WOODS HOLE LABORATORY REFERENCE DOCUMENT NO. 84-19

Status of Weakfish along the Atlantic Coast, 1984

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September 1984

EXECUTIVE SUMMARY

The weakfish (Cynoscion regalis) is growing in popularity as a food and recreational resource along the Atlantic coast. Recently, the North Carolina Division of Marine Fisheries completed a biological and fisheries profile on weakfish for the Atlantic States Marine Fisheries Commission as a first step in drafting a coastwide management plan (Mercer 1983). The purpose of this document is to provide information that was not available during the preparation of the profile. This information includes trawl survey data collected by the Northeast Fisheries Center, updated catch statistics, results of a yield-per-recruit analysis, and the results of an analysis of the potential effects of fishing on reproductive capacity.

Harvest of weakfish along the Atlantic coast increased during the 1970s. By 1980, reported commercial landings were the third highest on record. Landings have since declined for three consecutive years and available indices of recruitment suggest they will continue to drop. Based on the yield-per-recruit and eggs-per-recruit analyses, it appears that weakfish from Maryland to North Carolina have been experiencing growth overfishing and recruitment overfishing in recent years. The degree of overfishing that may be currently occurring on the entire coastal population depends on the extent that weakfish north and south of Maryland intermingle, on the applicability of the estimated values of total mortality to the current fisheries, and on the appropriateness of the chosen values for natural mortality.

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INTRODUCTION

Weakfish (*Cynoscion regalis*) is a food and recreational resource along the Atlantic coast that is growing in popularity. The 1980 commercial harvest of this species was the third highest in recorded statistics that extend back to 1880 (Mercer 1983), and the number of recreational anglers seeking weakfish doubled during the 10-year period 1965-1974 (Wilk 1979). Recently, the State of North Carolina, Division of Marine Fisheries, prepared a species "profile" that summarizes the available biological and fisheries data on weakfish (Mercer 1983). The Atlantic States Marine Fisheries Commission (ASMFC) plans to use the profile as a basis for the preparation of a coastwide management plan.

The purpose of this document is to provide information not available during the preparation of the profile. This information includes results of the Northeast Fisheries Center (NEFC) trawl surveys off the Northeast coast (Maine to Cape Hatteras, North Carolina) and catch statistics updated through 1983. This document also presents results of analyses of the potential effects of fishing on yield per recruit and reproductive capacity of the weakfish resource. Information on management, biology, and fisheries characteristics is also briefly summarized to provide a more complete basis for the analyses and conclusions.

MANAGEMENT

A synoptic overview of state regulations regarding the catch of weakfish in territorial waters (0-4.8 km offshore) is given in Table 1. All Atlantic coastal states require a general permit or license for the commercial harvest of weakfish, and some states have specific gear and area restrictions. All the coastal states from Connecticut to Maryland have minimum size limits for their commercial fisheries ranging from 22.9 cm to 30.5 cm (9-12 in). New York, Delaware, and Maryland also have minimum size restrictions for weakfish taken in their recreational fisheries.

At present, there is no regional plan providing for the coordinated management of the weakfish resource along the Atlantic coast. However, the ASMFC designated weakfish and two other sciaenids (spotted seatrout and red drum) as species with high priority to be managed under the ASMFC Interstate Management Program. The North Carolina Division of Marine Fisheries is currently under contract to prepare a fishery management plan in cooperation with State and Federal fishery managers (Sciaenid Technical Committee). The scheduled completion date of the plan preparation is March 1985. In addition, during the last quarter of 1986 the Mid-Atlantic Fishery Management Council will determine if a fishery management plan (FMP) is required for the species in the Fishery Conservation Zone (FCZ, 3-200 miles or 4.8-320 km offshore). If the species is identified for management in the FCZ, preparation of the FMP will begin during the first quarter of 1987.

CATCH STATISTICS

The fishery for weakfish along the Atlantic coast coincides with the species' north-south migration habits (McHugh 1980). Weakfish are caught in the summer months at the northern end of their range (Cape Cod) and in the winter months at the southern end (Florida). An extensive review of the catch statistics and characteristics of the fisheries for weakfish along the Atlantic coast was prepared by Mercer (1983). The catch statistics and fishery characteristics are briefly summarized and updated in this section.

Commercial Fishery

Reported commercial landings of weakfish along the Atlantic coast have fluctuated between 1,000 and 20,000 metric tons (mt) from 1880 to 1983 (Figure 1). Peaks in reported landings occurred in the early 1900s, the early 1930s, the mid-1940s, and in 1980. Reported landings for 1980 (16,000 mt) were the third highest in the 104-year record. However, reported landings declined steadily to 8,000 mt in 1983. Since 1970, approximately 50% of the landings reported annually have been from the South Atlantic Region (North Carolina to Florida), 27% have been from the Middle Atlantic Region (New York to Delaware), 21% have been from the Chesapeake Region (Maryland and Virginia), and 1% from the New England Region (Maine to Connecticut). Increases in reported landings in the New England Region during the 1940s and 1970s coincide with increases in landings farther south, suggesting a wider distribution of the species during periods of high stock abundance (Wilk 1981).

North Carolina has reported the highest commercial landings of the Atlantic coastal states since 1957; Virginia had the highest reported landings for most of the earlier years (Appendix I). However, the shift in catch to North Carolina is probably more a reflection of the increased mobility of the North Carolina fishing fleet than an actual shift in the distribution of weakfish (Mercer 1983). The large increase in reported landings in Delaware from 1979 (212 t) to 1980 (403 t) may be due to increased reporting or improved statistics rather than a major increase in the size of the fishery (Seagraves and Rockland 1983).

Gear used to harvest weakfish for commercial purposes are principally pound nets, haul seines, gill nets, and trawls. A comparison of the distribution of total reported landings by gear between the 1940s and 1970s (Wilk 1981) reveals a shift in the dominance of pound nets (63% of total catch, 1940-1949) to the dominance of trawls (60% of total catch, 1970-1979). Other gear used to catch weakfish are hand lines, purse seines, and trammel, hoop, and fyke nets (Wilk 1981). A substantial amount of young-of-the-year weakfish are also captured and discarded in the shrimp fishery that operates from North Carolina to Florida. Wolff (1972) determined that the amount of weakfish discard from shrimping operations in North Carolina during 1969-1971 was approximately 64% of the total North Carolina landings of weakfish during those years.

A 51-mm (2-in) stretched mesh has traditionally been used in pound nets, resulting in a 50% retention length of 203 mm for weakfish (Meyer and Merriner 1976). Weakfish of this length are approximately age 1, based on Wilk (1979, p.24). Fifty-percent retention lengths for the trawl stretched mesh size used in the Delaware Bay commercial fishery (51 mm, 2 in) is 66 mm; however, fish less than 185 mm (age 1, Wilk 1979) are culled from the catch (Daiber 1957, 1958). Increasing the stretched mesh size to 76 mm (3 in) would increase the 50% retention length to 204 mm (Daiber loc. cit.). Shepherd (1982) presents length and size composition data from the commercial trawl fishery operating out of Cape May, New Jersey in the spring and fall, 1980-1981, and notes that spring landings consisted of fish from age 1 to 10 (majority age 5) while the fall landings were primarily age 1. No information is available on the size selectivity of the haul seine and gill net fisheries for weakfish.

Recreational Fishery

Wilk (1981) and Mercer (1983) provide a description of the recreational fishery for weakfish. Estimates of weakfish catch in the recreational fishery along the Atlantic coast are available for 1965 (Deuel and Clark 1968), 1970 (Deuel 1973), and annually since 1979 (USDOC 1980, NMFS unpublished data). The 1960 coastwide survey (Clark 1962) did not list weakfish as a separate species; therefore, results of this survey cannot be used in comparison to the later surveys. The 1965 and 1970 surveys are suspected of overestimating catch due to a lengthy recall period (Hiett and Worral 1977). The surveys conducted since 1979 used a different sampling method than the earlier surveys, aimed at improving the accuracy of angler recall (USDOC 1980).

Results of the coastwide surveys (Table 2) indicate that the recreational fishery for weakfish increased substantially from a catch of 1.8 million fish in 1965 (suspected of being an overestimate) to a catch of over 12.6 million fish in 1980. The catch then steadily declined to 1.3 million fish in 1982, mimicking the trend in commercial harvest during the same period. The average weight per fish caught has also fluctuated from an average of 0.6 kg per fish in 1965 to 2.2 kg per fish in 1982. According to the growth and length-weight equations provided in Wilk (1979), the age of a 0.6 kg fish would be approximately 2.5 years, and the age of a 2.2 kg fish would be approximately 6 years. Variation in average weights of the catch since 1979 are subject to the number of fish inspected in a given sample wave; sample sizes for the 1979-1982 survey interceptions of weakfish have not yet been evaluated as to their adequacy for providing robust estimates.

Annual total landings (in weight) since 1965 may be calculated by adding the reported commercial landings and estimated weight of the recreational catch. For years where recreational survey data are unavailable, total landings may be estimated by interpolating the ratio of recreational/commercial landings ratio in years with recreational surveys to the intervening years and multiplying the commercial catch in those years by the appropriate ratio. The resultant values (Table 3) indicate that total landings of weakfish along the Atlantic coast increased from 2,300-6,000 mt in the late 1960s to over 34,000 mt in 1980. The estimate of total landings for 1983 is 24,262 mt.

BIOLOGY

Stocks

Lack of homogeneity in age and size composition and growth characteristics of weakfish along the Atlantic coast has lead to the hypothesis that two or more stocks exist (in this paper, races, sub-groups, and stocks are assumed to be synonomous terms). Nesbit (1954) hypothesized that distinct northern and southern stocks of weakfish exist along the Atlantic Coast based on differences in scale sculpturing in age 0+ weakfish collected in estuaries from New York to North Carolina. Perlmutter et al. (1956) concurred with Nesbit's hypothesis based on their examination of meristics, scale sculpturing, and growth rates. However, differences found in both studies were only marginally significant.

Seguin (1960) separated three stocks based on morphometric and meristic characters of age 0+ weakfish: (1) New York and New Jersey, (2) Delaware and Virginia, and (3) North Carolina. Shepherd (1982) also separated three stocks, but with different ranges, based on differences in total length/scale length relationships for adults: (1) Cape Cod to Ocean City, Maryland, (2) Ocean City to Virginia Beach, Viriginia, and (3) Virginia

Beach to Cape Fear. In addition, he noted differences in growth and fecundity rates between weakfish from northern and southern locations. Crawford and Grimes (1983) found no genetic basis for the separation of stocks based on an electrophoretic study of juvenile weakfish collected from New York to North Carolina. This suggests that differences found by the other investigators are of phenotypic (rather than genotypic) origin.

Spawning

Weakfish spawning, hatching, and larval development occurs in estuarine and near-shore oceanic waters along the Atlantic coast during spring and summer (Mercer 1983). Colton et al. (1979) indicated that the principal area of spawning extends from the Chesapeake Bay northward to Long Island, New York, based on ichthyoplankton surveys. However, spawning adults have been observed in or near virtually every estuary from the east coast of Florida to the Gulf of Maine (Mercer 1983).

Most weakfish reach sexual maturity during their second summer, although the smaller members of a given year class may not reach maturity until 2 years of age (Mercer 1983). Merriner (1976) reported that males in North Carolina waters attain maturity at a smaller size (13.0-15.0 cm standard length, SL) than females (14.5-19.0 cm SL). Shepherd (1982) reported an overall 1:1 ratio of males to females for weakfish from North Carolina to Cape Cod, but also found that significant differences in the sex ratio existed for various size intervals because of differences in growth rates between the sexes. Males predominated the smaller size intervals and the proportion of females increased to greater than 50% for all size intervals greater than 50 cm.

Fecundity data for weakfish indicate a logarithmic relationship between body length and number of eggs per female and a linear relationship between body weight and number of eggs per female. Merriner (1976) derived relationships between fecundity and body size for weakfish sampled in North Carolina that are substantially different than relationships derived by Shepherd (1982) for weakfish sampled in the New York Bight. While Shepherd's relationships indicate a lower fecundity rate for weakfish, he hypothesized that cumulative lifetime fecundity is nearly the same for weakfish in both coastal regions due to the greater longevity and larger maximum size of fish sampled farther north.

Migration

Weakfish follow a seasonal migration pattern along the Atlantic coast, moving south and offshore during the autumn and winter (Figure 2), and north and inshore during the spring and summer (Figure 3). During the autumn migration, younger weakfish (less than 4 years of age) tend to stay inshore, moving southward to the inner shelf waters from North Carolina to Florida (Nesbit 1954; Wilk 1979). Larger and older weakfish (age 4 years and older) move south but offshore, probably no farther than North Carolina, and then return to their inshore northern grounds during spring (Wilk 1979). The largest and presumably fastest-swimming weakfish tend to congregate in the northern parts of their range during the summer months (Nesbit 1954; Wilk 1979; Shepherd 1982).

Age and Growth

Weakfish eggs hatch in 36-40 h at 20-21 C (Welsh and Breder 1923). Larvae range in size from 1.5 mm to 1.75 mm total length (TL) at hatching and become demersal at 8 mm TL. Larvae have been collected from near shore to 70 km offshore, as well as within estuaries and tidal passes (Mercer 1983). Juvenile weakfish are euryhaline and rely chiefly on estuarine habitat during their first growing season. Growth is rapid during their first year and by December they attain an average length of approximately 17 cm TL (Hildebrand and Cable 1934).

Mercer (1983) summarized the numerous investigations of the age composition and growth rate of weakfish. The mean back-calculated length at first annulus formation (age 1) ranged from 15.5 cm to 18.0 cm TL and was fairly constant in time and location. However, variation in size after age 1 was considerable among locations and years of collection. Nesbit (1954), Perlmutter et al. (1956), and Shepherd (1982) reported larger size-at-age estimates for weakfish older than age 1 collected from northern waters than for those collected from southern waters. In addition, Merriner (1973) and Seagraves (1981) reported temporal variation in growth of weakfish from North Carolina waters and Delaware Bay, respectively. Merriner

(1973), in his study of North Carolina weakfish, was the only investigator to report significant differences in the length-weight relationship between males and females (males weighing less at a given length than females).

Trophic Relationships

Chao and Musick (1977) classified weakfish as "upper midwater" feeders based on external feeding morphology. Numerous studies of weakfish feeding habits are summarized by Mercer (1983). Weakfish tend to feed throughout the water column with the size and type of prey dependent on local food supply and size of the weakfish. In general, juvenile weakfish and smaller adults principally feed on fish, mysid shrimp, and other small invertebrates. As weakfish get larger, they tend to feed more predominantly on larger fishes. Among the fishes most frequently consumed are butterfish, herrings, sand lance, silversides, anchovies, weakfish (young), Atlantic croaker, spot, scup, and killifishes. Invertebrates observed in the diet include assorted shrimps, squids, crabs, annelid worms, and clams (Wilk 1979).

Weakfish are preyed upon by larger predators including bluefish, striped bass, and numerous shark species. Reviews of the parasites and diseases reported found in weakfish are contained in Merriner (1973), Wilk (1979), and Mercer (1983).

STOCK ABUNDANCE AND RECRUITMENT

Information on stock abundance and recruitment of weakfish along the Atlantic coast is available from surveys conducted by the Northeast Fisheries Center and by various states from Georgia to Rhode Island. As discussed in this section, information on stock abundance is relatively weak; however, abundance measurements of young-of-the-year and yearling weakfish may be adequate to project the level of availability to the fishable stock.

NEFC Surveys

Bottom trawl surveys have been conducted by the NEFC off the northeastern US coast since 1963 in offshore waters (>27 m depth) and since 1972 in inshore waters (<27 m depth). The ALBATROSS IV and DELAWARE II have been used for the offshore surveys since 1963 and for the inshore surveys since 1974; the ATLANTIC TWIN was used for inshore surveys in 1972 and 1973. A "36 Yankee" trawl equipped with 41 cm rollers has been used in all summer and autumn surveys, and in all spring surveys before 1973 and after 1981. A modified high-opening "41 Yankee" trawl equipped with 30-46 cm rollers was used in the spring surveys during 1973-1981. Both trawls employed 13 mm codend liners. A 30-minute tow was made at each station at a vessel speed of 6.5 km/hour (3.5 knots) in all surveys. Additional information concerning the surveys is provided in Grosslein (1969), Azarovitz (1981), and Clark (1981).

Catches of weakfish in the NEFC surveys have been limited to principally fish <30 cm in total length (TL) in the autumn inshore surveys. Clark et al. (1969) also found that juvenile weakfish were distributed inshore along the coast from Long Island to North Carolina at depths of 9-26 m in late summer and autumn. Mercer (1983) reports that young-of-the-year weakfish were caught in inshore trawl surveys along the coast of North Carolina, 1968-1981, in depths of 9-18 m during the autumn and winter months. Occasionally weakfish are caught in the other NEFC surveys, but in insufficient quantities to allow meaningful statistical comparisons. Therefore, only the autumn inshore survey data are used to calculate catch-per-tow indices of abundance. The catch-per-tow index is the stratified mean of the average catch per tow within each sample stratum of a defined set of strata, weighted by the surface area of the corresponding stratum.

The average size of weakfish caught in the NEFC autumn inshore survey, 1974-1982, was 17 cm, and an average of 98% of the weakfish caught were less than 30 cm TL (Figure 4). Weakfish in this size range have been aged as young-of-the-year and yearlings by Shepherd (1982). Wilk (1979) gave a range of 13 to 32 cm (average = 19 cm) for published estimates of sizes for yearling weakfish. If this range reflects back-calculated lengths at annulus formation, then it should be slightly above expected sizes of young-of-the-year weakfish in autumn surveys. As such, it is very likely that weakfish under 20 cm TL caught in the autumn inshore survey were almost entirely young-of-the-year. Weakfish between 20 cm and 30 cm TL are likely to be both young-of-the year and yearlings.

Weakfish were caught in all but one inshore stratum between Cape Cod and Cape Hatteras during the autumn surveys (Appendix II and Figure 5). The highest densities were found in strata less than 5 fathoms deep from Cape May to Cape Hatteras. The stratified number of weakfish caught per tow (strata 1-45) ranged from 263.3 fish per tow in 1978 to 29.6 fish per tow in 1982 with no discernable trend (Figure 6). These values are significantly correlated ($r=0.89$, $df=6$, $P<0.01$) with total (recreational and commercial) coastwide landings of weakfish two years later (Figure 7), indicating that the survey catch-per-tow index may also be an index of future stock availability to the fishery (i.e. an index of recruitment strength). The correlation may, however, be spurious due to the strong influence of one data point (1978 index vs 1980 catch). Without this data point, the relationship remains positive, but is non-significant ($r=0.56$, $df=5$, $P<0.05$).

State Surveys

Most of the survey data on weakfish collected by state agencies is not as extensive, in both years and area of coverage, as the NEFC survey data based on standardized trawls. However, state survey data does provide insight into seasonal trends and differences among juvenile weakfish in the various estuaries along the Atlantic coast.

Trawl surveys conducted in the Cape Fear River, North Carolina, indicate that abundance of juveniles increased from

1973 to 1976, declined in 1977, increased in 1978 to 1980, and declined sharply thereafter (Mercer 1983). Trawl surveys in the York River, Virginia, from 1955 to 1982 indicate that peaks in abundance occurred at approximately 10-year intervals with the highest peak occurring in 1980 (Austin 1981). As with the relationship between the NEFC abundance index and subsequent catch, increases in the commercial pound net fisheries in Virginia occurred 2-3 years after increases in juvenile abundance. A blue crab trawl survey conducted by Maryland, 1980-1982, indicated that juvenile weakfish abundance declined from 1980 to 1982 in upper Chesapeake Bay, but increased during the same time period in Chincoteague Bay on the Atlantic coast (Dintaman 1981, 1982, 1983).

Seagraves (1981) summarized trawl survey data collected during the spring and summer months in Delaware Bay, 1953-1955, 1967-1971, and 1979. A considerable reduction in mean density, coupled with an increase in average size, was observed when the 1979 collections were compared to those from earlier years. During 1953-1955, the trawl catch of weakfish was composed mainly of young-of-the-year and yearling fish; the majority of fish sampled were between 15.0 cm and 25.0 cm SL. In comparison, length-frequency distributions from 1979 trawl collections indicated the presence of older individuals which were virtually absent from the earlier collections. Older age groups first began to appear in trawl collections in 1969. Catch rates of juvenile weakfish in Delaware Bay dropped in 1981 (Smith 1982) and were similar in 1981 and 1982 (Seagraves 1982). Weakfish juveniles underwent an increase in relative abundance in Rhode Island waters from 1979 to 1981 (Ordzie, cited in Mercer 1983).

None of the juvenile abundance indices in State waters appear to coincide with indices from other State waters nor with the NEFC inshore survey abundance index. If factors that control year class strength of weakfish in the individual coastal areas are different, or the same set of factors have different effects, then a correspondence of juvenile indices would not be expected and the NEFC survey index would be an "integrator" of the individual indices. The close associations between the Virginia index and subsequent Virginia landings, and between the NEFC index and subsequent coastwide landings, suggest that this assertion may be valid.

HARVEST AND REPRODUCTIVE CAPACITY

Two analyses were performed to examine the effects of various fishing strategies on harvest and reproductive capacity of weakfish. A yield-per-recruit analysis was undertaken to determine the level of fishing mortality that would result in maximum yield per fish for a given age at entry to the fishable stock. Also, an egg-per-recruit analysis was performed to relate the effects of changes in fishing mortality or age at entry on the reproductive capacity of the stock.

Input data for these analyses were based on life history parameter values presented in Table 4. Length-at-age values are from Shepherd and Grimes (in press) for weakfish sampled from Cape Cod to Maryland. Weight-at-age values are derived from the corresponding length-at-age values by applying a length-weight relationship reported by Shepherd (1982) for weakfish in the same coastal area. Maturity-at-age values are based on the statement by Wilk (1979) that most, if not all, weakfish sampled in the Middle Atlantic Bight were mature by two years of age. Fecundity-at-age values are based on a relationships between fecundity and total length derived by Merriner (1976) for weakfish in North Carolina and derived by Shepherd (1982) for weakfish in more northern waters. Both relationships were used in the yield-per-recruit and eggs-per-recruit analyses because (as mentioned previously) of the substantial differences in their estimates of the number of eggs at a given size. For example, a 500 mm TL female would produce over 2 million eggs based on Merriner's relationship and only 600,000 based on Shepherd's relationship.

Yield per Recruit

A Thompson and Bell (1934) model was used to estimate yield per recruit for various levels of instantaneous fishing mortality (F) and age at entry to the fishery (tc). Values of F were varied between 0 and 1, and values of tc were varied between age 0.5 and age 4. Two levels of instantaneous natural mortality (M) were arbitrarily chosen, M=0.25 and M=0.35, because of the lack of available estimates and because they lie within the range of values used by Murawski (1977) for his preliminary assessment of weakfish in the Middle Atlantic Bight (M=0.2 to M=0.4). The maximum number of ages used in the analysis was 15, based on a recommendation by Anthony (1982) that the maximum number should be greater than the age when the cumulative value of M is greater than or equal to 3.0 (= 12 years for M=0.25 and 8.5 years for M=0.35) in yield-per-recruit analyses.

Results of the yield-per-recruit analysis are expressed as the value of Fmax (level of F that produces the highest yield per recruit) and F0.1 (level of F that corresponds to a point on the yield-per-recruit curve where the slope is equal to 10% of the slope at the origin) for a given age at entry to the fishable stock. The F0.1 level is a reference level of fishing mortality that is frequently used by managers to avoid overfishing.

If current values of F for the weakfish fishery along the Atlantic coast are higher than the estimates of Fmax, then growth overfishing is occurring. Values for F can be calculated from available estimates of total instantaneous mortality (Z = F + M), which range from 0.38 to 0.42 for weakfish north of Maryland, and from 0.65 to 1.14 for weakfish from Maryland to North Carolina (Table 6) in recent years (post 1960). Assuming M=0.25 or M=0.35, values of F are 0.05-0.15 for weakfish north of Maryland and 0.52-0.62 for weakfish from Maryland to North Carolina.

Age at entry to the weakfish fishery along the Atlantic coast is generally age 1 (see CATCH STATISTICS), indicating that weakfish south of Maryland may be undergoing exploitation at a level higher than Fmax, while weakfish north of Maryland are being exploited at a level near or below F0.1 (Table 5). The age at entry that results in maximum yield per recruit is 4 years with M=0.25 or M=0.35. Delaying age at entry from age 1 to age 2 will increase yield per recruit by 25% at Fmax and M=0.25, and by

29% at Fmax and M=0.35. Murawski (1977) estimated that delaying age at entry from age 1 to age 2 would increase yield per recruit by 30% at Fmax and M=0.2 to M=0.4. Delaying age at entry from age 1 until age 4 will increase yield per recruit by 64% at Fmax and M=0.25, and by 70% at Fmax and M=0.35.

Effects of Fishing on Reproductive Capacity

The yield-per-recruit analysis relies on the assumption that recruitment to age 1 remains constant for all fishing conditions. It is possible, however, for stocks to be reduced by fishing to a level where the total egg production (or other measures of reproductive capacity) is insufficient to maintain recruitment at or above a level that allows the spawning stock to replace itself (termed recruitment overfishing). One measure of the relative effects of fishing on the reproductive capacity of a fish stock is a comparison of the expected lifetime fecundity of an age 1 female recruit (eggs per recruit, EPR) under varying levels of F to that female's maximum expected lifetime fecundity (EPRmax) when F=0.

The EPR-value can be calculated using the following equation:

$$EPR = \sum_{i=1}^{n} N_i P_i E_i \quad ;$$

where N_i = number of age i females (N_1 = 1,

$$N_{i+1} = N_i \exp-(F_i + M_i);$$

where:

P_i = proportion of age i females that are mature;

E_i = average fecundity of an age i female; and

n = oldest age in the spawning population.

In the EPR analysis for weakfish, F-values were varied between 0 and 1, M-values were 0.25 or 0.35, P-values and E-values were taken from Table 4, and n was equal to 15 to conform with the yield-per-recruit analysis. Age at entry to the fishery (tc) was varied between 0.5 and 4 years. Four analyses were performed, representing the two levels of M and the two fecundity schedules.

Resultant estimates of EPR are expressed as the percentage of EPRmax (Figure 8). The estimates are sensitive to the fecundity schedule chosen. For example, at tc=2 and F=0.3, the EPR estimate is equal to 24-30% of EPRmax using Merriner's (1976) fecundity relationship for weakfish in North Carolina. Using Shepherd's (1982) fecundity relationship for weakfish from Cape Cod to Maryland, estimates of EPR range from 18% to 20% of EPRmax.

Also plotted in Figure 8 are the Fmax and F0.1 values for the corresponding values of tc (from Table 5). Managing the fishery at Fmax would result in EPR-values that are between 30% and 40% of EPRmax, and EPR-values based on F0.1 lie between 40% and 60% of EPRmax for Merriner's fecundity schedule. For Shepherd's fecundity schedule, EPR-values based on Fmax lie between 10% and 30% of EPRmax, and EPR-values based on F0.1 lie between 30% and 50% of EPRmax.

Using Shepherd's fecundity schedule for weakfish north of Maryland and the most recent estimates of F based on sampling in the same region (0.05-0.15, Table 6), estimates of EPR are 38%-71% of EPRmax for tc=1, and 44%-75% of EPRmax at tc=2. Using Merriner's fecundity schedule for weakfish in North Carolina and the most recent estimates of F based on sampling south of Maryland (0.52-0.62, Table 6), estimates of EPR are less than 20%, and may be as low as 10%, of EPRmax at tc=1 (Figure 8). Delaying entry to the fishery in North Carolina until an age of 2 years would raise the estimates of EPR to 20-30% of EPRmax.

The minimum egg production per recruit that is necessary to maintain stock levels cannot be estimated from available data; however, analyses done on other fish species (silver hake, haddock, and cod; Gabriel et al. 1984) indicate that 20-40% of the maximum spawning stock biomass per recruit is necessary to maintain stock size for those species. Percent of maximum spawning stock biomass per recruit is equivalent to percent of maximum eggs per recuit if fecundity and biomass are linearly related, as is the case for weakfish (Merriner 1976).

DISCUSSION

Weakfish catch (commercial and recreational) along the Atlantic coast was near the highest on record in 1980; however, available recruitment indices suggest that harvest will continue to drop from that peak. Based on the yield-per-recruit and eggs-per recruit analyses, it appears that weakfish from Maryland to

North Carolina have been experiencing both growth overfishing and recruitment overfishing in recent years. The degree of growth or recruitment overfishing that may currently be occurring on the total coastal population of weakfish depends on the extent of intermingling by weakfish north and south of Maryland, on the applicability of the estimated value of total mortality to the current fishery, and on the appropriateness of the chosen range of values for natural mortality.

The presence of much older weakfish in the northern region along the Atlantic coast (age 11+, Shepherd 1982) versus the southern region (less than age 6, Merriner 1973), coupled with the lower fecundity rate of the fish in the northern region (Table 4), suggests that the lower estimates of total mortality rate for weakfish in the northern region may be a reflection of lower natural mortality rather than a lower fishing mortality. Given the lack of estimates for either natural or fishing mortality, it is currently impossible to rule out this hypothesis. If the natural mortality rate is higher than M=0.35 for weakfish in the southern region, then growth and recruitment overfishing may not be occurring to that portion of the total coastal population. It is suggested that future biological investigations on this species focus on estimation of natural mortality and fecundity rates, in addition to estimation of fishing mortality. A coordinated, coastwide tagging program is one method that could be used to obtain estimates of fishing and natural mortality.

A coastwide tagging program may also provide additional evidence on the degree of stock separation for weakfish along the Atlantic coast. The different fecundity schedules and range of total mortality values for weakfish sampled south and north of Maryland lends support to the hypothesis that at least two stocks occur along the coast. Delineation of separate races of weakfish and their distribution through time and location under differing stock densities is not well-defined at present. Past racial studies have demonstrated geographic differences in certain characters indicating that some degree of separation exists; however, mixing among the subgroups does occur. Considering the available evidence, the most likely point of stock separation occurs at Cape Hatteras (Nesbit 1954; Joseph 1972).

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Table 1. State Regulations Concerning the Catch of Weakfish*

State	Commercial	Recreational
Rhode Island	Permit or license	None
Connecticut	Permit or license Minimum size limit (12 in)	None
New York	Permit or license Gear restrictions Minimum size limit (12 in)	Minimum size limit (12 in)
New Jersey	Permit or license Gear restrictions Minimum size limit (9 in)	None
Delaware	Permit or license Gear restrictions Minimum size limit (10 in)	Minimum size limit (10 in)
Maryland	Permit or license Gear restrictions Minimum size limit (9 in)	License in Chesapeake proposed for 1985 Minimum size limit (9 in)
North Carolina	Permit or license Gear restrictions	None
South Carolina	Permit or license Gear restrictions	None
Georgia	Permit or license Gear restrictions	None
Florida	Permit or license Gear restrictions	None

*Source: Mercer (1983)

Table 2. Estimates of Weakfish Catch in the Recreational Fishery along the Atlantic Coast, 1965-1982*

Survey Year	Total Number (millions of fish)	Total Weight (t)	Average Weight (kg)
1965	1,799	1,029	0.57
1970	10,142	7,113	0.70
1979	4,417	5,066	1.15
1980	12,571	18,154	1.44
1981	9,142	6,619	0.72
1982	1,342	2,918	2.17

*1965 based on Deuel and Clark (1968); 1970 based on Deuel (1973); 1979 based on USDOC (1981); and 1980-1982 based on NMFS (unpublished data)

Table 3. Estimated Total Landings (t) of Weakfish along the Atlantic Coast

Year	North Atlantic (ME-CT)			Middle Atlantic (NY-VA)			South Atlantic (NC-FL)			Grand Total
	Comm.	Recr.	Total	Comm.	Recr.	Total	Comm.	Recr.	Total	
1965	2	205	207	1,427	822	2,249	1,035	0	1,035	3,491
1966	1	97	98	749	824	1,573	957	0	957	2,628
1967	1	91	92	535	803	1,338	862	0	862	2,292
1968	1	86	87	849	1,698	2,547	1,136	0	1,136	3,770
1969	6	481	487	1,382	3,317	4,699	767	0	767	5,953
1970	10	746*	756	2,208	6,638*	8,576	1,242	0*	1,242	10,574
1971	84	4,729	4,813	3,325	9,310	12,635	1,719	0	1,719	19,167
1972	83	3,154	3,237	3,784	10,217	14,001	3,423	0	3,423	20,661
1973	85	1,666	1,751	4,447	11,118	15,565	2,981	30	3,011	20,327
1974	236	299**	535	3,568	8,581**	12,149	2,806	28	2,834	15,518
1975	224	269	493	4,992	10,483	15,475	3,104	31	3,135	19,103
1976	159	175	334	5,313	9,032	14,345	4,007	40	4,047	18,726
1977	154	139	293	4,443	6,220	10,663	3,931	39	3,970	14,926
1978	134	107	241	4,640	4,640	9,280	4,290	49	4,969	14,490
1979	221	163*	384	6,979	4,801*	11,780	6,694	102*	6,796	18,960
1980	130	356**	486	6,854	17,601**	24,455	9,307	197**	9,504	34,455
1981	181	133**	314	4,020	6,397**	10,417	7,745	89**	7,834	18,565
1982	112	56**	168	3,074	2,717**	5,791	5,545	145**	5,690	11,649
1983	90	45	135	3,170	2,853	6,023	4,697	141	4,838	10,996

Reported commercial landings from Fisheries Statistics of the U.S. and NMFS (unpublished data)

*Source: 1965 (Deuel and Clark 1968); 1970 (Deuel 1973); 1979 (USDOC 1981)

**Source: NMFS (unpublished data)

Table 4. Life History Parameters for Weakfish along the Atlantic Coast*

Age	Average Length (mm SL)	Average Weight (kg)	Percent Mature	Fecundity (millions of eggs)	
				NC	MA-MD
1	159	0.06	50	0.15	0.00
2	285	0.33	100	0.75	0.05
3	381	0.79	100	1.68	0.21
4	453	1.32	100	2.73	0.47
5	508	1.86	100	3.75	0.80
6	550	2.35	100	4.68	1.16
7	582	2.78	100	5.47	1.50
8	606	3.14	100	6.12	1.82
9	625	3.44	100	6.66	2.09
10	639	3.67	100	7.08	2.33
11	649	3.86	100	7.42	2.51
12	657	4.00	100	7.68	2.66
13	663	4.11	100	7.88	2.78
14	668	4.20	100	8.03	2.87
15	672	4.27	100	8.15	2.94

*Average lengths based on Shepherd and Grimes (in press); average weights based on length-weight relationship derived by Shepherd (1982); percent maturity from Wilk (1979); and fecundity based on relationships between fecundity and length derived by Merriner (1976) for North Carolina weakfish, and by Shepherd (1982) for weakfish from Cape Cod to Ocean City, Maryland.

Table 5. Results of Yield-per-Recruit Analysis for Weakfish*

	Age at Entry to Fishery (tc)							
	0.5	1	1.5	2	2.5	3	3.5	4
M=0.25								
Fmax	0.198	0.214	0.249	0.312	0.371	0.521	0.628	**
F0.1	0.138	0.146	0.164	0.189	0.211	0.243	0.267	0.303
M=0.35								
Fmax	0.240	0.267	0.323	0.442	0.546	1.087	1.230	**
F0.1	0.166	0.179	0.206	0.246	0.279	0.333	0.368	0.423

*See text for definitions of M, Fmax, and F0.1

**Undefined (yield-per-recruit curve has no maximum value)

Table 6. Estimates of Total Instantaneous Mortality Rates (Z) and Corresponding Estimates of Instantaneous Fishing Mortality (F) for Weakfish along the Atlantic Coast (Modified from Merriner 1973 and Mercer 1983)

Region	Z	F		Source
		M=0.25	M=0.35	
Cape Cod, MA - Ocean City, MD	0.42	0.17	0.07	Shepherd (1982)
New York	0.66	0.41	0.31	Perlmutter et al. (1956)
N. New Jersey	0.51	0.26	0.16	Nesbit (1954)
Wildwood, New Jersey	0.52	0.27	0.17	Nesbit (1954)
Cape May, NJ	0.38	0.13	0.03	Shepherd (1982)
Ocean City, MD - Virginia Beach, VA	0.93	0.68	0.58	Shepherd (1982)
Chesapeake Bay	0.76	0.51	0.41	Nesbit (1954)
	0.66	0.41	0.31	Massman (1963)
Exmore, Virginia	0.71	0.46	0.36	Nesbit (1954)
Virginia Beach, VA - Cape Fear, NC	1.14	0.89	0.79	Shepherd (1982)
North Carolina	0.62	0.37	0.27	Nesbit (1954)
North Carolina (pound nets)	0.76 (ages 2-5) 0.97 (ages 3-5)	0.51 0.72	0.41 0.62	Merriner (1973)
North Carolina (otter trawls)	0.65	0.40	0.30	Merriner (1973)

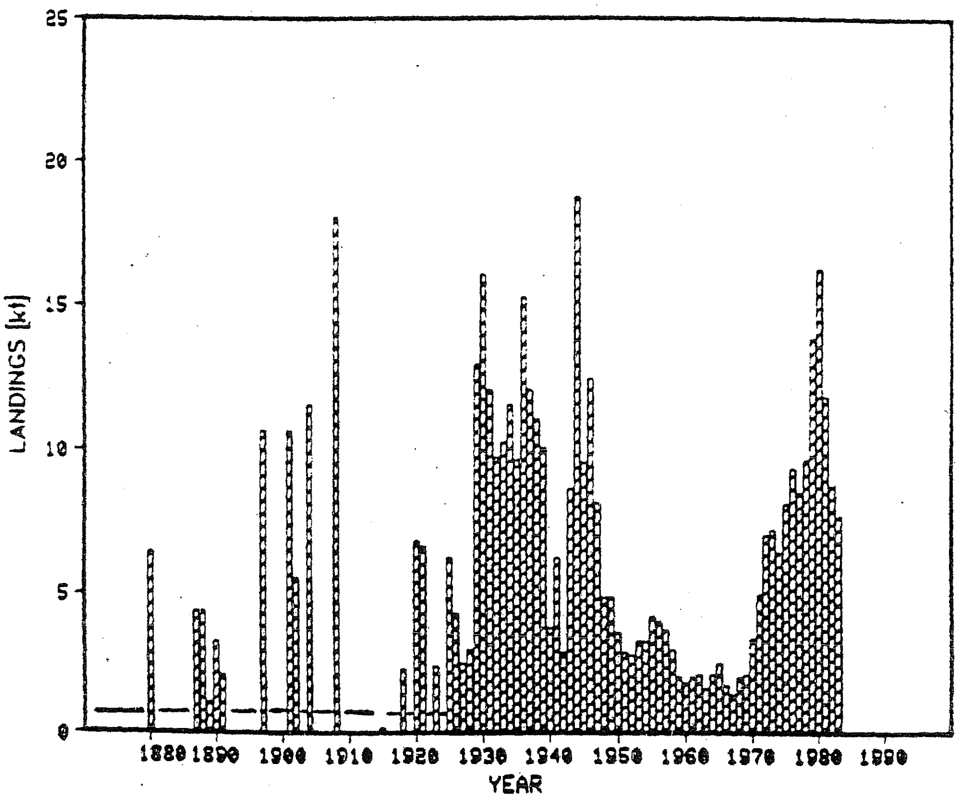

Figure 1. Reported commercial landings of weakfish along the Atlantic Coast, 1880-1983.

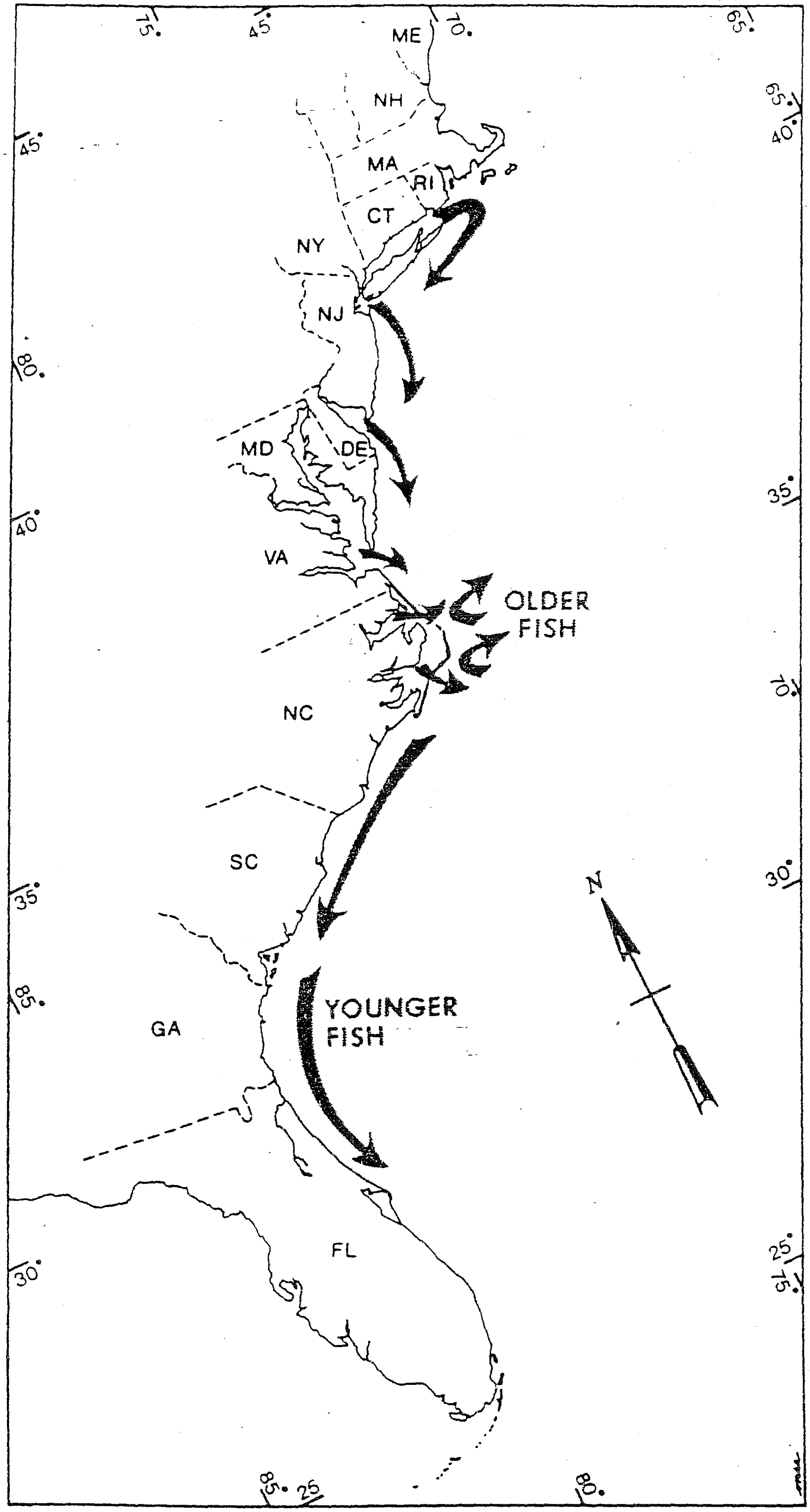

Figure 2. Movements of weakfish along the Atlantic Coast during autumn and winter (from Wilk 1976).

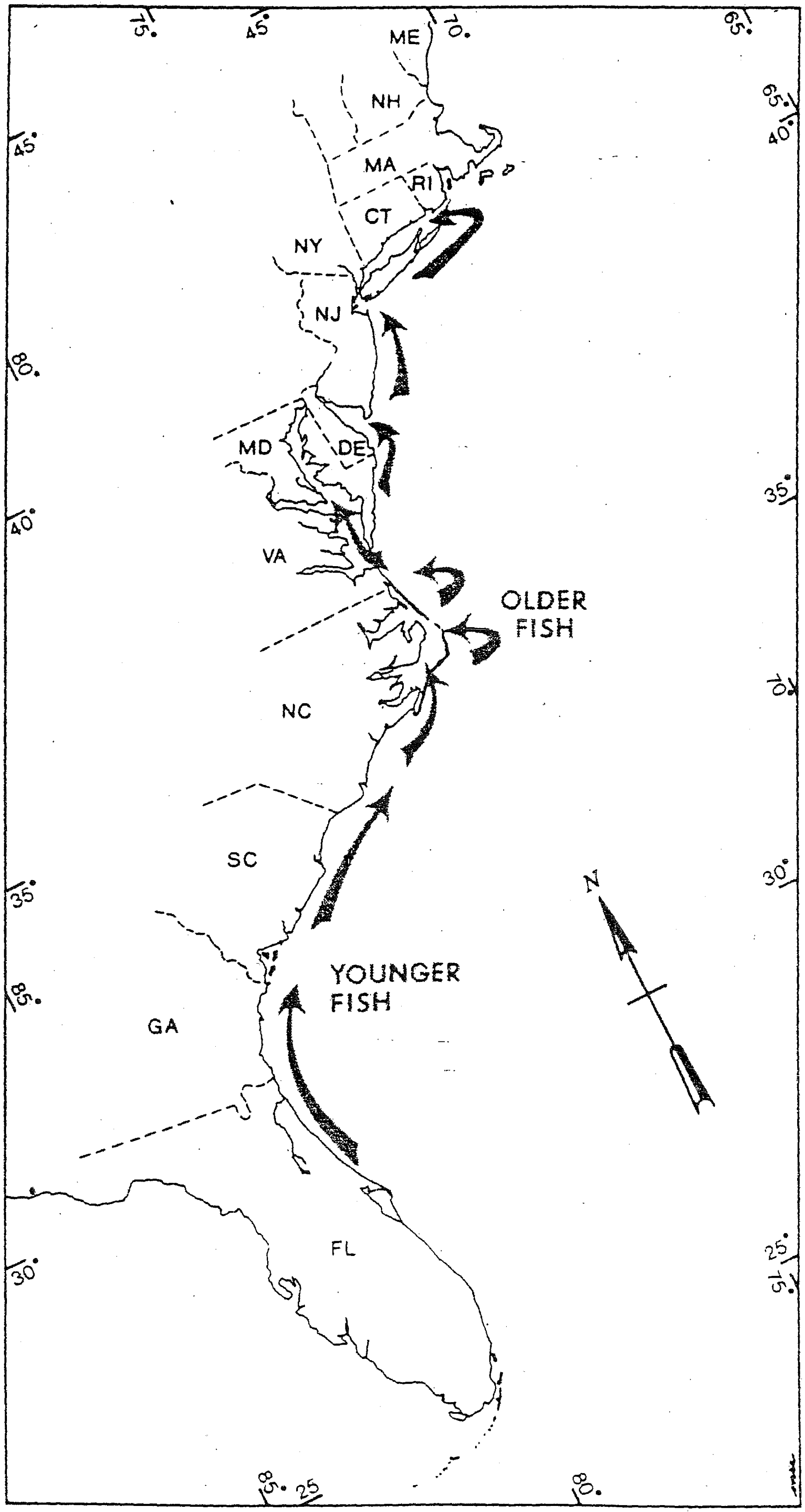

Figure 3. Movements of weakfish along the Atlantic Coast during spring and summer (from Wilk 1976).

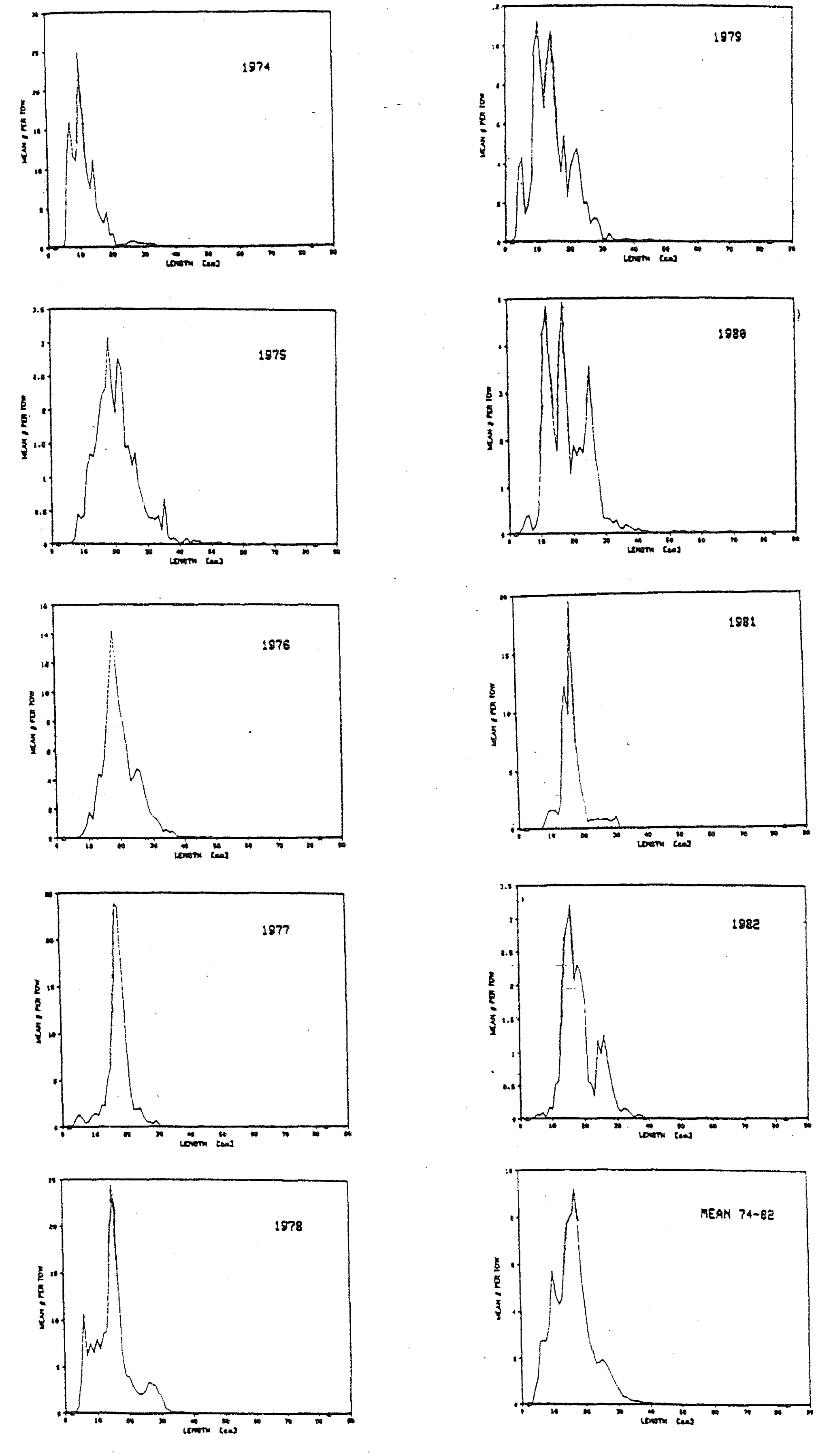

Figure 4. Length frequency distributions of weakfish captured in the NEFC autumn inshore surveys, 1974-1982.

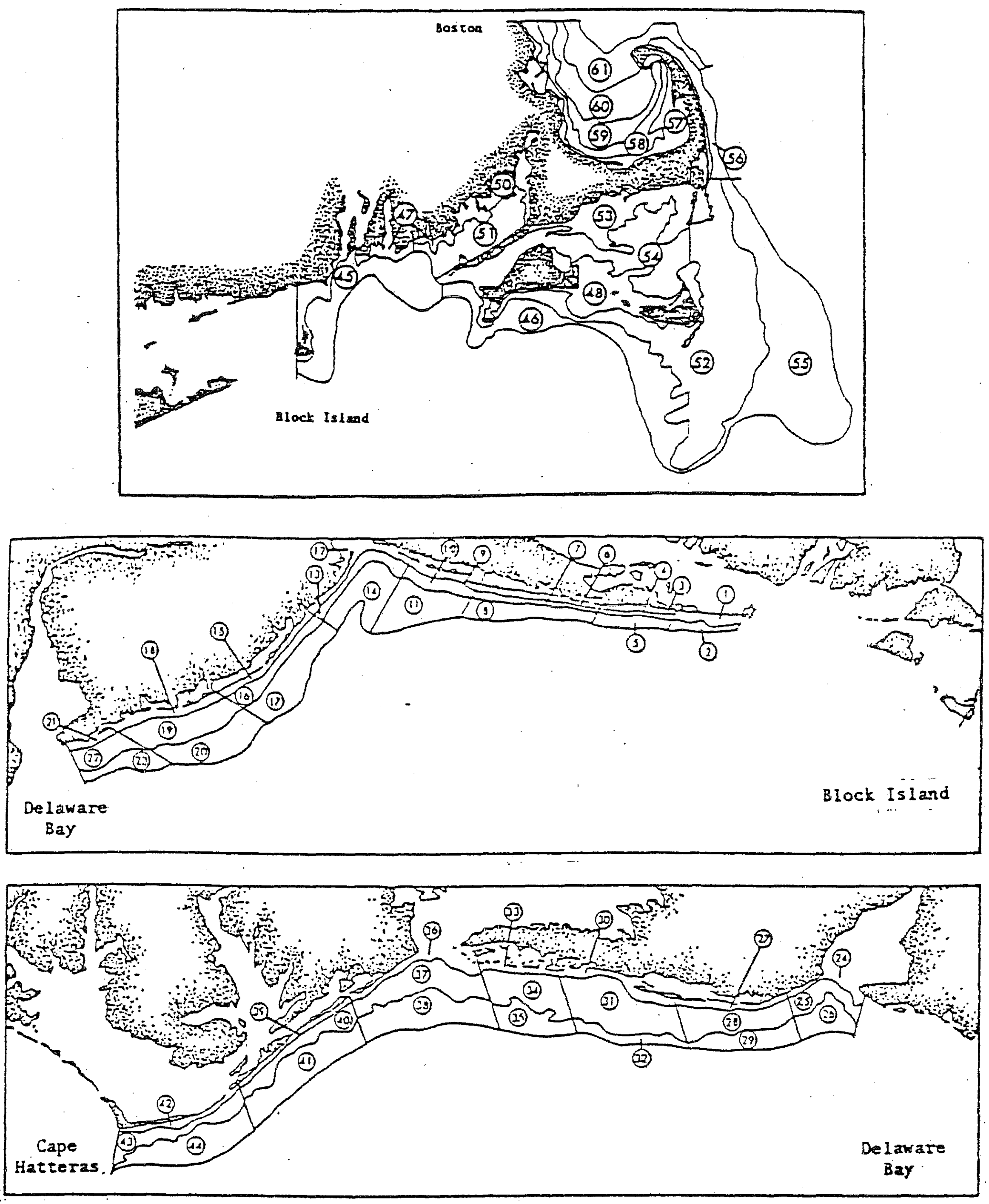

Figure 5. Sample strata used in the NEFC inshore surveys.

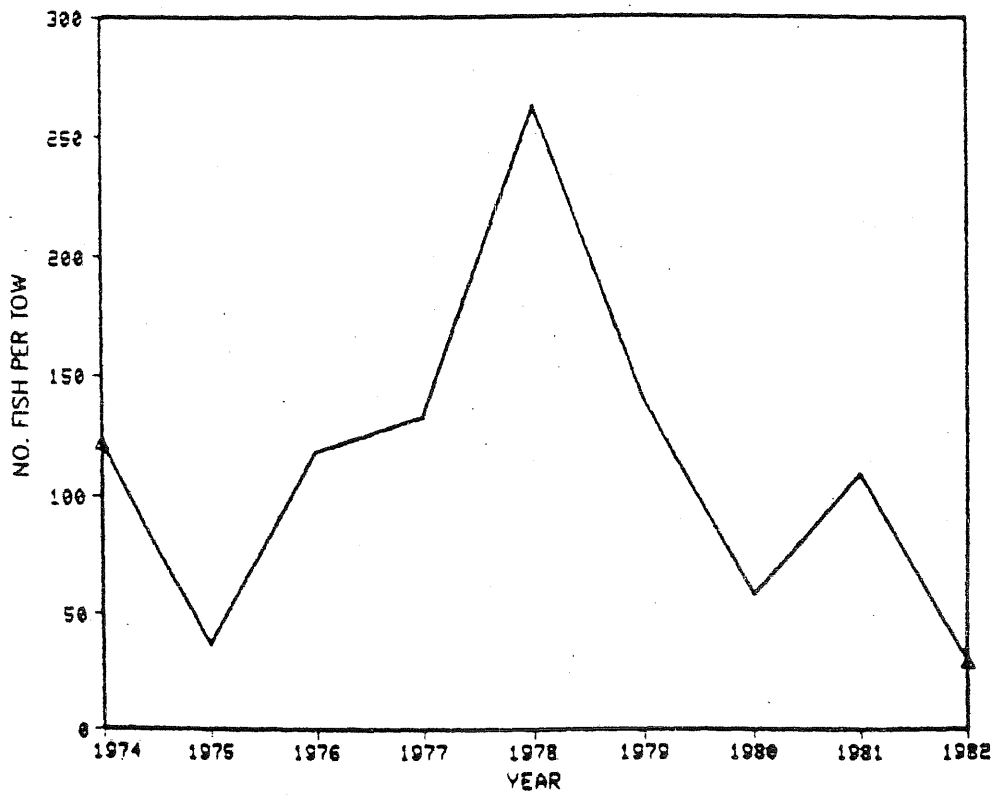

Figure 6. Stratified mean number per tow of weakfish caught in the NEFC autumn inshore surveys, 1974-1982.

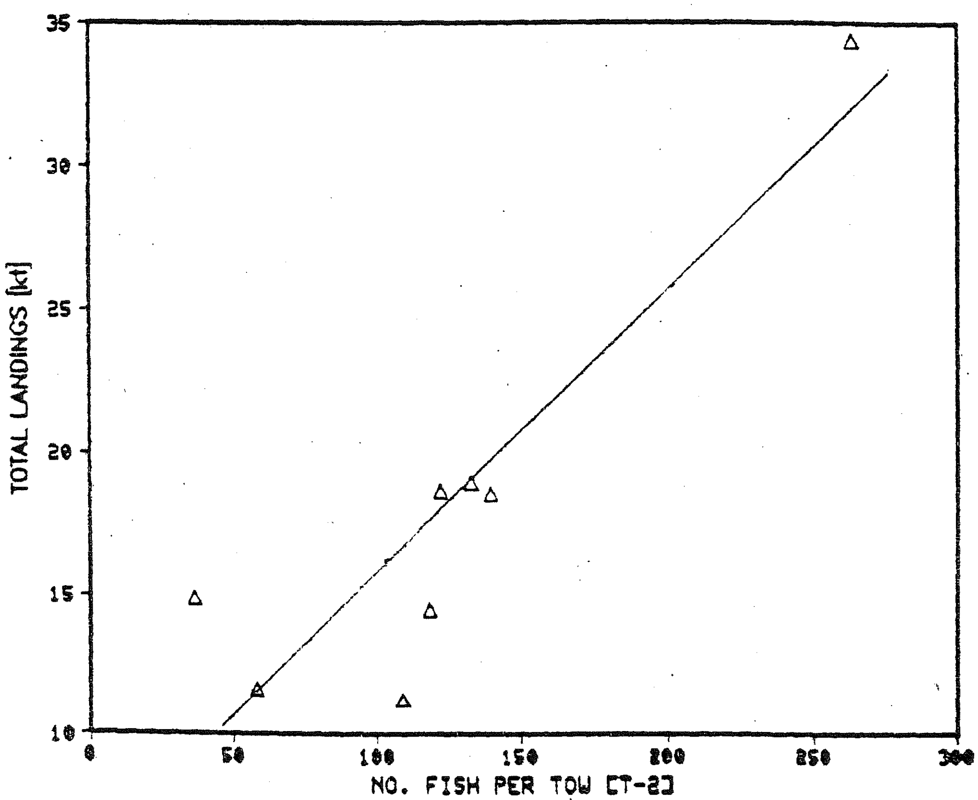

Figure 7. Stratified mean number per tow of weakfish caught in the NEFC autumn inshore survey plotted against estimated total landings of weakfish along the Atlantic Coast two years later.

Appendix I. Reported commercial landings (t) of weakfish in Atlantic coastal states, 1930-1983. 0 = less than 500 kg or none reported.

YEAR	MA	RI	CT	NY	NJ	DE	MD	VA	NC	SC	GA	FL	TOTAL
1930	0	64	20	431	5033	560	1702	7035	1058	11	1	272	16187
1931	68	24	13	665	5299	181	979	4662	1358	2	0	11	13262
1932	26	26	8	307	3766	48	819	5430	1649	1	1	10	12091
1933	130	29	9	374	3141	56	523	5583	0	0	0	0	9845
1934	0	0	0	0	0	0	670	6080	3505	1	0	5	10261
1935	118	17	13	744	3662	194	595	6096	0	0	0	0	11439
1936	0	0	0	0	0	0	608	4693	4067	1	0	0	9369
1937	58	29	4	661	8431	132	494	5717	3413	3	0	0	18942
1938	123	28	3	479	2852	89	485	5690	2311	2	0	0	12062
1939	56	26	5	646	2761	187	662	5487	1288	1	0	0	11119
1940	49	17	4	684	1353	136	620	5581	1646	1	0	0	10091
1941	0	0	0	0	0	0	553	3280	0	0	0	0	3833
1942	2	24	8	821	1905	78	666	2778	0	0	0	0	6282
1943	10	21	11	950	2300	99	0	0	0	0	0	0	3391
1944	17	98	31	684	2140	123	938	4677	0	0	0	0	8708
1945	20	135	19	956	4138	130	1074	10149	2149	0	0	15	18785
1946	19	181	68	1045	0	0	1028	8295	0	0	0	0	10636
1947	27	148	31	700	2581	264	743	8017	0	0	0	0	12511
1948	6	72	39	454	1499	290	503	5376	0	0	0	0	8239
1949	0	7	1	184	1142	471	278	2749	0	0	0	0	4832
1950	0	2	0	64	491	260	268	1819	0	0	0	0	2904
1951	0	0	1	69	887	302	106	897	573	0	0	37	2872
1952	0	1	2	76	987	127	127	684	737	0	0	20	2761
1953	0	8	3	49	980	332	114	922	860	0	0		3268
1954	0	4	1	58	908	167	119	962	1080	12	0	27	3338
1955	0	2	3	93	851	716	187	1737	615	0	0	7	4211
1956	0	5	5	96	908	434	216	1478	835	0	0	3	3980
1957	0	10	10	90	918	581	154	916	1002	5	0	9	3695
1958	0	4	1	40	248	147	95	711	1728	3	0	13	2990
1959	0	0	0	20	169	83	49	309	1321	3	0	15	1969
1960	0	1	0	40	239	4	123	367	1016	6	0	24	1820
1961	0	0	1	24	190	61	127	541	1047	11	0	26	2028
1962	0	3	2	22	295	65	88	675	980	5	0	12	2147
1963	0	1	0	39	151	67	43	498	799	3	0	33	1634
1964	0	0	0	25	247	58	78	722	892	3	0	49	2074
1965	0	2	0	33	270	100	112	910	888	10	1	135	2461
1966	0	0	0	12	156	41	68	472	860	13	0	83	1705
1967	0	1	0	14	207	4	39	272	802	1	0	58	1398
1968	0	1	0	29	241	2	69	508	1037	0	0	99	1986
1969	0	6	0	53	848	10	79	395	698	3	0	65	2157
1970	0	10	0	134	889	67	146	971	1107	2	0	132	3458
1971	0	83	0	580	1397	97	185	1058	1653	0	0	65	5118
1972	0	79	0	830	1442	184	142	1154	3343	0	0	79	7253
1973	1	81	0	575	1162	151	245	2312	2822	1	0	93	7443
1974	22	208	0	647	1218	127	186	1389	2746	1	0	59	6603
1975	3	211	0	620	1982	132	402	1855	3050	1	1	51	8308
1976	6	148	0	610	2589	112	196	1803	3952	0	0	40	9456
1977	5	149	0	775	1461	151	94	1962	3932	0	0	0	8529
1978	11	115	8	748	1753	136	238	1765	4920	0	0	0	9694
1979	16	190	15	686	2956	212	304	2821	6694	0	0	0	13894
1980	10	105	15	723	2220	822	258	2831	9226	6	0	78	16294
1981	15	166	0	615	1701	477	141	1086	7661	0	0	84	11946
1982	10	102	0	569	1039	365	127	975	5466	0	0	79	8732
1983	3	69	18	386	985	408	214	1177	4642	0	0	54	7956

Source: Fishery Statistics of the U.S.

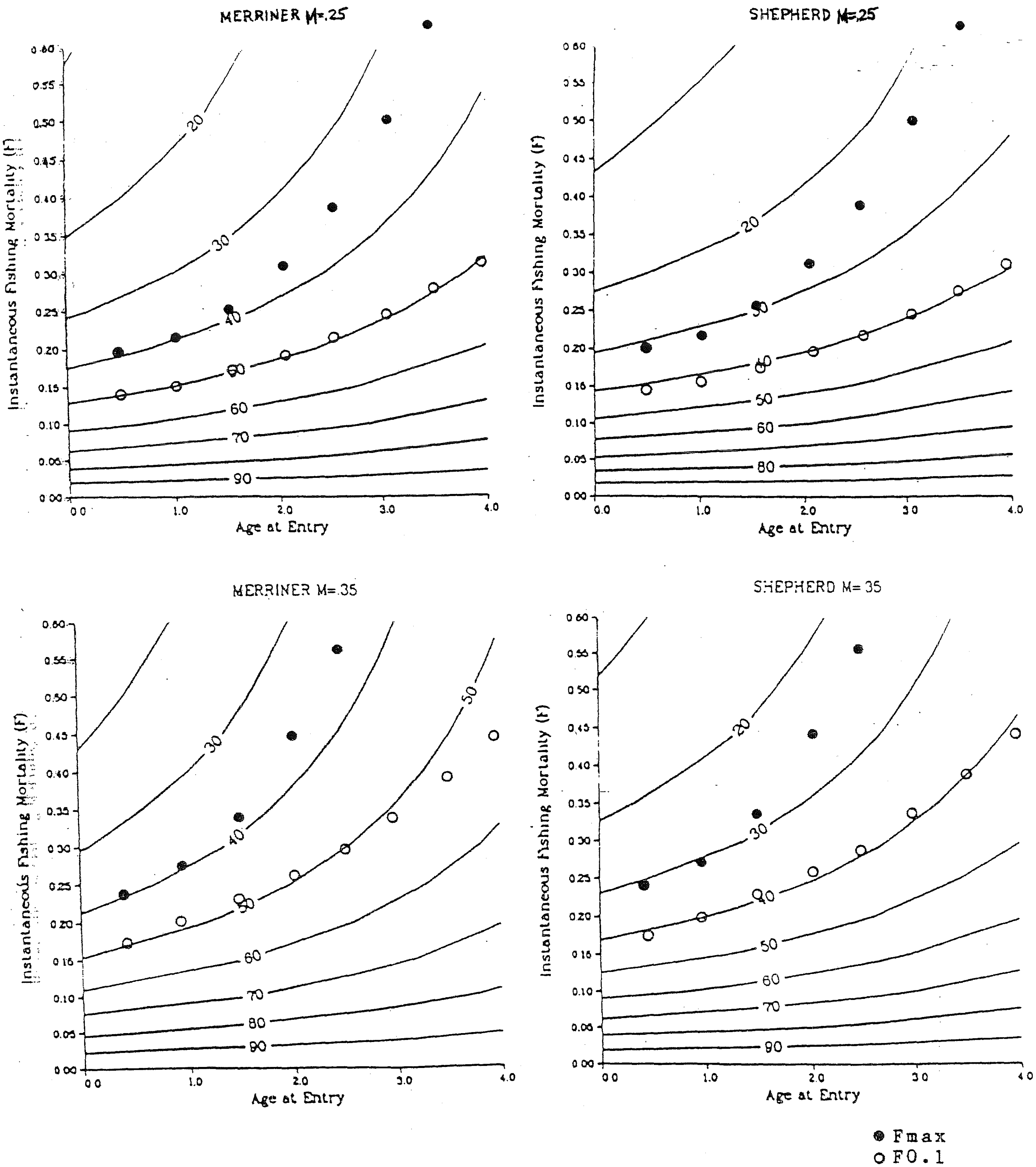

Figure 8. Isopleths of the percent maximum eggs per age 1 female recruit under varying fishing mortality and age at entry conditions, including associated values of Fmax and F0.1 from the yield-per-recruit analysis.

Appendix II. Average number of weakfish caught per tow in NEFC autumn inshore survey sampling strata*, Cape Cod to Cape Hatteras, 1974-1982.

STRATUM	1974	1975	1976	1977	1978	1979	1980	1981	1982	AVERAGE
1	.00	.50	11.00	.00	.00	13.00	.00	.00	.00	2.72
2	.00	1.00	1.00	2.00	.00	.00	.00	10.50	.00	1.61
3	.00	35.50	5.00	.00	11.00	2.00	2.00	40.00	.00	10.61
4	.50	.00	.00	.00	.00	1.00	.00	1.50	2.00	.56
5	.00	.00	.50	.00	.00	.00	.00	.00	2.00	.28
6	.00	8.00	.00	45.00	.00	19.00	14.00	50.00	.00	15.11
7	3.00	.00	2.00	47.50	187.00	2.00	2.30	.00	1.00	27.20
8	.80	.00	.00	1.50	1.00	.00	.50	.00	.30	.46
9	.00	30.50	1.00	246.00	564.00	.00	44.00	26.00	5.00	101.83
10	451.00	.50	13.00	37.00	21.00	.00	8.50	1.00	.00	59.11
11	.70	.30	.50	1.00	.00	.30	.50	.00	.00	.37
12	.00	.00	22.00	245.00	.00	370.00	8.00	.00	.00	71.67
13	70.00	6.00	4.00	.50	2.00	75.50	11.00	30.00	.30	22.14
14	.30	.30	.00	5.00	1.00	1.00	10.00	.00	.00	1.96
15	.00	.00	.00	272.00	157.00	91.00	.00	.00	.00	57.78
16	.00	1.70	2.00	21.50	10.00	45.50	77.00	51.00	.50	23.24
17	.70	.00	.50	.00	.00	14.50	8.50	.00	.00	2.69
18	.00	1.50	12.00	.00	73.00	24.00	121.00	42.00	.00	30.39
19	.00	.00	7.00	6.00	32.00	2.50	.00	.00	7.67	6.13
20	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
21	.00	10.50	11.00	.00	298.00	114.00	48.00	751.00	49.00	142.39
22	.00	.00	16.50	.00	45.00	.50	49.00	1592.50	26.50	192.22
23	.00	.50	3.50	.00	1.00	.00	.00	409.50	8.50	47.00
24	.00	.50	217.00	1496.00	5096.00	15.00	1487.00	314.00	652.00	1030.83
25	210.70	57.50	5.50	52.00	70.00	231.00	6.50	1130.00	219.00	220.24
26	.00	.00	.00	77.00	3.00	.50	204.50	86.50	10.50	42.44
27	.00	63.50	965.00	1612.00	1234.00	571.00	226.00	.00	.00	519.06
28	2227.30	29.50	167.00	9.00	1047.00	385.50	.00	46.50	197.30	456.57
29	.00	1.50	.00	.00	148.00	.00	.00	48.00	27.00	24.94
30	.00	110.50	999.00	798.00	939.00	.00	.00	.00	.00	316.28
31	59.30	111.70	480.00	184.50	1156.00	973.00	187.00	19.00	105.70	364.02
32	1.50	34.50	17.50	4.50	3.00	128.50	.00	70.00	20.00	31.06
33	.00	149.50	648.00	3009.00	2409.00	375.00	70.00	13.00	.00	741.50
34	.00	20.00	446.50	7.00	194.00	24.50	10.00	8.50	37.30	83.09
35	1.00	.00	1209.50	1.00	3.00	21.50	6.00	110.50	.00	150.28
36	1164.50	332.00	187.00	1398.00	636.00	1917.00	.00	61.00	.00	632.83
37	27.80	15.00	153.50	37.50	9.00	69.00	329.50	72.00	4.50	79.76
38	7.50	4.00	57.00	.50	2.00	17.50	.00	.00	.00	9.83
39	.00	305.00	570.00	58.00	194.00	234.00	54.00	100.00	.00	168.33
40	1.50	85.50	136.00	72.50	23.00	165.00	87.50	10.50	8.70	65.58
41	2.30	2.50	23.00	.50	1.00	.00	.00	.50	2.00	3.53
42	.00	234.00	32.00	81.00	2340.00	144.00	133.00	1.00	.50	329.50
43	2.30	234.00	60.50	2.00	308.00	5.50	3.50	.00	.00	68.42
44	.00	36.00	.00	6.50	5.50	.00	7.00	.00	.00	6.11
45	.00	.50	.00	.50	.00	.00	.00	.00	.00	.11
OVERALL MEAN	122.46	36.74	118.59	133.09	263.34	139.88	58.33	109.70	29.58	112.41

*See Figure 5 for locations of strata.