NOAA TECHNICAL MEMORANDUM NMFS-SEFC-313

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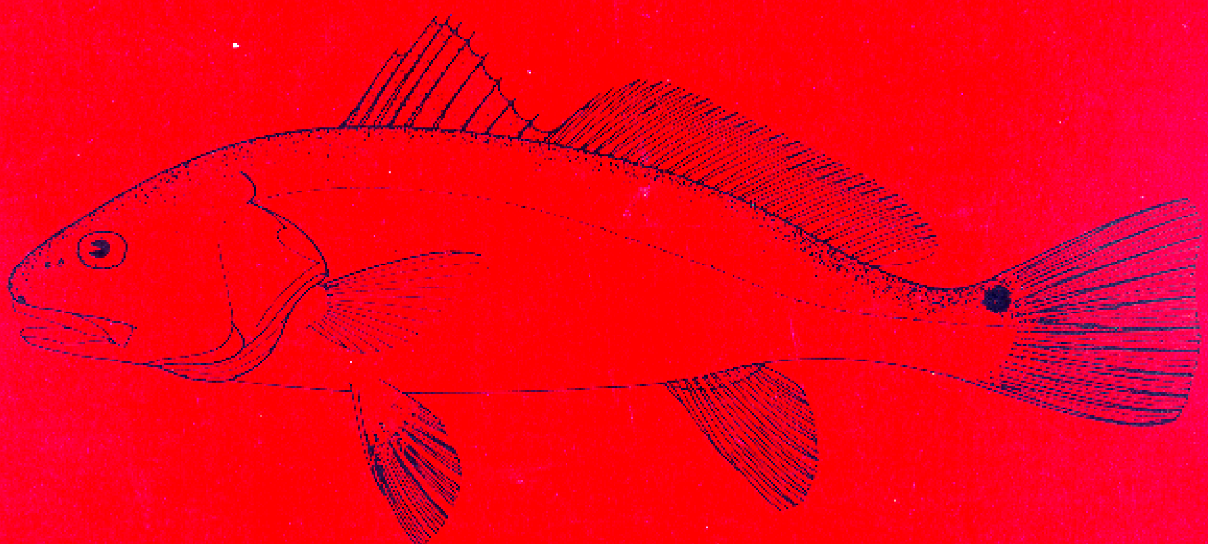

January 1993

U.S Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southeast Fisheries Science Center
Beaufort Laboratory
Beaufort, NC 28516-9722

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**Douglas S. Vaughan**

U.S DEPARTMENT OF COMMERCE
Barbara Hackman Franklin, Secretary
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
John A. Knauss, Administrator
NATIONAL MARINE FISHERIES SERVICE
William W. Fox, Jr., Assistant Administrator for Fisheries

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NOTICE



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National Marine Fisheries Service
Beaufort Laboratory
101 Pivers Island Road
Beaufort, NC 28516-9722

or

National Technical Information Service
5258 Port Royal Road
Springfield, VA 22161

**EXECUTIVE SUMMARY**

An assessment of the status of the Atlantic stock of red drum is conducted using recreational and commercial data from 1986 through 1991. This assessment updates data and analyses from the 1989 and 1991 stock assessments on Atlantic coast red drum (Vaughan and Helser 1990, Vaughan 1992). Since 1980, coastwide recreational catches ranged between 513,500 pounds in 1990 and 2,179,400 pounds in 1984, while commercial landings ranged between 127,800 pounds in 1991 and 439,900 pounds in 1980. In numbers of fish caught, Atlantic red drum constitute predominantly a recreational fishery (generally 87 to 94% 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 6, and maximum spawning potential [MSP, equivalent to spawning stock ratios (SSR) based on both female biomass and egg production].

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.

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) of no fishing mortality on adults (ages 6 and older), causes a bias that tends to result in underestimates of fishing mortality. Estimates of escapement range from 0.7 to 0.9% for M equal 0.23 and about 1.0% for M equal 0.46. Similarly, estimates of maximum spawning potential range from 0.6 to 1.1% for M equal 0.23 and 1.4 to 1.5% for M equal 0.46. These estimates are similar to those obtained in the 1991 stock assessment (Escapement: 0.4% for M = 0.3 and 0.8-1.5% for M = 0.5; and %MSP: 0.6-0.9% for M = 0.3 and and 1.4-2.4% for M = 0.5).

Management options were investigated including more recent data (generally 1986-1991). Recreational fishery data (MRFSS) are employed to investigate potential savings in numbers of fish, and subsequent improvements in escapement and maximum spawning potential, through bag and size limits. In general bag and size

limits are assumed to be applied only to the recreational fishery, and a 10% release mortality is introduced. Although not specifically considered, seasonal closures can easily be incorporated into this analysis.

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## INTRODUCTION

This, the third 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), and in Vaughan (1992) (referred to as the 1991 assessment) with one additional year of fishery data (1991). Following submission of the 1989 assessment to the South Atlantic Fishery Management Council, three management measures were adopted by the Council in the Atlantic Red Drum Fishery Management Plan (SAFMC 1990b). The first management measure establishes the fishing year from January 1 through December 31. The second management measure requires that 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."

In addition to new fishing data for 1991 (including commercial length frequency data from Virginia and age-length data from Florida), a number of changes in approach have been made to the 1991 stock assessment. Corrections to data include commercial landings from Virginia and age-length data from Georgia. Additions to data for the period 1986-90 include commercial length frequency data from Virginia for 1989 and age-length data from Florida for 1987-89. Additional data from different commercial gears permit all major gears to be treated separately, rather than grouped as in previous assessments. A linear von Bertalanffy growth curve is used rather than the double von Bertalanffy growth curve. Updated total length-fork length, weight-length and age-total length relationships are developed.

## DESCRIPTION OF THE DATA

Recreational landings and length frequency information were obtained from 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

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 caught fish for which direct measurements are available. Catch in weight includes 10% of the catch-release (type B2) fish catch using the mean weight of the type A fish. This may tend to overestimate the weight loss from catches of type B2 red drum, but the use in this assessment is solely for comparing recreational with commercial catches in weight.

As in the earlier reports, 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 Florida. Recreational landings generally are much 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 caught red drum in recent years (especially 1987, 1988, and 1991) (Fig. 2a). Hence, 10% of the type B2 caught 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 assessment. Catch in numbers by region further emphasize the importance for the South Region compared to the North

Region. The mean weight of type A red drum show no particular trend (Fig. 3), averaging about 2.6 pounds between 1979 and 1991.

Recreational length frequency distributions are summarized annually in 1" increments from 1979-1990 (Fig. 4). The length frequency distribution for 1991 (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 1986-91 are applied to corresponding catch estimates (and single annual age-length key) to estimate catch in numbers at age by region (same as in 1989 and 1991 stock assessments). The relatively small number of intercepts in recent years (222 in 1990 and 277 in 1991) raise concerns about the adequacy of the MRFSS intercept data base to represent the size frequency of the recreational catch (specifically for ages 0-5 used in virtual population analysis).

**Commercial Fishery Data**

Historical commercial landings in weight are summarized for years 1950-1990 (Fig. 6). Landings prior to 1980 are from SAFMC (1990a; Table 22), and landings for years 1980-1991 are shown in Table 1. Landings were high during the early 1950's (exceeding 400,000 pounds), and have generally fluctuated between 200,000 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 26% in 1981 to 98% in 1990 by weight), except in 1981 and 1982 when 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, 45% and 17% of the commercial landings by weight, respectively, were from Virginia; otherwise the contribution of landings from this state ranged from 0.1 to 2.9%. As reported in the previous assessments, North Carolina's commercial fishery for red drum is largely a bycatch fishery.

Unlike earlier assessments, where inadequate commercial length sampling data resulted in artificial groupings of gears, commercial gears have been expanded into five gear groupings (gill net, haul seine, trawl, pound net, and hook & line). Landings for these categories are shown in Fig. 7b. Through most of the 1980's, landings from gill nets dominated the commercial landings (59% of the landings by weight for the period 1980-91). Haul seines contributed about 14% of the landings during this period, trawls contributed about 12%, pound nets about 8%, and hook & lines about 7%. In 1991, gill nets made up 61% of the landings, 14% for haul seines, 9% for trawls, 13% for pound nets, and 3% 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 landed by gill net in the South Region (Fig. 8a). This is further reflected in the the gear comparison (Fig. 8b). Landings in the North Region have been generally consistent 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 1988-91, gill nets in the South Region for 1986-88, haul seines coastwide for 1989-91, and pound nets coastwide for 1987-91. 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).

In the 1991 stock assessment, all lengths were converted to total length in millimeters based on equations in Murphy and Taylor (1990). This was necessary for North Carolina and Georgia whose data were in fork length. New data provided by Murphy (FL DNR; 1987-89 and 1991) allow this relationship to be updated.

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 in 1984, declined through 1990, and rose in 1991; largely due to changes in recreational landings in weight (Fig. 13a). Since 1986, combined landings in numbers peaked in 1987, declined through 1990, and also rose in 1991 (Fig. 13b).

## STOCK CHARACTERIZATION

Aspects of the biology of red drum can be found in the Atlantic Coast Red Drum Fishery Management Plan (SAFMC 1990b). Herein, updated biological information that was not included in SAFMC (1990b) or in the 1989 and 1991 stock assessments is reported along with aspects of red drum biology relevent 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 sub-adults 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 Pafford et al. (1990), Wenner et al. (1990), and Ross and Stevens (1989). 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:

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

where $L_t$ is length at age t, and $L_{inf}$, 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, 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 1986-91 data set resulting in the following parameter estimates: $L_{inf}$ = 46.2" TL, $k_1$ = 0.41 $yr^{-1}$, $k_2$ = 0.08 $yr^{-1}$, $t_{01}$ = -0.04 yr, and $t_{02}$ = -13.67 yr.

More recently another model has been found to better represent the growth dynamics of red drum (developed by Geaghan at LSU and referenced in Hoese et al. 1991). This model assumes that $L_{inf}$ in the regular 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,

$$L_{inf} = b_0 + b_1 * t, \quad (2)$$

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)].

Age-length data sets were available during 1986-1991 from Florida Department of Natural Resources (64 fish from 1987-89 and 1991), Georgia Department of Natural Resources (1380 fish from 1988-91), South Carolina Wildlife and Marine Resources Division (7991 fish from 1986-91), and North Carolina Division of Marine Fisheries (1094 fish from 1988-91), with the preponderence of specimens being ages 0 to 3 (10470 out of 11359 fish or 92%). A weighting scheme to decrease the impact of these young fish on the regression results is used such that for ages 0 through 5 a weight based on the inverse of the sample size for that age is used.

Regression fits using both the 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 coastwide model for 1986-91 are used in later population analyses to represent the growth of red drum during the period 1986-1991. As tested statistically in the 1989 stock assessment report for the single von Bertalanffy growth equation, there is no significant difference in growth apparent between female and male red drum based on the linear von Bertalanffy growth curves (Fig. 14b).

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 age-length keys were developed directly for 1986 and 1991 (overall in Table 3). Total length is divided into 2" increments from 7" (6"-8") to 43" (42" 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 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 1986-1991 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.

**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 1981-91 supplied by FL DNR (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.

Also, total lengths were converted to weight when calculating mean weight of fish by commercial gear and year, and for calculating spawning stock biomass. The weight (lbs)-total length (in) relationships based on the state-provided aged data for years 1986-1991 is used in subsequent analyses in favor of the MRFSS-based weight-length relationship used in the earlier 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 South Carolina and North Carolina is combined to produce a mean female maturity schedule representative of the period 1985-1991 (Fig. 14d). Hence a single maturity schedule is used in the maximum spawning potential estimates presented in this assessment. Female red drum are immature at age 1 and younger, 9% female red drum are mature at age 2, 39% female mature at age 3, 70% female mature at age 4, and all female red drum are mature at age 5 and older. There is concern over the adequacy of sampling that obtained the fish used in determining maturity (Wenner, pers. comm.). However, when two widely different maturity schedules were used in the 1989 stock assessment, they yielded very similar results (e.g., %MSP).

In general the spawning season for red drum (August through October, SAFMC 1990a) 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):

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

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.

Hoenig et al. (1987) suggest a length-based method for estimating total instantaneous mortality rate Z. It is based on the mean or median length of fish exceeding the modal length increment and estimated parameters $L_{inf}$ and k from the von Bertalanffy growth equation. Using MRFSS length data, estimates of Z based on mean lengths tend to be lower than those based on median lengths (Fig. 15a). Estimates of Z based on means range between 0.5 in 1990 and 1.0 in 1985; while estimates of Z based on medians range between 0.8 in 1991 and 1.6 in 1987. In general, no obvious trend is noted.

Estimates of Z are more often 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, recruitment and mortality is not constant from year to year.

Rates of instantaneous total mortality (Z) are estimated from the annual catch curves using the MRFSS data (1980-1991) for ages 1 through 3 (Fig. 15b). These estimates assume that recruitment to the fishery is complete by age 1, and that the recreational fishery is representative of the population from that age through age 3 (Table 6). Estimates of Z range between 1.0 in 1981 to 2.5 in 1985. These estimates are higher than those produced from the same MRFSS data set using the length-based approach (based on either mean or median lengths). Because these are based on catch in numbers at age within individual fishing years, the assumption of constant recruitment is necessary.

Similar estimates of Z are made from the annual catch in numbers at age data that combine the recreational and commercial estimates (1986-1991). These estimates of Z range from 1.5 in 1989 (ages 1-3) to 2.4 in 1986 (ages 1-3).

Additional coastwide estimates of Z are obtained from the combined fisheries catch at age data (1984-1989 year classes) by following a single year class or cohort through age 3. This approach does not require the assumption of constant recruitment, but does assume constant fishing mortality at age for the ages and years included in the catch curve. Estimates of Z range from 0.8 for the 1989 year class (ages 1-2) to 2.1 for the 1987 year class (ages 1-3).

**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 since older fish exhibit emigration or reduced availability to capture by the gear. Z becomes the sum of M, F and E (losses due to emigration or other reasons) (i.e.; $Z = M+F'+E$, where $F'<F$). 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 ($L_{inf}$ 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). Estimates of the instantaneous rate of natural mortality for the subadults ($M_1$) and adults ($M_2$) were 0.6 and 0.2, respectively. An estimate of M (assumed constant over all ages), based on Hoenig (1983), with a maximum age 55 for an unfished stock, suggests M equals 0.075.

Neither of the above estimates for subadult natural mortality seem reasonable (nor the adult natural mortality from Pauly's method). Goodyear (1989) 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. This last estimate appears to be a more reasonable estimate of subadult natural mortality than 0.075 or 0.6.

## Virtual Population Analysis

Application of two types of virtual population analysis (VPA) is made to the catch in numbers at age matrix for ages 0 to 5 and years 1986 to 1991. Application is made of VPA techniques to only the subadult population (ages 0-5) and not to the adult population (ages greater than age 5) because sufficient data on the exploitation of older fish is currently unavailable. Both VPA techniques (Murphy 1965 and Doubleday 1976) require estimates of natural mortality (on subadults) and a starting value of a particular age-specific fishing mortality rate.

Application of both types of virtual population analysis requires adequate estimates of catch in numbers at age. This depends primarily on the adequacy of length frequency distributions and age-length keys. 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 first type of virtual population analysis conducted uses the approach based on Murphy (1965) and uses the individual age-specific estimates of $M_1$ (ages 0-5) for subadults based on Boudreau and Dickie (1989). As in the earlier stock assessments, age 3 is used as a pivotal age about which backward and forward calculations are made. Although backward calculations tend to converge towards more accurate estimates of age specific F and population numbers, forward calculations tend to diverge. The cohort-based catch curve estimates of Z (year classes 1984-1989 in Table 6) are used to start the VPA for year classes 1984-1987 (F = Z - M with M = 0.17 at age 3). Mean age specific F for these analyses are summarized in Table 7 under the column labeled 'Variable M Murphy', because separate estimates of M are used for each age 0 through 5 (Fig. 16).

The second type of virtual population analysis used is based on a separability assumption described in Doubleday (1976). This method assumes that age- and year-specific F can be partitioned or 'separable' into the product of an age component and a year component. Clay (1990) developed a Fortran program based on separable VPA as described in Pope and Shepherd (1982). This computer program was applied to catch at age data for ages 0 to 5 from 1986-1991 with two levels of natural mortality for subadults (0.23 and 0.46). The ASMFC Technical Review Committee recommended adjusting partial recruitment for age 5 to force F for ages 2 and 3 to be equal (Fig. 17a). Starting F is based on a Z of 1.72 (mortality from 1988 year class - age 1 in 1989, age 2 in 1990 and age 3 in 1991; Table 6). Mean age specific F for these sets of Separable VPA with two levels of subadult M are summarized in Table 7 under the columns labelled 'Separable' and 'Coastal'. Similar estimates of partial recruitment at age were obtained for both estimates of M used (Fig. 17a). These vectors suggest increasing reduction in availability at ages 4 (41-44% of age 2) and 5 (15-21% of age 2). These estimates of reduced availability may be indicative of offshore movements. With the assumption that F for ages 2 and 3 are equal, F for age 1 is about 97% of the F for those two ages.

Similar separable virtual population analyses were conducted on the catch matrices from the North and South Regions (Fig. 17b). But with differing results. For the North Region, F for ages 2 and 3 were set equal by adjusting the partial recruitment for age 5. A smaller reduction in F for ages 4 and 5 compared to age 2 is noted for the North Region to the coastwide analysis (72% and 33%, respectively). However, F for ages 2 and 3 are about 69% below estimated F for age 1. For the South Region, F for ages 2 and 3 were set equal by adjusting the partial recruitment for age 5. A much greater reduction in availability at ages 4 and 5 is suggested (F on age 4 is 7% of F for age 2, and F for age 5 is 1% of F for age 5). This is largely dependent on the lack of ages 4 and 5 estimated for the 1991 catches. When the separable VPA is applied to the catch matrix for 1986-90, estimates of F for ages 4 and 5 are not so reduced compared to age 2 (26% and 6%, respectively), though still more than for the coastwide analysis. For 1986-91, estimated F for age 1 is approximately 87% of that for ages 2 and 3. But for 1986-90, F for age 1 is about 0.1% higher than for ages 2 and 3, suggesting equal availability for these three ages.

Annual coastwide results from three virtual population analyses (1 Murphy and 2 Separable) are compared with respect to estimates of recruitment to age 1 and age specific estimates of F (Fig. 18). Recruitment to age 1 was relatively high during 1986-1987 (670,000 to 870,000 recruits). The lower estimates of recruitment in 1991 (290,000 to 340,000 recruits) are more sensitive to the starting values used in the VPA process. Age specific estimates of F follow the pattern of partial recruitment and are generally low on age 0 red drum (only partially recruited), high on ages 1-3 (generally fully recruited), declining for age 4, and low for age 5.

## 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 6 to address whether there is adequate survival through the subadult phase; 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 1990b). 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 continuing viability of the coastwide stock 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 overall linear von Bertalanffy growth equation (Table 2), the overall state weight-length relationship (Table 5), and age-specific fishing mortality rates (F) (Table 7).

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 double von Bertalanffy growth function accurately describes individual growth during the exploited phase (subadult), (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. However, since the form that much of the uncertainty in our application of yield per recruit is itself unknown (especially with respect to potential bias), 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.

Yield per recruit (Y/R) increases with age at entry to the fishery until about age 3, and then declines through age 5 (Fig. 19a). Values for the current age at entry (age 0) and level of fishing mortality are summarized in Table 7 (and corresponding estimates used for adult $M_2$). For an $M_1$ of 0.23 (SVPA), Y/R rose from 1.3 lbs with an age at entry of 0 to 3.7 lbs with an age at entry of 3, and declined to 0.9 lbs with an age at entry of 5. Meanwhile, for an $M_1$ of 0.46, Y/R rose from 0.9 lbs with an age at entry of 0 to 1.6 lbs with an age at entry of 3, and declined to 0.3 lbs with an age at entry of 5. Higher M implies greater rate of removal of red drum from the stock, and hence lower estimates of Y/R. The lower the underlying natural mortality rate (M), the greater the peak value of yield per recruit. Because M for the subadult phase ($M_1$) is likely closer to 0.23 than to 0.46, estimates of Y/R based on $M_1$ of 0.23 are likely to be more realistic.

**Escapement**

Following up the earlier stock assessment, SAFMC (1990b; Appendix 1) requested an investigation of the effects of different management options (i.e., bag limits, size limits, and seasonal closures) on the escapement of red drum from state waters to the EEZ. For these analyses, escapement (E) is defined as the relative survival of red drum from age at entry to the fishery to the beginning of age 6; 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 7), and $\Pi$ indicates the product from t equals 0 to t equals 5. The numerator represents the number of survivors to age 6 with fishing mortality while the denominator represents the number of survivors without fishing mortality.

Escapement, expressed as a percent of survivorship to age 6 without fishing mortality, increases dramatically when age at entry is increased above age 3 (about 27" TL), because at this age the fish become much less vulnerable to the gear. Escapement declines with increasing multiples of fishing mortality (Fig. 20a). Escapement for greater ages at entry decline more slowly with increasing F. Escapement for age at entry of 0 yr and F multiple of 1 are summarized in Table 7. Escapement for F from coastal SVPA is estimated from 0.5% for $M_1 = 0.23$, and to 1.0% for $M_1 = 0.46$.

**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:

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

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 $\Sigma$ 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. Because sexual dimorphism in growth was not found in the 1989 or this stock assessment (Fig. 14b), the equations actually used for growth in length and weight (Tables 2 and 5) were developed from both sexes combined. The second method uses Eq. 5 (Overstreet 1983) to estimate an age-specific index of egg production ($E_t$) and substitute this for $W_t$ in Eq. 9, as suggested by Goodyear (1989).

As with the yield per recruit analysis, a range of natural mortality rates are used: 0.23 to 0.46 for subadults, but only 0.11 for adults. 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 section apply here as well. In addition, assumptions as to the validity of sex ratios, maturity schedules and fecundity estimates are needed. How uncertainty in the input parameters are expressed in the model output has not been described in the literature. Results of computer runs, which bracket some of the uncertainty in specific input parameters (e. g., natural and fishing mortality), are intended to partially address these questions.

Similar to escapement, %MSP increases dramatically above an age at entry of 3 in biomass (Fig. 19c) or in eggs (Fig. 19d.). A similar pattern in %MSP in biomass to escapement with respect to fishing mortality F is also noted (Fig. 20b). Percent maximum spawning potential for age at entry of age 0 and F multiple of 1 are summarized in Table 7. Based on female biomass, %MSP ranged from 0.6% for $M_1$ = 0.23 to 1.5% for $M_1$ = 0.46 (based on Separable VPA). Based on egg production, %MSP similarly ranged from 0.6% for $M_1$ = 0.23 to 1.4% for $M_1$ = 0.46 (based on Separable VPA). An estimate for %MSP in biomass of 0.7% was obtained for the North Region and 1.0-1.1% for the South Region.

## MANAGEMENT CONSIDERATIONS

An evaluation of a range of potential management options is updated from the 1991 stock assessment and Appendix 1 in SAFMC (1990b). Most coastal Atlantic states have instituted a minimum size limit and a combination of bag limit and a maximum size (SAFMC 1990a, Fig. 13). Most of these size limits were instituted in 1986 and 1987, with more recent changes in 1991. Florida has a 1 fish bag limit between 18" and 27" TL, Georgia and South Carolina have a 5 fish bag limit between 14" and 27" TL, and North Carolina has a 5 fish bag limit between 18" and 32" TL. Georgia, South Carolina and North Carolina currently permit 1 fish over the maximum size limit.

This section of the document has four parts, the first three separately describe potential savings of red drum by means of bag limits, size limits, and seasonal closures based on data from the recreational fishery since 1986. These estimates of savings refer to the initial proportion of fish saved and will tend to overestimate the long term savings. When savings are translated into fishing mortality rates and subsequently in maximum spawning potential, the implication is that there is no increase in fishing mortality on those sizes/ages not effected by management measures. In the final part, these savings are related through the population models described in the previous section to escapement and maximum spawning potential. One should keep in mind that saving a single age 1 red drum is not equivalent to saving a single age 4 red drum. The former has to undergo several years of natural and fishing mortality before it attains the likelihood of spawning or reaches age 6, while the latter has attained spawning age and has 3 fewer years of mortality to undergo before reaching age 6.

### Savings from Bag Limits

The number of fish caught per angler trip based on MRFSS data for years 1979-1991 is useful in evaluating potential benefits from bag limits (Fig. 21). Of 1398 successful angler trips sampled (at least one red drum caught) during 1986-1991 (Fig. 21b), 789 angler trips resulted in only a single red drum caught (57%). A greater percentage of angler trips during 1990-1991 (Fig. 21c) resulted in only a single red drum caught (69% or 188 out of 272 angler trips). Meanwhile, 13% of the angler trips caught more than 5 fish during 1986-1991 compared to only 5% of the angler trips caught more than 5 fish during 1990-1991. The anglers in the North Region caught fewer numbers of fish per trip (7% over 5) than anglers in the South Region (15% over 5) (Fig. 21d).

Calculation of potential bag limit savings are made for two time periods: 1986-1991 and 1990-1991 (Table 8). The latter should be more representative because of recent management changes. The number of legal red drum is calculated by summing all fish caught less than or equal to the bag limit. The percent saved is calculated from 100 times the difference between the number of legal and total number of fish (4111 for 1986-1991 and 531 for 1990-1991 sampled in the MRFSS) divided by the total number of fish. This can be adjusted for release mortality by multiplying the proportion of red drum saved by the proportion surviving release (e.g., multiply by 0.9 if 10% release mortality is assumed). Similar results are presented for the North and South Regions for the years 1986-91 (Table 8).

The number of red drum caught per angler trip is probably related to the population abundance at that time. As population abundance increases, the effectiveness of bag limits increase. However, as population abundance decreases, the effectiveness of bag limits decrease. The effectiveness of bag limits cannot be assessed once in place without an independent data source that is unaffected by the bag limit. Furthermore, one cannot assume that the proportion protected by the bag limit can be simply multiplied by the age-specific estimated F's, because angler's are likely to retain the larger red drum while they catch and release (alive or dead) smaller red drum. Thus, most of any reduction in F is likely to occur for the younger ages and less for the older aged red drum.

**Savings from Size Limits**

An analysis is also made of the MRFSS data base (1986-1991) to explore what proportion of the recreational catch would have been protected if a minimum size limit (12 to 22 inches) or a maximum size limit (24 to 32 inches) were instituted (Table 9). Length measurements are available on 2858 red drum during the period 1986-1991. Potentially significant savings are available from minimum size limits increasing from 12" TL (5%) to 14" TL (22%) to 18" TL (73%). Again, to account for a release mortality of 10%, these savings should be multiplied by 0.9.

Comparatively small savings are available when reducing the maximum size limit from 32" TL (4%) to 27" TL (2%) (Table 9). As suggested in the 1989 stock assessment, data supplied by North Carolina (Ross, pers. comm.) indicate considerably greater gains likely from a maximum size limit than does the MRFSS data. Although maximum size limits show much less potential reduction in F than minimum size limits, they do protect those fish that have managed to survive to maturity. Direct savings in numbers of fish from minimum and maximum size limits are compared in Fig. 22b.

Because most states with maximum size limits would continue to permit the retention of 1 red drum over this size limit, the MRFSS data set for 1986-1991 was investigated for the catch frequency of red drum exceeding a maximum size limit (27" TL through 32" TL). The proportion of these large fish that would be saved with a 1 fish over allowance ranged between 33% for 27" TL maximum size limit to 39% for 29" TL maximum size limit. No trend in percent saved was evident for the range of maximum size limits investigated (27" to 32" in 1" increments), so a mean value of 37% savings from a maximum size limit is used for subsequent analyses when 1 fish over is allowed.

To determine the effect of size limits on escapement of %MSP, it is necessary to estimate the reduction of age-specific F for a given size limit. However, it is first necessary to determine the age equivalent to the size limit. The preferred method is to re-estimate age ($t_d$, yr) as a function of length (TL, in) directly:

$$t_d = \exp(-2.170 + 0.922\, ln(\mathrm{TL}) + \tfrac{1}{2}(0.040). \qquad (10)$$

The expression [$\frac{1}{2}(0.040)$] is a correction factor from the lognormal distribution when retransforming back to the original units. Parameter estimates in Eq. (10) were estimated from MRFSS data for lengths less the 40" TL and ages less than 8 yr during the period 1986-1991. Because age equals 1 at 10" TL (Table 9), a minimum size limit of 10" would imply that all age 0 red drum were protected (i.e., $F_0 = 0$ or 10% of the original value with release mortality). However 14" TL produces an estimate of age of 1.33. As applied in this analysis, it is assumed that all (or 90%) of the age 0 red drum are protected, and 33% (or 90% of 33%) of the age 1 red drum are protected. Similar calculations are carried out for maximum size limits.

## Savings from Seasonal Closure

Seasonal closures for periods that do not coincide with the two month waves used for the catch expansions by the MRFSS (Essig et al. 1991) cannot be directly assessed. However, the intercept sampling for fish size information closely agree with the catch estimates when compared by 2-month wave (Fig. 23a). Based on this relationship, potential savings of red drum (all ages) can be approximated monthly based on the MRFSS intercept data (1986-1991) (Fig. 23b). This, of course, assumes no shifting of effort due to the closure. Even with no shift in effort, some of the seasonal closure gains are lost due to the greater availability of fish following the closure (F is a proportional cropping).

**Population Level Considerations**

To incorporate savings from bag limits, size limits, and seasonal closures at the population level, their effects on age specific estimates of fishing mortality rates must be considered. Because bag limits only apply to recreational fishing and size limits may not be applied identically between recreational and commercial fishing, age-specific fishing mortality rates need to be separated into recreational and commercial components. This is accomplished proportional to the relative catch in numbers at each age (0 to 5). The proportion of catch in numbers that are recreational are summarized in Table 10 for fishing years 1986-1991. An annual mean for ages 0 through 5 was determined for 1988-91 as most representative of recent fishing conditions and is used in subsequent analyses described in this section.

Savings from bag limits (Table 8) are applied to the recreational fishing mortality component for all ages. However, this savings is reduced by 10% to reflect a release mortality of that amount (i.e., proportion that F is to be reduced is multiplied by 0.9). In the analysis presented, bag limit savings are based on the MRFSS data during 1986-1991.

Bag and size limit savings could be applied to both recreational and commercial fishing mortality components, but for the analysis that follows they are applied only to recreational fishing mortality components. As the program is constructed, savings from seasonal closures would be applied to both recreational and commercial fisheries, all ages, and with or without release mortality.

Once these adjustments to age-specific fishing mortality rates are made, the SAS program then performs simultaneous calculations of escapement to age 6 and maximum spawning potential (female biomass and egg production) to those described in the previous section. These parallel the analysis presented in SAFMC (1990b, Appendix 1) except as follows: 1) all the data are updated as described above, 2) a direct estimate of age from length is used, and 3) reductions from size limits are based directly on age.

Estimates of escapement and maximum spawning potential from separate application of bag and size limits to recreational fishing only are summarized in Table 11 (these are conditioned on the bag and size limits extant during 1986-91). A 10% release mortality is assumed for the recreational fishery, and the fishing mortality rates are based on the Separable VPA with $M_1 = 0.23$ (and $M_2 = 0.11$). A bag limit of one red drum produces an escapement to age 6 of 8% and a maximum spawning potential (biomass) of 8%. A minimum size limit of at least 20" TL is needed for a noticeable gain in escapement and %MSP. Greater gains in escapement and MSP are possible from maximum size limits, except when one red drum over the maximum size limit is permitted.

Higher estimates of %MSP (eggs) occur when different management options are combined. Again, a 10% release mortality for the recreational fishery is assumed and the estimated fishing mortality rates are based on the Separable VPA with $M_1 = 0.23$ (and $M_2 = 0.11$). Estimates of %MSP (biomass) for a range of bag limits and minimum size limits are summarized in Table 12 with 27" TL maximum size limit with either no fish or one fish allowed over this limit. Estimated %MSP values above 30% cannot be obtained when 1 fish is permitted over the maximum size limit; but at least 1 fish may be retained (1 fish bag limit) when no fish over the maximum size limit is permitted.

## RESEARCH NEEDS

As referred to in this and the earlier stock assessments, a major concern in the analyses concerns the rates at which ages 3-5 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's. 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 this assessment. Also they may ultimately provide useful estimates of emigration rates at age.

Primary needs for continued stock assessments imply 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 in 1991 from Florida, Georgia, South Carolina, and North Carolina). It is important to emphasize the need to improve the number of MRFSS intercepts over recent years (222 in 1990 and 277 in 1991), because recreational landings represent about 91% of total landings by number. 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 (Fig. 23b). The main weakness in the commercial sampling is in the trawl fishery, but this is much less critical because landings by trawl represent only about 1% of the total landings by number.

Parameters for population models still require better estimates of natural mortality rates (subadult $M_1$ and adult $M_2$), although implications from sensitivity analyses suggest that model results will not change appreciably. Escapement and MSP are very low for all reasonable estimates of natural mortality. A determination of fecundity as a function of Atlantic red drum length or weight would prove useful, although it is not unreasonable to assume a similar relationship as red drum from the Gulf of Mexico. As used in this and the 1989 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.

Population models used in this report assume equilibrium conditions and reflect short-term, initial percent savings from management regulations. These limitations are largely due to the data available for analyses. However, better refinement of these models is desirable to obtain longer term estimates of gains from management regulations.

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 an index of abundance, and permit greater confidence in the more recent estimates of fishing mortality rates (and population size). In particular, these methods may permit detection of a decline in fishing mortality rates in the most recent years since management actions have taken place. Short of application of these methods, several years of data must be collected before there is any hope of detecting such a decline if it takes place.

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.

I remind the reader that the population models used in this assessment (specifically yield per recruit and percent maximum spawning potential) are based on equilibrium assumptions. Model results are valid in assessing long-term effects, direct estimates as to the current status of the adult (or spawning) stock are unavailable.

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Table 1. Red drum catches for recreational and commercial fisheries, 1980-1991. Recreational catches are in numbers and weight, commercial catches are in weight, and total catches are in weight.

| Year | Recreational[a] | | | Commercial | Total |
|---|---|---|---|---|---|
| | Numbers | | Weight[b] | Weight | Weight |
| | A+B1 (1000) | 0.1*B2 (1000) | A+B1+0.1*B2 (1000 lbs) | (1000 lbs) | (1000 lbs) |
| 1980 | 269.8 | 14.7 | 720.8 | 439.9 | 1160.7 |
| 1981 | 186.1 | 1.4 | 632.7 | 353.1 | 985.8 |
| 1982 | 388.6 | 1.8 | 682.7 | 196.1 | 878.8 |
| 1983 | 635.0 | 7.3 | 1066.2 | 370.3 | 1336.5 |
| 1984 | 1068.6 | 6.4 | 2179.4 | 422.5 | 2601.9 |
| 1985 | 1027.3 | 26.6 | 2028.3 | 249.8 | 2278.1 |
| 1986 | 428.6 | 18.2 | 1825.4 | 345.9 | 2171.3 |
| 1987 | 657.3 | 66.2 | 1467.9 | 314.6 | 1782.5 |
| 1988 | 502.2 | 61.9 | 1671.4 | 264.8 | 1906.2 |
| 1989 | 268.5 | 28.7 | 909.8 | 286.9 | 1196.7 |
| 1990 | 224.0 | 25.3 | 513.5 | 186.3 | 699.8 |
| 1991 | 364.4 | 87.2 | 1325.9 | 127.8 | 1453.7 |

[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 assumed same as expanded mean weight of A+B1. Since numbers of fish, rather than weight, are used in assessment, this assumption does not effect assessment results, but only for comparison with commercial landings in weight.

Table 2. Red drum growth characterized by single and linear von Bertalanffy equations weighting inversely by number of fish at age. Units of $L_{max}$ and $b_0$ are total length in inches; $b_1$ is total length in inches per year; k is $yr^{-1}$, and $t_0$ is years.

| Type | n | Single Parameters $L_{max}$ | k | $t_0$ |
|---|---|---|---|---|
| 1981-91 | 11359 | 43.6 (0.04) | 0.22 (0.003) | -1.35 (0.10) |
| 1981-85 | 830 | 42.6 (0.14) | 0.31 (0.008) | -0.36 (0.06) |
| 1986-91 | 10529 | 43.6 (0.05) | 0.22 (0.003) | -1.34 (0.10) |
| Female | 997 | 44.2 (0.16) | 0.21 (0.007) | -1.18 (0.16) |
| Male | 913 | 42.7 (0.16) | 0.24 (0.009) | -0.82 (0.14) |

| Type | Linear Parameters[a] $b_0$ | $b_1$ | k | $t_0$ |
|---|---|---|---|---|
| 1981-91 | 39.2 (0.08) | 0.17 (0.017) | 0.38 (0.006) | 0.03 (0.05) |
| 1981-85 | 39.6 (0.39) | 0.14 (0.070) | 0.39 (0.016) | -0.11 (0.06) |
| 1986-91 | 39.1 (0.08) | 0.17 (0.018) | 0.38 (0.007) | 0.04 (0.05) |
| Female | 39.2 (0.36) | 0.18 (0.080) | 0.34 (0.018) | -0.35 (0.12) |
| Male | 37.7 (0.37) | 0.21 (0.094) | 0.39 (0.020) | -0.15 (0.09) |

[a] For the linear model, $L_{max} = b_0 + b_1$ Age.

Table 3. Overall red drum age-length key, 1986-91.

| Length Class (TL, in) | Age (yr) 0 | 1 | 2 | 3 | 4 | 5 | 6+ |
|---|---|---|---|---|---|---|---|
| 7 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0.823 | 0.177 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0.689 | 0.311 | 0 | 0 | 0 | 0 | 0 |
| 13 | 0.174 | 0.825 | 0.001 | 0 | 0 | 0 | 0 |
| 15 | 0.022 | 0.977 | 0.001 | 0 | 0 | 0 | 0 |
| 17 | 0.004 | 0.986 | 0.010 | 0 | 0 | 0 | 0 |
| 19 | 0.007 | 0.900 | 0.093 | 0 | 0 | 0 | 0 |
| 21 | 0 | 0.393 | 0.607 | 0 | 0 | 0 | 0 |
| 23 | 0 | 0.082 | 0.902 | 0.016 | 0 | 0 | 0 |
| 25 | 0 | 0.014 | 0.907 | 0.077 | 0.002 | 0 | 0 |
| 27 | 0 | 0.005 | 0.654 | 0.333 | 0.008 | 0 | 0 |
| 29 | 0 | 0.003 | 0.276 | 0.667 | 0.054 | 0 | 0 |
| 31 | 0 | 0 | 0.162 | 0.671 | 0.154 | 0.009 | 0.004 |
| 33 | 0 | 0 | 0.027 | 0.527 | 0.339 | 0.045 | 0.062 |
| 35 | 0 | 0 | 0 | 0.226 | 0.500 | 0.210 | 0.064 |
| 37 | 0 | 0 | 0 | 0 | 0.137 | 0.192 | 0.671 |
| 39 | 0 | 0 | 0 | 0 | 0.016 | 0.033 | 0.951 |
| 41 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 43+ | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

Table 4. Red drum catch in numbers at age for combined recreational and commercial fisheries (1986-1990).

| Age (yr) | Year 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
|---|---|---|---|---|---|---|
| | | | Coastal | | | |
| 0 | 176996. | 173693. | 66845. | 14219. | 20414. | 26497. |
| 1 | 457729. | 673380. | 459029. | 268414. | 204467. | 382708. |
| 2 | 44398. | 73406. | 66210. | 79660. | 58739. | 91378. |
| 3 | 3760. | 15414. | 17217. | 13329. | 6529. | 8580. |
| 4 | 372. | 1057. | 1155. | 981. | 2936. | 344. |
| 5 | 477. | 174. | 488. | 134. | 670. | 51. |
| 6+ | 17931. | 6999. | 8090. | 5718. | 8581. | 3978. |
| | | | North | | | |
| 0 | 14947. | 12215. | 33680. | 5848. | 3706. | 10622. |
| 1 | 95877. | 101889. | 91440. | 106754. | 62051. | 102557. |
| 2 | 3624. | 10375. | 23490. | 27213. | 5591. | 7977. |
| 3 | 1204. | 3031. | 10997. | 4234. | 1476. | 1121. |
| 4 | 218. | 898. | 949. | 511. | 661. | 344. |
| 5 | 397. | 151. | 282. | 134. | 386. | 51. |
| 6+ | 17172. | 5615. | 6237. | 5020. | 7063. | 3975. |
| | | | South | | | |
| 0 | 162049. | 161478. | 33164. | 8371. | 16708. | 15875. |
| 1 | 361853. | 571491. | 367589. | 161660. | 142416. | 280151. |
| 2 | 40774. | 63031. | 42720. | 52447. | 53148. | 83401. |
| 3 | 2556. | 12383. | 6220. | 9094. | 5052. | 7459. |
| 4 | 154. | 159. | 205. | 470. | 2275. | 0. |
| 5 | 79. | 23. | 205. | 0. | 284. | 0. |
| 6+ | 759. | 1384. | 1853. | 698. | 1518. | 0. |

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] |
|---|---|---|---|---|---|
| | | State Commercial Data (1979-91) | | | |
| All | 2304 | -7.611 | 2.921 | 0.99 | 0.016 |
| Gill Net | 1559 | -7.638 | 2.928 | 0.99 | 0.012 |
| Haul Seine | 382 | -7.497 | 2.885 | 0.99 | 0.010 |
| Hook & Line | 173 | -8.052 | 3.049 | 0.98 | 0.045 |
| Pound Net | 175 | -7.222 | 2.811 | 0.99 | 0.010 |
| Trawl | 15 | -7.472 | 2.830 | 0.96 | 0.099 |
| | | State Aged Data (1981-91) | | | |
| All | 1903 | -7.731 | 2.939 | 0.99 | 0.018 |
| 1981-85 | 667 | -7.585 | 2.877 | 0.99 | 0.008 |
| 1986-91 | 1236 | -7.769 | 2.960 | 0.99 | 0.022 |
| | | (0.024) | (0.008) | | |
| | | MRFSS (1986-91) | | | |
| All | 2436 | -7.524 | 2.921 | 0.93 | 0.041 |
| | | (0.045) | (0.016) | | |

[a] MSE equals mean squared error.

Table 6. Red drum estimates of total instantaneous mortality rates (Z) from catch curve analysis using data within a single year or by cohort over several fishing years. SE equals standard error.

| | Z | SE | $r^2$ | n | Ages |
|---|---|---|---|---|---|
| | **Using Recreational Data Only** | | | | |
| **Fishing Year** | | | | | |
| 1980 | 1.45 | 0.13 | 0.98 | 3 | 1-3 |
| 1981 | 1.01 | 0.13 | 0.97 | 3 | 1-3 |
| 1982 | 1.32 | 0.45 | 0.79 | 3 | 1-3 |
| 1983 | 1.96 | 0.02 | 1.00 | 3 | 1-3 |
| 1984 | 1.61 | 0.73 | 0.66 | 3 | 1-3 |
| 1985 | 2.50 | 0.27 | 0.98 | 3 | 1-3 |
| 1986 | 2.48 | 0.18 | 0.99 | 3 | 1-3 |
| 1987 | 1.88 | 0.17 | 0.98 | 3 | 1-3 |
| 1988 | 1.63 | 0.18 | 0.97 | 3 | 1-3 |
| 1989 | 1.41 | 0.21 | 0.96 | 3 | 1-3 |
| 1990 | 1.66 | 0.35 | 0.91 | 3 | 1-3 |
| 1991 | 1.84 | 0.31 | 0.95 | 3 | 1-3 |
| | **Using Recreational/Commercial Data** | | | | |
| **Fishing Year** | | | | | |
| 1986 | 2.40 | 0.04 | 1.00 | 3 | 1-3 |
| 1987 | 1.89 | 0.19 | 0.98 | 3 | 1-3 |
| 1988 | 1.64 | 0.17 | 0.98 | 3 | 1-3 |
| 1989 | 1.50 | 0.17 | 0.98 | 3 | 1-3 |
| 1990 | 1.72 | 0.27 | 0.95 | 3 | 1-3 |
| 1991 | 1.90 | 0.27 | 0.96 | 3 | 1-3 |
| | **Using Recreational/Commercial Data** | | | | |
| **Cohort** | | | | | |
| 1984 | 1.06 | - | - | 2 | 2-3 |
| 1985 | 1.64 | 0.11 | 0.99 | 3 | 1-3 |
| 1986 | 1.96 | 0.21 | 0.98 | 3 | 1-3 |
| 1987 | 2.13 | 0.22 | 0.98 | 3 | 1-3 |
| 1988 | 1.72 | 0.12 | 0.99 | 3 | 1-3 |
| 1989 | 0.81 | - | - | 2 | 1-2 |

Table 7. Red drum mean fishing mortality rates (1986-1991) from different virtual population analyses (M = instantaneous natural mortality rate for subadults, ages 0-5). In addition, estimated values for yield per recruit (Y/R), escapement to age 6, and maximum spawning potential (MSP) based on female biomass and egg production are presented.

| Age/ Values | Variable M Murphy[a] | Separable | | | |
|---|---|---|---|---|---|
| | | Coastal | | North | South |
| | | $M_1$=0.23 | $M_1$=0.46 | $M_1$=0.23 | $M_1$=0.23 |
| 0 | 0.15 | 0.09 | 0.07 | 0.08 | 0.09 |
| 1 | 1.44 | 1.45 | 1.22 | 1.72 | 1.36 |
| 2 | 1.44 | 1.49 | 1.27 | 1.18 | 1.56 |
| 3 | 1.44 | 1.49 | 1.27 | 1.18 | 1.56 |
| 4 | 0.30 | 0.62 | 0.56 | 0.72 | 0.11 |
| 5 | 0.15 | 0.23 | 0.26 | 0.39 | 0.01 |
| Adult M ($M_2$) | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 |
| Y/R (lbs) | 0.88 | 1.34 | 0.92 | 1.26 | 1.36 |
| Escapement (%) | 0.63 | 0.47 | 0.96 | 0.51 | 0.92 |
| MSP Biomass (%) | 0.74 | 0.64 | 1.46 | 0.71 | 1.06 |
| MSP Eggs (%) | 0.72 | 0.60 | 1.37 | 0.67 | 1.03 |

[a] Based on Boudreau and Dickie (1989): For age 0, M=0.46; for age 1, M=0.29; for age 2, M=0.20; for age 3, M=0.17; for age 4, M=0.15; and for age 5, M=0.14.

Table 8. Potential savings of red drum from management bag limits based on MRFSS data base for 1986-1991 and 1990-1991 (assumes no release mortality).

| Bag Limit | Percent Saved[a] | | | |
|---|---|---|---|---|
| | 1986-91 | | | 1990-91 |
| | Coastal | North | South | Coastal |
| N | 4111 | 638 | 3473 | 531 |
| 1 | 66 | 51 | 69 | 49 |
| 2 | 51 | 37 | 54 | 33 |
| 3 | 42 | 26 | 44 | 23 |
| 4 | 34 | 18 | 37 | 16 |
| 5 | 29 | 13 | 32 | 11 |
| 6 | 25 | 10 | 27 | 8 |
| 7 | 21 | 7 | 24 | 6 |
| 8 | 18 | 6 | 21 | 4 |
| 9 | 16 | 4 | 18 | 3 |
| 10 | 14 | 3 | 16 | 2 |
| 11 | 12 | 2 | 14 | 1 |
| 12 | 11 | 1 | 13 | 1 |
| 13 | 10 | 1 | 11 | 0 |
| 14 | 9 | 1 | 10 | 0 |
| 15 | 7 | 0 | 9 | 0 |
| None | 0 | 0 | 0 | 0 |

[a] Percent of red drum that would have been caught if bag limit had been in effect.

Table 9. Potential savings of red drum from management size limits based on MRFSS data base for 1986-1990 (assumes to release mortality).

| Size Limit | Age[a] | No. Fish Legal | Percent Savings |
|---|---|---|---|
| 12 | 1.15 | 2706 | 5 |
| 13 | 1.24 | 2512 | 12 |
| 14 | 1.33 | 2242 | 22 |
| 15 | 1.41 | 1674 | 41 |
| 16 | 1.50 | 1261 | 56 |
| 17 | 1.59 | 957 | 67 |
| 18 | 1.67 | 778 | 73 |
| 19 | 1.76 | 631 | 78 |
| 20 | 1.84 | 537 | 81 |
| 21 | 1.93 | 457 | 84 |
| 22 | 2.01 | 407 | 86 |
| 24 | 2.18 | 2581 | 10 |
| 25 | 2.27 | 2654 | 7 |
| 26 | 2.35 | 2704 | 5 |
| 27 | 2.43 | 2743 | 4 |
| 28 | 2.52 | 2767 | 3 |
| 29 | 2.60 | 2781 | 3 |
| 30 | 2.68 | 2791 | 2 |
| 31 | 2.76 | 2798 | 2 |
| 32 | 2.84 | 2805 | 2 |
| Total | - | 2858 | - |

[a] Age at length estimated by linearized regression from the model:

$$A = \exp(-2.170 + 0.922*ln(L) + \tfrac{1}{2}(0.040))$$

where A = age in years, L = total length in inches, 0.040 is the mean squared error and corrects for bias between normal and lognormal error models, and $r^2 = 0.89$. Age-length data from Florida, Georgia, South Carolina, and North Carolina, between 1986-1991, and restricted to total lengths less than 40" and age less than 8.

Table 10. Proportion of red drum in numbers by age (0-5) that were caught by the recreational fishery. Total and mean based on fishing years 1988-91 because commercial landings in 1986-87 contained large number of small gill net caught fish mostly in Florida.

| Year | Age (yr) | | | | | | Total |
|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | (0-6+) |
| | | | | **Coastwide** | | | |
| 1986 | 0.19 | 0.84 | 0.92 | 0.63 | 0.36 | 0.75 | 0.67 |
| 1987 | 0.26 | 0.91 | 0.96 | 0.88 | 0.63 | 0.40 | 0.78 |
| 1988 | 0.93 | 0.95 | 0.97 | 0.92 | 0.77 | 0.71 | 0.94 |
| 1989 | 0.88 | 0.87 | 0.94 | 0.82 | 0.41 | 0.48 | 0.87 |
| 1990 | 0.93 | 0.89 | 0.98 | 0.92 | 0.86 | 0.83 | 0.90 |
| 1991 | 0.83 | 0.92 | 0.98 | 0.94 | 0.43 | 0.11 | 0.92 |
| Total (1988-91) | 0.90 | 0.92 | 0.97 | 0.89 | 0.70 | 0.66 | 0.92 |
| Mean (1988-91) | 0.89 | 0.91 | 0.97 | 0.90 | 0.62 | 0.53 | 0.91 |
| | | | | **North Region** | | | |
| Mean (1988-91) | 0.49 | 0.46 | 0.68 | 0.73 | 0.65 | 0.75 | 0.50 |
| | | | | **South Region** | | | |
| Mean (1988-91) | 0.990 | 0.997 | 0.997 | 0.997 | 0.998 | 1.0 | 0.997 |

Table 11. Escapement and percent maximum spawning potential (female biomass) for Atlantic red drum expressed as percent based on separate application of bag and size limits with a 10% release mortality to recreational fishery only. Fishing mortality rates from Separable VPA with $M_1 = 0.23$. Bag and size limits based on MRFSS data for 1986-1991.

| Limit | Escapement | % Maximum Spawning Potential | |
|---|---|---|---|
| | | Biomass | Eggs |
| No Limits | 1 | 1 | 1 |
| **Bag Limit** | | | |
| 0 | 33 | 34 | 34 |
| 1 | 8 | 8 | 8 |
| 2 | 4 | 5 | 5 |
| 3 | 3 | 3 | 3 |
| 4 | 2 | 2 | 2 |
| 5 | 2 | 2 | 2 |
| 6 | 1 | 2 | 2 |
| 7 | 1 | 1 | 1 |
| 8 | 1 | 1 | 1 |
| 9 | 1 | 1 | 1 |
| 10 | 1 | 1 | 1 |
| **Minimum Size Limit** | | | |
| 12" TL | 1 | 1 | 1 |
| 14" | 1 | 1 | 1 |
| 16" | 1 | 1 | 1 |
| 18" | 1 | 1 | 1 |
| 20" | 2 | 2 | 2 |
| **Maximum Size Limit** | | | |
| No fish allowed over: | | | |
| 27" TL | 6 | 6 | 6 |
| 30" | 4 | 5 | 5 |
| 32" | 4 | 4 | 4 |
| One fish allowed over: | | | |
| 27" TL | 1 | 1 | 1 |
| 30" | 1 | 1 | 1 |
| 32" | 1 | 1 | 1 |

Table 12. Percent maximum spawning potential (biomass) for Atlantic red drum expressed as percent based on combined application of bag and size limits with a 10% release mortality to recreational fishery only (27" maximum size limit). Fishing mortality rates from Separable VPA with $M_1$ = 0.23. Bag and size limits based on MRFSS data for whole coast for 1986-91.

| Bag Limit | Minimum Size Limits (TL) | | | | | |
|---|---|---|---|---|---|---|
| | None | 12" | 14" | 16" | 18" | 20" |
| **One Fish Over Maximum Size Limit** | | | | | | |
| 0 | 37 | 38 | 39 | 39 | 40 | 41 |
| 1 | 12 | 13 | 14 | 15 | 17 | 18 |
| 2 | 7 | 8 | 9 | 10 | 11 | 13 |
| 3 | 5 | 6 | 7 | 8 | 9 | 10 |
| 4 | 4 | 5 | 6 | 7 | 7 | 8 |
| 5 | 4 | 4 | 5 | 6 | 6 | 7 |
| 6 | 3 | 4 | 4 | 5 | 6 | 7 |
| 7 | 3 | 3 | 4 | 5 | 5 | 6 |
| 8 | 3 | 3 | 4 | 4 | 5 | 6 |
| 9 | 2 | 3 | 3 | 4 | 5 | 5 |
| 10 | 2 | 3 | 3 | 4 | 4 | 5 |
| None | 1 | 2 | 2 | 3 | 3 | 4 |
| **No Fish Over Maximum Size Limit** | | | | | | |
| 0 | 43 | 44 | 45 | 46 | 47 | 48 |
| 1 | 22 | 25 | 27 | 30 | 31 | 33 |
| 2 | 17 | 19 | 21 | 23 | 26 | 29 |
| 3 | 14 | 16 | 18 | 20 | 23 | 26 |
| 4 | 12 | 14 | 16 | 19 | 21 | 24 |
| 5 | 11 | 13 | 15 | 17 | 20 | 23 |
| 6 | 10 | 12 | 14 | 16 | 19 | 22 |
| 7 | 9 | 11 | 13 | 15 | 18 | 21 |
| 8 | 9 | 11 | 13 | 15 | 17 | 20 |
| 9 | 9 | 10 | 12 | 14 | 17 | 20 |
| 10 | 8 | 10 | 12 | 14 | 16 | 19 |
| None | 6 | 8 | 10 | 12 | 14 | 17 |

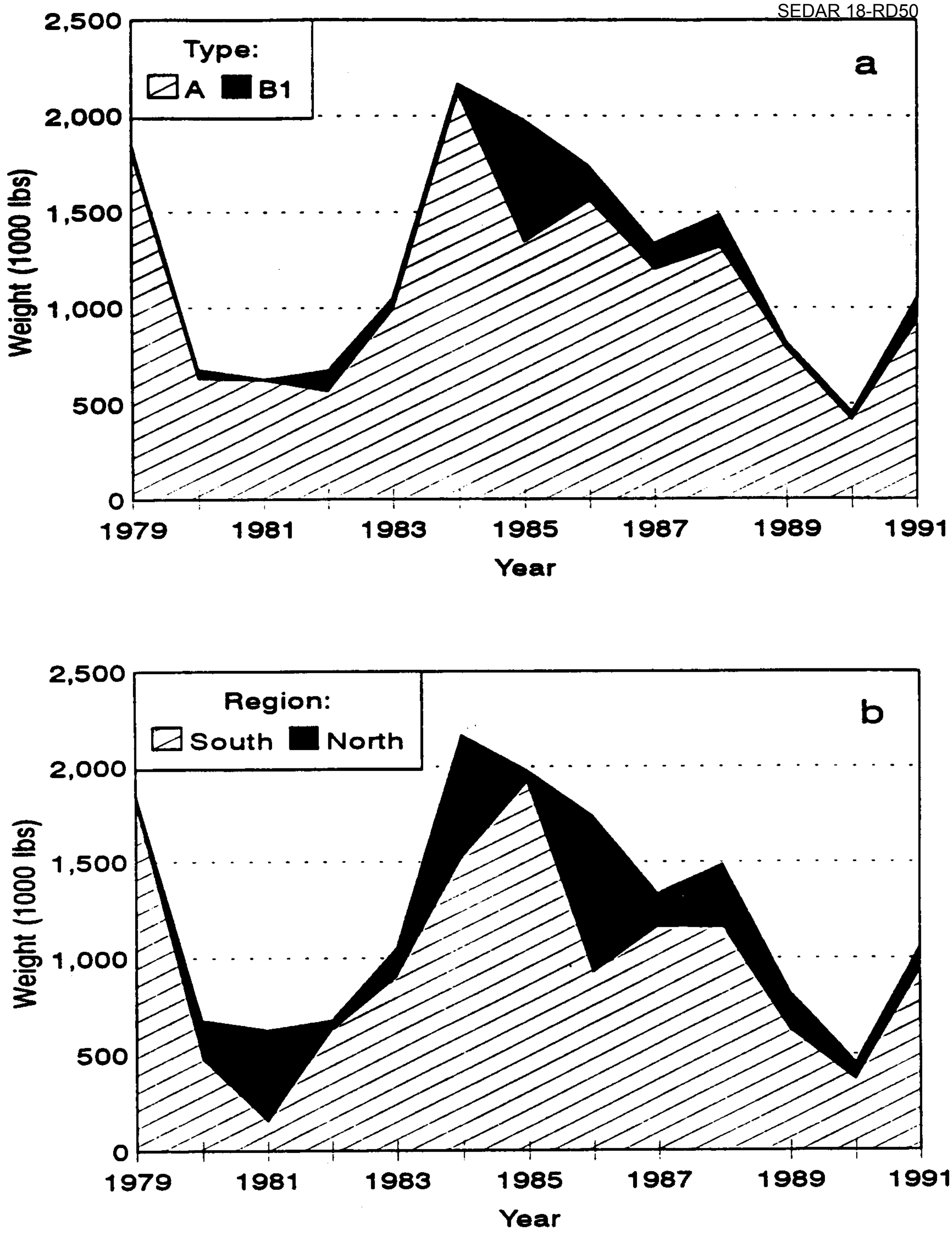



Figure 1. Atlantic red drum recreational catches in weight by type (a: A, B1) and by region (b: South, North), 1979-1991.

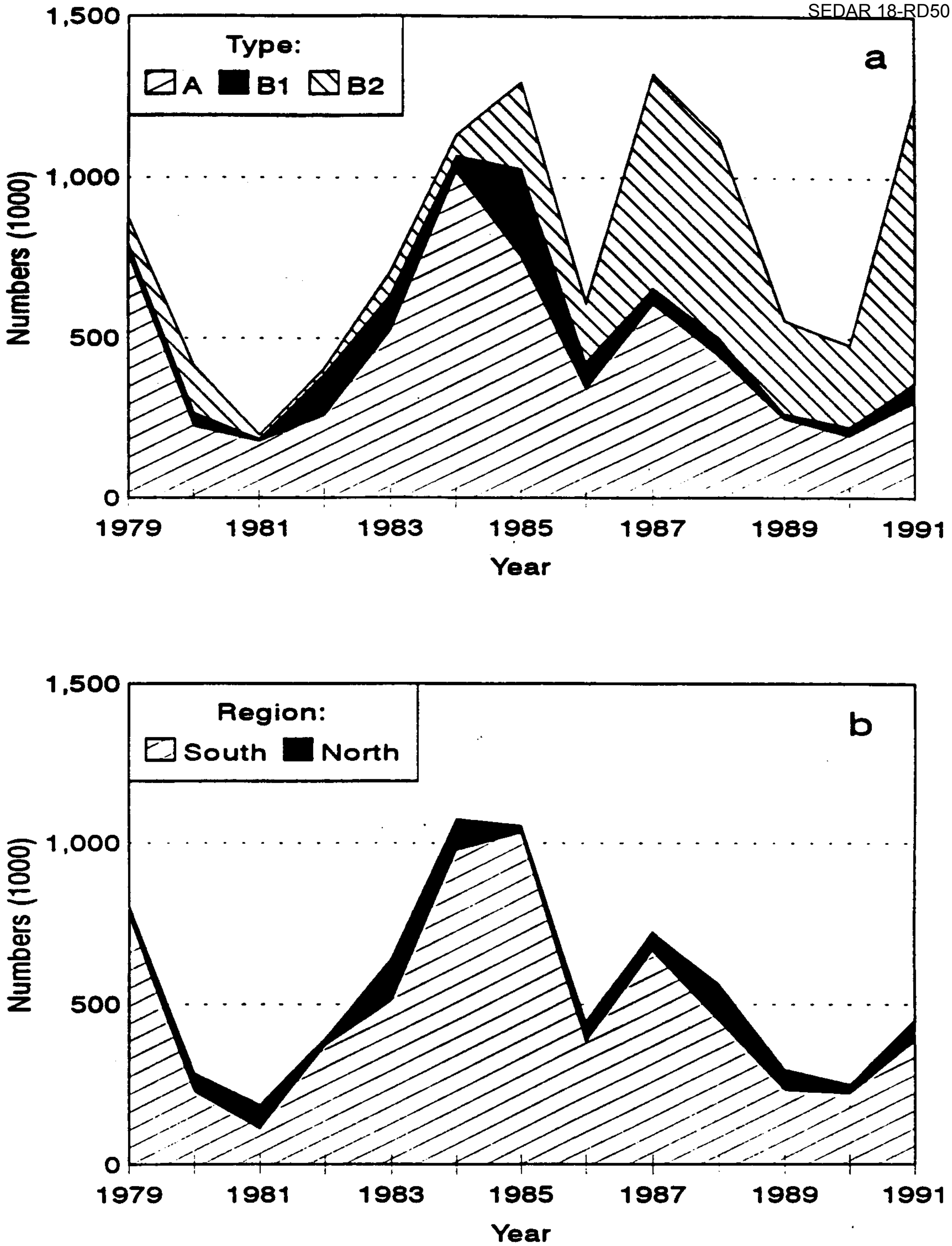



Figure 2. Atlantic red drum recreational catches in numbers by type (**a**: A, B1, B2) and by region (**b**: South, North), 1979-1991.

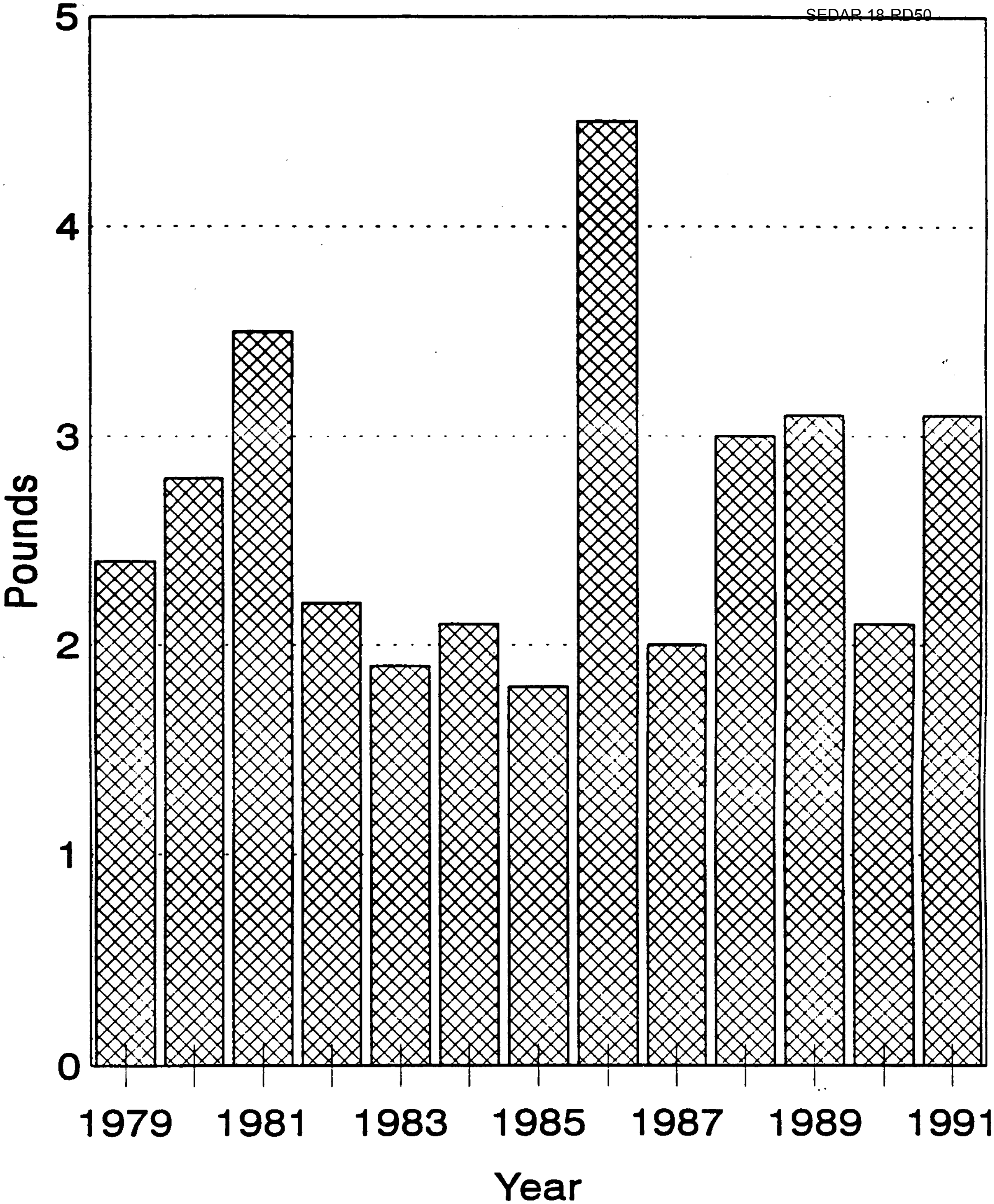



Figure 3. Mean weight of intercepted (type A) recreational caught Atlantic red drum, 1979-1991.

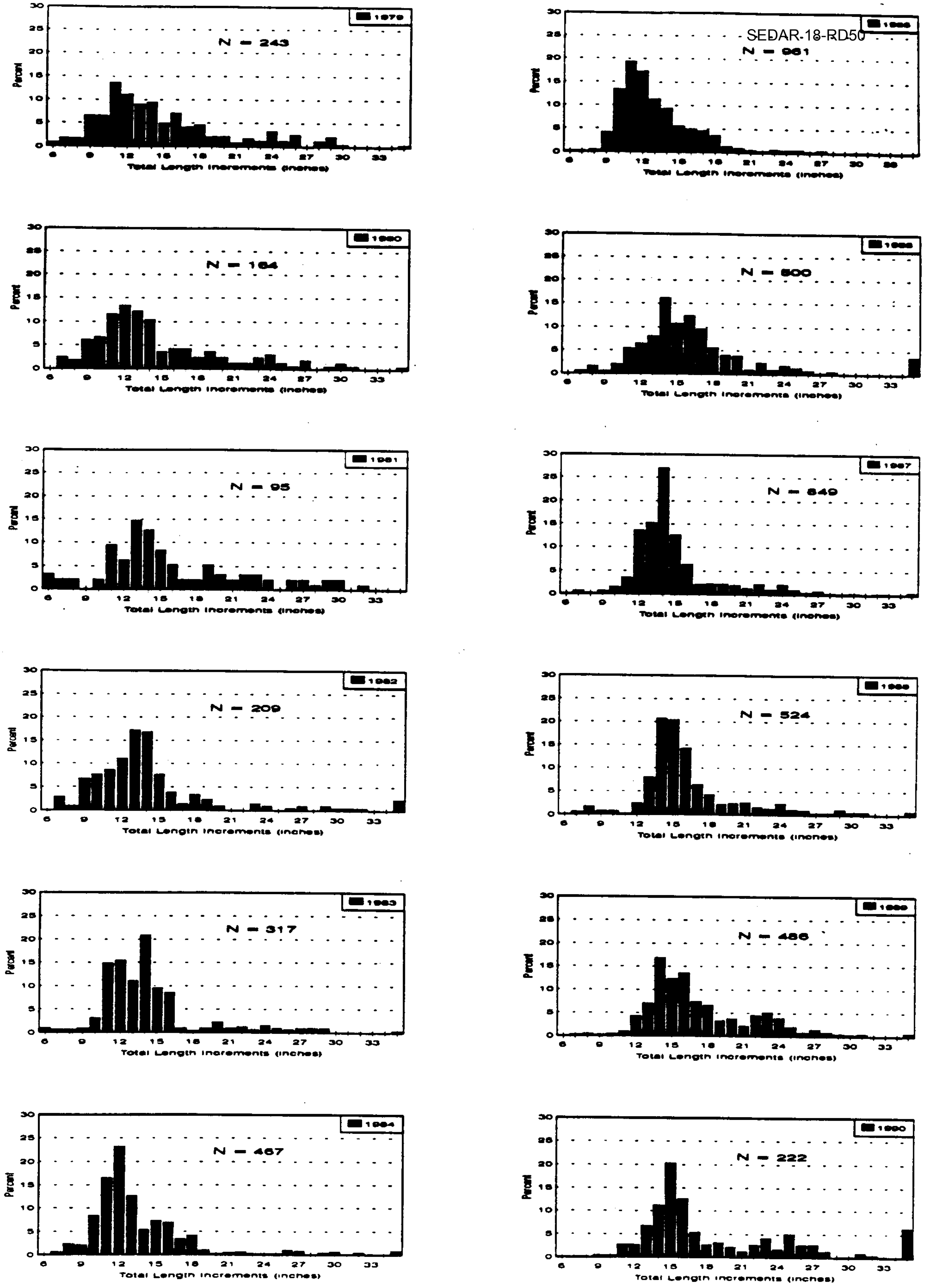



Figure 4. Length frequency distributions for intercepted recreational caught Atlantic red drum, 1979-1990.

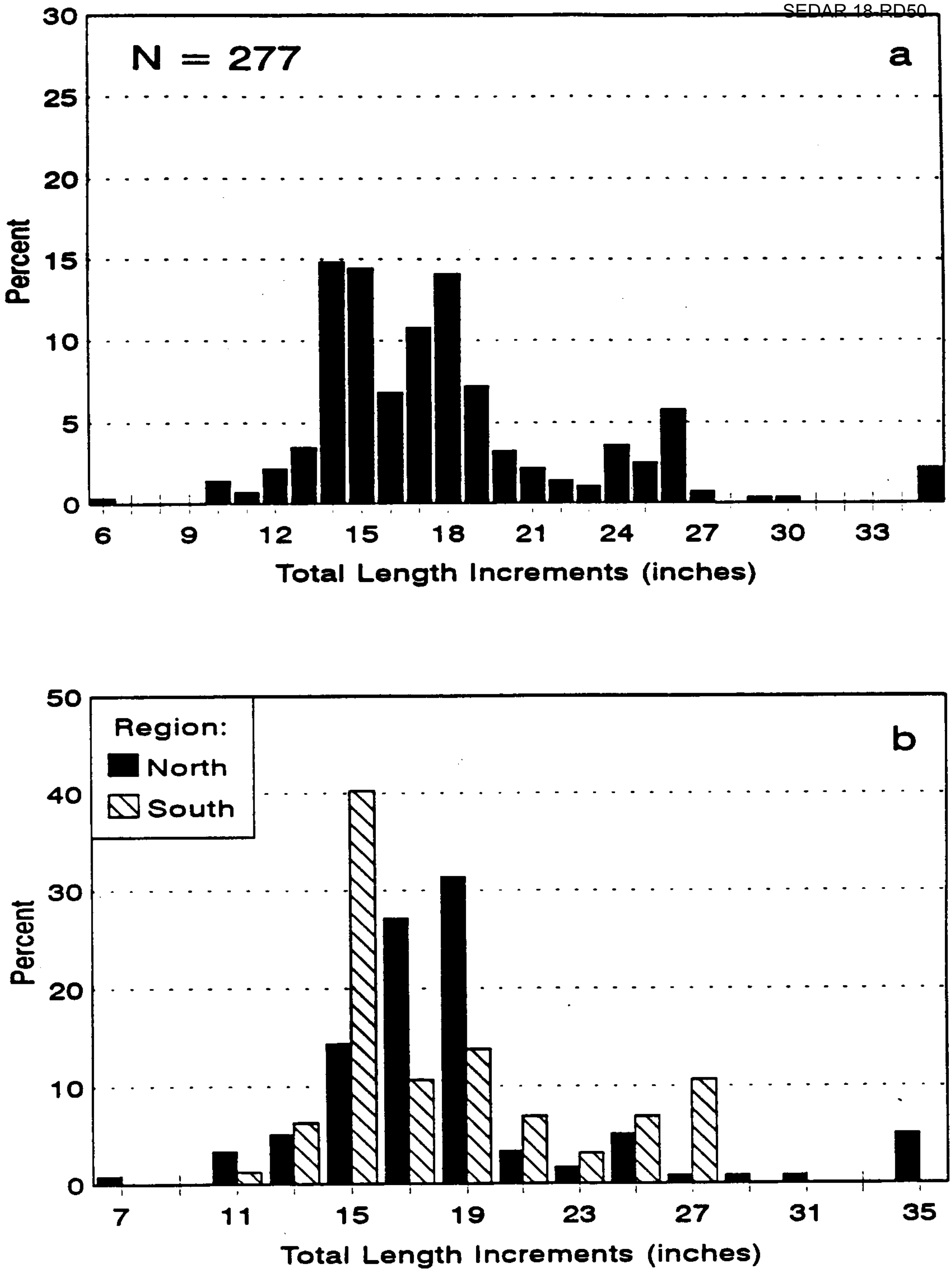



Figure 5. Length frequency distributions for intercepted recreational caught Atlantic red drum in 1991 coastwide (**a**) and by region (**b**: South, North).

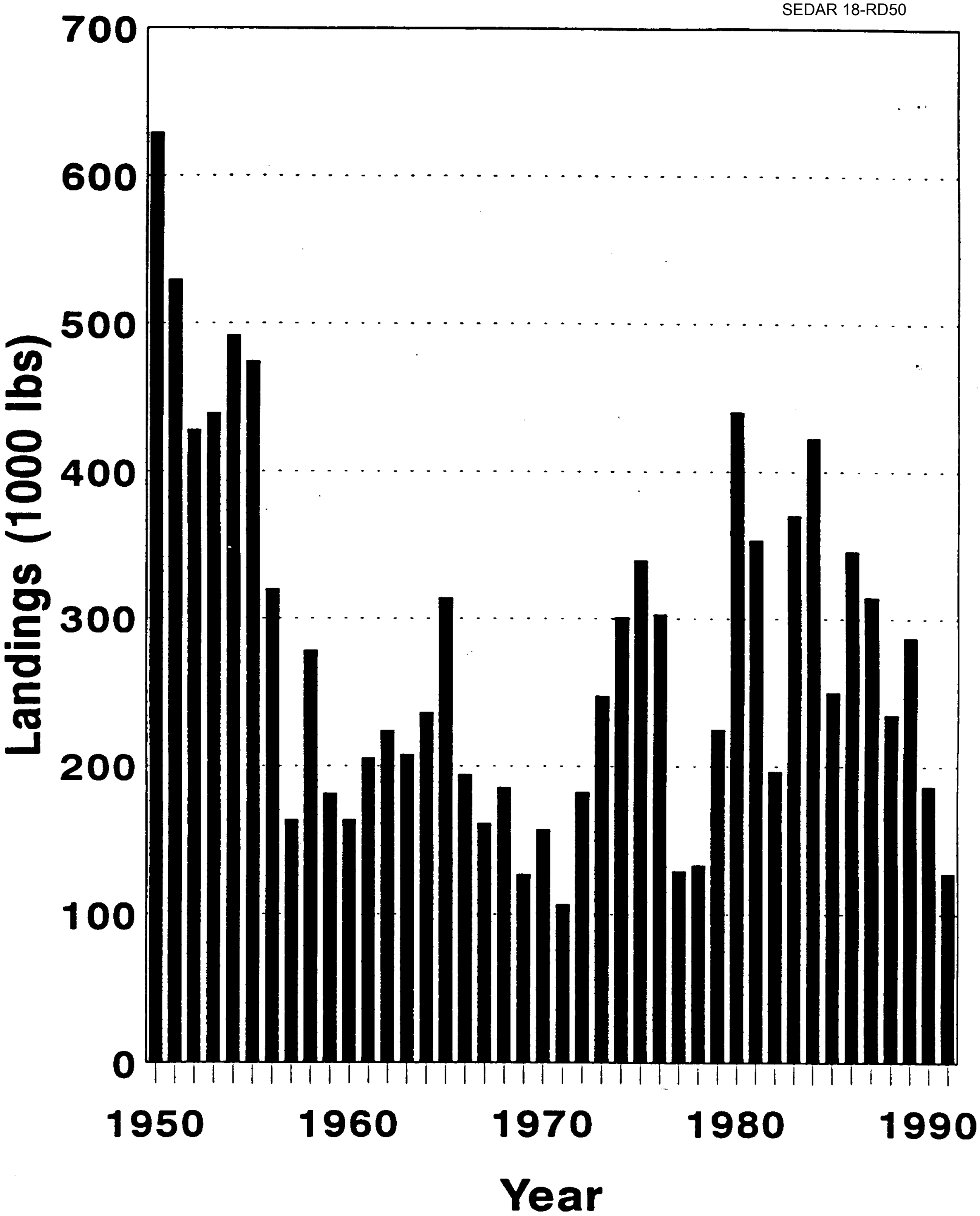
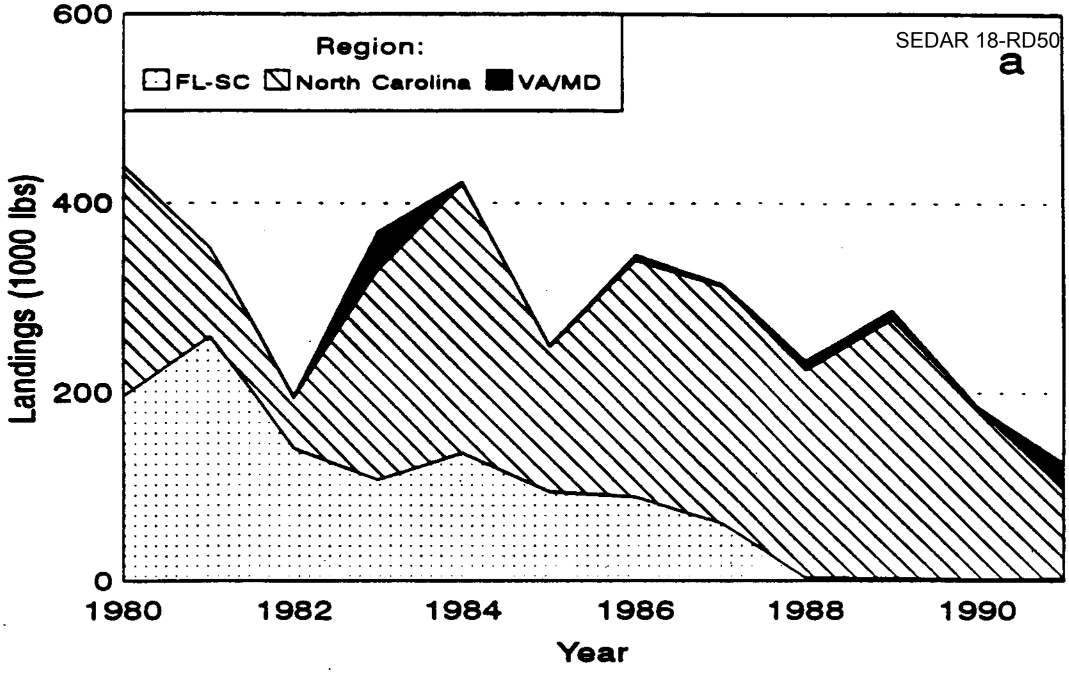



Figure 6. Atlantic red drum commercial landings in weight, 1950-1991.



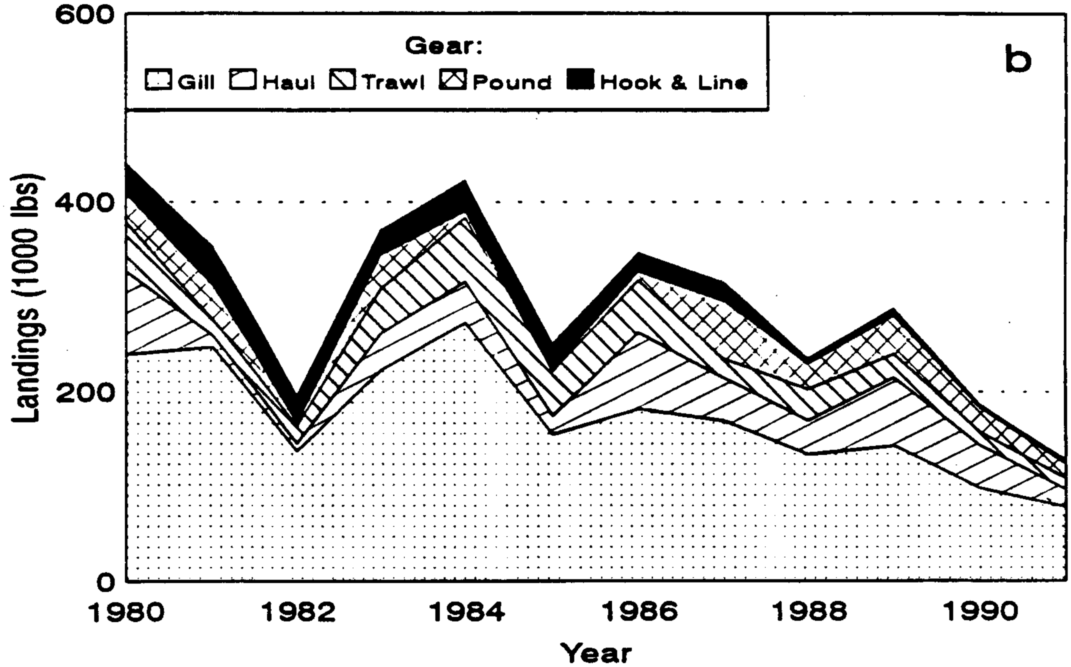




Figure 7. Atlantic red drum commercial landings in weight by region (**a**: South, NC, and VA/MD) and by gear (**b**: gillnet, haul seine, trawl, pound net, and hook & line), 1980-1991.

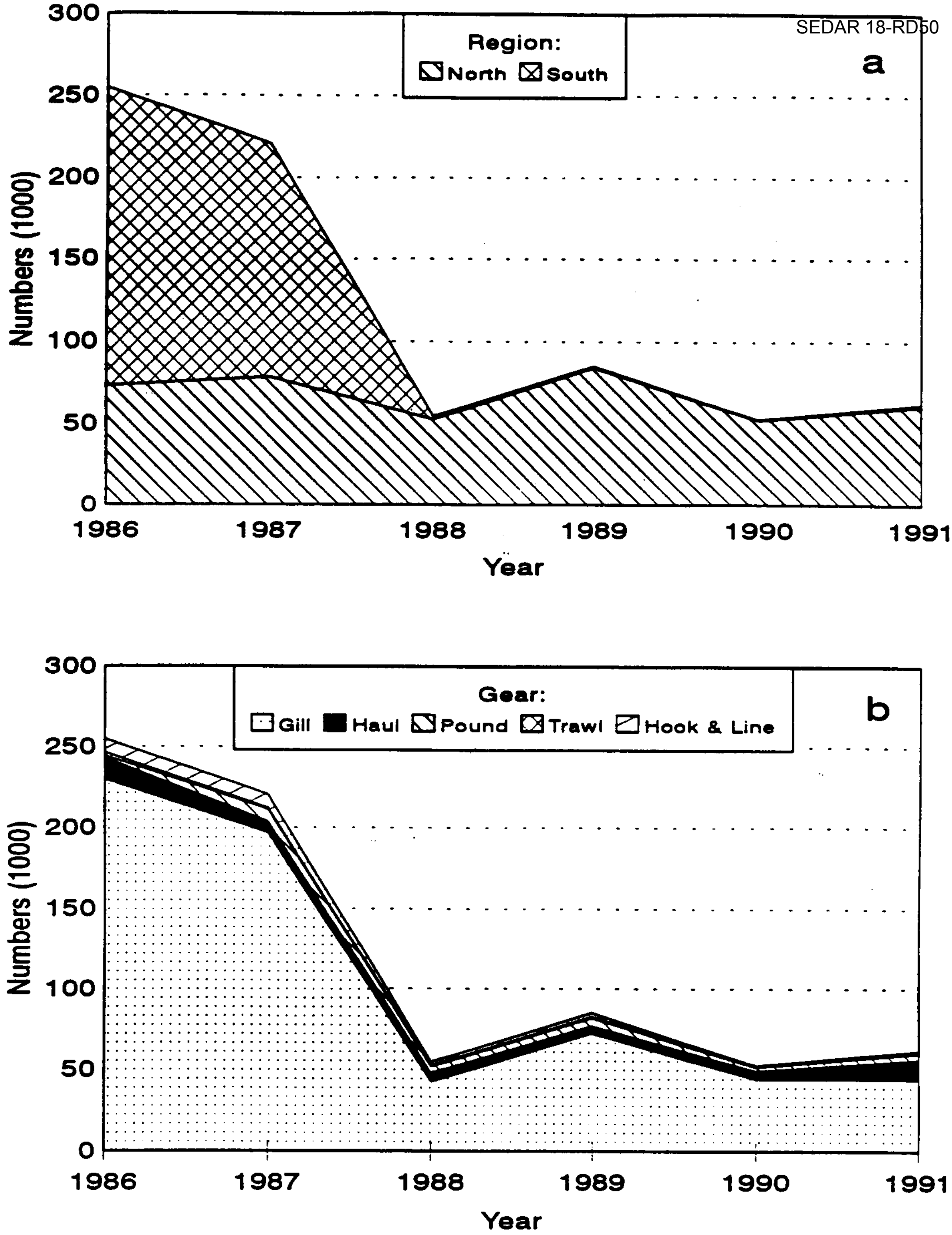



Figure 8. Atlantic red drum commercial landings in numbers by region (**a**: South, North) and by gear (**b**: gillnet, haul seine, trawl, pound net, and hook & line), 1986-1991.

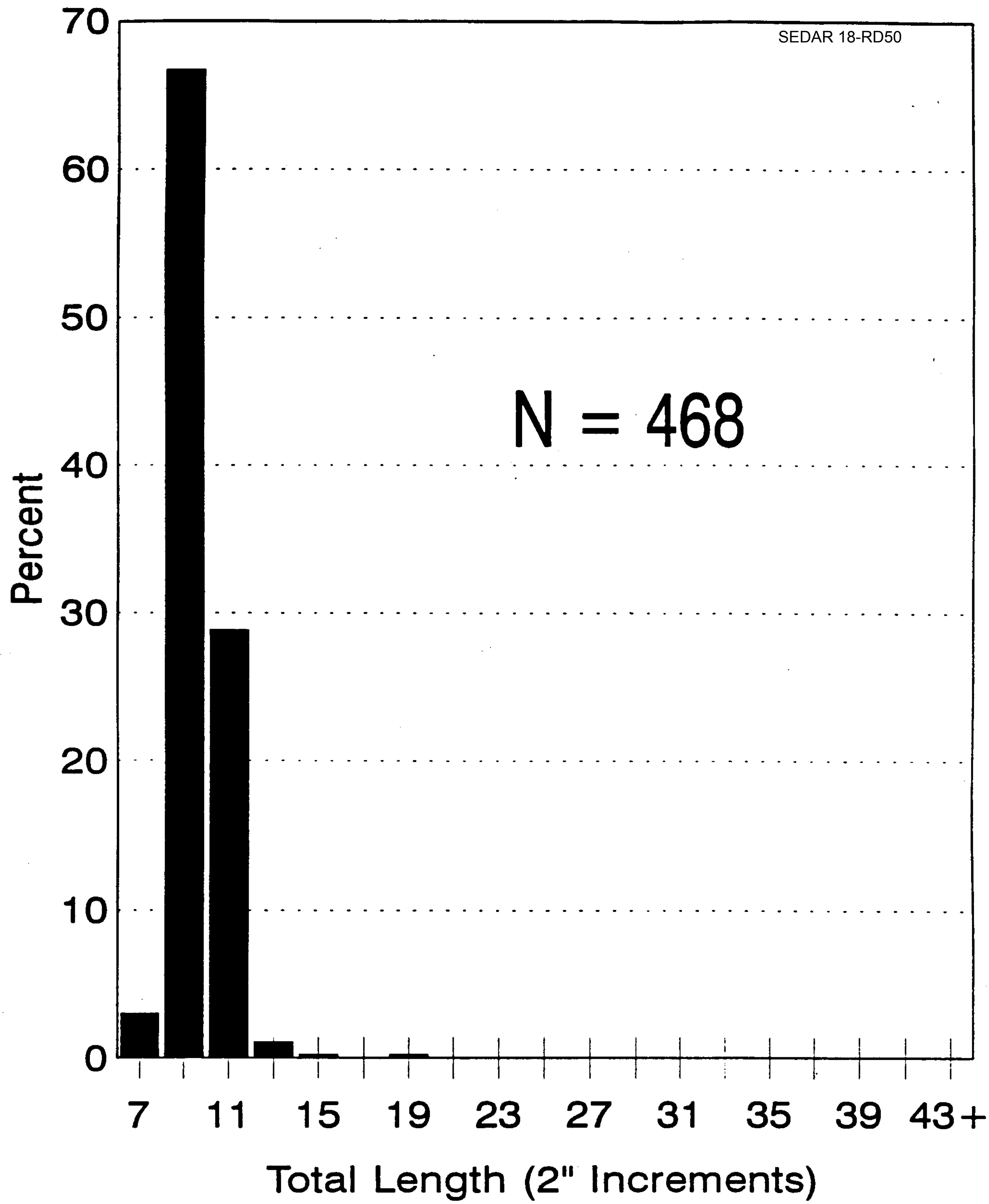



Figure 9. Georgia red drum gill net length frequency distribution combined over 1986-1988.

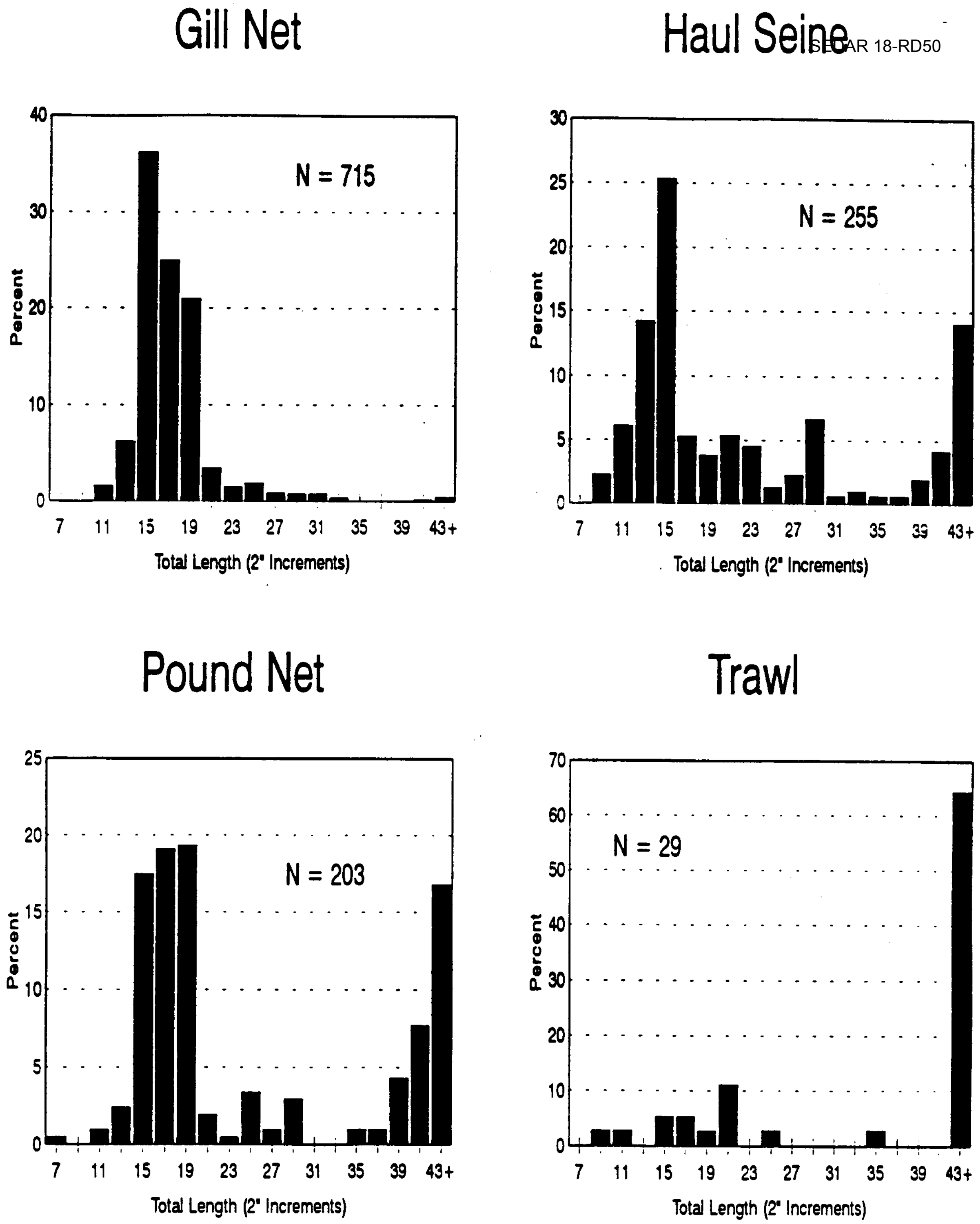



Figure 10. North Carolina red drum length frequency distributions by gear (gill net, haul seine, pound net, and trawl) combined over 1986-1991.

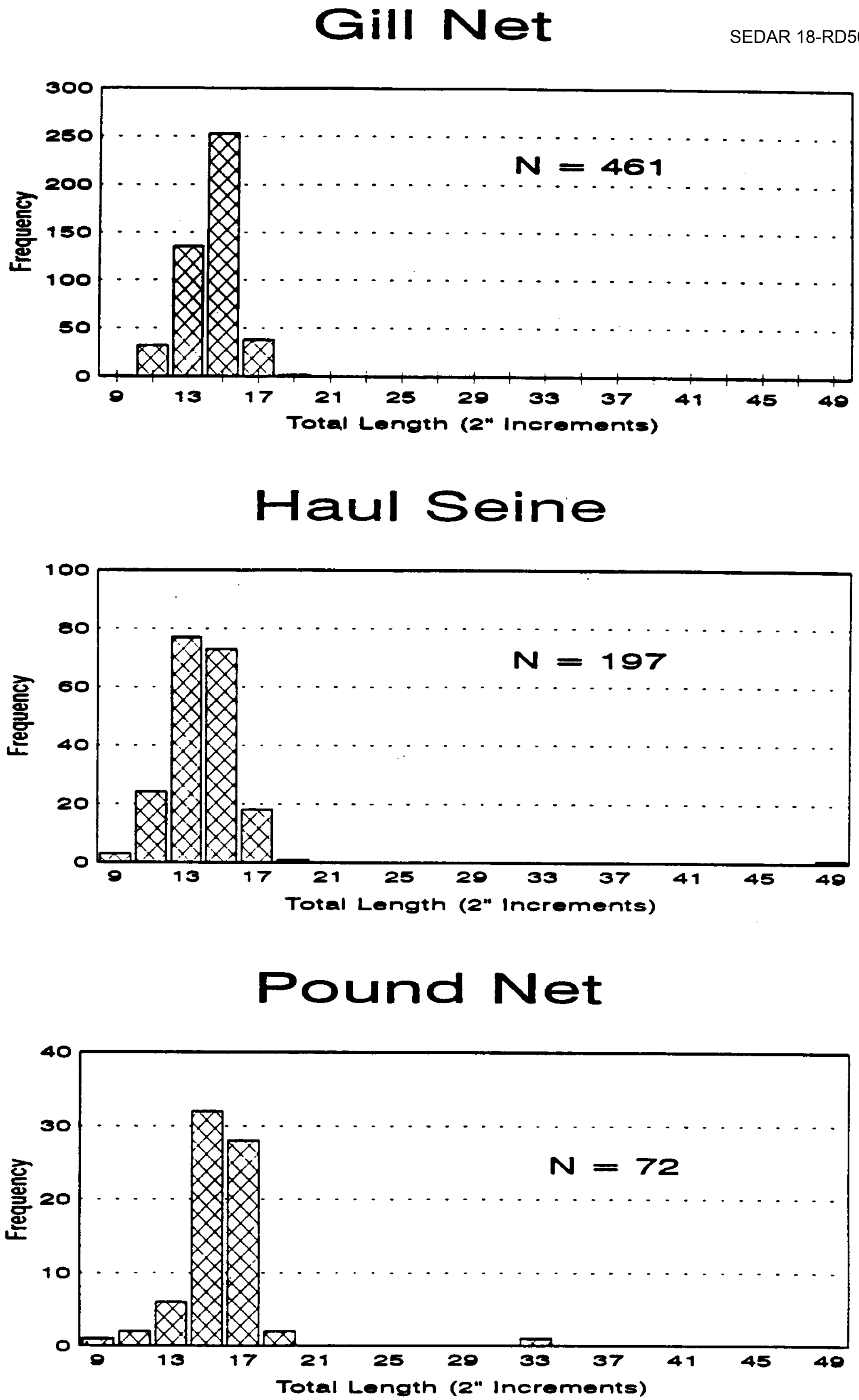



Figure 11. Virginia red drum length frequency distributions by gear (gill net, haul seine, and pound net) combined over 1989 and 1991.

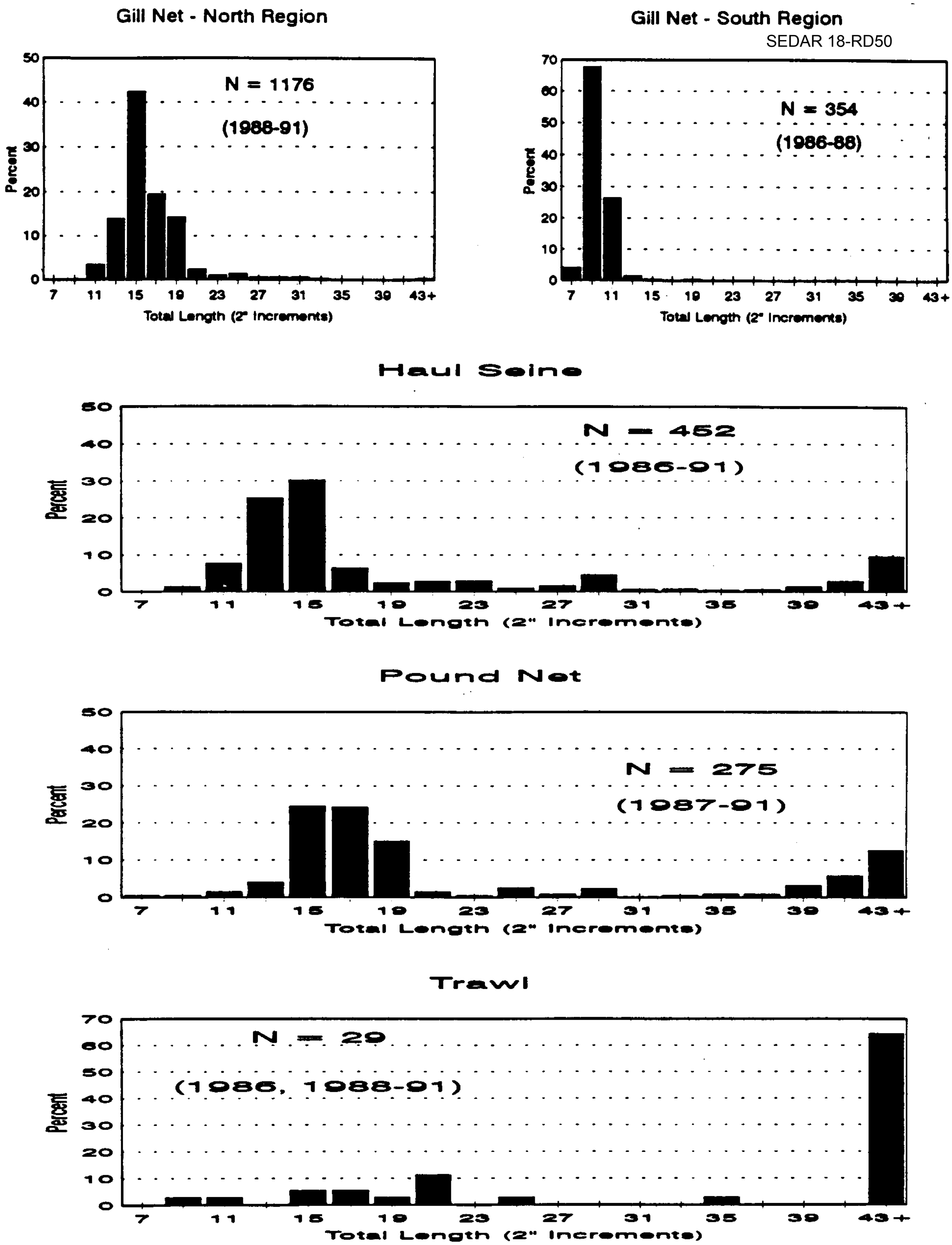



Figure 12. Commercial Atlantic red drum length frequency distributions by gear (gill net also by region) combined over 1986-1991.

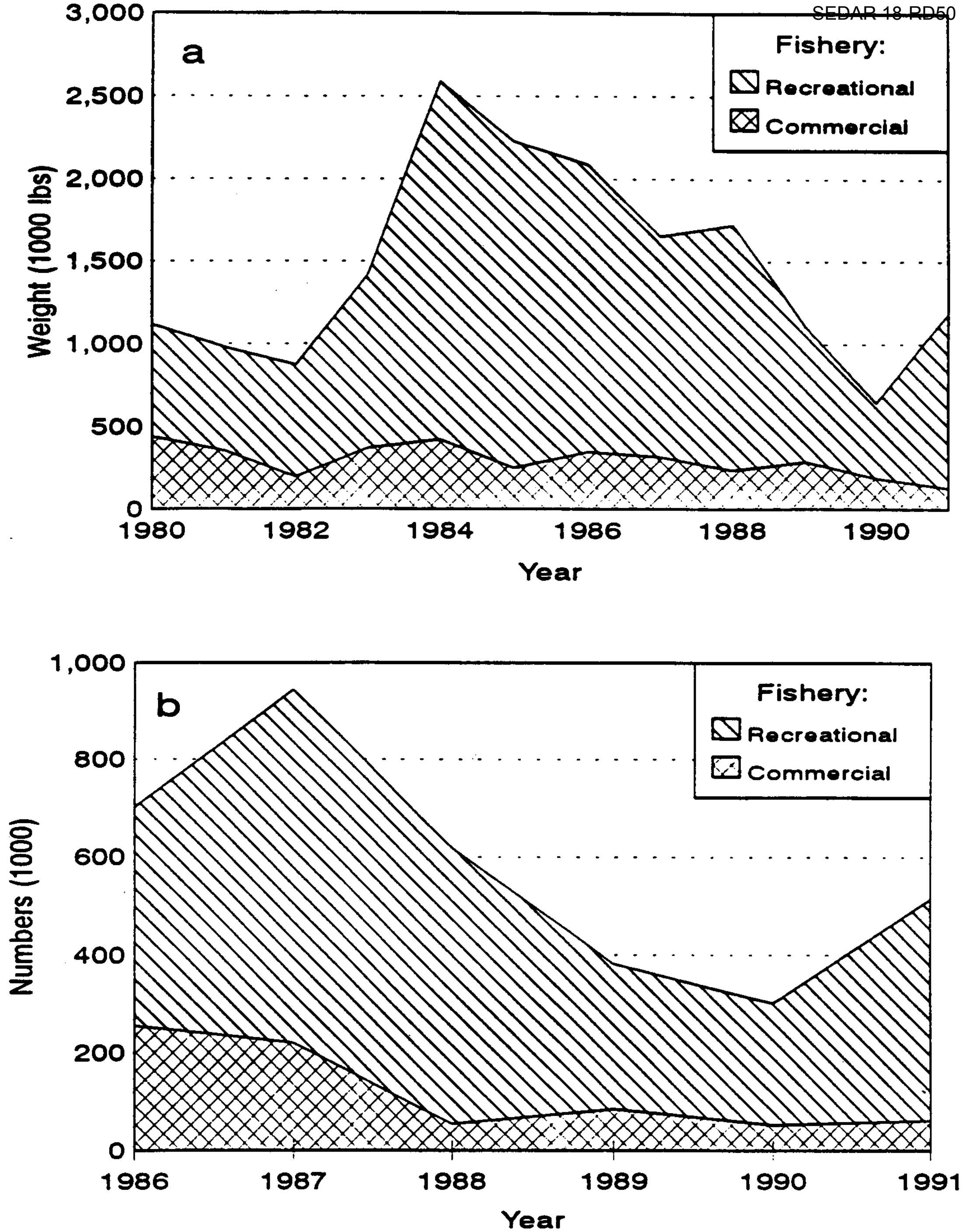



Figure 13. Total Atlantic red drum landings by fishery (recreational and commercial) in weight (1980-1991) and numbers (1986-1991).

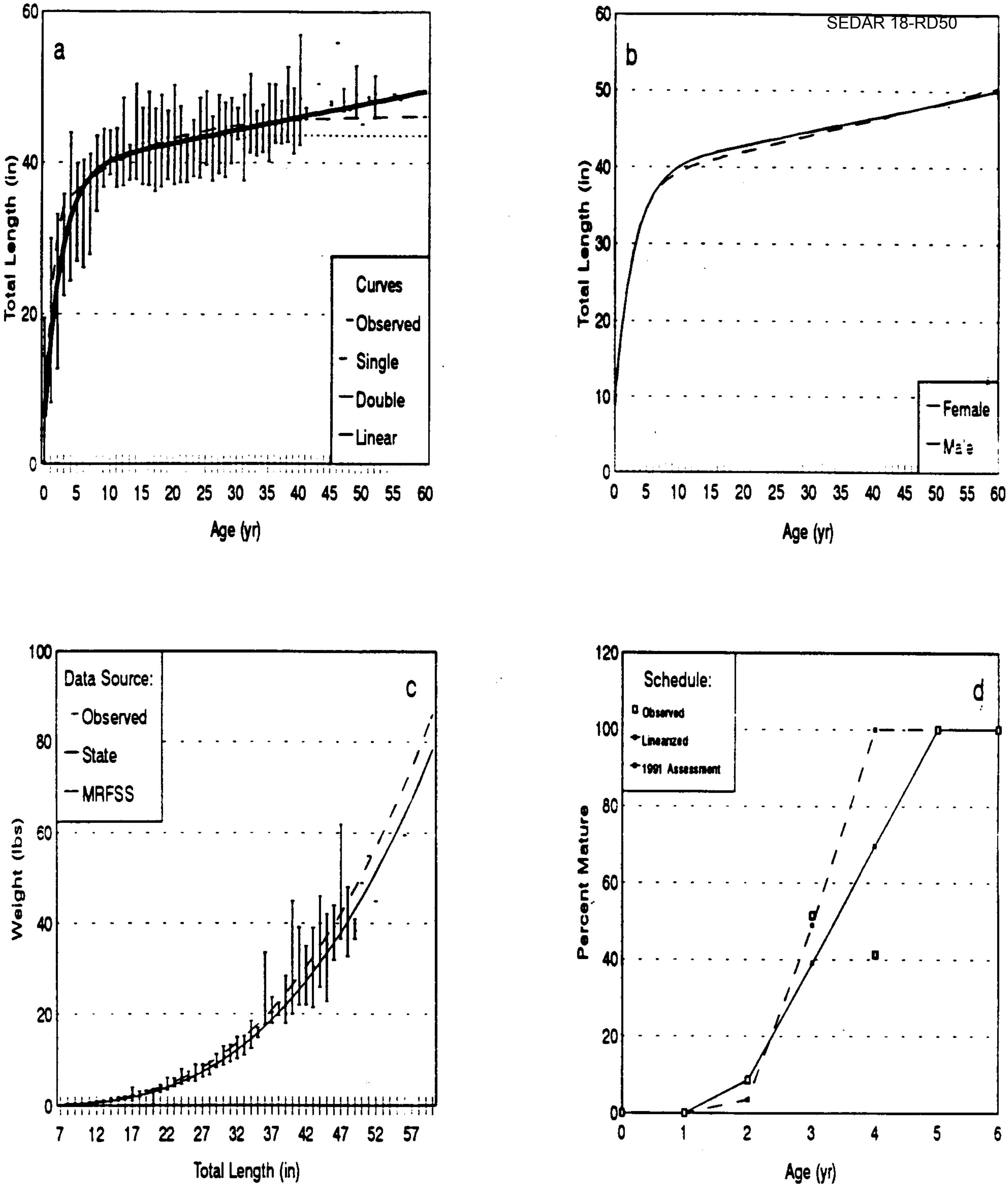



Figure 14. **Atlantic red drum growth curves (a,b), weight-length relationships (c), and female maturity schedule (d). Growth curves compared for three versions of the von Bertalanffy growth equation (single, double, and linear) with range of observed data (a). Linear von Bertalanffy growth equations are compared between sexes (b).**

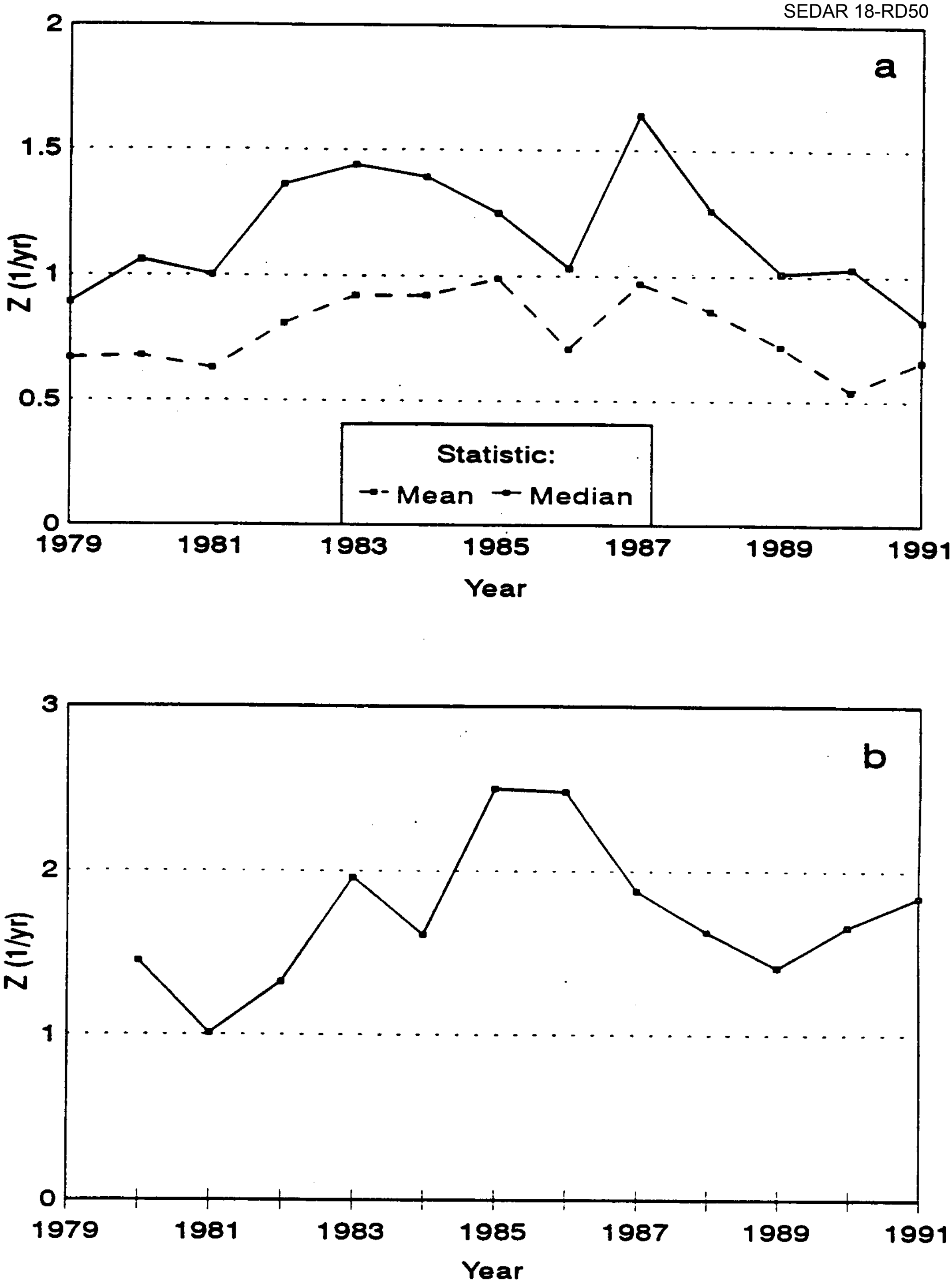



Figure 15. Length based (a) and catch curve (b) estimates of instantaneous total mortality for Atlantic red drum, 1979-1991.

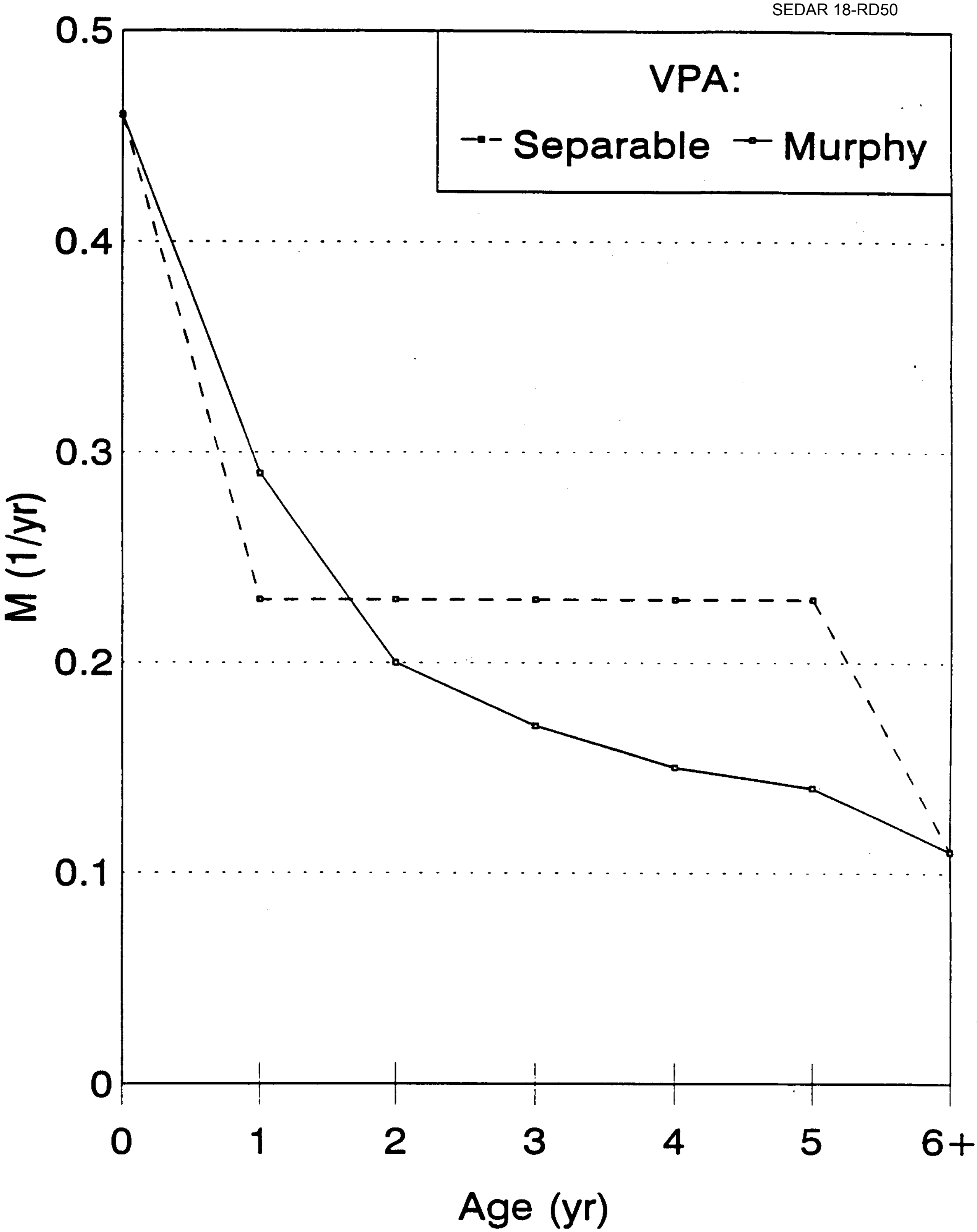



Figure 16. Estimates of age-specific instantaneous natural mortality rate, M, (Boudreau and Dickie 1989) for ages 0 through 5 and 6+ used in Murphy virtual population analysis (VPA), and mean of subadult M used for ages 1 through 5 in separable VPA for Atlantic red drum.

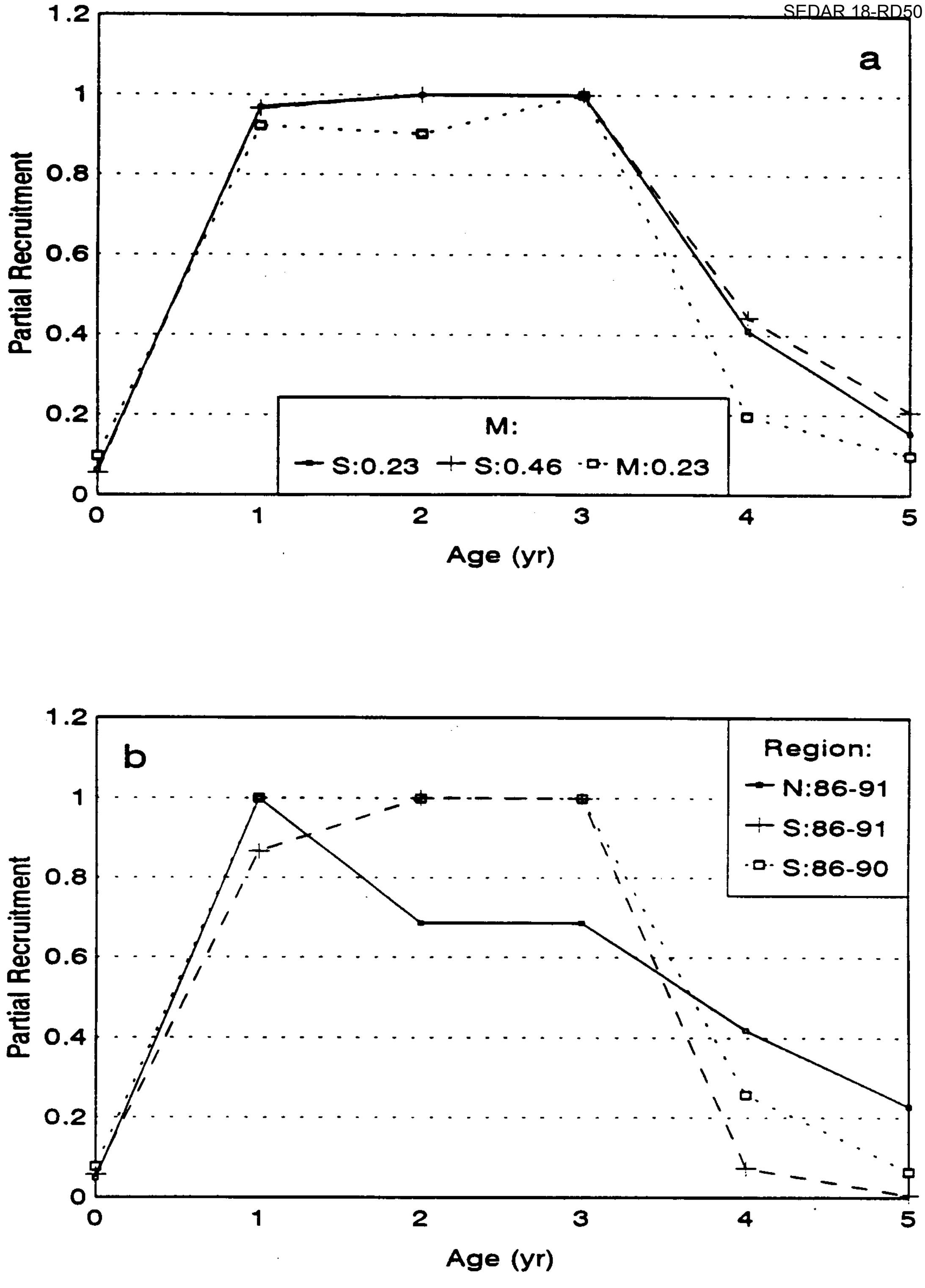



Figure 17. Partial recruitment of Atlantic red drum from separable virtual population analyses for coastal (**a**) and regional (**b**) catch matrices. South region catch matrix estimated for years 1986-1990 and 1986-1991 to test sensitivity to 1991 estimated catch in numbers at age.

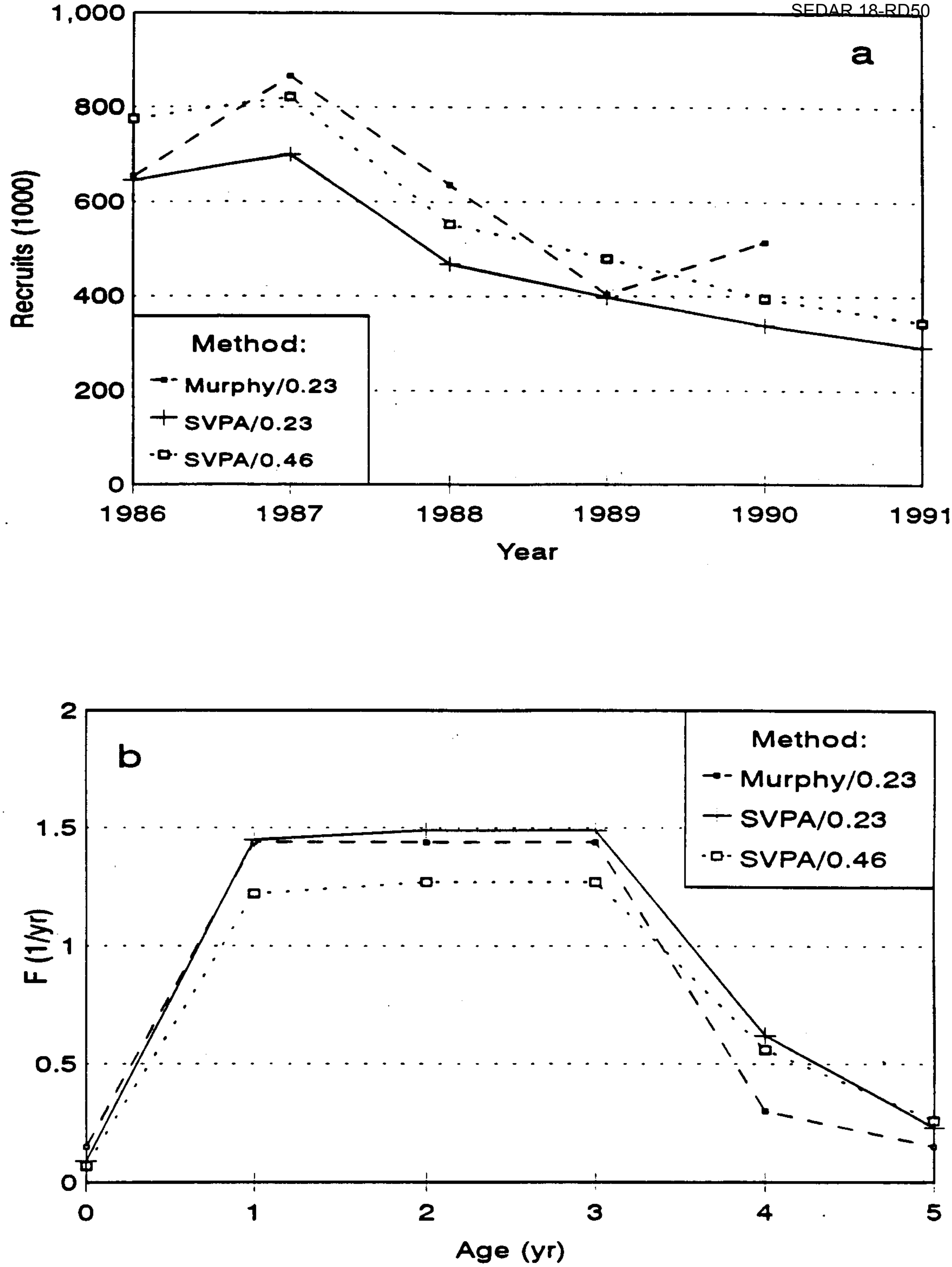



Figure 18. Estimates of recruits to age 1 (**a**) and age-specific instantaneous fishing mortality rates (**b**) of Atlantic red drum for Murphy and separable virtual population analyses (VPA). Two separable VPAs were conducted for two levels of instantaneous natural mortality rates, M (0.23 and 0.46).

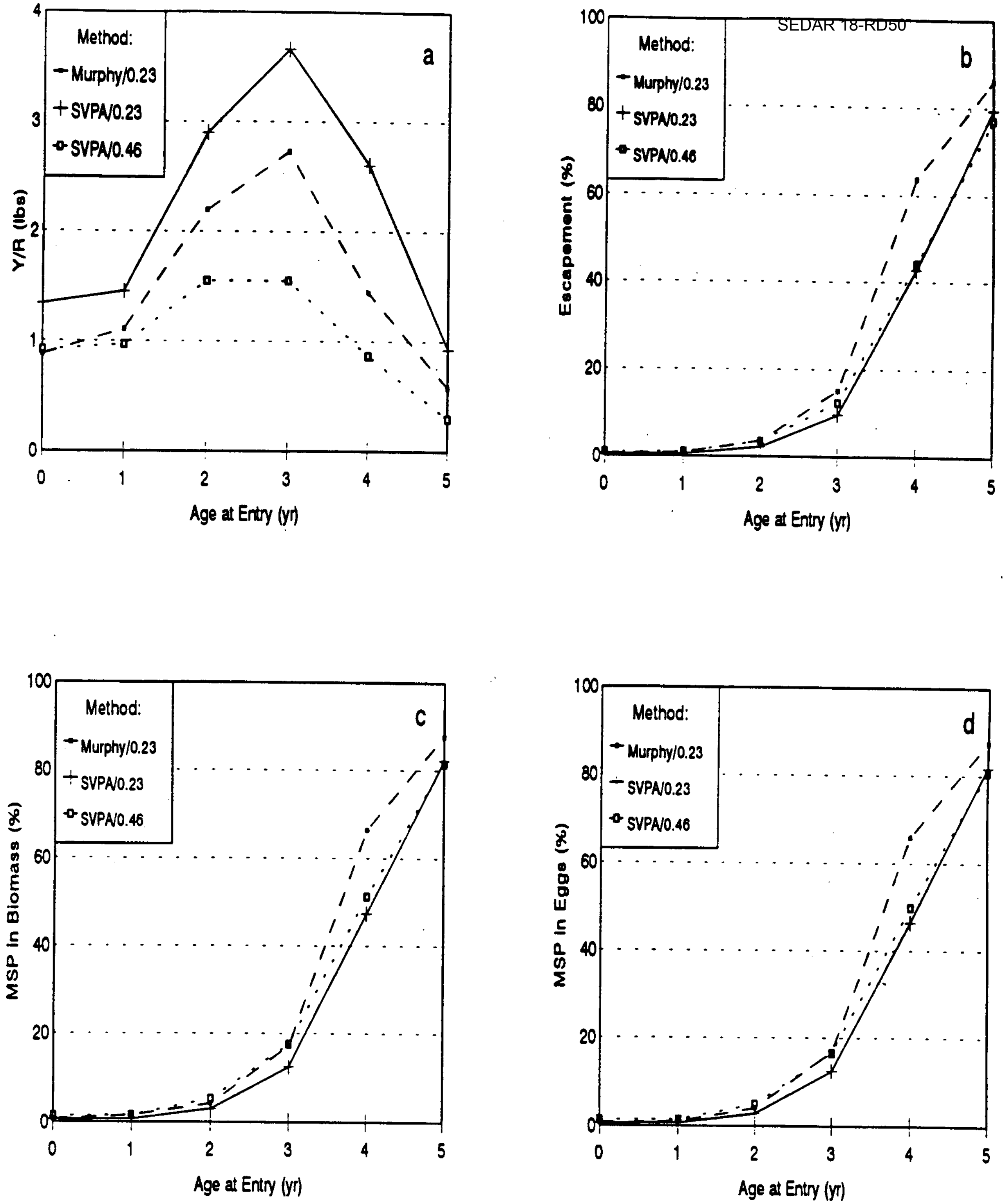



Figure 19. Estimates of yield per recruit (**a**), escapement to age 6 (**b**), and % maximum spawning potential in female biomass (**c**) and in egg production (**d**) for Murphy and separable virtual population analyses for Atlantic red drum with increasing age at entry. Two separable VPAs were conducted for two levels of instantaneous natural mortality rates, M (0.23 and 0.46).

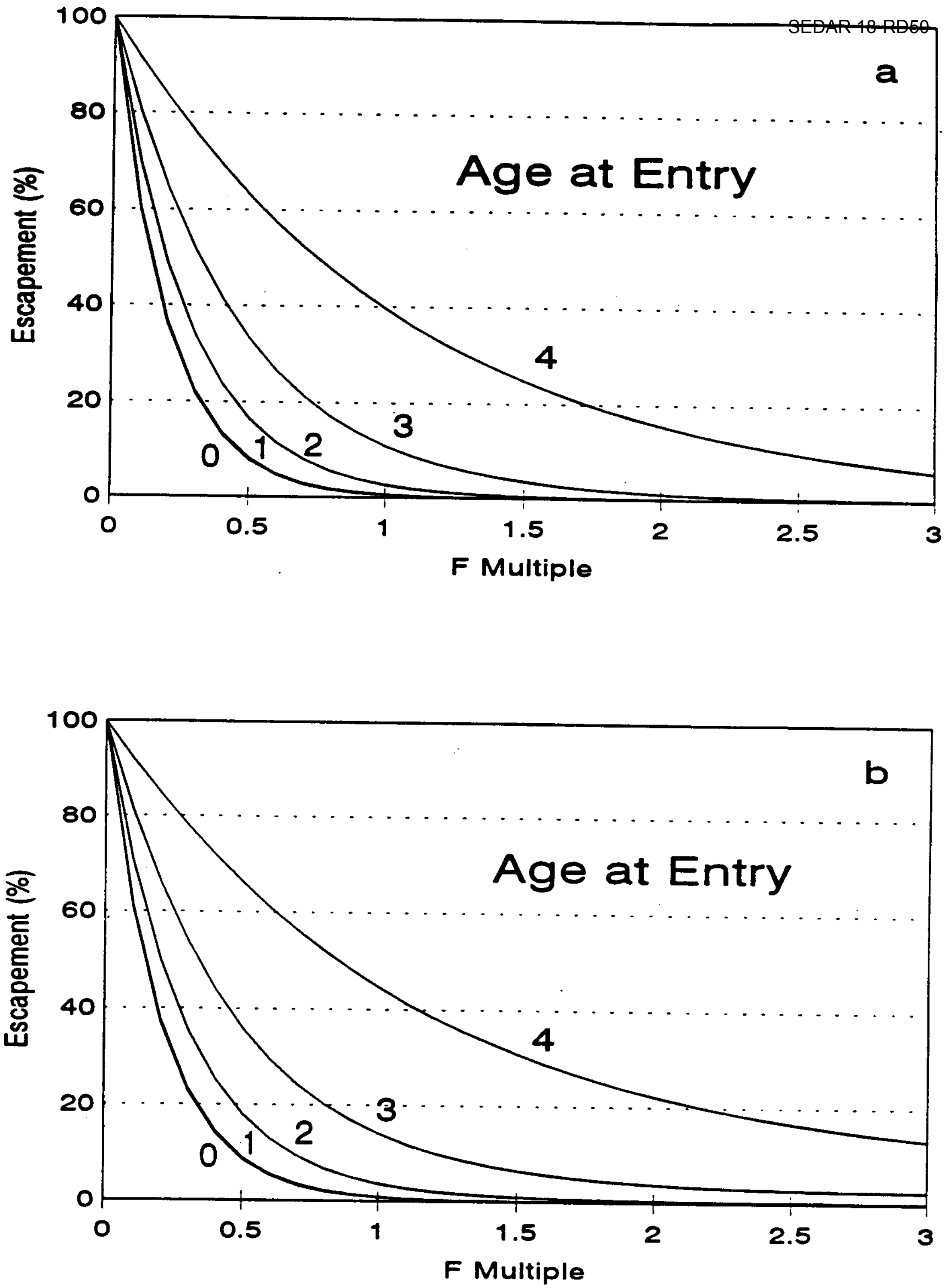



Figure 20. Estimates of escapement to age 6 (**a**) and % maximum spawning potential in female biomass (**b**) from separable virtual population analyses (M = 0.23) for Atlantic red drum with increasing age at entry.

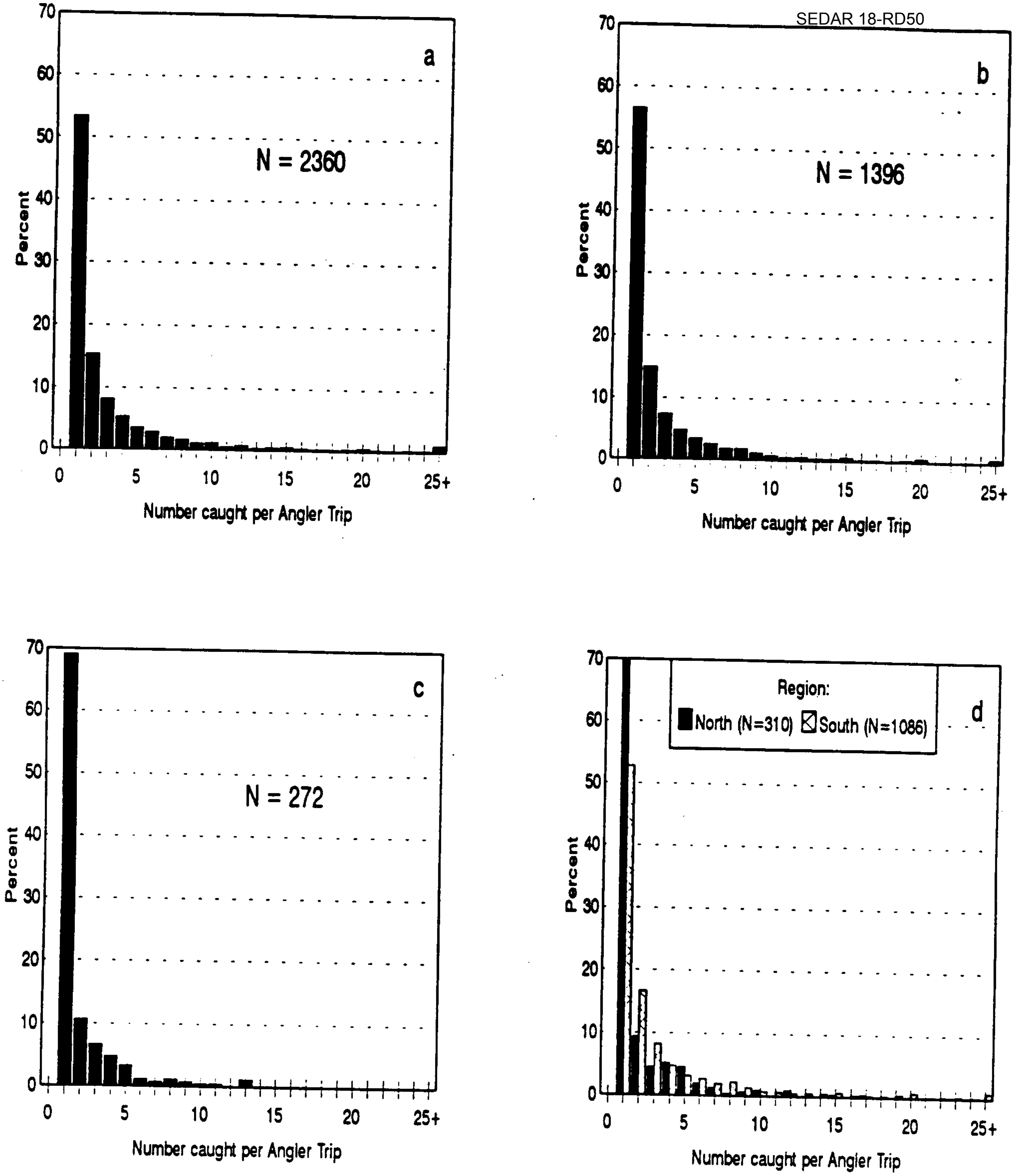



Figure 21. Estimated number of Atlantic red drum caught per angler-trip from the recreational survey for 1979-1991 (**a**), 1986-1991 (**b**), 1990-1991 (**c**), and by region for 1986-1991 (**d**).

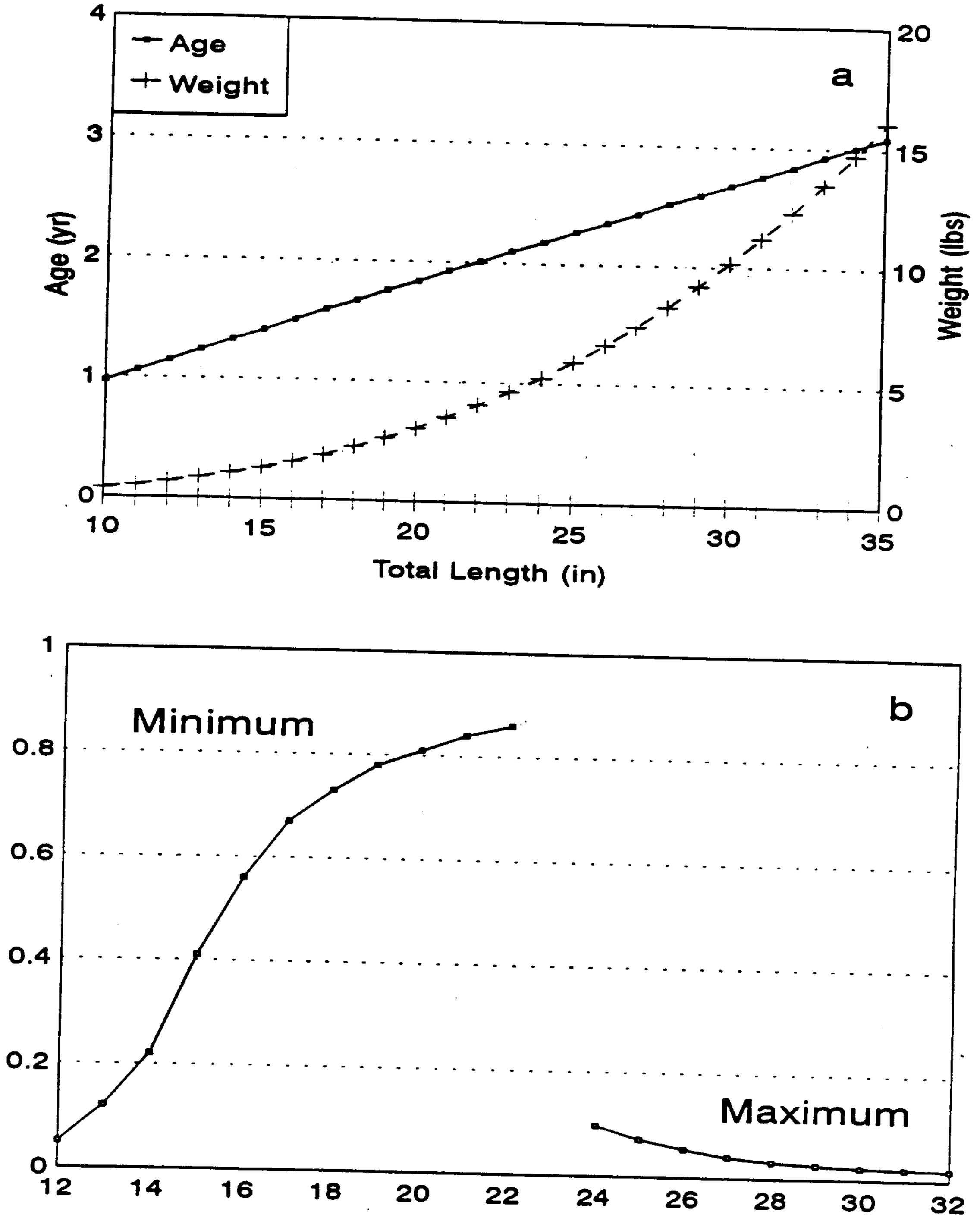



Figure 22. Age of subadult Atlantic red drum as a function of total length and weight (a) and proportion in numbers of red drum below given total length (minimum size limit) or above given total length (maximum size limit) (b).

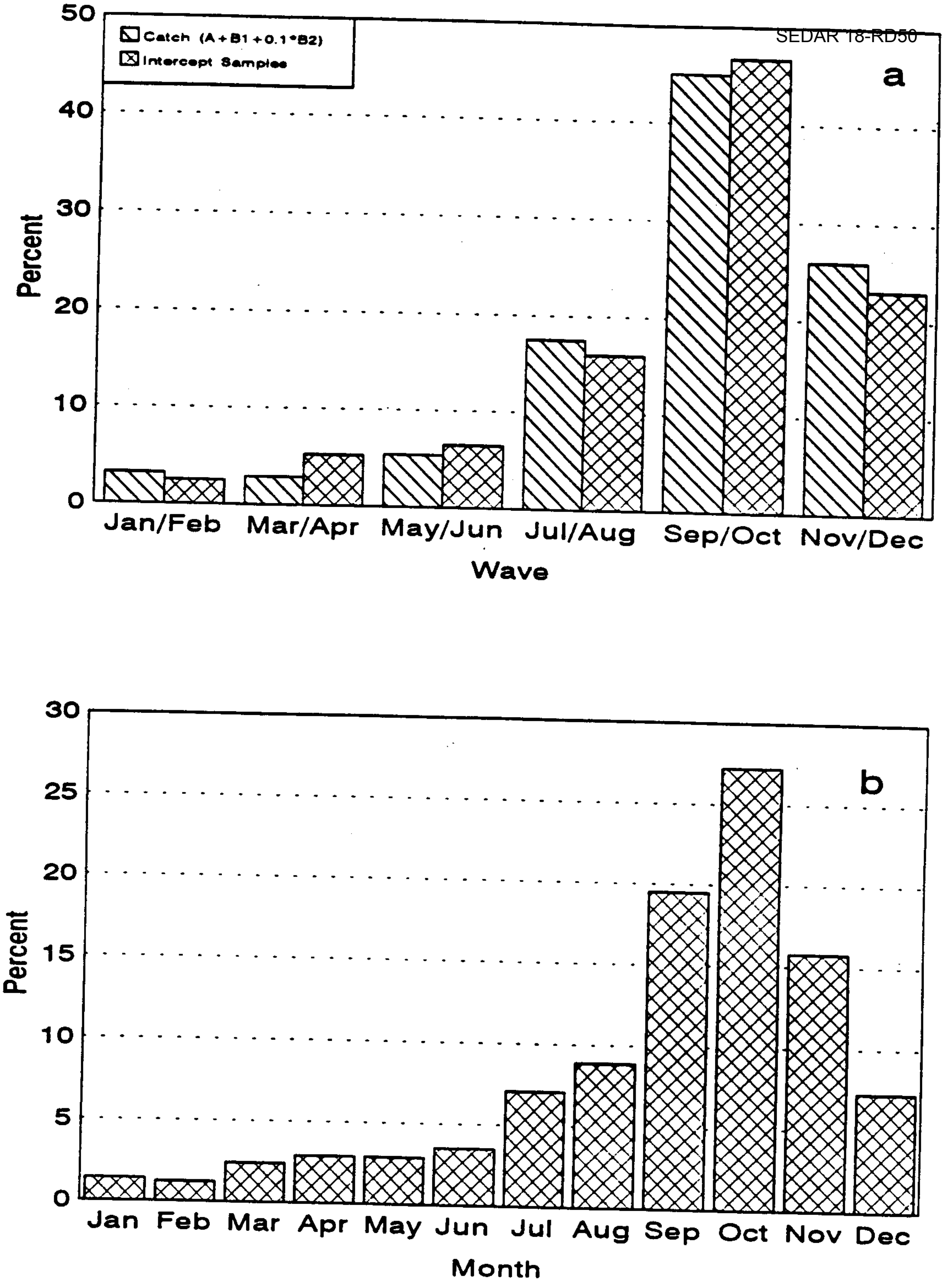



Figure 23. Catch in numbers versus number of intercept samples of Atlantic red drum from the recreational survey (**a**) and proportion of landings by month during 1986-1991 (**b**).