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Abstract

Changes in the age structure and population size of red snapper, *Lutjanus campechanus*, from North Carolina through the Florida Keys were examined using records of landings and size frequencies of fish from commercial, recreational, and headboat fisheries from 1986 to 1995. Population size in numbers at age was estimated for each year by applying separable virtual population analysis (SVPA) to the landings in numbers at age. SVPA was used to estimate annual, age-specific fishing mortality (F) for four levels of natural mortality (M=0.15, 0.20, 0.25, and 0.30). Although landings of red snapper for the three fisheries have declined, minimum fish size regulations have also resulted in an increase in the mean size of red snapper landed. Age at entry and age at full recruitment were age-1 for 1986–1991, compared with age-2 and age-6, respectively, for 1992–1995. Levels of mortality from fishing (F) ranged from 0.31 to 0.69 for the entire period. Spawning potential ratio (SPR) increased from 0.09 to 0.24 (M=0.25) from 1986 to 1995. The SPR level could be improved with a decrease in F, or an increase in age at entry to the fisheries. The latter could be enhanced now if fishermen, particularly recreational fishermen, comply with minimum size regulations.

Keywords: Stock assessment; Red snapper; Southeastern United States

1. 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. Although the species is important to the commercial fisheries of South Carolina, Georgia, and northeast Florida, with the exception of Georgia, it seldom ranks among the 10 most important marketed species to commercial fishermen of the southeastern United States (Linda Hardy, NMFS, Beaufort Laboratory, pers. comm.).

The species is distributed throughout the Gulf of Mexico and along the Atlantic coast to North Carolina, sometimes to Massachusetts. Red snapper occur throughout the Exclusive Economic Zone (EEZ) and territorial seas, and are an important component of the catch in the deeper shelf waters. Off the southeastern United States, the red snapper typically occurs in depths of 50–100 m over both low- and high-relief hard bottom.

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Lutjanus campechanus is an opportunistic bottom feeder that consumes a variety of invertebrates and small fishes. The species is gonochoristic, and sexual maturity occurs as early as the second year of life (South Atlantic Fishery Management Council, 1983). Spawning extends through the warmer months, beginning as early as April off North Carolina, and in the Gulf of Mexico spawning usually extends from May through September (South Atlantic Fishery Management Council, 1983). The spawning grounds of the species are not well known, although fishermen off Texas reported ripe females at depths of 37 m. Two spawning areas off Panama City, FL, were found at water depths between 18–37 m (South Atlantic Fishery Management Council, 1983). Females as small as 250 mm and males 225 mm have been documented as sexually mature. The free-floating eggs have been hatched in the laboratory in 24–27 h, and the larvae feed 3 days after hatching (Manooch, 1984). The species is relatively slow growing, but may exceed 955 mm in total length and an age of 25 years (Manooch and Potts, 1998).

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 (South Atlantic Fishery Management Council, 1983) includes discussions of the species, no separate stock assessment has been made for the red snapper along the southeastern United States.

In this study, we 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 as indices of the status of the southeastern U.S. red snapper stock.

2. Methods

2.1. Landings

For purposes of this study, 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 the fishery, only data from 1986 to 1995 were available for all the three fisheries. Landings were used with fish length at age information derived by Manooch and Potts (1998) to develop an age–length key and in turn a catch-in-numbers-at-age matrix.

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 (CPE) 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).

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 ton of that species landed (U.S. Department of Commerce, 1996). We computed the proportional standard error (PSE=100×SE/mean number of fish), which expresses the standard error in percent. It provides a measure of precision of an estimate. PSE values $\leq$20% are deemed acceptable by the U.S. Atlantic States Marine Fisheries Commission (ASFMC) and the U.S. National Marine Fisheries Service (NMFS), Marine Recreational Fisheries Statistical Survey (MRFSS) (David van Voorhees, NMFS, Silver Spring, MD, pers. comm.).

2.2. Age–growth

Growth parameters, length–length conversions, weight–length relationship, and a fish age–fish length key were obtained from a recent study of red snapper (Manooch and Potts, 1998).

2.3. 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) database (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 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) (Manooch and Potts, 1998) by a length frequency distribution (L, vector) to obtain the catch in numbers by fish age (N, vector: $N_{a\times 1} = n \cdot A_{a\times b} \cdot \mathrm{L}_{b\times 1}$ (Vaughan et al., 1992)), where a is the number of ages (1–25 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 (from the General Canvas) by mean weight of the fish landed (from TIP) 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 (Manooch and Potts, 1998) with length frequency data to calculate mean weight per red snapper for that fishery for each year.

2.4. Total instantaneous mortality (Z)

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 (i.e., constants M, F, and recruitment) were obtained by regressing the natural log of the catch in numbers against age for fully recruited fish (ages 1–12, or 6–12, depending upon the time period, 1986–1991 and 1992–1995). Few fish older than 12 years were landed.

2.5. Natural mortality (M)

Natural mortality (M) is often estimated from relatively weak life history and ecological analogies, yet is a very important step in determining the portion of total mortality attributed to fishing. Perhaps natural mortality is best estimated by using bioprofile characteristics as demonstrated by Pauly (1979) and later by Hoenig (1983). Pauly (1979) used two of the von Bertalanffy parameters ($\mathbf{L}_\infty$, and K, year^{-1}), as well as mean water temperature (T°C) of the general habitat:

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

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 min, 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, South Carolina, where data from 1995 were used for October to 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.

To estimate M, Hoenig (1983) utilized the maximum age (t_{max}) in an unfished stock, where:

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

Since this relationship is based on *Z*, rather than *M*, the maximum age in the virgin population (F=0; M=Z−F) provides 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

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

where t_c=first age fully represented in the catches.

We also estimated natural mortality with Roff's (1984) method, using optimal age at 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*.

2.6. Fishing mortality (F) and virtual population analysis (VPA)

Fishing mortality, *F*, was derived by subtraction, that is, F=Z−M. A problem arises from the equilibrium assumption of constant *F* and recruitment in catch curve analysis. In this assessment, age-specific fishing mortality rates, and estimates of red snapper age-specific population size were obtained by applying different VPA techniques to avoid this equilibrium assumption. Due to the short time frame of the catch matrix (1986–1995) relative to ages (1–13+), this was not completely successful, especially because two temporal periods (1986–1991 and 1992–1995) are required, due to the 508 mm 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 VPA approaches to obtain annual age-specific estimates of population size and fishing mortality rates. VPA 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 in applying this technique to the full-time period for 1986–1995 because of the imposition of a 508 mm minimum size limit just prior to the 1992 fishing year. Therefore, this technique was 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. Since this approach does not depend on a separability assumption it is applied to the entire catch at age history (1986–1995).

2.7. Yield per recruit

A YPR 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 fishery. Unlike the full-dynamic pool model (Beverton and Holt, 1957), the Ricker-type model only requires parameters that are easily derived *M*, *F*, *K*, $\mathbf{L}_\infty$, 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 YPR reacts to various levels of fishing effort). The above-mentioned parameters were estimated as discussed previously.

2.8. 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 for the Gulf of Mexico Fishery Management Council (see also Mace and Sissenwine, 1993; Mace, 1994). Equilibrium, or static, SPR was calculated as a ratio of spawning stock size when fishing mortality was equal to the currently observed or estimated F divided by the spawning stock size calculated when F is 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. Static, rather than transitional, SPR was used because there were more year classes (species aged to 25 years) than years in landings and biological sampling data (10 years).

The SAFMC defines SPR 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'' (South Atlantic Fishery Management Council, 1996). The SAFMC considers a stock to be overfished if the SPR is <0.30 (<30%), and is recovering with SPR values ranging from 0.30–0.39 (30%–39%). The target is to attain a SPR of 0.40 or greater (>39%) (Gregg Waugh, SAFMC, Charleston, SC, pers. comm.). 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 prepared 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 is by Collins et al. (1996) that presents total annual fecundity estimate equations for red snapper from the Gulf of Mexico. They also report a conversion equation, 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.

3. Results and discussion

3.1. Landings

We used an informal standard developed by the NMFS, Northeast Regional Stock Assessment Workshop (U.S. Department of Commerce, 1996) to determine the adequacy of biological sampling of red snapper landings (Table 1). 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 inadequate according to this criteria for five of 10 years (Table 1). Proportional standard errors (PSE) for U.S. South Atlantic red snapper generally ranged from 20% to 30%. Although these values are generally above the 20% criteria established by the ASFMC, they are probably sufficiently close to the 20% criteria value to be useful (Fig. 1). The sampling 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.

3.2. Trends in landings

Although historical commercial landings data are available from 1908, the most reliable and uninterrupted time series is from 1951 to 1995. Most red snapper were landed at ports along the East Coast of Florida. From 1951–1995, landings averaged about 227 mt with catches exceeding 454 mt in 1968 and 1982. Landings generally declined since 1982. For our assessment period, 1986–1995, commercial catches have averaged 83 mt and have not exceeded 90 mt since 1990. Landings from 1951–1985 averaged 272 mt. Some of the decrease in catches in recent years is attributable to regulations, such as that imposed in 1992 (508 mm minimum size; 10 snapper bag limit for recreational anglers with a daily

Table 1
Level of sampling per year by fishery (mt/100 length samples) for red snapper landed in the U.S. South Atlantic

Year	MRFSS		Headboat		Commercial and hook line	
	mt/No. of samples	Level	mt/No. of samples	Level	mt/No. of samples	Level
1986	51.5/226	22.8	24.7/434	5.7	98.4/999	9.8
1987	55.8/63	88.6	37.1/305	12.2	86.5/1174	7.4
1988	102.1/87	117.3	59.0/207	28.5	78.6/594	13.2
1989	121.9/22	**554.2**	32.1/377	8.5	120.6/1168	10.3
1990	52.3/18	**290.6**	29.8/434	6.9	97.8/790	12.4
1991	59.7/16	**372.8**	32.7/152	21.5	59.3/731	8.1
1992	280.2/17	**1648.2**	17.7/ 73	24.2	39.7/532	7.5
1993	60.3/23	**262.3**	19.4/203	9.5	83.8/1339	6.3
1994	75.4/38	198.4	19.5/563	3.5	82.1/976	8.4
1995	30.4/26	117.0	26.1/147	17.7	80.4/1069	7.5

Informal criteria is set at 200 mt/100 length samples (e.g. <200 mt/100 length samples, sampling is adequate; >200 mt/100 length samples, sampling is inadequate).

maximum of two red snapper) rather than abundance of the species.

Headboat data are available for all geographical areas, from 1982 to 1995. Landings averaged 30 mt for 1986–1995. Catches exceeded 50 mt in 1988. Catches generally increased since 1992 (13 mt in 1992 to 26 mt in 1995). Overall, commercial landings of red snapper are about three times greater than those reported by headboat anglers for 1986–1995.

Recreational fishing statistics are available for 1981–1995. During the 15 year period, the average recreational catch was 135 mt. Landings peaked in 1985 when approximately 605 mt were landed. This weight seems unrealistic. In fact the 15 year area-wide average is higher than that reported for vermilion snapper, *Rhomboplites aurorubens*, raising the possibility that some of the red snapper reported by the MRFSS were actually vermilion snapper. Since 1985 recreational landings have averaged 89 mt. There is no distinct trend in the landings over the past 10 years, except the 1995 catch of 30 mt was by far the lowest of record (Table 2). 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.

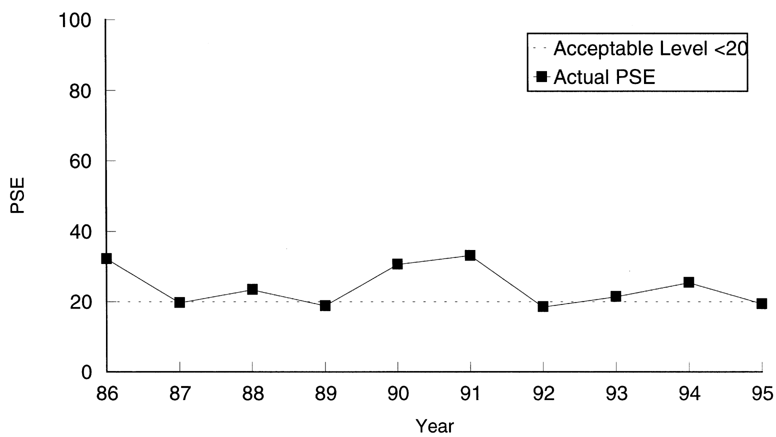

Fig. 1. Proportional standard error (PSE) from number of red snapper landed in the southeastern United States.

Table 2
Weight (mt) and number (10^3) of red snapper landed by the commercial, headboat, and other recreational (MRFSS) fisheries in the southeastern United States

Year	Commercial	Headboat	MRFSS	Total
Metric tons				
1986	102	25	51	178
1987	89	37	56	182
1988	80	59	102	241
1989	117	32	122	271
1990	91	30	52	173
1991	62	33	59	154
1992	43	13	280	336
1993	85	20	60	165
1994	86	20	75	181
1995	75	26	30	131
Thousands of fish				
1986	33	16	181	230
1987	35	25	63	123
1988	22	37	170	229
1989	40	23	169	232
1990	52	21	150	223
1991	22	14	46	82
1992	11	5	81	97
1993	33	7	16	56
1994	29	8	24	61
1995	21	8	14	43

3.3. Trends in catch/effort

Catch per unit effort (CPUE) data for the commercial data base are unavailable.

CPUE data for headboat anglers are available for 1972–1995 for North Carolina and South Carolina, and from 1982 to 1995 for North Carolina to the Florida Keys. CPUE values for the entire region are presented in Fig. 2 as number of red snapper per angler day. Catch rate has declined dramatically since 1981. Since 1985 CPUE has remained low, usually less than 0.2 fish per angler day. CPUE has improved slightly since 1992. It appears that regulations on minimum size and bag limits have reduced catch rates for the species.

Recreational CPUE data (MRFSS) are available for the southeastern United States from 1981 to 1995 (Fig. 2). 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 (9 fish/angler trip, remained relatively high (3–5

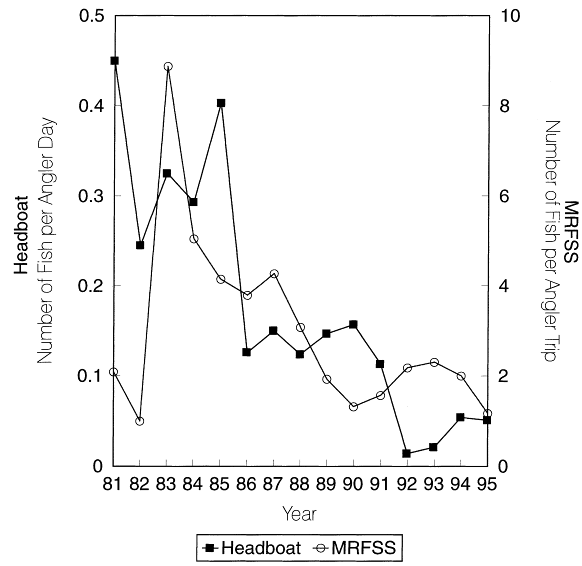

Fig. 2. Catch per unit effort in number of fish for the Georgia and northeast Florida headboat fishery and other recreational (MRFSS) fisheries operating in the southeastern United States.

red snapper/angler trip) from 1984–1988, and then declined to 1–2 fish per angler trip from 1989 to 1995.

From 1988 to 1996, South Carolina, Department of Natural Resources personnel made over 2200 sets of Chevron traps to capture reef fishes. This fishery independent gear was only marginally successful and caught 189 red snapper. These data offer limited value for the assessment.

3.4. Trends in mean weights

Mean size data are available for the commercial fishery from 1983 to 1995 and are presented in Fig. 3 as weight in kg. Mean size for red snapper was largest in 1983 (5.3 kg) and smallest in 1984 (1.8 kg); however, only North Carolina fish were sampled for those years. Mean size has generally increased since 1984, especially since 1990 (3–4 kg). It appears that 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.

The mean weights of red snapper caught by headboat anglers have generally increased since 1985 (Fig. 3), especially since 1991 for all geographic areas combined. This increase is most likely due to the

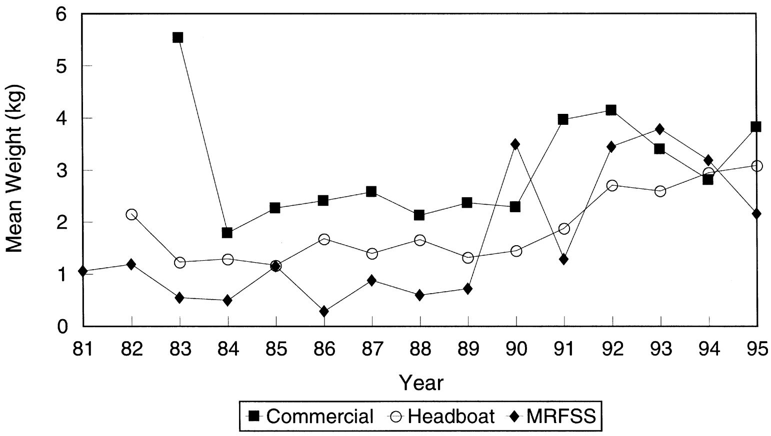

Fig. 3. Red snapper mean weight (kg) from the commercial, headboat (GA/NFL), and other recreation (MRFSS) fisheries operating along the southeastern United States.

size restrictions intended to reduce the harvest of smaller fish (508 mm minimum size was imposed in 1992). Mean weights, which were about 1.5 kg from 1983 to 1990, increased to about 3–4 kg from 1992 to 1995 (Fig. 3).

Mean size data are available for the recreational fishery from 1981 to 1995 (Fig. 3). Less than 20 red snapper were sampled in the entire southeastern United States for each of the years: 1990–1992 (N= 18, 16, and 17, respectively). Mean fish size for the area was remarkably small, averaging less than 1 kg from 1983 to 1989, except for 1985 (1.2 kg). Since 1991 the mean size has generally increased up to 3–4 kg (Fig. 3).

3.5. Age–growth

Age and growth information is based on Manooch and Potts (1998) study on red snapper because the last one for the species along the southeastern United States, written by Nelson and Manooch (1982), utilized fish collected almost 20 years ago. The aging data were updated to ensure that the best information available would be used in this population assessment. Red snapper were aged 1–25 years, although few fish lived longer than 12 years.

Back-calculated lengths from the last annulus for each age group (Vaughan and Burton, 1994) were used to derive the Bertalanffy growth equation $L_\infty=955$, $K=0.146$, $t_0=0.182$ (Manooch and Potts, 1998). The 95% confidence intervals for L_∞, K, and t_0, respectively are: 921–990; 0.134–0.159; and 0.011–0.353. Nelson and Manooch (1982) derived the following growth equation: $L_t=975(1-e^{-0.16(t-0.0)})$.

3.6. Weight–length

Fish lengths may be converted into fish weights and vice versa by the following equation: $W=1.5\times 10^{-8}(L)^{2.99}$ (N=84; r^2=0.97), where W=whole weight in kg and L=total length in mm (Manooch and Potts, 1998). Nelson and Manooch (1982) derived the equation, $W=2.04\times 10^{-5}\ TL^{2.953}$ for red snapper, where W=weight in gm.

3.7. Development of catch-in-numbers-at-age matrix

Annual application of the catch-in-numbers-at-age matrix equation (see Section 2) 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 (Table 3). This is the catch matrix. The same technique was applied to the SCDNR fishery independent, Chevron trap red snapper CPUE and length frequency data.

3.8. Total instantaneous mortality (Z)

Catch curves using data for 1986–1991 were different from those calculated for 1992–1995. We

Table 3
Catch-at-age matrix of red snapper from the U.S. South Atlantic for all fisheries combined

Year	Age																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17+
1986	10 6719	42 160	25 307	14 986	12 834	9281	5828	1834	626	404	184	152	432	432	37	928	1512
1987	21 831	15 924	32 499	30 801	13 052	8112	5016	1683	330	163	81	61	247	296	22	541	1714
1988	92 410	43 086	33 524	23 889	10 520	9281	6465	3897	1603	938	1119	104	171	372	7	209	2589
1989	90 030	38 697	35 088	24 535	19 186	10 975	4316	1787	1139	846	682	507	827	1293	189	824	1060
1990	6065	5849	16 679	18 160	10 803	5065	1770	957	462	398	291	323	427	734	130	242	1201
1991	23 347	11 508	13 554	10 792	7341	4472	2376	942	514	314	226	177	231	365	64	419	1222
1992	9	3697	11 956	12 984	25 702	16 986	9947	2287	565	241	1021	666	2207	2533	320	1681	1126
1993	0	706	2371	3636	22 150	13 098	4052	1080	540	295	405	226	714	779	92	594	1243
1994	0	1153	3711	4231	17 488	16 706	6039	1572	339	223	340	238	679	784	102	670	817
1995	0	1240	3643	3012	11 805	11 051	6323	1842	723	303	209	162	412	518	67	418	937

believe this to be mainly attributable to minimum size regulation differences for the two time periods. Smaller (younger) fish were landed in the earlier period.

Catch curves for 1986–1991 were based on red snapper aged 1–12 years; those produced for 1992–1995 were based on fish aged 6–12 years. 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.

3.9. Natural mortality (M)

There is often great uncertainty in deriving a value for natural mortality, M. Yet this is an important input parameter in 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 natural mortality, 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
Alverson and Carney (1975)		0.15

Both Hoenig (1983) and Alverson and Carney (1975) use maximum age in their equations for calculating M. Using a maximum observed age of 25 years from the study by Manooch and Potts (1998), the two methods return similar values of M. The Hoenig method relating maximum observed age to total mortality and sample size yields a higher value of M=0.30. This method assumes random sampling. Since most of the samples from Manooch and Potts' 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 (M, 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). Mean seawater temperature input into Pauly's (1979) equation was 22°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 an age at 75% maturity agrees more closely with estimates derived by other methods.

Our estimates of M ranged from 0.15 to 0.33. Based on the estimates of maximum age (25 years) we

Table 4
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

Time period	Natural mortality (*M*)				
		0.15	0.20	0.25	0.30
1986–1991	Full *F*	0.48	0.43	0.37	0.31
	SPR	0.03	0.05	0.09	0.15
	Y/*R* (kg)	0.40	0.35	0.32	0.28
1992–1995	Full *F*	0.69	0.63	0.57	0.50
	SPR	0.11	0.11	0.24	0.32
	Y/*R* (kg)	1.01	0.68	0.60	0.45

believe that *M* does not exceed 0.30. Ault et al. (1998) used a natural mortality of 0.19 for the species in the Florida Keys National Marine Sanctuary. Goodyear (1995) references a red snapper from the Gulf of Mexico with an age of 53 years, reducing his estimate of *M* using Hoenig (1983) equation to 0.078. We have no evidence to suggest that we have fish this old in the South Atlantic Bight. We choose to run the analyses with a range of values for natural mortality, 0.15, 0.20, 0.25, and 0.30.

3.10. Fishing mortality and virtual population analysis

For the SVPA runs, two catch matrices were analyzed consisting of catch in numbers for ages 1–12 for fishing years 1979–1991 (generally modal age-1) and ages 2–12 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 $year^{-1}$ for 1991 and 0.76 $year^{-1}$ 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.

Due to the short duration of the catch matrix and large number of ages, mean values only for the pre- and post-minimum size limits are considered. Mean values of age-specific estimates of *F* were obtained from the SVPA applied to the catch at age data (Table 4) using the uncalibrated SVPA. The calibrated approach used MARMAP CPE from the Chevron trap data that was broken into age-specific values comparable to development of the fishery-dependent catch matrix (Table 3). 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 4). 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.

3.11. Yield per recruit

YPR increased for the later years due to the imposition of the minimum size limits (Table 4). Data are presented graphically in Fig. 4(a) and (b) and Fig. 5(a). We incorporated an adjustment for released fish mortality to determine what impact this would have on yield at entry to the fishery. Two released fish mortality values for red snapper (25% and 10%) were provided as a result of field research conducted by NMFS personnel (Robert Dixon and R.O. Parker, NMFS, Beaufort Laboratory, Beaufort, NC). Since the *F* on ages protected by the minimum size limit were so small, the released mortality rates did not have any effect on the yield at entry to the fishery.

a. b.

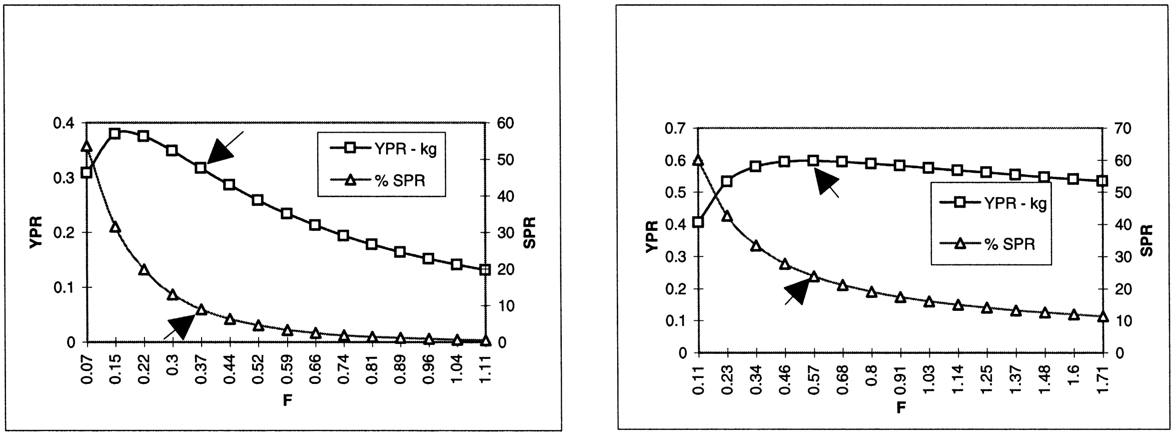

Fig. 4. YPR vs. SPR for red snapper from the southeastern United States (arrows indicate present state). (a) 1986–1991; M=0.25; age-at-entry=1; (b) 1992–1995; M=0.25; age-at-entry=2.

3.12. Spawning potential ratio

We received red snapper reproductive data from SCDNR personnel 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 at 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% a 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 SPVA using four different levels of natural mortality (M=0.15, 0.20, 0.25, and 0.30) (Table 4). Again, the two values of released fish mortality (0.10 and 0.25) were incorporated into the model. Percent maximum spawning potential was greater for the more recent time period, particularly for M=0.25, and M=0.30 (SPR=0.24 and 0.32, respectively) (Table 4), and would be even higher if fishermen complied fully with the 508 mm minimum regulation. At these levels of release mortality (0.10 and 0.25), the age of recruitment to the fishery in order to obtain 30% and 40% SPR was not impacted. Ault et al. (1998) derived SPR=0.31 for red snapper in the Florida Keys.

Estimates of equilibrium spawning potential ratio (static SPR) using estimated F from the two VPA approaches are summarized by time period and assumed level of M (Table 4). Using SVPA estimates of F (with M=0.25) for two periods, SPR estimates based on female biomass are compared (Table 4). Note that even though full F may be higher for the latter time period, it is applied to fewer older ages, so that SPR is actually lower. SPR values with M=0.25 are shown in Fig. 4(a) for the period 1986–1991 and in Fig. 4(b) and Fig. 5(b) for 1992–1995.

4. Management

We believe that our assessment of red snapper is on the one hand conservative, and on the other flexible enough in its presentation to allow the reader independently to judge the status of the stock. It is conservative in that our use of the MRFSS data, which often include inadequate sample sizes for length frequency analysis (Mays and Manooch, 1997), and present questionably large estimates of small fish landed (possibly misidentified vermilion snapper), would tend to underestimate age of fish at entry to

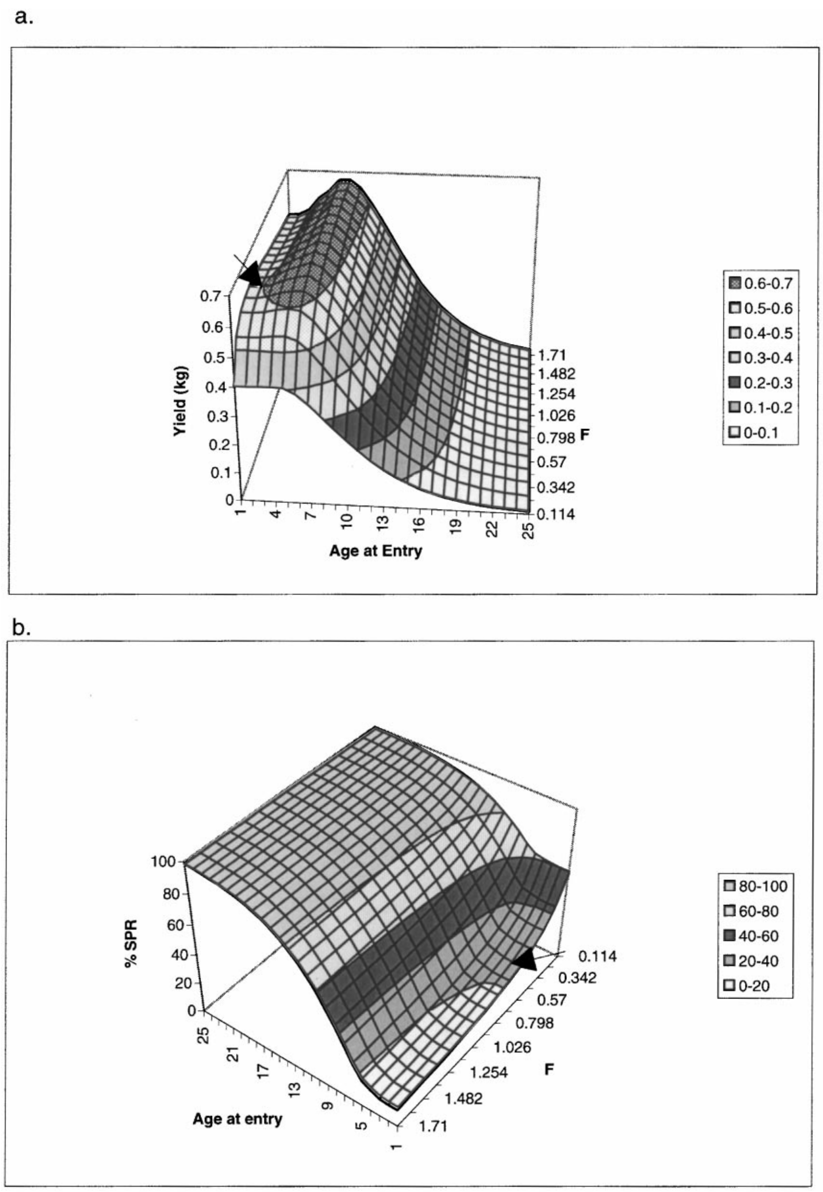

Fig. 5. Most recent time period (1992–1995) yield per recruit and spawning potential ratio with M=0.25 and present F=0.57 for red snapper from the southeastern United States. Arrows indicate present condition. (a) YPR (b) SPR.

the fishery, thus, erroneously lowering SPR. Also, the sexual maturity schedule that we used does not consider any age-2 fish mature. Some probably are, and this input correction would result in a greater spawning potential for the species throughout life. Consideration was given to release fish mortality, and though the estimates are conservative, they represent the best scientific data available.

Although trends in landings and CPUE have generally decreased, the mean size of red snapper landed has increased during the past several years. This is a positive indication that the minimum size

Table 5
Two management actions that could increase red snapper SPR values to 30% or 40% based on the most recent time period 1992–1995

Action	Current SPR	Current F	% Reduction in F to achieve	
			30%	40%
1. Reduce F				
M=0.20	11%	0.63	63% (F=0.24)	68% (F=0.20)
M =0.25	24%	0.57	30% (F=0.40)	55% (F=0.26)
M=0.30	32%	0.50	*N/A*	33% (F=0.34)
2. Raise minimum size	To achieve SPR level			
	30%		40%	
M=0.20	584 mm		660 mm	
M=0.25	508 mm		584 mm	
M=0.30	*N/A*		533 mm	

limits are having an effect on landings, and are increasing age at entry to the fishery. Fully recruited age and age at entry are age-1 for 1986–1991, and age-6 and age-2, respectively, for 1992–1995.

SPR values were derived using natural mortality (M) values of 0.15, 0.20, 0.25, and 0.30. We believe that the most accurate estimate of M is between 0.20 and 0.30. This would result in an SPR ranging from 0.11 to 0.32 for the most recent time period 1992–1995 (Table 4). The SPR level could be improved if F is decreased, or if age at entry to the fisheries is increased. The latter could be realized now if fishermen, particularly recreational, complied fully with the 508 mm minimum size regulation. Reductions in F and increase in legal minimum size needed to achieve 30% and 40% SPR are presented in Table 5.

We conclude that the red snapper stock is in a 'transitional' condition. That is, the status is less than desirable, but does appear to be responsive to recent management actions. Current regulations should remain in place.

The status of the red snapper stock off the southeastern United States as reported in this assessment is very different from that of the Gulf of Mexico stock as detailed by Goodyear (1995). We believe that the difference is largely attributable to two factors. First, juvenile red snapper off North Carolina through the Florida Keys are not subjected to a high bycatch mortality from shrimp trawling vessels as they are in the Gulf of Mexico. Snapper nursery grounds and trawling grounds do not overlap off the southeastern United States as they do in the Gulf of Mexico. Second, the maximum age of the species is judged to be vastly different, 25 years in the Atlantic compared with 53 years in the Gulf of Mexico. This discrepancy results in drastically different estimates of natural mortality, and thus, fishing mortality.

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