects of pollution. The increased frequency of algal blooms, particularly along the coast of northern New Jersey in the last decade may be related to the increased nutrient loading of New York Bight. A principal concern over higher nutrient levels is that heavier and more frequent algal blooms may increase the frequency of severe oxygen depletion in coastal waters.

Occasional mass mortalities of menhaden and other species in central Chesapeake Bay and lower parts of its tributaries and in western Long Island Sound, have been associated with low oxygen levels attributed in part to greater oxygen demand from domestic wastes (McHugh 1977*b*). Higher nutrient levels may also increase the incidence of toxic blooms that cause direct mortality of fish and shellfish; and toxic blooms increase the risk to man of paralytic shellfish poisoning. Such poisoning occurred at dangerous levels for the first time in central New England during 1972 and 1974 (Sindermann 1976). Also, high levels of contamination with sewage wastes increase the risk of viral and bacterial diseases for man and fish.

But not all of the effects of increased nutrients have necessarily been negative. Increased striped bass populations during the 1940s and 1950s may have been partly due to improved feeding conditions in the estuaries as a result of domestic wastes (Mansueti 1961*b*).

Pollution abatement programs seem to be having some positive effects: increases in blue crab populations of New York Bight in the 1970s have been associated with the ban on DDT (McHugh 1977*b*).

Total Impact of Pollution in the Bight. Substantial losses of shellfish production areas have occurred as an *indirect* effect of pollution; and these losses are continuing but at a reduced rate in recent years. It is much more difficult to measure the total *direct* effect of pollution on whole populations. Although there are numerous examples of localized effects of pollutants on small segments of fish and shellfish populations in the mid-Atlantic, particularly in the New York Bight apex where pollutant levels are the highest, Sindermann (1976) concluded that there is no specific evidence of widespread damage to major fishery resource populations that can be attributed to direct effects of pollution. With the exception of certain estuaries, basically the same picture has emerged from extensive study of the North Sea fisheries (Johnston 1976). On the basis of the existing evidence we have come to the same conclusion.

The likelihood of significant impact of pollution is probably greatest for those species whose early life stages occur in estuarine and coastal waters where concentrations of most pollutants exceed levels in offshore waters by an order of magnitude or more. After review of the historical fluctuations and current population status of the various species in this monograph, taking into account their life history and effects of fishing, it appears that inshore fishes have not shown any more declines than offshore fishes. Analysis of catch records from 1950 to 1970 for supposed estuarine-dependent species on the east coast of the United States shows that catches of most of these species were fairly steady or, as in the case of striped bass and bluefish, increased (Wise 1974). Catch levels have been due in part to increasing fishing effort, but drastic direct effects of pollution on whole populations are not indicated.

There is the possibility that pollution is having a significant and direct deleterious effect on productive potential, but so far we have been unable to measure the effects. We still do not know enough about the distribution and the biochemistry of pollutants in the marine environment, particularly in the organisms and populations themselves and the effects on their critical life processes, to be able to deduce the overall impact of various types and levels of pollution. It is a difficult and long-term problem. We cannot afford to be complacent about pollution in the marine environment just because we cannot absolutely confirm a major impact there. New industrial chemicals are being produced at a high rate and the problems of toxic waste disposal on land are increasing at such an alarming rate that legal and illegal dumping or drainage into the sea is likely to continue at an increasing rate, current legislation notwithstanding.

Natural Environmental Effects

Although the circumstantial evidence is overwhelming that natural factors play the dominant role in controlling distribution and abundance of marine fishes, in fact, our understanding is extremely limited as to the actual mechanisms exerting this control. Variations in survival of larvae are generally believed to control the major fluctuations in population size and we have a conceptual understanding of what those factors must be, chiefly, food, predators, and transport within some range of satisfactory temperatures. But so far we have been unable to sort out and measure the relative importance of each of these factors and how they interact. With few exceptions we have been unable to relate variability in fish populations with either short-term or long-term meterological records, or with the few long-term oceanographic records that are available, chiefly sea surface temperature.

The answers probably lie in the complex small-scale (hours to days and tens of meters to kilometers) and medium-scale (one to ten weeks and ten to hundreds of kilometers) dynamics of plankton communities over the several months when the fate of a population of larvae is determined. The short-term high frequency physical processes, such as tides, internal waves, small-scale vertical turbulence, diurnal heating and cooling, and wind effects (particularly storms) are the scales of time and motion dominating the structure and dynamics of these communities; wind is probably the single most important factor. On the biological side, larval mortality is a complex function of the density distribution (patchiness) of the larvae, their prey and predators, and other forms (including other species of larvae) that may be competitors or alternate prey for their predators. We have very little quantitative information on such a fine scale for either biological or physical processes in the shelf waters of the Bight. Thus, it is not surprising that we have not yet been very successful in linking population fluctuations to environmental data.

Comprehensive efforts by oceanographic and fishery research agencies to study the circulation and plankton dynamics of our continental shelf waters have begun only during the past decade. Such efforts constituted response to increasing national concern over man's impacts on the fish and shellfish resources. Also, for the first time new instrumentation made it economically feasible to measure the small-scale dynamics of coastal waters. Many of the methods and instruments needed for rapid, accurate, and automatic measurements of oceanographic variables from shipboard did not become generally available until the 1960s (expendable bathythermographs, electronic salinity — temperature — depth recorders, automatic recording current meters, fluorometers to measure chlorophyll concentration, thermistor strings for continuous high resolution temperature profiles, autoanalyzers for automatic chemical analyses of nutrients and other chemicals in sea water). Also, routine remote sensing of the ocean environment from oceanographic buoys and satellites did not become operational until the 1970s. A review of the nature and adequacy of the physical data base, both meterological and oceanographic, for the Middle Atlantic Bight region is given by Rasmusson and Williams (1978). Similarly, equipment for obtaining high-speed quantitative samples of plankton, and particularly instruments for automatic counting and sizing of microscopic plankton organisms including microzooplankton, the main food of fish larvae, have become available only in recent years. The consequence of all this is that we have too short a time series of too limited scope to clarify the dynamics of both the physical and biological processes controlling the critical early life stages. Until we have a better understanding of these mechanisms it is unlikely that we will be able to determine how larger-scale environmental factors, such as seasonal and annual variations in average oceanographic and meteorological patterns (for which we have a longer time series), may impact the recruitment process of a species.

Our aim here is to highlight the known larger-scale environmental effects (chiefly on adult stages) and to indicate the probable linkages with the smaller-scale processes.

Catastrophic Events. Large anomalies and catastrophic events like severe storms or epidemic disease provide the clearest evidence of environmental effects, especially in inshore areas. Examples include:

— the reduction of oyster production in Chesapeake Bay due to lowered salinity and siltation following torrential rains from hurricane Agnes in 1972;

— unusual intrusions of cold water at the slope front or shelf break (150 to 200 m or 492 to 646 ft) that probably accounted for the mass mortality of tilefish in 1882;

— sudden severe drops in temperature, such as the unusual cold spell in winter 1976-77 that caused mass mortality of spot and juvenile croakers in upper Chesapeake Bay;

— high mortality of surf clams, significant mortality of other invertebrates, and interruption of migrations of lobster and bluefish from anoxic conditions over a large area off New Jersey in summer 1976 (Azarovitz et al 1979);

— sudden outbreaks of disease, such as the "MSX" disease that decimated oysters in Delaware Bay and lower Chesapeake Bay in the late 1950s and early 1960s;

— population explosions such as the invasion of starfish that preyed upon oysters in Long Island Sound in the 1950s.

In cases like the tilefish episode, where catastrophic events almost eliminated entire populations, it can take years for recovery. Undoubtedly, catastrophes or sudden mass mortalities occur in egg and larval populations, but we are seldom on hand to distinguish these events from the more gradual mortality processes by which the vast majority of young perish in the end anyway. Whatever the cause, large natural fluctuations in reproductive success occur frequently making it very difficult to determine overall impact of pollution.

Seasonal and Annual Variations. The more common events are the regular seasonal patterns and normal annual variations in hydrographic properties and circulation of shelf waters. The associated seasonal cycles of migration and spawning of the marine fishes are closely correlated with and probably controlled to a large extent by the temperature cycle. The main features of this cycle in New York Bight are as follows (Bowman and Wunderlich 1977):

— Vertically isothermal structure is down to about 80 m (262 ft) in mid-winter with coldest temperatures (◄5°C or ◄41°F) near shore and increasing steadily to the shelf/slope front near the 100 to 200 m (328 to 656 ft) contour where a maximum bottom temperature of 13°C (55°F) is found.

— Onset of spring warming is near shore in April and development of thermocline begins in May, with surface temperatures rising rapidly to 9° to 12°C (48° to 53°F). Bottom temperatures remain between 4° to 10°C (39° to 50°F), contributing to a "cool pool" or "cold cell," a dominant feature of bottom shelf waters throughout the summer between the 30 to 100 m (98 to 328 ft) depth contours, with warmer waters both shoreward and seaward of this cell.

— Surface temperatures reach maximum values of 24° to 26°C (75° to 79°F) usually in early August, bottom temperatures also reach high levels (►20°C or ►68°F) near shore; water column is highly stable below 15 m (49 ft), the depth of the mixed layer, and most of the thermocline is between 15 to 30 m (49 to 98 ft).

— Surface cooling in September breaks down thermocline and increases depth of vertical mixing; surface temperatures reach 12° to 17°C (54° to 56°F) over the shelf by early November and mixing down to 30 to 50 m (98 to 164 ft); bottom waters on central shelf (location of cold cell in summer) reach their annual maximum of about 16°C

(61°F). Increasing frequency of storms in autumn also contributes to breakdown of the thermocline.

— Maximum range of surface temperatures near shore is about 25°C (◄1°C or ◄34°F in winter to 26°C or 79°F in summer), whereas maximum temperature range at surface near the shelf break is about 14°C (10°C or 50°F in winter to 24°C or 75°F in summer).

— Maximum range of bottom temperatures near shore is about 20°C (◄1°C or ◄34°F in winter *vs* 21°C or 70°F in summer) and maximum range near shelf break (200 m or 656 ft) is only 6° to 7°C (7°C or 45°F in winter *vs* 13°C or 55°F in summer).

Most fish species found in the Bight have temperature tolerances exceeded by the normal seasonal temperature cycle of ◄1° to 26°C (◄34° to 79°F) in inshore waters. Few of the resident species tolerate temperatures ◄4°C (◄39°F) and some, such as scup and squid, are seldom found in temperatures ◄7°C (◄45°F), or butterfish in ◄10°C (◄50°F). Most resident species are forced to migrate offshore in winter, where they find bottom temperatures ranging from about 5°C (41°F) at midshelf to a maximum of about 13°C (55°F) at the shelf edge. The range of 5° to 13°C (41° to 55°F) encompasses the preferred temperature range of many of the Bight's resident species and represents the optimum range to which they have become adapted. Southern species have even higher minimum temperature tolerances and preferences, and they migrate south as well as offshore in autumn. For example, striped bass begin their southward migration in autumn when temperatures drop below about 7°C or 45°F (Smith and Wells 1977). Declining temperatures in late autumn and winter in the Bight also make it possible for some northern species to migrate south. Mackerel prefer temperatures in the range 7° to 20°C (45° to 68°F) and can find extensive areas along the mid-Atlantic shelf in winter where temperatures in the water column are above 7°C (45°F).

The reverse migrations take place in spring, and by summer when maximum temperatures occur inshore, upper temperature tolerances limit the inshore distribution of some resident species. However, due to stratification, cooler waters within the tolerances of most species are found fairly close inshore throughout the northern half of the Bight.

Annual variations in the timing and intensity of seasonal warming and cooling cause marked changes in migration and spawning cycles for resident species as well as migratory species. For example, inshore/offshore migrations of scup vary from year to year with the timing and shifts in location of the 7°C (45°F) isotherm (Neville and Talbot 1964). NMFS spring trawl surveys in the Bight since 1968 have shown that mackerel, sea robins, and fourspot flounder remained offshore during cold springs (1968, 1969, 1971), whereas they were distributed over much of the shelf mid- to late March during warmer springs since 1972 (Davis 1979). The spring surveys also showed that smooth dogfish were caught further north and in greater abundance during the warmer spring bottom water temperatures observed from 1972 to 1976 (Davis 1979). Autumn surveys have shown that spotted hake (*Urophycis regius*) generally avoid the cold cell and distribution of their catches is closely associated with the location and temperature of this cold water (Davis 1979).

Most species spawn within relatively narrow temperature ranges, thus, time of spawning is usually closely linked to the seasonal temperature cycle. Spawning of resident species in the Bight, such as the flounders, shows a close linkage with the temporal and geographic progression of seasonal warming and cooling — progressing from south to north for spring spawners and north to south for autumn spawners (Smith et al 1975). Variations in the areal extent and temperature of the cold cell probably play an important role in controlling spawning of demersal species in the Bight. For example, in 1966 spawning of both summer flounder and windowpane in New York Bight appeared to be restricted close inshore due to the low temperatures in the nearby cold cell (Smith 1973*a*; Smith et al 1975).

Yellowtail spawn chiefly in temperatures from 4° to 9°C (39° to 48°F), which corresponds to the range of temperatures frequently found in the cold cell; since they occur on the same part of the shelf where the cold cell rests, it is possible that the spawning success of yellowtail may be related to the extent and temperatures of the cold cell. In addition to effects on spawning, the changes in degree and location of fish aggregations due to temperature anomalies can affect their vulnerability to fishing. Most fisheries are concentrated in the times and places where the fish are aggregated.

Variations in salinity are much less pronounced than temperature and are believed to be less important to fish since annual salinity variations often exceed the normal seasonal variations.

A key aspect of the oceanography of the Middle Atlantic Bight involves water motion. The major feature of average circulation is a relatively slow surface flow (2 mi/day or 3.2 km/day) to the southwest parallel to the coast over most of the shelf, the speed decreasing to only 1.6 km/day or 1 mi/day or less close to the bottom (Hansen 1977). There is evidence of a persistent shoreward flow of water near the bottom, whereas both onshore and offshore flows occur at the surface depending on wind direction. Cross-shelf flow is generally much weaker than alongshelf flow. Near the principal estuaries there is an exchange circulation characterized by seaward flow of less saline estuarine waters near the surface and landward flow of deeper, more saline waters into the estuaries; there is also an indication of a clockwise eddy in the inner New York Bight. However, the mean flow features are usually masked by much stronger and highly variable wind-driven currents on a day-to-day basis, and may be drastically altered for prolonged periods under unusual conditions.

For example, reversals of the mean southwest flow occurred in the mid-1960s during the drought when salinity and density gradients were reduced. Such reversals are most likely in summer when prevailing winds are from the south. Average speed of flow can vary widely from year to year as shown when they were much weaker than usual with reversals off New Jersey during the 1976 anoxic event. Flows can be more than an order of magnitude larger during storms, and variations between years may exceed seasonal variations.

The most significant direct effects of currents on fishes are likely to be through transport of pelagic eggs and larvae. The slow mean drift to the southwest along the coast would seem to pose little risk of transport loss of eggs out of the Bight because eggs of most species hatch in a week or less, particularly in the warm part of the year (late spring to early autumn) when most species spawn in the Bight. Offshore transport of eggs may represent a greater risk; in addition to the surface offshore flow off large estuaries, southerly winds, predominant in summer, also generate offshore flow at the surface. However, only with unusually strong and prolonged southerly winds does it seem likely that eggs released near the coast would be transported as far as the edge of the shelf before hatching. Offshore flows at the surface would generally be stronger in winter with the stronger prevailing winds from the west and northwest, but very few species spawn in the Bight in winter. Transport of larvae is probably the more significant effect and it is more complex because larvae are more widely distributed in the water column than eggs, and their development time is much longer. As larvae develop they begin to make directed vertical movements and larvae of some species go to the bottom rather quickly.

Among species that spawn offshore in the Bight whose larvae or juveniles use estuaries for nursery grounds (such as menhaden, summer flounder, black sea bass, spot, croaker), all except menhaden probably go to the bottom during larval development. Onshore transport of menhaden larvae in the southern part of the Bight has been associated with wind driven currents (Nelson, Ingham, and Schaaf 1977). There is some suggestion that unusually weak year-classes of mackerel may be associated with very strong offshore winds (Anderson and McBride 1976). In general, however, we have very little quantitative data on the actual dispersal, drift, and vertical distribution of fish larvae. Much more detailed information on both larval distribution and circulation will be required to clarify this problem. The fact that mean transport is so slow suggests that even though larval development extends over several months, larvae will still be retained in the Bight. The more important role of circulation in larval survival may be its influence on abundance and distribution of larval prey and predators.

Gulf Stream eddies occasionally impinge on the edge of the shelf, sometimes persisting for months, and gradually moving southwest, parallel to the shelf edge. It is possible they may entrain some shelf waters including plankton and larvae, and transport it off the shelf. However, the specific impacts of these eddies are not well known.

Species that spawn in estuaries and their tributaries are faced with a more variable environment. Temperature extremes are greater and there is also the runoff cycle. This tends to be broadly similar throughout the Bight in any given year or period, but each estuary has unique characteristics. Consequently, a species may have much greater spawning success in one estuary than another in a given year, greatly complicating the problem of evaluating environmental effects on estuarine species. Water flow, salinity, temperature, oxygen concentration, and turbidity all may impact significantly at one time or another on early life stages and older individuals in estuaries.

Long-Term Trends in Temperature. Sea surface temperatures are the only regular environmental measurements of the offshore shelf waters for which a time series goes back more than a decade. Fortunately, trends in both surface and subsurface sea temperatures on the shelf are broadly similar, as are offshore and onshore records of water temperature. Therefore, it is possible to extrapolate shelf temperatures further back in time. Correlation between air and sea temperatures in coastal waters also permits some extrapolation based on trends in regional air temperatures alone.

The scale and nature of temperature trends vary with the size and location of the regions considered. For the whole northern hemisphere there was a gradual warming trend in mean annual air temperatures from the late 1800s until about 1940, and then a cooling trend until about the mid-1960s (Rasmusson and Williams 1978). Waters of the North Atlantic also showed a general warming trend during the first half of the century (Stearns 1965). Analysis of mean annual sea surface temperatures at coastal stations along the US east coast from Maine to Florida revealed a pronounced warming trend beginning in the 1940s and peaking in the early 1950s, with the trend progressively stronger from Charleston, SC, northward (Stearns 1965). The warming trend resulted more from milder winters than warmer summers, and there was a distinct change in trends from north to south as follows:

— very strong warming trend in the Gulf of Maine;

— weakening warming trend progressing from north to south along the middle and south Atlantic coasts; and

— moderate cooling trend around Key West.

Following the peak temperatures in the early 1950s, the trend was reversed and sea surface temperatures declined until 1967, after which another warming trend began as illustrated by surface temperatures in Boothbay Harbor, ME (Colton 1972). Similar warming and cooling trends have occurred offshore in the New England area both at the surface and at depth (Colton 1968). Since about

1967 temperatures have been rising again until about 1973-74 as indicated by mean bottom temperatures on Georges Bank and in the Gulf of Maine (Davis 1978).

Analysis of all available sea surface temperature data (inshore and offshore) from 1948 to 1976 for the Middle Atlantic Bight region alone shows the same picture: cooling from a peak in 1948 to a low in 1967, a decline of about 4°C (39°F), and subsequent warming of nearly the same amount until the mid-1970s (Cook, personal communication). The upward trend of 2° to 3°C (36° to 38°F) from 1967 to the mid-1970s also occurred in bottom temperatures in the Bight as observed on NMFS trawl surveys (Davis 1979). Air temperature trends in the Bight show a pattern similar to sea surface temperatures as do river runoff data, decreasing from highs in the late 1940s to lows in the mid-to-late 1960s and then increasing again (Cook, personal communication). Average water temperatures have probably dropped since 1976 due to the colder winters in the New England area; a possible indication of this is a drop of about 2°C (36°F) in water temperatures observed during May 1977-79 in the cold cell in New York Bight, as compared with the 1973-76 period (Cook 1979).

In summary, sea water temperatures in the Bight have shown a series of warming and cooling trends at least since the 1940s similar in pattern to those in the Gulf of Maine, but less pronounced especially in the southern part of the Bight. These trends are positively correlated with air temperatures and runoff cycles, and they appear to be more the result of milder or colder winters than warmer or cooler summers. A significant feature of the summer hydrography of the Bight is the cold cell whose size and temperature appear to be a carryover from the previous winter. Other factors influencing temperature in the Bight include location of the slope front and exchanges and temperature of slope water; size and frequency of Gulf Stream warm core eddies; timing and extent of spring warming and autumn cooling of surface waters; and drift of water from the Nantucket Shoals — Georges Bank area (Davis 1979). The extent these are related to or causes of temperature trends in the Bight is not known.

Trends in Fish *vs* Temperature. Analysis of distribution records of fish and invertebrates in the Gulf of Maine during the warming trend of the 1940s revealed a northward shift in the recorded ranges of a number of species. Two species, the striped mummichog and the green crab, established resident populations north of their previous range (Taylor et al 1957). On the basis of landings statistics and other data, Taylor and associates concluded that abundance and distribution of several resident species (notably, mackerel, lobster, menhaden, silver hake, and yellowtail flounder) had also shifted northward. However, the basic faunal structure of the Gulf of Maine was unaltered.

During the cooling trend that followed, from the 1950s to 1967, analysis of NMFS trawl surveys from Long Island to the Gulf of Maine showed slight southward shifts in American plaice (*Hippoglossoides platessoides*) and butterfish; plaice extended their southern limit and butterfish retracted their northern limit (Colton 1972). In the same survey series, however, haddock and yellowtail showed no change, and there was no major change noted in distribution or composition of the demersal fish population in general. Colton also noted that during the cooling trend, green crab abundance declined in the Gulf of Maine, unusual numbers of spiny dogfish migrated south of Cape Hatteras in winter, and capelin appeared in the Bay of Fundy where they had not been reported for many years.

When NMFS extended its spring and autumn trawl surveys south to Cape Hatteras, shifts in the distribution of some species in the Bight were observed during the recent period of warming from 1967 to the mid-1970s (Davis 1979). However, the survey time series is too short for a definitive analysis of fish populations *vs* long-term temperature trends. In general, the degree of effect and association between trends in mean annual temperatures and the distribution and abundance of a species in a given area will depend on whether there is a change in the living space or a change in reproduction potential. Larger effects could occur if temperature altered the amount of successful spawning, thereby changing the total population size for either a resident or a migratory species. Since the factors controlling year-class success operate chiefly during the first few months of life, it is very unlikely that a close linear correlation will be observed between mean annual temperature and population abundance. Ideally, comparisons should be made between the temperature conditions present during the egg and larval development of a population and the subsequent strength of that particular year-class. We do not have such detailed temperature data and have only begun to monitor abundance of year-classes for a few major commercial species in a quantitative way since about 1960; for many species there are only total population abundance indices. Prior to about 1960, even total population abundance indices are lacking for most species and we are limited primarily to landings statistics. In spite of these limitations we have considered it worthwhile to examine the available data and to draw some tentative conclusions about the importance of temperature trends to abundance of major fish species in the Bight.

Population trends prior to 1960 have been inferred from commercial and recreational catch statistics (McHugh and Ginter 1978), and since 1960 they have been based on NMFS assessments. Qualitative associations between temperature and population trends were made, and each species was classified (see Table 21) according to the type and strength of association, faunal group (southern *vs* northern *vs* resident species), and type of reproductive cycle (time and area of spawning, nursery areas). The first thing to note is that of the six species showing moderate or strong inverse associations with temperature, all were northern species — shortfin squid, winter flounder, yellowtail, mackerel, lobster, and cod. On the other hand, out of

Table 21. Qualitative associations between temperature trends and abundance, and descriptions of reproductive cycles for Middle Atlantic Bight fishes.

	Species	Faunal Group	Relative Strength of Association	Location and Time of Spawning	Type of Egg	Nursery Ground for Juveniles
Species showing *increased* Middle Atlantic abundance during warming trends.	Black Sea Bass	Southern	Strong	Offshore/Summer	Pelagic	Estuaries/Inshore
	Weakfish	Southern	Moderate	Inshore/Spring	Pelagic	Inshore/Estuaries
	Atlantic Croaker	Southern	Moderate	Offshore/Autumn	Pelagic	Estuaries/Inshore
	Spot	Southern	Moderate	Offshore/Winter	Pelagic	Estuaries
	Long-finned Squid	Resident	Moderate	Inshore/Spr.-Sum.	Pelagic	Inshore
	Atlantic Menhaden	Southern	Weak	*Inshore/Sum.-Spr.	Pelagic	Estuaries
	Summer Flounder	Resident	Weak	Offshore/Autumn	Pelagic	Estuaries
	Scup	Resident	Weak	Inshore/Spring	Pelagic	Estuaries/Inshore
Species showing *decreased* Middle Atlantic abundance during warming trends.	Yellowtail Flounder	Northern	Strong	Offshore/Spring	Pelagic	Offshore
	Atlantic Mackerel	Northern	Moderate	Offshore/Spring	Pelagic	Offshore/Inshore
	Atlantic Cod	Northern	Moderate	Offshore/Winter	Pelagic	Offshore
	Winter Flounder	Northern	Moderate	Estuaries/Winter	Demersal	Estuaries
	Short-finned Squid	Northern	Moderate	Offshore/Sum.-Aut.	Pelagic	Offshore
	Northern Lobster	Northern	Moderate	Offshore/Summer	Pelagic	Offshore
	Alewife	Northern	Weak	Tributaries/Spring	Demersal	Offshore
	Silver Hake	Northern	Weak	Offshore/Summer	Pelagic	Offshore
	Red Hake	Northern	Weak	Offshore/Summer	Pelagic	Offshore
	Bluefish	Southern	Weak	Offshore/Summer	Pelagic	Inshore/Estuaries
	Striped Bass	Southern	Weak	Tributaries/Spring	Pelagic	Tributaries
No associated change	Butterfish	Southern	None	Inshore/Summer	Pelagic	Inshore

**In the New York Bight area adult menhaden stay close to shore. Offshore spawning occurs south of Cape Hatteras.*

the five species showing moderate to strong positive associations with temperature, four were southern species (black sea bass, weakfish, croaker, and spot) and one was a resident (long-fin squid). Among the five species showing weak negative associations with temperature, three were northern (alewife, silver hake, and red hake) and two were southern (striped bass and bluefish). Of the three species showing weak positive associations with temperature, two were residents (summer flounder and scup) and one was southern (menhaden). Considering all the species from Table 21 together (except butterfish), 11 show inverse associations (of which 9 were northern) and 8 show positive associations, all of which were southern or resident species. This is, in general, what one might expect since lower temperatures are presumed to enhance the suitability of the Bight for northern species and warmer temperatures presumably enhance conditions for southern species. Although the associations are not conclusive proof of the effects of temperature, the fact that they are consistent with expectations lends strength to the notion that they may be real effects and not just spurious associations. The data are not adequate to distinguish between simple extensions of seasonal migrations and real population changes, and there does not seem to be any clear pattern as to the strength of association with temperature and reproductive characteristics in terms of dependence on estuaries or time and area of spawning. Among the 11 species with strong or moderate associations, 6 used inshore or estuarine areas for spawning and/or nursery grounds and 5 used offshore areas; also, there was a wide mixture of spawning time for both inshore and offshore spawners. Among the 8 species with weak associations, 6 used inshore areas and 2 used offshore areas for nursery grounds. On the other hand, all 8 species that showed positive associations used inshore areas as nursery grounds, and all of these were southern or resident species. Among the 11 species showing inverse associations (of which 9 are northern species) only 4 use inshore nursery areas and 7 use offshore areas. It seems apparent that southern and resident species are more dependent on estuaries than are northern species.

The observed associations have not yielded any firm clues as to the possible mechanisms by which temperature may affect survival of young stages. Given that warming trends are due more to milder winters than warmer summers, and that southern and resident species spawn principally during spring and summer months, then the possible deleterious effects of cold winters would impact more on juveniles than on larvae (the mass mortalities of young spot and croaker during severe winters is an example). However, it must also be remembered that runoff is positively correlated with temperature in the Bight, and survival of larval and juvenile stages of estuarine-dependent species may be more related to runoff than temperature. Major trends in runoff may well affect the average circulation pattern in the Bight, possibly by enhancing the shoreward flow near the bottom which would improve chances of some offshore larvae reaching inshore areas. However, much more research will have to be done on the early life history of fishes and the associated environmental factors before we can go much beyond speculation about controlling mechanisms; and a longer time series will be required to determine whether temperature and population trends maintain a consistent pattern.

Summary

A high proportion of the fish species of the Bight is migratory, exhibiting significant migrations in close synchrony with the large seasonal fluctuations in temperature. When water temperatures rise in the spring, there is a large influx of warm water species from the south (Cape Hatteras or beyond); and a number of cold water species migrate north out of the Bight. In the autumn the reverse migrations take place. Most resident species, of which there are few, migrate offshore in autumn and inshore in spring. Annual variations in the seasonal temperature cycle can cause significant changes in the timing and geographic extent of migration, and may affect both the availability of fish to specific fisheries and spawning success. Longer-term changes in average temperature, such as the alternating warming and cooling trends in the Bight waters observed since the 1940s, also influence the distribution and abundance of migratory species. In general, southern and resident fish species in the Bight show positive associations between abundance and temperature trends, and northern species show inverse associations. For most species the data are not adequate to distinguish between simple shifts in the geographic center of populations and effects on their spawning success.

Most species found in the Bight also spawn there. Eggs and larvae may be found in all areas of the Bight throughout the year, although relatively few species spawn during winter. The spawning of many species follows closely the temporal and geographic progressions of the seasonal temperature cycle, and often extends over several months or more. Individual species populations often cover large areas of the Bight and, therefore, eggs of any one species are usually widespread. Larvae become even more widespread through transport by currents during the developmental period of several months for the average larva. Major mortality factors controlling the success of spawning are believed to operate chiefly during the larval stages — probably a combination of the effects of inadequate food, predators, and transport into unfavorable temperatures. So far we have only limited understanding of how these factors interact. Small-scale and medium-scale dynamics of plankton communities and shelf circulation probably hold the key to understanding larval mortality processes but our knowledge of these processes is still quite limited.

The tendency for positive associations of abundance and trends in mean annual temperatures for southern and resident species in the Bight suggests that their reproduction is enhanced by warmer temperatures when most of these species spawn. However, since the warming trends are due more to milder winters than warmer summers, it is difficult to attribute increased spawning success directly to higher temperatures. One possible mechanism may be through the areal extent and temperature of water in the cold cell. This cell appears to be partly the result of the degree of regional cooling during the previous winter; it obviously affects the distribution and spawning of many demersal species in the Bight. Runoff is also correlated with temperature and may play a more important role than temperature in survival of early life stages especially for species that use estuaries for nursery grounds. Runoff may also influence the survival of offshore eggs and larvae by influencing the circulation in the Bight.

Although the natural environment appears to play the major role in controlling distribution and abundance of marine species, in recent years the effects of man's activities have become more evident and have been shown to be far from negligible. A massive buildup of foreign fleets occurred in the Northwest Atlantic in the 1960s and during the period of heaviest fishing in the Bight, from 1967 to 1974, many species showed declines in abundance of 50% or more. At that time it was estimated that fishing pressure had exceeded the productive capacity of the total finfish resource, and this contributed to the establishment of a 200-mile limit by the United States. By 1978, just four years after the first restrictions on total finfish harvests were imposed, the abundance of most species showed significant recovery. For a number of less valuable species, the rate of fishing required to meet current domestic demand appears less than that which would achieve maximum sustainable yield. However, for a number of preferred species the domestic commercial fishing effort alone is now above the level that will provide maximum weight yields. With rising food prices and a rapidly expanding recreational fishery, some controls on domestic fisheries for preferred species appear inevitable. Setting optimum levels of catch and effort is a complex problem and will require much better statistics on the total harvest by both commercial and recreational fishermen. Perhaps the greatest single need in the Middle Atlantic Bight relative to assessing direct effects of fishing is for improved recreational fishery statistics. Recreational catches far exceed commercial catches for a number of species in the Bight and adequate assessments cannot be done without measures of removals.

The quality of estuarine and coastal waters for fish and shellfish in the Bight has been degraded through the physical and chemical effects of industrial development and population growth, particularly in New York Bight. Physical effects include losses of spawning rivers due to dams and loss of shellfish producing areas due to harbor dredging, siltation, and pathogens from domestic wastes. Chemical degradation is due to a wide variety of contaminants including toxic metals, pesticides, PCBs, petroleum, and sewage. Specific deleterious effects of pollution on a number of fish species have been documented at localized sites, and significant losses in shellfish producing areas have occurred through closure due to the high human health risks from sewage contamination. Also, there is increasing evidence of more widespread damage to the fish and shellfish resources of the Bight, for example, crustacean diseases, fin rot in fish, and mortality in mackerel eggs. Although there is increasing awareness of the degradation of the Bight from pollution, there is continuing pressure for dumping wastes at sea because of the cost and risks of land disposal. Therefore, there is a clear need for continued research on the impact of pollutants in the marine environment, and for monitoring the state of "health" of the living resources of the Bight.*

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* A recent update on the ecological effects of pollution in the New York Bight is provided in the proceedings of a June 1979 symposium. Mayer, Garry F. (ed.) 1982. *Ecological stress in the New York Bight: Science and Management.* 715 pp. Columbia, S.C. Estuarine Research Federation.

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