The 2005 update of the stock assessment for striped mullet, *Mugil cephalus*, in Florida

by

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Executive Summary

- This report updates commercial and recreational fisheries statistics through 2004. The commercial fishery constituted 84% percent of the total landings during 2000-2004. The west coast of Florida contributed to 85% of the total commercial landings during 2000-2004.

- Since the 1995 net-ban, Florida's commercial landings have sharply declined to an annual average of 8.1 million pounds, a 67% reduction if compared to the recent historical (1967-1990) average level of 25 million pounds. The total commercial landings in 2004 were 7.6 million pounds. The number of commercial fishing trips declined from an annual average of 62,345 trips before the net-ban took effect (1986-1994) to 28,785 trips after the net-ban took effect (1995-2004), a total reduction of 54%. Total number of fishing trips in 2004 was 23,768.

- The proportion of the roe-season landings to the total landings increased during the post net-ban period in the southwest region and remained unchanged in the east coast and northwest regions. In the southwest region, the roe season landings in 1999, 2001, and 2002 ranged from 4.0 to 4.4 million lbs, similar to the landings levels observed in 1993 and 1994 (4.6 million lbs in 1993 and 4.2 million pounds in 1994). There has been a substantial decline of the no-roe season landings since the 1995 net-ban on both coasts of Florida.

- Statewide recreational landings of striped mullet have been variable from 1.0 million pounds in 1985 to 5.1 million pounds in 1996. Recreational landings have averaged 1.6 million pounds during 2000-2004.

- Commercial catch rates for striped mullet increased following the elimination of entangling gears in Florida waters on both coasts. This increase probably reflects the increase in the stock size.

- A non-equilibrium, surplus production model indicated that the F/F_{msy} trajectories for the post net-ban period were consistently below 1 with average F/F_{msy} ratios of 0.43 for the east coast region, 0.19 for the NW region, and 0.35 for the SW region, indicating that overfishing of striped mullet stocks was not occurring in these regions in recent years.

- A forward–projecting, statistical catch-at-age model indicated a significant decline in total fishing mortality rate since the 1995 net-ban on both coasts of Florida. The fishing mortality rates in recent years (2001-2004) were below the management target levels ($F_{35\%}$ = 0.69 for the east coast, $F_{35\%}$ = 0.55 for the NW region, and $F_{35\%}$ = 0.64 for the SW region) and they ranged from 0.32 to 0.65 per year on the east coast region, from 0.28 to 0.40 per year on the NW region, and from 0.19 to 0.42 per year on the SW region. The decline in fishing mortality rates since the net-ban has resulted in gradual increase of the spawning stock biomass especially in the NW and SW regions where over 85% of striped mullet were landed. The fishing mortality estimates for the SW region were comparable to the fishing mortality rate of 0.5 per year estimated from the fishery-independent age compositions data collected during the spawning season in Tampa Bay and Charlotte Harbor.

- Current stocks in the east coast, NW, and SW regions appear to be healthy and current levels of fishing effort appear to be sustainable. Future values of fishing mortality rates in the striped mullet fishery are affected by amount of catch, changes in gear selectivity, and stock size and recruitment. Landings trends in the recent years suggest that mullet production has stabilized at about 1.8 million pounds on the east coast region, 2.3 million pounds on the NW region, and 6.5 million pounds on the southwest region. Given current regulations, at these recent landings levels, fishing mortality rates should decline further if recoveries of the mullet stocks continue at the present rate.

1. Introduction

The striped mullet has supported an important inshore fishery in Florida. With development of the roe export market in the early 1980s, demand for ripe female mullet significantly increased. The striped mullet fishery has been increasingly regulated since 1989, and commercial fishing has been severely restricted since1995 by Florida's constitutional amendment eliminating the use of entangling nets in Florida waters. This has caused a rapid decline in landings and fishing effort since 1995, especially on the west coast of Florida.

This report updates the analysis of fishery data and the stock assessment conducted in 2000 (Mahmoudi 2000) and includes additional data from 2000 to 2005. The 2000 stock assessment suggested that the regulatory changes since 1993 and the net-ban in 1995 caused a substantial decline in fishing mortality rates during 1995-1999. During this period, transitional spawning potential ratios (SPR) had increased to 35% indicating that for the first time since the threshold of 35% transitional SPR had been established for the mullet fishery, the stock was not in the overfished condition.

2. Fishery-Dependent Data

Analyses of fishery-dependent data were based on commercial landings data (1978-1984) from the NMFS general canvass, commercial landings and trip data (1985-2005) from the FWC-FWRI's Marine Fisheries Information System (Trip ticket), Trip Information Program (TIP)-bio sampling data (1991-2005), and recreational landings and length composition data (1981-2005) from the NMFS-MRFSS program. Additionally, commercial landings data (1870-1977) were compiled from various sources, including the U.S. Commissioner of Fisheries and Florida State Board of Conservation.

2.1 Commercial Fishery

Striped mullet is one of the most important inshore finfish fisheries in Florida (Table 1). In 2004, commercial landings of striped mullet (7,610,694 million pounds) constituted fourteen percent of total finfish landings (53,521,886 million pounds) and eight percent of total commercial finfish dockside dollar value. The commercial fishery contributes to the majority of striped mullet landings (about 84% percent of the total landings during 2000-2004). Historically, entangling nets (gill nets and trammel nets ranging 600-1,200 yards in length and from 2-1/2 to 4-1/4 inches in stretched-mesh size) and large haul seines (1,000 to 1,200 yards in length) were primarily used in Florida's mullet fishery, but since the 1995 net-ban, cast nets and small seines (limited to 500 square feet in area and a maximum of 2 inches in stretched-mesh size) have been the types of gear most often used in the fishery. Commercial landings were reported from nearly every coastal county. Landings were greater on the west coast, where they averaged about 88% of the statewide landings during 1985-1994 and about 84% during 1995-2004. Most of the striped mullet landings on the west coast of Florida come from the central and southwest portions of the state near Tampa Bay and Charlotte Harbor (about 74% of the Florida west coast landings during 1995-2004). Landings statistics by county showed no significant regional shift during the post net-ban period. Striped mullet are primarily landed in the late fall and winter (roe season). The proportion of the roe-season landings to the total landings increased during the post net-ban period in the southwest region and remained unchanged in the east and northwest regions (Figure 1).

2.1.1 Commercial Landings

Trends in commercial landings of striped mullet in Florida are influenced by several factors, including market supply and demand, environmental conditions, changes in gear compositions, and regulatory changes. Significant regulations adopted for managing the mullet fishery included seasonal closures in the early 1950s, minimum-size restrictions in 1989, gear restrictions and time closures in the early 1990s, and finally the elimination of the use of entangling nets that became effective in July 1995 (see http://myfwc.com/marine/history/MULLET.htm for more details on mullet regulations).

The first recorded commercial catch of striped mullet was in 1879, when 3.5 million pounds of striped mullet were landed in Florida (U.S. Commission of Fisheries report 1880). Landings gradually increased to about 30 million pounds from1880 to 1900 and fluctuated at that level from 1900 to 1940 (Figure 2). Landings reached a historical peak of about 50 million pounds during 1941 and1942 when the demand for fish protein sharply increased during World War II. Mullet production declined back to the historical level of 30 million pounds during 1945-1966. Mullet landings dropped to a new production level during1967-1991, averaging about 25 million pounds annually. Landings further declined during 1992-1994 to an annual average of 18 million pounds, primarily due to regulations adopted in 1992. Since the 1995 net-ban, Florida's landings have sharply declined to an annual average of 8.1 million pounds, a 55% reduction if compared to 1992-1994 landings level and a 67% reduction if compared to the recent historical (1967-1990) average level of 25 million pounds. Trends in fishing effort followed those of the landings (Figure 3). The number of commercial fishing trips declined from an annual average of 61,449 trips before the net-ban took effect (1985-1994) to 28,785 trips after the net-ban took effect (1995-2004), a total reduction of 53%.

Because of regional growth and population dynamics differences, previous assessments have been conducted separately for striped mullet inhabiting waters in the northwest region (NW, Escambia-Hernando), in the southwest region (SW, Pasco- Monroe), and along the east coast. Commercial landings statistics for these three regions were updated to allow examination of changes in landings, effort, size composition, and catch- per-unit-effort (CPUE). Landings and number of fishing trips declined sharply after the 1995 net ban in all three regions. Mullet landings declined from an average of 14.9 million lbs during the pre net-ban period of 1978-1994 to an average of 5.1 million lbs during the post net-ban period of 1995-2004 on the SW region (a total of reduction 66%), from an average of 6.4 million lbs during this pre net-ban period to an average of 1.7 million lbs during this post net-ban period on the NW region (a total reduction of 73%), and from an average of 2.4 million lbs during this pre net-ban period to an average of 1.3 million lbs during this post net-ban period on the east coast region (a total reduction of 45 %)(Figure 4a). Similarly, the annual average number of fishing trips declined by 58%, 62%, and 31% in the SW, NW, and the east coast regions, respectively, during the post net-ban period compared to the annual average number of fishing trips during the pre net-ban period when the number of trips was available (1986-1994)(Figure 4b).

Since the 1995 net-ban, the roe season landings have increased substantially in the southwest region but have remained stable on the northwest and east coast regions (Figures 5a and b). In the southwest region, the roe season landings in 1999, 2001, and 2002 ranged from 4.0 to 4.4 million lbs, similar to the landings levels observed in 1993 and 1994 (4.6 million lbs in 1993 and 4.2 million pounds in 1994).

The length-frequency distributions of the commercial landings showed a slight shift toward smaller fish in the NW region and shift toward larger mullet on the SW and east coast regions during the post net-ban period compared to the mullet in those regions during the pre net-ban period (Figures 6a, b, and c). The shift toward the larger fish in the southwest region may reflect the recent increase of the roe season landings of larger fish targeted for the roe market.

2.1.2 Commercial Catch-Per-Unit-Effort

Standardized commercial catch rates (pounds/trip) for striped mullet were calculated for the pre net-ban and post net-ban periods using a general linear model that adjusts trip catches for year, month, county, and trip duration in days. The pre net-ban catch rates were generally stable between 1985 and 1993 on the NW and east coast regions and between 1985 and1991 on the SW region. Catch rates declined during 1992-1994 on the SW region and in 1994 on the NW region (Figure 7a). Catch rates have increased gradually since 1995 in all three regions (Figure 7b). This increase probably reflects the increase in the stock size.

2.2 Recreational Fishery

Recreational fishermen use cast nets almost exclusively to harvest striped mullet for food and bait. The estimated recreational landings of striped mullet are relatively small (less than 14% of the total statewide striped mullet landings during 1998-2001) and fluctuate widely from year to year (Figure 8a, b, and c). Since 1995, annual recreational harvests have averaged 489,069 fish (449,448 pounds) on the east coast region, 356,909 fish (373,132 pounds) on northwest region, and 425,055 (777,600 pounds) on the southwest region. Estimates of recreational catch rates were imprecise due to small sample sizes and thus were not used in the stock assessment as indices of abundance.

Few length measurements of striped mullet harvested by the recreational fishery have been taken; however, those taken seem to indicate that median fork length ranged from 300-350 mm on the east coast and NW regions and from 350 to 400 mm on the SW region (Figure 9a, b, and c). Median fork length remained fairly stable throughout the time series for the three assessment regions.

3. Fishery-Independent Survey Data

The fishery-independent data for striped mullet included juvenile abundance indices and adult size and age compositions. The juvenile and adult fishery-independent surveys are conducted by the Fish and Wildlife Research Institute's Fishery Independent Monitoring (FIM) program in major estuaries along the east and west coasts of Florida. The juvenile sampling is conducted monthly via a 70-ft seine. The proportion of positive sets were used as a simple index of abundance of young-of-the-year based on length for the east coast (1992-2004), the northwest (1997-2004), and the southwest (1991-2004) regions. The juvenile indices were generally variable, with no particular trends on any of the three coasts (Figures 10a, b, and c).

The FIM surveys of adult striped mullet included the monthly seine (600-ft) sampling in major estuaries on the east and west coasts of Florida and the trammel-net sampling during the spawning season (September-February) in Tampa Bay and Charlotte Harbor on the southwest coast. Few adult striped mullet were captured in the 600-ft seine because a large proportion of mullet jump over the net. The small and sporadic catches of striped mullet from this survey precluded the generation of realistic estimates of adult catch rates that could be used to examine trends in relative abundance. The directed trammel net survey has generated valuable information on size composition since 1993 and age composition since 1995. Inconsistencies associated with searching and capturing methods and schooling behavior prevented us from using this survey to develop relative abundance estimates. The trammel net size-frequency distributions indicated a buildup of larger size mullet during 1996-1998, followed by strong recruitment of young mullet in 1998 and subsequent years in both Tampa Bay and Charlotte Harbor (Figure 11a and b). The Chapman-Robson catch curves (Robson-Chapman 1961, Murphy 1997) fitted to the age data had an average total mortality (Z) of 0.72 (0.69-0.74,95% confidence interval) per year or a fishing mortality rate (F) of 0.42 per year, assuming the natural mortality rate (M) of 0.3 per year for the 1995-2000 period, and had an average total mortality (Z) of 0.8 (0.78-0.83, 95% confidence interval) per year or F of 0.5 per year for the 2001-2004 period (Figure 12). These mortality estimates represented mortality rates during the most intense fishing season of the year, when the landings and fishing effort increased substantially during the spawning (roe) season in the southwest region.

4. Population Models

This year's assessment was based on the non-equilibrium surplus production model (ASPIC) developed by Prager (1994, 2004) and the forward statistical age-structured model (ASAP) developed by Legault and Restrepo (1999). The surplus production models provide information on population status based on trends in landings and fishing effort and the model relies heavily on the assumption that changes in the catch-rate data reflect changes in exploitable stock biomass. No specific information is needed about the age-structure of the population in the surplus production modeling. The age-structured modeling approach on the other hand requires information on age composition of the catch and biological information such as natural mortality estimates, age/size at maturity, and average weight at age. The ASAP model projects population numbers at age forward from the initial year to create a time series of predicted stock sizes and total fishery catches. The predicted stock size and total fishery catch are compared to observed catch and population indices using statistical approaches. The statistical age-structured models account for errors associated with the observed catch at age and allows for selectivity and catchability to vary over time and age.

4.1 Non-Equilibrium Surplus Production Model

Surplus production models are used to describe the dynamics of a fished stock in terms of biomass by simply using the previous year's biomass, growth in biomass in that year, and catch

$$B_{t+1} = B_t + r\, B_t\,(1- B_t /K) - C_t$$

where B_t = biomass at time t, r=rate of growth in biomass, K= maximum population size, C_t = catch during time t. The predicted CPUE was calculated by the model,

$$CPUE_{pred} = q\, B_t$$

where q = catchability coefficient linking CPUE to biomass. We used the logistic formulation available in ASAPIC-version5 to solve for biomass B_1, K, and q by minimizing the differences between observed and predicted CPUE. ASPIC then calculates the biological reference points such as maximum sustainable yield (MSY), B_{msy} (the biomass that could produce maximum sustainable yield), F_{msy} (the fishing mortality rate that would produce the maximum sustainable yield), and F/F_{msy} and B/B_{msy} ratios.

4.1.1 Data Input, Parameters Estimations, and Uncertainty

Separate production models were developed for each assessment region. Model input data and parameters included combined commercial and recreational annual landings (1985-2004), standardized commercial CPUE for the pre (1985-1994) and post (1995-2004) net-ban periods and initial starting values for B_1/K, K, q, and MSY. A separate q for the pre and post net-ban periods were used. This was accomplished by putting the periods of time in separate data series of catch and standardized CPUE. This approach allowed q to change, reflecting the major shift in the gear used in the fishery, from primarily a gill net fishery prior to the 1995 net-ban to a cast net-seine fishery after the 1995 net-ban.

Only estimates of F/F_{msy}, and B/B_{msy} were used to evaluate the condition of striped mullet stocks. According to Prager (2004), these relative measures are the most robust parameters generated by the model for evaluating the stock condition. The measures of uncertainty associated with the F/F_{msy} and B/B_{msy} estimates in 2004 were calculated based on the bootstrapping routine provided in ASPIC, which recalculates these parameters 500 times. In the bootstrapping routine, the catch and residual estimates from the base run are used to generate new predicted catches using randomly-chosen adjusted residuals. The model is then refit and process is repeated 500 times to generate a bias corrected 80% confidence intervals. Sensitivity of the model runs was tested for different random seed numbers. The input and output data and parameter estimations for the three assessment regions are shown in Appendecies1-3.

4.1.2 Model Results

The surplus production model predicted the commercial CPUE well for all the three assessment regions (Figure 13). Fishing mortality rates were consistently higher than F_{msy} (F/F_{msy} >1) during the pre net-ban period (1985-94) with average F/F_{msy} ratios of 1.4 for the NW and 1.3 for the SW regions (Figures 14b, and c). The pre net-ban Fs or the east coast region were higher than F_{msy} during 1992-1994 (Figure 1a). As expected with these high fishing mortality rates during the pre net-ban the biomass has consistently been below B_{msy} with average B/B_{msy} ratios of 0.60 for the NW, 0.80 for the SW regions, and 0.95 for the east coast region. This is consistent with the substantial fishery for striped mullet in 1980s and early 1990s suggesting that overfishing (in terms of MSY) may have occurred throughout the pre net-ban period in the mullet fishery in these regions. The F/F_{msy} and B/B_{msy} trajectories indicated the opposite fishery status for the post net-ban period. The F/F_{msy} were consistently below 1 (with average F/F_{msy} ratios of 0.43, 0.19, and 0.35 for the east coast, NW, and SW regions, respectively) and the B/B_{msy} were consistently above 1 (with average B/B_{msy} ratios of 1.2, 1.3, and 1.2 for the east coast, NW, and SW regions, respectively), indicating that mullet stocks were no longer overfished and overfishing was not occurring in recent years. The likelihood estimates of B/B_{msy} and F/F_{msy} ratios in 2004, calculated by the bootstrapping method, indicated with high level of certainty that the F_{2004}/F_{msy} ratio was less than 0.5 on the east coast region and less than 0.25 in the NW and SW regions; and the B_{2004}/B_{msy} ratio was greater than 1.60 on the east coast region and greater than 1.75 in the NW and SW regions (Figure 15). The production model parameters estimates were robust given different starting random seed values.

4.2 Age-Structured Model

The age-structured method used for this assessment was a forward – projecting, statistical catch-at-age model (Age Structured Assessment Program, ASAP) developed by Legault and Restrepo (1998). The model formulations as described by Legault and Restrepo are presented in Appendix-4. Conceptually, ASAP solves for the numbers of striped mullet by age and year by estimating for selectivity at age (S), catchability coefficients (q) by index, numbers by age in the population in the first year being considered (1991) and annual recruitment. The stock dynamics follow the standard Baranov equations which assume exponential decay in population size due to fishing and natural mortality processes. The fleet-specific selectivity and catchability patterns are allowed to vary over time for every age as do the fleet-specific fishing mortality rate multipliers. The forward projection begins by computing recruitment as deviation from an average value (constrained by a Beverton and Holt stock-recruit curve) and a first year population number at age followed by calculations of population number at age, and predicted catches and indices. One of the advantages of this approach over the standard VPA is that VPA assumes the catch at age is measured without error, while ASAP accounts for errors associated with the observed catch at age.

4.2.1 Model Input, Parameter Estimation, and Uncertainty

The main data sources for the ASAP included observed catch at age, total annual catch in biomass, weights at age, maturity schedule, age-specific natural mortality rates, and observed abundance indices. For the base runs, catch-at-age matrices were constructed based on annual combined commercial and recreational landings (number) for period 1991-2004 and age composition data for the three assessment regions. In the ASAP base run for the SW region, annual age composition tables were developed from the TIP length-frequency data (1991-2004) and age-length keys estimated from the fishery-independent trammel-net data collected during September-February 1994-2004 in Tampa Bay and Charlotte Harbor. Annual age-length keys were not available for the NW and east coast regions, however, reasonable age-length keys from biological studies conducted during 1987-1989 in the NW region and during 1997-99 in the east coast were available and were used to construct the catch-at-age tables. The total annual catch in biomass as calculated from commercial and recreational statistics for fishing years January-December during 1991-2004 for the NW and east coast regions and for the fishing years February-January during 1991-2005 for the SW region. Average weights at age were calculated from the region specific estimates of mean length at age and length-weight equations. The maturity schedule and natural mortality estimates (M=0.3 constant for all ages) were obtained from the previous assessments. The tuning indices for the base runs included the commercial CPUE and FIM juvenile catch rates. The commercial catch rates for each of the assessment regions were standardized (GLM, Hilborn and Walters 1992) for geographic location, season, year, gear type, and length of fishing trips in hours for the 1991-2004 period. The standardized juvenile catch rates were calculated (using the method described above) for the 1995-2004 period on the east coast region, for the 1997-2004 period in the NW region, and for the 1991-2004 period in the SW region. Because of the short overlap time (1991-1994) of the gears used during the pre and post net-ban periods, additional ASAP runs were conducted using two separate standardized CPUE times series for the 1985-1994 (pre net-ban) and 1995-2004 (post net-ban) periods.

ASAP also requires starting values for the virgin stock size, a stock-recruitment steepness value, fishing mortality rate in 1st year, selectivity schedule, and initial catchability coefficients (q) for the tuning indices. The initial selectivity curve followed a dome shape pattern with the age at full selectivity set at 3. In ASAP, constraints can be placed on how much parameters can vary over time and the relative importance of different parts of the objective function by assigning relative weighting values. Moderate weights were assigned to the total catch (1000, representing a cv value of 15%) and to the tuning indices (50, representing a cv value of 25%). Due to uncertain nature of the stock-recruitment relationship the steepness in the base-run was set at 0.9999, which is essentially a constant recruitment pattern. The measure of steepness is necessary to define the condition of a given stock in relation to virgin biomass (B_0) and biomasses that support maximum sustainable yields (B_{MSY}). However, in this assessment the management reference points are based on the Spawning Potential Ratio (SPR) as a measure of stock condition. To examine the model sensitivity to the steepness parameter, additional ASAP runs were conducted for a range of steepness values from 0.4-1.0. Input data, parameter and weightings values used in the base runs are presented in Appendices 5-7.

The forward projection begins by computing recruitment as deviation from an estimated stock-recruitment relationship (equation 8 in Appendix 4). Given initial stock size and recruitment, the numbers of striped mullet for each age group in 1991 and subsequent years are computed using equations 9 and 10 in Appendix-4. The age-specific fishing mortality is estimated as the product of the selectivity at age within a year and a year specific fishing mortality multiplier(equations 2 and 3 in Appendix 4). The fishing selectivity is calculated for each age using equation 1 in Appendix-4. ASAP then uses estimates of population size at age, the age-specific fishing and natural mortality rates, and the age-specific q to generate estimates of total catch in weight and catch proportions in numbers of fish (equation 5 in Appendix-4) and indices of abundance (equation 11 in Appendix-4). The model is then fit to observed total catch using a lognormally distributed function (equation 16 in Appendix 4), catch proportions by age using a multinominally distributed function (equation 17 in Appendix 4), and observed indices using a lognormally distributed function (equation 18 in Appendix 4). The function to be minimized is then the sum of the likelihoods and penalties. The number of parameters estimated in ASAP includes initial recruitment values by year (1991-2004), population abundance in 1991, fishing mortality multiplier by year, selectivity by age, tuning indices catchabilities, and 2 stock recruitment parameters. The inclusion of time varying selectivity and catchability would increase the number of parameters to be estimated. The AD model Builder software package used in ASAP allows for estimating the relatively large number of parameters and fast convergence.

4.2.2. Results

The ASAP fits to the total catch and tuning indices are shown in Figures 16, 17, and 18 for the east coast, NW, and SW regions, respectively. The ASAP fit the total catch well. The CPUE tuning indices could not all be fit well due to different trends exhibited by indices that were measuring the same relative abundance. The fits to the catch at age proportions were reasonable for the east coast region (Figure

19), for the NW region (Figure 20) and for the SW region (Figure 21). The selectivity pattern overtime indicated a slight shift toward older ages from the pre net-ban period to the post net-ban period on the east coast and SW regions, while selectivity changes over time was less pronounced for the NW region (Figures 22a, b, and c). The shift toward larger fish for the SW region may reflect the apparent increase in the proportion of the roe season landings to the total annual landings in recent years (Figure 1).

The age-specific fishing mortality rate estimates showed a significant decline after the 1995 net-ban in each of the three assessment regions, particularly between 1995 and 1996 when the lowest catches were observed (Table 2, Figures 23a, b, and c). Fully recruited fishing mortality rates declined from 0.57-1.12 per year during the pre net-ban period (1991-1994) to 0.32-0.77 per year during the post net-ban period (1995-2004) in the east coast region; from 0.56-1.08 per year during the pre net-ban period (1991-1994) to 0.28-0.40 per year during the post net-ban period (1995-2004) in the NW region; and from 0.66-0.77 per year during the pre net-ban period (1991-1994) to 0.19-0.51per year during the post net-ban period (1995-2004) in the SW region. The fishing mortality rates in recent years (2001-2004) ranged from 0.32 to 0.63 per year on the east coast region, from 0.28-0.40 per year on the NW region, and from 0.19-0.42 per year on the SW region. These recent fishing mortality rates were estimated well below the management target ($F_{35\%}$) of 0.69 for the east coast, 0.55 for the NW region, and 0.64 for the SW region (Table 3). Because of lack of fishery age data, selectivity patterns estimated by ASAP may not represent the true selectivity in the fishery. The estimates of the *F* targets are strongly influenced by the selectivity pattern. Recent fishing mortality rates of 0.19-0.45 estimated by the ASAP for the southwest region were comparable to the fishing mortality rate of 0.5 per year estimated from the fishery-independent age compositions data collected in Tampa Bay and Charlotte Harbor (Table 3). The decline in fishing mortality rates since the net-ban has resulted in gradual increase of the spawning stock biomass especially in the NW and SW regions where over 85% of striped mullet are landed (Figure 24a, b, and c). The recruitment estimates from the ASAP base runs were variable and followed the patterns observed in the fishery-independent juvenile indices (Figures 25a, b, and c).

The fishing mortality rate and spawning stock biomass estimates from the alternative ASAP runs with two CPUE time series were similar to those estimated in the base-run except for slightly higher fishing mortality rates and lower spawning stock biomass estimates generated by the alternative runs (Figures 26a-c and 27a-c). The ASAP sensitivity runs for a range of steepness values (0.4-0.8) also generated similar fishing mortality rate and SSB values as those generated from the base run with the steepness value of 0.999 shown in Figure 28 for the northwest region as an example.

4.3 Conclusions and Recommendations

Overall, the two assessment models produced similar results on the status of striped mullet populations in the three assessment regions, indicating higher fishing mortality rates during the pre net-ban period followed by a sharp decline in fishing mortality rates after the 1995 net-ban. The F/ F_{msy} (<1) and B/B_{msy} (>1) trajectories from the ASPIC models suggested that mullet populations were not been overfishing in recent years. The fishing mortality rates estimated by the ASAP model for the recent years were below the management target levels in all the three assessment regions except for the east coast in 2004.

The ASAP model assumed that the standardized CPUE were a reliable index of population abundance, although greater weighting was allowed to the catch. Due to the lack of signals in the age composition data, the model results become heavily dependent on the trends observed in the catch and CPUE indices. Given the observed trend in the CPUE time series, both models suggested that striped mullet stocks have been increasing in the recent years especially in the NW and SW regions where over 85% of the fishery is occurring. The decline in fishing mortality rates for the recent years and apparent stock recovery was consistent with the sharp decline of the commercial landings and fishing trips observed since the 1995 net-ban.

Because of lack of aging data from the fishery, the age data used in the ASAP were derived from age length keys (ALK) that were derived from biological studies and fishery-independent samplings. Consequently, the age structures to which the models were fit for this assessment may not be representative of a particular year because the pooled ALK would tend to minimize apparent differences among years. In addition, the pooled ALK would under-estimate apparent decline in older age over time and or the influence of weak or strong year classes. Thus, it is critical that future sampling and data collection for striped mullet assessment include direct age sampling of the commercial and recreational catches with sufficient spatial and temporal resolutions. Since the net-ban, the gear selectivity pattern has changed, cast nets and small seine or combinations of two have been used in the fishery. The age data from various sectors of the fishery should be incorporated into assessment for accurate measurements of the selectivity patterns. Future data collection should include comprehensive on-board observations for characterizing the spatial and temporal patterns in fishing activities and effort in the mullet fishery. Finally, fishery-independent samplings should be conducted to update estimates of biological and population parameters needed for calibrating the stock assessment models.

For the near future, the ASAP model or Stochastic Stock Reduction Analysis (SRA, Walters et al 2005) should be extended to include the long-term historical catches. These approaches will provide historical perspectives of the recruitment patterns and stock conditions and may add useful information concerning management reference points. In addition, the feasibility of the length-based modeling approaches should be evaluated and compared against the ASAP model results. Many of our stock assessments rely on the TIP and MRFSS length-frequency data with little or no direct age information from the fishery. Thus, further development and explorations of the length-based modeling is recommended.

Future values of fishing mortality rates in the striped mullet fishery are affected by amount of catch, changes in gear selectivity, and stock size and recruitment. Landings trends in the recent years suggest that mullet production has stabilized at about 1.8 million pounds on the east coast region, 2.3 million pounds on the NW region, and 6.5 million pounds on the southwest region. Given current regulations, at these recent landings levels, fishing mortality rates should decline further if recoveries of mullet stocks continue at the present rate.

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Table 1. The top ten species or groups harvested in 2004 by commercial and recreational anglers along the Atlantic and Gulf coasts of Florida.

	Gulf Coast			Atlantic Coast	
	Species or group	landings (pounds)		Species or group	landings (pounds)
1	FOOD SHRIMP	15,014,912	1	SHRIMP, ROCK	5,909,244
2	GROUPER, RED	9,923,714	2	MACKEREL, KING	5,613,283
3	CRAB, BLUE	8,078,140	3	FOOD SHRIMP	4,854,417
4	MULLET, STRIPED	7,722,828	4	MACKEREL, SPANISH	3,971,791
5	GROUPER, GAG	7,490,916	5	DOLPHIN	3,900,070
6	LOBSTER, SPINY	4,550,292	6	CRAB, BLUE	3,838,139
7	MISC. INVERTEBRATES	4,042,285	7	MULLET, STRIPED	2,428,625
8	PINFISH	3,761,291	8	SHARK	1,373,902
9	HERRING, THREAD	3,116,780	9	JACK, CREVALLE	1,195,896
10	CRAB, STONE	2,966,099	10	TUNNY, LITTLE (BONITO)	1,178,717

Table 2. Fishing mortality rates and population numbers at age estimated by the ASAP base runs for striped mullet on the east, northwest, and southwest coasts of Florida.

East Coast- Fishign Mortality rate (F)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.03	0.05	0.04	0.05	0.04	0.03	0.03	0.04	0.02	0.02	0.02	0.02	0.02	0.03
3	0.26	0.45	0.37	0.52	0.24	0.18	0.18	0.23	0.13	0.14	0.12	0.10	0.11	0.19
4	0.57	0.98	0.80	1.12	0.77	0.58	0.58	0.75	0.41	0.46	0.40	0.32	0.35	0.63
5	0.54	0.93	0.76	1.07	0.73	0.55	0.55	0.71	0.39	0.44	0.38	0.31	0.33	0.59
6	0.51	0.89	0.72	1.01	0.70	0.52	0.52	0.67	0.37	0.41	0.36	0.29	0.31	0.56
7	0.49	0.84	0.68	0.95	0.66	0.49	0.50	0.64	0.35	0.39	0.34	0.27	0.29	0.53
8	0.46	0.79	0.64	0.90	0.62	0.46	0.47	0.60	0.33	0.37	0.32	0.26	0.28	0.50
9	0.43	0.74	0.60	0.84	0.58	0.43	0.44	0.56	0.31	0.34	0.30	0.24	0.26	0.47

Population Numbers at Age (thousands)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
1	5965	5636	4683	4596	5818	6828	1991	5532	2148	6170	4496	1896	3604	2538
2	6310	4413	4165	3462	3395	4309	5058	1475	4098	1591	4570	3330	1405	2670
3	3514	4552	3123	2972	2434	2421	3102	3640	1053	2974	1152	3320	2428	1023
4	2172	2002	2145	1599	1314	1421	1500	1919	2140	687	1912	755	2226	1616
5	1096	909	555	712	385	449	590	620	672	1049	321	954	405	1166
6	404	472	264	192	181	137	192	251	226	337	503	164	520	216
7	241	179	144	95	52	67	60	84	95	115	165	261	91	282
8	175	110	57	54	27	20	30	27	33	50	58	87	147	50
9	254	205	110	67	38	26	22	25	21	29	41	54	81	129

Northwest- Fishing Mortality Rate (F)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.03	0.04	0.06	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04
3	0.36	0.50	0.68	0.61	0.23	0.20	0.23	0.24	0.24	0.21	0.25	0.17	0.17	0.20
4	0.56	0.79	1.08	0.97	0.38	0.32	0.37	0.39	0.40	0.35	0.40	0.28	0.28	0.33
5	0.54	0.75	1.02	0.92	0.36	0.31	0.35	0.37	0.38	0.34	0.38	0.27	0.27	0.32
6	0.51	0.71	0.97	0.87	0.34	0.29	0.34	0.35	0.36	0.32	0.36	0.26	0.25	0.30
7	0.48	0.67	0.92	0.82	0.32	0.28	0.32	0.33	0.34	0.30	0.34	0.24	0.24	0.28
8	0.45	0.63	0.86	0.77	0.31	0.26	0.30	0.31	0.32	0.28	0.32	0.23	0.23	0.27

Population Numbers at Age (thousands)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
1	11246	8400	7196	6598	6779	6867	6566	8566	9521	9719	9151	6260	3679	8011
2	11446	8320	6211	5317	4876	5020	5086	4862	6344	7050	7198	6777	4636	2724
3	5833	8238	5919	4355	3749	3440	3568	3592	3428	4463	4992	5062	4841	3312
4	4590	3019	3690	2211	1745	2202	2092	2107	2102	1988	2667	2891	3155	3020
5	2177	1935	1014	931	623	882	1179	1067	1059	1041	1035	1318	1612	1762
6	969	944	676	270	276	321	480	613	547	535	552	522	745	913
7	551	432	343	190	84	145	178	254	320	282	289	284	299	428
8	578	526	370	218	136	119	150	178	232	293	319	322	355	384

Southwest-Fishing Mortality rate at Age (F)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
1	0.02	0.02	0.02	0.02	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.00
2	0.27	0.29	0.30	0.32	0.08	0.08	0.13	0.12	0.14	0.09	0.12	0.11	0.08	0.05
3	0.50	0.54	0.56	0.59	0.13	0.13	0.22	0.20	0.24	0.15	0.20	0.18	0.13	0.09
4	0.66	0.70	0.73	0.77	0.27	0.27	0.45	0.41	0.51	0.32	0.42	0.38	0.27	0.19
5	0.64	0.69	0.72	0.76	0.26	0.27	0.45	0.40	0.49	0.31	0.42	0.37	0.26	0.19
6	0.62	0.67	0.69	0.73	0.26	0.26	0.43	0.39	0.48	0.30	0.40	0.36	0.26	0.18
7	0.59	0.63	0.66	0.69	0.24	0.25	0.41	0.37	0.45	0.29	0.38	0.34	0.24	0.17
8	0.56	0.60	0.62	0.66	0.23	0.23	0.39	0.35	0.43	0.27	0.36	0.32	0.23	0.16
9	0.53	0.56	0.58	0.62	0.22	0.22	0.36	0.33	0.40	0.26	0.34	0.30	0.22	0.15

Population Number at Age (thousands)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
1	15918	9297	13371	11379	13121	10405	12816	19335	11930	12980	18279	14261	15834	11240
2	16268	11552	6737	9681	8228	9682	7677	9432	14238	8773	9571	13457	10507	11684
3	7770	9190	6406	3694	5217	5647	6635	4998	6216	9136	5933	6284	8956	7208
4	3227	3477	3973	2711	1514	3402	3673	3961	3045	3623	5813	3593	3892	5836
5	1966	1238	1276	1418	928	857	1917	1727	1945	1362	1948	2817	1826	2200
6	906	765	461	462	493	528	486	910	855	878	737	952	1442	1038
7	608	359	291	171	164	283	302	234	456	392	480	365	493	827
8	521	249	141	112	63	96	164	148	120	214	218	243	192	286
9	789	566	341	197	122	110	121	145	155	134	198	217	249	262

Table 3. Comparison of fishing mortality rates estimated by the ASAP base runs for the three assessment regions to fishing mortality target rates and fishing mortality rates calculated from the fishery-independent age data collected in the southwest region.

	East Coast	Northwest	Southwest
F targets			
$F_{0.1}$	0.42	0.41	0.40
$F_{35\%}$	0.69	0.55	0.64
$F_{40\%}$	0.51	0.42	0.48
F estimates, ASAP Model			
F_{2001}	0.39	0.40	0.42
F_{2002}	0.32	0.28	0.38
F_{2003}	0.34	0.28	0.27
F_{2004}	0.65	0.33	0.19
F estimates, fishery-independent survey, southwest region			
$F_{1995-2000}$	NA	NA	0.42
$F_{2001-2004}$	NA	NA	0.50

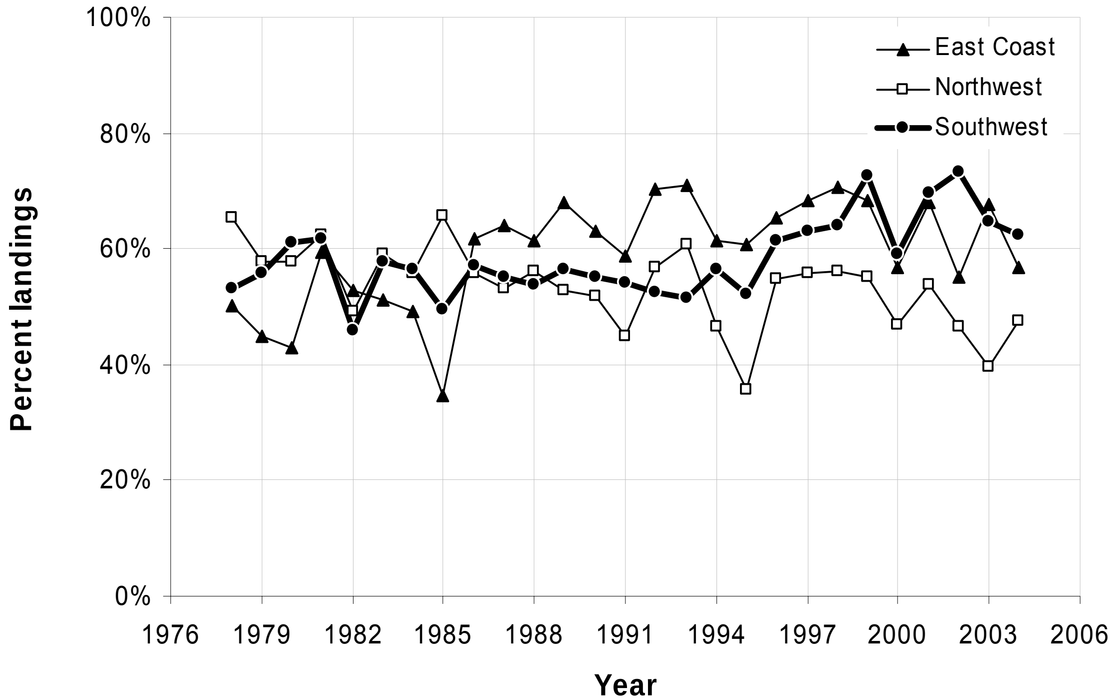


Figure 1. The proportion of striped mullet caught commercially during the spawning (roe) season on the east, northwest, and southwest coasts of Florida.

Figure 2. Historical landings of striped mullet in Florida.

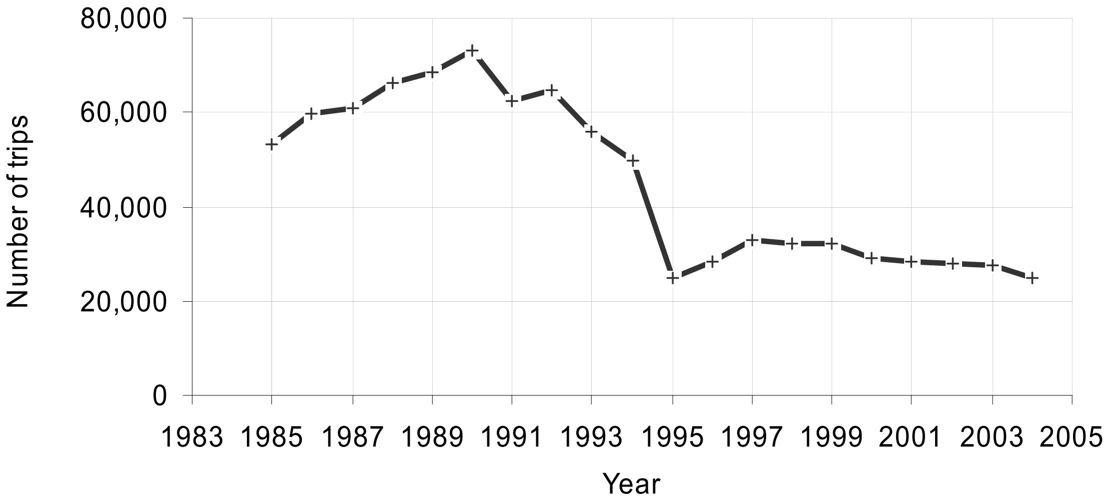


Figure 3. Number of commercial fishing trips in the striped mullet fishery in Florida.

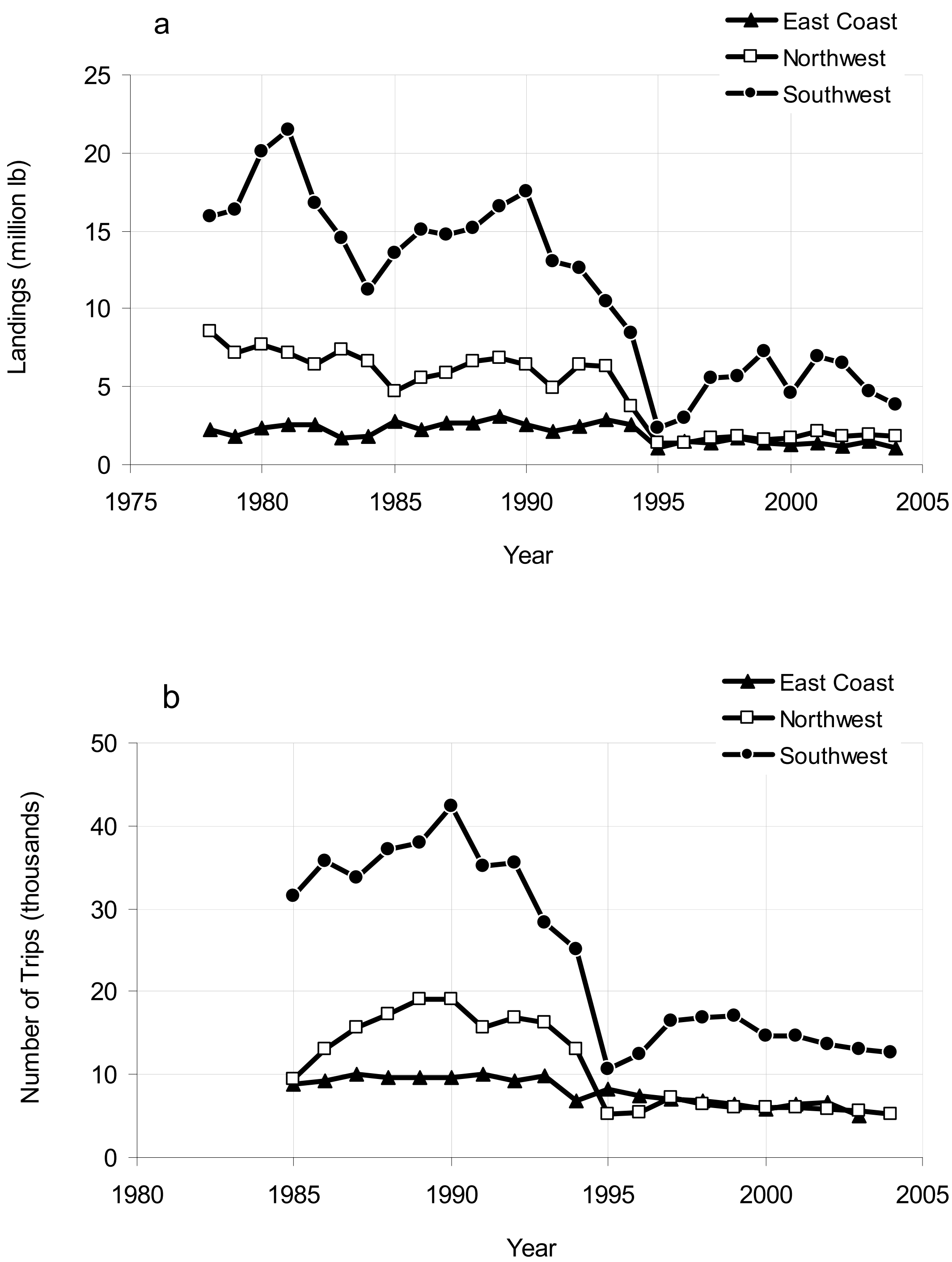
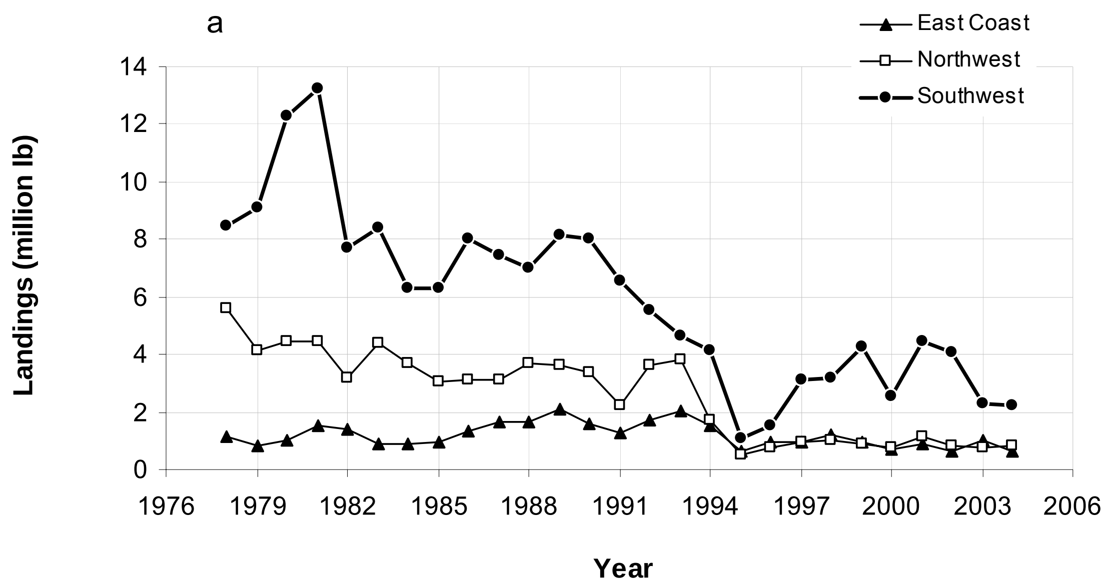


Figure 4. Annual commercial landings (a) and number of fishing trips (b) in the striped mullet fishery on the east, northwest, and southwest coasts of Florida.



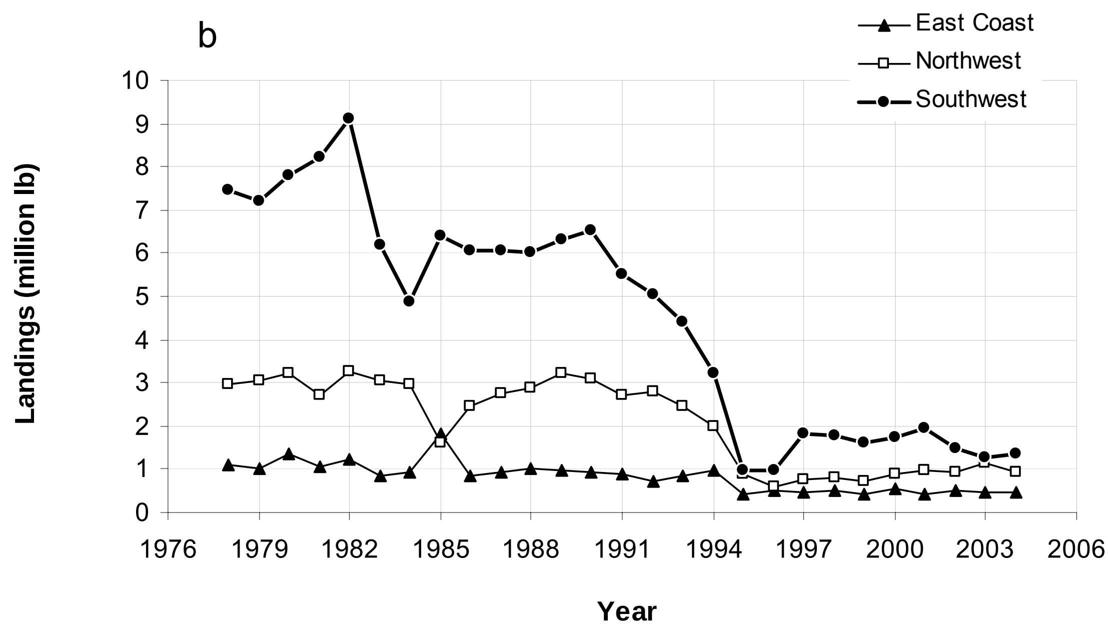


Figure 5. Commercial landings of striped mullet during the roe (a) and non-roe seasons (b) on the east, northwest, and southwest coasts of Florida.

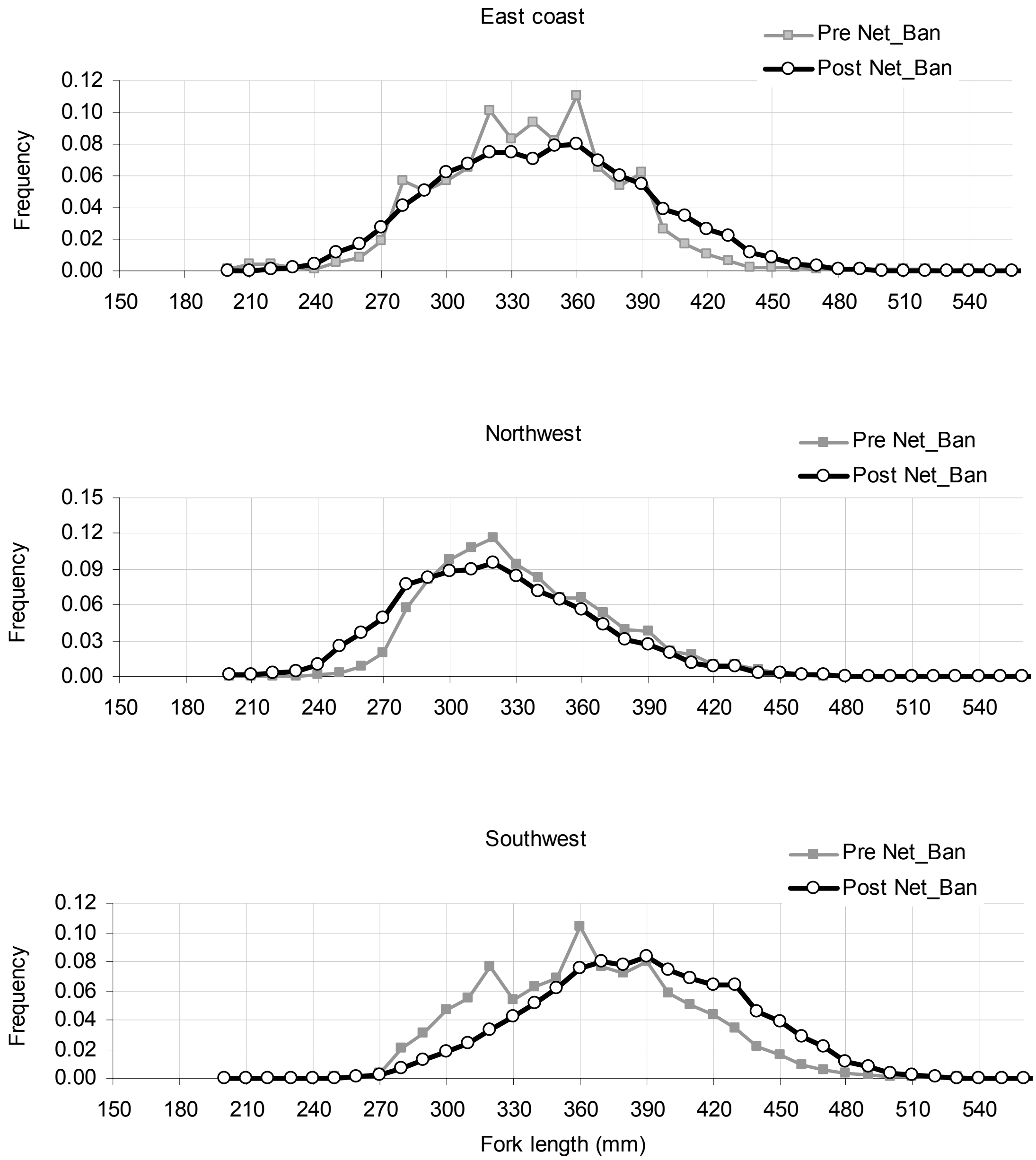


Figure 6. The length-frequency distributions of striped mullet caught commercially during the pre (1991-1994) and post (1995-2004) net-ban periods on the east, northwest, and west coasts of Florida.

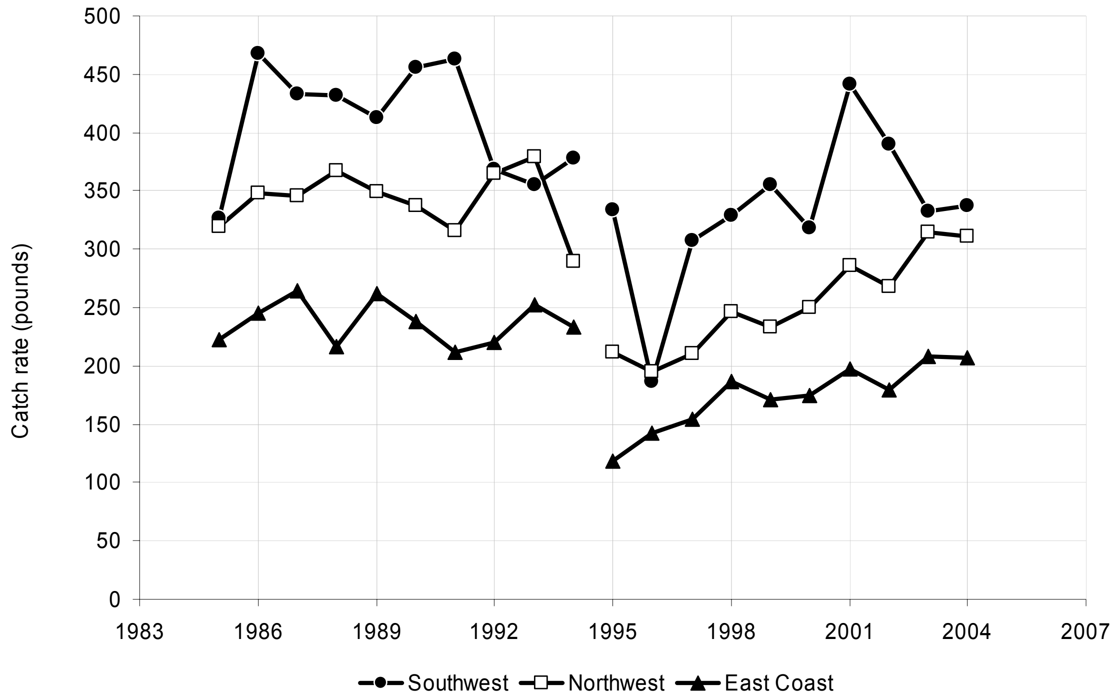


Figure 7. Annual standardized commercial catch rates for striped mullet during the pre (1985-1994) and post (1995-2004) net-ban periods on the east, northwest, and southwest coasts of Florida.

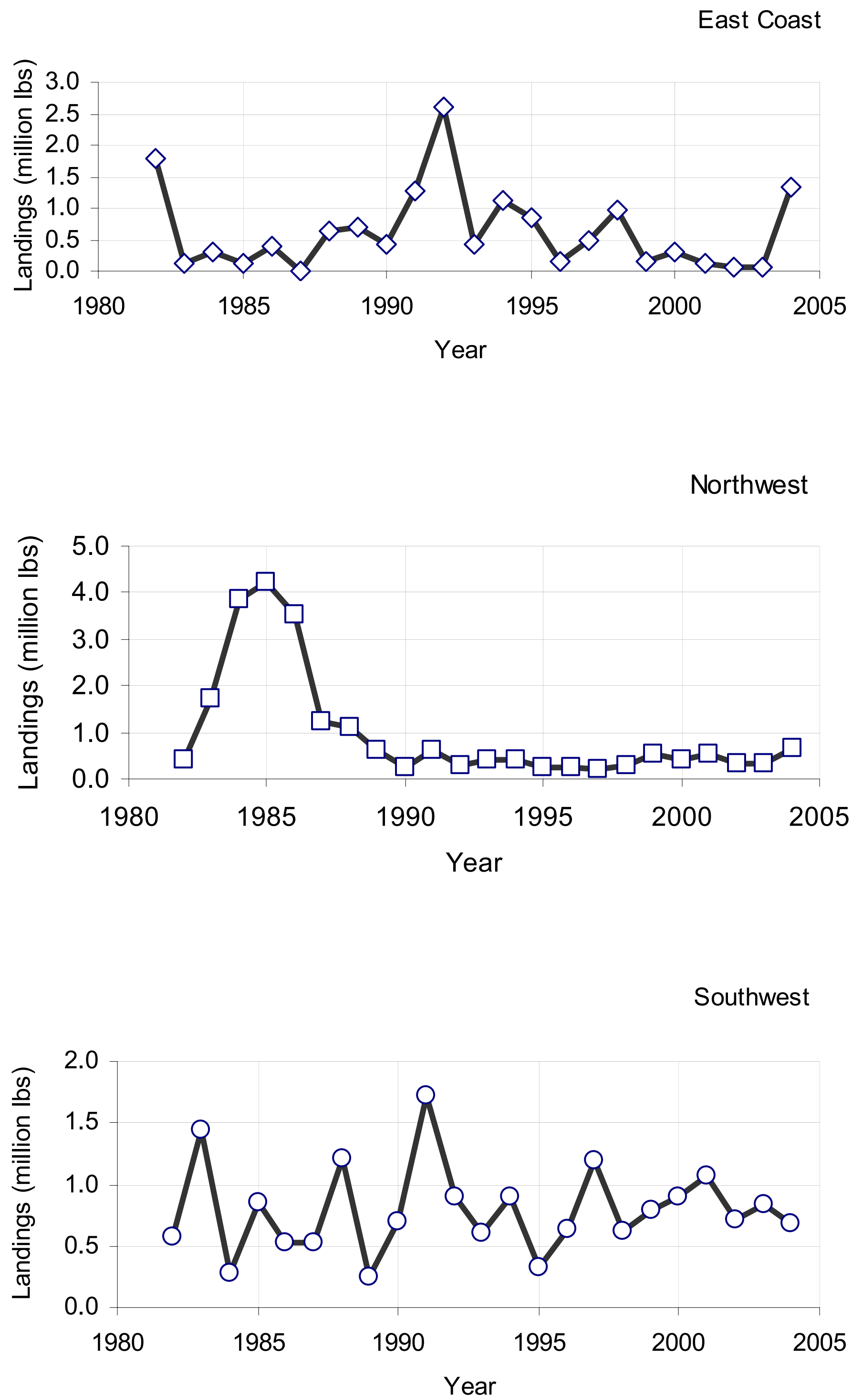


Figure 8. Estimated annual recreational landings of striped mullet from MRFSS by coast.

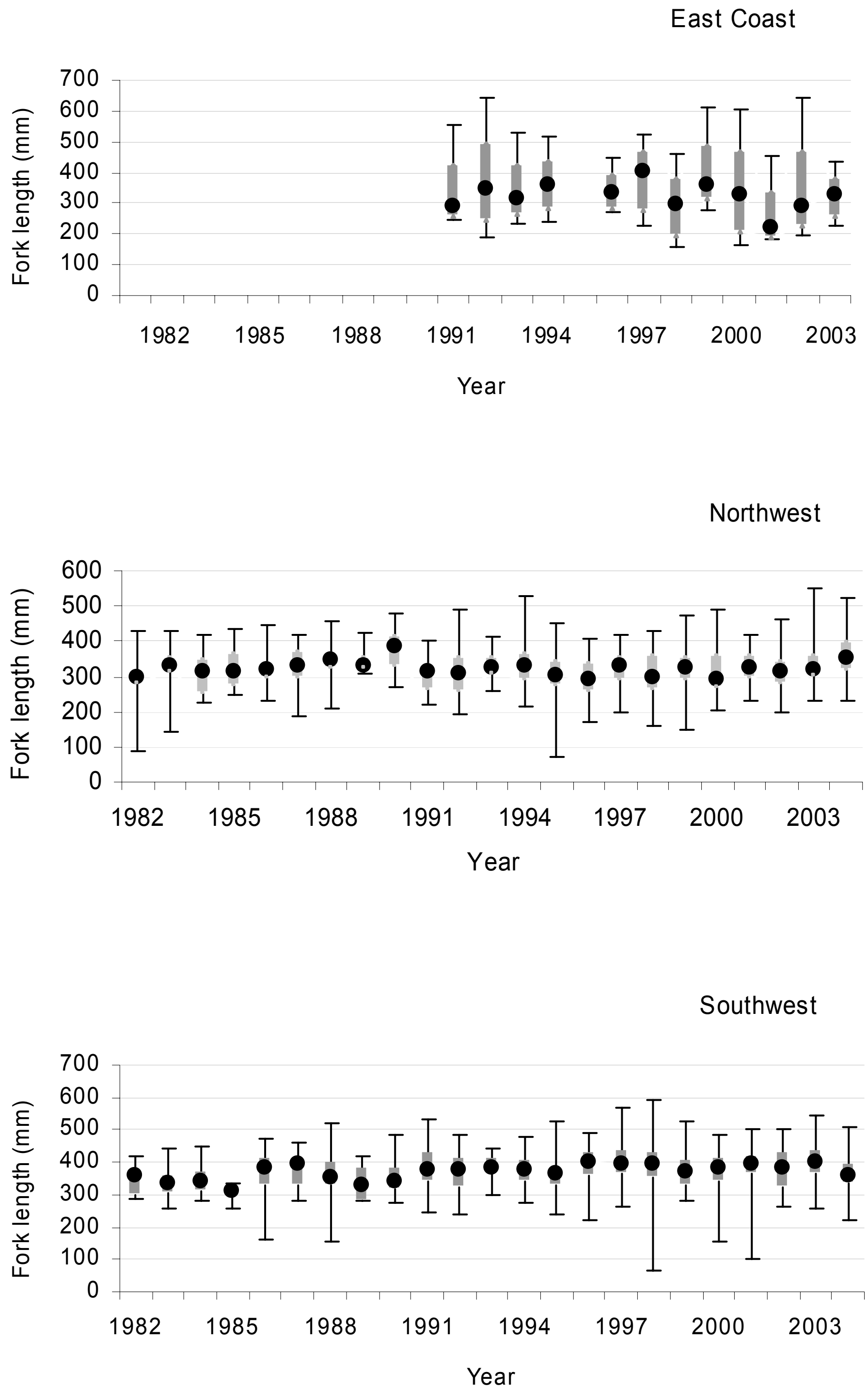


Figure 9. Mean fork lengths estimated for recreationally caught striped mullet on the east, northwest, and southwest coasts of Florida. The vertical line is the 95% confidence interval, the box is the inter-quartiles (25 to 75 percentiles) and the black circle is the median.

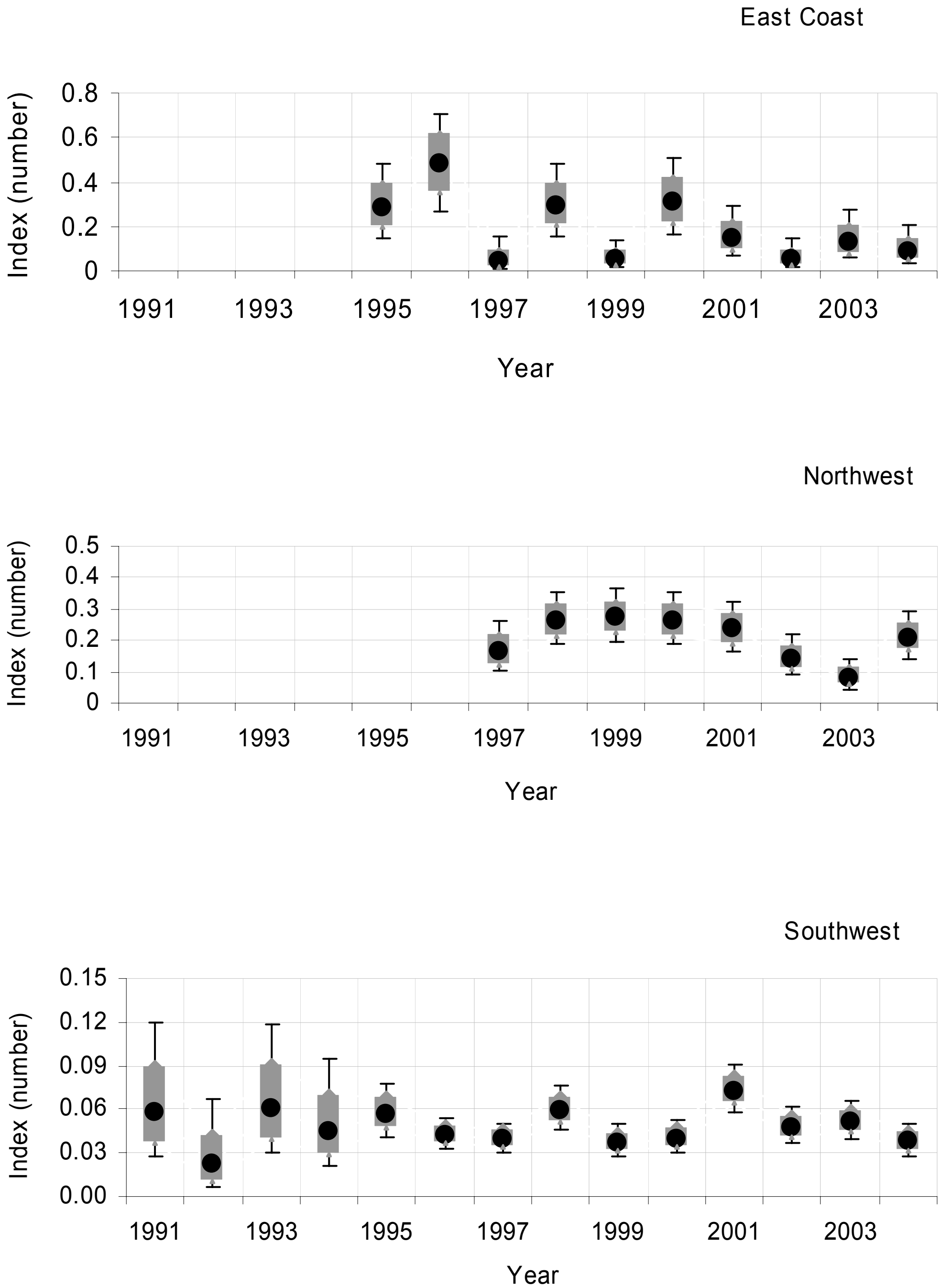
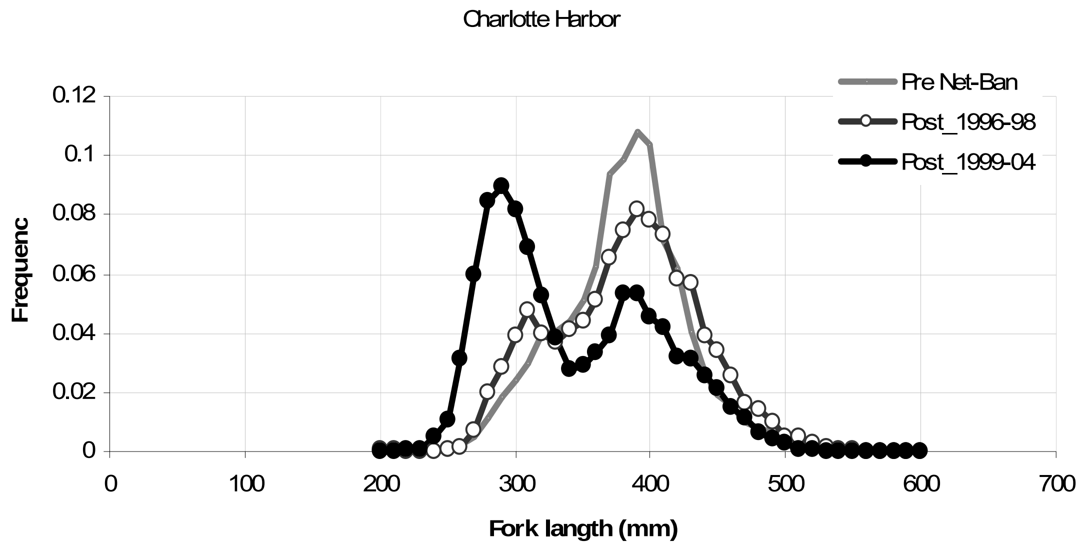


Figure 10. Trends in standardized juvenile indices on the east, northwest, and southwest coasts of Florida. The vertical line is the 95% confidence interval, the box is the inter-quartiles (25 to 75 percentiles) and the black circle is the median.



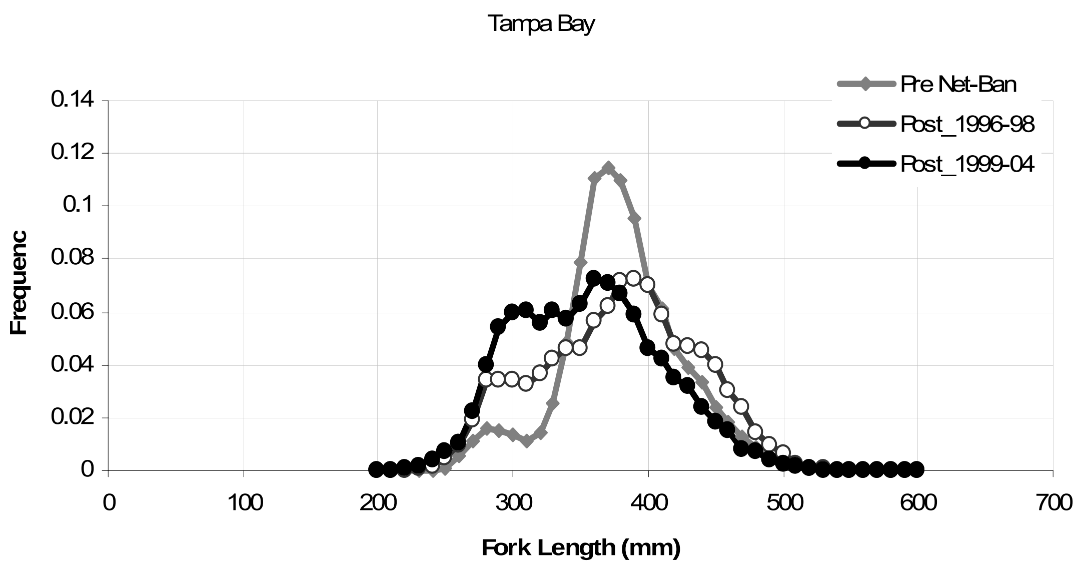


Figure 11. The spawning season length-frequency distributions of striped mullet collected by the fishery-independent trammel-net survey during the pre (1993-1994) and post (1996-98 and 1999-04) net-ban periods in Charlotte Harbor and Tampa Bay.

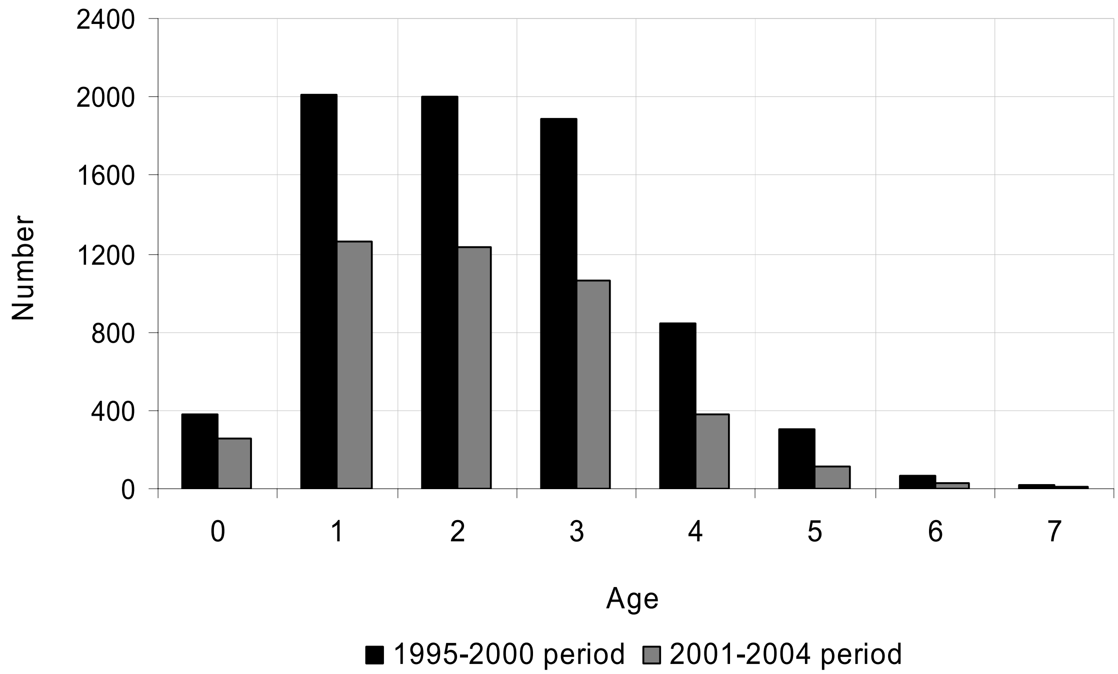


Figure 12. The spawning season age-frequency distributions of striped mullet collected by the fishery-independent trammel-net survey during 1995-2000 and 2001-2004 periods in the southwest region.

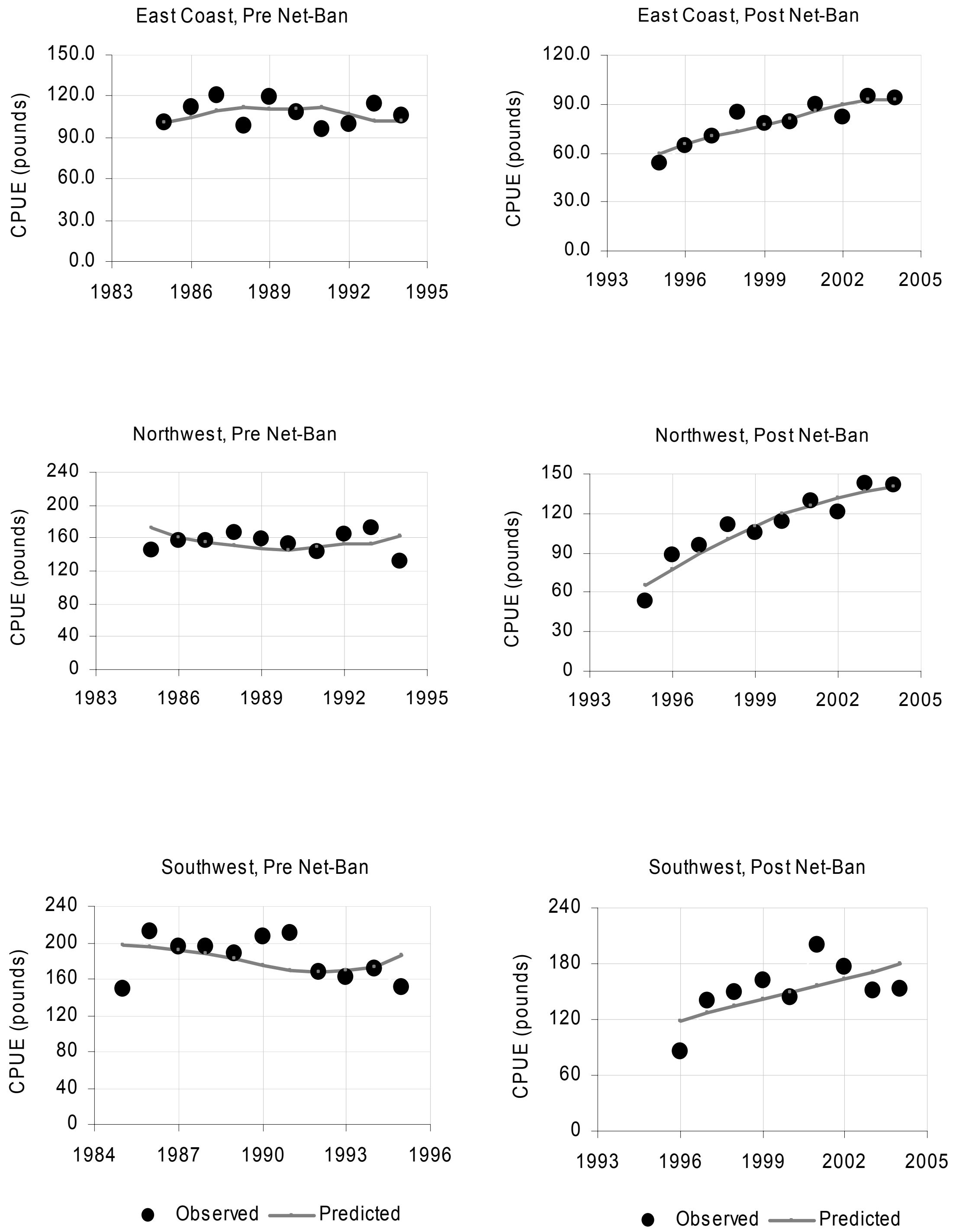


Figure 13. Fits of ASPIC-generated catch rates to the observed standardized commercial CPUE tuning indices.

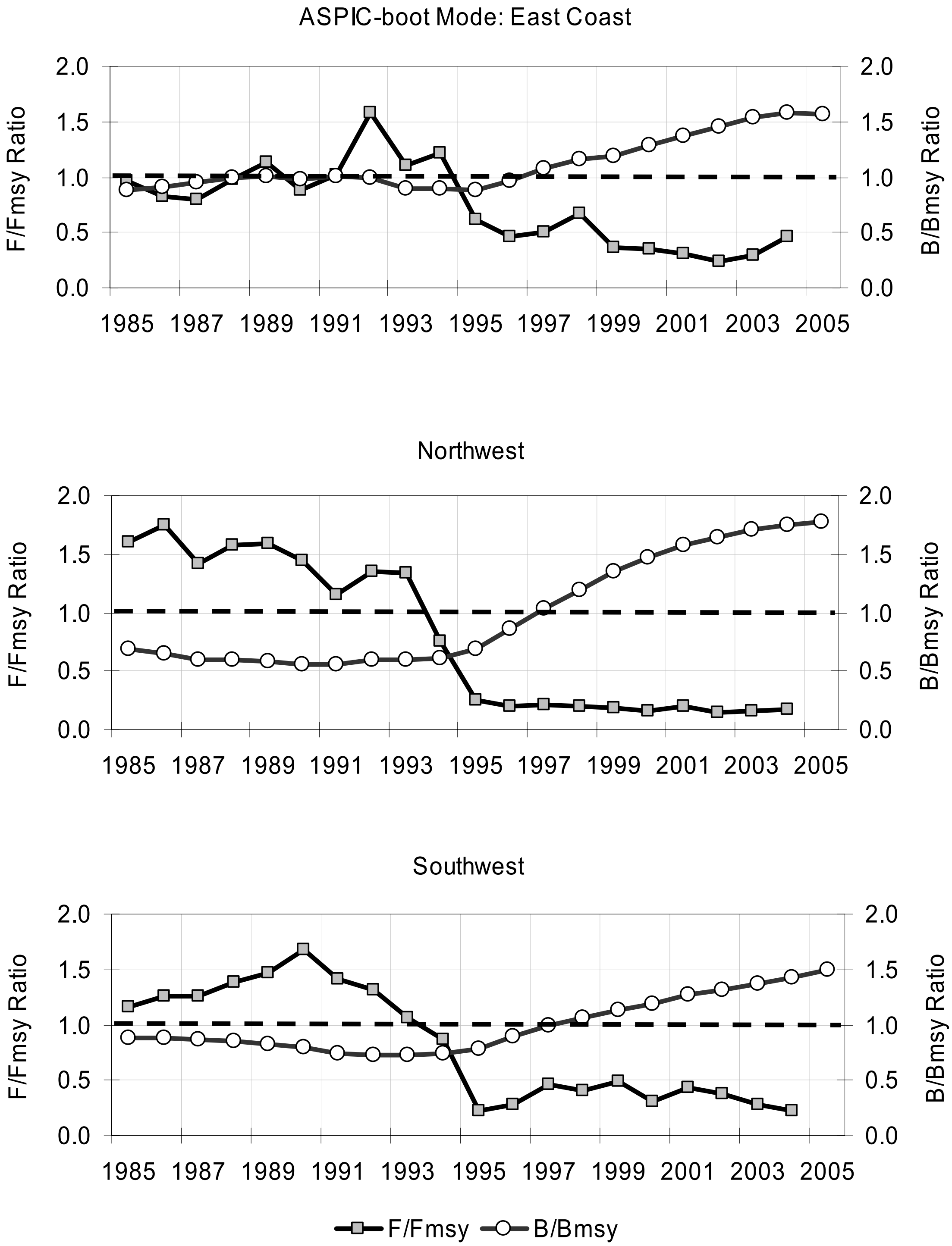


Figure 14. ASPIC estimated ratios of annual fishing mortality rate to the fishing mortality rate that would produce the long term maximum sustainable yield (F_{msy}) (solid square) and estimated ratio of annual biomass to the biomass associated with maximum sustainable yield (B_{msy}) (open circle).

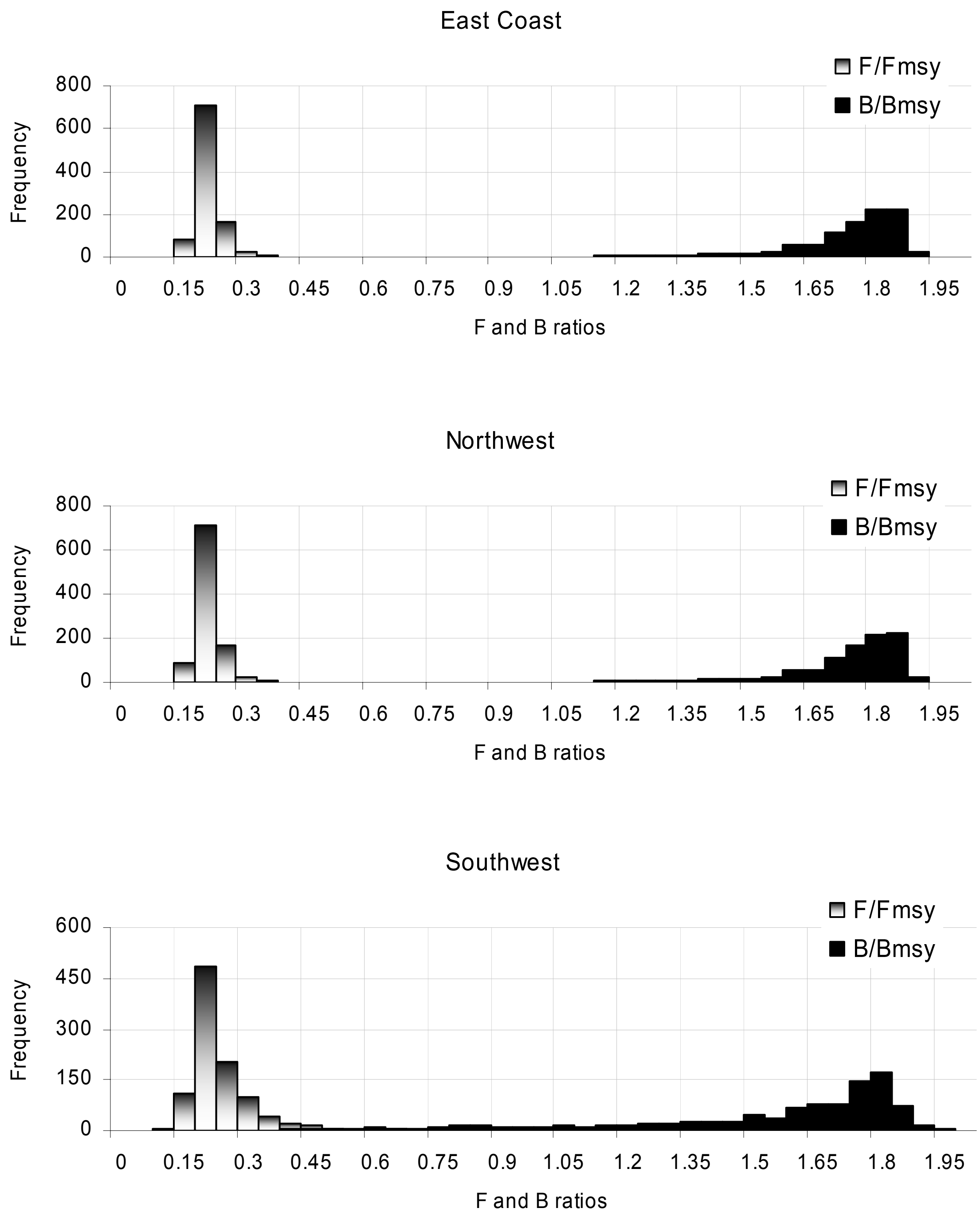


Figure 15. Likelihood profiles of F/ F_{msy} and B/ B_{msy} estimated for 2004 by the ASPIC model for the three assessment regions.

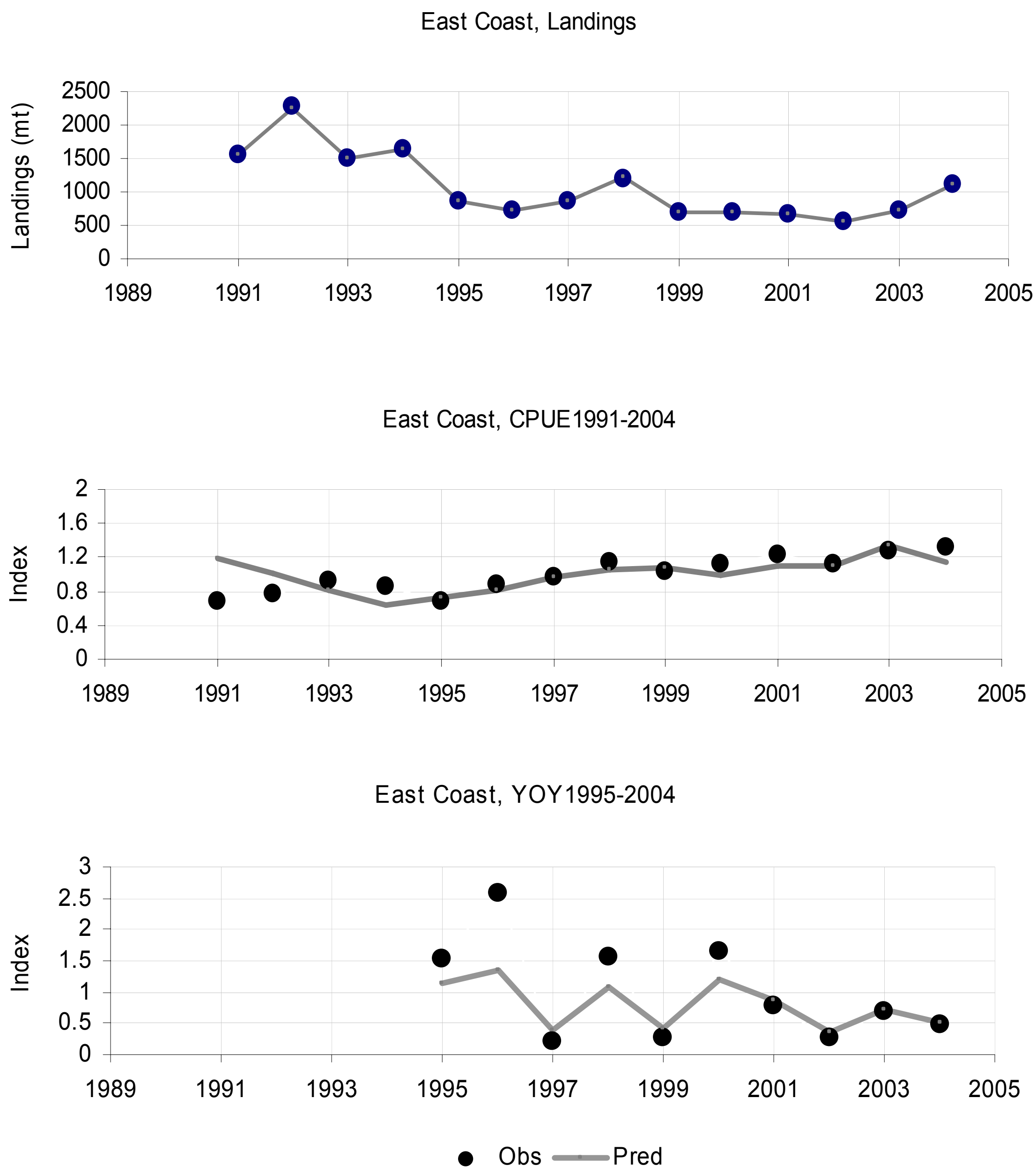


Figure 16. Estimated (line) and observed (circles) annual landings (1991-2004), commercial CPUE index (1991-2004), and juvenile index (1995-2004) from the ASAP base-run for striped mullet on the east coast.

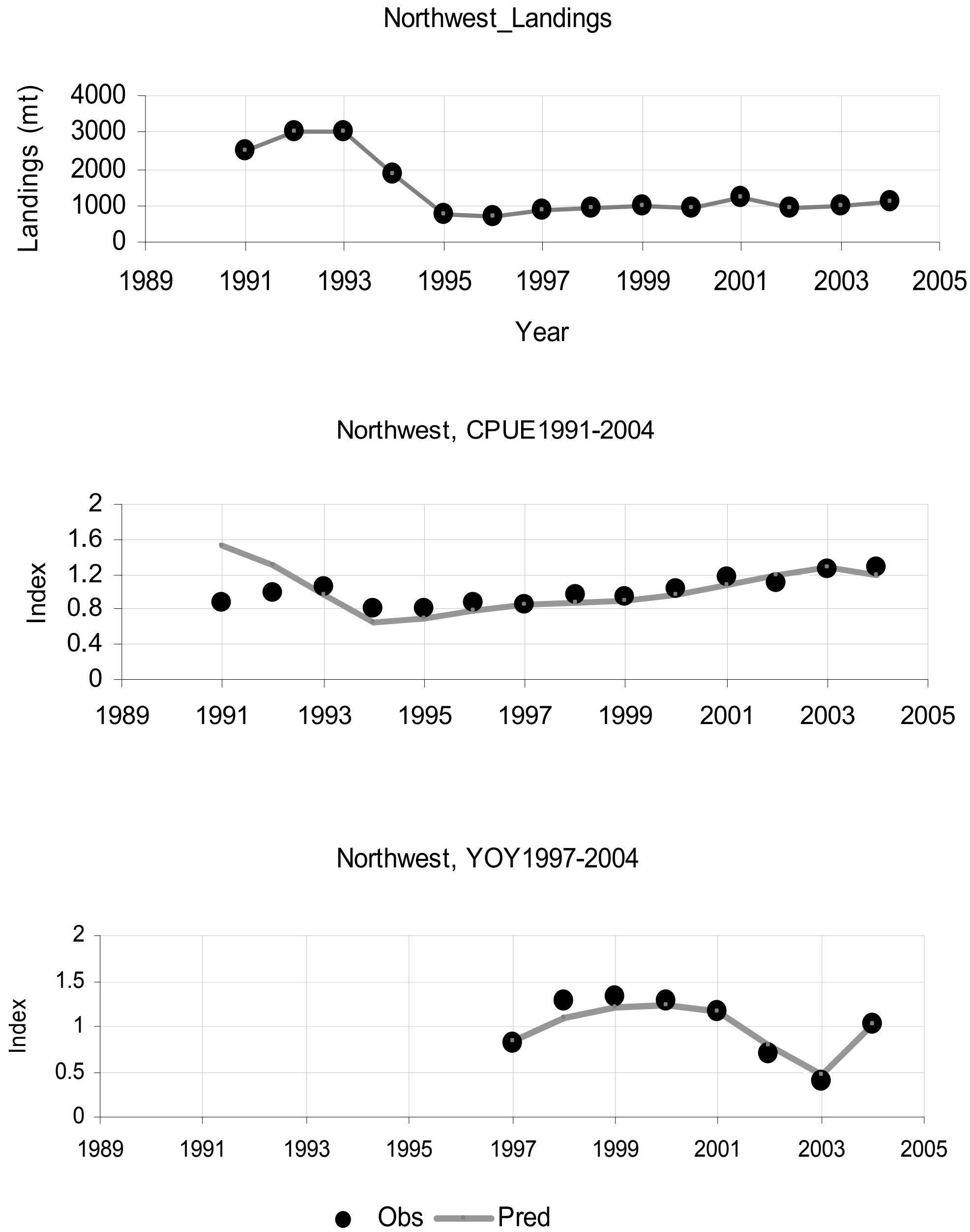


Figure 17. Estimated (line) and observed (circles) annual landings (1991-2004), commercial CPUE index (1991-2004), and juvenile index (1997-2004) from the ASAP base-run for striped mullet on the northwest coast.

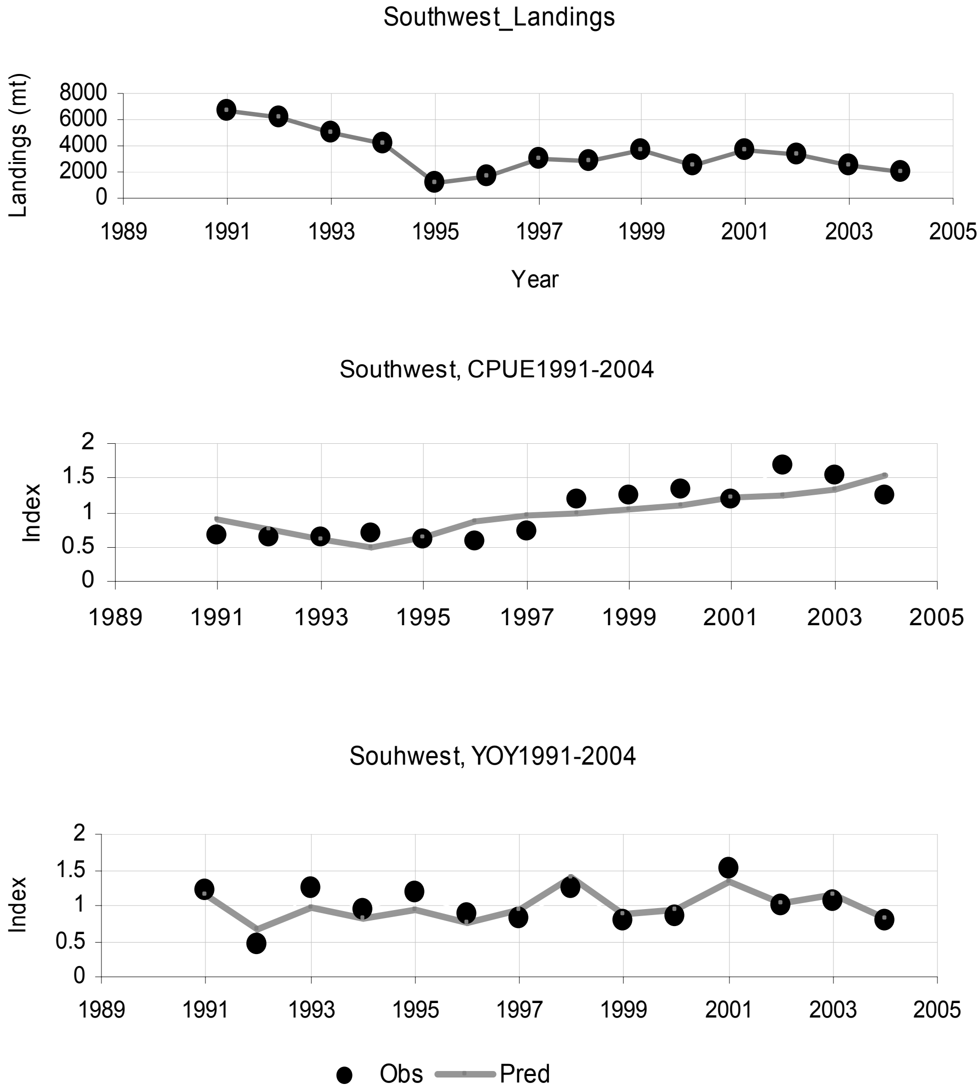


Figure 18. Estimated (line) and observed (circles) annual landings (1991-2004), commercial CPUE index (1991-2004), and juvenile index (1991-2004) from the ASAP base-run for striped mullet on the southwest coast.

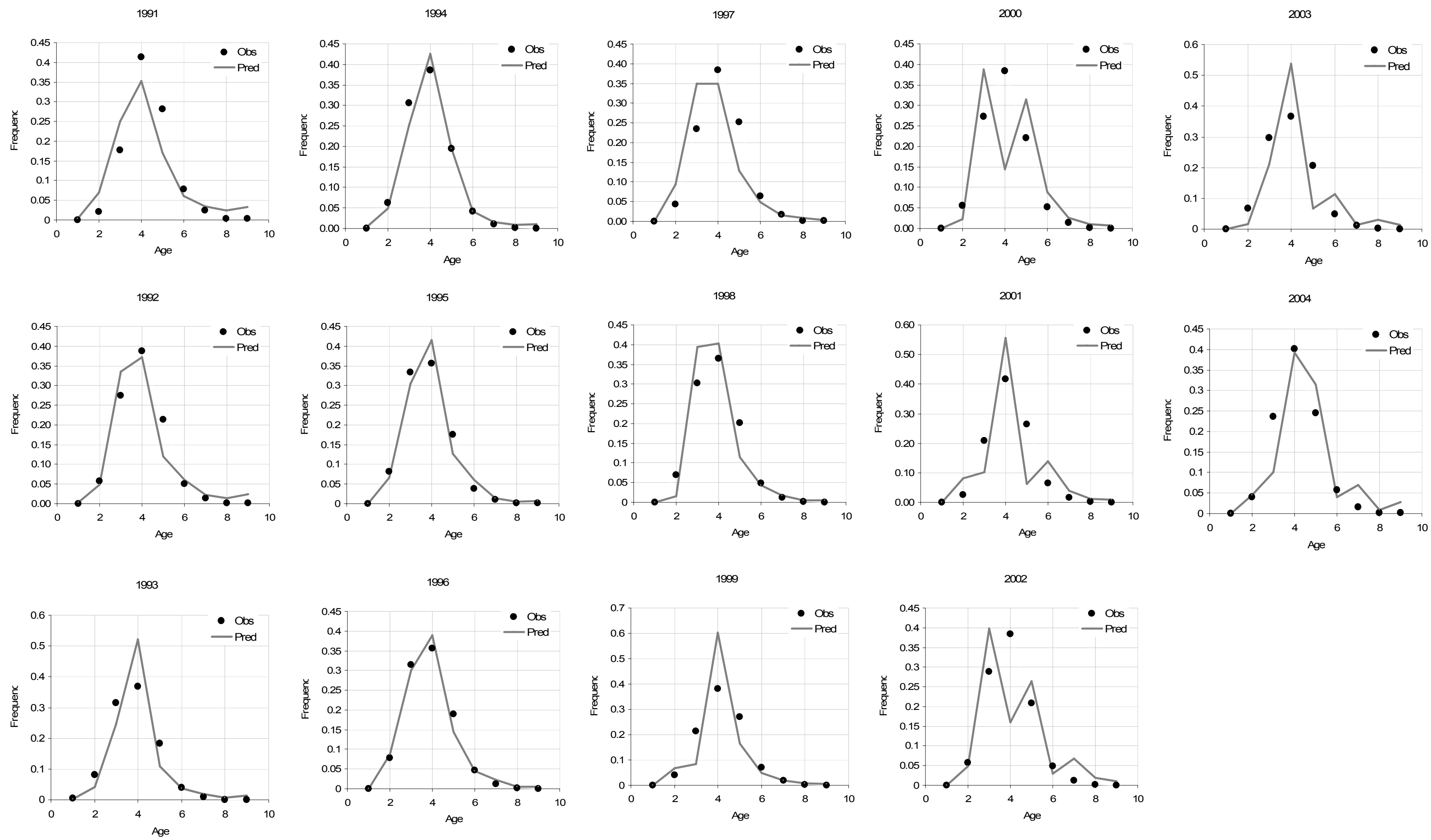


Figure 19. Estimated (line) and observed (circle) annual age compositions of striped mullet from the ASAP base run for the east coast of Florida.

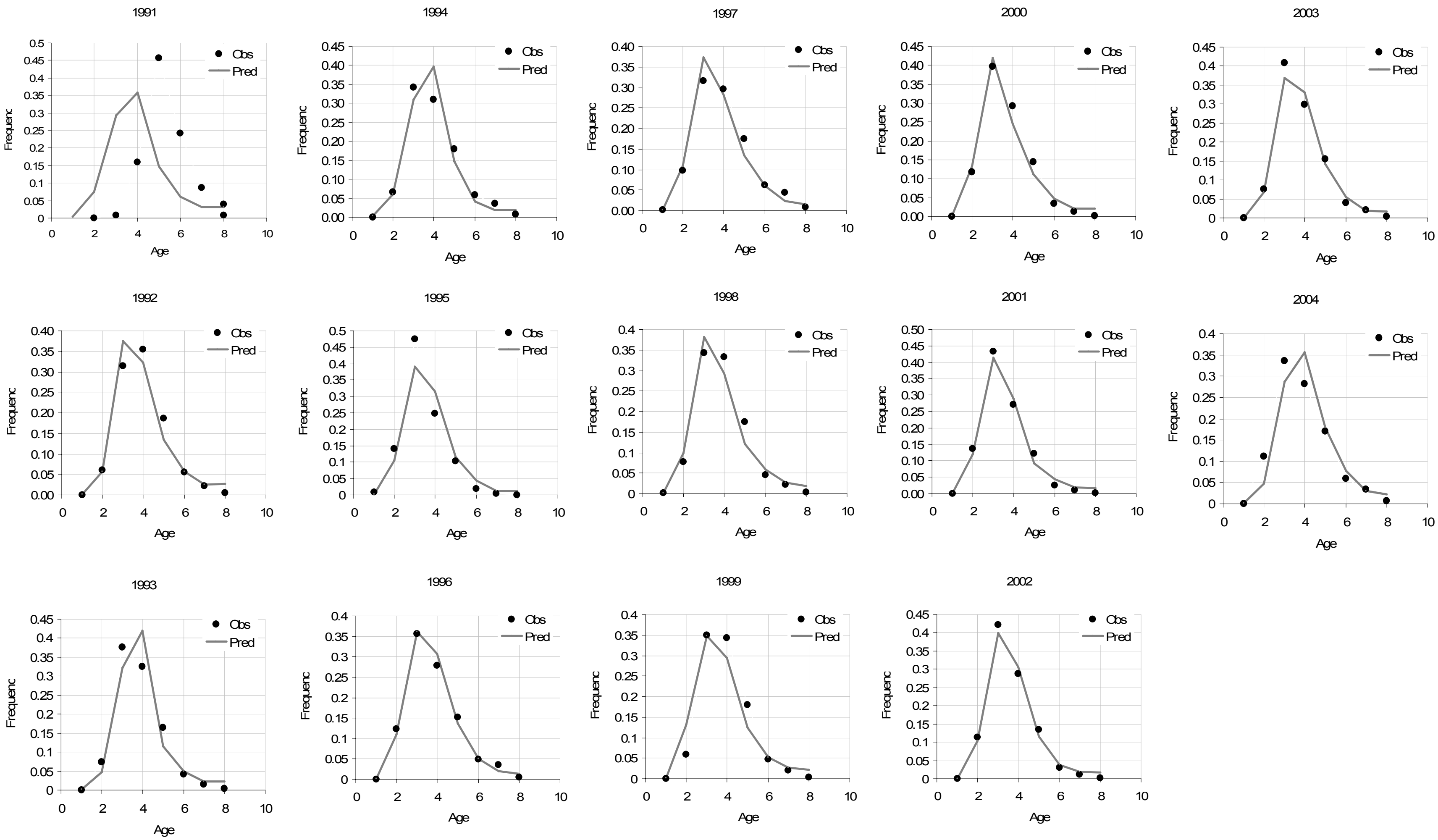


Figure 20. Estimated (line) and observed (circle) annual age compositions of striped mullet from the ASAP base run for the northwest coast of Florida.

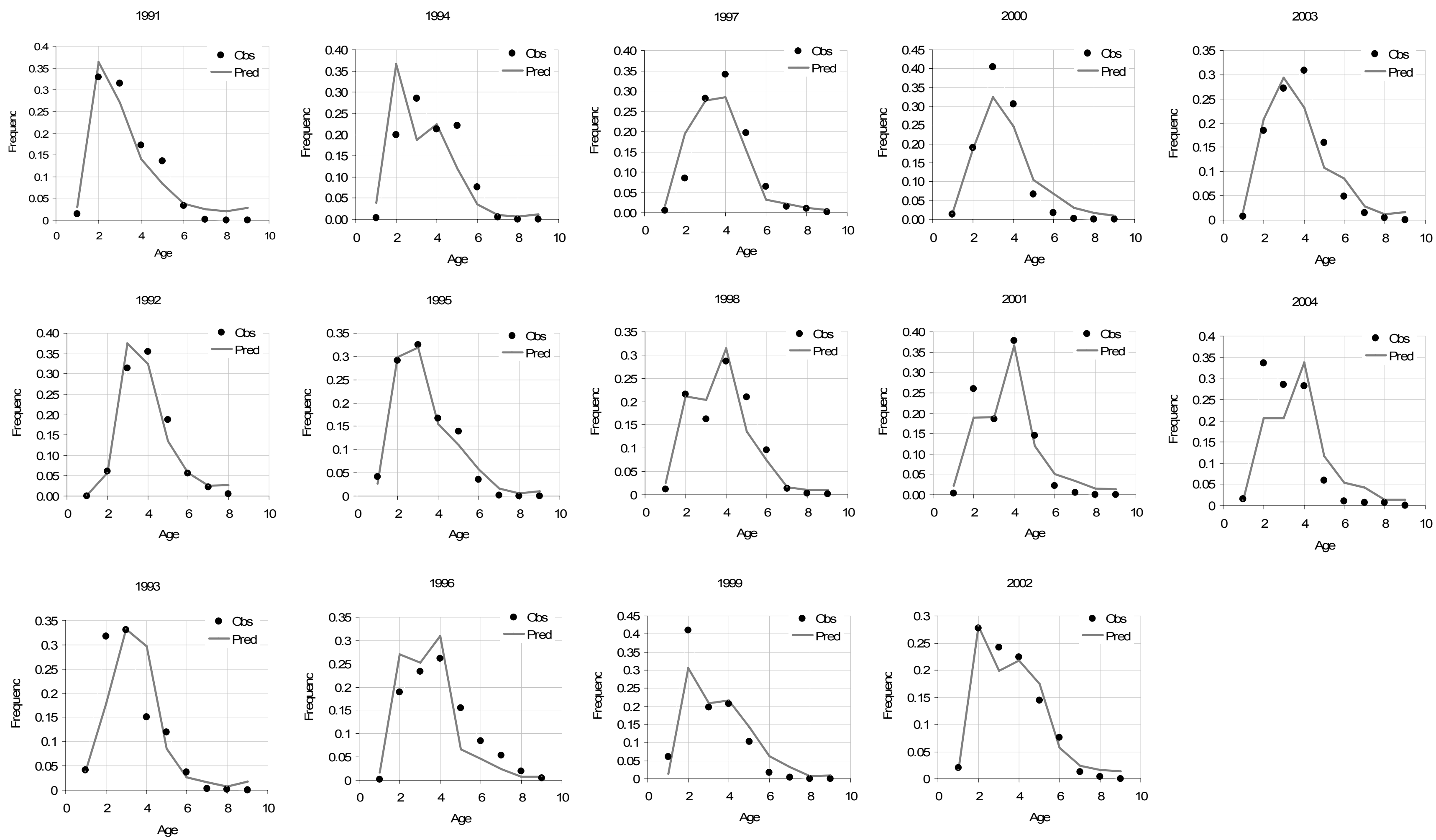


Figure 21. Estimated (line) and observed (circle) annual age compositions of striped mullet from the ASAP base run for the southwest coast of Florida.

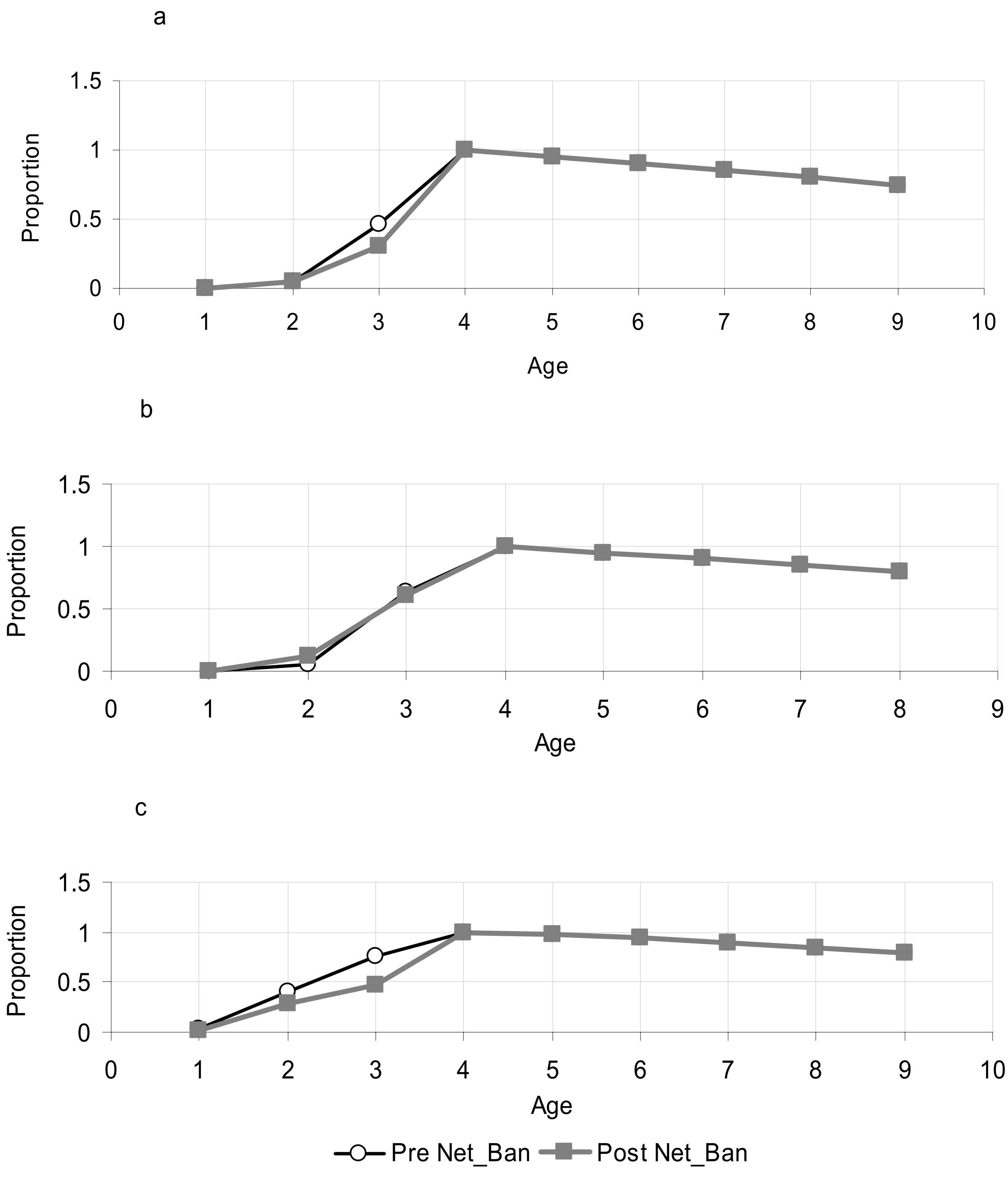


Figure 22. Estimated selectivities in the striped mullet commercial fishery during the pre (1991-1994) and post (1995-2004) net-ban periods on the east (a), northwest (b), and southwest (c) coasts of Florida.

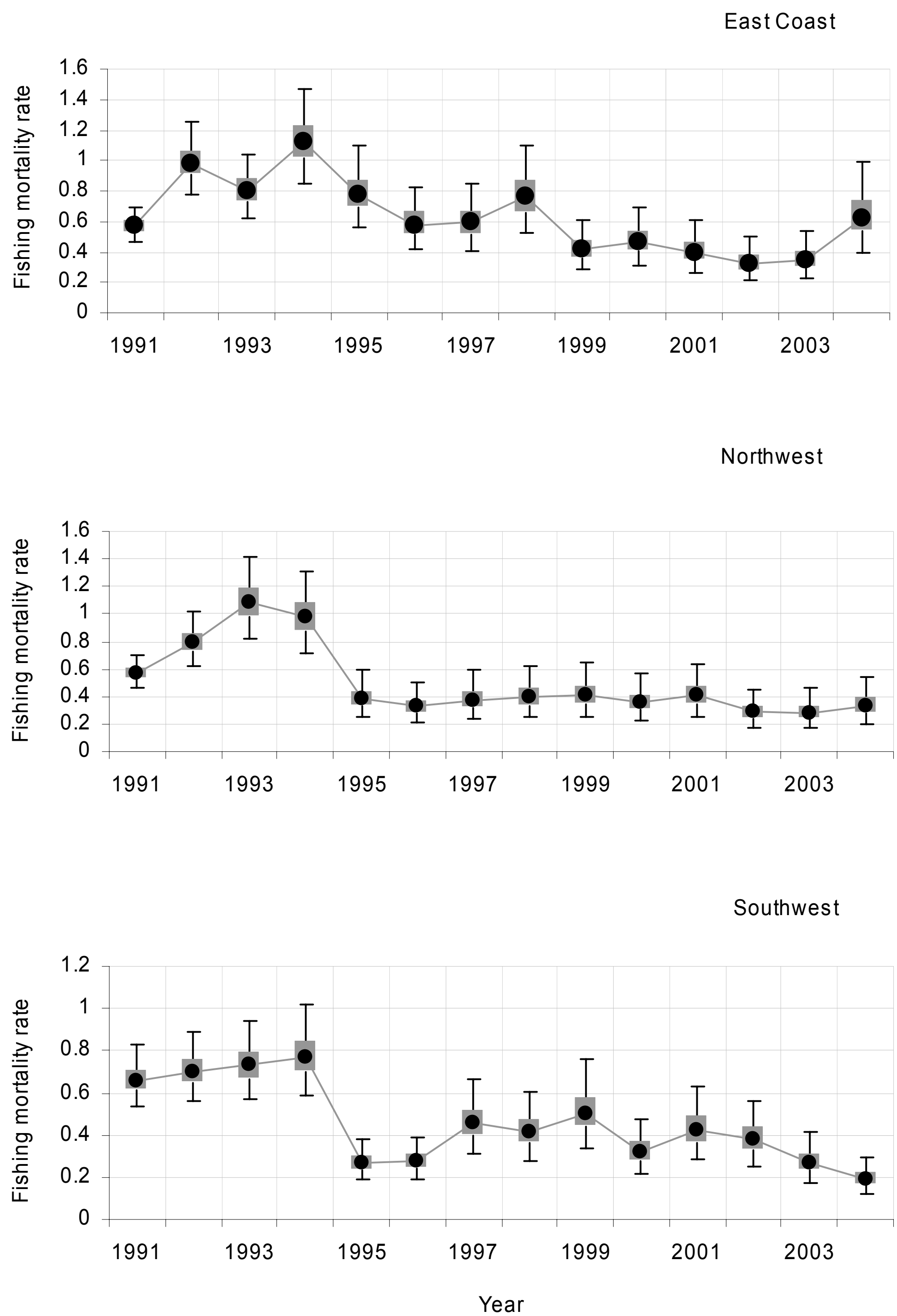


Figure 23. Estimated fishing mortality rates (fully selected) of striped mullet from the ASAP base-run for the east (a), northwest (b), and southwest (c) coasts of Florida. The vertical line is the 95% confidence interval, the box is the inter-quartiles (25 to 75 percentiles) and the black circle is the median.

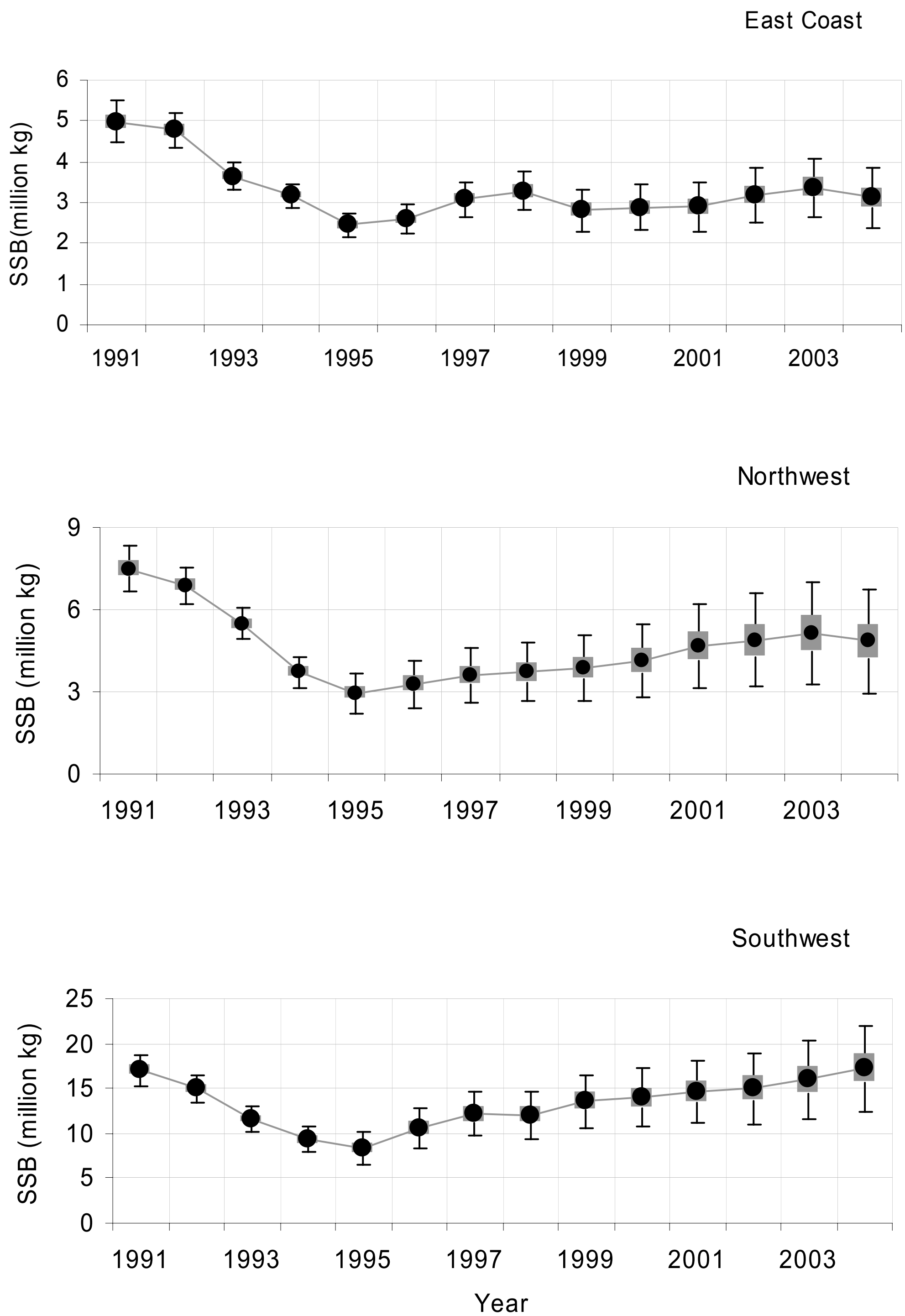


Figure 24. Estimated spawning stock biomass of striped mullet from the ASAP base-run for the east (a), northwest (b), and southwest (c) coasts of Florida. The vertical line is the 95% confidence interval, the box is the inter-quartiles (25 to 75 percentiles) and the black circle is the median.

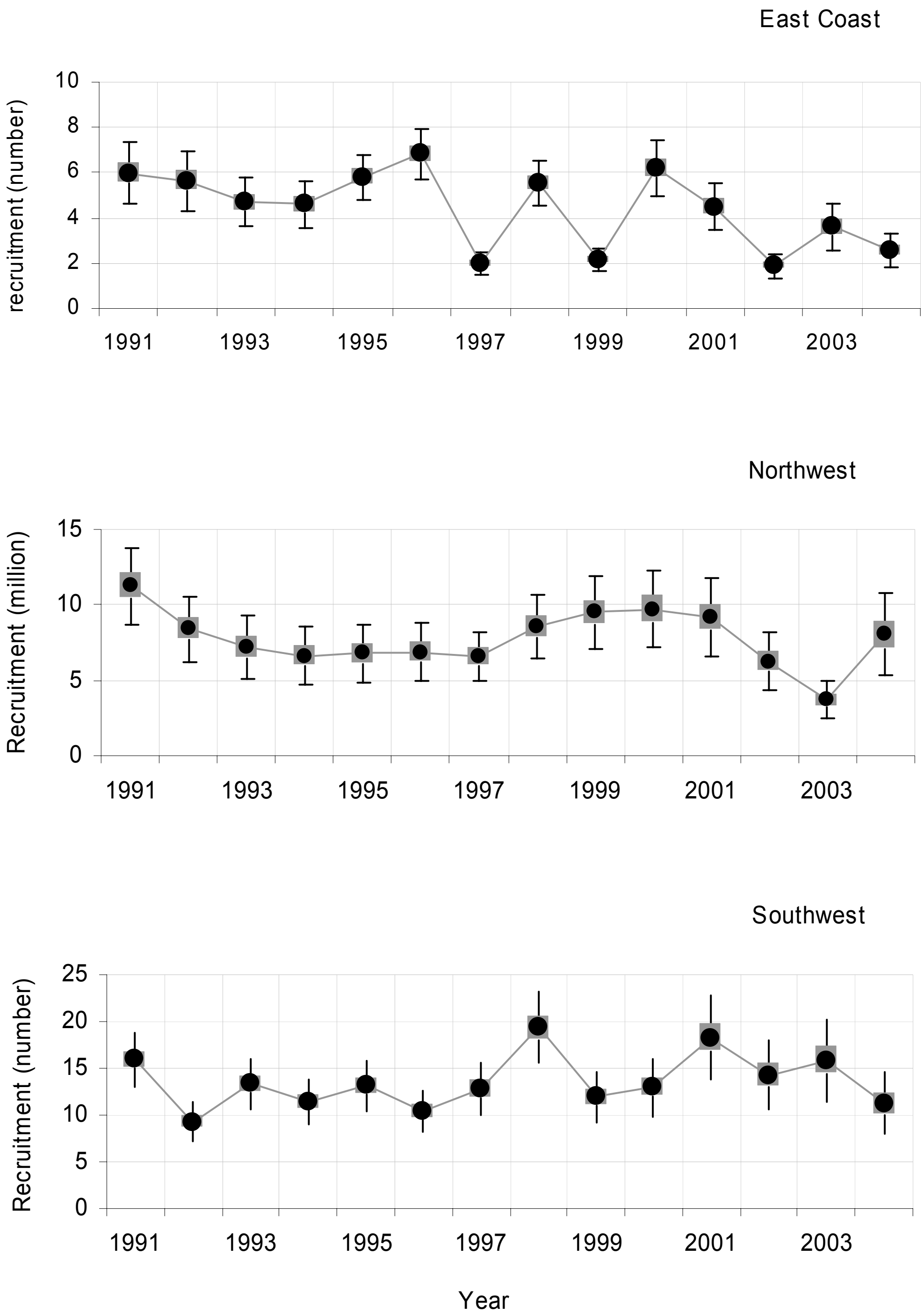


Figure 25. Estimated recruitment of striped mullet from the ASAP base-run for the east (a), northwest (b), and southwest (c) coasts of Florida. The vertical line is the 95% confidence interval, the box is the inter-quartiles (25 to 75 percentiles) and the black circle is the median.

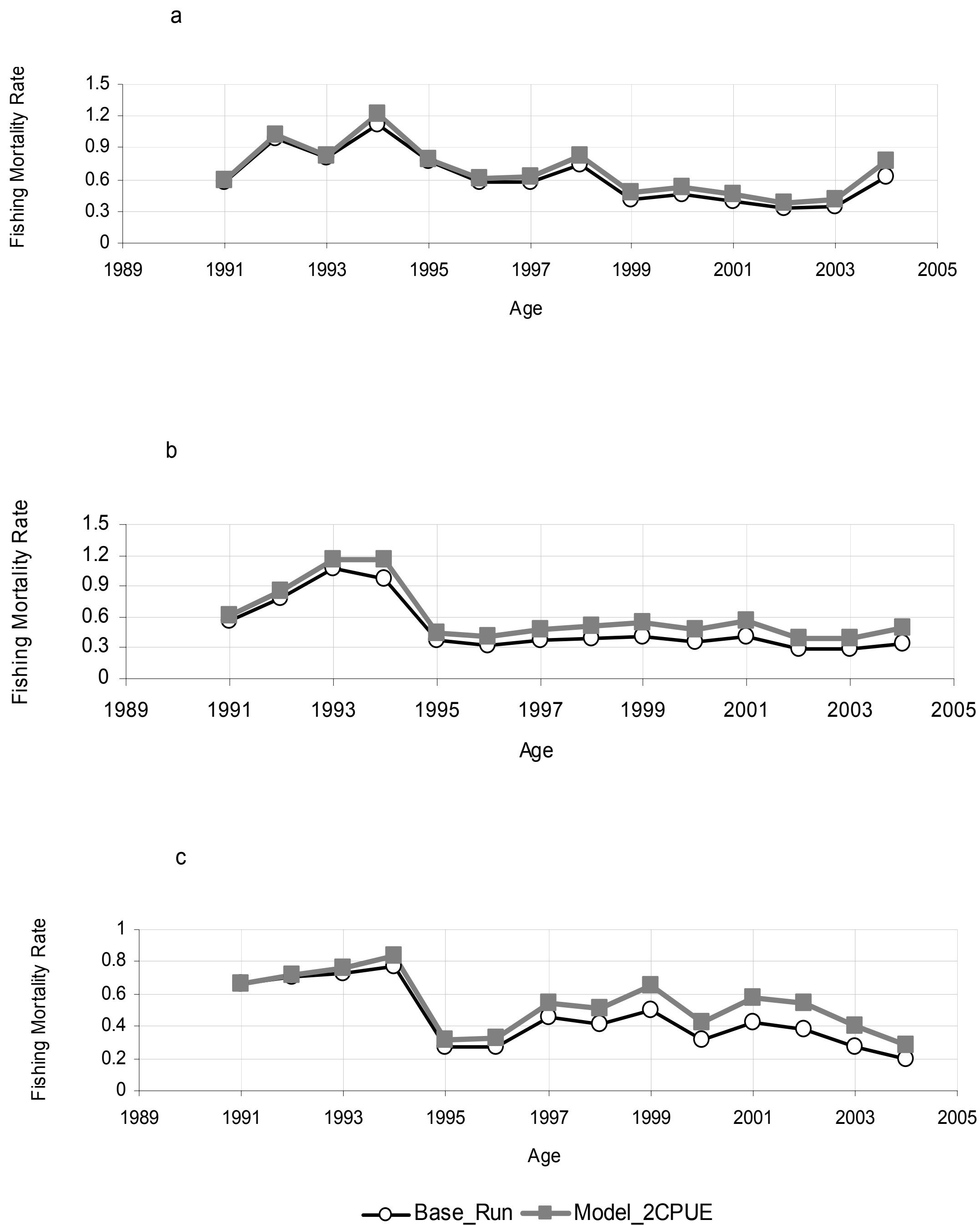


Figure 26. Comparison of fishing mortality estimates from the ASAP base runs with one CPUE time series and alternative ASAP runs with two CPUE time series (filled squres) for the east (a), northwest (b), and southwest (c) coasts of Florida.

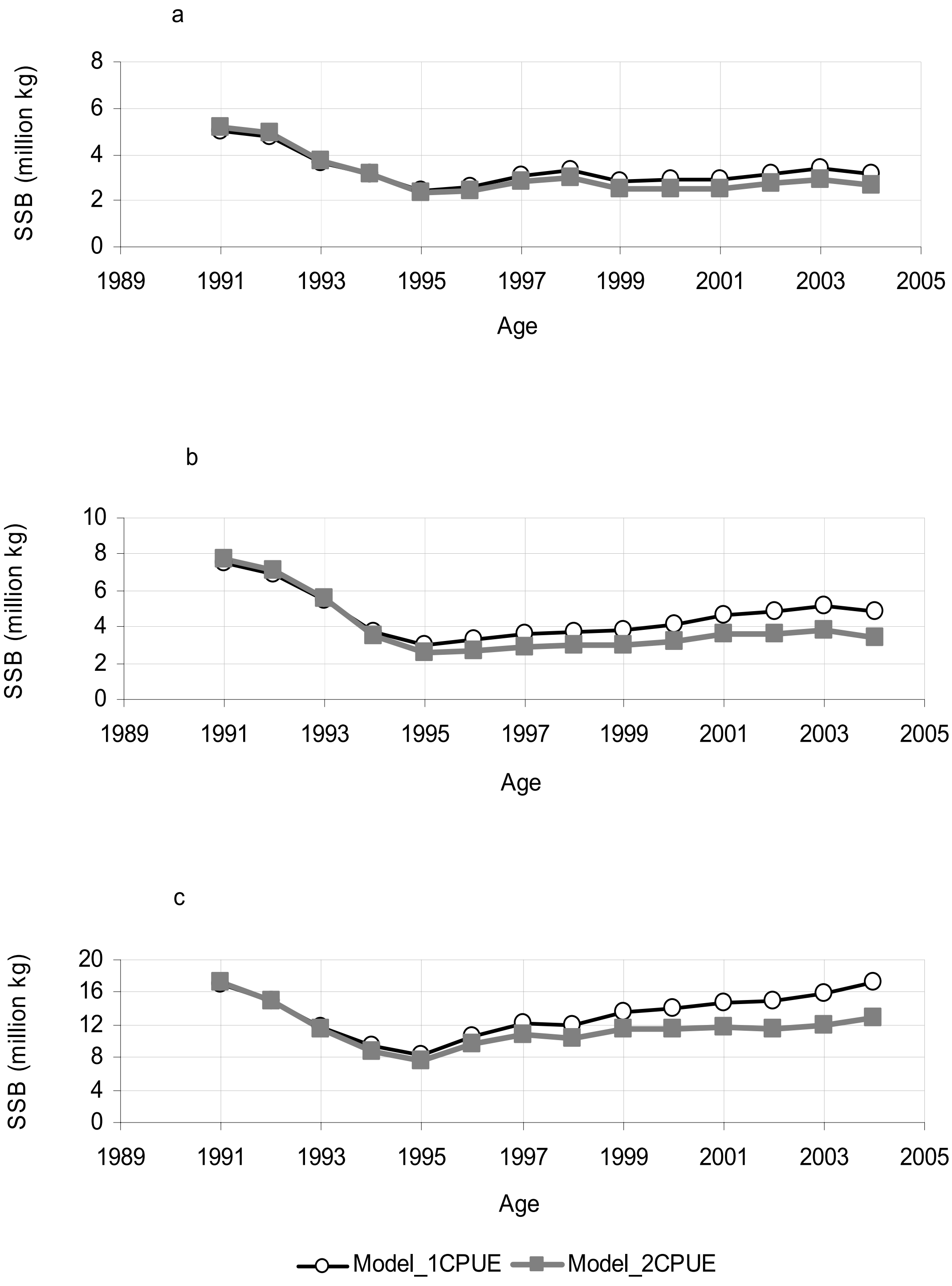
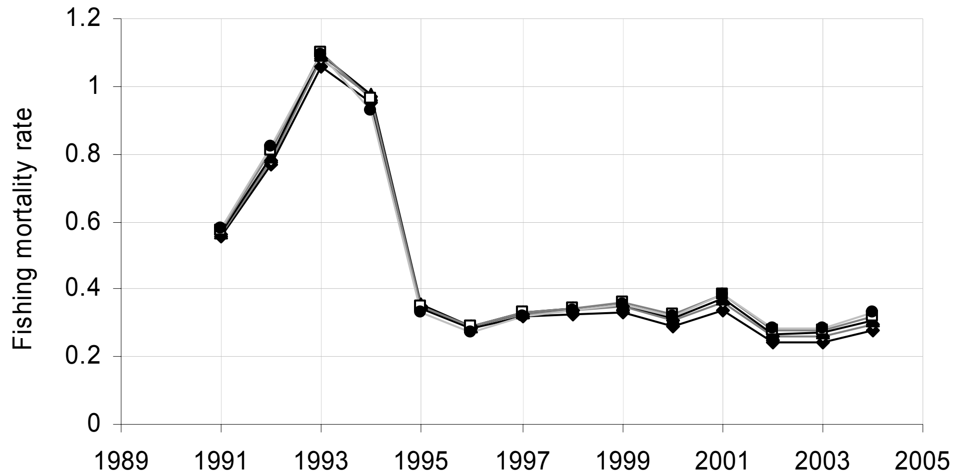


Figure 27. Comparison of spawning stock biomass estimates from the ASAP base runs with one CPUE time series and alternative ASAP runs with two CPUE time series (filled squres) for the east (a), northwest (b), and southwest (c) coasts of Florida.



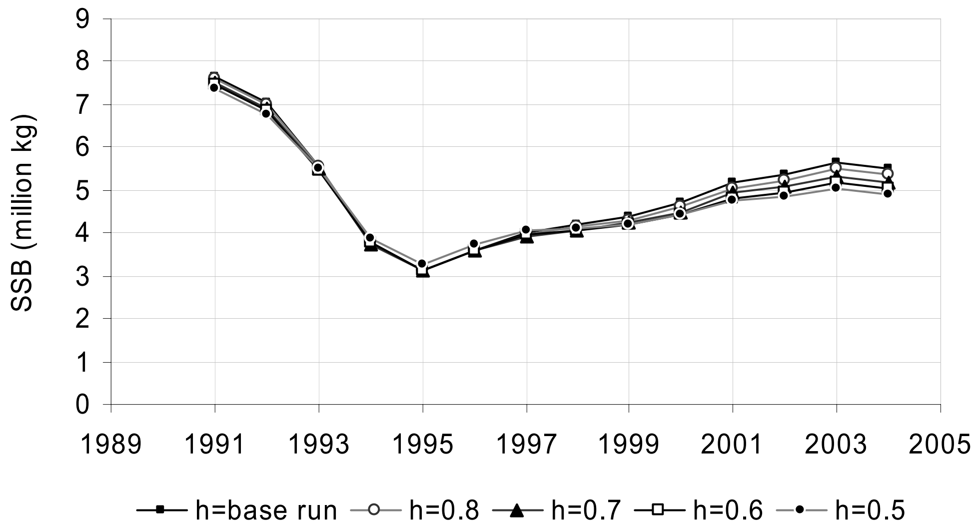


Figure 28. The ASAP fishing mortality rate and spawning stock biomass estimates for steepness (h) values ranging from 0.5 to 1.0, northwest region.