Appendix N. Population Assessment of the Red Snapper, *Lutjanus campechanus*, from the Southeatern United States.

Population Assessment of the Red Snapper, Lutjanus campechanus, from the Southeastern United States

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April 7, 1997

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INTRODUCTION

The red snapper, Lutjanus campechanus, a member of the Lutjanidae family, is considered to be the most prized species of the snapper-grouper complex along the southeastern United States. It consistently ranks just ahead of Florida pompano, Trachinotus carolinus, as the most valuable commercially-harvested species of finfish on a price per pound basis. From 1990 through 1996, fishermen were able to wholesale red snapper for approximately $2.00 to $3.00 per pound (Table 1). The species is particularly important to the commercial fisheries of South Carolina, Georgia, and northeast Florida (Table 2). However, with the exception of Georgia, the red snapper very seldom ranks among the 10 most important marketed finfish species to commercial fisheries of the southeastern United States.

The species is distributed throughout the Gulf of Mexico and up the Atlantic coast to North Carolina, very occasionally to Massachusetts. The red snapper may be found throughout the FCZ (EEZ) and territorial seas, and is an important component of the catch in the deeper shelf waters (deeper than 20 meters; 66 feet (SAFMC 1983)). Off the southeastern United States, the red snapper typically occurs in depths of 50 to 100 meters over both low- and high-relief hard bottom.

Lutjanus campechanus is an opportunistic bottom feeder that consumes a variety of invertebrates and small fishes. The species

Table 1. Red snapper ranking in commercial finfish value ($) for the southeastern U.S.

Year	Rank	Value	$/Lb.
1990	29	636,033	2.83
1991	37	420,443	2.85
1992	42	286,750	2.81
1993	31	622,646	2.74
1994	33	529,253	2.62
1995	34	505,864	2.75
1996[1]	37	325,041	2.76

1. Incomplete reporting as of January 1997.

Table 2. Red snapper ranking in commercial finfish value ($) by state/area.

	NC		SC		GA		NFL		SFl	
Year	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value
1990	37	82,731	13	196,289	10	37,811	14	297,780	47	21,422
1991	44	45,868	14	111,322	10	29,866	18	204,795	43	28,592
1992	50	27,054	15	64,186	12	22,713	19	153,179	49	19,618
1993	35	116,146	9	218,618	9	33,482	20	152,142[1]	29	102,258
1994	38	92,171	12	151,333	8	40,544	17	212,730[1]	44	32,475
1995	48	46,330	13	99,854	6	46,574	15	266,526	34	46,580
1996[2]	52	25,692	17	53,475	6	29,957	14	159,197	29	56,720

1. Includes landings that came in on the east coast but were reported in an inland county.
2. Incomplete reporting as of January 1997.

remains the same sex throughout its lifespan; it is not hermaphroditic. Sexual maturity may occur as early as the second year of life (SAFMC 1983). Spawning extends through the warmer months, beginning as early as April off North Carolina, although in the Gulf of Mexico spawning usually extends from May through September (SAFMC 1983). The spawning grounds of the species are not well know, although fishermen off Texas reported ripe females at depths of 37 m (121 feet), and two spawning areas off Panama City, Florida were found at water depths between 18-37 m (59-121 feet) (SAFMC 1983). Females as small as 250 millimeters (10 inches) and males 225 mm (9 inches) have been documented as sexually mature. The free-floating eggs have been hatched in the laboratory in 24-27 hours, and the larvae feed three days after hatching (Manooch 1984). The species is relatively slow growing, and may attain a length of approximately 950 mm (37 inches) and an age of 25 years (this study).

This analysis of the red snapper stock from North Carolina (south of Cape Hatteras) through the Florida Keys, was conducted at the request of the South Atlantic Fishery Management Council (SAFMC). Although the SAFMC Snapper-Grouper Fish Management Plan (SAFMC 1983) does include discussions of the species, no separate stock assessment has been made for the red snapper along the southeastern United States.

In this report we conduct an updated age and growth study using sectioned otoliths, and compute and document changes in the age structure and population size for the species. Specifically, given age-specific estimates of instantaneous fishing mortality rates and information on growth, sex ratios, maturity and fecundity, analyses of yield per recruit (YPR), and spawning potential ratio (SPR) are used to determine the status of the southeastern U.S. red snapper stock.

METHODS

Landings

For purposes of this report, red snapper are landed by three fisheries: commercial, recreational, and headboat. The commercial fishery is principally prosecuted by hydraulically- and manually-operated hook-and-line gear, although a few landings are made by trawls and traps. The recreational fishery includes hook and line fishing from shore or any platform other than headboats. This includes small private boats and charter boats (six passengers or less). Headboats are those usually carrying more than six passengers and charge on a per person basis, thus by the "head", and are considered separate for our analyses from the other recreational vessels. Although landings are available for different years depending on fishery, only data from 1986-1996 were available for all three fisheries. Landings were used with fish length at age information (derived from this study) to develop a catch-in-numbers-at-age matrix, which is found under the appropriate heading below.

Landings data are used to describe annual trends in catches, including catch in number, catch in weight, mean fish size, and mean fish age. Catch-per-effort are provided for the headboat data, recreational data, and fishery independent data. Whenever possible, the databases were stratified by state or area: North Carolina, South Carolina, Georgia, North Florida, and South Florida (both East Coast only).

In order to draw conclusions about the red snapper population from fish that are sampled from catches, it is very important that samples are representative of the stock (e.g., size, sex, distribution, etc.), and are adequate in number. Although assumptions must be made pertaining to the former, biologists and managers should have some control over the latter. To evaluate the adequacy of sampling intensity for the three fisheries (headboat, recreational, and commercial), we used the informal criterion of 100 fish sampled per 200 metric tons of that species landed (USDOC 1996).

Age/Growth Study

Collection and Examination of Otoliths

Otoliths were collected from headboats and commercial fishing vessels from Beaufort, North Carolina through the Florida Keys (N = 331) by port samplers of various state agencies and the National Marine Fisheries Service (NMFS). Additional otoliths (N = 206) were obtained by the Marine Resources Monitoring, Assessment and

Prediction (MARMAP) Program. These fishery-independent samples were collected by employees of the South Carolina Department of Natural Resources, Charleston, South Carolina. The total number of otoliths examined was 537.

Sagittae were removed by entering the cranium from under the operculum and opening the otic bulla with a wood chisel. Otoliths were stored dry in coin envelopes. Fish weight (kg) total length (mm), date, and area of capture were recorded on each envelope. Fork length (mm) and standard length (mm) were recorded for some fish (N = 206). Otoliths were ground down along the transverse plane (dorsoventral). Grinding was accomplished using a high speed technique developed by Cowan et al. (1995). Once the 0.50-mm sections had been obtained, they were quickly polished on a 1200-grit wet/dry sand paper to remove any micro-scratches left by the grinder.

Sections were viewed on a video monitor connected to a dissecting microscope (25X) equipped with a camera and using reflected light. Two types of rings were visible: an opaque ring that appeared white, and a translucent ring that was dark. Lateral measurements from the otolith focus to each opaque ring and to the otolith margin were recorded directly off the monitor screen by hand, and then transferred to a microcomputer for analysis.

Validation

Marginal increment analysis was used to determine if opaque rings formed only once each year, and could therefore, be called annuli. Monthly mean distance plots of the last ring to the otolith margin for age groups 1-6 combined were analyzed. If the rings are formed once each year, then the plot should reveal a minimum ring-to-margin increment followed by increased increment as additional growth follows the formation of the annulus. We also identified the months where marginal increments equaled zero. The latter analysis indicated the month(s) when the annuli were formed.

Back-Calculated Growth

The relationship between fish length and otolith radius was described by regressing the log-transformed fish length on log-transformed otolith radius (R_c). The linearized equation is $\ln(L) = a + b\ \ln(R_c)$, where L = total length in mm. The back-calculated total lengths at each age were determined from the log transformed, otolith proportional equation (Carlander 1981; Johnson et al. 1994):

$$L_A = \exp[a + (\ln L_c - a) * (\ln R_A/\ln R_c) + MSE/2]$$

Where L_A = Back-calculated length to annulus A,

a = intercept from the log transformed total length-otolith radius regression,

L_c = total length at capture,

R_A = otolith radius to annulus A,

R_c = total otolith radius at capture, and

MSE = mean square error (σ^2) from regression used to correct for the transformation bias.

Growth Parameters

Growth parameters L_∞ (mean asymptotic fish length), K (growth coefficient), and age at beginning of growth (t_o) are used to construct theoretical growth models. These parameters were derived from the von Bertalanffy equation: $L_t = L_\infty(1-\exp[-K(t-t_o)])$, which is the most widely used growth model in fisheries and is fitted to back-calculated length-at-age data (Ricker 1975; Everhart et al. 1975). Two equations were derived: one using all the back-calculated data; the other using back-calculated data from the last ring only (Vaughan and Burton 1994). Growth parameters were estimated using SAS PROC NLIN with the Marquardt Option (SAS Institute 1982), and we weighted the data by the number of fish sampled at each age.

Size Relationships

To describe the relationship of fish weight to fish length we used log-log regression and transformed the equation to: $\ln W = a + b \ln L$, where W = weight in kilograms, and L = total length in millimeters. Linear relationships: TL = a+b(FL), TL = a+b(SL), and FL = a+b(SL) were used to convert lengths where TL = total length, FL = fork length, and SL = standard length, all in millimeters.

Fish Age-Fish Length Key

Observed ages at lengths (lengths of red snapper at the time of capture for each age) were used to obtain a fish age-fish length key. Fish for which we had determined ages were assigned to 25-mm length intervals. Age distribution (shown as percent) was identified for each size interval. Thus, the unaged fish were assigned age percentage compositions based on their lengths.

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

Data used in the construction of the matrix were derived from several sources and covered the geographical area extending from North Carolina through the Florida Keys. Fishery-independent information, including fish length, weight, and age data for hook and line and trap gear were provided by fisheries personnel of the South Carolina Department of Natural Resources, MARMAP (Marine Resources Monitoring, Assessment, and Prediction) Program, Charleston, SC. Recreational landings and fish lengths and weights were obtained from the Marine Recreational Fisheries Statistics Survey (MRFSS) data base (NMFS, Washington DC) for 1981-1995. Headboat catch estimates, fish length, and fish weight data were obtained from the NMFS for 1972-1995 (NMFS, Beaufort, NC). Commercial fishery data were obtained from two data sets: the General Canvas for catch statistics for 1986-1995, and from the Trip Interview Program (TIP) for length and weight statistics for 1983-1995 (NMFS, Miami, FL).

Derivation of catch in numbers at fish age consists of multiplying the catch in numbers (n, scalar) by the fish age-fish length key (A, matrix) by a length frequency distribution (L, vector) to obtain the catch in numbers by fish age (N, vector:

$N_{ax1} = n \cdot A_{axb} \cdot L_{bx1}$ (Vaughan et al. 1992)),

where a is the number of ages (1 to 25 years), and b is the number of length intervals. Since only weight (and not length) was available for commercially-caught red snapper, catch was converted to numbers by dividing catch in weight by mean weight of the fish landed by the same gear for the same period of time (annual) and geographic area. Otherwise, length data for a given fishery were converted by the weight-length equation (this study) with length frequency data to calculate mean weight per red snapper for that fishery for each year.

Mortality Estimates

Total Instantaneous Mortality

Total instantaneous mortality (Z) was estimated by analyzing catch curves (Beverton and Holt 1957) based on fully recruited age fish and older. The fish age-fish length key was used to construct catch curves by assigning ages to the landed unaged red snapper. Mortality estimates under equilibrium assumption were obtained by regressing the natural log of the catch in numbers against age for fully recruited fish (ages 2 through 12, or 6-12, depending on time period, 1986-1991 and 1992-1995).

Natural Mortality

Natural mortality (M) is often estimated from relatively weak life history and ecological analogies, yet is a very important step in determining that portion of total mortality which may be attributed to fishing. Natural mortality can perhaps be best estimated by using bioprofiles characteristics as demonstrated by Pauly (1979) and later by Hoenig (1983). Pauly (1979) uses two of the von Bertalanffy parameters (L_∞, and K, yr^{-1}) as well as mean water temperature (T ^{0}C):

$$\log_{10}M = 0.0066 - 0.279 \log_{10}L + 0.6543 \log_{10}K + 0.4634 \log_{10}T.$$

Sea surface temperature readings from buoys operated by NOAA's National Oceanographic Data Center were used to calculate mean annual seawater temperature. Buoys recorded temperature every 30 minutes, and monthly averages were calculated at four different locations throughout the South Atlantic Bight (SAB). These monthly averages were averaged across locations and a SAB-wide value for mean annual temperature obtained. All data were from 1996 for all buoys except Edisto, where 1995 data were used for October through December. Buoys used and their locations are:

1) Edisto - 32.5° N 79.1° W
2) Savannah - 31.9° N 80.7° W
3) St. Augustine - 29.9° N 81.3° W
4) Cape Canaveral - 28.5° N 80.2° W

Hoenig (1983) utilizes the maximum age (t_{max}) in an unfished stock of a species:

$$\ln M = 1.46 - 1.01 \ln t_{max}.$$

Because this relationship is based on Z, rather than M, the maximum age in the virgin population (F = 0; M = Z-F) would provide an approximate estimate of natural mortality. Hoenig (1983) also provides an estimate of Z which takes into account the sample size used in the study, the rationale being one has a greater chance of encountering the true maximum age of the fish with increasing sample size. The equation used is

$$Z = \ln (2n + 1)/t_{max} - t_c,$$

where t_c = first age fully represented in the catches.

We also estimated natural mortality using the methods of Roff (1983), using optimal age at maturity, and Rikhter and Evanov (1977), using age at 50 % maturity. For both methods, we used the logistic function to obtain length at 50 % maturity, and then used the von Bertalanffy growth equation to solve for the corresponding age at 50 % maturity. One final method we used to estimate M was the method of Alverson and Carney (1975), which allows prediction of M from estimates of maximum age and the Brody growth coefficient K.

Fishing Mortality and Virtual Population Analysis

Once natural mortality and total instantaneous mortality have been estimated, it is an easy exercise to obtain fishing mortality, F (e.g., Z = M + F; F = Z - M). The problem arises from the equilibrium assumption of constant F and recruitment. In this assessment, age-specific fishing mortality rates, and estimates of red snapper age-specific population size were obtained by applying different virtual population analysis (VPA) techniques to get around this equilibrium assumption. However, because of the short time frame of the catch matrix (1986-1995) relative to ages (1-13+), this is not completely successful. Especially because two temporal periods (1986-1991 and 1992-1995) are defined, due to the 20-inch minimum size limit imposed just prior to the 1992 fishing year. The VPA methods are explained briefly below:

The catch matrix was interpreted using two different virtual population analysis (VPA) approaches to obtain annual age-specific estimates of population size and fishing mortality rates. 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, usually assumed constant across years and ages, was also required. The separable method of Doubleday (1976) assumes that age- and year-specific estimates of F can be separated into products of age and year components. There are obvious problems with applying this technique to the full time period for 1986-1995 because of the imposition of a 20" minimum size limit just prior to the 1992 fishing year. Therefore, this techniques is applied separately to the two time periods (1986-1991 and 1992-1995). We used the FORTRAN program developed by Clay (1990), based on Pope and Shepherd (1982).

Additionally, we used a second method that calibrates the VPA to fishery-independent indices of abundance (Pope and Shepherd 1985). The specific calibration approach was that developed by Gavaris (1988) and modified by Victor Restrepo (Cooperative Institute of Fisheries Oceanography, University of Miami, Miami, FL) as the program FADAPT. An index for calibration was obtained from MARMAP data for Chevron traps (1988-1995), for which concern about adequacy of sampling is discussed later. Because this approach does not depend on a separability assumption it is applied to the entire catch at age history (1986-1995).

Yield Per Recruit

The yield per recruit model was used to estimate the potential yield in weight for red snapper and was based on the method of Ricker (1975). The model estimates total weight of fish taken from a cohort divided by the number of individuals of that cohort that entered the fishing grounds. Unlike the full-dynamic pool model (Beverton and Holt 1957), the Ricker-type model only requires parameters that are relatively easily obtainable: M, F, K, L_∞, t_r (age at recruitment to the fishery), and fishing at ages prior to full recruitment, all shape the response surface (i.e. how the red snapper yield per recruit reacts to various levels of fishing effort). The above-mentioned parameters were estimated as discussed previously.

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 equilibrium or static spawning potential ratio (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)). Equilibrium, or static, 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.

The SAFMC defines and explains static Spawning Potential Ratio (SPR, also known as Percent Maximum Spawning Potential (aka %MSP)) as "a measure of an average female's egg production over its lifetime compared to the number of eggs that could be expected if there was no fishing. When there is fishing pressure, a fish's life expectancy is reduced, and so is its average lifetime egg production. A species is considered overfished if its SPR drops below a level beyond which the ability of the stock to produce enough eggs to maintain itself is in jeopardy" (SAFMC 1996). The

SAFMC is proposing to change the overfished level to 20% (0.20 SPR), and the target (OY) to 40%. Longevity, age-specific fecundity, and age-specific fishing mortality are critical to the derivation of SPR.

In this study, comparisons of age-specific spawning stock biomass were based on mature female biomass and egg production. Three sources of information pertaining to red snapper reproductive characteristics are utilized. The first is a draft manuscript by Collins et al. (in prep.). The report contains sexual maturity schedule and fecundity information for the species sampled along the southeastern United States as well as the Gulf of Mexico. The second source of information is a publication by Collins et al. (1996) that presents total annual fecundity estimate equations for red snapper from the Gulf of Mexico. A conversion equation is also presented which allows batch fecundity estimates as discussed in the first paper for fish collected off the southeastern United States to be converted to total annual fecundity by fish age and size. The third data source is sexual maturity at age (size) data provided by the SCDNR (Jack McGovern, pers. comm.) for a recently-completed study.

RESULTS

Landings

We used an informal standard developed by the NMFS, Northeast

Regional Stock Assessment Workshop (USDOC 1996) to determine the adequacy of biological sampling of red snapper landings (Table 3). According to this standard, 100 fish lengths should be recorded for each 200 mt of the species landed. Thus, a value greater than 200 mt/100 samples indicates an inadequate sample. Using 1986-1995 data, we found that recreational (MRFSS) landings were frequently not as often sampled as they should have been. Samples were inadequate for 1989, 1990, 1991, 1992, and 1993. They were essentially inadequate for 1994, therefore six of the 10 years evaluated (Table 3). The problem identified here for red snapper probably holds true for other species of reef fish as well. We encourage an increase of biological sampling intensity by MRFSS personnel. Conversely, headboat and commercial landings were sampled sufficiently for stock descriptive purposes.

Trends - Landings

Commercial

Although some commercial landings data are available dating back to 1908, the most reliable and uninterrupted time series begins in 1950 and continues through 1996. 1950 was the first year that Florida landings were separated into East Coast and West Coast (Table 4). From 1950-1996, landings averaged 494,723 pounds (N=47) with catches exceeding a million pounds recorded in 1968 and 1982. Landings have generally trended downwards since 1982 (Figure 1). Commercial catches have not exceeded 200,000 pounds since 1990.

Table 3. Level of sampling per year by fishery (mt/100 length samples) for red snapper landed in the U.S. South Atlantic. Informal criteria is set at 200mt/100 length samples (USDOC 1996) (eg. <200mt/100 length samples, sampling is adequate; >200mt/100 length samples, sampling is inadequate).

Year	MRFSS	Headboat	Commercial				
			HL	Trawl	Trap	Divers	Gillnets
1986	22.8	5.7	9.8	2.2	*	3.2	--
1987	88.6	12.2	7.4	2.5	*	9.8	--
1988	117.3	28.5	13.2	0.6	*		--
1989	**554.2**	8.5	10.3	--	*		--
1990	**290.6**	6.9	12.4	--	69.2		--
1991	**372.8**	21.5	8.1	*	1.1	69.0	*
1992	**1648.2**	24.2	7.5	*	--	47.9	29.0
1993	**262.3**	9.5	6.3	*	1.0	31.4	*
1994	198.4	3.5	8.4	--	0.3	87.5	*
1995	117.0	17.7	7.5	*	*	*	--

* Landings recorded but no samples from that gear type, but landings were insignificant to the overall landings.

Table 4. Red snapper commercial landings-- weight (lbs*10³) and value ($*10) from U.S. South Atlantic.

Year	NC		SC		GA		FL		Total	
	Wt	Value	Wt	Value	Wt	Value	Wt	Value	Wt	Value
1908	13	0.300	12	0.400	880[1]	30,000[1]	60	------	965	------
1918	------	------	------	------	112	------	20	------	132	------
1919	------	------	------	------	------	------	------	------	------	------
1920	------	------	------	------	------	------	------	------	------	------
1921	------	------	------	------	------	------	------	------	------	------
1922	------	------	------	------	------	------	------	------	------	------
1923	1	------	2	------	105	------	12	------	120	------
1924	------	------	------	------	------	------	------	------	------	------
1925	------	------	------	------	------	------	------	------	------	------
1926	------	------	------	------	------	------	------	------	------	------
1927	1	------	------	------	64	------	59	------	123	------
1928	2	------	------	------	22	------	47	------	71	------
1929	15	------	(1)[2]	------	33	------	19	------	67	------
1930	5	------	------	------	30	------	34	------	69	------
1931	2	------	------	------	------	------	112	------	114	------
1932	------	------	------	------	------	------	49	------	49	------
1933	------	------	------	------	------	------	------	------	------	------
1934	------	------	------	------	------	------	152	------	152	------
1935	------	------	------	------	------	------	------	------	------	------
1936	------	------	------	------	------	------	140	------	140	------
1937	------	------	------	------	------	------	210	------	210	------

Table 4. Continued

Year	NC Wt	NC Value	SC Wt	SC Value	GA Wt	GA Value	Fl Wt	Fl Value	Total Wt	Total Value
1938	1	------	------	------	------	------	117	------	118	------
1939	2	------	------	------	------	------	96	------	98	------
1940	------	------	------	------	------	------	14	------	14	------
1941	------	------	------	------	------	------	------	------	------	------
1942	------	------	------	------	------	------	------	------	------	------
1943	------	------	------	------	------	------	------	------	------	------
1944	------	------	------	------	------	------	------	------	------	------
1945	4	0.410	------	------	------	------	246	54	250	54
1946	------	------	------	------	------	------	------	------	------	------
1947	------	------	------	------	------	------	------	------	------	------
1948	------	------	------	------	------	------	------	------	------	------
1949	------	------	------	------	------	------	------	------	------	------
1950	------	------	5	2	------	------	358	79	363	81
1951	8	2	------	------	------	------	510	141	518	142
1952	5	1	------	------	------	------	384	100	389	101
1953	------	------	------	------	2	(1)[2]	402	125	404	125
1954	------	------	------	------	3	1	596	161	599	162
1955	------	------	------	------	------	------	498	134	498	134
1956	130	36	12	3	(1)[2]	(1)[2]	342	105	484	144
1957	225	63	1	(1)[2]	(1)[2]	(1)[2]	643	197	869	260
1958	28	8	(1)[2]	(1)[2]	------	------	589	189	617	197
1959	15	4	18	5	------	------	629	175	662	184
1960	(1)[2]	(1)[2]	2	(1)[2]	8	3	667	197	677	200

Table 4. Continued

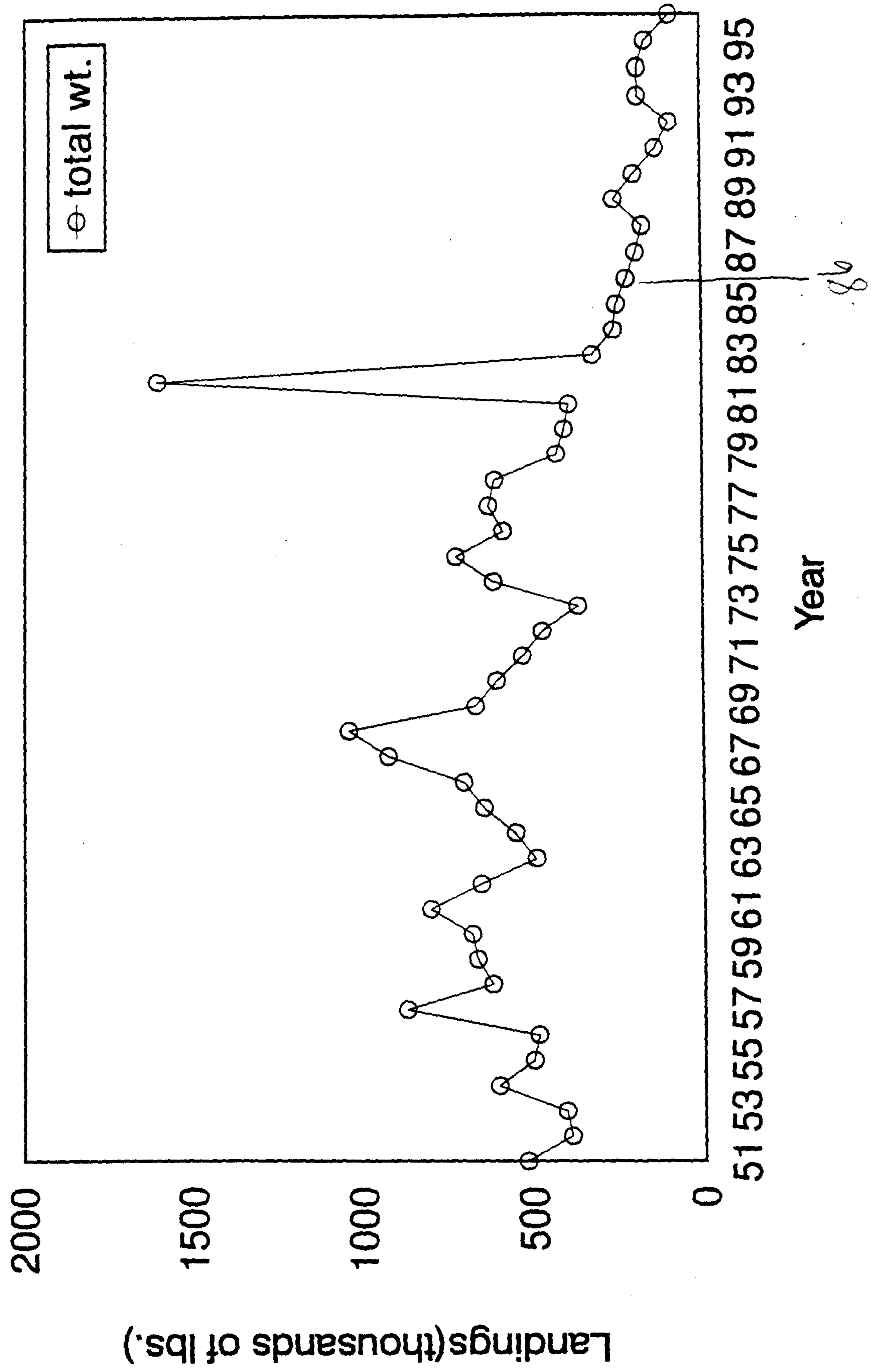
Year	NC Wt	NC Value	SC Wt	SC Value	GA Wt	GA Value	Fl Wt	Fl Value	Total Wt	Total Value
1961	6	1	113	16	3	1	678	187	800	205
1962	2	1	7	2	1	(1)[2]	640	191	650	194
1963	2	1	(1)[2]	(1)[2]	2	1	485	151	489	153
1964	(1)[2]	(1)[2]	8	3	(1)[2]	(1)[2]	542	194	550	197
1965	------	------	16	6	(1)[2]	(1)[2]	625	215	641	221
1966	11	4	------	------	(1)[2]	(1)[2]	690	292	701	296
1967	4	1	3	1	55	21	864	317	926	340
1968	42	16	37	15	18	7	946	409	1,043	447
1969	(1)[2]	(1)[2]	16	11	14	9	635	367	665	387
1970	(1)[2]	(1)[2]	12	8	16	11	575	383	603	402
1971	------	------	8	5	54	40	465	325	527	370
1972	------	------	15	13	52	41	402	333	469	387
1973	(1)[2]	(1)[2]	17	17	20	17	328	304	365	338
1974	------	------	13	13	42	42	557	495	612	550
1975	------	------	6	6	31	33	685	676	722	715
1976	------	------	39	57	56	76	488	607	583	740
1977	------	------	75	133	72	125	479	788	626	1,046
1978	24	37	95	180	99	189	390	714	608	1,120
1979	86	159	49	105	28	59	264	539	427	862
1980	77	149	55	109	18	35	255	518	405	811
1981	95	211	54	125	24	53	219	476	392	865
1982	76	151	59	138	11	27	1,460	1,430	1,606	1,746
1983	73	157	63	142	7	17	179	419	322	7[illegible]2
1984	24	54	56	131	29	71	152	362	261	6[illegible]8

Table 4. Continued

Year	NC		SC		GA		Fl		Total	
	Wt	Value	Wt	Value	Wt	Value	Wt	Value	Wt	Value
1985	19	43	38	96	35	84	161	393	253	616
1986	32	85	25	68	26	82	141	365	224	600
1987	13	33	31	88	18	49	134	357	196	527
1988	11	27	41	115	12	30	113	310	177	482
1989	40	105	82	232	20	50	116	328	258	715
1990	31	83	47	134	14	37	109	313	201	567
1991	18	46	37	111	11	30	71	205	137	392
1992	10	27	22	64	9	23	54	153	95	267
1993	44	116	79	219	13	33	52	152	188	520
1994	40	92	58	151	16	41	75	212	189	496
1995	17	46	38	100	18	47	93	267	166	460
1996	10	26	18	47	12	30	55	159	95	262

[1] Snappers unclasified.
[2] Under 500lbs. and /or $500.

Fig. 1. Red snapper commercial landings weight (lbs.*1000).



Some of the decrease in catches is attributable to regulations, such as that imposed in 1983 (a 12-inch minimum size limit), 1990 (a 13-inch size limit), and 1992 (20-inch minimum size; 10 snapper bag limit for recreational anglers with a daily maximum of two red snapper) rather than abundance of the species.

Most red snapper were landed at ports along the East Coast of Florida (unweighted mean = 85.13% of the southeastern U.S. catch for 1950-1996). However, a clear shift occurred relative to percentage of total landings made by each state as minimum size limits were imposed after 1982. Apparently vessels landing catches in Florida were impacted more than those which reported landings in North Carolina, South Carolina, and Georgia. From 1983-1996 the percentage of red snapper landed at Florida ports had decreased to an average of 54.49% (28%-68%).

Headboat

Headboat data are available for all geographical areas for the years 1982 through 1995 (Table 5; Figure 2). For the 14-year period, landings averaged 73,591 pounds. Catches exceeded 100,000 pounds in 1985 and 1988. Catches have generally increased in 1993, 1994, and 1995. Overall, commercial landings of red snapper are four times greater than those reported by headboat anglers for 1982-1995.

Table 5 underscores the importance of the northeast Florida-Georgia (NEFL-GA) area to headboat landings of red snapper, 58% of the total weight. Conversely, the species is less frequently caught

Table 5. Red snapper headboat landings -- numbers and weight (lbs) -- from the U.S. South Atlantic.

	North Carolina		South Carolina		NE Florida-Georgia		SE Florida		Total	
Year	Number	Weight	Number	Weight	Number	Weight	Number	Weight	Number	Weight
1972	1222	21952	965	18834					2187	40786
1973	2267	30943	1615	27705					3882	58648
1974	1439	16284	1511	14047					2950	30331
1975	782	7977	3872	26897					4654	34874
1976	1948	13127	3546	39875	59473	171692			64967	224695
1977	1049	7218	1316	11059	42110	171090			44475	189367
1978	959	12395	1663	8030	43228	146073			45850	166498
1979	441	5091	668	9108	30924	165480			32033	179678
1980	424	2944	2893	11625	17840	56307			21157	70875
1981	1194	7726	1371	8745	32415	98256			34980	114728
1982	747	10465	1612	14505	16412	69632	754	3216	19525	97819
1983	416	5304	1844	10157	27124	55249	1314	3137	30698	73847
1984	740	4572	1841	6860	27934	67971	631	1841	31146	81244
1985	8426	31264	2183	11744	38072	83787	1655	5012	50336	131806
1986	997	7115	881	4506	14286	40410	461	2235	16625	54265
1987	5346	21472	1934	6296	17155	52217	561	1681	24996	81666
1988	9555	36751	5235	15217	13589	50096	8148	27733	36527	129798
1989	1134	6677	6207	26404	15114	35908	998	1659	23453	70649
1990	525	2743	3650	13312	15422	45980	1322	3513	20919	65549
1991	725	15957	3290	21736	9580	33057	262	1129	13857	71878
1992	2306	12023	1275	5911	1310	8395	410	2526	5301	28855
1993	1639	9024	3623	19822	1541	10575	544	3203	7347	42625
1994	567	3623	2454	6336	3576	21861	1628	11103	8225	42924
1995	3791	23676	866	6327	3034	23683	535	3667	8226	57354

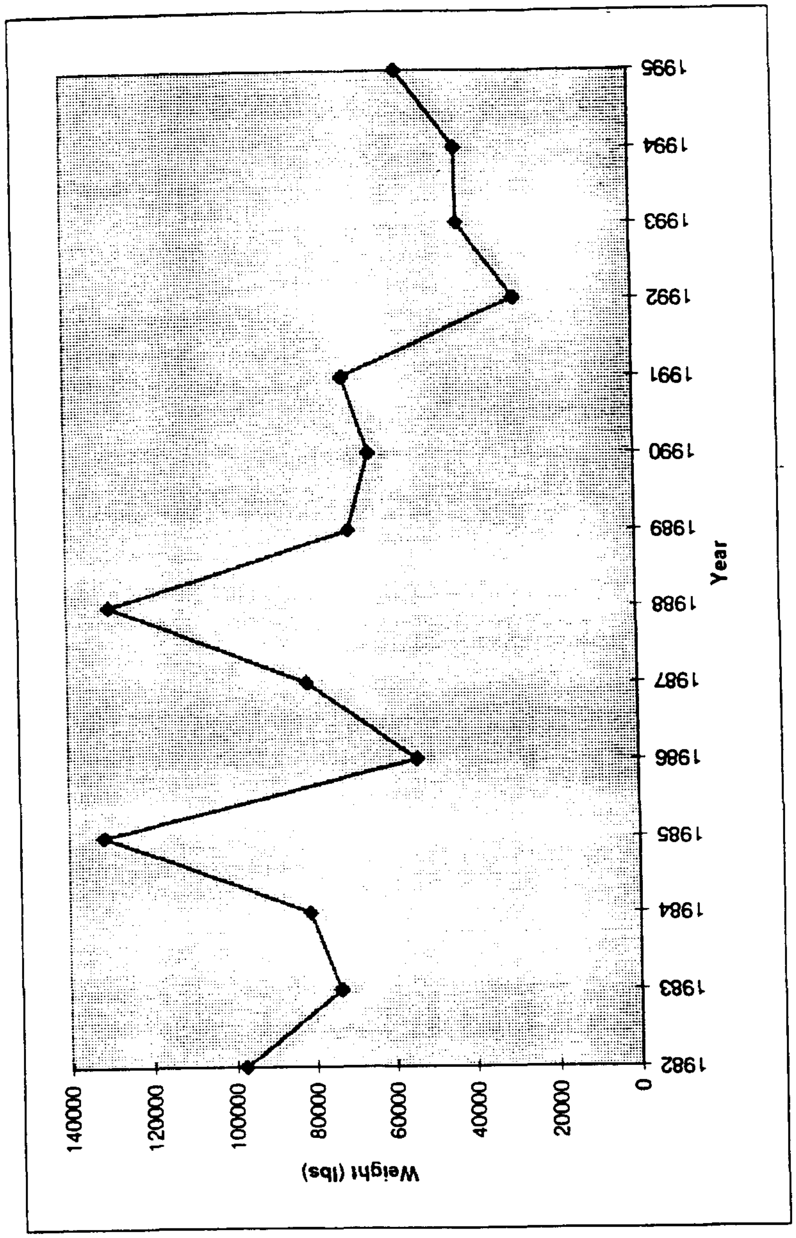


Fig. 2. Red snapper headboat landings by weight (lbs) from the U.S. South Atlantic.

off southeast Florida. The same pattern would have been obvious for commercial landings, but East Coast of Florida catches could not be divided into northeast and southeast regions.

Recreational (MRFSS)

Recreational fishing statistics are available for 1981 through 1995. Landings of red snapper are presented by number and weight (pounds) in Table 6 by year and area. During the 15-year period, the average recreational catch was 298,800 pounds. Landings peaked in 1985 when approximately 1,333,000 pounds were landed. There is no distinct trend in the landings, except the 1995 catch of 66,953 pounds was by far the lowest of record.

As was the case with the commercial and headboat landings data, recreational catches of red snapper along the East Coast of Florida were usually higher than those from North Carolina, South Carolina, or Georgia (Table 6). Red snapper caught off the East Coast of Florida accounted for approximately 85% of the total regional landings for the 15-year period by weight. Florida landings represented between 35% and 98% of the catch. In only two years, 1987 and 1995, were Florida catches less than 50% of the total.

Trends - Catch/Effort

Commercial

There are no catch per unit effort (CPUE) data for the

Table 6. Red Snapper Recreational (MRFSS) Landings ---number of fish and weight (lbs) from U.S.South Atlantic.

	NC		SC		GA		FL		Total	
Year	#	lbs	#	lbs	#	lbs	#	lbs	#	lbs
1981	—	—	4,836	6.915	—	—	158.775	375.305	163.611	382.219
1982	—	—	4,361	4.690	—	—	56.013	153.078	60.374	157.769
1983	—	—	21.902	30,144	1.634	2.398	142.426	166.533	165.962	199.076
1984	9,322	19.631	15.330	42.007	2.832	3,364	384.544	388.043	412.028	453.044
1985	54.874	48,959	45.735	107.184	5.481	10,793	422.249	1.165.787	528.339	1.332.723
1986	1,409	1,188	902	1,005	807	638	177,385	110.442	180.503	113.274
1987	26.044	77,689	766	1,685	1,790	2,000	34,651	41,476	63.251	122,850
1988	14,365	52,811	1.449	1,562	255	350	153.797	169.803	169.866	224.522
1989	8.896	34,569	9.828	26.030	3.434	4,726	146.809	202.908	168.967	268.233
1990	4.904	13.039	0	0	—	—	10,023	102.021	14.927	115.060
1991	6.056	15,932	1,426	5,271	944	10,248	37,849	99.785	46.275	131,237
1992	1,190	6,285	—	—	1,649	10,503	78,438	599.639	81.277	616.427
1993	218	1,606	0	0	5,190	45.624	10.505	85.485	15.913	132.715
1994	1.335	6,345	0	0	5.821	51,115	16,494	108.431	23.650	165.891
1995	5.877	25.403	—	—	3.227	17.926	4.997	23.624	14.101	66.953

commercial data base.

Headboat

Catch per unit effort data are available for 1972 through 1995 for North Carolina and South Carolina, and from 1976 through 1995 for North Carolina to the Florida Keys. CPUE for all areas combined are presented in Table 7 and Figure 3 as weight in pounds of red snapper per angler day. Catch rate has declined dramatically since 1981. The highest catch rates were recorded in 1976, 1977, and 1979, all greater than 1.0. Since 1985 CPUE has remained low, usually less than 0.2 pounds per angler day. Regulations on minimum size and bag limit obviously had an impact on catch rates.

CPUE in number of fish and weight are presented by area (NC, SC, NEFL-GA, and SEFL-Dry Tortugas) in Tables 8-11; Figures 4-7). The highest catch rates were documented for the northeast Florida-Georgia area (Table 10). That area also revealed the most dramatic decline in catch rate compared with the other areas.

Recreational (MRFSS)

Recreational CPUE data are available for the southeastern United States from 1981 through 1995 (Table 12). Catch rates are recorded as number of red snapper per angler trip. CPUE values seem unrealistically high compared with the headboat CPUE data. Recreational catch rates for red snapper peaked in 1983 (8.88 fish/angler trip, remained relatively high (3-5 red snapper/angler trip) from 1984-1988, and then declined to 1-2 fish per angler trip

Table 7. **Red snapper CPUE - headboats all areas combined.**

Year	CPUE-Wt
1972	0.824
1973	0.492
1974	0.354
1975	0.371
1976	1.488
1977	1.255
1978	0.970
1979	1.191
1980	0.456
1981	0.762
1982	0.252
1983	0.201
1984	0.211
1985	0.386
1986	0.131
1987	0.183
1988	0.309
1989	0.186
1990	0.155
1991	0.185
1992	0.079
1993	0.124
1994	0.125
1995	0.184

Fig. 3.

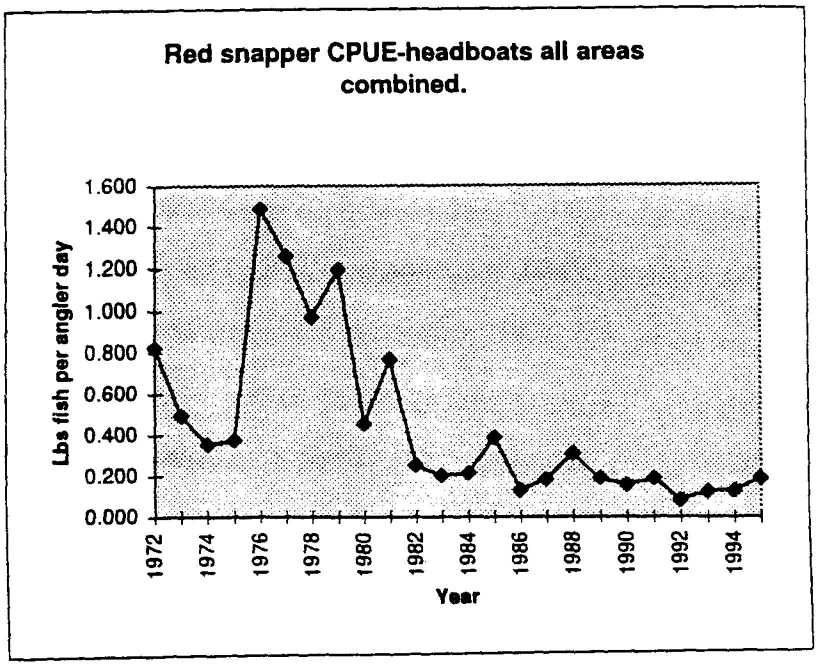


Table 8. North Carolina headboat catch-per -effort (by number & weight) for red snapper.

Year	Number	Weight	ANGDAYS	CPUE-#	CPUE-WT
1972	1222	21952	30659	0.040	0.716
1973	2267	30943	38768	0.058	0.798
1974	1439	16284	33223	0.043	0.490
1975	782	7977	32725	0.024	0.244
1976	1948	13127	31314	0.062	0.419
1977	1049	7218	22660	0.046	0.319
1978	959	12395	26032	0.037	0.476
1979	441	5091	26490	0.017	0.192
1980	424	2944	23714	0.018	0.124
1981	1194	7726	19372	0.062	0.399
1982	747	10465	26939	0.028	0.388
1983	416	5304	23830	0.017	0.223
1984	740	4572	28865	0.026	0.158
1985	8426	31264	31346	0.269	0.997
1986	997	7115	31187	0.032	0.228
1987	5346	21472	35261	0.152	0.609
1988	9555	36751	42421	0.225	0.866
1989	1134	6677	38678	0.029	0.173
1990	525	2743	43240	0.012	0.063
1991	725	15957	40936	0.018	0.390
1992	2306	12023	41177	0.056	0.292
1993	1639	9024	42785	0.038	0.211
1994	567	3623	36693	0.015	0.099
1995	3791	23676	40294	0.094	0.588

Fig. 4.

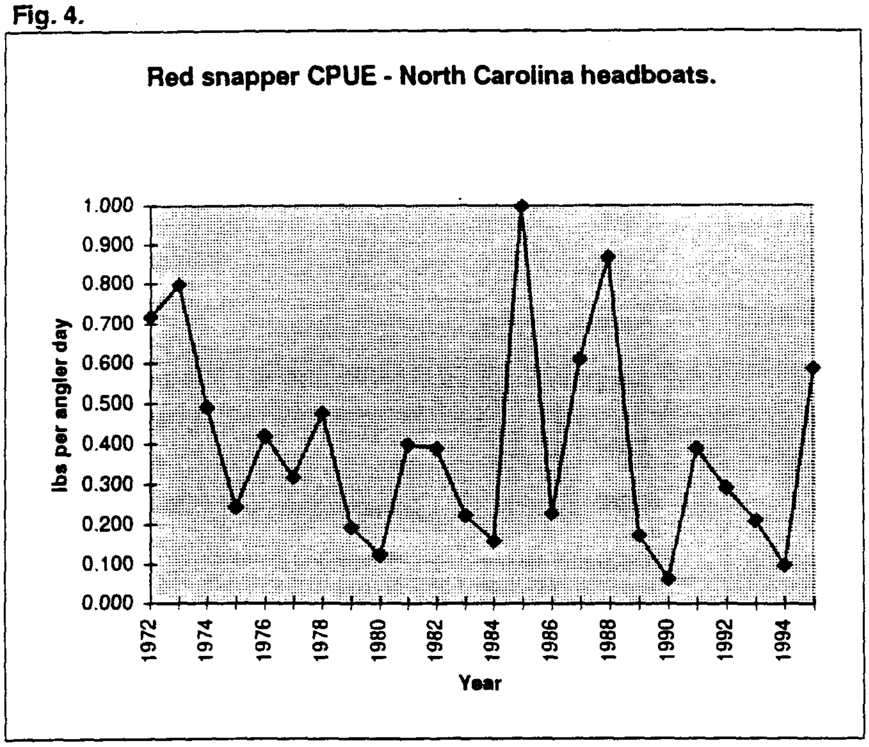


Table 9. South Carolina headboat catch-per-effort (by number & weight) for red snapper.

YEAR	NUMBER	WEIGHT	ANGDAYS	CPUE-#	CPUE-WT
1972	965	18834	18830	0.051	1.000
1973	1615	27705	80352	0.020	0.345
1974	1511	14047	52384	0.029	0.268
1975	3872	26897	61225	0.063	0.439
1976	3546	39875	61318	0.058	0.650
1977	1316	11059	69910	0.019	0.158
1978	1663	8030	67462	0.025	0.119
1979	668	9108	56935	0.012	0.160
1980	2893	11625	64244	0.045	0.181
1981	1371	8745	59030	0.023	0.148
1982	1612	14505	67539	0.024	0.215
1983	1844	10157	65713	0.028	0.155
1984	1841	6860	67313	0.027	0.102
1985	2183	11744	29042	0.075	0.404
1986	881	4506	67227	0.013	0.067
1987	1934	6296	78806	0.025	0.080
1988	5235	15217	76468	0.068	0.199
1989	6207	26404	24861	0.250	1.062
1990	3650	13312	57151	0.064	0.233
1991	3290	21736	67982	0.048	0.320
1992	1275	5911	61790	0.021	0.096
1993	3623	19822	64457	0.056	0.308
1994	2454	6336	63231	0.039	0.100
1995	866	6327	61739	0.014	0.102

Fig. 5.

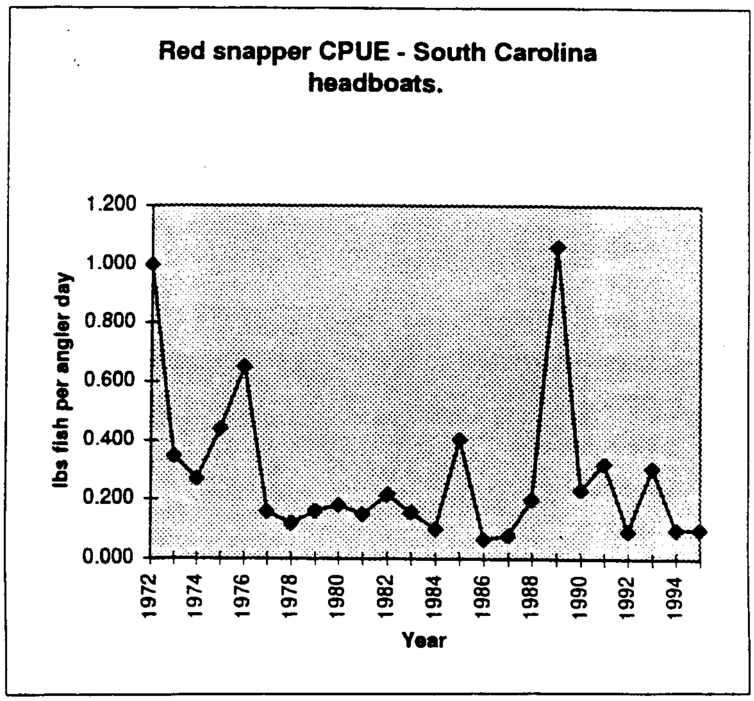


Table 10. **Northeast Florida -Georgia headboat catch-per -effort (by number & weight) for red snapper.**

YEAR	NUMBER	WEIGHT	ANGDAYS	CPUE-#	CPUE-WT
1976	59473	171692	58404	1.018	2.940
1977	42110	171090	58330	0.722	2.933
1978	43228	146073	78099	0.554	1.870
1979	30924	165480	67461	0.458	2.453
1980	17840	56307	67466	0.264	0.835
1981	32415	98256	72069	0.450	1.363
1982	16412	69632	66961	0.245	1.040
1983	27124	55249	83499	0.325	0.662
1984	27934	67971	95234	0.293	0.714
1985	38072	83787	94446	0.403	0.887
1986	14286	40410	113101	0.126	0.357
1987	17155	52217	114144	0.150	0.457
1988	13589	50096	109156	0.124	0.459
1989	15114	35908	102920	0.147	0.349
1990	15422	45980	98234	0.157	0.468
1991	9580	33057	85111	0.113	0.388
1992	1310	8395	90810	0.014	0.092
1993	1541	10575	74494	0.021	0.142
1994	3576	21861	65745	0.054	0.333
1995	3034	23683	59104	0.051	0.401

Fig. 6.

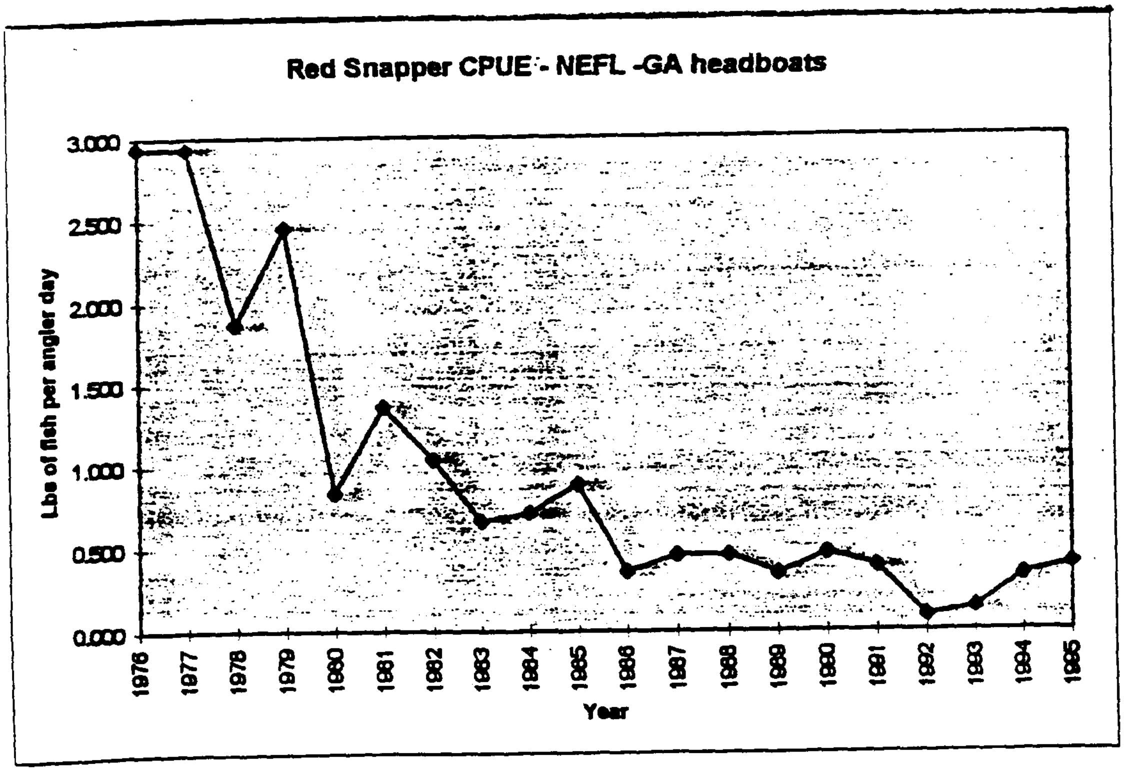


Table 11. **South Florida catch-per-effort (by number & weight) for red snapper.**

YEAR	NUMBER	WEIGHT	ANGDAYS	CPUE-#	CPUE-WT
1982	754	3216	226172	0.003	0.014
1983	1314	3137	194364	0.007	0.016
1984	631	1841	193760	0.003	0.010
1985	1655	5012	186398	0.009	0.027
1986	461	2235	203960	0.002	0.011
1987	561	1681	218897	0.003	0.008
1988	8148	27733	192618	0.042	0.144
1989	998	1659	213944	0.005	0.008
1990	1322	3513	224661	0.006	0.016
1991	262	1129	194991	0.001	0.006
1992	410	2526	173714	0.002	0.015
1993	544	3203	162478	0.003	0.020
1994	1628	11103	177035	0.009	0.063
1995	535	3667	150957	0.004	0.024

Fig. 7.

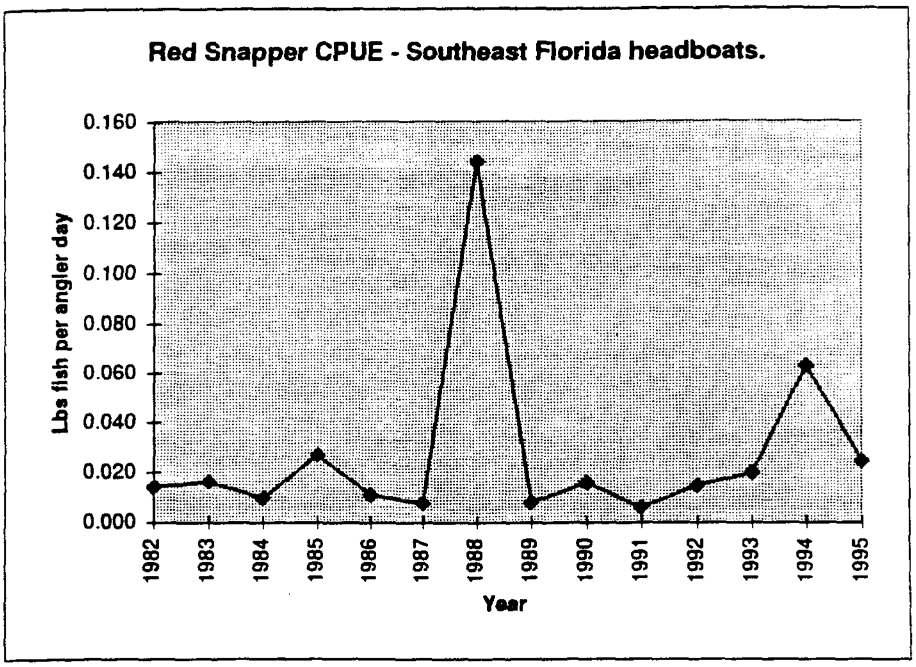
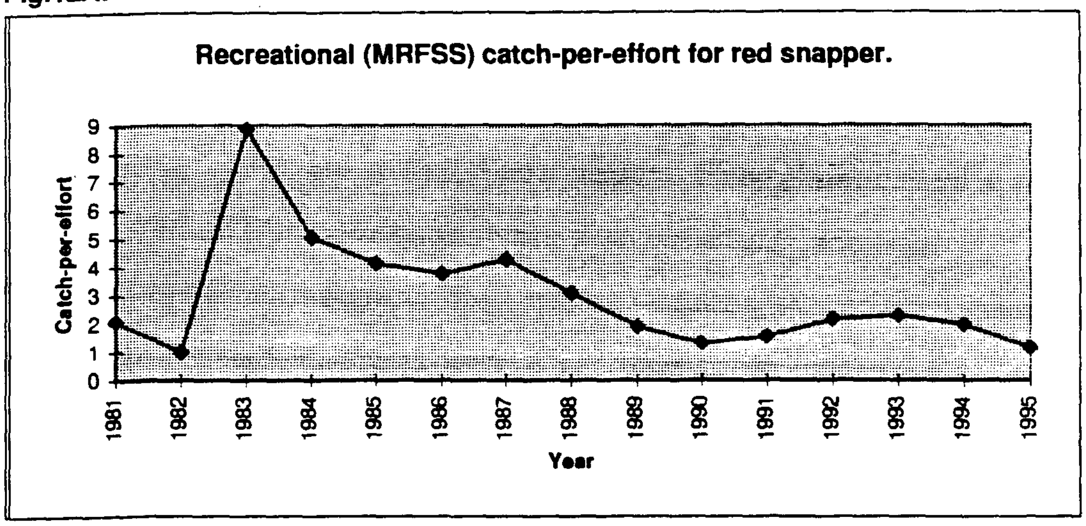


Table 12. Recreational (MRFSS) data for red snapper from the U.S. South Atlantic from 1981-1995.

Year	Total Catch #	Total Angler Trips /Hour	CPUE
1981	165548	79114	2.09
1982	60373	60297	1.00
1983	206006	23207	8.88
1984	539335	106739	5.05
1985	618629	148971	4.15
1986	180503	47653	3.79
1987	169979	39766	4.27
1988	270359	87714	3.08
1989	195706	101439	1.93
1990	17425	13195	1.32
1991	90895	58058	1.57
1992	115989	53291	2.18
1993	87340	37834	2.31
1994	95268	47580	2.00
1995	69033	59190	1.17

Fig.12A.



from 1989 through 1995.

Fishery Independent Data (SCDNR)

From 1988 through 1996 South Carolina Department of Natural Resources personnel made over 2,200 sets of Chevron traps to capture reef fishes (Table 13). This gear was only marginally successful and caught 189 red snapper. Catch per unit effort is recorded in number and weight per trap hour. Catch rates for all years were low; the highest in 1988 (Table 13). These data offer limited value for the assessment.

Trends - Mean Weights

Commercial

Mean size data are available for the commercial fishery from 1983 through 1995 and are presented in Table 14 and Figure 8 by lengths and weights. Mean size for red snapper was largest in 1983 and smallest in 1984, however, only North Carolina fish were sampled for those years. Mean size has generally increased since 1984. It appears that with the exception of 1984, commercial fishermen typically catch larger red snapper than do recreational anglers, therefore minimum size regulations have not produced a drastic change in mean size for the commercial fishery.

Headboat

The mean weights of red snapper caught by headboat anglers

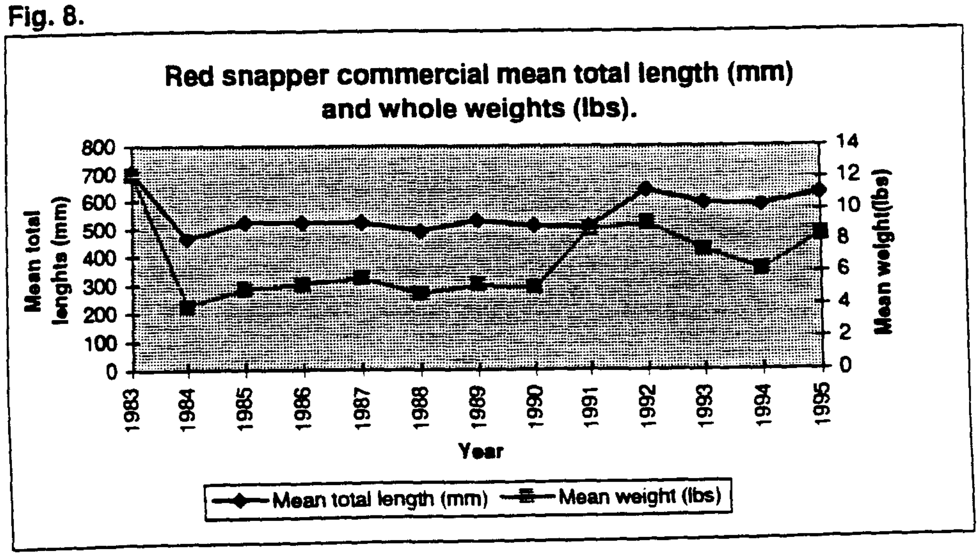
Table 13. Red snapper CPE from MARMAP chevron trap from U.S. South Atlantic.

Year	Number Trap Samples	Number Fish	Mean Number CPE (SE)	Mean Weight CPE (SE)
1988	85	24	0.27 (0.16)	0.30 (0.17)
1989	66	4	0.06 (0.04)	0.14 (0.09)
1990	292	24	0.05 (0.03)	0.06 (0.03)
1991	247	17	0.06 (0.04)	0.02 (0.01)
1992	282	21	0.05 (0.02)	0.08 (0.04)
1993	323	31	0.06 (0.02)	0.13 (0.05)
1994	340	45	0.08 (0.04)	0.19 (0.07)
1995	253	13	0.03 (0.01)	0.08 (0.03)
1996	350	10	0.02 (0.01)	0.04 (0.02)
TOTAL	2238	189		

Table 14. Red snapper commercial mean total lengths (mm) and whole weights (lbs).

	NC		SC		GA		NFL		SFL		Overall	Weighted Mean
Year	TL	lbs.	TL	lbs.	TL	lbs.	TL	lbs.	TL	lbs.	TL	lbs.
1983	706	12.19	----	----	----	----	----	----	----	----	706	12.19
1984	464	3.94	----	----	----	----	----	----	----	----	464	3.94
1985	524	5.10	----	----	525	5.13	----	----	----	----	524	5.00
1986	523	4.95	525	5.10	577	7.50	----	----	----	----	523	5.30
1987	544	6.51	541	5.46	479	4.86	----	----	----	----	524	5.68
1988	481	4.51	476	4.00	522	5.63	758	14.28	540	4.88	493	4.69
1989	531	5.15	527	4.88	503	4.99	671	10.96	----	----	530	5.22
1990	531	5.28	461	3.67	----	----	499	5.48	591	6.73	511	5.03
1991	538	6.34	468	4.07	526	6.23	602	8.47	737	13.22	507	8.74
1992	622	8.16	593	7.11	626	8.84	699	11.62	600	7.19	640	9.14
1993	554	5.57	538	4.99	590	7.19	724	13.02	625	8.36	596	7.48
1994	583	6.47	582	6.29	589	6.69	605	7.70	577	7.11	587	6.19
1995	649	8.82	610	7.41	623	8.10	641	9.04	461	3.41	629	8.42

Fig. 8.



have generally increased since 1985 (Table 15; Figure 9) for all geographic areas combined. This increase is most probably caused by the size restrictions intended to reduce the harvest of smaller fish (remember a 20-inch minimum size was imposed in 1992). Mean weights which had been about 3 pounds from 1983 through 1990 had increased to between 6 and 7 pounds from 1992 through 1995 (Table 15).

The same pattern of increased mean weights did not prevail for each geographic area (Tables 16-19; Figures 10-13). The decrease in mean size of red snapper landed in North Carolina is dramatic. The species averaged over 20 pounds in 1973, ranged from about 10-15 pounds from 1974 through 1983, and has since declined to 5-6 pounds. These mean weights should be viewed with caution because of small sample sizes. Red snapper landed in South Carolina showed a similar mean size pattern by year as those from North Carolina, except the mean size of South Carolina fish increased in the most recent years. Sample sizes were larger (Table 17). Mean size for the NEFL-GA area increased dramatically from 1992-1995 (Table 18), again reflecting the 20-inch minimum size regulation. As the size increased, the number of fish sampled decreased.

Recreational (MRFSS)

Mean size data are available for the recreational fishery from 1981 through 1995 (Table 20; Figure 14). The data could not be stratified by geographic area because of small sample sizes. Less than 20 red snapper were sampled for the entire southeastern United

Table 15. **Mean weight (lbs) of red snapper from headboats for all areas combined.**

YEAR	MEAN WT	N
82	4.76	431
83	2.70	947
84	2.84	1261
85	2.57	1156
86	3.70	419
87	3.07	303
88	3.65	196
89	2.91	362
90	3.20	311
91	4.13	89
92	5.96	62
93	5.73	194
94	6.49	108
95	6.80	131

Fig.9.

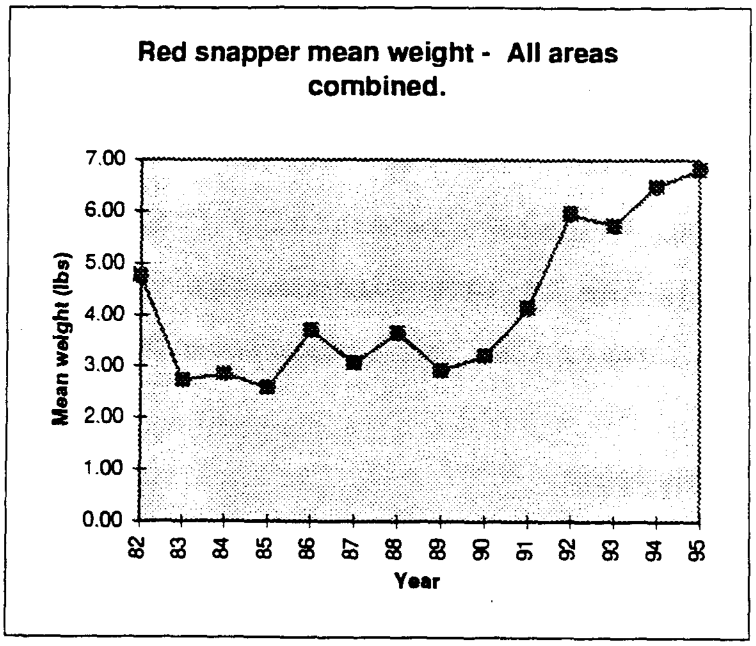


Table 16. Red snapper mean weight (lbs) North Carolina headboats.

YEAR	MEAN WT	N
72	16.40	20
73	20.14	21
74	13.54	26
75	10.26	58
76	9.38	112
77	10.97	50
78	14.56	47
79	15.58	7
80	13.65	9
81	6.77	17
82	13.59	30
83	12.28	50
84	6.05	48
85	3.69	170
86	6.24	51
87	4.29	48
88	3.25	64
89	4.85	39
90	5.52	33
91	4.64	7
92	5.48	18
93	5.36	22
94	6.91	11
95	5.63	13

Fig. 10.

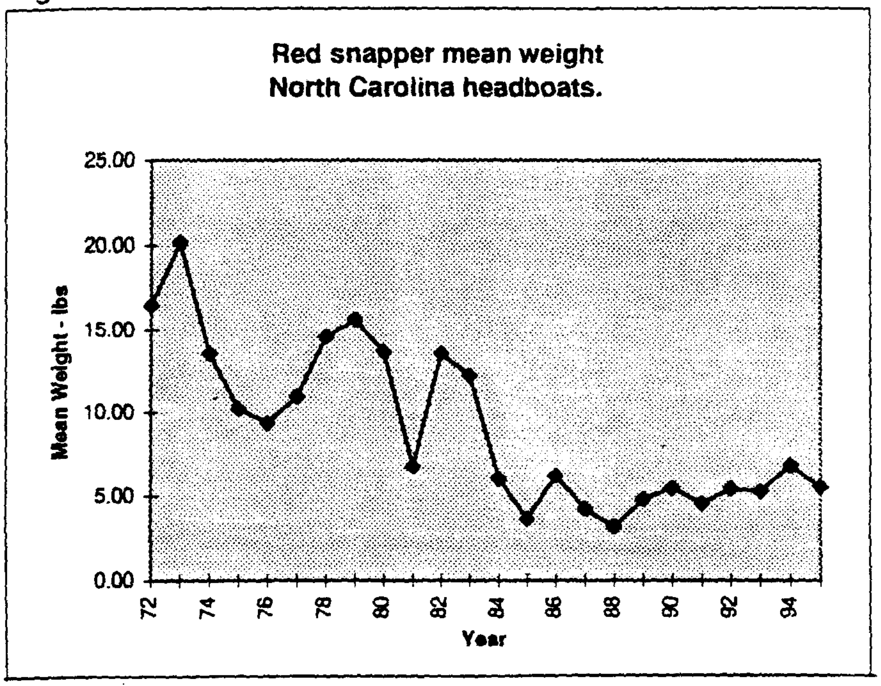


Table 17.

Red snapper mean weight (lbs)
South Carolina headboats.

YEAR	MEAN WT	N
72	18.44	30
73	17.14	20
74	8.91	66
75	6.26	85
76	10.20	51
77	8.61	76
78	7.56	43
79	7.89	8
80	4.02	14
81	4.23	3
82	10.82	6
83	5.44	24
84	3.87	101
85	4.71	51
86	5.25	30
87	3.20	53
88	3.67	43
89	4.04	51
90	3.74	41
91	6.07	18
92	4.55	24
93	5.62	127
94	6.32	45
95	7.25	41

Fig. 11.

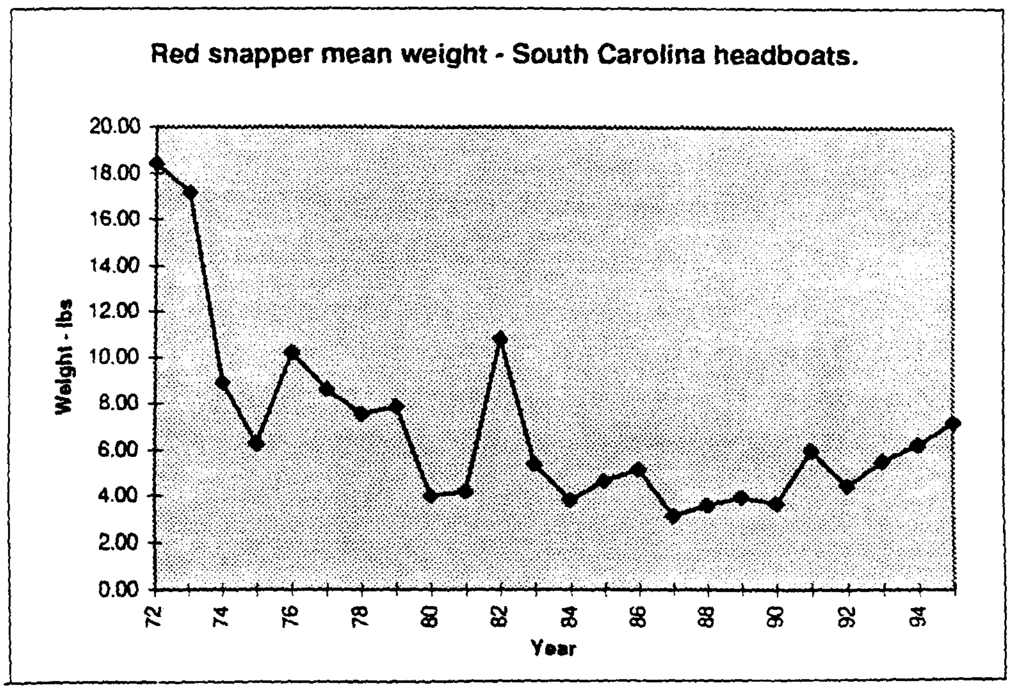


Table 18. **Red snapper mean weight (lbs) northeast Florida - Georgia headboats.**

YEAR	MEAN WT	N
76	2.85	283
77	3.32	523
78	3.53	509
79	5.45	216
80	4.02	204
81	3.41	584
82	3.98	390
83	2.06	861
84	2.60	1019
85	2.25	865
86	3.10	327
87	2.68	197
88	3.92	95
89	2.51	244
90	2.79	247
91	3.29	65
92	7.49	25
93	6.62	37
94	6.70	49
95	6.84	81

Fig. 12.

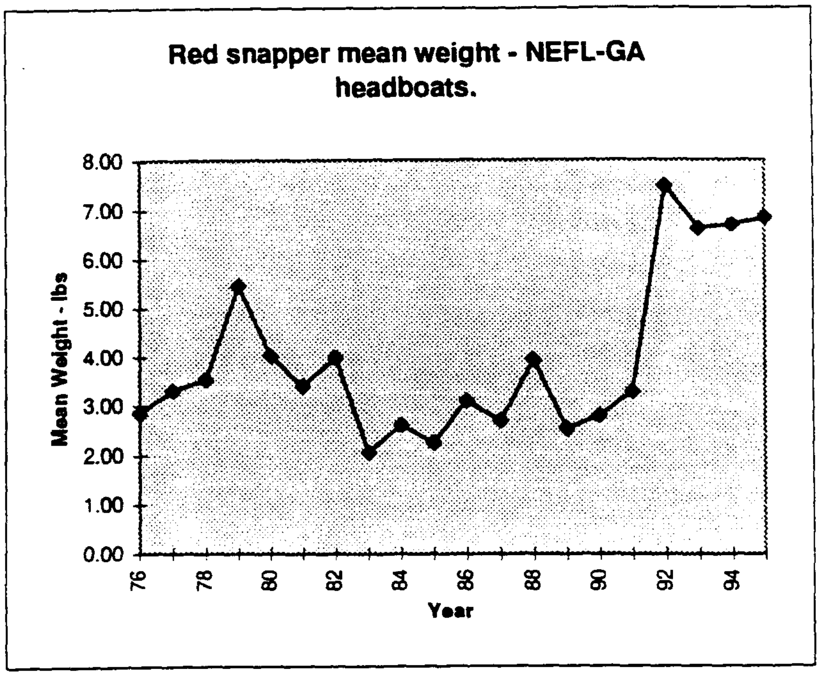


Table 19. **Red snapper mean weight (lbs) Southeast Florida headboats.**

YEAR	MEAN WT	N
82	4.15	6
83	2.64	26
84	2.66	107
85	2.26	74
86	4.55	19
87	4.77	6
88	4.04	5
89	1.89	21
90		0
91	8.77	3
92		0
93	4.79	10
94	4.48	6
95	3.72	2

Fig. 13.

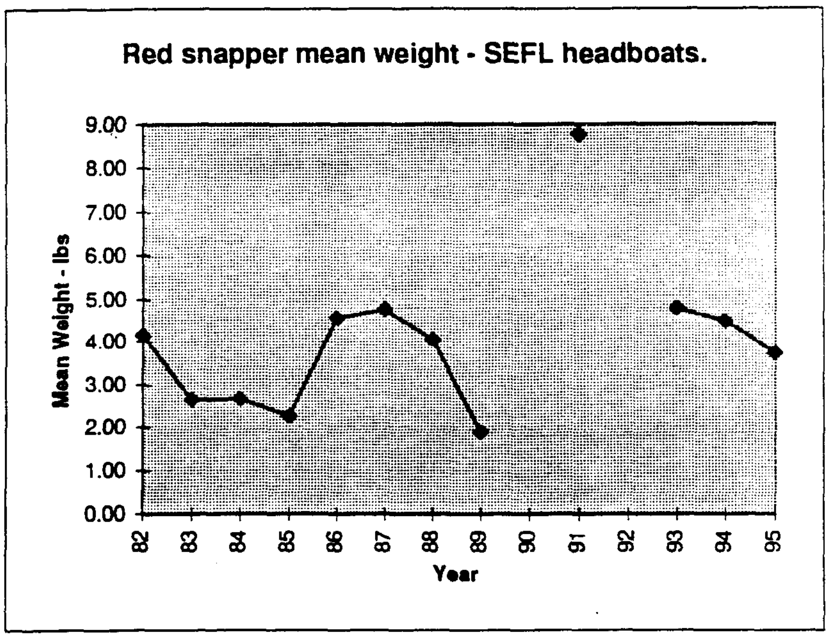
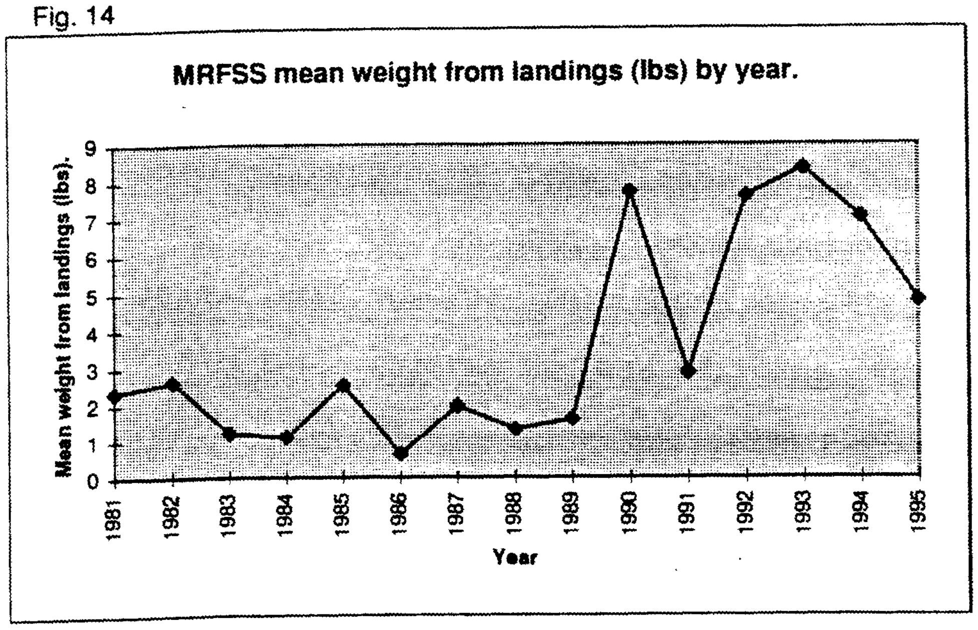


Table 20. Recreational (MRFSS) mean weights of red snapper landed in the U.S. South Atlantic, generated from the length samples and l-w relationship and from the landings in weight/landings in number of fish.

	Mean Weight (lbs)	
Year	From length frequency	From landings
1981	1.50	2.33
1982	2.71	2.62
1983	1.17	1.21
1984	0.95	1.10
1985	0.92	2.53
1986	0.40	0.64
1987	1.76	1.94
1988	1.50	1.32
1989	1.61	1.58
1990	3.56	7.70
1991	3.17	2.84
1992	2.49	7.59
1993	6.69	8.34
1994	5.70	7.02
1995	3.54	4.75

Fig. 14



States for each of the years: 1990, 1991, and 1992 (N = 18, 16, and 17, respectively). Mean fish length for the entire area was remarkably small, averaging less 400 mm TL until 1991 when it reached 413 mm TL (16.3 inches) and about three pounds. Since 1991 the mean size has remained above 400 mm (15.7 inches) and between about five and eight pounds (Table 20; Figure 14).

Age/Growth Study

Examination of Otoliths

We conducted an age and growth study on red snapper because the last one for the species along the southeastern U.S., written by Nelson and Manooch (1982), utilized fish collected almost 20 years ago, during the late 1970s. We felt that we should update the aging data to ensure that the best information available would be used in this population assessment.

A total of 537 otolith samples collected from 1988 through 1996 were examined. Two hundred-twenty came from headboat landings, 206 from fishery-independent sampling, and 111 were from red snapper harvested by the commercial hook and line fishery. Of the total, 523 (97.4%) could be aged by counting the number of rings, and 470 (87.5%) were legible enough to record growth measurements. Red snapper were aged 1-25 years. Individuals at capture averaged 213 mm TL at age 1, 506 mm at age 5, 763 mm at age 10, 840 mm at age 15, 886 mm at age 20, and 937 mm at age 25 (Table 21).

Table 21. Observed mean total length (TL) at age for red snapper from the U.S. South Atlantic.

Age	N	Mean TL (mm)	STD	Range
1	4	213	10.9	197 - 220
2	17	272	30.7	233 - 338
3	81	366	36.8	245 - 425
4	121	419	35.7	360 - 515
5	95	506	37.6	430 - 598
6	75	587	47.1	492 - 680
7	63	637	43.4	557 - 730
8	22	688	57.5	610 - 780
9	9	750	28.9	710 - 787
10	6	763	11.7	747 - 780
11	7	792	17.6	780 - 827
12	3	813	48.5	757 - 842
13	4	820	23.1	800 - 852
14	7	822	21.7	787 - 850
15	1	840		
16	2	868	31.8	845 - 890
17	1	865		
20	3	886	26.6	855 - 902
23	1	900		
25	1	937		

Validation

When using a calcareous structure, like an otolith, to age a fish, it is very important to determine the usefulness of the structure in predicting age. Critical to this determination is that there must be a positive relationship between fish size and otolith size. Also, rings must be consistently formed on the structure, and must be formed periodically, in our study, annually. Several observations support the use of otoliths in determining age of red snapper, and validate rings as annual marks. First, the mean lengths of fish increased as the number of rings increased (Tables 21 and 22). Second, there was a strong correlation between otolith radii and fish lengths (r^2 = 0.93; Figure 15). And third, marginal increment analyses reveal formation of rings during March-May (Figure 16). The latter was confirmed by documenting months when zero marginal increment occurred, January, March, April, and May (Figure 16). Nelson and Manooch (1982) found that annuli formed on red snapper otoliths and scales during the spring.

Back-Calculated Growth

The relationship between fish length and otolith radius is represented by $TL = 1.14(R_C)^{1.26}$ (r^2 = 0.93; n = 526; MSE = 0.006). Lengths at ages using all data were back-calculated from the otolith proportional equation: $TL = \exp[1.14 + (\ln L_C - 1.14)*(\ln R_A/\ln R_C) + 0.006/2]$. We calculated the mean length of the red snapper at the time of each annulus formation, and the mean annual growth increment at each age (Table 22). Growth appears most

Table 22. All back-calculated total lengths in mm (± 1 SE.) based on the ln ln proportional equation for red snapper from the U.S. South Atlantic

		Age Rings										
Age	N	1	2	3	4	5	6	7	8	9	10	11
1	4	176±7.2										
2	16	166±3.8	231±4.7									
3	77	165±2.0	252±3.0	331±3.9								
4	107	167±1.5	251±1.9	331±2.3	388±2.7							
5	81	177±1.4	268±2.2	352±2.8	422±3.5	479±4.1						
6	67	175±1.7	271±2.9	361±3.9	436±4.6	502±5.0	559±5.7					
7	53	174±2.0	268±2.8	361±3.9	436±4.4	502±5.1	560±5.8	611±6.1				
8	22	177±2.9	273±3.6	371±6.5	443±7.5	507±8.6	563±10.1	616±11.1	662±12.0			
9	9	177±4.3	276±7.0	370±8.3	448±9.1	516±11.4	581±12.1	631±11.5	677±11.9	721±11.7		
10	6	178±5.6	275±9.6	361±9.7	436±14.1	498±14.6	559±19.3	611±21.8	653±18.2	695±14.6	733±8.5	
11	6	171±4.0	262±4.6	346±6.3	420±10.3	485±9.1	546±10.8	599±9.3	652±6.0	698±4.6	739±4.3	771±6.6
12	3	182±8.7	271±9.3	354±6.2	421±17.9	472±18.9	522±18.8	585±10.6	624±10.1	672±9.6	721±10.8	762±15.7
13	4	156±4.0	238±1.1	320±0.5	386±7.2	443±8.0	496±7.7	543±8.6	595±12.1	645±18.7	691±18.8	737±19.4
14	7	165±3.1	253±3.9	334±4.9	397±5.1	451±3.5	498±4.9	545±5.8	587±6.7	632±6.8	673±5.8	711±6.9
15	1	184	269	351	432	469	516	564	613	662	688	713
16	2	179±1.5	270±3.1	340±5.3	397±11.4	464±3.5	534±0.2	575±1.1	612±12.4	652±16.2	686±19.8	711±23.2
17	1	165	261	329	390	454	511	555	586	632	678	706
20	2	177±13.3	256±19.6	331±31.9	387±38.3	445±49.6	500±51.6	548±55.1	589±50.8	627±55.3	662±47.6	697±40.0
23	1	192	272	353	416	481	548	616	662	700	723	742
25	1	150	224	288	358	415	474	534	575	595	616	637
Weighted Mean TL	470	172	261	346	417	491	555	603	642	675	702	730
Annual Increment		172	89	85	71	74	64	48	39	33	27	28

Continued

Table 22 (continued).

	Ageing													
Age	12	13	14	15	16	17	18	19	20	21	22	23	24	25
12	790±20.9													
13	772±17.9	796±14.8												
14	750±8.3	780±8.5	804±8.5											
15	739	764	790	816										
16	743±24.2	762±22.1	787±20.1	812±23.6	839±24.4									
17	729	748	772	795	819	843								
20	728±36.0	751±36.1	770±33.4	789±30.7	811±25.7	828±25.2	846±24.6	858±23.5	871±22.4					
23	757	771	785	805	819	834	849	858	868	879	888	898		
25	658	679	700	721	743	764	786	807	829	851	873	895	909	922
Weighted Mean TL	752	770	786	792	812	820	832	846	860	865	880	896	909	922
Growth Increment	22	18	16	6	20	8	12	14	14	5	15	16	13	13

Figure 15. Otolith radius - total length relationshp of red snapper from the U.S. South Atlantic.

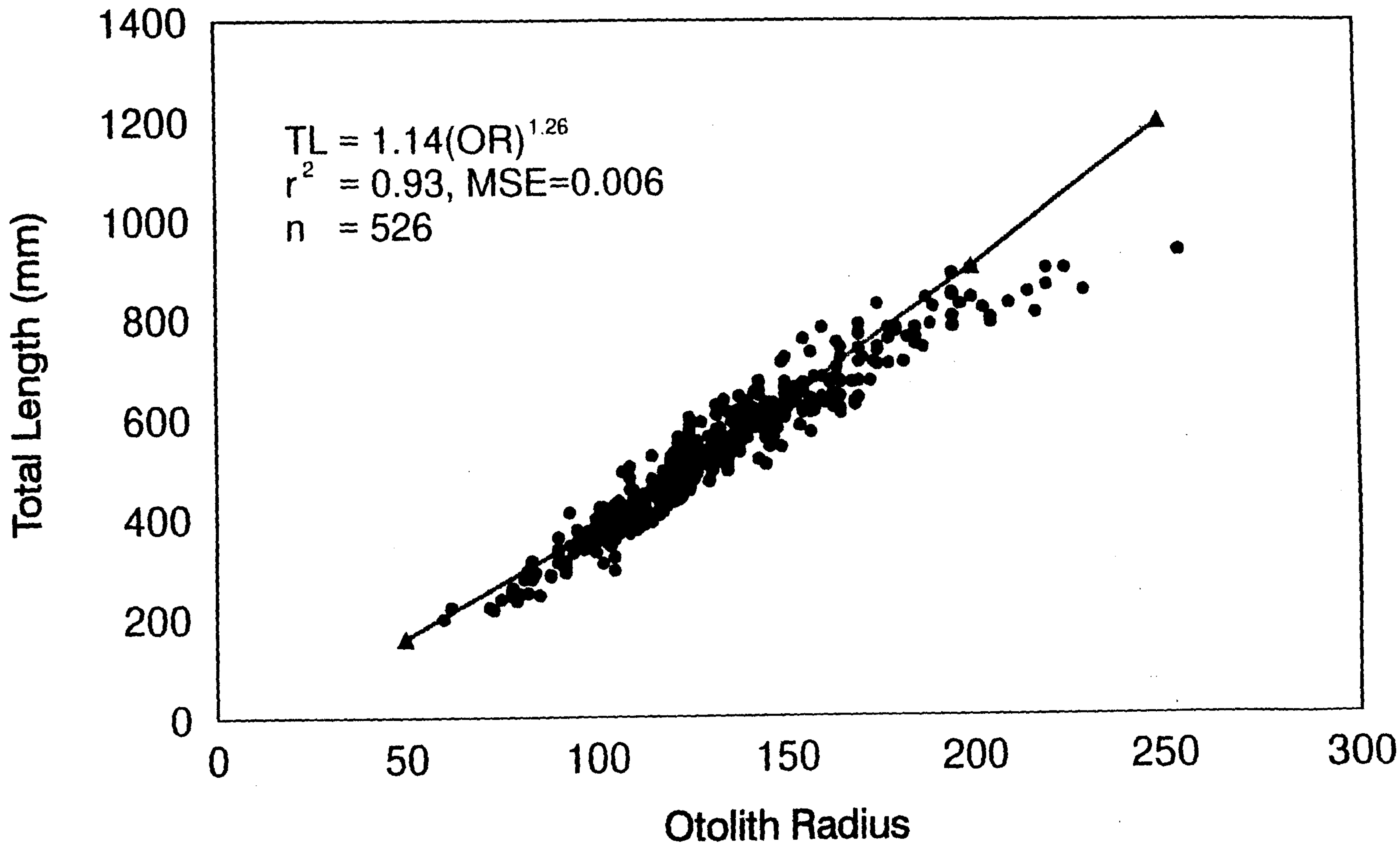
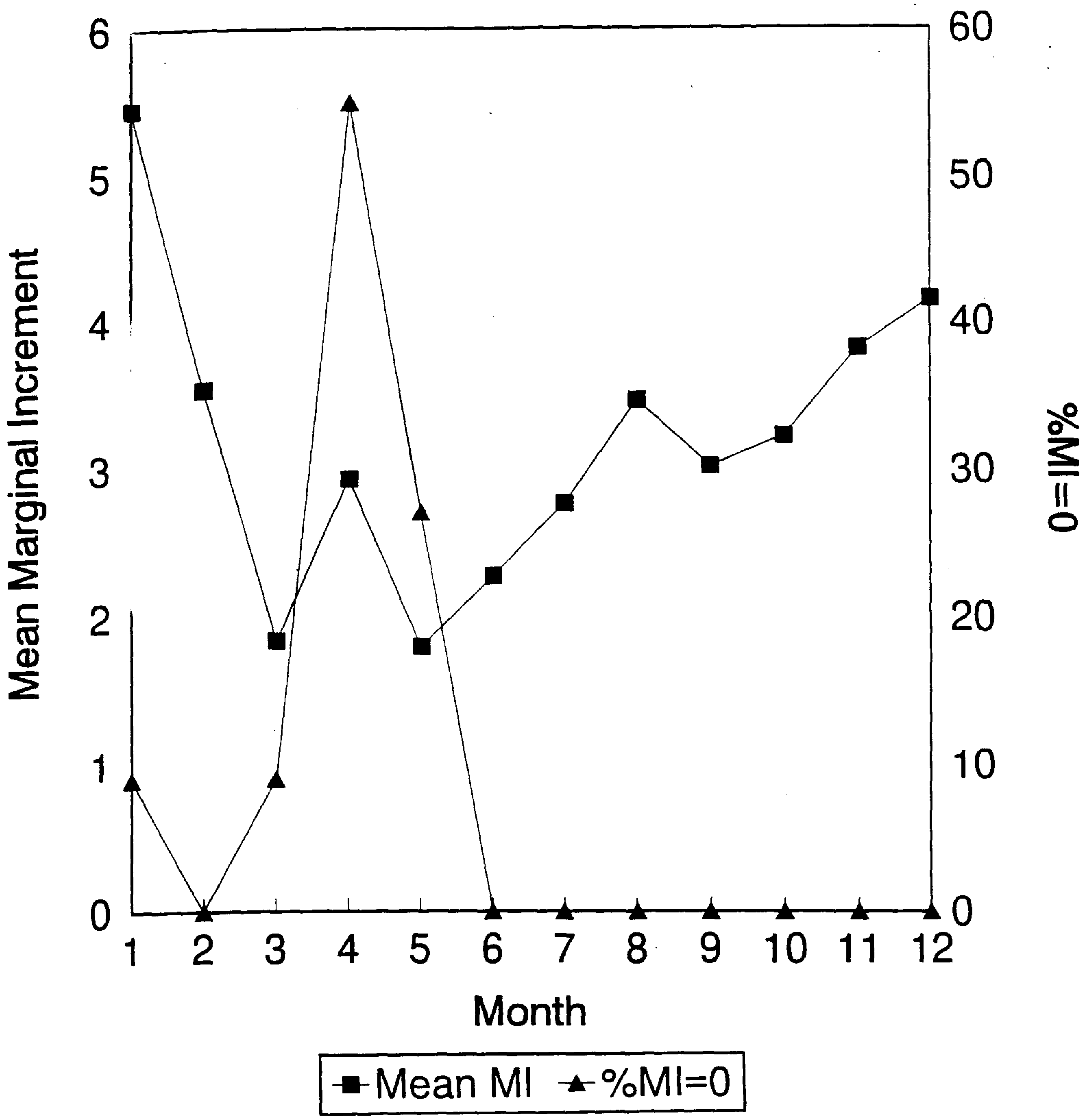


Figure 16. Marginal increment analysis for red snapper from the U.S. South Atlantic.



rapid for the first three years of life, then levels off (Figure 17 ; Table 22). Mean back-calculated total lengths ranged from 172 mm at age 1 to 922 mm at age 25.

Growth Parameters

Back-calculated lengths from the last annulus for each age group (Vaughan and Burton 1994) were used to derive the Bertalanffy growth equation: $L_t = 955.3(1-e^{-0.146(t-0.182)})$. The 95% confidence intervals for L_∞, K, and t_o, respectively are: 921.0-989.6; 0.134-0.159; and 0.011-0.353. Nelson and Manooch (1982) aged red snapper captured along the southeastern United States by scales, and derived the growth equation: $L_t = 975(1-e^{-0.16\ (t-0.0)})$. The two equations are presented for comparative purposes in Figure 18.

Size Relationships

To convert fish lengths into fish weights and vice versa, we derived the following equation: $W = 1.5 \times 10^{-8}(L)^{2.99}$ ($N = 84$; $r^2 = 0.97$ (Figure 19), where W = whole weight in kilograms and L = total length in millimeters. According to this equation, a red snapper 200 mm TL is predicted to weigh 0.11 kg; a 600 mm fish, 3.04 kg; and a 900 mm red snapper, 10.22 kg. Nelson and Manooch (1982) derived the equation: $W = 2.04 \times 10^{-5}\ TL^{2.953}$ for red snapper, where W = weight in grams. This equation predicts that a 200-mm red snapper weighs 0.13 kg; a 600-mm fish weighs 3.26 kg; and a red snapper 900 mm TL weighs 10.8 kg.

The following linear relationships were calculated to convert

Figure 17. Mean observed, back-calculated (last annulus data, ln-ln proportional equation), and theoretical total lengths for red snapper from the U.S. South Atlantic.

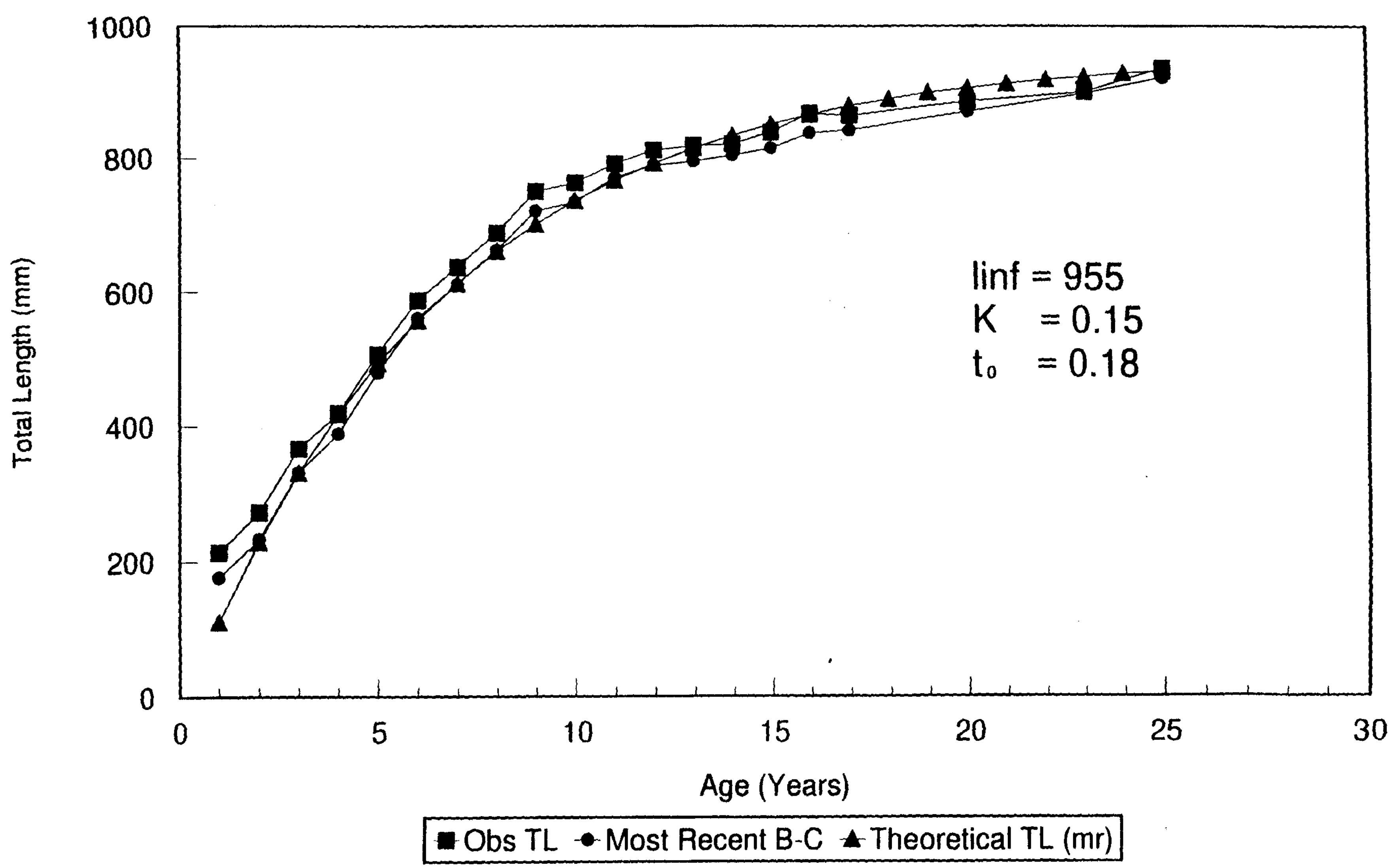


Figure 18. Comparison of theoretical growth equations from present study and Nelson and Manooch 1982.

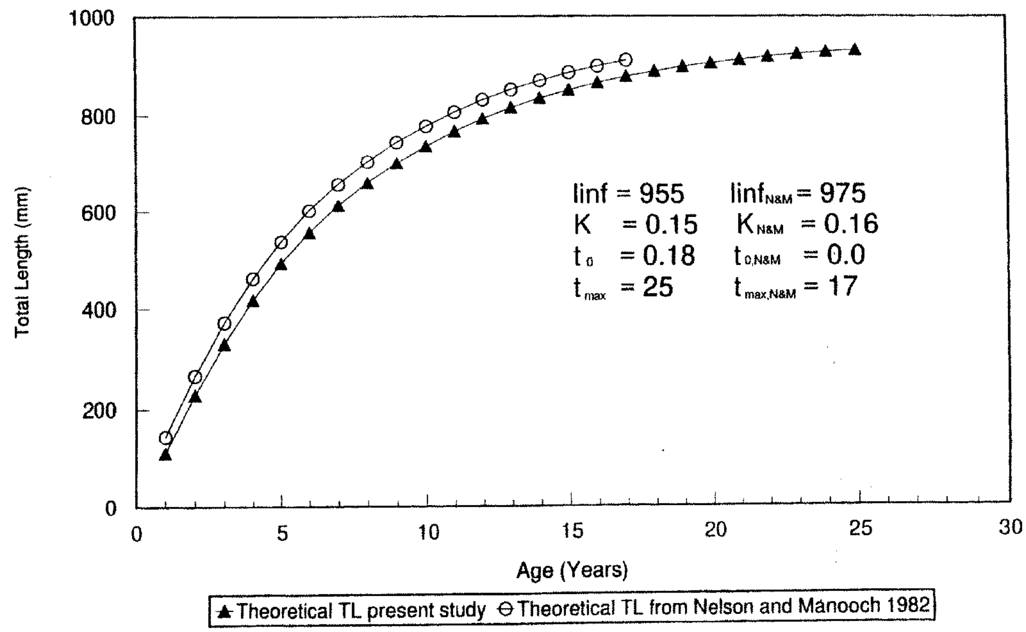
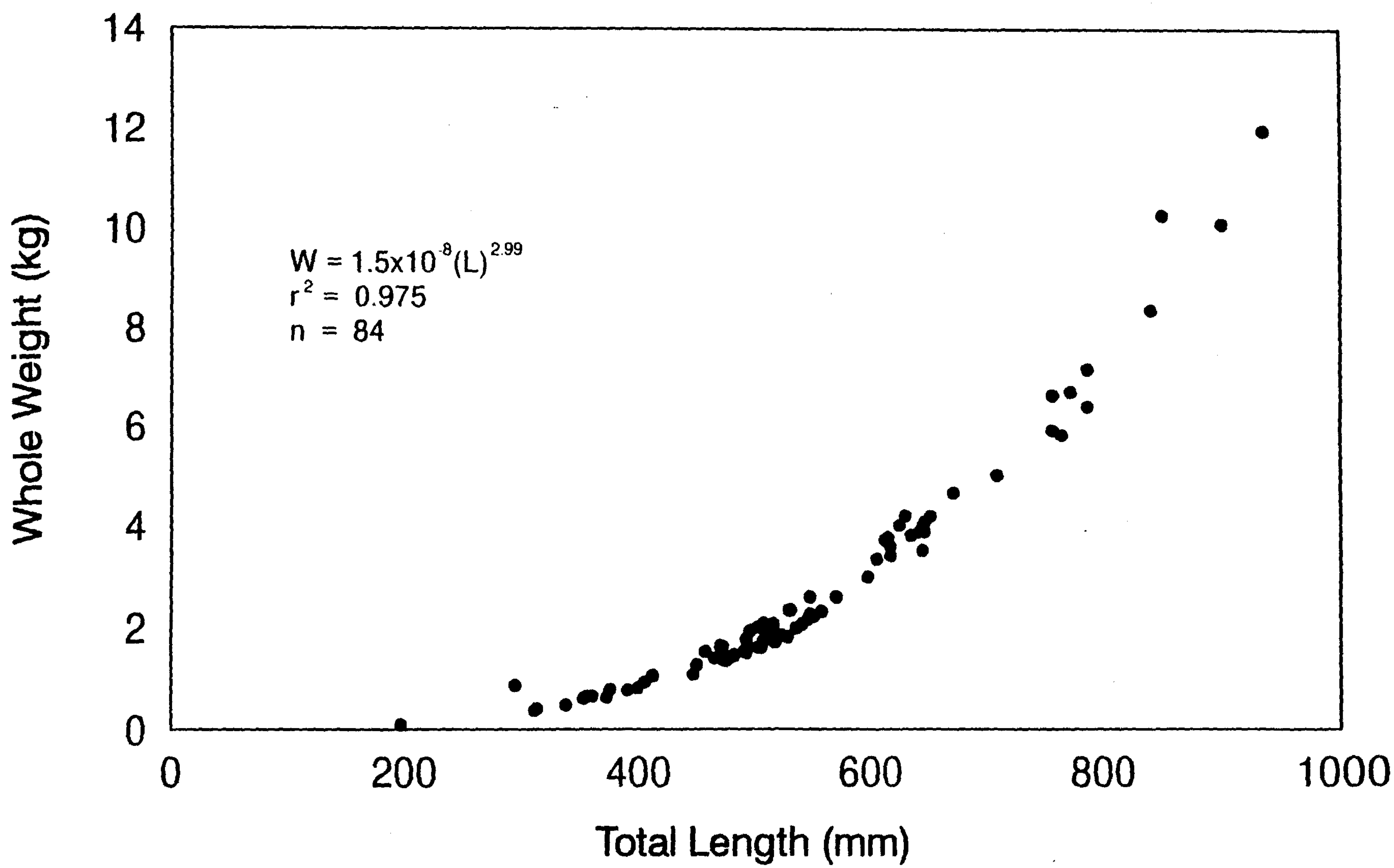


Figure 19. Total length (mm) - whole weight (kg) relationship for red snapper from the U.S. South Atlantic.



fish lengths: TL = -3.21 + 1.08 (FL) ($N = 240$; $r^2 = 0.99$); TL = 10.26 + 1.24 (SL) ($N = 203$; $r^2 = 0.99$); and FL = 11.67 + 1.15 (SL) ($N = 203$; $r^2 = 0.99$), where FL = fork length in millimeters, and SL = standard length in millimeters (Figure 20).

Fish Age-Fish Length Key

Fish lengths at time of capture were used to tabulate an age-length key (Table 23). The table is easy to interpret. As an example, red snapper that were 175-199 mm total length at capture, indicated by the 175 size interval, were all (100%) age 1 fish.

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

Annual application of the catch-in-numbers-at-age matrix equation (see Methods section) to each fishery (commercial, recreational, and headboat) was performed separately and tabulated for each year to obtain annual estimates of catch in numbers for different ages for 1986-1995. This is the catch matrix. The same technique was applied to the SCDNR fishery independent, Chevron trap red snapper catch per unit effort and length frequency data.

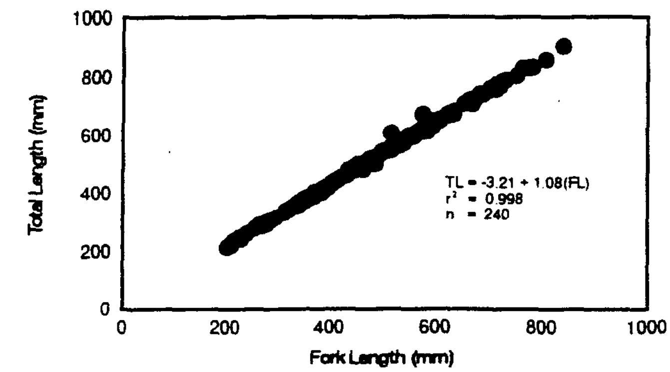
Mortality Estimates

Total Instantaneous Mortality (Z)

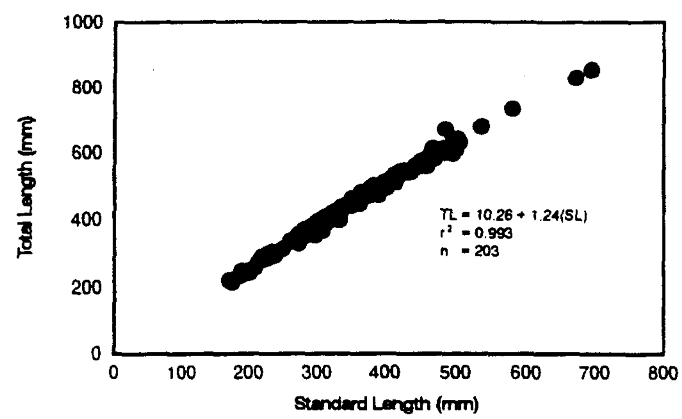
Catch curves using data for 1986-1991 were very different from those calculated for 1992-1995. We believe this to be mainly

Figure 20. Length relationships for red snapper from the U.S. South Atlantic.

a. Fork length - total length



b. Standard length - total length



c. Standard length - fork length

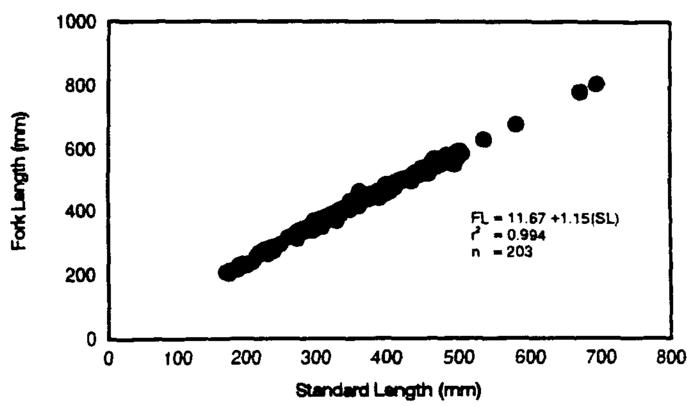


Table 23. Fish age - fish length key for red snapper from the U.S. South Atlantic.

	Age											
TL (mm)	1	2	3	4	5	6	7	8	9	10	11	12
175	1 (1.00)											
200	3(1.00)											
225		7(0.88)	1(0.12)									
250		1(1.00)										
275		6(0.60)	4(0.40)									
300		2(0.29)	5(0.71)									
325		1(0.08)	11(0.92)									
350			24(0.73)	9(0.27)								
375			21(0.41)	30(0.59)								
400			14(0.29)	34(0.71)								
425			1(0.03)	21(0.72)	7(0.24)							
450				15(0.48)	16(0.52)							
475				9(0.36)	14(0.56)	2(0.08)						
500				3(0.08)	29(0.76)	6(0.16)						
525					15(0.60)	10(0.40)						
550					12(0.43)	13(0.46)	3(0.11)					
575					2(0.10)	9(0.45)	9(0.45)					
600						21(0.57)	13(0.35)	3(0.08)				
625						5(0.18)	18(0.67)	4(0.15)				
650						8(0.40)	8(0.40)	4(0.20)				
675						1(0.17)	3(0.50)	2(0.33)				
700							8(0.73)	1(0.09)	2(0.18)			
725							1(0.12)	4(0.50)	2(0.25)	1(0.13)		
750								3(0.27)	3(0.27)	4(0.37)		1(0.09)
775								1(0.10)	2(0.20)	1(0.10)	5(0.50)	
800											1(0.17)	
825											1(0.12)	2(0.25)
850												
875												
900												
925												

Continued

Table 23. Continued

TL (mm)	Age 13	14	15	16	17	18	19	20	21	22	23	24	25
175													
200													
225													
250													
275													
300													
325													
350													
375													
400													
425													
450													
475													
500													
525													
550													
575													
600													
625													
650													
675													
700													
725													
750													
775		1(0.10)											
800	3(0.50)	2(0.33)											
825		3(0.38)	1(0.13)	1(0.12)									
850	1(0.25)	1(0.25)			1(0.25)			1(0.25)					
875				1(1.00)									
900								2(0.67)			1(0.33)		
925													1(1.00)

attributable to minimum size regulation differences for the two time periods. Smaller (younger) fish could be landed in the earlier period than the later.

Catch curves for 1986-1991 were based on red snapper aged 2-12 years; those produced for 1992-1995 were based on fish aged 6-12 years (Figures 21 and 22). Therefore, total instantaneous mortality estimates were very different for the two periods: Z = 0.48 for 1986-1991; and Z = 0.76 for 1992-1995; using the last years only.

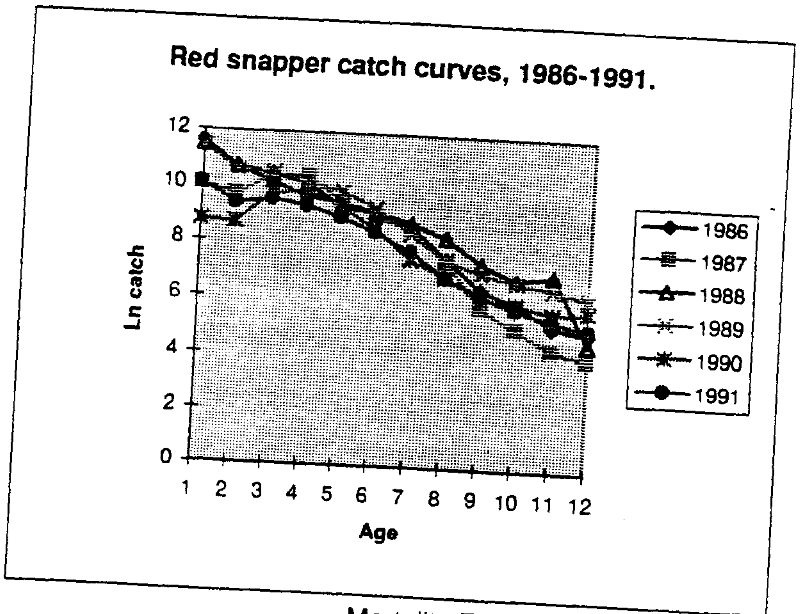
Natural Mortality (M)

There is often great uncertainty in deriving a value for natural mortality, M. Yet this is an important parameter input into stock assessment analysis, and ultimately dictates the selection of the initial values of fishing mortality, F, to be used in the analyses. Caution suggests using a range of possible values for M in the analyses, and that is what we have done in this assessment. We estimated natural mortality using several methods, and then four values were chosen as a range to use in the VPA runs. Methods used to estimate M and their resulting values are:

Hoenig (1983) - original equation -	0.17
adjusted for sample size -	0.30
Pauly (1979) -	0.33
Roff (1984) -	0.31, 0.43
Rikhter and Evanov (M. Burton, pers. comm) -	0.32
Alverson and Carney (1975) -	0.15

Both Hoenig (1983) and Alverson and Carney (1975) use maximum

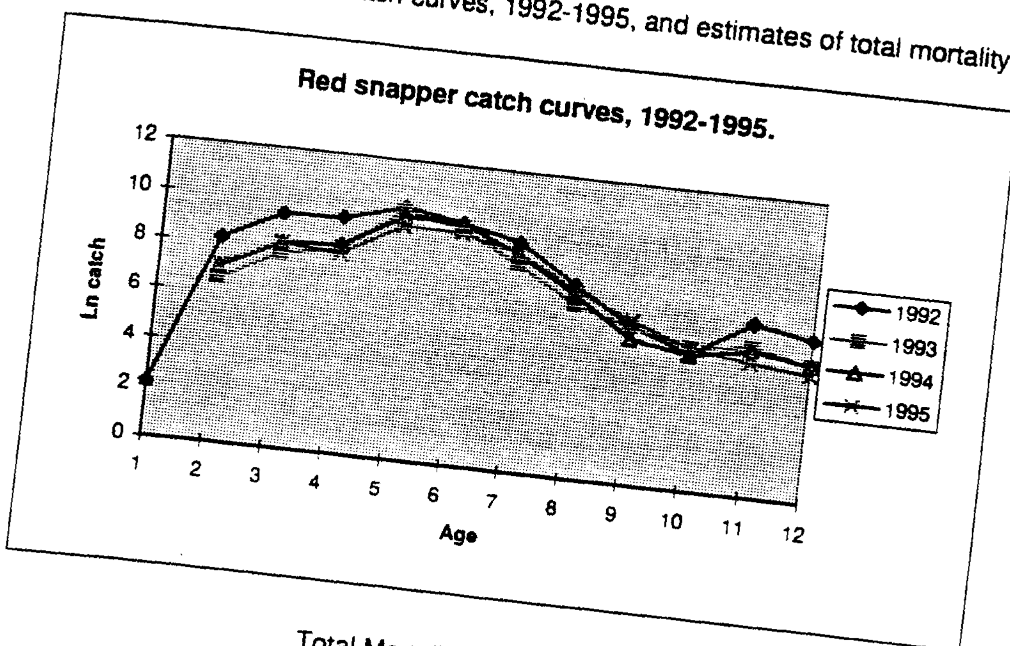
Fig. 21. Red snapper catch curves, 1986-1991, and estimates of total mortality (z).



Mortality Estimates

Year	Ages 1- 12
1986	0.6
1987	0.62
1988	0.52
1989	0.5
1990	0.39
1991	0.48

Fig. 22. Red snapper catch curves, 1992-1995, and estimates of total mortality (z)



Total Mortality Estimates

Year	Ages 6-12
1992	0.59
1993	0.64
1994	0.73
1995	0.76

age in their equations for calculating M. Using a maximum observed age of 25 years from this study, the two methods return similar values of M. The Hoenig method relating maximum observed age to total mortality and sample size returns a higher value of M = 0.30. This method assumes random sampling. Since most of the samples from this age-growth study came from the South Atlantic headboat survey and the NMFS commercial sampling program, we feel this assumption is met. The Hoenig estimates are really estimates of Z (assuming absence of fishing), though, and therefore the true value of M would be less than 0.30.

Our value for the Pauly (1979) estimate of M compares favorably with the values obtained by Nelson and Manooch (1982) for east Florida (0.34) and the Carolinas (0.35). Our mean seawater temperature input into Pauly's (1979) equation was 21.95° C.

Roff (1984) predicts M using the Brody growth coefficient K and the age at maturity. He does not define age at maturity, so we used ages corresponding to both 50% and 75% maturity. It seems unlikely that a fish with a maximum age of at least 25 years would have a natural mortality value as high as the Roff (1984) method estimate of 0.43 returned using 50% maturity. The value of 0.31 returned by using a age at 75% maturity agrees more closely with estimates derived by other methods.

Our estimates of M generally fall into the range 0.15 to 0.33. It seems unlikely that a fish with a lifespan of 25 or more years has an M greater than 0.30. Goodyear (1995) references a red snapper from the Gulf of Mexico with an age of 53 years, driving his estimates of M using Hoenig's (1983) equation down to M = 0.078. We have no evidence to suggest that we have fish this old in the South Atlantic Bight. However, it seems unlikely that the true value of M exceeds our upper estimate, approximately 0.35. We therefore choose to run the analyses with a range of values for natural mortality including 0.15, 0.20, 0.25, and 0.30.

Fishing Mortality (F) and Virtual Population Analysis (VPA)

For the separable VPA runs, two catch matrices were analyzed consisting of catch in numbers for ages 1 through 12 for fishing years 1979-1991 (modal age generally 1) and ages 2 through 12 for 1992-1995 (modal age 5). For the SVPA, starting values for F were based on the estimates of Z from the final fishing year of each catch matrix (0.48 yr^{-1} for 1991 and 0.76 yr^{-1} for 1995) and final F obtained by subtracting M from Z. Sensitivity of estimated F to uncertainty in M was investigated by conducting the above VPAs with alternate values of M (0.15, 0.20, 0.25, and 0.30). A starting partial recruitment vector for FADAPT was based on the SVPA run for the period 1992-1995.

Because of the short duration of the catch matrix and large number of ages, mean values only for the pre- and post-minimum size limit are considered. Mean values of age-specific estimates of F were obtained from the separable VPA applied to the catch at age data (Table 24) using the uncalibrated separable (SVPA). The calibrated approach used MARMAP catch-per-effort (CPE) from the Chevron trap that was broken into age-specific values comparable to

Table 24. Spawning potential ratio (SPR) and yield per recruit (Y/R) of female red snapper based on mean age-specific fishing mortality rates for two time periods (1986-1991 and 1992-1995) from separable virtual population analysis.

		Natural Mortality (M)			
Time Period		0.15	0.20	0.25	0.30
1986-91	Full F	0.48	0.43	0.37	0.31
	SPR	0.03	0.05	0.09	0.15
	Y/R (lbs)	0.87	0.78	0.70	0.61
1992-95	Full F	0.69	0.63	0.57	0.50
	SPR	0.11	0.11	0.24	0.32
	Y/R (lbs)	2.21	1.50	1.32	0.99

development of the fishery-dependent catch matrix (Table 25). FADAPT requires input of the age-specific availability of each age in the 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 were averaged over fully-recruited ages (ages 2-12 for 1986-1991 and ages 6-12 for 1992-1995), weighted by catch in numbers for those ages (referred to as full F).

Using the uncalibrated separable approach (SVPA) with M of 0.25, mean estimates of full F (ages 2+) tended to be lower for the period 1986-1991 (mean of 0.37 for full F) compared to the period 1992-1995 (mean of 0.57 for full F) (Table 24). Recruits to age 1 are higher for the earlier period, with the FADAPT estimates showing a much greater drop in recruitment for the recent time period.

Yield Per Recruit

Yield-per-recruit increased for the later years due to the imposition of the minimum size limits. Data are presented graphically in Figures 23-26. We incorporated an adjustment for released fish mortality to determine what impact this would have on yield at entry to the fishery. Two values, 25% and 10%, provided by NMFS researchers (Bob Dixon and Pete Parker, NMFS, Beaufort Laboratory, Beaufort, NC), were used and neither had an impact on recruitment.

Table 25. Catch-at-age matrix of red snapper from the U.S. South Atlantic.

Year/Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17+
1986	106719	42160	25307	14986	12834	9281	5828	1834	626	404	184	152	432	432	37	928	1512
1987	21831	15924	32499	30801	13052	8112	5016	1683	330	163	81	61	247	296	22	541	1714
1988	92410	43086	33524	23889	10520	9281	6465	3897	1603	938	1119	104	171	372	7	209	2589
1989	90030	38697	35088	24535	19186	10975	4316	1787	1139	846	682	507	827	1293	189	824	1060
1990	6065	5849	16679	18160	10803	5065	1770	957	462	398	291	323	427	734	130	242	1201
1991	23347	11508	13554	10792	7341	4472	2376	942	514	314	226	177	231	365	64	419	1222
1992	9	3697	11956	12984	25702	16986	9947	2287	565	241	1021	666	2207	2533	320	1681	1126
1993	0	706	2371	3636	22150	13098	4052	1080	540	295	405	226	714	779	92	594	1243
1994	0	1153	3711	4231	17488	16706	6039	1572	339	223	340	238	679	784	102	670	817
1995	0	1240	3643	3012	11805	11051	6323	1842	723	303	209	162	412	518	67	418	937

Figure 23. Ricker Yield per Recruit for Red Snapper, U.S. South Atlantic:

Based on Separable VPA from 1986-1991 (M=0.25)

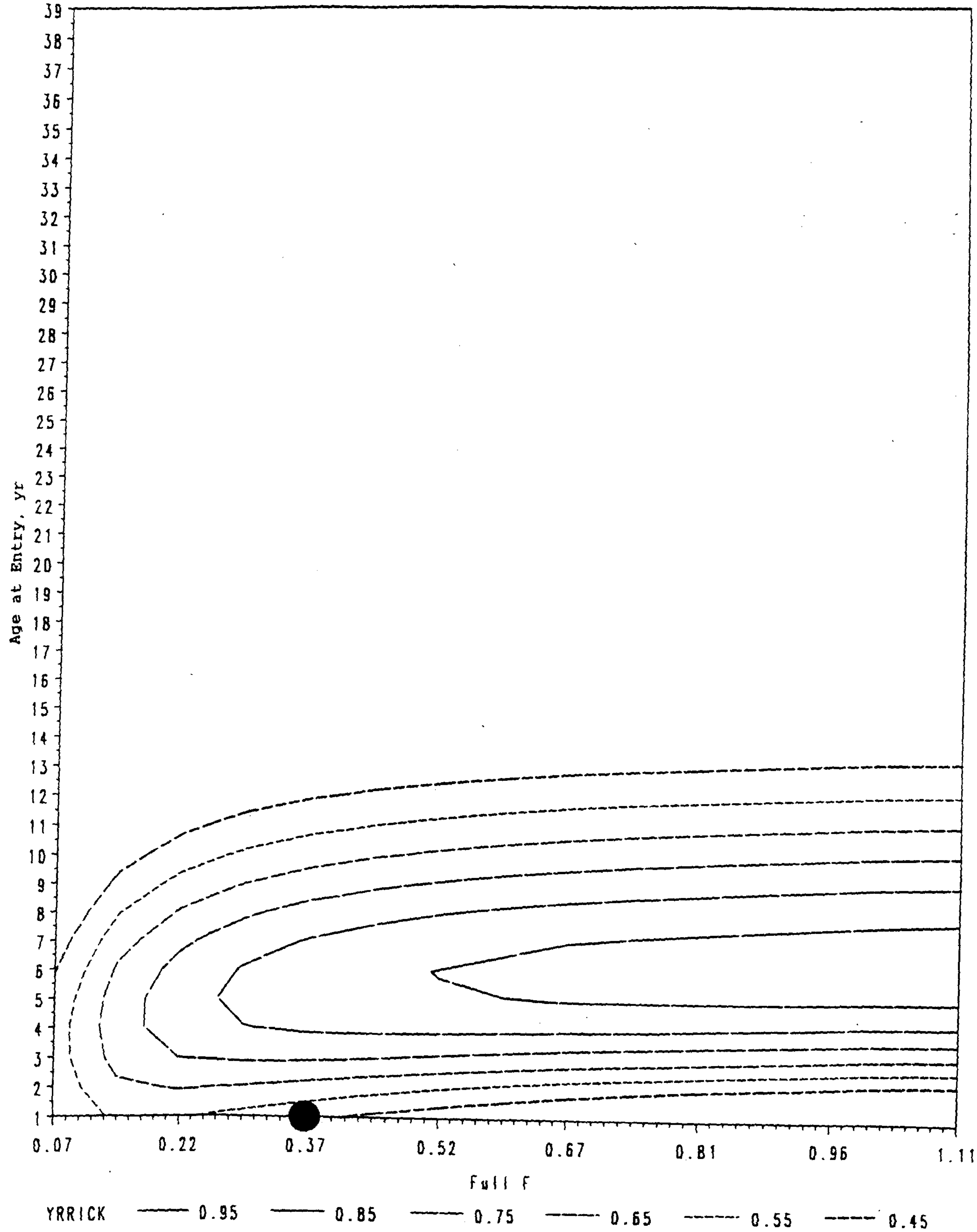


Figure 24. Ricker Yield per Recruit for Red Snapper, U.S. South Atlantic:

Based on Separable VPA from 1986-1991 (M=0.30)

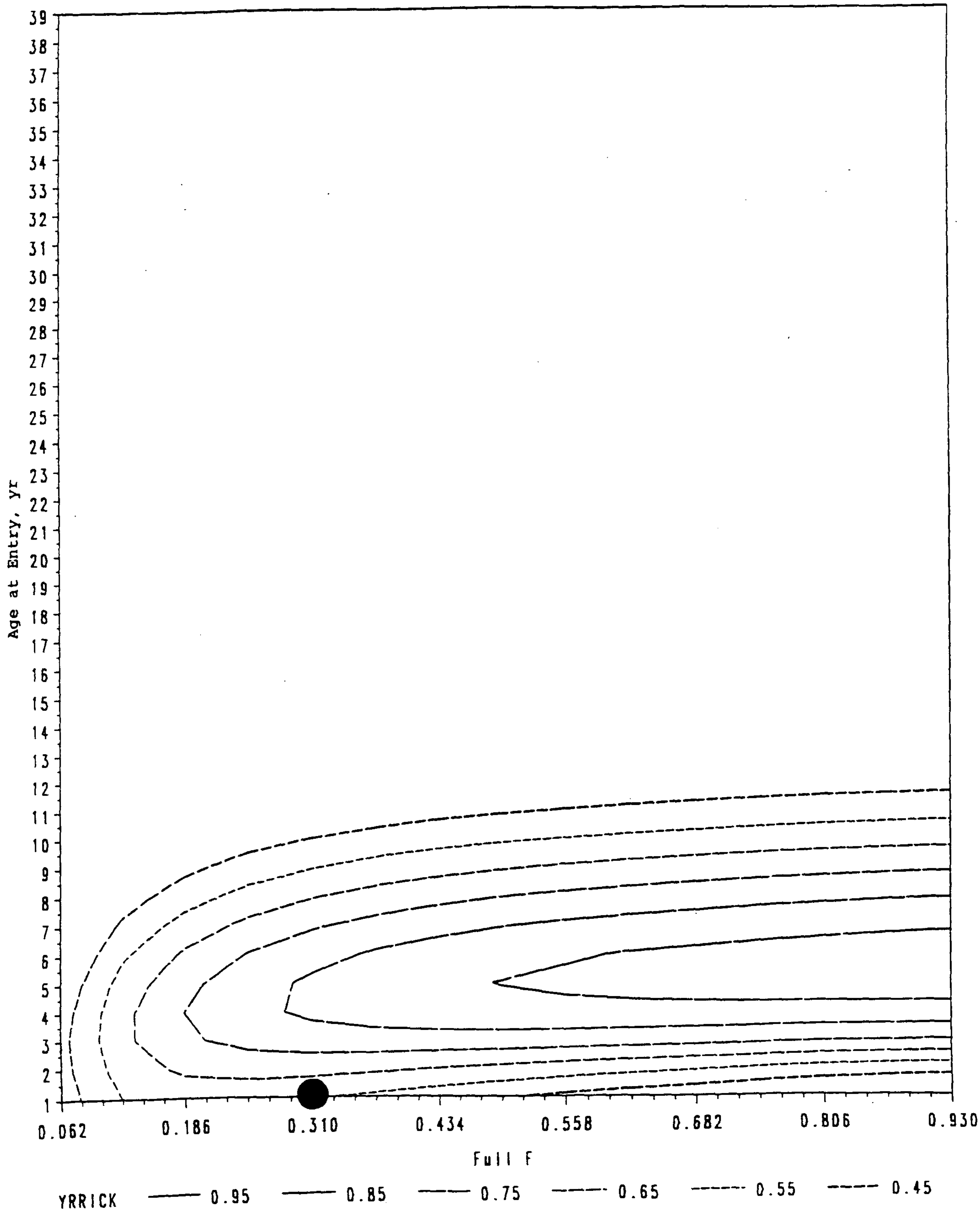


Figure 25. Ricker Yield per Recruit for Red Snapper, U.S. South Atlantic:

Based on Separable VPA from 1992-1995 (M=0.25)

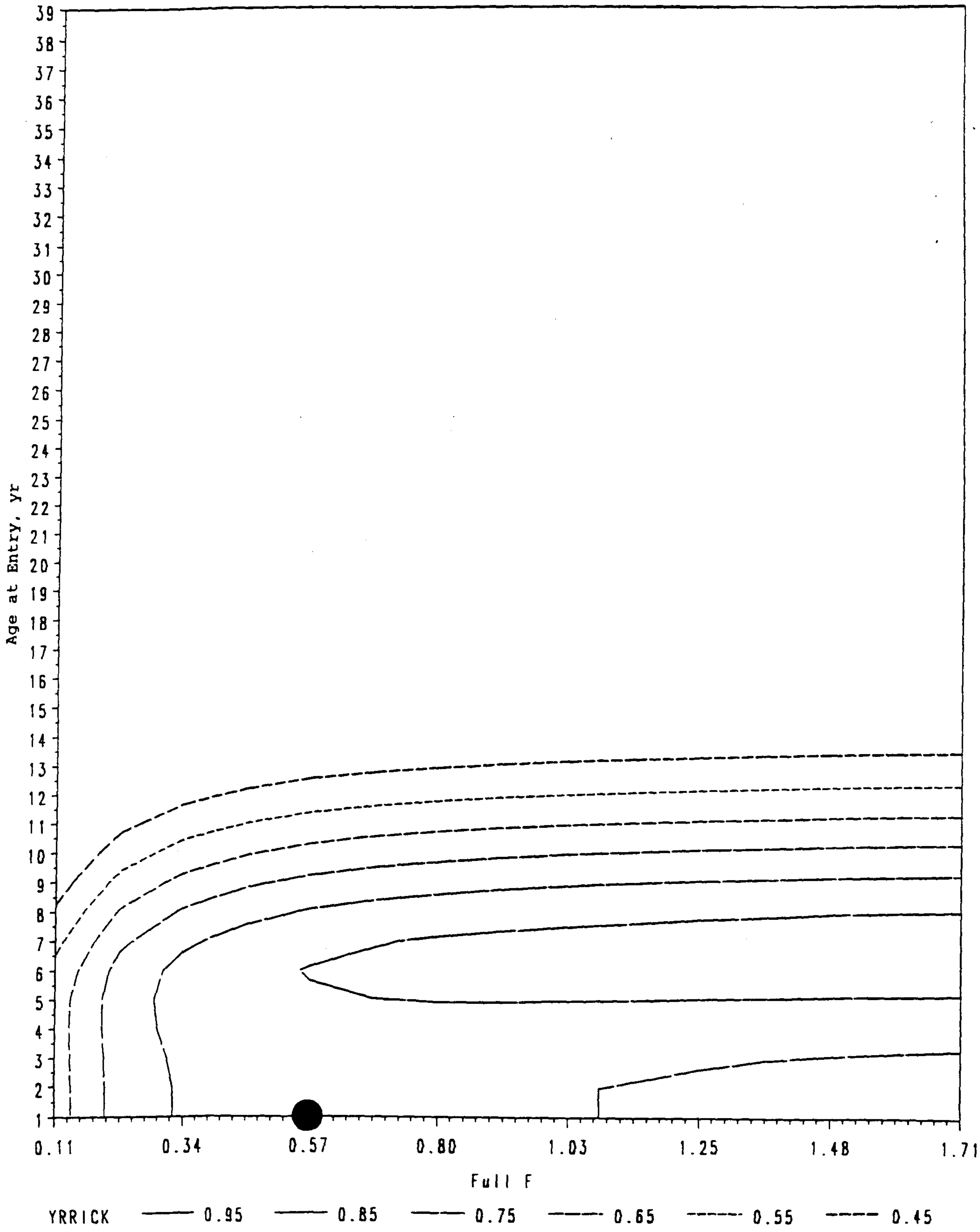
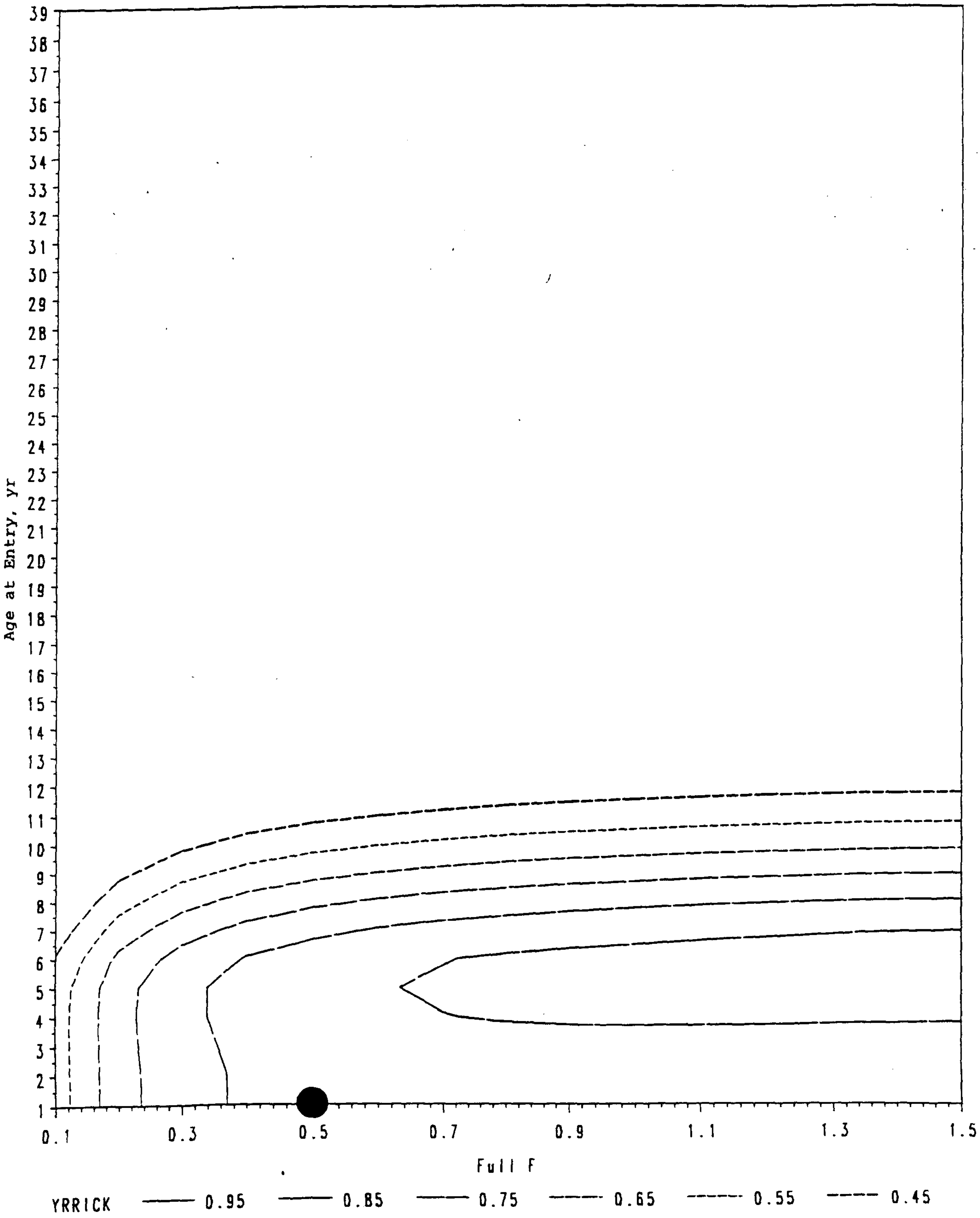


Figure 26. Ricker Yield per Recruit for Red Snapper, U.S. South Atlantic:

Based on Separable VPA from 1992-1995 (M=0.30)



Spawning Potential Ratio

We received red snapper reproductive data from SCDNR personnel collected throughout the year for 1988-1995. A total of 324 fish were collected by hook and line and fish traps; 276 could be sexed. Of the sexed fish, 127 (46%) were males, and 149 (54%) were females, essentially a 1:1 ratio. The smallest sexually mature female was 350 mm TL. The sexual maturity schedule by age for females is 0% at age 1; 0% at age 2; 30% at age 3; 74% at age 4; and 100% at age 5. All female red snapper age 5 and older are considered mature in this assessment.

Spawning potential ratio, or percent maximum spawning potential, of female red snapper was calculated for two time periods (1986-1991 and 1992-1995) based on mean age specific fishing mortality from separable virtual population analysis using four different levels of natural mortality (M = 0.15, 0.20, 0.25, and 0.30) (Table 24). Percent maximum spawning potential was greater for the more recent time period, particularly for M = 0.25, and M = 0.30 (Figures 27-30).

Estimates of equilibrium spawning potential ratio (static SPR) using estimated F (Table 24) from the two VPA approaches are summarized by time period and assumed level of M (Table 24). Using separable VPA estimates of F (with M of 0.25) for two periods, SPR estimates based on female biomass are compared (Table 24). Note that even though full F may be higher for the latter

Figure 27. Spawning Stock Ratio for Red Snapper, U.S. South Atlantic:

Based on Separable VPA from 1986-1991 (M=0.25)

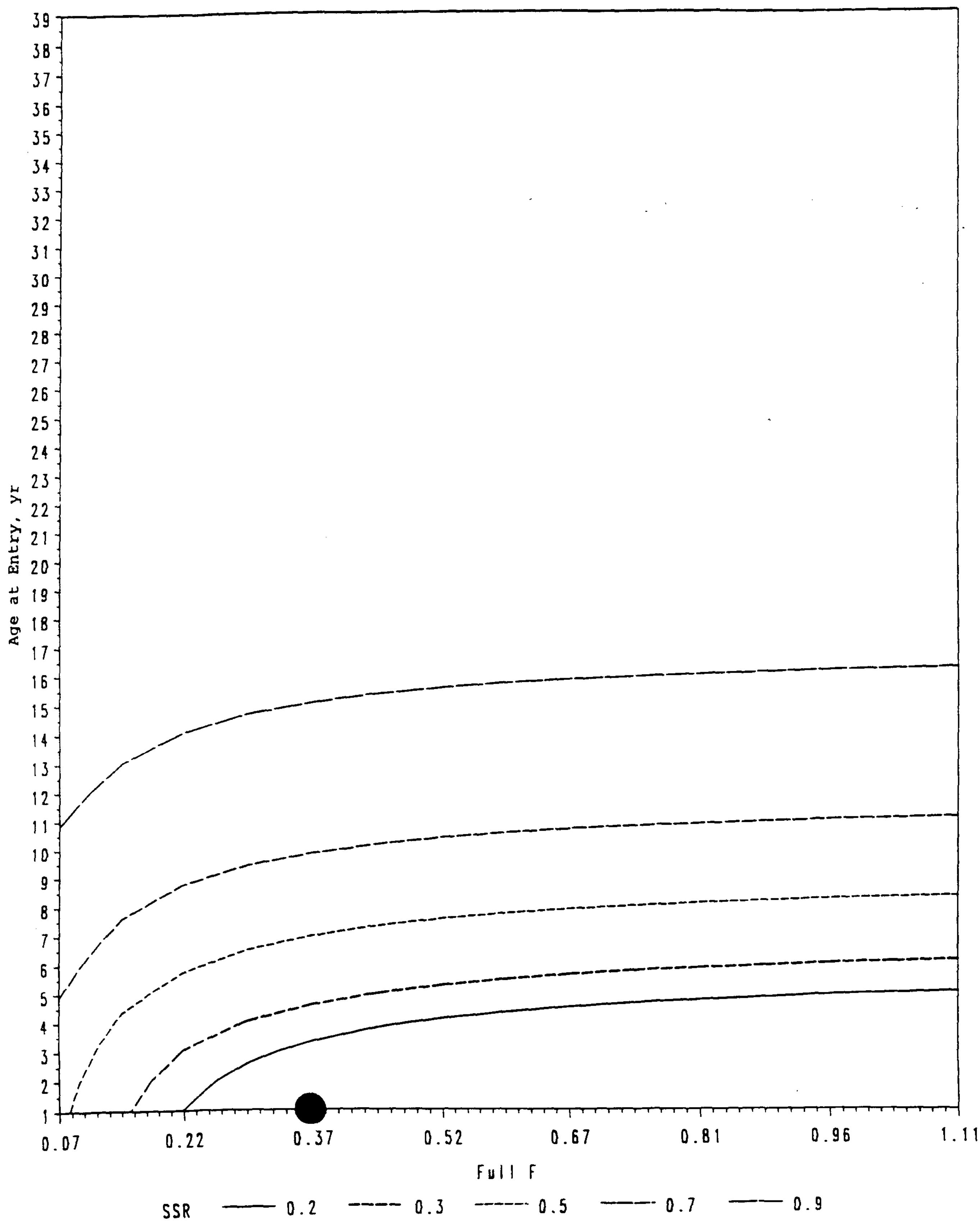


Figure 28. Spawning Stock Ratio for Red Snapper, U.S. South Atlantic:

Based on Separable VPA from 1986-1991 (M=0.30)

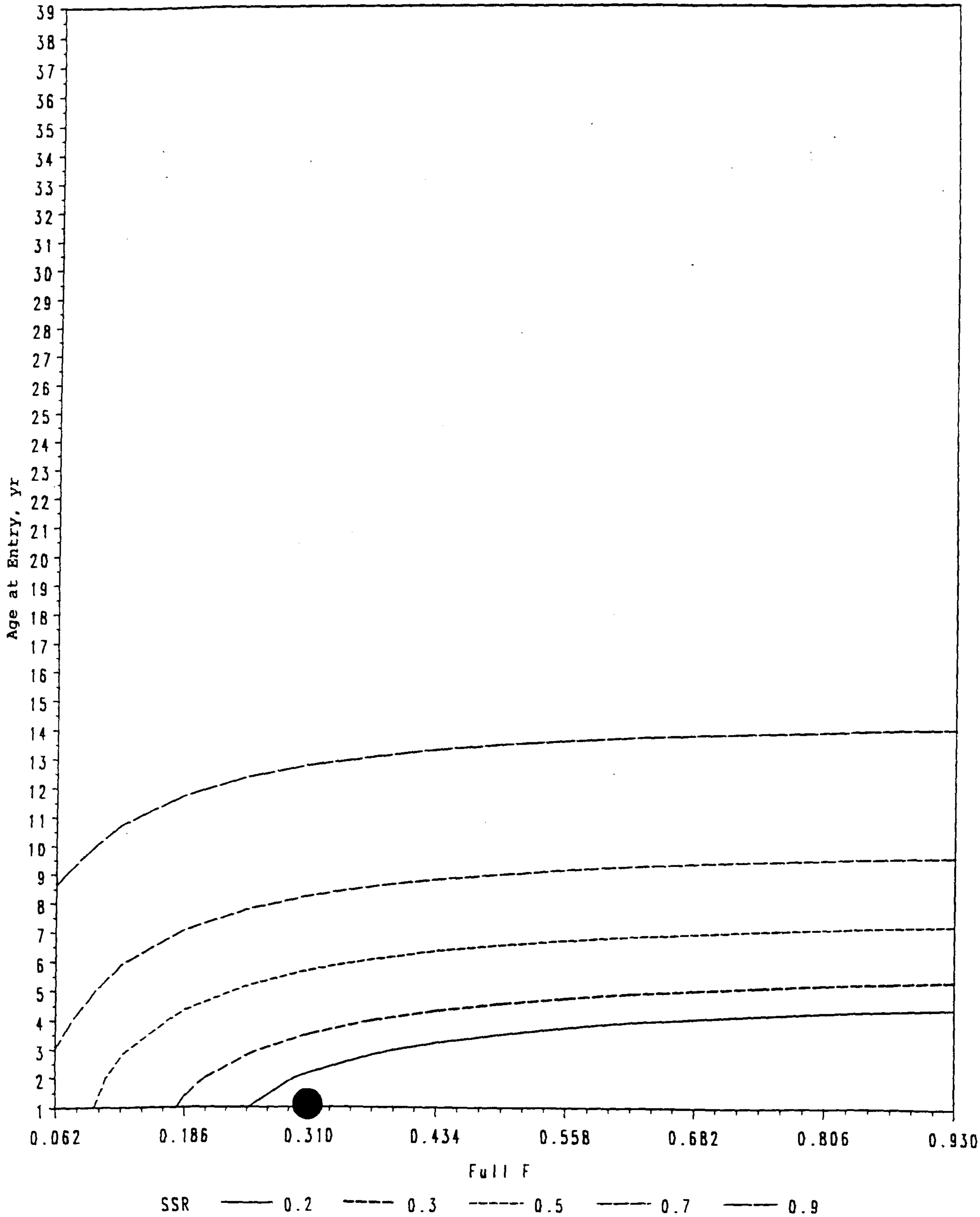


Figure 29. Spawning Stock Ratio for Red Snapper, U.S. South Atlantic:

Based on Separable VPA from 1992-1995 (M=0.25)

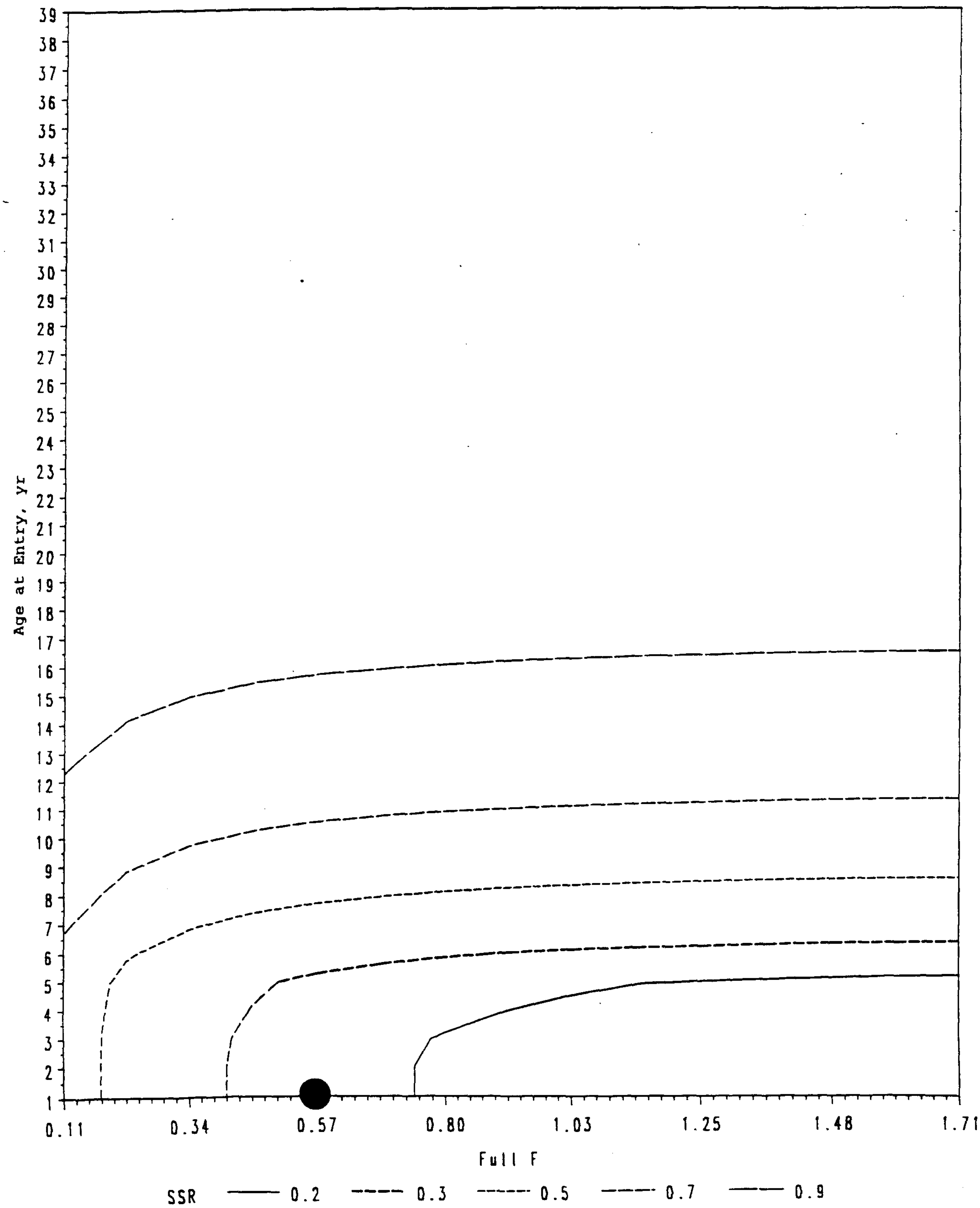
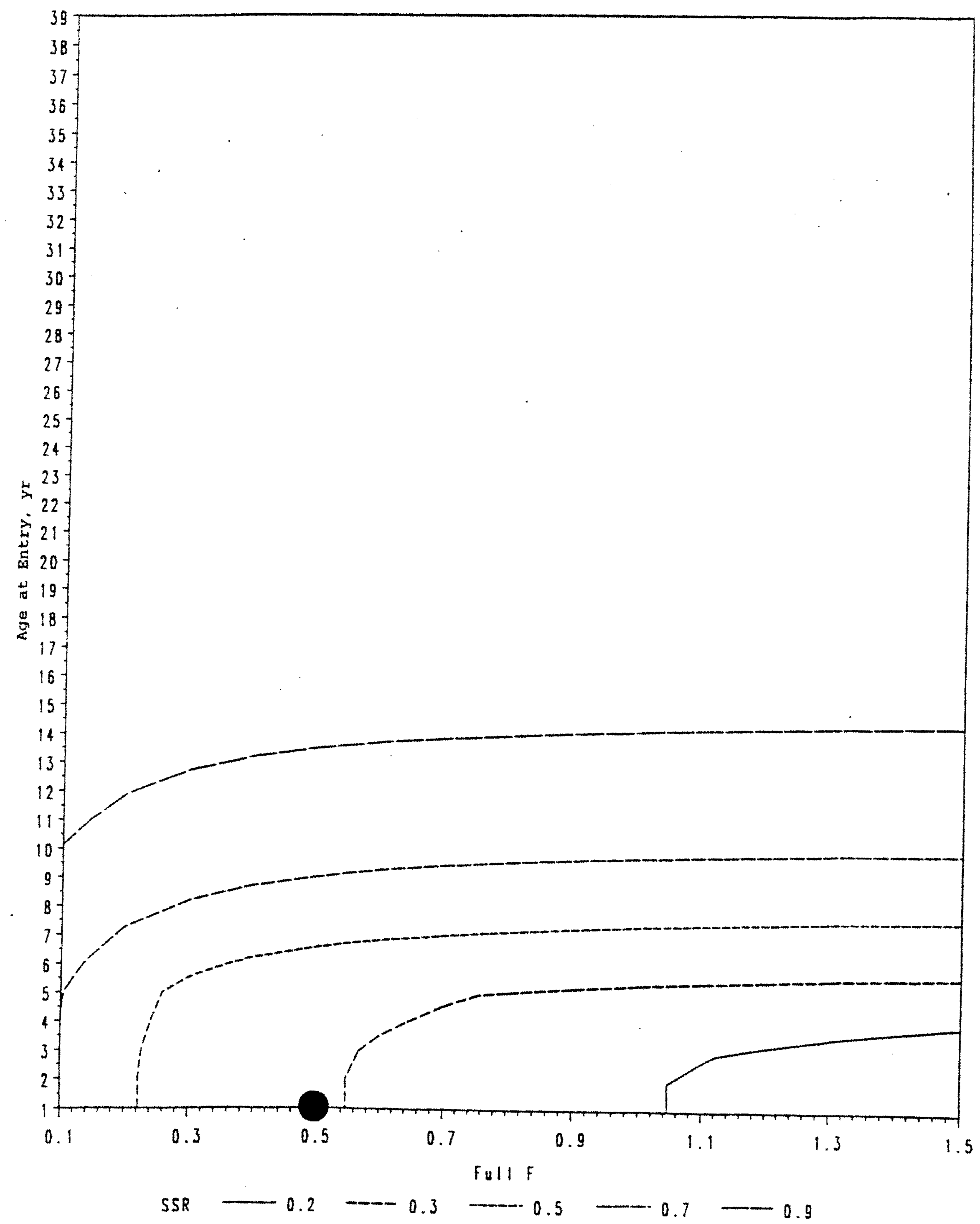


Figure 30. Spawning Stock Ratio for Red Snapper, U.S. South Atlantic:

Based on Separable VPA from 1992-1995 (M=0.30)



time period, it is applied to fewer older ages, so that SPR is actually lower.

CONCLUSIONS

We believe that the MRFSS size-freqency sampling is very limited (see Table 3), and yet may be driving this assessment. We consider the numbers reported landed for recreational anglers to be unusually high, and may over-estimate the landing of smaller (younger) fish. This would tend to underestimate the value of M.

The overall commercial landings have trended downward from mid-70s to the present time (Table 4). However, this decline may reflect management regulations, economic factors, industry attrition, effort, etc. rather than actual abundance of red snapper.

Headboat landings (overall, Fig. 2) are not as high now as they were in 1985 and 1988, but have increased from 1992-1995. Minimum size and bag limit regulations have undoubtedly influenced the landings.

MRFSS catches remain low since 1989 (Table 6).

Headboat CPE (overall) has dropped since 1981 and remains low (Fig. 3). This gives the appearance of declining abundance, but probably reflects the imposition of minimum size and bag limit regulations.

MRFSS CPE values are down from 1989-1991. They rebounded from

1992-1994, and then trended downward again in 1995 (Table 12).

MARMAP CPE could not be used in this assessment (Table 13).

The mean fish sizes from commercially-caught red snapper have increased since 1990 (Table 14; Fig. 8). However, this condition is probably influenced by larger minimum size and bag limit regulations. In any case, this is a positive sign.

Headboat mean sizes (overall) are up since 1989 (Table 15; Fig. 9), particularly GA-NEFL. Another good sign, but influenced by size and bag limit regulations.

MRFSS mean sizes are generally up since 1989 (Table 20; Fig. 14); down slightly in 1995.

We identified 25 age groups, but few fish older than age-12 were landed.

Total instantaneous mortality (Z) was 0.48 for 1991 and 0.76 for 1995. The increase for the later time period reflects more fishing pressure on the larger (older) red snapper because of imposed size and bag limits.

We derived spawning stock ratio (SPR) values using natural mortality (M) values of 0.15, 0.20, 0.25, and 0.30. We believe that natural mortality is probably over 0.20, but not over 0.30.

We found that SPR equals 0.24 for a M of 0.25 for the period 1992-1995, and SPR equals 0.32 for an M of 0.30 for 1992-1995.

We conclude that the red snapper stock is in a "transitional" condition. That is, the status of the stock is less than desirable, but does appear to be responding for the better to something, possibly management, in the most recent years.

ACKNOWLEDGMENTS

We would like to express our appreciation to Jack McGovern, SCDNR, Charleston SC, for providing otolith samples and MARMAP fishery-independent and reproduction data, and Alan Collins, NMFS, Panama City Laboratory, Panama City, FL for sending us data pertaining to red snapper reproduction. Our thanks are extended to Joe Powers, NMFS, Miami, FL, for providing comments on a draft of the document. We are particularly grateful to Paula Moon, Reef Fish Team port sampler stationed in Wilmington, NC, for constructing many of the tables and figures presented in this report.

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