NOAA TECHNICAL MEMORANDUM NMFS-SEFSC-469

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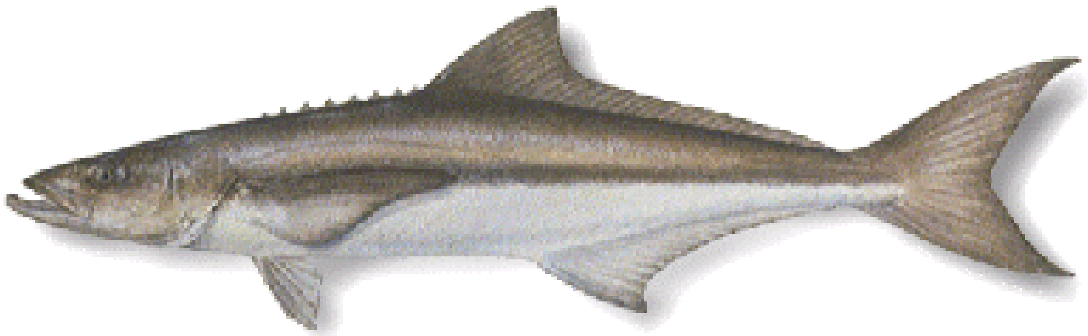

November 2001

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National Oceanic and Atmospheric Administration
Center for Coastal Fisheries and Habitat Research
101 Pivers Island Road
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NOTICE

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EXECUTIVE SUMMARY

This assessment applies to cobia (*Rachycentron canadum*) located in the territorial waters of the U.S. Gulf of Mexico. Separation of the Gulf of Mexico and Atlantic Ocean is defined by the seaward extension of the Dade/Monroe county line in south Florida. Mixing of fish between the Atlantic and Gulf of Mexico occurs in the Florida Keys during winter months. Cobia annually migrate north in early spring in the Gulf to spawning grounds in the northern Gulf of Mexico, returning to the Florida Keys by winter.

Catches of cobia in the Gulf of Mexico are dominated by recreational landings, accounting for nearly 90% of the total. Since 1980, the landings of cobia in the recreational fishery have remained fairly stable at around 400-600 mt with a slight peak of 1,014 mt in 1997. The recreational fishery was estimated to have landed 471 mt in 2000. The landings from the commercial fishery have shown a steady increase from 45 mt in 1980 to a peak of 120 mt in 1994, followed by a decline to 62 mt in 2000.

The previous assessment of cobia occurred in 1996 using a virtual population analysis (VPA) model. For this analysis a surplus-production model (ASPIC) and a forward-projecting, age-structured population model programmed in the AD Model Builder (ADMB) software were applied to cobia data from the Gulf of Mexico. The primary data consisted of four catch-per-unit-effort (CPUE) indices derived from the Marine Recreational Fisheries Statistics Survey (MRFSS) (1981-1999), Southeast region headboat survey (1986-1999), Texas creel survey (1983-1999), and shrimp bycatch estimates (1980-1999). Length samples were available from the commercial (1983-2000) and recreational (1981-2000) fisheries.

The ASPIC model applied to the cobia data provided unsatisfactory results. The ADMB model fit described the observed length composition data and fishery landings fairly well based on graphical examination of model residuals. The CPUE indices indicated some disagreement for various years, but the model fit an overall increasing trend from 1992-1997 for the MRFSS, headboat, and Texas creel indices. The shrimp bycatch CPUE was treated as a recruitment index in the model. The fit to these data followed an upward trend in recruitment from 1988-1997, but did not fit the 1994-1997 data points very well. This was likely the result of conflicting information from other data sources.

Natural mortality (*M*) for cobia is unknown. As a result, a range of values for *M* from 0.2-0.4, based on longevity and growth parameters, were selected for use in the age-structured model. The choice of natural mortality appears to greatly influence the perceived status of the population. Population status as measured by spawning stock biomass in the last year relative to the value at maximum sustainable yield (SSB_{2000}/SSB_{MSY}), spawning stock biomass in the last year relative to virgin spawning stock biomass (SSB_{2000}/S_0), and static spawning stock biomass per recruit (SSBR) all indicate the population is either depleted, near MSY, or well above MSY depending on the choice of *M*. The variance estimates for these benchmarks are very large and in most cases ranges from depleted to very healthy status. The only statement that can be made with any degree of certainty about cobia in the Gulf of Mexico is that the population has increased since the 1980s.

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INTRODUCTION

Cobia (*Rachycentron canadum*), the only member of the family Rachycentridae in North America, is a widely distributed species of pelagic fish found worldwide, except the Eastern Pacific; in tropical, subtropical, and warm temperate waters (Shaffer and Nakamura 1989). In the U.S., cobia are found in the Atlantic Ocean from the Florida Keys to Massachusetts and throughout the Gulf of Mexico. Cobia exhibit seasonal migrations in the Atlantic and Gulf of Mexico. In the Atlantic Ocean cobia begin their spring migration north from wintering grounds in the Florida Keys, generally appearing by late spring and early summer in the poly/mesohaline areas of coastal Virginia and the Carolinas (Schwartz et al. 1981, Smith 1995). In the Gulf of Mexico, cobia migrate in early spring from their wintering grounds in the Florida Keys to the northeastern Gulf where they occur in the nearshore and coastal waters off northwestern Florida to Texas from March through October (Biesiot et al. 1994, Franks et al. 1999). In the Atlantic and Gulf of Mexico there is evidence of some cobia overwintering in deeper waters (100-125 m) off the Carolinas and northern Gulf (Franks et al. 1999, Joseph W. Smith personal communication).

Tagging studies have revealed migrations of fish in both directions between the northern Gulf of Mexico and the Carolinas, indicating some level of exchange of fish from the Gulf of Mexico and Atlantic Ocean (Franks et al. 1992, Franks and McBee 1994, Franks and Moxey 1996). A genetics study of mtDNA of cobia samples from the Atlantic and Gulf of Mexico did not reveal differences (Hrincevich 1993). Despite the evidence of mixing and genetic similarity, Thompson (1993) suggested that cobia be managed based on a two stock hypothesis (Thompson 1996). The two stock approach was endorsed by the Mackerel Stock Assessment Panel in 1993 and is used for this analysis.

Cobia are relatively uncommon fish and rarely appear in large numbers or high concentrations. Adult cobia tend to travel as lone fish or in small schools or “pods” often residing in the shadow of near-surface objects including buoys, boats, piers, platforms, sharks, turtles, and rays. Cobia are large predators occasionally exceeding 45 kg (100 pounds) in weight. For these reasons, cobia is a highly prized gamefish caught in both commercial and recreational fisheries, with the recreational component constituting 80-90 % of the total landings in the Gulf of Mexico. The caption under a picture of a large cobia from a 1957 Florida fishing book reads, “Cobia, the most sought-after foodfish, by sportsmen who have tried them all” (Lewis 1957).

In the commercial fishery cobia tends to be an incidental species and is most commonly captured in various hook and line fisheries, which account for more than 90 % of the commercial landings. Other commercial gears that capture cobia include shrimp and fish trawls, fish traps and pots, pound nets, gill nets, cast nets, and spears. Florida and Louisiana historically account for most of the commercial landings from the Gulf of Mexico.

The recreational fishery is by far the most important fishery for cobia in the Gulf of Mexico. As with the commercial landings, Florida and Louisiana account for most of the landings, with Florida generally reporting the highest landings. In the recreational fishery, cobia are most commonly caught from private boats, fishing piers, and charter boats.

Cobia are managed jointly by the Gulf of Mexico and South Atlantic Fishery Management Councils as part of Coastal Pelagics Fishery Management Plan. Federal regulations, which apply to recreational and commercial fisheries, for cobia consist of a 33 inch (83.8 cm) fork length minimum size limit and a two fish per person bag limit, originally imposed in 1983 and 1990, respectively.

DATA

Biological Information

Cobia are batch spawners with spawning occurring from April to September (Biesiot et al. 1994). Mean batch fecundity has been estimated to range from 377,000 to 1,980,500 eggs, with some indication of a positive relationship with fork length. Cobia from the north-central Gulf of Mexico appear to spawn once every 9 to 12 d, while cobia in western Gulf of Mexico may spawn once every 5 d (Brown-Peterson et al. 2001). Cobia mature at young ages. Males begin maturing at 64 cm FL (approximately age 1 fish) and most are mature by age 2 (Thompson et al. 1991, Smith 1995, Lotz et al. 1996). Female cobia do not begin maturing until 83.4 cm FL (approximately age 2 fish) and most are mature at age 3 (Thompson et al. 1991, Lotz et al. 1996). Smith (1995) found that most females caught off the southeastern United States were mature by 80 cm FL. No immature cobia age 4 or greater have been observed. Based on this information, a logistic maturity function for female cobia with the following parameter values was used in the assessment model:

$$m_a = 1 \Big/ \left[1 + e^{-\eta\left(a - a_{50}\right)}\right]$$

where m_a is the percent mature at age a with slope parameter $\eta = 2.0$ and age at 50 % maturity parameter $a_{50} = 2.0$ (Fig. 1).

Growth of cobia is rapid for the first two years, after which it slows gradually. Females attain a larger size at age than males (Thompson et al. 1991, Burns et al. 1998, Franks et al. 1999). For this analysis, sample data from Burns et al. (1998) and Franks et al. (1999) were combined into a single dataset. Based on marginal increment analysis of cobia otoliths by Franks et al. (1999), annulus formation occurs during June in the Gulf of Mexico, which coincides with the spawning season. However, Franks et al. (1999) suggest that annulus formation may be more related to migration. Nevertheless, for this analysis, the sample dates from the combined age-length data were adjusted to reflect a June 1 annulus formation date. A von Bertalanffy growth curve was then fit to each sex separately using a non-linear regression method. The von Bertalanffy growth function is:

$$L_a = L_\infty \left[1 - e^{-K\left(a - t_0\right)}\right]$$

where L_a is the fork length in mm at age a with asymptotic length parameter L_4, growth coefficient K, and hypothetical size at age zero, t_0. The parameter estimates used in this analysis for cobia in the Gulf of Mexico are:

Parameter	Females	Males
L_4	1852	1148
K	0.125	0.38
t_0	-3.07	-1.15

and are shown in Figure 2.

The relationship of weight to length for cobia was determined from commercial samples in the Gulf of Mexico and data from Burns et al. (1998) study. A power function,

$$W = aL^b$$

where W is the weight in kg computed from fork length L in mm and parameters a and b (Fig. 3). No difference was observed between the sexes; therefore, a single function with $a = 1.4\text{X}10^{-8}$ and $b = 2.97$ was applied to both sexes for this analysis.

Landings

Commercial fishery landings of cobia in the Gulf of Mexico were obtained from the Southeast Fisheries Science Center (SEFSC) and the National Marine Fisheries Service (NMFS) Fisheries Statistics and Economics Division (pers. comm.). The commercial catch data are provided in whole fish weight. Landings in the commercial fishery were not separated into gear categories for this analysis since hook-and-line gear represents over 90 % of the landings. The majority of the commercial landings of cobia in the Gulf of Mexico occur in Florida and Louisiana (Table 1, Fig. 4). The historical trend of commercial landings has shown a steady increase from 45 mt in 1980 to nearly 120 mt in 1994. Since 1996 there has been a steady decrease in commercial landings of cobia to 62 mt in 2000 (Table 1, Fig. 4).

Recreational landings in weight were derived from an estimate of total numbers (catch A + B1) of cobia landed. To date there is no estimate of hooking mortality for cobia. Numbers of fish captured and released alive (catch B2) were assumed to have 0 % hooking mortality. To derive whole weight, size samples from the Marine Recreational Fisheries Statistics Survey (MRFSS), Texas Parks and Wildlife creel survey, and Southeast region headboat survey were used to convert length measurements to weight estimates. The Texas and headboat estimates were not updated for 2000 in time for this analysis; therefore, the average landings from 1997-1999 were used as estimates of the 2000 landings in these two sources of information. The MRFSS landings estimates include updated estimates for 2000. As in the case for the commercial landings, Florida and Louisiana account for the majority of the cobia landings from the Gulf of Mexico (Table 2, Fig. 4). The historical trend of recreational landings has remained relatively stable since 1981, with estimated landings generally between 400-650 mt (Table 2,

Fig. 4). There does not appear to be any correlation between the commercial and recreational landings time series.

Length Samples

Length measurements were obtained from samples of the commercial fishery and samples from the MRFSS (1981-2000), headboat survey (1986-1999), and Texas creel survey (1983-1999), which were combined to form the recreational fishery samples. For some cobia samples from the recreational and commercial fisheries, lengths were given in fork length (FL), total length (TL), and/or standard length (SL). All length measurements were converted to fork length using the following relationships derived from Smith's (1995) data:

$$FL = 0.889TL$$
$$FL = 1.607 + 1.067SL$$

In some cases there were weight measurements with no length measurement in which case the weight was converted to FL using the inverse of the length-weight relationship shown above.

The mean length of captured cobia in the Gulf of Mexico indicates an increasing trend in the commercial and recreational fisheries (Fig. 5). The commercial fishery has shown a steady increase in mean length throughout the time series, while the recreational mean length appears to have leveled off for the 1990-2000 time period (Fig. 5). The best explanation for the increasing trends in the early part of the time series is gradual compliance with the federal minimum size limit of 33 in FL (838 mm) imposed in 1983. A look at the proportion of samples above the 33 in (838 mm) size limit shows a pattern very similar to the mean length time series (Fig. 5). The commercial fishery proportion of fish over 33 in (838 mm) reveals a leveling off after 1990, indicating the increase in mean length in the fishery may be an actual population trend. The mean length of cobia in the commercial fishery was inexplicably low in 1989, bringing these samples into question.

For use in the population model, the length samples were pooled into length intervals and converted to composition data. Length intervals of 25, 50, and 75 mm were investigated for binning the length samples. The choice of length intervals involved obtaining a balance between smoothing and signal retention. It is generally accepted that sufficient length samples from a fish population will exhibit smooth multi-modal distributions (Erzini 1990). The strength of each mode indicates the relative year class strength of the cohort that it represents. If sample sizes are small and length intervals are relatively small, the resulting distributions will be "noisy", containing many peaks and troughs that might be falsely interpreted by an assessment model as recruitment fluctuations. On the other hand, if length intervals are too large, there will be too much overlap of adjacent ages and no information on recruitment strength for an assessment model to draw upon.

The number of length samples per year for each fishery is shown in Table 3. In a couple of the years there are some sample sizes < 50, in which case some years could be pooled, but these years were ultimately kept separate in the final analysis since the sample size was used in the model to adjust the relative influence of each year's data. The 2000 recreational length samples are only from the MRFSS data, as the headboat and Texas length samples were unavailable at the time of this analysis.

Based on visual examination of the length composition data, 50 mm (≅ 2 in) length bins were chosen for developing length composition data for the assessment model. The pattern of length composition over time for the commercial and recreational fisheries are shown in Fig. 6 and 7, respectively. For completeness, the values for the length composition information are listed in Tables 4 and 5. In 1989 the commercial samples show a marked change in the length composition data, which was also reflected in the mean length analysis mentioned above. The 1989 data indicated a large proportion of small (< 500 mm) fish. Based on the age-length data and growth model fits, these are young-of-the-year, age 0 fish, well below the legal minimum size limit of 33 in (838 mm) (Fig. 2). The lack of any substantial numbers of larger fish, the low sample size for this year (Table 3), and the fact that this distribution differs tremendously from the rest of the data resulted in the decision to ignore the 1989 commercial sample data in the assessment model (Fig. 6).

CPUE Indices

Catch-per-unit-effort (CPUE) indices were developed from the MRFSS, Southeast region headboat survey, Texas creel survey, and shrimp fishery bycatch. The general approach taken to develop an index of cobia abundance from each of these data sources was to use a general linear model (GLM). In some cases there were observations with zero CPUE values. Typically CPUE information is modeled as a lognormally distributed variable, which simply involves taking the natural logarithm of CPUE. However, the logarithm of zero cannot be computed. To get around this problem there have been several suggestions for added constants to CPUE ranging from 0.001 up to 10 times the maximum positive value (Porch and Scott 1994, Ortiz et al. 2000). An alternate suggestion to the additive constant has been to model the proportion positive as a binomial or gamma distributed process in a GLM. This can then be combined with a log(CPUE) GLM of the positive values into a delta-lognormal process, an approach that was adopted here (Lo et al. 1992, Stefansson 1996, Ortiz et al. 2000). Error estimates were obtained from a bootstrap procedure which re-samples residuals from the lognormal GLM model of the positive values and randomly draws values from a binomial distribution based on the observed and predicted proportion positive data from the GLM results (Efron and Tibshirani 1993). It should be noted that this bootstrap method for obtaining error estimates only accounts for modeling error and does not incorporate any sampling error from aggregated CPUE estimates.

The MRFSS data (1981-1999) were obtained by downloading compressed data files from the MRFSS web site (NMFS 1997). These data files were summarized at the trip level and sorted for records with cobia listed as a caught species or reported as a primary or secondary target species. This resulted in trip records with zero cobia caught, which led to the use of the delta-lognormal GLM method using a binomial distribution for the proportion positive GLM. CPUE was computed as the number of cobia caught divided by the product of anglers/trip and hours/trip. Exploratory analysis of the MRFSS CPUE data revealed inadequate sample size for some factors. For this reason, some factors were combined in order to reach a more balanced distribution of data. Each year and 2-month wave remained as separate factors. All shore modes (bridge, jetty, pier) were combined and boat modes (private, charter, party) were combined to make two modes. The area factors were ocean < = 3 miles, ocean > 3 miles, ocean < =10 miles, and ocean > 10 miles. The use of 3 miles or 10 miles to delineate different areas is state specific. The state factor remained intact, which in the case of the MRFSS data does not include Texas. The results of the delta-lognormal GLM and error estimates for the MRFSS CPUE index are indicated in Table 6 and Fig. 8.

The Southeast region headboat survey data (1986-1999) was obtained from the Beaufort Laboratory, North Carolina, for the Gulf of Mexico. The catch and effort data per trip as reported in captain's logbooks was extracted for all trips. The effort included all recreational trips and was computed as angler hours from the product of anglers/trip and hours/trip. The catch was simply the number of cobia reported. Exploratory analysis revealed the need for some collapsing of factors to increase cell sizes for use in the delta-lognormal GLM method. Both year and month were retained as factors and area was collapsed into 5 categories consisting of South Florida (areas 17, 18, and 21), North Florida (areas 22 and 23), Louisiana (area 24), North Texas (area 25), and South Texas (areas 26 and 27).   The results of the delta-lognormal GLM and error estimates are indicated in Table 6 and Fig. 8.

The Texas Parks and Wildlife creel survey data (1983-1999), like the MRFSS and headboat surveys, is based on intercept sampling of the recreational fishery. CPUE was computed as the number of cobia caught divided by effort, which included all trips and was calculated as the product of anglers/trip and hours/trip. As was done with the MRFSS and headboat data sources, an exploratory analysis was performed to determine if any factors needed to be collapsed due to inadequate sample sizes. None of the factors needed to be pooled or collapsed. The delta-lognormal GLM was applied to the data with 1983-1999 years, 12 months, 2 modes (charter, private), and 3 areas (ocean < = 10 miles, ocean > 10 miles, inland) (Table 6 and Fig. 9).

<u>Shrimp Bycatch</u>

The shrimp bycatch data and CPUE time series were analyzed and provided by Scott Nichols at the NMFS Pascagoula Laboratory, Mississippi. The CPUE time series was computed from a GLM analysis of the log(CPUE+1) data, where CPUE is the number of cobia per hour. Factors in the analysis include year, season (4 trimesters), 4 areas (statistical zones), 2 depth zones (inside 10 fathoms, outside 10 fathoms). Cobia are relatively uncommon in the shrimp trawl fishery. One of the components of the GLM analysis includes data from the R/V Oregon II trawl survey; however, it appears that the highest cobia catches occur with the pink shrimp fishery off Florida, almost disconnected from the bulk of the R/V Oregon II data, so its inclusion is questionable. Another complicating factor in the data set is the use of Bycatch Reduction Devices (BRD's) in the shrimp fishery. BRD's are designed to reduce finfish bycatch by shrimp trawls. Several GLM analyses were performed with inclusion and exclusion of BRD sets and various assumptions about their affect on cobia catches. Year 2000 data and beyond are considered invalid due to the widespread use of BRD's. Scott Nichols best recommendation GLM analysis results are shown in Table 6 and Fig. 9. Unfortunately, no usable error estimates are available and for this analysis an assumption of a constant coefficient of variation (CV) of 20 % was applied based on CV estimates from the other CPUE indices.

In the previous assessment of cobia, estimated numbers of cobia captured in the shrimp fishery were used in the virtual population analysis (VPA) assessment model (Thompson 1996). The estimates are in the hundreds of thousands per year. To distribute these numbers into catch at age, an estimate of the age composition of these fish would be required. A limited sample of 39 fish were measured for length with no recorded sex information, resulting in a very poor estimate of the age distribution of the fish captured in the shrimp trawl fishery. Because of the poorly estimated age composition, the numbers of fish were not used in this assessment. Even though the number and age distribution of cobia caught as bycatch are unknown, it is still possible that the trend seen in the GLM analysis of CPUE is valid. Thus, the CPUE time series from the shrimp bycatch GLM analysis was kept in the analysis. Based on limited size samples of cobia caught in the shrimp fishery, it was estimated that > 80 % of the fish are young-of-the-year (age 0) fish and this CPUE index was therefore treated as a recruitment index in the assessment model (Fig. 10).

MODELING

In previous assessments of Gulf of Mexico cobia a VPA was used for the analysis with values of natural mortality (M) of 0.2 and 0.4 (Thompson 1996). In that assessment it was estimated that fishing mortality (F) at age at the fully recruited ages in the mid 1994 was higher than $F_{0.1}$ and F_{max} (Thompson 1996). Spawners per recruit (SPR) in the previous assessment were estimated as about 25 % and 50 % for M values of 0.2 and 0.4, respectively (Thompson 1996).

For this new assessment both surplus-production and age-structured modeling approaches were applied to the Gulf of Mexico cobia data. The surplus-production models were fit using the ASPIC program (Prager 1994, 1995). A series of production models, applying both the logistic and generalized form, were fit to the estimated landings and CPUE indices, in combination and separately. The details of this program may be found in Prager (1994, 1995).

A forward projecting, age-structured population model programmed in the AD Model Builder (ADMB) software (Otter Research, Ltd.) was also applied to Gulf of Mexico cobia data (Fournier 1996). The ADMB software allows for more rapid and accurate computation of derivative calculations, via automatic differentiation, used in the quasi-Newton optimization routine (Chong and Zak 1996). Further advantages of the ADMB software include automatic calculation of the variance-covariance matrix which can be used via the Delta method for estimating standard deviations on any dependent and independent parameters. Also, the ADMB software allows for other methods of parameter error estimation such as likelihood profiling and Markov chain-Monte Carlo (MCMC) simulation using the Hasting-Metropolis importance sampling algorithm (Gelman et al. 1995, Fournier 1996).

The age-structured assessment model used in this analysis is very similar to models used for West Coast Pacific Ocean perch and gemfish in Eastern Australia (Smith and Punt 1998, Ianelli et al. 2000). The model is essentially a maximum likelihood analysis based on catch-age theory, similar to the "stock synthesis" approach (Methot unpublished manuscript, Quinn and Deriso 1999). The ADMB software allows for parameters to be added to the model in phases. In this case an age-structured production model is estimated in the first phase and additional parameters for time-varying selectivity, recruitment, and growth are added in subsequent phases. The details of this model are discussed below.

Age-Structured Model Description

The model estimates male and female numbers at age for the years 1980 to 2000 and ages 0 to 11+. With age 11+ representing a pooled age group of all fish older than age 10. Selectivity at age in the commercial and recreational fisheries was modeled with separate logistic functions for each fishery, but constant for both sexes,

$$s_{a,y} = 1\Big/\left(1 + e^{-\eta\left[a-\left(\bar{\delta}+\delta'_y\right)\right]}\right),$$

where $s_{a,y}$ is the percent selection for age a in year y, η is the slope of the selectivity function, $\bar{\delta}$ is the average age at 50 % selection, and δ'_y is the annual deviation in age at 50 % selection. The δ'_y allow for the fishery selectivity to vary from year to year, with the deviations constrained to be normally distributed with mean zero (see below).

Fishing mortality at age for each fishery was computed as,

$$F_{a,y} = \left(\bar{F} + F'_y\right)s_{a,y}$$

where $F_{a,y}$ is the fishing mortality at age a in year y, $s_{a,y}$ is the selectivity, $\bar{F}$ is the average fishing mortality, and F'_y is the annual fishing mortality deviation constrained to be normally distributed with mean zero (see below).

The numbers at age matrix is computed from the exponential decay of cohorts through time for each sex using the following formulae,

$$\begin{aligned}
N_{a,1} &= N_{a-1,1}e^{-\left(F_{a-1,1}+M\right)} \\
N_{A,1} &= N_{A-1,1}e^{-\left(F_{A-1,1}+M\right)}\Big/\left[1-e^{-\left(F_{A-1,1}+M\right)}\right] \\
N_{a,y} &= N_{a-1,y-1}e^{-\left(F_{a-1,y-1}+M\right)} \\
N_{A,y} &= N_{A-1,y-1}e^{-\left(F_{A-1,y-1}+M\right)} + N_{A,y-1}e^{-\left(F_{A,y-1}+M\right)}
\end{aligned}$$

where $N_{a,y}$ is the number of fish at age a (for $a > 1$, in this case age > 0 fish) in year y and subscript A represents the pooled age group (11+), F is the fishing mortality, and M is natural mortality. Numbers of fish for $a = 1$ (in this case age 0) are estimated via a Beverton-Holt stock-recruit function for $y > 1$. The number of fish at age 0 in 1980, $N_{1,1}$, is a parameter of the model.

The sex ratio is assumed to be 1:1 for all numbers at age. Subsequent recruits, numbers at age 0, are estimated using a re-parameterization of the Beverton-Holt equation, as follows,

$$R_y = \frac{0.8 R_0 h S_{y-1}}{\left[0.2 R_0 \phi (1-h) + (h-0.2) S_{y-1}\right]} + R'_y$$

where R_0 is the virgin recruitment, h is the steepness parameter representing the proportion of R_0 which will result when the spawning biomass (S), is reduced to 20 % of its virgin level (S_0), and ϕ is the spawning biomass per recruit at $F = 0$ (Mace and Doonan 1988, Francis 1992). The R'_y parameters are the annual recruitment deviations which are constrained to be lognormally distributed (see below). The spawning biomass is computed as,

$$S_y = \sum N_{a,y} m_a w_a \ ,$$

where m is the percent maturity at age and w is the weight at age. The spawning biomass per recruit at F = 0 (ϕ) is computed as follows,

$$\begin{aligned} N_1 &= 1.0 \\ N_{a>1} &= N_{a-1} e^{-M} \\ N_A &= N_{a-1} e^{-M} / \left(1 - e^{-M}\right) \\ \phi &= \sum N_a m_a w_a \end{aligned}$$

The virgin spawning biomass (S_0) is simply the product of R_0 and ϕ. For comparison, the equivalent α and β parameters of the Beverton-Holt equation (Francis 1992) are as follows,

$$R = \frac{S}{\alpha + \beta S} \text{, with}$$

$$\alpha = \frac{\phi(1-h)}{4h} \text{ and } \beta = \frac{5h-1}{4hR_0}.$$

Catch at age in numbers is computed using the Baranov catch equation,

$$C_{a,y} = N_{a,y} \frac{F_{a,y}}{F_{a,y} + M}\left(1 - e^{-\left[F_{a,y}+M\right]}\right).$$

The predicted landings for each year are computed from the sum of the product of catch at age and weight at age for each year. The predicted CPUE ($\hat{U}$) indices for the MRFSS, headboat, and Texas creel surveys were computed from the exploitable biomass as follows,

$$\hat{U}_y = q \sum N_{a,y} s_{a,y} w_a \,,$$

where $\hat{U}$ is the predicted CPUE in year *y*, *q* is the catchability coefficient, *N* is the numbers at age, *s* is the percent selection at age, and *w* is the weight at age. Predicted CPUE values for the shrimp bycatch index were just simply the $N_{1,y}$ values multiplied by a *q* parameter.

The catch at age of cobia in numbers (*C*) in combination with sex-specific, smoothed age-length keys is used to compute the predicted length composition ($\hat{P}$) for each year. Mean length at age ($\overline{L}_a$) for each sex is computed from the von Bertalanffy function with fixed parameters. The probability of length at age (age-length key) ($\rho_{a,L}$) is then computed as follows,

$$\rho_{a,L} = \frac{e^{-\left[\frac{\left(L_a - \overline{L}_a\right)^2}{2\sigma^2}\right]}}{\sqrt{2\pi}\sigma_a}$$

where $\overline{L}_a$ is the mean length at age from the von Bertalanffy growth function, L_a is the length at age, and σ is the standard deviation of length at age. This equation assumes length at age is normally distributed. In the assessment model the coefficient of variation of length at age (γ_a) is actually estimated, which is related to the standard deviation as $\sigma = \overline{L}\gamma$. The ρ's of the age-length key are scaled to sum to 1 across ages. The predicted length compositions ($\hat{P}$) are then computed simply as,

$$\hat{P}_{y,L} = \frac{\rho_{L,a} C_{y,a}}{\sum C_y}$$

where the product of the age-length key ($\rho_{L,a}$) and the catch at age (C_a) is a matrix multiplication operation performed for each year, resulting in a vector of catches for each year re-distributed into length bins, which are then scaled to sum to 1 across the length bins for each sex. Since the cobia observed length composition data is not sex-specific, the sex-specific predicted length compositions ($\hat{P}$) are summed and re-scaled to sum to 1 across length bins.

The advantage of fitting a stock-recruit function within the model is not necessarily better stock-recruit parameter estimates, but the ability to compute MSY within the model framework, which then provides error distributions about the estimate of MSY. The determination of MSY for iteroparous species with age-specific selectivities involves iterative solutions for F_{MSY} to maximize the yield function. For this analysis, the Newton-Raphson method with a fixed number of iterations is used to estimate F_{MSY} and MSY within the model optimization routine. A fixed number of iterations is used in order to maintain differentiability for the automatic differentiation process in ADMB (Ianelli and Zimmerman 1998). The Newton-Raphson method requires first and second derivatives of the yield function $f(F)$ with respect to fishing mortality (F) which are computed by difference approximations as follows,

$$f'(F) = \frac{f(F+d) - f(F-d)}{2d} \text{ and } f''(F) = \frac{f(F+d) - 2f(F) + f(F-d)}{d^2},$$

respectively. For these derivative approximations d is the difference value set at an arbitrarily low value of $1\text{x}10^{-7}$. The Newton-Raphson algorithm is then updated by taking the starting value of F and subtracting the ratio of the first and second derivatives, $f'(F)/f''(F)$ (Ianelli and Zimmerman 1998). In this analysis the Newton-Raphson is iterated 8 times with a constant starting value of $F = 0.3$.

Since selectivity is modeled with a time varying component, a decision about which time period to use needed to be made for MSY and per-recruit analyses. For this analysis the last three years of selectivities were averaged using a weighted average based on the landings in each fishery. The result is a single selectivity function for use in all MSY and per-recruit calculations.

Overall, the parameters of the age-structured model which are being estimated during the optimization routine in ADMB are listed in Table 7. In many cases the logarithm of the parameter is being estimated in order to prevent negative values from occurring. By fixing the fishery selectivities, eliminating the recruitment deviations, and fixing the standard deviation of length at age, the resultant model is essentially an age-structured production model consisting of $N_{1,1}$, R_0, h, and 4 q's as parameters to be estimated. The fishing mortalities in this case become nuisance parameters which could be solved internally using something akin to the Newton-Raphson method. The R_0 parameter in this situation is analogous to K, the carrying capacity, in the ASPIC surplus-production model and the q's have an obvious analogy. The $N_{1,1}$ parameter is similar to B_1/B_{MSY} in the ASPIC model except $N_{1,1}$ scales to K (R_0 actually) rather than B_{MSY}. The h parameter is a measure of the population productivity and is most analogous to the growth rate r of a population, which can be considered analogous to F_{MSY}. Estimating F_{MSY} is very similar to estimating MSY as is done in the ASPIC production model. The first phase of estimation for the age-structured ADMB model consists of these parameters, essentially resulting in a production model fit for starting values of the final forward projecting catch-age model.

The ADMB optimizer operates by changing parameter estimates in order to minimize the objective function. The objective function for this model is based on maximum likelihood methods, in which the negative of the maximum or log likelihood functions are summed. More specifically the length composition data is modeled with a multinomial likelihood function,

$$L = -\sum n_y \sum P_{a,y} \log(\hat{P}_{a,y}),$$

where n is the annual sample size, and P and $\hat{P}$ are the observed and predicted length compositions, respectively. The landings and CPUE indices are assumed to follow a lognormal distribution with likelihood function,

$$L = \frac{[\log(X_y) - \log(\hat{X}_y)]^2}{2(cv_y)^2} + \log(cv_y),$$

where X and $\hat{X}$ are the annual observed and predicted values and cv is the annual coefficient of variation. Other components include a simple sums of squares of the $\log(R_y)$ and δ'_y values to prevent extreme recruitment and selectivity deviations. Also, there is a component consisting of the sums of squares of the first difference values of the standard deviation of length at age (σ_a) in order to smooth changes across ages.

In order to scale the relative influence of some of the minor likelihood components, weighting factors of 20 and 0.005 were multiplied by the selection parameter deviation and recruitment deviation components, respectively. The selection parameter weight was needed to prevent extreme values occurring during the optimization process, resulting in poor model convergence. The recruitment deviations were downweighted by the 0.005 factor to allow for maximum freedom for these estimates, while still preventing extreme values during the optimization process. As mentioned earlier, the cv_y's for the landings were assumed to be 0.05 and the cv_y's for the shrimp bycatch were assumed to be 0.2.

Error estimates of the parameters and computed variables were obtained primarily from the Delta-method normal approximation. In some cases likelihood profiling was performed for a limited choice of parameters since this is a fairly computer intensive procedure. The Markov chain-Monte Carlo (MCMC) re-sampling method was run for 6 million iterations for the $M = 0.2$ and $M = 0.3$ cases. Due to highly questionable and often non-repeatable results, the likelihood profile and MCMC results will not be presented. The most likely reason for the “bad” likelihood profile and MCMC results is too much uncertainty in the model estimates.

RESULTS

Production Modeling

None of the ASPIC program runs produced satisfactory results. In many cases the *MSY* and *K* parameters during the optimization process would reach their upper bound even after being expanded to unrealistic levels. In other cases, the logistic model, which is used for initial starting values in the generalized model, could not find an optimal solution. For these reasons, none of the ASPIC results are presented herein, but these production model fitting attempts are mentioned to illustrate the lack of population information in the cobia fishery data.

Model Fits

Three values of natural mortality (0.2, 0.3, 0.4) were analyzed with the age-structured cobia assessment model. The total likelihood values for these model runs were,

Natural Mortality (*M*)	0.2	0.3	0.4
Total Likelihood	17721.6	17718.7	17723.4

indicating the choice of $M = 0.3$ is preferred by the data and this value of *M* results in a slightly better fit. The fits of the model to the data for all three of these choices of *M* are very similar. Fig. 11 shows the fits to the landings data and Fig. 12 and 13 show the fits to the CPUE indices for all three choices of M. The fit to the landings data is excellent, as it should be, since this is one of the better measured data for cobia. The fit to the CPUE indices for biomass are fairly good considering they are measuring the same thing and there is some disagreement between the indices. More importantly there is an overall increasing trend from 1992-1997 for the MRFSS, headboat, and Texas creel indices, which the model fits reasonably well (Fig. 12 and 13). The shrimp bycatch index indicates an upward trend in recruitment from 1988-1997, but the model does not seem to fit the 1994-1997 data points very well (Fig. 13). This could be a result of conflicting information from the length composition data.

The length composition data fits were graphically examined in two ways using bubble plots of the residuals and x-y plots of the observed and predicted data for each year of each fishery. The fits of all three choices of *M* revealed very similar fits to these data. To be concise, only the results from the $M = 0.3$ model are shown. The bubble plot for the commercial fishery indicates a reasonable fit with randomly distributed residuals (Fig. 14). The 1989 year stands out as a case of a poor fit, which is expected since it is ignored during the model fitting. There is a slight tendency for the commercial length composition fits in the last 4-5 years to overestimate the 825-975 mm lengths (indicated by positive residuals) followed by an underestimation of the 1075-1225 mm lengths (indicated by negative residuals) (Fig. 14). A look at the x-y plot of these fits also shows the tendency for the model fit the peak lengths at a smaller size than is indicated in the data (Fig. 15). It is likely information from the recreational length composition data is driving this slight bias.

The recreational length composition data is very “noisy” in the early years of the time series. Large residuals stand out in the bubble plot of the residuals in the early years, which suffer from small sample sizes (Table 3, Fig. 16). The overall pattern of the residuals is fairly random with a slight tendency for the model to overestimate the 625-775 mm lengths in 1989-2000 (Fig. 16). However, an examination of the x-y plots reveals that the overall fit of the model length compositions to the recreational fishery data is good for the 1989-2000 time period (Fig. 17). Overall, the fits of the length composition data for both fisheries are good considering the limited sample sizes resulting in relatively “noisy” data. The fits and residual patterns shown in Figures 14-17 are similar to the model runs with natural mortality values of 0.2 and 0.4 (not shown).

One factor resulting in good fits to the length composition data was the use of a set of time-varying age at 50 % selection parameters (δ'_y). The addition of these parameters was deemed necessary given the increase in mean length over time in both fisheries (Fig. 5). Perhaps some parameters could be eliminated and parsimony preserved by assuming a linear increase in the δ'_y's, but the addition of the likelihood constraint tends to reduce the effective power of these parameters, making some of them "nuisance-like" parameters. The changes in the δ'_y's for each fishery and each choice of *M* is shown in Fig. 18. The slope parameters of the selectivity functions for both fisheries were consistently stopping at the upper bound of 10. The only exception was the case of *M* = 0.4 in the recreational fishery where the slope was estimated to be 2.5. Essentially a selectivity function slope of > 10 is near "knife-edge" selection, and the fact that these parameters were stopping at their bounds is likely inconsequential to the final results.

Another factor improving the model fits to the length composition data came from the use of an age-dependent standard deviation of length at age. This has been suggested in other length-based assessment models (Quinn et al. 1998, Quinn and Deriso 1999). In the Gulf of Mexico cobia model separate age-length transition matrices were estimated for each sex. The model estimates of standard deviation of length at age for each sex are shown in Fig. 19.

Fishing Mortality

Fishing mortality estimates by fishery are shown in Fig. 20 and total fishing mortality values are listed in Table 8 for the three choices of natural mortality. The total fishing mortality is dominated by the recreational fishery, as expected. The general trend in *F* is fairly level through most of the time series, with a possible indication of a downward trend in the most recent years (Fig. 20).

Per-recruit Analysis

The per-recruit analysis involved computing a catch weighted average selectivity from the last three years of both fisheries. The F_{MSY} estimate from the model is consistently higher than the $F_{0.1}$ estimate and both are lower than the estimate of F_{MAX}, which does not appear in the cases for *M* of 0.3 and 0.4 (Fig. 21). The static spawning stock biomass per-recruit (SSBR) for each year and each value of *M* is shown in Fig. 22. The choice of natural mortality clearly influences the SSBR of the population (Fig. 22).

Spawning Stock, Recruitment, and Benchmarks

Numbers of recruits at age 0 and spawning stock biomass (mt) estimates from the three choices of *M* are shown in Table 9 and Fig. 23. The estimates of error in Table 9 are based on the normal approximation via the Delta-method. Likelihood profiling was not performed for each of these estimates. The general trend in both recruitment and spawning stock biomass is similar for all three choices of *M*. The trends for recruitment indicate fairly stable recruitment through the early 1980's, then a slight rise from the late 1980's to a peak in 1993, followed by a return to recruitment levels seen in the 1980's (Fig. 23). The spawning stock biomass estimates show a nearly identical pattern for the values of *M*. The trend shows a steady increase starting in 1992, which appears to level off in 1996 to a value higher than most historical values (Fig. 23).

The Beverton-Holt spawner-recruit function estimates are shown in Fig. 24 for the values of *M*. As seen from the recruitment and spawning biomass estimates in Fig. 23, the time series have very similar patterns, but the magnitude is affected by the choice of *M*. Not only is the magnitude affected, Fig. 24 indicates the location of the points relative to the estimate of MSY is also affected. The spawner-recruit data points are either below, at, or above MSY depending on the choice of *M* (Fig. 22). Based on the estimates of MSY, the relative trends of fishing mortality (*F*) and spawning stock biomass (*SSB*) are shown in Fig. 25. Again, *M* has a tremendous influence on the magnitude of these values, but the trends remain similar. The values of $F_{2000}/F_{\mathrm{MSY}}$ are below one for all choices of *M*; however, the $SSB_{2000}/SSB_{\mathrm{MSY}}$ values are highly dependent on the choice of *M*. An *M* of 0.3 or 0.4 results in the current status of the stock being above MSY, while an *M* of 0.2 results in an estimate of stock status that is below MSY (Fig. 25).

The level of variability in the MSY based benchmarks was quite large. Variance estimates for the suite of MSY related values (MSY, F_{MSY}, $F_{2000}/F_{\mathrm{MSY}}$, and $SSB_{2000}/SSB_{\mathrm{MSY}}$) were obtained from the Delta-method normal approximation and likelihood profiling. The 80 % confidence interval results are listed in Table 10. Negative values result from the symmetrical distribution assumption for the Delta-method approximation. These results indicate a high degree of variance for many of the parameters of interest. The difference in the variance between the two Beverton-Holt stock-recruit function parameters (R_0 and *h*) suggests that the shape of the curve is fairly well defined but the magnitude of the virgin stock size is poorly defined. This is also evident by the large variances for $SSB_{2000}/SSB_{\mathrm{MSY}}$, which suggests the population is equally likely to be severely depleted or quite healthy (Table 10).

Population Status

The main conclusion from this assessment is that the population status of Gulf of Mexico cobia is virtually unknown, given the degree of uncertainty in the estimates from this assessment model. The only statement that can be made with any degree of certainty about Gulf of Mexico cobia is that the population has increased since the 1980s. However it is not known what the status of the cobia population was in the 1980s. Historically, it appears the species has been a favorite target for recreational fishers and has never appeared in large abundances. Fishing pressure is similar to what it was in the early 1980s, yet the cobia stock appears to be increasing during this time, possibly suggesting that the stock is not in a depressed state now. Equally possible is that the stock was already in a depleted state in the late 1970s and the implementation of the 33 in regulation and two fish bag limit in 1983 and 1990, respectively, is just now beginning to show signs of reducing fishing pressure on cobia. The steady increase in proportion of cobia over 33 in from the length samples suggests the fishery is slow to respond to these regulations (Fig. 5).

Management Recommendations

It is clear that the status of Gulf of Mexico cobia is highly uncertain, but there is some evidence that overfishing is not taking place. The spawning biomass estimates have nearly doubled from the early 1980s to the present. The length at 50 % selection has increased from the early 1980's to the present in both the commercial and recreational fisheries. Also, fishing mortality in the last few years has decreased slightly with all the point estimates of $F_{2000}/F_{\mathrm{MSY}}$ falling below 1.0. All of this information suggests that the bag and minimum size limits are resulting in positive changes in the population. However, the uncertainty of this information cannot be ignored. The variance of the population estimates from this analysis suggest for every scenario that there is some probability the stock is overfished. A continuation of current management methods may be a reasonable course of action, hopefully resulting in a decreased probability that the stock is overfished in future assessments.

RESEARCH NEEDS

Cobia in the Gulf of Mexico are not a very abundant species and as a result are not sampled very well by standard intercept sampling methods of recreational and commercial fisheries, as shown in the 1989 commercial fishery samples. Length measurements can contain valuable information, but only when sampled in sufficient numbers. Increased sampling of cobia could improve population estimates by decreasing uncertainty. Increasing samples of cobia may require more directed sampling effort. Cobia exhibit sexual dimorphic growth; therefore, sex information should be collected in the future from fishery samples if possible.

Although length measurements are valuable information, age information is even better. Franks et al. (1999) and Smith (1995) suggest that ageing cobia is straightforward with potentially low error and bias. Comprehensive otolith sampling and ageing of cobia would certainly improve population estimates. Saggital otoliths could probably be excised from fish sampled for lengths with minimal additional time and effort. Additionally, in this analysis the percent maturity at size/age was fixed based on very limited information. A more detailed study of size/age at maturity of cobia would provide a more accurate estimate of this information. The shrimp bycatch data for cobia would be more useful in the future if sufficient samples of cobia are collected to allow better estimates of length and age composition.

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Table 1. Commercial landings (mt) of cobia by state in the Gulf of Mexico.

Year	TX	LA	MS	AL	FL	Total
1980	0.98	2.14	-	1.13	40.81	45.06
1981	6.21	1.32	-	0.82	45.23	53.58
1982	10.92	0.07	0.32	0.35	38.41	50.06
1983	7.79	0.47	0.05	1.49	50.28	60.08
1984	5.86	1.47	3.34	1.63	52.24	64.54
1985	2.94	7.65	2.50	0.95	47.76	61.81
1986	5.27	15.25	4.51	5.20	42.12	72.35
1987	3.95	17.73	5.18	2.34	49.96	79.17
1988	3.00	18.24	3.41	1.26	47.29	73.21
1989	6.34	22.76	7.13	1.93	57.62	95.79
1990	5.32	15.83	1.27	2.37	48.32	73.10
1991	3.94	15.83	-	0.89	59.58	80.24
1992	3.23	30.01	-	1.36	72.07	106.67
1993	4.54	34.67	-	1.77	77.49	118.47
1994	2.93	47.36	0.03	1.95	67.46	119.74
1995	2.55	34.74	-	0.37	71.55	109.21
1996	4.09	32.79	0.25	0.53	81.36	119.02
1997	2.92	28.23	1.10	0.57	62.73	95.55
1998	5.57	22.21	0.36	0.20	63.51	91.84
1999	5.03	11.10	0.13	0.78	57.96	74.98
2000	3.35	21.14	0.07	0.35	37.65	62.56

Table 2. Recreational landings (mt) of cobia by state in the Gulf of Mexico.

Year	TX	LA	MS	AL	FL	Total
1981	-	281.8	2.8	15.9	107.8	408.3
1982	-	138.8	37.3	55.7	181.0	412.8
1983	8.9	178.1	46.7	90.2	93.9	417.7
1984	4.1	103.0	2.6	44.6	251.1	405.4
1985	5.4	50.3	-	19.6	166.8	242.1
1986	13.3	39.4	15.0	16.1	543.4	627.2
1987	7.5	9.9	31.6	25.5	322.8	397.3
1988	7.9	33.7	64.7	24.8	479.5	610.7
1989	5.2	133.3	57.3	37.5	156.3	389.6
1990	9.4	128.6	9.2	15.6	183.6	346.4
1991	6.1	87.5	0.1	46.6	404.6	545.0
1992	31.7	21.4	30.2	44.7	296.4	424.4
1993	60.7	31.3	34.6	130.4	256.8	513.8
1994	20.1	140.9	20.0	78.4	374.0	633.5
1995	11.0	81.6	27.3	30.1	305.0	455.0
1996	25.2	149.4	21.0	54.7	491.2	741.4
1997	38.4	242.0	55.1	34.6	643.7	1013.8
1998	86.9	44.3	29.2	29.9	292.9	483.3
1999	20.1	95.8	16.0	66.0	295.7	493.6
2000	48.5	63.9	45.1	28.8	284.6	470.9

Table 3. Sample sizes of length measurements by year and fishery for cobia in the Gulf of Mexico.

Year	Commercial	Recreational
1981	-	24
1982	-	82
1983	-	71
1984	349	81
1985	271	61
1986	184	177
1987	51	131
1988	49	93
1989	51	81
1990	72	76
1991	222	137
1992	210	195
1993	140	181
1994	178	256
1995	154	243
1996	256	309
1997	319	408
1998	198	402
1999	162	380
2000	101	135

Table 4. Percent length composition of cobia by year from samples collected in the commercial fishery.

	Year																
Length (mm)	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
175	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
225	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
275	0.0	0.0	0.0	0.0	0.0	3.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
325	0.0	0.0	0.0	0.0	0.0	7.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
375	0.6	0.0	0.0	0.0	0.0	19.6	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
425	0.0	0.4	0.0	0.0	0.0	7.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
475	0.6	0.4	0.0	0.0	0.0	2.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
525	1.7	1.8	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
575	2.6	0.4	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0
625	4.9	3.7	1.6	0.0	0.0	2.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0
675	5.4	8.1	3.3	0.0	0.0	2.0	1.4	0.0	0.0	0.0	0.0	0.0	0.4	0.0	1.5	0.0	0.0
725	10.9	11.1	4.3	2.0	2.0	3.9	0.0	0.0	1.0	0.0	0.0	0.6	0.8	0.3	0.0	0.6	0.0
775	10.9	8.1	9.2	3.9	4.1	2.0	1.4	0.9	1.9	0.7	0.0	1.9	0.4	0.6	1.5	0.0	0.0
825	12.9	7.0	14.1	5.9	12.2	3.9	16.7	18.0	10.5	13.6	5.1	7.8	5.9	3.1	3.5	4.3	5.0
875	9.7	12.2	19.6	17.6	20.4	5.9	25.0	18.0	13.3	12.1	12.9	14.3	7.8	4.7	5.1	6.2	5.9
925	8.3	11.1	16.8	15.7	18.4	3.9	20.8	14.4	14.8	27.1	18.0	13.6	14.1	11.6	2.5	9.3	6.9
975	10.0	10.3	8.7	25.5	20.4	5.9	8.3	12.2	16.7	14.3	15.7	12.3	13.7	10.0	9.1	10.5	10.9
1025	7.7	5.2	10.9	7.8	10.2	3.9	11.1	7.2	11.9	10.0	14.0	15.6	14.8	12.2	16.2	11.7	10.9
1075	4.0	5.9	3.3	11.8	4.1	3.9	4.2	9.5	7.1	4.3	8.4	7.1	9.8	18.2	11.1	16.7	16.8
1125	4.9	3.3	2.7	7.8	6.1	3.9	4.2	7.2	11.0	3.6	11.8	10.4	10.2	18.5	11.6	11.7	10.9
1175	3.2	4.8	2.2	2.0	0.0	5.9	1.4	3.2	4.8	2.9	5.1	5.8	7.4	10.0	13.6	8.6	8.9
1225	0.3	2.2	0.5	0.0	0.0	5.9	2.8	4.5	2.4	3.6	3.4	5.2	6.3	6.6	10.1	7.4	5.9
1275	0.3	2.6	0.0	0.0	0.0	3.9	1.4	0.9	1.4	2.1	2.8	2.6	3.1	1.6	7.1	6.2	5.9
1325	0.6	0.4	0.0	0.0	2.0	0.0	1.4	0.9	1.0	2.1	1.7	1.3	1.6	1.6	4.0	3.7	4.0
1375	0.3	0.4	0.0	0.0	0.0	0.0	0.0	0.9	0.5	0.0	0.6	0.6	2.7	0.0	1.0	1.9	4.0
1425	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.5	0.5	1.4	0.0	0.0	0.4	0.0	0.5	1.2	0.0
1475	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.5	0.0	4.0
1525	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.6	0.0	0.4	0.0	0.0	0.0	0.0
1575	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
1625	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
1675	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.3	0.0	0.0	0.0
1725	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1775	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0
1825	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 5. Percent length composition of cobia by year from samples collected in the recreational fishery.

Length (mm)	Year 1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
175	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
225	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	1.3	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
275	0.0	3.7	0.0	1.2	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
325	0.0	3.7	1.4	0.0	0.0	1.7	0.8	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.4	0.0	0.5	0.0	0.0	0.0
375	0.0	7.3	2.8	4.9	0.0	0.6	2.3	1.1	0.0	3.9	0.0	0.0	0.0	0.4	0.0	1.0	2.0	0.0	0.0	0.0
425	0.0	9.8	1.4	3.7	0.0	0.0	2.3	3.2	6.2	0.0	4.4	1.5	0.6	0.0	0.0	1.3	4.7	0.0	0.0	0.0
475	0.0	6.1	1.4	6.2	1.6	0.6	0.8	0.0	0.0	0.0	0.7	0.5	1.1	0.8	0.8	1.9	3.7	0.0	0.0	0.0
525	8.3	9.8	1.4	4.9	1.6	1.1	3.1	1.1	0.0	0.0	0.0	0.5	0.6	1.2	1.2	2.9	5.6	0.2	0.0	0.7
575	12.5	6.1	4.2	6.2	3.3	1.1	3.8	2.2	0.0	1.3	1.5	0.5	0.0	0.8	1.2	2.9	4.2	0.5	2.1	0.0
625	4.2	13.4	1.4	4.9	6.6	1.7	6.9	3.2	2.5	0.0	0.7	1.0	0.0	2.0	0.4	0.6	3.2	0.2	0.3	0.0
675	0.0	0.0	4.2	3.7	3.3	2.3	7.6	0.0	3.7	0.0	1.5	0.5	0.0	0.4	0.0	0.6	1.0	0.2	0.0	0.0
725	8.3	8.5	2.8	7.4	1.6	2.8	3.8	3.2	2.5	2.6	0.7	0.5	1.1	1.2	0.4	0.6	0.7	0.5	1.1	1.5
775	0.0	8.5	0.0	4.9	9.8	7.9	5.3	9.7	3.7	1.3	2.2	3.1	5.5	1.6	3.3	0.6	1.2	1.7	2.1	1.5
825	16.7	2.4	8.5	6.2	4.9	15.8	4.6	11.8	12.3	10.5	10.9	14.9	12.2	10.9	13.6	11.7	7.6	10.2	7.1	3.7
875	12.5	3.7	11.3	8.6	16.4	13.6	11.5	15.1	6.2	6.6	14.6	16.9	26.0	19.1	18.9	11.7	14.2	14.7	11.8	11.1
925	4.2	2.4	15.5	1.2	14.8	14.7	10.7	17.2	13.6	6.6	18.2	11.8	14.4	20.7	14.4	17.8	11.3	13.4	11.6	14.8
975	16.7	1.2	9.9	8.6	6.6	8.5	9.9	11.8	18.5	9.2	10.9	12.8	12.7	12.1	15.2	14.2	11.8	14.2	18.7	10.4
1025	4.2	2.4	4.2	6.2	0.0	10.2	13.0	4.3	6.2	11.8	7.3	11.3	7.7	9.0	11.1	10.7	5.4	12.2	14.2	11.1
1075	8.3	2.4	5.6	1.2	4.9	5.1	4.6	2.2	8.6	7.9	10.2	6.2	6.1	8.6	3.7	5.2	8.3	9.7	11.6	8.1
1125	0.0	1.2	7.0	7.4	9.8	4.5	1.5	5.4	2.5	11.8	8.8	7.2	4.4	2.3	6.6	5.5	4.9	5.7	7.6	8.1
1175	0.0	1.2	0.0	4.9	8.2	2.3	3.1	5.4	2.5	6.6	1.5	1.0	1.1	2.3	3.3	4.2	3.4	5.5	3.7	6.7
1225	4.2	0.0	4.2	1.2	3.3	2.8	0.8	0.0	2.5	3.9	2.2	4.1	3.3	2.0	2.9	1.6	1.2	4.5	3.2	8.1
1275	0.0	1.2	2.8	3.7	0.0	1.1	1.5	2.2	0.0	3.9	0.7	2.6	1.7	1.6	0.8	2.9	2.0	2.7	2.6	5.9
1325	0.0	2.4	4.2	1.2	0.0	0.6	0.0	0.0	2.5	2.6	0.7	0.0	0.0	0.0	0.8	0.3	1.5	1.7	1.6	3.7
1375	0.0	2.4	2.8	0.0	0.0	0.6	0.8	0.0	1.2	2.6	0.0	1.5	0.6	2.0	0.4	1.0	0.7	0.7	0.3	1.5
1425	0.0	0.0	1.4	0.0	0.0	0.6	0.8	1.1	0.0	1.3	0.0	0.5	0.6	0.4	0.4	0.3	0.0	0.2	0.0	0.7
1475	0.0	0.0	1.4	1.2	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.6	0.4	0.0	0.0	0.2	0.2	0.5	1.5
1525	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	0.7	1.0	0.0	0.0	0.0	0.3	0.5	0.2	0.0	0.7
1575	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
1625	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1675	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1725	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1775	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1825	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.2	0.2	0.0	0.0

Table 6. Catch-per-unit-effort indices and associated coefficient of variation estimates derived from GLM model estimates of the Marine Recreational Fisheries Statistics Survey (MRFSS), Southeast region headboat survey (HB), Texas Parks and Wildlife creel survey (TPW), and shrimp fishery bycatch (SFB).

Year	MRFSS	HB	TPW	SFB	MRFSS (CV)	HB (CV)	TPW (CV)
1980				0.030			
1981	0.189			0.016	11.9%		
1982	0.181			0.026	9.4%		
1983	0.240		7.28E-05	0.049	6.9%		4.6%
1984	0.235		3.86E-05	0.024	8.0%		354.4%
1985	0.125		3.76E-05	0.026	17.2%		7.2%
1986	0.130	4.42E-04	4.05E-05	0.011	10.2%	26.8%	9.7%
1987	0.187	2.59E-04	5.02E-05	0.021	9.3%	32.4%	9.3%
1988	0.255	2.12E-04	3.78E-05	0.010	10.1%	39.6%	18.8%
1989	0.283	2.92E-04	6.07E-05	0.022	8.9%	31.3%	87.3%
1990	0.274	4.01E-04	3.64E-05	0.026	10.1%	31.3%	12.4%
1991	0.251	3.86E-04	7.03E-05	0.038	7.1%	25.1%	13.9%
1992	0.195	4.34E-04	8.58E-05	0.039	8.1%	20.5%	6.0%
1993	0.189	6.12E-04	4.17E-05	0.058	8.9%	16.6%	5.9%
1994	0.227	6.63E-04	8.53E-05	0.060	8.0%	16.2%	9.4%
1995	0.256	7.94E-04	7.35E-05	0.046	6.6%	14.0%	8.8%
1996	0.276	7.75E-04	1.20E-04	0.066	7.1%	14.9%	5.3%
1997	0.322	8.87E-04	1.02E-04	0.078	5.8%	15.0%	9.0%
1998	0.272	7.22E-04	1.50E-04	0.041	5.1%	15.3%	7.6%
1999	0.280	6.60E-04	8.17E-05	0.028	5.1%	18.3%	4.8%

Table 7. Parameters being estimated in the Gulf of Mexico cobia age-structured ADMB assessment model.

Parameters		**Number**
$\log(N_{1,1})$	Logarithm of recruitment at age 0 in 1980	1
$\log(R_y)$	Logarithm of recruitment deviations for each year (1981-2000)	20
$\log(R_0)$	Logarithm of virgin recruitment for the stock-recruit function	1
h	Steepness of the stock-recruit function	1
η	Slope of the logistic selectivity function for each fishery	2
$\bar{\delta}$	Average age at 50% selection for each fishery	2
δ_y	Annual age at 50% selection deviation for each year of length composition data for each fishery	37
$\log(q_i)$	Logarithm of CPUE catchability coefficient for each index	4
$\log(\bar{F})$	Logarithm of average fishing mortality for each fishery	2
$\log(F_y)$	Annual fishing mortality deviation for each year of landings data for each fishery	42
γ_a	Coefficient of variation of length at age for each age bin for each sex	24
	Total	136

Table 8. Total fishing mortality (*F*) estimates for fully selected ages for Gulf of Mexico cobia from the assessment model with 3 choices of natural mortality (*M*).

Year	*M* = 0.2	*M* = 0.3	*M* = 0.4
1980	0.36	0.26	0.17
1981	0.36	0.26	0.17
1982	0.33	0.23	0.15
1983	0.42	0.29	0.18
1984	0.36	0.24	0.15
1985	0.24	0.16	0.10
1986	0.47	0.34	0.21
1987	0.29	0.21	0.13
1988	0.41	0.30	0.20
1989	0.30	0.21	0.13
1990	0.31	0.22	0.13
1991	0.42	0.30	0.19
1992	0.40	0.28	0.17
1993	0.39	0.28	0.18
1994	0.46	0.33	0.20
1995	0.28	0.20	0.13
1996	0.36	0.26	0.17
1997	0.40	0.29	0.20
1998	0.29	0.21	0.14
1999	0.27	0.20	0.13
2000	0.26	0.20	0.13

Table 9. Number of recruits (age 0), spawning stock biomass (SSB), and associated coefficients of variation (CV), based on Delta-method approximations, for Gulf of Mexico cobia from the assessment model with 3 choices of natural mortality (*M*).

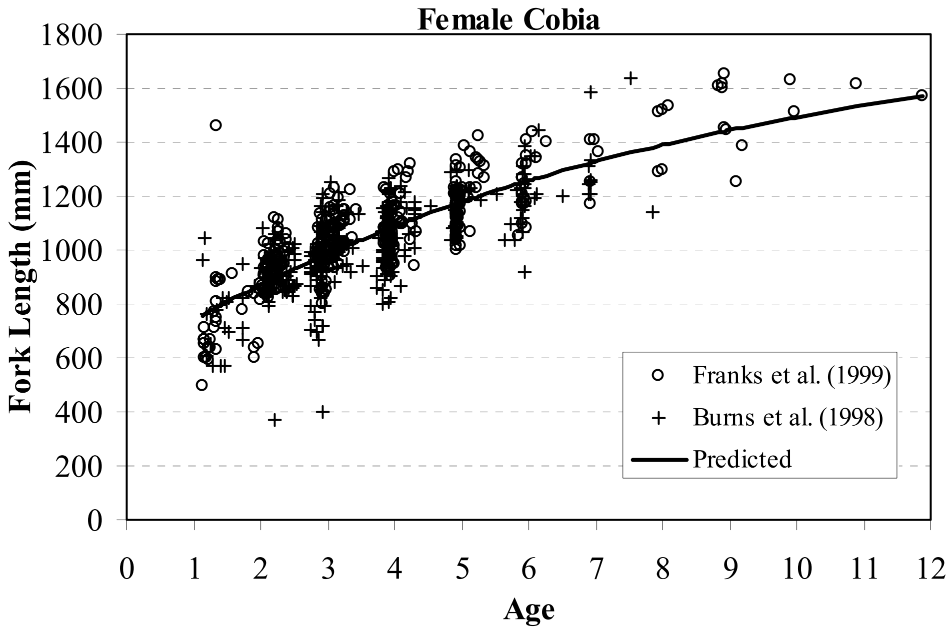
	***M* = 0.2**		***M* = 0.3**		***M* = 0.4**		***M* = 0.2**		***M* = 0.3**		***M* = 0.4**	
Year	Recruits	CV	Recruits	CV	Recruits	CV	SSB (mt)	CV	SSB (mt)	CV	SSB (mt)	CV
1980	93576	4.1%	147591	3.6%	275353	6.8%	693	7.9%	973	8.5%	1637	11.8%
1981	64824	16.3%	101925	16.4%	224369	16.7%	693	7.9%	973	8.5%	1637	11.8%
1982	118091	10.7%	176953	10.6%	288031	13.1%	680	7.4%	957	8.2%	1623	11.6%
1983	120139	8.5%	188267	9.0%	358259	11.5%	669	6.4%	938	7.5%	1595	11.2%
1984	163464	8.7%	254641	9.1%	468034	10.9%	618	6.5%	894	7.5%	1565	11.3%
1985	121900	11.9%	191950	12.2%	336183	13.3%	660	6.5%	966	7.5%	1677	11.5%
1986	77807	19.2%	121029	19.1%	270066	18.1%	845	6.0%	1185	7.0%	1972	10.9%
1987	151557	12.0%	237957	11.8%	440918	12.8%	831	6.5%	1184	7.5%	1997	11.4%
1988	80701	14.4%	128066	14.5%	217310	16.9%	893	6.0%	1237	7.0%	2048	10.8%
1989	136150	8.1%	220198	8.3%	435811	10.1%	836	5.5%	1173	6.6%	1992	10.6%
1990	102465	9.9%	164918	10.2%	307149	12.8%	864	5.0%	1203	6.1%	2022	10.2%
1991	168113	7.8%	275144	8.2%	546274	10.3%	919	4.7%	1261	5.9%	2084	10.0%
1992	141017	9.9%	232630	10.3%	449434	12.6%	899	4.9%	1258	6.1%	2112	10.4%
1993	215220	7.4%	362591	7.9%	705934	10.3%	973	4.9%	1363	6.1%	2294	10.3%
1994	151830	9.9%	255293	10.2%	500343	11.9%	1085	4.8%	1521	6.0%	2555	10.2%
1995	154210	10.3%	253335	10.7%	410277	13.8%	1188	4.7%	1688	5.9%	2842	10.2%
1996	146837	9.9%	230282	10.2%	541556	11.9%	1431	4.4%	1975	5.6%	3183	9.9%
1997	150541	9.8%	241881	10.4%	513858	12.8%	1452	4.6%	1994	5.8%	3157	10.3%
1998	98781	17.1%	158529	17.3%	239891	17.0%	1327	5.2%	1846	6.4%	3003	10.7%
1999	103785	20.6%	166044	20.7%	264019	20.2%	1349	6.0%	1840	7.0%	3061	10.7%
2000	138083	76.7%	222360	76.5%	239914	63.2%	1354	7.4%	1800	8.1%	2934	11.3%

Table 10. Parameter estimates and confidence intervals (90%) for selected parameters from the Gulf of Mexico cobia assessment model for the 3 choices of natural mortality (M).

			Delta-method	
Parameter	***M***	**Estimate**	lower 80% CI	upper 80% CI
MSY	0.2	711	327	1095
	0.3	676	575	777
	0.4	853	-175	1882
F_{MSY}	0.2	0.29	-0.04	0.62
	0.3	0.33	-0.19	0.85
	0.4	0.65	-0.80	2.11
F_{2000}/F_{MSY}	0.2	0.90	-0.49	2.29
	0.3	0.61	-0.98	2.19
	0.4	0.19	-5.26	5.64
SSB_{MSY}	0.2	1633	-1102	4367
	0.3	1372	-950	3690
	0.4	942	-1702	3585
SSB_{2000}/SSB_{MSY}	0.2	0.83	-0.20	1.86
	0.3	1.31	-0.19	2.82
	0.4	3.12	0.01	6.23
R_0	0.2	164039	1031	327047
	0.3	260425	18923	501927
	0.4	388561	191659	585463
steepness (*h*)	0.2	0.84	0.45	1.24
	0.3	0.71	0.16	1.26
	0.4	0.79	-0.20	1.78
SSB_{2000}/S_0	0.2	0.20	0.00	0.39
	0.3	0.36	0.03	0.69
	0.4	0.73	0.37	1.09

Figure 1. Percent maturity at age function used in the Gulf of Mexico cobia assessment model.

Figure 2. Gulf of Mexico cobia age-length data collected by Franks et al. (1999) and Burns et al. (1998) indicating von Bertalanffy growth function fits used in the assessment model.



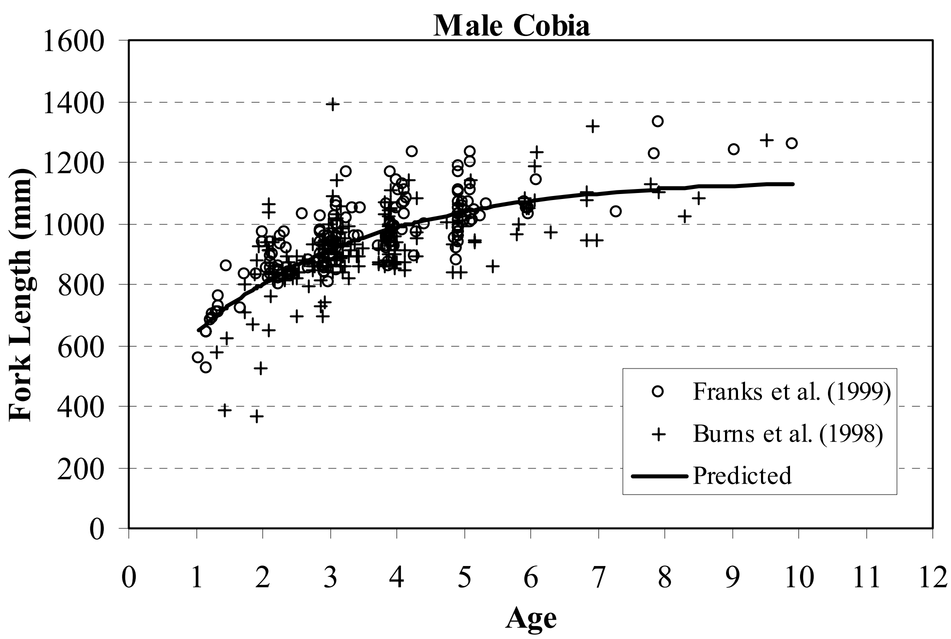


Figure 3. Gulf of Mexico cobia length-weight data showing the predicted relationship used in the assessment model.

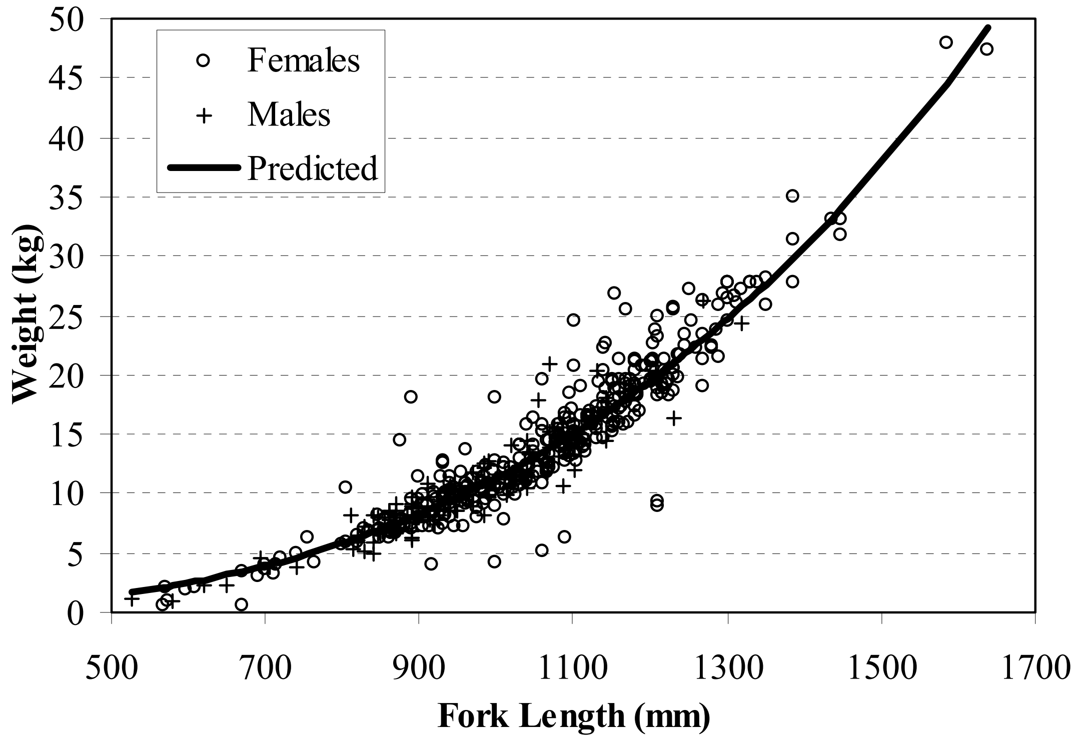
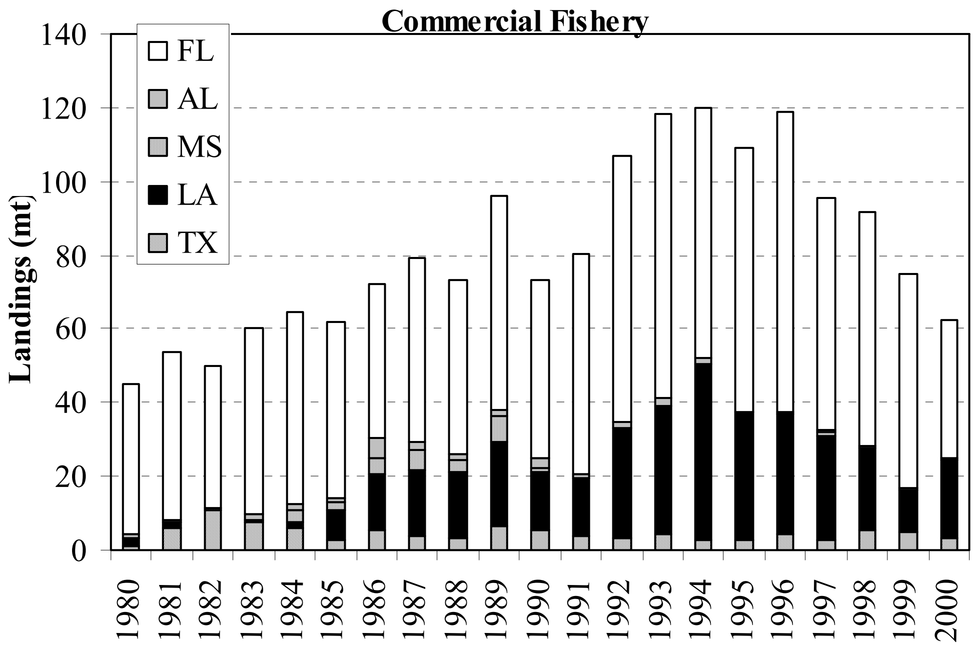


Figure 4. Commercial and recreational fishery landings (mt) of cobia by state from the Gulf of Mexico.



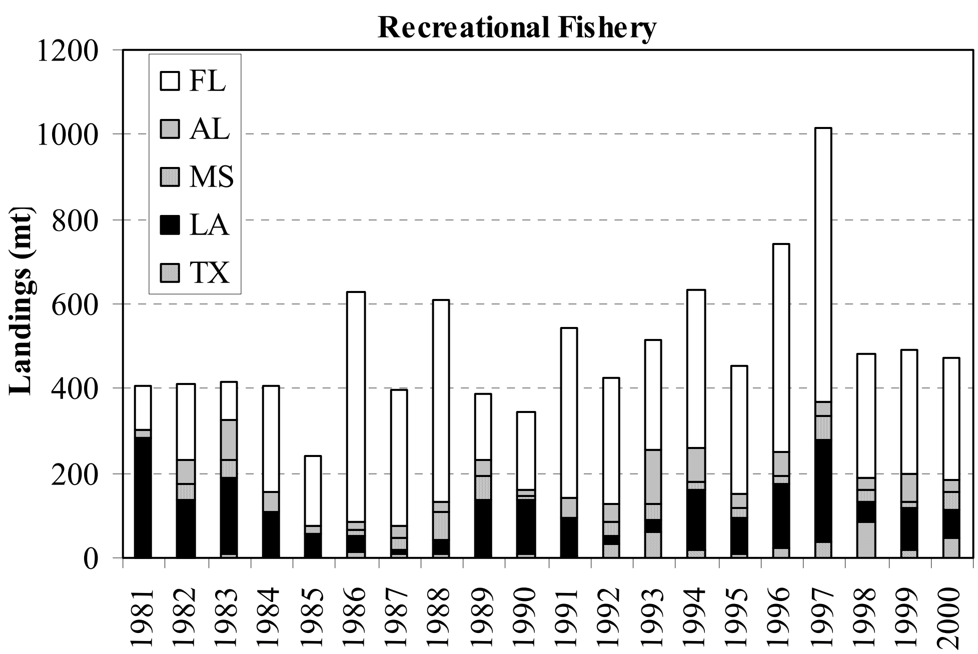
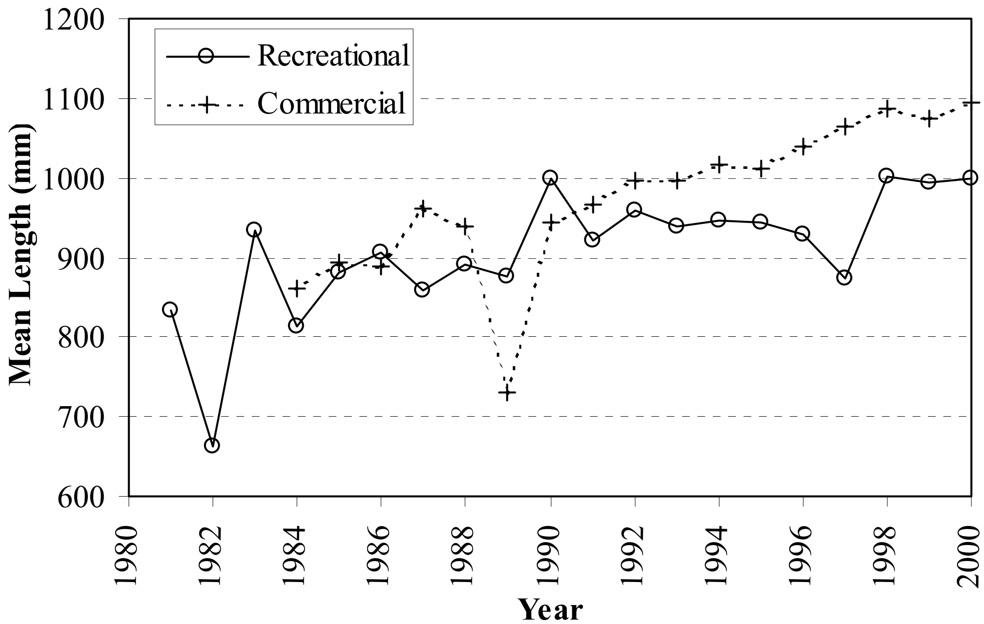


Figure 5. Mean length and proportion over 33 inches (828 mm) by year for Gulf of Mexico cobia samples taken in the commercial and recreational fisheries.



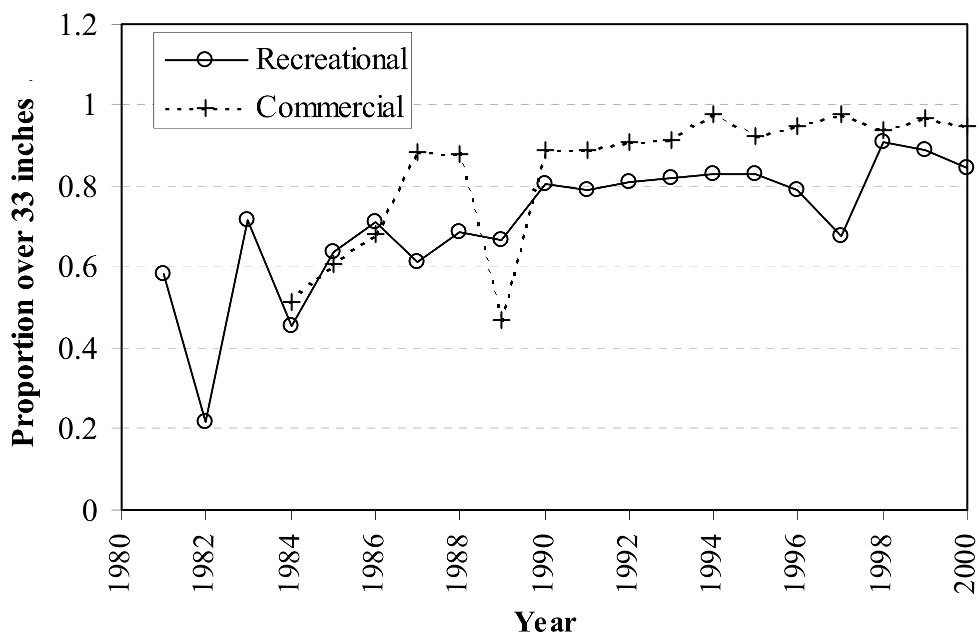


Figure 6. Percent length composition by year from samples of cobia taken in the commercial fishery throughout the Gulf of Mexico.

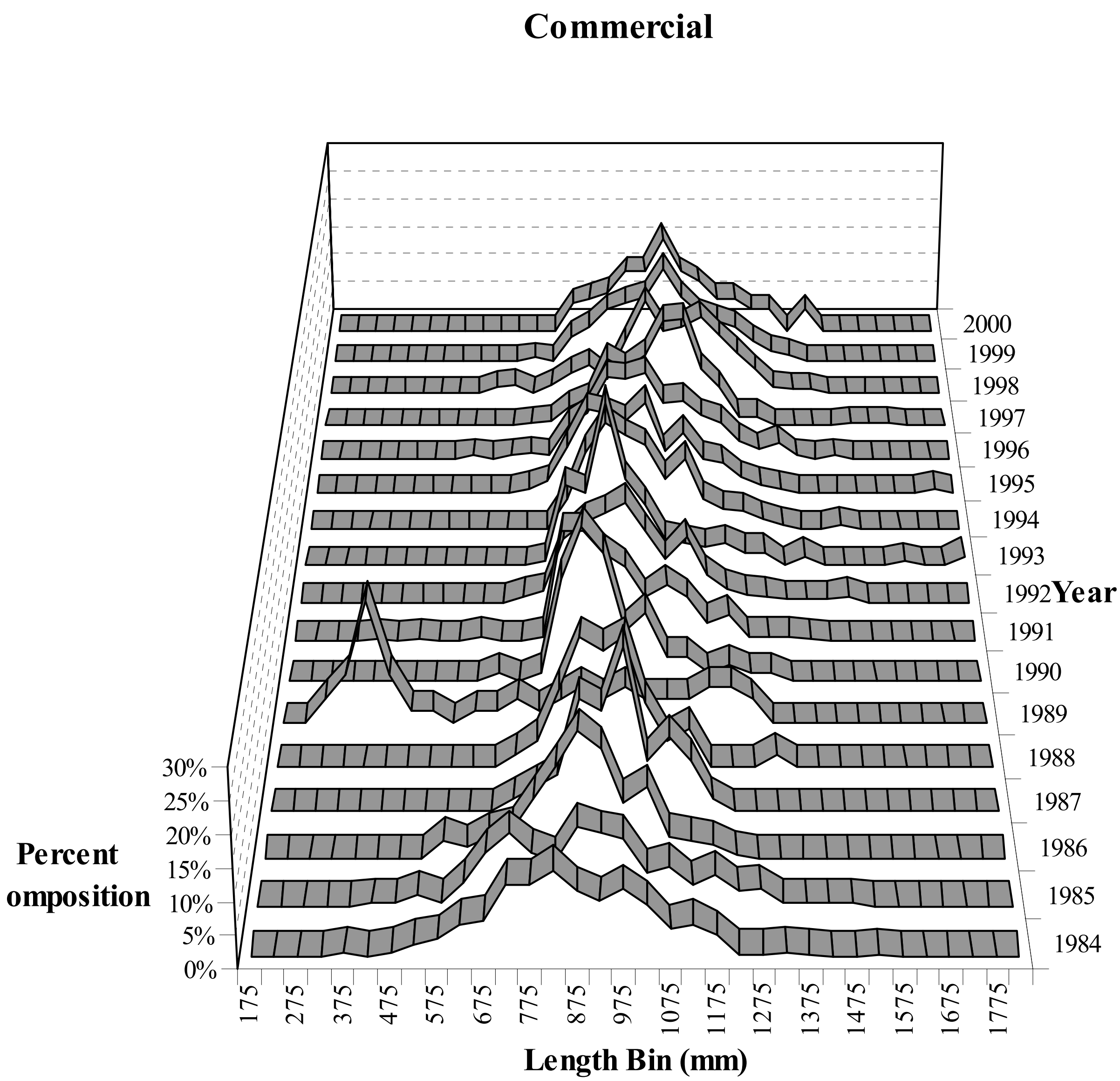


Figure 7. Percent length composition by year from samples of cobia taken in the recreational fishery throughout the Gulf of Mexico.

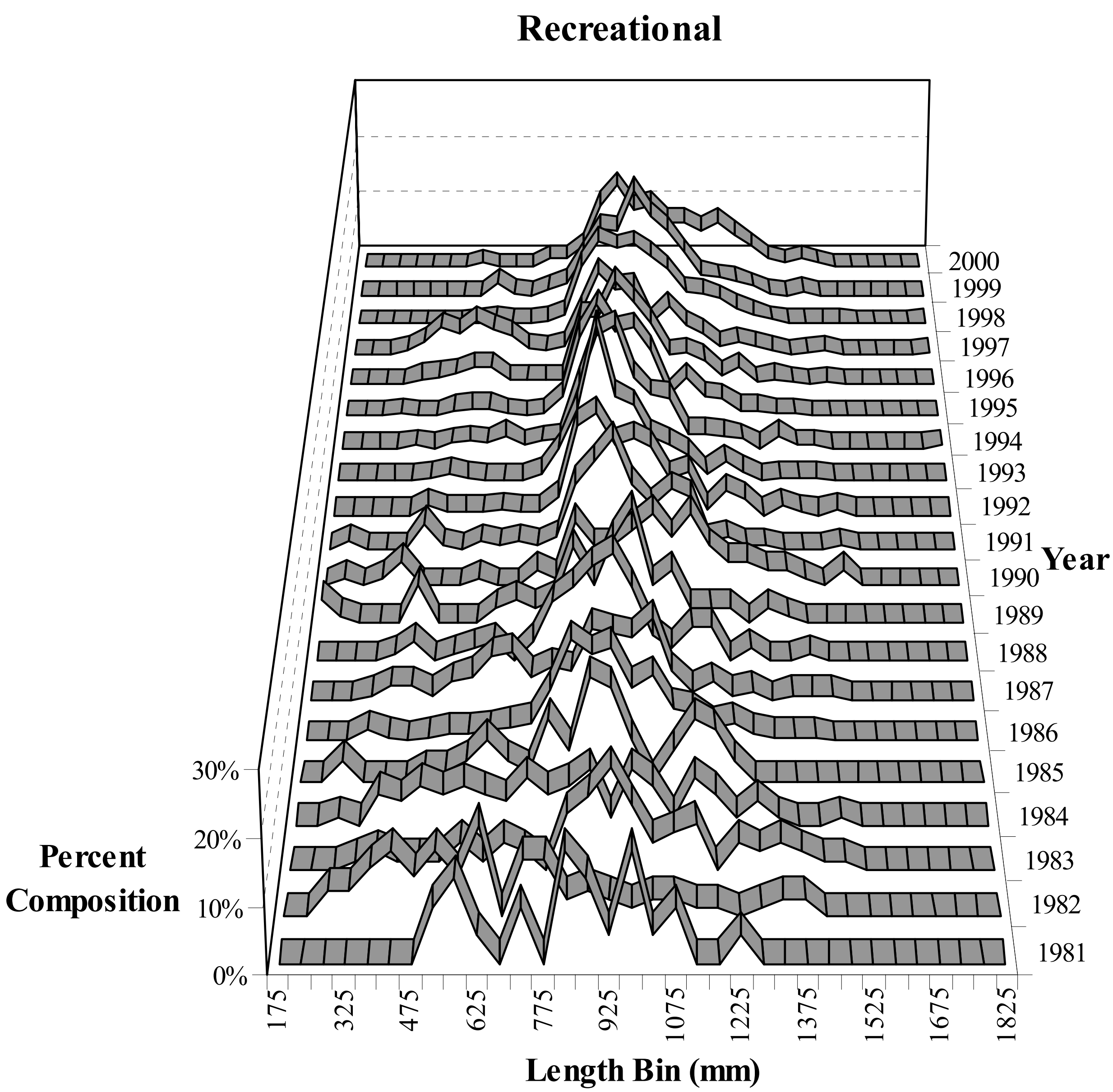
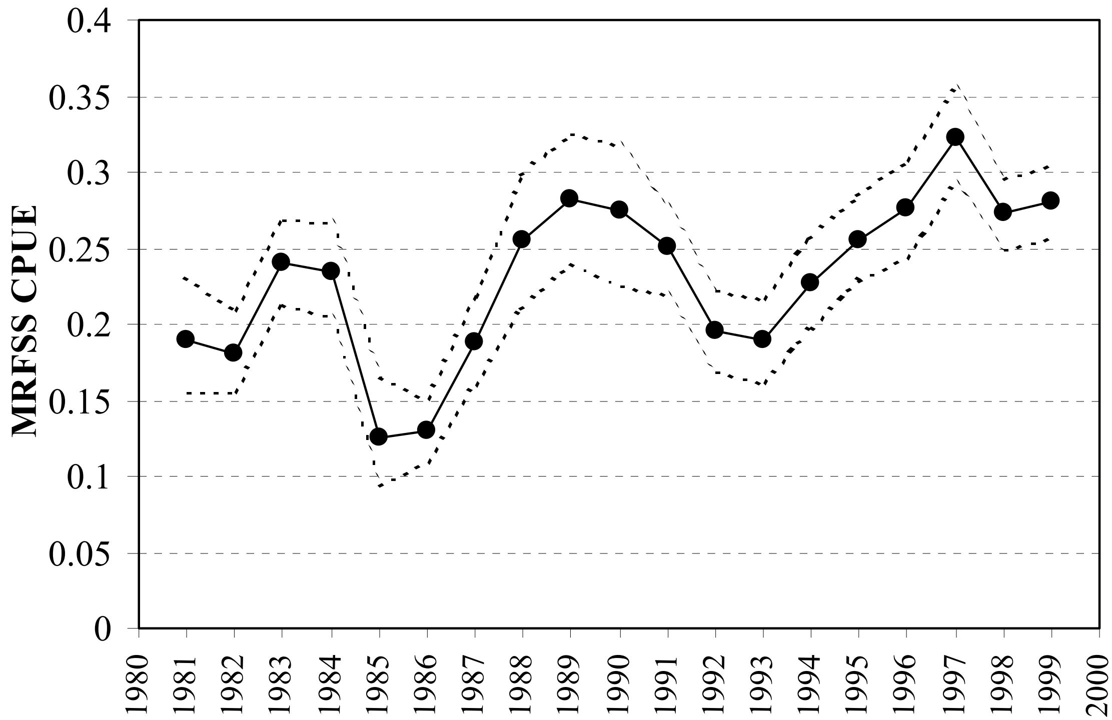


Figure 8. Gulf of Mexico cobia catch-per-unit-effort (CPUE) indices with bootstrapped 90% confidence intervals (dashed lines) derived from delta-lognormal GLM analyses of the Marine Recreational Fisheries Statisitcs Survey (MRFSS) and Southeast region headboat survey.



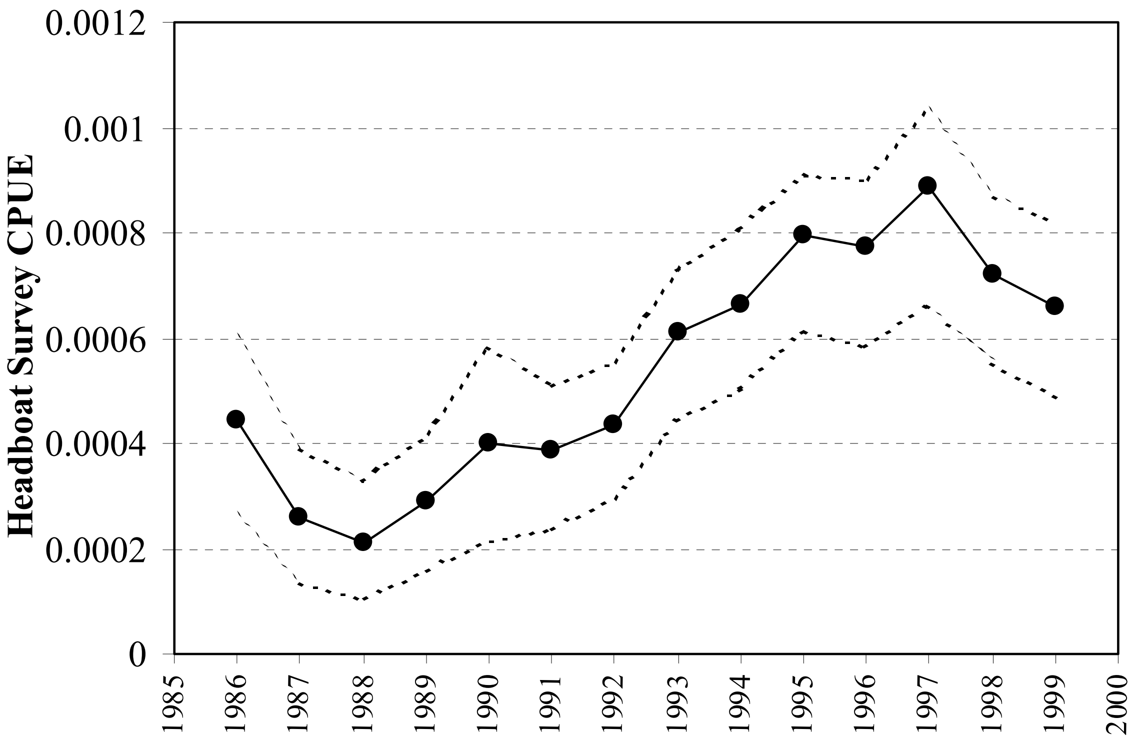
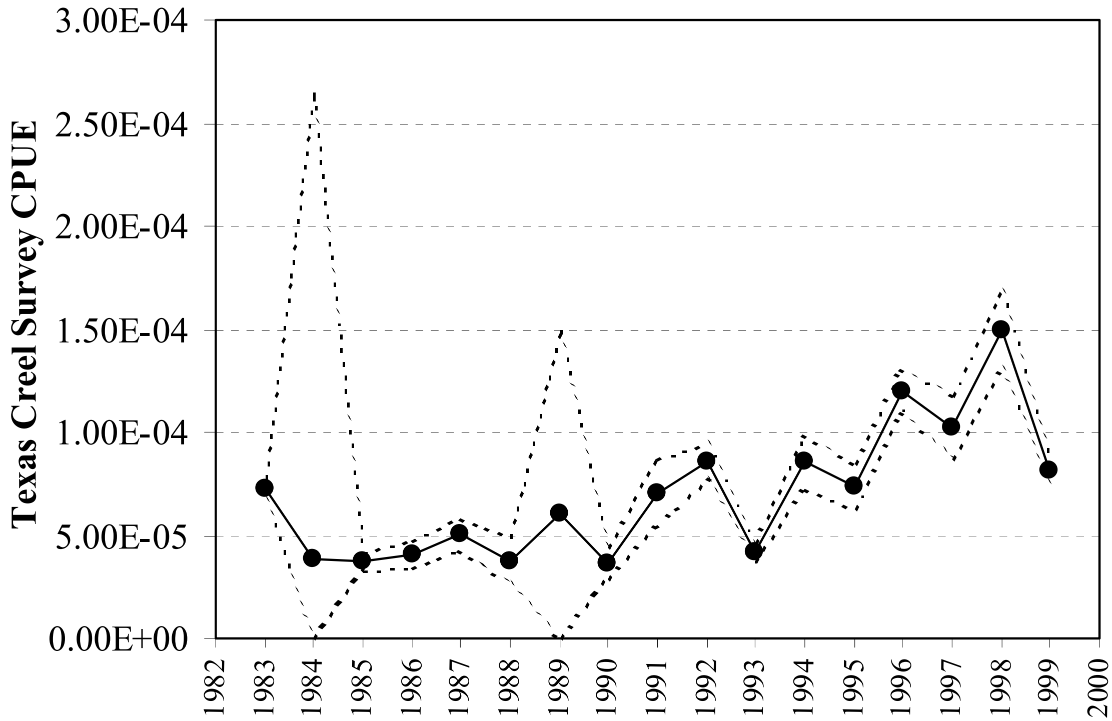


Figure 9. Gulf of Mexico cobia catch-per-unit-effort (CPUE) indices with bootstrapped 90% confidence intervals (dashed lines) derived from delta-lognormal GLM analyses of the Texas Parks and Wildlife creel survey and shrimp fishery bycatch.



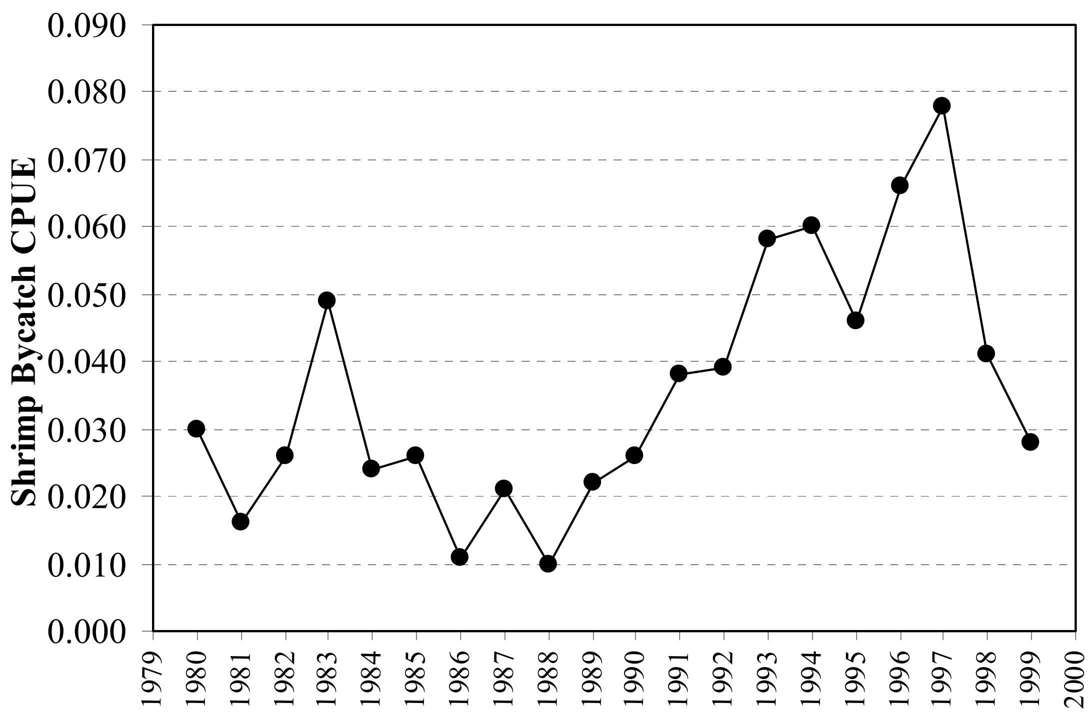


Figure 10. Cumulative frequency of length samples of cobia from the shrimp fishery bycatch. Length at age 1 for males and females is shown as dashed line.

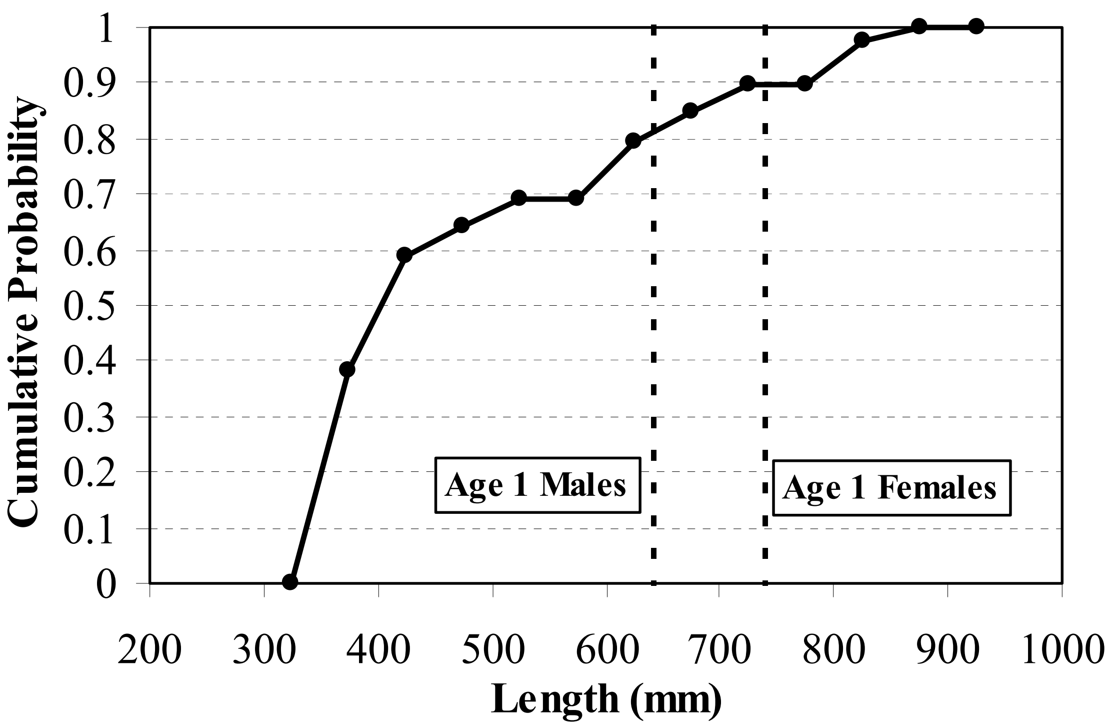


Figure 11. Observed and predicted landings for Gulf of Mexico cobia from 3 model runs with various levels of natural mortality (M).

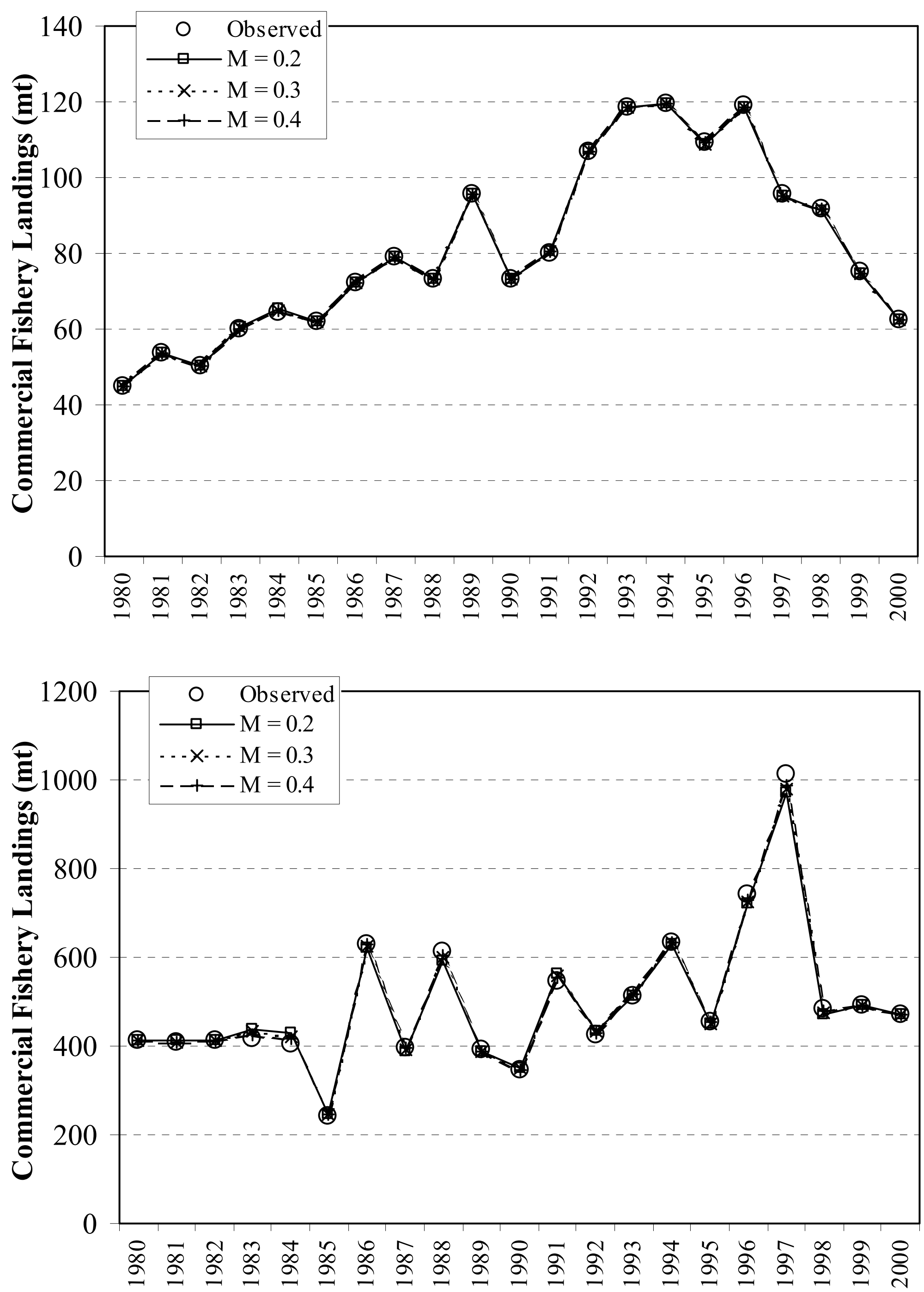
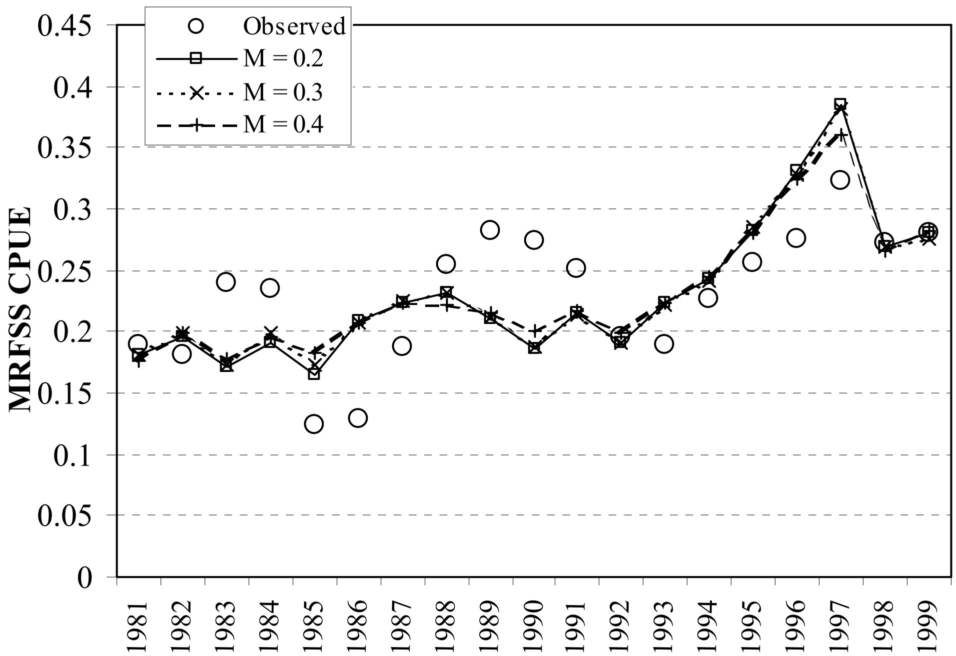


Figure 12. Observed and predicted catch-per-unit-effort (CPUE) index values for the Marine Recreational Fisheries Statistics Survey (MRFSS) and Southeast region headboat survey for Gulf of Mexico cobia from 3 model runs with various levels of natural mortality (M).



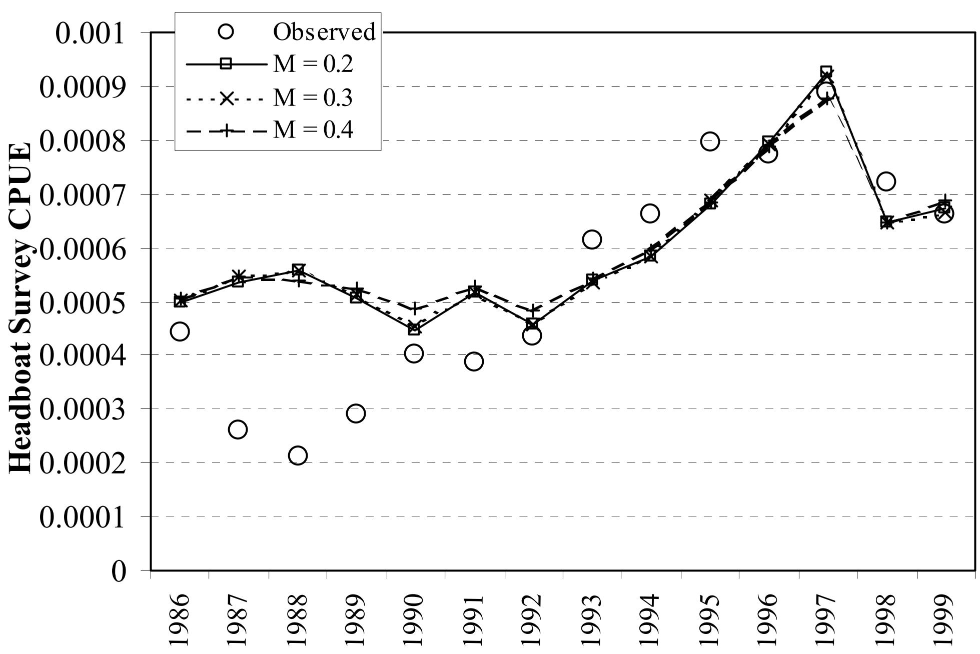


Figure 13. Observed and predicted catch-per-unit-effort (CPUE) index values for the Texas Parks and Wildlife creel survey and shrimp fishery bycatch for Gulf of Mexico cobia from 3 model runs with various levels of natural mortality (M).

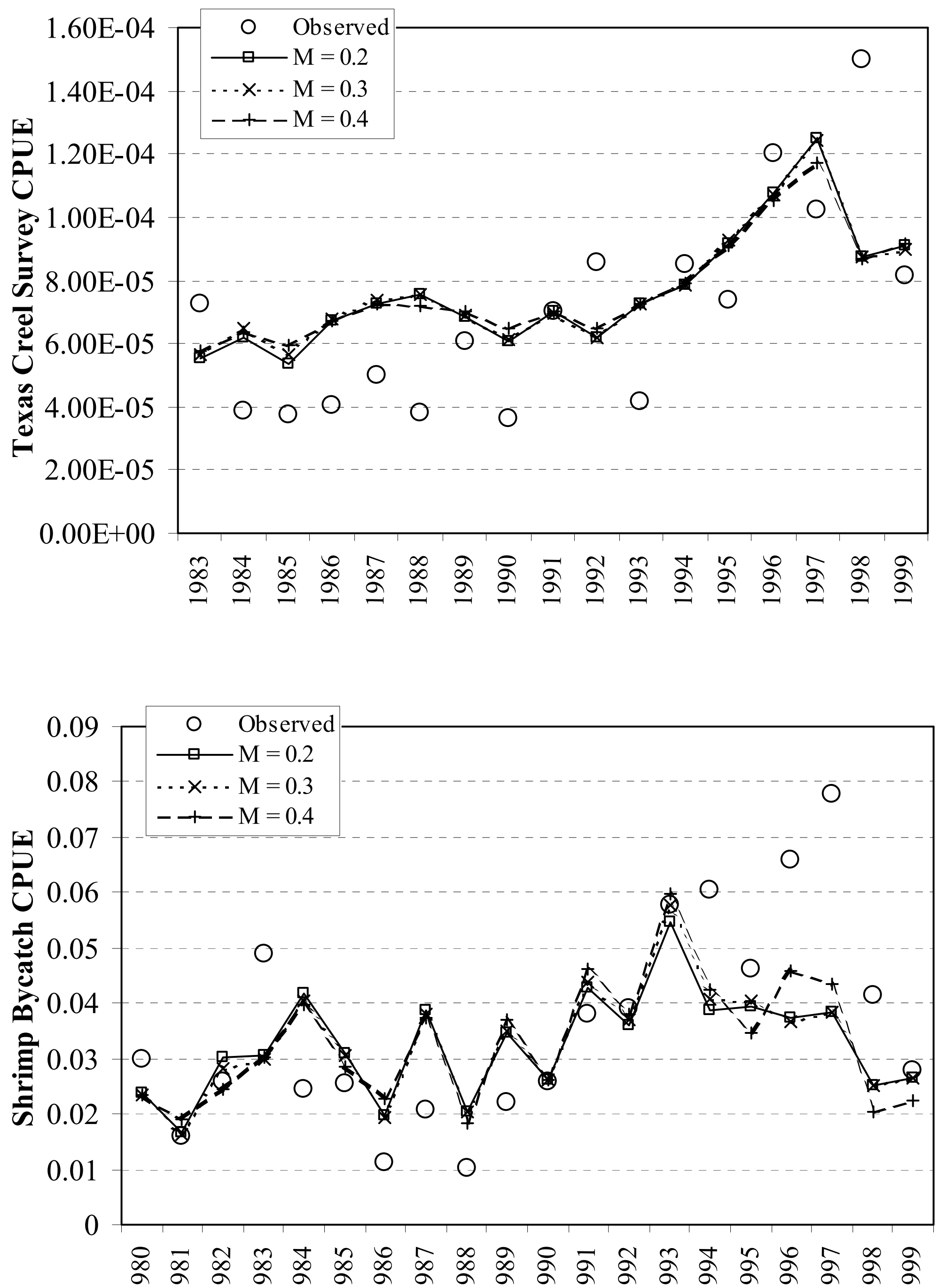


Figure 14. Bubble plot of commercial fishery length composition residuals (predicted - observed) from the age-structured model fit for Gulf of Mexico cobia for years 1984-2000 with a natural mortality of 0.3. Negative residuals are shaded, positive residuals are clear, and the area of the bubble is proportional to the magnitude of the residual.

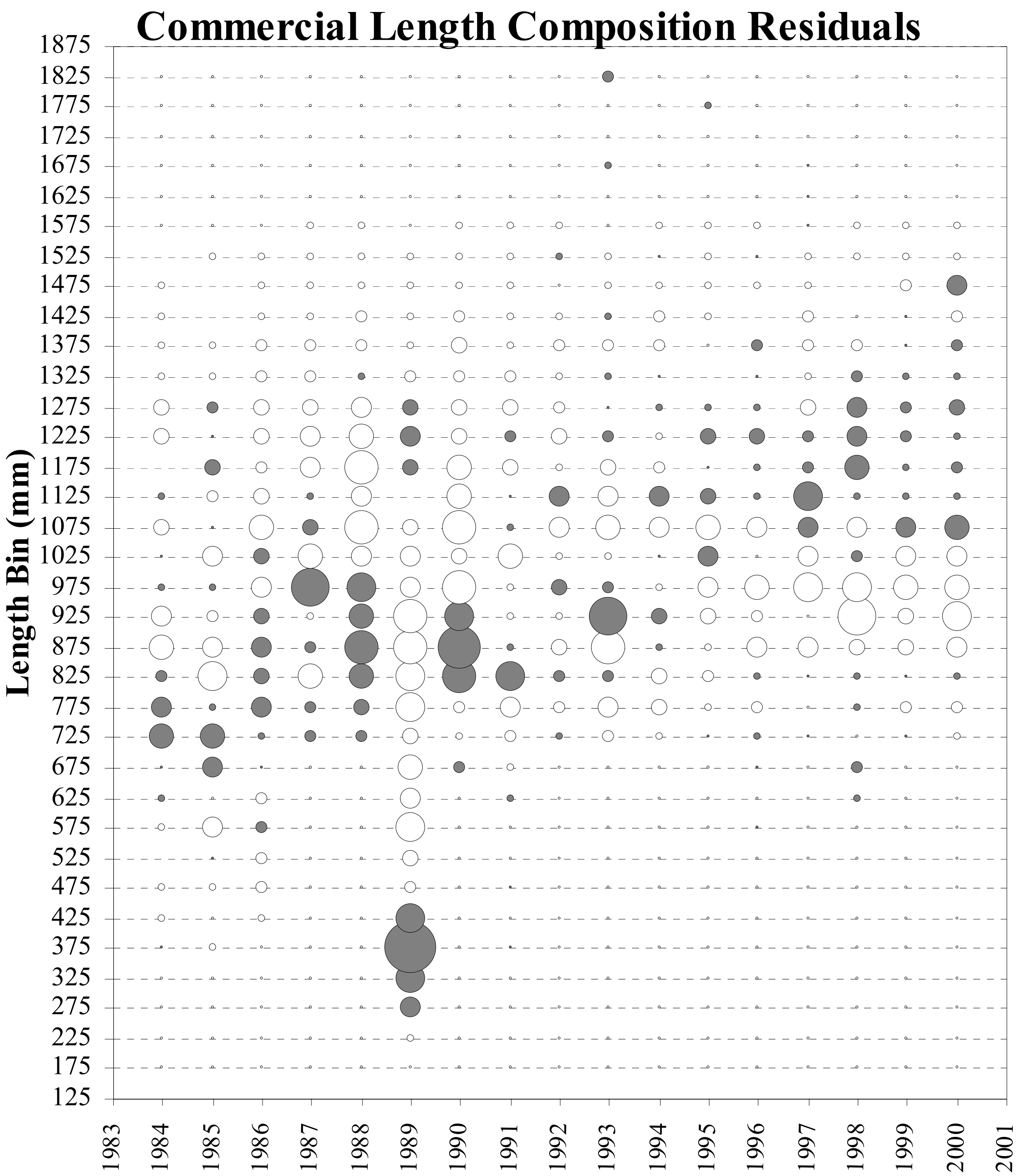


Figure 15. Observed and predicted length compositions from the commercial fishery samples for Gulf of Mexico cobia for years 1984-2000.

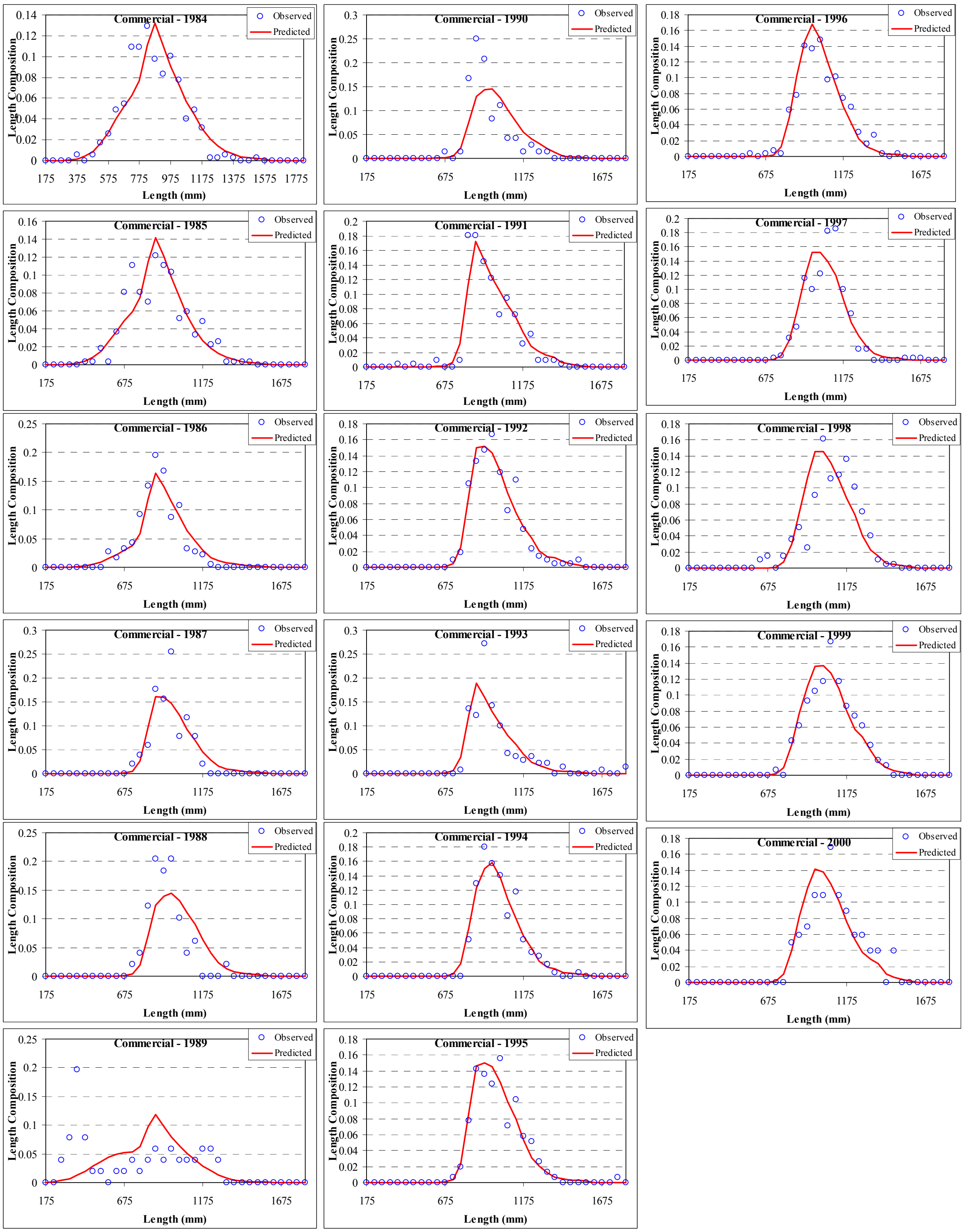


Figure 16. Bubble plot of recreational fishery length composition residuals (predicted - observed) from the age-structured model fit for Gulf of Mexico cobia for years 1981-2000 with a natural mortality of 0.3. Negative residuals are shaded, positive residuals are clear, and the area of the bubble is proportional to the magnitude of the residual.

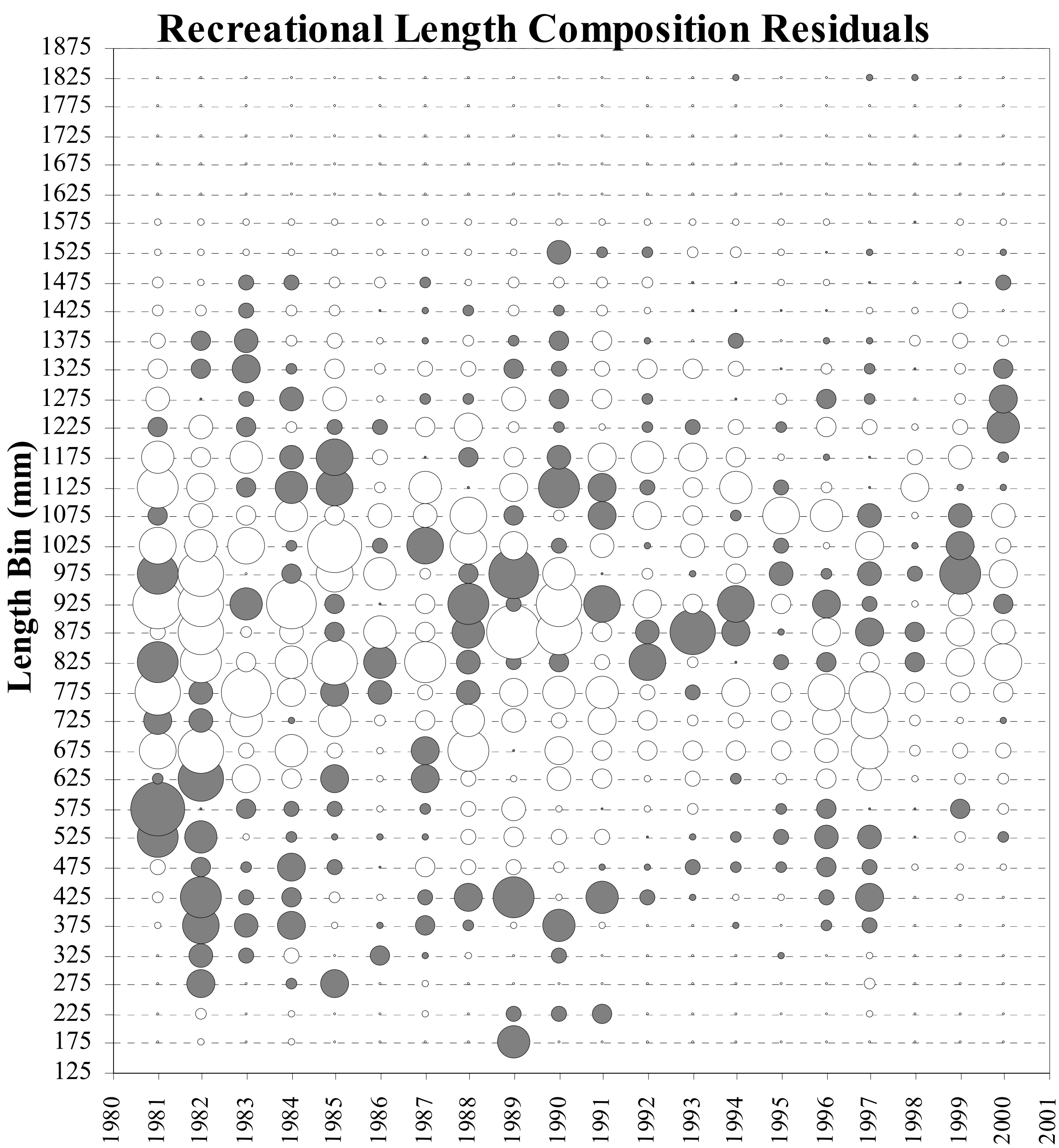


Figure 17. Observed and predicted length compositions from the recreational fishery samples for Gulf of Mexico cobia for years 1981-2000.

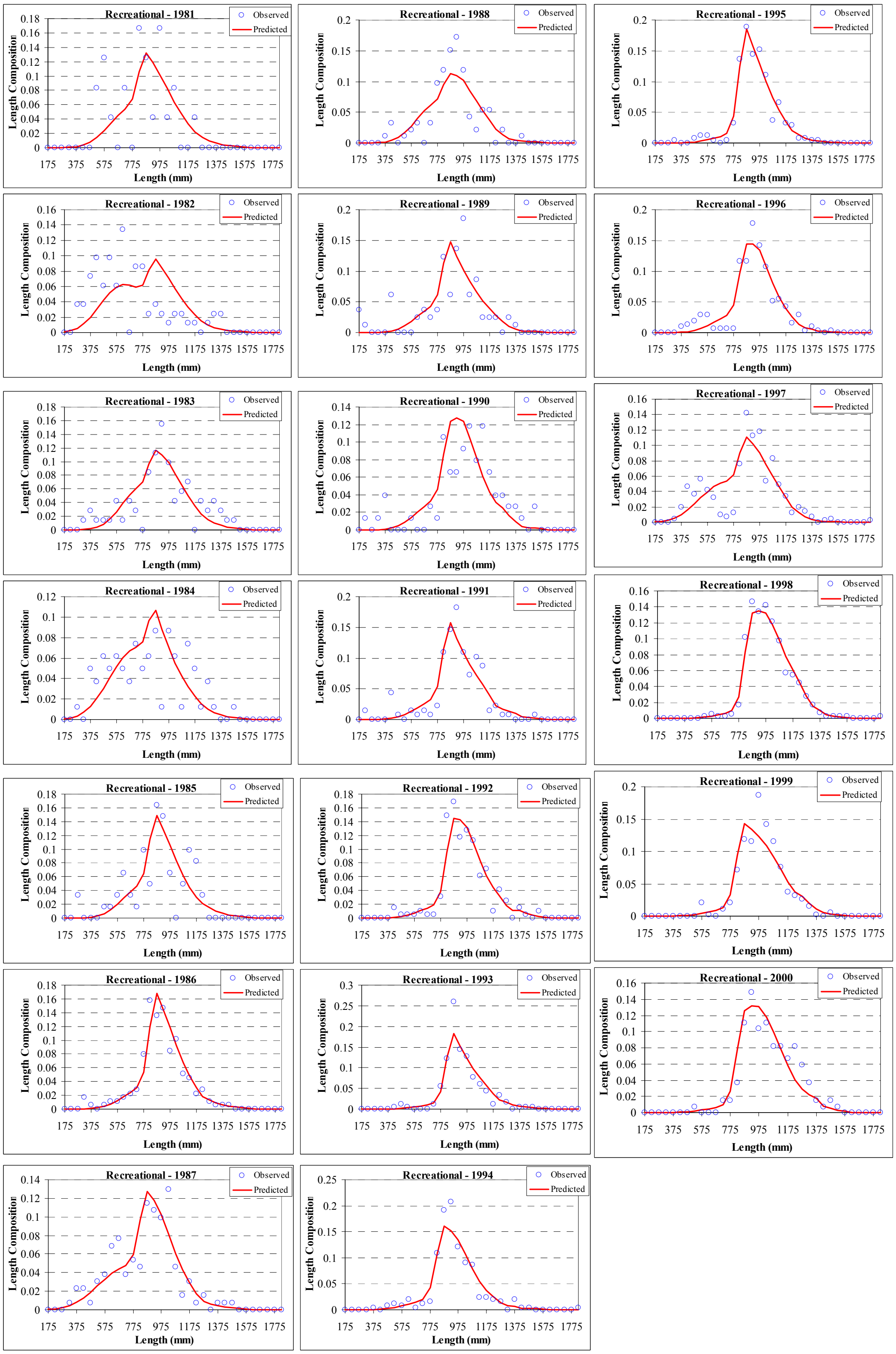


Figure 18. Age at 50% selectivity parameter estimates from the Gulf of Mexico cobia assessment model for 3 choices of natural mortality (M).

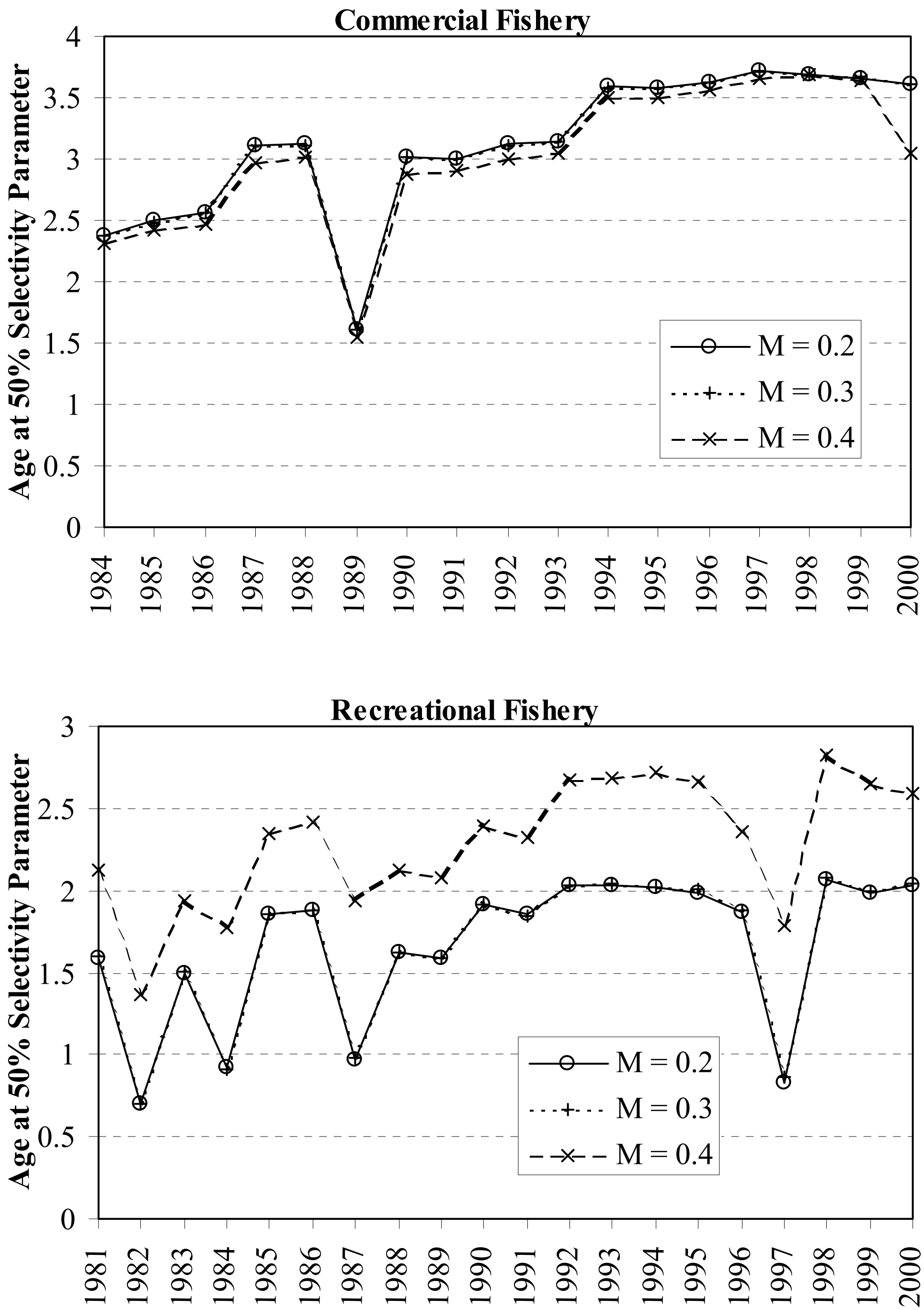


Figure 19. Gulf of Mexico assessment model estimates of standard deviation of length at age for 3 choices of natural mortality (M).

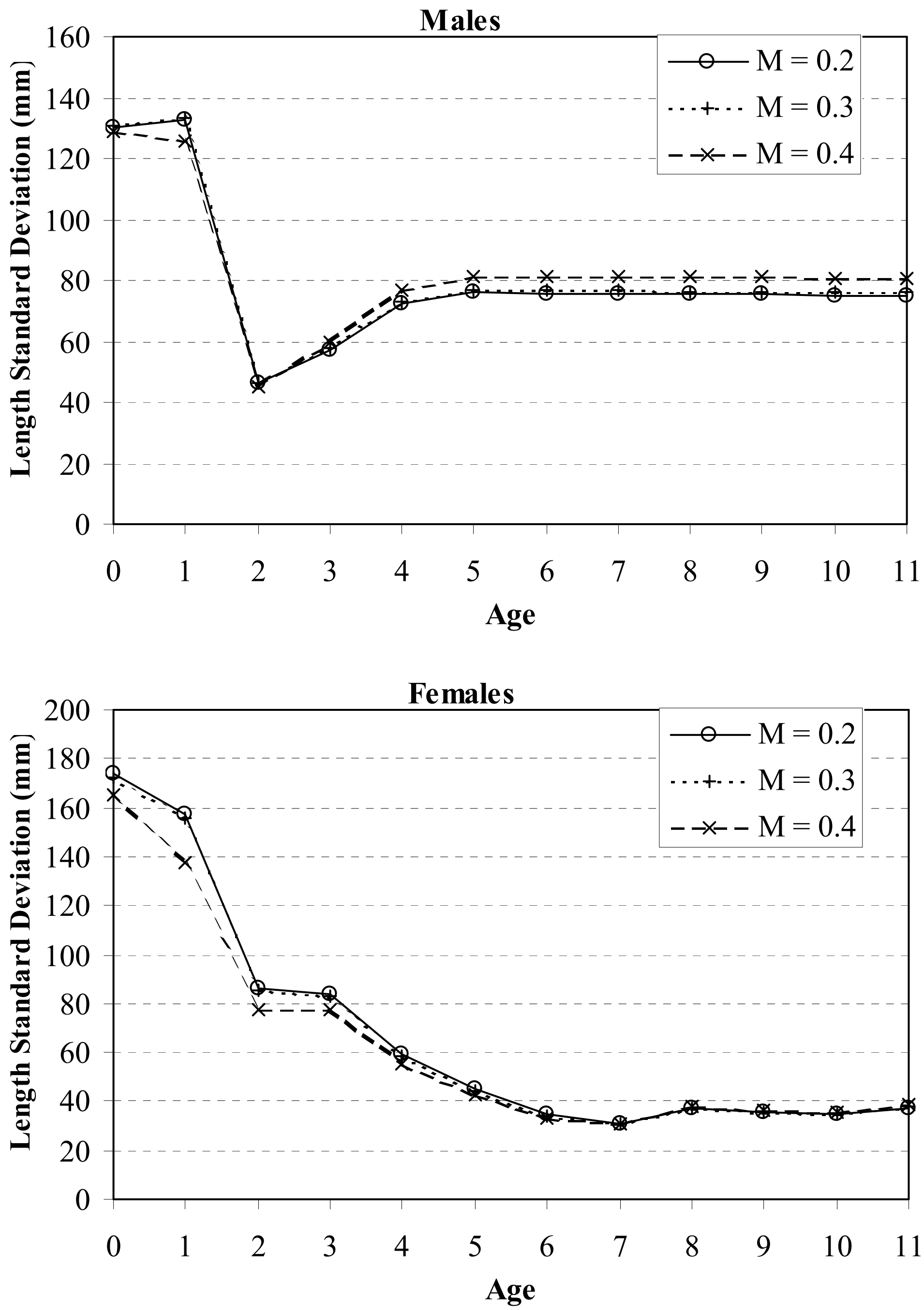


Figure 20. Total fishing mortality (F) estimates broken into fisheries for fully selected ages for Gulf of Mexico cobia from the assessment model for 3 choices of natural mortality (M).

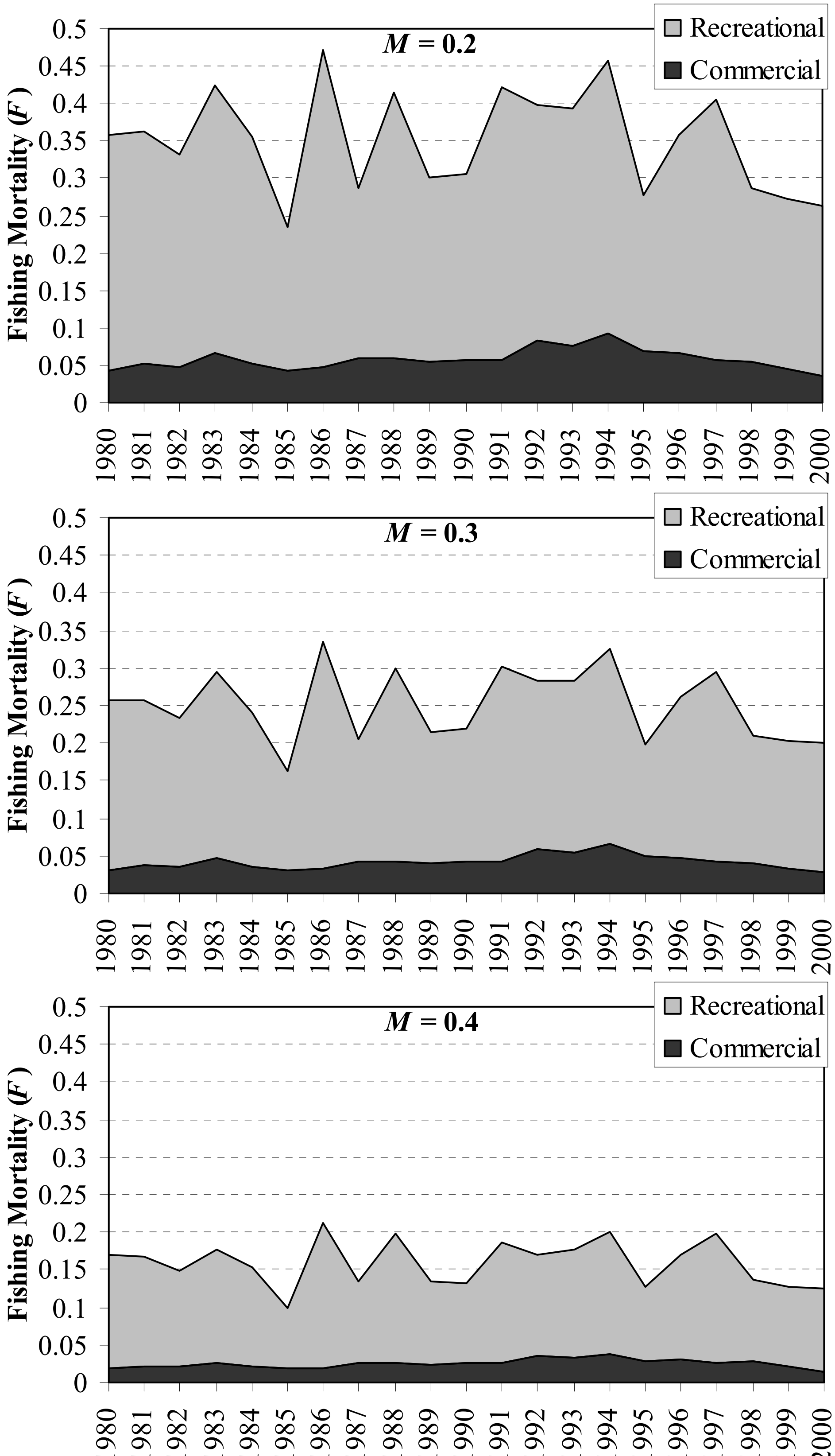


Figure 21. Spawning biomass per-recruit (SSBR) and yield per-recruit (YPR) estimates based on a catch weighted average selectivity from the last 3 years of data for the Gulf of Mexico cobia assessment model for 3 values of natural mortality (*M*).

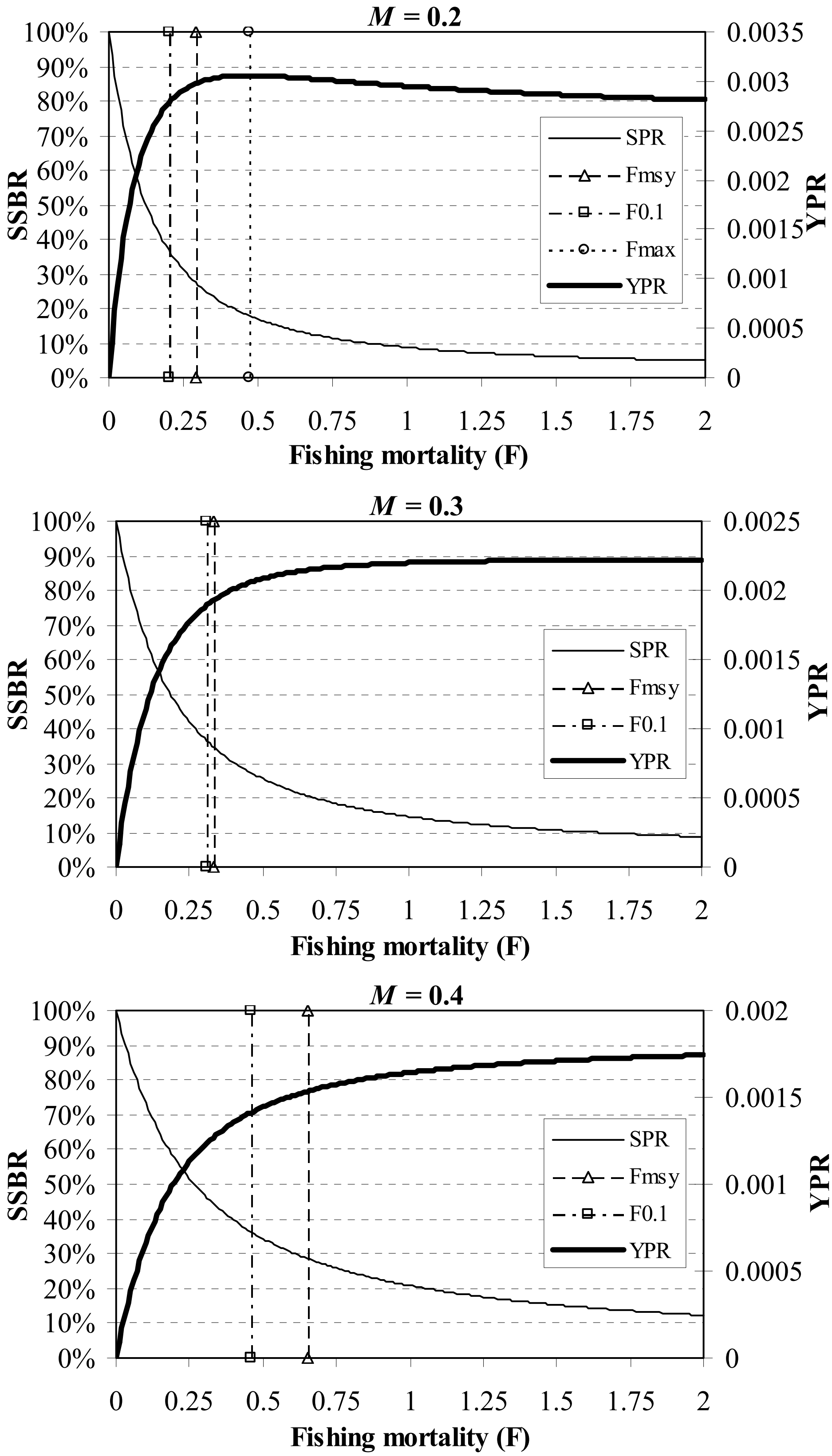


Figure 22. Static spawning biomass per-recruit (SSBR) estimates from the Gulf of Mexico cobia assessment model for 3 choices of natural mortality (*M*).

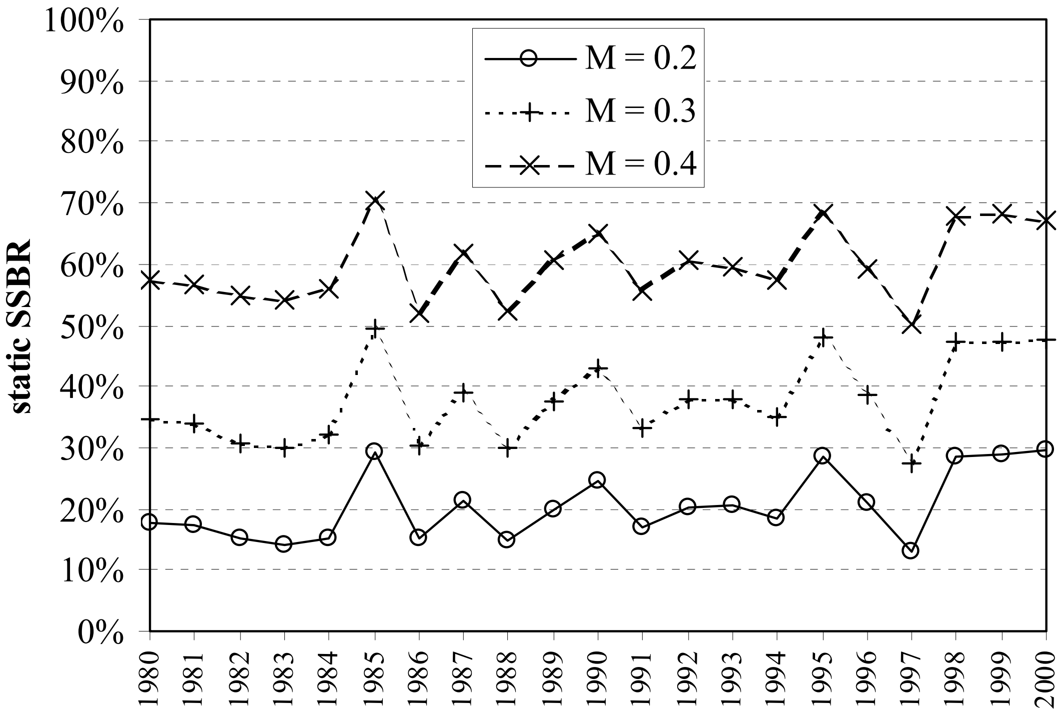


Figure 23. Recruitment (age 0) in numbers and spawning biomass (mt) for Gulf of Mexico cobia from the assessment model with 3 choices of natural mortality (*M*).

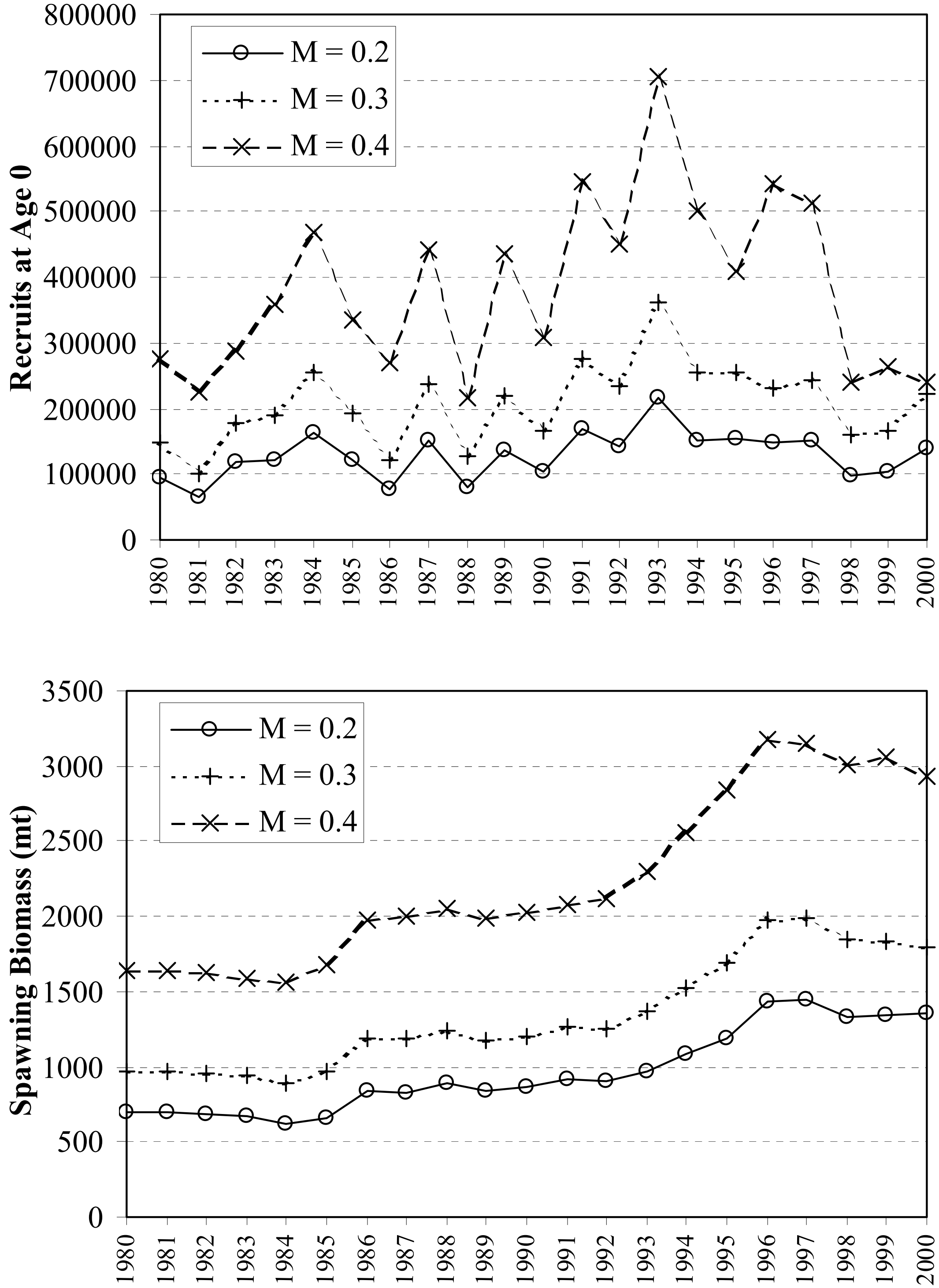


Figure 24. Spawner-recruit estimates (circles), functional relationship estimate (line), and estimate of spawning biomass at maximum sustainable yield (dashed line) for Gulf of Mexico cobia for 3 values of natural mortality (M).

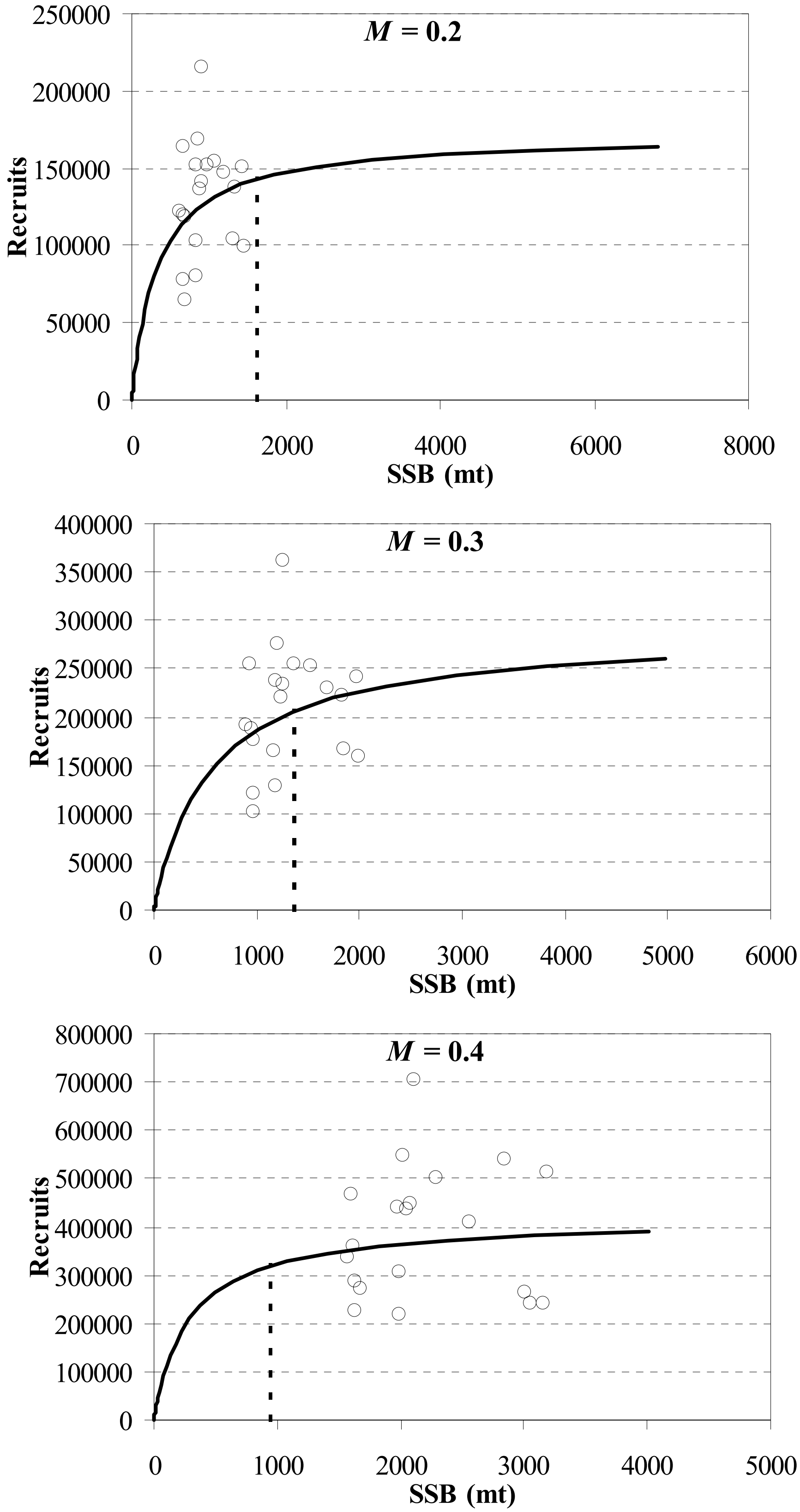


Figure 25. Fishing mortality (*F*) and spawning stock biomass (*SSB*) estimates relative to maximum sustainable yield (MSY) from the Gulf of Mexico cobia assessment model with 3 values of natural mortality (M).