Population Characteristics of the Red Porgy *Pagrus pagrus* from the U.S. Southern Atlantic Coast

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ABSTRACT

The age structure and status of the U.S. south Atlantic stock of red porgy is examined, using recorded and estimated landings and size frequencies of fish from commercial, recreational, and headboat fisheries from 1972-1997. Two catch-in-numbers-at-age matrices were developed from age-length keys based on fishery-dependent and fishery-independent data, respectively. For these two catch matrices, estimates of annual, age-specific population numbers and fishing mortality rates (F) for different levels of natural mortality (M = 0.20, 0.28, and 0.35 yr^{-1}) were obtained by application of a calibrated virtual population analyses (VPA) using fishery-independent data from MARMAP hook-and-line and trap gears in the calibration procedure.

With the catch matrix using fishery-dependent age-length keys, fishing mortality rates (F) increased from 0.05 in 1974 to 1.34 in 1997 for fully recruited ages (assumed 4+ throughout for comparative purposes) with M = 0.28, while spawning potential ratios declined from 90% to 32% based on mature female biomass and from 89% to 17% based on total mature (male and female) biomass. A similar pattern results from the catch matrix using fishery-independent age-length keys: fishing mortality rates (F) increased from 0.06 to 0.85 between 1974 and 1997 for fully recruited ages, while spawning potential ratios declined from 88% to 35% based on mature female biomass and from 80% to 19% based

on total mature biomass. The use of spawning potential ratio based on total mature biomass was used for comparison to biological reference points.

Recruits to age 1 declined from a peak in 1973 of 7.6 million age-1 red porgy to 12,000 age-1 red porgy in 1997 (based on catch matrix using fishery-dependent age-length keys); while total spawning stock (mature) biomass declined from a peak in 1978 of 11,700 mt to 323 mt in 1997. A similar pattern is noted for recruits to age 1 and total spawning stock biomass obtained from catch matrix using fishery-independent age-length keys. Retrospective bias in calibrated VPA (FADAPT) output suggests understimates of these population values in the most recent years.

Despite the retrospective problems with overestimation of F (and hence underestimation of total spawning stock biomass, recruits to age 1, and SPR) in the current year, long-term declining recruitment to age 1, headboat CPE, and MARMAP Survey CPE raise concerns about overfishing. Generally static SPR has been at or below the South Atlantic Fishery Management Council's criteria for overfishing (SPR = 30%) since 1981. During this time period, recruitment and spawning stock have continued to decline. Keeping in mind the difference between thresholds and targets, it would appear that reducing F to a level at or below that equivalent to 40% static SPR is necessary for rebuilding the U.S. south Atlantic red porgy stock.

Introduction

In this paper, changes in age structure and population size of the U.S. south Atlantic red porgy stock are computed and documented. The red porgy, a protogynous sparid also known as silver snapper and pink snapper, is a reef-associated, demersal species commonly found over very irregular and low profile hard bottom at depths ranging from 18 to 183 m (Manooch and Hassler 1978). Red porgy occur off the southern U.S. Atlantic coast, in the Gulf of Mexico, in the Atlantic off South America from Brazil to Argentina, off Portugal and Spain, in the Mediterranean Sea, off Africa south to the Cape Verde Islands, and around the Azores, Madeira, and Canary Islands.

In this analysis, the geographic range for the definition of stock from North Carolina and South Carolina has been expanded to include landings from Georgia and the east coast of Florida (Vaughan et al. 1992; Huntsman et al.[1]). Tagging studies show neither long range migrations nor extensive local movements of adult (>1 yr) red porgy (Manooch and Hassler 1978). Nor is there circumstantial or anecdotal information to suggest substantial movements. Red porgy are far less abundant in catches off

[1] Huntsman, G. R., D. S. Vaughan, and J. C. Potts. 1993. Trends in population status of the red porgy *Pagrus pagrus* in the Atlantic Ocean of North Carolina and South Carolina, USA, 1971-1992. South Atlantic Fishery Management Council, 1 South Park Circle, Charleston, SC 29422.

Georgia and Florida. Red porgy eggs and larvae are pelagic, are believed to survive transport by ocean currents for 30 days or more (Manooch et al. 1981), and could provide recruitment to the population off the U.S. south Atlantic coast from the Gulf of Mexico. However, it seems reasonable to treat the U.S. south Atlantic red porgy population off the coast of North Carolina through the east coast of Florida as a single stock.

Peak spawning occurs from March through April, with first maturation for females at age 2 (Manooch et al. 1981). Eggs are pelagic, spherical, and hatch 28 to 38 h after fertilization. Red porgy attain their maximum size slowly and live relatively long (18 yr or older). Red porgy are protogynous hermaphrodites, but mature males assumed to occur in all age groups. Thus, females predominate at smaller size intervals, and the existence of individuals with both testicular and ovarian tissue suggests protogyny. Age-specific sex ratios are provided by Roumillat and Waltz[2]. These are by age from their Table 6: 89% female at age 1, 91% at age 2, 77% at age 3, 67% at age 4, 59% at age 5, 51% at age 6, 25% at age 7, and 21% at age 8. They also found mature gonads in 18.8% of the females at age 1, 85.2% at age 2, 99.7% at age 3, and 100% at all older ages. These values for age-specific sex ratios and female maturity are used in preference to those

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[2] W. A. Roumillat, and C. W. Waltz. 1993. Biology of the red porgy *Pagrus pagrus* from the southeastern United States. Data Report 1993 MARMAP, South Carolina Wildlife and Marine Resources Department, P.O. Box 12559, Charleston, SC 29422-2559.

used in earlier assessments (Vaughan et al. 1991; Huntsman et al.[1])

At the request of the South Atlantic Fishery Management Council (SAFMC), this analysis of the status of stock for red porgy in the U.S. south Atlantic bight was conducted to update that of Vaughan et al. (1991) and Huntsman et al.[1]. The earlier analyses used commercial, recreational, and headboat data through 1986 and 1992, respectively. This new analysis expands the geographic range, revises the historical data, uses additional aging data, uses new information on sex ratios and sexual maturity, adds 11 more years of fishery-dependent data to the analysis, and uses fishery-independent MARMAP data to calibrate the VPA. The effect on VPA output from two sets of catch matrices developed from two sets of age-length keys are compared in this analysis: one set is based on ages obtained with fish collected from fishery-dependent sources, and one set is based on ages obtained with fish collected from fishery-independent sources. This new analysis uses a different calibrated virtual population analytic (VPA) approach based on ADAPT (Gavaris 1988).

In this report, changes in age structure and population size of red porgy found off the eastern Atlantic coast of the United States south of Cape Hatteras, North Carolina are computed and documented. Specifically, given age-specific estimates of instantaneous fishing mortality rates and information on growth, sex ratios, maturity and fecundity, analyses of trends in population values (fishing mortality, recruitment and spawning stock biomass), and biological reference points from yield per recruit (YPR), spawning potential ratio (SPR), and surplus production model(ASPIC) are used to determine the status of the U.S. south Atlantic red porgy stock.

Methods

There are three fisheries for red porgy in the U.S. south Atlantic: commercial, recreational, and headboat. The commercial fishery is principally prosecuted by hook & line, with some landings by trap and trawl. The recreational fishery includes fishing from shore, and from private and charter boats. For sampling purposes, the headboat fishery (charter-type operations that charge recreational fisherman per person or "head") is considered separate from the recreational fishery. Annual catch (number and weight) and length data from these three fisheries, together with length at age information, permitted development of a catch-in-numbers-at-age matrix (or simply catch matrix) for 1972-1997.

Development of estimates of catch in numbers at age allows application of catch curve approaches by year class or cohort for estimation of Z. Independent estimates of instantaneous natural mortality (M), based on life history relationships (Pauly 1979, Hoenig 1983), permit estimation of instantaneous fishing mortality rates (F = Z - M). Separable and calibrated virtual population analyses (Doubleday 1976; Pope and Shepherd 1982, 1985; and Gavaris 1988) are used to reconstruct the estimates of annual age-specific population size and instantaneous fishing mortality rates (F) for 1972-1997.

Development of Catch-in-Numbers-at-Age Matrices

Data for development of the catch matrices for the study area of the U.S. south Atlantic come from several sources. Commercial fishery data are obtained from NMFS (Southeast Fisheries Science Center, Beaufort, NC, and Miami, FL) from the General Canvas data base (for catch statistics, 1972-1997) and from the Trip Interview Program (TIP) data base (for length and weight statistics, 1983-1997). Length frequencies for commercial landings from South Carolina were available for 1976-1980 (Vaughan et al. 1992). Recreational catch and effort estimates and length and weight information are obtained through the Marine Recreational Fisheries Statistics Survey (MRFSS) data base (NMFS, Washington, DC) for 1979-1997. Headboat catch and effort estimates and length and weight sampling data are obtained from NMFS (Southeast Fisheries Science Center, Beaufort, NC) for 1972-1997. Fishery-independent length, weight and age data from commercial gears (hook & line and several types of traps, 1979-1997) are from the MARMAP (Marine Resources Monitoring, Assessment, and Prediction) Program (South Carolina Department of Natural Resources, Charleston).

Estimation of catch in numbers at age is similar to that in Vaughan et al. (1992). The basic approach consists of multiplying the catch in numbers (n, scalar) by an age-length key (A, matrix) by a length-frequency distribution (L, vector) to obtain catch in numbers at age (N, vector):

$$N_{ax1} = n \cdot A_{axb} \cdot L_{bx1}, \quad (1)$$

where a is the number of ages (e.g., ages 0 to 8+ years) and b is the number of length intervals (e.g., 25 mm increments from 200 mm to 550+ mm). If catch is available only in weight (as is the case with commercial landings), then catch is converted to numbers by dividing catch in weight by mean weight per fish landed for the same fishery/gear, time period (annual), and geographic region (U.S. south Atlantic coast). Length data for a given fishery/gear is converted to weight by a weight-length relationship and the average mean weight per fish for that fishery is calculated annually.

Historical Landings. Adjustments are necessary to obtain commercial landings for 1972-1983. As in Vaughan et al. (1992), commercial landings for that period were multiplied by 0.9, to account for reporting of the pooled category of porgies. Since then no adjustment is necessary (Huntsman et al.[1]). To obtain annual landings in numbers by gear from annual catch in weight by gear, landings in weight by gear (General Canvas data) are divided by mean weight of fish landed by that gear (TIP data).

Estimates of the recreational catch statistics in weight and numbers are obtained from the Marine Recreational Fishery

Statistics Survey conducted from 1979 through 1997 (Gray et al. 1994; **http://remora.ssp.nmfs.gov/index.html**). Three catch types are defined for the recreational fishery: **Type A** refers to catches that are available for identification and measurements; and **Type B** refers to catches that are not available for identification or measurement. The latter category is subdivided into: **Type B1** catches, used for bait, filleted, discarded dead, etc.; and **Type B2** catches, released alive. An estimate of 18% post-release mortality (Dixon and Huntsman[3]) was used to include a portion of the type B2 fish in the landings.

An additional adjustment to account for the inclusion of headboat estimates within the charter/party boat mode for 1979-1985 was required before the recreational catch data could be incorporated into the catch-at-age matrix (as for black sea bass in Vaughan et al. 1995). Intercept sampling for length is assumed proportional to catch for separating headboat from party/charter boat modes. Headboat landings for the period 1979-1985 are adjusted by state. About 90% of the intercept samples (e.g., length measurements) in Florida identified under the combined charter/headboat mode are from headboats, so about 90% of the landings for this mode are estimated as from headboats, and the remaining 10% from charter boats. Similarly, an estimate

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[3] Dixon, R. L. and G. R. Huntsman. Survival rates of released undersized fishes. Sixth Annual MARFIN Conference, Atlantic, GA, 12-13 October 1993.

of about 100% of the charter/headboat mode landings in Georgia are from charter boats, 4% in South Carolina, and 51% in North Carolina (south of Hatteras) based on intercept samples. Additionally, mean landings by mode of fishing from the recreational fishery is calculated for the period 1979-1997 and used for the period 1972-1978.

Headboat landings are estimated from the NMFS Beaufort Laboratory sampling program (Dixon and Huntsman, In Press). To aid in distinguishing from charter boats (sampled by MRFSS), which ordinarily charge by the trip, the working definition for headboat is any vessel that usually carries 15 or more passengers regardless of manner of payment. Headboat landings in weight and numbers are available for North and South Carolina from 1972 through 1997. Estimated landings for northeast Florida (south to Sebastian) are available from 1976 through 1997, and for southeast Florida (from Fort Pierce through Miami) from 1981 through 1997. No-intercept regressions northeast Florida or southeast Florida landings on Carolina landings were used to extend estimates of headboat landings in weight and number for northeast (0.052 for weight and 0.060 for numbers) and southeast (0.024 for weight and 0.033 for numbers) Florida back to 1972.

Total headboat effort in angler days and catch of red porgy in weight per unit effort are available for the same time period (1972-1997 for North and South Carolina, 1976-1997 for northeast

Florida, and 1981-1997 for southeast Florida. Catch per effort (CPE) is calculated by dividing catch in numbers by effort in angler days. Again no-intercept regressions of northeast Florida or southeast Florida effort on Carolina effort were used to extend effort estimates for northeast (0.819) and southeast (1.668) Florida back to 1972.

Length Frequency Distributions. Commercial length and weight data are available from sampling of commercial landings through the NMFS Trip Interview Program (TIP) database between 1984 through 1997 from North Carolina through the east coast of Florida. Only North Carolina data are available for 1983. Sampling adequacy (or intensity) is assessed using the informal standard developed by the NMFS, Northeast Regional Stock Assessment Workshop (USDOC 1996). This standard presumes that at least 100 fish lengths should be recorded per 200 mt of fish landed. Hence, a value greater than 200 mt/100 samples suggests inadequate sampling.

Commercial length frequencies for 1972-1982 are as in Vaughan et al. (1992). Separate annual length frequency distributions were developed for commercial hook & line, traps and trawls from 1983-1997. With trap and trawl landings being limited since the mid-1980's and few fish sampled (1611 for trap; and 1455, mostly between 1986-1988, trawl), one overall length frequency distribution for each gear is used for all years 1984-

1997. All annual gear-specific commercial length frequency distributions are weighted by catch in number caught by state.

The MARMAP Program collects standardized trap and hook & line data annually in the South Atlantic Bight (Collins and Sedberry 1991). The geographic scope of MARMAP is Cape Hatteras to Cape Canaveral, but with most sampling between Cape Fear and Jacksonville, Florida. The seasonal scope for reef fish sampling is late spring through summer (generally mid- to late-April through September). The data available for this analysis come from several gears: Hook & line (1979-1995), blackfish traps (1979-1989), Florida snapper traps (1980-1989), and Chevron traps (1988-1995). Based on analytic work in Vaughan et al. (In Press), the CPE from the Chevron trap is extended back to 1980 using the Florida snapper trap. For later calibration purposes only CPE from the MARMAP hook & line and extended Chevron trap are used. Length frequency distribution for red porgy (measured in total length to the nearest centimeter) are estimated by gear for the years available.

Recreational length frequency distributions from the MRFSS data base are available from 1979-1997. All length frequency distributions are weighted by catch in number (A+B1) caught during that mode, season (2-month wave), and state. Headboat length frequency distributions from the MRFSS (1979-1985) are not used in the development of the catch matrix.

Annual headboat length frequency distributions from NMFS

Beaufort Laboratory are available for the period 1972-1997, and used in developing the catch-in-numbers-at-age matrix. All length frequency distributions are weighted by catch in number caught during that season (Jan-May, Jun-Aug, Sep-Dec), and state (NC, SC, NE FL, and SE FL).

Age-Length Keys. Age-length keys were developed from data from two sources: fishery dependent and fishery independent (MARMAP).

The first set of age-length keys were based strictly on fish collected from fishery-dependent sources. Age-length keys were available for the period 1972-1974 (Manooch and Huntsman 1977) and for 1986 (Vaughan et al. 1992). Additionally, Potts et al.[4] recently aged red porgy collected from the commercial and headboat fisheries between 1989 and 1998 (511 fish, with 389 fish from 1996-1998) by sectioned otoliths. This last key was assumed to represent the period 1996-1997. As in Vaughan et al. (1992), age-length keys for missing periods (1975-1985 and 1987-1995) were obtained by linear interpolation from the three age-length keys for 1972-1974, 1986, and 1996-1997.

A second series of age-length keys were obtained from fish collected in MARMAP program samples taken from the South Atlantic Bight during 1979-1994 (Harris and McGovern 1997). Red porgy were

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[4] Potts, J. C., C. S. Manooch, III, and E. H. Laban. In preparation. Estimated ages of red porgy from fishery-dependent and fishery-independent data with comparison of growth parameters. National Marine Fisheries Service, 101 Pivers Island Road, Beaufort, NC 28516.

collected with a variety of gears, but primarily with hook & line, blackfish traps, Florida snapper traps, and more recently Chevron traps (Collins 1990). Weights (nearest g) and lengths (total and standard, nearest mm) were recorded, and otoliths (sagittae) were removed and stored dry. Otoliths were examined whole under reflected light with a dissecting microscope, and age estimates were based on the number of opaque zones visible.

MARMAP aging data were grouped in 3- and then 2-year periods from 1979-1994 (1979-1981, 1982-1984, 1985-1987, 1988-1990, 1991-1992, 1993-1994). Potts et al.[4] also aged 111 red porgy collected during 1996-1997 by the MARMAP program. An age-length key from these data was used for the period 1995-1997. Because no aging of fish from fishery-independent sources was available prior to 1979, the commercial key for 1972-1974 (Manooch and Huntsman 1977) was used, with linear interpolation between that key and the key from MARMAP data for 1979-1981.

Growth in total length as a function of age was fit to the von Bertalanffy (1938) growth equation using nonlinear regression with the Marquardt option (SAS Institute Inc. 1987). Parameters were estimated using various combinations of years and data sources with equal weights among the individual fish. The von Bertalanffy parameters were re-estimated so as not to include multiple, back-calculated length measurements, but only the most measurement of length at age per fish (Vaughan and Burton 1994). Total lengths in millimeters were used in the analysis.

Age-length keys (matrices) are needed to convert length frequency distributions to age frequency distributions. The keys consist of the proportion of fish of each age sampled from a given length interval. As regards the fishery-independent age-length keys, an overall age-length key for 1979-1994 with total length divided into 25 mm increments from 200 mm to 550+ and ages 0 through 8+ years was developed (n = 8,660 red porgy). Next, separate keys were developed for temporal periods described above. When fewer than 10 fish were available for a given length interval, data were used from a key representing the time period of greater duration (1979-1994). Total lengths greater than 575 mm (0 out of 8660 observations) and ages greater than 8 years (67 out of 8660 observations) are pooled with lengths of 550 mm and 8 years, respectively.

<u>Catch-in-Numbers-at-Age Matrix</u>. Annual application of Eq. (1) to each fishery/gear (commercial hook & line, commercial traps, commercial trawls, recreational, and headboat) were performed separately and accumulated for each year to obtain annual estimates of catch in numbers at age for 1972-1997 (referred to as catch matrix). Eq. (1) was also applied annually to the MARMAP Survey estimates of red porgy catch per effort (CPE), series of fishery-independent age-length keys, and corresponding length frequency data for each gear, available from 1979-1997, to obtain age-specific calibration indices (hook & line and extended

Chevron trap).

Coherency of the catch matrices are assessed by considering the pair-wise correlations among ages such that catch at age are lined up by cohort. One would expect that, after the age of full recruitment by the gear, high correlations should be obtained. Hence, one should be able to follow a strong or weak cohort through the catch matrix (fishery-dependent and fishery-independent age-length keys) and MARMAP CPE matrices (hook & line and extended Chevron trap).

Mortality and Population Dynamics

Instantaneous total mortality rate (Z) was estimated from catch curve analysis (Ricker 1975) by year class (cohort) from the fishery catch matrices (obtained from either fishery-dependent or fishery-independent age-length keys). Estimates were obtained by regressing the natural logarithm of catch in numbers against age for recent cohorts over fully recruited ages (descending right-hand limb, ages 4 through 7). These estimates are used solely to provide starting values for F in the application of separable VPA (obtain average Z from 1989-1991 cohorts for each catch matrix, and F from Z-M).

Natural Mortality. Pauly (1979) obtained the following relationship for estimating M based on growth parameters and mean environmental temperature:

$$\log_{10}M = 0.0066 - 0.279 \cdot \log_{10}L_\infty + 0.6543 \cdot \log_{10}K + 0.4634 \cdot \log_{10}T \quad (2)$$

where M equals instantaneous natural mortality rate, L_∞ (cm) and k (yr^{-1}) are parameters from the von Bertalanffy growth equation, and T(°C) is mean environmental temperature. A mean annual seawater temperature of 22°C (Manooch et al. 1998) was used to represent mean nearshore temperature off of the southeastern U.S. Atlantic coast. Estimates of M based on Pauly's (1979) approach ranged from 0.27 to 0.57. Lower estimates of M are associated with higher estimates of L_∞ and lower estimates of K.

Another major life history approach suggested by Hoenig (1983) is based on the maximum age observed in the population. Because the relationship he developed is based on Z, instead of M, the maximum age in the unfished population (F = 0; M = Z-F) would provide an estimate of M. The oldest fish in the MARMAP data set was age 14, yielding an estimate of M equal to 0.30; while the oldest age from fishery-dependent sources was 18 yielding an estimate of M equal to 0.23. Higher ages provide lower estimates of M.

A few other approaches were also considered. That of Ralston (1987), based solely on the growth parameter, K, gave estimates ranging from 0.22 for K = 0.1 to 0.64 for K = 0.3. The method of Alagaraja (1984), also based on maximum age, gave estimates ranging from 0.17 to 0.26 using the maximum age of 18, and a range of expected survival to maximum age (0.01 to 0.05).

Because aging data sets typically contain large numbers of young and relatively few older fish, problems often result in estimating L_∞ and K in the von Bertalanffy growth curve (Vaughan and Kanciruk 1982). Greater confidence is associated with aging, especially in recent years, with ages based on sectioned otoliths (Potts et al.[4]). Estimates based on maximum age tend to suggest lower M than those based on growth parameters. As in Vaughan et al. (1992), most of our analyses are based on M equal to 0.28, with additional analyses for M equal to 0.20 and 0.35.

Fishing Mortality and Population Estimates. The two catch matrices (based on fishery-dependent and fishery-independent age-length keys) were interpreted using virtual population analysis (VPA) approach to obtain annual age-specific estimates of fishing mortality rates and population size. Virtual population analysis sequentially estimates population size and fishing mortality rates for younger ages of a cohort from a starting value of fishing mortality for the oldest age (Murphy 1965). An estimate of natural mortality, typically assumed constant across years and ages, was also required. The separable method of Doubleday (1976), which assumes that age- and year-specific estimates of F can be separated into products of age and year components, was run on the 1992-1997 portion of the catch matrix to develop estimates of partial recruitment by age. These estimates of partial recruitment serve as input to the calibrated VPA program used. The period 1992-1997 represents the time period since the introduction of a 12-inch minimum size limit in Amendment 4 to the Snapper-Grouper FMP (SAFMC 1991). The FORTRAN program developed by Clay (1990), based on Pope and Shepherd (1982), was used to obtain estimates of age-specific availability, or the partial recruitment vector, to aid in setting up the calibrated VPA described next.

A method of VPA that uses fishery-independent indices of abundance (Pope and Shepherd 1985) in the calibration process was used. The specific calibration approach was that developed by Gavaris (1988) and modified by Dr. Victor Restrepo (Cooperative Institute of Fisheries Oceanography, University of Miami, Miami, FL) as the program FADAPT. Indices used for calibration was limited to MARMAP data for hook & line (1979-1997) and extended Chevron trap (1980-1997). The Chevron trap (1988-1997) was extended back in time (to 1980) with another trap gear using a conversion factor determined by the MARMAP program from synoptic sampling during 1988-1989 (Collins 1990, and Vaughan et al., In Press). This conversion factor (5.58) was applied to the Florida snapper trap for the period 1980-1987. Most calibration runs were made with both indices, but a few runs were made with each index separately.

The catch matrix analyzed consisted of catch in numbers for ages 1 through 8+ and fishing years 1972 through 1997 (partial recruitment for age-0 red porgy was essentially 0 for all years). For the SVPA, starting values for F were based on the mean of the final three year class estimates of Z (~0.8 yr^{-1}) and final F obtained by subtracting M from Z. Sensitivity of estimated F (and recruitment to age 1) to uncertainty in M was investigated by conducting the above VPAs with alternate values of M (0.20 and 0.35). A starting partial recruitment vector for FADAPT was based on an SVPA run for the period 1992-1997.

Retrospective analyses were conducted for the calibrated VPA approach to investigate the potential for bias in F (and recruitment to age 1) for the most recent years by varying the final year used in the analysis from 1992 to 1997 (initial year was 1972 throughout). The proportional difference (D) between estimates of F (or recruits to age 1) from historical data (last year of catch matrix used was varied between 1992 and 1996) and from the full catch matrix (last year of catch matrix used was 1997) were compared:

$$D = (X_i - X_{97})/X_{97} \qquad (3)$$

where X_{97} is the parameter estimate based on the analysis on catch matrix for 1972-1997, and X_i is the parameter estimate based on the reduced catch matrix beginning in 1972 and ending in year i: 1992-1996. The variable X can be mean F (ages 4-8), recruits to age 1, or any other value of interest.

Yield per Recruit. Equilibrium yield per recruit analysis was conducted based on the method of Ricker (1975), who subdivided the exploited phase into a number of segments (e.g., years) during which mortality and growth rates are assumed constant. This approach permits instantaneous natural and fishing mortality rates to vary during the fishable life span and permits a general growth pattern to be used. Total equilibrium yield per recruit is obtained by summing the catches in each segment over the total number of segments. Input data were based on both sexes and all years combined.

Spawning Potential Ratio. Gabriel et al. (1989) developed maximum spawning potential (%MSP) as a biological reference point. The currently favored acronym for this approach is referred to as static spawning potential ratio (static SPR). A recent evaluation of this reference point is given in a report by the Gulf of Mexico SPR Management Strategy Committee (1996) for the Gulf of Mexico Fishery Management Council (see also Mace and Sissenwine (1993), and Mace (1994)). Static or equilibrium SPR was calculated as a ratio of spawning stock size when fishing mortality was equal to the observed or estimated F divided by the spawning stock size calculated when F equal to zero. All other life history parameters were held constant (e.g., maturity schedule and age-specific sex ratios). Hence, the estimate of static SPR increases as fishing mortality decreases.

Comparisons of age-specific spawning stock biomass were based on mature female biomass, egg production, or even on total mature biomass (both males and females). To address the change in male to female ratio with increasing mortality, the reduction in the proportion of mature males to mature males and females in numbers was estimated compared to what that proportion would be when F equals zero.

We used the relationship between fecundity (E, number of eggs) and total length (TL, mm) based on the least-squares linear-regression equation ($r^2 = 0.66$, $n = 50$) (Manooch 1976):

$$\ln E = -14.1325 + 4.3598 (\ln TL), \qquad (4)$$

to provide an alternative to female spawning stock biomass as a measure of spawning potential. Separate sex-based growth relationships were used for males and females in these calculations.

<u>Spawner-Recruit Relationships.</u> As for spawning potential ratio, spawning stock biomass is calculated from age-specific estimates

of population numbers, mean weight, sex ratios, and sexual maturity. Because red porgy are gonochoristic, results presented are based mostly on total mature biomass. Recruits to age 1 are compared to the spawning stock biomass that produced them.

<u>Surplus Production Model (ASPIC).</u> The ASPIC program for estimation of the Schaefer surplus production model was implemented for the U.S. south Atlantic red porgy population (Prager 1994). Data used in this implementation included total landings (commercial, recreational and headboat landings combined in weight from 1972-1997) and catch per effort (CPE) indices from the MARMAP fishery-independent survey (hook & line for 1979-1997 and the extended Chevron trap for 1980-1997).

Results

Historical Data. For the study period (1972-1997), total landings in weight rose from about 339 mt in 1972, to a peak of 1,481 mt in 1982 (Table 1). Landings have been at or below 300 mt since 1992, with 228 mt in 1997. Peak in total landings in numbers was over 1.8 million in 1984. During the 1970s, the landings by weight were 53% commercial, 7% recreational, and 40% headboat. During the 1980s and 1990s, the importance of headboat landings to total landings by weight was reduced, with 81% commercial, 5% recreational, and 14% headboat for the 1980s, and 77%, 9%, and 14%, respectively, for the 1990s.

Commercial landings in weight rose from 60 mt in 1972, to 1,279 mt in 1982, and declining to near or under 200 mt during most of the 1990s (Table 1). Similarly, commercial landings in numbers rose from below 0.1 million fish in 1972, to just over 1.6 million fish in 1984, and generally below 0.3 million fish during most of the 1990s. Between 1975 and 1984, trawl landings in weight were as larger or larger than commercial hook & line landings (Fig. 1a). However, since 1985, commercial hook & line landings by weight made up about 93% of all commercial landings, with commercial trap landings making up about 5% and trawl landings less than 2%.

Recreational landings in weight fluctuated between 6 and 96 mt (Table 1). Recreational landings in numbers during the period 1979-1997 showed no particular trend, averaging about 69,000 fish (A + B1 + 18% B2), although some large estimates (>100,000) were obtained between 1985 and 1990. Catches by mode of fishing have been highly variable by (Fig. 1b). Shore-based catches have averaged 2,600 kg or 4,600 fish, charter boat catches have averaged 15,400 kg 27,300 fish, and private boat catches have averaged 20,800 kg or 36,900 fish over the period 1979-1997.

Similarly, headboat landings were consistently high during the 1970s (> 200,000 red porgy), were generally between 100,000-200,000 fish during the 1980s, and less than 100,000 fish beginning in 1992 (Table 1). Most of the landings have come from North and South Carolina, with only small landings from Georgia and the east coast of Florida (Fig. 1c). A declining trend in headboat catch in numbers per angler days is apparent for both North and South Carolina (Fig. 2).

Declines in catch per effort (CPE) are also noted in indices based on MARMAP sampling using hook & line and extended Chevron trap (Fig. 2). Trap effort was standardized by "soak time" and hook & line effort by "angling time" (Collins and Sedberry 1991). There is a precipitous decline in the extended Chevron trap CPE, with a similar, but somewhat less dramatic, decline noted in the hook & line CPE.

<u>Adequacy of Length Frequency Sampling.</u> Adequacy of sampling for

fish lengths was generally excellent for commercial and headboat landings, and adequate for recreational landings (Table 2). However, each fishery was stratified by year, area, etc., for which some cells were lacking samples.

Headboat sampling for lengths offered only slight problems in the early years when no length samples were available south of the Carolinas prior to 1976, and for southeast Florida prior to 1981. Length frequencies from Georgia and northeast Florida were used for southeast Florida between 1976 and 1980, and mean length frequency distributions for the period 1976-1980 were used for 1972-1975 from all areas south of the Carolinas. Because landings by headboat from these areas were minimal, little bias should be associated with these assumptions (Fig. 1b).

Even with generally small landings for the recreational component, the small sample sizes would suggest only occasional problems in certain years. However, when different areas and modes of fishing are considered, sample sizes are generally inadequate. Pooled length frequency distributions were obtained across years as weighted by catch in numbers by bi-monthly period (wave), state and mode of fishing.

Greater difficulties arise from sampling for fish lengths for the commercial fishery, especially when gear specific sampling is considered. As noted in Vaughan et al. (1992), no fish length samples were available for 1972-1975 and 1981-1982. Most of the commercial fish length samples are from the hook &

line gear. Of course most of the commercial landings have been from this gear, except when the trawl landings predominated between 1978 and 1984. Length samples from trawl landings were pooled and applied to landings from the trawl gear. Similarly, length samples from trap landings were also pooled and applied to landings from the trap gear. Generally annual length samples for hook & line were available. As in Vaughan et al. (1992), the length frequency distribution of 1976-1980 was used for 1972-1975, and linear interpolation was used for 1981-1982 from 1980 and 1983 length frequency distributions.

Growth in Weight and Length. The estimated relationship for weight (kg, W) as a function of total length (mm, L) are from published values. For fishery-dependent modeling, values for *a* and *b* (in $W = aL^b$) were from Manooch and Huntsman (1977; a = 0.00002524 and b = 2.8939) for the 1970s and 1980s; and from Potts et al.[4] (a = 0.00000885 and b = 3.060) for the 1990s). For fishery-independent modeling, values were from Manooch and Huntsman (1977) for 1972-78; and from MARMAP data (1979-1994 ; a = 0.00003064 and b = 2.8653) for the remaining years.

Parameter estimates were estimated for the von Bertalanffy growth equation are summarized in Table 3. Different estimates of von Bertalanffy parameters are for different time periods and from different data sources (fishery-dependent and fishery-independent sources).

Annual estimates of mean weight for commercial hook & line and headboat for the Carolinas are obtained directly from sampled fish lengths (using weight-length relations described above) (Fig. 3). Dividing catch in weight by catch in numbers, annual estimates of overall mean weight (kg) of fish landed were obtained. The overall trend was generally downward, especially since about 1978.

Fishery Catch Matrices and Coherency. Catch matrices were estimated using Eq. (1) using two sets of age-length keys (Table 4). Because catch in numbers for age-0 red porgy were often 0 or very small, they have been dropped from the catch matrices. The catch matrix, obtained using fishery-dependent age-length keys, shows a modal age of age 5 for 1972-1982, followed by an abrupt drop in modal age to age 2. Modal age has gradually increased back to age 4. Although the catch matrix, obtained using fishery-independent age-length keys, has some modal ages of age 5 in the 1970s, there are several exceptions (i.e., age 2 in 1975 or age 3 in 1976). The pattern is similar to the other catch matrix, but much more variable.

Pair-wise correlations among lagged catch at age were calculated for both catch matrixes (Table 5). Both generally showed significant (at 0.1 level) correlations between lagged catches at adjacent ages. A few significant correlations were found among lagged catches for non-adjacent ages.

MARMAP Indices and Coherency. The calibrated virtual population analysis (FADAPT) uses MARMAP catch-per-effort (CPE) that was broken into gear- and age-specific values comparable to development of the fishery catch matrix, but only using the fishery-independent age-length keys. Estimates of CPE at age for hook & line are from 1979-1997, and for the extended Chevron trap from 1980-1997 (Table 6). As with the fishery catch matrices, CPE for age 0 was always less than 0.001, so this age was dropped from the index CPE at age. Coherency of these matrices are also explored using pair-wise correlations among lagged CPE (Table 7). The hook & line gear shows greatest coherency among the younger ages (e.g., ages 1-4), while the extended Chevron trap appears very coherent over a wider, older range of ages (e.g., ages 3-7).

Trends in Mortality and Recruitment. As stated above, FADAPT requires input of the age-specific availability of each age in the calibration index, so ages greater than or equal to the modal age were set to one, and for ages younger than the modal age, the CPE for that age was divided by the CPE for the modal age. Estimates of F for ages 4 through 7 were assumed fully recruited for all years for the purpose of comparison across years. Estimates of F were averaged over these ages weighted by population numbers at those ages (referred to as mean or full F).

Recruitment is the population numbers at age 1 at the beginning of the calendar year (referred to as recruits to age 1).

Using FADAPT applied to the catch matrix based on fishery-dependent age-length keys with a range of M, annual estimates of F for all ages (1, 2, 3, 4+) tended to be lowest for the period 1972-1978 compared to the periods 1982-1986 and 1992-1996 (Table 8). F on ages 1 and 2 initially increased between 1972-1978 and 1982-1986, and then decreased between 1982-1986 and 1992-1996. Meanwhile F on ages 3 and 4+ initially increased between 1972-1978 and 1982-1986, but remained essentially unchanged between 1982-1986 and 1992-1996.

The trend in annual estimates of full F with M = 0.28 starts low, rising abruptly during the late 1970s, peaks in 1982, decreases (though not to the low values of the early-mid 1970s), and then gradually rises to very high estimates for the most recent years (Fig. 4a). A similar pattern is noted in full F from FADAPT applied to the catch matrix based on fishery-independent age-length keys with M = 0.28, but with lower values for the most recent years (Fig. 4b).

The FADAPT approach was conducted with M equal to 0.20 and 0.35 with the catch matrix based on fishery-dependent age-length keys (Fig. 5). Full F is underestimated slightly if M is overestimated (e.g., if M = 0.20 instead of assumed M = 0.28), and full F is overestimated slightly if M is underestimated (e.g., if M = 0.35 instead of assumed M = 0.28) (Fig. 5a).

The bias in estimates of recruits to age 1 due to mis-specification of M increases as one proceeds back in time (Fig. 5b). However, the pattern of initially high recruitment, followed by a long period of declining recruitment persists, regardless of level of M. With catch matrix from fishery-dependent age-length keys with M = 0.28, recruits to age 1 peaked in 1975 with 7.6 million fish, and steadily declined to 399,000 fish in 1995 and 12,000 fish in 1997. Corresponding values for M = 0.20 are 4.5 million in 1975, 321,000 in 1995, and 10,000 in 1997; and for M = 0.35, 12.5 million in 1975, 490,000 in 1995 and 15,000 in 1997.

In using FADAPT, the program was allowed to estimate the relative weighting among the fishery-independent indices used in the calibration process. Weighting varied slightly among the different FADAPT runs with varying M, yielding weighting values of 0.05 for hook & line and 0.95 for the extended Chevron trap from the catch matrix using fishery-dependent age-length keys (corresponding weightings of about 0.07 and 0.93 for the other catch matrix). A comparison is made based on using only the hook & line index, or only the extended Chevron trap index (Fig. 6). Very small differences are noted in full F or recruits to age 1, although some deviation in full F in the most recent two years (1996-1997) is apparent.

Because virtual population analyses work backwards from an assumed or starting F for the oldest age of a cohort to the youngest age, confidence in estimated F (or population biomass) was least for the most recent estimate and converges towards "truth" for the youngest ages. Estimates generally converged within about 2 to 3 years. Proportional differences in estimates of fully recruited fishing mortality rates (age 4+) and recruits to age 1 are compared for analyses based on catch matrices restricted to earlier final years (1992-1996) to analysis based on complete catch matrix (1997) to determine whether there was any consistent bias (Fig. 7). There was a large positive bias in full F (overestimate) in the most recent year. Subsequent population-level analyses were based on averaging instantaneous fishing mortality rates for three time periods: 1972-1978, 1982-1986, and 1992-1996 (Table 8 and 9).

Yield per Recruit. Estimates of equilibrium yield per recruit are summarized for the calibrated VPA (FADAPT) runs with catch matrix based on fishery-dependent age-length keys (Table 9) for different levels of M and three time periods (1972-1978, 1982-1986, and 1992-1996). Because of the bias observed in estimated F for 1997 (Fig. 7a), estimates of F for 1997 were not included in calculations for the recent time period. Increasing natural mortality led to decreasing estimates of yield per recruit. Yield per recruit is plotted against full fishing mortality (ages 4-8+) for three time periods (Fig. 8). Two traditional biological reference points obtained from the yield per recruit approach are F_{max} and $F_{0.1}$ (Sissenwine and Shepherd 1987). Using estimates of F for the most recent time period (1992-1996; assumes partial recruitment value based on average F at age) from calibrated VPA applied to each catch matrix, these reference points were estimated as F_{max} = 0.6 and 1.4, respectively, and $F_{0.1}$ = 0.3 and 0.4, respectively, for fully recruited ages (Table 10). The first value for each reference point (F_{max} = 0.6 and $F_{0.1}$ = 0.3) should be considered the appropriate value, since the age-length keys better represent the age-structure of fish removed by the fisheries.

Spawning Potential Ratio. Estimates of equilibrium spawning potential ratio using estimated F (Table 8) from calibrated VPA applied to the two catch matrices are summarized by time period and assumed level of M (Table 9). Because of the bias observed in estimated F for 1997 (Fig. 7a), estimates of F for 1997 were not included in calculations for the recent time period. Estimated equilibrium SPR is plotted against full F for three time periods. Using calibrated VPA (FADAPT) estimates of F from the catch matrix based fishery-dependent age-length keys (with M of 0.28) for three periods, SPR estimates based on total mature biomass, female biomass, and male biomass are compared (Fig. 9). Mature female biomass is less affected by increasing F than mature male biomass, precisely because the younger fish are predominantly females and the older fish are males. Full F that would produce an estimated 30% SPR was found to be about 0.45 for total mature biomass, and 0.27 for mature male biomass (Table 10).

Corresponding estimates were made of the reduction in proportion of males in the population for three periods (Table 9). For example, a value of 60% under 'Percent Male' implies that if the proportion of males in the unfished population (all mature ages) were 50%, then the introduction of fishing mortality would reduce this proportion to 30% (60% of 50%). If the initial proportion were 10%, then a reduction of 60% would reduce the proportion of males to 6%.

Spawning stock biomass, based on the total weight of mature males and females, is seen to peak about 1978 at 11,700 mt, and then decline to 670 mt in 1995 and 323 mt in 1997 (M=0.28) (Fig. 10a). Similar patterns are noted for M=0.20 and M=0.35.

Meanwhile, total static SPR was high during the 1970's (peaking in 1974 at 83%, and declining to a minimum in 1990 at 17%, increasing to a recent maximum in 1993 at 27%, in declining to about 17% in 1997 (M=0.28) (Fig. 10b). Similar patterns are found with M=0.20 and M=0.35. For M=0.28, total spawning potential ratio has been generally below 30% since 1981 (except during the period 1985-1987).

Spawner-Recruit Relationships. Recruits to age 1 are plotted against the total spawning stock biomass that produced them (lagged 1 year) for three levels of M. During the early to mid 1970's, high spawning stock was producing high recruitment (Fig. 11a). Note that the upper right represents the older years, while the lower left represents the most recent years. With high landings during the 1980's, the spawning stock was reduced to a level that has not supported good recruiment.

Following up on Huntsman et al.[1], recruits to age 1 was also plotted against total static SPR for three levels of M (Fig. 11b). Again, the values in the upper right represent the early years, while values in the lower left represent the most recent years.

<u>Surplus Production Model (ASPIC).</u> A series of runs were made with ASPIC to investigate this alternate approach to assessing the status of the red porgy stock. Separate runs were made using CPE from just MARMAP hook & line gear and from the extended Chevron gear, as well as both CPE indices included. All runs suggest that early relative biomass was high (B/B_{msy}>>1), and recent relative biomass is low (B/B_{msy}<<1). The reverse is noted for relative fishing mortality rate. As an example, plots of relative biomass and fishing mortality based on an ASPIC run, with both MARMAP CPE indices included, is shown with 80% bootstrapped confidence intervals (Fig. 12).

Discussion and Management Implications

Numerous changes have been made in this analysis to extend and improve on those shown in Vaughan et al. (1992) and Huntsman et al.[1]. The major improvement has been additional aging data from both fishery-dependent and fishery-independent sources, and fishery-independent indices for calibrating virtual population analysis. Linear interpolation for the catch matrix using fishery-dependent age-length keys was necessary for 1975-1985 (as in Vaughan et al. 1992) and for 1987-1995. Although more consistent aging data were available for the catch matrix using fishery-independent age-length keys, it was still necessary to substitute the fishery-dependent age-length keys for 1972-1974 and linearly interpolate for 1975-1978. These catch matrices demonstrate a moderate level of coherence (significant correlations between adjacent ages), but with relatively large F's significant correlations between catch at age lagged several years should not necessarily be expected. However, CPE at age for the MARMAP gear (hook & line and extended Chevron trap) showed a high degree of coherency, especially for the extended Chevron.

The analyses on the catch matrix from fishery-independent sources tend to provide lower estimates of fishing mortality rates and higher estimates of population and spawning biomass.

However, they do not differ in the temporal pattern, which suggests much higher population size and spawning biomass during the 1970's, and a significant degradation of this stock through the 1980's and 1990's. Other changes from earlier analyses include expanding the geographic range to include landings from the Atlantic coast of Georgia and Florida, new estimates of sex ratios and maturity schedules, new growth parameters, and application of FADAPT over SVPA and CAL.

At the fishery level, sampling intensity appears to be moderate to excellent. However, there are still data gaps with respect to fish length distributions that must be estimated, generally by linear interpolation from years when fish length data was available, or pooling data across many years. The latter were generally performed on gear (trawl or trap) and fishery (recreational) which contribute small amounts to the landings. The primary exception concerned the commercial trawl gear during the early 1980's, when commercial trawl landings dominated. Hence, additional uncertainty is probably extant for specific annual estimates, but minimal effect on temporal patterns and mean values across specific time periods.

Potential bias from mis-specification in M do little to change the overall pattern of a population in decline. Although higher M (e.g., M = 0.35) may suggest that static SPR is above the South Atlantic Fishery Management Council's definition of overfishing (30% static SPR), this long term population decline would then suggest that a higher level of static SPR may be required to prevent population collapse. Little difference was also noted when FADAPT was calibrated separately to either MARMAP hook & line or the extended Chevron. FADAPT calibrated to both indices was most similar to the results from calibration to the extended Chevron trap, because the final weighting value heavily favored CPE from this gear.

A major bias is associated with estimating fishing mortality (F) in the most recent years, but this bias as shown in the retrospective analyses is principally associated with the most recent year (Fig. 7a). In spite of this estimation problem, declining trends in headboat CPE and in CPE from MARMAP sampling (Fig. 2), combined with the observed decline in recruits to age 1 (other than the terminal year for FADAPT) (Fig. 7b), raise significant concerns about the possibility of overfishing.

Most of the protection from the implementation of the 12" minimum size limit (Amendment 4, SAFMC 1991) appears to have reduced F only on ages 1 and 2 (Table 8). Little, if any, improvements are evident for ages 3 and full recruited ages (4+).

With data through 1986 (and restricted to the Carolinas), Vaughan et al. (1992) noted the beginnings of population decline. For the two time periods that can be compared (1972-1978 and 1982-1986), mean F from this new analysis are somewhat lower than those in Vaughan et al. (1992) for the early period and somewhat higher for the later period. Vaughan et al. (1992) suggested static SPR of 69-86% for the early period and 38-53% for the later period. In this analysis, 60-85% was found for the early period (range based on range in M), and 15-40% for the later period. Results from Huntsman et al.[1], based on data from 1972 through 1992, are intermediate to those presented in this paper. They show the continued degradation in recruitment and spawning stock, increasing F and decreasing static SPR through the late 1980's.

Yield per recruit analysis was conducted to obtain two traditional biological reference points: F_{max} and $F_{0.1}$. Estimates for these two values are 0.6 and 0.3, respectively (for M = 0.28). Mean full F (0.64, averaging over 1992-1996; Table 10) is slightly above F_{max}, but about double $F_{0.1}$. Estimated full F for the early period (0.09 for 1972-1978) was well below both reference points, while the estimate for the middle period (0.56 for 1982-1986) is slightly less than F_{max}, but almost twice $F_{0.1}$.

Estimates of static SPR based on female biomass and egg production are higher than 40%, which is greater than the 30% biological reference point used to define overfishing by the South Atlantic Fishery Management Council (SAFMC 1991). However, red porgy are protogynous hermaphrodites with most functioning initially as females and then as males. Hence, increasing fishing mortality on all ages reduces the proportion of mature males to mature females. Whether this will alter the age of transition is not known, and it was not possible to account for the effect of population density on transformation rate in population models. Whether males are currently limiting, or the degree to which increasing fishing mortality can cause them to become limiting is unknown. Increased rate of transformation from females to males due to reduced abundance of males, which has been reported in other protogynous reef fish (Shapiro 1979), would lead to additional declines in mature female biomass. If females do not transform at a greater rate when the population is depressed, then the complementary concern may arise as to whether sufficient numbers of mature males will be present during spawning.

The modal values of age-specific mature female biomass, egg production, and mature male biomass are shifted to younger age with increasing F (Vaughan et al. 1995). Hence, the greatest effect of increasing F would be on males. This is because fewer older fish remain with higher F, and most older fish are males. Thus, estimates of SPR for males are smaller than for females. Estimates of SPR based on mature male biomass ranged between 10% and 14% during the recent period (1992-1996, M = 0.28), and between 38% and 45% for females for the same period. The proportion of mature males relative to mature females is expected to be reduced to about 64% from mean fishing mortality rate for 1992-1996 (M = 0.28), which is not obviously suggestive that there will be insufficient numbers of males for the spawning process.

Estimates of SPR for total mature biomass, recommended biological reference point in Vaughan et al. (1992, 1995), were generally found to be in the range of 20% to 27% during the recent period (1992-1996). Spawning potential ratio (based on total spawning stock biomass) for red porgy is estimated at 76% for 1972-1978, 28% for 1982-1986, and 24% for 1992-1996 (Table 9 for M of 0.28). Mean values for the two most recent periods are below the value of 30% used by the South Atlantic Fishery Management Council to define overfishing for red porgy (SAFMC 1991). However, it should be noted that the value of 24% for the recent period is slightly underestimated as suggested by the retrospective analysis (even with leaving out values for 1997), but the bias is unlikely to be enough to raise the mean estimate above 30%.

When plotting recruits to age 1 against either spawning stock biomass or static SPR, the decline over time is apparent (Fig. 11). The presumption is that high levels of fishing during the late 1970's into the early 1980's was the primary causative factor. While fishing mortality declined from the peak value in 1982, it has shown some increase over the 1990's for fully recruited ages (Fig. 4). Meanwhile estimates of static SPR have remained fairly consistent since about 1980, varying at or below 30% static SPR.

Population analyses based on a surplus production modeling approach (ASPIC; Fig. 12) also suggest that the population was well above the level capable of producing MSY during the 1970's, but since the early 1980s has been well below the level capable of producing MSY.

The U.S. south Atlantic red porgy stock appears to be in poor condition, given the long term decline noted in spawning stock biomass. Despite the retrospective problems with overestimation of F (and hence underestimation of total spawning stock biomass, recruits to age 1, and static SPR) in the current year, long-term declining recruitment to age 1, headboat CPE, and MARMAP Survey CPE raise concerns about overfishing. Generally static SPR has been at or below the South Atlantic Fishery Management Council's criteria for overfishing (SPR = 30%) since 1981. During this time period, recruitment and spawning stock have continued to decline. Keeping in mind the difference between thresholds and targets, it would appear that reducing F to a level at or below that equivalent to 40% static SPR (0.28 for M = 0.28) is necessary for rebuilding the U.S. south Atlantic red porgy stock.

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Table 1. U.S. south Atlantic red porgy landings in weight and numbers by fishery, 1972-1997.

Year	Commercial	Recreational	Headboat	Total
		Thousands of Kilograms		
1972	60.0	38.9[a]	240.4[b]	339.3
1973	54.7	38.9[a]	339.9[b]	433.4
1974	61.3	38.9[a]	234.7[b]	334.9
1975	131.9	38.9[a]	205.3[b]	376.0
1976	190.6	38.9[a]	177.5[c]	407.0
1977	234.0	38.9[a]	245.9[c]	518.8
1978	715.5	38.9[a]	240.2[c]	994.5
1979	969.0	50.1	157.3[c]	1176.4
1980	1046.4	31.9	162.4[c]	1240.7
1981	1274.5	16.8	147.3	1438.6
1982	1278.9	6.2	195.9	1481.0
1983	824.9	10.8	118.6	954.3
1984	878.1	46.5	98.4	1023.1
1985	251.5	95.8	118.1	465.4
1986	385.2	8.8	100.7	494.8
1987	328.1	32.8	100.0	460.9
1988	360.0	75.2	97.8	533.0
1989	403.4	62.8	74.9	541.1
1990	484.0	21.1	56.8	561.9
1991	341.8	20.5	63.9	426.2
1992	198.7	53.7	49.8	302.2
1993	185.3	29.7	45.8	260.9
1994	198.7	20.2	39.7	258.7
1995	207.3	37.8	42.2	287.2
1996	213.6	49.3	37.3	300.2
1997	185.9	8.0	34.2	228.0

[a] Estimated from MRFSS using mean of landings in weight and numbers for 1979-1997.

[b] Includes separate estimates for North and South Florida using no-intercept regression with North and South Carolina headboat landings.

[c] Includes estimates for South Florida using no-intercept regression with North and South Carolina headboat landings, with headboat landings available for North Florida.

Table 1. (cont.)

Year	Commercial	Recreational	Headboat	Total
		Thousands of Fish		
1972	82.5	68.8[a]	220.0[b]	371.3
1973	72.5	68.8[a]	299.7[b]	441.0
1974	82.6	68.8[a]	219.9[b]	371.2
1975	167.3	68.8[a]	215.5[b]	451.6
1976	210.3	68.8[a]	186.7[c]	465.7
1977	222.2	68.8[a]	243.6[c]	534.6
1978	647.0	68.8[a]	223.8[c]	939.5
1979	864.2	57.3	156.5[c]	1078.0
1980	929.5	61.2	168.5[c]	1159.2
1981	1162.8	27.2	168.0	1357.9
1982	1250.3	21.3	272.9	1544.5
1983	1304.7	28.9	155.7	1489.4
1984	1640.3	74.1	130.0	1844.3
1985	282.4	137.9	176.6	596.9
1986	497.3	16.1	161.0	674.4
1987	457.0	62.2	173.6	692.7
1988	522.8	127.9	168.6	819.2
1989	567.2	132.5	146.5	846.2
1990	748.9	212.4	104.8	1066.0
1991	566.9	52.9	129.9	749.7
1992	263.8	93.7	85.9	443.4
1993	245.3	35.7	81.7	362.7
1994	256.2	35.0	70.4	361.7
1995	276.0	61.3	70.7	408.0
1996	300.7	56.6	64.9	422.3
1997	260.5	12.5	53.9	326.8

[a] Estimated from MRFSS using mean of landings in weight and numbers for 1979-1997.

[b] Includes separate estimates for North and South Florida using no-intercept regression with North and South Carolina headboat landings.

[c] Includes estimates for South Florida using no-intercept regression with North and South Carolina headboat landings, with headboat landings available for North Florida.

Table 2. Sample size and sampling adequacy for U.S. south Atlantic red porgy fish lengths by fishery. Sampling adequacy, in parenthesis, is measured as tons of fish landed per 100 sampled fish. Informal standard of less than 200 tons of fish landed per 100 sampled fish is deemed adequate (USDOC 1996, inadequate samples in **bold**).

Year	Commercial	Recreational	Headboat
1972	0	0	4227 (6)
1973	0	0	4988 (7)
1974	0	0	3623 (7)
1975	0	0	2314 (9)
1976	1351 (14)	0	2511 (7)
1977	1694 (14)	0	2207 (11)
1978	2016 (35)	0	1720 (14)
1979	2365 (41)	29 (173)	906 (17)
1980	1429 (73)	53 (58)	1435 (11)
1981	0	**8 (210)**	1133 (13)
1982	0	7 (88)	2501 (8)
1983	**337 (244)**	26 (41)	2269 (5)
1984	3264 (27)	**13 (358)**	2517 (4)
1985	3397 (7)	**32 (295)**	1897 (6)
1986	5939 (7)	7 (126)	2056 (5)
1987	6027 (5)	57 (57)	2290 (4)
1988	4063 (9)	82 (92)	1602 (6)
1989	3430 (12)	122 (51)	1506 (5)
1990	3878 (13)	129 (16)	1289 (4)
1991	5257 (7)	45 (46)	645 (10)
1992	3239 (6)	101 (52)	824 (6)
1993	4999 (4)	46 (64)	1006 (5)
1994	3363 (6)	74 (27)	777 (5)
1995	6695 (3)	57 (63)	847 (5)
1996	4025 (5)	32 (151)	1012 (4)
1997	3189 (6)	25 (31)	649 (5)

Table 3. Estimated parameters for von Bertalanffy growth equation [TL(mm) = $L_\infty(1 - \exp(-k(\text{age} - t_0)))$] with U.S. south Atlantic red porgy data from 1972-1998. The maximum age in the sample is given by t_{max}. These parameters were estimated from observed mid-length interval at age for fishery-dependent data for 1972-1974 and 1986; from back-calculated length at oldest age for fishery-dependent data for 1989-1998 and fishery-independent data for 1996-1997; and from observed length at age adjusted from month of collection for fishery-independent data for 1979-1994.

Type	n	L_∞	k	t_0	t_{max}
Fishery-Dependent Data					
1972-74	1913	575.8	0.16	-1.88	15
1986	524	1252.9	0.40	-4.05	12
1989-98	631	650.8	0.14	-0.80	18
Fishery-Independent (MARMAP) Data					
1979-94	8601	485.5	0.23	-1.48	14
1979-81	1171	501.3	0.34	-0.15	13
1982-84	2159	626.1	0.15	-1.61	14
1985-87	2332	542.5	0.16	-2.24	12
1988-90	1268	424.2	0.31	-1.06	12
1991-92	842	425.1	0.25	-1.62	13
1993-94	829	375.7	0.43	-0.78	12
1996-97[a]	111	756.2	0.10	-1.28	6

[a] Otoliths from fish collect during 1996-1997 by MARMAP but aged by C. Manooch and J. Potts (NMFS Beaufort Laboratory).

Table 4. U.S. south Atlantic red porgy catch-in-numbers-at-age (in thousands) matrices for ages 1 through 8+ (and total numbers) and years 1972 through 1997. Note that 18% of catch-release recreationally caught fish (type B2 fish from MRFSS) are included in estimates by number (modal age underlined).

Year	Age (yr) 1	2	3	4	5	6	7	8+	Total (1000)
	Based on Fishery-Dependent Age-Length Key								
1972	13.2	61.2	58.4	61.1	98.0	50.7	28.4	26.4	397.6
1973	13.7	63.2	63.8	67.0	107.2	58.3	39.1	49.7	461.9
1974	13.7	65.3	65.1	63.6	86.6	41.5	26.2	32.7	394.6
1975	18.8	72.2	85.0	95.7	101.9	63.6	35.9	57.8	530.7
1976	15.2	59.6	81.2	116.6	143.2	93.8	53.0	68.6	631.1
1977	14.2	65.8	85.9	118.0	154.2	105.5	70.0	129.5	743.2
1978	16.7	89.8	145.7	247.5	401.0	305.4	186.9	289.5	1682.3
1979	16.3	103.5	180.1	300.5	474.3	367.7	239.1	349.9	2031.4
1980	16.2	107.2	229.9	406.9	569.1	330.3	203.4	432.3	2295.3
1981	17.3	144.4	279.2	455.8	648.2	391.8	254.7	404.7	2596.1
1982	26.5	233.9	367.4	503.7	643.6	335.9	211.2	323.4	2645.6
1983	208.5	409.1	258.5	215.2	199.5	77.2	51.4	70.1	1489.5
1984	300.1	588.8	348.5	258.4	212.6	65.3	32.1	38.5	1844.4
1985	28.5	116.8	126.9	116.5	127.3	43.4	18.4	19.2	596.9
1986	24.8	117.3	152.9	159.5	122.8	48.3	21.0	28.8	675.4
1987	6.9	86.6	196.4	171.3	122.2	52.9	24.4	32.1	692.7
1988	15.2	108.8	250.9	211.5	132.2	50.0	21.9	28.6	819.2
1989	15.1	131.2	251.7	195.6	138.3	57.5	24.8	32.0	846.2
1990	32.1	212.4	321.7	238.5	152.5	55.3	22.0	31.5	1066.0
1991	22.0	160.0	228.2	172.5	99.3	32.4	13.8	21.4	749.7
1992	10.5	63.1	127.2	117.4	80.0	26.7	8.8	9.8	443.4
1993	1.9	28.5	98.4	117.9	76.2	23.5	8.0	8.5	362.7
1994	1.7	27.1	91.7	119.5	79.6	24.1	9.0	8.9	361.7
1995	3.7	38.6	110.9	132.2	84.3	23.0	7.2	8.1	408.0
1996	0.3	9.5	110.4	151.1	95.6	33.0	10.3	12.0	422.3
1997	0.1	3.2	74.7	122.9	82.0	27.7	7.8	8.5	326.8

Table 4. (cont.)

Year	Age (yr)								Total
	1	2	3	4	5	6	7	8+	(1000)
				Based on Fishery-Independent Age-Length Key					
1972	13.2	61.2	58.4	61.1	98.0	50.7	28.4	26.4	397.6
1973	13.7	63.2	63.8	67.0	107.2	58.3	39.1	49.7	461.9
1974	13.7	65.3	65.1	63.6	86.6	41.5	26.2	32.7	394.6
1975	16.7	119.9	111.4	68.4	53.7	60.3	46.3	53.2	530.7
1976	13.8	93.8	115.9	95.9	97.6	85.5	62.6	65.6	631.1
1977	12.9	93.3	109.0	102.7	129.2	100.5	80.4	114.8	743.1
1978	15.3	119.1	176.1	232.7	397.1	279.1	201.7	260.8	1682.1
1979	15.0	197.6	342.6	282.7	199.5	353.2	305.7	334.4	2031.3
1980	15.0	216.3	468.2	340.3	212.5	346.3	291.9	404.2	2295.3
1981	24.3	357.3	493.4	559.5	432.7	256.3	166.6	306.1	2596.1
1982	37.3	504.1	556.3	553.4	393.6	216.7	136.4	247.8	2645.6
1983	180.1	391.2	352.2	263.7	116.0	72.5	48.3	65.3	1489.4
1984	260.2	554.9	469.3	310.6	113.6	61.8	32.8	41.2	1844.3
1985	35.2	111.4	105.9	130.4	102.4	66.3	29.0	16.4	596.9
1986	28.6	139.0	129.1	151.7	110.7	66.1	30.0	20.3	675.4
1987	70.2	218.9	168.2	90.4	36.0	41.7	30.3	36.4	692.7
1988	85.5	276.6	207.0	102.1	39.3	43.6	28.2	35.3	819.2
1989	39.7	230.1	243.4	120.9	91.0	36.8	35.9	45.9	846.2
1990	65.1	317.5	312.7	140.7	101.1	38.6	38.7	47.8	1066.0
1991	45.4	154.7	156.0	172.8	92.9	52.2	28.0	47.4	749.7
1992	19.0	60.8	88.0	113.7	67.1	38.6	20.1	35.6	443.4
1993	3.8	36.9	50.1	90.2	89.1	48.0	22.7	21.8	362.7
1994	3.3	32.5	47.6	89.1	90.8	50.3	24.6	23.5	361.7
1995	5.3	40.8	56.1	101.0	100.4	54.5	24.8	25.0	408.0
1996	5.1	47.5	61.5	106.1	101.8	54.2	23.2	22.8	422.3
1997	2.3	31.0	45.1	83.2	83.2	44.1	19.7	18.3	326.8

Table 5. Pair-wise correlations (and significance below) as a measure of coherency in two fishery catch matrices (based on fishery-dependent and fishery independent age-length keys) for the U.S. south Atlantic red porgy fishery. Values of significance below 0.10 are in bold; the lower the value, the greater the likelihood of significant correlation. Sample sizes range from 25 for adjacent ages to 20 between age 1 and age 7.

Age (yr)	Age (yr) 1	2	3	4	5	6	7
	Catch Matrix From Fishery Dependent Age Length Key						
1	1.0	0.46	-0.08	-0.11	-0.16	-0.18	-0.19
		0.0201	0.7060	0.6253	0.4795	0.4454	0.4121
2		1.0	0.37	-0.08	-0.22	-0.31	-0.36
			0.0720	0.7167	0.3222	0.1616	0.1094
3			1.0	0.42	-0.03	-0.39	-0.57
				0.0356	0.9020	**0.0679**	**0.0056**
4				1.0	0.66	0.21	-0.08
					0.0004	0.3192	0.7054
5					1.0	0.73	0.44
						0.0001	**0.0307**
6						1.0	0.84
							0.0001
	Catch Matrix From Fishery Independent Age Length Key						
1	1.0	0.32	-0.12	-0.23	-0.42	-0.36	-0.29
		0.1226	0.5787	0.2863	**0.0544**	0.1042	0.2085
2		1.0	0.55	-0.25	-0.20	-0.40	-0.46
			0.0043	0.2475	0.3494	**0.0677**	**0.0339**
3			1.0	0.74	-0.27	-0.18	-0.39
				0.0001	0.1935	0.3987	**0.0766**
4				1.0	0.50	0.09	-0.20
					0.0103	0.6648	0.3719
5					1.0	0.62	0.34
						0.0010	0.1031
6						1.0	0.82
							0.0001

Table 6. U.S. south Atlantic red porgy catch-per-effort in numbers-at-age from different MARMAP gears for ages 1 through 8+ (and total numbers) available for years 1979 through 1997.

Year	Age (yr)								CPE
	1	2	3	4	5	6	7	8+	
Hook & line									
1979	0.11	1.08	1.51	0.55	0.22	0.27	0.16	0.11	4.00
1980	0.08	1.05	1.25	0.64	0.42	0.79	0.75	0.61	5.59
1981	0.18	1.10	0.86	0.60	0.32	0.09	0.03	0.02	3.21
1982	0.11	1.75	1.23	0.80	0.44	0.14	0.07	0.15	4.69
1983	0.05	0.39	1.01	0.73	0.19	0.09	0.04	0.04	2.55
1984	0.04	0.37	0.90	0.89	0.35	0.17	0.05	0.04	2.82
1985	0.06	0.27	0.41	0.52	0.34	0.20	0.08	0.04	1.91
1986	0.11	0.43	0.39	0.45	0.30	0.15	0.05	0.01	1.88
1987	0.15	0.49	0.28	0.11	0.03	0.04	0.05	0.04	1.17
1988	0.10	0.43	0.32	0.13	0.04	0.05	0.03	0.04	1.13
1989	0.09	0.49	0.53	0.23	0.15	0.04	0.04	0.05	1.64
1990	0.01	0.15	0.17	0.07	0.04	0.01	0.01	0.01	0.47
1991	0.10	0.15	0.25	0.30	0.18	0.09	0.04	0.04	1.17
1992	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1993	0.11	0.49	0.41	0.43	0.30	0.11	0.05	0.04	1.94
1994	0.04	0.12	0.12	0.16	0.13	0.07	0.02	0.02	0.67
1995	0.11	0.11	0.09	0.18	0.17	0.09	0.05	0.04	0.83
1996	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1997	0.01	0.16	0.36	0.65	0.66	0.36	0.08	0.12	2.40
Extended Chevron Trap									
1980	0.15	1.83	2.17	1.11	0.73	1.37	1.31	1.06	9.74
1981	0.50	3.01	2.36	1.65	0.87	0.25	0.08	0.06	8.78
1982	0.23	3.53	2.49	1.61	0.89	0.28	0.14	0.30	9.45
1983	0.24	1.81	4.72	3.42	0.91	0.44	0.19	0.20	11.92
1984	0.06	0.57	1.36	1.34	0.53	0.25	0.08	0.07	4.26
1985	0.22	0.95	1.43	1.82	1.17	0.68	0.28	0.13	6.68
1986	0.43	1.77	1.57	1.83	1.22	0.62	0.21	0.02	7.66
1987	0.81	2.63	1.49	0.57	0.15	0.22	0.25	0.20	6.32
1988	0.76	0.71	0.35	0.12	0.03	0.04	0.03	0.03	2.14
1989	0.84	1.01	0.57	0.14	0.07	0.02	0.02	0.02	2.75
1990	0.31	0.73	0.50	0.14	0.08	0.02	0.03	0.02	1.85
1991	0.51	0.67	0.43	0.37	0.14	0.05	0.02	0.03	2.24
1992	0.46	0.81	0.46	0.37	0.14	0.06	0.03	0.03	2.38
1993	0.19	0.34	0.27	0.24	0.16	0.07	0.01	0.02	1.31
1994	0.22	0.33	0.30	0.34	0.26	0.12	0.02	0.03	1.62
1995	0.84	0.37	0.26	0.26	0.19	0.09	0.02	0.02	2.08
1996	0.11	0.30	0.26	0.27	0.20	0.09	0.02	0.02	1.27
1997	0.06	0.15	0.15	0.17	0.14	0.07	0.02	0.02	0.78

Table 7. Pair-wise correlations (and significance below) as a measure of coherency in two MARMAP gear indices (hook & line and extended chevron trap) for the U.S. south Atlantic red porgy fishery. Values of significance below 0.10 are in bold; the lower the value, the greater the likelihood of significant correlation. Sample sizes range from 18 for adjacent ages to 13 between age 1 and age 7 for the hook & line gear, and between 17 and 12 for the extended Chevron gear.

Age (yr)	Age (yr) 1	2	3	4	5	6	7
				Hook & Line Index			
1	1.0	0.48	0.56	0.20	0.47	-0.27	0.41
		0.0430	**0.0204**	0.4539	**0.0772**	0.3578	0.1621
2		1.0	0.77	0.72	0.22	0.43	0.26
			0.0002	**0.0010**	0.4194	0.1137	0.3778
3			1.0	0.64	0.41	0.13	0.41
				0.0045	0.1052	0.6270	0.1276
4				1.0	0.20	0.35	0.26
					0.4216	0.1717	0.3344
5					1.0	0.00	0.52
						0.9999	**0.0334**
6						1.0	0.17
							0.5010
				Chevron Trap Index			
1	1.0	-0.11	-0.25	-0.36	-0.12	-0.16	-0.16
		0.6760	0.3414	0.1855	0.6932	0.6103	0.6167
2		1.0	0.78	0.55	0.60	0.78	0.69
			0.0002	**0.0285**	**0.0187**	**0.0010**	**0.0089**
3			1.0	0.63	0.71	0.79	0.81
				0.0070	**0.0019**	**0.0004**	**0.0004**
4				1.0	0.59	0.76	0.58
					0.0125	**0.0006**	**0.0228**
5					1.0	0.71	0.68
						0.0014	**0.0035**
6						1.0	0.43
							0.0852

Table 8. Mean estimates of age-specific instantaneous fishing mortality rate (F) on U.S. south Atlantic red porgy for three time periods using FADAPT virtual population analysis. Exploitation rates are given in the final column based on catches for age 1-8 divided by population estimates for ages. Estimates given for different assumed levels of natural mortality.

Natural Mortality M	Age (yr) 1	2	3	4+	Exploitation Rate (Ages 1-8)
		1972-1978			
0.20	0.004	0.02	0.04	0.11	0.03
0.28	0.003	0.02	0.03	0.09	0.04
0.35	0.002	0.01	0.02	0.07	0.03
		1982-1986			
0.20	0.075	0.25	0.32	0.65	0.23
0.28	0.059	0.20	0.27	0.56	0.19
0.35	0.046	0.16	0.22	0.47	0.15
		1992-1996			
0.20	0.008	0.07	0.30	0.70	0.21
0.28	0.007	0.06	0.27	0.64	0.18
0.35	0.005	0.05	0.25	0.59	0.16

Table 9. Equilibrium yield per recruit (YPR) and spawning potential ratio (SPR) of U.S. south Atlantic red porgy based on mean age-specific fishing mortality rates for three periods from FADAPT virtual population analysis. Estimates based on separate Von Bertalanffy growth parameters for females and males.

Natural Mortality	YPR (g)	Spawning Potential Ratio Total	Female	Eggs	Male	Percent Male[a]
		1972-1978				
0.20	206.5	60	74	65	52	84
0.28	101.4	76	85	80	68	90
0.35	54.4	85	91	88	78	93
		1982-1986				
0.20	352.2	15	31	17	8	57
0.28	263.2	28	46	31	15	66
0.35	199.2	40	57	44	25	73
		1992-1996				
0.20	236.2	15	30	19	7	56
0.28	173.1	24	42	30	13	64
0.35	130.7	34	52	39	20	71

[a] Percent relative reduction in numbers of mature males between fished and unfished conditions.

Table 10. Biological reference points developed from equilibrium yield per recruit (YPR) and spawning potential ratio (SPR) analyses for U.S. south Atlantic red porgy estimated from output from FADAPT using catch matrix based on most recent time period and fishery-dependent age-length key (with corresponding value based on fishery-independent age-length key for M=0.28 in parenthesis).

Biological Reference Point	Natural Mortality (M)		
	0.20	0.28	0.35
YPR:			
$F_{0.1}$	0.2	0.3 (0.4)	0.4
F_{max}	0.4	0.6 (1.4)	0.9
SPR:			
Female:			
F_{30}	0.69	1.44 (>2.0)	>2.0
F_{40}	0.38	0.72 (1.40)	1.19
Male:			
F_{30}	0.20	0.27 (0.39)	0.35
F_{40}	0.14	0.19 (0.26)	0.24
Total:			
F_{30}	0.27	0.45 (0.96)	0.73
F_{40}	0.18	0.28 (0.52)	0.42
Observed Full F by Period:			
1972-78	0.11	0.09 (0.09)	0.07
1982-86	0.65	0.56 (0.48)	0.47
1992-96	0.70	0.64 (0.44)	0.59

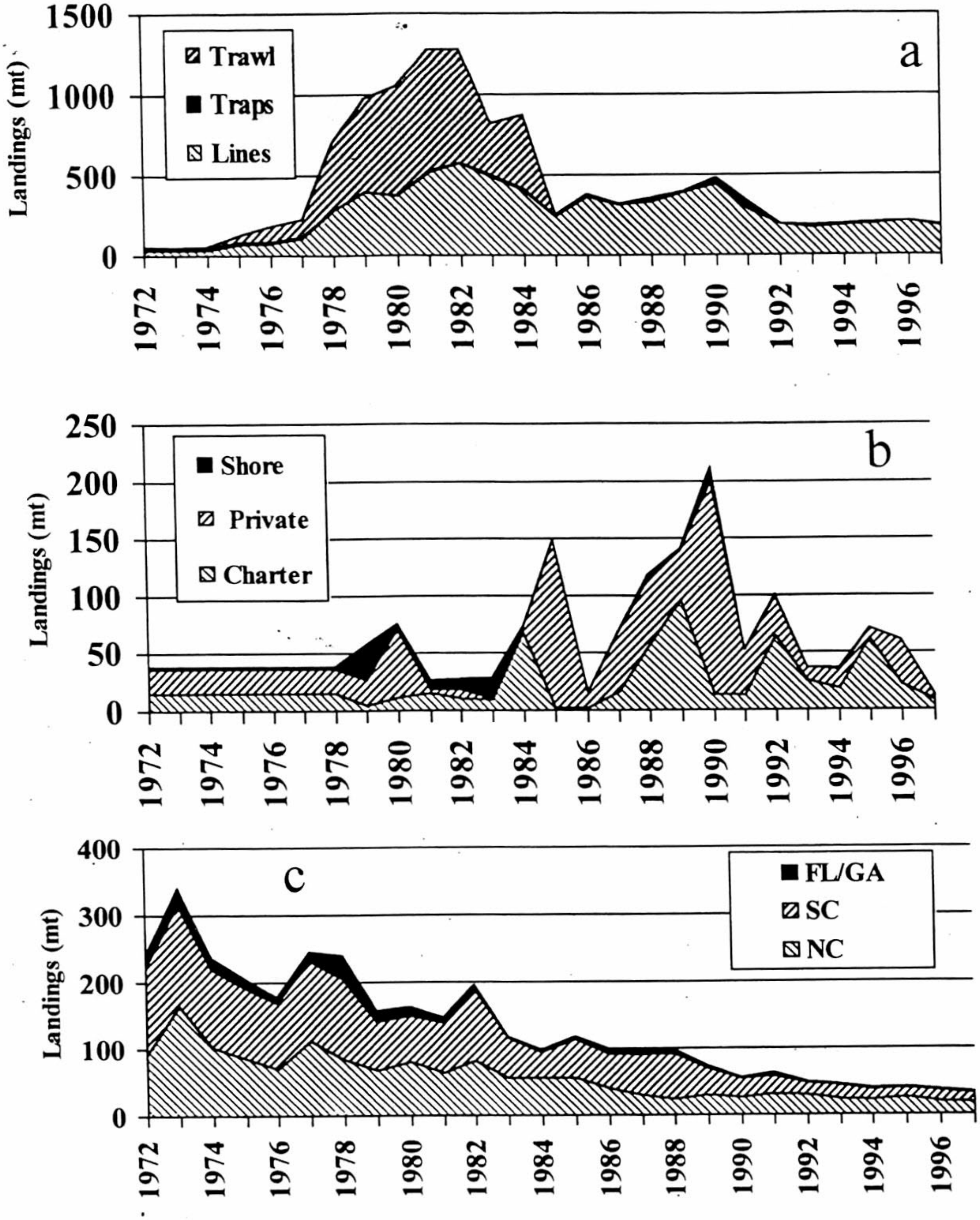


Figure 1. Annual landings of U.S. south Atlantic red porgy by category within fishery: a) commercial landings by gear, b) recreational landings by mode of fishing, and c) headboat landings by state.

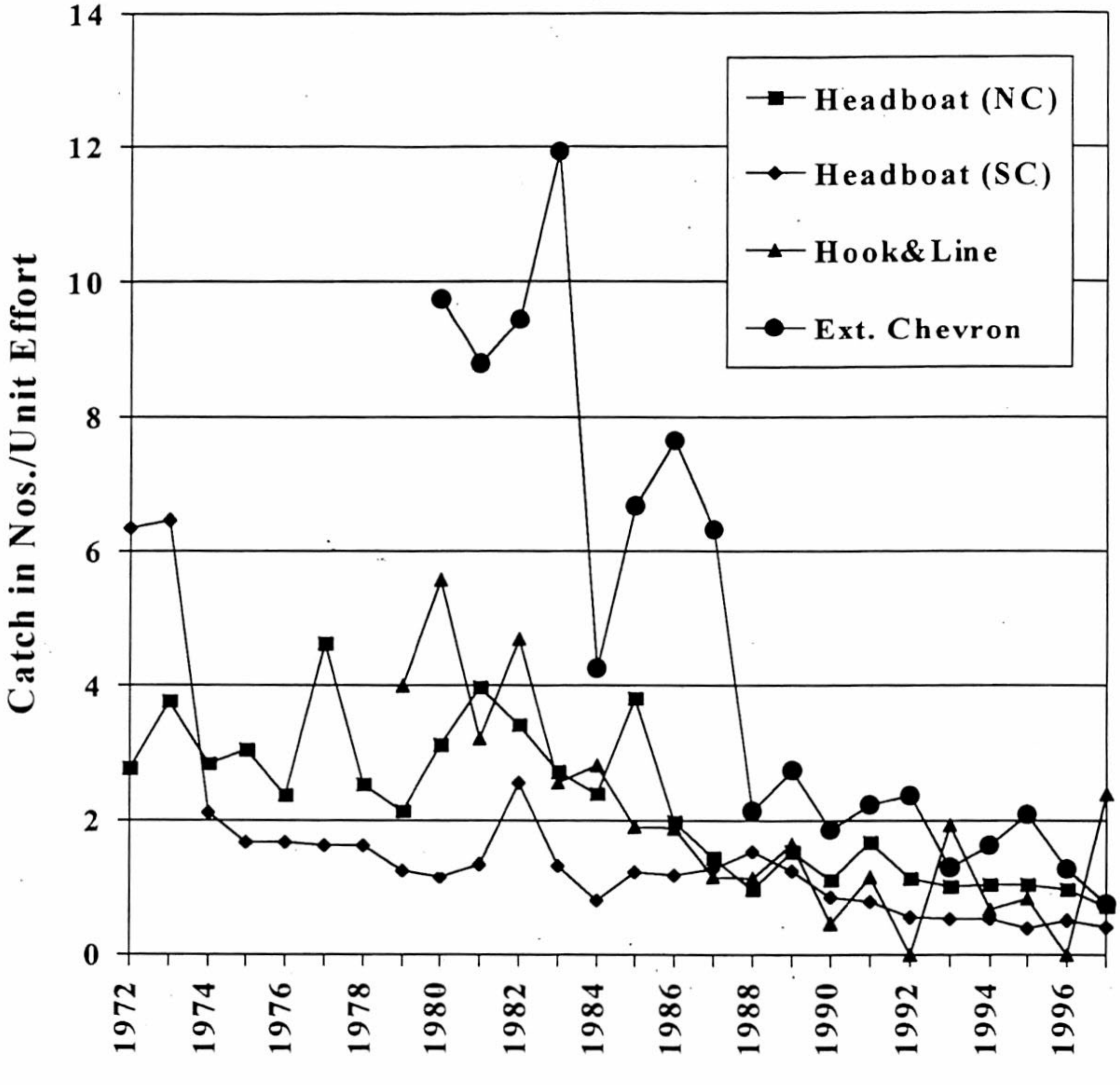


Figure 2. U.S. south Atlantic red porgy catch per unit effort from headboat fishery in North and South Carolina (effort in number fish caught per angler day, 1972-1997); and from MARMAP sampling by gear (hook & line, 1979-1997; and extended Chevron trap, 1980-1997).

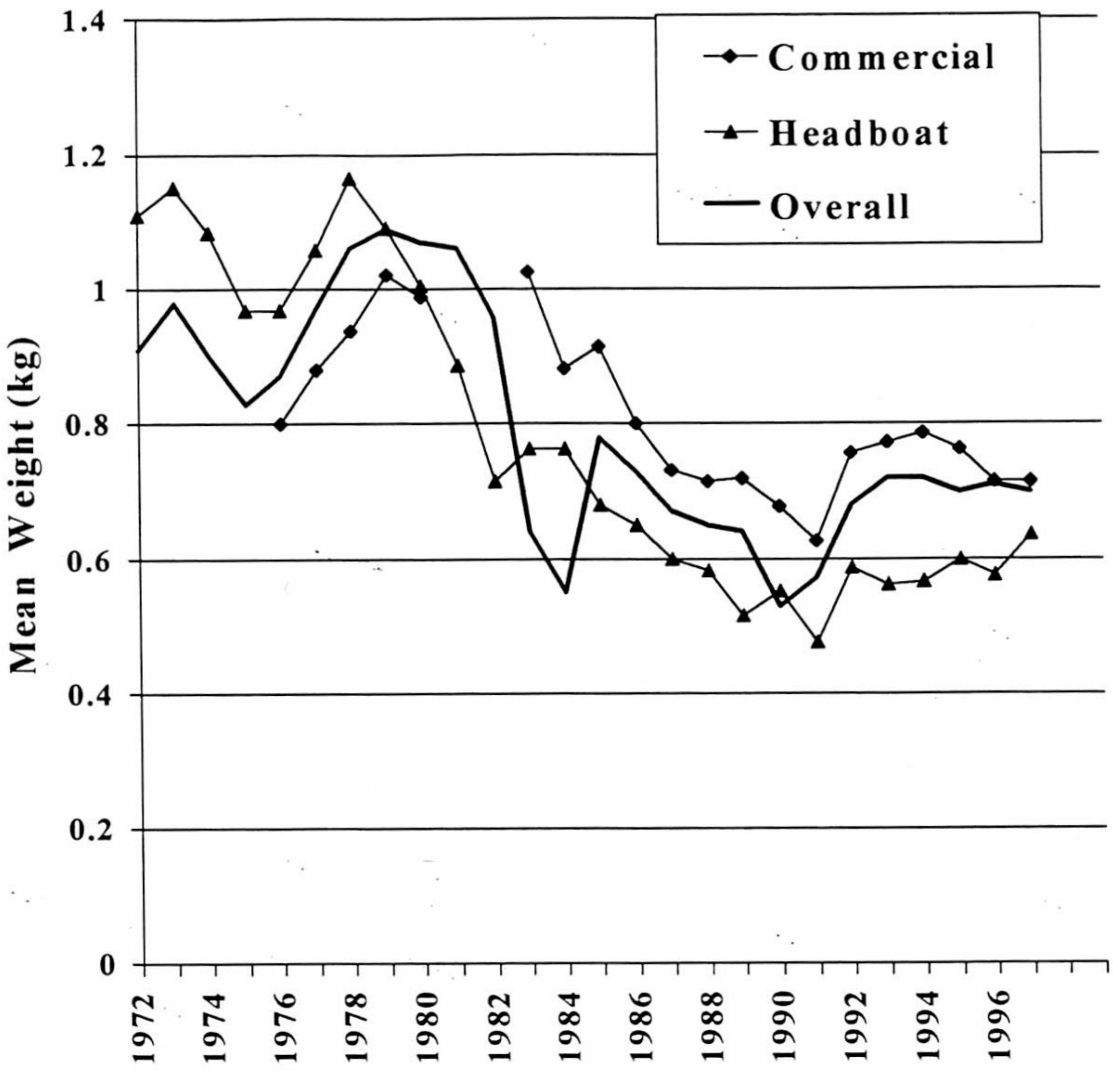


Figure 3. Annual mean weight of U.S. south Atlantic red porgy in the landings for commercial hook & line, headboat from the Carolinas, and overall all fisheries.

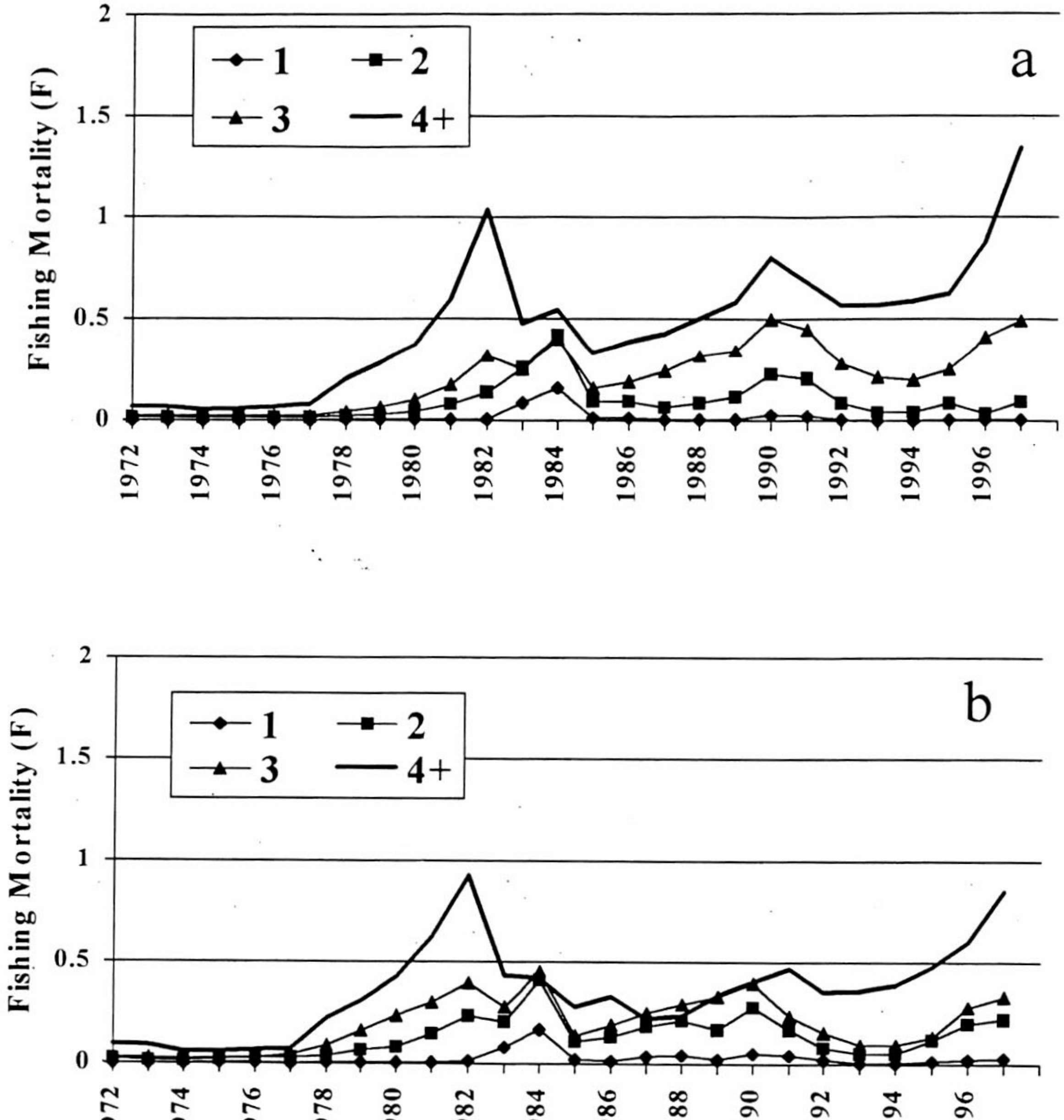


Figure 4. Annual estimates of age-specific instantaneous fishing mortality rate (F) for U.S. south Atlantic red porgy by calibrated virtual population analysis (FADAPT) using a) catch matrix based on fishery-dependent age-length keys, and b) catch matrix based on fishery-independent age-length keys (MARMAP).

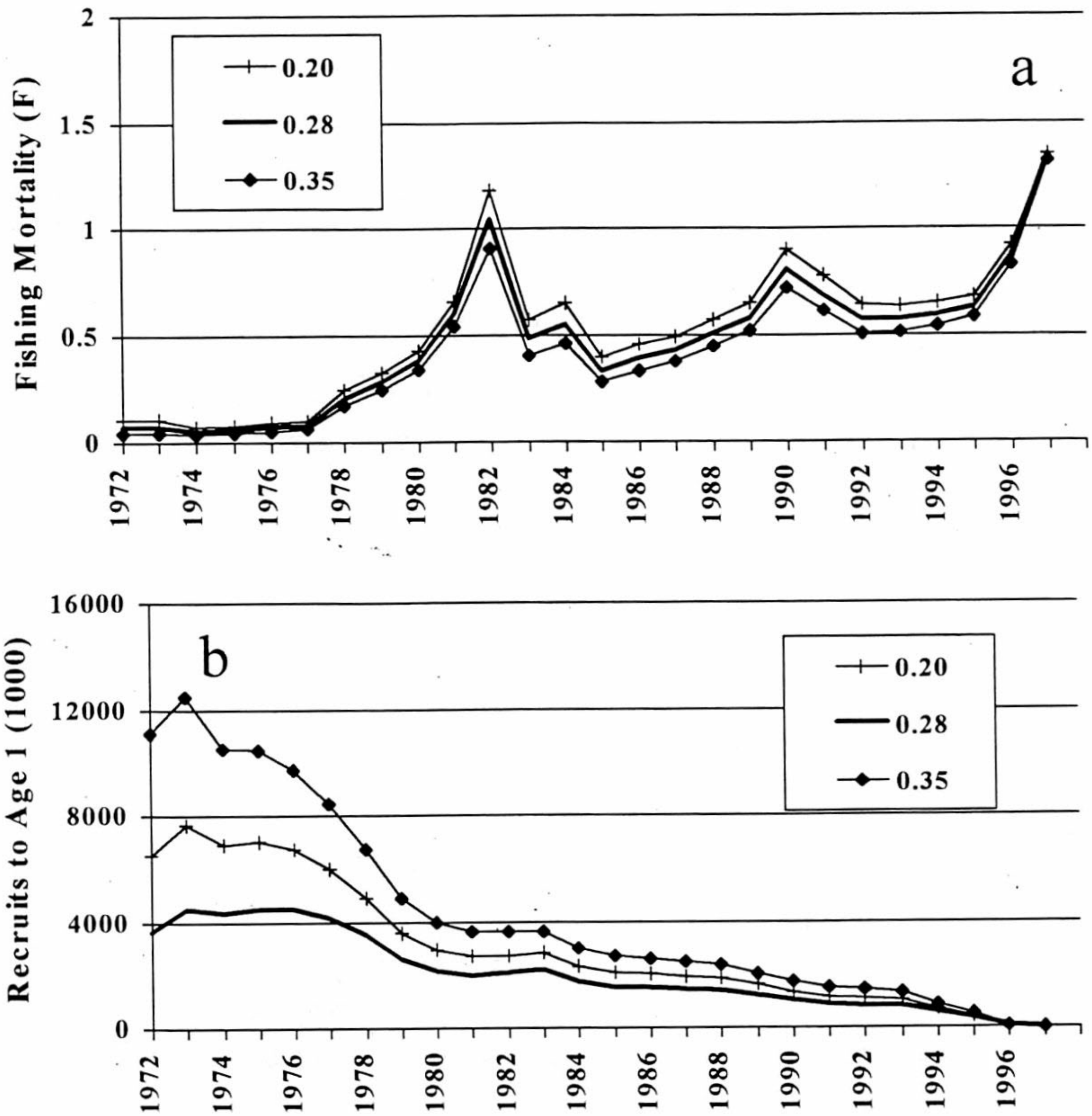


Figure 5. Sensitivity of a) annual estimated instantaneous fishing mortality rates (mean F on ages 4-8), and b) recruits to age 1 from calibrated virtual population analysis (FADAPT) applied to U.S. south Atlantic red porgy (catch matrix based on fishery-dependent age-length keys) to varying range of instantaneous natural mortality rate (M).

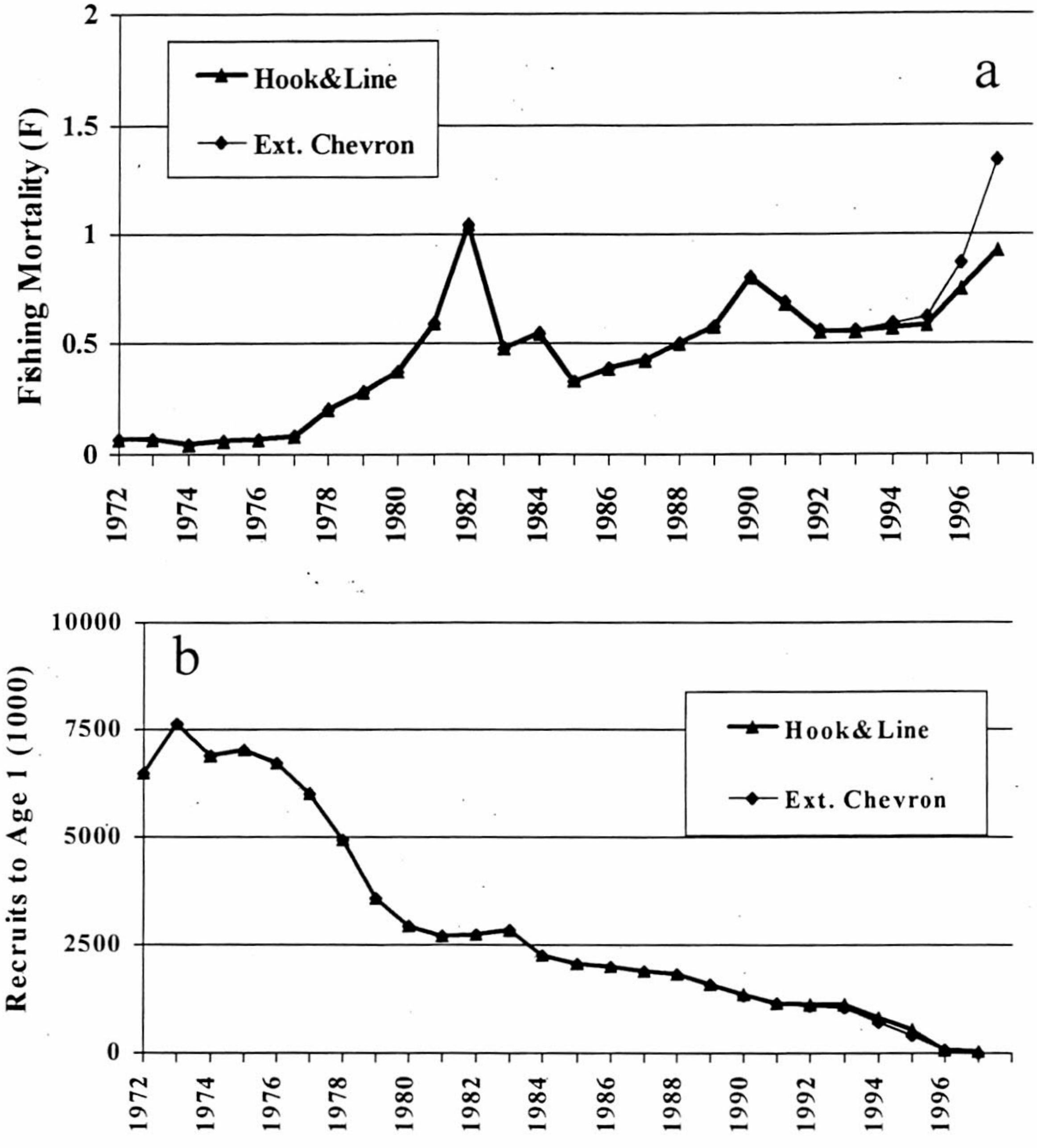


Figure 6. Sensitivity of a) annual estimated instantaneous fishing mortality rates (mean F on ages 4-8), and b) recruits to age 1 from calibrated virtual population analysis (FADAPT) applied to U.S. south Atlantic red porgy (catch matrix based on fishery-dependent age-length keys) using either only extended Chevron trap or only Hook & Line CPE indices.

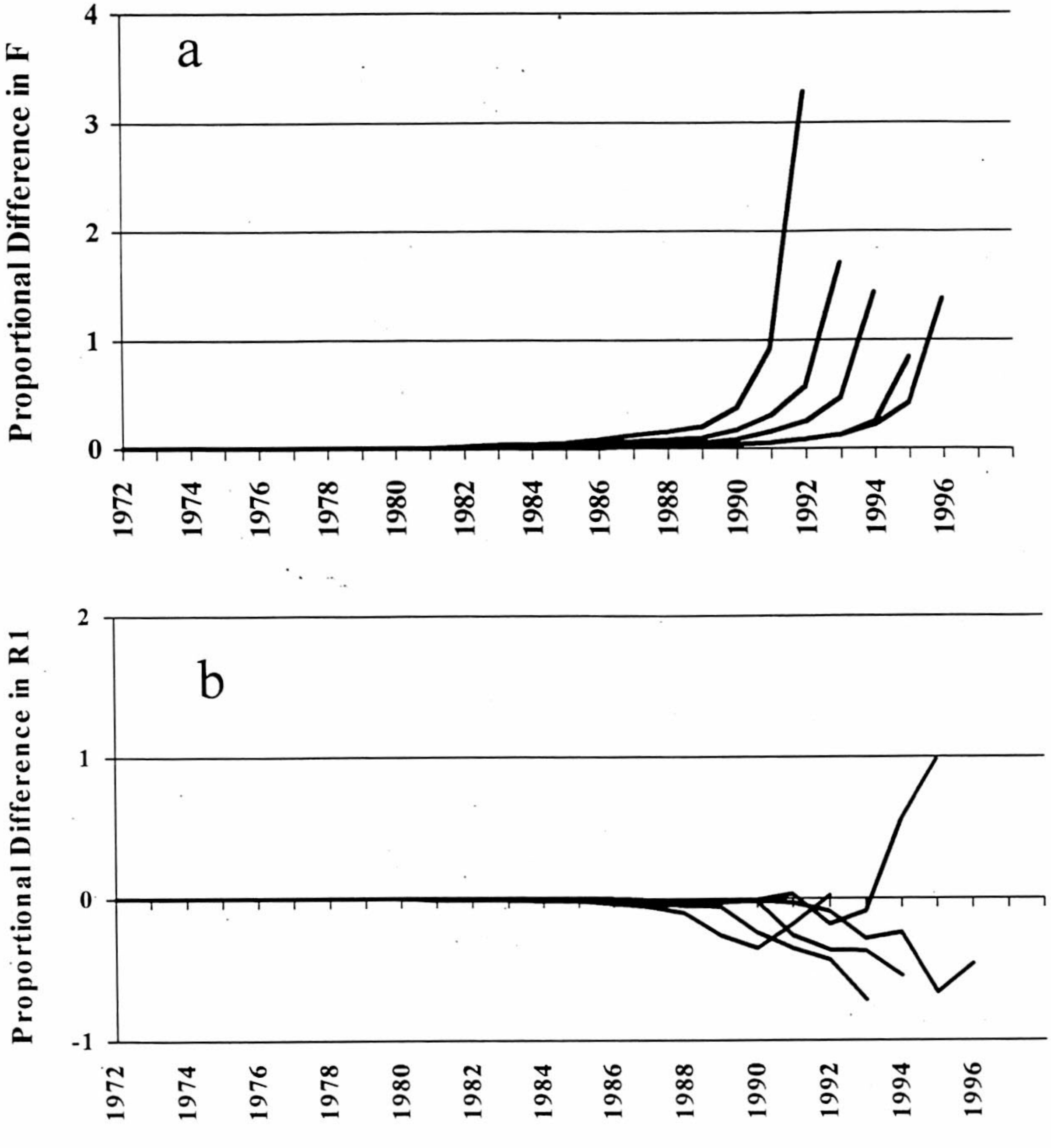


Figure 7. Proportional differences for a) annual estimated instantaneous fishing mortality rates (mean F on ages 4-8), and b) recruits to age 1 from calibrated virtual population analysis (FADAPT) applied to U.S. south Atlantic red porgy (catch matrix based on fishery-dependent age-length keys) with earlier final year compared to analysis with the most recent final year (1997).

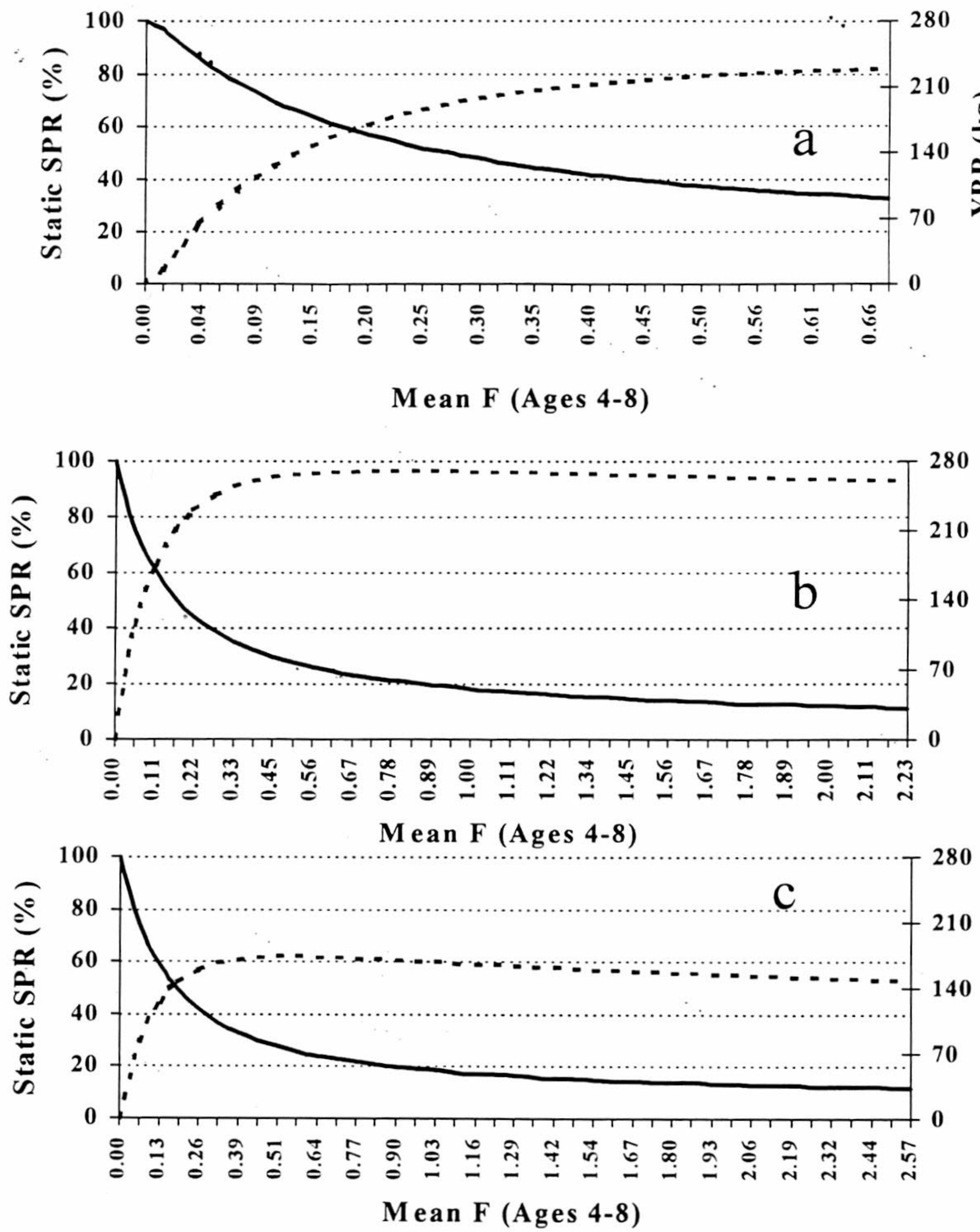


Figure 8. Overlay of equilibrium yield per recruit (YPR, dashed line) and spawning stock biomass (SPR, solid line) from U.S. south Atlantic red porgy (catch matrix based on fishery-dependent age-length keys and M=0.28) with increasing fishing mortality rate for three time periods: a) 1972-1978, b) 1982-1986, and c) 1992-1996.

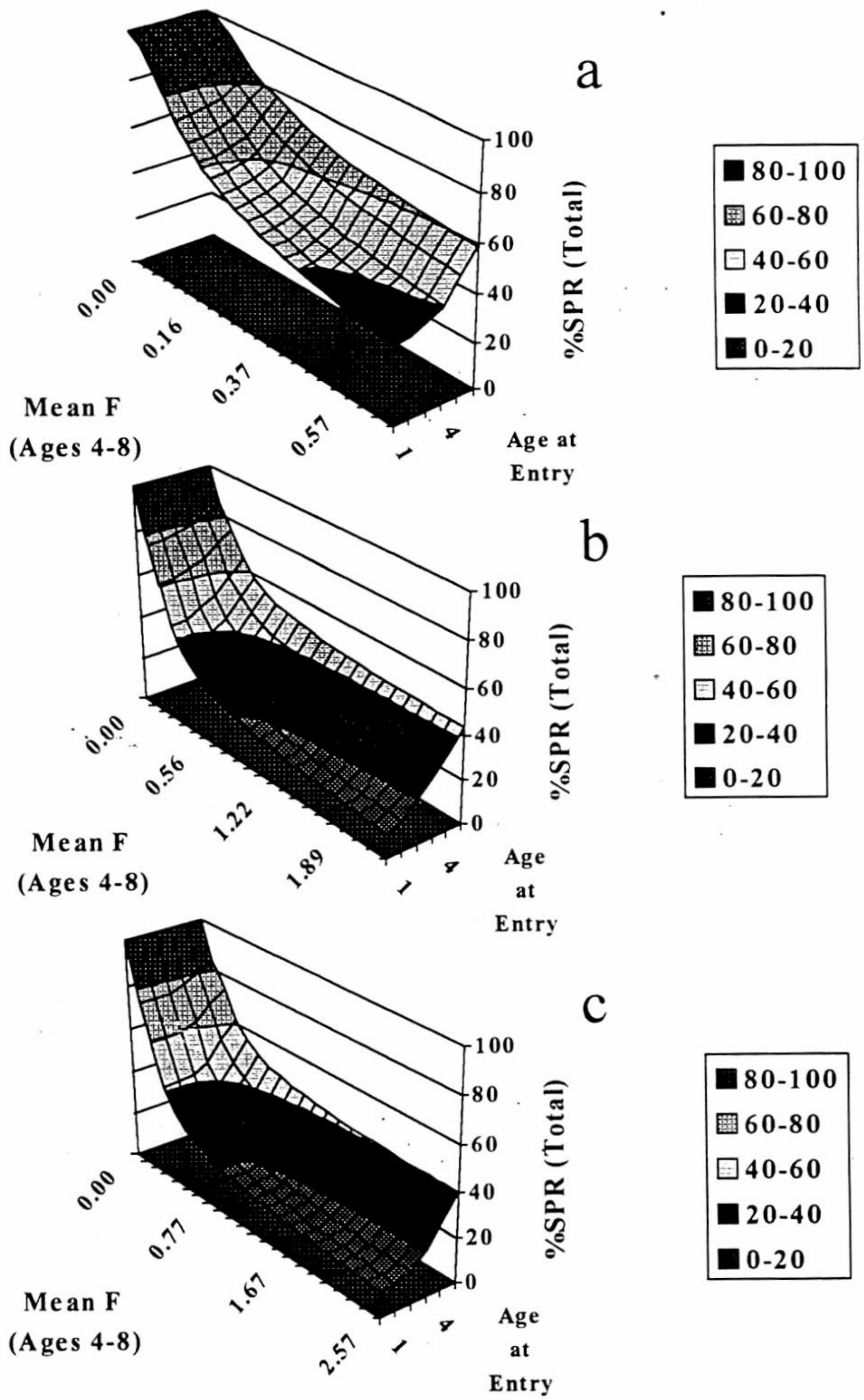
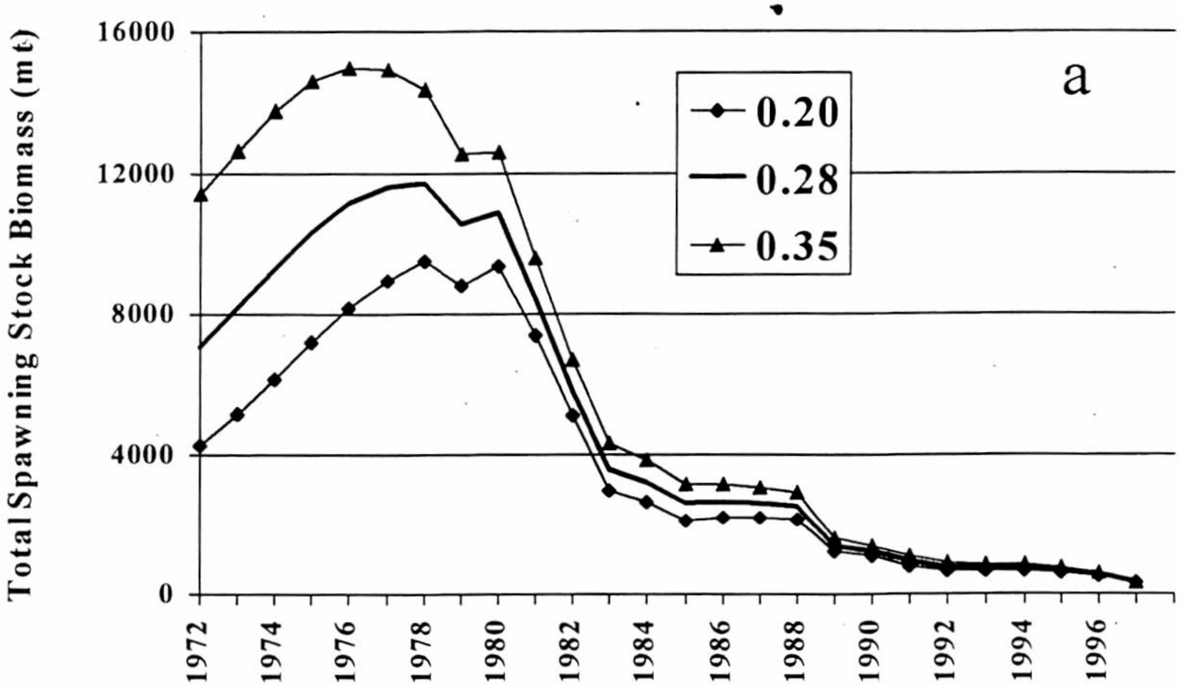


Figure 9. Equilibrium spawning potential ratio (static SPR) from U.S. south Atlantic red porgy (catch matrix based on fishery-dependent age-length keys and M=0.28) for increasing fishing mortality rate (F) and age-at-entry to the fishery for three time periods: a) 1972-1978, b) 1982-1986, and c) 1992-1996.



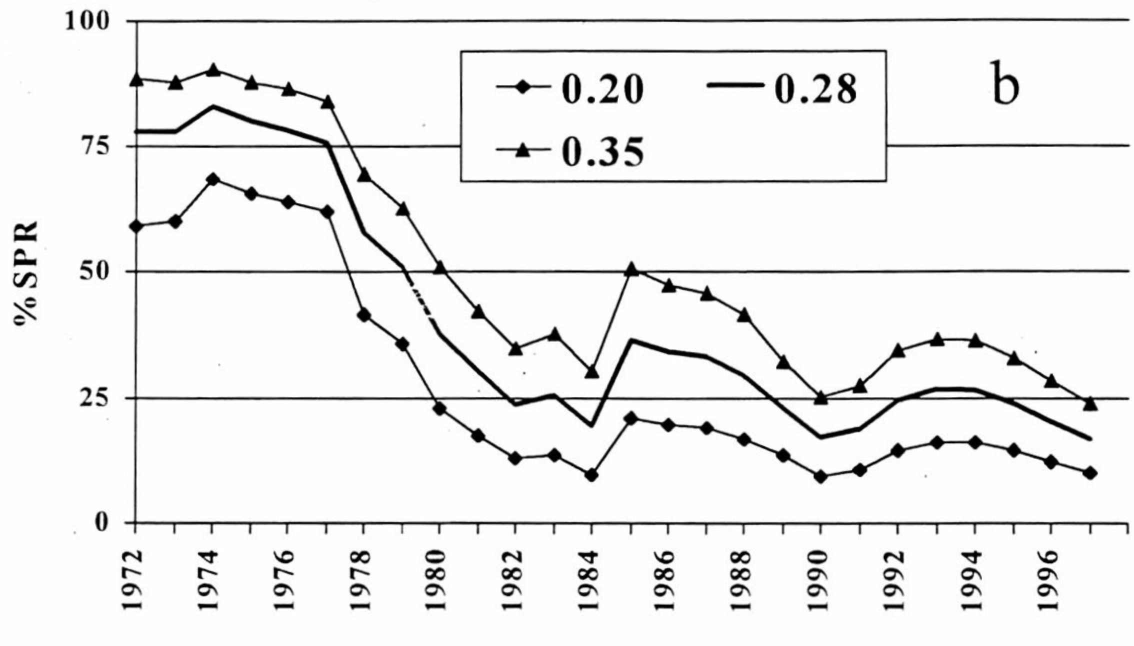


Figure 10. Population estimates from calibrated virtual population analysis (FADAPT) applied to U.S. south Atlantic red porgy (catch matrix based on fishery-dependent age-length keys) for: a) total spawning stock biomass, and b) equilibrium spawning potential ratio (SPR, based on total mature biomass).

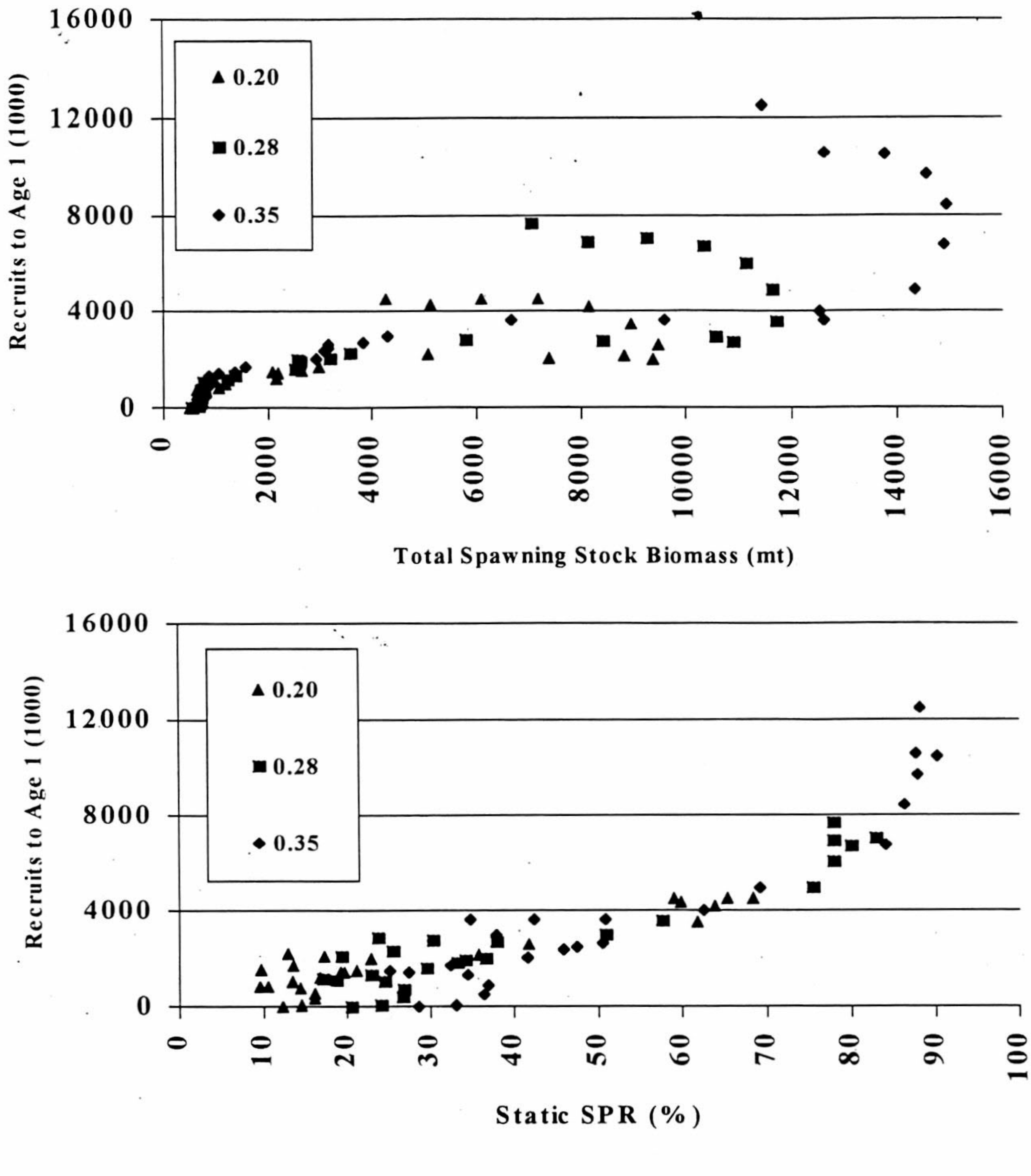


Figure 11. Recruits to age 1 compared with a) total spawning stock biomass and b) static spawning potential ratio (SPR) for U..S. south Atlantic red porgy (based on catch matrix using fishery-dependent age-length keys) from calibrated virtual population analysis (FADAPT) for three levels of M (0.20, 0.28, and 0.35).

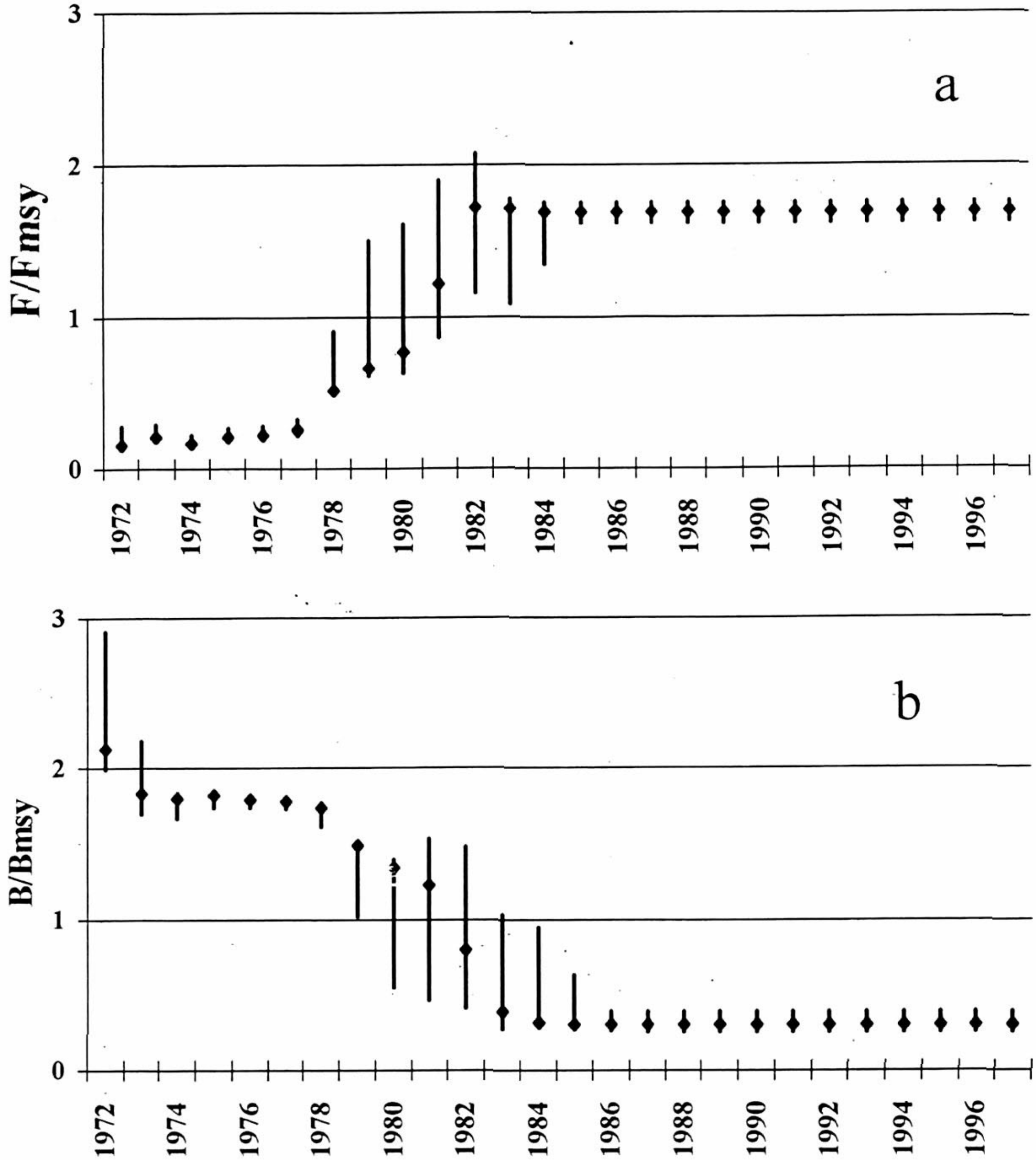


Figure 12. Plots of a) relative fishing mortality (F/Fmsy) and b) relative population biomass (B/Bmsy) from surplus production model (ASPIC) of U.S. south Atlantic red porgy population with total landings and CPE from MARMAP (hook & line and extended Chevron trap). [Vertical lines represent 80% confidence intervals from bootstrap procedure.]