NOAA TECHNICAL MEMORANDUM NMFS-SEFC-380

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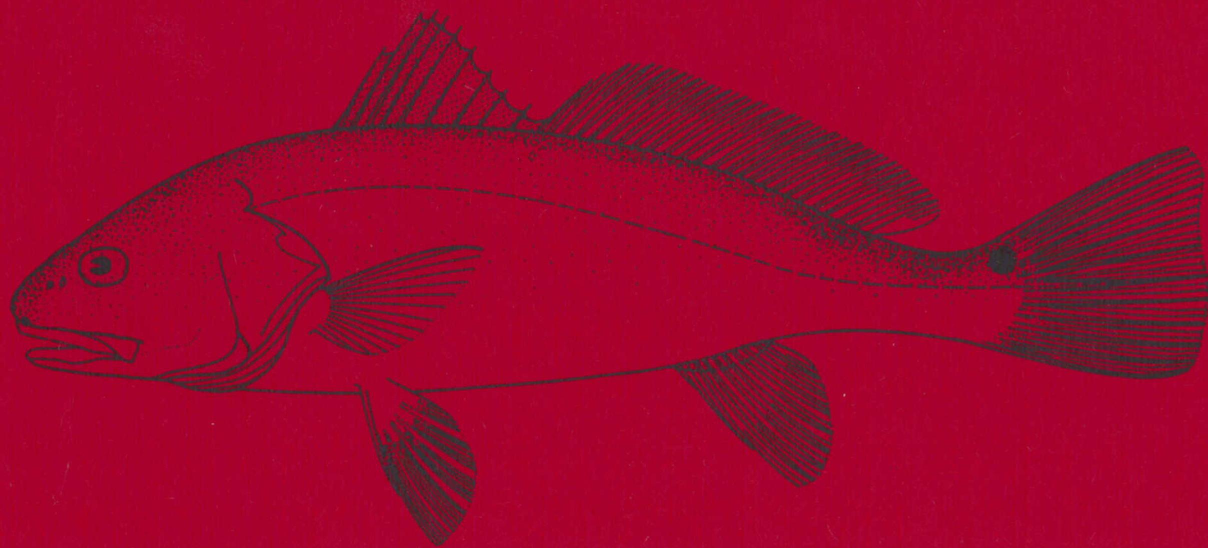

March 1996

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EXECUTIVE SUMMARY

An assessment of the status of the Atlantic stock of red drum is conducted using recreational and commercial data from 1986 through 1994. This assessment updates data and analyses from the 1989, 1991 and 1992 stock assessments on Atlantic coast red drum (Vaughan and Helser 1990; Vaughan 1992, 1993). Since 1980, coastwide recreational catches ranged between 694,400 pounds in 1980 and 2,623,900 pounds in 1984, while commercial landings ranged between 131,500 pounds in 1991 and 439,900 pounds in 1980. In numbers of fish caught, Atlantic red drum constitute predominantly a recreational fishery (generally 78 to 93% in recent years). Commercially, red drum continue to be harvested as part of mixed species fisheries.

Using available length frequency distributions and age-length keys, recreational and commercial catches are converted to catch in numbers at age. Cohort-based and separable virtual population analyses are conducted on the catch in numbers at age to obtain estimates of fishing mortality rates and population size (including recruitment to age 1). In turn, these estimates of fishing mortality rates combined with estimates of growth (length and weight), sex ratios, sexual maturity and fecundity are used to estimate yield per recruit, escapement to age 4, and maximum spawning potential [MSP, equivalent to spawning potential ratios (SPR) based on both female biomass and egg production].

The question of when offshore emigration or reduced availability begins (during or after age 3) continues to be a source of bias that tends to result in overestimates of fishing mortality. However, the continued assumption (Vaughan and Helser 1990; Vaughan 1992, 1993) of no fishing mortality on adults (ages 6 and older), causes a bias that results in underestimates of fishing mortality for adult ages (0 versus some positive value). In the North region (North Carolina and north), estimates of escapement to age 4 are about 0.6% for the period 1987-1991 and increase to approximately 10.5% for the period 1992-1994. For the South region (South Carolina through east coast of Florida), estimates of escapement to age 4 increased from about 0.2% for the period 1986-1987 when the Florida gill net fishery was quite large, to about 1.2% for the period 1988-1991, to 17.2% for the period 1992-1994. Similarly, estimates of percent maximum spawning potential increased from about 0.2% to 9.0% for the North region between the two time periods (1987-1991 and 1992-1994), and from 0.02% to 0.8% to 14.0% for the South region among three time periods (1986-1987, 1988-1991, and 1992-1994).

Population models used in this assessment (specifically yield per recruit and maximum spawning potential) are based on equilibrium assumptions: because no direct estimates are available as to the current status of the adult stock, model results imply

potential longer term, equilibrium effects. Because current status of the adult stock is unknown, a specific rebuilding schedule can not be determined. However, the duration of a rebuilding schedule should reflect, in part, a measure of the generation time of the fish species under consideration. For a long-lived, but relatively early spawning, species as red drum, mean generation time would be on the order of 17 to 20 years based on age-specific egg production. Maximum age is 50 to 60 years for the North region, and about 40 years for the South region. The ASMFC Red Drum Board's first phase recovery goal of increasing %MSP to at least 10% appears to have been met.

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INTRODUCTION

This, the fourth assessment for the Atlantic coast stock of red drum (*Sciaenops ocellatus*), updates analyses presented in Vaughan and Helser (1990) (referred to as the 1989 assessment), in Vaughan (1992) (referred to as the 1991 assessment), and in Vaughan (1993) (referred to as the 1992 assessment). Following submission of the 1989 assessment to the South Atlantic Fishery Management Council (SAFMC), three management measures were adopted by the Council in the Atlantic Red Drum Fishery Management Plan (SAFMC 1990a). The first management measure establishes the fishing year from January 1 through December 31. The second management measure requires that National Marine Fisheries Service (NMFS) prepare assessments for the Atlantic stock of red drum as requested by the Council, and creates a scientific stock assessment review group to review assessment analyses and to make recommendations to the Council based on these data. The third management measure prohibits the harvest or possession of Atlantic red drum in or from the extended economic zone (EEZ, 3 to 200 miles) until a total allowable catch (TAC) is specified by plan amendment. Overfishing in the plan is defined as "a fishing mortality rate that will, if continued, reduce the spawning stock biomass per recruit (SSBR) below 30% of the level that would exist at equilibrium without fishing."

The charge for the 1995 assessment from the Red Drum Technical Committee is to completely separate analytically the Atlantic red drum population into two stocks: a northern stock from North Carolina and north, and a southern stock from South Carolina through the east coast of Florida. In the process, separate age-length keys, growth curves, and management analyses are developed in this report. In addition, new fishing data for 1992-1994 are included, although 1994 data is in part preliminary. Recreational landings have been reestimated from revised data provided by the NMFS Marine Recreational Fishery Statistics Program for 1981 to present. Recreational length frequency distributions were recalculated by weighting by the catch of A+B1 (see Table 1 footnote for definitions for MRFSS data) fish.

DESCRIPTION OF THE DATA

Recreational landings and length frequency information were obtained from the NMFS Marine Recreational Fishery Statistics Survey (MRFSS; Essig et al., 1991). Commercial landings were obtained through the Southeast Fisheries Science Center (Florida through North Carolina) and Northeast Fisheries Science Center (north of North Carolina). Since 1980 no recreational or commercial catches of red drum have been reported north of Maryland. Corrected annual landings for Virginia were obtained from Virginia Marine Resources Commission (VMRC). New commercial length-frequency information by gear were obtained from the North Carolina Division of Marine Fisheries (NCDMF) and the VMRC.

To assess the potential effects of a fishery on a population it is useful to examine the age classes of fish which are vulnerable to the force of fishing. In constructing an age frequency distribution, it is first necessary to estimate the total catch in weight by gear of red drum from the commercial fishery. Weight is converted from kilograms to pounds for this assessment. Catch in numbers by gear are then obtained by dividing by the mean weight of an individual red drum (catch for the recreational fishery is already estimated in numbers as well as in weight). Application of length frequency distributions by gear and annual age length keys allows catch in numbers by gear to be converted to catch in numbers at age by gear. The smaller the subdivision of temporal/geographic fishing which the data allow in converting weight to numbers, the greater the precision in the final coastwide estimates of red drum catch in numbers at age. These numbers are then used in virtual population analysis to estimate fishing mortality and population size.

Recreational Fishery Data

All estimates for 1981 through 1994 reflect the new protocol used by the MRFSS (Gray et al., 1994). Recreational catches of red drum during the 1980's increased from a low of 632,700 pounds in 1981 to a peak of 2,179,400 pounds in 1984, declined to 513,500 pounds in 1990, and rose significantly to 1,325,900 in 1991 (Table 1). Definitions of catch types (A, B1, and B2) as used by the MRFSS are given in footnote *'a'* to Table 1. When comparing type A and B1 catches (Fig. 1a), most of the catches belong to type A fish for which direct measurements are available. Catch in weight includes 10% of the catch-release (type B2) fish using the mean weight of the type A fish (Table 1). Although this may tend to overestimate the loss in weight from catches of type B2 red drum, the numbers, not weight, are used in this assessment and the use of catch in weight is solely for comparing recreational with commercial catches in weight.

As in the 1992 assessment (Vaughan, 1993), the Atlantic coast has been subdivided geographically at the South Carolina/North Carolina border. The North Region includes data from North Carolina through Maryland, and the South Region includes South Carolina through the east coast of Florida. Recreational landings generally are greater in the South Region with the exception of 1981 (Fig. 1b).

Total recreational catches by number (A, B1, and B2) show an increased importance of type B2 red drum in recent years (especially 1987, 1988, and 1991) (Fig. 2a). Hence, 10% of the type B2 red drum by numbers are shown in Table 1 to represent a 10% hook and release mortality (Jordan, 1990) as was used in the 1991 and 1992 assessments. Catch in numbers by region further emphasize the importance of the South Region compared to the North Region. The mean weight of type A red drum show no particular trend (Fig. 3), averaging about 3.1 pounds between 1979 and 1994.

Recreational length frequency distributions are summarized annually in 1" increments from 1986-1993 (Fig. 4). The length frequency distribution for 1994 (including separate North and South distributions) are also presented, with the North and South distributions in 2" increments with the mid-point plotted on the x-axis (Fig. 5). Separate annual regional length frequency distributions from 1986-1994 are applied to corresponding catch estimates (and separate regional annual age-length keys) to estimate catch in numbers at age by region. The relatively small number of coastwide intercepts in two years (270 in 1990 and 277 in 1991) raised concerns about the adequacy of the MRFSS intercept data base to represent the size frequency of the recreational catch at the 1992 Red Drum Technical Committee meeting (specifically for ages 0-5 used in virtual population analysis). Recent increases for 1992 through 1994 (471, 433, and 447, respectively) are an improvement, but higher levels are desireable to enable these assessments to be conducted at the regional level (North and South).

Commercial Fishery Data

Historical commercial landings in weight are summarized for years 1950-1994 (Fig. 6). Landings prior to 1980 are from SAFMC (1990b; Table 22), and landings for years 1980-1994 are also shown in Table 1. Landings were high during the early 1950's (exceeding 400,000 pounds), and have generally fluctuated between 150,000 and 300,000 pounds since then. Landings reached their lowest level at 106,600 pounds in 1971, and the recent high was 439,900 pounds in 1980. The majority of commercial landings have been in North Carolina (ranging from 15% in 1977 to 99% in 1993 by weight), except in 1972, 1973, 1977, 1978, 1981 and 1982 when 71%, 67%, 80%, 78%, 73% and 71%, respectively, of the commercial landings occurred in Florida (Fig. 7a). Florida's commercial landings generally declined throughout the 1980's, and have been virtually non-existent since 1988 (less than 500 pounds) (by law, not due to dwindling stocks). North Carolina's share of commercial landings have exceeded 70% since 1986. In 1983 and 1991, 11% and 19% of the commercial landings by weight, respectively, were from Virginia; otherwise the contribution of landings from this state ranged from

0.1 to 6.1%. As reported in previous assessments, North Carolina's commercial fishery for red drum is largely a bycatch fishery.

Commercial gears have been delineated into five gear groupings (gill net, haul seine, trawl, pound net, and hook & line). Landings in weight for these categories are shown in Fig. 7b. Through most of the 1980's and 1990's, landings from gill nets dominated the commercial landings (62% of the landings by weight for the period 1980-1994). Trawls contributed about 10% of the landings during this period, pound nets contributed about 8%, haul seines about 14%, and hook & lines about 6%. In 1994, gill nets made up 76% of the landings, 5% for trawls, 4% for pound nets, 12% for haul seines, and 2% for hook & lines.

Catch in numbers for the period of assessment (1986-1991) were high for 1986 and 1987 when large numbers of small red drum were still landed by gill net in the South Region (Fig. 8a). This is further reflected in the gear comparison (Fig. 8b). Landings in the North Region have been generally trendless during this time period. Conversion from catch in weight to catch in numbers is accomplished based on gear-specific length frequency distributions and a weight-length relationship in the procedure described in the previous assessments.

Commercial length frequency distributions by gear are summarized across available years by state (Georgia in Fig. 9, North Carolina in Fig. 10, and Virginia in Fig. 11). Overall commercial length frequency distributions by gear are summarized in Fig. 12. Note the different gill net distributions for the North and South Regions. Annual age length distributions by gear were used as follows: Gill nets for the North Region for 1988-1991, gill nets in the South Region for 1986-1988, haul seines coastwide for 1989-1991, and pound nets coastwide for 1987-1991. For the remaining years of these gears and for all years for trawls, the overall (across years: 1986, 1988-1991) length frequency distributions were used. Annual MRFSS length frequency distributions by region were used for the corresponding commercial hook & lines (note the relative insignificance of hook & line landings to total commercial landings).

All lengths were converted to total length in millimeters based relationships estimated from data provided by Murphy (pers. comm., FL DEP; 1981-1983, 1987-1989 and 1991) (Vaughan 1993).

Since 1980, relatively small but slowly declining commercial landings with higher but more variable recreational landings have been made (Fig. 13). Combined landings in weight peaked at over three million pounds in 1984, and ranged generally between 1.5 and 2 million pounds since then (Fig. 13a). Since 1986, combined landings in numbers peaked in 1987, and ranged generally between 400,000 and 600,000 since then (Fig. 13b).

STOCK CHARACTERIZATION

Aspects of the biology of red drum can be found in the Atlantic Coast Red Drum Fishery Management Plan (SAFMC, 1990a). Herein, updated biological information not included in the SAFMC (1990a) or in the 1989, 1991 and 1992 stock assessments is reported along with aspects of red drum biology relevant to this stock assessment.

Life History and Distribution

Summarizing from the 1989 stock assessment, the red drum is an estuarine-dependent species which inhabits coastal and oceanic waters and ranges from southwest Florida to Mexico in the Gulf of Mexico and from Florida to Massachusetts in the Atlantic. Commercial landings were historically reported as far north as Massachusetts, however, none have been documented north of Chesapeake Bay since 1950. Management units of red drum include U.S. Atlantic and Gulf of Mexico stocks. The distribution of the adult and subadult red drum populations appears to be determined by habitat type, where subadult red drum inhabit shallow coastal estuarine environments and move into the deeper oceanic environment during maturation. For the purpose of this assessment, the subadult phase extends through age 5. The adults are often found in large schools which move inshore and offshore seasonally, while subadults remain in the estuaries. Adult red drum have been found year round in Pamlico Sound and behind the barrier islands in North Carolina. These data suggest that no clear distinction exists between the "inshore" and "offshore" stocks. Terms defining a particular life stage, therefore, will be restricted to "subadult" and "adult" stocks, implying no spatial reference for the purposes of this assessment.

Movement

Results of recent tagging studies on movements and mortality of subadult red drum are discussed in Ross and Stevens (1989), Pafford et al. (1990), and Wenner et al. (1990). They generally conclude that little movement occurs during the first few years of life when movement is over relatively short distances and recapture rates are high. With the onset of sexual maturity about ages 3 or 4 (Fig. 14d), reduced availability inshore or in estuaries is noted presumably due to movements offshore.

Age and Growth

The von Bertalanffy (1938) growth model has been used extensively to describe the growth of many marine fishes. This is a three parameter exponential function and is written:

$$L_t = L_\infty*(1 - \exp(-k*(t-t_0))), \qquad (1)$$

where L_t is length at age t, and L_∞, k, and t_0 are estimable parameters. Traditional von Bertalanffy growth kinetics, however, are inadequate to describe the growth of red drum which exhibits two very distinct life history stages.

In the earlier assessments (Vaughan and Helser, 1990; Vaughan, 1992), the double von Bertalanffy growth curve (Condrey et al., 1988) was used to represent the growth in length for red drum. This model was fit to the 1986-1994 data set resulting in the following parameter estimates (standard errors): L_∞ = 50.8" TL (0.3), k_1 = 0.231 yr^{-1} (0.004), k_2 = 0.032 yr^{-1} (0.001), t_{01} = -0.14 yr (0.02), and t_{02} = -36.09 yr (1.03).

Vaughan (1993) used the linear von Bertalanffy growth equation to model the growth dynamics of red drum (developed by Geaghan at LSU and referenced in Hoese et al. 1991). This model assumes that L_∞ in the regular (or single) von Bertalanffy growth curve is not constant, but a linear function of age (hence it will be referred to in this report as the linear von Bertalanffy growth curve). Hence,

$$L_\infty = b_0 + b_1 * t, \qquad (2)$$

adds an additional parameter to be estimated using a non-linear iterative least squares approach with the MARQUARDT option [PROC NLIN, SAS Institute Inc. (1987)]. An advantage for this model is that the parameter b_1 can be used directly to test whether the single or linear von Bertalanffy models should be used.

Age-length data sets were available during 1986-1991 from Florida Department of Natural Resources (120 fish from 1987-1989 and 1991), Georgia Department of Natural Resources (1,687 fish from 1988-1993), South Carolina Wildlife and Marine Resources Division (17,634 fish from 1986-1994), and North Carolina Division of Marine Fisheries (1,969 fish from 1987-1993), with the preponderance of specimens being ages 0 to 3 (about 94%). A weighting scheme to decrease the effect of these young fish on the regression results is used such that a weighting factor based on the inverse of the sample size for each age is used.

Parameter estimates from nonlinear regression fits using single and linear von Bertalanffy growth curves are summarized in Table 2 (using age in years and length as total length in inches). The linear von Bertalanffy growth curve is able to fit the rapid growth at earlier ages, while adequately describing the slower growth in later years (Fig. 14a). Parameters from the regional linear models for 1986-1994 are used in later population analyses to represent the growth of red drum for those regions during the period 1986-1994. The parameter b_1 is statistically different from 0 for all model fits, except for females (Table 2). Differences in growth patterns are noted between the North and South regions (Fig. 14a) and females and males (Fig. 14b). The regional differences in growth may be explained by the presence of older fish in the North region (maximum age is 62 years with 10 fish greater or equal to 50 years) compared to the South region (maximum age is 40 years).

Separate regional age-length keys are used to partition the catch in numbers by length category into catch in numbers at age. Using the observed state-supplied data sets of aged fish, annual regional age-length keys were developed directly for 1986 through 1994 (overall for each region in Table 3). Total length is divided into 2" increments from 7" (6"-8") to 41" (40" and larger). Age is divided into 0 through 5 and 6+ (all ages greater than or equal to 6). Keys were developed annually, rather than to a finer temporal scale, because of the scarcity of older subadult red drum (ages 3 through 5) in the aged data sets. When an annual total length increment contained fewer than 10 aged fish, then the overall age length key for that region and total length increment was used in its place. The primary assumptions in using annual coastwide age-length keys concern a constancy in growth across geographic areas and relative uniformity in fishing mortality.

Catches of red drum in numbers at age for the combined recreational and commercial fisheries from 1986-1994 were calculated for the North and South Regions and coastwide by multiplying length-frequency distributions by age-length keys (Table 4). Red drum appear to be fully recruited into the combined recreational and commercial fisheries by age 1 for 1986-1991. Since 1991, age 1 does not appear to be fully recruited relative to age 2, most likely due to the imposition of higher minimum size limits during 1991 and 1992 (14" TL in South Carolina and Georgia and 18" TL in North Carolina and Virginia).

Length-Length/Weight-Length Relationships

In preparing population level analyses, some of the length data were converted to total length from fork or standard lengths. Length-length relationships were updated from those presented in Murphy and Taylor (1990) and used in the earlier stock assessments. Using data from 1981-1991 supplied by FL DEP (Michael Murphy) the following relationships were obtained (n = 550):

$$TL = -26.274 + 1.094*FL, \quad r^2 = 0.999, \qquad (3)$$

and

$$TL = 15.961 + 1.179*SL, \quad r^2 = 0.995, \qquad (4)$$

where TL, FL, and SL, represent total length, fork length, and standard length, respectively in millimeters. Standard errors are 1.106 (intercept) and 0.002 (slope) for Eq. (3) and 1.863 (intercept) and 0.003 (slope) for Eq. (4), respectively.

Total lengths were converted to weight when calculating mean weight of fish by commercial gear and year, and for calculating spawning stock biomass. A coastwide weight (lbs)-total length (in) relationship based on the state-provided aged data is used in subsequent analyses in favor of the MRFSS-based weight-length relationship used in the 1989 and 1991 stock assessments (Table 5 and Fig. 14c).

Sex Ratios, Maturity and Fecundity

The proportion of females at age [2 and younger (0.5), and 3 and older (0.61)] were estimated from South Carolina and North Carolina data as in Vaughan (1992).

Maturity information on red drum sampled in North Carolina is combined to produce a mean female maturity schedule representative of the period 1986-1993 (Fig. 14d). It has been suggested (C. Wenner, SC MRRI, pers. com.) that North Carolina maturity data may be more reflective of the actual situation, because of the hypothesis that red drum tend to move offshore as they mature. This problem is thought to be less pronounced in North Carolina waters as compared to South Carolina where comparable data is also available. Hence a single maturity schedule is used in the maximum spawning potential estimates presented in this assessment. Based on a logistic model fit to North Carolina maturity data from Ross et al. (1995) and new data provided by NC Division of Marine Fisheries (data collected in 1993), female red drum are immature at age 1 and younger, 1% female red drum are mature at age 2, 44% female mature at age 3, 98% female mature at age 4, and all female red drum are mature at age 5 and older.

In general, the spawning season for red drum (August through October, SAFMC 1990b) is similar for both the Gulf and Atlantic coasts. Fecundity information on the Atlantic red drum are unavailable. However, in the Gulf of Mexico Overstreet (1983) found a linear relationship between the logarithm of the number of oocytes (N) and red drum standard length (SL, mm):

$$\log_{10} N = 3.6976 + 0.0050\ (SL),\ r^2 = 0.95,\ n = 22. \qquad (5)$$

NATURAL AND FISHING MORTALITY

Coastwide Total Mortality (Z)

The total mortality from all causes on a fish population is defined as the annual expectation of death of an individual fish which is expressed as the ratio of the number of fish that actually die from all causes during a year to the number of fish present at the beginning of the year (A). This annual mortality rate is related to survival rate (S):

$$(1\text{-}A) = S = N_1/N_0 = e^{-Z}, \qquad (6)$$

where N_1/N_0 expresses the number alive at the end of the year (fishing season) to the number alive at the start of that year and can ultimately be expressed as the instantaneous total mortality rate Z. In assessments of fish populations, Z is typically expressed on an annual basis and is equal to minus the natural logarithm of S.

Estimates of Z can be obtained using catch curve analysis where the natural logarithm of the catch is regressed against age for the ages at or beyond full recruitment (Ricker, 1975). Bias can be introduced if fish are not sampled randomly from the population (i.e., sampled in relation to their actual abundance) or, when applied to catch data from a single fishing year when recruitment and mortality are not constant from year to year.

Rates of instantaneous total mortality (Z) are estimated using catch curves applied to regional catch-at-age data (1984-1991 cohorts) for ages 1 through 3 (Fig. 15). These estimates assume that recruitment to the fishery is complete by age 1 and becomes incomplete after age 3 due to reduced availability, and that the two regions form separate stocks. Estimates of Z for the North region range between 2.8 for the 1984 cohort to 1.3 for the 1991 cohort; while estimates of Z for the South region range between 2.3 for the 1985 and 1987 cohorts and 1.1 for the 1991 cohort.

Fishing and Natural Mortality

In fisheries science, Z is partitioned into M (mortality due to natural causes) and F (mortality due to fishing) and expressed as $Z = F+M$. F is estimated from Z by subtracting an independent estimate of M (e.g.; $F = Z-M$). A source of bias for estimating F for red drum arises, because older fish exhibit emigration or reduced availability to capture by the gear. Then Z becomes the sum of M, F and E (losses due to emigration or other reasons) (i.e.; $Z = M+F'$, where $F'=F+E$). It is uncertain when partitioning Z from catch data in numbers at age whether one has estimated F or F'.

Whether red drum in the Atlantic emigrate from an estuarine habitat at the onset of maturity to join the spawning stock offshore as in the Gulf of Mexico or whether fish of mature age simply become less vulnerable to the fishery is not clear. Nor is it clear at which age red drum begin to move offshore if they do emigrate or what the rates of emigration might be. Because of these uncertainties, it is difficult to ascertain the proportion of declining numbers of red drum at age that are truly due to deaths compared to losses from emigration.

Natural mortality can be estimated from Pauly's (1979) equation, which estimates M from the von Bertalanffy growth parameters (L_∞ and k) and the average annual water temperature. Natural mortality is estimated separately for subadults and adults using k_1 and k_2, respectively, from the double von Bertalanffy growth model and average annual water temperatures recorded in South Carolina (Mathews and Shealy, 1978). Based on the double von Bertalanffy equation using all data given above, estimates of the instantaneous rate of natural mortality for the subadults (M_1) and adults (M_2) were 0.41 and 0.11, respectively. An estimate of M (assumed constant over all ages), based on Hoenig (1983), with a maximum age 55 for an unfished stock, would suggest M equal to 0.075. The recent estimate of 62 years of age for one fish from North Carolina collected in 1993 would suggest an even lower value for M.

Neither of the above estimates for subadult natural mortality seem reasonable. Goodyear[1] used an estimate for M of 0.2 for all ages of Gulf of Mexico red drum. An alternate life history-based method suggested by Boudreau and Dickie (1989) provides age-specific estimates of natural mortality from mean weight at age. This method has been applied to weakfish (Seagraves, 1992) where:

$$M = 2.88 * W^{-0.33}, \quad r^2 = 0.83, \qquad (7)$$

where W is weight converted to Kcal (1 lb = 592 Kcal). Using mean weight at age for U.S. Atlantic coast red drum estimated from the state-provided age-length data set, the following age-specific estimates of M were obtained: M = 0.46 at age 0; M = 0.29 at age 1; M = 0.20 at age 2; M = 0.17 at age 3; M = 0.15 at age 4; M = 0.14 at age 5; and the mean of M for all ages greater than or equal to 6 is 0.11 (ranging between 0.09 and 0.14). The mean M for subadult ages (0-5) is 0.23 (Fig. 15). This last estimate appears to be a more reasonable estimate biologically of subadult natural mortality than 0.075 or 0.41.

Virtual Population Analysis

Application of virtual population analysis (VPA) is made to the regional catch in numbers at age matrices for ages 0 to 5 and years 1986 to 1994. Application is made only to the subadult population (ages 0-5) and not to the adult population (ages greater than age 5) because sufficient data on the age-specific exploitation of older fish is unavailable. The approach used in this report (Doubleday, 1976) requires estimates of natural mortality (on subadults), a starting value of a particular age-specific fishing mortality rate, and assumed or independently estimated relationship of fishing mortality between two age classes.

Application of virtual population analysis requires adequate estimates of catch in numbers at age. Precision of estimates depends primarily on the adequacy of catch estimates, length frequency distributions and age-length keys. Significant errors in Atlantic coast red drum catch estimates in certain years can cause biases in model estimates. If the length frequency distributions are not representative of the length structure of the Atlantic coast red drum catch by gear, then resultant estimates of population size and fishing mortality will be in error. Likewise, if the age-length keys are inadequate, then resultant estimates of population size and fishing mortality will be biased. If natural mortality is overestimated, then age-specific fishing mortality will be underestimated, and vice versa. Because of the limited number of ages and years in our assessment, a poor selection of a starting F can result in significant error carried through to estimates at earlier ages and/or years.

The virtual population analysis used in this report is based on the separability assumption described in Doubleday (1976). This method assumes that age- and year-specific F can be partitioned or is 'separable' into the product of an age component and a year component for the time period to which it is applied. Clay (1990) developed a Fortran program based on separable VPA as described in Pope and Shepherd (1982). This computer program was applied to regional catch at age data for ages 0 to 5 for subsets of years during the interval 1986-1994 with natural mortality for subadults equal to 0.23.

A series of separable VPAs were conducted on the catch matrix for the North region (Table 4). A separable VPA was conducted on the base period 1987-1991, when management conditions (which affect partial recruitment) were relatively stable. The separable VPA on the final period 1992-1994 represents post-management conditions following the introduction of an 18" to 27" slot limit with 5 fish bag limit, with 1 fish allowed over the maximum size limit during 1991. The 1986 catch at age was deleted from the catch matrix for two reasons. First, age-length data from 1988-1991 were used for 1988 and 1989, so that data for year 1986 were at least two years from the source data. Second, and more importantly, a large number of older fish (ages 4 and 5) caused problems with the separability assumption, and were probably indicative of high recruitment from the 1981 and 1982 cohorts (Fig. 17a). Because of the difficulties of applying VPA techniques to relatively few years, these high values for ages 4 and 5 in 1986 cause unstable results from the VPA (because of large difference in partial recruitment for 1986 relative to 1987-1991 for ages 4 and 5). To obtain stable runs of the separable VPA from the North region catch matrix (Table 4: 1987-1991 and 1992-1994), F at age 4 was assumed equal to F at age 5. This assumption probably results in an overestimate of F on age 5. However, F on the earlier ages, principally ages 0 through 3 are relatively robust to large changes in F on age 5. Starting F for the base period 1987-1991 is based on a Z of 1.77 (catch curve mortality from the base period of 1987-1991 for ages 1 through 5; F is then 1.77 - 0.23 = 1.54). With the increased minimum size limit late in 1991 the availability of age 1 red drum was reduced relative to ages 2 and older (Fig. 17a), so starting F for the period 1992-1994 is based on a Z of 2.10 (catch curve mortality for the period 1992-1994 for ages 2 through 5; F = 1.87). Mean age-specific F for these sets of separable VPA are summarized for the two time periods of the North region in Table 6 under the columns labelled 1987-1991 and 1992-1994.

A series of separable VPAs also were conducted on the catch matrix for the South region. A separable VPA was conducted on the base period 1988-1991, when management conditions (which affect partial recruitment) were relatively stable. During 1986-1987, gill net landings in Florida were still contributing large numbers of age 0, and to a lesser extent age 1, red drum to the catch matrix for this region (Table 4). Hence, it is reasonable to assume that the partial recruitment for these ages would be considerably different between 1986-1987 and 1988-1991 based on their respective catch curves (Fig. 17b). Because the period 1986-1987 consists of only 2 years, a separable VPA run was made with 1986-1991 catch matrix to obtain estimates of F on this period (probably biased somewhat low). The separable VPA on the final period 1992-1994 again represents post-management conditions following the introduction of a 14" to 27" slot limit with 5 fish bag limit during 1991 in Georgia and South Carolina (Florida had been at an 18" to 27" slot limit with 1 fish bag since 1986). The ASMFC Technical Review Committee recommended using the assumption in the separable VPA that F for age 2 was equal to F for age 3 (Vaughan, 1993). Catch in numbers at age plots for the three time periods described above suggests that this assumption continues to be useful (Fig. 17b), because of the similar decline in log(catch) between ages 1 and 2 and ages 2 and 3. Hence, partial recruitment was adjusted on age 5, forcing F on ages 2 and 3 to be equal for the South region. Starting F for the base period 1988-1991 and the extended period 1986-1991 was based on a Z of 1.80 (catch curve mortality from the base period of 1988-1991 for ages 1 through 3; F is then 1.80 - 0.23 = 1.57). Starting F for the period 1992-1994 was based on a Z of 0.61 (catch curve mortality for the period 1992-1994 for ages 1 through 3; F = 0.38). Mean age-specific F for these sets of separable VPA are summarized for three time periods for the South region in Table 6 under the columns labelled 1986-1987, 1988-1991 and 1992-1994.

For both regions there is the suggestion of reduced availability of ages 4 and 5, ages coincident with onset of maturity and offshore movements (Fig. 18). The onset of significant maturity of females begins with age 3 (44%), and most age 4 and older female red drum are mature (Fig. 14d). This appears less pronounced for the North region where ages 4 and 5 red drum remain in higher relative availability where older fish can be found in the larger sounds of North Carolina and along the coast in the fall than in the South region.

POPULATION MODELS

Several population models are applied in an equilibrium context using age-specific estimates of F averaged across years from the virtual population analysis on the subadult stock (ages 0-5). These include: 1) a yield-per-recruit analysis to address the question of growth overfishing, or whether greater yields can be obtained from the subadult stock if fishing is delayed on younger fish so as to benefit from their rapid growth in weight (Ricker, 1975); 2) escapement to age 4 to address whether there is adequate survival through the subadult phase (age 4 parallels the approach used with Gulf of Mexico red drum); and 3) maximum spawning potential (ratio of spawning stock biomass per recruit with and without fishing mortality) based on both female biomass and egg production (Gabriel et al., 1989). The latter is investigated in the light of the SAFMC goal of 30% (SAFMC, 1990a). Approaches 2 and 3 address the question of recruitment overfishing. In particular, they attempt to determine whether sufficient spawning stock will be present to support the regional stocks through subsequent recruitment.

Caveats and sources of error in estimating parameters of growth, mortality, and reproduction must be kept in mind when estimating yield per recruit, escapement, and maximum spawning potential. To the extent that the above estimated parameters accurately reflect the underlying processes, the results of these population models are reasonable and produce useful information. Nevertheless, because of the sparseness of much of the data for which many assumptions were made, one must be careful about judgements derived from them. They are intended as best available estimates and are supportive of the results obtained from many of the individual states (e.g., North Carolina, South Carolina, and Georgia).

Yield-Per-Recruit Analysis

The trade off between decreasing numbers of fish and increasing biomass per average individual fish conceptually forms the basis for the yield-per-recruit analysis. As in the 1989 stock assessment, the Ricker (1975; eq. 10.4) formulation is used for yield per recruit, allowing use of age-specific estimates of size and fishing mortality. Estimates for size are based on the regional linear von Bertalanffy growth equation (Table 2), the overall state weight-length relationship (Table 5), and regional and period age-specific fishing mortality rates (F) (Table 6).

Reiterating from the earlier stock assessments, some implicit assumptions in applying the Ricker yield-per-recruit model include: (1) Estimates of natural and fishing mortality are accurate representations for the time periods to which they are applied, (2) these mortality estimates are independent of population density, (3) the linear von Bertalanffy growth function accurately describes individual growth throughout the exploitable phase, (4) recruitment occurs instantaneously on the same date each year, and (5) there is no appreciable net migration. Furthermore, the population processes represented by the yield-per-recruit model are stochastic and the input parameters under the best of conditions are point estimates with some associated uncertainty. Typically, uncertainty exists in any set of input parameters; however, this uncertainty in input parameters is augmented by additional uncertainty due to the sparseness of the data base, which results in greater uncertainty in the model predictions. Uncertainty arises from lack of precision (variability about a point estimate), lack of accuracy (or bias in a point estimate), and application of an inappropriate model. Restrepo and Fox (1988) note that "due to the nonlinearity in yield-per-recruit models, the input of apparently extreme parameter values does not necessarily result in extreme outcome ranges." They present a Monte Carlo-based method for incorporating parameter uncertainty into a Beverton and Holt formulation of yield per recruit. The form that uncertainty takes in our application of yield per recruit is itself unknown (especially with respect to potential bias). Hence, we attempt to use the most reasonable parameter estimates, and in some cases ranges of estimates, that are available in the model analyses that follow.

As in earlier assessments, yield per recruit (Y/R) increases with age at entry to the fishery until about age 3, and then declines rapidly through age 5. Calculated Y/R from regional and period values of partial recruitment and estimates of fishing mortality are summarized in Table 6. For the North region, Y/R rose from 1.5 lbs for the period 1987-1991 to 2.2 lbs for the period 1992-1994. For the South region, Y/R rose from 0.7 lbs for the period 1986-1987 to 1.3 lbs for the period 1988-1991 to 1.7 lbs for the period 1992-1994.

Escapement

Escapement (E) is defined as the relative survival of red drum from age at entry to the fishery to the beginning of age 4; i.e.,

$$E = \Pi R \exp(-(M_1+F_t) / \Pi R \exp(-M_1) = \Pi \exp(-F_t), \quad (8)$$

where R equals the number of recruits at the age at entry, M_1 equals subadult natural mortality, F_t equals age specific subadult fishing mortality (Table 6), and Π indicates the product from t equals 0 to t equals 3. The numerator represents the number of survivors to age 4 with estimated fishing mortality while the denominator represents the number of survivors to the same age without fishing mortality. Escapement was changed from survival to age 6 in earlier assessments (Vaughan, 1992; 1993) to survival to age 4 for comparability with Gulf of Mexico red drum assessments (e.g., Goodyear[1]).

Escapement estimates from regional and period values of partial recruitment and estimated fishing mortality are summarized in Table 6. For the North region, escapement to age 4 increased from 0.6% for the period 1987-1991 to 10.5% for the period 1992-1994. For the South region, escapement to age 4 increased from 0.02% for the period 1986-1987 to 1.2% for the period 1988-1991 to 17.2% for the period 1992-1994.

Maximum Spawning Potential

Gabriel et al. (1989) refer to the percent maximum spawning potential (MSP) as the ratio of spawning stock biomass per recruit with and without fishing mortality. Hence, the equilibrium spawning stock with an estimated level of fishing mortality is compared to a maximum potential spawning stock when no fishing occurs (ignoring adjustments to population parameters through compensatory mechanisms).

As in the earlier stock assessments, percent maximum spawning potential is calculated in two ways. The first method, described by Gabriel et al. (1989), accumulates female spawning stock biomass per recruit across all ages. Female biomass (B) is calculated by summing over female biomass at age t (B_t) as follows:

$$B = \Sigma B_t = \Sigma N_t * S_t * W_t * P_t, \quad (9)$$

where N_t = cohort numbers at age t, S_t = proportion of females, W_t = mean weight females at age t, P_t = proportion females mature at age t (maturity schedule), and Σ represents the summation over all ages. Cohort numbers for the youngest age (recruits) is the same when calculating female biomass with and without fishing mortality. The second method uses Eq. 5 (Overstreet, 1983) to estimate an age-specific index of egg production (E_t) and substitutes this for W_t in Eq. 9, as suggested by Goodyear[1].

As with the yield-per-recruit analysis, separate natural mortality rates are used for subadults (0.23) and for adults (0.11). The assumption from the earlier stock assessments that F for adults is 0 is continued in this assessment (no estimates available). This assumption causes estimates of percent maximum spawning potential to be high.

The assumptions described in the yield-per-recruit analysis section apply here as well. In addition, assumptions as to the validity of sex ratios, maturity schedules and fecundity estimates were needed. How uncertainty in the numerous input parameters are expressed in the model output is poorly known.

Estimates of percent maximum spawning potential from regional and period values of partial recruitment and fishing mortality are summarized in Table 6. For the North region, %MSP increased from about 0.2% for the period 1987-1991 to 9.0% for the period 1992-1994 for both %MSP in female biomass and egg production. For the South region, %MSP increased from 0.02% for the period 1986-1987 to 0.8% for the period 1988-1991 to 14.0% for the period 1992-1994 for both %MSP in female biomass and egg production.

The ASMFC Red Drum Management Board proposed a first phase recovery plan to raise %MSP above 10%. The recommended approaches were 18" to 27" TL slot limit with 5 fish bag limit (one allowed over 27" TL) which was adopted by Virginia and North Carolina during 1992, or 14" to 27" TL slot limit with 5 fish bag limit (none allowed over 27" TL) which was adopted by South Carolina and Georgia at about the same time. Florida already had a more restrictive 18" to 27" TL slot limit with 1 fish bag limit. The results of this assessment suggest that this first phase of the recovery plan has been met.

RESEARCH NEEDS

As referred to in this and earlier stock assessments, a major concern in these analyses relates to the rates at which ages 3-5 red drum emigrate or become less available to the fisheries. This is of special concern with the rate for age 3, because the rates for ages 4 and 5 are probably largely reflected in the reduced estimates of F from the VPA computer runs. Continued tag-recapture studies are important and useful, partly because they provide parallel information on fishing mortality rates that tend to confirm those obtained in these assessments. They may be used to estimate relative fishing mortality between adjacent ages, which has been assumed for the separable VPA runs (ages 4 and 5 for the North region and ages 2 and 3 for the South region). From such an analysis estimates of emigration rates at age could be made.

Primary needs for future stock assessments require continued and improved collection of the following data sets: 1) Catch statistics (some concerns about increasing nonreporting in commercial fishery), 2) length frequency distributions by gear (major need described below), and 3) age-length keys (much improved with data from Florida, Georgia, South Carolina, and North Carolina in the 1991 and 1992 stock assessments). It is important to continue to emphasize the need to improve the number of MRFSS intercepts, because recreational landings represent over 90% of total landings by number coastwide. These were increased in recent years (to 433-471 in 1992-1994 compared to 270-277 in 1990-1991). It is most important that MRFSS intercepts be increased during the fall months (say September through December) when the majority of recreational catches are made. The main weakness in the commercial sampling is in the North Carolina trawl fishery, but this is less critical because landings by trawl represent only about 1% of the total landings by number. However, larger, older fish are typical of the trawl fishery (Fig. 10 or 12), so that relatively small changes in numbers at age of these older fish can have a disproportionate effect.

Parameters for population models still require better estimates of natural mortality rates (subadult M_1 and adult M_2), to which VPA results can be quite sensitive. Estimates of fecundity as a function of Atlantic red drum length or weight would prove useful, although it does not appear to be unreasonable to assume a similar relationship as red drum from the Gulf of Mexico. As used in this and earlier stock assessments, it is not necessary that the absolute value of the estimates be correct, but that the rate of increase in egg production with female age be similar. A 3-year MARFIN Atlantic red drum reproduction project began in 1995 through the University of Georgia Research Foundation.

Continued standardized sampling of subadults is also needed to develop long-term indices of recruitment. This is necessary to permit short-term warning of potential recruitment failure that otherwise could result from a collapse of spawning stock. When a collapse occurs, it may appear in the catch or other fishery statistics too late for a recovery to occur. Furthermore, fishery independent indices are highly desirable as indices of abundance for use in so-called tuning approaches to VPA (Pope and Shepherd, 1985). These methods require one or more indices of abundance, and permit greater confidence in the more recent estimates of fishing mortality rates (and population size). In particular, these methods may increase our confidence in the detection of a decline in fishing mortality rates in the most recent years since management actions have taken place. A three-year, three-state MARFIN project began in 1994 to obtain these data.

Monitoring of adult red drum is needed in terms of a fisheries independent index of spawning stock (e.g., possibly by aerial counting of schools as in the Gulf of Mexico). Conceptually, the application of a VPA to the entire age structure (i.e., through age 50 or 55) is not practical. There are too many ages with relatively small growth from ages 6 through 55, thus an age-length key is not likely to be useful in assigning age to fish sizes. Furthermore, too few red drum of these ages are caught for application of VPA techniques.

Stock status is often assessed from two perspectives. What is the current level of the spawning stock biomass, and are fish being removed at too great a rate? There are currently no data available from which to estimate present levels of adult or spawning stock biomass. Hence, this report addresses the second perspective, but not the first. The population models used in this assessment (specifically yield per recruit, escapement and percent maximum spawning potential) are based on equilibrium assumptions, **so that the model results in this report are only valid in assessing long-term effects based on current removal (fishing) rates.**

Because the development of a rebuilding schedule assumes that information is available as to the current level of the stock, no rebuilding schedule can presently be developed. However, any subsequent rebuilding schedule must take into account the generation time of red drum. Maximum age of red drum from the North region is 62 years with several in their early to mid 50s, while maximum age for the South region is about 40 years. And yet the onset of sexual maturity is significant with age 3 females (44%). Because Atlantic red drum are both long-lived and mature relatively young, the generation time is on the order of 17-20 years as calculated from the mean age at reproduction of a cohort of females in the unfished stock (i.e., mean age of mature females weighted by age-specific egg production when F=0) (Charlesworth, 1980).

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Table 1. Red drum catches for recreational and commercial fisheries, 1980-1994. Recreational catches are in numbers and weight, commercial catches are in weight, and total catches are in weight.

Year	Recreational[a] Numbers A+B1 (1000)	Recreational[a] Numbers 0.1*B2 (1000)	Recreational[a] Weight[b] A+B1+0.1*B2 (1000 lbs)	Commercial Weight (1000 lbs)	Total Weight (1000 lbs)
1980	269.8	14.7	694.4	439.9	1134.3
1981	174.2	1.3	762.3	353.1	1115.4
1982	412.4	1.6	899.5	195.9	1095.4
1983	623.1	6.5	1141.2	370.2	1511.4
1984	1047.4	5.4	2623.9	422.4	3046.3
1985	1001.2	21.8	2240.7	249.7	2490.4
1986	467.4	18.8	2005.3	346.0	2351.3
1987	775.0	71.4	1795.4	314.5	2109.9
1988	591.4	70.9	2116.9	236.1	2353.0
1989	289.2	30.4	1004.5	287.7	1292.2
1990	273.7	34.1	1506.5	187.6	1694.1
1991	449.9	97.9	1638.5	131.5	1770.0
1992	337.5	53.5	1333.8	133.3	1467.1
1993[c]	338.9	93.0	1511.7	241.0	1752.7
1994[c]	412.8	126.3	1767.1	148.6	1915.7

[a] Definitions of catch type (Essig et al. 1991):

A = "fish brought ashore in whole form which were available for identification, enumeration, weighting and measuring by the interviewers",

B = "those not brought ashore in whole form were separated into":

B1 = "those used as bait, filleted, or discarded dead",

and

B2 = "those released alive".

[b] Mean weight of B2 is assumed the same as the expanded mean weight of A. Since numbers of fish, rather than weight, are used in assessment, this assumption does not effect assessment results, but is used only for comparison with commercial landings in weight.

[c] Recreational landings for 1993 and 1994 and commercial landings for 1994 are considered preliminary.

Table 2. Red drum growth characterized by single and linear von Bertalanffy equations weighting inversely by number of fish at age. Units of parameters L_∞ and b_0 are total length in inches; b_1 is total length in inches yr^{-1}; k is yr^{-1}, and t_0 is years. 'Late' refers to the the period 1986-1994. Number in parentheses is standard error for estimate above.

Type	Single Parameters			
	n	L_∞	k	t_0
1981-1994	22182	45.29	0.205	-0.79
		(0.03)	(0.001)	(0.02)
North (Late)	1969	46.71	0.184	-1.47
		(0.08)	(0.004)	(0.09)
South (Late)	19383	41.57	0.283	-0.23
		(0.02)	(0.001)	(0.01)
Female	1074	42.95	0.264	-0.59
		(0.12)	(0.007)	(0.07)
Male	1075	40.93	0.259	-0.69
		(0.14)	(0.007)	(0.08)

Type	Linear Parameters[a]			
	b_0	b_1	k	t_0
1981-1994	38.96	0.17	0.379	0.06
	(0.05)	(0.01)	(0.003)	(0.01)
North (Late)	41.08	0.15	0.363	-0.12
	(0.17)	(0.03)	(0.009)	(0.05)
South (Late)	39.09	0.09	0.344	-0.04
	(0.07)	(0.01)	(0.002)	(0.01)
Female	42.70	0.01	0.269	-0.56
	(0.45)	(0.02)	(0.011)	(0.08)
Male	35.73	0.22	0.424	-0.10
	(0.32)	(0.08)	(0.017)	(0.06)

[a] For the linear model, $L_\infty = b_0 + b_1$ Age.

Table 3. Overall red drum age-length keys for North and South regions, 1986-1994

Length Class (TL,in)	Age (yr) 0	1	2	3	4	5	6+
				North			
7	1	0	0	0	0	0	0
9	1	0	0	0	0	0	0
11	0.710	0.290	0	0	0	0	0
13	0.435	0.565	0	0	0	0	0
15	0.171	0.829	0	0	0	0	0
17	0.035	0.965	0	0	0	0	0
19	0	1	0	0	0	0	0
21	0	0.701	0.299	0	0	0	0
23	0	0.211	0.789	0	0	0	0
25	0	0.049	0.942	0.009	0	0	0
27	0	0.013	0.903	0.084	0	0	0
29	0	0.007	0.647	0.346	0	0	0
31	0	0	0.328	0.567	0.105	0	0
33	0	0	0	0.636	0.341	0.023	0
35	0	0	0	0.216	0.541	0.189	0.054
37	0	0	0	0	0.159	0.273	0.568
39	0	0	0	0	0	0.021	0.979
41+	0	0	0	0	0	0	1
				South			
7	1	0	0	0	0	0	0
9	0.841	0.159	0	0	0	0	0
11	0.614	0.386	0	0	0	0	0
13	0.119	0.880	0.001	0	0	0	0
15	0.007	0.992	0.001	0	0	0	0
17	0.001	0.992	0.007	0	0	0	0
19	0.004	0.761	0.234	0.001	0	0	0
21	0	0.162	0.837	0.001	0	0	0
23	0	0.022	0.954	0.024	0	0	0
25	0	0.004	0.813	0.182	0.001	0	0
27	0	0.001	0.359	0.612	0.027	0.001	0
29	0	0	0.094	0.754	0.151	0.001	0
31	0	0	0.035	0.655	0.293	0.015	0.002
33	0	0	0.017	0.451	0.399	0.087	0.046
35	0	0	0	0.164	0.448	0.224	0.164
37	0	0	0	0	0.079	0.132	0.789
39	0	0	0	0	0	0.016	0.984
41+	0	0	0	0	0	0	1

Table 4. Red drum catch in numbers at age for combined recreational and commercial fisheries (1986-1994).

Year	Year 0	1	2	3	4	5	6+
				Coastal			
1986	188662	445187	60626	5209	1608	2192	23264
1987	239866	750794	51984	6066	255	72	3876
1988	59839	575595	71910	5201	602	226	3595
1989	27999	275124	77219	17592	752	54	4338
1990	24041	254479	67040	6089	2180	436	4454
1991	52803	481468	73261	7109	295	332	806
1992	6219	296664	100826	10648	2171	678	3943
1993	3928	283216	167959	17513	741	48	509
1994	6273	385976	131299	31815	3176	349	2004
				North			
1986	16889	46146	14246	925	1238	2018	22198
1987	20962	71015	18639	878	172	71	3035
1988	14121	142983	39931	876	602	226	3586
1989	21882	105662	26250	721	234	54	4338
1990	6532	69001	4565	1268	172	192	4064
1991	37981	90817	5328	840	179	23	805
1992	1959	45321	25105	338	92	17	1165
1993	211	41359	76628	3543	86	48	508
1994	1440	24629	31230	3639	1126	155	1755
				South			
1986	171772	399040	46380	4284	370	1742	1066
1987	218904	679778	33344	5187	82	1	841
1988	45718	432612	31979	4325	0	0	9
1989	6117	169462	50969	16870	518	0	0
1990	17509	185478	62474	4820	2008	245	389
1991	14822	390650	67933	6269	117	309	1
1992	4261	251343	75721	10310	2079	661	2778
1993	3517	241857	91331	13693	655	0	1
1994	5133	361348	100068	28176	2051	194	249

Table 5. Red drum weight (lbs)-total length (in) relationships state and MRFSS data bases. Number in parentheses is standard error for estimate above.

Type	n	ln(a)	b	r^2	MSE[a]
		MRFSS (1986-1994)			
North	728	-7.373 (0.053)	2.880 (0.018)	0.97	0.029
South	3030	-7.511 (0.041)	2.914 (0.014)	0.93	0.033
		State Commercial Data (1979-1994)			
North	1750	-7.478 (0.021)	2.882 (0.007)	0.99	0.016
South	1102	-7.808 (0.016)	2.969 (0.005)	0.996	0.007
		State Aged Data (1981-1994)			
North (≥1986)	402	-7.925 (0.051)	3.013 (0.016)	0.99	0.025
South (≥1986)	1796	-7.808 (0.017)	2.966 (0.006)	0.99	0.016
All	2864	-7.807 (0.014)	2.964 (0.005)	0.99	0.016

[a] MSE equals mean squared error.

Table 6. Red drum mean fishing mortality rates by region from different catch curve runs using separable VPA program (M_1 = 0.23 for ages 0-5). In addition, estimated values for yield per recruit (Y/R), escapement to age 4, and percent maximum spawning potential (%MSP) based on female biomass and egg production are presented.

Values	Separable VPA				
	North		South		
	1987-91	1992-94	1986-87	1988-91	1992-94
0	0.09	0.01	0.15	0.04	0.0
1	1.75	0.52	2.90	1.27	0.46
2	1.93	1.44	2.86	1.56	0.65
3	1.35	0.28	2.87	1.56	0.65
4	0.87	0.09	0.19	0.39	0.24
5	0.87	0.10	0.02	0.28	0.01
Adult M (M_2)	0.11	0.11	0.11	0.11	0.11
Y/R (lbs)	1.50	2.19	0.75	1.26	1.72
Escapement (%)	0.60	10.54	0.02	1.19	17.17
MSP Biomass (%)	0.20	9.03	0.02	0.78	14.05
MSP Eggs (%)	0.18	8.96	0.02	0.75	13.94

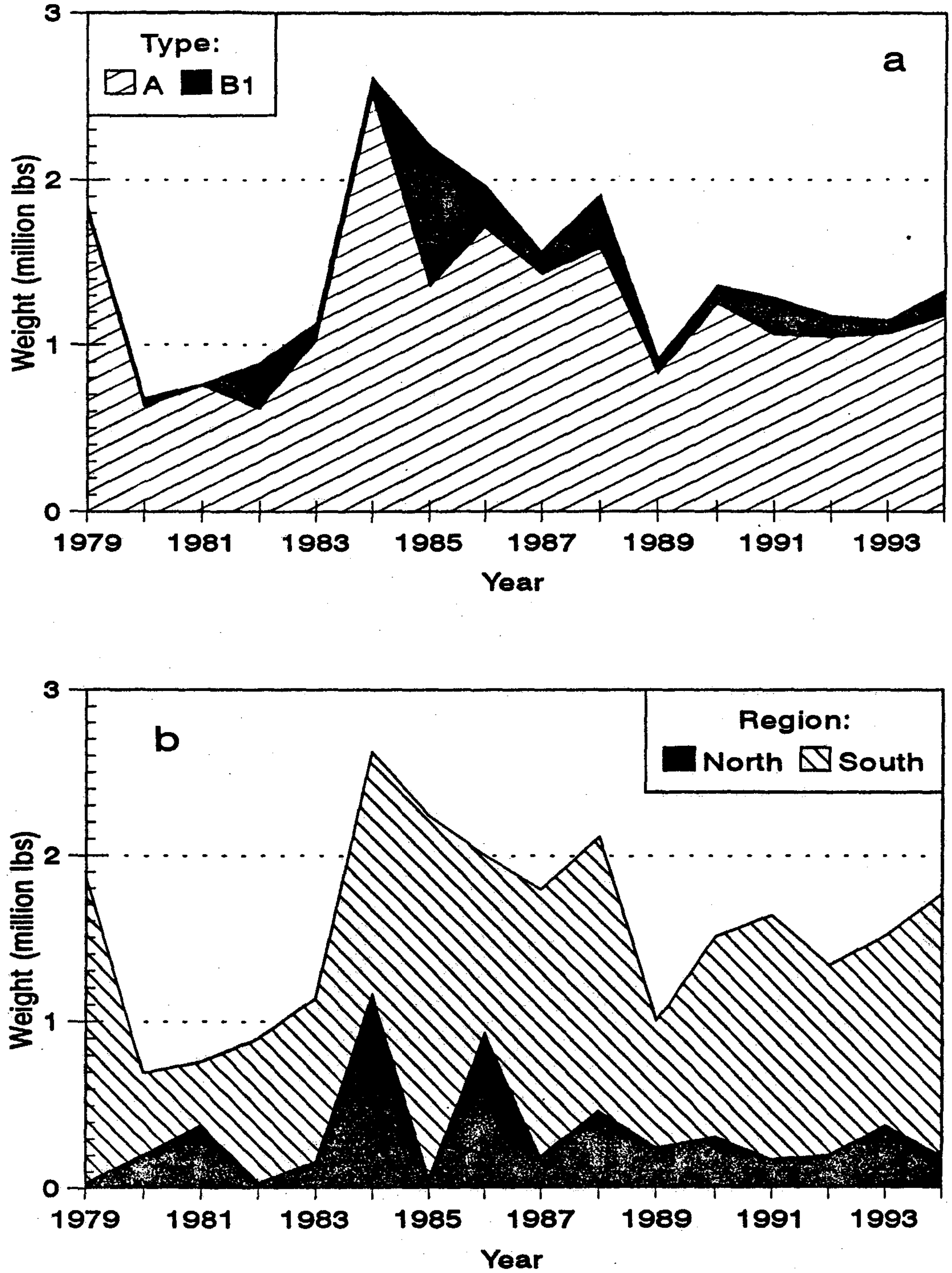


Figure 1. Atlantic red drum recreational catches in weight by type (**a**: A, B1) and by region (**b**: South, North), 1979-1994

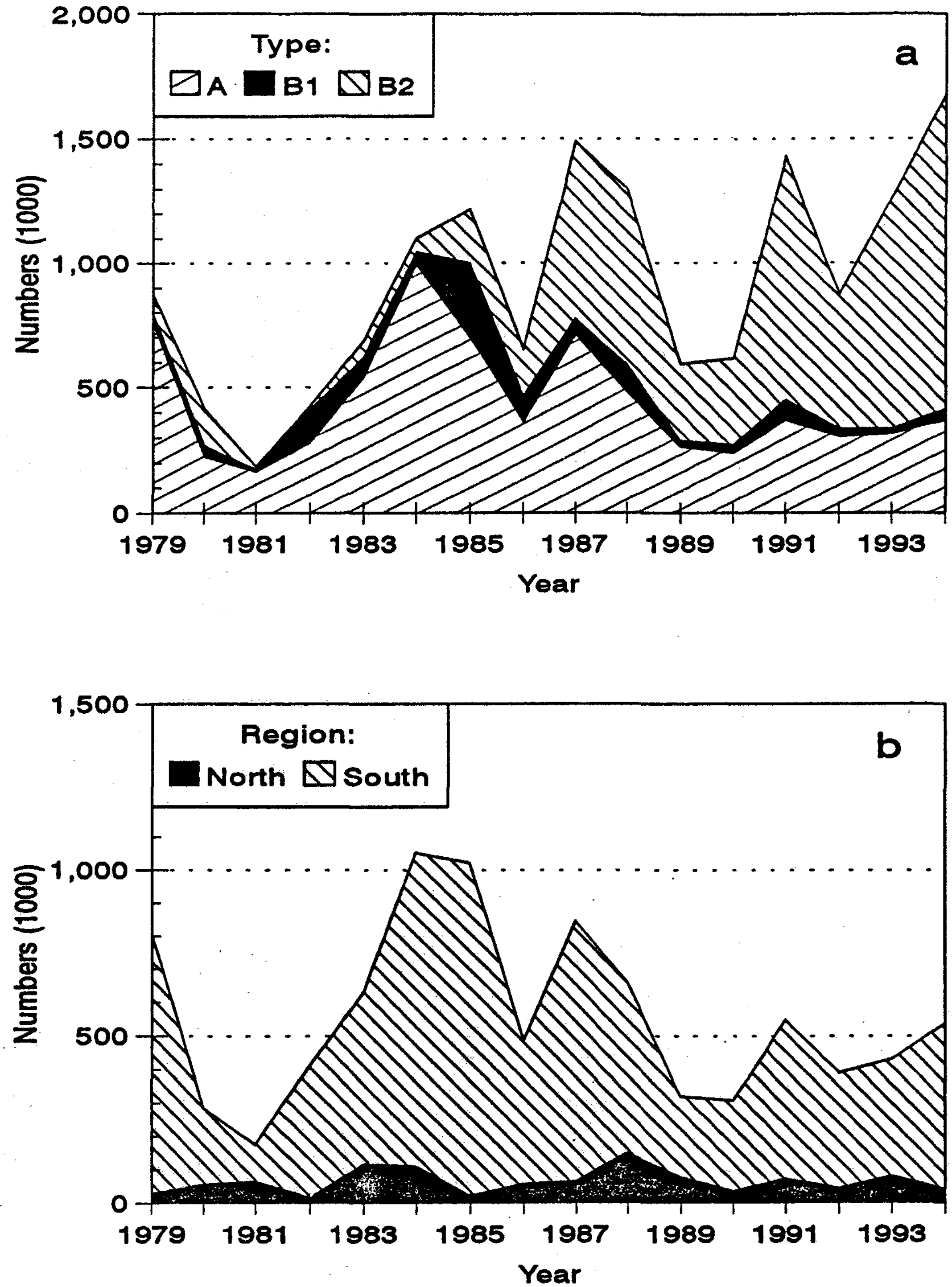


Figure 2. Atlantic red drum recreational catches in numbers by type (**a**: A, B1, B2) and by region (**b**: South, North), 1979-1994

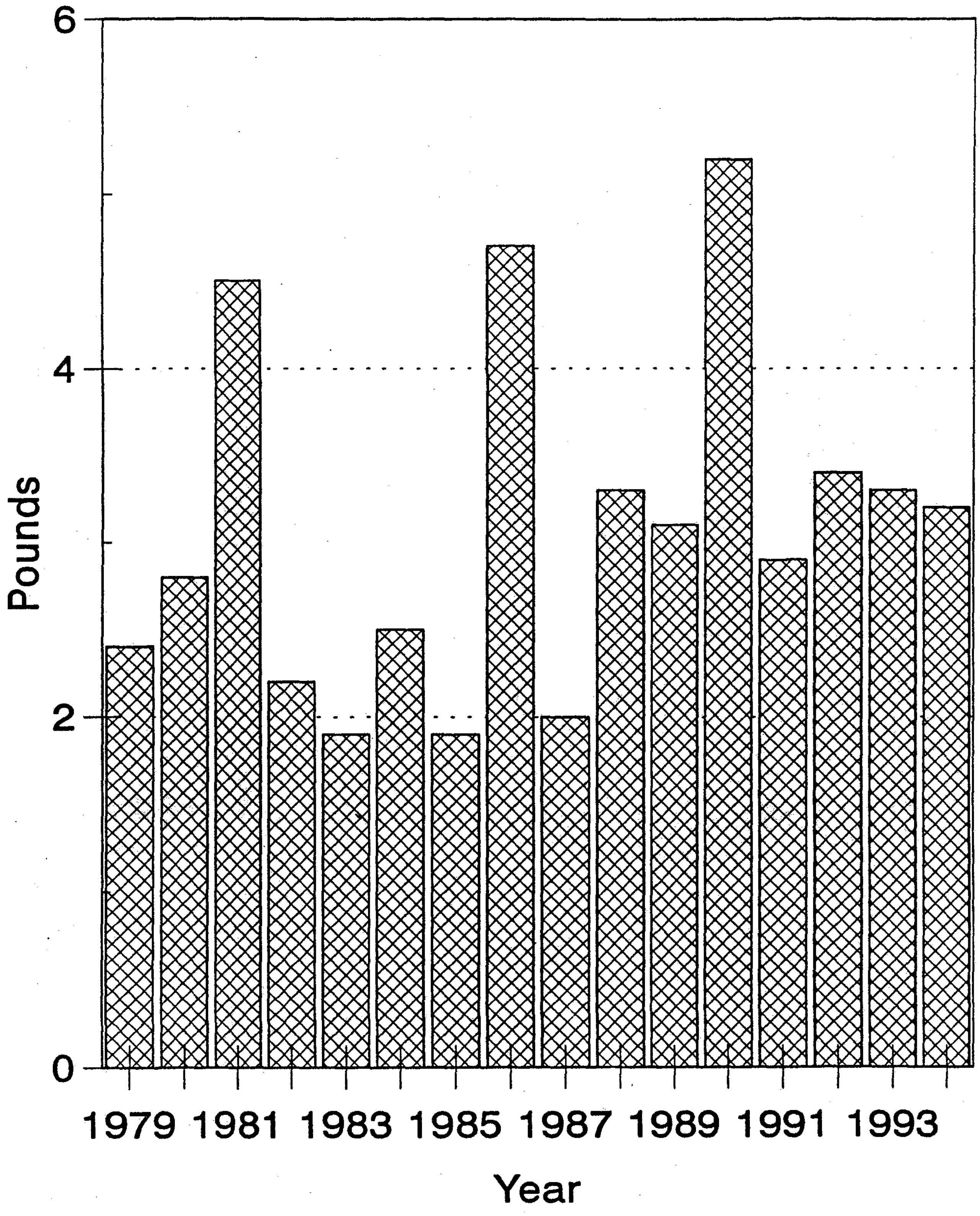


Figure 3. Mean weight of intercepted (type A) recreational caught Atlantic red drum, 1979-1994

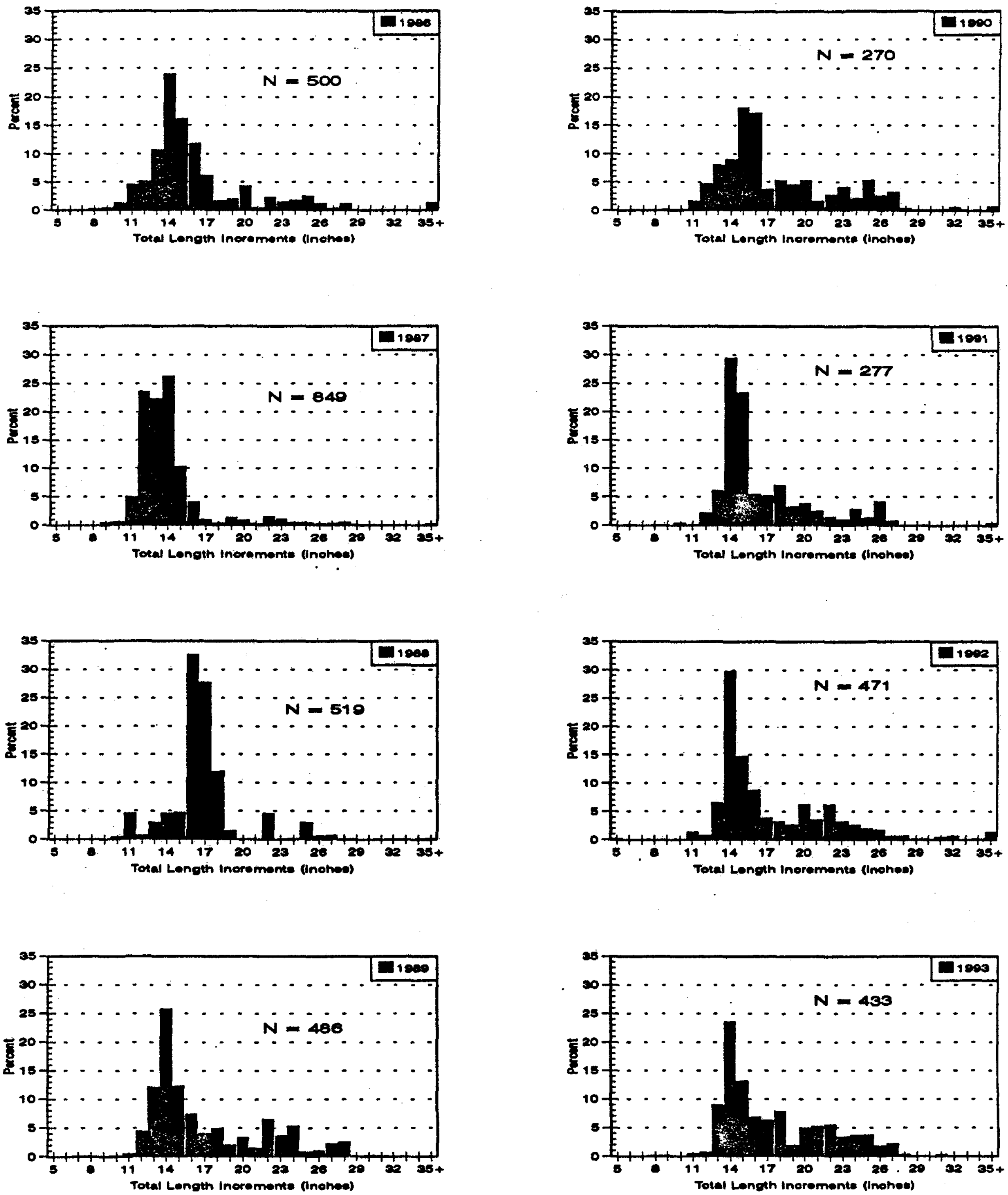
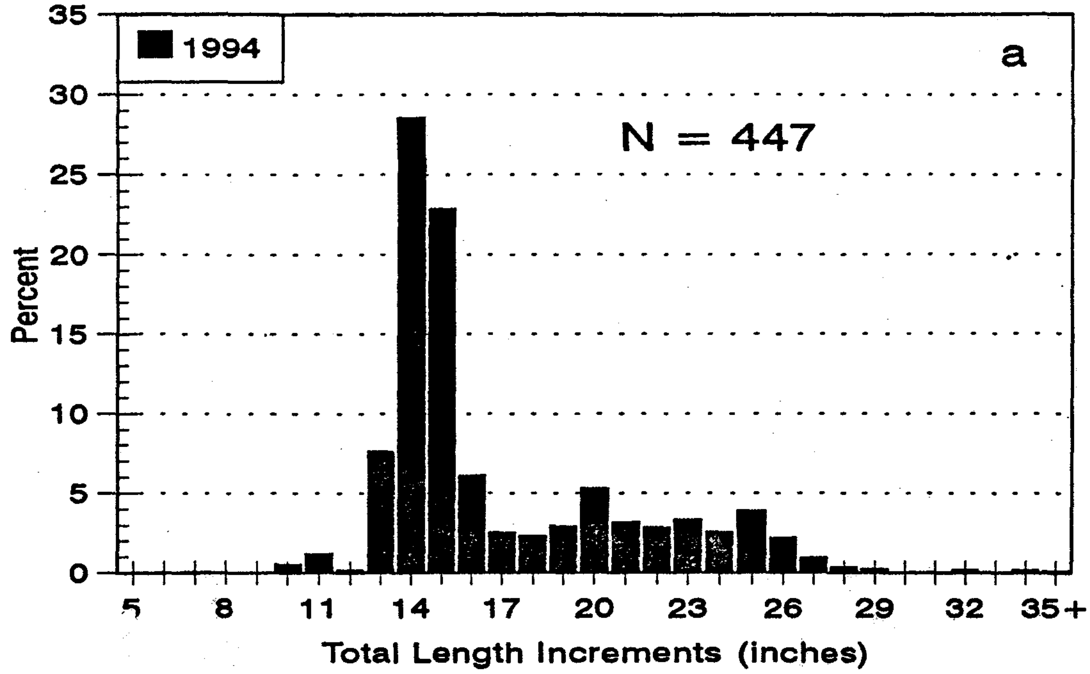


Figure 4. Length frequency distributions for intercepted recreational caught Atlantic red drum, 1986-1993.



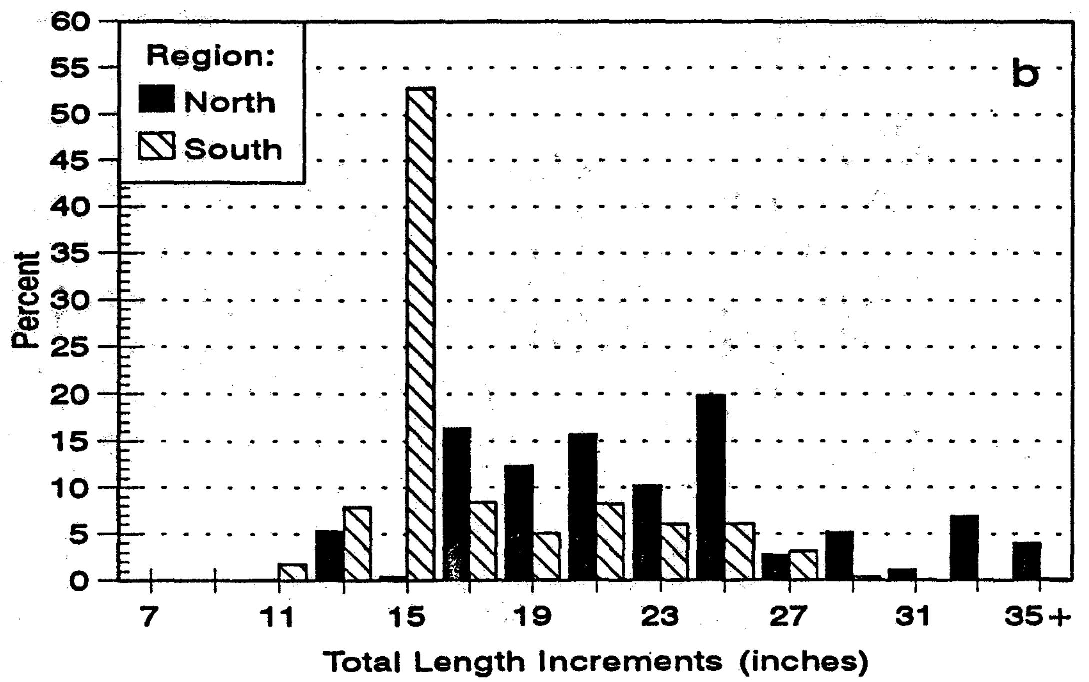


Figure 5. Length frequency distributions for intercepted recreational caught Atlantic red drum in 1994 coastwide (a) and by region (b: South, North).

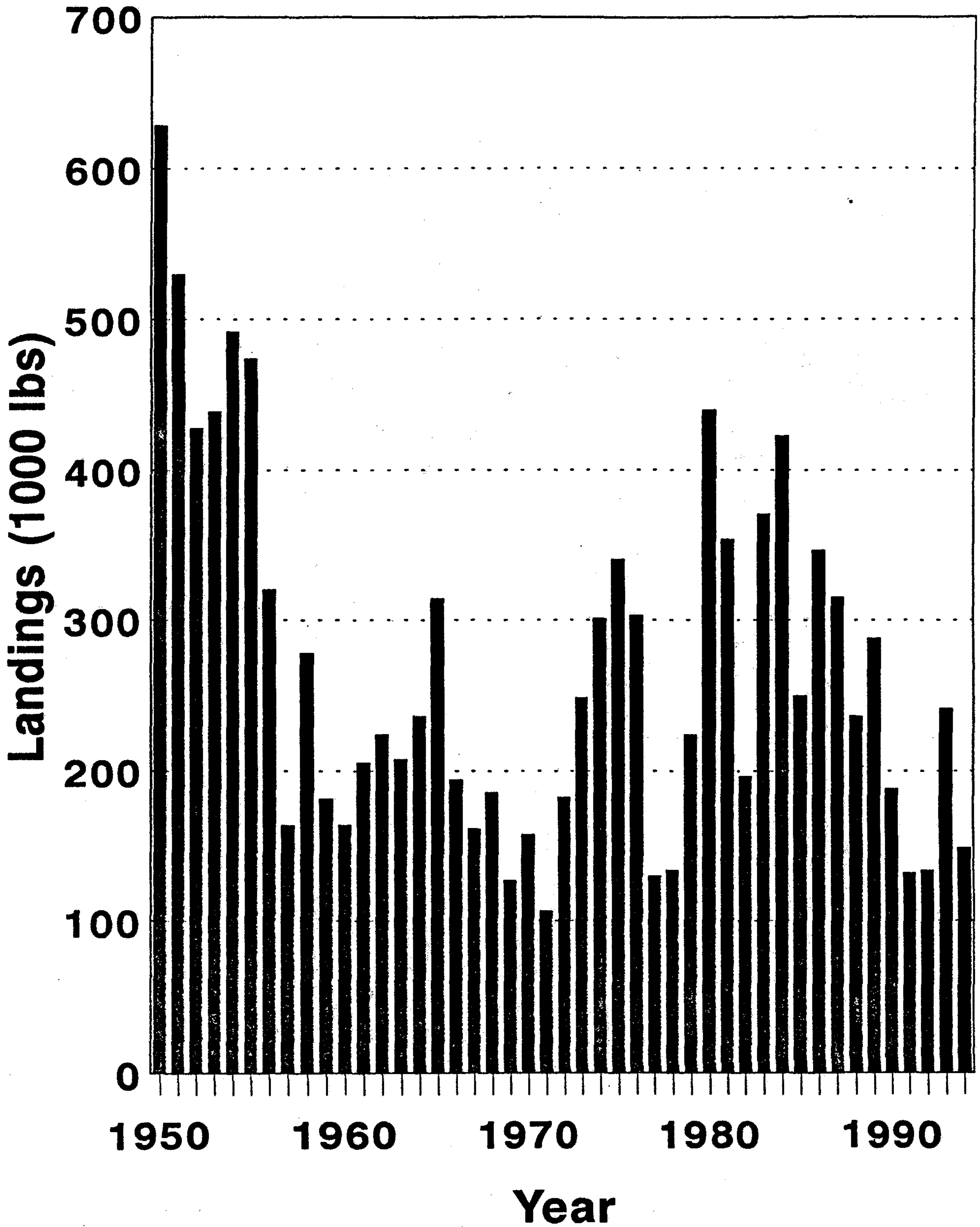


Figure 6. Atlantic red drum commercial landings in weight, 1950-1994.

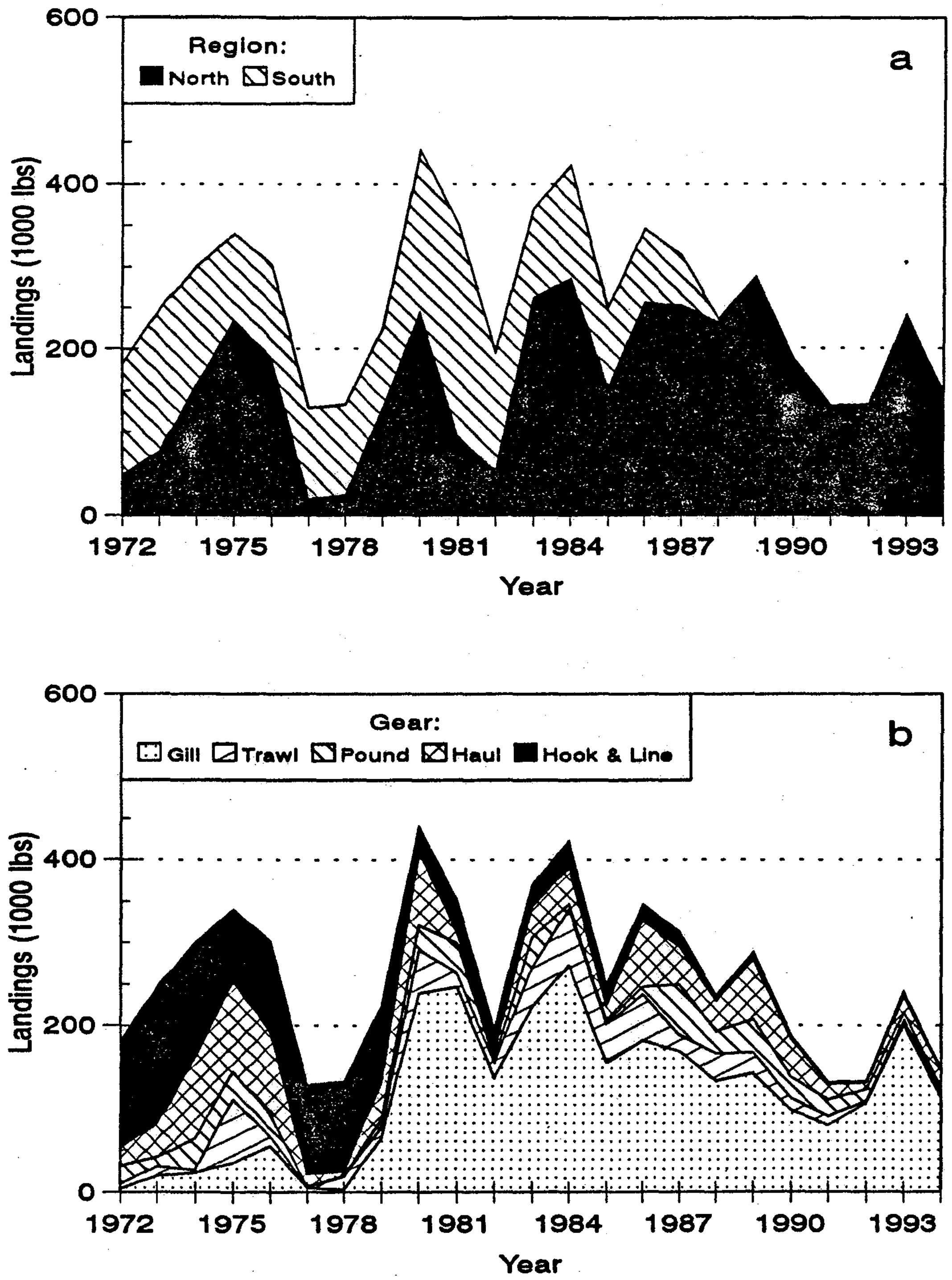


Figure 7. Atlantic red drum commercial landings in weight by region (**a**: South, North) and by gear (**b**: gillnet, haul seine, trawl, pound net, and hook & line), 1972-1994.

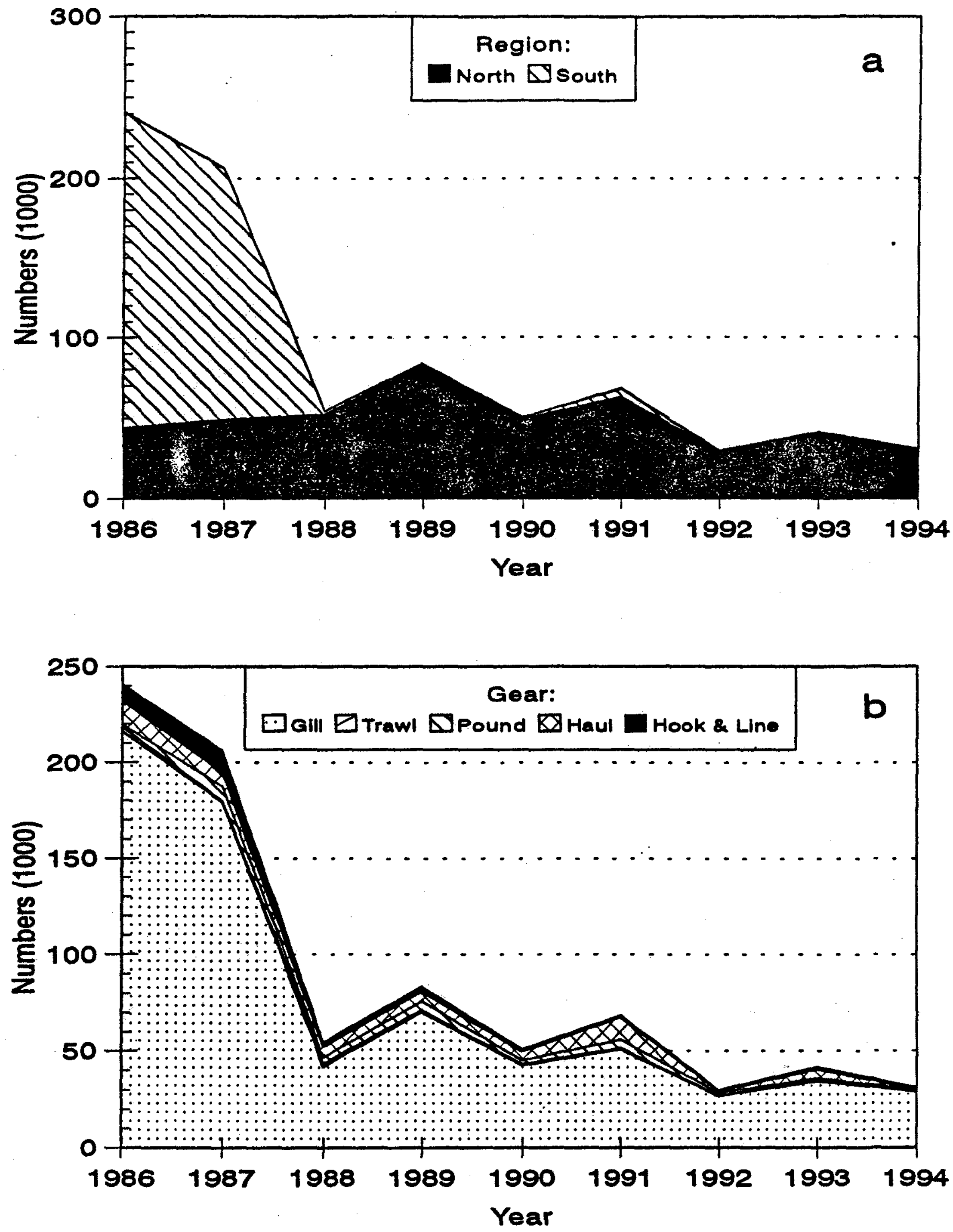


Figure 8. Atlantic red drum commercial landings in numbers by region (**a**: South, North) and by gear (**b**: gillnet, haul seine, trawl, pound net, and hook & line), 1986-1994.

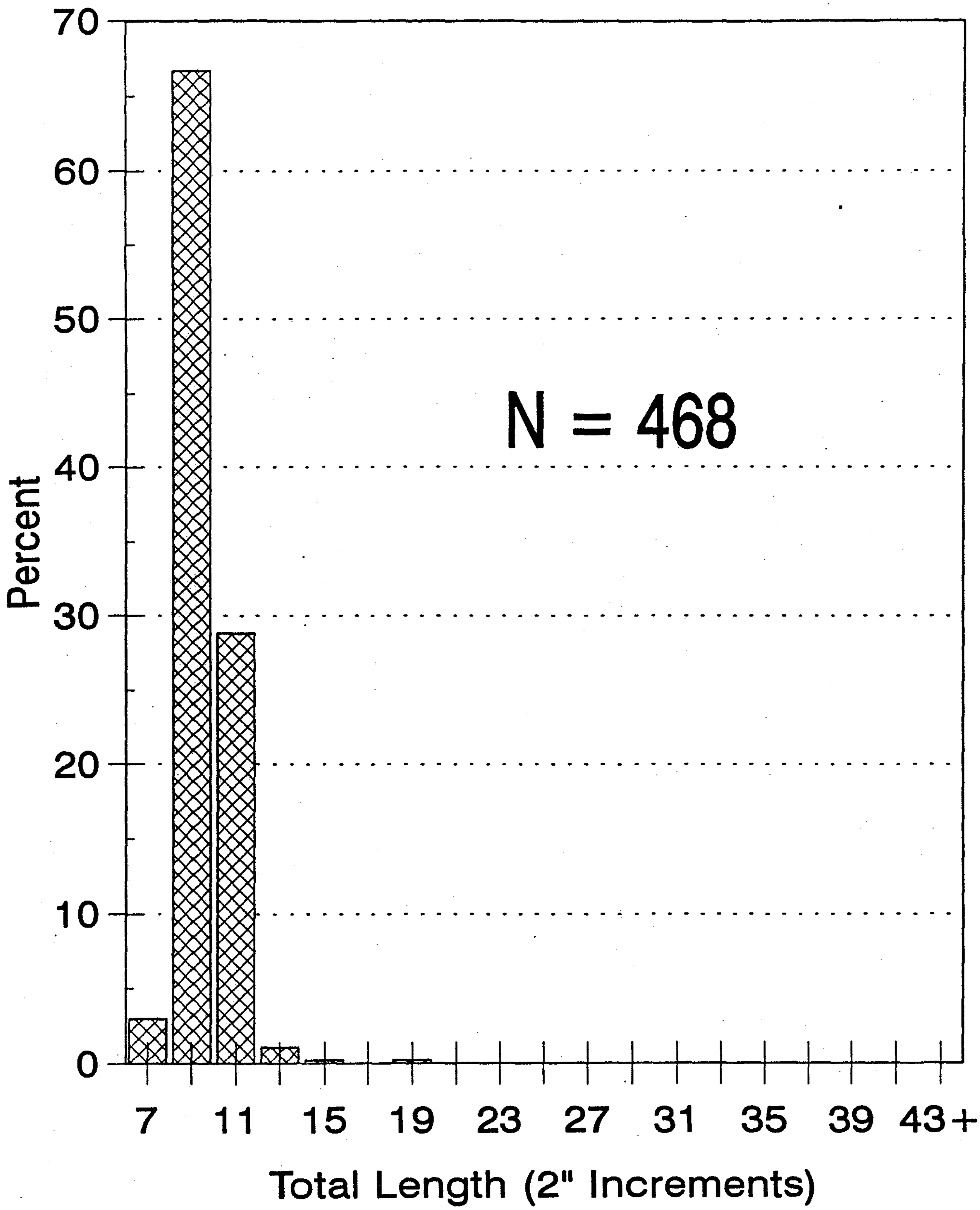


Figure 9. Georgia red drum gill net length frequency distribution combined over 1986-1988.

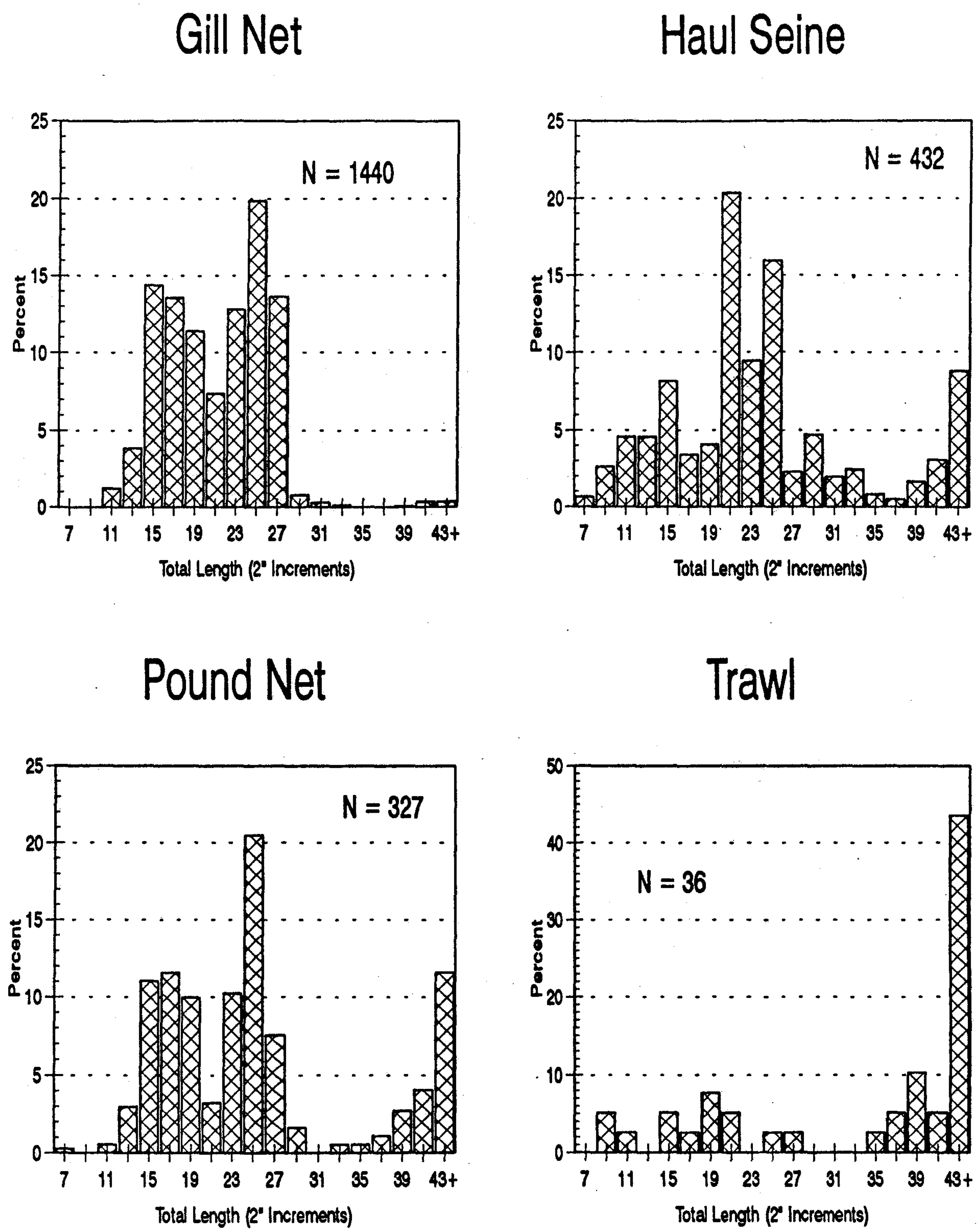


Figure 10. North Carolina red drum length frequency distributions by gear (gill net, haul seine, pound net, and trawl) combined over 1986-1993.

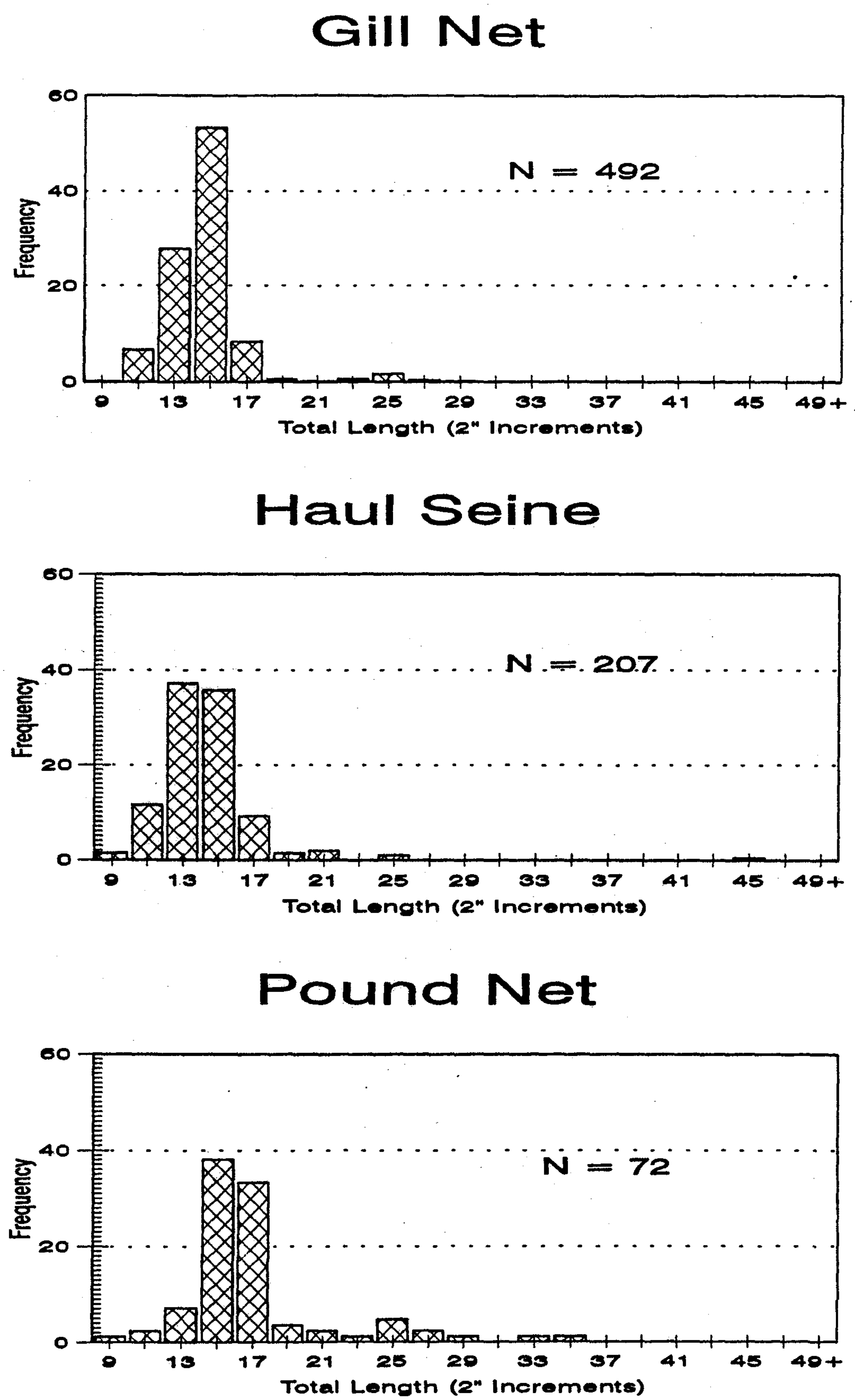


Figure 11. Virginia red drum length frequency distributions by gear (gill net, haul seine, and pound net) combined over 1989 and 1993.

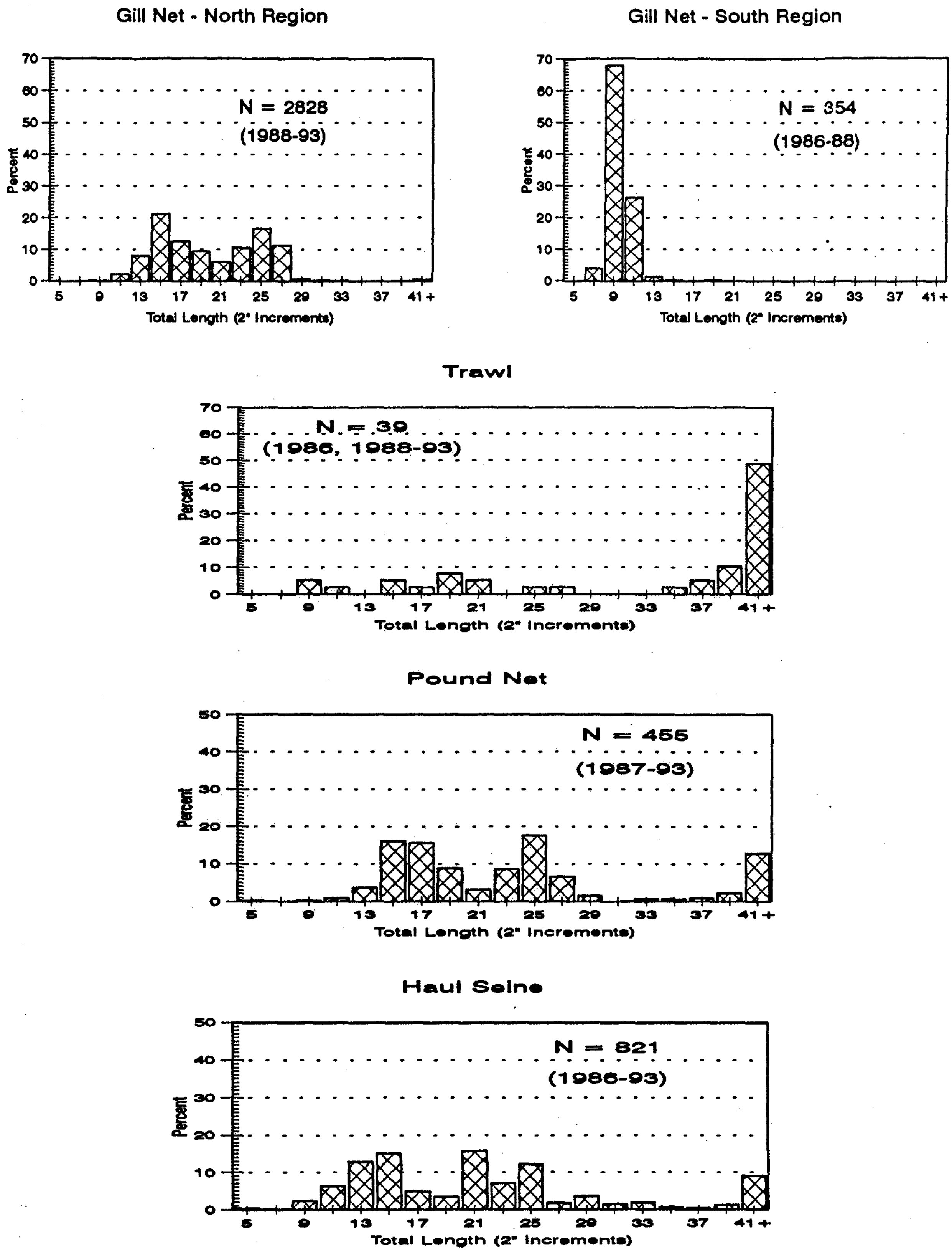


Figure 12. Commercial Atlantic red drum length frequency distributions by gear (gill net also by region) combined over 1986-1993.

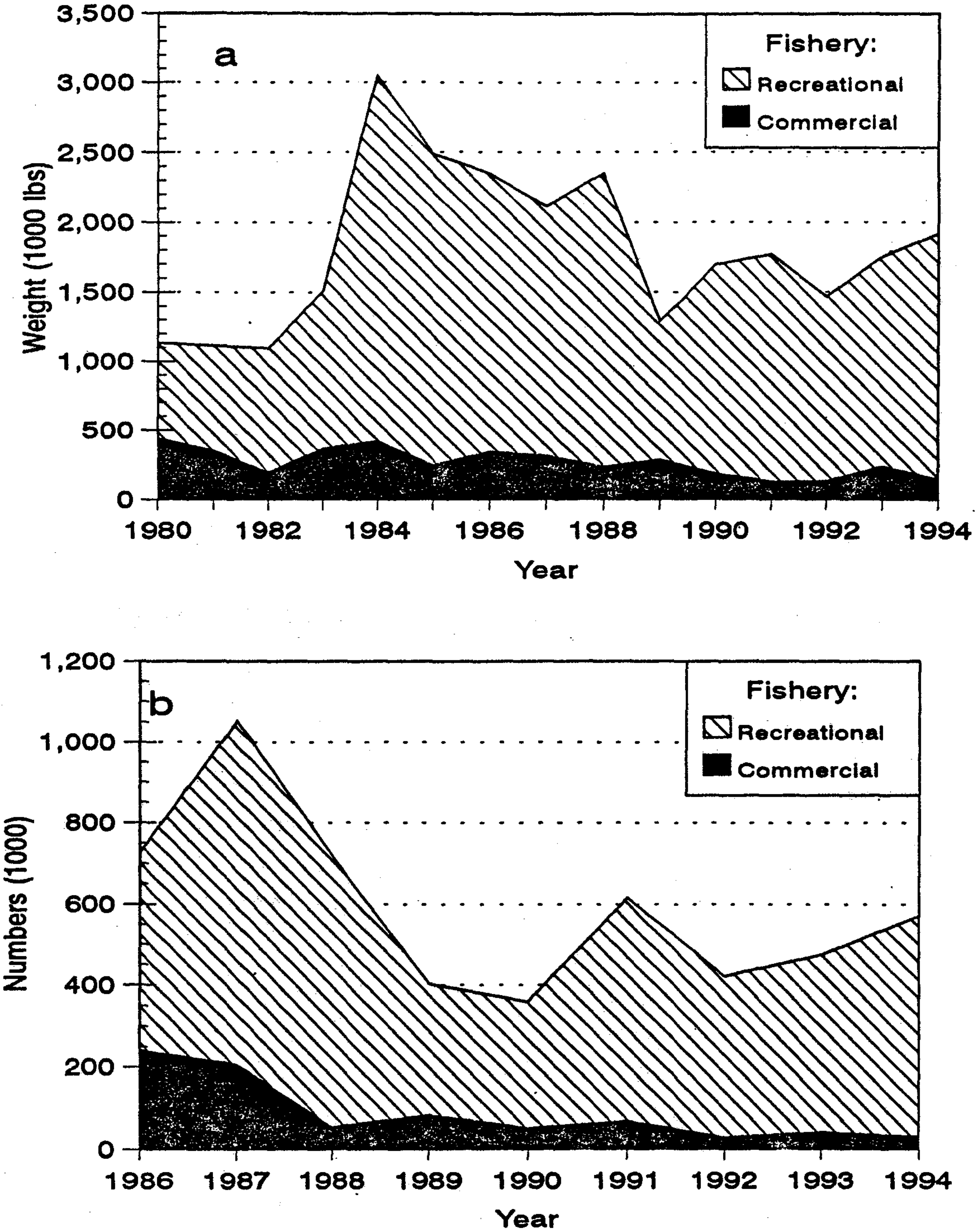


Figure 13. Total Atlantic red drum landings by fishery (recreational and commercial) in weight (1980-1991) and numbers (1986-1994).

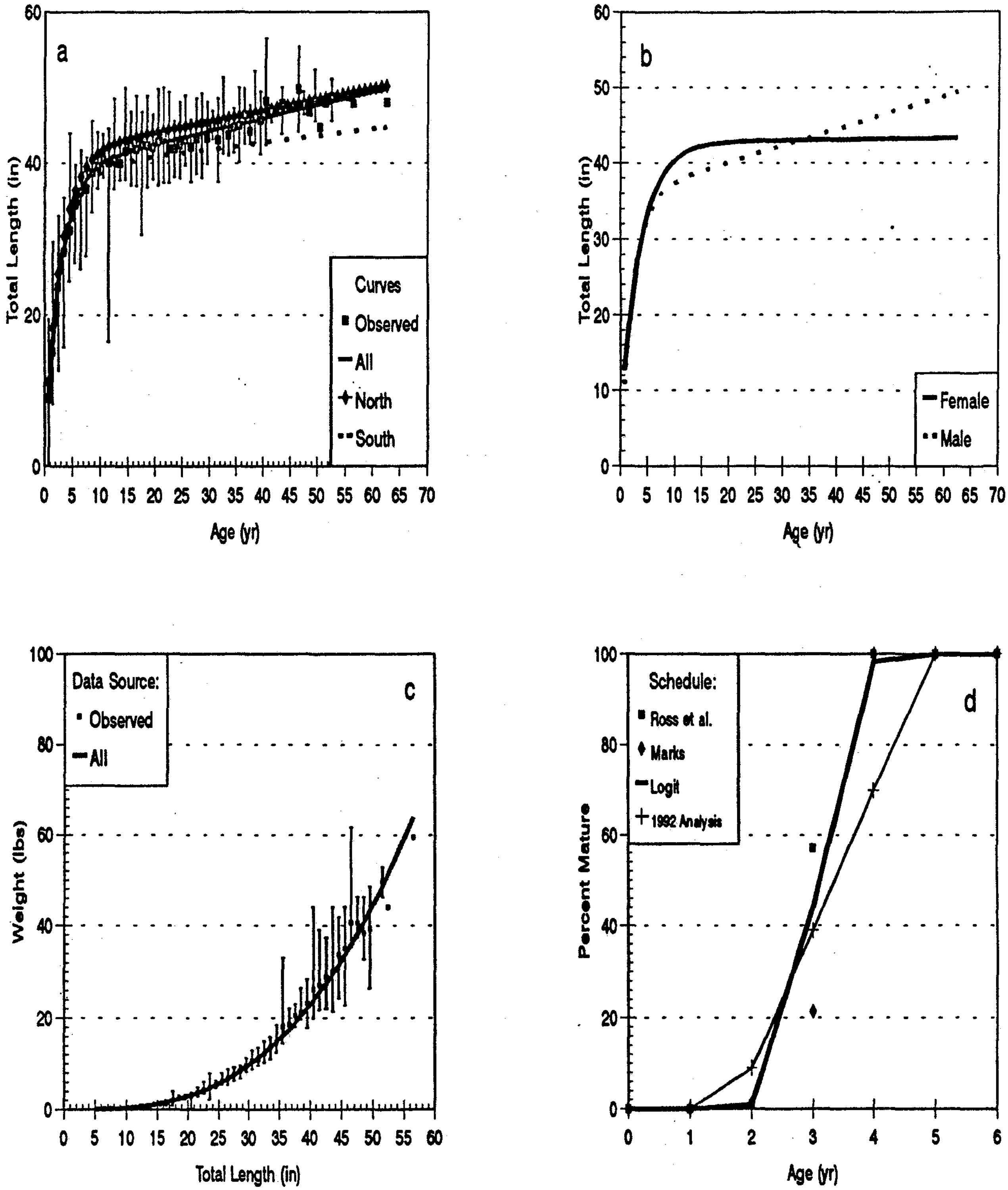


Figure 14. Atlantic red drum linear von Bertalanffy growth curves (**a**,**b**), overall weight-length relationship (**c**), and female maturity schedule (**d**). Growth curves compared overall and by region with range of observed data (**a**), and also between sexes (**b**).

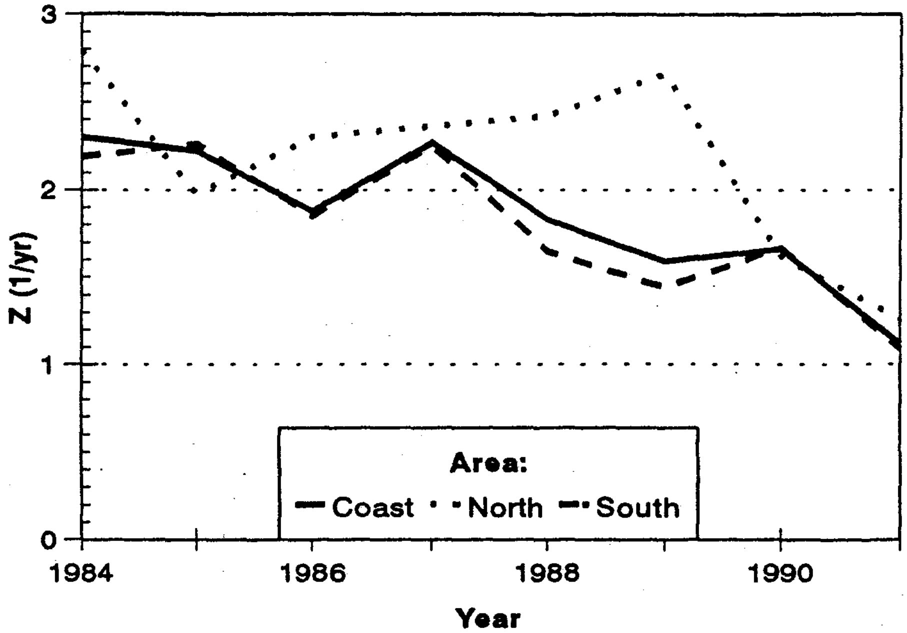


Figure 15. Region-specific catch curve estimates of instantaneous total mortality (Z) for Atlantic red drum, 1984-1991 cohorts.

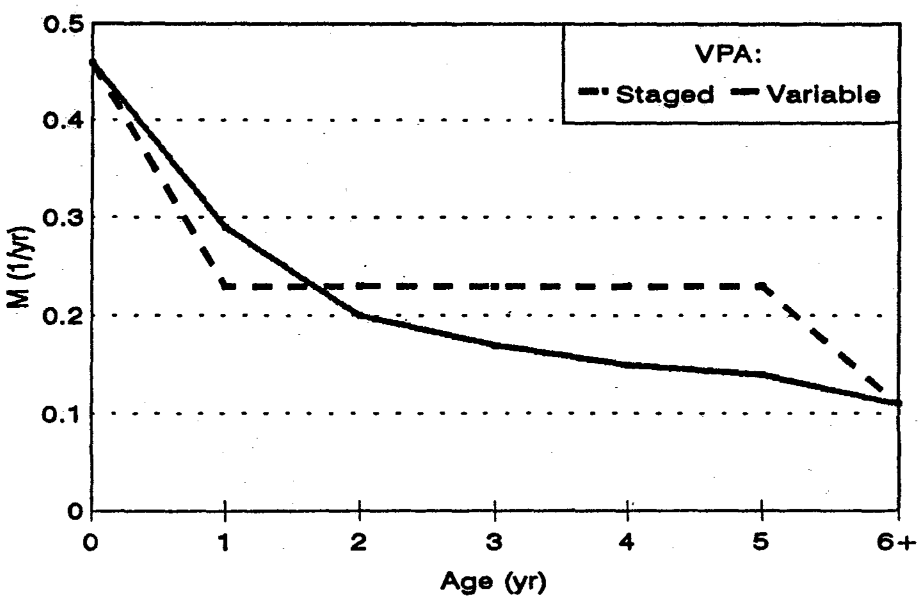
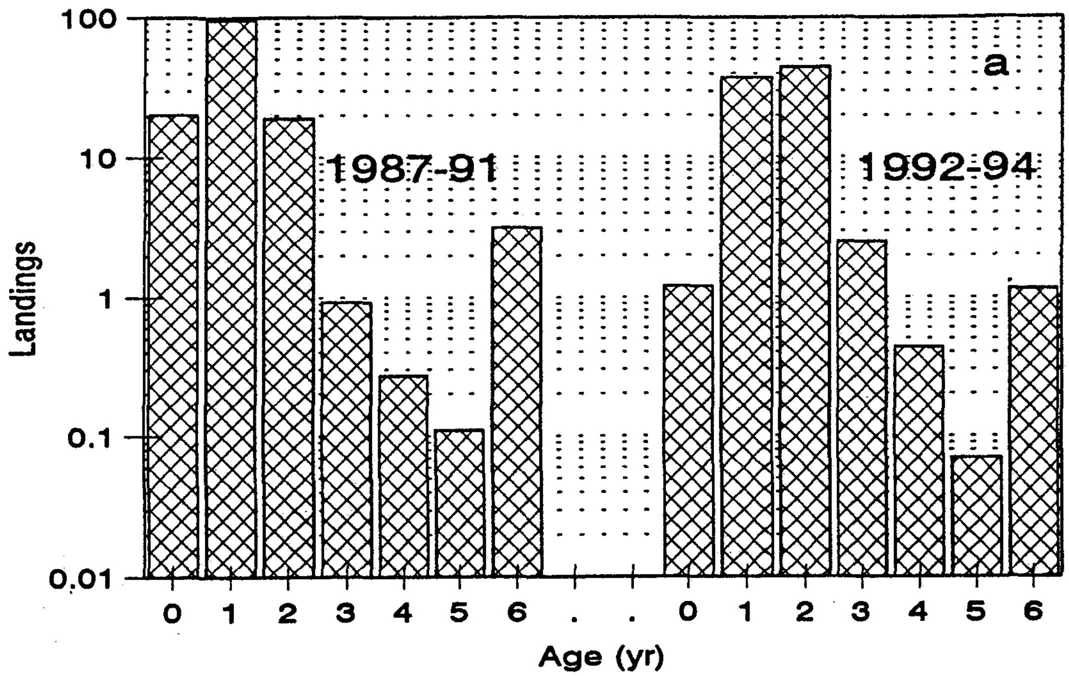


Figure 16. Estimates of age-specific instantaneous natural mortality rate, M, (variable, Boudreau and Dickie 1989) for ages 0 through 5 and 6+, and mean of subadult M used for ages 1 through 5 in separable VPA for Atlantic red drum (staged).



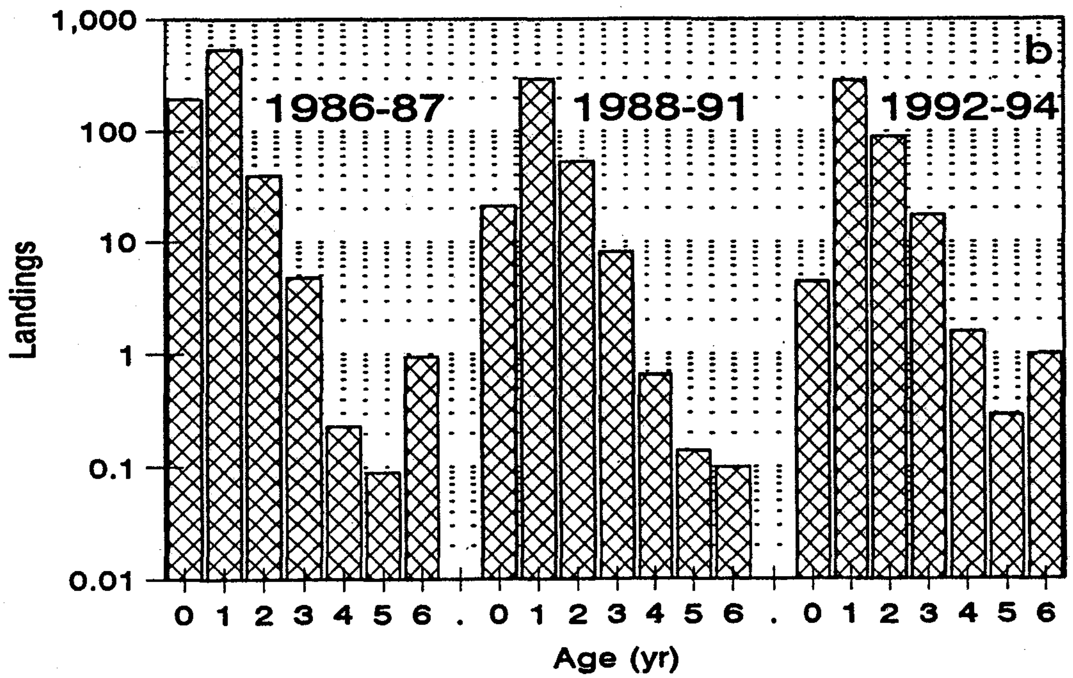


Figure 17. Catch curves of Atlantic red drum from regional catch matrices for different temporal periods: a) North and b) South.

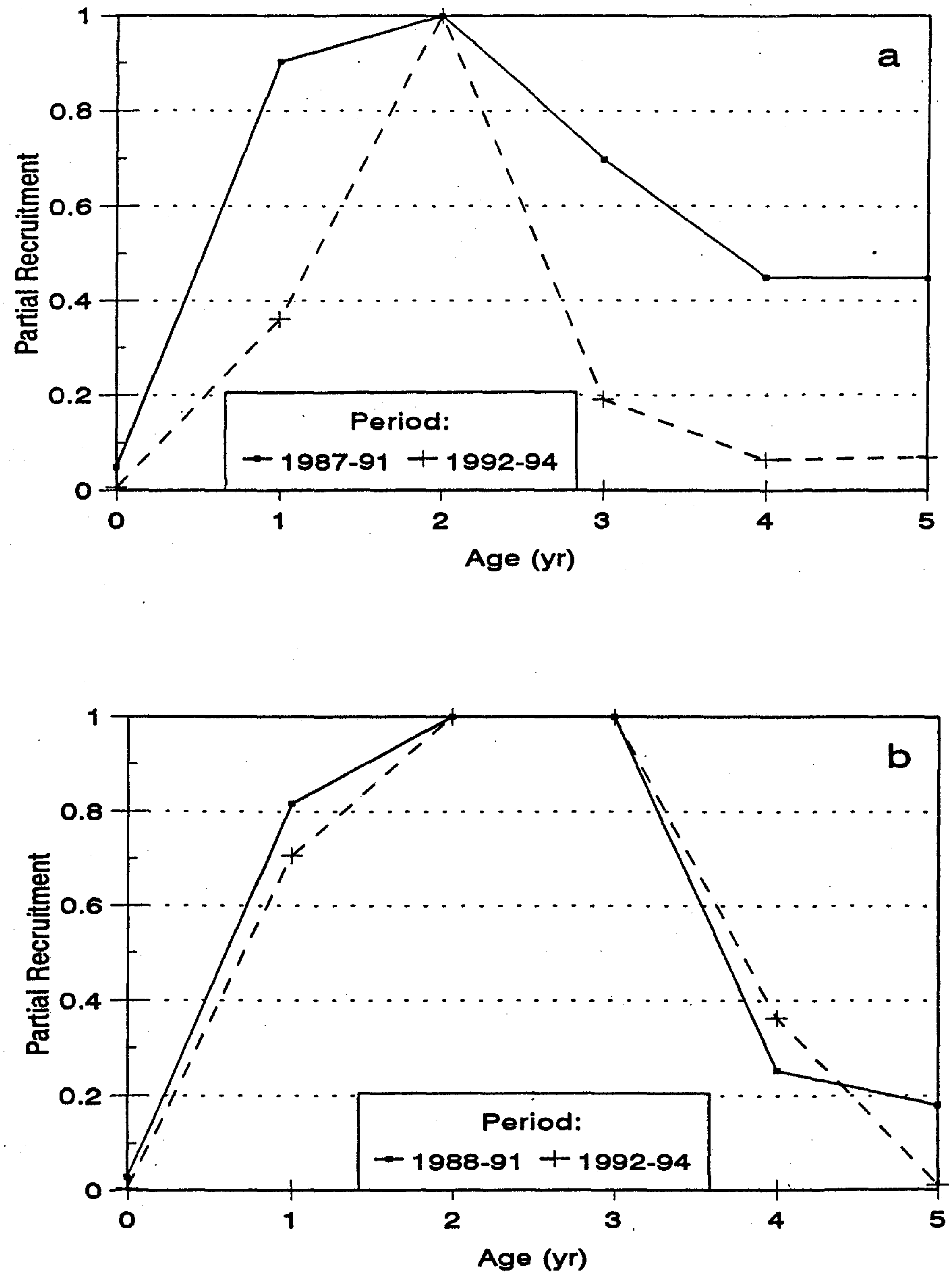


Figure 18. Partial recruitment for Atlantic red drum from separable virtual population analyses on regional catch matrices for pre- and post-management temporal periods: a) North and b) South.