SEDAR 11

LARGE COASTAL SHARK COMPLEX

ASSESSMENT WORKSHOP REPORT

Prepared by the
SEDAR 11 Stock Assessment Panel
8 May 2006

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1. Introduction

The current assessment for the Large Coastal Shark (LCS) Complex was to be run following, as close as possible, the procedures of the Southeast Data, Assessment, and Review (SEDAR) process. The process involves three meeting Workshops: Data, Assessment, and Review. The Data Workshop (DW) for the LCS complex was held in Panama City, FL October 31st through November 4th, 2005. The Assessment Workshop (AW) was held in Miami, FL 6 – 10 February 2006. Initial data compilations and exploratory analyses for SEDAR assessments were requested from participants in the form of "working documents" to be submitted in advance and evaluated over the course of the workshop.

This Report represents the discussions, analyses, and stock status determinations for four separate assessments: 1) LCS complex, 2) sandbar shark, 3) Gulf of Mexico blacktip sharks, and 4) northwestern Atlantic Ocean blacktip sharks. These assessments are being reported in one Report as many of the indices, data, and issues overlap among assessments. All discussions were conducted in a plenary format, with analysts conducting requested sensitivities and modifications and reporting back to the panel throughout the week.

This report is divided into four main sections, paralleling the separate assessments conducted. Structure within each section was determined by the lead analyst, following some general guidelines derived from SEDARs for other species and the content previously reported from Shark Evaluation Workshops (SEWs). The LCS complex, sandbar and blacktip sharks have a history of previous assessments via the SEWs, so this report has expanded discussion on issues that had been difficult or controversial in past work, but is fairly brief on issues that are reasonably well settled. Figures and tables remain within the individual sections, and are numbered in "Section number.figure number" sequence. Lists of references to the general literature (i.e. papers other than the working documents submitted to this Workshop) also remain with the individual sections. Citations to papers submitted to this workshop as "working documents" are made in the text using the identifying numbers assigned by the Shark SEDAR Coordinator (in the form SEDAR11-AW-xx). A minority statement provided by the directed shark fishing industry regarding certain components of the sandbar shark assessment can be found in an appendix at the end the report.

This report is a complete and final documentation of the activities, decisions, and recommendations of the Assessment Workshop. It will also serve as one of 4 components of the final SEDAR Assessment Report. The final SEDAR Assessment Report will be completed following the last workshop in the cycle, the Review Workshop, and will consist of the following sections: I) Introduction; II) Data Workshop Report; III) Assessment Workshop Report; and IV) Review Workshop Report.

1.1 SEDAR 11 Assessment Workshop Terms of Reference

1. Select several modeling approaches based on available data sources, parameters and values required to manage the stock, and recommendations of the data workshop.
2. Provide justification for the chosen data sources and for any deviations from data workshop recommendations.
3. Provide estimates of stock parameters (fishing mortality, abundance, biomass, selectivity, stock-recruitment relationship, etc); include appropriate and representative measures of precision for parameter estimates and measures of model 'goodness of fit'.
4. Characterize uncertainty in the assessment, considering components such as input data, modeling approach, and model configuration.
5. Provide yield-per-recruit, spawners per recruit, and stock-recruitment analyses when appropriate.
6. Provide complete SFA criteria. This may include evaluating existing SFA benchmarks or estimating alternative SFA benchmarks (SFA benchmarks include MSY, F_{MSY}, B_{MSY}, MSST, and MFMT); recommend proxy values where necessary; provide stock control rules.
7. Provide declarations of stock status relative to SFA benchmarks: MSY, F_{MSY}, B_{MSY}, MSST, MFMT.
   Project future stock conditions (biomass, abundance, and exploitation) and develop rebuilding schedules if warranted; include estimated generation time. Stock projections will be based on constant quotas or various F criteria.
8. Evaluate the results of past management actions and probable impacts of current management actions with emphasis on determining progress toward stated management goals.
9. Provide recommendations for future research and data collection (field and assessment); be as specific as practicable in describing sampling design and sampling intensity.
10. Provide the Assessment Workshop Report (Section III of the SEDAR Stock Assessment Report) including tables of estimated values within 5 weeks of workshop conclusion. SEE NOTE.

REPORT COMPLETION NOTE: The final Assessment Workshop report is due no later than Monday, May 1 2006. If final assessment results are not available for review by workshop panelists during the workshop, the panel shall determine deadlines and methods for distribution and review of the final results and completion of the workshop report.

1.2 List of participants

Workshop participants:

Panayiota Apostolaki	CEFAS Lowestoft Lab, UK
Elizabeth Babcock	Pew Institute for Ocean Science
Ramon Bonfil	Wildlife Conservation Society
Liz Brooks	NMFS/ SEFSC Miami, FL
Enric Cortés	NMFS/ SEFSC Panama City, FL
Frank Hester	Directed Shark Fisheries, Inc
Walter Ingram	NMFS/ SEFSC Pascagoula, MS

Observers:

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Staff:

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1.3 SEDAR 11 Assessment Workshop Documents

SEDAR 11–AW–01	Apostolaki: First estimates of the status of sandbar shark stock off the eastern coast of the US
SEDAR 11–AW–02	Apostolaki: First results on the status of blacktip shark stock in the western Atlantic
SEDAR 11–AW–03	Brooks: A State-Space, Age-Structured Production Model for Sandbar Shark
SEDAR 11–AW–04	Brooks: Preliminary Runs of a State-Space, Age-Structured Production Model for Blacktip Shark
SEDAR 11–AW–05	Cortés and Babcock: Assessment of Large Coastal, Blacktip, and Sandbar Sharks using Surplus Production Methods
SEDAR 11–AW–06	Cortés and Neer: Catch history for blacktip sharks – combined regions
SEDAR 11–AW–07	Freitas: Apex Predator Protection: Assessing Shark Landings and Conservation Measures in Rhode Island
SEDAR 11–AW–08	Hester and Hudson: Some Cautions on the Use of Pelagic Longline Logbook Data to Assess the Abundance of Large Coastal Sharks
SEDAR 11–AW–09	Merson: Length and age at maturity of the sandbar shark, *Carcharhinus plumbeus*
SEDAR 11-AW-10	Brooks and Cortés: Issues related to Biological Inputs to Blacktip and Sandbar assessments

2. SUMMARY OF DATA DOCUMENTS AND ISSUES

Several documents were submitted for review by the Assessment Panel regarding data and indices recommended for use by the Data Workshop. Document summaries and associated Panel discussions, if applicable, follow.

SEDAR11-AW-06
Catch history for blacktip sharks – combined regions
Summary: The Data Workshop Panel recommended that blacktip sharks should be assessed as two separate stocks, Gulf of Mexico and western Atlantic Ocean. Industry representatives disagreed with this decision and produced a Minority Opinion on the matter for inclusion in the Data Workshop Final Report. In response to that concern, the lead analysts agreed to conduct a sensitivity run for blacktip sharks with regions combined. Indices of relative abundance for the combined region analysis were developed, when necessary, for the blacktip series discussed by the Indices Working Group in the DW Final Report and appended to the appropriate DW Working papers. This document provides a description of how the catch history for this sensitivity analysis was developed.

SEDAR 11-AW-08
Some Cautions on the Use of Pelagic Longline Logbook Data to Assess the Abundance of Large Coastal Sharks
Summary Abstract: We challenge four assumptions used in constructing the Pelgaic Log Indices for blacktip sharks (*Carcharhinus limbatus*). These and our accompanying comment are:

1) CPUE reflects only change in abundance. We submit that the initial declines shown by the indices are too steep to be plausible if only change in abundance is involved.
2) Sampling covers the range of the fishery. The areas used in the analysis are too large to detect effects from closures of nearshore fishable grounds where most blacktip occur.
3) CPUE correctly reflects what was caught. There is a great difference in the species composition in catches reported in the Pelagic Log data and the Pelagic Observer Program data. Possible explanations are that other species were misidentified as blacktip shark, or that the Pelagic Log data include many inshore sets in the early years of the series.
4) Availability and catchability are constant over the period. Regulations implemented between 1992 and 1994 rather than a drastic decline in abundance can explain the steep decline in CPUE.

Document SEDAR 11-AW-08 discussed concerns with using the Pelagic Log index as a base case index as recommended by the Data Workshop. It asserted that a series of regulatory changes implemented between 1992 and 1995 affected the fisheries for nearshore large coastal shark species, particularly sandbar and blacktip by closing traditional areas where CPUE was high, and because of the anti-finning and 4000 lb trip limit causing a shift in targeting from blacktip to sandbar in the Atlantic. It was also noted that there was a significant discrepancy between the species composition between observer and commercial data. The point was brought up that observer data was collected in early years for swordfish/tunas etc., so observers were not

sent on directed shark boats. This could explain the discrepancy. Misidentification (recording black-tipped sharks [i.e. spinners, etc.] as blacktip shark) was another explanation offered.

The Panel was informed by G. Ortiz (NMFS/ SEFSC Miami, FL) that the Pelagic Log database consists of two types of gear: bottom longline (accounting for approximately 2% of the data) and pelagic longline. It was further noted that bottom longline records accounted for 50% of the catch records for LCS. There was much discussion about this fact and it was recommended that the Pelagic Log index be recalculated using only the pelagic records. This was completed by Tuesday morning and the new index provided to the AW Panel.

The consensus decision was to continue with the re-analyzed index despite the minority opinion presented in the DW Report and the paper presented at the AW (SEDAR 11-AW-08**)** as the panel felt the factors used in the standardization procedure of the revised index addressed the majority of the issues raised. As there was still some concern regarding the appropriateness of the index by one panel member, two sensitivity runs were agreed upon:

1) removing the Pelagic Log index
2) excluding 1992, 1993, and 1994 from the index for Blacktip Atlantic analysis in an to attempt to capture the adjustment by the fleet to the implementation of management polices during the first years after implementation

SEDAR 11-AW-09
Length and age at maturity of the sandbar shark, *Carcharhinus plumbeus*
Summary: The Data Workshop Panel recommended using the maturity ogive for sandbar sharks presented in document LCS05/06-DW-47. The industry members of the Panel questioned the ogive, specifically citing what they believed to be a discrepancy between the ogive developed using the historical NMFS Reproductive Database versus the samples collected directly by Merson during her directed reproductive study. To address this issue, along with the request to see the distribution in time of the samples in the NMFS database and, if possible, conduct an additional analysis by decade, Merson conducted further analyses which are described herein. This additional analysis did not differ from the information recommended by the Life History Working Group during the DW, with both data sets indicating size and age at 50% maturity of 156 cm FL and 18 years or 158 cm and 19 years for the Merson data and the NMFS Reproductive database, respectively. The NMFS Reproduction Database covered samples over three decades however the number of samples was deemed not sufficient to conduct a rigorous temporal comparison of length at maturity.

One AW panelist felt that the updated analysis still failed to address the industries' concerns. Outstanding issues including 1) looking at various time periods, 2) looking at slopes, 3) looking at differences by time, and 4) more statistical examination of the data, specifically the underlying distributions. After additional discussion regarding how the ages estimates used by Merson were obtained (length-age conversion equation rather than direct ageing), the AW Panel consensus was that the new analysis presented addressed the issues raised during and after the Data Workshop and chose to retain the ogive recommended by the DW Panel.

SEDAR 11-AW-10
Issues related to Biological Inputs to Blacktip and Sandbar assessments

Summary: Calculations based on the mean values agreed to by the DW as the best estimates for life-history parameters produce steepness values less than 0.2, the mathematical limit for that parameter. The only life history parameter estimated in the model is pup-survival; if the base case values for maturity, pup-production, and natural mortality at age-1+ are not altered, then in order for steepness to be above 0.2, pup survival must be >0.8 (or in the case of the Blacktip Gulf of Mexico model, pup survival must be >0.9). Considering that survival at age 1 was estimated to be in the range of 0.7-0.77 for these stocks, pup survivals of 0.8-0.9 may be unrealistically high. This document describes various ways to modify the biological input parameters in order for steepness to not hit its lower limit and provides rationale for the various alternatives.

Other data discussions

Finally, there was discussion about the Large Pelagic Survey (LCS05/06-DW-9) index. This recreational index was reanalyzed after the DW, following the recommendation of the Data Workshop Panel to use a zero-inflated binomial distribution as an attempt to decrease the large CVs. The reanalysis successfully reduced the CV values by half or more for most years; however one AW panelist continued to express concern with the size of the CV values. It was noted that despite reducing the CV values overall, the CV value in 1993 still increased by a factor of five over the 1992 value. It was suggested this may be related to changes in bag limits imposed that year; however, it was noted by an observer that this data set reports on both catch and landings, so regulatory changes and bag limits should not be of great concern. It was further noted that the frequency of occurrence also decreased after 1993, which will affect the CV values.

The suggestion of not using this index as an equal weighted index was proposed. However, sensitivity runs indicated that the model output was not significantly affected by changing the weighting method. Finally, it was noted that the standard error for the entire time series was similar; reflecting that the variability was relatively constant over time. It was decided to follow the Data Workshop recommendations and include the modified LPS series.

LARGE COASTAL SHARK COMPLEX ASSESSMENT

3. LARGE COASTAL SHARK COMPLEX ASSESSMENT

3.1 Summary of LCS Working Documents

SEDAR11-AW-05
Assessment of Large Coastal, Blacktip, and Sandbar Sharks using Surplus Production Methods
We used two complementary surplus production models (BSP and WinBUGS) to assess the status of three Large Coastal Shark (LCS) groupings, two stocks of blacktip shark, and a single stock of sandbar shark identified as baseline scenarios in the LCS Data Workshop report. Both methodologies use Bayesian inference to estimate stock status, and the BSP further performs Bayesian decision analysis to examine the sustainability of various levels of future catch. Extensive sensitivity analyses were performed with the BSP model to assess the effect of different assumptions on CPUE indices and weighting methods, catches, intrinsic rates of increase, initial depletion, and importance function on results. Baseline scenarios for the three LCS groupings considered predicted that the stock status is not overfished nor overfishing is occurring. Using the inverse variance method to weight the CPUE data changed the predictions on stock status for the LCS grouping, which would then be overfished, with overfishing occurring. The sandbar shark stock was estimated to be significantly depleted (64-71% depletion from virgin level). The Gulf of Mexico blacktip shark stock was healthy (depletion of only 8-23% of virgin level), whereas results for the Atlantic blacktip shark stock from the BSP and WinBUGS models conflicted. The BSP model predicted a considerable level of depletion for this stock regardless of the CPUE weighting method used. In contrast, the assessment of a single blacktip shark stock (GOM+ATL) resulted in very consistent results, with all models predicting a healthy status (depletions of only 10-16% of virgin level). Using the higher values of r from the 2002 SEW or accounting for some depletion from virgin levels in the first year of the model did not affect conclusions. Several assumptions on catches (notably changing the high value of recreational catch in 1983) also had no effect on conclusions. Removing the VIMS CPUE series from the LCS scenario reversed the conclusions on stock status when using inverse variance weighting, highlighting the influence of this series on results; removing the Pelagic Log CPUE series from the ATL blacktip shark analysis also drastically reversed the conclusions on stock status. Fitting one CPUE series at a time had a larger effect on results: the Pelagic Log series greatly influenced conclusions for the three LCS groupings and GOM and ATL blacktip shark, whereas the VIMS series affected conclusions on the two groups for which it is available, LCS and sandbar shark.

3.2 Background

The Large Coastal Shark (LCS) complex has traditionally been assessed through Shark Evaluation Workshops (SEW) using surplus production methods because it consists of a variety of species with widely varying life histories and for some of which both biological and fishery data are very limited, preventing the use of single-species, age-structured models in many cases.

3.3 Available Models

Two surplus production modeling approaches were available for discussion (SEDAR11-AW-05)

1) Bayesian surplus production model (BSP)
2) WinBUGS

The Bayesian Surplus Production (BSP) model program fits a Schaefer model to CPUE and catch data using the SIR algorithm. The BSP software is available, for example, in the ICCAT catalog of methods (McAllister and Babcock 2004) and has been used as the base model in previous assessments of large coastal sharks.

The WinBUGS implementation of the Schaefer surplus production model uses Gibbs sampling, an MCMC method of numerical integration, to sample from the posterior distribution (Spiegelhalter et al. 2000). The model was originally developed by Meyer and Millar (1999a) and modified by Cortés (2002) and Cortés et al. (2002) to apply it to small and large coastal sharks, respectively.

The BSP was selected as the final model because it generally provides a more flexible framework for examining the effects of various modeling issues (e.g., type of importance function used for Bayesian estimation, multiple CPUE weighting methods) and conducts Bayesian decision analysis to project population status into the future and estimate performance indicators under various management policies.

3.4 Model Scenarios

The Assessment Workshop (AW) panel recommended that surplus production models be used to assess the status of the three LCS groupings identified by the Data Workshop (DW) panel and report (the only type of model available for these complexes). Additionally, surplus production models were also used to assess the status of blacktip (Gulf, Atlantic, and areas combined) and sandbar sharks in document SEDAR11-AW-05, but those results are not presented herein (additional results can also be found in the addendum to SEDAR11-AW-05). In the present document we assessed the status of 1) LCS as originally defined (consisting of 22 species), 2) LCS without species presently classified by NMFS as prohibited (11 species), and 3) LCS without prohibited species, sandbar, or blacktip sharks. These three groupings respond to an effort on the part of the DW participants to attempt to examine the effect of prohibited species and the two most important species in the fishery—blacktip and sandbar sharks—on stock assessment results.

3.5 Discussion of weighting methods

The Data Workshop recommended that *equal weighting* for assigning weights to the different CPUE time series available during model fitting should be used for the baseline runs. The panel

discussed the advantages and disadvantages of the *equal weighting* vs. the *inverse CV weighting* methods:

Equal weighting ignores the better quality of some data (smaller CVs) but is more stable between assessments because yearly changes on CVs in a given CPUE series do not affect the importance of that time series for the overall fit.

Inverse CV weighting can provide better precision as it tracks individual indices, however, it could be less stable between assessments due to changes on the relative 'noise' of each time series. This method may also not be appropriate in cases in which different standardization techniques have been used for the standardization of the series and therefore, the same value of CV might reflect different levels of error depending on the CPUE it corresponds to.

It was requested by one Panelist to manually weight the indices that cover larger geographic areas to have a stronger influence on the model. The group commented that, while that may be possible in a spatially explicit model, a great deal more data would be required than presently available.

The Assessment Panel decided that equal weighting would be the default weighting method for the current assessment but noted that, as there is at present no objective way to decide which of these two methods is superior other than comparing model convergence diagnostics, future assessments may need to reexamine this issue.

3.6 Methods

3.6.1 Bayesian Surplus Production (BSP) Model description

The Bayesian Surplus Production (BSP) model program fits a Schaefer model to CPUE and catch data using the SIR algorithm. The BSP software is available, for example, in the ICCAT catalog of methods (McAllister and Babcock 2004) and has been used as the base model in previous assessments of large coastal sharks. Herein we used the discrete-time version of the model (although the continuous form is also implemented by the software), so that:

$$B_{t+1} = B_t + rB_t - \frac{r}{K} B_t^2 - C_t$$

where B_t= biomass at the beginning of year t, r is the intrinsic rate of increase, K is carrying capacity and C_t is the catch in year t.

The expected catch rate (CPUE) for each of the available time series j in year t is given by:

$$\hat{I}_{j,t} = q_j B_t e^{\varepsilon_t}$$

where q_j is the catchability coefficient for CPUE series j, and ε_t is the residual error, which is assumed to be normally distributed. The program allows for a variety of methods to weight

CPUE data points. As recommended in the DW report, we used equal weighting (or no weighting) in all baseline scenarios. The model log-likehood is given by:

$$\ln L = -\sum_{j}\sum_{y}\frac{\left[\ln(I_{j,y}) - \ln(\hat{q}_j \hat{B}_y)\right]^2}{2\sigma_{j,y}{}^2}$$

were $I_{j,y}$ is the CPUE in year y for series j, $\hat{q}_j$ is the constant of proportionality for series j, $\hat{B}_y$ is the estimated biomass in year y, and $\sigma_{j,y}{}^2$ is the variance (=1/weight; in this case weight=1) applied to series j in year y.

In the inverse variance method, the annual observations are proportional to the annual CV^2 (if available) and the average variance for each series is equal to the MLE estimate. The log likelihood function is expressed as:

$$\ln L = -\sum_{j=1}^{j=s}\sum_{t=1}^{t=y}\left\{\frac{0.5}{c_j CV_{j,t}{}^2 \hat{\sigma}_j{}^2}\left[\ln\left(\frac{I_{j,t}}{q_j N_t}\right)\right]^2 - 0.5\ln(c_j CV_{j,t}{}^2 \hat{\sigma}_j^2)\right\}$$

where s is the number of CPUE series, y is the number of years in each CPUE series, $CV_{j,t}{}^2$ is the coefficient of variation for series j in year t, c_j is a constant of proportionality for each series j chosen such that the average variance for each series equals its estimated average variance, σ_j^2 (the MLE estimate). The catchability coefficient for each time series (q_j) is also estimated as the MLE such that:

$$\hat{q}_j = e^{\left(\frac{\sum_{t=1}^{t=y}\left(\ln(I_{j,t}) - \ln(\hat{B}_t)\right)/c_j CV_{j,t}{}^2 \hat{\sigma}_j{}^2}{\sum_{t=1}^{t=y} 1/(c_j CV_{j,t}{}^2 \hat{\sigma}_j{}^2)}\right)}$$

3.6.2 Data inputs, prior probability distributions, and performance indicators

Baseline scenarios

LCS—Catch data (in numbers of fish) were available from 1981 to 2004 and CPUE data, from 1972 to 2004, as provided in the Data Workshop Report (Table 3.1). Eleven CPUE series identified as "base" in the DW report were used in the baseline scenario. The Pelagic Log series was updated during the AW as discussed previously. All CPUE series used are listed in **Appendix 1**. The fishery was assumed to begin in 1972, the first year for which CPUE data were available. The catches in the years 1972-1980 were assumed to be constant and equal to the model-estimated parameter C_0. The prior for C_0 was lognormal, with a mean equal to the

average catch during 1981-2004 (534.9 thousand individuals) and a log-standard deviation (SD) of 1, implying a wide distribution. Other estimated parameters were r, K, and the abundance (in numbers) in 1972 relative to K (N_{72}/K). The constant of proportionality between each abundance index and the biomass trend was calculated using the numerical shortcut of Walters and Ludwig (1994). The prior for K was uniform on log (K), weakly favoring smaller values, and was allowed to vary between 10^5 and 10^9 individuals. Informative, lognormally distributed priors were used for N_{72}/K and r. For N_{72}/K, the mean was set equal to 1, and the log-SD was 0.2. For r, the mean value was taken as recommended in the DW report when considering density dependence (0.045 yr^{-1}). Since no SD was provided in the report, we used a value that would correspond to the same proportion of the mean as used in the 2002 SEW (i.e., the mean r in the 2002 SEW was 0.113, with a log-variance of 0.49 [the BSP uses variance as an input], so the value of log-variance corresponding to a mean of 0.045 is 0.195). Input values can be found in Table 3.2.

LCS without prohibited species—Catch data (in numbers of fish) were available from 1981 to 2004 and CPUE data, from 1992 to 2004, as provided in the DW Report (Table 3.3). Seven CPUE series identified as "base" in the DW report were used in the baseline scenario. The Pelagic Log series was updated during the AW, as discussed previously. All CPUE series used are listed in **Appendix 1**. The fishery was assumed to begin in 1972 (for comparison with the LCS scenario). The catches in the years 1972-1980 were assumed to be constant and equal to the model-estimated parameter C_0. The prior for C_0 was lognormal, with a mean equal to the average catch during 1981-2004 (494.6 thousand individuals) and a log-standard deviation (SD) of 1, implying a wide distribution. The prior for K was uniform on log (K), and ranged between 10^5 and 10^9 individuals. The mean of N_{72}/K was set to 1 and the log-SD to 0.2. The mean value of r as recommended in the DW report when considering density dependence was 0.046 yr^{-1} and the resulting log-variance was 0.199. Input values can be found in Table 3.2.

LCS without prohibited species, blacktip or sandbar—Catch data (in numbers of fish) were available from 1981 to 2004 and CPUE data, from 1992 to 2004, as provided in the DW Report (Table 3.4). Seven CPUE series identified as "base" in the DW report were used in the baseline scenario. The Pelagic Log series was updated during the AW, as discussed previously. All CPUE series used are listed in **Appendix 1**. The fishery was assumed to begin in 1972 (for comparison with the LCS scenario). The catches in the years 1972-1980 were assumed to be constant and equal to the model-estimated parameter C_0. The prior for C_0 was lognormal, with a mean equal to the average catch during 1981-2004 (136.1 thousand individuals) and a log-standard deviation (SD) of 1, implying a wide distribution. The prior for K was uniform on log (K), and ranged between 10^5 and 10^9 individuals. The mean of N_{72}/K was set to 1 and the log-SD to 0.2. The mean value of r as recommended in the DW report when considering density dependence was 0.043 yr^{-1} and the resulting log-variance was 0.186. Input values can be found in Table 3.2.

Performance indicators included the maximum sustainable yield (MSY=rK/4), the stock abundance in the last year of data (N_{2004}), the ratio of stock abundance in the last year of data to carrying capacity and MSY (N_{2004}/K and N_{2004}/MSY), the fishing mortality rate in the last year of data as a proportion of the fishing mortality rate at MSY (F_{2004}/F_{MSY}), the catch in the last year of data as a proportion of the replacement yield (C_{2004}/R_y) and MSY (C_{2004}/MSY), the stock

abundance in the first year of the model (N_{init}), and the ratio of stock abundance in the last and first years of the model (N_{2004}/N_{init}). Additionally, the relative abundance (N_i/N_{MSY}) and fishing mortality (F_i/F_{MSY}) trajectories, as well as the predicted abundance trend, were obtained and plotted for the time period considered in each scenario.

3.6.3 Methods of numerical integration, convergence diagnostics, and decision analysis

Numerical integration was carried out using the SIR algorithm (Berger 1985, McAllister and Kirkwood 1998, McAllister et al. 2001) built in the BSP software. The marginal posterior distributions for each of the population parameters of interest were obtained by integrating the joint probability with respect to all the other parameters. Posterior CVs for each population parameter estimate were computed by dividing the posterior SD by the posterior expected value (mean) of the parameter of interest. Two importance functions were used in the SIR algorithm (depending on which function produced better convergence diagnostics): the multivariate Student t distribution and the priors. For the multivariate Student t distribution, the mean is based on the posterior mode of θ (vector of parameter estimates K, r, N_{init}/K, and C_0), and the covariance of θ is based on the Hessian estimate of the covariance at the mode (see McAllister and Kirkwood [1998] and references therein for full details). A variance expansion factor of at least 2 was generally used to make the importance function more diffuse (wider) and ensure that the variance of the parameters was not underestimated when using the multivariate Student t distribution.

Convergence diagnostics included examining the ratio of the CV of the weights to the CV of the product of the likelihood function and the priors, with values <1 indicating convergence and values >10 indicating likely convergence failure, and the maximum weight of any draw as a fraction of the total importance weight, which should be less than 0.5% (SB-02-25; McAllister and Babcock 2004). Predicted model fits to the CPUE series were plotted and examined.

For the BSP model, posterior expected values for several indices of policy performance were calculated using the resampling portion of the SIR algorithm built in the BSP software, which involves randomly drawing 5,000 values of θ with replacement from the discrete approximation to the posterior distribution of θ, with the probability of drawing each value of θ being proportional to the posterior probability calculated during the importance sampling phase. Details of this procedure can be found in McAllister and Kirkwood (1998) and McAllister et al. (2001), and references therein. Once a value of θ was drawn, the model was projected from the initial year of the model to 2007 (although the actual catch series only extended to 2004, catches in 2005, 2006, and 2007 were set equal to the 2004 catch to account for the fact that any management actions would not go into effect until 2008), and then forward in time beginning in 2008 up to 30 years to evaluate the potential consequences of future management actions. Projections were run using constant harvest rates as a fraction of F_{msy}, with F as a fraction of F_{msy} recalculated for each draw from the posterior distribution. The policies explored thus included using: 0.0 * F_{MSY}, 0.75 * F_{MSY}, 1.0 * F_{MSY}, and the median value of F_{2003}/F_{msy} calculated by the model * F_{MSY}. The projections included calculating multiple reference points, among others: the expected value of N_{fin}/K (with fin=2018, 2028, and 2038) and the probabilities that N_{fin} were <

0.2K, $N_{fin} > N_{msy}$, and $N_{fin} > N_{2008}$. Additionally, the probability that the stock in 2030 (present rebuilding target) were > N_{msy} with the F_{2003}/F_{msy} policy option was also calculated.

3.6.4 Sensitivity analyses

To examine the impact of the priors on the results, sensitivity analyses were performed by changing the following items with respect to those in the baseline scenario one at a time. These sensitivity analyses include those identified in the DW report and additional ones identified during the AW. All sensitivities run prior to the AW are referred to as "initial" to distinguish them from the "additional" sensitivities identified and run during or after the AW. All results for the initial sensitivities can be found in document SEDAR11-AW-05 or its addendum. Here, we only report results of the additional sensitivities.

The ***initial*** sensitivities included:

W — Using a complementary surplus production model (**WinBUGS**) that also takes account of process error (vs. observation error only in the BSP) and uses MCMC (vs. the SIR algorithm in the BSP) for numerical integration (all runs identified by a leading "W"). Input values can be found in Table 3.2.

IW — Changing the method for weighting the CPUE series: **inverse CV weighting** (weighting method 3) was used to compare with weighting method 1 in the baseline scenario

IF — Changing the **importance function** from the priors to a multivariate t distribution

As described in section 3.6.3, we only report results obtained with the importance function that yielded the best convergence diagnostics.

OLDR — Using the values of **intrinsic rate of increase** from the 2002 SEW

The values of r used in the baseline scenario were 0.045 yr^{-1} (LCS), 0.046 yr^{-1} (LCS-PRO), and 0.043 yr^{-1} (LCS-PRO-SB-BT). The value of r for LCS used in the 2002 SEW was 0.113 yr^{-1}.

ID — Decreasing the value for the **prior of N_{init}/K** to a mean=0.85

This prior reduces the probability that N_{init}/K (initial depletion) will be much higher than K (18% of the pdf is >1 with this prior vs. 45% if the mean=1).

AC — Considering an **alternative catch series for LCS** (Table 2.5 of the DW) to compensate for under-reporting of landings during the earliest years of the time series (1981-1994)

C83 — Changing the value of **recreational catch for 1983** to the geometric mean value of the 1982 and 1984 estimates

-SERIES NAME — Removing one CPUE series at a time from the full model (with all CPUE series considered in the baseline scenario)

In the initial sensitivities, this was done using the inverse CV weighting method.

+SERIES NAME — Fitting only one CPUE series (of those considered in the baseline scenario) at a time

In the initial sensitivities, this was done using the inverse CV weighting method.

The ***additional*** sensitivities were run during or after the AW and all use the updated Pelagic Log series. They include:

W — Using a complementary surplus production model (**WinBUGS**) that also takes account of process error (vs. observation error only in the BSP) and uses MCMC (vs. the SIR algorithm in the BSP) for numerical integration. This was applied to the LCS (22 species) grouping only.

IW — Changing the method for weighting the CPUE series: **inverse CV weighting** was used to compare with equal weighting in the baseline scenario

IF — Changing the **importance function** from the priors to a multivariate t distribution

As described in section 3.6.3, we only report results obtained with the importance function that yielded the best convergence diagnostics.

C — Considering a **continuity scenario** for the LCS complex with the CPUE series used in the last stock assessment (2002 SEW), extending the series up to 2004 if available, to compare to the predictions from the present baseline analysis. If the CPUE series had been GLM-standardized for the current assessment, the standardized values were used.

R-2001 — Conducting a **retrospective analysis** by stopping the baseline analysis for the LCS complex in 2001 (i.e., using only catch and CPUE data up to 2001 vs. 2004 in the baseline analysis) to compare to the predictions from the stock assessment conducted in 2002 (which included data up to 2001)

ALL — Adding **all the CPUE series** identified as "sensitivity" in the DW report to the baseline series. Two sub-scenarios were run: one that included the "requiem shark" category in the MRFSS series, and another one without that category.

-SERIES NAME — Removing one CPUE series at a time from the full model (with all CPUE series considered in the baseline scenario). This was now done using the equal weighting method.

+SERIES NAME — Fitting only one CPUE series (of those considered in the baseline scenario) at a time. This was now done using the equal weighting method.

FIXED CATCH — Fixing the 1972-1980 annual catch to the 1981 value (first year of catch data)

3.7 Results

3.7.1 Baseline scenarios

LCS—Although the two longest series (ENP and VA LL) showed a declining trend in the early years (1970s and 1980s), all series were rather flat or showed a slightly increasing tendency in the early 2000s (Fig. 3.1). The abundance trajectory at the mode of the posterior distribution showed a similar trend, decreasing from the early 1970s to the mid-1990s, and almost flattening thereafter. The median relative biomass trajectory indicated that the stock did not reach an overfished status in any year (Fig. 3.2A), whereas the median relative fishing mortality trajectory indicated that overfishing had occurred from the early 1980s to the late 1990s, but was no longer occurring from 1999 on (Fig. 3.2B). The model did not fit the early years of the VA LL or Pelagic Log CPUE series well probably because it attempted to track the ENP series (Fig. 3.3). The complete time series of median estimates of stock abundance (N_i), relative stock abundance (N_i/N_{MSY}), fishing mortality rate (F_i), and relative fishing mortality rate (F_i/F_{MSY}) are given in Table 3.5.

Current status of the population was above N_{MSY} and no overfishing was occurring (Table 3.6). The priors were used as an importance function for importance sampling. The SIR algorithm converged with good diagnostics of convergence (maximum weight of any draw <<0.5%, CV(weights) / CV(likelihood * priors) <1). The posterior distributions of K and r showed that the data supported relatively high values of these two parameters, whereas the posterior for C_0 was very similar to the prior distribution (Fig. 3.4). Population projections showed that there is a 78% probability that the stock will remain above N_{MSY} when applying the F_{msy} policy under any of the three time horizons explored (10, 20, and 30 years; Table 3.7) and that the stock will not become overfished (Fig. 3.5). The probability that the stock will be rebuilt in 2030 ($N_{2030}>N_{msy}$) is 91%.

LCS without prohibited species—The earliest CPUE data point went back to 1992, and with the exception of the Pelagic Log series, all remaining series showed increasing tendencies (Fig. 3.6). The abundance trajectory at the mode of the posterior distribution predicted a slow decrease starting in the early 1980s that progressively decelerated towards the end of the time series. Accordingly, the median relative biomass and fishing mortality trajectories indicated that the stock did not reach an overfished status and that overfishing did not occur for the duration of the time series (Fig. 3.7A and B). Model fits to the CPUE series were all almost flat, probably as a result of the model trying to compensate between the decreasing trend from the Pelagic Log series and the generally increasing tendencies of all remaining CPUE series (Fig. 3.8). The complete time series of median estimates of stock abundance (N_i), relative stock abundance (N_i/N_{MSY}), fishing mortality rate (F_i), and relative fishing mortality rate (F_i/F_{MSY}) are given in Table 3.8.

Current status of the population was above N_{MSY} and no overfishing was occurring (Table 3.6). The priors were used as an importance function for importance sampling. The SIR algorithm converged with good diagnostics of convergence (maximum weight of any draw <<0.5%, CV(weights) / CV(likelihood * priors) <1). The posterior distribution of K showed that the data supported relatively high values of this parameter (more so than in the LCS scenario), whereas the posteriors of r and C_0 were very similar to those in the LCS scenario (Fig. 3.9). Population projections showed that there is a 92% probability that the stock will remain above N_{MSY} when applying the F_{msy} policy under any of the three time horizons explored (10, 20, and 30 years) and that the stock will not become overfished (Fig. 3.10), and were more optimistic than for the LCS scenario (Table 3.7). The probability that the stock will be rebuilt in 2030 ($N_{2030}>N_{msy}$) is 99%.

LCS without prohibited species, blacktip or sandbar—The earliest CPUE data point also went back to 1992, and with the exception of the Pelagic Log series, all remaining series also showed increasing tendencies (Fig. 3.11). The abundance trajectory at the mode of the posterior distribution predicted a decrease starting in the early 1980s, followed by a flat trend starting in the mid-1990s. Accordingly, the median relative biomass and fishing mortality trajectories indicated that the stock did not reach an overfished status and that overfishing did not occur for the duration of the time series (Fig. 3.12A and B). Model fits to the CPUE series were all flat since the mid-1990s, probably as a result of the model trying to compensate between the decreasing trend from the Pelagic Log series and the increasing tendencies of all remaining CPUE series (Fig. 3.13). The complete time series of median estimates of stock abundance (N_i), relative stock abundance (N_i/N_{MSY}), fishing mortality rate (F_i), and relative fishing mortality rate (F_i/F_{MSY}) are given in Table 3.9.

Current status of the population was the most optimistic of the three LCS scenarios, being above N_{MSY} and with no overfishing occurring (Table 3.6). The priors were used as an importance function for importance sampling. The SIR algorithm converged with good diagnostics of convergence (maximum weight of any draw <<0.5%, CV(weights) / CV(likelihood * priors) <1). The posterior distribution of K showed that the data supported relatively high values of this parameter (less so than in the two scenarios considered above), the posterior of r was also very similar to those in the two previous scenarios, and the posterior of C_0 favored smaller values than predicted in the two previous scenarios (Fig. 3.14). Population projections showed that there is a 94% probability that the stock will remain above N_{MSY} when applying the F_{msy} policy under the three time horizons explored (10, 20, and 30 years) and were the most optimistic of the three LCS scenarios (Table 3.7; Fig. 3.15). The probability that the stock will be rebuilt in 2030 ($N_{2030}>N_{msy}$) is 99%.

3.7.2 Sensitivity analyses

W: Using WinBUGS—Using this structurally different surplus production model resulted in the same predictions of stock status as with the BSP: not overfished (N_{2004}/N_{MSY}=1.26 in both models; F_{2004}/F_{MSY}=0.74 in the BSP vs. 0.53 in WinBUGS).

IW: Changing the CPUE weighting method—We focused on changing the CPUE weighting method from equal weighting (baseline) to inverse variance weighting. We report only those results obtained with the importance function (prior vs. multivariate t) that produced the best convergence diagnostics.

***LCS*—**Current status of the population worsened considerably, dipping below N_{MSY} and overfishing occurred when considering this change (Table 3.10). The multivariate t distribution as an importance function yielded better convergence diagnostics than the priors for the SIR algorithm, but those diagnostics were still not good (maximum weight of any draw was 4.3% and CV (weights) / CV (likelihood * priors) was 3.3). Population projections estimated only a 1% probability of the population reaching N_{MSY} even after 30 years when applying the F_{MSY} policy, but F = 0 would result in an 81% probability of the population reaching N_{MSY} in only 10 years (Table 3.11).

***LCS without prohibited species*—**This change had little impact on results, with current status of the population improving with respect to the baseline scenario (Table 3.10). The priors as an importance function yielded better convergence diagnostics than the multivariate t distribution for the SIR algorithm (maximum weight of any draw <0.5%, but CV (weights) / CV (likelihood * priors) was 1.14). As in the baseline scenario, population projections were very optimistic, with no risk of the population going below N_{MSY} under any of the policies or time horizons considered (Table 3.11).

***LCS without prohibited species, blacktip or sandbar*—**This change had even less impact on results than the previous one, with F_{2004}/F_{MSY} decreasing from 0.29 (baseline scenario) to 0.23 scenario (Table 3.10). The priors as an importance function yielded better convergence diagnostics than the multivariate t distribution for the SIR algorithm (maximum weight of any draw <0.5%, but CV (weights) / CV (likelihood * priors) was 2.09). As in the previous case, population projections were very optimistic, with no risk of the population going below N_{MSY} under any of the policies or time horizons considered (Table 3.11).

C: Considering a continuity scenario for the LCS complex with the CPUE series used in the last stock assessment (2002 SEW)— Although the longest series (VA LL) and the early Port Salerno and Crooke LL series showed declining trends overall, several series showed increasing tendencies in the 1990s and early 2000s resulting in an abundance trajectory at the mode of the posterior distribution that showed a concave shape from the early 1990s to present (Fig. 3.16). The median relative abundance trajectory indicated that the stock was slightly overfished (barely below 1) during 1993-1998, but recovered thereafter (Fig. 3.17A), whereas the median relative fishing mortality trajectory indicated that overfishing had occurred during 1988-1996, but was no longer occurring from 1997 on (Fig. 3.17B). The model fits to several of the CPUE series showed the same concave shape probably as a result of the model trying to compensate between the early declining trends and the upswing in the latter part of the time series (Fig. 3.18).

The continuity scenario results did not vary significantly from those in the baseline scenario: current relative abundance was similar (no overfished status) and relative fishing mortality rate was lower (no overfishing) than in the baseline scenario (Table 3.12). The priors were used as

an importance function for importance sampling. The SIR algorithm converged with reasonable diagnostics of convergence (maximum weight of any draw <<0.5%, but CV(weights) / CV(likelihood * priors) = 1.43). The posterior distributions showed that the data supported lower values of K, higher values of r, and lower values of C_0 than in the baseline scenario (Fig. 3.19). Population projections showed that there is an 86% probability that the stock will remain above N_{MSY} when applying the F_{MSY} policy under any of the three time horizons explored (10, 20, and 30 years; Table 3.13), a probability that substantially increases when considering the F_{OY} (F_{MSY} * 0.75)or the other two policies (Fig. 3.20A).

Using inverse CV weighting resulted in an overfished stock status determination (as in the baseline scenario with inverse CV weighting for LCS), but with no overfishing (Table 3.12). The priors were used as an importance function and convergence diagnostics were poorer than when using equal weighting (Table 3.12). In this case, population projections indicated that there is only a 29% probability that the stock will be above N_{MSY} when applying the F_{MSY} policy under any of the three time horizons explored (10, 20, and 30 years; Table 3.13), but a 67% probability of reaching N_{MSY} when applying the)F_{2003}/F_{MSY}) * F_{MSY} policy after only 10 years (Fig. 3.20B).

The lack of reconciliation between these results and the predictions from the 2002 assessment, which indicated an overfished stock with overfishing (N/N_{MSY}=0.70 and F/F_{MSY}=2.04 with equal weighting), suggest that the continuity case we considered may not be a real "continuity" scenario, owing to the fact that the values in several of the CPUE series used in the present analysis have changed. Many of the series used in 2002 were nominal indices that were GLM-standardized for the current assessment. A closer examination of the CPUE series used in the 2002 SEW vs. those used in the continuity scenario reveals that the 2002 SEW and the present continuity analysis only had 53% of points in common up to 2001. Twelve of the 20 CPUE series remained unchanged between the 2002 SEW and the 2006 continuity analysis (Fig. 3.21), whereas eight series changed (Fig. 3.22). The MRFSS series, which in 2002 was split into two nominal indices (REC early and REC late, with the division in 1994), was combined into one single standardized series in the current assessment. Despite these changes due mainly to standardization, overall the trends were maintained (Fig. 3.22).

R-2001: Conducting a retrospective analysis by stopping the baseline analysis for the LCS complex in 2001—For large coastal sharks (all 22 species), we conducted a retrospective analysis by running the baseline assessment (equal weighting, new r prior, baseline CPUE series including the revised Pelagic Log series) using only catch and CPUE data through 2001, consistent with the assessment in 2002. The results were similar to the baseline model results (Figs. 3.23-3.25). Status of the population in 2001 was above N_{MSY} and no overfishing was occurring (Table 3.12). The priors were used as an importance function and convergence diagnostics were good. The retrospective model was also much more optimistic than the 2002 assessment base case model for large coastal sharks.

ALL: Adding the CPUE series identified as "sensitivity" in the DW report to the baseline series—Sensitivity analyses were conducted which included the CPUE series that were identified as sensitivity in the Data Workshop, in addition to the base case series, using equal weighting

and the baseline priors. The updated version of the Pelagic Log series was used. For large coastal sharks, the sensitivity series were PC Longline, MS Gillnet, Port Salerno, Crooke LL, and MRFSS. For LCS without prohibited species, they were PC longline, MS Gillnet, and MRFSS. There were no sensitivity series for large coastal sharks without prohibited species, sandbar or blacktip. All model runs converged satisfactorily using the priors as an importance function (Table 3.14). For large coastal sharks (all species), the results were similar to the baseline whether requiem sharks were included in the MRFSS series or not (compare Tables 3.6 and 3.14). For large coastal sharks without prohibited species, the run including MRFSS with requiem sharks was similar to the baseline, whereas the run with MRFSS excluding requiem sharks, unlike the baseline, implied that overfishing was occurring and the stock was barely above N_{MSY} (Table 3.14).

-/+ SERIES: Removing one CPUE series at a time from the full model (with all CPUE series considered in the baseline scenario) and fitting only one CPUE series at a time— For LCS, the priors were used as the importance function for each series removed. The status of the population was not overfished and overfishing was not occurring, as in the full model (Table 3.15). When the series were fitted one at a time, the priors also were the best importance function, and convergence diagnostics were good. As in the full model, six of the individual series fits showed that the population was not overfished and no overfishing. Overfishing occurred if the SC LL Recent, Pelagic Log or VA LL were fit (Table 3.16). The NMFS LL NE and SC LL Early series had too few points to estimate all four model parameters.

For LCS without prohibited species, convergence diagnostics were good drawing from the priors for all runs. The status of the population was not overfished and overfishing was not occurring in all cases regardless of the series being removed (Table 3.17). The runs fitting individual series found the same, except for the runs with the Bottom LL Logs and Pelagic Log series only, which found overfishing (Table 3.18). The BLLOP series failed to converge, and the NMFS LL NE series had too few data points to estimate all four model parameters.

For LCS without prohibited species, blacktip or sandbar, drawing from the priors produced good diagnostics of convergence in all cases. Removing one series did not change the assessment of status, which is not overfished, and overfishing is not occurring (Table 3.19). The runs by individual series were the same and the NMFS LL NE series had too few data points to estimate all four model parameters (Table 3.20).

FIXED CATCH: Fixing the 1972-1980 annual catch to the 1981 value (first year of catch data)—Introducing this change had a negligible effect on results for any of the three LCS groupings. Stock status determination did not change with respect to the corresponding baseline analyses (compare Tables 3.6 and 3.21).

3.8 Discussion

Baseline scenarios for the three LCS groupings considered predicted that the stock status is not overfished nor overfishing is occurring. Removing the species presently designated as prohibited from the LCS complex resulted in more optimistic results as one would expect given that the prohibited species are believed to be less resilient to fishing pressure. Further removing the two main species in the directed shark fisheries (blacktip and sandbar) resulted in even more optimistic results, with a depletion of only 19% of the virgin level, indicating that the sandbar and blacktip had opposing effects on the LCS complex, with the negative tendency of sandbar sharks outperforming the positive influence of blacktip sharks slightly.

The method to weight the CPUE data (equal vs. inverse variance) only had a significant effect on the LCS grouping, changing the predictions on stock status to overfished and overfishing occurring. However, convergence diagnostics for the inverse variance method were not good. Removing one CPUE series at a time from those used in the baseline scenarios did not reverse the conclusions on stock status for LCS, but fitting to the SC LL Recent, Pelagic Log, and VA LL series individually resulted in overfishing. Fitting to the Bottom LL Logs or Pelagic Log series alone also resulted in overfishing for the LCS without prohibited species grouping. Using all the CPUE series (baseline + sensitivities), using fixed catches for 1972-1980, or using the alternative model structure (WinBUGS) did not alter the stock status determination derived from the baseline analysis.

The continuity scenario for the LCS complex was an attempt to explain the large discrepancy between the 2002 SEW results and the present baseline analysis that essentially reversed the sign of stock status from overfished and overfishing to not overfished and no overfishing occurring (Fig. 3.26). The results of the continuity scenario supported the conclusions on stock status derived from the present baseline analysis, but these results must be interpreted cautiously as the two data sets (2002 assessment and continuity) only shared about half of the total number of data points up to 2001, indicating that it was not a continuity analysis per se. Many of the nominal series used in 2002 were GLM-standardized for the current analyses. The present results for LCS and those from the 2002 SEW are thus not directly comparable. Extracting the 2001 stock status criteria (N_{2001}/N_{msy} and F_{2001}/F_{msy}) from the continuity analysis revealed that the stock would also have been classified as not overfished with no overfishing and that the addition of three more years of data would have further improved stock status (Fig. 26). The retrospective analysis for LCS using baseline analysis data but only to 2001, also yielded similar results to those of the present baseline analysis, indicating that the addition of 3 years of data to the present analysis (from 2002 to 2004) did not explain the large change in stock status with respect to the 2002 SEW (Fig. 3.26).

3.9 References

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Table 3.1. Catch history for the Large Coastal Shark complex (22 species) in thousands of fish.

CATCHES OF LARGE COASTAL SHARKS: 22 species (in thousands)

Year	Commercial Landings	Pelagic longline discards	Recreational catches	Unreported catches	Bottom longline discards	Mexican catches	Menhaden fishery discards	Confiscated Mexican catches in US	Total
1981	16.2	0.9	285.1		0.5	119.971	37.5		460.2
1982	16.2	0.9	539.3		0.5	81.913	38.5		677.3
1983	17.5	0.9	791.1		0.6	85.437	38.0		933.5
1984	23.9	1.3	268.9		0.8	120.684	38.0		453.5
1985	22.2	1.2	400.8		0.7	87.748	34.2		546.9
1986	54	2.9	432.5	24.9	1.7	81.835	33.8		631.6
1987	104.7	9.7	313.9	70.3	3.3	80.16	35.2		617.3
1988	274.6	11.4	308.7	113.3	8.7	89.29	34.2		840.2
1989	351	10.5	228.1	96.3	11.1	105.562	36.1		838.7
1990	267.5	8	218.2	52.1	8.5	122.22	35.2		711.7
1991	200.2	7.5	299.9	11.3	6.3	95.695	27.2		648.1
1992	215.2	20.9	307.2		6.8	103.366	23.9		677.4
1993	169.4	7.3	255.0		5.4	119.82	24.4		581.3
1994	228	8.8	163.9		3.7	110.734	26.1		541.2
1995	222.4	5.2	187.2		5.2	95.996	24.0		540.0
1996	161.0	5.7	197.5		4.8	106.057	23.9		498.9
1997	130.6	5.6	169.7		6.7	83.051	24.4		420.0
1998	174.9	4.3	160.9		6.6	74.136	23.5		444.3
1999	111.5	9.0	82.1		2.9	57.061	25.8		288.4
2000	111.2	9.4	139.0		4.1	52.057	22.1	1.000	338.9
2001	95.8	5.6	136.7		5.5	52.057	20.6	1.470	317.7
2002	123.7	2.43	80.3		4.8	52.057	20.2	1.390	284.9
2003	122.8	3.5	88.4		6.9	52.057	19.7	1.310	294.7
2004	99.0	5.2	67.0		4.5	52.057	20.2	2.120	250.0

Table 3.2. Prior probability distributions of parameters used in the baseline scenarios (Bayesian Surplus Production Model [BSP] with the SIR algorithm) and the sensitivity analysis with WinBUGS (Bayesian state-space surplus production model with the MCMC algorithm). K is carrying capacity (in numbers), r is the intrinsic rate of population increase, C_0 is the annual catch from 1972 to 1980 (in thousands of individuals), N_{1972}/K is the ratio of abundance in 1972 to carrying capacity, q is the catchability coefficient, σ^2 is the observation error variance in the BSP model (but process error variance in WinBUGS), and τ^2 is observation error variance in WinBUGS.

Grouping/ Model	**K**	**r**	**C_0**	**N_{1972}/K**	**q**	**σ^2**	**τ^2**
BSP (SIR)							
LCS complex	Uniform on log K[1] (10^5-10^9)	Lognormal (0.045,0.44,0.001,2.0)	Lognormal (534.9,1,10,5x10^3)	Lognormal (1,0.2,0.2,1.1`)	Uniform on log[2]	Uniform on log	N/A
LCS - Prohibited	Uniform (10^5-10^9)	Lognormal (0.046,0.45,0.001,2.0)	Lognormal (494.6,1,10,5x10^3)	Lognormal (1,0.2,0.2,1.1)	Uniform on log	Uniform on log	N/A
LCS – Prohibited -sandbar -blacktip	Uniform (10^5-10^9)	Lognormal (0.043,0.43,0.001,2.0)	Lognormal (136.1,1,10,5x10^3)	Lognormal (1,0.2,0.2,1.1)	Uniform on log	Uniform on log	N/A
WinBUGS (MCMC)							
LCS complex	Uniform on log K (10^5-10^9)	Lognormal (0.045,0.44,0.01,1.0)	Normal (534.9,1,10,5x10^3)	Lognormal (1,0.2,0.2,1.1)	MLE[3]	Inverse gamma (0.04-0.08)	Inverse gamma (0.05-0.15)
LCS - Prohibited	Uniform (10^5-10^9)	Lognormal (0.046,0.45,0.01,1.0)	Normal (494.6,1,10,5x10^3)	Lognormal (1,0.2,0.2,1.1)	MLE	Inverse gamma (0.04-0.08)	Inverse gamma (0.05-0.15)
LCS – Prohibited -sandbar -blacktip	Uniform (10^5-10^9)	Lognormal (0.043,0.43,0.01,1.0)	Normal (136.1,1,10,5x10^3)	Lognormal (1,0.2,0.2,1.1)	MLE	Inverse gamma (0.04-0.08)	Inverse gamma (0.05-0.15)

[1] Values in parentheses are lower and upper bounds (uniform distribution), mean, SD, lower bound, and upper bound (lognormal distribution), 10% and 90% quantiles (inverse gamma distribution); [2] Priors for q and σ^2 were given a uniform distribution on a log scale, but were integrated from the joint posterior distribution using the method described by Walters and Ludwig (1994); [3] The maximum likelihood estimate of q for each CPUE series was used instead of a prior for q.

Table 3.3. Catch history for the Large Coastal Shark complex without the prohibited species (11 species) in thousands of fish.

CATCHES OF LARGE COASTAL SHARKS without prohibited species (thousands of fish)

Year	Commercial Landings	Pelagic longline discards	Recreational catches	Unreported catches	Bottom longline discards	Mexican catches	Menhaden fishery discards	Confiscated Mexican catches in US	Total
1981	15.1	0.7	223.7		0.5	119.971	37.5		397.5
1982	15.1	0.7	331.9		0.5	81.913	38.5		468.7
1983	16.3	0.7	683.1		0.5	85.437	38		824.1
1984	22.3	1.0	216.5		0.7	120.684	38		399.2
1985	20.7	1.0	355.7		0.7	87.748	34.2		500.0
1986	50.4	2.3	391.1	23.2	1.7	81.835	33.8		584.4
1987	97.7	7.7	274.6	65.6	3.2	80.16	35.2		564.3
1988	256.4	9.1	290.5	105.8	8.4	89.29	34.2		793.6
1989	327.7	8.3	212.9	89.9	10.8	105.562	36.1		791.3
1990	249.7	6.4	206.3	48.6	8.2	122.22	35.2		676.6
1991	186.9	6.0	284.3	10.5	6.1	95.695	27.2		616.7
1992	200.9	19.2	276.1		6.6	103.366	23.9		630.0
1993	158.1	6.3	244.5		5.2	119.82	24.4		558.3
1994	212.9	5.7	153.3		3.0	110.734	26.1		511.7
1995	207.6	4.5	177.3		4.9	95.996	24		514.2
1996	150.1	4.4	181.5		4.7	106.057	23.9		470.7
1997	127.5	5.0	154.0		6.9	83.051	24.4		400.8
1998	168.7	2.2	156.2		6.8	74.136	23.5		431.5
1999	109.0	7.3	76.7		2.8	57.061	25.8		278.7
2000	108.2	4.8	135.8		4.1	52.057	22.1	1.000	328.0
2001	95.7	4.2	129.9		5.0	52.057	20.6	1.470	308.9
2002	123.4	2.4	78.6		4.0	52.057	20.2	1.390	282.0
2003	122.1	3.5	85.7		6.0	52.057	19.7	1.310	290.4
2004	98.9	5.2	66.2		3.2	52.057	20.2	2.120	247.8

Table 3.4. Catch history for the Large Coastal Shark complex without the prohibited species, blacktip or sandbar sharks (9 species) in thousands of fish.

CATCHES OF LARGE COASTAL SHARKS: except Prohibited or BT or SB (in thousands)

Year	Commercial Landings	Pelagic longline discards	Recreational catches	Unreported catches	Bottom longline discards	Mexican catches	Menhaden fishery discards	Confiscated Mexican catches in US	Total
1981	3.8	0.7	38.1		0.4		19.8		62.9
1982	3.8	0.7	215.8		0.4		20.4		241.1
1983	4.1	0.7	222.1		0.5		20.1		247.6
1984	5.7	1.0	119.6		0.7		20.1		147.0
1985	5.3	0.9	169.8		0.6		18.1		194.7
1986	12.8	2.3	99.5	5.3	1.5		17.9		139.2
1987	24.8	7.6	111.8	15.1	2.9		18.6		180.8
1988	65.0	8.9	76.2	24.9	7.6		18.1		200.6
1989	83.1	8.2	67.5	21.1	9.7		19.1		208.7
1990	63.3	6.2	52.4	11.2	7.4		18.6		159.2
1991	47.4	5.9	93.3	2.4	5.5		14.4		168.9
1992	51.0	18.8	80.9		6.0		12.6		169.2
1993	40.1	5.6	105.0		4.7		12.9		168.3
1994	54.0	5.1	70.1		2.9		13.8		145.9
1995	63.9	4.3	82.8		5.2		12.7		168.9
1996	42.4	4.4	57.6		4.8		12.6		121.8
1997	17.3	5.0	38.3		2.9		12.9		76.4
1998	9.1	2.2	41.4		1.5		12.4		66.6
1999	8.5	7.3	24.9		0.6		13.6		54.9
2000	13.3	4.8	51.0		1.1		11.7	0.670	82.5
2001	6.0	4.2	44.3		1.4		10.9	0.985	67.8
2002	15.7	2.4	30.6		0.8		10.7	0.932	61.1
2003	14.0	3.5	40.2		1.6		10.4	0.878	70.6
2004	11.6	5.2	31.3		0.8		10.7	1.420	61.0

Table 3.5. Time series of estimates of stock abundance (N_i), relative stock abundance ((N_i/N_{MSY}), fishing mortality rate (F_i), and relative fishing mortality rate (F_i/F_{MSY}) for the BSP model **baseline scenario for the LCS (22 species) complex.** Values listed are medians.

Year	N_i	N_i/N_{MSY}	F_i	F_i/F_{MSY}
1972	27686	1.85	0.0102	0.47
1973	27244	1.83	0.0103	0.47
1974	26879	1.81	0.0104	0.48
1975	26549	1.79	0.0105	0.48
1976	26216	1.78	0.0105	0.48
1977	25910	1.76	0.0106	0.49
1978	25557	1.75	0.0106	0.49
1979	25282	1.74	0.0107	0.49
1980	24946	1.72	0.0108	0.49
1981	24678	1.70	0.0185	0.82
1982	24264	1.67	0.0276	1.22
1983	23626	1.61	0.0389	1.72
1984	23109	1.59	0.0195	0.86
1985	22791	1.57	0.0238	1.05
1986	22500	1.54	0.0279	1.23
1987	22106	1.51	0.0277	1.23
1988	21611	1.46	0.0383	1.70
1989	21039	1.42	0.0394	1.75
1990	20511	1.39	0.0343	1.53
1991	20119	1.36	0.0319	1.43
1992	19706	1.33	0.0340	1.52
1993	19367	1.31	0.0298	1.34
1994	19120	1.29	0.0281	1.27
1995	18862	1.27	0.0284	1.28
1996	18621	1.26	0.0266	1.20
1997	18442	1.25	0.0227	1.02
1998	18322	1.24	0.0242	1.08
1999	18294	1.24	0.0158	0.71
2000	18287	1.24	0.0185	0.83
2001	18263	1.24	0.0174	0.78
2002	18286	1.25	0.0156	0.70
2003	18311	1.25	0.0161	0.72
2004	18339	1.25	0.0137	0.61

Table 3.6. Expected values (EV) of the mean and coefficients of variation (CV) of marginal posterior distributions for output parameters from the Bayesian SPM using the SIR algorithm. Results for the three LCS groupings (**baseline scenario**) using equal weighting and values of r (intrinsic rate of increase) recommended in the Data Workshop report. Abundances are in thousands of fish.

	LCS		LCS-PROH		LCS-PROH-SB-BT	
	EV	CV	EV	CV	EV	CV
Importance function	priors		priors		priors	
K	35677	0.50	51387	0.45	31534	0.80
r	0.048	0.47	0.050	0.47	0.046	0.46
MSY	395.5	0.59	621.4	0.62	347.7	0.96
N_{2004}	24133	0.71	40500	0.56	27899	0.88
N_{2004}/K	**0.63**	0.25	**0.75**	0.19	**0.81**	0.20
N_{init}	32578	0.52	45485	0.46	27944	0.82
N_{2004}/N_{init}	0.69	0.23	0.85	0.21	0.92	0.21
C_{2004}/MSY	0.80	0.47	0.56	0.61	0.37	0.87
F_{2004}/F_{MSY}	**0.74**	0.70	**0.44**	0.95	**0.29**	1.32
N_{2004}/N_{MSY}	**1.26**	0.25	**1.49**	0.19	**1.61**	0.20
C_{2004}/repy	0.927	0.37	0.792	0.39	0.660	35.39
N_{MSY}	17839	0.50	25693	0.45	15767	0.80
F_{MSY}	0.024		0.025		0.023	
repy	299.2	0.30	351.2	0.33	115.9	0.56
C_0	421.7	1.00	467.0	1.11	137.1	1.24
Diagnostics						
CW (wt)	0.891		0.518		0.389	
CV (L*prior)	1.531		0.961		1.216	
CV (Wt) / CV (L*p)	0.58		0.54		0.32	
%maxpWt	0.006		0.002		0.003	

N_{init} is initial abundance (for the first year of the model), repy is replacement yield

Table 3.7. Decision analysis tables for various groupings and species corresponding to the results in Table 3.6.

LCS

Horizon	Policy	$E(N_{fin}/K)$	$E(N_{fin}/N_{msy})$	$P(N_{fin}<0.2K)$	$P(N_{fin}>N_{msy})$	$P(N_{fin}>N_{cur})$	$P(F_{fin}<F_{cur})$	$P(N_{cur}>N_{ref})$	$P(N_{fin}<0.01K)$
10 -year	HRmsy	0.59	1.18	0	0.78	0.22	0.22	0.22	0
	HRmsy* 0.75	0.62	1.24	0	0.83	0.48	0.37	0.48	0
	HRmsy*(HR/HRmsy)2003	0.62	1.25	0	0.84	0.51	0.39	0.51	0
	HRmsy*0	0.72	1.45	0	0.92	1	1	1	0
20 -year	HRmsy	0.56	1.13	0	0.78	0.22	0.22	0.22	0
	HRmsy* 0.75	0.62	1.23	0	0.88	0.48	0.37	0.48	0
	HRmsy*(HR/HRmsy)2003	0.62	1.25	0	0.89	0.51	0.39	0.51	0
	HRmsy*0	0.8	1.59	0	0.98	1	1	1	0
30 -year	HRmsy	0.55	1.1	0	0.78	0.22	0.22	0.22	0
	HRmsy* 0.75	0.62	1.23	0	0.91	0.48	0.37	0.48	0
	HRmsy*(HR/HRmsy)2003	0.62	1.25	0	0.92	0.51	0.39	0.51	0
	HRmsy*0	0.85	1.7	0	0.99	1	1	1	0

Table 3.7. (continued)

LCS-PROHIBITED

Horizon	Policy	$E(N_{fin}/K)$	$E(N_{fin}/N_{msy})$	$P(N_{fin}<0.2K)$	$P(N_{fin}>N_{msy})$	$P(N_{fin}>N_{cur})$	$P(F_{fin}<F_{cur})$	$P(N_{cu}r>N_{ref})$	$P(N_{fin}<0.01K)$
10 -year	HRmsy	0.66	1.32	0	0.92	0.08	0.08	0.08	0
	HRmsy* 0.75	0.7	1.39	0	0.94	0.2	0.15	0.2	0
	HRmsy*(HR/HRmsy)2003	0.75	1.51	0	0.96	0.59	0.41	0.59	0
	HRmsy*0	0.81	1.63	0	0.97	1	1	1	0
20 -year	HRmsy	0.62	1.23	0	0.92	0.08	0.08	0.08	0
	HRmsy* 0.75	0.67	1.35	0	0.96	0.2	0.15	0.2	0
	HRmsy*(HR/HRmsy)2003	0.76	1.53	0	0.98	0.59	0.41	0.59	0
	HRmsy*0	0.87	1.73	0	0.99	1	1	1	0
30 -year	HRmsy	0.59	1.17	0	0.92	0.08	0.08	0.08	0
	HRmsy* 0.75	0.66	1.32	0	0.97	0.2	0.15	0.2	0
	HRmsy*(HR/HRmsy)2003	0.77	1.55	0	0.99	0.59	0.41	0.59	0
	HRmsy*0	0.9	1.81	0	0.99	1	1	1	0

Table 3.7. (continued)

LCS-PROHIBITED-BLACKTIP-SANDBAR

Horizon	Policy	$E(N_{fin}/K)$	$E(N_{fin}/N_{msy})$	$P(N_{fin}<0.2K)$	$P(N_{fin}>N_{msy})$	$P(N_{fin}>N_{cur})$	$P(F_{fin}<F_{cur})$	$P(N_{cu}r>N_{ref})$	$P(N_{fin}<0.01K)$
10 -year	HRmsy	0.71	1.41	0	0.94	0.06	0.05	0.06	0
	HRmsy* 0.75	0.74	1.48	0	0.95	0.14	0.1	0.14	0
	HRmsy*(HR/HRmsy)2003	0.83	1.65	0	0.97	0.67	0.45	0.67	0
	HRmsy*0	0.86	1.71	0	0.98	1	1	1	0
20 -year	HRmsy	0.65	1.3	0	0.94	0.06	0.05	0.06	0
	HRmsy* 0.75	0.71	1.41	0	0.97	0.14	0.1	0.14	0
	HRmsy*(HR/HRmsy)2003	0.84	1.69	0	0.99	0.67	0.45	0.67	0
	HRmsy*0	0.89	1.79	0	0.99	1	1	1	0
30 -year	HRmsy	0.61	1.23	0	0.94	0.06	0.05	0.06	0
	HRmsy* 0.75	0.68	1.37	0	0.98	0.14	0.1	0.14	0
	HRmsy*(HR/HRmsy)2003	0.86	1.72	0	0.99	0.67	0.45	0.67	0
	HRmsy*0	0.92	1.85	0	1	1	1	1	0

Table 3.8. Time series of estimates of stock abundance (N_i), relative stock abundance ((N_i/N_{MSY}), fishing mortality rate (F_i), and relative fishing mortality rate (F_i/F_{MSY}) for the BSP model **baseline scenario** for the **LCS without prohibited species (11 species) complex.** Values listed are medians.

Year	N_i	N_i/N_{MSY}	F_i	F_i/F_{MSY}
1972	41477	1.80	0.0074	0.33
1973	41180	1.79	0.0074	0.33
1974	40894	1.78	0.0074	0.33
1975	40651	1.77	0.0074	0.33
1976	40429	1.75	0.0075	0.33
1977	40189	1.75	0.0075	0.34
1978	39987	1.74	0.0075	0.34
1979	39620	1.73	0.0075	0.34
1980	39385	1.73	0.0075	0.34
1981	39202	1.72	0.0101	0.47
1982	39068	1.71	0.0120	0.55
1983	38734	1.68	0.0211	0.98
1984	38335	1.67	0.0104	0.48
1985	38185	1.66	0.0131	0.60
1986	37968	1.65	0.0153	0.71
1987	37681	1.63	0.0149	0.69
1988	37346	1.61	0.0211	0.98
1989	36892	1.59	0.0213	0.99
1990	36487	1.57	0.0185	0.86
1991	36264	1.56	0.0169	0.79
1992	36038	1.54	0.0174	0.81
1993	35860	1.53	0.0155	0.72
1994	35754	1.53	0.0143	0.67
1995	35572	1.52	0.0144	0.67
1996	35503	1.52	0.0132	0.62
1997	35415	1.52	0.0113	0.53
1998	35339	1.51	0.0122	0.57
1999	35338	1.52	0.0079	0.37
2000	35429	1.52	0.0093	0.43
2001	35506	1.52	0.0087	0.41
2002	35559	1.53	0.0079	0.37
2003	35670	1.53	0.0082	0.38
2004	35773	1.54	0.0069	0.32

Table 3.9. Time series of estimates of stock abundance (N_i), relative stock abundance ((N_i/N_{MSY}), fishing mortality rate (F_i), and relative fishing mortality rate (F_i/F_{MSY}) for the BSP model **baseline scenario** for the **LCS without prohibited species, blacktip, and sandbar sharks (9 species) complex.** Values listed are medians.

Year	N_i	N_i/N_{MSY}	F_i	F_i/F_{MSY}
1972	19440	1.79	0.0046	0.22
1973	19347	1.79	0.0046	0.22
1974	19348	1.78	0.0046	0.22
1975	19275	1.77	0.0046	0.22
1976	19265	1.77	0.0046	0.22
1977	19213	1.76	0.0046	0.22
1978	19128	1.76	0.0046	0.22
1979	19109	1.76	0.0046	0.22
1980	19048	1.75	0.0046	0.22
1981	19029	1.76	0.0033	0.16
1982	18997	1.73	0.0126	0.63
1983	18863	1.71	0.0131	0.65
1984	18819	1.71	0.0078	0.39
1985	18737	1.69	0.0104	0.52
1986	18638	1.69	0.0074	0.37
1987	18551	1.68	0.0097	0.48
1988	18475	1.67	0.0108	0.54
1989	18399	1.66	0.0113	0.56
1990	18351	1.66	0.0087	0.43
1991	18309	1.65	0.0092	0.46
1992	18303	1.65	0.0092	0.46
1993	18278	1.64	0.0092	0.46
1994	18237	1.64	0.0080	0.40
1995	18224	1.64	0.0093	0.46
1996	18199	1.64	0.0067	0.33
1997	18254	1.65	0.0042	0.21
1998	18305	1.65	0.0036	0.18
1999	18398	1.66	0.0030	0.15
2000	18436	1.66	0.0045	0.22
2001	18481	1.67	0.0037	0.18
2002	18563	1.67	0.0033	0.16
2003	18625	1.68	0.0038	0.19
2004	18675	1.68	0.0033	0.16

Table 3.10. Expected values (EV) of the mean and coefficients of variation (CV) of marginal posterior distributions for output parameters from the Bayesian SPM using the SIR algorithm. Results for the three LCS groupings using **inverse CV weighting** and values of r (intrinsic rate of increase) recommended in the Data Workshop report. Results that alter the stock status determination derived from the baseline scenario are boxed and highlighted in red. Poor convergence diagnostics are shaded and highlighted in green. Abundances are in thousands of fish.

	LCS		LCS-PROH		LCS-PROH-SB-BT	
	EV	CV	EV	CV	EV	CV
Importance function	multivariate		priors		priors	
K	12624	0.18	54958	0.41	28497	0.86
r	0.100	0.33	0.058	0.46	0.057	0.51
MSY	298.8	0.19	744.0	0.53	341.8	0.90
N_{2004}	4604	0.14	44108	0.49	24665	0.94
N_{2004}/K	**0.37**	0.17	**0.78**	0.15	**0.79**	0.18
N_{init}	12411	0.18	47027	0.43	24074	0.88
N_{2004}/N_{init}	0.38	0.16	0.92	0.18	0.95	0.21
C_{2004}/MSY	0.88	0.25	0.42	0.51	0.31	0.70
F_{2004}/F_{MSY}	**1.24**	0.41	**0.30**	0.70	**0.23**	0.93
N_{2004}/N_{MSY}	**0.74**	0.17	**1.56**	0.15	**1.59**	0.18
C_{2004}/repy	0.968	0.31	0.659	0.33	0.541	29.45
N_{MSY}	6312	0.18	27479	0.41	14249	0.86
F_{MSY}	0.050		0.029		0.029	
repy	276.3	0.23	412.3	0.31	138.6	0.55
C_0	211	0.79	607	1.13	201.5	1.46
Diagnostics						
CW (wt)	38.622		1.136		2.395	
CV (L*prior)	11.693		0.999		1.147	
CV (Wt) / CV (L*p)	3.30		1.14		2.09	
%maxpWt	4.265		0.013		0.146	

N_{init} is initial abundance (for the first year of the model), repy is replacement yield

Table 3.11. Decision analysis tables for various groupings and species corresponding to the results in Table 3.10.

LCS

Horizon	Policy	$E(N_{fin}/K)$	$E(N_{fin}/N_{msy})$	$P(N_{fin}<0.2K)$	$P(N_{fin}>N_{msy})$	$P(N_{fin}>N_{cur})$	$P(F_{fin}<F_{cur})$	$P(N_{cur}>N_{ref})$	$P(N_{fin}<0.01K)$
10 -year	HRmsy	0.41	0.82	0	0.01	0.99	0.68	0.99	0
	HRmsy* 0.75	0.45	0.9	0	0.28	1	0.94	1	0
	HRmsy*(HR/HRmsy)2003	0.46	0.92	0	0.29	1	0.96	1	0
	HRmsy*0	0.61	1.22	0	0.81	1	1	1	0
20 -year	HRmsy	0.43	0.87	0	0.01	0.99	0.68	0.99	0
	HRmsy* 0.75	0.51	1.02	0	0.64	1	0.94	1	0
	HRmsy*(HR/HRmsy)2003	0.52	1.04	0	0.68	1	0.96	1	0
	HRmsy*0	0.79	1.57	0	0.96	1	1	1	0
30 -year	HRmsy	0.45	0.91	0	0.01	0.99	0.68	0.99	0
	HRmsy* 0.75	0.55	1.1	0	0.83	1	0.94	1	0
	HRmsy*(HR/HRmsy)2003	0.56	1.12	0	0.85	1	0.96	1	0
	HRmsy*0	0.89	1.77	0	0.99	1	1	1	0

Table 3.11. (continued)

LCS-PROHIBITED

Horizon	Policy	$E(N_{fin}/K)$	$E(N_{fin}/N_{msy})$	$P(N_{fin}<0.2K)$	$P(N_{fin}>N_{msy})$	$P(N_{fin}>N_{cur})$	$P(F_{fin}<F_{cur})$	$P(N_{cur}>N_{ref})$	$P(N_{fin}<0.01K)$
10 -year	HRmsy	0.68	1.35	0	0.97	0.03	0.01	0.03	0
	HRmsy* 0.75	0.72	1.43	0	0.98	0.12	0.04	0.12	0
	HRmsy*(HR/HRmsy)2003	0.78	1.56	0	0.99	0.53	0.24	0.53	0
	HRmsy*0	0.85	1.7	0	0.99	1	1	1	0
20 -year	HRmsy	0.62	1.24	0	0.97	0.03	0.01	0.03	0
	HRmsy* 0.75	0.69	1.37	0	0.99	0.12	0.04	0.12	0
	HRmsy*(HR/HRmsy)2003	0.79	1.57	0	1	0.53	0.24	0.53	0
	HRmsy*0	0.9	1.8	0	1	1	1	1	0
30 -year	HRmsy	0.59	1.18	0	0.97	0.03	0.01	0.03	0
	HRmsy* 0.75	0.67	1.33	0	0.99	0.12	0.04	0.12	0
	HRmsy*(HR/HRmsy)2003	0.79	1.58	0	1	0.53	0.24	0.53	0
	HRmsy*0	0.93	1.87	0	1	1	1	1	0

Table 3.11. (continued)

LCS-PROHIBITED-BLACKTIP-SANDBAR

Horizon	Policy	$E(N_{fin}/K)$	$E(N_{fin}/N_{msy})$	$P(N_{fin}<0.2K)$	$P(N_{fin}>N_{msy})$	$P(N_{fin}>N_{cur})$	$P(F_{fin}<F_{cur})$	$P(N_{cur}>N_{ref})$	$P(N_{fin}<0.01K)$
10 -year	HRmsy	0.69	1.38	0	0.95	0.05	0.01	0.05	0
	HRmsy* 0.75	0.73	1.46	0	0.97	0.14	0.03	0.14	0
	HRmsy*(HR/HRmsy)2003	0.83	1.66	0	0.99	0.74	0.45	0.74	0
	HRmsy*0	0.86	1.73	0	0.99	1	1	1	0
20 -year	HRmsy	0.63	1.27	0	0.95	0.05	0.01	0.05	0
	HRmsy* 0.75	0.7	1.39	0	0.98	0.14	0.03	0.14	0
	HRmsy*(HR/HRmsy)2003	0.85	1.71	0	1	0.74	0.45	0.74	0
	HRmsy*0	0.91	1.82	0	1	1	1	1	0
30 -year	HRmsy	0.6	1.2	0	0.95	0.05	0.01	0.05	0
	HRmsy* 0.75	0.68	1.35	0	0.99	0.14	0.03	0.14	0
	HRmsy*(HR/HRmsy)2003	0.87	1.74	0	1	0.74	0.45	0.74	0
	HRmsy*0	0.94	1.88	0	1	1	1	1	0

Table 3.12. Expected values (EV) of the mean and coefficients of variation (CV) of marginal posterior distributions for output parameters from the Bayesian SPM using the SIR algorithm. Results for the LCS complex with equal and inverse CV weighting: **continuity scenario** (using all CPUE series from the 2002 assessment, updated to 2004 when possible) and **retrospective analysis** (limiting the baseline scenario catch and CPUEs through 2001). Results that alter the stock status determination derived from the baseline scenario are boxed and highlighted in red. Poor convergence diagnostics are shaded and highlighted in green. Abundances are in thousands of fish.

	LCS-Continuity, Eq.W		LCS-Continuity, Inv. W		LCS-Retrospective*	
	EV	CV	EV	CV	EV	CV
Importance function	priors		priors		priors	
K	12298	0.65	8109	0.11	35750	0.49
r	0.203	0.55	0.210	0.17	0.047	0.47
MSY	481.3	0.37	417.0	0.07	397.9	0.62
N_{2004}	7492	0.86	3333	0.13	25426	0.70
N_{2004}/K	**0.60**	0.21	**0.41**	0.12	**0.66**	0.25
N_{init}	11292	0.67	8051	0.13	36151	0.52
N_{2004}/N_{init}	0.66	0.22	0.42	0.12	0.66	0.23
C_{2004}/MSY	0.56	0.31	0.60	0.08	0.94	0.52
F_{2004}/F_{MSY}	**0.51**	0.52	**0.74**	0.17	**0.83**	0.75
N_{2004}/N_{MSY}	**1.20**	0.21	**0.83**	0.12	**1.32**	0.25
C_{2004}/repy	0.617	0.27	0.638	0.10	1.711	55.40
N_{MSY}	6149	0.65	4054	0.11	17875	0.49
F_{MSY}	0.101		0.105		0.024	0.47
repy	422.7	0.17	395.6	0.10	279.7	0.38
C_0	291.9	0.94	138.6	0.65	415.3	1.00
Diagnostics						
CW (wt)	5.558		37.011		0.768	
CV (L*prior)	3.901		33.879		1.532	
CV (Wt) / CV (L*p)	1.43		1.09		0.50	
%maxpWt	0.096		2.500		0.015	

N_{init} is initial abundance (for the first year of the model), repy is replacement yield
* Stock status criteria for the retrospective analysis refer to 2001

Table 3.13. Decision analysis tables for various groupings and species corresponding to the results in Table 3.12.

LCS continuity scenario, equal weighting

Horizon	Policy	$E(N_{fin}/K)$	$E(N_{fin}/N_{msy})$	$P(N_{fin}<0.2K)$	$P(N_{fin}>N_{msy})$	$P(N_{fin}>N_{cur})$	$P(F_{fin}<F_{cur})$	$P(N_{cur}>N_{ref})$	$P(N_{fin}<0.01K)$
10 -year	HRmsy	0.53	1.07	0	0.86	0.14	0.04	0.14	0
	HRmsy* 0.75	0.61	1.23	0	0.95	0.4	0.11	0.4	0
	HRmsy*(HR/HRmsy)2003	0.67	1.34	0	0.97	0.65	0.22	0.65	0
	HRmsy*0	0.89	1.77	0	0.99	1	1	1	0
20 -year	HRmsy	0.51	1.03	0	0.86	0.14	0.04	0.14	0
	HRmsy* 0.75	0.62	1.23	0	0.98	0.4	0.11	0.4	0
	HRmsy*(HR/HRmsy)2003	0.69	1.38	0	0.99	0.65	0.22	0.65	0
	HRmsy*0	0.95	1.9	0	1	1	1	1	0
30 -year	HRmsy	0.51	1.01	0	0.86	0.14	0.04	0.14	0
	HRmsy* 0.75	0.62	1.24	0	0.99	0.4	0.11	0.4	0
	HRmsy*(HR/HRmsy)2003	0.7	1.39	0	0.99	0.65	0.22	0.65	0
	HRmsy*0	0.98	1.95	0	1	1	1	1	0

Table 3.13. (continued)

LCS continuity scenario, inverse CV weighting

Horizon	Policy	$E(N_{fin}/K)$	$E(N_{fin}/N_{msy})$	$P(N_{fin}<0.2K)$	$P(N_{fin}>N_{msy})$	$P(N_{fin}>N_{cur})$	$P(F_{fin}<F_{cur})$	$P(N_{cur}>N_{ref})$	$P(N_{fin}<0.01K)$
10 -year	HRmsy	0.49	0.97	0	0.29	0.71	0.02	0.71	0
	HRmsy* 0.75	0.57	1.14	0	0.97	0.99	0.25	0.99	0
	HRmsy*(HR/HRmsy)2003	0.51	1.01	0	0.67	0.84	0.04	0.84	0
	HRmsy*0	0.88	1.75	0	1	1	1	1	0
20 -year	HRmsy	0.49	0.99	0	0.29	0.71	0.02	0.71	0
	HRmsy* 0.75	0.61	1.22	0	1	0.99	0.25	0.99	0
	HRmsy*(HR/HRmsy)2003	0.52	1.04	0	0.94	0.84	0.04	0.84	0
	HRmsy*0	0.98	1.96	0	1	1	1	1	0
30 -year	HRmsy	0.5	0.99	0	0.29	0.71	0.02	0.71	0
	HRmsy* 0.75	0.62	1.24	0	1	0.99	0.25	0.99	0
	HRmsy*(HR/HRmsy)2003	0.53	1.05	0	0.99	0.84	0.04	0.84	0
	HRmsy*0	1	1.99	0	1	1	1	1	0

Table 3.14. Expected values (EV) of the mean and coefficients of variation (CV) of marginal posterior distributions for output parameters from the Bayesian SPM using the SIR algorithm. Results for the LCS and LCS- prohibited species groupings as in the baseline scenario but **including the additional CPUE series identified as "sensitivity"** in the Data Workshop report. The MRFSS series was included both with and without requiem sharks. Results that alter the stock status determination derived from the baseline scenario are boxed and highlighted in red.

	LCS				LCS-prohibited			
	MRFSS with requiem		MRFSS without requiem		MRFSS with requiem		MRFSS without requiem	
	EV	CV	EV	CV	EV	CV	EV	CV
Importance function	priors		priors		priors		priors	
K	35484	0.47	26781	0.44	55699	0.40	25945	0.57
r	0.05	0.49	0.05	0.48	0.05	0.47	0.05	0.48
MSY	430	0.53	313	0.49	704.57	0.56	289.37	0.65
N_{2004}	25804	0.64	16803	0.70	44461	0.48	14866	0.97
N_{2004}/K	**0.69**	0.21	**0.59**	0.25	**0.77**	0.15	**0.50**	0.35
N_{init}	36247	0.50	27462	0.49	48720	0.42	23466	0.59
N_{2004}/N_{init}	0.68	0.19	0.58	0.22	0.89	0.17	0.56	0.33
C_{2004}/MSY	0.72	0.46	0.95	0.42	0.46	0.55	1.09	0.46
F_{2004}/F_{MSY}	**0.58**	0.62	**0.90**	0.59	**0.33**	0.74	**1.32**	0.70
N_{2004}/N_{MSY}	**1.37**	0.21	**1.18**	0.25	**1.54**	0.15	**1.01**	0.35
C_{2004}/repy	0.94	3.82	1.09	3.10	0.70	0.37	1.23	0.44
N_{MSY}	17742	0.47	13390	0.44	27850	0.40	12972	0.57
F_{MSY}	0.03	0.49	0.03	0.48	0.03	0.47	0.02	0.48
repy	303	0.32	260	0.32	398	0.33	236	0.38
C_0	426	0.99	352	0.93	514	1.12	347	1.05
Diagnostics								
CW (wt)	1.13		1.47		0.81		1.33	
CV (L*prior)	1.56		2.04		1.04		2.02	
CV (Wt) / CV (L*p)	0.73		0.72		0.78		0.66	
%maxpWt	0.036		0.051		0.025		0.071	

N_{init} is initial abundance (for the first year of the model), repy is replacement yield

Table 3.15. Expected values (EV) of the mean of marginal posterior distributions for output parameters from the Bayesian SPM using the SIR algorithm. Results for LCS using equal weighting (baseline) and **removing one CPUE series at a time**. Abundances are in thousands of fish.

Series removed	Gillnet Observer	PC Gillnet	ENP	SC LL Recent	BLLOP	NMFS LL SE	Bottom LL Logs	NMFS LL NE	Pelagic Log	SC LL Early	VA LL
	EV	EV	EV	EV	EV	EV	EV	EV	EV	EV	EV
Importance function	priors	priors	priors	priors	priors	priors	priors	priors	priors	priors	priors
K	33401	35128	36517	35184	34807	34626	35113	34851	37259	37233	44171
r	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
MSY	367	396	415	397	390	382	395	390	433	422	514
N_{2004}	23054	24907	25825	24960	24556	24332	24889	24604	27133	27027	33867
N_{2004}/K	**0.64**	**0.66**	**0.65**	**0.66**	**0.65**	**0.65**	**0.66**	**0.66**	**0.68**	**0.68**	**0.72**
N_{init}	33903	35599	36520	35622	35274	35163	35576	35345	37555	37627	43283
N_{2004}/N_{init}	0.63	0.66	0.65	0.66	0.65	0.65	0.66	0.65	0.68	0.68	0.74
C_{2004}/MSY	0.87	0.81	0.80	0.81	0.82	0.84	0.81	0.82	0.74	0.76	0.65
F_{2004}/F_{MSY}	**0.80**	**0.71**	**0.74**	**0.70**	**0.72**	**0.75**	**0.71**	**0.72**	**0.62**	**0.64**	**0.51**
N_{2004}/N_{MSY}	**1.27**	**1.32**	**1.29**	**1.32**	**1.31**	**1.30**	**1.32**	**1.31**	**1.36**	**1.35**	**1.45**
C_{2004}/repy	1.08	1.04	1.03	1.04	1.05	1.07	1.04	1.05	0.98	1.01	0.92
N_{MSY}	16700	17564	18258	17592	17403	17313	17557	17425	18629	18616	22085
F_{MSY}	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02
repy	269	281	287	283	279	274	282	278	298	290	319
C_0	401	417	476	418	414	408	417	413	440	432	432
Diagnostics											
CW (wt)	0.88	0.85	0.72	0.85	0.85	0.84	0.85	0.85	0.84	0.78	0.57
CV (L*prior)	1.66	1.57	1.41	1.56	1.58	1.60	1.57	1.58	1.46	1.48	1.24
CV (Wt) / CV (L*p)	0.53	0.54	0.51	0.55	0.54	0.52	0.54	0.54	0.57	0.53	0.45
%maxpWt	0.014	0.017	0.019	0.017	0.016	0.012	0.017	0.015	0.032	0.016	0.009

N_{init} is initial abundance (for the first year of the model), repy is replacement yield

Table 3.16. Expected values (EV) of the mean of marginal posterior distributions for output parameters from the Bayesian SPM using the SIR algorithm. Results for LCS using equal weighting (baseline) and **fitting one CPUE series at a time**. Results that alter the stock status determination derived from the full model (all baseline CPUE series included) are boxed and highlighted in red. The NMFS LL NE and SC LL Early had too few data points to estimate all four model parameters. Abundances are in thousands of fish.

Series fit	Gillnet Observer	PC Gillnet	ENP	SC LL Recent	BLLOP	NMFS LL SE	Bottom LL Logs	NMFS LL NE	Pelagic Log	SC LL Early	VA LL
	EV	EV	EV	EV	EV	EV	EV	EV	EV	EV	EV
Importance function	priors	priors	priors	priors	priors	priors	priors		priors		priors
K	48638	44478	43111	43657	45699	46496	44535		36248		32714
r	0.05	0.05	0.05	0.05	0.05	0.05	0.05		0.04		0.04
MSY	574	509	477	498	526	542	509		396		347
N_{2004}	37801	33483	32636	32596	34778	35608	33549		24789		21468
N_{2004}/K	**0.73**	**0.68**	**0.70**	**0.66**	**0.69**	**0.70**	**0.68**		**0.56**		**0.57**
N_{init}	46467	42873	42572	42090	44014	44591	42942		35267		32798
N_{2004}/N_{init}	0.76	0.71	0.72	0.69	0.72	0.74	0.71		0.58		0.57
C_{2004}/MSY	0.63	0.76	0.74	0.79	0.72	0.69	0.76		1.03		1.01
F_{2004}/F_{MSY}	**0.56**	**0.90**	**0.63**	**1.22**	**0.75**	**0.66**	**0.90**		**1.99**		**1.22**
N_{2004}/N_{MSY}	**1.45**	**1.35**	**1.41**	**1.32**	**1.39**	**1.41**	**1.35**		**1.12**		**1.15**
C_{2004}/repy	0.94	1.10	1.03	1.22	1.04	0.99	1.10		1.58		1.28
N_{MSY}	24319	22239	21555	21828	22849	23248	22268		18124		16357
F_{MSY}	0.02	0.02	0.02	0.02	0.02	0.02	0.02		0.02		0.02
repy	334	303	296	296	311	321	303		245		245
C_0	475	451	411	448	456	464	451		421		449
Diagnostics											
CW (wt)	0.40	0.19	0.46	0.11	0.26	0.32	0.19		0.45		0.70
CV (L*prior)	1.00	1.07	1.26	1.08	1.04	1.02	1.06		1.63		1.59
CV (Wt) / CV (L*p)	0.40	0.18	0.37	0.11	0.25	0.31	0.18		0.28		0.44
%maxpWt	0.007	0.002	0.004	0.002	0.001	0.005	0.001		0.006		0.007

N_{init} is initial abundance (for the first year of the model), repy is replacement yield.

Table 3.17. Expected values (EV) of the mean of marginal posterior distributions for output parameters from the Bayesian SPM using the SIR algorithm. Results for LCS without prohibited species using equal weighting (baseline) and **removing one CPUE series at a time**.

Series removed	Gillnet Observer	PC Gillnet	BLLOP	NMFS LL SE	Bottom LL Logs	NMFS LL NE	Pelagic Log
	EV	EV	EV	EV	EV	EV	EV
Importance function	priors	priors	priors	priors	priors	priors	priors
K	48796	51093	50693	50383	50925	50770	52207
r	0.05	0.05	0.05	0.05	0.05	0.05	0.05
MSY	575	615	609	599	612	610	650
N_{2004}	37572	39888	39488	39168	39725	39572	40955
N_{2004}/K	**0.72**	**0.74**	**0.73**	**0.73**	**0.74**	**0.74**	**0.75**
N_{init}	43426	45271	44921	44764	45122	45003	45809
N_{2004}/N_{init}	0.81	0.84	0.83	0.83	0.84	0.84	0.86
C_{2004}/MSY	0.62	0.56	0.57	0.59	0.57	0.57	0.52
F_{2004}/F_{MSY}	**0.53**	**0.45**	**0.46**	**0.49**	**0.46**	**0.46**	**0.40**
N_{2004}/N_{MSY}	**1.44**	**1.48**	**1.47**	**1.46**	**1.47**	**1.47**	**1.49**
C_{2004}/repy	0.84	0.79	0.79	0.81	0.79	0.79	0.74
N_{MSY}	24398	25547	25346	25192	25463	25385	26104
F_{MSY}	0.02	0.03	0.03	0.02	0.03	0.03	0.03
repy	343	360	358	351	359	358	378
C_0	439	460	457	447	458	457	496
Diagnostics							
CW (wt)	0.41	0.52	0.50	0.47	0.51	0.51	2.83
CV (L*prior)	1.00	0.97	0.98	0.98	0.98	0.98	2.83
CV (Wt) / CV (L*p)	0.41	0.53	0.51	0.47	0.52	0.52	1.00
%maxpWt	0.006	0.004	0.009	0.006	0.008	0.008	0.062

N_{init} is initial abundance (for the first year of the model), repy is replacement yield.

Table 3.18. Expected values (EV) of the mean of marginal posterior distributions for output parameters from the Bayesian SPM using the SIR algorithm. Results for LCS without prohibited species using equal weighting (baseline) and **fitting one CPUE series at a time**. Results that alter the stock status determination derived from the full model (all baseline CPUE series included) are boxed and highlighted in red. The NMFS LL NE had too few data points to estimate all four model parameters. The model did not converge with the BLLOP series. Abundances are in thousands of fish.

Series fit	Gillnet Observer	PC Gillnet	BLLOP	NMFS LL SE	Bottom LL Logs	NMFS LL NE	Pelagic Log
	EV	EV	EV	EV	EV	EV	EV
Importance function	priors	priors		priors	priors		priors
K	49502	45234		47445	44399		40558
r	0.05	0.05		0.05	0.05		0.05
MSY	582	517		552	506		451
N_{2004}	38229	33826		36139	32951		28988
N_{2004}/K	**0.72**	**0.67**		**0.70**	**0.66**		**0.61**
N_{init}	44055	40423		42290	39687		36357
N_{2004}/N_{init}	0.81	0.75		0.79	0.74		0.68
C_{2004}/MSY	0.63	0.75		0.68	0.78		0.89
F_{2004}/F_{MSY}	**0.56**	**0.91**		**0.66**	**1.06**		**1.33**
N_{2004}/N_{MSY}	**1.44**	**1.34**		**1.40**	**1.31**		**1.22**
C_{2004}/repy	0.86	1.03		0.91	1.09		1.23
N_{MSY}	24751	22617		23723	22200		20279
F_{MSY}	0.02	0.02		0.02	0.02		0.02
repy	342	312		331	306		280
C_0	441	419		432	415		400
Diagnostics							
CW (wt)	0.40	0.19		0.32	0.15		0.23
CV (L*prior)	0.95	1.03		0.98	1.06		1.29
CV (Wt) / CV (L*p)	0.42	0.19		0.32	0.14		0.18
%maxpWt	0.007	0.003		0.005	0.002		0.003

N_{init} is initial abundance (for the first year of the model), repy is replacement yield.

Table 3.19. Expected values (EV) of the mean of marginal posterior distributions for output parameters from the Bayesian SPM using the SIR algorithm. Results for LCS without prohibited species, blacktip, and sandbar sharks using equal weighting (baseline) and **removing one CPUE series at a time**. Abundances are in thousands of fish.

Series removed	Gillnet Observer	PC Gillnet	BLLOP	NMFS LL SE	Bottom LL Logs	NMFS LL NE	Pelagic Log
	EV	EV	EV	EV	EV	EV	EV
Importance function	priors	priors	priors	priors	priors	priors	priors
K	30695	31190	30874	31255	31381	31270	32600
r	0.05	0.05	0.05	0.05	0.05	0.05	0.05
MSY	353	357	355	360	361	359	378
N_{2004}	27070	27548	27243	27611	27734	27636	28894
N_{2004}/K	**0.79**	**0.80**	**0.79**	**0.80**	**0.80**	**0.80**	**0.81**
N_{init}	27346	27804	27509	27819	27946	27887	28901
N_{2004}/N_{init}	0.90	0.90	0.90	0.91	0.91	0.90	0.93
C_{2004}/MSY	0.39	0.38	0.39	0.37	0.37	0.38	0.34
F_{2004}/F_{MSY}	**0.33**	**0.31**	**0.32**	**0.31**	**0.31**	**0.32**	**0.26**
N_{2004}/N_{MSY}	**1.59**	**1.60**	**1.59**	**1.60**	**1.60**	**1.60**	**1.63**
C_{2004}/repy	0.72	0.68	0.72	0.71	0.71	0.71	0.61
N_{MSY}	15347	15595	15437	15627	15690	15635	16300
F_{MSY}	0.02	0.02	0.02	0.02	0.02	0.02	0.02
repy	119	119	119	120	120	119	126
C_0	132	132	132	133	132	131	142
Diagnostics							
CW (wt)	0.31	0.31	0.31	0.33	0.32	0.30	3.00
CV (L*prior)	1.28	1.26	1.27	1.25	1.25	1.26	3.82
CV (Wt) / CV (L*p)	0.24	0.25	0.25	0.26	0.26	0.24	0.78
%maxpWt	0.008	0.002	0.008	0.008	0.008	0.006	0.074

N_{init} is initial abundance (for the first year of the model), repy is replacement yield.

Table 3.20. Expected values (EV) of the mean of marginal posterior distributions for output parameters from the Bayesian SPM using the SIR algorithm. Results for LCS without prohibited species, blacktip, and sandbar sharks using equal weighting (baseline) and **fitting one CPUE series at a time**. The NMFS LL NE had too few data points to estimate all four model parameters. Abundances are in thousands of fish.

Series fit	Gillnet Observer	PC Gillnet	BLLOP	NMFS LL SE	Bottom LL Logs	NMFS LL NE	Pelagic Log
	EV	EV	EV	EV	EV	EV	EV
Importance function	priors	priors	priors	priors	priors		priors
K	31490	30716	31153	30413	30168		27339
r	0.05	0.05	0.05	0.05	0.05		0.04
MSY	359	350	353	345	342		306
N_{2004}	27865	27099	27527	26804	26564		23791
N_{2004}/K	**0.79**	**0.78**	**0.79**	**0.77**	**0.77**		**0.72**
N_{init}	28220	27509	27918	27277	27064		24651
N_{2004}/N_{init}	0.89	0.88	0.89	0.87	0.87		0.81
C_{2004}/MSY	0.41	0.43	0.42	0.44	0.46		0.56
F_{2004}/F_{MSY}	**0.40**	**0.46**	**0.42**	**0.50**	**0.55**		**0.81**
N_{2004}/N_{MSY}	**1.58**	**1.56**	**1.57**	**1.55**	**1.54**		**1.45**
C_{2004}/repy	0.77	0.80	0.76	0.81	0.84		0.95
N_{MSY}	15745	15358	15577	15207	15084		13669
F_{MSY}	0.02	0.02	0.02	0.02	0.02		0.02
repy	116	114	115	112	112		102
C_0	128	127	127	126	126		121
Diagnostics							
CW (wt)	0.21	0.17	0.20	0.15	0.13		0.20
CV (L*prior)	1.27	1.31	1.28	1.34	1.36		1.70
CV (Wt) / CV (L*p)	0.16	0.13	0.15	0.11	0.09		0.12
%maxpWt	0.00	0.00	0.00	0.00	0.00		0.00

N_{init} is initial abundance (for the first year of the model), repy is replacement yield

Table 3.21. Expected values (EV) of the mean and coefficients of variation (CV) of marginal posterior distributions for output parameters from the Bayesian SPM using the SIR algorithm. Results for the three LCS groupings using equal weighting and values of r (intrinsic rate of increase) recommended in the Data Workshop report and the **1981 catch as a fixed catch for the years 1972-1980**. Abundances are in thousands of fish.

	LCS		LCS-PROH		LCS-PROH-SB-BT	
	EV	CV	EV	CV	EV	CV
Importance function	priors		priors		priors	
K	35553	0.49	50941	0.45	31162	0.81
r	0.048	0.47	0.050	0.47	0.046	0.46
MSY	393.9	0.58	614.9	0.63	343.1	0.97
N_{2004}	23777	0.72	40134	0.56	27695	0.89
N_{2004}/K	**0.62**	0.24	**0.74**	0.19	**0.81**	0.18
N_{init}	32414	0.52	45173	0.47	27701	0.83
N_{2004}/N_{init}	0.68	0.22	0.85	0.20	0.92	0.20
C_{2004}/MSY	0.79	0.45	0.56	0.60	0.39	0.88
F_{2004}/F_{MSY}	**0.74**	0.67	**0.44**	0.92	**0.30**	1.29
N_{2004}/N_{MSY}	**1.23**	0.24	**1.49**	0.19	**1.62**	0.18
C_{2004}/repy	0.9	0.4	0.8	0.4		
N_{MSY}	17777	0.49	25471	0.45	15581	0.81
F_{MSY}	0.024		0.025		0.023	
repy	305.9	0.30	355.0	0.31	113.6	0.60
C_0	n/a	n/a	n/a	n/a	n/a	n/a
Diagnostics						
CW (wt)	0.902		0.520		0.382	
CV (L*prior)	1.273		0.712		0.940	
CV (Wt) / CV (L*p)	0.71		0.73		0.28	
%maxpWt	0.005		0.002		0.002	

N_{init} is initial abundance (for the first year of the model), repy is replacement yield

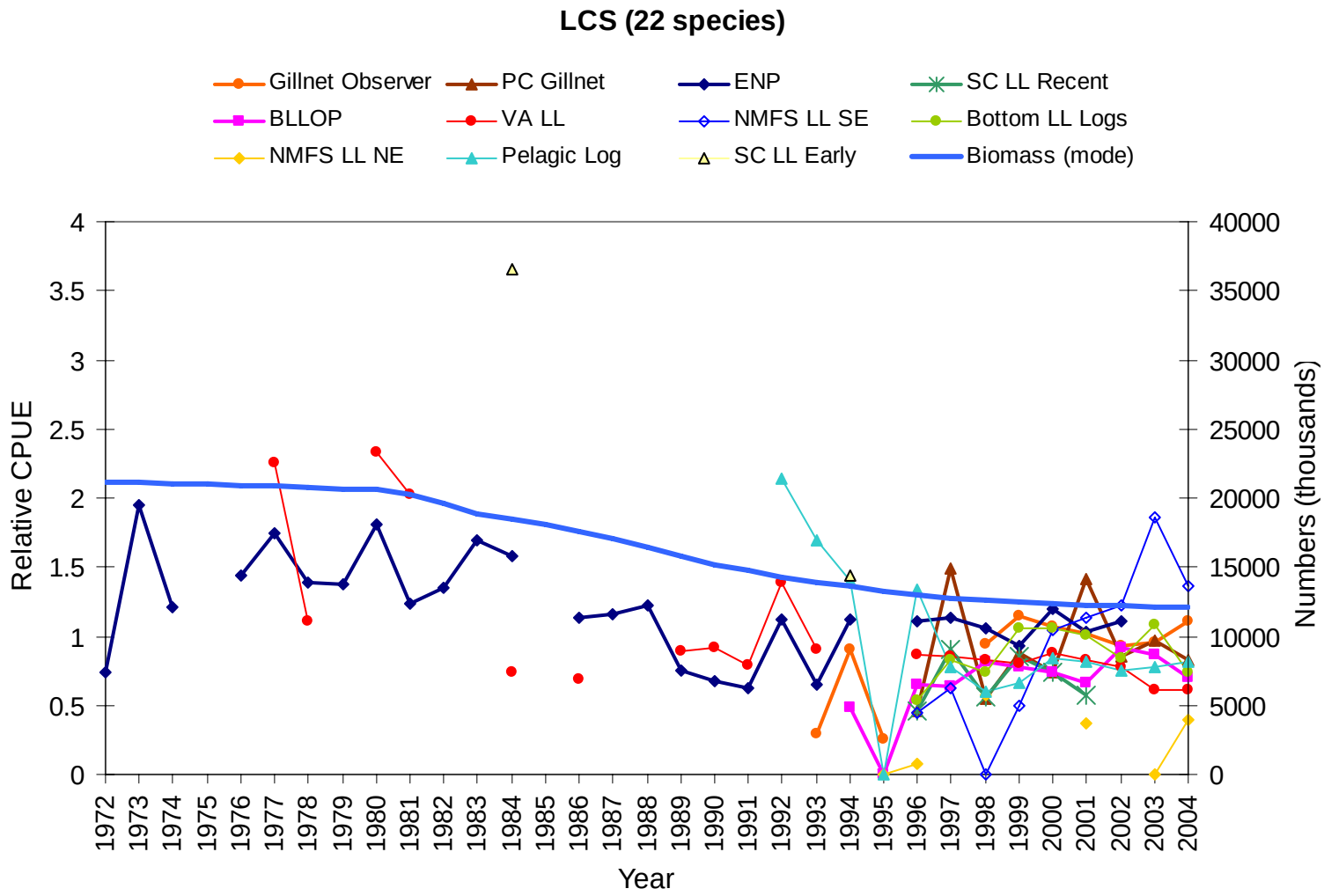
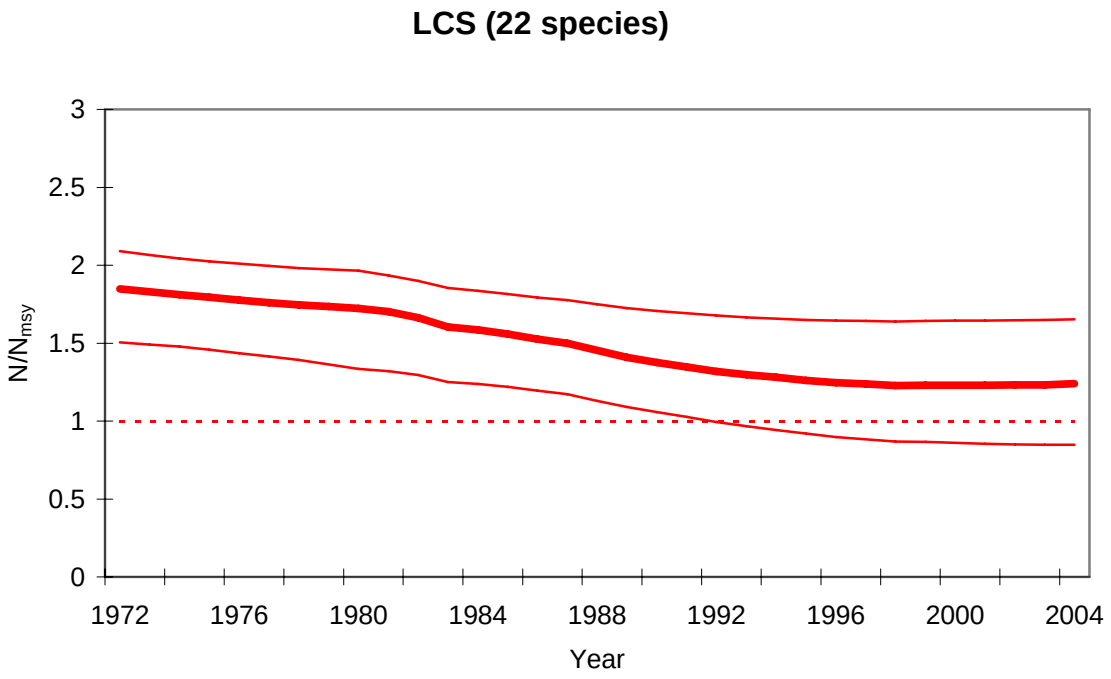


Figure 3.1. Predicted abundance trend of the BSP model fitted to the catch and CPUE data. CPUE series shown are scaled (divided by the mean of the overlapping years among all series, by the catchability coefficient for each series, and by the overall mean for all series).

A.



B.

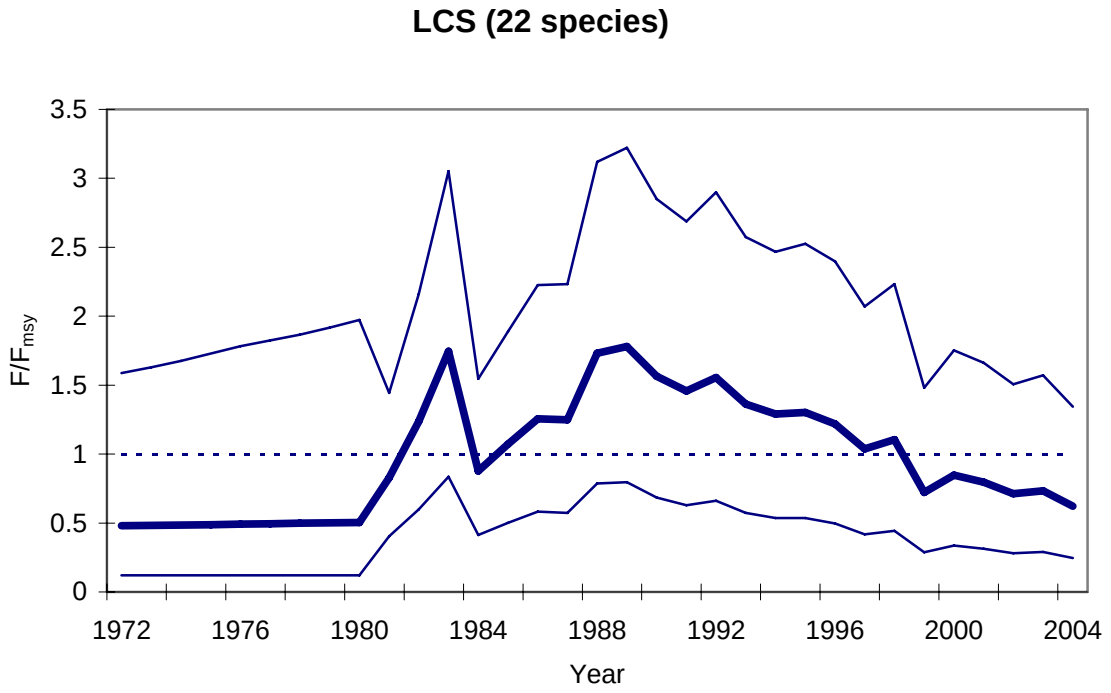


Figure 3.2. Predicted median relative abundance (A) and fishing mortality rate (B) trajectories for LCS with the BSP model. Values shown are medians with 80% probability intervals; horizontal lines at 1 denote MSY levels.

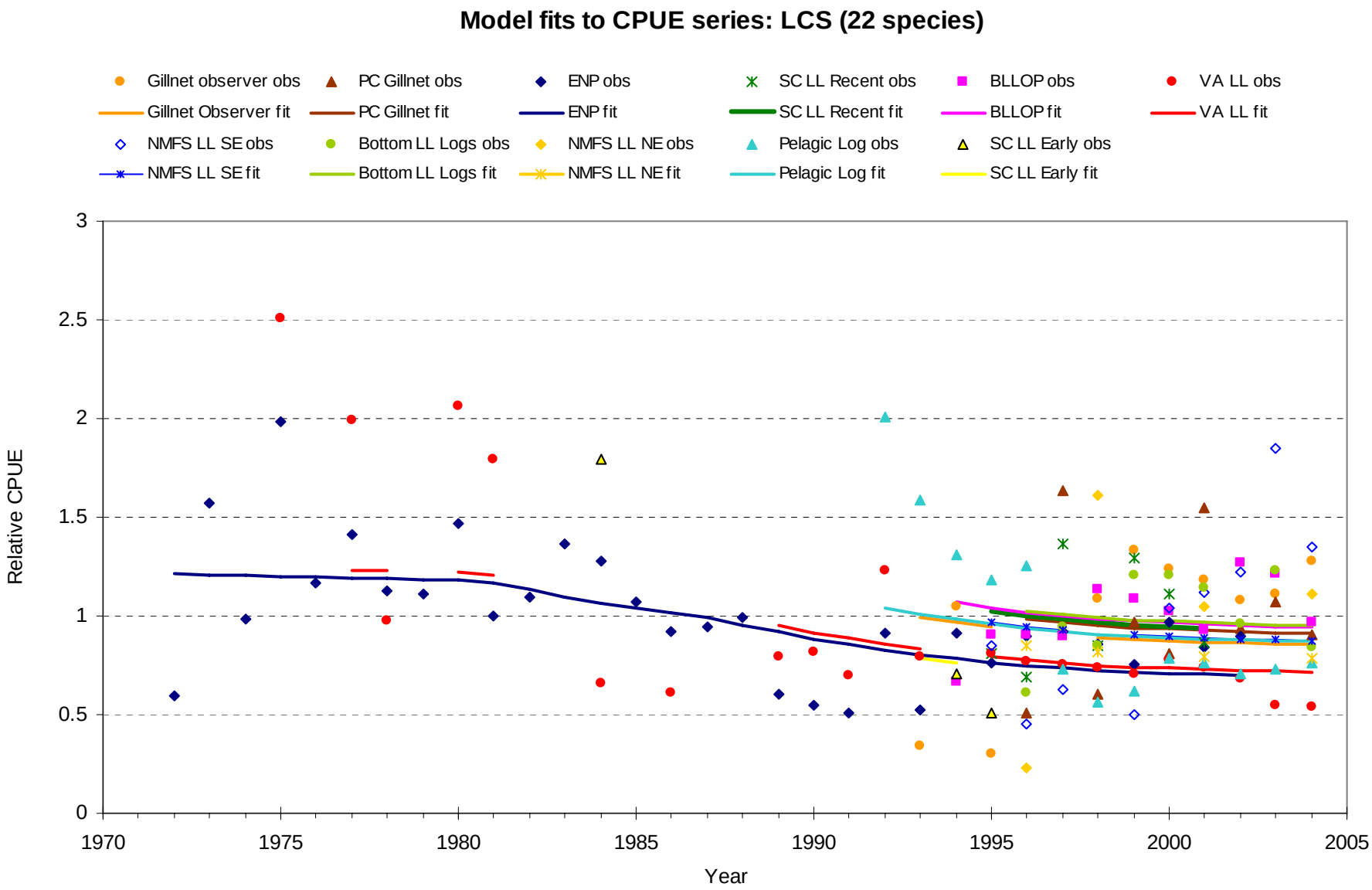


Figure 3.3. BSP model fits to the individual CPUE series for the LCS complex (22 species).

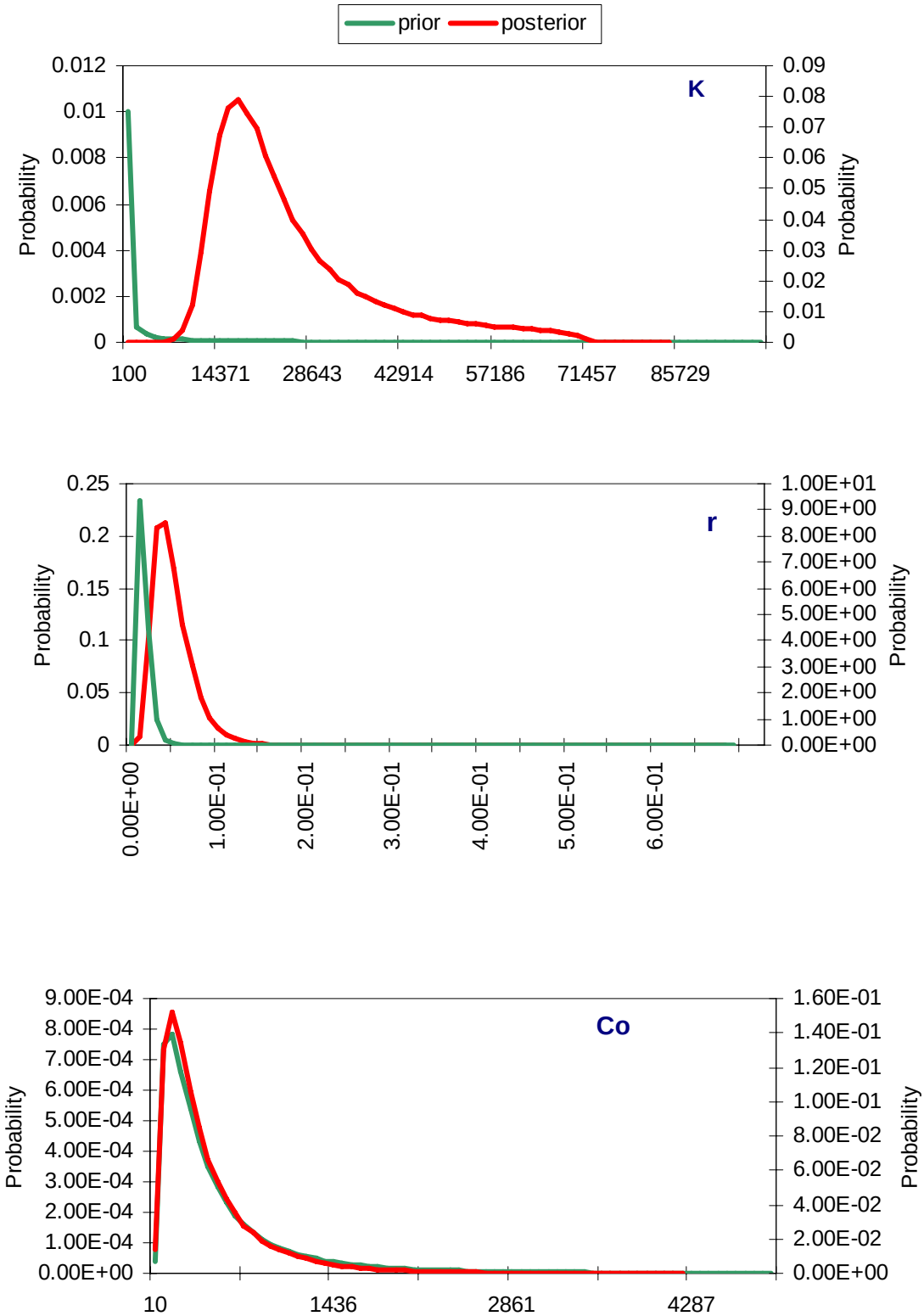


Figure 3.4. Prior (green) and posterior (red) probability distributions for K, r, and C_0 for LCS from the BSP model.

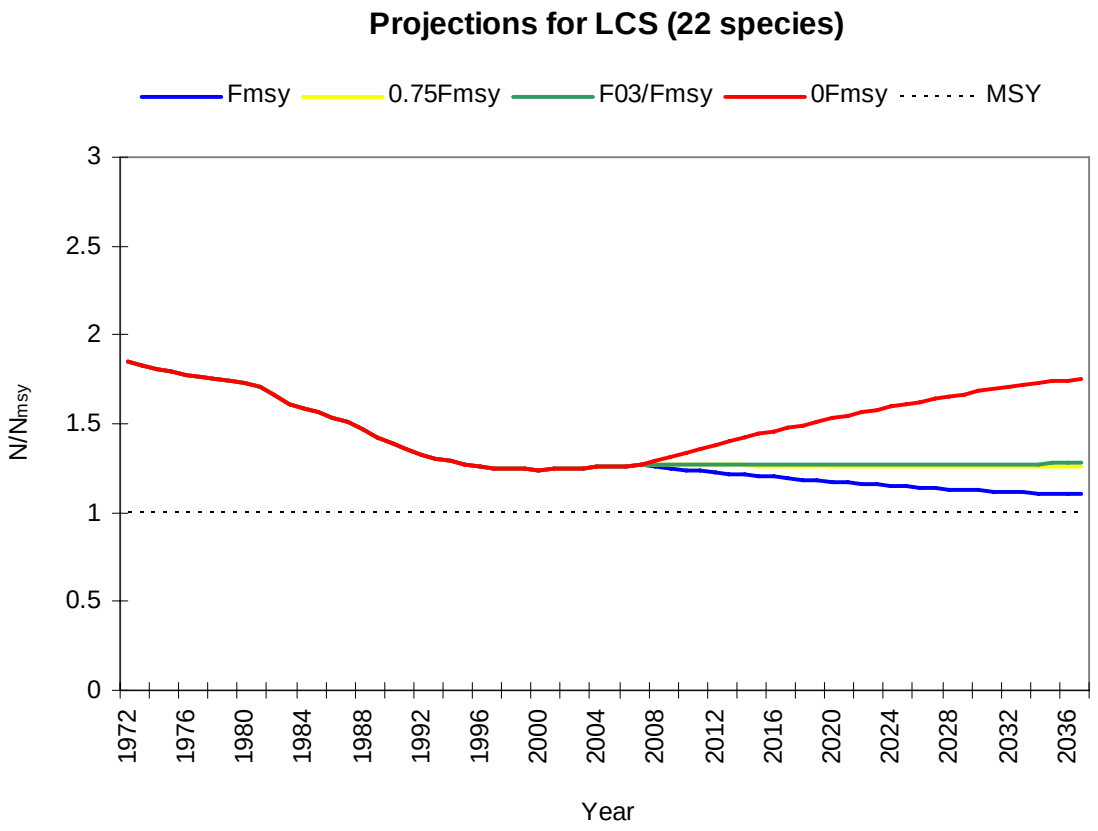


Figure 3.5. Estimated median relative abundance trajectory and projections (from 2008 to 2037) for alternative F_{MSY}-based harvesting policies (0, 0.75, and 1 times F_{MSY} and ((F_{2003}/F_{MSY}) * F_{MSY})) for the LCS complex (22 species) baseline scenario. The dashed horizontal line at 1 denotes the MSY level.

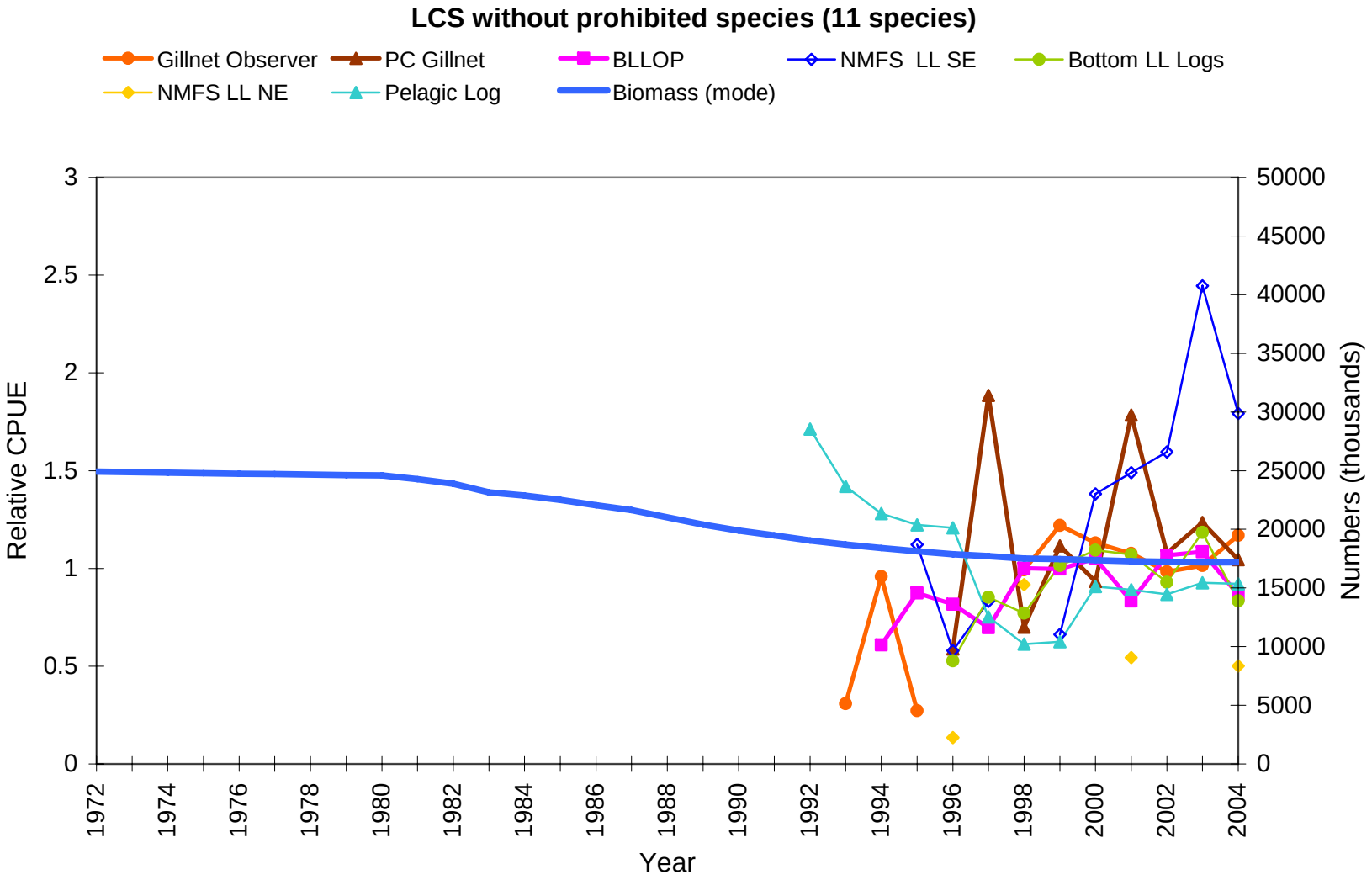
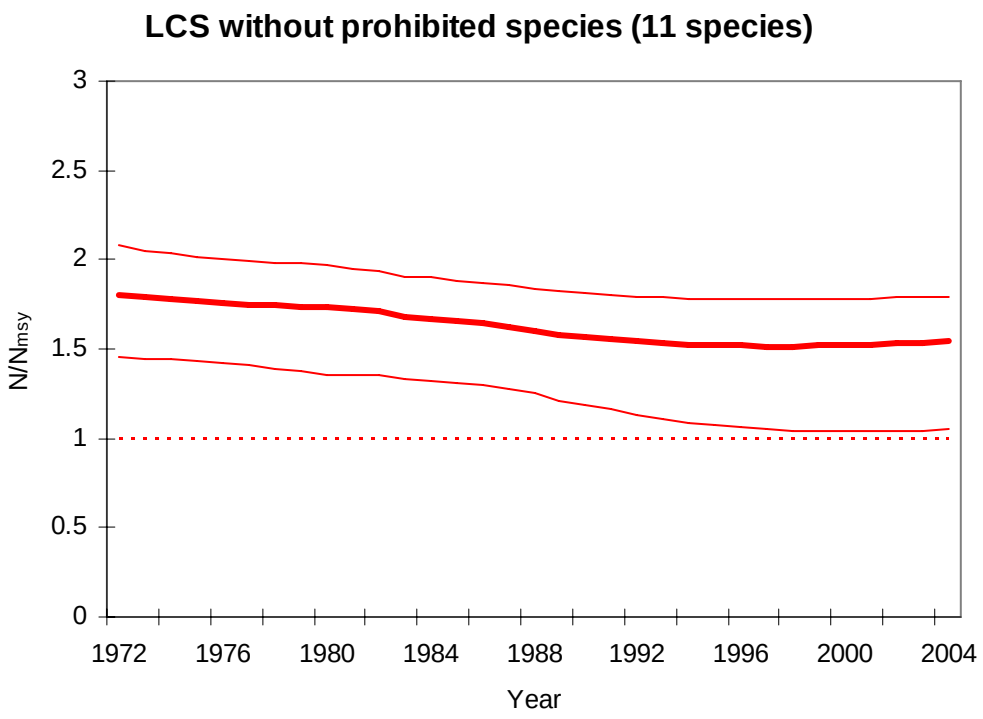


Figure 3.6. Predicted abundance trend of the BSP model fitted to the catch and CPUE data for LCS without prohibited species. CPUE series shown are scaled (divided by the mean of the overlapping years among all series, by the catchability coefficient for each series, and by the overall mean for all series).

A.



B.

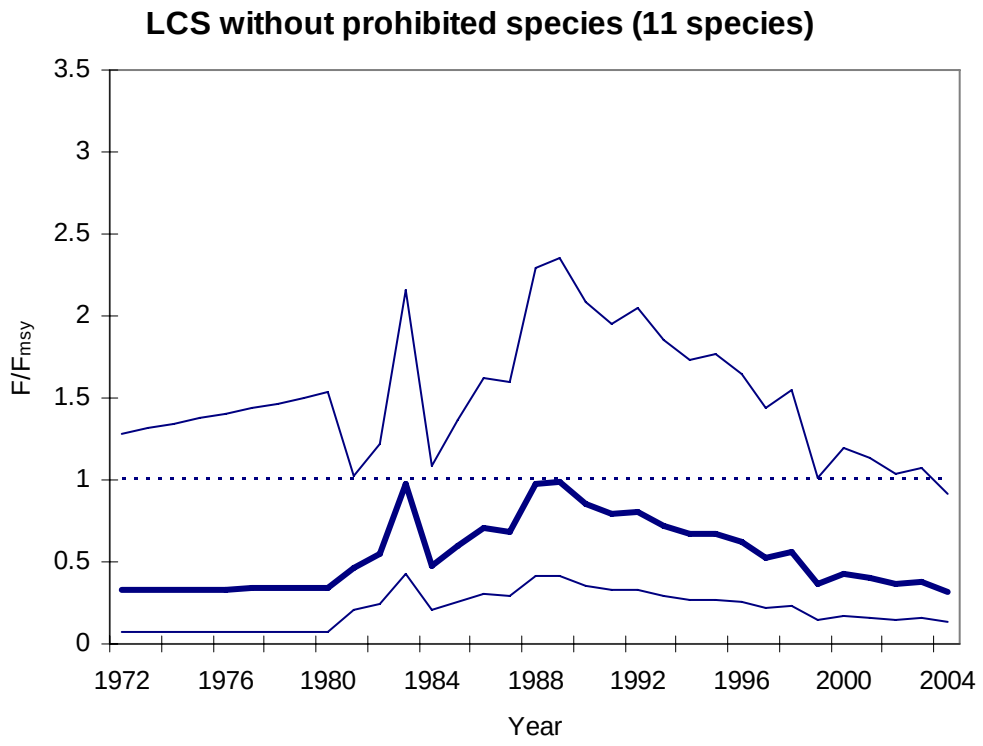
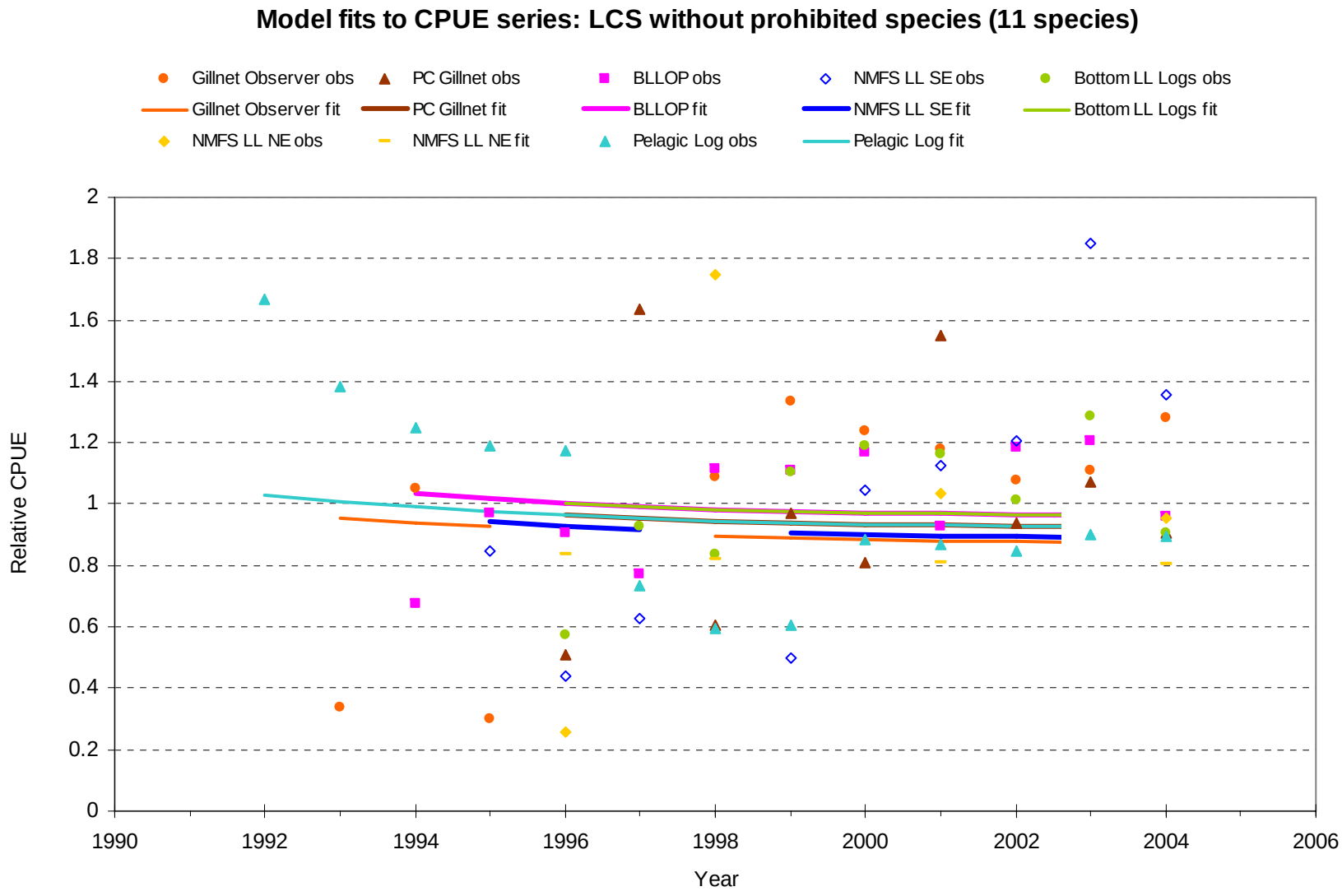


Figure 3.7. Predicted median relative abundance (A) and fishing mortality rate (B) trajectories for LCS without prohibited species with the BSP model. Values shown are medians with 80% probability intervals; horizontal lines at 1 denote MSY levels.



3.8. BSP model fits to the individual CPUE series for the LCS without prohibited species (11 species).

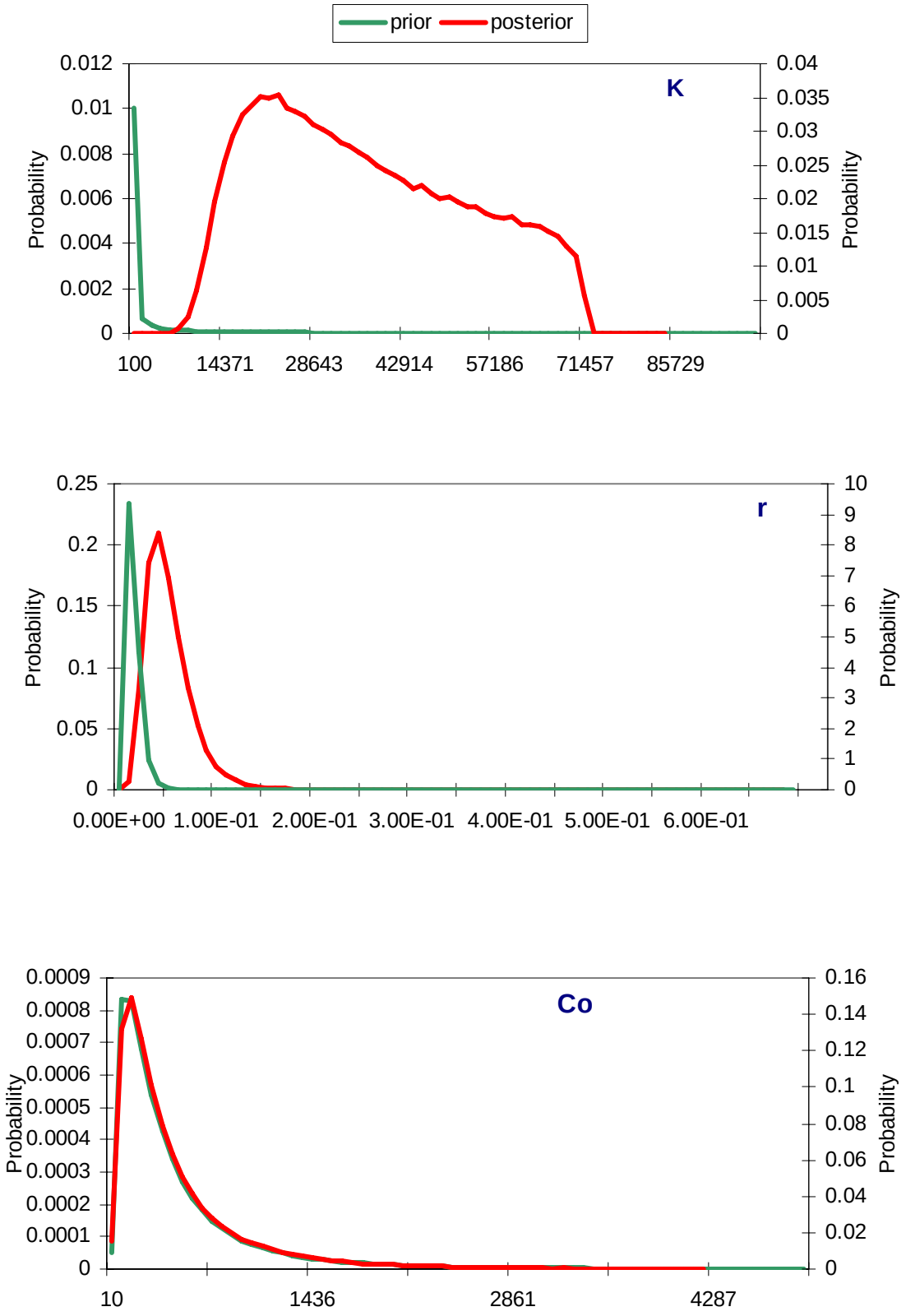


Figure 3.9. Prior (green) and posterior (red) probability distributions for K, r, and C_0 for LCS without prohibited species from the BSP model.

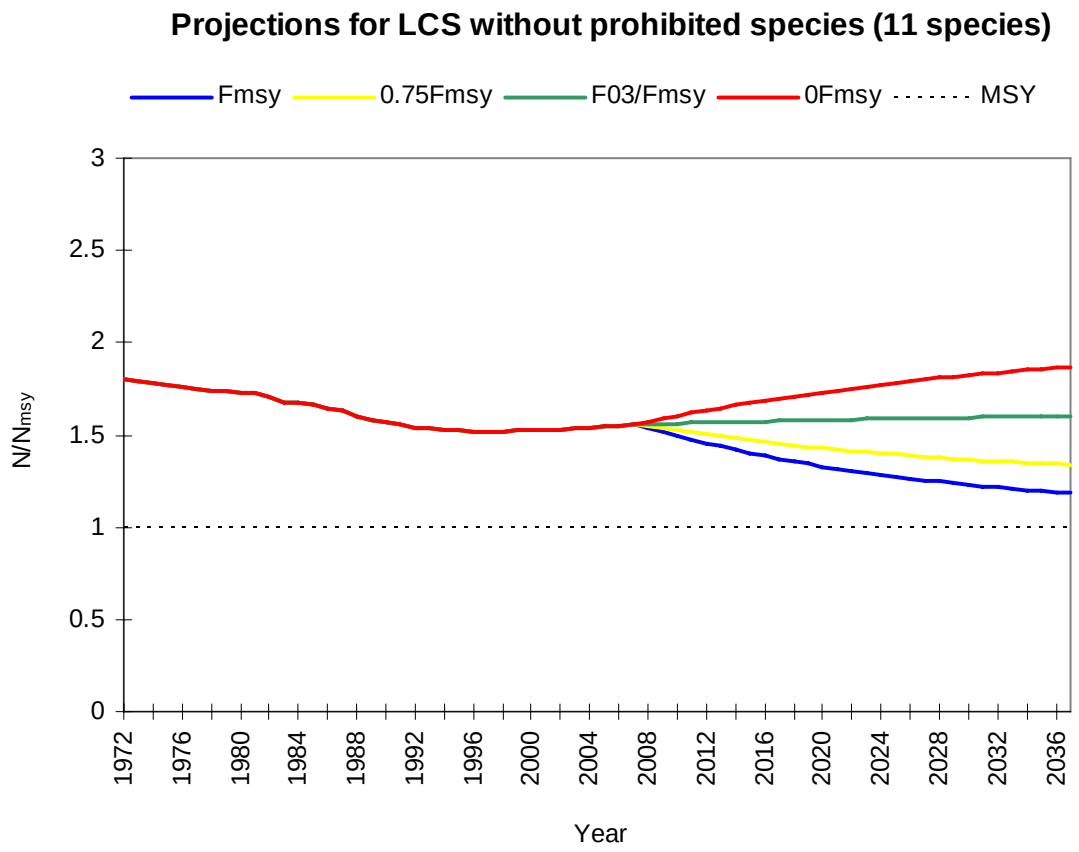


Figure 3.10. Estimated median relative abundance trajectory and projections (from 2008 to 2037) for alternative F_{MSY}-based harvesting policies (0, 0.75, and 1 times F_{MSY} and ((F_{2003}/F_{MSY}) * F_{MSY})) for the LCS without prohibited species (11 species) baseline scenario. The dashed horizontal line at 1 denotes the MSY level.

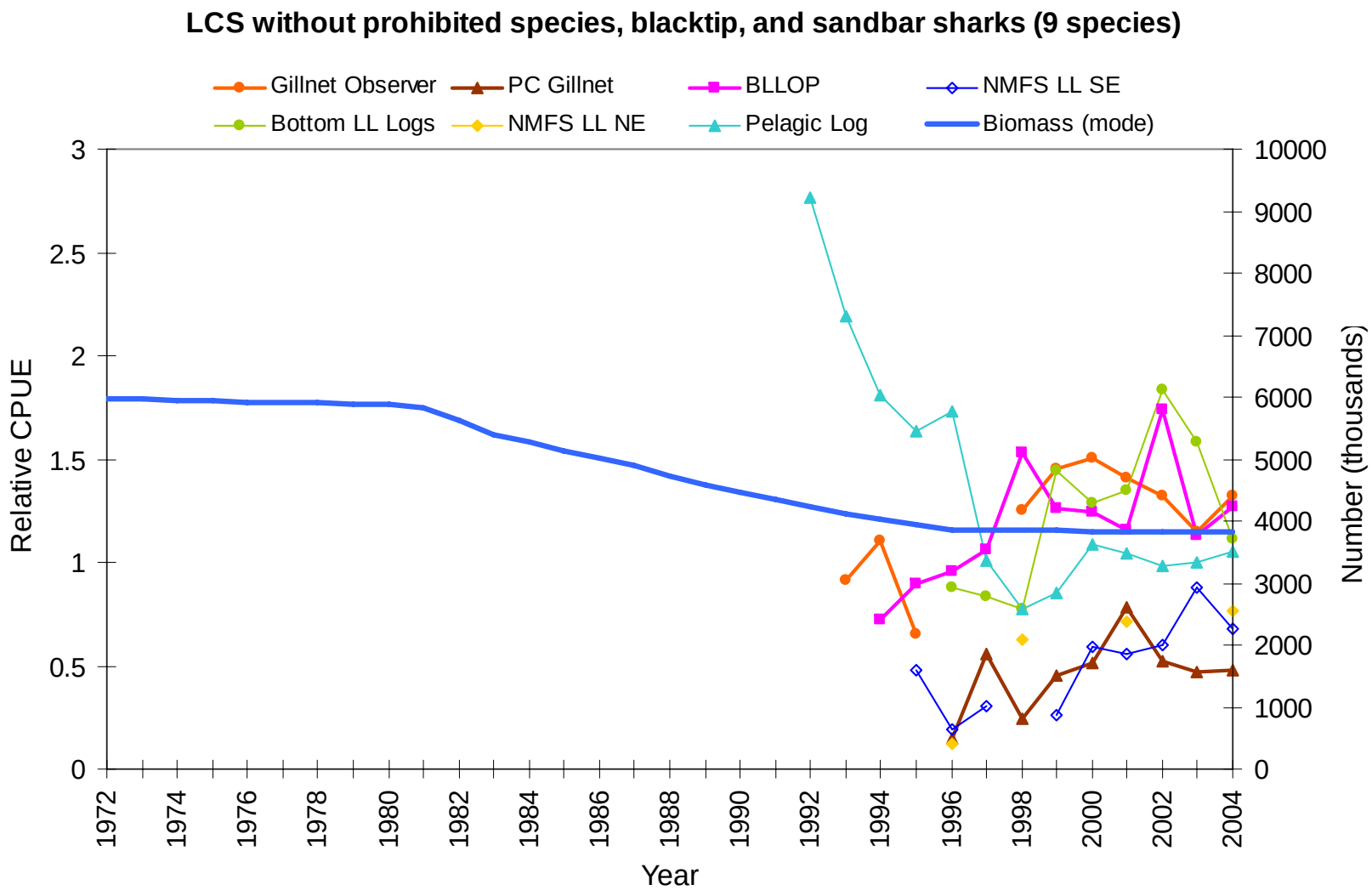
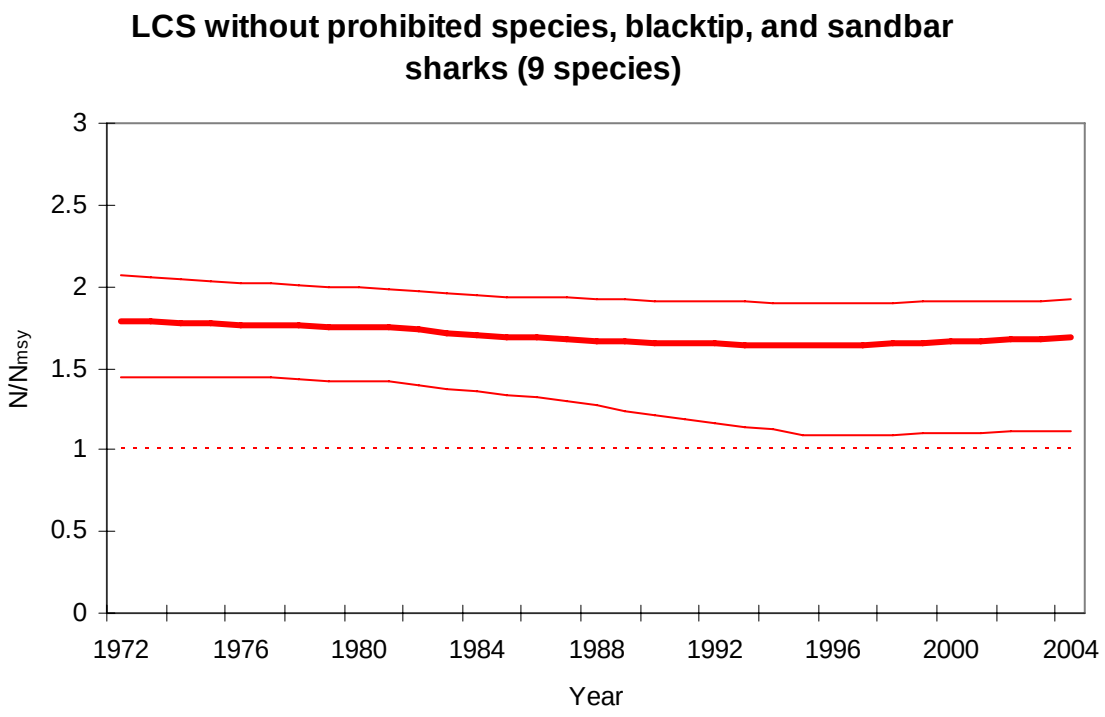


Figure 3.11. Predicted abundance trend of the BSP model fitted to the catch and CPUE data for LCS without prohibited species, blacktip, and sandbar sharks. CPUE series shown are scaled (divided by the mean of the overlapping years among all series, by the catchability coefficient for each series, and by the overall mean for all series).

A.



B.

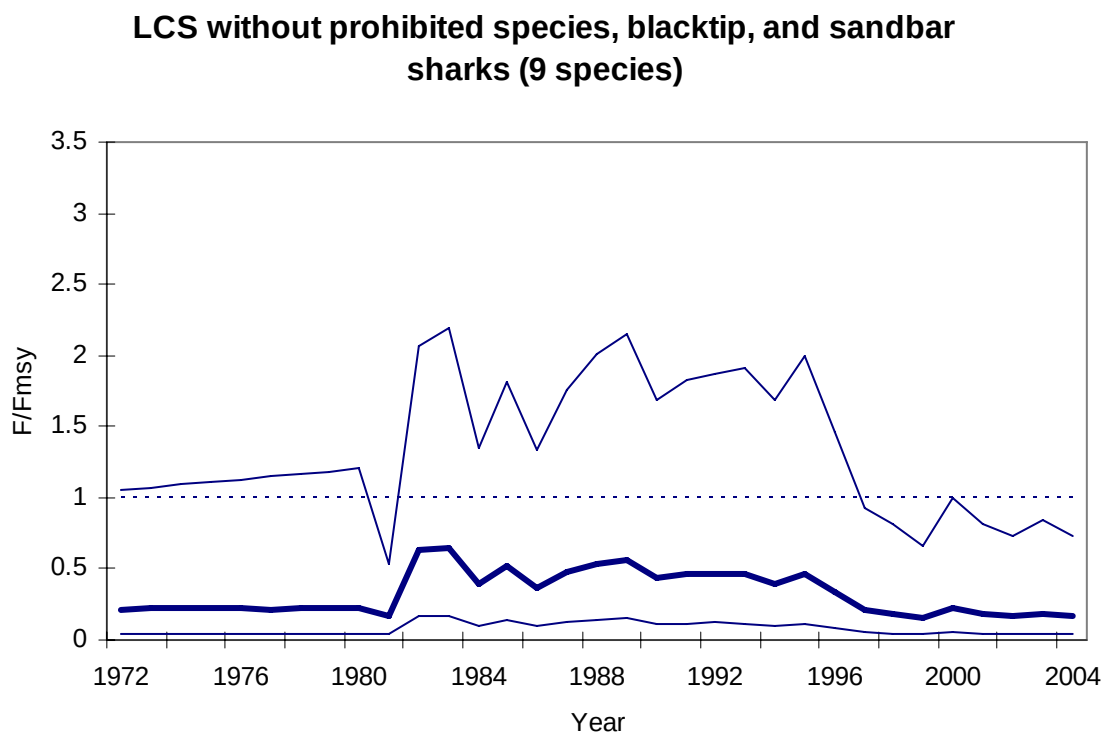
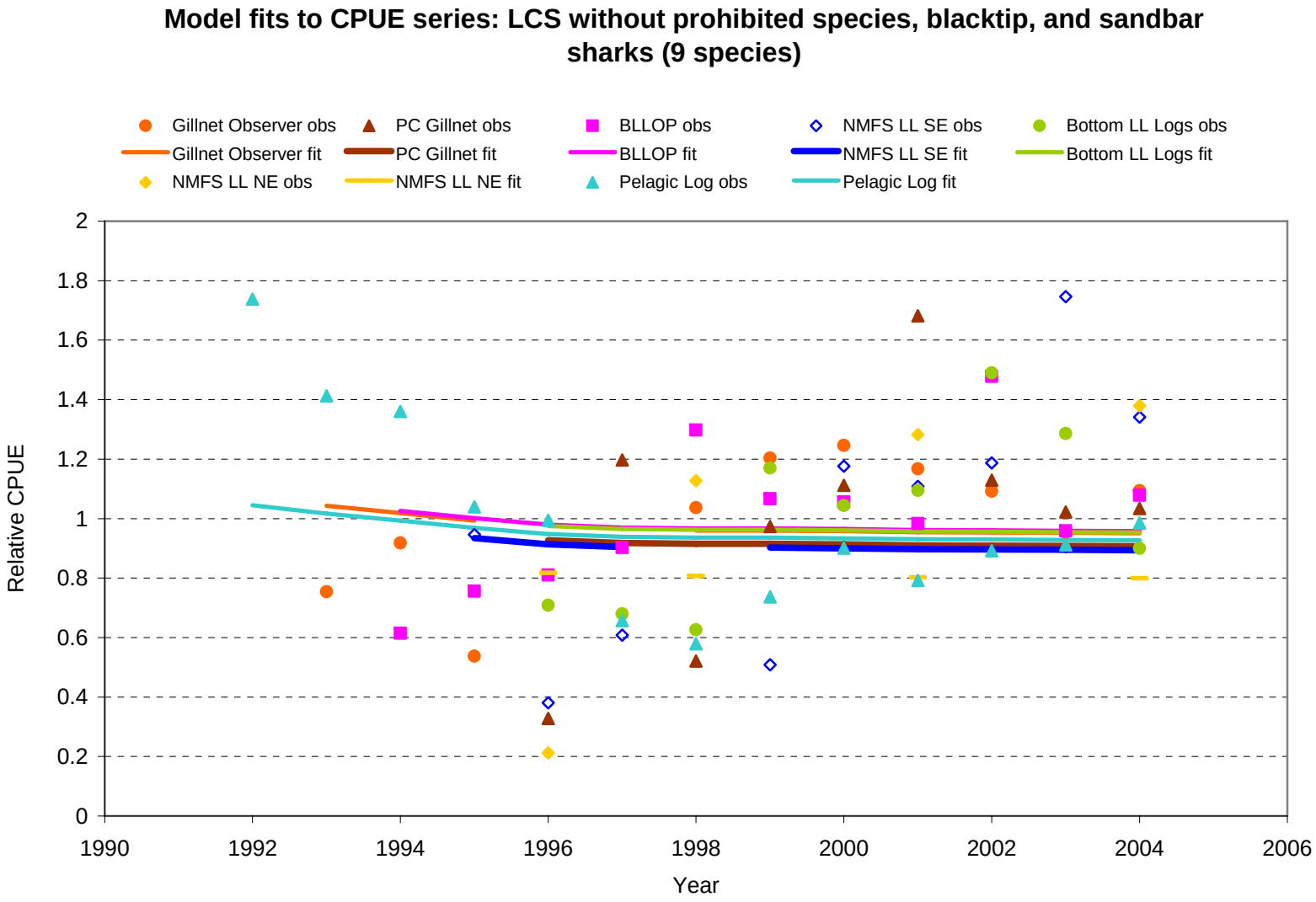


Figure 3.12. Predicted median relative abundance (A) and fishing mortality rate (B) trajectories for LCS without prohibited species, blacktip, and sandbar sharks with the BSP model. Values shown are medians with 80% probability intervals; horizontal lines at 1 denote MSY levels. .



3.13. BSP model fits to the individual CPUE series for the LCS without prohibited species, blacktip, and sandbar sharks (9 species).

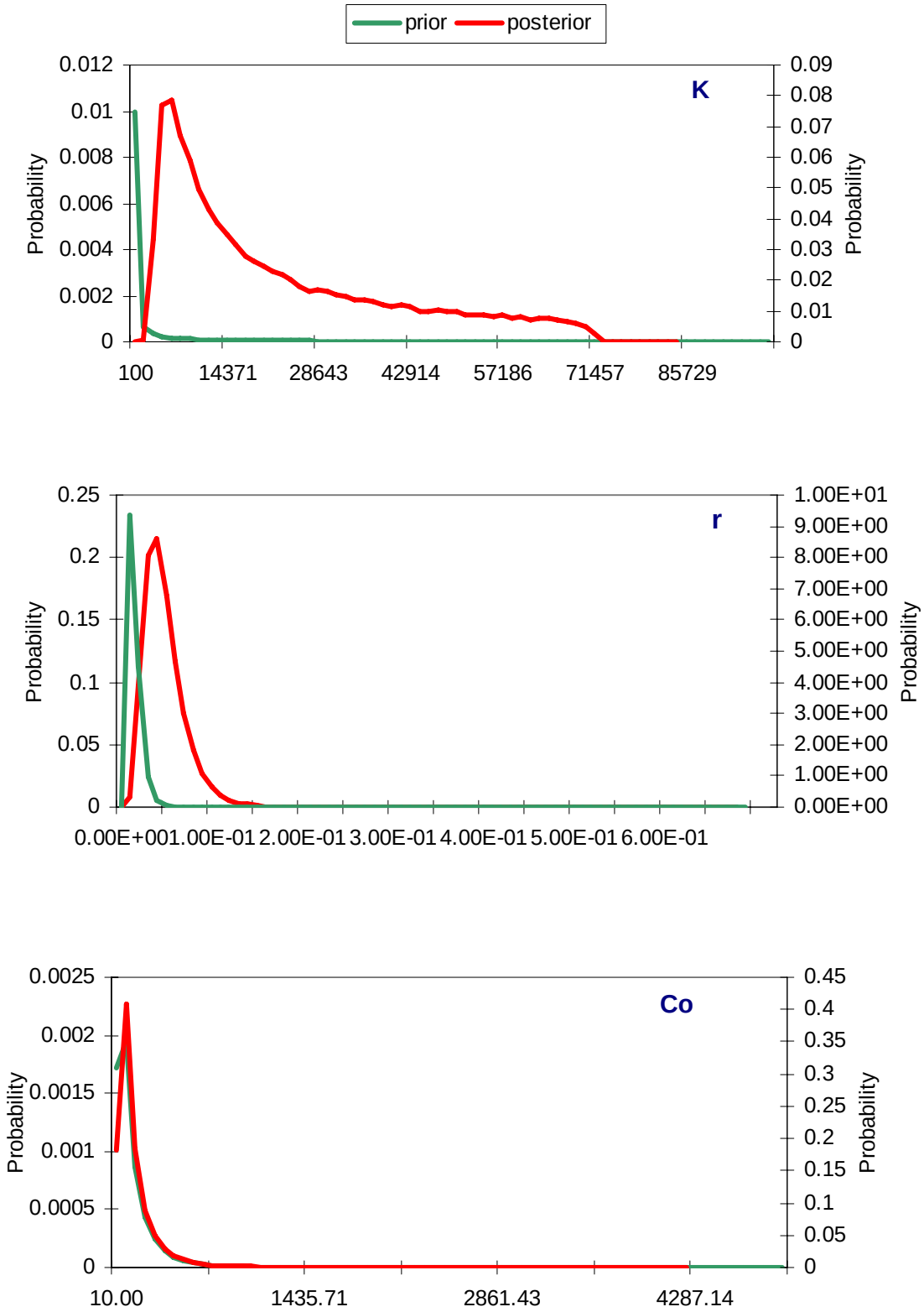


Figure 3.14. Prior (green) and posterior (red) probability distributions for K, r, and C_0 for LCS without prohibited species, blacktip, and sandbar sharks from the BSP model.

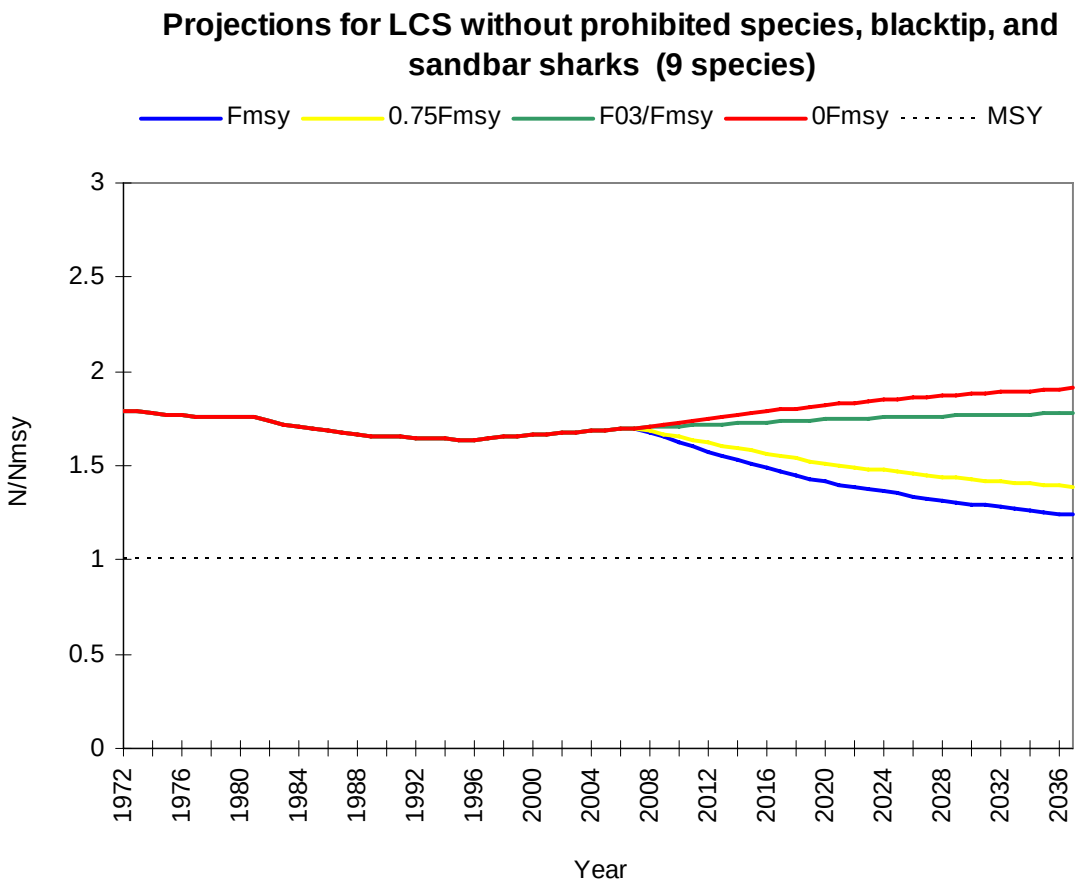


Figure 3.15. Estimated median relative abundance trajectory and projections (from 2008 to 2037) for alternative F_{MSY}-based harvesting policies (0, 0.75, and 1 times F_{MSY} and ((F_{2003}/F_{MSY}) * F_{MSY})) for the LCS without prohibited species, blacktip, and sandbar sharks (9 species) baseline scenario. The dashed horizontal line at 1 denotes the MSY level.

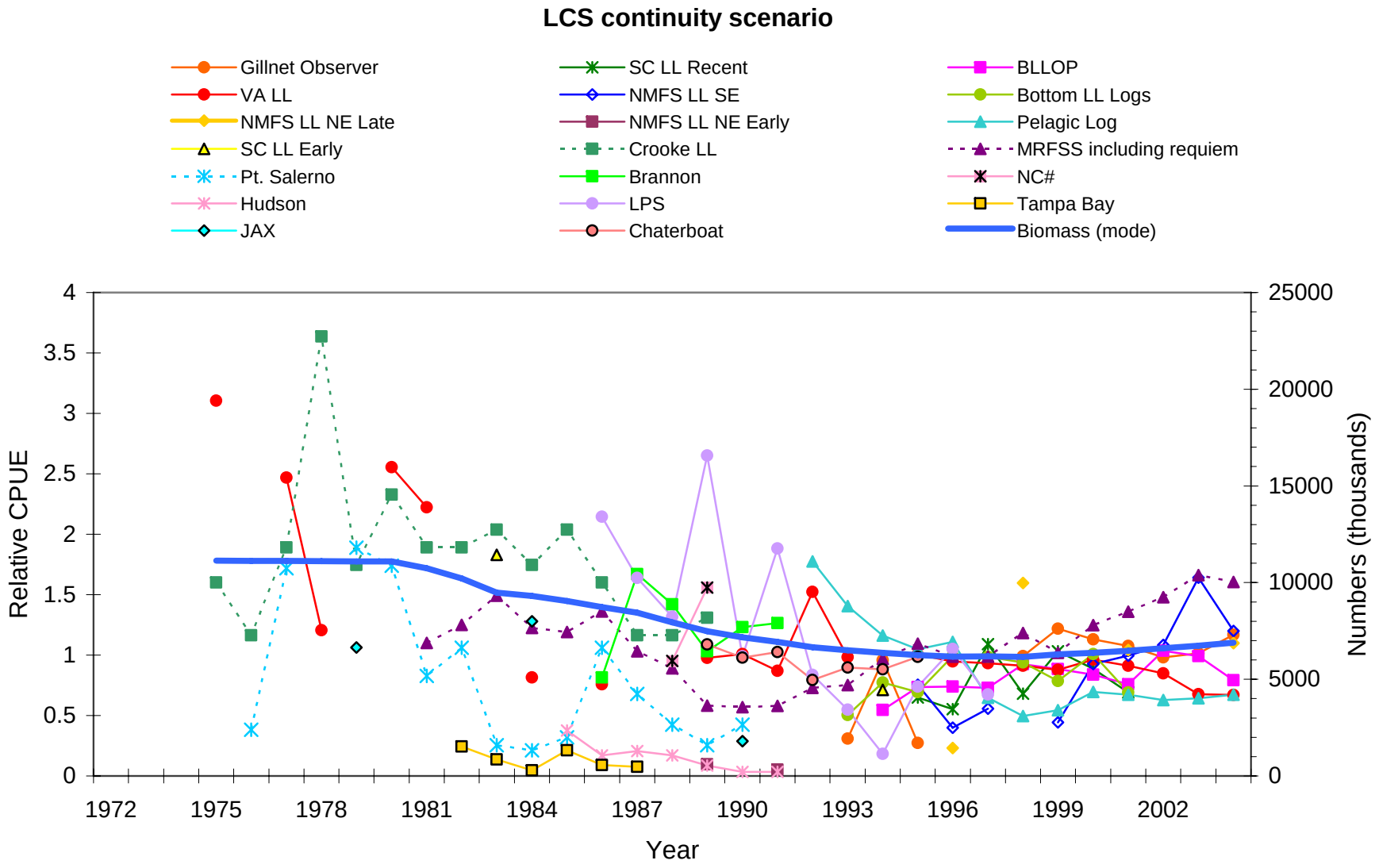
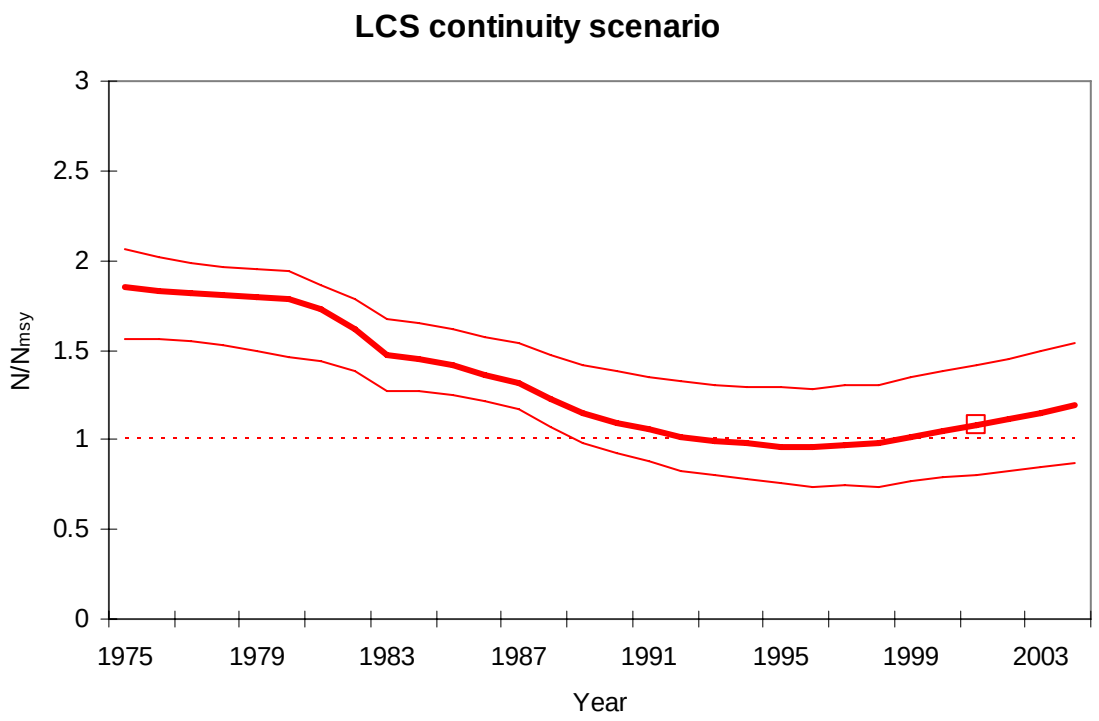


Figure 3.16. Predicted abundance trend of the BSP model fitted to the catch and CPUE data for LCS continuity analysis. CPUE series shown are scaled (divided by the catchability coefficient for each series, and by the overall mean for all series).

A.



B.

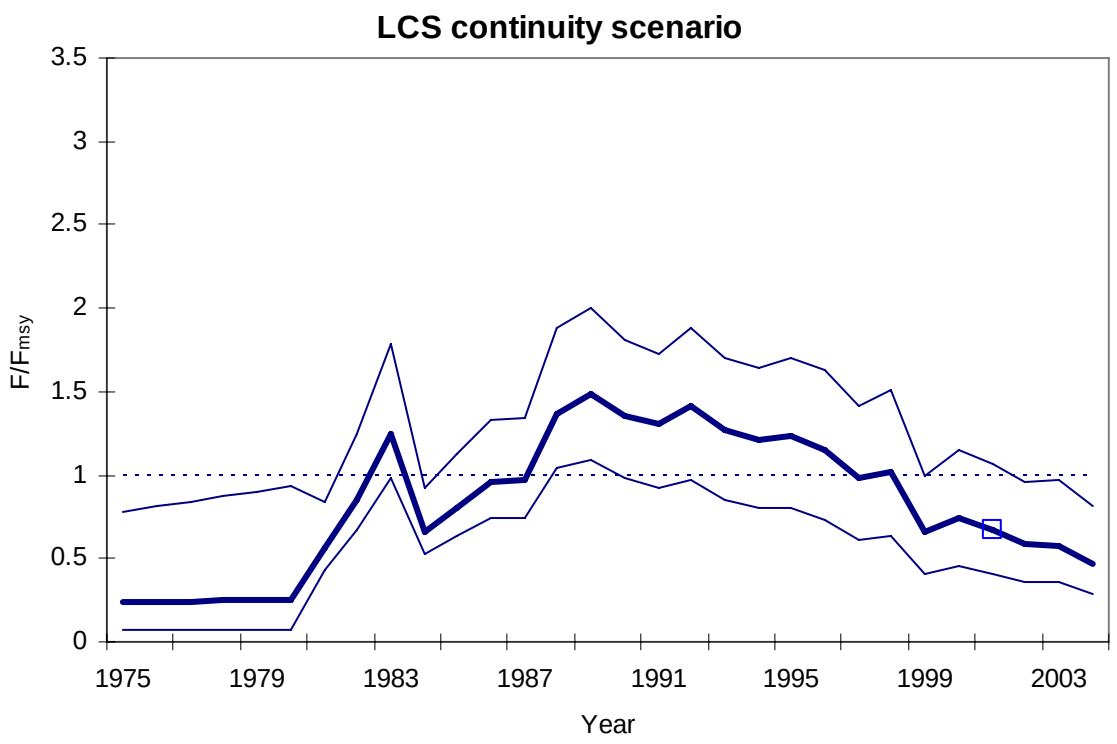
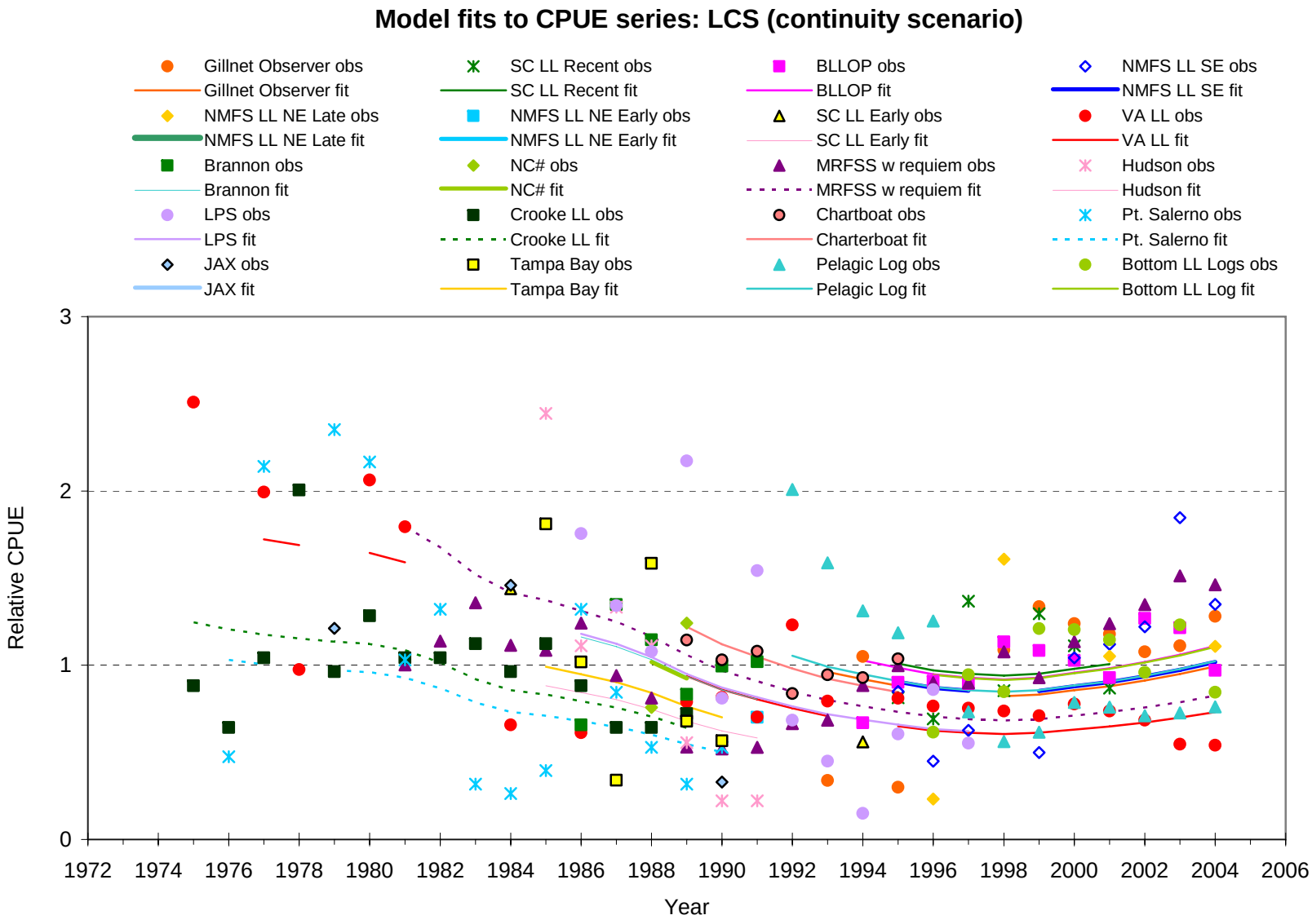


Figure 3.17. Predicted median relative abundance (A) and fishing mortality rate (B) trajectories for the LCS continuity scenario with the BSP model. Values shown are medians with 80% probability intervals; horizontal lines at 1 denote MSY levels. Open squares denote the status in 2001.



3.18. BSP model fits to the individual CPUE series for the LCS continuity scenario.

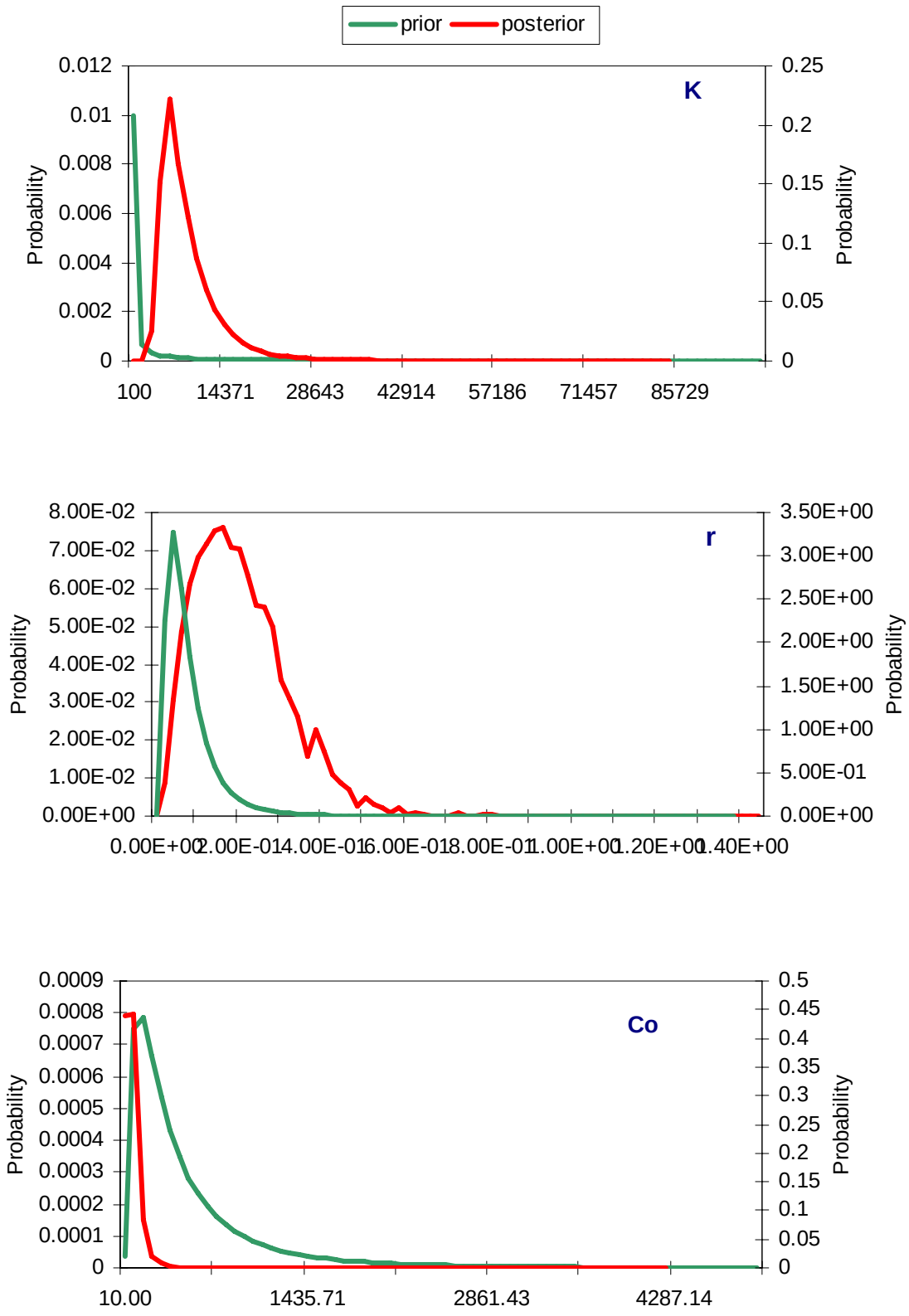
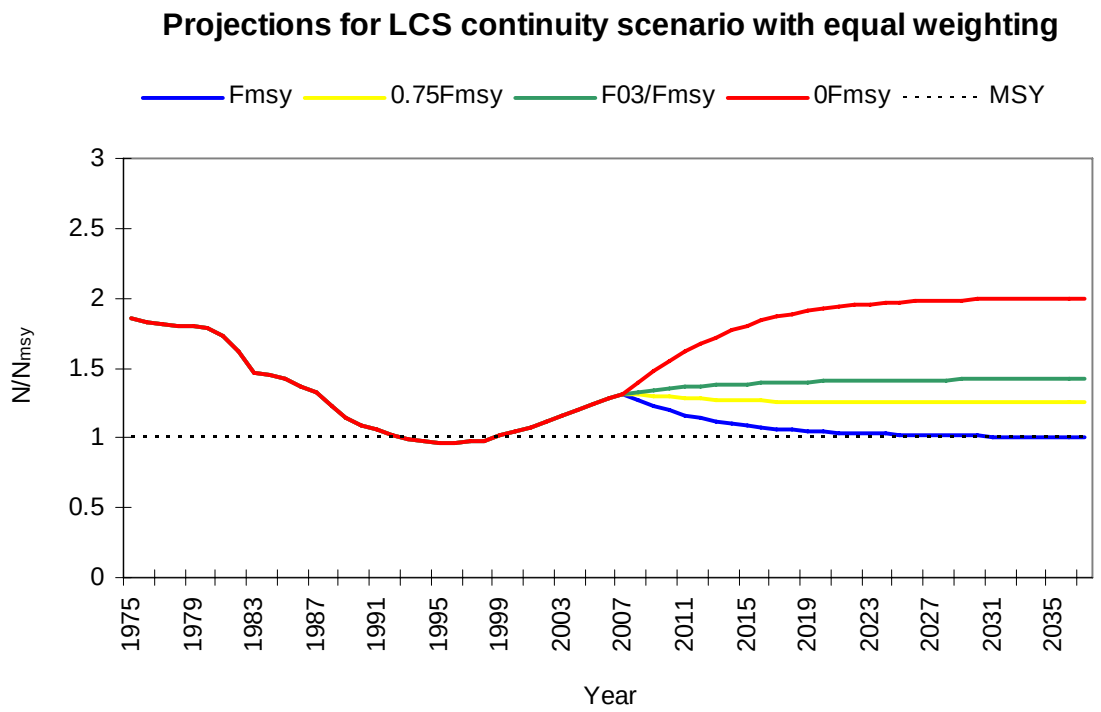


Figure 3.19. Prior (green) and posterior (red) probability distributions for K, r, and C_0 for LCS continuity scenario from the BSP model.

A.



B.

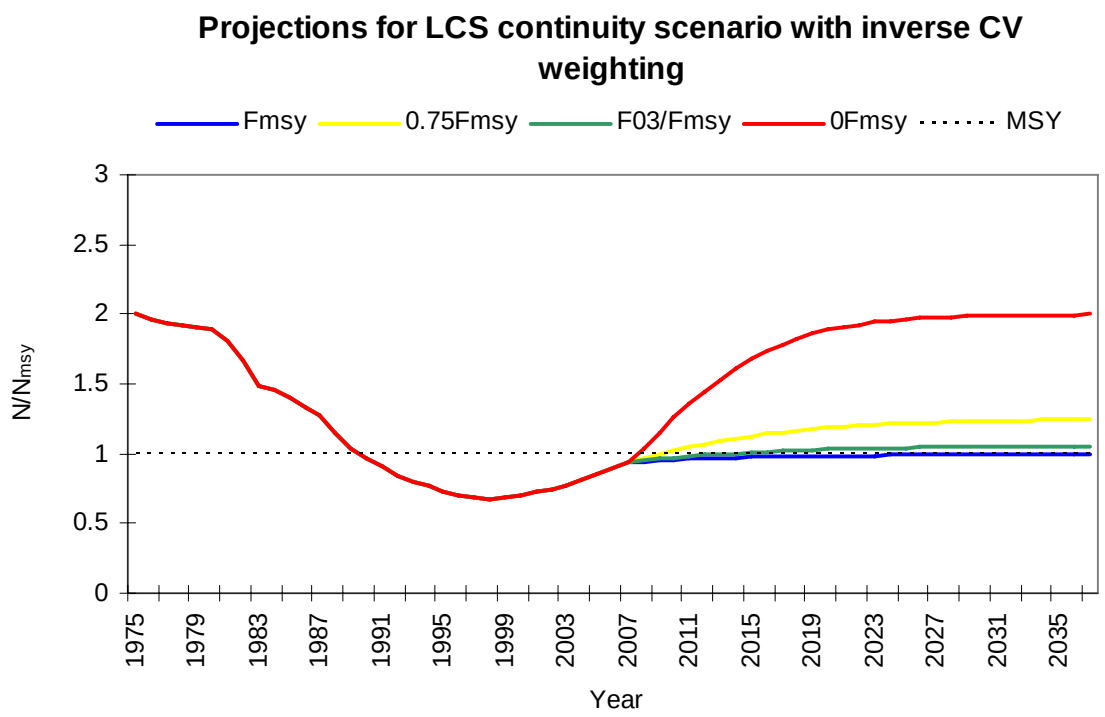


Figure 3.20. Estimated median relative abundance trajectory and projections (from 2008 to 2037) for alternative F_{MSY}-based harvesting policies (0, 0.75, and 1 times F_{MSY} and ((F_{2003}/F_{MSY}) * F_{MSY})) for the LCS continuity scenario with equal (A) and inverse CV weighting (B). The dashed horizontal line at 1 denotes the MSY level.

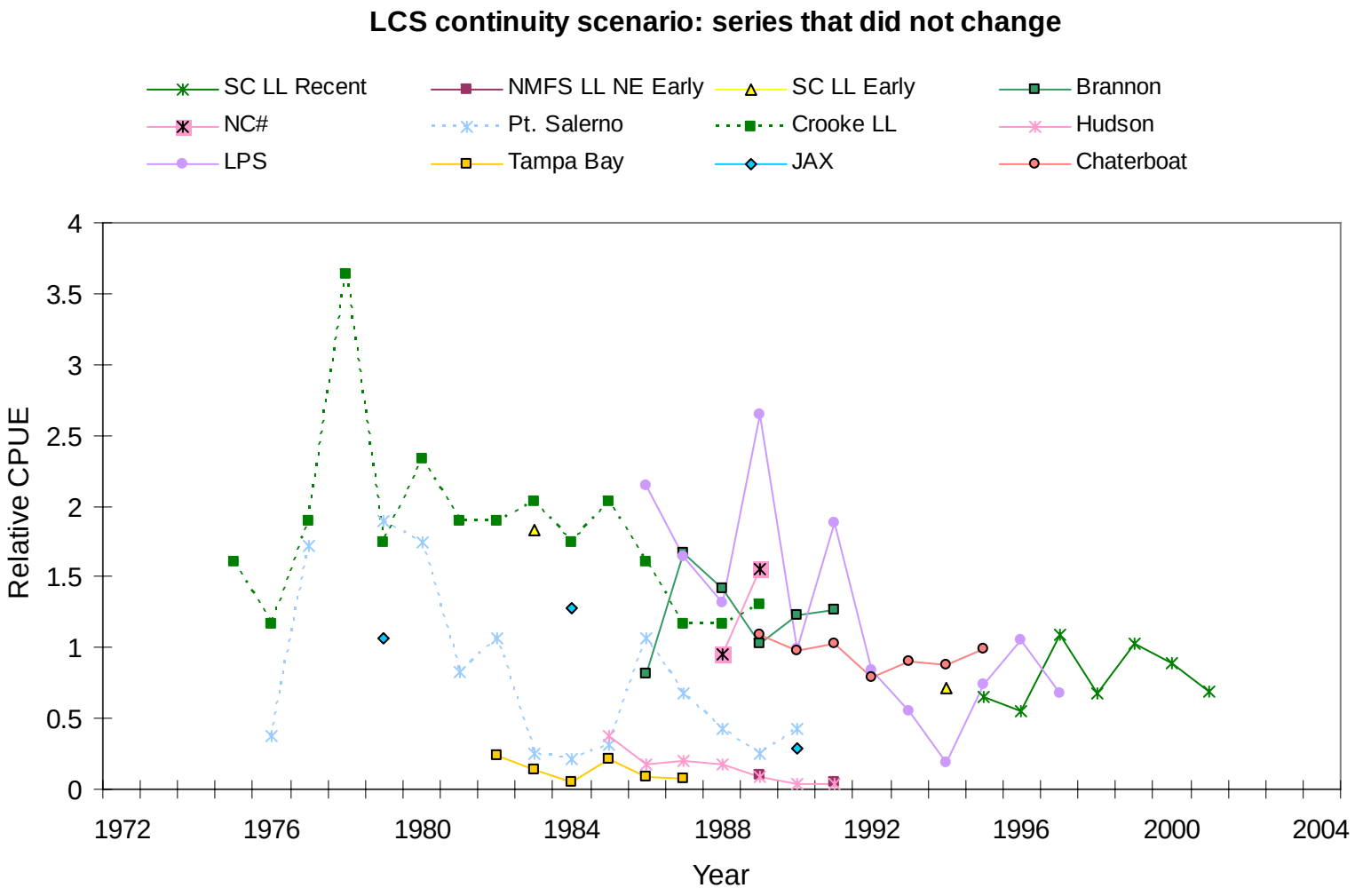


Figure 3.21. CPUE series used in the continuity analysis that did not change between the 2002 and current assessment. Series are scaled (divided by the mean of each series).

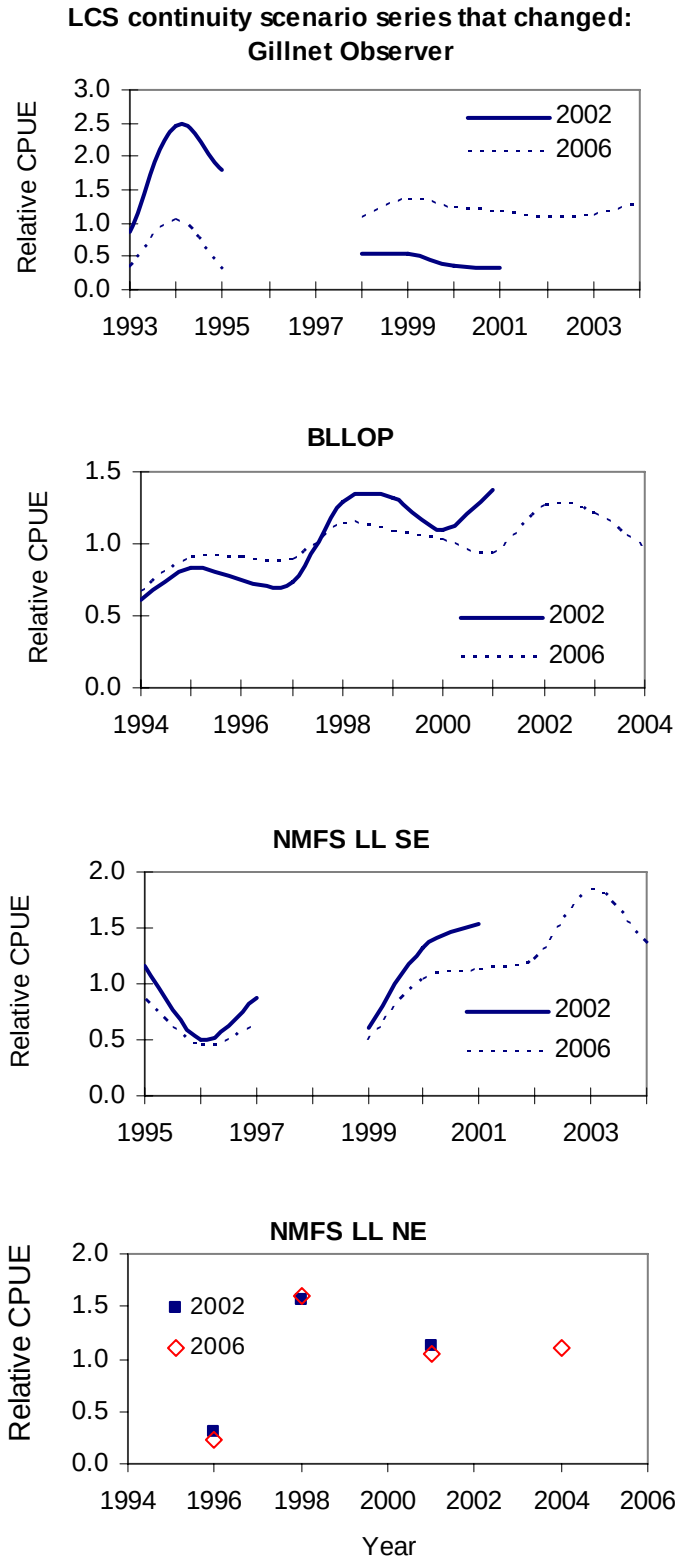


Figure 3.22. Series considered in the continuity analysis that changed between the 2002 and current assessment. Series shown are scaled (each series divided by its mean). The asterisk in the MRFSS graph indicates where the "early" and "recent" series from the 2002 assessment were connected for graphing.

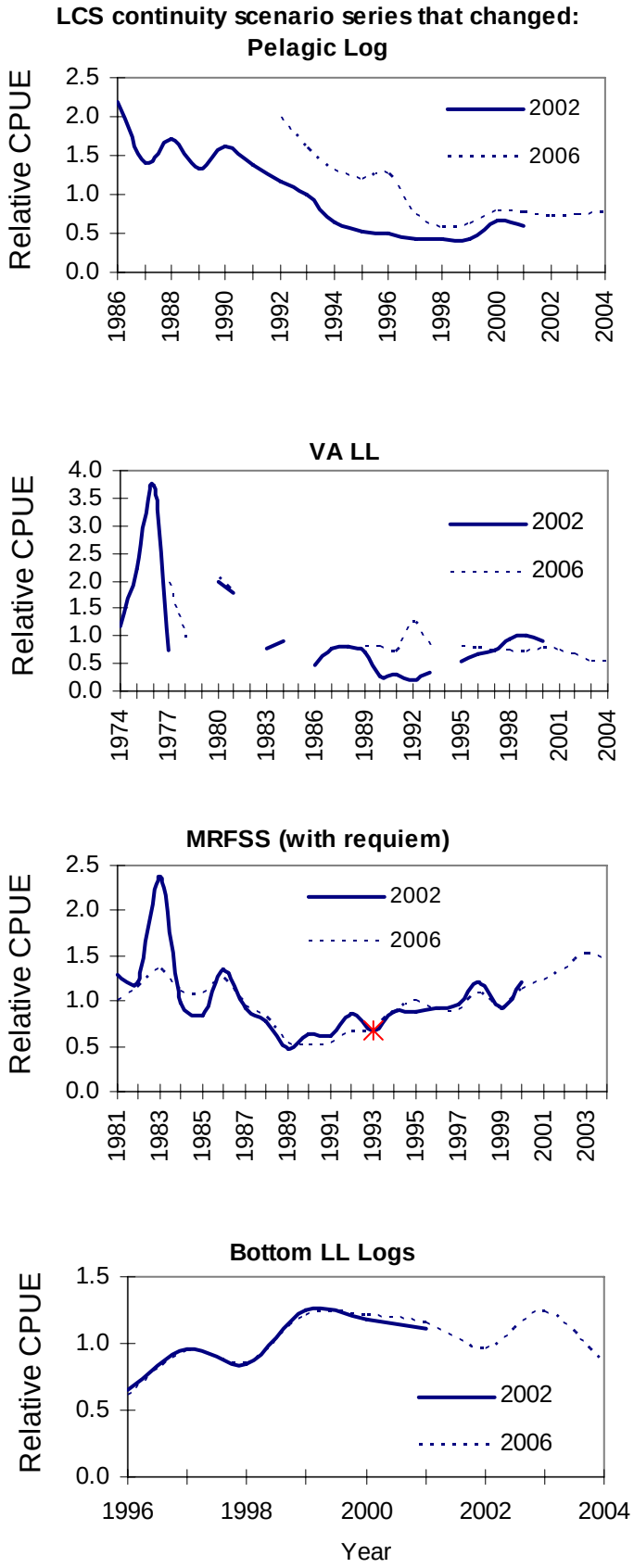


Figure 3.22. (continued)

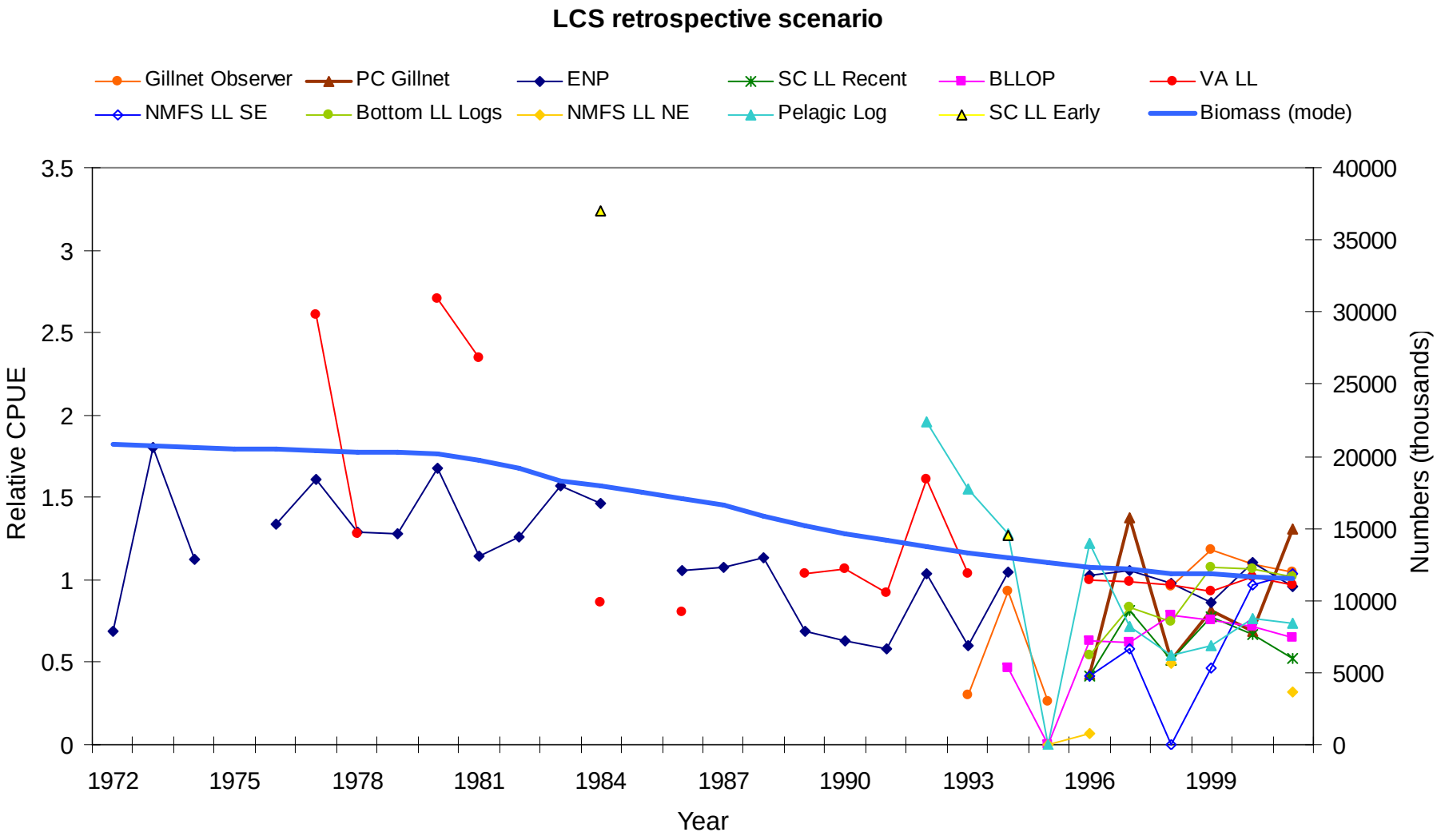
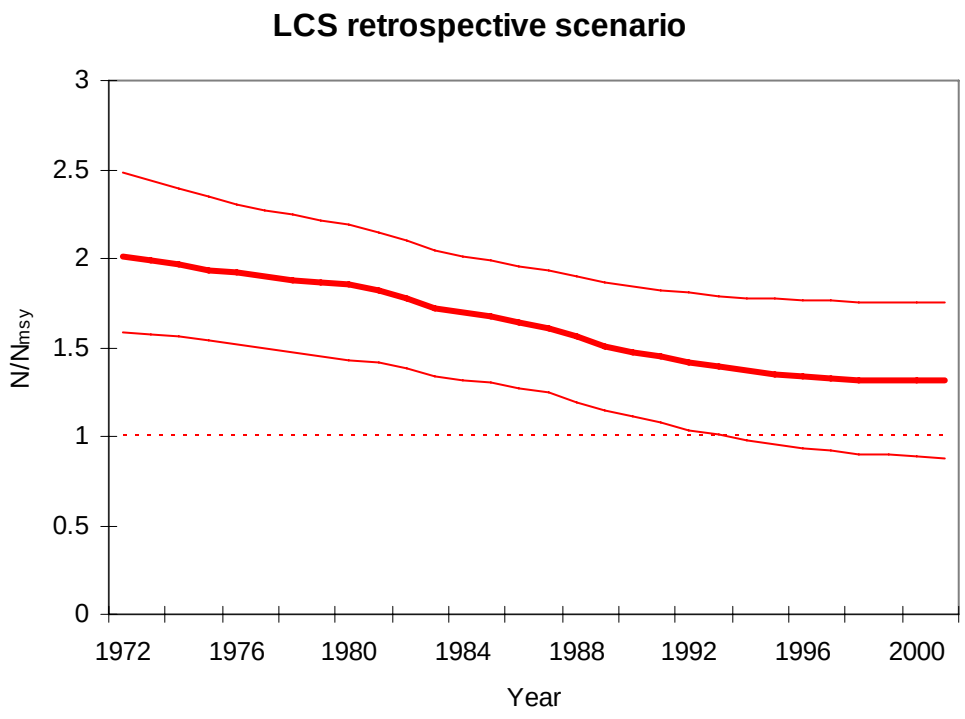


Figure 3.23. Predicted abundance trend of the BSP model fitted to the catch and CPUE data for LCS retrospective analysis. CPUE series shown are scaled (divided by the catchability coefficient for each series, and by the overall mean for all series).

A.



B.

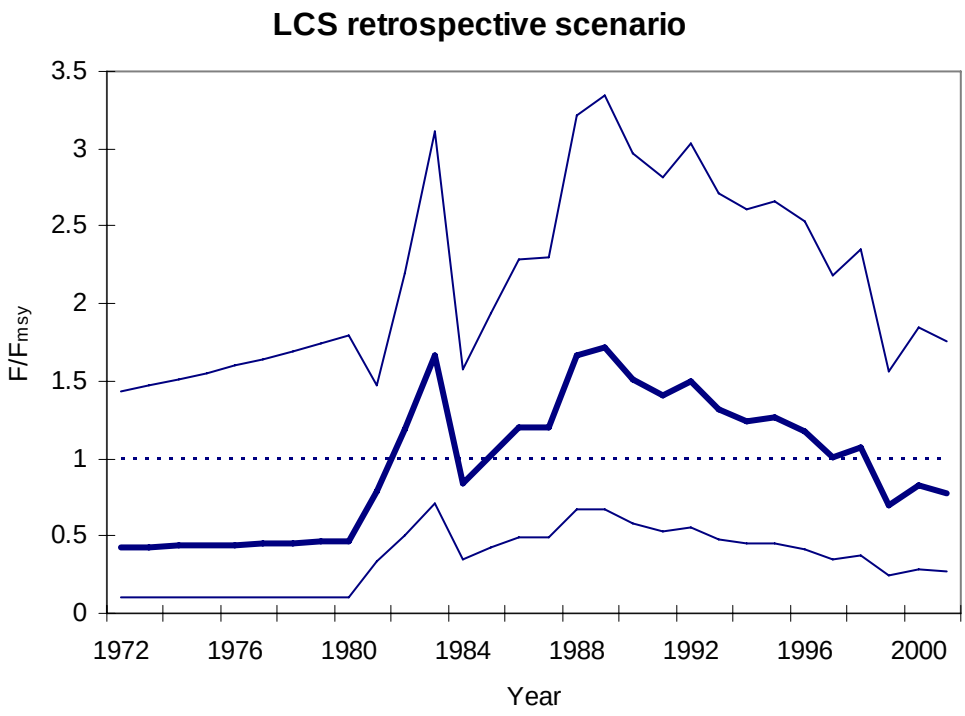


Figure 3.24. Predicted median relative abundance (A) and fishing mortality rate (B) trajectories for the LCS retrospective scenario with the BSP model. Values shown are medians with 80% probability intervals; horizontal lines at 1 denote MSY levels. .

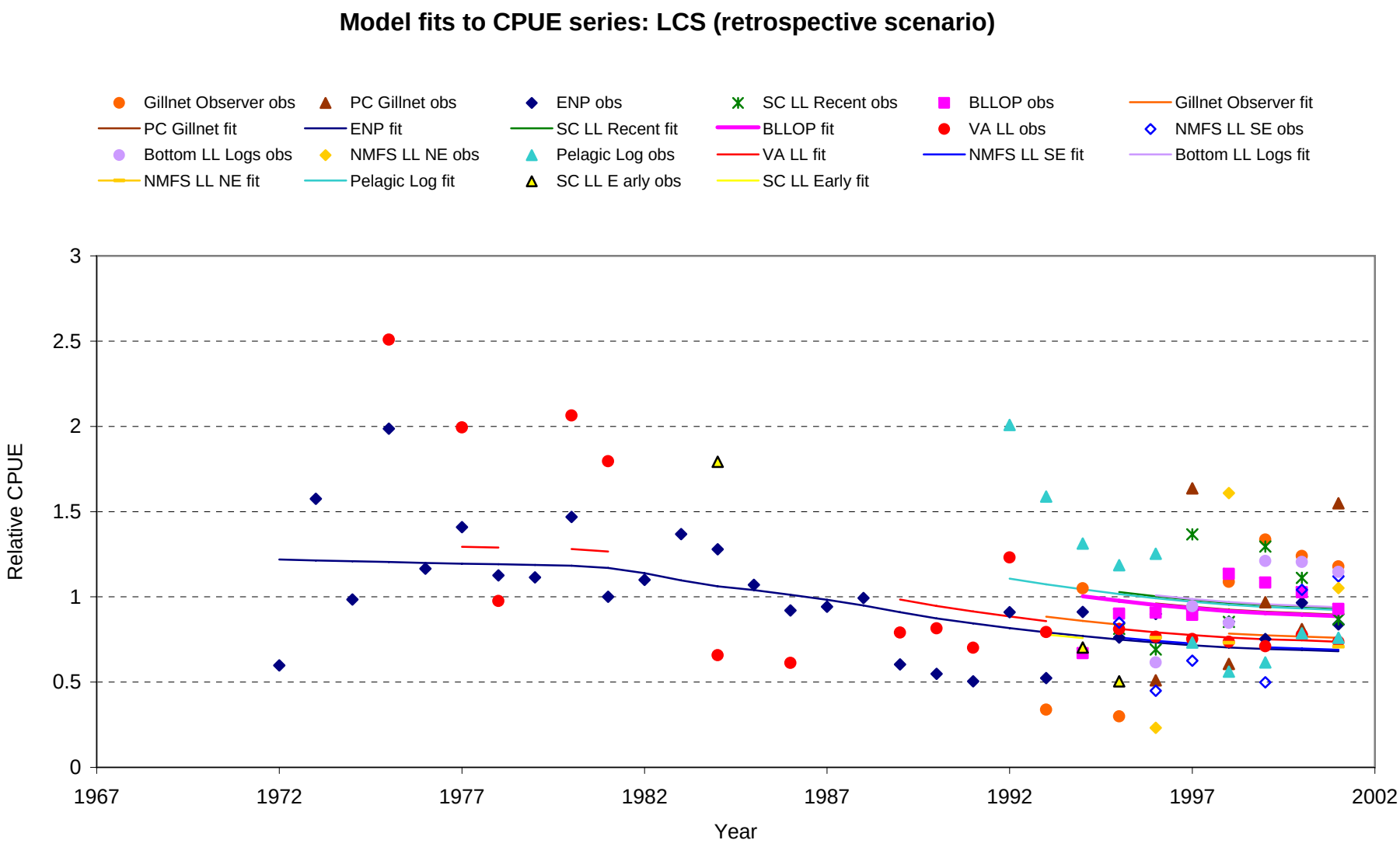


Figure 3.25. BSP model fits to the individual CPUE series for the LCS retrospective scenario.

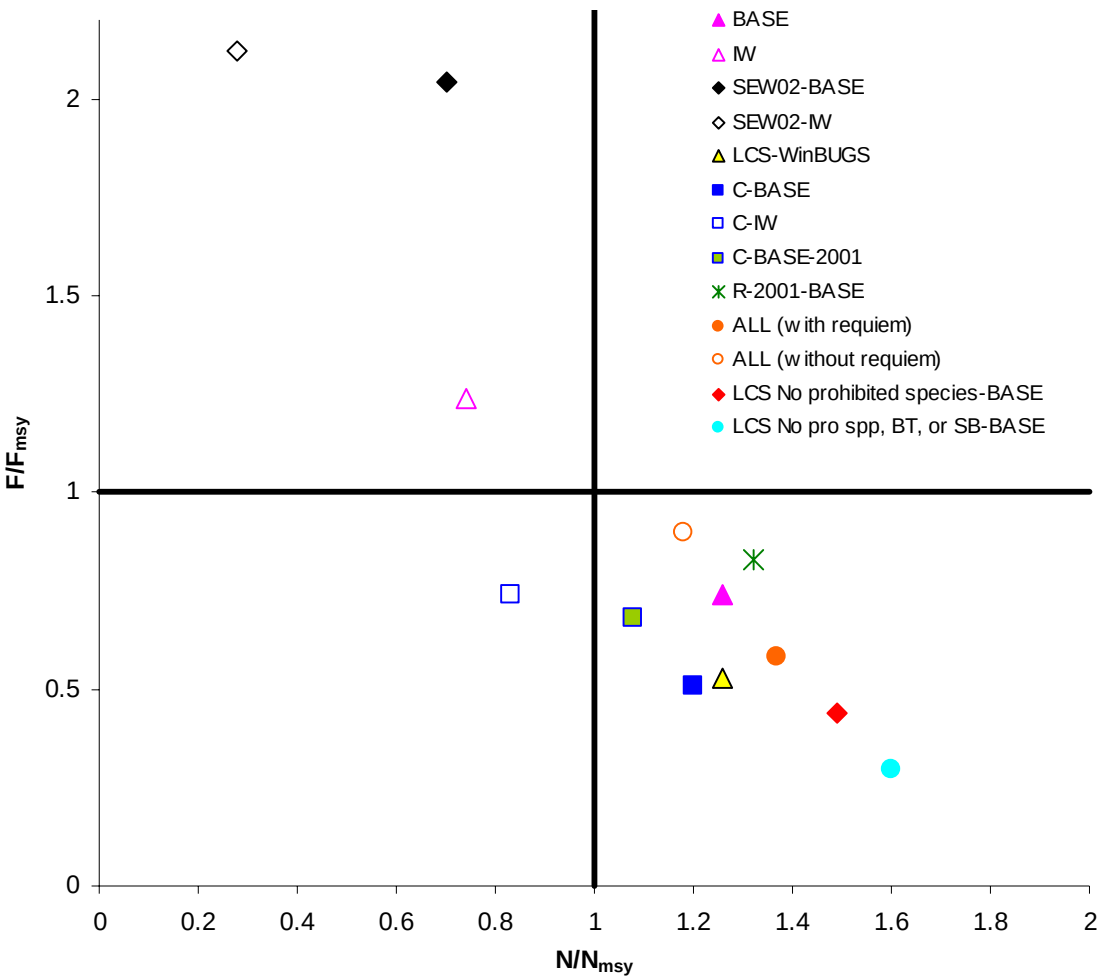


Figure 3.26. Phase plot for the LCS complex showing values of N_{2004}/N_{MSY} and F_{2004}/F_{MSY} obtained in the baseline scenarios using the BSP model. Selected sensitivity analyses and the baseline scenarios for the LCS without prohibited species, and LCS without prohibited species, blacktip or sandbar sharks are also included for comparison. The models include: BASE (LCS baseline), IW (LCS with inverse CV weighting), SEW02-BASE (results of 2002 LCS assessment with equal weighting), SEW02-IW (results of 2002 LCS assessment with inverse CV weighting), LCS-WinBUGS (LCS using WinBUGS surplus production model), C-BASE (continuity scenario for LCS with equal weighting), C-IW (continuity scenario for LCS, with inverse CV weighting), C-BASE-2001 (continuity scenario for LCS with equal weighting up to 2001 only), R-2001-BASE (retrospective scenario for LCS to 2001 only), ALL (with requiem) (LCS with all CPUE series including requiem shark category for MRFSS), ALL (without requiem) (LCS with all CPUE series excluding requiem shark category from MRFSS), LCS No prohibited species-BASE (baseline LCS without prohibited species), LCS No pro spp, BT, or SB – BASE (baseline without prohibited species, sandbar or blacktip shark). See text for full details. Several control rules are illustrated: the solid horizontal line indicates the MFMT (Maximum Fishing Mortality Threshold) and the solid vertical line denotes the target biomass (biomass or number at MSY). Note that the value of N_{2001}/N_{MSY} for SEW02-IW was 12.12 but was decreased to 2.12 here for viewing purposes only.

SANDBAR SHARK ASSESSMENT

4. SANDBAR SHARK ASSESSMENT

4.1 Summary of Sandbar Shark Working Documents

SEDAR 11–AW–01
First estimates of the status of sandbar shark stock off the eastern coast of the US
Summary: Predictions about the current status of sandbar shark stock off the eastern coast of the US are presented in this document. An age-structured population dynamics model has been used as part of a Bayesian statistical framework to analyze CPUE series and catch data. The model was run under a base case scenario but sensitivity runs were also conducted to evaluate model sensitivity to assumptions about the value of parameters such as pup survival. The results show that the size of the stock has been reduced to less than 35% of its virgin size. This prediction remained the same under both the base case and sensitivity runs.

SEDAR 11–AW–03
A State-Space, Age-Structured Production Model for Sandbar Shark
Two forms of an age-structured production model were employed to assess sandbar shark. The first was the continuity model used in the 2002 assessment. The second model (2006 base model) does not use catch, and all calculations are made relative to the unexploited stock. Both the continuity model and the 2006 base model (catch-free) reached the same conclusion that the stock is overfished and undergoing overfishing. Despite the differences in the way fishing mortality is estimated, and the fact that one model used catch and the other did not, both models agreed remarkably well on the estimates of biomass relative to MSY (continuity: 0.21-0.47; catch-free: 0.35-0.51) and on the level of current depletion (continuity: 0.15-0.26; catch-free: 0.19-0.26). One major input difference between the continuity model and the 2006 base model was the maturity ogive. Conclusions about status did not appear sensitive to this model input.

SEDAR11-AW-05
Assessment of Large Coastal, Blacktip, and Sandbar Sharks using Surplus Production Methods
We used two complementary surplus production models (BSP and WinBUGS) to assess the status of three Large Coastal Shark (LCS) groupings, two stocks of blacktip shark, and a single stock of sandbar shark identified as baseline scenarios in the LCS Data Workshop report. Both methodologies use Bayesian inference to estimate stock status, and the BSP further performs Bayesian decision analysis to examine the sustainability of various levels of future catch. Extensive sensitivity analyses were performed with the BSP model to assess the effect of different assumptions on CPUE indices and weighting methods, catches, intrinsic rates of increase, initial depletion, and importance function on results. Baseline scenarios for the three LCS groupings considered predicted that the stock status is not overfished nor overfishing is occurring. Using the inverse variance method to weight the CPUE data changed the predictions on stock status for the LCS grouping, which would then be overfished, with overfishing occurring. The sandbar shark stock was estimated to be significantly depleted (64-71% depletion from virgin level). The Gulf of Mexico blacktip shark stock was healthy (depletion of only 8-23% of virgin level), whereas results for the Atlantic blacktip shark stock from the BSP and WinBUGS models conflicted. The BSP model predicted a considerable level of depletion for this

stock regardless of the CPUE weighting method used. In contrast, the assessment of a single blacktip shark stock (GOM+ATL) resulted in very consistent results, with all models predicting a healthy status (depletions of only 10-16% of virgin level). Using the higher values of r from the 2002 SEW or accounting for some depletion from virgin levels in the first year of the model did not affect conclusions. Several assumptions on catches (notably changing the high value of recreational catch in 1983) also had no effect on conclusions. Removing the VIMS CPUE series from the LCS scenario reversed the conclusions on stock status when using inverse variance weighting, highlighting the influence of this series on results; removing the PELAGIC LOG CPUE series from the ATL blacktip shark analysis also drastically reversed the conclusions on stock status. Fitting one CPUE series at a time had a larger effect on results: the PELAGIC LOG series greatly influenced conclusions for the three LCS groupings and GOM and ATL blacktip shark, whereas the VIMS series affected conclusions on the two groups for which it is available, LCS and sandbar shark.

4.2 Background

Blacktip and sandbar sharks are the two most important species in the fishery, and have been the subjects of species-specific assessments in the past conducted through Shark Evaluation Workshops (SEWs). As such, the Panel was tasked with conducting species-specific assessments for these species. The Data Workshop (DW) determined catch histories, relative abundance indices, and biological input parameters for three assessments: one stock of sandbar sharks and two stocks of blacktip sharks, one for the Gulf of Mexico and one for the northwestern Atlantic Ocean.

4.3 Available Models

Five models were available for discussion for the sandbar shark assessment: two surplus production models, the BSP and WinBUGS models described previously, and three age-structured approaches. These included a catch free model which is an age-structured production model recast in terms relative to pre-exploitation levels (Porch et al. 2006), and two forms of an age-structured production model (Apostolaki et al. in press, Porch 2002).

4.4 Details about surplus production model and age-structured model

A surplus production model simulates the dynamics of a population using total population biomass as the parameter that reflects changes in population size relative to its virgin condition. In comparison to more complicated models, the surplus production model is simpler in its formulation, takes less time to run and requires less input information. However, due to its formulation, the surplus production model does not describe changes that occur in subgroups of the population (adults, juveniles, etc). In addition, the sensitivity of model predictions to key stage-dependent biological parameters cannot be evaluated using a surplus production model. Finally, surplus production models are not able to incorporate a lag time into the results.

An age-structured population dynamics model describes the dynamics of each age class in the population separately and therefore, requires age-specific input information. Due to the higher complexity of these models, they usually take longer to run and require a higher volume of information relative to simpler models. However, they can account for age-dependent differences in biology, dynamics and exploitation of fish and provide an insight into the structure of the population and the processes that are more important at different life stages. They also allow for the incorporation of age-specific selectivity information.

With regard to management benchmarks, the surplus production model generally assumes that the population biomass that corresponds to MSY is equal to half of the virgin population biomass, whereas the relative biomass at MSY calculated with an age-structured model (and other benchmarks associated to it) is species-specific and could be any fraction of virgin biomass.

The Assessment Panel decided to use the state-space, age-structured production model described in document SEDAR11-AW-03 for sandbar sharks. This model was selected as it allowed for the incorporation of age-specific biological and selectivity information, along with the ability to produce required management benchmarks.

4.5 Discussion of weighting methods

The Data Workshop recommended that *equal weighting* for assigning weights to the different CPUE time series available during model fitting should be used for the baseline runs. The panel discussed the advantages and disadvantages of the *equal weighting* vs. the *inverse CV weighting* methods:

Equal weighting ignores the better quality of some data (smaller CVs) but is more stable between assessments because yearly changes on CVs in a given CPUE series do not affect the importance of that time series for the overall fit.

Inverse CV weighting can provide better precision as it tracks individual indices however, it could be less stable between assessments due to changes on the relative 'noise' of each time series. This method may also not be appropriate in cases in which different standardization techniques have been used for the standardization of the series and therefore, the same value of CV might reflect different levels of error depending on the CPUE it corresponds to.

It was requested by one Panelist to manually weight the indices that cover larger geographic areas to have a stronger influence on the model. The group commented that, while that may be possible in a spatially explicit model, a great deal more data would be required than presently available.

The Assessment Panel decided that equal weighting would be the default weighting method for the current assessment but noted that, as there is at present no objective way to decide which of

these two methods is superior other than comparing model convergence diagnostics, future assessments may need to reexamine this issue.

4.6 New biological parameters derived during the assessment workshop

As discussed in SEDAR 11-AW-10, the values for life history parameters that the Data Workshop determined to be the best estimates did not produce viable estimates for steepness (steepness was <0.2 for all stocks). The group reviewed the inputs that produce steepness (pup-survival, M at age for ages 1+, maturity at age, and pup-production at age), and determined that pup-production and estimates of maturity should be known with greater certainty than estimates of mortality or pup survival. Therefore, in order to satisfy the lower bound on steepness, and to meet the data workshop recommendation that steepness should be between 0.2-0.4, the mode of the lognormal prior for pup survival was increased to 0.75 with a CV of 0.3. In addition, survival increased by 3% for ages 1+. The data workshop values for M at age as well as the values derived in plenary at the assessment workshop are given in Tables 4.1a and b, and plotted in Figure 4.1. Note that in the 2002 assessment, the same problem was encountered with the lower limit of steepness. In 2002, the base parameter values gave a steepness of about 0.16, so the analysts increased pup production from 8.4 to 12, achieving a steepness of about 0.22.

4.7 Methods

4.7.1 State-space, age-structured production model description

It was decided at the assessment workshop that the age-structured production model would be used as the base model for the 2006 assessment rather than the catchfree model, as catch was available. To derive N at age for the first model year, one must define a year when the stock could be considered to be at virgin conditions. Then, assuming that there is some basis for deriving historic removals, one can estimate a population trajectory from virgin conditions through a "historic period," until a more recent year when more data are available for model fitting.

Population Dynamics

The dynamics of the model are described below, and are extracted (and/or modified) from Porch (2002). The model begins with the population at unexploited conditions, where the age structure is given by

$$(1) \qquad N_{a,y=1,m=1} = \begin{cases} R_0 & a = 1 \\ R_0 \exp\left(-\sum_{j=1}^{a-1} M_j\right) & 1 < a < A \\ \dfrac{R_0 \exp\left(-\sum_{j=1}^{A-1} M_j\right)}{1-\exp(-M_A)} & a = A \end{cases} ,$$

where $N_{a,y,1}$ is the number of sharks in each age class in the first model year (y=1), in the first month (m=1), M_a is natural mortality at age, A is the plus-group age, and recruitment (R) is assumed to occur at age 1.

The stock-recruit relationship was assumed to be a Beverton-Holt function, which was parameterized in terms of the maximum lifetime reproductive rate, α:

$$(2) \qquad R = \frac{R_0 S \alpha}{S_0 + (\alpha - 1)S} \quad .$$

In (2), R_0 and S_0 are virgin number of recruits (age-1 pups) and spawners (units are number of mature adult females times pup production at age), respectively. The parameter α is calculated as:

$$(3) \qquad \alpha = e^{-M_0}\left[\left(\sum_{a=1}^{A-1} p_a m_a \prod_{j=1}^{a-1} e^{-M_a}\right) + \frac{p_A m_A}{1-e^{-M_A}} e^{-M_A}\right] = e^{-M_0}\varphi_0 \quad ,$$

where p_a is pup-production at age a, m_a is maturity at age a, and M_a is natural mortality at age a. The first term in (3) is pup survival at low population density (Myers et al. 1999). Thus, α is virgin spawners per recruit (φ_0) scaled by the slope at the origin (pup-survival).

The time period from the first model year (y_1) to the last model year (y_T) is divided into a historic and a modern period (mod), where y_i for i<mod are historic years, and modern years are y_i for which mod ≤ i ≤ T. The historic period is characterized by having relatively less data compared to the modern period. The manner in which effort is estimated depends on the period modeled. In the historic period, effort is estimated as either a constant (4a) or a linear trend (4b)

$$(4a) \qquad f_{y,i} = b_0 \qquad \text{(constant effort)}$$

or

(4b) $$f_{y,i} = b_0 + \frac{(f_{y=\text{mod},i} - b_0)}{(y_{\text{mod}} - 1)} f_{y=\text{mod},i} \qquad \text{(linear effort)},$$

where $f_{y,i}$ is annual fleet-specific effort, b_0 is the intercept, and $f_{y=\text{mod},i}$ is a fleet-specific constant. In the modern period, fleet-specific effort is estimated as a constant with annual deviations, which are assumed to follow a first-order lognormal autoregressive process:

(5) $$\begin{aligned} f_{y=\text{mod},i} &= f_i \exp(\delta_{y,i}) \\ \delta_{y,i} &= \rho_i \delta_{y-1} + \eta_{y,i} \\ \eta_{y,i} &\sim N(0, \sigma_i) \end{aligned} \quad .$$

From the virgin age structure defined in (1), abundance at the beginning of subsequent months is calculated by

(6) $$N_{a,y,m+1} = N_{a,y,m} e^{-M_a \delta} - \sum_i C_{a,y,m,i} \quad ,$$

where δ is the fraction of the year (m/12) and $C_{a,y,m,i}$ is the catch in numbers of fleet i. The monthly catch by fleet is assumed to occur sequentially as a pulse at the end of the month, after natural mortality:

(7) $$C_{a,y,m,i} = F_{a,y,i} \left(N_{a,y,m} e^{-M_a \delta} - \sum_{k=1}^{i-1} C_{a,y,m,k} \right) \frac{\delta}{\tau_i} \quad ,$$

where τ_i is the duration of the fishing season for fleet i. Catch in weight is computed by multiplying (7) by $w_{a,y}$, where weight at age for the plus-group is updated based on the average age of the plus-group.

The fishing mortality rate, F, is separated into fleet-specific components representing age-specific relative-vulnerability, v, annual effort expended, f, and an annual catchability coefficient, q:

(8) $$F_{a,y,i} = q_{y,i} f_{y,i} v_{a,i} \quad .$$

Catchability is the fraction of the most vulnerable age class taken per unit of effort. The relative-vulnerability would incorporate such factors as gear selectivity, and the fraction of the stock exposed to the fishery. For this model application to sandbar sharks, both vulnerability and catchability were assumed to be constant over years.

Catch per unit effort (CPUE) or fishery abundance surveys are modeled as though the observations were made just before the catch of the fleet with the corresponding index, i:

$$(9) \qquad I_{y,m,i} = q_{y,i} \sum_a v_{a,i} \left(N_{a,y,m} e^{-M_a \delta} - \sum_{k=1}^{i-1} C_{a,y,m,k} \right) \frac{\delta}{\tau_i} \qquad .$$

Equation (9) provides an index in numbers; the corresponding CPUE in weight is computed by multiplying $v_{a,i}$ in (9) by $w_{a,y}$.

State space implementation

In general, process errors in the state variables and observation errors in the data variables can be modeled as a first-order autoregressive model:

$$(10) \qquad \begin{aligned} g_{t+1} &= E[g_{t+1}] e^{\varepsilon_{t+1}} \\ \varepsilon_{t+1} &= \rho \varepsilon_t + \eta_{t+1} \end{aligned} \qquad .$$

In (10), g is a given state or observation variable, η is a normal-distributed random error with mean 0 and standard deviation σ_g, and ρ is the correlation coefficient. E[g] is the deterministic expectation. When g refers to data, then g_t is the observed quantity, but when g refers to a state variable, then those g terms are estimated parameters. For example, effort in the modern period is treated in this fashion.

The variances for process and observation errors (σ_g) are parameterized as multiples of an overall model coefficient of variation (CV):

$$(11a) \qquad \sigma_g = \ln\left[(\lambda_g CV)^2 + 1\right]$$

$$(11b) \qquad \sigma_g = \ln\left[(\omega_{i,y} \lambda_g CV)^2 + 1\right] \qquad .$$

The term λ_g is a variable-specific multiplier of the overall model CV. For catch series and indices (eq 11b), the additional term, $\omega_{i,y}$, is the weight applied to individual points within those series. For instance, because the indices are standardized external to the model, the estimated variance of points within each series is available and could be used to weight the model fit. Given the Data Workshop decision to use equal weighting between indices, all $\omega_{i,y}$ were fixed to 1.0 and the same λ_g was applied to all indices. To evaluate the sensitivity case where indices were weighted by the inverse of their CV, each $\omega_{i,y}$ was fixed to the estimated CV for point *y* in series *i*; an attempt was also made to estimate a separate λ_g for each series, however those multipliers were not estimable and so a single λ was applied to all indices.

In the present model, these multipliers on catches and indices were fixed after exploring the effects on model outputs for several different values. A fleet-specific effort constant was

estimated, but by allowing for large process error it was effectively a free parameter (a log-scale variance of 5 was used); the correlation was fixed at 0.5.

4.7.2 Data inputs, prior probability distributions, and performance indicators

Baseline scenario (ASPM-BASE)

The base model represented the decisions made by the Data Workshop as well as any additional decisions or modifications made by the assessment workshop. Data inputted to the model included maturity at age, fecundity at age (pups per mature female), spawning season, catches, indices, and selectivity functions (Tables 4.1a and b, 4.2, and 4.3; Figures 4.1 - 4.3). Catches were made by the commercial sector, the recreational sector, and the Mexican fishery. In addition, unreported commercial catches were estimated, as were Gulf of Mexico menhaden fishery discards. Because of similar selectivity functions, the commercial and unreported catches were combined, and recreational catches were combined with Mexican catches, yielding a model with 3 distinct "fleets" (Table 4.2). A total of 13 indices were made available after the data workshop (Table 4.3, Figure 4.2). The "DE Bay age 0" index was not used in this application, as this model began with age class 1.

Selectivities are imputed in the age-structured surplus production model (as a functional form) and linked to each individual catch or CPUE series. Individual selectivity functions to be applied to catch series were identified by the DW catch working group based on information used in previous assessments, length frequency data presented at the DW, and the collective knowledge of shark fisheries of the group members. The selectivity recommendations can be found on pages 38-39 of the DW report. Selectivities linked to individual catch series were a compromise because the series often encompass various components of the fishery (e.g., commercial + unreported selectivity refers to commercial fisheries, most of which are bottom longline fisheries, but also include pelagic longline and drift gillnet fisheries, which are likely to have somewhat different selectivity patterns). The selectivity functions identified were then applied to the individual CPUE series based on the type of index represented (e.g., the BLLOP and VA LL indices were assigned the commercial + unreported logistic selectivity function because both indices use bottom longline gear).

-Commercial landings + unreported catch series: a logistic curve was selected based on the 2002 SEW assessment. The rationale was that younger ages were relatively less selected by the commercial gear as a whole, which as stated above may also include pelagic longline gear that is set in deeper waters where juveniles are less available, and drift gillnet gear that uses large mesh sizes targeting adults (Figure 4.3).

-Recreational and Mexican catch series: this selectivity pattern was largely based on the MRFSS, which includes data from recreational anglers fishing in nearshore waters and targeting mostly juveniles. Based on this, very limited length-frequency information presented in document LCS05/06-DW-16, and information from the 2002 SEW assessment, selectivity for sandbars was given a dome-shaped curve covering mostly juvenile ages (Figure 4.3).

-Menhaden bycatch series: based on data from this fishery, all age groups were assumed to be fully selected and thus given a constant selectivity of 1 (Figure 4.3).

-Juvenile indices: this selectivity pattern was intended for surveys targeting juveniles and thus assumes full selectivity for the first age groups, with a rapid decline as sharks approach maturity (note that the 2002 ages at maturity were used; Figure 4.3).

Catch data begin in 1981, while the earliest data for the indices is 1975 (VA-LL). To make use of the longer time series of this index, and the possible contrast offered therein, catches from 1981 were imputed back to 1975, when a virgin assumption was imposed. The catches for each fleet were imputed as follows: the commercial+unreported was fixed to the 1981 value, the recreational+Mexican was fixed with a linear decrease from the 1981 value, and the menhaden catches were fixed at the series average (Table 4.2).

It was discussed at the assessment workshop that a commercial fishery existed in the mid-1930s for shark livers, but that this fishery disappeared after the development of synthesized vitamin A. A small amount of bycatch in the Pelagic Longline fishery and menhaden fishery probably began in the 1960s, but this is assumed to be negligible compared to the removals in the 1970s. Following the release of the movie JAWS in 1975, a recreational fishery rapidly developed. Thus, the assumption that the initiation of significant exploitation began in 1975 does not seem unreasonable.

Individual points within catch and index series can be assigned different weights, based either on estimated precision or expert opinion. The base case model configuration downweighted the historical catches, giving them ½ of the weight of catches from 1981-2004, on the rationale that they were less well known. In addition, several weighting factors were evaluated for the value of the recreational catch in 1983. Recreational catch in 1983 is roughly ten times the value in 1982 and six times the value in 1984; also, it is about nine times the series average without that point. For these reasons, the value for 1983 catch seems anomalously high. Downweighting it by ½ led to the predicted value matching it within 3%; downweighting it by 1/10 led to a predicted value within 25%. In both cases, the relative benchmarks were nearly identical. It was decided to proceed by downweighting that point by 1/10.

One further model specification was the degree to which the model predicted values matched catches versus indices. An overall model CV is estimated (see equations 11a and 11b), and multiples (λ_g) of this overall CV can be specified separately for catches and indices (see Porch 2002). All catch series were assigned the same CV multiple, and all indices were assigned a single CV multiple (this forces equal weighting of the indices). Initially, an attempt was made to estimate these multipliers. This resulted in boundary solutions for the multipliers. In a second attempt, the multiplier for catch was fixed at 1 and the index multiplier was estimated. Again, this resulted in the index multiplier estimate at the upper bound. An explanation for this behavior is that the interannual variability within indices is substantial in some cases, and additionally, indices with the same selectivity have conflicting trends (Figure 4.4). To deal with this, two values were evaluated for the CV multiplier of indices: a value that was 5 times the catch CV multiplier, and a value equal to the catch CV multiplier. The former case implies that indices are less certain than catches, while the latter case implies the same relative certainty in catches and indices. Both results indicated an overfished stock with overfishing. The estimate of relative biomass (B_{2004}/B_{MSY}) was nearly identical between these two configurations (0.72 vs.

0.73, respectively), while the degree of overfishing (F_{2004}/F_{MSY}) was about 10% less (3.72 vs. 3.29). Given that the estimated stock status did not vary based on the weighting between catch and indices, it was decided to proceed by placing relatively more confidence in the catch series (notwithstanding the weighting of individual points within the catch series, as described in the paragraph above).

Estimated model parameters were pup survival, virgin recruitment (R_0), catchabilities associated with catches and indices, and fleet-specific effort. Natural mortality at ages 1+ was fixed at the updated values (Table 4.1a), and the priors for pup survival and virgin recruitment are listed in Table 4.1b.

In summary, the base model configuration assumed virgin conditions in 1975, used the imputed historical catch series, the updated biological parameters, the updated prior for pup survival, and the base case indices with an updated Pelagic Longline Log index (referred to as Pelagic Log). In addition, historic catches (1975-1980) were downweighted by ½ and the 1983 recreational catch was downweighted by 1/10; lastly, catches were assumed to be 5 times more certain than the indices. All inputs are given in Tables 4.1, 4.2, and 4.3. Base indices are in black font in Table 4.3 (the DE Bay age 0 index was not used because the model started with age 1).

Performance indicators included estimates of absolute population levels and fishing mortality for year 2004 (F_{2004}, SSF_{2004}, B_{2004}, $Nmature_{2004}$), population statistics at MSY (F_{MSY}, SSF_{MSY}, SPR_{MSY}), current status relative to MSY levels, and depletion estimates (current status relative to virgin levels). In addition, trajectories for F_{year}/F_{MSY} and SSF_{year}/SSF_{MSY} were plotted. SSF spawning stock fecundity.

4.7.3 Methods of numerical integration, convergence diagnostics, and decision analysis

Numerical integration for this model was done in AD Model Builder (Otter Research Ltd. 2001), which uses the reverse mode of AUTODIF (automatic differentiation). Estimation can be carried out in phases, where convergence for a given phase is determined by comparing the maximum gradient to user-specified convergence criteria. The final phase of estimation used a convergence criterion of 10^{-6}. For models that converge, the variance-covariance matrix is obtained from the inverse Hessian. Likelihood profiling was performed to examine posterior distributions for several model parameters. Likelihood profiles are calculated by assuming that the posterior probability distribution is well approximated by a multivariate normal (Otter Research Ltd. 2001). Model fit was assessed by comparing components of the relative negative log-likelihood (relative rather than exact because the constants in the likelihood were not included). The relative negative log-likelihood (objective function) and AICc (small sample AIC) values are listed in the table of model results.

4.7.4 Sensitivity analyses

Three sensitivity runs to the base model were performed. In the first sensitivity (**ASPM-SB-1**), the base configuration was retained and observations within each index were weighted by the inverse CV of each point. An attempt was made to estimate a separate CV multiplier for each index, but there were boundary solutions again, so the multiplier from the base case was retained for all indices. In the second sensitivity (**ASPM-SB-2**), the base configuration was retained, and

all available indices were used. For the third sensitivity (**ASPM-SB-SPR$_{50}$**), the base case weighting and indices were used, but the model was forced to have SPR_{MSY}=0.5. To achieve this SPR level, the base case values for survival at age (the updated values as described in Section 4.6) were increased by 1.5% for ages 1+, and the median for pup survival was fixed at 0.82.

One Panel member noted that many of the sandbar indices are localized, seasonal surveys and requested that a sensitivity be run using the surplus production model including only the BLLOP, Pelagic Log, and Bottom LL Logs indices because they cover the greatest area and time. However, it was noted that the BSP was not the final model selected for sandbar sharks. Additionally, similar sensitivity runs had been completed using the BSP and did not change the stock status. It was also noted that the commercial indices do have gaps in time and space due to closed areas and fishing seasons. Additionally it was pointed out that many of the "seasonal" surveys are conducted in that fashion as the sharks are not present year-round in those areas so sampling when the sharks are not available to the gear would confound the data. Finally, it was noted that removing all the others indices would remove the indices which cover the greatest time span, including those prior to management intervention, which contain most of the contrast over time, leaving only relatively short, non informative indices beginning after management intervention for the model to fit to. It was decided not to conduct this sensitivity.

4.8. Results

4.8.1 Baseline scenario

The base model estimated an overfished stock with overfishing (Tables 4.4 and 4.5; Figure 4.5). The model estimate of F by fleet is dominated by the recreational fleet (includes recreational fishery plus estimated Mexican catches) for the first decade of the time series (1975-1986), and thereafter the commercial and recreational fleets are more or less on par (Figure 4.5). Model fits to catches are shown in Figure 4.6 and show very good agreement; the estimated recreational 1983 value is below the observed value due to the downweighting of that point (see discussion in section 4.7.2). The VA-LL index is the longest time series, beginning in 1975, and its trend was fit well by the model (Figure 4.7). The next longest series is LPS, which begins in 1986. The LPS index showed steep oscillations the first 8 years, which the model could not match (Figure 4.7). The remaining indices span only a few years, and the model adequately predicts an average trend through the observed points (Figure 4.7).

Likelihood profiling was performed in ADModel Builder (Otter Research Ltd. 2000) to obtain posterior distributions for several model parameters (Figures 4.8 and 4.9). The distributions for total biomass depletion or spawning stock fecundity depletion range from about 0.2-0.5 (Figure 4.8). The estimate of F_{2004} ranges from about 0.03-0.08 (Figure 4.9). The mode for the posterior of pup survival was estimated at a lower value than the prior mode (it was closer to the original data workshop specification of 0.6), while the posterior for virgin recruitment of pups became much more concentrated around the prior mode (Figure 4.9).

4.8.2 Sensitivity analyses

The results of the three sensitivity cases also estimated that the stock was overfished with overfishing (Table 4.4). For **ASPM-SB-1**, the results were very similar to the base case. Although the estimate of SSF_{2004}/SSF_{MSY} was similar to the base model, **ASPM-SB-2** estimated a much higher relative F (six to ten times larger than the other models). This is due to the model estimating a very low pup survival (0.37), which led to an F_{MSY} that was ten times lower than the other model. The low resiliency implied by these estimates is also reflected in the estimate of SPR_{MSY} (0.96). It appears that the flatter fit to indices (as compared to the base model) is the reason that SSF_{2004}/SSF_{MSY} is more similar to the base and sensitivity cases. **ASPM-SB-SPR$_{50}$** was the most optimistic scenario, but that is due to the fact that SPR_{MSY} was forced to be 0.5; the other models estimated SPR_{MSY} in the range of 0.7-0.96.

A phase-plot of stock-status shows the outcomes of the base model, the three sensitivity analyses, the continuity and retrospective analyses, and the estimates from BSP and WinBUGS (Figure 4.10). Note that the x values for BSP and WinBUGS are in numbers of fish (N_{2004}/N_{MSY}) rather than SSF_{2004}/SSF_{MSY}. These values from BSP and WinBUGS should be comparable, however, because they are relative statistics, and they only differ from the ASPM by the maturity ogive. No prior was assumed for catchability so its contribution to the likelihood is 0.0 for all models.

4.8.3 Comparison of model fits

The relative likelihood values by model source (catch, indices, effort, catchability, and recruitment) as well as a breakdown of likelihood by individual catch and index series are shown in Figures 11 and 12. The total approximate likelihood is lowest for the base model (see Table 4.4, value for "objective function"). Catches are best fit by the base model, while indices are better fit by the sensitivity using inverse CV to weight the series (ASPM-SB-1). However, the difference between the best versus the worst fit to indices is only 10 points, whereas there is a difference of about 60 points in the fit to catches. None of the model configurations impacted the contribution to the likelihood by effort or recruitment parameters (pup survival and virgin number of pups). The AICc is lowest for ASPM-SB-2, but this model run used 3 additional sensitivity indices (39 additional data points, and only 3 additional parameters estimated compared to the base model). The next lowest AICc used the same data as the base model, but estimated one fewer parameter (pup survival was fixed, ASPM-SB-SPR50). The AICc is about 3.5 points lower for this sensitivity, which may indicate a slightly better fit than the base model.

4.9 Projections of the base model

The base model was projected at F = 0 to determine the year when the stock could be declared recovered ($SSF/SSF_{MSY} > 1$). In making projections, the estimate of F in 2004 was applied for years 2005-2007, as it is unlikely that any management actions could be realized until that year.

Projections were done using Pro-2Box (Porch 2003). Projecting the stock at F = 0 (with $F = F_{2004}$ for years 2005-2007), a deterministic estimate indicates stock recovery by 2038 (SSF2038 = SSF_{MSY}), or 34 years from the current year of data (2004). This projection was bootstrapped 500 times by allowing for process error in the spawner-recruit relationship. Lognormal

recruitment deviations with CV = 0.4, with no autocorrelation, were assumed. No other variability was introduced into the projections. Under these assumptions, the year with 70% probability of recovering to SSF_{MSY} is 2041, which is a rebuilding time of 38 years from 2004.

Given that the rebuilding time is greater than 10 years, then management action should be implemented to rebuild the stock within the estimated **rebuild time+1 generation time** (Restrepo et al. 1998). The estimate of generation time is about 34 years, which gives (**38 years) + (34 years) = 72 years** to rebuild, or the **year 2076**. Generation time was calculated as

$$GenTime = \frac{\sum_i i f_i \prod_{j=1}^{i-1} s_j}{\sum_i f_i \prod_{j=1}^{i-1} s_j}$$

where i is age, f_i is the product of (fecundity at age) x (maturity at age), and s_j is survival at age. The calculations were carried out to an age, A, such that the difference between performing the calculation to age A or A+1 was negligible. This calculation is consistent with the assessment model, which treats survival of the plus group as the sum of a geometric series (e.g. see third line in equation 1). The 2006 maturity ogive was used, 8.4 pups per female was the fecundity for all ages, adjusted age-specific survival at age was used (see section 4.6), and the mode of 0.75 for the prior on pup survival was used. As was done in the assessment model, to account for the approximately one year gestation period, maturity at age was shifted by 1 year, and the number of pups was halved to account for the fact that only half of the mature population would reproduce in a given year. Note that because pup-production is constant for all ages, it factors out of both numerator and denominator, and the resulting estimate of generation time is insensitive to that value.

A fixed F strategy and a fixed TAC strategy were estimated that would attain rebuilding by the year 2076. Assumptions for these projections included the above process error in stock-recruitment, the selectivity vector was the geometric mean of the last 3 years (2002-2004), and it was assumed that any modification to F or a TAC would impact each fishery by the same proportion.

A constant F of 0.01 beginning in 2008 leads to rebuilding by the year 2076 with 70% probability, while F = 0.011 rebuilds the stock by 2076 with 50% probability (median of bootstraps; Figure 4.13). The current estimate of F (F_{2004}) is 0.065, implying that a reduction of about 83-85% is needed. The yield (kg) associated with these F values in 2008 is approximately 15-17% of the yield in 2007.

Constant TAC scenarios were explored by implementing a constant yield (in kg) beginning in 2008; in years 2005-2007 the estimated fishing mortality rate from 2004 was applied. A constant TAC of 2.4E+05 kg allows the population to rebuild by 2076 with 70% probability (70% of the bootstraps have $SSF_{2076}/SSF_{MSY}>1.0$; Fig. 4.14). A constant TAC of 2.7E+05 kg allows rebuilding by 2076 with 50% probability (median of the bootstrap runs). A TAC of 2.4E+05 kg or 2.7E+05 kg is 20% or 23% of the yield obtained in 2007.

4.10 Continuity analysis

A continuity base model was run using the 2002 state-space age structured production model. In that model formulation, a level of historic fishing (F_{hist}) is estimated. F_{hist} is then used to calculate the corresponding equilibrium population age structure for the first year that data is available. A historic selectivity vector is specified by the user, which is multiplied by F_{hist} to arrive at the historic age-specific fishing mortality rate. A historic selectivity vector of 1 for all ages was assumed. This methodology is fully documented in section 5.7.1 of the Gulf of Mexico blacktip shark assessment.

Biological inputs to the continuity model were the same as those used in 2002 (Table 4.1a). Catches and indices used were the updated values through 2004. The updated catches were nearly identical (Figure 4.15). All indices in Table 4.3 were used except the "Del Bay age 0," because the model started at age 1. The indices available for 2006 and those used in 2002 are plotted in Figures 4.2 and 4.16 respectively. Several of these indices were directly compared to see more clearly the recent trend (Figure 4.17). It was noted that several of the indices for the 2002 assessment had an upswing in the terminal year for input (2001). Several of those indices, when updated to 2004, showed a consistent decline from the upswing in 2001.

The direct comparisons between indices used in 2002 versus those used in 2006 is confounded somewhat by several issues. First, a number of the indices in 2002 were not available in 2006. In some cases, indices which were not standardized in 2002 were standardized in 2006; in other cases, indices which were not standardized and which were split into two separate nominal indices in 2002 were combined and standardized to one index in 2006 (MRFSS, e.g.). Also, the VIMS data were split into four age-specific indices and one biomass index in 2002, while in 2006 only one VIMS index in numbers for all ages was available. Despite these issues, the overlay of indices from similar data sources shows very similar trends for the years of overlap (Figure 4.17).

Because one index started in 1975, while the catch started in 1981, the model was allowed to estimate catch in the years 1975-1980. Alternative treatments of this 'missing catch' were evaluated in SEDAR11-AW-03.

The result of the continuity model was an overfished stock with overfishing (SSF_{2004}/SSF_{MSY} = 0.38, F_{2004}/F_{MSY} = 65.6). The estimate of F_{hist} was 9.8E-5, but the population was depleted to 72% of virgin conditions at the start of the time series (B_{1975}/B_0= 0.72). The estimate of SPR_{MSY} was 0.95 and F_{MSY} was 0.003, which explains why such a small level of fishing mortality had such a measurable effect on the population. This low resiliency compared to the 2002 result was driven in part by the estimated age-constant of M, which was 0.224 in this application versus 0.137 in 2002. The prior for M was specified the same for 2002 and 2006 (lognormal distribution with median = 0.18 and CV = 0.25).

4.11 Retrospective analyses

It was noted that the conclusion regarding stock status from the continuity and base models (an overfished stock with overfishing) in this 2006 assessment contradicted the base model conclusion from the 2002 assessment.

Given that direct comparisons between indices used in 2002 vs. those used in 2006 is confounded somewhat by the issues discussed in the continuity section above, several retrospective analyses were examined to try to determine what was driving the new results. All retrospective runs used the age structured production model from the 2002 assessment, 2002 values for biological parameters (Tables 4.1a and b), and catch and indices updated through 2004. The retrospective analyses examined were:

R1 – Using updated data through 2004, the updated Pelagic Log index, equal weighting, and using the imputed catches from 1975-1980 (Table 4.2; same as Catch Scenario 2 in SEDAR11-AW-03)
R2 – Using updated data through 2001, the updated Pelagic Log index, equal weighting, and using the imputed catches from 1975-1980 (Table 4.2; same as Catch Scenario 2 in SEDAR11-AW-03)
R3 – Using updated data through 2001, the updated Pelagic Log index, equal weighting, and model started in 1981 (did not use imputed historical catches)
R4 – Using updated data through 2001, the updated Pelagic Log index, equal weighting, and model started in 1981 (did not use imputed historical catches), added the VIMS age 0-1 index from the last assessment
R5 – Using updated data through 2001, the updated Pelagic Log index, equal weighting, and model started in 1981 (did not use imputed historical catches), added the VIMS age 13-max index from the last assessment
R6 – Using updated data through 2001, the updated Pelagic Log index, equal weighting, and model started in 1981 (did not use imputed historical catches), added all of the VIMS indices from the last assessment

Model runs R4 and R5 did not converge. All of the remaining retrospective model runs estimated that the stock was overfished with overfishing occurring (Table 4.6), and it was not possible (with this set of runs) to arrive at the 2002 assessment conclusion. It should be noted that using the data input files from 2002 reproduced exactly the output from 2002, which demonstrates that there were no changes to the model code that affected the estimation procedure.

4.12 Discussion

There was some uncertainty associated with the biological parameters, which led to the AW updating the fixed values for M at age, and the mode of the prior for pup-survival (corresponding to density-independent level). Even fixing pup survival to a relatively high level (median of 0.82) so that SPR_{MSY}=0.5 produced a very low sustainable level of fishing mortality (F_{MSY}=0.03). In the base model, total fishing mortality from 1990-2000 averages 0.12, and for 2001-2004 it averages 0.08. These levels are 3-4 times the estimate of F_{MSY}, assuming the most optimistic survival rates, and 6-8 times the base case estimate of F_{MSY}. A contributing factor to

having low resiliency to fishing is the late age at first maturity. The combination of life-history parameters and the vulnerability of sharks to the various gears long before they are mature suggest a population that cannot support much exploitation.

The result from 2002 ASPM with equal weighting was that the stock was not overfished, and no overfishing was occurring, although the value of $F_{2001}/F_{MSY} = 0.9$ was only slightly below 1.0. Retrospective analyses using the biological inputs from 2002 failed to identify a reason for the change in estimated status for 2006. However, these retrospective analyses did not use the exact same data sets, for the various reasons mentioned in Sections 4.10 and 4.11.

Between the 2002 and 2006 base cases, there are differences beyond the indices. The values and treatment of biological parameters differed. The maturity ogive for 2006 was shifted to older ages; a fixed M at age was used in 2006 while an age-constant M was estimated in 2002. Assumptions relating to virgin conditions and historic exploitation also differed. In 2002, the model began in 1981 and estimated a historical level of fishing (F_{hist}) that was used to calculate the initial equilibrium age structure under that fishing rate. The estimate of F_{hist} was 1E-8, which effectively started the population at virgin conditions in 1981. In 2006, the model began at virgin conditions in 1975, and catches were imputed for the years 1975-1980. The 2006 model result estimated the total biomass in 1981 to be at 93% of virgin levels, and $SSF_{1981}/SSF_{virgin} =$ 0.98. The estimate of virgin recruitment (age-1 pups) and pup-survival were similar between 2002 and 2006, but the estimate of MSY for the 2002 assessment was double that for 2006. This is because in 2002, the estimate of SPR_{MSY} was 0.46 (vs. 0.73 in 2006), a result of the different survival and maturity rates at age.

4.13 References

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Table 4.1a. Biological inputs from 2002 assessment, 2006 base case values from the data workshop, or values updated at the 2006 assessment workshop. In the continuity case, M was estimated, while in the 2006 base case, M at age values were fixed. The * for the age 0 entries in the first three columns is to distinguish those values as survival rates rather than natural mortality rates.

Age	M 2002	M 2006	M 2006 Updated	Female Maturity 2002	Female Maturity 2006	Pups-per-Female 2002	Pups-per-Female 2006
0	0.6*	0.6*	0.75*	0	0	0	0
1	0.18	0.26	0.232	0	0	12	8.4
2	0.18	0.23	0.198	0	0	12	8.4
3	0.18	0.2	0.174	0	0	12	8.4
4	0.18	0.19	0.156	0	0	12	8.4
5	0.18	0.17	0.143	0	0	12	8.4
6	0.18	0.16	0.132	0	0	12	8.4
7	0.18	0.15	0.123	0	0	12	8.4
8	0.18	0.15	0.116	0	0	12	8.4
9	0.18	0.14	0.109	0	0	12	8.4
10	0.18	0.13	0.104	0.01	0	12	8.4
11	0.18	0.13	0.100	0.04	0	12	8.4
12	0.18	0.13	0.096	0.15	0	12	8.4
13	0.18	0.12	0.093	0.43	0.01	12	8.4
14	0.18	0.12	0.090	0.76	0.05	12	8.4
15	0.18	0.12	0.088	0.93	0.125	12	8.4
16	0.18	0.11	0.085	0.98	0.200	12	8.4
17	0.18	0.11	0.083	1	0.300	12	8.4
18	0.18	0.11	0.082	1	0.425	12	8.4
19	0.18	0.11	0.080	1	0.550	12	8.4
20	0.18	0.11	0.079	1	0.675	12	8.4
21	0.18	0.11	0.078	1	0.775	12	8.4
22	0.18	0.11	0.076	1	0.85	12	8.4
23	0.18	0.11	0.075	1	0.90	12	8.4
24	0.18	0.10	0.075	1	0.93	12	8.4
25	0.18	0.10	0.074	1	0.95	12	8.4
26	0.18	0.10	0.073	1	0.96	12	8.4
27	0.18	0.10	0.072	1	0.96	12	8.4
28	0.18	0.10	0.072	1	0.97	12	8.4
29	0.18	0.10	0.071	1	0.98	12	8.4
30	0.18	0.10	0.071	1	0.99	12	8.4
31	0.18	0.10	0.070	1	1	12	8.4

Table 4.1b. Additional parameter specifications where L_∞, K, and t_0 are von Bertalanffy parameters; a is the scalar coefficient of weight on length; and b is the power coefficient of weight on length. Weight units are kg.

Parameter	**Value**	**Prior**
L_∞	164 (cm PCL)	*constant*
K	0.089	*constant*
t_0	-3.8	*constant*
a	1.09E-05	*constant*
b	3.012	*constant*
Pup Survival	0.75 (mode)	~LN with CV=0.30
Virgin Recruitment (R_0)	5.00E+05	~N with CV=0.7, defined on [1.0E+3, 1.0E+10]

Table 4.2. Catches of sandbar shark by fleet. For the missing historic catches (1975-1980), the commercial+unreported was fixed to the 1981 value, the recreational+Mexican was fixed with a linear decrease from the 1981 value, and the menhaden catches were fixed at the series average. The 1983 recreational catch (boxed; red font) was downweighted in the base model.

Year	Commercial +Unreported	Recreational + Mexican	Menhaden
1975	***6640***	***19880***	***531***
1976	***6640***	***39760***	***531***
1977	***6640***	***59640***	***531***
1978	***6640***	***79520***	***531***
1979	***6640***	***99400***	***531***
1980	***6640***	***119280***	***531***
1981	6640	139160	696
1982	6640	45402	713
1983	7173	**428112**	705
1984	9797	69503	705
1985	9100	88083	635
1986	25826	134938	626
1987	73983	39625	653
1988	124680	76875	635
1989	160712	36950	670
1990	122440	69559	653
1991	96680	45857	505
1992	100592	46081	444
1993	71977	35870	452
1994	126454	23738	486
1995	84371	36188	445
1996	65515	47403	444
1997	41415	50264	452
1998	62776	42200	435
1999	53248	28060	479
2000	37330	17909	409
2001	50138	43145	383
2002	56342	15278	374
2003	45190	12202	365
2004	39068	10669	374

Table 4.3. Indices available for use in the current sandbar shark assessment. Sensitivity indices in green (last 3 columns).

YEAR	LPS	BLLOP	VA LL	NMFS LL SE	DE Bay	DE Bay age 0	DE Bay Juveniles	Bottom LL Logs	NMFS LL NE	Pelagic Log	PC gillnet	SC LL recent	MRFSS
1975			1.900										
1976													
1977			2.077										
1978			1.085										
1979													
1980			1.995										
1981			1.925										2.011
1982													2.195
1983													2.766
1984			0.647										2.408
1985													2.094
1986	3.557		0.665										2.119
1987	0.859												1.167
1988	2.326												0.789
1989	3.204		0.911										0.714
1990	1.008		0.746										0.634
1991	2.327		0.788										0.431
1992	1.382		1.331										0.874
1993	0.739		0.915										0.402
1994	0.378	0.799								0.140			0.243
1995	0.302	0.882	0.860	1.293						0.912		0.458	0.492
1996	0.369	1	0.770	0.831				0.789	0.321	2.116		0.964	0.612
1997	0.530	0.956	0.721	1.301				1.002		0.762	2.250	0.643	0.504
1998	0.124	1.292	0.826					0.919	2.045	1.050	1.220	0.750	0.917
1999	0.202	0.849	0.528	0.390				1.150		1.022	0.530	2.547	0.524
2000	0.213	0.744	0.865	0.971				1.171		1.266	0.690	0.666	0.525
2001	0.986	1.650	0.754	1.041	0.950	0.645	1.162	1.115	1.004	1.161	1.250	0.972	0.503
2002	0.236	0.865	0.626	1.072	0.386	0.518	0.325	0.887		0.518	0.610		0.490
2003	0.181	1.007	0.547	0.880	1.409	1.776	1.163	1.170		0.801	0.970		0.386
2004	0.076	0.955	0.519	1.221	1.070	0.877	1.164	0.798	0.629	1.251	0.470		0.201
Ages Vulnerable													
	all	all	all	all	"juveniles"	0	"juveniles"	all	all	all	all	"juveniles"	"2-7"
Selectivity function													
	Comm+Unrep	Comm+Unrep	Comm+Unrep	Comm+Unrep	"juveniles"		"juveniles"	Comm+Unrep	Comm+Unrep	Comm+Unrep	Comm+Unrep	"juveniles"	MRFSS

Table 4.4. Results for the base model runs using the updated biological parameters. Pups-virgin is the number of age 1 pups at virgin conditions. SSF is spawning stock fecundity, which is the sum of number mature at age times pup-production at age (rather than SSB, since biomass does not influence pup production in sharks). For sensitivity case BS-SPR_{50}, pup survival was fixed to force an SPR_{MSY} of 50%. AICc is the small sample Akaike Information Criterion, which converges to the AIC statistic as the number of data points gets large.

Parameter	BASE Est	CV	SB-1 Est	CV	SB-2 Est	CV	SB-SPR_{50} Est	CV
AICc	145.129		247.833		120.087		141.61	
Objective Function	-118.92		-67.57		-109.1		-116.42	
MSY (kg)	4.03E+05	---	4.94E+05	---	7.96E+04	---	8.10E+05	---
Pups-virgin	4.61E+05	0.07	5.06E+05	0.07	6.13E+05	0.08	3.52E+05	0.06
SSF_{2004}	4.28E+05	0.19	5.38E+05	0.14	8.59E+05	0.15	4.95E+05	0.18
$Nmature_{2004}$	9.66E+04	0.19	1.22E+05	0.14	1.95E+05	0.15	1.13E+05	0.18
B_{2004}	3.06E+07	0.16	3.87E+07	0.12	5.42E+07	0.13	3.28E+07	0.16
B_{2004}/B_{virgin}	0.35	0.1	0.4	0.08	0.47	0.07	0.35	0.11
SSF_{2004}/SSF_{virgin}	0.31	0.13	0.35	0.1	0.47	0.07	0.28	0.13
$Nmature_{2004}/Nmature_{virgin}$	0.28	0.13	0.33	0.1	0.43	0.08	0.26	0.13
SSF_{2004}/SSF_{MSY}	0.72	0.46	0.85	0.37	0.83	2.28	0.82	0.14
SPR_{MSY}	0.73	---	0.7	---	0.96	---	0.5	---
F_{2004}	0.06	0.15	0.04	0.16	0.04	0.15	0.05	0.14
F_{MSY}	0.015	---	0.017	---	0.002	---	0.031	---
F_{2004}/F_{MSY}	3.72	0.15	2.62	0.16	18.3	0.15	1.73	0.14
Pup-survival	0.62	0.27	0.67	0.24	0.37	0.28	0.82	(fixed)
alpha	1.88	---	2.02	---	1.1	---	4.09	---
steepness	0.32	---	0.34	---	0.22	---	0.51	---

Table 4.5. Estimates of total number, spawning stock fecundity, and fishing mortality by year for base model for sandbar shark.

Year	N(year)	SSF(year)	F(year)
1975	3,678,734	1,385,200	0.027
1976	3,653,994	1,381,500	0.059
1977	3,610,142	1,377,800	0.092
1978	3,551,582	1,374,100	0.125
1979	3,482,026	1,370,500	0.157
1980	3,404,378	1,366,800	0.190
1981	3,321,045	1,363,100	0.223
1982	3,233,133	1,359,000	0.077
1983	3,233,953	1,354,800	0.576
1984	2,987,888	1,349,400	0.141
1985	2,992,174	1,342,800	0.160
1986	2,974,921	1,331,400	0.243
1987	2,897,082	1,300,000	0.092
1988	2,863,328	1,236,400	0.170
1989	2,736,323	1,144,600	0.121
1990	2,606,223	1,050,400	0.168
1991	2,475,767	975,470	0.121
1992	2,389,954	907,740	0.126
1993	2,293,942	845,410	0.098
1994	2,230,396	779,890	0.103
1995	2,117,106	709,430	0.112
1996	2,026,801	657,180	0.133
1997	1,940,705	616,840	0.134
1998	1,874,080	580,750	0.133
1999	1,792,962	543,750	0.099
2000	1,732,341	515,230	0.066
2001	1,694,431	491,310	0.142
2002	1,618,434	466,150	0.077
2003	1,563,336	444,230	0.063
2004	1,520,555	428,340	0.056

Table 4.6. Results of baseline and retrospective sensitivity model runs. Retrospective runs (R1-R6) were done with the continuity age structured production model from the 2002 assessment. The reference year for B/B_{MSY} and F/F_{MSY} depend on the terminal year for data in the model. In model run R1, the terminal year is 2004; model runs R2-R6 used 2001 as the terminal year.

Model Run	**SSF/SSF_{MSY}**	**F/F_{MSY}**
ASPM-SB-1	0.85	2.62
ASPM-SB-2	0.83	18.3
ASPM-SB-SPR_{50}	0.82	1.73
R1	0.15	235
R2	0.15	82.3
R3	0.18	124
R4	--	--
R5	--	--
R6	0.48	3.45

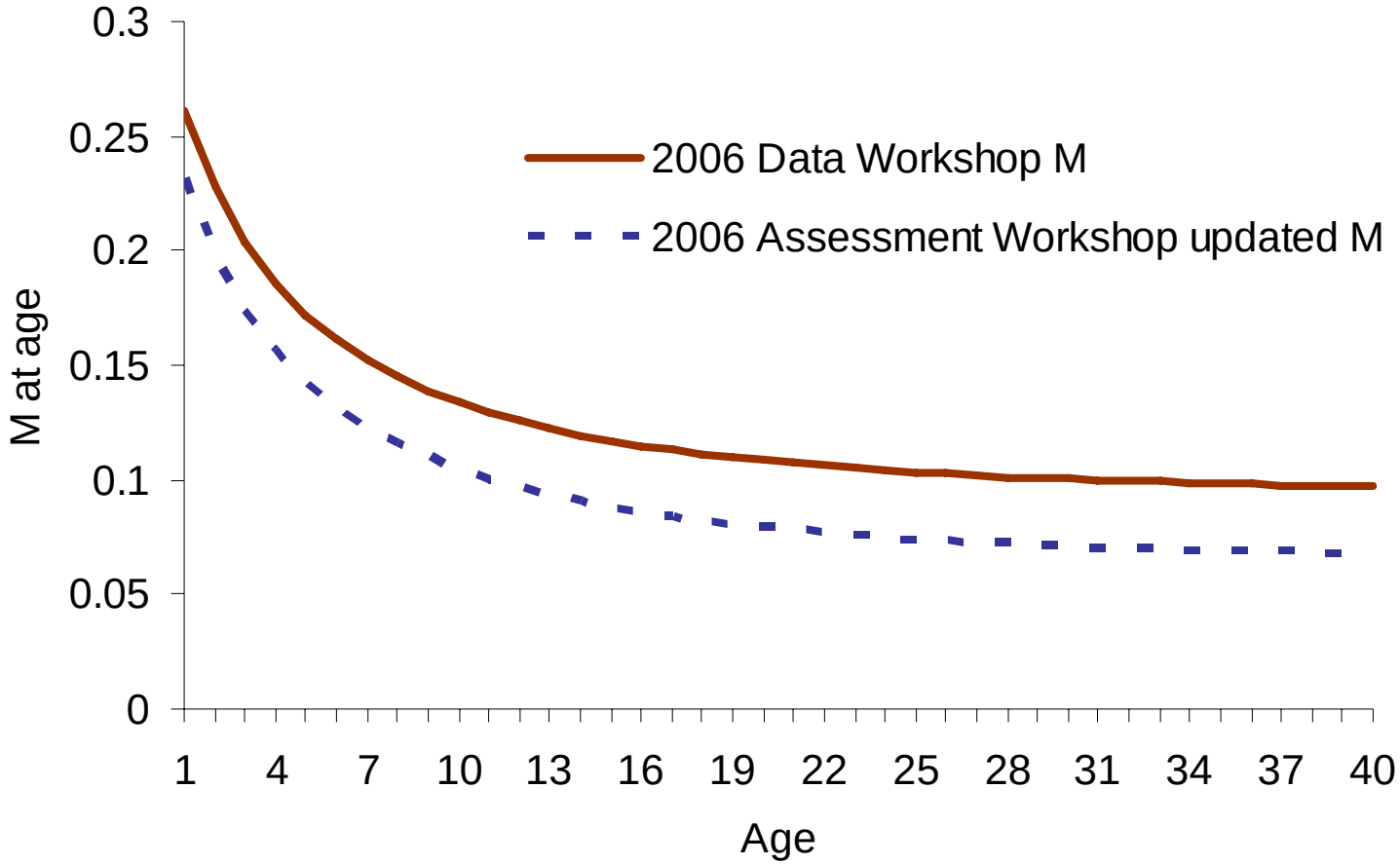


Figure 4.1 Comparison of natural mortality recommended by the data workshop (DW, solid line) and that agreed to in plenary at the assessment workshop (AW, dashed line).

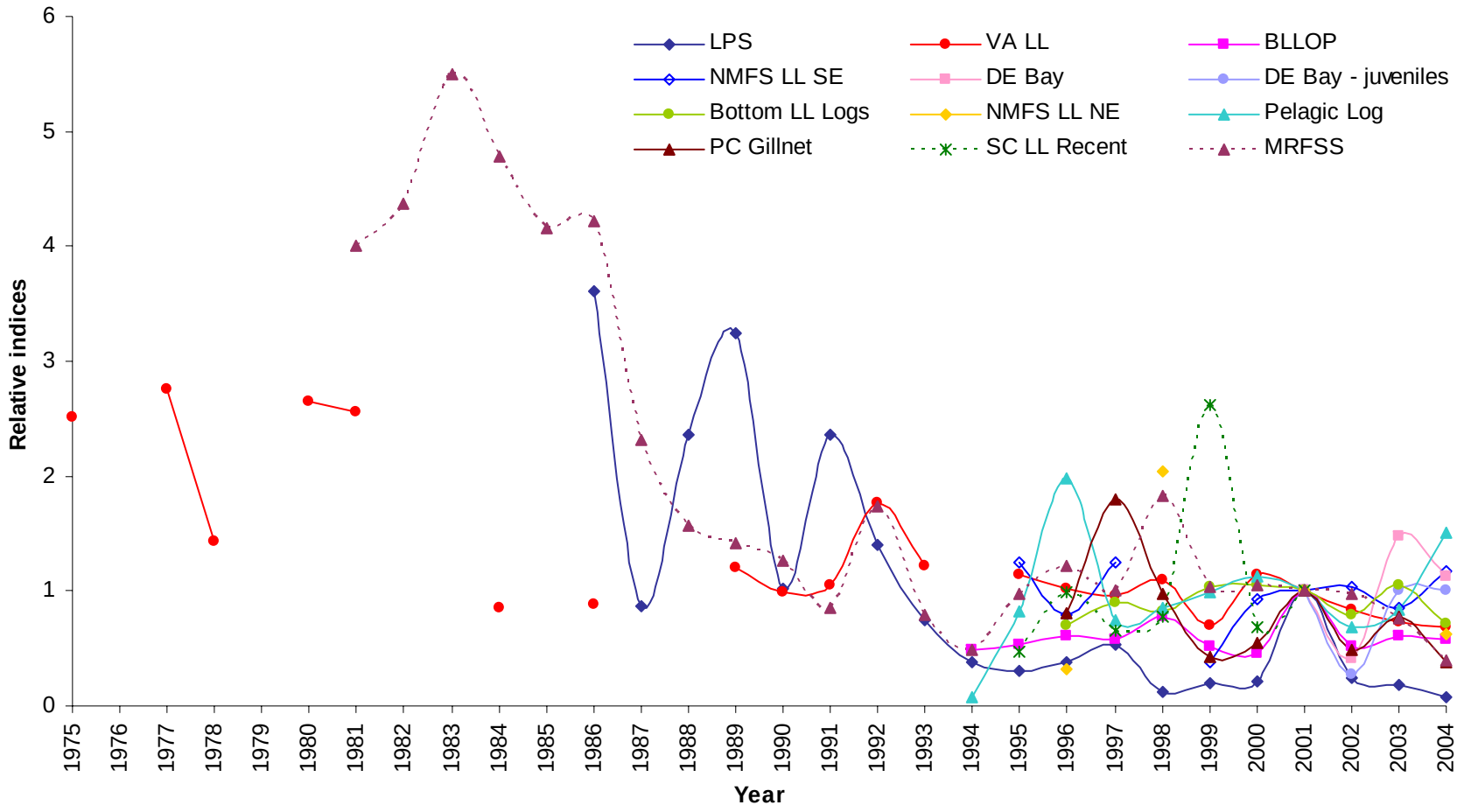


Figure 4.2 Indices available for the current sandbar shark assessment. Indices are scaled by the index-specific mean for overlapping years.

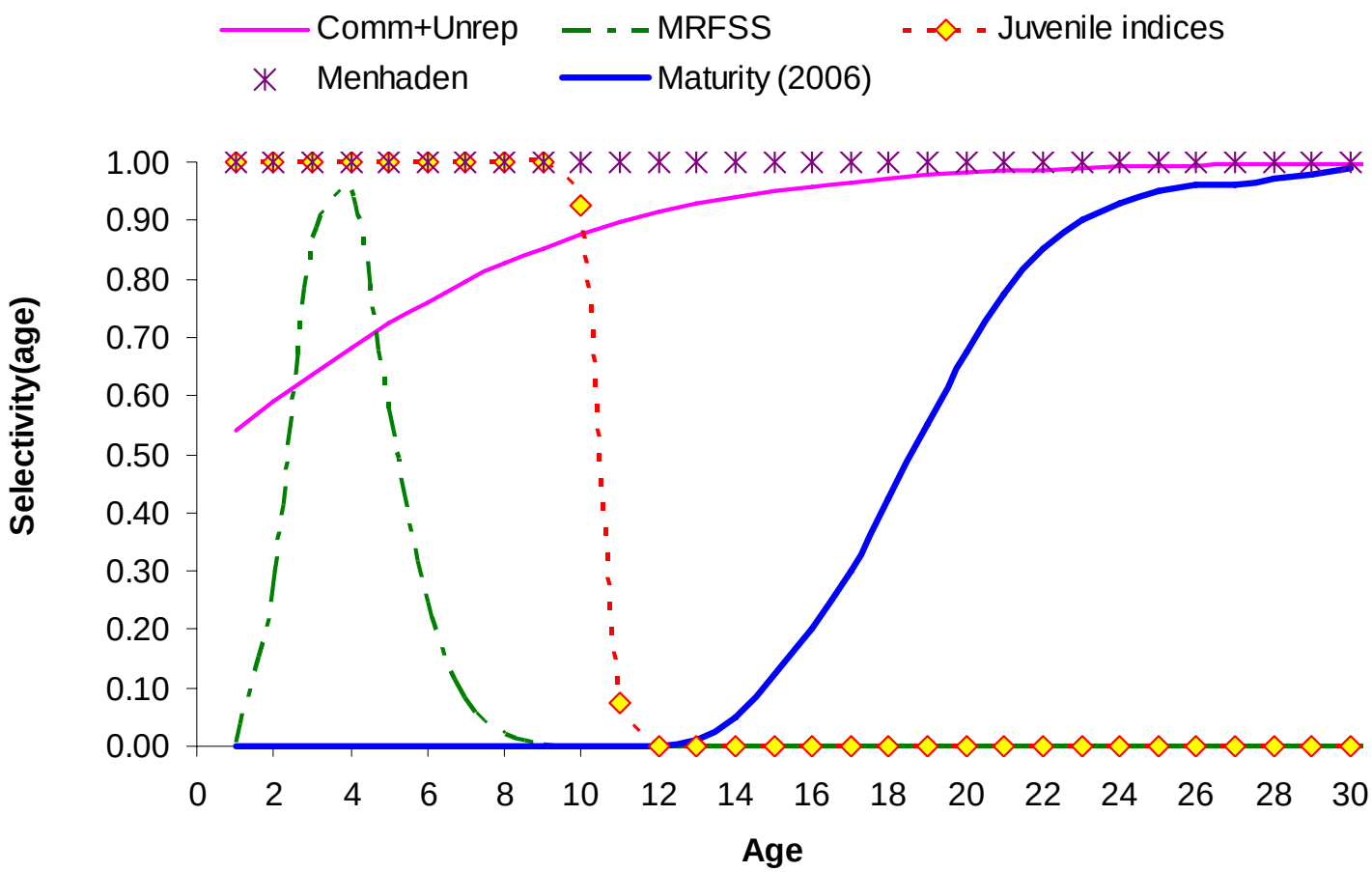
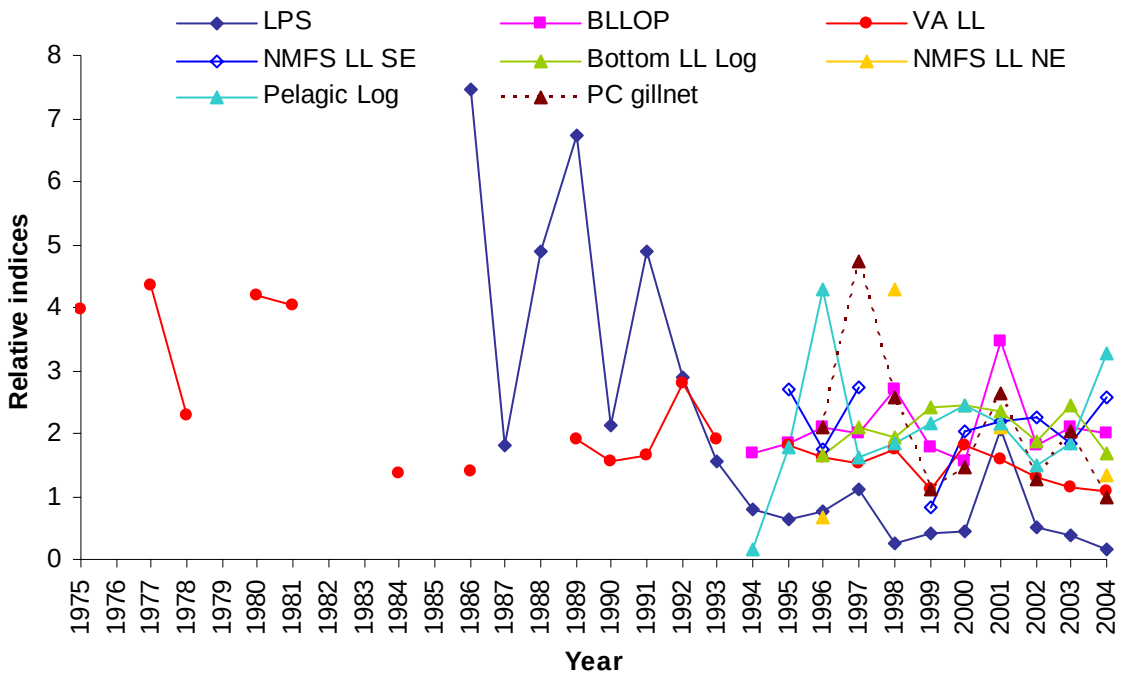


Figure 4.3 Selectivities used in sandbar assessment, with the maturity ogive (solid blue line) as decided at the data workshop. Labels are with the last row in Table 4.3 (all indices available for sandbar).



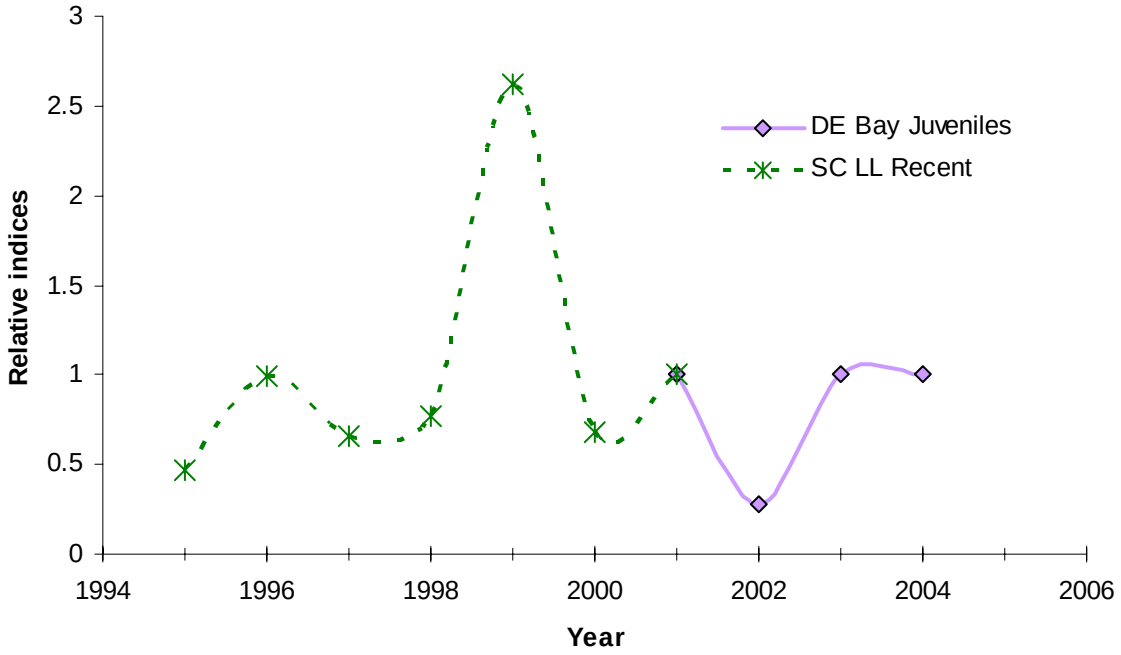


Figure 4.4. Indices with the same selectivity. In the top plot, all indices have the same selectivity as the commercial fishery; the bottom panel includes all indices that select for juveniles. Sensitivity indices, which were not used in the base case are: PC Gillnet and SC LL recent.

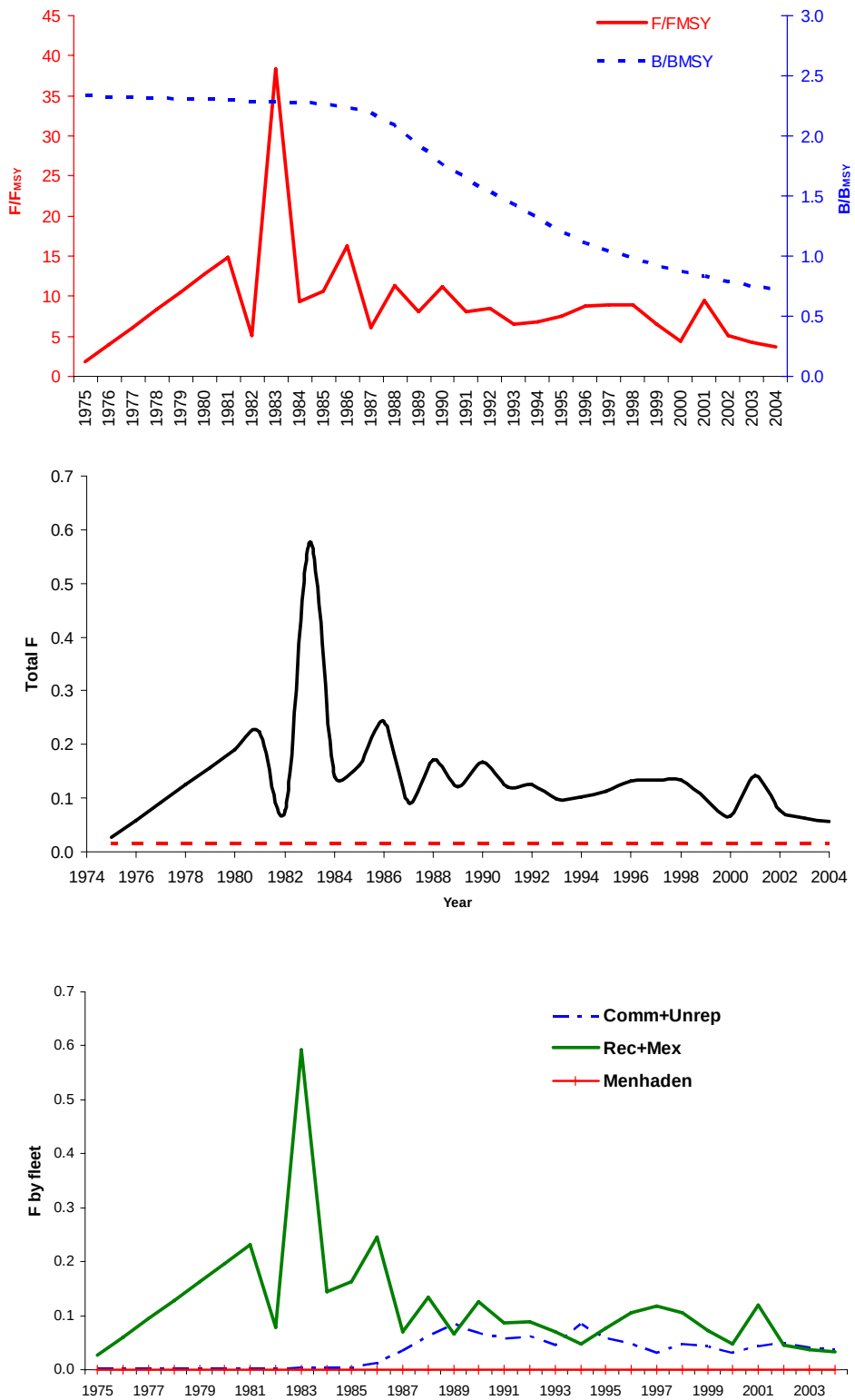


Figure 4.5. Estimated stock status (top), total fishing mortality (middle), and fleet-specific F (bottom). The dashed line in the middle panel indicates F_{MSY} (= 0.015).

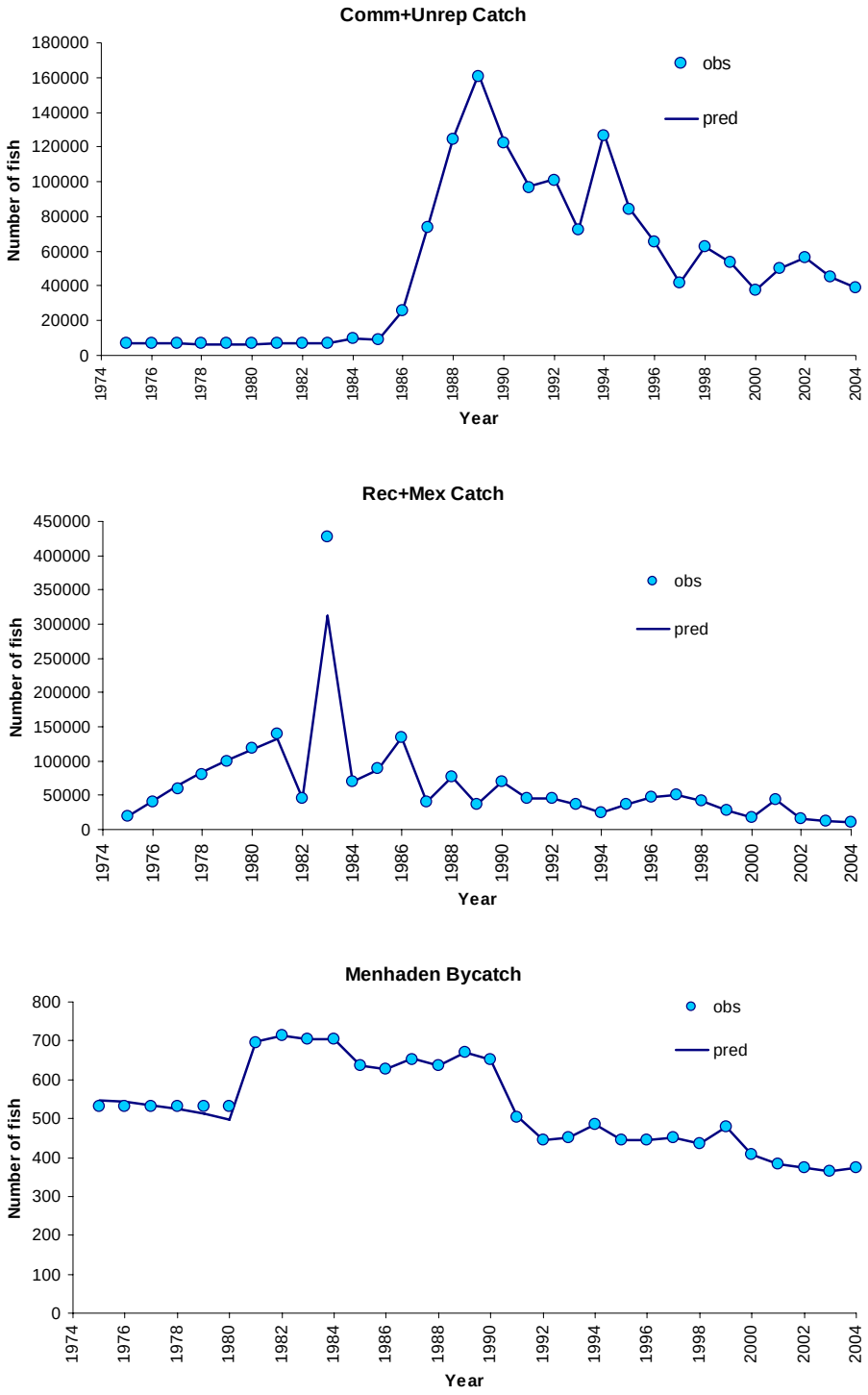


Figure 4.6. Model predicted fit to catch data. Circles represent observed data, solid line is predicted.

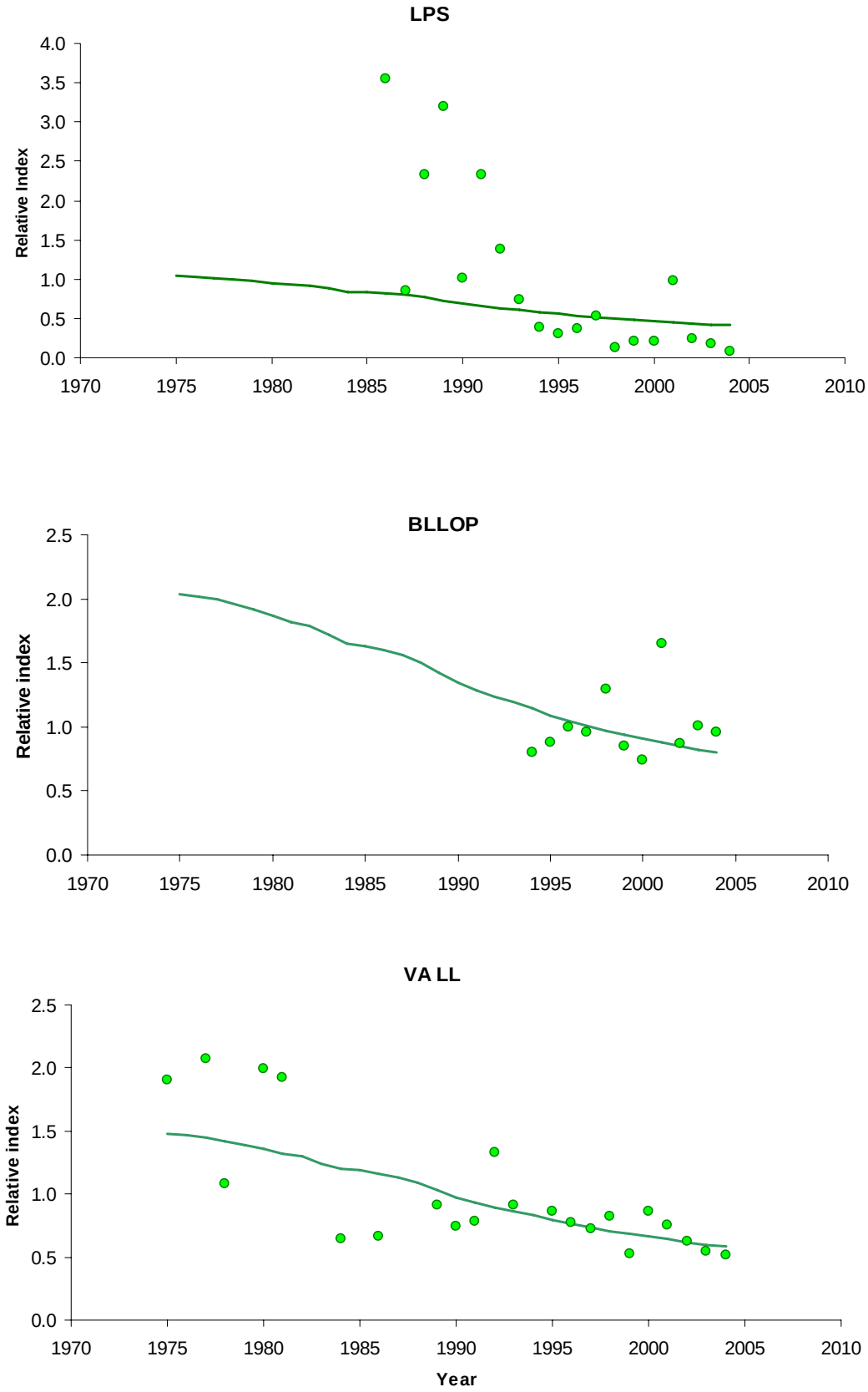


Figure 4.7. Model predicted fit to indices. Circles represent observed data, solid line is predicted.

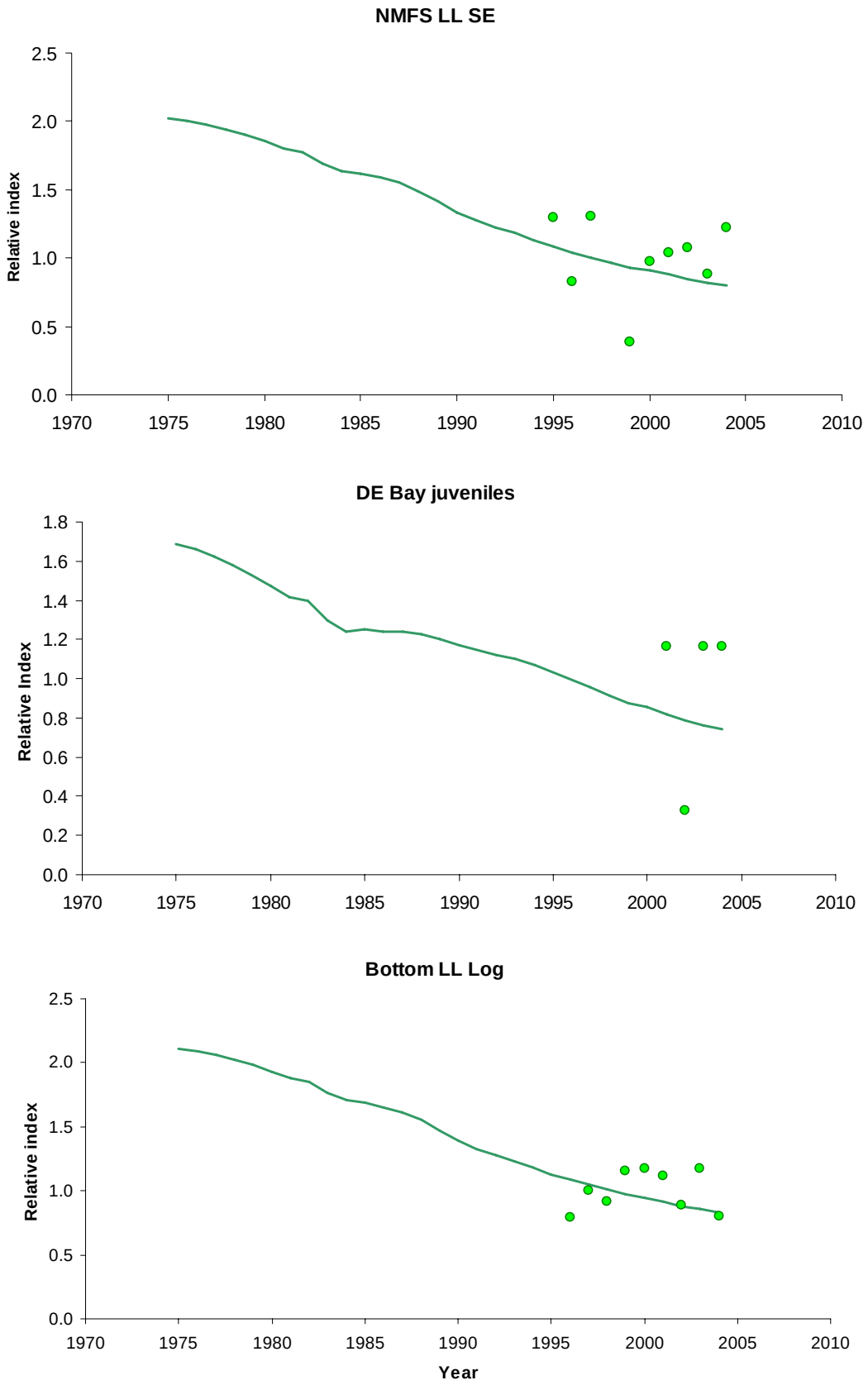
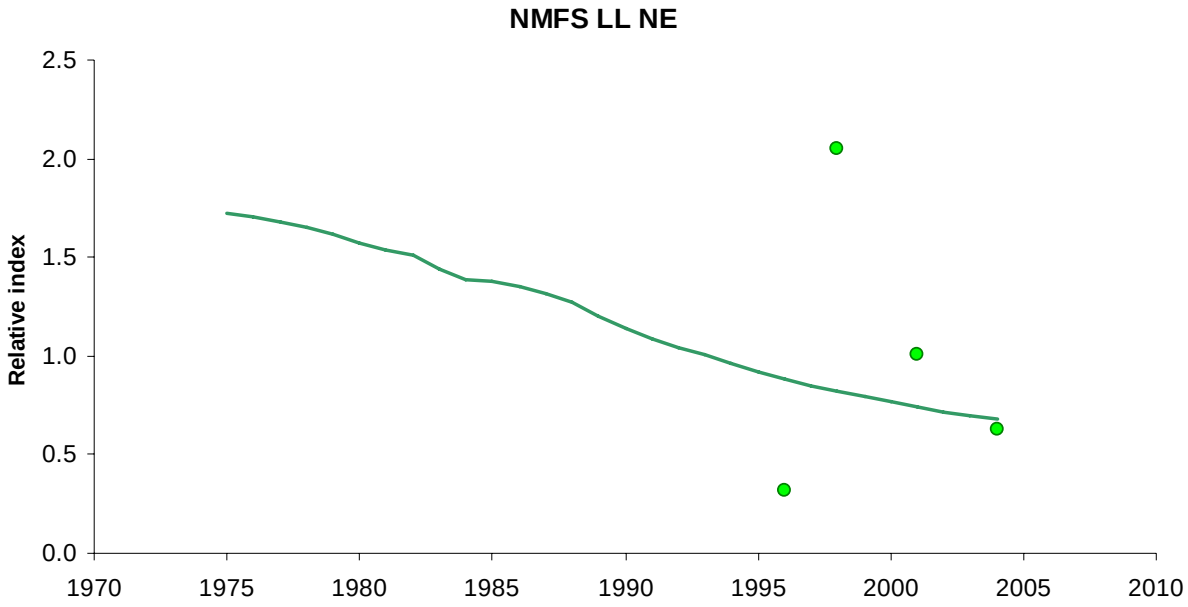


Figure 4.7. (continued)



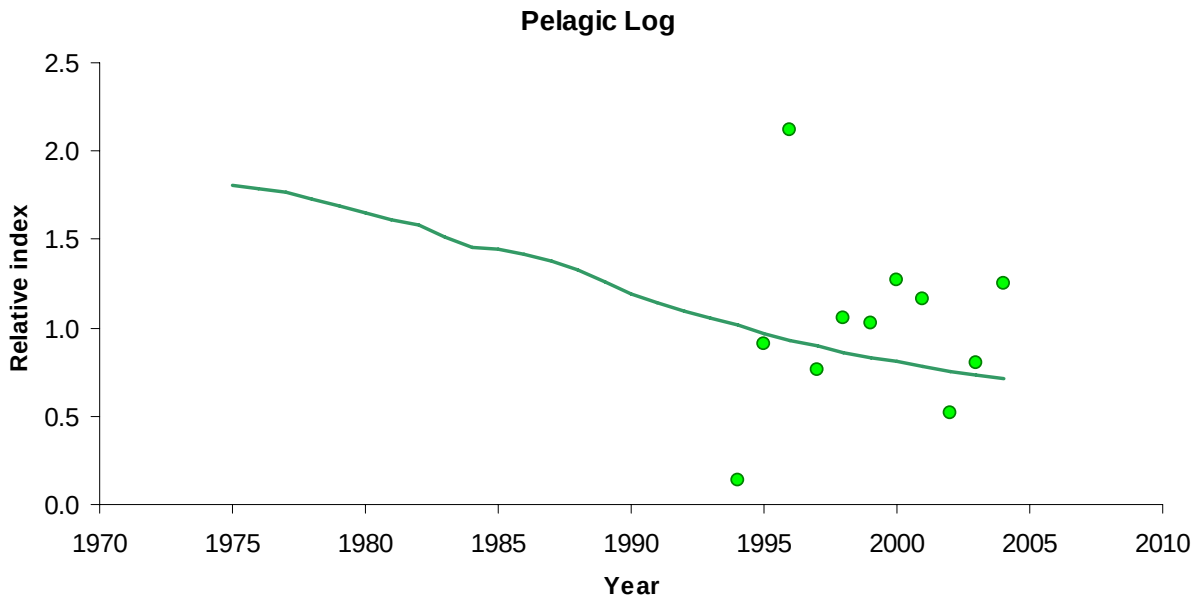


Figure 4.7. (continued)

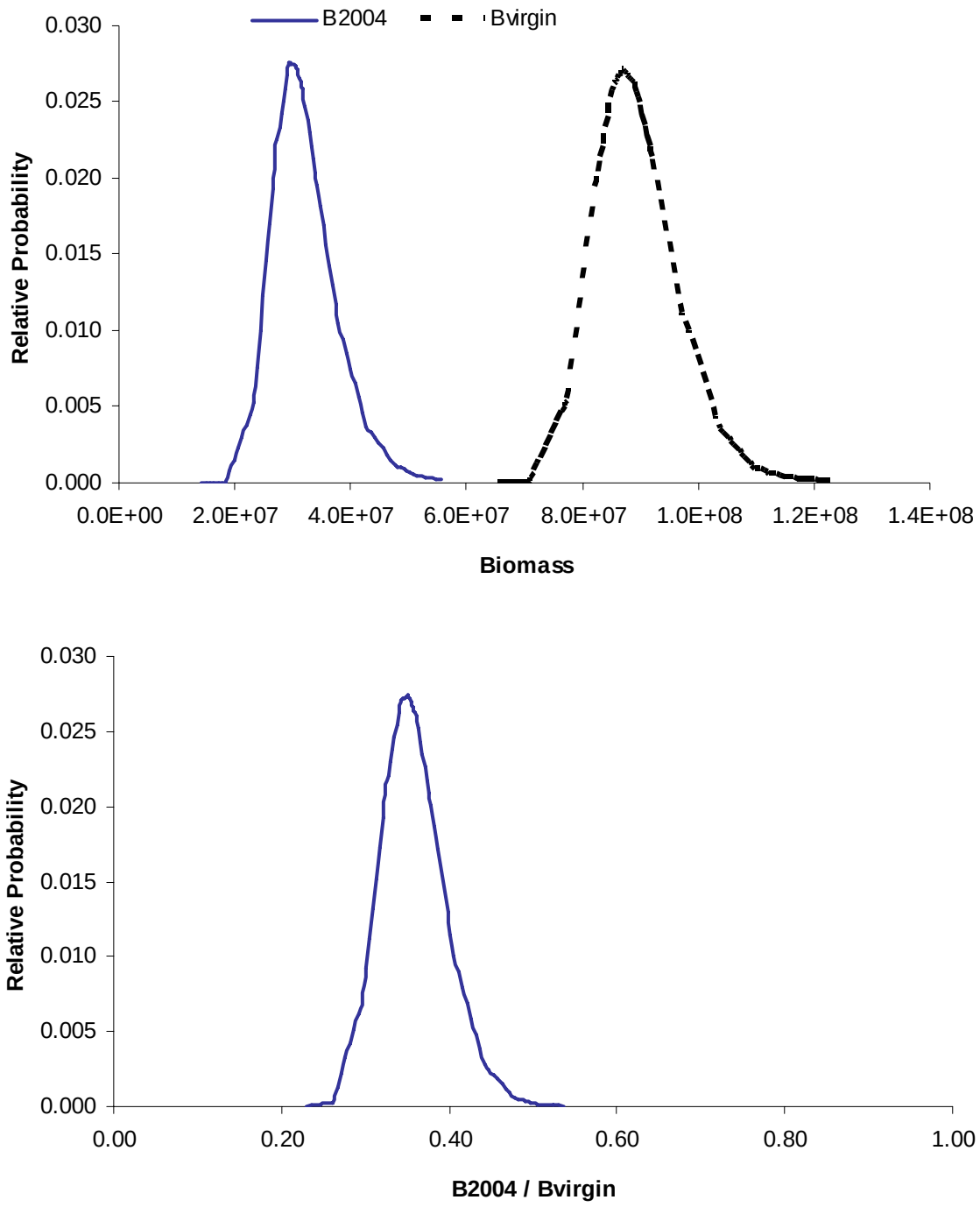
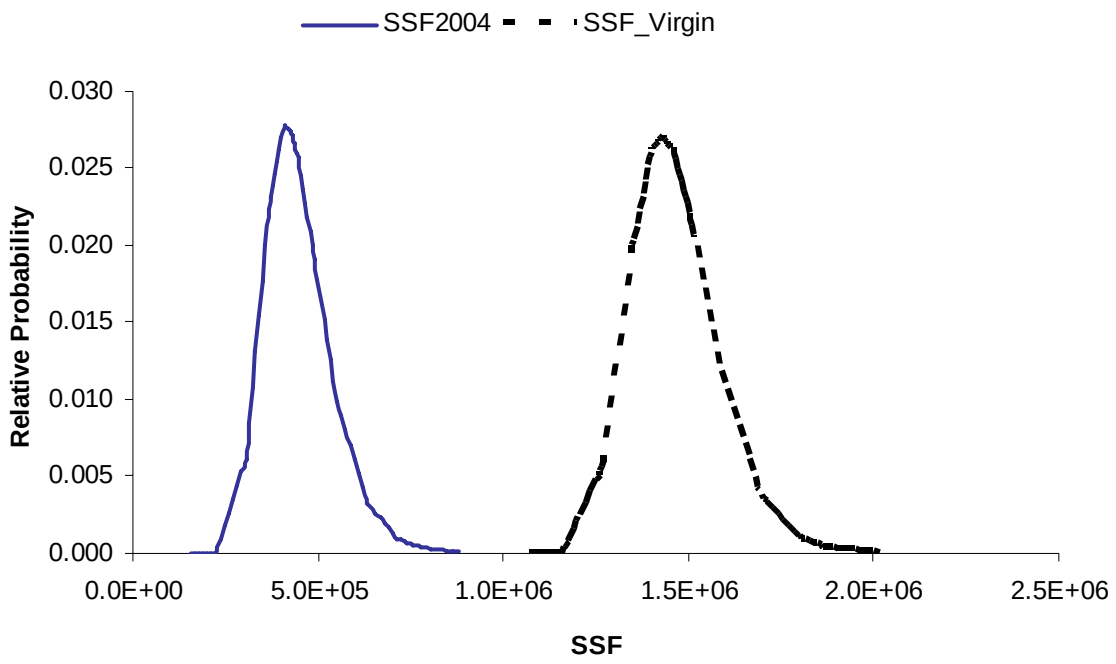


Figure 4.8. Profile likelihoods for biomass and SSF in 2004, as well as depletion estimates of these parameters.



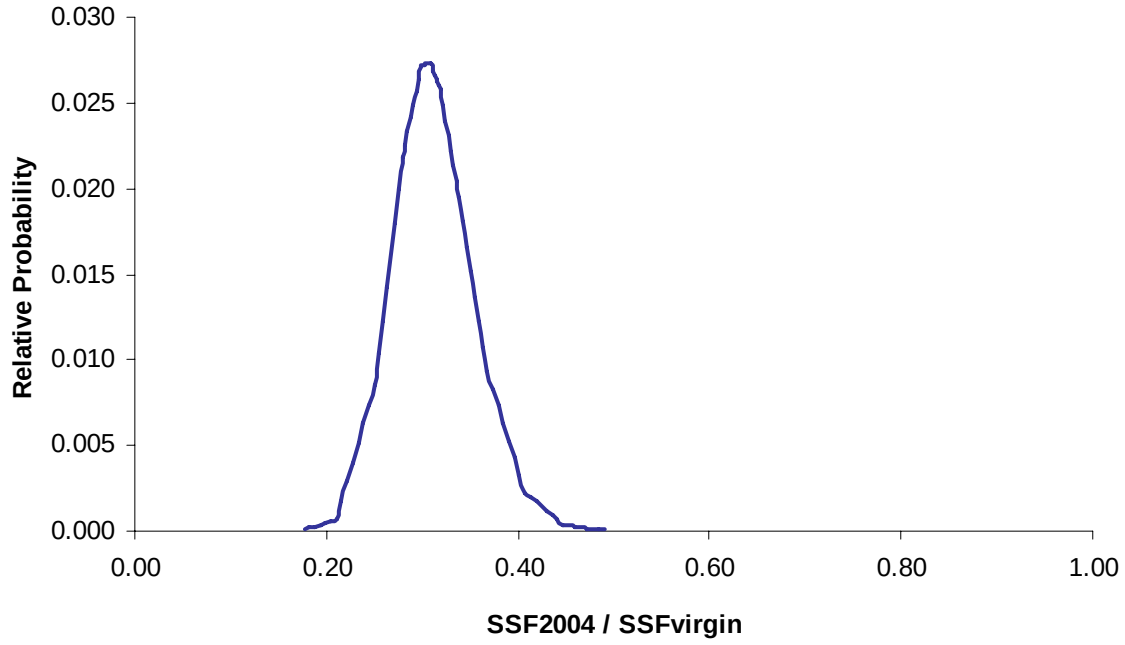


Figure 4.8 (continued)

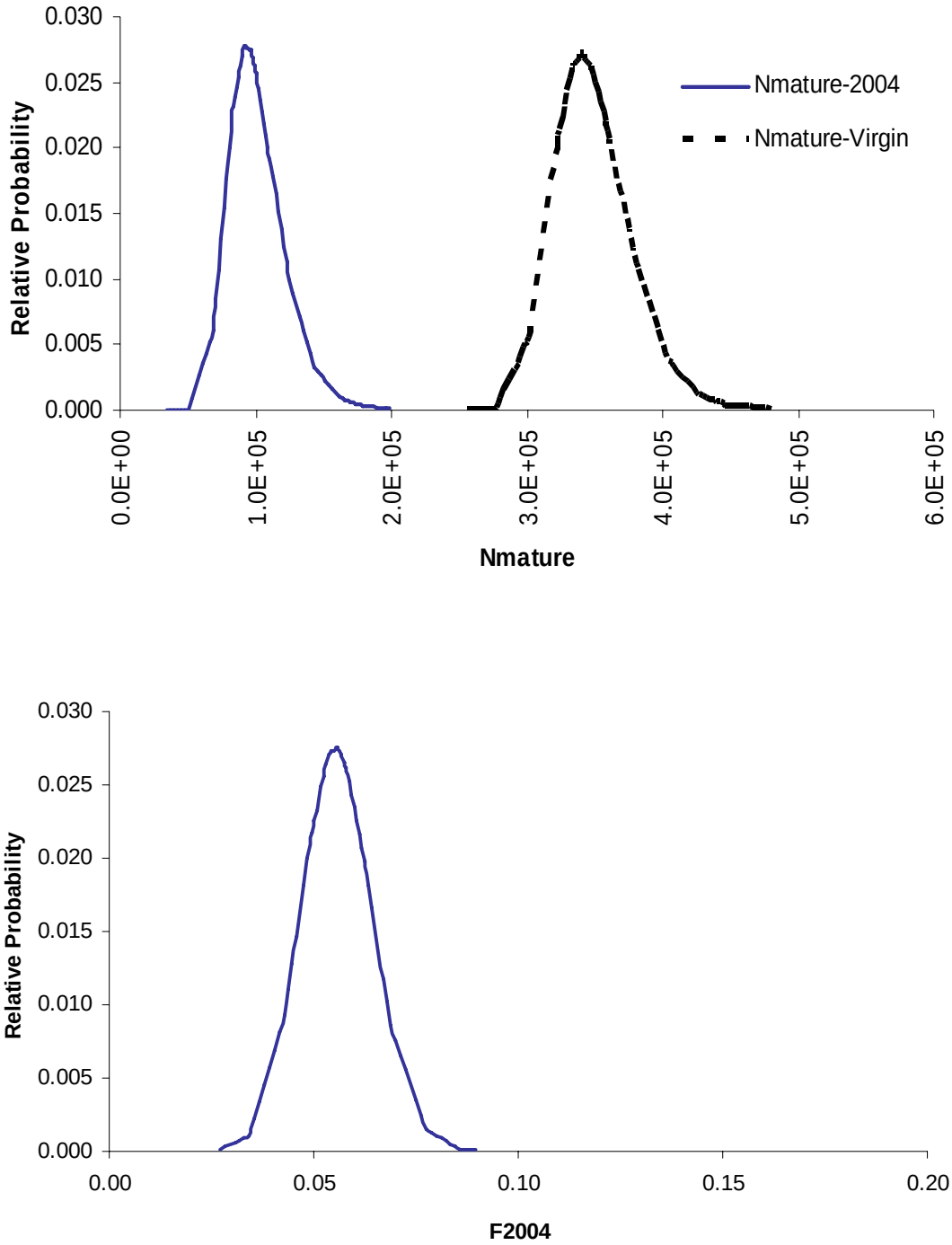
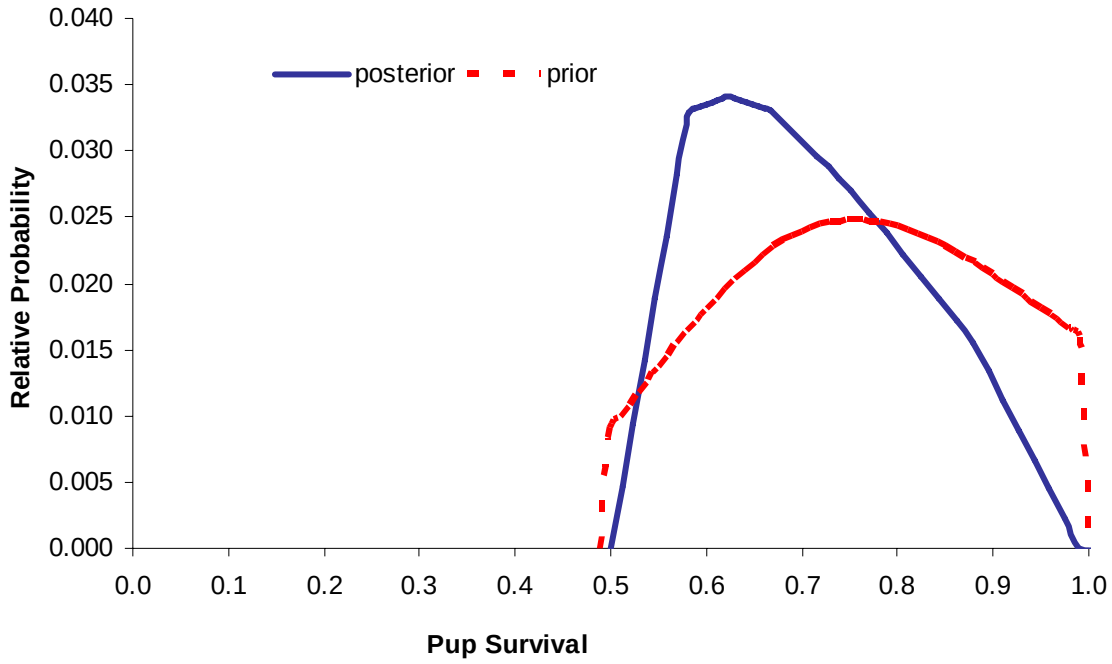


Figure 4.9. Profile likelihoods for number of mature individuals, fishing mortality in 2004; for pup survival and virgin recruitment, the posterior is plotted along with the prior.



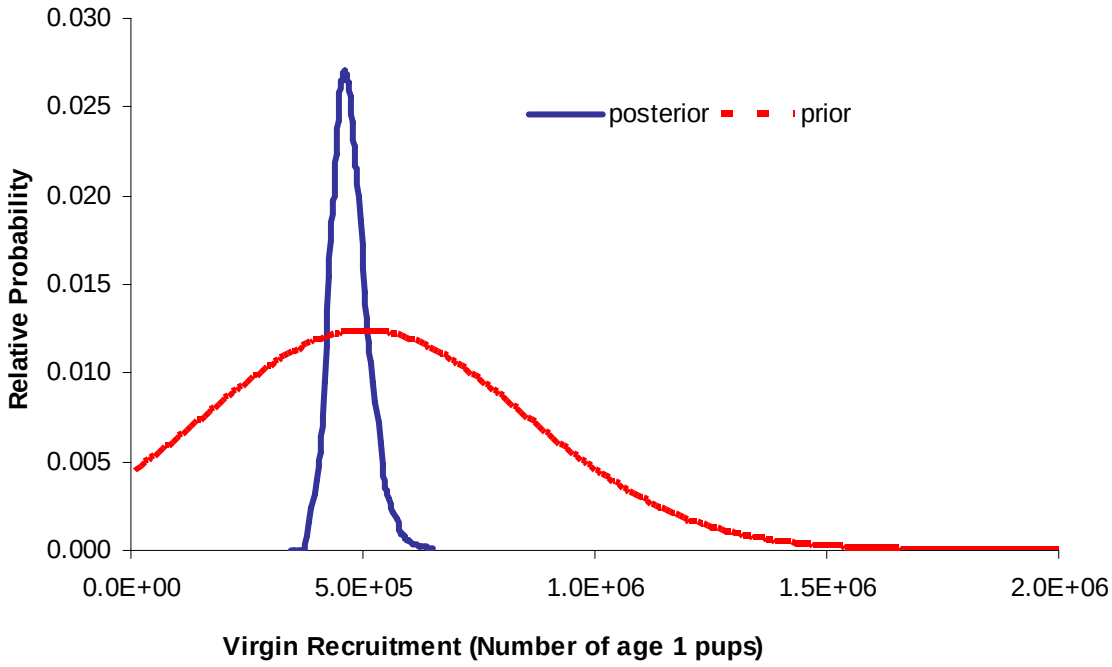


Figure 4.9 (continued)

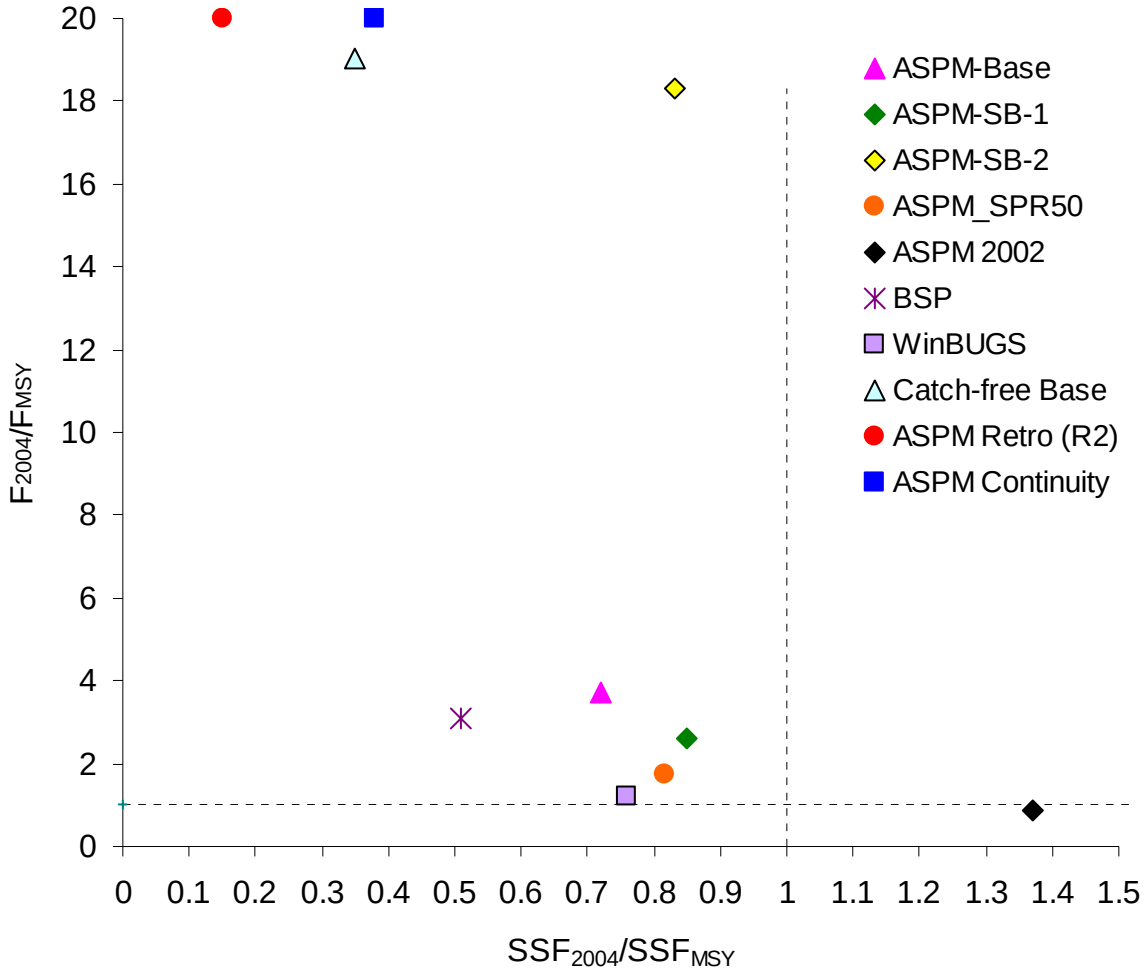


Figure 4.10. Phase-plot of sandbar stock status. Selected sensitivity analyses are also included for comparison. The models include: ASPM-Base, ASPM-SB-1 (base configuration was retained and observations within each index were weighted by the inverse CV of each point), ASPM-SB-2 (the base configuration was retained, and all available indices were used), ASPM_SPR$_{50}$ (base case weighting and indices were used, but the model was forced to have SPR$_{MSY}$=0.5), ASPM 2002 (results of 2002 sandbar assessment with equal weighting), BSP (sandbar results using the Bayesian surplus production model), WinBUGS (sandbar results using the WinBUGS SPM), Catch-free Base (results from the catch free approach baseline analysis), ASPM Retro (R2) (using updated data through 2001, the updated Pelagic Log index, equal weighting, and using the imputed catches from 1975-1980), and ASPM Continuity. See text for further details. Several control rules are illustrated: the dashed horizontal line indicates the MFMT (Maximum Fishing Mortality Threshold) and the dashed vertical line denotes the target biomass (biomass or number at MSY). Note for the BSP and WinBUGS x values denote N_{2004}/N_{MSY} rather than SSF_{2004}/SSF_{MSY}. SSF is spawning stock fecundity, which is the sum of number mature at age times pup-production at age (rather than SSB, since biomass does not influence pup production in sharks). Also note that the value of F_{2004}/F_{MSY} for ASPM Retro (R2) was 82.3 and for ASPM Continuity was 65.6 but was decreased to 20 here for viewing purposes only.

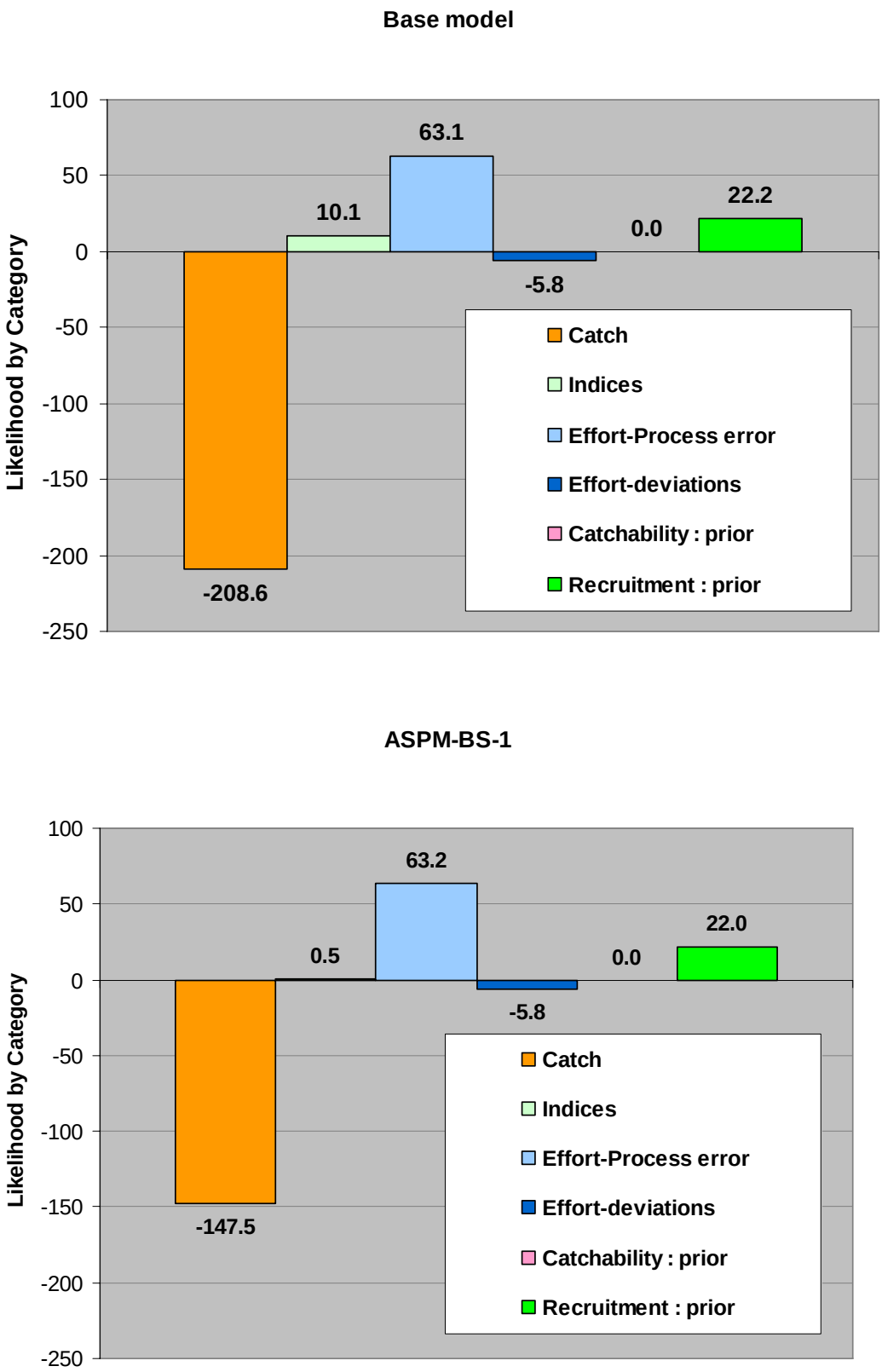
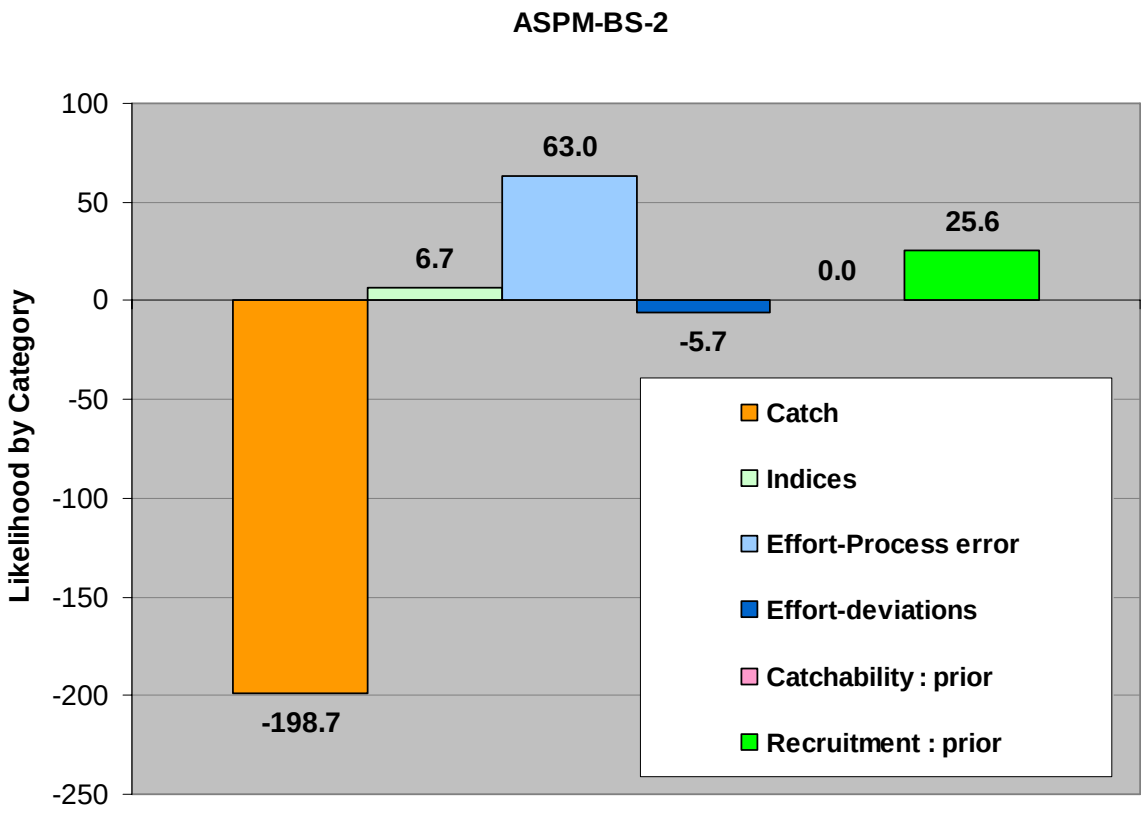


Figure 4.11. Contribution to relative likelihood by category. The recruitment component includes both priors on virgin number of pups and pup survival. Plots refer to the base model, ASPM-BS-1 (inverse CV weighting), ASPM-BS-2 (all indices) and ASPM-BS-3 (SPR50%).



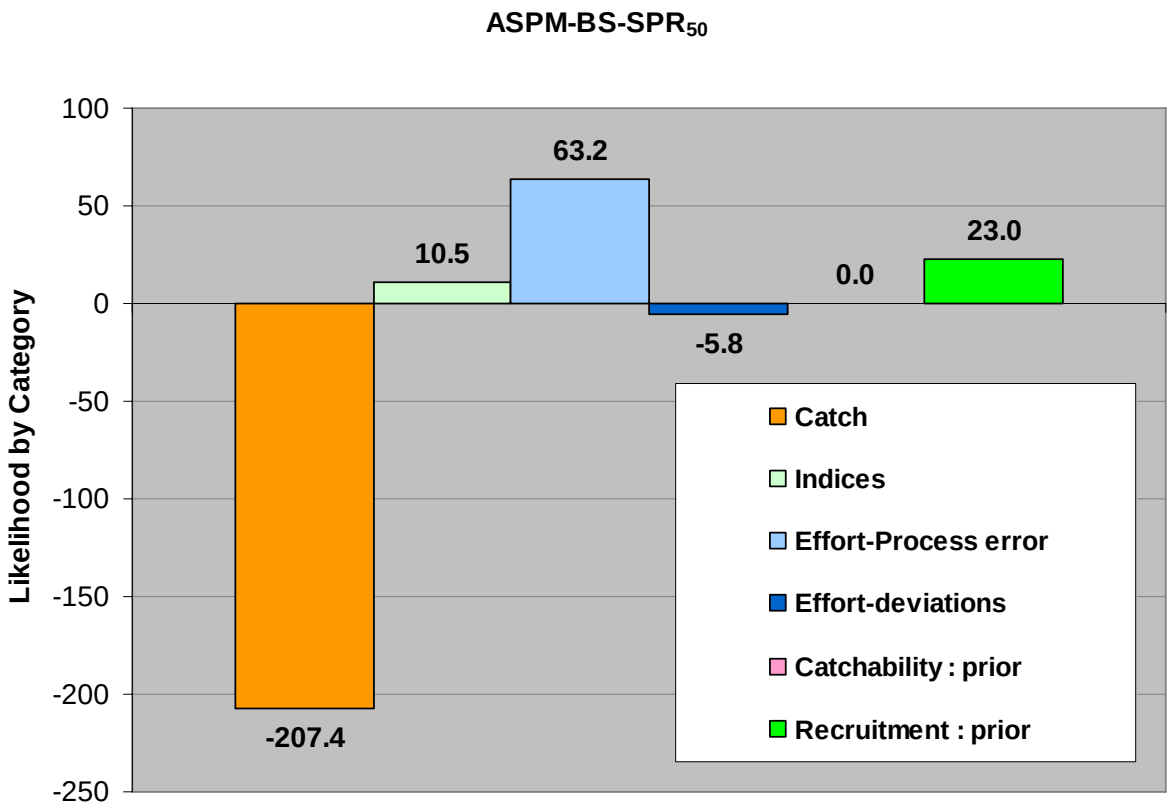
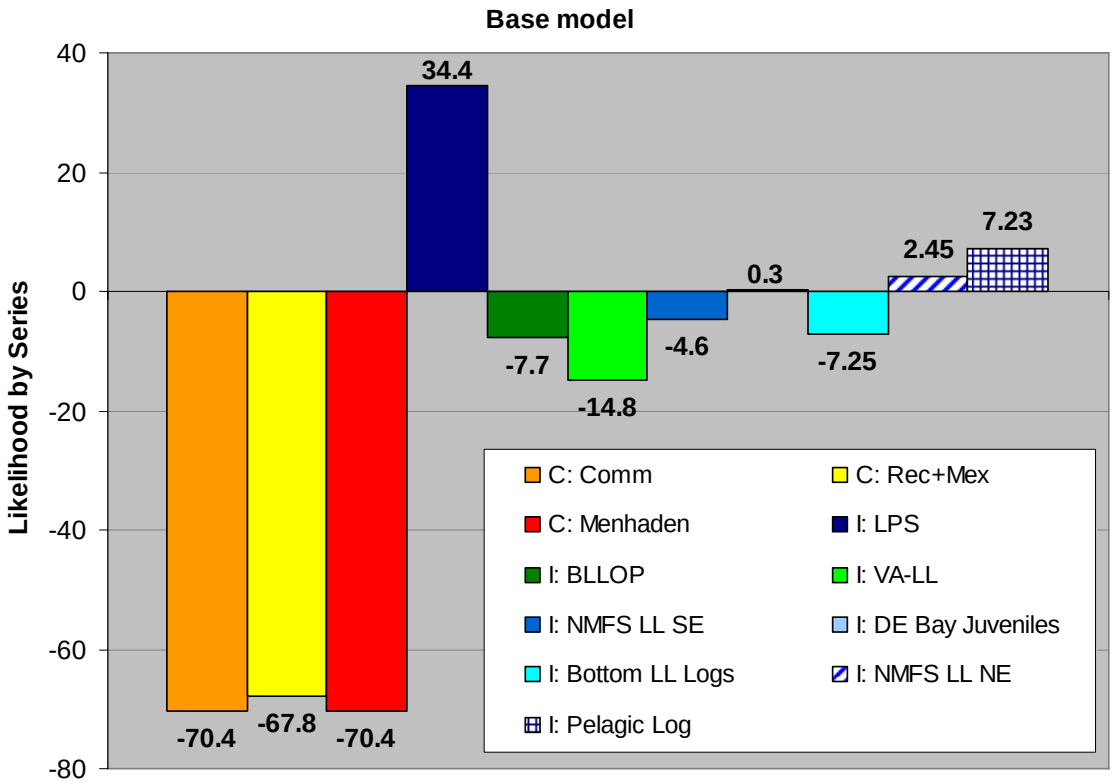


Figure 4.11. (continued)



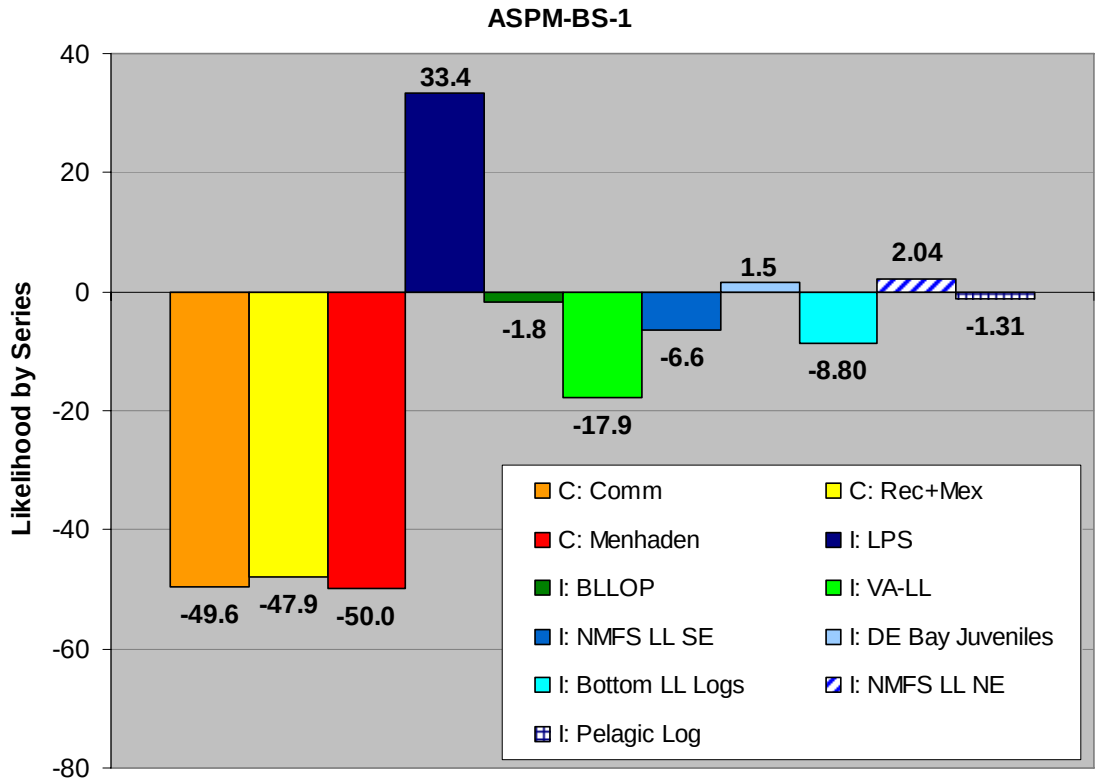
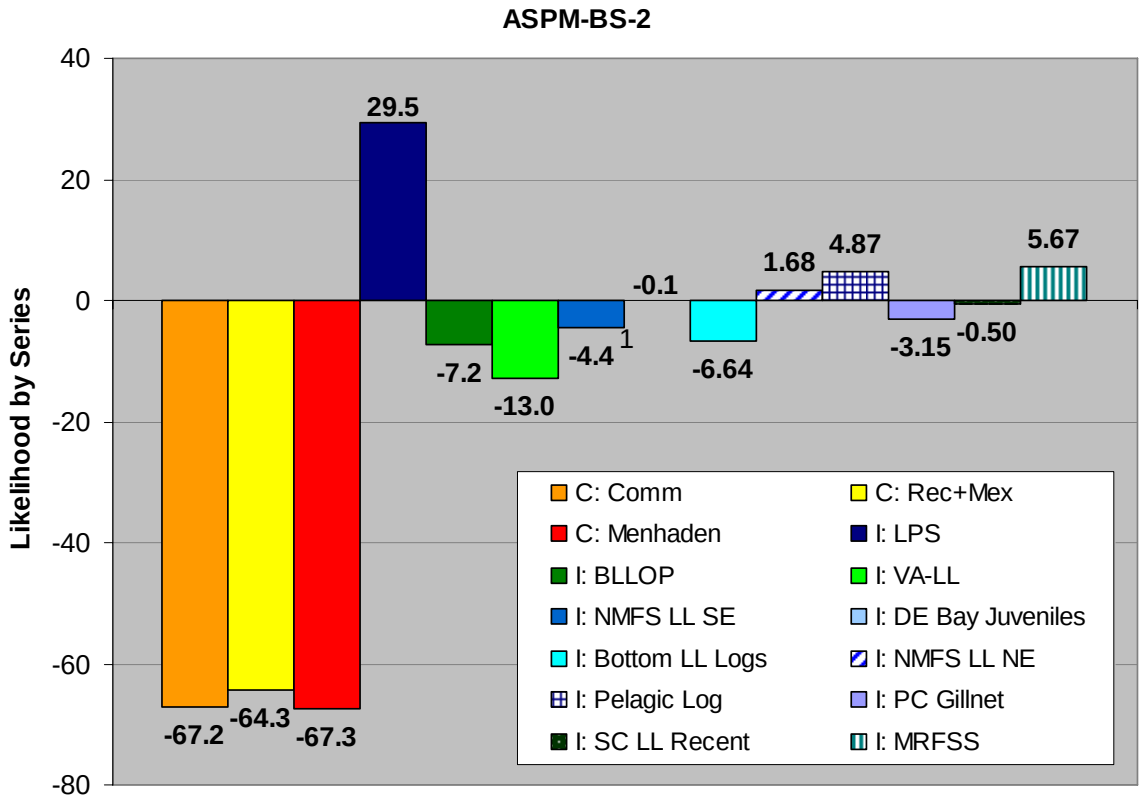


Figure 4.12. Contribution to relative likelihood by catch series and index series for the base model, ASPM-BS-1 (inverse CV weighting), ASPM-BS-2 (all indices) and ASPM-BS-3 (SPR50%). I indicates an index, C indicates a catch.



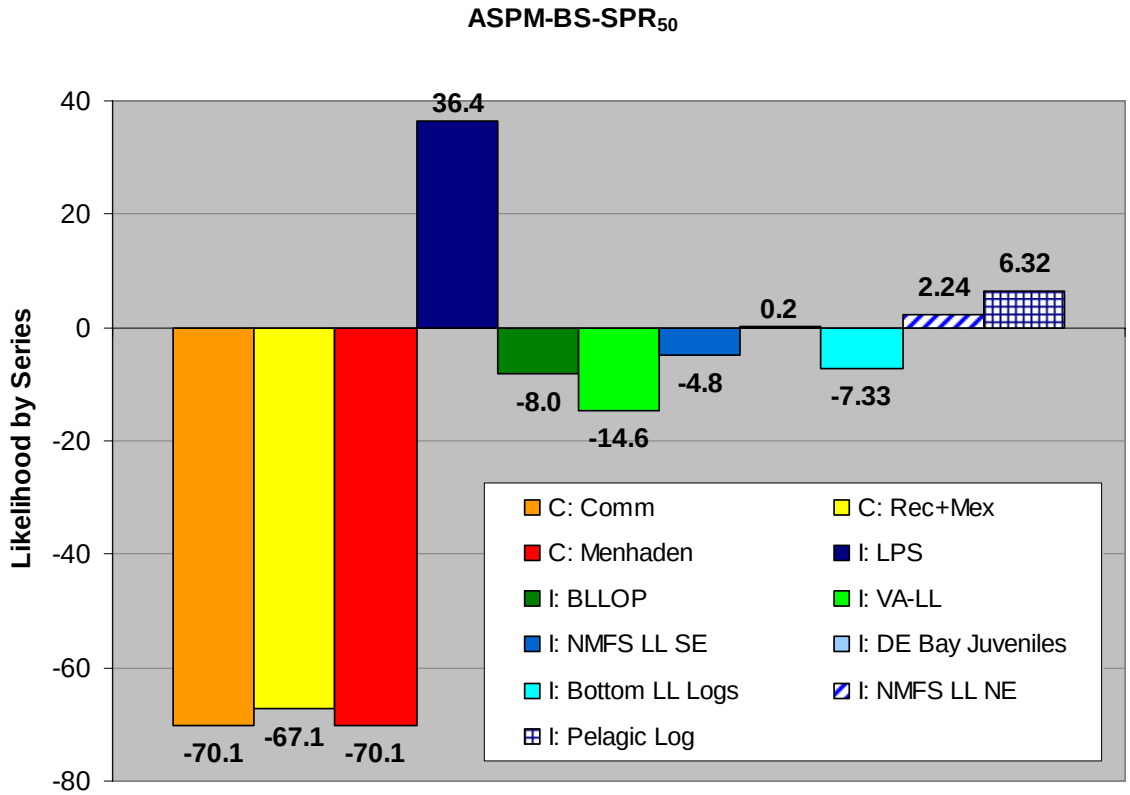


Figure 4.12. (continued)

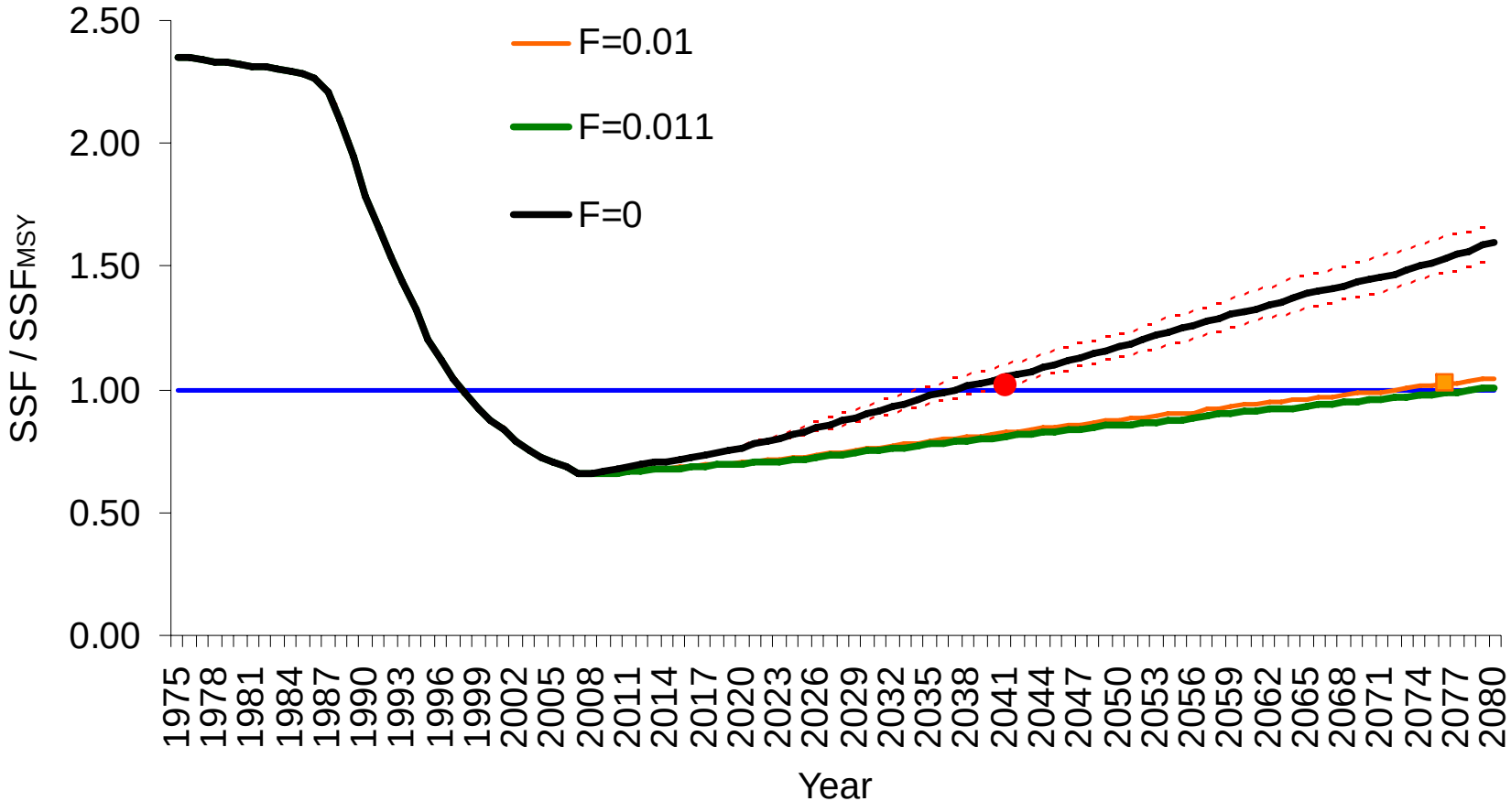


Figure 4.13 Projections with constant F (solid black , orange, and green lines). The dashed red lines represent the 30th percentile (lower) and the 70th percentile (upper). Rebuilding under F = 0 with 70% probability is achieved in year 2041 (solid red circle). F = 0.01 (solid orange) rebuilds by 2076 with 70% probability (indicated by solid orange box); F = 0.011 rebuilds by 2076 with 50% probability (median of the bootstraps).

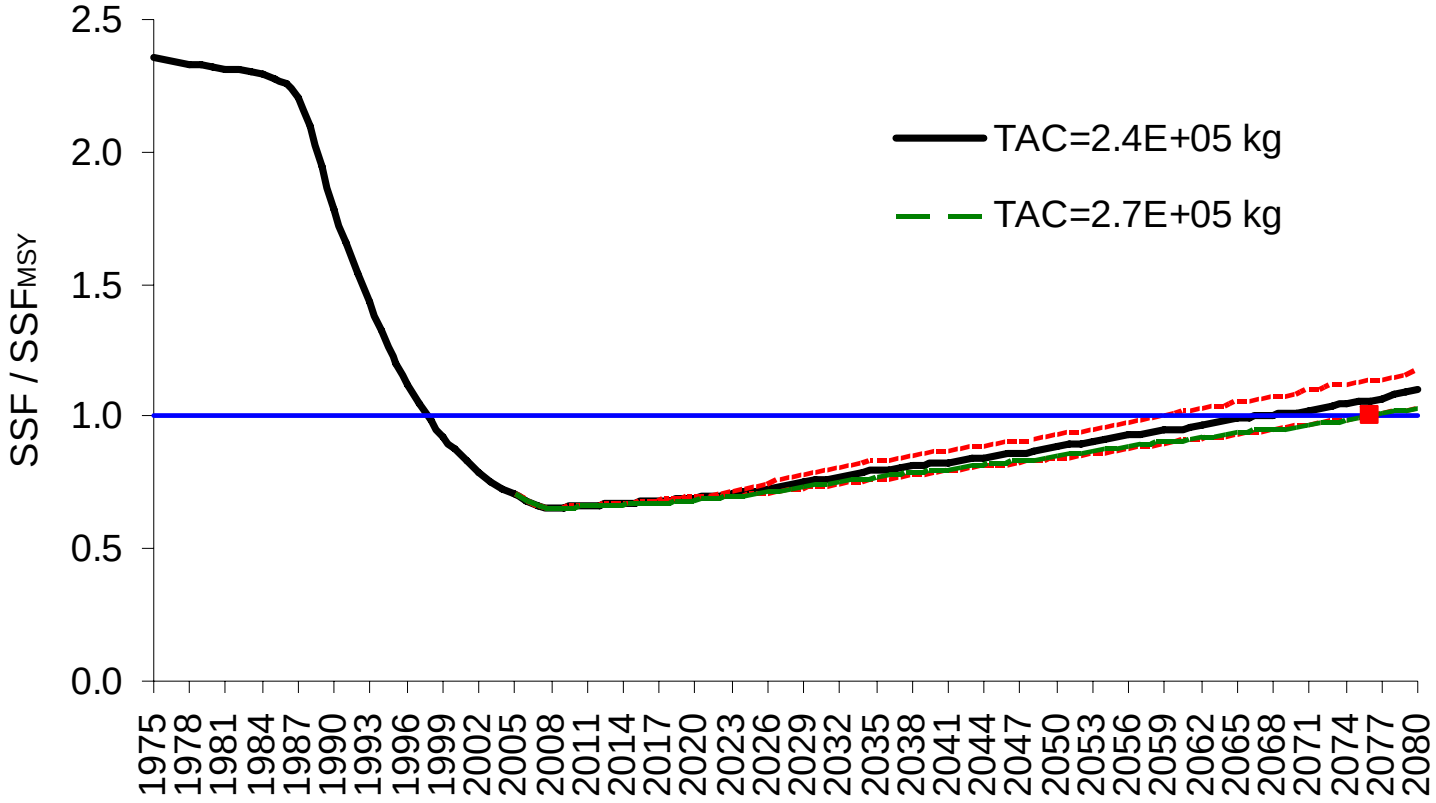


Figure 4.14 Projections with constant TACs (solid black and dashed green lines). The dashed red lines represent the 30th percentile (lower) and the 70th percentile (upper). Rebuilding by year 2076 with 70% probability is the year that the lower percentile crosses the horizontal blue reference line (indicated by a solid red box in year 2076). The dashed green line represents a 50% probability (median of bootstraps) of rebuilding by 2076.

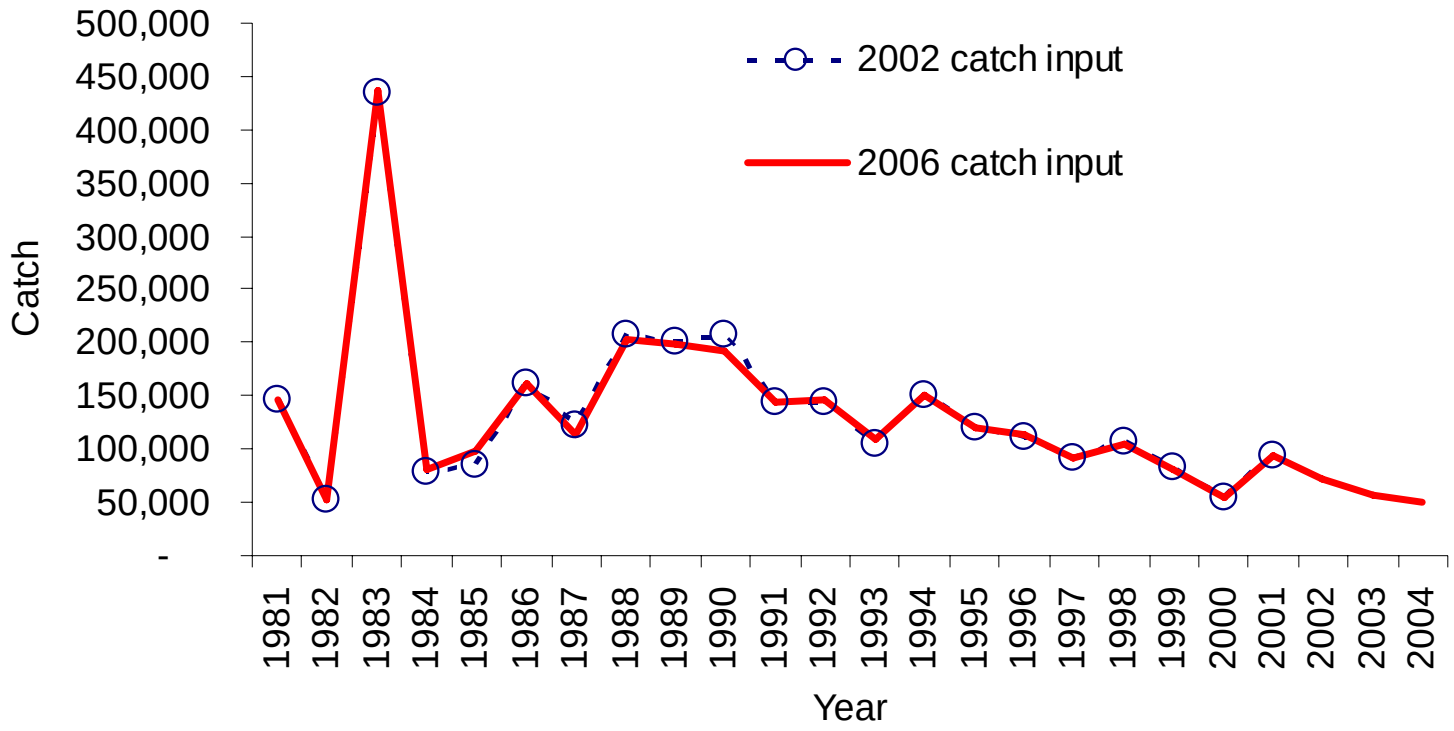


Figure 4.15. Comparison of 2002 and 2006 catch (in numbers of fish).

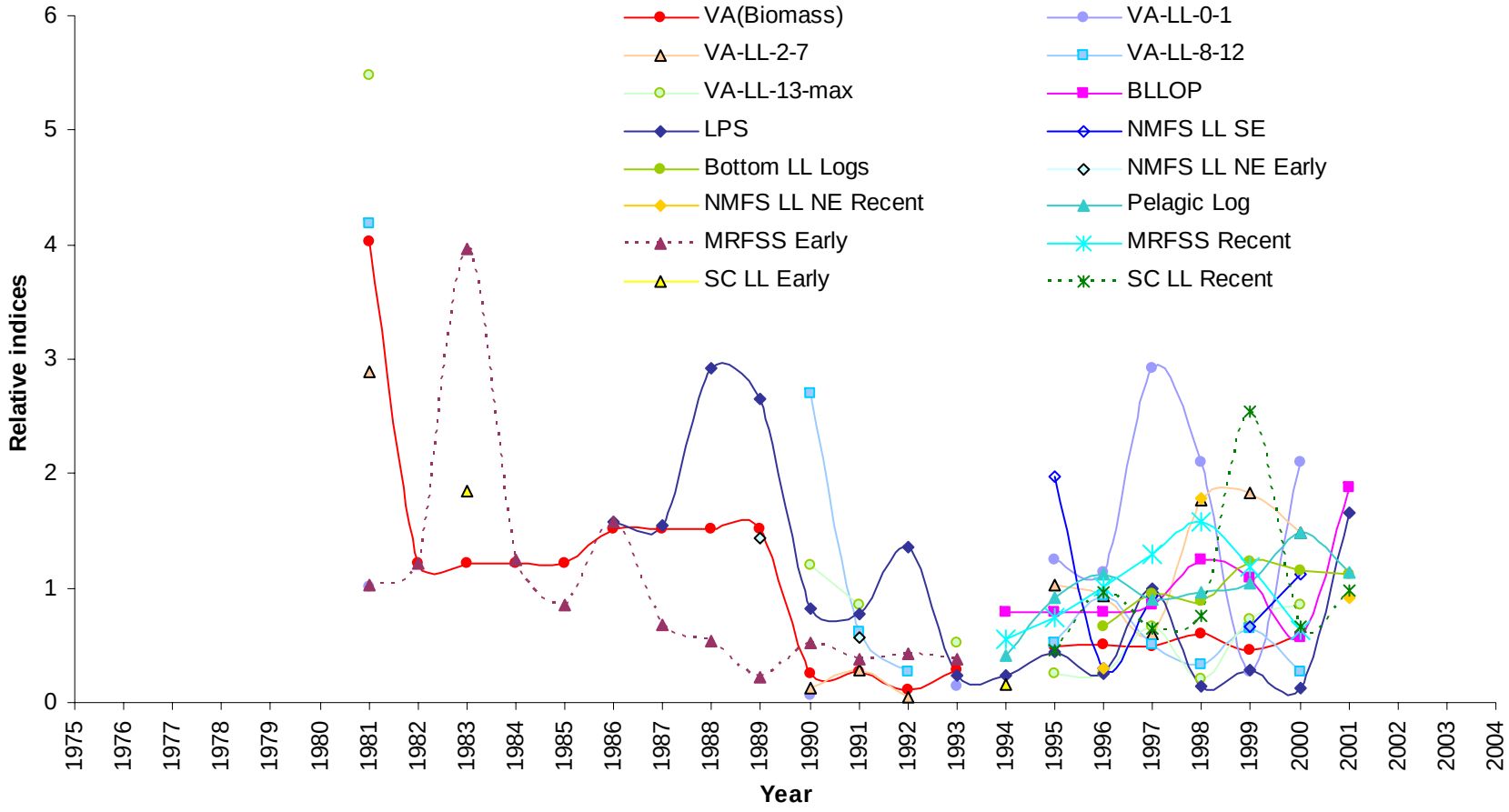
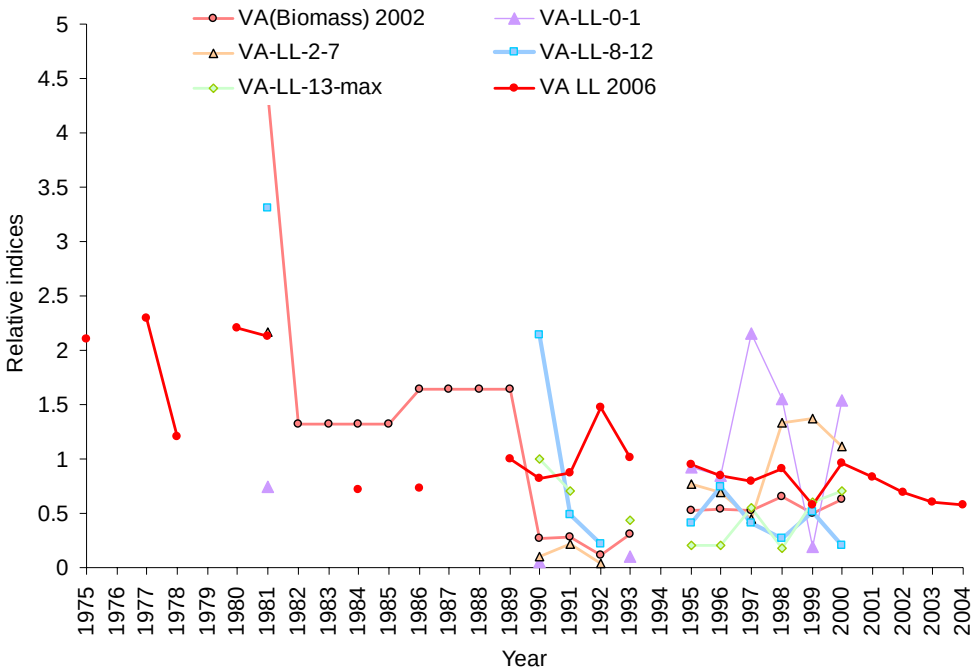


Figure 4.16 Indices available for the 2002 assessment. Note that these indices are scaled (divided by the index-specific mean) but are not relative to each other as there is no year of overlap.



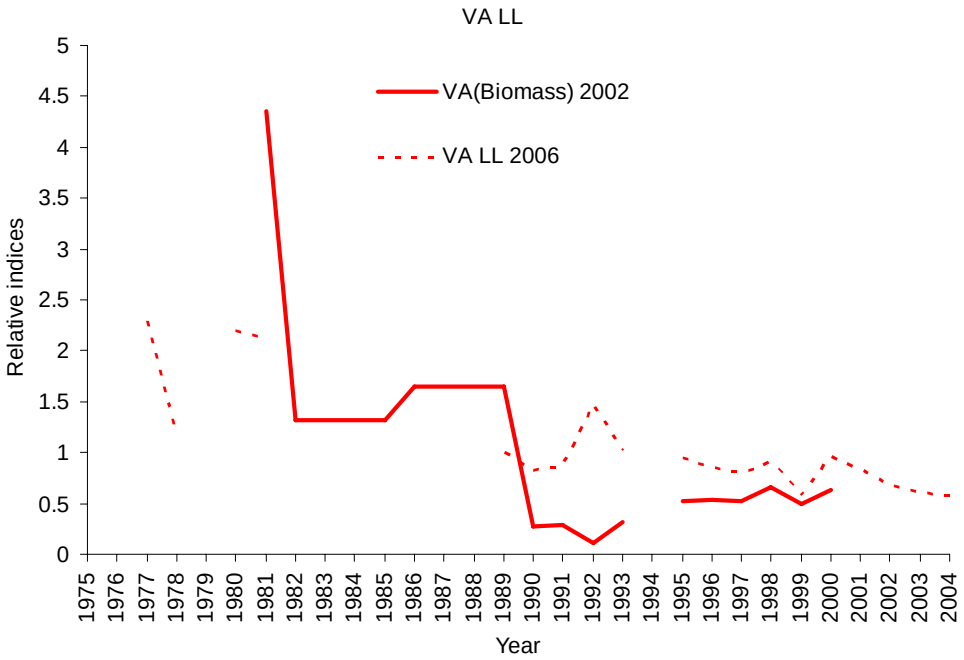
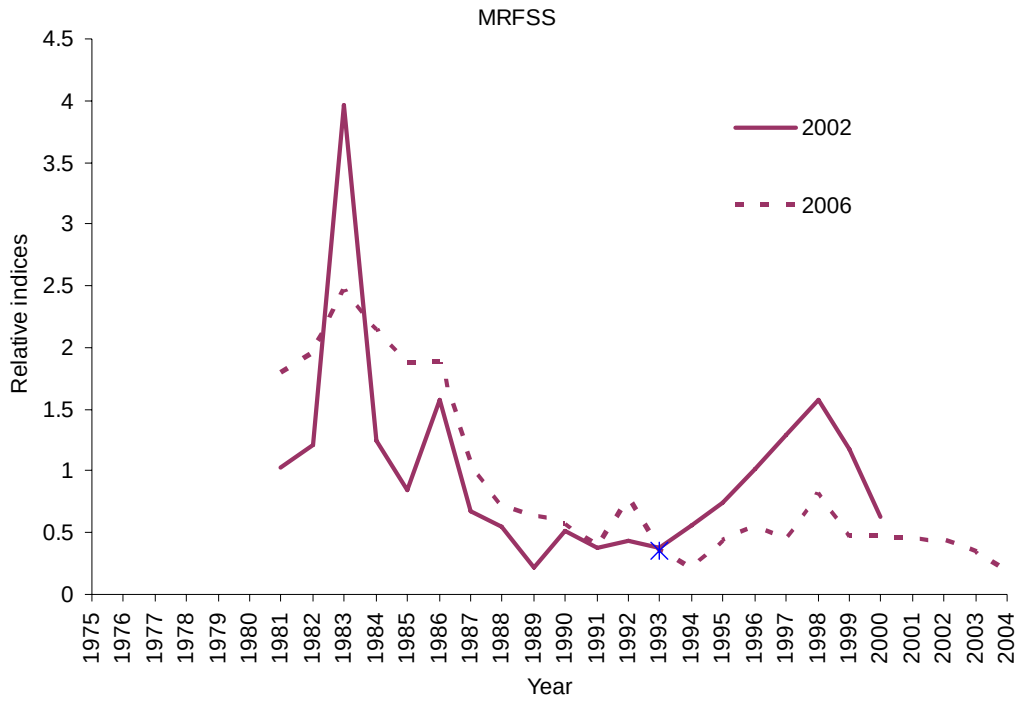


Figure 4.17. Overlaying indices from 2002 (solid lines) versus those indices in 2006 (dashed lines). Note that in 2002, five indices were available from the VA LL data; the 2006 VA LL index is plotted against the VA LL biomass index since it refers to the same age classes, even though the units are not the same. In 2002, the MRFSS index was split into two nominal indices, REC-early and REC-late, with the division in year 1994 (indicated by blue asterisk) whereas in 2006 there was a single MRFSS index that was standardized for the entire time interval.



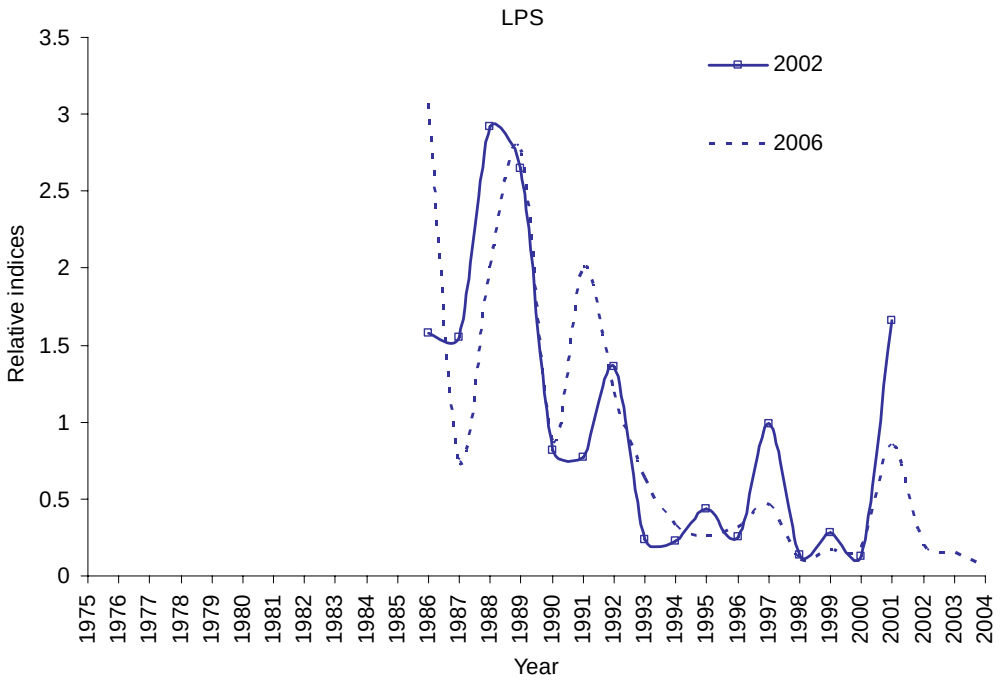
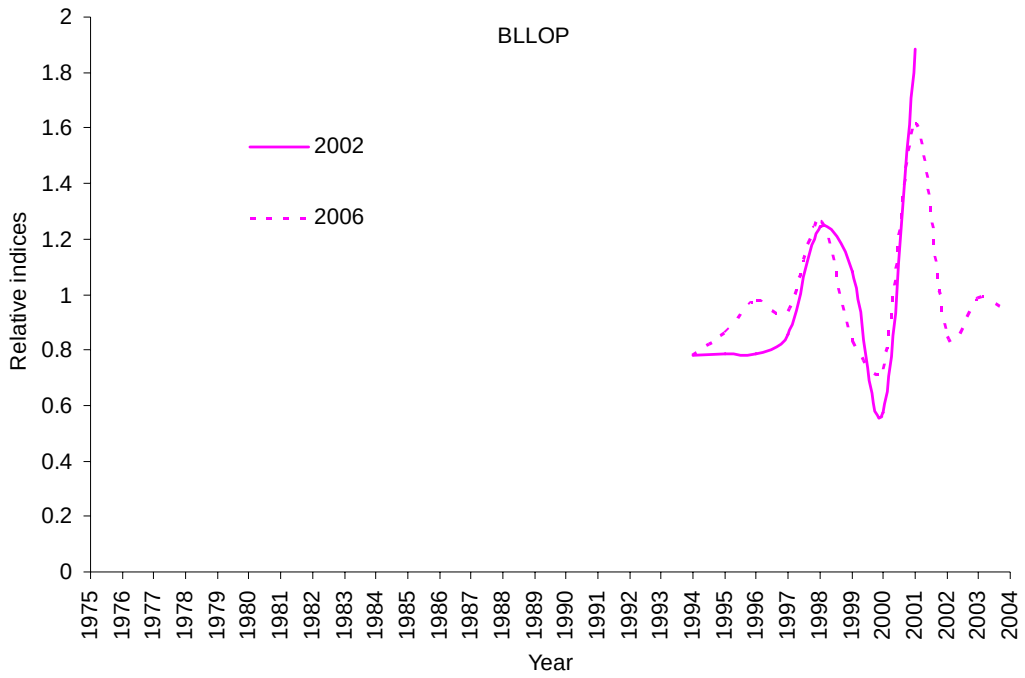


Figure 4.17 (continued)



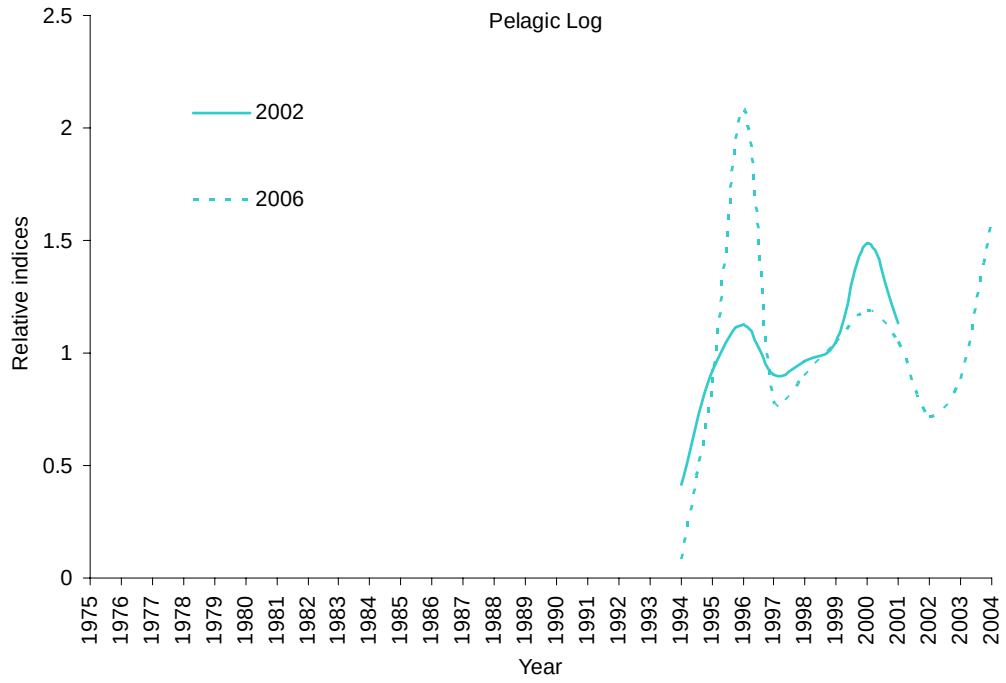


Figure 4.17 (continued)

GULF OF MEXICO BLACKTIP SHARK STOCK ASSESSMENT

5. GULF OF MEXICO BLACKTIP SHARK STOCK ASSESSMENT

5.1 Summary of Blacktip Shark Working Documents

SEDAR 11–AW–04
Preliminary Runs of a State-Space, Age-Structured Production Model for Blacktip Shark
Summary: An age-structured production model was used to assess blacktip shark, the same that was used in the 2002 assessment. A continuity run was made using the 2002 assessment decisions about biology and stock structure. Base models for the 2006 assessment were then run for the Gulf of Mexico and the Atlantic Ocean separately, using decisions made at the data workshop. All runs reached the same conclusion that the stock is not overfished nor, for the most recent years, is overfishing occurring. A number of adjustments to biological inputs were necessary to achieve model convergence, and this point warrants further discussion at the assessment workshop.

SEDAR11-AW-05
Assessment of Large Coastal, Blacktip, and Sandbar Sharks using Surplus Production Methods
We used two complementary surplus production models (BSP and WinBUGS) to assess the status of three Large Coastal Shark (LCS) groupings, two stocks of blacktip shark, and a single stock of sandbar shark identified as baseline scenarios in the LCS Data Workshop report. Both methodologies use Bayesian inference to estimate stock status, and the BSP further performs Bayesian decision analysis to examine the sustainability of various levels of future catch. Extensive sensitivity analyses were performed with the BSP model to assess the effect of different assumptions on CPUE indices and weighting methods, catches, intrinsic rates of increase, initial depletion, and importance function on results. Baseline scenarios for the three LCS groupings considered predicted that the stock status is not overfished nor overfishing is occurring. Using the inverse variance method to weight the CPUE data changed the predictions on stock status for the LCS grouping, which would then be overfished, with overfishing occurring. The sandbar shark stock was estimated to be significantly depleted (64-71% depletion from virgin level). The Gulf of Mexico blacktip shark stock was healthy (depletion of only 8-23% of virgin level), whereas results for the Atlantic blacktip shark stock from the BSP and WinBUGS models conflicted. The BSP model predicted a considerable level of depletion for this stock regardless of the CPUE weighting method used. In contrast, the assessment of a single blacktip shark stock (GOM+ATL) resulted in very consistent results, with all models predicting a healthy status (depletions of only 10-16% of virgin level). Using the higher values of r from the 2002 SEW or accounting for some depletion from virgin levels in the first year of the model did not affect conclusions. Several assumptions on catches (notably changing the high value of recreational catch in 1983) also had no effect on conclusions. Removing the VIMS CPUE series from the LCS scenario reversed the conclusions on stock status when using inverse variance weighting, highlighting the influence of this series on results; removing the PELAGIC LOG CPUE series from the ATL blacktip shark analysis also drastically reversed the conclusions on stock status. Fitting one CPUE series at a time had a larger effect on results: the PELAGIC LOG series greatly influenced conclusions for the three LCS groupings and GOM and ATL

blacktip shark, whereas the VIMS series affected conclusions on the two groups for which it is available, LCS and sandbar shark.

5.2 Background

Blacktip and sandbar sharks are the two most important species in the fishery, and have been the subjects of species specific assessments in the past conducted through Shark Evaluation Workshops (SEWs). As such, the Panel was tasked with conducting species specific assessments for these species. The Data Workshop determined catch histories, relative abundance indices, and biological input parameters for three assessments: one stock of sandbar sharks and two stocks of blacktip sharks, one for the Gulf of Mexico and one for the northwestern Atlantic Ocean.

5.3 Available Models

Four models were available for discussion for the Gulf of Mexico blacktip shark assessment: two surplus production models, the BSP and WinBUGS models described previously, and two age-structured production approaches (Apostolaki et al. in press, Porch 2002).

5.4 Details about surplus production model and age-structured model

A surplus production model simulates the dynamics of a population using total population biomass as the parameter that reflects changes in population size relative to its virgin condition. In comparison to more complicated models, the surplus production model is simpler in its formulation, takes less time to run and requires less input information. However, due to its formulation, the surplus production model does not describe changes that occur in subgroups of the population (adults, juveniles, etc). In addition, the sensitivity of model predictions to key stage-dependent biological parameters cannot be evaluated using a surplus production model. Finally, surplus production models are not able to incorporate a lag time into the results.

An age-structured population dynamics model describes the dynamics of each age class in the population separately and therefore, requires age-specific input information. Due to the higher complexity of these models, they usually take longer to run and require a higher volume of information relative to simpler models. However, they can account for age-dependent differences in biology, dynamics and exploitation of fish and provide an insight into the structure of the population and the processes that are more important at different life stages. They also allow for the incorporation of age-specific selectivity information.

With regard to management benchmarks, the surplus production model assumes that the population biomass that corresponds to MSY is always equal to half of the virgin population biomass, whereas the relative biomass at MSY calculated with an age-structured model (and other benchmarks associated to it) is species-specific and could be any fraction of virgin biomass.

The Assessment Panel decided to use the state-space, age-structured production model described in document SEDAR11-AW-04 for blacktip sharks from the Gulf of Mexico. This model was selected as it allowed for the incorporation of age-specific biological and selectivity information, along with the ability to produce required management benchmarks.

5.5 Discussion of weighting methods

The Data Workshop recommended that *equal weighting* for assigning weights to the different CPUE time series available during model fitting should be used for the baseline runs. The panel discussed the advantages and disadvantages of the *equal weighting* vs. the *inverse CV weighting* methods:

Equal weighting ignores the better quality of some data (smaller CVs) but is more stable between assessments because yearly changes on CVs in a given CPUE series do not affect the importance of that time series for the overall fit.

Inverse CV weighting can provide better precision as it tracks individual indices however, it could be less stable between assessments due to changes on the relative 'noise' of each time series. This method may also not be appropriate in cases in which different standardization techniques have been used for the standardization of the series and therefore, the same value of CV might reflect different levels of error depending on the CPUE it corresponds to.

It was requested by one Panelist to manually weight the indices that cover larger geographic areas to have a stronger influence on the model. The group commented that, while that may be possible in a spatially explicit model, a great deal more data would be required than presently available.

The Assessment Panel decided that equal weighting would be the default weighting method for the current assessment but noted that, as there is at present no objective way to decide which of these two methods is superior other than comparing model convergence diagnostics, future assessments may need to reexamine this issue.

5.6 New biological parameters derived during the assessment workshop

As discussed in SEDAR 11-AW-10, the values for life history parameters that the Data Workshop determined to be the best estimates did not produce viable estimates for steepness (steepness was <0.2 for all stocks). The group reviewed the inputs that produce steepness (pup-survival, M at age for ages 1+, maturity at age, and pup-production at age), and determined that pup-production and estimates of maturity should be known with greater certainty than estimates of mortality or pup survival. Therefore, in order to satisfy the lower bound on steepness, and to meet the data workshop recommendation that steepness should be between 0.2-0.4, the mode of the lognormal prior for pup survival was increased to 0.75 with a CV of 0.3. In addition, survival was increased by 10% for ages 1+ for the Gulf of Mexico stock, and by 7% for the Atlantic stock. The data workshop values for M at age as well as the values derived in plenary at

the assessment workshop are given in Tables 5.1a and b, and plotted in Figure 5.1. Note that in the 2002 assessment, the same problem was encountered with the lower limit of steepness. In 2002, the base parameter values gave a steepness of about 0.18, so pup production was increased from 3.85 to 10, achieving a steepness of about 0.37. As noted in the 2002 report (p. 24), increasing the fixed level of pup production implies either that there is an unexploited portion of the population that is contributing pups, or that the pups are recruiting from a different population altogether (basically an open population model).

5.7 Methods

5.7.1 State-space, age-structured production model description

It was decided at the assessment workshop that the age-structured production model (SEDAR11-AW-04) would be used as the base model for the 2006 assessment. For Gulf of Mexico blacktip sharks, catches and one index begin in 1981, with the remaining indices beginning in the 1990s. No attempt was made to impute catches prior to the observed values in 1981. The model adopted derives equilibrium N at age for the first model year by estimating a level of historic fishing (F_{hist}). A historic selectivity vector is specified by the user, which is multiplied by F_{hist} to arrive at the historic age-specific fishing mortality rate. A historic selectivity vector of 1 for all ages was assumed.

Population Dynamics

The dynamics of the model are described below, and are extracted (and/or modified) from Porch (2002). This model formulation was the same utilized in the 2002 blacktip shark assessment. A value of historic fishing mortality, F_{hist}, can be estimated or fixed by the user. If F_{hist} is fixed at 0, then this implies that the population begins at virgin conditions. If F_{hist} is estimated or fixed to a value greater than 0, then the population begins in equilibrium at that level of F_{hist}. Given a vector of vulnerability at age for this level of historic fishing, $v_{hist,a}$, then the initial population structure is given by

$$(1) \qquad N_{a,y=1,m=1} = \begin{cases} R_{F_{hist}} & a = 1 \\ R_{F_{hist}} \exp(-\sum_{j=1}^{a-1}(M_j + F_{hist} v_{hist,j}) & 1 < a < A \\ \dfrac{R_{F_{hist}} \exp(-\sum_{j=1}^{A-1}(M_j + F_{hist} v_{hist,j})}{1 - \exp(-M_A - F_{hist} v_{hist,A})} & a = A \end{cases},$$

where $N_{a,y,1}$ is the number of sharks in each age class in the first model year (y=1), in the first month (m=1), M_a is natural mortality at age, A is the plus-group age, and recruitment (R) is assumed to occur at age 1.

The stock-recruit relationship was assumed to be a Beverton-Holt function, which was parameterized in terms of the maximum lifetime reproductive rate, α:

$$(2) \qquad R = \frac{R_0 S \alpha}{S_0 + (\alpha - 1)S} \quad .$$

In (2), R_0 and S_0 are virgin number of recruits (age-1 pups) and spawners (units are number of mature adult females times pup production at age), respectively. The parameter α is calculated as:

$$(3) \qquad \alpha = e^{-M_0}\left[\left(\sum_{a=1}^{A-1} p_a m_a \prod_{j=1}^{a-1} e^{-M_a}\right) + \frac{p_A m_A}{1-e^{-M_A}} e^{-M_A}\right] = e^{-M_0}\varphi_0 \quad ,$$

where p_a is pup-production at age a, m_a is maturity at age a, and M_a is natural mortality at age a. The first term in (3) is pup survival at low population density (Myers et al. 1999). Thus, α is virgin spawners per recruit (φ_0) scaled by the slope at the origin (pup-survival).

At equilibrium, spawners per recruit with fishing is simply:

$$(4) \qquad \varphi_F = \left[\left(\sum_{a=1}^{A-1} p_a m_a \prod_{j=1}^{a-1} e^{-M_a - Fv_a}\right) + \frac{p_A m_A}{1-e^{-M_A - Fv_A}} e^{-M_A - Fv_A}\right] = \frac{S_F}{R_F} \quad ,$$

where R_F and S_F are the equilibrium recruits and spawners, respectively, F is the level of fishing, and v_a is the age-specific vulnerability to fishing. From (4) and (2), we have

$$(5) \qquad R_F = \frac{S_F}{\varphi_F} = \frac{R_0 S_F \alpha}{S_0 + (\alpha - 1)S_F} \quad .$$

Equation (5) can be solved for S_F, and then R_F is simply S_F/φ_F, which allows calculation of the initial number of pups under a non-zero amount of historic fishing:

$$(6) \qquad R_{F_{hist}} = \frac{R_0 \alpha \varphi_F - S_0}{(\alpha - 1)\varphi_F} \quad .$$

Note that if F_{hist} is positive, then in order for $R_{F_{hist}}$ to be positive, we must have the following condition:

(7) $$\alpha > \frac{S_0}{R_0 \varphi_{F_{hist}}} = \frac{\varphi_0}{\varphi_{F_{hist}}} \quad or \quad \frac{1}{\alpha} < \frac{\varphi_{F_{hist}}}{\varphi_0} \quad .$$

Effectively, condition (7) implies that the level of SPR corresponding to F_{hist} must be greater than 1/ α. For populations where α is near the lower bound of 1, this implies that the level of F_{hist} must be minimal.

Beyond the initial numbers in each age class as defined in (1), abundance at the beginning of subsequent months is calculated by

(8) $$N_{a,y,m+1} = N_{a,y,m} e^{-M_a \delta} - \sum_i C_{a,y,m,i} \quad ,$$

where δ is the fraction of the year (m/12) and $C_{a,y,m,i}$ is the catch in numbers of fleet i. The monthly catch by fleet is assumed to occur sequentially as a pulse at the end of the month, after natural mortality:

(9) $$C_{a,y,m,i} = F_{a,y,i} \left(N_{a,y,m} e^{-M_a \delta} - \sum_{k=1}^{i-1} C_{a,y,m,k} \right) \frac{\delta}{\tau_i} \quad ,$$

where τ_i is the duration of the fishing season for fleet i. Catch in weight is computed by multiplying (9) by $w_{a,y}$, where weight at age for the plus-group is updated based on the average age of the plus-group.

The fishing mortality rate, F, is separated into fleet-specific components representing age-specific relative-vulnerability, v, annual effort expended, f, and an annual catchability coefficient, q:

(10) $$F_{a,y,i} = q_{y,i} f_{y,i} v_{a,i} \quad .$$

Catchability is the fraction of the most vulnerable age class taken per unit of effort. The relative-vulnerability would incorporate such factors as gear selectivity, and the fraction of the stock exposed to the fishery. For this model application to blacktip sharks, both vulnerability and catchability were assumed to be constant over years.

Catch per unit effort (CPUE) or fishery abundance surveys are modeled as though the observations were made just before the catch of the fleet with the corresponding index, i:

(11) $$I_{y,m,i} = q_{y,i} \sum_a v_{a,i} \left(N_{a,y,m} e^{-M_a \delta} - \sum_{k=1}^{i-1} C_{a,y,m,k} \right) \frac{\delta}{\tau_i} \quad .$$

Equation (11) provides an index in numbers; the corresponding CPUE in weight is computed by multiplying $v_{a,i}$ in (11) by $w_{a,y}$.

State space implementation

Process errors in the state variables and observation errors in the data variables can be modeled as a first-order autoregressive model:

$$(12) \quad \begin{aligned} g_{t+1} &= E[g_{t+1}]e^{\varepsilon_{t+1}} \\ \varepsilon_{t+1} &= \rho\varepsilon_t + \eta_{t+1} \end{aligned} \quad .$$

In (12), g is a given state or observation variable, η is a normal-distributed random error with mean 0 and standard deviation σ_g, and ρ is the correlation coefficient. E[g] is the deterministic expectation. When g refers to data, then g_t is the observed quantity, but when g refers to a state variable, then those g terms are estimated parameters.

The variances for process and observation errors (σ_g) are parameterized as multiples of an overall model coefficient of variation (CV):

$$(13a) \quad \sigma_g = \ln\left[(\lambda_g CV)^2 + 1\right]$$

$$(13b) \quad \sigma_g = \ln\left[(\omega_{i,y}\lambda_g CV)^2 + 1\right] \quad .$$

The term λ_g is a variable-specific multiplier of the overall model CV. For catch series and indices (equation 13b), the additional term, $\omega_{i,y}$, is the weight applied to individual points within those series. For instance, because the indices are standardized external to the model, the estimated variance of points within each series is available and could be used to weight the model fit. Given the Data Workshop decision to use equal weighting between indices, all $\omega_{i,y}$ were fixed to 1.0 and the same λ_g was applied to all indices. To evaluate the sensitivity case where indices were weighted by the inverse of their CV, each $\omega_{i,y}$ was fixed to the estimated CV for point *y* in series *i*; an attempt was also made to estimate a separate λ_g for each series, however those multipliers were not estimable and so a single λ was applied to all indices.

In the present model, these multipliers on catches and indices were fixed after exploring the effects on model outputs for several different values. A fleet-specific effort constant was estimated, but by allowing for large process error it was effectively a free parameter (a value of 10 times the overall model CV was used); the correlation was fixed at 0.0.

5.7.2 Data inputs, prior probability distributions, and performance indicators

The base model represented the decisions made by the Data Workshop as well as any additional decisions or modifications made by the assessment workshop. Data inputted to the model included maturity at age, fecundity at age (pups per mature female), spawning season, catches,

indices, and selectivity functions (Tables 5.1a and b, 5.2, and 5.3; Figures 5.1-5.3). Catches were made by the commercial sector, the recreational sector, and the Mexican fishery. In addition, estimates of unreported commercial catches and Gulf of Mexico menhaden fishery discards were provided by the DW. Because of similar selectivity functions, the commercial and unreported catches were combined, and recreational catches were combined with Mexican catches, yielding a model with 3 distinct "fleets" (Table 5.2). A total of 13 indices for the Gulf of Mexico were available; eight of these included or were exclusive to age 0. As this model began with age class 1, none of the indices designated as sampling "age 0" were used. This left 5 indices for the base case, and 3 sensitivity indices (Table 5.3 and Fig.5.2).

Selectivities are imputed in the age-structured surplus production model (as a functional form) and linked to each individual catch or CPUE series. Individual selectivity functions to be applied to catch series were identified by the DW catch working group based on information used in previous assessments, length frequency data presented at the DW, and the collective knowledge of shark fisheries of the group members. The selectivity recommendations can be found on pages 38-39 of the DW report. Selectivities linked to individual catch series were a compromise because the series often encompass various components of the fishery (e.g., commercial + unreported selectivity refers to commercial fisheries, most of which are bottom longline fisheries, but also include pelagic longline and drift gillnet fisheries, which are likely to have somewhat different selectivity patterns). The selectivity functions identified were then applied to the individual CPUE series based on the type of index represented (e.g., the BLLOP and VA LL indices were assigned the commercial + unreported logistic selectivity function because both indices use bottom longline gear).

-Commercial landings + unreported catch series: a logistic curve was selected based on the 2002 SEW assessment. The rationale was that younger ages were relatively less selected by the commercial gear as a whole, which as stated above may also include pelagic longline gear that is set in deeper waters where juveniles are less available, and drift gillnet gear that uses large mesh sizes targeting adults (Figure 5.3)

-Recreational and Mexican catch series: this selectivity pattern was largely based on the MRFSS, which includes data from recreational anglers fishing in nearshore waters and targeting mostly juveniles. Based on this, very limited length-frequency information presented in document LCS05/06-DW-16, and information from the 2002 SEW assessment, selectivity for blacktip sharks was fixed at 1 for ages 0 and 1 and rapidly decreased thereafter to reflect the fact that larger and older sharks are progressively less targeted (Figure 5.3).

-Menhaden bycatch series: based on data from this fishery, all age groups were assumed to be fully selected and thus given a constant selectivity of 1 (Figure 5.3).

-Juvenile indices: this selectivity pattern was intended for surveys targeting juveniles and thus assumes full selectivity for the first age groups, with a rapid decline as sharks approach maturity (note that the 2002 ages at maturity were used; Figure 5.3).

Catch data begin in 1981 and the earliest base case index begins in 1992. The base case model in 2002 attempted to estimate a level of historic F, so an attempt was made to estimate F_{hist} for the

base model this time. Initial model runs found that F_{hist} was difficult to estimate or it converged to near 0. Therefore, for all runs presented here, F_{hist} was fixed to 0, which implies that the stock was unexploited prior to 1981.

Individual points within catch and index series can be assigned different weights, based either on estimated precision or expert opinion. All points within each catch series were given the same weight; likewise, all points within each index series were given the same weight.

One further model specification was the degree to which the model predicted values matched catches versus indices. An overall model CV is estimated (see equations 13a and 13b), and multiples (λ_g) of this overall CV can be specified separately for catches and indices (see Porch 2002). All catch series were assigned a single CV multiple, and all indices were assigned a single CV multiple (this forces equal weighting of the indices). Initially, an attempt was made to estimate these multipliers. This resulted in boundary solutions for the multipliers. In a second attempt, the multiplier for catch was fixed at 1 and the index multiplier was estimated. Again, this resulted in the index multiplier estimate at the upper bound. Several values were evaluated for the CV multiplier of indices: a value that was 1, 2.5, 4, or 5 times the catch CV multiplier. A value of 1 implies the same relative certainty in catches and indices; the remaining values imply that indices are less certain than catches. In the 2002 assessment, a value of 4 was used. In this assessment, model convergence was not obtained (Hessian could not be estimated) for values of 1, 2.5, or 4, but was obtained for a value of 5. The point estimates for all weighting levels tried (even those that did not converge) concluded that the stock was not overfished and that there was no overfishing. The relative status estimates displayed some spread; however, that depended on the CV multiplier. The estimate of relative biomass (B_{2004}/B_{MSY}) ranged from 1.43 to 2.56, respectively, while the degree of overfishing (F_{2004}/F_{MSY}) ranged from 0.79 to 0.027. Although these reported ranges reflect results from models that did not converge, they are mentioned primarily because the index fits showed a slight downward trend rather than the flat trend for the model that actually converged. Basically, forcing the model to fit the indices as well as catch reduced the relative biomass and increased the relative F benchmark (i.e., closer to overfished and closer to overfishing). Given that there was no convergence for a value less than 5, and that this value is close to the value used in 2002, the weighting scheme selected was to fit catches 5 times better than indices. Placing less certainty in indices relative to catch is further justified when one considers the lack of a consistent signal. The base indices show flat, increasing, or decreasing trends with fairly large annual changes (Figure 5.2 and 5.4). It is likely that one reason the model runs with CV multipliers <5 did not converge is that the model could not reconcile a better fit to those conflicting indices. Of the sensitivity indices, MRFSS is the longest (it begins in 1981), and the average trend is flat over the time period, although there are large interannual fluctuations (Figure 5.2). CV multipliers greater than 5 were not evaluated for the indices, as the model-predicted trend was already poor.

Estimated model parameters were pup survival, virgin recruitment (R_0), catchabilities associated with catches and indices, and fleet-specific effort. Natural mortality at ages 1+ was fixed at the updated values (Table 5.1a), and the priors for pup survival and virgin recruitment are listed in Table 5.1b.

In summary, the base model configuration assumed virgin conditions in 1981, used the data workshop recommended biological parameters, the updated survival at age, the updated prior for

pup survival, and the base case indices with an updated Pelagic Longline Log index (referred to as Pelagic Log). Catches were assumed to be 5 times more certain than the indices. All inputs are given in Tables 5.1a and b, 5.2 and 5.3. Base indices are in black font in Table 5.3.

Performance indicators included estimates of absolute population levels and fishing mortality for year 2004 (F_{2004}, SSF_{2004}, B_{2004}, $Nmature_{2004}$), population statistics at MSY (F_{MSY}, SSF_{MSY}, SPR_{MSY}), current status relative to MSY levels, and depletion estimates (current status relative to virgin levels). In addition, trajectories for F_{year}/F_{MSY} and SSF_{year}/SSF_{MSY} were plotted.

5.7.3 Methods of numerical integration, convergence diagnostics, and decision analysis

Numerical integration for this model was done in AD Model Builder (Otter Research Ltd. 2001), which uses the reverse mode of AUTODIF (automatic differentiation). Estimation can be carried out in phases, where convergence for a given phase is determined by comparing the maximum gradient to user-specified convergence criteria. The final phase of estimation used a convergence criterion of 10^{-6}. For models that converge, the variance-covariance matrix is obtained from the inverse Hessian. Model fit was assessed by comparing components of the relative negative log-likelihood (relative rather than exact because the constants in the likelihood were not included). The relative negative log-likelihood (objective function) and AICc (small sample AIC) values are listed in the table of model results.

5.7.4 Sensitivity analyses

Three sensitivity runs to the base model were performed. In the first sensitivity (**ASPM-BTG-1**), the Pelagic longline index was excluded. In the second sensitivity (**ASPM-BTG-2**), all indices were used (5 base and 3 sensitivity indices). The third sensitivity (**ASPM-BTG-3**) was the same set up as the base case except that observations within each index were weighted by the inverse CV of each point. An attempt was made to estimate a separate CV multiplier for each index, but there were boundary solutions again, so the multiplier from the base case was retained for all indices.

5.8 Results

5.8.1 Baseline scenario

The base model estimated a stock that was not overfished and there was no overfishing (Tables 5.4 and 5.5; Figure 5.5). The model estimate of F by fleet is dominated by the recreational fleet (includes recreational fishery plus estimated Mexican catches) throughout the time series (1981-2001), which matches the observed pattern in landings (Figure 5.6). Model fits to catches and indices are shown in Figures 5.7 and 5.8. Catches are fit very well. The base indices span at most 13 years, and the model predicts a relatively flat trend through the observed points. The precision is very poor for virgin pup production, and current measures of total biomass, number mature, spawning stock fecundity (SSF), and fishing mortality. No CV is given for steepness or

α as these parameters are calculated directly from pup survival and virgin spawners per recruit rather than estimated. Relative estimates of depletion are very precise, but current abundance estimates are correlated to the estimate of the virgin level. The estimate of pup survival did not move from the prior specification, indicating that there is probably little to no information in the data from which to estimate this parameter. No likelihood profiling was pursued.

5.8.2 Sensitivity analyses

Sensitivity analysis **ASPM-BTG-1**, the base case without the Pelagic longline index, did not converge, although the point estimates indicated that there was no overfishing and the stock was not overfished. The results for **ASPM-BTG-2**, which included all of the indices, and **ASPM-BTG-3**, which weighted the points within indices by their CV, were nearly identical to the base case (Table 5.4). As with the base case, the precision of the model estimates was very poor (CV>1) for the absolute measures of virgin level pups, and current measures of the stock. Given the high CV on virgin pup production, one can infer that the estimate of MSY is not well estimated either. The relative measures of depletion were very precise, however. Again, the estimate of pup survival did not move from the prior specification.

A phase-plot of stock-status shows the outcomes of the base model, the two sensitivity analyses, the continuity analysis (assuming a single stock; see section 5.10), and the estimates from BSP and WinBUGS (Figure 5.9). Note that the x values for BSP and WinBUGS are in numbers of fish (N_{2004}/N_{MSY}) rather than SSF_{2004}/SSF_{MSY}. These values from BSP and WinBUGS should be comparable, however, because they are relative statistics, and they only differ from the ASPM by the maturity ogive.

5.8.3 Comparison of model fits

The relative likelihood values by model source (catch, indices, effort, catchability, and recruitment) as well as a breakdown of likelihood by individual catch and index series are shown in Figures 10 and 11. The total approximate likelihood is lowest for sensitivity 2, where all indices were included, and was worst for sensitivity 3, where the inverse CV weighting scheme was used (see Table 5.4, value for "objective function" or AICc). Catches are best fit (lowest relative likelihood) by the base model. Almost all base indices have slightly smaller likelihoods under sensitivity 2, but the main reason that the objective function is lower is the catchabilities, which were specified with a uniform prior. Considering the fit to catches and indices alone, the base model performed best. None of the model configurations impacted the contribution to the likelihood by effort or recruitment parameters (pup survival and virgin number of pups). Both the base model and ASPM-BTG-3 had the same number of observations, and the same number of estimated parameters, and the AICc ranks the base model as having a better fit than ASPM-BTG-3.

5.9 Projections of the base model

The base model was projected at $F = F_{MSY}$ to the year 2030. Projections were done using Pro-2Box (Porch 2003). This projection was bootstrapped 500 times by allowing for process error in the spawner-recruit relationship. Lognormal recruitment deviations with CV=0.4, with no autocorrelation, were assumed. No other variability was introduced into the projections. The selectivity vector was the geometric mean of the last 3 years (2002-2004).

The estimate of generation time is about 17 years. Generation time was calculated as

$$GenTime = \frac{\sum_i i f_i \prod_{j=1}^{i-1} s_j}{\sum_i f_i \prod_{j=1}^{i-1} s_j}$$

where i is age, f_i is the product of(fecundity at age) x (maturity at age), and s_j is survival at age. The calculations were carried out to an age, A, such that the difference between performing the calculation to age A or A+1 was negligible. This calculation is consistent with the assessment model, which treats survival of the plus group as the sum of a geometric series (e.g., see third line in equation 1). The 2006 maturity ogive was used, 4.4 pups per female was the fecundity for all ages, adjusted age-specific survival at age was used (see section 5.6), and the mode of 0.75 for the prior on pup survival was used. As was done in the assessment model, to account for the approximately one year gestation time, maturity at age was shifted by 1 year, and the number of pups was halved to account for the fact that only half of the mature population would reproduce in a given year. Note that because pup-production is constant for all ages, it factors out of both numerator and denominator, and the resulting estimate of generation time is insensitive to that value.

The estimate of F_{2004} is far below the estimate of F_{MSY}, so projecting the stock at $F = F_{2004}$ does not further deplete the stock, rather it increases slightly (Figure 5.12). Projecting the stock at $F = F_{MSY}$, while allowing that $F_{2005\text{-}2007} = F_{2004}$ due to the time required to implement a new management regime, causes the estimated spawning stock to decrease towards the level that produces MSY (Figure. 5.13). By the year 2086, the stock is 1.27 times the size that would produce MSY.

5.10 Continuity analysis

A continuity base model was run using the 2002 state-space age structured production model (described above under methods). In 2002, blacktip was assessed as a single stock. F_{hist} was fixed at 0, all indices were used and given equal weighting; an age-constant M was estimated; catches for Gulf of Mexico and northwestern Atlantic Ocean combined (Table 5.6); 2002 biological parameters used; 10 pups per mature female was used for fecundity. Available combined blacktip stock indices and values can be found in Appendix 1.

The continuity model estimated a stock status of no overfishing, and not overfished. This model was not truly continuity per se, because the previous assessment had treated blacktip as one

stock, and different indices had been available. It also differs from the 2006 base model because the biological parameters were adjusted differently to elevate the steepness parameter above 0.2. Nevertheless, the estimate of stock status in 2002, in this continuity analysis, and in the 2006 base model all concluded that the stock does not appear to be overfished, nor does it appear that there is overfishing. All of these estimates were fairly imprecise, though.

5.11. Discussion

There was some uncertainty associated with the biological parameters, which led to the AW updating the fixed values for M at age, and the mode of the prior for pup-survival (corresponding to density-independent level). All model configurations examined arrived at the same estimate of stock status, namely that the stock is not overfished and there is no overfishing.

Due to lack of information for setting a prior on F_{hist}, and lack of information in the data to estimate this parameter, it was fixed at 0, which forces the model to start at virgin conditions in 1981. Scenarios that start the population at less than virgin levels were not explored. The estimate of current depletion (for year 2004) is that total biomass is about 87% of virgin levels, and spawning stock fecundity (SSF) is about 93% of virgin levels. This suggests relatively little impact over a 24 year time period, and is reflected in the relatively flat fit to all of the indices of abundance. This result may be driven by the relatively short, recent years covered by the indices of abundance, and the lack of consistent trend between those indices. The 2002 assessment estimated that there was 74% of virgin SSF in 2001; the 2006 result would imply an increase of 24% in just three years. Given that landings peaked in the years 1986-1994 (Figure 5.6), a time period for which only 1 sensitivity index is available, and given the large CVs in model estimates of absolute abundance, the results ought to be interpreted cautiously.

Compared to the 2002 assessment of a single blacktip stock, the estimate of virgin pup recruitment is slightly larger for the 2006 Gulf blacktip stock (1.44E7 versus 1.35E7), pup survival in 2006 is nearly double (0.82 versus 0.46). Consequently, estimated steepness in 2006 is larger (0.40 versus 0.27), and the benchmark SPR_{MSY} is lower (0.62 versus 0.83). Because the stock in 2006 is estimated to be more resilient, and the slightly greater estimate of virgin pups, MSY is double that estimated in 2002 (2.42E7 versus 1.14E7). As the higher steepness is a result of the adjusted survival on ages 1+ and the adjusted mode for pup survival (and the estimate did not move from the prior mode), this gives an additional reason to interpret the results cautiously.

5.12. References

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Table 5.1a. Biological inputs from 2002 assessment, 2006 base case values from the data workshop, or values updated at the 2006 assessment workshop for Gulf of Mexico blacktip sharks. In the continuity case, M was estimated, while in the 2006 base case, M at age values were fixed. The * for the age 0 entries in the first three columns is to distinguish those values as survival rates rather than natural mortality rates.

Age	M 2002	M 2006	M 2006 Updated	Female Maturity 2002	Female Maturity 2006	Pups-per-Female 2002	Pups-per-Female 2006
0	0.52*	0.52*	0.75*	0	0.001	0	0
1	0.22	0.358	0.263	0	0.002	10	4.4
2	0.22	0.303	0.208	0	0.006	10	4.4
3	0.22	0.271	0.176	0.02	0.019	10	4.4
4	0.22	0.250	0.155	0.09	0.059	10	4.4
5	0.22	0.235	0.140	0.35	0.166	10	4.4
6	0.22	0.225	0.130	0.74	0.387	10	4.4
7	0.22	0.218	0.123	0.94	0.667	10	4.4
8	0.22	0.212	0.117	0.99	0.865	10	4.4
9	0.22	0.208	0.113	1	0.953	10	4.4
10	0.22	0.205	0.110	1	0.985	10	4.4
11	0.22	0.203	0.107	1	0.996	10	4.4
12	0.22	0.201	0.106	1	0.999	10	4.4
13	0.22	0.200	0.104	1	1	10	4.4
14	0.22	0.198	0.103	1	1	10	4.4
15	0.22	0.198	0.102	1	1	10	4.4

Table 5.1b. Additional parameter specifications for Gulf of Mexico blacktip sharks where L_∞, K, and t_0 are von Bertalanffy parameters; a is the scalar coefficient of weight on length; and b is the power coefficient of weight on length. Weight units are kg.

Parameter	**Value**	**Prior**
L_∞	139 (cm FL)	*constant*
K	0.232	*constant*
t_0	-2.33	*constant*
a	1.00E-05	*constant*
b	3.05	*constant*
F_{hist}	0	*constant*
Historic Selectivity	1 for all ages	*constant*
Pups-per-mature female	4.4	*constant*
Pup Survival	0.75 (mode)	~LN with CV=0.30
Virgin Recruitment (R_0)	1.50E+07	~U on [1.0E+4, 1.0E+9]

Table 5.2. Catches of Gulf of Mexico blacktip shark by fleet. Units are numbers of sharks.

Year	Commercial + Unreported	Recreational + Mexican	Menhaden
1981	7,261	161,954	17,495
1982	7,261	124,603	17,933
1983	7,844	88,980	17,714
1984	10,712	131,959	17,714
1985	9,950	132,272	15,964
1986	71,435	224,930	15,746
1987	98,806	156,674	16,402
1988	174,842	207,083	15,964
1989	190,962	192,279	16,839
1990	115,002	199,323	16,402
1991	46,484	200,210	12,684
1992	53,236	232,849	11,153
1993	57,102	210,606	11,372
1994	120,028	154,194	12,200
1995	84,862	134,884	11,200
1996	58,666	154,722	11,153
1997	45,221	132,184	11,372
1998	62,486	125,280	10,935
1999	52,304	72,013	12,028
2000	42,131	112,581	10,279
2001	39,397	80,034	9,622
2002	30,040	79,944	9,404
2003	71,540	55,778	9,185
2004	44,174	72,734	9,404

Table 5.3. Indices available for use in the current Gulf of Mexico blacktip shark assessment. Sensitivity indices in green (last 3 columns).

Year	PC Gillnet juveniles	BLLOP	NMFS LLSE	Bottom LL Logs	Pelagic Log	PC longline	MS Gillnet juveniles	MRFSS
1981								1.358
1982								0.325
1983								1.130
1984								0.673
1985								0.816
1986								1.452
1987								0.636
1988								1.319
1989								1.186
1990								1.318
1991								1.477
1992					2.240			0.877
1993					1.541	0.768		0.772
1994		0.430			2.358	0.133		0.726
1995		0.817	0.554		1.572	1.018		1.027
1996	0.980	0.724	0.380	0.249	0.838	0.758		1.159
1997	1.513	0.588	0.409	0.931	0.924	1.299		1.090
1998	0.639	0.796		0.334	0.808	0.974	0.835	1.471
1999	1.068	1.055	0.341	1.506	0.364	1.136	0.412	0.737
2000	0.649		1.517	0.883	0.706	1.914	2.655	1.259
2001	1.408	0.162	0.898	0.985	0.689		0.409	0.661
2002	0.854	2.062	1.436	1.078	0.484			0.719
2003	0.790	1.542	2.237	1.967	0.328		0.092	1.064
2004	1.098	1.824	1.228	1.068	0.149		0.198	0.747
Ages Vulnerable								
	1 - 5	all	all	all	all	all	1 - 5	young
Selectivity Vector								
	Juvenile Indices	Comm+Unrep	Comm+Unrep	Comm+Unrep	Comm+Unrep	Comm+Unrep	Juvenile-Indices	MRFSS

Table 5.4. Results for the base model runs and two sensitivity analyses that converged using the updated biological parameters for Gulf of Mexioc blacktip sharks. Pups-virgin is the number of age 1 pups at virgin conditions. SSF is spawning stock fecundity, which is the sum of number mature at age times pup-production at age (rather than SSB, since biomass does not influence pup production in sharks). AICc is the small sample Akaike Information Criterion, which converges to the AIC statistic as the number of data points gets large.

	Base		BTG-2		BTG-3	
Parameter	**Est**	**CV**	**Est**	**CV**	**Est**	**CV**
AICc	282.495		47.6284		421.414	
Objective Function	-158.524		-179.614		-89.0644	
MSY (kg)	2.42E+07	--	2.28E+07	--	1.56E+07	--
$Pups_{virgin}$	1.44E+07	1.79	1.36E+07	1.01	9.99E+06	3.68
SSF_{2004}	4.55E+07	1.83	4.29E+07	1.03	3.12E+07	3.80
$Nmature_{2004}$	1.98E+07	1.83	1.86E+07	1.03	1.36E+07	3.80
B_{2004}	1.93E+09	1.83	1.82E+09	1.03	1.33E+08	3.80
B_{2004}/B_{virgin}	0.87	0.04	0.87	0.02	0.86	0.12
SSF_{2004}/SSF_{virgin}	0.93	0.04	0.92	0.03	0.92	0.13
$Nmature_{2004}/Nmature_{virgin}$	0.89	0.04	0.88	0.03	0.88	0.13
SSF_{2004}/SSF_{MSY}	2.56	0.29	2.54	0.29	2.54	0.33
SPR_{MSY}	0.62	--	0.62	--	0.61	--
F_{2004}	0.01	1.82	0.01	1.03	0.01	3.75
F_{MSY}	0.20	--	0.20	--	0.20	--
F_{2004}/F_{MSY}	0.03	1.82	0.03	1.03	0.04	3.75
Pup-survival	0.82	0.29	0.82	0.29	0.83	0.30
alpha	2.64	--	2.64	--	2.68	--
steepness	0.40	--	0.40	--	0.40	--

Table 5.5. Estimates of total number, spawning stock fecundity, and fishing mortality by year for base model for blacktip shark in the Gulf of Mexico.

Year	N(year)	SSF(year)	F(year)
1981	23,667,920	10,749,000	0.042
1982	23,500,270	10,740,000	0.033
1983	23,393,320	10,729,000	0.024
1984	23,331,750	10,715,000	0.035
1985	23,234,190	10,697,000	0.035
1986	23,150,150	10,669,000	0.066
1987	22,935,150	10,628,000	0.052
1988	22,783,720	10,575,000	0.073
1989	22,531,140	10,513,000	0.072
1990	22,304,540	10,440,000	0.066
1991	22,162,200	10,357,000	0.058
1992	22,090,320	10,265,000	0.067
1993	21,979,560	10,171,000	0.062
1994	21,887,040	10,082,000	0.054
1995	21,786,520	10,001,000	0.045
1996	21,737,270	9,931,500	0.048
1997	21,689,190	9,870,500	0.040
1998	21,670,440	9,816,100	0.040
1999	21,636,060	9,768,300	0.025
2000	21,655,030	9,730,200	0.035
2001	21,638,400	9,702,500	0.026
2002	21,652,720	9,683,200	0.025
2003	21,670,380	9,670,600	0.023
2004	21,667,370	9,663,300	0.024

Table 5.6. Catches of blacktip shark by fleet (regions combined) used in the blacktip shark continuity analysis. Units are numbers of sharks.

Year	Commercial + Unreported	Recreational + Mexican	Menhaden
1981	7812	166452	17495
1982	7812	152653	17933
1983	8439	118279	17714
1984	11525	148058	17714
1985	10705	185539	15964
1986	75607	238556	15746
1987	107379	203334	16402
1988	178868	226745	15964
1989	194834	214072	16839
1990	119898	206497	16402
1991	121804	240823	12684
1992	150426	252476	11153
1993	128624	223430	11372
1994	201273	170135	12200
1995	151157	154315	11200
1996	100567	182589	11153
1997	81244	148520	11372
1998	94904	146779	10935
1999	59111	80863	12028
2000	51797	119334	10279
2001	49051	94979	9622
2002	50674	85221	9404
2003	89896	85840	9185
2004	57571	77012	9404

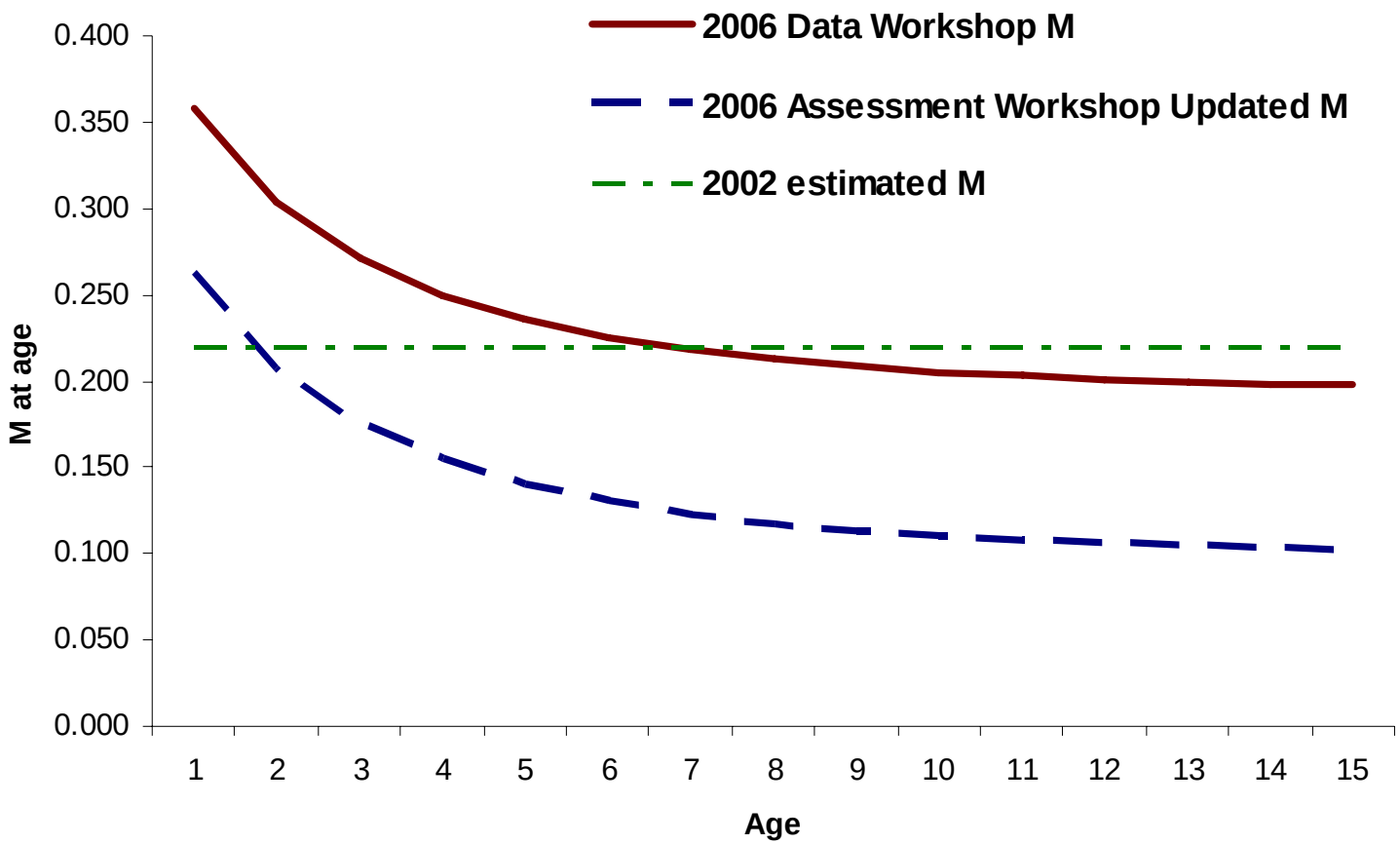


Figure 5.1 Comparison of natural mortality recommended by the data workshop (DW, solid line) and that agreed to in plenary at the assessment workshop (AW, dashed line) for Gulf of Mexico blacktip sharks. In 2002, and age-constant M at age was estimated (dot-dash green line).

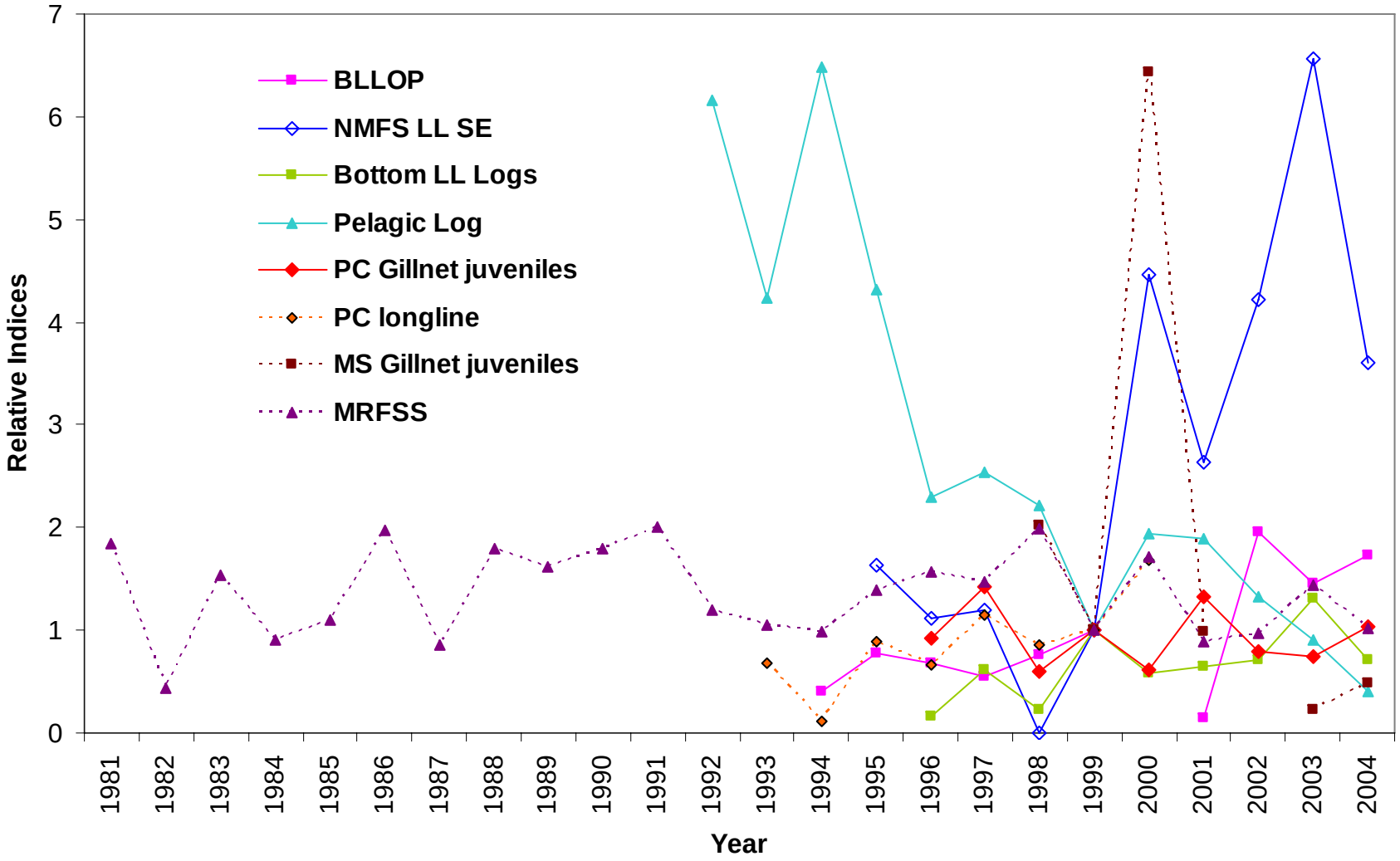


Figure 5.2 Indices available for the current Gulf of Mexico blacktip shark assessment. Indices are scaled by the value for 1998 (the only year of overlap).

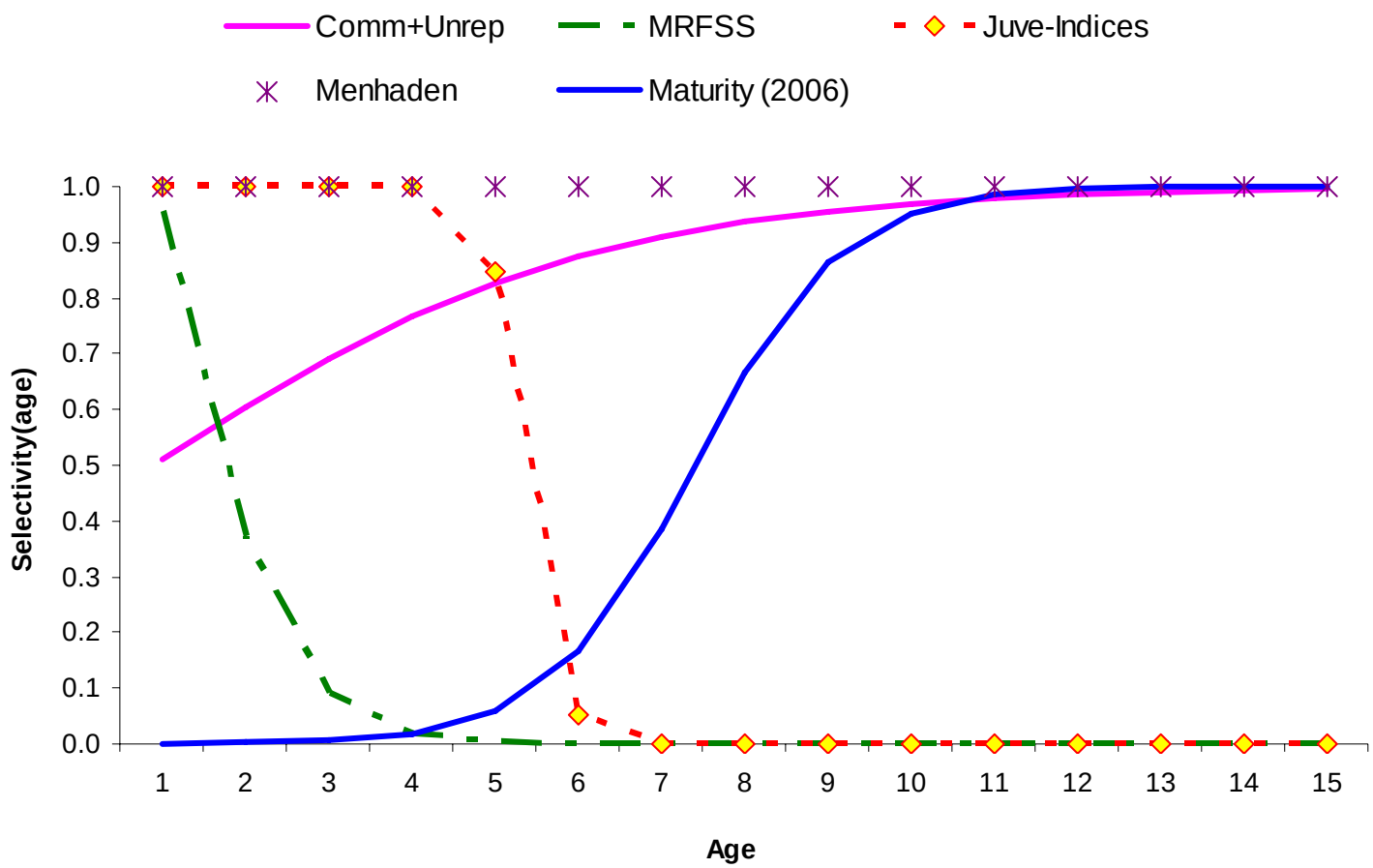
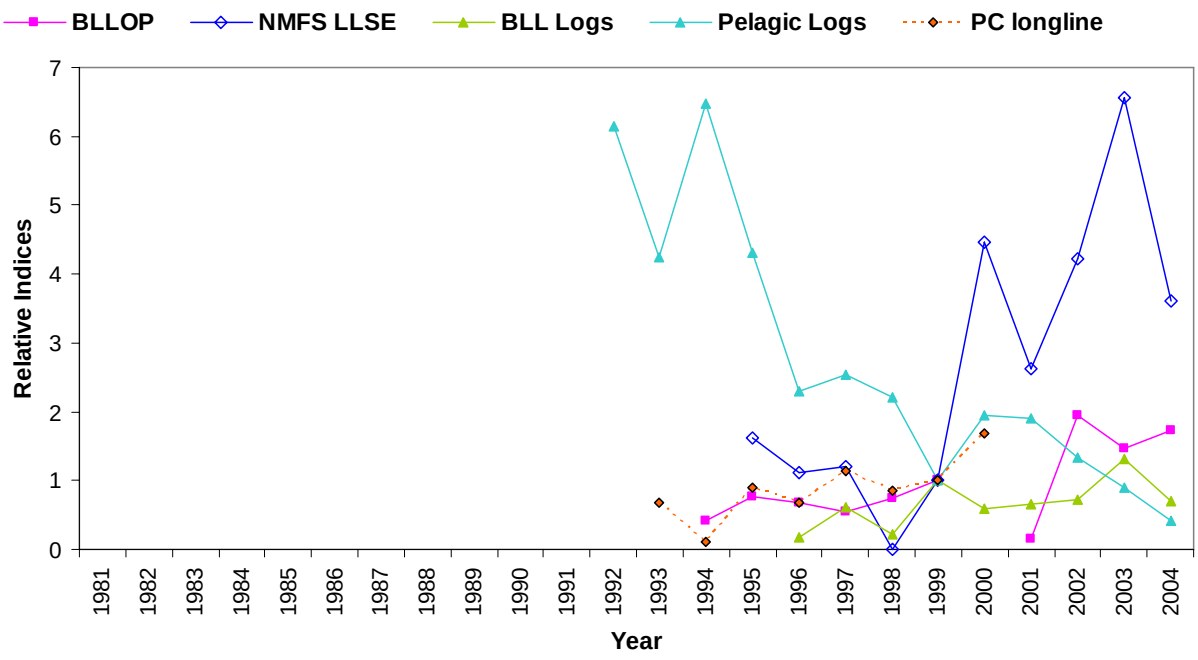


Figure 5.3 Selectivities used in blacktip Gulf of Mexico assessment, with the maturity ogive (solid blue line) as decided at the data workshop. Labels are with the last row in Table 5.3 (all indices available for Gulf of Mexico blacktip).



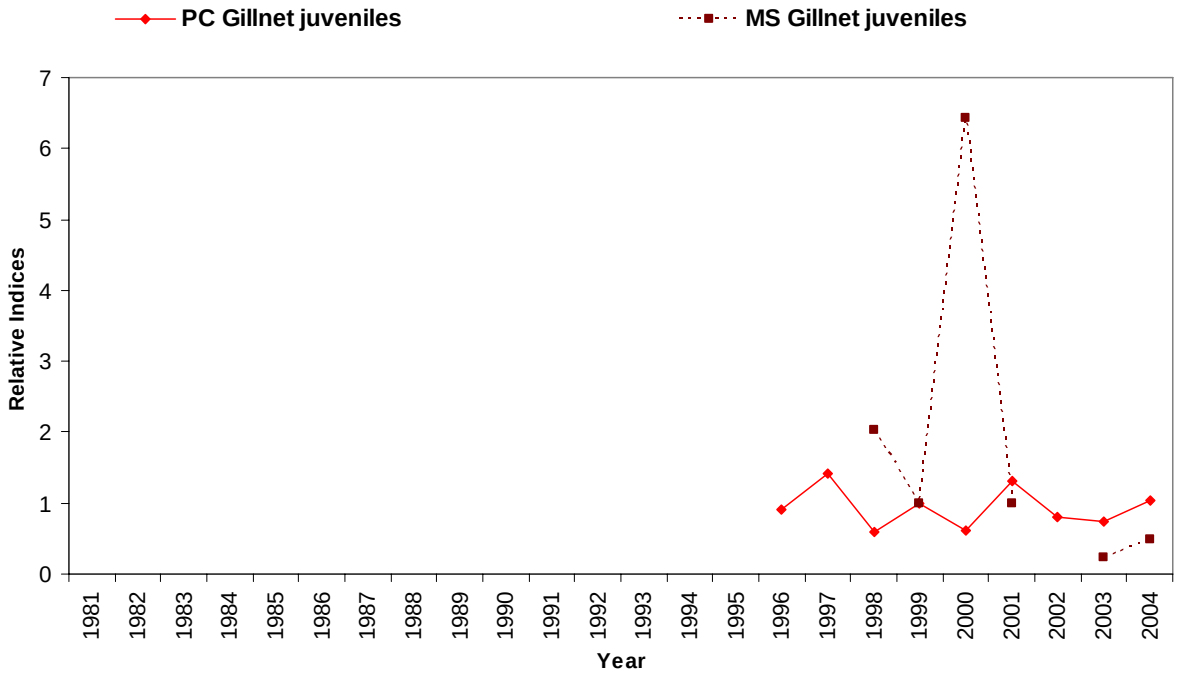


Figure 5.4. Indices with the same selectivity for Gulf of Mexico blacktip shark. In the top, all indices have the same selectivity as the commercial fishery; in the bottom, all indices select for juveniles. Sensitivity indices, which were not used in the base case are: PC Longline and MS Gillnet juveniles.

Figure 5.5. Gulf of Mexico blacktip estimated stock status (top), total fishing mortality (middle), and fleet-specific F (bottom). The dashed line in the middle panel indicates F_{MSY} (= 0.015).

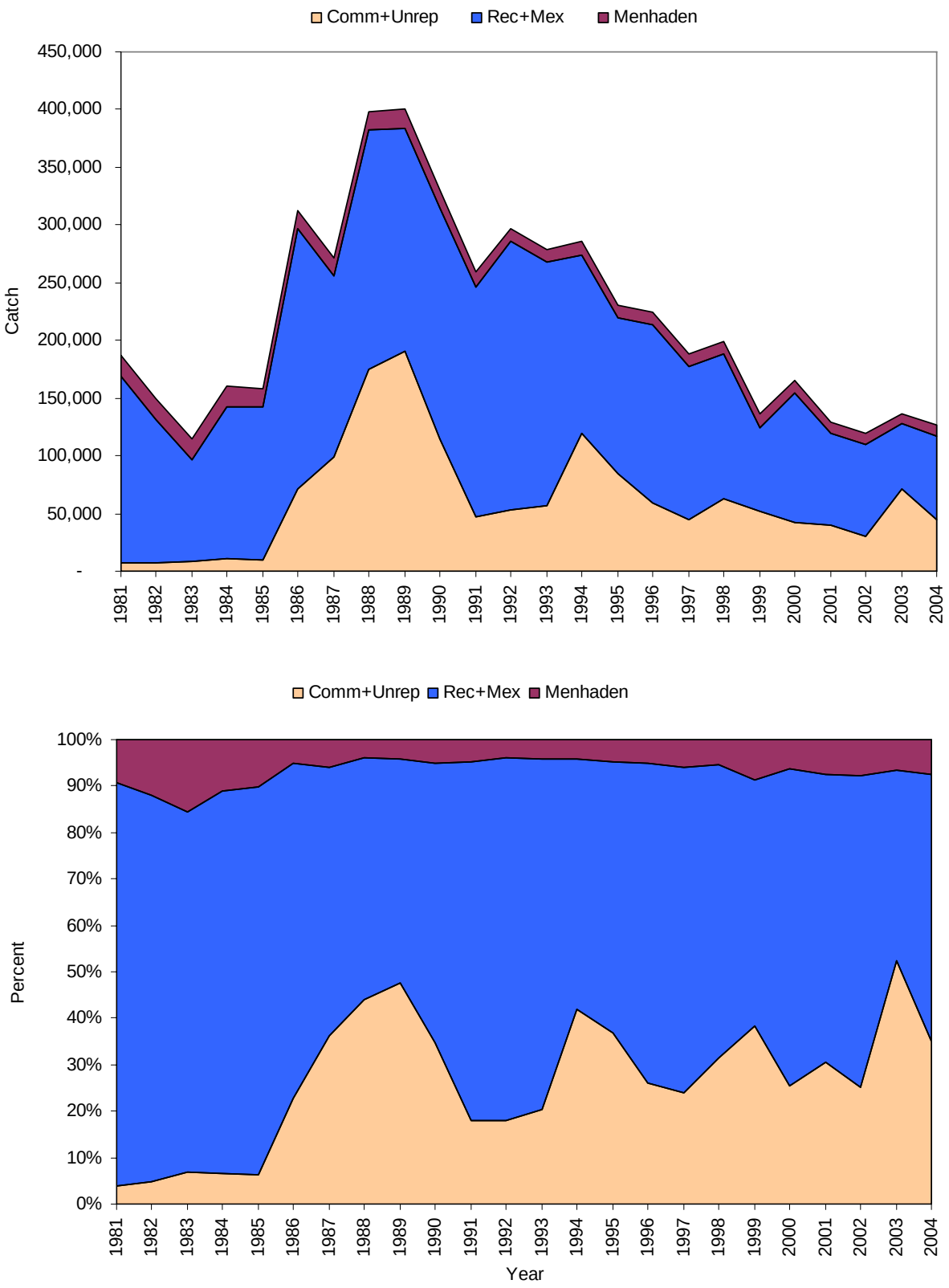


Figure 5.6. Total catch by fleet of blacktip in the Gulf of Mexico (top) and percent of total catch by fleet (bottom).

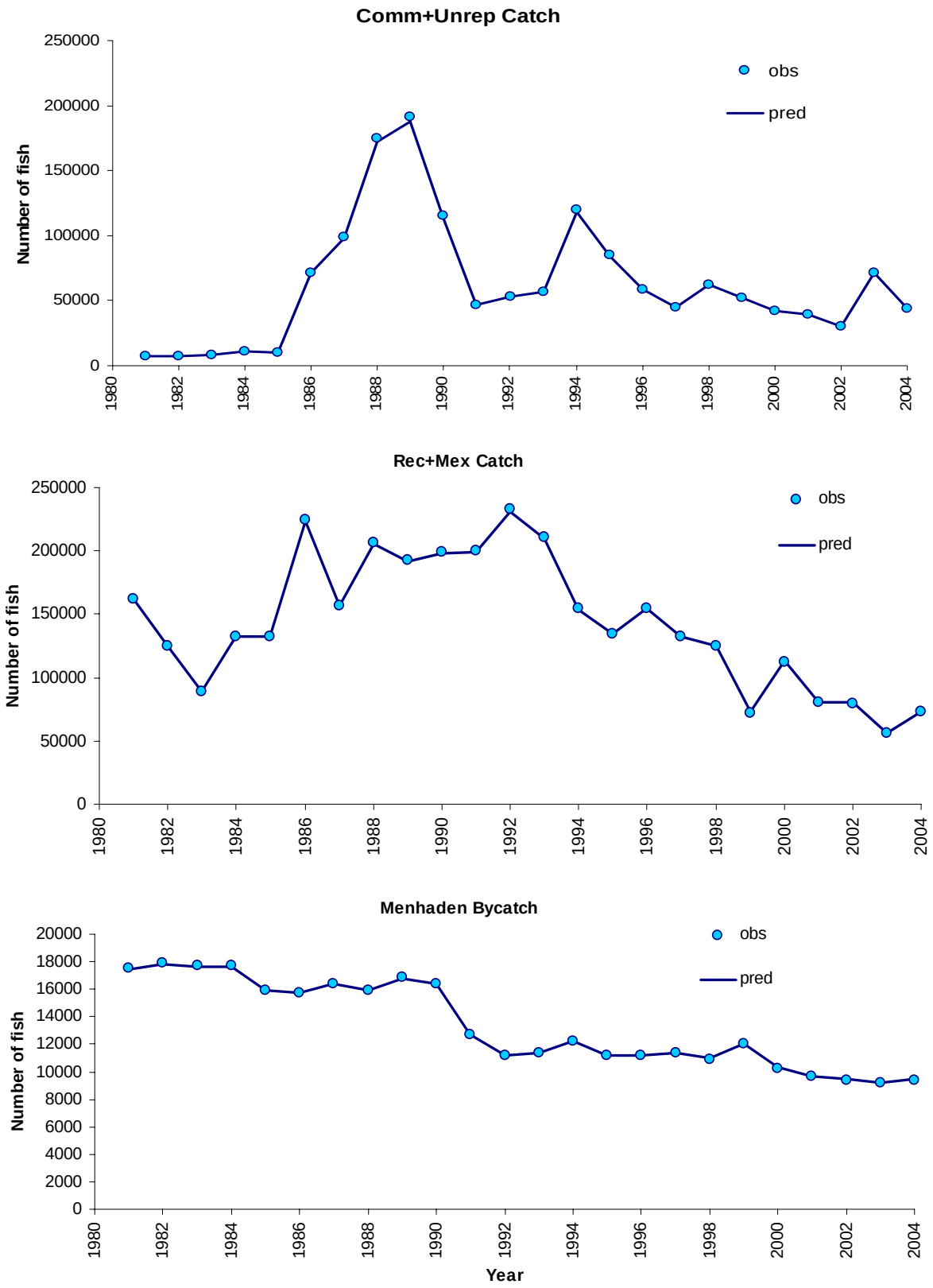


Figure 5.7. Gulf of Mexico blacktip model predicted fit to catch data. Circles represent observed data, solid line is predicted.

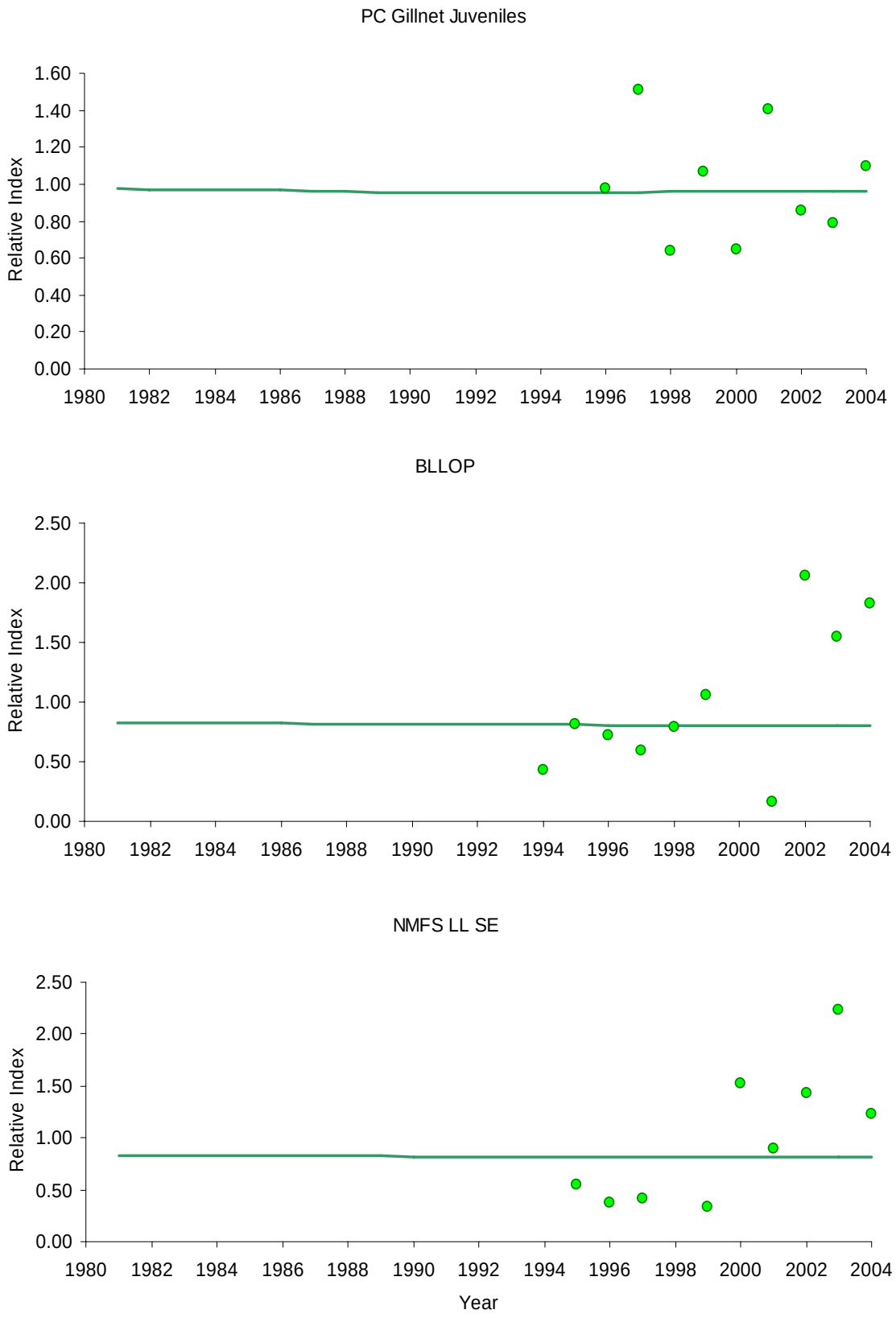
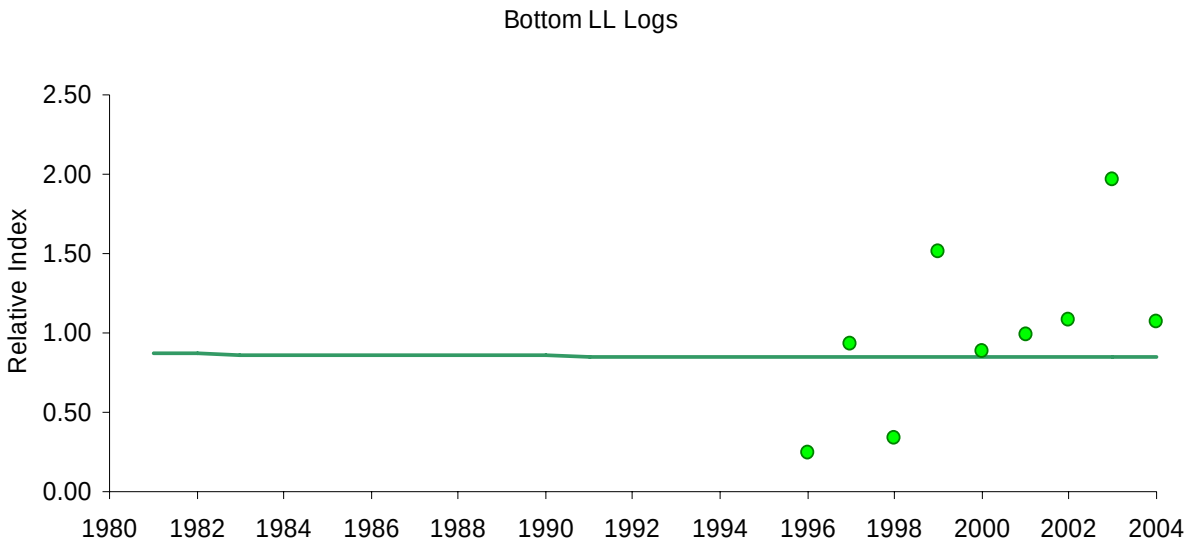


Figure 5.8. Gulf of Mexico blacktip model predicted fit to indices. Circles represent observed data, solid line is predicted.



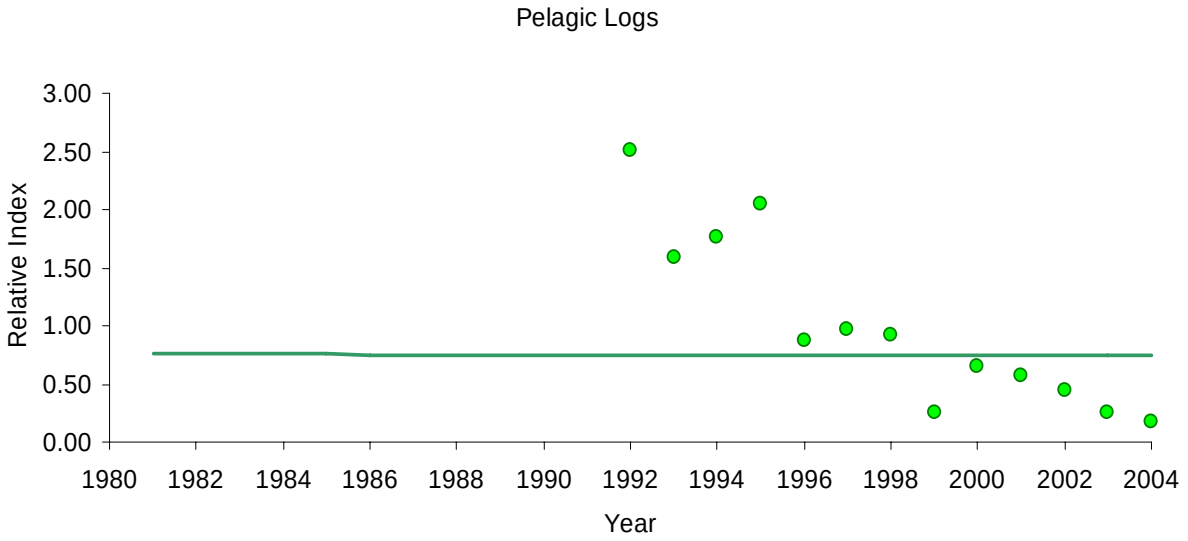


Figure 5.8. (Continued)

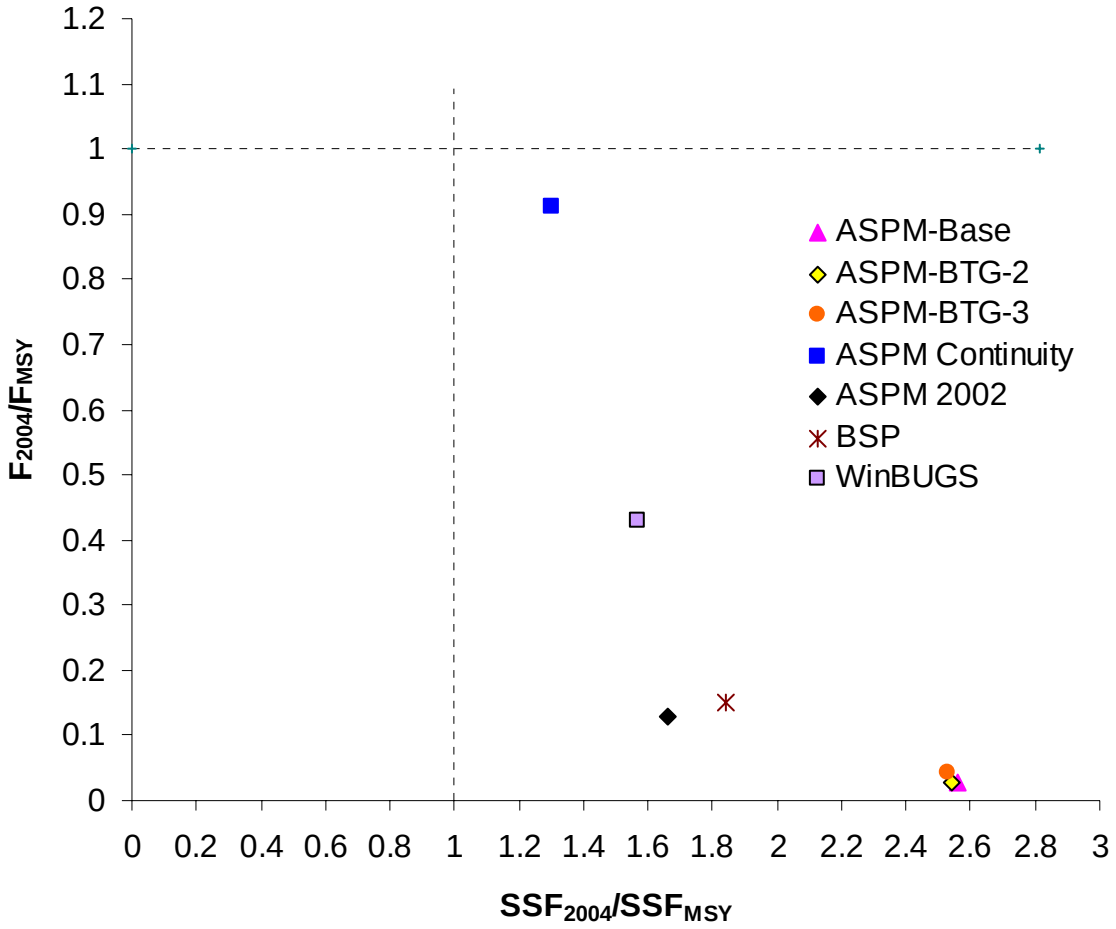


Figure 5.9. Phase-plot of stock status for Gulf of Mexico blacktip. Selected sensitivities are also included for comparison. The models include: ASPM-Base, ASPM-BTG-2 (all indices were used (5 base and 3 sensitivity indices)), ASPM-BTG-3 (same as the base case except that observations within each index were weighted by the inverse CV of each point), ASPM Continuity, ASPM 2002 (results of the 2002 blacktip single stock assessment using equal weighting), BSP (results using the Bayesian surplus production model), and WinBUGS (results using the WinBUGS SPM). See text for further details. Several control rules are illustrated: the dashed horizontal line indicates the MFMT (Maximum Fishing Mortality Threshold) and the dashed vertical line denotes the target biomass (biomass or number at MSY). Note for the BSP and WinBUGS x values denote N_{2004}/N_{MSY} rather than SSF_{2004}/SSF_{MSY}. SSF is spawning stock fecundity, which is the sum of number mature at age times pup-production at age (rather than SSB, since biomass does not influence pup production in sharks).

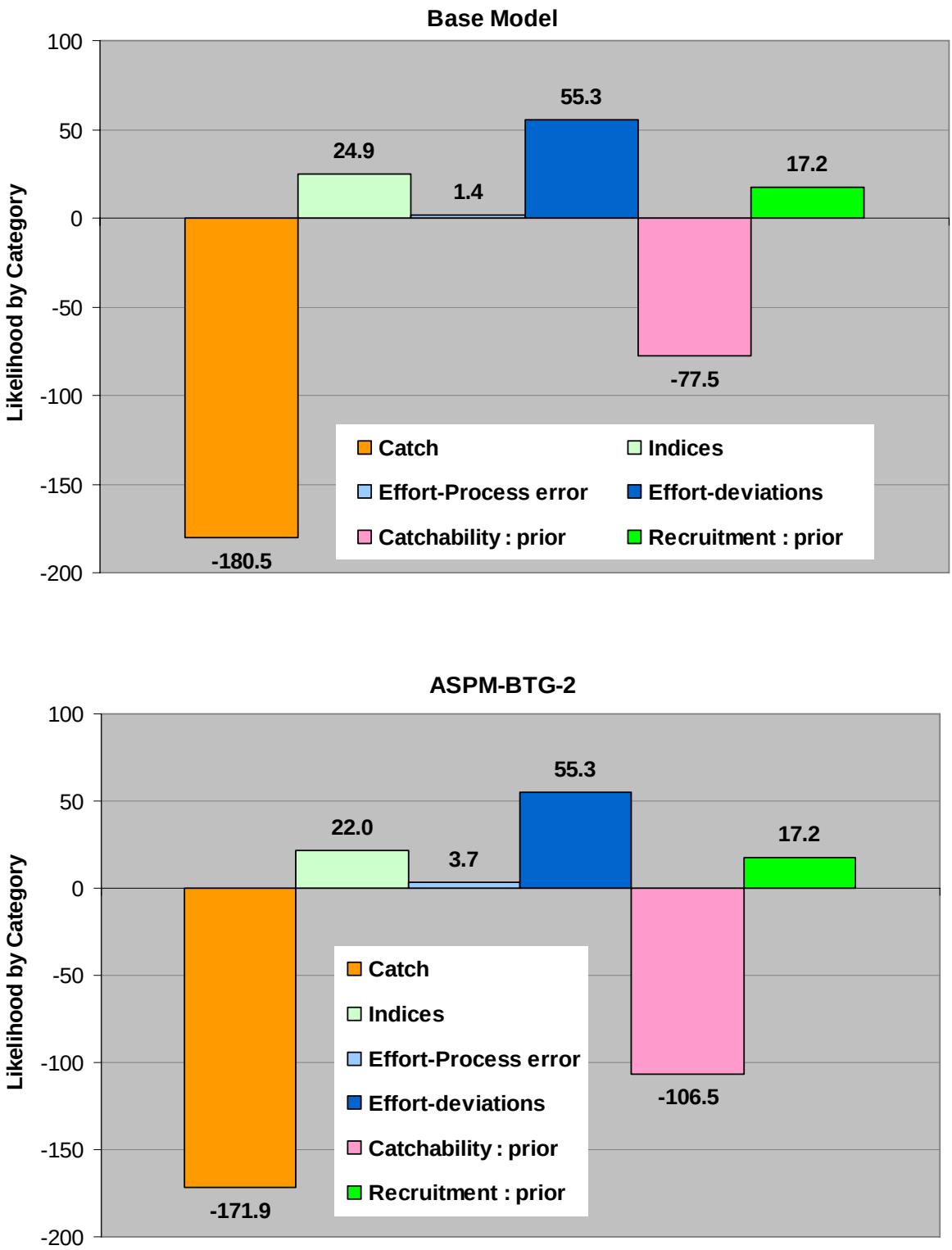


Figure 5.10. Contribution to relative likelihood by category for Gulf of Mexico blacktip sharks. The recruitment component includes both priors on virgin number of pups and pup survival.

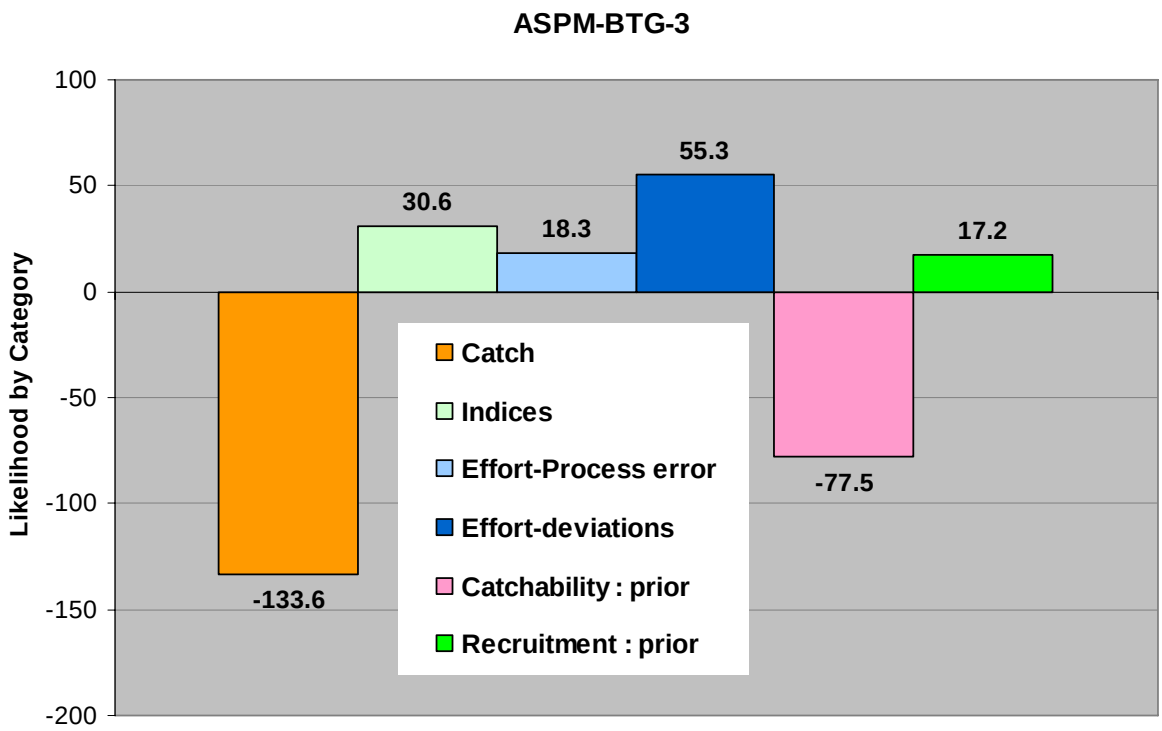
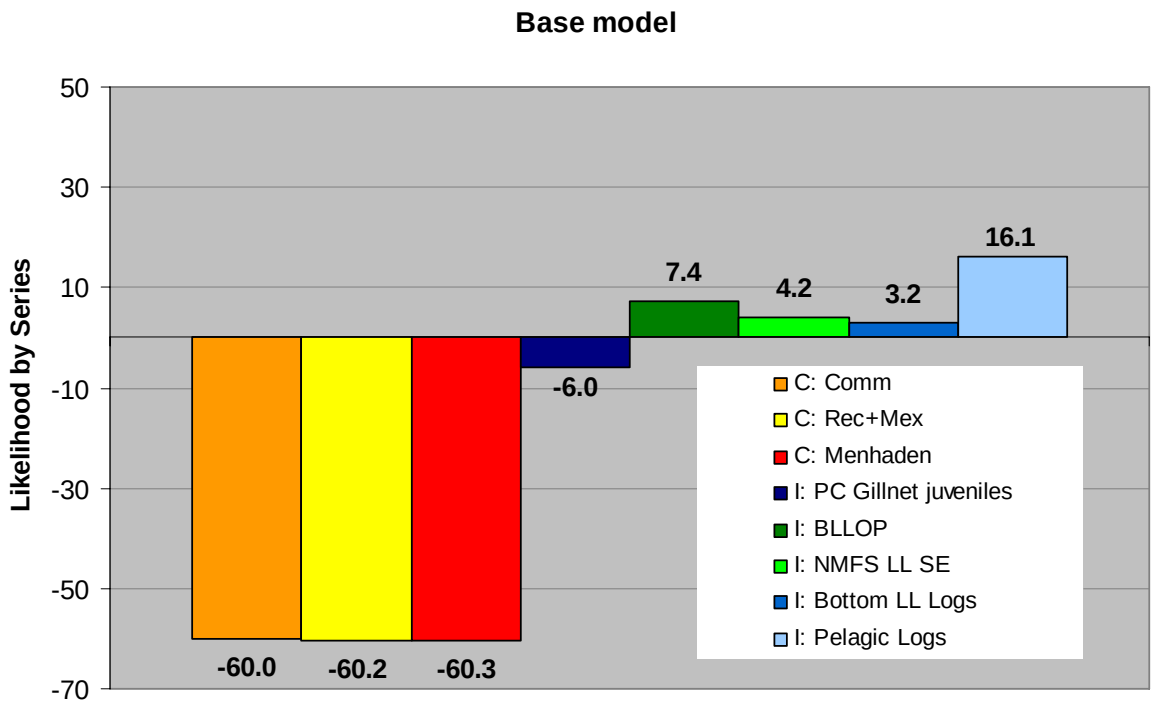


Figure 5.10 (continued)



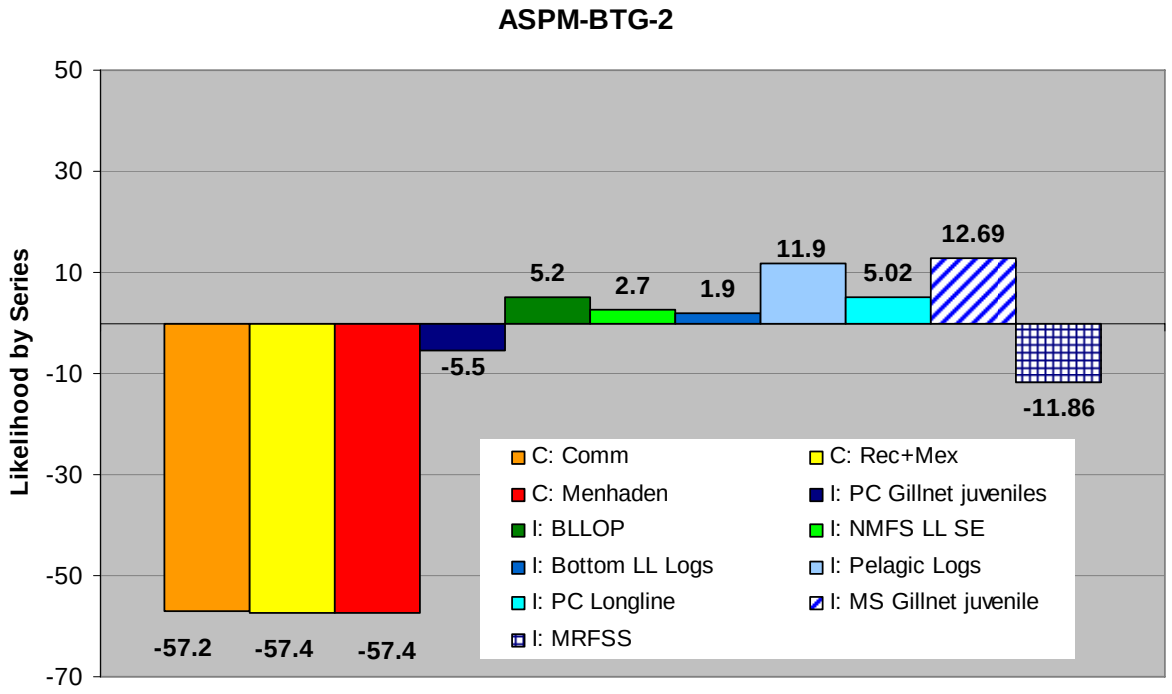


Figure 5.11. Contribution to relative likelihood by catch series and index series for Gulf of Mexico blacktip sharks.

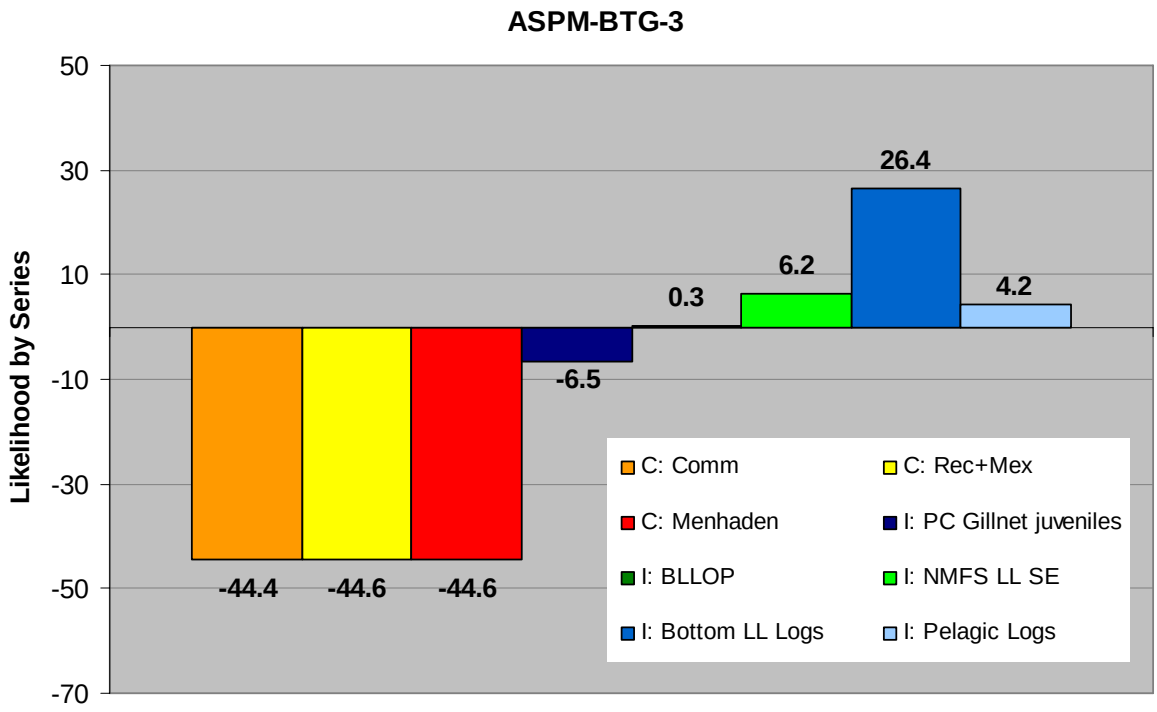


Figure 5.11 (continued)

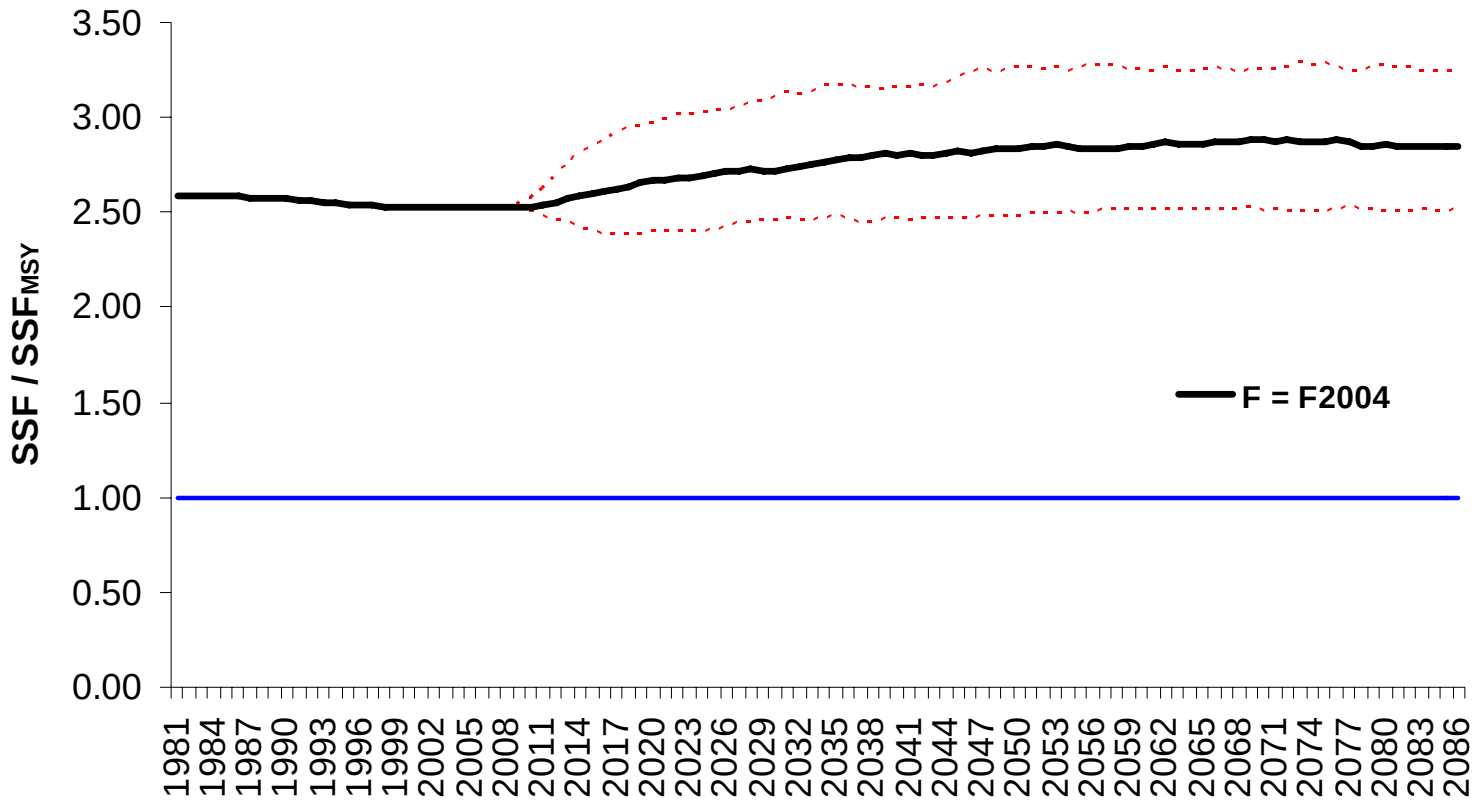


Figure 5.12. Projections at F_{2004} for Gulf of Mexico blacktip sharks. The dashed red lines represent the 10th percentile (lower) and the 90th percentile (upper), while the solid black line is the median of the bootstraps.

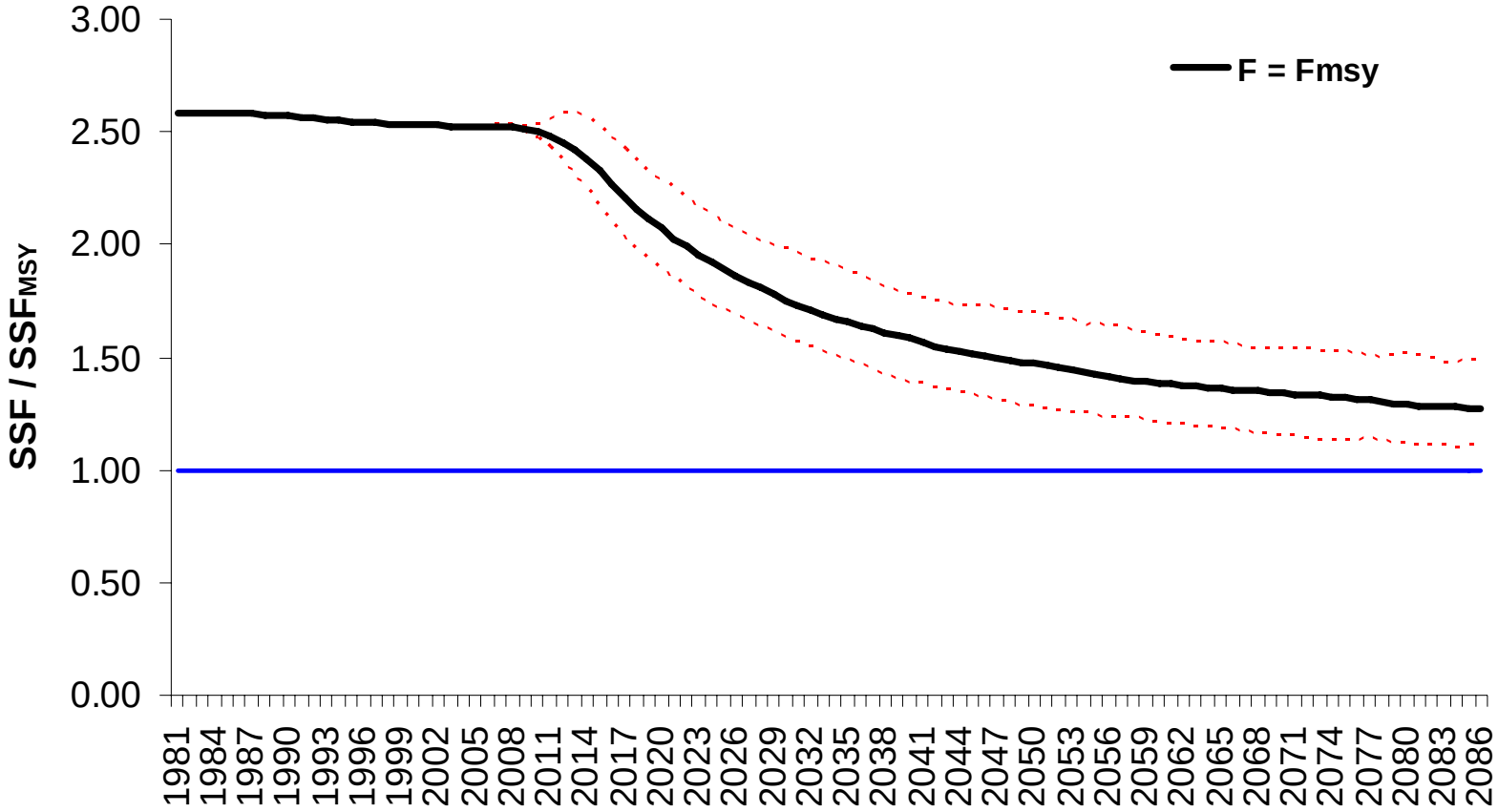


Figure 5.13. Projections at F_{MSY} for Gulf of Mexico blacktip sharks (years 2005-2007 used F_{2004}). The dashed red lines represent the 10th percentile (lower) and the 90th percentile (upper), while the solid black line is the median of the bootstraps.

NORTHWESTERN ATLANTIC OCEAN BLACKTIP SHARK STOCK ASSESSMENT

6. BLACKTIP SHARK NORTHWESTERN ATLANTIC OCEAN

6.1 Summary of Blacktip Shark Working Documents

SEDAR 11–AW–02
First results on the status of blacktip shark stock in the western Atlantic
Summary: The status of the stock of blacktip shark in the western North Atlantic was assessed using an age-structured population dynamics model in a Bayesian statistical framework. The model was run under different assumptions about key biological parameters, such as pup survival at low population densities and combination of CPUE series. There were several problems with the convergence of the model under most of the scenarios considered when the input data adopted in the data preparation workshop were used. For this reason, some changes were made in the input data after discussion during the stock assessment workshop. The results with the updated set of input values are presented here.

SEDAR 11–AW–04
Preliminary Runs of a State-Space, Age-Structured Production Model for Blacktip Shark
Summary: An age-structured production model was used to assess blacktip shark, the same that was used in the 2002 assessment. A continuity run was made using the 2002 assessment decisions about biology and stock structure. Base models for the 2006 assessment were then run for the Gulf of Mexico and the Atlantic Ocean separately, using decisions made at the data workshop. All runs reached the same conclusion that the stock is not overfished nor, for the most recent years, is overfishing occurring. A number of adjustments to biological inputs were necessary to achieve model convergence, and this point warrants further discussion at the assessment workshop.

SEDAR11-AW-05
Assessment of Large Coastal, Blacktip, and Sandbar Sharks using Surplus Production Methods
We used two complementary surplus production models (BSP and WinBUGS) to assess the status of three Large Coastal Shark (LCS) groupings, two stocks of blacktip shark, and a single stock of sandbar shark identified as baseline scenarios in the LCS Data Workshop report. Both methodologies use Bayesian inference to estimate stock status, and the BSP further performs Bayesian decision analysis to examine the sustainability of various levels of future catch. Extensive sensitivity analyses were performed with the BSP model to assess the effect of different assumptions on CPUE indices and weighting methods, catches, intrinsic rates of increase, initial depletion, and importance function on results. Baseline scenarios for the three LCS groupings considered predicted that the stock status is not overfished nor overfishing is occurring. Using the inverse variance method to weight the CPUE data changed the predictions on stock status for the LCS grouping, which would then be overfished, with overfishing occurring. The sandbar shark stock was estimated to be significantly depleted (64-71% depletion from virgin level). The Gulf of Mexico blacktip shark stock was healthy (depletion of only 8-23% of virgin level), whereas results for the Atlantic blacktip shark stock from the BSP and WinBUGS models conflicted. The BSP model predicted a considerable level of depletion for this stock regardless of the CPUE weighting method used. In contrast, the assessment of a single blacktip shark stock (GOM+ATL) resulted in very consistent results, with all models predicting a healthy status (depletions of only 10-16% of virgin level). Using the

higher values of r from the 2002 SEW or accounting for some depletion from virgin levels in the first year of the model did not affect conclusions. Several assumptions on catches (notably changing the high value of recreational catch in 1983) also had no effect on conclusions. Removing the VIMS CPUE series from the LCS scenario reversed the conclusions on stock status when using inverse variance weighting, highlighting the influence of this series on results; removing the PELAGIC LOG CPUE series from the ATL blacktip shark analysis also drastically reversed the conclusions on stock status. Fitting one CPUE series at a time had a larger effect on results: the PELAGIC LOG series greatly influenced conclusions for the three LCS groupings and GOM and ATL blacktip shark, whereas the VIMS series affected conclusions on the two groups for which it is available, LCS and sandbar shark.

6.2 Background

Blacktip and sandbar sharks are the two most important species in the fishery, and have been the subjects of species specific assessments in the past conducted through Shark Evaluation Workshops (SEWs). As such, the Panel was tasked with conducting species specific assessments for these species. The Data Workshop determined catch histories, relative abundance indices, and biological input parameters for three assessments: one stock of sandbar sharks and two stocks of blacktip sharks, one for the Gulf of Mexico and one for the northwestern Atlantic Ocean.

6.3 Available Models

Four models were available for discussion for the northwestern Atlantic Ocean blacktip shark assessment: two surplus production models, the BSP and WinBUGS models described previously, and two age-structured production approaches (Apostolaki et al. in press, Porch 2002).

6.4 Details about surplus production model and age-structured model

A surplus production model simulates the dynamics of a population using total population biomass as the parameter that reflects changes in population size relative to its virgin condition. In comparison to more complicated models, the surplus production model is simpler in its formulation, takes less time to run and requires less input information. However, due to its formulation, the surplus production model does not describe changes that occur in subgroups of the population (adults, juveniles, etc). In addition, the sensitivity of model predictions to key stage-dependent biological parameters cannot be evaluated using a surplus production model. Finally, surplus production models are not able to incorporate a lag time into the results.

An age-structured population dynamics model describes the dynamics of each age class in the population separately and therefore, requires age-specific input information. Due to the higher complexity of these models, they usually take longer to run and require a higher volume of information relative to simpler models. However, they can account for age-dependent differences in biology, dynamics and exploitation of fish and provide an insight into the structure

of the population and the processes that are more important at different life stages. They also allow for the incorporation of age-specific selectivity information.

With regard to management benchmarks, the surplus production model assumes that the population biomass that corresponds to MSY is always equal to half of the virgin population biomass, whereas the relative biomass at MSY calculated with an age-structured model (and other benchmarks associated to it) is species-specific and could be any fraction of virgin biomass.

The Assessment Panel decided to use the state-space, age-structured production model described in document SEDAR11-AW-04 for blacktip sharks in the northwestern Atlantic Ocean. This model was selected as it allowed for the incorporation of age-specific biological and selectivity information, along with the ability to produce required management benchmarks.

6.5 Discussion of weighting methods

The Data Workshop recommended that *equal weighting* for assigning weights to the different CPUE time series available during model fitting should be used for the baseline runs. The panel discussed the advantages and disadvantages of the *equal weighting* vs. the *inverse CV weighting* methods:

Equal weighting ignores the better quality of some data (smaller CVs) but is more stable between assessments because yearly changes on CVs in a given CPUE series do not affect the importance of that time series for the overall fit.

Inverse CV weighting can provide better precision as it tracks individual indices however, it could be less stable between assessments due to changes on the relative 'noise' of each time series. This method may also not be appropriate in cases in which different standardization techniques have been used for the standardization of the series and therefore, the same value of CV might reflect different levels of error depending on the CPUE it corresponds to.

It was requested by one Panelist to manually weight the indices that cover larger geographic areas to have a stronger influence on the model. The group commented that, while that may be possible in a spatially explicit model, a great deal more data would be required than presently available.

The Assessment Panel decided that equal weighting would be the default weighting method for the current assessment but noted that, as there is at present no objective way to decide which of these two methods is superior other than comparing model convergence diagnostics, future assessments may need to reexamine this issue.

6.6 New biological parameters derived during the assessment workshop

As discussed in SEDAR 11-AW-10, the values for life-history parameters that the data workshop determined to be the best estimates did not produce viable estimates for steepness (steepness was <0.2 for all stocks). The group reviewed the inputs that produce steepness (pup-survival, M at age for ages 1+, maturity at age, and pup-production at age), and determined that pup-production

and estimates of maturity should be known with greater certainty than estimates of mortality or pup survival. Therefore, in order to satisfy the lower bound on steepness, and to meet the data workshop recommendation that steepness should be between 0.2-0.4, the mode of the lognormal prior for pup survival was increased to 0.75 with a CV of 0.3. In addition, survival was increased by 10% for ages 1+ for the Gulf of Mexico stock, and by 7% for the Atlantic stock. The data workshop values for M at age as well as the values derived in plenary at the assessment workshop are given in Tables 6.1a and b, and plotted in Figure 6.1. Note that in the 2002 assessment, the same problem was encountered with the lower limit of steepness. In 2002, the base parameter values gave a steepness of about 0.18, so pup production was increased from 3.85 to 10, achieving a steepness of about 0.37. As noted in the 2002 report (p. 24), increasing the fixed level of pup production implies either that there is an unexploited portion of the population that is contributing pups, or that the pups are recruiting from a different population altogether (basically an open population model).

6.7 Methods

6.7.1 State-space, age-structured production model description

It was decided at the assessment workshop that the age-structured production model (SEDAR11-AW-04) would be used as the base model for the 2006 assessment. For northwestern Atlantic Ocean blacktip sharks, catches and one index begin in 1981, with the remaining indices beginning in the 1990s. No attempt was made to impute catches prior to the observed values in 1981. The model adopted derives equilibrium N at age for the first model year by estimating a level of historic fishing (F_{hist}). A historic selectivity vector is specified by the user, which is multiplied by F_{hist} to arrive at the historic age-specific fishing mortality rate. A historic selectivity vector of 1 for all ages was assumed.

Population Dynamics

The dynamics of the model are described below, and are extracted (and/or modified) from Porch (2002). This model formulation was the same utilized in the 2002 blacktip shark assessment. A value of historic fishing mortality, F_{hist}, can be estimated or fixed by the user. If F_{hist} is fixed at 0, then this implies that the population begins at virgin conditions. If F_{hist} is estimated or fixed to a value greater than 0, then the population begins in equilibrium at that level of F_{hist}. Given a vector of vulnerability at age for this level of historic fishing, $v_{hist,a}$, then the initial population structure is given by

$$(1) \qquad N_{a,y=1,m=1} = \begin{cases} R_{F_{hist}} & a = 1 \\ R_{F_{hist}} \exp(-\sum_{j=1}^{a-1}(M_j + F_{hist} v_{hist,j}) & 1 < a < A \\ \dfrac{R_{F_{hist}} \exp(-\sum_{j=1}^{A-1}(M_j + F_{hist} v_{hist,j})}{1 - \exp(-M_A - F_{hist} v_{hist,A})} & a = A \end{cases},$$

where $N_{a,y,1}$ is the number of sharks in each age class in the first model year (y=1), in the first month (m=1), M_a is natural mortality at age, A is the plus-group age, and recruitment (R) is assumed to occur at age 1.

The stock-recruit relationship was assumed to be a Beverton-Holt function, which was parameterized in terms of the maximum lifetime reproductive rate, α:

$$(2) \qquad R = \frac{R_0 S \alpha}{S_0 + (\alpha - 1)S} \quad .$$

In (2), R_0 and S_0 are virgin number of recruits (age-1 pups) and spawners (units are number of mature adult females times pup production at age), respectively. The parameter α is calculated as:

$$(3) \qquad \alpha = e^{-M_0}\left[\left(\sum_{a=1}^{A-1} p_a m_a \prod_{j=1}^{a-1} e^{-M_a}\right) + \frac{p_A m_A}{1-e^{-M_A}} e^{-M_A}\right] = e^{-M_0}\varphi_0 \quad ,$$

where p_a is pup-production at age a, m_a is maturity at age a, and M_a is natural mortality at age a. The first term in (3) is pup survival at low population density (Myers et al. 1999). Thus, α is virgin spawners per recruit (φ_0) scaled by the slope at the origin (pup-survival).

At equilibrium, spawners per recruit with fishing is simply:

$$(4) \qquad \varphi_F = \left[\left(\sum_{a=1}^{A-1} p_a m_a \prod_{j=1}^{a-1} e^{-M_a - Fv_a}\right) + \frac{p_A m_A}{1-e^{-M_A - Fv_A}} e^{-M_A - Fv_A}\right] = \frac{S_F}{R_F} \quad ,$$

where R_F and S_F are the equilibrium recruits and spawners, respectively, F is the level of fishing, and v_a is the age-specific vulnerability to fishing. From (4) and (2), we have

$$(5) \qquad R_F = \frac{S_F}{\varphi_F} = \frac{R_0 S_F \alpha}{S_0 + (\alpha - 1)S_F} \quad .$$

Equation (5) can be solved for S_F, and then R_F is simply S_F/φ_F, which allows calculation of the initial number of pups under a non-zero amount of historic fishing:

$$(6) \qquad R_{F_{hist}} = \frac{R_0 \alpha \varphi_F - S_0}{(\alpha - 1)\varphi_F} \quad .$$

Note that if F_{hist} is positive, then in order for $R_{F_{hist}}$ to be positive, we must have the following condition:

$$(7) \qquad \alpha > \frac{S_0}{R_0 \varphi_{F_{hist}}} = \frac{\varphi_0}{\varphi_{F_{hist}}} \quad or \quad \frac{1}{\alpha} < \frac{\varphi_{F_{hist}}}{\varphi_0} \quad .$$

Effectively, condition (7) implies that the level of SPR corresponding to F_{hist} must be greater than $1/\alpha$. For populations where α is near the lower bound of 1, this implies that the level of F_{hist} must be minimal.

Beyond the initial numbers in each age class as defined in (1), abundance at the beginning of subsequent months is calculated by

$$(8) \qquad N_{a,y,m+1} = N_{a,y,m} e^{-M_a \delta} - \sum_i C_{a,y,m,i} \quad ,$$

where δ is the fraction of the year (m/12) and $C_{a,y,m,i}$ is the catch in numbers of fleet i. The monthly catch by fleet is assumed to occur sequentially as a pulse at the end of the month, after natural mortality:

$$(9) \qquad C_{a,y,m,i} = F_{a,y,i} \left(N_{a,y,m} e^{-M_a \delta} - \sum_{k=1}^{i-1} C_{a,y,m,k} \right) \frac{\delta}{\tau_i} \quad ,$$

where τ_i is the duration of the fishing season for fleet i. Catch in weight is computed by multiplying (9) by $w_{a,y}$, where weight at age for the plus-group is updated based on the average age of the plus-group.

The fishing mortality rate, F, is separated into fleet-specific components representing age-specific relative-vulnerability, v, annual effort expended, f, and an annual catchability coefficient, q:

$$(10) \qquad F_{a,y,i} = q_{y,i} f_{y,i} v_{a,i} \quad .$$

Catchability is the fraction of the most vulnerable age class taken per unit of effort. The relative-vulnerability would incorporate such factors as gear selectivity, and the fraction of the stock exposed to the fishery. For this model application to blacktip sharks, both vulnerability and catchability were assumed to be constant over years.

Catch per unit effort (CPUE) or fishery abundance surveys are modeled as though the observations were made just before the catch of the fleet with the corresponding index, i:

$$(11) \qquad I_{y,m,i} = q_{y,i} \sum_a v_{a,i} \left(N_{a,y,m} e^{-M_a \delta} - \sum_{k=1}^{i-1} C_{a,y,m,k} \right) \frac{\delta}{\tau_i} \qquad .$$

Equation (11) provides an index in numbers; the corresponding CPUE in weight is computed by multiplying $v_{a,i}$ in (11) by $w_{a,y}$.

State space implementation

Process errors in the state variables and observation errors in the data variables can be modeled as a first-order autoregressive model:

$$(12) \qquad \begin{aligned} g_{t+1} &= E[g_{t+1}] e^{\varepsilon_{t+1}} \\ \varepsilon_{t+1} &= \rho \varepsilon_t + \eta_{t+1} \end{aligned} \qquad .$$

In (12), g is a given state or observation variable, η is a normal-distributed random error with mean 0 and standard deviation σ_g, and ρ is the correlation coefficient. E[g] is the deterministic expectation. When g refers to data, then g_t is the observed quantity, but when g refers to a state variable, then those g terms are estimated parameters.

The variances for process and observation errors (σ_g) are parameterized as multiples of an overall model coefficient of variation (CV):

$$(13a) \qquad \sigma_g = \ln\left[(\lambda_g CV)^2 + 1\right]$$

$$(13b) \qquad \sigma_g = \ln\left[(\omega_{i,y} \lambda_g CV)^2 + 1\right] \qquad .$$

The term λ_g is a variable-specific multiplier of the overall model CV. For catch series and indices (equation 13b), the additional term, $\omega_{i,y}$, is the weight applied to individual points within those series. For instance, because the indices are standardized external to the model, the estimated variance of points within each series is available and could be used to weight the model fit. Given the data workshop decision to use equal weighting between indices, all $\omega_{i,y}$ were fixed to 1.0 and the same λ_g was applied to all indices. To evaluate the sensitivity case where indices were weighted by the inverse of their CV, each $\omega_{i,y}$ was fixed to the estimated CV for point *y* in series *i*; an attempt was also made to estimate a separate λ_g for each series, however those multipliers were not estimable and so a single λ was applied to all indices.

In the present model, these multipliers on catches and indices were fixed after exploring the effects on model outputs for several different values. A fleet-specific effort constant was estimated, but by allowing for large process error it was effectively a free parameter (a value of 10 times the overall model CV was used); the correlation was fixed at 0.

6.7.2 Data inputs, prior probability distributions, and performance indicators

Baseline scenario (ASPM-BASE)

The base model represented the decisions made by the data workshop as well as any additional decisions or modifications made by the assessment workshop. Data inputted to the model included maturity at age, fecundity at age (pups per mature female), spawning season, catches, indices, and selectivity functions (Tables 6.1a and b, 6.2, and 6.3; Figures 6.1-6.4). Catches were made by the commercial and the recreational sector. In addition, estimates of unreported commercial catches were provided by the DW. Unlike the sandbar and Atlantic blacktip stocks, there were no menhaden discards, and no Mexican catches. Because of similar selectivity functions, the commercial and unreported catches were combined, yielding a model with 2 distinct "fleets". A total of 7 indices for the Atlantic were available; one of these included age 0. As this model began with age class 1, none of the indices designated as sampling "age 0" were used. This left 4 indices for the base case, and 2 sensitivity indices (Figure 6.2).

Selectivities are imputed in the age-structured surplus production model (as a functional form) and linked to each individual catch or CPUE series. Individual selectivity functions to be applied to catch series were identified by the DW catch working group based on information used in previous assessments, length frequency data presented at the DW, and the collective knowledge of shark fisheries of the group members. The selectivity recommendations can be found on pages 38-39 of the DW report. Selectivities linked to individual catch series were a compromise because the series often encompass various components of the fishery (e.g., commercial + unreported selectivity refers to commercial fisheries, most of which are bottom longline fisheries, but also include pelagic longline and drift gillnet fisheries, which are likely to have somewhat different selectivity patterns). The selectivity functions identified were then applied to the individual CPUE series based on the type of index represented (e.g., the BLLOP and VA LL indices were assigned the commercial + unreported logistic selectivity function because both indices use bottom longline gear).

-Commercial landings + unreported catch series: a logistic curve was selected based on the 2002 SEW assessment. The rationale was that younger ages were relatively less selected by the commercial gear as a whole, which as stated above may also include pelagic longline gear that is set in deeper waters where juveniles are less available, and drift gillnet gear that uses large mesh sizes targeting adults (Figure 6.3)

-Recreational: this selectivity pattern was largely based on the MRFSS, which includes data from recreational anglers fishing in nearshore waters and targeting mostly juveniles. Based on this, very limited length-frequency information presented in document LCS05/06-DW-16, and information from the 2002 SEW assessment, selectivity for blacktip sharks was fixed at 1 for ages 0 and 1 and rapidly decreased thereafter to reflect the fact that larger and older sharks are progressively less targeted (Figure 6.3).

Catch data begin in 1981 and the earliest base case index begins in 1992 (Pelagic Logs). The base case model in 2002 attempted to estimate a level of historic F, so an attempt was made to estimate F_{hist} for the base model this time. Initial model runs found that F_{hist} was difficult to estimate or it converged to near 0. Therefore, for all runs discussed here, F_{hist} was fixed to 0, which implies that the stock was unexploited prior to 1981.

Individual points within catch and index series can be assigned different weights, based either on estimated precision or expert opinion. All points within each catch series were given the same weight; likewise, all points within each index series were given the same weight.

One further model specification was the degree to which the model-predicted values matched catches versus indices. An overall model CV is estimated (see equations 13a and 13b), and multiples (λ_g) of this overall CV can be specified separately for catches and indices (see Porch 2002). All catch series were assigned a single CV multiple, and all indices were assigned a single CV multiple (this forces equal weighting of the indices). Initially, an attempt was made to estimate these multipliers. This resulted in boundary solutions for the multipliers. In a second attempt, the multiplier for catch was fixed at 1 and the index multiplier was estimated. Again, this resulted in the index multiplier estimate at the upper bound. Several values were evaluated for the CV multiplier of indices: a value that was 1, 4, or 5 times the catch CV multiplier. A value of 1 implies the same relative certainty in catches and indices; the remaining values imply that indices are less certain than catches. In the 2002 assessment, a value of 4 was used. In this assessment, model convergence was not obtained (Hessian could not be estimated) for values of 1, or 4, but was obtained for a value of 5. The point estimates for all weighting levels tried (even those that did not converge) concluded that the stock was not overfished and that there was no overfishing. The relative status estimates displayed some spread, however, that depended on the CV multiplier. Although these reported ranges reflect results from models that did not converge, they are mentioned primarily because the index fits showed a slight downward trend rather than the flat trend for the model that actually converged. Basically, forcing the model to fit the indices as well as catch reduced the relative biomass and increased the relative F benchmark (i.e., closer to overfished and closer to overfishing). Given that there was no convergence for a value less than 5, and that this value is close to the value used in 2002, the weighting scheme selected was to fit catches 5 times better than indices. Placing less certainty in indices relative to catch is further justified when one considers the lack of a consistent signal. The base indices show flat, increasing, or decreasing trends with fairly large annual changes (Figures 6.2 and 6.4). It is likely that one reason the model runs with CV multipliers <5 did not converge is that the model could not reconcile a better fit to those conflicting indices. Of the sensitivity indices, MRFSS is the longest index (it begins in 1981), and the average trend is flat over the time period, although there are large interannual fluctuations. CV multipliers greater than 5 were not evaluated for the indices, as the model-predicted trend was already a poor fit.

Estimated model parameters were pup survival, virgin recruitment (R_0), catchabilities associated with catches and indices, and fleet-specific effort. Natural mortality at ages 1+ was fixed at the updated values (Table 6.1a), and the priors for pup survival and virgin recruitment are listed in Table 6.1b.

In summary, the base model configuration assumed virgin conditions in 1981, used the data workshop recommended biological parameters, the updated survival at age, the updated prior for pup survival, and the base case indices with an updated Pelagic Longline Log index (referred to as Pelagic Log). Catches were assumed to be 5 times more certain than the indices. All inputs are given in Tables 6.1a and b, 6.2, and 6.3. Base indices are in black font in Table 6.3.

Performance indicators included estimates of absolute population levels and fishing mortality for year 2004 (F_{2004}, SSF_{2004}, B_{2004}, $Nmature_{2004}$), population statistics at MSY (F_{MSY}, SSF_{MSY},

SPR_{MSY}), current status relative to MSY levels, and depletion estimates (current status relative to virgin levels). In addition, trajectories for F_{year}/F_{MSY} and SSF_{year}/SSF_{MSY} were plotted.

6.7.3 Methods of numerical integration, convergence diagnostics, and decision analysis

Numerical integration for this model was done in AD Model Builder (Otter Research Ltd. 2001), which uses the reverse mode of AUTODIF (automatic differentiation). Estimation can be carried out in phases, where convergence for a given phase is determined by comparing the maximum gradient to user-specified convergence criteria. The final phase of estimation used a convergence criterion of 10^{-6}. For models that converge, the variance-covariance matrix is obtained from the inverse Hessian. Model fit was assessed by comparing components of the relative negative log-likelihood (relative rather than exact because constants in the likelihood were not included). The relative negative log-likelihood (objective function) and AICc (small sample AIC) values are listed in the table of model results.

6.7.4 Sensitivity analyses

Given the assessment workshop consensus that the stock status could not be determined, no sensitivity analyses were conducted.

6.8 Results

6.8.1 Baseline scenario

The base model estimated a stock that was not overfished and there was no overfishing occurring (Tables 6.4 and 6.5; Figure 6.5). The model estimate of F by fleet is dominated by the recreational fleet in the 1980s, and to a lesser extend in the 1990s. The landings are also dominated by the recreational fleet in the1980s, by the commercial fleet for most of the 1990s, and the fleets are more or less on par in recent years (Figure 6.6). Model fits to catches and indices are shown in Figures 6.7 and 6.8. Catches are fit very well. The base indices span at most 13 years, and the model predicts a relatively flat trend through the observed points. The flat trend predicted for the indices reflects the estimated flat change in biomass over time, implying that the stock has barely changed since 1981. A CV of about 0.54 was estimated for virgin pup production, and current measures of total biomass, number mature, spawning stock fecundity (SSF), and fishing mortality. No CV is given for steepness or α as these parameters are calculated directly from pup survival and virgin spawners per recruit rather than estimated. Relative estimates of depletion (the ratio of current to virgin level) are very precise, but current abundance estimates are correlated to the estimate of the virgin level. The estimate of pup survival did not move from the prior specification, indicating that there is probably little to no information in the data from which to estimate this parameter. No likelihood profiling was pursued.

A phase-plot of stock-status shows the outcomes of the base model, the continuity analysis (assuming a single stock), the estimates from BSP and WinBUGS, and the alternative age structured production model discussed in SEDAR10-AW-02 (Figure 6.9). Note that the x values for BSP and WinBUGS are in numbers of fish (N_{2004}/N_{MSY}) rather than SSF_{2004}/SSF_{MSY}. These

values from BSP and WinBUGS should be comparable, however, because they are relative statistics, and they only differ from the ASPM by the maturity ogive. The alternative age structured production model differs slightly in the relative F benchmark, as it gives the ratio of harvest rate relative to that rate at MSY. The range of outcomes spans the upper left quadrant (overfished with overfishing) and the bottom right (not overfished, with no overfishing).

6.8.2 Sensitivity analyses

No sensitivity analyses were conducted.

6.8.3 Comparison of model fits

The relative likelihood values by model source (catch, indices, effort, catchability, and recruitment) as well as a breakdown of likelihood by individual catch and index series are shown in Figure 6.10. Comparing the likelihood by index, the Bottom Longline Observer Program (BLLOP) index has the poorest fit. It is noted that the BLLOP and Bottom LL Logs have the same trend for the years of overlap (1996-2004), although interannual changes are greater for BLLOP. It is possible that the magnitude between annual changes is more pronounced in the BLLOP index as a result of smaller sample size (coverage is typically 2 -3 % of the fishery). While the likelihood for the indices other than BLLOP indicates a relatively better fit, the predicted values are nearly flat and capture no trend.

6.9 Projections of the base model

Given the uncertainty in assessment results, no projections were done. The estimate of generation time is about 18 years.

Generation time was calculated as

$$GenTime = \frac{\sum_i i f_i \prod_{j=1}^{i-1} s_j}{\sum_i f_i \prod_{j=1}^{i-1} s_j}$$

where i is age, f_i is the product of(fecundity at age) x (maturity at age), and s_j is survival at age. The calculations were carried out to an age, A, such that the difference between performing the calculation to age A or A+1 was negligible. This calculation is consistent with the assessment model, which treats survival of the plus group as the sum of a geometric series (e.g., see third line in equation 1). The 2006 maturity ogive was used, 4.4 pups per female was the fecundity for all ages, adjusted age-specific survival at age was used (see section 6.6), and the mode of 0.75 for the prior on pup survival was used. As was done in the assessment model, to account for the approximately 1 year gestation period, maturity at age was shifted by 1 year, and the number of pups was halved to account for the fact that only half of the mature population would reproduce in a given year. Note that because pup-production is constant for all ages, it factors out of both

numerator and denominator, and the resulting estimate of generation time is insensitive to that value.

6.10 Continuity analysis

A continuity base model was run using the 2002 state-space age structured production model (described above under methods). In 2002, blacktip was assessed as a single stock. F_{hist} was fixed at 0, all indices were used and given equal weighting; an age-constant M was estimated; catches for Gulf of Mexico and northwestern Atlantic Ocean combined (Table 5.6); 2002 biological parameters used; 10 pups per mature female was used for fecundity. Available combined blacktip stock indices and values can be found in Appendix 1.

The continuity model estimated a stock status of no overfishing, and not overfished. This model was not truly continuity per se, because the previous assessment had treated blacktip as one stock, and different indices had been available. It also differs from the 2006 base model because the biological parameters were adjusted differently to elevate the steepness parameter above 0.2. Nevertheless, the estimate of stock status in 2002, in this continuity analysis, and in the 2006 base model all concluded that the stock does not appear to be overfished, nor does it appear that there is overfishing. All of these estimates were fairly imprecise, though.

6.11 Discussion

There was some uncertainty associated with the biological parameters, which led to the AW updating the fixed values for M at age, and the mode of the prior for pup-survival (corresponding to density-independent level). The configuration of this model estimated that the stock was not overfished and that there is no overfishing. Other models at the assessment workshop estimated the stock to be overfished with overfishing (Figure 6.9). It was noted that the number of indices and the available time series of those indices were very limited (starting in 1992 at the earliest for base indices), while catch time series are about twice as long (they begin in 1981). An important concern expressed during the assessment workshop is that those limited indices, which cover the same time period and which are assigned the same selectivity vector, have conflicting trends. The model-predicted fits to those indices were essentially flat, and therefore the group expressed limited amount of confidence in the model results. In addition to the conflicting indices, the estimated status differed between assessment models. As a result of the conflicting, limited data, and the conflicting results between models, the group reached consensus that the status of blacktip in the northwestern Atlantic Ocean was uncertain.

6.12 References

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Table 6.1a. Northwestern Atlantic Ocean blacktip biological inputs from 2002 assessment, 2006 base case values from the data workshop, or values updated at the 2006 assessment workshop. In the continuity case, M was estimated, while in the 2006 base cases, M at age values were fixed. The * for the age 0 entries in the first three columns is to distinguish those values as survival rates rather than natural mortality rates.

Age	M 2002	M 2006	M 2006 Updated	Female Maturity 2002	Female Maturity 2006	Pups-per-Female 2002	Pups-per-Female 2006
0	0.52*	0.52*	0.75*	0	0	0	0
1	0.22	0.287	0.219	0	0	10	3.2
2	0.22	0.252	0.185	0	0	10	3.2
3	0.22	0.229	0.161	0.02	0.001	10	3.2
4	0.22	0.212	0.144	0.09	0.004	10	3.2
5	0.22	0.199	0.132	0.35	0.02	10	3.2
6	0.22	0.19	0.122	0.74	0.095	10	3.2
7	0.22	0.182	0.115	0.94	0.354	10	3.2
8	0.22	0.177	0.109	0.99	0.741	10	3.2
9	0.22	0.172	0.104	1	0.937	10	3.2
10	0.22	0.168	0.1	1	0.987	10	3.2
11	0.22	0.165	0.097	1	0.998	10	3.2
12	0.22	0.162	0.095	1	1	10	3.2
13	0.22	0.16	0.093	1	1	10	3.2
14	0.22	0.159	0.091	1	1	10	3.2
15	0.22	0.157	0.089	1	1	10	3.2

Table 6.1b. Additional parameter specifications for northwestern Atlantic Ocean blacktip shark. Weight units are kg.

Parameter	Value	Prior
L_∞	159(cm FL)	*constant*
K	0.16	*constant*
t_0	-3.432	*constant*
a	2.51E-09	*constant*
b	3.13	*constant*
F_{hist}	0	*constant*
Historic Selectivity	1 for all ages	*constant*
Pups-per-mature female	3.2	*constant*
Pup Survival	0.75 (mode)	~LN with CV=0.30
Virgin Recruitment (R_0)	1.50E+06	~U on [1.0E+3, 1.0E+9]

Table 6.2. Catches of blacktip shark by fleet in the northwestern Atlantic Ocean. Units are numbers of sharks.

Year	Commercial + Unreported	Recreational
1981	551	4,498
1982	551	28,050
1983	595	29,299
1984	813	16,099
1985	755	53,267
1986	4,172	13,626
1987	8,573	46,660
1988	4,025	19,662
1989	3,872	21,793
1990	4,896	7,174
1991	75,319	40,613
1992	97,190	19,627
1993	71,522	12,824
1994	81,244	15,941
1995	66,295	19,431
1996	41,901	27,867
1997	36,023	16,336
1998	32,418	21,499
1999	6,807	8,850
2000	9,667	6,753
2001	9,654	14,945
2002	20,634	5,277
2003	18,355	30,063
2004	13,397	4,278

Table 6.3. Indices available for use in the current northwestern Atlantic Ocean blacktip shark assessment. Sensitivity indices in green (last 3 columns).

Year	Gillnet Observer	BLLOP	Bottom LL Logs	Pelagic Log	SC LL Recent	NMFS LL NE	MRFSS
1981							1.046
1982							0.531
1983							1.186
1984							1.145
1985							1.285
1986							1.427
1987							0.755
1988							0.578
1989							0.567
1990							0.421
1991							0.748
1992				3.389			1.243
1993	0.455			2.373			0.523
1994	0.955	0.805		2.019			2.264
1995	0.419	2.042		0.924	1.75		1.039
1996		1.246	0.678	0.785	0.808	0.202	0.986
1997		0.131	0.474	0.603	2.094		0.515
1998	1.286	0.534	0.689	0.36	0.487	1.578	1.183
1999	1.384	0.426	0.423	0.411	0.482		0.536
2000	1.286	0.153	1.005	0.392	1.147		0.877
2001	1.001	0.971	1.62	0.263	0.232	0.797	1.73
2002	0.982	4.578	1.948	0.434			1.196
2003	1.029	0.004	1.081	0.494			1.249
2004	1.204	0.111	1.083	0.55		1.423	0.969
Ages Vulnerable							
	all	all	all	all	0-5	all	young
Selectivity Vector							
	Comm+Unrep	Comm+Unrep	Comm+Unrep	Comm+Unrep	not used	Comm+Unrep	MRFSS

Table 6.4. Results for the base model run for northwestern Atlantic Ocean blacktip using the updated biological parameters. Pups-virgin is the number of age 1 pups at virgin conditions. SSF is spawning stock fecundity, which is the sum of number mature at age times pup-production at age (rather than SSB, since biomass does not influence pup production in sharks). AICc is the small sample Akaike Information Criterion, which converges to the AIC statistic as the number of data points gets large.

Parameter	Base Est	CV
AICc	-99.96	
Objective Function	-2.51E+02	
MSY (kg)	1.49E+07	--
$Pups_{virgin}$	6.27E+06	0.53
SSF_{2004}	1.82E+07	0.54
$Nmature_{2004}$	1.09E+07	0.54
B_{2004}	1.23E+09	0.54
B_{2004}/B_{virgin}	0.89	0.01
SSF_{2004}/SSF_{virgin}	0.94	0.01
$Nmature_{2004}/Nmature_{virgin}$	0.9	0.01
SSF_{2004}/SSF_{MSY}	2.51	0.32
SPR_{MSY}	0.62	--
F_{2004}	0.001	0.53
F_{MSY}	0.2	--
F_{2004}/F_{MSY}	0.01	0.53
Pup-survival	0.82	0.29
alpha	2.41	--
steepness	0.38	--

Table 6.5. Estimates of total number, spawning stock fecundity, and fishing mortality by year for base model for blacktip shark in the northwestern Atlantic Ocean.

Year	N(year)	SSF(year)	F(year)
1981	50,996,300	18,484,000	0.001
1982	50,992,000	18,484,000	0.004
1983	50,967,100	18,483,000	0.004
1984	50,943,700	18,483,000	0.002
1985	50,936,300	18,482,000	0.007
1986	50,895,800	18,480,000	0.002
1987	50,893,900	18,475,000	0.006
1988	50,855,600	18,467,000	0.003
1989	50,849,800	18,458,000	0.003
1990	50,841,700	18,449,000	0.001
1991	50,844,500	18,422,000	0.005
1992	50,745,900	18,372,000	0.003
1993	50,649,800	18,325,000	0.002
1994	50,587,100	18,284,000	0.002
1995	50,514,100	18,247,000	0.003
1996	50,453,400	18,221,000	0.004
1997	50,411,500	18,205,000	0.002
1998	50,389,100	18,193,000	0.003
1999	50,365,100	18,190,000	0.001
2000	50,380,300	18,194,000	0.001
2001	50,392,900	18,198,000	0.002
2002	50,396,100	18,197,000	0.001
2003	50,398,200	18,194,000	0.004
2004	50,378,500	18,194,000	0.001

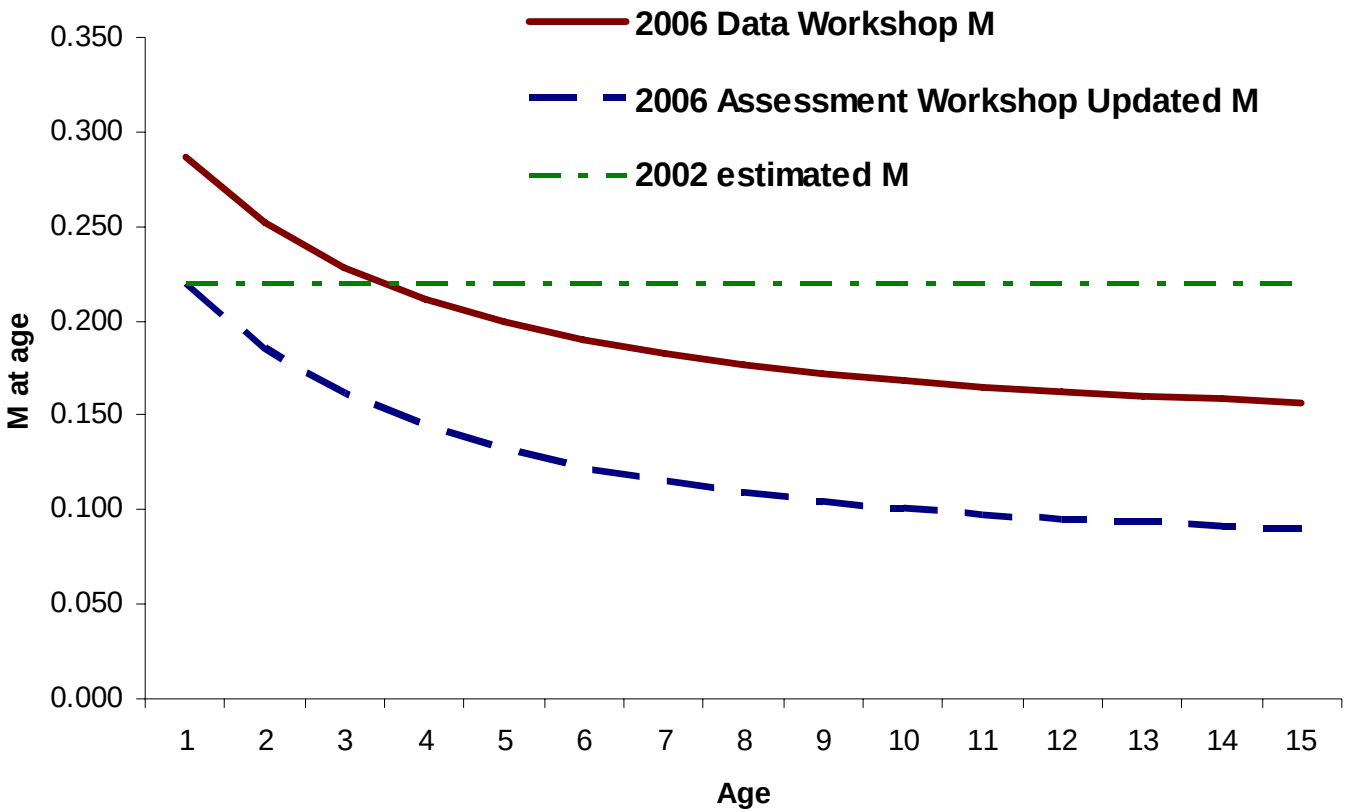


Figure 6.1. Comparison of natural mortality recommended by the data workshop (DW, solid line) and that agreed to in plenary at the assessment workshop (AW, dashed line) for northwestern Atlantic Ocean blacktip sharks.

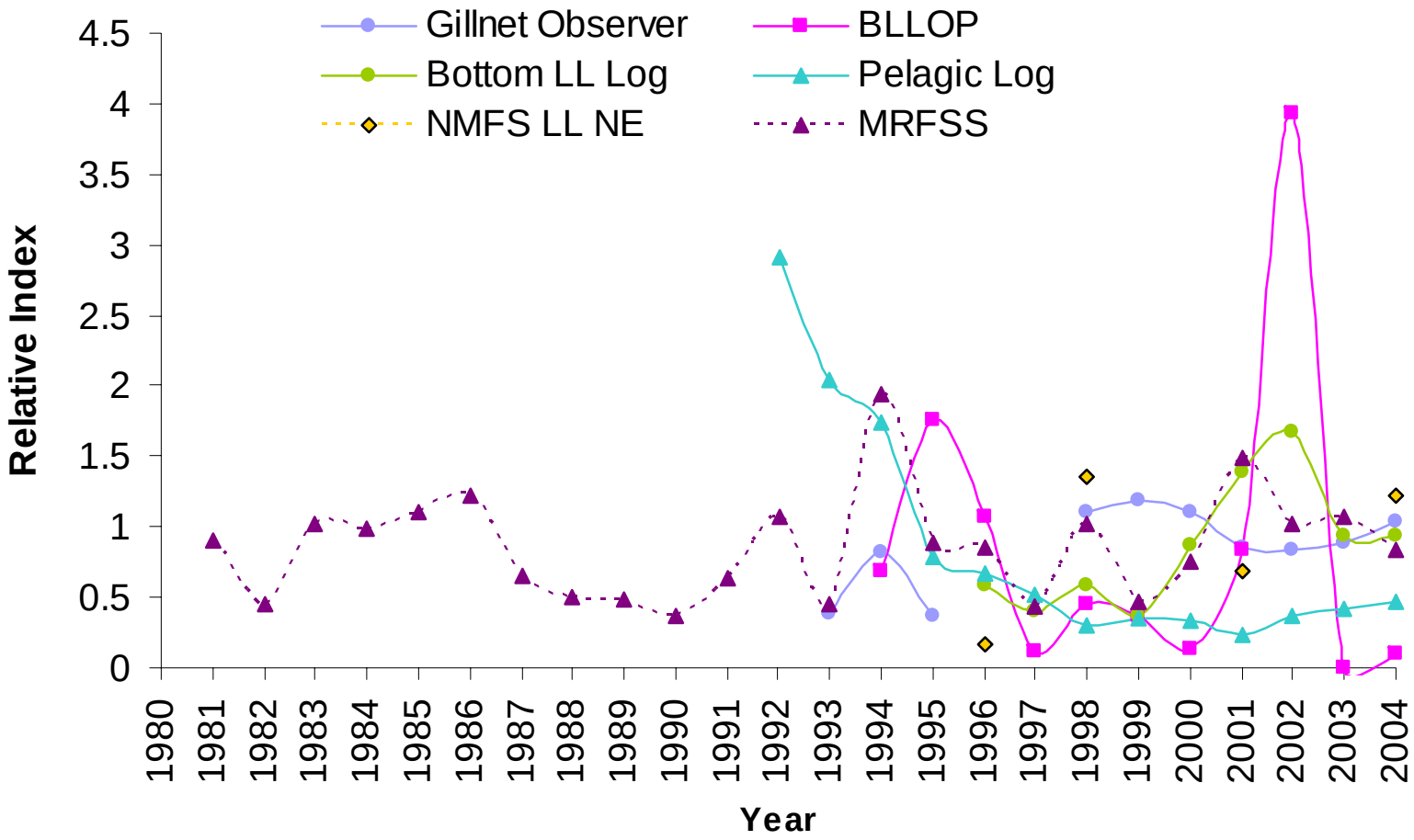


Figure 6.2. Indices available for the current northwestern Atlantic Ocean blacktip shark assessment. Indices are scaled by the value for 1998 (the only year of overlap).

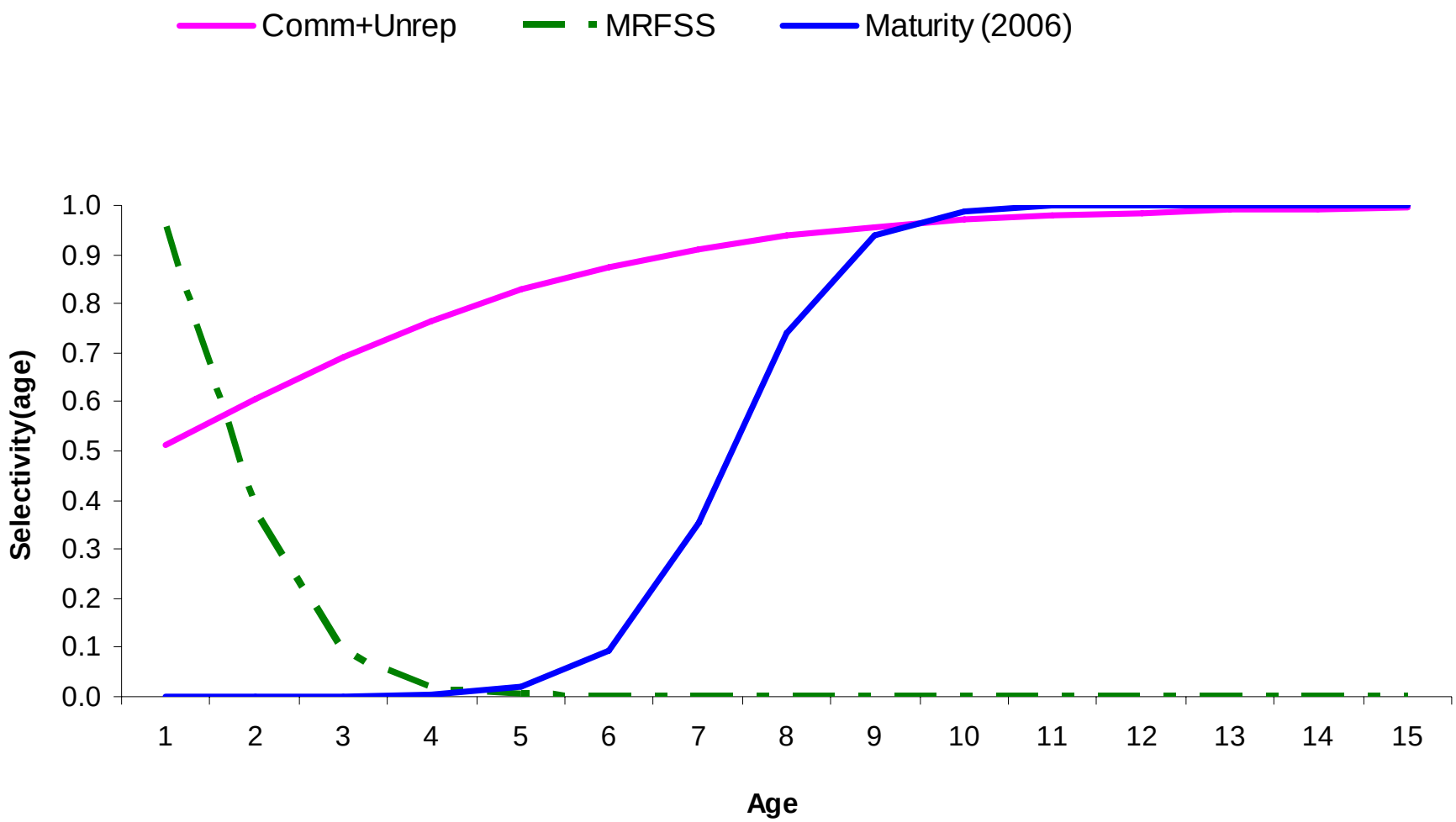


Figure 6.3. Selectivities used in northwestern Atlantic Ocean blacktip assessment, with the maturity ogive (solid blue line) as decided at the data workshop. Labels are consistent with the last row in Table 6.3 (all indices available for blacktip Atlantic)

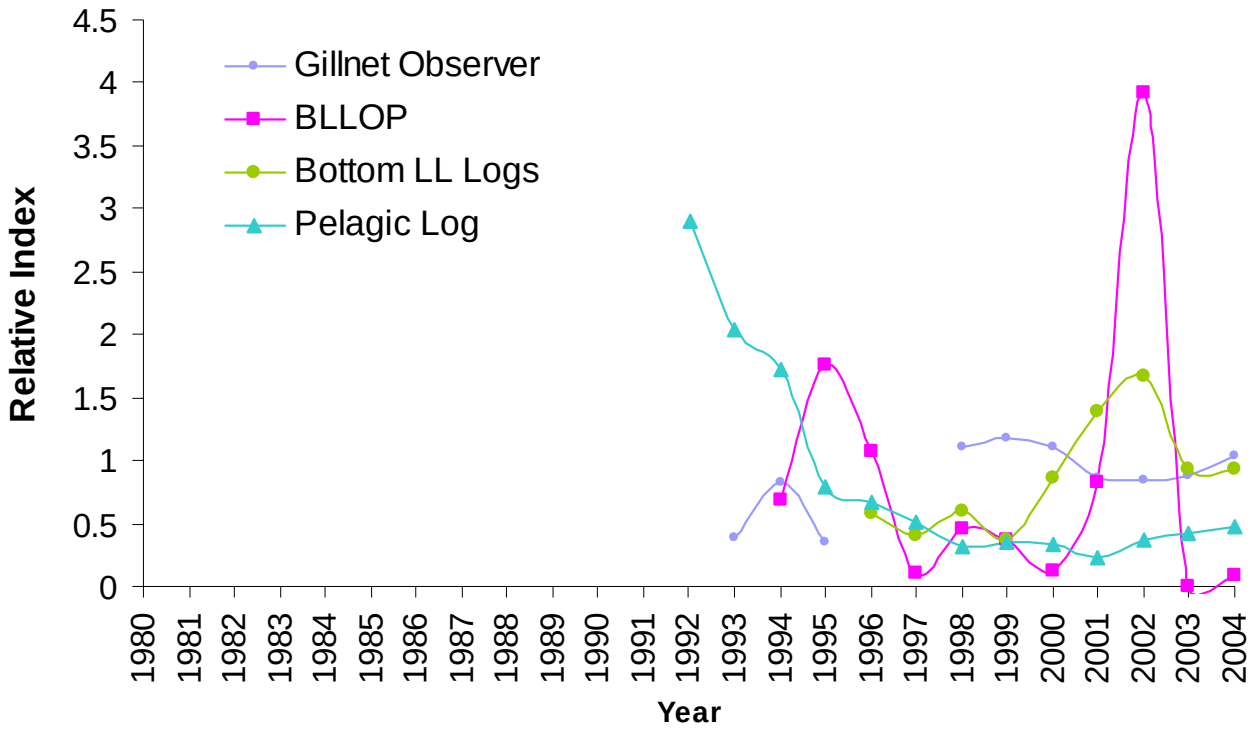


Figure 6.4. Indices with the same selectivity for blacktip sharks in the northwestern Atlantic Ocean.

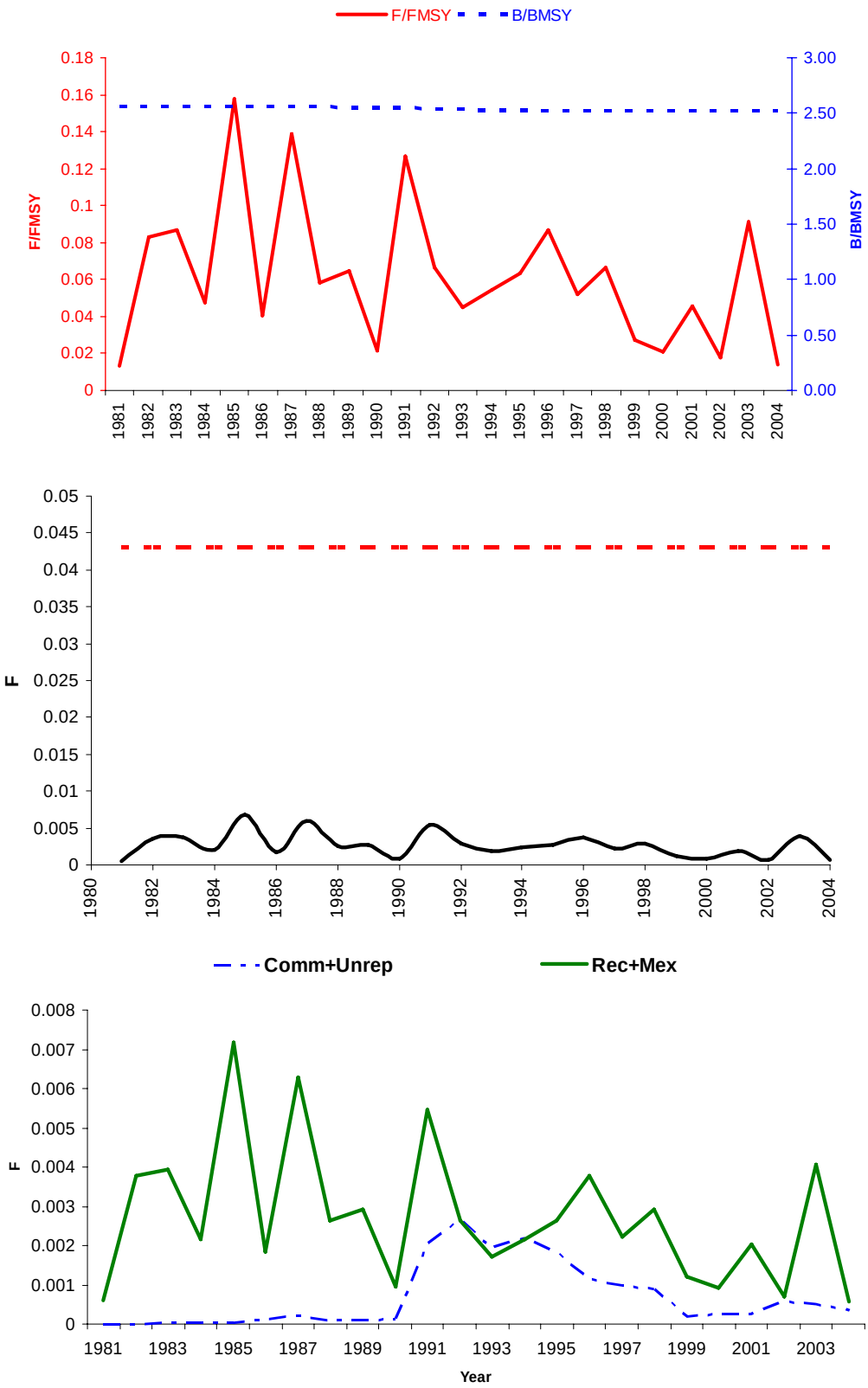


Figure 6.5. Estimated stock status (top), total fishing mortality (middle), and fleet-specific F (bottom) for northwestern Atlantic Ocean blacktip sharks. The dashed line in the middle panel indicates F_{MSY} (= 0.015).

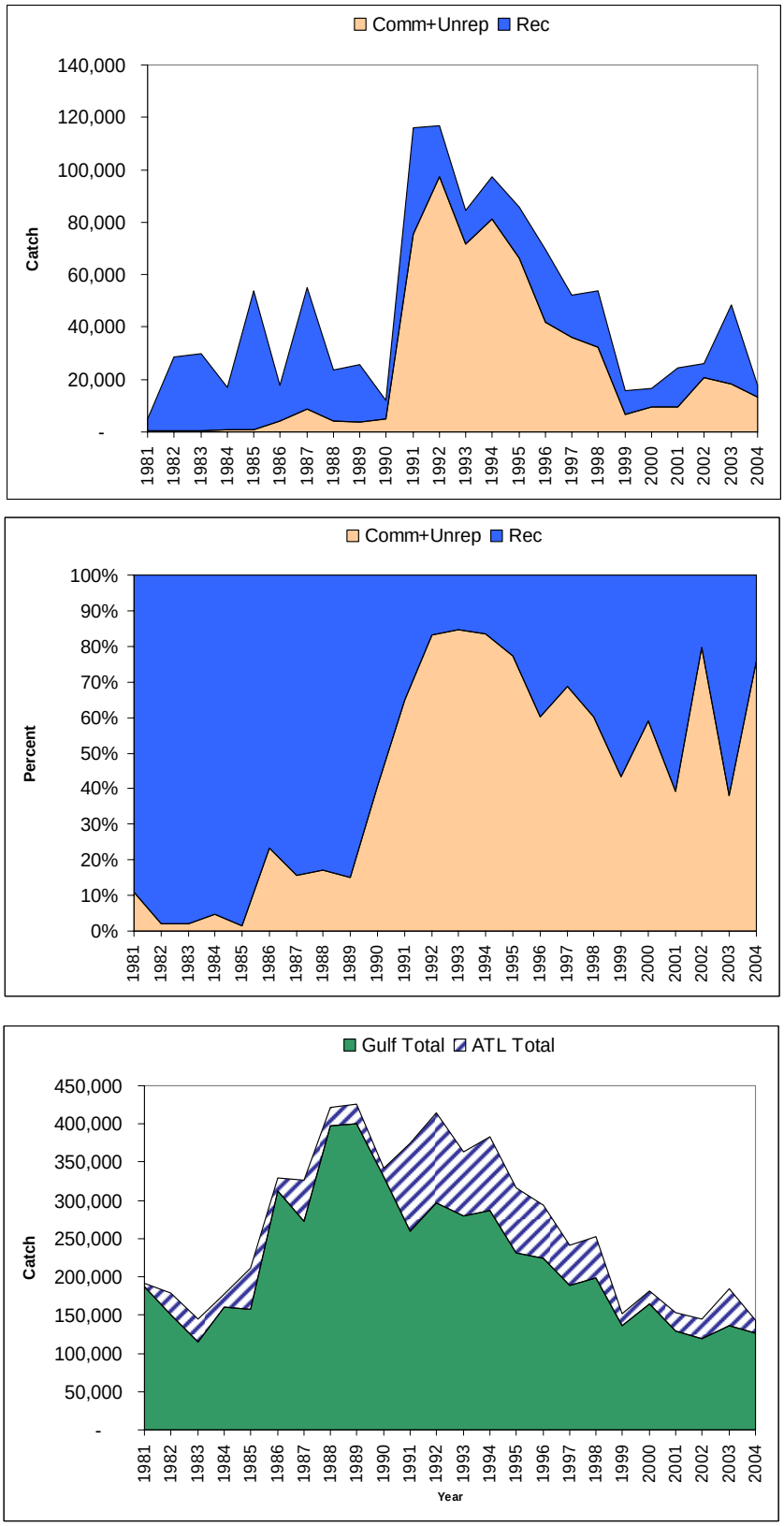
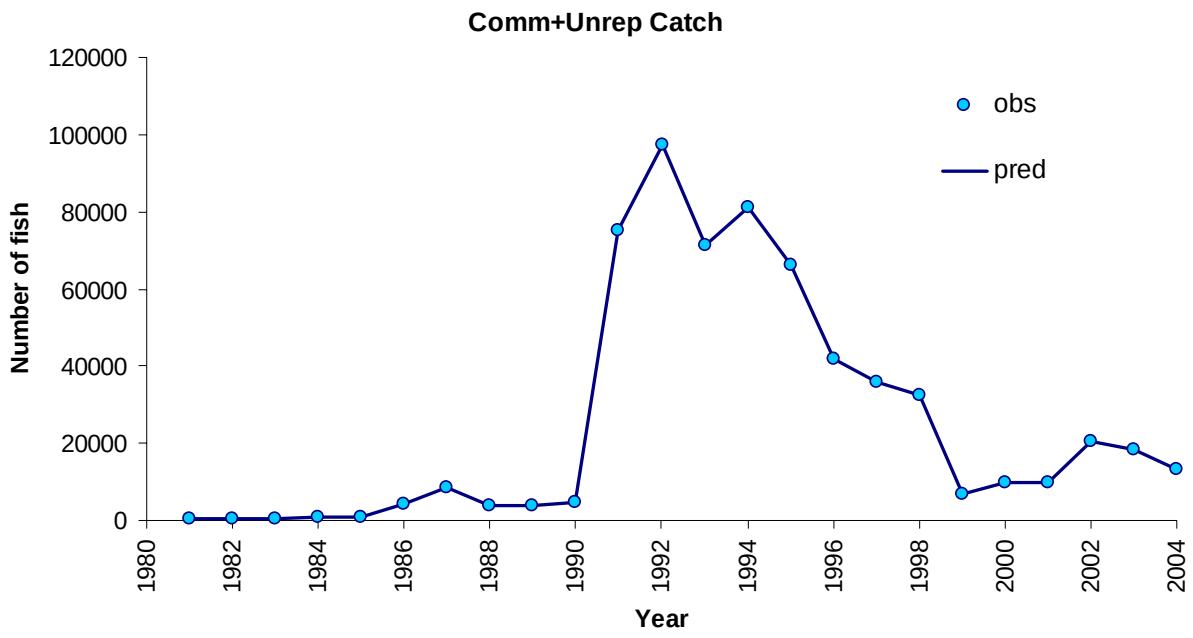


Figure 6.6. Total catch by fleet of blacktip in the northwestern Atlantic Ocean (top), percent of total catch by fleet (middle), and Atlantic versus Gulf of Mexico landings (bottom).



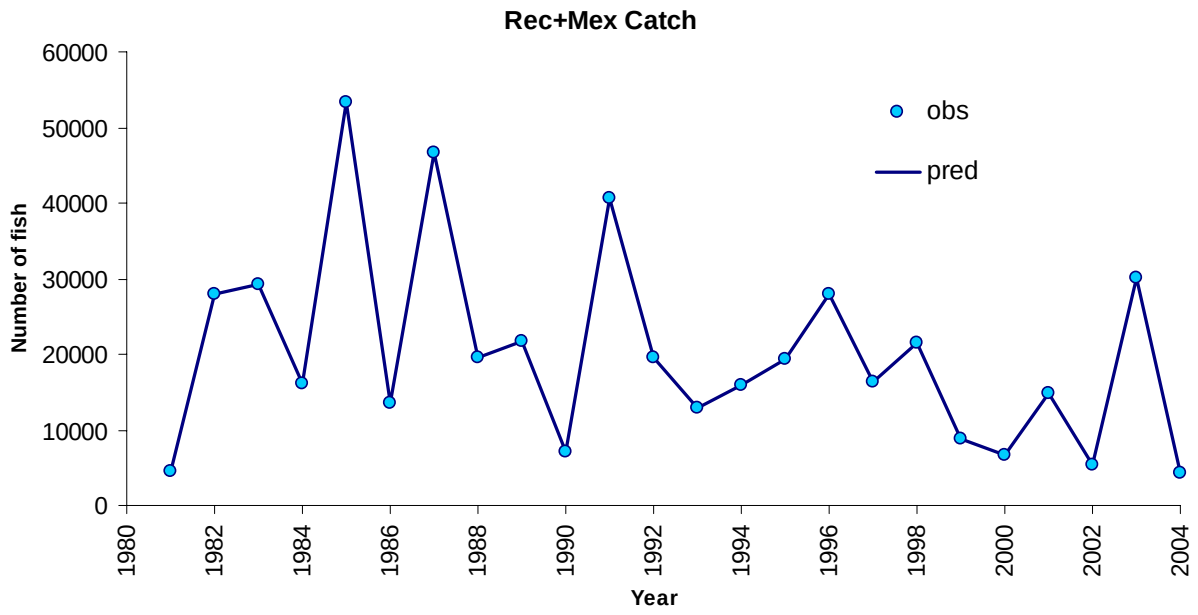
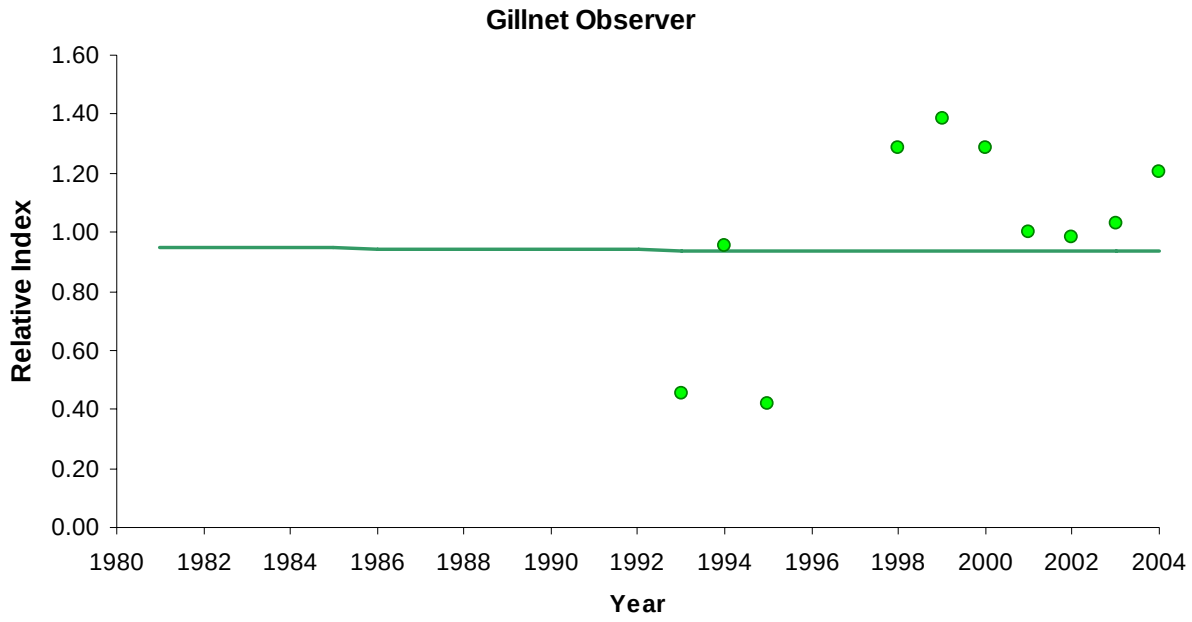


Figure 6.7. Model predicted fit to catch data for northwestern Atlantic Ocean blacktip sharks. Circles represent observed data, solid line is predicted.



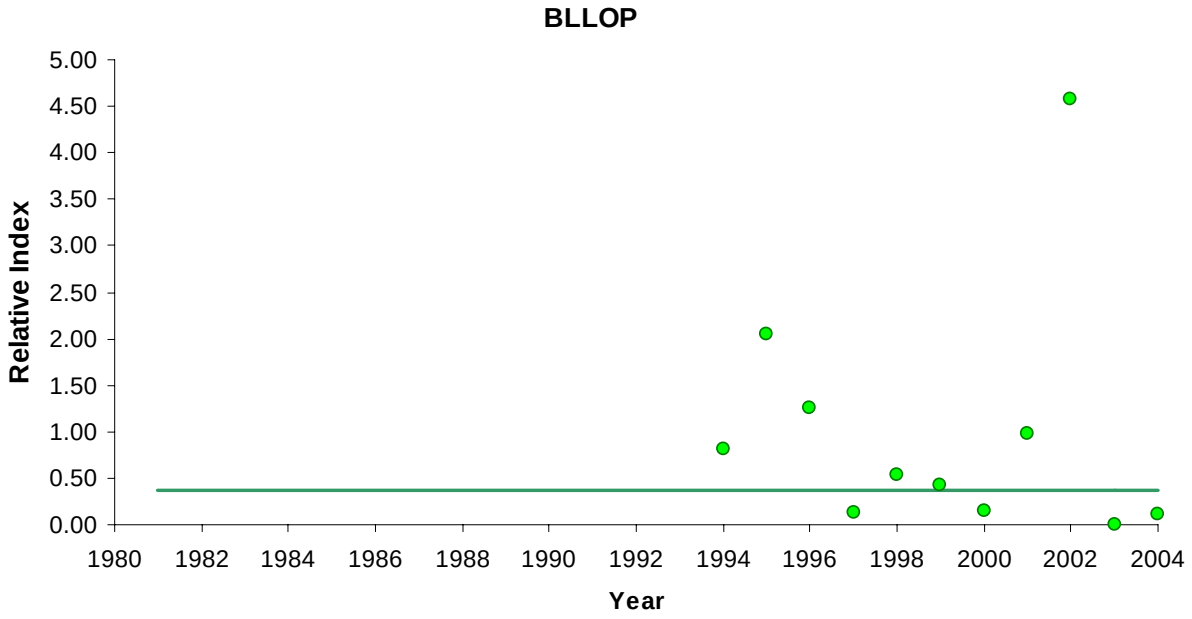
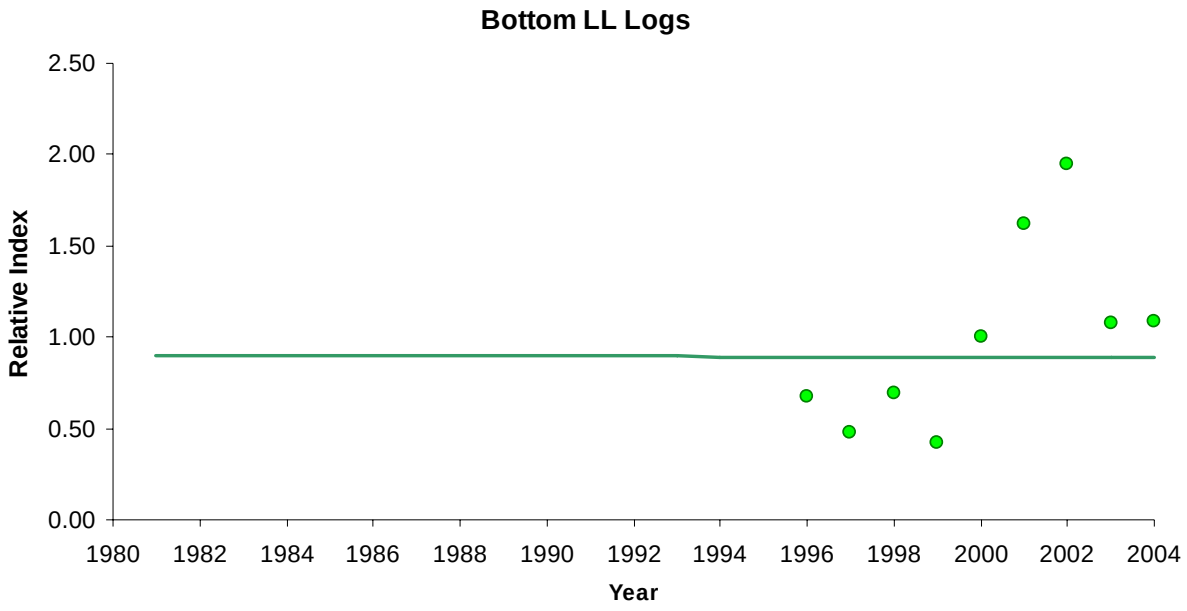


Figure 6.8. Model predicted fit to indices for northwestern Atlantic Ocean blacktip sharks. Circles represent observed data, solid line is predicted.



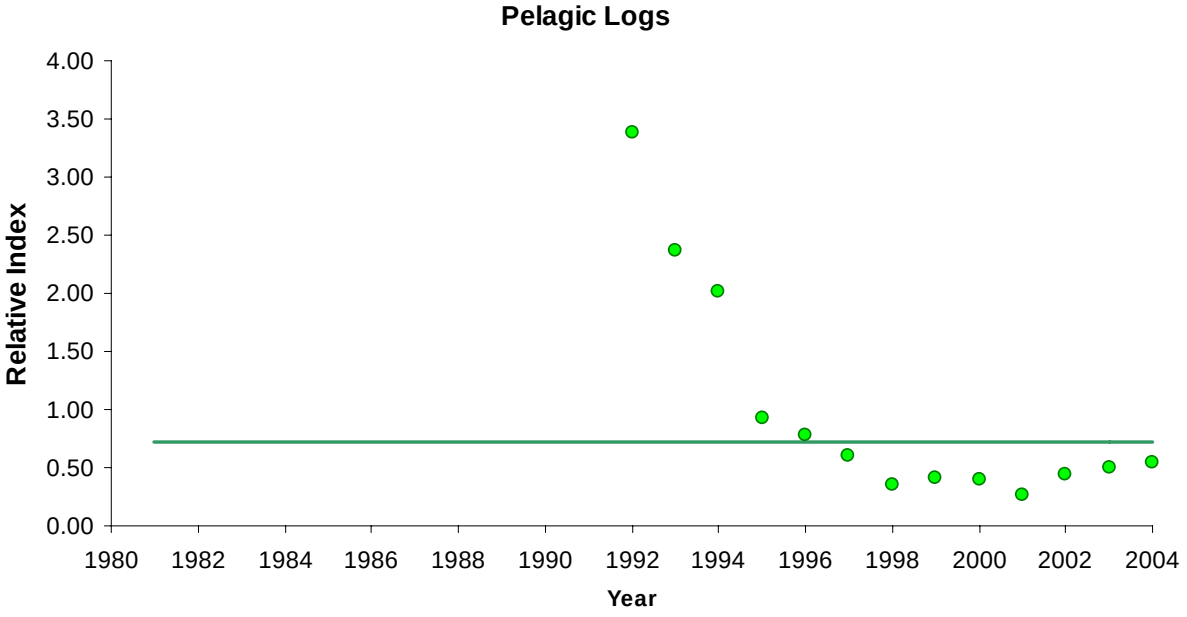


Figure 6.8. (continued)

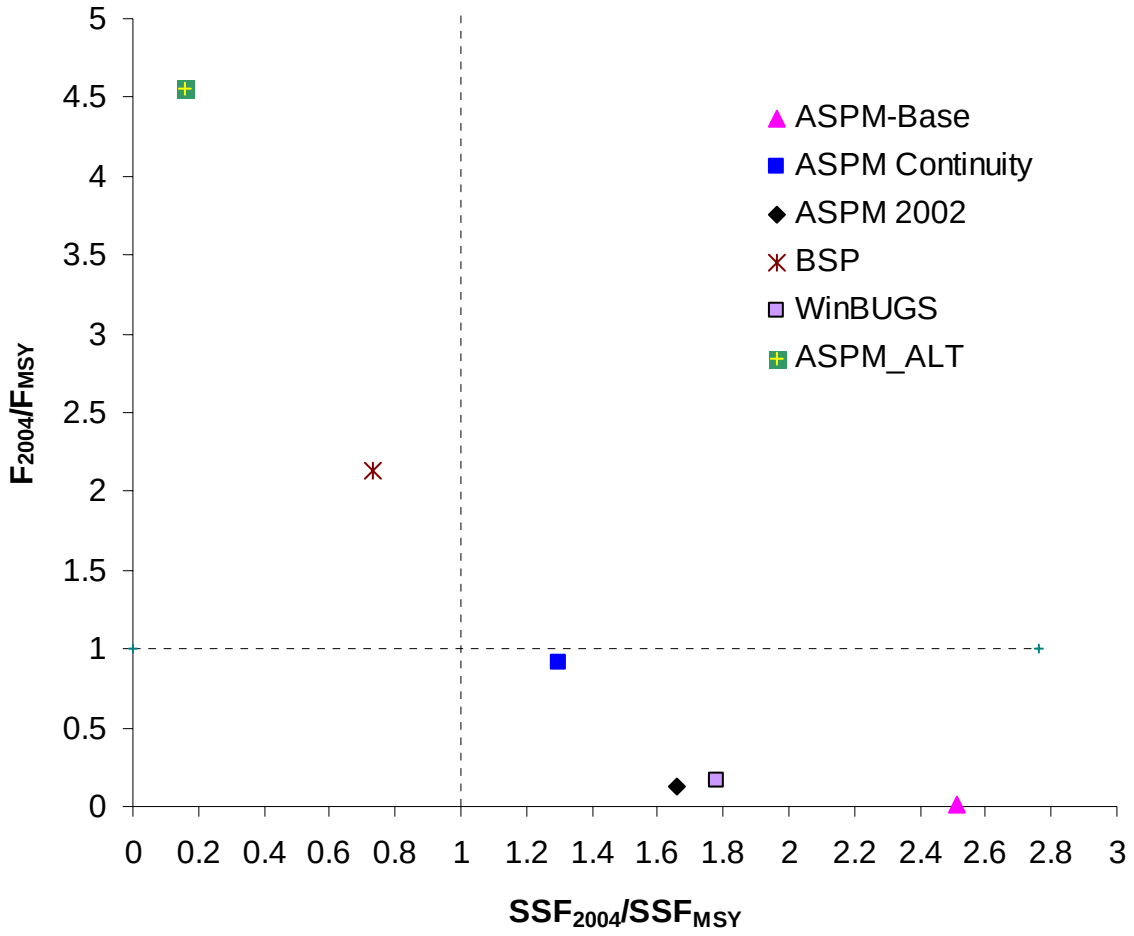


Figure 6.9. Phase-plot of stock status for northwestern Atlantic Ocean blacktip shark stock. Models include: ASPM-Base, ASPM Continuity, ASPM 2002 (results of the 2002 blacktip single stock assessment using equal weighting), BSP (results using the Bayesian surplus production model), and WinBUGS (results using the WinBUGS SPM) and ASPM_ALT. ASPM_ALT is the alternative age structured production model discussed in SEDAR10-AW-02. The F benchmark for ASPM_ALT is in terms of the harvest rate in 2004 relative to that rate at MSY. See text for further details. Several control rules are illustrated: the dashed horizontal line indicates the MFMT (Maximum Fishing Mortality Threshold) and the dashed vertical line denotes the target biomass (biomass or number at MSY). Note for the BSP and WinBUGS x values denote N_{2004}/N_{MSY} rather than SSF_{2004}/SSF_{MSY}. SSF is spawning stock fecundity, which is the sum of number mature at age times pup-production at age (rather than SSB, since biomass does not influence pup production in sharks).

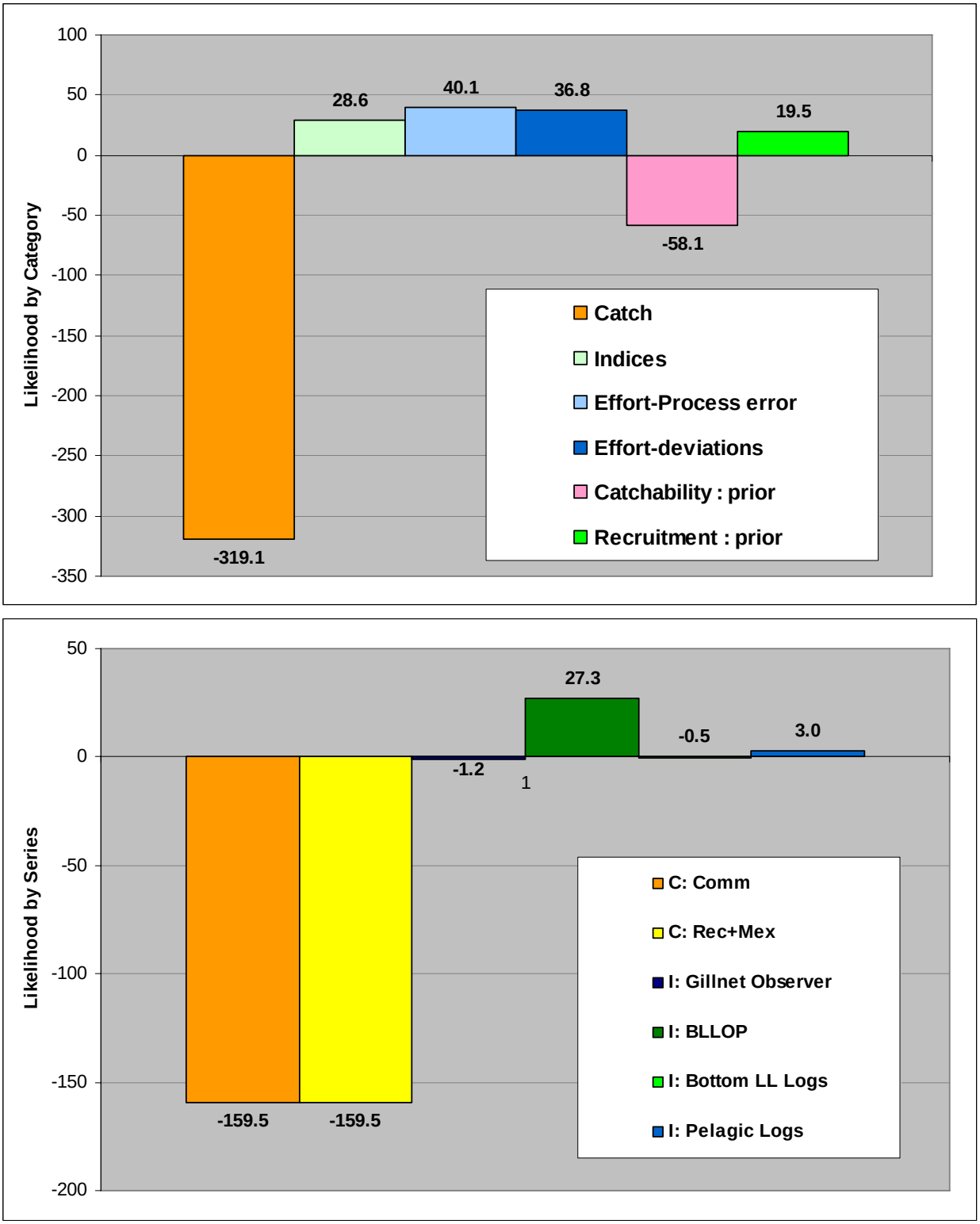


Figure 6.10. Contribution to relative likelihood by category (top) and by catch series and index series (bottom) for the base model for northwestern Atlantic blacktip sharks. The recruitment component includes both priors on virgin number of pups and pup survival.

7. RESEARCH RECOMMENDATIONS

The Assessment Workshop Panel identified the following Research Recommendations which will aid in future assessments.

- Data Workshop participants need to bring raw data to workshop to enable additional analysis to be conducted and reviewed during the workshop when practical

- Length frequency data should be provided when available, with particular reference to the VA LL dataset.

- Examination and analysis of the Pelagic Longline Observer data should be included.

- Identify nursery areas for sandbars in the northern Gulf of Mexico

- Additional life history studies for all complex species to allow for additional species-specific assessments.

- Additional life history research into sandbar sharks to supplement or replace the available data from the mid 1990s

- Incorporation of the University of North Carolina dataset collected by Dr. Frank Schwartz in the next LCS assessment, with recognition that it may also contain valuable information useful for the Small Coastal Shark assessment to be conducted in 2007.

- Examination of methods to incorporate tagging data information into the assessment

- Attempt to recover and quantify information on historic catch, with special emphasis prior to the 1993 FMP.

- Management to force contrast would improve the blacktip assessments.

- Additional length sampling and age composition collection to improve information for developing selectivities

- Initiation or expansion of dock side sampling for sharks

- Ensure that existing independent sampling programs be continued

- Ensure funding for the recently initiated (2002) pelagic survey being conducted by the Pascagoula laboratory- SEFSC

Appendix 1. Available catch rates series for the large coastal shark complex (3 scenarios) , sandbar, and blacktip shark. The index is the relative (divided by the overall mean) estimated mean CPUE and the CV is the estimated precision of the mean value. Type refers to whether the index is fishery – independent (FI) or fishery-dependent (FD), recreational (R) or commercial (C). Observations with a CV of 1.0 are nominal data for which no measure of the precision of the estimate was available. Recommendation refers to the recommendation by the Indices Working Group to include the particular index as a base index (Base), use it for sensitivity runs (Sensitivity) or not recommended for use in the assessment (NR). Indices labeled NR were used in the Continuity analysis.

Original LCS Definition (22 species)

Document Number	Series Name	Type	Recommendation	Year	Index	CV
LCS05/06-DW-01	NC #	FD - C	NR	1988	0.758	0.422
				1989	1.242	0.232
LCS05/06-DW-11	Gillnet Observer	FD - C	Base	1993	0.338	1.026
				1994	1.050	0.132
				1995	0.299	0.779
				1998	1.088	0.177
				1999	1.336	0.079
				2000	1.239	0.073
				2001	1.179	0.070
				2002	1.077	0.116
				2003	1.112	0.150
				2004	1.281	0.082
LCS05/06-DW-12	PC Longline	FI	Sensitivity	1993	0.816	0.730
				1994	0.386	0.894
				1995	1.272	0.610
				1996	0.858	0.583
				1997	0.926	0.539
				1998	0.725	0.967
				1999	1.174	0.564
				2000	1.844	0.508
LCS05/06-DW-12	PC Gillnet	FI	Base	1996	0.511	0.241
				1997	1.637	0.132
				1998	0.607	0.310
				1999	0.969	0.297
				2000	0.811	0.326
				2001	1.549	0.211
				2002	0.936	0.201
				2003	1.072	0.186
				2004	0.908	0.220
LCS05/06-DW-13	ENP	FD - R	Base	1972	0.598	0.255
				1973	1.575	0.085
				1974	0.985	0.093

				1975	1.987	0.066
				1976	1.165	0.094
				1977	1.409	0.079
				1978	1.126	0.094
				1979	1.114	0.123
				1980	1.469	0.079
				1981	1.001	0.080
				1982	1.099	0.081
				1983	1.368	0.068
				1984	1.279	0.066
				1985	1.071	0.074
				1986	0.921	0.070
				1987	0.942	0.080
				1988	0.993	0.099
				1989	0.604	0.127
				1990	0.548	0.098
				1991	0.504	0.113
				1992	0.910	0.089
				1993	0.523	0.105
				1994	0.911	0.070
				1995	0.762	0.091
				1996	0.900	0.070
				1997	0.922	0.066
				1998	0.855	0.078
				1999	0.753	0.085
				2000	0.966	0.076
				2001	0.838	0.083
				2002	0.900	0.087
LCS05/06-DW-14	SC LL Recent	FI	Base	1995	0.813	0.359
				1996	0.692	0.257
				1997	1.367	0.183
				1998	0.853	0.194
				1999	1.295	0.148
				2000	1.112	0.169
				2001	0.868	0.216
LCS05/06-DW-17	BLLOP	FD - C	Base	1994	0.669	0.335
				1995	0.901	0.219
				1996	0.907	0.143
				1997	0.894	0.287
				1998	1.134	0.178
				1999	1.084	0.280
				2000	1.027	0.363
				2001	0.929	0.299
				2002	1.269	0.265
				2003	1.214	0.188
				2004	0.971	0.187
LCS05/06-DW-20	VA LL	FI	Base	1975	2.508	0.307
				1977	1.994	0.344

				1978	0.975	1.006
				1980	2.063	0.246
				1981	1.795	0.237
				1984	0.658	1.611
				1986	0.612	2.715
				1989	0.790	0.526
				1990	0.815	0.437
				1991	0.702	0.524
				1992	1.231	0.560
				1993	0.794	0.619
				1995	0.811	0.448
				1996	0.766	0.406
				1997	0.753	0.276
				1998	0.737	0.318
				1999	0.710	0.437
				2000	0.777	0.365
				2001	0.737	0.356
				2002	0.685	0.509
				2003	0.546	0.373
				2004	0.541	0.514
LCS05/06-DW-21	Brannon	FD - C	NR	1986	0.657	1
				1987	1.348	1
	* nominal index			1988	1.146	1
				1989	0.833	1
				1990	0.994	1
				1991	1.020	1
LCS05/06-DW-24	MS Gillnet	FI	Sensitivity	1998	0.566	0.528
				1999	0.337	0.574
				2000	1.981	0.421
				2001	0.576	0.717
				2003	0.399	0.741
				2004	0.472	0.598
				2005	2.670	0.455
LCS05/06-DW-25	Hudson	FD - R	NR	1985	0.220	1
				1986	0.100	1
	* nominal index			1987	0.120	1
				1988	0.100	1
				1989	0.050	1
				1990	0.020	1
				1991	0.020	1
LCS05/06-DW-25	Jax	FD - R	NR	1979	0.590	1
				1984	0.710	1
	* nominal index			1990	0.160	1
LCS05/06-DW-25	Tampa Bay	FD - R	NR	1985	0.160	1
				1986	0.090	1
	* nominal index			1987	0.030	1

				1988	0.140	1
				1989	0.060	1
				1990	0.050	1
LCS05/06-DW-25	Port Salerno	FD - R	Sensitivity	1976	0.180	1
				1977	0.810	1
	* nominal index			1979	0.890	1
				1980	0.820	1
				1981	0.390	1
				1982	0.500	1
				1983	0.120	1
				1984	0.100	1
				1985	0.150	1
				1986	0.500	1
				1987	0.320	1
				1988	0.200	1
				1989	0.120	1
				1990	0.200	1
LCS05/06-DW-25	Crooke LL	FD - C	Sensitivity	1975	0.882	1
				1976	0.642	1
				1977	1.043	1
				1978	2.005	1
				1979	0.963	1
				1980	1.283	1
				1981	1.043	1
				1982	1.043	1
				1983	1.123	1
				1984	0.963	1
				1985	1.123	1
				1986	0.882	1
				1987	0.642	1
				1988	0.642	1
				1989	0.722	1
LCS05/06-DW-27	NMFS LL SE	FI	Base	1995	0.849	0.135
				1996	0.449	0.200
				1997	0.626	0.128
				1999	0.499	0.150
				2000	1.042	0.083
				2001	1.120	0.106
				2002	1.220	0.080
				2003	1.846	0.105
				2004	1.349	0.107
LCS05/06-DW-31	Bottom LL Logs	FD - C	Base	1996	0.615	0.164
				1997	0.945	0.103
				1998	0.848	0.099
				1999	1.210	0.090
				2000	1.204	0.098
				2001	1.146	0.095

				2002	0.958	0.092
				2003	1.231	0.089
				2004	0.844	0.103
LCS05/06-DW-33	NMFS LL NE	FI	Base	1996	0.232	0.263
				1998	1.609	0.124
				2001	1.051	0.141
				2004	1.108	0.147
LCS05/06-DW-35	Pelagic Log	FD - C	Base	1992	2.008	0.250
				1993	1.588	0.258
				1994	1.312	0.265
				1995	1.186	0.267
				1996	1.253	0.264
				1997	0.732	0.288
				1998	0.561	0.310
				1999	0.616	0.307
				2000	0.786	0.293
				2001	0.760	0.297
				2002	0.710	0.294
				2003	0.727	0.297
				2004	0.761	0.292
LCS05/06-DW-36	MRFSS - excluding requiem	FD - R	Sensitivity	1981	1.505	0.357
				1982	1.298	0.337
				1983	1.948	0.332
				1984	1.597	0.345
				1985	1.608	0.331
				1986	1.722	0.315
				1987	1.102	0.321
				1988	0.952	0.325
				1989	0.747	0.334
				1990	0.762	0.333
				1991	0.81	0.327
				1992	0.887	0.316
				1993	0.672	0.326
				1994	0.707	0.324
				1995	0.848	0.321
				1996	0.803	0.322
				1997	0.726	0.327
				1998	1.003	0.314
				1999	0.663	0.322
				2000	0.805	0.318
				2001	0.794	0.319
				2002	0.782	0.319
				2003	0.813	0.319
				2004	0.448	0.336
LCS05/06-DW-36	MRFSS - including requiem	FD - R	Sensitivity	1981	1.002	0.350
				1982	1.139	0.316
				1983	1.359	0.319

				1984	1.115	0.332
				1985	1.086	0.319
				1986	1.241	0.299
				1987	0.940	0.305
				1988	0.812	0.311
				1989	0.530	0.328
				1990	0.519	0.328
				1991	0.528	0.322
				1992	0.665	0.304
				1993	0.685	0.307
				1994	0.883	0.298
				1995	0.998	0.296
				1996	0.900	0.300
				1997	0.899	0.301
				1998	1.077	0.292
				1999	0.929	0.295
				2000	1.136	0.291
				2001	1.238	0.289
				2002	1.348	0.286
				2003	1.513	0.286
				2004	1.462	0.288
LCS05/06-DW-41	Charterboat	FD - R	NR	1989	1.145	0.469
				1990	1.031	0.125
				1991	1.080	0.121
				1992	0.837	0.118
				1993	0.945	0.125
				1994	0.928	0.156
				1995	1.036	0.152
LCS05/06-DW-45	SC LL Early	FI	Base	1984	1.79251	1
				1994	0.70317	1
				1995	0.50432	1

LCS minus prohibited species (11 species)

Document Number	Series Name	Type	Recommendation	Year	Index	CV
LCS05/06-DW-11	Gillnet Observer	FD - C	Base	1993	0.338	1.026
				1994	1.05	0.132
				1995	0.299	0.779
				1998	1.088	0.177
				1999	1.336	0.079
				2000	1.239	0.073
				2001	1.179	0.07
				2002	1.077	0.116
				2003	1.112	0.15
				2004	1.281	0.082
LCS05/06-DW-12	PC Longline	FI	Sensitivity	1993	0.816	0.730
				1994	0.386	0.894
				1995	1.272	0.610
				1996	0.858	0.583
				1997	0.926	0.539
				1998	0.725	0.967
				1999	1.174	0.564
				2000	1.844	0.508
LCS05/06-DW-12	PC Gillnet	FI	Base	1996	0.511	0.241
				1997	1.637	0.132
				1998	0.607	0.310
				1999	0.969	0.297
				2000	0.811	0.326
				2001	1.549	0.211
				2002	0.936	0.201
				2003	1.072	0.186
				2004	0.908	0.220
LCS05/06-DW-17	BLLOP	FD - C	Base	1994	0.676	0.238
				1995	0.972	0.172
				1996	0.907	0.153
				1997	0.774	0.295
				1998	1.113	0.172
				1999	1.108	0.253
				2000	1.168	0.333
				2001	0.926	0.242
				2002	1.187	0.160
				2003	1.206	0.131
				2004	0.962	0.150
LCS05/06-DW-24	MS Gillnet	FI	Sensitivity	1998	0.566	0.528
				1999	0.337	0.574
				2000	1.981	0.421

				2001	0.576	0.717
				2003	0.399	0.741
				2004	0.472	0.598
				2005	2.670	0.455
LCS05/06-DW-27	NMFS LL SE	FI	Base	1995	0.848	0.135
				1996	0.438	0.203
				1997	0.628	0.128
				1999	0.501	0.150
				2000	1.044	0.083
				2001	1.127	0.106
				2002	1.207	0.080
				2003	1.850	0.105
				2004	1.356	0.107
LCS05/06-DW-31	Bottom LL Logs	FD - C	Base	1996	0.574	0.152
				1997	0.927	0.110
				1998	0.839	0.103
				1999	1.103	0.092
				2000	1.188	0.101
				2001	1.165	0.099
				2002	1.011	0.097
				2003	1.287	0.094
				2004	0.907	0.107
LCS05/06-DW-33	NMFS LL NE	FI	Base	1996	0.258	2.973
				1998	1.750	0.578
				2001	1.037	0.880
				2004	0.955	0.953
LCS05/06-DW-35	Pelagic Log	FD - C	Base	1992	1.669	0.268
				1993	1.383	0.275
				1994	1.248	0.279
				1995	1.191	0.279
				1996	1.176	0.278
				1997	0.732	0.297
				1998	0.597	0.314
				1999	0.608	0.314
				2000	0.884	0.297
				2001	0.867	0.298
				2002	0.845	0.295
				2003	0.902	0.296
				2004	0.897	0.293
LCS05/06-DW-36	MRFSS - excluding requiem	FD - R	Sensitivity	1981	1.807	0.600
				1982	1.820	0.543
				1983	2.571	0.547
				1984	2.468	0.558
				1985	1.895	0.544
				1986	2.453	0.510
				1987	1.165	0.536

				1988	0.953	0.540
				1989	0.742	0.563
				1990	0.552	0.600
				1991	0.563	0.574
				1992	0.913	0.532
				1993	0.384	0.573
				1994	0.220	0.633
				1995	0.581	0.545
				1996	0.721	0.535
				1997	0.656	0.563
				1998	0.876	0.538
				1999	0.553	0.548
				2000	0.498	0.568
				2001	0.520	0.558
				2002	0.493	0.561
				2003	0.407	0.597
				2004	0.189	0.663
LCS05/06-DW-36	MRFSS - including requiem	FD - R	Sensitivity	1981	0.884	0.37
				1982	1.097	0.325
				1983	1.301	0.328
				1984	1.071	0.341
				1985	1.063	0.327
				1986	1.256	0.305
				1987	0.908	0.312
				1988	0.789	0.318
				1989	0.498	0.34
				1990	0.533	0.336
				1991	0.494	0.334
				1992	0.641	0.312
				1993	0.699	0.312
				1994	0.879	0.304
				1995	1.033	0.301
				1996	0.903	0.305
				1997	0.908	0.307
				1998	1.102	0.297
				1999	0.953	0.3
				2000	1.149	0.296
				2001	1.297	0.293
				2002	1.423	0.291
				2003	1.579	0.29
				2004	1.541	0.292

LCS minus prohibited species, blacktip, and sandbar sharks (9 species)

Document Number	Series Name	Type	Recommendation	Year	Index	CV
LCS05/06-DW-11	Gillnet Observer	FD - C	Base	1993	0.754	0.546
				1994	0.918	0.150
				1995	0.537	0.494
				1998	1.037	0.269
				1999	1.203	0.107
				2000	1.246	0.094
				2001	1.167	0.087
				2002	1.092	0.121
				2003	0.952	0.202
				2004	1.094	0.141
LCS05/06-DW-12	PC Gillnet	FI	Base	1996	0.328	0.532
				1997	1.197	0.272
				1998	0.521	0.494
				1999	0.973	0.463
				2000	1.112	0.411
				2001	1.682	0.309
				2002	1.129	0.280
				2003	1.022	0.276
				2004	1.034	0.314
LCS05/06-DW-17	BLLOP	FD - C	Base	1994	0.614	0.298
				1995	0.756	0.278
				1996	0.810	0.281
				1997	0.903	0.291
				1998	1.298	0.257
				1999	1.067	0.286
				2000	1.056	0.313
				2001	0.983	0.278
				2002	1.478	0.278
				2003	0.959	0.281
				2004	1.078	0.273
LCS05/06-DW-27	NMFS LL SE	FI	Base	1995	0.946	0.152
				1996	0.381	0.236
				1997	0.608	0.145
				1999	0.508	0.186
				2000	1.176	0.092
				2001	1.108	0.125
				2002	1.187	0.095
				2003	1.746	0.132
				2004	1.341	0.120
LCS05/06-DW-31	Bottom LL Logs	FD - C	Base	1996	0.709	0.266
				1997	0.680	0.199

				1998	0.626	0.199
				1999	1.170	0.167
				2000	1.044	0.184
				2001	1.095	0.176
				2002	1.490	0.175
				2003	1.286	0.167
				2004	0.900	0.225
LCS05/06-DW-33	NMFS LL NE	FI	Base	1996	0.212	6.866
				1998	1.127	1.735
				2001	1.282	1.292
				2004	1.379	1.244
LCS05/06-DW-35	Pelagic Log	FD - C	Base	1992	1.738	0.242
				1993	1.413	0.250
				1994	1.360	0.250
				1995	1.039	0.257
				1996	0.994	0.255
				1997	0.657	0.272
				1998	0.579	0.287
				1999	0.737	0.274
				2000	0.901	0.266
				2001	0.792	0.271
				2002	0.892	0.264
				2003	0.912	0.266
				2004	0.985	0.263

Blacktip - Gulf of Mexico

Document Number	Series Name	Type	Recommendation	Year	Index	CV
LCS05/06-DW-12	PC Longline	FI	Sensitivity	1993	0.768	1.288
				1994	0.133	3.244
				1995	1.018	1.244
				1996	0.758	1.087
				1997	1.299	0.704
				1998	0.974	1.328
				1999	1.136	1.011
				2000	1.914	0.92
LCS05/06-DW-12	PC Gillnet	FI	Base	1996	0.695	0.475
				1997	1.397	0.287
				1998	0.565	0.451
				1999	1.209	0.359
				2000	0.769	0.484
				2001	1.583	0.286
				2002	0.872	0.283
				2003	0.909	0.283
				2004	1.001	0.307
LCS05/06-DW-12	PC Gillnet - juveniles	FI	Base	1996	0.980	0.427
				1997	1.513	0.279
				1998	0.639	0.455
				1999	1.068	0.412
				2000	0.649	0.632
				2001	1.408	0.312
				2002	0.854	0.305
				2003	0.790	0.318
				2004	1.098	0.294
LCS05/06-DW-12	PC Gillnet - Age 0	FI	Base	1996	0.152	1.063
				1997	0.782	0.397
				1998	0.654	0.586
				1999	2.101	0.388
				2000	0.676	0.737
				2001	2.130	0.35
				2002	1.260	0.293
				2003	1.012	0.334
				2004	0.232	0.823
LCS05/06-DW-17	BLLOP	FD - C	Base	1994	0.430	1.666
				1995	0.817	0.855
				1996	0.724	1.215
				1997	0.588	2.248
				1998	0.796	1.620
				1999	1.055	1.270

				2001	0.162	9.019
				2002	2.062	0.496
				2003	1.542	0.509
				2004	1.824	0.401
LCS05/06-DW-24	MS Gillnet	FI	Sensitivity	1998	0.584	0.572
				1999	0.352	0.590
				2000	2.771	0.404
				2001	0.565	0.717
				2003	0.374	0.751
				2004	0.413	0.624
				2005	1.940	0.491
LCS05/06-DW-24	MS Gillnet - juveniles	FI	Sensitivity	1998	0.835	0.683
				1999	0.412	0.887
				2000	2.655	0.336
				2001	0.409	1.892
				2003	0.092	1.722
				2004	0.198	1.443
				2005	2.398	0.791
LCS05/06-DW-24	MS Gillnet - Age 0	FI	Sensitivity	1998	0.200	0.684
				1999	0.245	1.011
				2000	3.136	0.556
				2001	0.302	1.633
				2003	0.660	0.764
				2004	0.134	1.177
				2005	2.323	0.982
LCS05/06-DW-26	Mote Gillnet - Yankeetown	FI	Sensitivity	1995	0.578	1.287
				1996	1.564	0.910
				1997	1.299	1.186
				1999	0.541	1.368
				2000	0.530	1.836
				2001	0.966	1.521
				2002	0.823	1.463
				2003	1.126	1.256
				2004	1.574	0.994
LCS05/06-DW-26	Mote Gillnet - Charlotte Harbor	FI	Sensitivity	1995	1.143	1.273
				1997	0.444	2.328
				1999	0.901	1.358
				2000	1.851	0.944
				2002	1.502	1.147
				2003	0.564	1.885
				2004	0.595	1.498
LCS05/06-DW-27	NMFS LL SE	FI	Base	1995	0.554	0.682

				1996	0.380	0.788
				1997	0.409	0.634
				1999	0.341	0.630
				2000	1.517	0.327
				2001	0.898	0.353
				2002	1.436	0.327
				2003	2.237	0.242
				2004	1.228	0.307
LCS05/06-DW-31	Bottom LL Logs	FD - C	Base	1996	0.249	0.362
				1997	0.931	0.236
				1998	0.334	0.247
				1999	1.506	0.219
				2000	0.883	0.240
				2001	0.985	0.225
				2002	1.078	0.210
				2003	1.967	0.199
				2004	1.068	0.232
LCS05/06-DW-35	Pelagic Log	FD - C	Base	1992	2.512	0.525
				1993	1.586	0.614
				1994	1.756	0.608
				1995	2.047	0.581
				1996	0.877	0.685
				1997	0.965	0.685
				1998	0.915	0.716
				1999	0.252	1.202
				2000	0.651	0.822
				2001	0.567	0.859
				2002	0.439	0.960
				2003	0.255	1.140
				2004	0.179	1.430
LCS05/06-DW-36	MRFSS	FD - R	Sensitivity	1981	1.358	0.565
				1982	0.325	0.557
				1983	1.130	0.555
				1984	0.673	0.553
				1985	0.816	0.505
				1986	1.452	0.406
				1987	0.636	0.441
				1988	1.319	0.400
				1989	1.186	0.436
				1990	1.318	0.428
				1991	1.477	0.419
				1992	0.877	0.391
				1993	0.772	0.418
				1994	0.726	0.409
				1995	1.027	0.409
				1996	1.159	0.403
				1997	1.090	0.401
				1998	1.471	0.372

1999	0.737	0.382
2000	1.259	0.370
2001	0.661	0.390
2002	0.719	0.381
2003	1.064	0.378
2004	0.747	0.387

Blacktip Shark - Atlantic

Document Number	Series Name	Type	Recommendation	Year	Index	CV
LCS05/06-DW-11	Gillnet Observer	FD - C	Base	1993	0.455	0.888
				1994	0.955	0.174
				1995	0.419	0.681
				1998	1.286	0.164
				1999	1.384	0.081
				2000	1.286	0.068
				2001	1.001	0.098
				2002	0.982	0.145
				2003	1.029	0.187
				2004	1.204	0.122
LCS05/06-DW-14	SC LL Recent	FI	Sensitivity	1995	1.750	0.384
				1996	0.808	0.437
				1997	2.094	0.276
				1998	0.487	0.525
				1999	0.482	0.652
				2000	1.147	0.291
				2001	0.232	1.123
LCS05/06-DW-17	BLLOP	FD - C	Base	1994	0.805	2.423
				1995	2.042	0.854
				1996	1.246	1.640
				1997	0.131	9.878
				1998	0.534	3.352
				1999	0.426	3.775
				2000	0.153	8.354
				2001	0.971	2.814
				2002	4.578	0.012
				2003	0.004	39.339
				2004	0.111	6.517
LCS05/06-DW-27	NMFS LL SE	FI	NR	1995	0	
				1996	0.453	4.403
				1997	0.244	2.725
				1999	0.811	1.706
				2000	0	
				2002	2.748	0.649
				2004	0.745	3.586
				2005	0	
LCS05/06-DW-31	Bottom LL Logs	FD - C	Base	1996	0.678	0.370
				1997	0.474	0.512
				1998	0.689	0.352
				1999	0.423	0.459
				2000	1.005	0.371

				2001	1.620	0.327
				2002	1.948	0.264
				2003	1.081	0.333
				2004	1.083	0.447
LCS05/06-DW-33	NMFS LL NE	FI	Sensitivity	1996	0.202	49.744
				1998	1.578	8.270
				2001	0.797	14.861
				2004	1.423	9.114
LCS05/06-DW-35	Pelagic Log	FD - C	Base	1992	3.389	0.618
				1993	2.373	0.675
				1994	2.019	0.700
				1995	0.924	0.907
				1996	0.785	0.978
				1997	0.603	1.109
				1998	0.360	1.409
				1999	0.411	1.380
				2000	0.392	1.402
				2001	0.263	1.687
				2002	0.434	1.365
				2003	0.494	1.282
				2004	0.550	1.241
LCS05/06-DW-36	MRFSS	FD - R	Sensitivity	1981	1.046	1.023
				1982	0.531	0.787
				1983	1.186	0.718
				1984	1.145	0.747
				1985	1.285	0.621
				1986	1.427	0.577
				1987	0.755	0.637
				1988	0.578	0.681
				1989	0.567	0.684
				1990	0.421	0.755
				1991	0.748	0.627
				1992	1.243	0.545
				1993	0.523	0.687
				1994	2.264	0.511
				1995	1.039	0.577
				1996	0.986	0.577
				1997	0.515	0.660
				1998	1.183	0.546
				1999	0.536	0.633
				2000	0.877	0.583
				2001	1.730	0.529
				2002	1.196	0.550
				2003	1.249	0.560
				2004	0.969	0.585

Blacktip Shark - areas combined

Document Number	Series Name	Type	Recommendation	Year	Index	CV
LCS05/06-DW-11	Gillnet Observer	FD - C	Base	1993	0.455	0.888
				1994	0.955	0.174
				1995	0.419	0.681
				1998	1.286	0.164
				1999	1.384	0.081
				2000	1.286	0.068
				2001	1.001	0.098
				2002	0.982	0.145
				2003	1.029	0.187
				2004	1.204	0.122
LCS05/06-DW-12	PC Longline	FI	Sensitivity	1993	0.768	1.288
				1994	0.133	3.244
				1995	1.018	1.244
				1996	0.758	1.087
				1997	1.299	0.704
				1998	0.974	1.328
				1999	1.136	1.011
				2000	1.914	0.920
LCS05/06-DW-12	PC Gillnet	FI	Base	1996	0.695	0.475
				1997	1.397	0.287
				1998	0.565	0.451
				1999	1.209	0.359
				2000	0.769	0.484
				2001	1.583	0.286
				2002	0.872	0.283
				2003	0.909	0.283
				2004	1.001	0.307
LCS05/06-DW-12	PC Gillnet - juveniles	FI	Base	1996	0.980	0.427
				1997	1.513	0.279
				1998	0.639	0.455
				1999	1.068	0.412
				2000	0.649	0.632
				2001	1.408	0.312
				2002	0.854	0.305
				2003	0.790	0.318
				2004	1.098	0.294
LCS05/06-DW-12	PC Gillnet - Age 0	FI	Base	1996	0.152	1.063
				1997	0.782	0.397
				1998	0.654	0.586
				1999	2.101	0.388
				2000	0.676	0.737

				2001	2.130	0.350
				2002	1.260	0.293
				2003	1.012	0.334
				2004	0.232	0.823
LCS05/06-DW-14	SC LL Recent	FI	Sensitivity	1995	1.750	0.384
				1996	0.808	0.437
				1997	2.094	0.276
				1998	0.487	0.525
				1999	0.482	0.652
				2000	1.147	0.291
				2001	0.232	1.123
LCS05/06-DW-17	BLLOP	FD - C	Base	1994	0.448	0.919
				1995	1.099	0.310
				1996	0.802	0.480
				1997	0.460	1.386
				1998	0.796	0.714
				1999	1.204	0.423
				2000	1.062	0.646
				2001	0.903	0.739
				2002	1.823	0.239
				2003	1.083	0.374
				2004	1.319	0.264
LCS05/06-DW-24	MS Gillnet	FI	Sensitivity	1998	0.584	0.572
				1999	0.352	0.590
				2000	2.771	0.404
				2001	0.565	0.717
				2003	0.374	0.751
				2004	0.413	0.624
				2005	1.940	0.491
LCS05/06-DW-24	MS Gillnet - juveniles	FI	Sensitivity	1998	0.835	0.683
				1999	0.412	0.887
				2000	2.655	0.336
				2001	0.409	1.892
				2003	0.092	1.722
				2004	0.198	1.443
				2005	2.398	0.791
LCS05/06-DW-24	MS Gillnet - Age 0	FI	Sensitivity	1998	0.200	0.684
				1999	0.245	1.011
				2000	3.136	0.556
				2001	0.302	1.633
				2003	0.660	0.764
				2004	0.134	1.177
				2005	2.323	0.982

LCS05/06-DW-27	NMFS LL SE	FI	Base	1995	0.493	0.487
				1996	0.551	0.826
				1997	0.475	0.533
				1999	0.444	0.500
				2000	1.232	0.265
				2001	0.902	0.295
				2002	1.449	0.252
				2003	2.265	0.225
				2004	1.189	0.259
LCS05/06-DW-31	Bottom LL Logs	FD - C	Base	1996	0.328	0.288
				1997	0.760	0.218
				1998	0.699	0.220
				1999	0.861	0.200
				2000	0.970	0.212
				2001	1.242	0.192
				2002	1.463	0.186
				2003	1.735	0.182
				2004	0.943	0.228
LCS05/06-DW-33	NMFS LL NE	FI	Sensitivity	1996	0.202	49.744
				1998	1.578	8.270
				2001	0.797	14.861
				2004	1.423	9.114

Sandbar

Document Number	Series Name	Type	Recommendation	Year	Index	CV
LCS05/06-DW-09	LPS	FD - R	Base	1986	3.557	0.173
				1987	0.859	0.323
				1988	2.326	0.209
				1989	3.204	0.136
				1990	1.008	0.247
				1991	2.327	0.264
				1992	1.382	0.233
				1993	0.739	0.872
				1994	0.378	0.755
				1995	0.302	1.255
				1996	0.369	1.092
				1997	0.530	0.834
				1998	0.124	2.138
				1999	0.202	1.994
				2000	0.213	1.990
				2001	0.986	1.064
				2002	0.236	1.721
				2003	0.181	1.663
				2004	0.076	2.136
LCS05/06-DW-12	PC Gillnet	FI	Sensitivity	1996	1.00*	1.667
				1997	2.250	2.963
	* nominal index			1998	1.220	4.773
				1999	0.530	6.789
				2000	0.690	7.200
				2001	1.250	6.667
				2002	0.610	7.273
				2003	0.970	5.429
				2004	0.470	7.588
LCS05/06-DW-14	SC LL Recent	FI	Sensitivity	1995	0.458	1.049
				1996	0.964	0.446
				1997	0.643	0.576
				1998	0.750	0.377
				1999	2.547	0.207
				2000	0.666	0.396
				2001	0.972	0.344
LCS05/06-DW-17	BLLOP	FD - C	Base	1994	0.799	1.027
				1995	0.882	0.832
				1996	1.000	0.843
				1997	0.956	1.182
				1998	1.292	1.391
				1999	0.849	1.529
				2000	0.744	2.009

				2001	1.650	1.600
				2002	0.865	1.266
				2003	1.007	0.902
				2004	0.955	0.976
LCS05/06-DW-20	VA LL	FI	Base	1975	1.900	0.23271
				1977	2.077	0.28711
				1978	1.085	0.58275
				1980	1.995	0.20558
				1981	1.925	0.21419
				1984	0.647	1.01363
				1986	0.665	1.08966
				1989	0.911	0.35817
				1990	0.746	0.29514
				1991	0.788	0.30447
				1992	1.331	0.46767
				1993	0.915	0.40248
				1995	0.860	0.26193
				1996	0.770	0.27439
				1997	0.721	0.22527
				1998	0.826	0.20952
				1999	0.528	0.36478
				2000	0.865	0.28108
				2001	0.754	0.23611
				2002	0.626	0.34985
				2003	0.547	0.26489
				2004	0.519	0.37114
LCS05/06-DW-27	NMFS LL SE	FI	Base	1995	1.293	0.281
				1996	0.831	0.379
				1997	1.301	0.316
				1999	0.390	0.384
				2000	0.971	0.210
				2001	1.041	0.256
				2002	1.072	0.207
				2003	0.880	0.261
				2004	1.221	0.322
LCS05/06-DW-30	DE Bay	FI	Base	2001	0.950	0.205
				2002	0.386	0.332
				2003	1.409	0.182
				2004	1.070	0.212
				2005	1.185	0.212
LCS05/06-DW-30	DE Bay - Age 0	FI	Base	2001	0.645	0.373
				2002	0.518	0.442
				2003	1.776	0.272
				2004	0.877	0.357
				2005	1.183	0.311
LCS05/06-DW-30	DE Bay - juveniles	FI	Base	2001	1.162	0.184

				2002	0.325	0.377
				2003	1.163	0.194
				2004	1.164	0.207
				2005	1.185	0.199
LCS05/06-DW-31	Bottom LL Logs	FD - C	Base	1996	0.789	0.175
				1997	1.002	0.116
				1998	0.919	0.111
				1999	1.150	0.102
				2000	1.171	0.111
				2001	1.115	0.104
				2002	0.887	0.104
				2003	1.170	0.102
				2004	0.798	0.119
LCS05/06-DW-33	NMFS LL NE	FI	Base	1996	0.321	7.985
				1998	2.045	1.678
				2001	1.004	2.947
				2004	0.629	4.909
LCS05/06-DW-35	Pelagic Log	FD - C	Base	1994	0.140	1.275
				1995	0.912	0.682
				1996	2.116	0.619
				1997	0.762	0.699
				1998	1.050	0.685
				1999	1.022	0.703
				2000	1.266	0.682
				2001	1.161	0.688
				2002	0.518	0.773
				2003	0.801	0.735
				2004	1.251	0.687
LCS05/06-DW-36	MRFSS	FD - R	Sensitivity	1981	2.011	0.645
				1982	2.195	0.592
				1983	2.766	0.592
				1984	2.408	0.610
				1985	2.094	0.591
				1986	2.119	0.560
				1987	1.167	0.594
				1988	0.789	0.621
				1989	0.714	0.639
				1990	0.634	0.674
				1991	0.431	0.679
				1992	0.874	0.600
				1993	0.402	0.679
				1994	0.243	0.776
				1995	0.492	0.643
				1996	0.612	0.617
				1997	0.504	0.663
				1998	0.917	0.603
				1999	0.524	0.639

2000	0.525	0.660
2001	0.503	0.651
2002	0.490	0.656
2003	0.386	0.714
2004	0.201	0.836

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Minority Statement from the Directed Shark Industry

Three technical concerns with the sandbar assessment that we ask the reviewers to consider.

Prepared by Frank Hester and Russell Hudson
Directed Shark Fishery Industry

Sandbar is an import resource and one of the two mainstay species of our industry, and we want to assure the best scientific information has been used in this assessment. Section 4 of the current assessment indicates that sandbar are overfished and that overfishing is occurring. We believe that before accepting the results, some additional sensitivity runs should be made and some additional analyses performed. What these are and the reasons for these requests are addressed in the following three point.

1. Age at (50%) sexual maturity for the 2006 assessment has been increased to 18-19 years. The basis is the new SB maturity ogive (**AW-09: Length and age at maturity of the sandbar shark, *Carcharhinus plumbeus*).** However, we note that none of the specimens examined for maturity state were also aged. Instead, age was estimated from length using a Von Bertalanffy growth curve derived from a different set of animals.

Unfortunately, none of the material that could be used to age each specimen was preserved and there is no way that the study results can be confirmed, or properly aged. Still, we believe the study needs be redone wherein both aged and maturity state is determined for each specimen. This cannot be done immediately, but we asked that a sensitivity run be done using a lesser age to determine how great an effect this new estimate has on the outcome. The assessment group did not agree, and one was not done.

We believe one should be done and included in your report so that one can judge the priority to assign to getting a valid maturity ogive. We suggest using the Base Case and age 13 at 50% mature. This estimate was used for the last assessment. A range of 8-13 seems to be encompass the estimates from other studies of this species.

2. We had a considerable discussion of the LPS Index (**DW-09: Standardized Catch Rates of Sandbar Sharks (*Carcharhinus plumbeus*) in the Virginia - Massachusetts (U.S.) Rod and Reel Fishery during 1986-2004)** in the context of the changes to the sport angling regulations that were imposed in 1993, 1997 and 1999. The regulatory change in 1993 limited the landings to four LCS per trip; reduced to two per trip in 1997 and one in 1999. We question whether even the new analysis (DW-09-V2) deals adequately with the effect of the regulations. The index, if it is to be used at all, needs to

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be reanalyzed to include catches of other LCS species on the trip, as the limit can be (partially) filled by other LCS species.

3. The Virginia Longline Index. As we prepared this paper, the sandbar section of the AW Report lacks tables evaluating the influence of individual indices on the outlook. These should be prepared and included in the final report. The only sensitivity runs done so far provide no information on individual indices, (or the maturity question - our point 1 above).

In lieu of these sensitivity runs, we use the figures of model predicted fit to the indices (Fig 4.7ff) to evaluate how well the model fit the indices. Figure 4.7 shows that the VA – LL index **(LCS05/06-DW-20)** has a disproportioned influence on the outcome. This is not surprising since it the longest index in the base case, and has nice negative "contest."

When a single index essentially determines the results of an assessment, we believe it should be scrutinized carefully. Is it likely to truly reflect change in population size? Because this particular series comprises a few sets per year at a single point in space off Virginia where sandbar are seasonally present, we believe it needs to be regarded with caution. The sandbar population ranges along the Atlantic seaboard, throughout the Gulf of Mexico, and into Mexico, and the VA-LL trend is not reflected by the indices that are derived from catches throughout the range of the species.

A second concern we have with the VA-LL series is that the age composition of the catch changes over time, adults being taken mainly in the early years (age composition data are available, were used in the 2002 Assessment, but were not provided this year). The index this year was given the same selectivity as the commercial catch even though most of the catch after 1975 was juveniles. The biology of sandbar is such the adults are unlikely to be taken in this area early in the season or in shallow water (females may be present, but generally do no feed during pupping). The index needs to be reanalyzed to include age and sex of the catch along with the other factors.

Thank you for your consideration

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