NOAA TECHNICAL MEMORANDUM NMFS-SEFC-297

# STATUS OF THE RED DRUM STOCK OF THE ATLANTIC COAST: STOCK ASSESSMENT REPORT FOR 1991

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U.S Department of Commerce
National Oceanic and Atmospheric Asministration
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Southeast Fisheries Science Center
Beaufort Laboratory
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U.S DEPARTMENT OF COMMERCE
Robert A. Mosbacher, Secretary
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
John A. Knaus, Administrator
NATIONAL MARINE FISHERIES SERVICE
William W. Fox, Jr., Assistant Administrator for Fisheries

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NOTICE

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Beaufort Laboratory
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 1990. This assessment updates data and analyses from the 1989 stock assessment on Atlantic coast red drum (Vaughan and Helser 1990). Since 1980, coastwide recreational catches ranged between 511,800 pounds in 1990 and 2,179,100 pounds in 1984, while commercial landings ranged between 186,400 pounds in 1990 and 422,100 pounds in 1984. In numbers of fish caught, Atlantic red drum constitute predominantly a recreational fishery (generally 80 to 95% by age 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].

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 assumptions (Vaughan and Helser 1990) of no fishing mortality on adults (ages 6 and older) and selection of a relatively high subadult natural mortality ($M_1$) of 0.5, causes a bias that tends to result in underestimates of fishing mortality. For subadult natural mortality of 0.5, escapement ranges between 0.8 and 1.5% while maximum spawning potential ranged between 1.4 and 2.4%. These estimates are only slightly below those obtained in the 1989 stock assessment. It needs to be reiterated that the 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.

To follow up on the management options investigated at the request of Council staff following the 1989 stock assessment (SAFMC 1990b; Appendix 1), a comparable analysis is provided using more recent data (specifically 1989-1990). Recreational fishery data (MRFSS) is 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 second 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) with two additional years of fishery data (1989-1990). Following submission of the 1989 assessment to the South Atlantic Fishery Management Council, three management measures, adopted by the Council, are 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 red drum stock 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.

Some of the questions raised by the SAFMC Plan Development Team and Red Drum Committee following completion of the first assessment are addressed in this assessment to the extent that data permit. In general, this assessment follows the outline of the 1989 stock assessment (Vaughan and Helser 1990). Catches from recreational and commercial sources for fishing years 1986-1990 are converted to catches in numbers at age using length frequency information and age-length keys. As before, the assessment is limited to the subadult phase (ages 0 through 5). Additional information on weight as a function of length and length as a function of age are estimated for use in the population level analyses. In addition to yield per recruit (Ricker 1975) and maximum spawning potential (Gabriel et al. 1989) analyses, estimates are also made of escapement to age 6 as defined in SAFMC (1990b; Appendix 1). As before, concern remains about the apparent reduced availability and/or emigration of red drum between age 3 and age 5, although sensitivity analyses are presented that explore the assumption that reduced availability/emigration begins following age 3 rather than during age 3. Finally, the effect of various management options (bag limits, size limits, and seasonal closures) on escapement to age 6 are investigated.

## DESCRIPTION OF THE DATA

Recreational landings and length frequency information were obtained from NMFS's Marine Recreational Fishery Statistic Survey (MRFSS; Essig et al. 1991). Because of the similarity between the 'MRFSS' and 'Alternate' scenarios on population level results compared in the previous assessment (Vaughan and Helser 1990), only the 'MRFSS' scenario is used in this assessment. Commercial landings collected by the Southeast Fisheries Science Center

(Florida through North Carolina) and by the Northeast Fisheries Science Center (north of North Carolina) were used in these analyses. Commercial length-frequency information by gear for 1989 and 1990 were obtained from the North Carolina Division of Marine Fisheries.

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. 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 degree which the data allows the temporal/geographic fishing to be subdivided in this conversion process, the greater the precision in the final coastwide estimates of red drum catch in numbers at age that is 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 632,500 pounds in 1981 to a peak of 2,179,100 pounds in 1984, and then declined to 511,800 pounds in 1990 (Table 1). The weight of the catches include all of the type A and B1 and 10% of the type B2 caught red drum. Definitions of these catch types as used by the MRFSS are given in footnote a to Table 1. When comparing type A and B1 catches (Fig. 1), most of the catches belong to type A caught fish for which direct measurements were available. The mean weight of type A red drum show no particular trend (Fig. 2), averaging about 2.6 pounds between 1979 and 1990.

Total recreational catches by number (A+B1+B2) show an increase importance of type B2 caught red drum in recent years (especially 1987 and 1988) (Fig. 3). 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) suggests that hook and release mortality of red drum may range from 8.4% when hooked in the maxilla area, 32.5% when hooked in the gill region, to 52.8% when hooked in the gut region. In Jordan's (1990) study most red drum were hooked in the maxilla area (about 77% of 513 red drum collected); thus, a value of 10% was used in the analyses that follow. Although catch in numbers are used directly in the subsequent analyses, catch in weight that includes 10% of the type B2 catch is shown in Table 1 using the ratio of the catch in weight of type A+B1 divided by the catch in numbers of type A+B1. 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.

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Recreational length frequency distributions for 1979-1988 are presented in Vaughan and Helser (1990). Length frequency distributions for 1989-1990 are included in this report (Figs. 4c and 5c), and are in 2 inch increments with the mid-point plotted on the x-axis, which correspond approximately to the 50 millimeter increments used in the 1989 assessment. As in the earlier report, the Atlantic coast has been subdivided geographically at the South Carolina/North Carolina border. Hence, annual length measurements from above this border are pooled without a weighting factor to represent the length frequency for the 'north' (Figs. 4a and 5a), while annual length measurements from below this border are also pooled without a weighting factor to represent the length frequency for the 'south' (Figs. 4b and 5b). These are applied separately to corresponding catch estimates (and single annual age-length key) to estimate catch in numbers at age. In the earlier assessment, all lengths were converted to fork length in millimeters based on equations in Murphy and Taylor (1990). Because management options are presented to the public in total length in inches, this assessment has converted all lengths to total lengths in inches (and weight from kilograms to pounds).

## 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 1980-1990 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 (55% to 98% by weight), except in 1981 and 1982 when 71% and 73% of the commercial landings occurred in Florida. Beginning in 1985, Florida's commercial landings declined, and were virtually non-existent after 1987. North Carolina's share of commercial landings have exceeded 95% since 1988. As reported in the previous assessment, North Carolina's commercial fishery for red drum is a bycatch fishery.

In the earlier assessment, commercial gears were collapsed into three primary categories due to limited data. Landings for these categories are shown in Fig. 7a. Use of commercial length frequencies for these primary categories for 1986-1988 are as described in Vaughan and Helser (1990). Additional length frequency data from North Carolina in 1989 and 1990 permitted the category labelled as pound nets to be further subdivided into pound/trawl and haul seine (landings for four categories summarized in Fig. 7b). Catch in numbers for years 1986-1990 are compared for the three primary categories in Fig. 8. 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 assessment. Commercial length frequency distributions by gear for 1989 and 1990 are shown in Figs. 9 and 10. Recreational length frequency distributions for

1989 and 1990 are applied respectively to commercial hook and line landings for those years (note the relative insignificance of these landings to total landings).

Since 1980, relatively small but constant commercial landings and higher and more variable recreational landings have been made (Fig. 11a). Since 1986, both recreational and commercial landings in numbers of red drum have generally declined (Fig. 11b).

## STOCK CHARACTERIZATION

Aspects of the biology of red drum can be found in the Atlantic Coast Red Drum Fishery Management Plan (SAFMC 1990b). In this section, updated biological information not included in that document or in the 1989 stock assessment 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 the Chesapeake Bay since 1950. Management units of red drum include U.S. Atlantic and Gulf of Mexico stocks. The life histories of Gulf and Atlantic stocks of red drum are very similar. 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 the 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, reduced availability presumably due to movements offshore is noted.

**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. As in the 1989 stock assessment, the double von Bertalanffy growth curve (Condrey et al. 1988) is used for red drum using a non-linear iterative least squares approach [PROC NLIN, SAS Institute Inc. (1987)]. Data sets of aged fish were available during 1986-1990 from Georgia Department of Natural Resources, South Carolina Wildlife and Marine Resources Division, and North Carolina Division of Marine Fisheries, with the preponderence of specimens being ages 0 to 3. Regression fits using both the single and double von Bertalanffy growth curves are summarized by state and for the coastwide in Table 2 (using age in years and length as total length in inches). The double von Bertalanffy growth curve is able to fit the rapid growth at earlier ages, while adequately describing the slower growth in later years (Fig. 12). This formulation joins two single von Bertalanffy growth curves with a common $L_{inf}$ into a continous curve at some transition age ($t_x$) defined as:

$$t_x = (k_2*t_{02}-k_1*t_{01})/(k_2-k_1), \qquad (2)$$

Data less than or greater than the transition age were fit by the appropriate equations using the statements:

if $t < t_x$, then $L_t = L_{inf}*(1 - \exp(-k_1*(t-t_{01})))$, and
if $t > t_x$, then $L_t = L_{inf}*(1 - \exp(-k_2*(t-t_{02})))$

where $L_{inf}$ = asymptotic total length of the average fish in the population, $k_1$ = growth rate for fish in the population less than the transition age, $k_2$ = growth rate for fish in the population greater than the transition age, $t_{01}$ = theoretical age at which length is 0 for fish less than transition age, and $t_{02}$ = theoretical age at which length is 0 for fish greater than transition age. In the coastwide model the transition age ($t_x$, Eq. 2) was computed to be approximately age 5.9. Parameters from the coastwide model are used in later population analyses to represent the growth of red drum during the period 1986-1990.

In April 1990, unpublished data collected by William Foster, while a graduate student at North Carolina State University, was made available through the South Atlantic Fisheries Management Council. Red drum were collected by Foster on Hatteras and

Ocracoke islands of North Carolina between Avon and Ocracoke Inlet from 1969-1971. About 230 red drum were aged using otoliths. Obvious from Table 2 is the much larger estimate of $t_x$ for this early data set compared to estimates from the late 1980's. With respect to the double von Bertalanffy growth equation, $L_{inf}$ and $k_2$ estimates are similar between Foster's data and the more recent North Carolina data. However, the subadult growth rate parameter ($k_1$) is smaller for Foster's data than the more recent North Carolina data.

Age-length keys are used in the decomposition of catch in numbers by length category into catch in numbers at age. Using the observed data sets of aged fish from the North Carolina Division of Marine Fisheries, South Carolina Wildlife and Marine Resources Division, and Georgia Department of Natural Resources, age-length keys were developed directly for 1989 and 1990 (Table 3). Age-length keys for 1986-1988 are given in Vaughan and Helser (1990). 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. 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 recreational and commercial fisheries from 1986-1990 (Table 4) were calculated by multiplying length-frequency distributions by age-length keys. It appears that red drum less than age 1 are not yet fully recruited into the recreational or commercial fishery. These data suggest that the recreational fishery for red drum exploits mostly ages 1 and 2 red drum, although large number of age 0 red drum were caught during the period 1980-1985. The commercial fishery exploits generally younger red drum than the recreational fishery, largely age 1 red drum, with declining catches of age 0 red drum.

## 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. As in Vaughan and Helser (1990; Table 8), length-length relationships presented in Murphy and Taylor (1990) formed the basis of all such transformations.

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 MRFSS data for years 1986-1990 is used in subsequent analyses (Table 5 and Fig. 13).

## 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. These estimates are very similar to those used in the 1989 stock assessment (0.52 and 0.61, respectively).

Additional maturity information on red drum sampled in South Carolina and North Carolina is combined with the South Carolina information to produce a mean female maturity schedule representative of the period 1985-1989 (Fig. 14). 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, 3.5% female red drum are mature at age 2, 49% female mature at age 3, and all female red drum are mature at age 4 and older.

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):

$$\log_{10} N = 3.6976 + 0.0050\,(SL),\ r^2 = 0.95,\ n = 22. \qquad (3)$$

## 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):

$$(1\text{-}A) = S = N_1/N_0 = e^{-Z}, \qquad (4)$$

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 are most often obtained using a catch curve analysis where the natural logarithm of the catch is regressed against age for the ages at and 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 (1980-1990; Table 4) for ages 1 through 3 (Table 6). 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. Estimates of Z range from 1.04 in 1981 to 2.57 in 1986. 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 (1986-1990; Table 4). These estimates of Z range from 1.52 in 1990 (ages 1-5) to 2.57 in 1987 (ages 1-4).

Additional coastwide estimates of Z are obtained from the combined recreational/commercial catch at age data (1984-1988 year classes; Table 4) by following a single year class or cohort through its estuarine residence (through age 5). 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 2.57 for the 1984 year class (ages 2-5) to 1.70 for the 1988 year class (ages 1-2). Although only a small difference is noted in estimates of Z for the 1985 year class between using ages 1-5 (1.88) and ages 1-3 (1.90), a larger difference is noted in estimates of Z for the 1986 year class between using ages 1-4 (1.82) and ages 1-3 (2.09).

## 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 when 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 0.51 and 0.17, respectively. These estimates are slightly higher than those estimates determined for the 1989 stock assessment (0.44 and 0.13, respectively), because of the new estimates of $L_{inf}$, $k_1$, and $k_2$. In addition, an estimate of M (assumed constant over all ages) was made based on Hoenig (1983). Given a maximum age 55 for an unfished stock, M equals 0.075.

Estimates of Z are also available from some individual states. Pafford et al. (1990) obtained estimates of Z in the St. Simons system ranging 1.26 to 3.23 based on tagging, and estimates of 1.13 to 2.96 from catch curves applied to fishery independent collections throughout Georgia. Estimates of Z for North Carolina range 1.44 to 2.76 based on tagging, and range 1.56 to 2.88 based on catch curves from MRFSS data for North Carolina and Virginia (Ross, pers. comm.).

**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 1990. 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 parallels the cohort-based analyses made in the 1989 stock assessment. This approach is based on Murphy (1965) and uses the approximate estimate of $M_1$ (0.5) for subadults based on Pauly (1979). As in the 1989 stock assessment, 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 mean of four cohort-based estimates of Z (year classes 1985-1988 in Table 6) was used to start the VPA for year classes 1986-1988 (F = Z - M = 1.43 with

M = 0.5). Starting F (at age 3) for earlier year classes (1983-85) were obtained using the linking assumption of Murphy (1965) such that F for age 2 is assumed equal to F for age 3 in the same fishing year. Mean age specific F for these analyses are summarized in Table 7 under the column labeled 'Linked Murphy'.

The second type of virtual population analysis used is based on a separability assumption described in Doubleday (1976). This method assumes that age/year specific F can be decomposed or is '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 3 from 1986-1989 with three levels of natural mortality for subadults (0.1, 0.3 and 0.5). Pope and Shepherd (1982) recommend specifying the reference age as that age with the greatest number of fish caught (age 1). Using this recommendation and assuming a flat topped partial recruitment causes F for age 1 and 3 in the same fishing year to be the same. Starting F is based on a Z of 1.7 (mortality from 1988 year class - age 1 in 1989 and age 2 in 1990; Table 6). To obtain estimates for ages 4 and 5, Murphy's (1965) forward calculations were used given F for age 3 obtained from the Separable VPA. Mean age specific F for these sets of Separable VPA with three levels of subadult M are summarized in Table 7 under the three columns labelled 'Separable'.

Annual results from all four VPA computer analyses (1 Linked Murphy and 3 Separable) are compared with respect to estimates of recruitment to age 1 (Fig. 15) and age specific estimates of F (Fig. 16). Recruitment to age 1 was relatively high during 1986-1988 (700,000 to 1,100,000 recruits). The lower estimates of recruitment in 1989 (340,000 to 460,000 recruits) are more sensitive to the starting values used in the VPA process. Age specific estimates of F are generally low on age 0 red drum (only partially recruited), high on ages 1-3 (fully recruited), declining for age 4, and very low for age 5.

Separate sets of all VPA computer analyses were made using age 2 instead of age 3 as the pivotal age (both Linked Murphy and Separable). The intent was to compare mean age specific estimates of F between the two pivotal ages. However, with very few exceptions, forward calculations from age 2 quickly diverged to unacceptably high values (F exceeding 10). This instability in the VPA forward calculations when using the pivotal age 2 suggests that catches in number for age 3 are relatively high compared to ages 1 and 2, and therefore do not suggest any significant reduced availability at age 3 from emigration.

## POPULATION MODELS

Several population models are applied 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.

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 double von Bertalanffy growth equation (Table 2), the overall weight-length relationship (Table 5), and age-specific fishing mortality rates (F) (Table 7).

Reiterating from the 1989 stock assessment, 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 parameters estimates, and in some cases ranges of estimates, that are available in the model analyses that follow.

Yield per recruit increases with age at entry to the fishery until about age 3, and then declines through age 5 (Fig. 17). 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 0.1, Y/R rose from 1.6 lbs with an age at entry of 0 to 7.5 lbs with an age at entry of 3. Meanwhile, for an $M_1$ of 0.5, Y/R rose from 0.9 lbs with an age at entry of 0 to 1.8 lbs with an age at entry of 3. 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 0.5 than to 0.1, estimates of Y/R based on $M_1$ of 0.5 are likely to be more realistic.

**Escapement**

As a follow up to the 1989 stock assessment, an investigation was requested concerning 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 (SAFMC 1990b; Appendix 1). For the purposes of 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.,

$$E \;=\; \Pi\, R \exp(-(M_1+F_t) / \;\Pi\, R \exp(-M_1) \;=\; \Pi \exp(-F_t), \qquad (5)$$

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, declines with increasing multiples of fishing mortality (Fig. 18). Escapement for greater ages at entry decline more slowly. A series of contour plots of escapement (Figs. 19-22) show how escapement varies with ranges of age at entry (0 to 5 yr) and F multiples (0.1 to 2.8 times the F vectors summarized in Table 7). Escapement for age at entry of 0 yr and F multiple of 1 are summarized in Table 7. Escapement is estimated as low as 0.2% for $M_1$ = 0.1 (based on Separable VPA), and as high as 1.5% for $M_1$ = 0.5 (based on Linked Murphy VPA).

A series of computer analyses was made in which increasing emigration at age 3 was assumed by simply subtracting from $F_3$ a fixed amount ($E_3$) to test the sensitivity of population estimates to the questions raised concerning emigration at age 3. This fixed amount was varied from 0 (no emigration at age 3) up to 0.7 (closed to the value of $F_3$ for $M_1$ = 0.5). Based on the Separable VPA's, escapement increased from 0.8% to 1.6% when $M_1$ = 0.5 ($M_2$ = 0.17) with increasing emigration rate at age 3, and escapement increased from 0.4% to 0.8% when $M_1$ = 0.3 ($M_2$ = 0.135) (Fig. 23).

**Maximum Spawning Potential**

Confusion over terminology has arisen with this modeling approach. 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). Other labels have been applied to this ratio including spawning stock biomass per recruit (SSB/R) (SAFMC 1990a,b), spawning stock ratio (SSR) (Vaughan and Helser 1990), and spawning potential ratio (SPR) (Goodyear 1989). To reduce the level of confusion, the original nomenclature from Gabriel et al. (1989) is used in this assessment.

As in the 1989 stock assessment, 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 i ($B_t$) as follows:

$$B = \Sigma B_t = \Sigma N_t * S_t * W_t * P_t, \qquad (6)$$

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 stock assessment, 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. 3 (Overstreet 1983) to estimate an age-specific index of egg production ($E_t$) and substitute this for $W_t$ in Eq. 6, as suggested by Goodyear (1989).

As with the yield per recruit analysis, a range of natural mortality rates are used: 0.1 to 0.5 for subadults and 0.10 to

0.17 for adults. The assumption from the 1989 stock assessment 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. In addition estimates of sex ratios, schedules of female maturity, and fecundity relationships are needed.

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.

Corresponding to plots for escapement are similar contour plots for percent maximum spawning potential based on female biomass and egg production (Figs. 19-22). 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 increases from 0.3% for $M_1$ = 0.1 (based on Separable VPA) to 1.9% for $M_1$ = 0.5 (based on Linked Murphy VPA). Based on egg production, %MSP similarly increases from 0.4% for $M_1$ = 0.1 (based on Separable VPA) to 2.4% for $M_1$ = 0.5 (based on Linked Murphy VPA). %MSP based on egg production tends to produce higher estimates than %MSP based on female biomass, and both types of estimates of %MSP produce higher estimates than escapement.

Concern was indicated about the sensitivity of %MSP to variability in adult $M_2$ (Fig. 24). To address this, a series of analyses were made with a range of values for $M_2$ with the sets of fishing mortality rates based on the Separable VPA for $M_1$ = 0.3 and 0.5. For $M_1$ = 0.3, %MSP (based on egg production) increases from 0.8% with $M_2$ = 0.1 to 1.1% with $M_2$ = 0.2.

Corresponding to the sensitivity analyses made for escapement, increasing emigration at age 3 was assumed by simply subtracting from $F_3$ a fixed amount ($E_3$). This fixed amount was varied from 0 (no emigration at age 3) up to 0.7 (closed to the value of $F_3$ for $M_1$ = 0.5). Based on the Separable VPAs, %MSP (based on egg production) increased from 2.2% to 3.0% when $M_1$ = 0.5 ($M_2$ = 0.17) with increasing emigration rate at age 3, and %MSP increased from 0.9% to 1.4% when $M_1$ = 0.3 ($M_2$ = 0.135) (Fig. 25).

## MANAGEMENT CONSIDERATIONS

An evaluation of a range of potential management options is updated from the 1989 stock assessment and Appendix 1 in SAFMC (1990b). This section 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 1986-1990 is useful in evaluating potential benefits from bag limits (Fig. 26). Of 1238 successful angler trips sampled (at least one red drum caught) during 1986-1990, 684 angler trips resulted in only a single red drum caught (55%). A greater percentage of angler trips during 1989-1990 resulted in only a single red drum caught (65% or 235 out of 363 angler trips). Meanwhile, 14% of the angler trips caught more than 5 fish during 1986-1990 compared to only 10% of the angler trips caught more than 5 fish during 1989-1990.

Calculation of potential bag limit savings are made for two time periods: 1986-1990 and 1989-1990 (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 (3821 for 1986-1990 and 888 for 1989-1990 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).

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 (1986-1990) 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). Of course, most coastal Atlantic states have instituted a minimum size limit and a combination of bag limit combined with a maximum size (SAFMC 1990a, Fig. 13). Most of these size limits were instituted in 1986 and 1987. Length measurements are available on 2581 red drum during the period 1986-1990. Potentially significant savings are available from minimum size limits increasing from 12" TL (6%) to 14" TL (23%) to 18" TL (75%). 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 (2%) to 27" TL (4%) (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.

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 1986-1990 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 34% for 27" TL maximum size limit to 41% 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 38% savings from a maximum size limit is used for subsequent analyses when 1 fish over is allowed.

**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. 27). Based on this relationship, potential savings of red drum (all ages) can be approximated monthly based on the MRFSS intercept data (1986-1989; 1990 data for all waves were not available at the time this assessment was conducted) (Fig. 28). 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 1986-1990, and for the periods 1986-1990 and 1989-1990. An annual mean for ages 0 through 5 was determined 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 1989-1990.

To determine the reduction of age-specific F for a given size limit, it is first necessary to determine the age equivalent to the size limit. One method would be to simply solve the von Bertalanffy growth equation so that age ($t_{vb}$, yr) is expressed as a function of length (TL, in):

$$t_{vb} = -0.077 - (\log_e(1 - TL/45.93))/0.316. \qquad (7)$$

Statistically this presents certain theoretical problems. The preferred method is to re-estimate age ($t_d$, yr) as a function of length (TL, in) directly:

$$t_d = \exp(-0.666 + 0.061\ TL + \tfrac{1}{2}(0.204)^2. \qquad (8)$$

The expression $[\frac{1}{2}(0.204)^2]$ is a correction factor from the lognormal distribution when retransforming back to the original units. Parameter estimates in Eq. (8) were estimated from MRFSS data between 10" and 35" TL for the period 1986-1990. 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 1.24. As applied in this analysis, it is assumed that all (or 90%) of the age 0 red drum are protected, and 24% (or 90% of 24%) of the age 1 red drum are protected. Similar calculations are carried out for maximum size limits. These savings can be applied to both recreational and commercial fishing mortality components, but for the analysis that follows they are generally applied only to recreational fishing mortality components.

As programmatically 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 the late 1980's). A 10% release mortality is assumed for the recreational fishery, and the fishing mortality rates are based on the Separable VPA with $M_1 = 0.5$ (and $M_2 = 0.17$). A bag limit of one red drum produces an escapement to age 6 of 8% and a maximum spawning potential (eggs) of 11%. Minimum size limits of at least 16" to 20" TL are need for appreciable gains in escapement and %MSP, although absolute values of these are still very small. 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 $M_1 = 0.5$ (and $M_2 = 0.17$). Estimates of %MSP (eggs) for a range of bag limits and minimum size limits are summarized in Table 12 with two different maximum size limits (32" and 27" TL with no fish over this limit). Estimated %MSP values above 30% are only obtained with a zero fish bag limit for a maximum size limit of 32" TL and with a one fish or fewer bag limit for maximum size limit of 27" TL. Higher estimates of %MSP (eggs) are obtained when size limits are applied to both recreational and commercial fisheries (Table 13). For example, a bag limit of 5 fish and minimum size limit of 18" TL, yields an estimate of %MSP (eggs) of 12% with no fish kept over 32" TL and an estimate of %MSP (eggs) of 27% with no fish kept over 27" TL. Allowance of one fish over the maximum size limit significantly reduces the expected %MSP (eggs).

## RESEARCH NEEDS

As referred to in this and the 1989 stock assessments, a major weakness 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 forward calculations of the VPA's. Continued tagrecapture 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 (appear adequate, but must maintain at least this level of quality), 2) length frequency distributions by gear (appear adequate from MRFSS [at least for subadults], but need better sampling for commercial gears [e.g., differentiate between pound net and trawl caught red drum]), and 3) age-length keys (need improved coastwide coverage, although greatly improved since about 1988, before which only data from South Carolina was available).

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.

Some fishery independent indices are highly desirable. First, coverage of adult red drum is needed probably in terms of a fisheries independent index of spawning stock (e.g., possibly by areal 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. Furthermore, few red drum of these ages are caught for application of VPA techniques. It needs to be reiterated that the population models used in this assessment (specifically yield per recruit and percent maximum spawning potential) are based on equilibrium assumptions. These model results are valid in assessing long-term effects, but direct estimates are unavailable as to the current status of the adult (or spawning) stock.

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.

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**REFERENCES CITED**

Clay, D. 1990. TUNE: a series of fish stock assessment computer programs written in FORTRAN for microcomputers (MS DOS). International Commission for the Conservation of Atlantic Tunas, Collected Volume of Scientific Papers 32:443-460.

Condrey, R., D. W. Beckman, and C. A. Wilson. 1988. Management implications of a new growth model for red drum. Appendix D. In J. A. Shepherd (ed.), Louisiana Red Drum Research, MARFIN final report, Contract No. NA87-WC-H-06122. Louisiana Department of Wildlife and Fisheries, Seafood Division, Finfish Section, Baton Rouge, LA. 26 p.

Doubleday, W. G. 1976. A least squares approach to analysing catch at age data. Canadian Journal of Fisheries and Aquatic Sciences 39:1195-1207.

Essig, R. J., J. F. Witzig, and M. C. Holliday. 1991. Marine recreational fishery statistics survey, Atlantic and Gulf coasts, 1987-1989. U.S. Department of Commerce, Current Fisheries Statistics No. 8904. 363 p.

Gabriel, W. L., M. P. Sissenwine, and W. J. Overholtz. 1989. Analysis of spawning stock biomass per recruit: an example for Georges Bank haddock. North American Journal of Fisheries Management 9:383-391.

Goodyear, C. P. 1989. Status of the red drum stocks of the Gulf of Mexico: Report for 1989. U.S. National Marine Fisheries Service, Southeast Fisheries Science Center, Miami, FL, Contribution CRD 87/88-32. 64 p.

Hoenig, J. M. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bulletin, U.S. 82:898-903.

Jordan, S. R. 1990. Mortality of hook-caught red drum and spotted seatrout in Georgia. Georgia Department of Natural Resources, Brunswick, GA. 27 p.

Mathews, T. D., and M. H. Shealy, Jr. 1978. Hydrography of SOuth Carolina estuaries, with emphasis on the North and South Edisto and Cooper Rivers. South Carolina Marine Resources Center, Technical Report No. 30. 148 p.

Murphy, G. I. 1965. A solution of the catch equation. Journal of the Fisheries Research Board of Canada 22:191-201.

Murphy, M. D., and R. G. Taylor. 1990. Reproduction, growth, and mortality of red drum *Sciaenops ocellatus* in Florida waters. Fishery Bulletin, U.S. 88:531-542.

Overstreet, R. 1983. Aspects of the biology of the red drum, Sciaenops ocellatus, in Mississippi. Gulf Research Report, Supplement 1:45-68.

Pafford, J. M., A. G. Woodward, and N. Nicholson. 1990. Mortality, movement, and growth of red drum in Georgia. Georgia Department of Natural Resources, Brunswick, GA. 85 p.

Pauly, D. 1979. On the inter-relationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. Journal du Conseil 39:175-192.

Pope, J. G., and J. G. Shepherd. 1982. A simple method for the consistent interpretation of catch-at-age data. Journal du Conseil 40:176-184.

Restrepo, V. R., and W. W. Fox, Jr. 1988. Parameter uncertainty and simple yield-per-recruit analysis. Transactions of the American Fisheries Society 117:282-289.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada 191:1-382.

Ross, J. L., and T. M. Stevens. 1989. Marine fisheries research: red drum. North Carolina Department of Natural Resources and Community Development, Morehead City, NC. 36 p.

SAS Institute Inc. 1987. SAS/STAT guide for personal computers. Version 6 Edition. SAS Institute Inc., Cary, NC. 1028 p.

South Atlantic Fishery Management Council (SAFMC). 1990a. Profile of the Atlantic coast red drum fishery and source document for the Atlantic coast red drum fishery management plan. South Atlantic Fishery Management Council, Charleston, SC. 147 p.

South Atlantic Fishery Management Council (SAFMC). 1990b. The Atlantic coast red drum fishery management plan including an environmental impact statement and regulatory impact review. South Atlantic Fishery Management Council, Charleston, SC. 116 p.

Vaughan, D. S., and T. E. Helser. 1990. Status of the red drum stock of the Atlantic coast: Stock assessment report for 1989. NOAA Technical Memorandum NMFS-SEFC-263. 117 p.

von Bertalanffy, L. 1938. A quantitative theory of organic growth. Human Biology 10:181-213.

Wenner, C. A., W. A. Roumillat, J. E. Moran, Jr., M. B. Maddox, L. B. Daniel, III, and J. W. Smith. 1990. Investigations on the life history and population dynamics of marine recreational fishes in South Carolina: Part I. South Carolina Wildlife and Marine Resources Department, Charleston, SC.

Table 1. Red drum catches for recreational and commercial fisheries, 1980-1990. 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 | 716.9 | 439.9 | 1156.8 |
| 1981 | 186.1 | 1.4 | 632.5 | 353.1 | 985.6 |
| 1982 | 388.6 | 1.8 | 682.0 | 195.3 | 877.3 |
| 1983 | 635.0 | 7.3 | 1064.5 | 330.2 | 1394.7 |
| 1984 | 1068.6 | 6.4 | 2179.1 | 422.1 | 2601.2 |
| 1985 | 1027.3 | 26.6 | 2032.3 | 249.1 | 2281.4 |
| 1986 | 428.6 | 18.2 | 1816.9 | 341.9 | 2158.8 |
| 1987 | 657.3 | 66.3 | 1471.9 | 312.3 | 1784.2 |
| 1988 | 502.2 | 61.9 | 1672.0 | 229.2 | 1901.2 |
| 1989 | 268.5 | 28.7 | 907.6 | 286.0 | 1193.6 |
| 1990 | 224.0 | 25.3 | 511.8 | 186.4 | 698.2 |

[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 visual representation in this table and in Figure 11a.

Table 2. Red drum growth characterized by single and double von Bertalanffy equations, 1986-1990. $L_{max}$ is total length in inches; k, $k_1$, and $k_2$ are in $yr^{-1}$, and $t_0$, $t_{01}$, $t_{02}$ and $t_x$ are in years.

| Region | Single Parameters | | | |
|---|---|---|---|---|
| | n | $L_{max}$ | k | $t_0$ |
| GA | 341 | 40.8 | 0.25 | -1.94 |
| SC | 5939 | 41.3 | 0.35 | 0.09 |
| NC | 823 | 46.6 | 0.19 | -1.63 |
| All | 7103 | 42.4 | 0.36 | 0.09 |
| Foster[a] | 230 | 46.6 | 0.21 | -0.82 |

| Region | Double Parameters | | | | | |
|---|---|---|---|---|---|---|
| | $L_{max}$ | $k_1$ | $k_2$ | $t_{01}$ | $t_{02}$ | $t_x$ |
| GA | 41.1 | 0.27 | 0.16 | -1.64 | -6.14 | 4.9 |
| SC | 41.8 | 0.38 | 0.26 | 0.16 | -0.85 | 2.3 |
| NC | 49.1 | 0.29 | 0.06 | -0.14 | -16.66 | 4.5 |
| All | 45.9 | 0.32 | 0.06 | 0.08 | -25.30 | 5.9 |
| Foster[a] | 49.3 | 0.19 | 0.04 | -1.00 | -35.76 | 8.8 |

[a] Data from North Carolina during 1969-1971.

Table 3. Red drum age-length keys for 1989 and 1990.

| Length Class (TL,in) | Age (yr) 0 | 1 | 2 | 3 | 4 | 5 | 6+ |
|---|---|---|---|---|---|---|---|
| | | | | 1989 (n = 1638) | | | |
| 7 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 9 | 0.439 | 0.561 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 11 | 0.223 | 0.777 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 13 | 0.063 | 0.937 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 15 | 0.016 | 0.984 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 17 | 0.009 | 0.932 | 0.059 | 0.0 | 0.0 | 0.0 | 0.0 |
| 19 | 0.012 | 0.711 | 0.277 | 0.0 | 0.0 | 0.0 | 0.0 |
| 21 | 0.0 | 0.135 | 0.865 | 0.0 | 0.0 | 0.0 | 0.0 |
| 23 | 0.0 | 0.108 | 0.878 | 0.014 | 0.0 | 0.0 | 0.0 |
| 25 | 0.0 | 0.053 | 0.713 | 0.234 | 0.0 | 0.0 | 0.0 |
| 27 | 0.0 | 0.020 | 0.505 | 0.465 | 0.010 | 0.0 | 0.0 |
| 29 | 0.0 | 0.021 | 0.291 | 0.646 | 0.042 | 0.0 | 0.0 |
| 31 | 0.0 | 0.0 | 0.277 | 0.532 | 0.191 | 0.0 | 0.0 |
| 33 | 0.0 | 0.0 | 0.111 | 0.482 | 0.370 | 0.037 | 0.0 |
| 35 | 0.0 | 0.0 | 0.0 | 0.368 | 0.529 | 0.053 | 0.053 |
| 37 | 0.0 | 0.0 | 0.0 | 0.067 | 0.133 | 0.0 | 0.800 |
| 39 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 |
| 41 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 |
| | | | | 1990 (n = 1564) | | | |
| 7 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 9 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 11 | 0.845 | 0.155 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 13 | 0.195 | 0.805 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 15 | 0.016 | 0.979 | 0.005 | 0.0 | 0.0 | 0.0 | 0.0 |
| 17 | 0.009 | 0.982 | 0.009 | 0.0 | 0.0 | 0.0 | 0.0 |
| 19 | 0.0 | 0.967 | 0.033 | 0.0 | 0.0 | 0.0 | 0.0 |
| 21 | 0.0 | 0.475 | 0.525 | 0.0 | 0.0 | 0.0 | 0.0 |
| 23 | 0.0 | 0.427 | 0.573 | 0.0 | 0.0 | 0.0 | 0.0 |
| 25 | 0.0 | 0.274 | 0.655 | 0.071 | 0.0 | 0.0 | 0.0 |
| 27 | 0.0 | 0.089 | 0.759 | 0.127 | 0.025 | 0.0 | 0.0 |
| 29 | 0.0 | 0.0 | 0.569 | 0.379 | 0.052 | 0.0 | 0.0 |
| 31 | 0.0 | 0.0 | 0.541 | 0.243 | 0.216 | 0.0 | 0.0 |
| 33 | 0.0 | 0.0 | 0.087 | 0.304 | 0.478 | 0.0 | 0.131 |
| 35 | 0.0 | 0.0 | 0.0 | 0.133 | 0.667 | 0.067 | 0.133 |
| 37 | 0.0 | 0.0 | 0.0 | 0.0 | 0.139 | 0.194 | 0.667 |
| 39 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.048 | 0.952 |
| 41 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 |

Table 4. Red drum catch in numbers at age for recreational (1980-1990) and commercial (1986-1990) fisheries.

| Year | Age (yr) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6+ |
| | | | | Recreational Only | | | |
| 1980 | 149839 | 100970 | 28600 | 5102 | 492 | 267 | 362 |
| 1981 | 69166 | 73046 | 34200 | 9083 | 1567 | 262 | 231 |
| 1982 | 222056 | 137278 | 16116 | 8865 | 3110 | 1144 | 91 |
| 1983 | 336263 | 259042 | 34577 | 5246 | 659 | 699 | 5807 |
| 1984 | 446947 | 552465 | 25692 | 24529 | 25376 | 0 | 0 |
| 1985 | 498363 | 513518 | 32477 | 7486 | 2064 | 0 | 0 |
| 1986 | 34231 | 356245 | 39198 | 2082 | 0 | 405 | 13737 |
| 1987 | 46290 | 588581 | 70509 | 14489 | 258 | 0 | 2219 |
| 1988 | 46830 | 450634 | 46874 | 13651 | 831 | 0 | 2842 |
| 1989 | 6801 | 207317 | 69643 | 11024 | 667 | 0 | 1193 |
| 1990 | 14330 | 175753 | 44780 | 4956 | 2654 | 425 | 4924 |
| | | | | Commercial Only | | | |
| 1986 | 154051 | 252350 | 1241 | 40 | 0 | 30 | 156 |
| 1987 | 158276 | 225848 | 2045 | 204 | 5 | 0 | 76 |
| 1988 | 19787 | 143465 | 2085 | 77 | 6 | 0 | 22 |
| 1989 | 1153 | 55573 | 10992 | 1365 | 288 | 20 | 7551 |
| 1990 | 1070 | 42891 | 3103 | 716 | 292 | 21 | 4264 |
| | | | | Total (Recreational and Commercial) | | | |
| 1986 | 188283 | 608594 | 40439 | 2122 | 0 | 435 | 13893 |
| 1987 | 204566 | 814429 | 72554 | 14693 | 264 | 0 | 2295 |
| 1988 | 66617 | 594099 | 48958 | 13728 | 837 | 0 | 2864 |
| 1989 | 7955 | 262890 | 80634 | 12390 | 955 | 20 | 8744 |
| 1990 | 15401 | 218644 | 47883 | 5672 | 2947 | 446 | 9188 |

Table 5. Red drum weight (lbs)-total length (in) relationships from MRFSS data base, 1986-1990.

| Year | ln(a) | b | n | $r^2$ | RMSE[a] |
|---|---|---|---|---|---|
| 1986 | -7.73 | 2.98 | 487 | 0.92 | 0.220 |
| 1987 | -7.53 | 2.91 | 746 | 0.93 | 0.188 |
| 1988 | -7.42 | 2.91 | 379 | 0.93 | 0.220 |
| 1989 | -7.18 | 2.81 | 731 | 0.93 | 0.187 |
| 1990 | -7.63 | 2.96 | 138 | 0.98 | 0.154 |
| 1986-1990 | -7.58 | 2.94 | 2181 | 0.93 | 0.204 |

[a] RMSE equals root 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.

| | Z | $r^2$ | n | Ages |
|---|---|---|---|---|
| | Using Recreational Data Only | | | |
| Fishing Year | | | | |
| 1980 | 1.49 | 0.98 | 3 | 1-3 |
| 1981 | 1.04 | 0.95 | 3 | 1-3 |
| 1982 | 1.37 | 0.81 | 3 | 1-3 |
| 1983 | 1.95 | 0.999 | 3 | 1-3 |
| 1984 | 1.56 | 0.52 | 3 | 1-3 |
| 1985 | 2.11 | 0.94 | 3 | 1-3 |
| 1986 | 2.57 | 0.99 | 3 | 1-3 |
| 1987 | 1.85 | 0.99 | 3 | 1-3 |
| 1988 | 1.75 | 0.97 | 3 | 1-3 |
| 1989 | 1.47 | 0.96 | 3 | 1-3 |
| 1990 | 1.78 | 0.96 | 3 | 1-3 |
| | Using Recreational/Commercial Data | | | |
| Fishing Year | | | | |
| 1986 | 1.79 | 0.86 | 4 | 1-4 |
| 1987 | 2.57 | 0.95 | 4 | 1-4 |
| 1988 | 2.10 | 0.97 | 4 | 1-4 |
| 1989 | 2.34 | 0.94 | 5 | 1-5 |
| 1990 | 1.52 | 0.98 | 5 | 1-5 |
| | Using Recreational/Commercial Data | | | |
| Cohort | | | | |
| 1984 | 2.57 | 0.92 | 4 | 2-5 |
| 1985 | 1.88 | 0.97 | 5 | 1-5 |
| 1985 | 1.90 | 0.99 | 3 | 1-3 |
| 1986 | 1.82 | 0.95 | 4 | 1-4 |
| 1986 | 2.09 | 0.92 | 3 | 1-3 |
| 1987 | 2.33 | 0.99 | 3 | 1-3 |
| 1988 | 1.70 | 1.0 | 2 | 1-2 |

Table 7. Red drum mean fishing mortality rates (1986-1989) from different virtual population analyses (M = instantaneous natural mortality rate for subadults, ages 0-5). Assumes reduced availability or offshore movement begins following age 3. Estimates of adult mortality based on Hoenig (1983) when $M_1$ = 0.1 (note: $M_1 = M_2$), based on Pauly (1979) when $M_1$ = 0.5, and average of 0.1 and 0.17 when $M_1$ = 0.3. 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/ | Separable | | | Linked Murphy |
|---|---|---|---|---|
| Values | $M_1$=0.1 | $M_1$=0.3 | $M_1$=0.5 | $M_1$=0.5 |
| 0 | 0.183 | 0.149 | 0.118 | 0.150 |
| 1 | 1.92 | 1.69 | 1.46 | 1.59 |
| 2 | 1.31 | 1.14 | 0.98 | 1.09 |
| 3 | 1.92 | 1.69 | 1.46 | 1.09 |
| 4 | 0.98 | 0.88 | 0.77 | 0.25 |
| 5 | 0.026 | 0.025 | 0.024 | 0.005 |
| Adult M ($M_2$) | 0.100 | 0.135 | 0.170 | 0.170 |
| Y/R (lbs) | 1.6 | 1.2 | 0.9 | 0.8 |
| Escapement (%) | 0.2 | 0.4 | 0.8 | 1.5 |
| MSP Biomass (%) | 0.3 | 0.6 | 1.4 | 1.9 |
| MSP Eggs (%) | 0.4 | 0.9 | 2.2 | 2.4 |

Table 8. Potential savings of red drum from management bag limits based on MRFSS data base for 1986-1990 and 1989-1990 (assumes no release mortality).

| Bag Limit | 1986-1990 | | 1989-1990 | |
|---|---|---|---|---|
| | No. Caught[a] | % Saved | No. Caught[a] | % Saved |
| 1 | 1238 | 68 | 363 | 59 |
| 2 | 1792 | 53 | 491 | 45 |
| 3 | 2155 | 44 | 574 | 35 |
| 4 | 2429 | 36 | 635 | 29 |
| 5 | 2643 | 31 | 678 | 24 |
| 6 | 2816 | 26 | 713 | 20 |
| 7 | 2957 | 23 | 741 | 17 |
| 8 | 3074 | 19 | 763 | 14 |
| 9 | 3167 | 17 | 782 | 12 |
| 10 | 3245 | 15 | 797 | 10 |
| 11 | 3312 | 13 | 809 | 9 |
| 12 | 3372 | 12 | 820 | 8 |
| 13 | 3424 | 10 | 830 | 7 |
| 14 | 3471 | 9 | 837 | 6 |
| 15 | 3513 | 8 | 843 | 5 |
| None | 3821 | 0 | 888 | 0 |

[a] Number 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 | 1.01 | 2436 | 6 |
| 13 | 1.17 | 2248 | 13 |
| 14 | 1.24 | 1988 | 23 |
| 15 | 1.32 | 1461 | 43 |
| 16 | 1.41 | 1088 | 58 |
| 17 | 1.49 | 803 | 69 |
| 18 | 1.59 | 654 | 75 |
| 19 | 1.69 | 546 | 79 |
| 20 | 1.80 | 472 | 82 |
| 21 | 1.91 | 401 | 85 |
| 22 | 2.03 | 357 | 86 |
| 24 | 2.30 | 2347 | 9 |
| 25 | 2.44 | 2410 | 7 |
| 26 | 2.60 | 2453 | 5 |
| 27 | 2.76 | 2476 | 4 |
| 28 | 2.94 | 2498 | 3 |
| 29 | 3.12 | 2512 | 3 |
| 30 | 3.32 | 2521 | 2 |
| 31 | 3.53 | 2527 | 2 |
| 32 | 3.76 | 2534 | 2 |
| Total | - | 2581 | - |

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

$$A = \exp(-0.666 + 0.061*L + \tfrac{1}{2}(0.216^2))$$

where A = age in years, L = total length in inches, 0.216 is the root mean squared error and corrects for bias between normal and lognormal error models, and $r^2 = 0.99$. Age-length data from Georgia, South Carolina, and North Carolina, between 1986-1990, and restricted to total lengths of 10" and 35".

Table 10. Proportion of red drum in numbers by age (0-5) that were caught by the recreational fishery.

| Year | Age (yr) 0 | 1 | 2 | 3 | 4 | 5 | Total (0-5) |
|---|---|---|---|---|---|---|---|
| 1986 | 0.182 | 0.585 | 0.969 | 0.981 | - | 0.931 | 0.515 |
| 1987 | 0.226 | 0.723 | 0.972 | 0.986 | 0.977 | - | 0.651 |
| 1988 | 0.703 | 0.759 | 0.957 | 0.994 | 0.993 | - | 0.772 |
| 1989 | 0.855 | 0.789 | 0.864 | 0.889 | 0.698 | 0.0 | 0.767 |
| 1990 | 0.931 | 0.804 | 0.935 | 0.875 | 0.898 | 0.953 | 0.835 |
| Total[a] (1986-90) | 0.308 | 0.712 | 0.933 | 0.951 | 0.880 | 0.039 | 0.672 |
| Total[a] (1989-90) | 0.905 | 0.796 | 0.890 | 0.885 | 0.849 | 0.021 | 0.796 |
| Mean[b] | 0.893 | 0.797 | 0.939 | 0.945 | 0.891 | 0.942 | 0.708 |

[a] Total proportion based on sum of recreational catches in numbers across years divided by sum of all catches in numbers across years.

[b] Mean proportion based on selected years: Age 0 and 1 used mean of 1989-90 because increasing trend apparent with 1989-90 representing recent conditions, age 2, 3 and 4 used mean of 1986-90 with no apparent trend (no estimate available for age 4 in 1986), age 5 used mean of 1986 and 1990 with no estimate for 1987 and 1988, and 1989 estimate believed to be unrepresentative of current conditions).

Table 11. Escapement and percent maximum spawning potential 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 $M_1 = 0.5$.

| Limit (data source) | Escapement | % Maximum Spawning Potential Biomass | Eggs |
|---|---|---|---|
| No Limits | 1 | 1 | 2 |
| **Bag Limit (MRFSS 1989-90)** | | | |
| 0 | 38 | 40 | 42 |
| 1 | 8 | 10 | 11 |
| 2 | 5 | 6 | 7 |
| 3 | 3 | 4 | 6 |
| 4 | 2 | 3 | 5 |
| 5 | 2 | 3 | 4 |
| 6 | 2 | 3 | 4 |
| 7 | 2 | 2 | 3 |
| 8 | 1 | 2 | 3 |
| 9 | 1 | 2 | 3 |
| 10 | 1 | 2 | 3 |
| **Minimum Size Limit (MRFSS 1986-1990)** | | | |
| 12" TL | 1 | 2 | 3 |
| 14" | 1 | 2 | 3 |
| 16" | 1 | 2 | 4 |
| 18" | 2 | 3 | 4 |
| 20" | 2 | 4 | 6 |
| **Maximum Size Limit (MRFSS 1986-1990)** | | | |
| No fish allowed over: | | | |
| 27" TL | 7 | 7 | 7 |
| 30" | 4 | 4 | 5 |
| 32" | 2 | 3 | 3 |
| One fish allowed over: | | | |
| 27" TL | 2 | 2 | 3 |
| 30" | 1 | 2 | 3 |
| 32" | 1 | 2 | 2 |

Table 12. Percent maximum spawning potential (eggs) 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 (no fish permitted over maximum size limit). Fishing mortality rates from Separable VPA with $M_1 = 0.5$.

| Bag Limit | Minimum Size Limits (TL) None | 12" | 14" | 16" | 18" | 20" |
|---|---|---|---|---|---|---|
| | | | **Maximum Size Limit = 32" TL** | | | |
| 0 | 45 | 46 | 46 | 47 | 48 | 49 |
| 1 | 15 | 16 | 17 | 19 | 20 | 23 |
| 2 | 10 | 11 | 12 | 14 | 15 | 17 |
| 3 | 8 | 9 | 10 | 11 | 13 | 15 |
| 4 | 6 | 8 | 8 | 10 | 11 | 13 |
| 5 | 6 | 7 | 8 | 9 | 10 | 12 |
| 6 | 5 | 6 | 7 | 8 | 9 | 11 |
| 7 | 5 | 6 | 6 | 7 | 9 | 11 |
| 8 | 4 | 5 | 6 | 7 | 8 | 10 |
| 9 | 4 | 5 | 6 | 7 | 8 | 10 |
| 10 | 4 | 5 | 6 | 7 | 8 | 9 |
| None | 3 | 4 | 4 | 5 | 6 | 8 |
| | | | **Maximum Size Limit = 27" TL** | | | |
| 0 | 49 | 50 | 51 | 52 | 53 | 54 |
| 1 | 22 | 25 | 26 | 29 | 31 | 35 |
| 2 | 17 | 19 | 21 | 23 | 26 | 30 |
| 3 | 14 | 16 | 18 | 20 | 23 | 27 |
| 4 | 12 | 14 | 16 | 18 | 21 | 25 |
| 5 | 11 | 13 | 15 | 17 | 20 | 24 |
| 6 | 11 | 12 | 14 | 16 | 19 | 23 |
| 7 | 10 | 12 | 13 | 15 | 18 | 22 |
| 8 | 9 | 11 | 13 | 15 | 18 | 21 |
| 9 | 9 | 11 | 12 | 14 | 17 | 21 |
| 10 | 9 | 11 | 12 | 14 | 17 | 20 |
| None | 7 | 9 | 10 | 12 | 15 | 18 |

Table 13. Percent maximum spawning potential (eggs) for Atlantic red drum expressed as percent based on combined application of bag and size limits with a 10% release mortality to recreational and commercial fishery (no fish permitted over maximum size limit). Fishing mortality rates from Separable VPA with $M_1$ = 0.5.

| Bag Limit | Minimum Size Limits (TL) None | 12" | 14" | 16" | 18" | 20" |
|---|---|---|---|---|---|---|
| **Maximum Size Limit = 32" TL** | | | | | | |
| 0 | 48 | 51 | 53 | 57 | 61 | 66 |
| 1 | 15 | 18 | 20 | 22 | 26 | 30 |
| 2 | 10 | 12 | 14 | 16 | 19 | 23 |
| 3 | 8 | 10 | 11 | 13 | 16 | 19 |
| 4 | 7 | 8 | 10 | 11 | 14 | 17 |
| 5 | 6 | 7 | 8 | 10 | 12 | 16 |
| 6 | 5 | 7 | 8 | 9 | 12 | 15 |
| 7 | 5 | 6 | 7 | 9 | 11 | 14 |
| 8 | 5 | 6 | 7 | 8 | 10 | 13 |
| 9 | 4 | 6 | 7 | 8 | 10 | 13 |
| 10 | 4 | 5 | 6 | 8 | 10 | 12 |
| None | 3 | 4 | 5 | 6 | 8 | 10 |
| **Maximum Size Limit = 27" TL** | | | | | | |
| 0 | 56 | 59 | 62 | 66 | 71 | 77 |
| 1 | 25 | 29 | 32 | 36 | 42 | 49 |
| 2 | 19 | 22 | 26 | 30 | 35 | 42 |
| 3 | 16 | 19 | 22 | 26 | 31 | 38 |
| 4 | 14 | 17 | 20 | 23 | 28 | 35 |
| 5 | 13 | 16 | 18 | 22 | 27 | 33 |
| 6 | 12 | 15 | 17 | 21 | 25 | 32 |
| 7 | 11 | 14 | 16 | 20 | 24 | 31 |
| 8 | 11 | 13 | 16 | 19 | 24 | 30 |
| 9 | 10 | 13 | 15 | 18 | 23 | 29 |
| 10 | 10 | 12 | 15 | 18 | 22 | 29 |
| None | 8 | 10 | 12 | 15 | 20 | 26 |

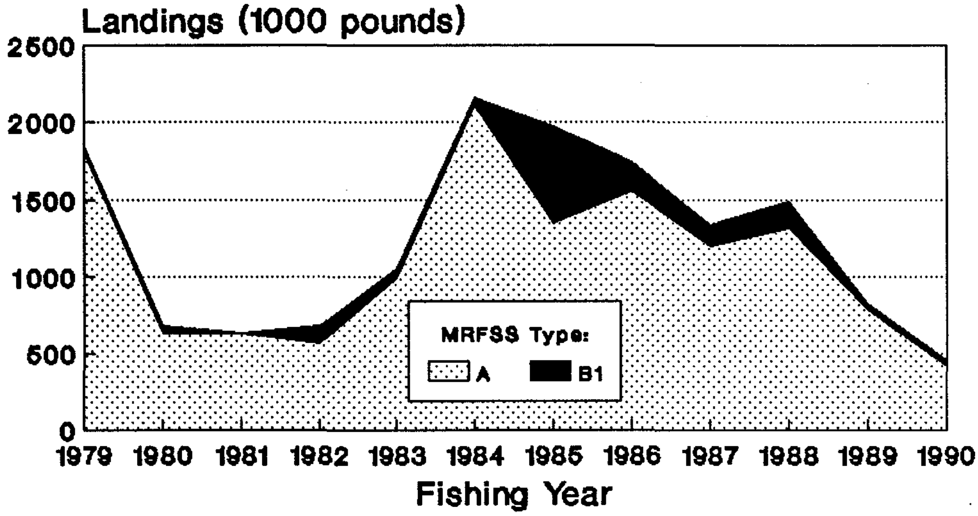



Fig. 1. Red drum recreational catches in weight.

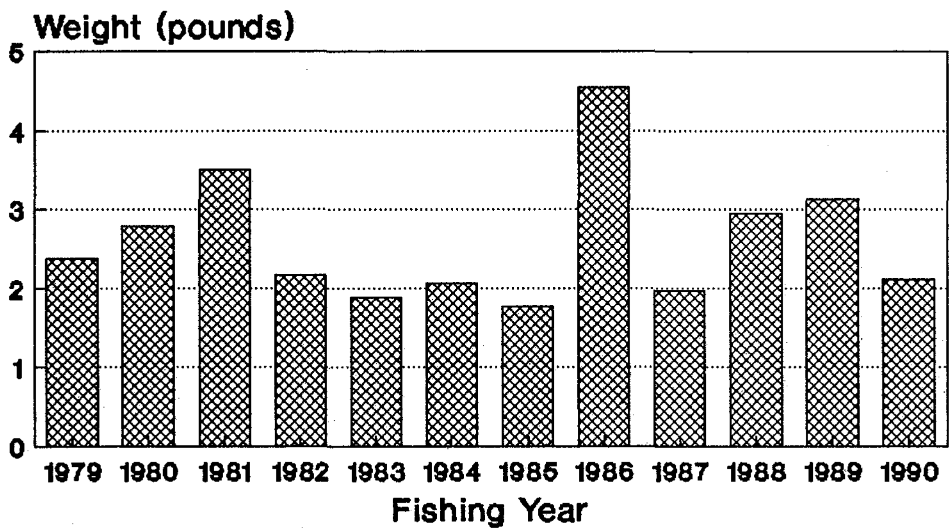



Fig. 2. Red drum recreational mean weight (Type A)

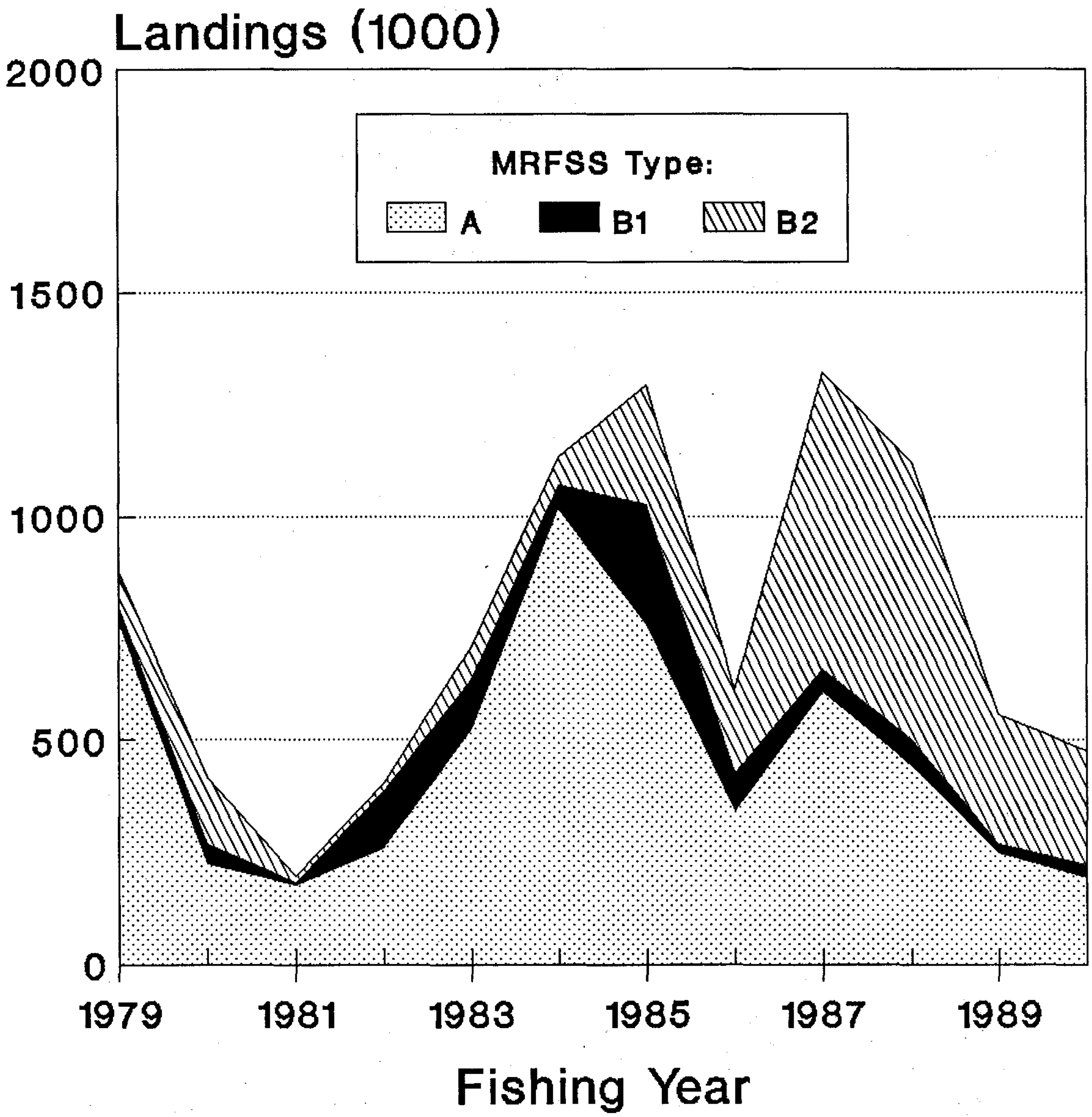



Fig. 3. Red drum recreational catches in numbers.

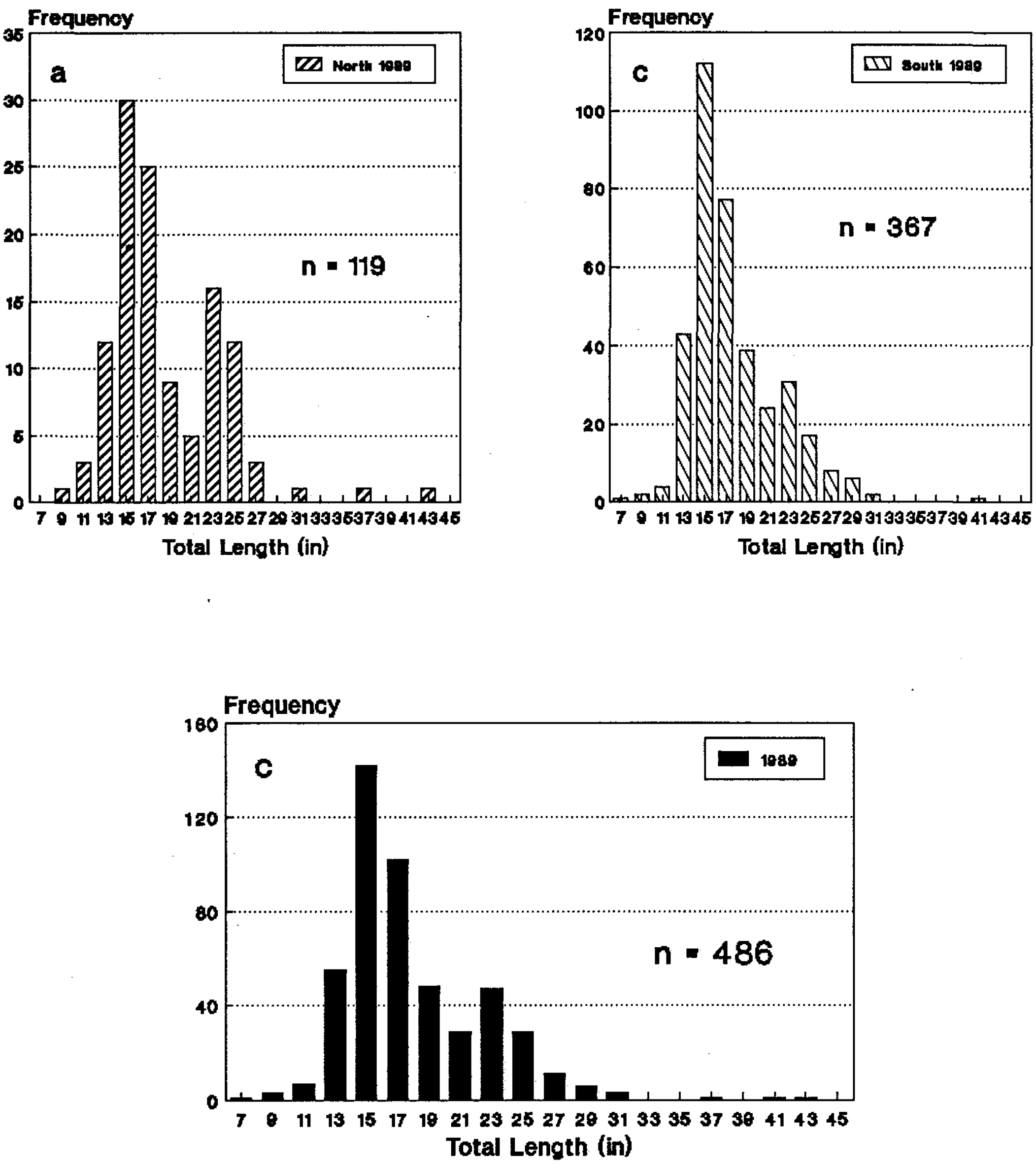



Fig. 4. Red drum recreational length frequencies, 1989.

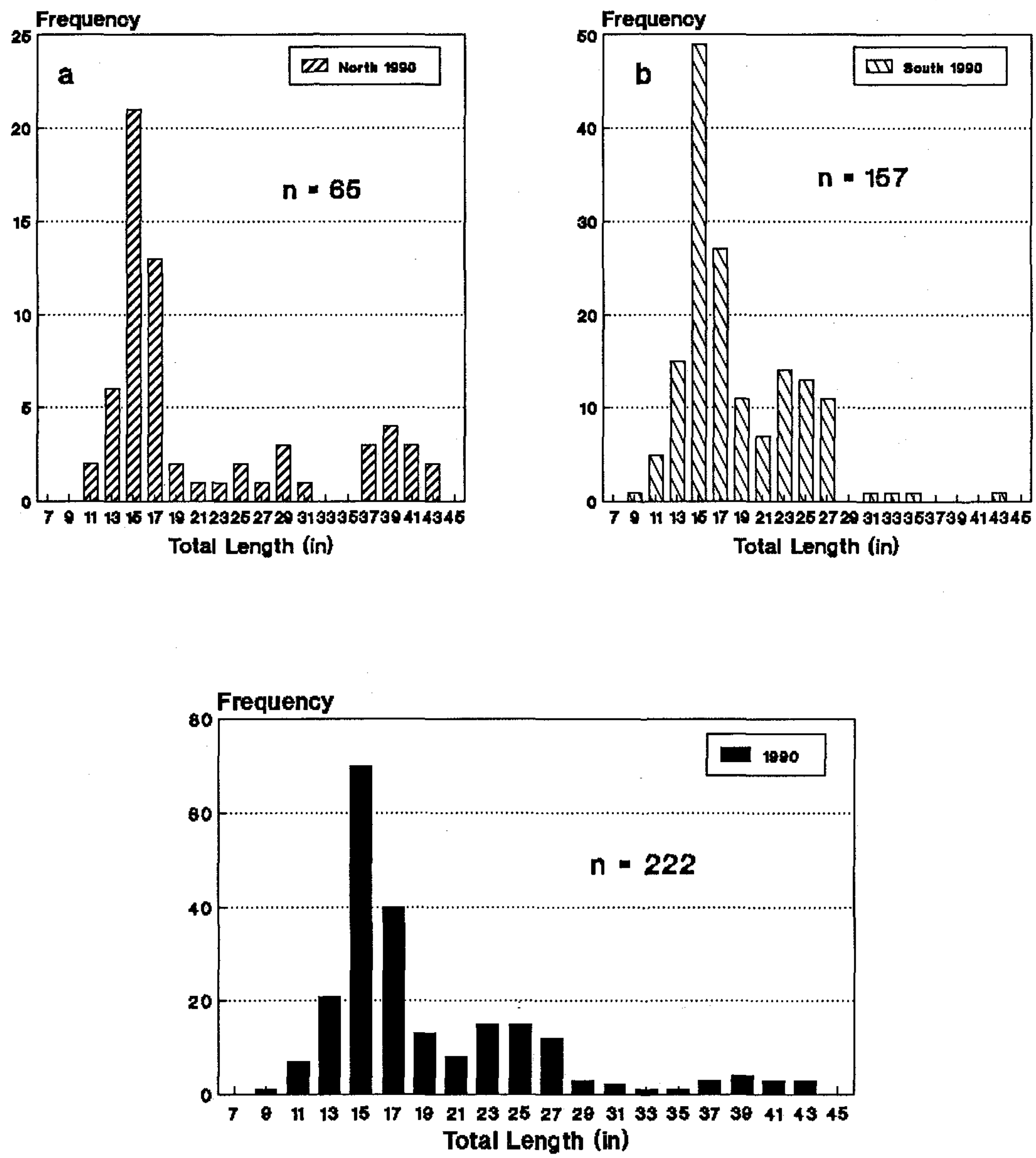



Fig. 5. Red drum recreational length frequencies, 1990.

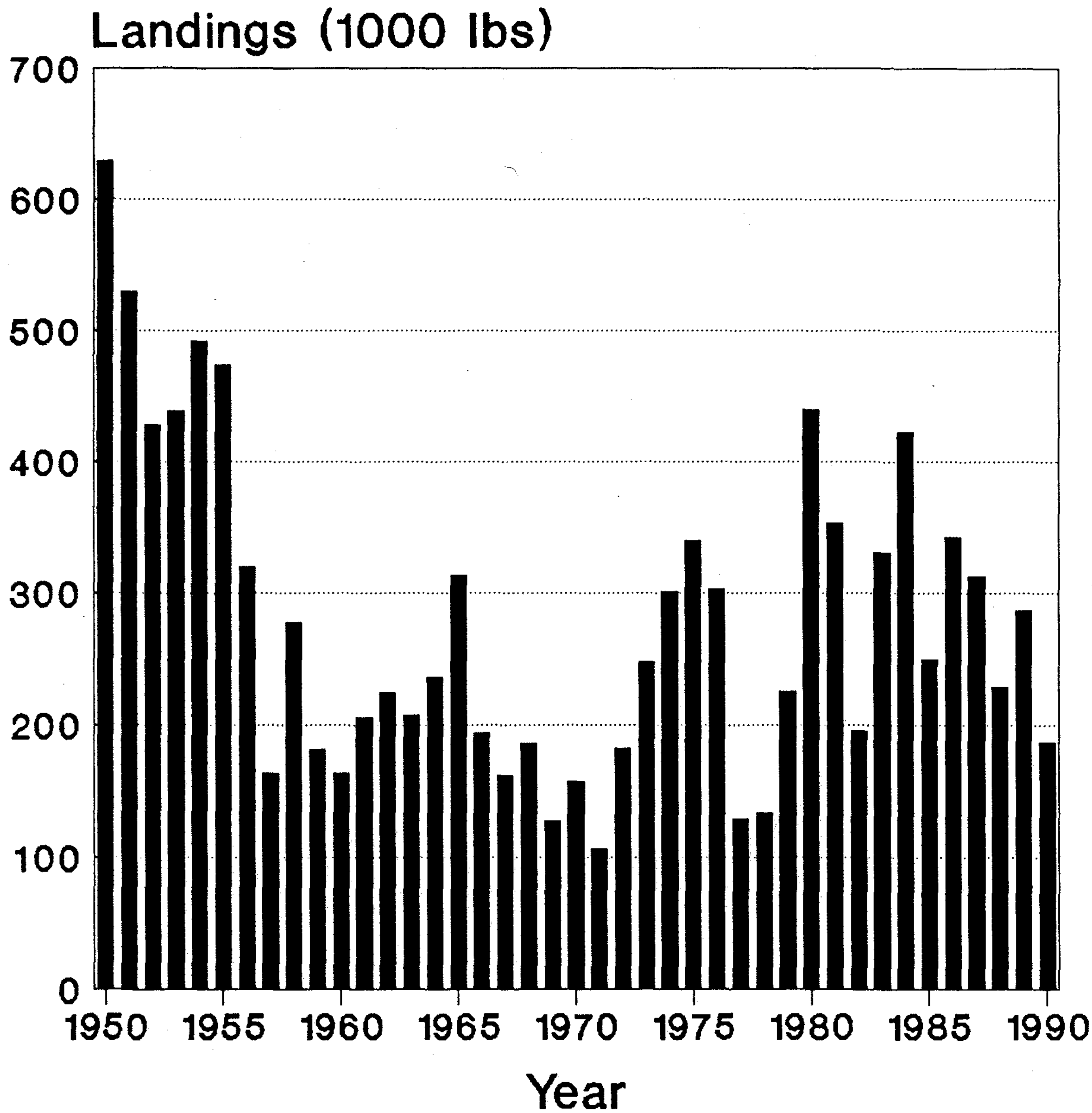



Fig. 6. Red drum commercial landing (1950-1990).

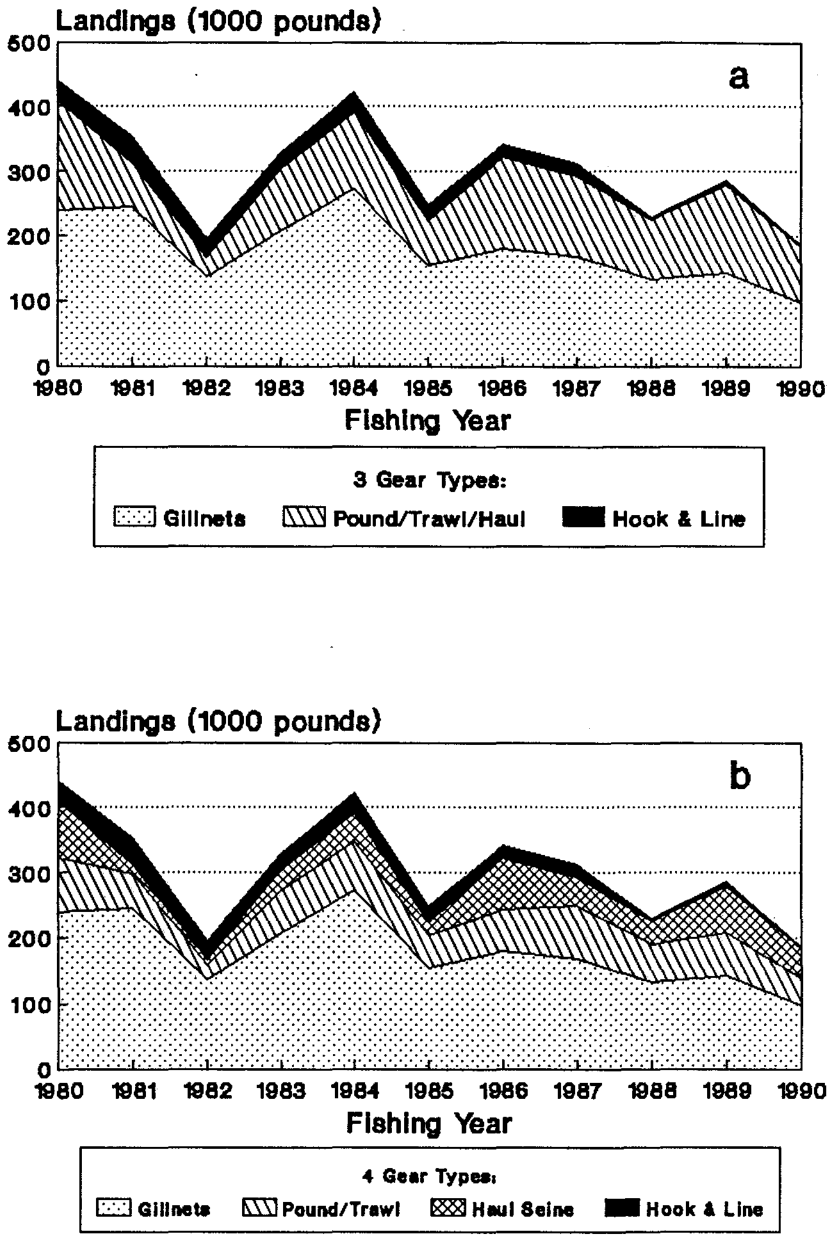



Fig. 7. Red drum commercial landings in weight by a) 3 or b) 4 gears.

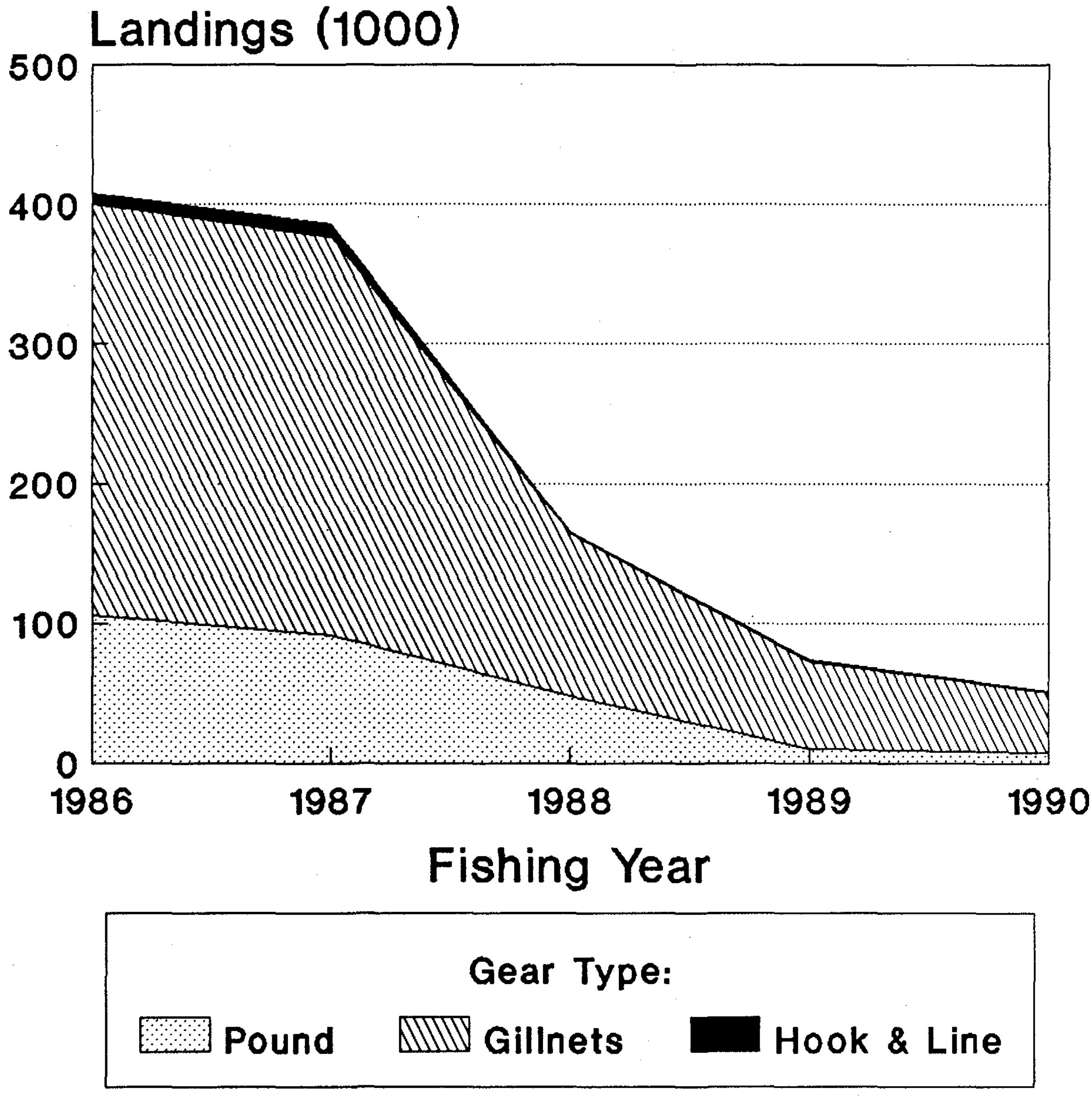



Fig. 8. Red drum commercial landing in numbers by gear.

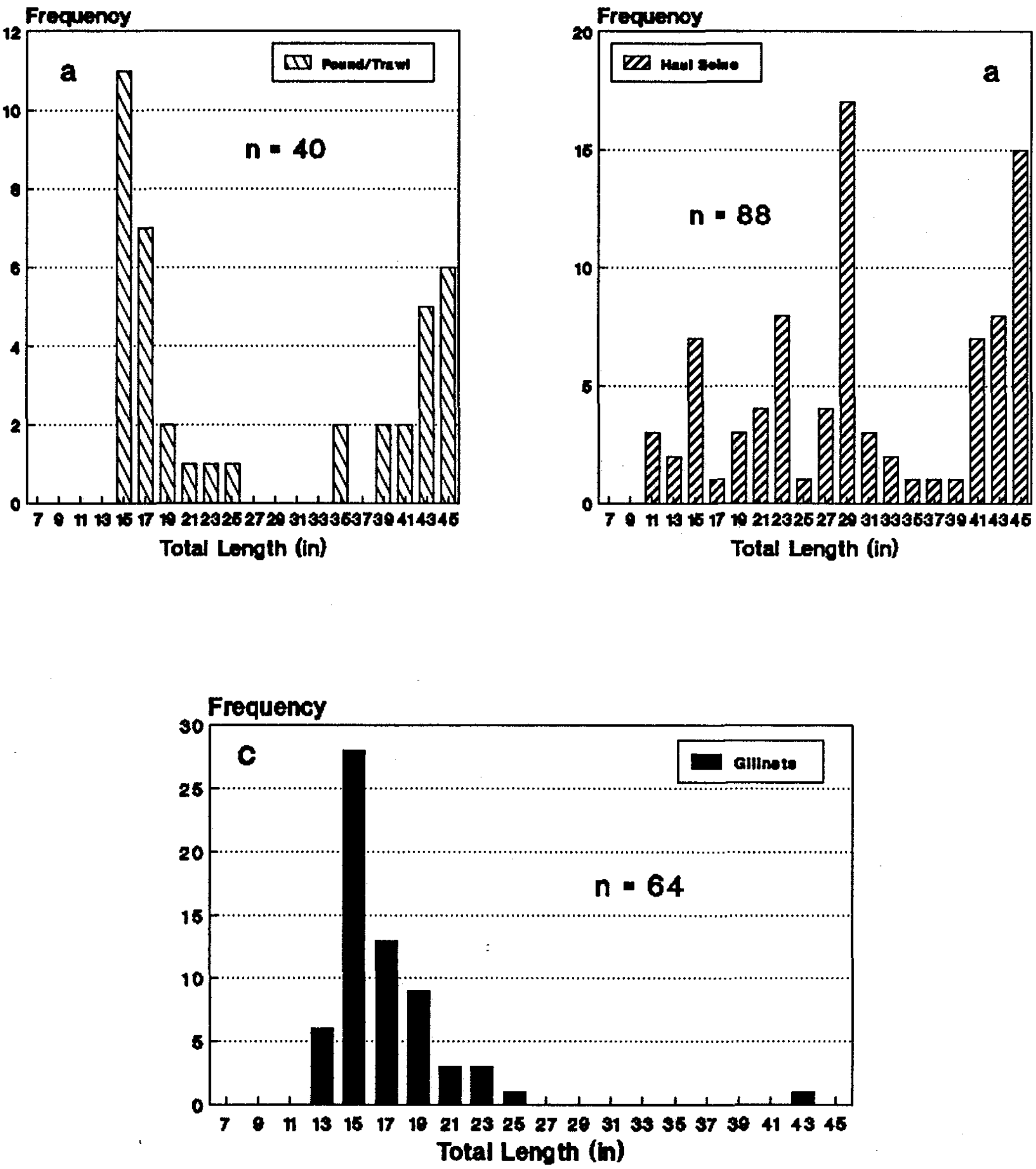



Fig. 9. Red drum commercial length frequencies, 1989.

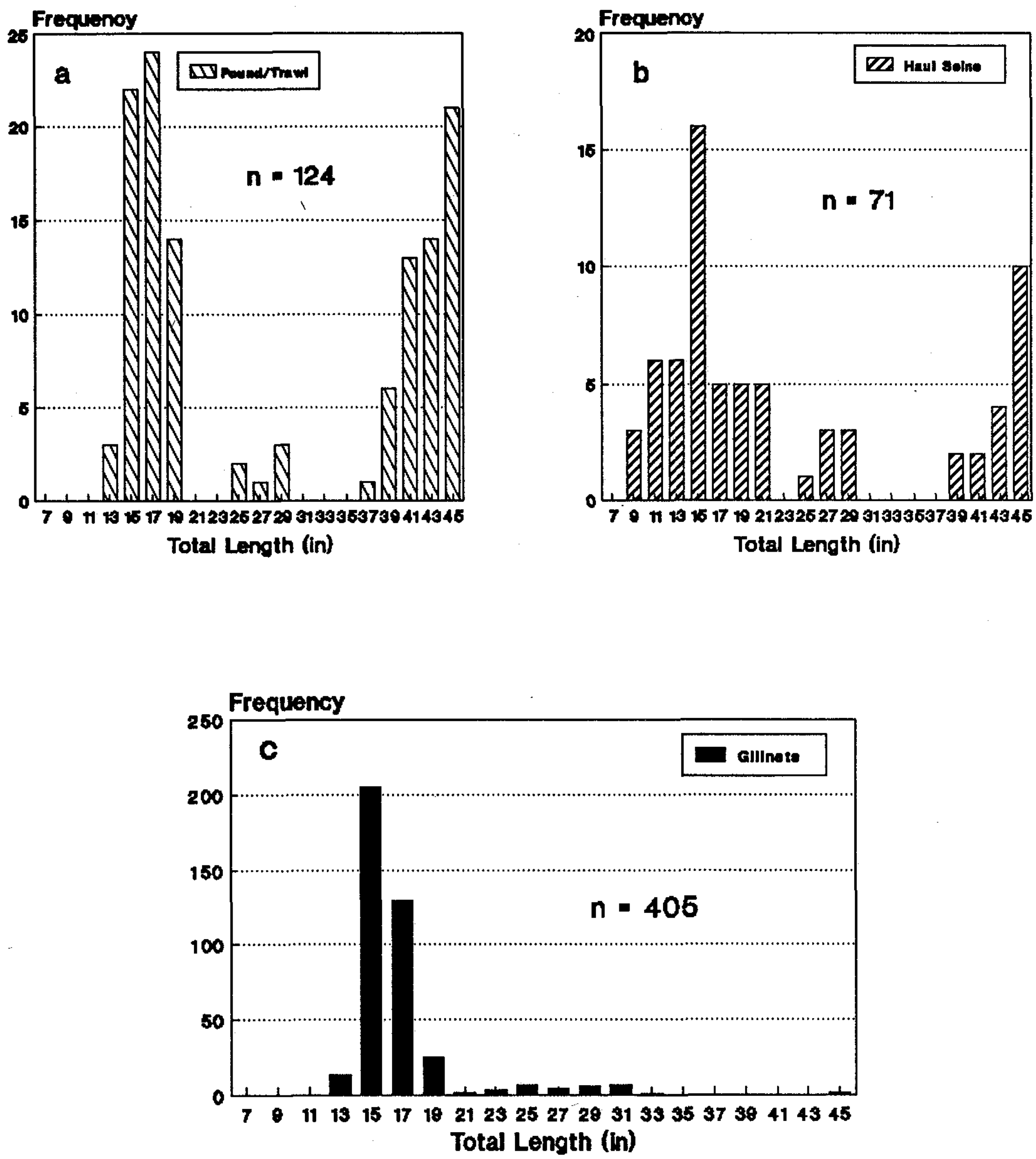
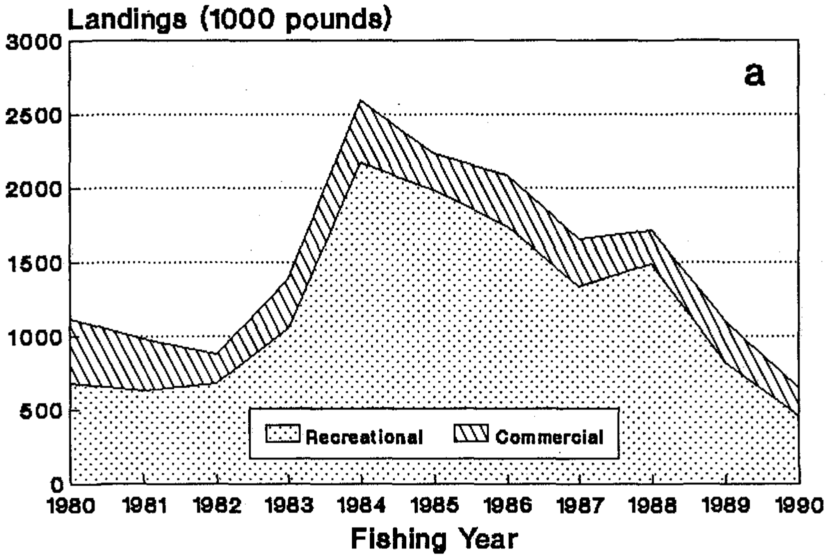



Fig. 10. Red drum commercial length frequencies, 1990.



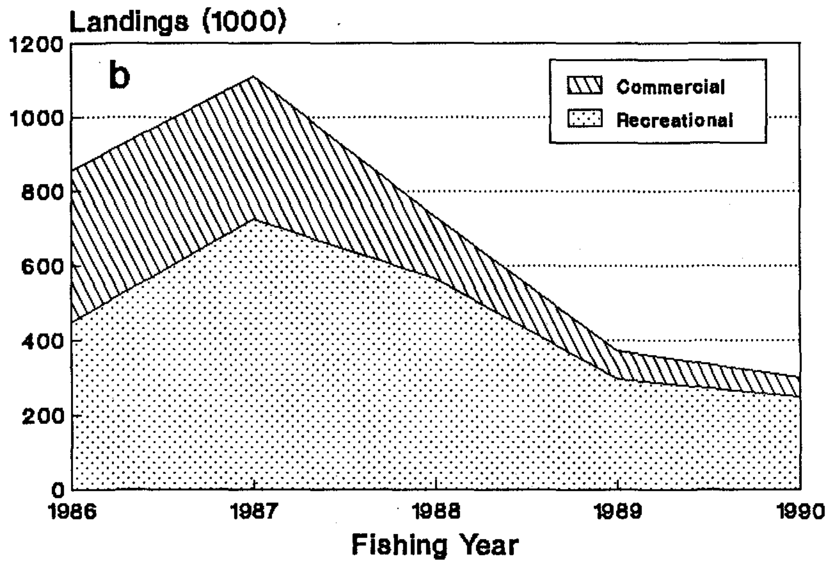




Fig. 11. Total red drum catch: a) weight and b) numbers.

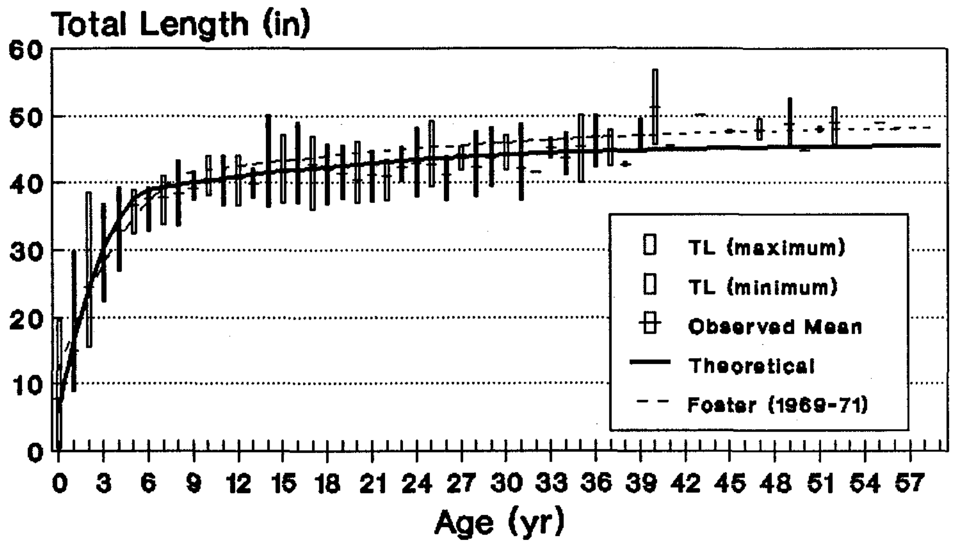



Fig. 12. Red drum double von Bertalanffy growth curve (1986-1990 data).

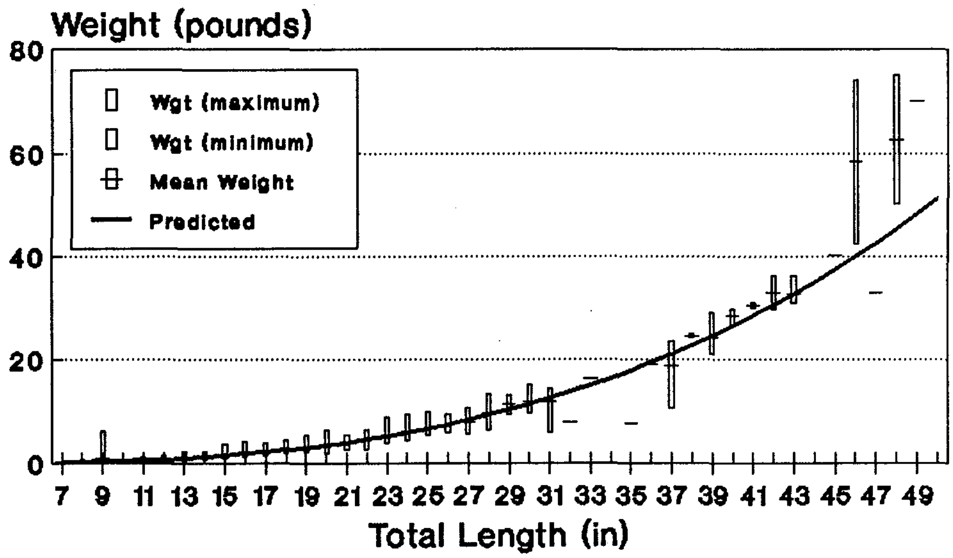



Fig. 13. Red drum mean weight at Length (MRFSS: 1986-1990).

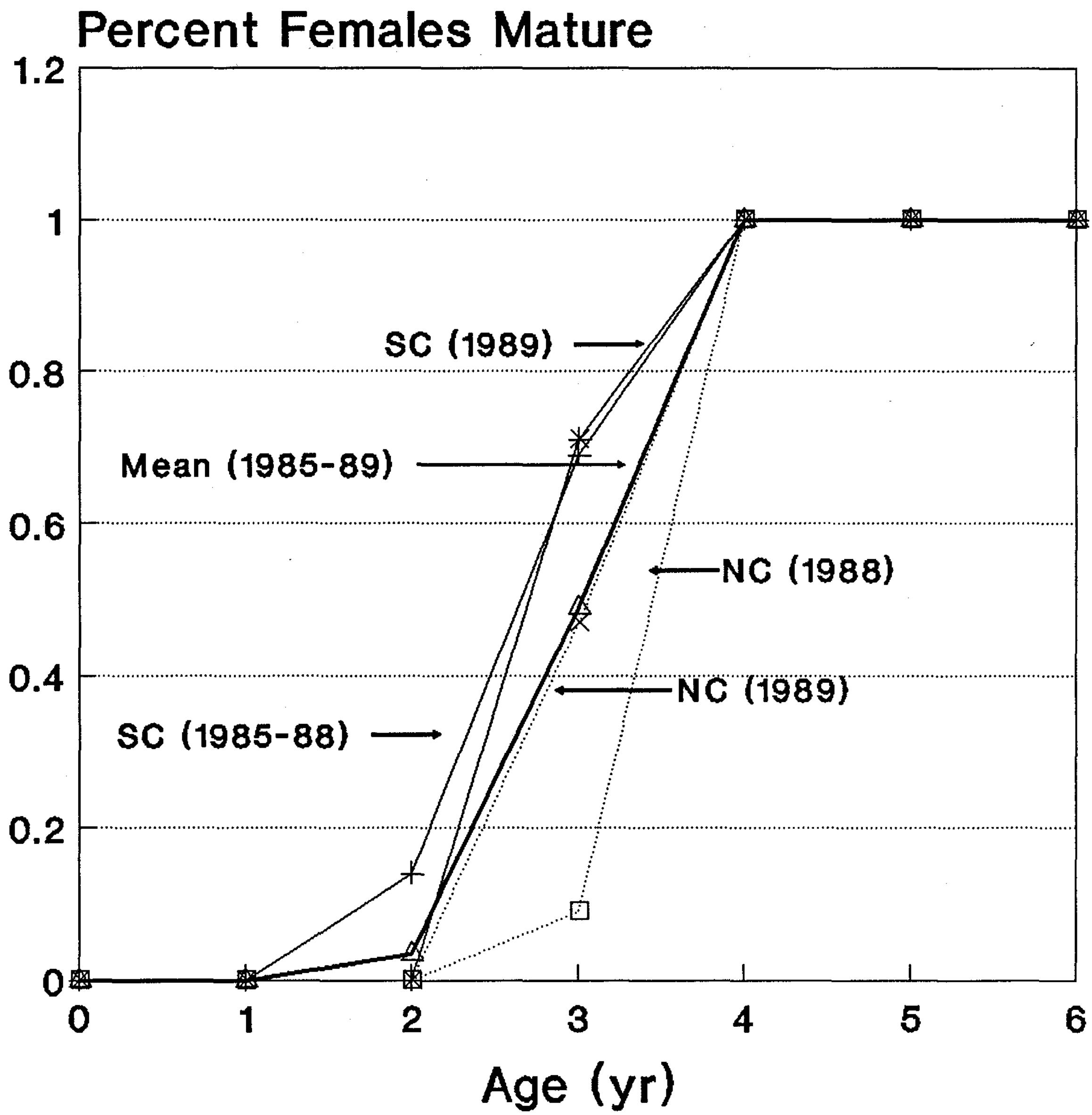



Fig. 14. Recent red drum maturity schedules.

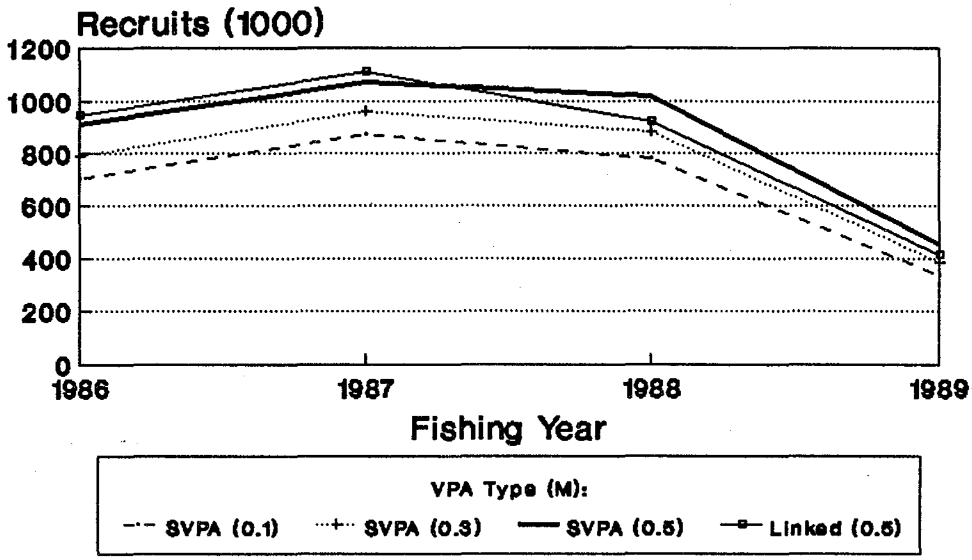



Fig. 15. Red drum recruitment to age 1.

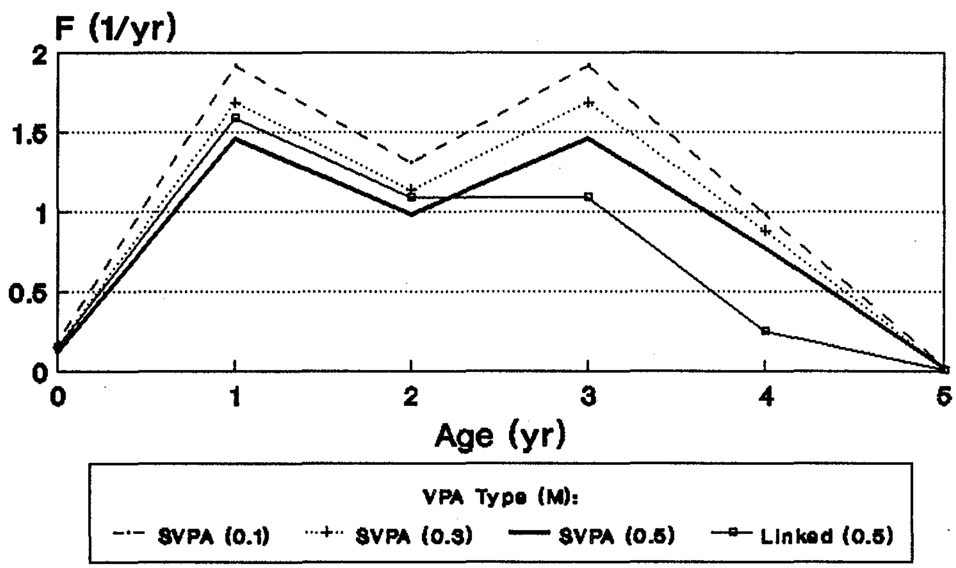



Fig. 16. Red drum mean F vectors.

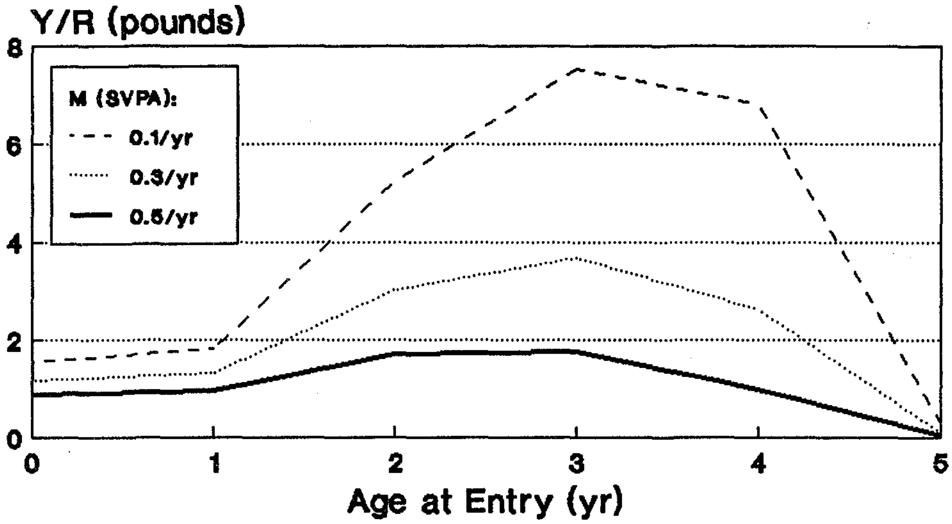



Fig. 17. Red drum yield per recruit with F multiple = 1.

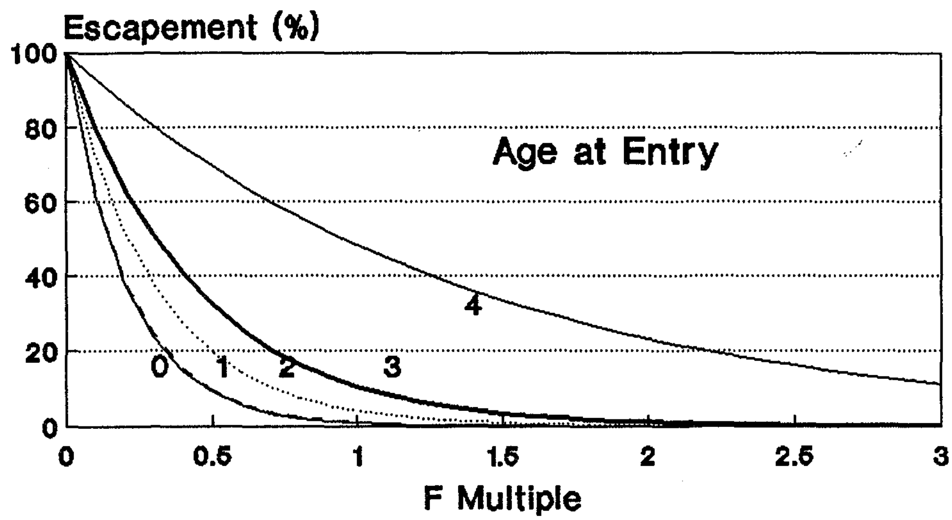



Fig. 18. Red drum escapement based on SVPA with subadult M = 0.5.

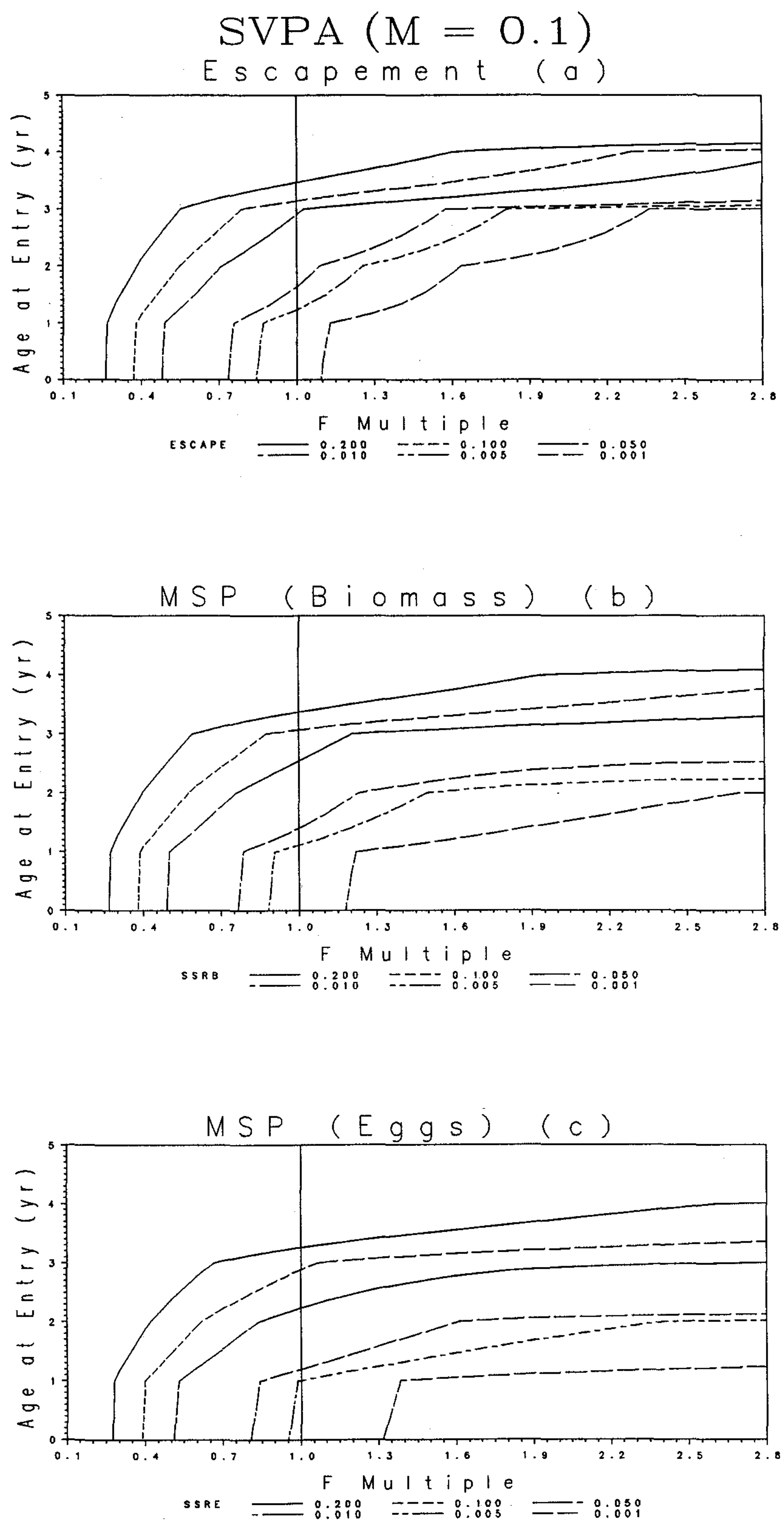



**Fig. 19.** Escapement and maximum spawning potential isopleths for red drum based on fishing mortalities estimated with subadult $M_1$ = 0.1 using Separable VPA ($M_2$ = 0.1). Contours are of proportion of a) escapement to age 6, b) maximum spawning potential in biomass, and c) maximum spawning potential in egg production.

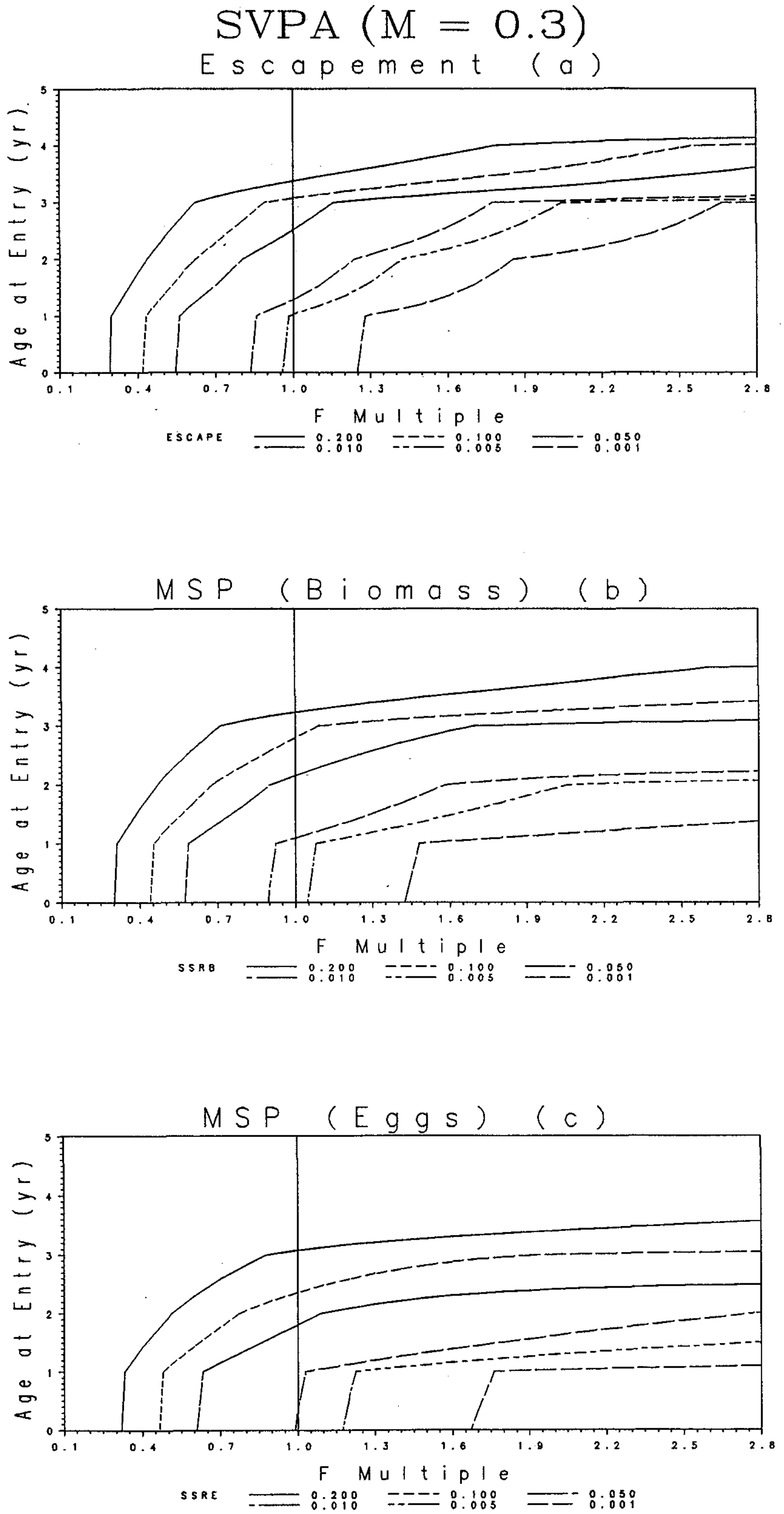



Fig. 20. Escapement and maximum spawning potential isopleths for red drum based on fishing mortalities estimated with subadult $M_1$ = 0.3 using Separable VPA ($M_2$ = 0.135). Contours are of proportion of a) escapement to age 6, b) maximum spawning potential in biomass, and c) maximum spawning potential in egg production.

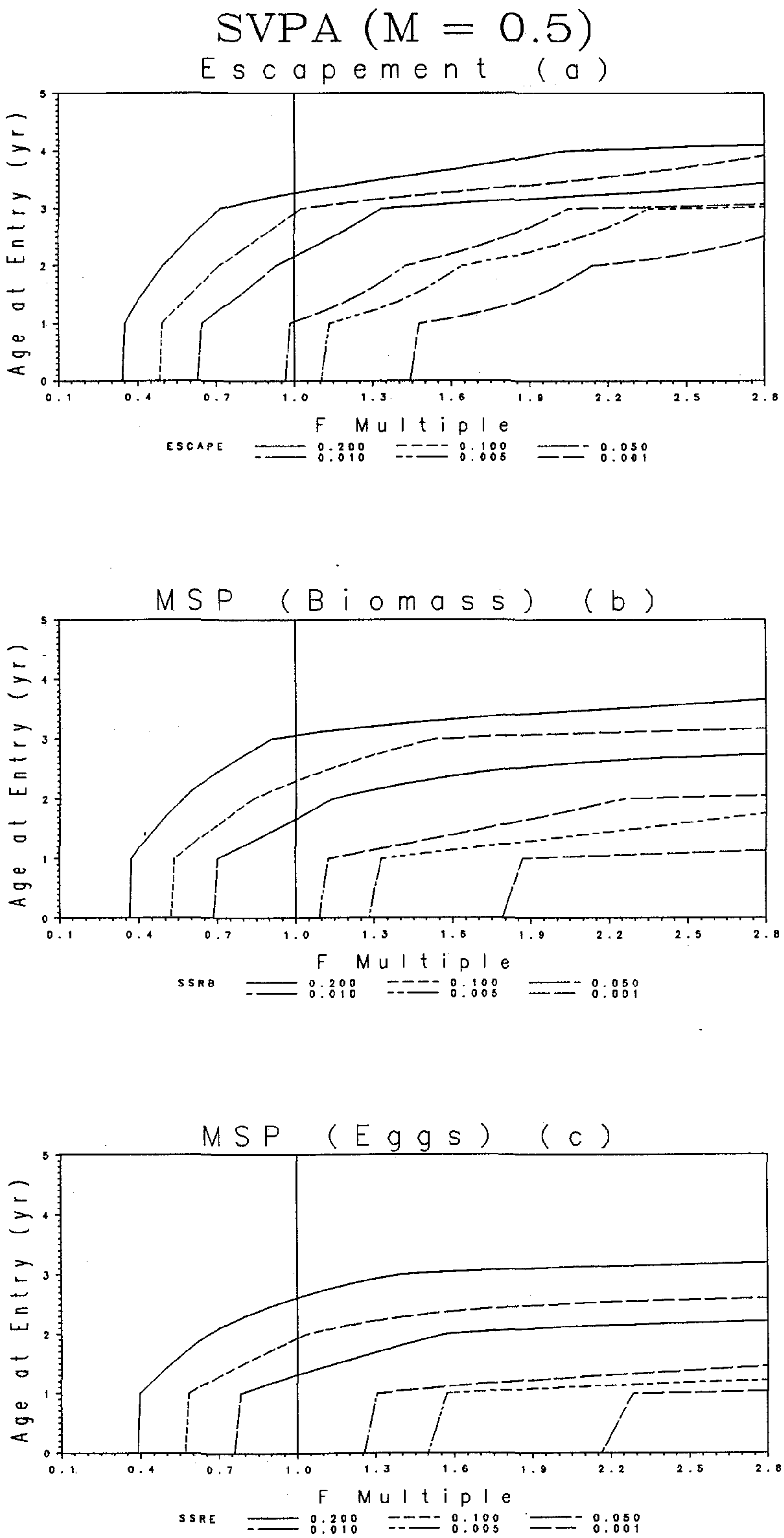



Fig. 21. Escapement and maximum spawning potential isopleths for red drum based on fishing mortalities estimated with subadult $M_1$ = 0.5 using Separable VPA ($M_2$ = 0.17). Contours are of proportion of a) escapement to age 6, b) maximum spawning potential in biomass, and c) maximum spawning potential in egg production.

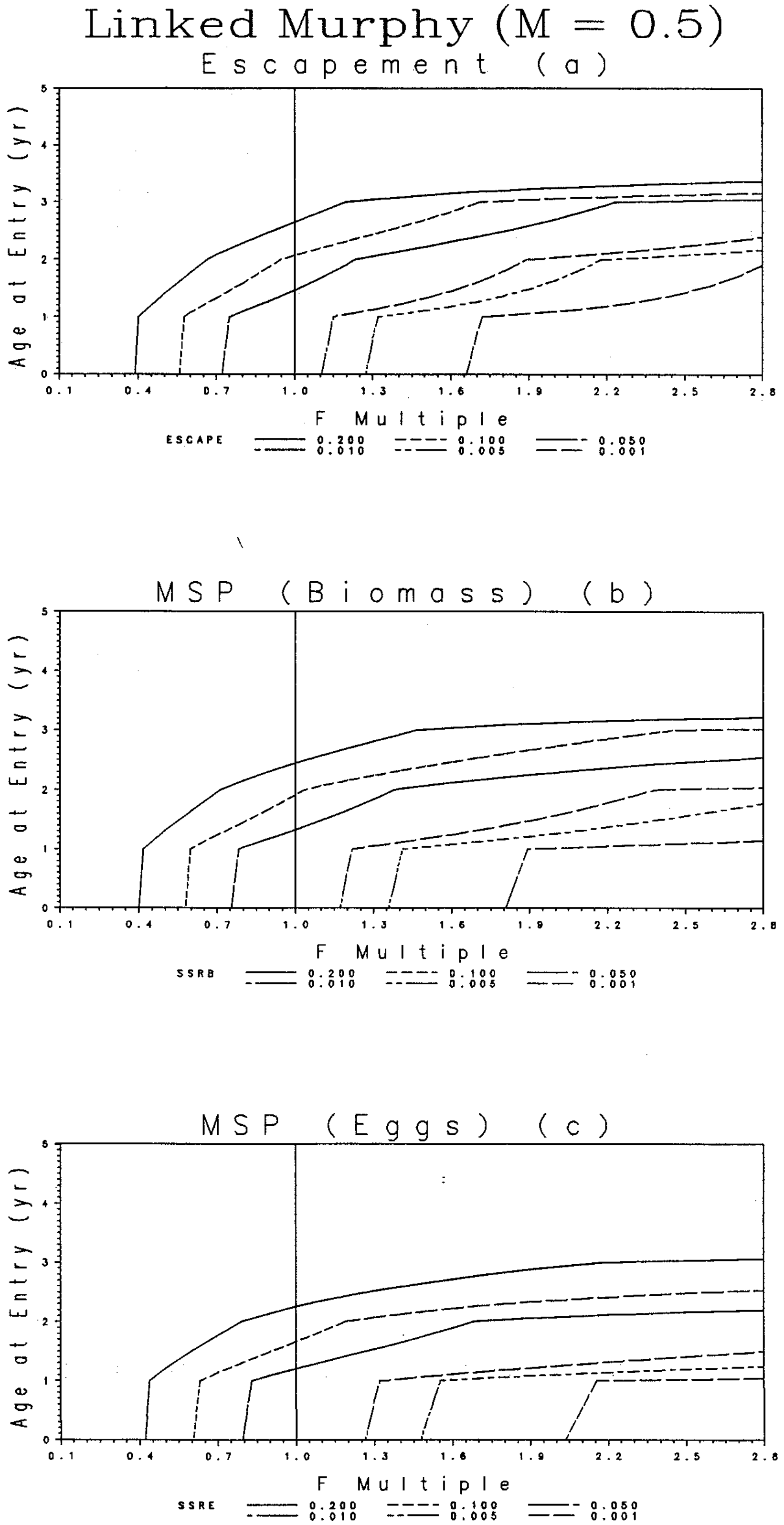



**Fig. 22.** Escapement and maximum spawning potential isopleths for red drum based on fishing mortalities estimated with subadult $M_1$ = 0.5 using Linked Murphy VPA ($M_2$ = 0.17). Contours are of proportion of a) escapement to age 6, b) maximum spawning potential in biomass, and c) maximum spawning potential in egg production.

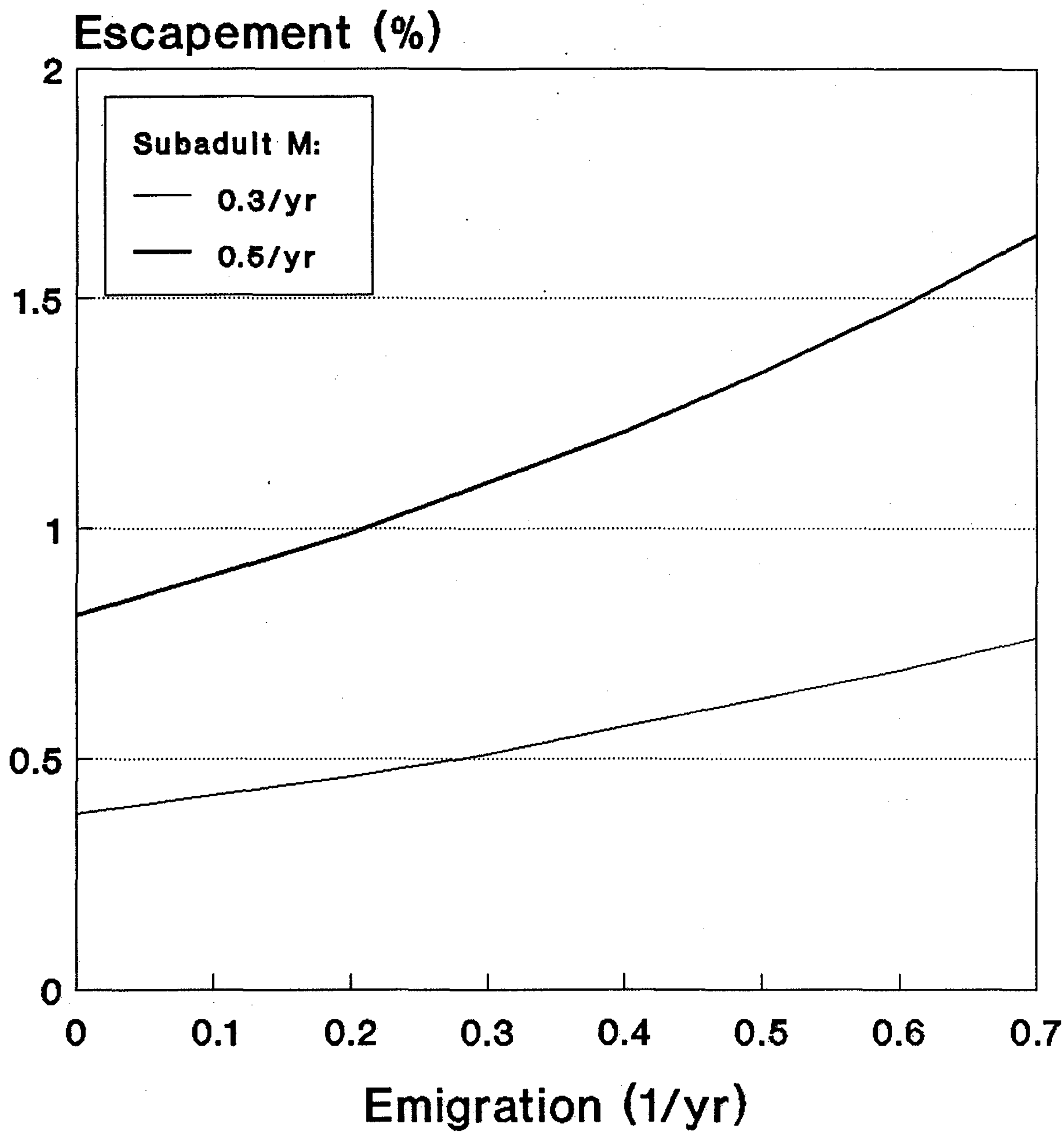



Fig. 23. Red drum escapement varying with emigration during age 3.

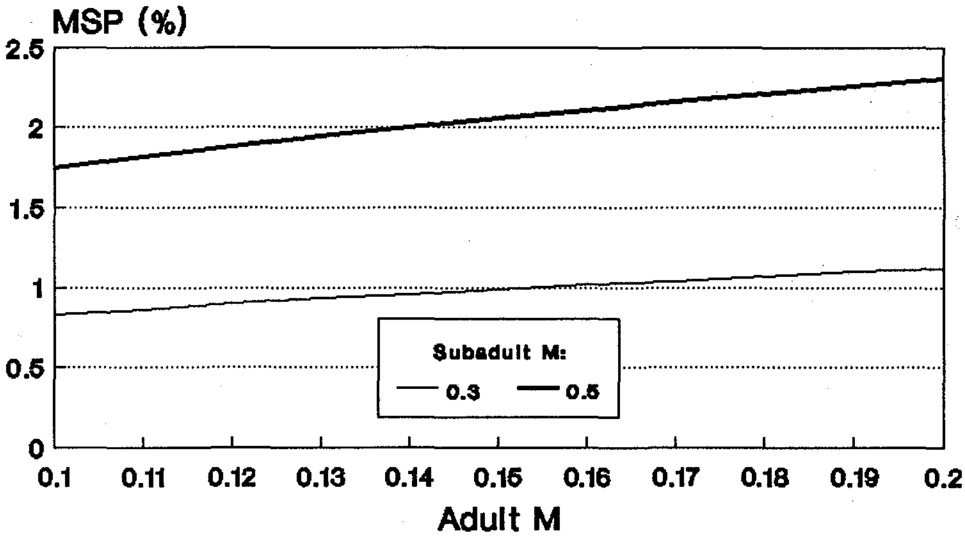



Fig. 24. Red drum MSP (egg production) varying with adult M.

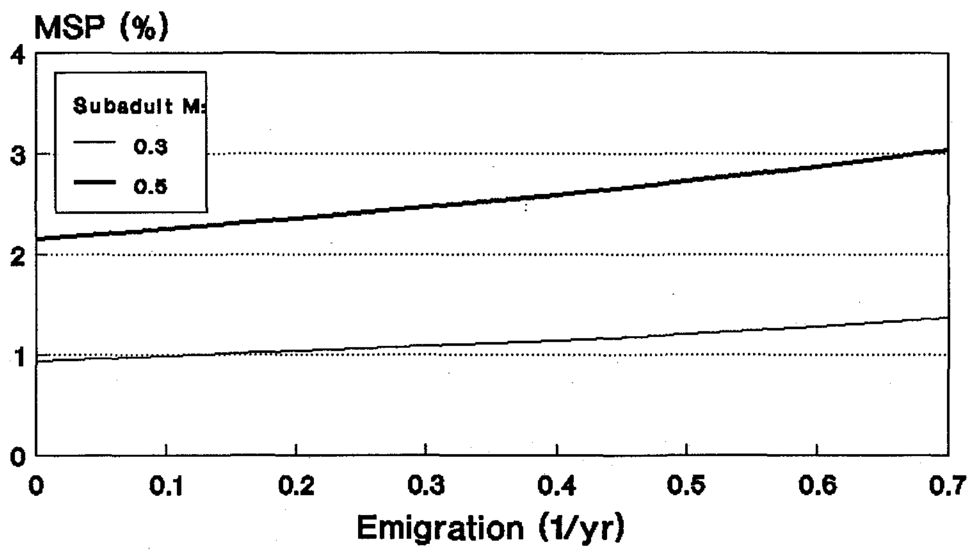



Fig. 25. Red drum MSP (egg production) varying with emigration during age 3.

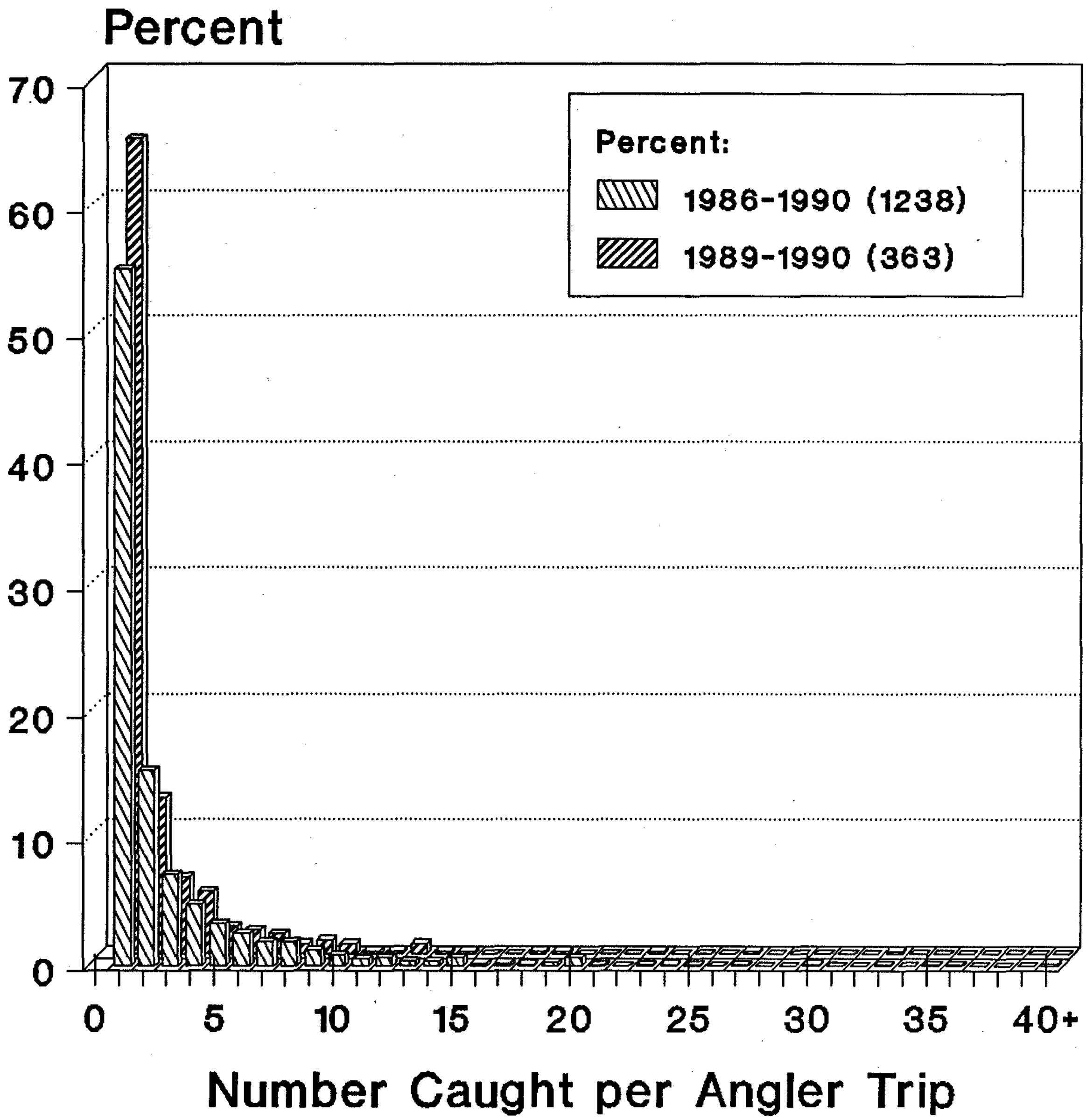



Fig. 26. Red drum catch in numbers per angler trip.

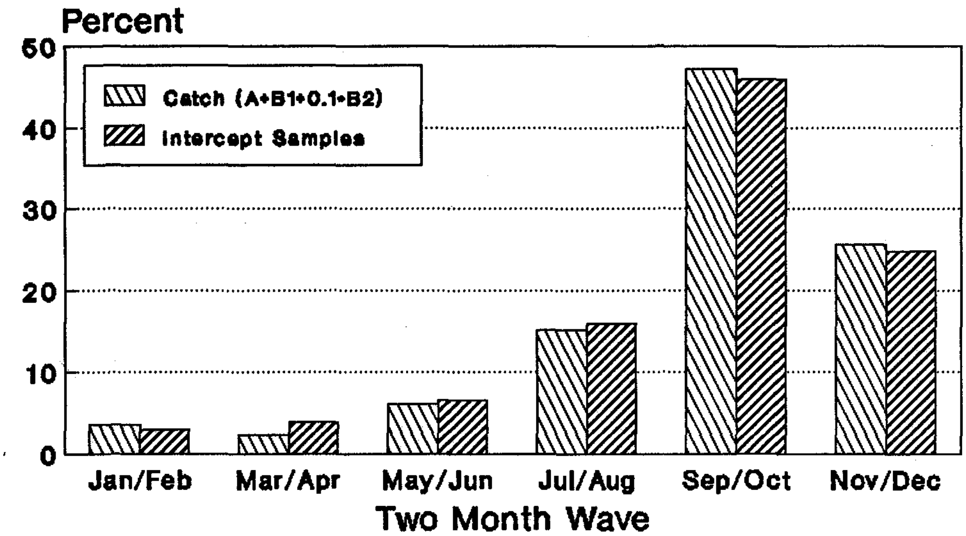



Fig. 27. Red drum recreation catch and sampling in 2-month waves (1986-90).

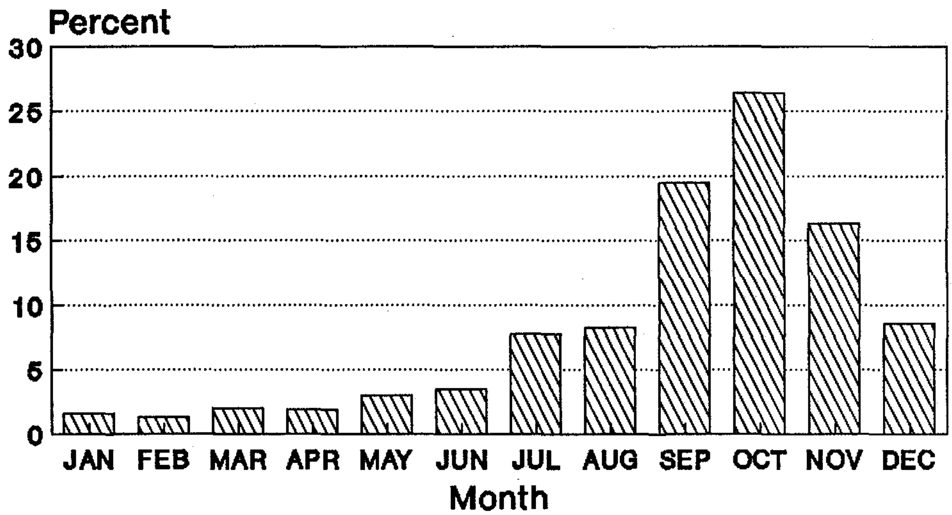



Fig. 28. Red drum monthly intercept sampling for seasonal savings.