Report of Red Porgy Stock Assessment Workshop

Beaufort, North Carolina

April 8 – May 6, 2002

Prepared for South Atlantic Fishery Management Council

Charleston, South Carolina

Issued May 6, 2002

Corrected October 28, 2002

Revision History

May 6, 2002 Original release.

July 1, 2002 Reissued to correct the following error in the original: In Table 3, rows x62 and x63, confidence intervals for $F_{2001}/F_{\mathrm{MSY}}$ and $\mathrm{SSB}_{2001}/\mathrm{SSB}_{\mathrm{MSY}}$ were reversed.

October 28, 2002 Minor errors were corrected in the Reference section.

Executive Summary

The red porgy stock assessment workshop (SAW)[1] was convened by the South Atlantic Fishery Management Council at the NOAA Center for Coastal Fisheries and Habitat Research, Beaufort, North Carolina on Monday, April 8. The SAW's objectives were to conduct an updated stock assessment of the red porgy, *Pagrus pagrus*, stock off the southeastern U.S. and to conduct stock projections based on several possible management regimes (terms of reference, Appendix A). Participants in the workshop (Appendix B) included state, federal, and university scientists, as well as observers from the Council. The SAW worked at Beaufort until April 12 and continued its work, communicating by email and conference call, through May 6. All decisions regarding stock assessment methods and acceptable data were made by a consensus of all participants.

Available data on red porgy include abundance indices and recorded data on landings, including data on size and age distributions of some landings and indices. Four abundance indices were developed by the preceding data workshop (DW): two indices derived from catch per unit effort (CPUE) in the NMFS headboat survey (1976–1991 and 1992–1998) and two derived from CPUE observed by the SC MARMAP fishery-independent monitoring program ("Florida" trap index, 1983–1987; and chevron trap index, 1990–2001). Landings data are available from all recreational and commercial fisheries.

In addition to this report, a CD–ROM was produced that contains all data used in the assessments, reports of the DW, detailed explanation of data used, model runs and results, and computer code that was used for projection and the detailed projection results. The CD–ROM supplements this report by providing complete technical detail of the assessment and SAW process.

The SAW applied both age-structured and age-aggregated models to available data. The age-structured model was considered the primary model, as recommended by the DW.

Results of both models depict a heavily exploited stock with considerable decline over the period examined. Based on results of the base-case run of the age-structured model, the 2001 spawning stock size is estimated at about 43% of B_{MSY} while the 2001 fishing mortality rate is estimated at about 45% of F_{MSY}. Thus by standards of the Sustainable Fisheries Act and given the Council's definition of MSST = $0.775B_{\mathrm{MSY}}$, the stock is estimated as overfished (55% of MSST), but not presently undergoing overfishing. The latter state reflects the restrictions imposed by Amendment 12. Estimates from sensitivity runs of the age-structured model and from several runs of the production model are quite similar. The picture of stock status is also consistent with the most recent previous assessment of the stock.

Stock projections were used to estimate the years in which the stock would have at least a 50% probability of reaching B_{MSY} under four possible management policies. Results are: under $F = 0$, by 2010; under a moratorium (bycatch mortality only), by 2013; under Amendment 12, by 2018; under Amendment 9, not within the 25–year span of the projections.

[1] Abbreviations and acronyms used in this report are defined in Appendix D on page 41.

Contents

List of Figures

List of Tables

1 Place, time, and tasks

The red porgy stock assessment workshop (SAW)[2] was convened at the NOAA Center for Coastal Fisheries and Habitat Research, Beaufort, North Carolina, by the South Atlantic Fishery Management Council (the Council) and the NMFS Southeast Fisheries Science Center (the Center). The SAW met from 3:00 p.m. on Monday, April 8, to 12:00 noon on Friday, April 12, 2002, with the SAW continuing its work through May 1, aided by e-mail and conference-call communications. Participation in the workshop (Appendix B) included scientists from the states of Florida, North Carolina, and South Carolina; from NMFS laboratories and offices in Beaufort, Miami, Pascagoula (MS), Silver Spring, and Woods Hole; representatives of the Council and its Scientific and Statistical Committee; and scientists from Virginia Polytechnic Institute and State University, including Dr. James Berkson, who chaired the SAW.

The SAW's major objectives were to conduct an assessment of the stock of red porgy, *Pagrus pagrus*, off the southeastern US, and to conduct stock projections under various management regimes (terms of reference, Appendix A). In support of those tasks, the SAW received data and recommendations from the red porgy data workshop (DW) that was convened in March by the Council and the Center. The DW was designed to be the first step in the assessment process, bringing together state and federal biologists with the needed expertise to decide which data were appropriate for use in the assessment. The SAW was designed to follow the DW, with many of the same state and federal biologists participating. Some of the decisions regarding data made at the DW were refined during the SAW. At both the DW and the SAW, all decisions affecting the assessment were made by consensus of all participants.

[2]Abbreviations, acronyms, and mathematical symbols used in the report are listed in Appendix D on page 41.

2 Stock and fishery characteristics

The following material is excerpted and expanded from the description of the stock and fishery in Vaughan and Prager (2002).

Red porgy have an extensive range in warm waters of the Atlantic Ocean and adjacent seas: they occur off the southeastern U.S. Atlantic coast; in the Gulf of Mexico; off the South American Atlantic coast from Brazil to Argentina; off Portugal and Spain; in the Mediterranean Sea; off west Africa south to the Cape Verde Islands; and around the Azores, Madeira, and Canary Islands. The stock unit analyzed here includes fish from U.S. Atlantic waters off North Carolina (NC) south of Cape Hatteras, South Carolina (SC), Georgia (GA), and the east coast of Florida (FL), including the Atlantic side of the Florida Keys (Monroe County). Within that stock definition, red porgy have been most abundant in NC and SC waters. Tagging studies show neither long-range migrations nor extensive local movements of adult red porgy (Manooch and Hassler 1978), and there is no circumstantial or anecdotal information to suggest such movements.

Peak spawning occurs in March and April (Manooch 1976). Red porgy eggs and larvae are pelagic, hatch 28 to 38 h after fertilization, and can survive transport by ocean currents for 30 days or more (Manooch et al. 1981). Thus, the population off the U.S. Atlantic coast could in theory receive eggs or larvae from the Gulf of Mexico. However, because of the distances involved and the variability of ocean currents, the likelihood of regular population mixing in this way seems small.

Red porgy attain maximum size slowly and live relatively long (an 18-year-old specimen is the oldest on record), but maturity occurs at younger ages. Roumillat and Waltz (1993) collected red porgy, 1979–87, along the continental shelf between Cape Fear, NC, and Cape Canaveral, FL, using trawl nets, traps, and hook-and-line. Life history information was obtained from 7,104 red porgy; 5,820 otoliths were examined (including 134 from historical or port samples), of which 5,491 had discernible rings; estimation of sex composition was based on 6,044 red porgy. The vast majority of females were mature by age 2.

Red porgy are protogynous hermaphrodites. Thus, females predominate at smaller size intervals, but males occur in all age groups.

Three major fisheries catch this stock of red porgy: commercial, recreational, and headboat. The fisheries were further subdivided for assessment purposes, but are discussed here without that subdivision. The most common commercial gear has been hook and line, with occasional commercial landings also from trawls and traps. Trawling for red porgy has been banned since January 12, 1989 (SAFMC 1988) (Table 1).

The recreational fishery is defined here to include all recreational fishing from shore, from private boats and from charter boats (for-hire vessels that usually accommodate six or fewer anglers as a group). The headboat fishery (larger for-hire vessels that charge per angler) is sampled separately, and for that reason is distinguished here from other recreational fisheries. Recreational and headboat fisheries, like the commercial fishery, use hook-and-line gear almost exclusively.

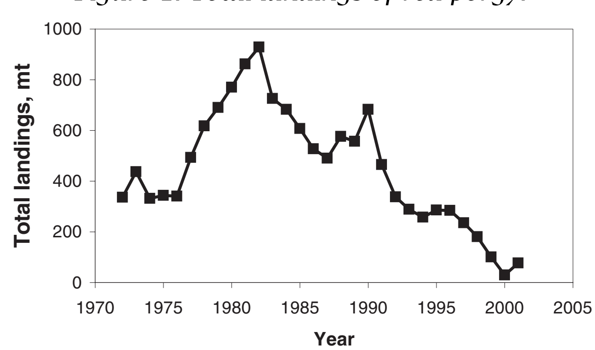
Total landings increased during the 1970s and early 1980s as the commercial fishery expanded, rising from about 335 mt in 1972 to over 900 mt in 1982. Except for a brief spike in 1988–1990, landings declined steadily from the 1982 peak to the low of under 30 mt in 2000 (Figure 1).

Table 1. Red porgy regulatory history

Period	Amendment	Details
to 1992	—	No size, bag, or trip limits or seasonal closures
Jan 1989 to present	1	Trawl gear banned
1992 to Jan 99	4	12" TL minimum size
Feb 99 to Aug 99	9	14" TL minimum size; 5-fish bag limit in recreational fishery; seasonal closure (March–April) of commercial fishery
Sep 99 to Aug 00	M[a]	No landings allowed
Aug 00 to present	12	1-fish bag limit in recreational fishery; seasonal closure (January–April) of commercial fishery; 50-lb trip limit in commercial fishery

[a] Moratorium

Figure 1. Total landings of red porgy.



The headboat fishery was predominant, 1972–1977, accounting for 64% on average of landings

Figure 2. Landings of red porgy by major fishery.

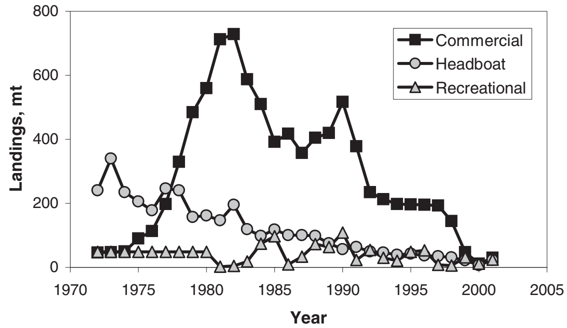
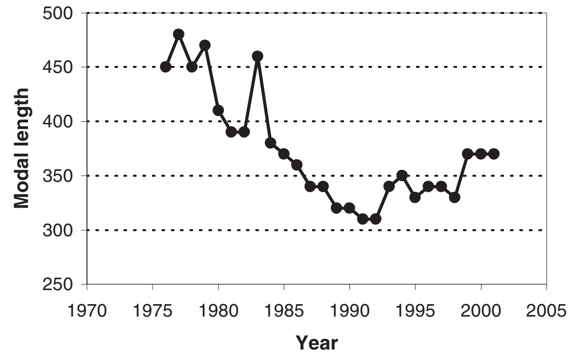


Figure 3. Modal lengths in commercial hook-and-line fishery.



in weight (Figure 2). From 1978, onward the commercial fishery predominated, representing 53–82% of annual landings. Recreational fisheries seldom landed more than 10% of the total until 1999–2001, when they represented 34% of total weight landed.

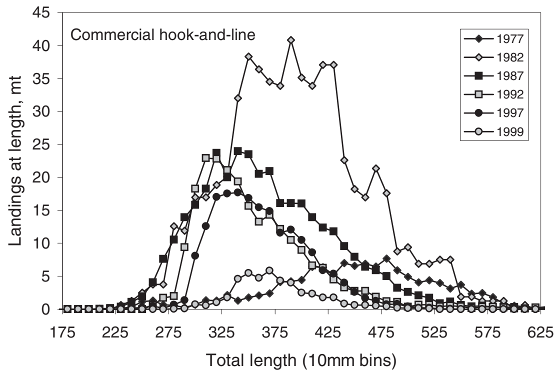
Commercial landings rose steeply during the 1970s, from 47 mt in 1972 to 729 mt in 1982, then declined to around 400 mt in the late 1980s (Figure 2). Landings during the 1990s averaged around 200 mt until falling again in 1997. Hook and line gear accounted for about 90% of commercial landings overall, although trawl landings accounted for as much as 25% of the annual total during some years in the early 1980s. Trawl landings soon declined considerably, and trawl gear was prohibited as of January 12, 1989, by Amendment 1 to the Fishery Management Plan (Table 1) (SAFMC 1988).

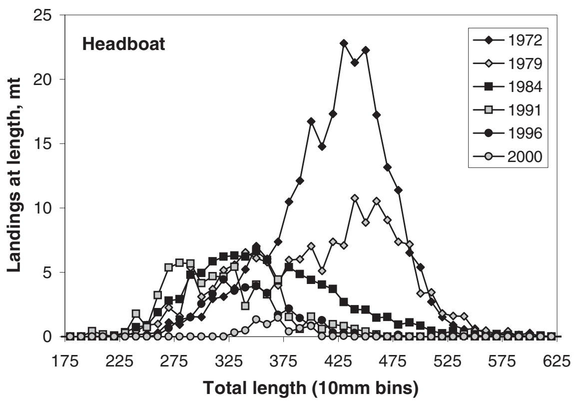
Length–frequency data show that the decline in total commercial landings was largely a decline in landings of large fish, accompanied by a decline in modal length. Those patterns are illustrated by the hook-and-line fishery, in which length–frequency data are available continuously since 1976. (Other commercial gear length–frequencies are only available sporadically through the time series). Modal length peaks in 1977 at 480 mm, then declines to 310 mm in 1992 (Figure 3). Increases and stability from 1993–1998 and 1999–2001 were the result of size limit restrictions. A 12" size limit was implemented on January 1, 1992 (SAFMC 1991), and a 14" size limit was implemented on February 24, 1999 (SAFMC 1998).

Expanding the commercial length–frequencies by annual landings shows considerable declines in landings of large fish over time. Most landings in 1977, before commercial fishery expansion, were distributed between 400 and 500 mm. By 1982, when commercial landings peaked, the mode dropped to just below 400 mm and landings dropped sharply at lengths above 430mm (Figure 4).

Total landings declined after 1982, with the 1987 length distribution revealing a large decline in landings over 330 mm as compared to the 1982 peak. This pattern continues into 1992, when the mode reached the series low of 310 mm and there was a further decline in landings above the mode. The mode increased to 340 mm during 1993–1998, reflecting an increase in minimum size of possession, with the 1997 distribution illustrating further drops in landings, due to declining harvest of fish below the minimum size. The 1999 distribution reflects both an ad-

Figure 4. Landings at length over time in two red porgy fisheries.





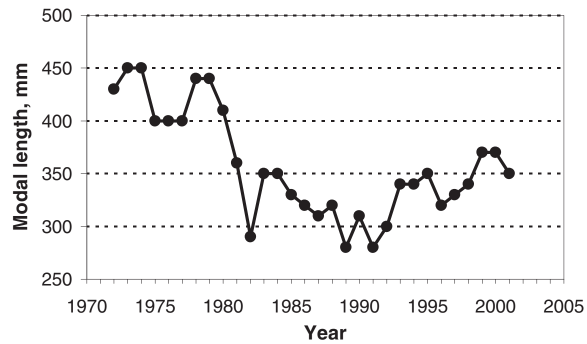
ditional minimum size increase (shown as an increase in the mode to 370 mm), and increased harvest restrictions (shown as overall reduction in landings across all size categories).

Recreational landings show no consistent trend, averaging about 38 mt per year from 1981–2000, with a few years of 50 to 100 mt from 1984–1996 (Figure 2). Catch by mode of fishing has been highly variable from year to year, but on average landings in weight are evenly split between private/rental and the charter boat categories. No adequate length–frequency data are available from recreational fisheries (other than the headboat fishery), because sampling has been insufficient.

Headboat landings declined steadily through the series, from 400 mt in 1973 to around 100 mt per year in the 1980s and then to fewer than 50 mt per year in the 1990s (Figure 2). Most headboat landings have come from NC and SC.

Length–frequency data available from the headboat fishery for 1972–2001 show trends similar to the commercial hook and line length frequency. Modal lengths vary without trend be-

Figure 5. Modal lengths in headboat fishery.

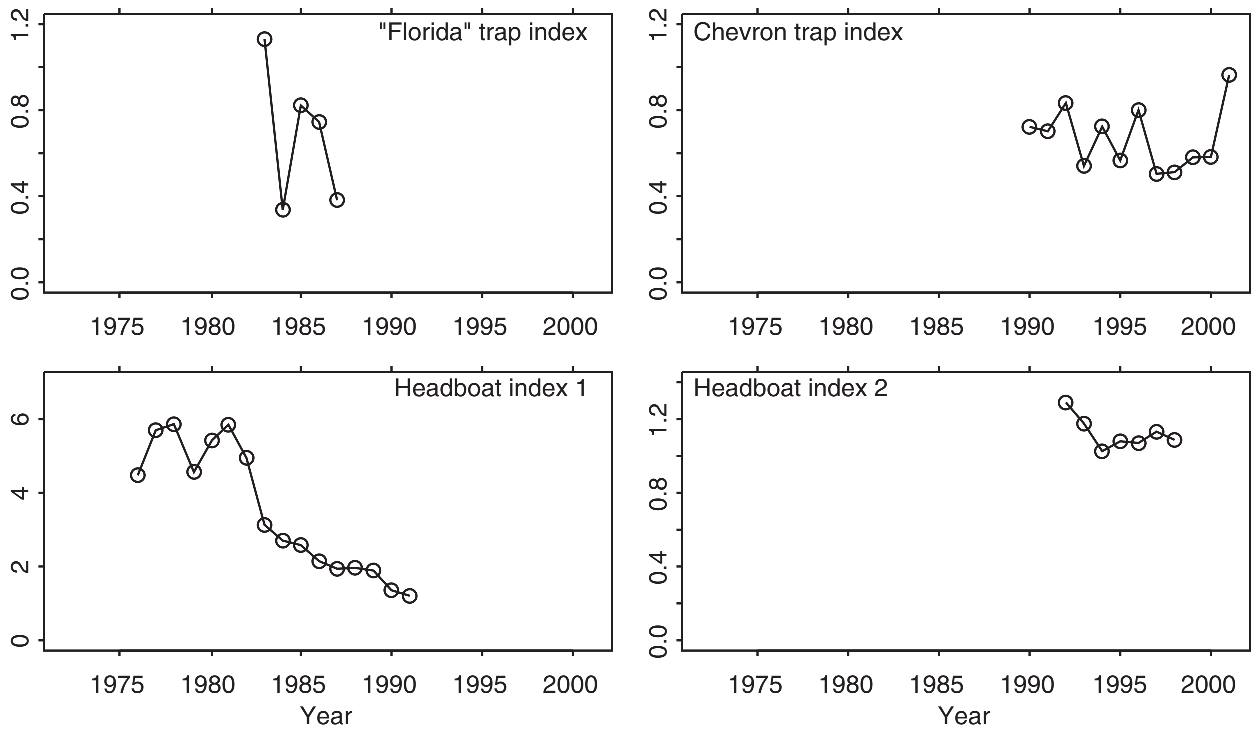


tween 400 and 450 mm from 1972–1979, then decline steadily to a low of 280 mm in 1991 (Figure 5). Regulatory related increases are apparent in the 1990s although generally less pronounced here than in the commercial hook and line data.

The trend in landings at length reflects both a decline in total landings and a shift toward smaller lengths through the series (Figure 4). Landings at length in 1972 were tightly centered around the mode from 430–450 mm. Initial declines in landings through 1979 did not show truncation of older ages or modal shifts, but by 1984 truncation was becoming apparent and the mode declined to 350 mm. In 1991 the mode declines further to 280 mm and landings at higher sizes decline further. The mode increased in 1996 and again in 1999, with landings declines apparent at lower sizes over this period.

Taken together, the abundance indices exhibit a pattern of long-term decline, with some indication of increase in recent years (Figure 6). The

Figure 6. Abundance indices for red porgy.



"Florida" trap index, considered alone, appears noisy; nonetheless, its highest value is in its first year (1983) and its second–lowest value in its last year. The chevron trap index declines slowly, with an increase in abundance in the final year. The two headboat indices show a long–term period of decline (by perhaps 80%), followed by a slight increase in abundance in the final years of the second index.

3 Data workshop

Data for this assessment were prepared by a Data Workshop (DW) that met for that purpose during the week of March 11, 2002, in Charleston, SC. Additional questions that arose during initial model development and testing before the SAW were resolved at the SAW itself.

Each working group at the DW made recommendations on data to be used in this assessment. All recommendations regarding the data were made by a consensus of all DW participants. Those recommendations are found in complete form in the documents of the Data Workshop (on the Red Porgy 2002 CD–ROM) and are summarized here.

3.1 Findings of life-history working group

Unit stock The group agreed that red porgy in the South Atlantic Bight form a unit stock.

Age–length keys It was noted that aging by the NOAA Beaufort (NC) Lab and the SCDNR Lab differs markedly. The decision not to use Virtual Population Analysis (defined here as a catch-at-age model that is solved backwards by cohort) made moot any discussion of the different age–length keys derived from the two labs' aging. Nonetheless, length-to-age conversion is an important aspect of any age–structured assessment. An otolith exchange program was initiated to provide data for computation of an age–conversion matrix to be used in the age–structured model planned for the stock assessment. That allowed the assessment to be conditioned on either group's aging estimates.

Natural mortality rate The group recommended a natural mortality rate *M* in the range 0.20–0.25/yr.

Release mortality The group recommended assuming release mortality of 35% (of fish caught and released) for all fisheries except the recreational fishery (MRFSS "B2" catches), for which 8% release mortality should be used. This recommendation was based on the study of Collins (1996).

Maturity schedules The DW stated that data from fishery-independent sampling are the best maturity data available and recommended that they be used in the assessment. Given the plasticity in maturity exhibited over time, gear- and period-specific maturity curves for females should be used except for 1984–89 data from blackfish and "Florida" traps (a type of trap, also called snapper trap, whose use is not limited to the waters off Florida), which could be pooled. For males, maturity data were pooled by gear for hook and line, blackfish trap, and Florida trap. Data from chevron trap samples were not pooled.

Spawning–stock biomass The issue of how to compute spawning–stock biomass is complicated by the species' protogyny. The DW recommended performing the assessment with two alternative methods of estimating spawning biomass, female biomass and total spawning biomass.

3.2 Findings of recreational fisheries working group

Two sources of recreational information are available for use in the red porgy stock assessment: the National Marine Fisheries Service (NMFS) Headboat Survey and the NMFS Marine Recreational Fisheries Statistics Survey.

Headboat landings Headboat landings are available from 1972 to present from North Carolina and South Carolina, and the majority of red porgy landings in the South Atlantic are from those states. Minor landings were reported for the Cape Hatteras area from 1973–1976 (around 1000–3500 fish/yr from area 1), but those landings were deleted on the recommendation of the DW, because the northern limit of the stock has been specified as below Cape Hatteras.

Landings from Georgia and northeast Florida are available, 1976–present. That landings series was extended back to 1972 through the use of regressions of Georgia and north Florida landings on Carolina landings. Similarly, landings from south FL, available since 1981, were extended back, 1972–1980, with zero-intercept regression of southeast Florida landings on NC and SC landings. These landing adjustments are relatively small, and any biases are unlikely to affect assessment results.

Before 1976, red porgies were reported in the general category "porgies" in Carolina landings. Data 1976–1980 were used to estimate the area-specific proportion of red porgy to combined porgies and the ratio was expanded based on correct data from the earlier period.

Size distributions of headboat catches Headboat samplers measure length and weight of the fish that they encounter. Those measurements are available for the same time periods as headboat landings data, with one exception: measurements are available from southeast FL, 1978–1980, prior to availability of landings data from the area. The group recommended that lengths be combined across areas. Lengths were applied to the estimated catch in numbers by year, area, and wave (months 1–5, 6–8, 9–12).

Headboat abundance indices Headboat catch rates were standardized with a general linear model (GLM) run on catch in numbers divided by anglers at the trip level (full day trips only) separately for 1976–1991 and 1992–1998. Class variables were year, month, area (2, 3, 5, 9, 10 and 2 combined with area 3)[3]. Breaking the time series between 1991 and 1992 accounted for the introduction of the 12" TL minimum size limit with Amendment 4.

MRFSS landings The Marine Recreational Fisheries Statistics Survey (MRFSS) began in 1979; however, the Data Workshop recommended excluding the first two years, as MRFSS revised their data collection and estimation procedures. The survey collects information from shore-based, private-boat and charter-boat anglers. (Headboat landings were included in the early years, but those data were removed from the MRFSS database because the NMFS Headboat Survey covers that sector more completely.)

Red porgy are rarely encountered near shore; thus, landings from the shore-based mode of MRFSS were excluded by the DW. Mean landings by private and charter boats from 1981–1990 were used to extend those landings series back to 1972. In estimating landings in weight, occasionally no fish were weighed in a given stratum (year, subregion, state, mode, area). Such missing weights were filled in using mean weight of fish from neighboring strata, based first on wave, then state, and worst case adjacent year. The estimated release mortality rate of 8% from Collins (1996) was used to modify catch of released fish. Concern continues about large variability in year-to-year estimates of private and charter boat landings and generally large proportional standard errors (ranging from about 20% up to almost 60%. A suggested alternate approach may be to apply an appropriate smoother (running average or lo(w)ess).

MRFSS catch rates The group recommended not using catch rates from MRFSS because few intercepts either caught or targeted red porgy. Similarly, the small numbers of red porgy encountered by MRFSS samplers precluded using length measurements from MRFSS.

3.3 Findings of working group on commercial landings

Red porgy landings data were not consistently reported as red porgy in the earlier years; some were placed in an "unclassified porgies" category. To extract red porgy from the unclassified category, the group examined reporting categories for all porgies by state. It is believed that red porgy from SC have been classified accurately from 1989 to the present. In NC, accurate reporting of red porgy began in 1994. In GA and FL, accurate reporting began in 1993.

To correct inaccurate reporting, years with accurate reporting were used to determine the ratio of red porgy to all porgies in each state. This ratio was then applied to all porgies in the past to compute the total landings of red porgy. How-

[3] The final analysis was done at the SAW.

ever, size restrictions can decrease the ratio of red porgy to all porgy. The regulatory history of red porgy involves a 12" minimum size limit implemented in 1992 and a 14" minimum size limit in 1999. South Carolina is the only state which was believed to accurately report red porgy before the 12" minimum size limit; therefore, the group used the ratio of red porgy to all porgy for 1989–1991 as the correction factor for previous red porgy data in SC. For NC, GA, and FL, the group used the ratio of ratios (red porgy:all porgy from SC in 1989–1991):(red porgy:all porgy from SC in 1992–1997) to compute the pre-size-restriction ratio of red porgy to all porgy for those states. Landings from SC and NC in the "all porgy" category were obtained from state records, while those from FL and GA were obtained from the NMFS general canvass database.

In NC, there have been landings of "unclassified porgies" from north of Cape Hatteras. Such landings, which are known to be composed entirely of scup, were not used in computing NC red porgy landings. Furthermore, there are some "unclassified porgy" reported from shrimp trawls, and such landings, which are known to be pinfish, were omitted.

Length data on red porgy from commercial fisheries, 1983–2001, were extracted directly from the NMFS TIP database. The group believes that all relevant data for that time period have been accumulated into that database.

3.4 Findings of MARMAP working group

The MARMAP working group at the Data Workshop addressed fishery-independent indices of abundance that could be derived from the South Carolina MARMAP survey program. MARMAP has conducted reef-fish related sampling since 1979.

The group recommended two separate abundance indices for use in the assessment: a "Florida" trap index, 1983–1987, and a chevron-trap index, 1990–2001. The group also calculated an abundance index from research hook-and-line data, but recommended against using it because of known variations in sampling procedures and low catch rates. A fourth abundance index, based on black seabass traps, was not recommended, as catch rates of red porgy in those smaller traps were low.

The snapper-trap index is based on sampling at fixed stations that primarily sampled the nearshore South Carolina area. The chevron-trap series, in contrast, sampled the Florida–North Carolina area out to 50 fathoms. Examination of many subsets of the data in space and time revealed no important differences from patterns seen in the candidate indexes using the entire data sets.

Because of the different gear types, different survey designs, and different geographic ranges, the working group recommended the chevron and snapper trap survey indices be used as separate time series, rather than being combined into one extended index. There were attempts to conduct paired trap stations in 1988–89, but because of variations in sampling procedures those years (tying traps to the vessel), closeness of the paired deployments, and differences in range between the surveys, the group recommended against development of a calibration factor to link the two surveys. Because gear efficiency was believed to be strongly affected by tying the traps to the vessel, the group also recommended against using 1988–89 observations as part of either time series.

Size– and age– composition data from the MARMAP database were brought forward for use in the assessment.

4 Data issues resolved at SAW

The SAW considered additional data issues that arose during development and preliminary application of the age-structured assessment model. A brief description of those issues and the resolution chosen by the SAW follows.

4.1 General data issues

- The DW specified a range for natural mortality, $M = 0.2$–0.25/yr. The SAW decided to run the age-structured model at the average value in the range, $M = 0.225$, and to make sensitivity runs at $M = 0.2$ and $M = 0.25$.

- For MRFSS private and charter landings, 1972–1980, the SAW used the 10-year average of landings, 1981–1990, to fill in otherwise missing values.

- For charter landings in 1981 (reported as zero by MRFSS), the SAW used value 0.0001 mt as a computational convenience. This was also done for the commercial trawl landings reported as zero in 1974. This decision simplifies programming but seems extremely unlikely to affect the assessment results.

- The SAW used a minimum sample size of 50 fish/yr for length frequencies in the trawl and trap fisheries. Smaller samples were omitted from these analyses. (These values are used in the age-structured model to characterize the length distribution of landings.)

- Fish lengths were aggregated into 10 mm bins (size categories) for better sampled fisheries (i. e., those with larger sample sizes), into 20 mm bins for less well sampled fisheries.

- The data workshop recommended using an abundance index based on headboat catch per unit effort (CPUE), 1972–1991, as the management regime changed in 1992. The SAW decided also to use a similar abundance index for 1992–1998, which reflects a period of consistent (but different) management, including a size limit but no bag limit. The two indices had selectivity and catchability estimated separately.

- The SAW used headboat abundance indices in weight per unit effort, for consistency with other data series.

- Additional fish length distributions for SC, 1976–1983, were provided by SCDNR between the DW and the SAW, and they were incorporated into the assessment data base.

- Florida commercial landings data for 1972–1973 were reported as zero by the DW. Corrected values were substituted from the NMFS general canvass data base, adjusted for "other porgies" as in other years.

- Length frequencies from MRFSS were dropped because of small sample sizes and to reduce model complexity; instead, MRFSS fisheries (charter and private boats) were assumed to have the same aggregate selectivity as headboats.

- The SAW noted that NC inshore and offshore catch rates for the headboat fishery were found similar by the DW, and no difference in trends was found. Only offshore catch rates were used in computing abundance indices from the SC headboat fishery.

- In the weeks preceding the SAW, narrow gaps were found in reported MARMAP and TIP length distributions. The gaps were attributed to rounding of reported lengths and subsequent length conversions (fork length to total length). The issue was resolved by redistributing measured fish across their own length bins and forming a new length distribution that does not display narrow gaps between well-represented lengths.

- Aging differs between NC and SC investigators. Two correction matrices were developed that allowed the analysis to be done based on either SC or NC aging. Maturity schedules were adjusted correspondingly for the age-structured model.

- The Data Workshop recommended computing spawning–stock biomass in two ways, total mature population and based on females only. Computations at the SAW were made in total mature biomass, but because of time constraints, it was not possible to make complete parallel computations and analyses in female biomass only. Even if such analyses had been possible, their interpretation would be problematic, as the relative importance of males and females to population spawning success is not known.

4.2 Determination of CVs for modeling

The forward-projection model requires annual estimates of the coefficient of variation (CV) of various data series used for fitting. The SAW spent considerable time discussing the best approach to take in specifying these, and reached the following conclusions:

Headboat landings Headboat landings are considered among the most reliable landings data available; they are considered a census and are adjusted for missed records. In a SC study conducted through the Atlantic Coastal Cooperative Statistics Program, excellent agreement was found between logbook data and validation data (R. Dixon, pers. comm.). The group decided to use the following ranges of CVs for headboat landings: for 1972–1981, 0.1–0.15; for 1982–2001, 0.05–0.1.

Commercial landings For commercial landings data from the NMFS general canvass and adjusted by the DW and SAW, the group decided to use the following ranges of CVs: for 1972–1983, 0.25–0.50; for 1984–93, 0.10–0.15; for 1994–2001, 0.05 (no range).

Headboat abundance indices For the two abundance indices based on CPUE in the headboat fishery, the group agreed to rescale the CVs from the estimation procedure that generated the indices to the range of 0.2–0.5, as the raw CVs from the estimation procedure seemed too large. Annual variation in CV was thus retained, while the average CV was adjusted to be comparable to those assumed for other data.

Fishery-independent (MARMAP) abundance indices The group decided to take the same approach as for the headboat abundance indices. The CVs computed for these abundance indices were rescaled to the range 0.2–0.5.

5 Description of assessment models

5.1 Age-structured model

The data workshop recommended use of a forward-projecting statistical age-structured model as the primary assessment tool for red porgy in 2002. This recommendation was made in preference to tuned virtual population analysis (VPA) for the following reasons:

- Forward–projecting models are more flexible in formulation. Here, the ability to use length–composition data without externally estimating the corresponding age-compositions was thought useful, especially because there is uncertainty about age determinations in this species, as described above.

- Forward–projecting models have not been observed to result in retrospective patterns; such patterns are common in virtual population analyses (the other major form of age-structured model), and were problematic in VPA analyses in the last red porgy assessment (Vaughan and Prager 2002).

The essence of forward–projecting age–structured models is to simulate a population that is projected forward in time like the population being assessed. Aspects of the fishing process (i. e., gear selectivity) are also simulated. Quantities to be estimated are systematically varied from starting values until the simulated population's characteristics match available data on the real population as closely as possible. Such data include total catch by fishery and year; observed length composition of catches by year and gear; estimated age compositions of catches by year and gear; and observed indices of abundance, along with their age and length compositions.

The method of forward projection has a long history in fishery models. It was introduced by Pella and Tomlinson (1969) for fitting production models and then used by Methot (1989) in his stock–synthesis model. The model developed for this assessment is an elaboration of Methot's stock–synthesis model and very similar in structure to models used for assessment of Gulf of Mexico cobia (Williams 2001) and Gulf of Alaska sablefish (Sigler et al. 1997).

Age–structured forward-projecting models share many attributes with ADAPT–style tuned VPAs. The two types of model are compared in Table 2.

5.1.1 Properties of age-structured model

The forward-projecting statistical age-structured model for this assessment was implemented in the AD Model Builder software (Otter Research 2000) on a microcomputer. The specific model formulation and implementation used in this assessment is here designated RPM2002. Its formal definition is found in a computer file provided separately on CD-ROM. The formulation's major characteristics can be summarized as follows:

Natural morality rate The natural mortality rate was assumed constant over time.

Stock dynamics The standard Baranov catch equation was assumed to apply. This implies exponential fishing and natural mortality processes.

Selectivity of fishery-independent gear The two fishery-independent abundance indices are assumed to have individual time–constant selectivity vectors; the corresponding selectivity vectors are estimated internally by RPM2002.

Selectivity of fishery-dependent gear Each fishery is assumed to have constant selectivity during each period of constant regulation and time-varying selectivity in the absence of regulation. The corresponding selectivity vectors are estimated internally by RPM2002 and applied to the corresponding fisheries and any abundance indices derived from them.

Selectivity functions Selectivity was fit parametrically, using logistic models (most gears) or double–logistic models (surveys using trap gear),

Table 2. Comparison of tuned VPA (ADAPT formalism) and forward-projecting age-structured models (as used in this assessment)

Model property	Tuned VPA (ADAPT)	Forward-projecting model
Catch equation	Baranov	Baranov
Order of computations	Backward by cohort	Forward by year
Natural mortality rate	Usually assumed constant	Same
Effort required to extend model	Moderate to high	Low to moderate
Data preprocessing prior to model application	Moderate to extensive	Much less
Estimated parameters	Few to several	Several to very many
Catch fitting	Tries to match previously estimated catch at age, influenced by abundance indices	Tries to match total catch and size composition, influenced by abundance indices
Separability	Varies; ADAPT not separable	Usually, and may vary over time
Length-at-age model	External to model	Estimated in model
Recruitment model	Fit from age-structured model results	Can be fit internally to age-structured model
Periods of imprecision	Retrospective patterns often observed in final years	Earliest years' estimates tend to be imprecise
Typical fixed parameters	F or N at age in last year, selectivity of oldest age	Earliest recruitments or stock sizes, possibly B/B_{MSY} in first year
Objective function	Total sum of squares on $N_{a,y}$ and indices	Total likelihood on size composition, total catch, indices, other data

rather than estimating independent selectivity values for each age. That approach reduces the number of estimated parameters and imposes theoretical structure on the estimates.

Growth A von Bertalanffy growth model, constant over time, was estimated internally to the model from length-composition and age-composition data. A set of standard deviation-at-age parameters were estimated for determining the variance of length-at-age, assuming normal distributions.

Recruitment A Beverton–Holt recruitment model was estimated internally, and estimated recruitments were loosely conditioned on that model. The strength of that conditioning was agreed upon by the SAW after examining a wide range of alternatives, which gave similar results.

Biological benchmarks The benchmarks F_{MSY} and B_{MSY} were estimated internally by the model using the method of Shepherd (1982). In that method, the point of maximum yield is identified from the recruitment curve and other biological parameters, such as those for growth and maturity. Selectivity at age must also be specified; here, the model incorporated the catch–weighted selectivities at age estimated for the last three years (1999–2001).

Fishing Six fisheries were modeled individually: commercial hook-and-line, commercial trawl, commercial trap; recreational headboat, recreational charterboat, recreational private boat. Separate fishing mortality rates were estimated for each fishery.

Abundance indices The model used four separately modeled indices of abundance, as described above. They were two fishery-independent indices ("Florida" trap, 1983–1987; and chevron trap, 1990–2001) and two fishery-dependent indices (headboat, 1976–1991 and headboat, 1992–1998)

Fitting criterion The fitting criterion was a total likelihood approach in which total catch was fit almost exactly, and the observed age– and length–compositions, as well as the abundance index patterns, were fit to the degree that they are compatible. Relative statistical weighting of each likelihood component for the base case was chosen by the SAW after examining many candidate model runs. The criteria for choice were a balance of reasonable fit to all available data and a good degree of biological realism in estimated population trajectory.

5.2 Age-aggregated production model

The age-aggregated production model used was the (Prager 1994) form of the Graham–Schaefer surplus-production model. This is a continuous-time formulation, conditioned on catch, that does not assume equilibrium conditions. By conditioning on catch, the landings data are assumed more precise than the abundance indices. The model fits more than one abundance index by assuming they are correlated measures of stock abundance and that differences between indices can be considered sampling error.

Two forms of the production model were fit. The first was the Schaefer (1954; 1957) model, which assumes $B_{\text{MSY}} = 0.5K$, where K is the carrying capacity of the stock (virgin stock size). The Schaefer form is often used as a default because of its theoretical simplicity and because it is considered a central case among possible shapes of production model. The second form was the Fox (1970) production model, which assumes $B_{\text{MSY}} = 0.368K$. The Fox model was used because of the recent theoretical finding (Thompson 1992) that in stocks with a nondeclining stock–recruitment curve, B_{MSY} should be less than $0.5K$. While that finding lacks empirical verification, its conclusion seems worthy of investigation, especially when a nondeclining (Beverton–Holt) recruitment curve is explicitly assumed, as in the age-structured modeling here.

To fit the production models, a revised version of the ASPIC software of Prager (1995) was used. The main revision compared to the implementation of Prager (1995) was the added ability to fit the Fox model.

6 Model application and results

6.1 Age-structured model

6.1.1 Description of base run and sensitivity runs

Several runs of the age-structured model were made, a base run (considered by the SAW the most likely case), and a number of additional runs to examine sensitivity of results to various assumptions. The base run used the data from the Data Workshop with all adjustments described above. The base run used $M = 0.225/\text{yr}$, length-to-age conversion data from South Carolina, and the high end of the range of coefficients of variation (CVs) for landings data.

In addition to the base run, analyses were run examining the effects of using the lower end of the CVs for commercial and headboat landings, North Carolina length-to-age conversion data, alternative natural mortality rates, a truncated time series of data (1984–2001), and approximate discard levels in recent years.

In the base run, the SC aging information was chosen because in a comparison of ages read by both groups from the same (approximately 100) otoliths, the SC researchers identified some fish as ages 0 and age 1, while the NC researchers identified no fish younger than age 2. The group was concerned that the NC aging might be compressed to an unrealistically small group of ages, although there was no way of determining at the DW or SAW which, if either, set of age determinations is correct. This issue is mentioned again as a research recommendation in Section 9.

Both commercial and headboat landings reports are assumed to be censuses, and as such there is no uncertainty estimated for the reported landings. However, issues of misidentification, discards, and other sources of uncertainty that would be ignored if we assumed that the landings are known without error. Therefore, the SAW approximated uncertainty in the commercial and headboat landings by using different coefficients of variation, the years with the earliest (1972–1984) landings having higher CV ranges, intermediate CVs for the middle period (1985–1993), and lower CVs for the recent years (1994–2001), as described in Section 4.2.

Another sensitivity analysis used only data from the shorter period 1984–2001 to evaluate whether the more recent, higher quality data would capture the same biological signal as the longer time series did. That analysis was not intended to be used as an estimate of stock status. A final sensitivity run included estimates of discarded fish not included in landings data.

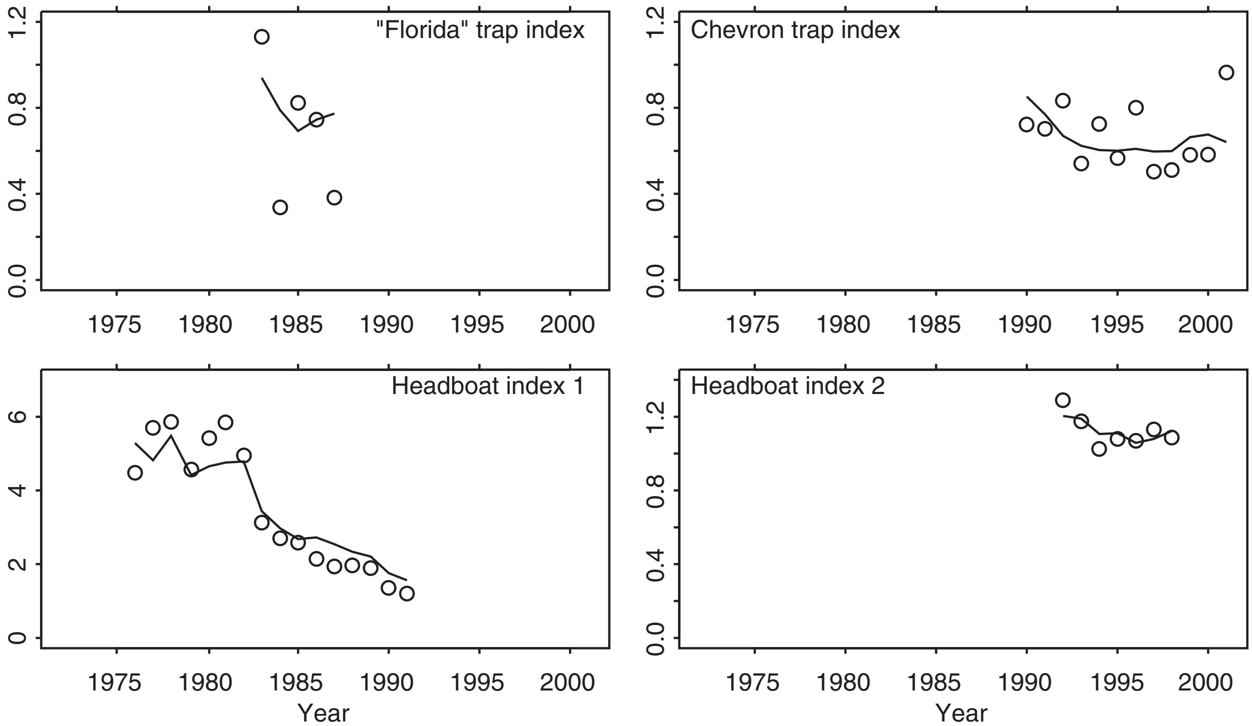
6.1.2 Results of base run

Fits of the RPM2002 model to the abundance indices were good (Figure 7), and the model was able to match observed catches almost exactly. Selectivities in the fisheries were estimated to have shifted towards smaller fish, but to have shifted back towards larger fish with recent management measures (Figure 8).

The model estimates that SSB has declined to about 10% of its 1972 value and that resulting recruitment has declined to about one-third of its 1972 value (Figure 9). It is important to consider that forward-projection models tend towards greatest uncertainty in the earliest years, and that catch sampling and catch statistics are thought least reliable from that time, as well. The interpretation of Figure 9 is that the stock in 1972 had many large fish that were gradually removed by the fisheries and not replaced as fishing mortality rates increased.

The estimated stock–recruitment relationship shows the usual scatter about the fitted Beverton–Holt recruitment curve (Figure 10). The apparent lack of fit for large SSB occurs because the model was required to generate large recruitments in a pre–1972 initialization period to account for the many large fish represented in the length compositions from the early years. Available data are consistent with Figures 9 and 10, but because of the nature of the model (Table 2), the earliest years' estimates represented in those figures may be inaccurate.

Figure 7. Observed (circles) and predicted (lines) abundance indices, from base run of age-structured model (RPM2002).



Exploitation rate over time is estimated to have peaked around 1990 at about 35% in weight (about 18% in numbers), and has dropped in recent years to less than 10% in numbers or in weight (Figure 11). The rate is higher in weight than numbers because the smallest fish are not taken in the fishery.

Table 3 presents additional estimates from the base run and sensitivity runs of RPM2002 and also results from the production models. Results of runs conducted strictly to check model function or decide on weighting are not tabulated. Estimates from the base run suggest that the moratorium (September, 1999–August, 2000) and Amendment 12 (September 2000–present) have lowered the fishing mortality rate to about 45% of F_{MSY} in 2001, but that 2001 spawning biomass was still only about 43% of SSB_{MSY}, which is below MSST, which the SAFMC has set at MSST = 0.775 B_{MSY} (Table 3, Figure 12). In the terms of the Sustainable Fisheries Act, the results imply that the fishery in 2001 was not undergoing overfishing (which the SAW believes is defined as $F > F_{MSY}$), but that the red porgy stock was overfished (depleted) in that year.

Confidence intervals in Table 3 are underestimates of uncertainty in the assessment, as the intervals reflect estimation error only, not uncertainty about the input quantities. Confidence intervals on RPM 2002 estimates were derived from delta-method (Normal) approximation.

6.1.3 Results of sensitivity runs

Lower CVs The run using the lower range of the commercial and headboat CVs on landings instead of the upper ranges (run x57) produced essentially the same estimates as the base run (Table 3).

Table 3. Summary of estimates from RPM2002 age-structured model and Schaefer and Fox production models applied to red porgy, with 80% confidence intervals given below corresponding estimates. Differences in assumptions from the base runs are $\boxed{\textit{boxed}}$. *Abbreviations and acronyms are listed in Appendix D on page 41.*

	Input assumption				Estimate					
Run	M	Aging	CV	Years	F_{MSY}	SSB_{MSY}	MSST	MSY	F_{2001}/F_{MSY}	SSB_{2001}/SSB_{MSY}
RPM2002 model—base run										
x47b	0.225	SC	high	1972–2001	0.19	3050	2364	375	0.45	0.44
					0.18–0.20	2924–3175	2266–2461	365–385	0.41–0.46	0.42–0.49
RPM2002 model—sensitivity runs										
x57	0.225	SC	$\boxed{\text{low}}$	1972–2001	0.19	2935	2275	364	0.44	0.46
					0.18–0.20	2818–3053	2184–2366	355–374	0.43–0.48	0.41–0.48
x60	$\boxed{0.2}$	SC	high	1972–2001	0.20	2888	2238	397	0.43	0.43
					0.19–0.22	2761–3014	2140–2336	388–406	0.41–0.46	0.40–0.46
x61	$\boxed{0.25}$	SC	high	1972–2001	0.18	3221	2496	374	0.48	0.41
					0.17–0.19	3082–3360	2389–2604	365–385	0.39–0.44	0.44–0.52
x58	0.225	$\boxed{\text{NC}}$	high	1972–2001	0.22	2719	2107	439	0.40	0.41
					0.21–0.24	2571–2866	1992–2221	429–450	0.38–0.44	0.37–0.43
x59	0.225	$\boxed{\text{NC}}$	$\boxed{\text{low}}$	1972–2001	0.22	2684	2080	427	0.39	0.43
					Confidence intervals could not be estimated for run x59.					
x62	0.225	SC	high	$\boxed{1984–2001}$	0.16	2741	2124	301	0.39	0.59
					0.15–0.18	2573–2909	1994–2254	288–313	0.35–0.43	0.54–0.64
x63[1]	0.225	SC	high	1972–2001	0.19	3049	2363	376	0.57	0.43
					0.18–0.20	2923–3175	2266–2461	366–386	0.52–0.61	0.40–0.45
Production model[2]										
Logistic (base run)				1972–2001	0.13	3598	2788	471	0.35	0.45
					0.06–0.19	2725–5326	2112–4128	287–535	0.28–0.54	0.35–0.56
Logistic				$\boxed{1984–2001}$	0.10	4695	3639	475	0.38	0.48
					0.04–0.14	3043–8597	2358–6663	335–882	0.30–0.64	0.20–0.66
$\boxed{\text{Fox}}$				1972–2001	0.11	3361	2605	362	0.41	0.51
					0.05–0.14	2552–5172	1978–4008	204–393	0.33–0.82	0.29–0.82

[1] Run with estimated discards in headboat and commercial fisheries, 1999–2001

[2] Production model estimates are in terms of total biomass, rather than spawning biomass. Absolute estimates of B, F, B_{MSY}, and F_{MSY} from production models are considered less reliable than estimates of ratios, e.g., F/F_{MSY} and B/B_{MSY}. The absolute estimates are generally not recommended for management use.

Figure 8. Selectivities over time in two major fisheries for red porgy, estimated from base case of RPM2002 model.

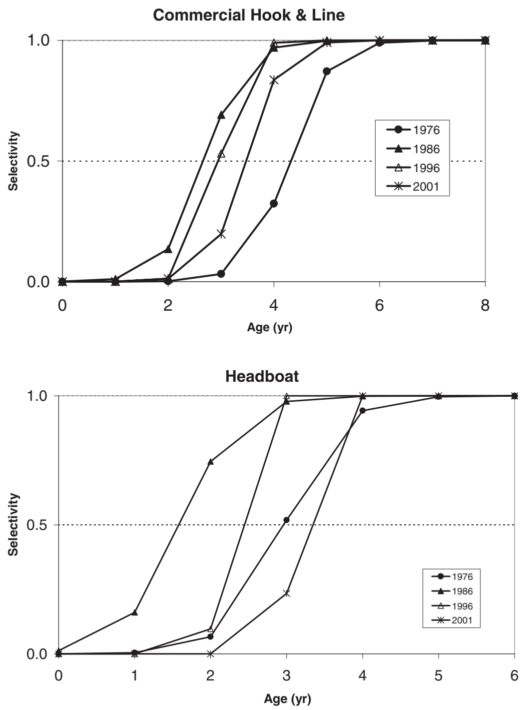


Figure 9. Trajectories of SSB and recruitment of red porgy, estimated from base case of RPM2002 model.

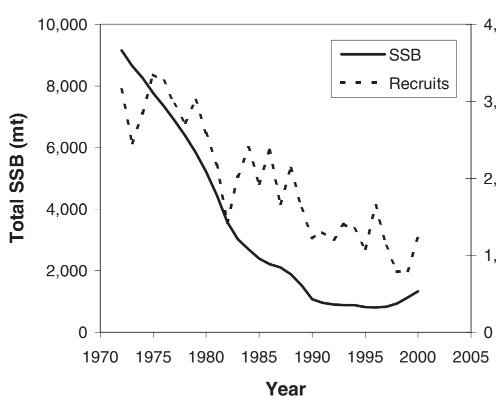


Figure 10. SSB and recruitment of red porgy estimated from RPM2002 model with estimated Beverton–Holt recruitment model.

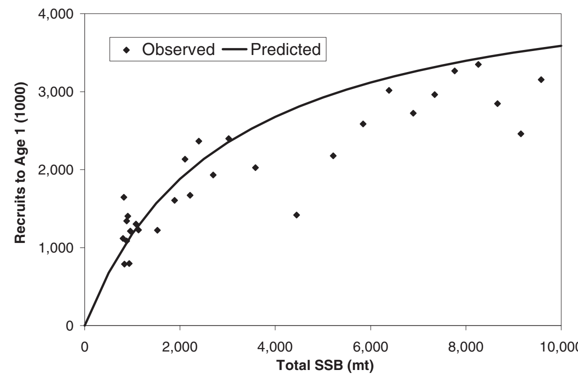
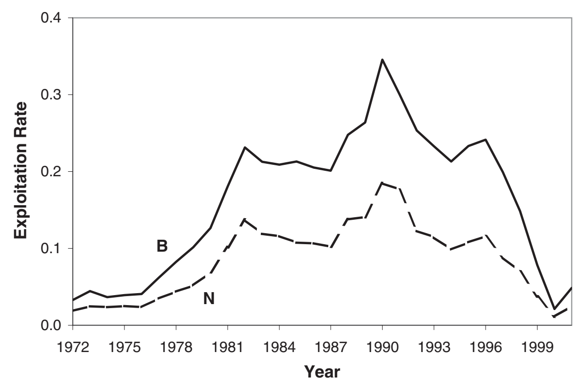
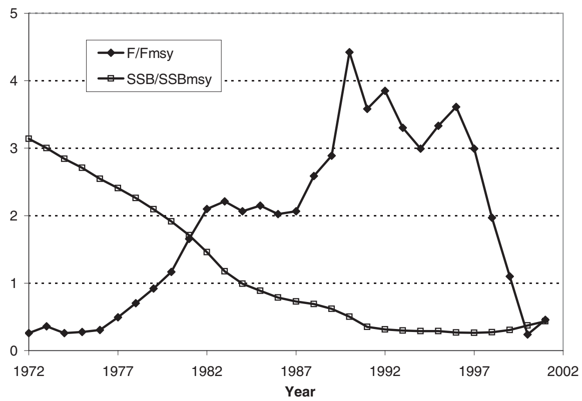


Figure 11. Exploitation rates (proportion of stock harvested per year) estimated by base run of age-structured model. B = rate in biomass; N = rate in numbers.



Age determination When the length-to-age information from North Carolina, which tends to assign older ages, was used (run x58, Table 3), the estimate of F_{MSY} increased slightly and the estimate of the ratio F_{2001}/F_{MSY} declined slightly. The estimate of stock status (B_{2001}/B_{MSY}) did not change appreciably; the most marked change was that MSY was estimated somewhat higher than in the base run. Use of NC aging in combination with low CVs (run x59) produced essentially the same results (Table 3).

Figure 12. Stock status and fishery status estimated from base run of age-structured model.



Natural mortality rate Model runs with a lower natural mortality rate ($M = 0.2$/yr, run x60) or higher mortality rate ($M = 0.25$/yr, run x61) resulted in estimates similar to those of the base run (Table 3).

Truncated data set This run was made to explore what our impression of stock status might be if we had only recent data. In that case (run x62), the estimate of stock status would be somewhat more optimistic than it is from the full data set, but MSY would be estimated somewhat lower (Table 3).

Approximated discards When an approximation for regulatory discards in recent years was added to commercial and headboat landings (run x63, Table 3), most results were not appreciably different from the base run. The exception is that fishing mortality rate in 2001 was estimated to be a substantially higher than in the base run.

6.1.4 Summary of age-structured model results

The sensitivity runs encompassed many changes to input data or model assumptions, yet the model estimates of stock status and fishery status did not change very much. The SAW believes that this occurred because the signal in the abundance indices (Figure 7) and patterns of size composition over time (Figures 3–5) are so strong that only one interpretation is consistent with the observed data. That interpretation is a severe decline in abundance of the stock over time, with signs of increase from the recent moratorium and Amendment 12.

6.2 Production model

6.2.1 Application of production model

Data used for production modeling were total landings and the four abundance indices described in Sections 3.2 and 3.4. Because the abundance indices were all given the same relative statistical weights by the SAW in the base age-structured model run, they were given equal weighting for the production model, as well.

In stocks that display a sharp initial decline, production model results can be sensitive to the value assumed for B_1/K, where B_1 is the biomass at the start of the time series, and K is the carrying capacity. Ideally B_1/K can be freely estimated as a parameter of the production model, but in some cases it can be quite poorly determined, and in such cases a frequently used technique is to fix the value of B_1/K (Punt 1990). To examine any such sensitivity, model fits were made with fixed B_1/K in the set of values $\{0.65, 0.75, 0.85, 0.95\}$ and B_1/K freely estimated.

6.2.2 Results of production model

Using the logistic (Schaefer) production model, fits to the index data series were generally good, with the rather ragged "Florida" trap series proving most difficult to fit. That seems a consequence of noise in the series, rather than model

Figure 13. Trajectories of B/B_{MSY} and F/F_{MSY} from logistic production model of red porgy. Plots with open circles represent B_1/K freely estimated [top curve in (a)] or fixed at values 0.95, 0.85, 0.75, 0.65. Plot with filled diamonds is from shorter data series, starting in 1984.

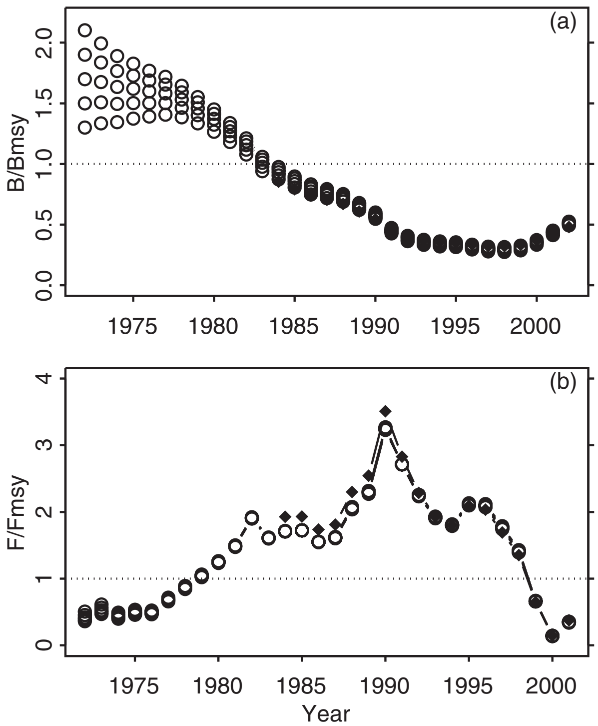
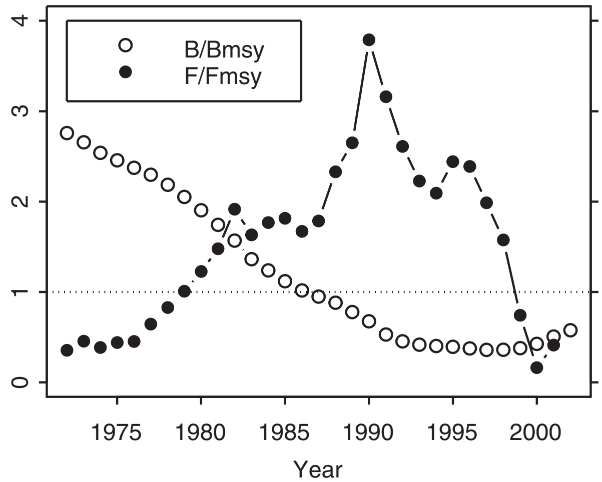


Figure 14. Trajectories of B/B_{MSY} and F/F_{MSY} from Fox (1970) production model of red porgy.



insufficiency.

Results from the logistic model were not sensitive to the value of B_1/K specified (or estimated), and estimated population trajectories for all values were indistinguishable after about 1990 (Figure 13a). Trajectories of relative fishing mortality rate differed even less (Figure 13b). The run with B_1/K freely estimated resulted in a reasonable population trajectory, and since model results were not sensitive to the value of B_1/K, the run with B_1/K freely estimated was chosen as most representative (base run for the production model).

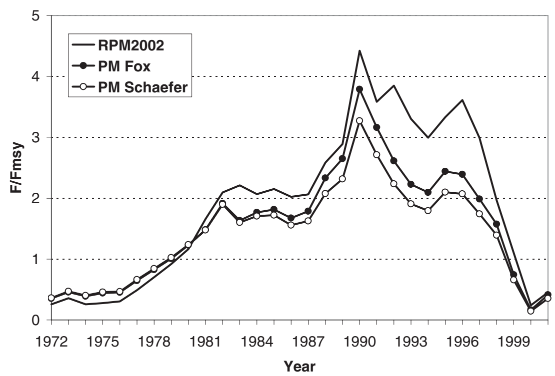
Estimates of management quantities from the logistic production model are similar to those of the base age-structured model (Table 3). Like the age-structured model, this model describes the stock in 2001 as overfished (depleted) but not undergoing overfishing. The confidence intervals reported for production–model estimates (Table 3) tend to underestimate the uncertainty in the analyses, as is true of most confidence intervals reported for fisheries model estimates. Confidence intervals for the production model were derived from bootstrapping.

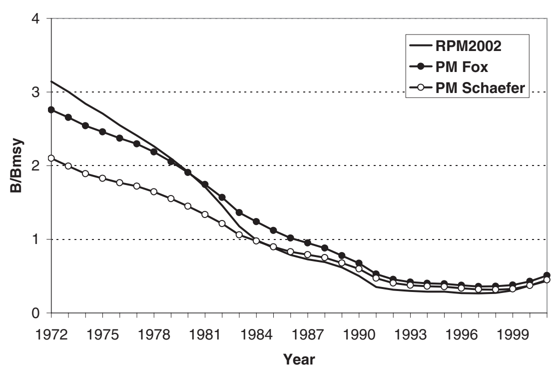
Trajectories estimated from the Fox production model were similar to those estimated from the Schaefer model (Figure 14), but slightly more optimistic in terms of present status. However, the estimates of MSY and F_{MSY} are both lower than from the logistic model (Table 3). As discussed below, some estimates from the Fox model are more similar to those from the age-structured model than are corresponding estimates from the Schaefer model.

6.3 Comparison of models

Estimated trajectories of stock status and fishery status from the models used in this assessment agree remarkably well, especially in the most recent years (Figure 15). Given the different assumptions used by each type of model and the lack of age structure in the production models, this degree of agreement increases the SAW's confidence in the assessment results.

Figure 15. Comparison of estimated fishery and stock trajectories from age-structured model (RPM2002) and Fox and Schaefer (logistic) production models.





Like the trajectories, estimates of management quantities are quite similar between the production models and the age-structured model (Table 3). As noted above, for theoretical reasons the Fox model may be more consistent with the use of a Beverton–Holt recruitment model by the age-structured model used. It is therefore interesting to see that, of the two production models, the Fox model provides estimates of management quantities that agree more closely to those from the RPM2002 model.

Because the age-structured model incorporates far more information on the stock's biology and on the characteristics of the fishery, the SAW considers the RPM2002 age-structured model (in particular, base run x47b) the more reliable assessment tool. As such, its estimates are considered most likely to be accurate, and the production models and sensitivity runs are considered to give less definitive views of the population. Nonetheless, all models give the same basic picture of the stock's status in 2001: the stock was overfished (depleted), being reduced to about 44% of SSB_{MSY}, yet it was not undergoing overfishing, as F_{2001} was about 45% of F_{MSY}. The production-model estimates vary from those figures by about ±5%, but are essentially the same.

6.4 Comparison to previous assessments

Results from the base run of RPM2002 are qualitatively consistent with results from earlier red porgy stock assessments and stock-status update reports. In an update report using age-aggregated and age-structured production models, Vaughan et al. (2001) concluded that the red porgy stock was in poor condition, i. e., that the fishing mortality rate in 2000 was well below MFMT (about 34%–44% of F_{MSY}), and stock biomass was well below MSST (about 13%–25% of SSB_{MSY}). Corresponding estimates from the present assessment for 2000 are F/F_{MSY} = 24% and B/B_{MSY} = 37%. The present results thus agree qualitatively with the results of the stock update report, but are more optimistic about the degree of stock depletion.

A full assessment using data through 1997 and a natural mortality rate of 0.28/yr (Vaughan and Prager 2002) estimated average F/F_{MSY} for

1992–1996 in the range 2.7–3.6 and B/B_{MSY} for the same period in the range 0.28–0.39. Those ranges of estimates include the average estimates of $F/F_{MSY} = 3.4$ and $B/B_{MSY} = 0.29$ for the same time period from the present assessment. Similarly, the previous assessment estimated a decline in spawning biomass of 89% from 1975 to 1997, which is essentially the same as the estimate of 88% from the present assessment (Figure 12). Estimates of other management quantities from the RPM2002 base run differ somewhat from the earlier assessment. Again, the two assessments are in good qualitative agreement, but quantitatively, they differ slightly.

The main differences between previous assessments and this assessment were the extensive data preparation by DW and SAW and the use of an age-structured model not subject to excessive recent-year uncertainty due to retrospective patterns. The data-preparation process was time consuming and labor intensive, yet because almost every data issue was resolved, the assessment could take place with more certainty. The use of RPM2002 instead of VPA allows much better presentation of results, which do not have to be averaged across recent years; and it is not necessary to dismiss the resulting estimates of fishing mortality rate or stock numbers in the most recent years as questionable.

6.5 Additional information on CD–ROM

The Red Porgy 2002 CD–ROM produced by DW and SAW participants contains additional information about the RPM2002 model as used in this assessment. Specifically, the CD–ROM includes code, input files, output files, graphs, tables, and similar technical material, as well as all data used in the assessment. The CD–ROM also contains input and output files from production modeling.

7 Biological reference points

7.1 Proxies and estimated reference points

The SAW's scientific advice is that estimates of F_{MSY}, B_{MSY}, and related quantities, from the base run of this assessment (Table 3 on page 20) be used instead of current proxies for MFMT and MSST. In particular the SAW recommends consideration of the status indicators F_{2001}/F_{MSY} and B_{2001}/B_{MSY}. There is no need to use proxies, because the actual quantities have been estimated. Also, existing proxies, which are based on spawning potential ratio (SPR), have not proven sufficiently restrictive to maintain the stock (Vaughan and Prager 2002, and this report).

Unfortunately, no firm theoretical basis is known for deriving an SPR value to maintain high sustainable yields without having detailed knowledge of the species' population characteristics, knowledge that is sufficient to compute actual benchmarks. Several levels of SPR have been recommended in the fisheries literature as general cases, and those levels have tended to increase as empirical experience has accumulated. For example, Goodyear (1993) recommended 20% to 30% as "critical levels," Clark (1993) recommended 40% (an increase from his earlier recommendation of 35%), and Mace (1994) recommended using 40% SPR as a default in many conditions. Clark (2002) found that "at low …levels of resiliency, the $F_{40\%}$ strategy results in undesirably low levels of biomass and recruitment by present-day standards."

In summary, SPR proxies can be useful approximations when management quantities cannot be estimated. For red porgy, the use of SPR proxies is unnecessary, and use of actual benchmarks has a firmer biological basis.

7.2 Relationship of F_{MSY} to M

The estimate of F_{MSY} from the base run model is 0.19/yr, which is about 16% less than the value $M = 0.225$/yr assumed for the natural mortality rate. Knowledge of the theoretical and practical relationships among biological reference points is still evolving in fishery science. Nonetheless, studies and reviews in the last 25 yr have concluded that M is best considered an upper bound for F_{MSY} and that assuming $F_{MSY} = M$ will lead to unsustainable fishing in some stocks (Francis 1974; Deriso 1982; Thompson 1993; Quinn and Deriso 1999). The estimate of F_{MSY} from the base case is consistent with those studies.

7.3 Protogyny and reference points

The protogynous nature of red porgy creates complications in management not encountered with gonochoristic species. Protogynous species may switch from female to male as they age. Selective removal of larger fish, predominantly males, can effect the reproductive potential of the population to some unknown degree. SSB in this assessment combines males and females and therefore assumes both sexes have equal contributions to production of recruits. Preliminary examination of SSB by sex indicates the fast drop in SSB in the early years of the fishery was due to the removal of large males and male spawning biomass. The female spawning biomass was reduced at a slower rate particularly after imposition of minimum size limits.

In such a situation, a target fishing mortality with large minimum sizes in the fishery is likely to result in differential mortality between the sexes. Consequently, the target fishing mortality may achieve the target SSB while the corresponding sex ratio of the population may not be optimal for sustaining yield. For that reason, Vaughan et al. (1992) recommended use of total mature biomass, rather than female mature biomass, in estimation of reference points based on spawning biomass. The effect of fishing on the transition rate from female to male has not been well studied. In devising management measures to rebuild the spawning stock, the size and sex structure of the target SSB should be considered as well as its total biomass.

8 Stock projections

To evaluate the likely effects of possible future management measures, simulations were used to project the stock forward, starting with stock status estimated by the base run. That stock status was projected ahead 25 years into the future based upon each of four fixed–F management regimes derived from recent regulations (Table 1). Projections under each management regime were repeated 1000 times. Details of projections are in spreadsheet file `rp_rebuild.xls` on the CD–ROM.

8.1 Structure of simulations

Projections used a simulated age-structured population with a stochastic spawner–recruit model to generate recruitments. Stochastic fishing mortality was applied in each of the 25 years of each simulation.

The 25-year projection under each management regime was repeated 1000 times, with different stochastic recruitment and fishing-mortality values applied for each realization. The rebuilt state was defined as the stock's reaching $SSB_{MSY} = 3049.5$ mt, a value estimated by the base case run (Table 3). The proportion of realizations that reached or exceeded the rebuilt state in each projection year was used as an estimate of the stock's probability of attaining the rebuilt state by January 1 of that year under that management regime.

Initial stock size and *F* Initial (2001) stock sizes at age were as estimated by the base run from this assessment. Each projection applied the estimated *F* from run x63 (the sensitivity run with estimated discards; Table 3) to the first year (2001) of the calculations.

Life-history parameters Proportions mature at age, sex ratios at age, and release mortality rates (35% commercial, 8% recreational) were those provided by the Data Workshop.

Stock–recruitment model Population projections require a stock–recruitment model. Here, the Beverton–Holt model and its parameters as estimated in the base run were used. The model was stochastic, as described below.

Biological reference points Biological reference points (MSY, F_{MSY}, B_{MSY}) were those estimated within the base run.

Stochasticity All projections carry an element of uncertainty greater than assessment itself; in these projections, stochasticity (randomness) was incorporated in two places, recruitment and fishing mortality.

Stochastic recruitments were simulated from the estimated stock–recruitment relationship with a nonparametric bootstrap procedure. In that procedure, predicted recruitments were based on the model's predicted recruitment, with a multiplicative error (variation) defined by the logarithm of a randomly-chosen residual from the stock–recruitment model fit. Thus, a degree of variation about the ideal stock–recruitment curve was maintained, similar in magnitude to the variation in the estimated SSB and recruitment values from the assessment.

Fishery management is thought to exercise imperfect control of fishing mortality rate; thus, implementation uncertainty of management is an important consideration. This was incorporated into the simulations by drawing each year's value of *F* from a random distribution. The distribution used was a uniform distribution with range 0.5 to 1.5 times the nominal value of *F*. In the following, the phrase "fixed *F*" is used to signify that this *nominal* value of *F* did not change from year to year. The realized value did change, in accordance with the stochastic procedure just described.

8.2 Fishing mortality rates for projections

Each projection began in 2001 by applying the fishing mortality rate estimated from the sensitivity run with discards (Table 3, run x63) for that year to population sizes estimated for the same year. In the remaining years of each projection, constant nominal *F* over time was applied, based on one of four management regimes. The regimes considered were:

1. $F = 0$
2. F = bycatch mortality only (moratorium)
3. F as in Amendment 9
4. F as in Amendment 12

Determining a nominal value of *F* to represent each of the preceding regimes was not completely straightforward. The exception was the $F = 0$ regime, which is trivial (no catch, bycatch, or catch-and-release mortality). However, setting *F* for the other regimes was more difficult.

8.2.1 Initial approach

An initial approach produced an approximation of F due to Amendment 12 much higher than the fishing mortality rate estimated by the base-case assessment for 2001, the only complete year in which Amendment 12 was in place. Therefore, the initial approach was modified to take into account the estimates from the base case.

The initial approach for the three management regimes with $F \neq 0$ was based on estimating proportional reductions in F, or *savings* (to the stock), due to the moratorium or Amendment 9 or 12. (The procedure is described in detail in Appendix C.) The raw savings proportion was calculated relative to average fishing mortality rates in 1992–1998, when Amendment 4 was in place (Table 1).

Raw savings proportions (Table 4 on page 40) were multiplied by $(1 - R_i)$ by fishery, where R_i is the catch-and-release mortality rate for fishery i, to compute net savings proportions. This step simply reduces the projected savings to the stock by the catch-and-release mortality rate, under the assumption that fishermen are unable to avoid catching fish, but release them in accordance with the management regime in place. The complement of net savings proportion P_i for fishery i is defined as $1 - P_i$. Multiplying the complements, weighted by fishery, by the mean F for 1992–1998 from the base run gave the overall approximation $F = 0.326$/yr for fishing under Amendment 12.

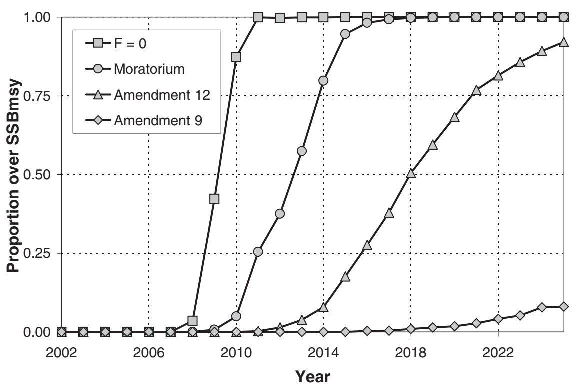
8.2.2 Final approach

Amendment 12 When considering the above approximation of $F = 0.326$/yr for Amendment 12, the SAW noted that F for 2001 (when Amendment 12 was in place) was estimated to be much lower (0.09/yr) by the base assessment. This discrepancy suggested that greater reductions in F were realized by Amendment 12 than were formalized in the initial calculations. The SAW decided, however, that simply using the estimate of F_{2001} from the base assessment would understate F under Amendment 12, because considerable unreported discarding is believed to have taken place under Amendment 12. An age-structured model sensitivity run was made with approximated increased discards during 1999–2001 (run x63, Table 3), and the SAW selected $F_{2001} = 0.107$/yr from that run as the most appropriate value for use in projections under Amendment 12.

Amendment 9 Because Amendment 9 was in place only from February through August of 1999, there is no estimate of F from the base run that would characterize Amendment 9. The SAW proceeded by assuming that the initial approach was biased in estimating F for Amendment 9 similarly to its bias in estimating F for Amendment 12. The SAW then made a proportional increase to the base-case F for Amendment 12 to arrive at F for Amendment 9.

To approximate the F under Amendment 9, then, the initial calculation of savings from Amendment 9 was adjusted by release mortality and then averaged across fisheries, giving overall savings of 11.1% (14.4% before adjustment for release mortality). Averaging savings by fishery and using the base-run mean F for 1992–1998 gives the initial approximation $F = 0.527$/yr. Applying the proportional reduction actually gained by Amendment 12, the SAW arrived at the approximate value $F = 0.527 \times 0.107/0.326 = 0.173$/yr for use in projections under Amendment 9.

Figure 16. Projections of the red porgy stock for 25 years. Annual probabilities of attaining rebuilt state under four management regimes.



Moratorium Fishing mortality under a moratorium would be composed solely of catch-and-release mortality. Unfortunately, there are no data that would allow approximation of the number of fish caught and released under a moratorium. Because of this uncertainty in knowing the gain from a moratorium, F for this situation was assumed to be one-half of that for Amendment 12, or 0.0535/yr.

8.3 Projection results

The first year of all projections applied the fishing mortality rate in 2001 (F_{2001}) to the stock biomass in that year (B_{2001}). In that sense, the first year was a direct extension of the assessment model, rather than a projection. That procedure estimates a slight increase in spawning–stock size during 2001, from 1326 mt to 1379 mt, or about 4%, equivalent to SSB_{2002}/SSB_{MSY} = 45.2%.

Under $F = 0$, the probability of attaining the target is essentially zero until 2008, when it reaches about 3.5%. The probability first exceeds 50% in 2010, when it is 87% (Figure 16). Under a moratorium, the probability of reaching the rebuilt state is about 5% in 2010 and first exceeds 50% in 2013, when it is 57%. Under Amendment 12, the probability of reaching the rebuilt state is about 4% in 2013 and first exceeds 50% in 2018, when it is 51%. Under Amendment 9, the probability of reaching the rebuilt state rises to 8% in 2025, the last year of the projections.

A more detailed picture of the projection results is given by looking at the 5th, 50th (median), and 95th percentiles of outcomes for each management regime by year (Figure 17). In particular, it can be seen that gradual stock building is predicted under Amendment 12, and an even more gradual stock building is predicted under Amendment 9. Projections are by nature uncertain, but these projections represent the SAW's best estimates of possible stock building scenarios for the four management options requested.

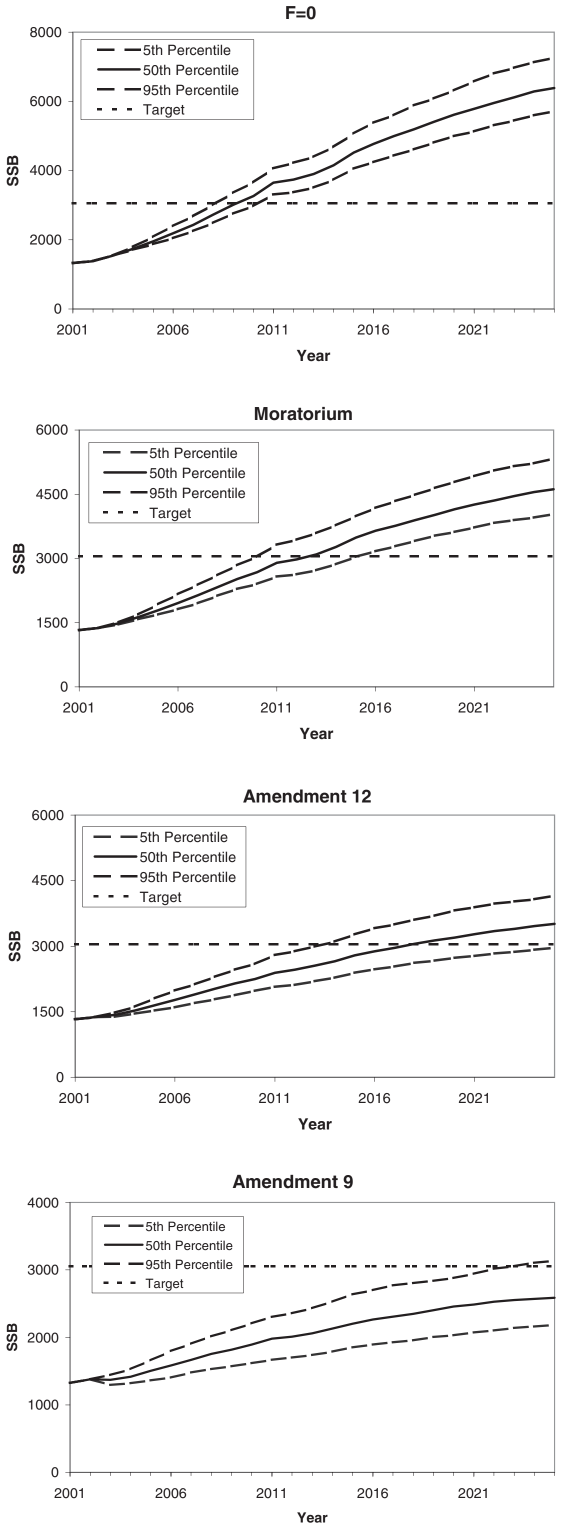
9 Research recommendations

The SAW discussed aspects of the biology, sampling, and assessment of this population that make accurate and precise assessment more difficult. Execution of the following recommendations for research and data management could improve future assessments of red porgy.

1. The discrepancy between SC and NC aging is a major one that must be resolved, preferably before the next assessment. The SAW recommends that as soon as possible, the NC and SC investigators meet and share age readings techniques, to resolve the systematic discrepancies in age determinations, if possible. The SAW further recommends that research be undertaken that will accomplish verification of aging in red porgy.

2. The protogyny of red porgy is a life–history feature that complicates assessment and management. The SAW recommends that

Figure 17. Projections of the red porgy stock for 25 years under four management regimes.



sampling for sex ratio at length be instituted in each fishery and that population sampling for sex ratio at length be continued by the MARMAP program. The SAW further recommends that research be instituted into assessment and population-projection methods that can make better use of sex-ratio data that exist now and that may exist in the future.

3. Under many forms of management, considerable discarding of red porgy could be expected to occur. The SAW recommends that sampling programs be initiated to quantify discard rates, especially in the commercial fishery, where the discard mortality rate is believed higher, and to estimate discard mortality rates. The SAW recommends that research be instituted on management strategies that could reduce discard mortality and also research to illustrate the effects of discard mortality. The SAW also recommends that socioeconomic research be considered on educational measures to assist fishery participants in minimizing discard mortality and understanding the value of doing so.

4. Fishery-independent data collected by the MARMAP program have served an important role in understanding the dynamics of this population, and the National Research Council has recommended that fishery-independent data play a more important role in stock assessment generally. However, the MARMAP sampling programs have been criticized by some as not having ideal extent, both in area coverage and in sampling intensity, for red porgy. The SAW recommends that the MARMAP program expand its coverage as needed.

5. During the DW and SAW, it was noted that some incomplete, or misleading data have been entered in the NMFS general canvass data base. In particular, some data are available only under aggregated categories (e. g., porgies), even when accepted corrections to provide estimates of red porgy landings exist. The SAW recommends that state agencies contact and work with NMFS personnel maintaining the general canvass data base to make sure that data in that central data base are at the most disaggregated level possible and as accurate as possible. The goal is that future red porgy assessment should be able to use data from the general canvass data base with confidence and without further corrections.

References

Clark, W. G. 1993. The effect of recruitment variability on the choice of a target level of spawning biomass per recruit. Pages 233–246 *in* Proceedings of the International Symposium on Management Strategies for Exploited Fish Populations. Alaska Sea Grant College Program, AK–SG–93–02.

Clark, W. G. 2002. $F_{35\%}$ revisited ten years later. North American Journal of Fisheries Management 22: 251–257.

Collins, M. R. 1996. Survival estimates for demersal reef fishes released by anglers. Proceedings of the 43rd Annual Gulf and Caribbean Fisheries Institute, Nassau, Bahamas, November 1991.

Deriso, R. B. 1982. Relationship of fishing mortality and growth and the level of maximum sustainable yield. Canadian Journal of Fisheries and Aquatic Sciences 39: 1054–1058.

Fox, W. W. 1970. An exponential surplus-yield model for optimizing exploited fish populations. Transactions of the American Fisheries Society 99: 80–88.

Francis, R. C. 1974. Relationship of fishing mortality to natural mortality at the level of maximum sustainable yield under the logistic stock production model. Journal of the Fisheries Research Board of Canada 31: 1539–1542.

Goodyear, C. P. 1993. Spawning stock biomass per recruit in fisheries management: foundation and current use. Pages 67–81 *in* S. J. Smith, J. J. Hunt, and D. Rivard, editors. Risk evaluation and biological reference points for fisheries management. Canadian Special Publications in Fisheries and Aquatic Sciences 120.

Mace, P. M. 1994. Relationships between common biological reference points used as threshold and targets of fisheries management strategies. Canadian Journal of Fisheries and Aquatic Sciences 51: 110–122.

Manooch, C. S., III. 1976. Reproductive cycle, fecundity, and sex ratios of the red porgy, *Pagrus pagrus* (pisces: Sparidae) in North Carolina. Fishery Bulletin 74: 775–781.

Manooch, C. S., III, L. E. Abbas, and J. L. Ross. 1981. A biological and economic analysis of the North Carolina charter boat fishery. Marine Fisheries Review 43(8): 1–11.

Manooch, C. S., III, and W. W. Hassler. 1978. Synopsis of biological data on the red porgy, *Pagrus pagrus* (Linnaeus). NOAA Technical Report NMFS Circ. 412, 19 p.

Methot, R. M. 1989. Synthetic estimates of historical abundance and mortality for northern anchovy. American Fisheries Society Symposium 6: 66–82.

Otter Research, Ltd. 2000. An introduction to AD Model Builder version 5.0.1 for use in nonlinear modeling and statistics. Otter Research, Sidney, B.C., Canada.

Pella, J. J., and P. K. Tomlinson. 1969. A generalized stock production model. Bulletin of the Inter-American Tropical Tuna Commission 13: 419–496.

Prager, M. H. 1994. A suite of extensions to a nonequilibrium surplus–production model. Fishery Bulletin 92: 374–389.

Prager, M. H. 1995. User's manual for ASPIC: A stock-production model incorporating covariates, program version 3.6x. NMFS Southeast Fisheries Science Center, Miami Laboratory Document MIA–2/93–55, 4th ed. Available from M.H.P.

Punt, A. E. 1990. Is $B_1 = K$ an appropriate assumption when applying an observation error production-model estimator to catch–effort data? South African Journal of Marine Science 9: 249–259.

Quinn, T. J., and R. B. Deriso. 1999. Quantitative Fish Dynamics. Oxford University Press, New York. 542 pp.

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

SAFMC (South Atlantic Fishery Management Council). 1988. Amendment number 1 and environmental assessment and regulatory impact review to the fishery management plan for the snapper–grouper fishery of the south Atlantic region. South Atlantic Fishery Management Council, Charleston, SC.

SAFMC (South Atlantic Fishery Management Council). 1991. Amendment number 4, regulatory impact review, initial regulatory flexibility analysis, and environmental assessment for the fishery management plan for the snapper–grouper fishery of the south Atlantic region. South Atlantic Fishery Management Council, Charleston, SC.

SAFMC (South Atlantic Fishery Management Council). 1988. Amendment number 9, final supplemental environmental impact statement, initial regulatory flexibility analysis/regulatory impact review, and socal impact plan for the snapper–grouper fishery of the south Atlantic region. South Atlantic Fishery Management Council, Charleston, SC.

SAFMC (South Atlantic Fishery Management Council). 2000. Final amendment number 12 to the fishery management plan for the snapper–grouper fishery of the south Atlantic region. South Atlantic Fishery Management Council, Charleston, SC. 159 p. + appendices.

Schaefer, M. B. 1954. Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. Bulletin of the Inter-American Tropical Tuna Commission 1(2): 27–56.

Schaefer, M. B. 1957. A study of the dynamics of the fishery for yellowfin tuna in the eastern tropical Pacific Ocean. Bulletin of the Inter-American Tropical Tuna Commission 2: 247–268.

Shepherd, J. G. 1982. A versatile new stock–recruitment relationship for fisheries, and the construction of sustainable yield curves. Journal du Conseil pour l'Exploration de la Mer 40: 67–75.

Sigler, M. F., J. T. Fujioka, and S. A. Lowe. 1997. Sablefish. *In* Stock assessment and fishery evaluation for the Gulf of Alaska, November, 1997. North Pacific Fishery Management Council, Anchorage, Alaska.

Thompson, G. G. 1992. Management advice from a simple dynamic pool model. Fishery Bulletin 90: 552–560.

Thompson, G. G. 1993. A proposal for a threshold stock size and maximum fishing mortality rate. Canadian Special Publication of Fisheries and Aquatic Science 120: 303–320.

Vaughan, D. S., G. R. Huntsman, C. S. Manooch III, F. C. Rohde, and G. F. Ulrich. 1992. Population characteristics of the red porgy, *Pagrus pagrus*, stock off the Carolinas. Bulletin of Marine Science 50: 1–20.

Vaughan, D. S., E. H. Williams, and M. H. Prager. 2001. Upated status of red porgy off southeastern United States. Unpublished manuscript dated November 7, 2001. NOAA Center for Coastal Fisheries and Habitat Research, Beaufort, NC 28516. Prepared for the South Atlantic Fishery Management Council. One Southpark Circle, Suite 306. Charleston, SC 29407.

Vaughan, D. S., and M. H. Prager. 2002. Severe decline in abundance of the red porgy, *Pagrus pagrus*, population off the southeastern United States. Fishery Bulletin 100: 351–375.

Williams, E. H. 2001. Assessment of cobia, *Rachycentron canadum*, in the waters of the U.S. Gulf of Mexico. U.S. Department of Commerce, NOAA, Technical Memorandum NMFS–SEFSC–469.

Appendix A Terms of reference for red porgy SAW

The Stock Assessment Workshop's task is to produce an assessment of the red porgy stock, including analyses of stock rebuilding. This work should be done with reference to the U.S. Sustainable Fisheries Act and its National Standards, which govern the Council's management. A written final report, providing an overview of the analyses, general findings, and recommendations of the workshop, will be available by conclusion of the workshop. A detailed technical addendum on the models used will be available no later than one week following the workshop.

1. Identify modeling approaches appropriate to the available data and management questions (e. g., production models, age-structured models, hybrids).

2. Determine suitability of current proxies for SFA benchmarks and suitable approaches for estimating actual SFA benchmarks.

3. Estimate stock status (biomass) and fishery status (fishing mortality rate) relative to appropriate SFA benchmarks. Is the stock overfished; is overfishing occurring?

4. Identify and conduct rebuilding analyses comparing management options from Amendment 9, Amendment 12, Moratorium, for $F = 0$, and for other possible scenarios.

5. Provide recommendations for future research (field and assessment).

A list of additional specific questions from the Council may be developed and if so, it will be presented to the Stock Assessment Workshop at its meeting.

Appendix B Workshop attendees

Dagger (†) denotes attendance at Data Workshop only; asterisk (*) denotes attendance at Stock Assessment Workshop only; others attended both workshops.

Virginia Polytechnic Institute and State University
Dept. of Fisheries and Wildlife Science
Cheatham Hall
Blacksburg, VA 24061

Dr. James Berkson (DW and SAW Chair)
(540) 231–5910 — jberkson@vt.edu

Ms. Michelle Davis
(540) 552–3984 — midavis1@vt.edu

Florida Fish and Wildlife Conservation Commission
Florida Marine Research Institute
100 Eighth Ave. Southeast
St. Petersburg, FL 33701–5020

Dr. Robert Muller
(727) 896–8626 — robert.muller@fwc.state.fl.us

† Mr. Joe O'Hop
(727) 896–8626

North Carolina Division of Marine Fisheries
Post Office Box 769
Morehead City, NC 28557

Mr. John Carmichael
(252) 726–7021 — john.carmichael@ncmail.net

Dr. Louis Daniel
(252) 726–7021 — louis.daniel@ncmail.net

† Mr. Jack Holland
(252) 726–7021

† Mr. Fritz Rohde
(252) 726–7021

South Carolina Department of Natural Resources
P.O. Box 12559
Charleston, SC 29422

† Ms. Nan Jenkins

† Dr. John McGovern
(843) 762–5414 —
mcgovernj@mrd.dnr.state.sc.us

Dr. Pat Harris
(843) 406-4034 — harrisp@mrd.dnr.state.sc.us

† Dr. George Sedberry
(843) 795–6350 —
sedberryg@mrd.dnr.state.sc.us

† Mr. David Wyanski

National Marine Fisheries Service—Beaufort
NOAA Center for Coastal Fisheries and Habitat Research
101 Pivers Island Road
Beaufort, NC 28516

Mr. Bob Dixon
(252) 728–8719 — robert.dixon@noaa.gov

† Dr. Charles Manooch (retired)

Dr. John Merriner
(252) 728–8708 — john.merriner@noaa.gov

Ms. Jennifer Potts
(252) 728–8715 — jennifer.potts@noaa.gov

* Dr. Michael Prager
(252) 728–8760 — mike.prager@noaa.gov

Dr. Douglas Vaughan
(252) 728–8761 — doug.vaughan@noaa.gov

Dr. Erik Williams
(252) 728–8603 — erik.williams@noaa.gov

National Marine Fisheries Service—Miami
Southeast Fisheries Science Center
75 Virginia Beach Drive
Miami, FL 33149

* Dr. Dennis Heinemann
(305) 361–4498 — dennis.heinemann@noaa.gov

† Mr. John Poffenberger (305) 361–4263 —
john.poffenberger@noaa.gov

National Marine Fisheries Service—Panama City
3500 Delwood Beach Road
Panama City, FL 32408

† Dr. Douglas DeVries
(850) 234–6541 — doug.devries@noaa.gov

National Marine Fisheries Service—Pascagoula
P.O. Drawer 1207
Pascagoula, MS 35968

Dr. Scott Nichols
(228) 762–4591, ext. 269 —
scott.nichols@noaa.gov

National Marine Fisheries Service—Woods Hole
Northeast Fisheries Science Center
166 Water Street
Woods Hole, MA 02543

* Mr. Gary Shepherd
(508) 495–2368 — gary.shepherd@noaa.gov

National Marine Fisheries Service—HQ
1315 East West Highway
Silver Spring, MD 20910

* Dr. Alan Lowther
(301) 713–2328 — alan.lowther@noaa.gov

South Atlantic Fishery Management Council—Snapper–Grouper Advisory Panel

† Mr. Mark Marhefka
1676 Culpepper Circle
Charleston, SC 29407
(843) 729–5497

South Atlantic Fishery Management Council—Snapper–Grouper Panel

Mr. Wayne Lee
3000 Raymond Avenue
Kill Devil Hills, NC 27948
(252) 480–1287 — cwlee2@mindspring.com

South Atlantic Fishery Management Council—staff
One Southpark Circle, Suite 306
Charleston, SC 29407

† Mr. Rick DeVictor
(843) 571–4366 — rick.devictor@safmc.net

† Mr. Vishwanie Maharaj (843) 571–4366 —
vishwanie.maharaj@safmc.net

† Ms. Margaret Murphy (843) 571–4366 —
margaret.murphy@safmc.net

† Ms. Kerry O'Malley
(843) 571–4366 — kerry.omalley@safmc.net

Ms. Megan Peabody
(843) 571–4366 — megan.peabody@safmc.net

Mr. Gregg Waugh
(843) 571–4366 — gregg.waugh@safmc.net

Invited Fishermen

Mr. Jodie Gay

Appendix C Initial approximation of effects of management measures

C.1 Introduction

Prior to 1992, no regulations on red porgy were in place. In 1992, a 12" TL minimum size limit was put in place, followed by a 14" TL minimum size limit in 1999. Amendment 12 to the SAFMC Fishery Management Plan for the Snapper–Grouper Complex consists of the following regulations concerning red porgy. For the recreational fisheries (charter and private boat and headboat) there was a 1–fish bag limit. For the commercial fishery (primarily lines and traps), there was a four–month closure (Jan–Apr) and 50-lb trip limit (May–Dec).

For the purpose of adjusting age-specific fishing mortality rates from a base period (e. g., 1992–1998 during which there was the 12" TL minimum size limit), savings from the above regulations are calculated based on the legal size fish (red porgy 14" TL), because savings are applied relative to *F* on legal size fish, while release mortality is used to reduce *F* on sublegal size fish.

Because comparisons are to a base period (1992–1998), it was assumed that the population size was approximately constant during the base period and that reductions in landings (as proportions) were proportional to reduction in average *F* for the base period.

C.2 Recreational fisheries

Charter and private boat data are from MRFSS; headboat data are from Beaufort Laboratory Headboat Program.

Because savings from the 1-fish bag limit are calculated conditioned on historical trip data (1992–1998) with information on size of fish captured, a subset of trips for which at least 1 fish was measured form the basis of this analysis. There were 79 trips representing 418 anglers from charter boats, 29 trips representing 77 anglers from private boats (no data for 1998), and 607 trips representing 24,533 anglers from headboats that met this criteria for 1992–1998. Because not all fish landed from a trip were measured, it was necessary to proportionally expand the observed size frequency for the subset of measured fish to all fish caught in a trip. The percent of red porgy measured for trips with at least one fish measured was 35% of fish landed for charter boat trips, 31% for private boats, and 10% for headboats. Thus, while there were a greater number of trips and anglers represented in the headboat data, expansion for unmeasured fish was significantly greater for the headboat analysis.

In addition, fish landed during a trip may represent landings from multiple anglers (especially for headboat). To convert these trips to angler-trips, two alternate approaches were used depending on the number of red porgy landed compared to the number of anglers on the trip. When the number of anglers for a trip equaled or exceeded the number of red porgy landed, then the landings per angler-trip was one fish and the number of trips equal to the number of red porgy landed (these trips would be unaffected by the one-fish bag limit). When the number of red porgy landed exceeded the number of anglers, then the number of legal fish under a one-fish bag limit was equal to the number of anglers. The proportion of red porgy saved by the one-fish bag limit would be the number of fish caught minus the number of fish landed with a one-fish bag limit divided by the number of fish landed. To separate savings due to the one-fish bag limit from that of the 14" TL minimum size limit, the above calculations were based only on the expanded number of fish landed greater or equal to 14" TL.

C.2.1 Charterboat fishery

There were 79 trips between 1992 and 1998 for which at least one red porgy was measured. Associated with these trips were 418 anglers and 816 red porgy landed. Because of the 14" TL minimum size limit, the number of fish per angler-trip, savings (unadjusted for release mortality) was calculated based on red porgy greater than or equal to 14" TL. For 1992–1998, 795 red porgy were landed, of which 147 were greater than or equal to 14" TL. If a 1-fish bag had been in place, then 95 red porgy would have been retained legally, or a savings of 35.1% $[100 \times (147-95)/147]$. Annual estimates range from 0% in 1997 (only 1 fish over 14" TL) to 63.6% in 1995 (39 fish over 14" TL and 14 landed under a 1-fish bag limit). Note that of the 5 trips and 46 fish reported caught in 1998, none of the fish measured were greater than or equal to 14" TL.

C.2.2 Private boat fishery

There were 29 trips between 1992 and 1998 for which at least one red porgy was measured. Associated with these trips were 77 anglers and 203 red porgy landed. Because of the 14" TL minimum size limit, the number of fish per angler-trip, savings (unadjusted for release mortality) was calculated based on red porgy greater than or equal to 14" TL. For 1992–1998, 203 red porgy were landed, of which 102 were greater than or equal to 14" TL. If a 1–fish bag had been in place, then 15 red porgy would have been retained legally, or a savings of 85.4% $[100 \times (102-15)/102]$. Annual estimates range from 0% in 1993 and 1995 (only 1 fish over 14" TL in each year) to 96.3% in 1996 (81 fish over 14" TL and 3 landed under a 1-fish bag limit).

C.2.3 Headboat fishery

There were 607 trips between 1992 and 1998 for which at least one red porgy was measured. Associated with these trips were 24,533 anglers and 30,746 red porgy landed. Because of the 14" TL minimum size limit, the number of fish per angler-trip, savings (unadjusted for release mortality) was calculated based on red porgy greater than or equal to 14" TL. For 1992–1998, 30,746 red porgy were landed, of which 11,650 were greater than or equal to 14" TL. If a 1-fish bag had been in place, then 8,478 red porgy would have been retained legally, or a savings of 27.2$[100 \times (11650-8478)/11650]$. Annual estimates range from 14.4% in 1996 (1,804 fish over 14" TL and 1,544 fish landed under a 1-fish bag limit) to 34.5% in 1992 (1,860 fish over 14" TL and 1,218 landed under a 1-fish bag limit).

C.3 Commercial fishery

A similar approach was used for the commercial fishery as for the recreational fisheries. Savings from 50-lb trip limit and seasonal closure were calculated from logbook data from 1992–1998 (logbook data for 1992 was based on 20% selection versus 100% selection for 1993-1998). Where necessary, gutted weight were converted to whole weight (whole = $1.04 \times$ gutted). Because of the difficulty associated with merging the logbook data base (trip information) with the TIP data base (size information), an alternate approach was used for reducing the trip estimates from the logbook data for fish less than 14" TL. Length information from the TIP data base was converted to weight based on the weight-length relationship determined from the MARMAP Aging Data Base (1979–1994). Stratifying the TIP data base by gear (lines and traps), year, month, and state, the weight was summed over fish less that 14" TL and fish greater than or equal to 14" TL. The proportion of fish greater than or equal to 14" TL was then applied to the trip estimates from the logbook within the same stratum. When this proportion was not available for a particular stratum, the following pooling was used. First, TIP data were pooled over months. This was sufficient for all of the line gears (the great majority of landings). For the trap data it was necessary in some cases to pool within a year, and finally the overall proportion for 1992–1997 was applied to 1998 when no trap lengths were available. Savings were calculated from both trip limit and seasonal closure jointly based on gutted weight.

For the period 1992–1998, total commercial landings of 2,324,125 pounds whole weight was landed as reported by logbook. A total of 1,534,293 pounds was landed that were greater than or equal to 14" TL, of which 412,757 pounds would have been landed with the closed season and a 50–lb trip limit, giving a savings of about 73.1%. Annual savings from closed season and trip limit ranged between 63.5% in 1998 and 77.8% in 1994.

Estimated savings from the recreational and commercial fisheries are summarized by year and overall in Table 4. Similar calculations were done for Amendment 9 and included in Table 5. These calculations consist of the same 14" TL minimum size limit, but with a 5-fish bag limit for recreational fisheries and a 2–month closed commercial season (Mar–Apr).

Table 4. Computed savings of red porgy from Amendment 12 for legal size fish (14" TL) compared to 1992–1998 base period. Recreational controls also include a 1-fish bag limit; commercial controls are a 4-month closure (Jan–Apr) and 50-lb trip limit (May–Dec).

Year	Charter	Private	Headboat	Comml.
1992	6.9%	52.9%	34.5%	71.3%
1993	38.0%	0.0%	24.5%	74.6%
1994	21.7%	54.5%	34.0%	77.8%
1995	63.6%	0.0%	27.6%	76.0%
1996	40.0%	96.3%	14.4%	70.7%
1997	0.0%	36.8%	29.8%	71.0%
1998	N/C	N/A	29.8%	63.5%
Overall	35.1%	85.4%	27.2%	73.1%

Note: see file `Recreation Bag Size.xls` for more detail on recreational calculations, and `Commercial Trip&Size.xls` for more detail on commercial calculations.

Table 5. Computed savings of red porgy from Amendment 9 for legal size fish (14" TL) compared to 1992–1998 base period (12" minimum size). Recreational controls also include a 5-fish bag limit; commercial control is a 2-month closure (Mar–Apr).

Year	Charter	Private	Headboat	Comml.
1992	0.0%	0.0%	0.6%	18.1%
1993	0.0%	0.0%	0.0%	15.1%
1994	0.0%	0.0%	0.0%	16.8%
1995	27.0%	0.0%	2.1%	20.3%
1996	10.0%	86.2%	0.0%	13.6%
1997	0.0%	0.0%	0.0%	13.2%
1998	N/C	N/A	0.3%	15.0%
Overall	9.2%	68.3%	0.4%	16.1%

Note: see file `Recreation Bag Size.xls` for more detail on recreational calculations, and `Commercial Trip&Size.xls` for more detail on commercial calculations.

Appendix D—Abbreviations and symbols

Table 6. Acronyms, abbreviations, and mathematical symbols used in this report

Symbol	Meaning
ADAPT	A type of tuned VPA often used in assessment of North Atlantic fish stocks
B	Total biomass of stock
B_{MSY}	Total stock biomass at which MSY can be attained (in production models)
CPUE	Catch per unit effort; used after adjustment as an index of abundance
DW	Data Workshop for red porgy
F	Instantaneous rate of fishing mortality
F_{MSY}	Fishing mortality rate at which MSY can be attained
FL	State of Florida
GA	State of Georgia
K	Average size of stock when not exploited by man; carrying capacity
M	Instantaneous rate of natural (non-fishing) mortality
MARMAP	Marine Resources Monitoring, Assessment, and Prediction Program, a fishery-independent data collection program of SCDNR
MFMT	Maximum fishing-mortality threshold; a limit reference point used in U.S. fishery management; often set to F_{MSY}
MRFSS	Marine Recreational Fisheries Statistics Survey, a data-collection program of NMFS
MSST	Minimum stock-size threshold; a limit reference point used in US fishery management. The SAFMC has defined MSST for red porgy as $(1 - M)B_{MSY} = 0.775B_{MSY}$.
MSY	Maximum sustainable yield
mt	Metric tons(s)
NC	State of North Carolina
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration; parent agency of NMFS
R	Recruitment
RPM2002	The forward-projecting age-structured assessment model used here; see §5.1
SAFMC	South Atlantic Fishery Management Council
SAW	Stock Assessment Workshop for red porgy
SC	State of South Carolina
SCDNR	Department of Natural Resources of SC
SSB	Spawning-stock biomass
SSB_{MSY}	Spawning-stock biomass at which MSY can be attained (in age-structured models)
TIP	Trip Interview Program, a fishery-dependent biodata collection program of NMFS
TL	Total length (of a fish), as opposed to FL (fork length)
VPA	Virtual population analysis, an age-structured assessment model characterized by cohort-wise computations backward in time; "tuned" VPA also employs abundance indices to influence the estimates
yr	Year(s)