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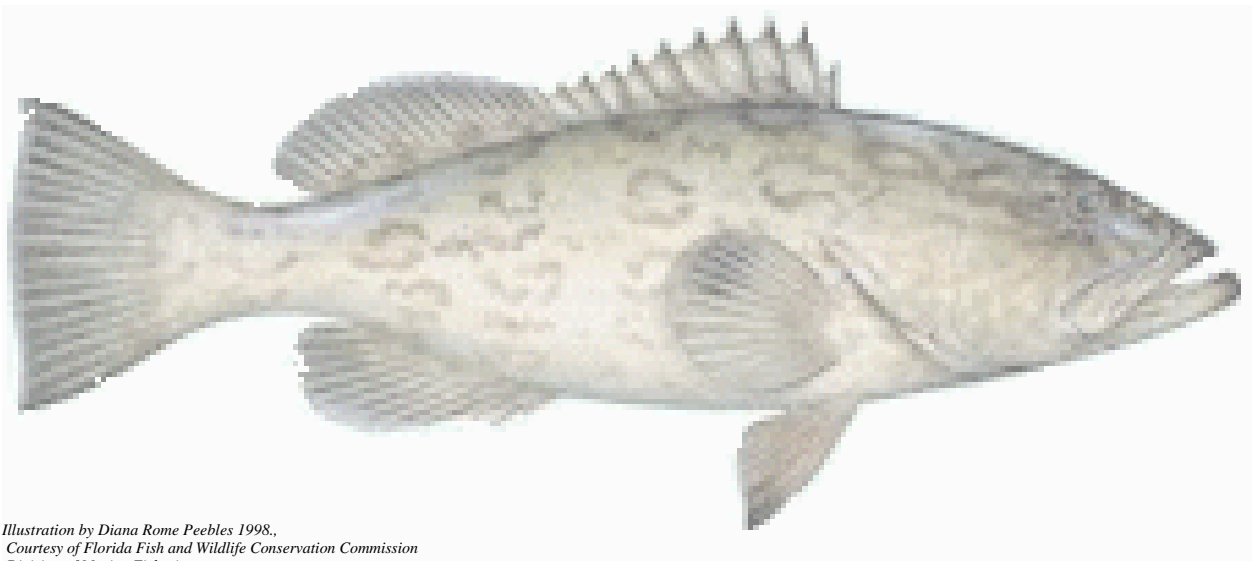
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# **Status of Gag in the Gulf of Mexico, Assessment 3.0**

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## 1. Introduction

The status of gag, *Micropogonias undulatus*, in the Gulf of Mexico was reviewed using information on landings and discards from 1986 primarily through 1999, size composition, size at age and catch rate information from multiple recreational and commercial fisheries. The general approaches used in previous assessments (Schirripa and Goodyear 1994 and Schirripa and Legault 1997) were followed in developing the catch history, the catch-at-size and the catch-at-age using a stochastic ageing method (Goodyear 1997). An additional catch-at-age derived from observed age composition (Fitzhugh *et al.* 2001) was developed by Cummings and Parrack (in prep). The data of Fitzhugh *et al.* were also used to develop a preliminary version of a revised growth curve. Additional emphasis was placed on development of indices of abundance.

### 1.1 Management history

Management actions that may have influenced the fisheries for gag and that could have an impact on the data used in examining the historical status of the stock include bag limits and size limits. A 20" (51 cm) minimum size became effective in February 1990, and a grouper bag limit of five groupers became effective in April of 1990. On June 19, 2000 the minimum size for landings was raised to 22" (56 cm) for recreational catches and to 24" for commercial landings. At the same time, sales of gag were prohibited from February 15 through March 15, and two marine reserves in which fishing for reef fish and bottom oriented species was prohibited year round, were established.

## 2. Biology

### 2.1 Species Identification

Historically gag often has been confused with black grouper, *Micropogonias undulatus* (Hoese and Moore, 1977, Bullock and Smith, 1991). In the 1994 assessment (Schirripa and Goodyear 1994) this problem was addressed by combining gag and black grouper catches and catch rates from areas where black were thought to be rare or absent, and by estimating fractions of the combined catch thought to be gag. Generally they restricted catch rate analyses to regions thought to have zero or low fractions of black grouper in the catch. The same approach was used in the 1997 assessment (Schirripa and Legault 1997).

Additionally, gag have, at times, been included in commercial landing statistics as unclassified grouper; prior to 1986 all grouper landings were recorded as unclassified grouper, and the majority of them were considered to have been red grouper, *Epinephelus morio*.

With some exceptions we have followed a similar approach. The various assumptions about species composition are explained in detail in the appropriate sections on catch and catch rates. We have tabulated catches of 'reported' and 'calculated' to make clear the impact of the assumptions about proportions of reported gag, black and unclassified grouper.

### 2.2 Review of Life History

Gag are found from Brazil to New England (Briggs 1958, Smith 1971), with the apparent center of distribution occurring in the eastern Gulf of Mexico (McErlean 1963). Spawning sites occur in association with drowned Pleistocene reefs found at depths of 40-120m over the continental shelf west of Florida, with the preferred areas being at depths of 70-90m (Coleman *et al.* 1996, Fitzhugh *et al.* 2000).

The reproductive season begins in November or December and doesn't end until May or June, but most spawning activity takes place in February and March (Hood & Schlieder 1992, Coleman *et al.* 1996, Collins *et al.* 1998, Fitzhugh *et al.* 2000). Gag appear to form loose spawning aggregations of 10s to 100s of individuals, and spawning sites may be traditional (Coleman *et al.* 1996). Larval gag spend 30-70 days drifting as part of the plankton before settling in shallow-water seagrass habitats, often in estuaries (McErlean 1963, Koenig & Coleman 1988, Hood & Schlieder 1992, Coleman *et al.* 1996, Koenig & Coleman 1998, Heinisch & Fable 1999, Fitzhugh *et al.* 2000). A recent study found no evidence of regional/latitudinal variation in the duration of the larval period, but, as is typical, did note a large degree of annual variation in recruitment (Fitzhugh *et al.* 2000). Settlement, which occurs primarily in April and May, is followed by a period of rapid growth, as juvenile gag increase from 20-70mm to 200-300mm in length by late in the year, at which time they depart the nursery habitats (an event referred to as 'egress'), apparently migrating to shelf reef habitats (Moe 1966, Hood & Schlieder 1992, Heinisch & Fable 1999, Koenig & Coleman 1998, Fitzhugh *et al.* 2000, Johnson & Koenig *in press*). Some evidence suggests that juveniles settle in relative near-shore, shallow areas and gradually move to deeper habitats as they age and increase in size (Hood & Schlieder 1992). Several studies have examined length-weight-age data and estimated growth rates of adult gag from fisheries data (McErlean & Smith 1964, Collins *et al.* 1987, Hood & Schlieder 1992, Johnson *et al.* 1993, Schirripa & Goodyear 1994, Schirripa & Burns 1997). Natural mortality rates appear to be low in the nursery habitats (Koenig & Coleman 1998), but are unknown for juveniles or adults after egress from seagrass habitats. Being protogynous hermaphrodites, gag are females in early life and later transform into males when they are larger. Females mature as early as 2 years of age, over half are mature by 4 years of age, and by 7 years of age, all are mature (Hood & Schlieder 1992). Sex transformation occurs in individuals as young as 5 years of age, but it is not until age 10-11 that the majority of individuals are male (Hood & Schlieder 1992). Virtually all individuals older than 16 years of age are males. Gag are a long-lived species, some males live to ages greater than 20 years (Collins *et al.* 1987, Hood & Schlieder 1992, Collins *et al.* 1987). Size appears to reach an asymptote around age 13-15 at approximately 1.0-1.1m and 15-17kg (Hood & Schlieder 1992, Schirripa & Goodyear 1994). Without fishing it is likely much larger and older individuals would be found in the population. Coleman *et al.* (1996) suggested that selective fishing that results in higher fishing pressure on larger individuals coupled with protogynous hermaphroditism would make this species especially vulnerable to recruitment overfishing (Coleman *et al.* 1996). Estimates of the sex ratio in this population from various time periods have indicated a large decrease in the proportion of males in the population to the point where it is feared that reproductive output may be limited by a scarcity of reproductive males (Coleman *et al.* 1996). Limited data suggest that females first reproduce at approximately 57-71 cm length, or 3-5 years old and that most males are reproductively mature following transformation, thus males first reproduce at 7 years of age when they are about 85 cm in length. Female gag appear to spawn repeatedly during the spawning season at intervals of a few days (Collins *et al.* 1998). Spawning frequency appears to vary considerably among years. As females age they spawn more frequently and their batch fecundity increases as their length (and weight) increase, thus producing an exponential increase in estimated annual fecundity, at least for females up to the age of eight (Collins *et al.* 1998).

### 2.3 Age Composition and Growth

Fitzhugh *et al.* (2001) presented an analysis of age composition of commercial and recreational fisheries from 1991-2000. They noted evidence of strong and weak year-classes which could be followed over multiple years, but found no evidence of differences in size at age between such year-classes. They noted gear and sector (recreational and commercial) differences in age composition, which they attributed to depth related differences in availability and, in part, to differences in areas of exploitation (northern and

southern regions of the west Florida shelf). They considered the apparent variation in year-class strength to be primarily due to variation in recruitment.

This information was used to examine growth (Calay *et al.* in prep), to develop age-length keys (Cummings *et al.* in prep) and to estimate the age composition of the catch using methods similar to those used for SEFSC mackerel stock assessments (Cummings and Parrack in prep). Size at age from 1992-2000 was provided by SEFSC, Panama City

### 2.3.1. Growth

This section is summarized from Cass-Calay *et al.* (in prep).

Length-at-age data from SEFSC, Panama City were obtained from the recreational and commercial fisheries, and from scientific surveys and tournaments. However, due to the limited number of samples, scientific survey and tournament data were excluded from analysis of growth. To model the growth of gag, von Bertalanffy growth equations were fit to length-at-age data using least squares nonlinear regression.

#### 2.3.1.1 Recreational

Three types of vessels participate in the recreational fishery in the Gulf of Mexico: charter boats, head boats and private boats. Cass-Calay *et al.* (in prep) fit von Bertalanffy growth equations to the length-at-age data from each vessel type to examine the effects of vessel type on the growth of gag grouper (Figure 1). Lengths are in mm. The von Bertalanffy equations fit to the recreational data are as follows.

**Charter:**  $TL = 2431.0(1 - \exp^{-0.0340(\text{Age} + 5.671)})$   $n = 859, r^2 = 0.590, p < 0.001$

**Head Boat:**  $TL = 1711.6(1 - \exp^{-0.0570(\text{Age} + 4.708)})$   $n = 107, r^2 = 0.660, p < 0.001$

**Private:**  $TL = 2869.9(1 - \exp^{-0.0334(\text{Age} + 3.591)})$   $n = 37, r^2 = 0.792, p < 0.001$

All the regression equations were significant, however, the solution for the private boat data was considered unreliable due to the limited number of data points and their distribution over ages. The three regression equations were quite similar (Figure 1D), especially over the common range of the data (Age = 2-10). This result indicated little difference in selectivity among vessel types with respect to overall size at age of gag. Therefore, the data were combined, and a single regression equation was calculated for the recreational data. The combined von Bertalanffy equation is given below. It should be noted that the combined data set included additional data points that were not identified by vessel type.

**All Recreational:**  $TL = 2071.3(1 - \exp^{-0.0479(\text{Age} + 4.119)})$   $n = 1466, r^2 = 0.644, p < 0.001$

### 2.3.1.2 Commercial

Commercial samples were collected using two gear types: handlines and longlines. Cass-Calay *et al.* (in prep) fit Von Bertalanffy growth equations to the handline and longline data (Figure 2). Those equations were:

**Handline:**  $TL = 1394.9(1 - \exp^{-0.1003(\text{Age} + 2.755)})$   $n = 1446, r^2 = 0.730, p < 0.001$

**Longline:**  $TL = 1292.9(1 - \exp^{-0.1279(\text{Age} + 2.418)})$   $n = 542, r^2 = 0.721, p < 0.001$

The two regression equations appeared to be similar (Figure 2C), and were not statistically different using a test for coincident regressions (Zar 1984) ( $0.05 < p < 0.10$ ). Again, for the purposes of modeling gag growth, gear type selectivity appeared to have little influence in the commercial sector. Therefore, the gear types were pooled to create a single commercial data set. The combined von Bertalanffy equation was:

**All Commercial:**  $TL = 1331.6(1 - \exp^{-0.1175(\text{Age} + 2.257)})$   $n = 2000, r^2 = 0.750, p < 0.001$

### 2.3.1.3 Pooling Recreational and Commercial Data

Finally, Cass-Calay *et al.* (in prep) compared the recreational and commercial growth curves (Figure 3). The curves were found to be statistically different using a test for coincident regressions (Zar 1984) ( $0.01 < p < 0.05$ ), which can be interpreted as resulting from selectivity differences between the fishing sectors. However it was thought that the curves were very similar between ages 2 and 10, and very few fish were collected from the recreational fishery that were older than 10 years. Also, the  $L_{\infty}$  value of the recreational growth equation (1745.9) was estimated with very few observations at older ages. With additional sampling, it is expected that the two growth curves would become more similar. Therefore data from the two sectors were combined and a single growth equation representative of all components of the harvested population was fit.

Using the combined recreational and commercial data, Cass-Calay *et al.* (in prep) estimated the von Bertalanffy and inverted von Bertalanffy equations (Figure 4) using least squares nonlinear regression. The equations were as follows.

$$TL = 1381.5(1 - \exp^{-0.1061(\text{Age} + 2.4359)}) \quad n = 3546, r^2 = 0.743, p < 0.001$$

$$\text{Age} = [\ln(1 - TL/1390.1)/-0.134] - 0.868 \quad n = 3546, r^2 = 0.754, p < 0.001$$

It was noted that there was substantial lack of fit for fish older than age 10. Attempts to improve the fit using a double von Bertalanffy equation and a more complex growth equation that allows  $k$ , the growth rate, to change with age (Porch *et al.* in press) were unsuccessful. Further research, perhaps using robust nonlinear regression techniques, should be considered in the future.

### 2.3.1.3. Conclusions

The combined growth model developed by Cass-Calay *et al.* (in prep) from the 1992-2000 data set provided by SEFSC, Panama City was selected for use as the primary growth model for use in this assessment to replace the model used in the previous assessments. The primary reason for making this

change was that the new growth curve was derived from a substantially larger number of observations obtained from a greater number of years. The  $L_{\infty}$  and  $k$  estimates from these curves were similar [143.5 and 0.1051 for the model first used by Schirripa and Goodyear (1994) versus 138.2 and 0.1061 for Cass-Calay *et al.* (in prep)]; however the  $t_0$ 's were quite different (1.3503 Schirripa and Goodyear versus 2.4359). The two curves predicted different sizes at age for younger gag (Figure 5) and would result in different estimates of age composition calculated using the curves. As noted above, the new growth curve also exhibited lack of fit at the older ages. These concerns suggested that the direct use of the length-at-age information in the assessment model should be investigated for gag.

The new growth model indicated that the average fish grew about 7 cm per year between age 3 and age 6, 5 cm per year between ages 6 and 9, 4 cm per year between ages 9 and 11 and more slowly thereafter. By age 8 the average gag had achieved 67% of its maximum size, 73% by age 10, and 81% by age 13. The observed age composition (Figure 4) suggested a 20-30 cm range of size at age roughly from age 4 to age 13.

### 3. Catch

As noted in section 2.1 gag and black grouper have been confused in the catch statistics and gag have been included in 'unclassified grouper' statistics. Grouper catches were first recorded in the landings statistics by species starting in 1986, and, for this reason, 1986 was the earliest year used in the analyses in the previous assessments (Schirripa and Goodyear 1994 and Schirripa and Legault 1997); we have followed the same approach. The previous assessments used a variety of approaches to calculate what was considered the actual gag catch; for instance all black grouper from Texas through Alabama were considered gag, and a large proportion of the combined gag and black grouper catch in Florida was considered gag. To demonstrate the effects of these assumptions, catch data were tabulated for records originally reported as gag in the various data bases (reported gag) and for the catches considered to be gag from reported catches of gag, black grouper and unclassified groupers (calculated gag).

#### 3.1 Landings

##### 3.1.1 Commercial

Commercial landings of gag were estimated from the SEFSC accumulated landings data base for 1986 and later. The accumulated landings data generally have information on capture gear and location for Texas and Louisiana through 1991, Mississippi and Alabama in all years, and for Florida landings for 1997 and later. To calculate the capture gear and location for west Florida landings from 1986-1996, the annual Florida general canvass data were used to calculate patterns of reported catches by gear and fishing location for each year, county and species. Catches from U.S. Gulf of Mexico waters were retained (shrimp grids 2-21 and the portions of grid 1 which did not include some Atlantic waters - 1.1, 741.1 and 748.1). The data from 2000 were considered to be preliminary. In addition, no data were available from Louisiana in most of July and all of August-December 1999, therefore landings for July-December were estimated.

Because of apparent misidentification of gag and black grouper commercial catches throughout the Gulf, the previous assessments used proportions of gag in the combined catches of gag and black grouper to calculate the total catch of gag (Schirripa and Goodyear 1994). For Florida catches, those

proportions were primarily based on dockside observations of recreational catches recorded by MRFSS samplers in 1990-1992 (species identification of gag and black grouper by MRFSS samplers prior to 1990 and especially prior to 1989 were considered inaccurate). For Texas to Alabama, and for most Florida counties, it was assumed that all commercial catches were gag. For southwestern Florida (Manatee county and south) it was assumed that decreasing fractions of the commercial catch were gag (Table 1). Those fractions were used for this assessment. It is recommended that these fractions be further investigated.

The proportion of gag (Table 2) in annual Florida landings of all identified groupers (gag, red grouper, black grouper, marbled grouper, nassau grouper, yellowfin grouper, yellowmouth grouper, scamp, yellowedge grouper, misty grouper, speckled hind, rock hind, red hind and snowy grouper) was multiplied times the unclassified grouper catch to estimate the part of that unclassified catch which was gag. Catches only from Gulf of Mexico waters were included. Landings of black grouper from Texas through Alabama were all assumed to be gag. During 1986-1990 Gulf-wide unclassified grouper landings by U.S. vessels ranged from about 109,000 lb to about 318,000 lb; during 1991-1995 they ranged from about 14,000 to about 52,000 lb, and from 1996 through 1999 they were less than 10,000 lb.

The July-December 1999 landings for Louisiana were estimated, because they had been partially reported for July and not reported for August-December. Monthly proportions of Louisiana annual landings showed higher proportions of gag landed in February-April in 1998- 2000 than in 1994-1997. Therefore the annual proportion of the combined catches from July-December in 1998 and 2000 was calculated and multiplied times the 1999 January - June landings to estimate the July-December 1999 landings for Louisiana.

Annual landings and average weights are generally recorded in the data bases as whole weight in pounds. The gutted to whole weight conversion factor used for groupers in creating the landings data bases was considered inaccurate (Schirippa and Goodyear, 1994). Therefore, landings data were reconverted to gutted weight (  $\text{gutted} = \text{whole} / 1.18$ ). All weight estimates and related statistics (MSY, etc) in this report are reported in gutted weight equivalents.

The calculated commercial landings of gag in gutted weight (Table 3) were between 1.5 million and 1.9 million pounds in all but three years. The lowest on record at about 1.2 million lb was in 1988. The 1998 commercial landings were the highest on record with about 2.5 million lb, the 1999 landings were about 2.0 million lb while the preliminary estimate for the year 2000 is about 1.7 million lb. Handlines (including rod and reel and bandit rigs) accounted for the largest amount of catch during 1986-2000 and longlines accounted for the second largest amount (Table 4 and Figure 6).

Schirippa and Legault (1997) reported landings in gutted weight, and their annual totals were similar to those calculated for this assessment (Table 5). The differences in those statistics between the assessments were due to corrections to the data base (primarily for 1996), small differences between the Florida general canvass data used in the previous assessment and the accumulated landings data used in this assessment, and differences in the treatment of catches reported from some inland counties in Florida and catches from some capture locations.



The calculated landings of gag were more than twice the reported landings of gag during the late 1980's (Figure 2). Since then it appears that dealers have reported the species landed more accurately.

### 3.1.2 Recreational

Recreational catches (landings -A - and discards, both B1 and B2) were obtained from MRFSS (Marine Recreational Fisheries Statistical Survey), headboat (Southeast Fisheries Center Headboat Survey) and Texas Parks and Wildlife data sets for 1986 and later. To address the uncertainties associated with species identification of gag and black grouper, the conventions established for the 1994 assessment (Schirippa and Goodyear 1994) were generally followed; for MRFSS all black grouper from Texas through Alabama and 87% of the combined catch of gag and black grouper in west Florida were considered gag. Headboat catches in west Florida were considered to be accurately identified. To maintain consistency with the treatment of the MRFSS data, all black grouper catches recorded in the headboat and Texas data sets between Texas and Alabama were considered to be gag. Further investigation into these assumptions may be warranted. Gag and black grouper catches taken by vessels from the Florida keys which usually fished in the Atlantic were excluded.

The reported (not including any black grouper) total number of gag landed by recreational fisheries is given in Table 6.

The total calculated recreational landings (including some fish reported as black grouper) ranged from about 200,000 fish to about 700,000 fish with the highest catches in the earliest 3 years (1986-1988) and the latest three years (1997-1999) (Table 7). Florida accounted for the largest fraction of the catch and Texas the smallest. The total estimated yield using average weights from the catch-at-size ranged from 1.4 million lb to 4.0 million lb (Table 8). The MRFSS accounted for the majority of the recreational catches (from about 175,000 to 650,000 fish annually), and the head boat survey accounted for roughly 10,000 to 50,000 fish annually (Table 9).

The amount of black grouper calculated to be gag using the procedure adopted by Schirippa and Goodyear (1994) decreased quite substantially during the late 1980's (Figure 8). In 1998 and 1999 the number of fish reported as gag was larger than the number calculated to be gag. This was probably due to increasing catches of reported gag and decreasing catches of reported black grouper and to the assumption that in Florida 87% of either species was actually gag. It is recommended that alternative methods of assigning species be investigated.

The MRFSS was the only survey with estimates of variance in the landings (including dead discards - type B1 catch). The MRFSS catches and the associated coefficients of variation for Florida are presented in Table 10 by year and wave; the table was restricted to Florida because the majority of the catches occurred there (Table 7).

### 3. Releases

Direct estimates of the number of discards was available only for the recreational fisheries covered by the MRFSS. For the other fisheries, ratios of observed, or assumed, number discarded to the observed, or assumed, number retained were used in estimating the total number discarded. To do so, those ratios were multiplied times the calculated number of fish landed at or above the minimum size. In a few instances at-sea observer data were available and were used to calculate the proportion discarded only for the year in which they were taken. However for most fisheries and years observer data were not available, and differences in size composition before and after the imposition of the minimum size in 1990 was used in calculating the proportion of the catch which might have been discarded. The proportion of the 1986-1989 catch which was less than 51 cm (20 in.) was calculated. It was assumed that 1991-1999 catches would have size distributions similar to the 1986-1989 size distribution. The total catch of gag less than 51 cm was calculated by multiplying the number caught which were larger than the size limit, times the proportion less than the size limit from the observer data or the 1986-1989 data. Those proportions were calculated from the 1986-1989 size composition aggregated by month, quarter or year depending on the fishery (commercial gear or recreational mode) being used to assign size to the released catch and the number of 1986-1989 size samples available (see section 5.1).

Following the approach used in previous assessments, it was assumed that 20% of recreational releases died, and 30% of commercial releases died. A higher proportion dead was assumed for the commercial fishery, because commercial catches of gag are thought to occur in deeper water than recreational catches and because release mortality apparently increases with depth.

If any undersized fish were recorded when fish were measured at the dock, they were included in the calculated catch-at-size in the usual manner. It was assumed that those fish (and the estimated total number of such fish in the total catch) would have been discarded dead at sea, but were landed because they were already dead. Therefore the calculated dead discards  $[(\text{proportion} < \text{minimum size}) * (\text{number landed} > \text{minimum size}) * \text{discard mortality rate}]$  was reduced by the calculated number landed less than the minimum size. As a result in some years for some gears no fish were calculated to have been discarded at sea, because the calculated total number landed less than the minimum size equaled or exceeded the calculated number of dead discards.

### 3.2.1 Commercial

SEFSC personnel observed catches taken aboard vessels using traps (Anon. 1995), vessels using bandit rigs (classified as handline in this assessment) and vessels using longlines in late 1994 through late 1995 (Anon. 1995). On the observed trap trips data were recorded from almost 4,000 trap hauls between December 1993 and November 1994; of the 35 gag observed, only 3 were retained and 32 were discarded (a 10.7 ratio of discarded catch to retained catch). The observed bandit rig trips occurred from January-July of 1995 and more than 26,000 drops ('sets') were observed. Fifty seven gag were observed caught, of which 51% were released. The observed longline trips occurred between January 1994 and February 1995; no gag were observed caught on more than 225,000 hooks. It is noted that most of these observations were made in 1994, when most of the fish in the large 1993 year-class would have been below the minimum size. As noted above, these ratios were applied only to the year from which most of the data were reported.

Because observer data were not available for most years, the 1986-1989 size composition was used to estimate the proportions in 1990-1999 which were released. During 1986-1989 about 2.6% of the landed gag which were measured were less than 20 in. (51 cm) for both the handline and the longline fisheries. During those years no trap sizes were recorded so the handline size composition was assumed.

### 3.2.2 Recreational

The number of gag released alive at sea was estimated for the fisheries covered by the MRFSS. Estimates for west Florida-Louisiana are given in Table 11.

Mote Marine Laboratory personnel have recorded data from observed head boat trips in recent years (K. Burns, personal communication) under a MARFIN grant (NA87FF0421) in cooperation with scientists from Florida State University (C. Koenig and F.Coleman). Those data were kindly made available for this assessment and were used to calculate that about 58% of the 43 gag observed in 1999 were less than the minimum size.

The ratio calculated from the 1999 Mote data, was similar to an overall ratio of roughly 55% calculated from the 1986-1989 measured landings.

### 3.3 Total Catch

The calculated number of fish landed and discarded dead by sector (recreational or commercial) is shown in Figure 9 and Table 12, and the corresponding yield is shown in Figure 10 and Table 13.

## **4. Size Composition**

The size composition of landings from the various fisheries was reviewed to determine how best to construct catch-at-size and catch-at-age.

### **4.1 Landings**

#### **4.1.1 Commercial**

The commercial gears exploited overlapping size ranges (Figure 11). The spear and trap fisheries exploited the smallest range of sizes of gag (roughly 50-95cm), the handline fishery exploited sizes of roughly 50-210 cm with the highest proportions between 55 and 95 cm, while the longline fishery exploited fish of roughly 65-130 cm with the highest proportions at 70-110 cm.

#### **4.1.2 Recreational**

The recreational fisheries had roughly similar size compositions during 1986-1989, when sample sizes were low for some of the fisheries (370 measured from charter boat anglers, 114 from private boat anglers, and 2157 from headboat anglers), and in 1991-2000 (Figure 12, head boat data is only through 1999).

## **5. Catch-at-size and Catch-at-age**

For the 1997 assessment catch-at-age and catch-at-size were developed using the same system to assign size composition to catches. Once a size sample was selected, the age composition was estimated by the probabilistic method of Goodyear (1997) (hereafter referred to as the recruitment-and-mortality modulated method, RMM). That approach was followed for this assessment, but the sample selection rules used to assign samples to a catch were somewhat different and the final catch-at-size was retained in fine stratifications (by state, month and gear) to permit contrasting the estimates with those from other methods. In addition an alternative ageing approach, which used an age-length-key and stochastic growth-curve-based method (Cummings and Parrack in prep), was used to estimate age composition from the catch-at-size..

### **5.1. Catch-at-size**

The catch-at-size was developed to: (1) use with alternative assessment methods such as estimating catch-at-age from the observed ageing samples or length based methods and (2) calculate the yield (weight of the catch) for fisheries sampled by surveys for which catch was primarily reported in number of fish (MRFSS, Texas Parks and Wildlife).

Size composition samples were assigned to catches based on a hierarchical set of rules. One set of rules was used for recreational landings, another for commercial landings, a third for discards for which observer samples were not available and a fourth for discards from a fishery in a year for which observer data were available. In all cases, size samples were pooled across states. For discards from a

stratum (year, commercial gear or recreational mode - shore, head boat, charter, private) from which observed sizes were available, size samples were used if there were at least 5 fish measured. For the remaining types of catches there had to be at least 25 fish measured for a sample to be selected. In all cases the most disaggregated stratum was year, month, and gear or mode and the next level of aggregation was the year, season (3 months long) and gear or mode. For recreational fisheries the third level of aggregation considered was by year, month and all modes pooled, the fourth was year, season and pooled modes and the last was all samples from all recreational fisheries from a year. For the commercial landings, samples were never aggregated across gears, because of the relatively large differences among gears in size composition of the catch (Figure 11). Thus, for the commercial catch-at-size, sample availability was checked first for the month, then the season and then for the entire year for each gear. For discards from years and fisheries without observer coverage, the pooled sizes from 1986-1989 were used to assign size composition and aggregation across gear or mode was permitted depending on the number of samples available. Sample availability was first checked for mode/gear and month, second for mode/gear and season; thirdly for month with modes (recreational) or gears (commercial) combined, fourthly for season and all modes or gears and finally for all samples from the sector. In a small number of instances there were not 25 size measurements within a sector for the entire year for the most aggregated sample assignment stratum considered for that mode or gear. In those instances samples from either of the surrounding two years were used, selecting which ever had the larger number of fish measured.

## 5.2. Catch-at-Age

Catches-at-age were developed using two different approaches. One was the recruitment-and-mortality modulated (RMM) method which uses an index of recruitment (Goodyear 1997), as was done for the previous assessments (Schirripa and Goodyear 1994, Schirripa and Legault 1997). The second was a combined age-length-key and stochastic growth-curve-based approach (ALK+) similar to methods which have been used for Gulf and Atlantic mackerels for several years (the Mackerel Stock Assessment Panel ageing method); for periods when there were sufficient observations, age-length-keys were developed, while for periods for which there were not sufficient numbers sampled, a probabilistic method was used (Cummings and Parrack in prep, Shepherd 1985). The probabilistic methods used in the two ageing methods differ. The RMM approach developed by Goodyear (1997) uses a growth curve, an index of recruitment and estimates of fishing and natural mortality to establish the probability that fish is an age given its size and date at capture. The probabilistic component of the age-length-key and stochastic growth-curve-based method (ALK+) involves a statistical search to find the age composition that when combined with the probability of age given length, provides the best fit between observed and expected size composition for a catch (Cummings and Parrack in prep) The growth curve developed by Cass-Calay *et al.* (in prep) was used in almost all probabilistic ageing for this assessment (the one exception was a sensitivity run).

For the assessments the age of the plus group was set at 10. By that age the average gag had achieved about 75% of the average maximum size and growth was slower than at younger ages (see section 2.3.1.3). Also by that age a significant fraction of the population may be male.

### 5.2.1 Ageing with Recruitment-and-Mortality Modulated Method

The catch-at-age was developed using the recruitment-and-mortality modulated (RMM) ageing approach (Goodyear 1997) using an index of young-of-the-year abundance from the sea grass trawl survey (Koenig and Coleman 1998) as was done by for the 1997 assessment (Schirripa and Legault 1997). Young-of-the-year indices of abundance were developed by Brown *et al.* (2001) using data provided by Koenig (personnel communication, Florida State University); the index that included the large 1993 year-class (designated ‘young of year, with 1993’) was selected for use in ageing (see section 6). The procedure requires having an index of recruitment for every year-class in the analysis; for the year classes prior to 1991 (1976-1990); the average catch rate from years without very large young-of-the-year catch rates (1992 and 1994-1999) was used, as was done for the 1997 assessment. The young-of-the-year index used in this assessment differed from the index used in the 1997 assessment in that the 1989 and 1990 values were not estimated from observed annual means for those years, instead the multi-year average was used (see section 6.1 and Figure 13). The same size-sample assignment criteria as were used for creating the catch-at-size were used to create the catch-at-age. The growth curve developed by Cass-Calay *et al.* (in prep) was used (section 2.1.3.2). The standard deviation of length given age estimated from the age-composition data was 0.12. The initial catch-at-age derived from these inputs is shown in Table 14.

The estimated catch-at-age was passed into a VPA along with a young-of-the-year abundance index (only 1991-1999 values were used; no averages of moderate recruitment years were included for earlier years), and additional indices of abundance derived from catch statistics (four additional indices were used in the base case, and two additional indices for some of the sensitivity runs). Subsequently, year-age specific fishing-mortality rates output by the VPA were passed back into the ageing procedure. This process was usually iterated five times (only once or twice for some sensitivity runs), and the results from the last iteration were considered final. For results of these analyses see section 7.

### 5.2.2 Age-length-key plus Stochastic Growth-Curve-Based Method

Cummings and Parrack (in prep) estimated gag catch-at-age using the method of the Mackerel Stock Assessment Panel from the data provided by SEFSC, Panama City Those data were considered sufficient to develop semi-annual age-length-keys for 1992-1994, January-June 1995, January-June 1996, and 1998-1999 (Cummings *et al.* in prep). For the remaining periods, we employed a stochastic method that consisted of using a statistical search to estimate the catch-at-age for each catch observation in the catch-at-size; deviations between the observed and expected size composition were minimized given the matrix of monthly probability of age from the Cass-Calay *et al.* (in prep) growth equation and a standard deviation of size-at-age of 0.12 (Cummings and Parrack in prep). The 1999 estimated catch-at-age had no age-1 fish. Because the VPA software had difficulty in calculating a fishing-mortality rate for a catch of zero under some conditions, we replaced the zero with a value of 1. The resulting catch-at-age is shown in Table 15.

## 6. Indices of abundance

Six indices of abundance were developed for this assessment: one from trawl tows over seagrass beds directed at juvenile gag, one each for the handline, longline and trap fisheries, one for the headboat fishery, and one from the MRFSS for charter and private boats combined (Table 16).

### 6.1. Young-of-the-year Seagrass Tows

Models were fit to the seagrass-tow catch rates using the delta-method approach, assuming a binomial distribution for the proportion positive and a poisson distribution for the positive catch rates (Brown *et al.* 2001). The initial index developed from the data was derived from a model for proportion positive that included fixed-effect terms for year and location, and a random-effect term for a year-location interaction, and a model of positive catch rates that included fixed-effect terms for year, month and location, and random-effect term for year-month and year-location interactions. Apparently because the 1993 sampling occurred at only one location, the model was unable to estimate a standardized mean for 1993. Therefore, a second set of analyses were conducted using only fixed effects (i.e. ignoring the year interactions). In the resulting models of the proportion positive and the positive catch rates the only significant effect was year. When scaled to the 1991 value, the random-effects and the fixed-effects models showed the same pattern, except that the fixed-effects model included an estimate for 1993, which was absent from the random-effects model.

Sea-grass catch rates for 1989 and 1990 were available only as annual aggregates. Therefore, they could not be included in the standardization procedure, and, as a result, the index used in the ageing and tuning algorithms did not include standardized estimates for those years; these years were included in the VPA tuning procedure used in the 1997 assessment (Schirripa and Legault 1997). That index and the one derived for this assessment (included the 1993 value) are contrasted in Figure 13. As noted in section 5.2, for the RMM ageing system used the juvenile-index values as indicators of abundance for each year-class; the fixed effects model including the value for 1993 was used, and the mean of the 1992 and 1994-1999 values was used for 1990 and earlier.

### 6.2 Commercial Handline, Longline and Trap Indices

Indices of abundance were derived from commercial trip reports included in the Reef Fish Logbook data base (Heinemann 2001a, 2001b and 2001c). In the handline and longline analyses, Heinemann did not find year interactions which met the criteria for inclusion in the model. In the analysis of the trap index a significant year-grid interaction was found in both the proportion positive and the positive catch rates. Because of the complexity of these interactions the trap index was derived from a fixed-effect model excluding these interactions. The handline, longline and trap indices are plotted in Figures 14-16.

### 6.3 MRFSS Index

An index was developed from the west-Florida sampling of charter and private/rental vessels conducted by MRFSS personnel. Information on targeting was incorporated in the model based on target information recorded during angler interviews, or, if not recorded, from the species composition of the catch. Targets were classified into five groups: gag, reef fish, pelagics and sharks combined, mixed and unknown. A delta model with a binomial error structure for the proportion positives and a log-normal error structure for the positive catch rates was used to develop the index. The final model for the proportion positive included the fixed-effects year, county, area (<10 mi, and > 10 mi), mode (private

and charter) and target. The final model for positive catch rates included those same fixed effects and a random year-mode interaction. The resulting index of abundance is shown in Figure 17.

#### 6.4 Headboat Index

An index of abundance was derived using a generalized-linear-model. Again, the delta-method approach was employed with a binomial error structure for the proportion positive and a poisson error structure for the positive catch rates (Brown 2001). The number of gag landed per angler hour was used as the measure of catch rates on trips which landed gag. The three zones in the eastern Gulf of Mexico were used in the analysis. The final proportion positive model included the fixed-effects year, month, vessel-within-zone and trip (half-day, three-quarter-day, full-day and multi-day). The final model of positive catch rates included the fixed effects year, month and vessel-within-zone. The standardized catch rates are shown in Figure 18.

### 7. Current Status, VPAs

VPAs were conducted on catches-at-age derived using (1) the recruitment-and-mortality modulated (RMM) approach of Goodyear (1997), which was used in previous gag assessments, or (2) the age-length-key plus stochastic growth-curve-based (ALK+) approach developed by Cummings and Parrack (in prep), using data provided by SEFSC, Panama City. The VPAs were similar to those used in the ADAPT approach (Powers and Restrepo 1992), with modifications added to provide greater flexibility in 1) the calculation/estimation of the fishing-mortality rates in the most recent year, 2) the fishing-mortality rates on the oldest ages in earlier years, and 3) the catchability coefficients (Porch 1999a).

The VPA analyses were conducted using one of two assumptions about the selectivity associated with the fishery dependent indices of abundance. For one set of analyses, the selectivity associated with each index was assumed to be constant over years. For the second set, the selectivity was assumed to vary annually. In assessments of other species, the year-constant selectivity has consistently provided better fits to the data (Porch personal communication, Turner *et al.* 2000), because it eliminates conflicting assumptions about catchability and selectivity. Nevertheless year-variable selectivity was considered here, because patterns in fishing-mortality rates estimated in the VPAs using the RMM catch-at-age under the constant index selectivity assumption indicated that very large year classes were less heavily exploited than less abundant year classes; thus, as those large year classes moved through the fishery, estimated selectivity at age changed from year to year (see section 7.1.2).

A summary of the four sets of VPA runs (two catches-at-age by two selectivity assumptions), and some additional runs, is provided in Table 17. One set of additional runs contrasted the effects of the different growth curves used in this assessment and the previous assessments. Additionally for each of the two catch-at-age types, and the two assumptions about index selectivity, two sensitivity runs were made (recruitment and commercial indices, and recruitment and recreational indices). For the ALK+



analyses with year constant index selectivity, an additional sensitivity analysis investigated the effects of assuming that selectivity in 1999 was the same for ages 6 years and older.

The natural mortality rate was assumed to be 0.15 in all models.

Unless otherwise noted, the fishing-mortality rates on ages 2, 4, 6, and 8 in the terminal year were estimated in the model. Based on assumptions made in the previous assessment, the fishing-mortality rates for other ages were based on assumed relationships to estimated values, as follows:  $\text{age}(0) = 0.05 * \text{age}(2)$ ,  $\text{age}(1) = 0.10 * \text{age}(2)$ ,  $\text{age}(3) = \text{age}(4)$ ,  $\text{age}(5) = \text{age}(6)$ , and  $\text{age}(7) = \text{age}(8) = \text{age}(9)$ . The fishing-mortality rate on the plus group (age 10 and greater) was set equal to the fishing-mortality rate on age 9.

All VPAs used the young-of-the-year index with the 1993 value estimated (Table 16, year-only model). Additionally, unless otherwise noted, four other indices were included: handline, longline, MRFSS and headboat. The trap index was not included because of the presence of significant year interactions, and because of possible effects of trap saturation.

For examination of results, abundances were tabulated for age 0, ages 1-4, 5-9 and 10+, and abundance-weighted average fishing-mortality rates were tabulated for ages 1-4, 5-9 and 10+. Ages 1-4 represent ages of fish with little or no reproductive output, ages 5-9 represent ages with substantial egg production, and ages 10+ should include some reproductive females and most of the reproductive males. Estimated abundances and fishing-mortality rates are shown in the tables only for year classes which recruited in 1996 and earlier, and through 1997 for ages 1-4 in the figures. These restrictions were used because the most recent year-class strengths, and the fishing-mortality rates on those year classes, typically were estimated with very high uncertainty and potential bias.

#### 7.1. Recruitment-and-Mortality Modulated Catch-at-Age VPAs

These analyses were conducted using the recruitment-and-mortality modulated (RMM) approach used in previous assessments. The approach incorporates expected abundances, which are derived from a recruitment index and total mortality rates (Goodyear 1997). For most analyses, RMM procedure was iterated 5 times, and at that point the VPA results were considered final. If fewer than 5 iterations were performed, the number of iterations is stated.

##### 7.1.1 Effect of different growth equations.

Catch-at-age was generated using the growth equation developed in the previous assessment and the one developed for this assessment (Cass-Calay *et al.* in prep). Both recruitment-and-mortality-ageing procedures used all five indices, and were run for one iteration. The catch-at-age estimated using the growth equation developed by Cass-Calay *et al.* is presented in Table 15, and the catch-at-age estimated using the growth equation from the 1994 and 1997 assessments is presented in Table 18. For most years, the estimated catch-at-age for age  $x$  from the equation developed by Cass-Calay *et al.* was of similar magnitude to the catch-at-age for age  $x+1$  estimated using the equation used in the earlier assessments. The differences in estimated fishing-mortality rates are shown in Figure 19.

The patterns in fishing mortality are similar, although the growth curve from this assessment suggests higher mortality rates for the 5-9 and 10+ age classes.

#### 7.1.2 Constant Index Selectivity

The RMM ageing was iterated five times with all five indices of abundance. The estimated catch-at-age from iteration 5 is presented in Table 19. The estimated catch of age 0 ranged from about 150,000 to about 350,000 fish per year, with values below 200,000 fish before 1993 and above that level thereafter. Estimated catches of ages 1-4 declined from about 700,000 fish annually in the mid-late 1980s to less than 300,000 fish in 1990, and then increased to about 800,000 annually in the mid- to late-1990s. Estimated catches of ages 10+ were estimated to be 5-8,000 fish annually in the period 1986-1995, with higher levels in the earlier part of that period; estimated catches then declined to less than 1,000 fish annually in 1998 and 1999.

The estimated abundances and fishing-mortality rates are presented in Tables 20 and 21, respectively. The selectivity patterns for each index of abundance (Figure 20) indicate that the MRFSS fisheries, dominated primarily by the private boat catch, exploited the youngest age composition, followed by the headboat fishery, the handline fishery and then the longline fishery. The fits to the indices of abundance are shown in Figure 21. The fit to the young-of-the-year index was much poorer than any of the other four indices, despite the inclusion of the index in the ageing phase. Neither of indices from the recreational fisheries were fit well in 1991-1994; the MRFSS index was poorly fit during the late 1990's. The indices from the commercial fisheries, which covered fewer years than those from the recreational fisheries, did not have residual runs for as many years as did the indices from the recreational fisheries. The summarized abundance estimates are shown in Figure 22, and the fishing-mortality rates in Figure 23. The estimated age-0 abundances showed three strong year classes in the early- to mid-1990s (1991, 1993 and 1996), with year classes from other years ranging from roughly 10% to 30% of the size of the 1993 year class. The abundance of 10+ gag was estimated to be relatively constant in 1986-1991, and then decreased until 1998-2000 when its estimates again relatively constant. Fishing-mortality rates were estimated to be generally higher on 5-9 and 10+ age groups than on 1-4 year olds. Estimated fishing-mortality rates on 1-4 year olds appeared to decrease in years when the larger year classes were age 1. Fishing mortality on ages 5-9 was estimated to have increased from the mid- to late-1980s to the mid-1990s, and then to have decreased.

The estimated fishing-mortality rates showed year-class effects (Table 21), particularly for age 3 and older. For instance, the fishing-mortality rate on the 1994 year class was substantially larger than the fishing-mortality rate on the 1993 year class in 1994-1998. Similarly, the fishing-mortality rate on the 1989 year class was larger than the fishing-mortality rate on the 1990 year class in 1990-1998. Such patterns suggested that the assumption of year-constant selectivity of indices of abundance might not be correct, and, therefore, year-variable index selectivity analyses were conducted (see section 7.1.3).

##### 7.1.2.1 Sensitivity Runs

Because of the differences in fits between indices from the recreational and commercial fisheries,

two sensitivity analyses were conducted to further investigate this feature – one with the commercial indices alone, which emphasized older ages, and another with recreational indices only, which emphasized younger ages. The young-of-the-year index was used in both sensitivity trials. The ageing procedures with each set of indices were iterated two times.

The analysis with the commercial indices had better fits to all three indices in the earlier parts of the time period (Figure 24), and a very different pattern of fishing-mortality rates compared to the base case (Figure 25). These results indicate that the current fishery has virtually no effect on the stock, and that the highest recruitment was on the order of 40 times larger than the smallest, unlike the prior run, which showed roughly a 10-fold range in year-class strength. This result is attributed to the estimation of two very large year classes (1993 and 1991), which were subsequently estimated to have reached the fishery, and are now entering into the plus group.

The run using the two indices from recreational fisheries had what appeared to be better fits to the MRFSS index in the most recent years, and the in earliest years. There was little change in the quality of the fits to the juvenile index, and a slight degradation in the fit to the headboat index (Figure 26). The estimated fishing-mortality rates were lower than in the runs with all indices (Figure 27).

### 7.1.3 Year Variable Index Selectivity

The catch-at-age derived with the RMM method, which used the recruitment index and mortality rates estimated from VPAs using year-variable index selectivity, is shown in Table 22. In general, the catch-at-age was similar to the catch-at-age estimated assuming year-constant index selectivity, although the 1998 and 1999 estimated recruitments were somewhat lower. However, the estimated catches of individual year classes aged 2-6 in 1999 were different between the year-constant and year-variable index selectivity runs – the 1997 year class showed a 30% increase, the 1996 year class a 55% decrease, the 1995 year class a 70% decrease, and the 1993 year class a 50% increase. The fits to the indices (Figure 28) were similar to those under the year-constant index selectivity assumption, although, in general, not quite as tight. The estimated abundance and fishing-mortality rates are presented in Tables 23 and 24, and are summarized in Figures 29 and 30, respectively. The estimated fishing-mortality rates in 1999 on ages 6 and 8 were 0.016 and 0.041, values substantially below the estimates from the run assuming year-constant selectivity (Table 21). The estimated recruitment of the 1993 year class (more than 50 million fish) was 10 times larger than the next largest year class (1991), and roughly 50-80 times larger than the remaining year classes (Table 22). The estimated fishing-mortality rates were somewhat lower than the fishing-mortality rates estimated under the year-constant index selectivity assumption through about 1991, then they declined to near zero by the late 1990s.

The Akaike Information Criteria (AIC) from the VPA assuming the year-variable index selectivity was substantially larger than the AIC from the VPA with the year-constant index selectivity assumption (Table 17), indicating that the model with the year-constant assumption was more parsimonious.

#### 7.1.3.1 Sensitivity Runs

The estimated fishing-mortality rates from both the recreational-only and commercial-only runs were unrealistically low for the older ages – less than 0.02 for ages 5 and older in the recreational analysis and for ages 3 and older in the commercial analysis (Table 17).

## 7.2 Age-Length-Key plus Stochastic growth-curve-based Catch-at-age

These analyses used the catch-at-age developed by Cummings and Parrack (in prep) based on the age-composition data provided by SEFSC, Panama City. It was anticipated that the VPA might have difficulty finding a solution with the catch of one fish at age 1 in 1999 (changed from 0 to 1, see section 5.2.2), and, therefore, it was decided to estimate 1999 fishing-mortality rates for both ages 0 and 1 in addition to ages 2, 4, 6 and 8, as was done for the RMM catch-at-age developed using the recruitment index and fishing mortality estimates.

The catch-at-age estimated with the ALK+ method differed in many respects from the catches-at-age estimated with the recruitment-and-mortality-modulated method. Catches of age 0 were estimated to be less than 10,000 fish before 1992, and less 65,000 fish later, compared to hundreds of thousands of fish estimated by the other approach. Catches of ages 1-4 were roughly 100,000 fish higher in 1986-1988, declined to about the same level as the recruitment-and-mortality-modulated catch-at-age in 1990, and, thereafter, were roughly 100-200,000 fish higher in most years. Catches of ages 5-9 were often 50-100,000 fish higher in this catch-at-age than in the RMM catches-at-age. Catches of ages 10+ were estimated to be roughly 15-25,000 fish annually in the 1986-1988, and since have ranged from about 6-14,000 fish, differing from the alternative catch-at-age in the 1986-1988 levels and the 1998 and 1999 levels.

### 7.2.1 Constant Index Selectivity

The selectivity patterns for each index of abundance (Figure 31) indicated that exploitation was primarily on 4-8 year olds in contrast to the selectivities estimated from the RMM catch-at-age (Figure 20) which indicated high exploitation rates by at least one gear on the 1-10+ age groups. Additionally in contrast to the RMM catch-at-age, the age with the highest selectivity was older for the recreational fisheries with the ALK+ catch-at-age, and the age with the highest selectivity was younger for the commercial fisheries. These estimated selectivity patterns all indicated that ages 9 and older were less vulnerable to fishing than younger ages. The reliability of that estimate will depend on the quality of the ageing data. Cummings (pers comm) has indicated low confidence in age-length-key estimates for ages over age 8, but a higher level of confidence in the stochastic ageing until age 15. It should be noted that the commercial index selectivity patterns were derived primarily with age-length-key estimates (1992-1994, January-June in 1995 and 1996, and 1998-1999), while the recreational index selectivity patterns are based on catches-at-age estimated with both components of this ageing approach (ALK+). The lower selectivity patterns for the 9 and 10+ groups might result in greater uncertainty about the estimates of abundance for those ages.

The fits to the indices are shown in Figure 32. AS would be expected, the fit to the trawl-survey index was much worse than in the VPAs run with the recruitment-and-mortality catch-at-age calibrated to that index, while the fits to the fishery dependent indices were generally tighter.

The estimated abundances and fishing-mortality rates derived using the ALK+ catch-at-age and the constant index selectivity assumption are given in Tables 25 and 26, and are summarized in Figures 33 and 34. The estimated recruitment patterns were less variable than those estimated using the recruitment modulated catch-at-age (Figures 22 and 30). In addition, the 1991 and 1993 year classes were estimated to be smaller and more similar to the surrounding year classes. The abundances of the 1-4 and 5-9 year old groups were estimated to be about twice as large as with the alternative catch-at-age. The changes in abundance of the 10+ group were completely different – much higher 1986 abundances followed by an increase (approximately 300%) during 1990-2000, compared to a decline (85%) during 1991-1998 in the analysis under the alternative catch-at-age. Fishing-mortality rates were estimated to be generally below 0.2, substantially less than with the RMM catch-at-age, and the fishing-mortality rates on 10+ gag were estimated to be quite low (Figure 34).

#### 7.2.1.1 Sensitivity Analyses

##### 7.2.1.1.1 Sector Specific Sensitivity Analyses

The estimated fishing-mortality rates from the sensitivity runs using the young-of-the-year and the recreational indices had fishing-mortality rates similar to those from the run with all four indices (Table 17). In contrast, the estimated fishing-mortality rates were higher for most ages, especially age 4.

##### 7.2.1.1.2 Uniform Selectivity on Older Ages

The decrease in index selectivity at the older ages (Figure 31) was considered questionable, because large changes in selectivity among age groups of similar average sizes may be unlikely in the presence of fisheries which exploit the larger fish in a population. Therefore additional analyses to explore alternative assumptions about selectivity on older ages were conducted. If the selectivities were equal for the oldest ages and if the estimated fishing-mortality rates for age-8 fish were greater than the 0.012 (for the analysis just described in section 7.2.1), then a more realistic abundance pattern might be estimated. In the primary analyses for ALK+ catch-at-age, the 1999 fishing-mortality rates on ages 0, 1, 2, 4, 6, and 8 years were estimated. For the sensitivity analysis, the 1999 fishing-mortality rates on ages 0, 1, 2, 4, and 6 years were estimated; the fishing-mortality rates for ages 5 and 7-9 were set equal to that for age 6. The estimated fishing-mortality rates were substantially higher on age 4 and on age 6 (Table 17). The associated fits are shown in Figure 35. Estimated abundances and fishing-mortality rates are given in Tables 27 and 28, and are summarized in Figures 36 and 37, respectively.

#### 7.2.2 Year Variable Index Selectivity

The AIC from the analysis assuming year-variable index selectivity was about 20% higher than in the analysis with the year-constant index selectivity assumption, indicating that the year-constant assumption provided a more parsimonious explanation of the data (Table 17).

The abundances and fishing-mortality rates estimated with the ALK+ catch-at-age and year-variable index selectivity are presented in Tables 29 and 30, and are summarized in Figures 39 and 40. The estimated levels of recruitment were more variable and somewhat smaller than in the corresponding

analysis with year-constant index selectivity (Figure 33). The estimated abundances of ages 1-4 increased in a similar pattern, but to lower levels, while the 5-9 year olds were at roughly similar levels in 2000 as in 1986 in the variable-selectivity case, but were roughly 2.5 times higher in 2000 than in 1986 in the constant-selectivity analysis. The abundances of ages 10+ in the year-variable analysis increased about 50% between 1986 and 2000, while in the year-constant analysis that group increased to about 4 times its initial levels.

#### 7.2.2.1 Sensitivity Analyses

The estimated fishing-mortality rates from the analysis with the young-of-the-year index and the recreational indices were substantially lower than the estimates from the analysis with all five indices (estimates for ages 2, 4 and 6 roughly one third lower; Table 17). In contrast, the estimates from the analysis with the young-of-the-year index and the commercial indices generally were 2-3 times larger than in the analysis with all five indices.

### 7.3 Overview of VPA Results

The catches-at-age used for the two sets of analyses differed. The recruitment-and-mortality-modulated catches-at-age indicated larger catches of age 0 and lower catches of age 1-4 and 5-9; the ALK+ catch-at-age had higher catches of ages 10+ in the earlier and later years (Tables 15, 22 and 25).

The estimated fishing-mortality rates in 1999 from the RMM catches-at-age were higher on age 2 and lower for age 4 (Table 17). In the year-constant selectivity analyses the selectivity patterns differed between the two catches-at-age (Figures 20 and 31).

Substantial increases occurred in all catch rates in all fisheries from the late 1980s/early-1990s to late-1990s. The catches (landings plus dead discards) did not necessarily match this patterns. Recreational catches were relatively high in the mid- to late-1980s, low in the early-1990s, and increased rapidly thereafter (Figure 9). That pattern was matched in the headboat, but not MRFSS, catch rates; the latter were at their lowest in the mid- to late-1980s and increased by 2-3 times in the early-1990s (Table 16). Commercial catches roughly doubled from the late-1980s/early-1990s to the late-1990s, whereas the commercial catch rates increased to 4-5 times over the early-1990s levels by the late-1990s. These differences in patterns between catches and catch rates can make it difficult for the VPAs to find solutions.

A wide range of fishing-mortality rates and associated abundances were estimated, and, therefore, there is uncertainty in the current (1999) status of gag in the Gulf of Mexico. Some of the estimates may be unrealistic based on what might be considered very large changes in abundance. For example, in the analysis using a catch-at-age derived with the ALK+ method under the assumption of constant-index selectivity when ages 0, 1, 2, 4, 6, and 8 were estimated, the age 10+ abundances were estimated to have increased approximately 4 times over 1986 level. Likewise, in the analysis using the RMM catch-at-age with year-variable index selectivity, the number of recruits from the 1993 year class was estimated to be roughly 50 times larger than most other year classes.

## 7.4 Comments and Recommendations Concerning VPAs

Both catches-at-age would have been impacted by the uncertainty in the size composition of the discarded catch (section 5.1). The discarded recreational catch represents roughly 40-50% of the total estimated number of fish killed in recent years (Figure 9). Size samples from discards were available from only a few years and gears; sizes less than 51 cm TL from 1986-1989 were almost always assumed to represent the size composition of discards since size limits were imposed. Additional at-sea sampling of kept and released fish, such as is being conducted at the Mote Marine Lab under a MARFIN contract, is needed.

The apparent selectivity of the commercial gears in the ALK+ analyses decreased above age 7 (gag average 90 cm at age 7.5 years), which was unexpected especially for the longline fishery which historically caught fish to 120 cm (on average 16 years old at 120 cm). From examination of the age-composition data, Cummings (pers. comm.) recommended using an 8+ group rather than a 10+ group with the catches-at-age estimated from an age-length-key, and suggested that the decrease in selectivity above age 8 could be associated with low numbers of fish sampled at age for those ages. In the future, alternative plus groups should be considered.

Imprecision and inaccuracies in the young-of-the-year index used in estimating the catch-at-age with the RMM catch-at-age could have resulted in inaccuracies in the estimated catches-at-age. There were no standardized estimates of recruitment for many of the year classes (1976-1990; a mean from years of moderate recruitment was used), and in order to include the 1993 year class an index without year interactions had to be used. Additionally, Fitzhugh *et al.* (2001) indicated that the 1996 year class appeared to be large, while the recruitment index indicated that it was only of moderate size, suggesting great imprecision if the age composition data is considered a reliable indicator of year class strength. The impact of using the mean of all observed catch rates, rather than the mean of catch rates from moderate years should be investigated.

In the future, if the recruitment-and-mortality modulated (RMM) ageing approach is to be used, consideration should be given to incorporating the ageing and assessment phases in the same routine so that a simultaneous solution for all parameters could be obtained in a statistical modeling approach.

It is also recommended that statistical estimation systems which assume error in catches and other inputs be considered.

The terminal year parameters estimated for this assessment were initially limited to fishing-mortality rates for ages 2, 4, 6 and 8 years, based on the selection of an assessment from 1997 (Schirripa and Legault 1997) by the Reef Fish Stock Assessment Panel. Some deviations from estimating those ages were investigated because of data limitations or for sensitivity analyses. It is recommended that in the future consideration be given to investigating other combinations of terminal year parameters.

## 8. Management Reference Points and Projections

Management reference points were calculated from the deterministic VPA results given a modified selectivity vector which attempted to account for recent management actions and two contrasting assumptions about possible stock-recruitment relationships. Bootstrapping was used to estimate the uncertainty about the deterministic results, and to provide an indication of bias in the estimates. Projections were conducted for possible use in estimating the impacts of various landings scenarios in the short term, and possible recovery times in the longer term.

Two of the VPAs from the four catch-at-age and index-selectivity combinations produced estimates of 1996-2000 stock sizes that were considered more likely than others to reflect stock status; namely the VPA using the recruitment-and-mortality modulated (RMM) catch-at-age with the year-constant selectivity assumption (section 7.1.2), and the VPA using the ALK+ catch-at-age with the year-variable index selectivity assumption (section 7.2.2). The VPA which used the RMM catch-at-age with the year-variable selectivity assumption (section 7.1.3) was considered unrealistic because of the estimated size of the 1993 recruitment (Figure 29). The VPA using the ALK+ catch-at-age with the year-constant index selectivity assumption (section 7.2.1) was considered unrealistic because of the rate of increase in the size of the 10+ group throughout the period, and its estimated size in 2000 (Figure 33). To provide information on the possible effects of assuming that the selectivity on the oldest ages was equal to that on ages 5 and 6 for the ALK+ catch-at-age with the year constant index selectivity assumption, reference points and projected stock sizes were calculated for the sensitivity case described in section 7.2.1.1.2. It is suggested that before the reference-point information from that sensitivity analysis be used for management, further exploration of the effects of estimating fishing-mortality rates for additional ages in 1999, and the effects of alternative plus group assumptions, should be conducted.

Gag grouper is a protogynous hermaphrodite, which means that females change to males. Generally the largest fish are males, and, as such, may be especially vulnerable to fishing. Because gag change sex the status of both the male and female portions of the population may be of concern to managers. Therefore, the status of both female and male reproductive condition in the Gulf of Mexico was calculated. For females, reproductive condition was measured in terms of total female gonad weight for the proportion of the population above 56 cm (22") using the model preferred by the Reef Fish Assessment Panel from the 1997 assessment. That metric was the product of the number of fish at age, the proportion female at age, and the truncated (56 cm and larger) gonad weight at age (Figure 41). Male reproductive condition was estimated as the product of numbers at age, the proportion male at age, male maturity at age (derived from Hood and Schlieder, 1992), and weight at age (Figure 42). Males age 7 and below were assumed to be immature, 75% of 8 and 9 year-old males were assumed to be mature, and all males age 10 and older were assumed to be mature.

Reference points needed for defining the current (1999) status of gag in the Gulf of Mexico were estimated based on the results of the various VPA analyses. The fishing-mortality rate that produces a 30% spawning potential ratio ( $SPR_{30\%}$ ) was used as the proxy for the fishing-mortality rate at MSY (maximum sustainable yield), and the fishing-mortality rate that produces a 40% spawning potential ratio ( $SPR_{40\%}$ ) was used as the proxy for OY (optimum yield). Because the female reproductive-potential function reaches a maximum at age 8, long-term fishing at  $F_{30\%}$  and  $F_{40\%}$  will generally result in the relatively low biomass levels of males. The combination of the female reproductive function and the assumed selectivity pattern (see below) results in estimates of  $F_{30\%}$  and  $F_{40\%}$  which are much higher



(about 2-3 times) than the assumed natural mortality rate. Because males are older, maximizing male biomass would require a lower fishing-mortality rate. A bench mark that maximizes the yield from the entire population, given estimated recruitments, is  $F_{\max}$ , the fishing mortality rate at which yield per recruit is maximized. Because of gag growth patterns and the female reproductive characteristics,  $F_{\max}$  is lower than both  $F_{30\%}$  and  $F_{40\%}$ . The obvious implication here is that larger long term yields could be obtained at fishing mortality levels lower than  $F_{30\%}$  and  $F_{40\%}$ .  $F_{\max}$  was selected as an additional reference fishing-mortality rate to provide some measure of the effects of lower fishing rates on both female and male gag.

A stock-recruitment relationship is needed to estimate potential yields such as the MSY and OY proxies. The estimated spawning-stock sizes and recruitments from the deterministic runs from each of the two VPAs in which fishing-mortality rates for ages 2, 4, 6 and 8 in 1999 were estimated are shown in Figures 43 and 44, and for the sensitivity run on the ALK+ catch-at-age using year variable index selectivity in which ages 0, 1, 2, 4 and 6 were estimated in Figure 45. The stock-recruitment estimates from the RMM catch-at-age showed little indication that recruitment was influenced by stock biomass over the range estimated, while with the analyses of ALK+ catch-at-age, there was some indication of increasing recruitment with spawning stock. The small number of spawning stock sized and recruitment observations, and their general distributions, suggested that it would not be possible to estimate reasonable Beverton and Holt stock-recruitment equations. Two hockey-stick stock-recruitment relationships, similar to those described by Barrowman and Meyers (2000) were examined for each set of VPAs. In one stock-recruit relationship, projected recruitment was assumed to equal the 1986-1996 geometric mean recruitment with recruitments below the minimum observed spawning-stock biomass assumed to decrease linearly to zero. The second stock recruitment relationship assumed that recruitment would increase linearly from zero to the highest spawning stock size observed along a linear regression slope fit to the observed data, and above the maximum observed spawning stock size, recruitment would equal the amount predicted by the regression at the maximum. For all analyses, recruitment was assumed to have a log-normal distribution with a standard deviation of 0.3.

Projections to 2012 were conducted to determine the time in might take for spawning-stock biomass to achieve the minimum spawning-stock size threshold, the yield associated with various fishing-mortality rate reference levels, as well as the mortality rates associated with possible future yield levels. Historical and predicted future yields and yield-per-recruit statistics under the various scenarios projected were in landed weight (estimated yield of discards was not included); however projected dead discards were accounted for in the calculations.

Recruitment estimates in the latest years of VPAs are often highly uncertain. Therefore, for each boot-strapped VPA, the 1997 through 1999 recruitments were replaced with estimates from the spawning stock-recruitment relationship and that year's estimated spawning-stock size. In those years, the associated fishing-mortality rates were recalculated to be consistent with the substituted levels of year class strength.

The selectivity pattern used in calculating the reference points, and in the projections, was derived from the geometric means of the estimated fishing-mortality rates for 1997-1999 for each bootstrap and then further modified to try to account for the effects of new size regulations that went into effect in 2000. While several of the fishing-mortality rates in 1999 were externally fixed rather than

having been estimated in the VPAs, the 1997-1999 period was selected for calculating the geometric means, because at least in some of the deterministic VPAs the estimated fishing-mortality rates were changing rapidly during that period. The new size limits raised the minimum size from 51 to 56 cm for recreational landings, and to 61 cm for commercial landings. Fish of 51 cm were assumed to be 1 year old, and fish of 52-60 cm were assumed to be 2 years old. The numbers landed in each of those ages during 1997-1999 were tabulated by sector from the catch-at-size. The number that would not have died was calculated assuming 80% survival for the recreational sector, and 70% for the commercial sector (sensitivity to those survival rates has not been investigated). The proportionate reduction in the total number killed was then calculated for each year, and the geometric mean of the annual values (about 0.05 for age 1, and 0.65 for age 2) was used to reduce the selectivity in the year 2000 and beyond.

For the projections, the removals in 2000 were calculated to be 5.4 million pounds including dead discards. The preliminary estimate of commercial landings was 1.7 million pounds. For the MRFSS, the A+B1 catches and the B2 catches were 544,188 fish and 1,306,024 fish respectively; as with the VPA inputs, 20% of the B2s were assumed to have died. The commercial discards, the headboat landings and the headboat discards were calculated from the geometric means of the 1997-1999 catches in numbers of fish. The yields from the MRFSS and headboat landings were calculated using the geometric means of the 1997-1999 average weights.

The uncertainty in current (1999) management reference points and their bias, as well as projected stock sizes along with their associated uncertainty, were estimated from 500 bootstraps of the VPAs. For bootstrapping, the residuals for each index were rescaled by their calculated variance and non-parametrically resampled (Porch 1999b). Bias is expected in non-linear modeling when limited numbers of observations are used to estimate relatively large numbers of parameters. The degree of bias may be an indicator of the ability of the model to provide meaningful information. There is debate about whether to correct estimates for bias in part because there is uncertainty in the estimate of the bias (Efron and Tibshirian 1993).

Both uncorrected and bias-corrected estimates are provided. The bias in the deterministic estimate was assumed equal to the difference between the bootstrap median and the deterministic estimate. Bias correction was attempted by subtracting the estimated bias from the deterministic estimate. For individual bootstrap results of current status, both uncorrected and bias corrected plots are presented.

## 8.1. Recruitment-and-Mortality Modulated Catch-at-Age with Year Constant Selectivity

### 8.1.1 Hockey Stick with Recruitment Increasing with Spawning Stock Biomass

Current relative spawning-stock biomass, current relative fishing-mortality rates and various management reference points are shown in Table 31 for the assumption that recruitment increases with female spawning stock size over the range of estimates from the VPA. The spawning-stock size was estimated to be 70% (75% after bias correction) of the stock size at  $F_{30\%}$  (about 82% of MSST; 88% after bias correction; MSST taken as  $(1-M)*SSB_{30\%}$ ). The current fishing-mortality rate was estimated

to be just below (7% after bias correction) the estimated MFMT proxy ( $F_{30\%}$ ). The empirical 80% confidence-interval range was relatively small (16%) for the spawning-stock biomass ratio to the benchmark, while that range for the fishing-mortality rate ratio was much broader (79%). Cumulative distribution plots for various reference statistics are shown in Figure 46.

The individual bootstrap estimates (not-bias corrected) of the status of gag in 1999 all indicated that spawning-stock biomass was less than the minimum spawning-stock threshold, and the majority of cases indicated that fishing exceeded the fishing-mortality limit for the associated stock size (Figure 47). The relationship between the deterministic and median bootstrapped estimates of the current status indicated that bias was small relative to the dispersion in the estimates, and, therefore, bias correction shifted the distribution very little, but resulted in a small fraction of the outcomes indicating fishing mortality rate less than MFMT and spawning stock biomass greater than MSST. The deterministic estimate was positively biased for  $F$  and negatively biased for SSB based on bootstrap results; bias corrected plots of individual bootstrap results showed an increased proportion of current fishing levels below the fishing-mortality rate limit (Figure 47). Similar plots for  $F_{\max}$  reference points, showed fishing-mortality rates roughly 1.5-10 times, and spawning stock sizes roughly 20-50%, of those that would optimize yield per recruit for the whole population (Figures 48); as with the  $F_{30\%}$  bootstraps, the bias was small relative to the dispersion in the estimates.

The projected recruitment under an assumption of no fishing mortality in 2002 and beyond showed relatively high levels of recruitment at about the year-2000 level for 2001 and later (Figure 49). When reference fishing-mortality rates ( $F_{30\%}$ ,  $F_{40\%}$ ,  $F_{\max}$ , and  $F_{\text{status quo}}$ ) were imposed in 2002-2012, possible annual yields of 8-10 million pounds by 2012 were projected (Figure 50). Historic (1986-1999) fishing-mortality rates exceeded the benchmark rates under the projected selectivity pattern (Figure 51). The projected median fishing-mortality rates relative to  $F_{30\%}$  and  $F_{\max}$ , associated with yields from 2 - 8 million pounds, indicated that constant removals of 6 million and 5 million pounds, respectively, would result in projected fishing-mortality rates equal to, or below, the reference level before 2012 (Figures 51 and 52). Projected female spawning-stock sizes relative to reference spawning-stock sizes indicated that the  $F_{30\%}$  and  $F_{40\%}$  levels of spawning stock biomass might be reached before 2012 with yields of 6 million pounds, while the spawning-stock size associated with  $F_{\max}$  would be achieved with yields of 4 million pounds under the projected selectivity pattern (Figures 53, 54 and 55). Male spawning-stock biomass was estimated to have been well below 1% of unexploited levels during the 1980's and most of the 1990's, and was projected to increase under all constant fishing-mortality rate scenarios, and under the yield scenarios of 6 million pounds and less (Figure 56 and 57).

#### 8.1.2 Hockey Stick with Average Recruitment above Minimum Spawning-Stock Biomass

The reference fishing-mortality rates and spawning stock sizes estimated under the average recruitment assumption were lower than under the assumption of increasing recruitment with spawning stock size while the reference spawning stock sizes were substantially lower (compare Tables 31 and 32). The relative current fishing-mortality rates and the spawning-stock biomass estimates for the most recent period were both estimated to be in excess of the reference levels for this model and stock-recruitment relationship. Cumulative distribution plots for various reference statistics are shown in Figure 58. The scatter plots of bootstrapped current status (Figures 59-60) reflected those patterns; for the

$F_{30\%}$ , reference points, nearly all estimated fishing-mortality rates exceeded  $F_{30\%}$ , while the spawning-biomass levels ranged from about equal to about three times the spawning stock produced by fishing at  $F_{30\%}$ . For the  $F_{\max}$  reference points, most fishing-mortality rates were 2-6 times higher than the levels that would produce the maximum yield per recruit and, most spawning-stock biomass estimates were less than the spawning-stock biomass at which yield per recruit would be maximized. The relationship between the deterministic and median reference points indicated that the estimated bias was substantially lower than the overall uncertainty in the estimates.

Median projected recruitment (Figure 61) was at a much lower level than under the assumption that recruitment would increase with spawning stock size (Figure 49), and was unaffected by the projected catch and mortality-rate levels. Projected yields at reference fishing-mortality rates ( $F_{30\%}$ ,  $F_{40\%}$ , and  $F_{\max}$ ) decreased to about 1.9 million pounds in about 5 years, and then climbed to levels similar to those observed in the early 1990s (roughly 2.5 million pounds) by 2012 (Figure 62). With yields of 4 million pounds or more, projected median spawning stock size relative to spawning stock size at  $F_{30\%}$  declined to very low levels in less than a decade (Figure 65).

## 8.2. Age-Length-Key and Stochastic growth-curve-based Catch-at-Age with Year Variable Selectivity

### 8.2.1 Hockey Stick with Recruitment Increasing with Spawning Stock Biomass

For the ALK+ catch-at-age combined with the assumptions of 1) year constant index selectivity, 2) increasing recruitment with spawning-stock size to the maximum 1986-1999 estimated spawning-stock size, and 3) the projected selectivity pattern, the estimated current stock size (without bias correction) was about 86% of the estimated spawning-stock size associated with  $F_{30\%}$  and slightly above the minimum stock size threshold (Table 33). The 1997-1999 geometric mean fishing mortality was estimated to be below  $F_{30\%}$  – approximately 23% for the uncorrected estimate, and just below for the bias-corrected estimate. Cumulative-distribution plots for various reference statistics are shown in Figure 70. Scatter plots of the current status relative to bench marks indicated that most of the spawning-stock size estimates were between 0.6 and 1.1 times the spawning-stock size associated with  $F_{30\%}$ , and the estimated fishing-mortality rates ranged from about 0.2 to 1.1 times  $F_{30\%}$  (Figure 71). There appeared to be little or no bias in the spawning-stock biomass ratios, but the deterministic estimate of the fishing-mortality rate ratio was about 33% higher than the median ratio from the bootstraps. The uncorrected and bias corrected scatter plots of the ratios with respect to  $F_{\max}$  indicated that nearly all estimated stock sizes were below the stock size that would produce the maximum yield per recruit (Figure 72). Roughly half of the estimated fishing-mortality rates were below  $F_{\max}$  in the uncorrected case, while nearly all were above  $F_{\max}$  after bootstrap bias correction.

The projected recruitments under all scenarios investigated increased to levels somewhat higher than highest level estimated for 1986-1996, and were highly variable with upper 80% empirical confidence limits over 35 million recruits (Figure 73). The median of projected yields under all fishing-mortality rate scenarios increased to levels considerably higher than those estimated for 1986-1999 (Figure 74). The median female spawning-stock sizes were estimated to have been less than 50% of reference levels through the mid 1990's (Figures 77-80). Historic median male spawning-stock biomass was estimated to have been less than 1% of equilibrium levels under no fishing (Figure 80).

### 8.2.2 Hockey Stick with Average Recruitment above Minimum Spawning-stock Biomass

Under the assumption that recruitment would equal the 1986-1996 average at spawning-stock sizes equal to or greater than the minimum observed during 1986-1999, the projected fishing-mortality rates were similar to those projected under the assumption that recruitment would increase with spawning-stock size (Table 34). In this case, the spawning-stock size in 2000 from the VPA was estimated to be well above the stock size associated with  $F_{30\%}$ , but the bootstrap bias corrected spawning-stock size was estimated to be at 68% of that level. Cumulative-distribution plots for various reference statistics are shown in Figure 82. The scatter plot of bootstrapped solutions to the VPA with statistics relative to the  $F_{30\%}$  reference points showed the wide spread in solutions, with respect to the spawning-stock status in 2000, and the relatively large differences in the deterministic VPA estimates and the bootstrapped medians (Figure 83). The wide scatter and relatively large estimated bias in spawning-stock biomass both suggest a great deal of uncertainty in the estimates of stock status, and the associated management reference points.

The median of projected recruitment was at levels similar to those estimated for late 1980's and early 1990's, and substantially below recent levels of recruitment (Figure 85). Estimated median yield at reference fishing-mortality rates was projected to stabilize near historically high levels (Figure 86). Yields of about 6 million pounds resulted in projected median spawning-stock sizes above the stock size associated with  $F_{30\%}$  in 2005-2012, although there was considerable uncertainty in the projected outcomes (Figure 89). Historic median mature male biomass was estimated to be about 1% of that which might occur under unfished conditions and to be at 4-5% of such levels by 2012 if fishing were to occur at  $F_{30\%}$  (Figure 92).

### 8.3. Age-Length-Key and Stochastic growth-curve-based Catch-at-Age with Year Constant Selectivity

This case, which is presented as a sensitivity treatment, was derived from the VPA in which fishing-mortality rates of ages 7-10+ were forced to be equal to the fishing-mortality rate on age 6 fish, to investigate alternatives to the dome shaped index selectivity patterns.

#### 8.3.1 Hockey Stick with Recruitment Increasing with Spawning-stock Biomass

For the ALK+ catch-at-age combined with the assumptions of 1) year constant index selectivity, 2) increasing recruitment with spawning-stock size to the maximum 1986-1999 estimated spawning-stock size, and 3) the projected selectivity pattern, the estimated current stock size was about 8% below the spawning-stock size associated with  $SPR_{30\%}$  without bias correction, and 2% below after bias correction (Table 35). Estimated fishing-mortality rates were 65-70% below  $F_{30\%}$ . Cumulative-distribution plots for various reference statistics are shown in Figure 94. The scatter plots of bootstrap estimates of the relative status measures indicated that the majority of solutions were below  $F_{30\%}$ , and that the majority of the estimated spawning-stock sizes were above the minimum stock-size threshold (Figures 95 and 96).

The median of projected recruitment was slightly higher than the estimated recruitments in 1993 and 1994 (Figure 97). Projected long term yields associated with the various reference fishing-mortality rates were on the order of 14 million pounds, more than twice the maximum historic (1986-1999) levels (Figure 98). Historic fishing-mortality rates were estimated to be between 0.5 and 1.5 times  $F_{30\%}$ , while projected fishing-mortality rates at yields of 8 million pounds and less were projected to decline to below one-half of  $F_{30\%}$  (Figure 99). Historic levels of spawning-stock biomass were estimated to have been roughly 25% of the spawning-stock biomass associated with  $F_{30\%}$ , and spawning-stock biomass was projected to reach levels more than 1.75 times the spawning-stock biomass associated with  $F_{30\%}$  at yields of 8 million pounds (Figure 101). Male spawning-stock biomass was estimated to have been below 1% of unfished levels in 1986 through 1999, and then was projected to increase (Figures 104 and 105).

### 8.3.2 Hockey Stick with Average Recruitment above Minimum Spawning-stock Biomass

For the ALK+ catch-at-age combined with the assumptions of 1) year constant index selectivity, 2) average recruitment above the minimum spawning-stock size estimated for 1986-1999, and 3) the projected selectivity pattern, the current stock size was estimated to be roughly 40% to 60% above the spawning-stock size at  $F_{30\%}$ , and, as with the increasing recruitment bootstrapped VPAs, the 1996-1999 geometric mean fishing-mortality rate was estimated to be roughly 30% below  $F_{30\%}$  (Table 36). Cumulative-distribution plots for various reference statistics are shown in Figure 106. The scatter plots of bootstrapped estimates of current status indicated a broad range of solutions with respect to relative spawning-stock size with most ranging from 0.85 (the minimum stock size threshold) to 3 times the stock size at  $F_{30\%}$  under equilibrium conditions; with most estimates of fishing-mortality rates less than  $F_{30\%}$  (Figure 107).

Median recruitment was projected to be at about the 1991 level; the higher levels of recruitment estimated for the mid- and late-1990s were close to, or above, the upper 80% empirical confidence level for the projected recruitments (Figure 109); projected recruitments were unaffected by fishing at reference fishing-mortality rates, or by levels of landings up to 8 million pounds. Projected yields by 2012 under reference fishing-mortality rates were at about 5.5 million pounds, which was about as high as, or higher than, all but two of the landings levels during 1986-1999 (Figure 110). If fishing mortality in 2000 and 2001 were at the projected levels, about 60% of  $F_{30\%}$ , then the projections indicated that yields of 6 million pounds would not result in  $F_{30\%}$  by 2012 (Figure 111). Median historic male spawning-stock biomass was estimated to have been at about 1% to 1.5% of levels under equilibrium unfished conditions; the projections indicated that male spawning-stock biomass would increase until about 2005, to at least 5% of the unfished condition (Figures 116 and 117).

### 8.4 Overview of Management Reference Point and Projection Results

The two stock-recruitment assumptions investigated had different implications for management with respect to spawning-stock status. The average recruitment assumption implied that the recruitment levels estimated for the mid- to late-1990s were unusual, and that recent harvest rates could not be sustained. It also implied that the minimum stock-size threshold is relatively low. The assumption that recruitment increases with spawning-stock size resulted in higher estimates of both long term yield and

the minimum stock size threshold. Under that stock-recruitment assumption, recent (1986-1999) estimated spawning-stock sizes would be below the minimum stock size threshold.

In contrast to the spawning-stock status results, the relative fishing-mortality rate measures were only slightly influenced by the assumed relationship between stock and recruitment.

An important point for the RFSAP to consider is the choice of MSY proxies given the protogynous hermaphroditic life history of gag grouper. As can be seen in Tables 31-36,  $F_{\max}$  is typically about half of  $F_{30\%}$  while the female SSB at  $F_{\max}$  is about double the SSB at  $F_{30\%}$ . This happens because reproductive potential for the average female decreases rapidly after age 9 (Figure 41), whereas the average weight per fish increases substantially. Accordingly, increasing  $F$  has a proportionally greater negative impact on the biomass of older fish. Under the projected selectivity scenario's examined here, an  $F_{\max}$  policy would achieve greater long-term yields and a higher SPR (43% - 65%) than would policies based on  $F_{30\%}$  or  $F_{40\%}$ . An  $F_{\max}$  policy also leads to less-optimistic appraisals of stock status-- in every case the stock is perceived as both overfished and undergoing overfishing (Figures 118 and 119).

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Table 1. Proportion of gag + black grouper in commercial landings assumed to be gag by state and for Florida by county as reported by Schirippa and Goodyear (1994).

state	county	proportion gag
TX	all	1.000
LA	all	1.000
MI	all	1.000
AL	all	1.000
wFL	Escambia	1.000
wFL	Santa Rosa	1.000
wFL	Okaloosa	1.000
wFL	Walton	1.000
wFL	Bay	1.000
wFL	Gulf	1.000
wFL	Franklin	1.000
wFL	Wakulla/Jefferson	1.000
wFL	Taylor	1.000
wFL	Dixie	1.000
wFL	Levy	1.000
wFL	Citrus	1.000
wFL	Hernando	1.000
wFL	Pasco	1.000
wFL	Pinellas	1.000
wFL	Hillsborough	1.000
wFL	Manatee	0.704
wFL	Sarasota	0.653
wFL	Charlotte	0.633
wFL	Lee	0.438
wFL	Collier	0.320
wFL	Monroe	0.298

Table 2. Annual proportion of unclassified groupers reported from Florida assumed to be gag as estimated from the proportion of calculated gag in the commercial landings of identified groupers in the accumulated landings data.

year	proportion gag
1986	0.1626
1987	0.1460
1988	0.1493
1989	0.1623
1990	0.2280
1991	0.1920
1992	0.2227
1993	0.1910
1994	0.1990
1995	0.2124
1996	0.2166
1997	0.1971
1998	0.3236
1999	0.2131
2000	0.2287

Table 3. Calculated commercial landings of gag from the U.S. waters in the Gulf of Mexico by year and state in thousands of pounds gutted weight. Landings for 2000 are preliminary.

	TX	LA	MI	AL	WFL	total
1986	8	34			1,537	1,578
1987	2	37		2	1,399	1,439
1988	2	30		16	1,091	1,139
1989	2	16		0	1,602	1,620
1990	0	19		1	1,748	1,768
1991	1	25			1,481	1,507
1992		16			1,555	1,571
1993	2	19	1		1,747	1,769
1994	1	16	1		1,519	1,537
1995	2	22	0		1,515	1,538
1996	0	22	1		1,446	1,469
1997	2	30	2		1,466	1,499
1998	1	50	6	1	2,347	2,405
1999	4	47	4		1,920	1,975
2000	3	45	6	1	1,620	1,675

Table 4. Calculated commercial landings (thousands of pounds) of gag from U.S. Gulf of Mexico waters by year and gear in thousands of pounds gutted weight.

	fish traps	handline	longline	other	spear	total
1986	13	1,084	476	6	0	1,578
1987	15	792	627	3	2	1,439
1988	9	699	404	24	4	1,139
1989	10	1,146	424	37	3	1,620
1990	24	1,075	627	40	1	1,768
1991	37	925	503	41	1	1,507
1992	28	921	578	43	1	1,571
1993	54	1,118	549	49		1,769
1994	26	1,090	376	45		1,537
1995	69	1,117	298	54	0	1,538
1996	31	1,077	297	57	7	1,469
1997	31	1,080	320	68	2	1,499
1998	19	1,780	507	99	0	2,405
1999	21	1,277	555	122	1	1,975
2000	21	1,003	391	241	19	1,675

Table 5. Comparison of calculated commercial landings (thousands of pounds) for the U.S. Gulf of Mexico waters in gutted weight from Schirippa and Legault (1997) and this assessment.

	Schirippa and Legault (1997)	this assessment	difference
1986	1590	1565	25
1987	1478	1427	51
1988	1171	1122	50
1989	1703	1612	92
1990	1812	1763	49
1991	1522	1503	19
1992	1575	1569	6
1993	1776	1766	10
1994	1547	1536	11
1995	1561	1536	25
1996	1478	1467	11

Table 6. Total estimated recreational landings (and dead discards from MRFSS) of reported gag (not including any black grouper) by state and year in number of fish.

year	state					total
	TX	LA	MI	AL	wFL	
1986	511	970	1741	9306	172926	185454
1987	761	361	2375	3312	199125	205934
1988	238	335	0	941	204249	205763
1989	199	4171	570	1340	171837	178117
1990	358	43	62	951	189054	190468
1991	480	1106	0	1978	272187	275751
1992	150	2014	613	1704	269179	273660
1993	358	1874	2116	3304	367740	375392
1994	238	2938	1278	6874	289645	300973
1995	183	1132	38	8479	406699	416531
1996	276	11344	6011	19049	331057	367737
1997	142	932	577	10603	418837	431091
1998	1144	3644	3814	11123	564947	584672
1999	280	17529	549	31323	533382	583063
2000		2888	2304	25523	585135	615850

Table 7. Total estimated landings (and dead discards from MRFSS) of calculated gag (including some black grouper) by state and year from recreational fisheries in number of fish.

year	state					total
	TX	LA	MI	AL	wFL	
1986	652	2,450	1,741	19,949	666,131	690,923
1987	808	4,425	2,375	5,927	462,858	476,393
1988	263	6,379	144	953	571,546	579,285
1989	219	4,174	1,174	1,391	384,458	391,416
1990	430	43	62	987	192,968	194,490
1991	487	1,110	0	2,004	262,074	265,675
1992	159	2,023	613	1,713	260,743	265,251
1993	364	1,880	2,116	3,344	343,255	350,959
1994	245	2,939	1,278	6,883	270,993	282,338
1995	186	1,136	38	8,481	373,692	383,533
1996	285	11,344	6,011	19,098	307,935	344,673
1997	149	940	577	10,605	396,525	408,796
1998	1,153	4,865	3,814	11,144	511,019	531,995
1999	285	18,018	549	31,375	473,880	524,107
2000		2,888	2,304	25,523	513,473	544,188

Table 8. Estimated total landed yield of Gulf of Mexico calculated gag (including some black and unclassified groupers) by year and mode from recreational fisheries in thousands of pounds gutted weight.

	charter	headboat	private	shore	total
1986	1,199	267	2,344	238	4,048
1987	802	167	1,496	13	2,479
1988	557	138	2,536	98	3,329
1989	367	276	2,067	70	2,781
1990	258	159	1,004	0	1,421
1991	126	94	1,755	130	2,104
1992	489	103	1,129	61	1,782
1993	649	132	1,288	67	2,136
1994	420	135	1,099	36	1,691
1995	512	100	1,456	82	2,151
1996	478	86	1,082	31	1,677
1997	851	82	1,586	24	2,544
1998	1,337	201	1,525	157	3,220
1999	899	158	1,943	41	3,041

Table 9. Estimated landings from recreational fisheries in the Gulf of Mexico of calculated gag (including some black grouper) by survey and year in number of fish.

	Texas P&W	Headboat	MRFSS (A+B1)	Grand Total
1986	102	44,927	645,894	690,923
1987	212	34,512	441,669	476,393
1988		26,521	552,764	579,285
1989	24	35,231	356,161	391,416
1990	269	19,195	175,026	194,490
1991	329	11,491	253,855	265,675
1992		13,838	251,413	265,251
1993	29	19,511	331,419	350,959
1994	71	20,637	261,630	282,338
1995		17,849	365,684	383,533
1996	121	16,144	328,408	344,673
1997		15,654	393,142	408,796
1998	44	36,419	495,532	531,995
1999	45	32,786	491,276	524,107
2000			544,188	544,188

Table 10. Estimated MRFSS landings plus dead discards (A+B1) in number of fish from Gulf of Mexico recreational fisheries for calculated gag (including some black grouper) and associated coefficients of variation by year and wave.

wave:	1		2		3		4		5		6	
year	catch	cv	catch	cv	catch	cv	catch	cv	catch	cv	catch	cv
1986	34,394	0.292	126,293	0.171	206,966	0.171	81,186	0.190	143,515	0.247	53,535	0.294
1987	35,094	0.340	121,981	0.220	68,497	0.220	69,000	0.213	110,756	0.271	36,341	0.272
1988	23,498	0.393	46,669	0.258	149,682	0.258	192,728	0.166	64,190	0.232	75,998	0.272
1989	105,848	0.192	61,109	0.275	128,926	0.275	9,308	0.359	34,590	0.323	16,379	0.523
1990	8,916	0.478	22,421	0.613	20,787	0.613	12,830	0.433	20,270	0.394	89,803	0.356
1991	51,184	0.330	31,924	0.303	24,553	0.303	59,553	0.369	40,533	0.230	46,107	0.356
1992	11,689	0.290	30,958	0.197	42,640	0.197	37,865	0.272	70,084	0.155	58,176	0.161
1993	54,251	0.183	48,901	0.238	78,063	0.238	39,130	0.164	42,800	0.237	68,274	0.172
1994	7,652	0.432	45,103	0.185	51,420	0.185	78,682	0.136	11,231	0.276	67,542	0.175
1995	56,780	0.246	89,717	0.233	69,379	0.233	41,037	0.250	45,644	0.269	63,126	0.201
1996	16,908	0.365	39,620	0.235	75,530	0.235	80,467	0.189	67,655	0.231	48,226	0.270
1997	69,711	0.249	38,919	0.226	77,589	0.226	56,846	0.237	43,345	0.234	106,729	0.171
1998	90,407	0.204	54,599	0.178	80,068	0.178	66,357	0.137	104,434	0.163	99,661	0.275
1999	75,065	0.166	101,206	0.129	104,583	0.129	57,252	0.137	49,844	0.183	103,323	0.159
2000	81,050	0.211	90,993	0.200	126,110	0.200	48,271	0.210	91,209	0.209	106,552	0.181



Table 11. Estimated MRFSS number of live discards (B2) of calculated gag (including some black grouper) and associated coefficients of variation by year and wave.

year	wave											
	1		2		3		4		5		6	
	catch	cv	catch	cv	catch	cv	catch	cv	catch	cv	catch	cv
1986	15,313	0.505	4,878	0.477	3,557	0.622	13,506	0.536	14,204	0.541	3,247	0.604
1987	1,949	1.000	23,760	0.414	20,280	0.511	0	0.000	19,213	0.465	58,886	0.484
1988	2,390	0.824	22,325	0.494	27,544	0.601	8,268	0.496	10,710	0.453	21,733	0.428
1989	57,295	0.323	48,339	0.537	32,761	0.365	51,562	0.424	33,361	0.278	66,203	0.498
1990	66,348	0.421	91,250	0.737	3,842	0.745	26,995	0.324	39,487	0.423	186,208	0.280
1991	121,240	0.341	52,186	0.386	135,419	0.376	52,858	0.539	268,795	0.307	244,562	0.226
1992	20,305	0.324	124,397	0.178	145,938	0.187	52,936	0.339	176,637	0.221	233,855	0.206
1993	216,277	0.207	66,736	0.249	158,177	0.200	202,376	0.165	183,875	0.205	468,609	0.128
1994	58,727	0.245	328,778	0.149	340,356	0.122	348,826	0.118	213,606	0.129	524,797	0.119
1995	349,869	0.144	302,932	0.137	382,346	0.151	244,559	0.142	265,092	0.163	480,653	0.133
1996	123,582	0.178	108,400	0.153	277,289	0.129	202,517	0.141	253,648	0.140	233,001	0.123
1997	183,597	0.146	156,303	0.170	442,287	0.159	273,349	0.142	225,660	0.121	447,388	0.138
1998	286,395	0.166	264,264	0.146	402,890	0.115	536,272	0.141	283,010	0.132	337,529	0.103
1999	300,331	0.105	317,132	0.083	318,519	0.121	191,218	0.104	182,531	0.148	234,581	0.115
2000	234,579	0.139	131,186	0.142	270,125	0.132	213,663	0.127	240,247	0.135	216,224	0.128

Table 12. Total catch (landings and discards) of gag in the Gulf of Mexico by sector for 1986-1999 in thousands of fish.

	commercial		recreational		total		all
	landings	discards	landings	landings	landings	discards	
1986	132.6	0.0	690.9	151.3	823.5	151.3	974.8
1987	97.6	0.0	476.4	111.0	574.0	111.0	685.0
1988	68.1	0.0	579.3	98.0	647.4	98.0	745.4
1989	100.2	0.0	391.4	173.0	491.6	173.0	664.6
1990	101.1	1.1	194.5	153.7	295.6	154.9	450.4
1991	96.3	1.1	265.7	328.4	362.0	329.4	691.4
1992	97.8	1.0	265.3	292.0	363.0	293.0	656.0
1993	122.0	1.2	351.0	467.3	472.9	468.5	941.5
1994	120.4	5.7	282.3	651.8	402.7	657.5	1,060.3
1995	122.3	12.4	383.5	715.7	505.8	728.0	1,233.9
1996	152.3	0.2	344.7	448.3	497.0	448.5	945.6
1997	158.4	0.5	408.8	625.3	567.2	625.8	1,193.0
1998	239.5	1.3	532.0	749.3	771.5	750.5	1,522.1
1999	165.5	1.3	524.1	556.1	689.6	557.4	1,247.0

Table 13. Total yield (landings and discards) of gag in the Gulf of Mexico by sector for 1986-1999 in thousands of pounds.

	commercial		recreational		total		all
	landings	discards	landings	discards	landings	discards	
1986	1,578	-	4,048	282	5,626	282	5,907
1987	1,438	-	2,479	197	3,917	197	4,114
1988	1,139	-	3,329	182	4,467	182	4,649
1989	1,619	-	2,781	320	4,400	320	4,720
1990	1,766	2	1,421	280	3,187	283	3,470
1991	1,506	2	2,104	611	3,611	613	4,223
1992	1,571	2	1,782	540	3,353	542	3,895
1993	1,768	3	2,136	860	3,904	862	4,767
1994	1,537	9	1,691	1,196	3,228	1,205	4,433
1995	1,538	27	2,151	1,332	3,688	1,359	5,047
1996	1,469	0	1,677	839	3,146	839	3,985
1997	1,499	1	2,544	1,162	4,043	1,163	5,206
1998	2,404	3	3,220	1,393	5,623	1,395	7,019
1999	1,974	3	3,041	1,021	5,015	1,023	6,038

Table 14. Initial catch at age (iteration 1) derived with the recruitment-and-mortality modulated method (Goodyear 1997), the Cass-Calay *et al.* growth curve, an M of 0.15, fishing mortality rates from age 0 and older of 0.0, 0.05, 0.1, 0.2 and 0.3 for ages and the young of the year index from seas grass tows with an average value for years prior to 1991.

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10+
1986	155,283	243,834	191,580	142,631	94,399	56,440	34,078	20,905	13,045	8,196	14,378
1987	112,266	160,485	140,165	101,163	66,796	40,408	24,617	15,140	9,348	5,759	8,883
1988	135,471	164,556	151,718	108,428	68,230	41,035	25,993	17,013	11,421	7,714	13,822
1989	134,813	138,225	85,639	78,921	73,473	55,587	37,997	24,377	14,939	8,848	11,798
1990	75,693	99,871	70,016	52,023	45,007	35,227	25,675	17,522	11,401	7,164	10,819
1991	173,627	168,684	100,828	67,379	58,150	44,266	29,551	18,423	11,402	7,178	11,946
1992	139,845	246,297	76,460	55,816	42,042	30,761	22,136	15,147	9,997	6,465	11,072
1993	230,927	198,975	324,585	53,768	43,942	30,753	20,689	13,728	8,990	5,764	9,371
1994	298,629	376,493	96,103	214,340	21,437	15,607	11,690	8,505	5,985	4,081	7,388
1995	309,870	306,087	400,914	34,630	143,684	11,667	7,976	5,714	4,214	3,053	6,056
1996	196,845	242,898	62,866	367,032	10,830	48,930	4,102	3,297	2,614	1,981	4,163
1997	279,306	318,044	181,441	18,125	337,382	8,462	37,663	2,722	2,138	1,800	5,870
1998	325,898	405,699	273,808	146,703	7,070	309,053	8,036	36,884	2,570	1,864	4,474
1999	224,178	333,328	261,062	155,804	73,164	2,510	164,093	4,724	23,264	1,594	3,236

Table 15. Catch-at-age estimated from semi-annual age-length-keys and stochastic growth as estimated by Cummings and Parrack (in prep.). Note that the estimated catch at age 1 in 1999 of 0 was replaced with a 1.

	age 0	age 1	age 2	age 3	age 4	age 5	age 6	age 7	age 8	age 9	age 10+
1986	7,231	64,461	350,531	177,896	189,066	62,866	60,744	11,497	20,485	6,572	23,421
1987	4,629	59,839	184,745	223,216	42,314	77,627	50,236	16,789	5,417	6,069	14,146
1988	18,540	70,832	191,872	198,666	117,687	43,311	41,574	26,223	7,078	1,910	27,709
1989	10,127	73,994	229,617	39,667	55,601	124,165	40,828	47,524	22,836	13,062	7,193
1990	9,380	32,472	122,281	88,743	32,786	56,295	39,734	37,125	14,955	5,004	11,628
1991	9,969	58,601	275,651	129,777	22,378	63,390	70,221	33,688	11,957	1,800	13,987
1992	32,513	50,295	210,549	229,639	27,754	38,242	29,874	22,935	1,186	1,710	11,334
1993	59,339	18,275	234,564	337,272	200,138	27,751	22,385	14,774	14,004	3,961	9,020
1994	64,289	32,608	208,020	293,465	257,854	152,644	17,866	9,691	8,648	6,267	8,898
1995	57,806	154,514	346,916	196,192	229,853	117,193	95,442	17,547	4,477	508	13,409
1996	54,530	32,625	460,958	253,663	68,591	30,673	24,639	6,839	4,705	2,008	6,319
1997	30,440	98,724	510,994	273,180	191,973	43,160	12,323	7,481	7,966	4,649	12,056
1998	36,753	283,133	252,555	233,295	363,554	280,989	31,926	15,772	10,428	2,301	11,345
1999	48,426	1	143,060	742,111	101,752	100,256	80,836	11,082	5,951	4,976	8,499

Table 16. Indices of abundance available for use in assessment.<sup>1</sup>

	Seagrass Tows year interacion		Seagrass Tows year only model		handline		longline		trap (fixed effects)		MRFSS charter + private		head boat	
indexing:	n fish index	cv	n fish index	cv	biomass index	cv	biomass index	cv	biomass index	cv	n fish index	cv	n fish index	cv
1981											9.394	0.523		
1982											5.312	0.512		
1983											23.116	0.482		
1984											8.168	0.607		
1985											3.182	0.652		
1986											5.188	0.409	1.080	0.285
1987											4.372	0.365	1.653	0.180
1988											2.267	0.396	0.931	0.257
1989											5.850	0.373	0.793	0.278
1990											12.703	0.374	0.635	0.265
1991	4.756	0.309	2.60	0.311	1587.5		939.9	0.277	38.84	0.401	15.519	0.363	0.552	0.326
1992	0.500	0.591	0.27	0.615	2235.9		1198.7	0.273	121.11	0.190	12.365	0.326	0.671	0.273
1993			4.63	0.316	3483.7		2808.4	0.134	267.17	0.118	17.682	0.317	0.789	0.240
1994	0.037	3.011	0.02	3.422	3369.5		1715.4	0.114	315.56	0.110	30.272	0.313	0.804	0.244
1995	0.624	0.446	0.34	0.463	4201.6		1678.2	0.118	678.19	0.135	26.310	0.311	0.826	0.299
1996	0.569	0.493	0.31	0.513	4497.3		1753.7	0.096	228.70	0.182	30.313	0.312	1.174	0.206
1997	0.488	0.514	0.27	0.536	4955.1		2195.1	0.096	332.01	0.157	32.746	0.302	1.341	0.191
1998	0.414	0.728	0.23	0.762	7897.4		4500.5	0.083	779.62	0.119	37.899	0.296	1.440	0.184
1999	0.612	0.684	0.33	0.709	6900.8		4934.3	0.095	757.67	0.143	29.007	0.294	1.313	0.188
2000											21.004	0.297		

1. For the recruitment-and-mortality modulated ageing, the sea-grass tows, year only model was used, with additional values (0.11) derived from the mean of 1992, and 1995-1999 used for 1976-1986.

Table 17. Summary of VPA analyses for Gulf of Mexico gag using data from 1986-1999.

					1999 fishing mortality rates							log likelihood	AIC2	
					age 0	age 1	age 2	age 4	age 6	age 7	age 8			
ageing method	growth curve	index selectivity	indices	n iterations										
probabilistic with rec and F	Cass-Calay	constant	all	1			1.218	0.130	0.178		0.042	3.61	17.77	sensitivity run
probabilistic with rec and F	prev. assessments	constant	all	1			0.365	0.152	0.119		0.022	5.33	14.34	sensitivity run
probabilistic with rec and F	Cass-Calay	constant	all	5			1.781	0.183	0.339		0.181	0.04	24.91	
probabilistic with rec and F	Cass-Calay	constant	yoy+ comm	2			0.635	0.058	0.016		0.004	7.74	8.52	sensitivity run
probabilistic with rec and F	Cass-Calay	constant	yoy + rec	2			1.311	0.124	0.179		0.074	-3.03	27.20	sensitivity run
probabilistic with rec and F	Cass-Calay	year variable	all	5			0.609	0.343	0.016		0.041	-9.23	43.47	
probabilistic with rec and F	Cass-Calay	year variable	yoy+ comm	2			0.079	0.011	0.004		0.002	8.82	6.36	sensitivity run
probabilistic with rec and F	Cass-Calay	year variable	yoy + rec	2			0.360	0.129	0.100		0.016	-9.17	39.49	sensitivity run
ALK plus stochastic		constant	all		0.018	0.000	0.096	0.239	0.118		0.012	-8.88	49.18	
ALK plus stochastic		constant	all		0.028	0.000	0.176	0.744	0.116			-10.67	54.99	sensitivity run
ALK plus stochastic		constant	yoy+ comm		0.022	0.000	0.146	0.657	0.203		0.010	-10.01	53.76	sensitivity run
ALK plus stochastic		constant	yoy + rec		0.018	0.000	0.098	0.234	0.152		0.012	-12.41	53.28	sensitivity run
ALK plus stochastic		year variable	all		0.031	0.000	0.237	0.509	0.376		0.081	-14.01	59.45	
ALK plus stochastic		year variable	yoy+ comm		0.037	0.000	0.325	1.332	0.729		0.182	-11.66	57.06	sensitivity run
ALK plus stochastic		year variable	yoy + rec		0.015	0.000	0.087	0.159	0.106		0.007	-12.86	54.18	sensitivity run

Table 18. Catch at age derived with the recruitment-and-mortality modulated growth method (Goodyear 1997) run for one iteration using the growth equation used in the 1994 and 1997 assessments, M of 0.15, fishing mortality rates from age 0 and older of 0.0, 0.05, 0.1, 0.2 and 0.3 for ages and the young of the year index from seas grass tows with an average value for years prior to 1991.

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10+
1986	21613	150249	253456	197546	138641	84539	50674	30330	18328	11188	18204
1987	22261	102875	168111	143642	97253	59969	36267	21902	13239	7965	11544
1988	40652	113575	172609	154379	101903	59509	36576	23341	15261	10116	17479
1989	30932	118230	137990	88232	82243	70743	52233	34514	21277	12493	15729
1990	24396	61462	101548	70098	52235	43215	33692	23934	15771	9874	14192
1991	40441	139703	175901	100826	68161	56435	41816	26761	16182	9827	15382
1992	39117	133381	166095	119159	68903	42275	29805	20744	13684	8736	14141
1993	72411	182263	330417	116475	93844	58568	34098	20546	12776	7963	12126
1994	75747	271777	270329	305570	43892	32276	21960	14146	9081	5826	9651
1995	90308	249289	487066	108706	230729	21997	15611	10448	6923	4619	8170
1996	88911	167446	186044	386609	19070	72452	6408	5329	4228	3120	5940
1997	74652	236905	301307	71279	424482	12251	54601	4094	3153	2562	7668
1998	91771	278553	411036	231615	17734	418805	10761	49133	3532	2651	6468
1999	49630	197489	345399	260952	120634	4430	225651	6162	29899	2116	4596

Table 19. Catch at age derived with the recruitment-and-mortality modulated growth method (Goodyear 1997) iterated 5 times, the Cass-Calay *et al.* growth equation, M of 0.15, the young of the year index from sea grass tows with an average for years before 1991., and year constant selectivity in the VPA

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10+
1986	166460	261922	193787	136815	85922	52077	31989	19885	11292	6582	8039
1987	119394	174302	141944	96543	61018	37382	23142	14330	7969	4543	4463
1988	142081	177841	156537	101084	62978	38166	24398	16658	11288	6366	8005
1989	144241	139407	86032	79846	73010	57354	37356	21864	12770	7085	5651
1990	81520	105176	63132	56043	46344	35074	25774	15366	9634	6234	6120
1991	185598	177902	89371	56732	67932	48211	27989	16517	8496	5268	7419
1992	148589	272807	58163	41630	35443	39425	24772	14802	9285	4580	6542
1993	245438	198416	363863	25640	24070	22162	26761	15803	8993	5229	5114
1994	317133	390736	70546	238215	6560	5128	5043	10051	7057	4437	5353
1995	328587	312227	400432	14770	159916	2860	1693	1391	3957	3168	4866
1996	209818	244036	48437	376918	2379	57568	993	573	403	1434	2997
1997	296727	328383	149779	8703	354794	1765	47585	646	342	219	4009
1998	347002	405345	265532	109928	1351	338306	1845	51328	563	183	677
1999	240073	375829	149723	189417	66482	154	186645	1298	36747	340	250

Table 20. Estimated abundance (thousands) from the VPA which used the recruitment-and-mortality modulated catch at age, five indices of abundance and the year-constant index selectivity assumption.

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10+
1986	1123.4	960.4	665.2	416.8	257.4	162.2	97.8	50.8	30.2	15.0	18.4
1987	921.3	813.0	584.9	393.7	232.6	142.3	91.6	54.7	25.4	15.6	15.3
1988	651.6	682.5	538.7	372.4	249.8	143.9	88.0	57.5	33.9	14.5	18.2
1989	552.1	429.6	423.3	319.2	227.2	156.8	88.6	53.2	34.1	18.8	15.0
1990	468.9	342.0	241.2	284.8	201.1	128.2	82.1	41.9	25.7	17.6	17.3
1991	2989.5	328.2	197.4	149.3	193.4	130.3	78.0	46.9	21.9	13.2	18.6
1992	568.6	2401.2	119.3	87.7	76.3	103.8	67.7	41.4	25.2	11.0	15.8
1993	5144.1	352.3	1814.3	49.3	37.3	33.1	53.1	35.5	22.0	13.1	12.8
1994	809.5	4200.2	121.3	1225.3	18.9	10.1	8.2	21.1	16.0	10.6	12.8
1995	1836.1	404.8	3253.5	39.8	834.5	10.2	4.0	2.5	8.9	7.3	11.2
1996	2924.8	1276.6	64.7	2429.8	20.7	570.5	6.2	1.8	0.9	4.1	8.5
1997		2323.1	873.2	11.6	1742.8	15.6	437.7	4.4	1.1	0.4	6.7
1998			1695.8	613.1	2.1	1172.2	11.8	332.7	3.2	0.6	2.2
1999				1214.0	426.1	0.6	696.8	8.4	238.9	2.2	1.6
2000					869.8	305.3	0.4	427.5	6.1	171.6	2.8

Table 21. Estimated fishing mortality rates from the VPA which used the recruitment-and-mortality modulated catch at age, five indices of abundance and the year-constant index selectivity assumption.

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10+
1986	0.173	0.346	0.374	0.433	0.442	0.421	0.431	0.543	0.512	0.631	0.631
1987	0.15	0.262	0.302	0.305	0.33	0.331	0.316	0.33	0.41	0.375	0.375
1988	0.267	0.328	0.373	0.344	0.315	0.335	0.353	0.372	0.441	0.633	0.633
1989	0.329	0.427	0.246	0.312	0.422	0.497	0.599	0.578	0.512	0.518	0.518
1990	0.207	0.4	0.329	0.237	0.284	0.347	0.41	0.498	0.513	0.477	0.477
1991	0.069	0.862	0.661	0.522	0.472	0.504	0.485	0.473	0.536	0.554	0.554
1992	0.329	0.13	0.734	0.706	0.685	0.521	0.497	0.483	0.502	0.586	0.586
1993	0.053	0.916	0.242	0.809	1.159	1.24	0.772	0.647	0.576	0.556	0.556
1994	0.543	0.105	0.964	0.234	0.465	0.784	1.052	0.71	0.638	0.592	0.592
1995	0.213	1.683	0.142	0.506	0.23	0.357	0.612	0.912	0.64	0.627	0.627
1996	0.08	0.23	1.565	0.182	0.132	0.115	0.19	0.404	0.699	0.476	0.476
1997		0.165	0.204	1.561	0.247	0.13	0.124	0.173	0.424	1.012	1.012
1998			0.184	0.214	1.147	0.37	0.184	0.181	0.211	0.397	0.397
1999				0.183	0.183	0.339	0.339	0.181	0.181	0.181	0.181

Table 22. Catch at age derived with the recruitment-and-mortality modulated growth method (Goodyear 1997) iterated 5 times, the Cass-Calay *et al.* growth equation, M of 0.15, the young of the year index from sea grass tows with an average for years before 1991, year variable selectivity and five indices in the VPA.

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10+
1986	165947	260937	193522	136980	86073	52235	32179	20058	11490	6777	8575
1987	119075	173528	141768	96679	61105	37489	23277	14466	8123	4685	4834
1988	141717	177090	156155	101290	63304	38265	24455	16707	11377	6501	8542
1989	143911	138685	86215	79541	72803	57475	37519	22037	12988	7304	6138
1990	81179	105365	61946	56129	46275	35324	26100	15497	9741	6328	6534
1991	184755	177230	91617	53969	67587	48438	28695	17132	8777	5424	7810
1992	148165	266598	64630	44201	31666	39028	25066	15260	9663	4801	6962
1993	244357	198328	352631	35573	28320	19615	26416	15901	9241	5496	5611
1994	316316	383518	74729	233808	11837	7884	5132	10174	6937	4367	5558
1995	327447	311596	390955	19481	160461	6183	3316	1829	4412	3241	4942
1996	209095	229714	49404	382987	5125	59793	2302	1320	696	1814	3306
1997	296024	320926	112876	9463	391687	4451	49852	1562	854	460	4800
1998	346027	413293	219915	51785	2015	427706	4732	52598	1462	632	1891
1999	238493	370357	193352	103942	19902	555	279611	3164	35671	899	1011

Table 23. Estimated abundance from the VPA which used the recruitment-and-mortality modulated catch at age, five indices of abundance and the year-constant index selectivity assumption.

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10+
1986	1156.9	985.7	684.5	426.1	263.2	166.6	101.2	52.7	31.8	16.1	20.4
1987	963.6	842.2	607.5	410.6	240.4	147.2	95.3	57.5	26.9	16.8	17.3
1988	644.3	719.2	564.6	392.0	264.1	150.5	92.1	60.5	36.1	15.6	20.5
1989	613.9	423.7	455.5	341.8	243.9	168.9	94.2	56.7	36.7	20.6	17.3
1990	606.2	395.5	236.8	312.4	220.8	142.8	92.4	46.6	28.5	19.6	20.2
1991	5326.4	446.7	243.1	146.6	217.0	147.2	90.3	55.4	25.8	15.6	22.4
1992	819.6	4413.3	221.3	124.9	76.5	124.4	82.1	51.2	31.9	14.1	20.5
1993	51803.6	568.5	3551.7	130.9	66.8	36.7	71.1	47.5	30.0	18.6	18.9
1994	896.4	44361.3	306.5	2730.6	79.8	31.4	13.6	36.9	26.3	17.3	22.0
1995	1020.1	480.1	37826.7	194.8	2133.8	57.7	19.8	7.0	22.4	16.2	24.7
1996	1545.0	576.1	128.5	32195.4	149.7	1688.0	44.0	13.9	4.3	15.2	27.6
1997		1136.4	284.4	65.1	27355.9	124.1	1397.5	35.7	10.8	3.1	32.1
1998			682.0	140.9	47.3	23182.5	102.7	1156.6	29.3	8.5	25.4
1999				384.2	73.6	38.8	19557.0	84.0	946.8	23.9	26.8
2000					234.8	44.9	32.9	16573.8	69.4	781.9	41.9



Table 24. Estimated fishing mortality rates from the VPA which used the recruitment-and-mortality modulated catch at age, five indices of abundance and the year-constant index selectivity assumption.

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10+
1986	0.167	0.334	0.361	0.422	0.431	0.409	0.416	0.523	0.489	0.597	0.597
1987	0.143	0.250	0.288	0.291	0.318	0.319	0.304	0.315	0.391	0.356	0.356
1988	0.269	0.307	0.352	0.325	0.297	0.318	0.335	0.351	0.412	0.588	0.588
1989	0.290	0.432	0.227	0.287	0.386	0.453	0.555	0.537	0.477	0.478	0.478
1990	0.155	0.336	0.329	0.214	0.255	0.309	0.361	0.441	0.456	0.425	0.425
1991	0.038	0.552	0.516	0.501	0.406	0.434	0.416	0.402	0.453	0.467	0.467
1992	0.216	0.067	0.375	0.476	0.584	0.410	0.396	0.385	0.392	0.453	0.453
1993	0.005	0.468	0.113	0.345	0.604	0.843	0.507	0.444	0.400	0.382	0.382
1994	0.474	0.009	0.303	0.097	0.174	0.314	0.517	0.351	0.333	0.316	0.316
1995	0.421	1.168	0.011	0.114	0.084	0.122	0.199	0.330	0.238	0.242	0.242
1996	0.157	0.556	0.530	0.013	0.038	0.039	0.058	0.107	0.190	0.138	0.138
1997		0.361	0.552	0.170	0.016	0.039	0.039	0.048	0.089	0.175	0.175
1998			0.424	0.500	0.047	0.020	0.051	0.050	0.055	0.083	0.083
1999				0.343	0.343	0.016	0.016	0.041	0.041	0.041	0.041

Table 25. Estimated abundance (thousands) from the VPA which used the age-length-key plus stochastic growth-curve-based catch-at-age, five indices of abundance and the year-constant index selectivity assumption.

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10+
1986	829.9	1524.3	1406.1	543.1	524.2	347.7	329.8	30.1	77.7	35.5	126.6
1987	1101.9	707.6	1252.2	886.6	303.5	277.0	241.1	227.7	15.3	48.0	111.8
1988	1132.8	944.1	553.7	906.9	557.0	222.1	166.8	161.1	180.5	8.2	118.8
1989	2106.7	957.8	747.0	299.7	597.1	370.7	151.1	105.2	114.4	148.8	81.9
1990	2516.2	1803.8	755.9	431.2	221.3	462.5	204.6	92.4	46.8	77.4	179.8
1991	2191.2	2157.0	1522.5	537.5	289.1	160.1	346.0	139.4	45.3	26.5	206.0
1992	2103.9	1876.8	1802.3	1055.6	342.8	228.1	79.5	232.9	88.9	28.0	185.5
1993	3192.4	1780.7	1568.8	1356.4	696.4	269.4	161.0	40.9	179.2	75.4	171.6
1994	3321.3	2692.7	1515.8	1133.3	856.1	414.8	206.2	117.9	21.6	141.3	200.6
1995	1599.0	2799.1	2287.4	1112.2	704.5	499.0	216.4	160.9	92.5	10.6	280.2
1996	2864.5	1322.8	2266.1	1648.0	775.9	394.5	321.2	98.5	122.3	75.4	237.4
1997		2415.0	1108.3	1524.5	1183.8	604.3	311.1	253.7	78.4	100.9	261.6
1998			1987.1	484.2	1059.6	841.4	480.2	256.4	211.4	60.1	296.5
1999				1476.7	202.5	577.0	465.2	383.7	206.1	172.3	294.3
2000					589.6	80.8	403.9	325.7	320.0	171.9	389.1

Table 26. Estimated fishing mortality rates from the VPA which used the age-length-key plus stochastic growth-curve-based catch-at-age, five indices of abundance and the year-constant index selectivity assumption.

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10+
1986	0.009	0.047	0.311	0.432	0.488	0.216	0.220	0.526	0.332	0.222	0.222
1987	0.005	0.095	0.173	0.315	0.162	0.357	0.253	0.083	0.476	0.146	0.146
1988	0.018	0.084	0.464	0.268	0.257	0.235	0.311	0.192	0.043	0.288	0.288
1989	0.005	0.087	0.400	0.153	0.106	0.444	0.342	0.659	0.241	0.099	0.099
1990	0.004	0.020	0.191	0.250	0.173	0.140	0.234	0.562	0.419	0.072	0.072
1991	0.005	0.030	0.216	0.300	0.087	0.551	0.246	0.300	0.332	0.076	0.076
1992	0.017	0.029	0.134	0.266	0.091	0.199	0.515	0.112	0.014	0.068	0.068
1993	0.020	0.011	0.175	0.310	0.368	0.117	0.162	0.489	0.088	0.058	0.058
1994	0.021	0.013	0.160	0.325	0.390	0.501	0.098	0.093	0.560	0.049	0.049
1995	0.040	0.061	0.178	0.210	0.430	0.290	0.637	0.125	0.054	0.053	0.053
1996	0.021	0.027	0.246	0.181	0.100	0.087	0.086	0.078	0.042	0.029	0.029
1997		0.045	0.678	0.214	0.191	0.080	0.044	0.032	0.116	0.051	0.051
1998			0.147	0.722	0.458	0.443	0.074	0.068	0.055	0.042	0.042
1999				0.768	0.768	0.207	0.207	0.032	0.032	0.032	0.032

Table 27. Estimated abundance (thousands) from the sensitivity VPA which used the age-length-key plus stochastic growth-curve-based catch-at-age, five indices of abundance and the year-constant index selectivity assumption and which estimated 1999 fishing mortality rates on ages 0, 1, 2, 4 and 6 years.

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10+
1986	804.7	1254.2	1288.3	507.9	497.4	285.9	237.6	26.8	63.4	28.2	100.5
1987	916.1	685.9	1019.8	785.4	273.2	254.0	188.0	148.4	12.5	35.7	83.1
1988	877.6	784.2	535.0	707.0	470.0	196.0	147.1	115.5	112.2	5.8	83.6
1989	1944.4	738.2	609.4	283.7	425.2	295.9	128.7	88.2	75.2	90.0	49.6
1990	2036.1	1664.2	566.9	313.0	207.5	314.5	140.4	73.1	32.3	43.6	101.4
1991	1697.1	1743.8	1402.3	374.9	187.5	148.3	218.7	84.2	28.9	14.1	109.5
1992	1315.9	1451.5	1446.6	952.2	203.1	140.7	69.3	123.5	41.5	13.8	91.7
1993	3999.4	1102.5	1202.7	1050.4	607.5	149.1	85.8	32.2	85.1	34.6	78.8
1994	4182.9	3387.3	932.0	818.4	593.1	338.4	102.7	53.2	14.1	60.3	85.6
1995	1607.2	3540.7	2885.3	610.0	434.0	273.3	150.9	71.9	36.8	4.2	111.5
1996	2915.0	1329.8	2904.4	2162.4	344.2	162.7	127.4	42.6	45.7	27.6	86.7
1997		2458.4	1114.3	2073.6	1626.5	232.8	111.7	86.9	30.4	35.0	90.7
1998			2024.6	489.4	1532.0	1222.3	160.5	84.7	67.9	18.8	92.7
1999				1508.9	206.9	982.9	792.5	108.6	58.3	48.8	83.3
2000					617.2	84.6	753.2	607.3	83.3	44.7	101.2

Table 28. Estimated fishing mortality rates from the sensitivity VPA which used the age-length-key plus stochastic growth-curve-based catch-at-age, five indices of abundance and the year-constant index selectivity assumption and which estimated 1999 fishing mortality rates on ages 0, 1, 2, 4 and 6 years.

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10+
1986	0.010	0.057	0.345	0.470	0.522	0.269	0.321	0.614	0.425	0.288	0.288
1987	0.005	0.099	0.216	0.363	0.182	0.397	0.338	0.130	0.623	0.202	0.202
1988	0.023	0.102	0.484	0.358	0.313	0.271	0.361	0.279	0.070	0.439	0.439
1989	0.006	0.114	0.516	0.163	0.151	0.595	0.415	0.854	0.394	0.170	0.170
1990	0.005	0.021	0.263	0.362	0.186	0.213	0.361	0.780	0.681	0.132	0.132
1991	0.006	0.037	0.237	0.463	0.137	0.611	0.422	0.558	0.585	0.148	0.148
1992	0.027	0.038	0.170	0.299	0.159	0.344	0.618	0.222	0.031	0.143	0.143
1993	0.016	0.018	0.235	0.422	0.435	0.223	0.328	0.674	0.195	0.131	0.131
1994	0.017	0.010	0.274	0.484	0.625	0.657	0.207	0.218	1.055	0.119	0.119
1995	0.039	0.048	0.138	0.422	0.831	0.613	1.114	0.304	0.140	0.138	0.138
1996	0.020	0.027	0.187	0.135	0.241	0.226	0.233	0.189	0.117	0.082	0.082
1997		0.044	0.673	0.153	0.136	0.222	0.126	0.097	0.330	0.154	0.154
1998			0.144	0.711	0.294	0.283	0.240	0.223	0.180	0.141	0.141
1999				0.744	0.744	0.116	0.116	0.116	0.116	0.116	0.116

Table 29. Estimated abundance (thousands) from the VPA which used the age-length-key plus stochastic growth-curve-based catch-at-age, five indices of abundance and the year-variable index selectivity assumption.

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10+
1986	808.8	1297.8	1307.4	513.6	501.8	295.9	252.5	27.3	65.7	29.4	104.7
1987	946.1	689.4	1057.4	801.7	278.1	257.8	196.6	161.2	12.9	37.6	87.8
1988	918.8	810.0	538.0	739.3	484.1	200.2	150.2	122.8	123.2	6.2	89.2
1989	1970.8	773.6	631.6	286.3	452.9	308.0	132.3	91.0	81.5	99.5	54.8
1990	2113.8	1686.9	597.4	332.1	209.7	338.4	150.8	76.2	34.7	49.1	114.1
1991	1777.1	1810.6	1421.8	401.2	203.9	150.2	239.2	93.1	31.5	16.1	125.0
1992	1443.1	1520.3	1504.1	969.0	225.7	154.8	70.9	141.1	49.1	16.1	106.8
1993	2725.3	1212.0	1261.9	1099.9	622.0	168.5	97.9	33.6	100.3	41.2	93.8
1994	2822.5	2290.7	1026.2	869.4	635.6	350.8	119.4	63.6	15.3	73.3	104.1
1995	1728.6	2369.8	1941.4	691.1	477.8	309.7	161.5	86.3	45.8	5.3	138.7
1996	3669.5	1434.3	1896.6	1350.3	413.8	200.1	158.7	51.7	58.0	35.3	111.0
1997		3107.8	1204.2	1206.8	927.7	292.7	143.8	113.8	38.1	45.6	118.2
1998			2583.5	566.4	786.3	621.1	212.0	112.4	91.0	25.5	125.5
1999				1989.8	272.8	342.7	276.3	153.0	82.1	68.7	117.3
2000					1029.2	141.1	202.4	163.2	121.4	65.2	147.6

Table 30. Estimated fishing mortality rates from the VPA which used the age-length-key plus stochastic growth-curve-based catch-at-age, five indices of abundance and the year-variable index selectivity assumption.

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10+
1986	0.010	0.055	0.339	0.463	0.516	0.259	0.299	0.598	0.407	0.274	0.274
1987	0.005	0.098	0.208	0.355	0.179	0.390	0.320	0.119	0.593	0.190	0.190
1988	0.022	0.099	0.481	0.340	0.302	0.264	0.352	0.260	0.064	0.405	0.405
1989	0.006	0.109	0.493	0.161	0.142	0.564	0.401	0.814	0.357	0.152	0.152
1990	0.005	0.021	0.248	0.338	0.184	0.197	0.332	0.733	0.618	0.116	0.116
1991	0.006	0.035	0.233	0.425	0.126	0.600	0.378	0.490	0.521	0.128	0.128
1992	0.025	0.036	0.163	0.293	0.142	0.308	0.598	0.192	0.026	0.121	0.121
1993	0.024	0.016	0.223	0.398	0.423	0.195	0.281	0.635	0.163	0.109	0.109
1994	0.025	0.015	0.245	0.449	0.569	0.625	0.175	0.179	0.920	0.096	0.096
1995	0.037	0.073	0.213	0.363	0.720	0.519	0.990	0.246	0.111	0.110	0.110
1996	0.016	0.025	0.302	0.225	0.196	0.180	0.183	0.154	0.091	0.063	0.063
1997		0.035	0.604	0.278	0.251	0.172	0.097	0.073	0.254	0.116	0.116
1998			0.111	0.580	0.681	0.660	0.176	0.163	0.131	0.102	0.102
1999				0.509	0.509	0.376	0.376	0.081	0.081	0.081	0.081

Table 31. Median and 80% empirical confidence intervals about current status and management reference points for Gulf of Mexico gag estimated from 500 bootstraps of the VPA based on the recruitment-and-mortality modulated catch-at-age under the assumption that recruitment increases to the maximum estimated spawning stock size during 1986-1999. Long-term potential yields are in millions of pounds gutted weight, yield per recruit is in pounds gutted weight, SSB is in thousands of metric tons of mature ovaries, and male SSB is in thousands of pounds gutted weight of mature males.

	Estimate	Bias-corrected Estimate	Range of 80% CI
SSB 2000 / SSB $F_{30\%}$	0.695	0.746	0.161
SSB 2000 / SSB $F_{\max}$	0.322	0.346	0.0883
F 1997-1999 (geometric mean) / $F_{30\%}$	0.986	0.931	0.792
F 1997-1999 (geometric mean) / $F_{\max}$	3.00	2.88	2.68
$F_{30\%}$ SPR	0.423	0.319	0.742
Yield at $F_{30\%}$	7.45	6.29	6.34
Y/R at $F_{30\%}$	2.01	2.04	0.457
S/R at $F_{30\%}$	286	287	0.477
SSB at $F_{30\%}$	1.06	0.902	0.741
Male SSB at $F_{30\%}$ / Male SSB at $F_0$	0.0135		
$F_{40\%}$ SPR	0.307	0.233	0.497
Yield at $F_{40\%}$	9.19	7.78	8.52
Y/R at $F_{40\%}$	2.48	2.52	0.783
S/R at $F_{40\%}$	382	382	0.663
SSB at $F_{40\%}$	1.41	1.20	0.987
Male SSB at $F_{40\%}$ / Male SSB at $F_0$	0.0320		
F at maximum Y/R	0.139	0.0980	0.128
Yield at $F_{\max}$	11.3	9.63	13.1
Y/R maximum	3.06	3.12	1.72
S/R at $F_{\max}$	618	623	146
SPR at $F_{\max}$	0.649	0.654	0.153
SSB at $F_{\max}$	2.29	1.94	2.05
Male SSB at $F_{\max}$ / Male SSB at $F_0$	0.155		

Table 32. Median and 80% empirical confidence intervals about current status and management reference points for Gulf of Mexico gag estimated from 500 bootstraps of the VPA based on the recruitment-and-mortality modulated catch-at-age under the assumption that recruitment would equal the historical average recruitment when spawning stock size equaled or exceeded the minimum observed in 1986-1999. Long-term potential yields are in millions of pounds gutted weight, yield per recruit is in pounds gutted weight, SSB is in thousands of metric tons of mature ovaries, and male SSB is in thousands of pounds gutted weight of mature males.

	Estimate	Bias-corrected Estimate	Range of 80% CI
SSB 2000 / SSB $F_{30\%}$	1.45	1.36	1.25
SSB 2000 / SSB $F_{\max}$	0.710	0.675	0.584
F 1997-1999 (geometric mean) / $F_{30\%}$	1.48	1.41	1.17
F 1997-1999 (geometric mean) / $F_{\max}$	3.70	3.55	3.30
$F_{30\%}$ SPR	0.310	0.267	0.413
Yield at $F_{30\%}$	2.28	2.27	0.886
Y/R at $F_{30\%}$	1.92	1.94	0.567
S/R at $F_{30\%}$	286	286	0.742
SSB at $F_{30\%}$	0.340	0.340	0.0524
Male SSB at $F_{30\%}$ / Male SSB at $F_0$	0.0275		
$F_{40\%}$ SPR	0.232	0.201	0.293
Yield at $F_{40\%}$	9.19	7.78	8.52
Y/R at $F_{40\%}$	2.30	2.33	0.882
S/R at $F_{40\%}$	382	382	1.06
SSB at $F_{40\%}$	0.453	0.454	0.0692
Male SSB at $F_{40\%}$ / Male SSB at $F_0$	0.0566		
F at maximum Y/R	0.124	0.0977	0.0922
Yield at $F_{\max}$	11.3	9.63	13.1
Y/R maximum	2.67	2.72	1.64
S/R at $F_{\max}$	583	589	155
SPR at $F_{\max}$	0.613	0.618	0.163
SSB at $F_{\max}$	0.693	0.692	0.202
Male SSB at $F_{\max}$ / Male SSB at $F_0$	0.182		

Table 33. Median and 80% empirical confidence intervals about current status and management reference points for Gulf of Mexico gag estimated from 500 bootstraps of the VPA based on the age-length-key plus stochastic growth catch-at-age under the assumptions (1) that index selectivity in the VPA varied by year and (2) that for the management bench marks and projections, recruitment would increase with spawning stock size to the maximum observed in 1986-1999. Long-term potential yields are in millions of pounds gutted weight, yield per recruit is in pounds gutted weight, SSB is in thousands of metric tons of mature ovaries, and male SSB is in thousands of pounds gutted weight of mature males.

	Estimate	Bias-corrected Estimate	Range of 80% CI
SSB 2000 / SSB $F_{30\%}$	0.857	0.859	0.334
SSB 2000 / SSB $F_{\max}$	0.588	0.619	0.324
F 1997-1999 (geometric mean) / $F_{30\%}$	0.773	0.968	0.650
F 1997-1999 (geometric mean) / $F_{\max}$	1.24	1.49	0.897
$F_{30\%}$ SPR	0.573	0.514	0.577
Yield at $F_{30\%}$	8.50	4.80	98.8
Y/R at $F_{30\%}$	2.84	2.77	0.765
S/R at $F_{30\%}$	287	287	0.328
SSB at $F_{30\%}$	0.859	0.415	8.97
Male SSB at $F_{30\%}$ / Male SSB at $F_0$	0.0345		
$F_{40\%}$ SPR	0.406	0.365	0.327
Yield at $F_{40\%}$	9.04	4.55	114
Y/R at $F_{40\%}$	3.02	2.92	1.06
S/R at $F_{40\%}$	381	381	0.528
SSB at $F_{40\%}$	1.14	0.551	11.9
Male SSB at $F_{40\%}$ / Male SSB at $F_0$	0.0861		
F at maximum Y/R	0.359	0.326	0.245
Yield at $F_{\max}$	9.07	4.68	128
Y/R maximum	3.03	2.93	1.29
S/R at $F_{\max}$	418	406	161
SPR at $F_{\max}$	0.439	0.427	0.169
SSB at $F_{\max}$	1.25	0.643	16.2
Male SSB at $F_{\max}$ / Male SSB at $F_0$	0.113		

Table 34. Median and 80% empirical confidence intervals about current status and management reference points for Gulf of Mexico gag estimated from 500 bootstraps of the VPA based on the age-length-key plus stochastic growth catch-at-age under the assumptions (1) that index selectivity in the VPA varied by year and (2) that for the management bench marks and projections, recruitment would equal the historical average recruitment when spawning stock size equaled or exceeded the minimum observed in 1986-1999. Long-term potential yields are in millions of pounds gutted weight, yield per recruit is in pounds gutted weight, SSB is in thousands of metric tons of mature ovaries, and male SSB is in thousands of pounds gutted weight of mature males.

	Estimate	Bias-corrected Estimate	Range of 80% CI
SSB 2000 / SSB $F_{30\%}$	1.27	0.683	7.06
SSB 2000 / SSB $F_{\max}$	0.871	0.450	4.03
F 1997-1999 (geometric mean) / $F_{30\%}$	0.797	0.988	0.643
F 1997-1999 (geometric mean) / $F_{\max}$	1.27	1.52	0.895
$F_{30\%}$ SPR	0.556	0.509	0.459
Yield at $F_{30\%}$	4.77	4.19	4.04
Y/R at $F_{30\%}$	2.79	2.75	0.775
S/R at $F_{30\%}$	286	286	0.350
SSB at $F_{30\%}$	0.490	0.440	0.286
Male SSB at $F_{30\%}$ / Male SSB at $F_0$	0.0368		
$F_{40\%}$ SPR	0.396	0.361	0.273
Yield at $F_{40\%}$	5.08	4.40	4.80
Y/R at $F_{40\%}$	2.97	2.88	1.04
S/R at $F_{40\%}$	381	381	0.539
SSB at $F_{40\%}$	0.652	0.584	0.381
Male SSB at $F_{40\%}$ / Male SSB at $F_0$	0.0894		
F at maximum Y/R	0.349	0.320	0.242
Yield at $F_{\max}$	5.10	4.39	5.44
Y/R maximum	2.98	2.88	1.22
S/R at $F_{\max}$	418	407	156
SPR at $F_{\max}$	0.439	0.428	0.164
SSB at $F_{\max}$	0.716	0.642	0.639
Male SSB at $F_{\max}$ / Male SSB at $F_0$	0.117		



Table 35. Median and 80% empirical confidence intervals about current status and management reference points for Gulf of Mexico gag estimated from 500 bootstraps of the VPA based on the age-length-key plus stochastic growth catch-at-age under the assumptions (1) that index selectivity in the VPA was constant over years and (2) that for the management bench marks and projections, recruitment would increase with spawning stock size to the maximum observed in 1986-1999. Long-term potential yields are in millions of pounds gutted weight, yield per recruit is in pounds gutted weight, SSB is in thousands of metric tons of mature ovaries, and male SSB is in thousands of pounds gutted weight of mature males.

	Estimate	Bias-corrected Estimate	Range of 80% CI
SSB 2000 / SSB $F_{30\%}$	0.923	0.976	0.209
SSB 2000 / SSB $F_{\max}$	0.559	0.592	0.209
F 1997-1999 (geometric mean) / $F_{30\%}$	0.664	0.683	0.489
F 1997-1999 (geometric mean) / $F_{\max}$	1.26	1.28	0.793
$F_{30\%}$ SPR	0.651	0.655	0.276
Yield at $F_{30\%}$	11.4	9.46	13.0
Y/R at $F_{30\%}$	2.85	2.83	0.568
S/R at $F_{30\%}$	287	287	0.319
SSB at $F_{30\%}$	1.15	0.953	1.21
Male SSB at $F_{30\%}$ / Male SSB at $F_0$	0.0224		
$F_{40\%}$ SPR	0.464	0.469	0.216
Yield at $F_{40\%}$	12.5	10.5	14.8
Y/R at $F_{40\%}$	3.13	3.11	0.793
S/R at $F_{40\%}$	382	382	0.540
SSB at $F_{40\%}$	1.53	1.27	1.61
Male SSB at $F_{40\%}$ / Male SSB at $F_0$	0.0582		
F at maximum Y/R	0.342	0.353	0.276
Yield at $F_{\max}$	12.9	10.7	15.8
Y/R maximum	3.21	3.19	0.979
S/R at $F_{\max}$	473	470	89.6
SPR at $F_{\max}$	0.497	0.493	0.0941
SSB at $F_{\max}$	1.89	1.62	2.10
Male SSB at $F_{\max}$ / Male SSB at $F_0$	0.114		

Table 36. Median and 80% empirical confidence intervals about current status and management reference points for Gulf of Mexico gag estimated from 500 bootstraps of the VPA based on the age-length-key plus stochastic growth catch-at-age under the assumptions (1) that index selectivity in the VPA was constant over years and (2) that for the management bench marks and projections, recruitment would equal the historical average recruitment when spawning stock size equaled or exceeded the minimum observed in 1986-1999. Long-term potential yields are in millions of pounds gutted weight, yield per recruit is in pounds gutted weight, SSB is in thousands of metric tons of mature ovaries, and male SSB is in thousands of pounds gutted weight of mature males.

	Estimate	Bias-corrected Estimate	Range of 80% CI
SSB 2000 / SSB $F_{30\%}$	1.58	1.38	1.43
SSB 2000 / SSB $F_{\max}$	0.954	0.816	0.825
F 1997-1999 (geometric mean) / $F_{30\%}$	0.704	0.722	0.491
F 1997-1999 (geometric mean) / $F_{\max}$	1.32	1.34	0.789
$F_{30\%}$ SPR	0.614	0.618	0.255
Yield at $F_{30\%}$	4.82	4.62	1.70
Y/R at $F_{30\%}$	2.77	2.74	0.619
S/R at $F_{30\%}$	286	286	0.348
SSB at $F_{30\%}$	0.499	0.489	0.098
Male SSB at $F_{30\%}$ / Male SSB at $F_0$	0.0255		
$F_{40\%}$ SPR	0.441	0.447	0.201
Yield at $F_{40\%}$	5.30	5.12	2.07
Y/R at $F_{40\%}$	3.04	3.02	0.847
S/R at $F_{40\%}$	382	382	0.551
SSB at $F_{40\%}$	0.665	0.654	0.131
Male SSB at $F_{40\%}$ / Male SSB at $F_0$	0.0634		
F at maximum Y/R	0.327	0.336	0.257
Yield at $F_{\max}$	5.44	5.25	2.40
Y/R maximum	3.13	3.09	1.03
S/R at $F_{\max}$	473	470	88.9
SPR at $F_{\max}$	0.497	0.493	0.0933
SSB at $F_{\max}$	0.824	0.810	0.247
Male SSB at $F_{\max}$ / Male SSB at $F_0$	0.121		

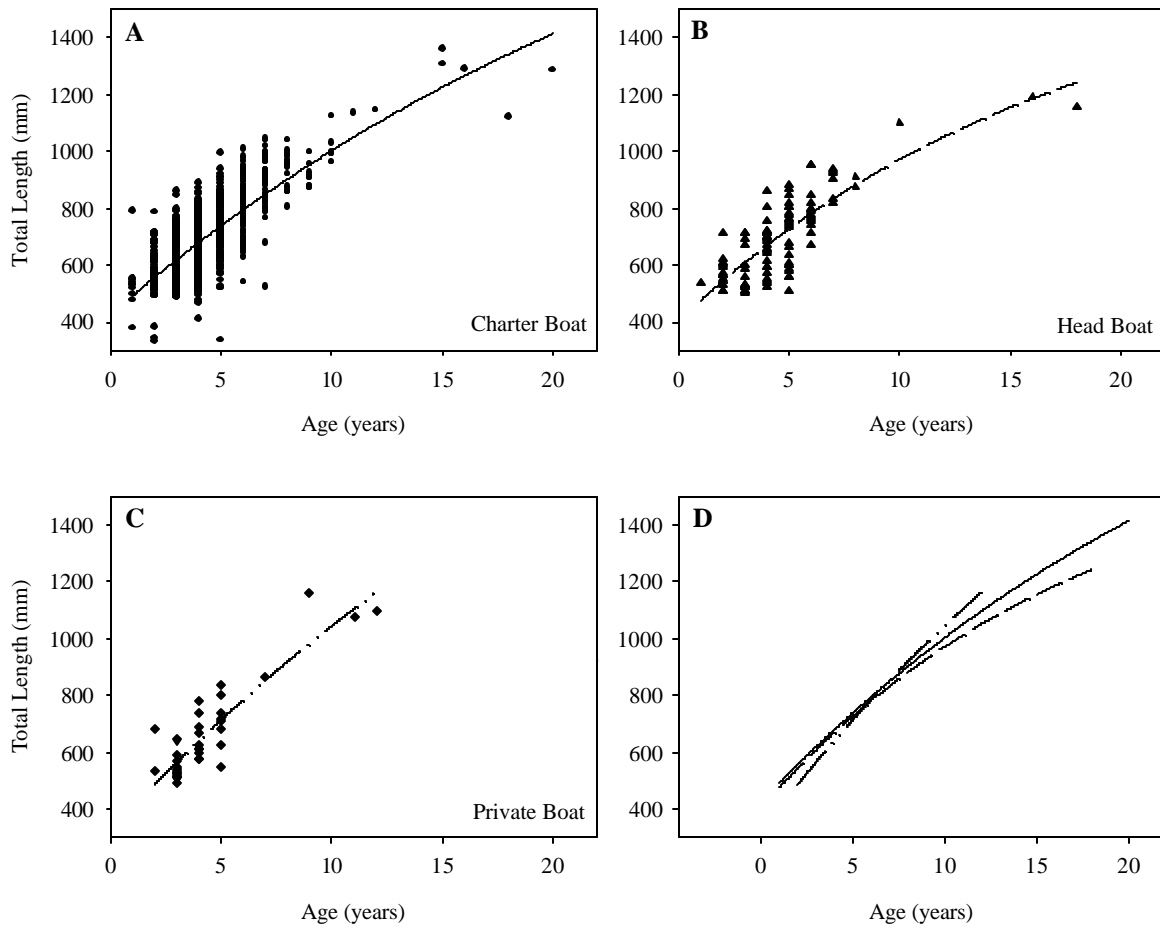


Figure 1. A comparison of length at age of gag caught by recreational fishing aboard charter (A), headboat (B), and private (C) vessels. Von Bertalanffy growth equations fit to the data are shown. The three curves are overlaid in panel D (charter=solid line, headboat=dashed line, and private = dash-dot-dot line).

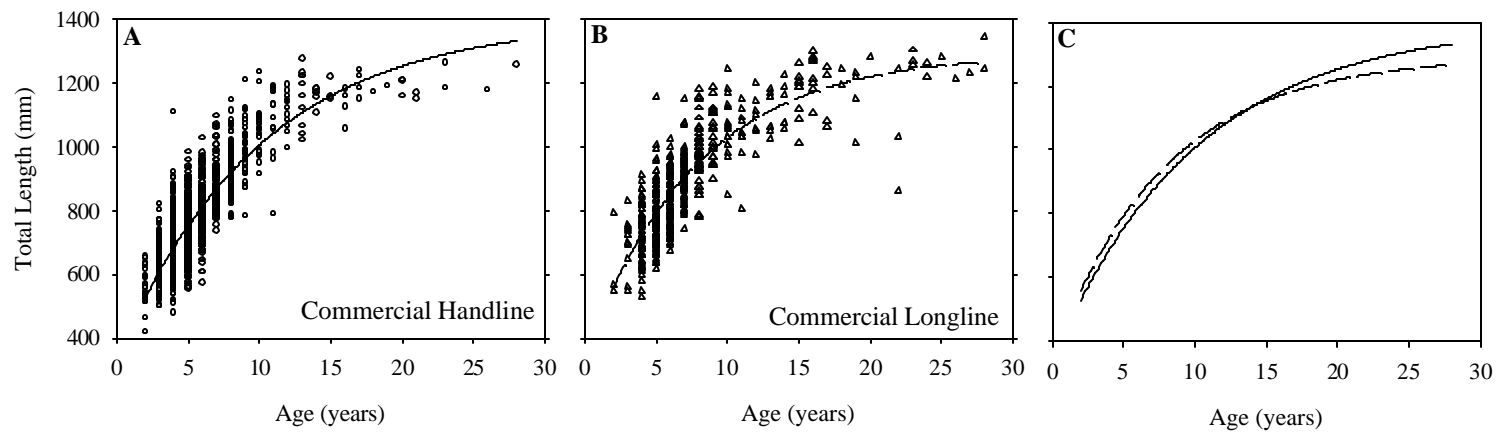


Figure 2. Comparison of the length at age of gag collected by handline (A) and longline (B) and fitted von Bertalanffy growth curves. In panel C the curves are overlaid (handline = solid and longline = dashed).

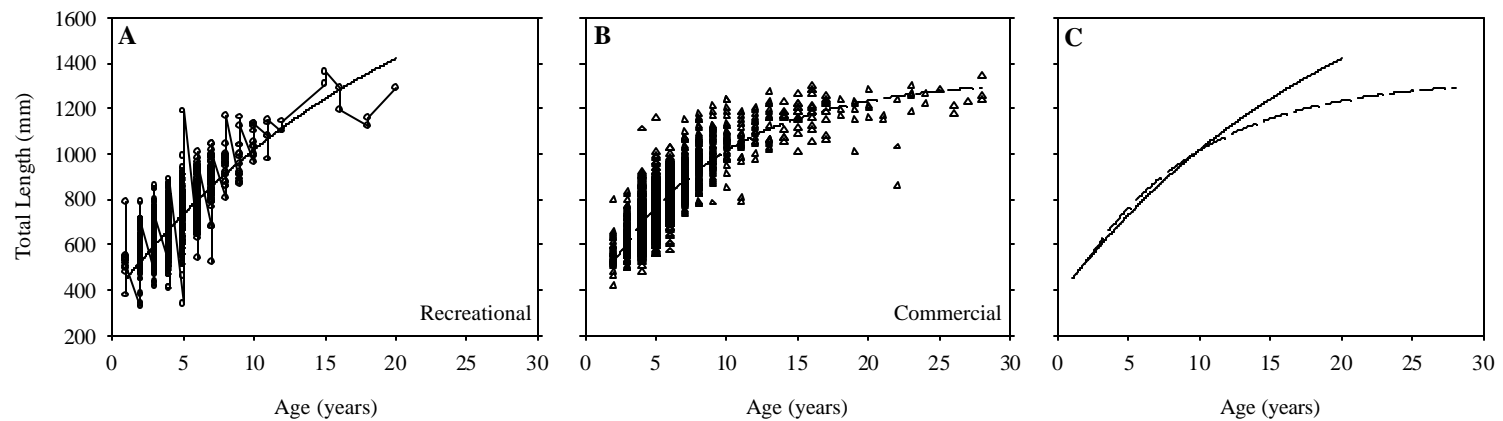


Figure 3. Comparison of length at age of gag caught in the recreational (A) and commercial (B) fisheries and fitted von Bertalanffy growth curves. In panel C the curves are overlaid (recreational = solid line and commercial = dashed line).

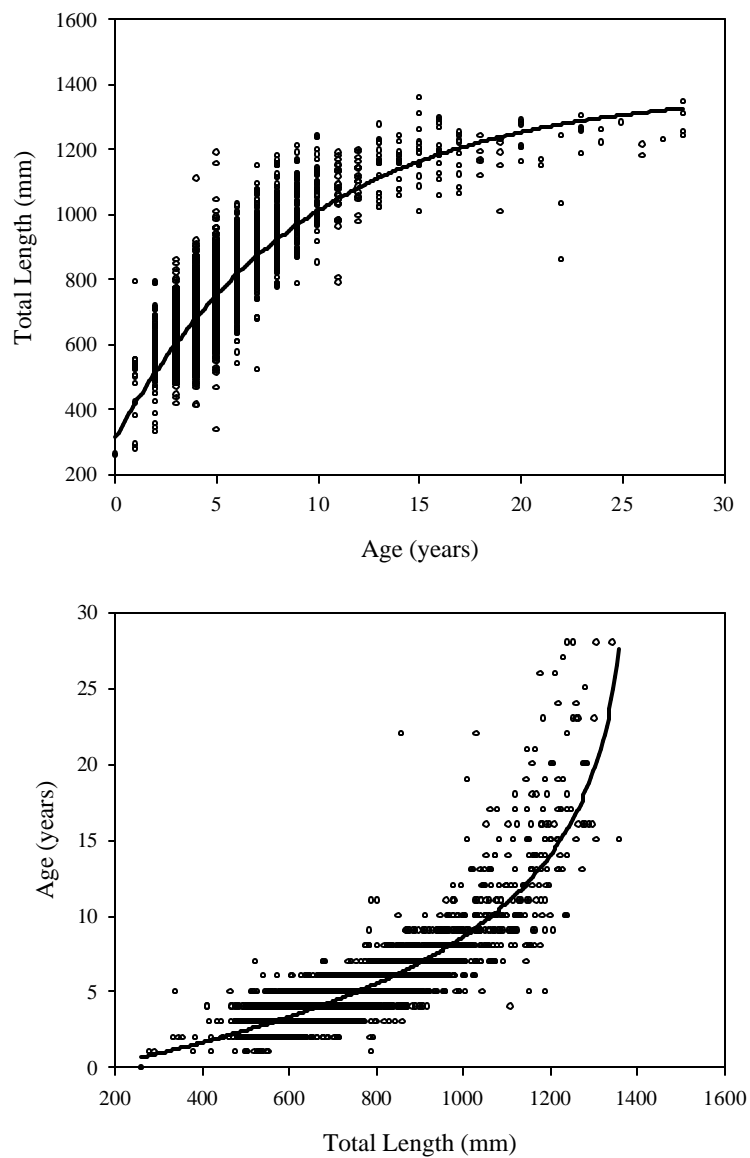


Figure 4. Von Bertalanffy (A) and inverted von Bertalanffy (B) growth curves fit to gag length-at-age data from recreational and commercial fisheries.

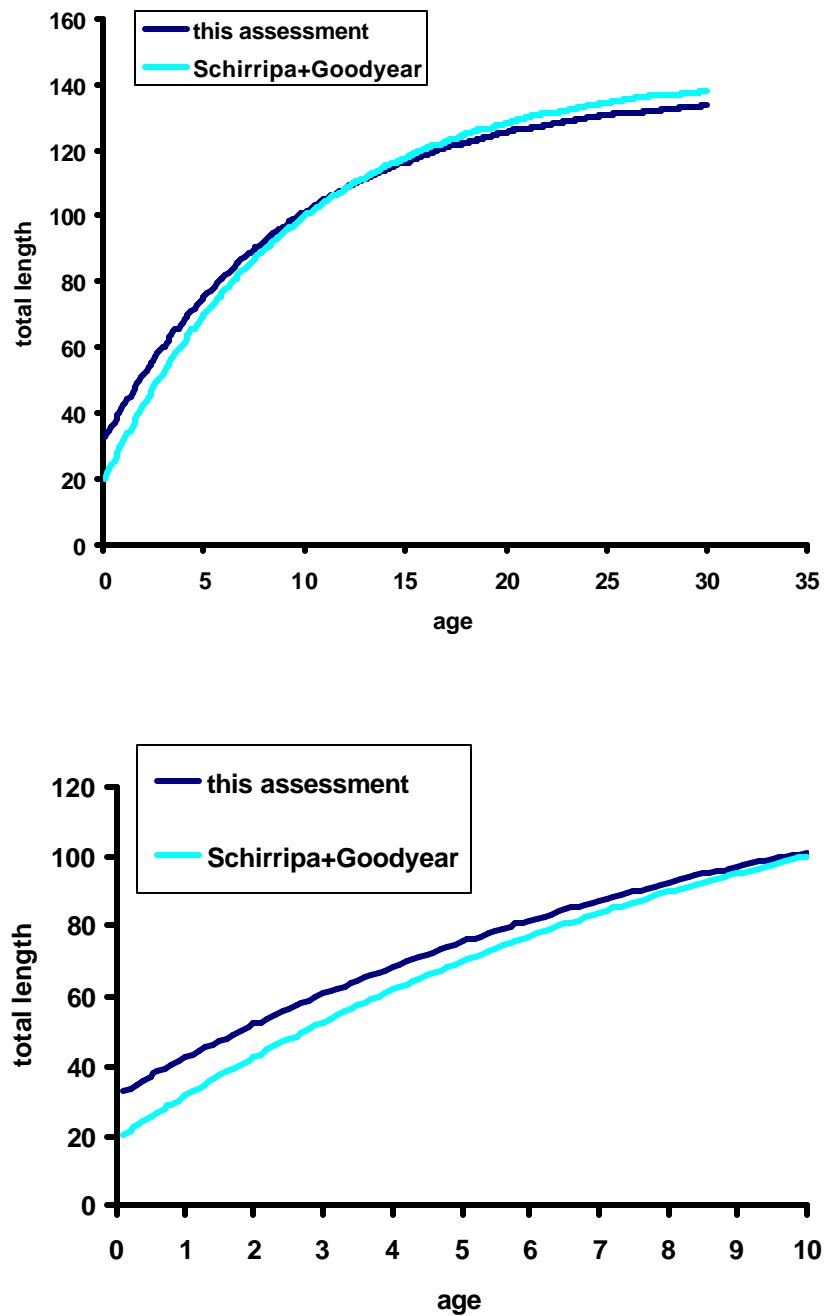


Figure 5. Comparison of the growth curve used for this assessment and the Schirripa and Goodyear (1994) curve used in the 1994 and 1997 assessments. Upper panel to age 30, lower to age 10.

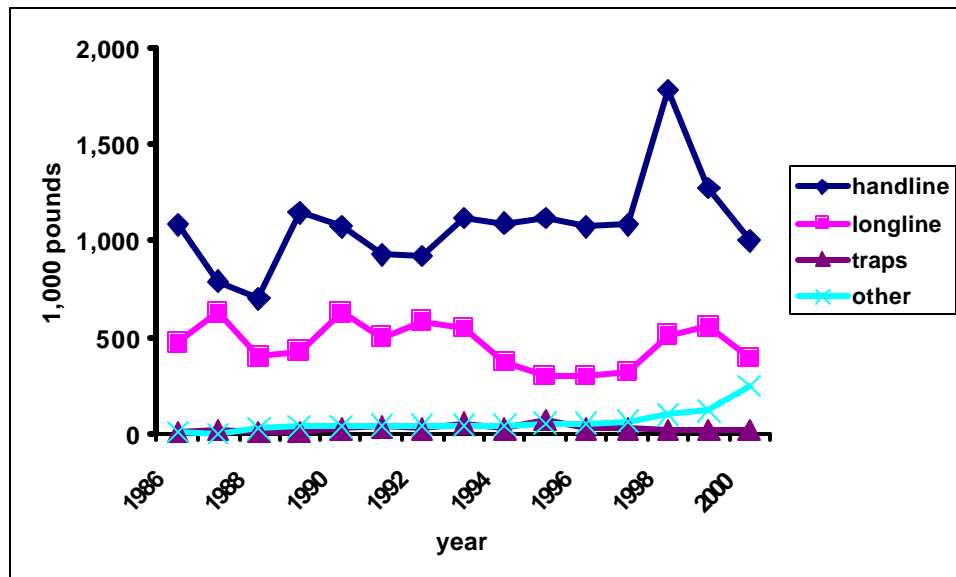


Figure 6. Commercial landings of calculated gag (including some black grouper and some unclassified groupers) by gear from U.S. Gulf of Mexico waters.

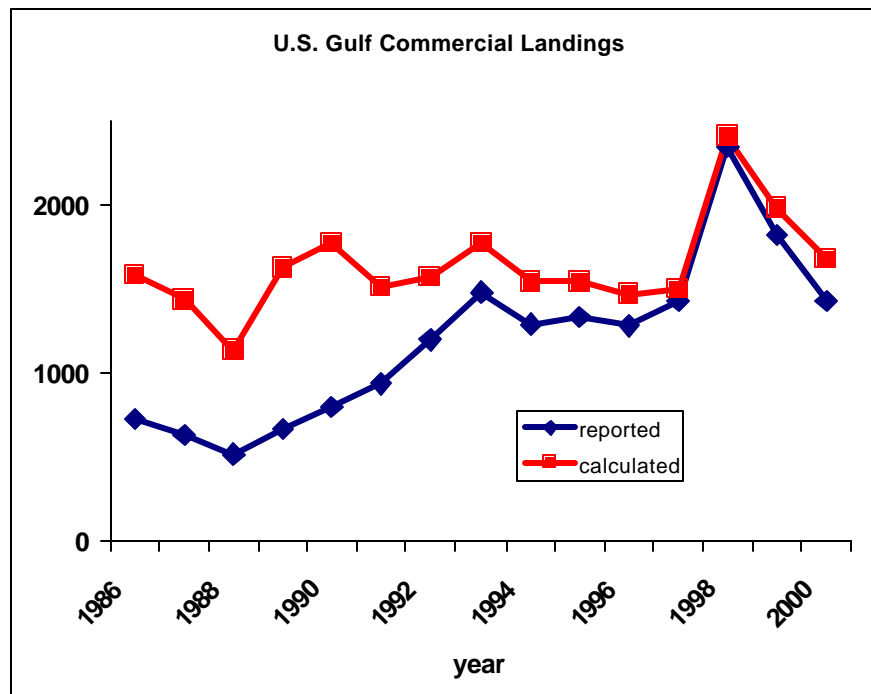


Figure 7. Reported and calculated gag from the U.S. Gulf of Mexico. Calculated gag is primarily derived from gag plus some black grouper

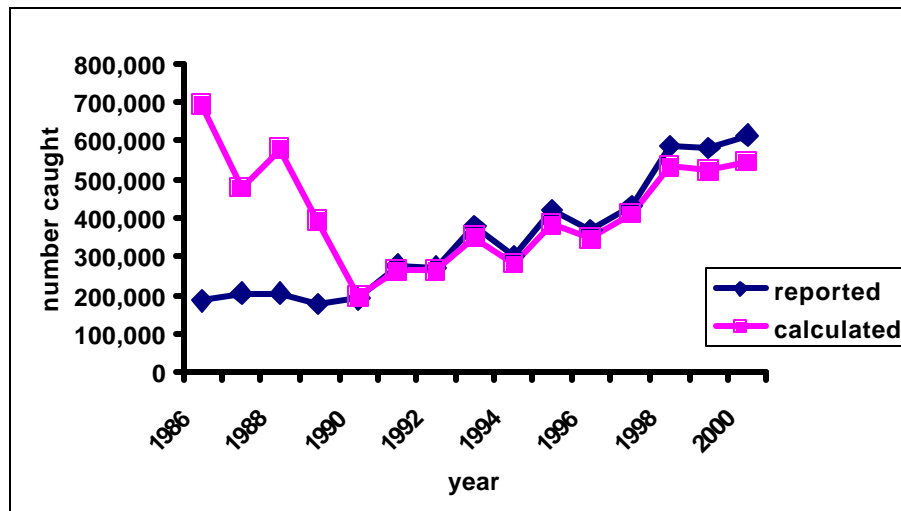


Figure 8. Recreational catches in number of fish reported to be gag and calculated to be gag. Calculated gag includes some black grouper.



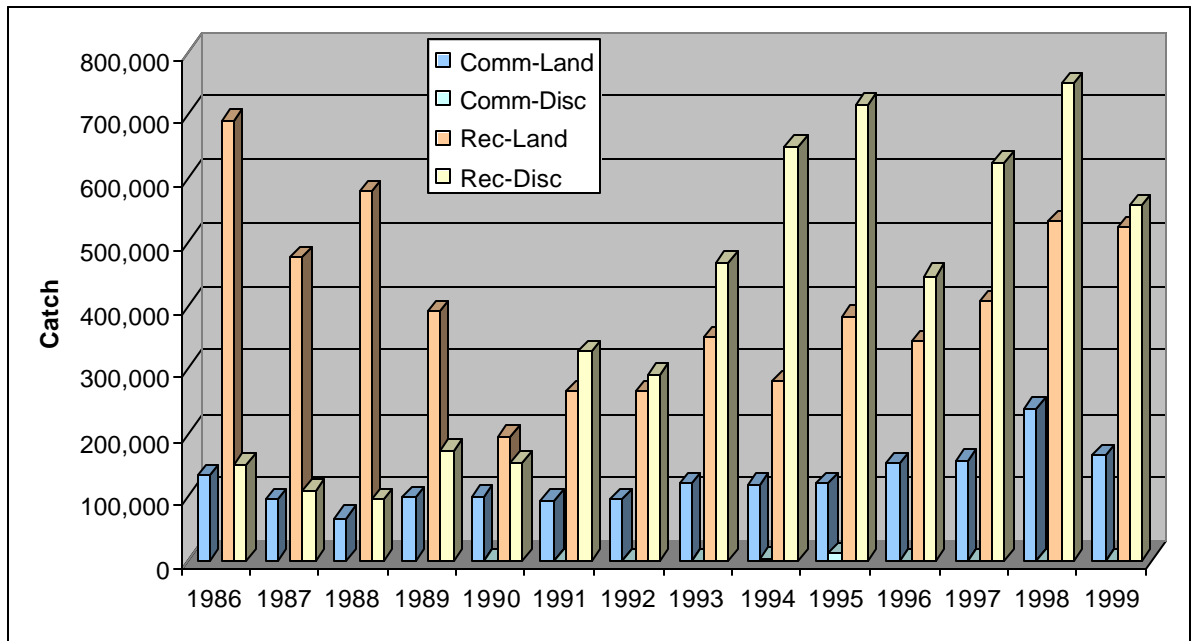


Figure 9. Calculated number of fish killed by recreational and commercial fisheries showing both landings and discards.

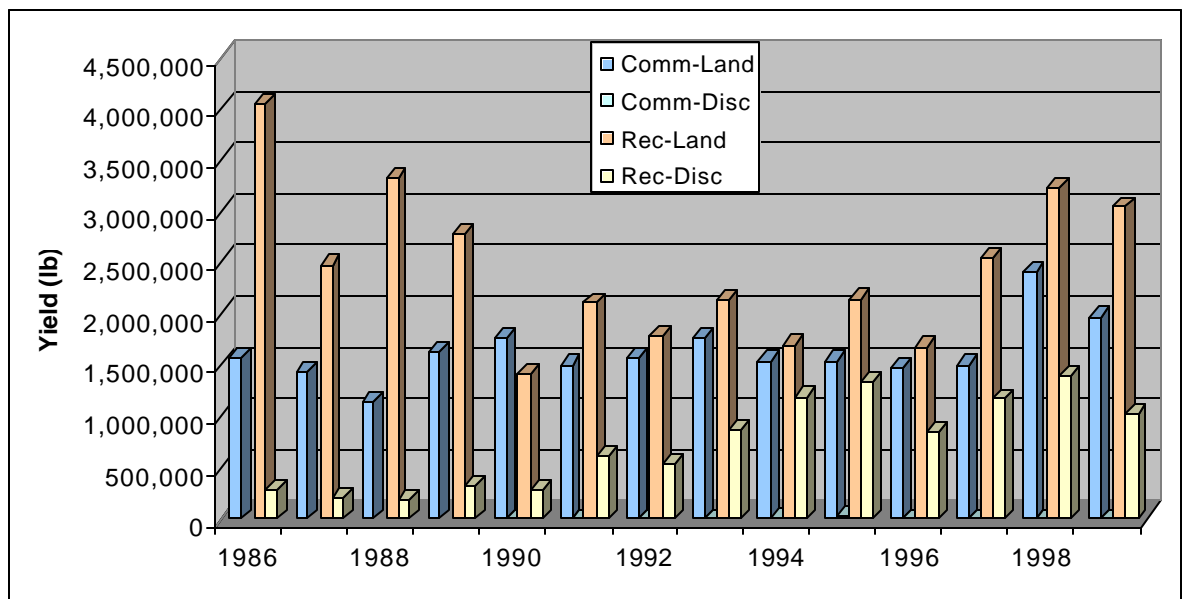


Figure 10. Calculated yield from the recreational and commercial fisheries showing both landings and discards.

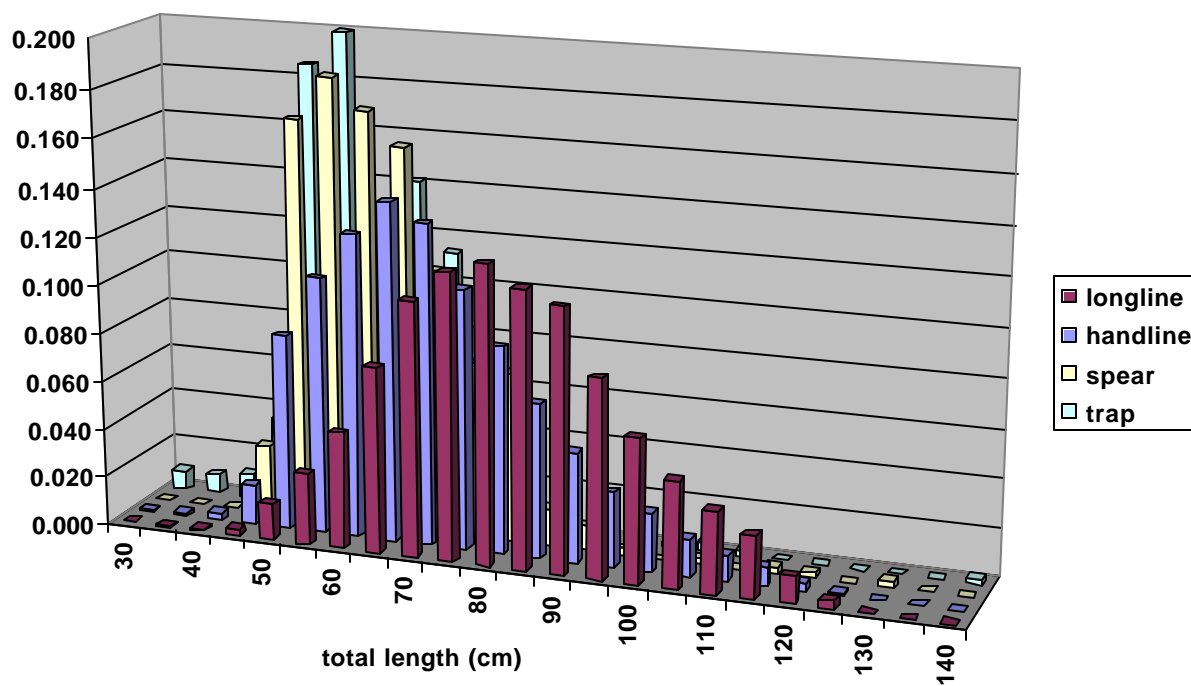
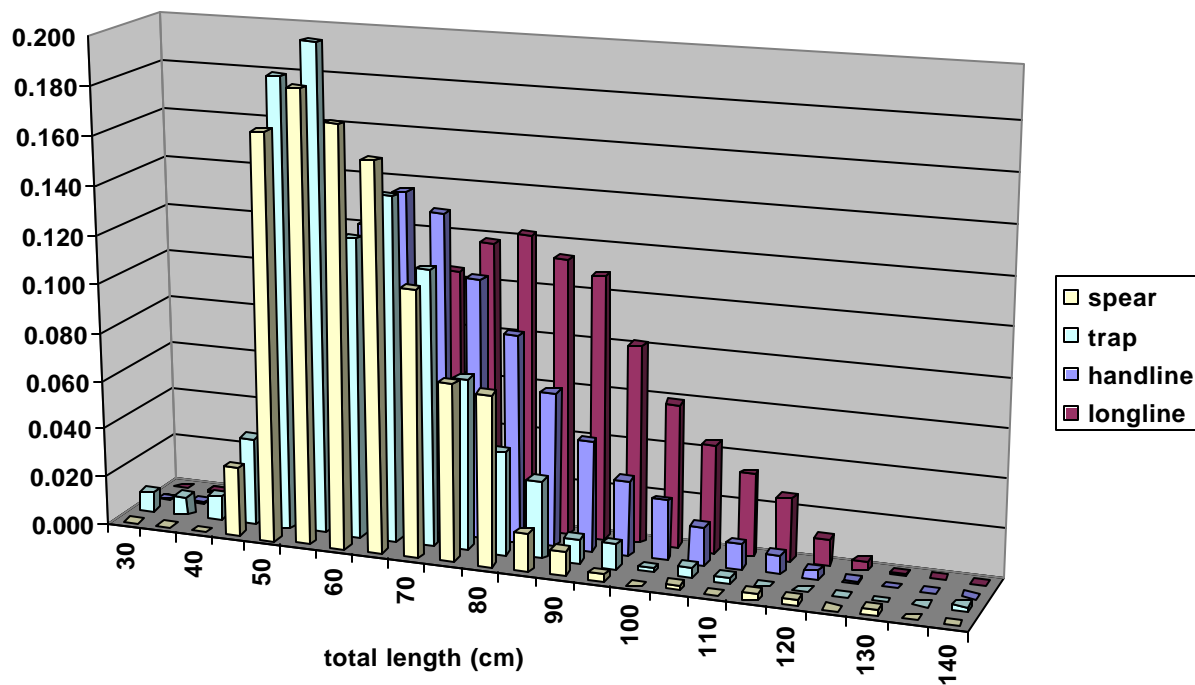


Figure 11. Commercial size composition by gear from 1986-1999.

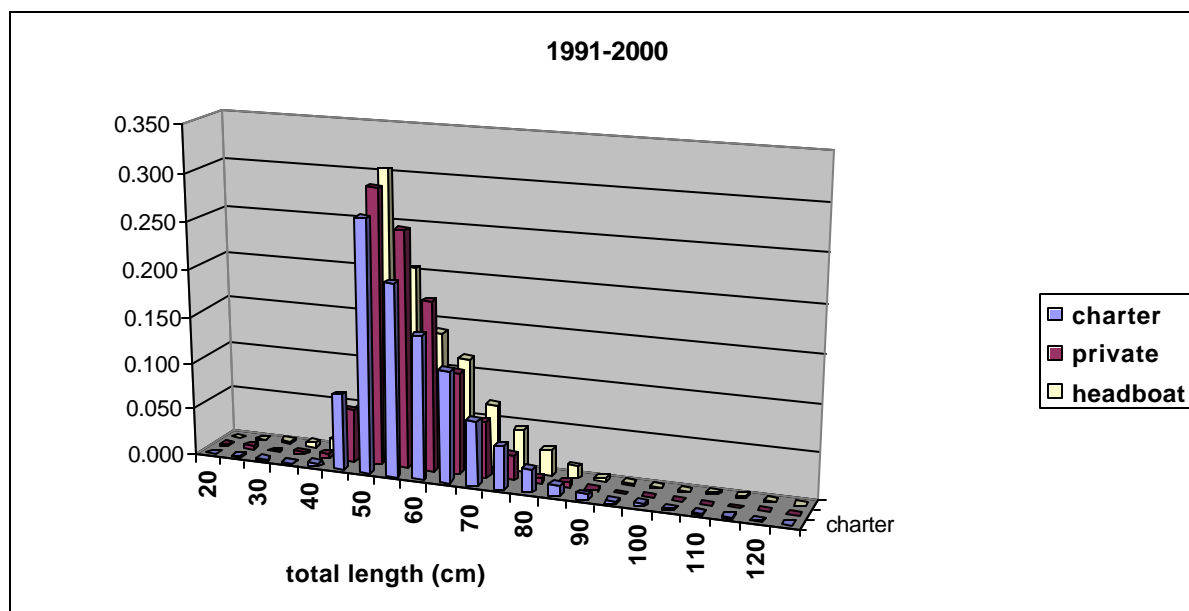
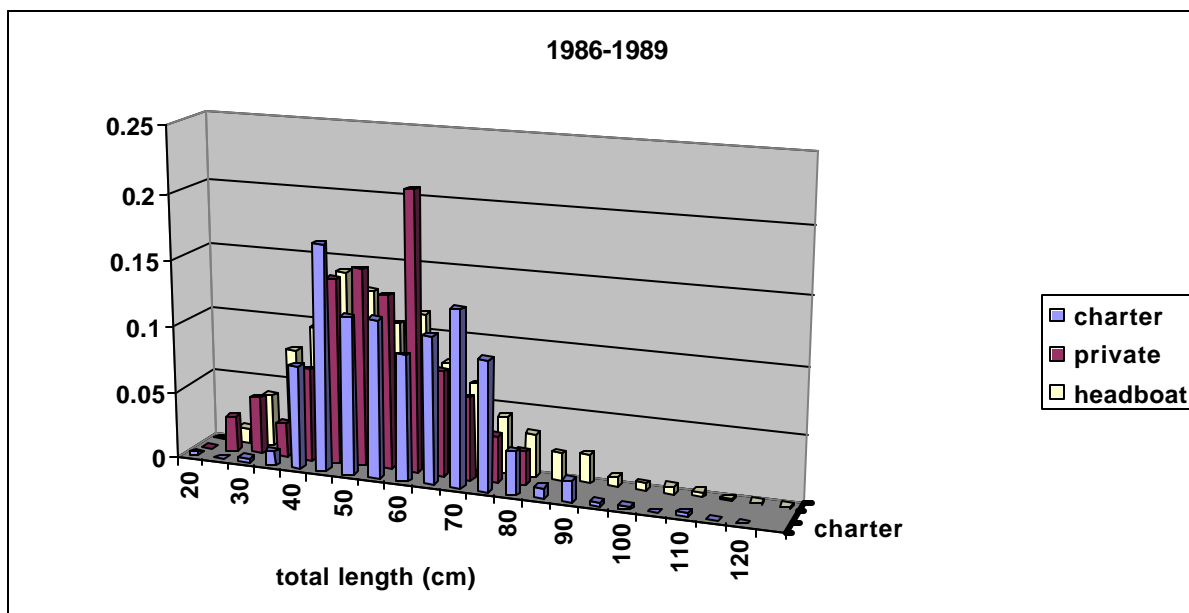


Figure 12. Size composition of recreational fisheries during 1986-1989 and 1991-2000 (1999 for head boat).

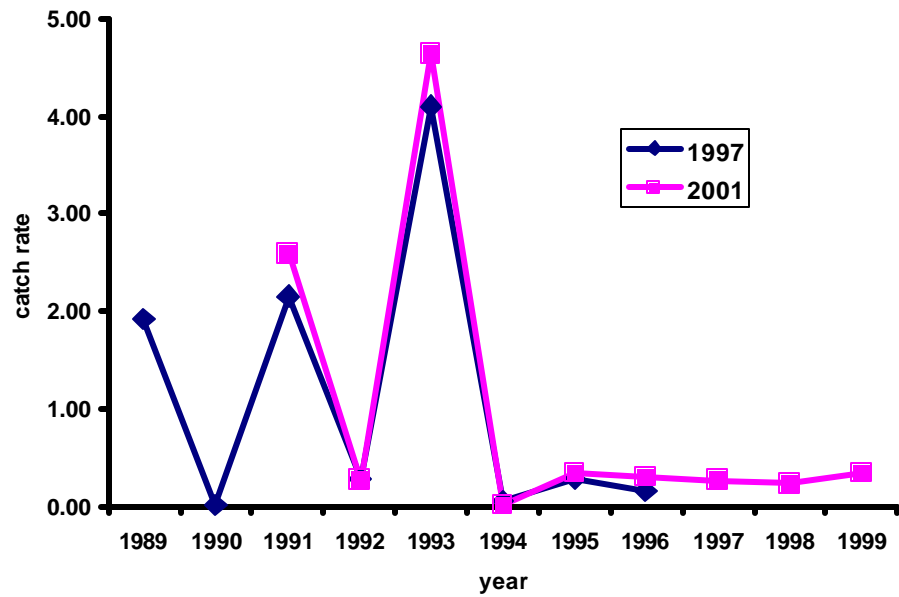


Figure 13. Indices of abundance from sea grass tows used for this assessment (2001) and the 1997 assessment by Schirripa and Legault.

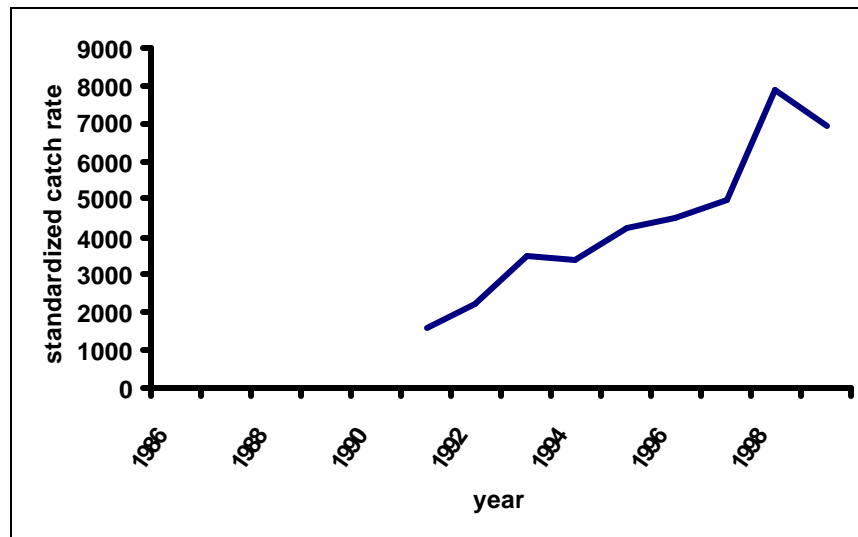


Figure 14. Standardized catch rates in pounds landed per day from handline effort in reef fish log book reports.

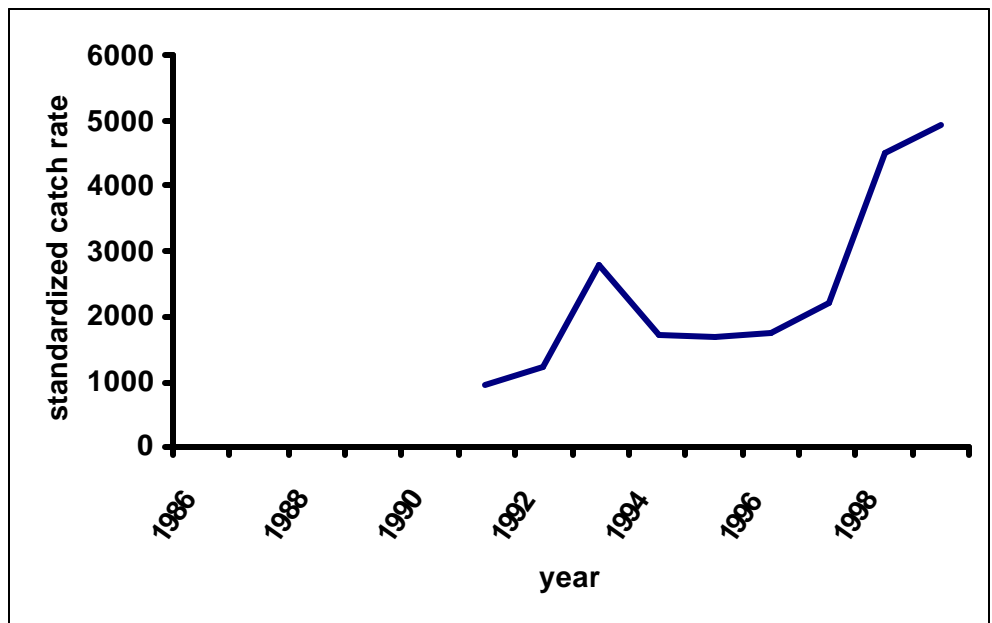


Figure 15. Standardized catch rates in pounds landed per day from longline effort in reef fish log book reports.

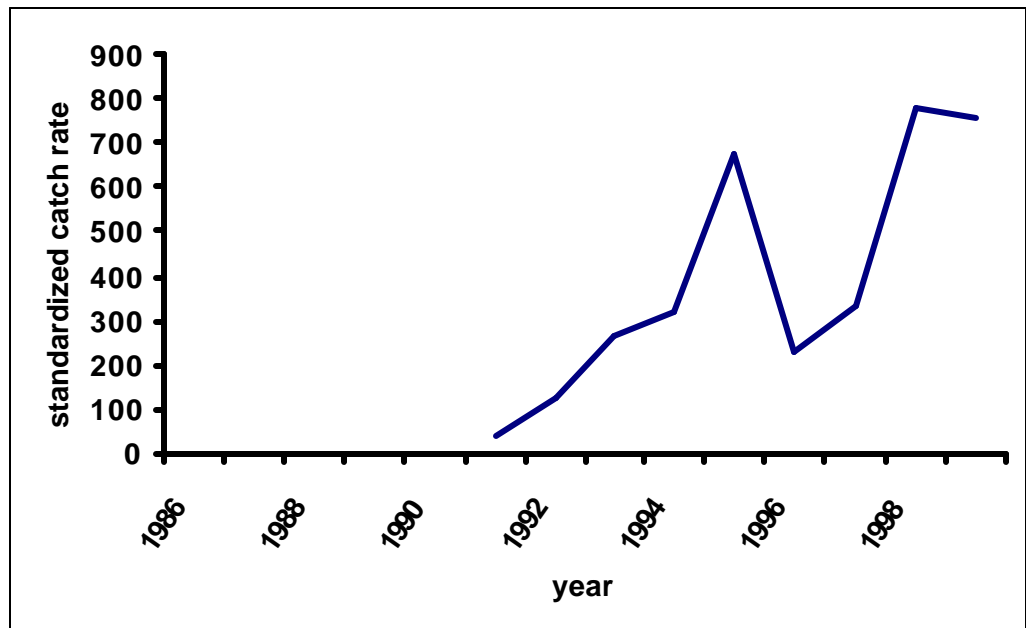


Figure 16. Standardized catch rates in pounds landed per day from trap effort in reef fish log book reports using a model without year interactions.

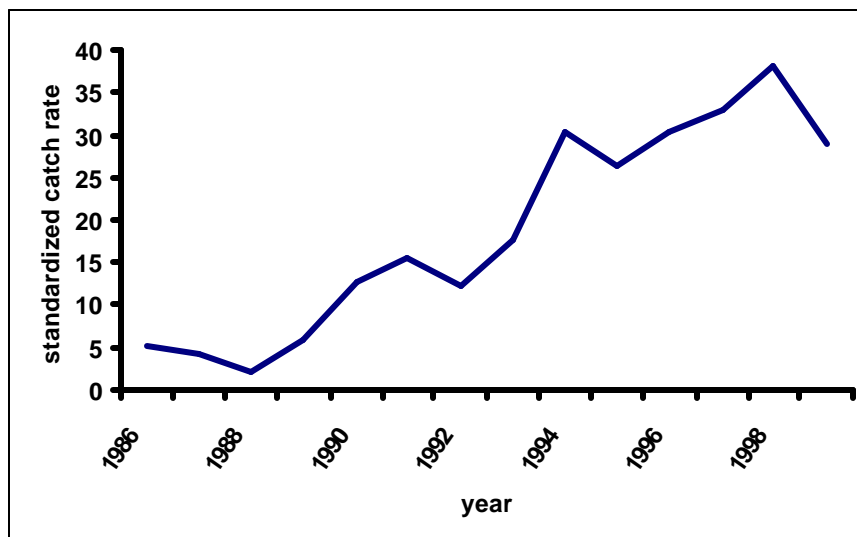


Figure 17. Standardized catch rates in fish per 1000 angler hours from MRFS dock-side sampling including both landed and discarded (dead and alive) catches.

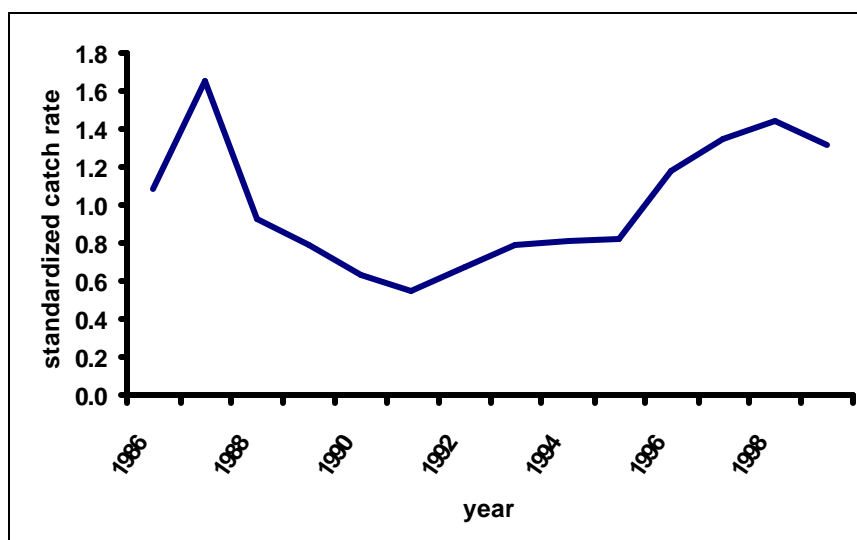


Figure 18. Standardized catch rates from headboat landings.

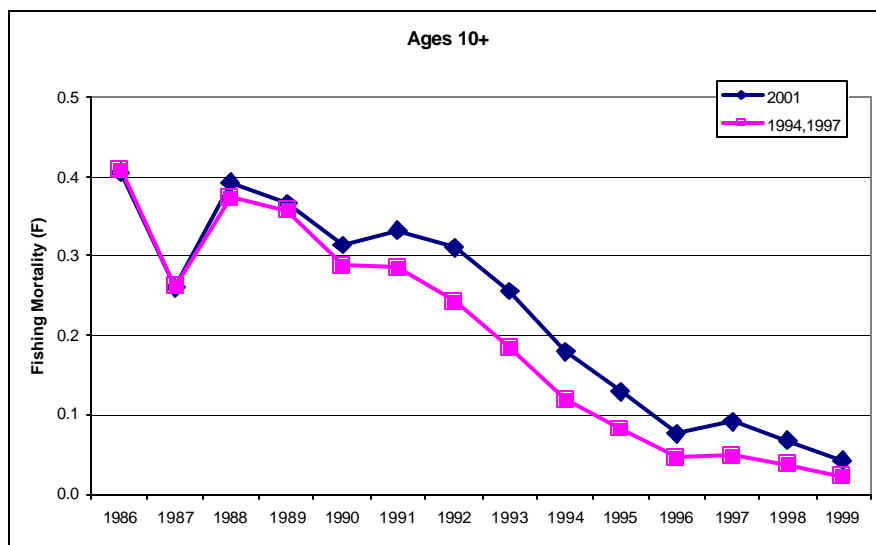
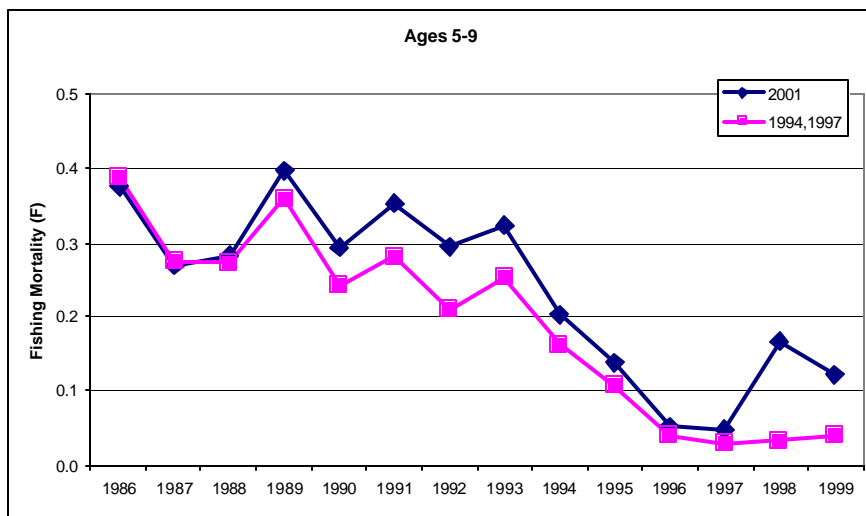
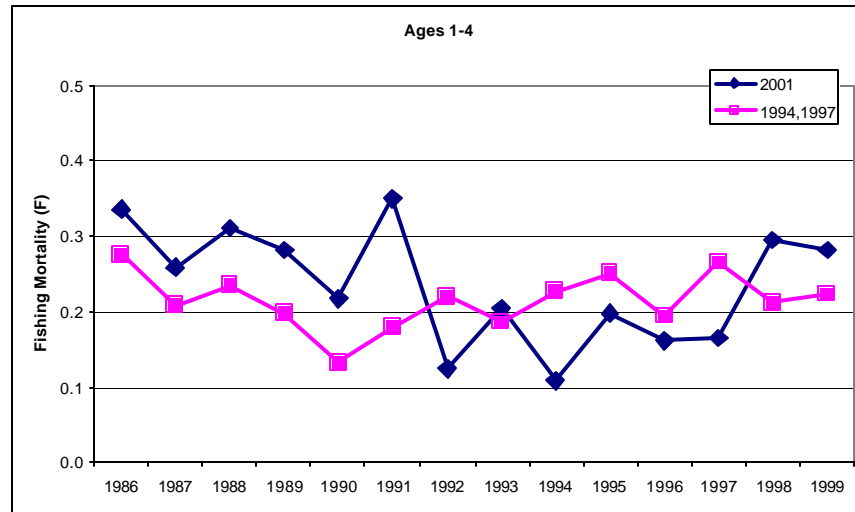


Figure 19. Comparison of the effect of different growth equations on fishing mortality rates by age.

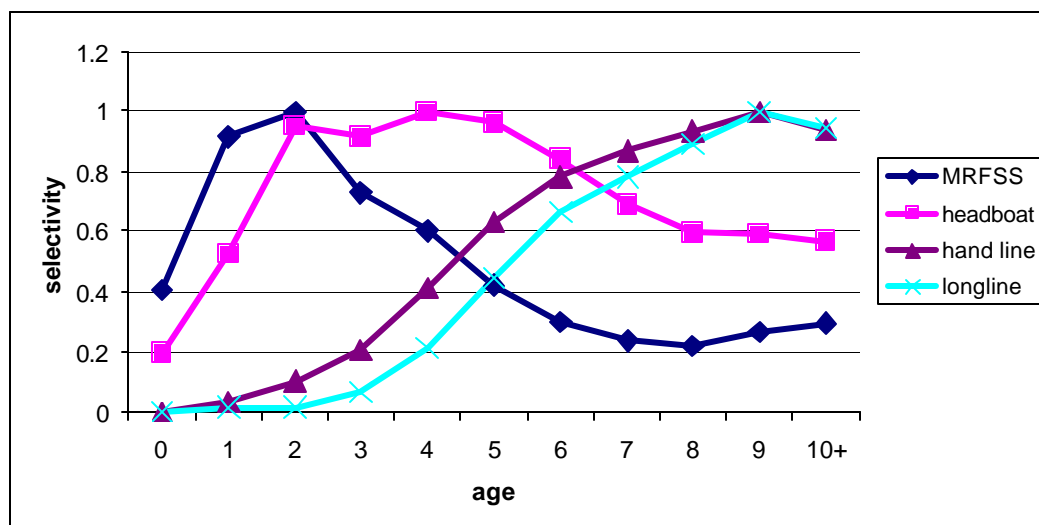


Figure 20. Selectivities of the fisheries with indices of abundance, assumed constant over the period of covered by the index.

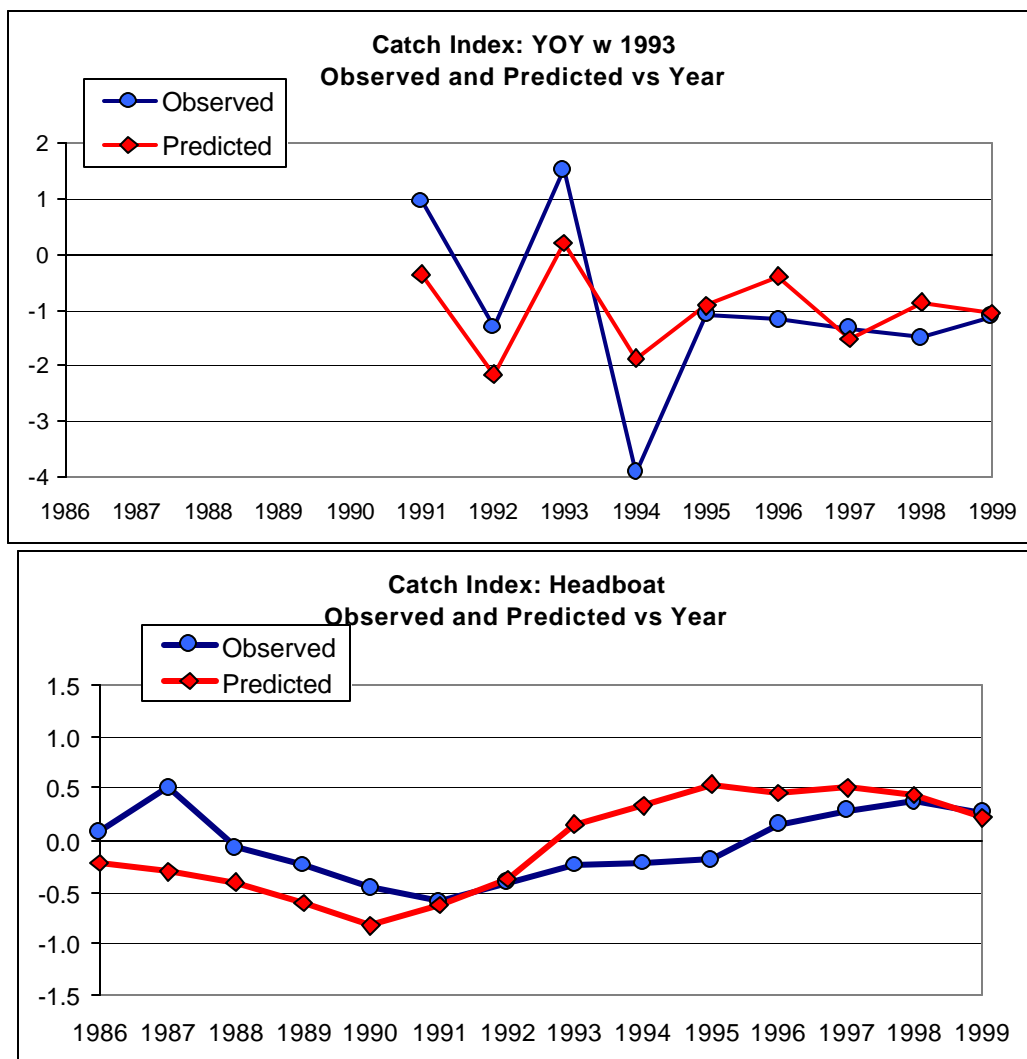


Figure 21. Fits to indices in VPA analysis of the RMM catch-at-age with year-constant selectivity (continued on next page).



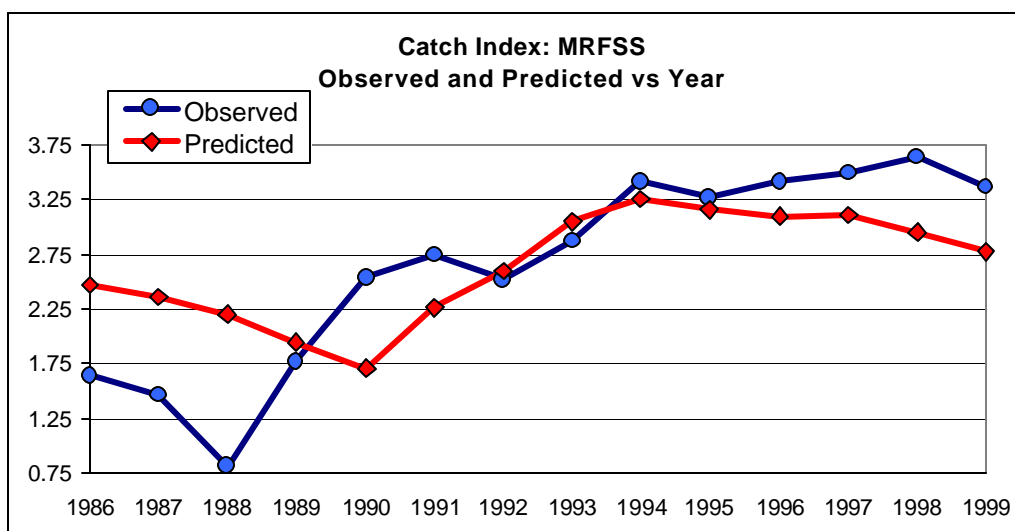
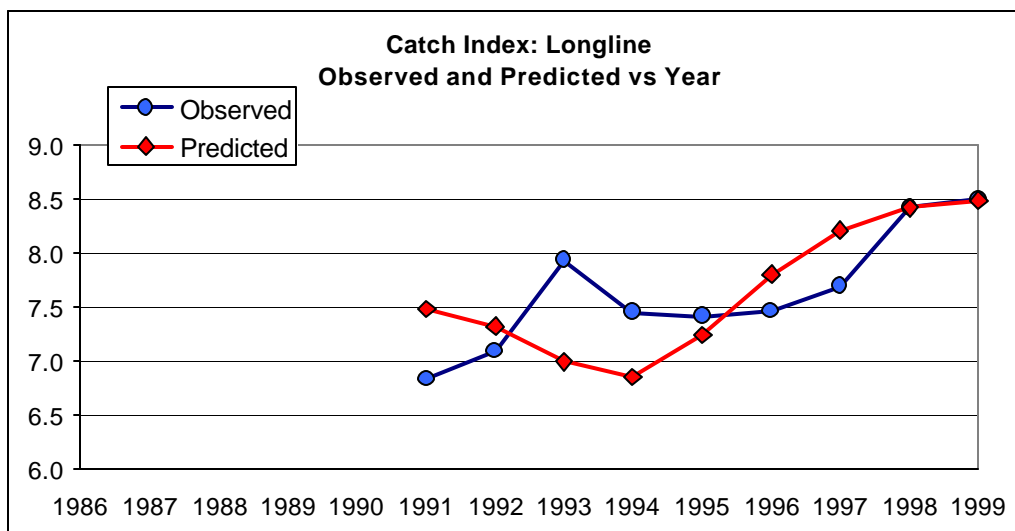
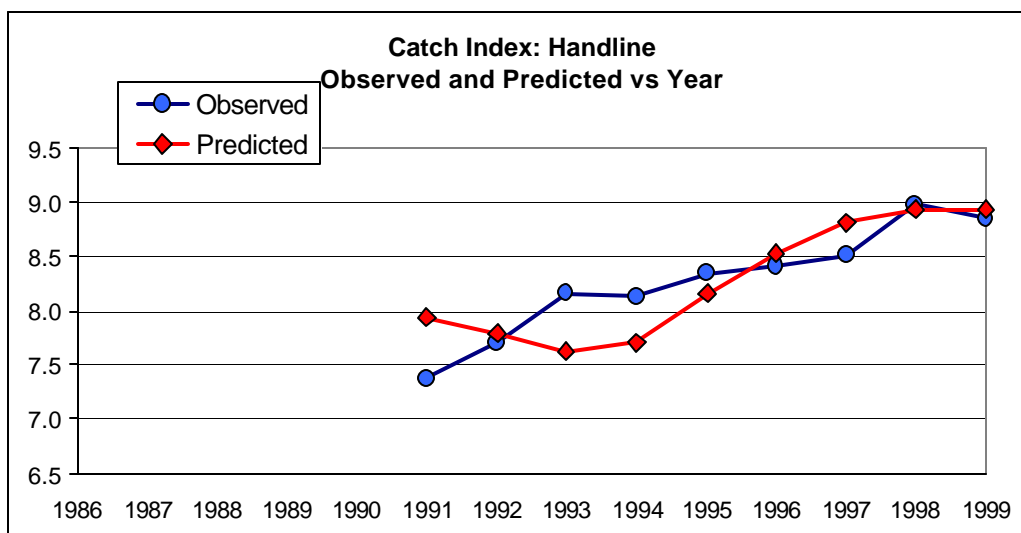


Figure 21, continued. Fits to indices from VPA on RMM catch-at-age with year-constant selectivity.

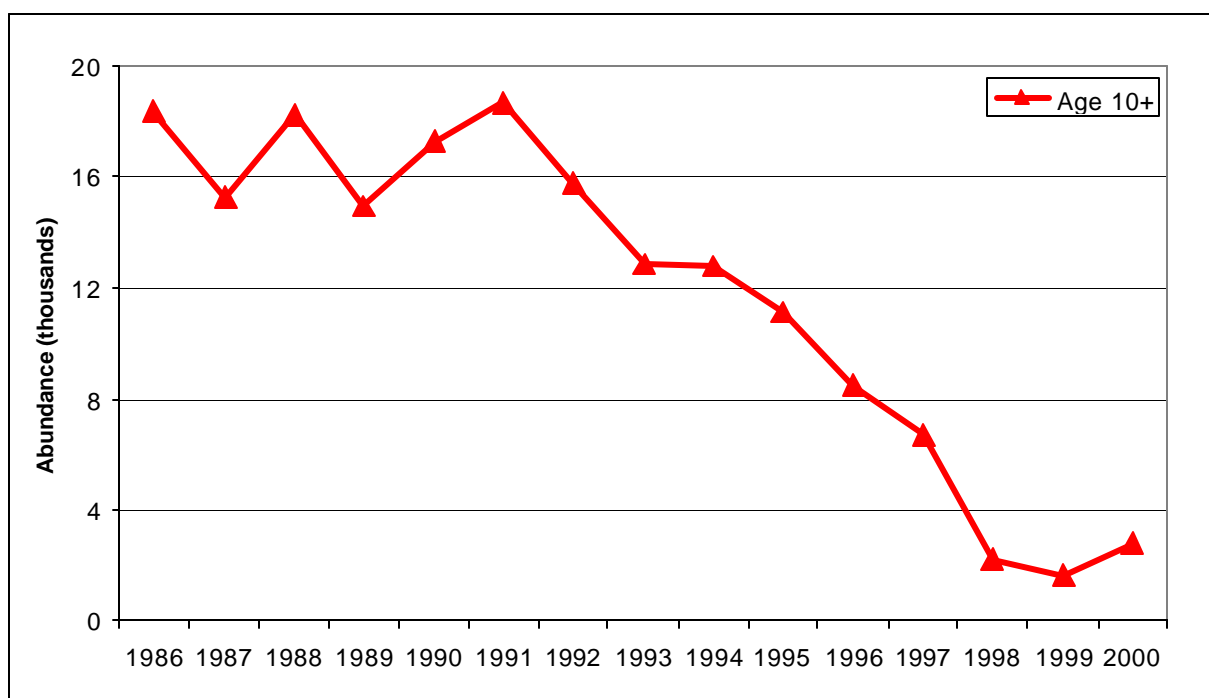
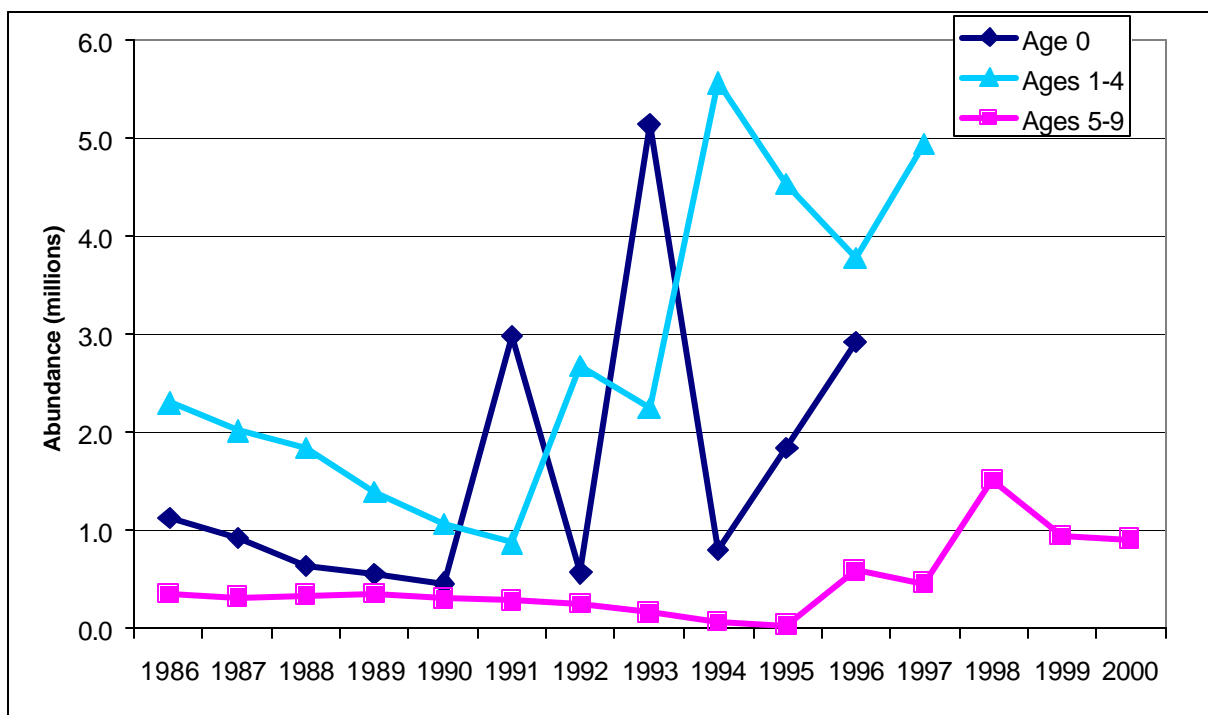


Figure 22. Estimated abundances from the VPA on the RMM catch-at-age with year-constant selectivity .

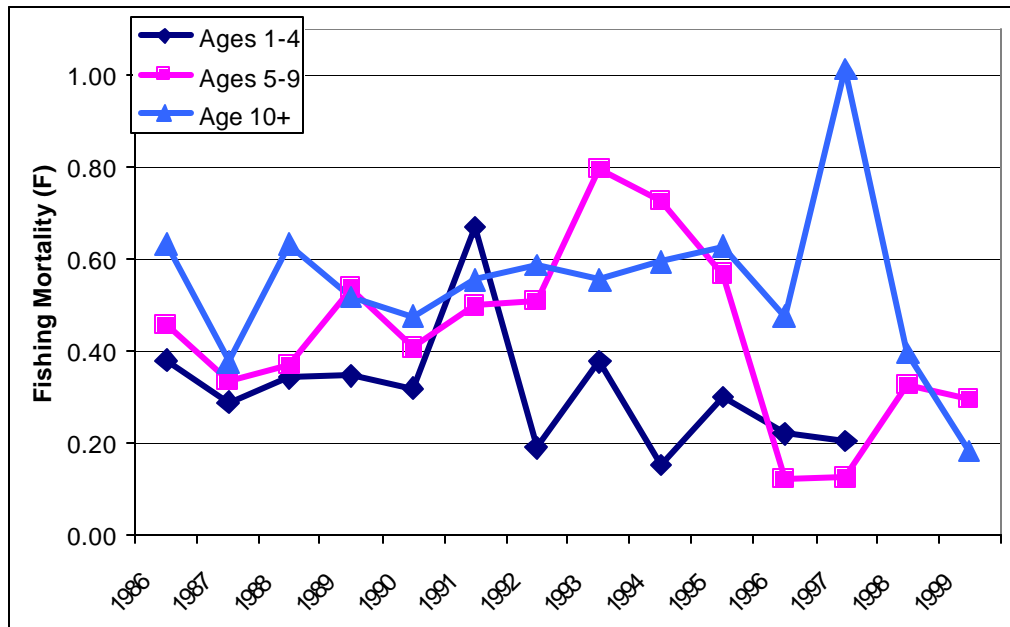


Figure 23. Estimated fishing mortality rate from the VPA. On the RMM catch-at-age with year-constant selectivity.

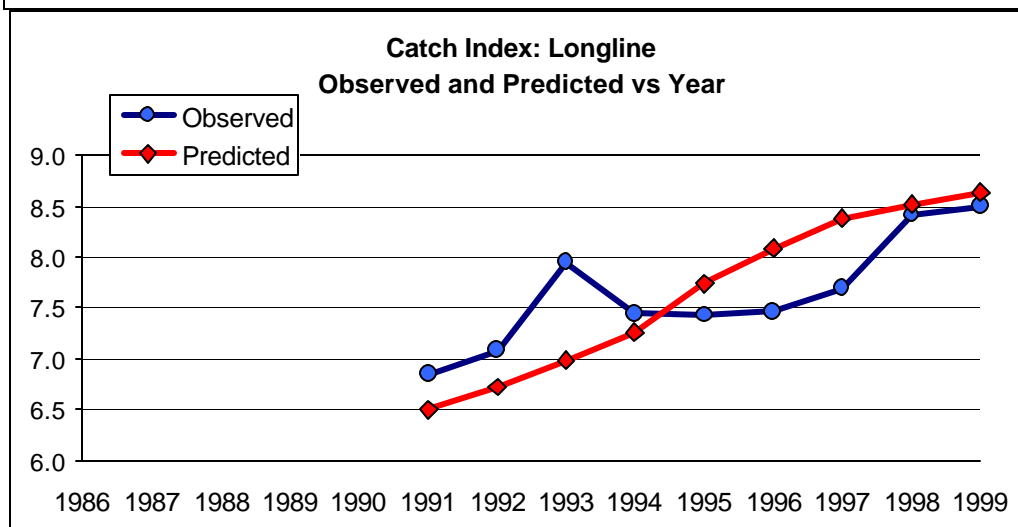
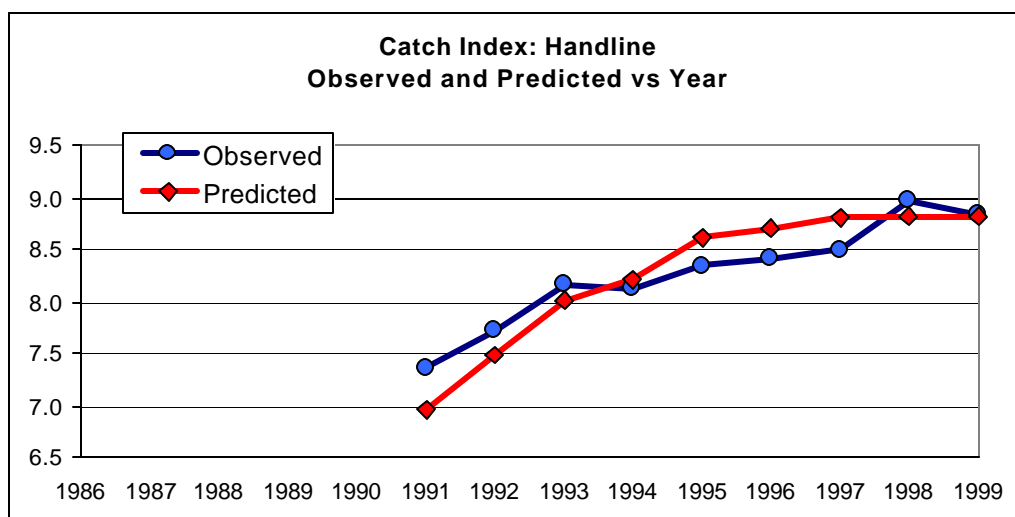
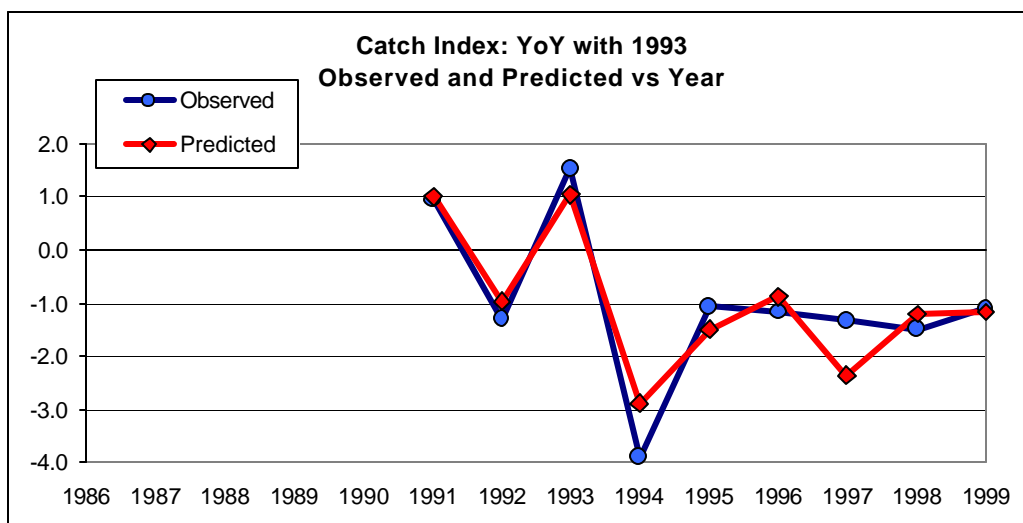


Figure 24. Fits to indices from the sensitivity analysis with the commercial indices and the young of the year index.

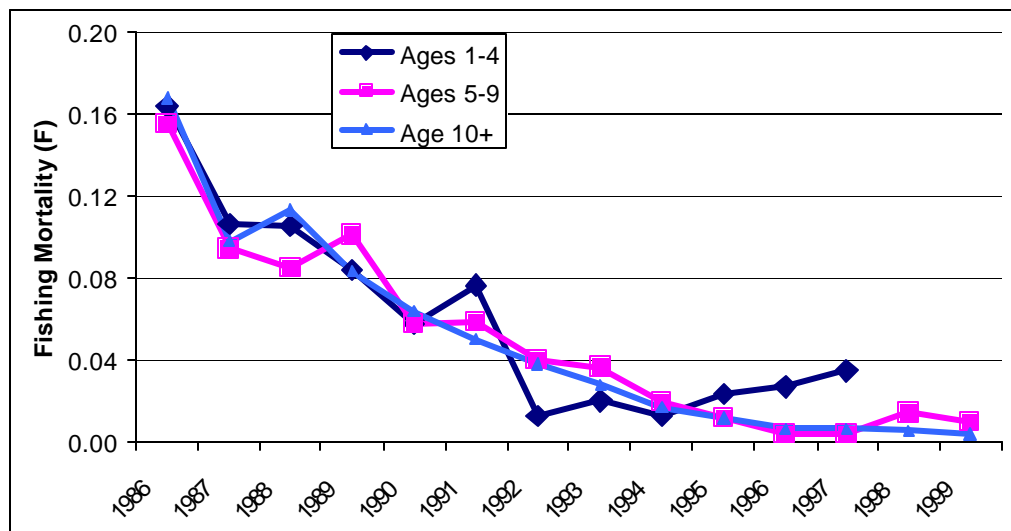


Figure 25. Fishing mortality rates from the sensitivity analysis using the commercial indices and the young of the year index.

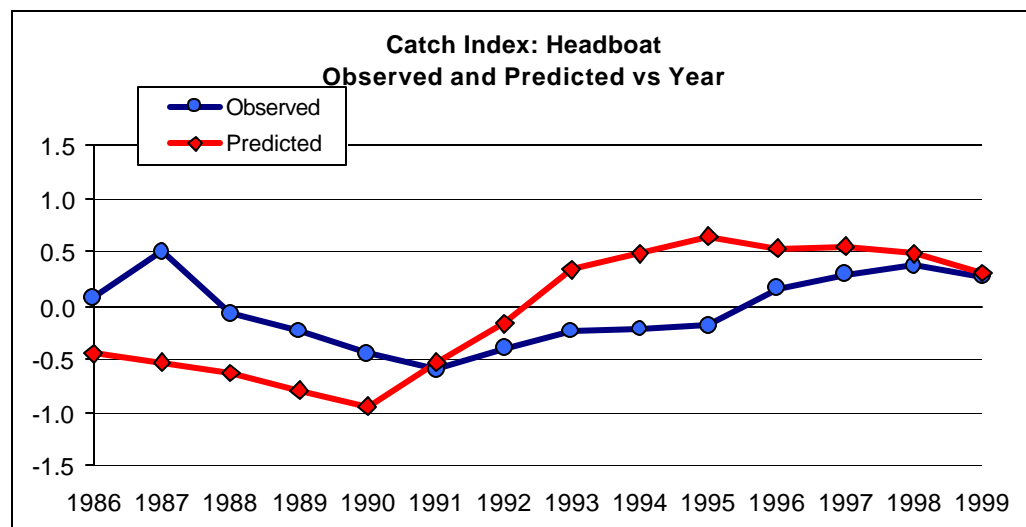
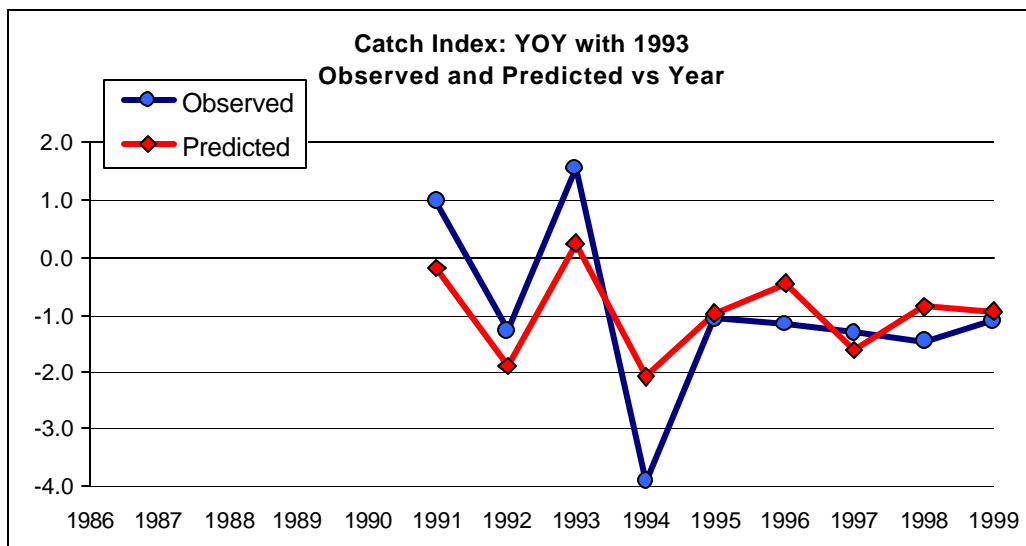


Figure 26. Fits to the indices from sensitivity analysis using recreational indices and the young of the year index (continued on next page).

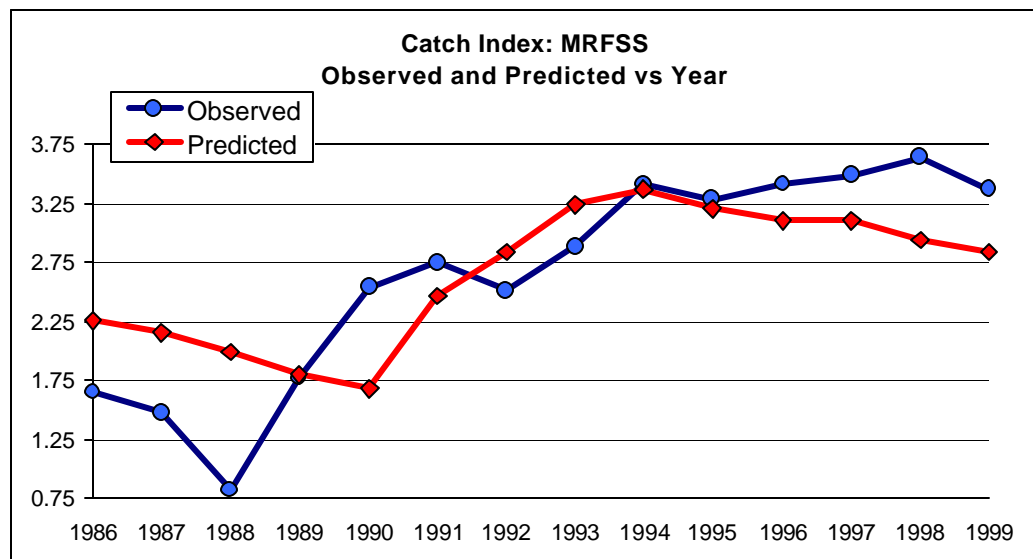


Figure 26 continued.

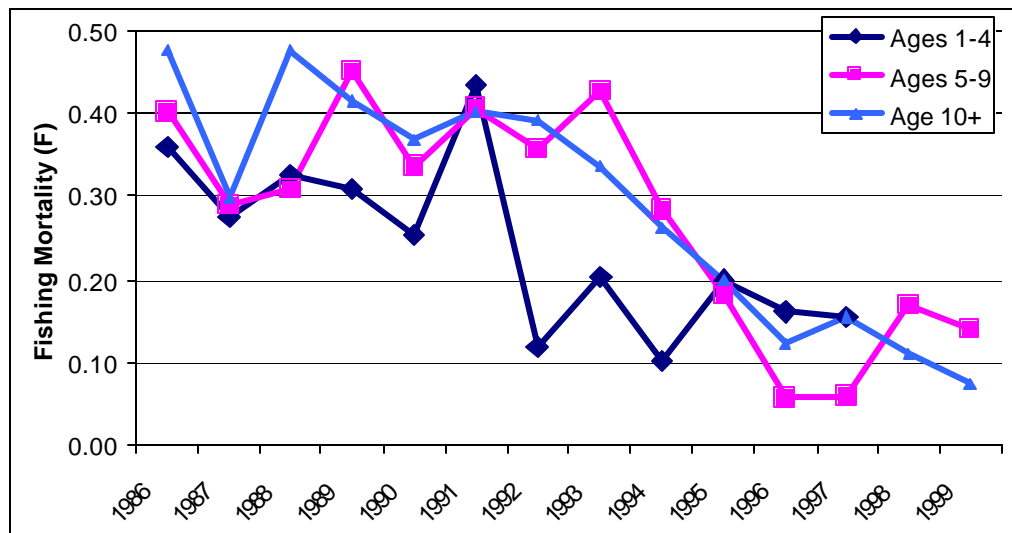


Figure 27. Fishing mortality rates estimated from analysis of recreational indices and the young of the year index.

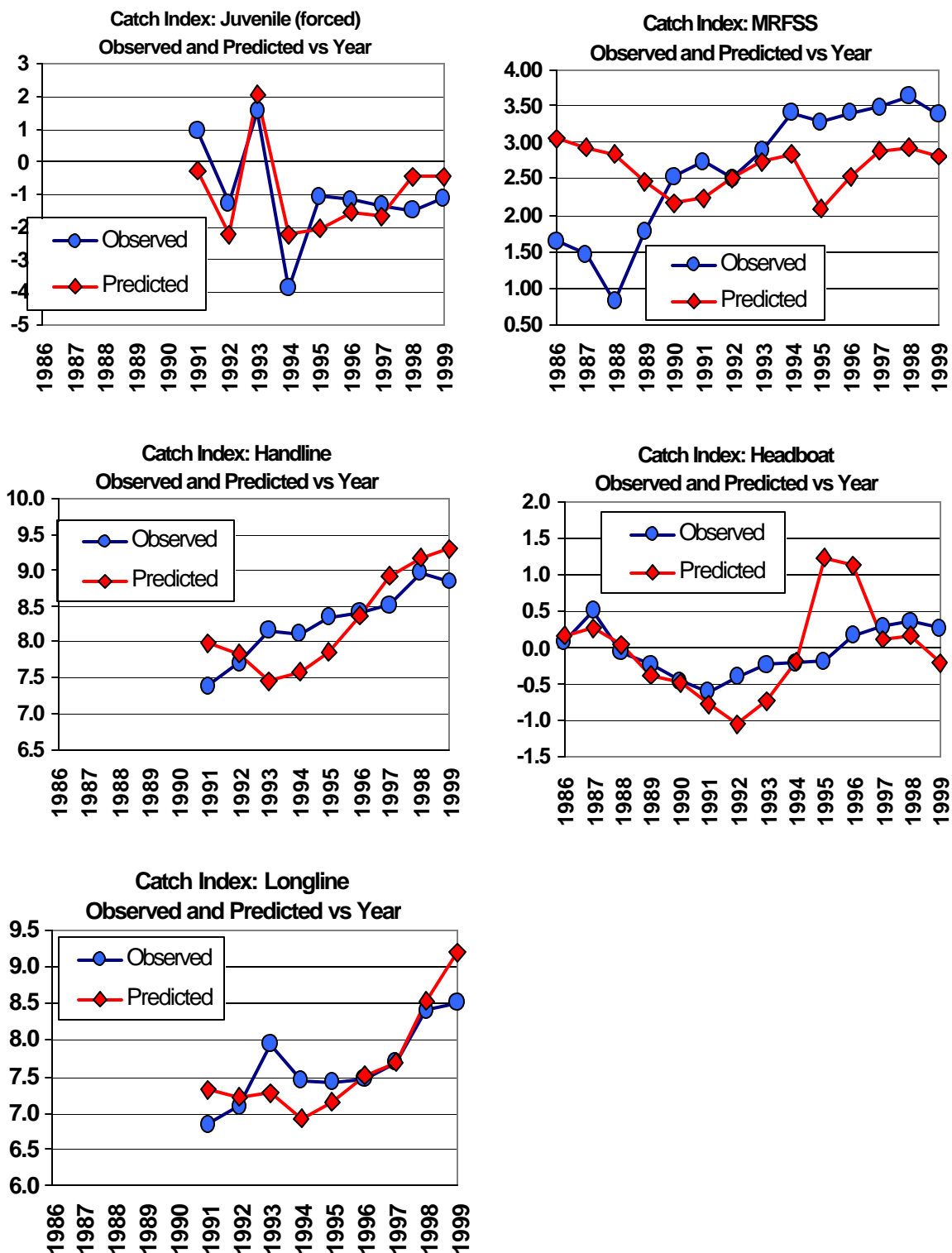


Figure 28. Index fits from the VPA using the recruitment-and-mortality modulated catch-at-age with year variable index selectivity.

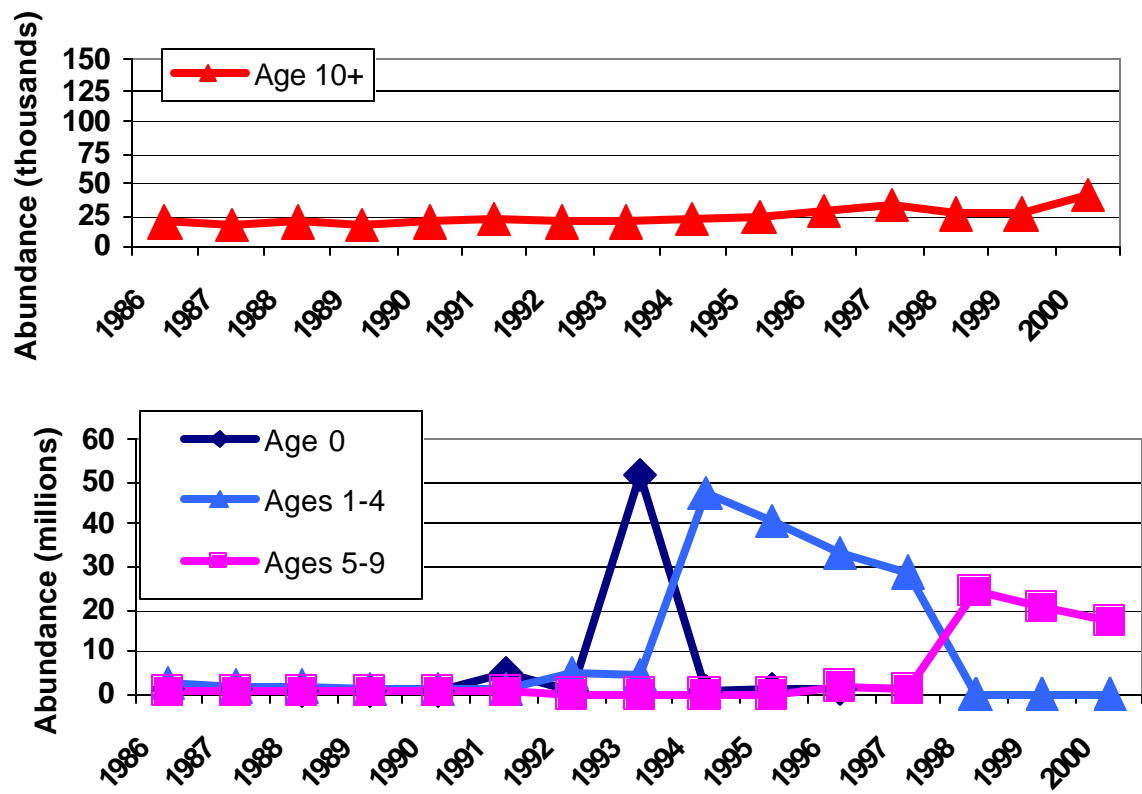


Figure 29. Estimated abundances from the VPA using the recruitment-and-mortality modulated catch-at-age and year variable index selectivity.



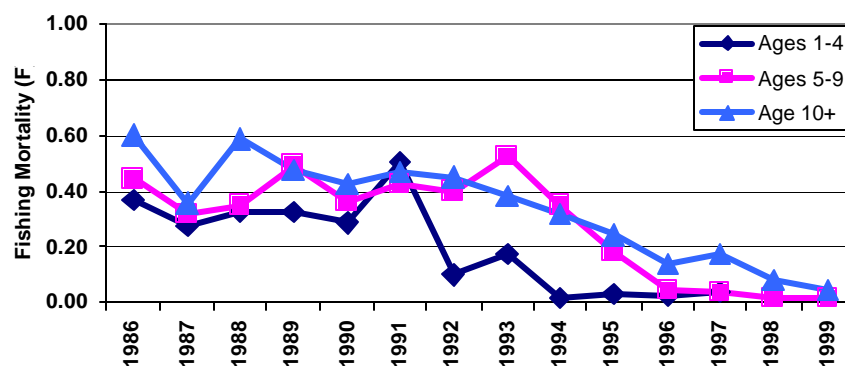


Figure 30. Estimated fishing mortality from the VPA which used the recruitment-and-mortality modulated catch-at-age with assumed year variable selectivity.

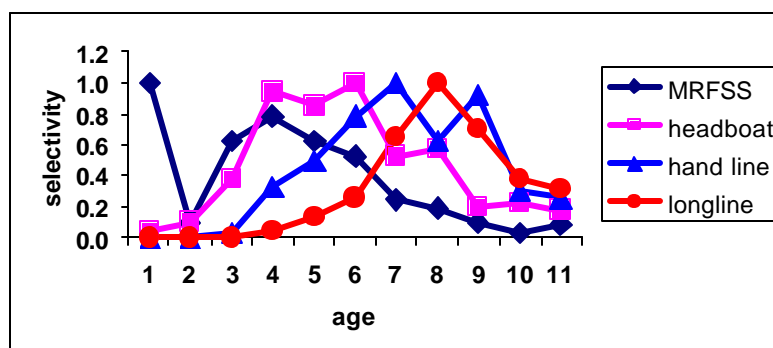


Figure 31. Index selectivity from the VPA which used the age-length-key plus stochastic growth catch-at-age and the assumed year constant selectivity.

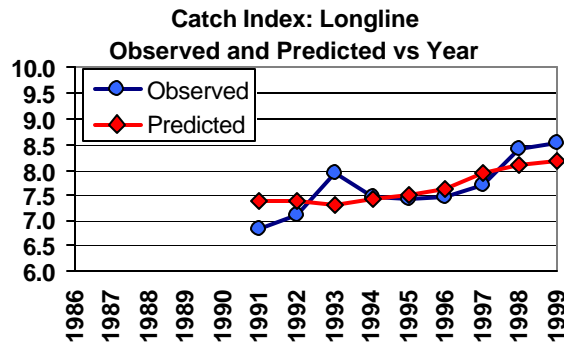
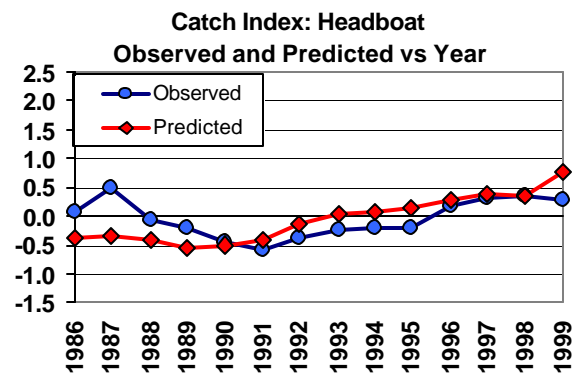
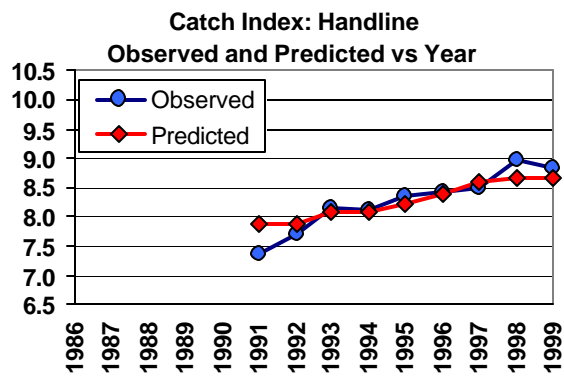
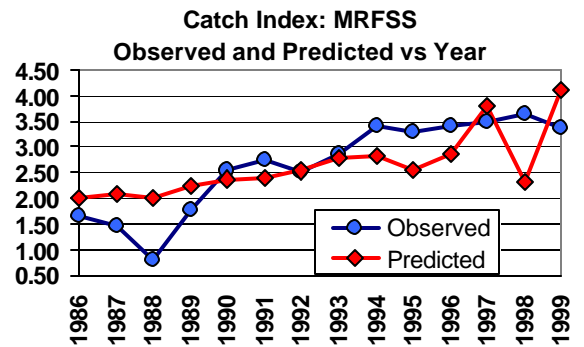
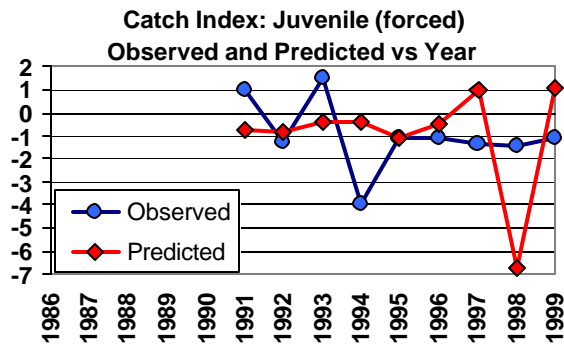


Figure 32. Index fits from the VPA which used the age-length-key plus stochastic growth catch-at-age with the assumed year constant index selectivity.

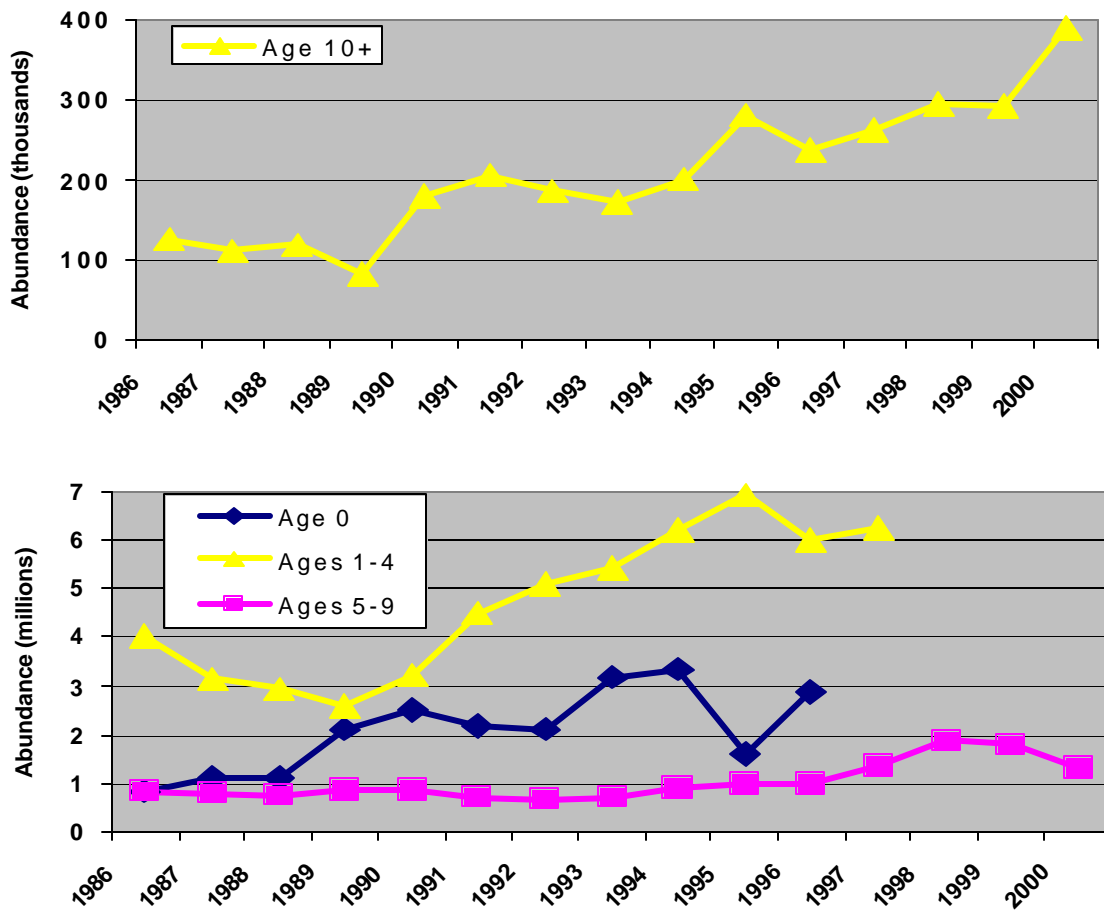


Figure 33. Estimated abundances from the VPA of the age-length-key with stochastic ageing catch-at-age with assumed year constant index selectivity.

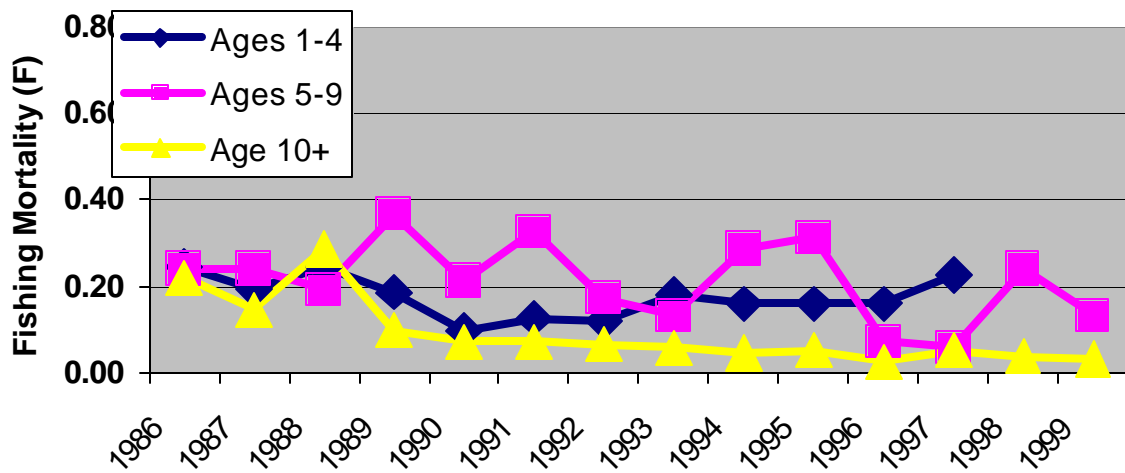


Figure 34. Estimated fishing mortality rates from the VPA which used the age-length-key plus stochastic ageing catch-at-age with assumed constant index selectivity.

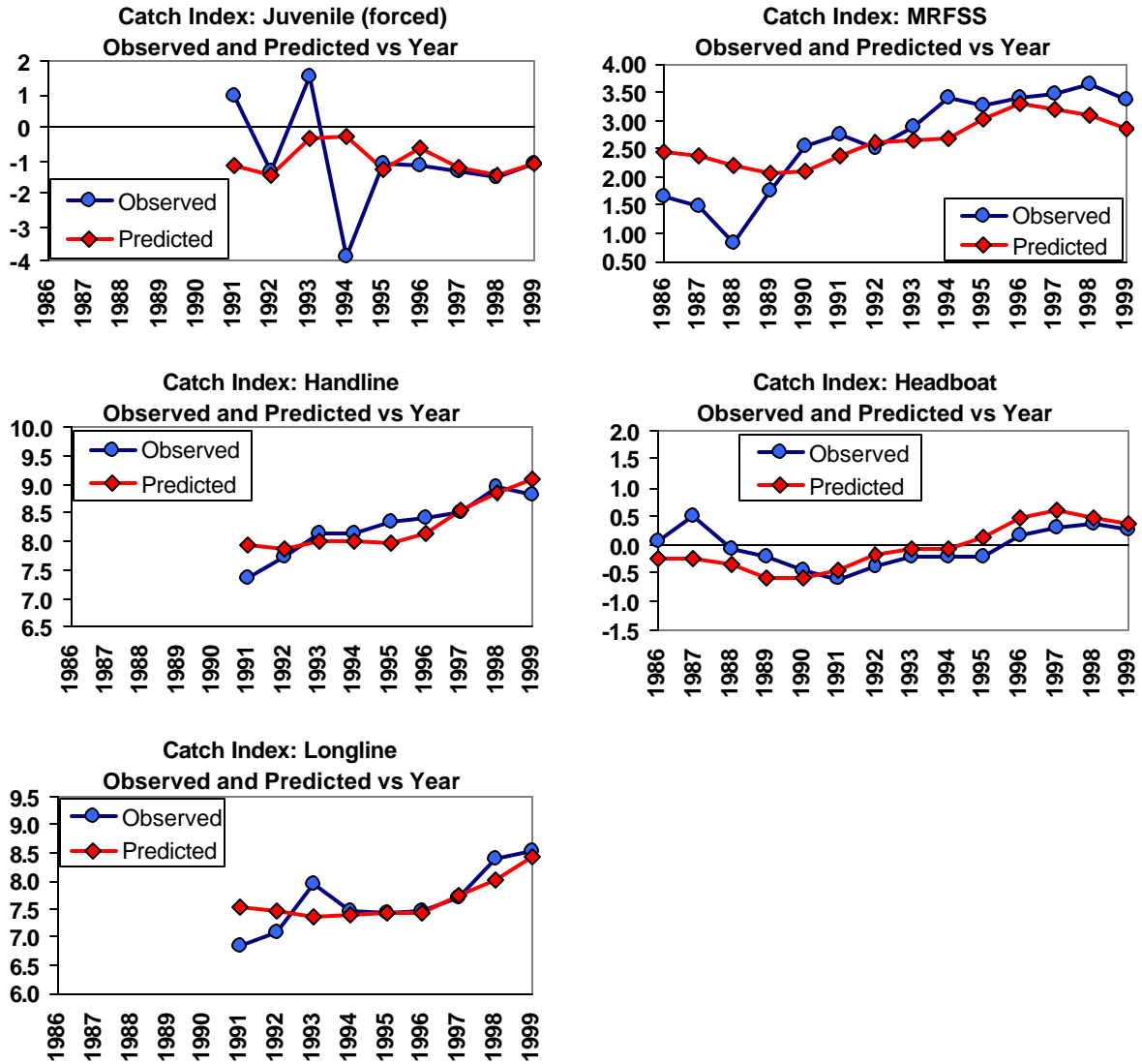


Figure 35. Index fits from the sensitivity VPA which used the age-length-key plus stochastic growth catch-at-age with the assumption of year constant index selectivity and in which fishing mortality rates in 1999 for ages 0, 1, 2, 4, and 6 years were estimated.

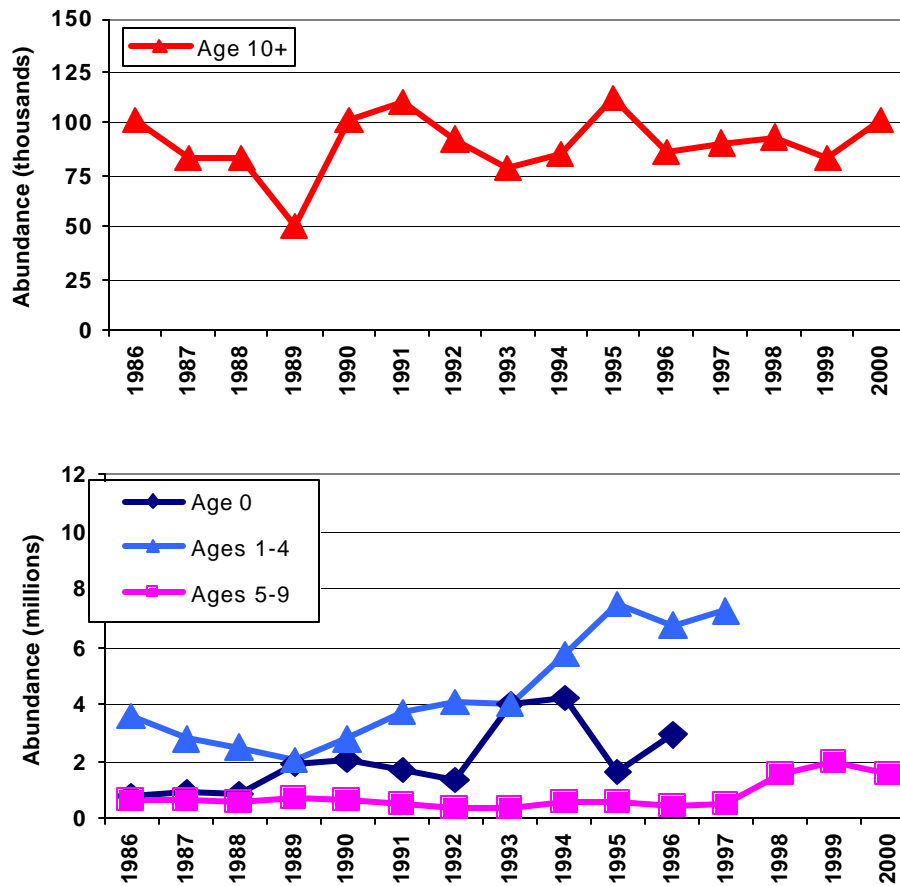


Figure 36. Estimated abundance from the sensitivity VPA which used the age-length-key plus stochastic growth catch-at-age with the assumption of year constant index selectivity and in which fishing mortality rates in 1999 for ages 0, 1, 2, 4, and 6 years were estimated.

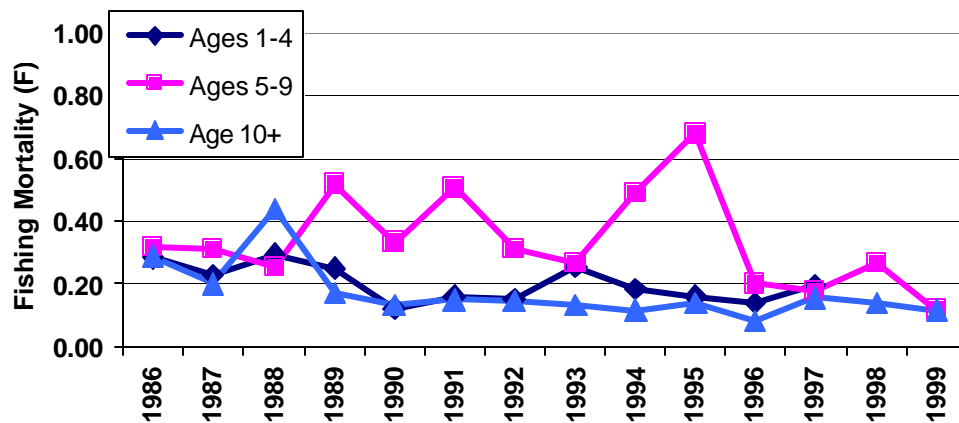


Figure 37. Estimated fishing mortality rates from the sensitivity VPA which used the age-length-key plus stochastic growth catch-at-age with the assumption of year constant index selectivity and in which fishing mortality rates in 1999 for ages 0, 1, 2, 4, and 6 years were estimated.

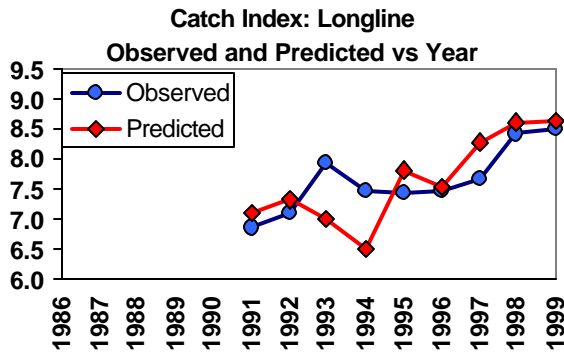
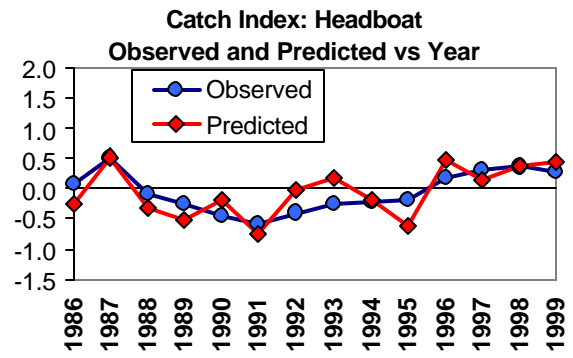
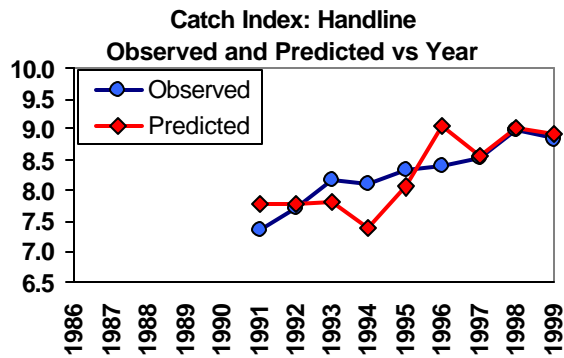
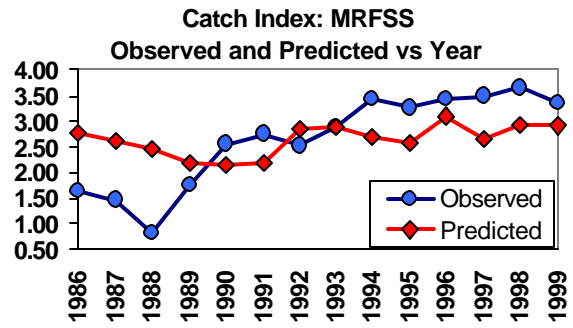
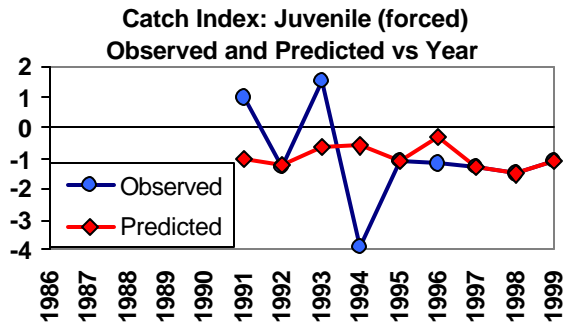


Figure 38. Index fits from the VPA which used the age-length-key plus stochastic growth catch-at-age with the assumption of year variable index selectivity.

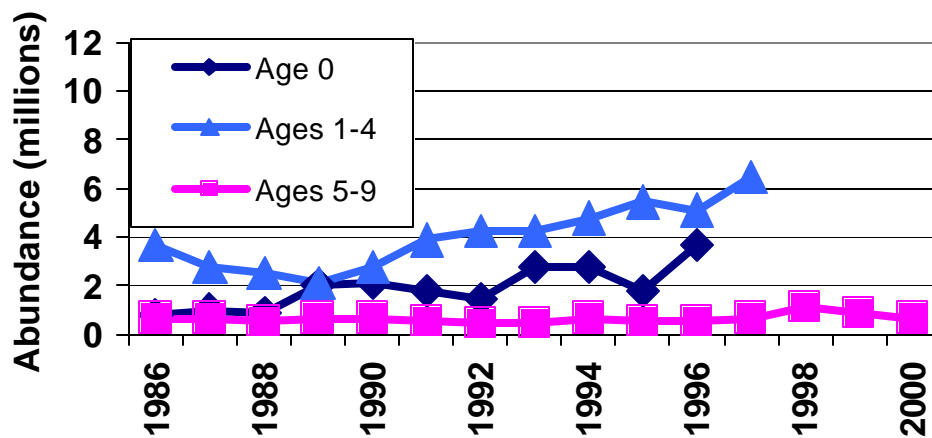
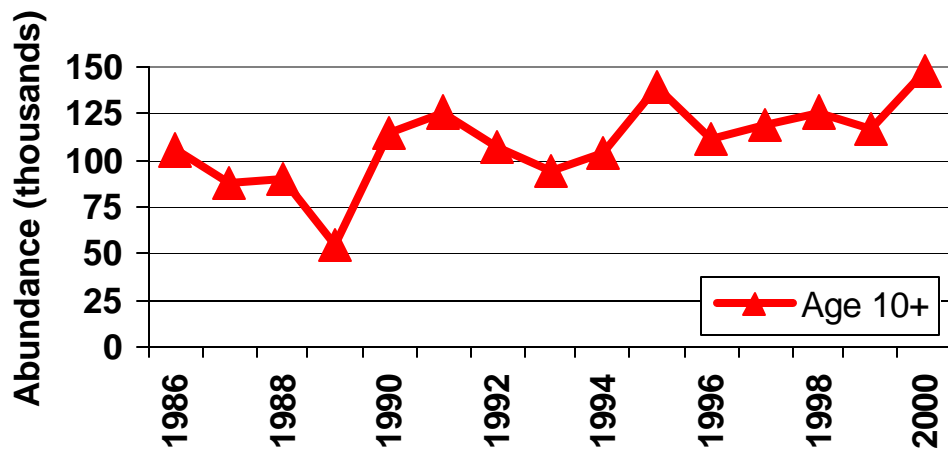


Figure 39. Estimated abundances from the VPA which used the age-length-key plus stochastic growth catch-at-age with the assumption of year variable index selectivity.

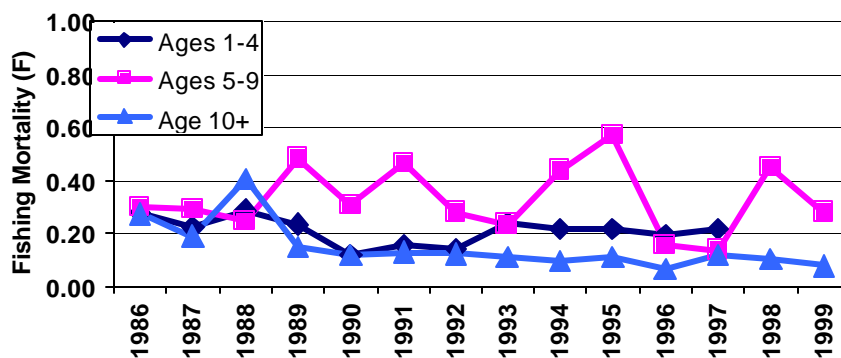


Figure 40. Estimated fishing mortality rates from the VPA which used the age-length-key plus stochastic growth catch-at-age with the assumption of year variable index selectivity.

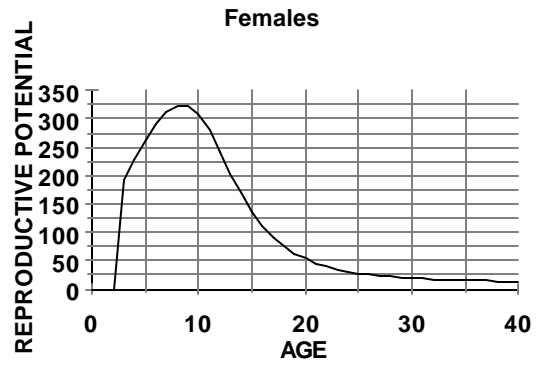


Figure 41. Female reproductive potential used in calculating spawning stock biomass. Units are grams of mature ovaries.



Figure 42. Male reproductive potential used in calculating male spawning stock biomass. Units are pounds of mature males.



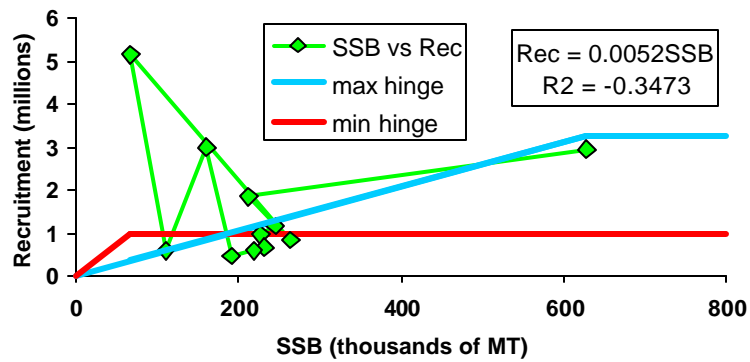


Figure 43. Spawning stock size, recruitment and stock recruitment functions from the VPA which used the recruitment-and-mortality modulated catch-at-age and assumed year constant index selectivity.

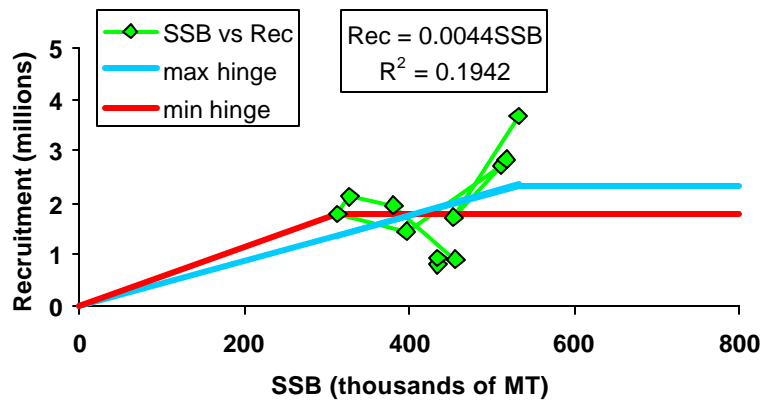


Figure 44. Spawning stock size, recruitment, and stock-recruitment functions from the VPA which used the age-length-key plus stochastic growth catch-at-age with assumed year variable index selectivity.

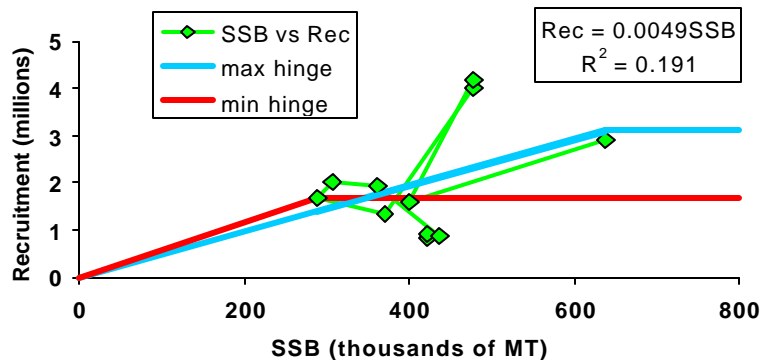


Figure 45. Spawning stock size, recruitment, and stock-recruitment functions from the sensitivity VPA which used the age-length-key plus stochastic growth catch-at-age with assumed year constant index selectivity and in which 1999 fishing mortality was estimates for ages 0, 1, 2, 4 and 6 years.

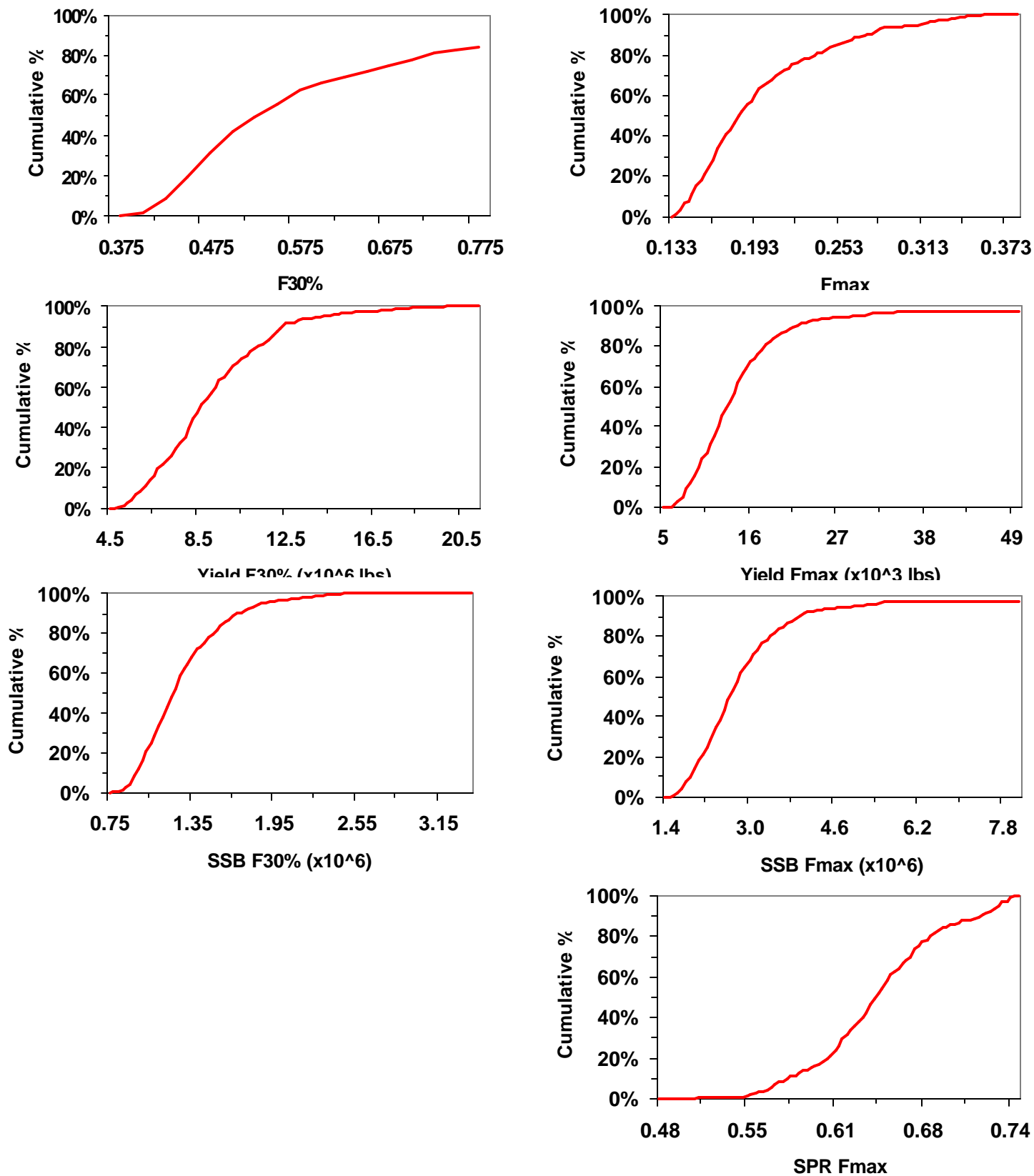


Figure 46. Cumulative frequency distributions for various reference statistics from bootstrapped estimates from the sensitivity VPA using the RMM catch-at-age with recruitment increasing to the maximum 1986-1999 spawning stock size.

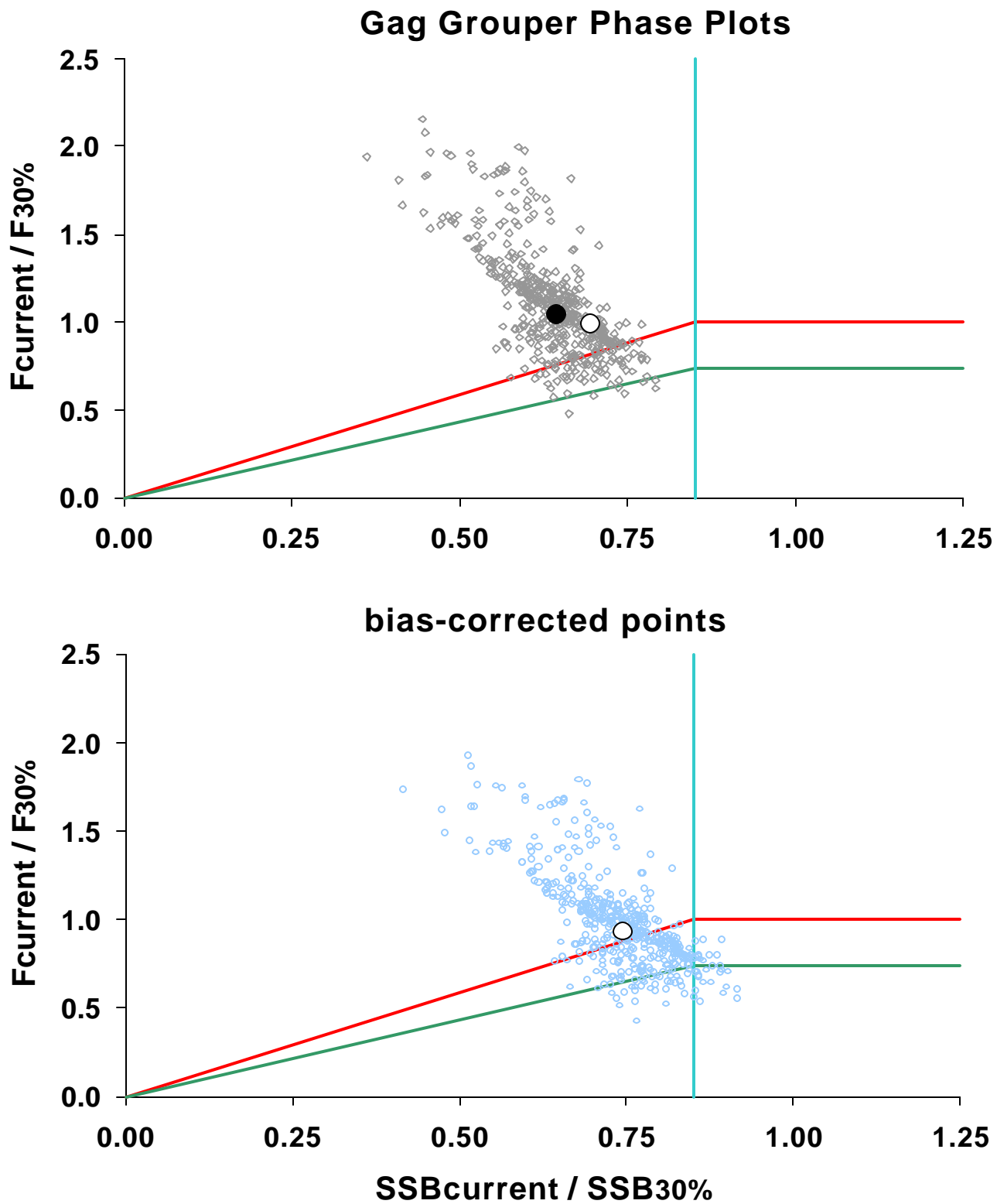


Figure 47. Individual bootstrap estimates of spawning stock biomass (SSB) and fishing mortality rate (F) relative to  $SSB_{30\%}$  and  $F_{30\%}$ , respectively, from the analysis of the RMM catch-at-age with recruitment increasing to the maximum 1986-1999 spawning stock size. The upper panel shows uncorrected results, with the median of the bootstraps (black oval) and the deterministic estimate (white oval). The lower panel shows the bias corrected individual bootstrap and the deterministic estimates.

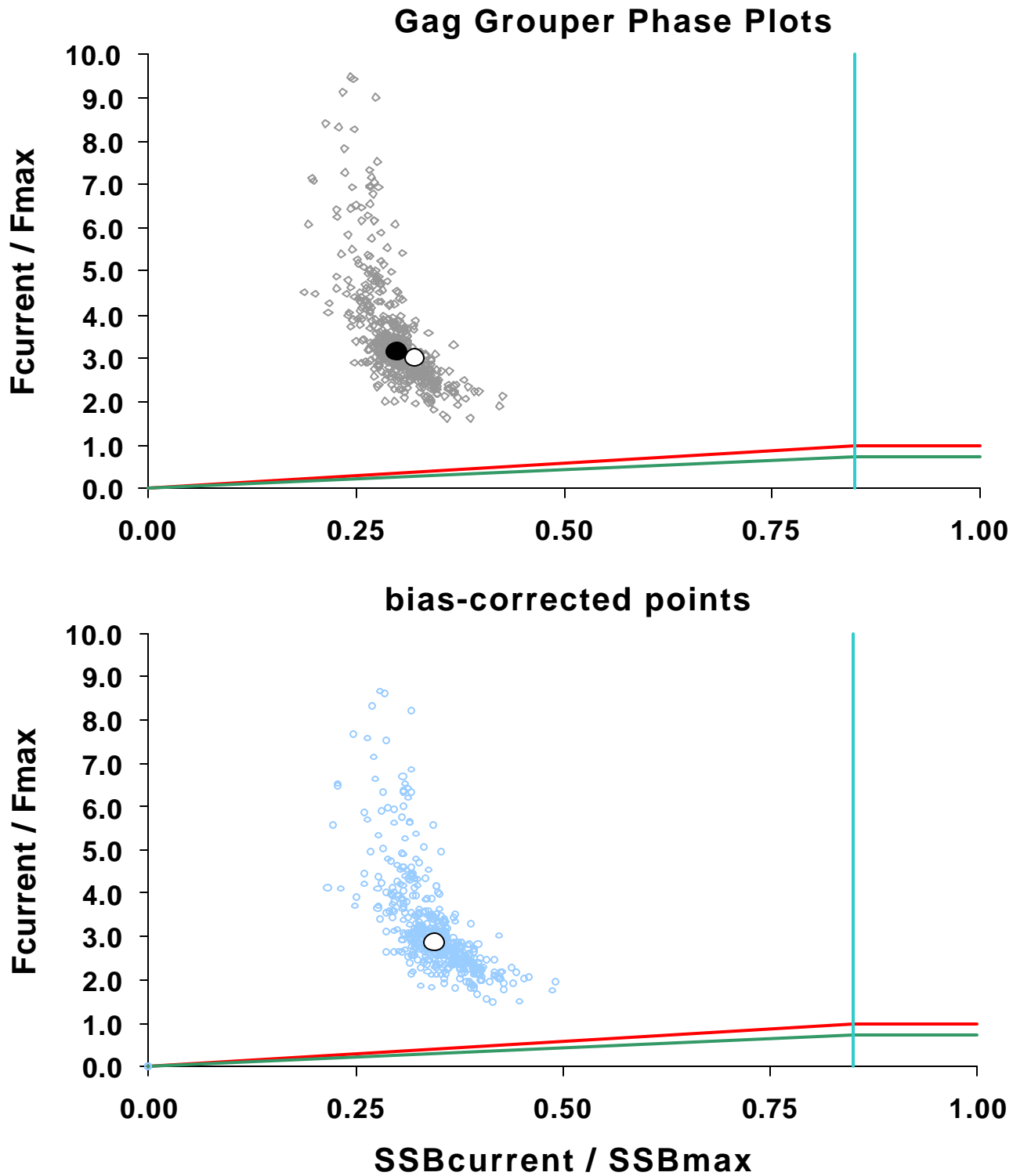


Figure 48. Individual bootstrap estimates of spawning stock biomass (SSB) and fishing mortality rate (F) relative to SSB and F at  $F_{max}$  from the analysis of the RMM catch-at-age with recruitment increasing to the maximum 1986-1999 spawning stock size. The upper panel shows uncorrected results, with the median of the bootstraps (black oval) and the deterministic estimate (white oval). The lower panel shows the bias corrected individual bootstrap and the deterministic estimates.

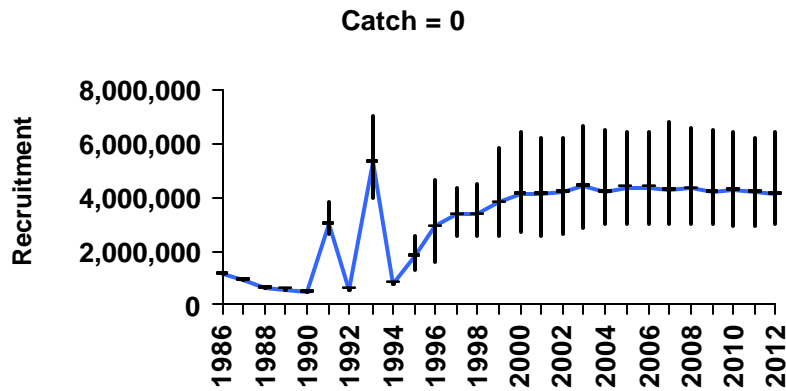


Figure 49. Historical and projected recruitment (median and the empirical 80% confidence interval) from bootstrapped VPA of the RMM catch-at-age with recruitment increasing to the maximum 1986-1999 spawning stock size. Projections assume no catch after 2001.

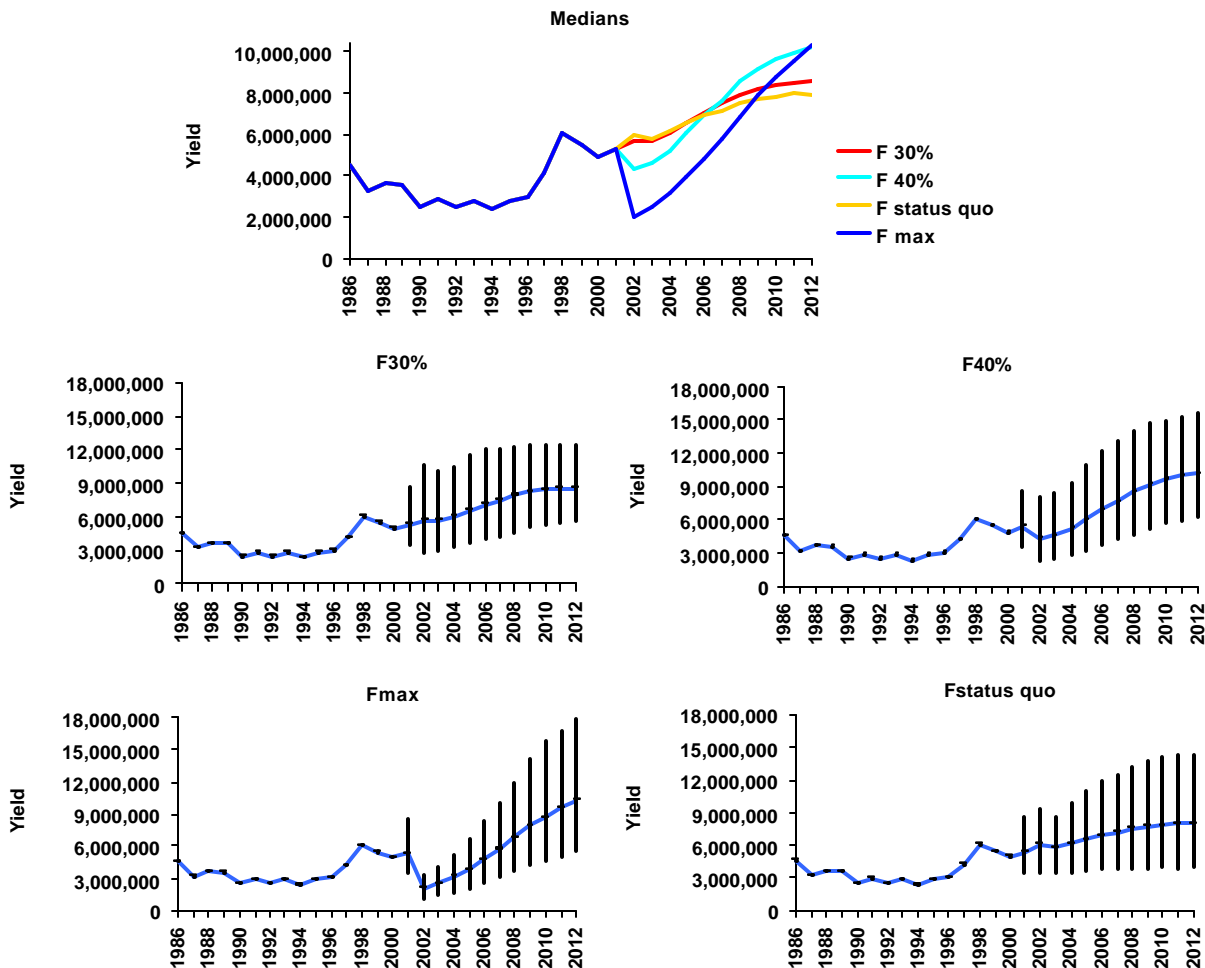


Figure 50. Historical and projected yield (median and the empirical 80% confidence interval) from bootstrapped VPA of the RMM catch-at-age with recruitment increasing to the maximum 1986-1999 spawning stock size. Projections assume fishing in 2002-2012 at  $F_{30\%}$ ,  $F_{40\%}$ ,  $F_{\max}$ , and  $F_{\text{status quo}}$ .

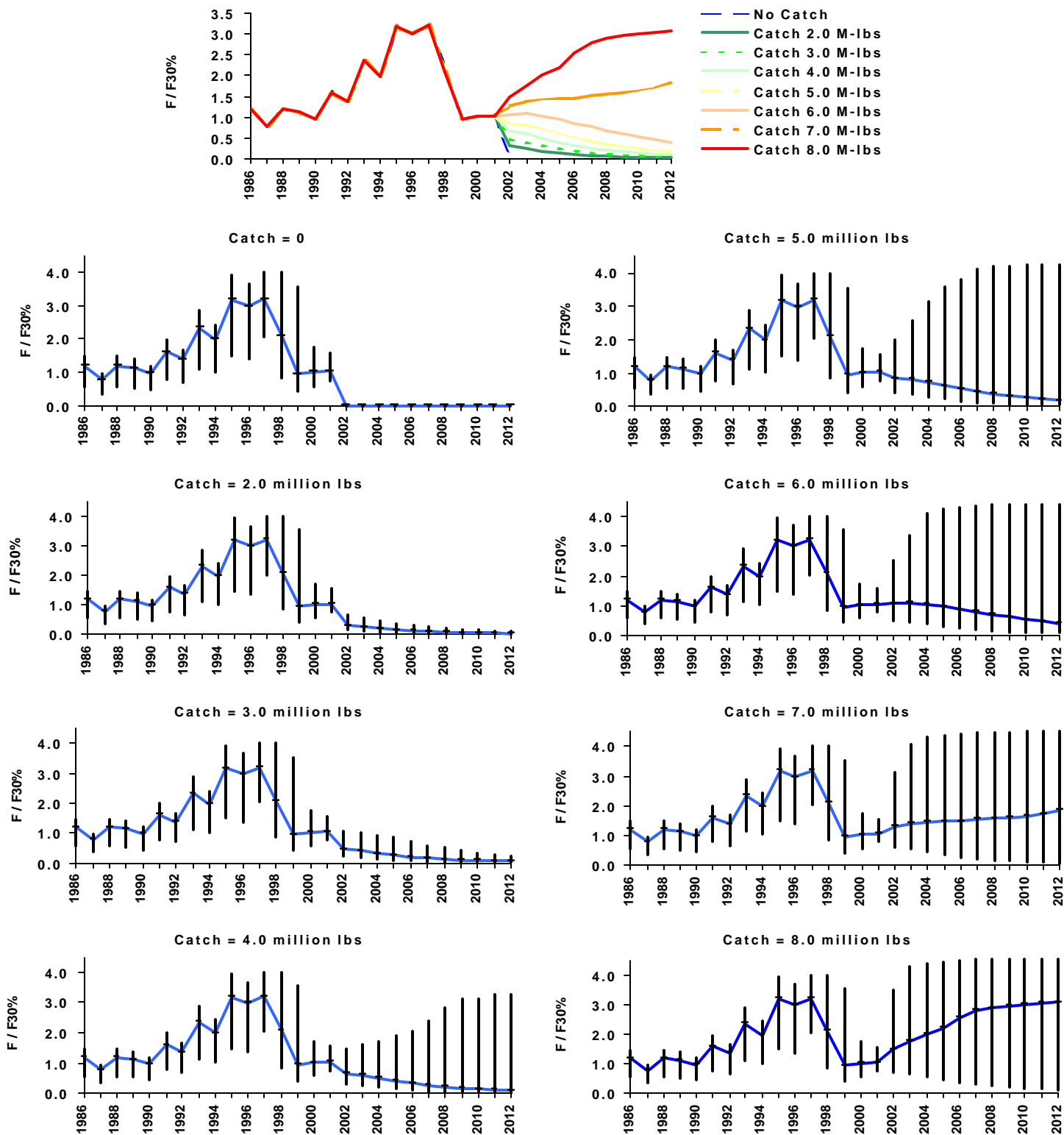


Figure 51. Historical and projected fishing mortality rate ( $F$ ) relative to  $F_{30\%}$  (median and the empirical 80% confidence interval) from bootstrapped VPA of the RMM catch-at-age with recruitment increasing to the maximum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

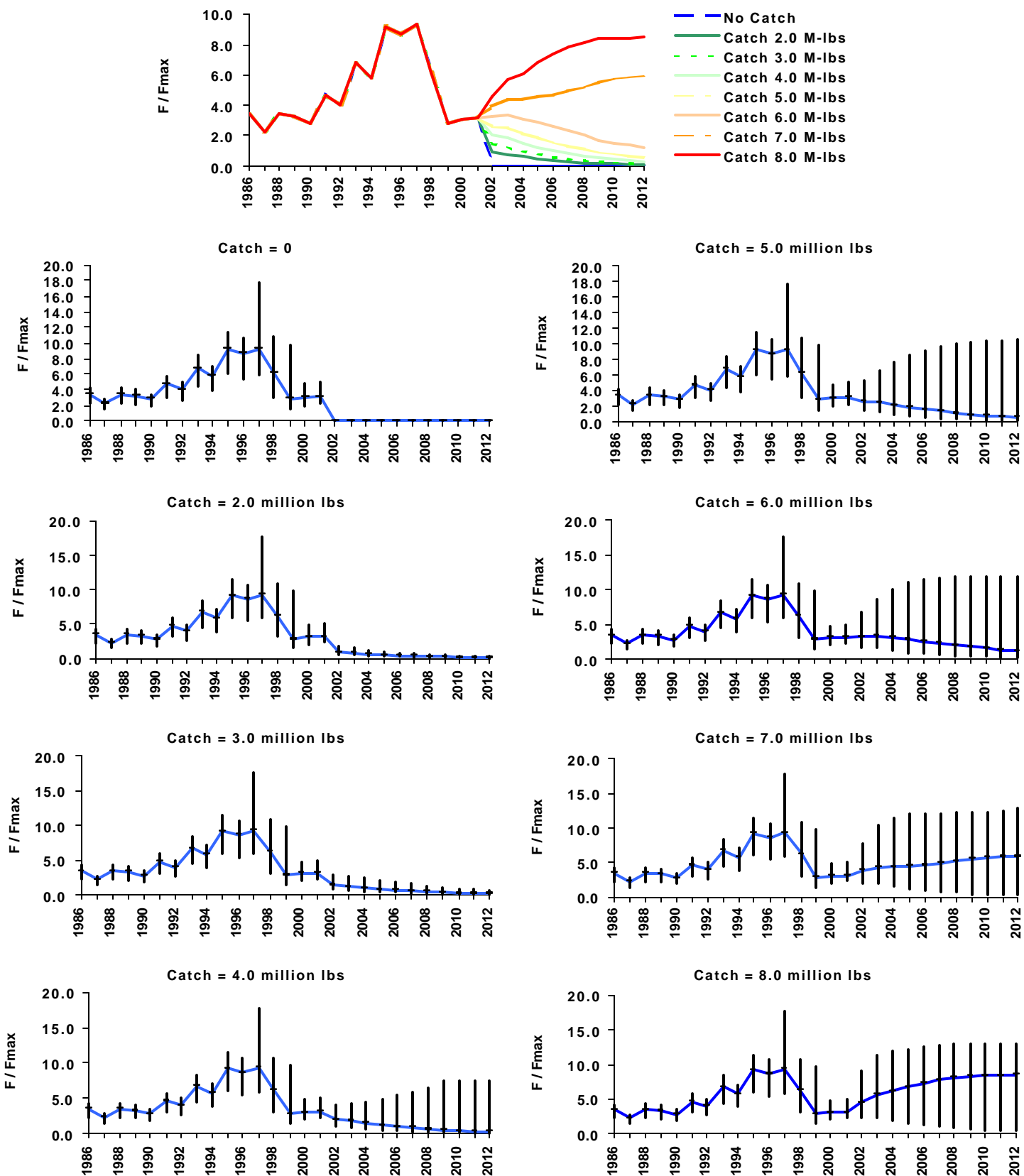


Figure 52. Historical and projected fishing mortality rate ( $F$ ) relative to  $F_{\max}$  (median and the empirical 80% confidence interval) from bootstrapped VPA of the RMM catch-at-age with recruitment increasing to the maximum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

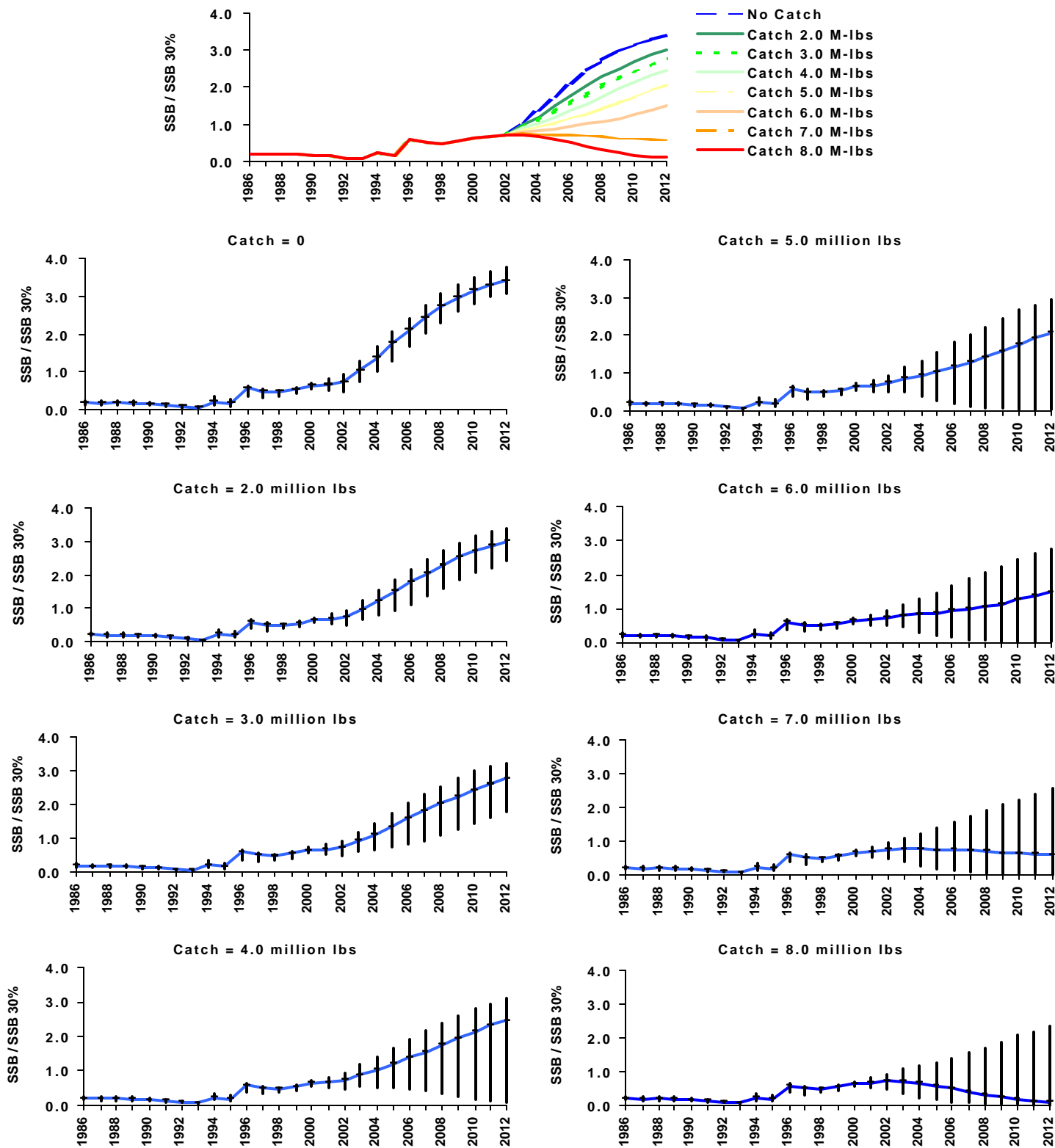


Figure 53. Historical and projected spawning stock biomass (SSB) relative to  $SSB_{30\%}$  (median and the empirical 80% confidence interval) from bootstrapped VPA of the RMM catch-at-age with recruitment increasing to the maximum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.



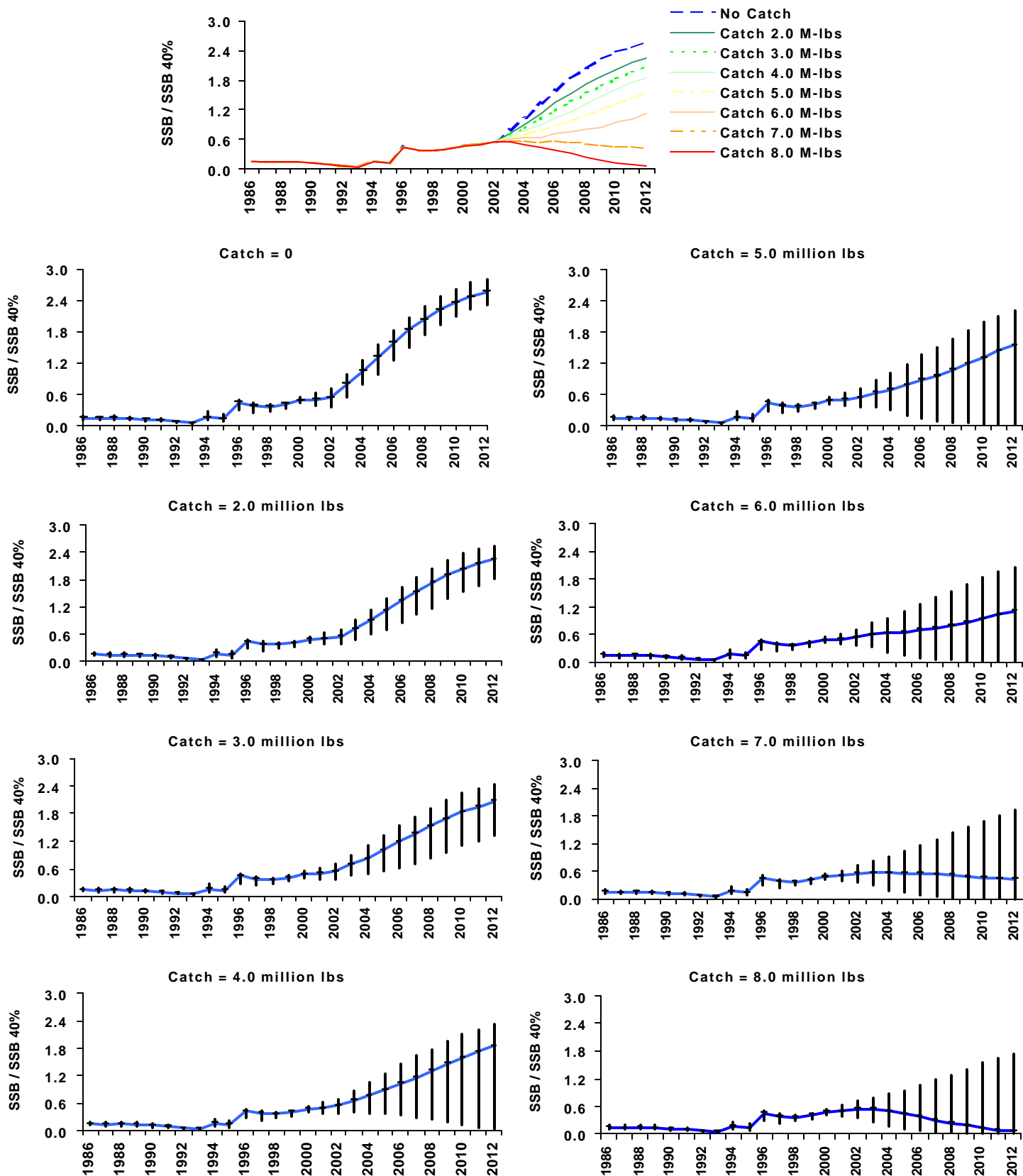


Figure 54. Historical and projected spawning stock biomass (SSB) relative to  $SSB_{40\%}$  (median and the empirical 80% confidence interval) from bootstrapped VPA of the RMM catch-at-age with recruitment increasing to the maximum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

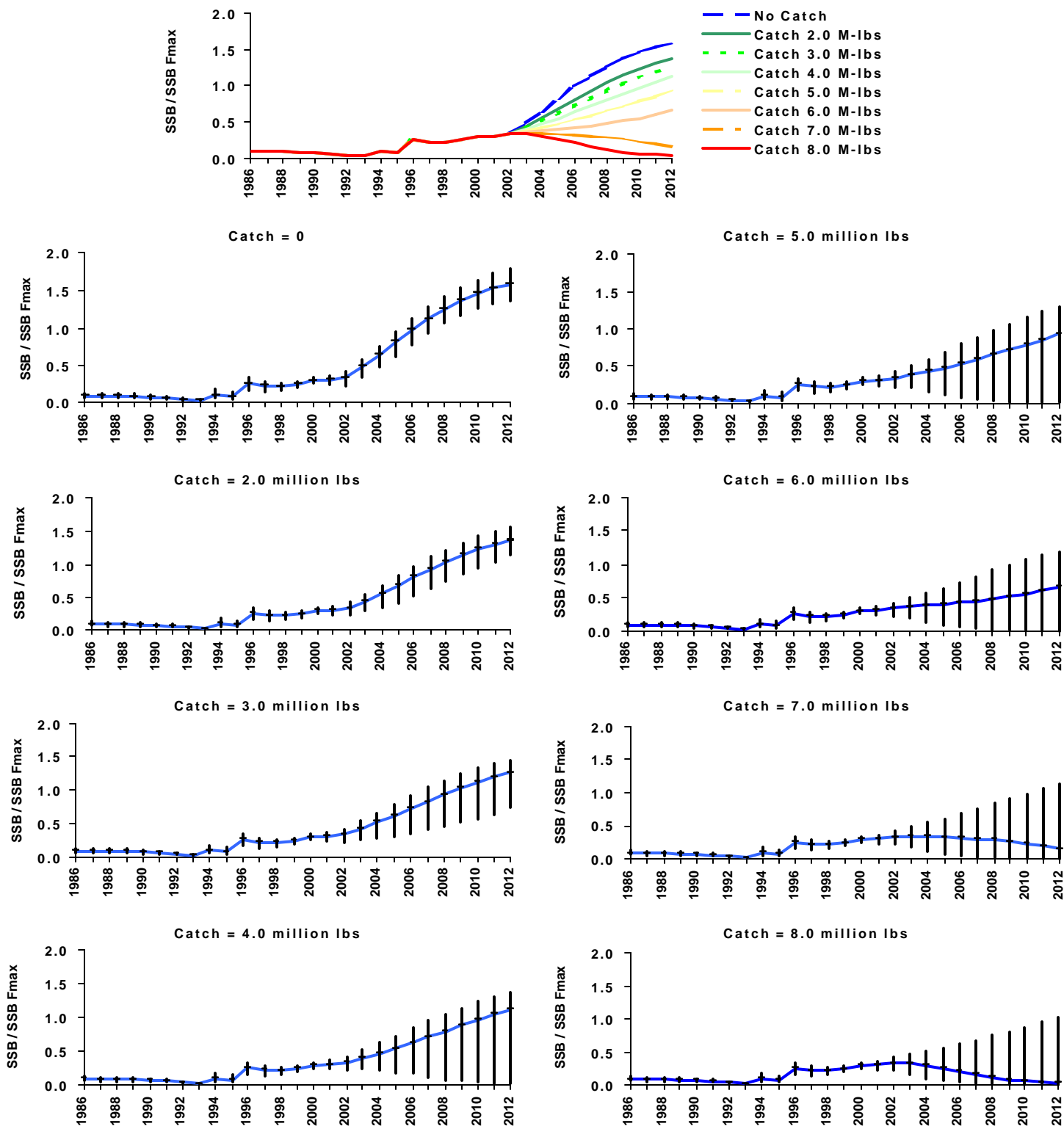


Figure 55. Historical and projected spawning stock biomass (SSB) relative to SSB at  $F_{\max}$  (median and the empirical 80% confidence interval) from bootstrapped VPA of the RMM catch-at-age with recruitment increasing to the maximum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

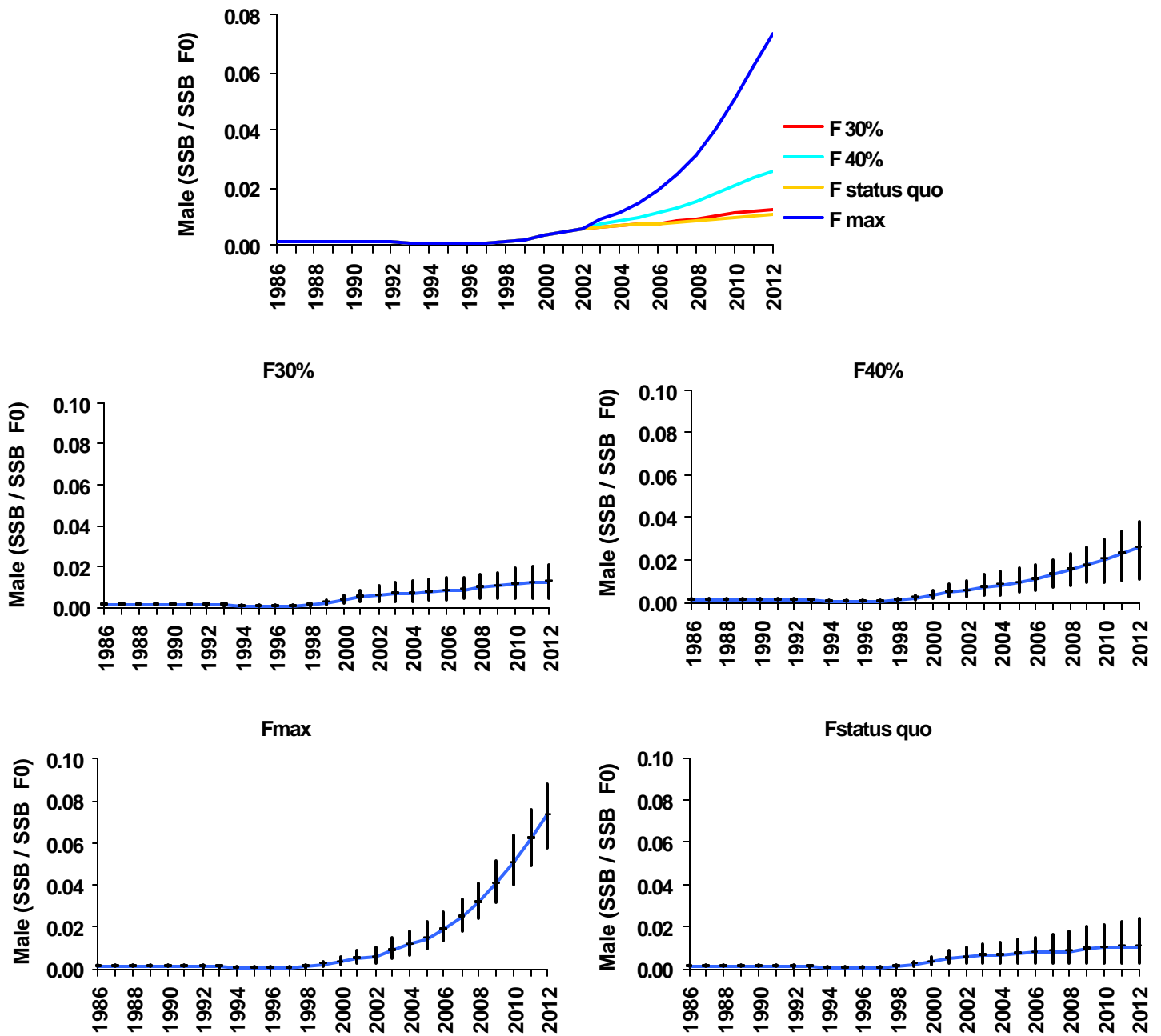


Figure 56. Historical and projected male spawning stock biomass (SSB) relative to male SSB in the unfished condition (median and the empirical 80% confidence interval) from bootstrapped VPA of the RMM catch-at-age with recruitment increasing to the maximum 1986-1999 spawning stock size. Projections assume fishing in 2002-2012 at  $F_{30\%}$ ,  $F_{40\%}$ ,  $F_{\max}$ , and  $F_{\text{status quo}}$ .

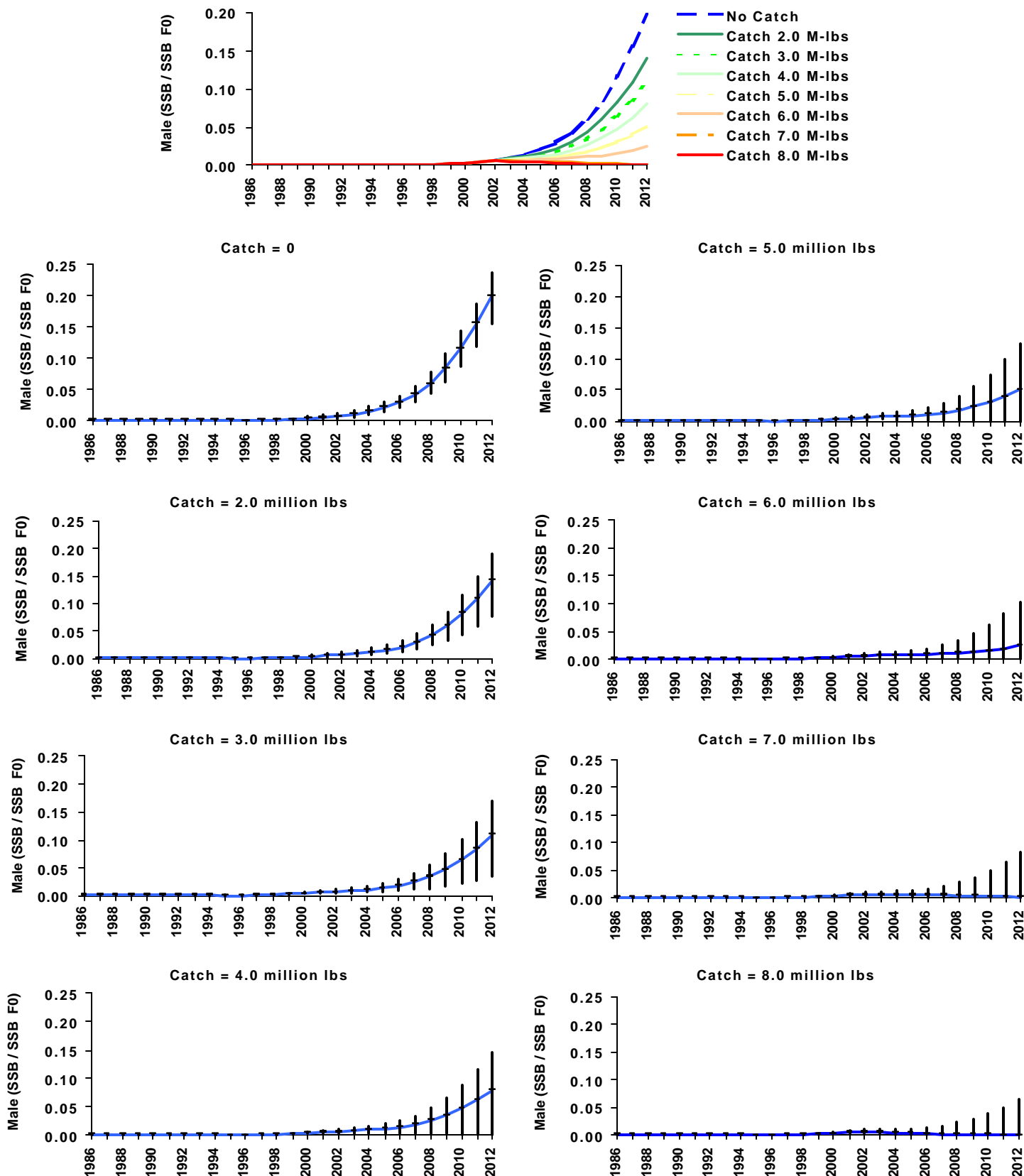


Figure 57. Historical and projected male spawning stock biomass (SSB) relative to male SSB in the unfished condition (median and the empirical 80% confidence interval) from bootstrapped VPA of the RMM catch-at-age with recruitment increasing to the maximum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

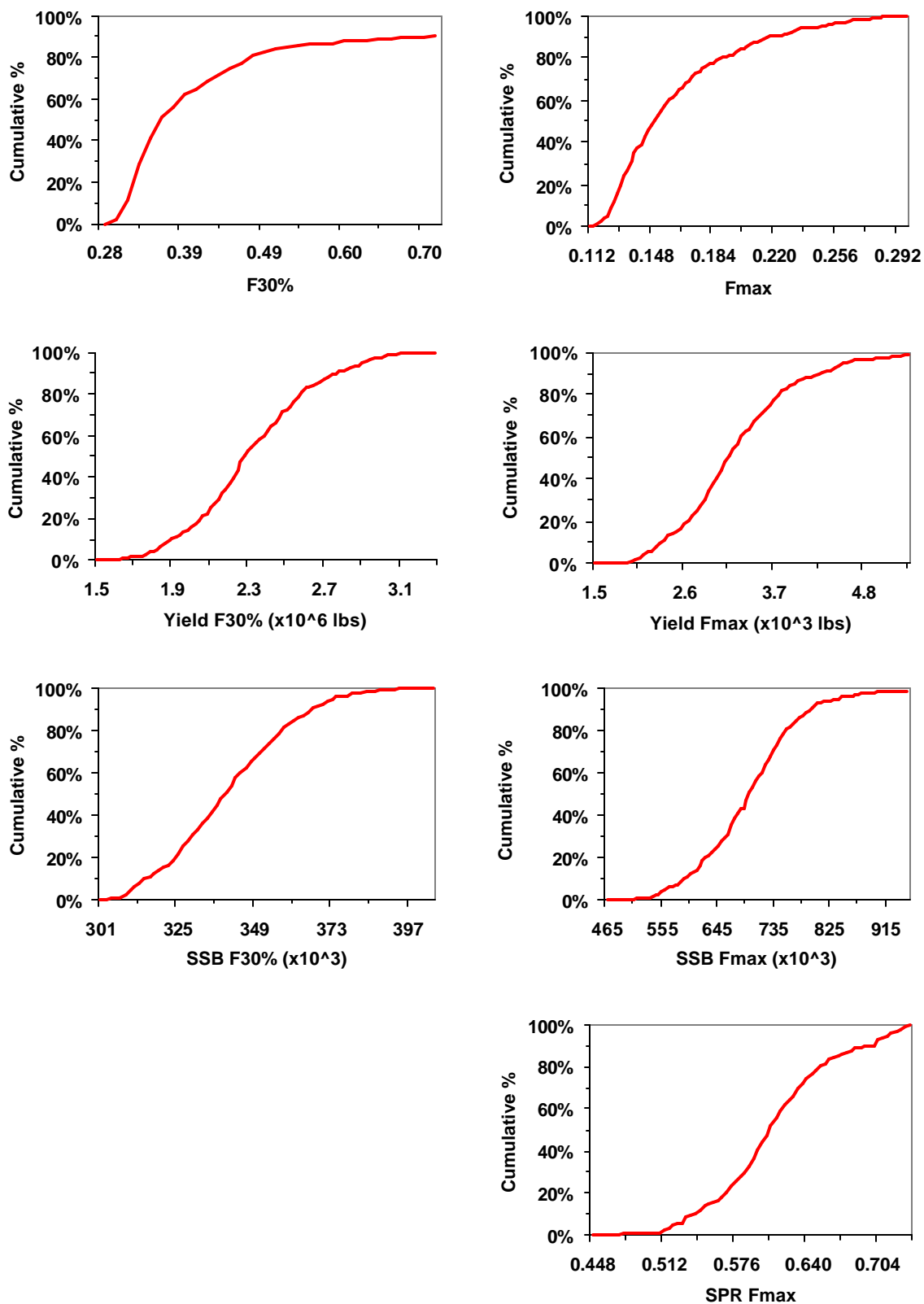


Figure 58. Cumulative frequency distributions for various reference statistics from bootstrapped estimates from the sensitivity VPA using the RMM catch-at-age with average recruitment above the minimum 1986-1999 spawning stock size.

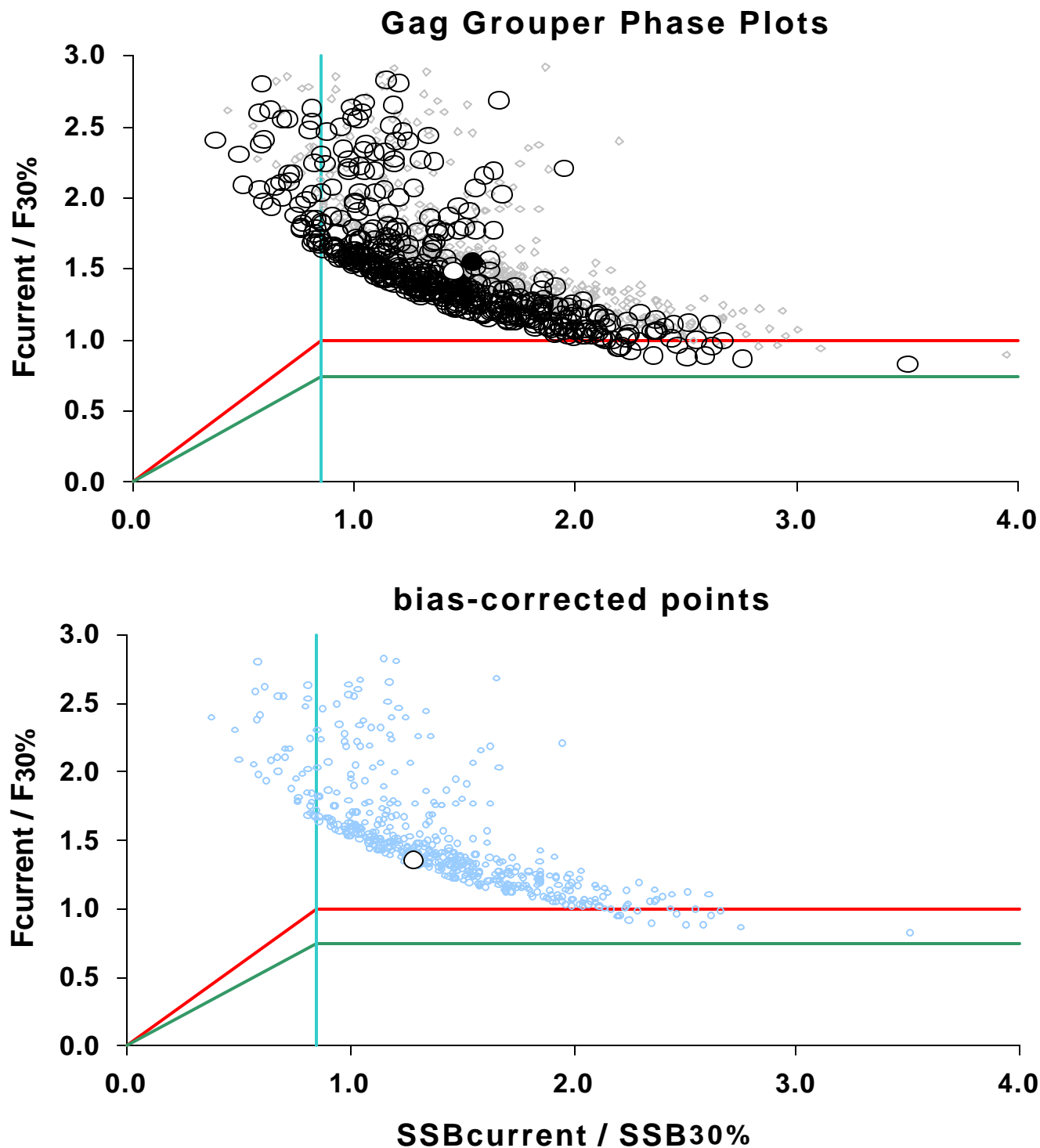


Figure 59. Individual bootstrap estimates of spawning stock biomass (SSB) and fishing mortality rate (F) relative to  $SSB_{30\%}$  and  $F_{30\%}$ , respectively, from the analysis of the RMM catch-at-age with average recruitment above the minimum 1986-1999 spawning stock size. The upper panel shows uncorrected results, with the median of the bootstraps (black oval) and the deterministic estimate (white oval). The lower panel shows bias corrected the individual bootstrap and the deterministic estimates.

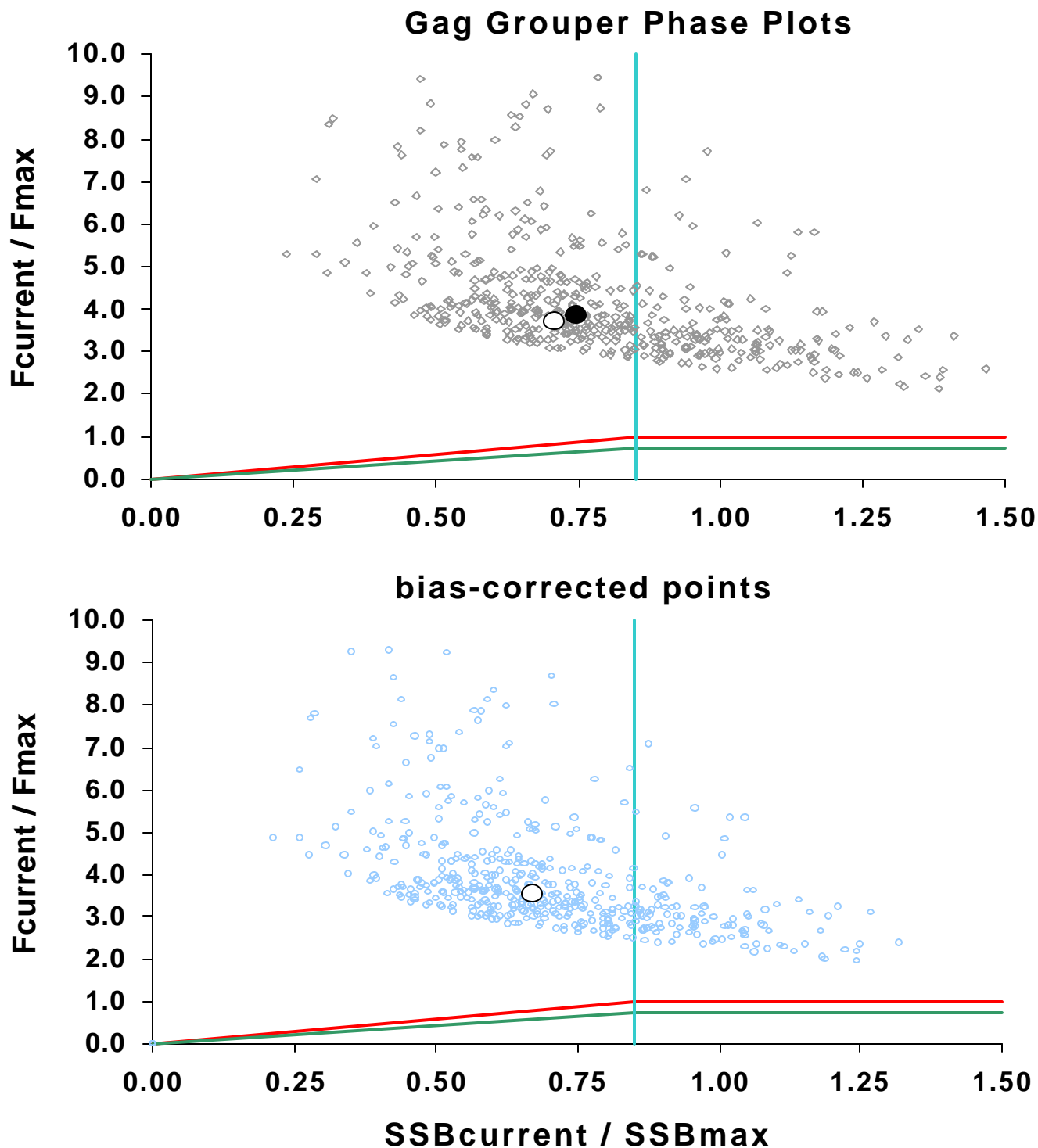


Figure 60. Individual bootstrap estimates of spawning stock biomass (SSB) and fishing mortality rate (F) relative to SSB and F at  $F_{max}$  from the analysis of the RMM catch-at-age with average recruitment above the minimum 1986-1999 spawning stock size. The upper panel shows uncorrected results, with the median of the bootstraps (black oval) and the deterministic estimate (white oval). The lower panel shows bias corrected the individual bootstrap and the deterministic estimates.

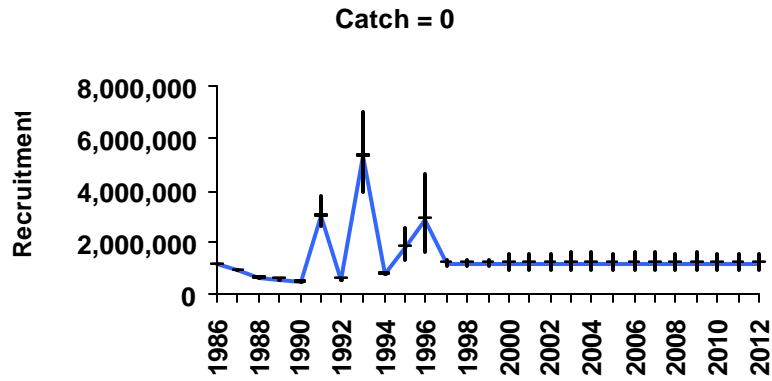


Figure 61. Historical and projected recruitment (median and the empirical 80% confidence interval) from bootstrapped VPA of the RMM catch-at-age with average recruitment above the minimum 1986-1999 spawning stock size. Projections assume no catch after 2001.

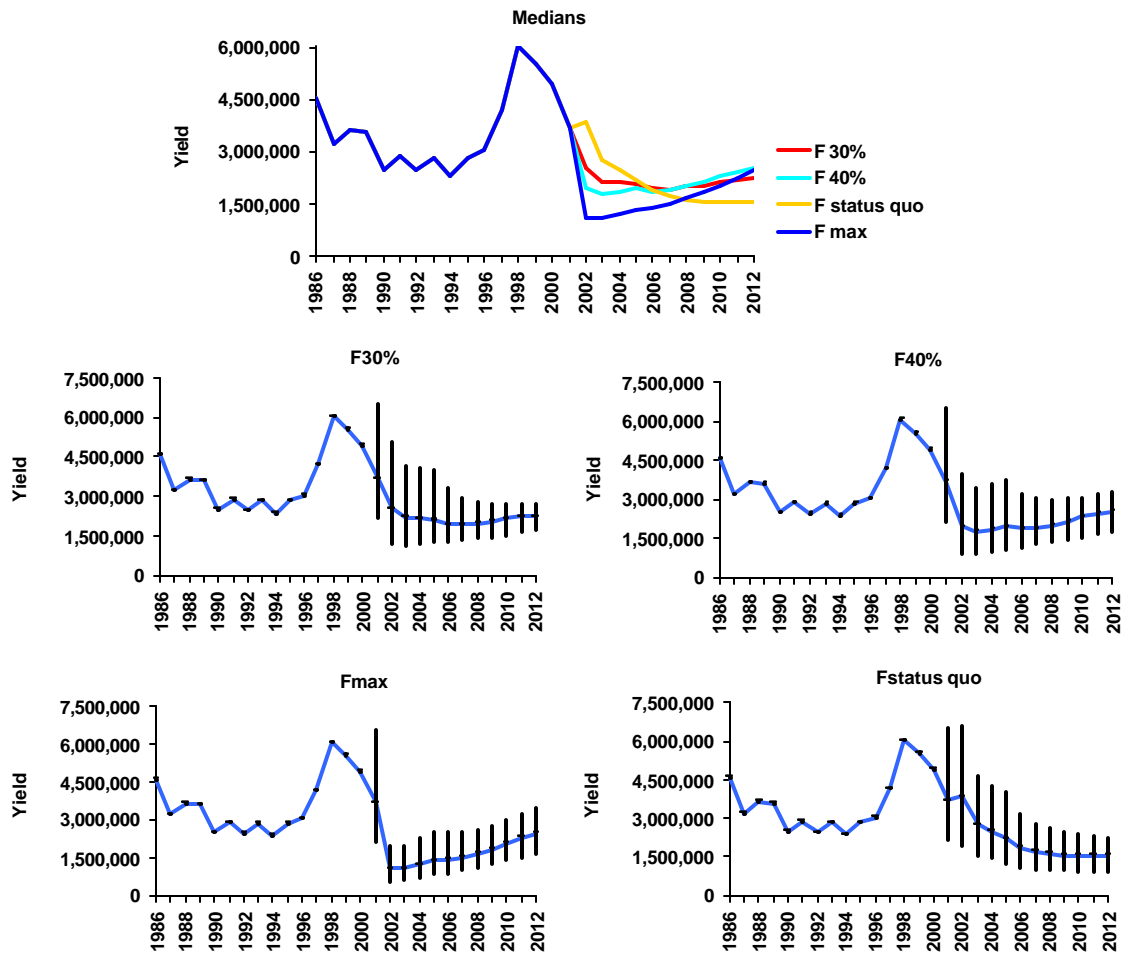


Figure 62. Historical and projected yield (median and the empirical 80% confidence interval) from bootstrapped VPA of the RMM catch-at-age with average recruitment above the minimum 1986-1999 spawning stock size. Projections assume fishing in 2002-2012 at  $F_{30\%}$ ,  $F_{40\%}$ ,  $F_{\max}$ , and  $F_{\text{status quo}}$ .



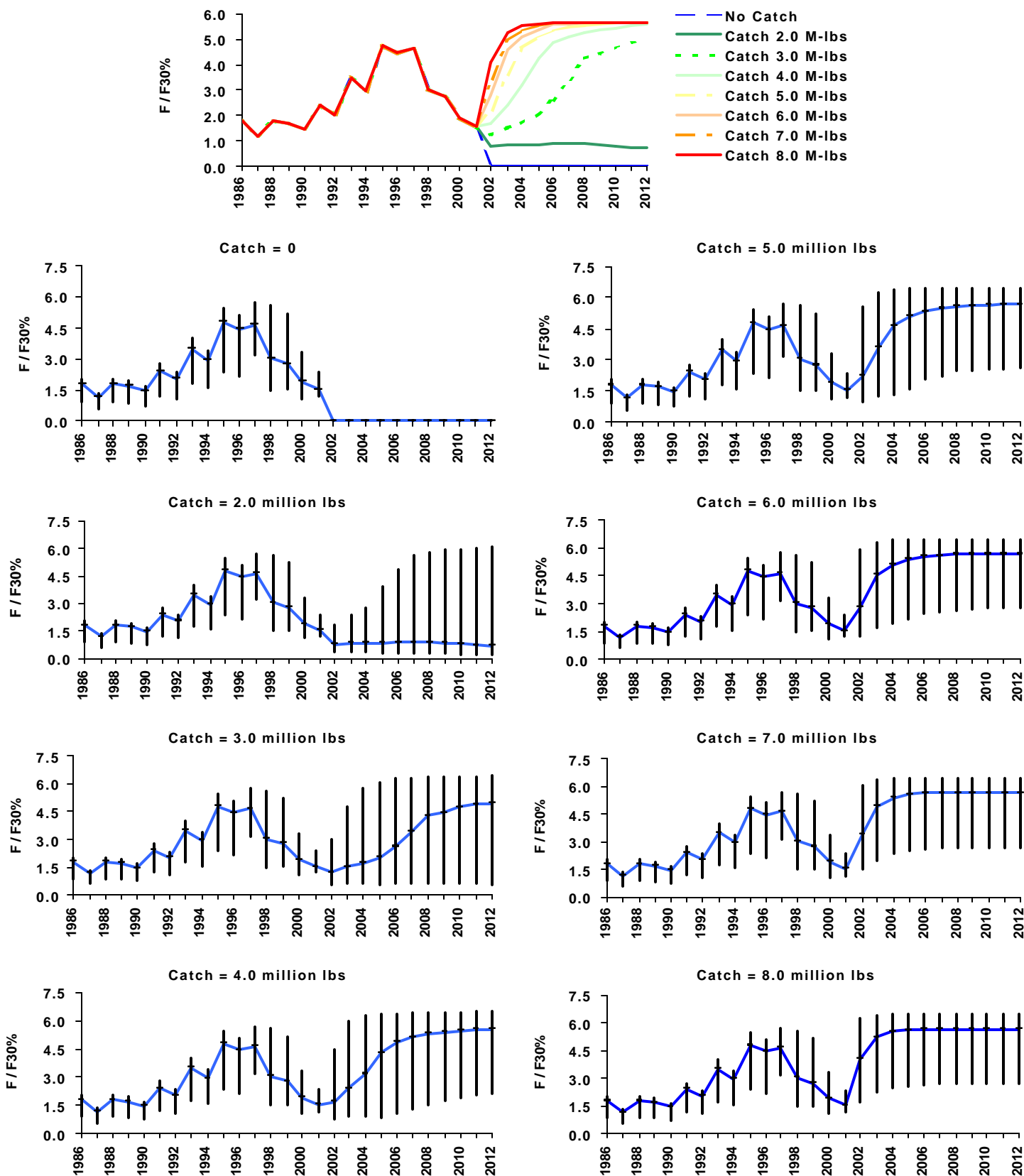


Figure 63. Historical and projected fishing mortality rate ( $F$ ) relative to  $F_{30\%}$  (median and the empirical 80% confidence interval) from bootstrapped VPA of the RMM catch-at-age with average recruitment above the minimum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

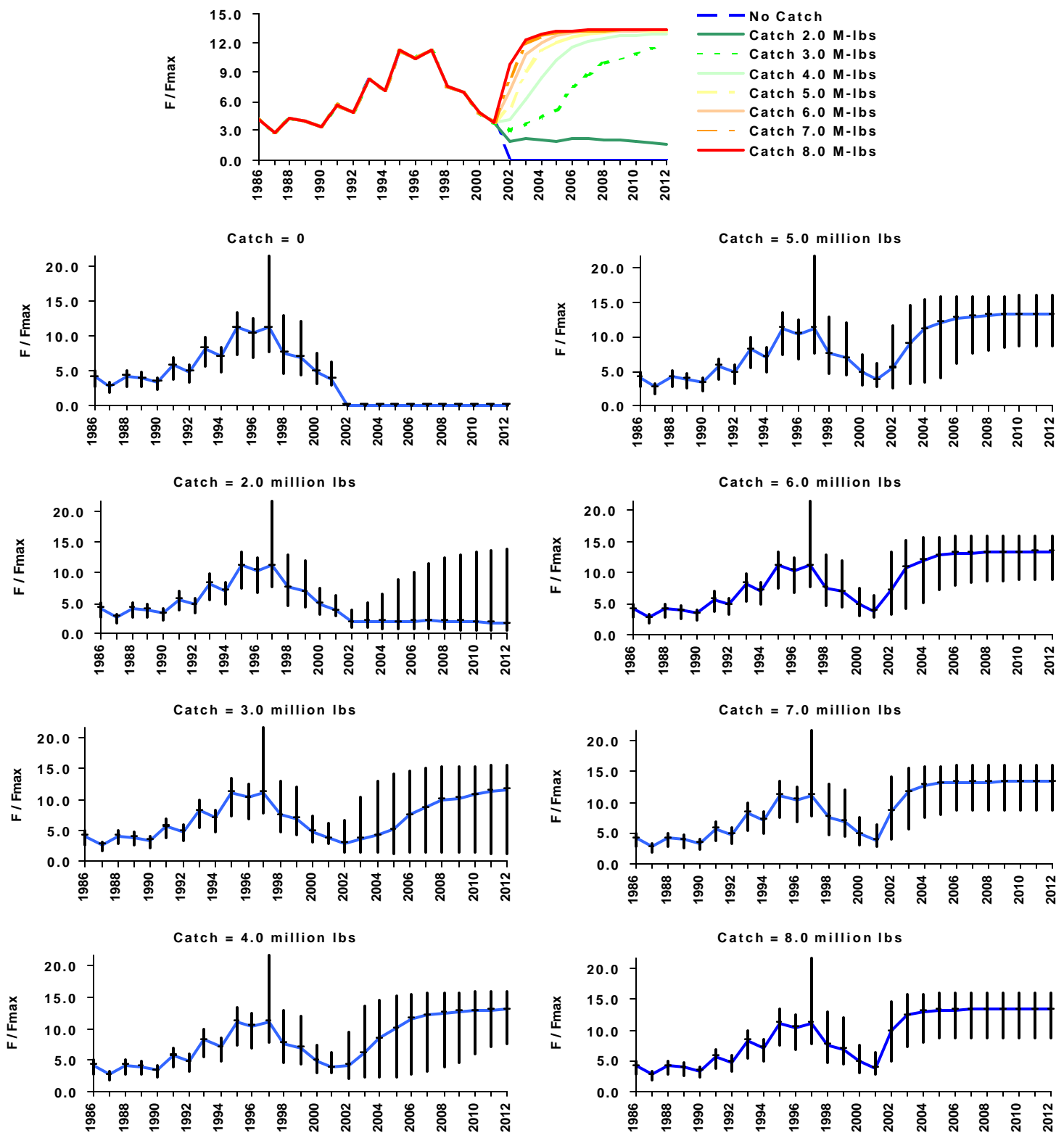


Figure 64. Historical and projected fishing mortality rate ( $F$ ) relative to  $F_{\max}$  (median and the empirical 80% confidence interval) from bootstrapped VPA of the RMM catch-at-age with average recruitment above the minimum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

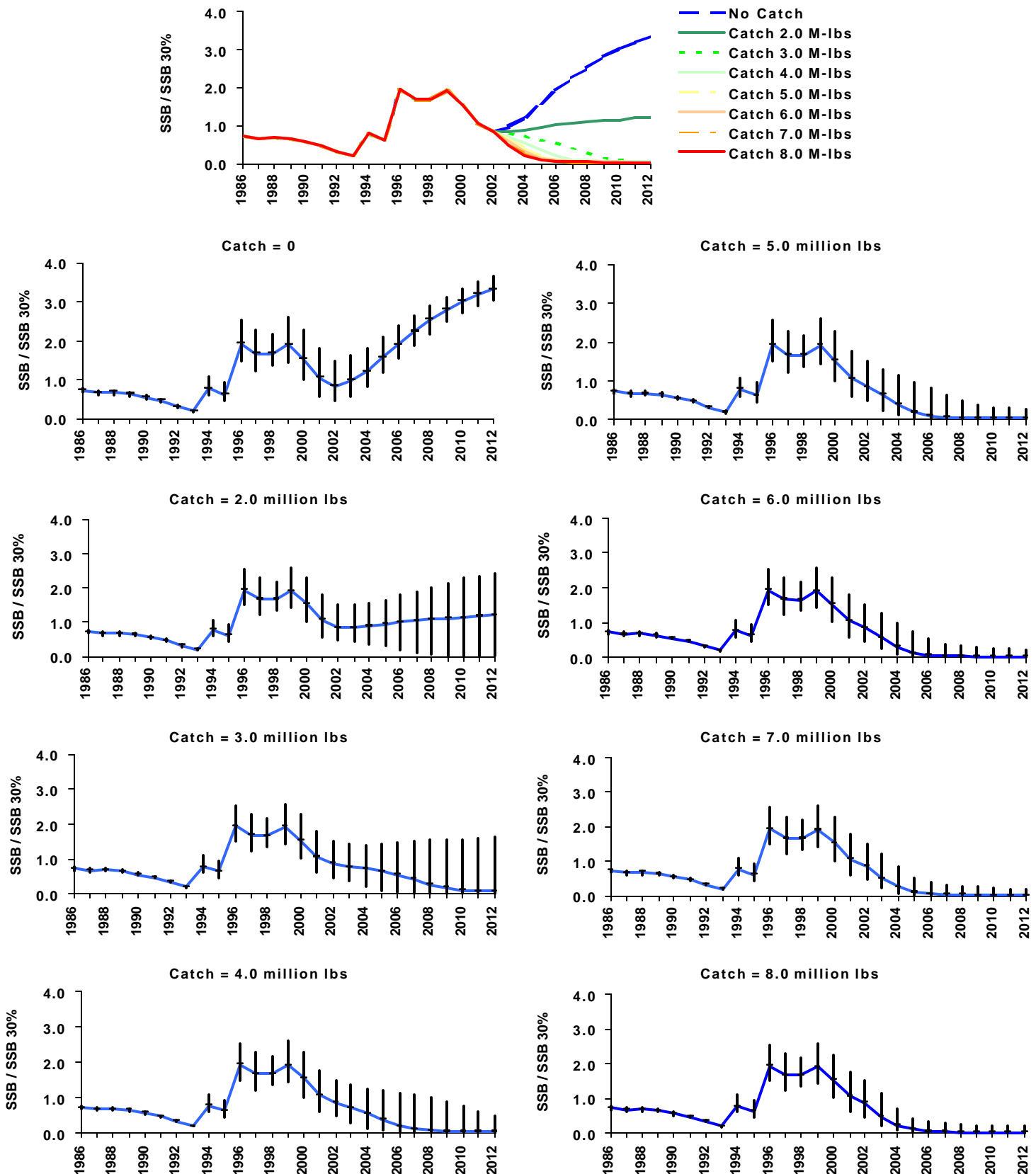


Figure 65. Historical and projected spawning stock biomass (SSB) relative to  $SSB_{30\%}$  (median and the empirical 80% confidence interval) from bootstrapped VPA of the RMM catch-at-age with average recruitment above the minimum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

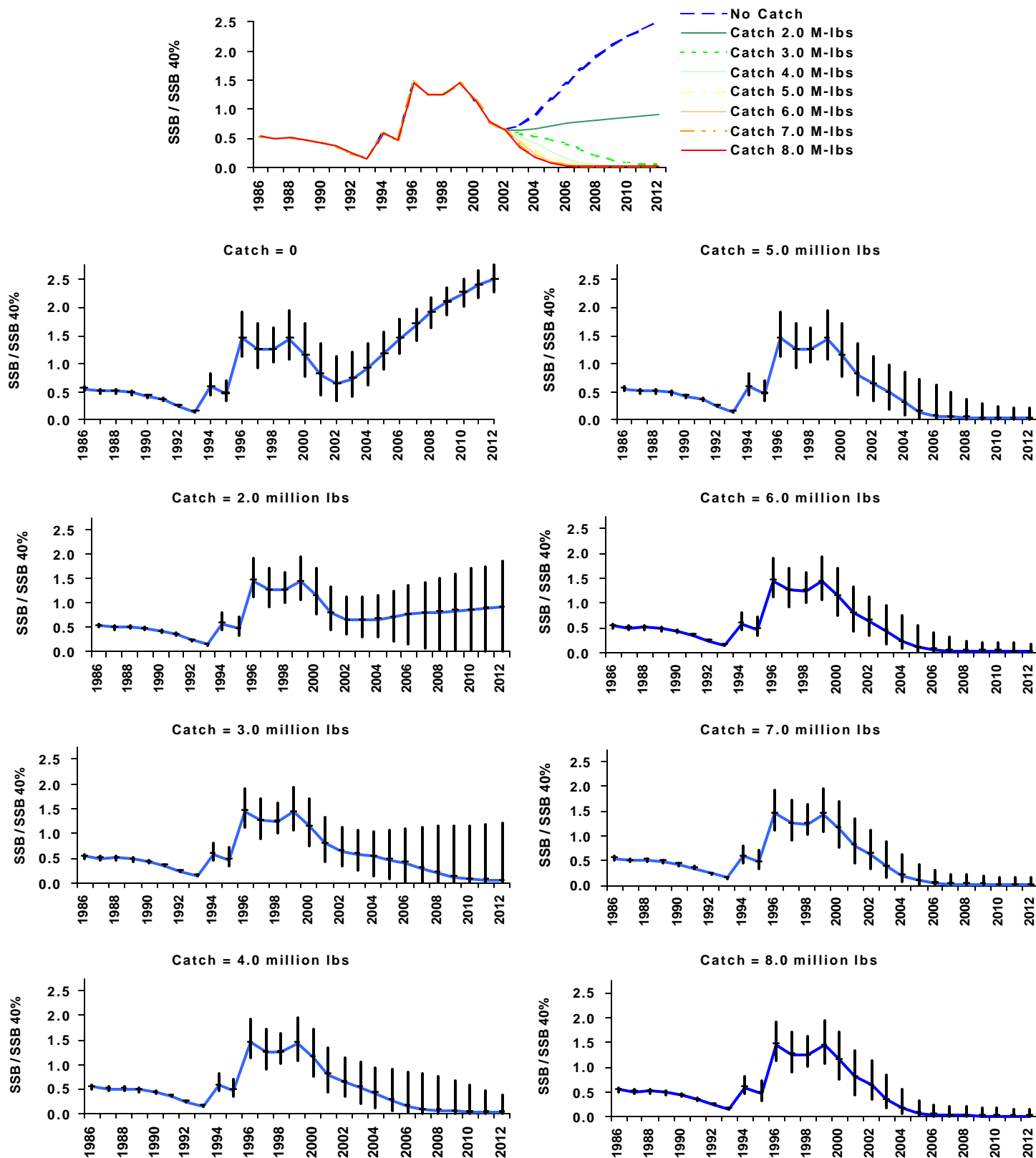


Figure 66. Historical and projected spawning stock biomass (SSB) relative to  $SSB_{40\%}$  (median and the empirical 80% confidence interval) from bootstrapped VPA of the RMM catch-at-age with average recruitment above the minimum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

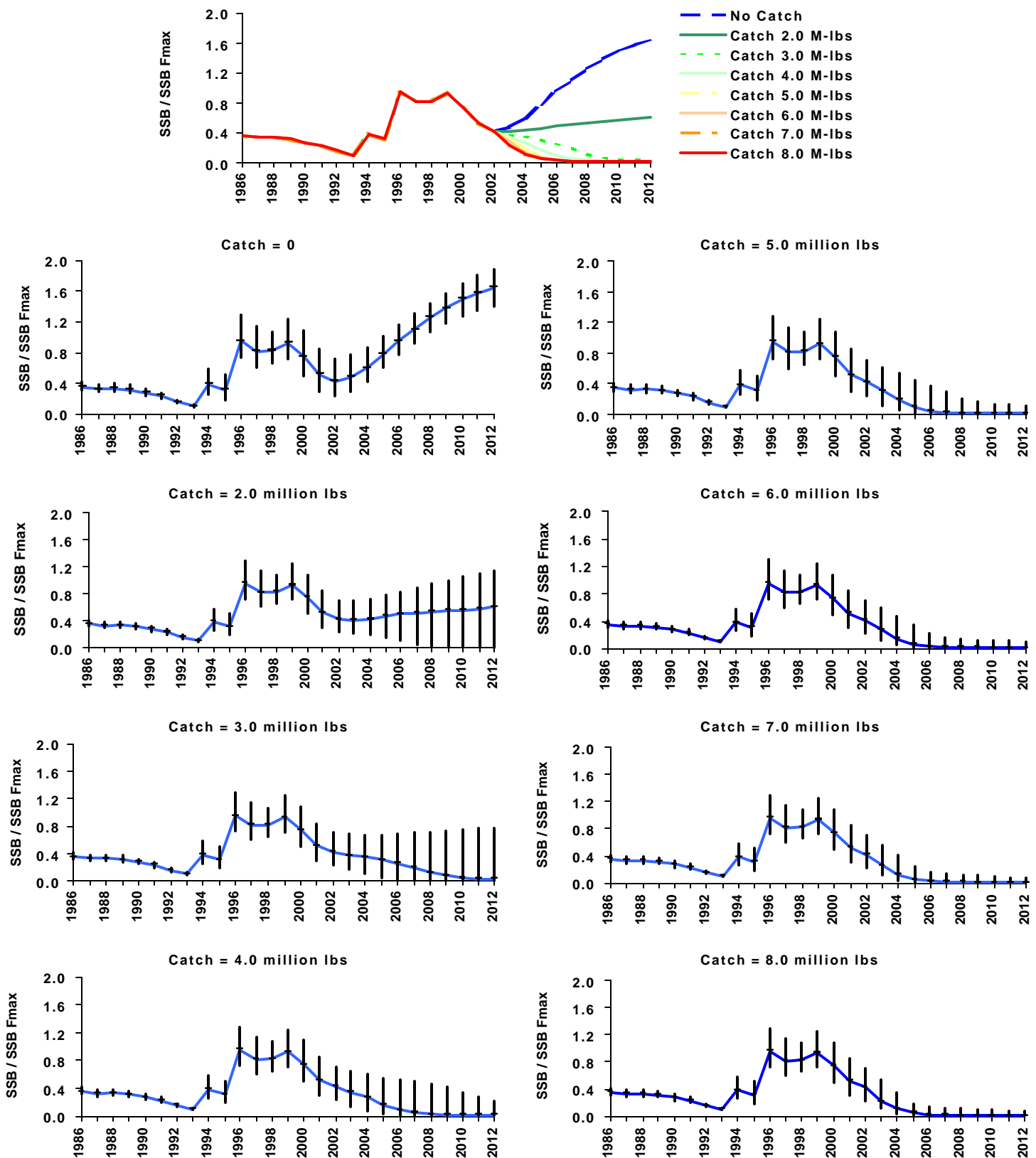


Figure 67. Historical and projected spawning stock biomass (SSB) relative to SSB at  $F_{max}$  (median and the empirical 80% confidence interval) from bootstrapped VPA of the RMM catch-at-age with average recruitment above the minimum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

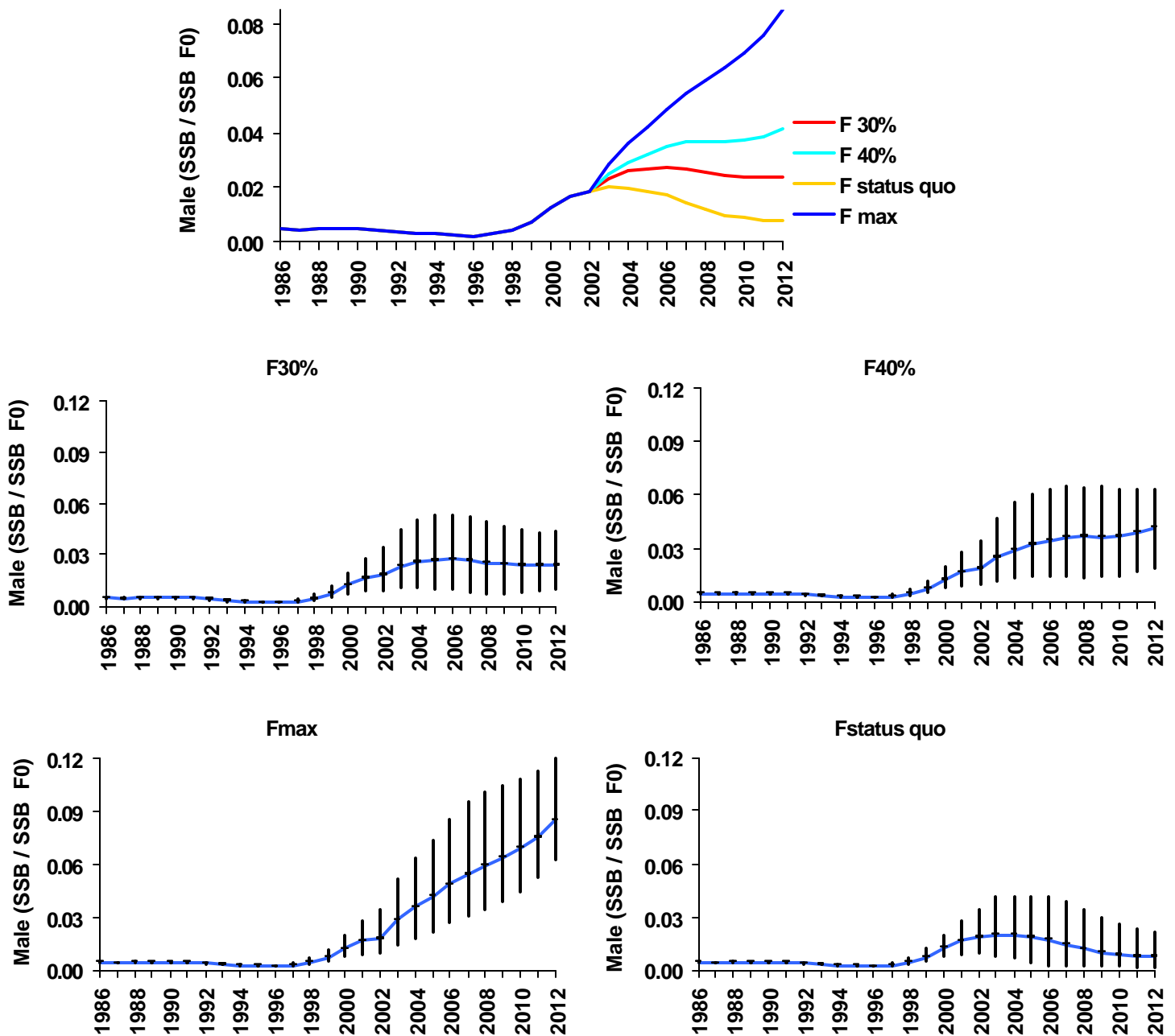


Figure 68. Historical and projected male spawning stock biomass (SSB) relative to male SSB in the unfished condition (median and the empirical 80% confidence interval) from bootstrapped VPA of the RMM catch-at-age with average recruitment above the minimum 1986-1999 spawning stock size. Projections assume fishing in 2002-2012 at  $F_{30\%}$ ,  $F_{40\%}$ ,  $F_{\max}$ , and  $F_{\text{status quo}}$ .

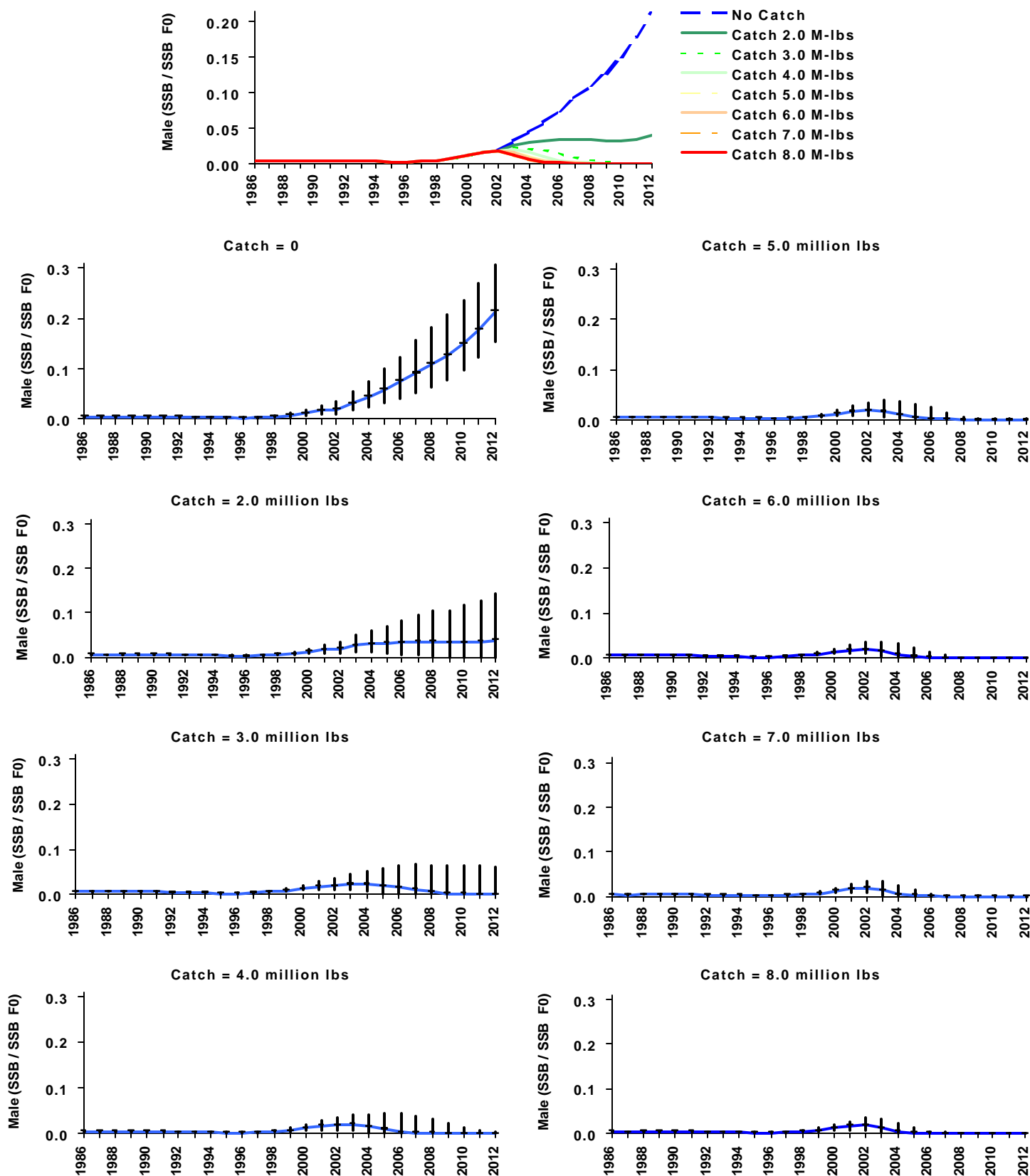


Figure 69. Historical and projected male spawning stock biomass (SSB) relative to male SSB in the unfished condition (median and the empirical 80% confidence interval) from bootstrapped VPA of the RMM catch-at-age with average recruitment above the minimum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

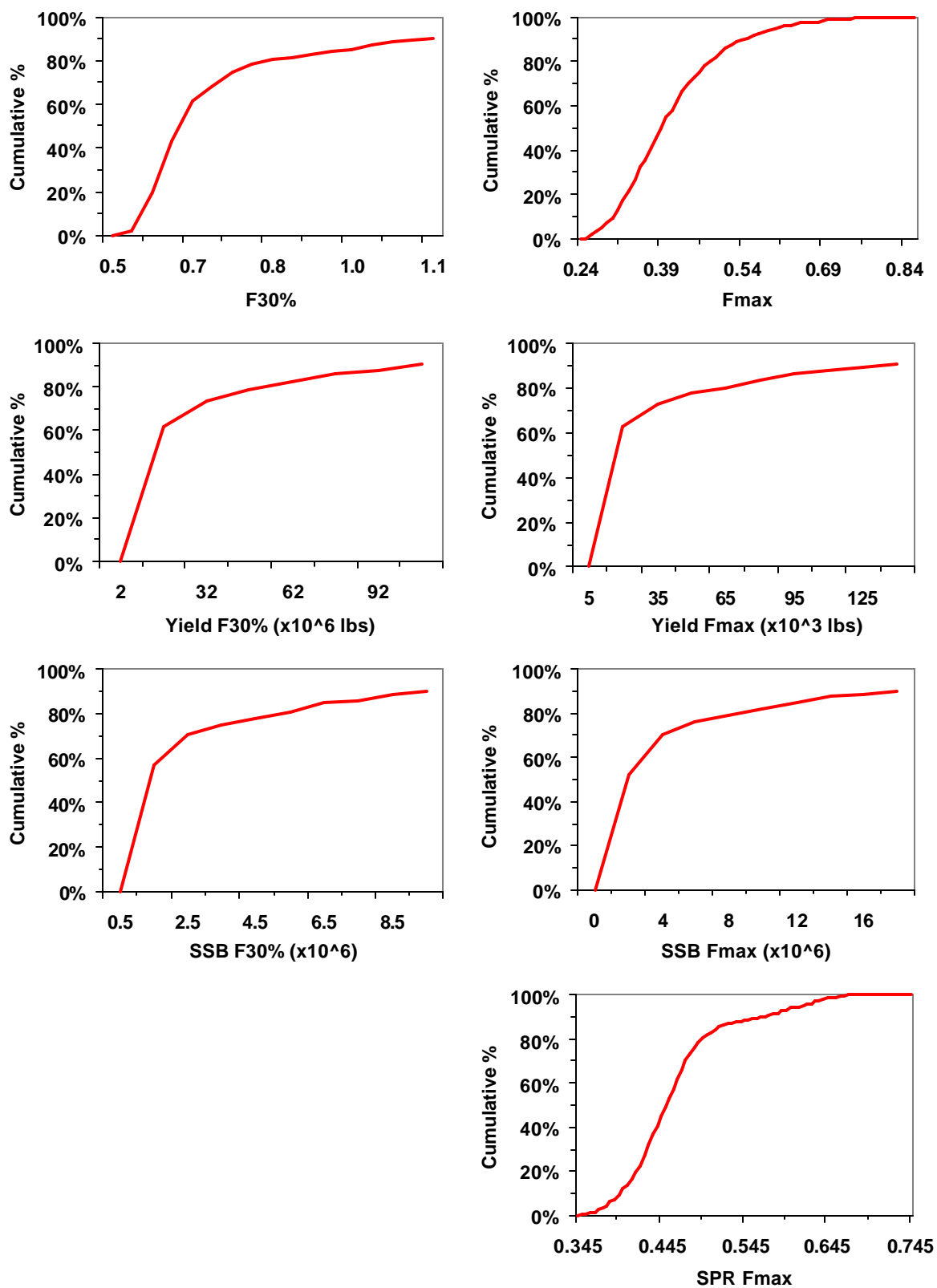


Figure 70. Cumulative frequency distributions for various reference statistics from bootstrapped estimates from the sensitivity VPA using the ALK+ catch-at-age with year-variable index selectivity and recruitment increasing to the maximum 1986-1999 spawning stock size.



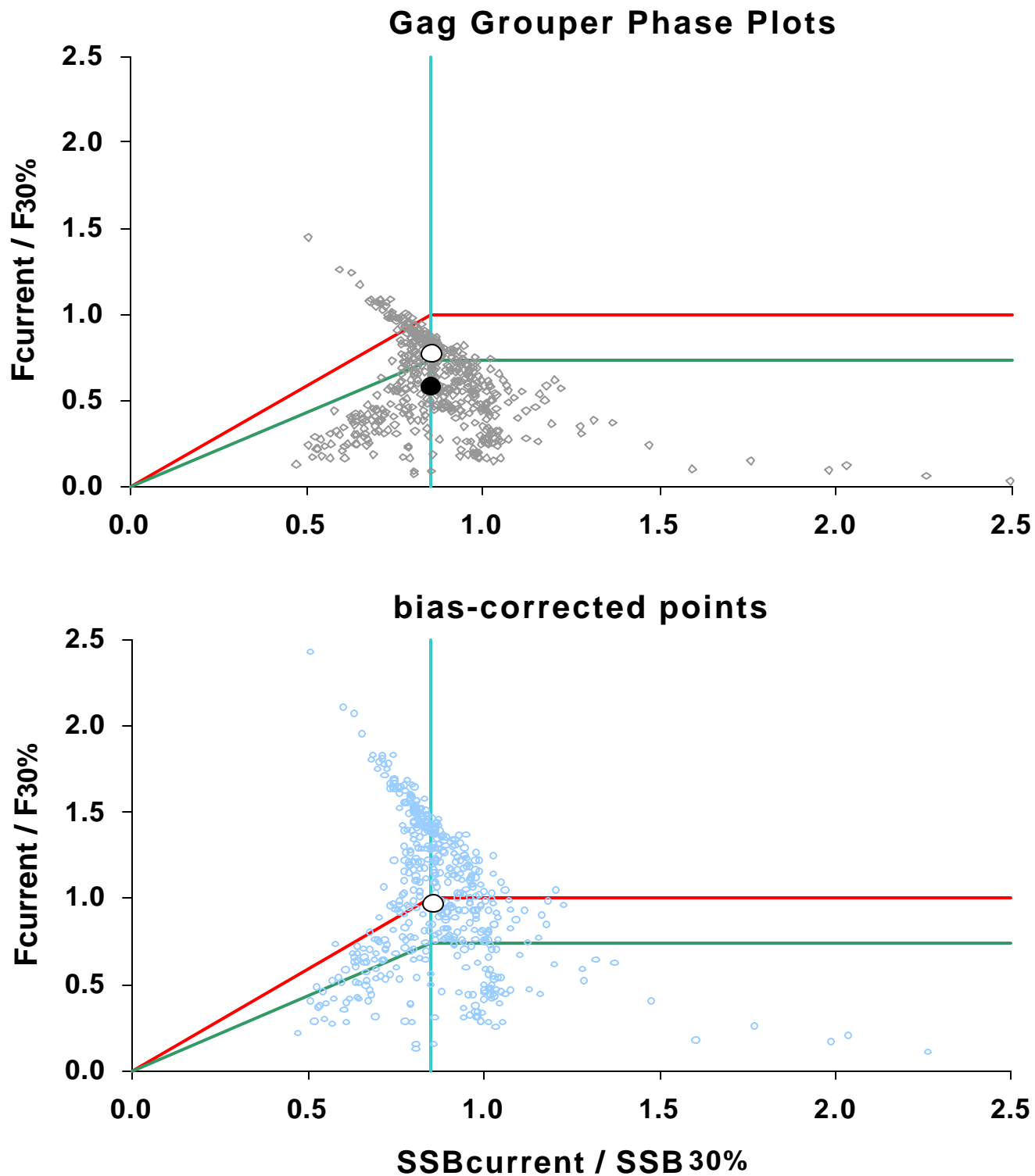
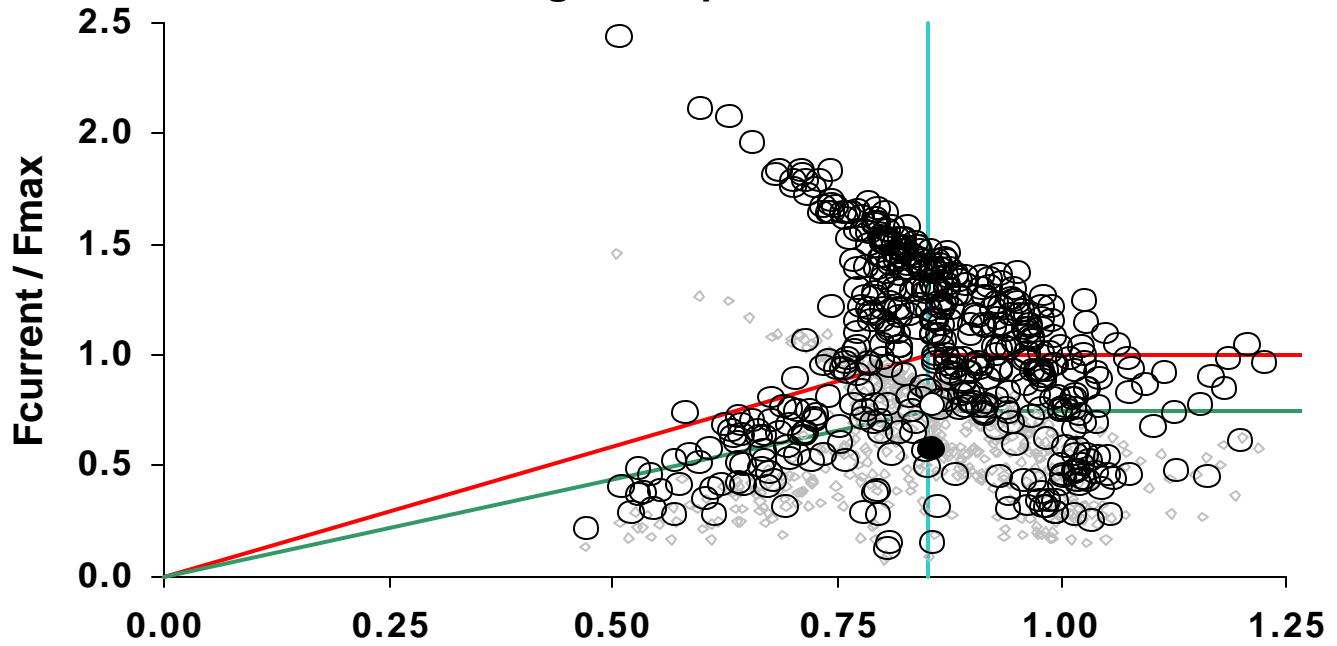


Figure 71. Individual bootstrap estimates of spawning stock biomass (SSB) and fishing mortality rate (F) relative to  $SSB_{30\%}$  and  $F_{30\%}$ , respectively, from the analysis of the ALK+ catch-at-age with year-variable index selectivity and recruitment increasing to the maximum 1986-1999 spawning stock size. The upper panel shows uncorrected results, with the median of the bootstraps (black oval) and the deterministic estimate (white oval). The lower panel shows the bias corrected individual bootstrap and deterministic estimates.

## Gag Grouper Phase Plots



## bias-corrected points

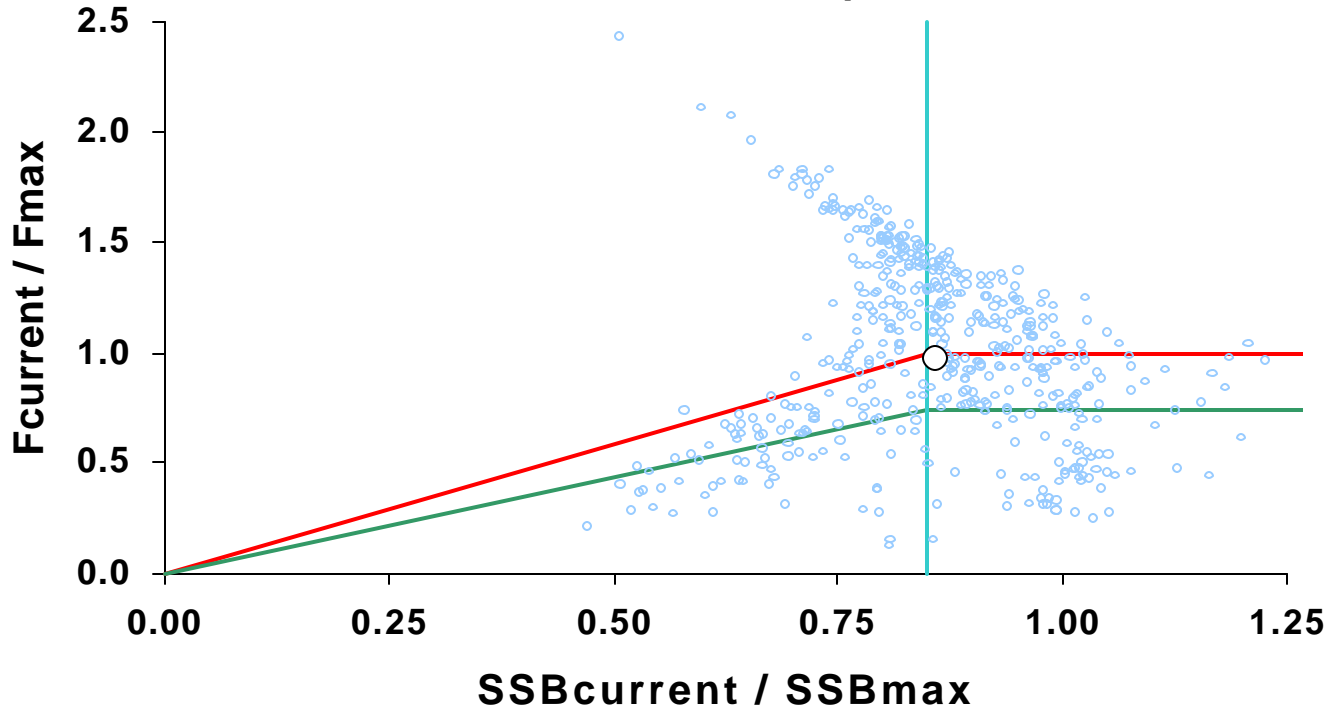


Figure 72. Individual bootstrap estimates of spawning stock biomass (SSB) and fishing mortality rate (F) relative to SSB and F at  $F_{\max}$  from the analysis of the ALK+ catch-at-age with year-variable index selectivity and recruitment increasing to the maximum 1986-1999 spawning stock size. The upper panel shows uncorrected results, with the median of the bootstraps (black oval) and the deterministic estimate (white oval). The lower panel shows the bias corrected individual bootstrap and deterministic estimates.

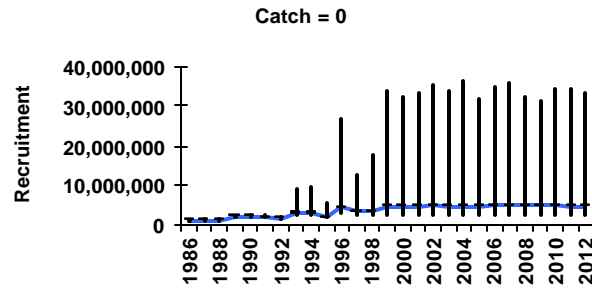


Figure 73. Historical and projected recruitment (median and the empirical 80% confidence interval) from bootstrapped VPA of the ALK+ catch-at-age with year-variable index selectivity and recruitment increasing to the maximum 1986-1999 spawning stock size. Projections assume no catch after 2001.

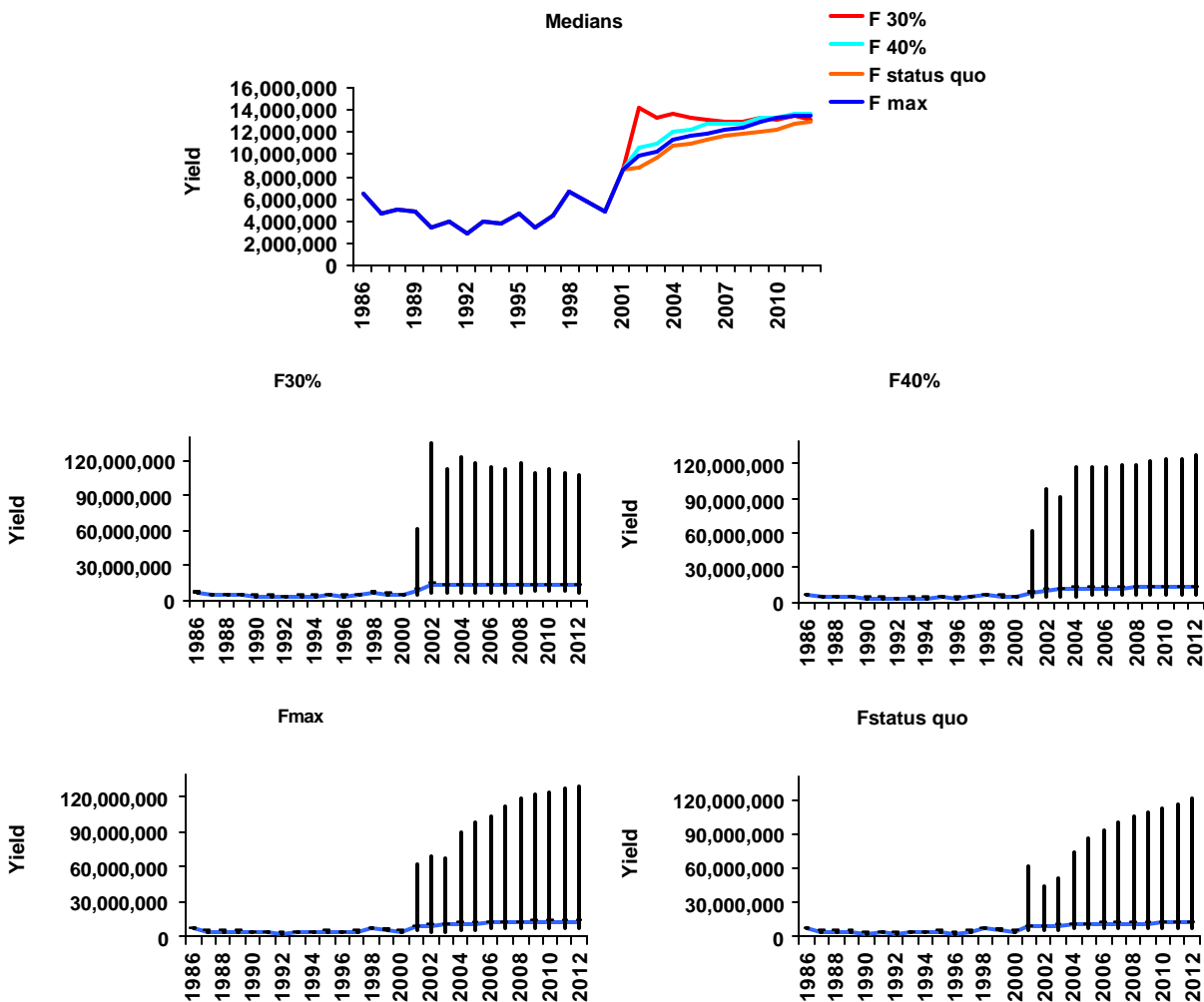


Figure 74. Historical and projected yield (median and the empirical 80% confidence interval) from bootstrapped VPA of the ALK+ catch-at-age with year-variable index selectivity and recruitment increasing to the maximum 1986-1999 spawning stock size. Projections assume fishing in 2002-2012 at  $F_{30\%}$ ,  $F_{40\%}$ ,  $F_{max}$ , and  $F_{status\ quo}$ .

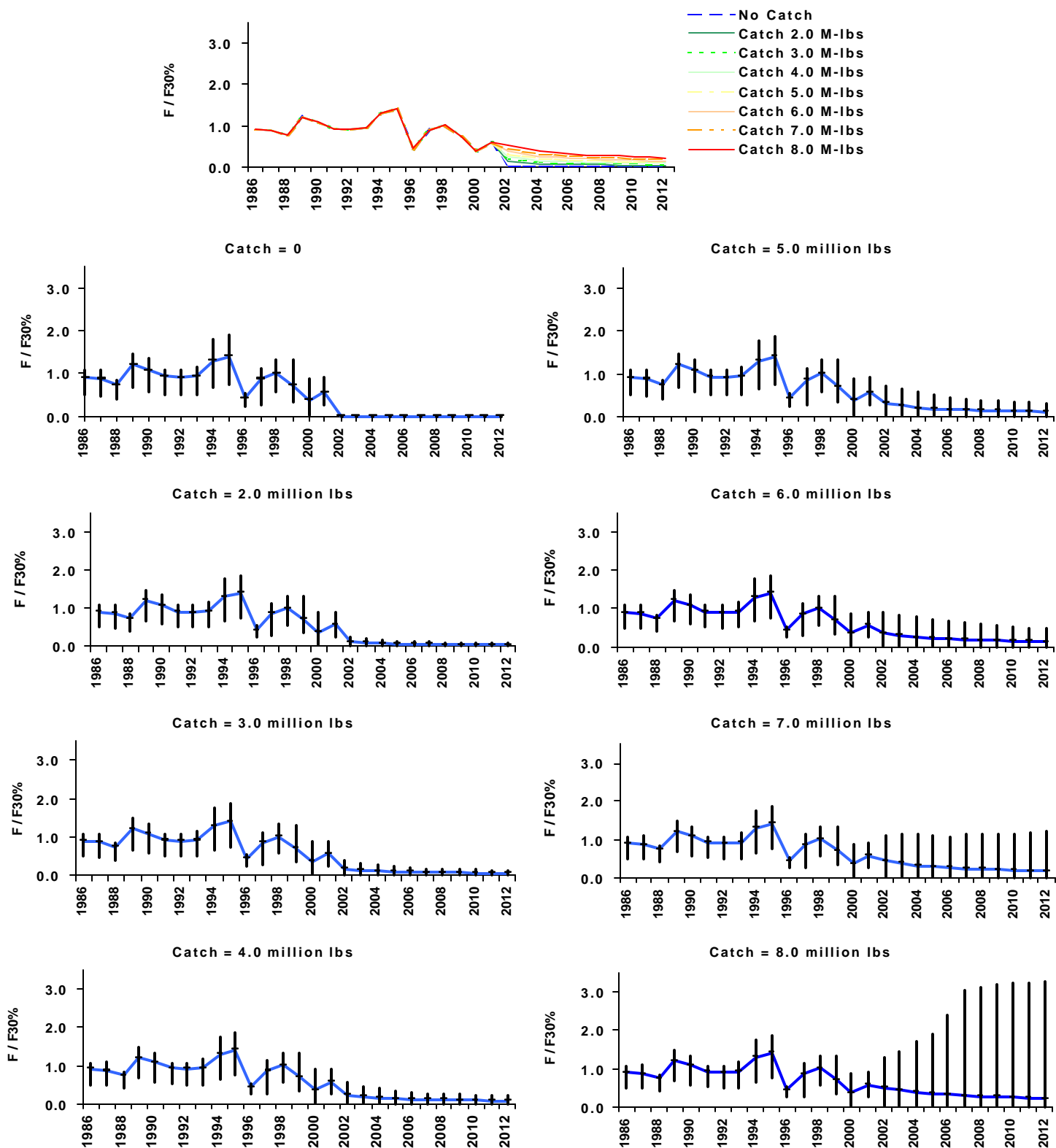


Figure 75. Historical and projected fishing mortality rate ( $F$ ) relative to  $F_{30\%}$  (median and the empirical 80% confidence interval) from bootstrapped VPA of the ALK+ catch-at-age with year-variable index selectivity and recruitment increasing to the maximum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

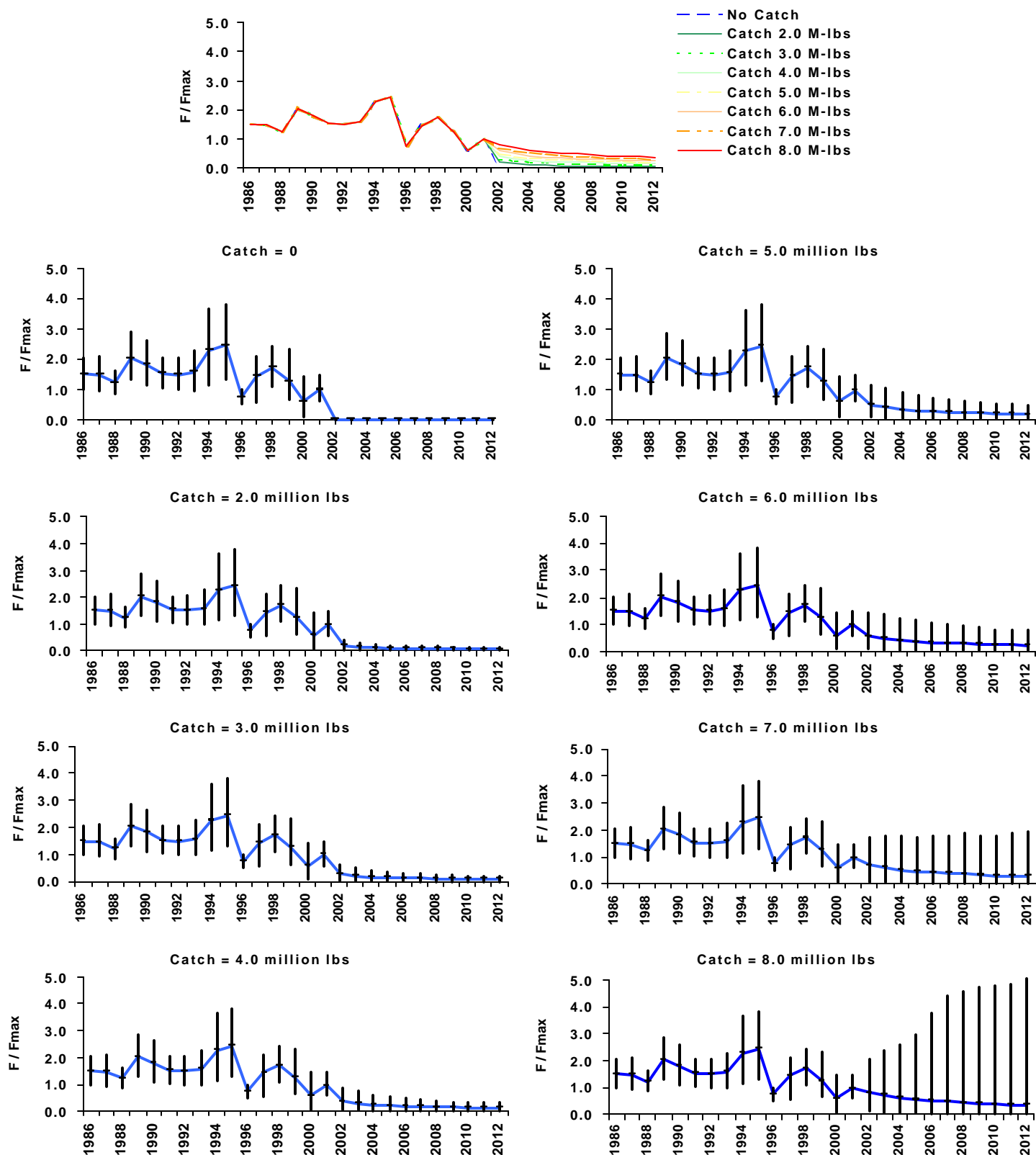


Figure 76. Historical and projected fishing mortality rate ( $F$ ) relative to  $F_{\max}$  (median and the empirical 80% confidence interval) from bootstrapped VPA of the ALK+ catch-at-age with year-variable index selectivity and recruitment increasing to the maximum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

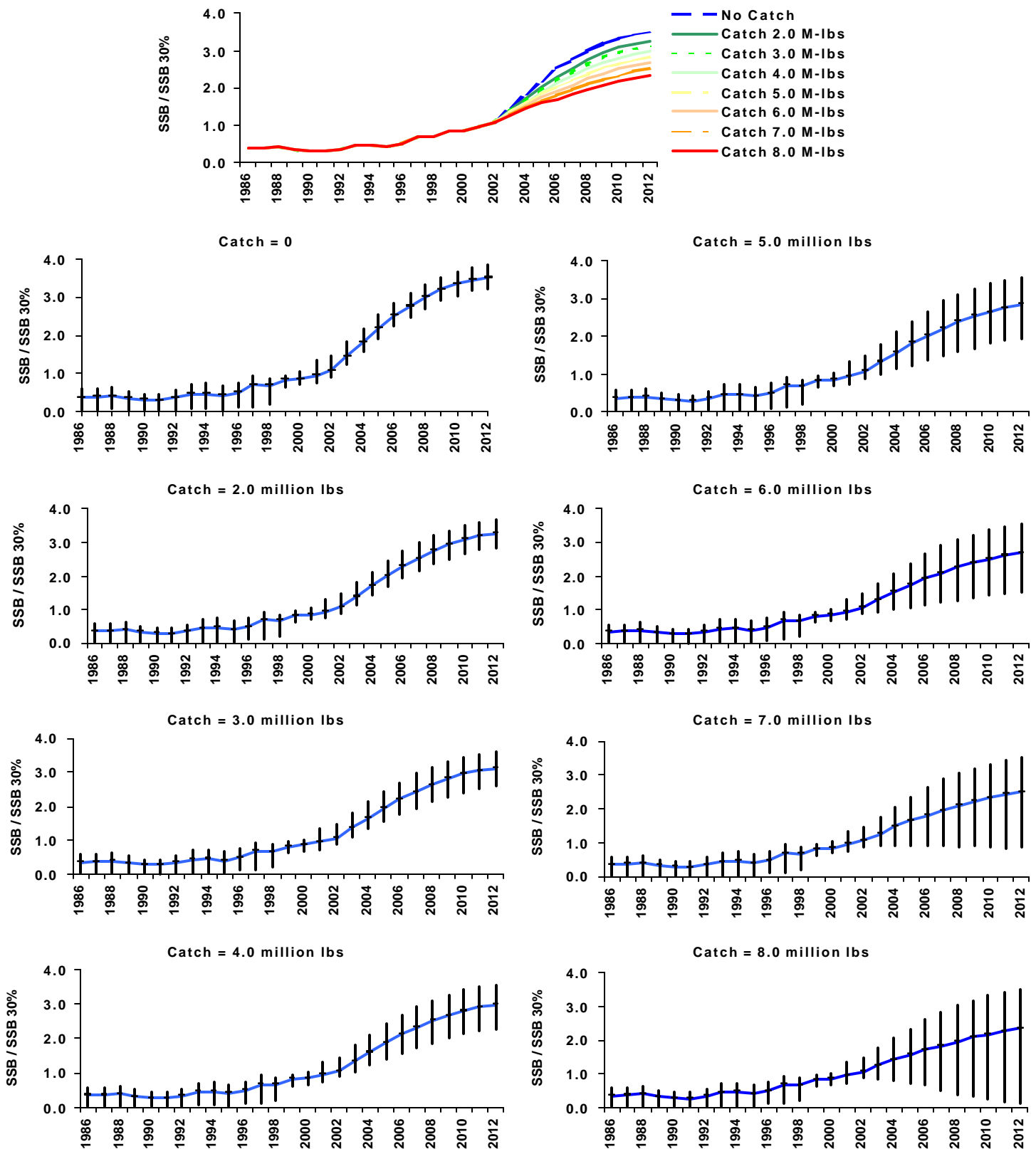


Figure 77. Historical and projected spawning stock biomass (SSB) relative to  $SSB_{30\%}$  (median and the empirical 80% confidence interval) from bootstrapped VPA of the ALK+ catch-at-age with year-variable index selectivity and recruitment increasing to the maximum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

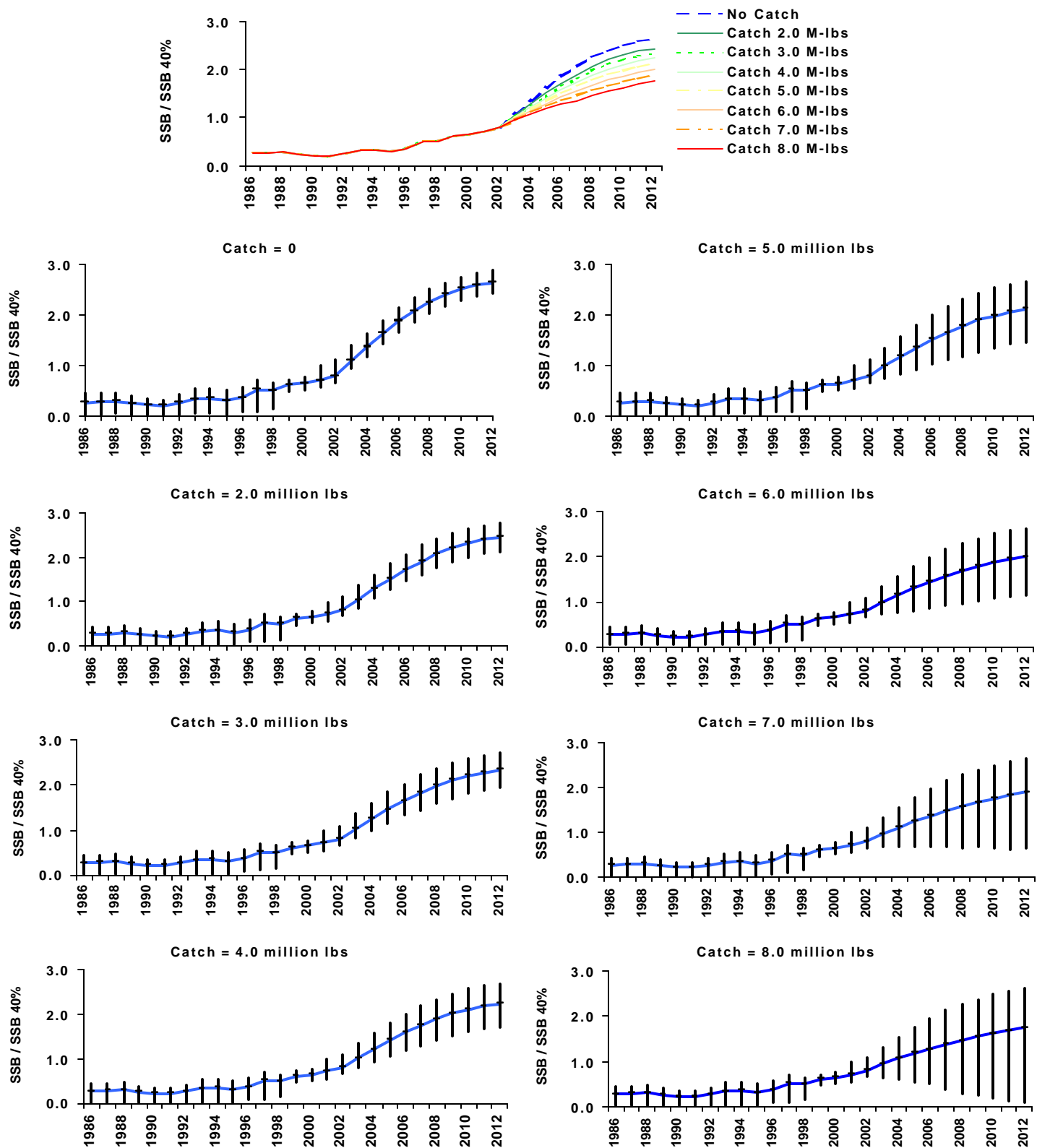


Figure 78. Historical and projected spawning stock biomass (SSB) relative to SSB<sub>40%</sub> (median and the empirical 80% confidence interval) from bootstrapped VPA of the ALK+ catch-at-age with year-variable index selectivity and recruitment increasing to the maximum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

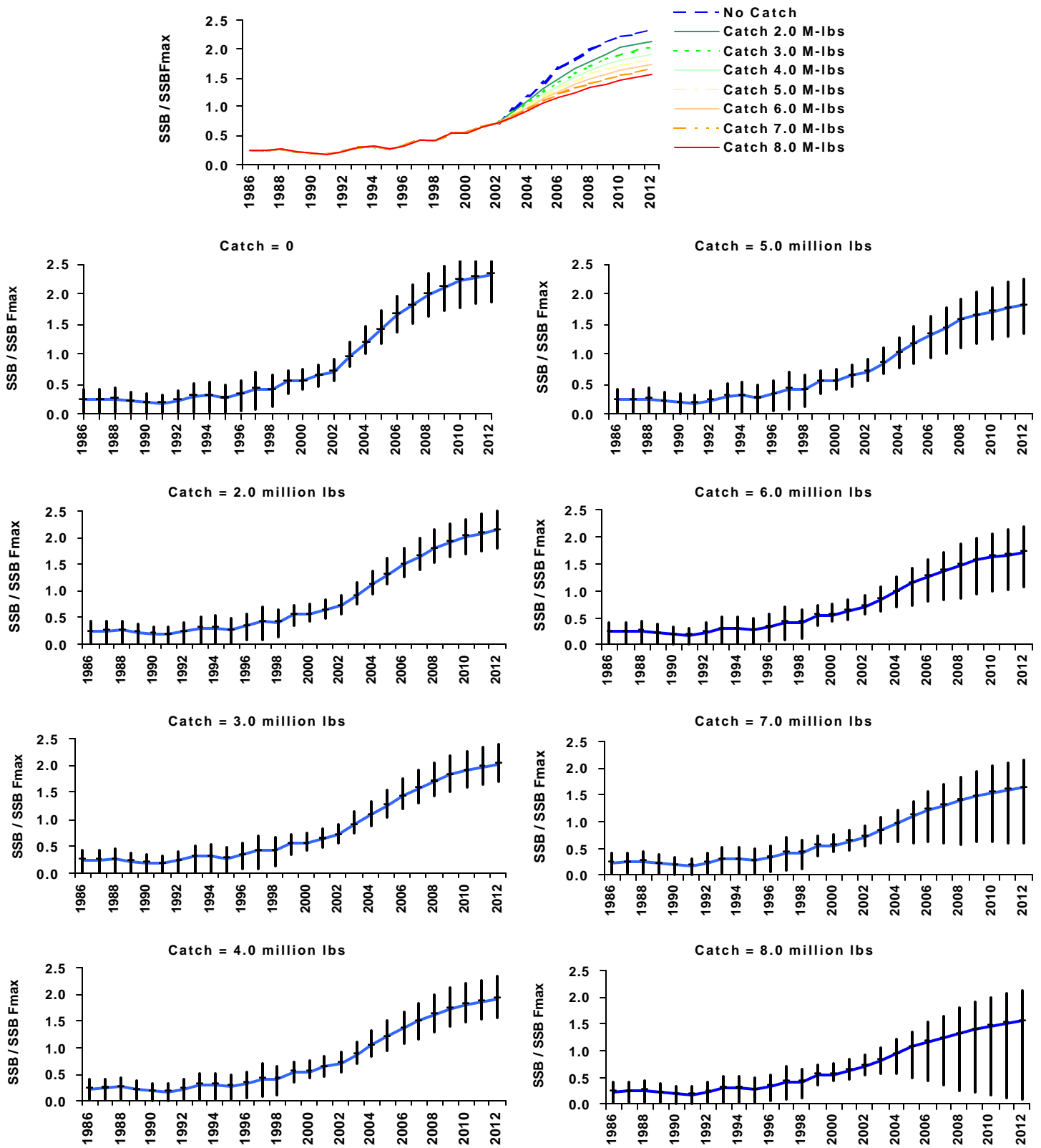


Figure 79. Historical and projected spawning stock biomass (SSB) relative to SSB at  $F_{max}$  (median and the empirical 80% confidence interval) from bootstrapped VPA of the ALK+ catch-at-age with year-variable index selectivity and recruitment increasing to the maximum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.



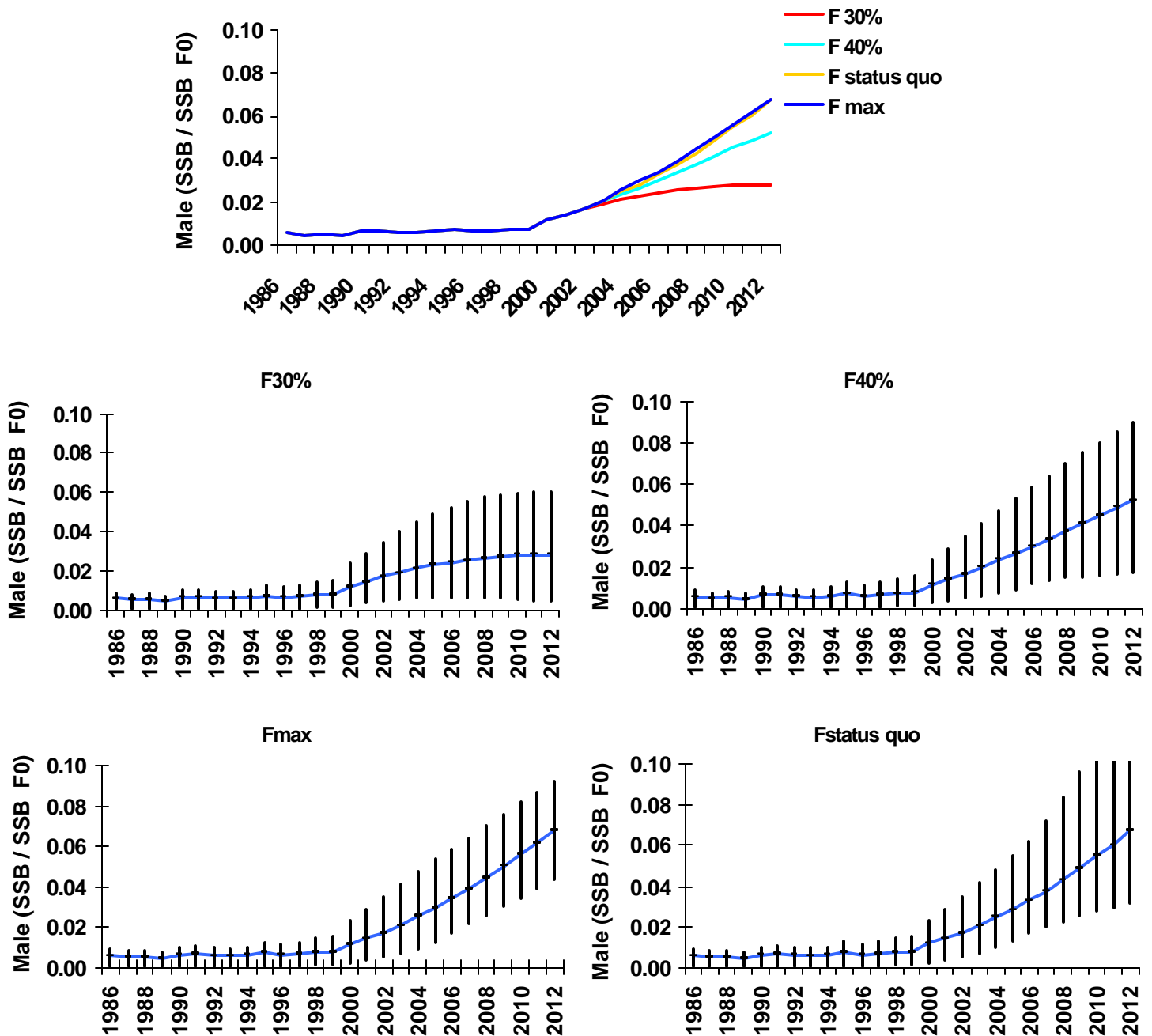


Figure 80. Historical and projected male spawning stock biomass (SSB) relative to male SSB in the unfished condition (median and the empirical 80% confidence interval) from bootstrapped VPA of the ALK+ catch-at-age with year-variable index selectivity and recruitment increasing to the maximum 1986-1999 spawning stock size. Projections assume fishing in 2002-2012 at  $F_{30\%}$ ,  $F_{40\%}$ ,  $F_{\max}$ , and  $F_{\text{status quo}}$

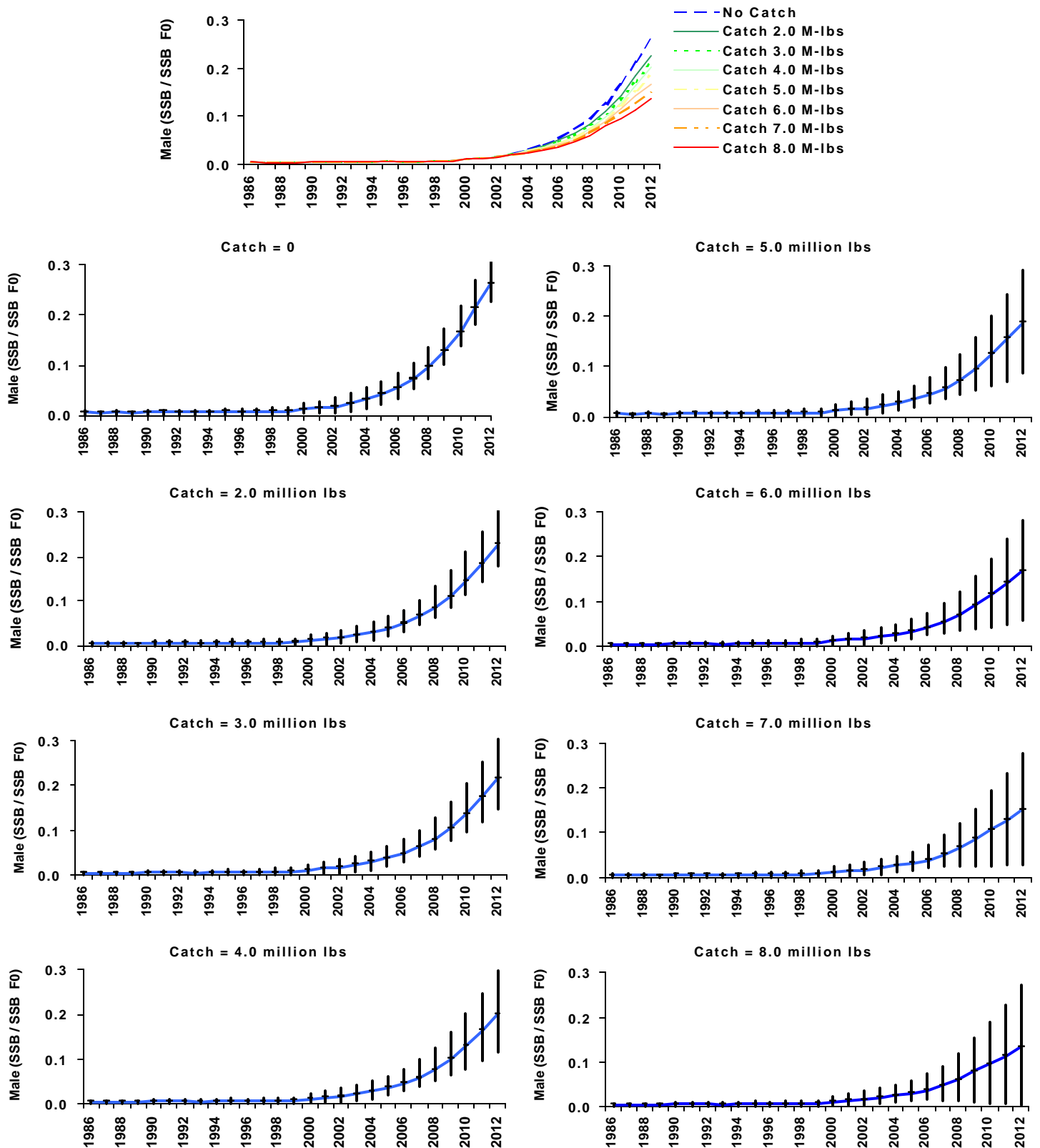


Figure 81. Historical and projected male spawning stock biomass (SSB) relative to male SSB in the unfished condition (median and the empirical 80% confidence interval) from bootstrapped VPA of the ALK+ catch-at-age with year-variable index selectivity and recruitment increasing to the maximum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

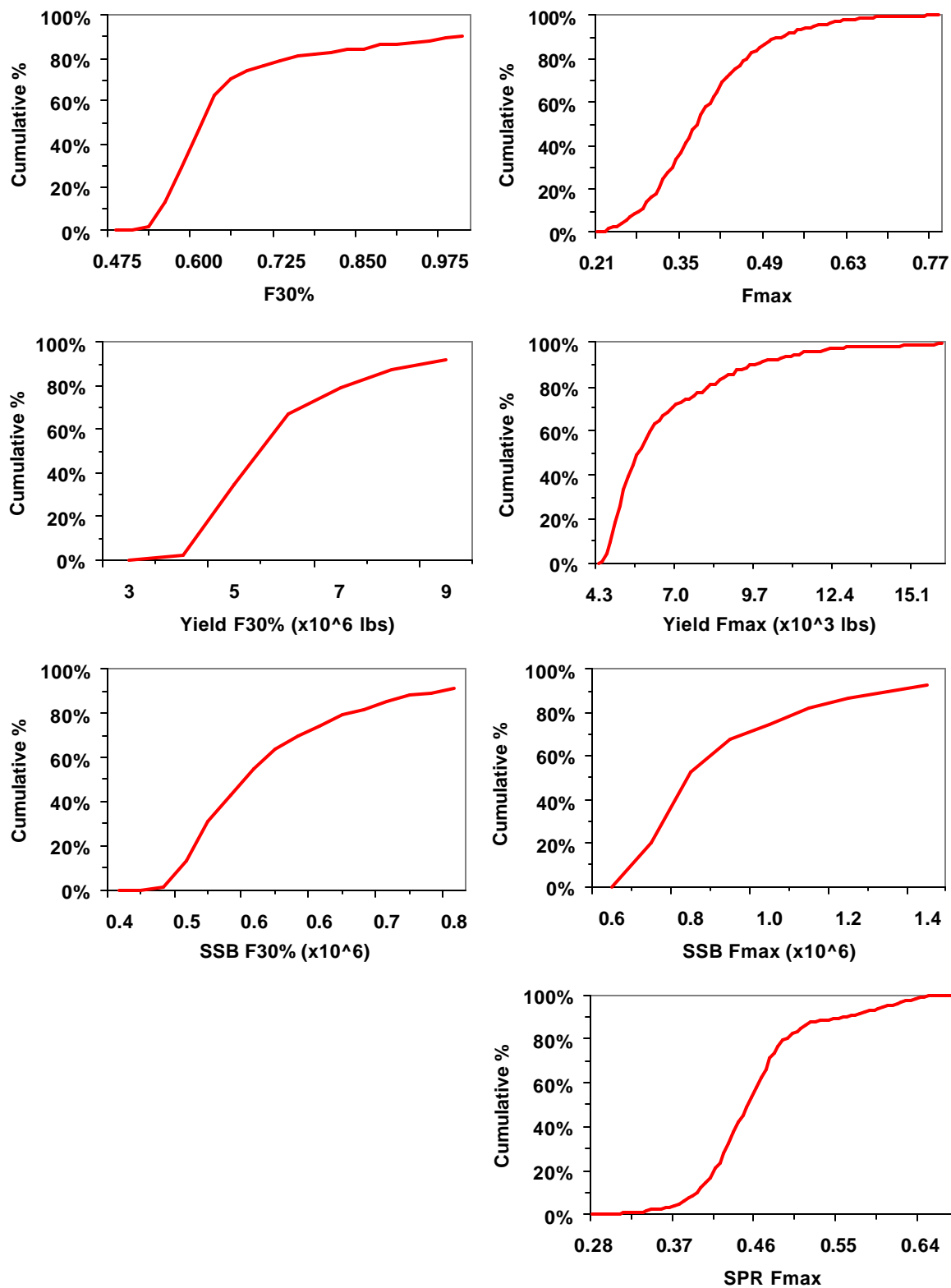
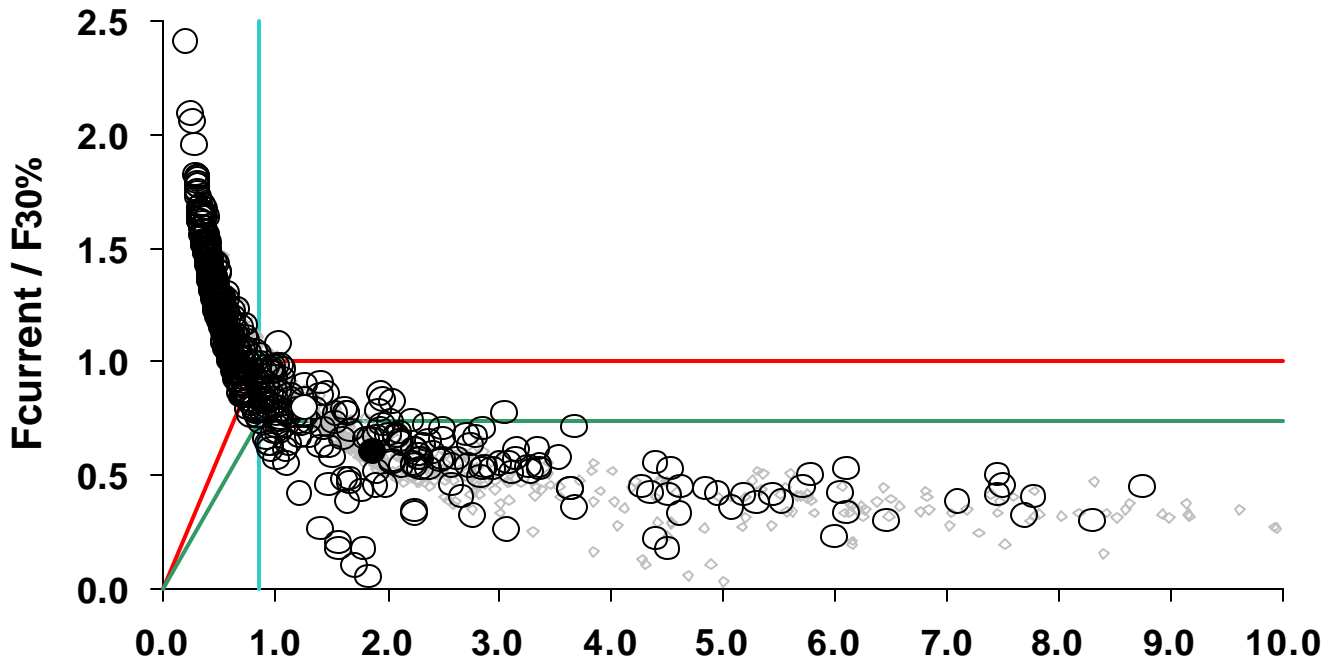


Figure 82. Cumulative frequency distributions for various reference statistics from bootstrapped estimates from the VPA using the ALK+ catch-at-age with year-variable index selectivity and average recruitment above the minimum 1986-1999 spawning stock size.

## Gag Grouper Phase Plots



## bias-corrected points

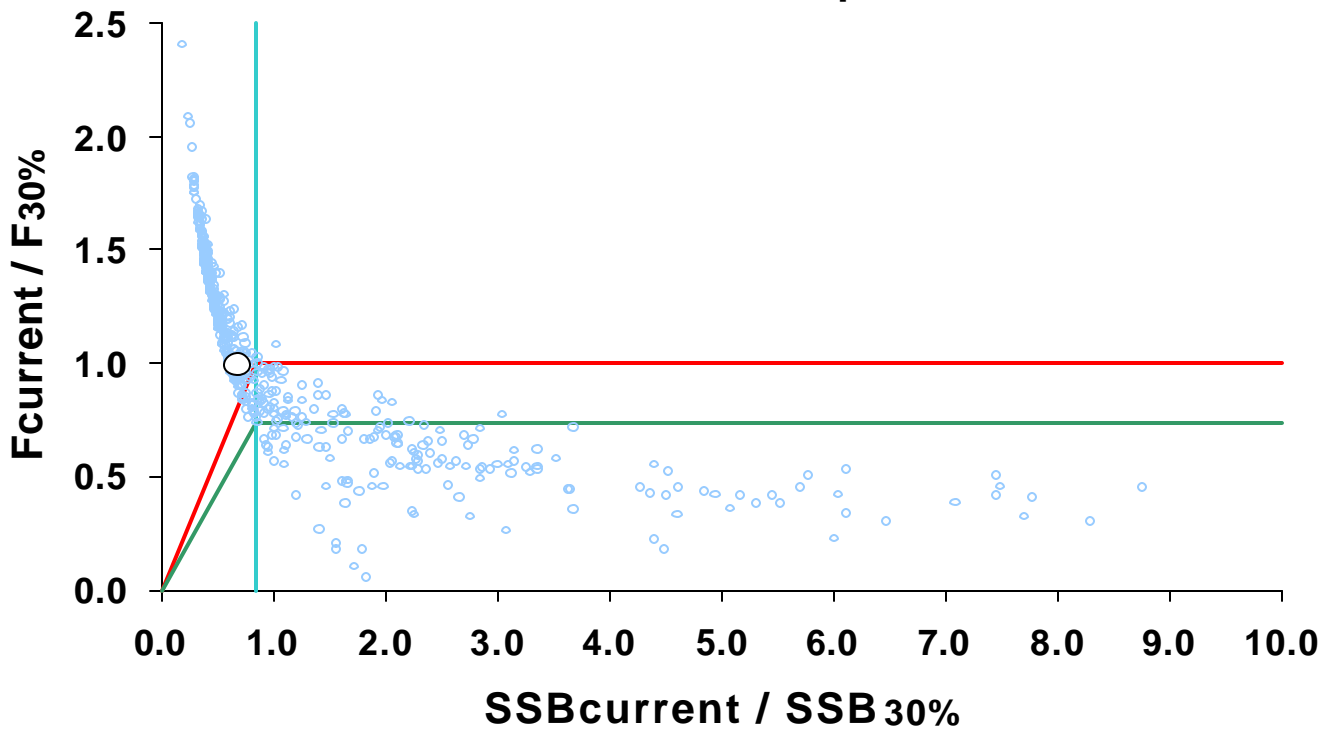
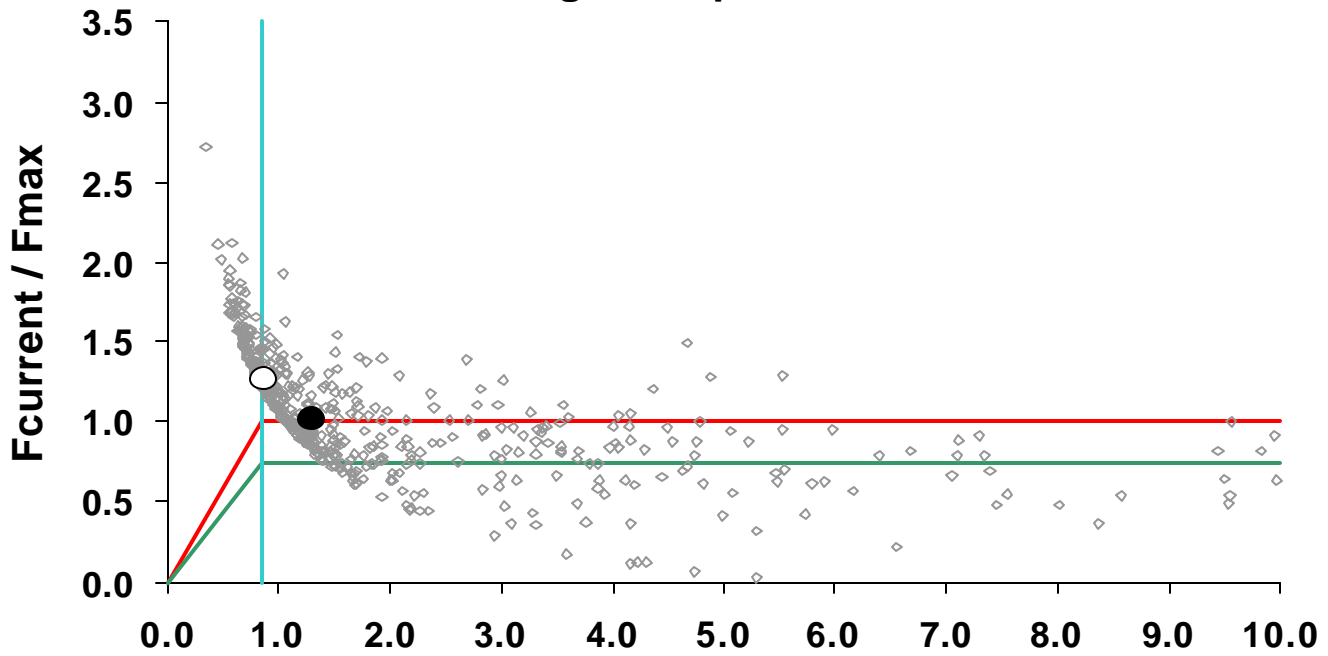


Figure 83. Individual bootstrap estimates of spawning stock biomass (SSB) and fishing mortality rate (F) relative to  $SSB_{30\%}$  and  $F_{30\%}$ , respectively, from the VPA using the ALK+ catch-at-age with year-variable index selectivity and average recruitment above the minimum 1986-1999 spawning stock size. The upper panel shows uncorrected results, with the median of the bootstraps (black oval) and the deterministic estimate (white oval). The lower panel shows the bias corrected individual bootstrap and deterministic estimates.

## Gag Grouper Phase Plots



## bias-corrected points

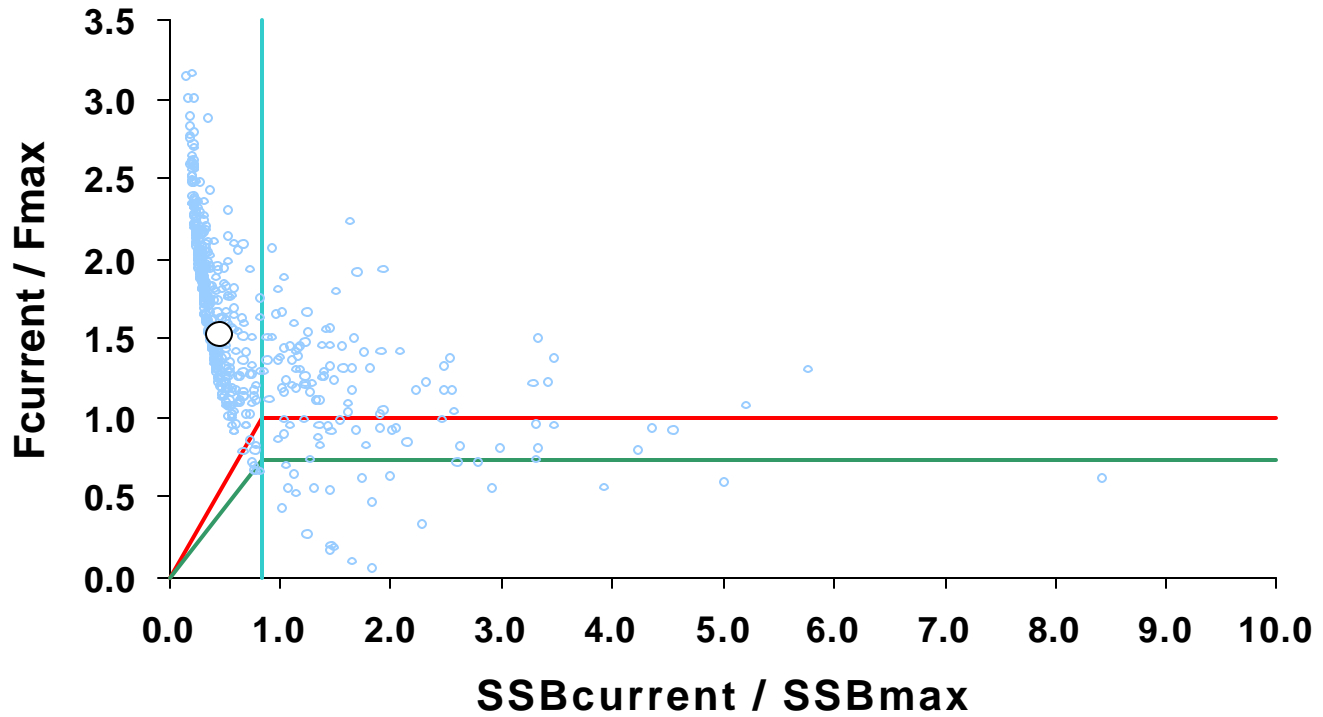


Figure 84. Individual bootstrap estimates of spawning stock biomass (SSB) and fishing mortality rate (F) relative to SSB and F at  $F_{\max}$  from the VPA using the ALK+ catch-at-age with year-variable index selectivity and average recruitment above the minimum 1986-1999 spawning stock size. The upper panel shows uncorrected results, with the median of the bootstraps (black oval) and the deterministic estimate (white oval). The lower panel shows the bias corrected individual bootstrap and deterministic estimates.

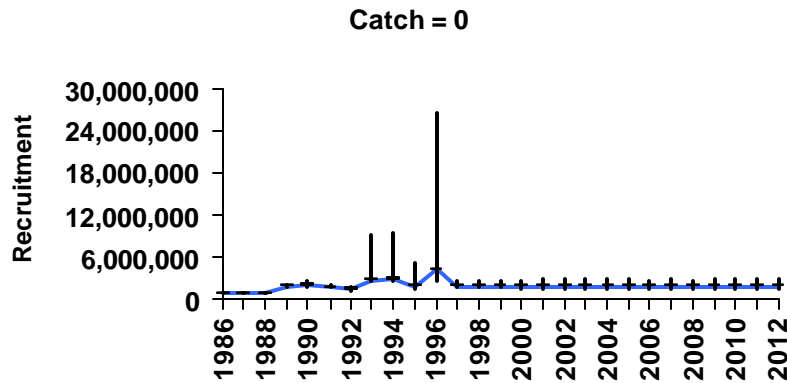


Figure 85. Historical and projected recruitment (median and the empirical 80% confidence interval) from bootstrapped VPA using the ALK+ catch-at-age with year-variable index selectivity and average recruitment above the minimum 1986-1999 spawning stock size. Projections assume no catch after 2001.

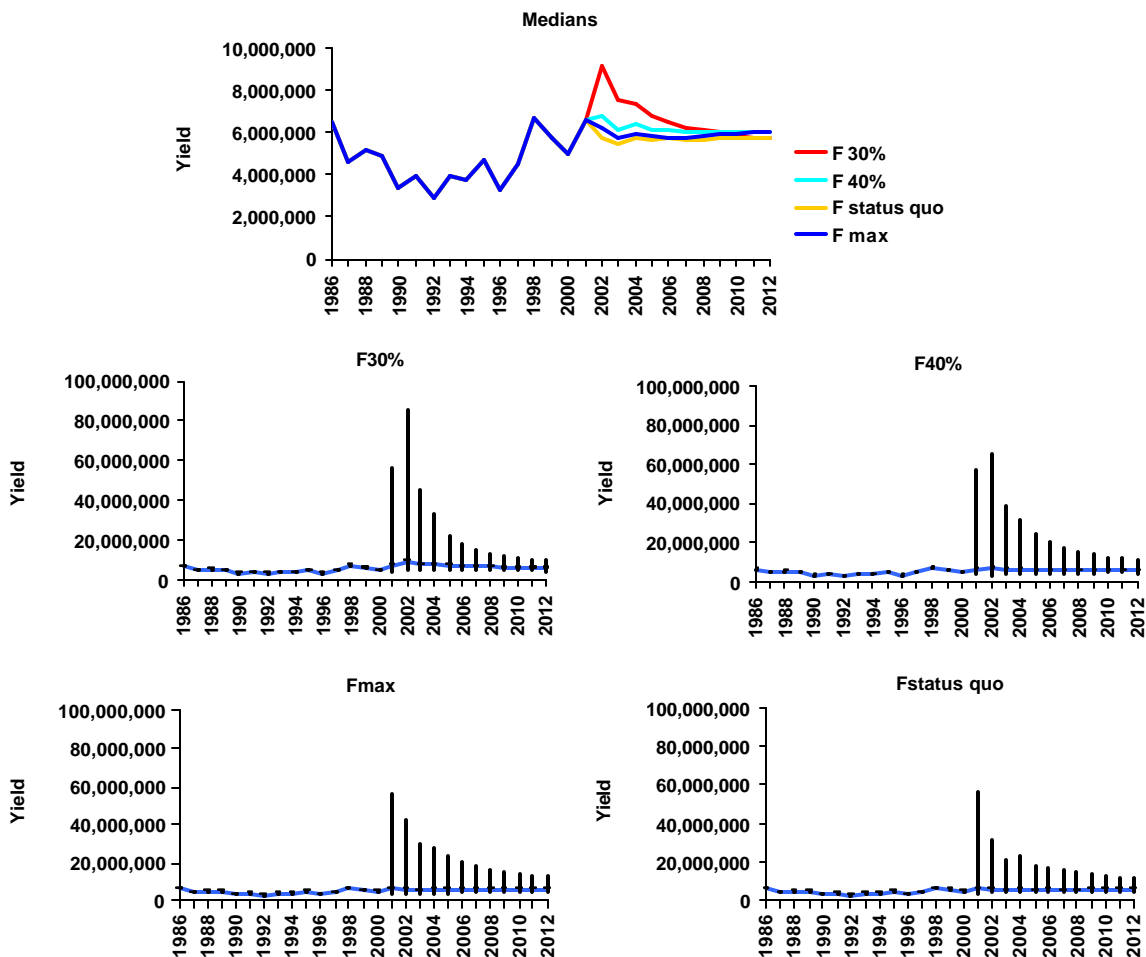


Figure 86. Historical and projected yield (median and the empirical 80% confidence interval) from bootstrapped VPA using the ALK+ catch-at-age with year-variable index selectivity and average recruitment above the minimum 1986-1999 spawning stock size. Projections assume fishing in 2002-2012 at  $F_{30\%}$ ,  $F_{40\%}$ ,  $F_{max}$ , and  $F_{status\ quo}$ .

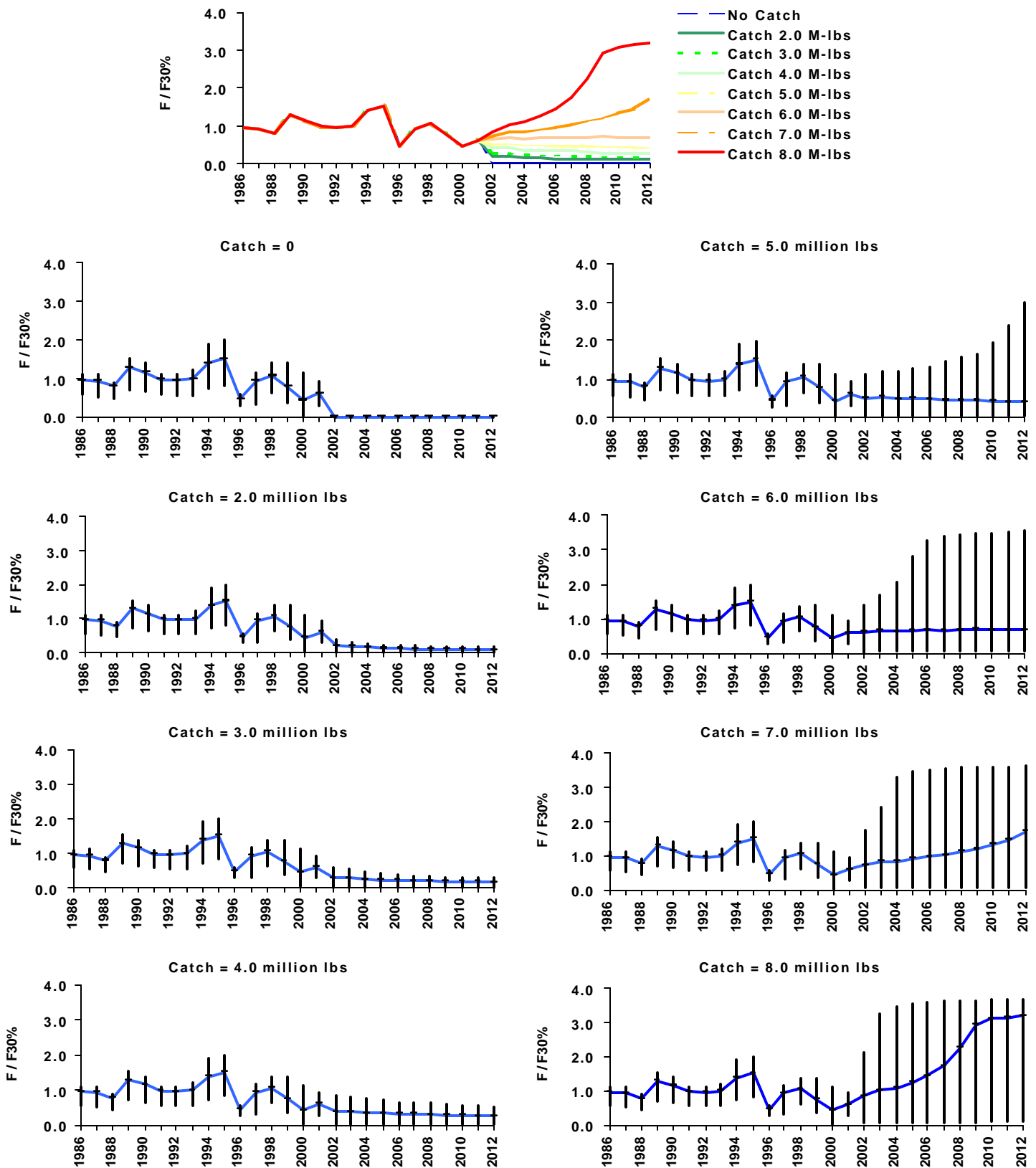


Figure 87. Historical and projected fishing mortality rate ( $F$ ) relative to  $F_{30\%}$  (median and the empirical 80% confidence interval) from bootstrapped VPA using the ALK+ catch-at-age with year-variable index selectivity and average recruitment above the minimum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

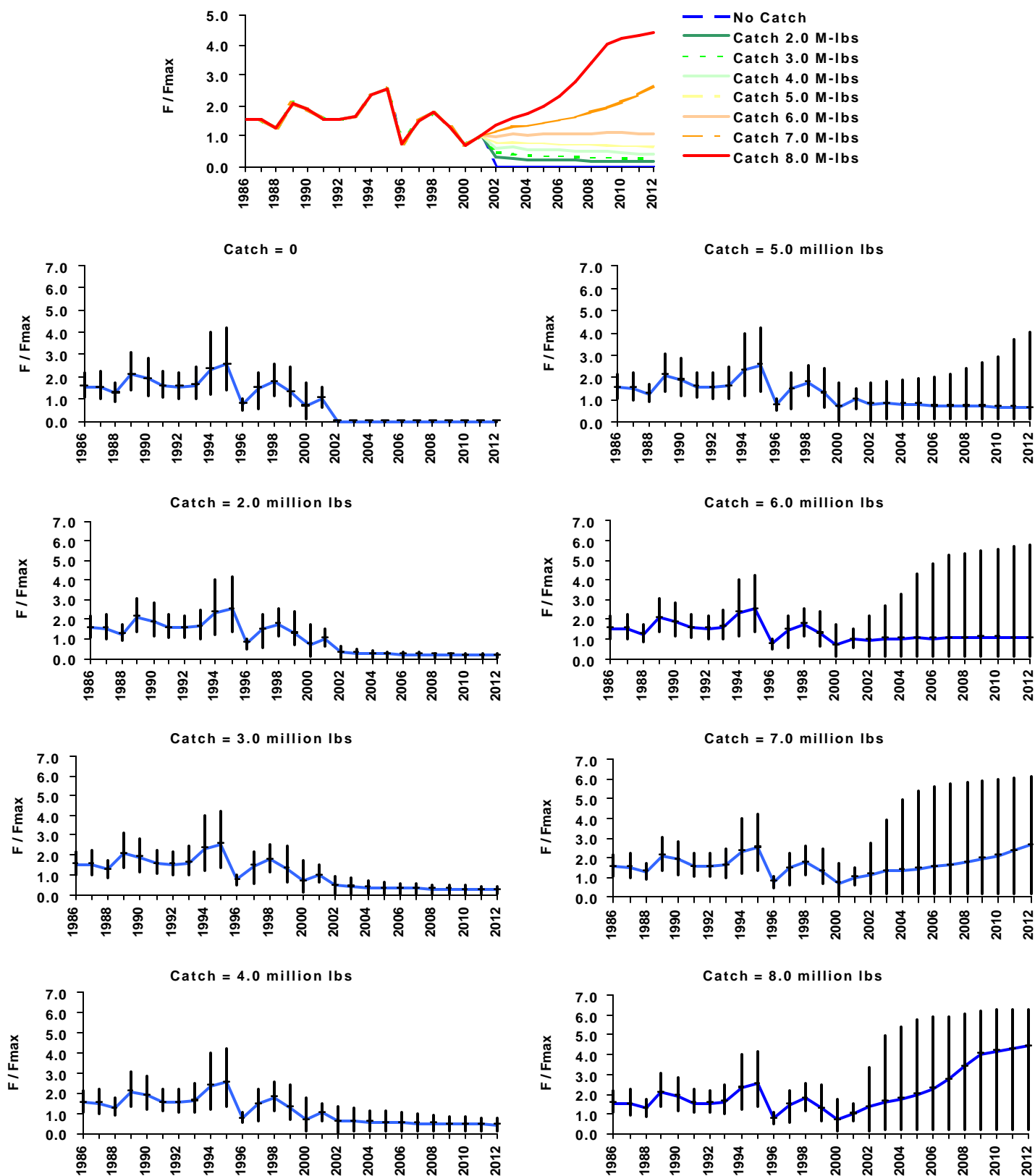


Figure 88. Historical and projected fishing mortality rate ( $F$ ) relative to  $F_{\max}$  (median and the empirical 80% confidence interval) from bootstrapped VPA using the ALK+ catch-at-age with year-variable index selectivity and average recruitment above the minimum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.



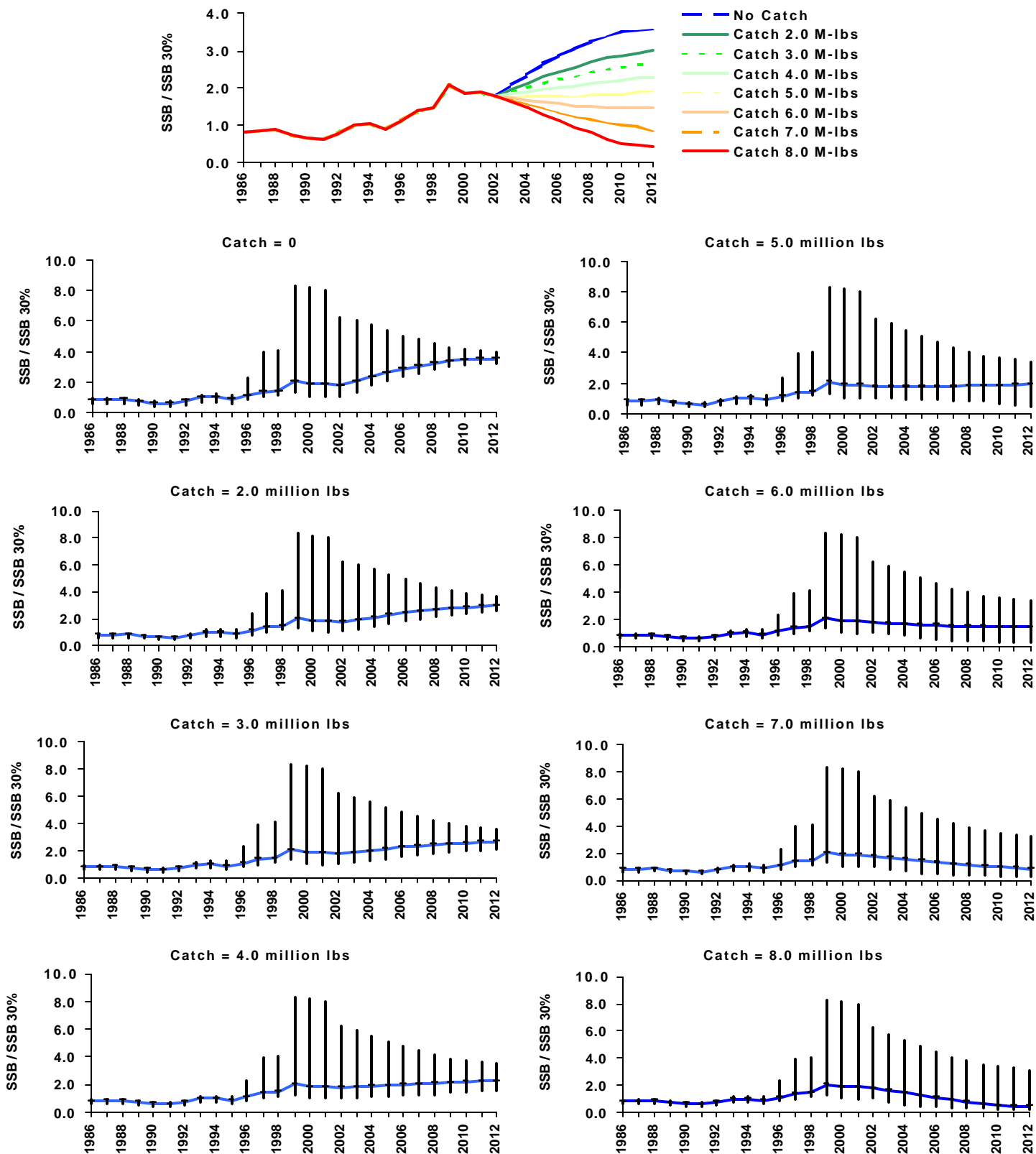


Figure 89. Historical and projected spawning stock biomass (SSB) relative to  $SSB_{30\%}$  (median and the empirical 80% confidence interval) from bootstrapped VPA using the ALK+ catch-at-age with year-variable index selectivity and average recruitment above the minimum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

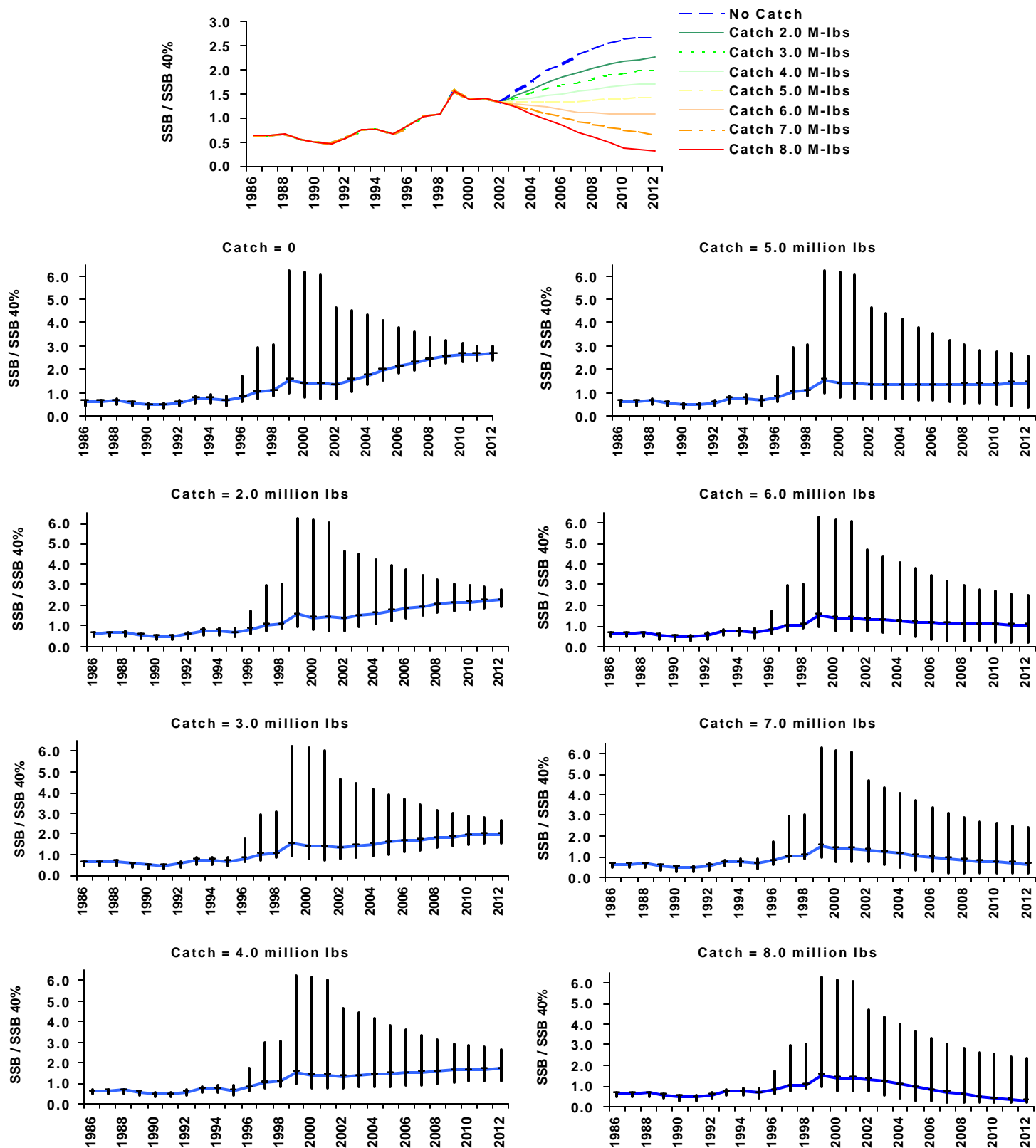


Figure 90. Historical and projected spawning stock biomass (SSB) relative to  $SSB_{40\%}$  (median and the empirical 80% confidence interval) from bootstrapped VPA using the ALK+ catch-at-age with year-variable index selectivity and average recruitment above the minimum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

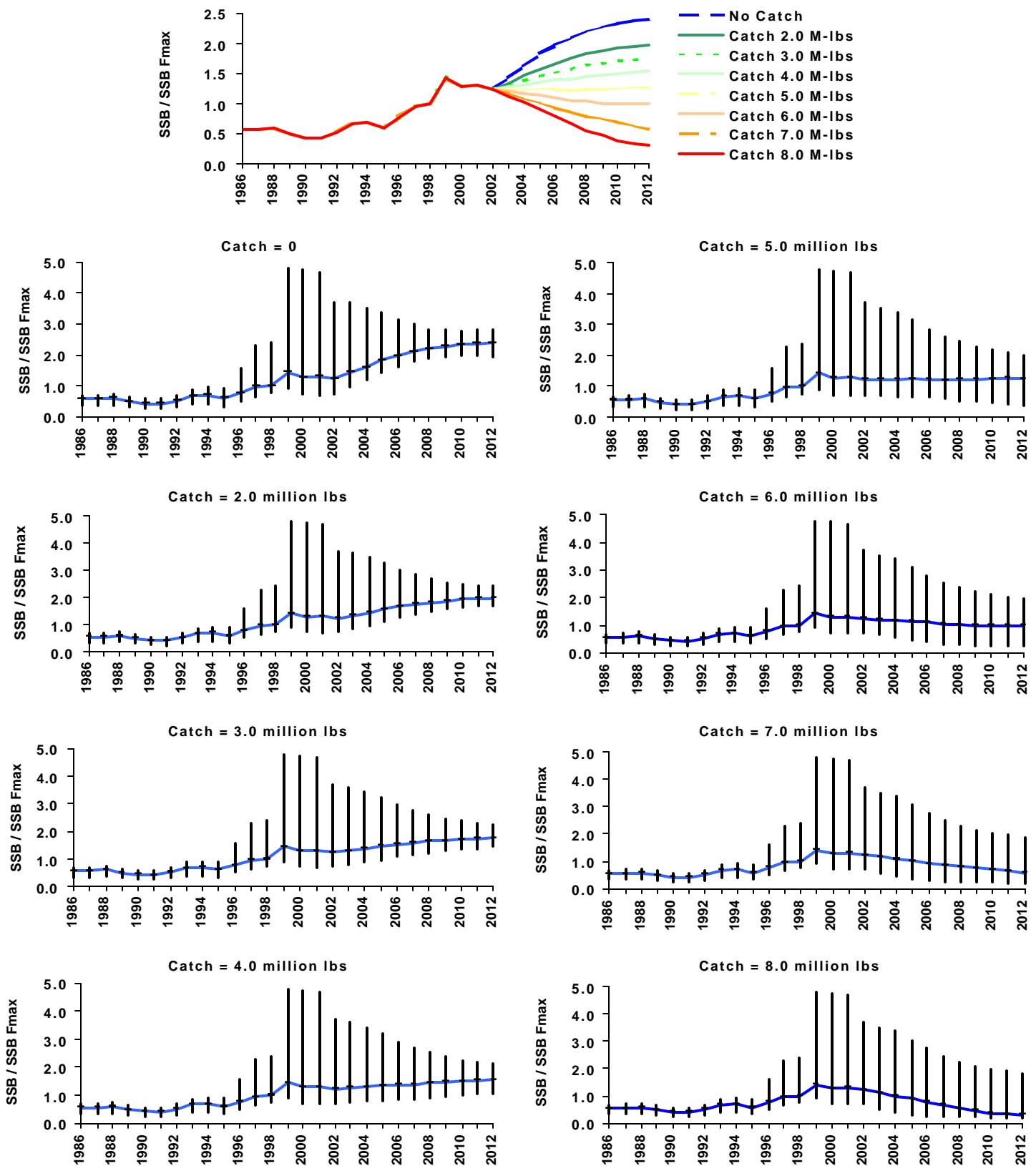


Figure 91. Historical and projected spawning stock biomass (SSB) relative to SSB at  $F_{max}$  (median and the empirical 80% confidence interval) from bootstrapped VPA using the ALK+ catch-at-age with year-variable index selectivity and average recruitment above the minimum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

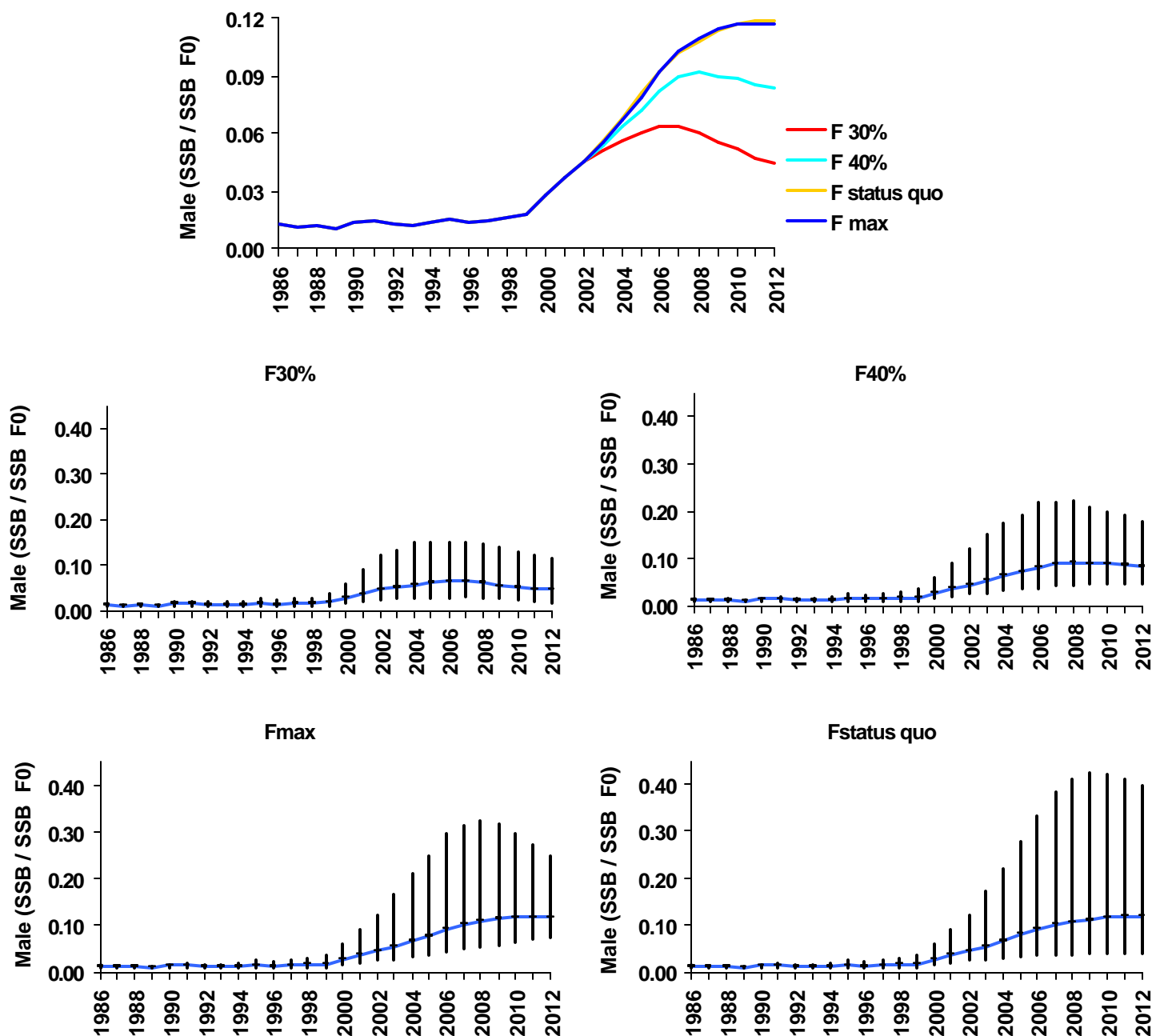


Figure 92. Historical and projected male spawning stock biomass (SSB) relative to male SSB in the unfished condition (median and the empirical 80% confidence interval) from bootstrapped VPA using the ALK+ catch-at-age with year-variable index selectivity and average recruitment above the minimum 1986-1999 spawning stock size. Projections assume fishing in 2002-2012 at  $F_{30\%}$ ,  $F_{40\%}$ ,  $F_{\max}$ , and  $F_{\text{status quo}}$ .

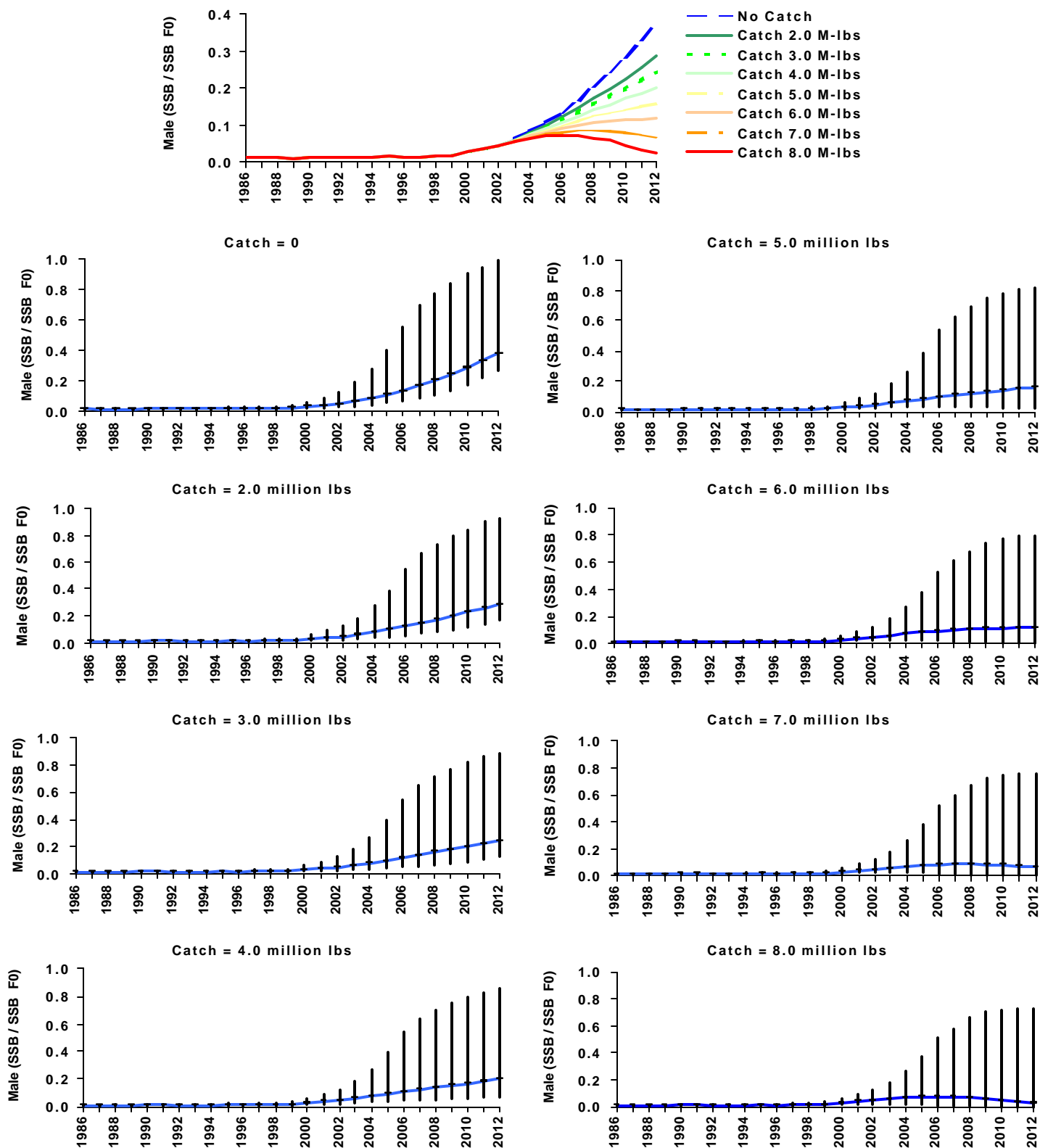


Figure 93. Historical and projected male spawning stock biomass (SSB) relative to male SSB in the unfished condition (median and the empirical 80% confidence interval) from bootstrapped VPA using the ALK+ catch-at-age with year-variable indexselectivity and average recruitment above the minimum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

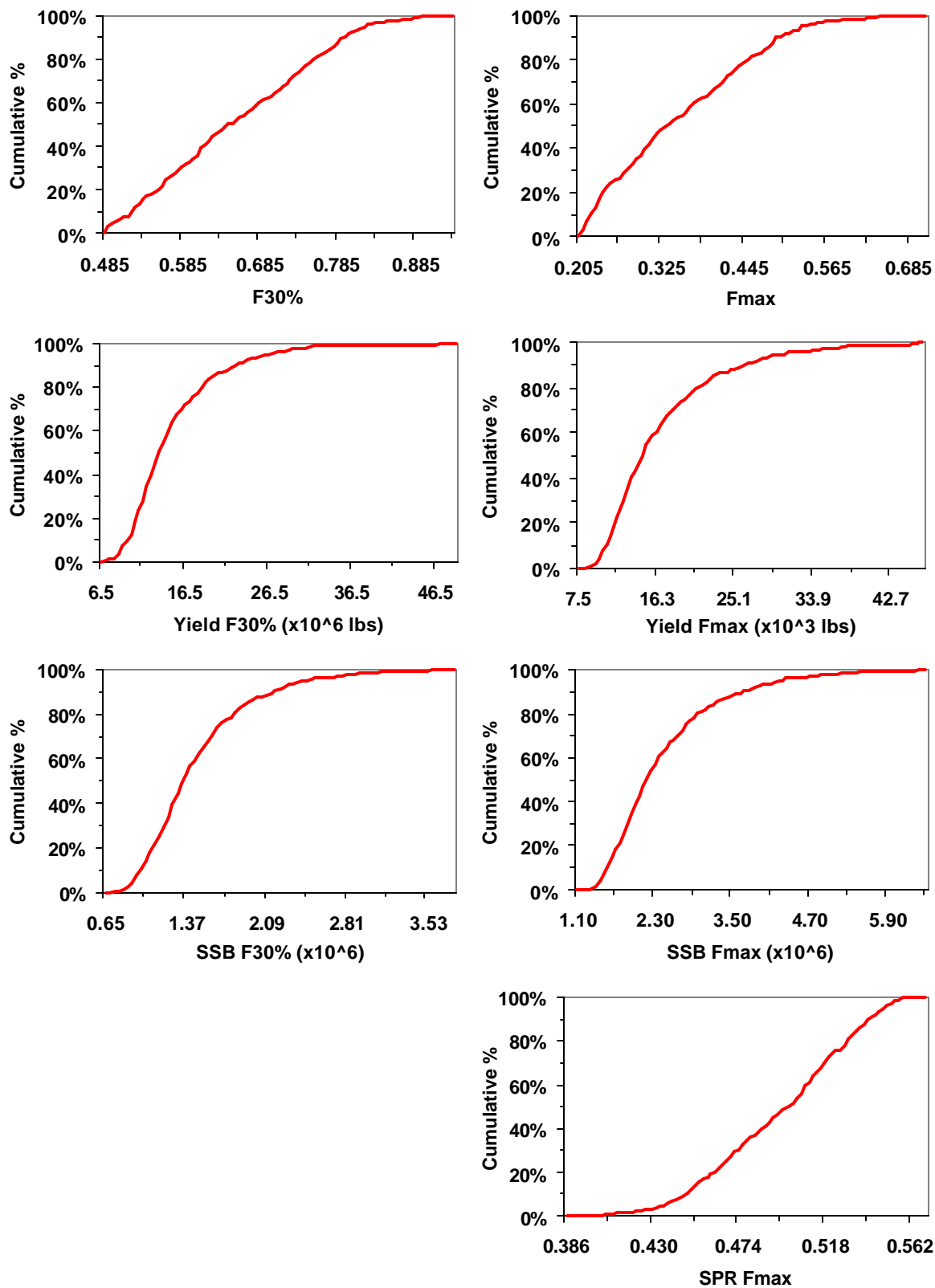
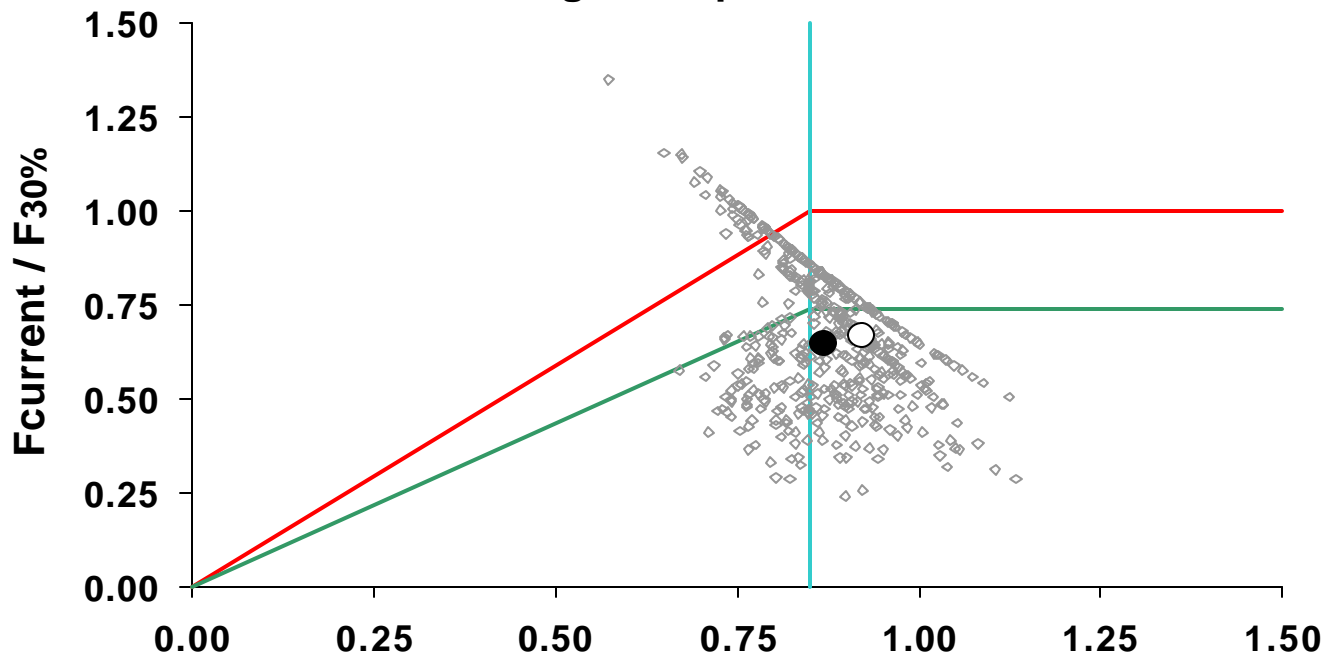


Figure 94. Cumulative frequency distributions for various reference statistics from bootstrapped estimates from the sensitivity VPA using the ALK+ catch-at-age with year-constant index selectivity and recruitment increasing to the maximum 1986-1999 spawning stock size.

## Gag Grouper Phase Plots



## bias-corrected points

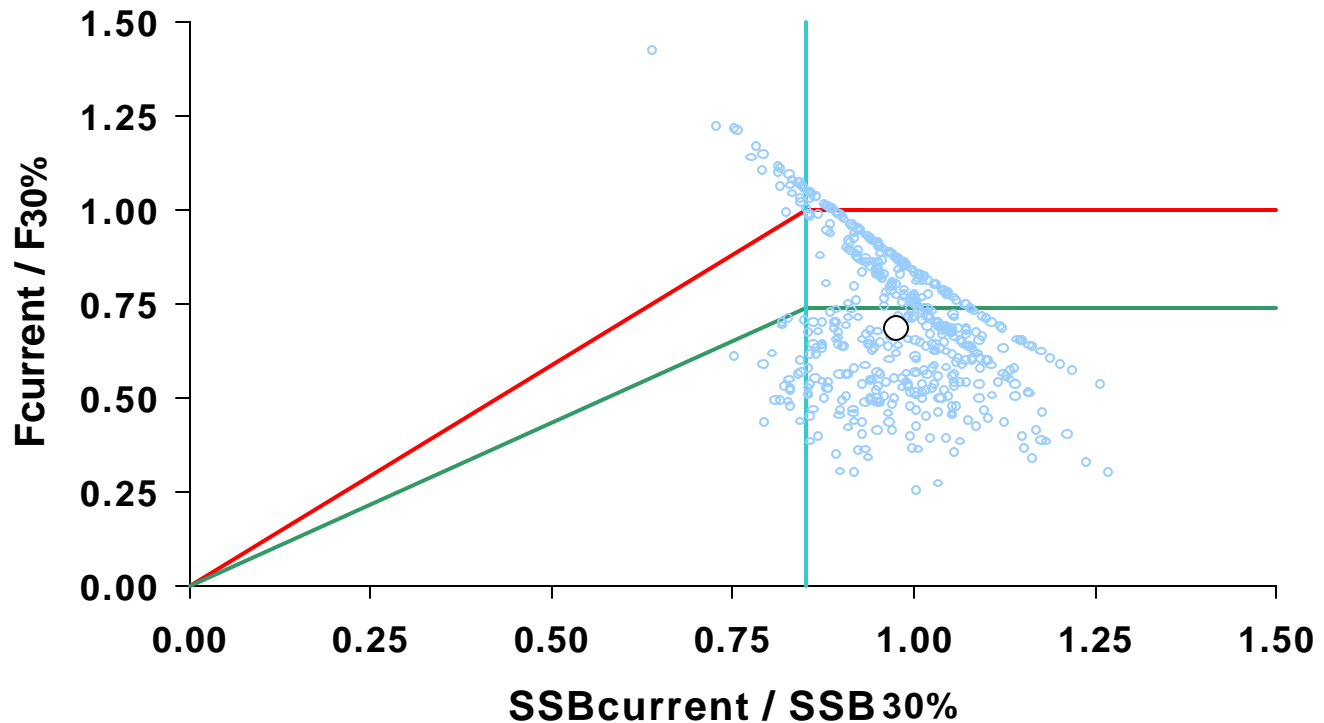
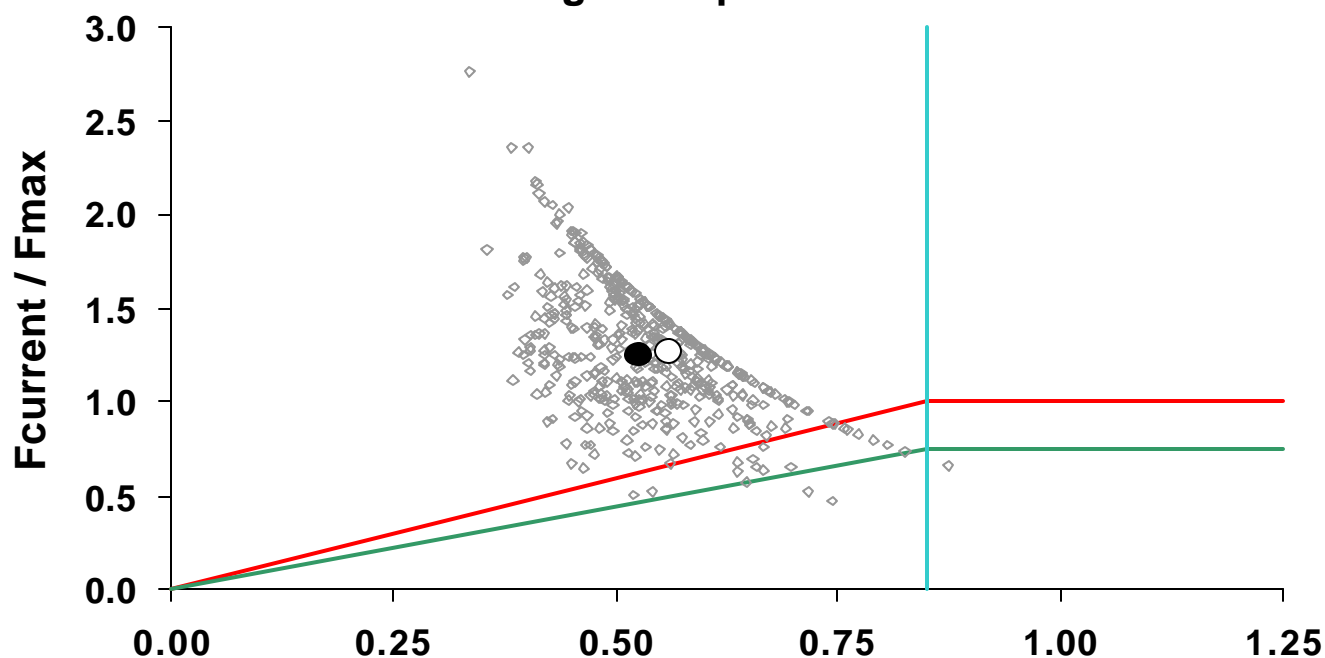


Figure 95. Individual bootstrap estimates of spawning stock biomass (SSB) and fishing mortality rate (F) relative to  $SSB_{30\%}$  and  $F_{30\%}$ , respectively, from the sensitivity VPA using the ALK+ catch-at-age with year-constant index selectivity and recruitment increasing to the maximum 1986-1999 spawning stock size. The upper panel shows uncorrected results, with the median of the bootstraps (black oval) and the deterministic estimate (white oval). The lower panel shows the bias corrected individual bootstrap and deterministic estimates.

## Gag Grouper Phase Plots



## bias-corrected points

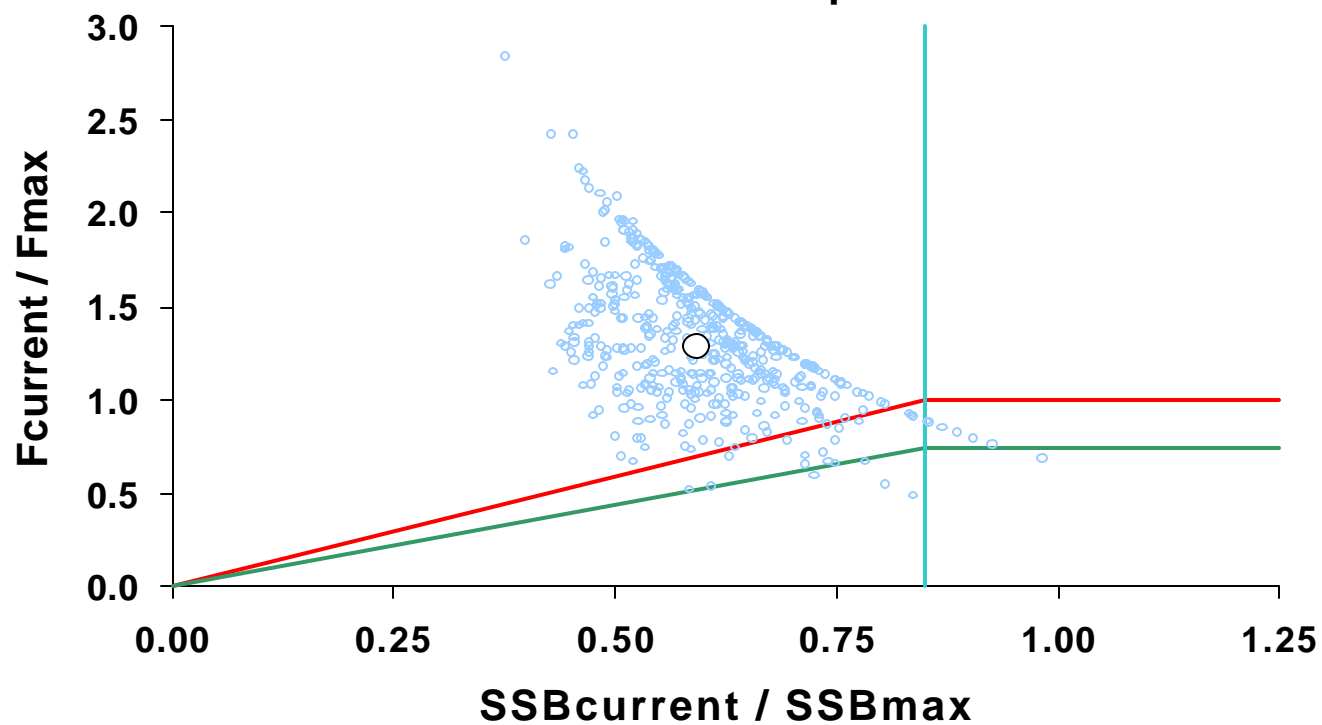


Figure 96. Individual bootstrap estimates of spawning stock biomass (SSB) and fishing mortality rate ( $F$ ) relative to SSB and  $F$  at  $F_{\max}$  from the sensitivity VPA using the ALK+ catch-at-age with year-constant index selectivity and recruitment increasing to the maximum 1986-1999 spawning stock size. The upper panel shows uncorrected results, with the median of the bootstraps (black oval) and the deterministic estimate (white oval). The lower panel shows the bias corrected individual bootstrap and deterministic estimates.



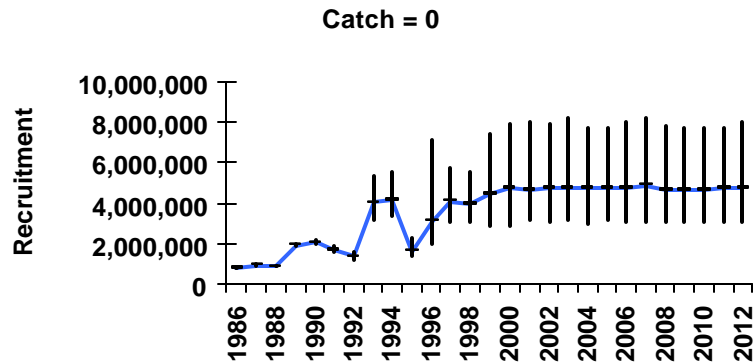


Figure 97. Historical and projected recruitment (median and the empirical 80% confidence interval) from bootstrapped sensitivity VPA using the ALK+ catch-at-age with year-constant index selectivity and recruitment increasing to the maximum 1986-1999 spawning stock size. Projections assume no catch after 2001.

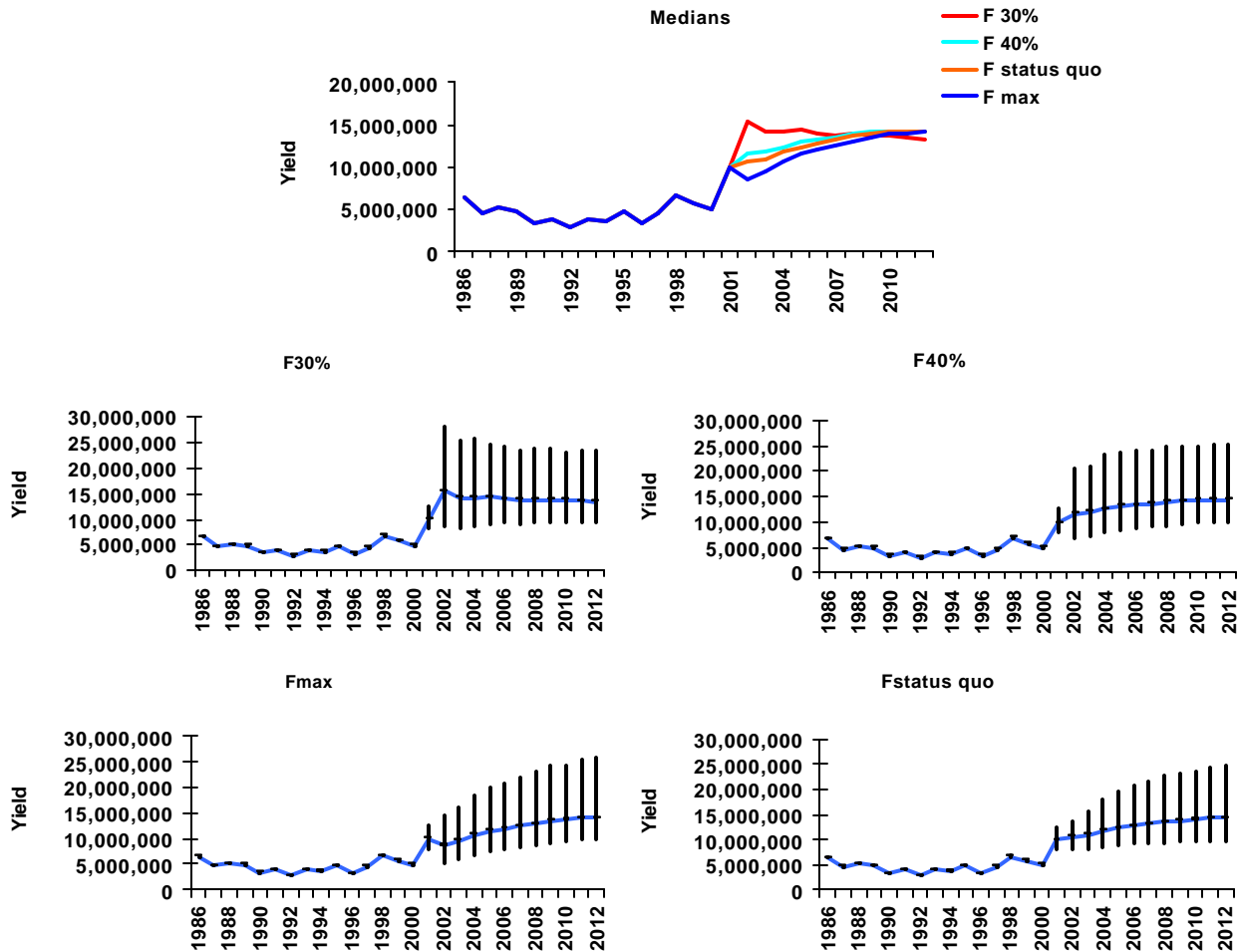


Figure 98. Historical and projected yield (median and the empirical 80% confidence interval) from bootstrapped sensitivity VPA using the ALK+ catch-at-age with year-constant index selectivity and recruitment increasing to the maximum 1986-1999 spawning stock size. Projections assume fishing in 2002-2012 at  $F_{30\%}$ ,  $F_{40\%}$ ,  $F_{\max}$ , and  $F_{\text{status quo}}$ .

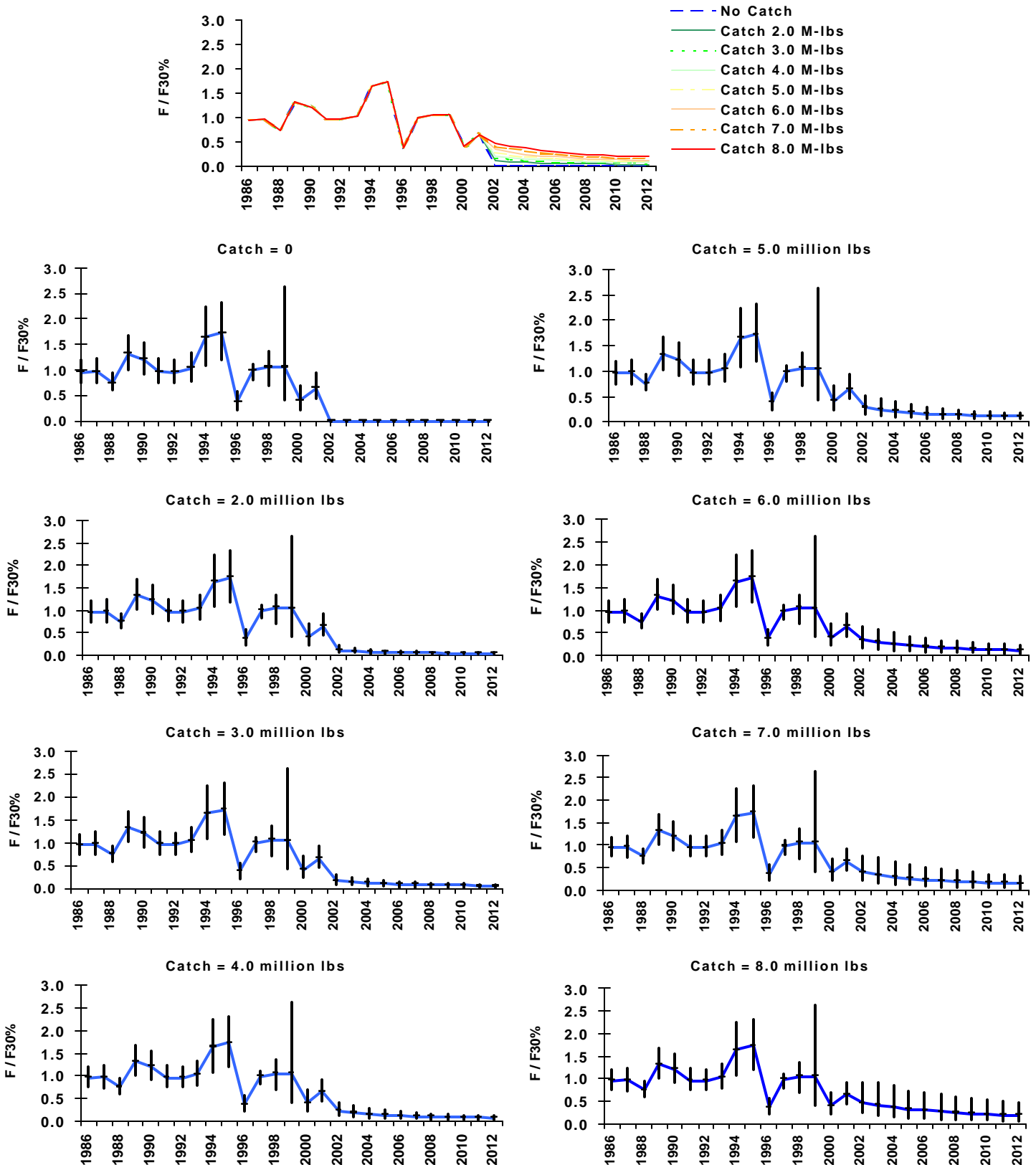


Figure 99. Historical and projected fishing mortality rate (F) relative to  $F_{30\%}$  (median and the empirical 80% confidence interval) from bootstrapped sensitivity VPA using the ALK+ catch-at-age with year-constant index selectivity and recruitment increasing to the maximum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

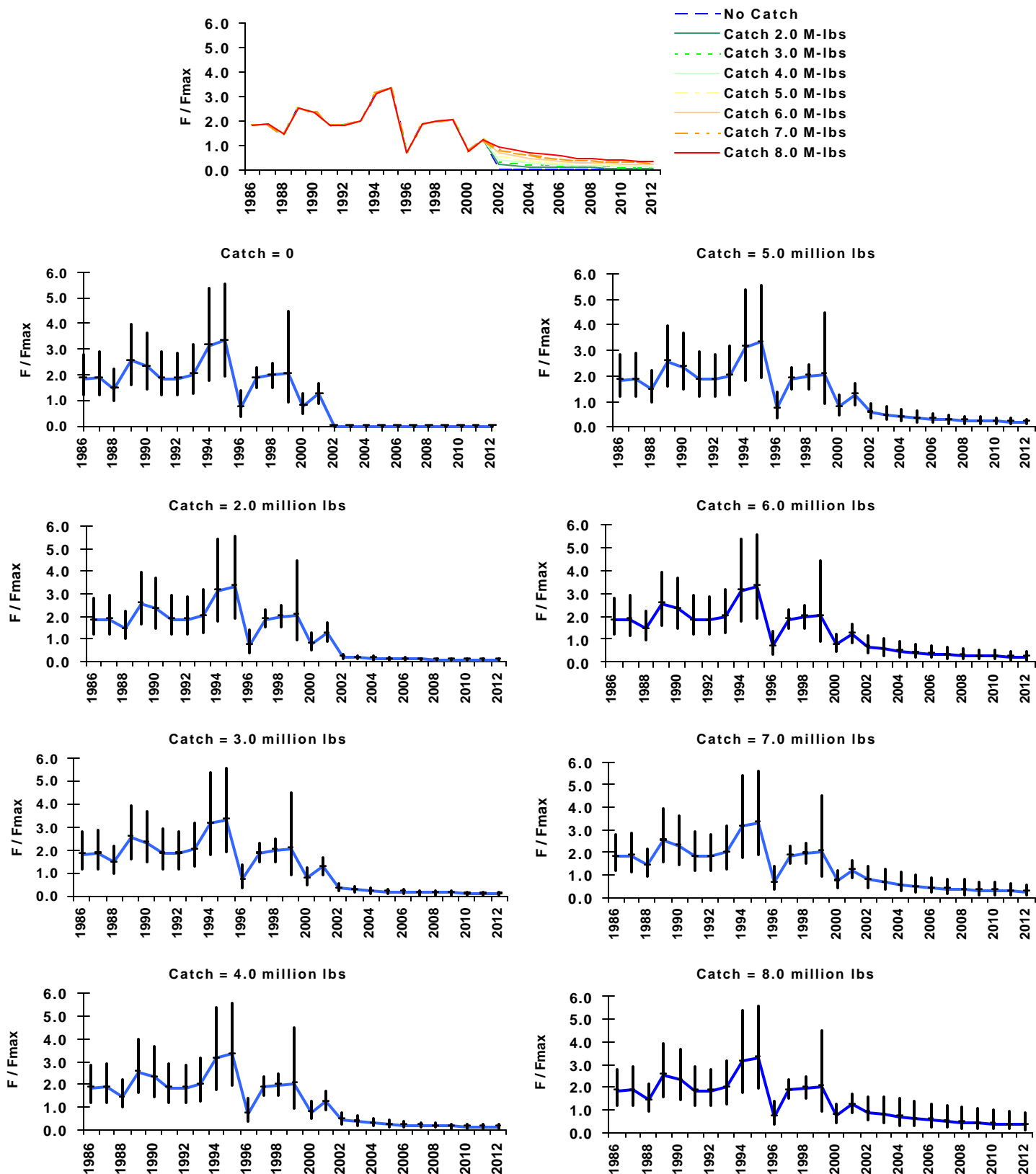


Figure 100. Historical and projected fishing mortality rate ( $F$ ) relative to  $F_{\max}$  (median and the empirical 80% confidence interval) from bootstrapped sensitivity VPA using the ALK+ catch-at-age with year-constant index selectivity and recruitment increasing to the maximum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

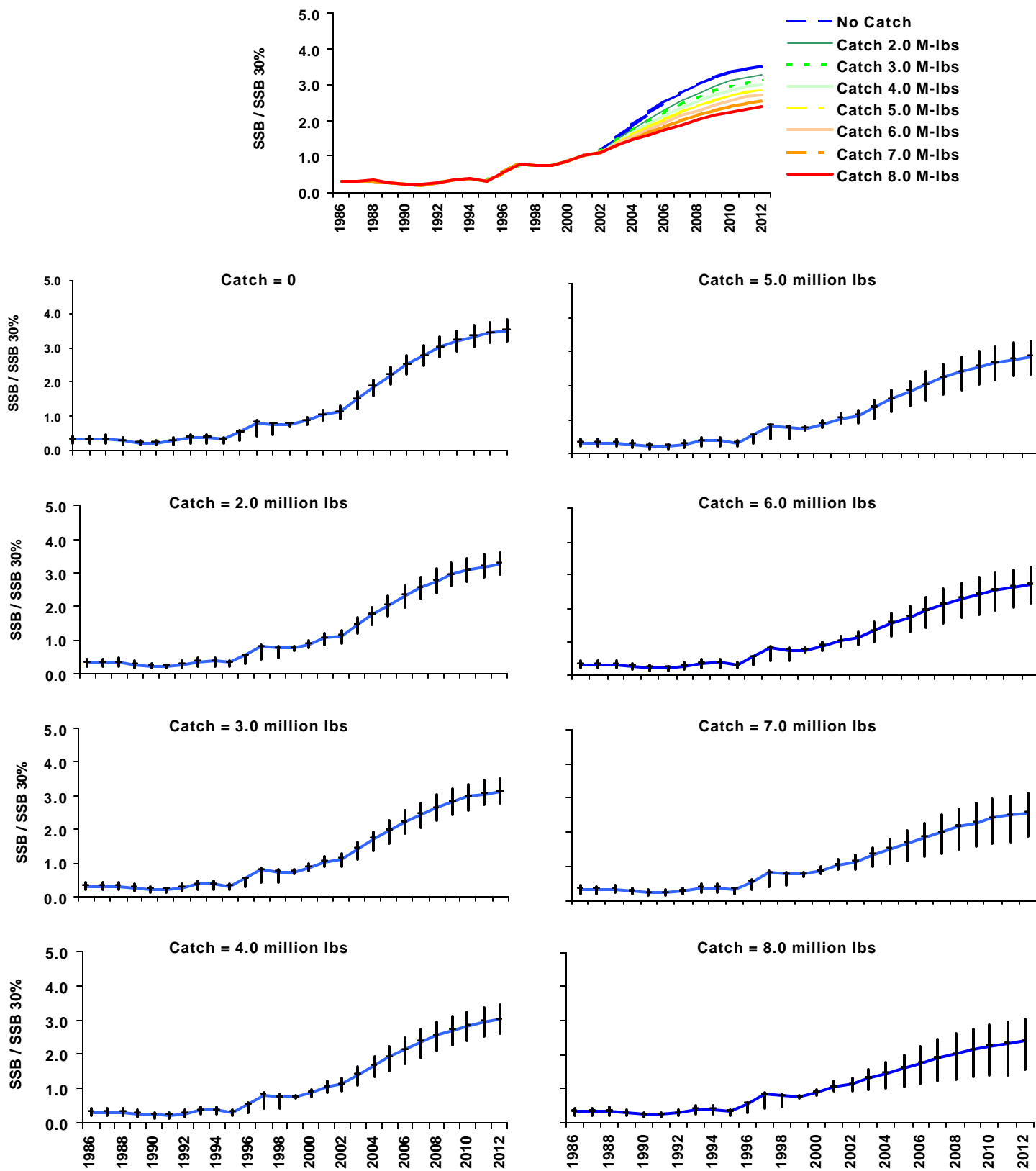


Figure 101. Historical and projected spawning stock biomass (SSB) relative to  $SSB_{30\%}$  (median and the empirical 80% confidence interval) from bootstrapped sensitivity VPA using the ALK+ catch-at-age with year-constant index selectivity and recruitment increasing to the maximum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

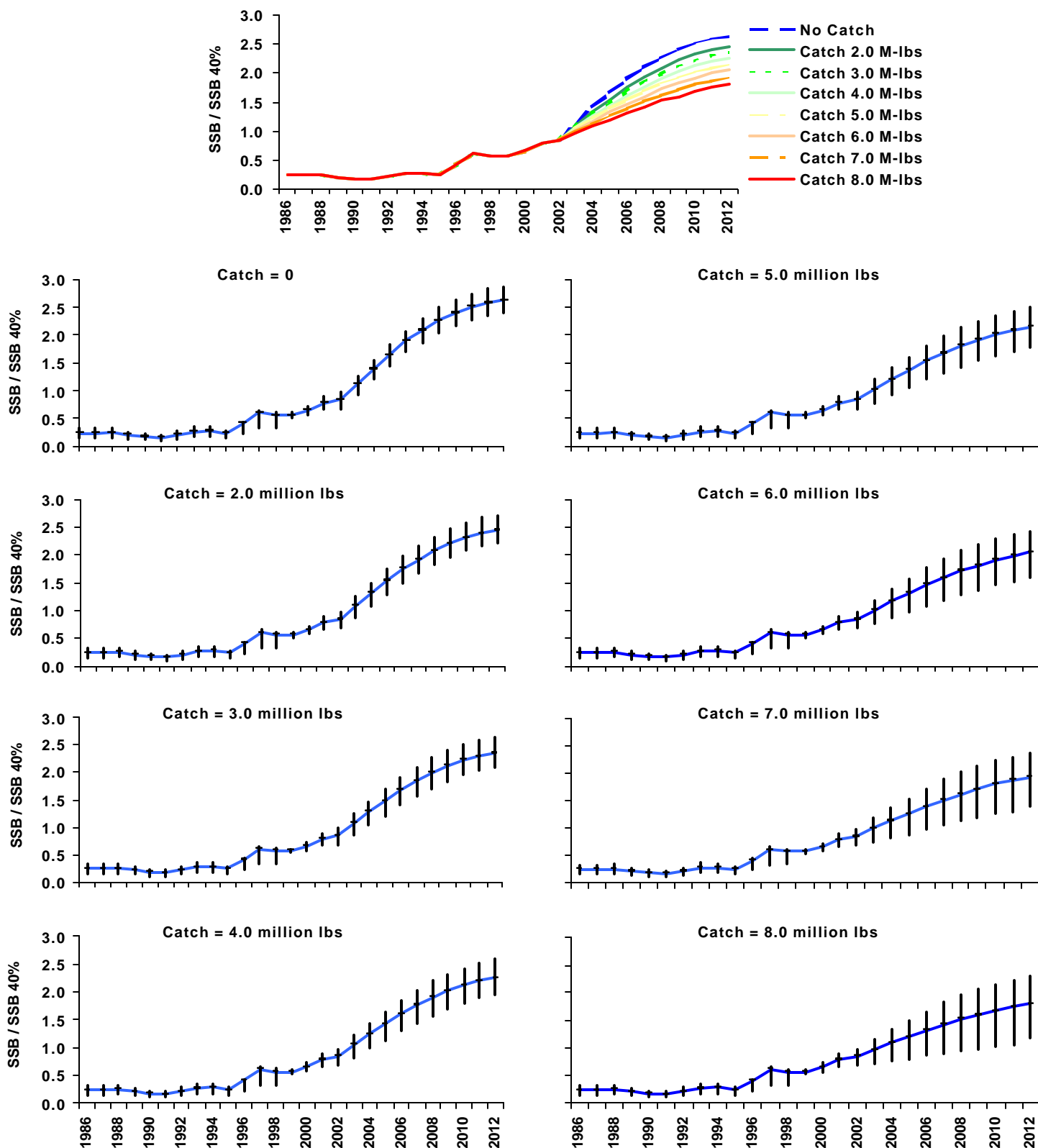


Figure 102. Historical and projected spawning stock biomass (SSB) relative to  $SSB_{40\%}$  (median and the empirical 80% confidence interval) from bootstrapped sensitivity VPA using the ALK+ catch-at-age with year-constant index selectivity and recruitment increasing to the maximum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

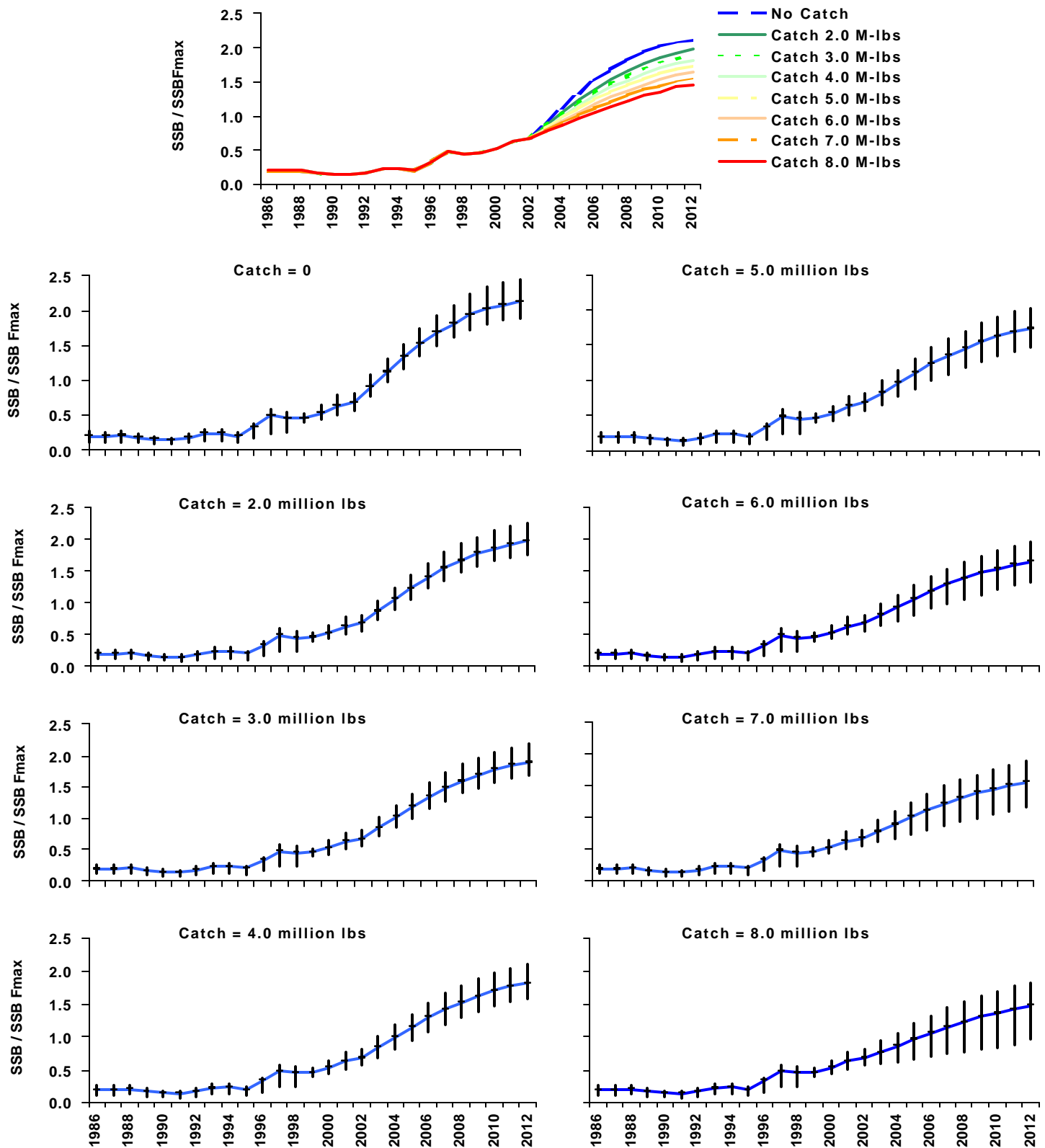


Figure 103. Historical and projected spawning stock biomass (SSB) relative to SSB at  $F_{max}$  (median and the empirical 80% confidence interval) from bootstrapped sensitivity VPA using the ALK+ catch-at-age with year-constant index selectivity and recruitment increasing to the maximum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

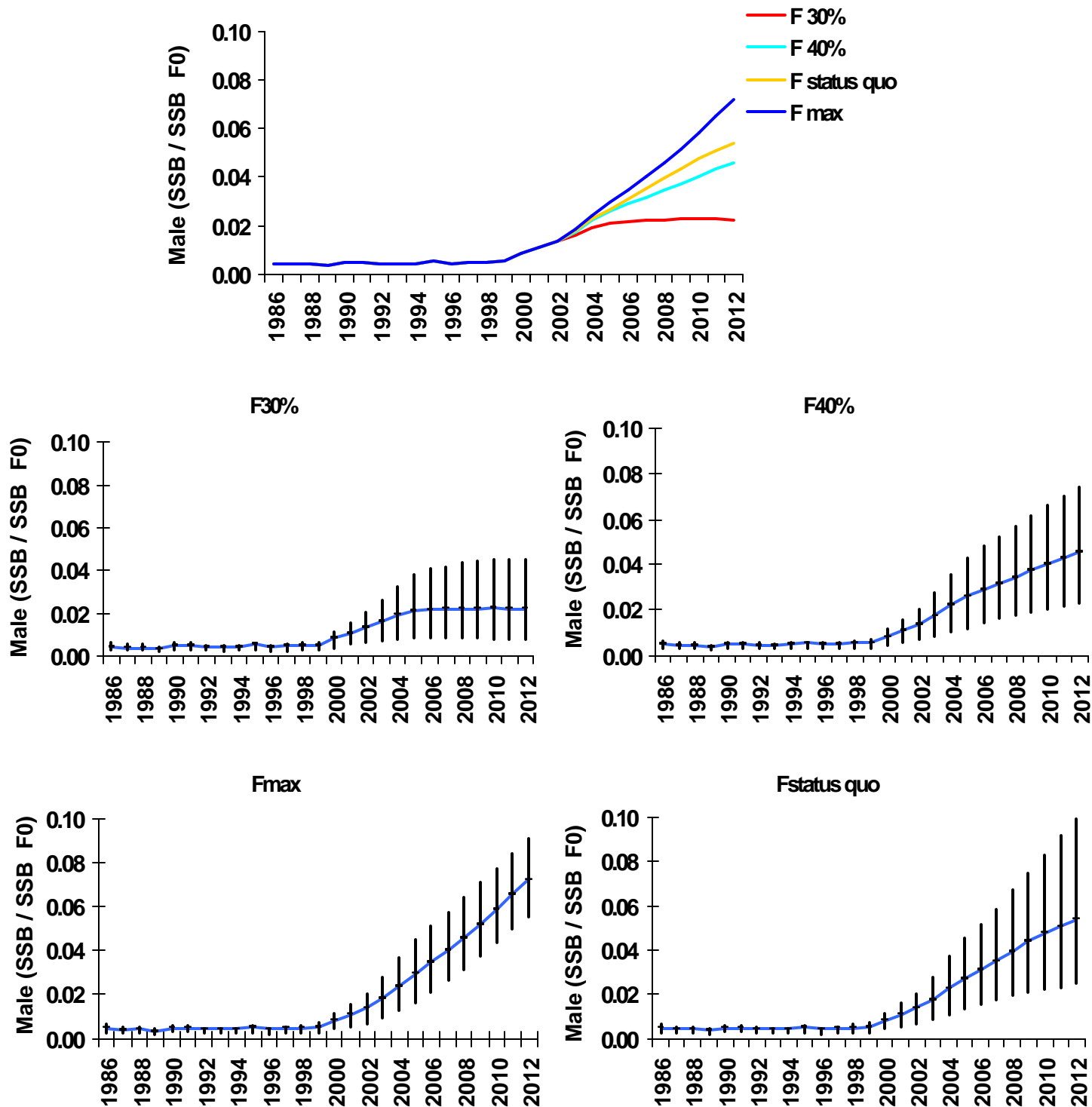


Figure 104. Historical and projected male spawning stock biomass (SSB) relative to male SSB in the unfished condition (median and the empirical 80% confidence interval) from bootstrapped sensitivity VPA using the ALK+ catch-at-age with year-constant index selectivity and recruitment increasing to the maximum 1986-1999 spawning stock size. Projections assume fishing in 2002-2012 at  $F_{30\%}$ ,  $F_{40\%}$ ,  $F_{\max}$ , and  $F_{\text{status quo}}$ .

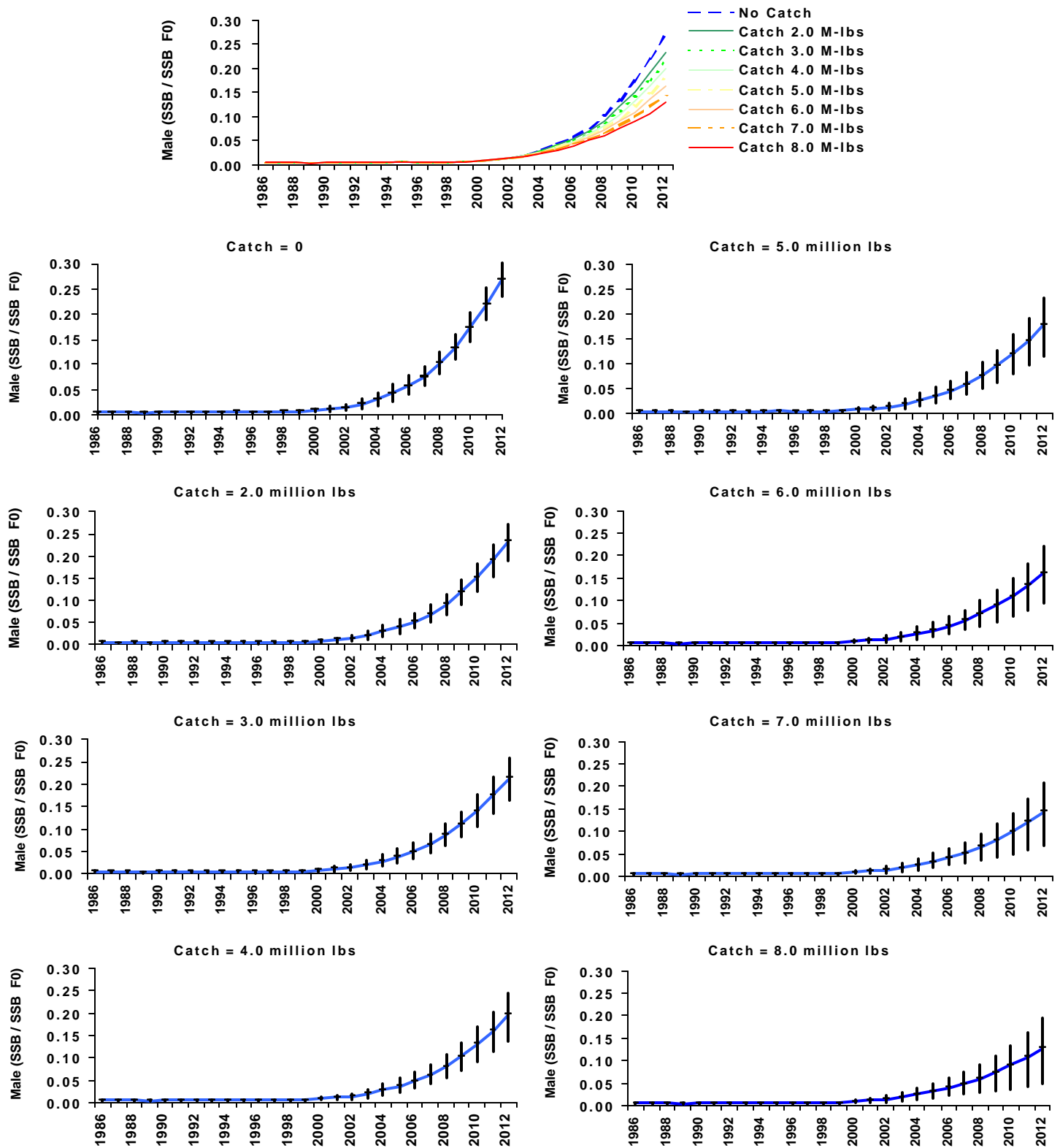


Figure 105. Historical and projected male spawning stock biomass (SSB) relative to male SSB in the unfished condition (median and the empirical 80% confidence interval) from bootstrapped sensitivity VPA using the ALK+ catch-at-age with year-constant index selectivity and recruitment increasing to the maximum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.



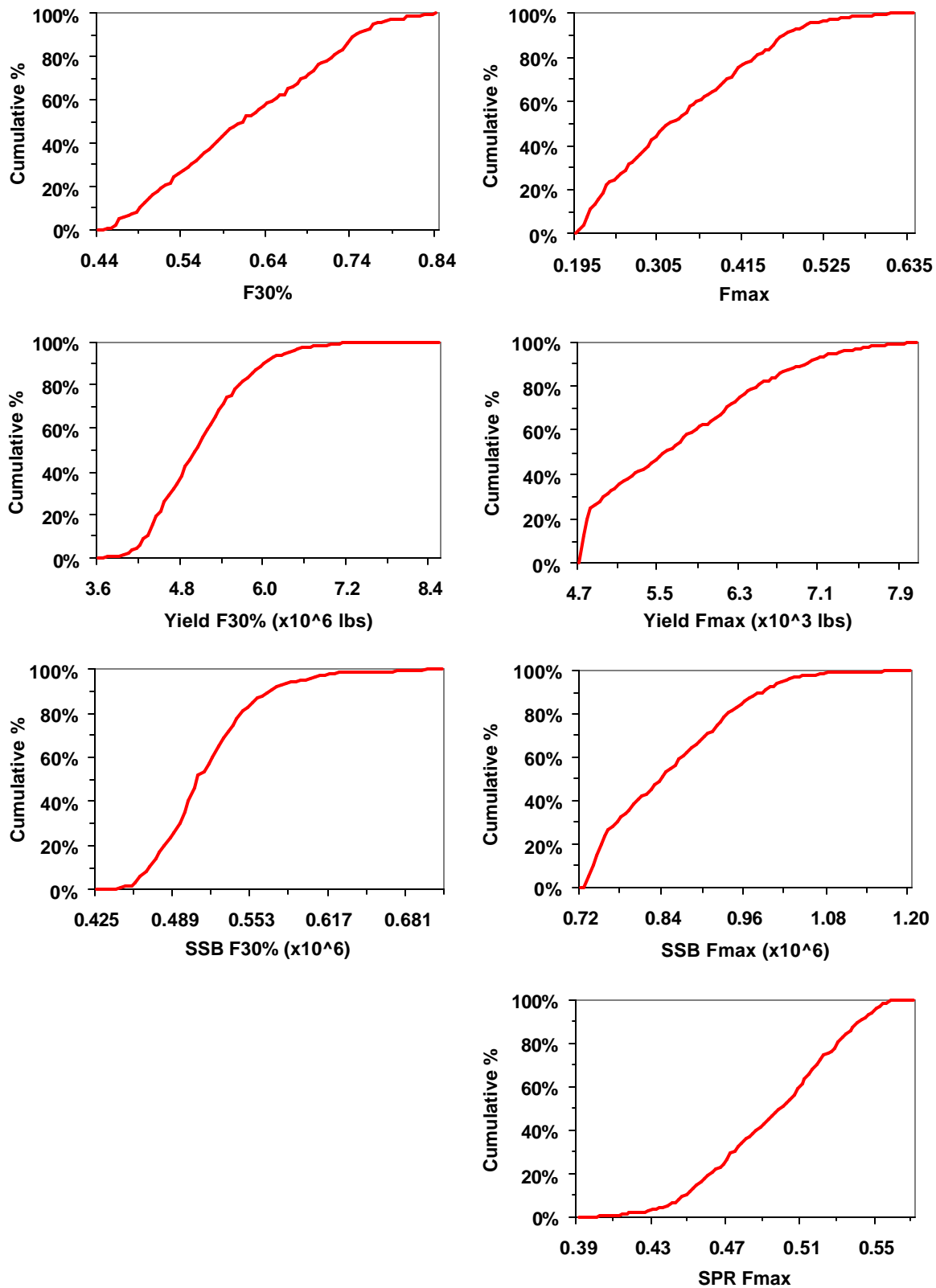
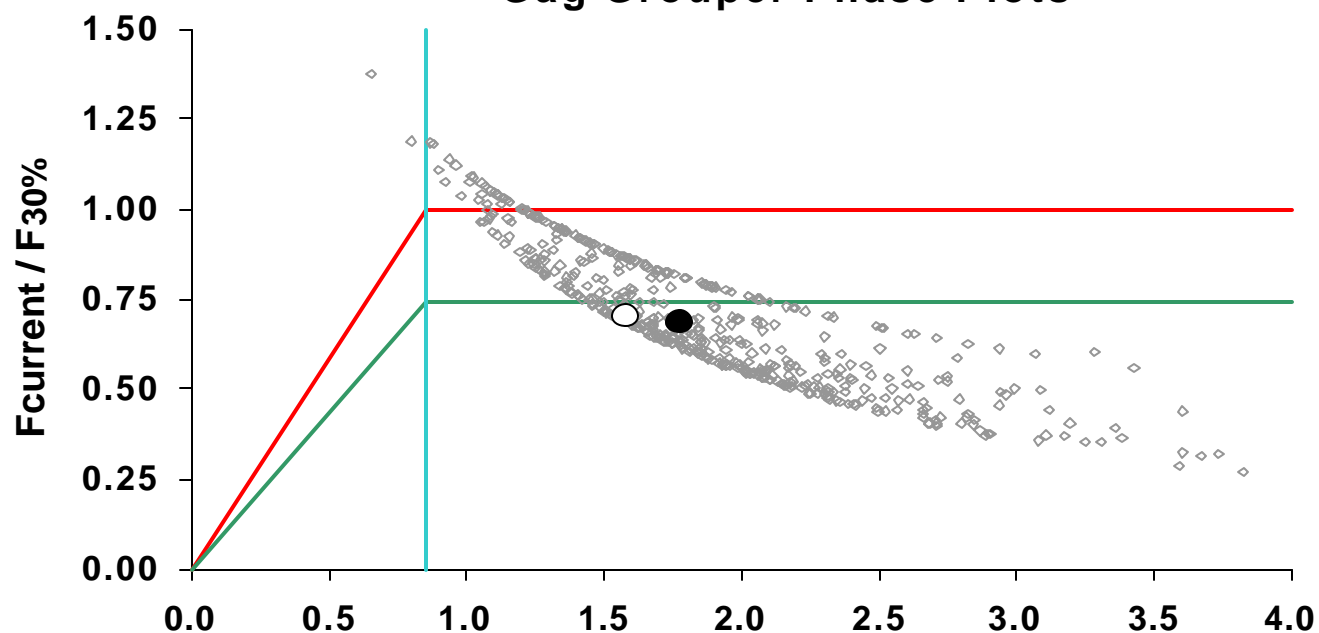


Figure 106. Cumulative frequency distributions for various reference statistics from bootstrapped estimates from the sensitivity VPA using the ALK+ catch-at-age with year-constant index selectivity and average recruitment above the minimum 1986-1999 spawning stock size.

## Gag Grouper Phase Plots



## bias-corrected points

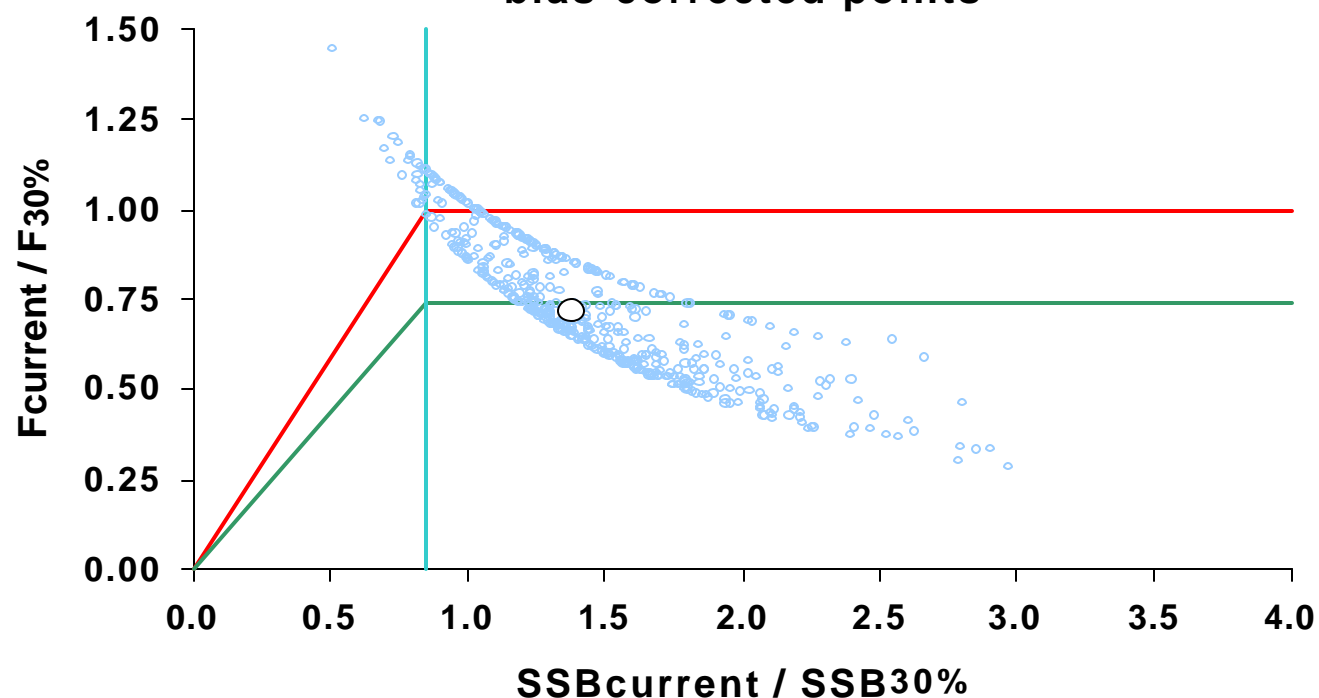


Figure 107. Individual bootstrap estimates of spawning stock biomass (SSB) and fishing mortality rate (F) relative to  $SSB_{30\%}$  and  $F_{30\%}$ , respectively, from the sensitivity VPA using the ALK+ catch-at-age with year-constant index selectivity and average recruitment above the minimum 1986-1999 spawning stock size. The upper panel shows uncorrected results, with the median of the bootstraps (black oval) and the deterministic estimate (white oval). The lower panel shows the bias corrected individual bootstrap and deterministic estimates.

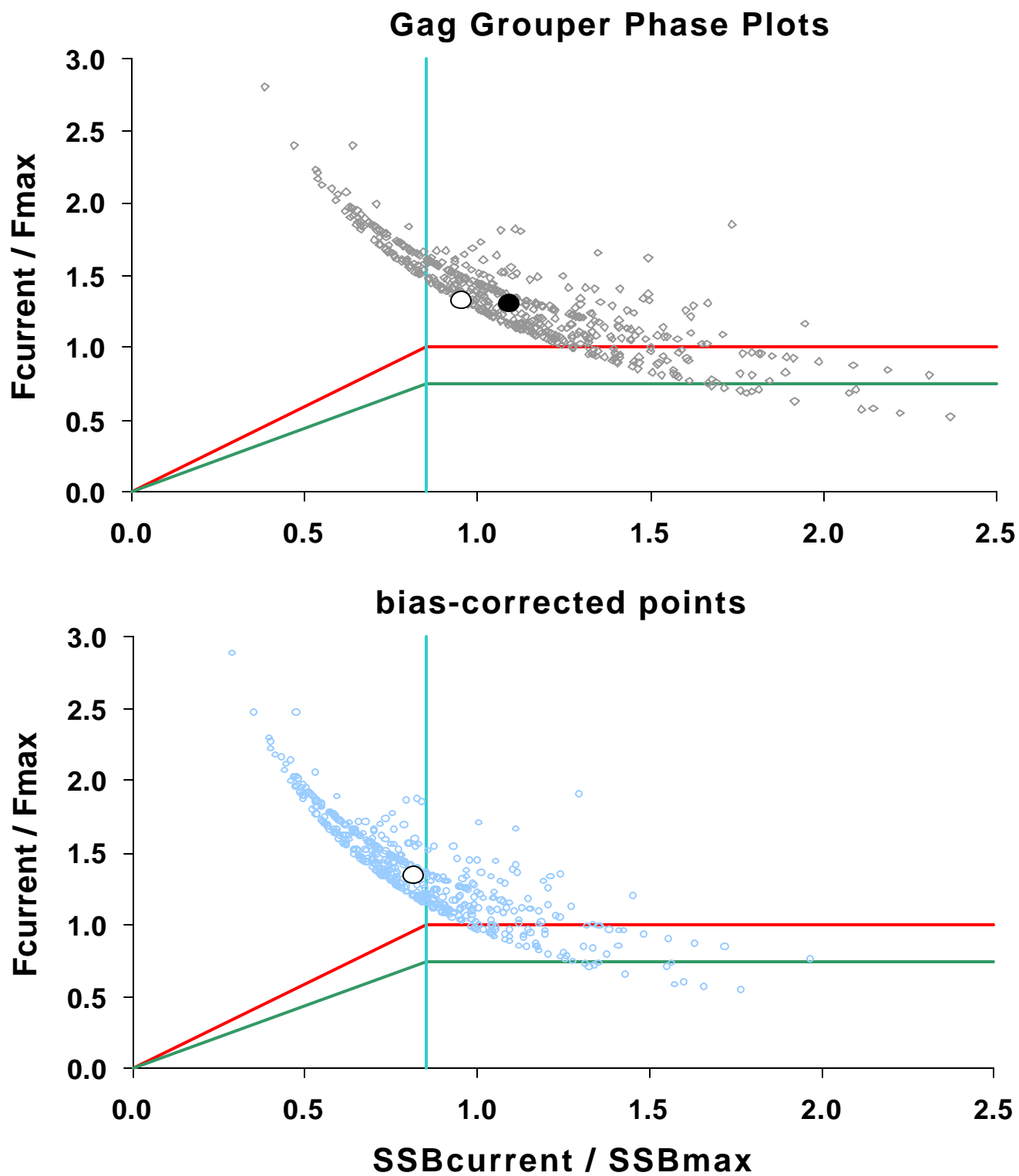


Figure 108. Individual bootstrap estimates of spawning stock biomass (SSB) and fishing mortality rate ( $F$ ) relative to SSB and  $F$  at  $F_{\max}$  from the sensitivity VPA using the ALK+ catch-at-age with year-constant index selectivity and average recruitment above the minimum 1986-1999 spawning stock size. The upper panel shows uncorrected results, with the median of the bootstraps (black oval) and the deterministic estimate (white oval). The lower panel shows the bias corrected individual bootstrap and deterministic estimates.

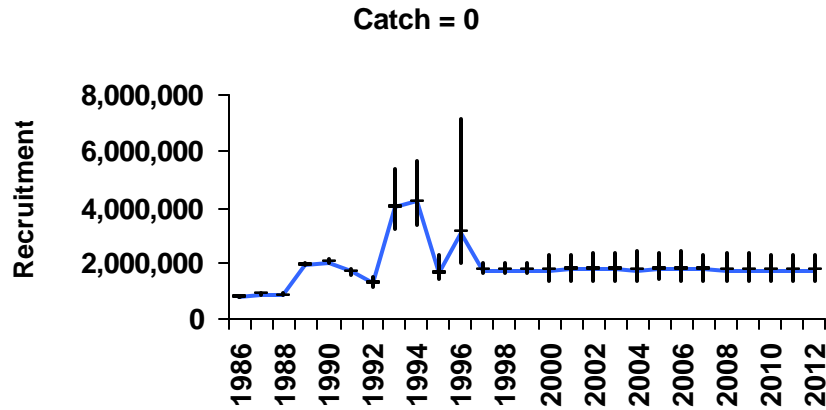


Figure 109. Historical and projected recruitment (median and the empirical 80% confidence interval) from bootstrapped sensitivity VPA using the ALK+ catch-at-age with year-constant index selectivity and average recruitment above the minimum 1986-1999 spawning stock size. Projections assume no catch after 2001.

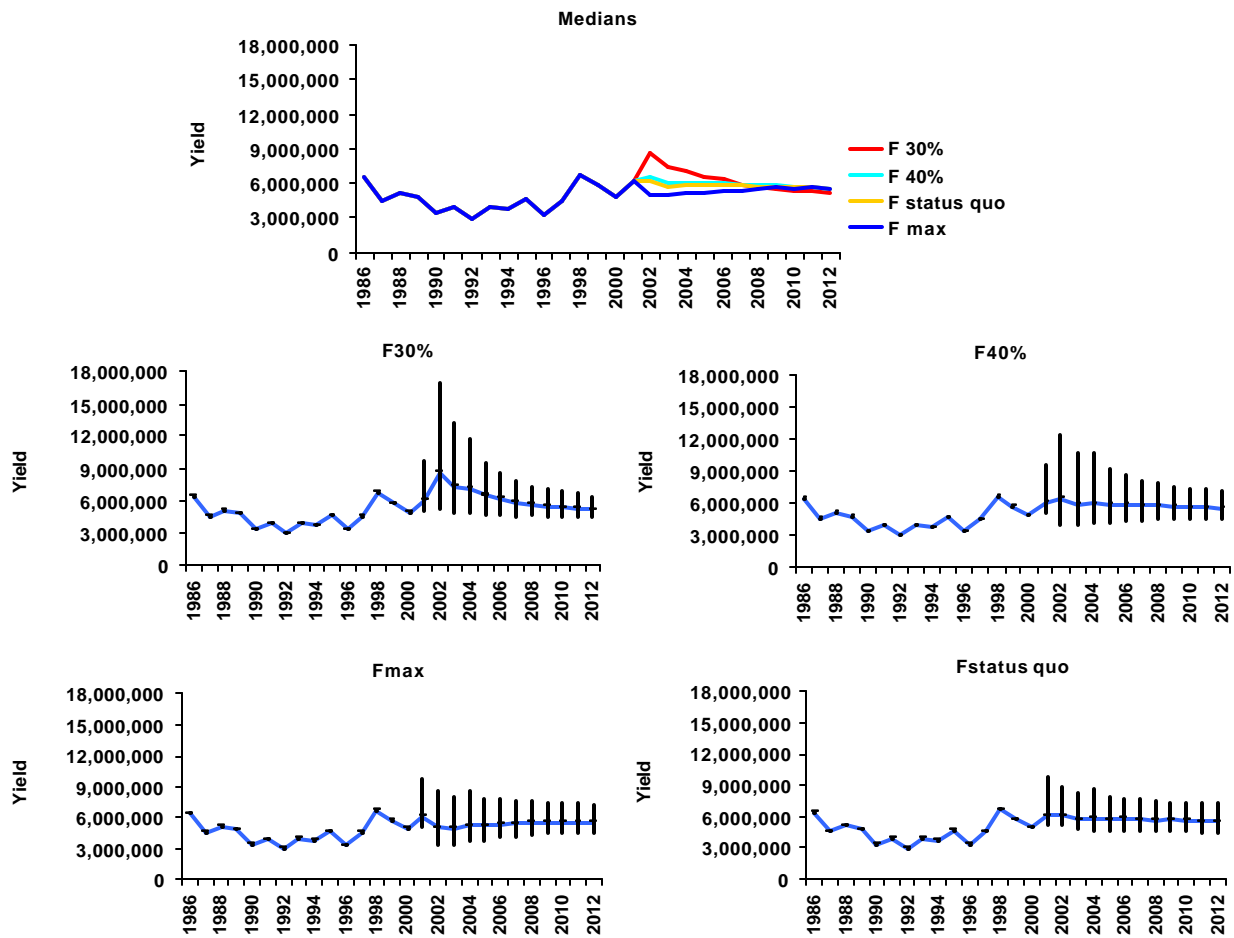


Figure 110. Historical and projected yield (median and the empirical 80% confidence interval) from bootstrapped sensitivity VPA using the ALK+ catch-at-age with year-constant index selectivity and average recruitment above the minimum 1986-1999 spawning stock size. Projections assume fishing in 2002-2012 at  $F_{30\%}$ ,  $F_{40\%}$ ,  $F_{\max}$ , and  $F_{\text{status quo}}$ .

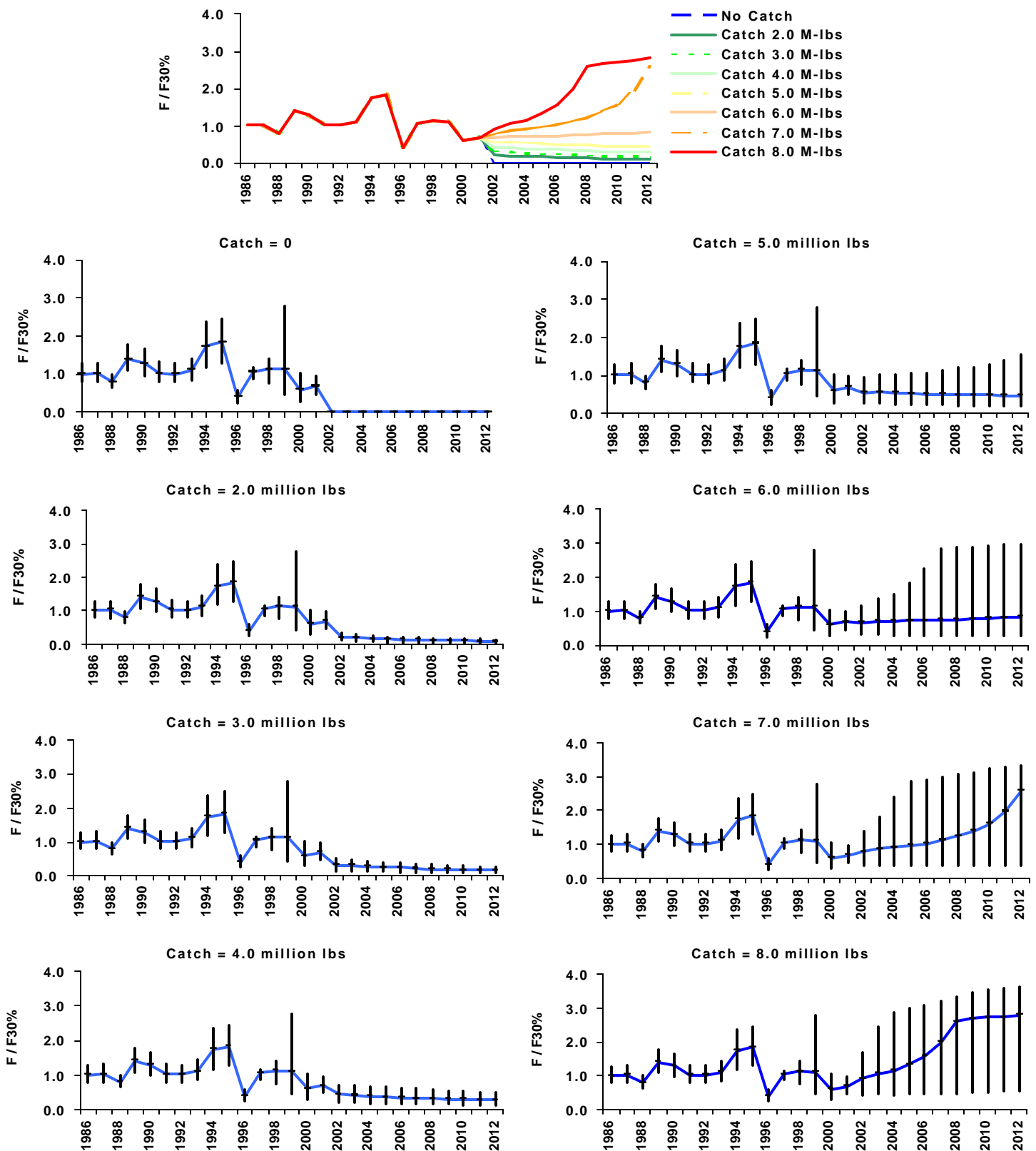


Figure 111. Historical and projected fishing mortality rate (F) relative to  $F_{30\%}$  (median and the empirical 80% confidence interval) from bootstrapped sensitivity VPA using the ALK+ catch-at-age with year-constant index selectivity and average recruitment above the minimum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

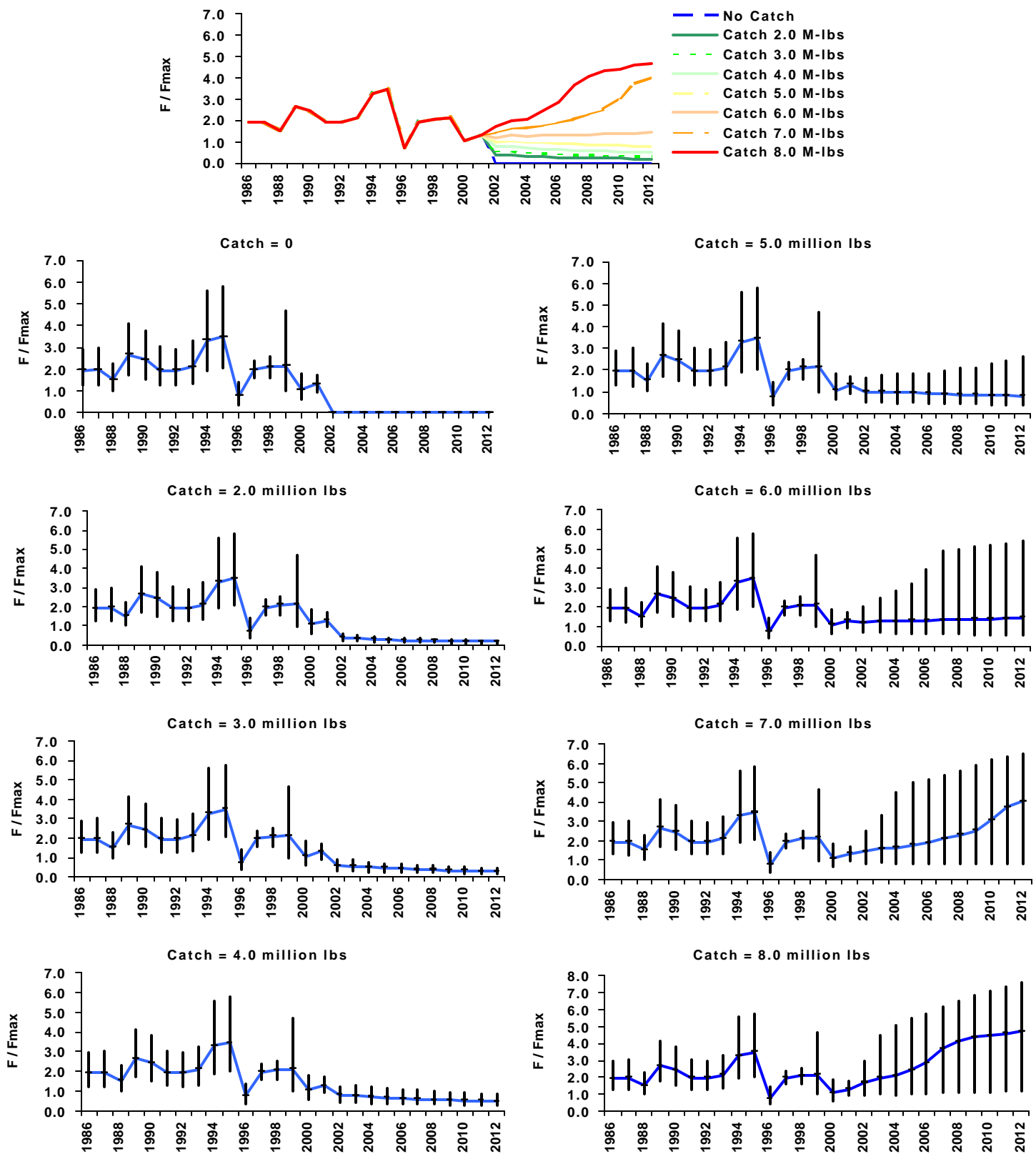


Figure 112. Historical and projected fishing mortality rate ( $F$ ) relative to  $F_{\max}$  (median and the empirical 80% confidence interval) from bootstrapped sensitivity VPA using the ALK+ catch-at-age with year-constant index selectivity and average recruitment above the minimum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

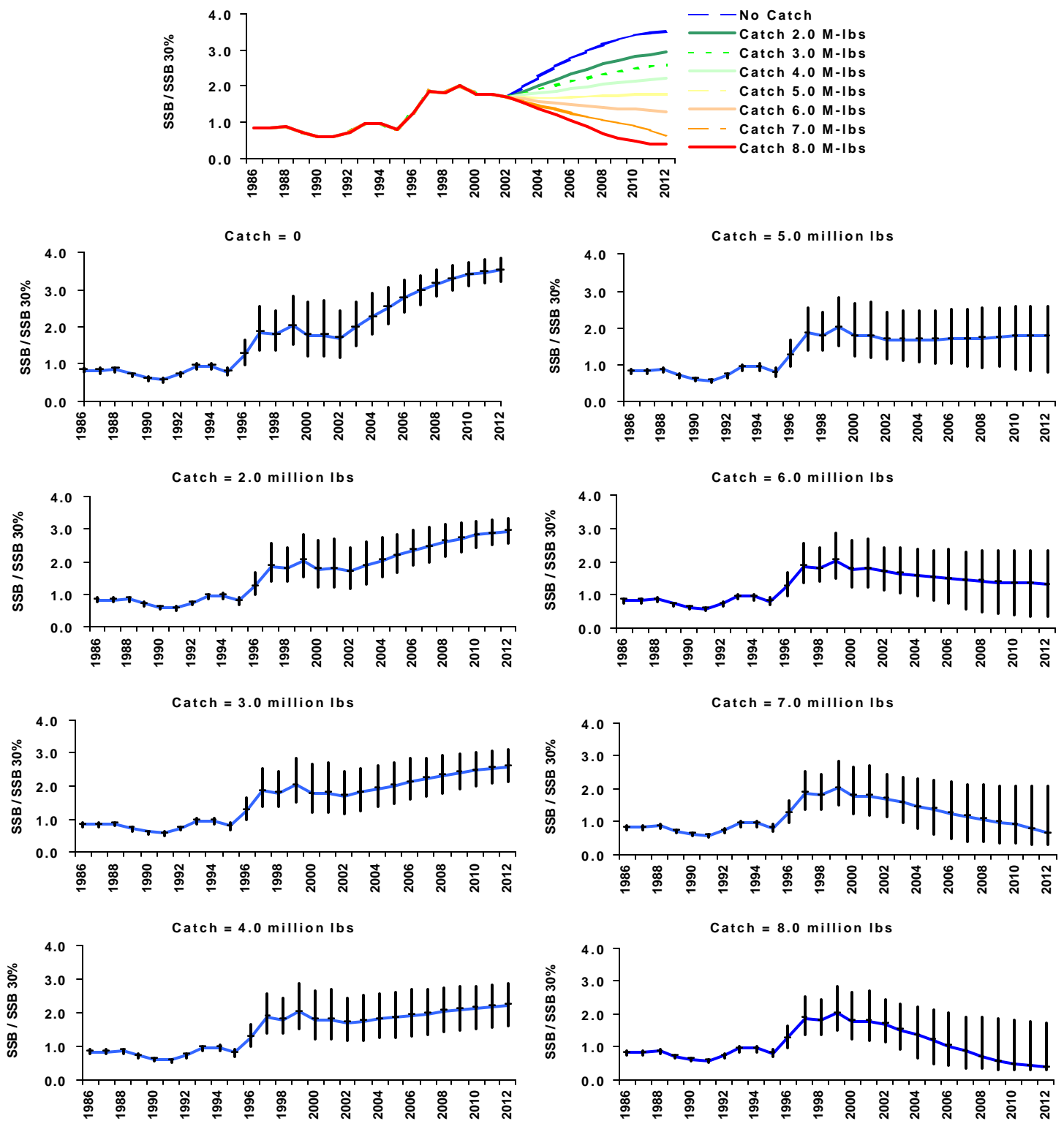


Figure 113. Historical and projected spawning stock biomass (SSB) relative to  $SSB_{30\%}$  (median and the empirical 80% confidence interval) from bootstrapped sensitivity VPA using the ALK+ catch-at-age with year-constant index selectivity and average recruitment above the minimum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

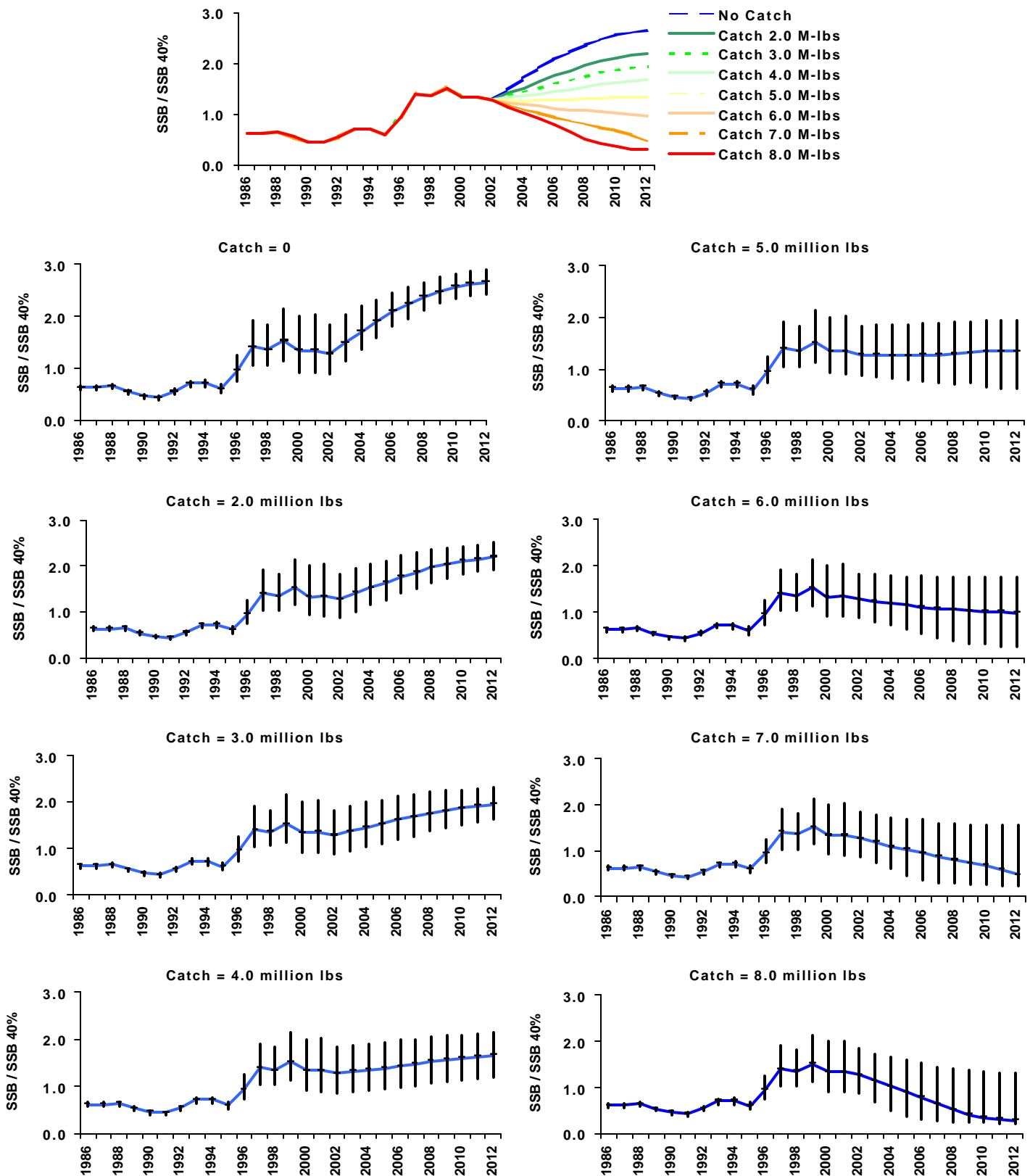


Figure 114. Historical and projected spawning stock biomass (SSB) relative to  $SSB_{40\%}$  (median and the empirical 80% confidence interval) from bootstrapped sensitivity VPA using the ALK+ catch-at-age with year-constant index selectivity and average recruitment above the minimum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012



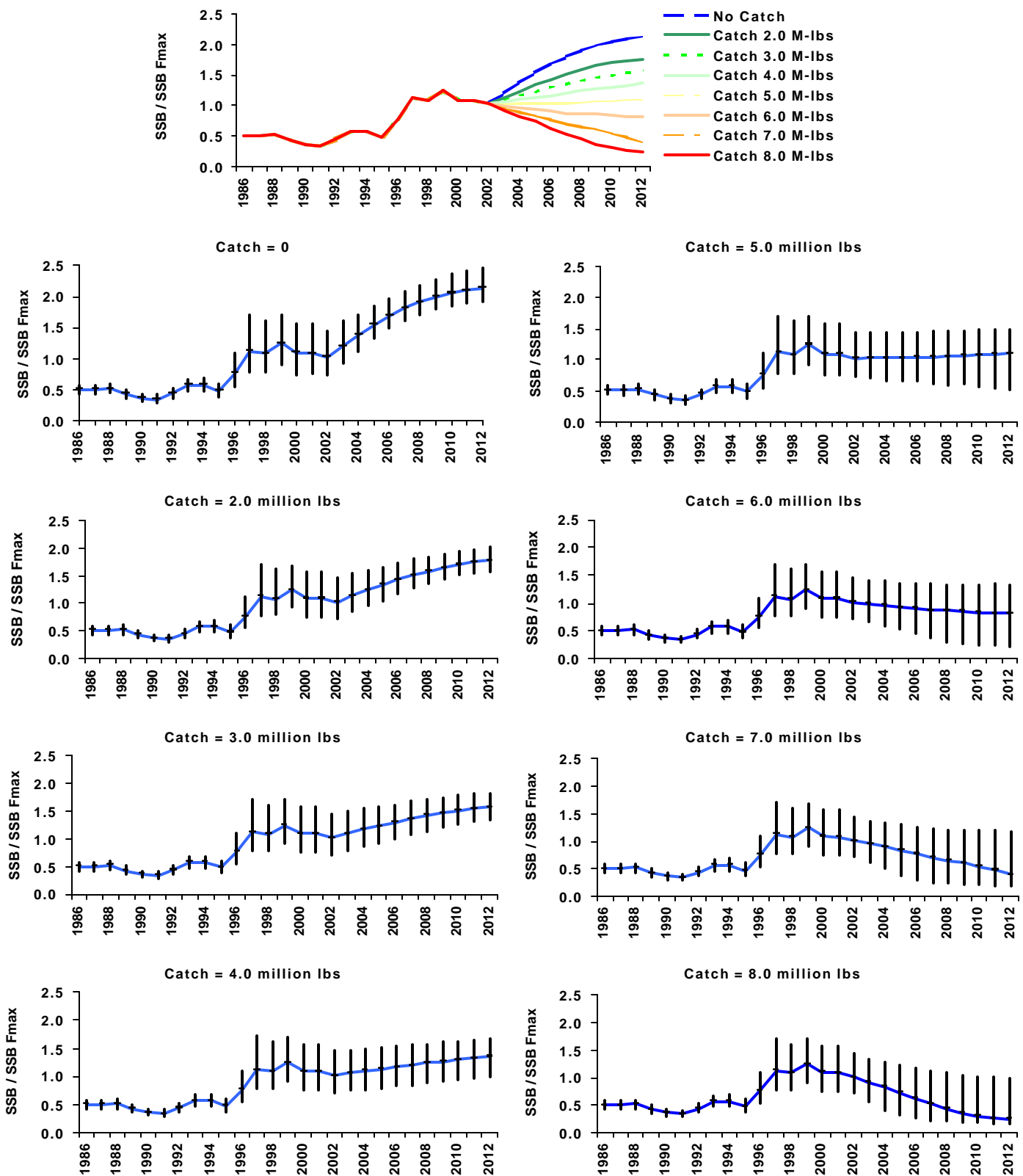


Figure 115. Historical and projected spawning stock biomass (SSB) relative to SSB at  $F_{max}$  (median and the empirical 80% confidence interval) from bootstrapped sensitivity VPA using the ALK+ catch-at-age with year-constant index selectivity and average recruitment above the minimum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012.

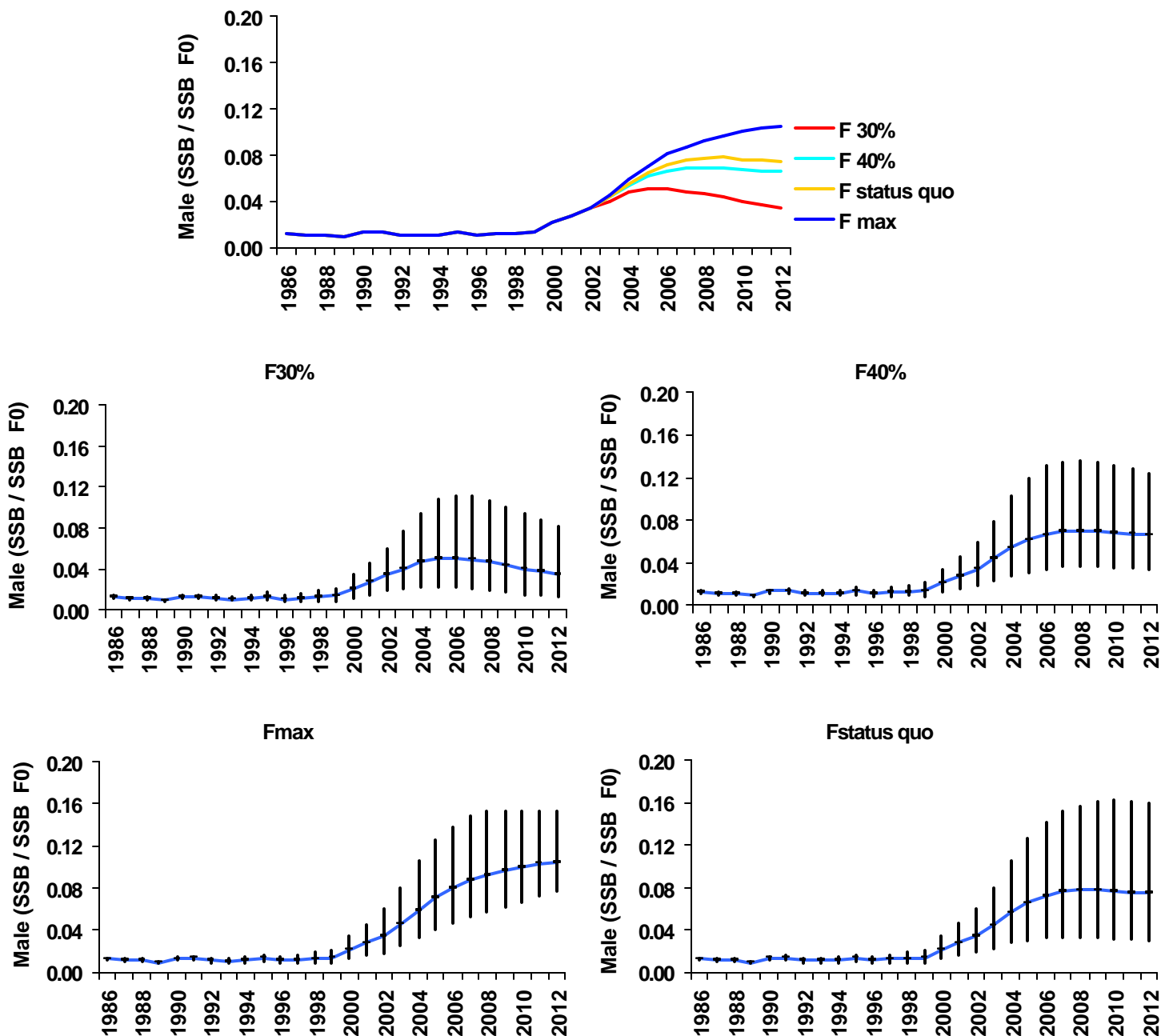


Figure 116. Historical and projected male spawning stock biomass (SSB) relative to male SSB in the unfished condition (median and the empirical 80% confidence interval) from bootstrapped sensitivity VPA using the ALK+ catch-at-age with year-constant index selectivity and average recruitment above the minimum 1986-1999 spawning stock size. Projections assume fishing in 2002-2012 at  $F_{30\%}$ ,  $F_{40\%}$ ,  $F_{\max}$ , and  $F_{\text{status quo}}$ .

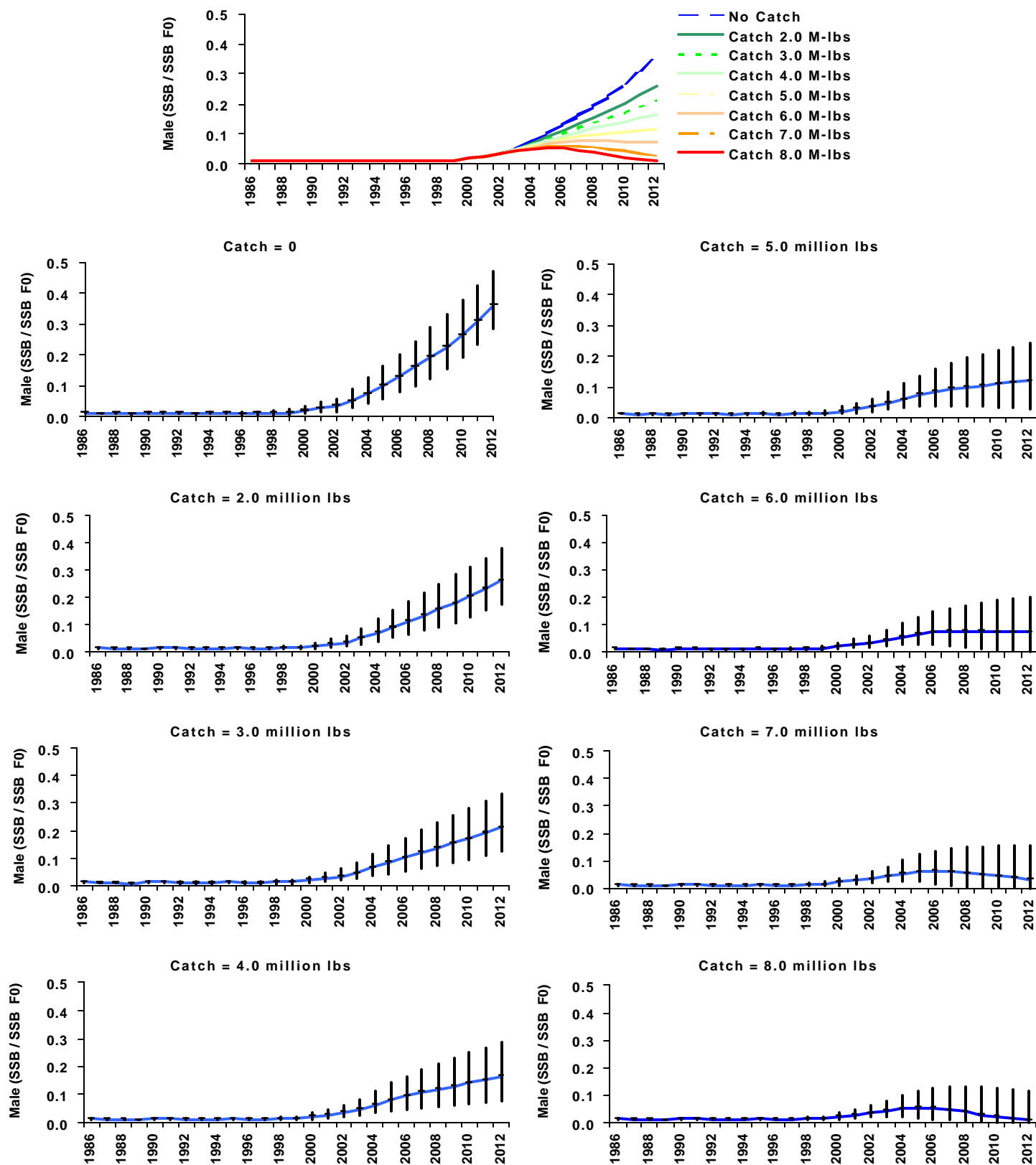


Figure 117. Historical and projected male spawning stock biomass (SSB) relative to male SSB in the unfished condition (median and the empirical 80% confidence interval) from bootstrapped sensitivity VPA using the ALK+ catch-at-age with year-constant index selectivity and average recruitment above the minimum 1986-1999 spawning stock size. Projections assume no catch or landings of 2 to 8 million pounds per year in 2002-2012

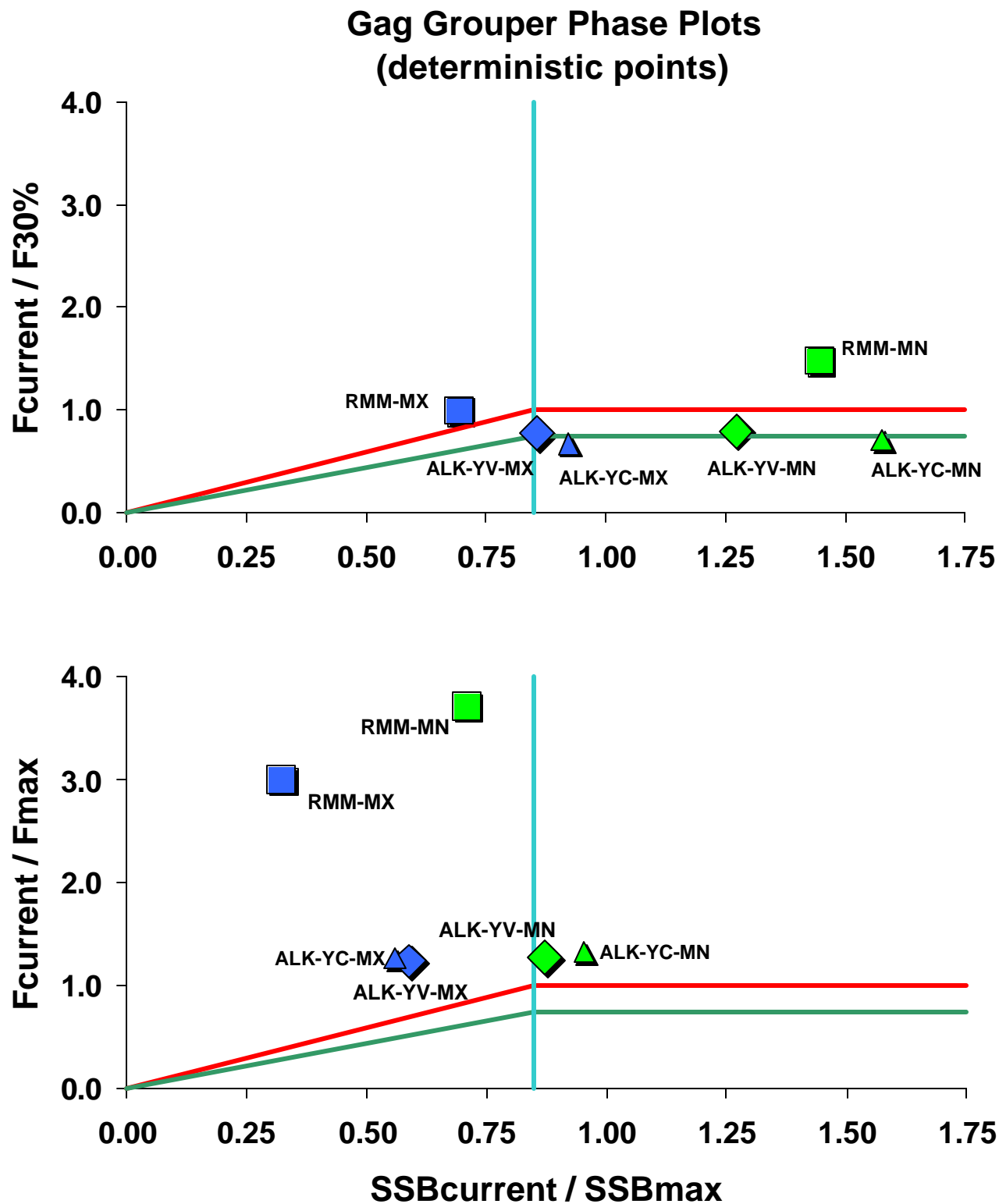


Figure 118. Deterministic estimates (not bias corrected) of current stock size and fishing mortality rate relative to reference statistics.

## Gag Grouper Phase Plots (bias-corrected deterministic points)

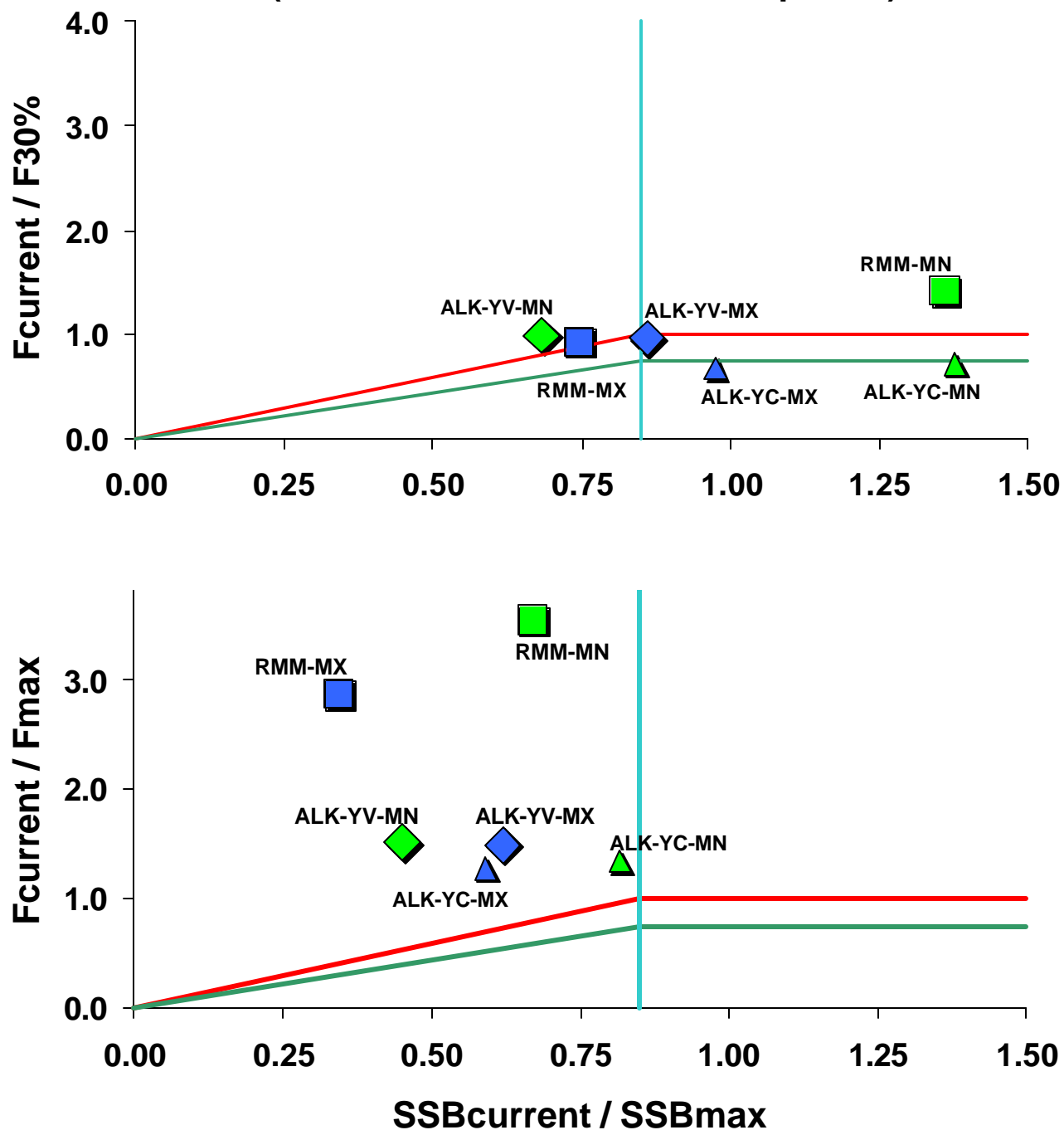


Figure 119. Bias corrected deterministic estimates of current stock size and fishing mortality rate relative to reference statistics.