STATUS OF THE VERMILION SNAPPER FISHERY IN THE GULF OF MEXICO:

ASSESSMENT 5.0

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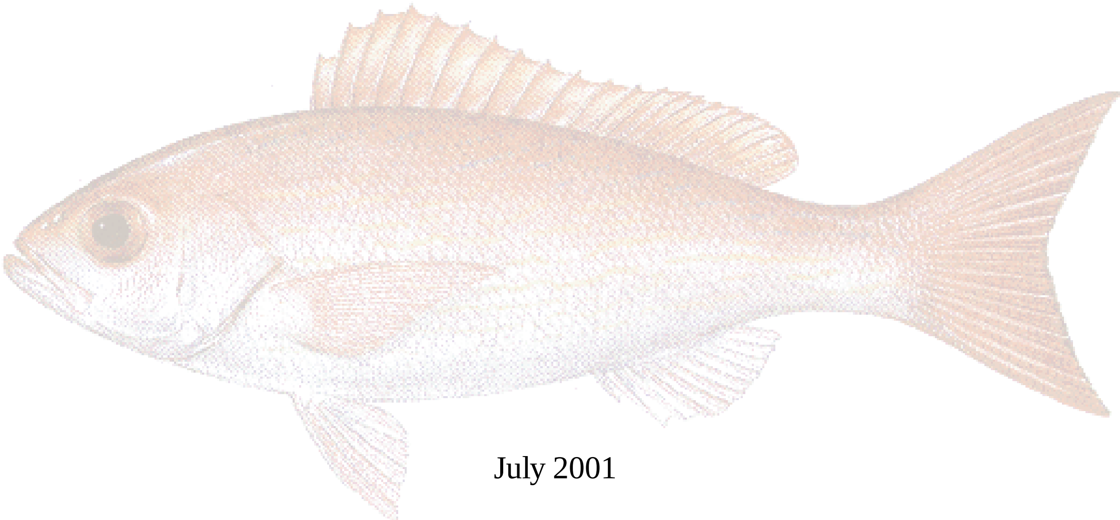

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BIOLOGICAL CHARACTERISTICS

The vermilion snapper (*Rhomboplites aurorubens*) typically occurs on, and shoreward of the shelf-break from Bermuda and the southeastern United States, through the Gulf of Mexico (Figure 1) and the West Indies to southeastern Brazil (Bohlke and Chaplin, 1968). This species can live 10-14 years (Zhao et al., 1997; Potts et al., 1998; Hood and Johnson, 1999), and reaches a maximum size of 24 inches and 5.7 pounds (Bohlke and Chaplin, 1968).

MORPHOMETRICS

Length Conversions

Measurements of vermilion snapper have been reported in terms of total length (*TL*), fork length (*FL*) and sometimes even standard length (*SL*). Each metric is strongly correlated with the others, and it is a simple matter to convert one to another (Table 1). When necessary, we converted to predicted total length using the regression equations reported by Hood and Johnson (1999).

Length-Weight Relationship

Several length-weight relationships have been reported. All are very similar, and are summarized in Figure 2 and Table 2. Eight of nine regression equations fall between those reported by Grimes (1976) and Nelson (1988). However, the length-weight relationship reported by Zastrow (1984) for fish collected at Port Aransas, TX, predicts considerably heavier fish than the others. We chose to use the relationship reported by Hood and Johnson (1999) to estimate weight-at-length because the data had been collected recently in the Gulf of Mexico:

$$\text{(1)} \qquad \mathrm{Log}_{10}(\mathrm{W}) = 2.87\ \mathrm{Log}_{10}(\mathrm{TL}) - 3.225$$

where *W* is the total weight in pounds, and *TL* is total length in inches.

AGE AND GROWTH

Growth curves were used to age the commercial and recreational catch. Published estimates of the growth of vermilion snapper vary widely (Figure 3, Table 3). Most of the growth curves published before 1992 relied on scale and whole otolith increment data, but these techniques have been largely abandoned in favor of sectioned otolith methods. Schirripa (1992) conducted an extensive study of the growth of vermilion snapper using increments from scales, sectioned otoliths and tag/recapture data to compute a single von Bertalanffy growth curve. Several authors have recently published conclusive evidence that otolith increment formation is in fact annual, and generally occurs from June-August (Zhao et al., 1997; Potts et al., 1998; Hood and Johnson, 1999). The age when the first ring is formed is generally presumed to be at one year, but this has yet to be validated.

Recently, the NMFS Panama City Laboratory has aged several thousand vermillion snapper collected during 1994-2000 from recreational and commercial catches throughout the Gulf of Mexico (see Allman et al., 2001). After visual examination of the size-at-age data, it was evident that at a given age, fish collected from the commercial fishery were generally larger than those collected from the recreational fishery. Inasmuch as this difference may be due to selection, we fitted separate growth equations for the two fisheries (Figure 4):

(2) $TL = 15.898\ [1 - e^{-0.118(\text{Age} + 8.329)}]$ (Recreational: n = 1151, $r^2 = 0.079$, $p<0.001$)
(3) $TL = 16.849\ [1 - e^{-0.333(\text{Age} + 2.747)}]$ (Commercial: n = 523, $r^2 = 0.187$, $p<0.001$)

where *TL* is the total length in inches and *Age* is in years. Inverted von Bertalanffy functions were fit to the same data to determine age from length (Figure 5). The fitted equations are

(4) $Age = -\ln(1-TL/22.73)/0.551 - 3.43$ (Recreational: n = 1151, $r^2 = 0.097$, $p<0.001$)
(5) $Age = -\ln(1-TL/23.12)/0.296 - 1.54$ (Commercial: n = 523, $r^2 = 0.156$, $p<0.001$).

It is important to note that our growth equations are quite different from the equations used during previous assessments (Schirripa 1992, 1998, 2000):

(6) $TL = 21.06\ [1 - e^{-0.2028(\text{Age} + 0.9401)}]$
(7) $Age = -\ln(1-TL/26.02)/0.1268 - 1.455$

Initially, we suspected a change in growth. However, R. Allman[1] recently examined several of the older samples and found that he would have assigned older ages to them than did the original reader. Hence, the apparent change in age may be more a reflection of reader bias than an actual change in growth rates. In view of this, and the uncertainty about when the first growth ring forms in the otolith, we consider the growth rate (and age structure) of vermilion snapper to remain questionable.

REPRODUCTION

Female vermilion snapper typically spawn from mid-April through September in the Gulf of Mexico and the South Atlantic Bight (Grimes, 1976; Grimes and Huntsman, 1980; Cuellar et al., 1996; Hood and Johnson, 1999). They are indeterminate spawners; their oocytes continue to mature throughout the spawning season, and there are no discontinuities in the size distribution of oocyte classes (Cuellar et al., 1996). Multiple annual spawnings are indicated by the co-occurrence of several oocyte stages within a single ovary, and it is estimated that each female vermilion snapper spawns 23-93 times during the spawning season (Cuellar et al., 1996; A. Collins[2], pers. com.).

Sex Ratio

Hood and Johnson (1999) report a sex ratio not significantly different from 1:1 in the Gulf of Mexico, but studies in the South Atlantic Bight contradict this result (Grimes and Huntsman, 1980;

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[1] Allman, R. Southeast Fisheries Science Center, Natl. Mar. Fish. Serv., 3500 Delwood Beach Road, Panama City, FL 32407. Personal communication.

[2] Collins, A. Southeast Fisheries Science Center, Natl. Mar. Fish. Serv., 3500 Delwood Beach Road, Panama City, FL 32407. Unpublished data.

Cuellar et al., 1996; Zhao and McGovern, 1997) (Table 4). Grimes and Huntsman (1980) concluded that the sex ratio was nearly equal at 100-150 mm TL, but that females made up an increasing percentage of the sample as fish length increased. This result suggests an initially equal proportion of males and females, with males either experiencing higher mortality rates or attaining lower maximum lengths. However, more recent investigations report that sex ratio is independent of fish length (Nelson, 1988; Zhao and McGovern, 1997). Zhao and McGovern (1997) report that sex ratio is also independent of the water depth sampled, but may be dependent on gear type. They found that females comprised 66-69% of hook-and-line catches but only 60-61% of trawl catches (Table 4).

Sexual Maturity

According to Grimes and Huntsman (1980), most female vermilion snapper first spawn at age 2 or 3 (186-324 mm TL), while a few precocious individuals spawn at age1 (>150 mm TL). However, more recent studies suggest a younger age at first reproduction (Collins and Pinckney, 1988; Zhao and McGovern, 1997) (Table 5). Furthermore, there is some evidence that age at first reproduction has decreased over the past two decades (Zhao and McGovern, 1997). These changes could be caused by increased fishing pressure (Goodyear and Schirripa, 1991; Zhao and McGovern, 1997) as genotypes that produce late-maturing individuals are more likely to be removed before first reproduction.

Like previous assessments (Schirripa 1998, 2000), we assumed that all vermilion snapper are sexually mature at age1. This assumption is supported by recent data published by Zhao and McGovern (1997). At 180 mm, virtually all vermilion snapper they examined were sexually mature (Table 5). According to the size-at-age data presented in Figure 4, one-year-old vermilion snapper are typically larger than 7 inches (178 mm).

Fecundity

We used length, gonad weight, and batch fecundity data provided by Alan Collins[3] to determine the relationships of gonad weight and batch fecundity to total length. The samples were collected during April-September 1993, 1994 and 2000 in the Gulf of Mexico. The relationship between gonad weight (*GW*) and total length was described by the equation:

$$GW = 1.43\text{ E-03 } TL^{\,3.878} \tag{8}$$

(see Figure 6). The relationship between batch fecundity (number hydrated oocytes) and total length was described using the equation:

$$BF = 1818.9\, e^{TL*0.3226} \tag{9}$$

(see Figure 7).

Schirripa (1998) reported a significant relationship between spawning frequency and length. However, further study has cast doubt on this relationship (A. Collins, pers. com.). Recent estimates

[3] Collins, A. Southeast Fisheries Science Center, Natl. Mar. Fish. Serv., 3500 Delwood Beach Road, Panama City, FL 32407. Unpublished data.

of spawning frequency range from 23-35 spawnings per season (Cuellar et al., 1996) to 93 spawnings per season (A. Collins, pers. com). For the purpose of this assessment, we assumed that female vermilion snapper spawn 93 times each season. Therefore, annual fecundity is assumed to be equal to batch fecundity (equation 9) multiplied by 93.

NATURAL MORTALITY RATE

The natural mortality rate (*M*) of vermilion snapper has never been estimated directly, however Schirripa (1998) examined a number of indirect techniques for inferring it from various other biological characteristics. He obtained estimates of *M* ranging 0.48 to 0.17 $yr^{-1}$and concluded that there was no evidence to reject the value of 0.25 yr^{-1} used in earlier assessments. We likewise have no basis for rejecting this value.

GENERATION TIME

Generation time depends on the fecundity and natural mortality rate of the stock. If the abundance of males is not limiting, then it may be computed as

(10)
$$G = \frac{\sum_{a=0}^{A} a\, E_a R_a P_a\, e^{-\sum_{i=0}^{a-1} M_i}}{\sum_{a=0}^{A} E_a R_a P_a\, e^{-\sum_{i=0}^{a-1} M_i}} ,$$

a = subscript denoting age
A = maximum age in the unfished stock (here 40)
E = average fecundity at age (product of eq. 5 and 6)
R = proportion of population that is female (0.5)
P = proportion of females that are mature.

Schirripa (1998) estimated the generation time to be 14.6, 10.6, and 8.0 years for natural mortality rates (M) of 0.15, 0.25 and 0.35 yr^{-1}, respectively. When the batch fecundity relationship of equation (9) is used (and multiplied by 93 for total annual fecundity), the corresponding generation times are about a year less at 13.7, 9.8, and 7.6 years, respectively.

STOCK STRUCTURE

Previous assessments have assumed that the population in the northern Gulf of Mexico is distinct from those in the Atlantic and Gulf of Campeche. This appears to be based largely on tag-recapture results which suggest that vermilion snapper do not travel very far (Beaumariage, 1964; Grimes et al., 1973; Fable, 1980). The spatial distribution of headboat catches (Brown and Calay, in prep.) and differences in the size composition of the catches suggest that there may also be distinct sub-populations in the eastern and western portions of the northern Gulf, however these patterns could also result from different fishing preferences and are not conclusive. Accordingly, we find insufficient evidence to reject the Gulf stock hypothesis.

FISHERIES

COMMERCIAL FISHERY

Commercial landings

The National Marine Fisheries Service (NMFS) and its predecessors have collected landings data by contacting fish dealers since 1880. These estimates are thought to account for most of the commercial catch passing through dealers, but do not include that part of the catch that bypasses the dealers and enters the retail market directly. Annual landings of vermilion snapper were available for each Gulf state from 1962 to 1999 (Table 6, Figure 8). They include vermilion snapper captured in both U.S. and foreign waters, however Schirripa (1998) showed that the foreign contribution during this period is negligible. The landings are reported in units of pounds whole weight except for Florida prior to 1986, which are in pounds gutted weight and were converted to whole weight by multiplying them by the factor 1.11. Schirripa (1998) reported that "some vermilion snapper are known to have been landed and sold as red snapper in 1984 and 1985, particularly in Louisiana. Consequently, the vermilion snapper landings were adjusted upward by the fraction of the total landings of snapper sold as red snapper which were estimated to have been vermilion." Our tallies of the landings for Louisiana and Mississippi in 1984-85 match those of Schirripa (1998) without making any such conversion, suggesting perhaps that these adjustments were incorporated into the landings database.

The largest landings were made in Florida, but substantial landings were also reported for the other states after 1983 (Figure 8a). Most of the landings were made using handlines (Figure 8b), with minor contributions from powerlines, bottom longlines and fish traps.

The Gulf-wide landings appear to have been insignificant from 1962 to the mid 1970's, but then increased markedly to a peak of nearly 3 million pounds in 1993 (Table 6). Since then, the commercial landings have steadily decreased to about what they were during the 1980's.

Commercial length composition

Data on the historical length composition of commercially caught vermilion snapper has been collected since 1984 as part of the trip interview program (TIP) administered by the Southeast Fisheries Science Center (SEFSC) of NMFS and carried out by federal and state fisheries personnel familiar with the fisheries in their areas.

The length distributions for the various gears seem rather similar (see Figure 9), however the fish landed in Texas are generally larger than those caught in Louisiana and Mississippi, which in turn are larger than those caught in Florida and Alabama. However, little or no length data were available for some states in some years, therefore the commercial fishery data were pooled into western (Texas, Louisiana and Mississippi) and eastern (Florida and Alabama) strata.

Commercial Catch Per Unit Effort

Catch per unit effort data (CPUE) were obtained from the Reef fish Logbook Program, 1990 through 2000. This program requires all vessels holding reef fish permits in the states of Alabama, Mississippi, Louisiana, and Texas to file a report detailing the catch and effort spent during each fishing trip. Before 1993, only 20% of the vessels permitted in Florida were required to report. These were randomly chosen each year. All vessels permitted in Florida were required to report after 1993.

The CPUE data were standardized by Brown and Calay (in prep.) using the Lo method (Lo et al., 1992) to account for the effects of significant factors on yearly changes in catch rate. The Lo method requires separate analyses of the proportion of successful trips, and the catch rates of successful trips (positive catch rates). Factors considered as possible influences on proportion of successful trips and positive catch rates included year, month, season, geographic area (Zone), days at sea (Sea_Days), red snapper permit class (Class), status of the red snapper season (Status_RS: e.g., open or closed), number of hooks per line and the “level” of hooks per line (high, medium and low). Fishing effort was defined as hooks * hours fished.

A forward step-wise procedure was taken to build a Generalized Linear Model (GLM). This procedure is described in detail by Brown and Turner (2000). The models were created using the delta-gamma approach. For the proportion of successful trips, we assumed a delta distribution with a binomial error distribution. For the positive catch rates, we assumed a gamma error distribution. The final models used to create the standardized commercial index were as follows:

Proportion Positive Tows: Hooks per line + Sea_Days + Year
Positive Catch Rates: Hooks per line + Status_RS+ Sea_Days + Year

Interaction terms were tested, but were not significant. The values of the standardized commercial index from the model above are compared with those calculated according the methods specified in the previous assessment (Schirripa, 1998) in Figure 10 and Table 7.

RECREATIONAL FISHERY

Recreational landings

The number vermilion snapper landed and released by recreational anglers has been estimated since 1979 as part of the NMFS Marine Recreational Fishery Statistics (MRFSS). Originally, the survey covered all five of the Gulf states and included modes of fishing from shore, private boats, charter boats and party (head) boats. Party boats have not been included in the MRFSS since 1985, but have been monitored instead by the NMFS Headboat Survey (conducted by the NMFS Beaufort Laboratory). MRFSS sampling was also discontinued in Texas, where the Texas Parks and Wildlife Department (TPWD) has conducted their own survey since 1983. The MRFSS estimates were used for the times when the two surveys overlapped inasmuch as they include all modes as well as estimates of releases and variances.

The MRFSS, TPWD and NMFS headboat surveys provided bimonthly estimates for all areas and modes except for the first bimonthly period (January and February) of 1981, 1982-1983 Texas boat modes and Texas shore modes after 1985 (the TPWD survey does not include shore-based fishing). There do not appear to be any viable estimates to replace these missing data. Therefore, a number of substitutions had to be made, which are summarized in Table 8.

The MRFSS survey estimates were revised in 1995 with the exception of the years 1979 and 1980 and bimonthly period (wave) 4 of 1981-85 in Texas. The estimates for these periods are considered less reliable than the subsequent revised estimates and are no longer available in the official MRFSS data base because some of the original raw data files are no longer available (P. Phares, Southeast Fisheries Science Center, NMFS). We used the original estimates for 1980, but discount those from 1979 because all of the vermillion snapper were reported as coming from inland waters (hence they were either misidentified or there was a major coding error).

The recreational landings (including estimates of dead discards and the substitutions from Table 8) are summarized in Table 9 by state, mode, distance from shore and year. Florida and Alabama anglers have accounted for most of the recreational harvest of vermilion snapper in nearly every year (Figure 11). Texas is next, with small contributions from Mississippi and Louisiana. Most of the harvest is from the EEZ; only Florida has any significant recreational fishery for vermilion snapper within state territorial seas (which extend 10 miles offshore along the Gulf coast).

Gulf-wide, the recreational harvest appears to have been highest in the early 1990's, fluctuating between 1 and 1.4 million fish, but then fell to about half that level after 1995. The harvest trends of the individual states all seem to match the overall pattern of increasing catches in the early 1990's, followed by a sharp decrease over the last four years.

Recreational length composition

Length composition data are available from all of the same sources discussed in the recreational landings section, with the same gaps. In addition, some data are available from the TIP program and miscellaneous sources collected by the NMFS Panama City laboratory. The Panama City data were not used because the sampling protocols were unknown, but this was of little consequence as those data were limited to a few observations in 1977, 1978 and 1994.

The length composition data are summarized by state, mode and habitat type (state territorial waters versus EEZ) in Figure 12. As for the commercial length composition, the fish caught in the western Gulf tend to be larger than those caught in the eastern portion. There does not appear to be any substantial difference in the size composition of fish caught in the territorial seas and EEZ. Accordingly, length observations were pooled by state as in previous assessments. However, owing to sparse sampling in some states in some years, the data for Alabama and Florida were pooled as were the data from Louisiana and Mississippi. This should have very little effect on the analysis as the length frequencies for Alabama and Florida were very similar and the recreational catch in Mississippi was negligible.

Recreational Catch per Unit Effort

Estimates of catch and effort are available from the Gulf of Mexico headboat fishery from 1986 through 1999. The CPUE series was standardized by Brown and Calay (in prep) using the Lo Method as described above (except that the positive catches were modeled using the Poisson distribution rather than the gamma). The Gulf of Mexico was divided into an eastern and western zone. Fishing effort was defined as angler hours. Only those vessels that fished during a majority of the years sampled were included. In addition, the vessels were ranked each year by vermilion snapper CPUE and included only if their average CPUE rank was above the median.

Factors considered as possible influences on proportion of successful trips and positive catch rates included vessel, year, month, season, trip length (Trip_Cat), and whether fishing occurred during day or night (Day_Night). Interaction terms were tested, but were not significant. The final models used to create the headboat CPUE index were as follows:

Western GOM Proportion Positive Tows: Vessel + Day_Night + Trip_Cat + Year

Western GOM Positive Catch Rates: Vessel + Year
Eastern GOM Proportion Positive Tows: Year + Trip_Cat
Eastern GOM Positive Catch Rates: Year + Trip_Cat

The values of the standardized indices from these models are compared with those calculated using the methods of the previous assessment (Schirripa 1998) in Figure 13 and Table 7.

Recreational releases

The MRFSS provides separate estimates of the number of fish discarded dead and released alive, however there are no data on the release rates in Texas after 1981. The estimated percent of vermilion snapper catch that is released alive from charter and private vessels fluctuated under 15 percent prior to 1992, but increased to nearly twice that during the mid 1990's (Table 10). As Schirripa (2000) points out, this trend may be partly explained by a higher percentage of smaller fish in the catch resulting from increased recruitment during those years (as suggested by the fall groundfish survey results discussed below), but there is no length information to corroborate this hypothesis. Surprisingly, the trend does not appear to be influenced by the 10 inch minimum size limit imposed in 1997 since the highest release rates occur before that time and the rates for 1998 and 1999 are rather low.

SHRIMP BY-CATCH

Vermilion snapper are also caught incidental to the offshore shrimp fishery. Estimates of the number caught (Figure 14) are available courtesy of S. Nichols, NMFS. The estimation approach used is described in detail by Nichols et al. (1987, 1990). The distribution of lengths from the NMFS observer program (Figure 14) is bimodal, suggesting that about 25 percent of the by-catch of vermilion snapper consists of young-of-the-year and the rest of one-year olds.

FISHERY INDEPENDENT SURVEYS

The Pascagoula laboratory of the National Marine Fisheries Service/Southeast Fisheries Science Center has conducted fishery independent trawl surveys in the north central Gulf of Mexico since 1972. These surveys are intended to quantify spatial, seasonal and inter-annual variations in groundfish resources, including vermilion snapper (Nichols and Pellegrin, 1989). The "Fall Groundfish Survey" occurred in October-November of every year from 1972-1986. The survey utilized a 40-foot-trawl to randomly sample a "primary area" between 5 and 50 fathoms, and 88˚W to 91.5˚W. Only stations included in the primary area are included in the Fall Groundfish Survey data set. Beginning in 1987, the Fall Groundfish Survey adopted the SEAMAP survey design. The SEAMAP survey randomly samples a greatly enlarged region from 5-100 fathoms, typically beginning offshore of southern Texas and continuing to Alabama. This survey design will hereafter be referred to as the "Fall SEAMAP Survey".

Previous assessments of vermilion snapper (Schirripa 1998, 2000) combined the two surveys to create a single time series. To accomplish this, Schirripa excluded stations outside of the primary area of the Fall Groundfish Survey from the Fall SEAMAP data set. For each year, the number of vermilion snapper caught and the trawl duration are known. This information was used to create two indices of abundance, a presence index (proportion positive tows) and a CPUE index (number captured per tow-hour). Schirripa (1998) found a significant relationship between the proportion of positive tows (PPT) and commercial landings ($p \ll 0.05$). Therefore, he concluded that the PPT time series could be used as an indicator of juvenile abundance. The CPUE index was not used as an index of abundance during previous assessments.

For this assessment, we utilized the PPT index reported by Schirripa (2000) (Figure 15, Table 11) as an index of the abundance of age-1 and 2 individuals. We also used the Fall SEAMAP CPUE index (created and provided by S. Nichols, NMFS Pascagoula Laboratory) in a sensitivity analysis.

POPULATION MODELS

Two approaches are used to evaluated the status of the stock: Age-structured VPA models based catch at age derived from length observations and a Pella-Tomlinson non-equilibrium production model.

AGE-STRUCTURED VPA

Construction of catch at age

Age was determined from length by use of equation (7), which was used in the previous assessment, and by use of equations (4) and (5) in one sensitivity run. In order to track year-classes, the age assigned for the VPA was calculated as INT[age+0.5], where INT truncates whole numbers to their integer part (i.e., INT[2.5]=2) and 0.5 accounts for an assumed July 1 birth date. The relative age frequency distribution was then constructed for each strata of the catch (east versus west for the commercial and Tx, La-Ms, Al-Fl for the recreational) and the catch at age computed by multiplying the total catch in numbers. In the case of the commercial catch the total catch in numbers was computed by dividing the total catch in weight by the average weight. The average weight was determined by averaging the recorded weights (and weights inferred from the length where no weight was recorded).

At this point it should be reiterated that there is much disagreement between the growth curves estimated by various authors. Further, although annual ring formation seems to be well-validated, it has not yet been established when the first ring is formed in the otolith. More importantly, recent aging work by Hood and Johnson (1999) and Allman et al. (2001) indicate huge variation in length at age (and age at length), as is evident in our Figures 4 and 5. Allman et al. (2001) suggest that this variation is due to differences in growth rate and cannot be explained merely by reader errors. If true, one cannot reasonably expect to determine age from length. We illustrate this in Figure 16 where we use the growth curve to determine the age composition of TIP samples from handline catches and compare it with the composition derived by directly aging the samples. Equation (7), derived by Schirripa (1992), over-represents age 2 and under-represents ages 4, 5 and 8 or older. In contrast, Equation (5) over-represents age 4 and under-represents ages 8 and older. Similarly, when equation (4) is applied to recreational samples, age groups under 4 will not be represented at all (see Figure 5).

It is difficult to say which set of equations would generally perform better, but the point is that neither Schirripa's (1992) equation nor ours perform acceptably given the most recent information on size at age. Therefore, we recommend against placing too much emphasis on the VPA results presented below or in previous assessments of vermilion snapper. The VPA's are conducted to provide a baseline for comparison with previous assessments, and to facilitate that comparison we have adopted the growth curves and fecundity ogives used in the 1998 and 2000 assessments (except as otherwise noted). However, we reiterate that, based on the most recent information on size at age, we do not believe the VPA approach can effectively characterize this stock without directly ageing samples of the catch.

VPA Methods

The previous assessment (Schirripa, 1998; Schirripa 2000; Schirripa and Legault, 2000) presented three VPA models using combinations of three different indices: Model A used the east headboat and commercial logbook indices, Model B added the groundfish index and Model C used the groundfish and east headboat indices (dropping the commercial CPUE index). The 2000 Reef Fish Stock Assessment Panel (RFSAP) decided that the proportion positive groundfish index should be used in the tuning process, excluding consideration of model A. Of the two remaining models, Schirripa (1998) and Schirripa and Legault (1998) focused more on C than B, possibly because the estimates from B were not well-determined owing to the combination of a short time series and the conflicting trends indicated by the headboat and commercial CPUE. Accordingly, it was decided to use an updated version of Model C as the starting point, but an updated version of model B was included as a sensitivity run.

The update to model C, hereafter referred to as VPA 1, includes the three new years of catch at age (1997-1999) and uses the proportion positive groundfish index updated to 1998 by Schirripa (2000) and a headboat index for the eastern Gulf updated to 1999 by Brown and Calay (in prep.). We were also able to reconstruct the catch at age two years further back in time to 1984 (the limit of the TIP length data for the commercial fishery). Recent advances in VPA software have also made possible three methodological changes. First, we determine the selectivites of the commercial and headboat fisheries from the partial catches and VPA estimates of F at age using the method of Butterworth and Geromont (1999), whereas previously they were assumed to be knife-edged (age 2 and older for the commercial and age 1 and older for the headboat). Second, past assessments assumed a flat-topped selectivity curve to estimate the fishing mortality rate on the oldest true age even though the trends in selectivity indicated by the final model are dome shaped (see Figure 18 of Shirripa and Legault, 2000), whereas we make no such assumption (both methods assume the fishing mortality rate on the plus group is the same as for the oldest true age). Finally, past assessments imposed an *ad hoc* partial selectivity vector on the last year and estimated the F on 5 ages (2, 3, 4, 6 and 7), whereas we estimate the F for all ages by assuming the selectivity in 1999 was similar to that in 1998 (this is accomplished by penalizing large departures from that hypothesis within the estimation routine, see Porch, 1998).

Five sensitivity analyses were run: VPA 2 replaces the eastern Gulf headboat index that emulated the methods of Schirripa (1998) with the new version developed by Brown and Calay (in prep). VPA 3 is like VPA 2 except that the catch at age was derived using the growth curves developed in this paper. VPA 4 is like VPA 2 except that it adds the shrimp bycatch of age 1 to the catch at age matrix. VPA 5 is like VPA 4, but replaces the Fall groundfish proportion positive series with the Fall SEAMAP CPUE index (which covers more of the Gulf). VPA 6 is like VPA 4, but adds the commercial logbook index (essentially equivalent to model B of previous assessments)..

VPA results, spawning potential ratio calculations and future projections

The Gulf of Mexico Fishery Management Council recently elected to use a spawning potential ratio (SPR) of 30% as a proxy for MSY-related thresholds (Anon., 1999). The equilibrium SPR is computed as the ratio of the fecundity per recruit with fishing to the fecundity per recruit without fishing:

$$SPR = \sum_{a=0}^{40} \mathrm{E_a P_a}\, e^{-\sum_{i=0}^{a-1} \mathrm{F_i + M_i}} \Bigg/ \sum_{a=0}^{40} \mathrm{E_a P_a}\, e^{-\sum_{i=0}^{a-1} \mathrm{M_i}} \quad . \tag{11}$$

Here a denotes age, E is the average number of eggs produced per female, and P is the fraction of females that are mature. As mentioned previously, we assumed $P_a = 1$ for ages 1 and older and adopted the fecundity oogives (E_a) used in the 1998 and 2000 assessments for comparability of results. The values for the fishing mortality rate at age F_a were computed as the product of the fishing mortality rate on the most heavily fished age class (F_{apical}) and the recent selectivity at age (s_a, the geometric mean fishing mortality rate for 1996-98 normalized to a maximum of 1.0).

The fishing mortality estimates from VPA 1 were fairly similar to those of model C from the previous assessment despite the new data and methodological changes, particularly for the early years which are not heavily influenced by the differing assumptions about the terminal-year fishing mortalities (Table 12). For the most part, the sensitivity runs estimated similar magnitudes of average fishing mortality (weighted by the corresponding abundance estimates), but VPA's 2-6 indicate higher F's in the most recent years (Table 12).

As for previous assessments, there was not a high degree of contrast within the data from which to derive an estimate of the stock-recruitment relation (Figure 17). Therefore, for the projections and equilibium benchmark statistics, recruitment was set equal to the average from 1984-1996 (discounting the last three recruitments which are poorly estimated by VPA methods). This was equivalent to the medium recruitment scenario used by Schirripa (2000). Under constant recruitment, the proxies for MSY, spawning fecundity at MSY ($SSF_{30\%}$) and fishing mortality rate at MSY ($F_{30\%}$) are simply the per recruit statistics multiplied by the constant (average) recruitment.

Figure 18 and Table 13 compare the estimates of stock status for 1999 from the six VPA models with the projected status for 1999 from models B and C of the previous assessment. According to the default control rule, overfishing is considered to be occurring when $F/F_{30\%}$ is greater than 1.0 and the stock is considered overfished when $SSF/SSF_{30\%}$ is less than 0.75 (1-M, when M = 0.25). The estimates of Fcurr/$F_{30\%}$ for VPA 1 (updated Model C) and VPA 2 (new east head boat index) were close to1.0, indicating that the population is being fully exploited, but the estimates of $B_{2000}/B_{30\%}$ were greater than1.0, indicating that the population is not currently over-fished (consistent with model C of the previous assessment). However, the estimates for all of the other models suggest that the population is now overfished and will remain so at the current rate of fishing (consistent with model B of the previous assessment).

Deterministic projections of the future abundance of the stock and equilibrium 30% SPR statistics were made using the geometric mean selectivities and constant recruitment scenario discussed above. The apical fishing mortality rate for 2000 and 2001 was set equal to the maximum of the geometric mean fishing mortality rates used to generate the selectivity vector (the assumed 'current' rate of fishing, F_{curr}). Thereafter, the apical fishing mortality rate was set to $F_{30\%}$ as defined above. The weight and fecundity of the plus group was estimated from the average age of the plus-group to allow for the increased survival of older fish. The results of the projections are shown in Figure 19. In all of the cases where the population is considered overfished, it shown to be able to recover close to $SSF_{30\%}$ within 10 years if fishing is reduced to $F_{30\%}$.

The VPA-based assessment of the stock is highly uncertain, as the bootstrap results sensitivity analyses in Figure 18 clearly show. Moreover, as discussed above, we argue that cohort slicing is inappropriate for vermillion snapper given the flat growth curve after age 2 and apparently huge variance in age at length (and length at age). For the same reason, length-based methods that take explicit account of the variance in length at age (e.g., Porch, 2000; Williams, 2001) are unlikely to fare much better. Therefore, if age-structured assessments are desired for the future, it will be necessary to age random samples from the catch directly, rather than try to infer them from length.

PELLA-TOMLINSON PRODUCTION MODEL

A state-space implementation of the Pella-Tomlinson non-equilibrium production model (Porch, 2001) was also used to assess the status of Gulf of Mexico vermilion snapper. The basic assumption behind the model is that one is dealing with a unit stock where all age classes have the same average fecundity and are equally vulnerable to fishing. This seems plausible for vermilion snapper of reproductive age (age 1 and older) because the growth curve is relatively flat and the variance in size at age is large. The VPA results suggest a dome-shaped selectivity pattern, but those results are far from conclusive, based as they are on a spurious ageing procedure.

Methods

Production models require a time series of the total catch and effort (or CPUE) of each fishery. Fishery independent time series are helpful if they index the total stock, but such is not available for vermillion snapper (the Fall groundfish/SEAMAP indices measure only very small fish which do not contribute significantly to the production of the stock in that year). We chose to model three distinct fisheries based on the expectation that their respective catchabilities would be different: (1) commercial (with logbook CPUE) , recreational (with eastern Gulf headboat CPUE), and shrimp bycatch (with shrimp effort estimates provided by S. Nichols, pers. comm.). The weight of the by-catch and recreational catch was computed by multiplying the total catch in numbers by the average weight. The average weight was determined from the recorded weights (when available) and from weights inferred from length via the weight-length relationship otherwise.

All of the catch and effort series were assumed to be lognormally distributed. The shrimp by-catch is poorly known and was assigned a relatively high coefficient of variation (CV) of 1.0, whereas the shrimp effort was assumed to be somewhat better known and assigned a CV of 0.5 The recreational catches were assigned CV's equal to the MRFSS estimates. The commercial catch, which is based on a census, was assumed to have relatively low CV of 0.1. Estimates of the CV's of the two CPUE series were available from the GLM's, but they were unrealistically small as they reflected only the uncertainty in measuring CPUE rather than the uncertainty that CPUE reflects abundance (owing for example to fluctuations in the spatial distribution of the stock relative to that of the fishery). Accordingly, we assumed the two indices have the same CV's in each year and estimate that value within the production model. In effect, this is equivalent to the equal-weighting scenario used with the VPA.

The parameters estimated in the model include three catchability coefficients (q_f, one for each of the three fisheries *f*), three sets of effort parameters (E_{fy}), the initial biomass (B_{1980}), carrying capacity (*K*), intrinsic rate of increase (*R*), and production exponent (*m*). No inter-annual variability was allowed for the state variables (m, r, k, q_f) owing to the relatively short time series (except in certain of the sensitivity analyses). The annual effort parameters, however, were assumed to be lognormally distributed about the overall mean of the series with a relatively large process CV of 0.5 (preliminary runs would not converge when the annual effort values were estimated as free parameters). A penalty was also incorporated that prevented MSY from being greater than the largest catch in the series. This was done because the model tended towards a solution where the estimates of B/B_{MSY} were much less than 1.0 but MSY was much greater than any of the observed catches (which is unlikely inasmuch as the catches in the 1990's were larger than in any previous time).

Unfortunately, although observations of catch were available as far back as 1980, the first year with actual observations of CPUE was 1986 (first year of the headboat CPUE series), therefore the analysis was conducted using data from 1986 to 1999. Originally, we elected to use the 1980-85 catches to help estimate the initial biomass in 1986, allowing the model to interpolate the effort for 1980-1985. However, we found that the model tended make the 1980-1985 effort values comparable to the 1986-1999 average and then reconciled these with the low observed catches in 1980-1985 by estimating very low abundances. This seemed to us to be an unrealistic scenario given that vermilion snapper were not then as heavily targeted as they are now.

The base model (Model P1) was constructed as described above with the exponent *m* set to a value of 2 (the usual Schaeffer type model). This model was then altered in a series of six sensitivity analyses. Model P2 estimated the exponent *m* (with a lognormal prior centered on $m = 2$ and having a CV of 0.5). Model P3 allowed the intrinsic rate of increase *r* to change from year to year as a correlated lognormal process (CV = 0.3 and correlation coefficient $\rho = 0.5$). Model P4 similarly allowed the catchabilities q_f, to change from year to year as correlated lognormal processes (CV = 0.3 and correlation coefficient $\rho = 0.5$). Model P5 estimated separate variances for each of the two CPUE indices. Model P6 dropped the by-catch data. Model P7 dropped the last three years of data. Models P3, P4, P6 and P7 were unable to estimate CV's of the CPUE indices, indicating they were over-parameterized. Therefore the CV's were fixed to the values estimated by model P1 (33%).

Results

The base model (P1) fit the data fairly well (Figure 20), but the CV's of the parameters computed from the inverse Hessian (asymptotic covariance matrix) were large, typically 60 percent or more (Table 14). The estimate of MSY had a CV of only 12 percent (Table 15), but this is an artifact of the MSY penalty which constrained the value of MSY near 3 million pounds. As discussed earlier, without the MSY penalty the model tended towards solutions where the value of MSY was two or three times larger than the catches but the stock was still estimated to be in an overfished condition. This implies that the catches prior to 1986 must have been much larger than those afterwards, which is untrue. The MSY penalty also effectively constrained the other models, although Model P3 was able to estimate a larger MSY of 4 million pounds for 1999 because it allowed the value of MSY to change each year with the changes in *r*, which allows it to downgrade the overall effect of the penalty by keeping the MSY below the catches in some years.

Models P2 to P5 extend model P1 by estimating *m*, annual *r* values, annual *q* values, and different CV's for the two CPUE indices, respectively. Akaike's information criteria for small samples (Burnham et al., 1999) suggests that model P1 provides the most parsimonious descriptions of the data (i.e., none of the additional parameters in models P2-P5 were statistically significant). The results from models P2 and P4 are very similar to those of P1 (Table 12, Figure 21), but model P3 predicts a more productive population with a lower biomass and slower rate of decline. Model P5, on the other hand, suggests a less productive population with a greater biomass and no decline in recent years (see Figure 22). This happens because a higher CV (45%) is estimated for the headboat CPUE index compared to the commercial index (22%), which causes it to have less influence on the model.

Model P6 is like Model P1 except that the by-catch information was not used (and the CV's of the CPUE indices had to be fixed to the levels estimated by P1-- 33%). The results were nearly identical to those of P1 (Figures 21, 22).

All six of the models based on the full time series (1986-1999) indicated that the stock was seriously overfished and would remain so under the current rate of fishing. However Model P7, which dropped the last three years, suggested a highly productive stock that had not been overfished.

Deterministic projections were made for models P1, P3, P5, P6 and P7 assuming future fishing mortality rates equal to (1) $F_{CURRENT}$ (the F in 1999), (2) F_{MSY}, or (3) $F_{RECOVER}$ (value of F that would allow the population to recover to B_{MSY} within ten years). The results are shown in Figure 22. Stock biomass and yield are projected by models P1, P3 and P6 to decline further at the current rates of fishing, but are projected to remain stable by model P5. Reducing F to slightly below FMSY produces a recovery within ten years. The yield in 2002 is projected to decrease to about 50% of current levels, however the forgone yield is usually more than made up for by 2011. In the case of model P7, the stock is not being fully exploited at $F_{CURRENT}$, so the biomass is projected to decrease and yields increase under an F_{MSY} policy.

DISCUSSION

The results from two types of assessment models have been presented: age-structured VPA's and nonequilibrium production models. VPA's 1 and 2 and production model P7 (which does not use the last three years of data) indicate that the stock is not overfished with respect to the default control rules and that no reduction in the current rate of fishing is required. However, the remaining VPA's and all six of the production models that used the full time series indicate that the stock is overfished and undergoing overfishing (compare Figures 18 and 21). The corresponding projections suggest that a recovery to the biomass at MSY can be achieved within 10 years (by 2011) if the fishing mortality rate is reduced to slightly below F_{MSY} ($F_{30\%}$ being used as a proxy for F_{MSY} in the case of the VPA's). In the case of VPA models 3 and 5, this implies that the current rate of fishing should be reduced by about two thirds, whereas for VPA models 4 and 6, the current rate of fishing need only be reduced by about one third. The production model projections are in the middle, indicating that the fishing mortality rate needs to be reduced to about half its current level.

The suggestion that the population has become overfished is consistent with the results of the VPA models from the previous assessment. Schirripa and Legault (2000) estimated that, for 1996, there was a 93% chance that overfishing was occurring ($F_{1996} > F_{30\%}$) and a 30% chance that the stock was overfished ($B_{1996} < 0.75B_{30\%}$). Similarly, their projections for 1999 indicated a 73% chance that overfishing would continue and a 59% chance that the stock would be overfished. Since that time the catches and headboat CPUE have continued to decline, which is interpreted by most of the models in this assessment as a sign of an overfished population. Even so, it is interesting to note that the deterministic results from VPA 1 and VPA 6 are more optimistic than their counterparts from the previous assessment (models C and B, respectively), suggesting that the condition of the stock may have improved relative to expectations (Figure 18). Such an interpretation should be made with caution, however, owing to the large uncertainty indicated by the bootstrap and sensitivity analyses.

Both the VPA and production models of vermilion snapper are plagued with a common problem-- short, conflicting CPUE time series. The commercial CPUE series suggest that there has been little change in the relative abundance of vermilion snapper, whereas the eastern headboat index suggests that vermillion snapper have declined dramatically. As Schirripa and Legault (2000) pointed out, both series may be influenced by factors other than those accounted for by the GLM standardization procedure, such as inter-annual changes in the species being targeted and the influence of the 10 inch minimum size limit that was implemented in 1997. Brown and Calay (in prep.) dealt with the former by selecting vessels that regularly caught vermillion snapper, but could not standardize for the effect of the size limit because it was confounded by the year effect. Moreover, the impact of the minimum size limit would be affected by the number of new recruits coming into the fishery (requiring a year/size limit interaction term).

In principle, one can allow the effective catchability to vary from year to year to try to account for these types of problems, as was done in production model P4. Indeed, model P4 did estimate a decrease in the q of the headboat fishery during the late 1990's, but not for the commercial fishery. This could be interpreted as a reflection of the impact of the size limit, which would be expected to affect the headboat fishery more than the commercial fishery because, on average, the headboat fishery catches smaller fish. However, this trend in q may simply be a statistical artifact of the model as the estimates are too poorly determined to draw concrete statistical inferences.

It is also possible to weight the two CPUE series according the accuracy and precision with which they track the abundance of the stock, but we found no evidence on which to base such a decision and adopted the equal-weighting approach of previous assessments. One may attempt to estimate the relative weights (CVs), as in production model P5, but these tend to be poorly determined and may improve the precision of the model at the expense of its accuracy (Legault and Porch, 2001).

If the Fall groundfish survey results are to be believed, then recruitment has fluctuated by an order of magnitude since 1984, and was generally high in the early 1990's but low after 1995, which may account for subsequent reductions in the catches, CPUE indices, and percentage of fish released. As Schirripa (1998) points out, it is possible that the perceived recruitment fluctuations are part of a long term trend that has little to do with spawning stock fecundity. The confidence intervals associated with the Fall groundfish/SEAMAP survey indices are too broad (Figure 23) to draw concrete inferences, but further support for the notion that the productivity of the stock has changed in recent years can be seen in the production models results. Models P1-P6 suggest a less productive stock that has become overfished, whereas model P7 (which drops the last three years) suggests a highly productive stock that is not overfished. The results from model P3 (which allows *r* to vary from year to year) are between model P1 and P7 in terms of estimated production rates, but the annual *r* values are too poorly estimated to make any concrete statistical inferences.

In summary, the results of this assessment, taken as a whole, suggest that the stock may have become overfished and that overfishing will continue to occur at the current rates of fishing. This is consistent with borderline status predicted by Shirripa and Legault (2000), particularly in the face of a continuing decline in catches and CPUE. Nevertheless, these results are uncertain owing to the short, conflicting, and possibly inaccurate time series of CPUE. In addition, the VPA models rely on poorly-determined catch at age data (derived from length using a growth curve, which in this case is highly imprecise owing to the huge variance in age at length and may be highly inaccurate owing to the unknown date of the first ring formation and possible reader biases). Of the two modeling approaches, we prefer the production model because we do not have to pretend we can actually age the fish. The tradeoff, of course, is that production models assume that biomass and production are independent of age structure. This may in fact be approximately true for vermilion snapper. As Figure 5 demonstrates, there is only a very weak relationship between size (and therefore fecundity) and age beyond the first year. Even so, the production model results still suffer from the short time series (in this case only 14 years) as evidenced by the need to restrict the solutions to produce a biologically plausible value of MSY.

There are several areas where the present state-space production model could be improved. First, the formulation of Bayes priors for initial biomass and carrying capacity, based on discussions with fishermen and others relating to the perceived historical abundance of the stock and environmental changes affecting carrying capacity, might help the estimation and circumvent the need for the MSY penalty. Further examination of the known biological characteristics of the stock and comparisons with production model estimates for species with similar traits might also improve our perception of the production parameters *m* and *r*. Of course it may turn out that a production model is not the most appropriate assessment tool for this species and it would be instructive to employ alternatives, such as delay-difference models, which implicitly take changes in age-structure into account (albeit crudely). VPA or other age-structured models would also be useful provided direct aging of samples from the catch is feasible. This sampling would need to be done on an annual basis in order to apply VPA models, but could be done less frequently if one is willing to assume the selectivity of each fishery is fairly constant during the periods when no sampling was conducted and apply a statistical catch-at-age model. It may even be possible to develop a statistical catch-at-age model based on the data that is available now, but this would require assuming that the selectivity for each fishery was constant prior to 1994.

Finally, there are several issues related to data that need further exploration. One is the possible use of the new index for headboat anglers in the western Gulf, which indicates a much less rapid decline in vermilion catch rates and would likely have a substantial effect on the model results. Another issue is the fate of fish released alive by the commercial and recreational fisheries. As shown in Table 10, the estimated number of releases by recreational anglers has generally been under 15% of the total catch-- except during the early 1990's when it reached as high as 32%. Owing to the depths in which vermilion snapper live, the mortality rate of released fish may be substantial (e.g., Wilson and Burns, 1996).

ADDENDUM

The 2001 reef fish stock assessment panel felt that production model P1 was the most plausible of the formulations presented. They requested an additional projection of that model under a constant yield scenario that allowed the stock to recover to B_{MSY} within 10 years (by 2011). The results from that exercise are summarized in Figure 24 and Table 16.

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Table 1. Equations used to convert various length measurements. TL is total length (mm), SL is standard length (inches), FL is fork length (inches), R^2 is the coefficient of determination for the reported linear regression and N is the number of observations.

Source: (Author, Year)	**Conversion**	R^2	**N**
(Grimes, 1978)	TL = 1.10 FL + 0.092	0.999	1804
	TL = 1.28 SL + 0.195	0.999	
	SL = 0.863 FL – 0.080	0.999	
(Zhao et al., 1997)	TL = 1.12 FL – 0.010	0.988	7494
	TL = 1.30 SL – 0.050	0.981	
	SL = 0.857 FL + 7.87E-5	0.978	
(Hood and Johnson, 1999)	TL = 1.13 FL – 0.102	0.995	854
	TL = 1.36 SL – 0.331	0.980	869
	SL = 0.820 FL + 0.295	0.990	857

Table 2. A summary of length-weight relationships from studies at various locations within the South Atlantic Bight and the Gulf of Mexico. TL is total length (inches), FL is fork length (inches), W is total weight (pounds), R^2 is the coefficient of determination for the reported regression and N is the number of observations.

Source and Location	Size Range (inches)	Equation	R^2	N
(Grimes, 1976)				
North and South Carolina	7.6-23.0	$W = 5.22E\text{-}4\ TL^{2.946}$	0.937	1804
(Zastrow, 1984)				
West Flower Garden (TX)	7.6-20.1	$W = 7.83E\text{-}4\ FL^{2.919}$	0.945	398
East Flower Garden (TX)	6.6-18.1	$W = 6.19E\text{-}4\ FL^{2.960}$	0.939	346
Port Aransas (TX)	7.3-16.3	$W = 1.67E\text{-}3\ FL^{3.215}$	0.880	393
(Nelson, 1988)				
East & West Flower Garden		$W = 9.53E\text{-}4\ FL^{2.882}$	0.980	906
(Barber, 1989)				
Gulf of Mexico (FL and TX)		$W = 5.92E\text{-}4\ TL^{2.922}$		
(Zhao et al., 1997)				
South Atlantic Bight	3.9-22.0	$\ln(W) = 2.899 \ln(TL) - 7.486$	0.960	7494
(Potts et al., 1998)				
South Atlantic Bight	7.3-21.4	$W = 2.90E\text{-}7\ TL^{3.04}$	0.950	443
(Hood and Johnson, 1999)				
Eastern Gulf of Mexico	7.6-23.0	$\log(W) = 2.87 \log(TL) - 3.225$	0.910	646

Table 3. A summary of von Bertalanffy growth curves from studies at various locations within the South Atlantic Bight and the Gulf.

Source and Location	Method	Equation	N
(Grimes, 1978)			
North and South Carolina	Scales	$L_t = 24.65 [1 - e^{-0.198 (t+0.128)}]$	706
(Nelson, 1988)			906
East & West Flower Garden	Scales	$L_t = 21.93 [1 - e^{-0.22 (t+0.30)}]$	
(Barber, 1989)			
St. Petersburg (FL)	Scales	$L_t = 36.85 [1 - e^{-0.050 (t+3.37)}]$	34
Pensacola (FL)	Scales	$L_t = 13.54 [1 - e^{-0.160 (t+3.56)}]$	194
Galveston (TX)	Scales	$L_t = 22.09 [1 - e^{-0.100 (t+2.81)}]$	799
Port Aransas (TX)	Scales	$L_t = 16.85\ 1 - e^{-0.150 (t+2.78)}]$	270
Brownsville (TX)	Scales	$L_t = 18.78\ 1 - e^{-0.160 (t+2.32)}]$	779
St. Petersburg (FL)	Whole Otoliths	$L_t = 18.46 [1 - e^{-0.090 (t+1.16)}]$	1113
Pensacola (FL)	Whole Otoliths	$L_t = 20.12 [1 - e^{-0.080 (t+1.44)}]$	600
Galveston (TX)	Whole Otoliths	$L_t = 21.81 [1 - e^{-0.080 (t+1.46)}]$	345
Port Aransas (TX)	Whole Otoliths	$L_t = 25.87 [1 - e^{-0.070 (t+1.18)}]$	715
Brownsville (TX)	Whole Otoliths	$L_t = 23.74 [1 - e^{-0.090 (t+0.87)}]$	551
(Schirripa, 1992)	All		886
Gulf and South Atlantic Bight		$L_t = 21.06 [1 - e^{-0.203 (t+0.940)}]$	
(Zhao et al., 1997)	Sectioned Otoliths		195
South Atlantic Bight (1979-81)	Sectioned Otoliths	$L_t = 22.12 [1 - e^{-0.202 (t+0.117)}]$	265
South Atlantic Bight (1982-84)	Sectioned Otoliths	$L_t = 14.37 [1 - e^{-0.315 (t+0.361)}]$	766
South Atlantic Bight (1985-93)		$L_t = 13.11 [1 - e^{-0.271 (t+0.899)}]$	
(Potts et al., 1998)	Sectioned Otoliths		983
South Atlantic Bight		$L_t = 25.59 [1 - e^{-0.144 (t+0.238)}]$	
(Hood and Johnson, 1999)			
Eastern Gulf of Mexico	Sectioned Otoliths	$L_t = 11.73 [1 - e^{-0.250 (t+3.9)}]$	841

Table 4. Percentage of females reported at various locations within the South Atlantic Bight and the Gulf of Mexico. Significant differences from a 1:1 ratio are noted. N.S. = not significant.

Source and Location	**% Females**	**N**	**Significance**
(Grimes and Huntsman, 1980)			
North and South Carolina	62.5	874	$p < 0.001$
(Nelson, 1988)			
East and West Flower Garden (TX)			$p < 0.001$
Spawning Season	41.7		N.S.
Non-spawning Season	~50		
(Cuellar et al., 1996)			
North and South Carolina	62.6		$p < 0.025$
(Zhao and McGovern, 1997)			
South Atlantic Bight			
Fish Traps	72.4	919	$p < 0.001$
Hook-and-Line	68.6	544	$p < 0.001$
Trawl	60.0	255	$p < 0.005$
(Hood and Johnson, 1999)			
Eastern Gulf of Mexico	52.3	822	N.S.

Table 5. The percentage of sexually mature vermilion snapper at a given length from various sources. Although the smallest fish are infrequently sampled, it appears that vermilion snapper mature at an earlier age that that reported by Grimes and Huntsman (1980).

Source	Collins and Pinckney 1988		Zhao and McGovern 1997							
TL (inches)	% Mature 1978-1980		% Mature 1979-1981		% Mature 1982-1984		% Mature 1985-1987		% Mature 1988-1990	
	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females
3.9			0	0						
4.7	5	5	19	7	67		100	0		
5.5	35	20	31	4	100		100	38	100	
6.3	90	60	100	42	100		100	64	100	100
7.1	90	80	100	100	100	100	100	100	100	100
7.9	100	98	100	100	100	98	100	100	100	100
8.7	100	100	100	100	100	100	100	100	100	100
9.4	100	100	100	100	100	100	100	100	100	100
1	88	100	100	100	100	100	100	100	100	100
11.0	100	100	100	100	95	100	100	100	100	100
11.8	100	100	100	100	100	100	100	100	100	100

Table 6. Reported U.S. commercial landings of vermilion snapper from the Gulf of Mexico (in thousands of pounds). The column labeled Gulf is the sum of the state-wide catches. The figures include fish caught in Mexican waters but landed in the U.S. (a negligible fraction of the total).

Year	Tx	La	Ms	Al	Fl	Gulf
1962	0	0	0	0	46	46
1963	0	0	0	0	76	76
1964	0	0	0	0	99	99
1965	0	0	0	0	79	79
1966	0	0	0	0	31	31
1967	0	0	0	0	57	57
1968	0	0	0	0	137	137
1969	0	0	0	0	120	120
1970	0	0	0	0	131	131
1971	0	0	0	0	140	140
1972	0	0	0	0	130	130
1973	0	0	0	0	196	196
1974	0	0	0	0	197	197
1975	0	0	0	0	392	392
1976	0	0	0	0	311	311
1977	0	0	0	0	532	532
1978	0	0	0	0	450	450
1979	0	0	0	0	439	439
1980	0	0	0	0	309	309
1981	0	0	0	0	371	371
1982	0	0	0	0	403	403
1983	0	0	0	9	565	574
1984	0	395	332	52	698	1476
1985	39	305	296	129	837	1604
1986	121	450	253	112	876	1813
1987	42	612	245	61	704	1664
1988	60	634	160	9	700	1563
1989	62	578	99	10	911	1661
1990	121	813	142	20	1071	2166
1991	40	603	117	7	1028	1795
1992	141	666	165	19	1293	2284
1993	306	646	116	22	1634	2725
1994	275	748	130	23	1468	2645
1995	208	378	105	4	1476	2171
1996	186	430	93	5	1146	1859
1997	255	614	130	7	1085	2091
1998	329	458	138	5	806	1736
1999	316	389	60	16	859	1641

Table 7. Commercial (Reeffish Logbook) and recreational (headboat) CPUE indices calculated during this assessment. CV is the coefficient of variation of the index. All indices were calculated using the Lo Method (Lo et al., 1992).

Year	Commercial		Recreational Eastern Gulf of Mexico		Recreational Western Gulf of Mexico	
	Index	**CV**	**Index**	**CV**	**Index**	**CV**
1986			0.972	0.061	0.98	0.100
1987			1.09	0.043	0.971	0.082
1988			1.747	0.021	0.761	0.105
1989			1.016	0.03	1.229	0.083
1990	1.281	0.175	1.191	0.027	2.015	0.054
1991	0.995	0.077	1.374	0.024	1.179	0.078
1992	0.773	0.080	1.662	0.02	0.981	0.074
1993	1.050	0.049	1.134	0.023	0.944	0.069
1994	1.498	0.037	0.981	0.027	1.032	0.063
1995	0.959	0.045	0.946	0.029	1.039	0.059
1996	0.895	0.045	0.645	0.035	0.765	0.075
1997	0.884	0.046	0.650	0.037	0.780	0.079
1998	0.819	0.052	0.241	0.067	0.653	0.098
1999	1.116	0.042	0.349	0.065	0.670	0.102
2000	0.729	0.062				

Table 8. Exceptions to the use of Marine Recreational Fishery Statistics Survey (MRFSS) catch estimates.

West Florida, Alabama, Mississippi, Louisiana						
Year	Waves	Shore	Private boat	Charter boat	Head boat (bay)	Head boat (Gulf)
1979-80	all	OLD	OLD	OLD, 1	OLD, 1	OLD, 1
1981	all			1	1	1
	1	2	2	2	2	
1982 - 85	all			1	1	1
1986-	all					HBS

Texas						
Year	Waves	Shore	Private boat	Charter boat	Head boat (bay)	Head boat (Gulf)
1979-80	all	OLD	OLD	OLD, 1	OLD, 1	OLD, 1
1981	all	OLD4	OLD4	OLD4 , 1	OLD4, 1	OLD4 , 1
	wave 1	2	2	2	2	2
1982	all	OLD4	3	3	3	3
1983	waves 1-2		3	3	3	3
	waves 3-6	OLD4	TPWD	TPWD	TPWD	TPWD
1984	waves 1-4	OLD4	TPWD	TPWD	TPWD	TPWD
	waves 5-6		TPWD	TPWD	TPWD	4
1985	all	OLD4	5	TPWD	TPWD	4
1986-	all	6	TPWD	TPWD	TPWD	HBS

OLD: MRFSS estimates for 1981 and later were recalculated in 1995; the only MRFSS estimates available for 1979-80 are the "old" ones. The "old" estimates are no longer available through the MRFSS, but are provided in file mr7985.oldcat.

OLD4: Some of the original raw data files were lost for wave 4 of 1981-85 in Texas, so only the 'old' estimates are available

TPWD: Texas Parks and Wildlife Department

HBS: Headboat Survey (NMFS, Beaufort), beginning 1986 (in Gulf)

1 Prior to 1986, MRFSS recorded charter and headboat (party) vessels together as mode 5 (CH/HB).
Solution: separate CH and HB using proportions from 1986 to1989 (from MRFSS CH and HBS, aggregated across __w__aves but not across __a__reas or __s__tates):

$$C_{CH,a,s,y} = C_{CH/HB,a,s,y} \frac{\sum_{y=1986}^{1989} \sum_{w=1}^{6} C_{CH,a,s,w,y}}{\sum_{y=1986}^{1989} \sum_{w=1}^{6} \left(C_{CH,a,s,w,y} + C_{HB,a,s,w,y}\right)}$$

2 Estimates not available for wave 1 in 1981 for any Gulf state.
Solution: interpolated as average of 1981 wave 2 and 1980 wave 6.

3 No MRFSS boat modes were sampled in Texas during 1982 and waves 1 and 2 of 1983.
*Solution: **(a)** for inshore species like red drum, they are computed from the MRFSS shore estimates for TX by use of the average ratio of each TX boat mode to TX shore during 1979-1985 (except 1982 and waves 1 and 2, 1983)*
***(b)** for offshore species like vermillion snapper, where there is little or no shore catch, they are computed from the combined catches of the other states by use of the average ratio of each TX boat mode to the combined catch of the other states during 1979-1985 (except 1982 and waves 1 and 2, 1983)*

4 The TPWD discontinued sampling Gulf headboats in September of 1984.
Solution: subtract Gulf charter (TPWD) from Gulf CH/HB (mode 5 MRFSS)

5 Estimates of the private boat mode are available from both the TPWD and MRFSS.
Solution: use MRFSS (P. Phares, per. comm.)

6 No shore estimates are available for Texas after 1985 (TPWD does not survey shore fishermen).
Solution: Compute by use of the average ratio of shore catch in Texas to boat-mode catch in Texas during 1983-1985 (except waves 1 and 2, 1983)

$$C_{shore,w,y} = C_{boat,w,y}\left(\sum_{y=1983}^{1985} C_{shore,w,y} \Big/ \sum_{y=1983}^{1985} C_{boat,w,y}\right)$$

Table 9. Estimated recreational harvest of Gulf of mexico vermillion snapper by state, mode, and area (inland waters, territorial sea, exclusive economic zone). The estimates are based on the Marine Recreational Fishery Statistics Syrvey (MRFSS), Texas Parks and Wildlife Department (TPWD) and NMFS Headboat Survey as described in Table yyy. The statistics for 2000 are preliminary and incomplete.

Area/mode	Year	Tx	La	Ms	Al	Fl	All
Charter boats in inland waters	1979	0	0	0	0	462218	462218
	1980	0	0	0	0	0	0
	1981	0	0	0	0	0	0
	1982	0	0	0	0	0	0
	1983	0	0	0	0	0	0
	1984	0	0	0	0	0	0
	1985	0	0	0	0	0	0
	1986	0	0	0	0	0	0
	1987	0	0	0	0	0	0
	1988	0	0	0	0	342	342
	1989	0	0	0	0	0	0
	1990	0	0	0	954	0	954
	1991	0	0	0	0	0	0
	1992	0	0	0	0	0	0
	1993	0	0	0	0	0	0
	1994	18	0	0	0	0	18
	1995	0	0	0	0	0	0
	1996	0	0	0	0	0	0
	1997	0	0	0	0	0	0
	1998	0	0	0	0	0	0
	1999	0	0	0	0	0	0
Private boats in inland waters	1979	0	0	0	0	190378	190378
	1980	0	0	0	0	0	0
	1981	0	0	0	0	0	0
	1982	0	0	0	0	0	0
	1983	0	0	0	0	0	0
	1984	46	0	0	0	0	46
	1985	0	0	0	0	0	0
	1986	56	0	0	0	0	56
	1987	0	0	0	0	0	0
	1988	0	0	0	0	0	0
	1989	0	0	0	0	0	0
	1990	0	0	0	0	0	0
	1991	0	0	0	0	0	0
	1992	0	0	431	277	0	708
	1993	0	0	0	0	0	0
	1994	0	0	0	0	0	0
	1995	0	0	0	0	0	0
	1996	0	0	0	0	0	0
	1997	0	0	841	0	0	841
	1998	0	0	0	0	0	0
	1999	0	0	0	0	0	0

Table 9. continued.

Area/mode	Year	Tx	La	Ms	Al	Fl	All
Shore-based fishing in Territorial Seas	1979	0	0	0	0	0	0
	1980	0	0	0	0	0	0
	1981	0	0	0	0	0	0
	1982	0	0	0	0	0	0
	1983	0	0	0	0	0	0
	1984	0	0	0	0	0	0
	1985	0	0	0	0	903	903
	1986	0	0	0	0	0	0
	1987	0	0	0	0	0	0
	1988	0	0	0	0	0	0
	1989	0	0	0	0	0	0
	1990	0	0	0	5916	0	5916
	1991	0	0	0	2665	131286	133951
	1992	0	0	0	0	0	0
	1993	0	0	0	0	0	0
	1994	0	0	0	0	0	0
	1995	0	0	0	0	0	0
	1996	0	0	0	0	0	0
	1997	0	0	0	0	0	0
	1998	0	0	0	0	0	0
	1999	0	0	0	0	0	0
Charter boats in Territorial Seas	1979	0	0	0	0	0	0
	1980	0	0	0	0	17853	17853
	1981	0	0	0	0	12786	12786
	1982	0	0	0	27812	47192	75004
	1983	0	0	0	394	38782	39176
	1984	0	0	0	0	22582	22582
	1985	0	0	0	0	49693	49693
	1986	0	0	0	0	58343	58343
	1987	0	0	0	153	21237	21390
	1988	0	0	0	28788	80217	109005
	1989	0	0	0	0	91688	91688
	1990	0	0	0	127	97306	97433
	1991	0	0	0	643	263408	264051
	1992	0	0	0	0	78291	78291
	1993	0	0	0	0	67647	67647
	1994	0	0	0	1124	127056	128180
	1995	0	0	0	0	239207	239207
	1996	0	0	0	0	62952	62952
	1997	0	0	0	1509	36594	38103
	1998	0	0	0	2611	33376	35987
	1999	0	0	0	35	66718	66753

Table 9. continued.

Area/mode	Year	Tx	La	Ms	Al	Fl	All
Private boats in Territorial Seas	1979	0	0	0	0	0	0
	1980	0	0	0	0	16977	16977
	1981	0	0	0	23200	52793	75993
	1982	0	0	0	0	0	0
	1983	0	0	0	0	0	0
	1984	0	489	0	0	0	489
	1985	0	0	0	0	0	0
	1986	0	0	0	0	52042	52042
	1987	0	0	0	0	102203	102203
	1988	0	0	0	0	123638	123638
	1989	0	0	0	0	29775	29775
	1990	0	0	0	1156	7684	8840
	1991	0	0	10646	0	12360	23006
	1992	0	0	0	0	54976	54976
	1993	0	0	0	4374	10222	14596
	1994	0	0	0	0	3451	3451
	1995	42	0	0	0	1852	1894
	1996	28	0	0	0	2288	2316
	1997	45	0	0	0	719	764
	1998	102	0	0	0	1495	1597
	1999	28	0	0	0	5544	5572
Head boats in EEZ	1979	27238	0	0	39466	0	66704
	1980	7627	101	0	4706	202733	215167
	1981	0	0	0	3915	3015	6930
	1982	82609	12848	0	0	194641	290098
	1983	58164	0	0	17921	20176	96261
	1984	70271	0	0	90672	16926	177869
	1985	0	4603	0	0	5924	10527
	1986	52499	792	0	244373	298946	596610
	1987	56607	54	0	229296	344193	630150
	1988	49133	1591	0	320979	388775	760478
	1989	74283	308	0	177866	296958	549415
	1990	102195	1272	0	205883	277370	586720
	1991	82548	787	0	204542	247429	535306
	1992	73043	3960	0	272678	306267	655948
	1993	73104	3502	0	205516	254317	536439
	1994	114755	3165	0	172325	206788	497033
	1995	101161	1097	0	160413	179173	441844
	1996	73409	1546	0	104707	122528	302190
	1997	76322	183	0	100087	111360	287952
	1998	61720	80	0	43814	61794	167408
	1999	40756	544	0	65000	79802	186102

Table 9. continued.

Area/mode	Year	Tx	La	Ms	Al	Fl	All
Charter boats in EEZ	1979	0	0	0	6253	0	6253
	1980	0	84	0	745	217573	218402
	1981	0	0	0	619	3235	3854
	1982	0	10680	0	0	208888	219568
	1983	0	0	0	2838	21650	24488
	1984	0	0	0	14367	18165	32532
	1985	0	3826	0	0	6358	10184
	1986	0	1243	0	47508	404011	452762
	1987	0	1039	0	30422	484596	516057
	1988	0	0	0	7610	371933	379543
	1989	0	0	0	68556	165594	234150
	1990	16	1563	493	232006	95025	329103
	1991	0	4136	0	158338	244198	406672
	1992	0	1288	0	141706	153426	296420
	1993	0	93	352	226204	272853	499502
	1994	0	8780	231	93088	284305	386404
	1995	0	3666	0	175099	153506	332271
	1996	0	717	0	111247	54974	166938
	1997	556	215	126	124657	92512	218066
	1998	216	75	0	94706	63147	158144
	1999	469	174	0	92620	149416	242679
Private boats in EEZ	1979	0	0	0	0	0	0
	1980	0	554	0	0	200652	201206
	1981	1058	23793	0	882	7348	33081
	1982	26	11749	0	0	954	12729
	1983	13	17910	0	0	0	17923
	1984	40	0	0	22056	0	22096
	1985	0	22940	0	0	241938	264878
	1986	0	0	0	0	26351	26351
	1987	292	0	0	11071	31629	42992
	1988	749	0	0	72823	102827	176399
	1989	229	0	0	48224	102949	151402
	1990	0	0	0	95526	11246	106772
	1991	0	0	0	20608	15902	36510
	1992	42	17095	0	142605	62926	222668
	1993	731	1056	914	101250	59673	163624
	1994	238	0	0	50749	35681	86668
	1995	475	763	0	67718	57587	126543
	1996	221	1656	0	4612	29635	36124
	1997	3017	3952	0	55523	0	62492
	1998	521	2460	0	9031	1626	13638
	1999	1006	1867	688	57277	13024	73862

Table 9. continued.

Area/mode	Year	Tx	La	Ms	Al	Fl	All
Total for all areas and modes	1979	27238	0	0	45719	652596	725553
	1980	7627	739	0	5451	655788	669605
	1981	1058	23793	0	28616	79177	132644
	1982	82635	35277	0	27812	451675	597399
	1983	58177	17910	0	21153	80608	177848
	1984	70357	489	0	127095	57673	255614
	1985	0	31369	0	0	304816	336185
	1986	52555	2035	0	291881	839693	1186164
	1987	56899	1093	0	270942	983858	1312792
	1988	49882	1591	0	430200	1067732	1549405
	1989	74512	308	0	294646	686964	1056430
	1990	102211	2835	493	541568	488631	1135738
	1991	82548	4923	10646	386796	914583	1399496
	1992	73085	22343	431	557266	655886	1309011
	1993	73835	4651	1266	537344	664712	1281808
	1994	115011	11945	231	317286	657281	1101754
	1995	101678	5526	0	403230	631325	1141759
	1996	73658	3919	0	220566	272377	570520
	1997	79940	4350	967	281776	241185	608218
	1998	62559	2615	0	150162	161438	376774
	1999	42259	2585	688	214932	314504	574968

Table 10. Percent of vermilion snapper caught that were reported to have been released alive from boats surveyed by MRFSS. Texas is not included because the TPWD survey does not estimate releases.

YEAR	LA	MS	AL	FL	TOTAL
1979	0	0	0	0	6
1980	0	0	0	0	0
1981	0	0	0	0	0
1982	0	0	0	1	1
1983	0	0	2	18	14
1984	0	0	0	11	4
1985	14	0	0	3	4
1986	0	0	0	11	10
1987	0	0	3	3	3
1988	0	0	0	18	15
1989	0	0	0	14	11
1990	0	0	3	14	7
1991	0	0	8	17	15
1992	0	72	5	29	20
1993	0	94	26	34	32
1994	0	67	23	12	14
1995	71	0	15	33	28
1996	0	100	16	28	24
1997	16	0	8	15	11
1998	0	0	12	14	13
1999	77	10	15	12	14
2000	100	0	12	10	11

Table 11. Indices of juvenile abundance used during this assessment. PPT is the proportion positive tows and CPUE is the number of fish collected per tow-hour. The first index (PPT: 1972-1998) was reported by Schirripa (2000) and combined two time series, the Fall Groundfish and Fall SEAMAP surveys. The CPUE indices for the Fall Groundfish Survey (FGS) and the Fall SEAMAP Survey (FSM) were provided by Scott Nichols at the NMFS Pascagoula Laboratory.

Year	PPT	N	CPUE: FGS	CPUE: FSM	N
1972	0.00699	143	0.03641		102
1973	0.03043	230	0.3903		225
1974	0.01732	231	0.30443		229
1975	0.00858	233	0.07779		232
1976	0.00746	268	0.05393		265
1977	0	242	0		237
1978	0.0081	247	0.02542		235
1979	0	260	0		255
1980	0.00957	209	0.04333		200
1981	0.00465	215	0.00962		211
1982	0.03175	252	0.14993		249
1983	0.00488	205	0.0186		202
1984	0.00474	211	0.03846		205
1985	0	116	0		102
1986	0.025	40	0.0815		41
1987	0.03704	54			
1988	0	45		0.06626	209
1989	0	62		0.4637	209
1990	0.05714	70		2.10206	209
1991	0.10938	64		0.80264	216
1992	0	53		0.30314	201
1993	0.07317	82		1.59699	213
1994	0.04286	70		1.34708	214
1995	0.05263	57		0.78781	216
1996	0.01887	53		0.37016	216
1997	0	53		0.24682	214
1998	0.01887	53		0.06609	213
1999				0.37003	216

Table 12. Comparison of fishing mortality rate estimates from VPA model C of Schirripa (1998) and Schirripa and Legault (2000) with the updated VPA's and production models from this assessment.The values corresponding to the VPA models are averages of the age-specific values weighted by abundance.

Year	Model C	VPA1	VPA2	VPA3	VPA4	VPA5	VPA6	P1	P2	P3	P4	P5	P6	P7
1986	0.18	0.16	0.17	0.15	0.25	0.27	0.26	0.44	0.44	0.75	0.41	0.29	0.39	0.39
1987	0.17	0.14	0.16	0.16	0.22	0.24	0.22	0.42	0.42	0.70	0.38	0.28	0.37	0.37
1988	0.16	0.12	0.14	0.16	0.17	0.21	0.18	0.39	0.39	0.62	0.36	0.26	0.34	0.34
1989	0.13	0.08	0.10	0.11	0.13	0.19	0.15	0.35	0.35	0.56	0.32	0.24	0.31	0.31
1990	0.15	0.08	0.10	0.14	0.13	0.21	0.15	0.42	0.42	0.67	0.39	0.30	0.38	0.39
1991	0.13	0.07	0.10	0.14	0.15	0.24	0.17	0.39	0.39	0.60	0.37	0.28	0.34	0.37
1992	0.11	0.09	0.12	0.17	0.15	0.24	0.17	0.47	0.47	0.68	0.45	0.34	0.42	0.45
1993	0.14	0.11	0.15	0.22	0.18	0.30	0.20	0.56	0.56	0.77	0.54	0.39	0.51	0.53
1994	0.13	0.11	0.15	0.23	0.17	0.29	0.19	0.62	0.62	0.81	0.58	0.42	0.57	0.55
1995	0.15	0.12	0.16	0.25	0.22	0.35	0.24	0.62	0.61	0.80	0.57	0.40	0.56	0.48
1996	0.11	0.10	0.13	0.20	0.21	0.32	0.23	0.53	0.52	0.70	0.48	0.33	0.48	0.36
1997		0.12	0.17	0.25	0.24	0.38	0.27	0.64	0.63	0.87	0.57	0.38	0.58	
1998		0.12	0.16	0.25	0.38	0.54	0.43	0.58	0.57	0.82	0.50	0.33	0.53	
1999		0.17	0.23	0.42	0.36	0.56	0.42	0.63	0.62	0.87	0.51	0.33	0.60	

Table 13. Estimates of equilibrium yield (YLD) in millions of pounds, spawning stock fecundity (SSF) in trillions of eggs, and fishing mortality rate (F) corresponding to an SPR of 30% from the various VPA formulations.

	VPA Model					
Benchmark	1	2	3	4	5	6
$YLD_{30\%}$ (~MSY)	3.24	2.80	2.66	2.65	2.72	2.58
$SSF_{30\%}$ (~SSF_{MSY})	279.66	233.62	228.77	277.50	202.49	257.95
$F_{30\%}$ (~F_{MSY})	0.34	0.30	0.39	0.26	0.24	0.24
$SSSF_{1999}/SSF_{30\%}$	1.58	1.10	0.35	0.91	0.21	0.74
$F_{Curr}/F_{30\%}$	0.81	1.10	2.68	1.47	3.02	1.63

Table 14. Parameter estimates from the various production model formulations.

	Model configuration	Point estimates	Standard error	CV (%)
B_{1986}	p1 (*m* = 2.0)	6182	4103	66
	p2 (*m* estimated)	6261	4204	67
	p3 (*r* variable)	3707	1766	48
	p4 (q variable)	6651	9617	145
	p5 (unequal CPUE weights)	9287	6682	72
	p6 (no bycatch)	6421	4116	64
	p7 (1986-1996)	6587	5347	81
m	p1 (*m* = 2.0)	2.00	0.00	0
	p2 (*m* estimated)	2.11	0.95	45
	p3 (*r* variable)	2.00	0.00	0
	p4 (q variable)	2.00	0.00	0
	p5 (unequal CPUE weights)	2.00	0.00	0
	p6 (no bycatch)	2.00	0.00	0
	p7 (1986-1996)	2.00	0.00	0
r	p1 (*m* = 2.0)	0.64	0.42	67
	p2 (*m* estimated)	0.61	0.47	78
	p3 (*r* variable)	0.99	0.53	54
	p4 (q variable)	0.60	0.78	130
	p5 (unequal CPUE weights)	0.43	0.30	71
	p6 (no bycatch)	0.55	0.36	65
	p7 (1986-1996)	1.21	0.57	47
k	p1 (*m* = 2.0)	21177	14792	70
	p2 (*m* estimated)	20713	14934	72
	p3 (*r* variable)	16253	7397	46
	p4 (q variable)	22241	26331	118
	p5 (unequal CPUE weights)	31017	21384	69
	p6 (no bycatch)	23313	16149	69
	p7 (1986-1996)	10922	5016	46

Table 15. Estimates of management benchmarks from the various production model formulations.

Variable	Model configuration	Point estimates	Standard error	CV (%)
MSY	p1 (m = 2.0)	3370.00	394	12
	p2 (m estimated)	3367	396	12
	p3 (r variable)	4025	1062	26
	p4 (q variable)	3317.00	561	17
	p5 (unequal CPUE weights)	3317	404	12
	p6 (no bycatch)	3182.00	391	12
	p7 (1986-1996)	3317.00	430	13
B_{MSY}	p1 (m = 2.0)	10589.00	7396.00	70
	p2 (m estimated)	10570	7376	70
	p3 (r variable)	8127.00	3698	46
	p4 (q variable)	11120.00	13165.00	118
	p5 (unequal CPUE weights)	15508	10692.00	69
	p6 (no bycatch)	11657	8075	69
	p7 (1986-1996)	5461	2508	46
F_{MSY}	p1 (m = 2.0)	0.32	0.21	67
	p2 (m estimated)	0.32	0.21	66
	p3 (r variable)	0.50	0.27	54
	p4 (q variable)	0.30	0.39	130
	p5 (unequal CPUE weights)	0.21	0.15	71
	p6 (no bycatch)	0.27	0.18	65
	p7 (1986-1996)	0.61	0.29	47
B_{2000}/B_{MSY}	p1 (m = 2.0)	0.32	0.11	34
	p2 (m estimated)	0.33	0.11	35
	p3 (r variable)	0.32	0.11	33
	p4 (q variable)	0.39	0.23	60
	p5 (unequal CPUE weights)	0.45	0.15	33
	p6 (no bycatch)	0.29	0.10	34
	p7 (1986-1996)	1.30	0.25	19
F_{CURR}/F_{MSY}	p1 (m = 2.0)	1.99	0.48	24
	p2 (m estimated)	1.96	0.51	26
	p3 (r variable)	1.76	0.59	33
	p4 (q variable)	1.70	0.69	41
	p5 (unequal CPUE weights)	1.53	0.40	26
	p6 (no bycatch)	2.20	0.55	25
	p7 (1986-1996)	0.59	0.20	34

Table 16. Projections of future yields (millions of pounds) based on model P1 assuming (a) the fishing mortality rate stays the same as estimated for 1999, (b) the fishing mortality rate is reduced to F_{MSY}, (c) the fishing mortality rate is reduced to the level that will allow recovery to B_{MSY} by 2011, and (d) the allowable catch in weight is fixed to the level that will allow recovery to B_{MSY} by 2011.

Year	*(a)* Status quo	*(b)* F_{MSY}	*(c)* $F_{RECOVER}$	*(d)* $Y_{RECOVER}$
1980	0.559	0.559	0.559	0.559
1981	0.577	0.577	0.577	0.577
1982	0.874	0.874	0.874	0.874
1983	0.802	0.802	0.802	0.802
1984	1.773	1.773	1.773	1.773
1985	1.951	1.951	1.951	1.951
1986	2.724	2.724	2.724	2.724
1987	2.660	2.660	2.660	2.660
1988	2.448	2.448	2.448	2.448
1989	2.358	2.358	2.358	2.358
1990	3.015	3.015	3.015	3.015
1991	2.900	2.900	2.900	2.900
1992	3.317	3.317	3.317	3.317
1993	3.685	3.685	3.685	3.685
1994	3.535	3.535	3.535	3.535
1995	3.141	3.141	3.141	3.141
1996	2.512	2.512	2.512	2.512
1997	2.766	2.766	2.766	2.766
1998	2.625	2.625	2.625	2.625
1999	2.288	2.288	2.288	2.288
2000	2.067	2.067	2.067	2.067
2001	1.896	1.896	1.896	1.896
2002	1.752	1.034	0.918	1.481
2003	1.629	1.267	1.166	1.481
2004	1.523	1.519	1.442	1.481
2005	1.430	1.778	1.730	1.481
2006	1.348	2.033	2.013	1.481
2007	1.275	2.272	2.277	1.481
2008	1.210	2.488	2.508	1.481
2009	1.151	2.673	2.701	1.481
2010	1.099	2.829	2.857	1.481
2011	1.051	2.955	2.978	1.481

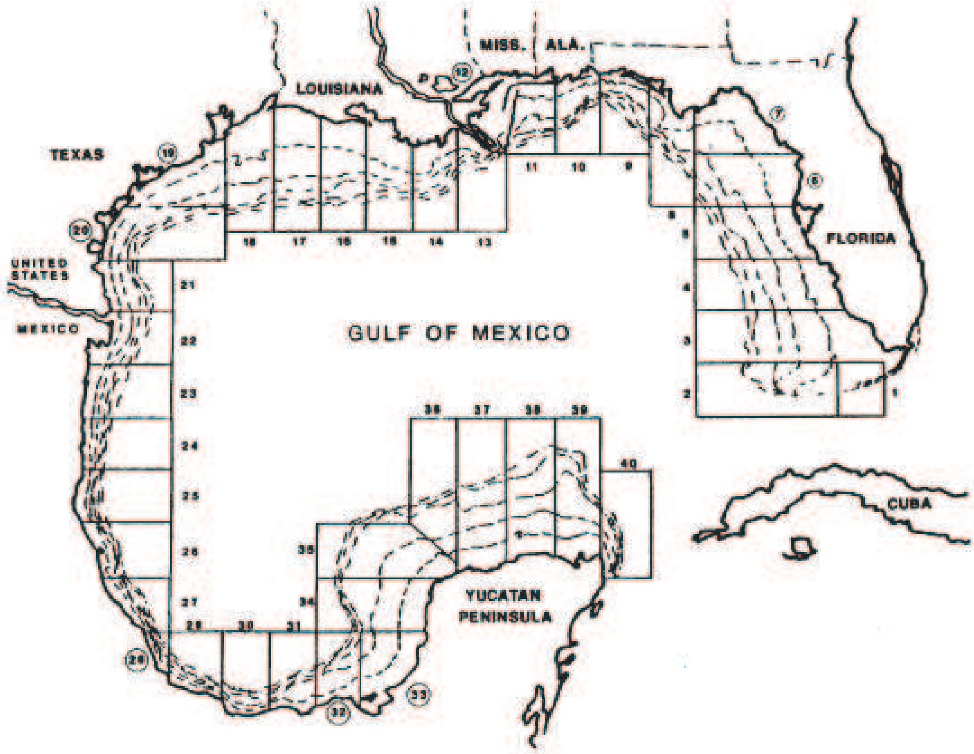


Figure 1. Gulf of Mexico with NMFS statistical grids.

Figure 2. A comparison of various published weight-length relationships.

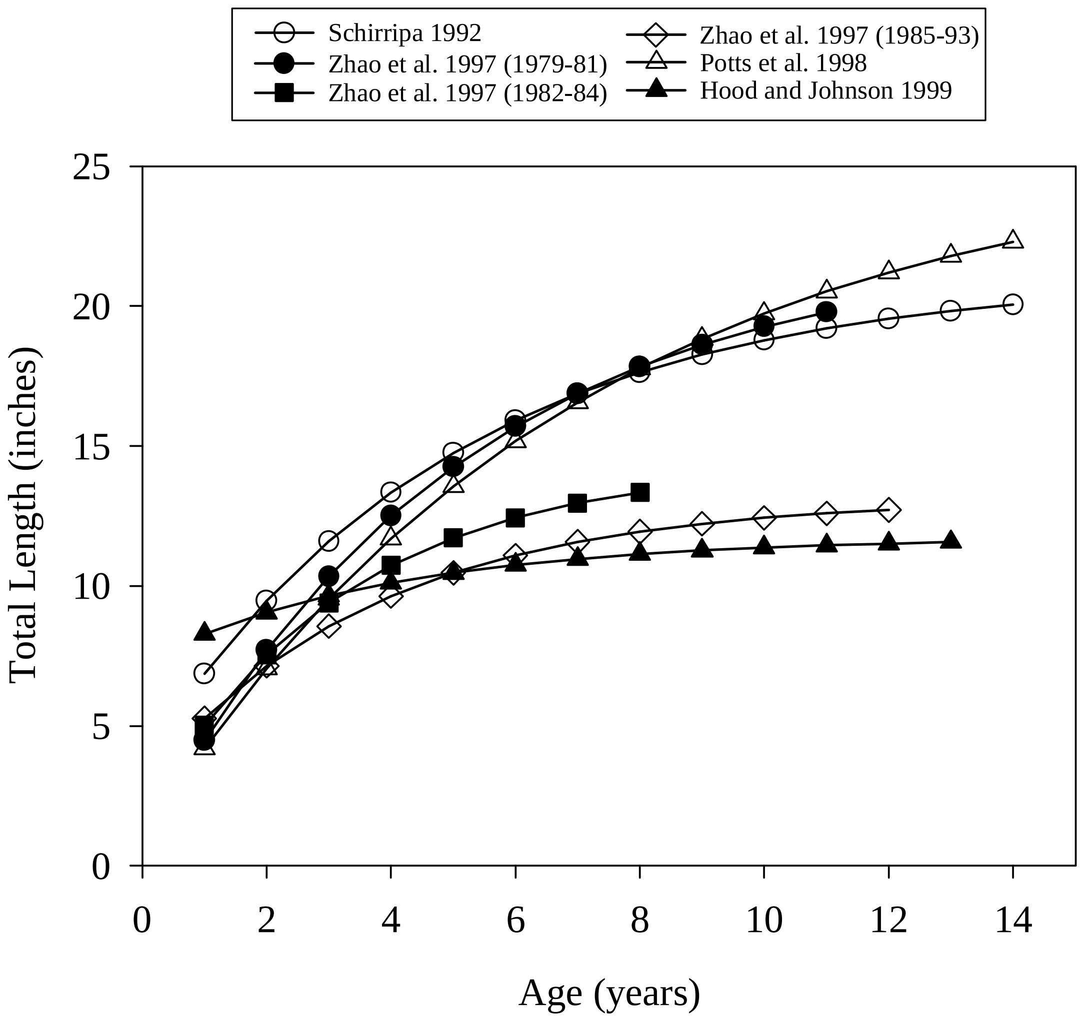


Figure 3. Estimated von Bertalanffy growth curves from sectioned otoliths.

Figure 4. Age-length observations of vermilion snapper collected from recreational and commercial landings from 1994 to 2000 with fitted von Bertalannfy curves (black lines) and Schirripa's (1992) curve (gray line).

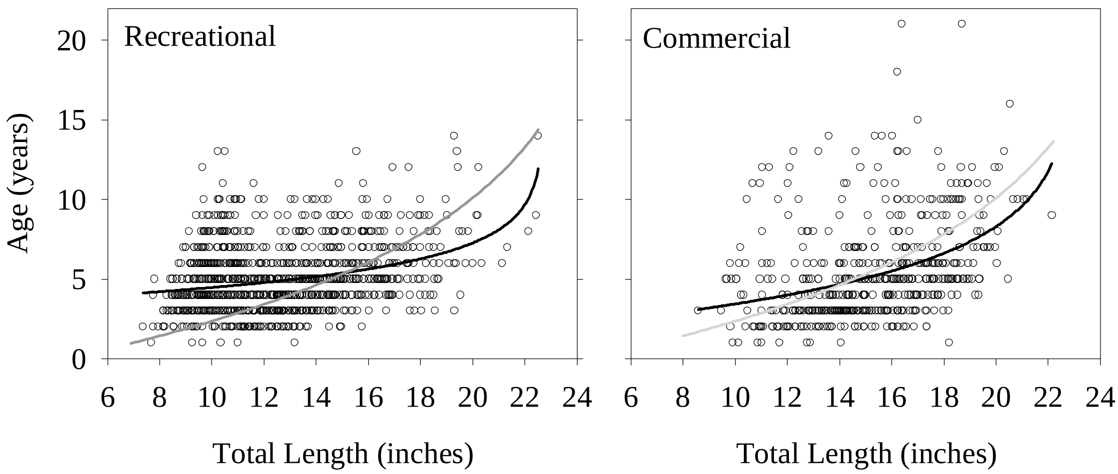


Figure 5. Age-length observations of vermilion snapper collected from recreational and commercial landings from 1994 to 2000 with fitted inverse-von Bertalannfy curves (black lines) and Schirripa's (1992) curve (gray line).

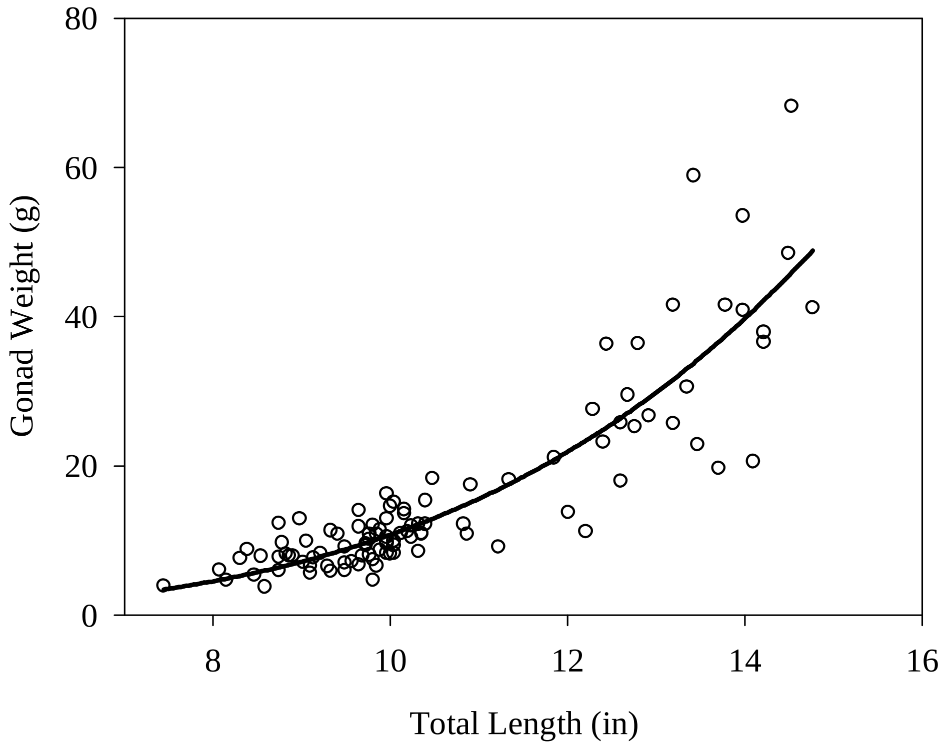


Figure 6. Gonad weight as a function of length for Gulf of Mexico vermilion snapper (N=103, r^2=0.787).

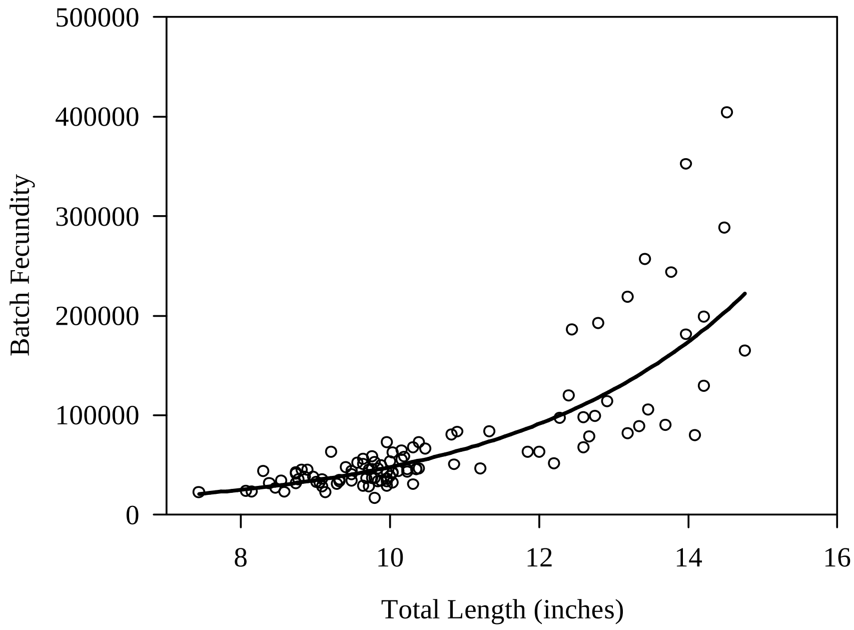


Figure 7. Batch fecundity as a function of length for Gulf of Mexico vermilion snapper (N=103, r^2=0.759).

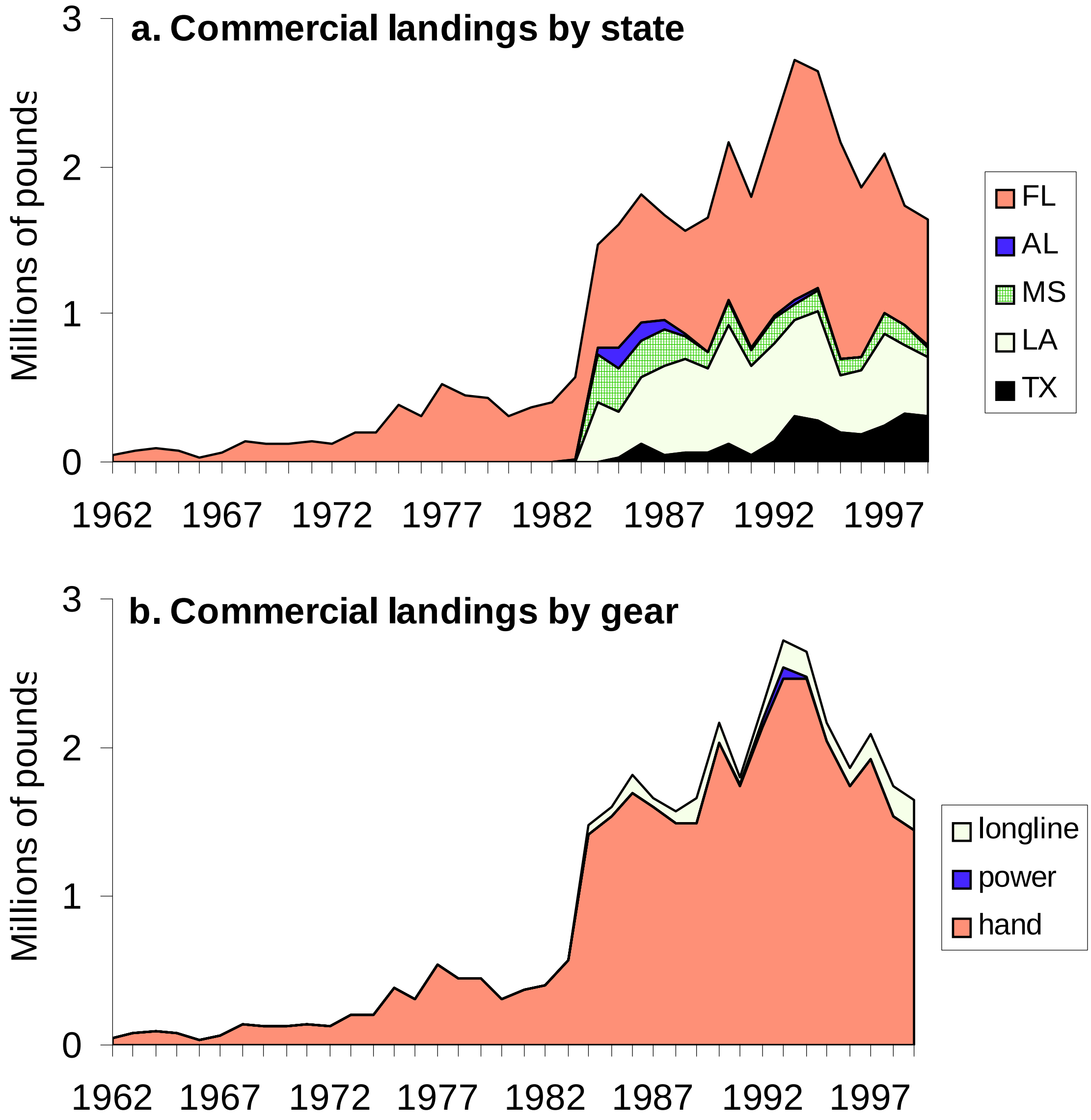


Figure 8. Commercial landings of Gulf of Mexico vermilion snapper by state (a) and gear category (b).

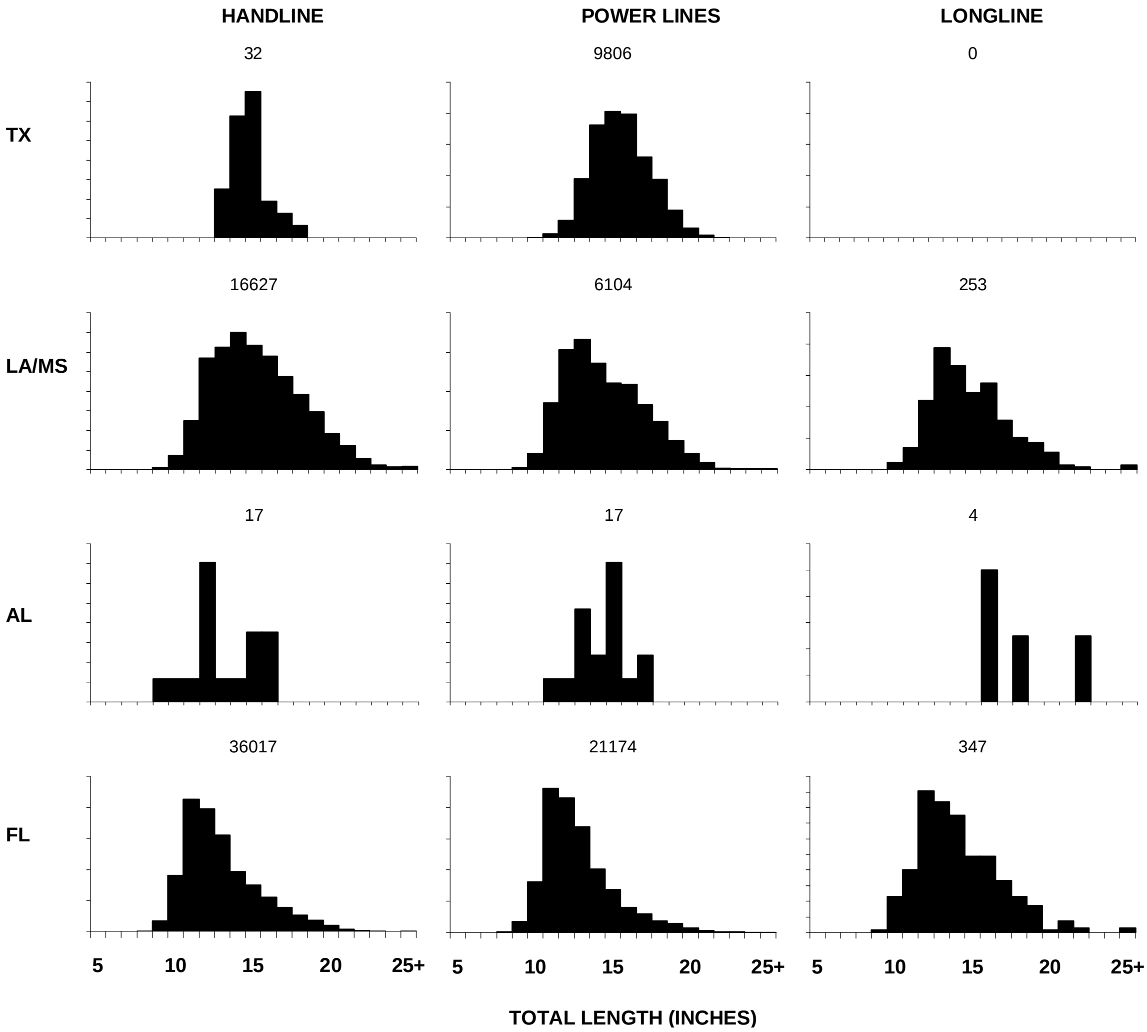


Figure 9. Length frequencies of vermilion snapper caught by commercial gear. The numbers above each graph give the sample size.

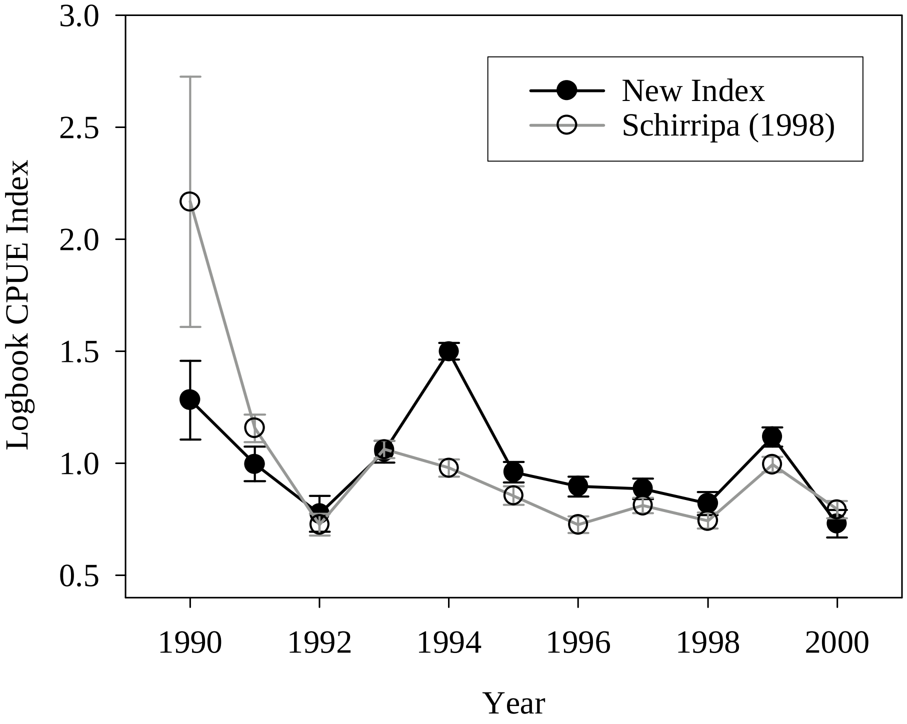


Figure 10. Commercial logbook CPUE indices standardized according to the methods of Schirripa (1998) and Brown and Calay (in prep.).

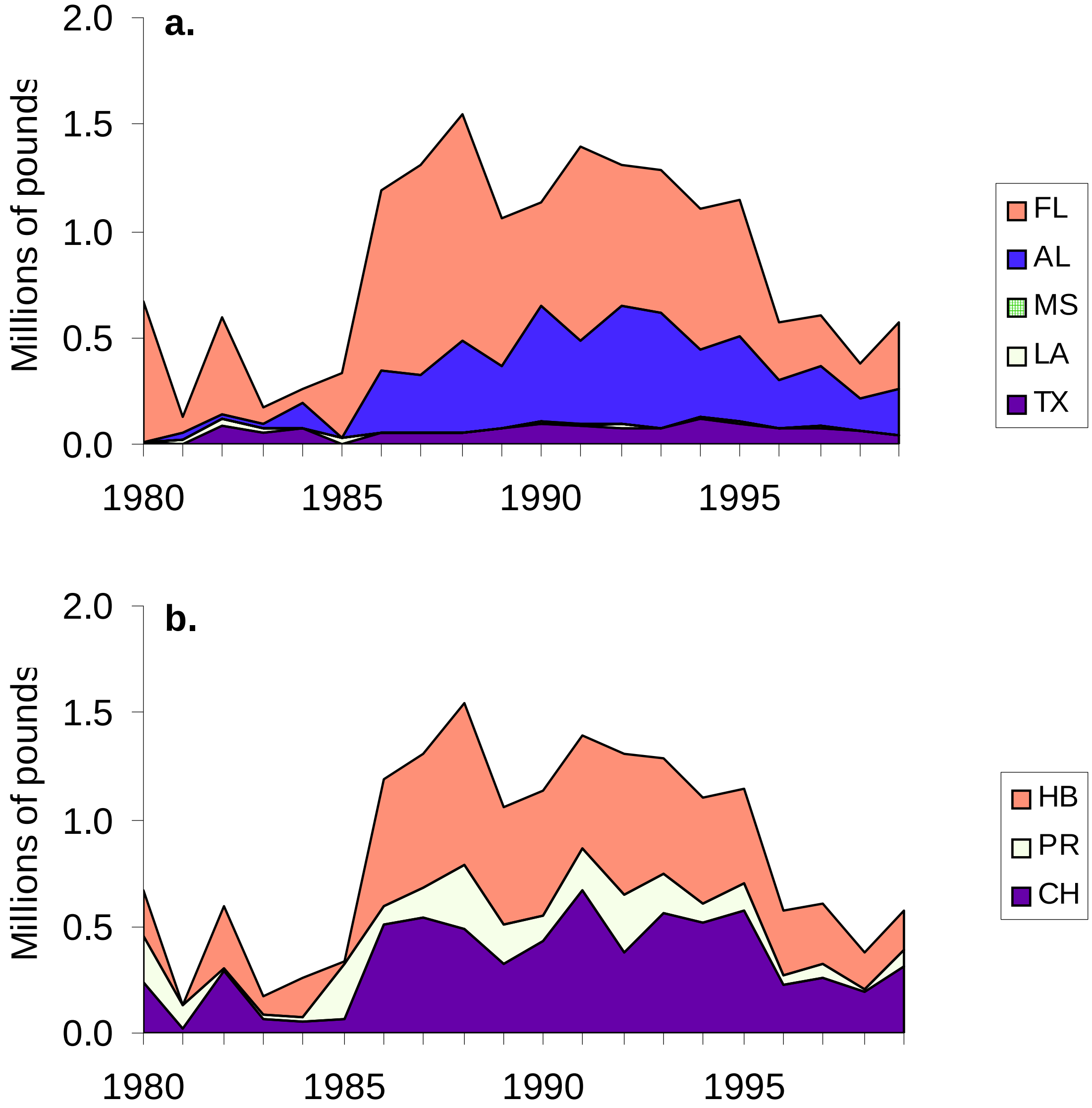


Figure 11. Recreational landings of Gulf of Mexico vermilion snapper by a) state and b) mode (HB = headboat, PR = private boats, CH = charter boats).

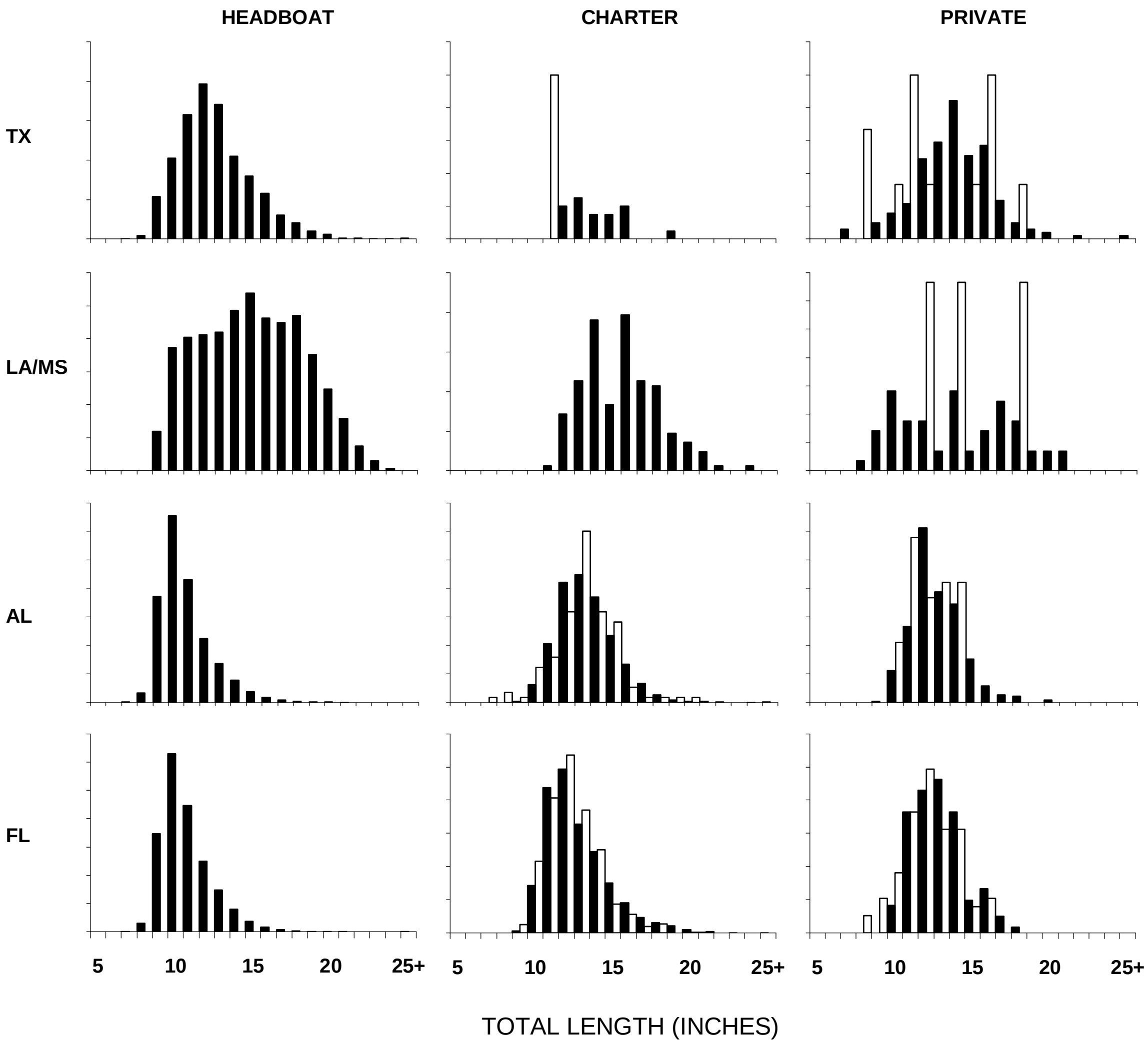


Figure 12. Relative length frequencies of vermilion snapper caught by recreational anglers in the EEZ (solid bars) and State Territorial Seas (hollow bars).

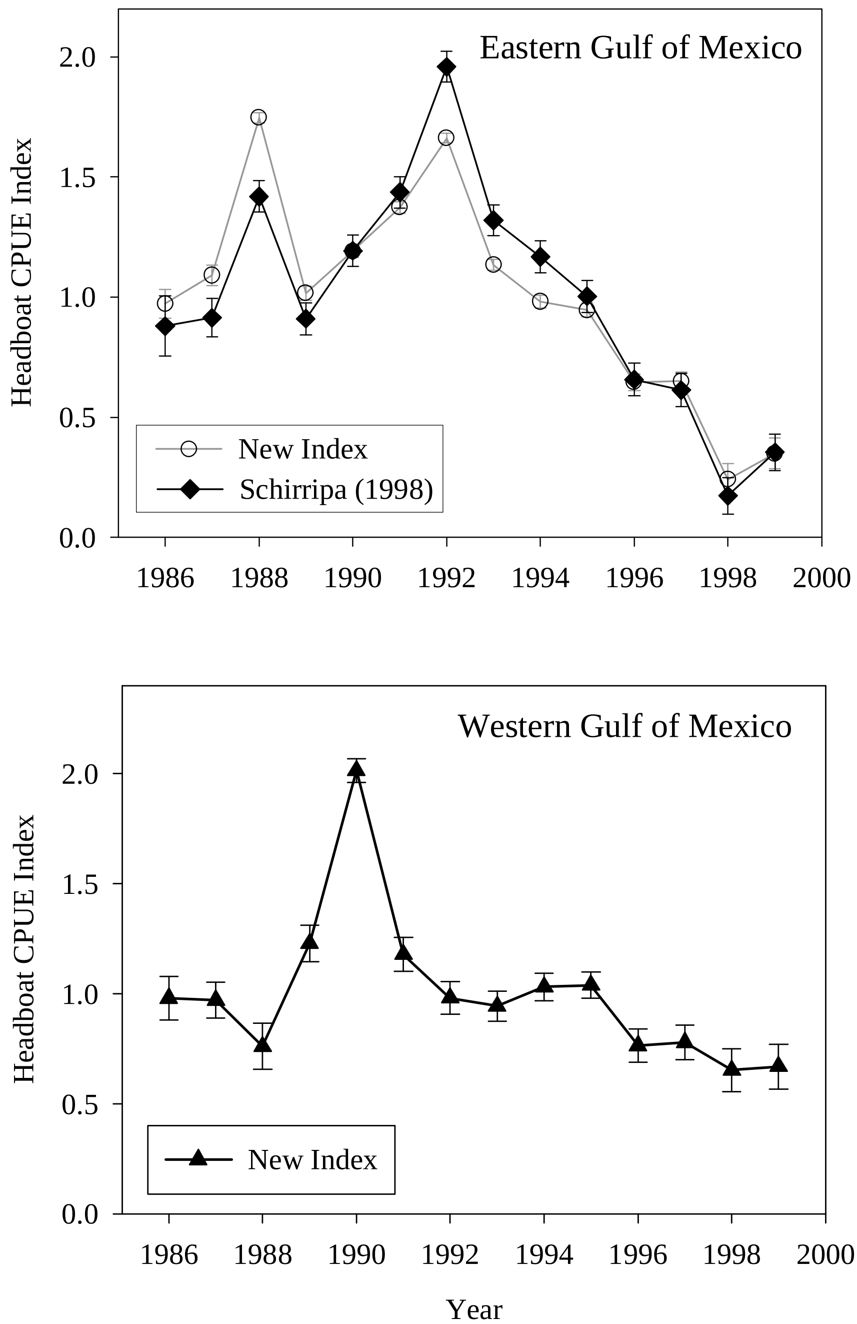
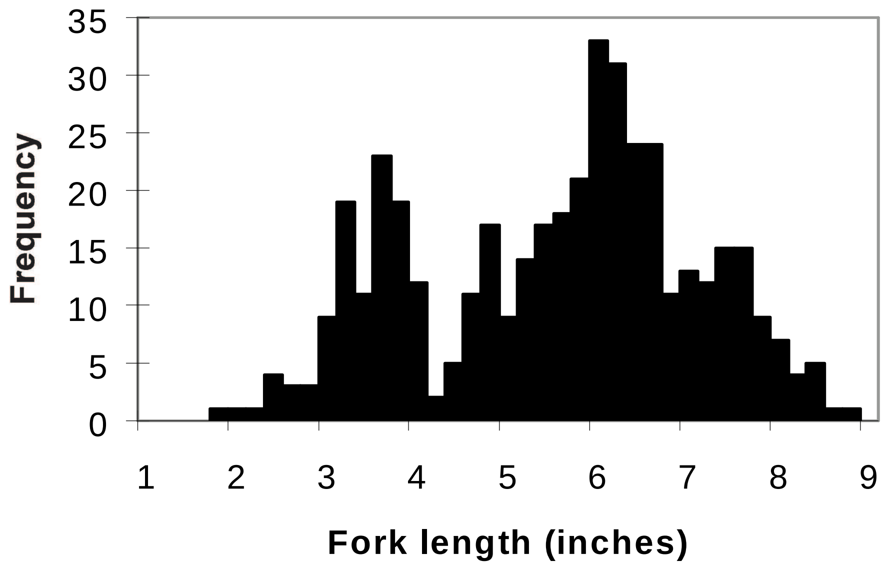


Figure 13. Headboat CPUE indices for the eastern and western Gulf of Mexico. The index for the eastern Gulf was standardized using the methods of both Schirripa (1998) and Brown and Calay (in prep.).



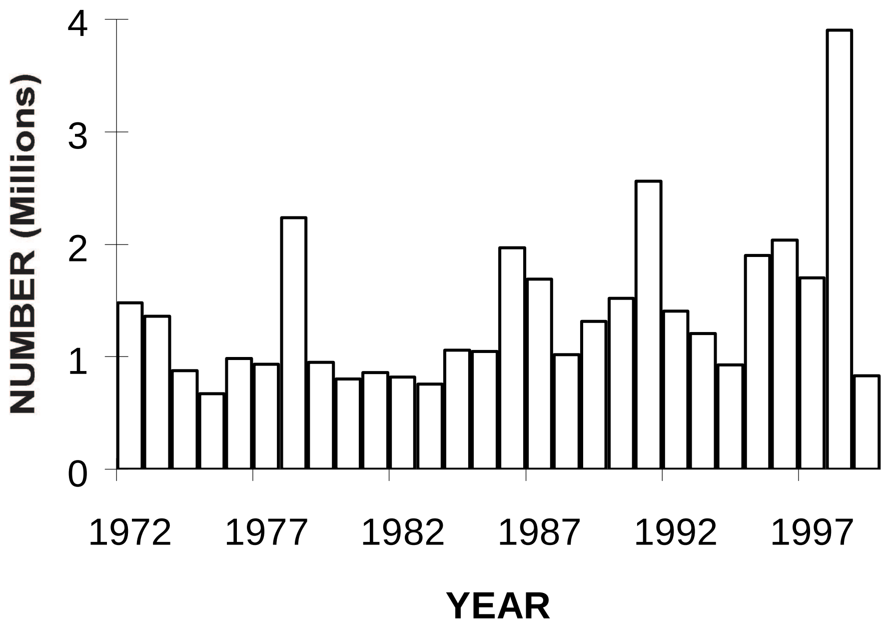


Figure 14. Length frequency distribution and estimated magnitude of the bycatch of vermilion snapper by the offshore shrimp fleet. The value for1999 has been replaced by one half the 1990-1997 average (supposing a 50 percent reduction owing to the use of BRDs).

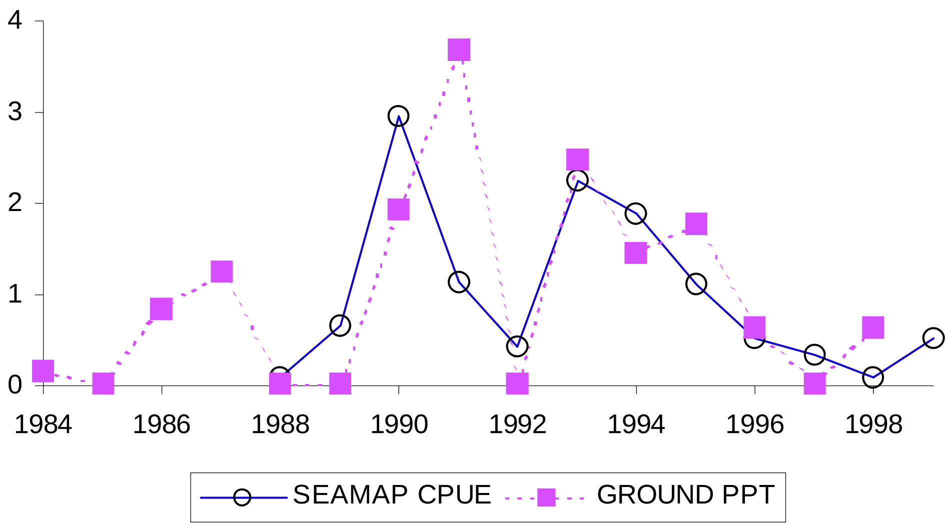


Figure 15. Standardized CPUE from the expanded SEAMAP groundfish survey contrasted with Schirripa's (2000) index of proportion positive tows from the original fall groundfish survey.

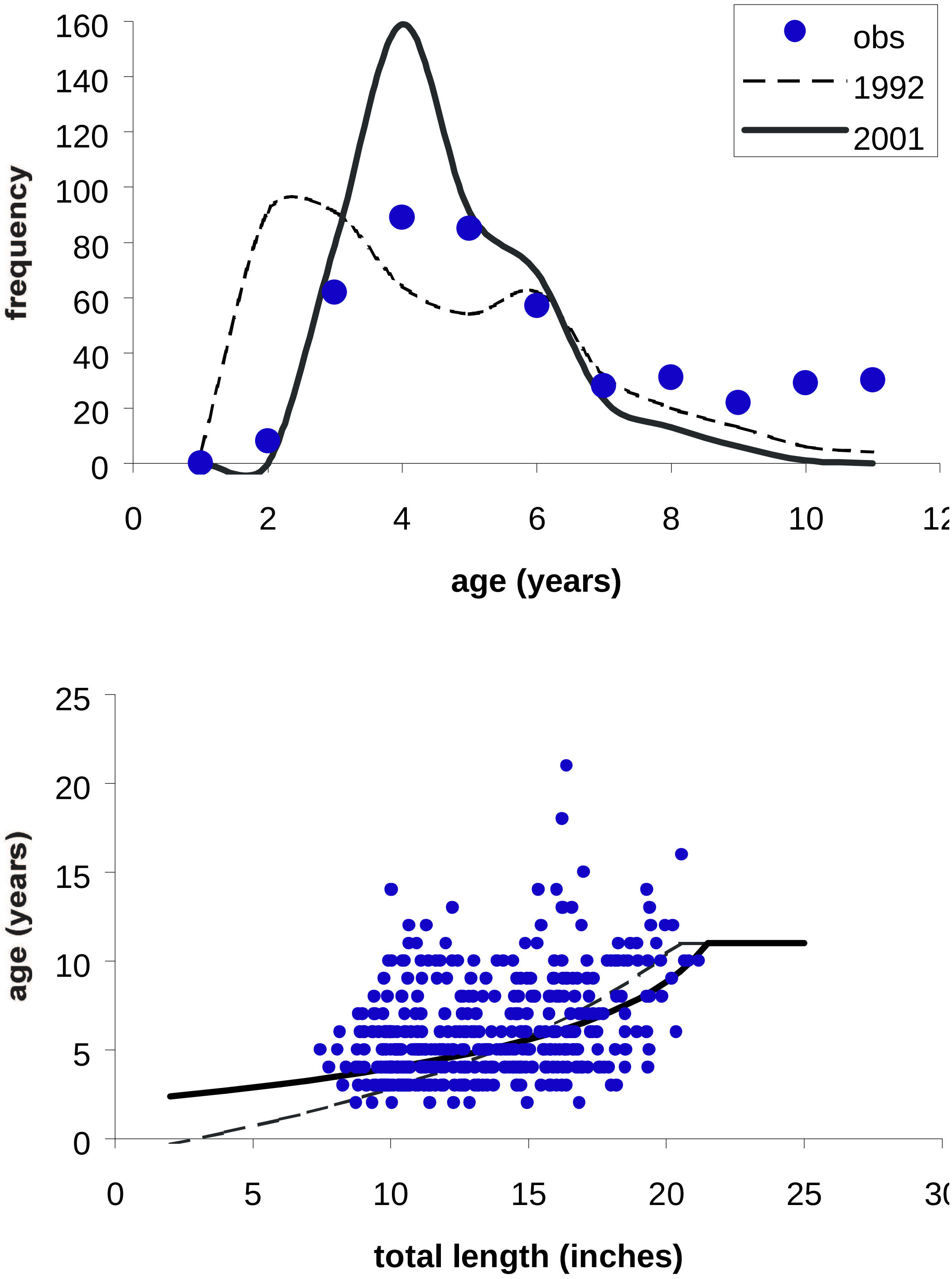


Figure 16. Observed age frequency distribution of vermilion snapper collected from commercial handline catches during the year 2000 (points) compared with the predictions from the growth curves estimated by Schirripa (1992) and in the present assessment (2001).

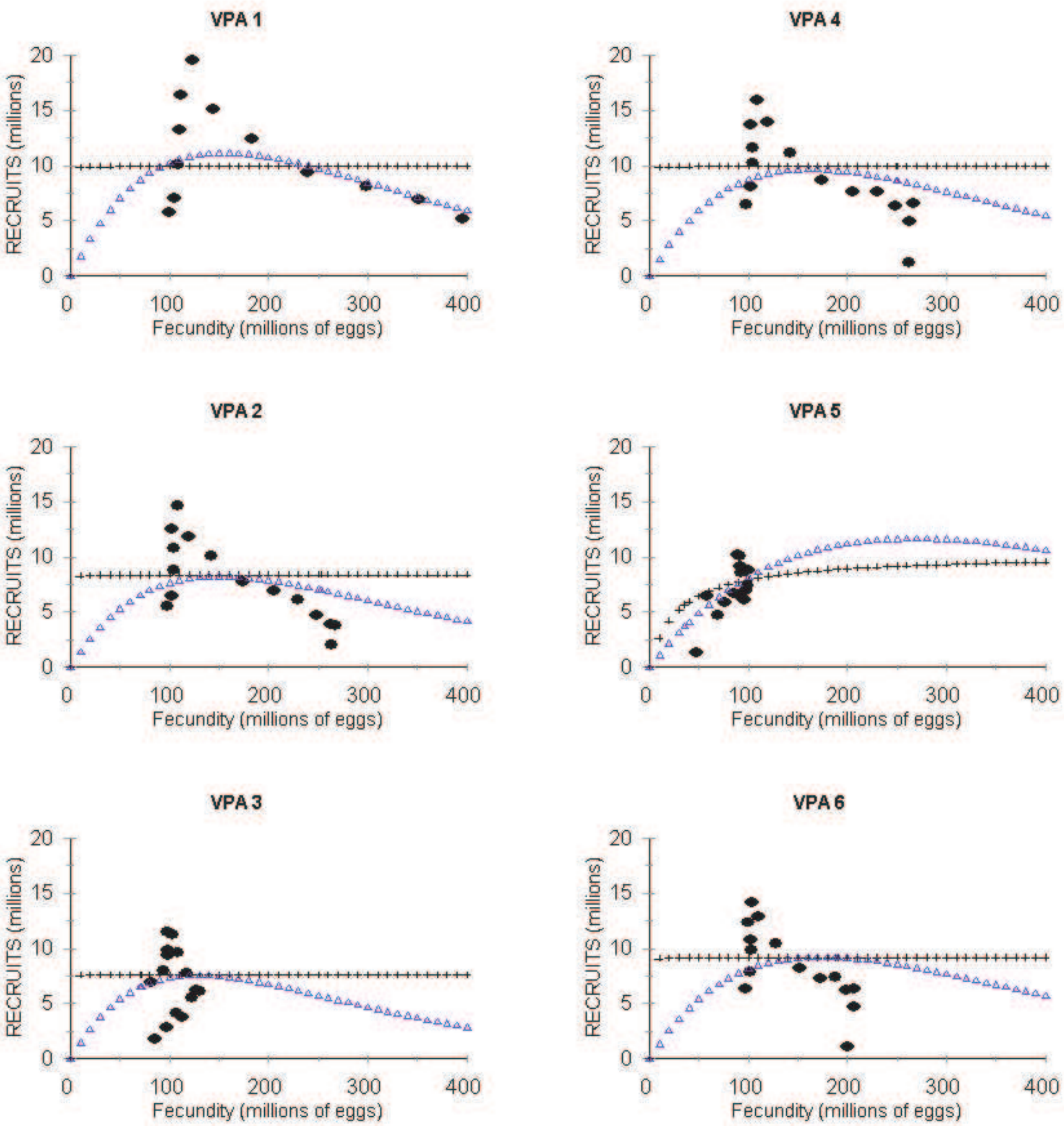


Figure 17. Estimates of one-year old recruits plotted against estimates of spawning stock fecundity for the six VPA models. The triangles and crosses represent fitted Ricker and Beverton and Holt curves. The Ricker curve (triangles) fit the estimates from models 1, 2 and 5, slightly better than the Beverton and Holt curve (crosses), whereas the opposite was true for models 3, 4, and 6. Nevertheless, neither curve fit well.

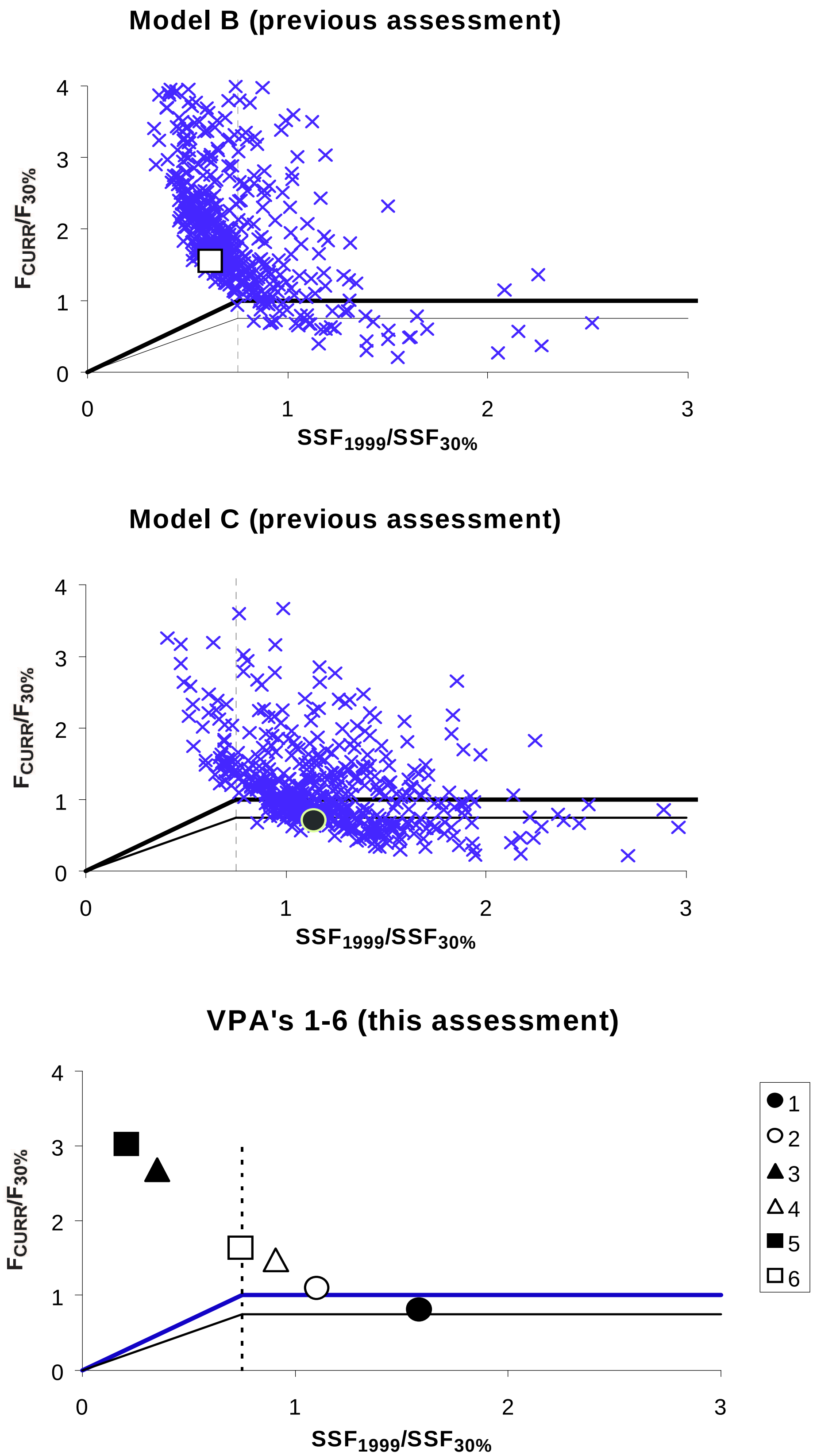


Figure 18. Projections of stock status in 1999 from models B and C of Shirripa and Legault (2000) compared with the point estimates for 1999 from the present assessment (bottom graph). Each cross represents one bootstrap and the other symbols denote the deterministic results. VPA 1 corresponds to model C and VPA 6 corresponds to model B (with the same symbols). The lower (thin) lines refer to the optimum yield fishing mortality rate (here $F_{40\%}$), which is close to 0.75 $F_{30\%}$ in all cases. Dotted line represents the default mimimum spawning stock threshold (MSST).

MODEL 1
1998 Model C

MODEL 2
Model 1 with
new headboat
index

MODEL 3
Model 2 with
catch at age
from new growth
curve

MODEL 4
Model 2 with
bycatch added

MODEL 5
Model 4 with
Seamap CPUE
rather than
prop. positive

MODEL 6
Model 4 with
commercial
logbook CPUE

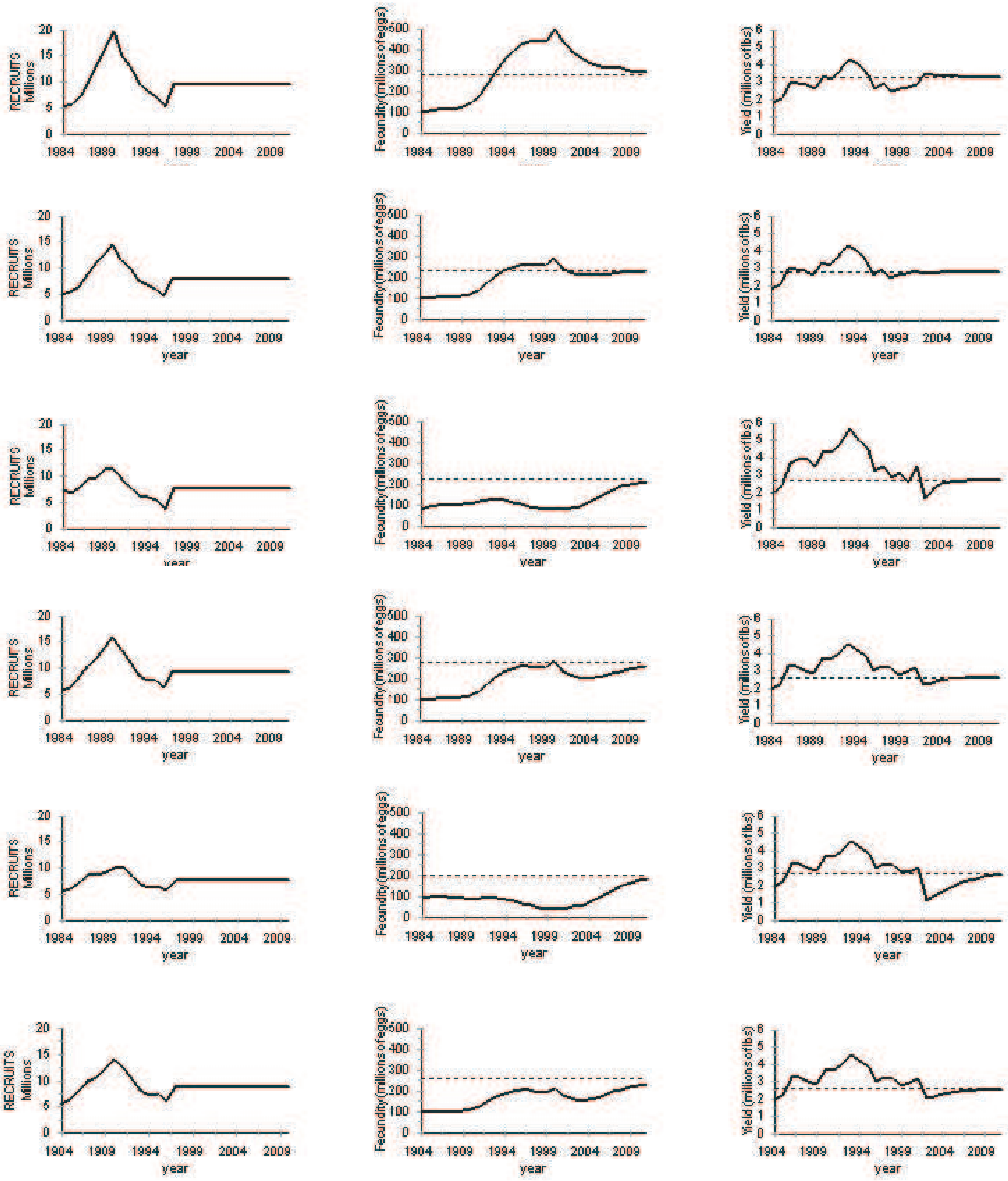


Figure 19. Synopsis of the results from each of the six VPA model formulations with projections to 2011 assuming fishing mortality occurs at a rate that leads to an SPR of 30 percent ($F_{30\%}$). The dotted lines represent the corresponding equilibrium values.

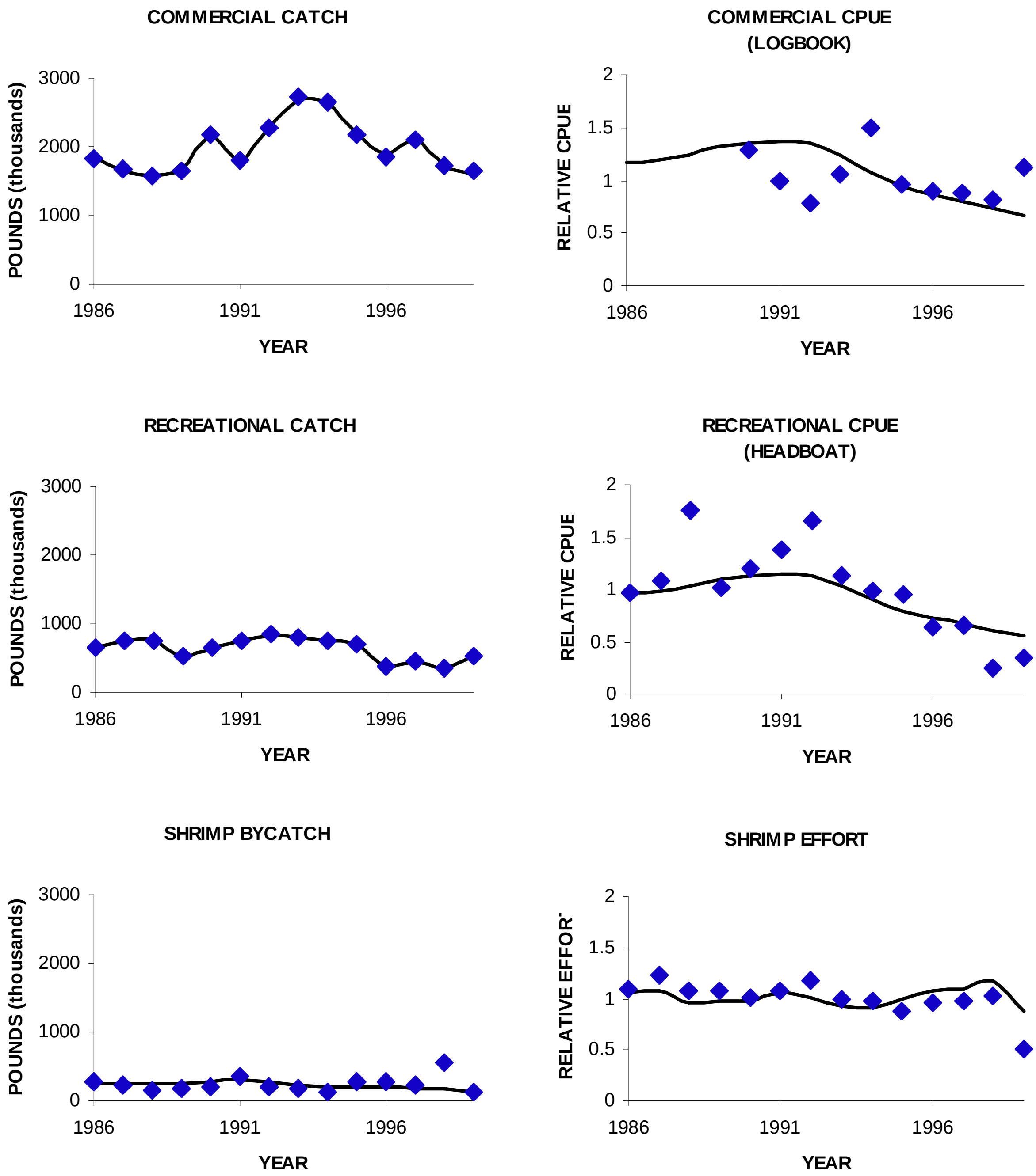


Figure 20. Base model P1 fits (lines) to data (points) from 1986 to 1999.

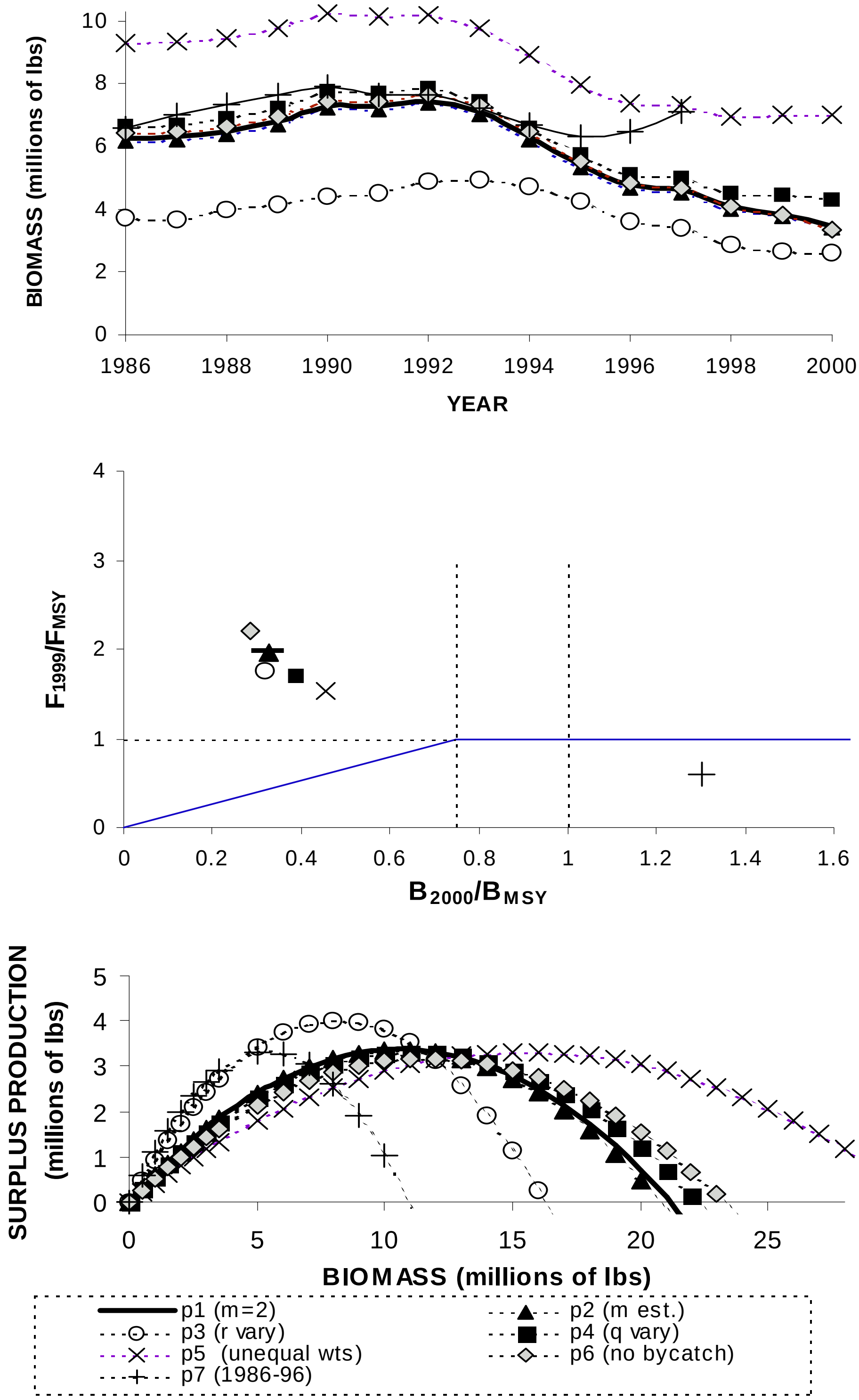


Figure 21. Synopsis of the results from each of the six production model formulations including estimates of biomass (top), phase plot of current status with respect to the default control rule (middle) and surplus production curves (bottom).

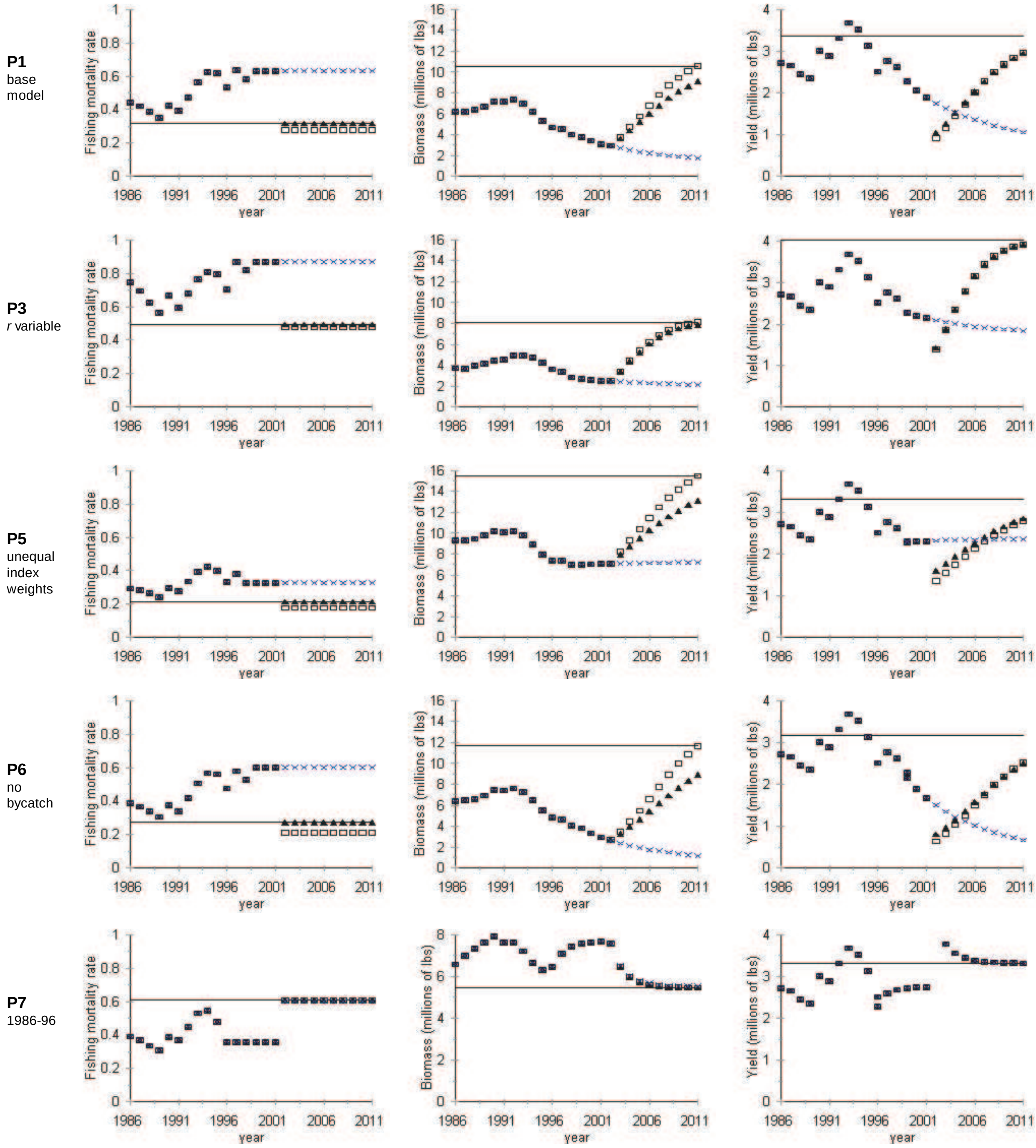


Figure 22. Projections of selected production models (P1, P3, P5, P6 and P7) at F_{CURR} (X's), F_{MSY} (triangles), and $F_{RECOVER}$ (squares). $F_{RECOVER}$ denotes the fishing mortality rate that will allow recovery to B_{MSY} in ten years (the year 2011). The results for models P2 and P4 are not shown because they were very similar to those for model P1.

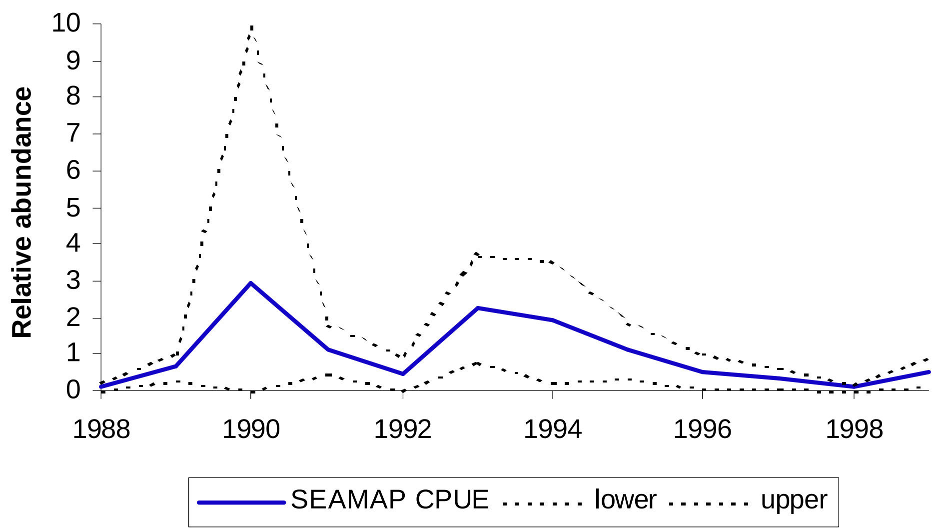


Figure 23. SEAMAP survey CPUE of vermilion snapper with approximate 95% confidence limits