SEDAR 13

SMALL COASTAL SHARKS

ASSESSMENT WORKSHOP REPORT

Prepared by the
SEDAR 13 Stock Assessment Panel
9 July 2007

Contents:

1. Introduction

The current assessment for the Small Coastal Shark (SCS) 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 SCS complex was held in Panama City, FL February 5-9 2007. The Assessment Workshop (AW) was also held in Panama City, FL May 7 – 11 2007. 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 five separate assessments: 1) SCS complex, 2) finetooth shark, 3) blacknose shark, 4) Atlantic sharpnose shark and 5) bonnethead shark. 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 SCS complex, and the individual species have been assessed in 2002 by NOAA Fisheries. 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 SEDAR13-AW-xx).

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 13 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 complete SFA criteria. This may include evaluating existing SFA benchmarks or estimating alternative SFA benchmarks (SFA benchmarks include MSY, Fmsy, Bmsy, MSST, and MFMT); recommend proxy values where necessary; provide stock control rules.
6. Provide declarations of stock status relative to SFA benchmarks: MSY, Fmsy, Bmsy, 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.
7. Evaluate the results of past management actions and probable impacts of current management actions with emphasis on determining progress toward stated management goals.
8. Provide recommendations for future research and data collection (field and assessment); be as specific as practicable in describing sampling design and sampling intensity.
9. 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, June 18 2007. 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 SEDAR 13 AW Participants

Workshop participants:

Liz Brooks	NMFS/ SEFSC Miami, FL
John K. Carlson,	NMFS/ SEFSC Panama City, FL
Enric Cortés	NMFS/ SEFSC Panama City, FL
Walter Ingram	NMFS/ SEFSC Pascagoula, MS
Genny Nesslage	Atlantic States Marine Fishery Commission
Katie Siegfried	NMFS/ SEFSC Panama City, FL

Observers:

Michael Clark	NMFS Highly Migratory Species Div., Silver Spring, MD
Russell Hudson	Directed Shark Fisheries, Inc
Fritz Rhode	North Carolina DMF Wilmington, NC

Staff:

Julie A. Neer	NMFS/ SEFSC Panama City, FL
Ivy Baremore	NMFS/ SEFSC Panama City, FL

1.3 SEDAR 13 Assessment Workshop Documents

SEDAR 13-AW-01	Cortés: Assessment of Small Coastal Sharks, Atlantic sharpnose, Bonnethead, Blacknose and Finetooth Sharks using Surplus Production Methods
SEDAR 13-AW-02	Siegfried et al: Determining Selectivities for Small Coastal Shark Species for Assessment Purposes
SEDAR 13-AW-03	Siegfried and Brooks: Assessment of Blacknose, Bonnethead, and Atlantic Sharpnose Sharks with a State-Space, Age-Structured Production Model

SMALL COASTAL SHARK COMPLEX ASSESSMENT

2. SMALL COASTAL SHARK COMPLEX ASSESSMENT

2.1 Summary of SCS Complex Working Documents

SEDAR13-AW-01
Assessment of Small Coastal Sharks, Atlantic sharpnose, Bonnethead, Blacknose and Finetooth Sharks using Surplus Production Methods
We used two complementary surplus production models (BSP and WinBUGS) to assess the status of the Small Coastal Shark (SCS) complex and four individual species (Atlantic sharpnose, bonnethead, blacknose, and finetooth sharks) identified as baseline scenarios in the SCS 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 rate of increase, and importance function on results. Baseline scenarios predicted that the stock status is not overfished and overfishing is not occurring in all cases. Using the inverse variance method to weight the CPUE data was problematic because of the nature of the CPUE time series and must be regarded with great caution, although predictions on stock status did not change, except for blacknose sharks. The alternative surplus production model implemented in WinBUGS supported the results from the BSP model, with the exception of blacknose sharks, which became overfished. None of the other sensitivity analyses examined had a large impact on results and did not affect conclusions on stock status in any case. Only blacknose sharks with the alternative catch scenario approached an overfishing condition.

2.2 Background

The Small Coastal Shark (SCS) complex was assessed in 2002 (Cortés 2002) using a variety of surplus production methods and a form of delay-difference model (lagged recruitment, survival and growth model). The SCS SEDAR Data Workshop (DW) panel and report recommended that the SCS complex and the finetooth shark be assessed with surplus production methods alone because of the nature of the complex (composed of the sum of four individual species with different life histories) and the lack of adequate biological data to conduct an age-structured assessment for the finetooth shark.

1.3 Available Models

Two surplus production modeling approaches were available for discussion (SEDAR13-AW-01):

1) Bayesian surplus production model (BSP)
2) WinBUGS state-space Bayesian surplus production model

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 and small coastal sharks as well as pelagic 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 baseline 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.

2.4 Model Scenarios

The Assessment Workshop (AW) panel recommended that surplus production models be used to assess the status of the SCS complex and finetooth sharks. Surplus production models were the only type of model presented for the SCS complex and finetooth sharks following the recommendations of the Data Workshop (DW) panel and report. Additionally, surplus production models were also used to assess the status of Atlantic sharpnose, bonnethead and blacknose sharks in document SEDAR13-AW-01, but those results are not presented herein. In the present document we thus assessed the status of the SCS complex (consisting of four species).

2.5. Discussion of weighting methods

The Data Workshop Panel 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.

The Assessment Workshop Panel further discussed the issue for weighting indices. It was noted that there are a variety of ways to weight indices in addition to equal and inverse CV weighting, however how to determine which weighting method is most appropriate is a discussion topic that is still without satisfying resolution. Given that fact, the Assessment Workshop Panel decided that equal weighting would be the base weighting method for the current assessment but noted that, as there is at present no objective way to decide which method is superior other than comparing model convergence diagnostics, future assessments may need to re-examine this issue.

2.6 Methods

2.6.1 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 and small 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 lognormally 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-likelihood is given by:

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

where $I_{j,y}$ 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, $\sigma_j{}^2$ (the MLE estimate). The catchability coefficient for each time series (q_j) is also estimated as the MLE such that:

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

2.6.2 WinBUGS State-Space Bayesian Surplus Production Model description

This implementation of the Schaefer surplus production model uses Gibbs sampling, an MCMC method of numerical integration, to sample from the posterior distribution using WinBUGS (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. To minimize correlations between model parameters and speed mixing of the Gibbs sampler, the surplus production model is reparameterized by expressing the annual biomass as a proportion of carrying capacity:

$$P_t = P_{t-1} + rP_{t-1}(1-P_{t-1}) - \frac{C_{t-1}}{K}e^{P_t}$$

where $P_t = B_t/K$. The model is a state-space model, which relates the observed catch rates (I_t) to unobserved states (B_t) through a stochastic observation model for I_t given Bt (Millar and Meyer 1999, Meyer and Millar 1999b):

$$I_t = qKP_t e^{O_t}$$

The model thus assumes lognormal error structures for both process and observation errors (e^P and e^O), with $P_t \sim N(0,\sigma^2)$ and $O_t \sim N(0,\tau^2)$. In the present implementation, the catchability coefficient for each CPUE series is taken as the MLE.

The crucial equation for Bayesian inference is the joint posterior distribution of the unobservable states given the data, which is equal to the product of the joint prior distribution and the sampling distribution (likelihood):

$$\begin{aligned}
&p(K,r,q,C_0,P_{72},\sigma^2,\tau^2,P_1,...,P_n,I_1,...,I_n) = \\
&p(K)p(r)p(q)p(C_0)p(P_{72})p(\sigma^2)p(\tau^2)p(P_1 \mid \sigma^2) \\
&\times \prod_{i=2}^{i=m+1} p(P_t \mid P_{t-1},K,r,C_0,P_{72}\sigma^2) \prod_{i=m+2}^{i=n} p(P_t \mid P_{t-1},K,r,P_{72},\sigma^2) \prod_{t=1}^{t=n} p(I_t \mid P_t,q,\tau^2)
\end{aligned}$$

where $P_{72}=N_{72}/K$ and m is the number of years of unobserved catches, if applicable (C_0).

2.6.3 Data inputs, prior probability distributions, and performance indicators

Catch data (in numbers) were available from 1972 to 2005 (**Table 2.1**) and CPUE data, also from 1972 to 2005, as provided in the DW report. Thirteen CPUE series identified as “base” in the DW report were used in the baseline scenario. All CPUE series are listed in Appendix 1. The fishery was assumed to begin in 1972, the first year for which CPUE data were available. 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 10^4 and 10^8 individuals. Informative, lognormally distributed priors were used for N_{72}/K and r. For N_{72}/K, the mean was set equal to 0.9 to reflect some depletion with respect to virgin levels, and the log-SD was 0.2. For r, there was no specific value recommended in the DW report; the mean was thus taken as the average of the values for the four individual species, weighted by their percent contribution to the total catch (0.17 yr^{-1}). For SD, we used a value of 0.32, which corresponds to a log-variance of 0.10 (the BSP uses variance as an input) and which is approximately of the same magnitude with respect to the mean as the value used for SCS in the 2002 assessment. Input values are listed in **Table 2.2**.

The input parameters and priors described above are those used in the BSP model. Model inputs and priors used with WinBUGS were almost exactly the same. Additionally, priors for the observation error variance (τ^2) and process error variance (σ^2) in the WinBUGS model were inverse gamma distributions as used in previous stock assessments (Millar and Meyer 1999, Cortés et al. 2002), i.e., the 10% and 90% quantiles were set at approximately 0.05 and 0.15, and 0.04 and 0.08, respectively.

Performance indicators for the BSP model included the maximum sustainable yield (MSY=rK/4), the stock abundance in the last year of data (N_{2005}), the ratio of stock abundance in the last year of data to carrying capacity and MSY (N_{2005}/K and N_{2005}/MSY), the fishing mortality rate in the last year of data as a proportion of the fishing mortality rate at MSY (F_{2005}/F_{MSY}), the catch in the last year of data as a proportion of the replacement yield (C_{2005}/R_y) and MSY (C_{2005}/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_{2005}/N_{init}). The same metrics, except for those containing replacement yield, were calculated for the WinBUGS model. 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.

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

For the BSP model, 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, B_{init}/K, and C_0 if applicable), 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.

WinBUGS uses an MCMC method called Gibbs sampling (Gilks et al. 1996) to sample from the joint posterior distribution. All runs were based on two chains of initial values (where the P_t values were set equal to 0.5 and 1.0, respectively) to account for over-dispersed initial values (Spiegelhalter et al. 2000), and included a 5,000 sample burn-in phase followed by a 100,000 iteration phase with a thinning rate of 2.

Convergence diagnostics for the BSP model included 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).

In the WinBUGS analyses, convergence of the MCMC algorithm for the two chains was tested by examining the time series history of the two MCMC chains to determine whether mixing was good, parameter autocorrelations, and the convergence diagnostic of Gelman and Rubin (Gelman and Rubin 1992).

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 2005, and then forward in time up to 30 years to evaluate the potential consequences of future management actions. The exploratory policies considered included setting the total allowable catch (TAC) equal to 0, to the catch in 2005, and doubling the 2005 catch. The projections included calculating the following reference points, among others: expected value of N_{fin}/K (with fin=2015, 2025, and 2035) and the probabilities that N_{fin} were $<$ $0.2K$ and $N_{fin} > N_{msy}$.

2.6.5 Sensitivity analyses

We conducted sensitivity analyses to explore the influence of multiple factors (sources of uncertainty) on results by changing the following items with respect to those in the baseline scenario one at a time. All sensitivities were implemented with the BSP model.

W—Sensitivity to model, sources of error and method of numerical integration used: this involved using a complementary surplus production model (in WinBUGS) that also takes into account process error (vs. observation error only in the BSP), and uses MCMC for numerical integration (vs. the SIR algorithm in the BSP)

WM—Sensitivity to weighting scheme used: this involved changing the method for weighting the CPUE series from equal weighting in the baseline scenario to inverse variance weighting

IF—Sensitivity to importance function used: this involved changing the importance function from the priors to a multivariate t distribution. Only results obtained using the importance function that produced the best convergence diagnostics are reported

AC—Sensitivity to extending the catch series back to 1950 to mimic the catch stream used with the age-structured model (for Atlantic sharpnose, bonnethead, and blacknose sharks)

ALL—Adding the CPUE series identified as “sensitivity” in Table 3.2 of the DW report to those in the baseline scenario

2.7 Results

2.7.1 Baseline scenarios

Figure 2.1 shows the relative contribution of the four individual species to the small coastal shark complex catches. Except for 1995, when bonnetheads were more important, commercial landings were dominated by Atlantic sharpnose, finetooth, and blacknose sharks. Atlantic sharpnose sharks were the dominant species caught recreationally, followed by bonnethead and blacknose sharks, whereas finetooth sharks are rarely reported caught. Bycatch in the shrimp trawl fishery also consists mostly of Atlantic sharpnose and bonnethead sharks, with blacknose sharks also caught, but to a much lesser degree. Estimates for finetooth sharks could not be produced (see DW report) because they are rarely caught. In all, the majority of the catches correspond to shrimp bycatch in the Gulf of Mexico (**Fig. 2.2A,B**).

The abundance trajectory at the mode of the posterior distribution showed a trend that only decreased slightly with respect to virgin levels in the early 1970s (**Fig. 2.3**). Two of the four longest CPUE series (UNC and TEXAS) showed a generally increasing trend, whereas the other two series (SEAMAP-GOM-Fall and SEAMAP-GOM-Summer) showed a flatter or slightly declining trend. Most of the other series showed increasing or fluctuating trends. The model interpreted these trends with rather flat fits (**Fig. 2.4**). The median relative biomass and fishing mortality trajectories indicated that the complex did not approach an overfished status or overfishing, respectively, in any year (**Fig. 2.5A,B**). 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 2.3**.

Current status of the population was accordingly above N_{MSY} and no overfishing was occurring (**Table 2.4**). 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 much higher values of K and relatively higher values of r, respectively (**Fig. 2.6A,B**). The joint posterior distribution of K and r showed a large area of probability for K and a much more confined probability for r (**Fig. 2.6C**). Population projections showed that the population would be expected to remain above N_{MSY} for at least 30 years even when doubling the current level of total catch (**Table 2.5**; **Fig. 2.7**).

2.7.2 Sensitivity analyses

W: Considering an alternative model, sources of error and method of numerical integration—This involved using WinBUGS as an alternative surplus production model methodology. The median relative abundance trajectory for the WinBUGS model showed an increasing trend that never approached an overfished status. The median relative fishing mortality trajectory was very similar to that obtained with the BSP, with the only exception that the 97.5th quantile (vs. 80th quantile in the BSP) reached overfishing in a number of years. In all, current status of the population was above N_{MSY} and no overfishing was occurring (**Table 2.6**). WinBUGS model fits to the CPUE series were all increasing, with the exception of the fit to the SEAMAP-GOM-Fall series, which was decreasing and was fitted exactly to the observed data. The UNC and MML Gillnet series also showed exact, but increasing fits. Convergence diagnostics for the WinBUGS model showed that there was good mixing of the two chains for all parameters. Autocorrelations for all parameters also decreased after an initial lag, but remained high for some parameters. The Gelman-Rubin diagnostic indicated good convergence for the main parameters of interest (the ratio of the width of the central 80% interval of the pooled runs and the average width of the 80% intervals within the individual runs converged to 1 and both the pooled and within interval widths stabilized).

WM: Changing the CPUE weighting method—This involved changing the CPUE weighting method from equal weighting to inverse variance weighting. The model did not converge (**Table 2.7**). We observed that the likelihood of the fit for multiple parameter combinations attempted was very low probably because the CVs of some CPUE values were very small (<0.1) so that if those points were not fitted exactly the likelihood became very small. In general, when data are noisy and contradictory and the CVs differ by several orders of magnitude, as is the case for the SCS complex, using inverse variance methods is problematic.

AC: Extending the catch series back to 1950—This involved using the alternative catch series (Table 2.7 of the DW) to mimic the catch stream used in the age-structured models for Atlantic sharpnose, bonnethead, and blacknose sharks. This change had little impact on results (**Table 2.7**). Convergence diagnostics were good.

ALL: Adding the CPUE series identified as "sensitivity" in the DW to those from the baseline scenario—This involved adding the MS Gillnet and Gillnet Logs series. This change had little impact on results (**Table 2.7**). Convergence diagnostics were also good.

2.8 Discussion and Conclusions

The baseline scenario for the SCS complex predicted that the stock status is not overfished nor overfishing is occurring and very little depletion in numbers with respect to virgin levels (15%). The inverse variance weighting scenario did not converge. In general, when data are noisy and contradictory and the CVs differ substantially in magnitude, as was notably the case for the SCS complex, using inverse variance methods is problematic.

Other technical issues, such as the type of surplus production model, types of error and method of numerical integration, all tested by using a model developed in WinBUGS, supported the results of the baseline scenario using the BSP software. Depletions were of the same magnitude (10%) as found in the baseline scenario (15%) and the stock did not approach an overfishing condition.

The other two sensitivity analyses conducted (extending the catch series available back to 1950 and adding all the "sensitivity" CPUE series to the baseline) had essentially no effect on stock status.

The baseline scenario assumed that the stock had experienced a depletion of about 10% with respect to virgin levels at the beginning of the model, when data were first available (1972). The catch reconstruction (to 1950) scenario was an attempt to account for some historical level of exploitation, but nevertheless resulted in the same conclusions on stock status as the baseline scenario.

Figure 2.8 is a phase plot summarizing the results on stock status found in the baseline scenario and sensitivity analyses in the present assessment of the SCS complex. The plot also shows the baseline results of the 2002 SCS stock assessment using the surplus production model implemented in WinBUGS (Cortés 2002) for comparison and to have a historical perspective. It is important to note, however, that the current assessment does not represent any form of continuity analysis of the 2002 assessment because the inputs (catch stream, CPUE series considered, and life history parameters) are different. In all, the current assessment using surplus production methods indicated that when considering small coastal sharks as a complex, they are not overfished and overfishing is not occurring. It is important to remember, however, that the vast majority of the total catches of SCS corresponded to Atlantic sharpnose (almost 2/3) and bonnethead (1/3) sharks, respectively.

2.9 References

Berger, J. O. 1985. Statistical decision theory and Bayesian analysis. 2nd ed. Springer-Verlag, New York.

Cortés, E. 2002. Stock assessment of small coastal sharks in the U.S. Atlantic and Gulf of Mexico. March, 2002. NOAA/NMFS/Panama City Laboratory. Sustainable Fisheries Division Contribution SFD-01/02-152.

Cortés, E., L. Brooks and G. Scott. 2002. Stock assessment of large coastal sharks in the U.S. Atlantic and Gulf of Mexico. September, 2002. NOAA/NMFS/Panama City Laboratory. Sustainable Fisheries Division Contribution SFD-02/03-177.

Gelman, A. and D. B. Rubin. 1992. Inference from iterative simulation using multiple sequences. Stat. Sci. 7:457-511.

Gilks, W. R., S. Richardson, and D. J. Spiegelhalter. 1996. Markov chain Monte Carlo in practice. Chapman and Hall, London, U.K.

McAllister, M.K. and E. A. Babcock. 2004. Bayesian surplus production model with the Sampling Importance Resampling algorithm (BSP): a user's guide. Available from www.iccat.es.

McAllister, M. K. and G. P. Kirkwood. 1998. Bayesian stock assessment: a review and example application using the logistic model. ICES J. Mar. Sci. 55:1031-1060.

McAllister, M. K., E. K. Pikitch, and E. A. Babcock. 2001. Using demographic methods to construct Bayesian priors for the intrinsic rate of increase in the Schaefer model and implications for stock rebuilding. Can. J. Fish. Aquat. Sci. 58: 1871–1890.

Meyer, R. and R. B. Millar. 1999a. BUGS in Bayesian stock assessments. Can. J. Fish. Aquat. Sci. 56:1078-1086.

Meyer, R. and R. B. Millar. 1999b. Bayesian stock assessment using a state-space implementation of the delay difference model. Can. J. Fish. Aquat. Sci. 56:37-52.

Millar, R. B. and R. Meyer. 1999. Nonlinear state-space modeling of fisheries biomass dynamics using Metropolis-Hastings within Gibbs sampling. Tech. Rep. STAT9901. Department of Statistics, University of Auckland, Auckland, New Zealand.

Simpfendorfer, C.A. and G. H. Burgess. 2002. Assessment of the status of the small coastal sharks in US waters using an age-structured model. Mote Marine Laboratory Tech. Rep. 386, Sarasota, FL.

Spiegelhalter D., A. Thomas, and N. Best. 2000. WinBUGS User Manual Version 1.4. August 2002.

Walters, C.J. and D. Ludwig. 1994. Calculation of Bayes posterior probability distributions for key population parameters: a simplified approach. Can. J. Fish. Aquat. Sci. 51:713-722.

Table 2.1. Catch history for the **Small Coastal Shark complex** (numbers of fish).

CATCHES OF SMALL COASTAL SHARKS: 4 species (in numbers)

Year	Commercial				Recreational catches	Bottom longline discards	Shrimp bycatch (GOM)	Shrimp bycatch (SA)	EFP	Total
	Total	Longline	Nets	Lines						
1972							840,633	105,680		946,313
1973							233,634	29,371		263,005
1974							411,643	51,749		463,392
1975							872,930	109,740		982,670
1976							292,878	36,819		329,697
1977							946,230	118,955		1,065,185
1978							635,527	79,895		715,422
1979							933,737	117,384		1,051,121
1980							1,738,982	218,615		1,957,597
1981					82,759		1,736,376	218,287		2,037,422
1982					67,647		409,794	51,517		528,958
1983					87,399		674,421	84,784		846,604
1984					57,342		377,532	47,461		482,335
1985					62,885		476,828	59,944		599,657
1986					111,425		485,197	60,996		657,618
1987					98,947		1,040,738	130,836		1,270,521
1988					172,684		580,306	72,953		825,943
1989					104,757		603,506	75,869		784,132
1990					96,977		614,590	77,263		788,830
1991					143,845		891,723	112,102		1,147,670
1992					111,829		1,172,572	147,409		1,431,810
1993	262				93,562		509,360	64,034		666,956
1994	3,308				140,473		443,215	55,718		639,406
1995	139,569	57,819	80,791	627	164,884	32,494	1,051,681	132,211		1,520,508
1996	118,425	39,967	75,317	3,134	114,007	15,627	920,627	115,736		1,284,416
1997	214,221	29,527	181,922	1,723	99,382	9,035	703,350	88,421		1,113,361
1998	187,931	22,044	163,396	2,397	123,593	9,038	806,300	101,363		1,228,131
1999	222,715	18,064	198,804	4,601	112,715	14,379	641,017	80,585		1,070,164
2000	168,544	24,689	141,425	2,377	199,043	22,196	796,602	100,144	11	1,286,476
2001	219,962	14,643	201,777	1,535	212,442	14,365	641,786	80,682		1,167,231
2002	173,847	25,133	146,719	1,949	153,810	24,906	1,104,353	138,833		1,595,703
2003	147,313	36,678	90,411	20,120	133,738	26,518	544,058	68,396	5	919,918
2004	133,937	35,741	97,080	1,374	125,711	30,165	797,000	101,330	1872	1,188,402
2005	138,792	34,964	100,874	1,349	122,688	29,020	530,943	66,893	484	886,732

Table 2.2. Prior probability distributions of parameters used in the baseline scenario (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) for the **SCS complex**. K is carrying capacity (in numbers), r is the intrinsic rate of population increase, 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)							
SCS complex	Uniform on log K[1] (10^4-10^8)	Lognormal (0.17,0.32,0.001,2.0)	n/a	Lognormal (0.9,0.2,0.2,1.1)	Uniform on log[2]	Uniform on log	N/A
WinBUGS (MCMC)							
SCS complex	Uniform on log K (10^4-10^8)	Lognormal (0.17,0.32,0.01,0.5)	n/a	Lognormal (0.9,0.2,0.2,1.1)	MLE[3]	Inverse gamma (0.04-0.08)	Inverse gamma (0.05-0.15)

[1] Values in parentheses are lower and upper bounds (uniform distribution), mean, log-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 2.3. 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 **SCS complex**. Values listed are medians.

Year	N_i	N_i/N_{MSY}	F_i	F_i/F_{MSY}
1972	50410989	1.79	0.019	0.22
1973	51211717	1.83	0.005	0.06
1974	51785881	1.85	0.009	0.11
1975	51951240	1.84	0.019	0.23
1976	52192325	1.86	0.006	0.08
1977	52345438	1.84	0.020	0.24
1978	52140884	1.84	0.014	0.16
1979	52040414	1.82	0.020	0.24
1980	51377381	1.77	0.038	0.45
1981	50350696	1.73	0.040	0.49
1982	50185314	1.76	0.011	0.13
1983	50659681	1.77	0.017	0.20
1984	51064590	1.79	0.009	0.11
1985	51424884	1.80	0.012	0.14
1986	51675748	1.81	0.013	0.15
1987	51432235	1.79	0.025	0.29
1988	51252483	1.79	0.016	0.19
1989	51381837	1.80	0.015	0.18
1990	51475609	1.80	0.015	0.18
1991	51326530	1.79	0.022	0.27
1992	50930729	1.76	0.028	0.34
1993	50821827	1.78	0.013	0.16
1994	51081583	1.79	0.013	0.15
1995	50880786	1.76	0.030	0.35
1996	50415234	1.75	0.025	0.30
1997	50136046	1.75	0.022	0.27
1998	49945417	1.74	0.025	0.29
1999	49796955	1.75	0.021	0.26
2000	49634759	1.74	0.026	0.31
2001	49440693	1.73	0.024	0.28
2002	49111864	1.71	0.032	0.38
2003	48979623	1.73	0.019	0.22
2004	49016160	1.73	0.024	0.29
2005	49087650	1.74	0.018	0.21

Table 2.4. 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 **SCS complex** (baseline scenario) using equal weighting. Abundances are in thousands of fish.

	SCS complex	
	EV	CV
Importance function	priors	
K	59566	0.35
r	0.181	0.32
MSY	2623	0.45
N_{2005}	51605	0.40
N_{2005}/K	**0.85**	0.09
N_{init}	53057	0.38
N_{2005}/N_{init}	0.97	0.13
C_{2005}/MSY	0.40	0.42
F_{2005}/F_{MSY}	**0.25**	0.55
N_{2005}/N_{MSY}	**1.69**	0.09
C_{2005}/repy	0.79	0.05
N_{MSY}	29783	0.35
F_{MSY}	0.091	
repy	1125	0.05
Diagnostics		
CW (Wt)	0.786	
CV (L*prior)	0.902	
CV (Wt) / CV (L*p)	0.87	
%maxpWt	0.002	

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

Table 2.5. Decision analysis table for the **SCS complex** corresponding to the results in Table 2.4.

SCS complex

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	TAC=0	1.29	1.93	0	1	1	1	1	0
	TAC=1C_{2005}	1.18	1.74	0	1	1	1	1	0
	TAC=2C_{2005}	1.06	1.52	0.01	0.95	0	0	0	0
20 -year	TAC=0	1.33	1.98	0	1	1	1	1	0
	TAC=1C_{2005}	1.19	1.75	0	1	1	1	1	0
	TAC=2C_{2005}	1.02	1.43	0.05	0.89	0	0	0	0.02
30 -year	TAC=0	1.33	2	0	1	1	1	1	0
	TAC=1C_{2005}	1.19	1.76	0	1	1	1	1	0
	TAC=2C_{2005}	0.99	1.36	0.08	0.84	0	0	0	0.05

Table 2.6. Expected values (EV) of the mean and coefficients of variation (CV) of marginal posterior distributions for output parameters for the **SCS complex** using WinBUGS as an alternative model formulation. Abundances are in thousands of fish.

	SCS complex	
	EV	CV
K	59700	0.36
r	0.150	0.38
MSY	2124	0.42
N_{2005}	54000	0.39
N_{2005}/K	**0.90**	0.12
N_{init}	44393	
N_{2005}/N_{init}	1.22	
C_{2005}/MSY	0.42	
F_{2005}/F_{MSY}	**0.28**	0.48
N_{2005}/N_{MSY}	**1.82**	0.11
N_{MSY}	29850	
F_{MSY}	0.075	
C_0	n/a	
N_{init}/K	0.74	0.17
Diagnostics		
Chain mixing	good	
Autocorrelations	high	
Gelman-Rubin	good	

N_{init} is initial abundance (for the first year of the model)

Table 2.7. 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 **SCS complex** using an alternative catch series starting in 1950, and all the CPUE series identified as "sensitivity" in the Data Workshop report. The run using inverse CV weighting did not converge. Abundances are in thousands of fish.

	Alternative catch		All CPUE series	
	EV	CV	EV	CV
Importance function	priors		priors	
K	60082	0.35	59511	0.35
r	0.184	0.32	0.181	0.32
MSY	2695	0.44	2621	0.45
N_{2005}	52193	0.40	51548	0.41
N_{2005}/K	**0.85**	0.09	**0.85**	0.09
N_{init}	51785	0.38	53006	0.38
N_{2005}/N_{init}	1.00	0.17	0.97	0.13
C_{2005}/MSY	0.39	0.41	0.41	0.42
F_{2005}/F_{MSY}	**0.24**	0.54	**0.25**	0.55
N_{2005}/N_{MSY}	**1.70**	0.09	**1.69**	0.09
C_{2005}/repy	0.77	0.04	0.79	0.05
N_{MSY}	30041	0.35	29756	0.35
F_{MSY}	0.092		0.090	
repy	1146	0.04	1125	0.05
C_0				
Diagnostics				
CW (Wt)	0.635		0.785	
CV (L*prior)	0.797		0.902	
CV (Wt) / CV (L*p)	0.80		0.87	
%maxpWt	0.001		0.002	

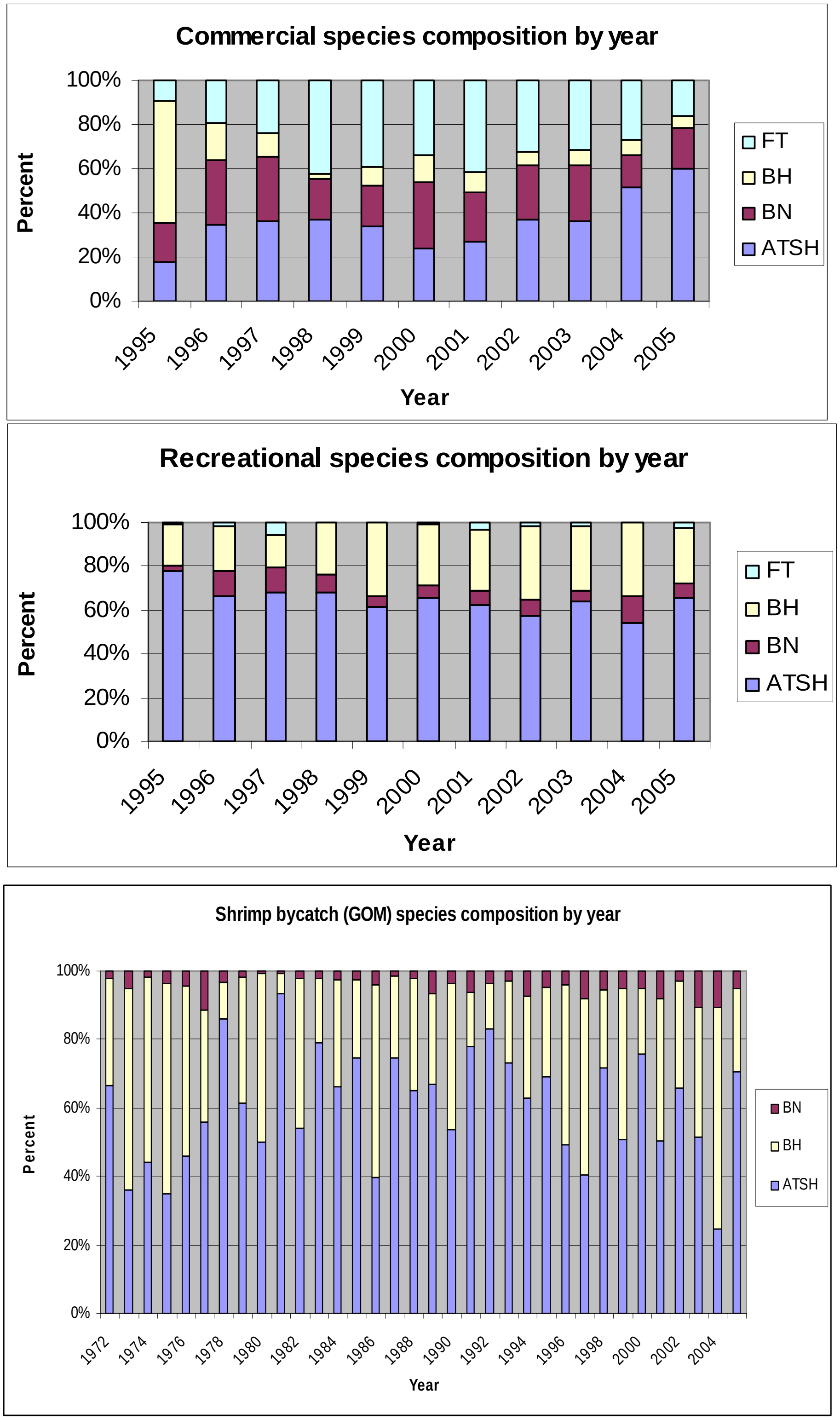


Figure 2.1. Relative species composition of commercial landings, recreational catches, and dead discards from the shrimp trawl fishery for the **SCS complex**.

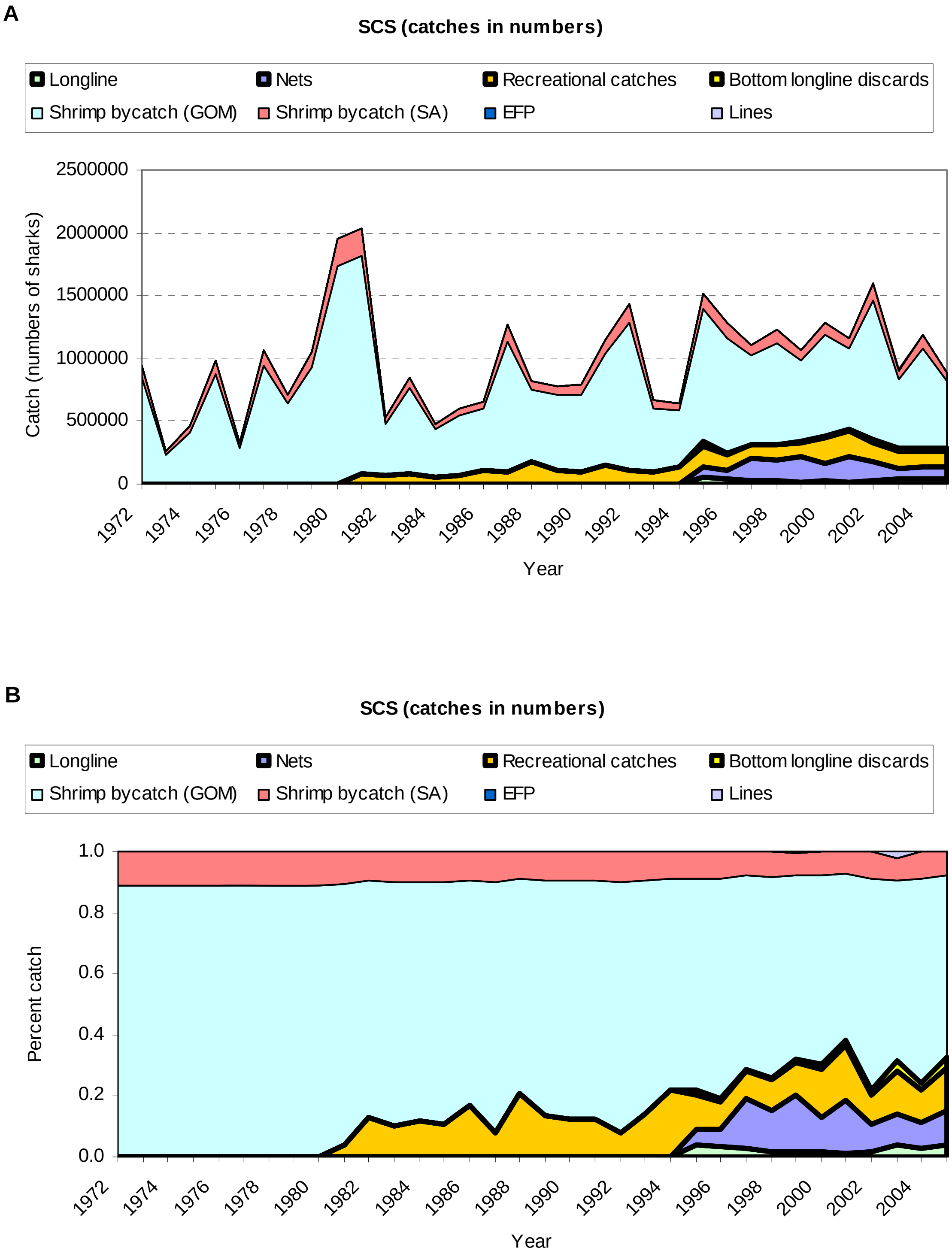


Figure 2.2. Total catches of the SCS complex by sector in (A) absolute and (B) relative terms.

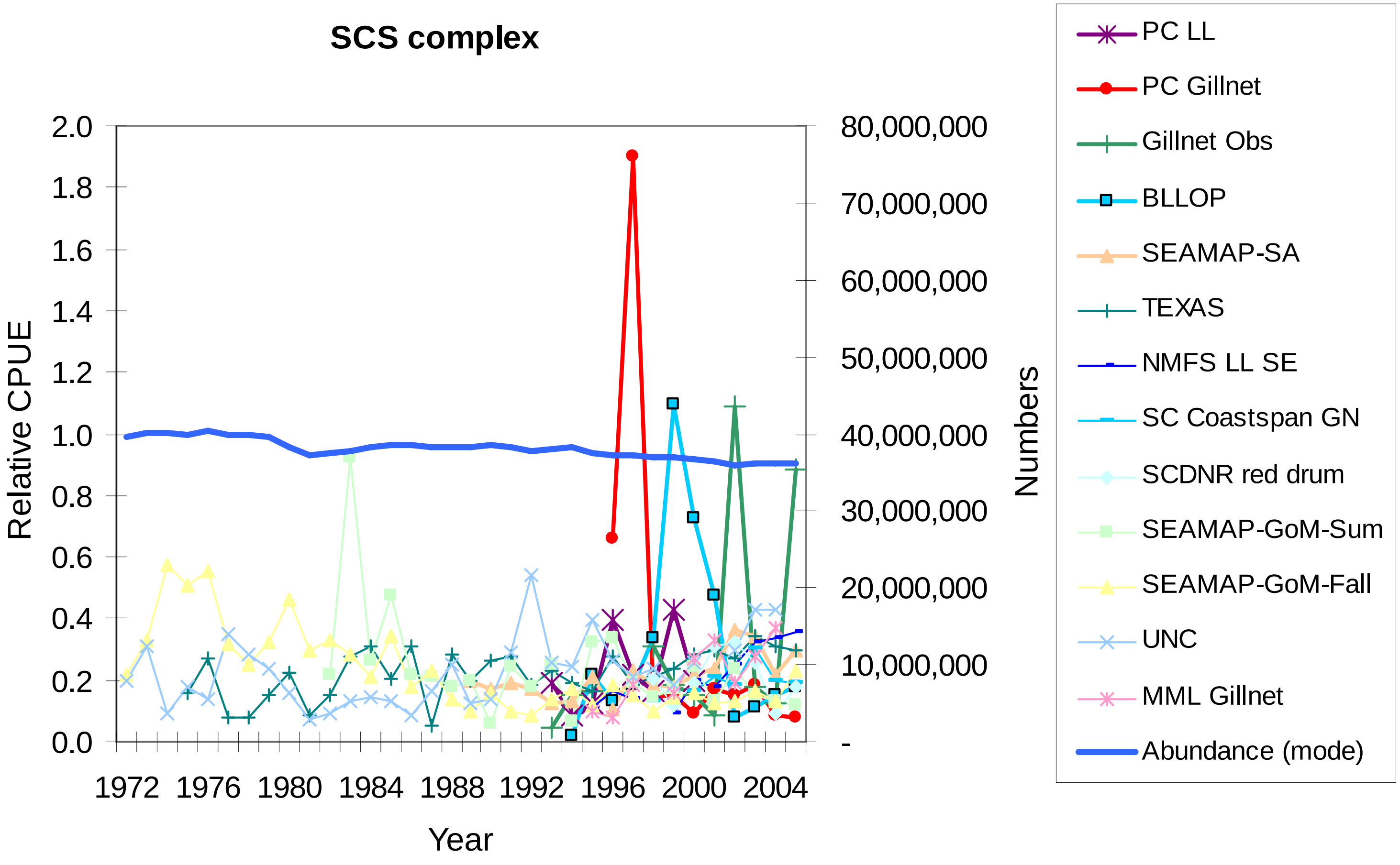


Figure 2.3. Predicted abundance trend of the BSP model fitted to the catch and CPUE data for the **SCS complex**. CPUE series shown are scaled (divided by the catchability coefficient for each series, the mean of the overlapping years, and the overall mean for all series).

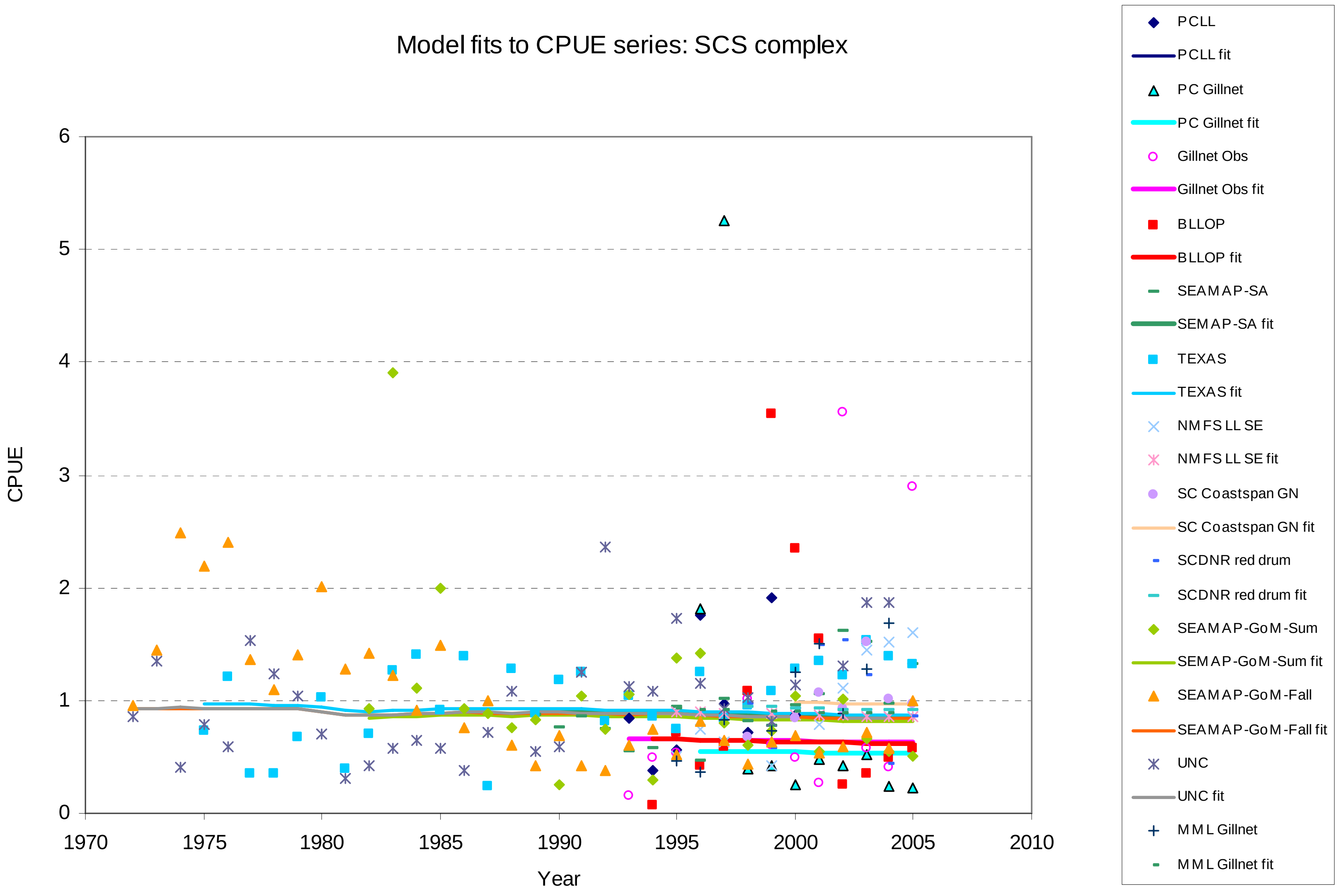
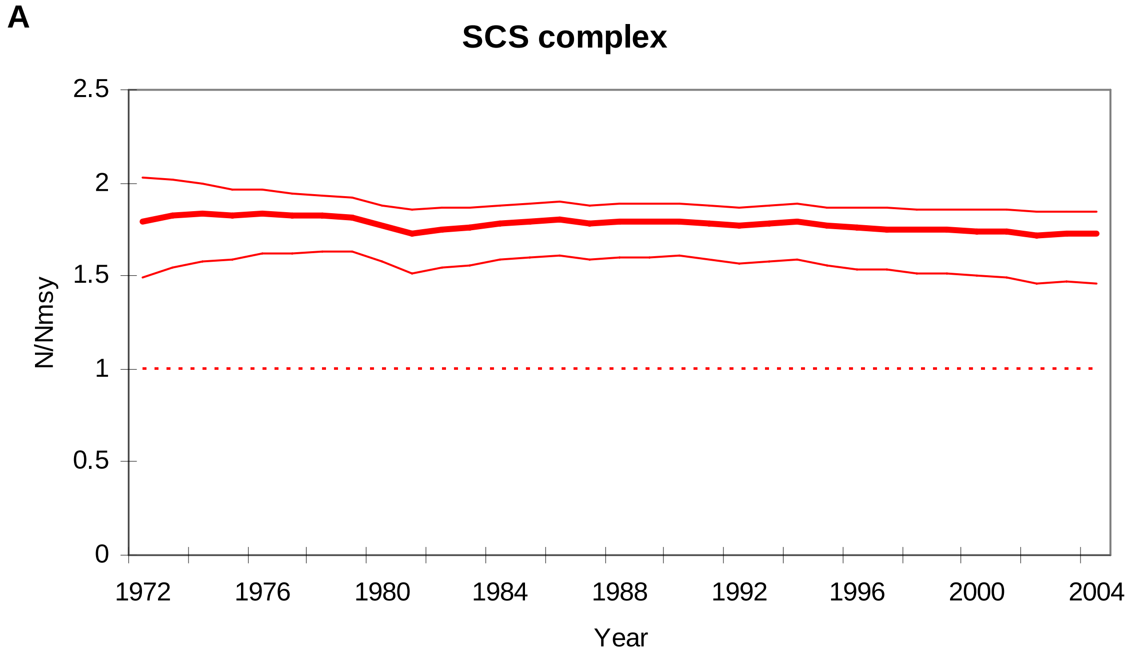


Figure 2.4. BSP model fits to the individual CPUE series for the **SCS complex**.



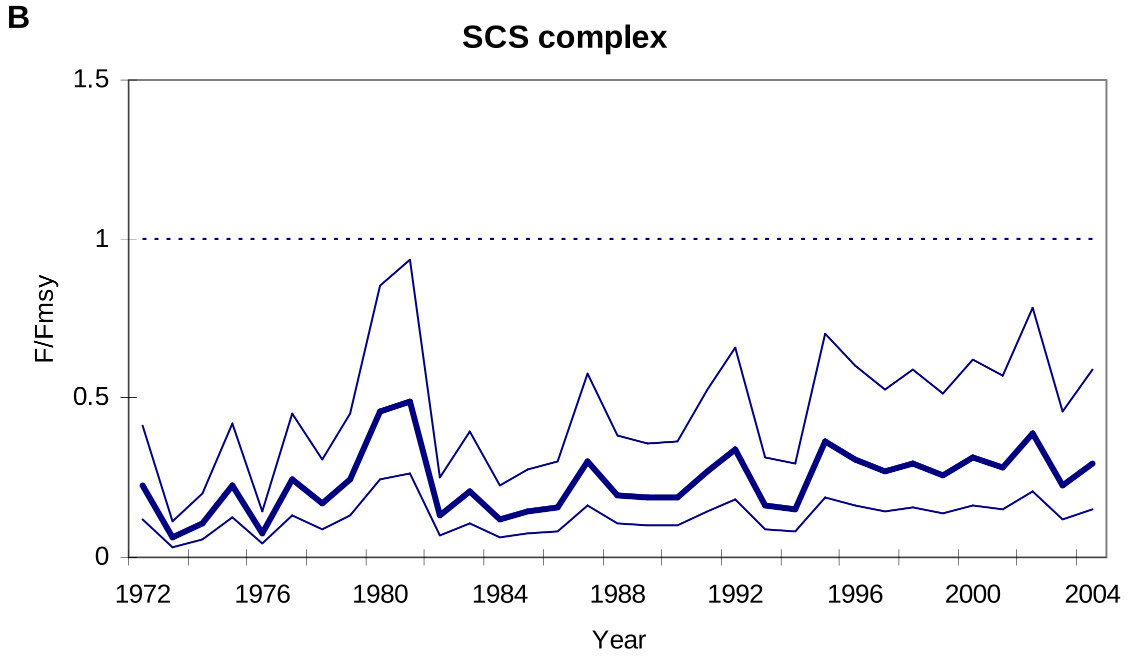


Figure 2.5. Predicted median relative abundance (A) and fishing mortality rate (B) trajectories for the **SCS complex** with the BSP model. Values shown are medians with 80% probability intervals; horizontal lines at 1 denote MSY levels.

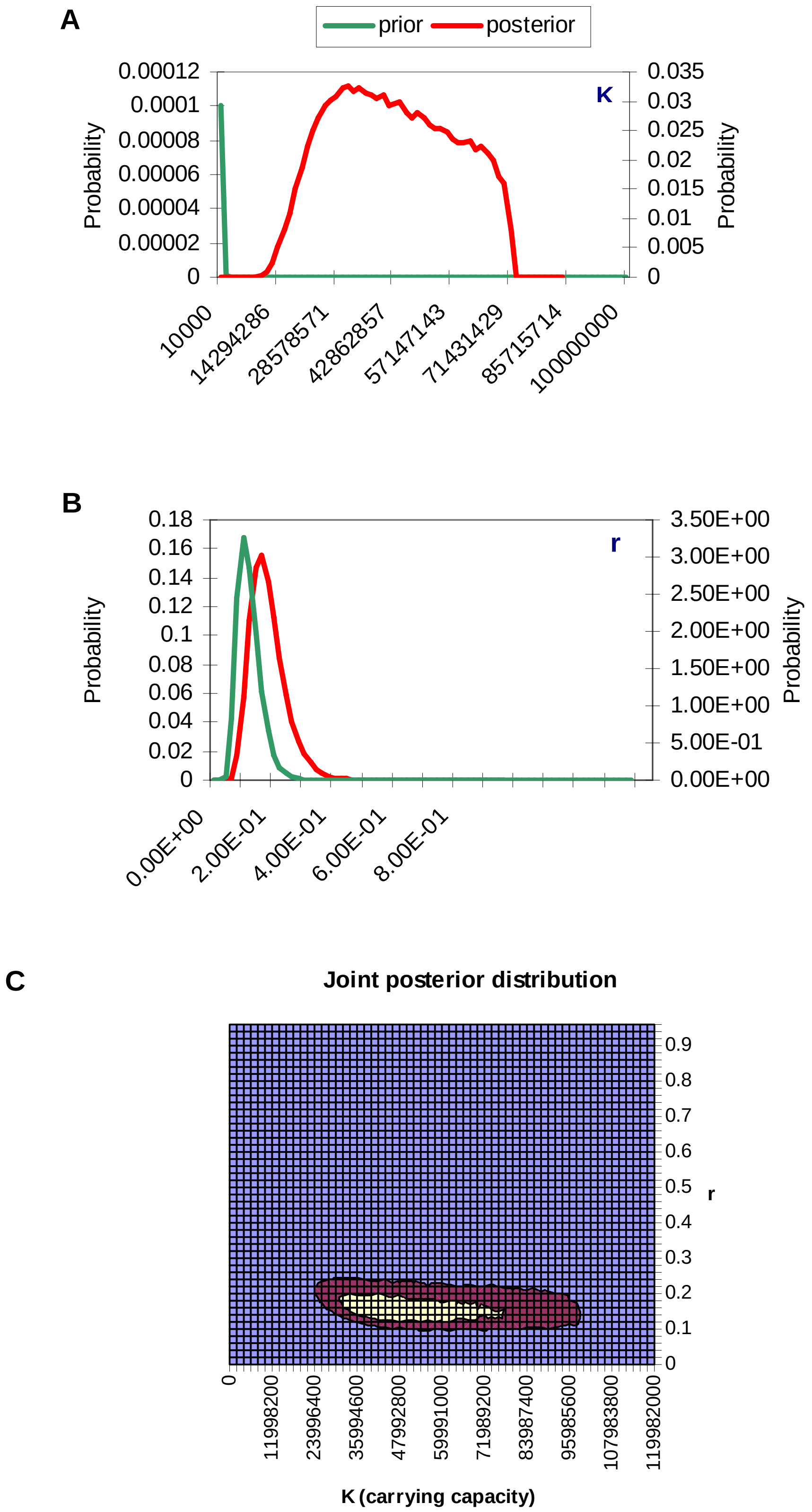


Figure 2.6. Prior (green) and posterior (red) probability distributions for (A) K and (B) r for the **SCS complex** from the BSP model. Also shown (C) is the joint posterior probability distribution for r and K.

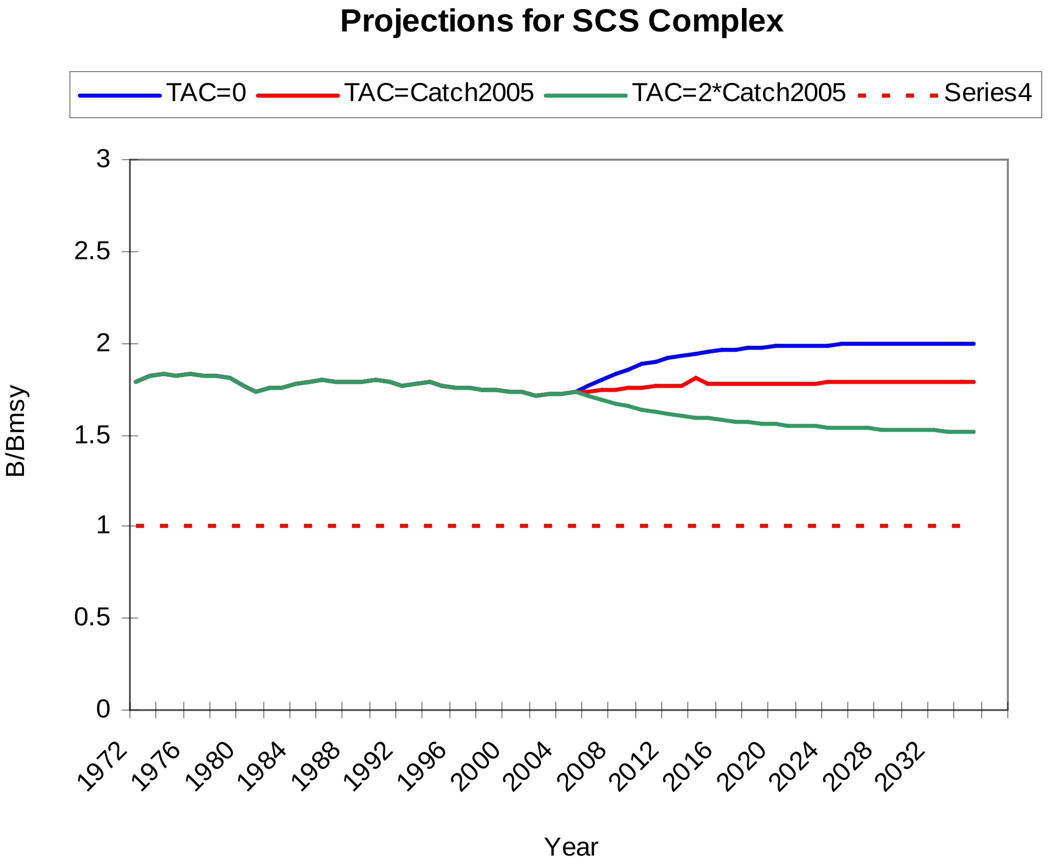


Figure 2.7. Estimated median relative abundance trajectory and projections (from 2006 to 2035) for alternative TAC-based harvesting policies (0, 1, and 2 times the 2005 TAC) for the **SCS complex** baseline scenario. The dashed horizontal line at 1 denotes the MSY level.

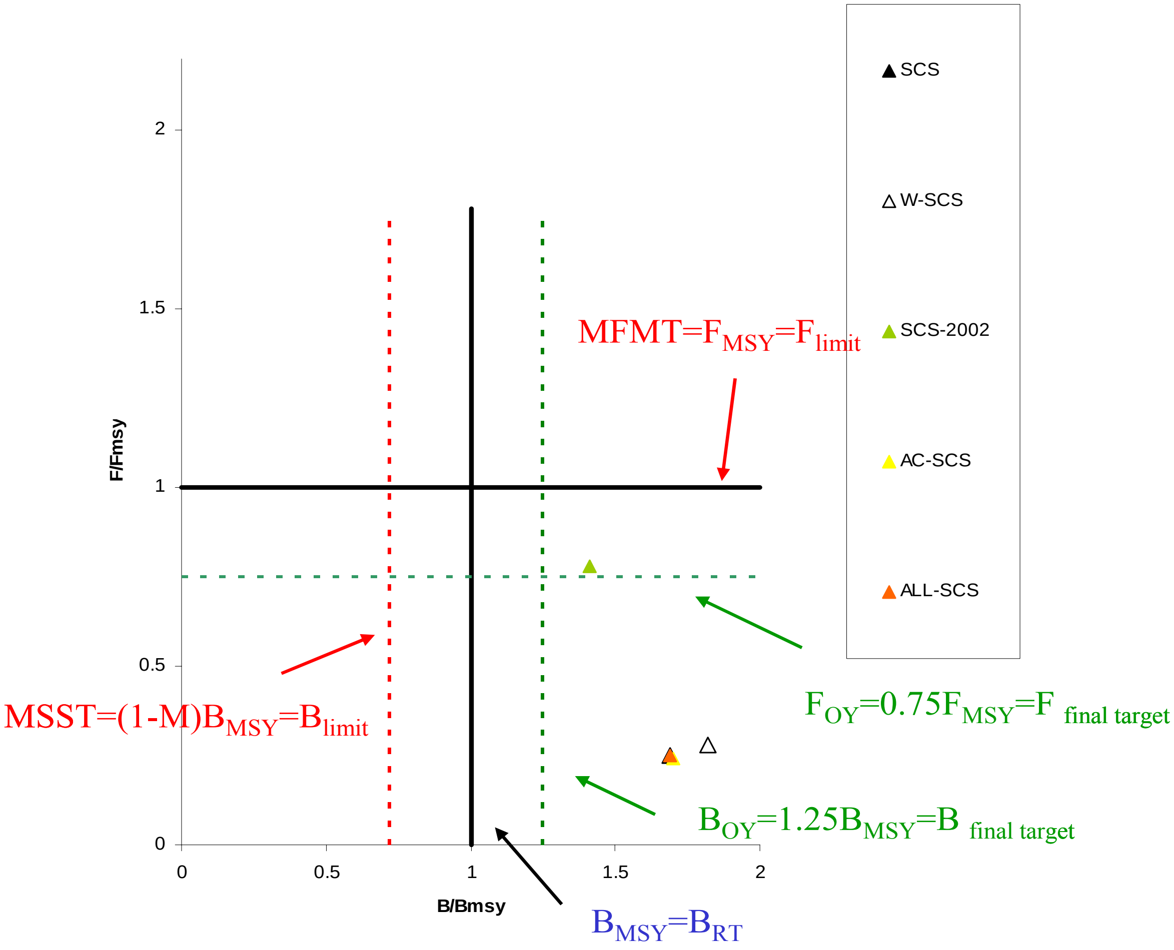


Figure 2.8. Phase plot for the **SCS complex** showing values of N_{2005}/N_{MSY} and F_{2005}/F_{MSY} obtained in the baseline scenario using the BSP model and various sensitivity analyses. The models include: SCS (baseline), W (WinBUGS surplus production model), AC-SCS (alternative catch starting in 1950), ALL-SCS (all CPUE series), and SCS-2002 (results of the 2002 SCS assessment using WinBUGS). See text for full details. Several control rules are illustrated: the solid horizontal line indicates the MFMT (Maximum Fishing Mortality Threshold), the solid vertical line denotes the target biomass (biomass or number at MSY), the dashed horizontal line indicates the F at optimum yield (final F target for rebuilding), and the dashed vertical lines denote the MSST (Minimum Stock Size Threshold or limit biomass) and B_{OY} (biomass at optimum yield or final B target for rebuilding).

FINETOOTH SHARK ASSESSMENT

3. FINETOOTH SHARK (*Carcharhinus isodon*) ASSESSMENT

3.1 Summary of Finetooth shark Working Documents

SEDAR13-AW-01
Assessment of Small Coastal Sharks, Atlantic sharpnose, Bonnethead, Blacknose and Finetooth Sharks using Surplus Production Methods
We used two complementary surplus production models (BSP and WinBUGS) to assess the status of the Small Coastal Shark (SCS) complex and four individual species (Atlantic sharpnose, bonnethead, blacknose, and finetooth sharks) identified as baseline scenarios in the SCS 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 rate of increase, and importance function on results. Baseline scenarios predicted that the stock status is not overfished and overfishing is not occurring in all cases. Using the inverse variance method to weight the CPUE data was problematic because of the nature of the CPUE time series and must be regarded with great caution, although predictions on stock status did not change, except for blacknose sharks. The alternative surplus production model implemented in WinBUGS supported the results from the BSP model, with the exception of blacknose sharks, which became overfished. None of the other sensitivity analyses examined had a large impact on results and did not affect conclusions on stock status in any case. Only blacknose sharks with the alternative catch scenario approached an overfishing condition.

3.2 Background

The finetooth shark, a component of the Small Coastal Shark (SCS) complex, was assessed in 2002 (Cortés 2002) using a variety of surplus production methods and a form of delay-difference model (lagged recruitment, survival and growth model). Additionally, an age-structured model was used in a parallel assessment (Simpfendorfer and Burgess 2002). The SCS SEDAR Data Workshop (DW) panel and report recommended that the SCS complex and the finetooth shark be assessed with surplus production methods alone because of the nature of the complex (composed of the sum of four individual species with different life histories) and the lack of adequate biological data to conduct an age-structured assessment for the finetooth shark.

3.3 Available Models

Two surplus production modeling approaches were available for discussion (SEDAR13-AW-01):

2) Bayesian surplus production model (BSP)
2) WinBUGS state-space Bayesian surplus production model

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 and small coastal sharks as well as pelagic 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 baseline 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 SCS complex and finetooth sharks. Surplus production models were the only type of model presented for the SCS complex and finetooth sharks following the recommendations of the Data Workshop (DW) panel and report. Additionally, surplus production models were also used to assess the status of Atlantic sharpnose, bonnethead and blacknose sharks in document SEDAR13-AW-01, but those results are not presented herein. In the present document we thus assessed the status of the finetooth shark.

3.5 Discussion of weighting methods

The Data Workshop Panel 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.

The Assessment Workshop Panel further discussed the issue for weighting indices. It was noted that there are a variety of ways to weight indices in addition to equal and inverse CV weighting, however how to determine which weighting method is most appropriate is a discussion topic that is still without satisfying resolution. Given that fact, the Assessment Workshop Panel decided that equal weighting would be the base weighting method for the current assessment but noted that, as there is at present no objective way to decide which method is superior other than comparing model convergence diagnostics, future assessments may need to re-examine 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 and small 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 lognormally 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-likelihood is given by:

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

where $I_{j,y}$ 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:

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

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:

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

3.6.2 WinBUGS State-Space Bayesian Surplus Production Model description

This implementation of the Schaefer surplus production model uses Gibbs sampling, an MCMC method of numerical integration, to sample from the posterior distribution using WinBUGS (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. To minimize correlations between model parameters and speed mixing of the Gibbs sampler, the surplus production model is reparameterized by expressing the annual biomass as a proportion of carrying capacity:

$$P_t = P_{t-1} + rP_{t-1}(1 - P_{t-1}) - \frac{C_{t-1}}{K} e^{P_t}$$

where P$_t$=B$_t$/K. The model is a state-space model, which relates the observed catch rates (I$_t$) to unobserved states (B$_t$) through a stochastic observation model for I$_t$ given Bt (Millar and Meyer 1999, Meyer and Millar 1999b):

$$I_t = qKP_t e^{O_t}$$

The model thus assumes lognormal error structures for both process and observation errors (e^P and e^O), with $P_t \sim N(0,\sigma^2)$ and $O_t \sim N(0,\tau^2)$. In the present implementation, the catchability coefficient for each CPUE series is taken as the MLE.

The crucial equation for Bayesian inference is the joint posterior distribution of the unobservable states given the data, which is equal to the product of the joint prior distribution and the sampling distribution (likelihood):

$$
\begin{aligned}
&p(K,r,q,C_0,P_{72},\sigma^2,\tau^2,P_1,\ldots,P_n,I_1,\ldots,I_n) = \\
&p(K)\,p(r)\,p(q)\,p(C_0)\,p(P_{72})\,p(\sigma^2)\,p(\tau^2)\,p(P_1 \mid \sigma^2) \\
&\times \prod_{i=2}^{i=m+1} p(P_t \mid P_{t-1},K,r,C_0,P_{72},\sigma^2) \prod_{i=m+2}^{i=n} p(P_t \mid P_{t-1},K,r,P_{72},\sigma^2) \prod_{t=1}^{t=n} p(I_t \mid P_t,q,\tau^2)
\end{aligned}
$$

where $P_{72}=N_{72}/K$ and m is the number of years of unobserved catches, if applicable (C_0).

3.6.3 Data inputs, prior probability distributions, and performance indicators

Catch data (in numbers) were available from 1983 to 2005 (**Table 3.1**) and CPUE data, from 1976 to 2005, as provided in the DW report. Four CPUE series identified as "base" in the DW report were used in the baseline scenario. All CPUE series are listed in Appendix 1. The fishery was assumed to begin in 1976, the first year for which CPUE data were available. Estimated parameters were r, K, and the abundance (in numbers) in 1976 relative to K (N_{76}/K). Additionally, the catches in the years 1976-1982 were assumed to be constant and equal to the model-estimated parameter C_0. 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 10^4 and $2\text{x}10^7$ individuals. Informative, lognormally distributed priors were used for N_{76}/K, r, and C_0. For N_{76}/K, the mean was set equal to 0.9 to reflect some depletion with respect to virgin levels, and the log-SD was 0.2. Since the value of r listed in the DW report was negative (-0.056 yr^{-1}), we opted to use the value from the 2002 assessment (0.060 yr^{-1}) as the mean of r and a log-variance of 0.04 (log-SD=0.2 also from the 2002 assessment). For C_0, the mean was set equal to the average catch during 1983-1988 (2,774 individuals) and the log-SD was 1, implying a wide distribution. Input values are listed in **Table 3.2**.

The input parameters and priors described above are those used in the BSP model. Model inputs and priors used with WinBUGS were almost exactly the same. Additionally, priors for the observation error variance (τ^2) and process error variance (σ^2) in the WinBUGS model were inverse gamma distributions as used in previous stock assessments (Millar and Meyer 1999, Cortés et al. 2002), i.e., the 10% and 90% quantiles were set at approximately 0.05 and 0.15, and 0.04 and 0.08, respectively.

Performance indicators for the BSP model included the maximum sustainable yield (MSY=rK/4), the stock abundance in the last year of data (N_{2005}), the ratio of stock abundance in the last year of data to carrying capacity and MSY (N_{2005}/K and N_{2005}/MSY), the fishing mortality rate in the last year of data as a proportion of the fishing mortality rate at MSY (F_{2005}/F_{MSY}), the catch in the last year of data as a proportion of the replacement yield (C_{2005}/R_y) and MSY (C_{2005}/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_{2005}/N_{init}). The same metrics, except for those containing replacement yield, were calculated for the WinBUGS model. 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.

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

For the BSP model, 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, B_{init}/K, and C_0 if applicable), 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.

WinBUGS uses an MCMC method called Gibbs sampling (Gilks et al. 1996) to sample from the joint posterior distribution. All runs were based on two chains of initial values (where the P_t values were set equal to 0.5 and 1.0, respectively) to account for over-dispersed initial values (Spiegelhalter et al. 2000), and included a 5,000 sample burn-in phase followed by a 100,000 iteration phase with a thinning rate of 2.

Convergence diagnostics for the BSP model included 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).

In the WinBUGS analyses, convergence of the MCMC algorithm for the two chains was tested by examining the time series history of the two MCMC chains to determine whether mixing was good, parameter autocorrelations, and the convergence diagnostic of Gelman and Rubin (Gelman and Rubin 1992).

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 2005, and then forward in time up to 30 years to evaluate the potential consequences of future management actions. The exploratory policies considered included setting the total allowable catch (TAC) equal to 0, to the catch in 2005, and doubling the 2005 catch. The projections included calculating the following reference points, among others: expected value of N_{fin}/K (with fin=2015, 2025, and 2035) and the probabilities that N_{fin} were $<$ $0.2K$ and $N_{fin} > N_{msy}$.

3.6.5 Sensitivity analyses

We conducted sensitivity analyses to explore the influence of multiple factors (sources of uncertainty) on results by changing the following items with respect to those in the baseline scenario one at a time. All sensitivities were implemented with the BSP model.

W—Sensitivity to model, sources of error and method of numerical integration used: this involved using a complementary surplus production model (in WinBUGS) that also takes into account process error (vs. observation error only in the BSP), and uses MCMC for numerical integration (vs. the SIR algorithm in the BSP)

WM—Sensitivity to weighting scheme used: this involved changing the method for weighting the CPUE series from equal weighting in the baseline scenario to inverse variance weighting

IF—Sensitivity to importance function used: this involved changing the importance function from the priors to a multivariate t distribution. Only results obtained using the importance function that produced the best convergence diagnostics are reported

AC—Sensitivity to extending the catch series back to 1950 to mimic the catch stream used with the age-structured model (for Atlantic sharpnose, bonnethead, and blacknose sharks)

ALL—Adding the CPUE series identified as “sensitivity” in Table 3.2 of the DW report to those in the baseline scenario

LOWr—Using a lower value of intrinsic rate of increase (0.02 yr^{-1})

3.7 Results

3.7.1 Baseline scenarios

Figure 3.1 shows the relative contribution of the four individual species to the small coastal shark complex catches. Except for 1995, when bonnetheads were more important, commercial landings were dominated by Atlantic sharpnose, finetooth, and blacknose sharks. Atlantic sharpnose sharks were the dominant species caught recreationally, followed by bonnethead and blacknose sharks, whereas finetooth sharks are rarely reported caught. Bycatch in the shrimp trawl fishery also consists mostly of Atlantic sharpnose and bonnethead sharks, with blacknose sharks also caught, but to a much lesser degree. Estimates for finetooth sharks could not be produced (see DW report) because they are rarely caught. The majority of the catches of finetooth sharks since the mid-1990s correspond to gillnets (**Fig. 3.2A,B** and see also SEDAR 13-DW-15).

The abundance trajectory at the mode of the posterior distribution showed a rather flat trend (**Fig. 3.3**). This trend in estimated abundance was reflective of the lack of signal from the four CPUE series available, which showed fluctuation but no clear trend. The model fits to the CPUE series were accordingly rather flat (**Fig. 3.4**). The median relative biomass and fishing mortality trajectories indicated that the stock did not approach an overfished status or overfishing, respectively, in any year (**Fig. 3.5A,B**). 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 3.3**.

Current status of the population was above N_{MSY} and no overfishing was occurring (**Table 3.4**). 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 higher values of these two parameters (**Fig. 3.6A,B**). The joint posterior distribution of K and r showed a restricted area of probability for r (**Fig. 3.6C**). Population projections indicated that the population would be expected to remain above N_{MSY} for at least 30 years even when doubling the current level of total catch (**Table 3.5**; **Fig. 3.7**).

3.7.2 Sensitivity analyses

W: Considering an alternative model, sources of error and method of numerical integration—This involved using WinBUGS as an alternative surplus production model methodology. The median relative abundance trajectory was very similar to that estimated by the BSP, with the stock never being overfished. The median relative fishing mortality trajectory was also very similar to that obtained with the BSP, but showing wider credibility intervals. In all, the stock was not currently overfished and overfishing was not occurring (**Table 3.6**). WinBUGS model fits to the four CPUE series were all essentially flat. Convergence diagnostics for the WinBUGS model showed that there was good mixing of the two chains for all parameters. Autocorrelations for all parameters also decreased after an initial lag, but remained high for some parameters. The Gelman-Rubin diagnostic indicated good convergence for the main parameters of interest (the ratio of the width of the central 80% interval of the pooled runs and the average width of the 80% intervals within the individual runs converged to 1 and both the pooled and within interval widths stabilized).

WM: Changing the CPUE weighting method—This involved changing the CPUE weighting method from equal weighting to inverse variance weighting. Only those results obtained with the importance function (prior vs. multivariate t) that produced the best convergence diagnostics are reported (**Table 2.7**). Stock status did not change with respect to the baseline scenario and convergence diagnostics were satisfactory.

AC: Extending the catch series back to 1950—This involved using the alternative catch series identified in Table 2.11 of the DW report. This change had very little impact on results (**Table 3.7**). Convergence diagnostics were good.

ALL: Adding the CPUE series identified as "sensitivity" in the DW to those from the baseline scenario—This involved adding the PC LL, MS gillnet and Gillnet Logs series. This change also had very little impact on results (**Table 3.7**). Convergence diagnostics were also good.

LOWr: Using a lower value of intrinsic rate of increase for finetooth sharks—This involved lowering the value of intrinsic rate of increase from 0.06 yr^{-1} to 0.02 yr^{-1}. Stock status was a little less optimistic than in the baseline scenario, but conclusions were not altered: no overfished status nor overfishing (**Table 3.7**). Convergence diagnostics were satisfactory.

3.8. Discussion and Conclusions

The baseline scenario for the finetooth shark predicted that the stock status is not overfished nor overfishing is occurring and very little depletion in numbers with respect to virgin levels (10%). None of the sensitivities explored (inverse CV weighting of the CPUE series, alternative surplus production model, types of error and method of numerical integration considered, considering alternative catches or CPUE series, or a lower productivity) affected results, and supported the outcome of the baseline scenario. Depletions were of the same magnitude (8-17%) as found in the baseline scenario (10%) and the stock did not approach an overfishing condition.

The baseline scenario assumed that the stock had experienced a depletion of about 10% with respect to virgin levels at the beginning of the model, when data were first available (1976). The catch reconstruction (to 1950) scenario was an attempt to account for some historical level of exploitation, but nevertheless resulted in the same conclusions on stock status as the baseline scenario.

Figure 3.8 is a phase plot summarizing the results on stock status found in the baseline scenario and sensitivity analyses in the present assessment of the finetooth shark. The plot also shows the baseline results of the 2002 SCS stock assessment using the surplus production model implemented in WinBUGS (Cortés 2002) for comparison and to have a historical perspective. It is important to note, however, that the current assessment does not represent any form of continuity analysis of the 2002 assessment because the inputs (catch stream and CPUE series considered) are different. In all, the current assessment using surplus production methods indicated that finetooth sharks are not overfished and overfishing is not occurring.

Unlike the other species of small coastal sharks (especially the Atlantic sharpnose and bonnethead sharks), which are mostly caught in shrimp trawl gear, the finetooth shark is predominantly caught in gillnets. In all, the magnitude of finetooth shark catches is much smaller compared to that of the other SCS species. Additionally, only 4 baseline CPUE series were available for this species, and none showed a clear trend. This was interpreted by the model as indicative of little depletion. Finetooth sharks appear to be much less naturally abundant than Atlantic sharpnose and bonnethead sharks. In light of the uncertain life history information and sketchy data on catches and catch rates, the results of the present assessment must be viewed cautiously.

3.9. References

Berger, J. O. 1985. Statistical decision theory and Bayesian analysis. 2nd ed. Springer-Verlag, New York.

Cortés, E. 2002. Stock assessment of small coastal sharks in the U.S. Atlantic and Gulf of Mexico. March, 2002. NOAA/NMFS/Panama City Laboratory. Sustainable Fisheries Division Contribution SFD-01/02-152.

Cortés, E., L. Brooks and G. Scott. 2002. Stock assessment of large coastal sharks in the U.S. Atlantic and Gulf of Mexico. September, 2002. NOAA/NMFS/Panama City Laboratory. Sustainable Fisheries Division Contribution SFD-02/03-177.

Gelman, A. and D. B. Rubin. 1992. Inference from iterative simulation using multiple sequences. Stat. Sci. 7:457-511.

Gilks, W. R., S. Richardson, and D. J. Spiegelhalter. 1996. Markov chain Monte Carlo in practice. Chapman and Hall, London, U.K.

McAllister, M.K. and E. A. Babcock. 2004. Bayesian surplus production model with the Sampling Importance Resampling algorithm (BSP): a user's guide. Available from www.iccat.es.

McAllister, M. K. and G. P. Kirkwood. 1998. Bayesian stock assessment: a review and example application using the logistic model. ICES J. Mar. Sci. 55:1031-1060.

McAllister, M. K., E. K. Pikitch, and E. A. Babcock. 2001. Using demographic methods to construct Bayesian priors for the intrinsic rate of increase in the Schaefer model and implications for stock rebuilding. Can. J. Fish. Aquat. Sci. 58: 1871–1890.

Meyer, R. and R. B. Millar. 1999a. BUGS in Bayesian stock assessments. Can. J. Fish. Aquat. Sci. 56:1078-1086.

Meyer, R. and R. B. Millar. 1999b. Bayesian stock assessment using a state-space implementation of the delay difference model. Can. J. Fish. Aquat. Sci. 56:37-52.

Millar, R. B. and R. Meyer. 1999. Nonlinear state-space modeling of fisheries biomass dynamics using Metropolis-Hastings within Gibbs sampling. Tech. Rep. STAT9901. Department of Statistics, University of Auckland, Auckland, New Zealand.

Simpfendorfer, C.A. and G. H. Burgess. 2002. Assessment of the status of the small coastal sharks in US waters using an age-structured model. Mote Marine Laboratory Tech. Rep. 386, Sarasota, FL.

Spiegelhalter D., A. Thomas, and N. Best. 2000. WinBUGS User Manual Version 1.4. August 2002.

Walters, C.J. and D. Ludwig. 1994. Calculation of Bayes posterior probability distributions for key population parameters: a simplified approach. Can. J. Fish. Aquat. Sci. 51:713-722.

Table 3.1. Catch history for the **finetooth shark** (numbers of fish).

CATCHES OF FINETOOTH SHARKS (in numbers)

Year	Commercial				Recreational catches	Bottom longline discards	Shrimp bycatch (GOM)	Shrimp bycatch (SA)	EFP	Total
	Total	Longline	Nets	Lines						
1972										0
1973										0
1974										0
1975										0
1976										0
1977										0
1978										0
1979										0
1980										0
1981					0					0
1982					0					0
1983					71					71
1984					1,572					1,572
1985					366					366
1986					11,845					11,845
1987					17					17
1988					22,352					22,352
1989					5					5
1990					82					82
1991					95					95
1992					1,944					1,944
1993					3,170					3,170
1994					3,103					3,103
1995	3,508	3,197	0	312	847	0				4,355
1996	8,240	1,336	6,768	136	1,584	445				10,269
1997	13,143	1,233	11,798	69	5,633	411				19,144
1998	20,692	961	19,663	68	147	0				20,839
1999	22,086	1,161	20,603	319	78	0				22,161
2000	15,686	1,359	14,278	50	1,390	0			0	17,076
2001	23,476	412	22,990	73	6,628	0				30,103
2002	12,681	674	11,949	51	3,027	0				15,701
2003	14,515	1,062	13,412	40	1,758	0			0	16,272
2004	14,804	865	13,715	221	285	0			0	15,086
2005	7,506	887	6,608	2	3,164	0		2	2	10,663

Table 3.2. Prior probability distributions of parameters used in the baseline scenario (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) for **finetooth shark**. K is carrying capacity (in numbers), r is the intrinsic rate of population increase, C_0 is the annual catch from 1976 to 1982 (in thousands of individuals), N_{1976}/K is the ratio of abundance in 1976 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_{1976}/K**	**q**	**σ^2**	**τ^2**
BSP (SIR)							
Finetooth shark	Uniform on log K[1] (10^4-$2x10^7$)	Lognormal (0.06,0.20,0.001,2.0)	Lognormal (2774,1,10,$5x10^3$)	Lognormal (0.9,0.2,0.2,1.1)	Uniform on log[2]	Uniform on log	N/A
WinBUGS (MCMC)							
Finetooth shark	Uniform on log K (10^4-$2x10^7$)	Lognormal (0.06,0.20,0.01,0.5)	Normal (2774,1,10,$5x10^3$)	Lognormal (0.9,0.2,0.2,1.1)	MLE[3]	Inverse gamma (0.04-0.08)	Inverse gamma (0.05-0.15)

[1] Values in parentheses are lower and upper bounds (uniform distribution), mean, log-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. 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 **finetooth shark**. Values listed are medians.

Year	N_i	N_i/N_{MSY}	F_i	F_i/F_{MSY}
1976	3715591	1.69	0.00037	0.013
1977	3746419	1.70	0.00037	0.013
1978	3782939	1.71	0.00036	0.012
1979	3804648	1.73	0.00036	0.012
1980	3853028	1.74	0.00036	0.012
1981	3886461	1.75	0.00036	0.012
1982	3914178	1.76	0.00035	0.012
1983	3947929	1.78	0.00002	0.001
1984	3973650	1.79	0.00040	0.014
1985	4007561	1.80	0.00009	0.003
1986	4029594	1.80	0.00294	0.101
1987	4050990	1.81	0.00000	0.000
1988	4060077	1.80	0.00550	0.188
1989	4067150	1.82	0.00000	0.000
1990	4086793	1.83	0.00002	0.001
1991	4101931	1.83	0.00002	0.001
1992	4125104	1.84	0.00047	0.016
1993	4134643	1.85	0.00077	0.026
1994	4149026	1.86	0.00075	0.026
1995	4160614	1.86	0.00105	0.036
1996	4165721	1.86	0.00246	0.084
1997	4168160	1.86	0.00458	0.156
1998	4162128	1.85	0.00500	0.171
1999	4159672	1.85	0.00532	0.182
2000	4158784	1.85	0.00411	0.140
2001	4147655	1.84	0.00724	0.247
2002	4144185	1.84	0.00379	0.129
2003	4146744	1.84	0.00392	0.134
2004	4152703	1.84	0.00364	0.124
2005	4157172	1.84	0.00257	0.088

Table 3.4. 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 **finetooth shark** (baseline scenario) using equal weighting and value of r (intrinsic rate of increase) from the 2002 stock assessment of small coastal sharks. Abundances are in thousands of fish.

	Finetooth shark	
	EV	CV
Importance function	priors	
K	6397	0.82
r	0.060	0.20
MSY	96	0.86
N_{2005}	6000	0.84
N_{2005}/K	**0.90**	0.08
N_{init}	5380	0.84
N_{2005}/N_{init}	1.09	0.14
C_{2005}/MSY	0.27	1.08
F_{2005}/F_{MSY}	**0.17**	1.32
N_{2005}/N_{MSY}	**1.80**	0.09
C_{2005}/repy	0.78	81.34
N_{MSY}	3199	0.82
F_{MSY}	0.030	
repy	21	0.83
C_0	2	0.69
Diagnostics		
CW (Wt)	0.609	
CV (L*prior)	1.163	
CV (Wt) / CV (L*p)	0.52	
%maxpWt	0.0004	

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

Table 3.5. Decision analysis table for the **finetooth shark** corresponding to the results in Table 3.4.

Finetooth shark

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	TAC=0	6.08	1.88	0	1	1	1	0.99	0
	TAC=1C_{2005}	5.99	1.81	0	1	0.71	0.71	0.71	0
	TAC=2C_{2005}	5.91	1.74	0.01	0.97	0.31	0	0.33	0
20 -year	TAC=0	6.18	1.93	0	1	1	1	0.99	0
	TAC=1C_{2005}	6.04	1.82	0.01	0.99	0.71	0.71	0.71	0
	TAC=2C_{2005}	5.9	1.7	0.03	0.95	0.31	0	0.33	0.01
30 -year	TAC=0	6.23	1.96	0	1	1	1	0.99	0
	TAC=1C_{2005}	6.07	1.82	0.01	0.99	0.71	0.71	0.71	0
	TAC=2C_{2005}	5.89	1.67	0.04	0.92	0.31	0	0.32	0.02

Table 3.6. Expected values (EV) of the mean and coefficients of variation (CV) of marginal posterior distributions for output parameters for the **finetooth shark** using WinBUGS as an alternative model formulation. Abundances are in thousands of fish.

	Finetooth shark	
	EV	CV
K	5357	0.95
r	0.071	0.53
MSY	91	0.12
N_{2005}	4731	0.99
N_{2005}/K	**0.85**	0.15
N_{init}	4232	
N_{2005}/N_{init}	1.12	
C_{2005}/MSY	0.12	
F_{2005}/F_{MSY}	**0.26**	1.44
N_{2005}/N_{MSY}	**1.70**	1.45
N_{MSY}	2679	
F_{MSY}	0.036	
C_0	2	0.58
N_{init}/K	0.79	0.15
Diagnostics		
Chain mixing	good	
Autocorrelations	high	
Gelman-Rubin	good	

N_{init} is initial abundance (for the first year of the model)

Table 3.7. 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 **finetooth shark** using inverse CV weighting, an alternative catch series starting in 1950, all the CPUE series identified as "sensitivity" in the Data Workshop report, and a lower value of r. Abundances are in thousands of fish.

	Inverse CV weighting		Alternative catch		All CPUE series		Lower r	
	EV	CV	EV	CV	EV	CV	EV	CV
Importance function	priors		priors		priors		priors	
K	5950	0.88	6466	0.81	6518	0.81	6949	0.76
r	0.061	0.20	0.060	0.20	0.060	0.20	0.020	0.20
MSY	91	0.92	97	0.85	97	0.85	35	0.80
N_{2005}	5496	0.91	6217	0.84	6113	0.83	6031	0.79
N_{2005}/K	**0.87**	0.12	**0.92**	0.08	**0.90**	0.08	**0.83**	0.13
N_{init}	4692	0.91	5494	0.83	5469	0.83	5836	0.78
N_{2005}/N_{init}	1.13	0.17	1.11	0.17	1.10	0.14	1.00	0.10
C_{2005}/MSY	0.33	1.15	0.26	1.05	0.26	1.06	0.67	1.04
F_{2005}/F_{MSY}	**0.22**	1.60	**0.16**	1.29	**0.16**	1.27	**0.45**	1.26
N_{2005}/N_{MSY}	**1.75**	0.12	**1.84**	0.08	**1.81**	0.08	**1.67**	0.13
C_{2005}/repy	0.71	59.22	0.87	0.29	0.76	82.85	1.18	68.60
N_{MSY}	2974	0.88	3233	0.81	3259	0.81	3474	0.76
F_{MSY}	0.031		0.030		0.030		0.010	
repy	24	0.84	13	0.37	22	0.83	15	0.99
C_0	2	0.69			2	0.69	2	0.69
Diagnostics								
CW (Wt)	0.823		0.558		0.637		0.654	
CV (L*prior)	1.207		0.944		1.167		1.124	
CV (Wt) / CV (L*p)	0.68		0.59		0.55		0.58	
%maxpWt	0.002		0.0004		0.0005		0.0005	

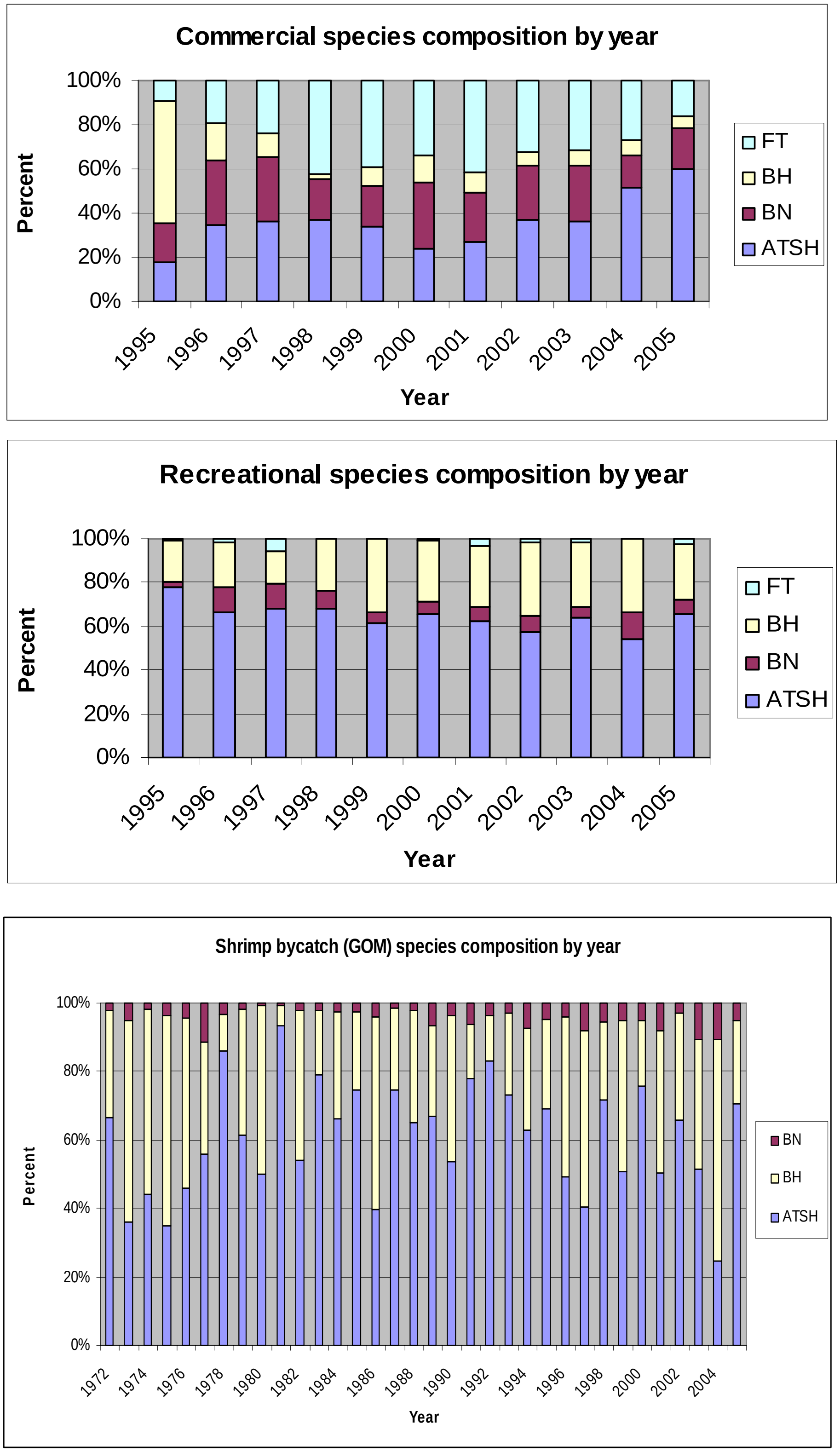


Figure 3.1. Relative species composition of commercial landings, recreational catches, and dead discards from the shrimp trawl fishery for the SCS complex.

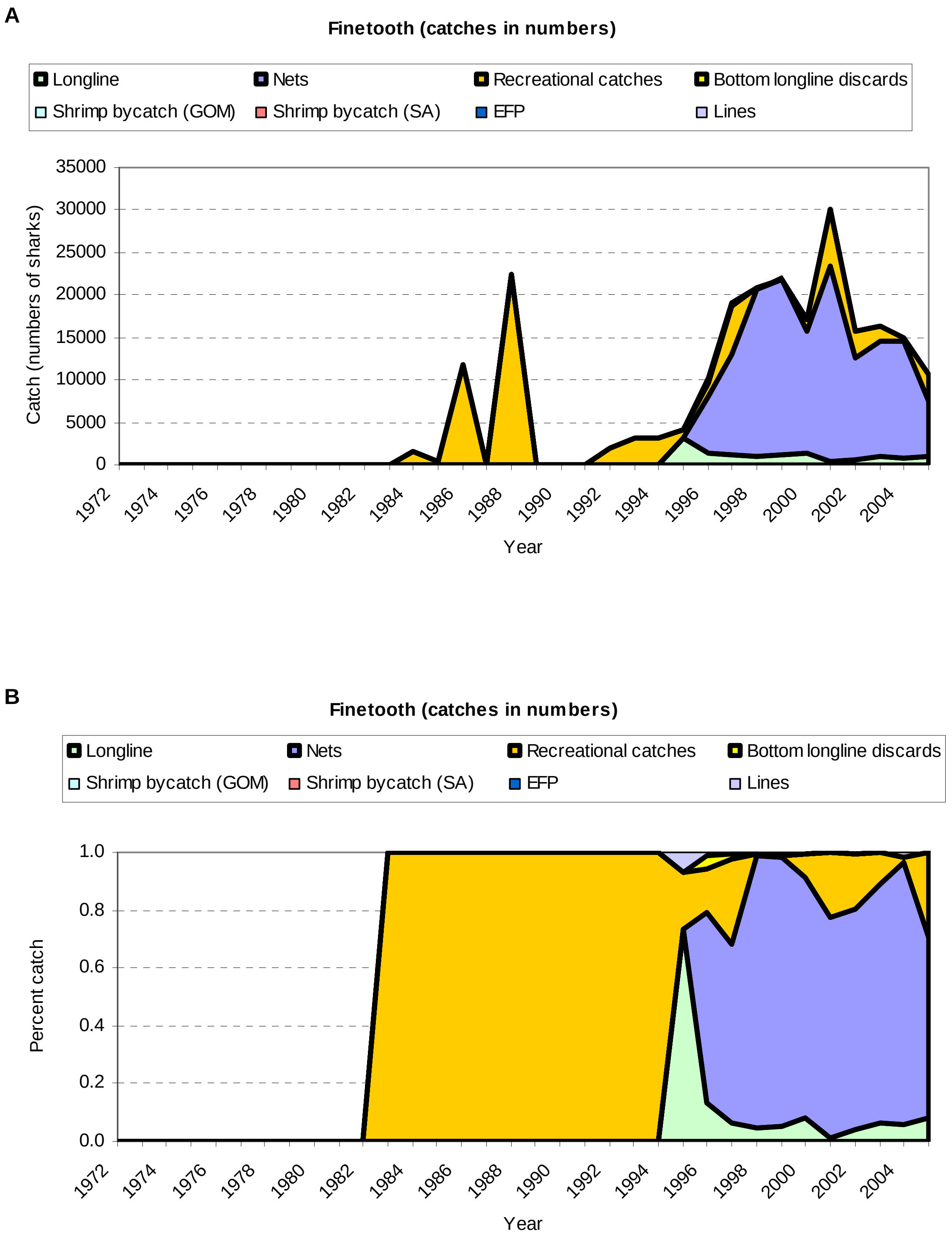


Figure 3.2. Total catches of the **finetooth shark** by sector in (A) absolute and (B) relative terms.

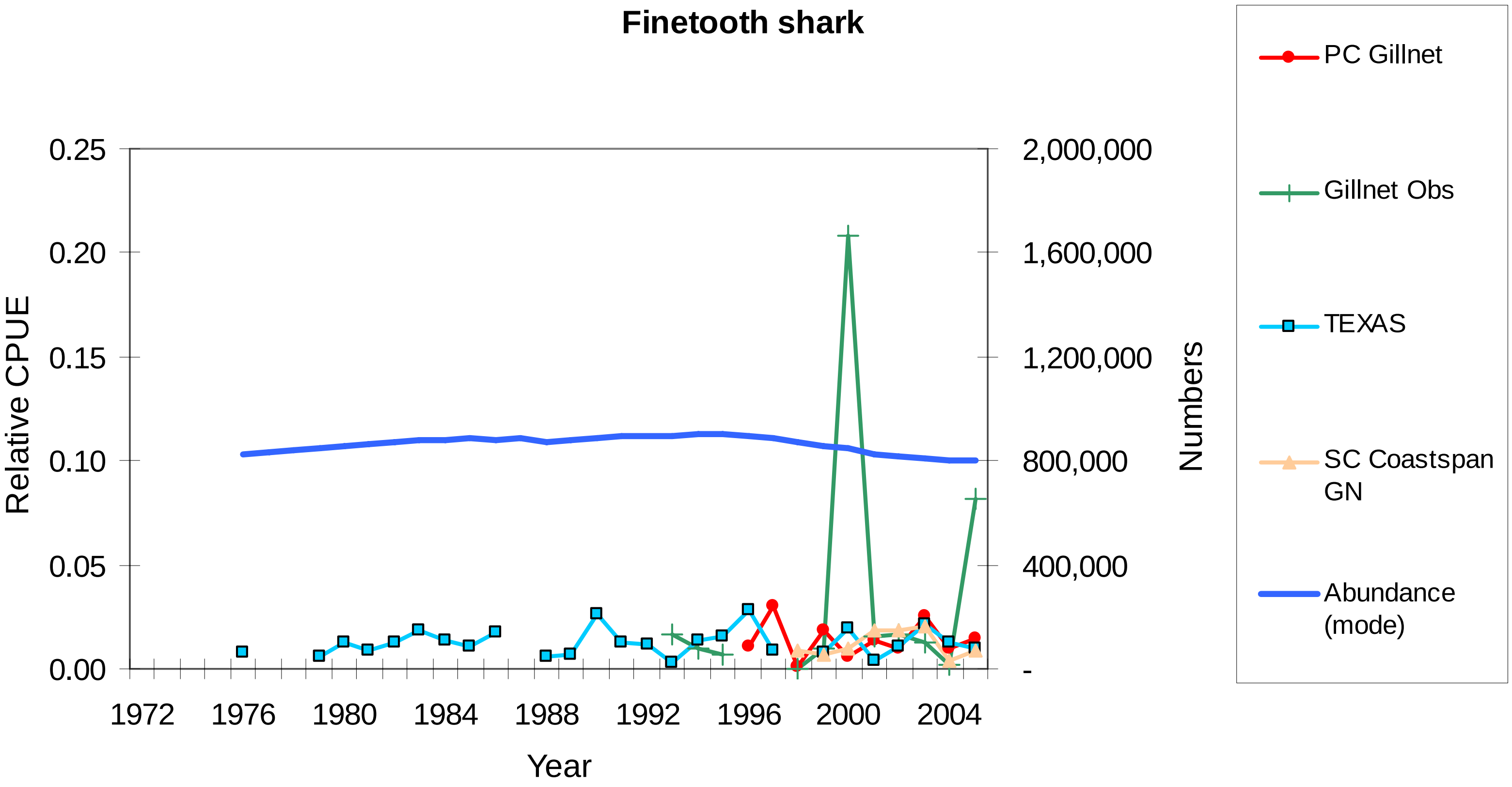


Figure 3.3. Predicted abundance trend of the BSP model fitted to the catch and CPUE data for **finetooth shark.** CPUE series shown are scaled (divided by the catchability coefficient for each series, the mean of the overlapping years, and the overall mean for all series).

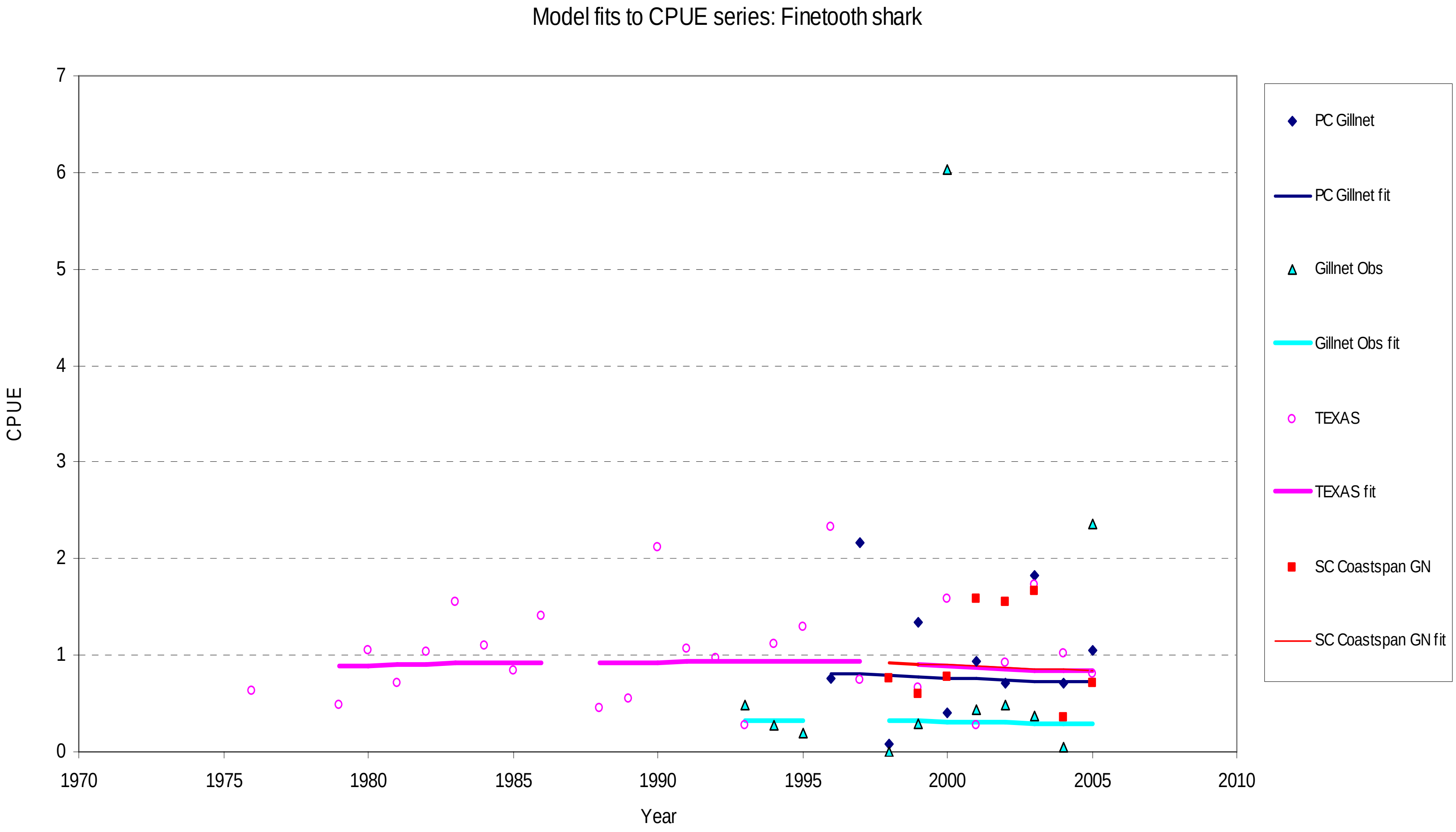
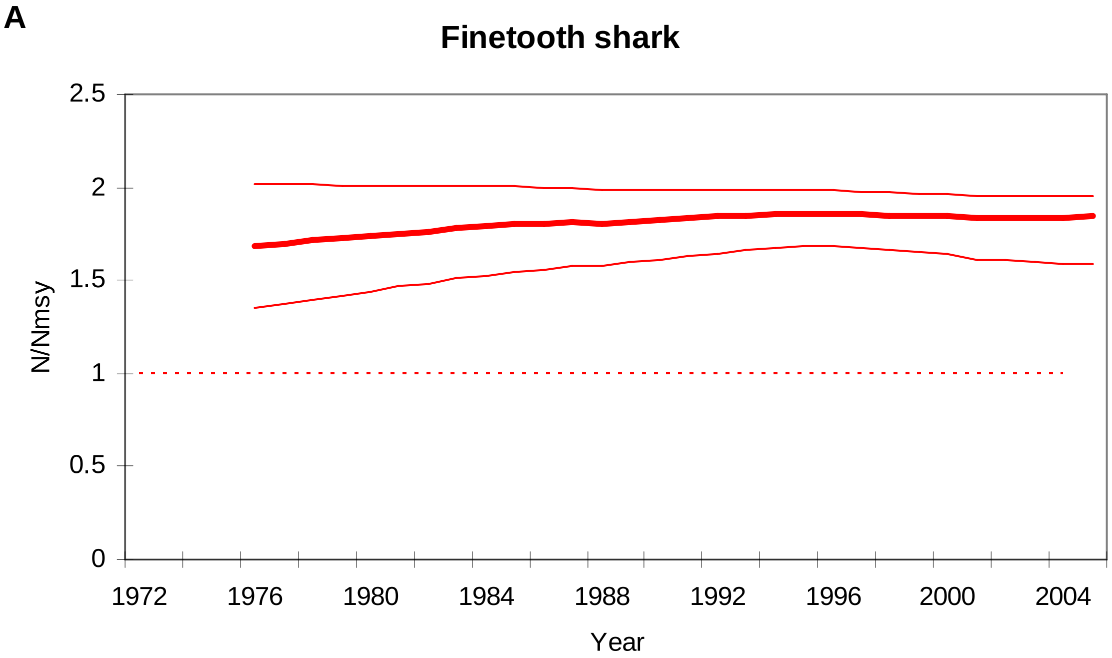


Figure 3.4. BSP model fits to the individual CPUE series for the **finetooth shark**.



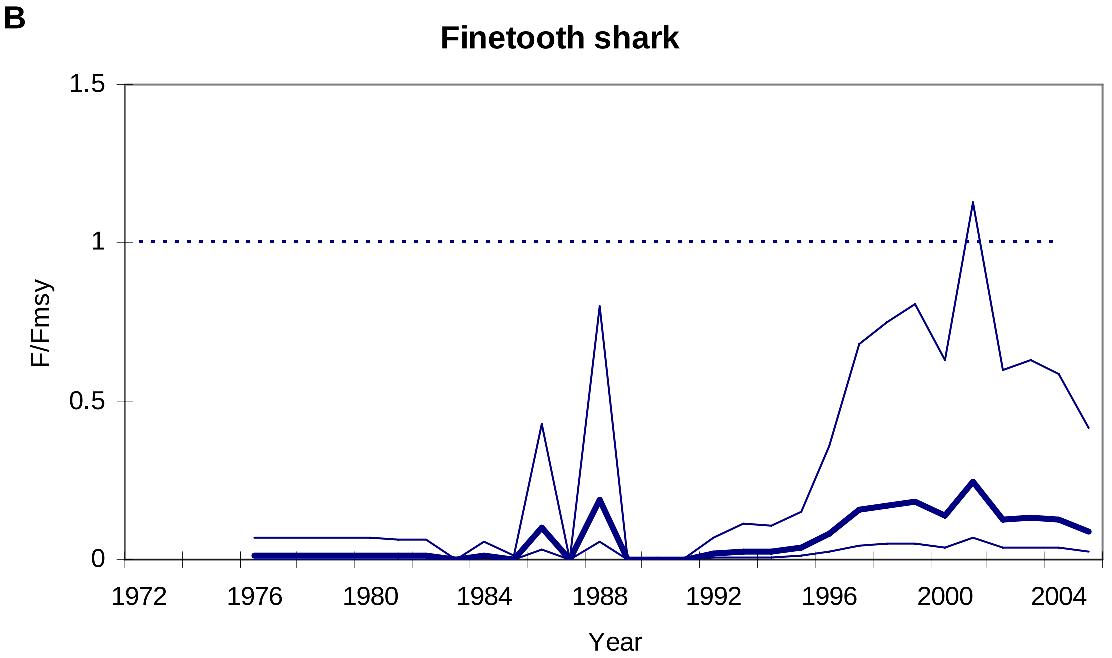


Figure 3.5. Predicted median relative abundance (A) and fishing mortality rate (B) trajectories for the **finetooth shark** with the BSP model. Values shown are medians with 80% probability intervals; horizontal lines at 1 denote MSY levels.

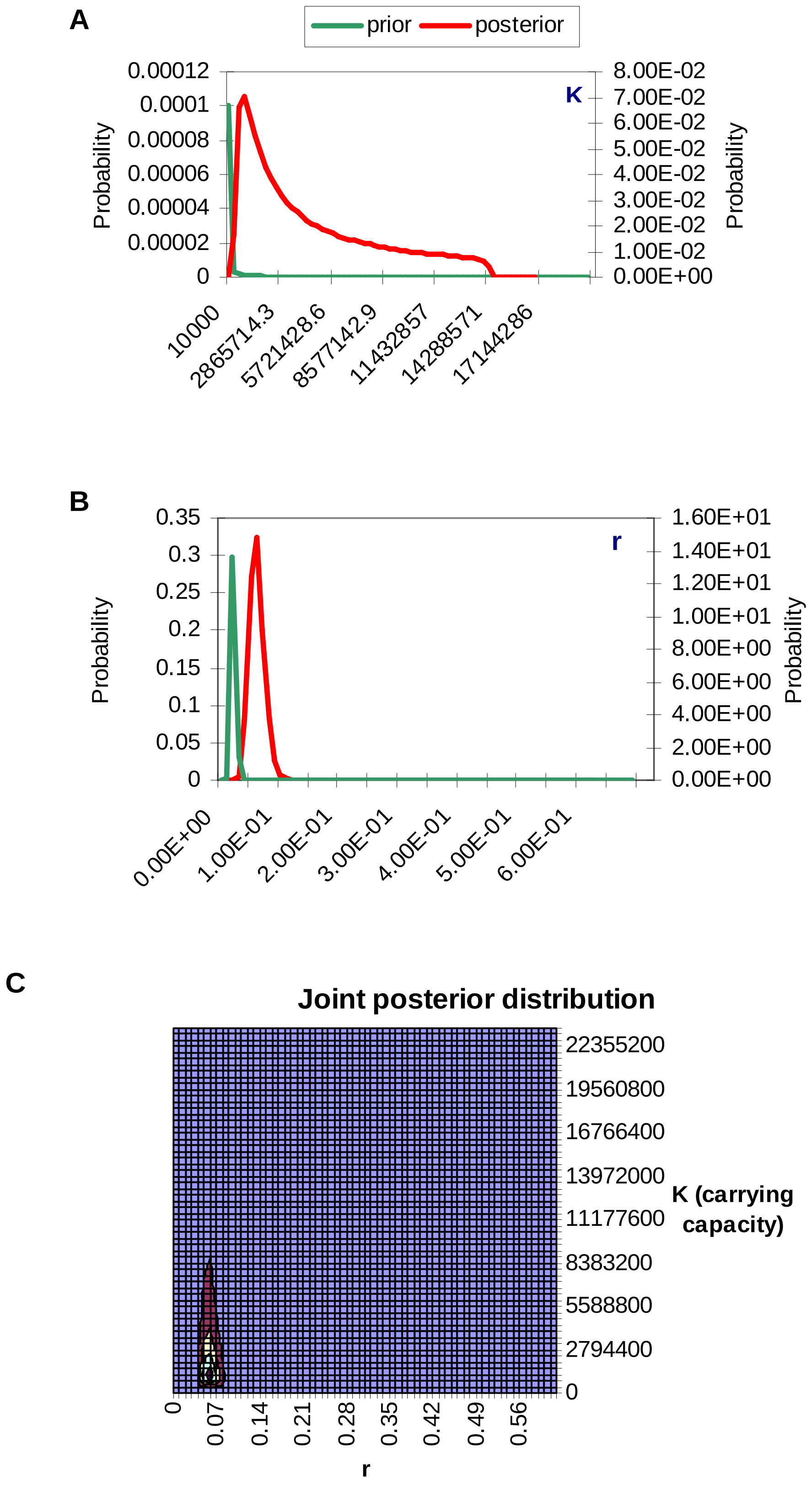


Figure 3.6. Prior (green) and posterior (red) probability distributions for (A) K and (B) r for the SCS complex from the BSP model. Also shown (C) is the joint posterior probability distribution for r and K.

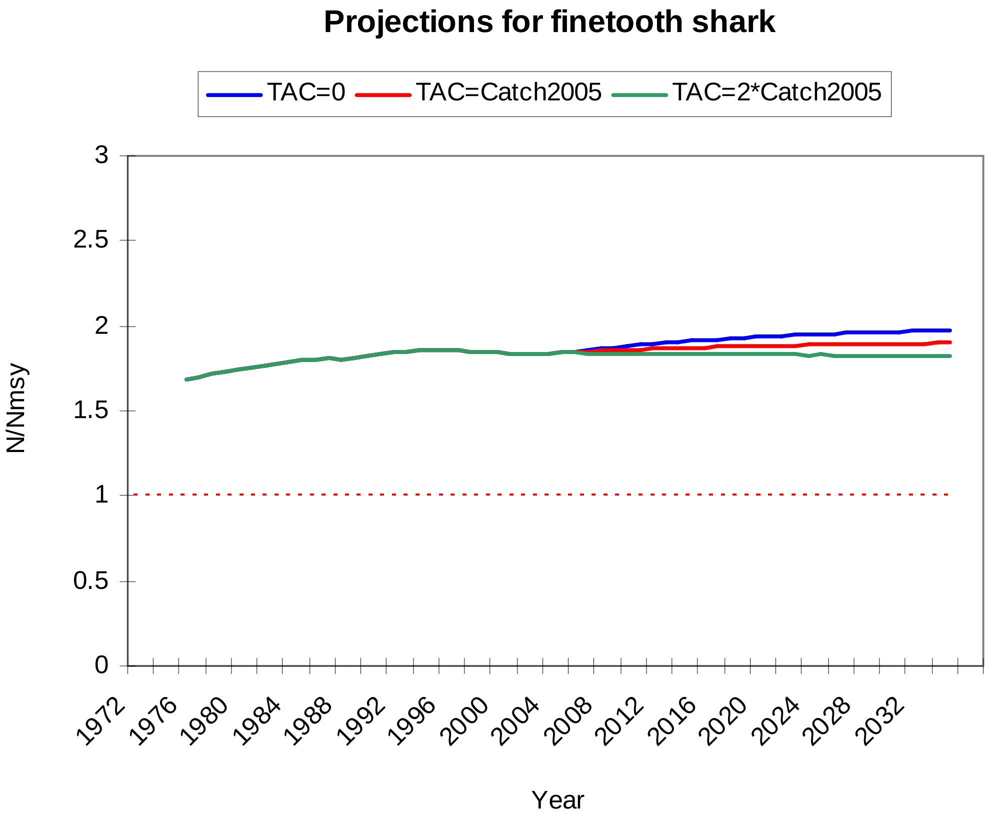


Figure 3.7. Estimated median relative abundance trajectory and projections (from 2006 to 2035) for alternative TAC-based harvesting policies (0, 1, and 2 times the 2005 TAC) for the **finetooth shark** baseline scenario. The dashed horizontal line at 1 denotes the MSY level.

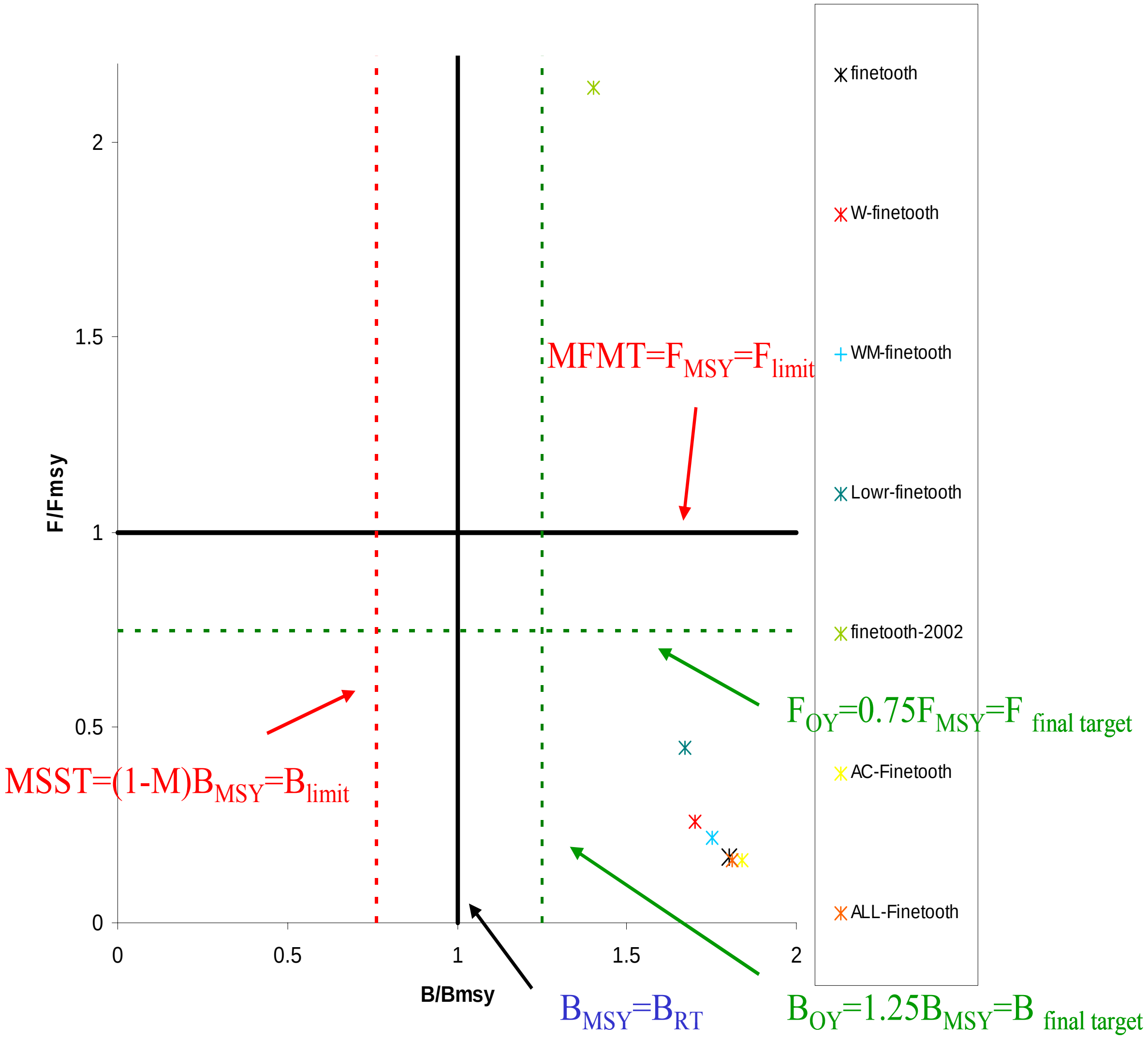


Figure 3.8. Phase plot for the **finetooth shark** showing values of N_{2005}/N_{MSY} and F_{2005}/F_{MSY} obtained in the baseline scenario using the BSP model and various sensitivity analyses. The models include: Finetooth (baseline), W-finetooth (WinBUGS surplus production model), WM-finetooth (inverse CV weighting), AC-finetooth (alternative catch starting in 1950), ALL-finetooth (all CPUE series), and finetooth-2002 (results of the 2002 SCS assessment using WinBUGS). See text for full details. Several control rules are illustrated: the solid horizontal line indicates the MFMT (Maximum Fishing Mortality Threshold), the solid vertical line denotes the target biomass (biomass or number at MSY), the dashed horizontal line indicates the F at optimum yield (final F target for rebuilding), and the dashed vertical lines denote the MSST (Minimum Stock Size Threshold or limit biomass) and B_{OY} (biomass at optimum yield or final B target for rebuilding).

BLACKNOSE SHARK ASSESSMENT

4. BLACKNOSE SHARK (*Carcharhinus acronotus*) ASSESSMENT

4.1 Summary of Blacknose Shark Working Documents

SEDAR 13-AW-01
Cortés: Assessment of Small Coastal Sharks, Atlantic sharpnose, Bonnethead, Blacknose and Finetooth Sharks using Surplus Production Methods
We used two complementary surplus production models (BSP and WinBUGS) to assess the status of the Small Coastal Shark (SCS) complex and four individual species (Atlantic sharpnose, bonnethead, blacknose, and finetooth sharks) identified as baseline scenarios in the SCS 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 rate of increase, and importance function on results. Baseline scenarios predicted that the stock status is not overfished and overfishing is not occurring in all cases. Using the inverse variance method to weight the CPUE data was problematic because of the nature of the CPUE time series and must be regarded with great caution, although predictions on stock status did not change, except for blacknose sharks. The alternative surplus production model implemented in WinBUGS supported the results from the BSP model, with the exception of blacknose sharks, which became overfished. None of the other sensitivity analyses examined had a large impact on results and did not affect conclusions on stock status in any case. Only blacknose sharks with the alternative catch scenario approached an overfishing condition.

SEDAR 13-AW-02
Siegfried, Cortés, and Brooks: Determining Selectivities for Small Coastal Shark Species for Assessment Purposes
Selectivities of catch series and indices had to be determined for sharpnose, blacknose, and bonnethead sharks for the 2007 small coastal shark stock assessment. Based on age frequencies, five selectivities were determined for sharpnose, four for blacknose, and two for bonnethead.

SEDAR 13-AW-03
Siegfried and Brooks: Assessment of Blacknose, Bonnethead, and Atlantic Sharpnose Sharks with a State-Space, Age-Structured Production Model
An age-structured production model was employed to assess the following small coastal sharks: Blacknose (*Carcharhinus acronotus*), Bonnethead (*Sphyrna tiburo*), and Atlantic Sharpnose (*Rhizoprionodon terraenovae*). All models assumed virgin conditions in 1950, and historically reconstructed catches were derived to inform the model on likely levels of removals for the years prior to the start of observed and recorded catches. The base models for all three species applied equal weight to all indices. Base model results for bonnethead shark indicate that the stock is overfished and that there is overfishing. The stock status appears to be quite sensitive to the reconstructed catches, particularly because of some extreme peaks in the bottom longline fishery reports and the shrimp bycatch reports. An initial sensitivity run indicates that the stock depletion decrease when less weight is given to the extreme peaks. Additional sensitivities will be performed at the assessment workshop. The base model results for blacknose suggest that the stock is overfished and that there is also overfishing. The base model for Atlantic sharpnose assumed a single stock, and results from this model indicate that the stock is not overfished nor is

overfishing occurring. A sensitivity analysis where inverse CV weights were applied to the base indices showed very little difference from the base model, and the stock status estimate was no overfishing and the stock is not overfished.

4.2 Background

In 2002, a stock assessment was conducted on the small coastal complex of sharks (finetooth (*Carcharhinus isodon*), blacknose (*Carcharhinus acronotus*), bonnethead (*Sphyrna tiburo*), and Atlantic sharpnose (*Rhizoprionodon terraenovae*), in the Gulf of Mexico and the Atlantic (Cortés 2002). The author used a variety of Bayesian statistical models, including a Schaefer biomass dynamic model, a Schaefer surplus production model (SPM), and a lagged-recruitment, survival and growth state-space model. There are more data available to assess the blacknose, bonnethead, and Atlantic sharpnose populations currently; therefore an age-structured model was applied in addition to the models used in the last assessment. This assessment report outlines the discussions and results of the current blacknose stock assessment

4.3 Available models

Three models were available for discussion for the blacknose shark assessment: two surplus production models, the BSP and WinBUGS models described previously, and one age-structured approach (Cortés 2002, SPASM, 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 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 SEDAR13-AW-03 for blacknose 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 Panel 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.

The Assessment Workshop Panel further discussed the issue for weighting indices. It was noted that there are a variety of ways to weight indices in addition to equal and inverse CV weighting, however how to determine which weighting method is most appropriate is a discussion topic that is still without satisfying resolution. Given that fact, the Assessment Workshop Panel decided that equal weighting would be the base weighting method for the current assessment but noted that, as there is at present no objective way to decide which method is superior other than comparing model convergence diagnostics, future assessments may need to re-examine this issue.

4.6 Data issues and solutions derived during the assessment workshop

It was noted by that Assessment Workshop Panel that the estimate of blacknose bycatch in the shrimp fishery in 1977 seemed anomalously large (orders of magnitude) compared to the rest of the series. The anomalous peak in the shrimp bycatch data was investigated in the working document (SEDAR 13-DW-32) and found to be outside of the limits of confidence. Panelists agreed to take the geometric mean of the three years before and after the anomalous peak and replace it with that geometric mean.

Another issue that concerned Panelists was the method by which the catches were reconstructed for the longline fishery for the period between the starting year of the model (1981) and the first year of observed catch data (1995). The Catch Working Group at the Data Workshop Panel recommended the reconstruction follow a linear increase between 1981 and 1995. The Panelists at the Assessment Workshop, along with input for industry representatives present at the Workshop argued that this was not a realistic representation of the level of catch, especially in the earlier years of fishery expansion. Panelists agreed upon an exponential increase in fishing for the longline fleet reconstruction after much discussion. The new reconstructions were applied to the commercial bottom longline catch and the bottom longline discards.

4.7 Methods

4.7.1 State-space age-structured production model description

The age-structured production model (originally derived in Porch 2002) starts from a year when the stock can 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 era," where data are sparse, and a "modern era," where more data are available for model fitting. In all three model applications, virgin conditions were assumed in 1950. The earliest index of abundance (SEAMAP) and the earliest catch series (Shrimp trawl bycatch) begin in 1972, thus the historic model years spanned 1950-1971 (22 years) and the modern model years spanned 1972-2005 (34 years).

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

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

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, 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 model period. 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

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

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:

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

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

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

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:

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

where τ_i is the duration of the fishing season for fleet i. Catch in weight is computed by multiplying (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:

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

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 small coastal 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):

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

The term λ_g is a variable-specific multiplier of the overall model CV. For catch series and indices (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 for the base model run, 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.

4.7.2 Data inputs, prior probability distributions, and performance indicators

Baseline scenario (SPASM-BASE)

The base model represented the decisions made by the Data Workshop Panelists 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 4.1b, 4.2, and 4.3; Figures 4.1–4.3). Catches were made by the commercial sector and the recreational sector and we included a catch series for the discards in the bottom longline fishery. A total of ten indices were made available after the data workshop (Table 4.3, Figure 4.2), eight of which were recommended as base indices.

Individual selectivity functions to be applied to indices and catch series were identified based on length frequencies and biological information provided by the Life History Working Group at the Data Workshop. The selectivity determination methods and recommendations were presented in SEDAR 13 AW-02 and summarized here in Figure 4.3.

Catch data begin in 1981, while the earliest data for the indices is 1972 (UNC). Catches from 1981 were imputed back to 1950, when a virgin assumption was imposed. The catches for each fleet were imputed as follows: the commercial longline was reconstructed to increase at an exponential rate from 1981 to 1995 (the year of the first data point). The commercial gillnet fishery was reconstructed to increase linearly from 1981 to 1995. The longline reconstruction changed from linear (a Data Workshop recommendation) to an exponential increase following the assessment workshop recommendations.

Individual points within catch series and indices can be assigned different weights, based either on estimated precision or expert opinion. The base case model configuration was to treat all points Assessment Workshop to downweight any individual or group of points.

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 values provided by the life history working group (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 1950, used the reconstructed catch series as agreed upon (whether it was a linear or exponential increase, and used the new value for the shrimp bycatch in 1977. All inputs are given in Tables 4.1, 4.2, and 4.3. Base indices are in black font and sensitivity indices in red in Table 4.3.

Performance indicators included estimates of absolute population levels and fishing mortality for year 2005 (F_{2005}, SSF_{2005}, B_{2005}), 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 is 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).

4.7.4 Sensitivity analyses

Four sensitivity runs to the base model were performed. The first sensitivity, recommended at the Data Workshop, was to include the indices labeled as “sensitivity indices” (PC-longline and GN logs) to the base model configuration. The second sensitivity, also recommended at the Data Workshop, was to use an inverse-CV weighting method for weighting the base indices.

The third and fourth sensitivities were requested at the Assessment Workshop. As is noted in the life history section of the Data Workshop Report, the blacknose shark has been observed to have both a one- and two-year reproductive cycle depending on the region. As the data were too sparse to conduct a region-specific analysis, it was agreed upon at the Data Workshop to use the average reproductive cycle of 1.5 years for the assessment. Sensitivities three and four were requested in order to assess the stock assuming a one- or two-year reproductive cycle.

No other sensitivities were requested at the assessment workshop.

4.8 Results

4.8.1 Baseline scenario

The base model estimated an overfished stock with overfishing (Tables 4.4 and 4.5; Figure 4.4). The stock has been experiencing an increasing level of overfishing since 1993 and became overfished in 1996. The model estimate of F by fleet is dominated by the shrimping fleet for the entire time period examined (1950-2005) (Figure 4.4). Model fits to catches are shown in Figure 4.5 and show very good agreement for all series. Model fits to the indices are shown in Figure 4.6. The UNC index is the longest time series, beginning in 1972, and its trend was fit well by the model, with the exception of the early years (Figure 4.6).

Likelihood profiling was performed in ADModel Builder (Otter Research Ltd. 2000) to obtain an approximation to the posterior distributions for several model parameters (Figures 4.7 and 4.8). The distributions for total biomass depletion or spawning stock fecundity depletion range from about 0.1-0.6 with a mode of 0.19 (Figure 4.7). The mode for the posterior of pup survival was estimated at a slightly higher value than the prior mode, while the mode of the posterior for virgin recruitment of pups was approximately 270,000 (Figure 4.8).

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 **S1** (where all indices were used) the results were very similar to the base case. Although the estimate of F_{2005}/F_{MSY} was similar to the base model, model **S2** (where the inverse-CV weighting method was used) estimated a slightly higher SSF_{2005}/SSF_{MSY}. However, the MSY and the pup survival are very similar. This sensitivity was requested by Panelists, but they agreed the results were not sufficiently different to make any changes to the base model. The results from the final two sensitivities, **S3** and **S4** (where we examined the way the model fit a one- and two-year reproductive cycle) were as expected. With a one-year reproductive cycle, the level of overfishing is reduced, as there is more production. For the two-year reproductive cycle used in **S4** the results show a more severe level of overfishing as well as a more overfished stock. Again, the Panelists requested S3 and S4 but agreed that the base case of a 1.5-year reproductive cycle was appropriate.

A phase plot of stock status for all available models shows very little agreement between the surplus production models and age structured models used in this assessment (Figure 4.9). Again, Panelists at the Assessment Workshop recommended the use of the age-structured model over that of the surplus production models. The estimate from the 2002 assessment (Cortés 2002) is shown for reference.

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 index and catch series are shown in Figures 4.10 and 4.11. These graphs show the relative contributions of each index, catch series and model source on the model's relative likelihood.

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 2005 was applied for the following year (2006) and then reduced by 50% in 2007-2009 to account for an assumed reduction in the shrimping due to Hurricane Katrina. It is unlikely that any management actions could be realized until 2009.

Projections were done using Pro-2Box (Porch 2003). Projecting the stock at F = 0 we used $F = F_{2005}$ for 2006 and 50% of F_{2005} for 2007 through 2009. 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 **2019**, which is a **rebuilding time of 11 years** from 2009 (Figure 4.12).

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 8 years, which gives (**11 years) + (8 years) = 19 years** to rebuild, or the **year 2027**. 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 2005 maturity ogive was used, 1.65 pups per female was the fecundity for all ages, adjusted age-specific survival at age was used, and the mode of 0.72 for the prior on pup survival was used. 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 TAC strategy was used to estimate a TAC that would attain rebuilding by the year 2027. Assumptions for these projections included the above process error in stock-recruitment, the selectivity vector was the geometric mean of the last 3 years (2003-2005), and it was assumed that any modification to a TAC would impact each fishery by the same proportion. A constant TAC of 19,200 individuals would lead to rebuilding with 70% probability by 2027(70% of the bootstraps have $SSF_{2027}/SSF_{MSY} > 1$; Figure 4.13). The constant TAC also allows for rebuilding with 50% confidence by 2024 (black line in Figure 4.13)

3.10 Discussion

The main issues, such as the anomalous shrimp peak and linear versus exponential reconstruction of the blacknose catch in the commercial longline fishery were debated and resolved agreeably. All models, including the sensitivities, that were agreed upon by the panelists show an overfished stock with overfishing occurring. The last assessment did not find an overfished stock or overfishing occurring; however, fewer data were available for the 2002 assessment. As shown in the phase plot in Figure 4.9, the SPMs gave far more optimistic scenarios for stock status than the age-structured models agreed upon by the Panelists. In the base model, total fishing mrtality from 1995-2005 averages 0.26, and for 2002-2005 it averages 0.32. These levels are 4-5 times the estimate of F_{MSY}. The combination of life-history parameters and the vulnerability of these sharks to the various gears long before they are mature suggest a population that cannot support more exploitation.

3.11 References

Cortés, E. (2002). Stock Assessment of Small Coastal Sharks in the U.S. Atlantic and Gulf of Mexico, NOAA-Fisheries Sustainable Fisheries Division
133.

Myers, R. A., K. G. Bowen, et al. 1999. Maximum reproductive rate of fish at low population sizes. *Canadian Journal of Fisheries and Aquatic Sciences* **56**: 2404-2419.

Otter Research Ltd. 2001. An introduction to AD MODEL BUILDER Version 6.0.2. Box 2040, Sidney, B. C. V8L 3S3, Canada.

Porch, C. E. 2002. A preliminary assessment of Atlantic white marlin (*Tetrapturus albidus*) using a state-space implementation of an age-structured model. SCRS/02/68 23pp.

Porch, C.E. 2003. Pro-2Box v.2.01 User's guide.

Restrepo, V. R., G. G. Thompson, P. M. Mace, W. L. Gabriel, L. L. Low, A. D. MacCall, R. D. Methot, J. E. Powers, B. L. Taylor, P.R. Wade, and J. F. Witzig. 1998. Technical guidance on the use of precautionary approaches to implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act. NOAA Technical Memo. NMFS-F/SPO-31, 54p. National Technical information Center, 5825 Port
Royal Road, Springfield, VA 22161.

Table 41a. Biological inputs for the **blacknose shark**

Age	M	Female Maturity	Pups-per-Female
1	0.33	0	1.65
2	0.28	0.07	1.65
3	0.26	0.10	1.65
4	0.25	0.48	1.65
5	0.25	0.92	1.65
6	0.24	0.99	1.65
7	0.24	1	1.65
8	0.24	1	1.65
9	0.24	1	1.65
10	0.24	1	1.65
11	0.24	1	1.65
12	0.24	1	1.65
13	0.22	1	1.65

Table 41b. Additional parameter specifications for the **blacknose shark**, 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_∞	104.3 (cm FL)	*constant*
K	0.3	*constant*
t_0	-1.71	*constant*
a	1.65E-06	*constant*
b	3.34	*constant*
Pup Survival	0.72	~LN with CV=0.30
Virgin Recruitment (R_0)	[1.0E+4, 1.0E+10]	~N with CV=0.7

Table 4.. Catches of **blacknose shark** by fleet with reconstructed catches in blue. The last row lists the selectivity applied to each catch series.

Year	Longline	Nets	Lines	Recreational catches	Bottom longline discards	Shrimp bycatch
1950	0	0	0	1,826	0	11,509
1951	0	0	0	2,051	0	14,783
1952	0	0	0	2,276	0	14,964
1953	0	0	0	2,501	0	17,204
1954	0	0	0	2,725	0	17,772
1955	0	0	0	2,950	0	16,105
1956	0	0	0	3,175	0	14,640
1957	0	0	0	3,400	0	13,157
1958	0	0	0	3,625	0	13,073
1959	0	0	0	3,849	0	14,664
1960	0	0	0	4,074	0	15,706
1961	0	0	0	4,174	0	7,878
1962	0	0	0	4,273	0	10,328
1963	0	0	0	4,372	0	15,560
1964	0	0	0	4,472	0	13,915
1965	0	0	0	4,571	0	14,953
1966	0	0	0	4,671	0	14,114
1967	0	0	0	4,770	0	17,335
1968	0	0	0	4,870	0	15,807
1969	0	0	0	4,969	0	16,546
1970	0	0	0	5,068	0	18,233
1971	0	0	0	4,658	0	18,674
1972	0	0	0	4,247	0	16,797
1973	0	0	0	3,836	0	17,085
1974	0	0	0	3,425	0	8,716
1975	0	0	0	3,014	0	22,969
1976	0	0	0	2,603	0	14,957
1977	0	0	0	2,193	0	14,791
1978	0	0	0	1,782	0	24,171
1979	0	0	0	1,371	0	14,823
1980	0	0	0	1,183	0	9,759
1981	7	0	0	0	3	11,475
1982	19	0	0	0	8	8,964
1983	75	0	0	14,233	34	10,731
1984	126	0	0	844	57	8,201
1985	191	0	0	1,918	86	11,025
1986	299	0	0	3,308	135	22,764
1987	467	1,457	0	15,382	211	13,656

1988	673	2,915	0	15,971	303	12,270
1989	1,023	4,372	0	1,793	461	29,999
1990	1,300	5,829	0	3,345	586	22,605
1991	2,000	7,286	0	8	902	41,979
1992	4,000	8,744	0	5,199	1,803	42,999
1993	6,000	10,201	0	2,875	2,705	17,464
1994	8,500	11,658	0	14,464	3,832	30,789
1995	15,652	13,116	20	2,954	7,056	45,384
1996	8,641	14,573	768	12,414	3,895	39,732
1997	17,628	26,004	88	11,079	7,947	65,639
1998	7,689	15,613	43	10,523	3,466	38,367
1999	5,968	21,812	539	6,139	2,691	30,913
2000	13,493	32,154	956	10,410	6,083	35,523
2001	5,732	28,549	29	15,445	2,584	51,325
2002	6,877	21,280	522	11,438	3,101	28,593
2003	10,385	12,498	90	6,615	4,683	61,079
2004	5,889	7,942	114	15,261	2,674	73,786
2005	8,178	9,055	212	7,548	3,718	23,154
Selectivity	1	3	1	1	3	1

Table 4.3 Indices available for use in the current **blacknose shark** assessment. Sensitivity indices are in red. The last row lists the selectivity applied to each index.

PC-GN adult	PC-GN juvenile	GNOP	BLLOP	NMFS LL SE	SCDNR	UNC	MML	PC-LL	GN logs	Year
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1950
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1951
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1952
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1953
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1954
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1955
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1956
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1957
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1958
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1959
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1960
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1961
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1962
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1963
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1964
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1965
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1966
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1967
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1968
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1969
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1970
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1971
-1	-1	-1	-1	-1	-1	3.967	-1	-1	-1	1972
-1	-1	-1	-1	-1	-1	4.233	-1	-1	-1	1973
-1	-1	-1	-1	-1	-1	1.600	-1	-1	-1	1974
-1	-1	-1	-1	-1	-1	3.326	-1	-1	-1	1975
-1	-1	-1	-1	-1	-1	2.489	-1	-1	-1	1976
-1	-1	-1	-1	-1	-1	6.276	-1	-1	-1	1977
-1	-1	-1	-1	-1	-1	4.048	-1	-1	-1	1978

-1	-1	-1	-1	-1	-1	3.115	-1	-1	-1	1979
-1	-1	-1	-1	-1	-1	1.866	-1	-1	-1	1980
-1	-1	-1	-1	-1	-1	0.728	-1	-1	-1	1981
-1	-1	-1	-1	-1	-1	1.503	-1	-1	-1	1982
-1	-1	-1	-1	-1	-1	0.849	-1	-1	-1	1983
-1	-1	-1	-1	-1	-1	1.814	-1	-1	-1	1984
-1	-1	-1	-1	-1	-1	0.953	-1	-1	-1	1985
-1	-1	-1	-1	-1	-1	0.595	-1	-1	-1	1986
-1	-1	-1	-1	-1	-1	1.099	-1	-1	-1	1987
-1	-1	-1	-1	-1	-1	2.135	-1	-1	-1	1988
-1	-1	-1	-1	-1	-1	0.812	-1	-1	-1	1989
-1	-1	-1	-1	-1	-1	0.565	-1	-1	-1	1990
-1	-1	-1	-1	-1	-1	1.052	-1	-1	-1	1991
-1	-1	-1	-1	-1	-1	2.315	-1	-1	-1	1992
-1	-1	12.832	-1	-1	-1	1.381	-1	0.008	-1	1993
-1	-1	110.912	17.126	-1	-1	0.819	-1	0.076	-1	1994
-1	-1	14.734	41.156	0.066	-1	1.012	-1	0.021	-1	1995
0.446	0.168	-1	35.776	0.1774	-1	1.396	-1	-1	-1	1996
0.161	0.082	-1	13.373	0.129	-1	0.419	-1	0.017	-1	1997
0.156	0.069	39.207	37.706	-1	0.016	0.189	-1	0.032	0.001	1998
0.308	0.086	55.567	44.055	0.139	0.008	0.131	-1	0.052	0.001	1999
0.025	0.105	96.643	130.194	0.139	0.033	0.194	-1	0.096	0.001	2000
0.157	0.114	40.011	14.477	0.251	0.016	0.597	-1	-1	0.004	2001
0.242	0.124	143.84	67.202	0.215	0.035	0.243	-1	-1	0.011	2002
0.216	0.117	63.992	34.63	0.483	0.023	0.1	0.988	-1	0.015	2003
0.232	0.131	46.179	28.78	0.347	0.015	0.387	2.548	-1	0.014	2004
0.118	0.119	251.732	130.604	0.204	0.034	0.405	1.717	-1	0.026	2005
3	3	2	1	1	1	4	4	1	2	Selectivity

Table 4.4. Results for the BASE, S1, S2, S3 and S4 model runs for **blacknose shark** using the updated catches. 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).

Blacknose	BASE		S1		S2		S3		S4	
	Estimate	CV	Estimate	CV	Estimate	CV	Estimate	CV	Estimate	CV
SSF_{2005}/SSF_{MSY}	0.48	0.67	0.52	0.59	0.60	0.73	0.601	0.66	0.43	0.65
F_{2005}/F_{MSY}	3.77	0.83	3.48	0.81	3.49	0.76	2.12	0.80	5.68	0.85
N_{2005}/N_{MSY}	0.48	-	0.52	-	0.51	-	0.55	-	0.30	-
MSY	89,415	-	99,876	-	99,236	-	91,681	-	88,911	-
SPR_{MSY}	0.71	0.38	0.71	0.39	0.70	0.14	0.54	0.28	0.64	0.45
F_{MSY}	0.07	-	0.07	-	0.07	-	0.11	-	0.05	-
SSF_{MSY}	349,060	-	347,930	-	343,050	-	434,590	-	108,920	-
N_{MSY}	570,753	-	569,595	-	564,628	-	522,800	-	603,536	-
F_{2005}	0.24	0.83	0.23	0.16	0.23	0.76	0.23	0.80	0.26	0.85
SSF_{2005}	168,140	0.75	179,870	0.77	204,720	0.71	261,240	0.82	133,250	0.78
N_{2005}	349,308	-	293,540	-	286,486	-	290,138	-	180,370	-
SSF_{2005}/SSF_0	0.20	0.65	0.22	0.63	0.21	0.58	0.22	0.23	0.19	0.49
B_{2005}/B_0	0.17	0.68	0.19	0.66	0.18	0.55	0.21	0.63	0.15	0.61
R0	317,590	0.19	321,470	0.19	316,810	0.18	265,620	0.19	358,870	0.20
Pup-survival	0.78	0.23	0.78	0.23	0.79	0.23	0.75	0.24	0.81	0.22
alpha	2.02	-	2.02	-	2.05	-	3.43	-	1.58	-
steepness	0.336	-	0.34	-	0.339	-	0.46	-	0.28	-

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

Year	N	SSF	F
1950	1.34E+06	9.11E+05	0.012
1951	1.33E+06	9.06E+05	0.013
1952	1.32E+06	8.99E+05	0.014
1953	1.31E+06	8.92E+05	0.015
1954	1.30E+06	8.84E+05	0.016
1955	1.30E+06	8.77E+05	0.017
1956	1.29E+06	8.71E+05	0.018
1957	1.28E+06	8.64E+05	0.019
1958	1.27E+06	8.57E+05	0.020
1959	1.26E+06	8.50E+05	0.021
1960	1.26E+06	8.43E+05	0.022
1961	1.25E+06	8.37E+05	0.023
1962	1.24E+06	8.30E+05	0.024
1963	1.23E+06	8.23E+05	0.025
1964	1.23E+06	8.16E+05	0.026
1965	1.22E+06	8.10E+05	0.027
1966	1.21E+06	8.03E+05	0.028
1967	1.20E+06	7.96E+05	0.029
1968	1.19E+06	7.90E+05	0.030
1969	1.19E+06	7.83E+05	0.031
1970	1.18E+06	7.77E+05	0.032
1971	1.17E+06	7.70E+05	0.033
1972	1.16E+06	7.64E+05	0.034
1973	1.16E+06	7.57E+05	0.031
1974	1.15E+06	7.52E+05	0.017
1975	1.15E+06	7.52E+05	0.040
1976	1.14E+06	7.47E+05	0.027
1977	1.14E+06	7.45E+05	0.044
1978	1.13E+06	7.39E+05	0.041
1979	1.12E+06	7.32E+05	0.026
1980	1.12E+06	7.30E+05	0.017
1981	1.13E+06	7.32E+05	0.019
1982	1.13E+06	7.36E+05	0.014

1983	1.14E+06	7.42E+05	0.031
1984	1.13E+06	7.34E+05	0.014
1985	1.14E+06	7.38E+05	0.020
1986	1.14E+06	7.40E+05	0.041
1987	1.13E+06	7.36E+05	0.041
1988	1.11E+06	7.23E+05	0.042
1989	1.10E+06	7.09E+05	0.062
1990	1.08E+06	6.99E+05	0.055
1991	1.07E+06	6.90E+05	0.090
1992	1.04E+06	6.72E+05	0.107
1993	1.01E+06	6.44E+05	0.067
1994	9.92E+05	6.23E+05	0.116
1995	9.47E+05	5.88E+05	0.157
1996	8.89E+05	5.48E+05	0.154
1997	8.39E+05	5.10E+05	0.279
1998	7.46E+05	4.47E+05	0.176
1999	7.05E+05	4.11E+05	0.169
2000	6.70E+05	3.85E+05	0.259
2001	6.05E+05	3.44E+05	0.305
2002	5.41E+05	3.05E+05	0.229
2003	5.02E+05	2.75E+05	0.345
2004	4.41E+05	2.39E+05	0.445
2005	3.72E+05	2.00E+05	0.245

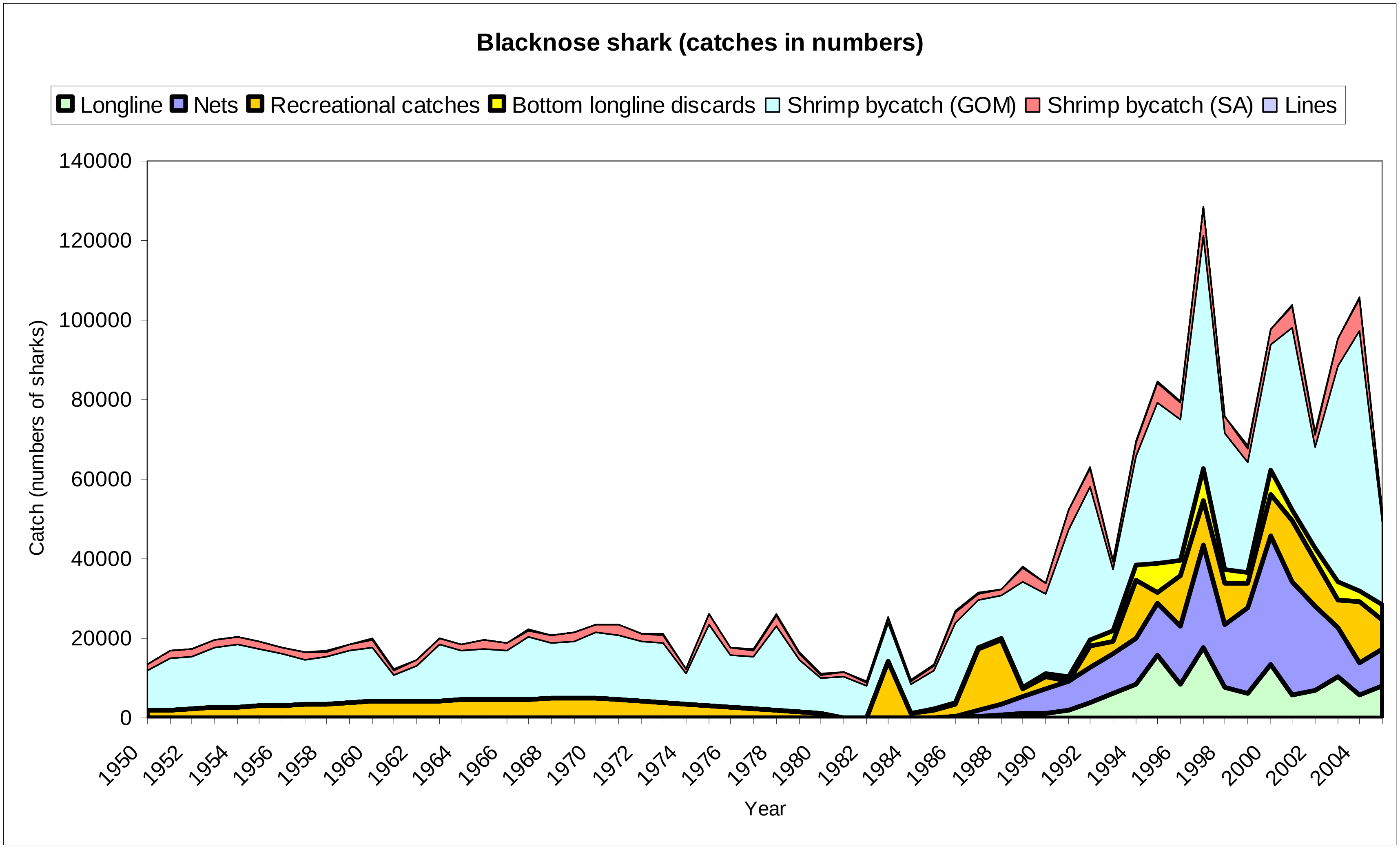


Figure 4.1. All catches by fleet for **blacknose shark** including reconstructed catches.

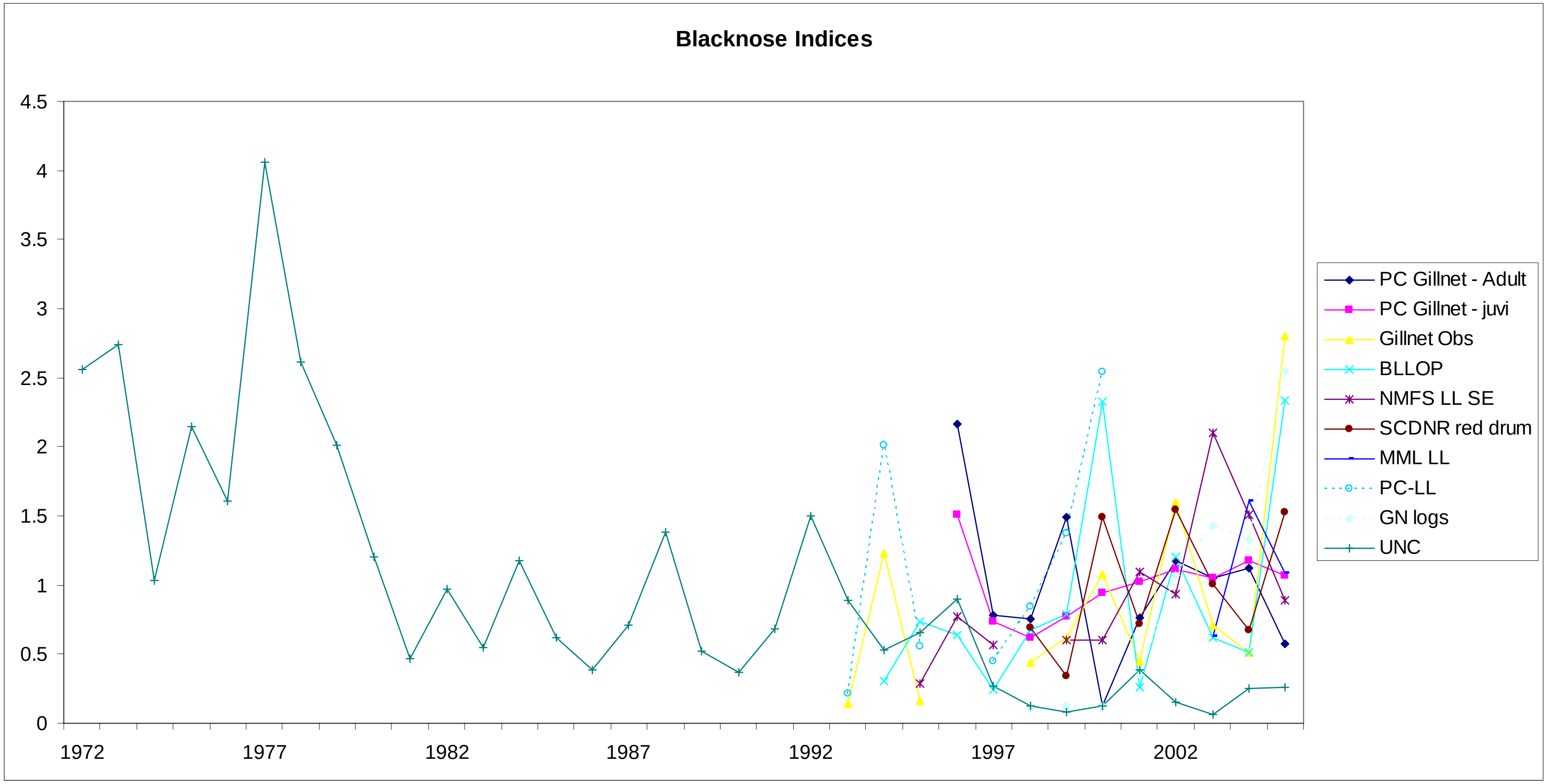


Figure 4.2. Indices available for the current **blacknose shark** assessment. The sensitivity indices are dashed lines.

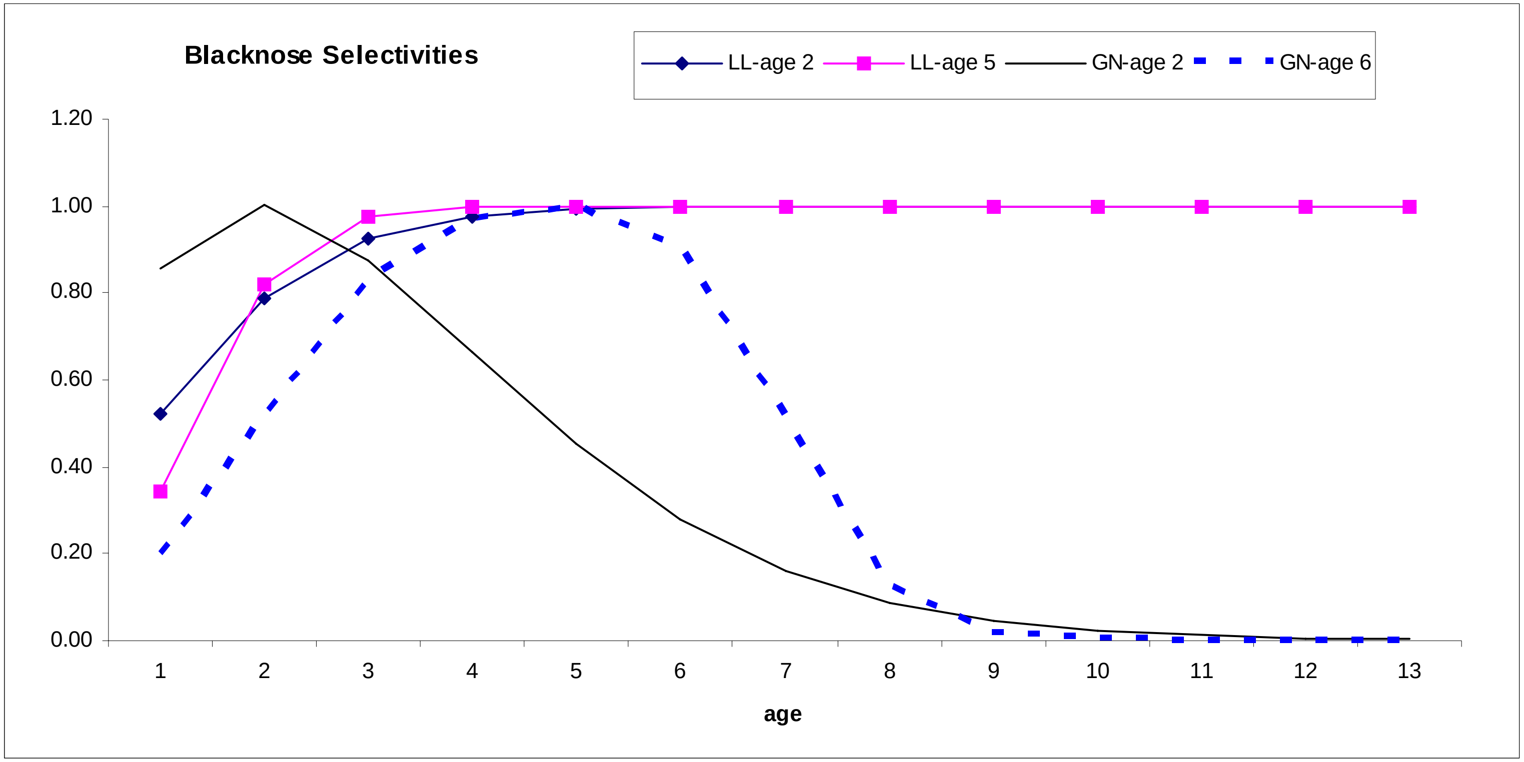


Figure 4.3. Selectivities used in **blacknose shark** assessment. In the text, they are reference as 1,2,3 and 4, which corresponds to the order in which they appear in the legend above.

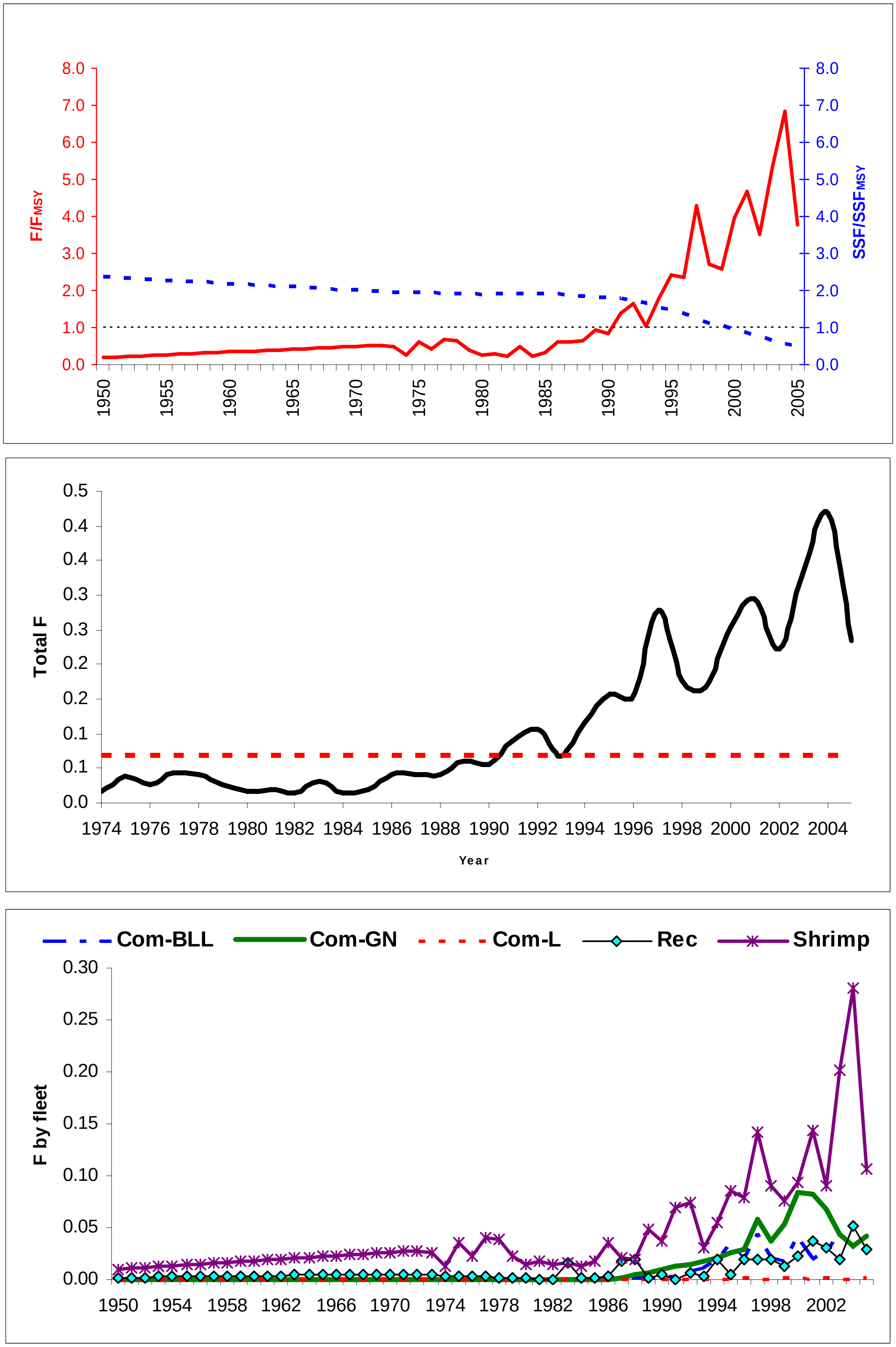


Figure 4.4. Estimated stock status (top), total fishing mortality (middle), and fleet-specific F (bottom) for **blacknose shark**. The dashed line in the middle panel indicates F_{MSY}.

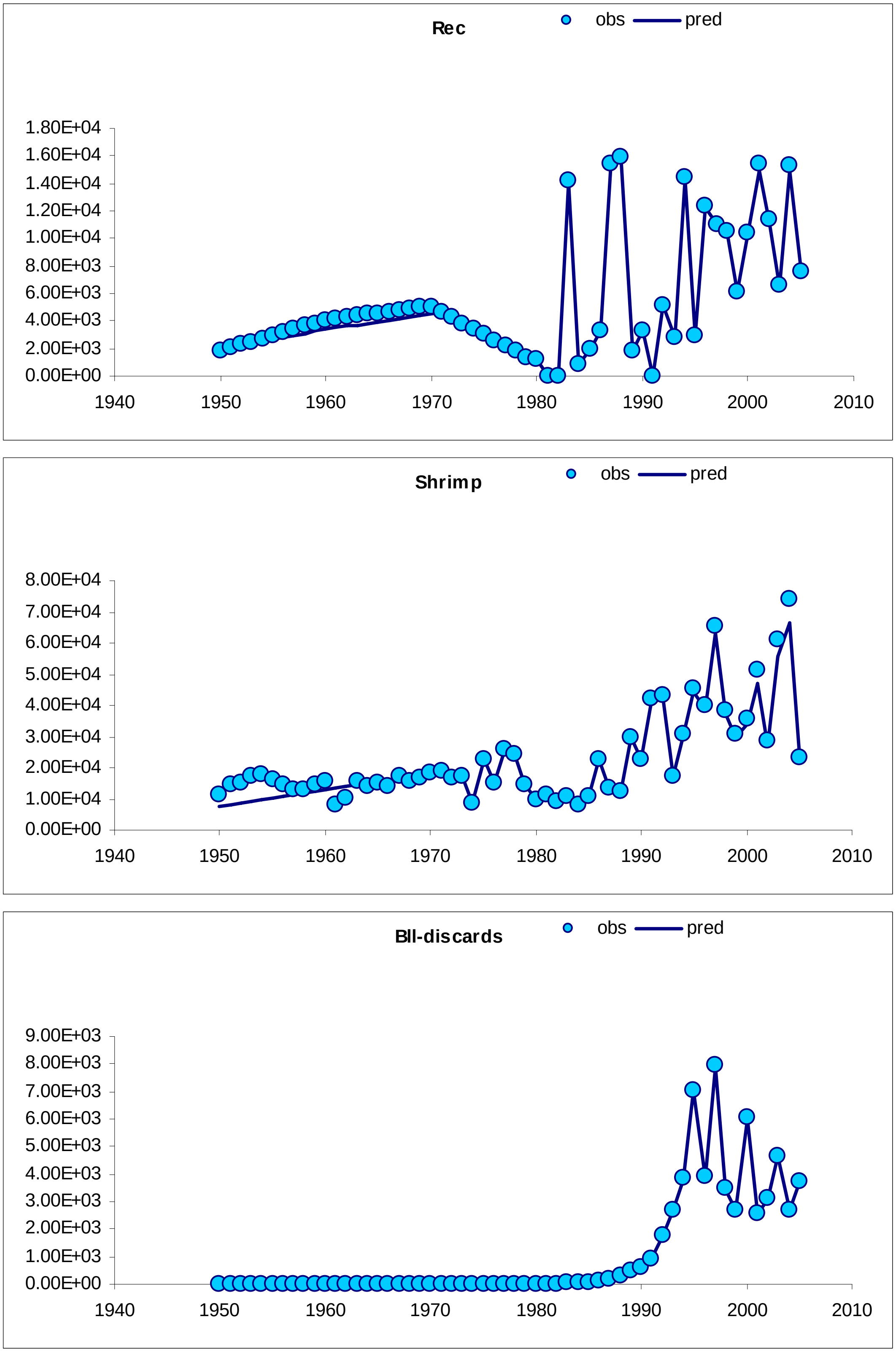
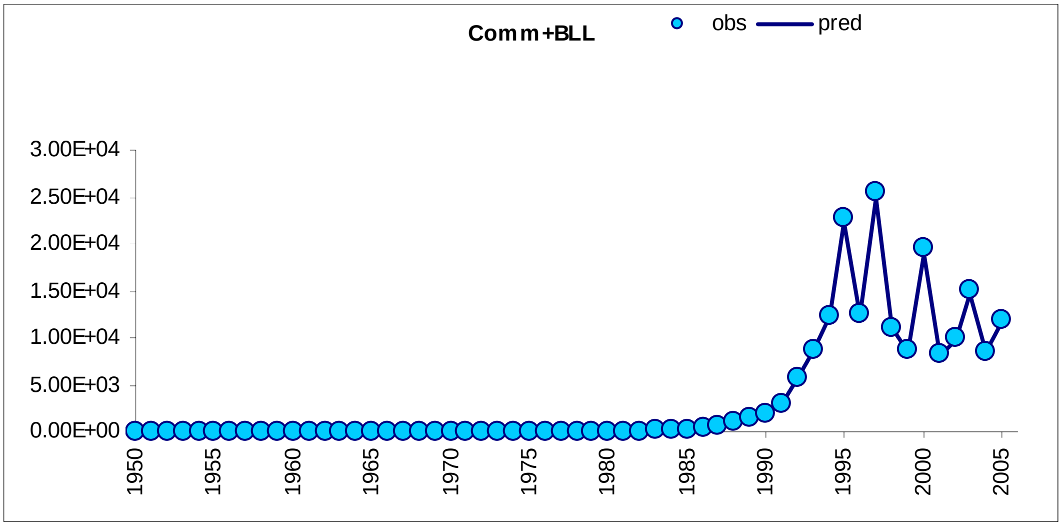


Figure 4.5. Model predicted fit to **blacknose shark** catch data. Circles represent observed data, solid line is predicted.



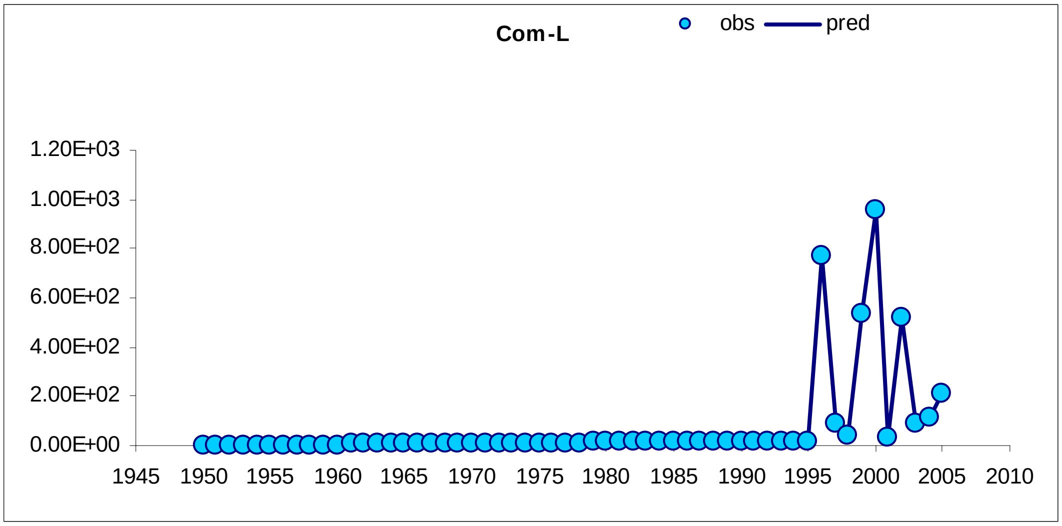


Figure 4.5. (continued).

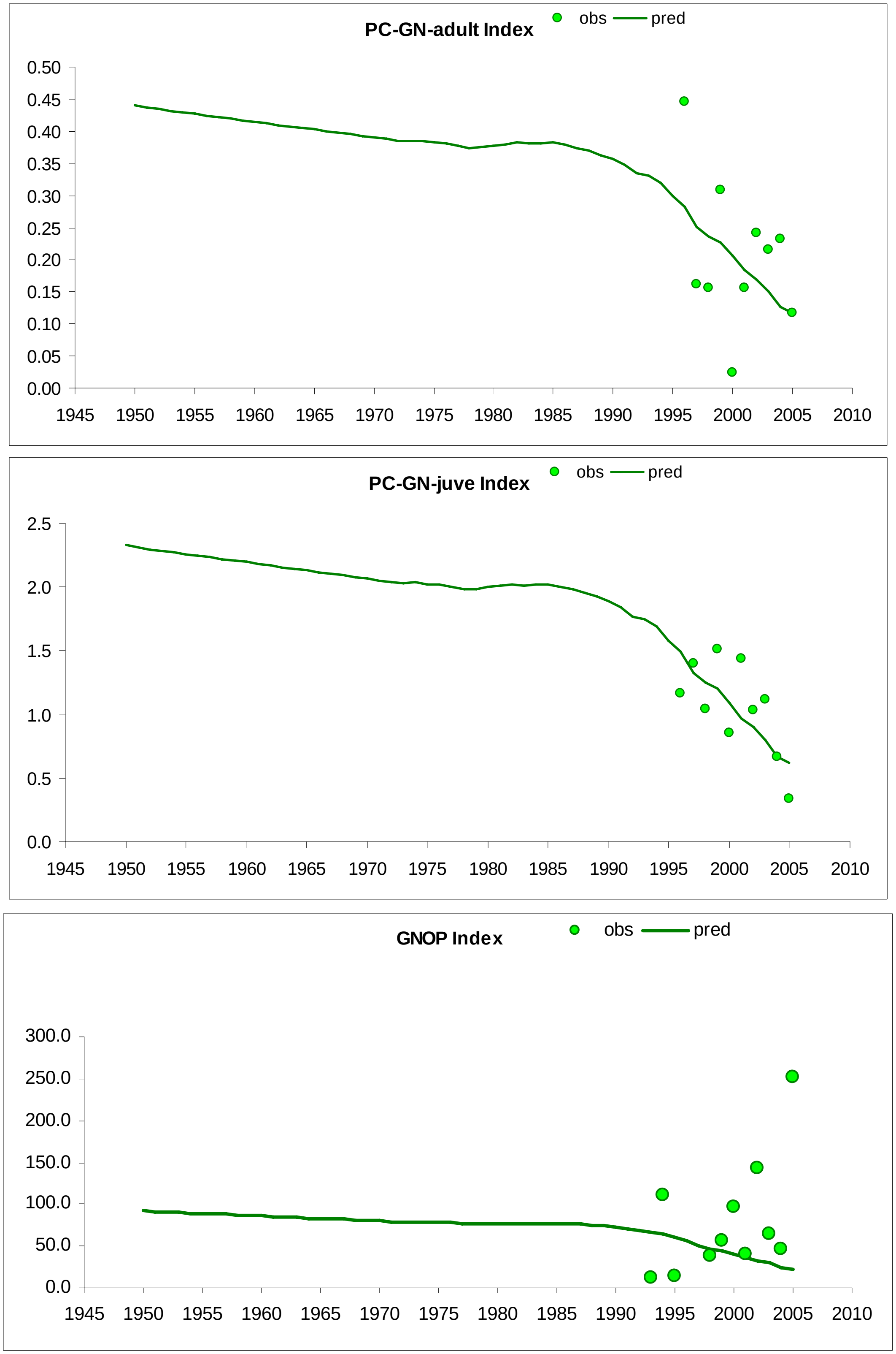


Figure 4.6. Model predicted fit to **blacknose shark** catch rate indices. Circles represent observed data, solid line is predicted.

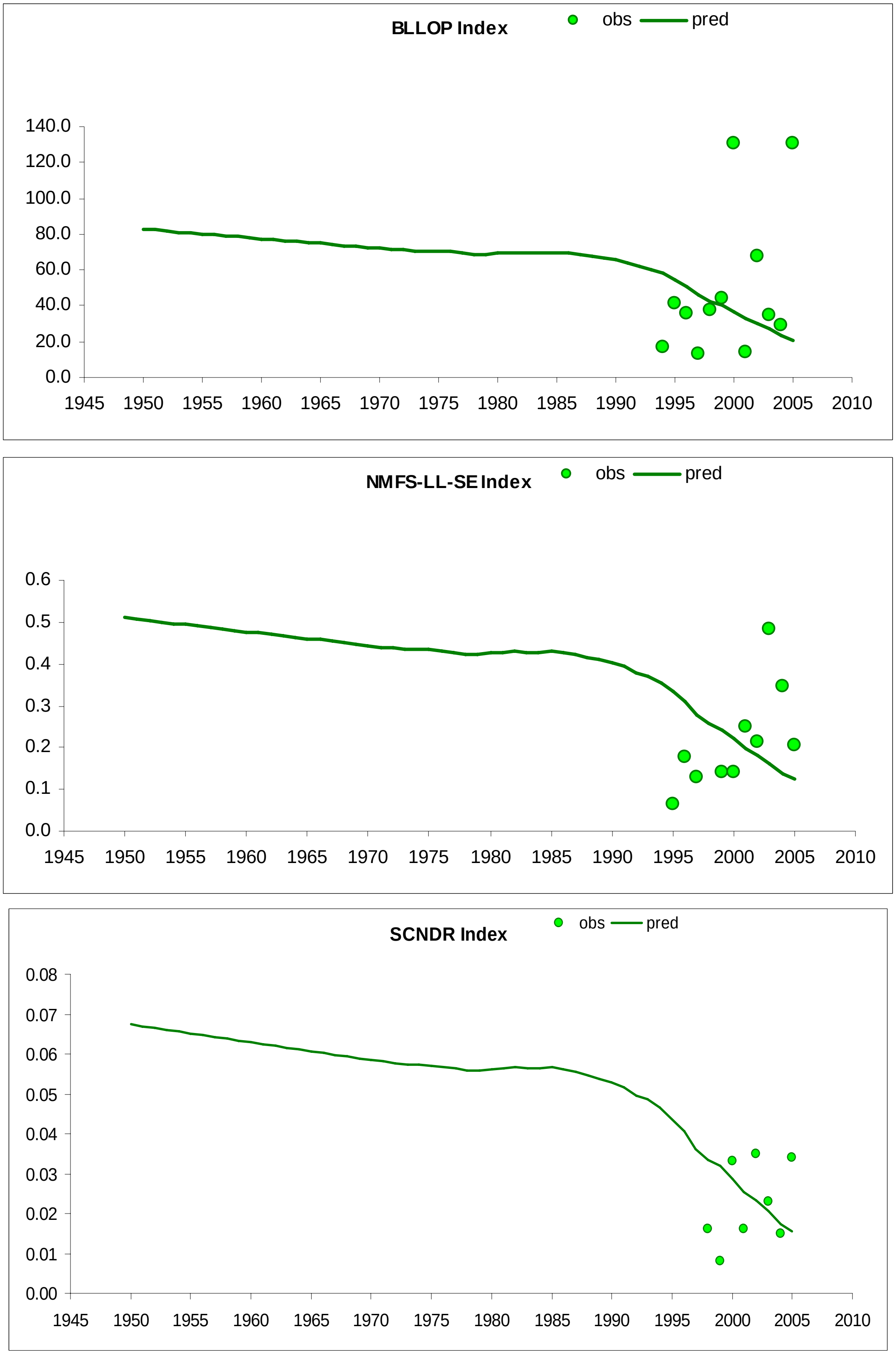
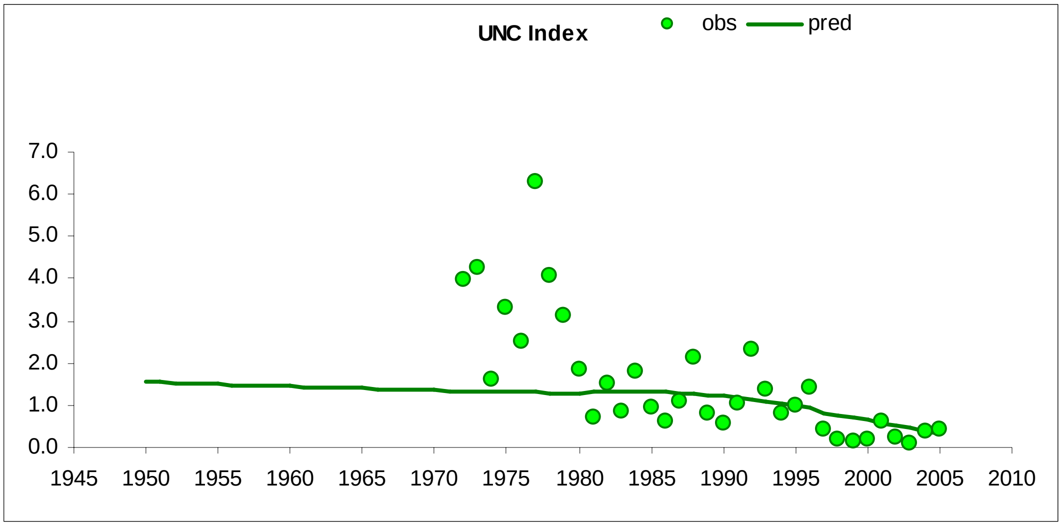


Figure 4.6. (Continued).



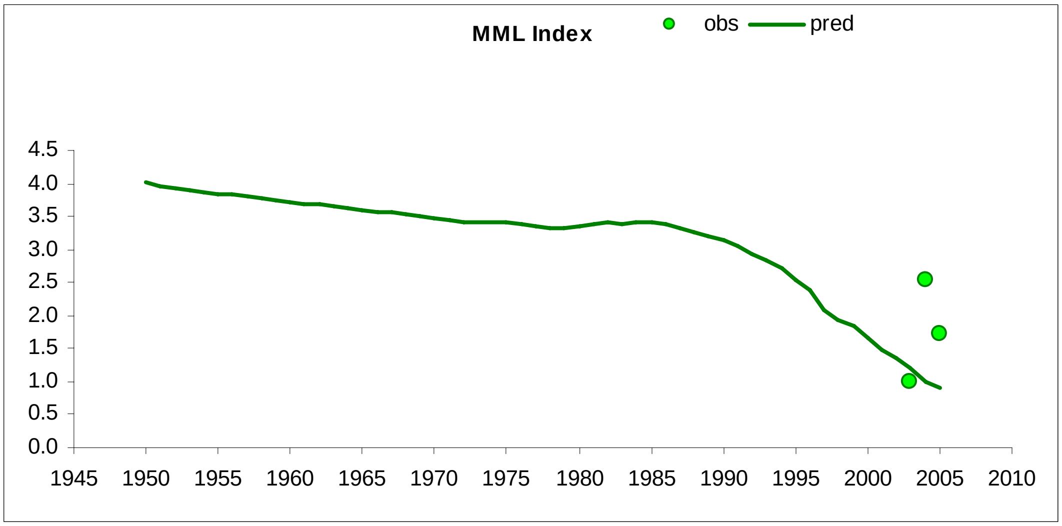


Figure 4.6. (Continued).

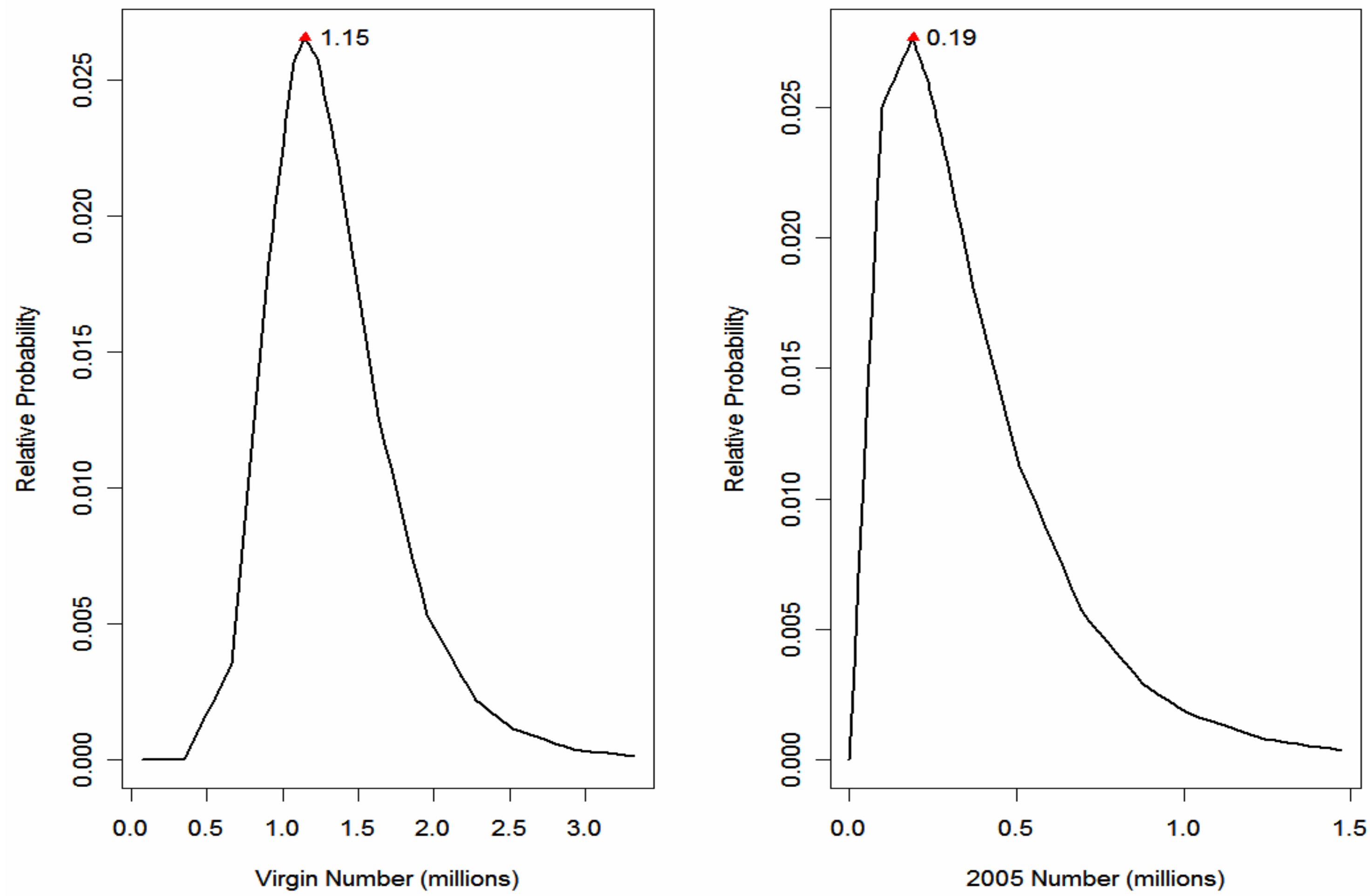


Figure 4.7. **Blacknose shark** profile likelihoods for virgin and current abundance (numbers), and virgin and current spawning stock fecundity, as well as depletion (current/MSY values) estimates of these parameters. The red triangles denote the modes of the distributions.

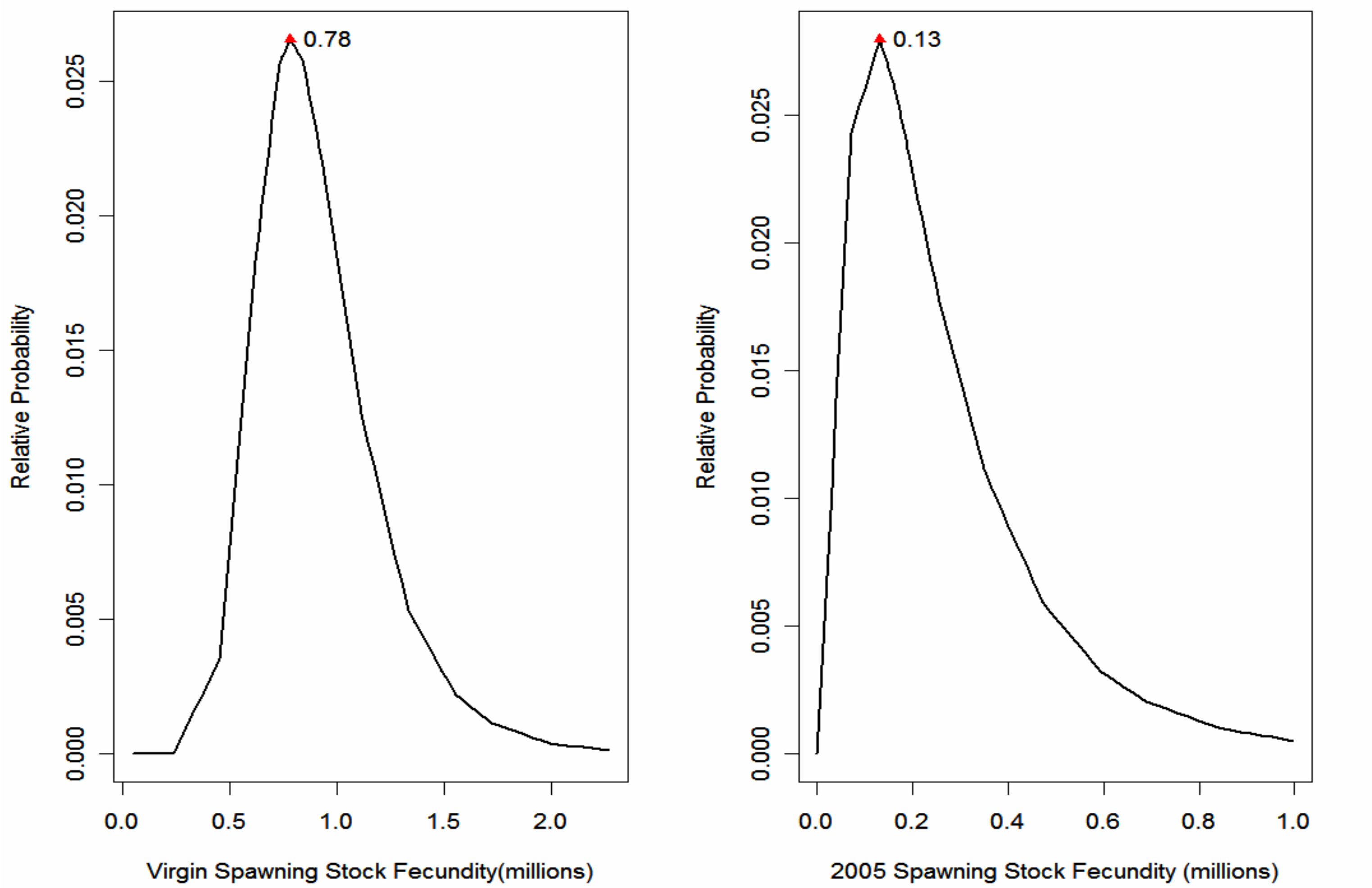


Figure 4.7. (continued)

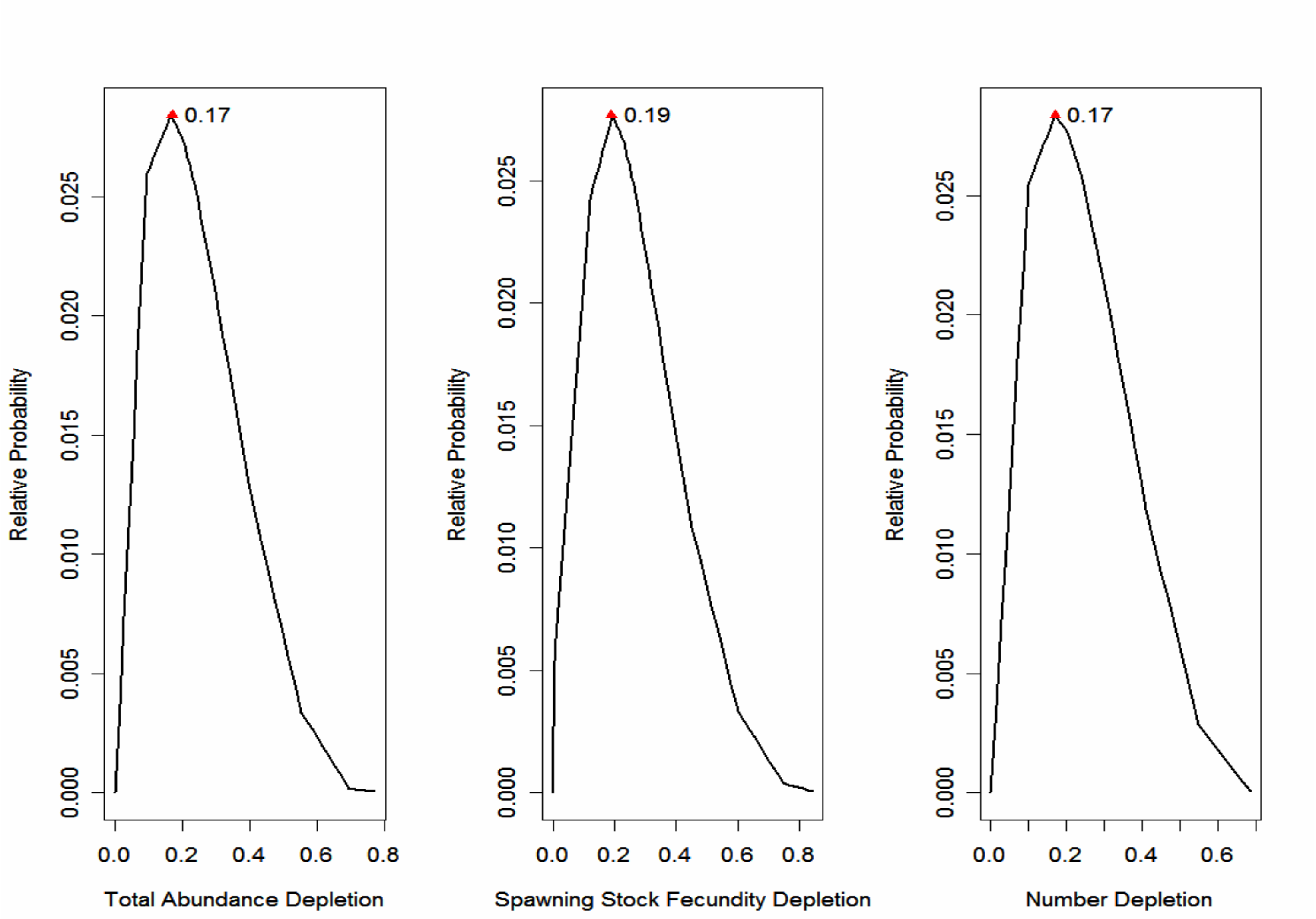


Figure 4.7. (continued)

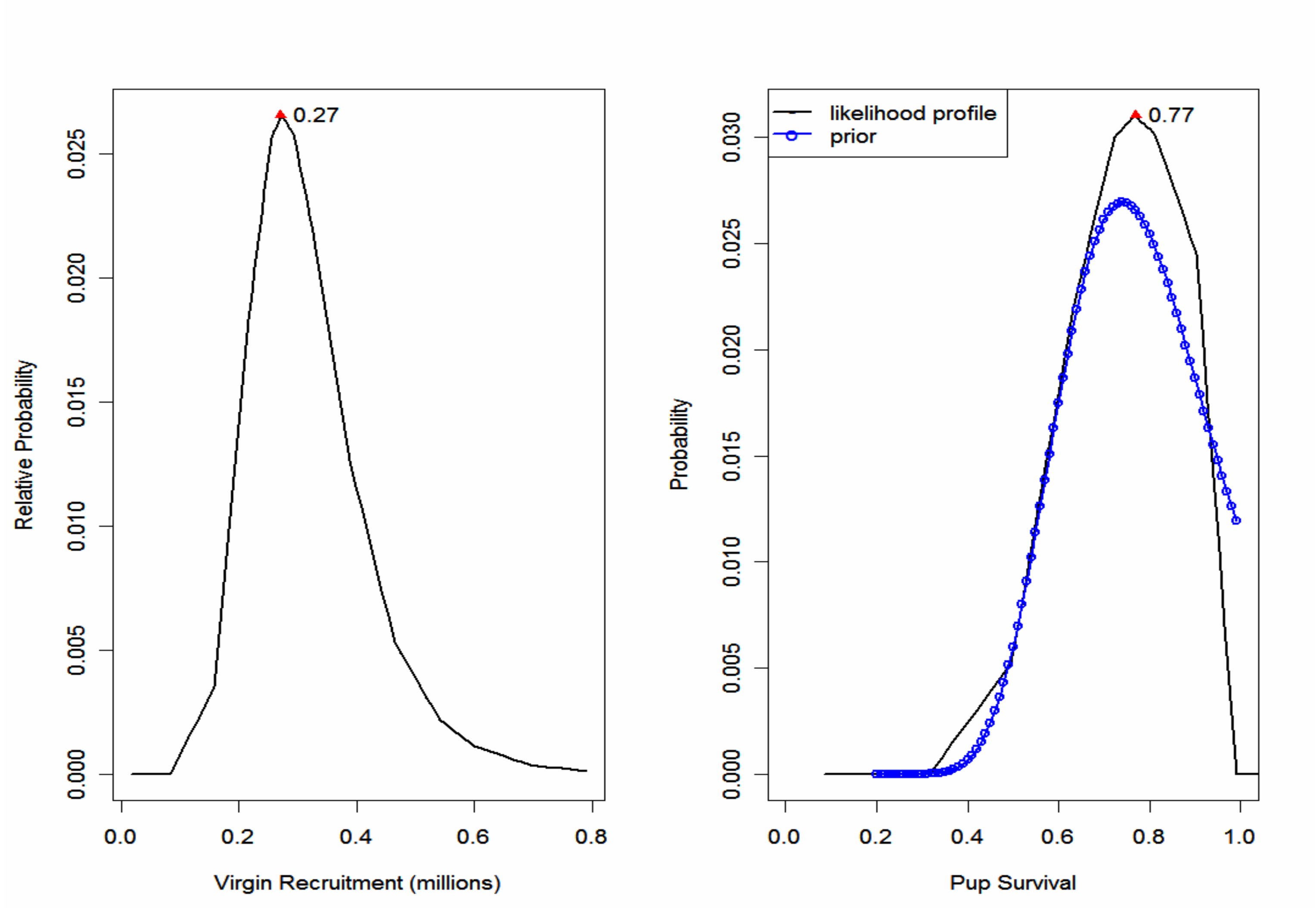


Figure 4.8. Profile likelihoods for pup survival and virgin recruitment, and for pup survival for **blacknose shark**. The prior is also plotted. The red triangles are the modes of the distributions.

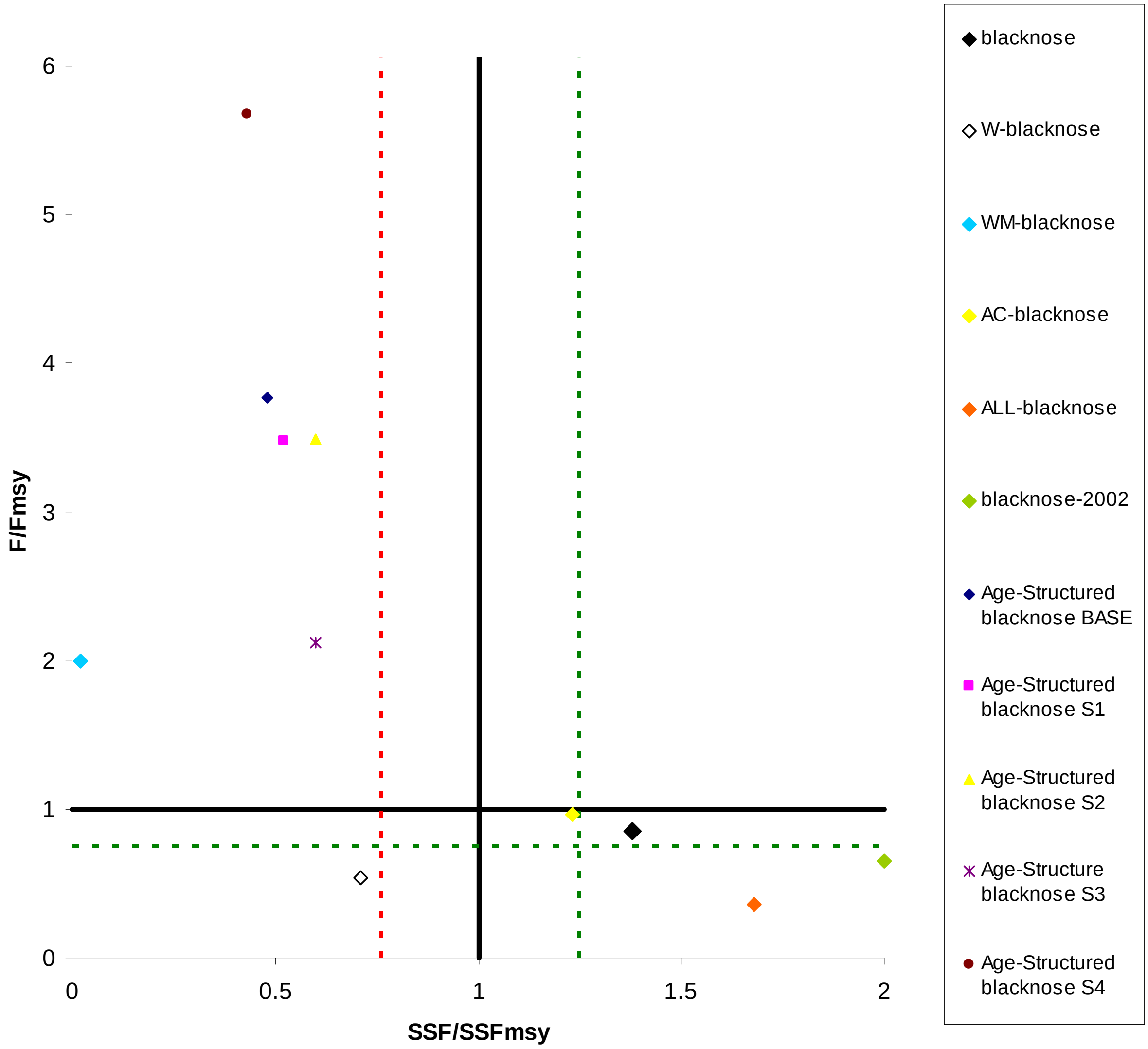


Figure 4.9. Phase-plot of **blacknose shark** stock status. Selected sensitivity analyses from the surplus production models (SPM) and the stock status from the 2002 assessment are included for reference. The age-structured models are in bold and include BASE, S1, S2, S3, S4. The SPM sensitivities are as follows: W— WinBUGS**,** complementary surplus production model. WM—SPM sensitivity to weighting scheme used: this involved changing the method for weighting the CPUE series from equal weighting in the baseline scenario to inverse variance weighting. IF—SPM sensitivity to importance function used: this involved changing the importance function from the priors to a multivariate t distribution. AC—SPM sensitivity to extending the catch series back to 1950. ALL—SPM sensitivity adding the CPUE series identified as “sensitivity” to those in the baseline scenario. 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). 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).

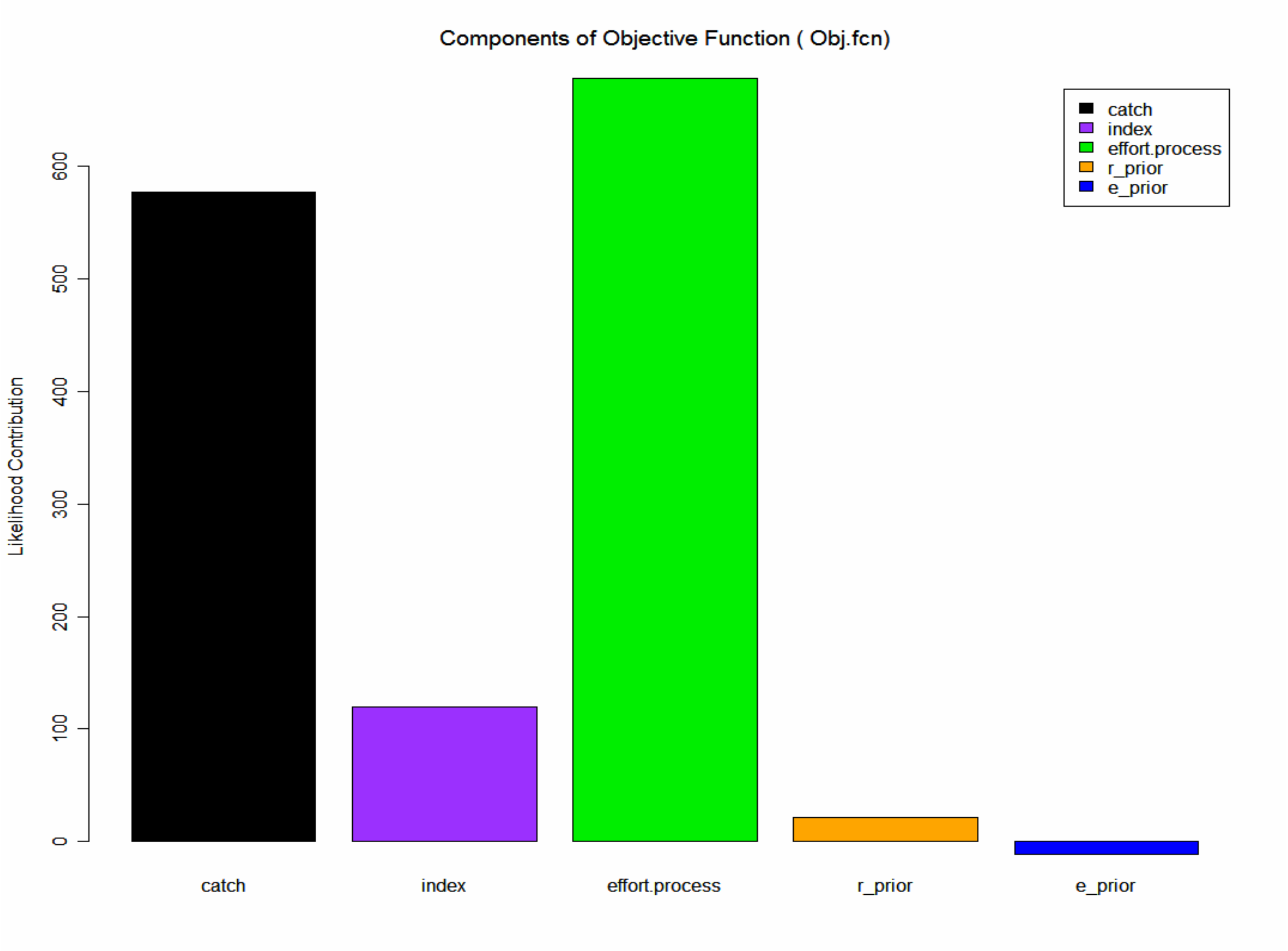


Figure 4.10. Contributions to the likelihood by model source for the **blacknose shark** base model.

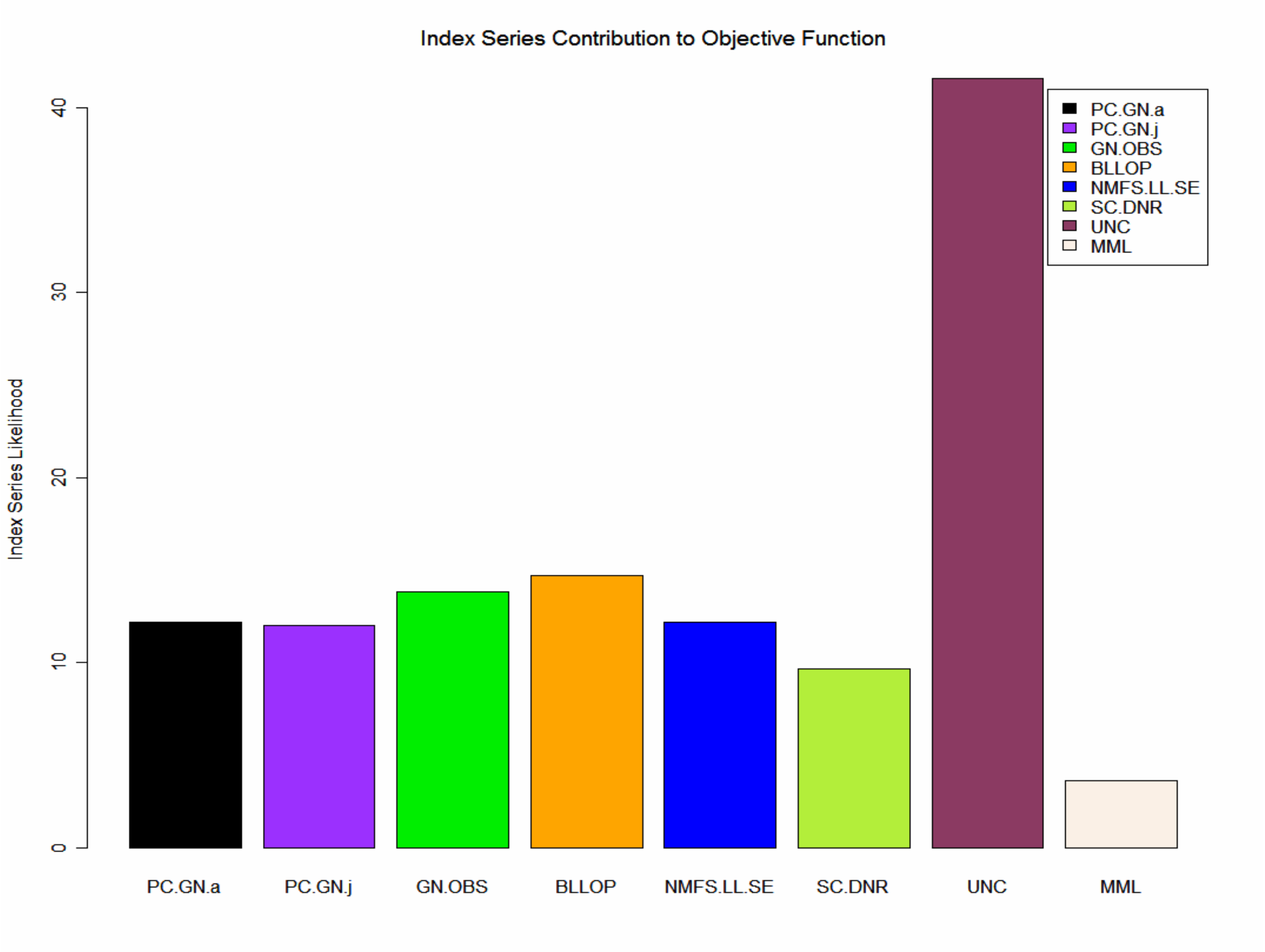


Figure 4.11. Contribution to relative likelihood by index series and catch series for the **blacknose shark** base model.

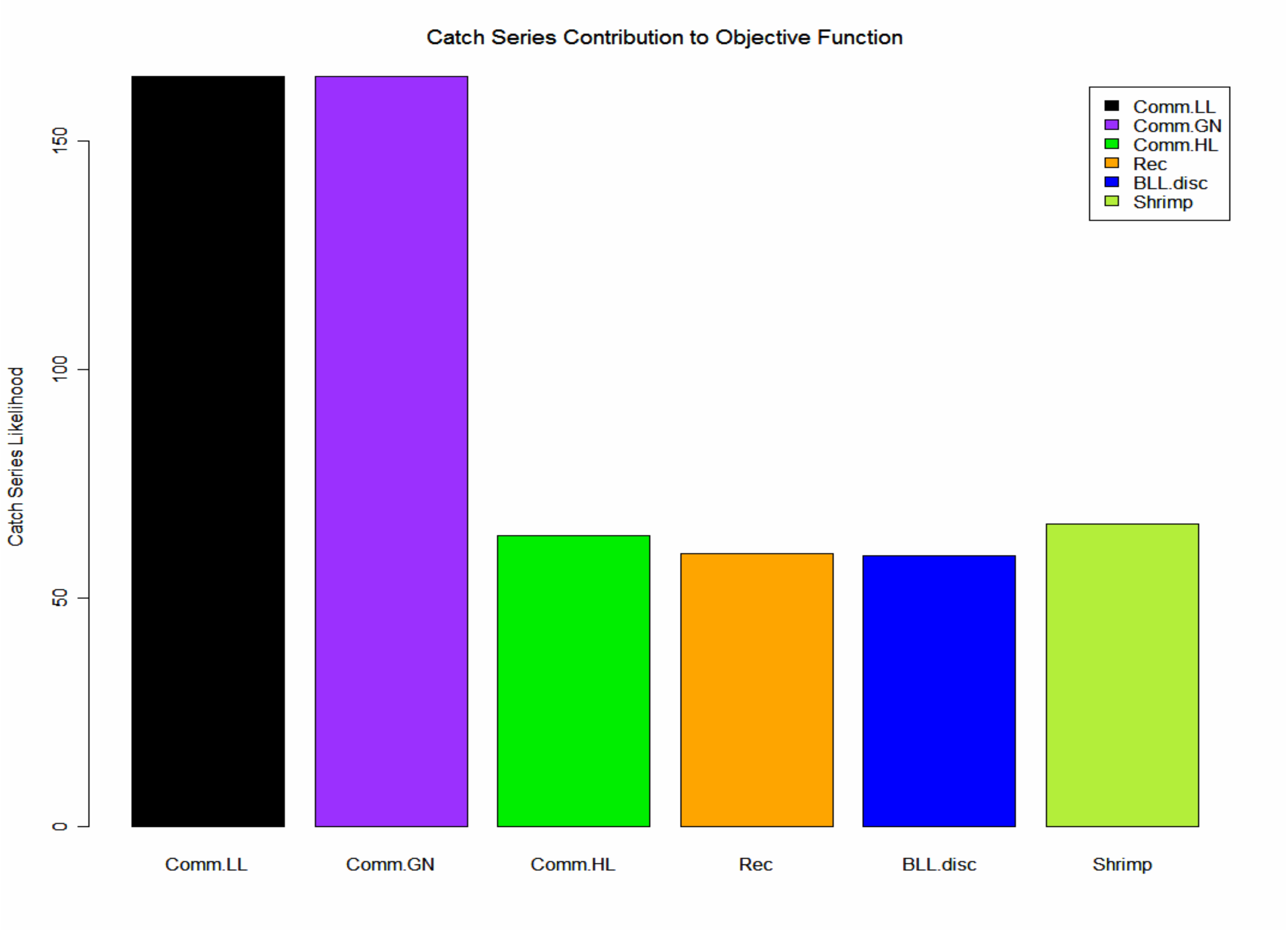


Figure 4.11. (Continued).

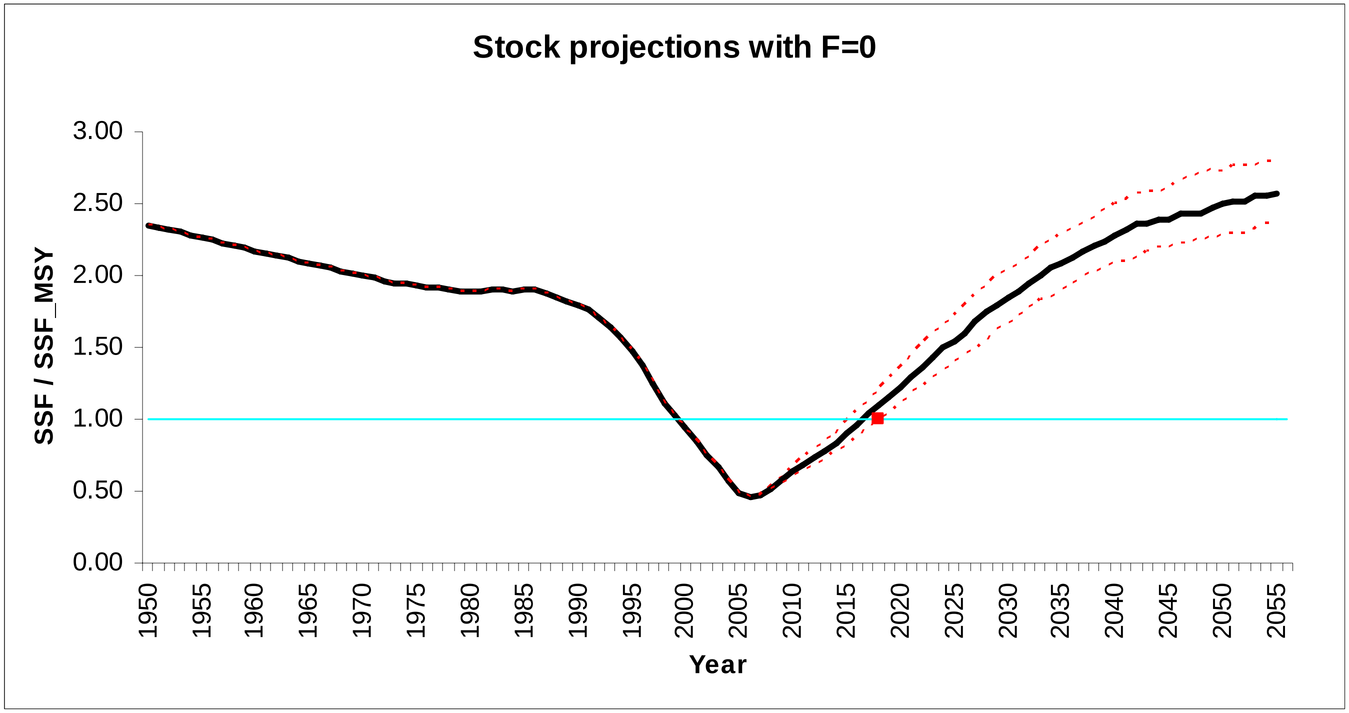


Figure 4.12. **Blacknose shark** stock projections with F=0 (solid black). The dashed red lines represent the 30th percentile (lower) and the 70th percentile (upper). Rebuilding under F = 0 with 70% probability is achieved in year 2019 (solid red square).

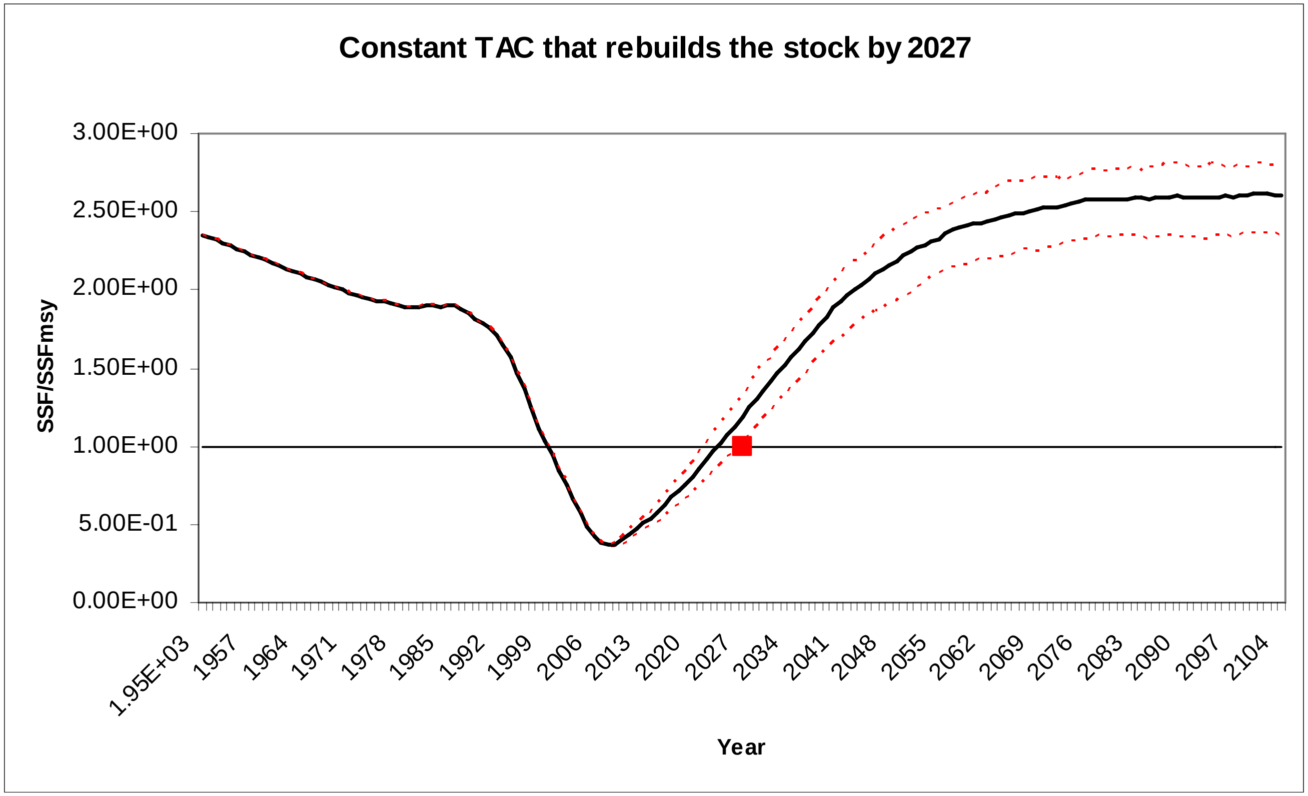


Figure 4.13. **Blacknose shark** stock projections with the constant TAC (19,200 individuals) required to rebuild the stock with 70% probability by 2027 (marked by the solid red square. The constant TAC allows the stock to rebuild with 50% confidence by 2024.

ATLANTIC SHARPNOSE SHARK

ASSESSMENT

5. ATLANTIC SHARPNOSE SHARK ASSESSMENT

5.1 Summary of Atlantic Sharpnose Shark Working Documents

SEDAR 13-AW-01
Assessment of Small Coastal Sharks, Atlantic sharpnose, Bonnethead, Blacknose and Finetooth Sharks using Surplus Production Methods
We used two complementary surplus production models (BSP and WinBUGS) to assess the status of the Small Coastal Shark (SCS) complex and four individual species (Atlantic sharpnose, bonnethead, blacknose, and finetooth sharks) identified as baseline scenarios in the SCS 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 rate of increase, and importance function on results. Baseline scenarios predicted that the stock status is not overfished and overfishing is not occurring in all cases. Using the inverse variance method to weight the CPUE data was problematic because of the nature of the CPUE time series and must be regarded with great caution, although predictions on stock status did not change, except for blacknose sharks. The alternative surplus production model implemented in WinBUGS supported the results from the BSP model, with the exception of blacknose sharks, which became overfished. None of the other sensitivity analyses examined had a large impact on results and did not affect conclusions on stock status in any case. Only blacknose sharks with the alternative catch scenario approached an overfishing condition.

SEDAR 13-AW-02
Determining Selectivities for Small Coastal Shark Species for Assessment Purposes
Selectivities of catch series and indices had to be determined for sharpnose, blacknose, and bonnethead sharks for the 2007 small coastal shark stock assessment. Based on age frequencies, five selectivities were determined for sharpnose, four for blacknose, and two for bonnethead.

SEDAR 13-AW-03
Siegfried and Brooks: Assessment of Blacknose, Bonnethead, and Atlantic Sharpnose Sharks with a State-Space, Age-Structured Production Model
An age-structured production model was employed to assess the following small coastal sharks: Blacknose (*Carcharhinus acronotus*), Bonnethead (*Sphyrna tiburo*), and Atlantic Sharpnose (*Rhizoprionodon terraenovae*). All models assumed virgin conditions in 1950, and historically reconstructed catches were derived to inform the model on likely levels of removals for the years prior to the start of observed and recorded catches. The base models for all three species applied equal weight to all indices. Base model results for bonnethead shark indicate that the stock is overfished and that there is overfishing. The stock status appears to be quite sensitive to the reconstructed catches, particularly because of some extreme peaks in the bottom longline fishery reports and the shrimp bycatch reports. An initial sensitivity run indicates that the stock depletion decrease when less weight is given to the extreme peaks. Additional sensitivities will be performed at

the assessment workshop. The base model results for Blacknose suggest that the stock is overfished and that there is also overfishing. The base model for Atlantic sharpnose assumed a single stock, and results from this model indicate that the stock is not overfished nor is overfishing occurring. A sensitivity analysis where inverse CV weights were applied to the base indices showed very little difference from the base model, and the stock status estimate was no overfishing and the stock is not overfished.

5.2 Background

In 2002, a stock assessment was conducted on the small coastal complex of sharks (finetooth (*Carcharhinus isodon*), blacknose (*Carcharhinus acronotus*), bonnethead (*Sphyrna tiburo*), and Atlantic sharpnose (*Rhizoprionodon terraenovae*), in the Gulf of Mexico and the Atlantic (Cortés 2002). The author used a variety of Bayesian statistical models, including a Schaefer biomass dynamic model, a Schaefer surplus production model, and a lagged-recruitment, survival and growth state-space model. This assessment report outlines the discussions and results of the current Atlantic sharpnose shark stock assessment

5.3 Available models

Three models were available for discussion for the Atlantic sharpnose shark assessment: two surplus production models, the BSP and WinBUGS models described previously, and one age-structured production approach (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 SEDAR13-AW-03 for sharpnose 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.

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 gives the same weight to residuals for all indices (annual points, and overall between each index), regardless of estimates of precision. Arguments in the past have pointed out that indices derived from many sample points typically have high precision (for example, fisheries dependent data) while scientific surveys may have higher variability due to sample size. In this situation, one must consider both precision *and accuracy*—the mere fact that an index is precise does not address whether or not it accurately reflects population trend. An index derived from data where sampling methodology or gear changed, or where fish finding technology improved could bias the estimated trend. Giving equal weighting to all indices is a way to balance the question of accuracy and precision.

Inverse CV weighting emphasizes the indices with greater estimated precision, and allows the model to fit those indices more closely. A caveat for this method is that it may not be appropriate for cases in which the standardization techniques differed between indices. In that situation, the same value of CV might reflect different levels of error depending on the CPUE it corresponds to.

The Assessment Panel further discussed the issue for weighting indices. It was noted that there are a variety of ways to weight indices in addition to equal and inverse CV weighting, however the determination of which weighting method is most appropriate is a discussion topic that is still without satisfying resolution. Given that fact, the Assessment Panel decided that equal weighting would be the base weighting method for the current assessment but noted that, as there is at present no objective way to decide which method is superior other than comparing model convergence diagnostics, future assessments may need to re-examine this issue.

5.6 Data issues and decisions made during the Assessment Workshop

Several of the catch series, and specifically the reconstruction of historic catches, were revisited during the Assessment Workshop. For the commercial bottom longline series, the DW fit a linear trend from 0 catches in 1980 to the first data point in 1995. At the AW, a discussion on how the fishery developed led the group to decide that an exponential fit from 1980 to 1995 was more appropriate. The bottom long line discard estimation methodology was revisited, and it was decided that discards for the whole time period of 1980-2005 would be estimated based on the average rate of discarding observed in 1995-2005. For the commercial hand line fishery, an anomalously high catch was recorded in 2003. The major source of data contributing to that point was traced to a record identifying the catch as “trolling in Alabama.” However, no landings for that region/gear had been recorded in previous or in subsequent years. The AW discussed this issue and decided that this was likely misreported gear. Noting that the landings for gillnet in that same year were lower than surrounding years, it was decided to re-assign those catches reported as “trolling” to the gillnet catch series in 2003. Finally, in the shrimp bycatch series, there were landings estimates for which the entire credibility interval did not contain the series average. Those estimates were generally very imprecise, and consistently larger than the series mean. The AW discussed the nature of those estimates, and given that year specific CVs were not applied to the bycatch estimates in the assessment model (nor to any catch series, for that matter), a decision was made to smooth those points by replacing the estimate with a geometric mean of 3 years before and after the questionable estimate.

5.7 Methods

5.7.1 State-space age-structured production model description

The age-structured production model (originally derived in Porch 2002) starts from a year when the stock can 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 era,” where data are sparse, and a “modern era,” where more data are available for model fitting. In all three model applications, virgin conditions were assumed in 1950. The earliest index of abundance (SEAMAP) and the earliest catch series (Shrimp trawl bycatch) begin in 1972, thus the historic model years spanned 1950-1971 (22 years) and the modern model years spanned 1972-2005 (34 years).

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

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

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, where y_i for i<mod are historic years, and modern years are y_i for which $\text{mod} \le i \le T$. 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 model period. In the historic period, effort is estimated as either a constant (4a) or a linear trend (4b)

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

or

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

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:

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

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

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

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:

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

where τ_i is the duration of the fishing season for fleet i. Catch in weight is computed by multiplying (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:

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

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 small coastal 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:

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

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:

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

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):

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

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

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 for the base model run, 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.

5.7.2 Data inputs, prior probability distributions, and performance indicators

Baseline scenario (SPASM-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 5.1 – 5.4; Figures 5.1 – 5.4). Catches were attributed to six different fleets: the commercial bottom longline, the commercial gillnet, the commercial handline, discards from the commercial bottom longline, the recreational sector, and bycatch from the shrimp trawl fishery. A comparison of the DW and the revised AW catch series are shown in Figures 5.2 (a-e). In addition to the catch series, a total of 13 indices were available from the Data Workshop.

Individual selectivity functions to be applied to catch and catch series were identified based on length frequencies and biological information provided by the Life History Working Group at the Data Workshop. The selectivity determination methods and recommendations were presented in SEDAR 13 AW-02 and summarized here in Figure 5.4.

Catch data begin in 1981, while the earliest data for the indices is 1972 (UNC). Catches from 1981 were imputed back to 1950, when a virgin assumption was imposed. The catches for each fleet were imputed as follows: the commercial longline was reconstructed to increase at an exponential rate from 1981 to 1995 (the year of the first data point). The commercial gillnet fishery was reconstructed to increase linearly from 1981 to 1995. The longline reconstruction changed from linear (a Data Workshop recommendation) to an exponential increase following the Assessment Workshop recommendations.

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 was to treat all points as having an equal weight. There were no recommendations by either the Data Workshop or the Assessment Workshop to downweight any individual or group of points.

Estimated model parameters were pup survival, virgin recruitment (R_0), catchabilities associated with all indices, fleet-specific effort and effort deviations in the modern period. Natural mortality at ages 1+ was fixed at the values provided by the Life History Working Group (Table 5.3), and the priors for pup survival and virgin recruitment are listed in Table 5.4.

In summary, the base model configuration assumed virgin conditions in 1950, used the revised reconstructed catch series as agreed upon at the Assessment Workshop. All inputs are given in Tables 5.1 – 5.4.

Performance indicators included estimates of absolute population levels and fishing mortality for year 2005 (F_{2005}, SSF_{2005}, B_{2005}), 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 is spawning stock fecundity.

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

Numerical integration for the age-structured production 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. Uncertainty in model parameters, and in a Bayesian context the posterior density, was examined with likelihood profiling. AD Model Builder calculates likelihood profiles by assuming that the posterior probability distribution is well approximated by a multivariate normal (Otter Research Ltd. 2001).

5.7.4 Description of Model Runs

The base model (described below) was the basis for management advice. Additional model runs (identified below with an S and a number) were explored to determine sensitivity of results to assumptions and the configuration of the base model. Each model configuration is described below.

BASE –base indices were used and given equal weighting; the revised AW catches were used;
S1 – base indices were used and given inverse CV weighting; the revised AW catches were used;
S2 – a separate assessment was conducted for the Gulf of Mexico and the Atlantic as an exploration of a “2-stock” hypothesis; base indices for the Gulf of Mexico and the Atlantic were used and given equal weighting; the revised AW catches were used;
S3 – all base and sensitivity indices were used and given equal weighting; the revised AW catches were used;
S4 – the SEAMAP extended fall index was split due to a change in sampling protocol; the extended summer SEAMAP index was dropped because the same sampling protocol change occurred but no data was available to estimate separate indices before and after the split; equal weighting applied to indices; the revised AW catches were used.

5.8 Results

5.8.1 Baseline scenario

The base model results (Table 5.5; Fig. 5.5) indicated that the stock was not overfished nor was overfishing occurring (SSF_{2005}/SSF_{MSY}=1.49 and F_{2005}/F_{MSY}=0.70). Although the level of fishing mortality exceeded F_{MSY} in several years, the last three years have all been less than F_{MSY} (Figure 5.5). Years where $F>F_{MSY}$ generally coincide with peaks in the shrimp landings (*cf.* Figures 5.1 and 5.6). Examining the pattern in estimated fishing mortality at age for the last decade, it appears that the highest F is occurring on ages 1-3

(Figure 5.7), i.e. fishing mortality is occurring on fish before they reach maturity (see maturity ogive plotted in Figure 5.4). The stock is estimated to be at 60-65% of virgin levels (for units of biomass or number, respectively; Figure 5.8). Catches were fit well in general, although the down-weighting of historically reconstructed catches caused them to be fit less closely than data in the modern period, defined as 1972-2005 (Figure 5.9). Indices were fit assuming lognormal error, and fits to these indices were acceptable (Figure 5.10).

The base model estimate of MSY is 1.21 million kg, or approximately 1.2 million sharks, given the selectivities derived for the various catch series. The virgin estimate of sharpnose sharks (in numbers) is about 11 million, while the 2005 population size is estimated to be close to 6 million.

Likelihood profiling was performed for the base model. Posterior distributions for several model parameters are plotted in Figures 5.11-5.15; where priors were specified, these are plotted with the estimated posterior.

The relative likelihood values by model source (catch, indices, effort, catchability, and recruitment) as well as a breakdown of likelihood by individual index and catch series are shown in Figure 5.16. These graphs show the relative contributions of each model source, catch series, and index on the model's relative likelihood. In general, the smaller the bar, the better a given component was fit. However, it is important to keep in mind that not all components have the same number of data points, nor do all model sources have the same assumed error structure.

5.8.2 Sensitivity analyses

Results for sensitivity model S1, which was configured exactly the same as the base model with the exception that indices were weighted by their inverse CV, were very similar to the base model (Table 5.5). For sensitivity model run S2, where assessments were run separately for a Gulf of Mexico and an Atlantic stock, only the Gulf of Mexico model converged. Results for the Gulf of Mexico stock support the base case results, in that the Gulf stock was also not estimated to be overfished, nor was overfishing occurring. MSY for the Gulf stock was 860,000 kg, or approximately 71% of the base model MSY estimate (single stock), while the estimate of virgin pup production (1.91 million pups) was about 61% of the base case model. Sensitivity model S3, where 4 additional sensitivity indices were inputted to the model, did not converge. Sensitivity model S4, with the fall SEAMAP index split, gave results that were very similar to the base model.

The estimated stock status for the base model and all converged sensitivity models is plotted in Figure 5.17. In addition, stock status estimates from the two production models (Bayesian Surplus Production and WinBUGS) and the result from the 2002 assessment are plotted. All results fall in the quadrant where $SSF_{2005}/SSF_{MSY}>1$ and $F_{2005}/F_{MSY}<1$, indicating that the stock is neither overfished nor is overfishing occurring.

5.9 Projections

As the base model results indicate that the stock status is not overfished and that no overfishing is taking place, no projections were made.

5.10 Discussions

While the estimated status of the Atlantic sharpnose stock is good, the selectivity pattern that indicates the highest selectivity occurring on immature or not fully mature age classes is a trend that could adversely the stock in the future. It is noted that much of the landings on smaller (younger) sharks comes in the form of bycatch in the shrimp fishery, and it is uncertain what level of effort to expect from that fleet in the future. Notwithstanding the shrimp bycatch, small sharpnose sharks are also caught by the recreational sector and the commercial gillnet fleet (SEDAR13-AW-02).

5.11 References

Cortés, E. 2002. Stock assessment of small coastal sharks in the U.S. Atlantic and Gulf of Mexico. Sustainable Fisheries Division Contribution SFD-01/02-152.

Otter Research Ltd. 2001. An introduction to AD MODEL BUILDER Version 6.0.2. Box 2040, Sidney, B. C. V8L 3S3, Canada.

Porch, C. E. 2002. A preliminary assessment of Atlantic white marlin (*Tetrapturus albidus*) using a state-space implementation of an age-structured model. SCRS/02/68 23pp.

Siegfried, K. I., E. Cortés, and E. Brooks. 2007. Determining selectivities for small coastal shark species for assessment purposes. SEDAR13-AW-02.

Table 5.1. Catches of **Atlantic sharpnose shark** by fleet, as updated by the AW. Values in italics were reconstructed or otherwise modified from the DW.

Year	Com-BLL	Com-GN	Com-Line	BLL-Discards	Recreational	Shrimp Bycatch
1950	*0*	*0*	*0*	*0*	*12,114*	*199,157*
1951	*0*	*0*	*12*	*0*	*13,314*	*255,841*
1952	*0*	*0*	*24*	*0*	*14,514*	*258,937*
1953	*0*	*0*	*36*	*0*	*15,714*	*297,766*
1954	*0*	*0*	*48*	*0*	*16,914*	*307,492*
1955	*0*	*0*	*61*	*0*	*18,114*	*278,697*
1956	*0*	*0*	*73*	*0*	*19,314*	*253,339*
1957	*0*	*0*	*85*	*0*	*20,514*	*227,780*
1958	*0*	*0*	*97*	*0*	*21,714*	*226,216*
1959	*0*	*0*	*109*	*0*	*22,914*	*253,769*
1960	*0*	*0*	*121*	*0*	*24,114*	*271,849*
1961	*0*	*0*	*133*	*0*	*24,815*	*136,426*
1962	*0*	*0*	*145*	*0*	*25,517*	*178,861*
1963	*0*	*0*	*157*	*0*	*26,218*	*269,133*
1964	*0*	*0*	*169*	*0*	*26,920*	*240,757*
1965	*0*	*0*	*182*	*0*	*27,621*	*258,877*
1966	*0*	*0*	*194*	*0*	*28,322*	*244,276*
1967	*0*	*0*	*206*	*0*	*29,024*	*299,894*
1968	*0*	*0*	*218*	*0*	*29,725*	*273,578*
1969	*0*	*0*	*230*	*0*	*30,427*	*286,401*
1970	*0*	*0*	*242*	*0*	*31,128*	*315,416*
1971	*0*	*0*	*254*	*0*	*34,310*	*323,214*
1972	*0*	*0*	*266*	*0*	*34,613*	546,849
1973	*0*	*0*	*278*	*0*	*34,916*	115,836
1974	*0*	*0*	*291*	*0*	*35,220*	208,340
1975	*0*	*0*	*303*	*0*	*35,523*	216,843
1976	*0*	*0*	*315*	*0*	*35,827*	159,043
1977	*0*	*0*	*327*	*0*	*36,130*	560,188
1978	*0*	*0*	*339*	*0*	*36,434*	651,041
1979	*0*	*0*	*351*	*0*	*36,737*	530,051
1980	*50*	*0*	*363*	*39*	41,970	852,586
1981	*75*	*0*	*375*	*58*	43,490	*424,066*
1982	*112*	*0*	*387*	*87*	40,656	235,138
1983	*168*	*0*	*399*	*130*	50,170	386,130
1984	*250*	*0*	*412*	*194*	37,539	217,712
1985	*373*	*0*	*424*	*289*	37,994	330,027
1986	*556*	*0*	*436*	*432*	45,392	228,189
1987	*830*	*726*	*448*	*644*	46,792	639,555
1988	*1,238*	*1,452*	*460*	*961*	103,375	362,917
1989	*1,847*	*2,178*	*472*	*1,433*	65,058	304,957
1990	*2,755*	*2,904*	*484*	*2,138*	45,233	342,124
1991	*4,110*	*3,630*	*496*	*3,190*	134,905	518,206
1992	*6,132*	*4,355*	*508*	*4,758*	85,972	968,330
1993	*9,148*	*5,081*	*521*	*7,099*	67,719	433,492

1994	*13,647*	*5,807*	*533*	*10,590*	101,774	259,349
1995	20,359	6,533	545	15,799	128,478	638,341
1996	12,074	35,721	1,318	9,369	73,114	503,193
1997	6,925	70,619	854	5,374	67,675	329,038
1998	6,580	64,506	1,794	5,106	83,748	512,281
1999	5,248	69,727	1,576	4,072	69,153	311,118
2000	3,951	35,610	1,145	3,066	130,727	539,085
2001	4,787	53,890	1,190	3,715	131,912	318,995
2002	11,635	59,098	819	9,029	88,297	639,044
2003	19,783	*40,159*	1,469	15,352	85,299	295,059
2004	25,639	47,693	644	19,896	67,870	173,326
2005	24,876	80,539	1,159	19,304	80,761	325,764

Table 5.2a. Base indices available for use in the 2006/2007 **Atlantic sharpnose shark** assessment. Selectivity series indicated in last row (see Figure 5.4).

Year	PC-LL	PC-GN.a	PC-GN.j	GNOP	BLLOP	SEAMAP-SA	Texas	VA-LL	NMFS-LL SE	SC-GN	SCDNR	SEAMAP-GOM ES	SEAMAP GOM-EF	UNC	MML-GN.a	MML-GN.j
1972	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0.424	-1	-1	-1
1973	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0.455	0.861	-1	-1
1974	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1.380	0.313	-1	-1
1975	-1	-1	-1	-1	-1	-1	1.7	-1	-1	-1	-1	-1	1.193	0.653	-1	-1
1976	-1	-1	-1	-1	-1	-1	0.9	0.036	-1	-1	-1	-1	1.296	0.372	-1	-1
1977	-1	-1	-1	-1	-1	-1	0.8	1.125	-1	-1	-1	-1	0.710	0.739	-1	-1
1978	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0.661	1.366	-1	-1
1979	-1	-1	-1	-1	-1	-1	1.6	-1	-1	-1	-1	-1	0.764	1.166	-1	-1
1980	-1	-1	-1	-1	-1	-1	0.5	3.406	-1	-1	-1	-1	1.263	1.139	-1	-1
1981	-1	-1	-1	-1	-1	-1	0.4	3.703	-1	-1	-1	-1	0.836	0.594	-1	-1
1982	-1	-1	-1	-1	-1	-1	0.3	-1	-1	-1	-1	0.855	0.896	0.34	-1	-1
1983	-1	-1	-1	-1	-1	-1	0.7	3.114	-1	-1	-1	3.329	0.776	1.353	-1	-1
1984	-1	-1	-1	-1	-1	-1	2.1	-1	-1	-1	-1	1.118	0.623	0.922	-1	-1
1985	-1	-1	-1	-1	-1	-1	1.7	-1	-1	-1	-1	1.550	0.941	1.322	-1	-1
1986	-1	-1	-1	-1	-1	-1	4	-1	-1	-1	-1	0.862	0.533	1.150	-1	-1
1987	-1	-1	-1	-1	-1	-1	0.7	5.103	-1	-1	-1	0.705	0.781	1.735	-1	-1
1988	-1	-1	-1	-1	-1	-1	3.4	1.765	-1	-1	-1	0.649	0.443	2.299	-1	-1
1989	-1	-1	-1	-1	-1	-1	1.4	0.946	-1	-1	-1	0.669	0.324	1.265	-1	-1
1990	-1	-1	-1	-1	-1	2.983	1	2.706	-1	-1	-1	0.189	0.474	1.750	-1	-1
1991	-1	-1	-1	-1	-1	3.163	1.7	3.147	-1	-1	-1	0.810	0.244	3.526	-1	-1
1992	-1	-1	-1	-1	-1	2.908	0.9	2.478	-1	-1	-1	0.587	0.237	6.286	-1	-1
1993	0.481	-1	-1	63.769	-1	2.24	0.8	3.154	-1	-1	-1	0.658	0.417	3.141	-1	-1
1994	0.136	-1	-1	520.751	10.534	1.623	1.1	-1	-1	-1	-1	0.232	0.500	2.164	-1	-1
1995	0.301	-1	-1	355.17	118.473	3.052	0.7	2.715	1.982	-1	-1	1.066	0.340	5.698	2.868	0.07
1996	0.951	0.339	1.166	-1	107.619	1.860	3	3.201	1.820	-1	-1	1.057	0.565	3.101	9.14	0.305
1997	0.531	0.679	1.401	-1	157.065	3.855	1.1	2.048	2.426	-1	-1	0.537	0.386	2.898	3.21	2.971
1998	0.38	0.408	1.039	-1	245.823	2.679	1	3.247	-1	8.28	0.154	0.500	0.315	3.780	-1	-1
1999	1.16	0.361	1.514	165.327	760.861	2.734	3.2	6.057	0.627	9.923	0.090	0.484	0.406	2.865	6.522	0.423
2000	0.445	0.616	0.852	27.34	828.94	3.835	2.5	1.156	4.592	5.892	0.148	0.786	0.489	4.001	5.041	0.161

2001	-1	0.706	1.442	634.326	292.945	3.385	0.3	2.55	-1	6.140	0.230	0.351	0.288	-1	32.431	0.505
2002	-1	1.037	1.036	831.673	272.197	5.306	2.6	1.85	14.949	5.182	0.227	0.822	0.286	4.872	13.662	0.897
2003	-1	1.091	1.117	814.365	167.911	5.686	2.9	1.557	-1	14.621	0.195	0.410	0.404	6.899	35.56	0.254
2004	-1	0.659	0.667	278.853	133.011	3.851	2.2	1.833	14.6	3.570	0.075	0.219	0.199	6.449	18.35	0.078
2005	-1	-1	0.339	984.79	148.218	4.969	1.8	7.879	21.693	6.018	0.138	0.359	0.380h	8.917	-1	-1
Selectivity series																
	3	5	3	4	1	3	3	2	1	3	2	3	3	2	5	3

Table 5.2b. Sensitivity indices available for use in the 2006/2007 **Atlantic sharpnose shark** assessment. Selectivity series indicated in last row (see Figure 5.4).

	MS.GN - a	MS.GN - j	Gillnet Logs	NE Exp LL
1979	-1	-1	-1	0.713
1980	-1	-1	-1	-1
1981	-1	-1	-1	-1
1982	-1	-1	-1	-1
1983	-1	-1	-1	1.086
1984	-1	-1	-1	-1
1985	-1	-1	-1	0.115
1986	-1	-1	-1	0.861
1987	-1	-1	-1	-1
1988	-1	-1	-1	-1
1989	-1	-1	-1	0.109
1990	-1	-1	-1	-1
1991	-1	-1	-1	0.273
1992	-1	-1	-1	-1
1993	-1	-1	-1	-1
1994	-1	-1	-1	-1
1995	-1	-1	-1	-1
1996	-1	-1	-1	-1
1997	-1	-1	-1	-1
1998	-1	-1	0.016	-1
1999	-1	-1	0.023	-1
2000	-1	-1	0.018	-1
2001	1.412	0.717	0.017	-1
2002	-1	-1	0.013	-1
2003	0.385	0.153	0.015	-1
2004	0.460	0.109	0.016	-1
2005	0.414	0.199	0.030	-1
Selectivity series				
	5	3	4	2

Table 5.3. **Atlantic sharpnose shark** biological inputs for natural mortality (M), maturity at age, and pups per female at age. *Note that age 0 M is actually a survival rate for pups, not a natural mortality rate.

Age	M at age	Female Maturity	Pups per female
0	0.7*	0	0
1	0.36	0.01	2.05
2	0.34	0.28	2.05
3	0.33	0.92	2.05
4	0.31	1	2.05
5	0.31	1	2.05
6	0.30	1	2.05
7	0.29	1	2.05
8	0.27	1	2.05
9	0.27	1	2.05
10	0.26	1	2.05
11	0.25	1	2.05
12	0.24	1	2.05

Table 5.4. **Atlantic sharpnose shark** parameter specifications for vonBertalanffy length at age, length-weight parameters, pup survival, virgin recruitment, and the number of pups per female.

Parameter	Atlantic sharpnose
L_∞ (cm FL)	80.2
K	0.61
t0	-0.84
a (Kg/cm)	5.56E-06
b	3.074
Pup Survival	~ LN(0.7, CV=0.30)
Virgin Recruitment (R0)	[1.0E+3, 1.0E+10] no prior

Table 5.5. **Atlantic sharpnose shark** stock assessment results of the base case (Base Model, entries given in **bold** type) and sensitivity runs (S1 inverse CV weighting, S2 Gulf of Mexico Stock, and S4 split Fall SEAMAP). CVs of model estimates are given beside each model estimate. SSF is spawning stock fecundity (not spawning stock *biomass*) and is calculated as the sum of the number of mature females multiplied by the number of pups produced per mature female. Parameters N_{2005} and N_{MSY} are numbers in the population in 2005 and numbers at MSY, respectively, and are calculated mid-year.

	Base Model		S1 (Inverse CV weight)		S2 (Gulf of Mexico Stock)		S4 (split Fall SEAMAP)	
Parameter	**Estimate**	**CV**	Estimate	CV	Estimate	CV	Estimate	CV
SSF_{2005}/SSF_{MSY}	**1.49**	**0.45**	1.54	0.42	1.92	0.45	1.52	0.44
F_{2005}/F_{MSY}	**0.7**	**0.78**	0.66	0.76	0.35	0.78	0.71	0.78
N_{2005}/N_{MSY}	**1.35**	**--**	1.39	--	1.69	--	1.37	--
MSY	**1.27E+06**	**--**	1.32E+06	--	1.47E+06	--	1.24E+06	--
SPR_{MSY}	**0.59**	**0.11**	0.59	0.11	0.6	0.11	0.59	0.11
F_{MSY}	**0.19**	**--**	0.19	--	0.24	--	0.19	--
SSF_{MSY}	**4.59E+06**	**--**	4.77E+06	--	4.96E+06	--	4.43E+06	--
N_{MSY}	**4.62E+06**	**--**	4.80E+06	--	4.89E+06	--	4.47E+06	--
F_{2005}	**0.13**	**0.78**	0.12	0.76	0.08	0.78	0.13	0.78
SSF_{2005}	**6.81E+06**	**0.65**	7.35E+06	0.61	9.54E+06	0.65	6.72E+06	0.65
N_{2005}	**6.22E+06**	**--**	6.67E+06	--	8.27E+06	--	6.11E+06	--
SSF_{2005}/SSF_0	**0.56**	**0.32**	0.59	0.29	0.73	0.32	0.57	0.31
B_{2005}/B_0	**0.49**	**0.31**	0.5	0.27	0.61	0.31	0.49	0.29
R_0	**3.24E+06**	**0.35**	3.36E+06	0.35	3.50E+06	0.35	3.13E+06	0.36
Pup-survival	**0.76**	**0.28**	0.76	0.28	0.74	0.28	0.77	0.28
alpha	**2.85**	**--**	2.87	--	2.8	--	2.88	--
steepness	**0.42**	**--**	0.42	--	0.41	--	0.42	--

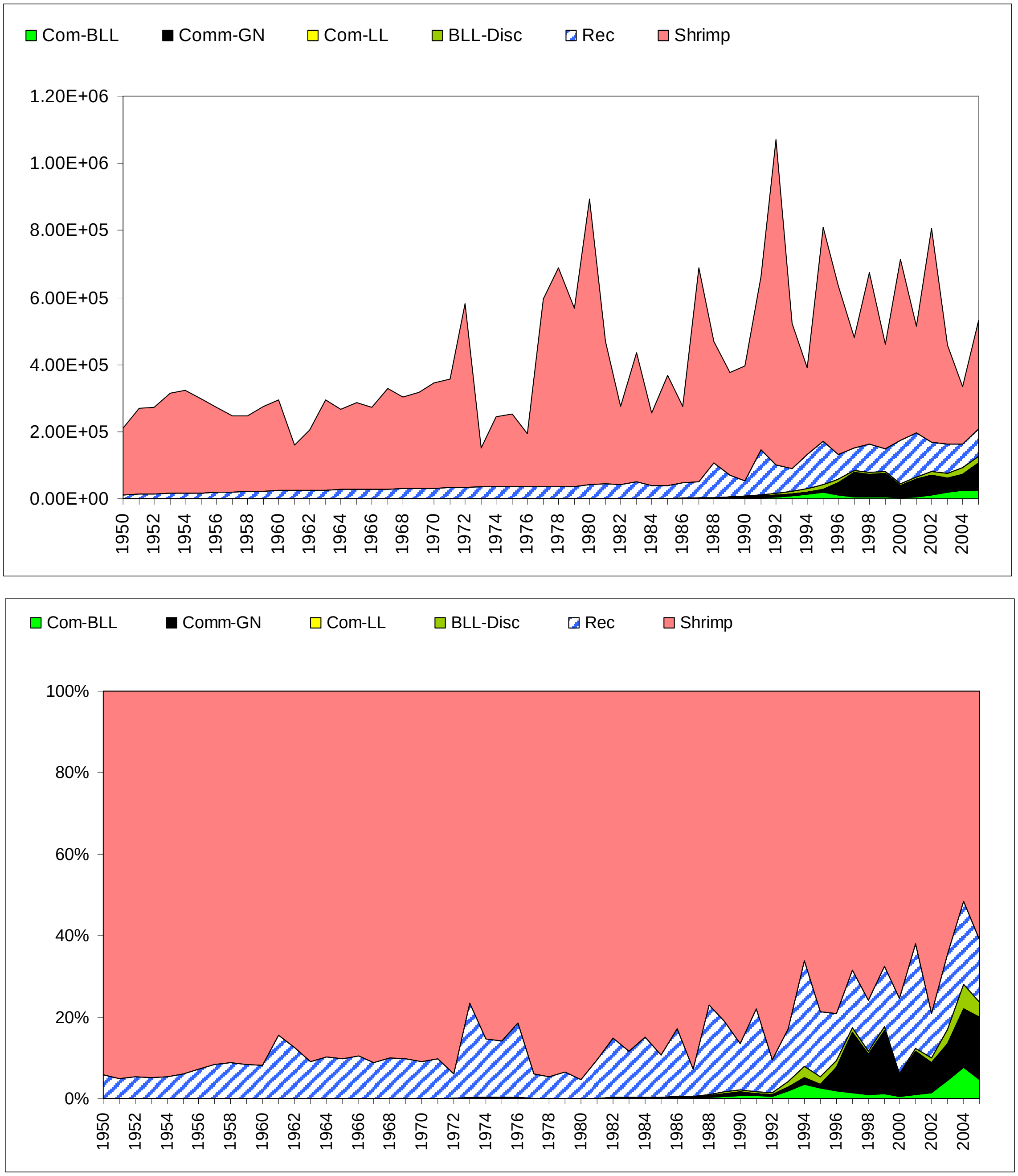


Figure 5.1. Catch of **Atlantic sharpnose shark** by fleet in numbers (top) and by proportion (bottom) from 1950-2005. Catches are the updated AW values.

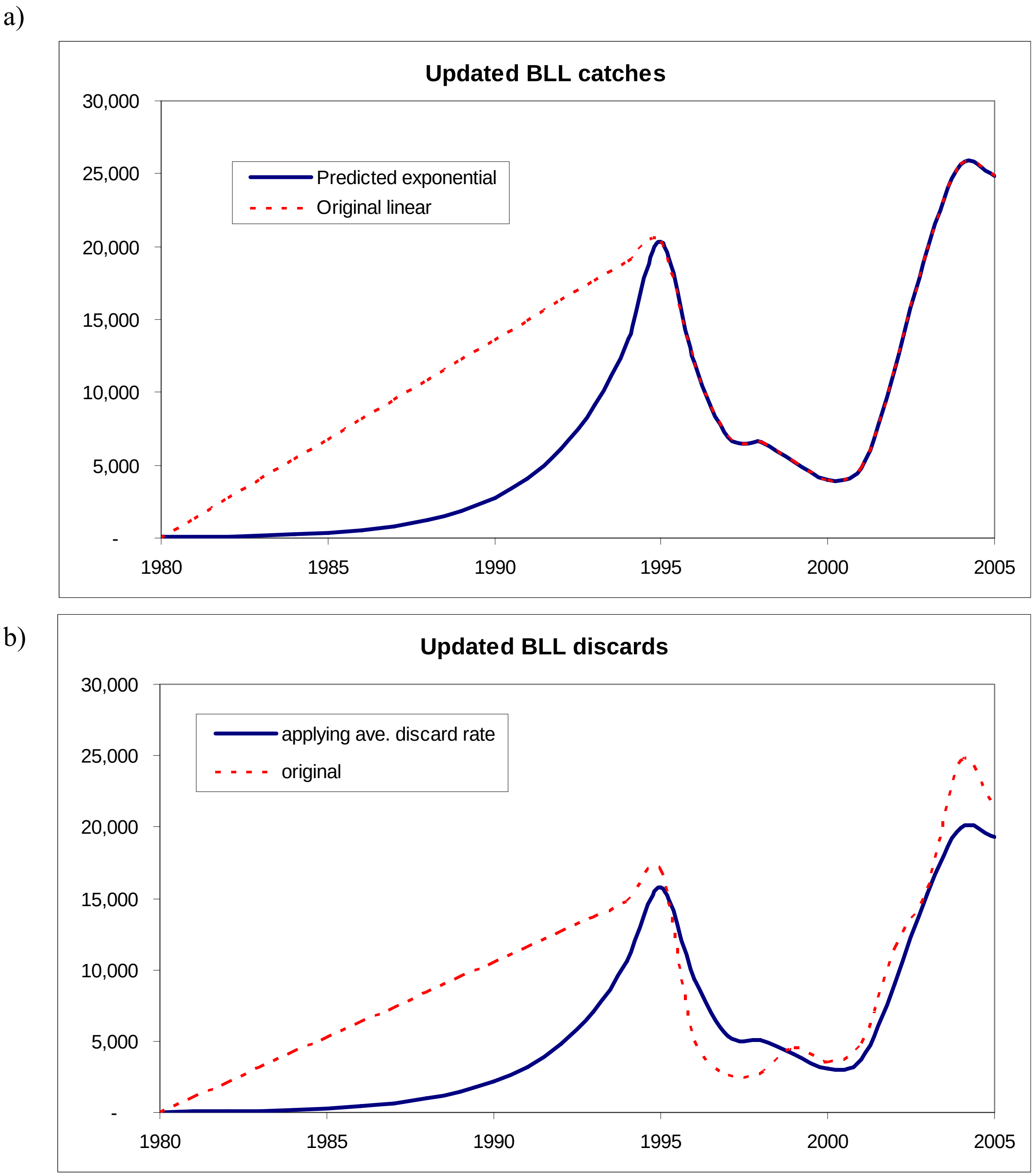
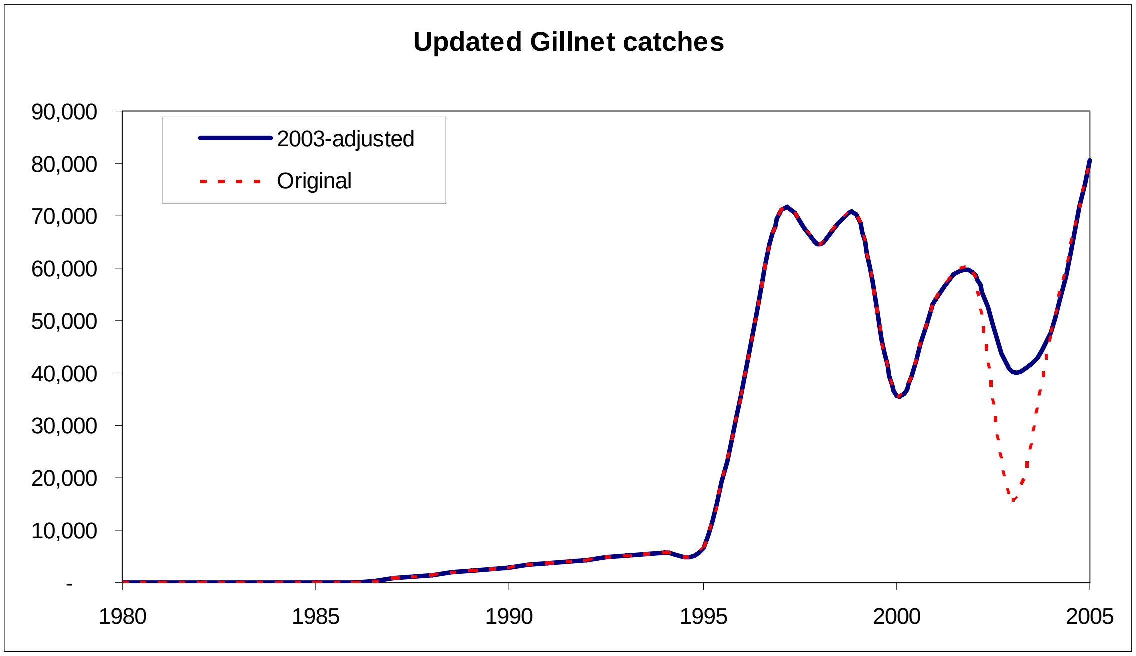


Figure 5.2. Series-specific updated catches for **Atlantic sharpnose shark** from the AW workshop for a) bottom long line; b) bottom long line discards; c) commercial hand line; d) commercial gill net; and e) shrimp bycatch.

c)



d)

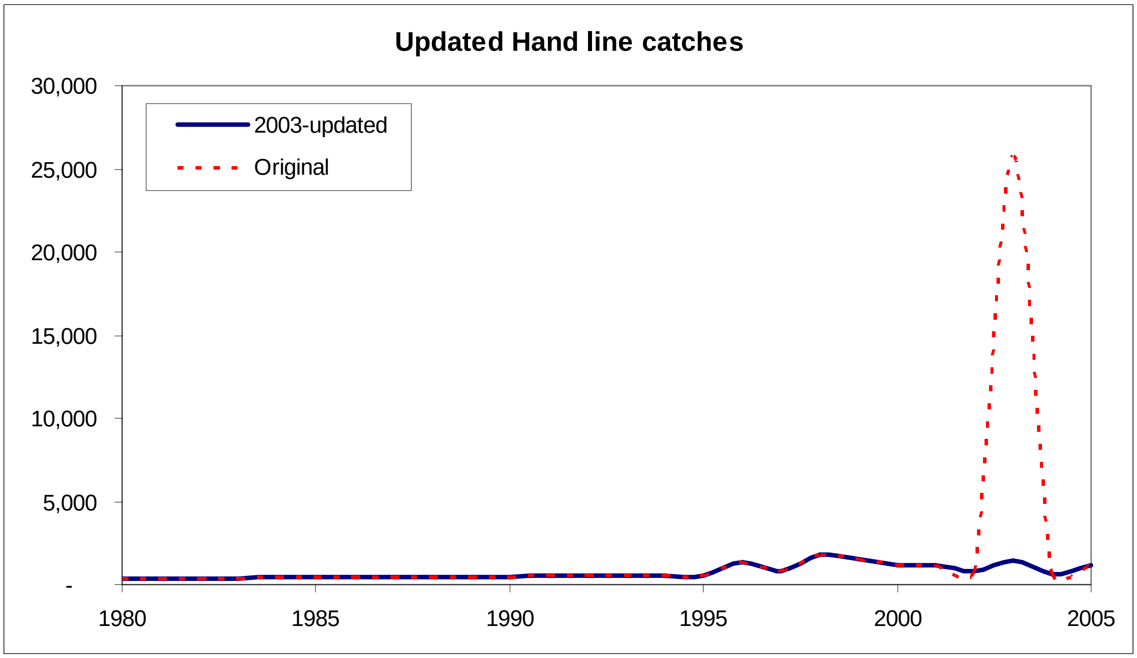


Figure 5.2 (cont.)

e)

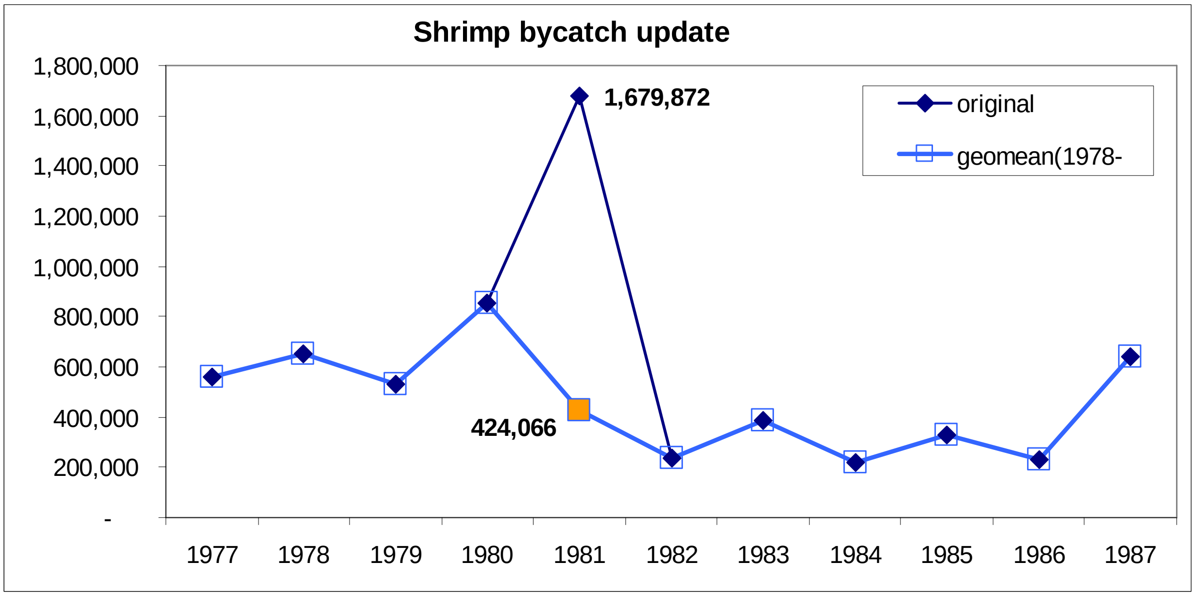


Figure 5.2 (cont.)

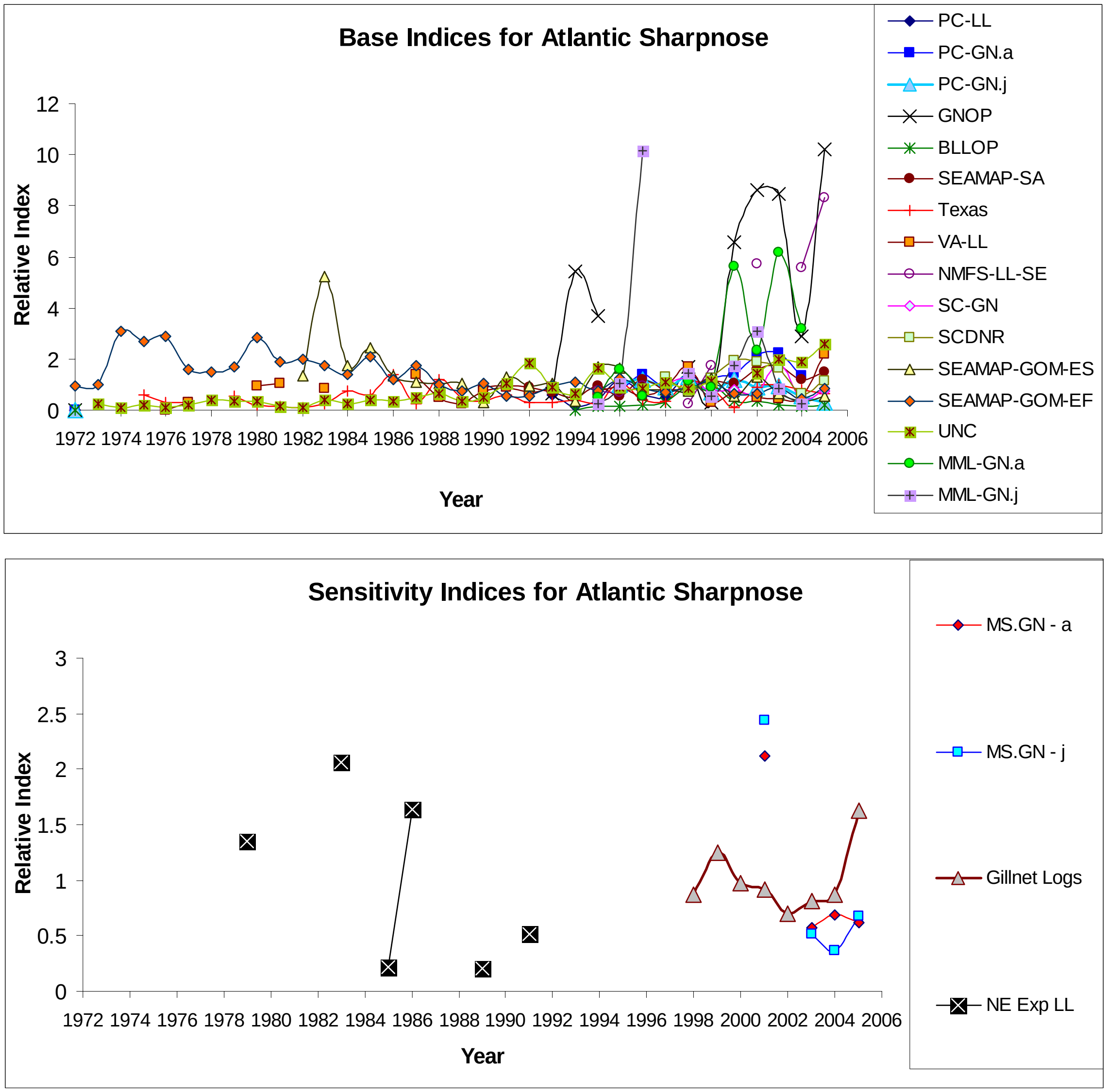


Figure 5.3. Indices for **Atlantic sharpnose shark**. The top panel shows the base indices, the bottom panel the sensitivity indices.

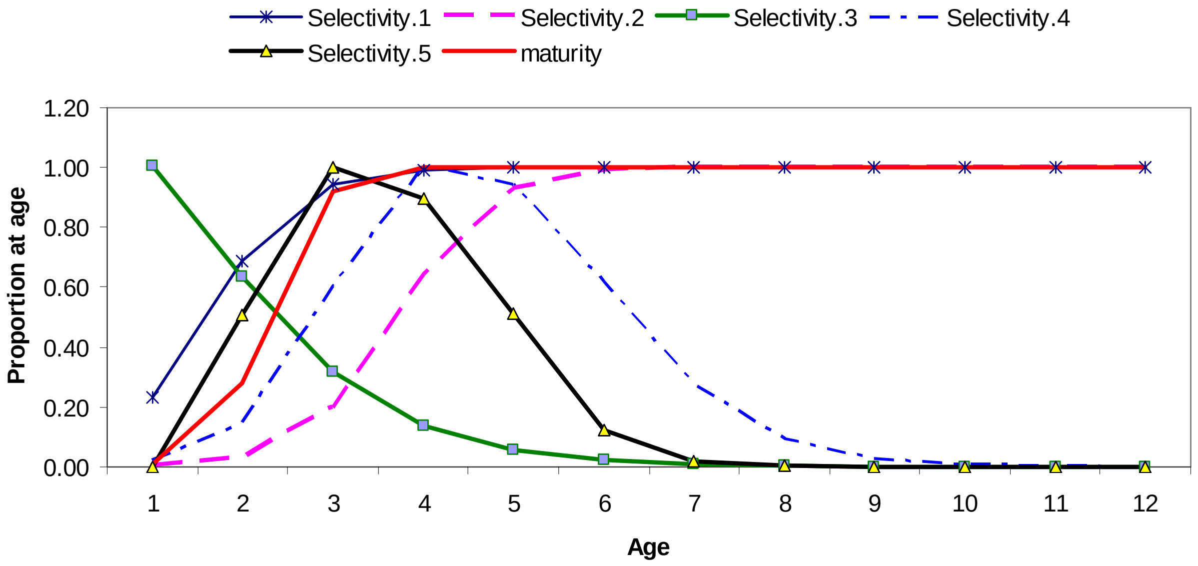


Figure 5.4. Selectivity at age and maturity at age (solid red line) for **Atlantic sharpnose shark**. The selectivity assigned to each index is given in the last row of the table of indices (Table 4.2).

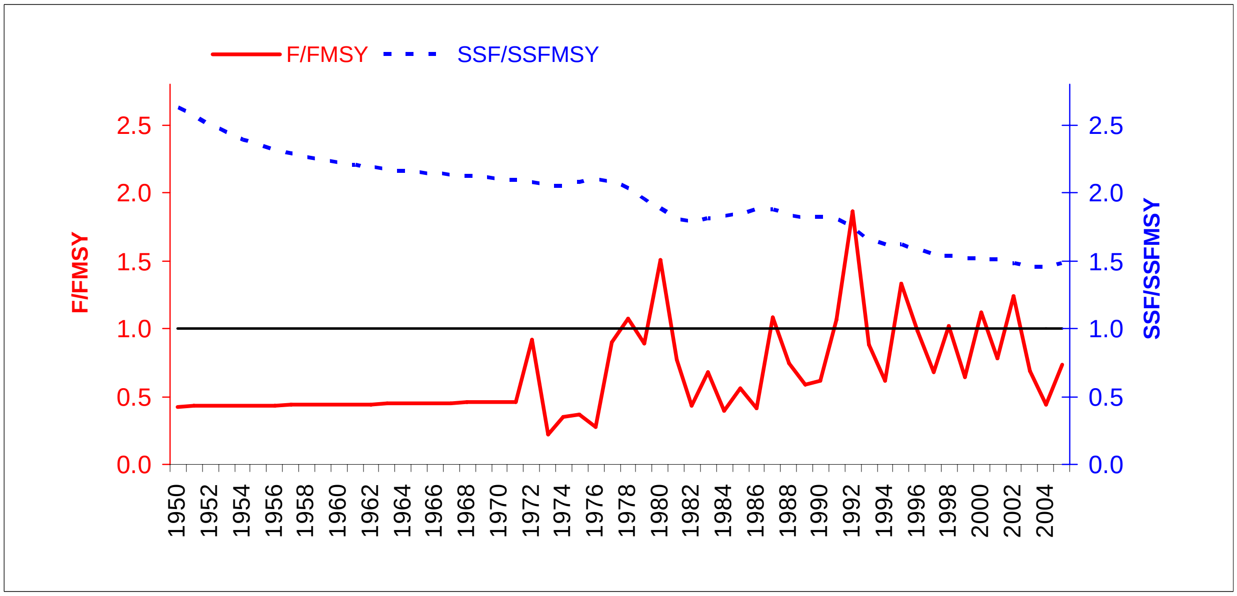


Figure 5.5. **Atlantic sharpnose shark** base model estimated relative fishing mortality (solid red) and spawning stock fecundity (dashed blue) for the base case with equal index weighting (top) and inverse CV weighting (bottom). The horizontal line at 1.0 is a reference line, such that $F/F_{MSY} > 1$ implies overfishing, while $B/B_{MSY} < 1$ implies an overfished stock.

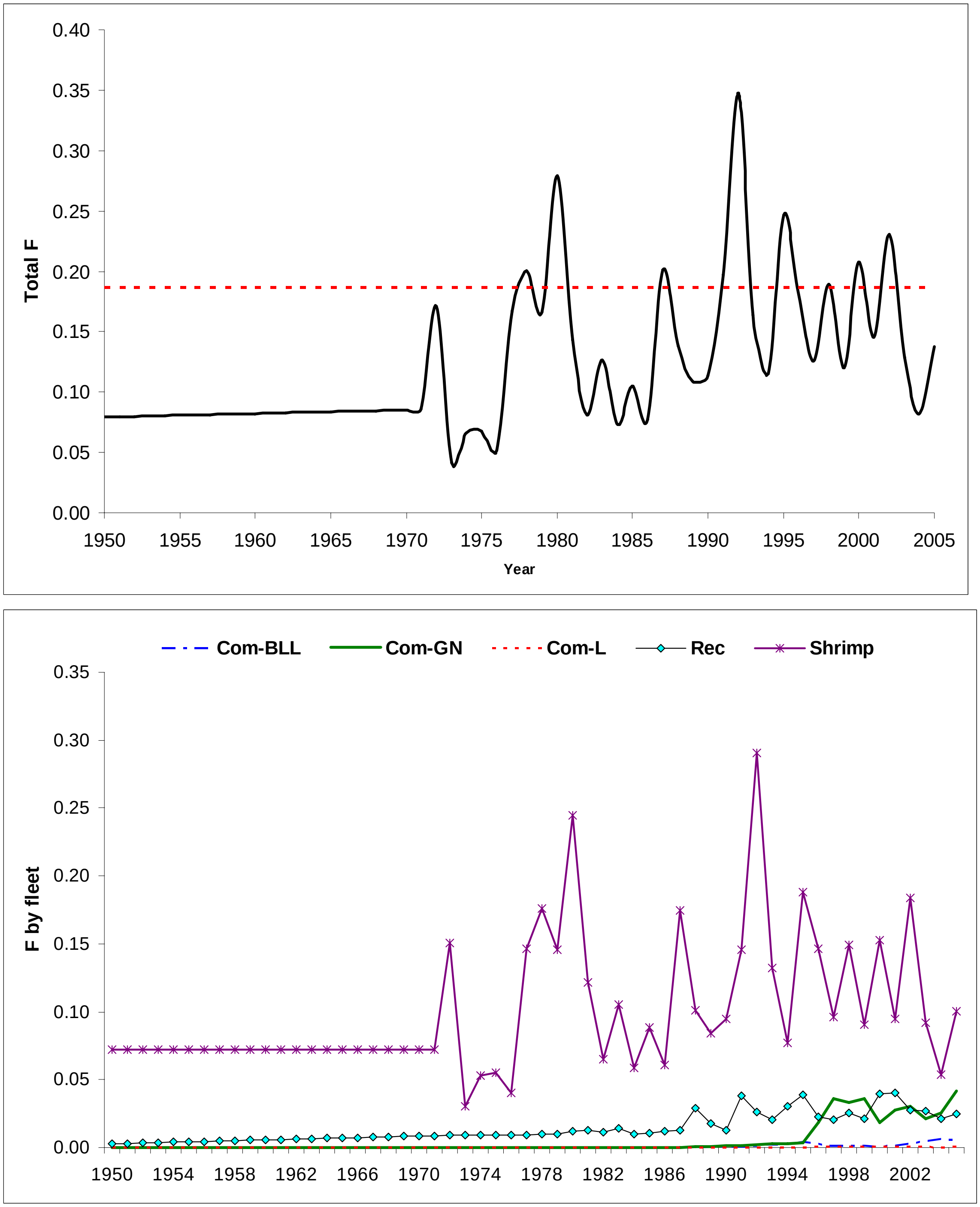


Figure 5.6. **Atlantic sharpnose shark** base model estimated total fishing mortality (solid black) and dashed reference line for F_{MSY} (top panel) and fishing mortality by fleet (bottom panel).

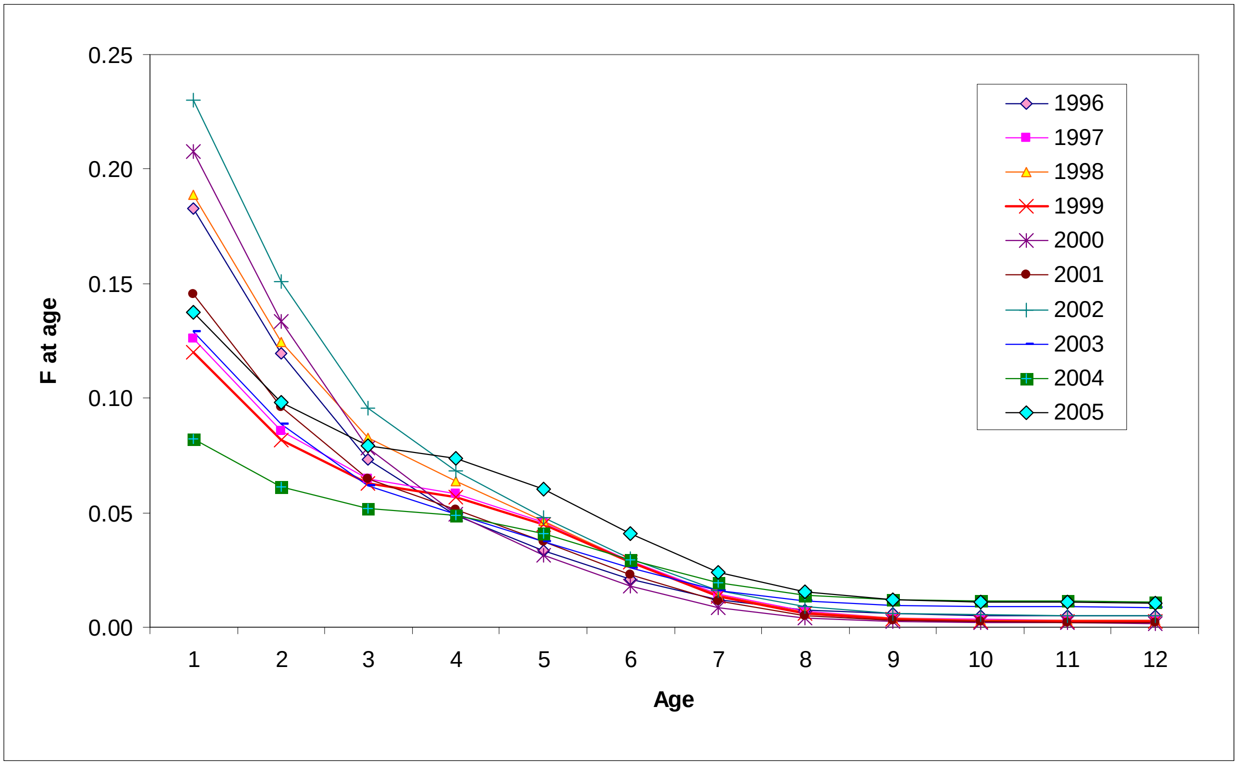
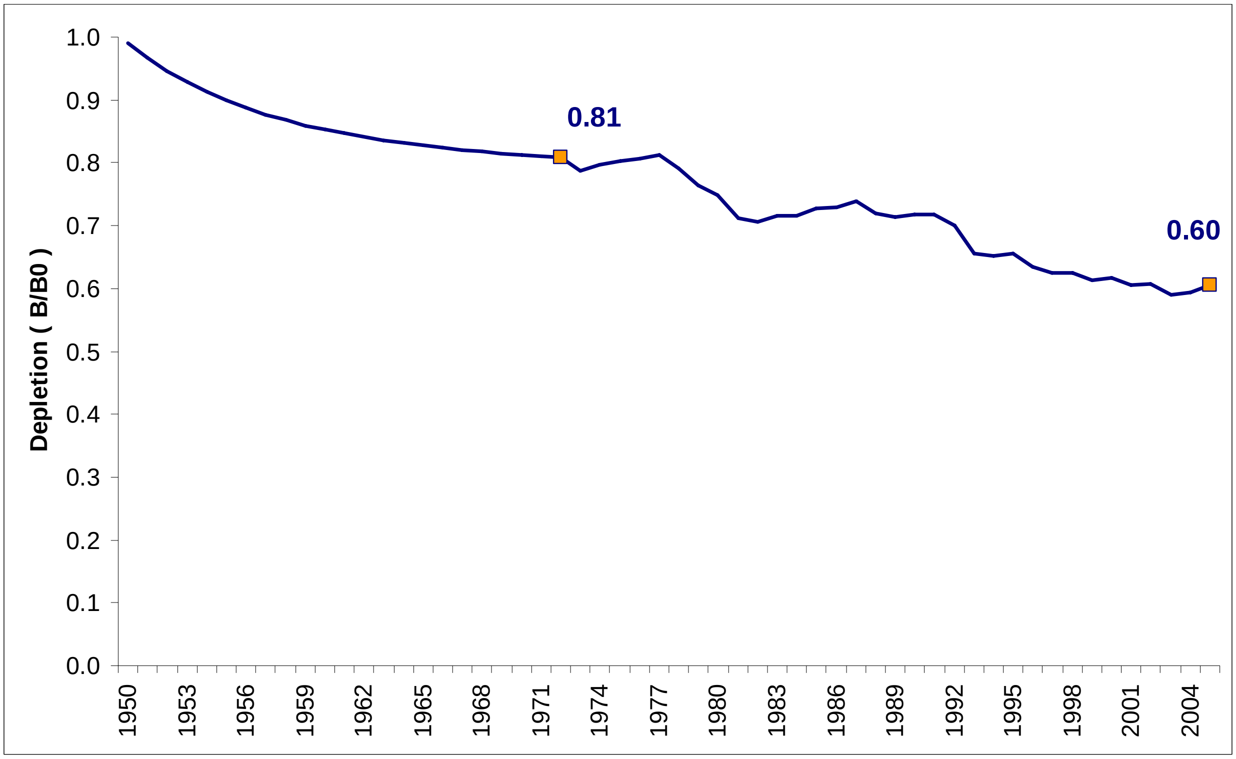


Figure 5.7. Base model estimated fishing mortality at age for **Atlantic sharpnose shark** for years 1996-2005.



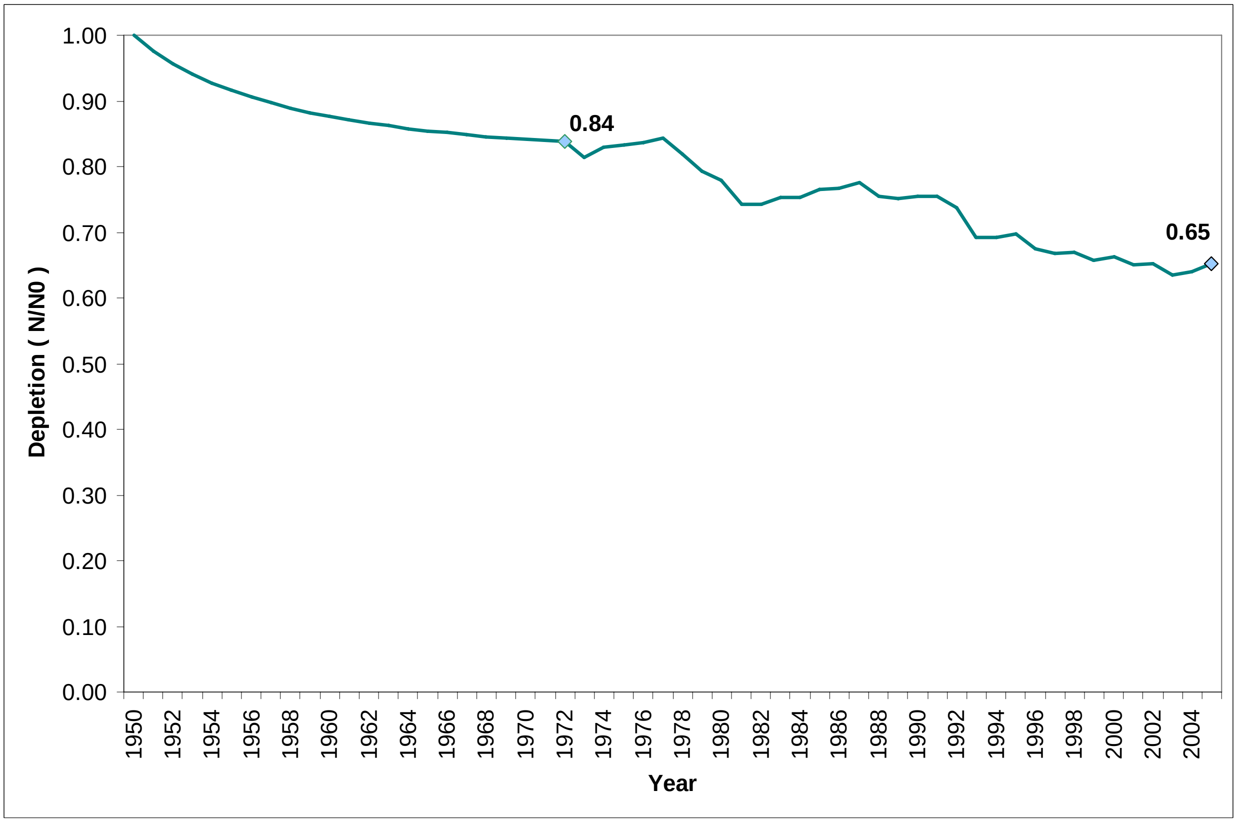


Figure 5.8. Base model estimated depletion of total biomass (top) and total number in the population (bottom) for **Atlantic sharpnose shark**. Labeled values correspond to the year 1972 (first year of 'modern period') and the final assessment year, 2005.

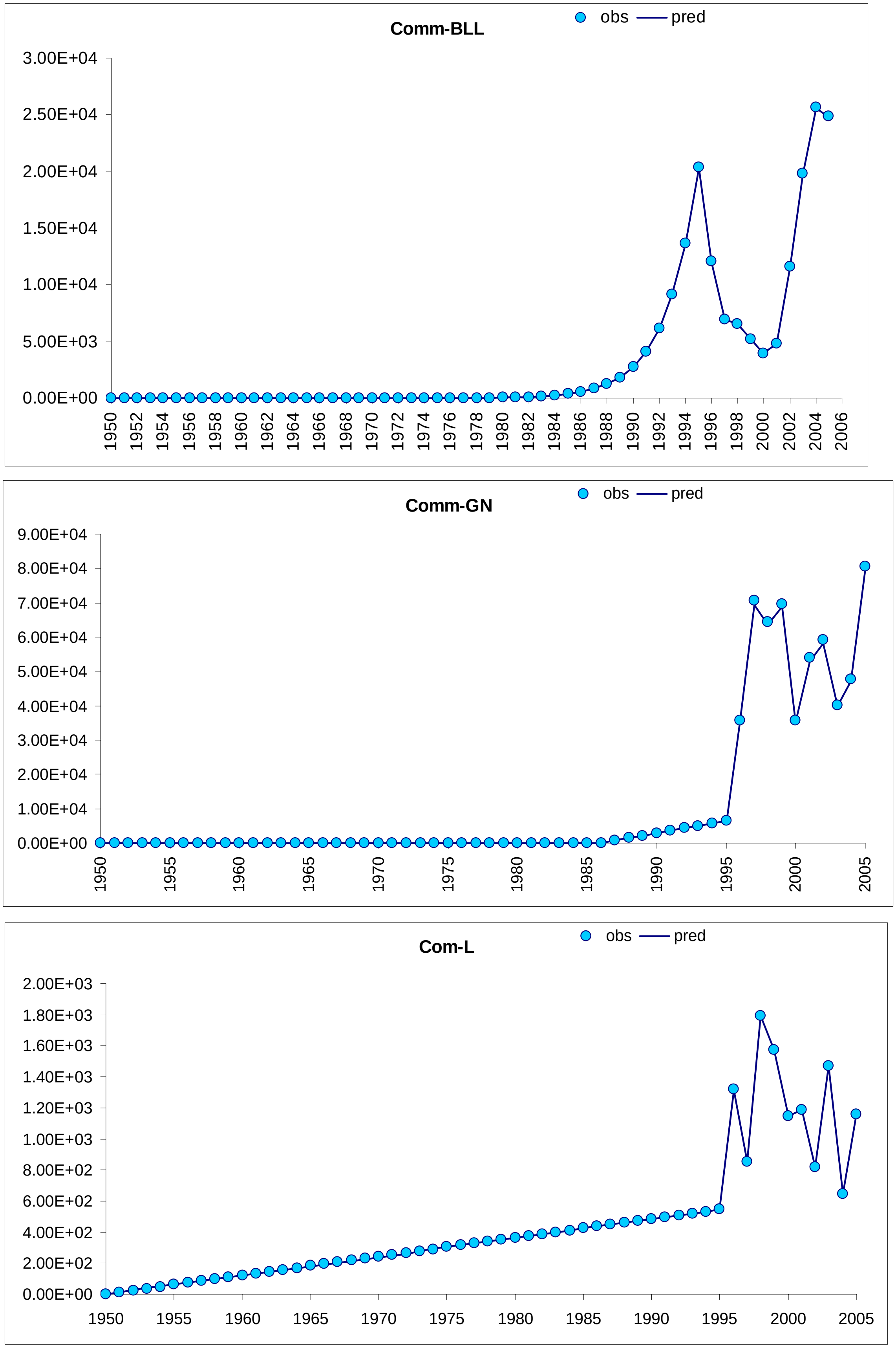
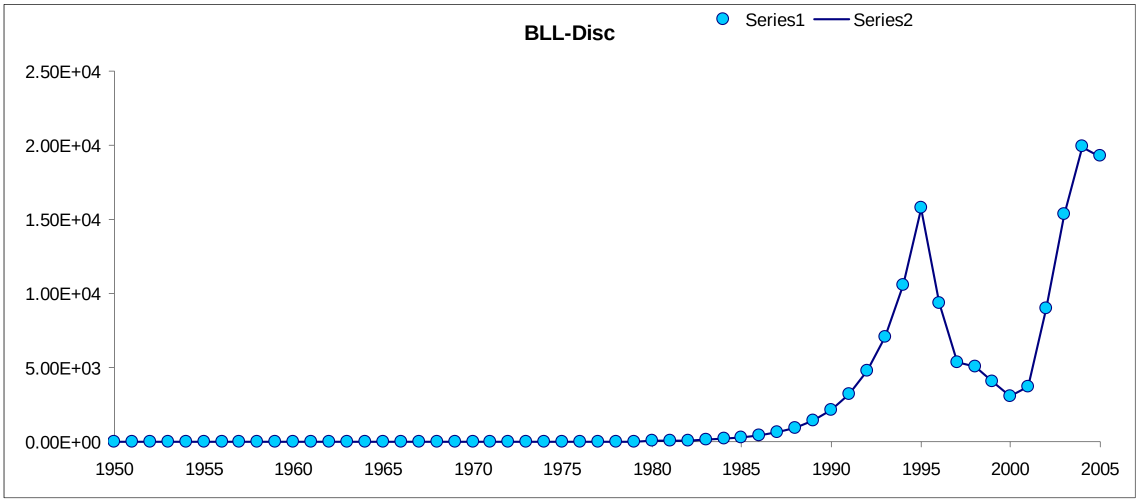
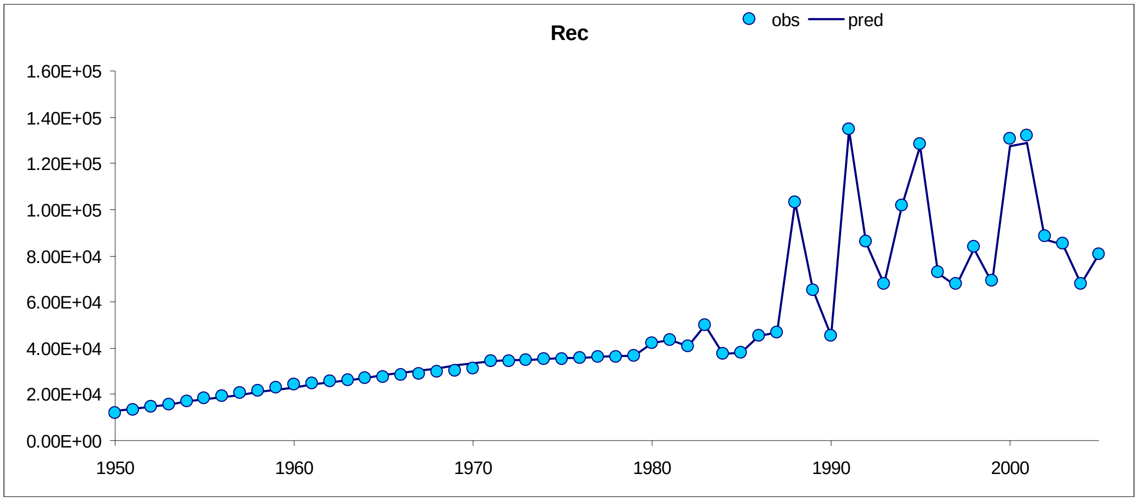


Figure 5.9. Base model fit to catch in number by fleet for **Atlantic sharpnose shark**.





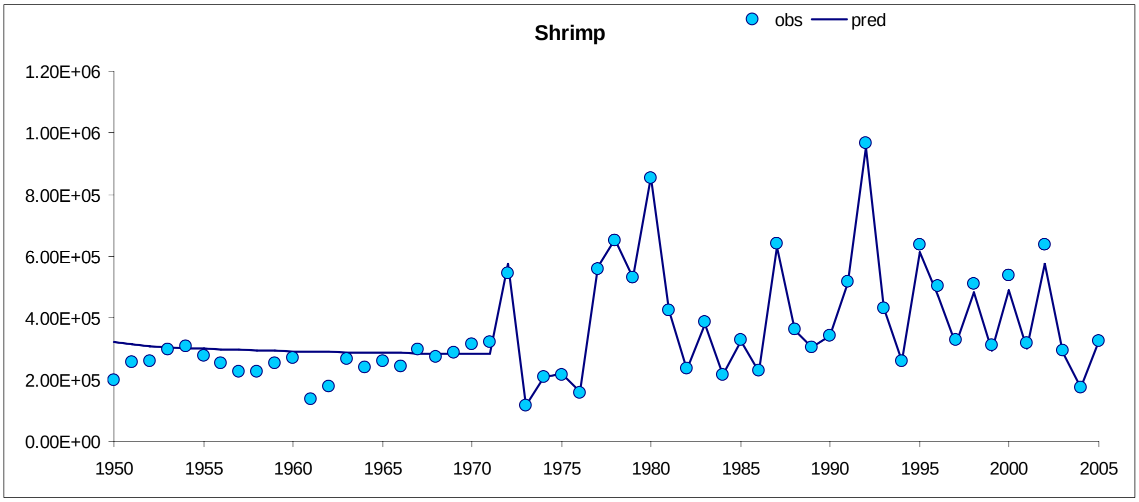


Figure 5.9 (cont.).

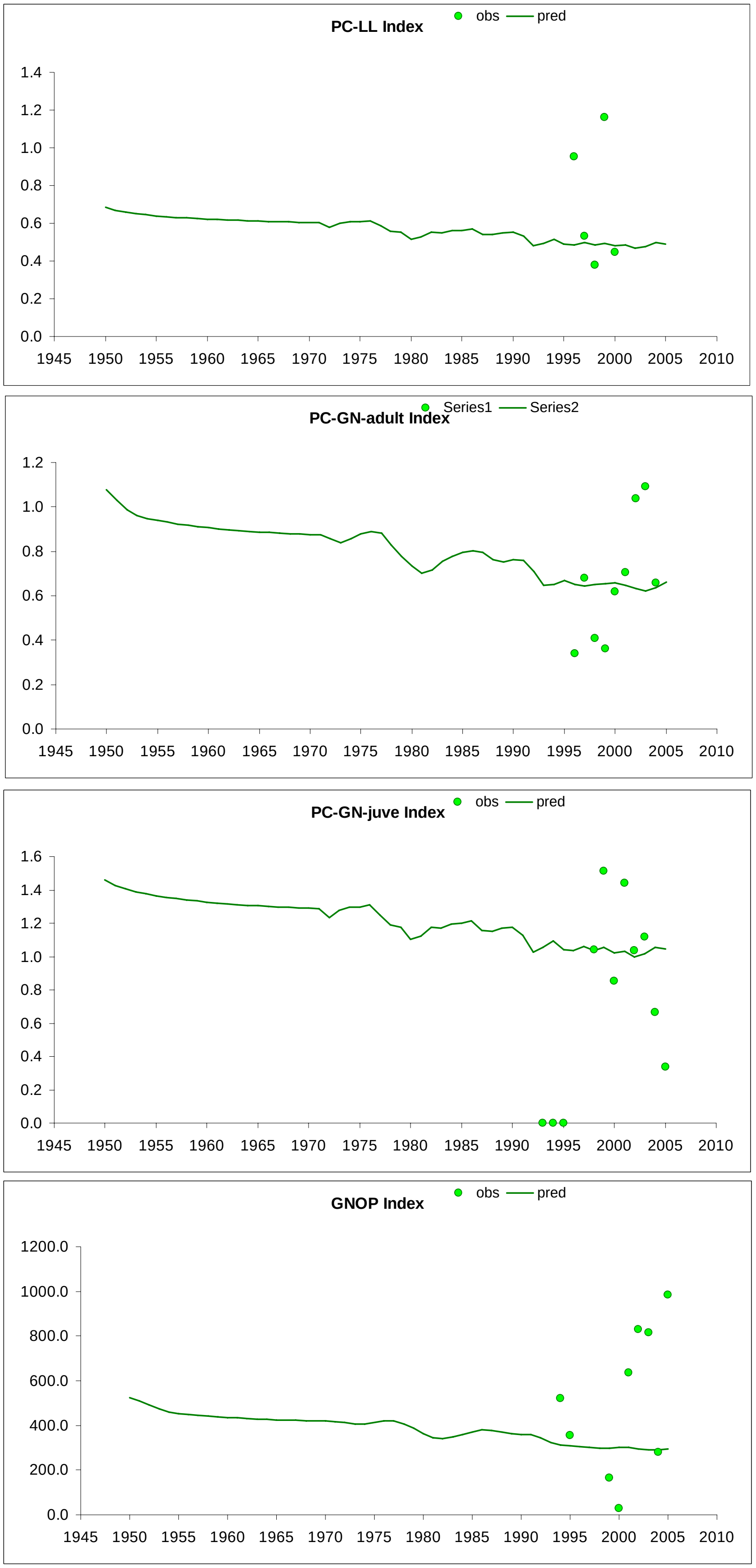


Figure 5.10. Base model estimated fits (solid line) to observed indices (circles) for **Atlantic sharpnose shark.**

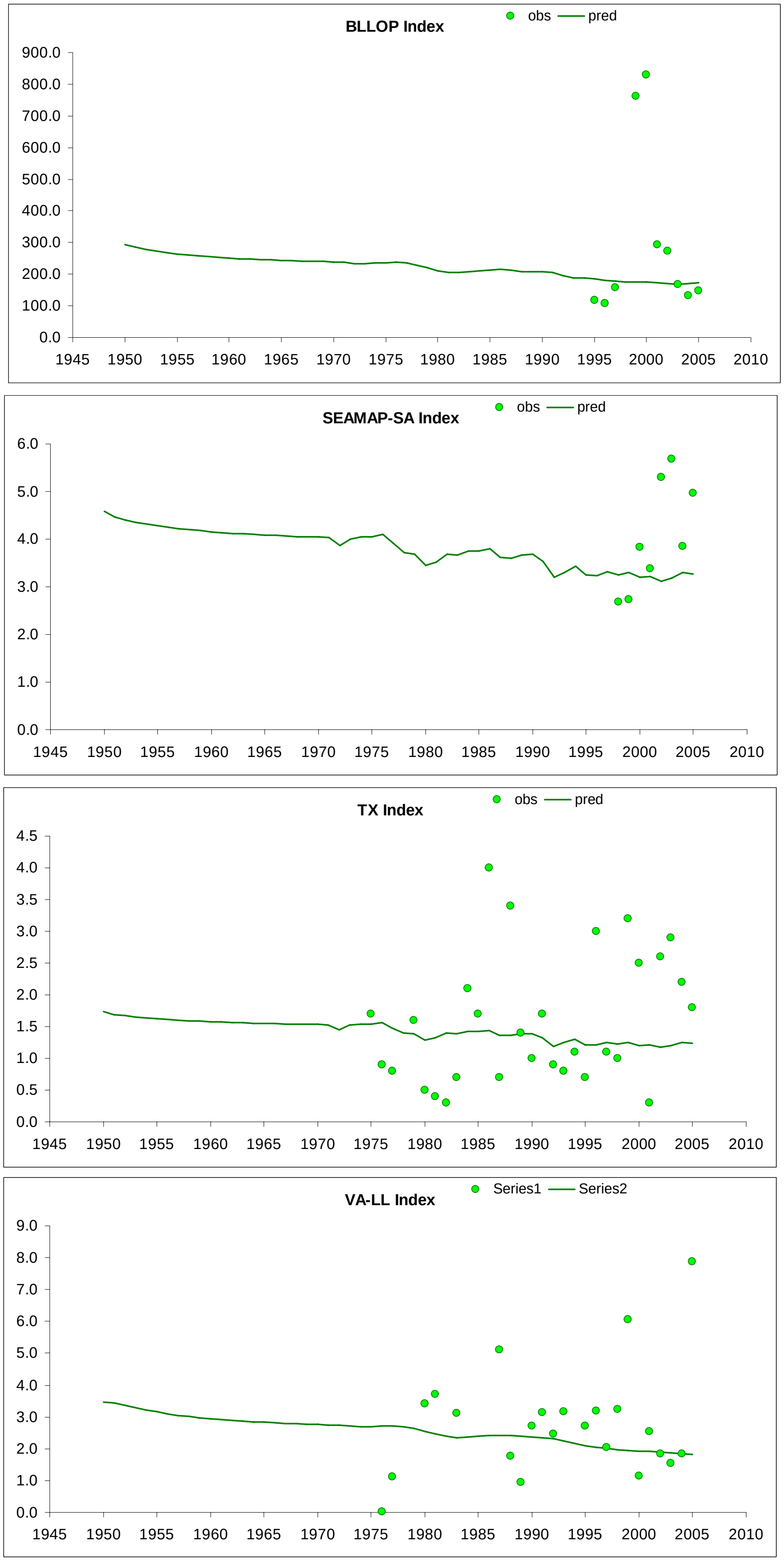
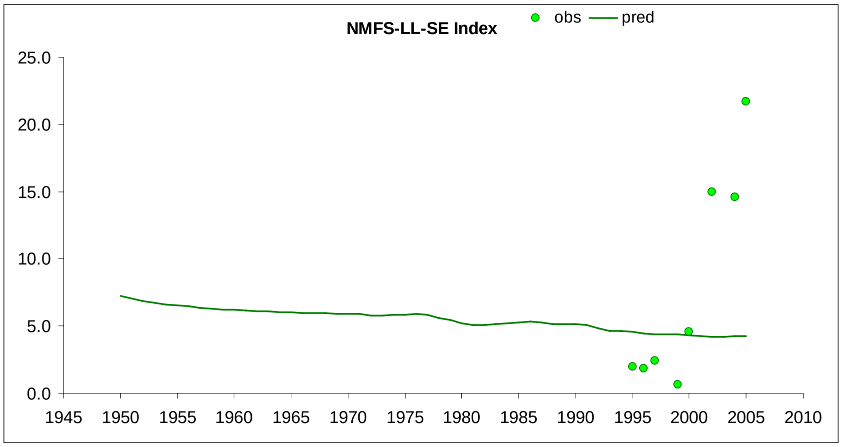
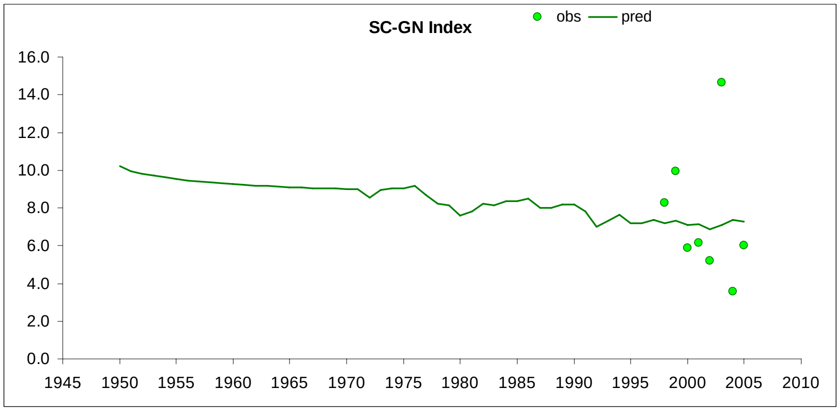
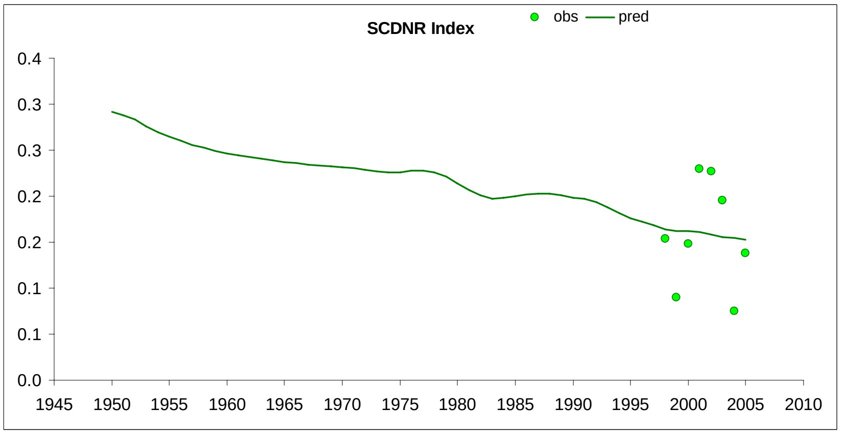


Figure 5.10. (cont).







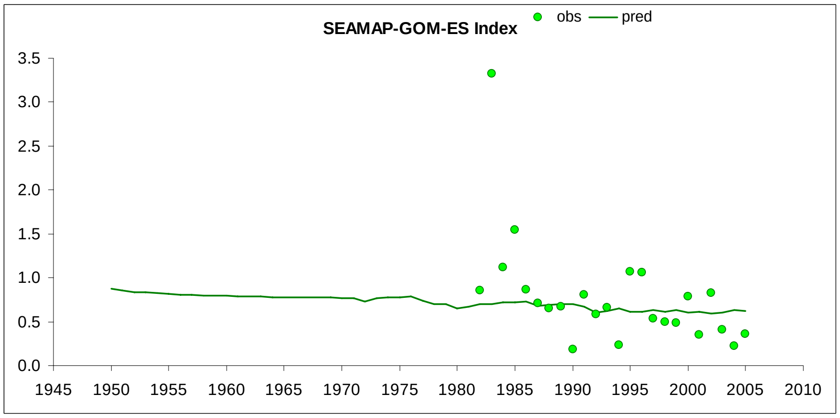
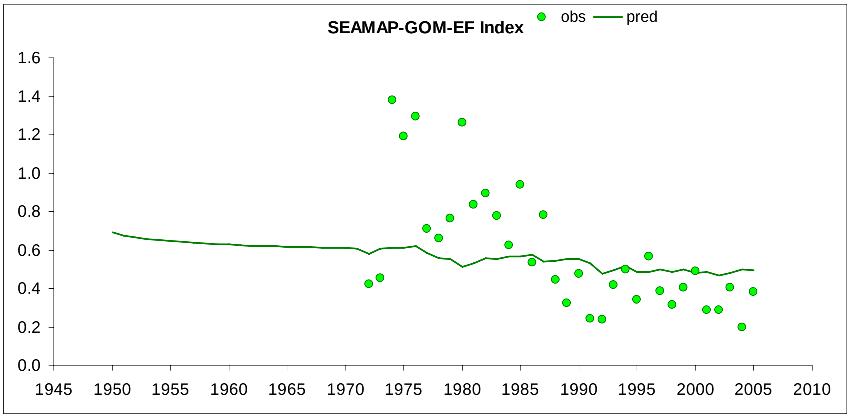
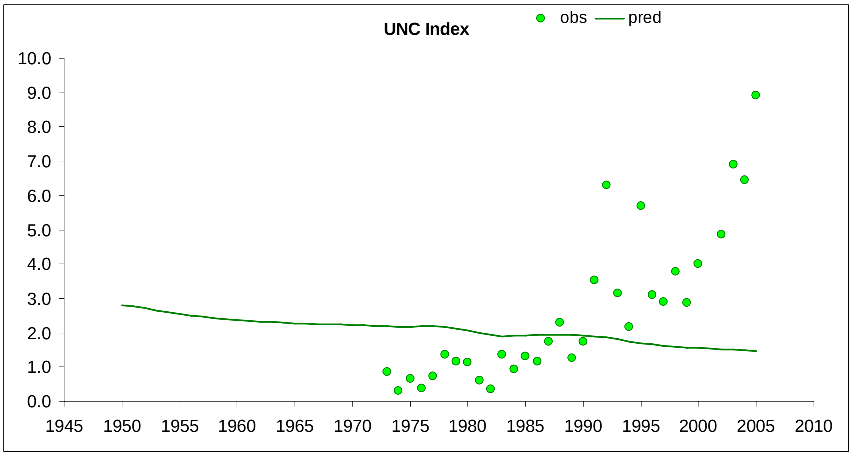
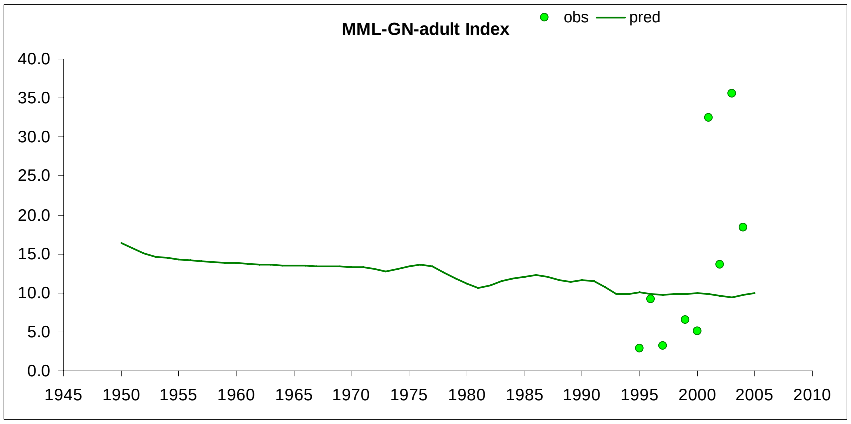


Figure 5.10. (cont).







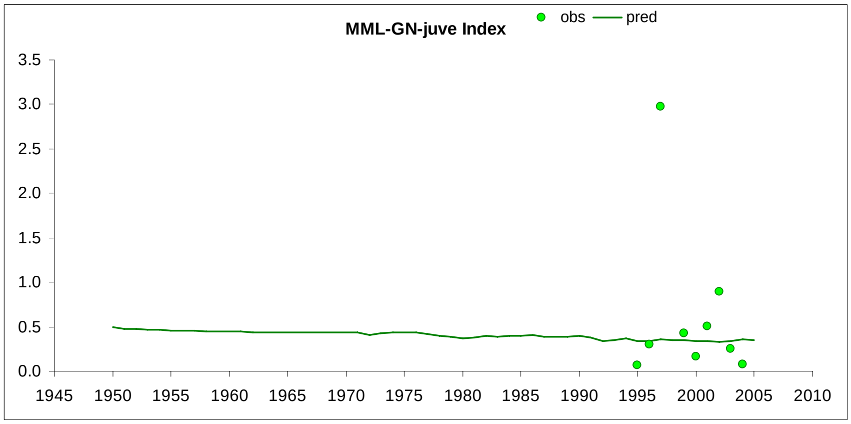


Figure 5.10. (cont).

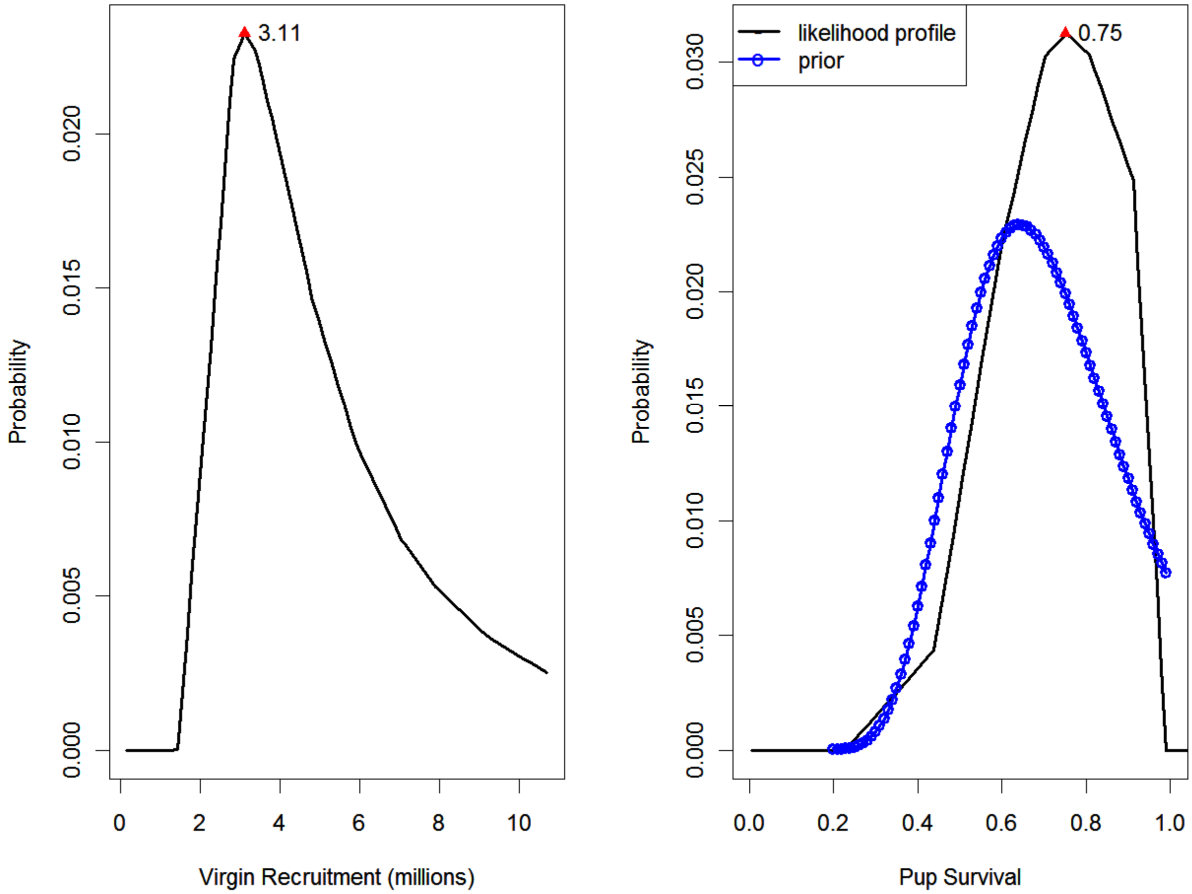


Figure 5.11. **Atlantic sharpnose shark** base model estimated likelihood profile for virgin recruitment (R_0, in millions) and pup-survival (prior plotted in blue with open circles). The mode of the posterior is indicated with a solid triangle, and the value is labeled.

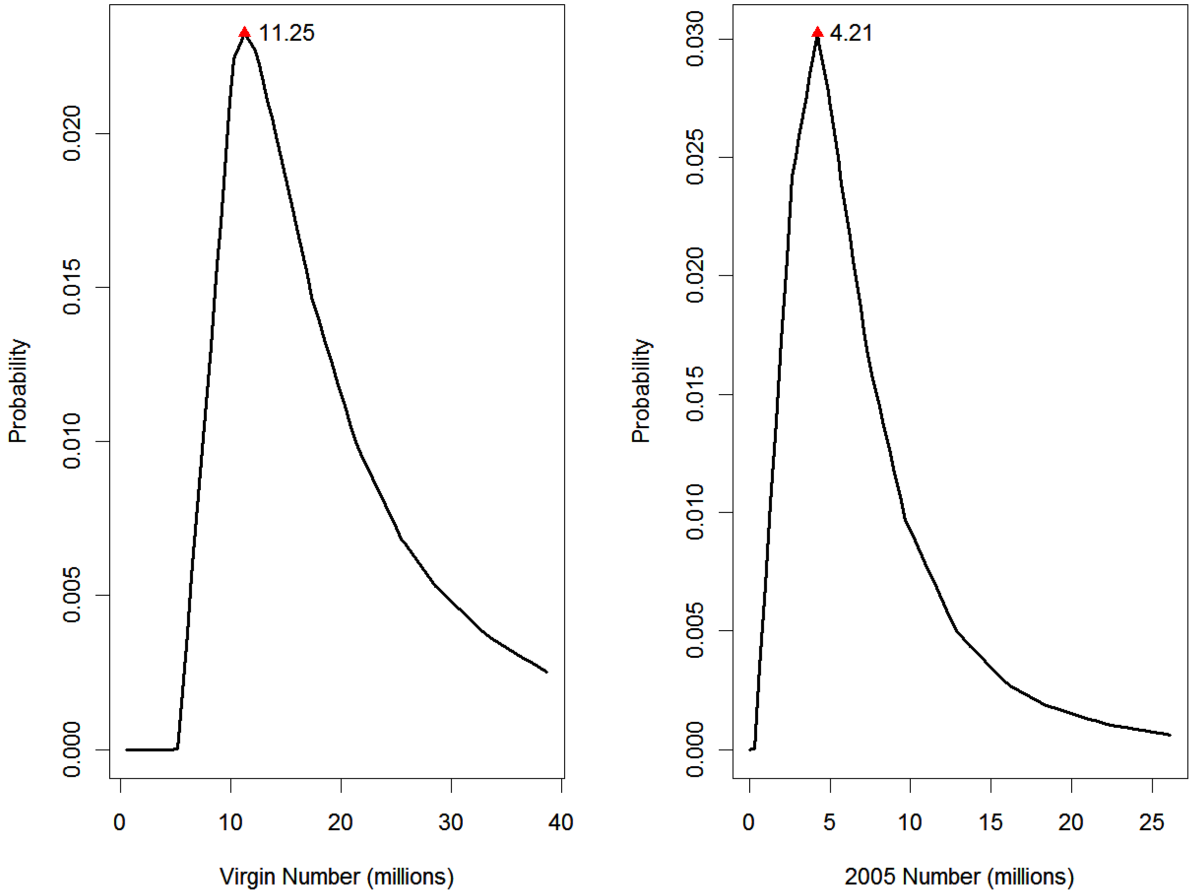


Figure 5.12. Base model estimated likelihood profile for total population size (in number) at virgin conditions, and current population size for **Atlantic sharpnose shark**. The mode of the posterior is indicated with a solid triangle, and the value is labeled.

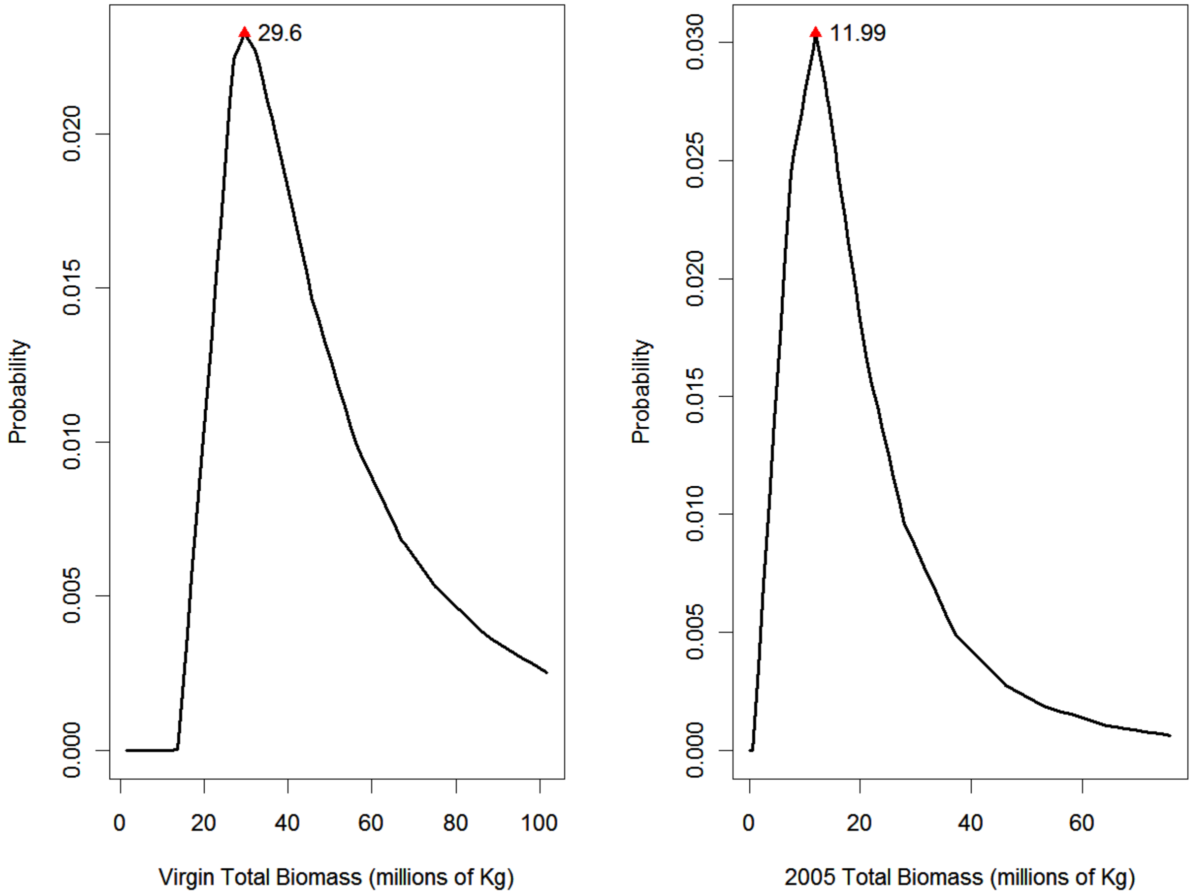


Figure 5.13. **Atlantic sharpnose shark** base model estimated likelihood profile for total population biomass (Kg.) at virgin conditions, and current population biomass (Kg.). The mode of the posterior is indicated with a solid triangle, and the value is labeled.

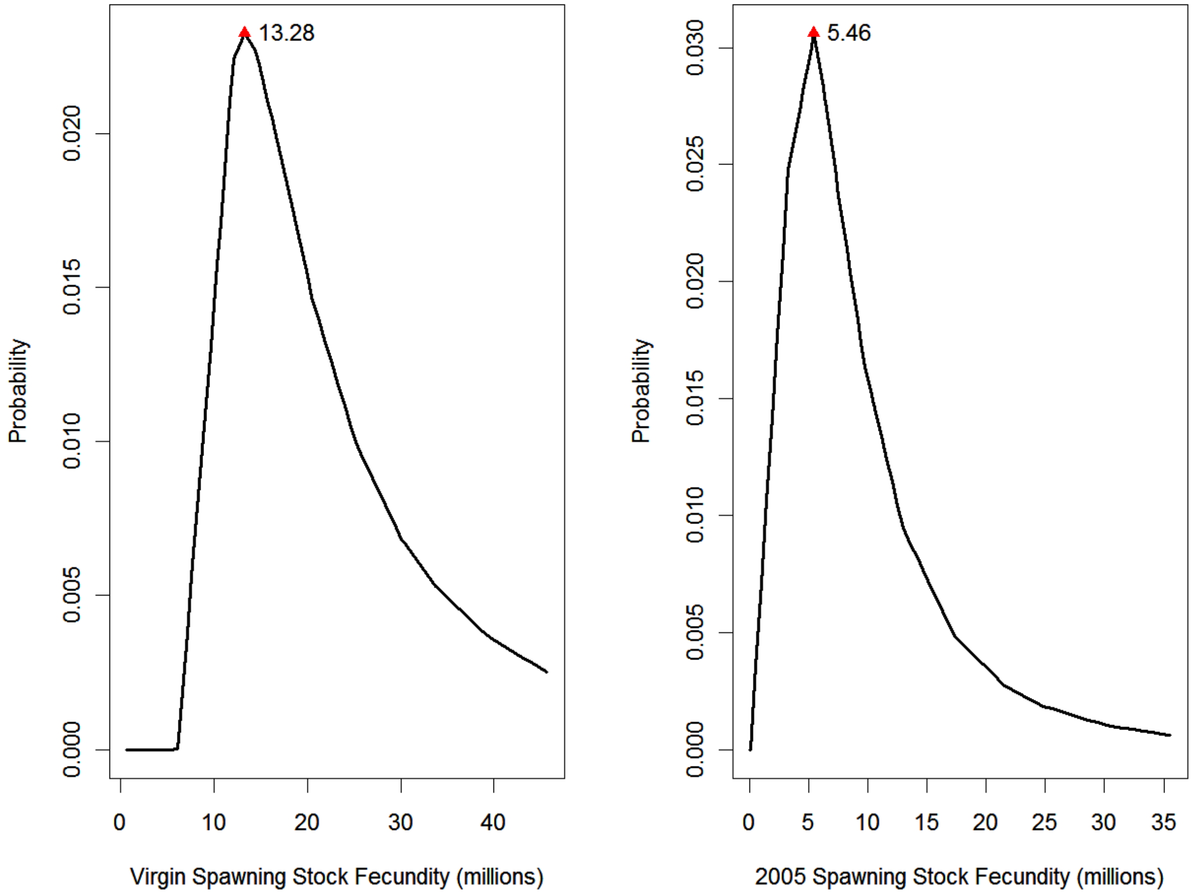


Figure 5.14. Base model estimated likelihood profile for spawning stock fecundity (SSF, millions of pups produced) at virgin conditions, and current spawning stock fecundity for **Atlantic sharpnose shark**. The mode of the posterior is indicated with a solid triangle, and the value is labeled.

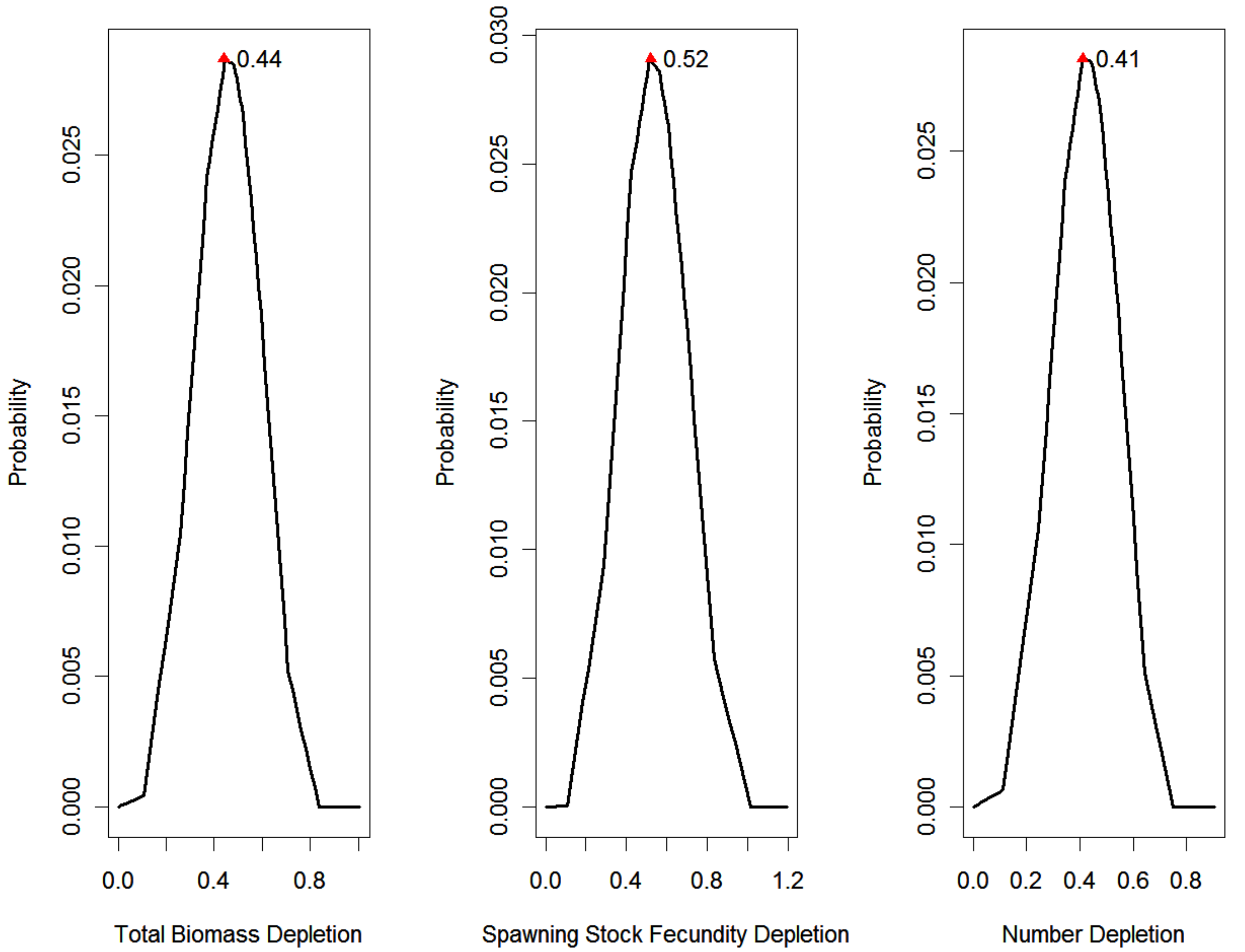


Figure 5.15. Base model estimated likelihood profile for depletion in biomass (B_{2005}/B_0), spawning stock fecundity (SSF_{2005}/SSF_0), and in number (N_{2005}/N_0) for **Atlantic sharpnose shark**. The mode of the posterior is indicated with a solid triangle, and the value is labeled.

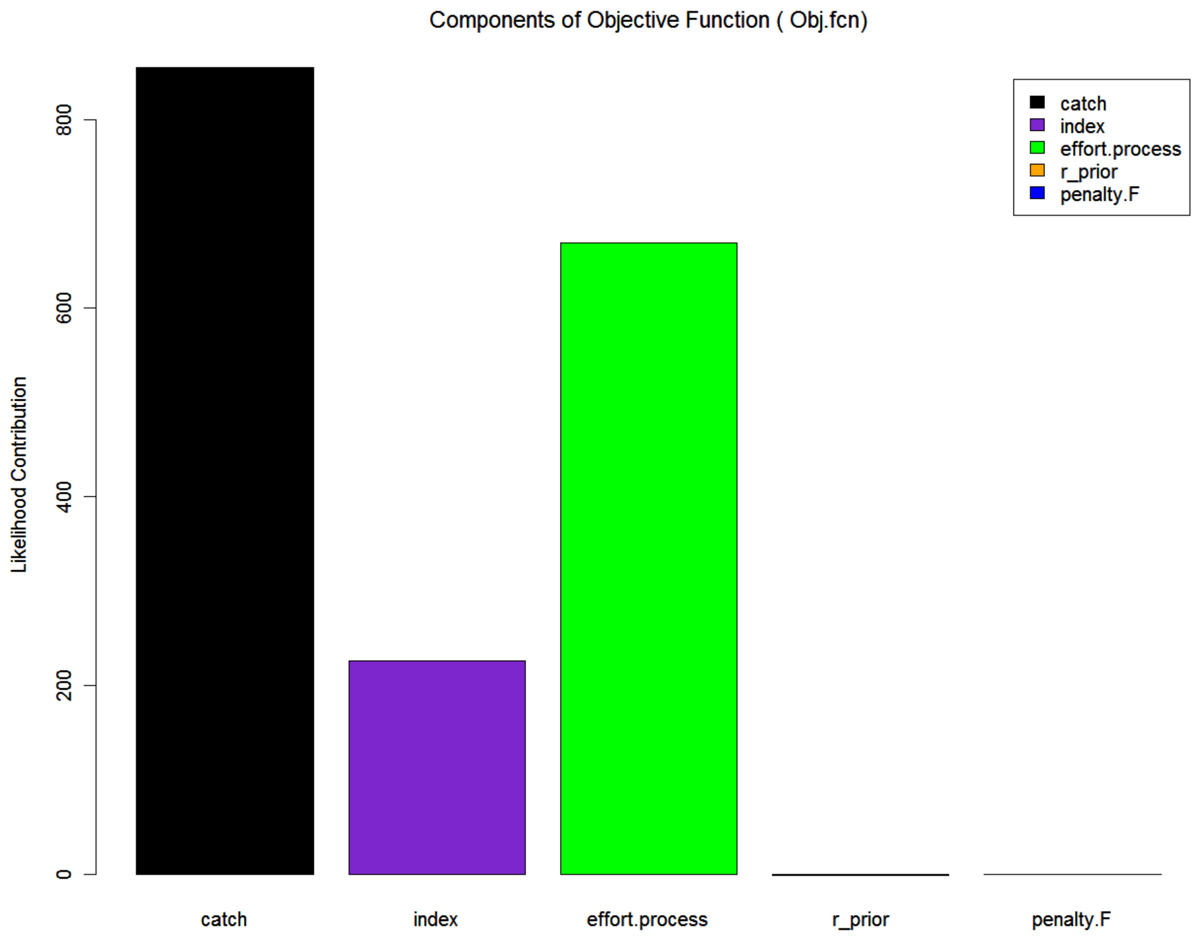


Figure 5.16. Contributions to the likelihood by model source for the **Atlantic sharpnose shark** base model.

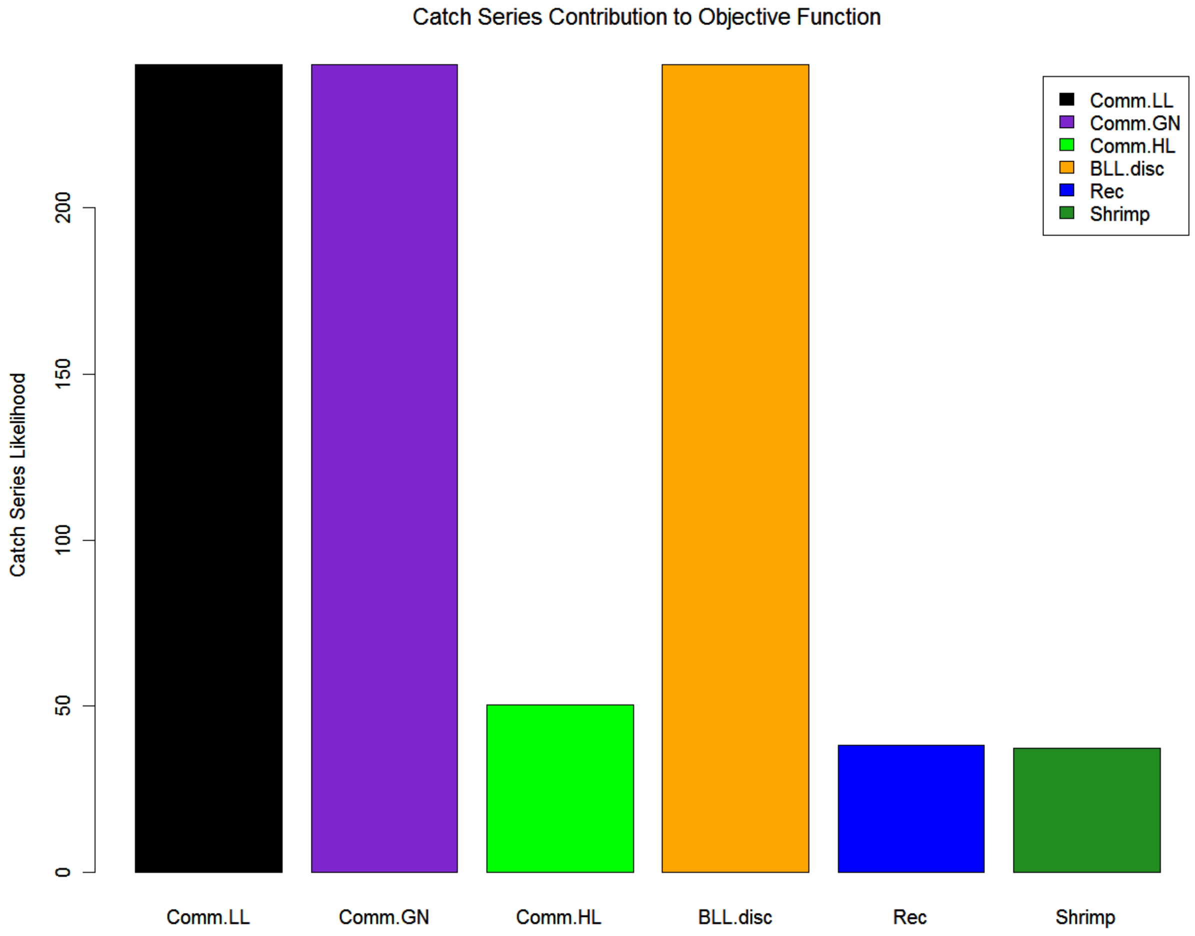


Figure 5.16 (cont.)

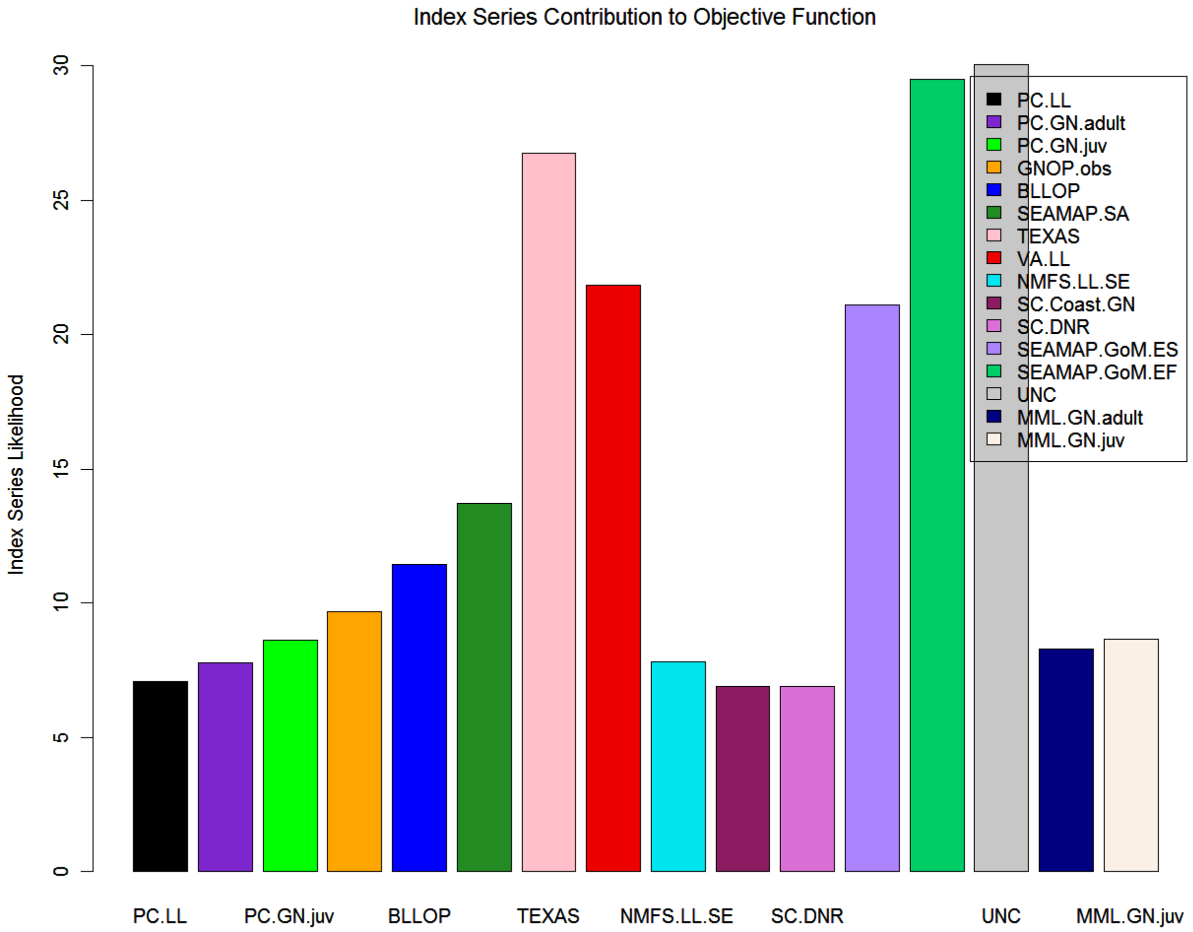


Figure 5.16 (cont.)

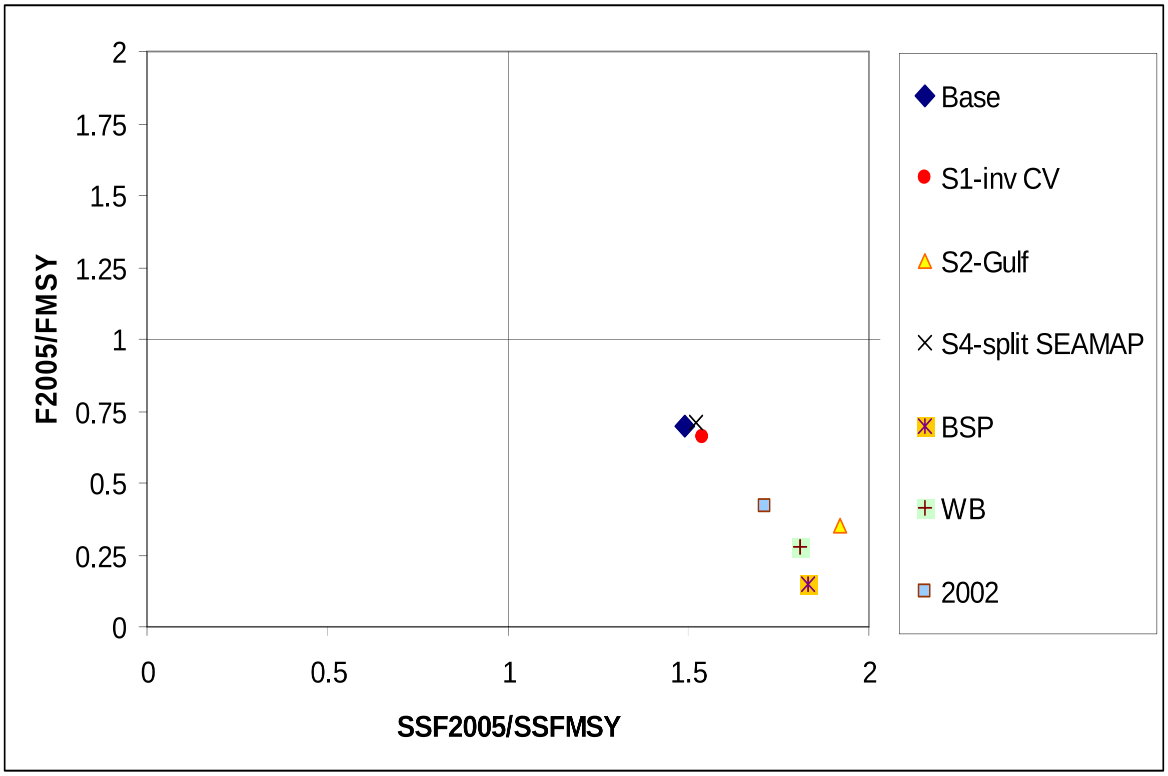


Figure 5.17. Phase plot of all model results for **Atlantic sharpnose shark.** The result from the 2002 assessment (labeled 2002) is included for comparison with 2006 assessment results. BSP and WB are the results from the Bayesian Surplus Production and the WinBUGS surplus production model, respectively.

BONNETHEAD SHARK STOCK ASSESSMENT

6. BONNETHEAD SHARK STOCK ASSESSMENT

6.1. Summary of Bonnethead Shark Working Documents

SEDAR 13-AW-01

Cortés: Assessment of Small Coastal Sharks, Atlantic sharpnose, Bonnethead, Blacknose and Finetooth Sharks using Surplus Production Methods

We used two complementary surplus production models (BSP and WinBUGS) to assess the status of the Small Coastal Shark (SCS) complex and four individual species (Atlantic sharpnose, bonnethead, blacknose, and finetooth sharks) identified as baseline scenarios in the SCS 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 rate of increase, and importance function on results. Baseline scenarios predicted that the stock status is not overfished and overfishing is not occurring in all cases. Using the inverse variance method to weight the CPUE data was problematic because of the nature of the CPUE time series and must be regarded with great caution, although predictions on stock status did not change, except for blacknose sharks. The alternative surplus production model implemented in WinBUGS supported the results from the BSP model, with the exception of blacknose sharks, which became overfished. None of the other sensitivity analyses examined had a large impact on results and did not affect conclusions on stock status in any case. Only blacknose sharks with the alternative catch scenario approached an overfishing condition.

SEDAR 13-AW-02

Siegfried, Cortés, and Brooks: Determining Selectivities for Small Coastal Shark Species for Assessment Purposes

Selectivities of catch series and indices had to be determined for sharpnose, blacknose, and bonnethead sharks for the 2007 small coastal shark stock assessment. Based on age frequencies, five selectivities were determined for sharpnose, four for blacknose, and two for bonnethead.

SEDAR 13-AW-03

Siegfried and Brooks: Assessment of Blacknose, Bonnethead, and Atlantic Sharpnose Sharks with a State-Space, Age-Structured Production Model

An age-structured production model was employed to assess the following small coastal sharks: Blacknose (*Carcharhinus acronotus*), Bonnethead (*Sphyrna tiburo*), and Atlantic Sharpnose (*Rhizoprionodon terraenovae*). All models assumed virgin conditions in 1950, and historically reconstructed catches were derived to inform the model on likely levels of removals for the years prior to the start of observed and recorded catches. The base models for all three species applied equal weight to all indices. Base model results for bonnethead shark indicate that the stock is overfished and that there is overfishing. The stock status appears to be quite sensitive to the reconstructed catches, particularly because of some extreme peaks in the bottom longline fishery reports and the shrimp bycatch reports. An initial sensitivity run indicates that the stock depletion decrease when less weight is given to the extreme peaks. Additional sensitivities will be performed at the assessment workshop. The base model results for blacknose suggest that the stock is overfished and that there is also overfishing. The base model for Atlantic sharpnose assumed a single stock, and results from this model indicate that the stock is not overfished nor is overfishing occurring. A sensitivity analysis where inverse CV weights were applied to the base indices showed very little difference from the base model, and the stock status estimate was no overfishing and the stock is not overfished.

6.2. Background

In 2002, a stock assessment was conducted on the small coastal complex of sharks (finetooth (*Carcharhinus isodon*), blacknose (*Carcharhinus acronotus*), bonnethead (*Sphyrna tiburo*), and Atlantic sharpnose (*Rhizoprionodon terraenovae*), in the Gulf of Mexico and the Atlantic (Cortés 2002). The author used a variety of Bayesian statistical models, including a Schaefer biomass dynamic model, a Schaefer surplus production model (SPM), and a lagged-recruitment, survival and growth state-space model. There are more data available to assess the blacknose, bonnethead, and Atlantic sharpnose populations currently; therefore an age-structured model was applied in addition to the models used in the last assessment. This assessment report outlines the results of the age-structured model applied to bonnethead shark data.

6.3 Available Models

Three models were available for discussion for the bonnethead shark assessment: two surplus production models (SPMs), the BSP and WinBUGS models described previously, and one age-structured production approach (Cortés 2002, SPASM, 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 Workshop Panel decided to use the state-space, age-structured production model described in document SEDAR13-AW-03 for bonnethead 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.

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.

The Assessment Workshop Panel further discussed the issue for weighting indices. It was noted that there are a variety of ways to weight indices in addition to equal and inverse CV weighting, however how to determine which weighting method is most appropriate is a discussion topic that is still without satisfying resolution. Given that fact, the Assessment Workshop Panel decided that equal weighting would be the base weighting method for the current assessment but noted that, as there is at present no objective way to decide which method is superior other than comparing model convergence diagnostics, future assessments may need to re-examine this issue.

6.6 Data issues and solutions derived during the assessment workshop

The estimate of bonnethead bycatch in the shrimp fishery in 1980 raised concern amongst the panelists. It was orders of magnitude larger than the points around it, and had no apparent explanation. The anomalous peak in the shrimp bycatch data was investigated in the working document (SEDAR 13-DW-32) and found to be outside of the limits of confidence. Panelists agreed to take the geometric mean of the three years before and after the anomalous peak and replace it with the geometric mean.

Another anomalous peak in the 1995 reports from the bottom longline fishery concerned panelists. The value, 19,009 sharks caught, was considered too high to be valid. It was argued that the point in question was larger than the total number of bonnetheads caught in the bottom longline in the last ten years. To resolve the issue, the panelists agreed to take the geometric mean of the observed points and replace the 1995 value with that mean.

An issue was brought up during the assessment workshop that involved the fit to the SEAMAP indices for bonnethead. The SEAMAP extended summer and extended fall indices covered a time period during which there was a sampling protocol change. Because of the low proportion positives of bonnethead (~1%), the panelists decided to replace the longer extended fall index with two new indices that cover the early years and late years of that sampling effort respectively. The SEAMAP extended summer index was also considered for replacement by two shorter time series, however two acceptable time series were not available. Therefore, it was excluded.

A final data issue that concerned panelists was the method by which the catches were reconstructed for the commercial longline fishery. It was agreed upon in the catch working group at the data workshop to start the reconstruction in 1981 with a linearly increasing trend ending at the first year of observed data (1995). The panelists at the assessment workshop argued that this was not a realistic representation of the level of catch, especially in the earlier years of fishery expansion. The panelists agreed upon an exponential increase in fishing for the longline fleet reconstruction after much discussion. The new reconstructions were applied to the commercial bottom longline catch and the bottom longline discards.

6.7 Methods

6.7.1 State-space age-structured production model description

The age-structured production model (originally derived in Porch 2002) starts from a year when the stock can 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 era," where data are sparse, and a "modern era," where more data are available for model fitting. In all three model applications, virgin conditions were assumed in 1950. The earliest index of abundance (SEAMAP) and the earliest catch series (Shrimp trawl bycatch) begin in 1972, thus the historic model years spanned 1950-1971 (22 years) and the modern model years spanned 1972-2005 (34 years).

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

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

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, 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 model period. 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

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

where $f_{y,i}$ is annual fleet-specific effort, b_0 is the intercept, and $f_{y=mod,i}$ 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:

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

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

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

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:

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

where τ_i is the duration of the fishing season for fleet i. Catch in weight is computed by multiplying (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:

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

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 small coastal 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:

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

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):

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

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

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 for the base model run, 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.

6.7.2. Data inputs, prior probability distributions, and performance indicators

Baseline scenario (SPASM-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 6.1b, 6.2, and 6.3; Figures 6.1-6.3). Catches were made by the commercial sector and the recreational sector and we included a catch series for the discards in the bottom longline fishery. A total of twelve indices were made available after the data workshop (Table 6.3, Figure 6.2), eleven of which were recommended as base indices.

Individual selectivity functions to be applied to catch series were identified based on length frequencies and biological information provided by the Life History Working Group. The selectivity recommendations can be found in the Assessment Workshop report on determining selectivities (Table 6.2, Figure 6.3, and SEDAR 13 AW-02).

Catch data begin in 1981, while the earliest data for the indices is 1972 (SEAMAP). Catches from 1981 were imputed back to 1950, when a virgin assumption was imposed. The catches for each fleet were imputed as follows: the commercial longline was reconstructed to increase at an exponential rate from 1981 to 1995 (the year of the first data point). The commercial gillnet fishery was reconstructed to increase linearly from 1981 to 1995. The longline reconstruction changed from linear (a Data Workshop recommendation) to an exponential increase following the Assessment Workshop recommendations.

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 was to treat all points as having an equal weight. There were no recommendations by either the data workshop or the assessment workshop to downweight any individual or group of points.

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 values provided by the life history working group (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 1950, used the reconstructed catch series as agreed upon (whether it was a linear or exponential increase) and used the new value for the shrimp bycatch in 1980. All inputs are given in Tables 6.1, 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 2005 (F_{2005}, SSF_{2005}, B_{2005}), 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 is spawning stock fecundity.

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. 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).

6.7.4 Sensitivity analyses

Two sensitivity runs were requested by Data Workshop. The first sensitivity recommended at the Data Workshop was to include the 12th index (GN logs) to the model run. The second sensitivity, also recommended at the Data Workshop, was to use an inverse-CV weighting method for weighting the indices. No additional sensitivities were requested.

6.8 Results

6.8.1 Baseline scenario

The base model estimated a stock that was not overfished with no overfishing occurring (Tables 6.4 and 6.5; Figure 6.4). The model estimate of F by fleet is dominated by the bycatch from the shrimp fleet (Figure 6.4). Model fits to catches are shown in Figure 6.5 and show very good agreement. The Texas index is the longest time series, beginning in 1975, and its trend was fit well by the model (Figure 6.6). The SEAMAP split series are fit well, especially through the late series and the ENP (beginning in 1978) is also well fit by the model. The South Carolina COASTSPAN gillnet survey is the index that is fit least well by the model.

Likelihood profiling was performed in ADModel Builder (Otter Research Ltd. 2000) to obtain posterior distributions for several model parameters (Figures 6.8 and 6.9). The distributions for total biomass depletion or spawning stock fecundity depletion (current/msy value for that parameter) range from about 0.1-0.8 with a mode of 0.36 (Figure 6.8). The mode for the posterior of pup survival was estimated at a higher value than the prior mode, while the mode of the posterior for virgin recruitment of pups was approximately 1,008,000 (Figure 6.9).

6.8.2 Sensitivity analyses

The first sensitivity (**S1**-inverse CV weighting method) is very slightly overfished, with a spawning stock fecundity ratio <1 (~0.99). **S1**, however, does not show any overfishing. Sensitivity 2 (**S2**, all indices are included) showed a status very similar to that of the base model. Panelists at the Data Workshop requested these sensitivities and Panelists at the Assessment Workshop agreed that the base model was most appropriate.

6.8.3 Comparison of model fits

A breakdown of the likelihood by individual catch and index series as well as the relative likelihood values by model source (catch, indices, effort, catchability, and recruitment) are shown in Figures 6.10-6.11. These graphs show the relative contributions of each index and catch series on the model objective function.

6.9 Projections of the base model

As the base model does not show an overfished stock or any overfishing in the current time period, projections were not calculated.

6.10 Discussion

The main issues, such as the anomalous shrimp peak and the linear versus exponential interpolation of catch data in the longline fishery were debated and resolved agreeably. The base SPASM model for bonnethead shows that the stock is not overfished and that there is no overfishing occurring. The first sensitivity, where the inverse-CV weighting method was used, shows a very negligible status of overfished, but there is not a history of an overfished status at any time for this stock. There have been years of overfishing (1975, 1980, 1997, etc. see Figure 6.4). The main contributor to population mortality is the recreational fleet followed more closely since 1990 by the commercial gillnet fleet. As shown in the phase plot in Figure 6.7, the SPMs gave more optimistic scenarios for stock status than the age-structured models agreed upon by the Assessment Workshop Panelists. In the base model, total fishing mortality from 1995-2005 averages 0.38, and for 2002-2005 it averages 0.4. These levels are 1.2-1.3 times the estimate of F_{MSY}.

5.11 References

Cortés, E. (2002). Stock Assessment of Small Coastal Sharks in the U.S. Atlantic and Gulf of Mexico, NOAA-Fisheries Sustainable Fisheries Division
133.

Myers, R. A., K. G. Bowen, et al. 1999. "Maximum reproductive rate of fish at low population sizes." *Canadian Journal of Fisheries and Aquatic Sciences* **56**: 2404-2419.

Otter Research Ltd. 2001. An introduction to AD MODEL BUILDER Version 6.0.2. Box 2040, Sidney, B. C. V8L 3S3, Canada.

Porch, C. E. 2002. A preliminary assessment of Atlantic white marlin (*Tetrapturus albidus*) using a state-space implementation of an age-structured model. SCRS/02/68 23pp.

Table 6.1a. Biological inputs for **bonnethead shark** from the data workshop.

Age	M	Female Maturity	Pups-per-Female
1	0.42	0.02	5
2	0.40	0.12	5
3	0.39	0.48	5
4	0.37	0.86	5
5	0.33	0.98	5
6	0.29	1	5
7	0.27	1	5
8	0.26	1	5
9	0.25	1	5
10	0.24	1	5
11	0.22	1	5
12	0.21	1	5

Table 6.1b. Additional parameter specifications for **bonnethead shark** 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_∞	113.9 (cm TL)	*constant*
K	0.22	*constant*
t_0	-1.25	*constant*
a	9.52E-11	*constant*
b	3.59	*constant*
Pup Survival	0.66	~LN with CV=0.30
Virgin Recruitment (R_0)	[1.0E+4, 1.0E+10]	~U on [1.0E+4, 1.0E+10]

Table 6.2. Catches of **bonnethead shark** by fleet. Units are numbers of sharks and the reconstructed catches are in blue. The last row lists which selectivity is assumed for the catch series.

Year	Longline	Nets	Lines	Recreational catches	Bottom longline discards	Shrimp bycatch
1950	0	0	0	7,469	0	103,005
1951	0	0	0	13,314	0	132,351
1952	0	0	0	14,514	0	133,902
1953	0	0	0	15,714	0	154,059
1954	0	0	0	16,914	0	158,973
1955	0	0	0	18,114	0	144,143
1956	0	0	0	19,314	0	131,016
1957	0	0	0	20,514	0	117,923
1958	0	0	0	21,714	0	116,978
1959	0	0	0	22,914	0	131,248
1960	0	0	0	15,058	0	140,670
1961	0	0	0	15,760	0	70,687
1962	0	0	0	16,461	0	92,678
1963	0	0	0	17,162	0	139,034
1964	0	0	0	17,864	0	124,463
1965	0	0	0	18,565	0	134,020
1966	0	0	0	19,267	0	126,382
1967	0	0	0	19,968	0	155,001
1968	0	0	0	20,669	0	141,535
1969	0	0	0	21,371	0	148,218
1970	0	0	0	18,450	0	162,989
1971	0	0	0	21,632	0	167,247
1972	0	0	0	21,935	0	259,608
1973	0	0	0	22,239	0	189,270
1974	0	0	0	22,542	0	255,743
1975	0	0	0	22,846	0	380,381
1976	0	0	0	23,149	0	171,773
1977	0	0	0	23,453	0	332,678
1978	0	0	0	23,756	0	81,139
1979	0	0	0	24,060	0	317,721
1980	0	0	0	25,067	0	235,763
1981	0	0	0	39,269	0	109,637
1982	1	0	0	26,115	0	190,028
1983	1	0	0	22,925	1	91,668
1984	3	0	0	15,418	2	103,355
1985	6	0	0	22,607	4	100,703

1986	10	0	0	50,474	6	323,168
1987	16	5,496	0	26,527	10	204,623
1988	24	10,991	0	30,986	14	182,213
1989	40	16,487	0	37,901	24	119,722
1990	74	21,983	0	48,317	44	271,557
1991	113	27,478	0	8,837	66	104,186
1992	190	32,974	0	18,692	112	154,342
1993	349	38,470	0	19,798	205	142,619
1994	680	43,965	0	20,524	400	121,775
1995	1,305	49,461	285	32,112	11,168	242,057
1996	7,324	5,259	209	22,519	4,303	479,034
1997	377	14,963	190	14,995	221	417,245
1998	957	1,468	225	29,065	562	164,872
1999	633	9,995	832	37,341	372	271,829
2000	899	16,500	42	56,436	528	137,164
2001	554	19,705	70	59,017	326	263,532
2002	2,344	36,840	578	51,048	1,377	305,874
2003	3,756	6,514	109	40,066	2,207	216,626
2004	924	7,063	58	42,295	543	453,898
2005	2,109	9,942	224	31,215	1,241	112,188
Selectivity	2	1	2	1	2	1

Table 6.3. Indices available for use in the current **bonnethead shark** assessment. Sensitivity index in green. The last row lists the sensitivity used for each index.

PC-GN a	PC-GN j	GN-obs	ENP	SEAMAP-SA	Texas	SC Coastspan GN	SEAMAP early	SEAMAP late	MML GN-adult	MML GN- juvi	GN Logs	Year
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1950
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1951
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1952
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1953
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1954
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1955
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1956
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1957
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1958
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1959
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1960
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1961
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1962
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1963
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1964
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1965
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1966
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1967
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1968
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1969
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1970
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1971
-1	-1	-1	-1	-1	-1	-1	0.182	-1	-1	-1	-1	1972
-1	-1	-1	-1	-1	-1	-1	0.558	-1	-1	-1	-1	1973
-1	-1	-1	-1	-1	-1	-1	0.308	-1	-1	-1	-1	1974
-1	-1	-1	-1	-1	0.164	-1	0.164	-1	-1	-1	-1	1975
-1	-1	-1	-1	-1	1.578	-1	0.321	-1	-1	-1	-1	1976
-1	-1	-1	-1	-1	0.178	-1	0.360	-1	-1	-1	-1	1977
-1	-1	-1	0.436	-1	0.199	-1	0.102	-1	-1	-1	-1	1978
-1	-1	-1	0.545	-1	0.559	-1	0.225	-1	-1	-1	-1	1979
-1	-1	-1	0.151	-1	1.092	-1	0.108	-1	-1	-1	-1	1980
-1	-1	-1	0.395	-1	0.997	-1	0.038	-1	-1	-1	-1	1981

-1	-1	-1	0.285	-1	0.645	-1	0.045	-1	-1	-1	-1	1982
-1	-1	-1	0.542	-1	1.076	-1	0.065	-1	-1	-1	-1	1983
-1	-1	-1	0.944	-1	1.397	-1	0.000	-1	-1	-1	-1	1984
-1	-1	-1	0.627	-1	0.453	-1	0.031	-1	-1	-1	-1	1985
-1	-1	-1	0.602	-1	0.779	-1	0.000	-1	-1	-1	-1	1986
-1	-1	-1	0.631	-1	0.090	-1	-1	0.072	-1	-1	-1	1987
-1	-1	-1	0.708	-1	1.222	-1	-1	0.073	-1	-1	-1	1988
-1	-1	-1	0.901	0.777	0.591	-1	-1	0.058	-1	-1	-1	1989
-1	-1	-1	0.818	1.37	1.560	-1	-1	0.107	-1	-1	-1	1990
-1	-1	-1	0.498	2.1	1.042	-1	-1	0.090	-1	-1	-1	1991
-1	-1	-1	0.971	1.448	0.399	-1	-1	0.054	-1	-1	-1	1992
-1	-1	-1	0.931	1.031	0.984	-1	-1	0.112	-1	-1	-1	1993
-1	-1	196.274	1.026	1.563	0.661	-1	-1	0.156	-1	-1	-1	1994
-1	-1	12.915	1.137	1.749	0.479	-1	-1	0.035	0.881	0.493	-1	1995
0.563	0.602	-1	1.102	0.711	0.558	-1	-1	0.148	0.597	0.316	-1	1996
0.204	0.827	-1	0.879	1.578	0.495	-1	-1	0.232	1.179	1.216	-1	1997
0.165	0.622	169.757	0.808	1.248	1.350	5.113	-1	0.048	-1	-1	0.001	1998
0.374	0.71	102.106	0.94	1.122	0.441	13.233	-1	0.139	1.409	0.607	0.001	1999
0.046	0.304	431.009	0.888	1.644	1.340	12.370	-1	0.070	2.479	1.350	0.002	2000
0.619	0.39	133.159	0.965	2.237	1.341	13.092	-1	0.093	2.728	1.204	0.003	2001
0.504	0.435	67.46	0.881	3.415	1.335	10.316	-1	0.165	1.695	0.581	0.003	2002
0.692	0.292	29.868	0.803	2.936	0.927	14.299	-1	0.126	2.346	1.110	0.004	2003
0.296	0.166	8.594	0.781	1.264	1.323	17.229	-1	0.430	2.811	1.867	0.014	2004
0.067	0.046	163.588	-1	2.731	0.999	16.121	-1	0.215	-1	-1	0.007	2005
2	1	1	1	2	1	1	1	1	2	1	1	Selectivity

Table 6.4. Results for the base model runs and two sensitivity analyses that converged using the updated biological parameters for **bonnethead shark**. 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).

	Base		S-1		S-2	
	Estimate	CV	Estimate	CV	Estimate	CV
SSF_{2005}/SSF_{MSY}	1.13	0.49	0.99	0.39	1.08	0.54
F_{2005}/F_{MSY}	0.61	0.82	0.64	0.68	0.61	0.54
N_{2005}/N_{MSY}	0.83	-	0.75	-	0.78	-
MSY	568,871	-	499,839	-	567,756	-
SPR_{MSY}	0.42	0.17	0.49	0.02	0.57	0.30
F_{MSY}	0.31	-	0.40	-	0.31	-
SSF_{MSY}	1.99E+06	-	1.99E+05	-	1.90E+06	-
N_{MSY}	1.92E+06	-	1.50E+06	-	1.93E+06	-
F_{2005}	0.19	0.82	0.25	0.68	0.19	1.84
SSF_{2005}	2.26E+06	0.72	1.97E+06	0.53	2.06E+06	0.67
N_{2005}	1.59E+06	-	1.13E+06	-	1.51E+06	-
SSF_{2005}/SSF_0	0.41	0.47	0.33	0.38	0.41	0.51
B_{2005}/B_0	0.41	0.47	0.34	0.34	0.39	0.50
R0	1.22E+06	0.29	9.8E+05	0.20	1.15E+06	0.32
Pup-survival	0.70	0.24	0.70	0.24	0.70	0.24
alpha	3.14	-	4.20	-	3.13	-
steepness	0.44	-	0.51	-	0.44	-

Table 6.5. Estimates of total number, spawning stock fecundity, and fishing mortality by year for base model for **bonnethead shark**.

Year	N	SSF	F
1950	3.99E+06	2.10E+06	0.085
1951	3.89E+06	2.09E+06	0.090
1952	3.82E+06	2.06E+06	0.096
1953	3.76E+06	2.01E+06	0.101
1954	3.71E+06	1.96E+06	0.106
1955	3.66E+06	1.92E+06	0.112
1956	3.61E+06	1.88E+06	0.117
1957	3.56E+06	1.84E+06	0.122
1958	3.51E+06	1.81E+06	0.127
1959	3.47E+06	1.78E+06	0.133
1960	3.42E+06	1.75E+06	0.138
1961	3.38E+06	1.72E+06	0.143
1962	3.34E+06	1.69E+06	0.149
1963	3.30E+06	1.66E+06	0.154
1964	3.26E+06	1.63E+06	0.159
1965	3.22E+06	1.60E+06	0.165
1966	3.19E+06	1.58E+06	0.170
1967	3.15E+06	1.55E+06	0.175
1968	3.11E+06	1.53E+06	0.181
1969	3.08E+06	1.50E+06	0.186
1970	3.04E+06	1.48E+06	0.191
1971	3.01E+06	1.46E+06	0.196
1972	2.97E+06	1.43E+06	0.202
1973	2.94E+06	1.41E+06	0.189
1974	2.92E+06	1.39E+06	0.259
1975	2.84E+06	1.37E+06	0.411
1976	2.68E+06	1.33E+06	0.189
1977	2.73E+06	1.28E+06	0.364
1978	2.61E+06	1.23E+06	0.100
1979	2.72E+06	1.21E+06	0.346
1980	2.58E+06	1.19E+06	0.276
1981	2.55E+06	1.18E+06	0.147
1982	2.62E+06	1.17E+06	0.213
1983	2.60E+06	1.15E+06	0.110
1984	2.67E+06	1.17E+06	0.112
1985	2.72E+06	1.19E+06	0.115
1986	2.76E+06	1.22E+06	0.410
1987	2.57E+06	1.24E+06	0.245
1988	2.58E+06	1.22E+06	0.220
1989	2.59E+06	1.18E+06	0.166
1990	2.63E+06	1.15E+06	0.341
1991	2.51E+06	1.15E+06	0.139
1992	2.59E+06	1.15E+06	0.199
1993	2.59E+06	1.14E+06	0.195
1994	2.59E+06	1.15E+06	0.182
1995	2.60E+06	1.16E+06	0.334

1996	2.50E+06	1.16E+06	0.557
1997	2.31E+06	1.12E+06	0.505
1998	2.22E+06	1.06E+06	0.210
1999	2.31E+06	9.91E+05	0.334
2000	2.25E+06	9.50E+05	0.225
2001	2.27E+06	9.54E+05	0.374
2002	2.19E+06	9.59E+05	0.468
2003	2.09E+06	9.45E+05	0.313
2004	2.11E+06	9.14E+05	0.635
2005	1.94E+06	8.68E+05	0.188

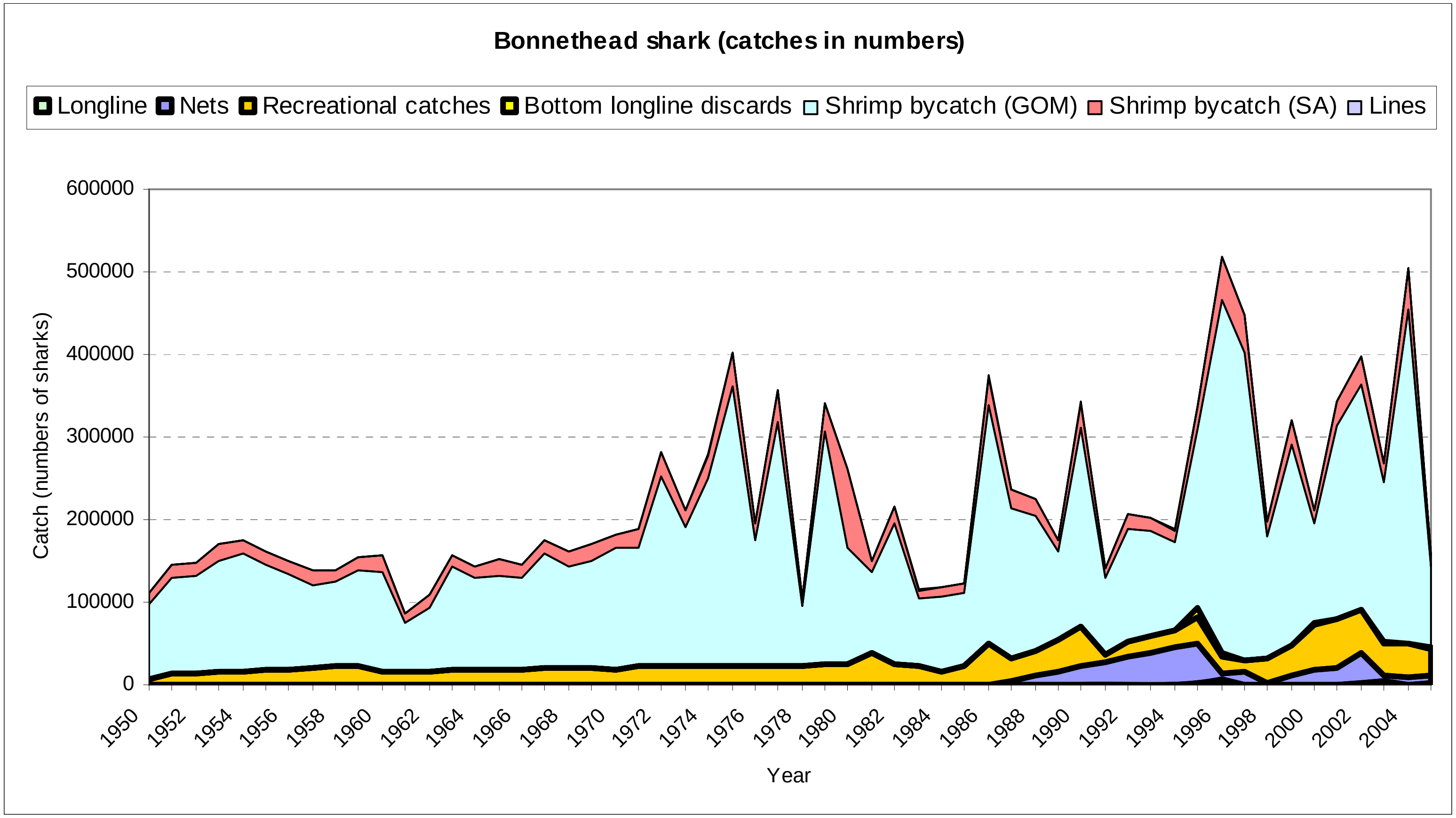


Figure 6.1. Catches of **bonnethead shark** by fleet.

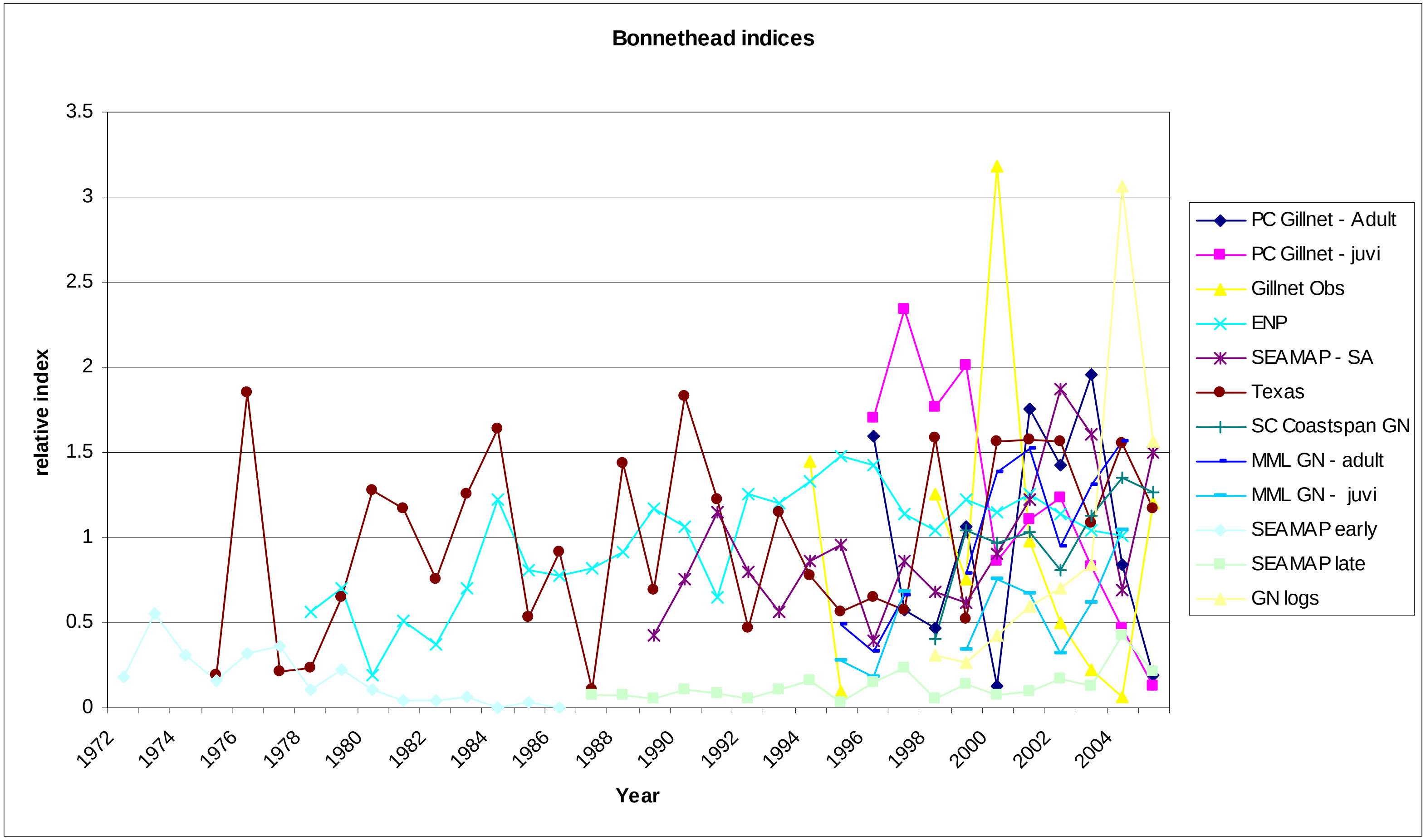


Figure 6.2 Indices available for the current **bonnethead shark** assessment.

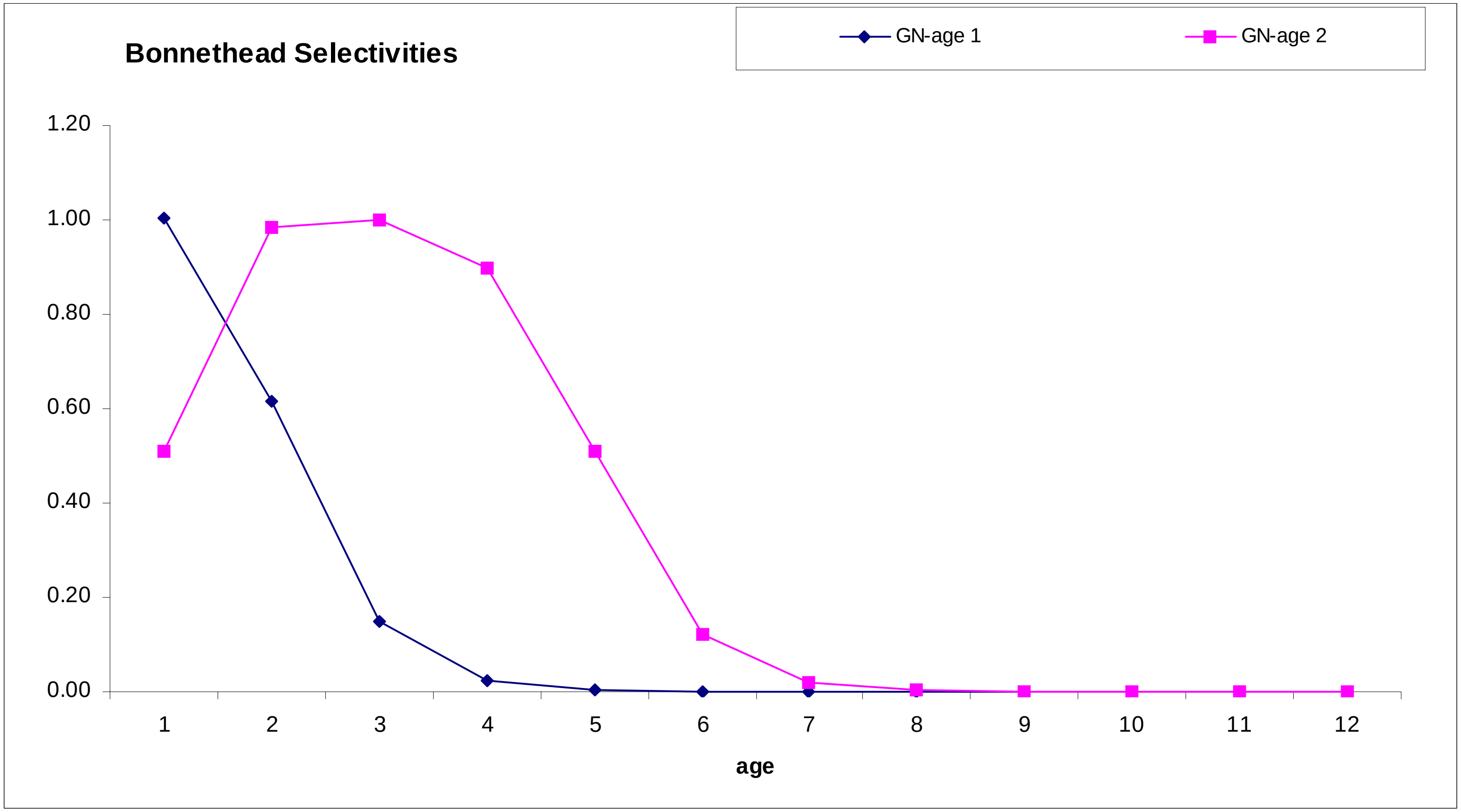


Figure 6.3 Selectivities used in **bonnethead shark** assessment.

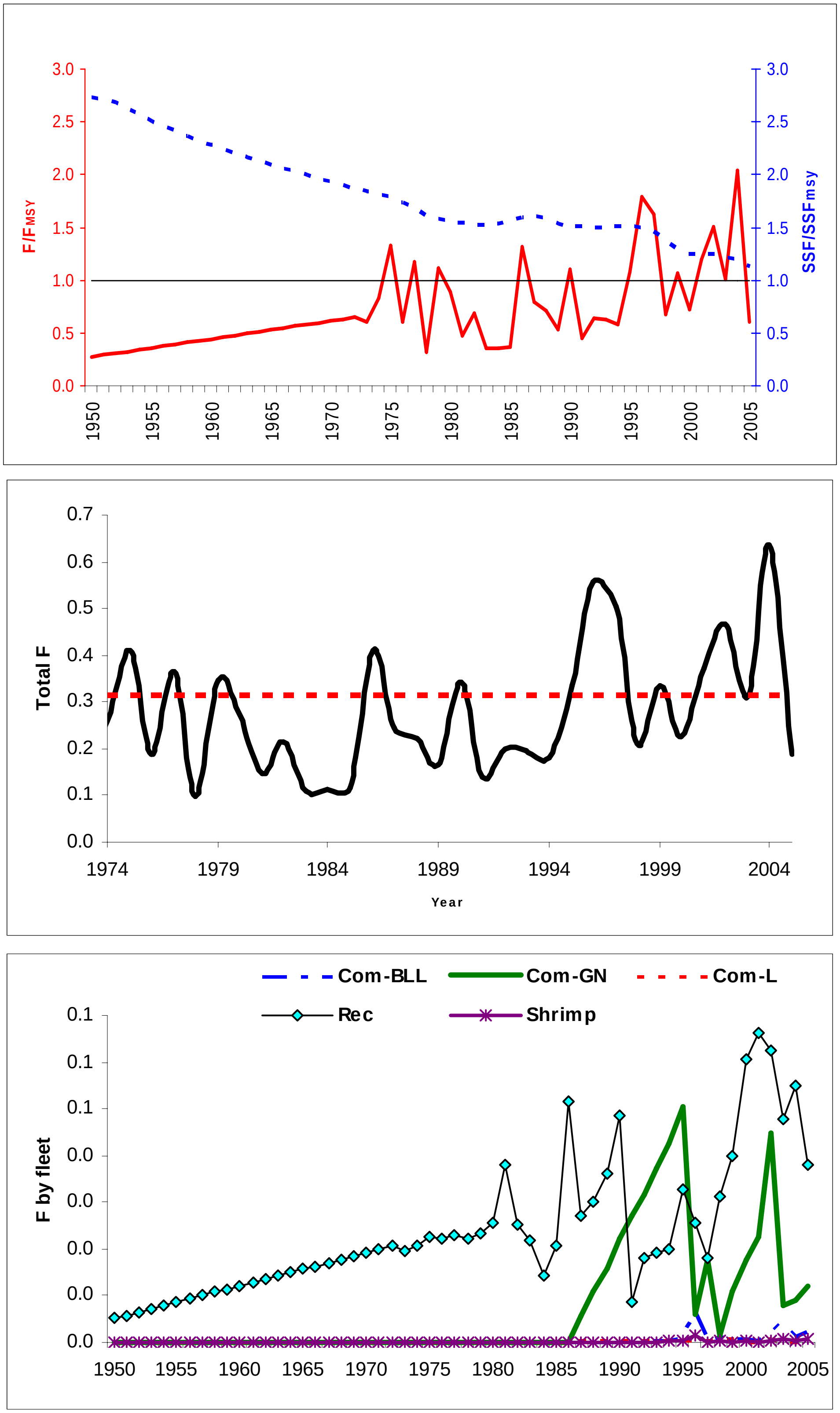


Figure 6.4. **Bonnethead shark** estimated stock status (top), total fishing mortality (middle), and fleet-specific F (bottom). The dashed line in the middle panel indicates F_{MSY} (0.311).

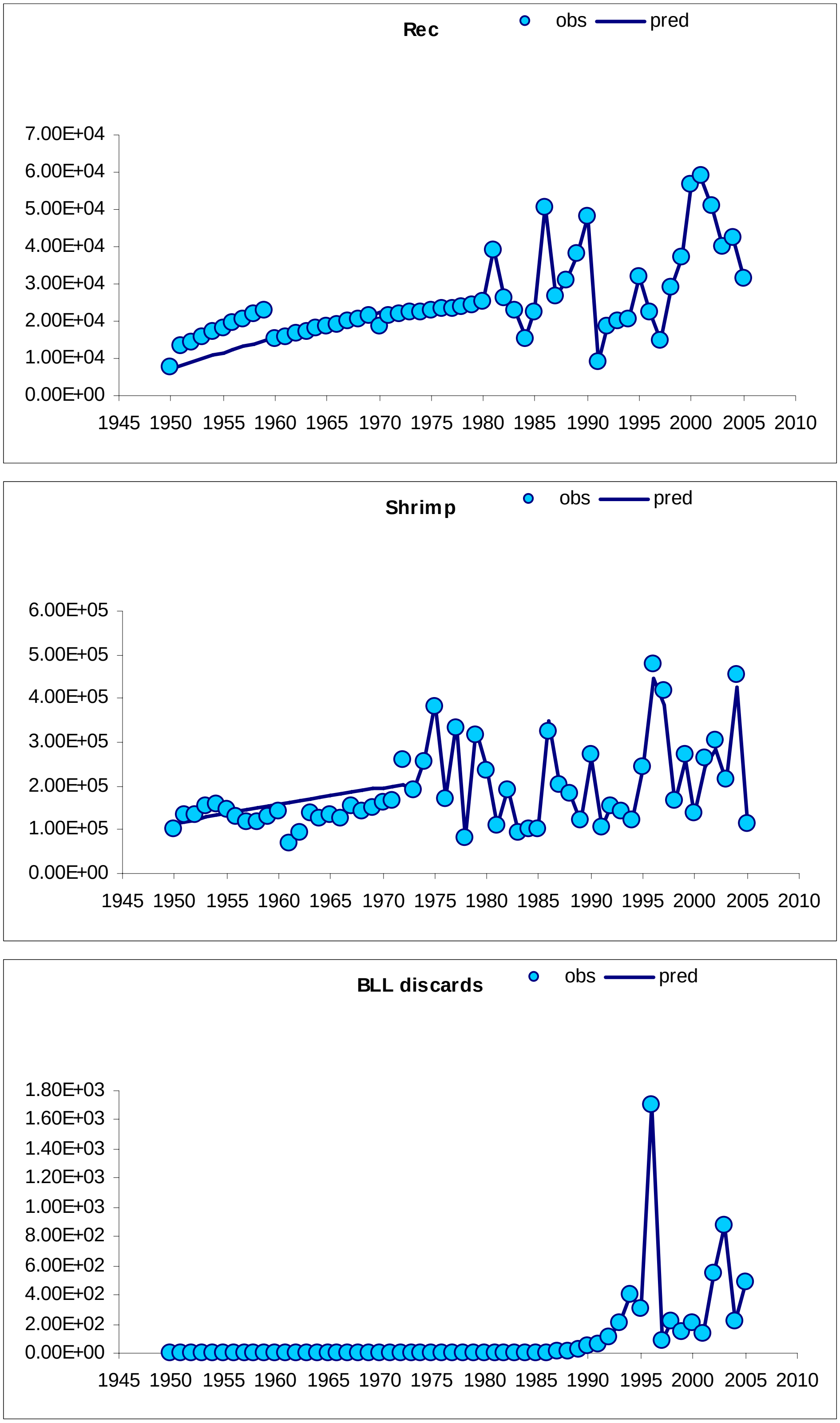
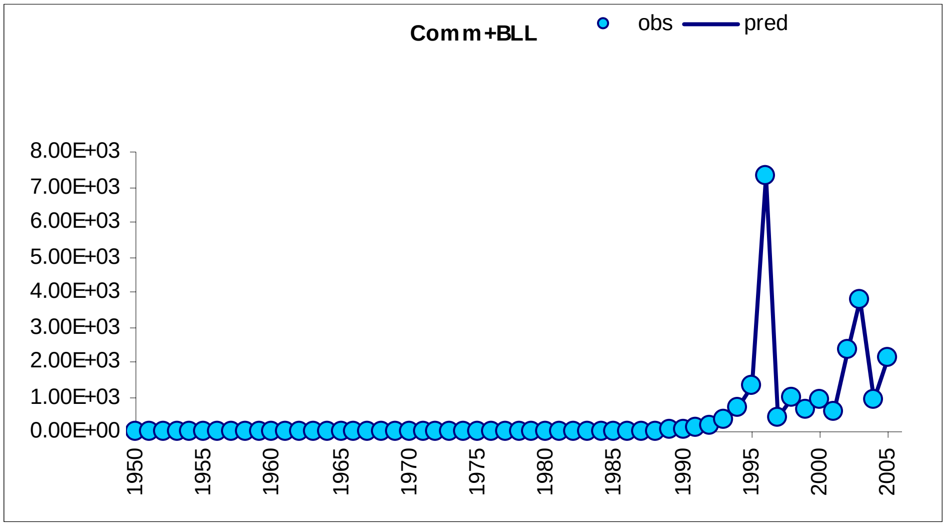
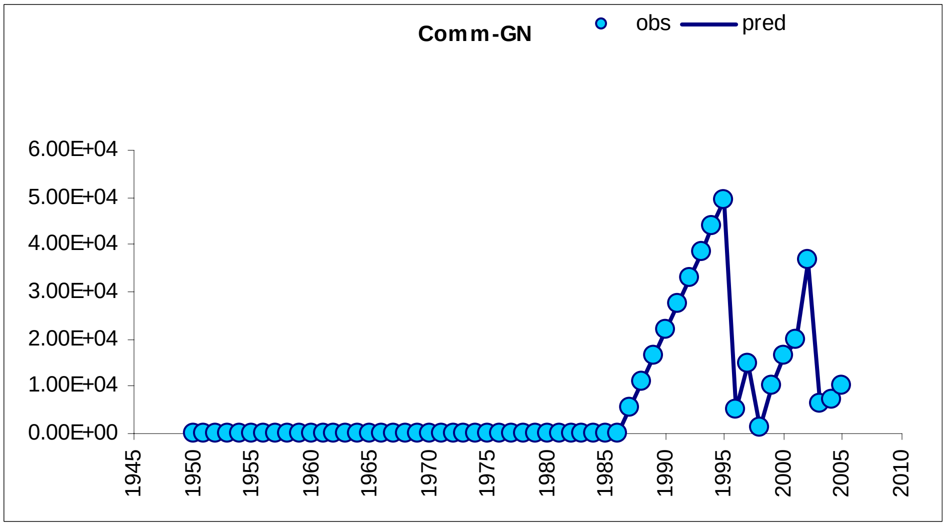


Figure 6.5. **Bonnethead shark** model predicted fit to catch data. Circles represent observed data, solid line is predicted.





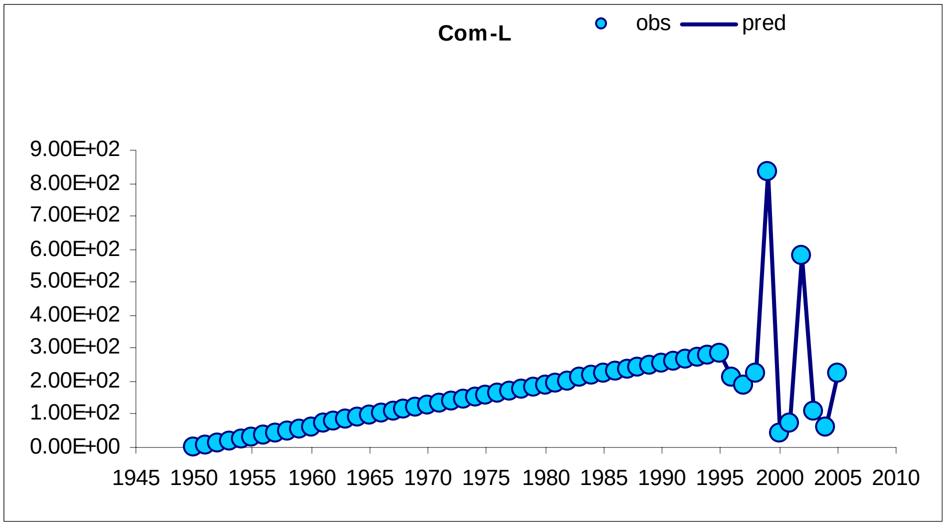


Figure 6.5 (Continued).

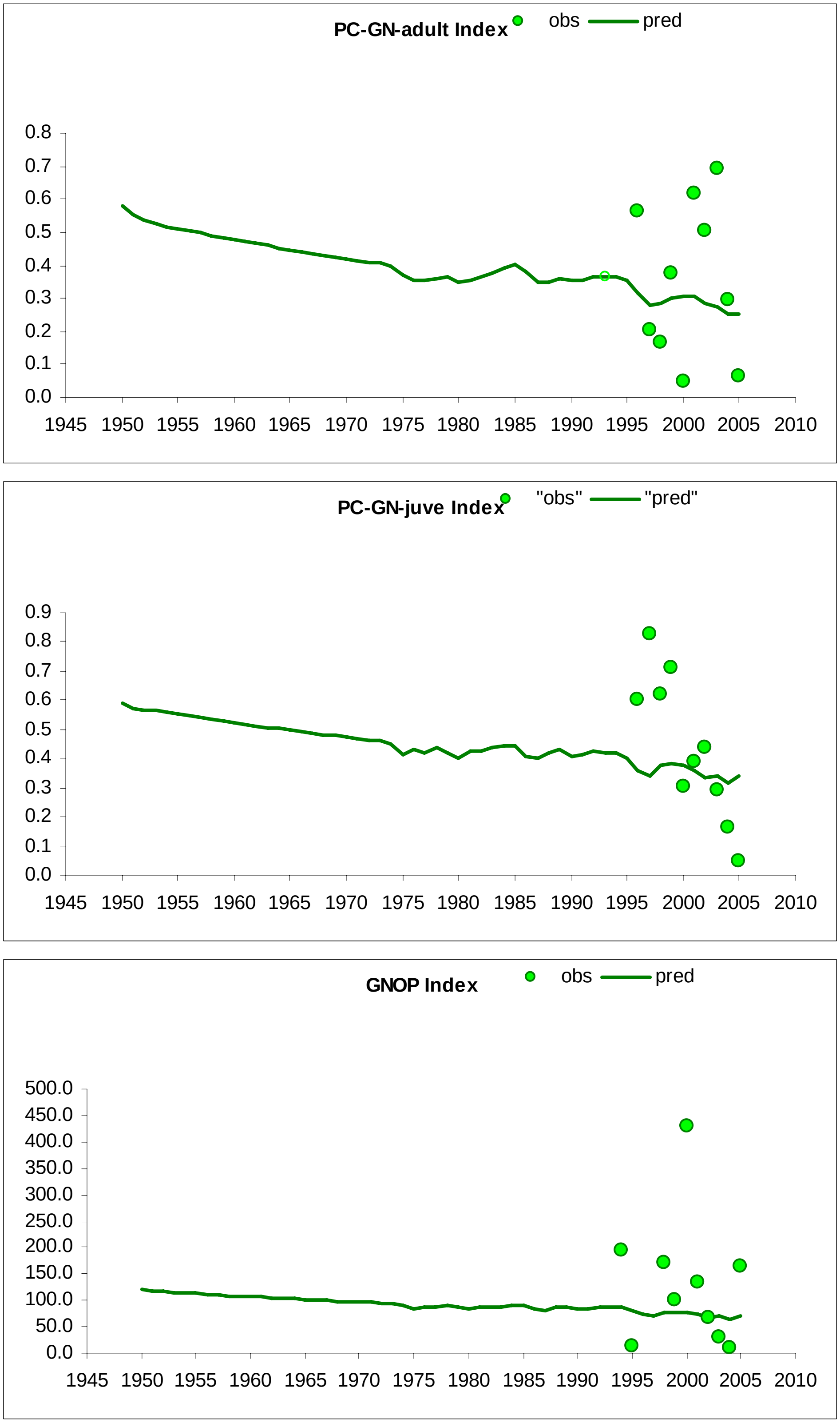
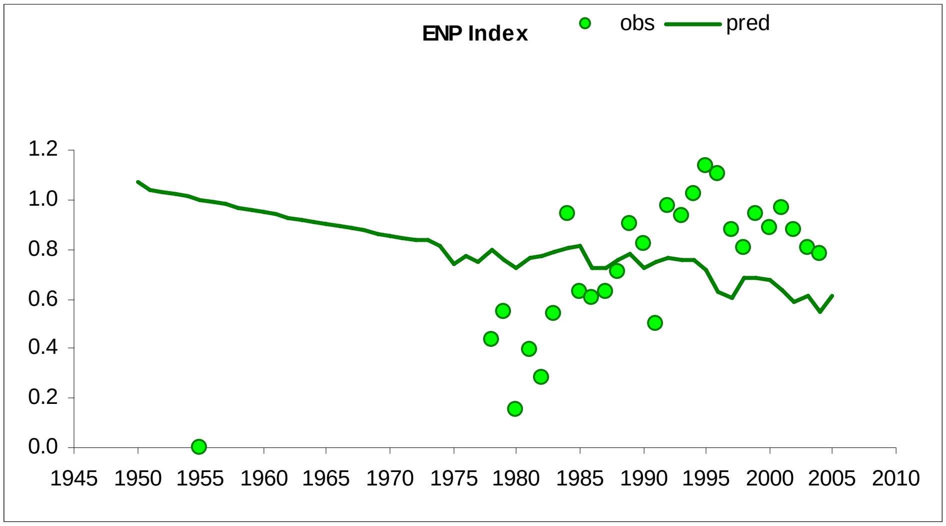
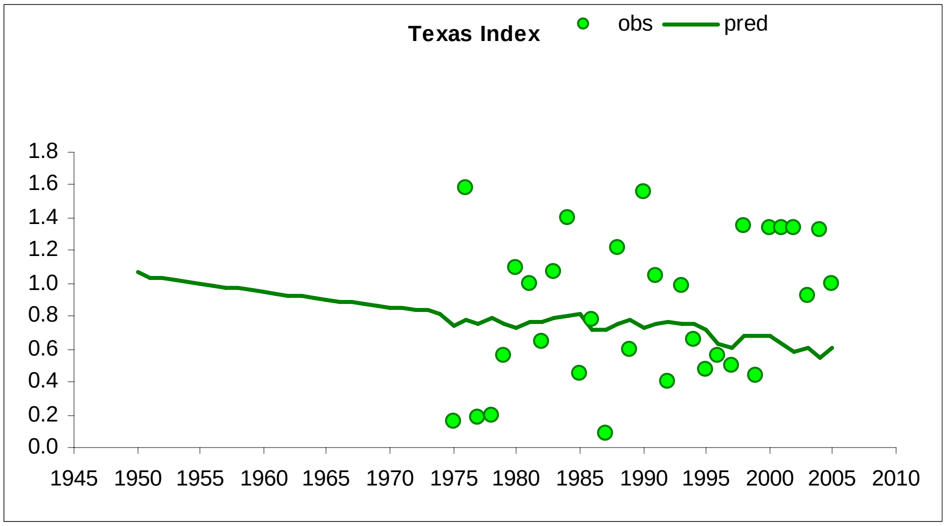


Figure 6.6. **Bonnethead shark** model predicted fit to indices. Circles represent observed data, solid line is predicted.



4



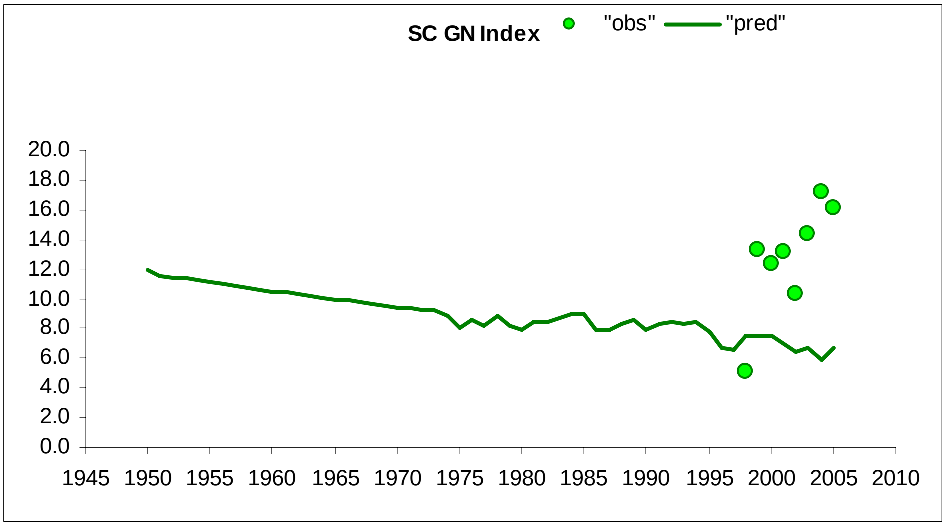


Figure 6.6. (Continued).

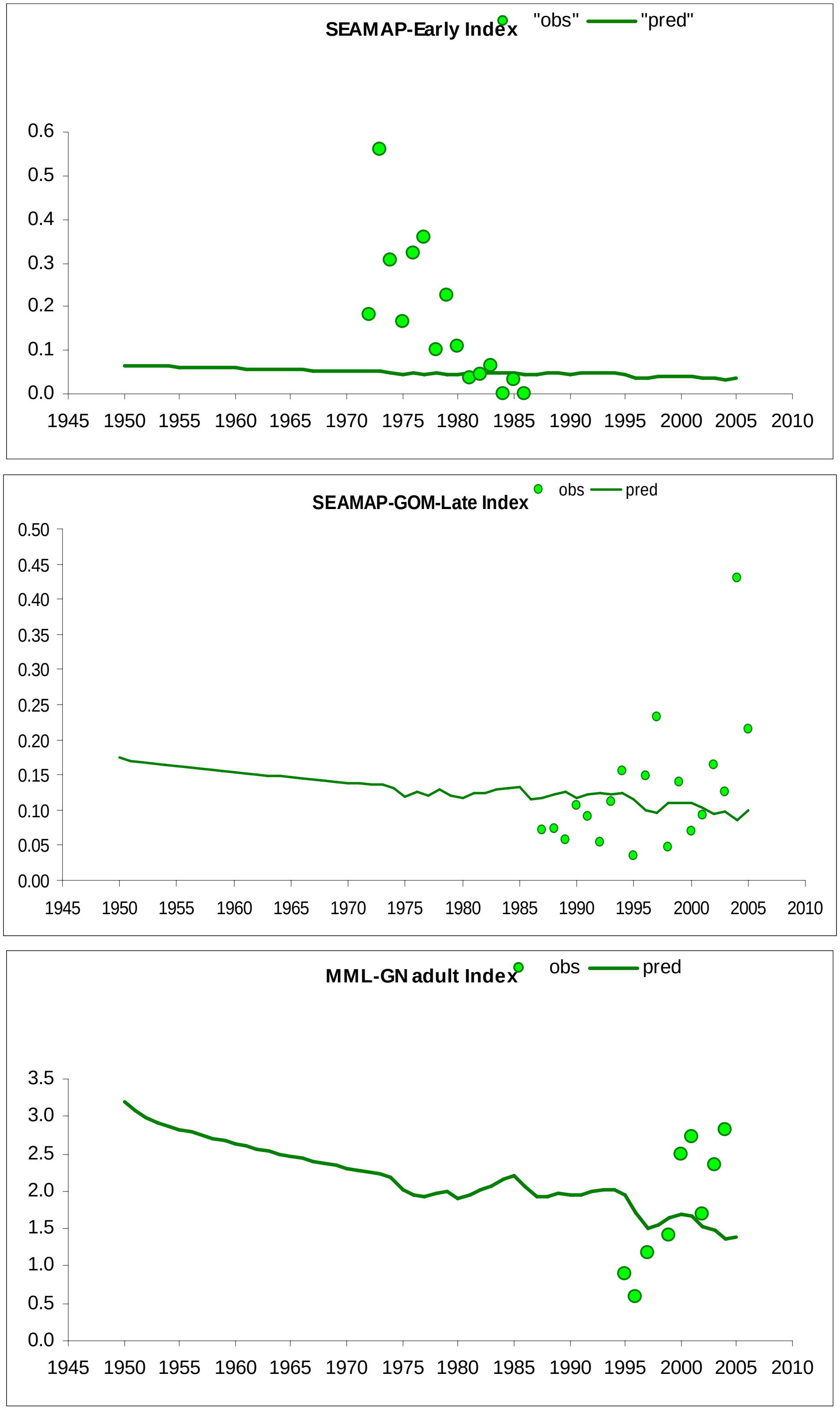
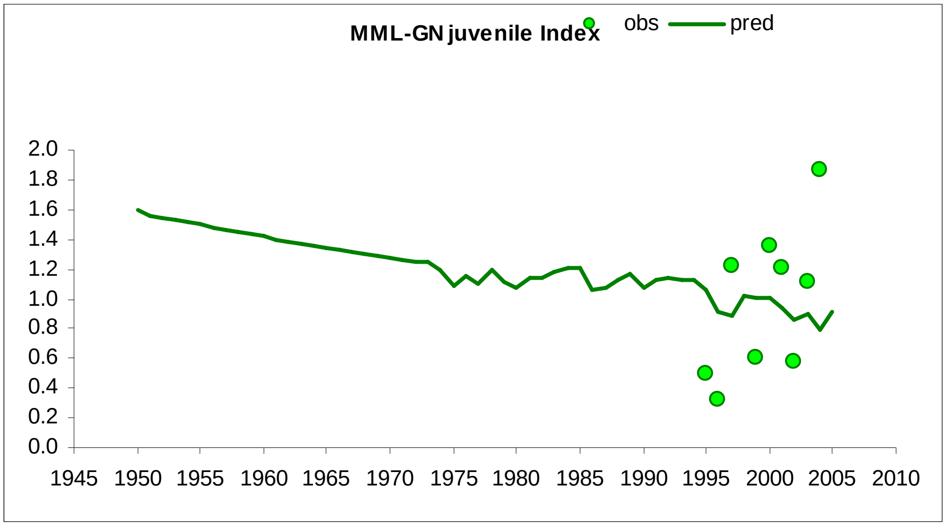


Figure 6.6. (Continued).



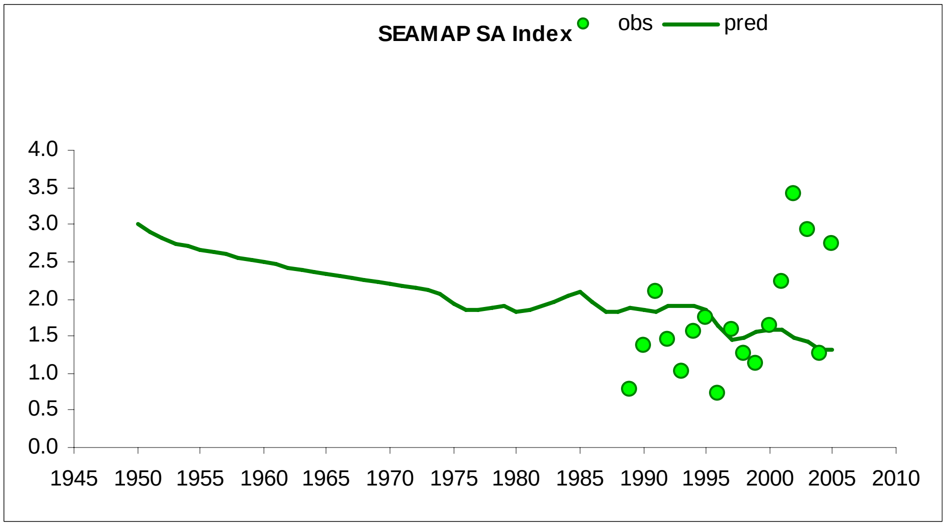


Figure 6.6. (Continued).

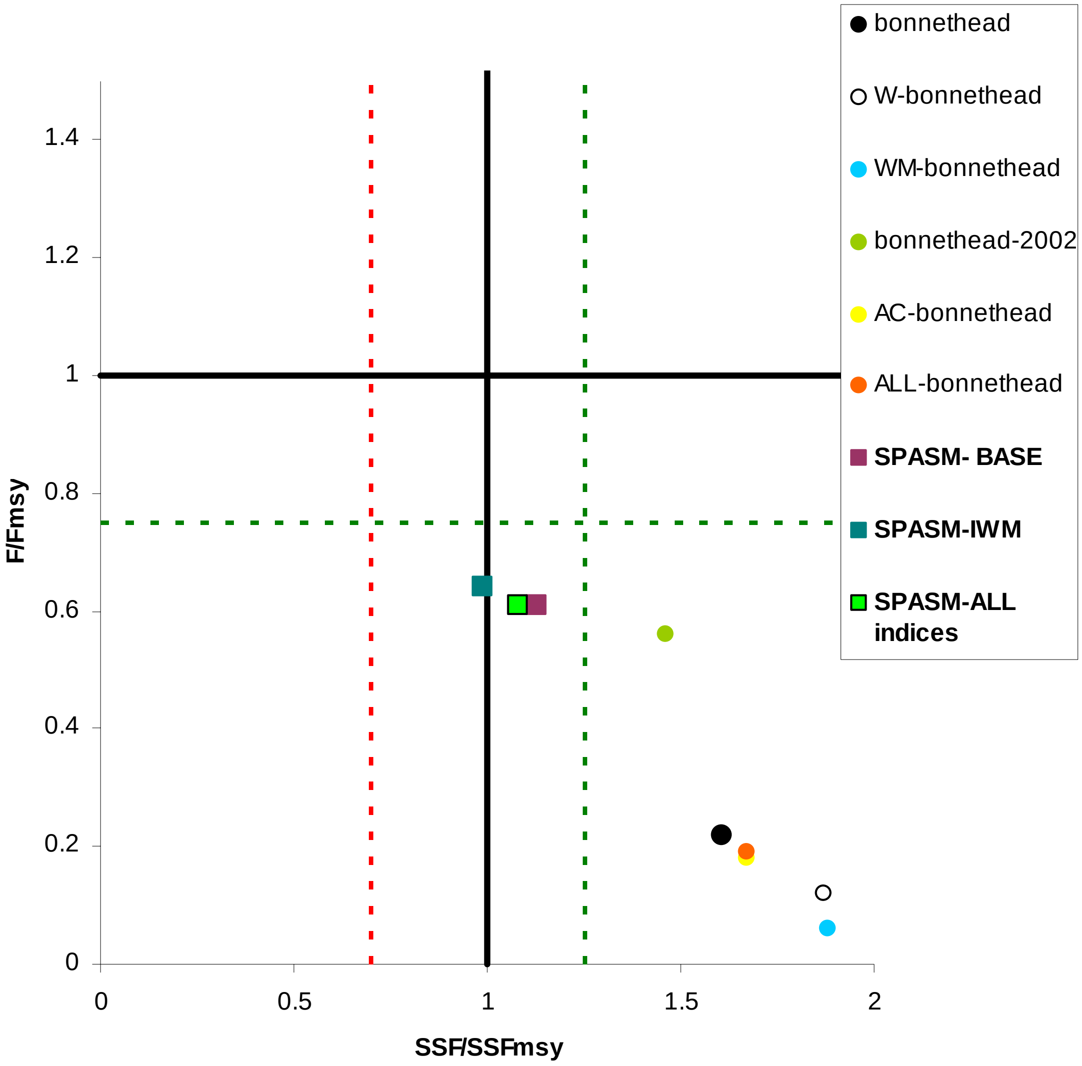


Figure 6.7. Phase-plot of **bonnethead shark** stock status. Baseline and selected sensitivity analyses from the surplus production models (SPM) and the stock status from the 2002 assessment are included for reference. The age-structured models are in bold and include BASE, S1 (IWM), and S2 (all indices). The SPM sensitivities are as follows: W— WinBUGS**,** complementary surplus production model. WM—SPM sensitivity to weighting scheme used: this involved changing the method for weighting the CPUE series from equal weighting in the baseline scenario to inverse variance weighting. IF—SPM sensitivity to importance function used: this involved changing the importance function from the priors to a multivariate t distribution. AC—SPM sensitivity to extending the catch series back to 1950. ALL—SPM sensitivity adding the CPUE series identified as "sensitivity" to those in the baseline scenario. 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). 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).

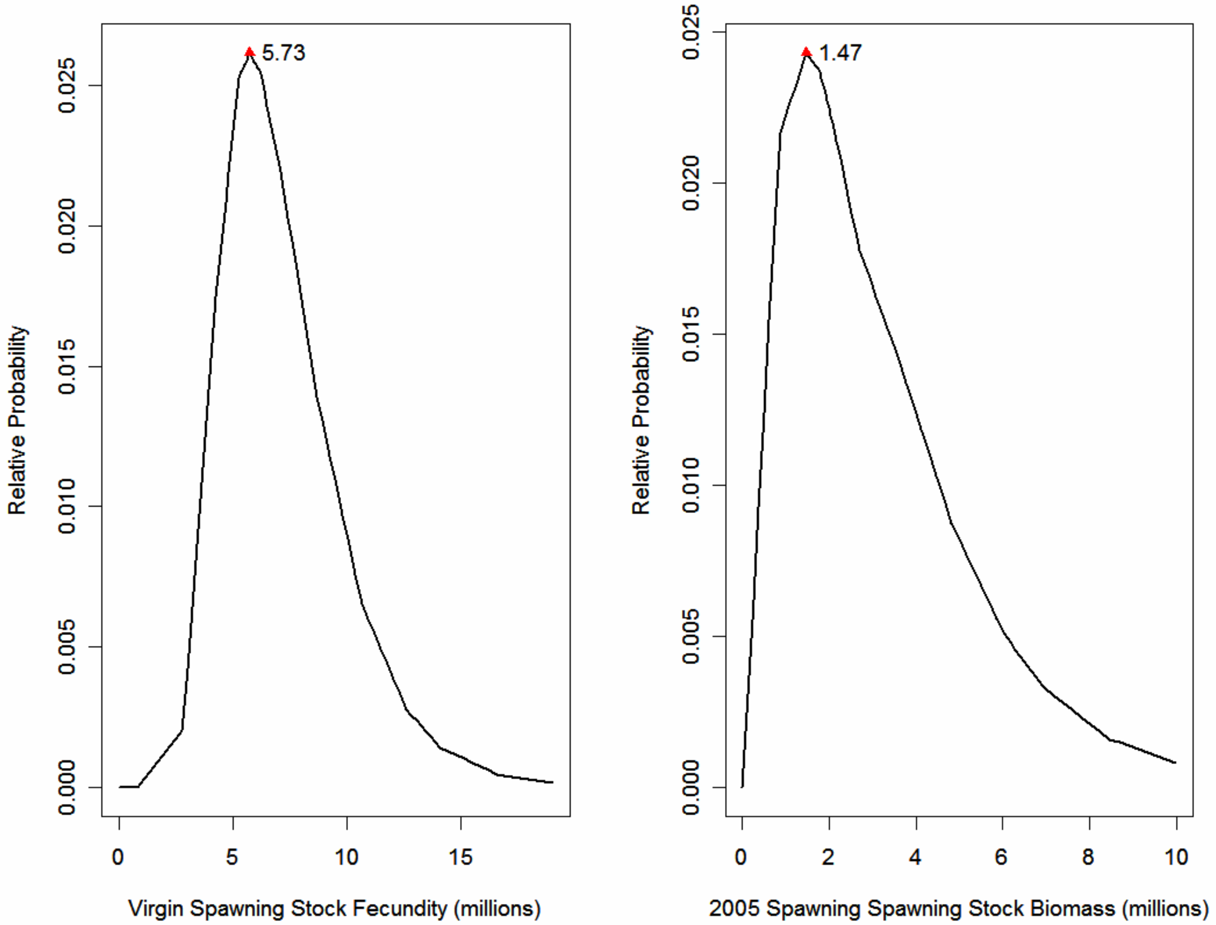


Figure 6.8. **Bonnethead shark** profile likelihoods for virgin number, current abundance, and spawning stock fecundity, as well as depletion estimates of these parameters. The red triangles are the modes of the distributions.

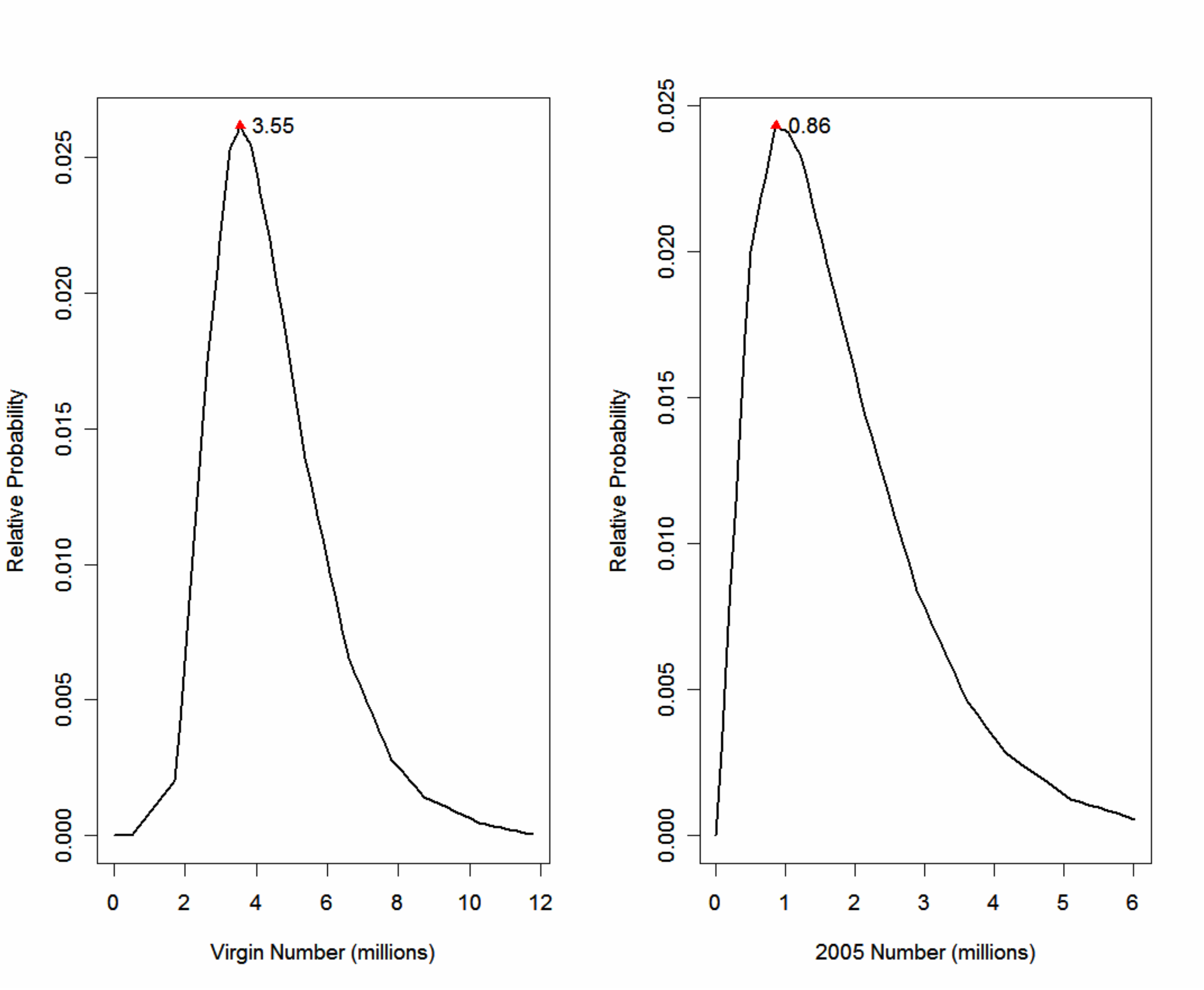


Figure 6.8 (Continued).

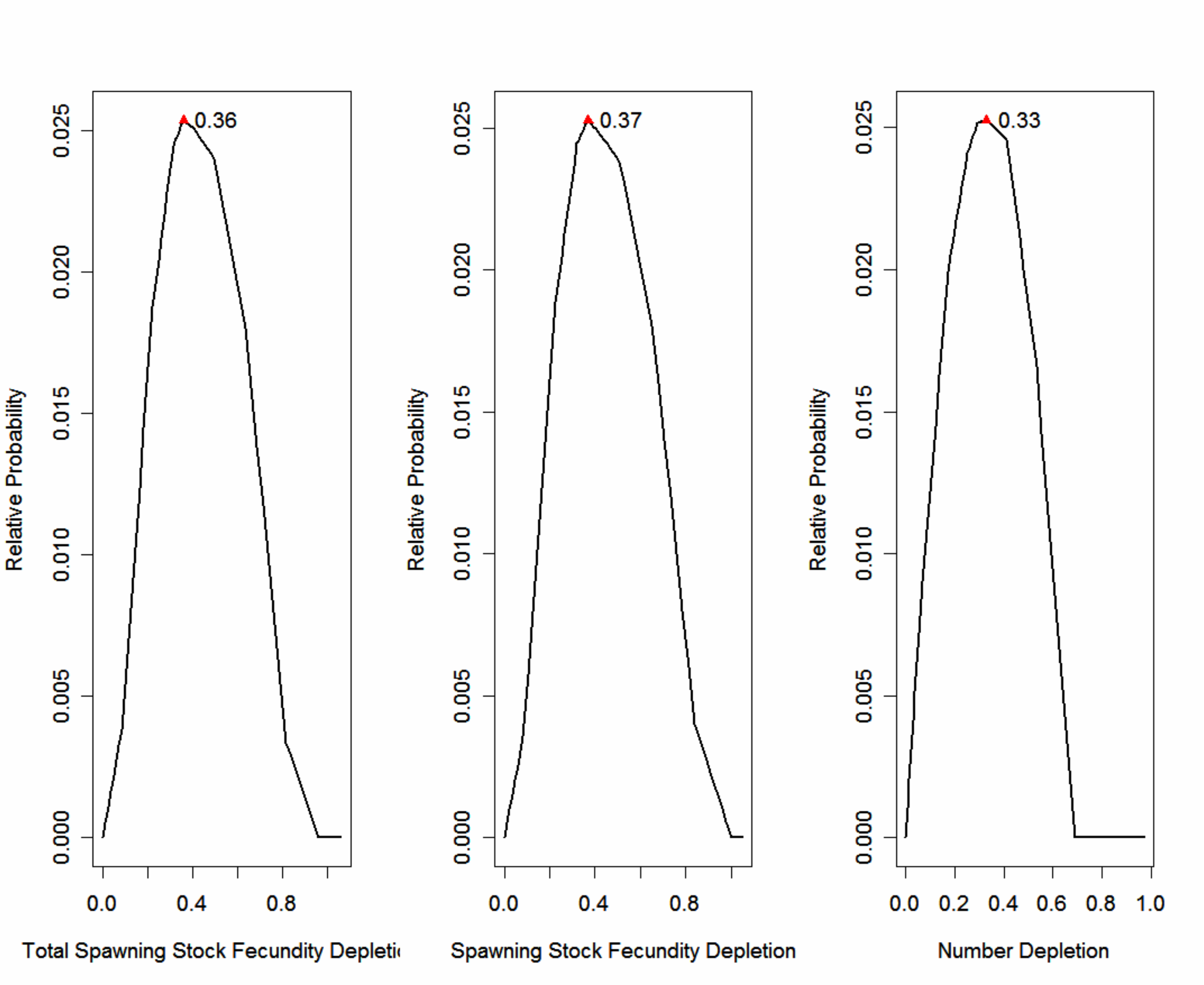


Figure 6.8 (Continued).

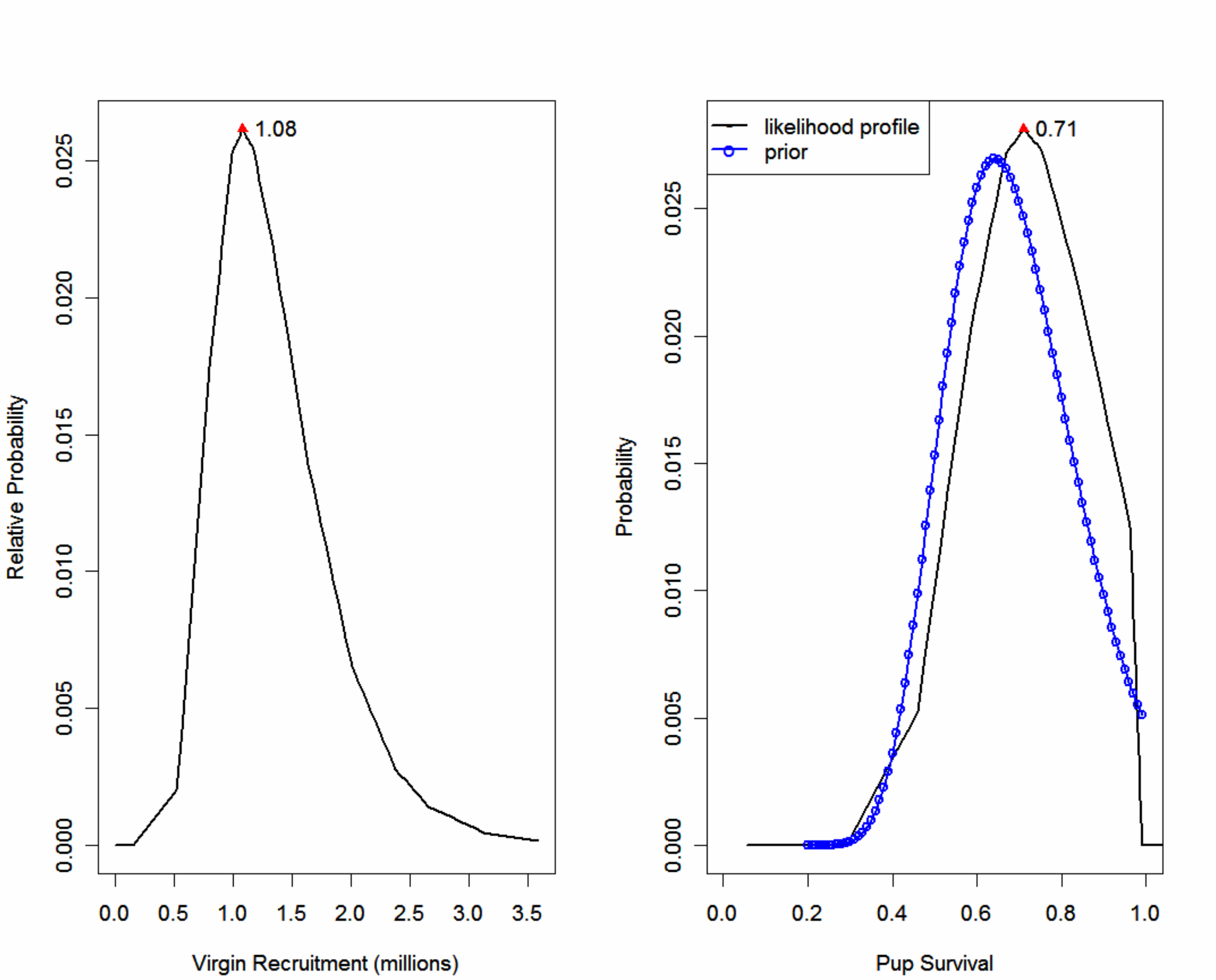


Figure 6.9. **Bonnethead shark** profile likelihoods for pup survival and virgin recruitment, and for pup survival, the prior is also plotted. The red triangles are the modes of the distributions.

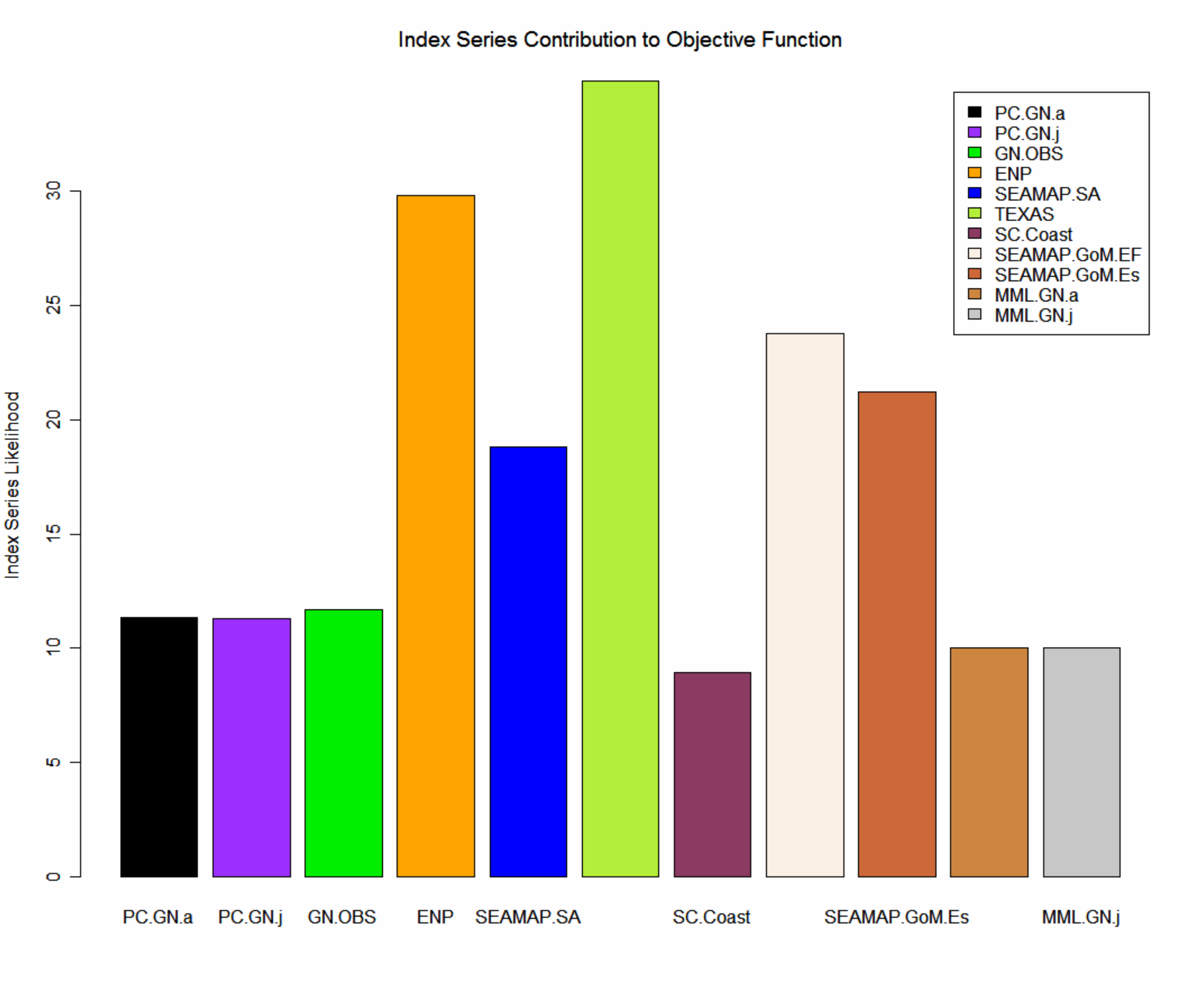


Figure 6.10. The contribution of the indices to the relative likelihood by category for **bonnethead sharks**.

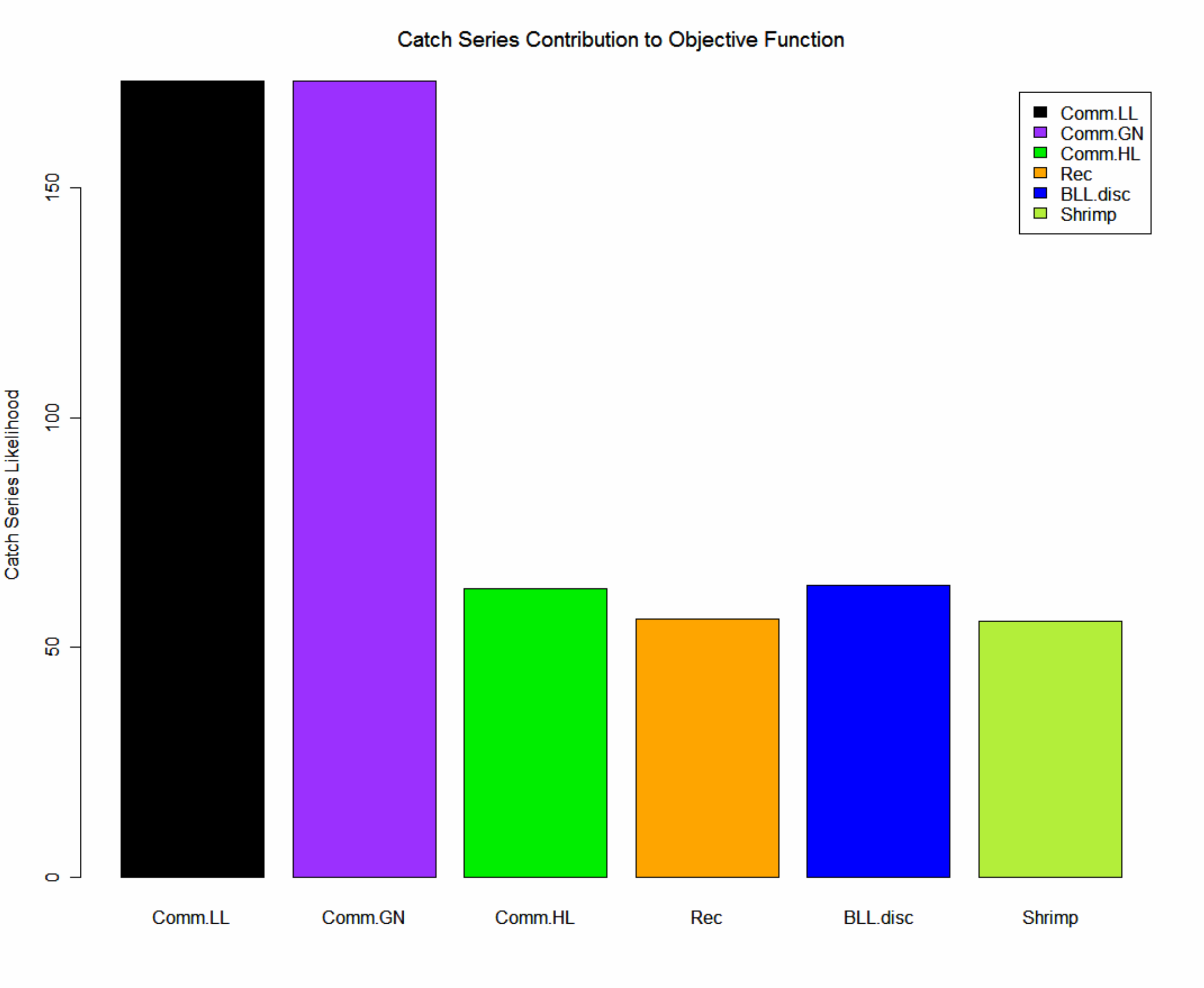


Figure 6.11. Catch series and model source contributions to relative likelihood by category for **bonnethead sharks**.

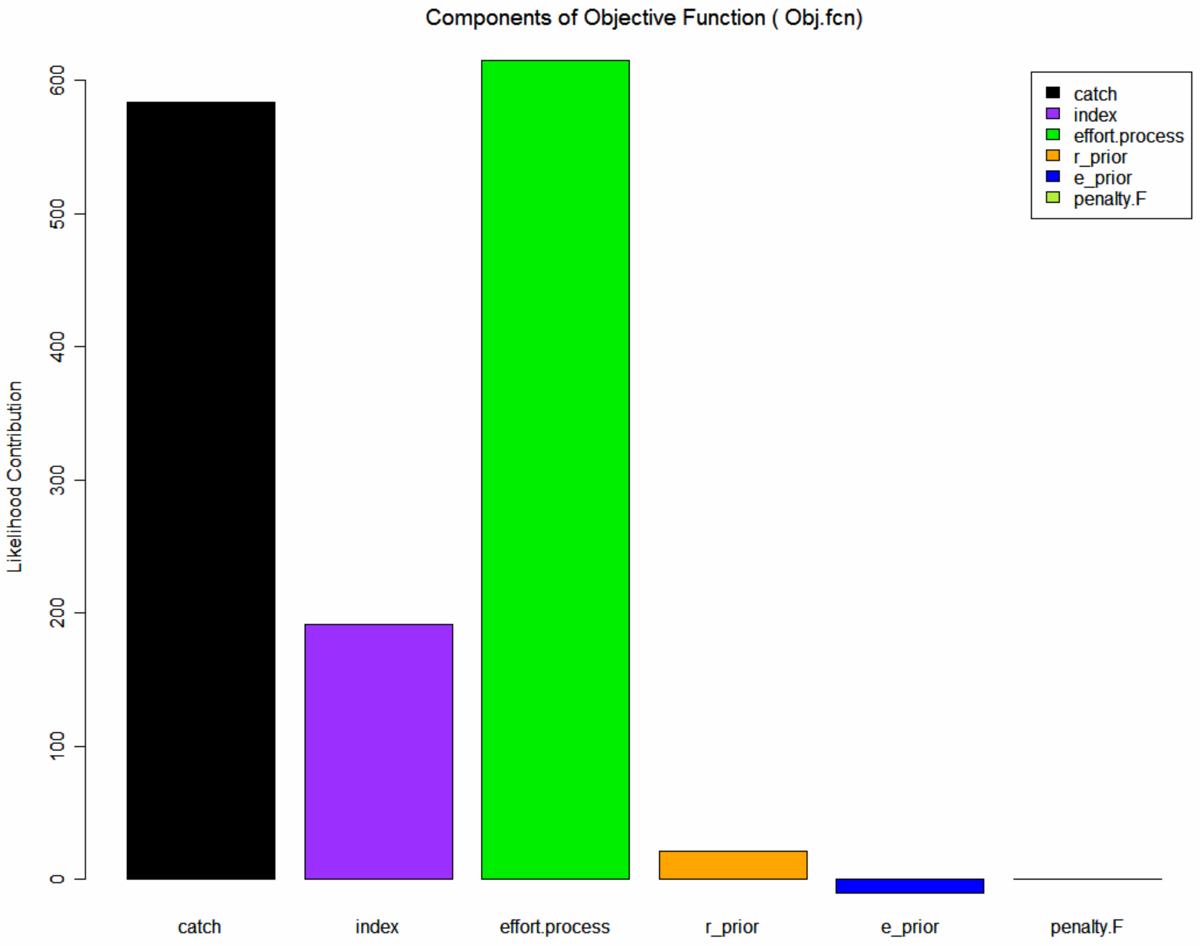


Figure 6.11. (Continued).

Appendix I. Catch rates series used for the small coastal shark complex, Atlantic sharpnose, blacknose, bonnethead, and finetooth sharks. Absolute index is the absolute estimated mean CPUE, relative index is the estimated mean CPUE divided by the overall mean 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). Recommendation refers to the recommendation by the Indices Working Group to include the particular index as a base index (Base) or use it for sensitivity runs (Sensitivity).

Small Coastal Shark Complex

					Index		
Document Number	Series Name	Type	Recommendation	Year	Absolute	Relative	CV
SEDAR 13-DW-05	PC LL	FI	Base	1993	0.517	0.843	0.507
				1994	0.235	0.383	0.544
				1995	0.343	0.559	0.483
				1996	1.073	1.750	0.092
				1997	0.594	0.969	0.185
				1998	0.439	0.716	0.378
				1999	1.170	1.908	0.116
				2000	0.534	0.871	0.296
SEDAR 13-DW-06	PC Gillnet	FI	Base	1996	5.091	1.817	0.238
				1997	14.715	5.251	0.144
				1998	1.121	0.400	1.436
				1999	1.174	0.419	1.253
				2000	0.697	0.249	1.294
				2001	1.327	0.474	0.732
				2002	1.167	0.416	1.013
				2003	1.454	0.519	0.531
				2004	0.668	0.238	0.896
				2005	0.611	0.218	0.645
SEDAR 13-DW-09	Gillnet Obs	FD-C	Base	1993	3.014	0.149	0.879
				1994	9.942	0.490	0.172
				1995	10.934	0.539	0.218
				1996			
				1997			
				1998	20.516	1.011	0.130
				1999	12.287	0.606	0.109
				2000	9.998	0.493	0.140
				2001	5.548	0.273	0.220
				2002	72.233	3.560	0.016
				2003	11.597	0.572	0.133
				2004	8.254	0.407	0.180
				2005	58.842	2.900	0.029
SEDAR 13-DW-12	BLLOP	FD-C	Base	1994	0.000	0.068	11.142
				1995	0.004	0.714	1.797
				1996	0.003	0.425	2.412
				1997	0.004	0.595	2.171

				1998	0.006	1.088	1.292
				1999	0.021	3.535	0.890
				2000	0.014	2.346	1.241
				2001	0.009	1.547	1.420
				2002	0.002	0.255	2.922
				2003	0.002	0.357	2.344
				2004	0.003	0.493	2.083
				2005	0.003	0.578	1.346
SEDAR 13-DW-14	SEAMAP - SA	FI	Base	1989	4.138	0.878	0.283
				1990	3.543	0.752	0.285
				1991	4.059	0.861	0.269
				1992	3.530	0.749	0.254
				1993	2.569	0.545	0.293
				1994	2.747	0.583	0.301
				1995	4.433	0.940	0.221
				1996	2.169	0.460	0.306
				1997	4.790	1.016	0.237
				1998	3.817	0.810	0.243
				1999	3.664	0.777	0.252
				2000	4.532	0.961	0.243
				2001	4.998	1.060	0.193
				2002	7.635	1.620	0.165
				2003	7.170	1.521	0.191
				2004	4.576	0.971	0.216
				2005	6.195	1.314	0.218
				2006	10.279	2.181	0.174
SEDAR 13-DW-18	Texas	FI	Base	1975	0.044	0.726	0.710
				1976	0.073	1.206	0.300
				1977	0.021	0.347	0.555
				1978	0.021	0.349	0.555
				1979	0.041	0.669	0.342
				1980	0.062	1.019	0.248
				1981	0.024	0.399	0.371
				1982	0.042	0.699	0.214
				1983	0.077	1.263	0.167
				1984	0.085	1.404	0.149
				1985	0.056	0.915	0.203
				1986	0.084	1.387	0.148
				1987	0.014	0.234	0.444
				1988	0.077	1.272	0.155
				1989	0.053	0.879	0.187
				1990	0.072	1.182	0.162
				1991	0.076	1.244	0.175
				1992	0.050	0.822	0.235
				1993	0.063	1.036	0.198
				1994	0.052	0.859	0.200
				1995	0.046	0.751	0.213

				1996	0.076	1.256	0.150
				1997	0.051	0.844	0.256
				1998	0.058	0.961	0.203
				1999	0.065	1.077	0.165
				2000	0.078	1.282	0.152
				2001	0.082	1.349	0.171
				2002	0.074	1.218	0.181
				2003	0.093	1.536	0.152
				2004	0.084	1.387	0.165
				2005	0.080	1.325	0.161
				2006	0.067	1.103	0.227
SEDAR 13-DW-21	MS Gillnet	FI	Sensitivity	2001	3.399	1.959	0.294
				2002			
				2003	1.401	0.807	0.509
				2004	1.176	0.678	0.298
				2005	1.465	0.844	0.277
				2006	1.235	0.712	0.232
SEDAR 13-DW-22	NMFS LL SE Atlantic	FI	Base	1995	1.977	0.210	0.310
				1996	1.839	0.195	0.335
				1997	2.481	0.263	0.321
				1998			
				1999	1.039	0.110	0.624
				2000	4.819	0.511	0.161
				2001			
				2002	14.822	1.571	0.128
				2003			
				2004	14.495	1.536	0.224
				2005	21.566	2.286	0.310
				2006	21.866	2.318	0.185
SEDAR 13-DW-22	NMFS LL SE GoM	FI	Base	1995	2.141	0.592	0.268
				1996	3.424	0.947	0.272
				1997	1.915	0.530	0.225
				1998		0.000	
				1999	1.799	0.498	0.174
				2000	3.765	1.042	0.162
				2001	2.996	0.829	0.188
				2002	3.723	1.030	0.175
				2003	5.410	1.497	0.146
				2004	5.542	1.533	0.157
				2005	4.330	1.198	0.301
				2006	4.715	1.305	0.183
SEDAR 13-DW-22	NMFS LL SE combined areas	FI	Base	1995	2.394	0.507	0.197
				1996	3.506	0.742	0.216
				1997	2.996	0.634	0.166
				1998			
				1999	1.962	0.415	0.171

				2000	4.133	0.875	0.114
				2001	3.707	0.785	0.176
				2002	5.251	1.111	0.132
				2003	6.868	1.454	0.133
				2004	7.157	1.515	0.132
				2005	7.582	1.605	0.236
				2006	6.414	1.358	0.154
SEDAR 13-DW-26	Gillnet Logs	FD-C	Sensitivity	1998	0.058	0.780	0.870
				1999	0.074	0.995	0.818
				2000	0.063	0.847	0.769
				2001	0.068	0.922	0.752
				2002	0.100	1.356	0.731
				2003	0.053	0.710	0.807
				2004	0.054	0.727	0.917
				2005	0.123	1.664	0.653
SEDAR 13-DW-30	SC Coastspan GN	FI	Base	1998	19.412	0.671	0.365
				1999			
				2000	24.300	0.840	0.293
				2001	30.937	1.070	0.157
				2002	26.974	0.933	0.170
				2003	43.688	1.511	0.127
				2004	29.077	1.006	0.513
				2005	28.029	0.969	0.190
SEDAR 13-DW-30	SCDNR red drum	FI	Base	1998	0.156	0.968	0.726
				1999	0.093	0.576	1.115
				2000	0.149	0.921	1.049
				2001	0.240	1.488	0.797
				2002	0.249	1.538	0.866
				2003	0.197	1.219	0.827
				2004	0.071	0.437	2.644
				2005	0.138	0.852	3.029
SEDAR 13-DW-31	SEAMAP-GoM Extended Summer	FI	Base	1982	0.720	0.925	2.001
				1983	3.042	3.906	1.517
				1984	0.864	1.110	1.952
				1985	1.555	1.997	1.860
				1986	0.720	0.925	1.927
				1987	0.689	0.884	0.439
				1988	0.596	0.765	0.401
				1989	0.651	0.836	0.464
				1990	0.199	0.256	0.540
				1991	0.811	1.041	0.383
				1992	0.576	0.740	0.423
				1993	0.821	1.054	0.400
				1994	0.228	0.292	0.488
				1995	1.072	1.376	0.394
				1996	1.103	1.416	0.382

				1997	0.626	0.803	0.431
				1998	0.473	0.607	0.411
				1999	0.570	0.732	0.423
				2000	0.805	1.033	0.423
				2001	0.427	0.548	0.588
				2002	0.789	1.013	0.405
				2003	0.510	0.654	0.468
				2004	0.428	0.550	0.435
				2005	0.389	0.499	0.467
				2006	0.808	1.037	0.402
SEDAR 13-DW-31	SEAMAP-GoM Extended Fall	FI	Base	1972	0.814	0.956	0.525
				1973	1.229	1.443	0.428
				1974	2.116	2.485	0.417
				1975	1.871	2.197	0.421
				1976	2.046	2.402	0.415
				1977	1.164	1.367	0.430
				1978	0.928	1.089	0.438
				1979	1.192	1.399	0.431
				1980	1.709	2.007	0.429
				1981	1.094	1.285	0.438
				1982	1.215	1.426	0.426
				1983	1.044	1.225	0.463
				1984	0.782	0.918	0.457
				1985	1.268	1.488	0.509
				1986	0.651	0.764	0.846
				1987	0.854	1.002	0.299
				1988	0.518	0.608	0.285
				1989	0.364	0.427	0.316
				1990	0.585	0.687	0.297
				1991	0.355	0.417	0.285
				1992	0.323	0.380	0.304
				1993	0.513	0.603	0.282
				1994	0.629	0.739	0.283
				1995	0.448	0.526	0.293
				1996	0.692	0.812	0.272
				1997	0.556	0.652	0.279
				1998	0.369	0.434	0.315
				1999	0.535	0.628	0.275
				2000	0.590	0.693	0.291
				2001	0.455	0.534	0.284
				2002	0.499	0.585	0.288
				2003	0.610	0.716	0.265
				2004	0.488	0.573	0.290
				2005	0.847	0.994	0.274
				2006	0.457	0.536	0.293
SEDAR 13-DW-34	UNC	FI	Base	1972	3.163	0.856	1.549
				1973	4.983	1.348	0.530
				1974	1.497	0.405	1.608

				1975	2.893	0.782	0.687
				1976	2.183	0.590	0.879
				1977	5.669	1.533	0.359
				1978	4.574	1.237	0.386
				1979	3.865	1.046	0.430
				1980	2.579	0.697	0.484
				1981	1.143	0.309	1.039
				1982	1.538	0.416	0.645
				1983	2.145	0.580	0.462
				1984	2.383	0.644	0.469
				1985	2.116	0.572	0.571
				1986	1.426	0.386	0.958
				1987	2.638	0.713	0.566
				1988	4.012	1.085	0.362
				1989	2.050	0.555	0.733
				1990	2.206	0.597	0.576
				1991	4.629	1.252	0.319
				1992	8.752	2.367	0.246
				1993	4.138	1.119	0.552
				1994	3.981	1.077	0.414
				1995	6.372	1.724	0.234
				1996	4.272	1.156	0.371
				1997	3.443	0.931	0.477
				1998	3.795	1.026	0.382
				1999	3.029	0.819	0.468
				2000	4.197	1.135	0.341
				2001			
				2002	4.831	1.307	0.347
				2003	6.917	1.871	0.288
				2004	6.883	1.862	0.274
				2005			
SEDAR 13-DW-38	MML Gillnet	FI	Base	1995	1.559	0.464	0.171
				1996	1.242	0.370	0.336
				1997	2.793	0.831	0.148
				1998			
				1999	2.441	0.727	0.190
				2000	4.185	1.246	0.197
				2001	5.070	1.509	0.158
				2002	2.978	0.887	0.178
				2003	4.300	1.280	0.190
				2004	5.665	1.686	0.165

Finetooth shark

					Index		
Document Number	Series Name	Type	Recommendation	Year	Absolute	Relative	CV
SEDAR 13-DW-05	PC LL	FI	Sensitivity	1993	0.014	0.418	3.924

				1994	0.046	1.373	0.610
				1995	0.012	0.358	2.759
				1996	0.123	3.672	0.182
				1997	0.057	1.701	0.425
				1998	0.006	0.179	6.800
				1999	0.010	0.299	2.972
				2000	0.000	0.000	0.000
SEDAR 13-DW-06	PC Gillnet	FI	Base	1996	0.479	0.763	0.391
				1997	1.363	2.174	0.291
				1998	0.051	0.081	0.915
				1999	0.840	1.339	0.465
				2000	0.252	0.401	0.833
				2001	0.589	0.940	0.519
				2002	0.451	0.719	0.504
				2003	1.147	1.828	0.361
				2004	0.447	0.712	0.551
				2005	0.654	1.043	0.476
SEDAR 13-DW-09	Gillnet Obs	FD-C	Base	1993	75.596	0.483	1.024
				1994	44.255	0.283	0.897
				1995	30.002	0.192	1.546
				1996			
				1997			
				1998	0.926	0.006	0.999
				1999	44.518	0.284	0.764
				2000	945.377	6.035	0.707
				2001	68.730	0.439	0.718
				2002	77.065	0.492	0.888
				2003	57.723	0.368	1.096
				2004	8.280	0.053	1.115
				2005	370.709	2.366	0.766
SEDAR 13-DW-18	Texas	FI	Base	1976	0.007	0.624	1.069
				1977			
				1978			
				1979	0.005	0.484	1.067
				1980	0.012	1.058	0.579
				1981	0.008	0.704	0.752
				1982	0.012	1.037	0.407
				1983	0.018	1.555	0.354
				1984	0.012	1.093	0.406
				1985	0.010	0.848	0.499
				1986	0.016	1.399	0.351
				1987			
				1988	0.005	0.451	0.752
				1989	0.006	0.556	0.584
				1990	0.024	2.116	0.286
				1991	0.012	1.074	0.445
				1992	0.011	0.974	0.502

				1993	0.003	0.279	1.066
				1994	0.013	1.123	0.407
				1995	0.015	1.293	0.378
				1996	0.026	2.323	0.264
				1997	0.008	0.748	0.752
				1998			
				1999	0.008	0.668	0.499
				2000	0.018	1.584	0.332
				2001	0.003	0.282	1.066
				2002	0.010	0.915	0.499
				2003	0.020	1.730	0.336
				2004	0.012	1.024	0.449
				2005	0.009	0.801	0.499
				2006	0.003	0.255	0.500
SEDAR 13-DW-21	MS Gillnet	FI	Sensitivity	2001	0.180	0.435	0.842
				2002			
				2003	0.562	1.360	0.656
				2004	0.481	1.162	0.626
				2005	0.398	0.962	0.502
				2006	0.447	1.080	0.447
SEDAR 13-DW-26	Gillnet Logs	FD - C	Sensitivity	1998	0.002	0.842	5.796
				1999	0.000	0.141	12.628
				2000	0.001	0.410	5.755
				2001	0.001	0.674	4.470
				2002	0.001	0.413	9.181
				2003	0.003	1.193	4.535
				2004	0.002	0.844	9.364
				2005	0.008	3.483	2.823
SEDAR 13-DW-30	SC Coastspan GN	FI	Base	1998	6.303	0.766	0.851
				1999	4.878	0.593	1.267
				2000	6.423	0.780	0.783
				2001	13.024	1.582	0.284
				2002	12.751	1.549	0.344
				2003	13.754	1.671	0.312
				2004	2.864	0.348	1.994
				2005	5.858	0.712	0.503

Blacknose shark

					Index		
Document Number	Series Name	Type	Recommendation	Year	Absolute	Relative	CV
SEDAR 13-DW-05	PC LL	FI	Sensitivity	1993	0.008	0.212	6.171
				1994	0.076	2.013	0.282
				1995	0.021	0.556	1.332
				1996			

				1997	0.017	0.450	1.201
				1998	0.032	0.848	0.981
				1999	0.052	1.377	0.493
				2000	0.096	2.543	0.294
SEDAR 13-DW-06	PC Gillnet - Adult	FI	Base	1996	0.446	2.164	0.269
				1997	0.161	0.781	0.710
				1998	0.156	0.757	0.724
				1999	0.308	1.494	0.833
				2000	0.025	0.121	5.613
				2001	0.157	0.762	0.971
				2002	0.242	1.174	0.741
				2003	0.216	1.048	0.759
				2004	0.232	1.126	0.763
				2005	0.118	0.573	1.159
SEDAR 13-DW-06	PC Gillnet - juvi	FI	Base	1996	0.168	1.507	0.356
				1997	0.082	0.735	0.351
				1998	0.069	0.619	0.250
				1999	0.086	0.771	0.268
				2000	0.105	0.942	0.282
				2001	0.114	1.022	0.289
				2002	0.124	1.112	0.300
				2003	0.117	1.049	0.296
				2004	0.131	1.175	0.309
				2005	0.119	1.067	0.294
SEDAR 13-DW-09	Gillnet Obs	FD-C	Base	1993	12.832	0.143	1.321
				1994	110.912	1.234	0.801
				1995	14.734	0.164	1.166
				1996			
				1997			
				1998	39.207	0.436	0.991
				1999	55.567	0.618	0.646
				2000	96.643	1.075	0.680
				2001	40.011	0.445	0.639
				2002	143.840	1.601	0.578
				2003	63.992	0.712	0.675
				2004	46.179	0.514	0.658
				2005	251.732	2.801	0.747
SEDAR 13-DW-12	BLLOP	FD-C	Base	1994	17.126	0.305915	0.615
				1995	41.156	0.735152	0.45
				1996	35.776	0.639052	0.459
				1997	13.373	0.238876	0.6
				1998	37.706	0.673526	0.465
				1999	44.055	0.786936	0.582
				2000	130.194	2.325601	0.522
				2001	14.477	0.258597	0.649
				2002	67.202	1.200401	0.368

				2003	34.63	0.618581	0.407
				2004	28.78	0.514085	0.501
				2005	130.604	2.332924	0.468
SEDAR 13-DW-22	NMFS LL SE	FI	Base	1995	0.066	0.287	0.511
				1996	0.177	0.773	0.399
				1997	0.129	0.564	0.317
				1998			
				1999	0.139	0.606	0.307
				2000	0.139	0.606	0.260
				2001	0.251	1.093	0.271
				2002	0.215	0.937	0.248
				2003	0.483	2.105	0.227
				2004	0.347	1.513	0.225
				2005	0.204	0.888	0.540
				2006	0.374	1.628	0.257
SEDAR 13-DW-26	Gillnet Logs	FD-C	Sensitivity	1998	0.001	0.110	2.524
				1999	0.001	0.128	3.298
				2000	0.001	0.123	1.293
				2001	0.004	0.355	1.210
				2002	0.011	1.065	0.850
				2003	0.015	1.430	0.963
				2004	0.014	1.328	1.301
				2005	0.026	2.547	0.981
SEDAR 13-DW-30	SCDNR red drum	FI	Base	1998	0.016	0.690	3.017
				1999	0.008	0.343	5.552
				2000	0.033	1.488	1.803
				2001	0.016	0.722	4.303
				2002	0.035	1.546	1.962
				2003	0.023	1.007	2.136
				2004	0.015	0.677	4.236
				2005	0.034	1.528	3.598
SEDAR 13-DW-34	UNC	FI	Base	1972	3.967	2.564	1.594
				1973	4.233	2.736	0.936
				1974	1.600	1.034	2.293
				1975	3.326	2.149	0.996
				1976	2.490	1.609	1.113
				1977	6.276	4.056	0.344
				1978	4.048	2.616	0.605
				1979	3.115	2.013	0.666
				1980	1.866	1.206	0.859
				1981	0.728	0.470	2.338
				1982	1.503	0.971	0.832
				1983	0.849	0.548	1.670
				1984	1.814	1.172	0.852
				1985	0.953	0.616	1.787
				1986	0.595	0.384	2.992

				1987	1.099	0.710	1.686
				1988	2.135	1.380	1.136
				1989	0.812	0.525	2.507
				1990	0.565	0.365	4.043
				1991	1.052	0.680	2.063
				1992	2.315	1.496	1.385
				1993	1.381	0.893	1.903
				1994	0.819	0.529	2.557
				1995	1.012	0.654	2.286
				1996	1.396	0.902	1.966
				1997	0.419	0.271	4.255
				1998	0.189	0.122	8.969
				1999	0.131	0.085	14.208
				2000	0.194	0.125	9.467
				2001	0.597	0.386	4.604
				2002	0.243	0.157	7.470
				2003	0.100	0.065	16.434
				2004	0.387	0.250	6.553
				2005	0.405	0.262	5.506
SEDAR 13-DW-37	MML LL	FI	Base	2003	0.988	0.624	0.473
				2004	2.548	1.610	0.424
				2005	1.717	1.085	0.473
				2006	1.077	0.680	0.459

Atlantic sharpnose shark

					Index		
Document Number	Series Name	Type	Recommendation	Year	Absolute	Relative	CV
SEDAR 13-DW-05	PC LL	FI	Base	1993	0.481	0.878	0.516
				1994	0.136	0.248	0.882
				1995	0.301	0.549	0.520
				1996	0.951	1.735	0.098
				1997	0.531	0.969	0.196
				1998	0.380	0.693	0.413
				1999	1.160	2.116	0.111
				2000	0.445	0.812	0.337
SEDAR 13-DW-06	PC Gillnet - Adult	FI	Base	1996	0.339	0.517	0.403
				1997	0.679	1.036	0.296
				1998	0.408	0.623	0.429
				1999	0.361	0.551	0.518
				2000	0.616	0.940	0.468
				2001	0.706	1.078	0.382
				2002	1.037	1.583	0.322
				2003	1.091	1.665	0.287

				2004	0.659	1.006	0.382
SEDAR 13-DW-06	PC Gillnet - juvi	FI	Base	1996	1.166	1.103	0.356
				1997	1.401	1.325	0.335
				1998	1.039	0.983	0.430
				1999	1.514	1.432	0.465
				2000	0.852	0.806	0.505
				2001	1.442	1.364	0.399
				2002	1.036	0.980	0.405
				2003	1.117	1.056	0.393
				2004	0.667	0.631	0.449
				2005	0.339	0.321	0.517
SEDAR 13-DW-09	Gillnet Observer combined	FD-C	Base	1993	63.769	0.136	1.458
				1994	520.751	1.114	0.590
				1995	355.170	0.760	1.454
				1996			
				1997			
				1998			
				1999	165.327	0.354	0.484
				2000	27.340	0.058	0.915
				2001	634.326	1.356	0.427
				2002	831.673	1.778	0.420
				2003	814.365	1.741	0.586
				2004	278.853	0.596	0.672
				2005	984.790	2.106	0.670
SEDAR 13-DW-09	Gillnet Observer Atlantic	FD-C	Sensitivity	1993	131.934	0.170	1.286
				1994	853.410	1.103	0.434
				1995	639.344	0.826	1.263
				1996			
				1997			
				1998			
				1999	196.219	0.254	0.355
				2000	47.828	0.062	0.825
				2001	989.642	1.279	0.274
				2002	1190.888	1.539	0.279
				2003	1496.536	1.934	0.404
				2004	403.973	0.522	0.446
				2005	1789.160	2.312	0.431
SEDAR 13-DW-12	BLLOP combined	FD-C	Base	1994	10.534	0.039	0.654
				1995	118.473	0.438	0.561
				1996	107.619	0.398	0.558
				1997	157.065	0.581	0.563
				1998	245.823	0.909	0.543
				1999	760.861	2.815	0.547
				2000	828.94	3.067	0.567
				2001	292.945	1.084	0.551
				2002	272.197	1.007	0.548

				2003	167.911	0.621	0.547
				2004	133.011	0.492	0.558
				2005	148.218	0.548	0.558
SEDAR 13-DW-12	BLLOP Atlantic	FD-C	Sensitivity	1994	36.151	0.111	0.62
				1995	203.128	0.625	0.552
				1996	146.506	0.451	0.55
				1997	177.954	0.548	0.571
				1998	400.443	1.232	0.549
				1999	674.209	2.075	0.582
				2000	977.488	3.008	0.569
				2001	498.29	1.533	0.567
				2002	395.279	1.216	0.573
				2003	98.901	0.304	0.594
				2004	75.067	0.231	0.653
				2005	216.165	0.665	0.597
SEDAR 13-DW-12	BLLOP GoM	FD-C	Sensitivity	1994	0.036	0.000	4.355
				1995	1.533	0.016	0.909
				1996	6.081	0.062	0.828
				1997	167.41	1.695	0.575
				1998	82.08	0.831	0.617
				1999	102.412	1.037	0.526
				2000			
				2001	41.426	0.419	0.677
				2002	92.86	0.940	0.498
				2003	108.793	1.101	0.46
				2004	170.67	1.728	0.463
				2005	313.232	3.171	0.453
SEDAR 13-DW-14	SEAMAP - SA	FI	Base	1990	2.983	0.833	0.305
				1991	3.163	0.884	0.284
				1992	2.908	0.812	0.296
				1993	2.240	0.626	0.325
				1994	1.623	0.453	0.361
				1995	3.052	0.853	0.255
				1996	1.860	0.520	0.347
				1997	3.855	1.077	0.264
				1998	2.679	0.748	0.293
				1999	2.734	0.764	0.290
				2000	3.835	1.071	0.271
				2001	3.385	0.946	0.228
				2002	5.306	1.482	0.207
				2003	5.686	1.588	0.233
				2004	3.851	1.076	0.239
				2005	4.969	1.388	0.269
				2006	6.730	1.880	0.221
SEDAR 13-DW-18	Texas	FI	Base	1975	0.017	1.080	1.063
				1976	0.009	0.554	1.068

				1977	0.008	0.479	1.067
				1978			
				1979	0.016	0.983	0.577
				1980	0.005	0.329	1.058
				1981	0.004	0.278	1.056
				1982	0.003	0.167	1.044
				1983	0.007	0.463	0.576
				1984	0.021	1.316	0.312
				1985	0.017	1.068	0.374
				1986	0.040	2.560	0.218
				1987	0.007	0.474	0.744
				1988	0.034	2.177	0.238
				1989	0.014	0.875	0.376
				1990	0.010	0.653	0.442
				1991	0.017	1.101	0.375
				1992	0.009	0.578	0.577
				1993	0.008	0.531	0.575
				1994	0.011	0.703	0.441
				1995	0.007	0.439	0.575
				1996	0.030	1.891	0.246
				1997	0.011	0.717	0.575
				1998	0.010	0.654	0.497
				1999	0.032	2.035	0.239
				2000	0.025	1.612	0.275
				2001	0.003	0.216	1.047
				2002	0.026	1.658	0.312
				2003	0.029	1.867	0.277
				2004	0.022	1.365	0.333
				2005	0.018	1.140	0.351
				2006	0.016	1.039	0.371
SEDAR 13-DW-19	VA LL	FI	Base	1976	0.036	0.013	1.893
				1977	1.125	0.400	0.728
				1978			
				1979			
				1980	3.406	1.209	0.444
				1981	3.703	1.315	0.261
				1982			
				1983	3.114	1.106	1.049
				1984			
				1985			
				1986			
				1987	5.103	1.812	0.587
				1988	1.765	0.627	1.223
				1989	0.946	0.336	0.533
				1990	2.706	0.961	0.380
				1991	3.147	1.117	0.547
				1992	2.478	0.880	0.434
				1993	3.154	1.120	0.532
				1994			

				1995	2.715	0.964	0.392
				1996	3.201	1.137	0.402
				1997	2.048	0.727	0.471
				1998	3.247	1.153	0.288
				1999	6.057	2.151	0.274
				2000	1.156	0.411	0.382
				2001	2.550	0.905	0.430
				2002	1.850	0.657	0.444
				2003	1.557	0.553	0.939
				2004	1.833	0.651	0.469
				2005	7.879	2.798	0.616
SEDAR 13-DW-21	MS Gillnet - Adult	FI	Sensitivity	2001	1.412	2.335	0.392
				2002			
				2003	0.385	0.637	0.989
				2004	0.460	0.761	0.460
				2005	0.414	0.685	0.407
				2006	0.352	0.582	0.380
SEDAR 13-DW-21	MS Gillnet - juvi	FI	Sensitivity	2001	0.717	1.749	0.515
				2002			
				2003	0.153	0.374	1.307
				2004	0.109	0.266	0.763
				2005	0.199	0.485	0.556
				2006	0.872	2.127	0.303
SEDAR 13-DW-22	NMFS LL SE Atlantic	FI	Sensitivity	1995	1.982	0.212	0.304
				1996	1.820	0.194	0.326
				1997	2.426	0.259	0.320
				1998			
				1999	0.627	0.067	1.018
				2000	4.592	0.490	0.169
				2001			
				2002	14.949	1.596	0.130
				2003			
				2004	14.600	1.559	0.223
				2005	21.693	2.317	0.309
				2006	21.588	2.305	0.186
SEDAR 13-DW-22	NMFS LL SE GoM	FI	Sensitivity	1995	1.893	0.577	0.298
				1996	2.847	0.868	0.320
				1997	1.322	0.403	0.270
				1998			
				1999	1.376	0.420	0.207
				2000	3.515	1.072	0.175
				2001	2.982	0.909	0.200
				2002	3.940	1.201	0.173
				2003	4.902	1.494	0.151
				2004	5.084	1.550	0.173
				2005	4.063	1.239	0.313

				2006	4.155	1.267	0.205
SEDAR 13-DW-22	NMFS LL SE combined	FI	Base	1995	2.120	0.483	0.221
				1996	2.904	0.662	0.256
				1997	2.430	0.554	0.192
				1998			
				1999	1.438	0.328	0.228
				2000	3.837	0.875	0.123
				2001	3.693	0.842	0.196
				2002	5.229	1.192	0.136
				2003	6.258	1.427	0.141
				2004	6.679	1.523	0.147
				2005	7.840	1.788	0.244
				2006	5.811	1.325	0.171
SEDAR 13-DW-26	Gillnet Logs	FD-C	Sensitivity	1998	0.016	0.873	0.261
				1999	0.023	1.216	0.237
				2000	0.018	0.956	0.236
				2001	0.017	0.922	0.243
				2002	0.013	0.721	0.284
				2003	0.015	0.832	0.265
				2004	0.016	0.871	0.259
				2005	0.030	1.610	0.253
SEDAR 13-DW-28	NE Exp LL	FI	Sensitivity	1979	0.713	1.355	4.316
				1980			
				1981			
				1982			
				1983	1.086	2.064	3.781
				1984			
				1985	0.115	0.219	10.572
				1986	0.861	1.636	0.932
				1987			
				1988			
				1989	0.109	0.207	7.822
				1990			
				1991	0.273	0.519	3.069
SEDAR 13-DW-30	SC Coastspan GN	FI	Base	1998	8.280	1.111	0.554
				1999	9.923	1.331	0.704
				2000	5.892	0.791	0.593
				2001	6.140	0.824	0.363
				2002	5.182	0.695	0.344
				2003	14.621	1.962	0.185
				2004	3.570	0.479	1.593
				2005	6.018	0.807	0.357
SEDAR 13-DW-30	SCDNR red drum	FI	Base	1998	0.154	0.983	0.747
				1999	0.090	0.573	1.170

				2000	0.148	0.939	1.070
				2001	0.230	1.463	0.863
				2002	0.227	1.442	0.967
				2003	0.195	1.243	0.826
				2004	0.075	0.479	2.642
				2005	0.138	0.878	3.001
SEDAR 13-DW-31	SEAMAP - GoM Extended Summer	FI	Base	1982	0.855	1.098	2.139
				1983	3.329	4.278	1.557
				1984	1.118	1.436	2.061
				1985	1.550	1.992	1.975
				1986	0.862	1.107	1.936
				1987	0.705	0.906	0.450
				1988	0.649	0.834	0.421
				1989	0.669	0.859	0.476
				1990	0.189	0.243	0.567
				1991	0.810	1.040	0.404
				1992	0.587	0.754	0.439
				1993	0.658	0.846	0.425
				1994	0.232	0.298	0.523
				1995	1.066	1.370	0.409
				1996	1.057	1.358	0.394
				1997	0.537	0.691	0.452
				1998	0.500	0.643	0.427
				1999	0.484	0.622	0.435
				2000	0.786	1.010	0.441
				2001	0.351	0.451	0.633
				2002	0.822	1.057	0.432
				2003	0.410	0.527	0.505
				2004	0.219	0.282	0.497
				2005	0.359	0.461	0.516
				2006	0.651	0.837	0.430
SEDAR 13-DW-31	SEAMAP - GoM Extended Fall	FI	Base	1972	0.424	0.725	0.731
				1973	0.455	0.777	0.656
				1974	1.380	2.357	0.618
				1975	1.193	2.038	0.622
				1976	1.296	2.213	0.619
				1977	0.710	1.212	0.632
				1978	0.661	1.129	0.629
				1979	0.764	1.305	0.628
				1980	1.263	2.156	0.621
				1981	0.836	1.428	0.624
				1982	0.896	1.529	0.624
				1983	0.776	1.324	0.658
				1984	0.623	1.064	0.642
				1985	0.941	1.607	0.688
				1986	0.533	0.909	1.004
				1987	0.781	1.334	0.327
				1988	0.443	0.756	0.334

				1989	0.324	0.554	0.375
				1990	0.474	0.810	0.335
				1991	0.244	0.417	0.368
				1992	0.237	0.404	0.398
				1993	0.417	0.712	0.348
				1994	0.500	0.854	0.340
				1995	0.340	0.581	0.346
				1996	0.565	0.965	0.312
				1997	0.386	0.659	0.336
				1998	0.315	0.538	0.382
				1999	0.406	0.694	0.352
				2000	0.489	0.834	0.371
				2001	0.288	0.492	0.370
				2002	0.286	0.488	0.363
				2003	0.404	0.690	0.333
				2004	0.199	0.340	0.411
				2005	0.380	0.649	0.336
				2006	0.267	0.456	0.401
SEDAR 13-DW-31	SEAMAP-GoM Fall Groundfish	FI	Sensitivity	1972	0.489	0.549	0.381
				1973	0.430	0.483	0.246
				1974	1.609	1.807	0.199
				1975	1.304	1.464	0.173
				1976	1.255	1.409	0.147
				1977	0.704	0.791	0.202
				1978	0.697	0.782	0.207
				1979	0.843	0.946	0.215
				1980	1.415	1.589	0.208
				1981	0.837	0.940	0.242
				1982	0.932	1.047	0.215
				1983	0.770	0.865	0.242
				1984	0.660	0.741	0.373
				1985	1.103	1.238	0.357
				1986	0.310	0.348	0.571
SEDAR 13-DW-31	SEAMAP-GoM Fall SEAMAP	FI	Sensitivity	1987	0.927	2.673	1.053
				1988	0.334	0.961	0.225
				1989	0.298	0.859	0.386
				1990	0.396	1.141	0.346
				1991	0.175	0.504	0.239
				1992	0.166	0.478	0.242
				1993	0.388	1.119	0.341
				1994	0.475	1.369	0.395
				1995	0.236	0.679	0.341
				1996	0.475	1.369	0.241
				1997	0.286	0.826	0.295
				1998	0.219	0.631	0.272
				1999	0.444	1.279	0.372
				2000	0.548	1.581	0.362
				2001	0.281	0.809	0.243

				2002	0.234	0.675	0.402
				2003	0.284	0.820	0.213
				2004	0.142	0.409	0.395
				2005	0.443	1.278	0.424
				2006	0.188	0.541	0.392
SEDAR 13-DW-34	UNC	FI	Base	1973	0.861	0.328	4.135
				1974	0.313	0.119	9.764
				1975	0.653	0.249	3.486
				1976	0.372	0.142	6.784
				1977	0.739	0.282	3.328
				1978	1.366	0.521	1.736
				1979	1.166	0.444	1.862
				1980	1.139	0.434	1.530
				1981	0.594	0.226	2.643
				1982	0.340	0.130	4.363
				1983	1.353	0.516	1.210
				1984	0.922	0.352	1.675
				1985	1.322	0.504	1.312
				1986	1.150	0.438	1.918
				1987	1.735	0.661	1.149
				1988	2.299	0.876	0.761
				1989	1.265	0.482	1.604
				1990	1.750	0.667	1.028
				1991	3.526	1.344	0.593
				1992	6.286	2.397	0.447
				1993	3.141	1.198	0.964
				1994	2.164	0.825	1.096
				1995	5.698	2.172	0.527
				1996	3.101	1.182	0.634
				1997	2.898	1.105	0.773
				1998	3.780	1.441	0.539
				1999	2.865	1.092	0.678
				2000	4.001	1.526	0.544
				2001	.		.
				2002	4.872	1.858	0.463
				2003	6.899	2.630	0.364
				2004	6.449	2.459	0.462
				2005	8.917	3.400	0.246
SEDAR 13-DW-38	MML GN - Adult	FI	Base	1995	2.868	0.204	0.731
				1996	9.140	0.649	0.629
				1997	3.210	0.228	1.500
				1998			
				1999	6.522	0.463	0.677
				2000	5.041	0.358	0.707
				2001	32.431	2.302	0.521
				2002	13.662	0.970	0.574
				2003	35.560	2.524	0.527
				2004	18.350	1.303	0.535

SEDAR 13-DW-38	MML GN - juvi	FI	Base	1995	0.070	0.111	1.837
				1996	0.305	0.485	0.756
				1997	2.971	4.721	0.398
				1998			
				1999	0.423	0.672	0.588
				2000	0.161	0.255	0.765
				2001	0.505	0.803	0.896
				2002	0.897	1.426	0.456
				2003	0.254	0.404	0.757
				2004	0.078	0.124	0.831

Bonnethead shark

					Index		
Document Number	Series Name	Type	Recommendation	Year	Absolute	Relative	CV
SEDAR 13-DW-06	PC Gillnet - Adult	FI	Base	1996	0.563	1.595	0.483
				1997	0.204	0.578	0.728
				1998	0.165	0.467	0.814
				1999	0.374	1.059	0.687
				2000	0.046	0.130	2.407
				2001	0.619	1.754	0.470
				2002	0.504	1.428	0.452
				2003	0.692	1.960	0.381
				2004	0.296	0.839	0.557
				2005	0.067	0.190	1.047
SEDAR 13-DW-06	PC Gillnet - juvi	FI	Base	1996	0.602	1.705	0.554
				1997	0.827	2.343	0.575
				1998	0.622	1.762	0.481
				1999	0.710	2.011	0.598
				2000	0.304	0.861	0.779
				2001	0.390	1.105	0.617
				2002	0.435	1.232	0.590
				2003	0.292	0.827	0.624
				2004	0.166	0.470	0.778
				2005	0.046	0.130	1.536
SEDAR 13-DW-09	Gillnet Obs	FD-C	Base	1994	196.274	1.447	0.619
				1995	12.915	0.095	1.359
				1996			
				1997			
				1998	169.757	1.252	0.841
				1999	102.106	0.753	0.519
				2000	431.009	3.178	0.538
				2001	133.159	0.982	0.530
				2002	67.460	0.497	0.545

				2003	29.868	0.220	0.875
				2004	8.594	0.063	0.882
				2005	163.588	1.206	0.665
SEDAR 13-DW-10	ENP	FD-R	Base	1978	0.436	0.565	0.313
				1979	0.545	0.706	0.341
				1980	0.151	0.196	0.443
				1981	0.395	0.512	0.205
				1982	0.285	0.369	0.222
				1983	0.542	0.702	0.137
				1984	0.944	1.223	0.078
				1985	0.627	0.813	0.114
				1986	0.602	0.780	0.115
				1987	0.631	0.818	0.109
				1988	0.708	0.917	0.112
				1989	0.901	1.168	0.104
				1990	0.818	1.060	0.090
				1991	0.498	0.645	0.130
				1992	0.971	1.258	0.077
				1993	0.931	1.206	0.089
				1994	1.026	1.330	0.077
				1995	1.137	1.473	0.075
				1996	1.102	1.428	0.072
				1997	0.879	1.139	0.083
				1998	0.808	1.047	0.094
				1999	0.940	1.218	0.087
				2000	0.888	1.151	0.088
				2001	0.965	1.251	0.087
				2002	0.881	1.142	0.100
				2003	0.803	1.041	0.101
				2004	0.781	1.012	0.119
SEDAR 13-DW-14	SEAMAP - SA	FI	Base	1989	0.777	0.426	0.543
				1990	1.370	0.751	0.359
				1991	2.100	1.152	0.343
				1992	1.448	0.794	0.323
				1993	1.031	0.565	0.407
				1994	1.563	0.857	0.347
				1995	1.749	0.959	0.324
				1996	0.711	0.390	0.439
				1997	1.578	0.865	0.331
				1998	1.248	0.684	0.356
				1999	1.122	0.615	0.382
				2000	1.644	0.902	0.340
				2001	2.237	1.227	0.277
				2002	3.415	1.873	0.243
				2003	2.936	1.610	0.260
				2004	1.264	0.693	0.343
				2005	2.731	1.498	0.269
				2006	3.901	2.139	0.251

SEDAR 13-DW-18	Texas	FI	Base	1975	0.164	0.192	1.634
				1976	1.578	1.848	0.440
				1977	0.178	0.208	1.091
				1978	0.199	0.233	0.877
				1979	0.559	0.654	0.622
				1980	1.092	1.279	0.405
				1981	0.997	1.168	0.674
				1982	0.645	0.755	0.355
				1983	1.076	1.260	0.281
				1984	1.397	1.636	0.232
				1985	0.453	0.531	0.376
				1986	0.779	0.913	0.284
				1987	0.090	0.105	1.009
				1988	1.222	1.431	0.263
				1989	0.591	0.692	0.338
				1990	1.560	1.827	0.261
				1991	1.042	1.220	0.287
				1992	0.399	0.467	0.431
				1993	0.984	1.152	0.295
				1994	0.661	0.774	0.368
				1995	0.479	0.560	0.407
				1996	0.558	0.654	0.321
				1997	0.495	0.579	0.465
				1998	1.350	1.582	0.308
				1999	0.441	0.517	0.393
				2000	1.340	1.569	0.274
				2001	1.341	1.570	0.243
				2002	1.335	1.564	0.299
				2003	0.927	1.085	0.283
				2004	1.323	1.549	0.273
				2005	1.000	1.171	0.264
				2006	1.071	1.254	0.310
SEDAR 13-DW-26	Gillnet Logs	FD-C	Sensitivity	1998	0.001	0.307	5.975
				1999	0.001	0.261	7.179
				2000	0.002	0.426	5.128
				2001	0.003	0.598	4.448
				2002	0.003	0.698	5.102
				2003	0.004	0.838	5.547
				2004	0.014	3.067	2.233
				2005	0.007	1.560	3.061
SEDAR 13-DW-30	SC Coastspan GN	FI	Base	1998	5.113	0.402	0.925
				1999	13.233	1.040	0.456
				2000	12.370	0.972	0.414
				2001	13.092	1.029	0.236
				2002	10.316	0.811	0.288
				2003	14.299	1.124	0.236
				2004	17.229	1.354	0.713

				2005	16.121	1.267	0.222
SEDAR 13-DW-31	Early SEAMAP-GoM Fall Groundfish	FI	Base	1972	0.182	0.944	0.419
				1973	0.558	2.892	0.258
				1974	0.308	1.599	0.275
				1975	0.164	0.849	0.433
				1976	0.321	1.667	0.254
				1977	0.360	1.864	0.651
				1978	0.102	0.530	0.405
				1979	0.225	1.167	0.556
				1980	0.108	0.561	0.543
				1981	0.038	0.195	0.496
				1982	0.045	0.235	0.404
				1983	0.065	0.339	0.568
				1984			
				1985	0.031	0.158	1.000
				1986			
SEDAR 13-DW-31	Late SEAMAP-GoM Fall SEAMAP	FI	Base	1987	0.072	0.560	0.466
				1988	0.073	0.566	0.412
				1989	0.058	0.451	0.594
				1990	0.107	0.836	0.456
				1991	0.090	0.700	0.324
				1992	0.054	0.419	0.471
				1993	0.112	0.870	0.343
				1994	0.156	1.215	0.462
				1995	0.035	0.270	0.635
				1996	0.148	1.151	0.318
				1997	0.232	1.805	0.412
				1998	0.048	0.373	0.376
				1999	0.139	1.082	0.359
				2000	0.070	0.545	0.336
				2001	0.093	0.723	0.417
				2002	0.165	1.287	0.633
				2003	0.126	0.984	0.452
				2004	0.430	3.354	0.385
				2005	0.215	1.678	0.244
				2006	0.145	1.130	0.400
SEDAR 13-DW-38	MML GN - adult	FI	Base	1995	0.881	0.492	0.217
				1996	0.597	0.333	0.425
				1997	1.179	0.658	0.180
				1998			
				1999	1.409	0.786	0.207
				2000	2.479	1.383	0.192
				2001	2.728	1.523	0.170
				2002	1.695	0.946	0.207
				2003	2.346	1.309	0.226
				2004	2.811	1.569	0.213

SEDAR 13-DW-38	MML GN - juvi	FI	Base	1995	0.493	0.275	0.239
				1996	0.316	0.176	0.403
				1997	1.216	0.679	0.252
				1998			
				1999	0.607	0.339	0.287
				2000	1.350	0.753	0.283
				2001	1.204	0.672	0.180
				2002	0.581	0.324	0.242
				2003	1.110	0.620	0.233
				2004	1.867	1.042	0.246