SEDAR13-AW-01

SMALL COASTAL SHARK SEDAR ASSESSMENT

WORKSHOP WORKING DOCUMENT

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

E. Cortés[1]

[1] NOAA Fisheries Service
NMFS SEFSC
Panama City Laboratory
3500 Delwood Beach Drive,
Panama City, FL 32408, USA

May 2006

Summary

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.

1. Introduction/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). Additionally, an age-structured model was used in a parallel assessment (Simpfendorfer and Burgess 2002). The SCS SEDAR Data Workshop (DW) report identified the SCS complex (composed of the sum of four individual species) and single stocks of Atlantic sharpnose, bonnethead, blacknose and finetooth sharks as baseline scenarios for assessment. In this document, we present assessments for the SCS complex and the four individual species, placing special emphasis on the SCS complex and finetooth shark because the SCS SEDAR DW report recommended that the SCS complex and finetooth shark be assessed with surplus production methods alone. We also conducted multiple sensitivity analyses.

In the present document we make use of two of the surplus production methodologies used in the previous assessment (BSP and WinBUGS; Cortés 2002). As has been reported before, use of these two methods in tandem allows us to examine the effect of different model structural assumptions (e.g., consideration of observation error alone vs. observation and process error) and methods for numerical integration (SIR vs. MCMC). The BSP also provides a flexible framework for examining the effects of the importance function used for Bayesian estimation (priors vs. multivariate) and numerous other technical issues, in addition to conducting Bayesian decision analysis to project population status into the future and estimate performance indicators under various levels of catch or fishing mortality.

2. Materials and Methods

2. 1. Model description

Bayesian Surplus Production (BSP) 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. 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-likehood is given by:

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

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 (method 3), the annual observations are proportional to the annual CV^2 (if available) and the average variance for each series is equal to the MLE estimate. The log likelihood function is expressed as:

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

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

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

WinBUGS Bayesian Surplus Production Model

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):

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

where m is the number of years of unobserved catches, if applicable (C_0).

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

SCS—Catch data (in numbers) were available from 1972 to 2005 (Table 2.2 of the DW) and CPUE data, also from 1972 to 2005 (Table 3.2 of the DW). Thirteen CPUE series identified as "base" in the DW report were used in the baseline scenario. 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 roughly of the same magnitude with respect to the mean as the value used for SCS in the 2002 assessment.

Atlantic sharpnose shark— Catch data were available from 1972 to 2005 (Table 2.3 of the DW) and CPUE data, also from 1972 to 2005 (Table 3.2 of the DW). Fifteen CPUE series identified as "base" in the DW report were used in the baseline scenario. The fishery was assumed to begin in 1972, the first year for which CPUE data were available. The prior for K was uniform on log (K), and ranged between 10^4 and 10^8 individuals. For N_{72}/K, the mean was set equal to 0.9 and the log-SD was 0.2. The mean value of r as recommended in the DW report was 0.165 yr^{-1} and the log-variance was 0.08.

Bonnethead shark— Catch data were available from 1972 to 2005 (Table 2.4 of the DW) and CPUE data, also from 1972 to 2005 (Table 3.2 of the DW). Ten CPUE series identified as "base" in the DW report were used in the baseline scenario. The fishery was assumed to begin in 1972, the first year for which CPUE data were available. The prior for K was uniform on log (K), and ranged between 10^4 and 10^8 individuals. For N_{72}/K, the mean was set equal to 0.9 and the log-SD was 0.2. The mean value of r as recommended in the DW report was 0.205 yr^{-1} and the log-variance was 0.08.

Blacknose shark— Catch data were available from 1972 to 2005 (Table 2.5 of the DW) and CPUE data, also from 1972 to 2005 (Table 3.2 of the DW). Seven CPUE series identified as "base" in the DW report were used in the baseline scenario. The fishery was assumed to begin in 1972, the first year for which CPUE data were available. The prior for K was uniform on log (K), and ranged between 10^4 and 10^8 individuals. For N_{72}/K, the mean was set equal to 0.9 and the log-SD was 0.2. The mean value of r as recommended in the DW report was 0.084 yr^{-1} and the log-variance was 0.06.

Finetooth shark— Catch data were available from 1983 to 2005 (Table 2.6 of the DW) and CPUE data, from 1976 to 2005 (Table 3.2 of the DW). Four CPUE series identified as “base” in the DW report were used in the baseline scenario. The fishery was assumed to begin in 1976, the first year for which CPUE data were available. The catches in the years 1976-1982 were assumed to be constant and equal to the model-estimated parameter C_0. The prior for C_0 was lognormal, with a mean equal to the average catch during 1983-1988 (2,774 individuals) and a log-SD of 1, implying a wide distribution. The prior for K was uniform on log (K), and ranged between 10^4 and $2x10^7$ individuals. This upper bound of K reflects the lower abundance of this species compared to Atlantic sharpnose or bonnethead sharks. For N_{72}/K, the mean was set equal to 0.9 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).

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}/Ry) 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 (Fi/F_{MSY}) trajectories, as well as the predicted abundance trend, were obtained and plotted for the time period considered in each scenario.

2. 3. 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 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. 4. 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

- **GOM or ATL-** Sensitivity to considering separate stocks (Gulf of Mexico or Atlantic) vs. a single stock in the baseline scenario for Atlantic sharpnose sharks only

- **AC-** Sensitivity to extending the catch series back to 1950 to mimic the catch stream used with the age-structured model

- **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}) for finetooth shark only

3. Results

3.1. Baseline scenarios

SCS complex— 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. 1A). Two of the four longest CPUE series (UNC and TEXAS) showed a generally increasing trend, whereas the other two series (SEAMAPGF and SEAMAPGS) showed a flatter or slightly declining trend. Most of the other series showed increasing or fluctuating trends. The model interpreted these trends by providing flat fits (Fig. 1B). 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. 2A,B).

Current status of the population was accordingly above N_{MSY} and no overfishing was occurring (Table 1). 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. 3A,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. 3C). 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; Fig. 4).

Atlantic sharpnose sharks— The abundance trajectory at the mode of the posterior distribution showed an increasing trend from the early 1970s to 2005 (Fig. 5A). As with the SCS complex, two of the four longest CPUE series (UNC and TEXAS) showed a generally increasing trend (very accentuated in the UNC series), whereas the other two series (SEAMAPGF and SEAMAPGS) showed large fluctuations towards the beginning and a generally declining trend. Most of the other series did not show clear trends. Again, the model interpreted these trends by providing flat or moderately increasing fits (Fig. 5B). 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. 6A,B).

Current status of the population was accordingly above N_{MSY} and no overfishing was occurring (Table 1). The priors were used as an importance function for importance sampling. The SIR algorithm converged according to the convergence criterion based on the maximum weight of any draw (<0.5%), but the model could not calculate the CV(likelihood * priors). 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. 7A,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. 7C). 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; Fig. 8).

Bonnethead sharks— The abundance trajectory at the mode of the posterior distribution showed some decline in the 1970s, but remained fairly flat thereafter (Fig. 9A). This decline mirrored the large decline in the 1970s seen in the longest CPUE series (SEAMAPGF). The two other longest CPUE series (ENP and TEXAS) showed moderately increasing trends, whereas the rest of the series did not show clear patterns. The model also interpreted these conflicting trends by fitting the series with flat or slightly decreasing tendencies (Fig. 9B). The median relative biomass and fishing mortality trajectories indicated that the stock did not approach an overfished status or overfishing, respectively, in any year, but the upper confidence limit of F/F_{MSY} exceeded 1 in some years (Fig. 10A,B).

Current status of the population was above N_{MSY} and no overfishing was occurring (Table 1). 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. 11A,B). The joint posterior distribution of K and r showed a very restricted area of probability for r and especially for K, indicating that the parameter space was not well sampled (Fig. 11C). 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 2; Fig. 12).

Blacknose sharks— The abundance trajectory at the mode of the posterior distribution showed some decline in the 1970s, but remained fairly flat thereafter (Fig. 13A). This decline mirrored the large decline in the 1970s seen in the longest CPUE series (UNC). The remaining CPUE series showed fluctuating but generally increasing trends. The model also interpreted these conflicting trends by fitting the series with flat or slightly decreasing tendencies (Fig. 13B). The median relative biomass trajectory showed a decreasing tendency, with B/B_{MSY} decreasing from 2 to 1.3 from beginning to end of the time series; the median relative fishing mortality trajectory indicated that the stock had experienced overfishing in 1977, 1997, and several times in the early 2000s, but not in 2005 (Fig. 14A,B).

Current status of the population was above N_{MSY} and no overfishing was occurring (Table 1). The priors were used as an importance function for importance sampling. The SIR algorithm converged with good diagnostics of convergence (maximum weight of any draw <<0.5%, CV(weights) / CV(likelihood * priors) <1). The posterior distribution of r showed that the data supported relatively higher values of this parameter, but the posterior for K showed values only slightly higher than the prior (Fig. 15A,B). The joint posterior distribution of K and r showed a very restricted area of probability for r and especially for K (Fig. 15C). Population projections indicated that the population would be expected to remain above N_{MSY} for at least 30 years even if maintaining the current level of total catch, but doubling the TAC would result in a population crash in about 30 years (Table 2; Fig. 16).

Finetooth sharks— The abundance trajectory at the mode of the posterior distribution showed a rather flat trend (Fig. 17A). 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. 17B). 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. 18A,B).

Current status of the population was above N_{MSY} and no overfishing was occurring (Table 1). 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. 19A,B). The joint posterior distribution of K and r showed a restricted area of probability for r (Fig. 19C). 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 2; Fig. 20).

3.2. 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.

SCS complex— The median relative abundance trajectory for the WinBUGS model showed an increasing trend that never approached an overfished status (Fig. 21A). 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 (Fig. 21B). In all, current status of the population was above N_{MSY} and no overfishing was occurring (Table 3). WinBUGS model fits to the CPUE series were all increasing, with the exception of the fit to the SEAMAPGF series, which was decreasing and was fitted exactly to the observed data. The UNC and MML 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).

Atlantic sharpnose sharks— The median relative abundance trajectory showed an increasing, but more fluctuating, trend than that from the BSP, never approaching an overfished status (Fig. 22A). As with the SCS complex, the median relative fishing mortality trajectory was almost identical to that obtained with the BSP, with the only exception that the 97.5th quantile reached overfishing in a number of years (Fig. 22B). In all, current status of the population was above N_{MSY} and no overfishing was occurring (Table 3). WinBUGS model fits to the CPUE series were all increasing, with the exception of the fit to the SEAMAPGF series, which was decreasing and was fitted exactly to the observed data. The UNC, MMLA and MMLJ 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.

Bonnethead sharks—In contrast to the BSP, which showed a moderate decline, the median relative abundance trajectory from WinBUGS showed an increasing trend, never approaching an overfished status (Fig. 23A). The median relative fishing mortality trajectory was almost identical to that obtained with the BSP (Fig. 23B). In all, current status of the population was well above N_{MSY} and no overfishing was occurring (Table 3). WinBUGS model fits to the CPUE series also were all increasing, with the exception of the fit to the SEAMAPGF series, which was decreasing and was fitted exactly to the observed data. The MMLA and MMLJ 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.

***Blacknose sharks*—**The decline in the median relative abundance trajectory was more accentuated than that estimated by the BSP, and the stock became overfished from 1984 to 2005 (Fig. 24A). The median relative fishing mortality trajectory was also very similar to that obtained with the BSP, but only reached an overfishing status in 1997, with the trajectory declining thereafter, although the probability intervals were very wide (Fig. 24B). In all, the stock was currently overfished but no overfishing was occurring (Table 3). Four of the seven CPUE series fits showed concave trends (PCGN, DGNOP, BLLOP, and NMFSLLSE), first decreasing and later increasing. The fit to the UNC series was clearly decreasing, whereas the fits to the remaining and shorter series (SCDNR and MML) were increasing. 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.

***Finetooth sharks*—**The median relative abundance trajectory was very similar to that estimated by the BSP, with the stock never being overfished (Fig. 25A). The median relative fishing mortality trajectory was also very similar to that obtained with the BSP, but showing wider credibility intervals (Fig. 25B). In all, the stock was not currently overfished and overfishing was not occurring (Table 3). 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.

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 4).

***SCS complex*—**The model did not converge. 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.

***Atlantic sharpnose sharks*—**Stock status did not change with respect to the baseline scenario, but there was evidence against model convergence because, as in the baseline scenario, the model could not calculate the CV(likelihood * priors).

***Bonnethead sharks*—**Stock status did not change with respect to the baseline scenario, but the CV(likelihood * priors) was >1.

***Blacknose sharks*—**The prediction of stock status was extremely pessimistic, but the model clearly did not converge because it was not able to calculate the CV(likelihood * priors) and the maximum weight of any draw was >>0.5%. As in the baseline scenario, the joint posterior distribution for r and K had a very restricted area of probability. Additionally, the CVs in one single CPUE series differed by almost 2 orders of magnitude.

***Finetooth sharks*—**Stock status did not change with respect to the baseline scenario and convergence diagnostics were satisfactory.

GOM or ATL-Considering separate stocks (Gulf or Atlantic) for Atlantic sharpnose sharks—This involved conducting separate assessments for Atlantic sharpnose sharks in the Gulf of Mexico and Atlantic Ocean. Accordingly, the catch series were split into Gulf and Atlantic (see Tables 2.12a and 2.12b of the DW report) and different values for the rate of increase were used (section1.6.1 of the DW report). Nine CPUE series were available for the Gulf of Mexico (PCLL, PCGN, BLLOP, TEXAS, NMFSLLSE, SEMAPGS, SEMAPGF, MMLA, and MMLJ) and eight series for the Atlantic (DGNOP, BLLOP, SEAMAPSA, VALL, NMFSLLSE, SCCOAST, SCDNR, and UNC). As with the baseline scenario for a single stock, catch data were available from 1972 to 2005; CPUE data were available for 1972-2005 for the Gulf and 1973-2005 for the Atlantic. The fishery was assumed to begin in 1972, the first year for which catch data were available, and thus C_0 was not required. As in the baseline scenario, the prior for K was uniform on log (K), ranging between 10^5 and 10^8 individuals, and the mean of N_{72}/K was set to 0.9 and the log-SD to 0.2. The mean values of r were 0.189 yr^{-1} for the Gulf and 0.134 yr^{-1} for the Atlantic.

For the Gulf, current status of the population was well above N_{MSY} and no overfishing was occurring (Table 5). Convergence diagnostics were good. For the Atlantic, current status of the population was also well above N_{MSY} and no overfishing was occurring (Table 5), but both convergence criteria were unsatisfactory (maximum weight of any draw >0.5% and CV (weights) / CV (likelihood * priors) >1).

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 5). Convergence diagnostics were satisfactory.

AC-Extending the catch series back to 1950—This involved using the alternative catch series for the SCS complex and the four individual species (Tables 2.7-2.11 of the DW) to mimic the catch streams used in the age-structured models. This change generally had little impact on results. However, for blacknose sharks, the status of the stock worsened and approached an overfishing condition (Table 6). Projections for blacknose sharks also indicated that the present (for 2005) level of catch would result in a 62% probability of the stock being above N_{MSY} in ten years. Convergence diagnostics were also good, except for Atlantic sharpnose sharks (as in the baseline scenario).

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 for the SCS complex, the MS gillnet, Gillnet Logs, and NE Exp LL for Atlantic sharpnose sharks, the Gillnet Logs for bonnethead sharks, the PC LL and Gillnet Logs for blacknose sharks, and the PC LL, MS gillnet, and Gillnet Logs for finetooth sharks. This change generally had little impact on results. For blacknose sharks, the outlook on the status of the stock became more optimistic (Table 7). Convergence diagnostics were also good, except for Atlantic sharpnose sharks (as in the baseline scenario).

4. Discussion and Conclusions

Baseline scenarios for the SCS complex and the four individual species predicted that the stock status is not overfished nor overfishing is occurring in all cases. With the exception of blacknose sharks, all models indicated very little depletion in numbers with respect to virgin levels (10-19%). Likewise, with the exception of blacknose sharks, none of the stocks approached an overfishing condition.

The method to weight the CPUE data (equal vs. inverse variance) only had a significant effect on the blacknose shark, drastically changing the predictions on stock status to overfished and overfishing occurring. However, convergence diagnostics for the inverse variance method were poor or very poor (with the exception of finetooth sharks) and the method could not even be applied to the SCS complex. In general, when data are noisy and contradictory and the CVs differ substantially in magnitude, as was notably the case for the SCS complex and blacknose sharks, 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 for the SCS complex, Atlantic sharpnose, bonnethead, and finetooth sharks were of the same magnitude (7-15%) as those found in the baseline scenario and no stocks approached an overfishing condition. As in the baseline scenario, the outlook for blacknose sharks was more pessimistic and actually predicted an overfished status.

None of the other sensitivity analyses conducted (considering two separate stocks of Atlantic sharpnose sharks, lowering the value of r for finetooth, extending the catch series available back to 1950, and adding all the "sensitivity" CPUE series to the baseline) had a significant effect or changed the predictions of stock status. Only when extending the catch series back to 1950 for blacknose sharks, did the stock approach an overfishing condition, whereas including the “sensitivity” CPUE series in the analysis improved the status of blacknose sharks.

All scenarios assumed that the populations 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) scenarios were an attempt to account for some historical level of exploitation, but nevertheless resulted in the same conclusions on stock status as the baseline scenarios.

Figure 26 is a phase plot summarizing the results on stock status found in the baseline scenario and selected sensitivity analyses in the present assessment. 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 only shows problems with blacknose sharks because the WinBUGS model estimated an overfished condition and the BSP model with the alternative catch series (back to 1950) estimated the stock was very near an overfishing condition.

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Table 1. 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 and the four individual species (**baseline scenario**) using equal weighting and values of r (intrinsic rate of increase) recommended in the Data Workshop report. Abundances are in thousands of fish.

	SCS		Atl. Sharpnose		Bonnethead		Blacknose		Finetooth	
	EV	CV	EV	CV	EV	CV	EV	CV	EV	CV
Importance function	priors		priors		priors		priors		priors	
K	59566	0.35	60833	0.36	21708	0.98	7529	1.88	6397	0.82
r	0.181	0.32	0.160	0.27	0.191	0.29	0.080	0.25	0.060	0.20
MSY	2623	0.45	2389	0.43	1058	1.11	155	1.98	96	0.86
N_{2005}	51605	0.40	56389	0.39	19631	1.09	6654	2.13	6000	0.84
N_{2005}/K	**0.85**	0.09	**0.91**	0.05	**0.81**	0.18	**0.69**	0.26	**0.90**	0.08
N_{init}	53057	0.38	41778	0.41	21433	0.99	7522	1.89	5380	0.84
N_{2005}/N_{init}	0.97	0.13	1.37	0.15	0.83	0.17	0.70	0.26	1.09	0.14
C_{2005}/MSY	0.40	0.42	0.27	0.46	0.31	0.64	0.95	0.56	0.27	1.08
F_{2005}/F_{MSY}	**0.25**	0.55	**0.15**	0.54	**0.22**	0.83	**0.85**	0.78	**0.17**	1.32
N_{2005}/N_{MSY}	**1.69**	0.09	**1.83**	0.05	**1.61**	0.18	**1.38**	0.26	**1.80**	0.09
C_{2005}/repy	0.79	0.05	0.90	0.08	0.52	0.13	1.22	2.27	0.78	81.34
N_{MSY}	29783	0.35	30416	0.36	10854	0.98	3764	1.88	3199	0.82
F_{MSY}	0.091		0.080		0.096		0.040		0.030	
repy	1125	0.05	597	0.10	309	0.11	47	0.28	21	0.83
C_0									2	0.69
Diagnostics										
CW (wt)	0.786		3.182		1.819		2.412		0.609	
CV (L*prior)	0.902		0.000		2.390		3.060		1.163	
CV (Wt) / CV (L*p)	0.87		n/a		0.76		0.79		0.52	
%maxpWt	0.002		0.070		0.008		0.006		0.0004	

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

Table 2. Decision analysis tables for the SCS complex and the four individual species corresponding to the results in Table 1.

SCS

Horizon	Policy	E(Bfin/K)	E(Bfin/Bmsy)	P(Bfin<0.2K)	P(Bfin>Bmsy)	P(Bfin>Bcur)	P(Ffin<Fcur)	P(Bcur>Bref)	P(Bfin<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

Atlantic sharpnose

Horizon	Policy	E(Bfin/K)	E(Bfin/Bmsy)	P(Bfin<0.2K)	P(Bfin>Bmsy)	P(Bfin>Bcur)	P(Ffin<Fcur)	P(Bcur>Bref)	P(Bfin<0.01K)
10 -year	TAC=0	1.4	1.96	0	1	1	1	1	0
	TAC=1C_{2005}	1.33	1.84	0	1	0.98	0.98	0.98	0
	TAC=2C_{2005}	1.26	1.72	0	1	0	0	0	0
20 -year	TAC=0	1.42	1.99	0	1	1	1	1	0
	TAC=1C_{2005}	1.33	1.85	0	1	0.98	0.98	0.98	0
	TAC=2C_{2005}	1.23	1.68	0.01	0.99	0	0	0	0
30 -year	TAC=0	1.42	2	0	1	1	1	1	0
	TAC=1C_{2005}	1.33	1.85	0	1	0.98	0.98	0.98	0
	TAC=2C_{2005}	1.22	1.66	0.01	0.98	0	0	0	0