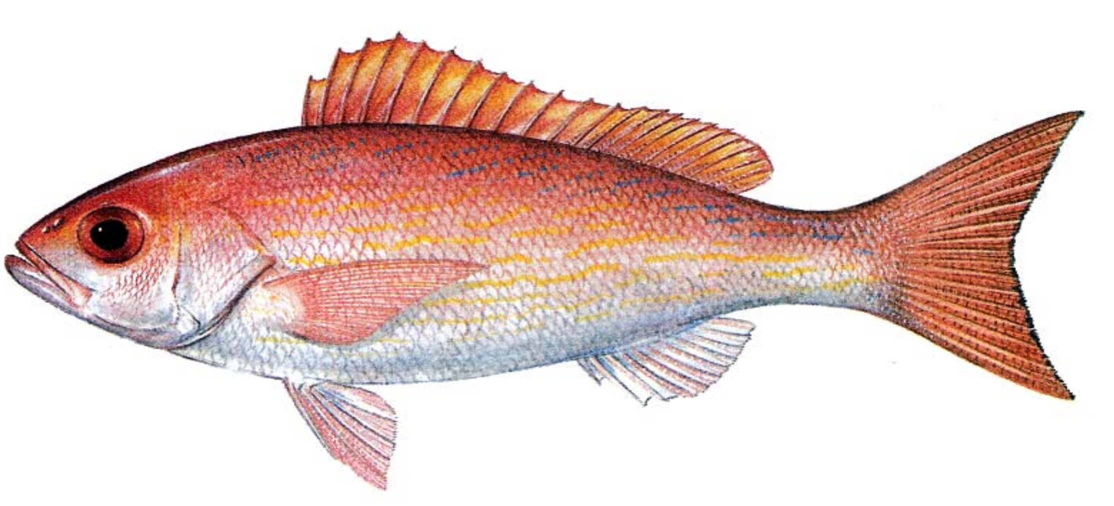
Report of Vermilion Snapper Assessment Workshop

Second SEDAR Process

Beaufort, North Carolina

January 6-10, 2003



Prepared for South Atlantic Fishery Management Council

Charleston, South Carolina

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Executive Summary

The SEDAR stock assessment workshop (AW)[1] was convened by the South Atlantic Fishery Management Council and the NMFS Southeast Fisheries Science Center at the NOAA Center for Coastal Fisheries and Habitat Research, Beaufort, North Carolina on Monday, January 6. The workshop's objectives were to conduct an assessment of the vermilion snapper, *Rhomboplites aurorubens*, stock of 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 AW worked at Beaufort until January 10 and continued its work by email through February 14. All decisions regarding stock assessment methods and acceptable data were made by consensus of participants.

Available data on vermilion snapper included abundance indices and recorded data on landings, including size and age compositions of some landings and indices. Four abundance indices were developed by the preceding data workshop: one from the NMFS headboat survey and three from the SC MARMAP fishery–independent monitoring program. Landings data were available from all recreational and commercial fisheries. Abundance indices showed neither marked increase nor decline during the assessment period (1976–2001).

A forward-projecting model of catch at length was formulated for this stock. Two other models were applied, but neither could provide estimates: a similar forward-projecting model of catch at age and an age-aggregated production model. Consequently, this assessment is based on the catch-at-length model, which was applied in a base run and eight sensitivity runs. The base run estimated that the spawning stock size has increased over the assessment period and that recruitment has been variable, poorly correlated to spawning-stock size, and on average has neither increased nor decreased.

Estimates of stock status from this assessment are quite uncertain. The base run estimated that the stock is not overfished (to use the terminology of the Sustainable Fisheries Act), but most sensitivity runs estimated that the stock is overfished. More technically put, spawning-stock biomass in this assessment was characterized by total egg production $\mathcal{E}$. The base run estimated that the stock status is above $\mathcal{E}_{\text{MSY}}$, and thus above the SFA limit reference point MSST. However, most sensitivity runs estimated that the population is below $\mathcal{E}_{\text{MSY}}$ and also below MSST.

Although still quite uncertain, estimates of fishery status (level of F relative to reference points) were more consistent. All runs estimated that F is excessive by SFA standards (overfishing is occurring). More technically, F was estimated by the base run and all sensitivity runs as substantially above F_{MSY}, and thus also above MFMT, the SFA limit reference point for F.

Stock projections estimated no marked change in stock status or yield with changes in F of $\pm 25\%$. However, given the highly variable recruitment of this stock and the difficulty in estimating reference points, it is difficult to place much confidence in the projection results.

[1] Abbreviations and acronyms used in this report are defined in Appendix C on page 40.

Contents

List of Figures

List of Tables

1 Place, time, and tasks

The vermilion snapper and black seabass stock assessment workshop (Second SEDAR AW)[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 Assessment Workshop (AW) met from 9:00 a.m. on Monday, January 6, to 12:00 noon on Friday, January 10, 2003. The AW continued its work through February 13, aided by e-mail 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, St. Petersburg (FL), and Miami; 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 AW.

The AW's major objectives were to conduct assessments of the stocks of vermilion snapper, *Rhomboplites aurorubens*, and black seabass, *Centropristis striata*, off the southeastern US, and to conduct stock projections under various management regimes (terms of reference, Appendix A). The AW received data and recommendations from the data workshop (DW) convened in October by the Council and the Center. Some of the decisions regarding data made at the DW were refined during the AW. At both workshops, all decisions affecting the assessment were made by consensus of all participants.

This report describes data and analyses for vermilion snapper only.

[2]Abbreviations, acronyms, and mathematical symbols used in the report are listed in Appendix C on page 40.

2 Stock and fishery characteristics

2.1 Natural history

The following description incorporates some material excerpted and expanded from Grimes (1978), Zhao et al. (1997), and Potts et al. (1998).

Vermilion snapper, *Rhomboplites aurorubens*, a small to moderate-sized reef fish, is the most frequently caught snapper along the southeastern United States. The species inhabits depths of 18 to 122 m but is most abundant at depths less than 55 m. This assessment describes the stock off the U.S. Atlantic coast from North Carolina through the Atlantic side of the Florida Keys, including landings from North Carolina (NC), South Carolina (SC), Georgia (GA), and the east coast of Florida (FL). Tagging studies show neither long-range migrations nor extensive local movements (unpublished MARMAP data), and there is no circumstantial or anecdotal information to suggest such movements.

Vermilion snapper is a gonochorist (a species of distinct sex throughout the life span) that spawns from April to September, with peak spawning occurring during July and August. Eggs and larvae are pelagic; however, the length of time before settling out of the water column is unknown. All vermilion snapper are sexually mature by age 2 and total length of 201 mm. Mature gonads were found in 69% of females at age 0, 84% at age 1, and 100% at all older ages.

2.2 Landings

Three major fisheries catch this stock of vermilion snapper: commercial, recreational, and headboat (larger for-hire boats that accept individual anglers and charge per person). Those fisheries were further subdivided for assessment purposes, but are discussed in this section without subdivision (Figure 1). The most common commercial gear

Figure 1. Landings of vermilion snapper, total (a) and by major fishery groups (b–d). Scale expanded for recreational landings in panel (d).

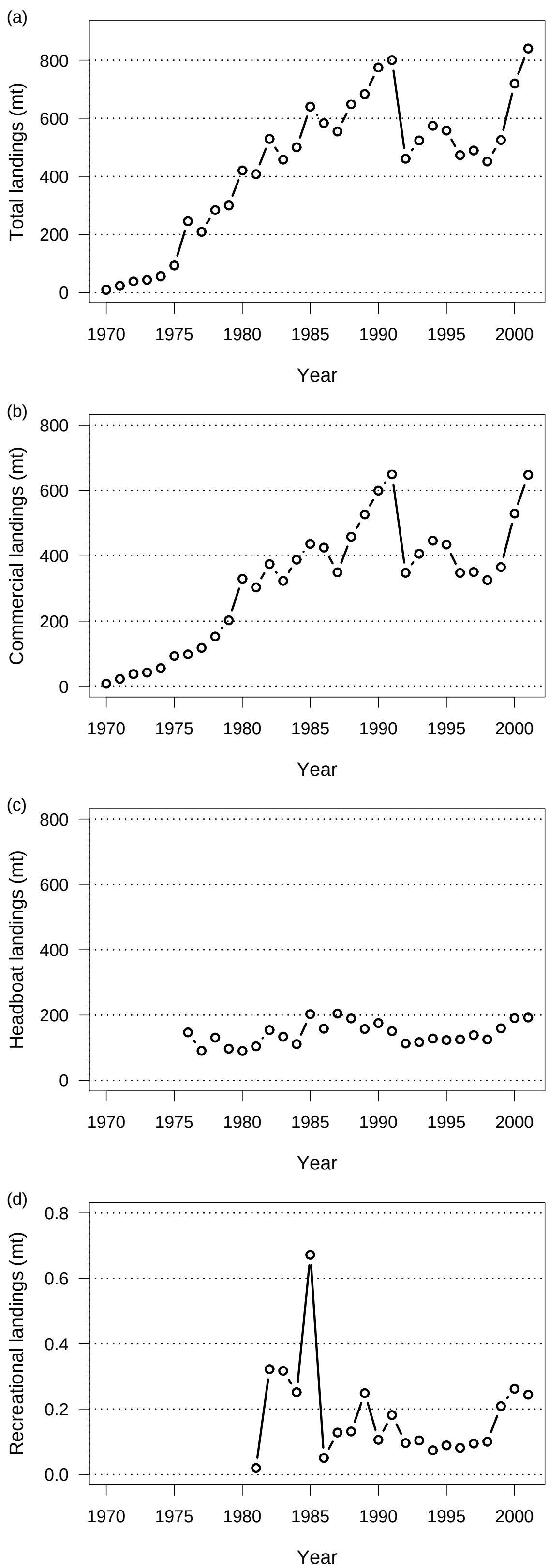


Table 1. Vermilion snapper regulatory history

Period	Amend-ment	Details
Aug 1983	FMP	4" trawl mesh size to achieve 12" TL minimum size limit
Jan 1989	1	Prohibits trawls
Jan 1992	4	Prohibits fish traps, entanglement nets, and longline gear within 50 fathoms; recreational bag limit of 10 fish per person per day; 10" TL recreational minimum size limit; 12" TL commercial minimum size limit
Dec 1998	8	Limited entry program; transferable permits and 225-pound non-transferable permits
Feb 1999	9	11" TL recreational minimum size limit; vessels with longlines may possess only deepwater species

has been hook and line, with additional commercial landings from trawling. Trawling for vermilion snapper has been banned since January 1989 (SAFMC 1988; Table 1).

The recreational fishery is defined here to include all recreational fishing from private boats and charter boats (for-hire vessels that usually accommodate six or fewer anglers). Recreational fishing from shore does not take vermilion snapper, and any reported landings from shore were considered data errors. The headboat fishery 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.

Vermilion snapper landings have increased through the years, but in total have barely exceeded levels seen in the late 1980s (Figure 1a). The commercial fishery accounts for the largest fraction of the landings, with the headboat fishery accounting for about a third of the landings and other recreational fishery components taking very little. This pattern is fairly constant through all years.

The commercial fishery landings have been the most variable through time (Figure 1b). Commercial landings increased from 300 mt in 1980 to over 600 mt in 1991. Landings declined to 375 mt in 1992 in conjunction with the implementation of minimum size limits. Landings rose from about 375 mt in 1998 to greater than 600 mt in 2001. Most (97%) of the fish landed by commercial fishermen were caught by hook and line.

Landings in the headboat fishery exhibit a slight increase through the time series (Figure 1c). Recreational landings (as estimated by MRFSS) are negligible compared to commercial and headboat landings (Figure 1d).

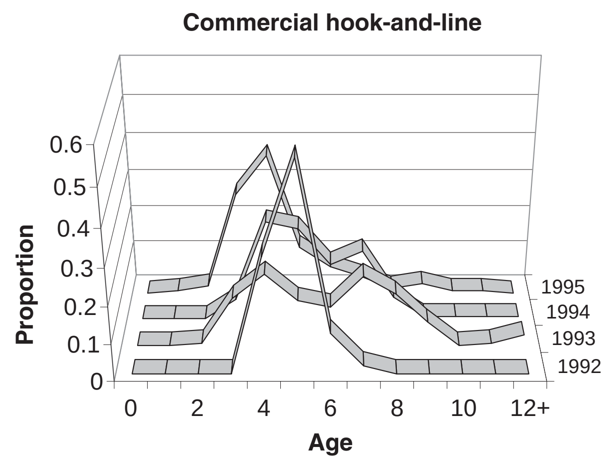
Few sets of age composition data were available for this assessment (Table 2). The age compositions that are available do not show any strong pattern over their limited time spans (Figure 2). Estimated ages were those provided by scientists on the staff of the NOAA Center for Coastal Fisheries and Habitat Research (NOAA Beaufort Lab) and from the MARMAP program.

It appears that the modal length has stayed fairly constant for vermilion snapper landed by the major commercial fishery (Figure 3a). However, the 1992 minimum size regulation of 12" (305 mm) TL commercial and 10" (254 mm) TL recreational resulted in an abrupt cut off in fish less than 280–300 mm TL being landed (Figure 3). After 1992, there was an abrupt decline in the capture of small fish and a shift to a larger modal length (Figure 3).

Length compositions from the recreational fisheries sampled by MRFSS (not shown) are extremely noisy, reflecting relatively low sample sizes of MRFSS. In any event, they would represent an extremely small fraction of the fishery (Figure 1).

Figure 2. Age compositions over time from (a) commercial hook and line fishery, (b) headboat fishery.

(a)



(b)

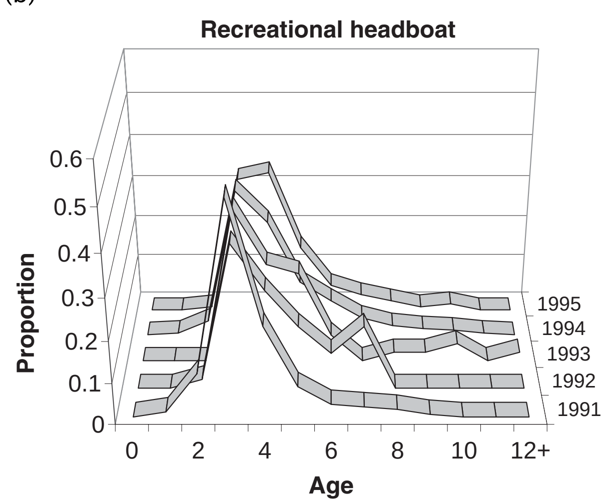
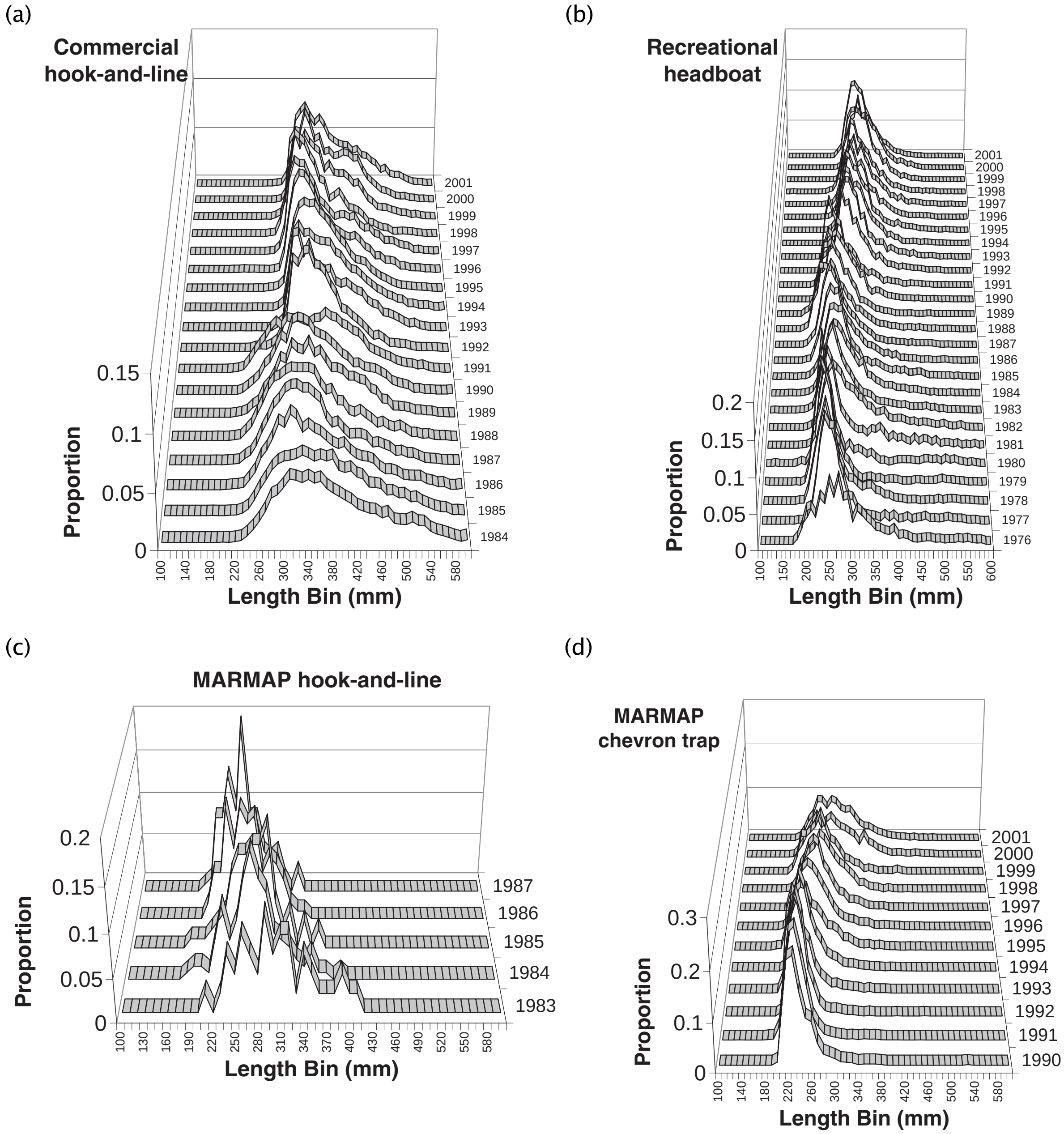


Table 2. Sample sizes of length- and age- composition data on vermilion snapper used in this assessment. MARMAP age samples before 1999 were also available, but because of nonrandom sampling, they were not used in the assessment (see §4.1).

	Length samples								**Age samples**		
	MARMAP			Commercial			Headboat	Recr.	Commercial	Headboat	MARMAP
Year	FL trap	hook–line	chev trap	hook–line	trawl	other	fishery	(MRFSS)	hook–line	fishery	chev trap
1976	—	—	—	—	—	—	1325	—	—	—	—
1977	—	—	—	—	—	—	1038	—	—	—	—
1978	—	—	—	—	—	—	1777	—	—	—	—
1979	—	—	—	—	—	—	1389	—	—	—	—
1980	—	—	—	—	—	—	1348	—	—	—	—
1981	—	—	—	—	—	—	1335	3	—	—	—
1982	—	—	—	—	—	—	2778	22	—	—	—
1983	460	45	—	—	—	—	4482	21	—	—	—
1984	264	130	—	6958	196	16	4545	14	—	—	—
1985	394	91	—	9704	—	96	5894	17	—	—	—
1986	267	106	—	7594	276	669	6160	19	—	—	—
1987	225	122	—	7158	616	157	6327	36	—	—	—
1988	—	—	—	5195	640	434	4759	145	—	—	—
1989	—	—	—	5295	—	330	4768	80	—	—	—
1990	—	—	830	4995	—	1017	5308	66	—	—	—
1991	—	—	3066	9379	—	1454	4029	50	—	160	—
1992	—	—	1514	5915	—	341	2828	114	45	46	—
1993	—	—	1326	7778	—	518	3318	75	168	46	—
1994	—	—	3350	6984	—	508	5724	77	164	252	—
1995	—	—	2495	11850	—	585	4799	74	144	124	—
1996	—	—	2745	6137	—	241	3858	16	—	—	—
1997	—	—	1805	5914	—	261	4133	68	—	—	—
1998	—	—	1240	6178	—	497	4239	76	—	—	—
1999	—	—	735	12274	—	153	4306	194	—	—	386
2000	—	—	1637	18871	—	358	4469	214	—	—	299
2001	—	—	1369	16470	—	1709	3387	400	—	—	350

Figure 3. Length compositions over time from (a) commercial hook and line fishery, (b) headboat fishery, (c) MARMAP (fishery-independent) hook-and-line samples, (d) MARMAP chevron trap samples.

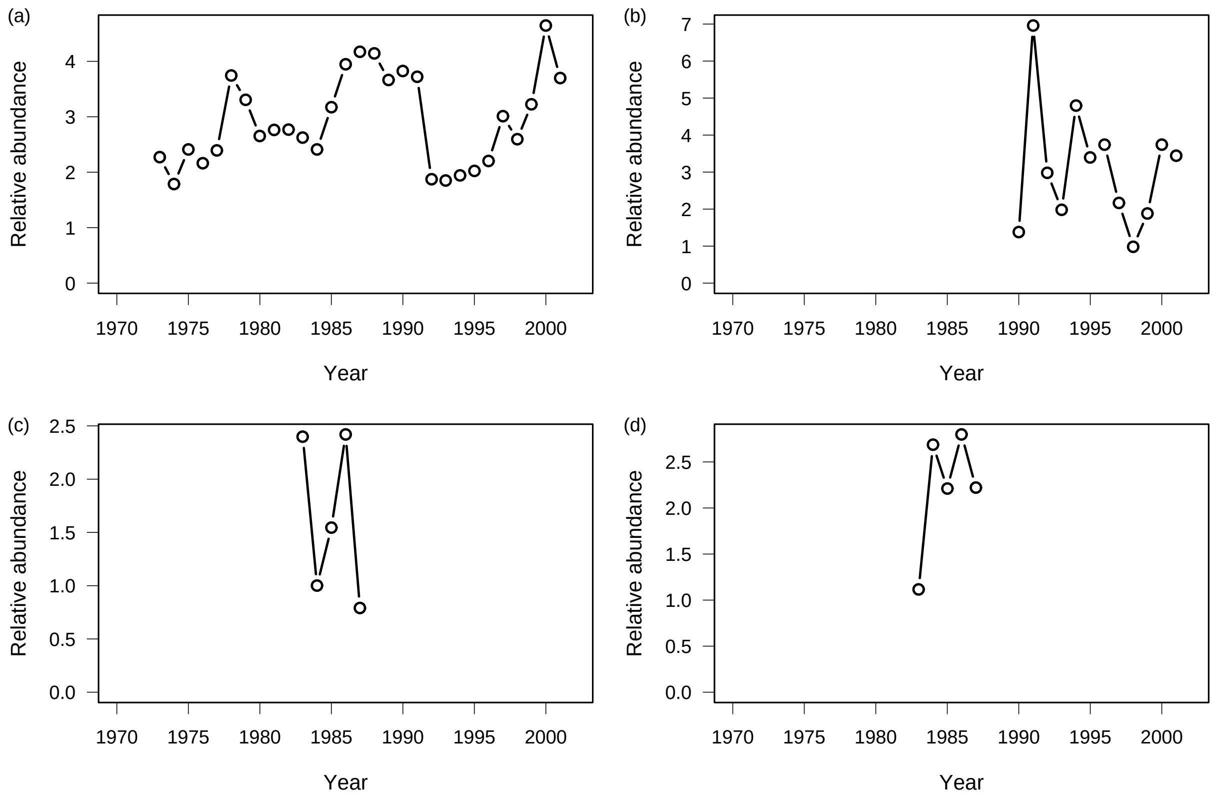


2.3 Relative abundance

This section describes patterns in abundance indices developed at the Data Workshop. Such indices were developed through statistical models described below.

The headboat abundance index shows little change between 1973 and 1984 (Figure 4a). Catch rates are high, 1986–1991, and drop markedly in 1992 with introduction of minimum sizes (Ta-

Figure 4. Abundance indices for vermilion snapper. Panel (a), headboat index; (b), MARMAP chevron trap index; (c), MARMAP "Florida" trap index; (d), MARMAP hook-and-line index.



ble 1). The index then rises steadily from 1992 through 2000, with a decline in 2001.

Several indices are from data of the MARMAP program, and are thus fishery-independent indices of abundance. The MARMAP chevron trap index (Figure 4b) shows similar trends to the headboat index, in that there was an apparent decline in catch rate during the early 1990s, followed by a gradual increase after 1998. The overall picture is one of a population that may be increasing slightly. The MARMAP "Florida" trap and hook-and-line indices (Figure 4c, d) show a good bit of fluctuation during the short time period that they represent (1983–1987).

An additional index of relative abundance was provided by the MRFSS program. However, AW participants decided not to use it because it omits trips with zero catches. This is described in more detail below.

2.4 Ages

Ages were available for 2,891 otoliths from fishery independent sampling and 1,149 from fishery dependent sampling. Estimation of sex composition was based on 4,276 vermilion snapper that were collected by the MARMAP program.

3 Data workshop

Data for this assessment were evaluated, selected, and prepared by a Data Workshop (DW) that met for that purpose during the week of October 7, 2002, in Charleston, SC. Additional questions that arose during initial model development and testing before the AW were resolved at the AW 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 SEDAR 2003 CD-ROM) and are summarized here.

3.1 Findings of life-history and MARMAP working group

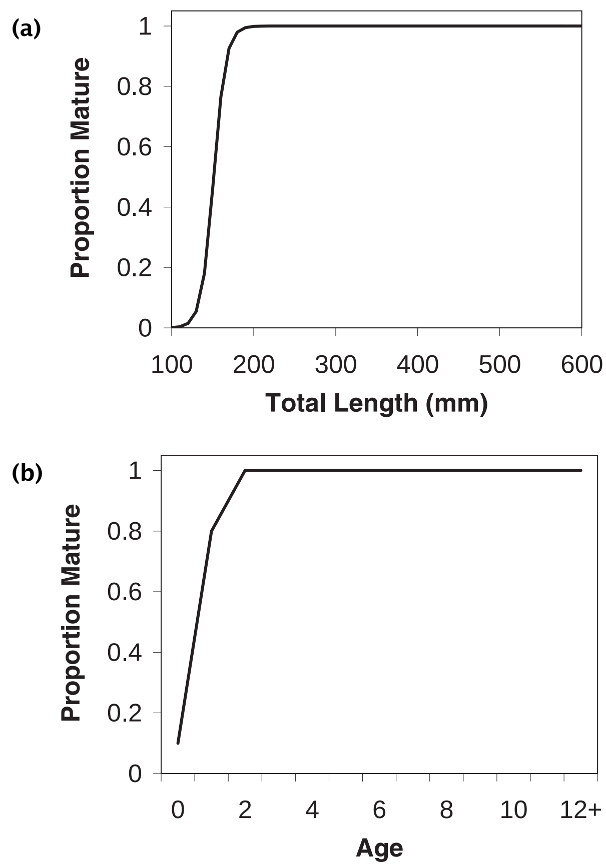
Unit stock The working group agreed that vermilion snapper in the South Atlantic Bight form a unit stock, and recommended that the extent of the analysis should be from the North Carolina coast south through the Atlantic coast of Florida, as described in Section 2.1.

Aging error matrix The group recommended that a number of otoliths be aged both by SCDNR and at the NOAA Beaufort Lab. That would provide an aging-error matrix for use in age- and length-structured assessment models.

Natural mortality rate The working group recommended using $M = 0.25$/yr with a range of 0.2–0.3/yr.

Release mortality Release mortality for vermilion snapper has been estimated at 17% of fish caught at depths of 43–55 m (Collins et al. 1999) and 27% of headboat catches (Dixon and Huntsman, unpublished data). The commercial fishery typically operates at greater depths than the headboat fishery, which the group believes would result in higher discard mortality rates. For that reason and based on the previous estimates, release mortality rates of 40% and 25% were recom-

Figure 5. Maturity of vermilion snapper (a) at length and (b) at age.



mended by the group for the commercial hook-and-line and headboat fisheries, respectively.

Maturity schedules The group recommended data from fishery-independent sampling as the best maturity data available and recommended that they be used in the assessment. Maturity curves (Figure 5) were derived from fishery–independent trawl data. Limited temporal samples did not reveal any time trends, and the group recommended using the same maturity–at–length relationship for all years in the assessment.

Sex ratio A high degree of consistency in sex ratio over time was noted for each gear type. A

Figure 6. Batch fecundity of vermilion snapper at length.

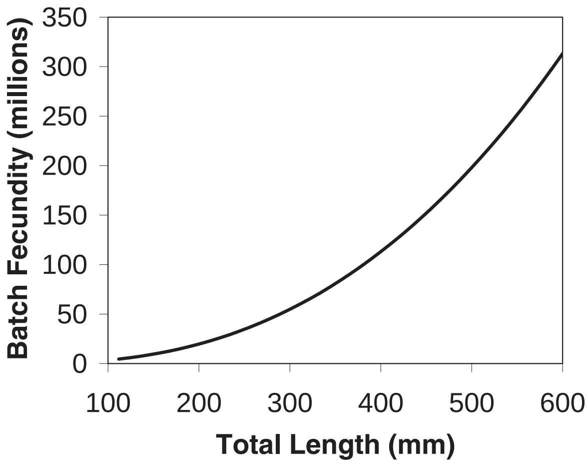
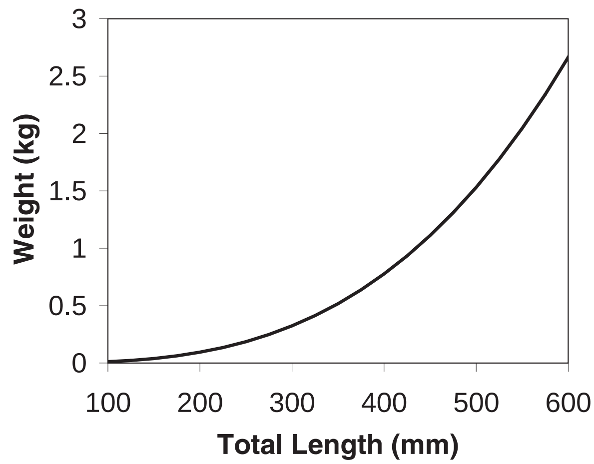


Figure 7. Weight of vermilion snapper at length.



percentage of females between 60–70% was noted by Cuellar et al. (1996). No decision was made about assumptions on sex ratio for assessment purposes.

Spawning–stock size The DW recommended using total population egg production (represented in this report by $\mathcal{E}$) as a measure of spawning–stock size, based on the analysis of Cuellar et al. (1996). Total egg production for this batch spawning species was based on the relationship in Figure 6 and an average annual batch number of 35.

MARMAP catch rates The group discussed fishery-independent indices of abundance that could be obtained from the South Carolina Department of Natural Resources Marine Resources Monitoring, Assessment and Prediction program (MARMAP). MARMAP has conducted reef-fish sampling since 1979.

The data workshop recommended three MARMAP abundance indices for use in the assessment: a "Florida" (snapper) trap index, 1983–1987, a hook-and-line index, 1983–1987, and a chevron trap index, 1990–2001 (Figures 4b–d). An additional abundance index, based on an inshore survey using blackfish traps, was not recommended for use in the vermilion snapper assessment, because vermilion snapper are rarely caught in such traps. The "Florida" trap index is based on sampling at four shelf edge locations (30 fathoms) off South Carolina. The chevron trap index, in contrast, is based on sampling the area off Florida and North Carolina to 50 fathoms. Examination of subsets of data in time and space (depth, latitude) revealed no important differences from patterns seen in the entire data sets.

Size, age, and reproductive data from the MARMAP database were brought forward for use in the assessment (Figures 6, 7).

3.2 Findings of headboat and recreational fisheries working group

Two sources of data on recreational and headboat fisheries were available for use in the stock assessment: the National Marine Fisheries Service (NMFS) Headboat Survey and the NMFS Marine Recreational Fisheries Statistics Survey (MRFSS).

Headboat landings Vermilion snapper landings in numbers and weight were available from 1973 through the present from North Carolina and South Carolina. Landings from Georgia and the Atlantic coast of Florida, north of Cape Canaveral, were available starting in 1976, and are a major part of vermilion snapper headboat landings. Preliminary landings data were available for southeast Florida from 1978. Landings for 1976–1977 were estimated by regressing Georgia and north Florida observations against south Florida observations of landings in numbers and weight. Apparent errors in mean weights recorded for some months were corrected using the mean weights from adjacent months for the same area. Headboat landings are shown in Figure 1c on page 6.

Size distributions of headboat landings Headboat samplers measure length and weight of the fish that they encounter. The group recommended that length measurements be weighted by landings in numbers when computing length compositions for use in the assessment model.

Headboat abundance indices Headboat catch rates in numbers and weight were available for 1973–2001 for vermilion snapper. Headboat catch rates were standardized with a delta–lognormal general linear model of catch in numbers divided by anglers at the trip level, based on full-day trips only (Figure 4a). Categorical independent variables were year, month, and area. (Because areas 2 and 3 were combined by survey personnel from 1988 on, area 3 from 1988–2001 was denoted area 13 for modeling.) The advantage of the delta–lognormal formulation is that it explicitly models both the proportion of trips with nonzero catches and the catch per trip observed in those trips.

MRFSS landings data The Marine Recreational Fisheries Statistics Survey (MRFSS) began in 1979; however, the group 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 MRFSS database through 1985, but those data were removed for this assessment based on the proportion of intercepts that were headboat intercepts for each year and state.

Vermilion snapper are rarely encountered near shore; thus, landings from the shore-based mode of MRFSS were excluded. Mean landings by private and charter boats, 1981–1989, were used to extend recreational landings back to 1976. Occasionally, no fish were weighed in a given stratum (year, subregion, state, mode, area), and 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 25% of Dixon and Huntsman (unpublished data) 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. However, because such landings of vermilion snapper are minimal (Figure 1d), that concern is not great for this species.

3.3 Findings of working group on commercial landings

Commercial landings data are available through the NMFS general canvass and Trip Interview Program (TIP) databases, 1958–2001. Data categories include those reported to species and those reported as "snapper, unclassified." State-maintained records were used for allocation of landings by gear type. Such records are available since 1972 from North Carolina and South Carolina, and since 1970 from Florida. No state records are available for Georgia.

Vermilion snapper landings have been variably recorded to species level and as unclassified snappers, especially in earlier years. Reporting to species is more prevalent in recent years, and the proportion of total snapper landings reported as unclassified declines over time. Total vermilion snapper landings were estimated for each state by combining landings reported to species and a portion of the unclassified snapper landings. In general, the ratio of vermilion snapper landings to total snapper landings reported by species was used as a multiplier to estimate the proportion of vermilion snapper landings in the unclassified category. For years in which no landings were reported by species, the time series average proportion of vermilion snapper was used to estimate the proportion of vermilion snapper in the unclassified category.

Vermilion snapper were partially recorded as "unclassified snapper" in North Carolina and South Carolina. In both states, state records were used to identify the proportion of unclassified snappers assigned to vermilion snapper. As no state records were available from Georgia, Georgia landings are taken from the NMFS commercial statistics website, based on the vermilion snapper category. Florida landings are from the Atlantic coast only, including all of Monroe county before 1986 and only Atlantic portions of Monroe County after 1986. All vermilion snapper landings are recorded to species in the Florida database, so no adjustments of unclassified landings were required.

Landings by gear are available since 1992 from Florida, since 1978 from North Carolina, and since 1972 from South Carolina. Between 1992 and 2001 (i.e., during the period when all three states recorded their landings by gear), 99% of vermilion snapper were landed by hook and line. However, substantial trawl landings were made in the 1970s and 1980s, especially in SC. Trawling for vermilion snapper has been prohibited since 1989 (Table 1). Therefore, three gear categories were established for use in this assessment: (1) hook and line (including ordinary hook-and-line and electric or "bandit" reels), (2) trawl, and (3) all others combined (longlines, gill nets, spears/gigs, traps and pots, etc.). For North Carolina and South Carolina, where landings are adjusted for the unclassified snapper category, adjusted vermilion snapper landings were allocated to gear categories based on the observed gear associated with landings reported to species and gear. No gear information was available for Georgia; therefore, landings were allocated into gear categories in the same annual proportion by category as for South Carolina, 1972–2001. In Florida, the average proportions by gear, 1992–2001, were used to allocate 1970–1991 landings to gear.

Length samples were obtained from the TIP database for 1984–2001 (Table 2). An average of 9,111 lengths were recorded annually: 8,592 in the hook-and-line category and 519 in the "other" category. Lengths were tabulated into 10 mm bins centered on lengths from 100 to 600 mm, combined across all areas but separated by gear type.

4 Data issues resolved at Assessment Workshop

The AW 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 AW follows.

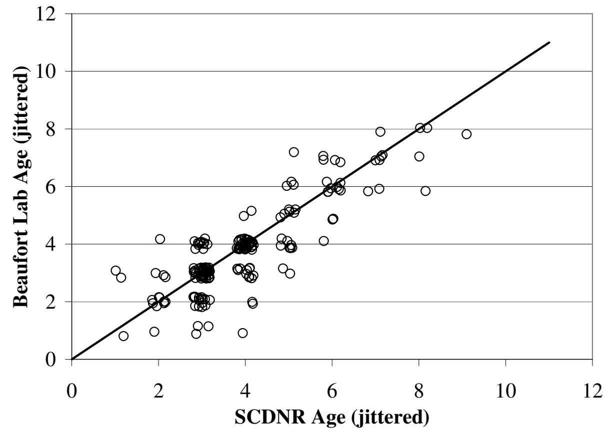
4.1 General data issues

- The DW recommended using a forward-projecting statistical age-structured model of catch at age as the primary assessment methodology for vermilion snapper. However, there is extremely poor correlation between length and age in the species, and age sampling has been quite limited. Thus, the AW concluded that use of a forward-projecting length-structured model would be preferable to using an age-structured model. The major difference is that in the length-structured model, fecundity, maturity, and selection are all modeled as functions of length. In addition, the AW decided to apply an age-aggregated production model to supplement the length-structured model.

- The AW decided not to use the MRFSS catch rate as an index of abundance for the base run of the catch-at-length model. This decision was made because of concerns that the method of accounting for targeting used by MRFSS personnel in computing the index might bias the results, as only positive trips were used.

- Aging data for fishery-independent (MARMAP) samples from 1979–1994 were excluded, as specimens had not been randomly selected for aging, but rather to provide detail in all length classes for use in age–length keys. The resulting age-composition estimates were therefore not representative of the entire sample and were considered inappropriate for use as age-composition data with this model. However, fishery-independent samples from 1999–2001 were collected in a suitable manner and were used in the assessment.

Figure 8. Determined ages of 198 fish aged both by scientists at the NMFS Beaufort Lab and by scientists at South Carolina Department of Natural Resources.



- The comparison of ages from the NMFS Beaufort lab and SCDNR lab demonstrated good agreement (Figure 8).

- Examination of sex-ratio data (§3.1) by size and age revealed a possible increase in proportion female with size, but the group was hesitant to accept that increase (1) for lack of biological mechanism, and (2) because the perception of increase was highly dependent on a few points in the data set. After discussion, the group decided to adopt the assumption of a constant proportion female of 67%

- The group decided to use the MARMAP hook and line catch rate for 1983–1987 as a third fishery-independent abundance index.

4.2 Stock–recruitment model

The model incorporates a Beverton–Holt stock–recruitment model of the form that includes a steepness parameter h and a parameter R_0 representing theoretical recruitment level in the unfished equilibrium state. The steepness parameter strongly affects estimates of management benchmarks related to maximum sustainable yield. In exploratory model runs used to arrive at a base run, h was not well estimated. To provide biologically reasonable estimates of the stock–recruitment curve, including h, the parameter R_0 was constrained to be close to the average recruitments estimated for the period 1983–1998. Sensitivity runs were therefore incorporated to investigate the implications of different assumed values of steepness on model estimates.

4.3 Additional constraints

Additional constraints were placed on the model to obtain biologically reasonable solutions. The constraints took the form of penalties added to the total objective function.

- Deviations of estimated recruitments from the estimated stock–recruitment model were weakly penalized.
- Recruitment deviations in the model initialization period (used to provide estimates of N at length in the first model year) were penalized more heavily, to prevent large fluctuations. This is necessary because the data are least complete in the initialization period.
- Recruitment deviations in the final three years were penalized more heavily. This is done because cohorts in the final years have been fished for only a few years and thus provide less certain information on recruitment (initial cohort strength).
- Parameters of the variance–of–length vs. age relationship were constrained to ensure that estimated variances of adjacent lengths were similar.

5 Description of assessment models

5.1 Length-structured model

The data workshop recommended use of a forward-projecting statistical model of catch at age as the primary assessment tool for vermilion snapper in this assessment. The AW revised that recommendation slightly, and used a similar model based on catch at length (rather than age). As noted above, this decision was based on the weak relationship observed in this stock between age and length, the relative scarcity of data on age composition, and difficulties in fitting an age-based model.

The essence of forward-projecting age- or length-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 the work of Sullivan et al. (1990); Quinn et al. (1998); Fu and Quinn (2000).

5.1.1 Properties of length-structured model

The forward-projecting length-structured model for this assessment was implemented in the AD Model Builder software (Otter Research 2000) on a microcomputer. The formulation's major characteristics can be summarized as follows:

Natural mortality rate The natural mortality rate was assumed constant across ages and over time.

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

Selectivity of fishery–independent gear The three fishery–independent (MARMAP) abundance indices were assumed to have individual time–constant selectivity functions, whose parameters were estimated internally in the course of model fitting.

Selectivity of fishery gear Each fishery was assumed to have constant selectivity during each period of constant regulation. The corresponding selectivity parameters were estimated internally and applied to the corresponding fisheries and any abundance indices derived from them. The scarcity of length samples in the MRFSS database prevented estimation of selectivity for the (very small) recreational fishery. Therefore, estimated selectivity of the headboat fishery was used for the recreational fishery. With that exception, separate selectivity patterns were estimated for each fishery component.

Form of selectivity functions Selectivity was fit parametrically, using logistic curves for most gears, but double-logistic curves (which are potentially dome shaped) for surveys using trap gear.

Growth A von Bertalanffy growth model, constant over time, was estimated internally during model fitting from length–composition and age–composition data. Two standard deviation parameters were estimated for determining the variance of length at age, assumed normal.

Recruitment Parameters of a Beverton–Holt recruitment model were estimated internally.

Biological benchmarks The benchmarks F_{MSY} and $\mathcal{E}_{\mathrm{MSY}}$ were estimated internally by the model using the method of Shepherd (1982). (The quantity $\mathcal{E}_{\mathrm{MSY}}$ is the amount of egg production $\mathcal{E}$, a measure of spawning stock size, that can provide maximum sustainable yield.) 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 formed a catch-weighted average of estimated selectivities at age by fishery for the final three years (1999–2001), a period of unchanging regulations.

Fishing mortality Five fishery components were modeled individually: commercial hook-and-line, commercial trawl, commercial "other"; headboat, and (MRFSS) recreational. Separate fishing mortality rates were estimated for each component.

Abundance indices The model used four separate indices of abundance (§2.3, Figure 4). They were three fishery-independent indices (MARMAP hook and line, 1983–1987; "Florida" trap, 1983–1987; and chevron trap, 1990–2001) and one fishery-dependent index (headboat, 1976–2001).

Discards Discarded fish are routinely estimated in the MRFSS and are included in the estimate of total landings in the model. However, no time series of discard data are available for other fisheries. An approximate measure of discards from the commercial hook-and-line and headboat fisheries, which account for the majority of landings (Figure 1), were modeled with separate selectivity curves. The discard selectivity curves were estimated from the difference between selectivity before and after size regulations in order to represent likely discards of undersized fish during periods of size regulation. This is viewed as an underestimate of discards, since the implicit assumption is that no discarding occurred before size regulations were in place.

Discard mortality rates were then estimated by assuming release mortality rates of 40% and 25% for the commercial hook-and-line and headboat fisheries, respectively. The product of release mortality rate, the estimated fishing mortality rate of kept fish, and the estimated discard selectivity curve provided length specific instantaneous mortality rates to estimate the number of discards using the Baranov catch equation.

CVs of landings The assessment model accommodates coefficients of variation (CVs) of each landings series. Where CVs were provided in data bases (i. e., MRFSS data only), those CVs were used. Where no CVs were provided (headboat survey and general canvass data), a CV of 0.05 was assumed.

Fitting criterion The fitting criterion was a total likelihood approach in which total catch was fit almost exactly and observed age and length-compositions, as well as abundance indices, were fit to the degree that they are compatible with each other and with other model components. Relative statistical weighting of each likelihood component was chosen by the AW 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

Table 3. Statistical weights used in averaging model estimates for vermilion snapper.

	Steepness, h		
M	0.5	0.7	free (h = 0.9)
0.20	1/16	1/16	1/8
0.25	1/8	1/8	1/4*
0.30	1/16	1/16	1/8

* base run

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. 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. To fit the production model, the ASPIC software of Prager (1995) was used.

6 Application of length-structured model

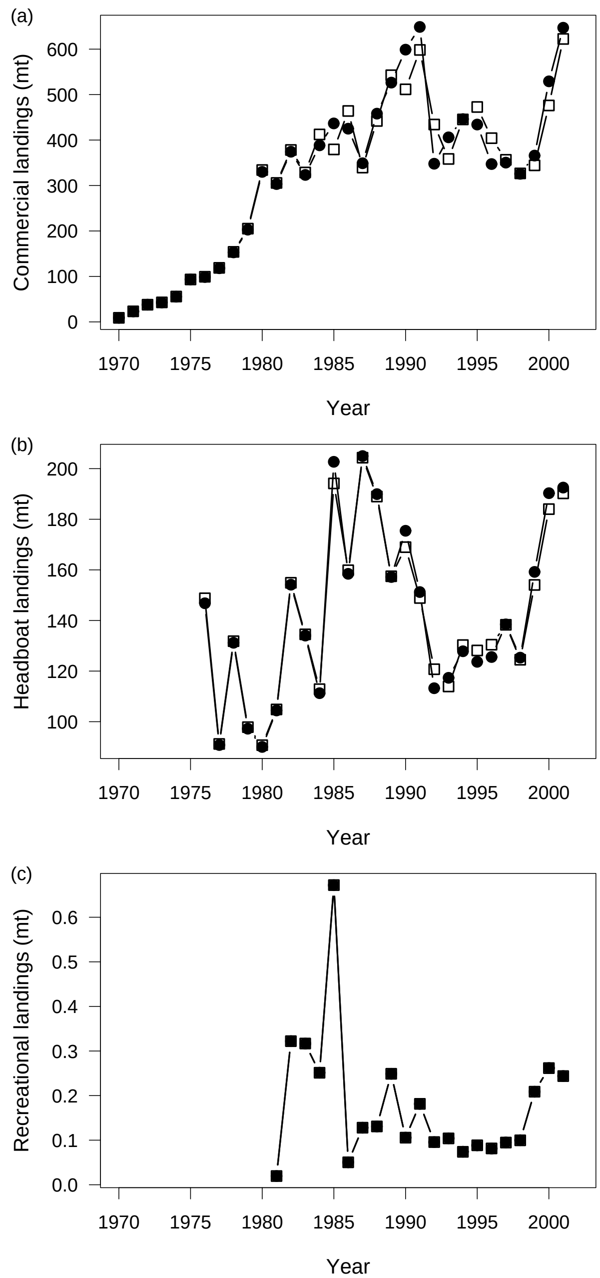
6.1 Specification of base and sensitivity runs

All model runs used the data from the Data Workshop with all adjustments described above. The base run used $M = 0.25/\mathrm{yr}$, and had a fitted steepness value of $h = 0.90$.

In addition to the base run, analyses were run to examine the effects of using different fixed steepness values and other values of the natural mortality rate. The values used included the steepness values $h = \{0.5, 0.7\}$ and the natural mortality rate values of $M = \{0.2, 0.3\}$.

Considering the three values of M and three values of h, nine model runs were conducted in total. The AW also decided to tabulate weighted averages of estimates of management quantities from the nine runs, with statistical weights as given in Table 3.

Figure 9. Observed (solid circles) and predicted (open squares) landings from base run of length-structured model of vermilion snapper. Note that symbols are entirely overlaid in panel (c).



6.2 Results of base run

Estimates from base and sensitivity runs of the length-structured model are summarized in Table 4. In that table, the base run chosen by the AW is labelled D and is set off by rules. Figures and results that follow reflect results of that base run, except when specified otherwise.

The length-structured model was able to match observed catches almost exactly (Figure 9), as expected. More importantly, fits to abundance indices were good (Figure 10). The only systematic lack of fit noted was failure of the estimated length compositions of the MARMAP chevron trap to match observed length compositions, particularly in later years (e.g., Figure 11). The observed length compositions from this gear exhibit increased contribution of larger fish near the end of the time series (Figure 3d). The group was unsure what caused the broadening of the observed length compositions during that period.

Estimated selectivity curves of fishery–independent (MARMAP) gears indicate that of the two trap gears, only the chevron trap is estimated to have dome-shaped selectivity (Figure 12). The hook-and-line selectivity curve was specified as logistic, not dome-shaped.

Estimated selectivity curves of commercial gears show the expected changes from minimum size regulations listed in Table 1 (Figure 13). Implementation of the 12" (305 mm) TL minimum size limit in 1992 for the commercial fishery resulted in a shift in selection to larger fish in the hook-and-line fishery. The trawl fishery operated prior to any size limits and captured significantly smaller fish than other commercial fisheries, although the 4" mesh size regulation (Table 1) was implemented with the goal of not catching fish

Figure 10. Observed (solid circles) and predicted (open circles) abundance indices from base run of length-structured model of vermilion snapper. Panel (a), headboat index; (b), MARMAP chevron trap index; (c), MARMAP "Florida" trap index; (d), MARMAP hook-and-line index.

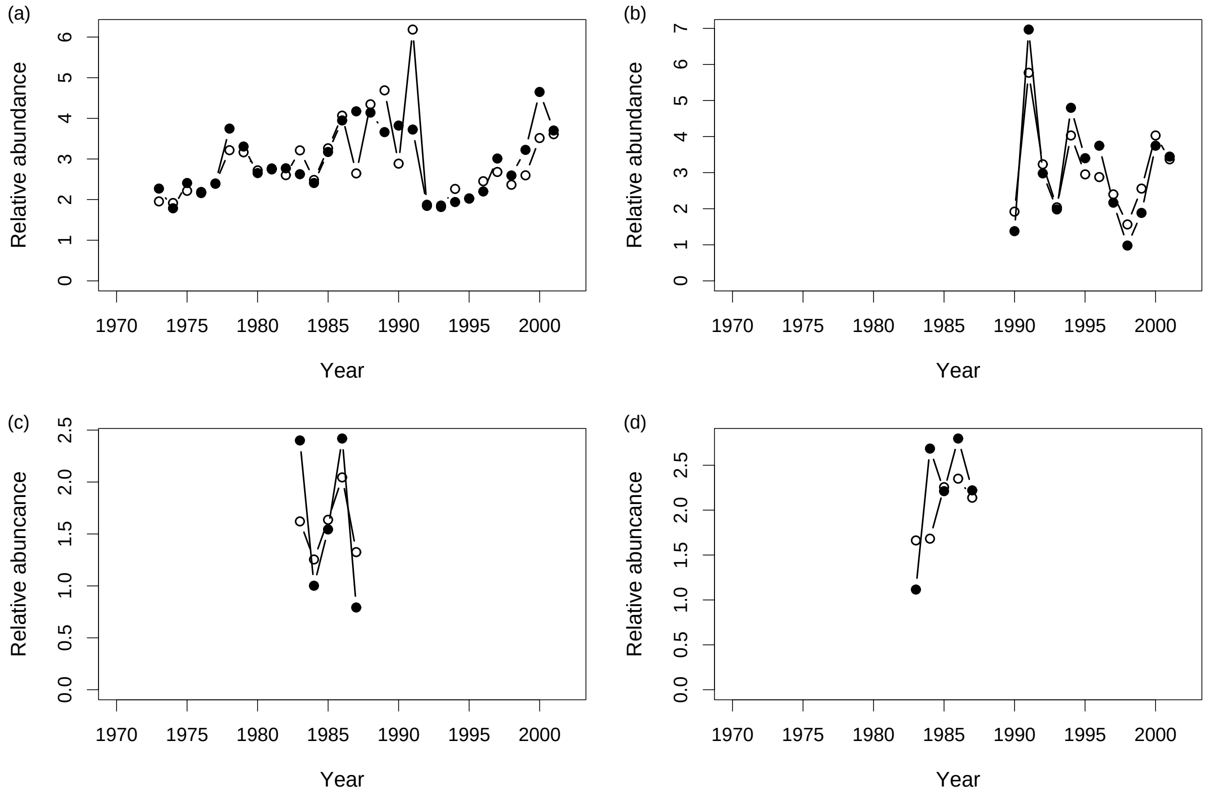
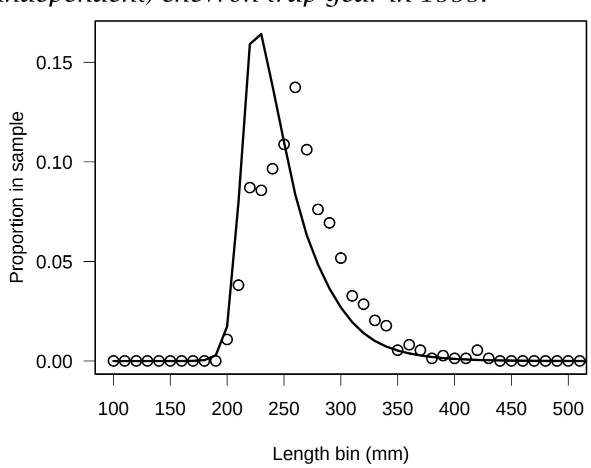


Figure 11. Observed (circles) and modeled (line) length composition of MARMAP (fishery-independent) chevron trap gear in 1999.



smaller than 12" TL. The combined "other" commercial fisheries did not appear affected by the minimum size regulation in 1992, and they appear to capture larger fish above that minimum size limit (Figure 13c).

Estimated selectivity curves of the headboat fishery show the changes expected due to the implementation of the 10" (254 mm) TL minimum size limit in 1992. The change to an 11" (279 mm) TL minimum size limit in 1999 does not appear to have further affected estimated selectivity to any degree (Figure 14 on page 23). Indeed, the estimated selectivity curve for 1999–2001 suggests a lack of compliance with the 11" TL minimum size regulation.

Estimated fully-selected fishing mortality rates

Table 4. Summary of estimates from length-structured model of vermilion snapper. Symbols, abbreviations, and acronyms are listed in Appendix C on page 40. Vertical rules mark base case.

Quantity	Run									
	A[1]	B	C	D[1,2]	E	F	G[1]	H	J	avg[3]
Input conditions										
M	0.20	0.20	0.20	0.25	0.25	0.25	0.30	0.30	0.30	—
h	0.93	0.70	0.50	0.90	0.70	0.50	0.95	0.70	0.50	—
Estimates										
F_{2001}	0.56	0.56	0.55	0.51	0.56	0.55	0.53	0.54	0.54	0.54
F_{MSY}	0.30	0.24	0.16	0.32	0.27	0.18	0.34	0.28	0.20	0.27
$F_{2001}/F_{\mathrm{MSY}}$	1.89	2.37	3.45	1.60	2.10	3.06	1.55	1.93	2.78	2.13
$F_{0.1}$	0.20	0.21	0.22	0.23	0.24	0.23	0.23	0.25	0.25	0.23
$F_{40\%}$	0.27	0.28	0.29	0.32	0.34	0.33	0.35	0.37	0.37	0.32
$F_{\max}$	0.32	0.33	0.35	0.35	0.36	0.36	0.35	0.37	0.37	0.35
MFMT	0.26	0.18	0.0002	0.32	0.22	0.001	0.34	0.28	0.007	0.21
F_{proj}[4]	0.45	0.50	0.49	0.44	0.50	0.49	0.46	0.48	0.48	—
$\mathcal{E}_{\mathrm{MSY}} \times 10^9$	396	466	257 000	247	504	56 500	276	338	15 200	24 300
MSST $\times 10^9$	317	373	206 000	185	378	42 400	193	237	10 600	19 010
$\mathcal{E}_{2002}/\mathcal{E}_{\mathrm{MSY}}$	0.69	0.62	0.001	1.23	0.61	0.01	1.13	0.92	0.02	0.71
MSY, mt	756	743	294 000	465	848	69 586	542	571	19 364	28 730
MSY, lb.	1667	1638	648 159	1025	1970	153 410	1195	1259	42 699	63 339

Notes: [1] Runs with steepness h freely estimated. [2] Base run. [3] Weighted average of runs. [4] Geometric mean, used in projections, of estimated F for 1998–2001.

reflect the relative landings of the various fisheries (Figures 1, 15). The largest sources of fishing mortality are the commercial hook-and-line fishery and the headboat fishery. The recreational (MRFSS), commercial trawl, and commercial "other" fisheries contribute small or negligible fractions of the fishing mortality. It appears that the fully selected fishing mortality rate has recently (1996–2001) remained relatively stable at between 0.4/yr and 0.5/yr. Fully-selected F is complex to interpret because of changes in selectivity over time (Figures 13–14) and the changing contributions of different fishery components, which changes the overall selectivity pattern. This is also true of fully selected F compared to F_{MSY} (Figure 16). Periods of consistent regulation are marked by dotted vertical lines in Figure 16, and examining F within such periods removes one of the two main sources of confounding.

Spawning stock as measured by total egg production $\mathcal{E}$ is estimated to have increased substantially from its 1976 value (Figure 17a on page 25). The time trajectory of spawning–stock biomass shows the same pattern (Figure 17b). Although $\mathcal{E}$ has shown a significant ($P = 0.004$) increasing trend, no trend is apparent in the recruitment estimates (Figure 17c). Recruitment appears highly variable since 1983, with the largest variation occurring between 1983–1994. Forward-projection models tend towards greatest uncertainty in the

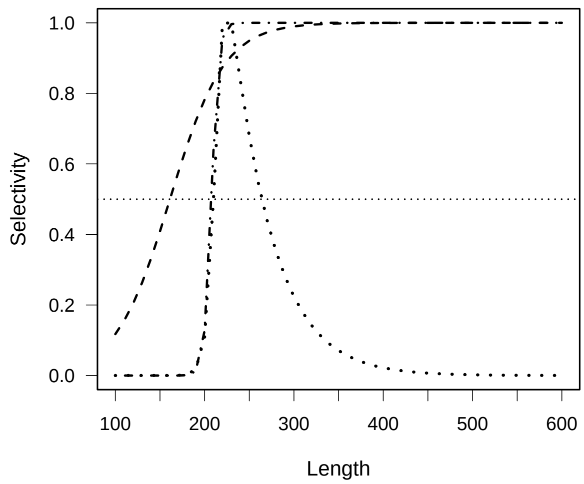


Figure 12. Estimated selectivity of fishery-independent (MARMAP) gear estimated for vermilion snapper (base case model run). Dotted line, chevron trap; dashed line, hook-and-line; dot–dash line, "Florida" trap.

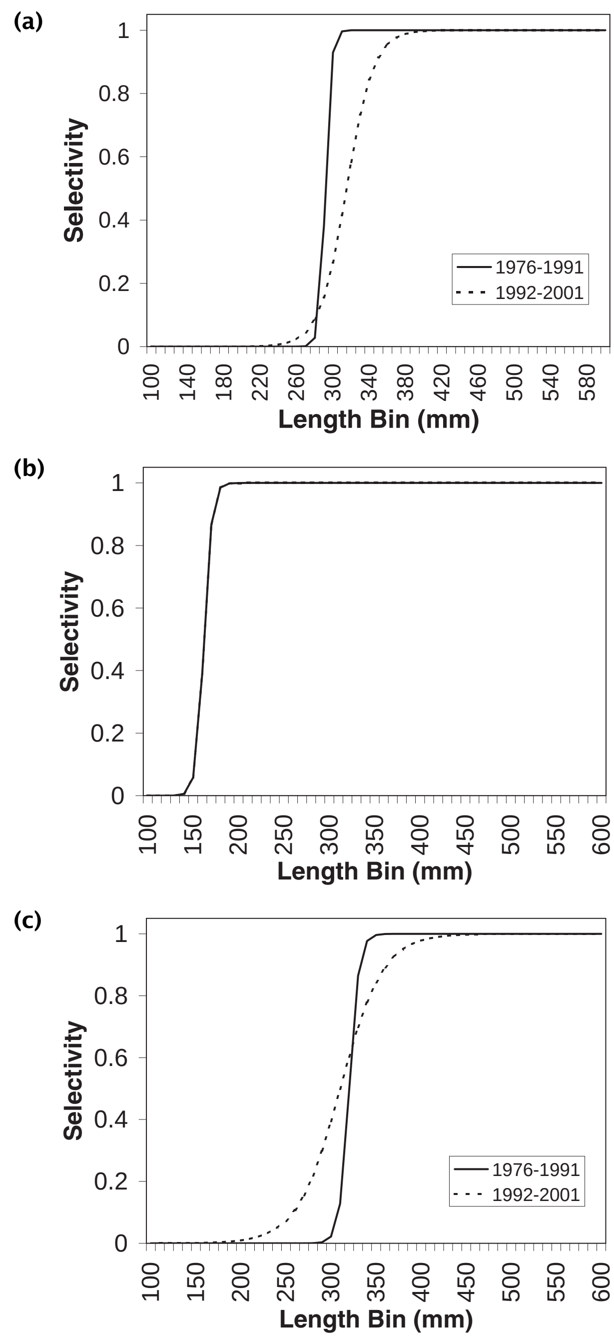


Figure 13. Estimated selectivity of commercial gears fishing for vermilion snapper (from base model run): (a) hook and line; (b) trawl; (c) other gears.

earliest and latest years. For that reason, the constraints on those years' recruitment values were highest, and the near-constant recruitment in the recent three years may be an artifact of that procedure.

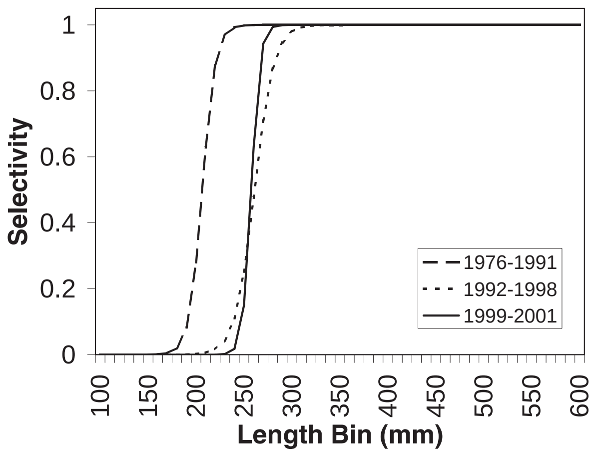
The estimated spawner–recruitment relationship (using egg production $\mathcal{E}$ as the measure of spawning-stock size) shows the usual scatter about the fitted Beverton–Holt recruitment curve (Figure 18).

6.3 Results of sensitivity runs

Table 4 on page 21 contains estimates of management quantities from the base run and sensitivity runs of the length–structured model. Results of runs conducted strictly to check model function or decide on weighting are not tabulated.

In runs with steepness h freely estimated, estimated values of h tended to be high, ranging from $h = 0.9$ to the upper bound allowed in this model, $h = 0.95$ (Table 4). Steepness itself has its theo-

Figure 14. Estimated selectivity in headboat fishery for vermilion snapper.



retical upper bound of $h = 1.0$, which would be considered an infeasible result. In fitting stock–recruit models, h often tends toward extremely high or low values when there is very little contrast in the abundance time series, as is the case here. Therefore, sensitivity runs with fixed lower values of steepness were also run. The lowest fixed values for steepness, $h = 0.5$, resulted in unreasonably high estimates of R_0, which in turn resulted in much lower estimates of $\mathcal{E}_{2002}/\mathcal{E}_{\text{MSY}}$, accompanied by much higher estimates of MSY and $\mathcal{E}_{\text{MSY}}$ (Table 4).

The general pattern observed in the sensitivity runs is for estimates of F_{MSY} to be positively related to values of M and h, but for the ratio F_{2001}/F_{MSY} to be negatively related to values of M and h. The estimates of F_{2001}/F_{MSY} range from 1.55 to 3.45 (Table 4). Estimates of $\mathcal{E}_{\text{MSY}}$ were negatively related to steepness and showed a tendency toward a negative relationship with M. Estimates of the dimensionless status indicator $\mathcal{E}_{2002}/\mathcal{E}_{\text{MSY}}$ ranged from 0.001 to 1.23, with the base run having the highest value of all runs (Table 4).

Model runs with a lower steepness showed increases in F_{MSY} as steepness decreased, while MSY and $\mathcal{E}_{\text{MSY}}$ increased towards unrealistic levels (Table 4). Thus, the sensitivity runs demonstrate that the lowest steepness value examined, $h = 0.5$, seems incompatible with the other data and assumptions of this assessment. The middle steepness value examined $h = 0.7$ is lower than the value of steepness freely estimated, but also appears consistent with the model, data, and assumptions used.

6.4 Biological reference points

Management benchmarks in the U.S. are currently based on the theory of maximum sustainable yield. That means that target and limit reference points depend on the size- and age-selectivities of the fisheries. The estimates of reference points given here assume the same catch–weighted selectivities that have been observed during the past three years of constant regulation.

All estimates of MSY and related benchmarks also depend on a stock–recruitment relationship, either one explicitly estimated (as in this report), or one implicitly estimated (as in fitting an age-aggregated production model). When that relationship cannot be estimated with confidence, the corresponding estimates of MSY–related benchmarks are estimated with limited confidence as well. Probably the weakest part of this assessment is the estimated stock–recruitment relationship (Figure 18), which exhibits a wide range in recruitment corresponding to a rather limited range of spawning-stock sizes (the latter measured as eggs produced). The observed data do not preclude the existence of an underlying stock–recruitment relationship, masked by noise, but they make accurate estimation of its form quite unlikely. Because of the scatter in the stock–recruitment data, all MSY–related benchmarks estimated in this assessment must be considered

Figure 15. Estimates of full fishing mortality rate F by major fishery, from base run of length-structured model. The recreational fishery is inconsequential (F $\ll 0.01$) and is not plotted.

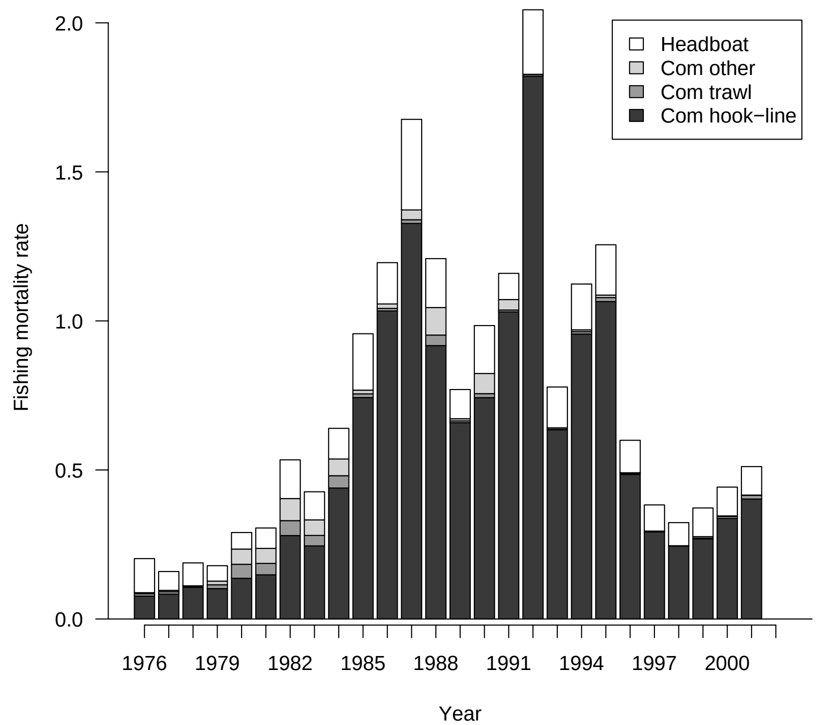


Figure 16. Estimates of full fishing mortality rate F relative to F_{MSY}, from base run of length-structured model. Comparison among years is best made during periods of consistent regulation, which are separated by vertical dotted lines.

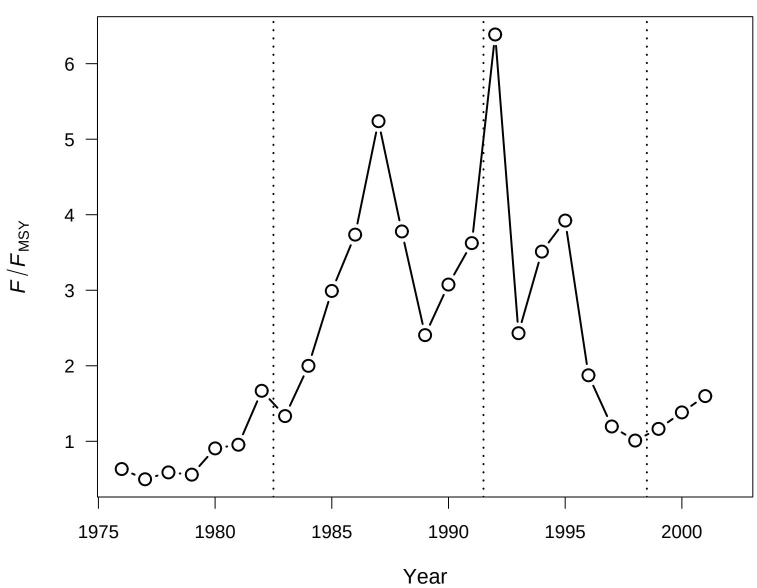
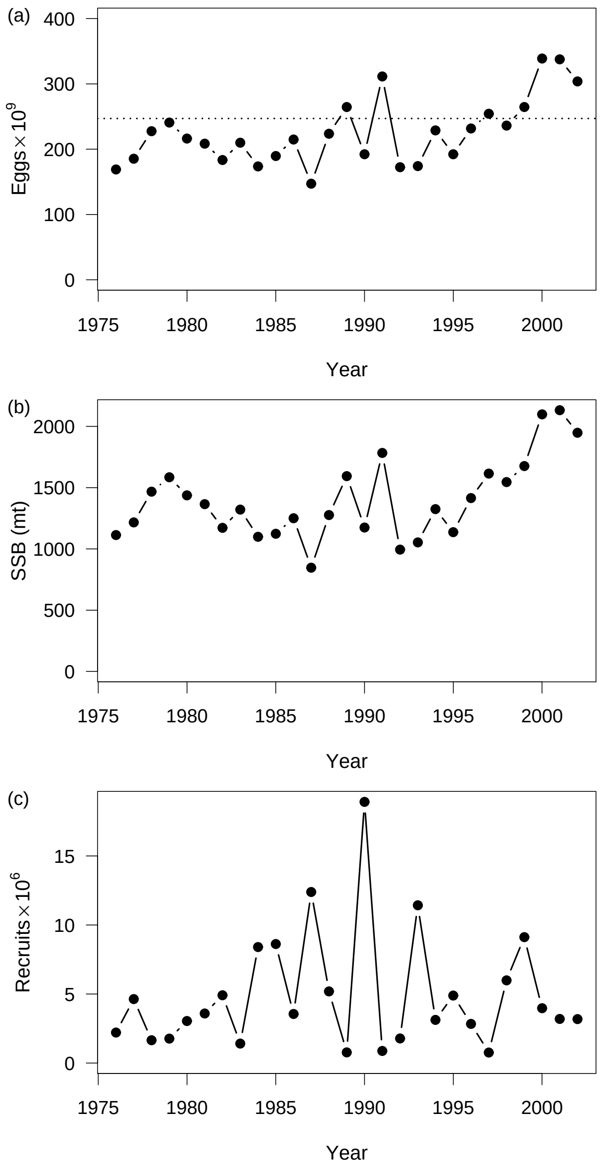


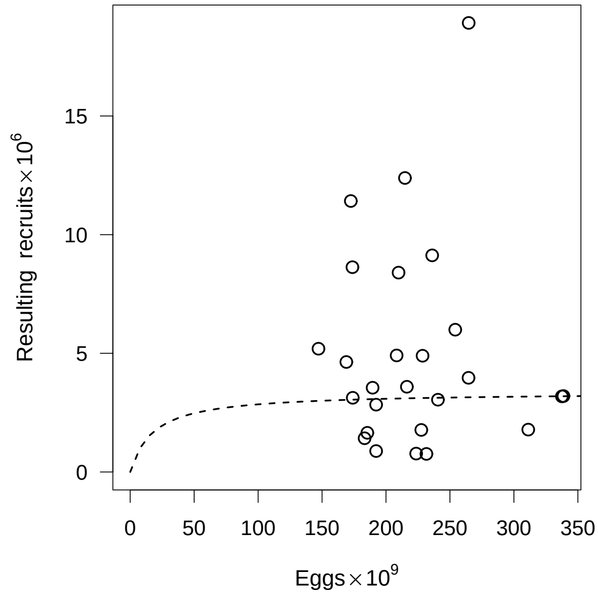
Figure 17. Trajectories of (a) population egg production $\mathcal{E}$, (b) spawning–stock biomass, and (c) recruitment, estimated from base case of length-structured model. Dotted line in (a) is level of egg production $\mathcal{E}_{\mathrm{MSY}}$ at which MSY can be attained.



quite uncertain.

In this report, egg production $\mathcal{E}$ is used as the measure of spawning stock size, and MSST is measured in terms of egg production. Using the Council's customary formulation of MSST = $(1 - M)\mathcal{E}_{\mathrm{MSY}}$, MSST for the base run would be

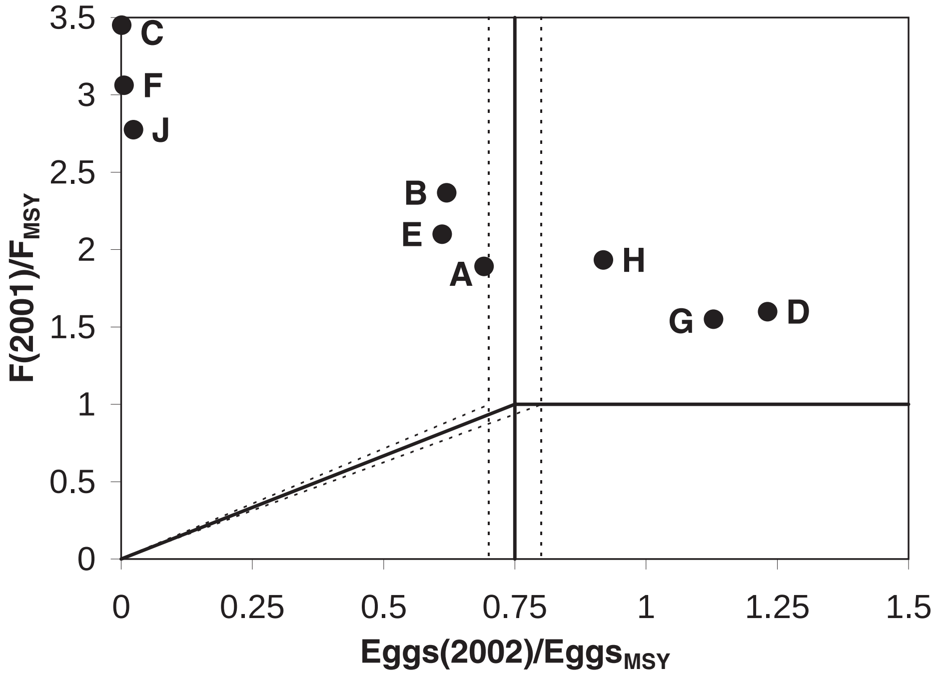
Figure 18. Population egg production $\mathcal{E}$ and recruitment of vermilion snapper estimated from length-structured model with integrated Beverton–Holt recruitment model.



$\mathcal{E} = 185 \times 10^9$ eggs. The base run is the most optimistic of all runs made (Table 4), and the estimate of spawning stock status from the base run is $\mathcal{E}_{2002}/\mathcal{E}_{\mathrm{MSY}} = 1.23$. Most other sensitivity runs estimate that current egg production is below $\mathcal{E}_{\mathrm{MSY}}$ (Figure 19, Table 4).

The limit reference point in fishing mortality rate is the maximum fishing mortality threshold, or MFMT. The value of MFMT depends on the MSY control rule adopted by the Council. Here, the default control rule recommended by Restrepo et al. (1998) is used. In that case, MFMT is a variable, and depends on the current stock size. If stock size is at or above MSST, the MFMT is equal to F_{MSY}. However, if the stock size is below MSST, the MFMT declines linearly to zero (Figure 19). Under the base case assessment, the stock is estimated to be above MSST, and the corresponding estimate of MFMT is $F_{\mathrm{MSY}} = 0.32/\mathrm{yr}$. Present F is estimated to exceed F_{MSY} by about 60% (Fig-

Figure 19. Phase plot of status indicators estimated from length-structured model. Letters correspond to run labels in Table 4. Base run is point **D**. *Solid vertical line is MSST for $M = 0.25$. Dotted vertical lines are MSST for $M = 0.2$ (right) and $M = 0.3$ (left). Solid horizontal and oblique lines are MFMT for $M = 0.25$. Dotted oblique and horizontal lines are MFMT for $M = 0.2$ (lower) and $M = 0.3$ (upper line), according to default MSY control rule of Restrepo et al. (1998).*



ure 19, Table 4). All runs (base and sensitivity) estimate that current F is above F_{MSY} and consequently above MFMT.

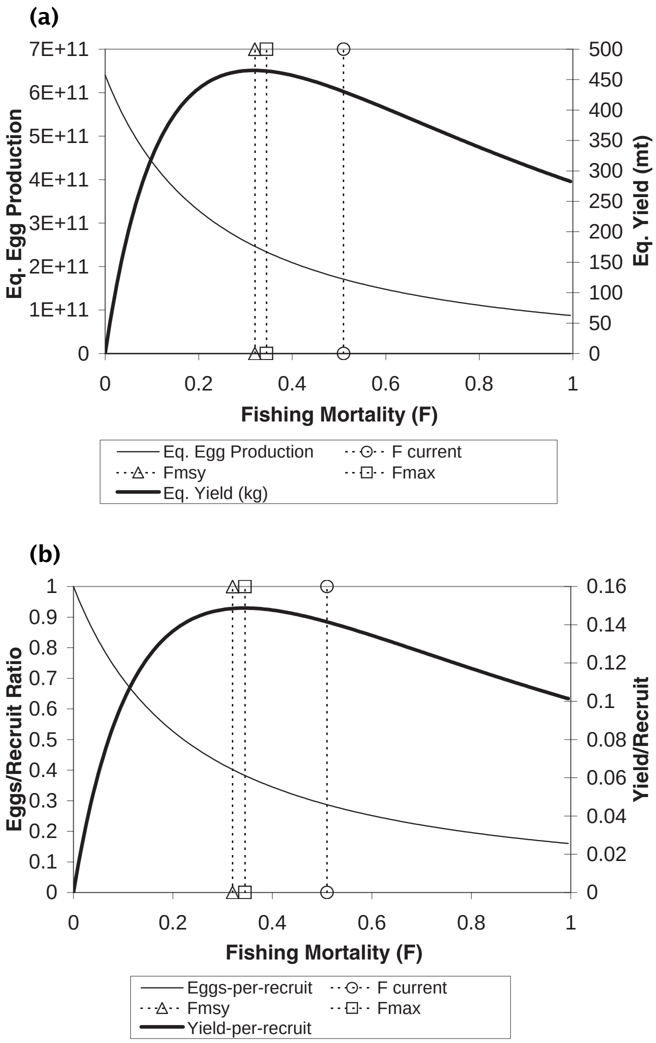
6.4.1 Equilibrium yield and egg production per recruit

Equilibrium yield and yield-per-recruit as functions of F show distinct maxima corresponding to F_{MSY} and F_{max} in panels a and b, respectively, of Figure 20. The value of F_{MSY} corresponds closely to $F_{40\%}$. Present F is estimated to be above the value that would maximize yield per recruit. The implication of that estimate is that decreasing the fishing mortality rate could increase average yield from the fishery, assuming that recruitment remains approximately stable.

6.5 Summary of length-structured model results

In general, the base run and eight sensitivity runs in Tables 3 and 4 resulted in similar fits and estimated population trends, despite wide variation in estimates of management quantities (Table 4, Figure 19). In all cases, fits to landings and abundance indices were good and were better than fits to length– and age–composition samples. All runs estimated an increasing trend in egg production $\mathcal{E}$ during the last third of the modeled time period, along with highly variable recruitment during 1983–1994. This resulted in spawner–recruit scatter plots in all cases very similar to the one pictured in Figure 18, i.e., quite noisy with little guidance as to the underlying relationship. The uncertainty about the spawner–recruit relation-

Figure 20. (a) Equilibrium total-population egg production $\mathcal{E}$ and yield as a function of F. (b) Egg production relative to unfished state and yield, both on per-recruit basis. All from base run of length-structured model.



ship, in turn, necessarily caused great uncertainty in benchmark estimates.

Because of the uncertainty in benchmarks, status of the stock is uncertain, and it is not clear from the assessment whether it is overfished (in the technical sense) or not. The base case suggests it is not, but most sensitivity runs estimate that it is overfished. Status of the fishery (level of F) is uncertain but is consistently estimated by all runs as excessive by SFA standards (overfishing occurring). The yield-per-recruit analysis (Figure 20b) does not depend on the spawner–recruit model, but is characterized by uncertainty stemming from the weak relationship between age and size and other assumptions. It estimates that yield per recruit could be increased by decreasing the fishing mortality rate.

7 Application of production model

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

It proved impossible to obtain successful parameter estimation using the production model. The AW concluded that data available for vermilion snapper were not sufficiently informative for successful implementation of the production model, and it was not considered further.

8 Comparison to previous assessment

A previous assessment of vermilion snapper from the southeastern United States was conducted by Manooch et al. (1998). That study applied an age-structured, untuned separable virtual population analysis (SVPA) to landings in estimated numbers at age over two time periods of constant selectivity: 1986–1991 and 1992–1996. The natural mortality rate was fixed at four levels ($M = 0.2, 0.25, 0.3, 0.35$), and age at full recruitment to the fishery was assumed to be age-3 and age-4 for the 1986–1991 and 1992–1996 time periods, respectively. Manooch et al. (1998) estimated full fishing mortality rate for 1992–1996, assuming $M = 0.25$, as $F = 0.55$/yr. Their per–recruit analysis assumed knife–edged selection and given the estimated F's from the SVPA, resulted in %SPR values of 21% to 27% for 1996. Their recommendation was that %SPR should be raised to 30% to 40%. No attempt was made by Manooch et al. (1998) to estimate a stock-recruit curve or MSY based benchmarks.

Several differences between the Manooch et al. (1998) and this analysis make meaningful comparisons difficult. All analyses in the present assessment use estimated domed or logistic selection functions, rather than the knife-edged selection in the per-recruit analyses of Manooch et al. (1998) or the individually estimated selectivities at age of their SVPA. These selectivity differences are particularly important because both assessments report full F, which is the maximum F exerted on any size or age. The present assessment does not consider selectivity, maturity, and fecundity as functions of age, as in Manooch et al. (1998), but rather as functions of length, which is believed to be the more accurate approach. The current analysis also models release mortality in the commercial hook-and-line and the headboat fisheries, assumed zero in the Manooch et al. (1998) analysis. Recognizing those limitations, some comparison is made. Our mean estimate of full F for the period 1992–1996 is 1.2/yr, which corresponds roughly to %SPR of 40% (an extrapolation from Figure 20b). That value can be compared to the 17% SPR estimate of Manooch et al. (1998) for the same period.

9 Stock projections

To evaluate the likely effects of possible future management measures, simulations were used to project the stock forward. These projections were made separately for each of the nine runs listed in Table 4. For each, corresponding parameter estimates were used, and the projection began with current stock status estimated by that run.

9.1 Structure of projections

Projections employed a population simulation model following the same equations used in the length-structured assessment model. In each projection year, the spawner–recruit model with randomly sampled recruitment residuals from the fitted model (using years 1983–1998) were used to forecast future recruitment levels. An important assumption of this method is that past recruitment patterns will continue into the future. Future fishing mortality rate was fixed at three values, the geometric mean of the last three years' estimates from the assessment model (termed F_{proj}) and $F = F_{\text{proj}} \pm 25\%$. Values of F_{proj} are included in Table 4 on page 21.

Under each of the three values of F, the simulated population was projected forward, 2001–2011, for 1000 trials (each with randomly selected recruitments). The corresponding trajectories of egg production $\mathcal{E}$ and yield were recorded for each simulation.

The 1000 ten-year projections were made for each of nine run scenarios (base run and eight sensitivity runs) listed in Tables 3 and 4. Results of each scenario were then summarized at the 5th, 25th, 50th (median), 75th, and 95th percentiles. As requested by the Assessment Workshop, weighted averages of the model scenario percentiles were then computed, and are summarized along with projection results for the base-case assessment in Figures 21–23.

Figure 21. Projected yields under three management scenarios. (a) and (b) weighted average and base-run projections, respectively, under current F; (c) and (d) same at 75% of current F; (e) and (f) same at 125% of current F. Current F for projections is computed as geometric mean of last 3 years (Table 4).

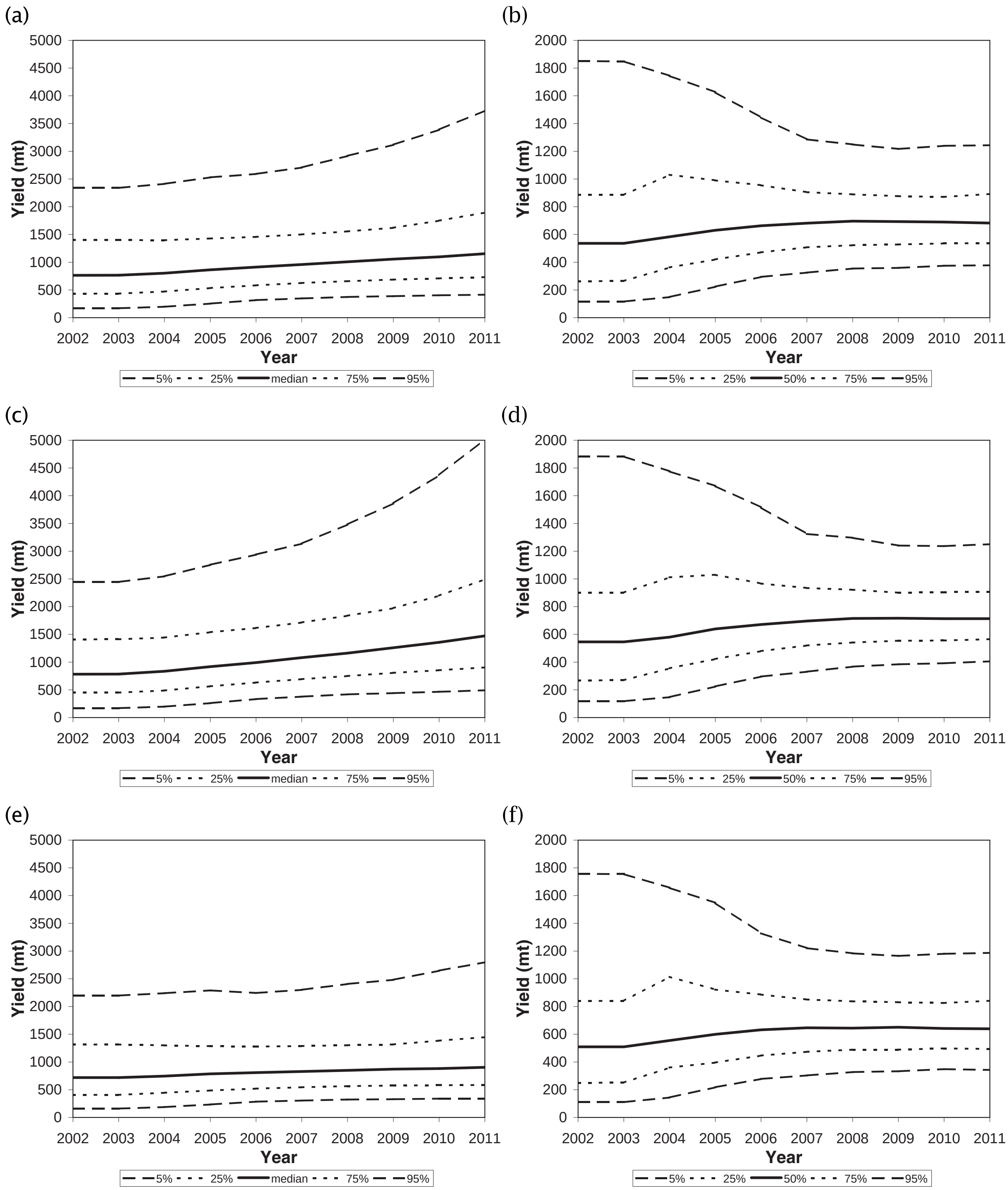


Figure 22. Projected eggs production (a measure of spawning stock size under three management scenarios. (a) and (b) weighted average and base-run projections, respectively, under current F; (c) and (d) same at 75% of current F; (e) and (f) same at 125% of current F. Current F for projections is computed as geometric mean of last 3 years (Table 4).

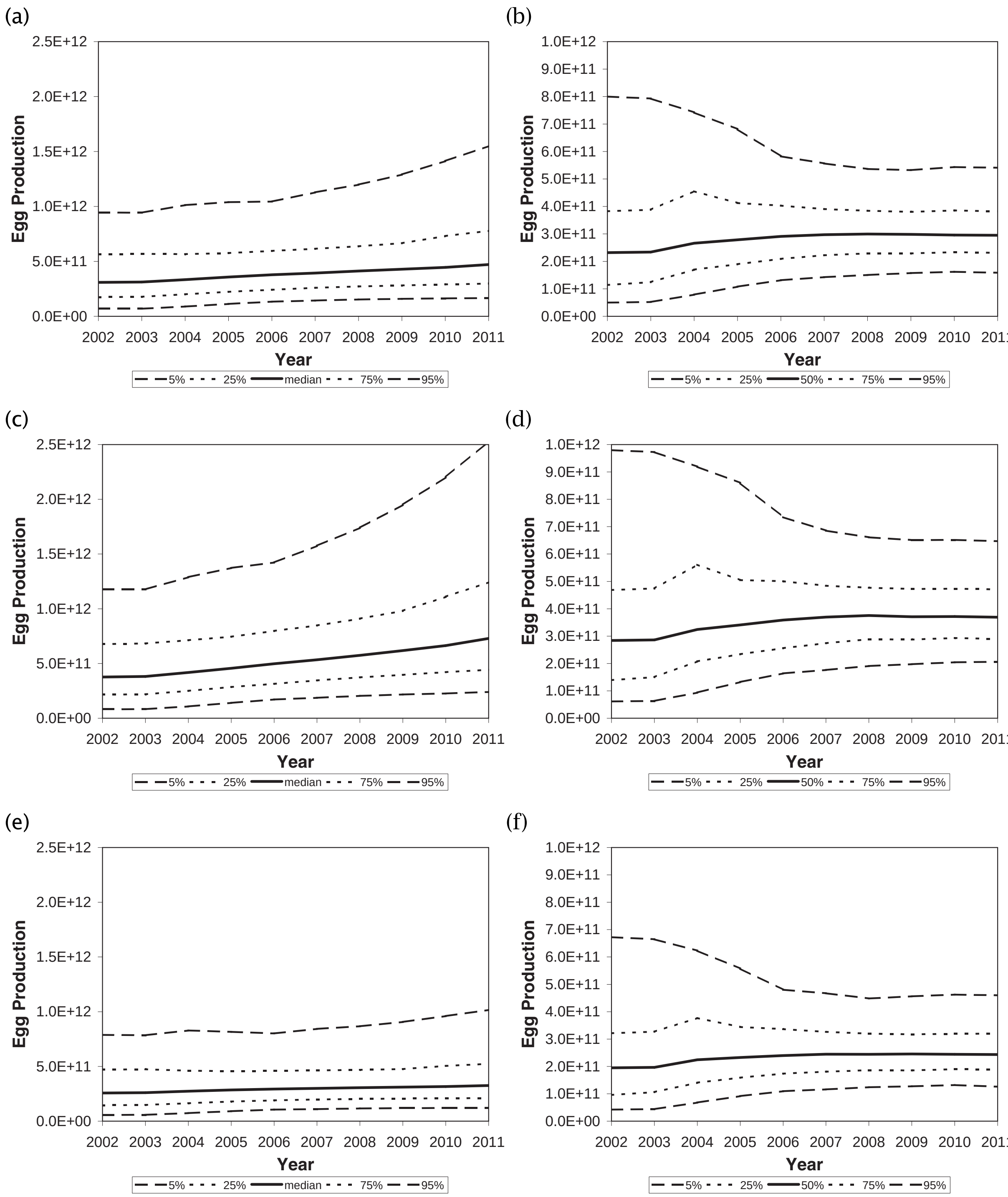
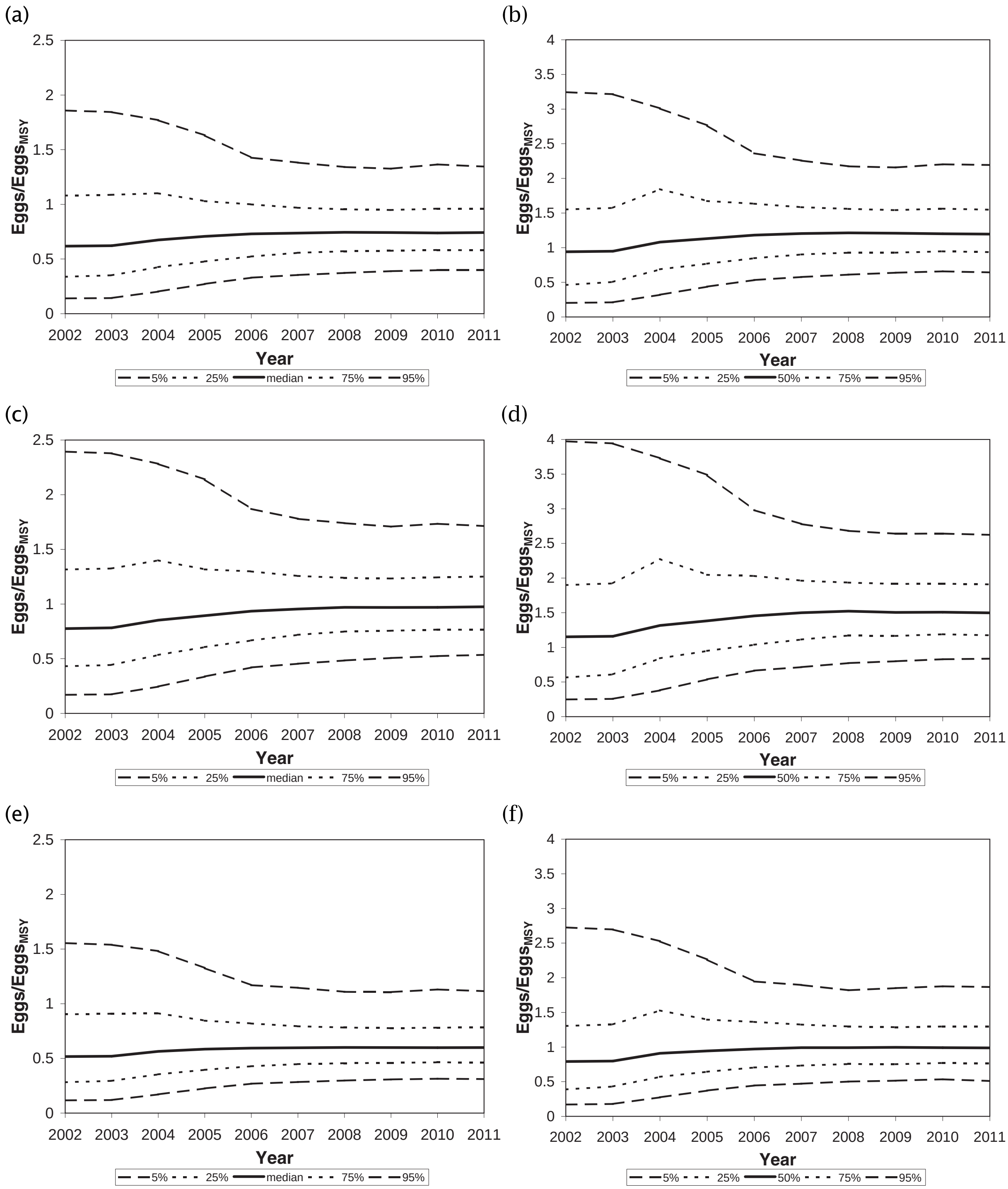


Figure 23. Projected egg production $\mathcal{E}$ relative to $\mathcal{E}_{\mathrm{MSY}}$, under three management scenarios. (a) and (b) weighted average and base-run projections, respectively, under current F; (c) and (d) same at 75% of current F; (e) and (f) same at 125% of current F. Current F for projections is computed as geometric mean of last 3 years (Table 4).



9.2 Projection results

Although starting conditions for the projections were taken from the assessment model, there is a difference in the method of computing spawning stock size $\mathcal{E}$ in 2002 (the first projection year). In both models, population numbers are computed at the start of each year (January 1). In the assessment proper, population size estimates for 2002 were calculated from N_{2001}, F_{2001}, landings for 2001, and a deterministic forecast of recruitment, using the Beverton–Holt spawner–recruit model estimated by the assessment model. As part of those population size estimates, an estimate of $\mathcal{E}_{2002}$ is shown in Table 4. However, in projections, a *stochastic* recruitment was computed in 2002. Also, to simplify computations in the limited time available, F_{2001} in the projections was set to the same value used in other projection years (Table 4). For those reasons, and because median values are shown in Figures 21–23, the values of $\mathcal{E}$ and $\mathcal{E}/\mathcal{E}_{\mathrm{MSY}}$ in 2002 in Figures 21–23 differ from those in Table 4.

Projection results indicate that the population and yield are not expected to change markedly under any scenario considered. Substantial uncertainty in the projections is apparent from the range of the computed percentiles. It is also apparent that the distribution of egg production and yield is skewed toward higher values. The projections are considered somewhat optimistic because the years (1983–1998) chosen by the AW as the basis of recruitment in the projections are years of higher than average recruitment variability, and thus (given the approximately lognormal distribution of recruitment) years of higher than average recruitment. This explains the difference between the projection results and the per–recruit analysis (Figure 20b), which estimated that a reduction in F would lead to slightly higher yield under constant average recruitment.

10 Research recommendations

The group 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 vermilion snapper.

1. The statistical weights assigned various data sources in the assessment model can influence the results. At present, weights are determined heuristically to provide a balance of fit to all data sources. The group recommends further research to investigate methods of weighting data sources, e. g., based on their apparent significance, relevance, or reliability.

2. Fishery-independent data collected by the MARMAP program are used in many stock assessments in this region, 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 do not having ideal extent, either in area coverage or in sampling intensity, for vermilion snapper. The group recommends that the MARMAP program expand its coverage, particularly into deeper water, as needed.

3. Under many forms of management, considerable discarding of vermilion snapper could be expected to occur. The group recommends that sampling programs be strengthened to quantify discard rates, especially in the commercial fishery, where the discard mortality rate is believed higher, and to estimate discard mortality rates better. The group recommends that research be instituted on management strategies that could reduce discard

mortality.

4. Data have been recorded from commercial catch logbooks since 1993. However, logbook data have not been incorporated into stock assessments in the South Atlantic because of apparent difficulties in analyzing the data. The DW and AW both recommended that an investigation be undertaken to determine the feasibility of and best methodology for using commercial logbooks to develop an abundance index for the commercial fishery for vermilion snapper.

5. An important data element for stock assessment, including vermilion snapper, is routinely collected age-composition data for major fisheries. The DW and AW recommend that regular statistical sampling and analysis of vermilion snapper for aging is needed, in both the commercial hook-and-line and headboat fisheries. A minimum sample size of 500 ages per year is recommended from each fishery.

6. Abundance indices for vermilion snapper indicate only minor fluctuations in population abundance during the model time period. This low population contrast is partly responsible for the large uncertainty in estimates derived from the model. The AW recommends that alternative age-structured models be investigated for vermilion snapper and other low contrast populations to determine whether more robust population estimates might be achieved.

7. Recreational landings estimates for vermilion snapper (and other species) in the MRFSS database are often highly variable, resulting in large year-to-year swings in the estimates. Those swings apparently reflect sampling error, rather than true fluctuations in fishery landings. Such large year-to-year changes can influence assessment models in undesirable ways. The AW recommends that smoothing techniques be investigated to potentially reduce some of those large year-to-year changes. This will be particularly important for other species, many of which are taken in larger fractions by the recreational fisheries sampled by MRFSS.

8. Although an age-structured model was ultimately not used in this assessment of vermilion snapper, it was noticed when developing this model that fecundity estimates were available only by length and not by age. The AW recommends that fecundity estimates at age be developed for future use in age-structured models.

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Appendix A Terms of reference for the second SEDAR Assessment Workshop

The Assessment Workshop's task is to produce a stock assessment for the Black Seabass and Vermilion Snapper stocks in the SAFMC's area of jurisdiction. This work is done with reference to the U.S. Sustainable Fisheries Act and its National Standards, which govern the Council's management. A written final report (using word or wordperfect software), 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 and distributed on or before January 27, 2003.

1. Identify modeling approaches appropriate to the available data and management questions (e. g., production models, age-structured models, hybrids). The Data Workshop recommended the Forward Projection Model approach.

2. Determine all SFA-required benchmarks (MSY, B_{MSY}, MSST, MFMT, and F_{MSY}). Other standard benchmarks should also be provided (e.g., $F_{0.1}$, $F_{\max}$, etc.).

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

4. If the stock(s) are overfished, identify and conduct rebuilding analyses (projections of rebuilding to MSST [sic] and B_{MSY}; yield streams over the rebuilding time-frame). The rebuilding analyses should include: (a) $F = 0$, (b) $F =$current management measures, and (c) other possible scenarios.

5. Provide recommendations for future research (field and assessment) and data collection necessary to improve assessment results.

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.

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

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Appendix C—Abbreviations and symbols

Table 5. Acronyms, abbreviations, and mathematical symbols used in this report

Symbol	Meaning
AW	Assessment Workshop (here, for vermilion snapper)
B	Total biomass of stock
CPUE	Catch per unit effort; used after adjustment as an index of abundance
DW	Data Workshop (here, for vermilion snapper)
$\mathcal{E}$	Population egg production, a measure of spawning-stock size
$\mathcal{E}_{\mathrm{MSY}}$	Level of $\mathcal{E}$ at which MSY can be attained
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
lb	Pound(s)
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 based on F_{MSY}
mm	millimeter(s)
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 vermilion snapper as $(1 - M)\mathcal{E}_{\mathrm{MSY}} = 0.75\mathcal{E}_{\mathrm{MSY}}$.
MSY	Maximum sustainable yield
mt	Metric tons(s)
N	Number of fish in the population at the start of a time period
NC	State of North Carolina
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration; parent agency of NMFS
R	Recruitment
SAFMC	South Atlantic Fishery Management Council
SC	State of South Carolina
SCDNR	Department of Natural Resources of SC
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)